4

Observations: Temperature Records

Sherwood Idso (USA)

Craig Idso (USA)

Contributing: S. Fred Singer (USA), Ross McKitrick (Canada), Roy Spencer (USA)

Key Findings

The following bulleted points summarize the main findings of this chapter:

- The Intergovernmental Panel on Climate Change (IPCC) contends the warming of the past half-century is unprecedented in the past millennium and anthropogenic in origin. In contrast, based upon the evidence presented here and in other chapters of this volume, the Nongovernmental International Panel on Climate Change (NIPCC) concludes natural variability is responsible for late twentieth century warming and the cessation of warming since 1998. The modern rise of carbon dioxide and other atmospheric greenhouse gases has had little, if any, measurable effect on twentieth century climate.

- Filtering out urbanization and related land-use effects in the temperature record is a complicated task, and there is solid evidence the methods currently used are inadequate. Urbanization may account for a larger portion of the modern temperature rise than the IPCC acknowledges.

- Surface-based temperature histories of the globe almost certainly contain a significant warming bias introduced by insufficient corrections for the non-greenhouse-gas-induced urban heat island effect. It may be next to impossible to make proper corrections for this deficiency, as the urban heat island of even small towns dwarfs any concomitant augmented greenhouse effect that may be present.

- The IPCC claim of robust evidence of amplified CO_2-induced warming in Earth's polar regions is patently false, having been invalidated time and again by real-world data. From the birth and death of ice ages to the decadal variations of modern-day weather patterns, studies in Earth's polar regions demonstrate the atmosphere's CO_2 concentration is not a major player in bringing about significant changes in Earth's climate.

- Earth's climate has both cooled and warmed independent of its atmospheric CO_2 concentration, revealing the true inability of carbon dioxide to drive climate change throughout the Holocene. Conditions as warm as, or warmer than, the present have persisted across the Holocene for decades and centuries even though the atmosphere's CO_2 concentration remained approximately 30 percent lower than it is today.

- The IPCC concludes "there is high confidence that the Medieval Climate Anomaly was not characterized by a pattern of higher temperatures that were consistent across seasons and regions" (p. 5–4 of the Second Order Draft of AR5, dated October 5, 2012). Quite to the contrary, an enormous body of literature clearly demonstrates the IPCC's assessment of the Medieval Climate Anomaly (MCA) is incorrect. The degree of warming and climatic influence during the MCA indeed varied from region to region, and hence its consequences were manifested in a variety of ways. But literally hundreds of peer-reviewed scientific articles confirm it occurred and was a global phenomenon.

- Computer model simulations have given rise to three claims regarding the influence of global warming on ENSO events: (1) global warming will increase the frequency of ENSO events, (2) global warming will increase the intensity of ENSO events, and (3) weather-related disasters will be exacerbated under El Niño conditions. Observational data do not agree with the models' claims: In nearly all historical records, frequent and strong El Niño activity increases during periods of colder temperatures (e.g., the Little Ice Age) and decreases during warm ones (e.g., Medieval Warm Period, Current Warm Period).

Introduction

In its current and prior assessment reports the IPCC makes clear its position that the past few decades were the warmest of the past hundred years on the planet, and possibly of the entire past millennium. Their statements on this topic include:

> Starting in the 1980s each decade has been significantly warmer than all preceding decades. … All ten of the warmest years have occurred since 1997, with 2010 and 2005 effectively tied for the warmest year on record (Second Order Draft of AR5, dated October 5, 2012, p. 2–33).
>
> Palaeoclimatic information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1,300 years (Summary for Policy Makers, Fourth Assessment Report, p. 9).
>
> Better understanding of pre-instrumental data shows that warming since the mid-20th century is far outside the range of internal climate variability estimated from such records (Second Order Draft of AR5, dated October 5, 2012, p. 10-3).

The IPCC further asserts the supposedly unprecedented high air temperatures of the present are largely the consequence of increasing anthropogenic CO_2 emissions resulting from the burning of fossil fuels, claiming:

> It is *very unlikely* that reconstructed temperatures since 1400 can be explained by natural internal variability alone. Climate model simulations that include only natural forcings can explain a substantial part of the pre-industrial inter-decadal temperature variability since 1400 on hemispheric scales. However such simulations fail to explain more recent warming since 1950 without the inclusion of anthropogenic increases in greenhouse gas concentrations. The warming since 1950 is far outside the range of similar length trends estimated in residual internal variability estimated from reconstructions of the past millennium (Second Order Draft of AR5, dated October 5, 2012, p. 10-5).
>
> We conclude it is *extremely likely* that human activities have caused most of (at least 50%) the observed increase in global average temperatures since the 1950s and that it is *virtually certain* that this warming is not due to internal variability alone (Second Order Draft of AR5, dated October 5, 2012, p. 10-3)

These two most basic assertions of the IPCC—that the warming of the past half century is unprecedented in the past millennium and anthropogenic in origin—serve as the foundation of nearly all of the work conducted by the IPCC. These assertions are the basic building blocks upon which politicians and governments have sought to radically reformulate the energy basis of the industrialized world to avoid a host of climatic consequences they insist will occur (or are occurring) as temperatures continue to rise.

The present chapter examines these two temperature-related claims and finds the IPCC's assertions are based on a limited and narrow interpretation of the available scientific literature. Many published studies, for example, question the accuracy of the surface temperature record, collectively demonstrating the datasets upheld by the IPCC likely overestimate the warming that has occurred over the past half-century. In addition, the publication of many historical paleoclimate records reveal there is nothing unusual, unnatural, or unprecedented about the current level of planetary warmth. These facts, coupled with the problems inherent in climate models (Chapter 1 of this volume), the failure of the models to properly account for and incorporate important forcings and feedbacks into their model runs (Chapters 2 and 3), and the array of real-world observations that run counter to the model projections with respect to various climate and other related phenomena (this chapter and Chapters 5, 6, and 7), all demonstrate the IPCC is premature—if not flat-out wrong—in attributing recent warming to anthropogenic CO_2 emissions.

4.1 Global Temperature Records

4.1.1 Discerning the Cause of Late Twentieth Century Global Warming

The IPCC has concluded it is "*extremely likely*" the anthropogenic release of greenhouse gases into the atmosphere has caused most of the increase in global average temperature they claim has been observed since the 1950s.

In brief, the reason for the IPCC's confidence stems from comparisons of global climate model runs of the twentieth century using natural forcings and natural *plus* anthropogenic forcings. When the models are run throughout the twentieth century using natural forcings alone, they are unable to reproduce the rise seen in various global temperature datasets. When they are run with the added anthropogenic forcing due to CO_2 and other greenhouse gases, there is relatively good agreement between the model projections and temperature observations. Thus, the IPCC attributes the mid- to late-twentieth century observational warming to rising greenhouse gases.

In making this attribution, however, the IPCC makes several assumptions. First, it assumes the magnitude of the mid- to late-twentieth century rise in temperature, as presented in the global land and ocean datasets, is robust. (It is not; see Section 4.1.2.) Second, the IPCC assumes the models are using an accurate temperature sensitivity to represent the modern rise in greenhouse gases. (They are not; see Chapter 1.1.5.) Third, the IPCC assumes the models correctly capture and portray each of the important processes that affect climate. (They do not; see Chapters 1, 2, and 3.) Fourth, the IPCC assumes the models correctly depict and account for natural variability. (They do not, as evidenced by material presented in all chapters of this volume.)

With respect to the first assumption, a number of difficulties are encountered in obtaining accurate global temperature measurements and assembling them into aggregate histories of global climate change over the era of modern instrumentation. These difficulties, if not properly addressed, can induce significant errors into the global temperature record. The magnitude of these errors in many instances has been reported to be as large as or larger than the anthropogenic signal anticipated by the IPCC to be residing in such datasets.

Among such potential errors are temporal changes in microclimate surrounding temperature measurement sites, such as urbanization, which often go unrecognized or for which insufficient adjustments are made; long-term degradation of the shelters that house the temperature-measuring equipment, such as the shelters' white paint becoming less reflective and their louvers partially obstructed; changes in what is actually being measured, such as true daily maximum and minimum temperatures or temperatures at specified times of day; changes in measurement devices and ways of accessing the data, such as changing from having to open the shelter door to read the temperature, as was done in earlier days, to not having to do so, due to the automatic recording of the data, as has become commonplace in more recent times; general station degradation and many station closures over time; the changing and uneven geographical representation of the surface temperature network; poor attention to careful acquisition of data in many parts of the world; and numerous problems associated with obtaining a correct and geographically complete record of surface air temperature over the 70 percent of the globe that is covered by oceans.

Arguably the most serious of the potential inaccuracies is that related to urbanization, addressed in more detail in Section 4.1.2. As demonstrated there, the impact of population growth on the urban heat island effect is very real and can be very large, vastly overshadowing the effects of natural temperature change. Towns with as few as a thousand inhabitants, for example, typically create a warming of the air within them that is more than twice as great as the increase in mean global air temperature presumed to have occurred since the end of the Little Ice Age. Urban heat islands of the great metropolises of the world are much larger, creating warmings that rival those that occur between full-fledged ice ages and interglacials. Given the potential of this phenomenon to introduce errors of such magnitude into the temperature records of the past century, it is surprising the IPCC is mostly dismissive of this topic and its significance in its *Fifth Assessment Report*.

Other observations also point to problems with the global surface air temperature record. The satellite microwave-sounding-unit temperature record shows less warming when compared with surface temperature records since coming online in 1979, and the weather-balloon temperature record also shows less warming than the surface temperature records since the 1940s.

The second major assumption made by the IPCC in attributing the late twentieth century rise in temperature to the modern rise in atmospheric greenhouse gases pertains to climate sensitivity. Most models use a climate sensitivity in which global temperatures rise between 1.5 and 4.5°C in response to a doubling of the atmosphere's CO_2 concentration. However, as discussed in Chapter 1.1.5, these values could be as much as a factor of ten too high compared to what actually occurs in nature.

A simple test demonstrating the IPCC's faulty assessment of climate sensitivity was performed a little over a decade ago by Stanhill (2001), who examined the relationship between temperature and CO_2 over the prior 140 years. In describing the character of the global surface temperature record over this period, he said it can be broken into four parts, beginning with "a long and very irregular but generally cool first period between 1860 and 1910, followed by a very rapid, regular and prolonged period of global warming between 1910 and 1943, succeeded by an equally long period of small and irregular cooling from 1943 to 1975 and, since then, the current warming period," which latter warming stopped about the time of Stanhill's writing, revealing no statistical trend in the temperature data since 1998.

During the prolonged period of global warming in the early part of the past century, Stanhill notes, "the rate of anthropogenic releases of radiatively active gasses, the presumed cause of the current global warming, was approximately one tenth of that in the present warming period," the temperature increase of which "has been shorter, more irregular and less rapid than the earlier warming." The order-of-magnitude-greater release of greenhouse gases since 1975 has not produced a warming as dramatic as the one that occurred in the early part of the century that was coeval with the release of but one-tenth as much CO_2 and other greenhouse gases. There is thus little reason to put much credence in the IPCC's estimates on climate sensitivity. This point is further driven home in Chapter 1.1.1, where several additional examples from the peer-reviewed literature are cited to show climate is relatively insensitive to changes in CO_2, and CO_2 is a *follower* of temperature change as opposed to an *initiator* of it.

The third major assumption the IPCC makes in attributing the late twentieth century rise in temperature to the modern rise in atmospheric greenhouse gases is that the models correctly capture and portray each of the important processes that affect climate. Chapter 1 of this volume presents an in-depth discussion of the inner workings and limitations of climate models.

Climate models are important tools used to advance our understanding of current and past climate. They provide qualitative and quantitative information about potential future climate. But in spite of their sophistication, they remain only *models*. They represent simulations of the real world, constrained by their ability to correctly capture and portray each of the important processes that operate to affect climate. Chapter 1 demonstrates the models remain deficient in many aspects of their portrayal of the climate, which reduces their ability to provide reliable simulations of the future.

Confidence in a model is further based on the careful evaluation of its performance. Just because one, two, or several models agree on a particular outcome, such agreement is not sufficient grounds to conclude the model projections are robust, for the model projections must be validated against real-world observations at the appropriate temporal and spatial scales. Without such a comparison, the true performance of a model cannot be verified.

A large portion of this volume, therefore, is devoted to the evaluation of climate model projections against real-world climate and other biospheric data, including material from this chapter. That evaluation, summarized in the findings of numerous peer-reviewed scientific papers, reveals the models consistently fail to accurately simulate important components of the Earth-atmosphere-ocean system.

Climate models predict a unique anthropogenic “fingerprint” of CO_2-induced global warming in which there is a warming trend in the tropical troposphere that increases with altitude (see Figure 4.1.1.1.) The models further suggest climate changes due to solar variability or other known natural factors do not yield this pattern, whereas sustained greenhouse warming does.

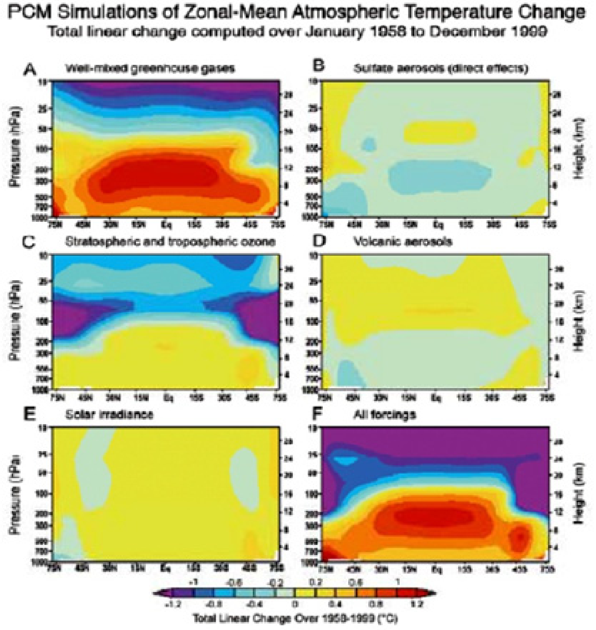


Figure 1.3. PCM simulations of the vertical profile of temperature change due to various forcings, and the effect due to all forcings taken together (after Santer *et al.*, 2000).

Figure 4.1.1.1. Model-calculated zonal mean atmospheric temperature change from 1890 to 1999 (degrees C per century) as simulated by climate models from [A] well-mixed greenhouse gases, [B] sulfate aerosols (direct effects only), [C] stratospheric and tropospheric ozone, [D] volcanic aerosols, [E] solar irradiance, and [F] all forcings (U.S. Climate Change Science Program 2006, p. 22). Note the pronounced increase in warming trend with altitude in figures A and F, which the IPCC identified as the ‘fingerprint’ of greenhouse forcing.

The comparison of these projections with observations was first attempted in the IPCC’s *Second Assessment Report* (SAR) (IPCC-SAR, 1996, p. 411). Its Chapter 8, titled “Detection and Attribution,” attributed observed temperature changes to anthropogenic factors: greenhouse gases and aerosols. The attempted match of warming trends with altitude turned out to be spurious, since it depended entirely on a particular choice of time interval for the comparison (Michaels and Knappenberger, 1996). Similarly, an attempt to correlate the observed and calculated geographic distribution of surface temperature trends (Santer *et al.* 1996) involved making changes on a published graph that could and did mislead readers (Singer, 1999, p. 9; Singer, 2000, pp. 15, 43–44). In spite of these shortcomings, IPCC-SAR concluded the data matched the observations and “the balance of evidence” therefore supported anthropogenic global warming.

With the availability of higher-quality temperature data, especially from balloons and satellites, and with improved models, it has become possible to make this comparison in a more realistic way. This was done in a report issued by the U.S. Climate Change Science Program (CCSP) in April 2006, making it readily available to the IPCC for its *Fourth Assessment Report*. It permits a more realistic comparison of the data (Karl *et al.,* 2006).

The CCSP report is an outgrowth of a National Academy of Sciences (NAS) report, “Reconciling Observations of Global Temperature Change,” issued in January 2000 (NAS, 2000). The NAS report compared surface and troposphere temperature trends and concluded they cannot be reconciled. Six years later, the CCSP report expanded considerably on the NAS study. It was essentially a specialized report addressing the most crucial issue in the global warming debate: Is current global warming anthropogenic or natural? The CCSP findings were unequivocal. Although all greenhouse models show an increasing warming trend with altitude, peaking around 10 km at roughly two times the surface value, the temperature data from balloons give the opposite result: no increasing warming, but rather a slight cooling with altitude in the tropical zone. See Figures 4.1.1.2 and 4.1.1.3, reproduced directly from the CCSP report.

The CCSP executive summary inexplicably claims agreement between observed and calculated patterns, the opposite of what the report itself documents. It tries to dismiss the obvious disagreement shown in the body of the report by suggesting there might be something wrong with balloon and satellite data instead of the model projections. Unfortunately, many people do not read

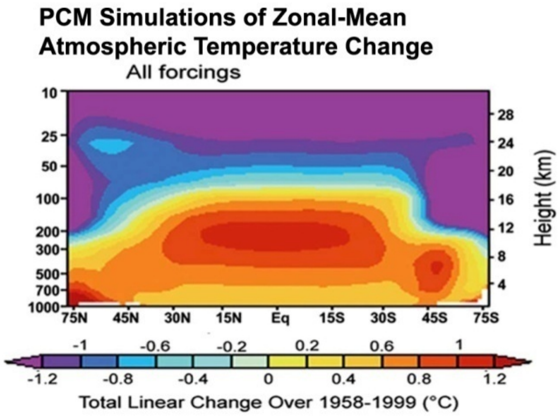


Figure 4.1.1.2. Greenhouse-model-predicted temperature trends versus latitude and altitude; this is figure 1.3F from CCSP 2006, p. 25. Note the increased temperature trends in the tropical mid-troposphere, in agreement also with the IPCC result (IPCC-AR4 2007, p. 675).

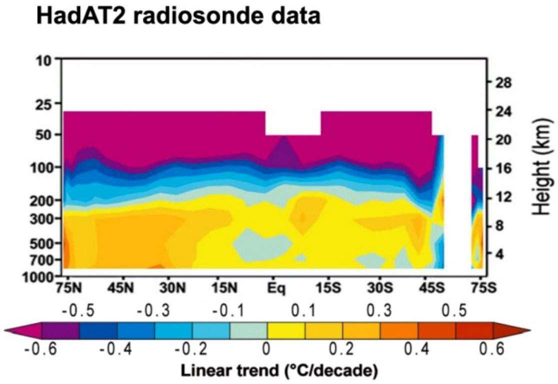
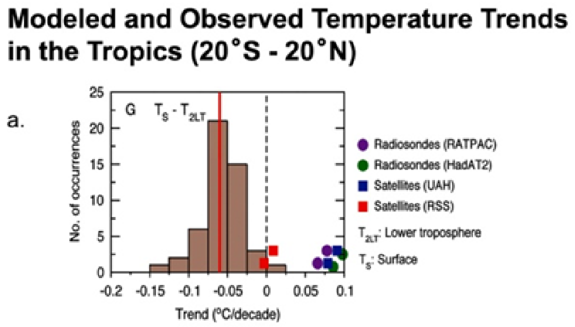


Figure 4.1.1.3. By contrast, observed temperature trends versus latitude and altitude; this is figure 5.7E from CCSP 2006, p. 116. These trends are based on the analysis of radiosonde data by the Hadley Centre and are in good agreement with the corresponding U.S. analyses. Notice the absence of increased temperature trends in the tropical mid-troposphere.



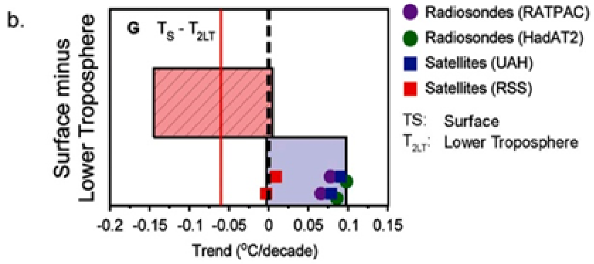


Figure 4.1.1.4a. Another way of presenting the difference between temperature trends of surface and lower troposphere; this is figure 5.4G from CCSP 2006, p. 111. The model results show a spread of values (histogram); the data points show balloon and satellite trend values. Note that the model results hardly overlap with the actual observed trends. (The apparent deviation of the RSS analysis of the satellite data is as yet unexplained.)

Figure 4.1.1.4b. By contrast, the executive summary of the CCSP report presents the same information as Figure 4.2.1.4a in terms of "range" and shows a slight overlap between modeled and observed temperature trends (Figure 4G, p. 13). However, the use of "range" is clearly inappropriate (Douglass et al. 2007) because it gives undue weight to outliers.

beyond the summary and have therefore been misled to believe the CCSP report supports anthropogenic warming. It does not.

The same information also can be expressed by plotting the difference between surface trend and troposphere trend for the models and for the data (Singer, 2001). As seen in Figure 4.1.1.4a and 4.1.1.4b, the models show a histogram of negative values (i.e., surface trend less than troposphere trend) indicating atmospheric warming will be greater than surface warming. By contrast, the data show mainly positive values for the difference in trends, demonstrating measured warming is occurring principally on the surface and not in the atmosphere.

The same information can be expressed in yet a different way, as seen in research papers by Douglass *et al.* (2004, 2007), as shown in Figure 4.1.1.5. The models show an increase in temperature trend with altitude, but the observations show the opposite.

This mismatch of observed and modeled warming of the tropical troposphere has been upheld most recently by Singer (2013), and this incongruity between model projection and data observations clearly falsifies the model output. The IPCC seems to be aware of this contrary evidence but has tried to ignore it or wish it away. The summary for policymakers of IPCC's *Fourth Assessment Report* (IPCC 2007-I, p. 5) distorts the key result of the

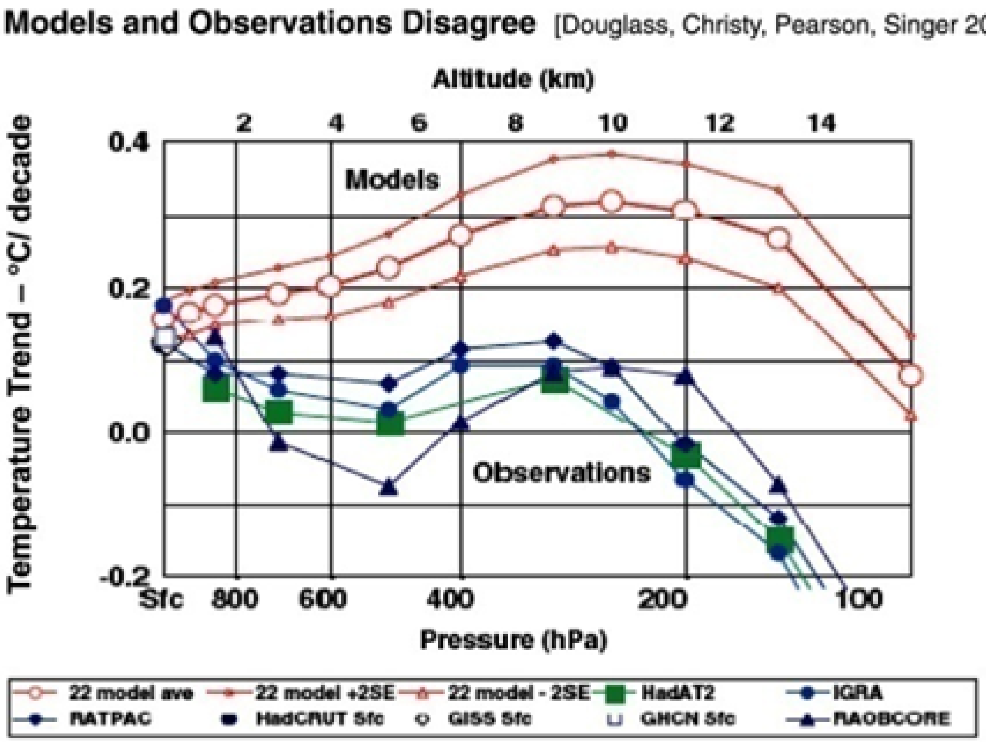


Figure 4.1.1.5. A more detailed view of the disparity of temperature trends is given in this plot of trends (in degrees C/decade) versus altitude in the tropics. Models show an increase in the warming trend with altitude, but balloon and satellite observations do not. Adapted from Douglass, D.H., Christy, J.R., Pearson, B.D., and Singer, S.F. 2007. A comparison of tropical temperature trends with model predictions. *International Journal of Climatology* (Royal Meteorological Society). DOI:10.1002/joc.1651.

CCSP report: "New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates that are similar to those of the surface temperature record, and are consistent within their respective uncertainties, largely reconciling a discrepancy noted in the TAR." How is this possible? It is done partly by using the concept of "range" instead of the statistical distribution shown in Figure 4.1.1.4a. But "range" is not a robust statistical measure because it gives undue weight to "outlier" results. If robust probability distributions were used, they would show an exceedingly low probability of any overlap of the modeled and observed temperature trends.

If one takes greenhouse model results seriously, the greenhouse fingerprint would suggest the true surface trend should be only 30 to 50 percent of the observed balloon/satellite trends in the troposphere. In that case, one would end up with a much-reduced surface warming trend, an insignificant anthropogenic effect, and a minor greenhouse-induced warming in the future.

While discussing other important failures in model performance, Spencer (2013) also highlights this model vs. observation discrepancy of temperatures in the tropical troposphere. In written testimony before the U.S. Senate Environment and Public Works Committee, he notes "the only truly global temperature measurements, unaffected by artifacts such as urban heat island effects, are for the bulk atmosphere from Earth-orbiting satellites," adding, "all other measurements are at points and so are geographically incomplete."

The composite satellite record of temperature anomalies of the lower troposphere is presented in Figure 4.1.1.6. Spencer discusses several significant features elucidated by this record:

1. The magnitude of global-average atmospheric warming between 1979 and 2012 is only about

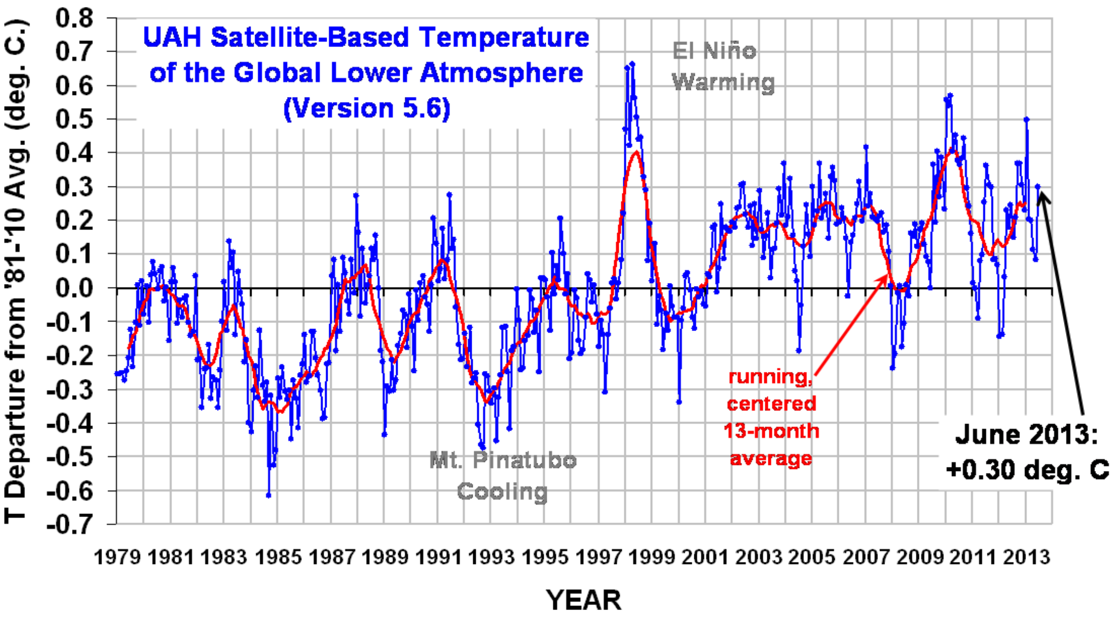


Figure 4.1.1.6. UAH global lower tropospheric (LT) temperature variations between January 1979 and June 2013. Adapted from Spencer, R.W. 2013. Statement to the U.S. Senate Environment and Public Works Committee, 19 July 2013, Washington, DC.

50% that predicted by the climate models relied upon by the IPCC in their projections of global warming.

2. The level of warming in the most recent 15 year period is not significantly different from zero, despite this being the period of greatest greenhouse gas concentration. This is in stark contrast to claims that warming is "accelerating."

3. The level of observed tropical atmospheric warming since 1979 is dramatically different from that predicted by climate models; it is below the projections of all 73 models we have analyzed (see Figure 4.1.1.7).

With respect to his third point, Spencer provides a graph of mid-tropospheric temperature variations for the tropics (20°N to 20°S) in 73 current (CMIP5) climate models versus measurements made from two satellite and four weather balloon datasets. His graph is reproduced here as Figure 4.1.1.7.

The level of disagreement between the models and observations of tropical mid-tropospheric temperatures in Figure 4.1.1.7 is striking. It reveals, for example, the models' projected average values are 0.5°C higher than observations at the end of the record. Although these data are restricted to the tropics (from 20°N to 20°S), Spencer notes "this is where almost 50% of the solar energy absorbed by the Earth enters the climate system."

Comparing the models' output with observational data, Spencer notes the difference is "related to the lack of a middle- and upper-tropospheric 'hotspot' in the observations, which the models produce in response to surface warming combined with positive water vapor feedback," leading him to state, "the observations might be telling us that the global warming response to increasing CO_2 (and any natural warming influence) is not being amplified by water vapor."

Spencer candidly concludes:

> It is time for scientists to entertain the possibility that there is something wrong with the assumptions built into their climate models. *The fact that all of the models have been peer reviewed does not mean that any of them have been deemed to have any skill for predicting future temperatures.* In the parlance of the *Daubert* standard for rules of scientific evidence, the models have not been successfully *field tested* for predicting climate change, and so far their *error rate* should preclude their use for predicting future climate change (Harlow & Spencer, 2011) .

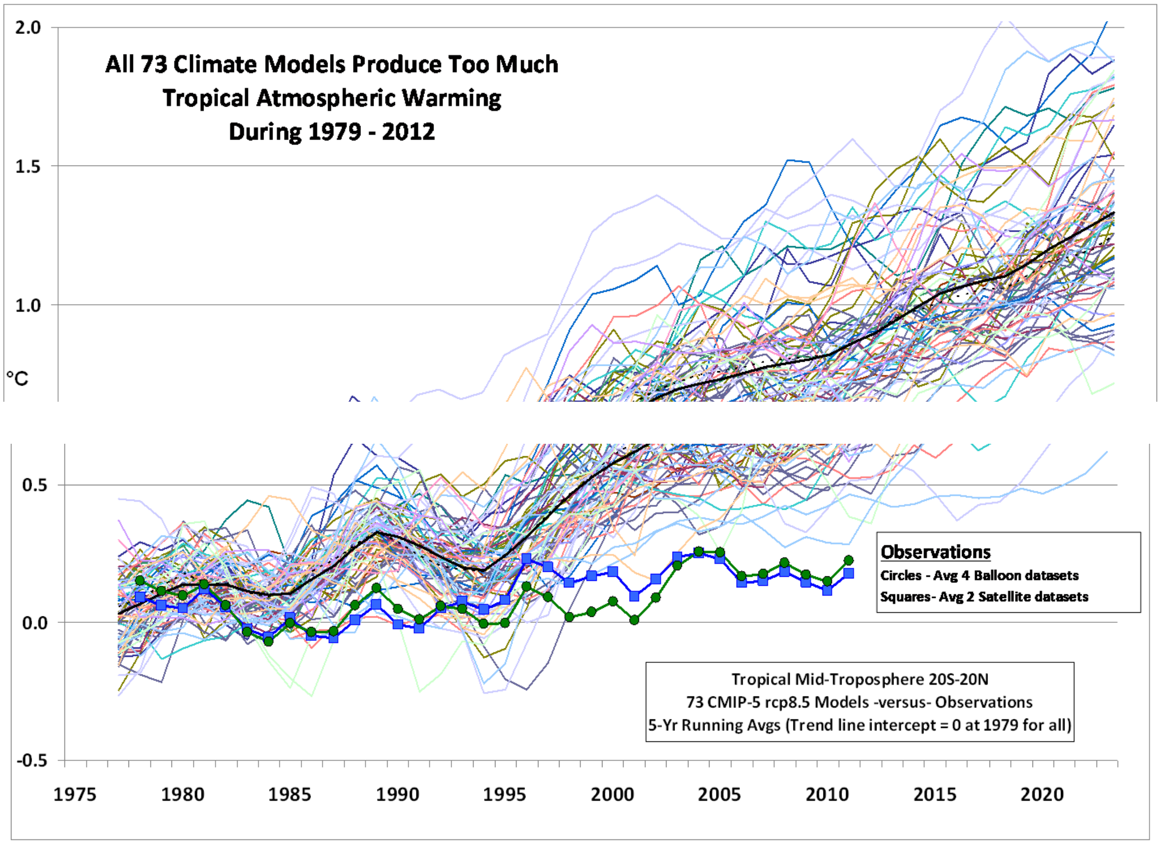


Figure 4.1.1.7. Mid-tropospheric (MT) temperature variations for the tropics (20°N to 20°S) in 73 current (CMIP5) climate models versus measurements from two satellite datasets and four weather balloon datasets. Adapted from Spencer, R.W. 2013. Statement to the U.S. Senate Environment and Public Works Committee, 19 July 2013, Washington, DC.

The fourth assumption made by the IPCC in its attribution of the late twentieth century rise in temperature to anthropogenic greenhouse gas increases is that the models correctly depict and account for natural variability. They most certainly do not, as evidenced by material presented in all of the chapters of this volume. The material presented in Section 4.2 emphasizes this point with respect to temperature, demonstrating repeatedly the reality of decadal, centennial, and millennial oscillations that occur naturally and are fully capable of explaining all of the warming experienced during the Current Warm Period. In addition, the warming of the global oceans to 2,000 m depth since the 1950s corresponds to a radiative energy imbalance of only 1 part in 1,000 (Levitus *et al*., 2012), raising the question of whether scientists can attribute this small change to humans rather than nature.

Hundreds of peer-reviewed papers have presented evidence indicating temperatures of the past several decades are not unusual, unnatural, or unprecedented on a hemispheric or global scale. It is very likely the magnitude of prior warmth, such as what was experienced during both the Roman and Medieval Warm Periods, exceeded or was at least equal to the warmth of the Current Warm Period. Since temperatures were as warm back then, when atmospheric CO_2 concentrations were much lower than they are now, there are valid empirical reasons to conclude the temperature increase of the past century has occurred independently of the concomitant 40 percent increase in atmospheric CO_2. Real-world observations reveal the Current Warm Period is simply a manifestation of the natural progression of a persistent millennial-scale climate oscillation that regularly brings Earth several-hundred-year periods of modestly higher and lower temperatures totally independent of variations in atmospheric CO_2 concentration.

Clearly, the IPCC's attribution of recent twentieth century warming to rising greenhouse gas concentrations is speculative at best.

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4.1.2 Urbanization Biases Still Taint Modern Temperature Records

The warming of near-surface air over non-urban areas of the planet during the past one to two centuries is believed to have been less than 1°C. Warming in many growing cities, on the other hand, may have been a full order of magnitude greater. Thus, since nearly all near-surface air temperature records of this period have been obtained from sensors located in population centers that have experienced significant growth, it is essential that urbanization-induced warming be removed from all original temperature records when attempting to accurately assess what has truly happened in the natural non-urban environment.

According to the IPCC, such urban influences have been mathematically accounted for and removed from the temperature records they utilize, effectively allowing them to conclude most of the remaining warming of the past few decades is the result of a human influence.

> Recent studies confirm that effects of urbanization and land use change on the global temperature

> record are negligible (less than 0.006°C per decade over land and zero over the ocean) as far as hemispheric and continental-scale averages are concerned. All observations are subject to data quality and consistency checks to correct for potential biases. The real but local effects of urban areas are accounted for in the land temperature data sets used (Technical Summary of AR4, p. 36)

> It is *likely* that urban heat-island effects and land use change effects have not raised the centennial global land surface air temperature trends by more than 10% of the observed trend. This is an average value; in some regions that have rapidly developed, urban heat island and land use change impacts on regional trends have been substantially larger (Second Order Draft of AR5, dated October 5, 2012, p. 2-4)

The 0.006°C per decade figure is presented as a research finding, but it is derived from mere conjecture. Section 2.3.3 of Brohan *et al*. (2006) states that to properly adjust the data would require a global comparison of urban versus rural records, but classifying records in this way is not possible since "no such complete meta-data are available" (p. 11), so the authors instead made an arbitrary assumption (p. 11) that the bias is no larger than 0.06 degrees per century.

As shown in the subsections below, filtering out urbanization and related land-use effects in the temperature record is a complicated task. There is solid evidence the methods currently used are inadequate, implying urbanization may account for a larger portion of the modern temperature rise than the IPCC acknowledges. Based on the studies reviewed below, it would appear almost certain surface-based temperature histories of the globe contain a significant warming bias introduced by insufficient corrections for the urban heat island effect. It may be impossible to make proper corrections for this deficiency, as the urban heat island effect of even small towns dwarfs any concomitant augmented greenhouse effect that may be present.

4.1.2.1 Global

Using a global dataset developed by Van Aardenne *et al*. (2001) that reveals the spatial distribution of levels of industrial activity over the planet as quantified by the intensity of anthropogenic CO_2 emissions, De Laat and Maurellis (2004) divided the surface of Earth into nonindustrial and industrial sectors of various intensity levels. They then plotted the 1979–2001 temperature trends (°C/decade) of the sectors using data from the surface and the lower and middle troposphere. The two scientists determined "measurements of surface and lower tropospheric temperature change give a very different picture from climate model predictions and show strong observational evidence the degree of industrialization is correlated with surface temperature increases as well as lower tropospheric temperature changes." They found the surface and lower tropospheric warming trends of all industrial regions were greater than the mean warming trend of Earth's nonindustrial regions, and the difference in warming rate between the two types of land-use grows ever larger as the degree of industrialization increases.

De Laat and Maurellis note, "areas with larger temperature trends (corresponding to higher CO_2 emissions) cover a considerable part of the globe," which implies "the 'real' global mean surface temperature trend is very likely to be considerably smaller than the temperature trend in the CRU [Hadley Center/Climate Research Unit] data," since the temperature measurements in that database "are often conducted in the vicinity of human (industrial) activity." These observations, they write, "suggest a hitherto-overlooked driver of local surface temperature increases, which is linked to the degree of industrialization" and lend "strong support to other indications that surface processes (possibly changes in land-use or the urban heat effect) are crucial players in observed surface temperature changes (Kalnay and Cai, 2003; Gallo *et al*., 1996, 1999)." Thus they conclude "the observed surface temperature changes might be a result of local surface heating processes and not related to radiative greenhouse gas forcing."

McKitrick and Michaels (2004) calculated 1979–2000 linear trends of monthly mean near-surface air temperature for 218 stations in 93 countries, using raw station data obtained from the Goddard Institute of Space Studies (GISS). They regressed the results against indicators of local economic activity such as income, gross domestic product growth rates, and coal use. They found, as expected, correlations between the spatial patterns of local socioeconomic measures and the magnitude of warming trends.

They repeated the process using the gridded surface air temperature data of the Climatic Research Unit (CRU) that had been adjusted to remove such effects. They found smaller but similar patterns that were statistically significant and added up to a net warming bias, although they note "precise estimation of its magnitude will require further work." Providing that estimation in a follow-up paper three years later, McKitrick and Michaels (2007) conclude the net warming bias accounted for "about half" of the estimated 1980–2002 global average temperature trend over land.

These and similar studies evidently posed a problem for the lead authors of the IPCC AR4, since their estimates of the magnitude of twentieth century warming and its attribution to GHGs relied on the assumption that the surface temperature record was more or less uncontaminated. For example, in one of the Climategate emails from IPCC Lead Author Phil Jones to his colleague Michael Mann, dated July 8, 2004, Jones confided he and IPCC coauthor Kevin Trenberth were determined to keep this evidence out of the IPCC report:

> I can't see either of these papers being in the next IPCC report. Kevin [Trenberth] and I will keep them out somehow—even if we have to redefine what the peer-review literature is!

Consistent with that plan, no mention of these studies was made in the IPCC report drafts shown to reviewers. After the close of expert review, a statement was inserted into the published version (IPCC 2007, Chapter 3, p. 244) acknowledging the spatial pattern of warming matched that of industrialization but claiming "the correlation of warming with industrial and socioeconomic development ceases to be statistically significant" once the effects of atmospheric circulation changes are taken into account, a claim for which there was no supporting evidence. McKitrick (2010) subsequently tested the claim and showed it to be untrue. The U.S. Environmental Protection Agency nevertheless relied verbatim on this claim in its dismissal of comments on an endangerment finding related to greenhouse gas emissions (see http://www.epa.gov/climatechange/endangerment/comments/volume2.html#2).

Klotzbach *et al.* (2009) tested the data contamination issue in a different way. If there is no contamination of surface data due to land use changes, they noted, the difference between surface trends and satellite-based measures of the lower troposphere should be constant over time. But the trends diverge, and the divergence runs opposite to the direction predicted by climate models. They conclude contamination of the surface data through land surface changes was a likely explanation.

Schmidt (2009) claims the McKitrick and Michaels results are likely spurious because of spatial autocorrelation in the temperature data, and he asserts it was unlikely similar patterns could be found across different climate datasets. He claims similar correlations could be found in GCM-generated data that, by construction, is not contaminated with urbanization. But Schmidt did not test his assertion about spatial autocorrelation, and his model-generated data failed to exhibit the claimed correlations.

McKitrick and Nierenberg (2010) tested Schmidt's conjectures in detail and showed them to be untrue. The evidence of data contamination was shown to be consistent across multiple combinations of surface and satellite data. It was not affected by spatial autocorrelation and it could not be replicated in data generated by the GISS climate model.

McKitrick and Tole (2012) went further and examined all 22 climate models used for the AR4, testing the models' ability to explain the spatial pattern of trends over 1979–2002, alone or in any linear combination, in comparison with indicators of urbanization and fixed geographical factors. After removing the 10 GCMs that generated predicted surface temperature trends anti-correlated with observations, they used Bayesian Model Averaging to evaluate 2^{19} possible linear combinations of explanatory models. They conclude only 2 of 22 climate models had significant explanatory power, and the optimal model of surface temperature changes required inclusion of measures of industrialization.

The IPCC also has relied on an argument by Parker (2004, 2006), who examined nighttime minimum urban temperature trends. He argues if urbanization had a significant effect, the observed warming would be less in a sample selected on nights with higher wind speed, but he found no such differences. He concludes urban warming could not be a significant factor in global averages. More recently, Wickham *et al.* (2013) tested the issue by partitioning the Berkeley Earth Surface Temperature (BEST) dataset using satellite-based measures of rural and urban locations and found no significant difference in average trends, likewise concluding land surface changes could not be a factor in global average trends.

Neither of these approaches addressed the evidence in the original McKitrick and Michaels (2004, 2007) studies. McKitrick (2013) demonstrated a Parker-type result, with equivalent trends on calm and windy nights, could be replicated on a dataset known on independent grounds to be contaminated with strong urbanization effects. And he demonstrated the Wickham *et al.* methodology was defective because their results were consistent either with the absence of an urbanization bias or its presence, and a more detailed statistical model would be required to determine which actually was the case.

That an urban heat island-induced error has indeed corrupted databases claimed to be immune from it is also suggested by the work of Hergerl and Wallace (2000), who attempted to determine whether trends in recognizable atmospheric modes of variability could account for all or part of the observed trend in surface-troposphere temperature differential; i.e., lapse rate, which has been driven by the upward-inclined trend in surface-derived temperatures and the nearly level trend in satellite-derived tropospheric temperatures over the last two decades of the twentieth century.

The two researchers found "modes of variability that affect surface temperature cannot explain trends in the observed lapse rate," and "no mechanism with clear spatial or time structure can be found that accounts for that trend." In addition, they acknowledge "all attempts to explain all or a significant part of the observed lapse rate trend by modes of climate variability with structured patterns from observations have failed," and "an approach applying model data to isolate such a pattern has also failed." Nor could they find any evidence "that interdecadal variations in radiative forcing, such as might be caused by volcanic eruptions, variations in solar output, or stratospheric ozone depletion alone, offer a compelling explanation." They conclude, "there remains a gap in our fundamental understanding of the processes that cause the lapse rate to vary on interdecadal timescales."

One reason no meteorological or climatic explanation could be found for the ever-increasing difference between the surface- and satellite-derived temperature trends of the past 20-plus years may be that one of the temperature records is incorrect. Faced with this possibility, one might want to determine which of the records is likely to be erroneous and then assess the consequences of that determination. Although this task may seem daunting, it is not that difficult. Hergerl and Wallace found good correspondence between the satellite and radiosonde temperature trends, leaving little reason to doubt the veracity of the satellite results, since this comparison essentially amounts to an *in situ* validation of the satellite record. It would be easy for a spurious warming of 0.12°C per decade to be introduced into the surface air temperature trend as a consequence of the worldwide intensification of the urban heat island effect likely driven by the worldwide population increase that manifested in most of the places where surface air temperature measurements were made over the last two decades of the twentieth century.

Other scientists have considered whether the urban heat island is affected by the direct heating of near-surface air in towns and cities by the carbon dioxide dome that occurs above them. Balling *et al.* (2002) obtained vertical profiles of atmospheric CO_2 concentration, temperature, and humidity over Phoenix, Arizona from measurements made in association with once-daily aircraft flights conducted over a 14-day period in January 2000 that extended through, and far above, the top of the city's urban CO_2 dome during the times of the latter's maximum manifestation. They employed a one-dimensional infrared radiation simulation model to determine the thermal impact of the urban CO_2 dome on the near-surface temperature of the city.

The researchers found the CO_2 concentration of the air over Phoenix dropped off rapidly with altitude, returning from a central-city surface value on the order of 600 ppm to a normal non-urban background value of approximately 378 ppm at an air pressure of 800 hPa, creating a calculated surface warming of only 0.12°C at the time of maximum CO_2-induced warming potential, about an order of magnitude less than the urban heat island effect of cities the size of Phoenix. The authors conclude the warming induced by the urban CO_2 dome of Phoenix is possibly two orders of magnitude smaller than what is produced by other sources of the city's urban heat island. Although human activities are indeed responsible for high urban air temperatures, which can rise 10°C or more above those of surrounding rural areas, these high values are not the result of a local CO_2-enhanced greenhouse effect.

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4.1.2.2 Asia

In a study of the urban heat island effect in South Korea, Choi *et al*. (2003) compare the mean station temperatures of three groupings of cities (one comprised of four large urban stations with a mean 1995 population of 4,830,000, one of six smaller urban stations with a mean 1995 population of 548,000, and one of six "rural" stations with a mean 1995 population of 214,000) over the period 1968–1999. They found the "temperatures of large urban stations exhibit higher urban bias than those of smaller urban stations and that the magnitude of urban bias has increased since the late 1980s." They note "estimates of the annual mean magnitude of urban bias range from 0.35°C for smaller urban stations to 0.50°C for large urban stations," concluding "none of the rural stations used for this study can represent a true non-urbanized environment." They say their results are underestimates of the true urban effect, and "urban growth biases are very serious in South Korea and must be taken into account when assessing the reliability of temperature trends."

In a second study conducted in South Korea, Chung *et al.* (2004a) report there was an "overlapping of the rapid urbanization-industrialization period with the global warming era," and the background climatic trends from urbanized areas might therefore be contaminated by a growing urban heat island effect. To investigate this possibility, "monthly averages of daily minimum, maximum, and mean temperature at 14 synoptic stations were prepared for 1951–1980 (past normal) and 1971–2000 (current normal) periods," and "regression equations were used to determine potential effects of urbanization and to extract the net contribution of regional climate change to the apparent temperature change." Twelve of these stations were growing urban sites of various size, and two (where populations actually decreased) were rural, one being located inland and one on a remote island.

Over the 20 years that separated the two normal periods, Chung *et al*. report that in Seoul, where population increase was greatest, annual mean daily minimum temperature increased by 0.7°C, while a 0.1°C increase was detected at one of the two rural sites and a 0.1°C decrease was detected at the other, for no net change in their aggregate mean value. In the case of annual mean daily maximum temperature, a 0.4°C increase was observed at Seoul and a 0.3°C increase was observed at the two rural sites. Thus the change in the annual mean daily mean temperature was an increase of 0.15°C at the two rural sites, indicative of regional background warming of 0.075°C per decade. The change of annual mean daily mean temperature at Seoul was an increase of 0.55°C, or 0.275°C per decade, indicative of an urban-induced warming of 0.2°C per decade in addition to the regional background warming of 0.075°C per decade. Corresponding results for urban areas of intermediate size defined a linear relationship that connected these two extreme results when plotted against the logarithm of population increase over the two-decade period.

In light of the significantly intensifying urban heat island effect detected in their study, Chung *et al.* say it is "necessary to subtract the computed urbanization effect from the observed data at urban stations in order to prepare an intended nationwide climatic atlas," noting "rural climatological normals should be used instead of the conventional normals to simulate ecosystem responses to climatic change, because the urban area is still much smaller than natural and agricultural ecosystems in Korea."

Chung *et al*. (2004b) evaluated temperature changes at ten urban and rural Korean stations over the period 1974–2002. They found “the annual temperature increase in large urban areas was higher than that observed at rural and marine stations.” Specifically, they note, “during the last 29 years, the increase in annual mean temperature was 1.5°C for Seoul and 0.6°C for the rural and seashore stations,” while increases in mean January temperatures ranged from 0.8 to 2.4°C for the ten stations. In addition, they state, “rapid industrialization of the Korean Peninsula occurred during the late 1970s and late 1980s,” and when plotted on a map, “the remarkable industrialization and expansion ... correlate[s] with the distribution of increases in temperature.” Consequently, Chung *et al.* (2004b) found much, and in many cases most, of the warming experienced over the past several decades in the urban areas of Korea was the result of local urban influences not indicative of regional background warming.

Kim and Kim (2011) derived values of the total warming for cities on the Korean peninsula with temperature data from four cities covering the period 1909–2008, 12 cities covering 1954–2008, and 20 cities covering 1969–2008. Values of the urban warming effect were derived “by using the warming mode of Empirical Orthogonal Function (EOF) analysis of the 55 years of temperature data from 1954 to 2008.” The estimated amounts of urban warming were verified by means of a multiple linear regression equation with two independent variables: rate of population growth and total population. By subtracting the temperature increase due to urbanization from the total temperature increase of each city, they obtained what they call “greenhouse warming,” although it should more appropriately be identified as background warming, natural warming, or non-urban-induced warming, because forcings other than greenhouse gases may play a major role in the non-urban-induced portion of the total observed warming.

Kim and Kim report the mean total warming of the 12 cities over the period 1954–2008 was 1.37°C, of which 0.77°C was due to the growth of their urban heat islands and the remaining 0.60°C was due to other factors. In addition, they found “urban warming depends more on the population percent growth rate than the average population.” In the case of Pohang and Incheon, for example, which “have rapidly increasing populations due to rapid industrialization,” they note “the degree of urbanization was great.” In the case of Busan, which has a large and steady population, they discovered “the degree of urbanization was weak.” Thus “the rising trend of temperature appeared stronger in newly industrialized cities more than in large cities.”

Weng (2001) evaluated the effect of land cover changes on surface temperatures of the Zhujiang Delta (an area of slightly more than 17,000 km^2) via a series of analyses of remotely sensed Landsat Thematic Mapper data. They found between 1989 and 1997 the area of land devoted to agriculture declined by nearly 50 percent, while urban land area increased by close to the same percentage. After normalizing the surface radiant temperature for the years 1989 and 1997, they used image differencing to produce a radiant temperature change image, which they overlaid with images of urban expansion. The results indicated “urban development between 1989 and 1997 has given rise to an average increase of 13.01°C in surface radiant temperature.”

Chen *et al.* (2003) evaluated several characteristics of Shanghai’s urban heat island, including its likely cause, based on analyses of monthly meteorological data from 1961 to 1997 at 16 stations in and around this hub of economic activity that is one of the most flourishing urban areas in all of China. Defining the urban heat island of Shanghai as the mean annual air temperature difference between urban Longhua and suburban Songjiang, Chen *et al.* found its strength increased in essentially linear fashion from 1977 to 1997 by 1°C.

Chen *et al.* conclude “the main factor causing the intensity of the heat island in Shanghai is associated with the increasing energy consumption due to economic development,” noting in 1995 the Environment Research Center of Peking University determined the annual heating intensity due to energy consumption by human activities was approximately 25 Wm^{-2} in the urban area of Shanghai but only 0.5 Wm^{-2} in its suburbs. In addition, they point out the 0.5°C/decade intensification of Shanghai’s urban heat island is an order of magnitude greater than the 0.05°C/decade global warming of Earth over the past century, suggesting the ongoing intensification of even already-strong urban heat islands cannot be discounted.

Kalnay and Cai (2003) used differences between trends in directly observed surface air temperature and trends determined from the NCEP-NCAR 50-year Reanalysis (NNR) project (based on atmospheric vertical soundings derived from satellites and balloons) to estimate the impact of land-use changes on surface warming. Over undisturbed rural areas of the United States, they found the surface- and reanalysis-derived air temperature data yielded essentially identical trends, implying differences between the two approaches over urban areas would represent urban heat island effects. Zhou *et al.* (2004) applied the same technique over southeast China, using an improved version of reanalysis that includes newer physics, observed soil moisture forcing, and a more accurate characterization of clouds.

For the period January 1979 to December 1998, the eight scientists derived an "estimated warming of mean surface [air] temperature of 0.05°C per decade attributable to urbanization," which they say "is much larger than previous estimates for other periods and locations, including the estimate of 0.027°C for the continental U.S. (Kalnay and Cai, 2003)." They note, however, because their analysis "is from the winter season over a period of rapid urbanization and for a country with a much higher population density, we expect our results to give higher values than those estimated in other locations and over longer periods."

Zhang *et al.* (2005) used the approach of Kalnay and Cai (2003) to determine the impacts of land-use changes on surface air temperature throughout eastern China (east of 110°E), where rapid urbanization, deforestation, desertification, and other changes in land use have occurred over the past quarter-century, focusing on daily mean, maximum, and minimum air temperatures from 259 stations over the period 1960–1999. Their analyses indicate changes in land use had little or no influence on daily maximum temperatures, but they explain about 18 percent of the observed daily mean temperature increase and 29 percent of the observed daily minimum temperature increase in this region over the past 40 years, yielding decadal warming trends of about 0.12°C and 0.20°C for these two parameters, respectively.

Frauenfeld *et al.* (2005) used daily surface air temperature measurements from 161 stations located throughout the Tibetan Plateau (TP) to calculate the region's mean annual temperature for each year from 1958 through 2000, plus 2-meter temperatures from the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis (ERA-40), which "are derived from rawinsonde profiles, satellite retrievals, aircraft reports, and other sources including some surface observations." This approach, they write, results in "more temporally homogeneous fields" that provide "a better assessment of large-scale temperature variability across the plateau." Over the period 1958–2000, Frauenfeld *et al.* report, "time series based on aggregating all station data on the TP show a statistically significant positive trend of 0.16°C per decade," as also has been reported by Liu and Chen (2000). However, they state, "no trends are evident in the ERA-40 data for the plateau as a whole."

In discussing this discrepancy, the three scientists suggest "a potential explanation for the difference between reanalysis and station trends is the extensive local and regional land use change that has occurred across the TP over the last 50 years." They note, for example, "over the last 30 years, livestock numbers across the TP have increased more than 200% due to inappropriate land management practices and are now at levels that far exceed the carrying capacity of the region (Du *et al.*, 2004)." The resultant overgrazing, they write, "has caused land degradation and desertification at an alarming rate (Zhu and Li, 2000; Zeng *et al.*, 2003)," and "in other parts of the world, land degradation due to overgrazing has been shown to cause significant local temperature increases (e.g., Balling *et al.*, 1998)."

They also note "urbanization, which can result in 8°–11°C higher temperatures than in surrounding rural areas (e.g., Brandsma *et al.*, 2003), has also occurred extensively on the TP," as "construction of a gas pipeline in the 1970s and highway expansion projects in the early 1980s have resulted in a dramatic population influx from other parts of China, contributing to both urbanization and a changed landscape." Thus they state, "the original Tibetan section of Lhasa (i.e., the pre-1950 Lhasa) now only comprises 4% of the city, suggesting a 2400% increase in size over the last 50 years." And they note "similar population increases have occurred at other locations across the TP," and "even villages and small towns can exhibit a strong urban heat island effect."

Frauenfeld *et al.* contend "these local changes are reflected in station temperature records." We agree, and we note when the surface-generated anomalies are removed, as in the case of the ERA-40 reanalysis results they present, it is clear there has been no warming of the Tibetan Plateau since at least 1958. Other results reported in this section imply much the same about other parts of China and greater Asia. Thus the dramatic surface-generated late twentieth century warming of the world claimed by the IPCC, Mann *et al.* (1998, 1999), and Mann and Jones (2003) to represent mean global background conditions likely significantly overestimates the warming over the past 30 years and is therefore not a true representation of Earth's recent temperature history.

Based on temperature data obtained at the "national reference and basic stations" at Beijing and Wuhan, China, plus similar data from six rural stations near Beijing and four rural stations near Wuhan, Ren *et al*. (2007) calculated the rates of temperature rise over the periods 1961–2000 and 1981–2000 to determine what portion of the observed warming at these stations is truly background warming and what is spurious, urban-induced warming.

The authors determined the rate of increase in annual mean surface air temperature over the period 1961–2000 was 0.32°C/decade and 0.31°C/decade, respectively, for Beijing and Wuhan, but only 0.06°C/decade and 0.11°C/decade for the corresponding sets of rural stations that surround them. Spurious urban warming was responsible for more than 80 percent of the 1961–2000 temperature increase at Beijing and a little more than 64 percent of the temperature increase at Wuhan. For the period 1981–2000, spurious urban warming accounted for 61 percent of the Beijing temperature increase and 40 percent of the Wuhan increase. The researchers also report the Beijing and Wuhan stations are not located in the central parts of the cities, and their findings are thus not representative of the cities' downtown areas, where urban heat island effects would be expected to be even greater.

Ren *et al*. note the impact of urbanization on the surface air temperature trends of the two mega-city stations is much larger than what is reported for North China as a whole and for Hubei Province. Consequently, they conclude "it is likely that a larger part of the surface air temperature increase in the country as obtained from … national reference and basic stations has been caused by [an] enhanced urban heat island effect during the past decades." They say there is "a need for paying more attention to the selection of observational sites, and for further detecting and adjusting the urbanization-induced bias probably existing in surface air temperature records of city stations."

Ren *et al*. (2008) employed a dataset obtained from 282 meteorological stations, including all of the ordinary and national basic and reference weather stations of north China, to determine the urbanization effect on surface air temperature trends of that part of the country over the period 1961–2000. They categorized the stations based on city size expressed in millions of people: rural (<0.05), small city (0.01–0.10), medium city (0.10–0.50), large city (0.50–1.00), and metropolis (>1.00). They found mean annual surface air temperature trends over the period, in degrees C per decade, were 0.18 (rural), 0.25 (small city), 0.28 (medium city), 0.34 (large city), 0.26 (metropolis), and 0.29 (national), making the urban-induced component of the warming trend 0.07 (small city), 0.10 (medium city), 0.16 (large city), 0.08 (metropolis), and 0.11 (national), all of which are significant at the 0.01 level. The seven Chinese researchers conclude it is "obvious that, in the current regional average surface temperature series in north China, or probably in the country as a whole, there still remain large effects from urban warming," noting "the contribution of urban warming to total annual mean surface air temperature change as estimated with the national basic/reference dataset reaches 37.9%."

Yang *et al*. (2011) note the IPCC's *Fourth Assessment Report* states urban heat island (UHI) effects are real but only "local and have a negligible influence on global warming trends." However, Yang *et al.* write, the UHI effect is regarded by others "as one of the major errors or sources of uncertainty in current surface warming studies," citing Gong and Wang (2002) and Heisler and Brazel (2010). They state, "some research results indicate that this effect may play a more significant role in temperature trends estimated at multiple geographic scales," noting Pielke (2005) and Stone (2009) suggest "such results should be accorded more consideration in the mitigation of climate change."

Yang *et al*. use monthly mean surface air temperature data from 463 meteorological stations, including those from the 1981–2007 ordinary and national basic reference surface stations in east China and from the National Centers for Environmental Prediction and National Center for Atmospheric Research (NCEP-NCAR) Reanalysis, to investigate the effect of rapid urbanization on temperature change for six different categories of population size or density—metropolis, large city, medium-sized city, small city, suburban, and rural—as determined from satellite-measured nighttime light imagery and census data. The three researchers state their findings indicate "rapid urbanization has a significant influence on surface warming over east China," noting, "overall, UHI effects contribute 24.2% to regional average warming trends" and "the strongest effect of urbanization on annual mean surface air temperature trends occurs over the metropolis and large city stations, with corresponding contributions of about 44% and 35% to total warming, respectively," with UHI trends of 0.398°C and 0.26°C per decade. They also say the UHI warming trends and their contributions to the overall warming over east China provided in their paper "can still be regarded as conservative."

If such UHI trends continue, the Chinese scientists conclude, "certain metropolitan areas may experience a rate of warming well beyond the range projected by the global climate change scenarios of the IPCC," referencing Stone (2007), while adding, "the increasing divergence between urban and rural surface temperature trends highlights the limitations of the response policy to climate change [that] focus only on greenhouse gas reduction," citing Stone (2009).

Zhou and Ren (2011) used the daily temperature records of 526 measurement stations included among the China Homogenized Historical Temperature Datasets compiled by the National Meteorological Information Center of the China Meteorological Administration to evaluate trends in 15 extreme temperature indices for the period 1961–2008. Based on the earlier findings of Zhou and Ren (2009), which indicated the contribution of urban warming to overall warming often exceeded 50 percent, they adjusted their results to account for the impact of each site's urban heat island effect.

They discovered "urbanization intensified the downward trend in cold index series and the upward trend in warm indices related to minimum temperature." They report "the urbanization effect on the series of extreme temperature indices was statistically significant for the downward trends in frost days, daily temperature range, cool nights, and cool days," as well as for "the upward trends in summer days, tropical nights, daily maximum temperature, daily minimum temperature, and warm nights." For these indices, they state, "the contributions of the urbanization effect to the overall trends ranged from 10 to 100%, with the largest contributions coming from tropical nights, daily temperature range, daily maximum temperature and daily minimum temperature," adding, "the decrease in daily temperature range at the national stations in North China was caused entirely by urbanization."

Regarding the urban heat island phenomenon, the two researchers conclude their paper by stating "more attention needs to be given to the issue in future studies."

Gao and Liu (2012) studied the effect of the deforestation of portions of Heilongjiang Province in Northeast China, which has an annual temperature ranging from -4°C to +4°C, with its winters being "long and frigid" and its summers "short and cool." Their study covered two periods: 1958–1980, when forest cover was reduced from 238,335 km^2 to 216,009 km^2; and 1980–2000, when forest cover was further reduced to 207,629 km^2. Over the entire period the two researchers analyzed (1958–2000), there was a nationwide warming of 0.99°C, whereas the annual temperature of Heilongjiang Province rose by 1.68°C, which suggests a concomitant deforestation-induced warming of 0.69°C. Thus, in response to the 13 percent reduction in forest cover over the 42-year interval Gao and Liu analyzed, the mean annual temperature of Heilongjiang Province rose by 0.69°C, a substantial amount considering the temperature of the globe had risen by an average of only about 0.7°C since the start of the Industrial Revolution.

Tokairin *et al.* (2010) note the population of Jakarta, the capital of Indonesia, was approximately 12 million in 2000, whereas it had been about 5 million in the 1970s. They note the rapid population increase of the past few decades brought a rapid expansion of the city's urban area, adding to the strength of the urban heat island of the original "old city" of the 1970s. To evaluate the warming power of the newer infrastructure added around the central old city, Tokairin *et al.* analyzed the air temperature increase in the initially urbanized area of Jakarta over the 30-year period between the 1970s and the 2000s, using air temperature data provided by the country's National Climatic Data Center. They made a rough estimate of the sensible heat in the old city during the 2000s that originated in, and was transported from, the newly developed urban area.

The three researchers report "the sea breeze developed at an earlier time of day in the present day than in the 1970s" and "in the present-day case, a converging flow developed over the old city in association with the low pressure which formed over the same location." They further note "the daytime average and maximum air temperature in the old city were higher in the present day than in the 1970s by 0.6 and 0.9°C , respectively, due to the advection of heat from the new area" and "the amount of heat advected into the old city was estimated to be -0.7 Wm^{-2} in the 1970s and 77 Wm^{-2} in the 2000s."

Fujibe (2011) writes, "in the context of global climate change, urban warming can bias results obtained for background monitoring, as many of the observatories that have been in operation for a long time are located in cities." Nevertheless, Fujibe notes, the IPCC (2007) has suggested "the globally averaged temperature trend is hardly affected by urbanization." Unconvinced of the validity of the IPCC's assertion, the Japanese researcher reviews what is known about the subject based on research conducted in Japan.

Fujibe reports "the recorded rate of temperature increase is a few degrees per century in large cities and tends to be larger at night than during the daytime." In some cities, "the increase in annual extreme minimum temperature exceeds 10°C per century." Fujibe notes numerous studies have detected heat islands in small settlements "with a population of 1000 or less," as reported by Tamiya (1968), Tamiya and Ohyama (1981), Sakakibara and Morita (2002), Sakakibara and Kitahara (2003), and Sakakibara and Matsui (2005), where statistically significant trends on the order of 0.04°C per decade have been observed. Fujibe concludes, "urban warming can be a biasing factor that may contaminate data used for monitoring the background temperature change," with locations with low population densities of 100–300 people per square kilometer "showing a statistically significant anomalous trend of 0.04°C per decade."

Clearly, a substantial part of the past half-century's global warming, which the IPCC attributes to the greenhouse effect of CO_2 and methane, is nothing more than a manifestation of the well-known urban heat island effect, which is not properly removed from the various databases discussed here and probably many others. If such spurious warming is not accounted and appropriately adjusted for, public and scientific confidence in the quality of global temperature datasets will continue to decline.

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4.1.2.3 North America

In studying the urban heat island (UHI) of Houston, Texas, Streutker (2003) analyzed 82 sets of nighttime radiation data obtained from the split-window infrared channels of the Advanced Very High Resolution Radiometer on board the NOAA-9 satellite during March 1985 through February 1987 and from 125 sets of similar data obtained from the NOAA-14 satellite during July 1999 through June 2001. Between these two periods, the mean nighttime surface temperature of Houston rose by 0.82 ± 0.10 °C. In addition, Streutker notes the growth of the Houston UHI, both in magnitude and spatial extent, "scales roughly with the increase in population," and the mean rural temperature measured during the second interval was "virtually identical to the earlier interval."

Streutker's work demonstrates the UHI phenomenon can be very powerful, for in just 12 years the UHI of Houston grew by more than the IPCC contends the mean surface air temperature of the planet rose over the entire past century, when Earth's population rose by approximately 280 percent, or nearly an order of magnitude more than the 30 percent population growth experienced by Houston over the 12 years of Streutker's study.

Maul and Davis (2001) analyzed air and seawater temperature data obtained over the past century at the sites of several primary tide gauges maintained by the U.S. Coast and Geodetic Survey. Noting each of these sites "experienced significant population growth in the last 100 years," and "with the increase in maritime traffic and discharge of wastewater one would expect water temperatures to rise" (due to a maritime analogue of the urban heat island effect), they calculated trends for the 14 longest records and derived a mean century-long seawater warming of 0.74°C, with Boston registering an anomalous 100-year warming of 3.6°C. In addition, they report air temperature trends at the tide gauge sites, which represent the standard urban heat island effect, were "much larger" than the seawater temperature trends.

Dow and DeWalle (2000) analyzed trends in annual evaporation and Bowen ratio measurements on 51 eastern U.S. watersheds that experienced various degrees of urbanization between 1920 and 1990. They determined as residential development progressively occurred on what originally were rural watersheds, watershed evaporation decreased and sensible heating of the atmosphere increased. And from relationships derived from the suite of watersheds investigated, they calculated complete transformation from 100 percent rural to 100 percent urban characteristics resulted in a 31 percent decrease in watershed evaporation and a 13 Wm^{-2} increase in sensible heating of the atmosphere.

Climate modeling exercises suggest a doubling of the air's CO_2 concentration will result in a nominal 4 Wm^{-2} increase in the radiative forcing of Earth's surface-troposphere system, which often has been predicted to produce an approximate 4°C increase in the mean near-surface air temperature of the globe, indicative of an order-of-magnitude climate sensitivity of 1°C per Wm^{-2} change in radiative forcing. Thus, to a first approximation, the 13 Wm^{-2} increase in the sensible heating of the near-surface atmosphere produced by the total urbanization of a pristine rural watershed in the eastern United States reported by Dow and DeWalle could be expected to produce an increase of about 13°C in near-surface air temperature over the central portion of the watershed, which is consistent with maximum urban heat island effects observed in large and densely populated cities. Therefore, a 10 percent rural-to-urban transformation could produce a warming on the order of 1.3°C, and a mere 2 percent transformation could increase the near-surface air temperature by as much as a quarter of a degree Centigrade.

This powerful anthropogenic but non-greenhouse-gas-induced effect of urbanization on the energy balance of watersheds and the temperature of the boundary-layer air above them begins to express itself with the very first hint of urbanization and, hence, may be readily overlooked in studies seeking to identify a greenhouse-gas-induced global warming signal. In fact, the fledgling urban heat island effect already may be present in many temperature records routinely been considered "rural enough" to be devoid of all human influence, when in fact that may be far from the truth.

A case in point is provided by the study of Changnon (1999), who used a series of measurements of soil temperatures obtained in a completely rural setting in central Illinois between 1889 and 1952 and a contemporary set of air temperature measurements made in an adjacent growing community (plus similar data obtained from other nearby small towns) to evaluate the magnitude of unsuspected heat island effects that might be present in small towns and cities typically assumed to be free of urban-induced warming. This work revealed soil temperature in the completely rural setting increased by 0.4°C between the decade of 1901–1910 and 1941–1950.

This warming is 0.2°C less than the 0.6°C warming determined for the same time period from the entire dataset of the U.S. Historical Climatology Network, which is supposedly corrected for urban heating effects. It is also 0.2°C less than the 0.6°C warming determined for this time period by 11 benchmark stations in Illinois with the highest-quality long-term temperature data, all of which are located in communities with populations of less than 6,000 people as of 1990. And it is 0.17°C less than the 0.57°C warming derived from data obtained at the three benchmark stations closest to the site of the soil temperature measurements and with populations of less than 2,000 people.

Changnon states his findings suggest "both sets of surface air temperature data for Illinois believed to have the best data quality with little or no urban effects may contain urban influences causing increases of 0.2°C from 1901 to 1950." He further notes "this could be significant because the IPCC (1995) indicated that the global mean temperature increased 0.3°C from 1890 to 1950."

Clearly, the efforts of this world-renowned climate specialist call all near-surface global air temperature histories into question. Until the influence of very-small-town urban heat island effects is identified and accounted for, the so-called "unprecedented" global warming of the past century, and especially the past quarter-century, cannot be accepted at face value.

DeGaetano and Allen (2002b) used data from the U.S. Historical Climatology Network to calculate trends in the occurrence of maximum and minimum temperatures greater than the 90th, 95th, and 99th percentile across the United States over the period 1960–1996. In the case of daily warm minimum temperatures, the slope of the regression line fit to the data of a plot of the annual number of 95th percentile exceedences vs. year was found to be 0.09 exceedences per year for rural stations, 0.16 for suburban stations, and 0.26 for urban stations, making the rate of increase in extreme warm minimum temperatures at urban stations nearly three times greater than the rate of increase at rural stations less affected by growing urban heat islands. The rate of increase in the annual number of daily maximum temperature 95th percentile exceedences per year over the same time period was found to be 50 percent greater at urban stations than at rural stations.

Balling and Idso (2002) analyzed and compared temperature trends for the period 1979–2000 in the conterminous United States using six temperature databases:

- the unadjusted temperature data of the United States Historical Climatology Network (RAW);
- the RAW data adjusted for (a) time of observation biasing, (b) changes to the new maximum/ minimum temperature system equipment, (c) station history, including other instrument adjustments, and (d) an interpolation scheme for estimating missing data from nearby highly correlated station records (FILNET);
- essentially the FILNET data adjusted for urbanization effects (URB-ADJ);
- the updated dataset developed by Jones (1994) of the University of East Anglia (IPCC);
- the satellite-based lower-tropospheric temperature dataset (MSU2LT); and
- the radiosonde (balloon-based) temperature data that comprised "the surface reading taken the moment the balloon is launched," which "typically occurs near 1.5 m above the surface, which is near the shelter heights used in the USHCN data set" (SONDE).

In comparing the difference between the FILNET and RAW temperature trends, Balling and Idso found a nearly monotonic increase of more than 0.05°C per decade, which they found to be highly significant at the 0.0001 level of confidence. In addition, they found "the trends in the unadjusted temperature records [were] not different from the trends of the independent satellite-based lower-tropospheric temperature record or from the trend of the balloon-based near-surface measurements." The two Arizona State University Office of Climatology researchers state the adjustments made to the raw USHCN temperature data were "producing a statistically significant, but spurious, warming trend" that "approximates the widely-publicized 0.50°C increase in global temperatures over the past century."

Hinkel *et al.* (2003) installed 54 temperature-recording instruments on the Arctic Coastal Plain near the Chuckchi Sea at Barrow, Alaska in mid-June of 2001, half within the urban area and the other half distributed across approximately 150 km^2 of surrounding land, all of which provided air temperature data at hourly intervals approximately two meters above the surface of the ground. They describe the area as "the northernmost settlement in the USA and the largest native community in the Arctic," the population of which "has grown from about 300 residents in 1900 to more than 4600 in 2000."

Based on urban-rural spatial averages for the entire winter period (December 2001–March 2002), the four researchers determined the urban area to be 2.2°C warmer than the rural area. During this period, the mean daily urban-rural temperature difference increased with decreasing temperature, "reaching a peak value of around 6°C in January–February." They also determined the daily urban-rural temperature difference increased with decreasing wind speed, such that under calm conditions (< 2 m s^{-1}) the daily urban-rural temperature difference was 3.2°C in the winter. Finally, under simultaneous calm and cold conditions, the urban-rural temperature difference was observed to achieve hourly magnitudes exceeding 9°C.

For the period December 1 to March 31 of four consecutive winters, Hinkel and Nelson (2007) report the spatially averaged temperature of the urban area of Barrow was about 2°C warmer than that of the rural area, and it was not uncommon for the daily magnitude of the urban heat island to exceed 4°C. On some days, they note, the magnitude of the urban heat island exceeded 6°C, and values in excess of 8°C were sometimes recorded. The warmest individual site temperatures were "consistently observed in the urban core area," they report.

These findings indicate just how difficult it is to measure a background global temperature increase believed to have been less than 1°C over the past century (representing a warming of less than 0.1°C per decade), when the presence of a mere 4,500 people can create a winter heat island two orders of magnitude greater than the signal being sought. Temperature measurements made within the range of influence of even a small village cannot be adjusted to the degree of accuracy required to reveal the true magnitude of the pristine rural temperature change.

Ziska *et al*. (2004) characterized the gradual changes that occur in a number of environmental variables as one moves from a rural location (a farm approximately 50 km from the city center of Baltimore, Maryland) to a suburban location (a park approximately 10 km from the city center) to an urban location (the Baltimore Science Center, approximately 0.5 km from the city center). At each of these locations, four 2 x 2 m plots were excavated to a depth of about 1.1 m, after which they were filled with identical soils, the top layers of which contained seeds of naturally occurring plants of the area. These seeds sprouted in the spring of the year, and the plants they produced were allowed to grow until they senesced in the fall, after which all were cut at ground level, removed, dried, and weighed.

Along the rural-to-suburban-to-urban transect, the only consistent differences in the environmental variables they measured were a rural-to-urban increase of 21 percent in average daytime atmospheric CO_2 concentration and increases of 1.6 and 3.3°C in maximum (daytime) and minimum (nighttime) daily temperatures, respectively. These changes, they write, are "consistent with most short-term (~50 year) global change scenarios regarding CO_2 concentration and air temperature." They state, "productivity, determined as final above-ground biomass, and maximum plant height were positively affected by daytime and soil temperatures as well as enhanced CO_2, increasing 60 and 115% for the suburban and urban sites, respectively, relative to the rural site."

George *et al*. (2007) reported on five years of work at the same three transect locations near Baltimore, stating, "atmospheric CO_2 was consistently and significantly increased on average by 66 ppm from the rural to the urban site over the five years of the study," and "air temperature was also consistently and significantly higher at the urban site (14.8°C) compared to the suburban (13.6°C) and rural (12.7°C) sites." They note the increases in atmospheric CO_2 and air temperature they observed "are similar to changes predicted in the short term with global climate change, therefore providing an environment suitable for studying future effects of climate change on terrestrial ecosystems," specifically pointing out, "urban areas are currently experiencing elevated atmospheric CO_2 and temperature levels that can significantly affect plant growth compared to rural areas."

LaDochy *et al*. (2007) report, "when speculating on how global warming would impact the state [of California], climate change models and assessments often assume that the influence would be uniform (Hansen *et al*., 1998; Hayhoe *et al*., 2004; Leung *et al*., 2004)." To assess the validity of this assumption, they calculated temperature trends over the 50-year period 1950–2000 to explore the extent of warming in various subregions of the state. They then evaluated the influence of human-induced changes to the landscape on the observed temperature trends and determined their significance compared to those caused by changes in atmospheric composition, such as the air's CO_2 concentration.

The three researchers found "most regions showed a stronger increase in minimum temperatures than with mean and maximum temperatures," and "areas of intensive urbanization showed the largest positive trends, while rural, non-agricultural regions showed the least warming." They report the Northeast Interior Basins of the state experienced cooling. Large urban sites, by contrast, exhibited rates of warming "over twice those for the state, for the mean maximum temperature, and over five times the state's mean rate for the minimum temperature." They conclude, "if we assume that global warming affects all regions of the state, then the small increases seen in rural stations can be an estimate of this general warming pattern over land," which implies "larger increases," such as those they observed in areas of intensive urbanization, "must then be due to local or regional surface changes."

Rosenzweig *et al*. (2009) compared "the possible effectiveness of heat island mitigation strategies to increase urban vegetation, such as planting trees or incorporating vegetation into rooftops, with strategies to increase the albedo of impervious surfaces." They report, "surface air temperatures elevated by at least 1°C have been observed in New York City for more than a century (Rosenthal *et al*., 2003; Gaffin *et al*., 2008), and the heat island signal, measured as the difference between the urban core and the surrounding rural surface air temperature readings taken at National Weather Service stations, averages ~4°C on summer nights (Kirkpatrick and Shulman, 1987; Gedzelman *et al*., 2003; Gaffin *et al*., 2008)." The greatest temperature differences typically were sustained "between midnight and 0500 Eastern Standard Time (EST; Gaffin *et al*., 2008)." On a day they studied quite intensively (14 August 2002), they report at 0600 EST, "the city was several degrees warmer than the suburbs, and up to 8°C warmer than rural areas within 100 km of the city."

With respect to mitigation strategies, the 12 researchers determined "the most effective way to reduce urban air temperature is to maximize the amount of vegetation in the city with a combination of tree planting and green roofs." Based on modeling studies of these approaches, they estimate this strategy could reduce simulated citywide urban air temperature by 0.4°C on average and 0.7°C at 1500 EST, and reductions of up to 1.1°C at 1500 EST could be expected in some Manhattan and Brooklyn neighborhoods, "primarily because there is more available area in which to plant trees and install vegetated roofs." These findings reveal New York City already has experienced an urban-induced warming equivalent to what is predicted to occur by the end of the current century as a result of business-as-usual greenhouse gas emissions; planting additional vegetation throughout the city would likely moderate its thermal environment more than all the greenhouse-gas emissions reductions the world's governments are ever likely to make.

Imhoff *et al*. (2010) note the urban heat island (UHI) phenomenon is "caused by a reduction in latent heat flux and an increase in sensible heat in urban areas as vegetated and evaporating soil surfaces are replaced by relatively impervious low-albedo paving and building materials," and this replacement "creates a difference in temperature between urban and surrounding non-urban areas." Most studies of this phenomenon have evaluated its magnitude by means of ground-based measurements of near-surface air temperature made at urban and rural weather stations, and they have found the urban-rural air temperature difference is expressed most strongly at night. Imhoff *et al*., however, employed satellite-based measurements of surface temperature, and they found this alternative measure of the UHI was most strongly expressed during the day.

The authors' analysis included 38 of the most populous cities in the continental United States and their rural surroundings, where Imhoff *et al*. obtained land surface temperature (LST) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on NASA's Earth Observing System (EOS) satellites, which they used in a spatial analysis to assess UHI skin temperature amplitude and its relationship to development intensity, size, and ecological setting over three annual cycles (2003–2005), where urban impervious surface area (ISA) was obtained from the Landsat TM-based NLCD 2001 dataset.

The researchers report a city's fractional ISA was a good linear predictor of LST for all cities in the continental United States in all biomes except deserts and xeric shrublands, and the fraction of ISA explains about 70 percent of the total variance in LST for all cities combined, with the highest correlations (90 percent) in the northeastern United States, where urban areas are often embedded in temperate broadleaf and mixed forests. They also determined the largest urban-rural LST differences for all biomes occurred during the summer around midday, and the greatest amplitudes were found for urban areas that displaced forests (6.5–9.0°C) followed by temperate grasslands (6.3°C) and tropical grasslands and savannas (5.0°C). Finally, they determined the contrast between urban cores and rural zones was typically "accentuated during the time when the vegetation is physiologically active, especially in forested lands," and "the amplitude of the UHI is significantly diminished during the winter season when vegetation loses its leaves or is stressed by lower temperatures." Imhoff *et al*. conclude "the use of ISA as an estimator of the extent and intensity of urbanization is more objective than population density based methods and can be consistently applied across large areas for inter-comparison of impacts on biophysical processes."

Gonzalez *et al*. (2005) note "breezy cities on small tropical islands ... may not be exempt from the same local climate change effects and urban heat island effects seen in large continental cities," describing research they conducted in and around San Juan, Puerto Rico. A NASA Learjet carrying the Airborne Thermal and Land Applications Sensor (ATLAS) that operates in visual and infrared wavebands flew several flight lines, both day and night, over the San Juan metropolitan area, the El Yunque National Forest east of San Juan, and other nearby areas, obtaining surface temperatures, while strategically placed ground instruments recorded local air temperatures. They found surface temperature differences between urbanized areas and limited vegetated areas were higher than 30°C during daytime, creating an urban heat island with "the peak of the high temperature dome exactly over the commercial area of downtown," where noontime air temperatures were as much a 3°C greater than those of surrounding rural areas. In addition, the 11 researchers report, "a recent climatological analysis of the surface [air] temperature of the city has revealed that the local temperature has been increasing over the neighboring vegetated areas at a rate of 0.06°C per year for the past 30 years."

Gonzalez *et al*. state "the urban heat island dominates the sea breeze effects in downtown areas," and "trends similar to those reported in [their] article may be expected in the future as coastal cities become more populated."

Velazquez-Lozada *et al*. (2006) evaluated the thermal impacts of historical land cover and land use (LCLU) changes in San Juan, Puerto Rico over the last four decades of the twentieth century by analyzing air temperatures measured at a height of approximately two meters above ground level within four different LCLU types (urban-coastal, rural-inland, rural-coastal, and urban-inland). They estimated what the strength of the urban heat island might be in the year 2050, based on anticipated LCLU changes and a model predicated on their data of the past 40 years. Their work revealed "the existence of an urban heat island in the tropical coastal city of San Juan, Puerto Rico that has been increasing at a rate of 0.06°C per year for the last 40 years." They report predicted LCLU changes between now and 2050 will lead to an urban heat island effect "as high as 8°C for the year 2050."

Noting a mass population migration from rural Mexico into medium- and large-sized cities took place throughout the second half of the twentieth century, Jáuregui (2005) examined the effect of this rapid urbanization on city air temperatures, analyzing the 1950–1990 minimum air temperature series of seven large cities with populations in excess of a million people and seven medium-sized cities with populations ranging from 125,000 to 700,000 people. Temperature trends were positive at all locations, ranging from 0.02°C per decade to 0.74°C per decade. Grouped by population, the average trend for the seven large cities was 0.57°C per decade, and the average trend for the seven mid-sized cities was 0.37°C per decade. These results, Jáuregui writes, "suggest that the accelerated urbanization process in recent decades may have substantially contributed to the warming of the urban air observed in large cities in Mexico," once again illustrating the magnitude of the urban heat island effect compared to the global warming of the past century, as well as the urban heat island's dependence on the nature of the urban landscape. This further suggests it is next to impossible to adjust surface air temperature measurements made within an urban area to the degree of accuracy required to correctly quantify background or rural climate change, which may be an order of magnitude or two smaller than the perturbing effect of the city.

Garcia Cueto *et al*. (2009) used daily records of maximum and minimum temperature from six weather stations "in Mexicali City [Mexico] and its surroundings" covering the period 1950–2000, and "a climatic network of rural and urban weather stations in Mexicali and its valley and the Imperial Valley, California" over the "contemporary period (2000–2005)," to characterize the spatial and temporal development of the city's urban heat island over the latter half of the twentieth century and the first five years of the twenty-first century. Mexicali City is located along the border of the United States at the northern end of Mexico's Baja California. It is an urban settlement that had its beginnings in the first decade of the twentieth century, when it had an area of approximately 4 km^2; by 1980 it covered a little more than 40 km^2, and by 2005 it extended over more than 140 km^2.

The researchers found Mexicali City "changed from being a cold island (1960–1980) to a heat island with a maximum intensity of 2.3°C in the year 2000, when it was compared with rural weather stations of Imperial, California," concluding "the replacement of irrigated agricultural land by urban landscapes, anthropogenic activity and population growth, appear to be the major factors responsible for the observed changes." From "more updated information (2000–2005)," they found "the greatest intensity of the urban heat island was in winter with a value of 5.7°C, and the lowest intensity in autumn with 5.0°C."

These North American studies confirm the impact of population growth on the urban heat island effect is very real and can be very large, vastly overshadowing the effects of natural temperature change. As Oke (1973) demonstrated four decades ago, towns with as few as a thousand inhabitants typically create a warming of the air within them that is more than twice as great as the increase in mean global air temperature believed to have occurred since the end of the Little Ice Age, and the urban heat islands of the great metropolises of the world create warmings that rival those that occur between full-fledged ice ages and interglacials.

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4.2.2.4 Rest of World

The previous two subsections examined the effects of urbanization on temperatures in Asia and North America. This section reviews studies examining this phenomenon in other parts of the world.

Bohm (1998) studied nine urban, suburban, and rural temperature records (three of each type, determined to be the best available on the basis of careful study from a total of 34 available records) to determine the evolving nature of the heat island of Vienna, Austria between 1951 and 1996, a 45-year period in which the city experienced zero population growth. Simultaneously, however, there was a 20 percent decrease in woodland and a 30 percent decrease in grassland within the city, as well as a doubling of the number of buildings; a tenfold increase in the number of cars; a 60 percent increase in street, pavement, and parking area; and a 2.5-fold increase in energy consumption. Bohm found the suburban stations exhibited city-induced temperature increases ranging from 0.11 to 0.21°C over the 45-year period of the study, while the urban stations experienced city-induced temperature increases ranging from zero, in the historic center of the city, to 0.6°C in the area of most intensive urban development.

Bohm writes, "the case study of Vienna illustrates the weakness inherent in studies which use only two stations to describe urban heat islands or use linear regression models to connect population directly to heat island intensity and trend." Both of these procedures are typically used in making corrections for urban heat island effects in studies of global near-surface air temperature trends. More detailed analyses of urban development characteristics are needed to correct the global temperature record of the past century to account for these phenomena.

Bottyan *et al.* (2005) examined the influence of built-up areas on the near-surface air temperature field of Debrecen, Hungary, which sits on nearly flat terrain in the Great Hungarian Plain with a population of 220,000. The researchers used mobile measurements made under different types of weather conditions between March 2002 and March 2003. The researchers found "the area of the mean maximum UHI [urban heat island] intensity of higher than 2°C is 76 times larger in the non-heating season than in the heating season (0.5% and 38% respectively)," and "the strongest developments of UHI occurring in the warmer and colder periods were 5.8°C and 4.9°C respectively." They also state they "proved a strong linear relationship between the mean UHI intensity and the urban parameters studied, such as built-up ratio and its areal extensions, in both seasons."

Hughes and Balling (1996) analyzed near-surface air temperature data from what they describe as "five very large metropolitan areas and 19 stations from non-urban locations" of South Africa for the period 1960–1990, comparing their results with those of Jones (1994) for the same time interval. The pair of scientists report the mean annual air temperature trend of the five large cities averaged 0.24°C per decade, and the mean warming rate of the 19 non-urban centers was a statistically insignificant 0.09°C per decade over the 1960–1990 period, compared to the overall warming rate of 0.31°C per decade derived by Jones for the entire country.

In addition, Hughes and Balling note, the mean rate-of-warming difference between their urban and non-urban sites was driven primarily by increases in daily minimum temperatures, which rose at a mean rate of 0.07°C per decade at the non-urban stations but an average rate of 0.34°C per decade at the five large cities. The "disparate trends in temperature" between the urban and non-urban stations "suggest that urbanization has influenced the Jones (1994) records for South Africa over the 1960–1990 period of apparent rapid warming," and "half or more of this recent warming may be related to urban growth, and not to any widespread regional temperature increase."

Torok *et al.* (2001) studied urban heat islands in several cities in Australia with populations ranging from approximately 1,000 to 3,000,000 people. They report the maximum urban-rural temperature differences of the Australian cities were found to scale linearly with the logarithms of their populations, and Torok *et al.* note the same was true for cities in Europe and North America. The heat islands of Australian cities were generally less than those of similar-size European cities (which were less than similar-size North American cities), and they increased at a slower rate with population growth than did European cities (which increased more slowly than did cities in North America). The regression lines of all three continents essentially converged in the vicinity of a population of 1,000 people, however, where the mean maximum urban-rural temperature difference was approximately 2.2 ± 0.2 °C.

The four researchers note their experimental results "were sampled during atypical conditions which were suitable for maximum urban heat island genesis," and therefore "they cannot be used to adjust long-term annual mean temperature records for urban influences." Nevertheless, they say their results imply "climatological stations in large cities should preferably be excluded from studies into long-term climate change," and "those in small towns should be located away from the town centers."

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4.1.3 Potential Problems with Climate Proxies

In addition to the errors that can affect temperature records of the modern era, such as those associated with urbanization as discussed in the previous section, several potential inaccuracies can, if not properly accounted for, adversely influence proxy temperature records of the more distant past. This section highlights some of the problems that have been identified, starting with a discussion of tree-ring proxies, as the IPCC has heavily relied on such proxies in the past.

Two tree-ring characteristics have been used to reconstruct histories of past air temperature trends around the world: tree-ring *density* and tree-ring *width*. Temperature histories derived from the first of these properties are considered to be more accurate than reconstructions based on tree-ring width, as the latter are falsely influenced by the productivity-enhancing effect of the rise in the air's CO_2 content, which has dramatically increased tree-ring widths, particularly over the past 70 years. This tree-ring growth record has been falsely attributed to a dramatic increase in air temperature, when in reality Earth has experienced no net warming over this period.

Cowling and Sykes (1999) note many methods of palaeoclimate reconstruction "are built upon the assumption that plant-climate interactions remain the same through time or that these interactions are independent of changes in atmospheric CO_2." This assumption had been challenged nearly a dozen years earlier by Idso (1989a) and a few years later by Polley *et al.* (1993). Other scientists reached the same conclusion, resulting in a sufficient volume of published research on the topic to conduct a review of it. Cowling and Sykes conducted such a review and conclude "a growing number of physiological and palaeoecological studies indicate that plant-climate interactions are likely not the same through time because of sensitivity to atmospheric CO_2." They explain "C_3-plant physiological research shows that the processes that determine growth optima in plants (photosynthesis, mitochondrial respiration, photorespiration) are all highly CO_2-dependent." Moreover, "the ratio of carbon assimilation per unit transpiration (called water-use efficiency) is sensitive to changes in atmospheric CO_2 and "leaf gas-exchange experiments indicate that the response of plants to carbon-depleting environmental stresses are strengthened under low CO_2 relative to today."

These phenomena combine to produce dramatic increases in plant growth and water use efficiency with increases in the air's CO_2 content. Such increases in vegetative vigor had been interpreted (to the date of their writing) almost exclusively not in terms of atmospheric CO_2 variations but in terms of changes in air temperature and/or precipitation. Therefore, all previous plant-based climate reconstructions for a period of time over which the air's CO_2 content had experienced a significant change must have been in error to some degree unless they accounted for the growth-enhancing effects of the CO_2 increase, which none had yet done, except LaMarche *et al.* (1984) and Graybill and Idso (1993).

Many scientists (including the IPCC) had been using long-term tree-ring chronologies—specifically, Mann *et al*. (1998, 1999)—to create a climate history of Earth that exhibits dramatic late-twentieth century warming that was likely far too great. As Briffa (2000) explains, the recent high growth rates of the trees in these chronologies "provide major pieces of evidence being used to assemble a case for anomalous global warming, interpreted by many as evidence of anthropogenic activity." However, he continues, "the empirically derived regression equations upon which our reconstructions are based may be compromised if the balance between photosynthesis and respiration is changed" by anything other than air temperature. And as Cowling and Sykes conclude, "implicit in the assumption that plant-climate relationships remain the same through time is the notion that temperature-plant interactions are independent of changes in atmospheric CO_2, which is not supported by physiological data."

The flawed studies of Mann *et al*. fast became the centerpiece (Crowley, 2000; Mann, 2000) of the IPCC's characterization of current climate, professing to show what they misguidedly concluded was an unusual and unprecedented rise in late-twentieth century temperatures, which they concluded to be largely the product of CO_2-induced global warming.

In another review paper conducted nearly a decade later, D'Arrigo *et al*. (2008) dissected this *divergence problem*, which they describe as "an offset between warmer instrumental temperatures and their underestimation in reconstruction models based on tree rings," assessing the possible causes and implications of the phenomenon.

The four researchers identified more than a dozen possible causes of the problem: moisture stress, non-linear or threshold responses to warming, local pollution, delayed snowmelt, changes in seasonality, differential responses to maximum and minimum temperatures, global dimming, methodological issues related to "end effects," biases in instrumental target data, the modeling of such data, declining stratospheric ozone concentrations, increased UV-B radiation at ground level, and "an upward bias in surface thermometer temperature measurements in recent years related to heat island effects."

D'Arrigo *et al*. note "reconstructions based on northern tree-ring data impacted by divergence cannot be used to directly compare past natural warm periods (notably, the Medieval Warm Period) with recent 20th century warming, making it more difficult to state unequivocally that the recent warming is unprecedented." With respect to a resolution of the issue, they state their review "did not yield any consistent pattern that could shed light on whether one possible cause of divergence might be more likely than others," leading them to conclude "a combination of reasons may be involved that vary with location, species or other factors, and that clear identification of a sole cause for the divergence is probably unlikely." Such findings suggest it is premature to claim, as the IPCC does, that recent warming is unprecedented over the past millennium or more, particularly on the basis of tree-ring width data.

In another paper examining the potential influence of atmospheric carbon dioxide on proxy records Gonzales *et al*. (2008) write, "there has been a growing awareness that past variations in CO_2 may have globally influenced plant physiology, vegetation composition, and vegetation structure (Idso, 1989b; Cowling, 1999; Cowling and Sykes, 1999; Wu *et al*., 2007a,b)." They also note "this information has spurred a debate over the relative importance of CO_2 versus climate as drivers of Quaternary vegetation change." Gonzales *et al*. compared simulated and pollen-inferred leaf area index (LAI) values with regional vegetation histories of northern and eastern North America "to assess both data and model accuracy and to examine the relative influences of CO_2 and climate on vegetation structure over the past 21,000 years." They made use of BIOME4, "a biogeochemistry-biogeography equilibrium vegetation model (Kaplan, 2001)" that "was designed in part for paleo-vegetation applications, and has been widely used to simulate vegetation responses to late-Quaternary CO_2 and climates." Concurrently, and "to provide paleo-climate scenarios for the BIOME4 simulations," the three researchers "used surface temperature, precipitation and cloudiness values from a series of Hadley Centre Unified Model simulations."

Gonzales *et al*. note theirs was the first study "to use both BIOME4 simulations and pollen-based reconstructions to develop detailed Quaternary LAI histories for North America," and they report their "BIOME4 sensitivity experiments indicated that climate was the primary driver of late-Quaternary changes in LAI in northern and eastern North America, with CO_2 a secondary factor." More importantly, Gonzales *et al*. observed their work "emphasizes the need for models to incorporate the effects of both CO_2 and climate on [the reconstruction of] late-Quaternary vegetation dynamics and structure." Vegetation-based climate reconstructions must incorporate the biological effects of changes in atmospheric CO_2 concentration, especially when attempting to compare late-twentieth century reconstructed temperatures with reconstructed temperatures of the Roman and Medieval Warm Periods and the Holocene Climatic Optimum. Until this deficiency is corrected, truly valid comparisons between these earlier times and the present cannot be made based on tree-ring width data.

Knapp and Soule (2008) examined recent radial growth increases in western juniper trees (*Juniperus occidentalis* var. *occidentalis* Hook.) based on their analysis of a master tree-ring chronology dating from AD 1000–2006, developed from 11 semi-arid sites in the interior U.S. Pacific Northwest that had experienced minimal anthropogenic influence other than that provided by the historical increase in the air's CO_2 content that is everywhere present.

They then used measured climate data for the period 1907–2006 to determine which climatic parameter tree radial growth was most responsive to: temperature, precipitation, or drought severity, as represented by the Palmer Drought Severity Index (PDSI) for the month of June. They found June PDSI to be the most important factor, explaining fully 54 percent of annual radial growth variability. When they added CO_2 as a second predictive factor, they found it "accounted for a 14% increase in explanatory power." In addition, they report, "use of the PDSI-only regression model produced almost exclusively positive residuals since 1977," but "the +CO_2 model has a greater balance of positive (53%) and negative residuals over the same period." They conclude, "climatic reconstructions based on pre-1980 data would not be significantly influenced by rising CO_2 levels," but reconstructions produced after that time would be.

During the period 1977–2006, which Knapp and Soule describe as being "unlike any other period during the last millennium," the late-twentieth century/early-twenty-first century radial growth of the western juniper trees was 27 percent greater than the long-term (AD 1000–2006) average. That growth could not have been caused by any increase in air temperature, for they report "western juniper responds negatively to temperature, negating any linkages to regional warming." Neither could the anomalous growth increase have been due to anomalous nitrogen fertilization, for the two researchers note "the eleven chronology sites do not fall under any of the criteria used to identify ecosystems significantly impacted by N-deposition," citing the work of Fenn *et al.* (2003). They were left to conclude the growth increase was likely due to the increase in the air's CO_2 content over the latter period.

Esper *et al.* (2005) weigh in on why there are differences among climate reconstructions and what it would take to reduce present uncertainties to gain a more complete and correct understanding of temperature changes over the past thousand years. The six scientists note we generally understand the shape of long-term climate fluctuations better than their amplitudes. For instance, nearly all 1,000-year temperature reconstructions capture the major climatic episodes of the Medieval Warm Period, Little Ice Age, and Current Warm Period, but for various reasons they exhibit differences in the degree of climatic warming or cooling experienced in the transitions between them, which for decadal means may amount to as much as 0.4 to 1.0°C. They suggest the discrepancies might be reduced by reducing the calibration uncertainty among the proxies, ensuring the accurate preservation and assessment of low-to-high frequency variation in proxy data, using appropriate frequency bands to best fit instrumental data, avoiding the use of regional tree-ring and other paleo records in which long-term trends (low-frequency variations) are not preserved, selecting instrumental data with which to compare proxy records to avoid incorrect alterations to the observational data that can result from homogeneity adjustments and methodological differences, and obtaining more proxy data that cover the full millennium and represent the same spatial domain as the instrumental target data (e.g., hemisphere).

In an important paper published in the peer-reviewed journal *Climatic Change*, Swiss scientists Jan Esper (of the Swiss Federal Research Institute) and David Frank (of the Oeschger Centre for Climate Change Research) took the Intergovernmental Panel on Climate Change (IPCC) to task for concluding in its *Fourth Assessment Report* (AR4) that, relative to modern times, there was "an increased heterogeneity of climate during medieval times about 1000 years ago."

This finding, if true, would be of great significance to the ongoing debate over the cause of twentieth century global warming, because, Esper and Frank write, "heterogeneity alone is often used as a distinguishing attribute to contrast with present anthropogenic warming." If the IPCC's contention is false, it would mean the warmth of the Current Warm Period is not materially different from that of the Medieval Warm Period, suggesting there is no need to invoke anything extraordinary (such as anthropogenic

CO_2 emissions) as the cause of Earth's current warmth.

With mathematical procedures and statistical tests, Esper and Frank demonstrated the records reproduced in the AR4 "do not exhibit systematic changes in coherence, and thus cannot be used as evidence for long-term homogeneity changes." And even if they could be thus used, they note "there is no increased spread of values during the MWP," and the standard error of the component datasets "is actually largest during recent decades." Consequently, the researchers conclude, their "quantification of proxy data coherence suggests that it was erroneous [for the IPCC] to conclude that the records displayed in AR4 are indicative of a heterogeneous climate during the MWP." The IPCC's conclusion appears even more erroneous today in light of the hundreds of papers discussed in Section 4.2.2 that collectively demonstrate the homogeneity of a global MWP.

There are additional challenges in quantifying historical temperatures from other proxy methods. Correia and Safanda (1999) reviewed a set of 20 temperature logs derived from boreholes located at 14 sites in the small region of mainland Portugal in an attempt to reconstruct a five-century surface air temperature history for that part of the world, which proved to be a difficult task. Seven of the borehole temperature logs were too "noisy" to use, and six displayed evidence of groundwater perturbations and were thus not usable. Of the remaining seven logs, all depicted little temperature change over the first three centuries of record. Thereafter, four exhibited warming trends that began about 1800 and peaked around 1940, one showed a warming that peaked in the mid-1800s, another was constant across the entire five centuries, and one revealed cooling over the last century. These differences are surprising considering the relatively small distance separating the borehole locations. The two researchers conclude "the single inversions cannot be interpreted individually."

Correia and Safanda next performed a joint analysis of the seven usable borehole records, obtaining a warming of 0.5–0.6°C since the second half of the eighteenth century, followed by a cooling of 0.2°C. They compared the joint borehole record with the surface air temperature record directly measured at a meteorological station in Lisbon, about 150–200 km to the northwest. From the beginning of the surface air temperature record in 1856 until 1949, the Lisbon data yielded a warming of 0.8°C, whereas the borehole record displayed a warming of only 0.3–0.4°C.

The two temperature histories could both be right, but they also could both be wrong. The Lisbon record, for example, could suffer from urban heat island-type problems, and the joint borehole record was obtained only after several individual records were rejected for various reasons and a number of simplifying assumptions were invoked in the analyses of the remaining records. The authors reluctantly recognize these problems, noting the issue was not yet resolved and much more work needed to be done to arrive at a satisfactory conclusion. This study demonstrates several common difficulties in deriving borehole temperature records.

Bodri and Cermak (2005) note temperature profiles derived from borehole records had been increasingly used to obtain proxy climate signals at various locations across the surface of Earth. They caution the techniques employed in reconstructing pre-observational (pre-instrumental era) mean temperatures from borehole data suffer from certain limitations, one of the major ones being the presence of underground fluids that can distort the true climatic signal (Lewis and Wang, 1992). Bodri and Cermak thus developed a corrective measure to account for vertical conductive and advective heat transport in a 1-D horizontally layered stratum—as opposed to the then-popular purely conductive approach—which they proceeded to apply to four borehole records drilled near Tachlovice in the Czech Republic.

The duo's analyses of the four borehole temperature logs revealed the conductive/advective approach was far superior to the purely conductive approach, explaining 83 to 95 percent of the temperature signal where the purely conductive model could explain no more than 27 to 58 percent. In addition, the purely conductive approach was found to underestimate the pre-observational mean temperature by 0.3 to 0.5°C. This underestimate produces a significant overestimate of the degree of warming experienced from the pre-observational period to the present. The two scientists also report both of the pre-observational mean temperature values for eighteenth-century Bohemia (the one derived from the conductive/advective approach and the one derived from the purely conductive approach) "exceed the annual temperatures characteristic for the 19th/20th centuries," which "may indicate that the warming has still not achieved its earlier (late 18th century) level."

Considering another type of possible proxy error, Darling *et al*. (2000) reported on their examination of the genetic variation in the small subunit ribosomal

RNA gene of three morphospecies of planktonic foraminifera from Arctic and Antarctic subpolar waters, which led to the discovery that foraminiferal morphospecies can consist of a complex of genetic types. They found each "species," as these entities previously had been designated, was composed of three to five distinct genetic varieties that could be classified as individual species themselves. The morphological, chemical, and stable-isotope differences associated with the calcitic shells of the three morphospecies they studied are used extensively by palaeoceanographers for purposes of climate reconstruction, based on the assumption that each morphospecies represents a genetically continuous species with a single environmental/habitat preference. They write, "if this is not the case"—as indicated by their study and others—"stable-isotope and geochemical analyses of planktonic foraminiferal shells, and census-based transfer-function techniques derived from such pooled data, must include significant noise, if not error." As more is learned about the diversity of these biotic climate indicators, it is likely certain additional palaeoclimatic histories will have to be revised.

Cohn and Lins (2005) analyzed statistical trend tests of hydroclimatological data such as discharge and air temperature in the presence of long-term persistence (LTP), in order to determine what LTP, if present, implied about the significance of observed trends. They determined "the presence of LTP in a stochastic process can induce a significant trend result when no trend is present, if an inappropriate trend test is used." They also note, "given the LTP-like patterns we see in longer hydroclimatological records ... such as the periods of multidecadal drought that occurred during the past millennium and our planet's geologic history of ice ages and sea level changes, it might be prudent to assume that hydroclimatological processes could possess LTP." They add "nearly every assessment of trend significance in geophysical variables published during the past few decades has failed to account properly for long-term persistence."

In discussing the implications of their work with respect to temperature data, Cohn and Lins note there is overwhelming evidence the planet has warmed during the past century. However, they ask, "could this warming be due to natural dynamics?" They state, "given what we know about the complexity, long-term persistence, and non-linearity of the climate system, it seems the answer might be yes." Although reported temperature trends may be real, they note, those trends also may be insignificant. Cohn and Lins say this leads to "a worrisome possibility": that "natural climatic excursions may be much larger than we imagine, ... so large, perhaps, that they render insignificant the changes, human-induced or otherwise, observed during the past century."

Another potential problem with paleoclimate proxies was identified by Loehle (2004), who used a pair of 3,000-year-long proxy climate records with minimal dating errors to characterize the pattern of climate change over the past three millennia in a paper that provides the necessary context for properly evaluating the cause or causes of twentieth century global warming.

The first of the two temperature series was the sea surface temperature (SST) record of the Sargasso Sea, derived by Keigwin (1996) from a study of the oxygen isotope ratios of foraminifera and other organisms contained in a sediment core retrieved from a deep-ocean drilling site on the Bermuda Rise. This record provided SST data for about every 67th year from 1125 BC to AD 1975. The second temperature series was the ground surface temperature record derived by Holmgren *et al.* (1999, 2001) from studies of color variations of stalagmites found in a cave in South Africa, which variations are caused by changes in the concentrations of humic materials entering the region's groundwater that have been reliably correlated with regional near-surface air temperature.

Explaining why he used these two specific records and only these two records, Loehle writes, "most other long-term records have large dating errors, are based on tree rings, which are not reliable for this purpose (Broecker, 2001), or are too short for estimating long-term cyclic components of climate." Also, in a repudiation of the approach employed by Mann *et al.* (1998, 1999) and Mann and Jones (2003), he states, "synthetic series consisting of hemispheric or global mean temperatures are not suitable for such an analysis because of the inconsistent timescales in the various data sets." In addition, his testing indicates "when dating errors are present in a series, and several series are combined, the result is a smearing of the signal."

Loehle reports "a comparison of the Sargasso and South Africa series shows some remarkable similarities of pattern, especially considering the distance separating the two locations," and he states this fact "suggests that the climate signal reflects some global pattern rather than being a regional signal only." He also notes a comparison of the mean record with the South Africa and Sargasso series from which it was derived "shows excellent agreement" and "the patterns match closely," concluding, "this would not be the case if the two series were independent or random."

Proceeding with his approach of fitting simple periodic models to the temperature data as functions of time, with no attempt to make the models functions of solar activity or any other physical variable, Loehle fit seven time-series models to the two temperature series and to the average of the two series, using no data from the twentieth century. In all seven cases, he reports good to excellent fits were obtained. As an example, the three-cycle model he fit to the averaged temperature series had a simple correlation of 0.58 and an 83 percent correspondence of peaks when evaluated by a moving window count.

Comparing the forward projections of the seven models through the twentieth century leads directly to the most significant conclusions of Loehle's paper. He first notes six of the models "show a warming trend over the 20th century similar in timing and magnitude to the Northern Hemisphere instrumental series," and "one of the models passes right through the 20th century data." These results clearly suggest, in his words, "20th century warming trends are plausibly a continuation of past climate patterns" and, therefore, "anywhere from a major portion to all of the warming of the 20th century could plausibly result from natural causes."

Loehle's analyses also reveal a long-term linear cooling trend of 0.25°C per thousand years since the peak of the interglacial warm period that occurred some 7,000 years ago, essentially identical to the mean value of this trend derived from seven prior assessments of its magnitude and five prior climate reconstructions. In addition, Loehle's analyses reveal the existence of the Medieval Warm Period of AD 800–1200, which is shown to have been significantly warmer than the Current Warm Period Earth has experienced so far, as well as the existence of the Little Ice Age of AD 1500–1850, which is shown to have been the coldest period of the entire 3,000-year record.

As corroborating evidence for the global nature of these major warm and cold intervals, Loehle cites 16 peer-reviewed scientific journal articles that document the existence of the Medieval Warm Period in all parts of the world and 18 articles that document the worldwide occurrence of the Little Ice Age. In addition, both the Sargasso Sea and South African temperature records reveal the existence of a major temperature spike that began sometime in the early 1400s (though Loehle makes no mention of this feature in his paper). This abrupt warming pushed temperatures considerably above the peak warmth of the twentieth century before falling back to pre-spike levels in the mid-1500s, providing support for the similar finding of higher-than-current temperatures in that time interval by McIntyre and McKitrick (2003) in their reanalysis of the data Mann *et al*. used to create their controversial "hockey stick" temperature history, which gives no indication of the occurrence of this high-temperature regime.

The models developed by Loehle confirm the existence of three climate cycles previously identified by others. In his seventh model, for example, there is a 2,388-year cycle he describes as comparing "quite favorably to a cycle variously estimated as 2,200, 2,300, and 2,500 years (Denton and Karlen, 1973; Karlen and Kuylenstierna, 1996; Magny, 1993; Mayewski *et al*., 1997)." In addition, there is a 490-year cycle that likely "corresponds to a 500-year cycle found previously (e.g. Li *et al*., 1997; Magny, 1993; Mayewski *et al*., 1997)" and a 228-year cycle that "approximates the 210-year cycle found by Damon and Jirikowic (1992)."

Loehle concludes, "solar forcing (and/or other natural cycles) is plausibly responsible for some portion of 20th century warming" or, as he indicates in his abstract, maybe even all of it.

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4.2 The Non-Uniqueness of Current Temperatures

The IPCC has long asserted CO_2-induced global warming accelerated significantly over the twentieth century and is unprecedented in the past millennium or more. However, as shown in the preceding section of this chapter, the temperature datasets upon which these claims are based are likely contaminated with errors of sufficient magnitude to render that assessment questionable at best.

The following section evaluates the correctness of the IPCC's claim. If temperatures of the past millennia—when atmospheric CO_2 concentrations were 30 percent lower than they are now—were as warm as or warmer than the present, then it must be recognized there is nothing unusual or unnatural about the planet's current level of warmth. This would invalidate the IPCC's claims that "it is *extremely likely* that human activities have caused most of (at least 50%) the observed increase in global average temperatures since the 1950s" and "it is *virtually certain* that this warming is not due to internal variability alone" (Second Order Draft of AR5, dated October 5, 2012, p. 10-3).

Our review of the literature, highlighted in the subsections below, reveals many scientists have indeed presented evidence of *multiple* prior warm periods around the world. Much of this work focuses on a period of warmth about a thousand years ago, but some studies identify multiple periods throughout the Holocene when it was warmer than the present, at much lower atmospheric CO_2 concentrations. We begin with a discussion of current temperatures within the longer-term context of the past few interglacial climates.

4.2.1 The Warmth of Prior Interglacial Climates

Throughout Earth's geologic history, major ice ages have occurred repeatedly, with ten affecting the planet in the past one million years and another ten in the million or so years before that. Each persists for about 90,000 years, after which it is followed by an approximate 10,000-year interglacial.

Our understanding of climatic conditions during glacial–interglacial cycles is limited, but a constant flow of new studies is providing additional information about the topic. This growing body of knowledge provides a long historical baseline against which the current state of Earth's climate may be compared, enabling a better understanding of the significance of current climate trends and their causes.

Some scientists have claimed the ongoing rise in the air's CO_2 content made the decade of the 1990s the warmest period of the entire past millennium (Mann *et al*., 1998, 1999). "Unprecedented" is the word proponents of this idea routinely use to describe the current temperature of the globe. However, when the mean temperature of the 1990s or 2000s is compared with the warmest temperatures of the four prior interglacials (for which we have high-quality reconstructed temperature records), the two decades are found to have been much cooler than *all* of these other periods.

Petit *et al*. (1999), for example, analyzed an ice core recovered from the Russian Vostok drilling station in East Antarctica, from which they extracted a 420,000-year history of Earth's near-surface air temperature and atmospheric CO_2 concentration (see Figure 4.2.1.1). This record covered the current interglacial period, the Holocene, and the preceding four such climatic intervals. This record is important for what it reveals about the uniqueness or non-uniqueness of the Holocene: The current interglacial is by far the coldest of the five most recent such periods. The four interglacials that preceded the Holocene were, on average, more than 2°C warmer than the one in which we currently live. Also, atmospheric CO_2 concentrations during all four prior interglacials never rose above approximately 290 ppm, whereas the air's CO_2 concentration in mid-2013 stood at about 400 ppm. If there was anything unusual, unnatural, or unprecedented about late-twentieth century air temperatures, it is that they were so *low* in the presence of such *high* CO_2 concentrations.

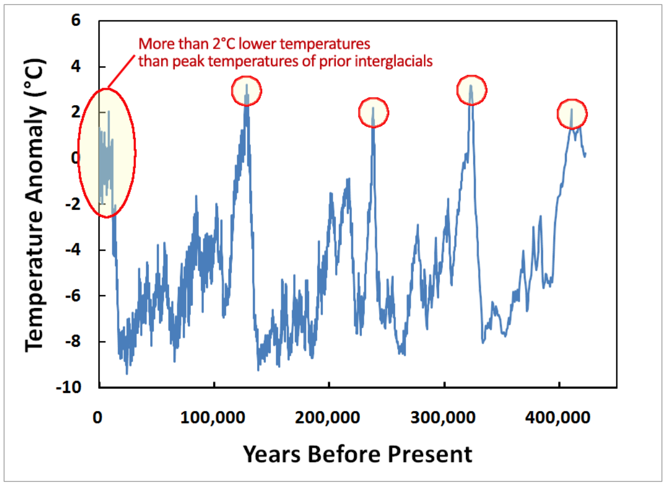

Figure 4.2.1.1. A 420,000-year history of Earth's near-surface air temperature extracted from an ice core recovered from the Russian Vostok drilling station in East Antarctica, revealing temperatures of the present are more than 2°C cooler than peak temperatures of all four prior interglacials. Adapted from Petit, J.R., Jouzel, J., Raynaud, D., Barkov, N.I., Barnola, J.-M., Basile, I., Bender, M., Chappellaz, J., Davis, M.., Delaygue, G., Delmotte, M., Kotlyakov, V.M., Legrand, M., Lipenkov, V.Y., Lorius, C., Pepin, L., Ritz, C., Saltzman, E., and Stievenard, M. 1999. Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* **399**: 429–436..

Similar findings have been obtained from the Dome Fuji ice core, extracted from a site in an entirely different sector of East Antarctica that is separated from the Vostok ice core site by 1,500 km (Watanabe *et al*., 2003). Although of somewhat shorter duration, covering only the past three glacial-interglacial periods (marine stages 5.5, 7.5, and 9.3), this independent proxy temperature record also reveals the past three interglacials, in the words of Watanabe *et al*., "were much warmer than the most recent 1,000 years (~4.5°C for stage 5.5 and up to 6°C for stage 9.3)."

This prior interglacial warmth is also evident in a 550,000-year sea surface temperature (SST) dataset derived by Herbert *et al*. (2001) from marine sediment cores obtained along the western coast of North America, from around 22°N latitude at the southern tip of the Baja Peninsula to around 42°N latitude off the coast of Oregon. According to this reconstructed SST dataset, the nine researchers who developed it write, "the previous interglacial (isotope stage 5e) produced surface waters several degrees warmer than today," such that "waters as warm as those now at Santa Barbara occurred along the Oregon margin." Their data show SSTs for this region in the current interglacial have not reached the warm peaks witnessed in all four of the preceding interglacial periods, falling short by 1 to 4°C.

Thus, over the past half-million years and within the context of the most recent five full interglacials, it is clear the average near-surface air temperature of Earth during the 1990s was not unusually warm, but unusually *cool*, despite the 1990s' much greater atmospheric CO_2 content.

These observations suggest Earth's current temperature is not indicative of dangerous human interference with the planet's thermoregulatory system. The IPCC's claim of a human influence on today's climate is based solely on its contention that Earth's current temperature is uncommonly high (Crowley, 2000), when it clearly is not. Earth was significantly warmer than it is today in all of the preceding interglacials for which we have good temperature data, and it is highly implausible to attribute those high temperatures of the past to human influence or even natural increases in the air's CO_2 content, which during the four previous interglacials never rose above approximately 290 ppm.

The supposed causal relationship between Earth's atmospheric CO_2 concentration and global temperature has been further weakened by the work of Fischer *et al*. (1999), Indermuhle *et al*. (1999), and Stephens and Keeling (2000). Fischer *et al*. examined records of atmospheric CO_2 and air temperature derived from Antarctic ice cores across a quarter of a million years. Over this time span, the three most dramatic warming events were those associated with the terminations of the past three ice ages, and for each of these global warmings, Earth's air temperature rose well *before* any increase in atmospheric CO_2. The air's CO_2 content did not begin to rise until 400 to 1,000 years *after* the planet began to warm. Increases in the air's CO_2 content did not trigger these massive changes in climate.

In addition, during a 15,000-year period following one of the glacial terminations the air's CO_2 content was essentially constant but air temperatures dropped to values characteristic of glacial times. Also, just as increases in atmospheric CO_2 did not trigger any of the major global warmings that ended the past three ice ages, neither was the induction of the most recent ice age driven by a decrease in CO_2. And when the air's CO_2 content finally did begin to drop after the last ice age was fully established, air temperatures either remained fairly constant or rose, doing just the opposite of what climate models suggest should have happened if changes in atmospheric CO_2 drive changes in climate.

Indermuhle *et al*. (1999) determined the CO_2 content of the air gradually rose after the termination of the last great ice age, by approximately 25 ppm in almost linear fashion between 8,200 and 1,200 years ago, in a time of slow but steady *decline* in global air temperature—again just the opposite of what would be expected if changes in atmospheric CO_2 affect climate in the way suggested by the popular CO_2-greenhouse effect theory.

Another problem for this theory arises from the work of Stephens and Keeling (2000), who in a study of the influence of Antarctic sea ice on glacial-interglacial CO_2 variations proposed a mechanism to explain the observed synchrony between Antarctic temperature and atmospheric CO_2 concentration during glacial-interglacial transitions. Their mechanism presumes temperature is the independent variable that alters sea ice extent, which then alters the sea-to-air CO_2 flux in the high-latitude region of the Southern Ocean and consequently changes the CO_2 content of the atmosphere. In their explanation for the gross correlation of CO_2 and air temperature over glacial-interglacial cycles, atmospheric CO_2 variations are clearly the result of temperature variations, not vice versa. (For a more in-depth discussion on the leads and lags of the historic temperature/CO_2 relationship, see Chapter 2.)

Ding *et al*. (1999) developed a high-resolution record of climate changes over the past two glacial-interglacial cycles based on a study of grain sizes in soil cores removed from sections of the northwestern part of the Chinese Loess Plateau. The scientists detected the presence of large-amplitude millennial-scale climatic oscillations over both of the previous glacial periods, but very little such variation during the prior interglacial. Greater climatic stability during warmer interglacial periods also has been reported by Shemesh *et al*. (2001) and Alley (2000). Because interglacials appear to be more climatically stable than cooler glacial periods, we will likely not experience a significant increase in extreme weather events of the type routinely predicted by climate alarmists to accompany global warming, such as rapid climate changes of the type suggested to become more likely by Alley *et al*. (2002, 2003).

Across the long history of glacial-interglacial cycles, there is little doubt the atmosphere's CO_2 concentration is strongly correlated with its temperature, as has been demonstrated by numerous scientific studies (Petit *et al*., 1999; Augustin *et al*., 2004; Siegenthaler *et al*., 2005). Nor is there any doubt changes in air temperature generally occur anywhere from 800 to 2,800 years *before* changes in the air's CO_2 content, as is demonstrated by even more studies (Fischer *et al*., 1999; Monin *et al*., 2001; Caillon *et al*., 2003; Siegenthaler *et al*., 2005). But the evidence shows carbon dioxide cannot be the primary cause of glacial-interglacial temperature changes, nor is it likely a significant amplifier of them.

Antarctic ice core data suggest the air's current CO_2 concentration is some 40 percent higher than it was at any other time in the past 650,000 years (Siegenthaler *et al*., 2005), and its current methane concentration is approximately 130 percent higher (Spanhi *et al*., 2005)—values some scientists have referred to as "geologically incredible." If the IPCC and others were correct in attributing tremendous warming power to these two greenhouse gases, Earth should be experiencing incredibly high temperatures compared to those of prior interglacial periods. Yet this is not the case.

Greenland and Antarctica ice core data, in particular, suggest the mean recent temperature of the current interglacial, the Holocene, was not incredibly higher than temperatures reached during the past four interglacials, the earliest of which is believed to have been nearly identical to the Holocene in terms of Earth's orbit around the Sun. The mean recent temperature of the Holocene did not exceed temperatures reached during *any* of the four prior interglacials, by even a fraction of a degree. On the contrary, the mean recent temperature of the Holocene was lower. The work of Petit *et al*. referred to earlier suggests the mean recent temperature of the Holocene was more than 2°C lower than the highest temperatures of the prior four interglacials, while another analysis of the subject (Sime *et al*., 2009) suggests the "maximum interglacial temperatures over the past 340,000 years were between 6.0°C and 10.0°C above present-day values."

The empirical observations cited above reveal a relationship opposite of what is expected if carbon dioxide and methane were the powerful greenhouse gases the IPCC claims them to be. Clearly, if there is anything at all that is unusual, unnatural, or unprecedented about Earth's current surface air temperature, it is that it is so *cold*.

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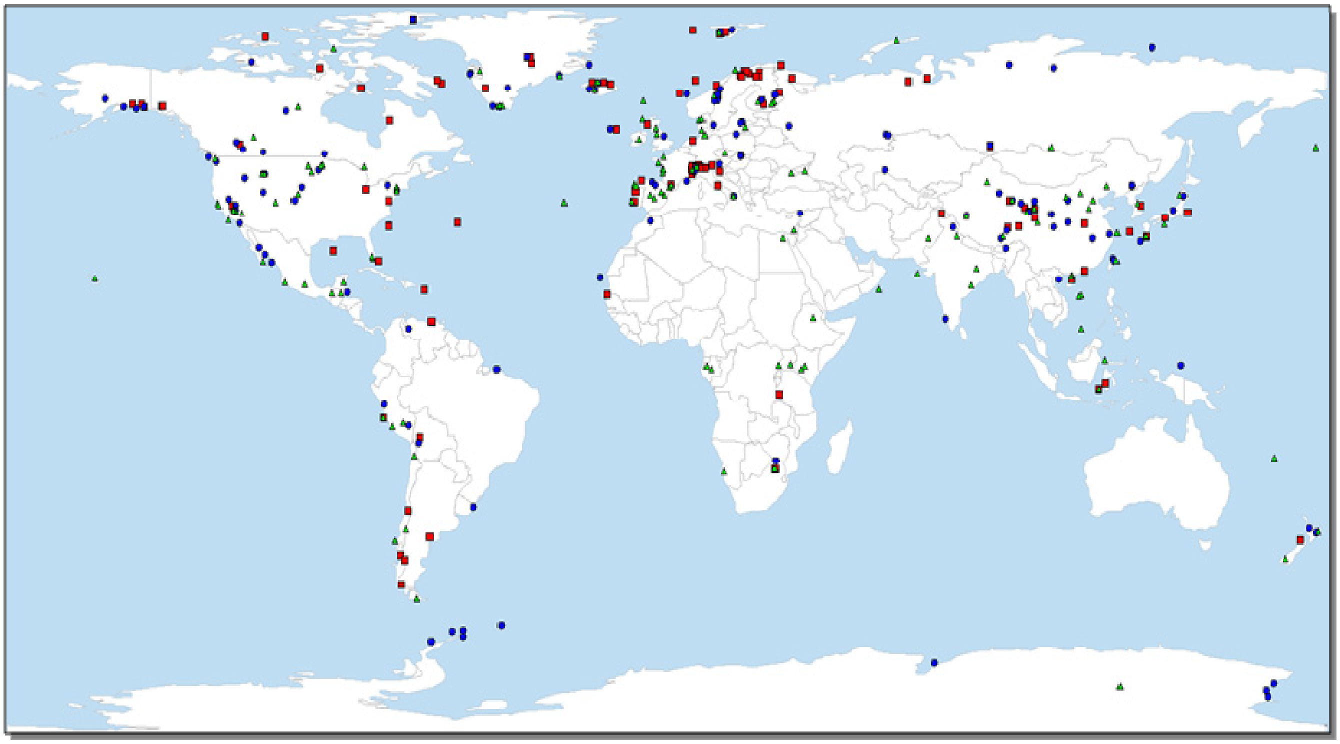

Figure 4.2.2.1. Plot of the locations of proxy climate studies for which (a) quantitative determinations of the temperature difference between the MWP and CWP can be made (red squares), (b) qualitative determinations of the temperature difference between the MWP and CWP can be made (blue circles), and (c) neither quantitative nor qualitative determinations can be made, with the studies simply indicating the Medieval Warm Period did indeed occur in the studied region (green triangles).

Spahni, R., Chappellaz, J., Stocker, T.F., Loulergue, L., Hausammann, G., Kawamura, K., Fluckiger, J., Schwander, J., Raynaud, D., Masson-Delmotte, V., and Jouzel, J. 2005. Atmospheric methane and nitrous oxide of the late Pleistocene from Antarctic ice cores. *Science* **310**: 1317–1321.

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4.2.2 A Global Medieval Warm Period

After initially acknowledging in its *First Assessment Report* the existence of a several-hundred-year global Medieval Warm Period (MWP) centered about a thousand years ago, during portions of which temperatures were often warmer than those of the present, the IPCC has since backtracked in succeeding reports. In its latest report (*Fifth Assessment*), for example, the IPCC states:

> In contrast to the late 20th century there is *high confidence* that the Medieval Climate Anomaly was not characterized by a pattern of higher temperatures that were consistent across seasons and regions (Second Order Draft of AR5, dated October 5, 2012, p. 5-4)

As demonstrated in this subsection and those that follow, there is in fact an enormous body of literature that clearly demonstrates the IPCC is wrong in its assessment of the MWP. The degree of warming and climatic influence during the MWP varied from region to region, and hence its consequences were manifested in a variety of ways. But that it occurred and was a global phenomenon is certain, and there are literally hundreds of peer-reviewed scientific articles that certify this truth.

In what is likely the largest synthesis of MWP research articles in the world, *CO_2 Science* (http://www.co2science.org/data/mwp/mwpp.php) has highlighted more than 350 peer-reviewed research papers documenting the global nature of this warm-temperature era.

Figure 4.2.2.1 illustrates the spatial distribution of the proxy climate studies analyzed by CO_2 *Science* according to three different categories. The first of these categories, denoted by the red squares, is comprised of studies where the scientists who conducted the work provided quantitative data that enable a determination of the degree by which the peak temperature of the MWP differed from the peak temperature of the Current Warm Period (CWP). The second category (blue circles) is comprised of studies where the scientists who conducted the work provided qualitative data that enable a determination of which of the two periods was warmer, but not by how much. The third category (green triangles) comprises studies where the MWP was evident in the study's data but the data did not provide a means by which the warmth of the MWP could be compared with that of the CWP. Such studies contradict the claim that the MWP, if it occurred at all, was only a regional phenomenon experienced by lands significantly influenced by the North Atlantic Ocean. This category also includes some studies based on data related to parameters other than temperature, such as precipitation. These studies help define the timeframe of the MWP, but they are not employed to infer anything about either its quantitative or qualitative thermal strength. Figure 4.2.2.1 reveals the truly global nature of this phenomenon.

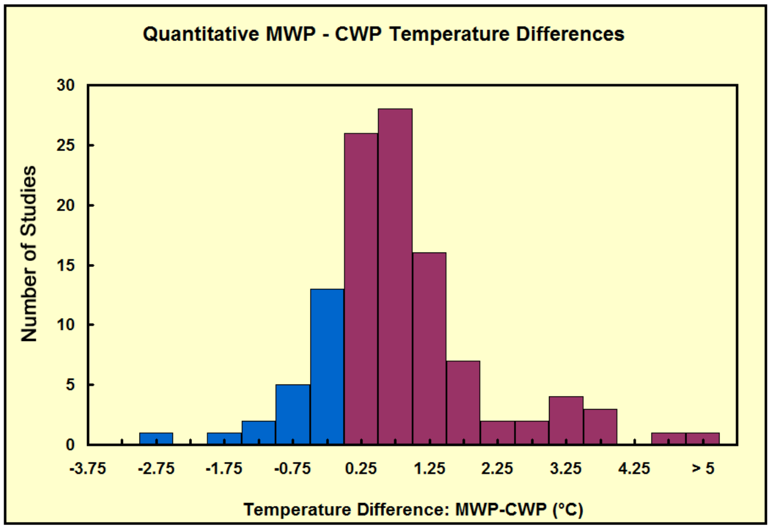

Figure 4.2.2.2. The distribution, in 0.5°C increments, of studies that allow the identification of the degree by which peak Medieval Warm Period temperatures either exceeded (positive values, red) or fell short of (negative values, blue) peak Current Warm Period temperatures.

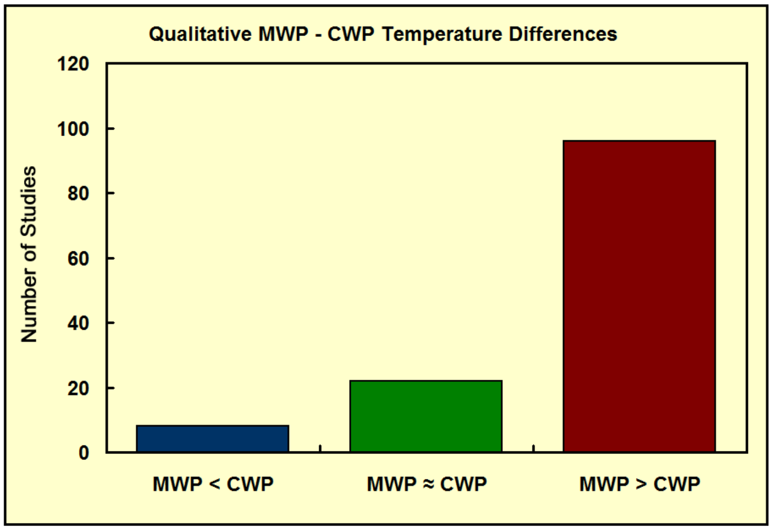

Figure 4.2.2.3. The distribution of studies that allow a qualitative determination of whether peak Medieval Warm Period temperatures were warmer than (red), equivalent to (green), or cooler than (blue) peak Current Warm Period temperatures.

With respect to how consistent the MWP was in time, of the 379 studies examined by CO_2 *Science*, 371 overlapped during the period 900–1200 AD. This number dips slightly to 365 if the time window is reduced to the period 1000–1200 AD, and to 337 if it is shortened further to the one hundred year period between 1000 and 1100 AD. A basic histogram of the timeframe (start year to end year) associated with the MWP of all the studies plotted in Figure 4.2.2.1 reveals the peak timeframe occurred around 1050 AD, within a more generalized 800 to 1300 AD warm era generally attributed to the MWP.

As to how warm it likely was during this period, Figure 4.2.2.2 presents a plot of the frequency distribution of all MWP-CWP temperature differentials from all quantitative studies (red squares) shown in Figure 4.2.2.1. As Figure 4.2.2.2 reveals, some studies found the MWP to have been cooler than the CWP (blue columns), but the vast majority of the temperature differentials are positive (red columns), indicating the MWP was warmer than the CWP. The average of all such differentials is 0.91°C, while the median is 0.70°C.

The greater warmth of the MWP can be generalized further by analyzing the qualitative studies in Figure 4.2.2.1, which is illustrated in Figure 4.2.2.3. Here, the numbers of studies in Figure 4.2.2.1 in which the MWP was warmer than, cooler than, or about the same as, the CWP are plotted, based on actual data presented by the authors of the original works. Again, a few studies found the MWP to have been cooler than the CWP, and a few found them to be of approximately the same warmth, but the majority of studies find the MWP to have been warmer than the CWP.

The existence of a global period of warmth in Earth's recent past comparable to that of the present indicates there is nothing unusual, unnatural, or unprecedented about the warmth of the post-1950 CWP. It is not surprising that there would be a significant warming of the globe at the conclusion of what was likely the coldest period of the entire Holocene (the Little Ice Age). Thus there is no compelling reason to believe twentieth century warming (which essentially ceased about 15 years ago) is a manmade phenomenon produced by the burning of coal, gas, and oil. The CWP is much more likely to be merely the most recent phase of the natural millennial-scale oscillation of Earth's climate that has been shown to operate throughout glacial and interglacial periods alike. And since the air's CO_2 concentration has risen by some 40 percent since the MWP, and Earth is no warmer now than it was then, there is no compelling reason to conclude any of Earth's current warmth is being caused by the increase in the atmosphere's CO_2 content.

We continue our analysis of the MWP by summarizing individual research papers on the subject, which together confirm the conclusions presented above.

Initial work from Lamb (1977, 1984, 1988) and Grove (1988) suggest Earth's average global temperature may have been warmer between the tenth and fourteenth centuries AD than it is today. The existence of this Medieval Warm Period initially was deduced from historical weather records and proxy climate data from England and Northern Europe. The warmer conditions of that era are known to have had a largely beneficial impact on Earth's plant and animal life. The environmental conditions of this time period have been determined to have been so favorable that it was often referred to as the Little Climatic Optimum (Imbrie and Imbrie, 1979; Dean, 1994; Petersen, 1994; Serre-Bachet, 1994; Villalba, 1994).

The degree of warming associated with the Medieval Warm Period varied from region to region, and its consequences were manifested in a variety of ways (Dean, 1994). In Europe, temperatures reached some of the warmest levels of the past 4,000 years, allowing enough grapes to be successfully grown in England to sustain an indigenous wine industry (Le Roy Ladurie, 1971). Horticulturists in China extended their cultivation of citrus trees and perennial herbs further and further northward, resulting in an expansion of their ranges that reached its maximum extent in the thirteenth century (De'er, 1994). It has been estimated annual mean temperatures in the region must have been about 1.0 °C higher than at present, with extreme January minimum temperatures fully 3.5 °C warmer than they are today (De'er, 1994).

In North America, tree-ring chronologies from the southern Canadian Rockies provide evidence for higher treelines and wider ring-widths between AD 950 and 1100, suggesting warmer temperatures and more favorable growing conditions (Luckman, 1994). Similar results were derived from tree-ring analyses of bristlecone pines in the White Mountains of California, where much greater growth was recorded in the eleventh and twelfth centuries (Leavitt, 1994). Analysis of $^{13}C/^{12}C$ ratios in the rings of these trees suggests soil moisture conditions were more favorable in this region during the Medieval Warm Period (Leavitt, 1994). Simultaneous increases in precipitation were found to have occurred in monsoonal locations of the United States desert southwest, where there are indications of increased lake levels from AD 700–1350 (Davis, 1994). Other data document vast glacial retreats during the MWP in parts of South America, Scandinavia, New Zealand, and Alaska (Grove and Switsur, 1994; Villalba, 1994), and ocean-bed cores suggest global sea surface temperatures were warmer then as well (Keigwin, 1996a, 1996b).

The Arctic ice pack substantially retreated during the MWP, allowing the settlement of both Iceland and Greenland, and alpine passes normally blocked with snow and ice became traversable, opening trade routes between Italy and Germany (Crowley and North, 1991). On the northern Colorado Plateau in America, the Anasazi Indian civilization reached its climax as warmer temperatures and better soil moisture conditions allowed them to farm a region twice as large as is currently possible (MacCracken *et al.*, 1990).

Huang and Pollack (1997) searched the large database of terrestrial heat flow measurements compiled by the International Heat Flow Commission of the International Association of Seismology and Physics of the Earth's Interior for measurements suitable for reconstructing an average ground surface temperature history of the planet over the past 20,000 years. Working with a total of 6,144 qualifying sets of heat flow data obtained from every continent, they produced a global climate reconstruction independent of other proxy interpretations and of any preconceptions or biases as to the nature of the actual climate history. In this reconstruction of what they called "a global climate history from worldwide observations," the two researchers found strong evidence the MWP was indeed warmer than it had been during any prior portion of the twentieth century, by as much as 0.5°C.

Bard *et al*. (2000) describe some of the many different types of information used to reconstruct past solar variability, including "the envelope of the SSN [sunspot number] 11-year cycle (Reid, 1991), the length and decay rate of the solar cycle (Hoyt and Schatten, 1993), the structure and decay rate of individual sunspots (Hoyt and Schatten, 1993), the mean level of SSN (Hoyt and Schatten, 1993; Zhang *et al*., 1994; Reid, 1997), the solar rotation and the solar diameter (Nesme-Ribes *et al*., 1993), and the geomagnetic aa index (Cliver *et al*., 1998)." They note, "Lean *et al*. (1995) proposed that the irradiance record could be divided into 2 superimposed components: an 11-year cycle based on the parameterization of sunspot darkening and facular brightening (Lean *et al*., 1992), and a slowly-varying background derived separately from studies of Sun-like stars (Baliunas and Jastrow, 1990)."

In their own paper, Bard *et al*. take a different approach. Rather than directly characterizing some aspect of solar variability, certain consequences of that variability are assessed. They note magnetic fields of the solar wind deflect portions of the primary flux of charged cosmic particles in the vicinity of Earth, leading to reductions in the creation of cosmogenic nuclides in Earth's atmosphere, with the result that histories of the atmospheric concentrations of ^{14}C and ^{10}Be can be used as proxies for solar activity, as noted many years previously by Lal and Peters (1967).

Bard *et al*. first created a 1,200-year history of cosmonuclide production in Earth's atmosphere from ^{10}Be measurements of South Pole ice (Raisbeck *et al*., 1990) and the atmospheric ^{14}C/^{12}C record as measured in tree rings (Bard *et al*., 1997). This record was then converted to Total Solar Irradiance (TSI) values by "applying a linear scaling using the TSI values published previously for the Maunder Minimum," when cosmonuclide production was 30 to 50 percent above the modern value. The end result of this approach was an extended TSI record suggesting "solar output was significantly reduced between 1450 and 1850 AD, but slightly higher or similar to the present value during a period centered around 1200 AD." They conclude "it could thus be argued that irradiance variations may have contributed to the so-called 'little ice age' and 'medieval warm period.'"

Also noting "the most direct mechanism for climate change would be a decrease or increase in the total amount of radiant energy reaching the Earth," Perry and Hsu (2000) developed a simple solar-luminosity model and used it to estimate total solar-output variations over the past 40,000 years. The model was derived by summing the amplitude of solar radiation variance for fundamental harmonics of the 11-year sunspot cycle throughout an entire 90,000-year glacial cycle, after which the model output was compared with geophysical, archaeological, and historical evidence of climate variation during the Holocene.

They determined model output was well correlated with the amount of carbon 14 (which is produced in the atmosphere by cosmic rays that are less abundant when the Sun is active and more abundant when it is less active) in well-dated tree rings going back to the time of the Medieval Warm Period (about AD 1100). This finding, they write, "supports the hypothesis that the Sun is varying its energy production in a manner that is consistent with the superposition of harmonic cycles of solar activity." The model output also was well correlated with the sea-level curve developed by Ters (1987). Present in both of these records over the entire expanse of the Holocene is a "little ice age"/"little warm period" cycle with a period of approximately 1,300 years. In addition, the climate changes implied by these records correlate well with major historical events. Specifically, the researchers note, "great civilizations appear to have prospered when the solar-output model shows an increase in the Sun's output," and such civilizations "appear to have declined when the modeled solar output declined."

Perry and Hsu note, "current global warming commonly is attributed to increased CO_2 concentrations in the atmosphere," but "geophysical, archaeological, and historical evidence is consistent with warming and cooling periods during the

Holocene as indicated by the solar-output model." They conclude the idea of "the modern temperature increase being caused solely by an increase in CO_2 concentrations appears questionable."

Bond *et al*. (2001) consider what was responsible for the approximate 1,500-year cycle of global climate change in the North Atlantic Ocean that had been intensely studied and demonstrated to prevail throughout both glacial and interglacial periods alike. They studied ice-rafted debris found in three North Atlantic deep-sea sediment cores and cosmogenic nuclides sequestered in the Greenland ice cap (^{10}Be) and Northern Hemispheric tree rings (^{14}C).

Based on analyses of the deep-sea sediment cores that yielded the variable-with-depth amounts of three proven proxies for the prior presence of overlying drift-ice, the scientists were able to discern and (using an accelerator mass spectrometer) date a number of recurring alternate periods of relative cold and warmth in the 12,000-year expanse of the Holocene. They determined the mean duration of the several complete climatic cycles was 1,340 years, and the cold and warm nodes of the most recent of these oscillations were "broadly correlative with the so called 'Little Ice Age' and 'Medieval Warm Period.'"

The ten scientists linked these millennial-scale climate oscillations and their embedded centennial-scale oscillations with similar-scale oscillations in cosmogenic nuclide production, which are known to be driven by oscillations in the energy output of the Sun. Bond *et al*. report, "over the last 12,000 years virtually every centennial time-scale increase in drift ice documented in our North Atlantic records was tied to a solar minimum." They conclude, "a solar influence on climate of the magnitude and consistency implied by our evidence could not have been confined to the North Atlantic," suggesting the cyclical climatic effects of the variable solar inferno are experienced throughout the world.

The international team of scientists verified that in spite of the contrary claims, the Little Ice Age and Medieval Warm Period were real, global, solar-induced, and but the latest examples of alternating intervals of relative cold and warmth stretching back in time through glacial and interglacial periods alike. Because these subjects are of such great significance to the debate over climate model-predicted consequences of anthropogenic CO_2 emissions, Bond *et al.* cite additional evidence in support of the implications of their work.

With respect to the global extent of the climatic impact of the solar radiation variations they detected, they make explicit reference to confirmatory studies conducted in Scandinavia, Greenland, the Netherlands, the Faroe Islands, Oman, the Sargasso Sea, coastal West Africa, the Cariaco Basin, equatorial East Africa, and the Yucatan Peninsula, demonstrating the footprint of the solar impact on climate they documented extends "from polar to tropical latitudes." They also note "the solar-climate links implied by our record are so dominant over the last 12,000 years ... it seems almost certain that the well-documented connection between the Maunder solar minimum and the coldest decades of the Little Ice Age could not have been a coincidence." They further note their findings support previous suggestions that both the Little Ice Age and Medieval Warm Period "may have been partly or entirely linked to changes in solar irradiance."

Bond *et al*. reiterate that the oscillations in drift-ice "persist across the glacial termination and well into the last glaciation, suggesting that the cycle is a pervasive feature of the climate system." At two of their coring sites, they identified a series of cyclical variations that extended throughout all of the previous interglacials and were "strikingly similar to those of the Holocene." Here, they also could have cited the work of Oppo *et al*. (1998), who observed similar climatic oscillations in a sediment core that covered the period from 340,000 to 500,000 years before present, and of Raymo *et al*. (1998), who pushed back the time of the cycles' earliest known occurrence to well over one million years ago.

With respect to how the small changes in solar radiation inferred from cosmogenic nuclide variations bring about such significant and pervasive shifts in Earth's global climate, a question that had long plagued proponents of a solar-climate link, Bond *et al.* describe a scenario whereby solar-induced changes high in the stratosphere are propagated downward through the atmosphere to Earth's surface, where they likely provoke changes in North Atlantic deep water formation that alter the global thermohaline circulation. They suggest the solar signals "may have been transmitted through the deep ocean as well as through the atmosphere, further contributing to their amplification and global imprint."

Concluding their landmark paper, the ten scientists state the results of their study "demonstrate that the Earth's climate system is highly sensitive to extremely weak perturbations in the Sun's energy output," noting their work "supports the presumption that solar variability will continue to influence climate in the future."

Rigozo *et al.* (2001) reconstructed a history of sunspot numbers for the past 1,000 years "using a sum of sine waves derived from spectral analysis of the time series of sunspot number R_Z for the period 1700–1999," and from that record derived the strengths of a number of parameters related to solar variability over the past millennium.

The four researchers state, "the 1,000-year reconstructed sunspot number reproduces well the great maximums and minimums in solar activity that are identified in cosmonuclide variation records, and, more specifically, in the epochs of the Oort, Wolf, Sporer, Maunder, and Dalton Minimums, as well as the Medieval and Modern Maximums," the latter of which they describe as "starting near 1900." They report the mean sunspot number for the Wolf, Sporer, and Maunder Minimums was 1.36; for the Oort and Dalton Minimums it was 25.05; for the Medieval Maximum it was 53.00; and for the Modern Maximum it was 57.54. The mean sunspot number of the Oort and Dalton Minimums was thus 18.42 times greater than the average of the Wolf, Sporer, and Maunder Minimums, while the mean sunspot number of the Medieval Maximum was 38.97 times greater and the Modern Maximum 42.31 times greater. Similar strength ratios for the solar radio flux were 1.41, 1.89, and 1.97, respectively, and for the solar wind velocity the corresponding ratios were 1.05, 1.10, and 1.11, while for the southward component of the interplanetary magnetic field they were 1.70, 2.54, and 2.67.

Clearly, the sunspot number and solar variability paramenters of the Medieval and Modern Maxima are dramatically greater than all other periods of the past thousand years. Thus, for entirely natural reasons, future temperatures may be higher than at any other time during the past millennium. Of course, other natural factors also affect Earth's climate system and may mitigate that conclusion. In any event, the observations of Rigozo *et al.* and those of Bond *et al.* suggest there is no need for invoking variations in the air's CO_2 content as the primary cause of mean global temperature variations during any period of the past thousand or more years.

Esper *et al.* (2002) employed a technique that allows accurate long-term climatic trends to be derived from individual tree-ring series of much shorter duration than the potential climatic oscillation being studied, and they applied this technique to more than 1,200 tree-ring series derived from 14 locations over the extratropical region of the Northern Hemisphere.

Two chronologies were thus developed: one from trees that exhibited weakly linear age trends and one from trees with nonlinear age trends. The results, they write, were "two nearly independent tree-ring chronologies covering the years 800–1990," which were "very similar over the past ~1200 years." These tree-ring histories were calibrated against Northern Hemispheric (0 to 90°N) mean annual instrumental temperatures from the period 1856–1980 to make them compatible with the temperature reconstructions of Mann *et al.* (1998, 1999), which were being cited by the IPCC and others as evidence current temperatures were greater than any previously experienced over the prior thousand years.

The biggest difference between the Esper *et al.* and Mann *et al.* temperature histories was the degree to which the coolness of the global Little Ice Age was expressed. It was much more evident in the record of Esper *et al.*, and its significantly lower temperatures made the Medieval Warm Period stand out more dramatically in their temperature reconstruction. Also, they note, "the warmest period covers the interval 950–1045, with the peak occurring around 990." This finding, they write, "suggests that past comparisons of the Medieval Warm Period with the 20th-century warming back to the year 1000 have not included all of the Medieval Warm Period and, perhaps, not even its warmest interval."

In a companion "perspective" paper, Briffa and Osborn (2002) acknowledge "the last millennium was much cooler than previously interpreted" and "an early period of warmth in the late 10th and early 11th centuries is more pronounced than in previous large-scale reconstructions." The Esper *et al.* record makes it abundantly clear the peak warmth of the MWP was equivalent to the warmth of the late twentieth and early twenty-first centuries.

This reaffirms the point raised by Idso (1988): that there is no need to invoke CO_2-induced global warming as a cause of the planet's recovery from the global chill of the Little Ice Age. "Since something other than atmospheric CO_2 variability was ... clearly responsible for bringing the planet into the Little Ice Age," he writes, "something other than atmospheric CO_2 variability may just as well have brought the planet out of it." That something else, as suggested by Esper *et al.*, was probably "the 1000- to 2000-year climate rhythm (1470 ± 500 years) in the North Atlantic, which may be related to solar-forced changes in thermohaline circulation," as had been described by Bond *et al.* (2001).

Briffa and Osborn also note Esper *et al.*'s record clearly shows the warming of the twentieth century was simply "a continuation of a trend that began at the start of the 19th century." In addition, the Esper *et al*. record indicates the Northern Hemisphere warmed in a consistent near-linear fashion over this 200-year period, contrary to the IPCC's claim of unprecedented warming over only the last century. The new data did great damage to the assertion CO_2-enhanced greenhouse warming was responsible for the temperature increase that brought the planet out of the Little Ice Age, since the increase in the air's CO_2 concentration over this period was highly nonlinear, rising by only 10 to 15 ppm over the nineteenth century but fully 70 to 75 ppm over the twentieth century, with no analogous increase in the latter period's rate of warming.

Briffa and Osborn also state, "we need to know why it was once so warm and then so cool, before we can say whether 21st-century warming is likely to be nearer to the top or the bottom of the latest IPCC [predicted temperature] range." We probably already know the answer to that question: The extremes of warmth and coolness to which they refer likely were caused by "solar-forced changes in thermohaline circulation," as suggested by Esper *et al.* and described by Bond *et al.*

Krenke and Chernavskaya (2002) review the then-current state of knowledge about the Medieval Warm Period and Little Ice Age, throughout the world in general and in Russia in particular, based on written historical, glaciological, and hydrologic evidence and dendrological, archaeological, and palynological data. "Concerning the Medieval Warm Period (MWP)," they write, "it is currently known that, from the 9th century to, apparently, the mid-15th century, the climatic conditions were warmer than during most of the subsequent five centuries, including the early 20th century." In some places it was warmer during the MWP than during the latter part of the twentieth century. For example, they note "the northern margin of boreal forests in Canada was shifted by 55 km [north] during the MWP, and the tree line in the Rocky Mountains in the southern United States and in the Krkonose Mountains was higher by 100–200 m than that observed at the present time."

Regarding the temperature reconstructions of Mann *et al*. (1998, 1999), the two members of the Russian Academy of Sciences state "the temperature averaged over the 20th century was found to be the highest among all centennial means, although it remained within the errors of reconstructions for the early millennium." They further note, "one should keep in mind that the reconstructions of the early period were based nearly entirely on tree-ring data, which, because of the features of their interpretation, tend to underestimate low-frequency variations, so the temperatures of the Medieval Warm Period were possibly underestimated." They provide further evidence for that conclusion, reporting, "the limits of cultivated land or receding glaciers have not yet exceeded the level characteristic of the early millennium."

Specifically with respect to Russia, Krenke and Chernavskaya report large differences in several variables between the period of the Little Ice Age and the preceding Medieval Warm Period. With respect to the annual mean temperature of northern Eurasia, they report an MWP to LIA drop of 1.5°C. They also state, "the frequency of severe winters reported was increased from once in 33 years in the early period of time, which corresponds to the MWP, to once in 20 years in the LIA," and they note "the abnormally severe winters [of the LIA] were associated with the spread of Arctic air masses over the entire Russian Plain." Finally, they note the data they used to draw these conclusions were "not used in the reconstructions performed by Mann *et al*.," which may explain why the Mann *et al*. temperature history of the past millennium does not reproduce the Little Ice Age nearly as well as does the more appropriately derived temperature history of Esper *et al*. (2002).

In contradiction of another of Mann *et al*.'s contentions, Krenke and Chernavskaya unequivocally state, based on the results of their study of the relevant scientific literature, "the Medieval Warm Period and the Little Ice Age existed globally."

Soon and Baliunas (2003) also reviewed evidence pertaining to the climatic and environmental history of Earth over the past millennium. They found "the assemblage of local representations of climate establishes both the Little Ice Age and Medieval Warm Period as climatic anomalies with worldwide imprints, extending earlier results by Bryson *et al.* (1963), Lamb (1965), and numerous intervening research efforts." In addition, they write, "across the world, many records reveal that the 20th century is probably not the warmest nor a uniquely extreme climatic period of the last millennium."

Mayewski *et al.* (2004) examined 50 globally distributed paleoclimate records in search of evidence for what they called *rapid climate change* (RCC) over the Holocene. This terminology is not to be confused with the rapid climate changes typical of glacial periods, but is used in the place of what the 16 researchers call the "more geographically or temporally restrictive terminology such as 'Little Ice Age' and 'Medieval Warm Period.'" RCC events, as they also refer to them, are multi-century periods characterized by extremes of thermal and/or hydrological properties, rather than the much shorter periods when the changes that led to these situations took place.

Mayewski *et al*. say they identified six RCCs during the Holocene: 9,000–8000, 6,000–5000, 4200–3800, 3500–2500, 1200–1000, and 600–150 cal yr BP, the last two of which are the "globally distributed" Medieval Warm Period and Little Ice Age, respectively. They note, "the short-lived 1200–1000 cal yr BP RCC event coincided with the drought-related collapse of Maya civilization and was accompanied by a loss of several million lives (Hodell *et al*., 2001; Gill, 2000), while the collapse of Greenland's Norse colonies at ~600 cal yr BP (Buckland *et al*., 1995) coincides with a period of polar cooling."

With respect to the causes of these and other Holocene RCCs, the international team of scientists concludes, "of all the potential climate forcing mechanisms, solar variability superimposed on long-term changes in insolation (Bond *et al*., 2001; Denton and Karlen, 1973; Mayewski *et al*., 1997; O'Brien *et al*., 1995) seems to be the most likely important forcing mechanism." They also declare "negligible forcing roles are played by CH_4 and CO_2," and "changes in the concentrations of CO_2 and CH_4 appear to have been more the result than the cause of the RCCs."

Braun *et al*. (2005) note many palaeoclimate records from Earth's North Atlantic region depict a millennial-scale oscillation of climate, which during the last glacial period was highlighted by Dansgaard-Oeschger events that regularly recurred at approximately 1,470-year intervals, as reported by Rahmstorf (2003). Because of the consistency of their occurrence, it was generally believed these well-tuned periodic events were orchestrated by similarly paced solar activity, but no known solar process or orbital perturbation exhibited the periodicity of the Dansgaard-Oeschger events. Braun *et al*. (2005) performed an analysis that successfully explains this dichotomy.

Noting the periods of the DeVries-Suess and Gleissberg solar cycles (~210 and 87 years, respectively) are close to prime factors of 1,470 years, the team of eight German scientists write, "the superposition of two such frequencies could result in variability that repeats with a 1,470-year period." They proceed to show "an intermediate-complexity climate model with glacial climate conditions simulates rapid climate shifts similar to the Dansgaard-Oeschger events with a spacing of 1,470 years when forced by periodic freshwater input into the North Atlantic Ocean in cycles of ~86 and ~210 years." The researchers state this exercise is "not aimed at suggesting a certain mechanism for solar influence on freshwater fluxes," as they describe it, but merely to demonstrate "the glacial 1,470-year climate cycles could have been triggered by solar forcing despite the absence of a 1,470-year solar cycle."

Braun *et al*.'s work suggests the similarly paced millennial-scale oscillation of climate that has reverberated throughout the Holocene, but with less perfect regularity, also is driven by the combined effect of the DeVries-Suess and Gleissberg solar cycles. The German scientists state the stimulus for their idea that "a multi-century climate cycle might be linked with century-scale solar variability comes from Holocene data," citing the work of Bond *et al*. (2001), who had found "over the last 12,000 years virtually every centennial time-scale increase in drift ice documented in our North Atlantic records was tied to a solar minimum," and who concluded, "a solar influence on climate of the magnitude and consistency implied by our evidence could not have been confined to the North Atlantic."

Bond *et al*. report the climatic oscillation's most recent cold node and the warm node that preceded it were "broadly correlative with the so called 'Little Ice Age' and 'Medieval Warm Period.'" Similarly, Rahmstorf states "the so-called 'little ice age' of the 16th–18th century may be the most recent cold phase of this cycle." The logical extension of these observations is that the global warming of the past century or so, which propelled Earth out of the Little Ice Age and into the Current Warm Period, was a result of the most recent upswing in this continuing cycle of solar-induced climate change rather than any increase in the atmosphere's CO_2 concentration.

Esper *et al*. (2005) sought to explain the significant differences among climatic reconstructions and what might be necessary to reduce uncertainties in order to gain a more complete and correct understanding of temperature changes over the past thousand years. According to the six scientists, for the most part we understand the *shape* of long-term climate fluctuations better than their *amplitudes*. For example, nearly all 1,000-year temperature reconstructions capture the major climatic episodes of the Medieval Warm Period, Little Ice Age, and Current Warm Period, but they exhibit differences in the degree of warming or cooling identified in the transitions between them, which for decadal means may amount to as much as 0.4 to 1.0°C.

Esper *et al.* suggest these discrepancies might be addressed by reducing the calibration uncertainty among the proxies, ensuring the accurate preservation and assessment of low-to-high frequency variation in proxy data, using appropriate frequency bands to best fit instrumental data, avoiding the use of regional tree-ring and other paleo-records in which long-term trends (low-frequency variations) are not preserved, selecting instrumental data with which to compare proxy records to avoid incorrect alterations to the observational data that can result from homogeneity adjustments and methodological differences, and obtaining more proxy data that cover the full millennium and represent the same spatial domain as the instrumental target data.

Esper *et al.* note knowledge of the correct amplitude of the major climatic episodes of the past millennium is "critical for predicting future trends." If the amplitudes of the major historical climate episodes were as large as, or even greater than, the twentieth century global warming, there would be what they describe as a "redistribution of weight towards the role of natural factors in forcing temperature changes, thereby relatively devaluing the impact of anthropogenic emissions and affecting future predicted scenarios." Efforts to reduce greenhouse gas emissions via national or international agreements "would be less effective than thought."

Using data from 18 non-tree-ring-based 2,000-year proxy temperature series from around the world, Loehle (2007) smoothed the data in each series with a 30-year running mean, converted the results to anomalies by subtracting the mean of each series from each member of that series, and derived the final mean temperature anomaly history defined by the datasets by a simple averaging of the individual anomaly series. The results depict the Medieval Warm Period and Little Ice Age quite clearly, with the peak warmth of the MWP showing as approximately 0.3°C warmer than the peak warmth of the twentieth century. In a subsequent paper, Loehle and McCulloch (2008) obtained the results depicted in Figure 4.2.2.4. Although instrumental data are not strictly comparable to the reconstructed proxy data, the rise in global data from NASA GISS from 1935 (the end point of the figure) to 1992 (with data from 1978 to 2006) is 0.34°C, and "adding this rise to the 1935 reconstructed value, the MWP peak still remains 0.07°C above the end of the 20th-century values, though the difference is not significant."

Based on data obtained from hundreds of moisture-sensitive Scots pine tree-ring records originating in Finland and using regional curve standardization (RCS) procedures, Helama *et al.* (2009) developed "the first European dendroclimatic precipitation reconstruction," which "covers the classical climatic periods of the Little Ice Age (LIA), the Medieval Climate Anomaly (MCA), and the Dark Ages Cold Period (DACP)," running from AD 670 to AD 1993. These data indicate "the special feature of this period in climate history is the distinct and persistent drought, from the early ninth century AD to the early thirteenth century AD," which "precisely overlaps the period commonly referred to as the MCA, due to its geographically widespread climatic anomalies both in temperature and moisture." In addition, they write, "the reconstruction also agrees well with the general picture of wetter conditions prevailing during the cool periods of the LIA (here, AD 1220–1650) and the DACP (here, AD 720–930)."

The three Finnish scientists note "the global medieval drought that we found occurred in striking temporal synchrony with the multi-centennial droughts previously described for North America (Stine, 1994; Cook *et al*., 2004, 2007), eastern South America (Stine, 1994; Rein *et al*., 2004), and equatorial East Africa (Verschuren *et al*., 2000; Russell and Johnson, 2005, 2007; Stager *et al*., 2005) between AD 900 and 1300." Noting further "the global evidence argues for a common force behind the hydrological component of the MCA," they report "previous studies have associated coeval megadroughts during the MCA in various parts of the globe with either solar forcing (Verschuren *et al*., 2000; Stager *et al*., 2005) or the ENSO (Cook *et al*., 2004, 2007; Rein *et al*., 2004; Herweijer *et al*., 2006, 2007; Graham *et al*., 2007, Seager *et al*., 2007)." They conclude, "the evidence so far points to the medieval solar activity maximum (AD 1100–1250), because it is observed in the $\Delta^{14}C$ and ^{10}Be series recovered from the chemistry of tree rings and ice cores, respectively (Solanki *et al*., 2004)."

Esper and Frank (2009) took the IPCC to task for concluding in its *Fourth Assessment Report* (AR4) that, relative to modern times, there was "an increased heterogeneity of climate during medieval times about 1000 years ago." This finding, if true, would be of

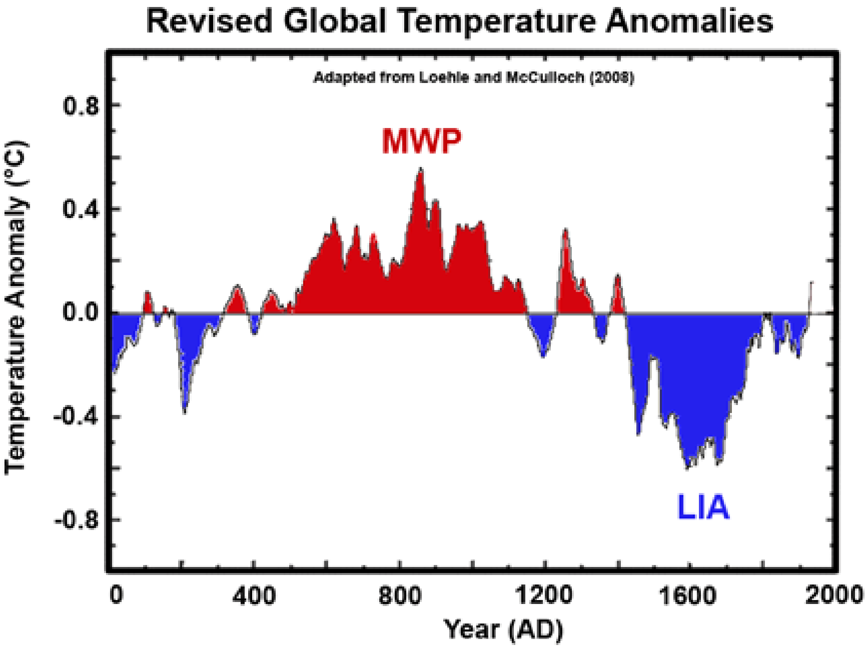

Figure 4.2.2.4. Mean relative temperature history of the globe. Adapted from Loehle, C. and McCulloch, J.H. 2008. Correction to: A 2000-year global temperature reconstruction based on non-tree ring proxies. *Energy & Environment* **19**: 93–100.

great significance to the ongoing debate over the cause of twentieth century global warming because, as Esper and Frank note, "heterogeneity alone is often used as a distinguishing attribute to contrast with present anthropogenic warming." But if the IPCC's contention is false, it would mean the warmth of the Current Warm Period is not materially different from that of the Medieval Warm Period, suggesting there is no need to invoke anthropogenic CO_2 emissions as the cause of Earth's current warmth.

With mathematical procedures and statistical tests, Esper and Frank demonstrate the records reproduced in the AR4 "do not exhibit systematic changes in coherence, and thus cannot be used as evidence for long-term homogeneity changes." They also note "there is no increased spread of values during the MWP," and the standard error of the component datasets "is actually largest during recent decades." Consequently, the two researchers conclude their "quantification of proxy data coherence suggests that it was erroneous [for the IPCC] to conclude the records displayed in AR4 are indicative of a heterogeneous climate during the MWP."

The studies cited in this section clearly establish the verity of a global Medieval Warm Period. Hundreds of additional papers are cited in Sections 4.2.3 and 4.2.4.

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4.2.3 Prior Warm Periods in the Northern Hemisphere

Citing the work of Mann *et al*. (1998, 1999), the IPCC concluded in its *Fourth Assessment Report* that late twentieth century warming was unprecedented over the past millennium, a conclusion that remains intact in the IPCC's most recent report:

> For average annual Northern Hemisphere temperatures, there is *medium confidence* that 1981–2010 CE was the warmest 30-year period of the last 1300 years and it is *very likely* that it was the warmest of the last 800 years (Second Order Draft of AR5, dated October 5, 2012, p 5–4)

As shown in this subsection, the IPCC is clearly ignoring the findings of several research teams who have presented results that counter their claims.

The Medieval Warm Period and subsequent Little Ice Age, which followed the Roman Warm Period and the Dark Ages Cold Period (McDermott *et al*., 2001), were long considered classic examples of the warm and cold phases of a millennial-scale climate oscillation that has reverberated throughout glacial and interglacial periods (Oppo *et al*., 1998; McManus *et al*., 1999) as well as across the early Pleistocene (Raymo *et al*., 1998).

In addition to their intrinsic historical value, the last of these alternating warm and cold periods are of particular relevance to the global warming debate. If there truly was a period near the beginning of the past millennium when temperatures were as warm as they are presently, but when the atmosphere's CO_2 concentration was only about 40 percent of today's level (280 ppm vs. 400 ppm), and if that period was followed by a several-centuries-long cold period with essentially no decline in the air's CO_2 content, there would be little basis for invoking the twentieth century increase in atmospheric CO_2 concentration as a reason for the planet's return to the warmth it had experienced a millennium earlier, as Idso (1988) argued a quarter-century ago and Broecker (1999) noted a decade later.

A pair of papers published by Mann *et al*. (1998, 1999) near the turn of the twenty-first century presented an interpretation of Earth's climatic history vastly different from what previously had been accepted by even the IPCC (Houghton *et al*., 1990), which up to at least 1995 had depicted the existence of both the Medieval Warm Period and the Little Ice Age. The new history, derived from select proxy temperature records, showed, in the words of Esper *et al*. (2002), "an almost linear temperature decrease from the year 1000 to the late 19th century, followed by a dramatic and unprecedented temperature increase to the present time," which is now routinely described by the IPCC as "the warmest period of the past millennium." A few years later, the work of Esper *et al*. (2002) reaffirmed the earlier understanding of these unique climatic periods.

Esper *et al*. employed an analysis technique that allowed long-term climate trends to be derived from individual tree-ring series of much shorter duration than the potential climatic oscillation being studied, and they applied this technique to more than 1,200 tree-ring series derived from 14 locations over the extratropical region of the Northern Hemisphere. Two separate chronologies were developed: one from trees that exhibited weakly linear age trends and one from trees with nonlinear age trends. The outcome, they write, was "two nearly independent tree-ring chronologies covering the years 800–1990," which were "very similar over the past ~1200 years." These tree-ring histories were calibrated against Northern Hemispheric (0 to 90°N) mean annual instrumental temperatures from the period 1856–1980 to make them compatible with the temperature reconstructions of Mann *et al.*

The biggest difference between the Esper *et al.* and Mann *et al.* temperature histories is the degree to which the coolness of the Little Ice Age is expressed. The Little Ice Age is much more evident in the record of Esper *et al.*, and its significantly lower temperatures make the Medieval Warm Period stand out more dramatically. Esper *et al.* note, "the warmest period covers the interval 950–1045, with the peak occurring around 990." This finding, they write, "suggests that past comparisons of the Medieval Warm Period with the 20th-century warming back to the year 1000 have not included all of the Medieval Warm Period and, perhaps, not even its warmest interval."

In a companion "perspective" paper, Briffa and Osborn (2002) acknowledge the last millennium "was much cooler than previously interpreted" and "an early period of warmth in the late 10th and early 11th centuries is more pronounced than in previous large-scale reconstructions."

Esper *et al.*'s work reaffirms the point raised by Idso (1988): There is no need to invoke CO_2-induced global warming as a cause of the planet's recovery from the global chill of the Little Ice Age. "Since something other than atmospheric CO_2 variability was ... clearly responsible for bringing the planet into the Little Ice Age," he notes, "something other than atmospheric CO_2 variability may just as well have brought the planet out of it." That something else, as suggested by Esper *et al.*, is probably "the 1000- to 2000-year climate rhythm (1470 ± 500 years) in the North Atlantic, which may be related to solar-forced changes in thermohaline circulation" as described by Bond *et al.* (2001).

Briffa and Osborn also note Esper *et al.*'s record clearly shows the warming of the twentieth century was "a continuation of a trend that began at the start of the 19th century." In addition, the Esper *et al.* record indicates the Northern Hemisphere warmed in a consistent near-linear fashion over this 200-year period, contrary to the claim of unprecedented warming over only the last century.

Briffa and Osborn conclude, "we need to know why it was once so warm and then so cool, before we can say whether 21st-century warming is likely to be nearer to the top or the bottom of the latest IPCC [predicted temperature] range." The answer to this question is already known: The extremes of warmth and coolness to which Briffa and Osborn refer were likely caused by "solar-forced changes in thermohaline circulation," as suggested by Esper *et al.* and described by Bond *et al.* It has become increasingly clear these significant climatic changes were not caused by changes in the air's CO_2 content.

Briffa *et al.* (2002) worked with a network of high-latitude and high-elevation tree-ring chronologies obtained from 387 conifer sites that circled the extra-tropical Northern Hemisphere, comprised of almost 10,000 individual tree cores with chronologies ranging in length from 85 to more than 600 years, to reconstruct a "near-hemispheric scale" April-to-September temperature history. Based on the trees' maximum latewood density, this temperature reconstruction exhibits a strong, spatially coherent response to decadal-scale temperature variability, but because of the particular standardization procedure they employed, Briffa *et al.* state their reconstruction was "likely to remove the century to multicentury timescale power." The following discussion is limited to a consideration of what their work implied about the warming of the Northern Hemisphere in only the late twentieth century.

The year of coldest growing-season temperature in Briffa *et al.*'s reconstruction was 1912, after which temperatures rose in zigzag fashion to about 1930, whereupon they flattened out until approximately 1945, after which they declined in zigzag fashion until sometime in the late 1970s, when they began to fluctuate about a well-defined mean that persisted to the end of the century. At the dawning of the new millennium, Briffa *et al.*'s proxy temperatures were considerably below the peak warmth of the 1930s and early 1940s, in striking contrast to the instrumental temperature record, which soared to new heights in the 1980s and 1990s to achieve the century's highest values, which were several tenths of a degree Centigrade greater than the temperatures derived from the 10,000 trees' maximum latewood density data. Mann *et al.* (1998, 1999) used instrumental temperatures in lieu of proxy temperatures over the latter part of the century to arrive at what they called the "unprecedented" warming of its last two decades.

Is it appropriate, as Mann *et al.* did, to "switch horses" and compare two different things—early-century *proxy* temperatures and late-century *instrumental* temperatures—to conclude the twentieth century experienced unprecedented warming over its final two decades? Or is it more appropriate to finish the comparison with the parameter with which you began, which leads to the conclusion that the end of the century was likely no warmer than it was in the 1930s and early 1940s?

Briffa *et al*. approached this predicament by first acknowledging the existence of the problem, which they describe as "a deviation between reconstructed and observed temperature during the most recent three or four decades," noting the deviation increases with time, "particularly since about 1970 (although perhaps starting as early as 1935)." They admit they could not find a "substantiated explanation for it," so they *assumed* the deviation "is likely to be a response to some kind of recent anthropogenic forcing." And they also assumed the anthropogenic forcing had perturbed the *proxy* temperature record.

A much less convoluted course of action would have been to assume the anthropogenic forcing had perturbed the *instrumental* temperature record. There is, after all, a well-known and "substantiated explanation" for this point of view: that Earth's increasing population has been increasing the strength of urban heat island and altered land-use effects nearly everywhere on the land surface of the planet, and sufficiently accurate adjustments to the instrumental temperature record for these phenomena had not yet been made throughout the regions investigated by Briffa *et al*.

Since 1970, for example, the world's population had grown by approximately 64 percent, and since 1935, when the first signs of the deviation between the proxy and instrumental temperature records began to occur, the number of people on the planet had grown by more than 200 percent. With urban heat islands routinely raising city air temperatures several degrees Centigrade above the temperatures of their surrounding rural environs, and since towns with as few as a thousand inhabitants have been shown to possess heat islands of two degrees Centigrade or more (Oke, 1973; Torok *et al*., 2001), it is clear population growth easily could have produced a gradually increasing elevation of the instrumental temperature record (typically developed from temperatures measured in cities and towns) relative to the basically rural temperature record typical of the locations where the tree-ring chronologies studied by Briffa *et al*. were obtained. This phenomenon easily could account for the several tenths of a degree Centigrade by which instrumental and proxy temperature records differed at the end of the twentieth century.

There are several other reasons for accepting this analysis of the diverging-temperature-records dilemma instead of yielding to the six scientists' default assumption. Briffa *et al.* could identify no credible mechanism for producing the problem they imagined to exist with the late twentieth century proxy temperatures, so they gave up, saying "to search for an explanation is beyond the scope of this paper." They could not produce an explanation that would apply to the entire Northern Hemisphere and be readily comprehended by most reasonable people as having at least the potential to be correct.

One also wonders what kind of "recent anthropogenic forcing" could have had such a substantial negative effect on tree growth and wood density over the latter part of the twentieth century. Atmospheric pollution is one possibility, especially rising ozone (O_3) concentrations. However, in numerous studies of the net effect of elevated O_3 and CO_2 acting together on trees, the positive effects of elevated CO_2 often have been found to compensate, and sometimes even more than compensate, for the negative effects of elevated O_3 (Grams *et al*., 1999; Noormets *et al*., 2001; Liu *et al*., 2004). The positive effects of elevated CO_2 also have been found to compensate for the negative effects of elevated sulfur dioxide concentrations (Deepak and Agrawal, 2001; Izrael *et al*. (2002); Agrawal and Deepak, 2003). Rising atmospheric CO_2 concentrations are known to significantly stimulate the growth rates of essentially all woody plants and increase the density of the wood produced by trees (Kilpelainen *et al*., 2003; Kostiainen *et al*., 2004).

In light of these observations, it is highly unlikely human activity is reducing the growth and wood density of Earth's trees, especially those growing in the relatively remote locations used to develop the data analyzed by Briffa *et al*. It is far more likely the divergence of the instrumental and proxy temperature records analyzed by Briffa *et al.* is caused by an anthropogenic effect on the *instrumental* record than on proxy record. Thus the hockey stick temperature record of Mann *et al*. (1998, 1999) would appear to be patently erroneous over the last few decades of the twentieth century, substituting as it does the increasingly inflated instrumental temperature record for the more correct and stable proxy temperature record.

Esper and a group of five new coauthors—Esper *et al*. (2003)—processed several long juniper tree-ring-width chronologies for the Alai Range of the western Tien Shan in Kirghizia in way that preserved multi-centennial growth trends typically "lost during the processes of tree ring data standardization and chronology building (Cook and Kairiukstis, 1990; Fritts, 1976)." They used two techniques that maintain low frequency signals—long-term mean standardization (LTM) and regional curve standardization (RCS)—as well as the more conventional spline standardization (SPL) technique that obscures (actually removes) such long-term trends.

Carried back in time a full thousand years, the SPL chronologies depicted significant interdecadal variations but no longer-term trends. The LTM and RCS chronologies, by contrast, showed long-term decreasing trends until about AD 1600, broad minima from 1600 to 1800, and long-term increasing trends from about 1800. Esper *et al*. write, "the main feature of the LTM and RCS Alai Range chronologies is a multi-centennial wave with high values towards both ends."

This result has essentially the same form as the Northern Hemispheric extratropic temperature history of Esper *et al*. (2002), which is vastly different from the hockey stick temperature history of Mann *et al*. (1998, 1999) and Mann and Jones (2003), in that it depicts the existence of both the Little Ice Age and the preceding Medieval Warm Period, which are nowhere to be found in the Mann reconstructions. The new result—especially the LTM chronology, which has a much smaller variance than the RCS chronology—depicts several periods in the first half of the past millennium that were warmer than any part of the past century. These periods include much of the latter half of the Medieval Warm Period and a good part of the first half of the fifteenth century, which also has been found to have been warmer than it is currently (McIntyre and McKitrick, 2003; Loehle, 2004).

Briffa *et al*. (2004) reviewed several analyses of maximum latewood density data derived from a widespread network of tree-ring chronologies that spanned three to six centuries and were obtained from nearly 400 different locations. For the land area of the globe poleward of 20°N latitude, their work reveals the warmest period of the past six centuries occurred in the 1930s and early 1940s. Thereafter, the mean temperature of the region declined dramatically. It recovered somewhat over the last two decades of the twentieth century, but its final value was still below the mean value of the 1400s and portions of the 1500s.

Averaged over all land area poleward of 50°N latitude, there was a marked divergence of reconstructed and instrumental temperatures subsequent to 1960, with measured temperatures rising and reconstructed temperatures falling, such that by the end of the record there was an approximate 1.5°C difference between them. The three researchers attempted to relate this large temperature differential to a hypothesized decrease in tree growth caused by a hypothesized increase in ultraviolet radiation, which they hypothesized to have been caused by declining stratospheric ozone concentrations over this period. The results of this effort, however, proved "equivocal," as they describe them, leaving considerable room for urban heat island effects and other land-cover changes to have been the principal causes of the observed temperature divergence, as suggested by Gallo *et al*. (1996, 1999) and Kalnay and Cai (2003). Briffa *et al.* state these unsettled questions prevented them "from claiming unprecedented hemispheric warming during recent decades on the basis of these tree-ring density data alone." Their analyses also fail to provide convincing evidence for the validity of the Northern Hemispheric temperature reconstructions of Mann *et al*. (1998, 1999) and thus fail to support the IPCC's contention that the warming of high northern latitudes should be significantly greater than that of the rest of the Northern Hemisphere.

While studying lichens of the subspecies *Rhizocarpon geographicum* found on avalanche boulder tongues in the eastern part of the Massif des Ecrins of the French Alps, Jomelli and Pech (2004) made an important discovery: High-altitude avalanche activity during the Little Ice Age reached an early maximum prior to 1650, after which it decreased until about 1730, whereupon it increased once again, reaching what was likely its greatest maximum about 1830. The two researchers note "a greater quantity of snow mobilized by avalanches during the LIA can be supported by the fact that the two periods, AD 1600–1650 and 1830, during which the run-out distances [of the avalanches] were maximum at high elevation sites, have corresponded overall to the periods of maximum glacial advances for these last 500 years (Le Roy Ladurie, 1983; Reynaud, 2001)." In addition, they report "since 1850 most French Alpine glaciers have decreased" and "the mass balance of these glaciers is directly correlated with summer temperature and spring precipitation (Vincent and Vallon, 1997; Vincent, 2001, 2002)."

These findings and those of other scientists cited by Jomelli and Pech suggest the beginning of the end of the Little Ice Age started somewhere in the early to mid-1800s. Moore *et al*. (2002) determined a similar start-time for the demise of the Little Ice Age from temperature data gathered on Mount Logan in Canada, and further support for this conclusion has come from studies of still other parameters, including deep soil temperatures (Gonzalez-Rouco *et al*., 2003), deep ocean temperatures (Lindzen, 2002), and dates of ice break-up of lakes and rivers (Yoo and D'Odorico, 2002). This is also when the temperature record of Esper *et al*. (2002) indicates the Northern Hemisphere began its nearly-linear-with-time recovery from the depths of the Little Ice Age. As Briffa and Osborn (2002) describe it, Esper *et al*.'s record clearly shows the warming of the twentieth century was actually "a continuation of a trend that began at the start of the 19th century."

The temperature history of Mann *et al*. (1998, 1999) suggests post-Little Ice Age warming did not begin until about 1910. They appear to have missed as much as half the warming experienced by Earth in recovering from what was likely the coldest part of the Little Ice Age. An even greater part of the total warming occurred before the air's CO_2 concentration began increasing in earnest (approximately 1930, close to the time when warming peaked in the United States and many other parts of the world). Thus the lion's share of the warming of the past nearly two centuries must owe its existence to something other than rising atmospheric CO_2 concentrations.

Gray *et al*. (2004) write, "natural, low-frequency variations" in near-surface air temperature may "mask or amplify secular trends in the climate system." Hence, it is important—even necessary—to study such phenomena in order to determine the cause or causes of recent climate change. Gray *et al*. developed a reconstruction of the leading mode of low-frequency North Atlantic (0–70°N) sea surface temperature variability—i.e., the Atlantic Multidecadal Oscillation (AMO)—for the period AD 1567–1990, based on tree-ring records from regions known to border on strong centers of AMO variability: eastern North America, Europe, Scandinavia, and the Middle East.

In terms of both duration and magnitude, the four researchers found the "AMO variability observed in late-19th and 20th century instrumental records is typical of North Atlantic multidecadal behavior over longer periods." They also observed a new warming phase had begun in the mid-1990s and the most intense warm phase of the AMO record occurred between 1580 and 1596.

Gray *et al*. say the first of these findings suggests "the mechanisms driving AMO variability have operated in a similar fashion for (at least) the previous 500 years," and "trace-gas forcing has yet to significantly affect the low-frequency component of THC [thermohaline circulation] variability." Their work also suggests trace-gas forcing has yet to significantly affect the near-surface air temperature of the Northern Hemisphere, and the identification of the start of a new warming phase in the mid-1990s suggests the supposedly record temperatures of the past decade or so may have been driven more by natural AMO variability than increasing greenhouse gas concentrations.

The most intense warm phase of the AMO record of Gray *et al*. occurred near the end of the time frame associated with evidence of what could be called the "Little" Medieval Warm Period, when global air temperature may have been significantly warmer than it has been at any subsequent time, clearly evident in Gray *et al*.'s reconstruction of North Atlantic SST anomalies. Thus the evidence continues to mount for the existence of a warm period in the general vicinity of the 1500s, when the air's CO_2 content was much less than it is today.

von Storch *et al*. (2004) used a coupled atmosphere-ocean model simulation of the climate of the past millennium as a surrogate climate to test the skill of the empirical reconstruction methods used by Mann *et al*. (1998, 1999) in deriving their thousand-year "hockey stick" temperature history of the Northern Hemisphere. They generated several pseudo-proxy temperature records by sampling a subset of the model's simulated grid-box temperatures representative of the spatial distribution of the real-world proxy temperature records used by Mann *et al*. They degraded these pseudo-proxy records with statistical noise, regressed the results against the measured temperatures of the historical record, and used the relationships thus derived to construct a record they could compare against their original model-derived surrogate temperature history.

The six scientists discovered the centennial variability of Northern Hemisphere temperature was underestimated by the regression-based methods they applied, suggesting past variations in real-world temperature "may have been at least a factor of two larger than indicated by empirical reconstructions."

The consequences of this result are readily evident in the reduced degree of Little Ice Age cooling and Medieval warming that resulted from the techniques employed by Mann *et al.*

In an accompanying commentary on von Storch *et al.*'s paper, Osborn and Briffa (2004) state, "if the true natural variability of [Northern Hemisphere] temperature is indeed greater than is currently accepted, the extent to which recent warming can be viewed as 'unusual' would need to be reassessed." The need for this reassessment is also suggested by what von Storch *et al.* refer to as "empirical methods that explicitly aim to preserve low-frequency variability (Esper *et al.*, 2002)," which show much more extreme Medieval warming and Little Ice Age cooling than do the reconstructions of Mann *et al.*

These observations indicate the temperature record of Esper *et al.* is likely to be much more representative of reality than is the IPCC-endorsed record of Mann *et al.* The lion's share of the warming experienced since the end of the Little Ice Age occurred well before mankind's CO_2 emissions significantly perturbed the atmosphere, suggesting most of the post-Little Ice Age warming was due to something other than rising atmospheric CO_2 concentrations. That further suggests the lesser warming of the latter part of the twentieth century also may have been due to something else.

Cook *et al.* (2004) reviewed the work of Esper *et al.* (2002) and conducted further analyses of the data the latter team of scientists had employed in its reconstruction effort. Cook *et al.* determined the "strongly expressed multi-centennial variability [of the Esper *et al.* reconstruction] is highly robust over the AD 1200–1950 interval, with strongly expressed periods of 'Little Ice Age' cooling indicated prior to AD 1900," and "persistently above-average temperatures in the AD 960–1050 interval also suggest the large-scale occurrence of a 'Medieval Warm Period' in the Northern Hemisphere extra-tropics."

Cook *et al.* draw this conclusion despite what they describe as strong criticism personally communicated to them by R.S. Bradley of the Mann *et al.* group of researchers. The existence of a global Medieval Warm Period is hotly debated and critical to the climate change debate, because if Earth was as warm as it is today a thousand or more years ago, when the air's CO_2 concentration was more than 100 ppm less than it is today, there is no compelling reason to believe atmospheric CO_2 concentrations had anything to do with the global warming of the past century.

Moberg *et al.* (2005) presented a new temperature history of the Northern Hemisphere spanning the past two millennia, produced from two sources of paleoclimatic data: tree rings, which capture very high frequency climate information, and lake and ocean sediments, which "provide climate information at multi-centennial timescales that may not be captured by tree-ring data."

The new temperature history clearly revealed the existence of one full cycle of the roughly 1500-year climatic oscillation that reverberates throughout the Holocene and across prior glacial and interglacial periods alike (Oppo *et al.*, 1998; Raymo *et al.*, 1998; McManus *et al.*, 1999). Moberg *et al.* noted, for example, "high temperatures—similar to those observed in the twentieth century before 1990—occurred around AD 1000 to 1100, and minimum temperatures that are about 0.7°C below the average of 1961–90 occurred around AD 1600," whereas the twentieth century has seen a return to a new period of relative warmth.

Moberg *et al.* say the low-frequency variability missing from the temperature reconstructions of Mann *et al.* originates from a set of 11 non-tree-ring proxy climate records that cover most of the past two millennia, nine of which already had been calibrated to local/regional temperatures by their developers. Moberg *et al.* say simple averages of temperature proxy series, such as the ones they used, "can yield adequate estimates of Northern Hemisphere century-scale mean-temperature anomalies," citing the work of von Storch *et al.* (2004). When simple averaging is all that is done, as is evident in Moberg *et al.*'s graphical results, the Medieval Warm Period is observed to peak just prior to AD 900 and is strongly expressed between about AD 600 to 1100, very possibly the most correct temperature reconstruction of all (see Figure 4.2.3.1).

Figure 4.2.3.1 shows the final twentieth century temperature of the record developed by Moberg *et al.* is cooler than the temperatures of the entire 500-year time span of the MWP. It is only when the directly measured instrumental temperatures of the latter part of the twentieth century are added to the new temperature history that the Swedish and Russian scientists observe a recent ("post-1990") modern warming that "appears to be unprecedented" over the prior two millennia. Note they say the warming *appears* to be unprecedented, for one cannot make a definitive comparative judgment on the matter when the two types of data involved are significantly different from each other. One cannot compare real apples with reconstructed oranges, especially when the apples may have been contaminated by a factor (the growing urban heat island and land-use change effects) that likely had little or no influence on the oranges.

McIntyre and McKitrick (2005) also analyzed the procedures used by Mann *et al*. (1998) to develop their hockey stick temperature reconstruction. In an analysis of an unusual data transformation employed by Mann *et al*., which strongly affects the resulting principal components (PCs) of their tree-ring-based temperature reconstructions, the two researchers discovered the unusual method nearly always produced a hockey stick-shaped first principal component (PC1) when tested on persistent red noise. "In effect," they write, "the Mann *et al*. (1998) data transformation results in the PC algorithm mining the data for hockey stick patterns."

The researchers also demonstrate the data transformation used by Mann *et al*. "effectively selects only one species (bristlecone pine) into the critical North American PC1, making it implausible to describe it as the 'dominant pattern of variance.'" The selected tree-ring records were ones that had been developed and analyzed by Graybill and Idso (1993), who suggested they were particularly good candidates for exhibiting CO_2-induced increases in growth as opposed to temperature-induced increases in growth, as assumed by Mann *et al*. Graybill and Idso describe in detail how they investigated "the possibility that changes in climate during the past century might be responsible for the unusual increases in ring width growth" that were exhibited by the trees, "considering temperature, precipitation and computed drought values," and it is their stated conclusion—clearly available for Mann *et al*. to read before using their data—that "it is notable that trends of the magnitude observed in 20th century ring width growth are conspicuously lacking in all of the time

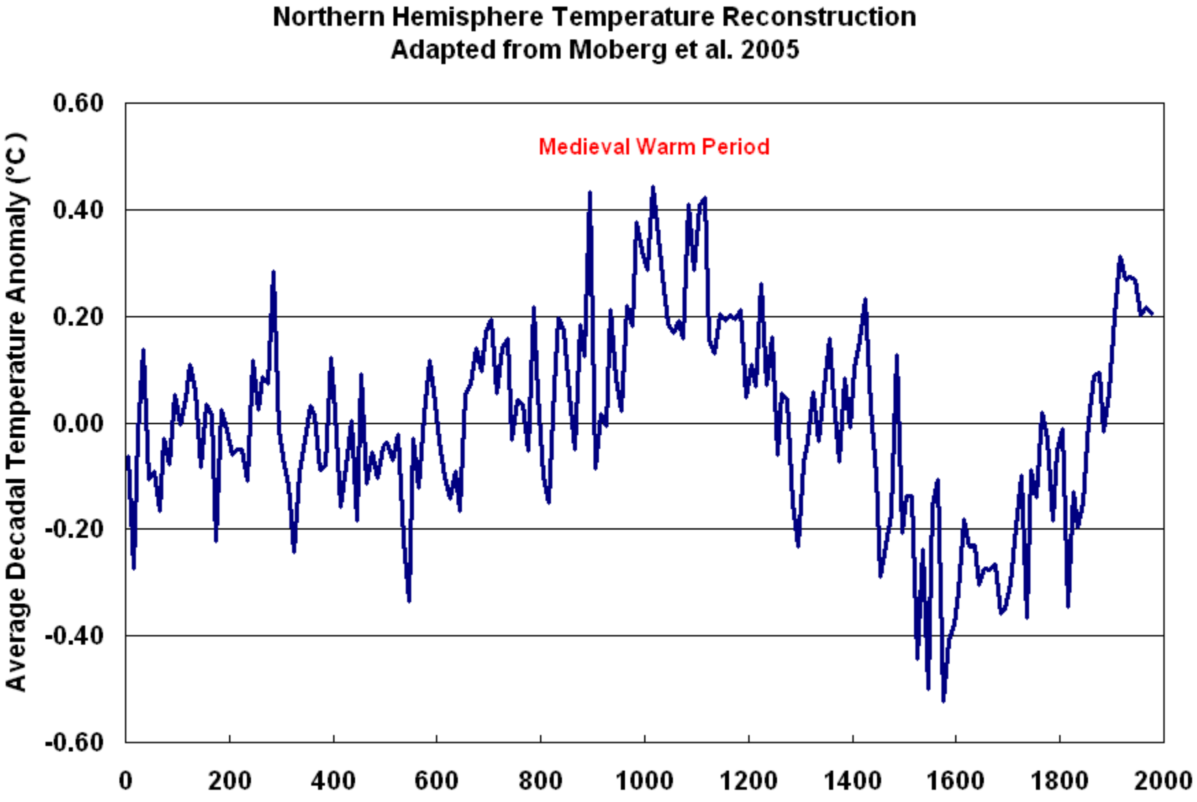

Figure 4.2.3.1. Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data covering the past 2,000 years. Adapted from Moberg, A., Sonechkin, D.M., Holmgren, K., Datsenko, N.M., and Karlen, W. 2005. Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data. *Nature* **433**: 613–617.

series of instrumented climatic variables that might reasonably be considered growth-forcing in nature." These facts are particularly "disquieting," as McIntyre and McKitrick put it, "given that the NOAMER PC1 has been reported to be essential to the shape of the Mann *et al*. (1998) Northern Hemisphere temperature reconstruction."

McIntyre and McKitrick also show the Mann *et al*. (1998) benchmarks for significance of their Reduction of Error statistic were "substantially under-stated," and using a range of cross-validation statistics, they show Mann *et al*.'s reconstruction "lacks statistical significance."

Esper *et al*. (2005) selected four representations of Earth's surface air temperature history over the past thousand years (Jones *et al*., 1998; Mann *et al*., 1999; Briffa, 2000; Esper *et al*., 2002) for inclusion in an analysis designed to reveal the significance of problems associated with some of those histories. They note "these records were developed using tree ring data alone or using multi-proxy data, and are reported to represent different regions (e.g. Northern Hemisphere (NH) extra-tropics, or full NH)," thereby highlighting two of several factors (different types of data, different areas of applicability) that lead to different results. The four researchers also investigated methodological differences, including "using scaling or regression, the calibration time period, and smoothing data before calibration." They also point out different histories sometimes represent different seasons of the year; they either include or exclude sea surface temperatures; the available data are "more uncertain back in time"; and the record "becomes biased towards Europe, North America, and areas in Asia" moving back in time.

Reporting on the results of their analyses of the effects of scaling and regression approaches applied in the recent scientific literature to proxy-based temperature records, Esper *et al*. (2005) state, "these various approaches alone can result in differences in the reconstructed temperature amplitude ["measured from the coldest to warmest decades"] of about 0.5°C." This difference, they write, is "equivalent to the mean annual temperature change for the Northern Hemisphere reported in the last IPCC report for the 1000–1998 period." In addition, they point out "consideration of temporally changing spatial coverage and uncertainty in both the instrumental and proxy data, as expressed by confidence limits accompanying such records, would further increase the range of amplitude estimates over the past millennium."

Esper *et al*. also note, "when linear regression is used for calibration, the variance of a proxy record remains below that of the target data, leaving the visual impression that the recent dynamics are substantially larger than the historic ones when splicing such records together," which is precisely the impression conveyed when the modern instrumental record is attached to the end of calibrated proxy data, as in the hockey stick temperature record of Mann *et al*. (1999).

Asami *et al*. (2005) derived a monthly resolved 213-year (1787–2000) time series of carbon and oxygen isotope variations measured in a 273-cm-long coral core retrieved from a *Porites labata* colony located on the northwestern coast of Guam, where it had been exposed to open sea surface conditions over the entire period of its development. "On the basis of the Guam δ^{18}O coral record," according to the six scientists, "the early 19th century (1801–1820) was the coolest in the past 210 years, which is consistent with SST reconstructions from a δ^{18}O coral record from New Caledonia (Crowley *et al*., 1997)." This period, they write, "was characterized by a decrease in solar irradiance (Lean *et al*., 1995; Crowley and Kim, 1996) and by a series of large volcanic eruptions in 1808–1809 and 1818–1822 (Crowley *et al*., 1997)." From the early nineteenth century on, "the long-term δ^{18}O coral trend is characterized by its overall depletion throughout the period," indicative of a gradual warming of approximately 0.75°C.

The existence of the Little Ice Age, missing from the Mann *et al.* (1998, 1999) reconstruction, is clearly manifest at the beginning of the Guam coral record and at about the same time in the New Caledonia coral record. The Guam coral record also depicts essentially continuous warming from about 1815, just as the Esper *et al*. record does, whereas the Mann *et al*. record does not depict warming until after 1910, about a century later. A 0.75°C rise in temperature from the start of the warming until the end of the twentieth century is not at all unusual, since it begins at one of the coldest points of the coldest multi-century period (the Little Ice Age) of the entire Holocene, the current interglacial.

The extreme cold of the early 1800s and the warming that followed it were not caused by changes in the air's CO_2 concentration. Instead, a reversal of the forces that produced the cold in the first place (Asami *et al*. mention a decrease in solar irradiance and large volcanic eruptions) likely led to the subsequent warming. This represents the entirely natural recovery of Earth from the global chill of one of the coldest portions of the coldest multi-century period of the past 10,000 years.

D'Arrigo *et al.* (2006) note the Northern Hemispheric temperature reconstruction of Mann *et al.* (1999) "demonstrates minimal temperature amplitude (e.g., during the 'Medieval Warm Period' and 'Little Ice Age') while others (Briffa, 2000; Esper *et al*., 2002; Cook *et al*., 2004; Moberg *et al*., 2005) exhibit more pronounced variability." To determine the reasons for this discrepancy, they assembled mostly tree-ring width (but some density) data from living and subfossil wood of coniferous tree species found at 66 high-elevation and latitudinal treeline North American and Eurasian sites, analyzing these data via both standard (STD) and regional curve standardization (RCS) detrending techniques. STD (used by Mann *et al*.) does not accurately capture the low-frequency variability required to compare the temperatures of periods separated in time by many hundreds of years or more. In addition, D'Arrigo *et al*. report, "the North American data are much improved with new or extended millennial-length records and updates of most of the data sets until at least the late 1990s." Also, they did not use the long bristlecone pine datasets from Colorado and California that Mann *et al*. employed, "as many appear to portray a mixed precipitation and temperature signal (in addition to a purported CO_2 fertilization effect)," and they did not use the Mackenzie Mountains, Boreal, Upperwright, and Gotland datasets utilized by Esper *et al*. (2002) because they "(1) did not demonstrate a significant temperature signal on the local to regional scale, (2) displayed significant correlations with precipitation, or (3) were located at lower latitudes than those compiled for the present analysis."

D'Arrigo *et al*.'s STD and RCS Northern Hemisphere temperature reconstructions spanned the period AD 713–1995. They found "the long-term trends of the STD reconstruction most closely match the Mann *et al*. (1999) and Jones *et al*. (1998) series, whereas the RCS reconstruction compares best with the Esper *et al*. (2002) and Cook *et al*. (2004) series." This observation, they write, "validates the hypothesis (Esper *et al*., 2004) that one reason for the relative lack of long-term variability in the work of Mann *et al*. (1999) was their use of standard detrending procedures that removed low-frequency variation." They conclude "the RCS reconstruction is superior to the more traditional STD method with regards to the ability to retain low-frequency (centennial to multi-centennial) trends."

In comparing the temperatures of the Medieval Warm Period with those of the Current Warm Period, based on the six longest (>1000 years) chronologies they analyzed, D'Arrigo *et al*. conclude "the recent period does not look particularly warmer compared to the MWP." They note the mean of the six series does depict a warmer CWP, but they describe this apparent relationship as "a bias/artifact in the full RCS reconstruction (and likely in many of the other reconstructions) where the MWP, because it is expressed at different times in the six long records, is 'averaged out' (i.e., flattened) compared to the recent period which shows a much more globally consistent signal."

D'Arrigo *et al*. conclude "not enough proxy records yet exist for this time," meaning the MWP. Working with the records they had, they found "late twentieth century warming exceeds peak MWP conditions by 0.67°C when comparing decadal averages (960–969 (reconstruction) = -0.12°C versus 1991–2000 (instrumental) = 0.55°C)." This conclusion, of course, is based on an "apples and oranges" comparison, and the three researchers report, "peak twentieth century warmth for the period covered only by the proxy data (1937–1946, 0.17°C) exceeds peak MWP conditions by 0.29°C," a significantly smaller number than that obtained by comparing the reconstructed and instrumental results.

A further confounding fact, according to D'Arrigo *et al*., is the "apparent decrease in recent temperature sensitivity for many northern sites ... with divergence from instrumental temperatures after ~1986." So great has this divergence been that the late 1990s instrumental temperatures are essentially a full degree Centigrade higher than those of the proxy reconstructions. The three researchers conclude, "until valid reasons for this phenomenon have been found, [we] can only question the ability of tree-ring data to robustly model earlier periods that could have been similarly warm (or warmer) than the present." To resolve the issue of the relative warmth of the CWP compared to that of the MWP, they suggest "many long records from new NH locations and updating of existing records to the present are required."

D'Arrigo *et al*. (2008) tackled the divergence problem, which they describe as "an offset between warmer instrumental temperatures and their underestimation in reconstruction models based on tree rings." This problem was "detected in tree-ring width and density records from many circumpolar northern latitude sites since around the middle 20th century." They "review[ed] the current literature published on the divergence problem to date, and assess[ed] its possible causes and implications."

The four researchers identified several possible causes for the divergence: moisture stress, nonlinear or threshold responses to warming, local pollution, delayed snowmelt, changes in seasonality, differential responses to maximum and minimum temperatures, global dimming, methodological issues related to "end effects," biases in instrumental target data, the modeling of such data, declining stratospheric ozone concentrations, increased UV-B radiation at ground level, and "an upward bias in surface thermometer temperature measurements in recent years related to heat island effects."

D'Arrigo *et al*. report their review "did not yield any consistent pattern that could shed light on whether one possible cause of divergence might be more likely than others," leading them to conclude "a combination of reasons may be involved that vary with location, species or other factors, and clear identification of a sole cause for the divergence is probably unlikely."

Ljungqvist (2010) developed a 2,000-year temperature history of the extra-tropical portion of the Northern Hemisphere (i.e., that part covering the latitudinal range 30–90°N) based on 30 temperature-sensitive proxy records with annual to multi-decadal resolution: two historical documentary records, three marine sediment records, five lake sediment records, three speleothem $\delta^{18}O$ records, two ice-core $\delta^{18}O$ records, four varved thickness sediment records, five tree-ring width records, five tree-ring maximum latewood density records, and one $\delta^{13}C$ tree-ring record. Ljungqvist did not employ tree-ring width records from arid and semi-arid regions, because they may have been affected by drought stress and thus may not have shown a linear response to warming if higher summer temperatures also reduced the availability of water, as suggested by the work of D'Arrigo *et al*. (2006) and Loehle (2009).

The results of the Swedish scientist's efforts are depicted in Figure 4.2.3.2. Ljungqvist states this tempereatue history depicts "a Roman Warm Period *c.* AD 1–300, a Dark Age Cold Period *c.* AD 300–800, a Medieval Warm Period c. AD 800–1300 and a Little Ice Age c. AD 1300–1900, followed by the twentieth-century warming." These alternating

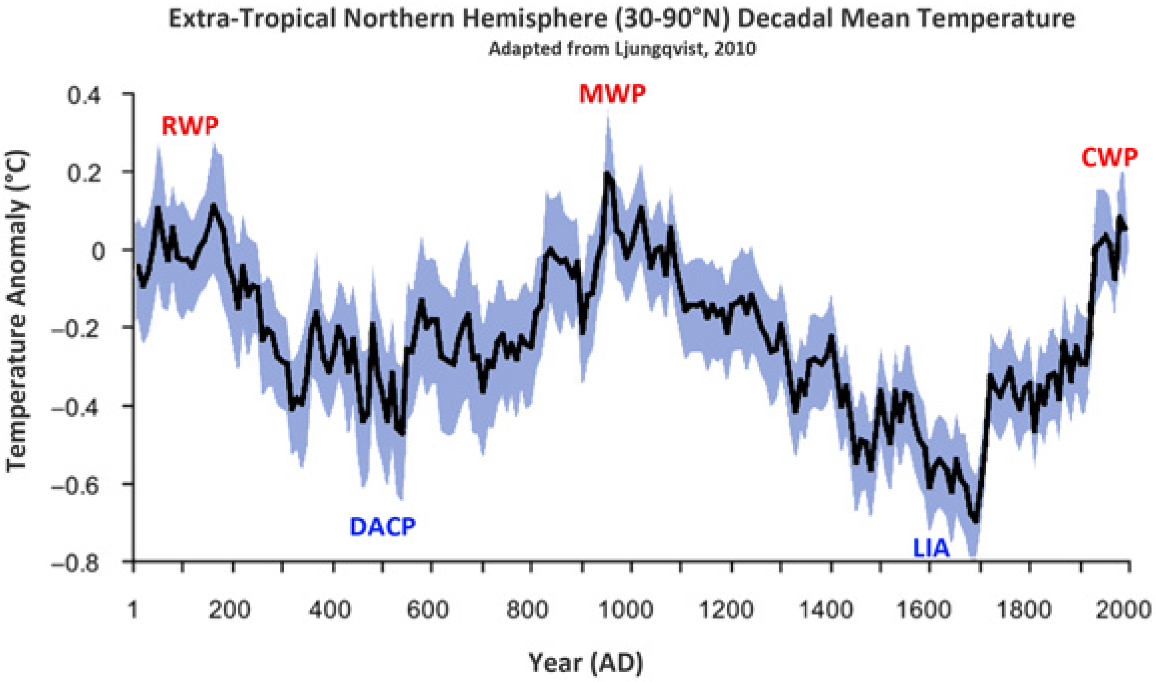

Figure 4.2.3.2. Reconstructed extra-tropical (30-90°N) mean decadal temperature variations relative to the 1961-1990 mean of the variance-adjusted 30-90°N CRUTEM3+HadSST2 instrumental temperature data of Brohan et al.(2006) and Rayner et al. (2006). Adapted from Ljungqvist, F.C. 2010. A new reconstruction of temperature variability in the extra-tropical Northern Hemisphere during the last two millennia. *Geografiska Annaler* **92A**: 339–351.

warm/cold periods, he writes, "probably represent the much discussed quasi-cyclical *c.* 1470 ± 500-year Bond Cycles (Bond and Lotti, 1995; O'Brien *et al.*, 1995; Bond *et al.*, 1997, 2001; Oppo, 1997)," which "affected both Scandinavia and northwest North America synchronically (Denton and Karlen, 1973)" and have "subsequently also been observed in China (Hong *et al.*, 2009a,b), the mid-latitude North Pacific (Isono *et al.*, 2009) and in North America (Viau *et al.*, 2006), and have been shown to very likely have affected the whole Northern Hemisphere during the Holocene (Butikofer, 2007; Wanner *et al.*, 2008; Wanner and Butikofer, 2008), or even been global (Mayewski *et al.*, 2004)."

Ljungqvist also notes "decadal mean temperatures in the extra-tropical Northern Hemisphere seem to have equaled or exceeded the AD 1961–1990 mean temperature level during much of the Roman Warm Period and the Medieval Warm Period," and "the second century, during the Roman Warm Period, is the warmest century during the last two millennia." In addition, "the highest average temperatures in the reconstruction are encountered in the mid to late tenth century," during the Medieval Warm Period. He warns the temperature of the last two decades "is possibly higher than during any previous time in the past two millennia," but adds, "this is only seen in the instrumental temperature data and not in the multi-proxy reconstruction itself."

Ljungqvist's study is especially important because it utilizes "a larger number of proxy records than most previous reconstructions" and "substantiates an already established history of long-term temperature variability."

Syun-Ichi Akasofu (2010), founding director of the International Arctic Research Center of the University of Alaska-Fairbanks (USA), employed "openly available data on sea level changes, glacier retreat, freezing/break-up dates of rivers, sea ice retreat, tree-ring observations, ice cores and changes of the cosmic-ray intensity, from the year 1000 to the present" to show Earth's recovery from the Little Ice Age "has proceeded continuously, roughly in a linear manner, from 1800–1850 to the present," with the rate of recovery being about 0.5°C/century. He suggests Earth is "still in the process of recovery from the LIA," being brought about by whatever was responsible for the mean linear warming of the twentieth century as modulated by a "multi-decadal oscillation of a period of 50 to 60 years" that is superimposed upon it and "peaked in 1940 and 2000, causing the halting of warming temporarily after 2000." Extending these two phenomena into the future, Akasofu predicts the non-CO_2-induced temperature increase over the twenty-first century will be 0.5°C ± 0.2°C, rather than the much greater 4°C ± 2°C predicted by the IPCC.

Ljungqvist *et al.* (2012) write, "a number of Northern Hemispheric (NH) temperature reconstructions covering the last 1–2 millennia, using temperature-sensitive proxy data, have been made to place the observed 20th century warming into a long-term perspective." They state, "these studies generally agree on the occurrence of warmer conditions ca. 800–1300 AD and colder conditions ca. 1300–1900 AD, followed by a strong warming trend in the 20th century," noting "the earlier warm period is usually referred to as the Medieval Warm Period ... whereas the later colder period is usually referred to as the Little Ice Age." "Related to this issue," they continue, "is the question of whether or not the current warmth has exceeded the level and geographic extent of the warmth in the last millennium."

Ljungqvist *et al.* developed "a new reconstruction of the spatio-temporal patterns of centennial temperature variability over the NH land areas for the last twelve centuries based on 120 proxy records," which were "retrieved from a wide range of archives including, but not limited to, ice-cores, pollen, marine sediments, lake sediments, tree-rings, speleothems and historical documentary data." With respect to how big an improvement their database is over those used in prior studies of this type in terms of the amount and distribution of data employed, they present a list of antecedent analyses where the number of proxy records used ranged from only three to 46 (compared to their 120), and where the number of records with annual resolution ranged from only three to 30, whereas their study included 49 such annual-resolution records.

The result of Ljungqvist *et al.*'s work is depicted in Figure 4.2.3.3. The four Swedish scientists report, "during the 9th to 11th centuries there was widespread NH warmth comparable in both geographic extent and level to that of the 20th century." They also note their results indicate "the rate of warming from the 19th to the 20th century is clearly the largest between any two consecutive centuries in the past 1200 years," but this is not surprising, given that the Little Ice Age is universally recognized as having been the coldest multi-century period of the current interglacial (Barclay *et al.*, 2009; Briner *et al.*, 2009; Menounos *et al.*, 2009) and its most extensively glaciated period (Calkin *et al.*, 2001;

Clague *et al*., 2004; Joerin *et al*., 2006). Recovery from such an extremely cold condition would be expected to be quite dramatic.

In light of the results depicted in Figure 4.2.3.3, it should be clear there is nothing unusual, unnatural, or unprecedented about Earth's current level of warmth when compared to that of the Medieval Warm Period, when there was significantly less CO_2 in the air than there is currently (~280 ppm then vs. ~400 ppm now). There is no compelling reason to attribute the post-Little Ice Age warming to changes in the concentration of this trace gas of the atmosphere.

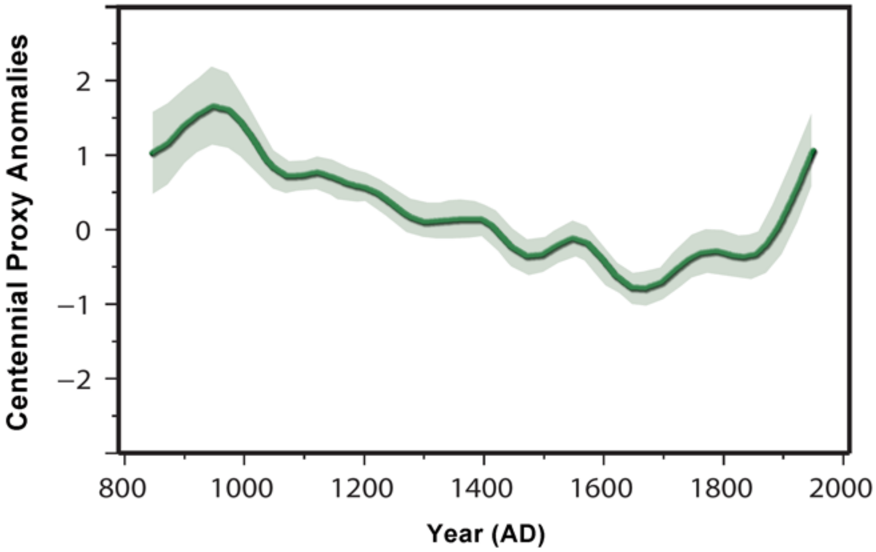

Figure 4.2.3.3. Mean whole-year centennial temperature proxy anomalies (standard deviations from the AD 1000-1899 mean) vs. year AD, where the shaded area represents ± 2 standard errors. Adapted from Ljungqvist, F.C., Krusic, P.J., Brattstrom, G., and Sundqvist, H.S. 2012. Northern Hemisphere temperature patterns in the last 12 centuries. *Climate of the Past* **8**: 227–249.

Christiansen and Ljungqvist (2012) used a variety of temperature proxies "shown to relate to local or regional temperature," together with a reconstruction method shown to "confidently reproduce low-frequency variability," to develop a new multi-proxy reconstruction of the mean temperature of the extratropical Northern Hemisphere (30–90°N) stretching back to the BC/AD transition. This two-millennia-long temperature history shows a well-defined Medieval Warm Period with "a well-defined peak in the period 950–1050 AD with a maximum temperature anomaly of 0.6°C" relative to the reference period of 1880–1960, the timing of which they say "is in agreement with the reconstructions of Esper *et al*. (2002) and Ljungqvist (2010)." They report "the level of warmth during the peak of the MWP in the second half of the 10th century, equal[s] or slightly exceed[s] the mid-20th century warming." This result, they say, is "in agreement with the results from other more recent large-scale multi-proxy temperature reconstructions," citing among others the studies of Moberg *et al*. (2005), Ljungqvist (2010), and Ljungqvist *et al*. (2012).

As for the timing of the MWP in different parts of the extra-tropical Northern Hemisphere, they report Ljungqvist *et al*. (2012) showed, "on centennial time-scales, the MWP is no less homogeneous than the Little Ice Age if all available proxy evidence, including low-resolution records are taken into consideration in order to give a better spatial data coverage."

This research adds to the growing body of real-world evidence demonstrating the global nature and temporal consistency of the MWP. It also confirms the MWP's peak temperatures throughout the extratropical Northern Hemisphere strongly rivaled or exceeded those of the Current Warm Period, even though the atmospheric CO_2 concentrations of today are 40 percent greater than they were during the MWP. Taken together, these observations strongly suggest the warmth of the Current Warm Period is due to something other than the current high atmospheric CO_2 concentration.

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4.2.4 Regional Manifestations of the Non-Uniqueness of Current Temperatures

Sections 4.2.1 through 4.2.3 present evidence temperatures of the past several decades are not unusual, unnatural, or unprecedented on a hemispheric or global scale, contrary to the conclusions of the IPCC. The Roman and Medieval Warm Periods were likely as warm as or warmer than the Current Warm Period. And since temperatures were as warm when atmospheric CO_2 concentrations were much lower than they are now, there are valid empirical reasons to conclude the temperature increase of the past century has occurred independently of the concomitant 40 percent increase in atmospheric CO_2. Real-world observations reveal the Current Warm Period is simply a manifestation of the natural progression of a persistent millennial-scale climate oscillation that regularly brings Earth several-hundred-year periods of modestly higher and lower temperatures independent of variations in atmospheric CO_2 concentration.

In this section, additional evidence is presented by region that there is nothing unusual, unnatural, or unprecedented about current temperatures. Although much of the material focuses on the reality and temperatures of the Roman and Medieval Warm Periods, some discussion is included on temperatures both before and after these important climate epochs.

4.2.4.1 Africa

Based on the temperature and water needs of the crops cultivated by the first agropastoralists of southern Africa, Huffman (1996) constructed a climate history of the region using archaeological evidence acquired from various Iron Age settlements. Dated relic evidence of the presence of cultivated sorghum and millets was considered by Huffman to be so strong as to prove the climate of the subcontinent-wide region must have been warmer and wetter than it is today from approximately AD 900–1300, for these crops cannot be grown in this part of southern Africa under current climatic conditions, which are much too cool and dry.

Other evidence for this conclusion comes from Tyson *et al.* (2000), who obtained a quasi-decadal record of oxygen and carbon-stable isotope data from a well-dated stalagmite of Cold Air Cave in the Makapansgat Valley (30 km southwest of Pietersburg, South Africa). They augmented those data with five-year-resolution temperature data reconstructed from color variations in banded growth-layer laminations of the stalagmite derived from a relationship calibrated against actual air temperatures obtained from a surrounding 49-station climatological network over the period 1981–1995, which had a correlation of +0.78 that was significant at the 99% confidence level. This record revealed a significantly warmer-than-present period that began prior to AD 1000 and lasted to about AD 1300 (see Figure 4.2.4.1.1). Tyson *et al.* report the "maximum warming at Makapansgat at around 1250 produced conditions up to 3–4°C hotter than those of the present."

Holmgren *et al.* (2001) used Cold Air Cave records to derive a 3,000-year temperature record for South Africa that revealed several multi-century warm and cold periods. They found a dramatic warming at approximately AD 900, when temperatures reached a level 2.5°C higher than that prevailing at the time of their analysis of the data (see Figure 4.2.4.1.2).

Holmgren *et al.* (2003) developed a 25,000-year temperature history from a stalagmite retrieved from Cold Air Cave based on $\delta^{18}O$ and $\delta^{13}C$ measurements dated by ^{14}C and high-precision thermal ionization mass spectrometry using the $^{230}Th/^{234}U$ method. The nine researchers found "cooling is evident from ~6 to 2.5ka [thousand years before present, during the long interval of coolness that preceded the Roman Warm Period], followed by warming between 1.5 and 2.5 ka [the Roman Warm Period] and briefly at ~AD 1200 [the Medieval Warm Period, which followed the Dark

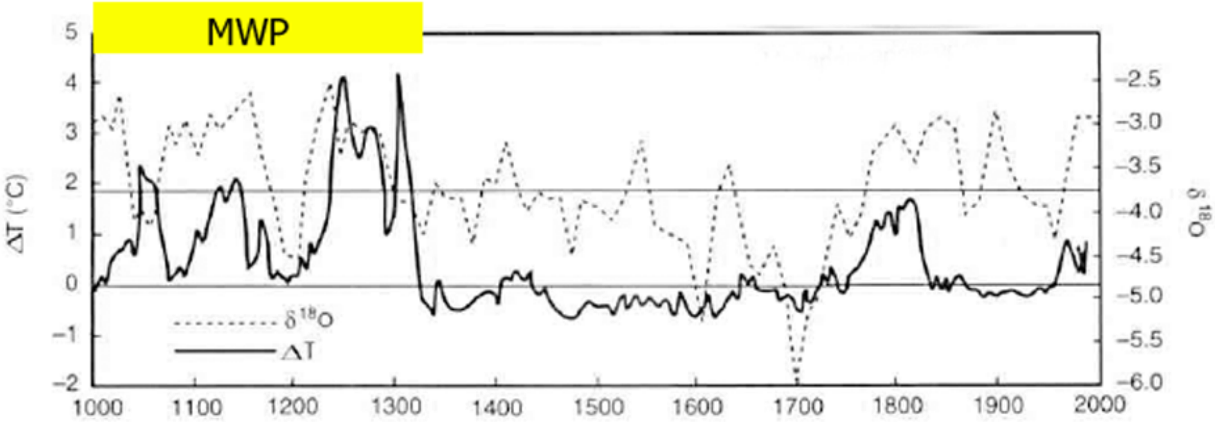

Figure 4.2.4.1.1. Temperature reconstruction from Cold Air Cave in the Makapansgat Valley, South Africa. Adapted from Tyson, P.D., Karlén, W., Holmgren, K., and Heiss, G.A. 2000. The Little Ice Age and medieval warming in South Africa. *South African Journal of Science* **96**: 121–126.

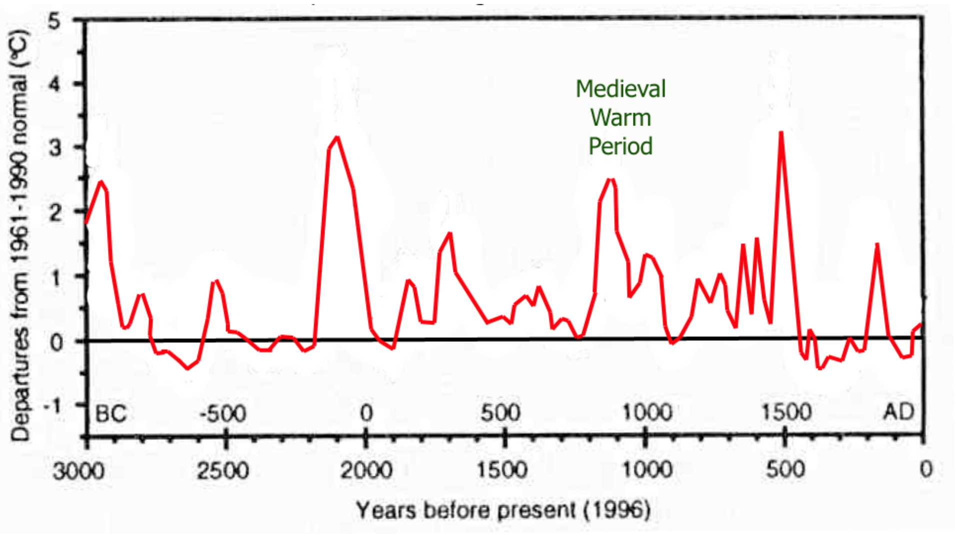

Figure 4.2.4.1.2. Temperature reconstruction from Cold Air Cave in the Makapansgat Valley, South Africa. Adapted from Holmgren, K., Tyson, P.D., Moberg, A., and Svanered, O. 2001. A preliminary 3000-year regional temperature reconstruction for South Africa. *South African Journal of Science* **97**: 49–51.

Ages Cold Period],” after which “maximum Holocene cooling occurred at AD 1700 [the depth of the Little Ice Age].” They also note “the Little Ice Age covered the four centuries between AD 1500 and 1800 and at its maximum at AD 1700 represents the most pronounced negative δ^{18}O deviation in the entire record.” This temperature record reveals the existence of all of the major millennial-scale oscillations of climate that are evident in data collected from regions surrounding the North Atlantic Ocean.

Working with the vertical sediment profile of Ocean Drilling Program Hole 658C, which was cored off Cap Blanc, Mauritania (20°45’N, 18°35’W) at a water depth of 2,263 meters, DeMenocal *et al*. (2000) analyzed various parameters, including planktonic foraminiferal assemblage census counts, from which they calculated warm- and cold-season sea surface temperatures based on transfer functions derived from faunal analyses of 191 other Atlantic core tops. The authors report finding a series of abrupt millennial-scale cooling events followed by compensatory warming events that “appear to have involved the entire North Atlantic basin (O'Brien *et al*., 1995; Keigwin, 1996; Bond *et al*., 1997; Bianchi and McCave, 1999; Bond *et al*., 1999), recurred with a ~1,500 ± 500 year period throughout glacial and interglacial intervals (O'Brien *et al*., 1995; Bond *et al*., 1997; Bianchi and McCave, 1999; Bond *et al*., 1999), were accompanied by terrestrial climate changes (COHMAP Members, 1988; Gasse and Van Campo, 1999), and involved large-scale ocean and atmosphere reorganizations that were completed within decades or centuries (Alley *et al*., 1993)." The four researchers go on to state, "these climate perturbations continue to persist during 'our time,'" noting "the most recent of these, the Little Ice Age, ended in the late 19th century" and "some of the warming since that time may be related to the present warming phase of this millennial-scale oscillation." They add, "the warming in recent decades is unprecedented relative to the past millennium."

This work further revealed that between about AD 800 and 1050 the "Medieval Warm Period," as they describe it, "was only marginally warmer than present." The graphical presentation of their results (see Figure 4.2.4.1.3) depicts between 0.6 and 1.2°C for the cold and warm season SST estimates, respectively.

Figure 4.2.4.1.3 shows the peak warmth of the Medieval Warm Period, which occurred roughly one thousand years ago, was approximately 1.2°C higher than what their data show for the end of the twentieth century. There is some uncertainty, however, with respect to what year corresponds with the authors' definition of the present. The SST graphic reproduced from their paper indicates the "present" corresponds to around the year 1900, whereas the text of their paper indicates the first data point represents conditions from between a sediment depth of 0 and 2 cm and the core "was continuously subsampled at 2-cm intervals, which is equivalent to between 50 and 100 years temporal resolution." Because of this ambiguity and erring on the side of caution, it can be concluded the MWP warmth was about the same as the warmth of the past two to three decades. This assessment is arrived at by noting the surface air temperature of the globe has warmed by about 0.7 °C over the past 100 years, which falls between the 0.6 and 1.2°C sea surface temperature differential between the peak warmth of the MWP and that of deMenocal *et al*.'s "present."

Lamb *et al*. (2003) provide strong evidence for a hydrologic fingerprint of the Medieval Warm Period in Central Kenya in a study of pollen data obtained from a sediment core taken from Crescent Island Crater, a sub-basin of Lake Naivasha. Of particular interest is the strong similarity between their results and those of Verschuren *et al*. (2000). The most striking of these correspondences occurred over the period AD 980 to 1200, when lake level was at a 1,100-year low and woody taxa were significantly underrepresented in the pollen assemblage.

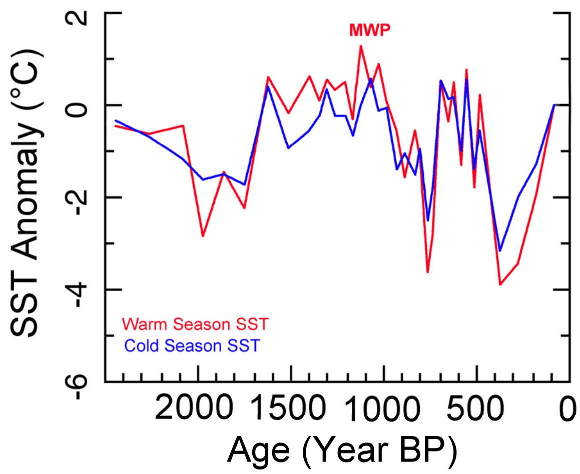

Figure 4.2.4.1.3. West African sea surface temperature vs. time. Adapted from deMenocal, P., Ortiz, J., Guilderson, T., and Sarnthein, M. 2000. Coherent high- and low-latitude climate variability during the Holocene warm period. *Science* **288**: 2198–2202.

Stager *et al*. (2003) analyzed diatom types and abundances found in a sediment core retrieved from Pilkington Bay, Lake Victoria, East Africa (0°18'N, 33°20'E), relating them to the ratio of precipitation to evaporation (P/E) and/or lake depth. This revealed, they write, "major droughts occurred ca. 1200–600 yr B.P. during Europe's Medieval Warm Period."

Fraedrich *et al*. (1997) examined records of historical maximum and minimum flood-level time series of the River Nile (AD 622–1470) "to identify abrupt climate changes by applying global and local analysis techniques: the Mann-Kendall test and a non-hierarchical cluster analysis method to improve the Mann-Kendall test; a multi-scale moving *t*-test with correction to the degree of freedom and an anti-symmetric wavelet transform." They noted the River Nile and its source regions, with their "links to other climatic zones of the world, may represent a key region to demonstrate the possible global nature of climate variability." The four researchers report "three climate epochs of longer time-scales, AD 622–1078, 1079–1325 and 1326–1470, coinciding with larger-scale climate changes reported in Europe: a relatively cool age, the Little Climatic Optimum of the Middle Ages, and an interim period before the Little Ice Age."

Kondrashov *et al*. (2005) applied advanced spectral methods to fill data gaps and locate interannual and interdecadal periodicities in historical records of annual low- and high-water levels on the Nile River over the 1,300-year period AD 622–1922. Several statistically significant periodicities were noted, including cycles at 256, 64, 19, 12, 7, 4.2, and 2.2 years. With respect to the causes of these cycles, the three researchers state the 4.2- and 2.2-year oscillations are likely due to El Niño-Southern Oscillation variations, the 7-year cycle may be related to North Atlantic influences, and the longer-period oscillations could be due to astronomical forcings. They also note the annual-scale resolution of their results provides a "sharper and more reliable determination of climatic-regime transitions" in tropical east Africa, including the documentation of fairly abrupt shifts in river flow at the beginning and end of the Medieval Warm Period.

Lamb *et al*. (2007) developed a 2,000-year history of effective precipitation based upon oxygen and carbon isotope and pollen stratigraphy data derived from a sediment core taken from Lake Hayq (11°21'N, 39°43'E) on the eastern margin of the north-central highlands in South Wollo, Ethiopia. This record revealed, they write, a "similar, but slightly moister climate than today, with high interdecadal variability, prevailed from AD 800 to AD 1200, equivalent to the European 'Mediaeval Warm Period,'" and "a period of high effective precipitation followed, from AD 1200 to AD 1700, during the 'Little Ice Age.'" A moister climate was also inferred during the MWP by Vogel (2003), who upon examining radiocarbon-dated stands of dead *Acacia erioloba* trees from locations within the central Namib Desert concluded trees growing near Sossusvlei (24.75°S, 15.28°E) started growing in the eleventh and twelfth centuries "during the relatively humid conditions of the Medieval Warm Period and died out after the more arid conditions of the Little Ice Age set in during the 14th century."

Ngomanda *et al*. (2007) derived high-resolution (<40 years) paleoenvironmental reconstructions for the past 1,500 years based on pollen and carbon isotope data obtained from sediment cores retrieved from Lakes Kamalete and Nguene in the lowland rainforest of Gabon. After a sharp rise at ~1200 cal yr BP, the nine researchers note, "A/H [aquatic/hygrophytic] pollen ratios showed intermediate values and varied strongly from 1150 to 870 cal yr BP, suggesting decadal-scale fluctuations in the water balance during the 'Medieval Warm Period.'" Thereafter, lower A/H pollen ratios "characterized the interval from ~500 to 300 cal yr BP, indicating lower water levels during the 'Little Ice Age.'" In addition, they report, "all inferred lake-level low stands, notably between 500 and 300 cal yr BP, are associated with decreases in the score of the TRFO [Tropical Rainforest] biome."

Ngomanda *et al*. state, "the positive co-variation between lake level and rainforest cover changes may indicate a direct vegetational response to regional precipitation variability," noting "evergreen rainforest expansion occurs during wet intervals, with contraction during periods of drought." In this part of Western Equatorial Africa, it appears the Little Ice Age was a time of low precipitation, low lake levels, and low evergreen rainforest presence, while much the opposite was the case during the Medieval Warm Period, when fluctuating wet-dry conditions led to fluctuating lake levels and a greater evergreen rainforest presence.

Placing these findings within a broader temporal context, Ngomanda *et al*. note "rainforest environments during the late Holocene in western equatorial Africa are characterized by successive millennial-scale changes according to pollen (Elenga *et al*., 1994, 1996; Reynaud-Farrera *et al*., 1996; Maley and Brenac, 1998; Vincens *et al*., 1998), diatom (Nguetsop *et al*., 2004), geochemical (Delegue *et al*., 2001; Giresse *et al*., 1994), and sedimentological data (Giresse *et al*., 2005; Wirrmann *et al*., 2001)," and "these changes were essentially driven by natural climatic variability (Vincens *et al*., 1999; Elenga *et al*., 2004)."

Esper *et al*. (2007) used *Cedrus atlantica* ring-width data "to reconstruct long-term changes in the Palmer Drought Severity Index (PDSI) over the past 953 years in Morocco, Northwest Africa." They report "the long-term PDSI reconstruction indicates generally drier conditions before ~1350, a transition period until ~1450, and generally wetter conditions until the 1970s," after which there were "dry conditions since the 1980s." In addition, they determined "the driest 20-year period reconstructed is 1237–1256 (PDSI = -4.2)," adding, "1981–2000 conditions are in line with this historical extreme (-3.9)." Also of significance, the six researchers note "millennium-long temperature reconstructions from Europe (Buntgen *et al*., 2006) and the Northern

Hemisphere (Esper *et al*., 2002) indicate that Moroccan drought changes are broadly coherent with well-documented temperature fluctuations including warmth during medieval times, cold in the Little Ice Age, and recent anthropogenic warming." The latter coherency suggests the peak warmth of the Medieval Warm Period was at least as great as that of the last two decades of the twentieth century throughout the entire Northern Hemisphere. If the coherency is strictly interpreted, it suggests the warmth of the MWP was even greater than that of the late twentieth century.

Working with sediment cores extracted from East Africa's Lake Tanganyika near the remote and sparsely settled Mahale Mountains (6°33.147'S, 29°58.480'E), Tierney *et al*. (2010) developed a 1,500-year history of lake-surface water temperature (LST) using the TEX86 proxy technique, which relates the degree of cyclization of aquatic archaeal glycerol dialkyl glycerol tetraethers found in membrane lipids of certain marine picoplankton to LST. This work revealed the existence of "a period of extended warmth between AD 1100 and 1400," which clearly represents the Medieval Warm Period. The peak LST of this period was 1.4°C cooler than the peak LST at the end of the twentieth century.

Kuhnert and Mulitza (2011) derived sea surface temperatures from Mg/Ca ratios of *Globigerinoides ruber* foraminifers extracted from gravity core GeoB 9501-5 recovered off southern Mauritania at 16°50'N, 16°44'W from a water depth of 323 m during Meteor cruise M65/1, described by Mulitza (2006), using the calibration for the 250–350 µm fraction of *G. ruber* (pink) from Anand *et al*. (2003) to produce a 1,700-year summer–fall SST history. Between AD 850 and AD 1150, Kuhnert and Mulitza identify a period of warmth they equate with the Medieval Warm Period, the peak 50-year mean SST of which was 1.1°C greater than the corresponding 50-year mean SST at the end of the record, which had been trending upward over the prior half-century.

The research findings summarized here suggest the Medieval Warm Period occured over wide reaches of Africa and was probably more extreme in Africa than the Current Warm Period has been to this point in time.

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4.2.4.2 Antarctica

The IPCC has long predicted CO_2-induced global warming, which they assert has accelerated significantly over the twentieth century and is unprecedented in the past millennium or more, should be greatly amplified in Earth's polar regions. The IPCC has claimed the following:

> Robust evidence for polar amplification in either one or both hemispheres has been found in climate model experiments of past and future climate change, paleo-climate data and recent instrumental temperature records" (Second Order Draft of AR5, dated October 5, 2012, p. 5–14).

The research reviewed in this section shows the IPCC's claim of "robust evidence" of amplified CO_2-induced warming in Earth's polar regions is patently incorrect, as their thesis has been invalidated by real-world data. From the birth and death of ice ages to the decadal variations of modern-day weather patterns, studies of Antarctica demonstrate the atmosphere's CO_2 concentration is not a major player in bringing about significant changes in Earth's climate.

4.2.4.2.1 The Past Few Centuries through the Past Few Millennia

The study of Antarctic temperatures has provided valuable insight into global climate change. Key among early pertinent findings was the observation of a large-scale correlation between proxy air temperature and atmospheric CO_2 measurements obtained from ice cores drilled in the interior of the continent. In the mid- to late-1980s, this broad correlation dominated much of the climate change debate and led many to claim the gross CO_2-temperature correlation proved changes in atmospheric CO_2 concentration caused corresponding changes in air temperature, and future increases in the air's CO_2 content due to anthropogenic CO_2 emissions would therefore intensify global warming.

This contention was challenged by Idso (1989), who wrote in reference to the data used to support the claim, "changes in atmospheric CO_2 content never precede changes in air temperature, when going from glacial to interglacial conditions; and when going from interglacial to glacial conditions, the change in CO_2 concentration actually lags the change in air temperature (Genthon *et al*., 1987)." He concludes "changes in CO_2 concentration cannot be claimed to be the cause of changes in air temperature, for the appropriate sequence of events (temperature change *following* CO_2 change) is not only never present, it is actually violated in [at least] half of the record (Idso, 1988)."

Petit *et al*. (1999) reconstructed histories of surface air temperature and atmospheric CO_2 concentration from data obtained from a Vostok ice core that covered the prior 420,000 years, determining "the CO_2 decrease lags the temperature decrease by several thousand years" during glacial inception and "the same sequence of climate forcing operated during each termination." Fischer *et al*. (1999), working with sections of ice core records from the most recent three glacial terminations, found "the time lag of the rise in CO_2 concentrations with respect to temperature change is on the order of 400 to 1000 years during all three glacial-interglacial transitions."

By the turn of the century, ice-coring instrumentation and techniques had improved considerably, and newer studies with finer temporal resolution began to reveal increases (decreases) in air temperature drive increases (decreases) in atmospheric CO_2 content and not vice versa, as suggested, for example, by the work of Indermuhle *et al*. (2000) and Monnin *et al*. (2001). A good example of this relationship was provided by Caillon *et al.* (2003), who showed during Glacial Termination III "the CO_2 increase lagged Antarctic deglacial warming by 800 ± 200 years." Although this finding "confirms that CO_2 is not the forcing that initially drives the climatic system during a deglaciation," they and many others continued to argue the subsequent increase in atmospheric CO_2—believed to be due to warming-induced CO_2 outgassing from the world's oceans—serves to amplify the warming caused by whatever it is that prompts the temperature to rise in the first place. This conviction, however, is founded on unproven assumptions about the strength of CO_2-induced warming, and it is applied without any regard for biologically induced negative climate feedbacks that can occur in response to atmospheric CO_2 enrichment.

Yoon *et al.* (2002) write, "the maritime record on the Antarctic Peninsula shelf suggests close chronological correlation with Holocene glacial events in the Northern Hemisphere, indicating the possibility of coherent climate variability in the Holocene." Similarly, Khim *et al.* (2002) state, "two of the most significant climatic events during the late Holocene are the Little Ice Age (LIA) and Medieval Warm Period (MWP), both of which occurred globally (Lamb, 1965; Grove, 1988)," further noting "evidence of the LIA has been found in several studies of Antarctic marine sediments (Leventer and Dunbar, 1988; Leventer *et al.*, 1996; Domack *et al.*, 2000)." Khim *et al.*'s paper can be added to this list of scientific journal articles documenting the existence of the LIA in Antarctica, for it also demonstrates the presence of the MWP in Antarctica, as well as earlier cold and warm periods of similar intensity and duration.

As more studies have been conducted, it has become increasingly clear these several-hundred-year cold and warm periods were not confined to lands bordering the North Atlantic Ocean, as the IPCC suggests. These periods clearly were global, and they demonstrate the reality of the likely solar-induced millennial-scale climatic oscillation that is manifest in the post-1850 warming of the world.

Stenni *et al.* (2002) examined several paleoclimatic indicators in two firn cores retrieved from the Talos Dome area of East Antarctica in 1996, with accurate dating provided by non-sea-salt sulfate spikes associated with well-documented volcanic eruptions and tritium activity associated with known atmospheric thermonuclear bomb tests. The results of their work were compared with those based on other East Antarctic ice core records obtained from Dome C EPICA, Taylor Dome, and the South Pole. The seven scientists state the several records suggest "cooler climate conditions between the middle of [the] 16th and the beginning of [the] 19th centuries, which might be related to the Little Ice Age (LIA) cold period." After discussing other findings, they conclude "more and more evidence coming from ice core records, glacier extension and other proxy records are leading to the idea that the Antarctic continent or at least East Antarctica also experienced the LIA cool episode."

Cremer *et al.* (2003) reconstructed a history of environmental change in the southern Windmill Islands, East Antarctica, based upon diatom assemblages obtained from two long and well-dated sediment cores removed from two marine bays, comparing their findings with those of studies of several other parts of Antarctica. The four researchers note, "the diatom assemblage in the upper sediments of both cores indicates Neoglacial cooling from ~1000 cal yr BP," and this latest thousand-year period "is generally marked by distinct cooling leading to glacial re-advances, more extensive sea-ice, lower precipitation, and lower bioproductivity." In addition, they report "this climatic deterioration is visible in nearly all available Antarctic terrestrial and marine records (e.g. Ingolfsson *et al.*, 1998; Jones *et al.*, 2000; Roberts *et al.*, 2000, and references therein)."

Hemer and Harris (2003) extracted a sediment core from beneath the Amery Ice Shelf, East Antarctica, about 80 km landward of its present edge. In analyzing the core's characteristics over the past 5,700 ^{14}C years, the two scientists observed a peak in absolute diatom abundance in general, and the abundance of *Fragilariopsis curta* in particular. These parameters, they write, "are associated with increased proximity to an area of primary production, such as the sea-ice zone" at about 750 ^{14}C yr B.P., which puts the time of maximum Ice Shelf retreat in close proximity to the Medieval Warm Period.

Roberts *et al.* (2004) conducted a fossil diatom analysis of an 82-cm sediment core covering the approximate time period 2,000–1,700 ^{14}C yr BP, removed from the deepest part of Beall Lake in the northern Windmill Islands in one of the more significant ice-free oases on the East Antarctic coastline. Samples of the core were radiocarbon dated and corrected for the Antarctic reservoir effect. Based on the species of diatoms found in this sample, Roberts *et al.* inferred the existence of a multi-centennial period of warmth characterized by summer temperatures "much higher than present summer temperatures." Supporting this inference, they also note observations made at both Casey and Law Dome indicated "during the late Holocene, a warm period existed with precipitation and summer temperatures higher than at present (Goodwin, 1993)." They conclude, "the diatom-inferred Holocene palaeosalinity record from Beall Lake indicates the late Holocene warm period was much warmer than at present." The dates they give for this period suggest it was part of the Roman Warm Period.

Hall *et al*. (2006) collected skin, hair, and whole-body mummified remains from Holocene raised-beach excavations at locations along Antarctica's Victoria Land Coast, which they identified by visual inspection and DNA analysis as coming from southern elephant seals (*Mirounga leonina*) and which they analyzed for age by means of radiocarbon dating. Data from 14 locations within the region of study, which they describe as being "well south" of the seals' current "core sub-Antarctic breeding and molting grounds," indicate the period of time they denominate the Seal Optimum began about 600 BC and ended about AD 1400, "broadly contemporaneous with the onset of Little Ice Age climatic conditions in the Northern Hemisphere and with glacier advance near [Victoria Land's] Terra Nova Bay," although they found evidence of southern elephant seal presence stretching back to the mid-Holocene.

The U.S., British, and Italian researchers say their findings indicate "warmer-than-present climate conditions" at the times and locations of the southern elephant seal presence and "if, as proposed in the literature, the [Ross] ice shelf survived this period, it would have been exposed to environments substantially warmer than present." Their data also indicate this warmth, which began with the inception of the Roman Warm Period and ended with the demise of the Medieval Warm Period, was so significant that the intervening Dark Ages Cold Period was not intense enough to drive the seals from Antarctica.

Khim *et al*. (2002) analyzed a sediment core removed from the eastern Bransfield Basin just off the northern tip of the Antarctic Peninsula for grain size, total organic carbon content, magnetic susceptibility, biogenic silica content, ^{210}Pb geochronology, and radiocarbon (^{14}C) age. These data clearly depicted the presence of the "Little Ice Age and Medieval Warm period, together with preceding climatic events of similar intensity and duration," they write.

Hall *et al*. (2010) write, "over the past 50 years, the Antarctic Peninsula warmed ~2°C" and resultant rapid ice breakups "have destroyed several small, thin ice shelves fringing the Antarctic Peninsula (i.e., Cook and Vaughan, 2009, and references therein)," leading them to ask, "is the recent warming of the Antarctic Peninsula unique in the Holocene?" The three researchers "examined organic-rich sediments exposed by the recent retreat of the Marr Ice Piedmont on western Anvers Island near Norsel Point," where glaciers "have been undergoing considerable retreat in response to the well-documented warming." They "obtained moss and reworked marine shells from natural sections within 26 meters of the present ice front" as well as "both peat and reworked shells from sediments exposed in a tunnel beneath the residual ice mass," samples of which were radiocarbon-dated and the results converted to calendar years.

The results indicated peat from the overrun sediments dated to between 707 ± 36 and 967 ± 47 cal. yr B.P., which led them to conclude, "ice was at or behind its present position at ca. 700–970 cal. yr B.P. and during at least two earlier times, represented by the dates of shells, in the mid-to-late Holocene." The three researchers say their findings imply "the present state of reduced ice on the western Antarctic Peninsula is not unprecedented." This leads them to pose another important question: "How widespread is the event at 700–970 cal. yr B.P.?"

They observe "Khim *et al*. (2002) noted a pronounced high-productivity (warm) event between 500 and 1000 cal. yr B.P. in magnetic susceptibility records from Bransfield Basin" and "dates of moss adjacent to the present ice front in the South Shetland Islands (Hall, 2007) indicate ice there was no more extensive between ca. 650 and 825 cal. yr B.P. than it is now." They also note "evidence for reduced ice extent at 700–970 cal. yr B.P. is consistent with tree-ring data from New Zealand that show a pronounced peak in summer temperatures (Cook *et al*., 2002)" and "New Zealand glaciers were retracted at the same time (Schaefer *et al*., 2009)." They conclude their findings "are compatible with a record of glacier fluctuations from southern South America, the continental landmass closest to Antarctica (Strelin *et al*., 2008)." It would appear much of the southernmost portion of Earth experienced a period of significantly enhanced warmth within the broad timeframe of the planet's global MWP.

Lu *et al*. (2012) constructed "the first downcore

δ^{18}O record of natural ikaite hydration waters and crystals collected from the Antarctic Peninsula (AP)" they say were "suitable for reconstructing a low resolution ikaite record of the last 2000 years." According to the group of nine UK and U.S. researchers, ikaite "is a low temperature polymorph of calcium carbonate that is hydrated with water molecules contained in its crystal lattice," and they write, "ikaite crystals from marine sediments, if collected and maintained at low temperatures, preserve hydration waters and their intact crystal structures, both of which have the potential to provide isotopic constraints on past climate change."

Lu *et al*. report "the ikaite record qualitatively supports that both the Medieval Warm Period and Little Ice Age extended to the Antarctic Peninsula." They also note the "most recent crystals suggest a warming relative to the LIA in the last century, possibly as part of the regional recent rapid warming," but they add, "this climatic signature is not yet as extreme in nature as the MWP," suggesting even the recent warming of the AP may not have returned that region to the warmth experienced there during the MWP.

Hall and Denton (2002) mapped the distribution and elevation of surficial deposits along the southern Scott Coast of Antarctica in the vicinity of the Wilson Piedmont Glacier, which runs parallel to the coast of the western Ross Sea from McMurdo Sound north to Granite Harbor. The chronology of the raised beaches they studied was determined from more than 60 ^{14}C dates of incorporated organic materials previously collected from hand-dug excavations (Hall and Denton, 1999). The record shows "the Wilson Piedmont Glacier was still less extensive than it is now" near the end of the Medieval Warm Period, "as late as 890 ^{14}C yr BP."

Bertler *et al*. (2011) obtained new deuterium (δD) data acquired via analysis of the top 50 meters of a 180-meter-long ice core extracted from the ice divide of Victoria Lower Glacier in the northernmost McMurdo Dry Valleys, which they converted to temperature data by means of a temperature-isotope relationship developed by Steig *et al*. (1998) from data obtained from the Taylor Dome ice core record (see Figure 4.2.4.2.1.1). Bertler *et al*. report they identified three distinct time periods in their record: the last 150 years of the Medieval Warm Period (AD 1140 to 1287), the Little Ice Age (AD 1288 to 1807), and the Modern Era (AD 1808 to 2000). With respect to the Medieval Warm Period, they write, "the McMurdo Dry Valleys were 0.35°C warmer during the MWP than during ME, accompanied by warmer conditions in the Ross Sea." The three researchers also note "a magnetic susceptibility record from Palmer Deep marine core (PD92 30MS) also supports warmer MWP conditions, this time in Drake Passage (Domack and Mayewski, 1999)."

Noon *et al*. (2003) used oxygen isotopes preserved in authigenic carbonate retrieved from freshwater sediments of Sombre Lake on Signy Island (60°43'S, 45°38'W) in the Southern Ocean to construct a 7,000-year history of that region's climate. They found the general trend of temperature at the study site has been downward. Approximately 2,000 years ago, after a thousand-year gap in the data, Signy Island experienced the relative warmth of the last vestiges of the Roman Warm Period as delineated by McDermott *et al*. (2001) on the basis of a high-resolution speleothem δ^{18}O record from southwest Ireland. Then the record shows the Dark Ages Cold period, contemporaneous with what McDermott *et al*. observe in the Northern Hemisphere, after which the Medieval Warm Period appears at the same point in time and persists for the same length of time it does in the vicinity of Ireland, whereupon the Little Ice Age sets in just as it does in the Northern Hemisphere. Finally, there is an indication of late twentieth century warming, still a long way from conditions comparable to those of the Medieval Warm Period (see Figure 4.2.4.2.1.2).

Castellano *et al*. (2005) derived a detailed history of Holocene volcanism from the sulfate record of the first 360 meters of the Dome Concordia ice core that covered the period 0–11.5 kyr BP. They compared their results for the past millennium with similar results obtained from eight other Antarctic ice cores. Before doing so, they normalized the results at each site by dividing its several volcanic-induced sulfate deposition values by the value produced at that site by the AD 1816 Tambora eruption, in order to reduce deposition differences among sites that might have been induced by differences in local site characteristics. This work revealed most volcanic events in the years 1000–1500 AD exhibited greater among-site variability in normalized sulphate deposition than was observed thereafter.

Castellano *et al.* cited Budner and Cole-Dai (2003) in noting "the Antarctic polar vortex is involved in the distribution of stratospheric volcanic aerosols over the continent." Assuming the intensity and persistence of the polar vortex in both the troposphere and stratosphere "affect the penetration of air masses to inland Antarctica, isolating the

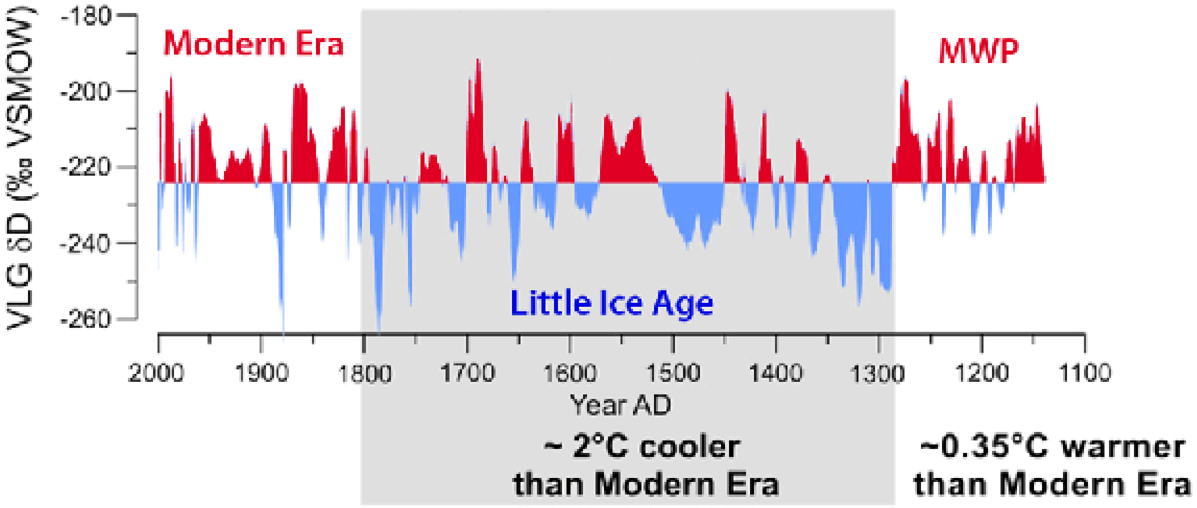

Figure 4.2.4.2.1.1. Deuterium (δD) data acquired from an ice core that had been extracted from the ice divide of Victoria Lower Glacier in the northernmost McMurdo Dry Valleys. Adapted from Bertler, N.A.N., Mayewski, P.A., and Carter, L. 2011. Cold conditions in Antarctica during the Little Ice Age: implications for abrupt climate change mechanisms. *Earth and Planetary Science Letters* **308**: 41–51.

continental area during cold periods and facilitating the advection of peripheral air masses during warm periods (Krinner and Genthon, 1998)," Castellano *et al.* "support the hypothesis that the pattern of volcanic deposition intensity and geographical variability [higher values at coastal sites] could reflect a warmer climate of Antarctica in the early last millennium," and "the re-establishment of colder conditions, starting in about AD 1500, reduced the variability of volcanic depositions."

Castellano *et al*. state "this warm/cold step could be like a Medieval Climate Optimum-like to Little Ice Age-like transition." They additionally cite Goosse *et al*. (2004) as reporting evidence from Antarctic ice-core δD and δ^{18}O data "in support of a Medieval Warming-like period in the Southern Hemisphere, delayed by about 150 years with respect to Northern Hemisphere Medieval Warming." The researchers conclude by postulating, "changes in the extent and intra-Antarctic variability of volcanic depositional fluxes may have been consequences of the establishment of a Medieval Warming-like period that lasted until about AD 1500."

Hall *et al*. (2006) collected skin, hair, and whole-body mummified remains from Holocene raised-beach excavations at locations along Antarctica's Victoria Land Coast, which they identified by both visual inspection and DNA analysis as coming from southern elephant seals, and which they analyzed for age by radiocarbon dating. They obtained data from 14 locations within their study region, which they describe as being "well south" of the seals' current "core sub-Antarctic breeding and molting grounds." The data indicate the Seal Optimum began about 600 BC and ended about AD 1400; Hall *et al.* describe the latter date as being "broadly contemporaneous with the onset of Little Ice Age climatic conditions in the Northern Hemisphere and with glacier advance near [Victoria Land's] Terra Nova Bay." The U.S., British, and Italian researchers say their findings indicate "warmer-than-present climate conditions" at the times and locations of the southern elephant seal presence and "if, as proposed in the literature, the [Ross] ice shelf survived this period, it would have been exposed to environments substantially warmer than present," which would have included both the Roman Warm Period and Medieval Warm Period.

Williams *et al*. (2007) presented methyl chloride (CH_3Cl) measurements of air extracted from a 300-m ice core obtained at the South Pole, Antarctica, covering the time period 160 BC to AD 1860. The researchers found "CH_3Cl levels were elevated from 900–1300 AD by about 50 ppt relative to the previous 1000 years, coincident with the warm Medieval Climate Anomaly (MCA)," and they "decreased to a minimum during the Little Ice Age cooling (1650–1800 AD), before rising again to the modern atmospheric level of 550 ppt." Given that "today,

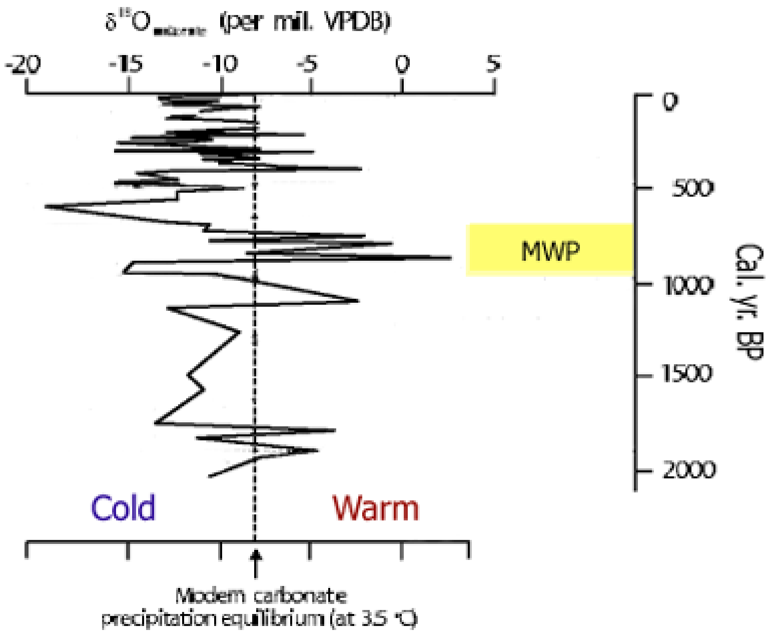

Figure 4.2.4.2.1.2. Sombre Lake $\delta^{18}O$ record showing the relative warmth of the MWP compared to the CWP. Adapted from Noon, P.E., Leng, M.J., and Jones, V.J. 2003. Oxygen-isotope ($\delta^{18}O$) evidence of Holocene hydrological changes at Signy Island, maritime Antarctica. *The Holocene* **13**: 251–263.

more than 90% of the CH_3Cl sources and the majority of CH_3Cl sinks lie between 30°N and 30°S (Khalil and Rasmussen, 1999; Yoshida *et al*., 2004)," they conclude "it is likely that climate-controlled variability in CH_3Cl reflects changes in tropical and subtropical conditions." They state, "ice core CH_3Cl variability over the last two millennia suggests a positive relationship between atmospheric CH_3Cl and global mean temperature."

As best as can be determined from the graphical representation of their data, the peak CH_3Cl concentration measured by Williams *et al*. during the MCA is approximately 533 ppt, which is within 3 percent of its current mean value of 550 ppt and well within the range of 520 to 580 ppt that characterizes methyl chloride's current variability. It therefore may be validly concluded the mean peak temperature of the MCA (Medieval Warm Period) over the latitude range 30°N to 30°S—and possibly over the entire globe—may not have been materially different from the mean peak temperature so far attained during the Current Warm Period.

Hall (2007) presented "radiocarbon and geomorphologic data that constrain [the] late-Holocene extent of the Collins Ice Cap on Fildes Peninsula (King George Island, South Shetland Islands: 62°10'51"S, 58°54'13"W)," which "yield information on times in the past when climate in the South Shetland Islands must have been as warm as or warmer than today," based on field mapping of moraines and glacial deposits adjacent to the ice cap as well as radiocarbon dates of associated organic materials. Such data, Hall writes, "indicate ice advance after ~650 cal. yr BP (AD ~1300)," which she notes is "broadly contemporaneous with the 'Little Ice Age', as defined in Europe." She also says this was "the only advance that extended beyond the present ice margin in the last 3500 years, making the Little Ice Age in that part of the world likely the coldest period of the current interglacial. And since "the present ice cap margin ... is still more extensive than it was prior to ~650 cal. yr BP" she concludes the climate prior to that time, which would have comprised the Medieval Warm Period, may have been "as warm as or warmer than present."

Working with an ice core (IND-22/B4) extracted during the austral summer of 2003 from the coastal region of Dronning Maud Land, East Antarctica (70°51.3'S, 11°32.2'E) as part of the 22nd Indian Antarctic Expedition, Thamban *et al.* (2011) developed 470-year histories of $\delta^{18}O$ and δD that "showed similar down core fluctuations with [an] excellent positive relationship (R^2 = 0.9; n = 216) between the two." Based on a $\delta^{18}O$ vs. surface air temperature (SAT) relationship developed for this region by Naik *et al.* (2001), they derived the regional temperature history depicted in Figure 4.2.4.2.1.3.

In describing the temperature history, the four Indian researchers state, "the estimated surface air temperature at the core site revealed a significant warming of 2.7°C with a warming of ~0.6°C per century for the past 470 years," not surprising given that the starting point for this record is the depth of the Little Ice Age. While the record shows decadal fluctuations, there has been no net warming for the entire twentieth century, with the warmest

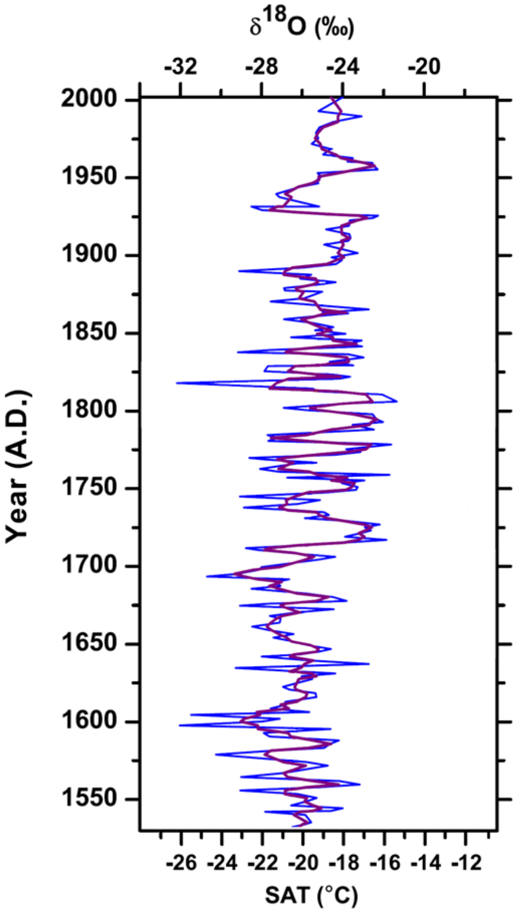

Figure 4.2.4.2.1.3. Surface air temperature (SAT) as derived from δ^{18}O data vs. time in years AD. Adapted from Thamban, M., Laluraj, C.M., Naik, S.S., and Chaturvedi, A. 2011. Reconstruction of Antarctic climate change using ice core proxy records from coastal Dronning Maud Land, East Antarctica. *Journal of the Geological Society of India* **78**: 19–29.

temperatures of the century occurring around 1925 and 1960.

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4.2.4.2.2 The Past One to Two Centuries

Another significant impediment to the CO_2-induced global warming hypothesis comes from the instrumental temperature record of the more recent past. According to nearly all climate models, CO_2-induced global warming should be most evident in Earth's polar regions, but analyses of Antarctic near-surface and tropospheric air temperature records tell a radically different story.

Doran *et al*. (2002) examined temperature trends in the McMurdo Dry Valleys of Antarctica over the period 1986 to 2000, reporting a cooling rate of approximately 0.7°C per decade. This dramatic rate of cooling "reflects longer term continental Antarctic cooling between 1966 and 2000." In addition, the 14-year temperature decline in the dry valleys occurred in the summer and autumn, as did most of the 35-year cooling over the continent as a whole exclusive of the dry valley data.

Comiso (2000) assembled and analyzed Antarctic temperature data from 21 surface stations and from infrared satellites operating since 1979, finding for all of Antarctica, temperatures declined by 0.08°C and 0.42°C per decade, respectively. Thompson and Solomon (2002) also report a cooling trend for the interior of Antarctica.

In spite of the decades-long cooling observed for the continent as a whole, one region of Antarctica has warmed over the same time period: the Antarctic Peninsula/Bellingshausen Sea region. But the temperature increase there is not evidence of CO_2-induced global warming.

According to Vaughan *et al*. (2001), "rapid regional warming" has led during the past 50 years to the loss of seven ice shelves, including the Prince Gustav Channel Ice Shelf, which collapsed in this region in 1995. However, they note sediment cores from 6,000 to 1,900 years ago suggest the Prince Gustav Channel Ice Shelf "was absent then and climate was as warm as it has been recently," although there was much less CO_2 in the air than there is today. Vaughan *et al*. say it "is superficial" to cite the twentieth century increase in atmospheric CO_2 concentration as the cause of the recent regional warming without providing an explanatory mechanism.

Thompson and Solomon (2002) suggest much of the warming can be explained by "a systematic bias toward the high-index polarity of the SAM," or Southern Hemispheric Annular Mode, such that the ring of westerly winds encircling Antarctica has recently been spending more time in its strong-wind phase. A similar conclusion was reached by Kwok and Comiso (2002), who report over the 17-year period 1982–1998 the SAM index shifted towards more positive values (0.22/decade). They also note a positive polarity of the SAM index "is associated with cold anomalies over most of Antarctica with the center of action over the East Antarctic plateau." At the same time, the Southern Oscillation (SO) index shifted in a negative direction, indicating "a drift toward a spatial pattern with warmer temperatures around the Antarctic Peninsula, and cooler temperatures over much of the continent."

Thus Kwok and Comiso conclude the positive trend in the coupled mode of variability of these two indices represents a "significant bias toward positive polarity." Also, the SAM "has been shown to be related to changes in the lower stratosphere (Thompson and Wallace, 2000)" and "the high index polarity of the SAM is associated with the trend toward a cooling and strengthening of the Southern Hemisphere stratospheric polar vortex during the stratosphere's relatively short active season in November," as Thompson and Solomon (2002) hypothesized.

Mulvaney *et al*. (2012) drilled an ice core to the bed of the ice cap on James Ross Island, which lies just off the northeastern tip of the Antarctic Peninsula, next to an area that has experienced a series of recent ice-shelf collapses. Based on deuterium/hydrogen isotope ratios of the ice (δD), they developed a temperature history of the region that spans the entire Holocene and extends into the last glacial period. They found "the Antarctic Peninsula experienced an early Holocene warm period followed by stable temperatures, from about 9200 to 2500 years ago, that were similar to modern-day levels." They also found "the high rate of warming over the past century is unusual (but not unprecedented) in the context of natural climate variability over the past two millennia." More specifically, they state, "over the past 100 years, the James Ross Island ice-core record shows that the mean temperature there has increased by 1.56 ± 0.42°C," which ranks as one of the fastest (upper 0.3%) warming trends since 2,000 years before present, according to a set of moving 100-year analyses that demonstrate "rapid recent warming of the Antarctic Peninsula is highly unusual although not outside the bounds of natural variability in the pre-anthropogenic era." Although the temperature of the northern Antarctic Peninsula has risen at a rate of 2.6 ± 1.2°C over the past half-century, they state, "repeating the temperature trend analysis using 50-year windows confirms the finding that the rapidity of recent Antarctic Peninsula warming is unusual but not unprecedented."

Watkins and Simmonds (2000), who analyzed region-wide changes in sea ice, suggest Antarctica as a whole appears to be experiencing a cooling trend. Reporting on trends in several Southern Ocean sea ice parameters over the period 1987 to 1996, they found statistically significant increases in sea ice area and total sea ice extent, as well as an increase in sea ice season length since the 1990s. Combining these results with those from a previous study revealed the trends to be consistent back to at least 1978. And in another study of Antarctic sea ice extent, Yuan and Martinson (2000) report the net trend in the mean Antarctic ice edge over the past 18 years has been an equator-ward expansion of 0.011 degree of latitude per year.

Liu *et al*. (2004) used sea ice concentration data retrieved from the scanning multi-channel microwave radiometer on the Nimbus 7 satellite and the spatial sensor microwave/imager on several defense meteorological satellites to develop a quality-controlled history of Antarctic sea ice variability covering an entire 22-year solar cycle (1979–2002) that included different states of the Antarctic Oscillation and several ENSO events. They then evaluated total sea ice extent and area trends by means of linear least-squares regression. They report, "overall, the total Antarctic sea ice extent (the cumulative area of grid boxes covering at least 15% ice concentrations) has shown an increasing trend (~4,801 km^2/yr)." In addition, they determined "the total Antarctic sea ice area (the cumulative area of the ocean actually covered by at least 15% ice concentrations) has increased significantly by ~13,295 km^2/yr, exceeding the 95% confidence level," while noting "the upward trends in the total ice extent and area are robust for different cutoffs of 15, 20, and 30% ice concentrations (used to define the ice extent and area)."

Turner *et al*. (2005) used a "new and improved" set of Antarctic climate data, described in detail by Turner *et al*. (2004), to examine "the temporal variability and change in some of the key meteorological parameters at Antarctic stations." This revealed a warming at low elevations on the western coast of the Antarctic Peninsula, which they describe as being "as large as any increase observed on Earth over the last 50 years," and which at the Faraday (now Vernadsky) station was about 2.5°C. However, they note the "region of marked warming is quite limited and is restricted to an arc from the southwestern part of the peninsula, through Faraday to a little beyond the tip of the peninsula."

Outside the Antarctic Peninsula, they report "there has been a broad-scale change in the nature of the temperature trends between 1961–90 and 1971–2000." Specifically, of the ten coastal stations that have long enough records to allow 30-year temperature trends to be computed for both of these periods, "eight had a larger warming trend (or a smaller cooling trend) in the earlier period." Four changed from warming to cooling, as did the interior Vostok site, and at the South Pole the rate of cooling intensified by a factor of six. Thus, over the latter part of the twentieth century—during which the IPCC claims to have found the most dramatic global warming of the past two millennia—fully 80 percent of the Antarctic coastal stations with sufficiently long temperature records revealed either an intensification of cooling or a reduced rate of warming, while four coastal sites and one interior site shifted from warming to cooling. All of this occurred in one of the planet's high-latitude polar regions, where CO_2-induced global warming has been predicted to be more strongly expressed than any other place on the planet.

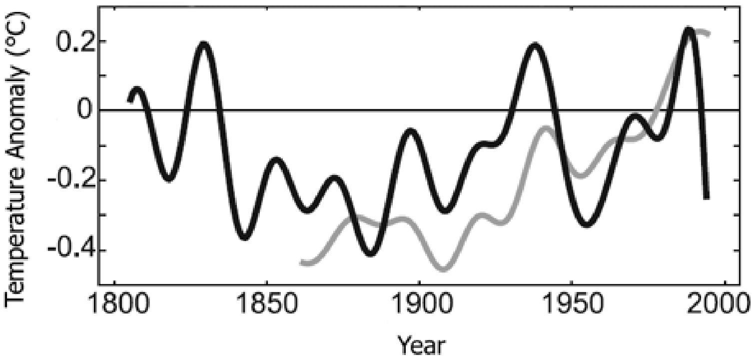

Figure 4.2.4.2.2.1. Mean temperature histories of Antarctica (dark line) and the Southern Hemisphere (lighter line), adapted from the paper of Schneider, D.P., Steig, E.J., van Ommen, T.D., Dixon, D.A., Mayewski, P.A., Jones, J.M., and Bitz, C.M. 2006. Antarctic temperatures over the past two centuries from ice cores. *Geophysical Research Letters* **33**: 10.1029/ 2006GL027057.

Schneider *et al.* (2006)_utilized 200 years of sub-annually resolved $\delta^{18}O$ and δD records from precisely dated ice cores obtained from Law Dome, Siple Station, Dronning Maud Land and two West Antarctic sites of the United States component of the International Trans-Antarctic Scientific Expedition to create a 200-year-long Antarctic temperature reconstruction representing the main part of the continent. The results of this undertaking, after application of a multi-decadal low-pass filter to the yearly data, are illustrated in Figure 4.2.4.2.2.1, along with the similarly treated data of the Southern Hemisphere instrumental temperature record, where the zero line represents the 1961–1990 climatological means of the two records.

Schneider *et al.* say "it is notable that the reconstructed Antarctic temperature record is in phase with the Southern Hemisphere mean instrumental record." This statement roughly describes the relationship between the two histories, but only until 1990, after which the Antarctic temperature history dramatically diverges from the Southern Hemisphere record. The seven scientists also state the Antarctic temperature reconstruction "provides evidence for long-term Antarctic warming," and if all the data they had were those that stretch from 1840 to 1990, they would be correct. However, when their "before and after" data are included, this statement is readily seen to be incorrect.

Schneider *et al.*'s data suggest there was nothing unusual, unnatural, or unprecedented about any Antarctic temperatures of any part of the twentieth century. Their data also demonstrate it was significantly colder in Antarctica near the end of the twentieth century than in the early decades of the nineteenth century, when the air's CO_2 concentration was about 100 ppm less than it is today, while data compiled by others indicates it may be even colder there today.

Chapman and Walsh (2007) used monthly surface air temperatures from manned and automatic weather stations along with ship/buoy observations from the high-latitude Southern Hemisphere to develop a gridded database with resolution appropriate for applications ranging from spatial trend analyses to climate change impact assessments. These data came from 460 locations in the Southern Hemisphere, where temperatures over land were obtained from 19 manned stations of the World Monthly Surface Station Climatology network, most of which were located in coastal areas of the Antarctic continent, plus 73 stations of the Automated Weather Station network, many of which were situated further inland. Temperatures over the sea were obtained from the International Comprehensive Ocean-Atmosphere Data repository. The two researchers used correlation length scaling "to enhance information content while limiting the spatial extent of influence of the sparse data in the Antarctic region."

The final results of Chapman and Walsh's efforts in this regard are presented in Figure 4.2.4.2.2.2. This figure clearly shows a post-1958 warming of Antarctica and much of the surrounding Southern

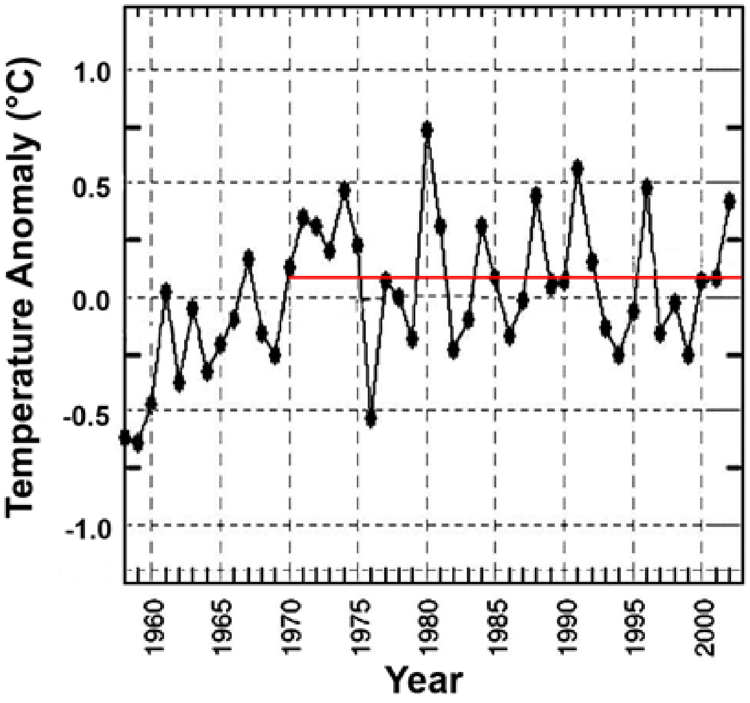

Figure 4.2.4.2.2.2. Annual surface air temperature anomalies relative to the 1958-2002 mean for the region of the Southern Hemisphere extending from 60 to 90°S. Adapted from Chapman, W.L. and Walsh, J.E. 2007. A synthesis of Antarctic temperatures. *Journal of Climate* **20**: 4096–4117.

Ocean. From approximately 1970 to the end of the record, however, temperatures of the region simply fluctuated around an anomaly mean of about 0.12°C, neither warming nor cooling. This is rather surprising in light of the fact that the region of study includes the Antarctic Peninsula, which experienced phenomenal warming during this period. Nevertheless, the mean surface air temperature of the entire region changed not at all, over a period of time that saw the air's CO_2 concentration rise by approximately 47 ppm, about 15 percent of its 1970 value, as per the Mauna Loa CO_2 record. Clearly, the continent of Antarctica, together with much of the Southern Ocean that surrounds it, has been unaffected by the warming supposedly produced by anthropogenic emissions of CO_2 and other greenhouse gases over the last three decades of the twentieth century.

Concentrating on the spring–summer period of November/December/January, Laine (2008) determined 1981–2000 trends of Antarctic ice-sheet and sea-ice surface albedo and temperature, as well as sea-ice concentration and extent, based on Advanced Very High Resolution Polar Pathfinder data in the case of ice-sheet surface albedo and temperature, and the Scanning Multichannel Microwave Radiometer and Special Sensor Microwave Imagers in the case of sea-ice concentration and extent. These analyses were carried out for the continent as a whole and for five longitudinal sectors emanating from the South Pole: 20°E–90°E, 90°E–160°E, 160°E–130°W, 130°W–60°W, and 60°W–20°E.

Laine found "all the regions show negative spring–summer surface temperature trends for the study period" and "the slight cooling trends seem to be parallel with the results of Comiso (2000), who studied Antarctic temperature trends using both satellite and station data." In addition, the Finnish researcher states, "the sea ice concentration shows slight increasing trends in most sectors, where the sea ice extent trends seem to be near zero." Laine also reports "the Antarctic region as a whole and all the sectors separately show slightly positive spring–summer albedo trends."

Monaghan and Bromwich (2008) reviewed what has been learned about snowfall and near-surface air temperature over the past five decades in Antarctica. They point out, "snowfall is the largest contributor to the growth of the ice sheets, and near-surface temperature controls surface melting, which in turn has important impacts on the stability of Antarctic ice shelves and glaciers," which ultimately impact global sea level.

The two researchers from the Byrd Polar Research Center of Ohio State University (USA) first note "instrumental records indicate statistically insignificant seasonal and annual near-surface temperature changes over continental Antarctica from the late 1950s through 2000," citing the work of Turner *et al.* (2005). On the Antarctic Peninsula, by contrast, temperature measured at the Faraday/Vernadsky station rose at the phenomenal rate of 0.56°C per decade from 1951 to 2000. But the peninsula comprises a mere 4 percent of the continent's total surface area, and its warming, although dramatic, is only a small-scale anomaly.

In describing another study of the temperature history of Antarctica, Monaghan and Bromwich report, "Chapman and Walsh (2007) performed an objective analysis of Antarctic near-surface temperatures from the early 1950s through 2002 and found the overall Antarctic temperature trends depend on the period for which they are calculated, being positive prior to 1965 (through 2002), and mainly negative thereafter, although never statistically significant for any period.” Similarly, after citing the work of Kwok and Comiso (2002) with skin temperature records derived from Advanced Very High Resolution Radiometer instrumentation flown aboard polar-orbiting satellites, the work of Schneider *et al*. (2006) with temperatures derived from ice-core stable isotopes, and the work of Monaghan *et al*. (2008) that blended the instrumental temperature record with model reanalysis temperature fields, Monaghan and Bromwich conclude, “overall there have not been statistically significant Antarctic near-surface temperature trends since the International Geophysical Year” of 1957–1958.

Turning their attention to snowfall, Monaghan and Bromwich note “atmospheric models have been the primary tool for assessing temporal variability,” and they report the latest such studies of Antarctic snowfall “indicate that no statistically significant increase has occurred since ~1980,” citing the analyses of Monaghan *et al*. (2006) and van de Berg *et al*. (2005), although there have been cyclical changes related to similar changes in temperature. When the two variations are compared on decadal time scales, it appears snowfall over Antarctica could rise by as much as 5 percent for each 1°C increase in temperature.

As to what the future might hold for Antarctic snowfall in a warming world, the two researchers state, “if global climate model projections of 2–3.5°C temperature increases over Antarctica by the end of this century are accurate”—which is highly debatable—“a ~10%–20% increase in snowfall might be expected if the 1960–2004 sensitivity relationship holds.” They note “a 15% increase of Antarctic snowfall would mitigate an additional ~1 mm per year [rise] of global sea level in 2100 compared to today.” Thus the rise in sea level predicted by the IPCC to occur this century appears to be highly unlikely, especially in light of Monaghan and Bromwich’s ultimate observation that “a widespread signal of Antarctic climate change is not obvious over the past ~50 years.”

Sinclair *et al*. (2012) write, “although the Antarctic ice sheet plays a pivotal role in the global ocean and atmospheric circulation systems and their response to warming climates, there are few long-term observations of surface temperature across the continent,” which they say is “particularly true for areas pole-ward of the Antarctic Peninsula because of the sparsity of scientific bases and problems associated with satellite measurements of surface temperature (Mayewski *et al*., 2009).” Consequently, they assert there is a “pressing need for a better understanding of climate variability and the forcings that underlie these changes.”

Thus Sinclair *et al*. studied isotope-temperature relationships at a site on the Whitehall Glacier in northern Victoria Land (72°54’S, 169°5’E) on a flat ice divide about 12 km from the nearest seasonally open water. Working with an ice core drilled to a depth of 105 meters there in 2006/2007, they developed a well-calibrated isotope-temperature relationship and used it to reconstruct annual temperatures, as well as summer (December–February) and cold season (April–September) temperatures, for the 125-year span of their data. Over the full length of their record, the three researchers state, they could find “no significant [temperature] trends between 1882 and 2006.” Neither were there any significant trends in either summer or cold season temperatures since 1958. However, they report “a decrease in cold season temperatures of -1.59°C ± 0.84°C/decade at 90% confidence ($p = 0.07$) since 1979,” and this cooling was “coincident with a positive trend in the southern annular mode, which is linked to stronger southerly winds and increased sea ice extent and duration in the western Ross Sea,” which they say “is one of the few regions experiencing a significant positive trend in sea ice and a negative trend in sea surface temperatures,” citing Comiso *et al*. (2011).

It is clear the temperature history of Antarctica provides no evidence for the CO_2-induced global warming hypothesis and in fact argues strongly against it.

And even if the Antarctic were to warm as a result of some natural or anthropogenic-induced change in Earth’s climate, the consequences likely would not be grave. Both the number and diversity of penguin species (Smith *et al*., 1999; Sun *et al*., 2000) likely would improve, as would the size and number of the continent’s only two vascular plant species (Xiong *et al*., 2000). The great ice sheets likely would survive, as not even a warming event as dramatic as 10°C is predicted to result in a net change in the East Antarctic Ice Sheet (Näslund *et al*., 2000), which suggests predictions of catastrophic coastal flooding due to melting from the world’s polar ice sheets are off the mark.

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4.2.4.3 Arctic

The IPCC has long predicted CO_2-induced global warming—which they assert has accelerated significantly during the twentieth century and is unprecedented in the past millennium or more—should be greatly amplified in Earth's polar regions:

> Robust evidence for polar amplification in either one or both hemispheres has been found in climate model experiments of past and future climate change, paleo-climate data and recent instrumental temperature records (Second Order Draft of AR5, dated October 5, 2012, p. 5-14).

As shown in the subsections below, the IPCC's claim of "robust evidence" of amplified CO_2-induced warming in Earth's polar regions is patently false, having been invalidated time and again by real-world data. From the birth and death of ice ages to the decadal variations of modern-day weather patterns, studies of the Arctic's climate show the atmosphere's CO_2 concentration is not a major player in bringing about significant changes in Earth's climate. In the following sections, we present brief reviews of pertinent studies of glacial periods, the Holocene, and the past few decades.

4.2.4.3.1 The Past Several Interglacial Cycles

Beginning with the current interglacial or Holocene, Darby *et al*. (2001) developed a 10,000-year multi-parameter environmental record from a thick sequence of post-glacial sediments obtained from cores extracted from the upper continental slope off the Chukchi Sea Shelf in the Arctic Ocean. They uncovered evidence that revealed "previously unrecognized millennial-scale variability in Arctic Ocean circulation and climate," along with evidence suggesting "in the recent past, the western Arctic Ocean was much warmer than it is today." They state, "during the middle Holocene the August sea surface temperature fluctuated by 5°C and was 3–7°C warmer than it is today," and they report their data revealed "rapid and large (1–2°C) shifts in bottom water temperature." They conclude, "Holocene variability in the western Arctic is larger than any change observed in this area over the last century."

Miller *et al*. (2005) summarize the main characteristics of the glacial and climatic history of the Canadian Arctic's Baffin Island since the Last Glacial Maximum by presenting biotic and physical proxy climate data derived from six lacustrine sediment cores recovered from four sites on Baffin Island. The paleoenvironmental implications of the new data were combined with the findings of prior studies to develop a regional picture of climatic conditions during deglaciation, the subsequent Holocene thermal maximum, the onset of Neogolaciationm and its intensification in the late Holocene. This work revealed "glaciers throughout the Canadian Arctic show clear evidence of Little Ice Age expansion, persisting until the late 1800s, followed by variable recession over the past century." Wherever the Little Ice Age advance can be compared to earlier advances, they note, "the Little Ice Age is the most extensive Late Holocene advance" and "some glaciers remain at their Little Ice Age maximum." Because the Little Ice Age in the Canadian Arctic spawned the region's most extensive glacial advances of the entire Holocene, and because many of the resulting glaciers persisted into the late 1800s, with some remaining at their maximum Little Ice Age extensions, it is only to be expected the region would experience a significant warming as the planet recovers from this coldest phase of the Holocene, independent of the air's CO_2 concentration.

Frechette *et al*. (2006) employed radiocarbon and luminescence dating of macrofossils contained in sediment cores recovered from three mid-Arctic lakes on the Cumberland Peninsula of eastern Baffin Island in the Canadian Arctic to isolate and study the portions of the cores pertaining to the interglacial that preceded the Holocene, which occurred approximately 117,000–130,000 years ago. They reconstructed the past vegetation and climate of the region during this period based on pollen spectra derived from the cores. "In each core," they write, "last interglacial sediments yielded remarkably high pollen concentrations, and included far greater percentages of shrub (*Betula* and *Alnus*) pollen grains than did overlying Holocene sediments." Also, "from applications of both correspondence analysis regression and best modern analogue methodologies, we infer July air temperatures of the last interglacial to have been 4 to 5°C warmer than present on eastern Baffin Island," greater warmth than in any interval within the Holocene. They say their temperature reconstruction is "directly comparable to both earlier qualitative estimates (LIGA Members, 1991; Bennike and Bocher, 1994), as well as more recent quantifications from ice core (NGRIP Members, 2004) and pollen (Andreev *et al*., 2004) analyses."

In a companion study, Francis *et al*. (2006) analyzed midge remains found in cores recovered from two of the same Baffin Island lakes (Fog Lake and Brother of Fog Lake) for which Frechette *et al*. analyzed pollen spectra, reconstructing lake water temperatures and mean July air temperatures for the Holocene and the prior interglacial period. They write, "reconstructions at both [lake] sites indicate that summer temperatures during the last interglacial were higher than at any time in the Holocene, and 5 to 10°C higher than present."

The 25 authors of a major review paper (CAPE-Last Interglacial Project Members, 2006) present "quantitative estimates of circum-Arctic Last Interglaciation (LIG) summer air and sea-surface temperatures reconstructed from proxy records preserved in terrestrial and marine archives," including beach morphology, beetles, benthic foraminifera, chironomids, coccoliths, δD, $\delta^{18}O$, dinocysts, insects, invertebrates, Mg/Ca ratio, mollusks, nanofossils, needles, ostracodes, planktic foraminifera, plant microfossils, pollen, soils, spores, tephra, and treeline position. They report, "quantitative reconstructions of LIG summer temperatures suggest that much of the Arctic was 5°C warmer during the LIG than at present." With respect to the impacts of this warmth, they state Arctic summers of the LIG "were warm enough to melt all glaciers below 5 km elevation except the Greenland Ice Sheet, which was reduced by ca 20–50% (Cuffey and Marshall, 2000; Otto-Bliesner *et al*., 2006)." In addition, they note, "the margins of permanent Arctic Ocean sea ice retracted well into the Arctic Ocean basin and boreal forests advanced to the Arctic Ocean coast across vast regions of the Arctic currently occupied by tundra."

Clearly, if there is anything strange or unusual about current Arctic temperatures it is that they are so much lower than they were during the maximum warmth of the current interglacial and, even more so, the prior interglacial. If the Arctic behaves anything like the Antarctic in this regard, one can extend this comparison back in time through three more interglacials, all of which were also warmer than the current one (Petit *et al*., 1999; Augustin *et al*., 2004).

White *et al*. (2010) produced a comprehensive review of past climate change in Earth's north polar region. The nine researchers describe how "processes linked with continental drift have affected atmospheric circulation, ocean currents, and the composition of the atmosphere over tens of millions of years," and "a global cooling trend over the last 60 million years has altered conditions near sea level in the Arctic from ice-free year-round to completely ice covered." They also report, "variations in arctic insolation over tens of thousands of years in response to orbital forcing have caused regular cycles of warming and cooling that were roughly half the size of the continental-drift-linked changes," and, in turn, this glacial-interglacial cycling "was punctuated by abrupt millennial oscillations, which near the North Atlantic were roughly half as large as the glacial-interglacial cycles." They also note "the current interglacial, the Holocene, has been influenced by brief cooling events from single volcanic eruptions, slower but longer lasting changes from random fluctuations in the frequency of volcanic eruptions, from weak solar variability, and perhaps by other classes of events."

White *et al*. conclude "thus far, human influence does not stand out relative to other, natural causes of climate change." They say the data "clearly show" that "strong natural variability has been characteristic of the Arctic at all time scales considered" and "the human influence on rate and size of climate change thus far does not stand out strongly from other causes of climate change."

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4.2.4.3.2 The Past Few Centuries through the Past Few Millennia

The IPCC contends current temperatures are both unnatural and unprecedented, a result of global warming caused by anthropogenic CO_2 emissions, and they claim this "unnaturalness" is most strongly expressed in the world's Arctic regions. This section investigates that claim in the context of the latter part of the current interglacial or Holocene, based on studies conducted in the Arctic.

The Arctic—which climate models suggest should be sensitive to greenhouse-gas-induced warming—is still not as warm as it was many centuries ago, especially during portions of the Medieval Warm Period, when there was much less CO_2 and methane in the air than there is today. This further suggests there is no compelling reason to conclude, as does the IPCC, that the twentieth century increase in the air's CO_2 content (a 120ppm rise above what it was during the warmer Medieval Warm Period) was the cause of twentieth century warming, especially when it is claimed such warming should be most evident and earliest expressed in high northern latitudes, and in light of the millennial-scale climatic cycle that alternately brings the Earth relatively warmer and cooler century-scale conditions throughout both glacial and interglacial periods alike.

4.2.4.3.2.1 Canada

Moore *et al*. (2001) analyzed sediment cores extracted from Donard Lake, Baffin Island, Canada (~66.25°N, 62°W), to produce a 1,240-year record of mean summer temperature for this region that averaged 2.9°C over the period AD 750–1990 (see Figure 4.2.4.3.2.1.1). Within this period there were several anomalously warm decades with temperatures as high as 4°C around AD 1000 and 1100, and at the beginning of the thirteenth century Donard Lake

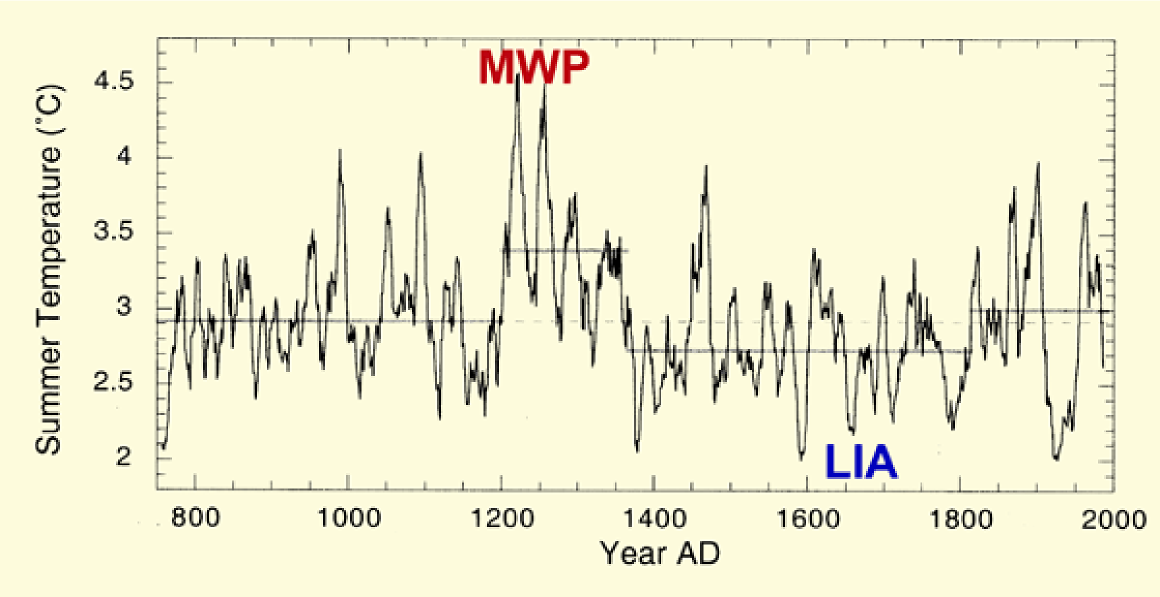

Figure 4.2.4.3.2.1.1. A 1,240-year proxy record of mean summer temperature from sediment cores extracted from Donard Lake, Baffin Island, Canada. Adapted from Moore, J.J., Hughen, K.A., Miller, G.H., and Overpeck, J.T. 2001. Little Ice Age recorded in summer temperature reconstruction from varved sediments of Donard Lake, Baffin Island, Canada. *Journal of Paleolimnology* **25**: 503–517.

witnessed what Moore *et al.* called "one of the largest climatic transitions in over a millennium," as "average summer temperatures rose rapidly by nearly 2°C from AD 1195–1220, ending in the warmest decade in the record," with temperatures near 4.5°C. That temperature rise was followed by a period of extended warmth that lasted until an abrupt cooling event occurred around AD 1375, resulting in the following decade being one of the coldest in the record and signaling the onset of the Little Ice Age on Baffin Island, which lasted for 400 years.

At the modern end of the record, a gradual warming trend occurred over the period 1800–1900, followed by a dramatic cooling event that brought temperatures back down to levels characteristic of the Little Ice Age, which lasted until about 1950. Thereafter, temperatures rose once more throughout the 1950s and 1960s, whereupon they trended downward toward cooler conditions to the end of the record in 1990.

Kasper and Allard (2001) examined soil deformations caused by ice wedges, a widespread and abundant form of ground ice in permafrost regions that can grow during colder periods and deform and crack the soil. Working near Salluit, northern Quebéc (approx. 62°N, 75.75°W), they found evidence of ice wedge activity prior to AD 140, reflecting cold climatic conditions. Between AD 140 and 1030 this activity decreased, indicating warmer conditions. Trom AD 1030 to 1500 conditions cooled, and from 1500 to 1900 ice wedge activity was at its peak, when the Little Ice Age ruled, suggesting this climatic interval exhibited the coldest conditions of the past 4,000 years. Thereafter, a warmer period prevailed from about 1900 to 1946, followed by a return to cold conditions during the last five decades of the twentieth century, during which more than 90 percent of the ice wedges studied reactivated and grew by 20–30 cm, in harmony with a reported temperature decline of 1.1°C observed at the meteorological station in Salluit. This cooling is vastly different from the "unprecedented warming" the IPCC contends was occurring during this same period of time.

Besonen *et al*. (2008) derived thousand-year histories of varve thickness and sedimentation accumulation rate for Canada's Lower Murray Lake (81°20'N, 69°30'W), which is typically covered for about 11 months of each year by ice that reaches a thickness of 1.5 to 2 meters at the end of each winter. Citing seven other studies, they write, "field-work on other High Arctic lakes clearly indicates sediment transport and varve thickness are related to temperatures during the short summer season that prevails in this region, and we have no reason to think that this is not the case for Lower Murray Lake." The six scientists report the varve thickness and sediment accumulation rate histories of Lower Murray Lake reveal "the twelfth and thirteenth centuries were relatively warm" and often much warmer during this time period (AD 1080–1320) than at any point in the twentieth century.

Cook *et al*. (2009) examined sediment cores extracted from Lower Murray Lake in 2005 and 2006 to calculate annual mass accumulation rate (MAR) for the past five millennia, which they used to derive a relationship between MAR and July temperature at the two nearest permanent weather stations over the period of instrumental measurements. This revealed several periods over the past 5,000 years when the temperature of the region exceeded the peak temperature of the twentieth century, the most recent of which was during the Medieval Warm Period, delineated in Figure 4.2.4.3.2.1.2 as occurring between about AD 930 and 1400. The peak temperature of that period can be seen to have been about 0.6°C higher than the peak temperature of the Current Warm Period.

Vare *et al*. (2009) used a novel biomarker (IP25), which they describe as a mono-unsaturated highly branched isoprenoid synthesized by sea ice diatoms that have been shown to be stable in sediments below Arctic sea ice, together with "proxy data obtained from analysis of other organic biomarkers, stable isotope composition of bulk organic matter, benthic foraminifera, particle size distributions and ratios of inorganic elements," to develop a spring sea ice record for the central Canadian Arctic Archipelago. They discovered evidence for a decrease in spring sea ice between approximately 1,200 and 800 years before present (BP), which they associate with "the so-called Mediaeval Warm Period."

Fortin and Gajewski (2010) developed an 8,000-year history of mean July air temperature in the Wynniatt Bay region of Canada's Northern Victoria Island (72.29°N, 109.87°W) using two replicate sediment cores extracted from the central point of Lake WB02 in June 1997. They employed the modern analogue technique (MAT) and weighted averaging partial least squares (WAPLS) regression, utilizing chironomid species assemblage data. As best as can be determined from their graphical results, late-Holocene temperatures peaked about 1,100 years ago in both reconstructions, at values approximately 3.8°C warmer than the peak temperature of the Current Warm Period, which occurs at the end of their record in the AD 1990s in their MAT analysis, and approximately 1.0°C warmer than the peak temperature of the CWP, which also occurs at the end of their record in their WAPLS analysis.

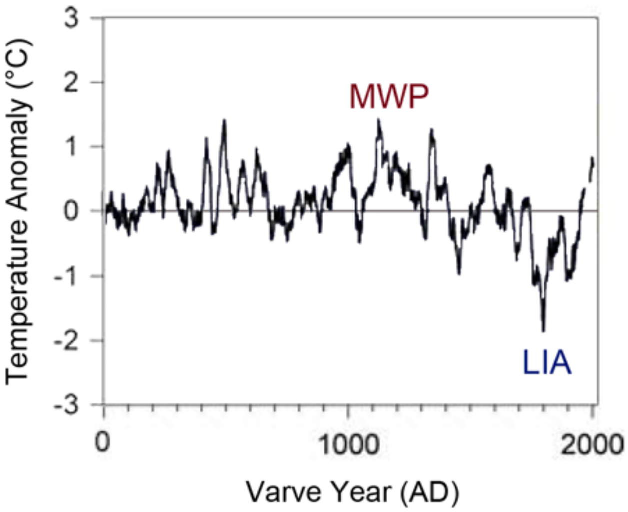

Figure 4.2.4.3.2.1.2. A proxy temperature reconstruction obtained from sediment cores extracted from Lower Murray Lake, Ellesmere Island, Nunavut, Canada. Adapted from Cook, T.L., Bradley, R.S., Stoner, J.S., and Francus, P. 2009. Five thousand years of sediment transfer in a high arctic watershed recorded in annually laminated sediments from Lower Murray Lake, Ellesmere Island, Nunavut, Canada. *Journal of Paleolimnology* **41**: 77–94.

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4.2.4.3.2.2 Greenland

For many millennia, the Arctic climate, like that of Earth as a whole, has both cooled and warmed independent of its atmospheric CO_2 concentration. Conditions as warm as, or warmer than, the present have persisted across the Holocene for decades to centuries even though the atmosphere's CO_2 concentration remained at values approximately 30 percent lower than today's. This subsection highlights studies that address the temperature history of Greenland.

Benthic foraminifera and lithofacies analyses were conducted by Jennings and Weiner (1996) on two marine sediment cores from Nansen Fjord, eastern Greenland (~68.25°N, 29.6°W) in an effort to infer changes in sea-ice conditions and water masses in the region since AD 730. The analyses revealed the presence of a Medieval Warm Period between about AD 730 and 1110, as depicted in Figure 4.2.4.3.2.2.1. The authors describe the climate during this time as "the warmest and most stable in the last millennium including the present day," in which sea ice in the fjord was "never or rarely" present in the summer.

Dahl-Jensen *et al.* (1998) used temperature measurements from two Greenland Ice Sheet boreholes to reconstruct the temperature history of this part of Earth over the past 50,000 years. Their data indicated that after the termination of the glacial period, temperatures steadily rose to a maximum of 2.5°C warmer than at present during the Holocene Climatic Optimum (4,000 to 7,000 years ago). The Medieval Warm Period (MWP) and Little Ice Age (LIA) also were observed in the record, with temperatures 1°C warmer and 0.5–0.7°C cooler than at the time of their writing, respectively. After the Little Ice Age, they report, temperatures once again rose, but they "decreased during the last decades," indicating the MWP in this part of the Arctic was significantly warmer than it was just before the turn of the century.

Wagner and Melles (2001) extracted a 3.5-m-long sediment core from a lake (Raffels So) on an island (Raffles O) located just off Liverpool Land on the east coast of Greenland, which they analyzed for several properties related to the past presence of seabirds there, obtaining a 10,000-year record that tells much about the region's climate history. Key to the study were biogeochemical data, which, in the words of the two researchers, reflect "variations in seabird breeding colonies in the catchment which influence nutrient and cadmium supply to the lake." These data revealed sharp increases in the values of the parameters they represented between about 1,100 and 700 years before present (BP), indicative of the summer presence of significant numbers of seabirds during that "medieval warm period," as Wagner and Melles describe it, which was preceded by a several-hundred-year period (the Dark Ages Cold Period) with little or no bird presence. After the Medieval

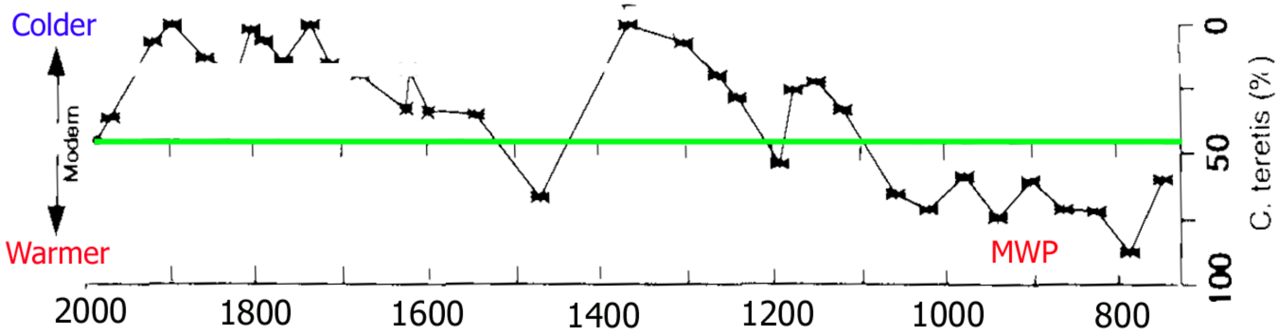

Figure 4.2.4.3.2.2.1. Percentage of Cassidulina teretis, an indicator of Atlantic Intermediate Water, in Nansen Fjord, Eastern Greenland. The horizontal green line indicates the modern percentage of C. teretis. Derivations below (above) this line indicate warmer (cooler) conditions. Adapted from Jennings, A.E. and Weiner, N.J. 1996. Environmental change in eastern Greenland during the last 1300 years: evidence from foraminifera and lithofacies in Nansen Fjord, 68°N. *The Holocene* **6**: 179–191.

Warm Period, their data suggest another absence of birds during what they call "a subsequent Little Ice Age," which they say was "the coldest period since the early Holocene in East Greenland."

The Raffels So data also show signs of a resettlement of seabirds during the last century, as indicated by an increase of organic matter in the lake sediment and confirmed by bird counts. Values of the most recent measurements of seabird numbers were not as great as those inferred for the earlier Medieval Warm Period, suggesting higher temperatures prevailed during much of the period from 1,100 to 700 years BP than those observed over the most recent hundred years.

Kaplan *et al*. (2002) derived a climate history of the Holocene by analyzing the physical-chemical properties of sediments obtained from a small lake in the southern sector of Greenland. The interval from 6,000 to 3,000 years BP was marked by warmth and stability, but the climate cooled thereafter until its culmination in the Little Ice Age. From 1300–900 years BP, there was a partial amelioration during the Medieval Warm Period, which was associated with an approximate 1.5°C rise in temperature.

Working on a floating platform in the middle of a small lake (Hjort So) on an 80-km-long by 10.5-km-wide island (Store Koldewey) just off the coast of Northeast Greenland, Wagner *et al*. (2008) recovered two sediment cores of 70 and 252 cm length, which they analyzed for grain-size distribution, macrofossils, pollen, diatoms, total carbon, total organic carbon, and several other parameters. The sequences for those parameters were dated by accelerator mass spectrometry, with radiocarbon ages translated into calendar years before present. This revealed an "increase of the productivity-indicating proxies around 1,500–1,000 cal year BP, corresponding with the medieval warming," and "after the medieval warming, renewed cooling is reflected in decreasing amounts of total organic carbon, total diatom abundance, and other organisms, and a higher abundance of oligotrophic to meso-oligotrophic diatom taxa." They continue, "this period, the Little Ice Age, was the culmination of cool conditions during the Holocene and is documented in many other records from East and Northeast Greenland, before the onset of the recent warming [that] started ca. 150 years ago."

In addition to finding evidence for the Medieval Warm Period, the six researchers' statement that the Little Ice Age was the culmination, or most extreme subset, of cool conditions during the Holocene, suggests it would not be at all unusual for such a descent into extreme coolness to be followed by some extreme warming, which further suggests there is nothing unusual about the degree of subsequent warming experienced over the twentieth century.

Norgaard-Pedersen and Mikkelsen (2009) analyzed materials obtained from a sediment core retrieved in August 2006 from the deepest basin of Narsaq Sound in southern Greenland, inferring various "glacio-marine environmental and climatic changes" that had occurred over the prior 8,000 years. This work revealed the existence of two periods (2.3–1.5 ka and 1.2–0.8 ka) that appeared to coincide roughly with the Roman and Medieval Warm Periods. They identified the colder period that followed the Medieval Warm Period as the Little Ice Age and the colder period that preceded it as the Dark Ages Cold Period. Citing the work of Dahl-Jensen *et al*. (1998), Andresen *et al*. (2004), Jensen *et al*. (2004), and Lassen *et al*. (2004), the two Danish scientists say the cold and warm periods identified in those studies "appear to be more or less synchronous to the inferred cold and warm periods observed in the Narsaq Sound record," providing additional evidence for the reality of the naturally occurring phenomenon that governs this millennial-scale oscillation of climate.

Vinther *et al*. (2010) analyzed 20 ice core records from 14 sites, all of which stretched back at least 200 years, as well as near-surface air temperature data from 13 locations along the southern and western coasts of Greenland that covered approximately the same time interval (1784–2005), plus a similar temperature dataset from northwest Iceland, said by the authors to be employed "in order to have some data indicative of climate east of the Greenland ice sheet." This work demonstrated winter δ^{18}O was "the best proxy for Greenland temperatures." Based on that determination and working with three longer ice core δ^{18}O records (DYE-3, Crete and GRIP), they developed a temperature history that extended more than 1,400 years back in time.

This history revealed "temperatures during the warmest intervals of the Medieval Warm Period"—which they define as occurring some 900 to 1300 years ago—"were as warm as or slightly warmer than present day Greenland temperatures." Vinther *et al*. also acknowledge the independent "GRIP borehole temperature inversion suggests central Greenland temperatures are still somewhat below the high temperatures that existed during the Medieval Warm Period."

Kobashi *et al*. (2010) state, "in Greenland, oxygen isotopes of ice (Stuiver *et al*., 1995) have been extensively used as a temperature proxy, but the data are noisy and do not clearly show multi-centennial trends for the last 1,000 years in contrast to borehole temperature records that show a clear ‘Little Ice Age’ and ‘Medieval Warm Period’ (Dahl-Jensen *et al*., 1998).” They further note nitrogen (N) and argon (Ar) isotopic ratios—^{15}N/^{14}N and ^{40}Ar/^{36}Ar, respectively—can be used to construct a temperature record that “is not seasonally biased, and does not require any calibration to instrumental records, and resolves decadal to centennial temperature fluctuations.

They use this new approach to construct a history of the last thousand years of central Greenland surface air temperature, based on values of the isotopic ratios of nitrogen and argon previously derived by Kobashi *et al*. (2008) from air bubbles trapped in the GISP2 ice core that had been extracted from central Greenland, obtaining the result depicted in Figure 4.2.4.3.2.2.2.

This figure depicts the central Greenland surface temperature reconstruction produced by the six scientists. The peak temperature of the latter part of the Medieval Warm Period—which began some time prior to the start of their record, as demonstrated by the work of Dansgaard *et al*. (1975), Jennings and Weiner (1996), Johnsen *et al*. (2001), and Vinther *et al*. (2010)—appears to have been approximately 0.33°C greater than the peak temperature of the Current Warm Period and about 1.67°C greater than the temperature of the last decades of the twentieth century.

In a study based on the identification and quantification of various foraminiferal species found in a sediment core extracted from the bottom of a deep-water trough (Egedesminde Dyb) in the southwestern Disko Bugt of West Greenland at coordinates of ~68°38’N, 53°49’W, Perner *et al*. (2011) derived a 3,600-year proxy-temperature history of the West Greenland Current at that location. This history revealed “a marked long-term cooling trend over the last 3.6 ka BP,” but superimposed on this longer-term cooling trend was evidence of millennial to centennial scale variability, where one of the warm intervals is said by them to constitute “the time period of the ‘Medieval Climate Anomaly,’” which they identify as occurring over the period AD 1000–1500. Their proxy-temperature graph indicates the entire period was significantly warmer than the Current Warm Period has been to date.

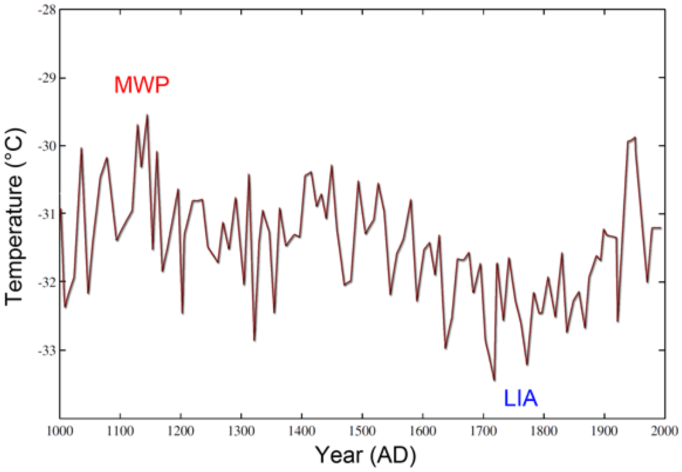

Figure 4.2.4.3.2.2.2. Central Greenland surface temperature reconstruction for the last millennium. Adapted from Kobashi, T., Severinghaus, J.P., Barnola, J.-M., Kawamura, K., Carter, T., and Nakaegawa, T. 2010. Persistent multi-decadal Greenland temperature fluctuation through the last millennium. *Climatic Change* **100**: 733–756.

Perner *et al*. (2013) identified and quantified the different types of benthic foraminiferal species found in two sediment cores beneath the path of the West Greenland Current (WGC) southwest of Disko Bugt (68°28.311’N, 54°00.119’W) on the West Greenland margin, determining the relative thermal history of the WGC over the past 7,300 years. This record revealed “(1) cooling at ~2.5 ka BP, linked to the 2.7 ka BP ‘cooling event’, (2) a warm phase centered at 1.8 ka BP, associated with the ‘Roman Warm Period’, (3) slight warming between 1.4 and 0.9 ka BP, linked to the ‘Medieval Climate Anomaly’ [MCA], (4) severe cooling of the WGC after 0.9 ka BP, culminating at 0.3 ka BP during the ‘Little Ice Age.’” As to the degree of warmth of the MCA, the authors state, “our data show that oceanographic conditions (WGC) are relatively cool and remained cooler during the last 100 years than during the MCA,” indicating the warmth of the Current Warm Period has not reached that experienced during the MCA.

Axford *et al*. (2013) examined sedimentary records from five lakes (North, Fishtote, Loon, Iceboom, and Pluto) near Jakobshavn Isbrae in central West Greenland to investigate the timing and magnitude of major Holocene climate changes, with their primary objective being “to constrain the timing and magnitude of maximum warmth during the early to middle Holocene positive anomaly in summer insolation.” They did this by analyzing various properties of sediment cores extracted from the lakes in the summers of 2008 and 2009.

They write, "Based upon chironomid assemblages at North Lake, and supported by records of organic sedimentation in all five study lakes, we infer warmer-than-present temperatures by at least 7.1 ka [thousands of years before present] and Holocene maximum warmth between 6 and 4 ka," when they indicate "the local ice sheet margin was at its most retracted Holocene position" and "summer temperatures were 2–3°C warmer than present during that time of minimum ice sheet extent." A graphical representation of this temperature history is presented in Figure 4.2.4.3.2.2.3, with the concomitant history of Earth's atmospheric CO_2 concentration.

As illustrated in the figure, there is no relationship between the Holocene temperature history derived by Axford *et al.* and the air's CO_2 content. Over the first 1,800 years of the record, when the atmosphere's CO_2 concentration rose by just 10 ppm, Holocene temperatures rose, in the mean, by about 2.3°C. Then, over the following 2,400 years, when the air's CO_2 content rose by about 20 ppm, mean summer air temperatures dropped by approximately 2.6°C. And over the next 1,900 years, when the air's CO_2 content rose by 10 to 15 ppm,

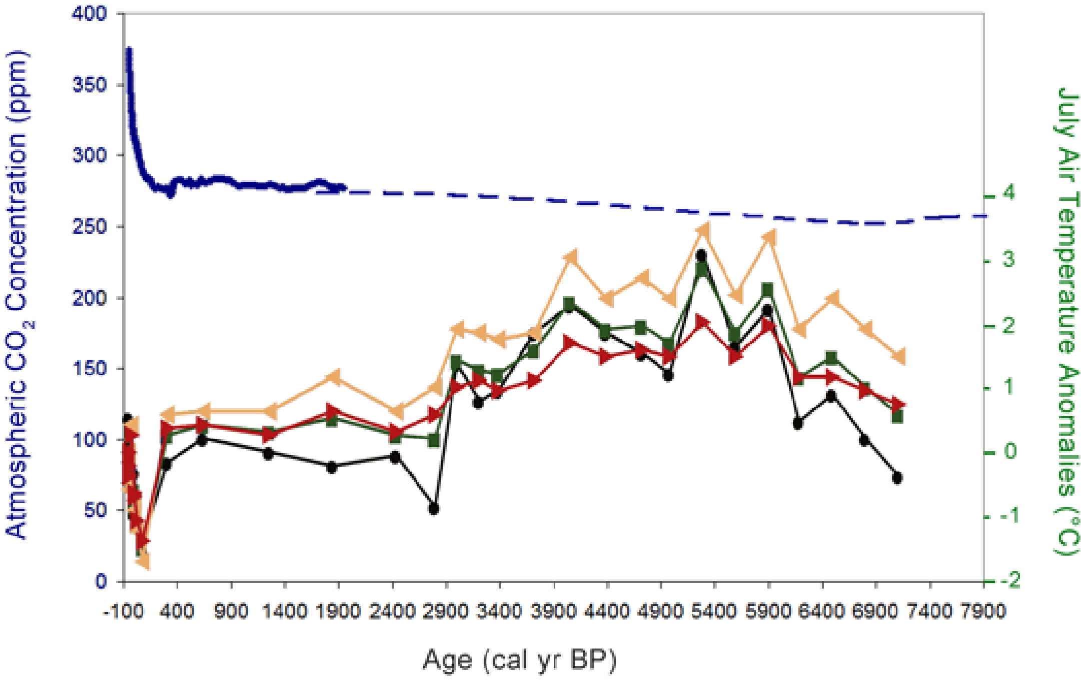

Figure 4.2.4.3.2.2.3. Reconstructed July air temperature anomalies in the vicinity of North Lake, inferred from chironomid data using three different calibration formulas: (1) Weighted-averaging, orange line with triangle data points, (2) Weighted-averaging with tolerance downweighting, red line with triangle data points, (3) Weighted-averaging partial-least-squares, black line with circle data points), plus the mean of the three sets of results (green line, square data points), as adapted from Axford, Y., Losee, S., Briner, J.P., Francis, D.R., Langdon, P.G., and Walker, I.R. 2013. Holocene temperature history at the western Greenland Ice Sheet margin reconstructed from lake sediments. *Quaternary Science Reviews* **59**: 87–100. Also shown is the concomitant history of Earth's atmospheric CO_2 concentration, as obtained from atmospheric measurements carried out at Mauna Loa, Hawaii (Boden, T.A., Kaiser, D.P., Sepanski, R.J., and Stoss, F.W. (Eds.) 1994. *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee), together with ice core data obtained at Law Dome (Etheridge, D.M., Steele, L.P., Langenfelds, R.L, Francey, R.J., Barnola, J.-M., and Morgan, V.I. 1998. Historical CO_2 records from the Law Dome DE08, DE08-2, and DSS ice cores. In *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.) and Vostock, Antarctica (Keeling, C.D. and Whorf, T.P. 1998. Atmospheric CO_2 concentrations—Mauna Loa Observatory, Hawaii, 1958–1997 (revised August 1998). NDP-001. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee).

mean air temperature did not change. But over the final 300 or so years, when the atmospheric CO_2 concentration rose by 125 ppm, summer air temperatures first declined by about 1.9°C and then rose by about 1.9°C, for essentially no net change. The CO_2 concentration of Earth's atmosphere shows no consistent impact on July air temperatures in the vicinity of North Lake, Greenland, over the past seven millennia.

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4.2.4.3.2.3 Russia/Asian Arctic

Naurzbaev and Vaganov (2000) developed a 2,200-year temperature history using tree-ring data obtained from 118 trees near the upper-timberline in Siberia for the period 212 BC to AD 1996, as well as a similar history covering the period of the Holocene Climatic Optimum (3300 to 2600 BC). They compared their results with those obtained from an analysis of isotopic oxygen data extracted from a Greenland ice core. Fluctuations in average annual temperature derived from the Siberian record agreed well with air temperature variations reconstructed from the Greenland data, suggesting "the tree ring chronology of [the Siberian] region can be used to analyze both regional peculiarities and global temperature variations in the Northern Hemisphere."

Naurzbaev and Vaganov report several warm and cool periods prevailed for several multi-century periods throughout the last two millennia: a cool period in the first two centuries AD, a warm period from AD 200 to 600, cooling again from 600 to 800 AD, followed by the Medieval Warm Period from about AD 850 to 1150, the cooling of the Little Ice Age from AD 1200 through 1800, followed by the recovery warming of the twentieth century. The latter temperature rise was "not extraordinary," they write, and "the warming at the border of the first and second millennia [AD 1000] was longer in time and similar in amplitude." In addition, their reconstructed temperatures for the Holocene Climatic Optimum reveal there was an even warmer period about 5,000 years ago, when temperatures averaged 3.3°C more than over the past two millennia.

Vaganov *et al*. (2000) also used tree-ring width as a temperature proxy, reporting temperature variations for the Asian subarctic region over the past 600 years. Their graph of these data reveals temperatures in this region exhibited a small positive trend from the beginning of the record until about AD 1750. Thereafter, a severe cooling trend ensued, followed by a 130-year warming trend from about 1820 through 1950, after which temperatures fell once again. Vaganov *et al*. determined the amplitude of twentieth century warming "does not go beyond the limits of reconstructed natural temperature fluctuations in the Holocene subarctic zone." They further report finding a significant correlation with solar radiation and volcanic activity over the entire 600-year period (r = 0.32 for solar radiation, r = -0.41 for volcanic activity), which improved over the shorter interval (1800–1990) of the industrial period (r = 0.68 for solar radiation, r = -0.59 for volcanic activity).

Naurzbaev *et al*. (2002) developed a 2,427-year proxy temperature history for the part of the Taimyr Peninsula, northern Russia, lying between 70°30' and 72°28' North latitude, based on a study of ring-widths of living and preserved larch trees, noting it has been shown "the main driver of tree-ring variability at the polar timber-line [where they worked] is temperature (Vaganov *et al*., 1996; Briffa *et al*., 1998; Schweingruber and Briffa, 1996)." They found "the warmest periods over the last two millennia in this region were clearly in the third [Roman Warm Period], tenth to twelfth [Medieval Warm Period] and during the twentieth [Current Warm Period] centuries." With respect to the second of these three periods, they emphasize "the warmth of the two centuries AD 1058–1157 and 950–1049 attests to the reality of relative mediaeval warmth in this region." Their data also reveal the Roman and Medieval Warm Periods were warmer than the Current Warm Period has been to date; the beginning of the end of the Little Ice Age was somewhere in the vicinity of 1830; and the Current Warm Period peaked somewhere around 1940.

All of these observations are at odds with what is portrayed in the Northern Hemispheric hockey stick temperature history of Mann *et al*. (1998, 1999) and its thousand-year global extension developed by Mann and Jones (2003), in which the Current Warm Period is depicted as the warmest such era of the past two millennia, recovery from the Little Ice Age does not begin until after 1910, and the Current Warm Period experiences its highest temperatures in the latter part of the twentieth century's final decade.

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4.2.4.3.2.4 Scandinavia and Iceland

Jiang *et al*. (2002) analyzed diatom assemblages from a high-resolution core extracted from the seabed of the north Icelandic shelf, which led to their reconstruction of a 4,600-year history of summer sea surface temperature at that location. Starting from a maximum value of about 8.1°C at 4,400 years BP, the climate was found to have cooled fitfully for about 1,700 years and then more consistently over the final 2,700 years of the record. The most dramatic departure from this long-term decline was centered on about 850 years BP, during the Medieval Warm Period, when the temperature rose by more than 1°C above the line describing the long-term downward trend to effect an almost complete recovery from the colder temperatures of the Dark Ages Cold Period, after which temperatures continued their descent into the Little Ice Age, ending with a final most recent value of approximately 6.3°C. Their data clearly show the Medieval Warm Period in this part of the Arctic was significantly warmer than it is there now.

Grudd *et al*. (2002) assembled tree-ring widths from 880 living, dead, and subfossil northern Swedish pines into a continuous and precisely dated chronology covering the period 5407 BC to AD 1997. The strong association between these data and summer (June–August) mean temperatures of the last 129 years of the period enabled them to produce a 7,400-year history of summer mean temperature for northern Swedish Lapland.

The most dependable portion of this record, based on the number of trees that were sampled, consisted of the last two millennia, which Grudd *et al.* say "display features of century-timescale climatic variation known from other proxy and historical sources, including a warm 'Roman' period in the first centuries AD and a generally cold 'Dark Ages' climate from about AD 500 to about AD 900." They also note "the warm period around AD 1000 may correspond to a so-called 'Mediaeval Warm Period,' known from a variety of historical sources and other proxy records." They state, "the climatic deterioration in the twelfth century can be regarded as the starting point of a prolonged cold period that continued to the first decade of the twentieth century," and this "Little Ice Age," in their words, is also "known from instrumental, historical and proxy records." Going back even further in time, the tree-ring record displays several more of these relatively warmer and colder periods. They report "the relatively warm conditions of the late twentieth century do not exceed those reconstructed for several earlier time intervals."

Seppa and Birks (2002) used a recently developed pollen-climate reconstruction model and a new pollen stratigraphy from Toskaljavri, a tree-line lake in the continental sector of northern Fennoscandia located just above 69°N latitude, to derive quantitative estimates of annual precipitation and July mean temperature. Their reconstructions "agree with the traditional concept of a 'Medieval Warm Period' (MWP) and 'Little Ice Age' in the North Atlantic region (Dansgaard *et al*., 1975) and in northern Fennoscandia (Korhola *et al*., 2000)." In addition, they report there was "a clear correlation between [their] MWP reconstruction and several records from Greenland ice cores," and "comparisons of a smoothed July temperature record from Toskaljavri with measured borehole temperatures of the GRIP and Dye 3 ice cores (Dahl-Jensen *et al*., 1998) and the δ^{18}O record from the Crete ice core (Dansgaard *et al*., 1975) show the strong similarity in timing of the MWP between the records." They also note, "July temperature values during the Medieval Warm Period (ca. 1400–1000 cal yr B.P.) were ca. 0.8°C higher than at present," where present means the last six decades of the twentieth century.

Isaksson *et al*. (2003) retrieved two ice cores (one from Lomonosovfonna and one from Austfonna) far above the Arctic Circle in Svalbard, Norway, after which the 12 scientists from Norway, Finland, Sweden, Canada, Japan, Estonia, and the Netherlands used δ^{18}O data to reconstruct a 600-year temperature history of the region. As would be expected in light of Earth's transition from the Little Ice Age to the Current Warm Period, the scientists report "the δ^{18}O data from both Lomonosovfonna and Austfonna ice cores suggest that the 20th century was the warmest during at least the past 600 years." However, the warmest decade of the twentieth century was centered on approximately 1930, and the instrumental temperature record at Longyearbyen also shows the decade of the 1930s to have been the warmest. The authors note, "as on Svalbard, the 1930s were the warmest decade in the Trondheim record." There was no net warming over the last seven decades of the twentieth century in the parts of Norway cited in this study.

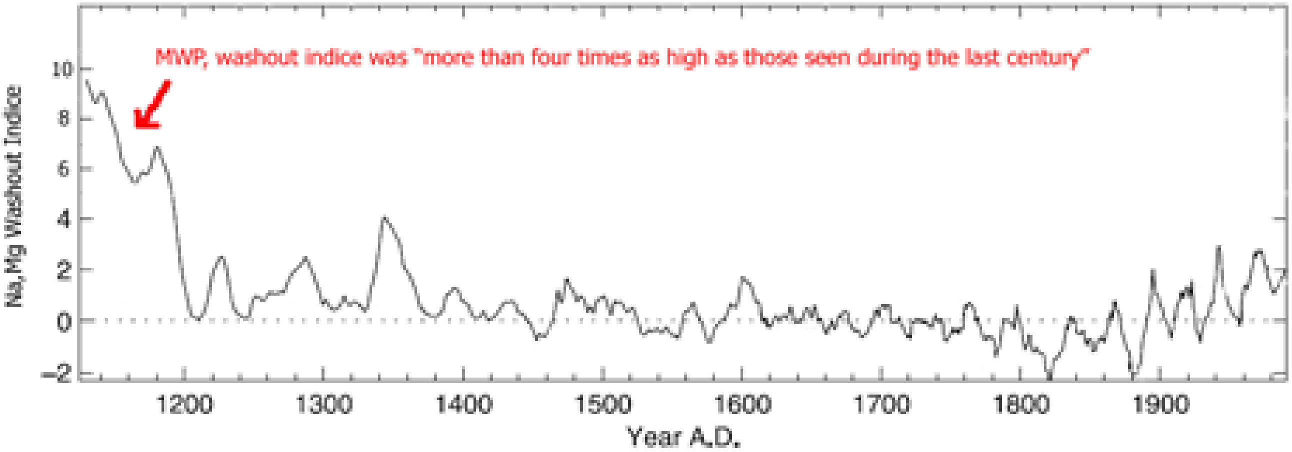
Knudsen *et al*. (2004) documented climate changes over the past 1,200 years via high-resolution multi-proxy studies of benthic and planktonic foraminiferal assemblages, stable isotopes, and ice-rafted debris found in three sediment cores retrieved from the North Icelandic shelf. They learned "the time period between 1200 and around 7–800 cal. (years) BP, including the Medieval Warm Period, was characterized by relatively high bottom and surface water temperatures," after which "a general temperature decrease in the area marks the transition to ... the Little Ice Age." They also found "minimum sea-surface temperatures were reached at around 350 cal. BP, when very cold conditions were indicated by several proxies." Thereafter, they report, "a modern warming of surface waters ... is not registered in the proxy data" and "there is no clear indication of warming of water masses in the area during the last decades," even in sea surface temperatures measured over the period 1948–2002.

Bradwell *et al*. (2006) examined the link between late Holocene fluctuations of Lambatungnajokull (an outlet glacier of the Vatnajokull ice cap of southeast Iceland) and variations in climate, using geomorphological evidence to reconstruct patterns of past glacier fluctuations and lichenometry and tephrostratigraphy to date glacial landforms created by the glacier over the past four centuries. This work revealed "a particularly close correspondence between summer air temperature and the rate of ice-front recession of Lambatungnajokull during periods of overall retreat" and "between 1930 and 1950 this relationship is striking." They also report, "ice-front recession was greatest during the 1930s and 1940s, when retreat averaged 20 m per year." Thereafter, the retreat "slowed in the 1960s" and "there has been little overall retreat since the 1980s."

The researchers also report, "the 20th-century record of reconstructed glacier-front fluctuations at Lambatungnajokull compares well with those of other similar-sized, non-surging, outlets of southern Vatnajokull," including Skaftafellsjokull, Fjallsjokull, Skalafellsjokull, and Flaajokull. They find "the pattern of glacier fluctuations of Lambatungnajokull over the past 200 years reflects the climatic changes that have occurred in southeast Iceland and the wider region."

Bradwell *et al*.'s findings indicate twentieth century summer air temperature in southeast Iceland and the wider region peaked in the 1930s and 1940s, and this warming was followed by a cooling that persisted through the end of the century. This history is about as different as can be imagined from the claim the warming of the globe over the last two decades of the twentieth century was unprecedented over the past two millennia, and this is especially significant for a high-northern-latitude region, where the IPCC claims CO_2-induced global warming should be earliest and most strongly expressed.

Grinsted *et al*. (2006) developed "a model of chemical fractionation in ice based on differing elution rates for pairs of ions ... as a proxy for summer melt (1130–1990)," based on data obtained from a 121-meter-long ice core they extracted from the highest ice field in Svalbard (Lomonosovfonna: 78°51'53"N, 17°25'30"E), which was "validated against twentieth-century instrumental records and longer historical climate proxies." This history shows, as illustrated in Figure 4.2.4.3.2.4.1, "in the oldest part of the core (1130–1200), the washout indices [were] more than 4 times as high as those seen during the last century, indicating a high degree of runoff." In addition, regular snow pit studies conducted near



15-year moving average of a washout indice derived from Na and Mg data from a Lomonosovfonna ice core, which data are a proxy for summer ice melt. Adapted from Grinsted et al. 2006

Figure 4.2.4.3.2.4.1. Fifteen-year moving average of a washout indice derived from Na and Mg data from a Lomonosovfonna ice core on Svalbard, which data are a proxy for summer ice melt. Adapted from Grinsted, A., Moore, J.C., Pohjola, V., Martma, T., and Isaksson, E. 2006. Svalbard summer melting, continentality, and sea ice extent from the Lomonosovfonna ice core. *Journal of Geophysical Research* **111**: 10.1029/2005JD006494..

the ice core site since 1997 (Virkkunen, 2004) found "the very warm 2001 summer resulted in similar loss of ions and washout ratios as the earliest part of the core." Grinsted *et al.* state, "this suggests that the Medieval Warm Period in Svalbard summer conditions [was] as warm (or warmer) as present-day, consistent with the Northern Hemisphere temperature reconstruction of Moberg *et al.* (2005)." In addition, they conclude "the degree of summer melt was significantly larger during the period 1130–1300 than in the 1990s," which suggests a large portion of the Medieval Warm Period was significantly warmer than the peak warmth of the Current Warm Period.

Noting the varve thicknesses of annually laminated sediments laid down by Hvitarvatn, a proglacial lake in the central highlands of Iceland, is controlled by the rate of glacial erosion and efficiency of subglacial discharge from the adjacent Langjokull ice cap, Larsen *et al.* (2011) employed a suite of environmental proxies contained in those sediments to reconstruct the region's climate variability and glacial activity over the past 3,000 years. These proxies included varve thickness, varve thickness variance, ice-rafted debris, total organic carbon (mass flux and bulk concentration), and the C:N ratio of sedimentary organic matter. The scientists found "all proxy data reflect a shift toward increased glacial erosion and landscape destabilization from ca 550 AD to ca 900 AD and from ca 1250 AD to ca 1950 AD, separated by an interval of relatively mild conditions." They note, "the timing of these intervals coincides with the well-documented periods of climate change commonly known as the Dark Ages Cold Period, the Medieval Warm Period, and the Little Ice Age."

In the case of the Medieval Warm Period, they note, "varve thickness decreases after 950 AD and remains consistently low through Medieval time with slightly thinner annual laminations than for any other multi-centennial period in the past 3000 years," which suggests the MWP was the warmest period of the past three millennia. They state, "the LIA was the most severe multi-centennial cold interval of the late Holocene" and "likely since regional deglaciation 10,000 years ago."

The 12 researchers of Esper *et al.* (2012), from Finland, Germany, Scotland, and Switzerland, write, "solar insolation changes, resulting from long-term oscillations of orbital configurations (Milankovitch, 1941), are an important driver of Holocene climate," referencing the studies of Mayewski *et al.* (2004) and Wanner *et al.* (2008). They note this forcing has been "substantial over the past 2000 years, up to four times as large as the 1.6 Wm^{-2} net anthropogenic forcing since 1750," as suggested by the work of Berger and Loutre (1991). On the basis of "numerous high-latitude proxy records," they note "slow orbital changes have recently been shown to gradually force boreal summer temperature cooling over the common era," citing Kaufman *et al.* (2009).

Esper *et al.* (2012) developed "a 2000-year summer temperature reconstruction based on 587 high-precision maximum latewood density (MXD) series from northern Scandinavia," accomplished "over three years using living and subfossil pine (*Pinus sylvestris*) trees from 14 lakes and 3 lakeshore sites above 65°N, making it not only longer but also much better replicated than any existing MXD time series." After calibrating the pine MXD series against regional June–July–August mean temperature over the period 1876–2006, they obtained their final summer temperature history for the period stretching from 138 BC to AD 2006, as depicted in Figure 4.2.4.3.2.4.2.

Esper *et al.* calculate a long-term cooling trend of -0.31 ± 0.03°C per thousand years, which they say is "missing in published tree-ring proxy records" but is "in line with coupled general circulation models (Zorita *et al.*, 2005; Fischer and Jungclaus, 2011)." These computational results portray, as they describe it, substantial summer cooling over the past two millennia in northern boreal and Arctic latitudes.

"These findings," the researchers continue, "together with the missing orbital signature in published dendrochronological records, suggest that large-scale near-surface air temperature reconstructions (Mann *et al.*, 1999; Esper *et al.*, 2002; Frank *et al.*, 2007; Hegerl *et al.*, 2007; Mann *et al.*, 2008) relying on tree-ring data may underestimate pre-instrumental temperatures including warmth during Medieval and Roman times," although they suggest the impacts of the omitted long-term trend in basic tree-ring data may "diminish towards lower Northern Hemisphere latitudes, as the forcing and radiative feedbacks decrease towards equatorial regions."

Why was much of the CO_2-starved world of Medieval and Roman times decidedly warmer (by about 0.3 and 0.5°C, respectively) than during the peak warmth of the twentieth century? If the greenhouse effect of atmospheric CO_2 has not been grossly overestimated, then it must currently be significantly tempered by some unappreciated negative-feedback phenomenon such that the basic greenhouse effect of Earth's rising atmospheric CO_2 concentration cannot fully compensate for the

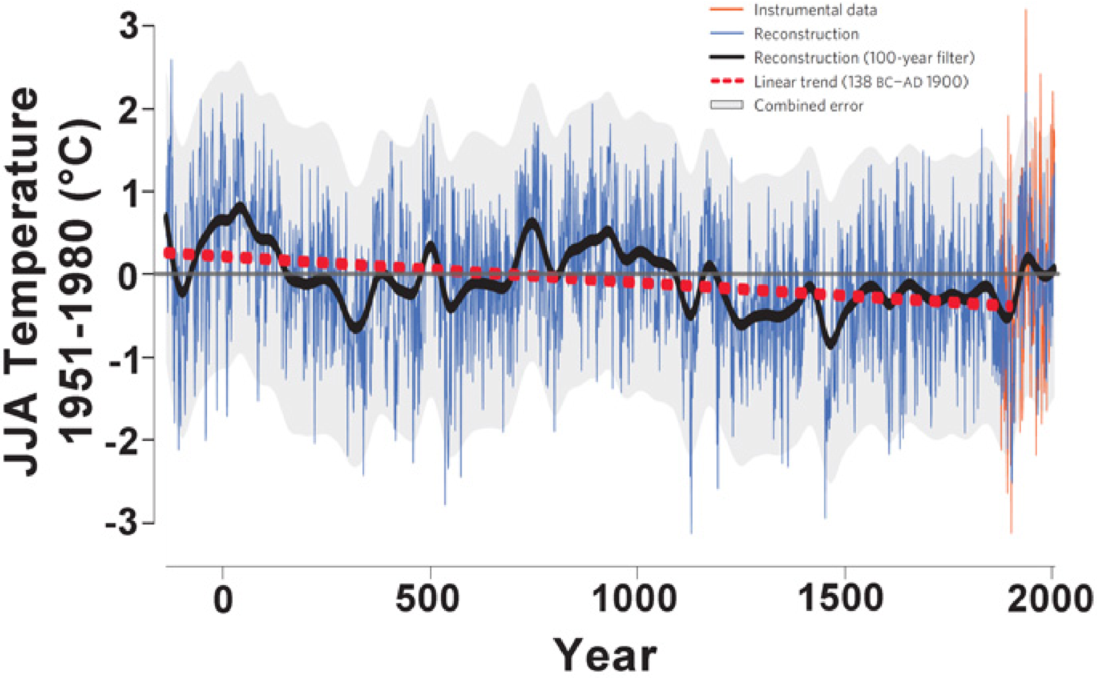


Figure 4.2.4.3.2.4.2. The summer (June–July–August) temperature reconstruction of Esper *et al.* (2012), adapted from Esper, J., Frank, D.C., Timonen, M., Zorita, E., Wilson, R.J.S., Luterbacher, J., Holzkamper S., Fischer, N., Wagner, S., Nievergelt, D., Verstege, A., and Buntgen, U. 2012. Orbital forcing of tree-ring data. *Nature Climate Change*: DOI 10.1038/NCLIMATE1589.

decrease in solar insolation experienced over the past two millennia as a result of the "long-term oscillations of orbital configurations" cited by Esper *et al*. (2012).

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4.2.4.3.2.5 The Rest of the Arctic

Overpeck *et al*. (1997) combined paleoclimatic records obtained from lake and marine sediments, trees, and glaciers to develop a 400-year history of circum-Arctic surface air temperature. From this record they determined the most dramatic warming of the last four centuries of the past millennium (1.5°C) occurred between 1840 and 1955, over which period the air's CO_2 concentration rose by 28 ppm, from approximately 285 ppm to 313 ppm. From 1955 to the end of the record (about 1990), the mean circum-Arctic air temperature declined by 0.4°C, while the air's CO_2 concentration rose by 41 ppm, from 313 ppm to 354 ppm.

Thus, over the first 115 years of Overpeck *et al*.'s record, as the air's CO_2 concentration rose by an average of 0.24 ppm/year, air temperature rose by an average of 0.013°C/year. Over the final 35 years of the record, when the air's CO_2 content rose at a mean rate of 1.17 ppm/year (nearly five times as fast), the rate-of-rise of surface air temperature *decelerated*, to a mean value (0.011°C/year), just the opposite of what one would have expected on the basis of greenhouse gas-induced warming theory.

Benner *et al*. (2004) noted, "thawing of the permafrost which underlies a substantial fraction of the Arctic could accelerate carbon losses from soils (Goulden *et al*., 1998)." In addition, "freshwater discharge to the Arctic Ocean is expected to increase with increasing temperatures (Peterson *et al*., 2002), potentially resulting in greater riverine export of terrigenous organic carbon to the ocean." And since the organic carbon in Arctic soils "is typically old, with average radiocarbon ages ranging from centuries to millennia (Schell, 1983; Schirrmeister *et al*., 2002)," they set about to measure the age of dissolved organic carbon (DOC) in Arctic rivers to determine whether increasing amounts of older carbon were being transported to the ocean, which would indicate enhanced regional warming.

The researchers sampled two of the largest Eurasian rivers, the Yenisey and Ob', which drain vast areas of boreal forest and extensive peat bogs, accounting for about a third of all riverine DOC discharge to the Arctic Ocean, as well as two much smaller rivers on the north slope of Alaska, the Ikpikpuk and Kokolik, whose watersheds are dominated by Arctic tundra. They found modern radiocarbon ages for all samples taken from all rivers, which indicate, they write, Arctic riverine DOC "is derived primarily from recently fixed plant litter and near-surface soil horizons." Because warming should have caused the average radiocarbon age of the DOC of Arctic rivers to increase, the absence of aging implied by their findings provides strong evidence for the absence of recent large-scale warming there.

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4.2.4.3.3 The Past One to Two Centuries

The IPCC contends current temperatures are both unnatural and unprecedented, as a result of global warming caused by anthropogenic CO_2 emissions, and they claim this "unnaturalness" is most strongly expressed in the world's Arctic regions. Here we investigate that claim in the context of the past one to two centuries.

The studies reviewed here lead to the conclusion that, in spite of the model-based concerns about the Arctic being at a "tipping point" and beginning to experience unprecedented warming and irreversible ice loss, there is nothing unusual, unnatural, or unprecedented about current Arctic temperatures. Warming over the past three decades or so has been generally less impressive than a similar warming that occurred several decades earlier in the 1920s–1940s, and it becomes still less impressive when taking into consideration the atmosphere's CO_2 concentration rose by only about 5 ppm during the earlier period of stronger warming but by fully 25 ppm during the later period of weaker warming.

4.2.4.3.3.1 Greenland

Comiso *et al*. (2001) utilized satellite imagery to analyze and quantify several attributes of the Odden ice tongue, a winter ice-cover phenomenon that occurs in the Greenland Sea with a length of about 1,300 km and an aerial coverage of as much as 330,000 square kilometers, including its average concentration, maximum area, and maximum extent over the period 1979–1998. In addition, they used surface air temperature data from Jan Mayen Island, located within the region of study, to infer the behavior of the phenomenon over the past 75 years.

The Odden ice tongue was found to vary in size, shape, and length of occurrence during the 20-year period, displaying a fair amount of interannual variability. Trend analyses revealed the ice tongue had exhibited no statistically significant change in any of the parameters studied over the short 20-year period, but a proxy reconstruction for the past 75 years revealed the ice phenomenon to have been "a relatively smaller feature several decades ago," due to the significantly warmer temperatures that prevailed at that time.

The Odden ice tongue's persistence, virtually unchanged in the mean during the past 20 years, is in direct contrast with model predictions of rapid and increasing warmth in Earth's polar regions as a result of CO_2-induced global warming. This observation, along with the evidence from Jan Mayen Island that temperatures there actually cooled at a rate of 0.15 ± 0.03°C per decade during the past 75 years, confirms there has been little or no warming in this part of the Arctic over the past seven decades.

Hanna and Cappelen (2003) determined the air temperature history of coastal southern Greenland from 1958–2001 based on data from eight Danish Meteorological Institute stations in coastal and near-coastal southern Greenland, as well as the concomitant sea surface temperature (SST) history of the Labrador Sea off southwest Greenland based on three previously published and subsequently extended SST datasets (Parker *et al*., 1995; Rayner *et al*., 1996; Kalnay *et al*., 1996). The coastal temperature data showed a cooling of 1.29°C over the period of study, while two of the three SST databases also depicted cooling: by 0.44°C in one case and by 0.80°C in the other. The land-based air temperature and SST series followed similar patterns and were strongly correlated, but with no obvious lead/lag either way. In addition, the researchers determined the cooling was "significantly inversely correlated with an increased phase of the North Atlantic Oscillation (NAO) over the past few decades." The two researchers state this "NAO-temperature link doesn't explain what caused the observed cooling in coastal southern Greenland but it does lend it credibility." In referring to what they call "this important regional exception to recent 'global warming,'" Hanna and Cappelen note the "recent cooling may have significantly added to the mass balance of at least the southern half of the [Greenland] Ice Sheet." Since this part of the ice sheet would likely be the first to experience melting in a warming world, it would appear whatever caused the cooling has not only protected the Greenland Ice Sheet against warming-induced disintegration but actually fortified it against that possibility.

Taurisano *et al*. (2004) studied the temperature history of the Nuuk fjord during the past century, and their analyses of all pertinent regional data led them to conclude "at all stations in the Nuuk fjord, both the annual mean and the average temperature of the three summer months (June, July and August) exhibit a pattern in agreement with the trends observed at other stations in south and west Greenland (Humlum 1999; Hanna and Cappelen, 2003).” They report the temperature data “show that a warming trend occurred in the Nuuk fjord during the first 50 years of the 1900s, followed by a cooling over the second part of the century, when the average annual temperatures decreased by approximately 1.5°C.” Coincident with this cooling trend there was “a remarkable increase in the number of snowfall days (+59 days).” Moreover, they report “not only did the cooling affect the winter months, as suggested by Hannna and Cappelen (2002), but also the summer mean,” noting “the summer cooling is rather important information for glaciological studies, due to the ablation-temperature relations.”

Chylek *et al*. (2004) analyzed data from three coastal stations in southern and central Greenland that possessed almost uninterrupted temperature records between 1950 and 2000, discovering “summer temperatures, which are most relevant to Greenland ice sheet melting rates, do not show any persistent increase during the last fifty years.” Working with the two stations with the longest records (both over a century in length), they determined coastal Greenland’s peak temperatures occurred between 1930 and 1940, and the subsequent decline in temperature was so substantial and sustained that temperatures at the end of the millennium were “about 1°C below their 1940 values.” They also found “at the summit of the Greenland ice sheet the summer average temperature has decreased at the rate of 2.2°C per decade since the beginning of the measurements in 1987.” Therefore, much of Greenland did not experience any net warming, but rather cooled significantly, over the most dramatic period of atmospheric CO_2 increase on record.

At the start of the twentieth century, however, Greenland was warming, as it emerged, along with the rest of the world, from the depths of the Little Ice Age. Between 1920 and 1930, when the atmosphere’s CO_2 concentration rose by a mere 3 to 4 ppm, there was a phenomenal warming at all five coastal locations for which contemporary temperature records are available. Chylek *et al*. report, “average annual temperature rose between 2 and 4°C [and by as much as 6°C in the winter] in less than ten years.” This warming, they note, “is also seen in the $^{18}O/^{16}O$ record of the Summit ice core (Steig *et al*., 1994; Stuiver *et al*., 1995; White *et al*., 1997).”

In commenting on this dramatic temperature rise, which they call the great Greenland warming of the 1920s, Chylek *et al*. conclude, “since there was no significant increase in the atmospheric greenhouse gas concentration during that time, the Greenland warming of the 1920s demonstrates a large and rapid temperature increase can occur over Greenland, and perhaps in other regions of the Arctic, due to internal climate variability such as the NAM/NAO [Northern Annular Mode/North Atlantic Oscillation], without a significant anthropogenic influence.”

Laidre and Heide-Jorgensen (2005) published a somewhat unusual paper, in that it dealt with the danger of oceanic cooling. Using a combination of long-term satellite tracking data, climate data, and remotely sensed sea-ice concentrations to detect localized habitat trends of narwhals in Baffin Bay between Greenland and Canada, home to the largest narwhal population in the world, they studied the species’ vulnerability to recent and possible future climate trends. They report, “since 1970, the climate in West Greenland has cooled, reflected in both oceanographic and biological conditions (Hanna and Cappelen, 2003),” with the result that “Baffin Bay and Davis Strait display strong significant increasing trends in ice concentrations and extent, as high as 7.5% per decade between 1979 and 1996, with comparable increases detected back to 1953 (Parkinson *et al*., 1999; Deser *et al*., 2000; Parkinson, 2000a,b; Parkinson and Cavalieri, 2002; Stern and Heide-Jorgensen, 2003).”

The two researchers also report, “cetacean occurrence is generally negatively correlated with dense or complete ice cover due to the need to breathe at the surface,” and “lacking the ability to break holes in the ice,” narwhals are vulnerable to reductions in the amount of open water available to them, as has been demonstrated by ice entrapment events “where hundreds of narwhals died during rapid sea ice formation caused by sudden cold periods (Siegastad and Heide-Jorgensen, 1994; Heide-Jorgensen *et al*., 2002).” Such events were becoming increasingly likely as temperatures continued to decline and sea-ice cover and variability increased, and the scientists found the latter two trends to be “highly significant at or above the 95% confidence level.” They conclude, “with the evidence of changes in sea ice conditions that could impact foraging, prey availability, and of utmost importance, access to the surface to breathe, it is unclear how narwhal sub-populations will fare in light of changes in the high Arctic.”

Chylek *et al*. (2006) studied the characteristics of two century-long temperature records from southern coastal Greenland—Godthab Nuuk on the west and Ammassalik on the east, both close to 64°N latitude—concentrating on the period 1915–2005. As they describe it, "although the whole decade of 1995–2005 was relatively warm, the temperatures at Godthab Nuuk and Ammassalik were not exceptionally high," as "almost all decades between 1915 and 1965 were warmer than, or at least as warm as, the 1995 to 2005 decade, suggesting the current warm Greenland climate is not unprecedented and that similar temperatures were [the] norm in the first half of the 20th century." They also note "two periods of intense warming (1995–2005 and 1920–1930) are clearly visible in the Godthab Nuuk and Ammassalik temperature records," but "the average rate of warming was considerably higher within the 1920–1930 decade than within the 1995–2005 decade." They report the earlier warming rate was 50 percent greater than the most recent one.

In comparing the southern coastal Greenland temperature record with that of the entire globe for the same time period, Chylek *et al.* note, "while all the decadal averages of the post-1955 global temperature are higher than the pre-1955 average, almost all post-1995 temperature averages at Greenland stations are lower than the pre-1955 temperature average." The three researchers also note, "the summer temperature at the Summit of the Greenland ice sheet shows a decreasing tendency since the beginning of the measurements in 1986 (Chylek *et al*., 2004)."

In light of these observations, Chylek *et al.* say, "An important question is to what extent can the current (1995–2005) temperature increase in Greenland coastal regions be interpreted as evidence of man-induced global warming?" They note "the Greenland warming of 1920 to 1930 demonstrates that a high concentration of carbon dioxide and other greenhouse gases is not a necessary condition for [a] period of warming to arise," and "the observed 1995–2005 temperature increase seems to be within [the] natural variability of Greenland climate." In addition, "a general increase in solar activity (Scafetta and West, 2006) since [the] 1990s can be a contributing factor, as well as the sea surface temperature changes of [the] tropical ocean (Hoerling *et al*., 2001)."

Chylek *et al.* note, "glacier acceleration observed during the 1996–2005 period (Rignot and Kanagaratnam, 2006) has probably occurred previously," and "there should have been the same or more extensive acceleration during the 1920–1930 warming as well as during the Medieval Warm Period in Greenland (Dahl-Jensen *et al*., 1998; DeMenocal *et al*., 2000) when Greenland temperatures were generally higher than today." As Chylek *et al.* put it, "we find no direct evidence to support the claims that the Greenland ice sheet is melting due to increased temperature caused by increased atmospheric concentration of carbon dioxide."

Hansen *et al.* (2006) analyzed meteorological data from Arctic Station (69°15'N, 53°31'W) on-Disko Island (West Greenland) for the period 1991–2004, after which their results were correlated "to the longest record available from Greenland at Ilulissat/Jakobshavn (since 1873)." Marked changes were noted over the study period, including "increasing mean annual air temperatures on the order of 0.4°C per year and 50% decrease in sea ice cover." In addition, due to "a high correlation between mean monthly air temperatures at the two stations (1991–2004)," Hansen *et al.* placed the air temperature trend observed at Disko "in a 130 years perspective." This led them to conclude the climate changes of the last decade were "dramatic," but "similar changes in air temperatures [had] occurred previous[ly] within the last 130 years." They report the changes they observed over the last decade "are on the same order as changes [that] occurred between 1920 and 1930."

Drinkwater (2006) "provide[d] a review of the changes to the marine ecosystems of the northern North Atlantic during the 1920s and 1930s and … discuss[ed] them in the light of contemporary ideas of regime shifts," where he defined regime shift as "a persistent radical shift in typical levels of abundance or productivity of multiple important components of the marine biological community structure, occurring at multiple trophic levels and on a geographical scale that is at least regional in extent." He first determined "in the 1920s and 1930s, there was a dramatic warming of the air and ocean temperatures in the northern North Atlantic and the high Arctic, with the largest changes occurring north of 60°N," and this warming "led to reduced ice cover in the Arctic and subarctic regions and higher sea temperatures," as well as northward shifts of multiple marine ecosystems. This change in climate occurred, he writes, "during the 1920s, and especially after 1925," when "average air temperatures began to rise rapidly and continued to do so through the 1930s," at which point "mean annual air temperatures increased by approximately 0.5–1°C and the cumulative sums of anomalies varied from 1.5 to 6°C between 1920 and 1940 with the higher values occurring in West

Greenland and Iceland." Thereafter, "through the 1940s and 1950s air temperatures in the northernmost regions varied but generally remained relatively high," declining in the late 1960s in the northwest Atlantic and slightly earlier in the northeast Atlantic. This cooling only recently has begun to be reversed in certain parts of the region.

In the realm of biology, the early twentieth century warming of North Atlantic waters "contributed to higher primary and secondary production," in the words of Drinkwater, and "with the reduced extent of ice-covered waters, more open water allow[ed] for higher production than in the colder periods." Cod "spread approximately 1200 km northward along West Greenland" and "migration of 'warmer water' species also changed with earlier arrivals and later departures." In addition, Drinkwater notes, "new spawning sites were observed farther north for several species or stocks while for others the relative contribution from northern spawning sites increased." Also, "some southern species of fish that were unknown in northern areas prior to the warming event became occasional, and in some cases, frequent visitors." Drinkwater concludes, "the warming in the 1920s and 1930s is considered to constitute the most significant regime shift experienced in the North Atlantic in the 20th century."

Vinther *et al.* (2006) combined early observational records from 13 locations along the southern and western coasts of Greenland to extend the overall temperature history of the region—which stretches from approximately 60 to 73°N latitude—back to AD 1784, adding temperatures for 74 complete winters and 52 complete summers to what previously was available to the public. The authors report, "two distinct cold periods, following the 1809 'unidentified' volcanic eruption and the eruption of Tambora in 1815, [made] the 1810s the coldest decade on record." They found "the warmest year in the extended Greenland temperature record [was] 1941, while the 1930s and 1940s [were] the warmest decades." Their newly lengthened record revealed there has been no net warming of the region over the past 75 years.

Approximately half of the Vinther *et al.* study region was located above the Arctic Circle, where CO_2-induced global warming is suggested by climate models to be most evident and earliest expressed. One thus would have expected to see southwestern coastal Greenland's air temperature responding vigorously to the 75 ppm increase in the atmosphere's CO_2 concentration since 1930, even if the models were only half-correct. But no net change in air temperature has occurred there in response to the 25 percent increase in the air's CO_2 content experienced over that period.

Mernild *et al.* (2008) described "the climate and observed climatic variations and trends in the Mittivakkat Glacier catchment in Low Arctic East Greenland from 1993 to 2005 ... based on the period of detailed observations (1993–2005) and supported by synoptic meteorological data from the nearby town of Tasiilaq (Ammassalik) from 1898 to 2004." The authors report, "the Mittivakkat Glacier net mass balance has been almost continuously negative, corresponding to an average loss of glacier volume of 0.4% per year." During the past century of general mass loss, they found "periods of warming were observed from 1918 (the end of the Little Ice Age) to 1935 of 0.12°C per year and 1978 to 2004 of 0.07°C per year." They state, "the warmest average 10-year period within the last 106 years was the period from 1936–1946 (-1.8°C)," while the second warmest period was from 1995–2004 (-2.0°C). In addition, they note "also on West Greenland the period 1936–1946 was the warmest period within the last 106 years (Cappelen, 2004)."

"Using a set of 12 coastal and 40 inland ice surface air temperature records in combination with climate model output," Box *et al.* (2009) reconstructed "long-term (1840–2007) monthly, seasonal, and annual spatial patterns of temperature variability over a continuous grid covering Greenland and the inland ice sheet," after which they compared "the 1919–32 and 1994–2007 warming episodes" and made "a comparison of Greenland ice sheet surface air temperature temporal variability with that of the Northern Hemisphere average." The near-surface air temperature history Box *et al.* derived for Greenland is reproduced in Figure 4.2.4.3.3.1.1, along with the corresponding history of Northern Hemispheric near-surface air temperature.

The four researchers determined "the annual whole ice sheet 1919–32 warming trend is 33% greater in magnitude than the 1994–2007 warming," and "in contrast to the 1920s warming, the 1994–2007 warming has not surpassed the Northern Hemisphere anomaly." They note "an additional 1.0°–1.5°C of annual mean warming would be needed for Greenland to be in phase with the Northern Hemisphere pattern." The results of Box *et al.* demonstrate there is nothing unusual, unnatural, or unprecedented about the nature of Greenland's 1994–2007 warming episode, when the atmosphere's CO_2 concentration rose by about

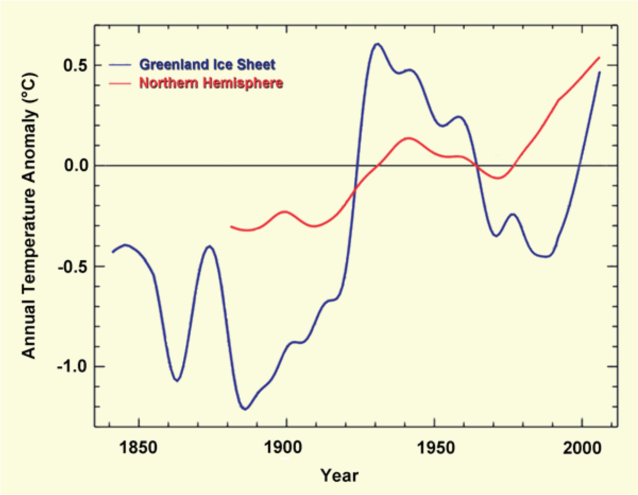

Figure 4.2.4.3.3.1.1. Low-pass-filtered Greenland and Northern Hemispheric near-surface air temperature anomalies with respect to the 1951-1980 base period vs. time. Adapted from Box, J.E., Yang, L., Bromwich, D.H., and Bai, L.-S. 2009. Greenland ice sheet surface air temperature variability: 1840–2007. *Journal of Climate* **22**: 4029–4049.

25 ppm, which is much less impressive than the 1919–1932 warming, when the atmosphere's CO_2 concentration rose by about 5 ppm.

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4.2.4.3.3.3 Russia/Asian Arctic

Zeeberg and Forman (2001) analyzed twentieth century changes in glacier terminus positions on north Novaya Zemlya, a Russian island located between the Barents and Kara Seas in the Arctic Ocean, providing a quantitative assessment of the effects of temperature and precipitation on glacial mass balance. This work revealed a significant and accelerated post-Little Ice Age glacial retreat in the first and second decades of the twentieth century, but by 1952, the region's glaciers had experienced 75–100% of their net twentieth century retreat. During the next 50 years the recession of more than half the glaciers stopped, and many tidewater glaciers began to advance.

These glacial stabilizations and advances were attributed by the two scientists to observed increases in precipitation and/or decreases in temperature. In the four decades since 1961, for example, weather stations at Novaya Zemlya show summer temperatures to have been 0.3 to 0.5°C colder than they were over the prior 40 years, while winter temperatures were 2.3 to 2.8°C colder. Zeeberg and Forman say such observations are "counter to warming of the Eurasian Arctic predicted for the twenty-first century by climate models, particularly for the winter season."

Polyakov *et al*. (2002) used newly available long-term Russian observations of surface air temperature from coastal stations to gain new insights into trends and variability in the Arctic environment poleward of 62°N. Throughout the 125-year history they developed, they identified "strong intrinsic variability, dominated by multi-decadal fluctuations with a timescale of 60–80 years" and found temperature trends in the Arctic to be highly dependent on the particular time period selected for analysis. They found they could "identify periods when Arctic trends were actually smaller or of different sign than Northern Hemisphere trends." Over the bulk of the twentieth century, however, when "multi-decadal variability had little net effect on computed trends," the temperature histories of the two regions were "similar" but did "not support amplified warming in polar regions predicted by GCMs."

Raspopov *et al*. (2004) presented and analyzed two temperature-related datasets: "a direct and systematic air temperature record for the Kola Peninsula, in the vicinity of Murmansk," which covered the period 1880–2000, and an "annual tree-ring series generalized for 10 regions (Lovelius, 1997) along the northern timberline, from the Kola Peninsula to Chukotka, for the period 1458–1975 in the longitude range from 30°E to 170°E," which included nearly all of northern Eurasia that borders the Arctic Ocean. The researchers' primary objectives were to identify any temporal cycles present in the two datasets and determine what caused them. They report discovering "climatic cycles with periods of around 90, 22–23 and 11–12 years," which were found to "correlate well with the corresponding solar activity cycles."

Of even more interest was what they learned about the temporal development of the Current Warm Period (CWP). Raspopov *et al.*'s presentation of the mean annual tree-ring series for the northern Eurasia timberline clearly shows the region's recovery from the coldest temperatures of the Little Ice Age (LIA) may be considered to have commenced as early as 1820 and was in full swing by at least 1840. It shows the rising temperature peaked just prior to 1950 and then declined to the end of the record in 1975. The Kola-Murmansk instrumental record indicates a significant temperature rise that peaked in the early 1990s at about the same level as the pre-1950 peak but then declined to the end of the record in 2000.

The last of these findings—that there was no net warming of this expansive high-latitude region over the last half of the twentieth century—is in harmony with the findings of the many studies we have reviewed here. The first first finding—that the thermal recovery of this climatically sensitive region of the planet began in the first half of the nineteenth century—is also supported by several other studies (Esper *et al.*, 2002; Moore *et al.*, 2002; Yoo and D'Odorico, 2002; Gonzalez-Rouco *et al.*, 2003; Jomelli and Pech, 2004). All demonstrate the Little Ice Age-to-Current Warm Period transition began somewhere in the neighborhood of 1820 to 1850, well before the date (~1910) indicated in the Mann *et al.* (1998, 1999) "hockey stick" temperature history promulgated by the IPCC.

This difference is important, for it indicates the LIA-to-CWP transition in the Arctic was likely halfway or more complete before the Mann *et al.* temperature history suggests it even began, demonstrating most of the transition occurred well in advance of anthropogenic-caused increases in CO_2 emissions. That there was no net warming between somewhere in the 1930s or 1940s and the end of the twentieth century in the part of the world where CO_2-induced global warming is supposed to be most evident (the Arctic) makes it abundantly clear anthropogenic CO_2 emissions have had no discernible impact on any part of the LIA-to-CWP transition, the "global warming" some continue to claim is still occurring and can be stopped by reducing CO_2 emissions.

Groisman *et al.* (2006) write, "a new Global Synoptic Data Network consisting of 2100 stations within the boundaries of the former Soviet Union created jointly by the [U.S.] National Climatic Data Center and Russian Institute for Hydrometeorological Information was used to assess the climatology of snow cover, frozen and unfrozen ground reports, and their temporal variability for the period from 1936 to 2004." They determined "during the past 69 years (1936–2004 period), an increase in duration of the period with snow on the ground over Russia and the Russian polar region north of the Arctic circle has been documented by 5 days or 3% and 12 days or 5%, respectively," and they note this result "is in agreement with other findings."

Commenting on this development and the similar findings of others, the five researchers state, "changes in snow cover extent during the 1936–2004 period cannot be linked with 'warming' (particularly with the Arctic warming)" because "in this particular period the Arctic warming was absent."

Opel *et al.* (2009) worked with the uppermost 57 meters of a surface-to-bedrock ice core retrieved from the Akademii Nauk (AN) ice cap (~80°31'N, 94°49'E) of the Severnaya Zemlya archipelago (located in the central Russian Arctic between the Kara and Laptev Seas) to derive a $\delta^{18}O$ history covering the period 1883–1998. They compared this history with surface air temperatures (SATs) measured at 15 weather stations distributed throughout the Atlantic and Eurasian sub-Arctic, finding "good correlations and similarities." They note their $\delta^{18}O$ data also had "a strong correlation with the composite Arctic (north of 62° N) SAT anomalies time series of Polyakov *et al.* (2003)," demonstrating their $\delta^{18}O$ data can serve as a proxy for the region's SAT. They found "the $\delta^{18}O$ values show pronounced 20th-century temperature changes, with a strong rise about 1920 and the absolute temperature maximum in the 1930s." As shown in Figure 4.2.4.3.3.3.1, there was no net warming of the Atlantic and Eurasian sub-Arctic over the last 80 years of the twentieth century.

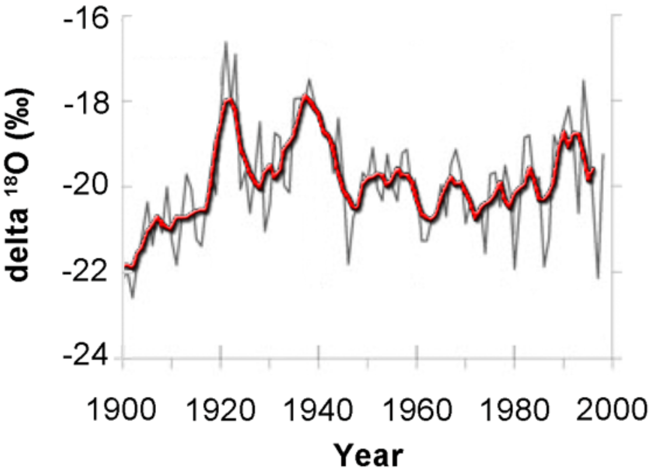

Figure 4.2.4.3.3.3.1. δ^{18}O (‰) vs. time (Years AD). Adapted from Opel, T., Fritzsche, D., Meyer, H., Schutt, R., Weiler, K., Ruth, U., Wilhelms, F., and Fischer, H. 2009. 115 year ice-core data from Akademii Nauk ice cap, Severnaya Zemlya: high-resolution record of Eurasian Arctic climate change. *Journal of Glaciology* **55**: 21–31.

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4.2.4.3.3.4 Scandinavia and Iceland

Humlum *et al*. (2005) note state-of-the-art climate models predict "the effect of any present and future global climatic change will be amplified in the polar regions as a result of feedbacks in which variations in the extent of glaciers, snow, sea ice and permafrost, as well as atmospheric greenhouse gases, play key roles." They also note Polyakov *et al*. (2002a,b) "presented updated observational trends and variations in Arctic climate and sea-ice cover during the twentieth century, which do not support the modeled polar amplification of surface air-temperature changes observed by surface stations at lower latitudes," and "there is reason, therefore, to evaluate climate dynamics and their respective impacts on high-latitude glaciers." They proceeded to do so for the Archipelago of Svalbard, focusing on Spitsbergen (the Archipelago's main island) and the Longyearbreen glacier located in its relatively dry central region at 78°13'N latitude.

Humlum *et al*. report, "a marked warming around 1920 changed the mean annual air temperature (MAAT) at sea level within only 5 years from about -9.5°C to -4.0°C," which "represents the most pronounced increase in MAAT documented anywhere in the world during the instrumental period." Then, they report, "from 1957 to 1968, MAAT dropped about 4°C, followed by a more gradual increase towards the end of the twentieth century."

Their work reveals the Longyearbreen glacier "increased in length from about 3 km to its present size of about 5 km during the last c. 1100 years" and they state, "this example of late-Holocene glacier growth represents a widespread phenomenon in Svalbard and in adjoining Arctic regions," which they describe as a "development towards cooler conditions in the Arctic," which "may explain why the Little Ice Age glacier advance in Svalbard usually represents the Holocene maximum glacier extension."

Temperatures in Svalbard rose more rapidly in the early 1920s than has been documented anywhere else before or since, only to be followed by a nearly equivalent temperature drop four decades later, both of which were out of line with what climate models suggest should have occurred. The current location of the terminus of the Longyearbreen glacier suggests, even now, Svalbard and "adjoining Arctic regions" are still experiencing some of the lowest temperatures of the entire Holocene, at a time when atmospheric CO_2 concentrations are higher than they likely have been for millions of years. These observations are also at odds with what the IPCC claims about the strong warming power of rising atmospheric CO_2.There is little reason to put much confidence in the IPCC's claims, or to get too excited if the Arctic were to warm a bit—or even substantially and at a rapid rate. It has done so before, and it likely will do so again.

Hanna *et al*. (2006) developed a 119-year history of Icelandic Sea Surface Temperature (SST) based on measurements made at ten coastal stations located between latitudes 63°24'N and 66°32'N. This work revealed the existence of past "long-term variations and trends that are broadly similar to Icelandic air temperature records: that is, generally cold conditions during the late nineteenth and early twentieth centuries; strong warming in the 1920s, with peak SSTs typically being attained around 1940; and cooling thereafter until the 1970s, followed once again by warming—but not generally back up to the level of the 1930s/1940s warm period."

This brief section concludes with a short synopsis of a brief communication from Karlen (2005), in which he asks whether temperatures in the Arctic are "really rising at an alarming rate," as the models suggest they should be doing. His short answer is a resounding no; his explanation follows.

Focusing on Svalbard Lufthavn (located at 78°N latitude), which he later showed to be representative of much of the Arctic, Karlen reports "the Svalbard mean annual temperature increased rapidly from the 1910s to the late 1930s"; "the temperature thereafter became lower, and a minimum was reached around 1970"; and "Svalbard thereafter became warmer, but the mean temperature in the late 1990s was still slightly cooler than it was in the late 1930s," indicative of an actual cooling trend of 0.11°C per decade over the last 70 years of the twentieth century.

In support of his contention that cooling was the norm in the Arctic over this period, Karlen states "the observed warming during the 1930s is supported by data from several stations along the Arctic coasts and on islands in the Arctic, e.g. *Nordklim* data from Bjornoya and Jan Mayen in the north Atlantic, Vardo and Tromso in northern Norway, Sodankylaeand Karasjoki in northern Finland, and Stykkisholmur in Iceland." He also notes "there is also [similar] data from other reports; e.g. Godthaab, Jakobshavn, and Egedesmindde in Greenland, Ostrov Dikson on the north coast of Siberia, Salehard in inland Siberia, and Nome in western Alaska." All of these stations "indicate the same pattern of changes in annual mean temperature: a warm 1930s, a cooling until around 1970, and thereafter a warming, although the temperature remains slightly below the level of the late 1930s." In addition, "many stations with records starting later than the 1930s also indicate cooling, e.g. Vize in the Arctic Sea north of the Siberian coast and Frobisher Bay and Clyde on Baffin Island." Karlen reports the 250-year temperature record of Stockholm "shows that the fluctuations of the 1900s are not unique" and "changes of the same magnitude as in the 1900s occurred between 1770 and 1800, and distinct but smaller fluctuations occurred around 1825."

Noting the IPCC suggests the lion's share of the temperature increase during the 1920s and into the 1930s, which in the Arctic was the most dramatic warming of the twentieth century, was primarily due to solar effects (because the increase in CO_2 over this period was so small they had to go with something else), Karlen points out, "during the 50 years in which the atmospheric concentration of CO_2 has increased considerably, the temperature has decreased," which leads him to conclude "the Arctic temperature data do not support the models predicting that there will be a critical future warming of the climate because of an increased concentration of CO_2 in the atmosphere." As the first and only period of net warming in the Arctic occurred at a time when CO_2 could not have been its cause, it should be clear the modern theory of CO_2-induced global warming is an unreliable guide to the future.

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4.2.4.3.3.5 The Rest of the Arctic/Multiple Regions

Przybylak (2000) used mean monthly temperatures measured at 37 Arctic and 7 sub-Arctic stations, as well as temperature anomalies of 30 grid-boxes obtained from the updated dataset of Jones, to derive a number of spatial and temporal histories of Arctic near-surface air temperature. These analyses led the author to conclude, "In the Arctic, the highest temperatures since the beginning of instrumental observation occurred clearly in the 1930s." He reports, "even in the 1950s the temperature was higher than in the last 10 years"; "since the mid-1970s, the annual temperature shows no clear trend"; and "the level of temperature in Greenland in the last 10–20 years is similar to that observed in the 19th century." Przybylak concludes, "the observed variations in air temperature in the real Arctic are in many aspects not consistent with the projected climatic changes computed by climatic models for the enhanced greenhouse effect," because "the temperature predictions produced by numerical climate models significantly differ from those actually observed."

Two years later in a similar analysis, Przybylak (2002) examined intraseasonal (within season) and interannual (between years) variability in maximum, minimum, and average air temperature and diurnal air temperature range for the entire Arctic, as delineated by Treshnikov (1985), for the period 1951–1990, based on data from ten stations "representing the majority of the climatic regions in the Arctic." He found "trends in both the intraseasonal and interannual variability of the temperatures studied did not show any significant changes," leading Przybylak to conclude "this aspect of climate change, as well as trends in average seasonal and annual values of temperature investigated earlier (Przybylak, 1997, 2000), proves that, in the Arctic in the period 1951–90, no tangible manifestations of the greenhouse effect can be identified."

Polyakov *et al*. (2003) derived a surface air temperature history that stretched from 1875 to 2000, based on measurements carried out at 75 land stations and a number of drifting buoys located poleward of 62°N latitude. From 1875 to about 1917, the team of eight U.S. and Russian scientists found the surface air temperature of the northern region rose hardly at all, but then it climbed 1.7°C in just 20 years to reach a peak in 1937 that was not eclipsed over the remainder of the record. During this 20-year period of rapidly rising air temperature, the atmosphere's CO_2 concentration rose by a mere 8 ppm. Over the next six decades, when the air's CO_2 concentration rose by approximately 55 ppm—nearly seven times more than it had during the 20-year period of dramatic warming that preceded it—the surface air temperature of the region poleward of 62°N experienced no net warming and may have cooled.

Polyakov *et al*. (2004) developed a long-term history of Atlantic Core Water Temperature (ACWT) in the Arctic Ocean using high-latitude hydrographic measurements initiated in the late nineteenth century. They compared this history with the long-term history of Arctic Surface Air Temperature (SAT) developed a year earlier by Polyakov *et al.* (2003). The ACWT record revealed the existence of "two distinct warm periods from the late 1920s to 1950s and in the late 1980s–90s and two cold periods, one at the beginning of the record (until the 1920s) and another in the 1960s–70s." The SAT record depicted essentially the same thing, with the peak temperature of the latter warm period being not quite as high as the peak temperature of the former warm period. In the case of the ACWT record, this relationship was reversed, with the peak temperature of the latter warm period slightly exceeding the peak temperature of the former warm period. The most recent temperature peak was very short-lived and it rapidly declined, ending approximately 1°C cooler over the last few years of the record.

Like Arctic SATs, Arctic ACWTs are dominated "by multidecadal fluctuations with a time scale of 50–80 years," Polyakov *et al.* write. Both records indicate late twentieth century warmth was no different from that experienced in the late 1930s and early 1940s, offering no compelling reason to believe late twentieth century warmth was the result of CO_2-induced global warming, for the air's CO_2 concentration in the late 1930s and early 1940s was fully 80 ppm less than it is today.

Soon (2005) sought to determine whether rising atmospheric CO_2 concentration or variations in solar irradiance was the more dominant driver of twentieth century temperature change in the Arctic. He examined the roles the two variables may have played in forcing decadal, multi-decadal, and longer-term variations in surface air temperature (SAT), performing statistical analyses on a composite Arctic-wide SAT record constructed by Polyakov *et al.* (2003), global CO_2 concentrations taken from estimates made by the NASA GISS climate modeling group, and a total solar irradiance (TSI) record developed by Hoyt and Schatten (1993, updated by Hoyt in 2005) over the period 1875–2000.

Soon's analyses show a much stronger statistical relationship between SAT and TSI than between SAT and atmospheric CO_2 concentration. Solar forcing generally explained more than 75 percent of the variance in decadal-smoothed seasonal and annual Arctic temperatures, whereas CO_2 forcing explained only between 8 and 22 percent. Wavelet analysis further supported the case for solar forcing of SAT, revealing similar time-frequency characteristics for annual and seasonally averaged temperatures at decadal and multi-decadal time scales. In contrast, wavelet analysis gave little to no indication of a CO_2 forcing of Arctic SSTs. It would appear the Sun, not atmospheric CO_2, drove temperature change in the Arctic over the twentieth century.

Chylek *et al.* (2009) write, "one of the robust features of the AOGCMs [Atmosphere-Ocean General Circulation Models] is the finding that the temperature increase in the Arctic is larger than the global average, which is attributed in part to the ice/snow-albedo temperature feedback." They note "the surface air temperature change in the Arctic is predicted to be about two to three times the global mean," citing the IPCC (2007). Utilizing Arctic surface air temperature data from 37 meteorological stations north of 64°N, Chylek *et al.* explored the latitudinal variability in Arctic temperatures within two latitude belts—the low Arctic (64°N–70°N) and the high Arctic (70°N–90°N)—comparing the results with the mean measured air temperatures of these two regions over three periods: 1910–1940 (warming), 1940–1970 (cooling), and 1970–2008 (warming).

In initial apparent harmony with state-of-the-art AOGCM simulations, the five researchers report "the Arctic has indeed warmed during the 1970–2008 period by a factor of two to three faster than the global mean." The Arctic amplification factor was 2.0 for the low Arctic and 2.9 for the high Arctic. But that was the end of the real world's climate-change agreement with theory. During the 1910–1940 warming, for example, the low Arctic warmed 5.4 times faster than the global mean, while the high Arctic warmed 6.9 times faster. Even more out of line with climate model simulations were the real-world Arctic amplification factors for the 1940–1970 cooling: 9.0 for the low Arctic and 12.5 for the high Arctic.

These findings constitute yet another important example of the principle described and proven by Reifen and Toumi (2009): A model that performs well in one time period will not necessarily perform well in another time period. Since AOGCMs suffer from this shortcoming, they ought not be considered adequate justification for imposing dramatic cuts in anthropogenic CO_2 emissions, as their simulations of future temperature trends may be far different from what will actually transpire.

Ladd and Gajewski (2010) evaluated the position of the Arctic front—defined as "the semi-permanent, discontinuous front between the cold Arctic air mass and the intermediate Polar air mass, bounded in the south by the Polar Front (Oliver and Fairbridge, 1987)"—based on gridded data obtained from the National Center for Environmental Prediction/ National Center for Atmospheric Research reanalysis (NNR) for each July between 1948 and 2007, and from 1958 to 2002 using data from the European Centre for Medium-Range Weather Forecasts ERA-40, as well as the period 1948–1957 "for comparison with the results of Bryson (1966)." The two researchers report "the position of the July Arctic front varies significantly through the period 1948–2007," but they find it does so "with a mean position similar to that found by Bryson (1966)," which "close similarity is striking," they say, "given that the Bryson study was completed over 40 years ago."

Wood and Overland (2010) note "the recent widespread warming of the Earth's climate is the second of two marked climatic fluctuations to attract the attention of scientists and the public since the turn of the 20th century," and the first of these—"the major early 20th century climatic fluctuation (~1920–1940)"—has been "the subject of scientific enquiry from the time it was detected in the 1920s." They write "the early climatic fluctuation is particularly intriguing now because it shares some of the features of the present warming that has been felt so strongly in the Arctic." Wood and Overland reviewed what is known about the first warming through "a rediscovery of early research and new assessments of the instrumental record," which allowed them to compare what they learned about the earlier warming with what is known about the most recent one.

With respect to the first of the two warmings, the U.S. researchers say "there is evidence that the magnitude of the impacts on glaciers and tundra landscapes around the North Atlantic was larger during this period than at any other time in the historical period." In addition, "the ultimate cause of the early climatic fluctuation was not discovered by early authors and remains an open question," noting "all of the leading possibilities recognized today were raised by the 1950s, including internal atmospheric variability, anthropogenic greenhouse gas (CO_2) forcing, solar variability, volcanism, and regional dynamic feedbacks (e.g. Manley, 1961)." They add, "greenhouse gas forcing is not now considered to have played a major role (Hegerl *et al*., 2007)." Thus, they suggest "the early climatic fluctuation was a singular event resulting from intrinsic variability in the large-scale atmosphere/ocean/land system and that it was likely initiated by atmospheric forcing."

Wood and Overland conclude the "early climatic fluctuation is best interpreted as a large but random climate excursion imposed on top of the steadily rising global mean temperature associated with anthropogenic forcing." However, the early warming also could be interpreted as a large but random climate excursion imposed on top of the steadily rising global mean temperature associated with Earth's natural recovery from the global chill of the Little Ice Age. And there is no reason not to conclude the same about the most recent Arctic warming; in a major analysis of past rates of climate change in the Arctic, White *et al*. (2010) conclude, "thus far, human influence does not stand out relative to other, natural causes of climate change."

Wood *et al*. (2010) constructed a two-century (1802–2009) instrumental record of annual surface air temperature within the Atlantic-Arctic boundary region, using data obtained from "recently published (Klingbjer and Moberg, 2003; Vinther *et al*., 2006) and historical sources (Wahlen, 1886)" that yielded "four station-based composite time series" pertaining to Southwestern Greenland, Iceland, Tornedalen (Sweden), and Arkhangel'sk (Russia). This added 76 years to the previously available record. The credibility of their results, Wood *et al*. note, "is supported by ice core records, other temperature proxies, and historical evidence."

The U.S. and Icelandic researchers report the newly extended temperature history and their analysis of it reveal "an irregular pattern of decadal-scale temperature fluctuations over the past two centuries," of which the early twentieth century warming (ETCW) event—which they say "began about 1920 and persisted until mid-century"—was by far "the most striking historical example." Wood *et al*. write, "as for the future, with no other examples in the record quite like the ETCW, we cannot easily suggest how often—much less when—such a comparably large regional climate fluctuation might be expected to appear." Nevertheless, they state, "it would be reasonable to expect substantial regional climate fluctuations of either sign to appear from time to time" and, therefore, "singular episodes of regional climate fluctuation should be anticipated in the future." This conclusion also implies any rapid warming that may subsequently occur within the Atlantic-Arctic boundary region need not be due to rising greenhouse gas concentrations, as it could be caused by the same factor that caused the remarkable ETCW event.

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4.2.4.4 Asia

As indicated in the introduction of Section 4.2.4, numerous peer-reviewed studies reveal modern temperatures are not unusual, unnatural, or unprecedented. For many millennia, Earth's climate has both cooled and warmed independent of its atmospheric CO_2 concentration. This reality is further illustrated by the fact that conditions as warm as, or warmer than, the present have persisted across the Holocene for decades to centuries even though the atmosphere's CO_2 content remained at values approximately 30 percent lower than today's.

The following subsections highlight such research from Asia, where much of the material focuses on the most recent millennium of Earth's history, detailing the historical fluctuations of Earth's climate that long ago ushered in the Roman Warm Period, which gave way to the Dark Ages Cold Period, which was followed by the Medieval Warm Period and subsequent Little Ice Age. These natural climate oscillations are the product of a millennial-scale climate forcing; the Current Warm Period is simply a manifestation of its latest phase. Carbon dioxide had little to do with the warmth (or cold) of these prior epochs, and there is no compelling reason to believe it is having any measurable impact on climate today.

4.2.4.4.1 China

Using a variety of climate records derived from peat, lake sediment, ice core, tree-ring, and other proxy sources, Yang *et al*. (2002) identified a period of exceptional warmth throughout China between AD 800 and 1100. Yafeng *et al*. (1999) also observed a warm period between AD 970 and 1510 in $\delta^{18}O$ data obtained from the Guliya ice cap of the Qinghai-Tibet Plateau, while Hong *et al*. (2000) developed a 6,000-year $\delta^{18}O$ record from plant cellulose deposited in a peat bog in the Jilin Province (42° 20' N, 126° 22' E), within which they found evidence of "an obvious warm period represented by the high $\delta^{18}O$ from around AD 1100 to 1200 which may correspond to the Medieval Warm Epoch of Europe" (see Figure 4.2.4.4.1.1).

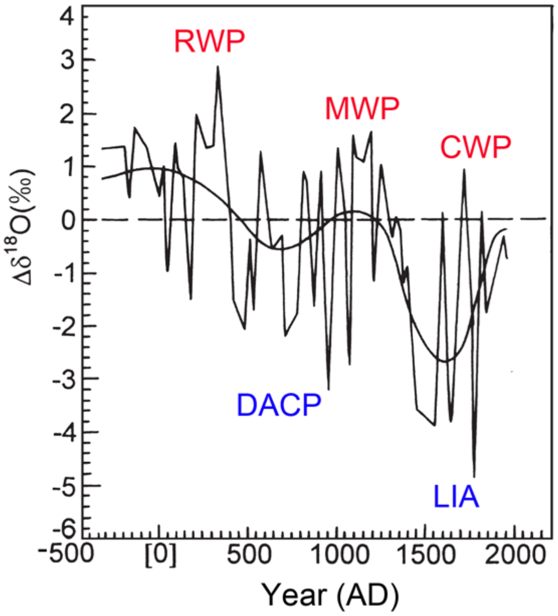

Figure 4.2.4.4.1.1. A 6,000-year $\delta^{18}O$ record from a peat bog in the Jilin Province. Adapted from Hong, Y.T., Jiang, H.B., Liu, T.S., Zhou, L.P., Beer, J., Li, H.D., Leng, X.T., Hong, B., and Qin, X.G. 2000. Response of climate to solar forcing recorded in a 6000-year $\delta^{18}O$ time-series of Chinese peat cellulose. *The Holocene* **10**: 1–7.

Hong *et al*. (2000) had previously reported that at the time of the MWP, "the northern boundary of the cultivation of citrus tree (*Citrus reticulata* Blanco) and *Boehmeria nivea* (a perennial herb), both subtropical and thermophilous plants, moved gradually into the northern part of China, where it has been estimated that the annual mean temperature was 0.9–1.0°C higher than at present." Considering the climatic conditions required to successfully grow these plants, they further note annual mean temperatures in that part of the country during the Medieval Warm Period must have been about 1.0°C higher than at present, with extreme January minimum temperatures fully 3.5°C warmer than they are today, citing De'er (1994).

Xu *et al*. (2002) also determined, from a study of plant cellulose $\delta^{18}O$ variations in cores retrieved from peat deposits at the northeastern edge of the Qinghai-Tibet Plateau, from AD 1100–1300 "the $\delta^{18}O$ of Hongyuan peat cellulose increased, consistent with that of Jinchuan peat cellulose and corresponding to the 'Medieval Warm Period.'" Qian and Zhu (2002) analyzed the thickness of laminae in a stalagmite found in Shihua Cave, Beijing, from which they inferred the existence of a relatively wet period from approximately AD 940 to 1200.

Chu *et al*. (2002) studied the geochemistry of 1,400 years of dated sediments recovered from seven cores taken from three locations in Lake Huguangyan (21°9'N, 110°17'E) on the low-lying Leizhou Peninsula in the tropical region of South China, together with information about the presence of snow, sleet, frost, and frozen rivers over the past 1,000 years obtained from historical documents. They note "recent publications based on the phenological phenomena, distribution patterns of subtropical plants and cold events (Wang and Gong, 2000; Man, 1998; Wu and Dang, 1998; Zhang, 1994) argue for a warm period from the beginning of the tenth century AD to the late thirteenth century AD," as their own data also suggest. In addition, they note there was a major dry period from AD 880–1260, and "local historical chronicles support these data, suggesting the climate of tropical South China was dry during the 'Mediaeval Warm Period.'"

In an analysis of past sea-level history in the South China Sea, Zicheng *et al*. (2003) cite the work of Honghan and Baolin (1996, in Chinese), stating these authors found "the climate temperature at 1000 a B.P. is 1–2°C higher than that at present time," referring to the Futian section on the eastern bank of the Pearl River, Shenzhen Bay, China (~22.5°N, 113.5°E). Zicheng *et al*. also cited the work of Baofu *et al*. (1997), who investigated palaeotemperatures of the coral reef at Dengloujao, Leizhou Peninsula, China (~20.25°N, 110°E) and report “sea-surface temperature at 1170 a B.P. is 2°C higher than that at present time.”

Paulsen *et al*. (2003) used high-resolution δ^{13}C and δ^{18}O data derived from a stalagmite found in Buddha Cave (33°40’N, 109°05’E) to infer changes in climate in central China over the prior 1,270 years. Among the climatic episodes evident in their data were, they write, “those corresponding to the Medieval Warm Period, Little Ice Age and 20th-century warming, lending support to the global extent of these events.” The dry-then-wet-then-dry-again MWP began about AD 965 and continued to approximately AD 1475.

Ma *et al*. (2003) analyzed a stalagmite from Jingdong Cave, about 90 km northeast of Beijing, to assess the climatic history of the past 3,000 years at 100-year intervals on the basis of δ^{18}O data, the Mg/Sr ratio, and the solid-liquid distribution coefficient of Mg. The researchers found between 200 and 500 years ago “air temperature was about 1.2°C lower than that of the present,” but between 1,000 and 1,300 years ago, there was an equally aberrant but warm period that “corresponded to the Medieval Warm Period in Europe.”

Based on 200 sets of phenological and meteorological records extracted from a variety of historical sources, many of which are described by Gong and Chen (1980), Man (1990, 2004), Sheng (1990), and Wen and Wen (1996), Ge *et al*. (2003) produced a 2,000-year history of winter half-year temperature (October to April, when CO_2-induced global warming is projected to be most evident) for the region of China bounded by latitudes 27 and 40°N and longitudes 107 and 120°E. This work revealed a significant warm epoch from the AD 570s to the 1310s, the peak warmth of which was “about 0.3–0.6°C higher than present for 30-year periods, but over 0.9°C warmer on a 10-year basis” (see Figure 4.2.4.4.1.2).

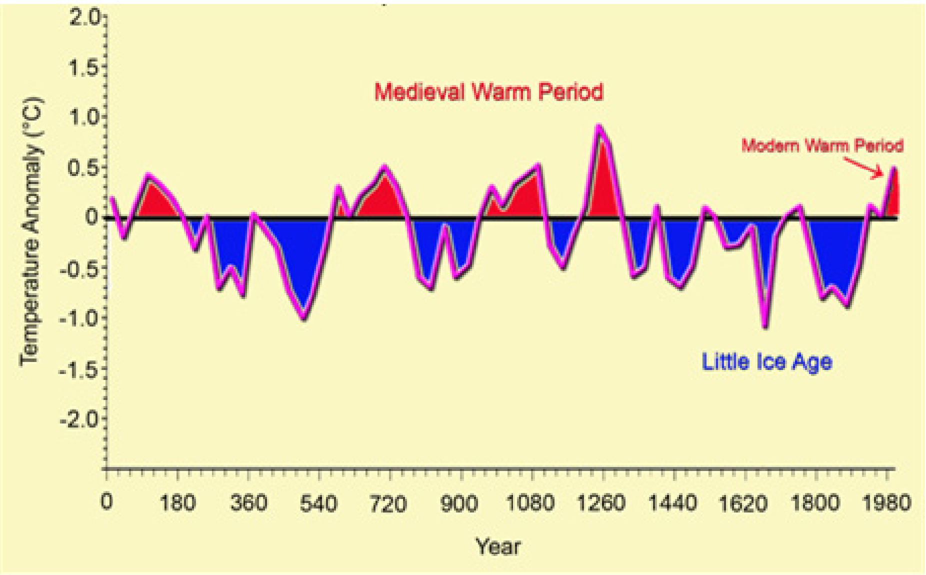

Figure 4.2.4.4.1.2. Winter half-year temperature anomalies for eastern China. Adapted from Ge, Q., Zheng, J., Fang, X., Man, Z., Zhang, X., Zhang, P., and Wang, W.-C. 2003. Winter half-year temperature reconstruction for the middle and lower reaches of the Yellow River and Yangtze River, China, during the past 2000 years. *The Holocene* **13**: 933–940.

Zhu *et al*. (2003) worked with a sediment core extracted from lake Chen Co in the Yamzhog Yum Co drainage basin of southern Tibet in the delta of the Kaluxiong River, dated by comparing sedimentary rates measured by ^{210}Pb and absolute time horizons measured by ^{137}Cs (Wan 1997, 1999; Benoit and Rozan, 2001). Several environmentally related magnetic properties of sections of the core were measured and analyzed. This work revealed a “Middle Ages Warm-period” (around ca. 1120–1370 AD) followed by “an intensively cold stage during ca. 1550–1690 AD, a cold-humid stage from ca. 1690–1900 AD and a warm-dry stage since ca. 1900 AD.” They note the warm period of the past century was not as warm as the earlier 250-year warm period of the Middle Ages.

Bao *et al*. (2003) utilized proxy climate records (ice-core δ^{18}O, peat-cellulose δ^{18}O, tree-ring widths, tree-ring stable carbon isotopes, total organic carbon, lake water temperatures, glacier fluctuations, ice-core CH_4, magnetic parameters, pollen assemblages, and sedimentary pigments) obtained from 20 prior studies to derive a 2,000-year temperature history of the northeastern, southern, and western sections of the Tibetan Plateau. In each case, there was more than one prior 50-year period when the mean temperature of each region was warmer than it was over the most recent 50-year period. In the case of the northeastern sector of the plateau, all of the maximum-warmth intervals occurred during the Medieval Warm Period; in the western sector, they occurred near the end of the Roman Warm Period; and in the southern sector they occurred during both warm periods. With respect to the entire Tibetan Plateau, the researchers found nothing extraordinary about the recent past. For the whole region, there was one prior 50-year period when temperatures were warmer than they were over the most recent 50-year period, and that was near the end of the Roman Warm Period, some 1850 years ago.

Bao *et al*. (2004) collected and analyzed proxy climate data derived from ice cores, tree rings, river and lake sediments, and lake terraces and paleosols, as well as historical documents, to determine the climatic state of northwest China during the Western and Eastern Han Dynasties (206 BC–AD 220) relative to the past two millennia. Their analysis revealed "strong evidence for a relatively warm and humid period in northwest China between 2.2 and 1.8 kyr BP," during the same time interval as the Roman Warm Period, which period experienced higher tempera-tures than those of today. They note "the warm-wet climate period during 2.2–1.8 kyr BP also occurred in central and east China, after [which] temperatures decreased rapidly (Zhu, 1973; Hameed and Gong, 1993; Yan *et al*., 1991, 1993; Shi and Zhang, 1996; Ge *et al*., 2002)." They found historical records report "an abrupt climate change from warmer and wetter to cooler and drier conditions occurred around AD 280 (Zhang *et al*., 1994)." In addition, "three alternate China-wide tempera-ture composites covering the last 2000 years display an obvious warm stage in 0–240 AD (Yang *et al*., 2002)," and "according to a 2650-year warm-season temperature reconstruction from a stalagmite from Shihua Cave of Beijing (Tan *et al*., 2003), the temperatures during 2.1–1.8 ka BP were basically above the average of the entire temperature series."

Bao *et al*. conclude, "the warm and moist conditions during the Western and Eastern Han Dynasties [i.e., the Roman Warm Period] might have been responsible for the large-scale agricultural production and the local socioeconomic boom that is documented by the occurrence of the famous ruin groups of Loulan, Niya, and Keriya." Citing the existence of plant remains such as walnuts, rice, barley, millet, and wheat grains found in the area, they also indicate the water and temperature conditions of the Roman Warm Period "were suitable for rice cultivation and much better than today."

Wei *et al*. (2004) measured high-resolution Sr/Ca ratios in two *Porites* corals off the coast of the Leizhou Peninsula in the northern South China Sea, using inductively coupled plasma atomic spectrometry, and their ages were determined via U-Th dating. The transfer function relating the Sr/Ca ratio to temperature was established on a modern *Porites lutea* coral by calibrating against sea surface temperatures (SSTs) measured from 1989 to 2000 at the nearby Haikou Meteorological Station. By these means one of the two coral sections was dated to AD 489–500 in the middle of the Dark Ages Cold Period, and the other was dated to 539–530 BC in the middle of the Roman Warm Period.

From the Dark Ages Cold Period portion of the coral record, Wei *et al*. determined the average annual SST was approximately 2.0°C colder than that of the last decade of the twentieth century (1989–2000), and from the Roman Warm Period portion of the record they obtained a mean annual temperature identical to that of the 1989–2000 period as measured at the Haikou Meteorological Station.

Yu *et al*. (2005) also derived high-resolution Sr/Ca ratios for *Porites lutea* coral samples taken off the coast of the Leizhou Peninsula and determined their ages by means of U-Th dating, and the transfer function relating the Sr/Ca ratio to temperature was obtained from a modern *P. lutea* coral in the same location by calibrating the ratio against SSTs measured from 1960 to 2000 at the Haikou Ocean Observatory. The researchers found the coral Sr/Ca ratio to be "an ideal and reliable thermometer," after which they employed it to reveal a coral sample dated to ~541 BC during the Roman Warm Period yielded "a mean of Sr/Ca-SST maxima of 29.3°C and a mean of Sr/Ca-SST minima of 19.5°C, similar to those of the 1990s (the warmest period of the last century)." Yu *et al*. say "historic records show that it was relatively warm and wet in China during 800–300 BC (Eastern Zhou Dynasty)," noting "it was so warm during the early Eastern Zhou Dynasty (770–256 BC) that rivers in today's Shangdong province (35–38°N) never froze for the whole winter season in 698, 590, and 545 BC."

Zhang *et al*. (2004) reconstructed the salinity history of Qinghai Lake (the largest inland saline lake in China) for the period AD 1100–2000 based on a relationship between the shell length of the ostracod *Limnocythere inopinata* and the salinity of the water in which it lives, a relationship developed by Yin *et al*. (2001) from data gathered from 50 lakes of different salinities scattered across the Tibetan Plateau. Zhang *et al*. used ostracod shell-length data derived from a 114-cm sediment core to discover “low salinity during 1160–1290 AD showed the humid climate condition [of] the Medieval Warm Period in this area, while the high salinity during 1410–1540 AD, 1610–1670 AD and 1770–1850 AD [prevailed during] the three cold pulses of the Little Ice Age with a dry climate condition,” where the evidence for the occurrence of these warm and cold intervals came from the climate change studies of Yao *et al*. (1990) and Wang (2001).

Qinghai Lake’s modern salinity has not reached even the halfway point between the near-record high salinity of the last cold extreme of the Little Ice Age and the record low salinity experienced during the Medieval Warm Period, suggesting the warmth recently experienced in this region of China is nowhere near that experienced during the Medieval Warm Period. The salinity drop marking the “beginning of the end” of the last stage of the Little Ice Age began sometime prior to 1850, in harmony with the Northern Hemisphere temperature history of Esper *et al*. (2002) but in striking contradiction of the Northern Hemisphere temperature history of Mann *et al*. (1998, 1999), which does not depict any increase in temperature until after 1910, some 60 years later.

Ji *et al*. (2005) applied reflectance spectroscopy to a sediment core taken from the southeastern basin of Qinghai Lake. Sediment redness, related to iron oxide content, was judged to be an indicator of paleoclimatic changes in the core. Lower redness values were found to correlate with light, laminated sediments “associated with cold periods including the Little Ice Age (LIA),” whereas “warm periods, e.g., Medieval Warm Period (MWP), ... were marked by the accumulation of reddish-colored sediments.” Based upon these findings the MWP is observed to have been a long warm and wet period (AD 400–1200) sandwiched between the cold and dry spells of the Dark Ages Cold Period (100 BC–200 AD) and Little Ice Age (AD 1220–1600) (see Figure 4.2.4.4.1.3).

Liu *et al*. (2006a) developed a quantitative reconstruction of temperature changes over the past 3,500 years based on alkenone distribution patterns in a sediment core retrieved from Qinghai Lake, based on the alkenone unsaturation index ($U^{k}37$) and its simplified form ($U^{k'}37$), which they say “have been calibrated to growth temperatures of marine alkenone producers (Prahl *et al*., 1988)” and “to temperature changes in lacustrine settings on a regional scale (Chu *et al*., 2005; Zink *et al*., 2001).” They state their temperature record “based on $U^{k'}37$ clearly shows oscillating warm/cold periods,” with periods at 0–200 yr BP, 500–1,100 yr BP, and 1,500–2,000 yr BP that were relatively warm and “could be related to the 20th-century warm period, the Medieval Warm Period, and the Roman Warm Period,” and “cold periods at 200–500 yr BP and 1100–1500 yr BP [that] corresponded to the Little Ice Age and the Dark Ages Cold Period.” In addition, their data indicate the peak warmth of the Roman Warm Period exceeded the temperature of the latter part of the twentieth century by about 0.4°C, and the peak warmth of the Medieval Warm Period exceeded the temperature of the latter part of the twentieth century by nearly 1°C. The existence of this millennial-scale oscillation of climate, with its prior periods of higher-than-current temperatures, clearly demonstrates there is nothing unusual about Earth’s present climatic state.

Ge *et al*. (2004) introduce their study of two thousand years of reconstructed winter half-year temperatures of eastern China by stating, “it is important to study the temperature change during the past 2000 years for understanding the issues such as the greenhouse effect and global warming induced by human activities.” They also note “China has advantages in reconstructing historical climate change for its abundant documented historical records and other natural evidence obtained from tree rings, lake sediments, ice cores, and stalagmites.”

The five climate scientists found “an about 1350-year periodicity in the historical temperature change,” which revealed a number of multi-century warm and cold periods. Preceding the Current Warm Period, for example, was the Little Ice Age (LIA), which “in China, began in the early 14th century (the 1320s) and ended in the beginning of the 20th century (the 1910s).” It included four cold stages and three short warming phases. The LIA, in turn, was preceded by the Medieval Warm Period, which Ge *et al*. say “began in the 930s and ended in the 1310s.” It was composed of two warm stages, each of more than 100 years duration, and a shorter intervening cold stage.

Looking further back in time, the Chinese scientists found a cold period from the 780s to the 920s and a warm period from the 570s to the 770s, which was in turn preceded by a cold period from the 210s to the 560s, which they say “was the only one comparable with [the] LIA for the past 2000 years.” This ultra-cold spell was the Dark Ages Cold Period that followed on the heels of the Roman Warm Period.

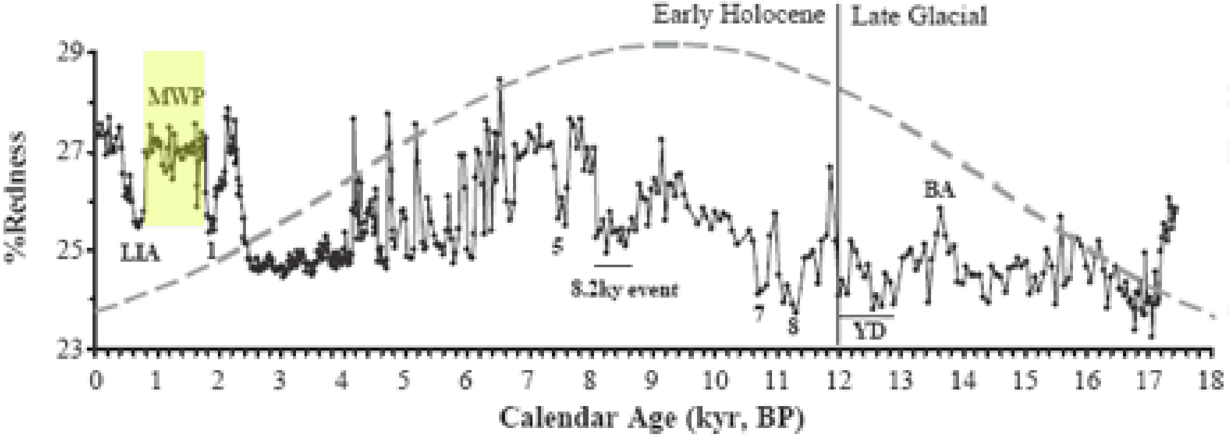

Figure 4.2.4.4.1.3. Qinghai Lake climate proxy showing the presence of the Little Ice Age and Medieval Warm Period as determined by the % redness value in a lake sediment core. Adapted from Ji, J., Shen, J., Balsam, W., Chen, J., Liu, L., and Liu, X. 2005. Asian monsoon oscillations in the northeastern Qinghai-Tibet Plateau since the late glacial as interpreted from visible reflectance of Qinghai Lake sediments. *Earth and Planetary Science Letters* **233**: 61–70.

Ge *et al*. state one of the purposes of their study was "to test whether the warming in the 20th century has exceeded the maximum magnitude in the past 2000 years." At the centennial scale, they report, "the temperature anomaly of the 20th century is not only lower than that of the later warm stage of the Medieval Warm Period (the 1200s~1310s), but also slightly lower than that of the warm period in the Sui and Tang dynasties (the 570s~770s) and the early warm stage of the Medieval Warm Period (the 930s~1100s)."

On a 30-year scale, they report, "the warmest 30-year temperature anomaly in the 20th century is roughly equal to the warmest 30-year one in the Sui and Tang dynasties warm period, but a little lower than that of the Medieval Warm Period." On the decadal scale, they note "the warmest decadal temperature anomaly in the 20th century is approximately at the same level of the warmest decade of the early stage of the Medieval Warm Period."

Ge *et al*. find "although the warming rate in the early 20th century has reached 1.1°C per century, such a rapid change is not unique during the alternation from the cold period[s] to the warm period[s]" of the prior 2,000 years. For example, they report the per-century warming rate from the 480s~500s to the 570s~590s was 1.3°C, from the 1140s~1160s to the 1230s~1250s was 1.4°C, and from the 1650s~1670s to the 1740s~1760s was 1.2°C.

Ge *et al.* say their analysis "gives a different viewpoint from that 'the 20th century is the warmest century in the past 1000 years', presented by IPCC, and is of great significance for better understanding the phenomena of the greenhouse effect and global warming etc. induced by human activities." With respect to what that "different viewpoint" might be, Ge *et al*. state it is that "the temperature of the 20th century in eastern China is still within the threshold of the variability of the last 2000 years."

Jin *et al*. (2004) analyzed percent organic carbon and Rb/Sr ratios in a sediment core extracted from the deepest part of Daihai Lake (112°32'–112°48'E, 40°28'–40°39'N) in Inner Mongolia, which they describe as being located "in the transitional zone between semi-arid and semi-humid conditions that is sensitive to East Asian monsoon variability." They found the data they obtained "support two distinct Little Ice Age cooling events centered at ~850 yr BP and ~150 yr BP," as well as "the Medieval Warm Period between 1200 and 900 yr BP," which they say "was warmer than the present, with higher chemical weathering than at present," citing Jin *et al*. (2002). Such findings echo the results of Zhangdong *et al.* (2002), who also used rubidium/strontium ratio, calcium carbonate, and organic concentration data of sediments cored from Daihai Lake (112°38'E, 40°33'N) to reconstruct the climate of that region over the past 2,200 years. Their results indicate the existence of a "warm and humid" climate that defined the Medieval Warm Period between AD 800 and 1100, which also exhibited the "strongest chemical weathering during the last 2,200 years."

Qiang *et al*. (2005) conducted stable carbon isotope analyses conducted on sediment cores taken from Lake Sugan (38°51.19'N, 93°54.09'E), located in the northeastern region of the Tibetan Plateau, to produce a proxy of winter temperatures over the past 2,000 years. The results indicate a warm and dry period between 580 and 1200 AD, which they state "corresponds to the Medieval Warm Period." The author's Figure 3 reveals the MWP was probably at least as warm between ~AD 1100 and 1200 as it is today.

Chen *et al*. (2009) studied varved sediments retrieved from cores extracted from Lake Sugan to develop a 1,000-year high-resolution (~10 years) salinity history of the lake, based on the relative abundances of chironomid species they identified via microscopic examination of head capsules found in the sediments. This work suggested, they write, "over the last millennium, the Sugan Lake catchment has alternated between contrasting climatic conditions, having a dry climate during the period AD 990–1550, a relative humid climate during the Little Ice Age (AD 1550–1840), and a dry climate again from AD 1840 onwards." They associate the first of the three periods with "the Medieval Warm Period in China," which they describe as being "warm and dry."

Li *et al*. (2006) conducted a variety of proxy analyses, including palynology, microfossil charcoal, stable isotopes ($\delta^{13}C$ and $\delta^{15}N$), and sediment geochemistry, on a 3.6-m sediment core taken from a relict oxbow lake in the Western Liaohe River Basin (42.07°N, 119.92°E) of northeastern China to reconstruct the environmental history of that region over the past 5,400 years. The results indicate the existence of a period of enhanced warmth and wetness from about AD 800 to 1400, which the researchers associate with the Medieval Warm Period.

Liu *et al*. (2006b) used three well-dated *Sabina Przewalskii* ring-width chronologies derived from 77 trees growing in three locations near Dulan, China on the northeastern Tibetan Plateau (36.0–36.3°N, 98.2–98.6°E) to reconstruct annual precipitation variations in that region over the period AD 850–2002. They compared their results with instrumental temperature data for that region at that time..

Working with 10-year moving averages, the 13 scientists found precipitation and temperature were "significantly correlated with r = 0.85 (p<0.0001), after the precipitation lagged temperature for 2 years." They produced a 40-year moving average curve that was "significantly correlated with seven temperature curves of the Northern Hemisphere," which led them to conclude their 40-year smoothed reconstruction "could be regarded as the millenary temperature curve for the northeastern Tibetan Plateau."

Liu, *et al.*'s "millenary temperature curve" clearly shows the 40-year-averaged temperature proxies in the vicinity of AD 915 are greater than those at the end of the twentieth century, which comprise the next highest peak of the record. Thus this study documents another specific instance where peak temperatures of the Medieval Warm Period likely were greater than peak temperatures of the twentieth century.

Jin *et al*. (2007) studied "the evolutionary history of permafrost in the central and eastern Qinghai-Tibetan Plateau since the end of the late Pleistocene, using relict permafrost and periglacial phenomena along the Qinghai-Tibet Highway from Gomud to Lhasa, the Qinghai-Kang (western Sichuan) Highway from Xi'ning to Yusu, adjacent areas, and the Xinjiang-Tibet Highway from Yecheng to Lhasa." They described permafrost and deduced environmental conditions during "the Megathermal period in the middle Holocene (~8500–7000 to ~4000–3000 years BP)" as well as "the warm period in the later Holocene (1000 to 500 years BP)." In comparing environmental and permafrost characteristics of those periods of elevated warmth with those of the present, the three researchers from the Chinese Academy of Sciences report "the total areas of permafrost [during the Megathermal period of the middle Holocene] were about 40–50% of those at present," while "mean annual air temperatures were ~2-3°C higher." Moreover, during the warm period of the late Holocene "the retreating of permafrost resulted in a total permafrost area of ~20–30% less than at present," and mean annual air temperatures were "1.5–2.0°C warmer than at present."

Liu *et al*. (2007) reconstructed a 1,000-year temperature history of the middle Qilian Mountains of China (37–39°N, ~99–103°E) at the convergence of the Qinghai-Xizang Plateau, the Inner Mongolia-Xinjiang Plateau, and the Loess Plateau, working with ring-width and $\delta^{13}C$ data derived from long-lived Qilian juniper (*Sabina przewalskii* Kom.) trees. Their reconstruction captured about 75 percent of the temperature variance over the calibration period 1960–2000 and correlated well with the Northern Hemisphere temperature reconstruction of Esper *et al*. (2002). As the six scientists describe it, the two sets of reconstructed temperature data (theirs and that of Esper *et al*) "reveal that the Medieval Warm Period and Little Ice Age were synchronous in China and the Northern Hemisphere." In addition, they note the two warmest intervals in their temperature reconstruction were 1060–1150 and 1900–2000, with corresponding peaks occurring around 1100 and 1999 that are essentially identical. Their results do not extend as far back in time as those of Esper *et al.*, which rise to their highest level before Liu *et al.*'s history begins. Liu *et al.* acknowledge their reconstructed temperature history "has not included all of the Medieval Warm Period and, perhaps, not even its warmest period."

Ge *et al.* (2007) reviewed proxy temperature records of China that spanned the entire Holocene, focusing on the last two millennia, noting it is widely believed "increasing concentrations of greenhouse gases in the atmosphere are causing higher global atmospheric temperatures" and, therefore, "paleoclimate data are essential for both checking the predictions of climate models and characterizing the natural variability of [Earth's] climate system."

They found the warmest period of the Holocene occurred between 9,600 and 6,200 years ago, during portions of which temperatures "were about 1°C–5°C higher than the present in China." They also report "during the past two millennia, a warming trend in the 20th century was clearly detected, but the warming magnitude was smaller than the maximum level of the Medieval Warm Period," which they describe as having occurred between AD 900 and 1300. They state, "the Current Warm Period has lasted [only] 20 years from 1987 to 2006," and the annual mean temperature series of China since AD 1880 indicates the country was warmer in the mid-1940s than at the time of their study.

Tan *et al.* (2008) developed a precipitation history of the Longxi area of the Tibetan Plateau's northeast margin since AD 960 based on an analysis of Chinese historical records. They compared the result with the same-period Northern Hemisphere temperature record and contemporaneous atmospheric ^{14}C and ^{10}Be histories. This work revealed, "high precipitation of Longxi corresponds to high temperature of the Northern Hemisphere, and low precipitation of Longxi corresponds to low temperature of the Northern Hemisphere." They used their precipitation record to infer a Medieval Warm Period that stretched from about AD 960 to 1230, with temperature peaks in the vicinity of AD 1000 and 1215 that clearly exceeded the twentieth century peak temperature of the Current Warm Period. They also found "good coherences among the precipitation variations of Longxi and variations of atmospheric ^{14}C concentration, the averaged ^{10}Be record and the reconstructed solar modulation record." These findings harmonize, they write, with "numerous studies [that] show that solar activity is the main force that drives regional climate changes in the Holocene," in support of which they attached 22 scientific references. The four scientists conclude the "synchronous variations between Longxi precipitation and Northern Hemisphere temperature may be ascribed to solar activity," which apparently produced a Medieval Warm Period both longer and stronger than what has been experienced to date during the Current Warm Period in the northeast margin of the Tibetan Plateau.

Zhang *et al.* (2008) studied a stalagmite found in China's Wanxiang Cave (33°19'N, 105°00'E), which they say is located on the fringes of the area currently affected by the Asian Monsoon and is thus sensitive to (and integrates broad changes in) that annually recurring phenomenon. The 17 researchers developed a δ^{18}O record with an average resolution of 2.5 years that "largely anti-correlates with precipitation" and runs continuously from AD 190 to 2003. Zhang *et al.* demonstrate the record "exhibits a series of centennial to multi-centennial fluctuations broadly similar to those documented in Northern Hemisphere temperature reconstructions, including the Current Warm Period, Little Ice Age, Medieval Warm Period and Dark Age Cold Period." When one compares the peak warmth implied by their data for the Current and Medieval Warm Periods, it is easy to see the Medieval Warm Period was the warmer of the two.

Zhang *et al.* superimposed their δ^{18}O record upon individual plots of Northern Hemispheric temperature as derived by Esper *et al.* (2002), Moberg *et al.* (2003), and Mann and Jones (2003). In the first of these comparisons, the two records were closely matched, both indicating greater peak warmth during the Medieval Warm Period than during the Current Warm Period. The same was true of the second comparison, and in the third comparison the records also were closely matched over the majority of their expanse. Over the last decades of the twentieth century, however, the temperatures of the Mann and Jones record rise far above the temperatures implied by the Zhang *et al.* record (and, therefore, those of the Esper *et al.* and Moberg *et al.* records as well), suggesting this anomalous behavior of the Mann and Jones record is the result of a defect not found in the other three datasets. That defect is likely Mann and Jones' use of directly measured as opposed to reconstructed temperatures over their record's last few decades, which leads to their anomalous end-point "oranges" not telling the same story as told by everyone else's "apples."

It is also interesting to note the Zhang *et al.* record "correlates with solar variability, Northern Hemisphere and Chinese temperature, Alpine glacial retreat, and Chinese cultural changes." Since none of the last four phenomena can influence the first, it stands to reason solar variability is likely what has driven the variations in the other factors. In a commentary accompanying Zhang *et al.*'s article, Kerr (2008) notes the Zhang *et al.* record had been described by other researchers as "amazing," "fabulous," and "phenomenal," and it "provides the strongest evidence yet for a link among sun, climate, and culture." In addition, it provides equally strong evidence for at least the Northern-Hemispheric extent of the Medieval Warm Period and its greater and more persistent warmth than that of the Current Warm Period.

Based on a study of historical documents covering the period AD 1000–1950 and instrumental data from meteorological stations for the period 1950–2003, Zhang *et al.* (2008) developed a millennial-scale temperature index for the Yangtze Delta region of China that revealed "three distinct climate periods": the "Warm Medieval Period (AD 1000–1400), Little Ice Age (AD 1400–1920), and the ongoing well-established Global Warming Period (AD 1920–present)." This record documents a continuous period from about AD 1200 to 1235 when it was significantly warmer than the peak warmth recorded during the "well-established Global Warming Period." Similar results were found previously by Yi *et al.* (2006) , who analyzed arboreal pollen, non-arboreal pollen, and spores contained in a sediment core retrieved from the Changjiang prodelta (31°01.1'N, 122°47.0'E). This effort revealed, they write, "relatively warm/wet conditions comparable to [the] Medieval Warm Period (AD 910–1085) with a strengthen[ed] summer monsoon." Based on the findings of others, Yi *et al.* further state, "the mean temperature during this period was 1–2°C warmer than that of today."

Xiao *et al.* (2012) analyzed pollen, charcoal, and magnetic susceptibility data from a 150-cm-long sediment core extracted from the central portion of northern Taibai Lake (29°59'43"N, 115°48'27"E) in the middle reach of the Yangtze River. They concluded "vegetation changes [over the time interval AD 1050–1320] were mainly controlled by climatic changes, with limited influence from human activity," and this period was "more warm and humid" than those that preceded and followed it. They say these observations mean "the 'Medieval Warm Period' occurred in the middle reach of the Yangtze River," further noting "the reconstructed results of Ge *et al.* (2003, 2004) and the simulated results of Liu *et al.* (2005) also verified its existence in eastern China and even the whole of China."

Ma *et al.* (2008) analyzed multi-proxy data, including "^{14}C, grain size, microfossil, plant seeds, and geochemical elements," obtained from sediment retrieved from excavations made in the dry lake bed of Lop Nur China's West Lake (40°27'129" N, 90°20'083" E) in order "to amply discuss," as they describe it, "the climate and environment changes during the MWP," which they identify as occurring between AD 900 and 1300. They found the "sedimentary environment was stable around the MWP, with weak storm effect" and "the upper and lower sediments showed frequent strong storm effect." They also report "microfossils and plant seeds were abundant in this stage [MWP], which indicated a warm and humid fresh or brackish lake environment." Thereafter, "in the late period [AD 1300 to 1650], the environment turned worse, storm effect was intensified ... and the climate began to dry, leading to shriveling and death of many plants such as red willows." Ma *et al.* conclude "the environment was the best" over the period AD 1100 to 1300, stating, "temperature was almost the same [as] or a little higher than nowadays," providing another example of the widespread occurrence of the Medieval Warm Period, which they describe as "one of the most significant climate episodes in the world."

Yang *et al.* (2009) synthesized proxy records of temperature and precipitation in arid central Asia over the past two thousand years, focusing on the relationship between temperature and precipitation on timescales ranging from annual to centennial (Figure 4.2.4.4.1.4). With respect to temperature, they report "the most striking features are the existence of the Medieval Warm Period (MWP) and the Little Ice Age (LIA)," as well as the earlier Roman Warm Period (RWP) and Dark Ages Cold Period (DACP), plus what they call "a recent warming into the 20th century" they identify as the Current Warm Period (CWP). As for precipitation, the five researchers state the MWP "corresponded to an anomalously dry period whereas the cold LIA coincided with an

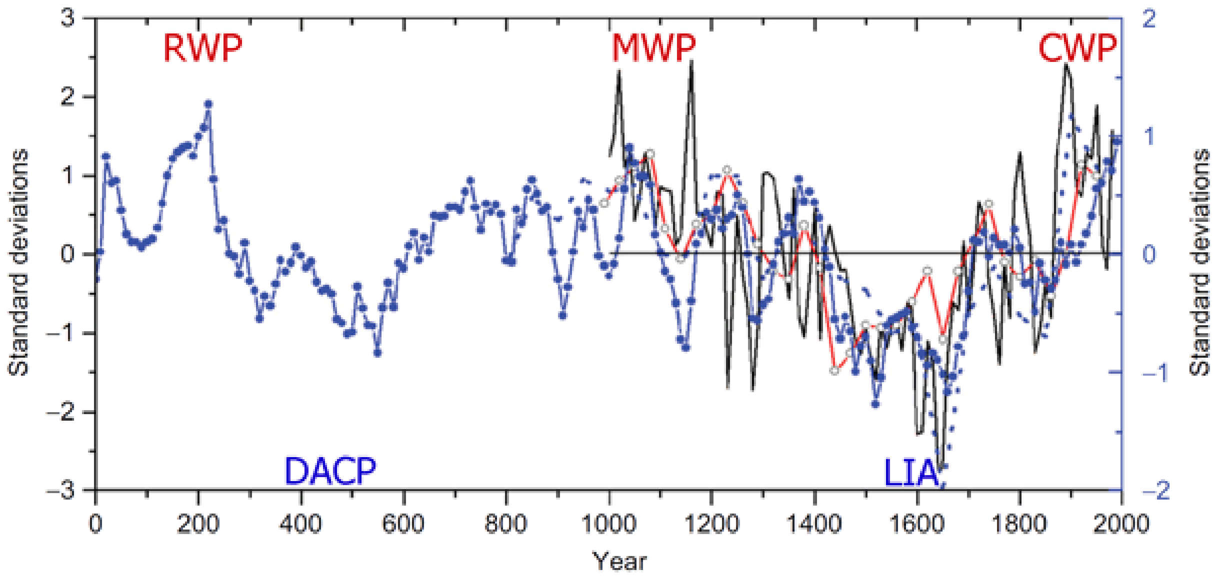

Figure 4.2.4.4.1.4. Standardized representations of various reconstructions of the temperature history of arid central Asia. Adapted from Yang, B., Wang, J., Brauning, A., Dong, Z., and Esper, J. 2009. Late Holocene climatic and environmental changes in arid central Asia. *Quaternary International* **194**: 68–78.

extremely wet condition.” Once again, a substantive body of evidence is presented for the natural, non-CO_2-induced, millennial cycling of climate that has alternately brought the world into and then out of the Roman Warm Period, the Dark Ages Cold Period, the Medieval Warm Period, and the Little Ice Age, providing good reason to conclude the continuation of that cycle has likely brought the planet into the Current Warm Period and will ultimately bring the world out of its latest extended “heat wave.”

Hong *et al*. (2009) write of the Medieval Warm Period, “because it is a distinct warm period nearest to the modern warming period and happened before the Industrial Revolution, it naturally becomes a [source of] comparison with modern warming.” They add, “a universal concern in academic circles is [1] whether it also existed outside the European region and [2] whether it is a common phenomenon.” In a study designed to broach both questions, they extracted cores of peat from a location close to Hani Village, Liuhe County, Jilin Province, China (42°13’N, 126°31’E) and used them to develop “a peat cellulose δ^{18}O temperature proxy record proximately existing for 14,000 years.”

These efforts revealed the existince of the MWP on the Chinese mainland over the period AD 700–1400, peaking at about AD 900. The eight researchers report phenological data from east China (Ge *et al*., 2006) and tree-ring records from west China (Yang *et al*., 2000) also indicate “the temperature on the Chinese mainland was distinctly warmer during the MWP.” They say MWP temperatures were as much as “0.9–1.0°C higher than modern temperatures (Zhang, 1994).”

Hong *et al*. further note, “sudden cooling events, such as the Older Dryas, Inter-Allerod, Younger Dryas, and nine ice-rafted debris events of the North Atlantic,” described by Stuiver *et al*. (1995) and Bond *et al*. (1997, 2001), “are almost entirely reiterated in the temperature signals of Hani peat cellulose δ^{18}O.” And “these cooling events show that the repeatedly occurring temperature cooling [and warming] pattern not only appeared in the North Atlantic Region in the high latitudes, but also in the Northwest Pacific Region in the middle latitudes,” indicating the recurring warming and cooling occurred “outside the European region” and was “a common phenomenon.”

Hong *et al*. also note the earlier paper of Hong *et al*. (2000), which describes a 6,000-year peat cellulose δ^{18}O record derived from nearby Jinchuan Town, Huinan County, Jilin Province, China (42°20’N, 126°22’E), identified δ^{18}O periodicities of 86, 93, 101, 110, 127, 132, 140, 155, 207, 245, 311, 590, 820 and 1,046 years, which they say “are similar to those detected in solar excursions” and which they consider “further evidence for a close relationship between solar activity and climate variations on timescales of decades to centuries."

The findings of Hong *et al*. (2000) were highly praised by Fairbridge (2001), who notes "almost identical equivalents are seen in solar emission periodicities and their harmonics, e.g., 86.884 years = 40 x 2.172 year Quasi Biennial Oscillation (QBO) as well as in the lunar tidal/apsides beat frequency (17.3769 years) which also matches closely with most of the longer spectral peaks, e.g., 140 (139) years, 207 (208.5), 311 (312.8), 590 (590.8) and 1046 (1042.6) years." For these spectacular spectral findings, Fairbridge writes, "Hong *et al.* deserve the appreciation of the entire Holocene community." And the case for a global and solar-induced Medieval Warm Period grows ever stronger, as it also does for the similar warm periods that preceded it in the prior 13,000 years, making the case for a similar origin for the Current Warm Period increasingly likely as well.

Liu *et al*. (2009) obtained a mean annual temperature history of the mid-eastern Tibetan Plateau based on Qilian juniper (*Sabina przewalskii*) tree-ring width chronologies obtained from living trees and archaeological wood for the 2,485-year period 484 BC–AD 2000, which data were calibrated against measured air temperatures for the period AD 1958–2000. They demonstrate their work to be well correlated with several temperature histories of the Northern Hemisphere. The eight researchers found four periods with average temperatures similar to "or even higher than" the mean of AD 1970–2000, beginning with the warm period of AD 401–413, which they say "was the warmest period within the last 2.5 thousand years." They also note an archaeological documentary record from Loulan in Xinjiang province shows pomegranate was employed as currency during the Eastern Jin Dynasty (AD 317–589), because the appearance of pomegranate during that period "suggests that the temperature at that time was higher than nowadays," citing Zhang and Zhang (2006). In addition, they note the rate of warming that led to the early ultra-warm period of their record was "unprecedented in the last 2500 years." And the last of the four ultra-warm periods was also slightly warmer than it was at the end of the twentieth century.

Liu *et al.* also suggest the high-temperature intervals of the AD 400–1000 period were relatively good times, as the downfalls of most of the major dynasties in China coincided with intervals of low temperature, citing the demise of the Qin, Three Kingdoms, Tang, Song (North and South), Yuan, Ming, and Qing Dynasties.

Chen *et al*. (2009) studied a sediment core taken from a mountain lake (Duck Pond, 25°10.441'N, 121°33.013'E) in Northern Taiwan that "represents deposition from AD 650 to present." They identified, measured, and analyzed "pollen, spores, diatoms, organic carbon, nitrogen, and $\delta^{13}C$ of organic matter in lake sediments to infer climate changes and reconstruct the paleo-environment of subtropical Taiwan over the past ~1300 years," temporally delineating five climate zones in the process. Zone III (AD 1050–1250) was "wet and warmer; ~MWP [Medieval Warm Period]", Zone IV (AD 1250–1790) was "wetter and colder than in Zone III; corresponding to LIA [Little Ice Age]," and Zone V (AD 1790–2000) was "drier and warmer than in Zone IV." They state, "in Europe and other regions, there was a short warm period (the medieval warm period, or MWP) prior to the LIA," and their "Zones III and IV likely correspond to such warm and cold periods." They also found the ratio of arboreal pollen (AP) to non-arboreal pollen (NAP) "showed a positive correlation with temperature" They report the peak AP/NAP ratio of the MWP was about three times greater than the peak AP/NAP ratio of the CWP, suggesting the peak warmth of the former period must have been considerably greater than the peak warmth of the latter period.

Wang *et al*. (2011) analyzed pollen data obtained from ten lake sediment cores and two land cores to assess the species abundances and alterations of forest-covered areas in northern Taiwan (23°17'N–25°18'N, 120°54'E–122°02'E) in response to changes in humidity and temperature over the past 2,000 years. The researchers found the climate of northern Taiwan was "wet and warm during 1000–500 cal. yr BP, which corresponded to the Medieval Warm Period (MWP)." They also note "an increased density and dispersal of *Tsuga* pollen corresponding to 500-200 cal. yr BP was observed, which corresponded to the Little Ice Age (LIA)." The authors' Figure 6, which presents a relationship between *Tsuga* pollen and temperature, shows the MWP was slightly warmer than the CWP.

Ge *et al*. (2010) write, "knowledge of past climate can improve our understanding of natural climate variability and also help address the question of whether modern climate change is unprecedented in a long-term context." They report "regional proxy temperature series with lengths of 500–2000 years from China have been reconstructed using tree rings with 1–3 year temporal resolution, annually resolved stalagmites, decadally resolved ice-core information, historical documents with temporal resolution of 10–30 years, and lake sediments resolving decadal to century time scales," noting "these proxies provide quantitative estimates of past climate through statistical calibration against instrumental temperature measurements."

Ge *et al*. divided China into five regions for their analysis and developed temperature reconstructions for each: three composite temperature reconstructions that extended back in time a full two millennia (Northeast, Tibet, Central East), one that extended back approximately 950 years (Northwest), and one that went back only about 550 years (Southeast). In the Northeast, the six scientists found a warm period "between approximately 1100 and 1200 that exceeded the warm level of the last decades of the 20th century." In Tibet, there was a "warming period of twenty decadal time steps between the 600s and 800s" that was "comparable to the late 20th century." In the Central East, there were two warm peaks (1080s–1100s and 1230s–1250s) with "comparable high temperatures to the last decades of the 20th century," although the graph of their data indicates these two periods were warmer than the last decades of the twentieth century. And in the Northwest, "comparable warm conditions in the late 20th century are also found around the decade 1100s."

Gen *et al*.'s work clearly shows there is nothing unusual, unnatural, or unprecedented about the country's current level of warmth. Thus there is no compelling reason to attribute late twentieth century warmth in China to twentieth century increases in the the atmospheric concentrations of CO_2 or any other greenhouse gases.

Shi *et al*. (2010) extracted 67 cores from 29 healthy trees in an old-growth forest in Nangcai, Zaduo County, at a site (32°39'36"N, 95°43'14"E) undisturbed by human activities. They developed a ring-width history covering the period AD 1360–2005 based on what they considered to be the best 46 cores from 23 trees. For the period AD 1961–2005, they derived a relationship between annual tree-ring width and directly measured May–June mean maximum air temperature, which they used to reconstruct a similar temperature history for the entire 645-year period. Based on an 11-year moving average of these results, they identified a 17-year warm period (AD 1438–1455), which occurred in the latter stages of the global MWP. As best as can be determined from the graphs of their results, this period was about 1.2°C warmer than the last decade of their temperature history (AD 1995–2005).

Li *et al*. (2010) developed a composite temperature history of the Hetao region of China stretching 5,000 years back in time from the early 2000s, based on pollen data from Daihai Lake (40°N, 112°E), oxygen isotope data from a salt lake in Yikezhaomeng, Inner Mongolia (39°N, 109°E), and total organic carbon data from Jingbian County (37°N, 108°E). This temperature history revealed "the climate was relatively warm" between 1450 and 1,000 calendar years before present (AD 550–1000), which "corresponded to the Medieval Warm Period." It is clear from their graph of the data that the peak warmth of the MWP was greater than the peak warmth of the CWP.

Zhou (2011), a scientist with the State Key Laboratory of Severe Weather of the Chinese Academy of Meteorological Sciences in Beijing, wrote in an introductory editorial in a special issue of the *Chinese Science Bulletin* (October 2011), "research on global climate change has been at the frontier of the contemporary sciences" and "debate has focused on whether the greenhouse effect produced by human activities is a major factor responsible for modern climate warming."

Zhou reports "in 2009, the major project 'Research on tree-ring and millennium climate change in China' was implemented under the support of the National Natural Science Foundation of China." Noting eight articles published in this special issue of the *Bulletin* "present partly preliminary results obtained by the project over the past two years," he summarizes their findings: The eight articles "reveal some characteristics and regularities of changes in temperature and precipitation in China and in East Asian monsoons over the past 1000 years" that qualify as "notable conclusions," of which he lists only two. But those two are extremely important: (1) "temperatures in the Medieval Warm Period are comparable to those in the current warm period over China," and (2) "the effect of solar activity on climate cannot be neglected in any period of the millennium."

Tian *et al*. (2011) reconstructed a 1,910-year-long time series—stretching from AD 2 to AD 1911—of outbreaks of Oriental migratory locusts in China, based on information the researchers extracted from more than 8,000 historical documents and relationships they developed between these data and indices of temperature at annual and decadal time scales. They found "a negative association between locust abundance and annual temperature," which was most strongly manifest when the temperature index was representative of the whole of China. As Figure 4.2.4.4.1.5 shows, the interval of lowest locust index during this period (~AD 1030–1250)—which would thus represent the warmest period of the record—falls right in the middle of the mean global Medieval Warm Period.

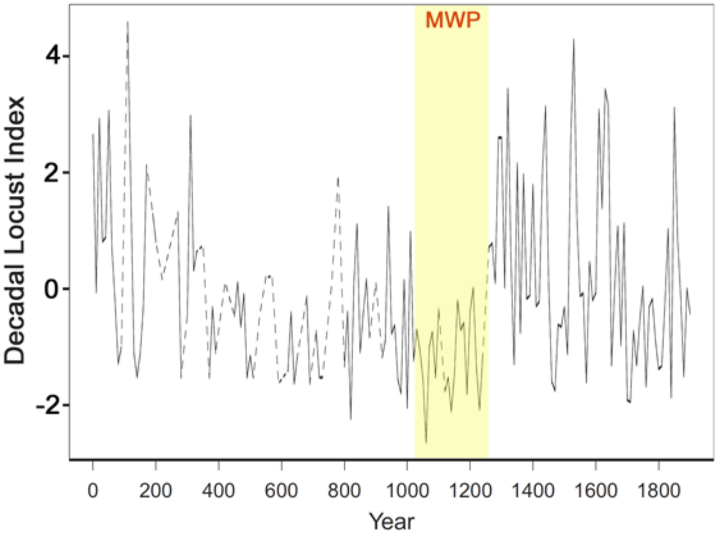

Figure 4.2.4.4.1.5. Chinese decadal locust abundance index vs. year. Dashed lines connect data points across periods with no locust reports. Adapted from Tian, H., Stige, L.C., Cazelles, B., Kausrud, K.L., Svarverud, R., Stenseth, N.C., and Zhang, Z. 2011. Reconstruction of a 1,910-y-long locust series reveals consistent associations with climate fluctuations in China. *Proceedings of the National Academy of Sciences USA* **108**: 14,521–14,526.

Wang *et al*. (2012) note “lakes are excellent sensors of environmental change” and “lake sediments can provide well-resolved records of change on different time scales.” They also note “crater and maar lakes are especially sensitive to climate change because typically they have a small catchment area and limited inflow/outflow.” Moreover, such lakes “often provide high-resolution records due to limnological processes favorable to the development and preservation of seasonally laminated sediments,” citing Zolitschka *et al*. (2000). They add, “diatoms are excellent indicators of environmental conditions and have been widely used to reconstruct Holocene climate variability,” citing Smol and Cumming (2000), Battarbee *et al*. (2001), and Mackay *et al*. (2003).

Wang *et al*. retrieved a 66.5-cm-long sediment core from Lake Erlongwan, one of eight maar lakes in the Long Gang Volcanic Field of Jilin Province, NE China (42°18’N, 126°21’E), which they describe as a closed dimictic lake that occupies an area of 0.3 km^2 and has a small catchment (0.4 km^2) with no natural inflows or outflow. They dated the sediment using radiometric ^{210}Pb, ^{137}Cs and ^{14}C analyses and analyzed it for diatom species and quantities. Although they note diatoms “are generally not known to be very sensitive to water temperature,” they state, “climate affects the physical properties of the lake water column, especially as it controls the seasonal durations of ice cover, water column mixing and stratification, which all have profound effects on the availability of nutrients and light necessary for algal photosynthesis and growth.” Thus “climate has an indirect influence on the composition and productivity of phytoplankton, especially non-motile organisms such as diatoms.”

The ten researchers made “a detailed qualitative paleolimnological interpretation of the Lake Erlongwan sediment sequence based mainly on the growing body of literature that focuses on the ecology of planktonic diatoms, especially their responses to climate-driven changes in limnology.” They report “three intervals were identified by their diatom assemblages and correspond within dating uncertainties to the Medieval Warm Period, the Little Ice Age and the 20th century warming trend.” During the MWP, “the duration of the summer was longer while the spring and autumn were shorter than the 20th century.” And they state “the period between ca. AD 1150 and 1200 was the warmest interval of the past 1000 years.”

He *et al*. (2013) extracted sediment cores from the center of Lake Gahai (37°08’N, 97°31’E) and Lake Sugan (38°52’N, 93°75’E) and developed a decadally resolved alkenone-based temperature record for that part of the Qaidam Basin of the northern Tibetan Plateau that covered the last 2,600 and 2,200 years, respectively. Both records revealed the presence of the MWP between AD 700 and 1350. The ten Chinese researchers report regional temperatures during the peak warmth of the MWP, which occurred over the period AD 1100–1200 in Lake Gahai (see Figure 4.2.4.4.1.6) and AD 1000–1100 in Lake Sugan (see Figure 4.2.4.4.1.7), exceeded those in the recent warm period by approximately 1.9 and 4.0 °C, respectively.

The studies reviewed in this section make it clear that for a considerable amount of time during the Medieval Warm Period, most if not all of China exhibited warmer conditions than those of modern times. Those earlier high temperatures were caused by something other than elevated atmospheric CO_2 concentrations, and whatever was responsible for them also could be responsible for today's warmth. A growing body of evidence speaks to the reality of a global millennial-scale oscillation of climate totally independent of the air's CO_2 concentration. There is every reason to believe the most recent warming phase of this cycle, which ended the Little Ice Age and launched the Current Warm Period, was entirely natural and not the result of the coincidental increase in the air's CO_2 content.

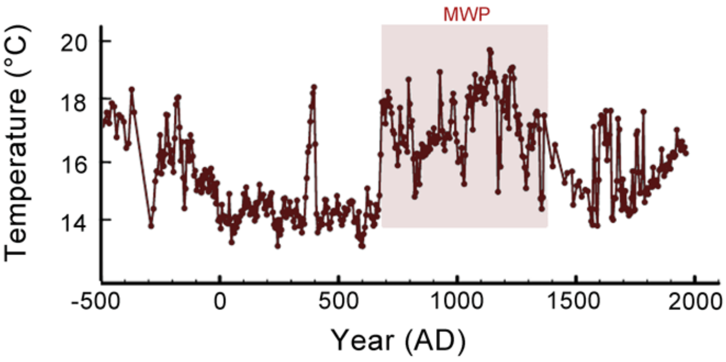

Figure 4.2.4.4.1.6. Alkenone-based temperature proxy from Lake Gahai. Adapted from He, Y.-X., Liu, W.-G., Zhao, C., Wang, Z., Wang, H.-Y., Liu, Y., Qin, X.-Y., Hu, Q.-H., An, Z.-S., and Liu, Z.-H. 2013. Solar influenced late Holocene temperature changes on the northern Tibetan Plateau. *Chinese Science Bulletin* **58**: 1053–1059.

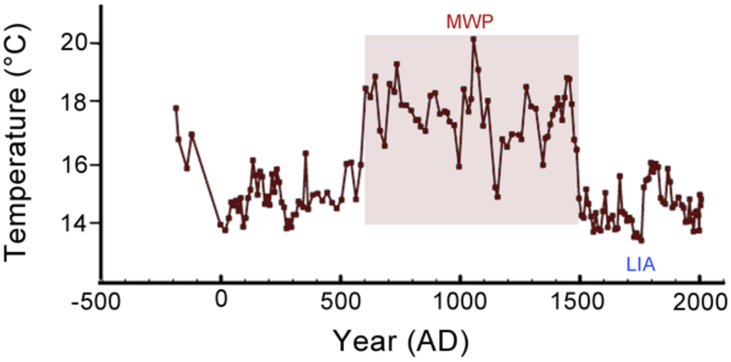

Figure 4.2.4.4.1.7. Alkenone-based temperature proxy from Lake Sugan. Adapted from He *et al.* (2013).

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4.2.4.4.2 Japan

The Medieval Warm Period (MWP) was a global climate anomaly that encompassed a few centuries on either side of AD 1000, when temperatures in many parts of the world were even warmer than they are currently. The degree of warmth and associated changes in precipitation varied from region to region, and the MWP was expressed somewhat differently in different parts of the world. How it manifested itself in Japan is the subject of this subsection.

Kitagawa and Matsumoto (1995) analyzed $\delta^{13}C$ variations of Japanese cedars growing on Yakushima Island, southern Japan (30°20’N, 130°30’E) to reconstruct a high-resolution proxy temperature record covering the past two thousand years. They applied spectral analysis to the $\delta^{13}C$ time series to determine if any significant periodicities were present in the data. They found significant decadal to centennial-scale variability throughout the record, with temperatures fluctuating by about 5°C across the series (see Figure 4.2.4.4.2.1). Most notable among the fluctuations were multi-century warm and cold epochs. Between AD 700 and 1200, for example, there was about a 1°C rise in average temperature, which “appears to be related to the ‘Medieval Warm Period.’” In contrast, they found temperatures were about 2°C below the long-term pre-1850 average during the multi-century Little Ice Age that occurred between AD 1580 and 1700.

Kitagawa and Matsumoto also report finding significant temperature periodicities of 187, 89, 70, 55, and 44 years. Noting the 187-year cycle closely corresponds to the well-known Suess cycle of solar activity, and the 89-year cycle compares well with the Gleissberg solar cycle, they conclude their findings provide strong support for a Sun-climate relationship. Their findings also support the growing body of evidence indicating the Medieval Warm Period and Little Ice Age were global phenomena. They thus conclude there was nothing unusual, unnatural, or unprecedented about Current Warm Period temperatures in this region, which remain about one degree Celsius lower than the peak warmth of the Medieval Warm Period.

Noting instrumental climate records are insufficient to be used alone in understanding natural climate variability, Adhikari and Kumon (2001) analyzed the total organic carbon, total nitrogen, and sand content of sediment cores extracted from Lake Nakatsuna in central Japan (36°30’N, 137°51’E) to produce a proxy record of climate for this region that covered the past 1,300 years. This project revealed both the Medieval Warm Period (AD 900–1200), which the two researchers said was “warmer than any other period during the last 1300 years,” and the Little Ice Age (AD 1200–1950), which was punctuated by three major cold phases (AD 1300–1470, 1700–1760 and 1850–1950). Their work thereby provides more evidence for a global Medieval Warm Period and a global Little Ice Age and suggests the Intergovernmental Panel on Climate Change (IPCC)

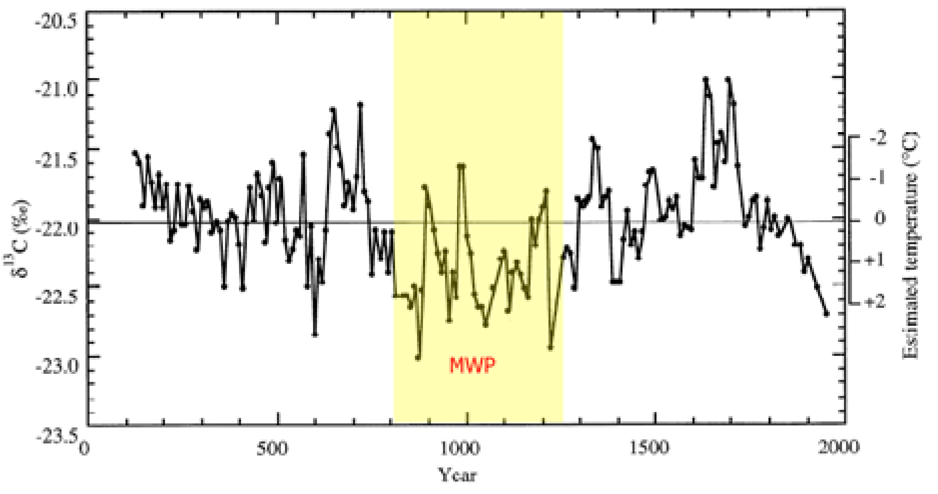

Figure 4.2.4.4.2.1. Proxy temperature record obtained from a δ^{13}C record of a giant Japanese cedar tree on Yakushima Island. Adapted from Kitagawa, H. and Matsumoto, E. 1995. Climatic implications of δ^{13}C variations in a Japanese cedar (*Cryptomeria japonica*) during the last two millennia. *Geophysical Research Letters* **22**: 2155–2158.

should never have abandoned its original climate history of the world—which more accurately depicted these significant temperature excursions (Houghton *et al*., 1990)—in favor of the flawed "hockey stick" temperature history of Mann *et al*. (1998, 1999).

Daimaru *et al*. (2002) write, "in snowpatch grasslands, plant distributions follow the contours of the snowmelt gradient around summer snowpatches," producing "similarly steep gradients in plant productivity and topsoil (e.g. Billings and Bliss, 1959; Helm, 1982; Kudo, 1991; Stanton *et al*., 1994.)" They state, "in the subalpine zone of northeastern Japan, sites where the snow cover disappears after July are usually occupied by 'snowpatch bare grounds' with extremely poor vegetation cover" that is "encircled by snowpatch grassland," citing Yamanaka (1979). As a result, "litter fall and the organic content in topsoil decrease toward the center of a snowpatch because the period for plant growth becomes shorter with delay in the time of snow disappearance," so in current "snowpatch grass-lands, peaty topsoil is restricted to sites where snowmelt comes early." The unique situation provided by a snowpatch can provide a good opportunity for paleoclimatic reconstructions based on vertical profiles of soil characteristics at various locations along transects moving outwards from summer snowpatches.

Daimaru *et al*. dug 27 soil pits at various locations in and around the center of a snowpatch grassland within a shallow depression of landslide origin on the southeastern slope of Japan's Mt. Zarumori (~39.8°N, 140.8°E), determining its age based on ^{14}C dating and tephrochronology. They state, "peaty topsoils were recognized at seven soil pits in the dense grassland, whereas sparse grassland lacked peaty topsoil." They also note, "most of the buried peat layers contained a white pumice layer named 'To-a' that fell in AD 915." This observation and the ^{14}C dating led them to conclude the buried peat layers in the poor vegetation area indicate "warming in the melt season" as well as "a possible weakened winter monsoon in the Medieval Warm Period," which their data suggest prevailed at the site throughout the tenth century; i.e., AD 900–1000. They observe "many studies have reported climatic signals that are correlated with the Medieval Warm Period from the 9th to 15th centuries in Japan," suggesting the possibly weakened winter monsoon of AD 900–1000 may have been a consequence of the warmer temperatures of that period.

Kitagawa *et al*. (2004) analyzed pollen in a sediment core retrieved from Karikomi Lake in the border area between the Hida and Echizen regions of Japan in the Hakusan mountains, as well as numerous local histories. They described the historical development of a practice called *hansaibai*, whereby local inhabitants encouraged the growth of horse-chestnut (*Aesculus turbinata*) trees as a food source during cold-induced famines of the Little Ice Age. Prior to that time, when the Medieval Warm Period prevailed, the mix of tree species in the local forest was that of "a warm temperate forest," they found. At about AD 1360, however, the warm-climate species "decreased, suggesting cooler climatic conditions," corresponding to "the beginning of the Little Ice Age as generally recognized in Japan (Sakaguchi, 1995)."

During this multi-century cold spell, Kitagawa *et al*. report "serious famines frequently occurred because of adverse climatic conditions," three of which were especially serious: "both the Kyoho famine in 1732 and the Tenmei famine (1782–1787) resulted in population decreases of about one million, and during the Tenpo famine (1823–1839) the population declined by ca. 290,000 (Nakajima, 1976)."

These observations clearly reveal the existence of both the Medieval Warm Period and Little Ice Age in Japan, strengthening the proposition that these distinctive climatic intervals were in fact global as opposed to merely regional phenomena restricted to countries bordering the North Atlantic Ocean. They also reveal the harshness of the Little Ice Age, which the five Japanese scientists say "caused serious famines in Europe, Argentina, and Mexico (Appleby, 1980; Cioccale, 1999; Post, 1984; Swan, 1981)," the latter two of which locations are also far removed from the North Atlantic Ocean.

Goto *et al*. (2005) reconstructed the ground surface temperature history from a borehole off the southern coast of Lake Biwa, the largest and oldest lake in Japan, to produce a proxy climate record spanning the past 3,000 years. The Medieval Warm Period was described as a period of warmth from the eighth to the twelfth century A.D. A comparison between the Medieval and Current Warm Periods could not be made because of anthropogenic and environmental factors influencing the record.

Isono *et al*. (2009) studied three sediment cores retrieved off the coast of central Japan in the northwestern Pacific Ocean (36°02'N, 141°47'E) to generate a multi-decadal-resolution record of alkenone-derived sea surface temperature (SST) that covers the full expanse of the Holocene. This record, they write, "showed centennial and millennial variability with an amplitude of ~1°C throughout the entire Holocene," and "spectral analysis for SST variation revealed a statistically significant peak with 1470-year periodicity." Isono *et al*. report, "SST minima centered at ca. 0.3 ka and ca. 1.5 ka are correlated with the Little Ice Age and the Dark Ages Cold Period in Europe, respectively, whereas the SST maximum centered at ca. 1.0 ka is correlated with the Medieval Warm Period." From data presented in the authors' Figure 2, it can be estimated the MWP was about 1°C warmer than the Current Warm Period.

Yamada *et al*. (2010) analyzed sediment cores they obtained in July 2007 from Lakes Ni-no-Megata (39°57'N, 139°43'E) and San-no-Megata (39°56'N, 139°42'E) on the Oga Peninsula of northeastern Japan, measuring a variety of properties including sulfur content and coarse mineral grains. The former served as a proxy for paleo-Asian summer monsoon activity, and the latter provided a proxy for paleo-Asian winter monsoon activity over the last two millennia. These data reveal the presence of a cold/dry interval from AD 1 to 750, a warm/humid interval from AD 750 to 1200, and another cold/dry interval from AD 1200 to the present. The scientists say these intervals could represent, respectively, "the Dark Ages Cold Period (DACP), the Medieval Warm Period (MWP) and the Little Ice Age (LIA)."

They note their findings complement those of Kitagawa and Matsumoto (1995), whose study of tree-ring records in southern Japan "suggested the existence of one warm interval at AD 750–1300 and two cold intervals at AD 200–750 and AD 1600–1800," and the findings of Sakaguchi (1983), whose study of the pollen record of peaty sediments in central Japan revealed "an unusual warm interval (AD 700–1300) and a cool interval (ca. AD 250–700)." In addition, they write, the "strong summer monsoon and weak winter monsoon at Lakes Ni-no-Megata and San-no-Megata from AD 750–1200 correlates with the lower $\delta^{18}O$ values from Wangxiang Cave (Zhang *et al*., 2008) and lower values of minerogenic clastic content (Chu *et al*., 2009)." This is further evidence of the global scope of the millennial-scale oscillation of climate that reverberates throughout both glacial and interglacial periods.

Aono and Saito (2010) "investigated documents and diaries from the ninth to the fourteenth centuries to supplement the phenological data series of the flowering of Japanese cherry (*Prunus jamasakura*) in Kyoto, Japan, to improve and fill gaps in temperature estimates based on previously reported phenological data." They "reconstructed a nearly continuous series of March mean temperatures based on 224 years of cherry flowering data, including 51 years of previously unused data, to clarify springtime climate changes" and estimated other cherry full-flowering dates "from phenological records of other deciduous species, adding further data for six years in the tenth and eleventh centuries by using the flowering phenology of Japanese wisteria (*Wisteria floribunda*)."

The two researchers report their reconstruction "showed two warm temperature peaks of 7.6°C and 7.1°C, in the middle of the tenth century and at the beginning of the fourteenth century, respectively," and "the reconstructed tenth century temperatures [AD 900–1000] are somewhat higher than present temperatures after subtracting urban warming effects." They add, "the general pattern of change in the reconstructed temperature series in this study is similar to results reported by previous studies, suggesting a warm period in Asia corresponding to the Medieval Warm Period in Europe."

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4.2.4.4.2 Russia

Early evidence for the Medieval Warm Period in Russia was provided by Naurzbaev and Vaganov

(2000), who developed a 2,200-year proxy temperature record (212 BC to 1996 AD) using tree-ring data obtained from 118 trees near the upper timberline in Siberia. They conclude the warming experienced in the twentieth century was "not extraordinary," and "the warming at the border of the first and second millennia was longer in time and similar in amplitude."

Demezhko and Shchapov (2001) studied a borehole extending to more than 5 km depth, reconstructing an 80,000-year history of ground surface temperature in the Middle Urals within the western rim of the Tagil subsidence (58°24' N, 59°44'E). This history revealed a number of climatic excursions, including, they write, the "Medieval Warm Period with a culmination about 1000 years ago." Several years later, and working along the eastern slope of the Ural Mountains (~50–58°N, ~57–62°E), Golovanova *et al.* (2012) employed temperature data obtained from 44 boreholes and calculated "the ground surface temperature at the maximum of the Medieval Warm Period in [AD] 1100–1200 was approximately the same as the present temperature."

Hiller *et al.* (2001) analyzed subfossil wood samples from the Khibiny mountains on the Kola Peninsula of Russia (67–68°N, 33–34°E) to reconstruct that region's climate history over the past 1,500 years. They determined between AD 1000 and 1300 the tree-line was located at least 100–140 m above its current elevation, which suggests, they write, mean summer temperatures during this "Medieval climatic optimum" were "at least 0.8°C higher than today" and "the Medieval optimum was the most pronounced warm climate phase on the Kola Peninsula during the last 1500 years."

Hantemirov and Shiyatov (2002) examined remains of subfossil Siberian larch trees in Holocene deposits of the Yamal Peninsula over an area stretching from approximately 67°15'N to 67°40'N and from 69°50'E to 71°E, which they used to develop a 4,000-year tree-ring width chronology covering the period 2000 BC to AD 1996. Based on a transfer function that yielded mean June–July air temperatures, which they developed from temperatures measured at a meteorological station 150 km southwest of their research area over the period AD 1883–1996, the two researchers transformed their tree-ring width chronology into a June–July summer air temperature history. Hantemirov and Shiyatov write, "relatively favorable conditions existed in 1200–900 BC, 100 BC–AD 200, and during the 'Medieval Optimum' (AD 700–1400)," the last of which they indicate was most pronounced over the time interval AD 1100–1350. From their Figure 11, which presents the reconstruction after applying a 20-year low-pass filter, it can be determined temperatures peaked during this interval about 0.5°C above those experienced at the end of the twentieth century.

Krenke and Chernavskaya (2002) reviewed what was known about the MWP within Russia and throughout the world based on historical, glaciological, and hydrologic evidence and dendrological, archaeological, and palynological data. They report, for example, "the northern margin of boreal forests in Canada was shifted [north] by 55 km during the MWP, and the tree line in the Rocky Mountains in the southern United States and in the Krkonose Mountains was higher by 100–200 m than that observed at the present time."

The two members of the Russian Academy of Sciences write, "the temperature averaged over the 20th century was found to be the highest among all centennial means, although it remained within the errors of reconstructions for the early millennium." But in reference to the "hockey stick" temperature reconstruction of Mann *et al*. (1998, 1999), they note, "one should keep in mind that the reconstructions of the early period were based nearly entirely on tree-ring data, which, because of the features of their interpretation, tend to underestimate low-frequency variations, so the temperatures of the Medieval Warm Period were possibly underestimated." They provide further evidence for that conclusion, reporting, "the limits of cultivated land or receding glaciers have not yet exceeded the level characteristic of the early millennium."

With respect to Russia, Krenke and Chernavskaya report large differences in several variables between the Little Ice Age (LIA) and MWP. They report, for example, an MWP to LIA drop of 1.5°C in the annual mean temperature of northern Eurasia. They also state, "the frequency of severe winters reported was increased from once in 33 years in the early period of time, which corresponds to the MWP, to once in 20 years in the LIA," additionally noting "the abnormally severe winters [of the LIA] were associated with the spread of Arctic air masses over the entire Russian Plain." They point out the data they used to draw these conclusions were "not used in the reconstructions performed by Mann *et al*.," which perhaps explains why the Mann *et al*. temperature history of the past millennium does not depict the coolness of the LIA or the warmth of the MWP nearly as well as the more appropriately derived temperature history of Esper *et al*. (2002).

Krenke and Chernavskaya point out "an analysis of climate variations over 1000 years should help reveal natural multi-centennial variations possible at present but not detectable in available 100–200-year series of instrumental records." Their research contradicts the claim twentieth century warming is outside the realm of natural variability and must therefore be due to anthropogenic CO_2 emissions. And in contradiction of another of Mann *et al*.'s contentions, Krenke and Chernavskaya unequivocally state "the Medieval Warm Period and the Little Ice Age existed globally."

Esper and Schweingruber (2004) analyzed treeline dynamics over western Siberia during the twentieth century by comparing nine undisturbed polar sites located between 59° and 106°E and 61° and 72°N. They merged the information in such a way that, they write, "larger-scale patterns of treeline changes are demonstrated, and related to decadal-scale temperature variations," while also relating current treeline positions to former treeline locations "by documenting in-situ remnants of relict stumps and logs."

The results showed two main pulses of northward treeline advance in the mid- and late-twentieth century. The first of these recruitment phases occurred between 1940 and 1960, and the second started around 1972 and lasted into the 1980s. These treeline advances corresponded closely to annual decadal-scale temperature increases. The two researchers note "the lack of germination events prior to the mid-20th century indicates this is an exceptional advance," but the relict stumps and logs found at most sites "show that this advance is part of a long-term reforestation process of tundra environments." They note, for example, "stumps and logs of *Larix sibirica* can be preserved for hundreds of years (Shiyatov, 1992)," and "above the treeline in the Polar Urals such relict material from large, upright trees were sampled and dated, confirming the existence, around AD 1000, of a forest treeline 30 m above the late 20th century limit (Shiyatov, 2003)." They also state, "this previous forest limit receded around 1350, perhaps caused by a general cooling trend (Briffa, 2000; Esper *et al*., 2002."

"Synchronous with the advance shown from the western Siberian network," Esper and Schweingruber write, a mid-twentieth century tree recruitment period was occurring in "central Sweden (Kullmann, 1981), northern Finland (Kallio, 1975), northern Quebec (Morin and Payette, 1984) and the Polar Urals (Shiyatov, 1992)." Considering this with their own results from Asia, they conclude, "these findings from Europe and North America support a circumpolar trend, likely related to a global climate warming pattern," thereby recognizing these data demonstrate the positive response of the biosphere to the warming that accompanied the demise of the Little Ice Age and the establishment of the Current Warm Period.

The international team of Kremenetski *et al.* (2004), composed of Russian, German, and U.S. scientists, conducted a multi-proxy study of climate-related factors in the Khibiny Mountains in the central part of the Kola Peninsula (67–68°N, 33–34°E), analyzing and dating a series of subfossil soil profiles buried in avalanche cones and living and subfossil pine trees. The researchers report finding "a period of exceptionally warm and dry conditions commenced at ca. AD 600 and was most pronounced between ca. AD 1000 and 1200." They note, "warmer summer temperatures during this period (coeval with the 'Medieval Warm Period' observed in other parts of Europe) are evident in a 100–140 m upward shift in the pine (*Pinus sylvestris* L.) limit." Applying a simple environmental lapse rate of 0.7°C/100 m to this finding, they state, "this warming can be estimated as being on the order of at least 1°C compared to the modern summer temperature." In addition, they report, "on average, the cellulose of pine trees that grew between ca. AD 1000 and 1300 is enriched by $\delta^{13}C$ values of around 1 [per mil] compared to the modern trees from the region, further suggesting warmer summer climate than at present." They also report "there was also a stabilization of slopes on avalanche cones and formation of soils on them" during this warmer and drier period. Finally, they note "this period of warming extends to northwestern Russia as well as other parts of Europe."

Solomina and Alverson (2004) reviewed and synthesized the findings of papers presented at a conference held in Moscow in May 2002, which brought together more than 100 local paleo-environmental researchers from Bellarussia, Estonia, Georgia, Kyrgyzstan, Russia, Ukraine, and Uzbekistan, plus another 30 scientists from 18 other countries. The two researchers summarized the meeting's overall findings for five distinct regions: the Arctic and Sub-Arctic, the Russian Plain and Caucasus, Central Asia and the Caspian Region, Eastern and Southern Siberia, and the Far East.

The Arctic and Sub-Arctic. "The 9th-14th centuries were relatively warm, though at least two colder periods probably occurred in the 11th and 13th centuries," after which "the 15th-early 20th centuries were generally cold," and "subsequent warming is recorded with almost all proxies."

The Russian Plain and Caucasus. "The climate of the Russian plain was relatively warm from the 11th to 14th centuries, with the exception of the late 12th-early 13th centuries, and colder from the 15th to 19th centuries, except for a warm interval in the first half of the 16th century." In the Central Caucasus, they also report the existence of a "relatively warm climate around the end of the first to the beginning of the second millennium AD," followed by "numerous glacier advances ... during the 14th-19th centuries," the timing of which correlates well with glacier advances in the European Alps.

Central Asia and the Caspian Region. "A milder, less continental climate with more precipitation approximately from the 9th to 12th centuries" was indicated by most of the available data, and "cold conditions dominated from the 13th to 19th centuries, though interrupted by a brief warm period from the end of the 14th-early 15th century," after which "the coldest conditions were probably in the 17th and 19th centuries, when glaciers advanced several times, lake level was high, and permafrost depth increased."

Eastern and Southern Siberia. "Two periods of warmer and drier climate can be roughly identified in this huge area as having occurred from the 9th to 11th centuries and in the 14th century," and "the 15th-19th centuries were clearly cold and the 20th century has seen a return to warm conditions."

The Far East. "There is some evidence suggesting moderately warm conditions in the North Pacific region from the end of the first to the beginning of the second millennium," with "a subsequent cooling after the 14th century."

Summarizing their findings for the bulk of Northern Eurasia, Solomina and Alverson write, "a number of records allow one to distinguish the climatic pattern of the 9th-13th centuries [i.e., the Medieval Warm Period] from earlier and later colder conditions [i.e., the Dark Ages Cold Period and Little Ice Age, respectively]." They also note "the spatial pattern of temperature anomalies ca. 1000 years ago is similar to the earlier mid-Holocene 'optimum.'" They write, "the warming of the 14th century in several regions, including the Russian plain, Altai and Central Asia, was at least as intense as the earlier one at ca. 1000 years before present or even warmer." The latter widely detected event might correspond to what some have called the Little Medieval Warm Period, or it may be the final years of the Medieval Warm Period before it relinquished control of Earth's climate to the Little Ice Age.

Kalugin *et al*. (2005) analyzed sediment cores from Lake Teletskoye in the Altai Mountains of Southern Siberia (51°42.90'N, 87°39.50'E), producing a multi-proxy climate record spanning the past 800 years. This record revealed several distinct climate periods over the past eight centuries. The regional climate was relatively warm with high terrestrial productivity from AD 1210 to 1380. Thereafter, temperatures cooled, reaching peak deterioration between 1660 and 1700, which "corresponds to the age range of the well-known Maunder Minimum (1645–1715)" and is "in agreement with the timing of the Little Ice Age in Europe (1560–1850)." Recovery to prior-level warmth did not occur until late in the twentieth century.

With respect to moisture and precipitation, Kalugin *et al*. state the period between 1210 and 1480 was more humid than today, whereas the period between 1480 and 1840 was more arid. In addition, they report three episodes of multi-year drought (1580–1600, 1665–1690, and 1785–1810). These findings agree with other historical data and tree-ring records from the Mongolia-Altai region (Butvilovskii, 1993; Jacoby *et al*., 1996; Panyushkina *et al*., 2000). Their findings prove problematic for those who claim global warming will lead to more severe droughts, as all of the major multi-year droughts detected in this study occurred during the cool phase of the 800-year record.

Mackay *et al*. (2005) analyzed paleolimnological data obtained from a sediment core taken from the south basin of Lake Baikal, Russia, to reconstruct the climatic history of this area of central Asia over the past millennium. Their use of cluster analysis identified three significant zones of variability in the sediment core coincident with the Medieval Warm Period (c. 880 AD to c. 1180 AD), the Little Ice Age (c. 1180 AD to 1840 AD), and the Current Warm Period. The seven scientists say their diatom data supported the idea that "the period known as the MWP in the Lake Baikal region was a relatively warm one." Following the MWP, diatom species shifted toward taxa indicative of colder climates, implying maximum snow depth values during the Maunder Minimum (1645–1715 AD), after which the diatom-derived snow accumulation data indicated a warming trend in the Lake Baikal region that began as early as c. 1750 AD. That the warming began around 1750 AD, nearly 100 years before the modern rise in atmospheric CO_2 concentration, suggests the planet’s current warmth is the result of nothing more than the most recent and expected upward swing of this natural climatic oscillation.

Mazepa (2005) notes “dead trees located above the current tree-line ecotone provide evidence of the dynamic behavior in the location of the tree line in the recent past (Shiyatov, 1993, 2003)” and “previous studies have concluded that increases in tree-line elevation, and associated increases in tree abundance within the transient tree-line ecotone, are associated with extended warm periods (Tranquillini, 1979; Kullman, 1986; Payette *et al*., 1989; Lloyde and Fastie, 2003; Lloyd *et al*., 2003; Grace *et al*., 2002; Helama *et al*., 2004).”

Mazepa evaluated the uniqueness of Polar Ural tree-line and density response “to what is widely considered to be anomalous 20th-century warming,” examining evidence of tree growth dynamics along a continuous altitudinal transect 860 meters long and 40–80 meters wide on the eastern slope of the Polar Ural Mountains (66°48’57”N, 65°34’09”E) by repeating what Shiyatov had done four decades earlier. Mazepa discovered “a large number of well-preserved tree remains can be found up to 60–80 meters above the current tree line, some dating to as early as a maximum of 1300 years ago,” and “the earliest distinct maximum in stand density occurred in the 11th to 13th centuries, coincident with Medieval climatic warming,” when “summer air temperatures may have been 0.42–0.56°C warmer than they were over the last decades of the 20th century.”

Andreev *et al.* (2007) analyzed pollen and charcoal stratigraphy in a sediment core extracted from the central and deepest part of Lake Teletskoye in the northeastern part of the Altai Mountains in southern Siberia (51°43’N, 87°39’E), developing what they describe as “the first detailed climate and vegetation reconstruction for the last millennium in the northern Altai Mountains” (see Figure 4.2.4.4.3.1).

They found “dense Siberian pine forest dominated the area around the lake at least since ca. AD 1020,” when “climate conditions were similar to modern.” Then, “between AD 1100 and 1200, a short dry period with increased fire activity occurred,” and “around AD 1200, climate became more humid with the temperatures probably higher than today.” This period of relatively stable climate, “possibly reflecting [the] Medieval Warm Epoch, lasted until AD 1410,” after which “slightly drier climate conditions occurred between AD 1410 and 1560.” Thereafter, “a subsequent period with colder and more arid climate conditions between AD 1560 and 1820 is well correlated with the Little Ice Age,” after which the evidence indicated a climate warming they “inferred from the uppermost pollen spectra, accumulated after AD 1840,” which was “consistent with the instrumental data” of the modern period.

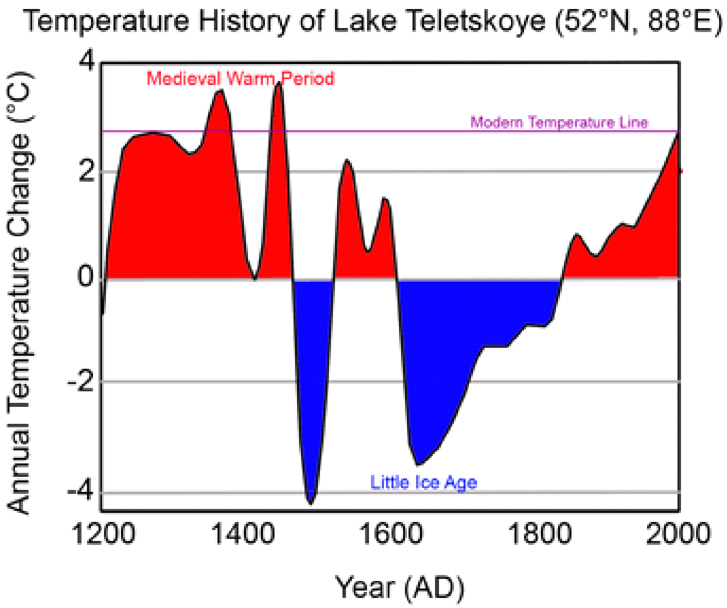

Figure 4.2.4.4.3.1. Proxy temperature record of Lake Teletskoye in the northeastern part of the Altai Mountains in southern Siberia. Adapted from Andreev, A.A., Pierau, R., Kalugin, I.A., Daryin, A.V., Smolyaninova, L.G., and Diekmann, B. 2007. Environmental changes in the northern Altai during the last millennium documented in Lake Teletskoye pollen record. *Quaternary Research* **67**: 394–399.

It is clear from Andreev *et al.*’s findings that the Altai Mountain region of southern Siberia displays the characteristic millennial-scale cycling of climate, from Medieval Warm Period to Little Ice Age to Current Warm Period conditions, that is characteristic of most of the rest of the world. That temperatures in the region from approximately AD 1200 to 1410 were “probably higher than today” provides yet another example of times and places when and where low-CO_2 Medieval Warm Period temperatures were likely higher than high-CO_2 Current Warm Period temperatures.

Kalugin *et al*. (2007) collected several sediment cores from the deepest area of Teletskoye Lake and measured the spectra of numerous elements—including Ba, Cd, Ce, I, La, Mo, Nb, Rb, Sb, Sn, Sr, Th, U, Y, and Zr—after which "artificial neural networks (Veelenturf, 1995) were used for reconstruction of annual temperature and precipitation by sediment properties (Smolyaninova *et al*., 2004)." The six scientists state, "a global cold period, the Little Ice Age with Maunder minimum, is clearly designated in their data, as well as global warming during the 19–20th centuries," implying the existence of the Medieval Warm Period that preceded the Little Ice Age. Their plot of the data (see Figure 4.2.4.4.3.2) shows the mean peak temperature of the latter part of the Medieval Warm Period was about 0.5°C higher than the mean peak temperature of the Current Warm Period, which occurred at the end of the record.

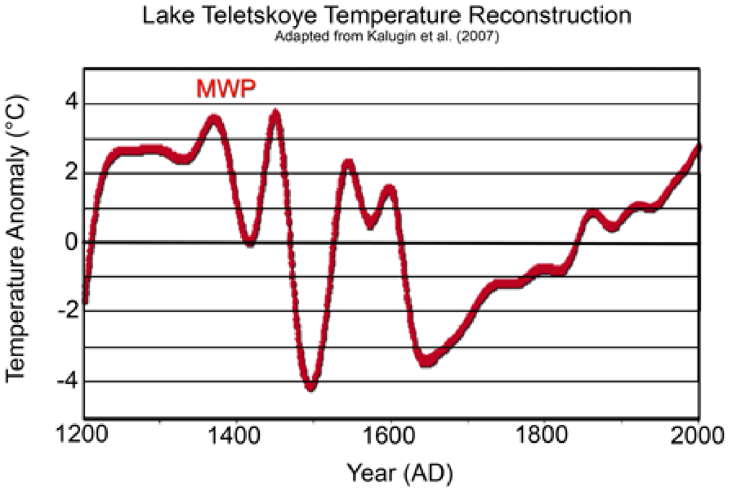

Figure 4.2.4.4.3.2. Proxy temperature record of Lake Teletskoye in the Altai Mountains in southern Siberia. Adapted from Kalugin, I., Daryin, A., Smolyaninova, L., Andreev, A., Diekmann, B., and Khlystov, O. 2007. 800-yr-long records of annual air temperature and precipitation over southern Siberia inferred from Teletskoye Lake sediments. *Quaternary Research* **67**: 400–410.

Matul *et al*. (2007) studied the distributions of siliceous microflora (diatoms), calcareous microfauna (foraminifers), and spore-pollen assemblages found in sediment cores retrieved from 21 sites on the inner shelf of the southern and eastern Laptev Sea, starting from the Lena River delta and moving seaward between about 130 and 134°E and stretching from approximately 71 to 78°N. The cores were acquired by a Russian-French Expedition during the cruise of R/V *Yakov Smirnitsky* in 1991. The research revealed, in the words of the five Russian scientists, "(1) the warming at the beginning of the Common Era (terminal epoch of the Roman Empire) during ~1600–1900 years BP; (2) the multiple, although low-amplitude, cooling episodes at the beginning of the Middle Ages, 1100–1600 years BP; (3) the Medieval Warm Period, ~600–1100 years BP; (4) the Little Ice Age, ~100–600 years BP, with the cooling maximum, ~150–450 years BP; and (5) the 'industrial' warming during the last 100 years." They conclude, "judging from the increased diversity and abundance of the benthic foraminifers, the appearance of moderately thermophilic diatom species, and the presence of forest tundra (instead of tundra) pollen, the Medieval warming exceeded the recent 'industrial' one."

Sidorova *et al*. (2007) developed a history of trunk radial growth increment of larch (*Larix gmelinii* Rupr.) trees in the middle reaches of the Bol'shoi Avam River on the northern edge of the Putoran Plateau, central Taimyr (70°30'N, 93°01'E), for the period AD 886–2003, which they found to be correlated with summer air temperature. This work revealed a period from the start of the record to approximately AD 1200 when inferred temperatures were generally much greater than those of the final decades of the twentieth century.

MacDonald *et al*. (2008) conducted an analysis of past changes in the location of the northern Russian treeline, as reconstructed from tree-ring data and radiocarbon-dated subfossil wood, to ascertain whether "the pattern of recent warming over the late nineteenth and the twentieth centuries caused significant changes in the density of trees at the treeline and/or an extension of the geographical location of the treeline." They report "temperature increases over the past century are already producing demonstrable changes in the population density of trees, but these changes have not yet generated an extension of conifer species' limits to or beyond the former positions occupied during the Medieval Warm Period (MWP: *ca* AD 800–1300) or the Holocene Thermal Maximum treeline extension (HTM: broadly taken here to be *ca* 10,,000–3,000 years ago)."

On the Khibiny uplands of the central Kola Peninsula, for example, "the treeline was located 100–140 m higher in elevation than today during the MWP," and "forest has yet to recolonize these elevations (Kremenetski *et al.*, 2004).” Of the northern Polar Urals they state, “the treeline was at its highest elevation during the MWP between *ca* AD 900 and 1300 when it reached 340 m,” after which it “descended to approximately 270 m during the Little Ice Age and then ascended to its present elevation of approximately 310 m during the recent warming of the late nineteenth and twentieth centuries.”

The three researchers conclude, “at the Russian sites studied, the impact of twentieth century warming has not yet compensated fully for the mortality and range constriction caused by the cold temperatures of the Little Ice Age,” and they note “these results are similar to observations in some other northern treeline regions such as uplands in eastern Quebec and interior Labrador where *Picea mariana* (P. Mill.) B.S.P. and *Picea glauca* (Moench) Voss trees remain below their pre-Little Ice Age limits despite recent warming (Gamache and Payette, 2005; Payette, 2007).”

Noting the long-term decrease in seasonal peaks of water levels allows human settlement of low geomorphic locations, such as river and lake floodplains, whereas a rise in flood levels causes settlements to be shifted to higher elevations, Panin and Nefedov (2010) noted “ancient settlements could not persist under the impact of regular inundations.” In a study of the Upper Volga and Zapadnaya Dvina Rivers of Russia, the two researchers determined “the geomorphological and altitudinal positions of [human] occupational layers corresponding to 1224 colonization epochs at 870 archaeological sites in river valleys and lake depressions in southwestern Tver province,” identifying “a series of alternating low-water (low levels of seasonal peaks, many-year periods without inundation of flood plains) and high-water (high spring floods, regular inundation of floodplains) intervals of various hierarchical rank.”

They found “low-water epochs coincide with epochs of relative warming, while high-water epochs [coincide] with cooling epochs,” because “during the climate warming epochs, a decrease in duration and severity of winters should have resulted in a drop in snow cover water equivalent by the snowmelt period, a decrease in water discharge and flood stage, and a decrease in seasonal peaks in lake levels,” while noting “a model of past warming epochs can be the warming in the late 20th century.” They also report finding “in the Middle Ages (1.8–0.3 Ky ago), the conditions were favorable for long-time inhabiting [of] river and lake floodplains, which are subject to inundation nowadays.” They found the period AD 1000–1300 hosted the greatest number of floodplain settlements..

Panin and Nefedov argue this last period and other “epochs of floodplain occupation by humans in the past can be regarded as hydrological analogues of the situation of the late 20th-early current century,” which they say “is forming under the effect of directed climate change.” This relationship clearly implies the current level of warmth in the portion of Russia that hosts the Upper Volga and Zapadnaya Dvina Rivers is not yet as great as it was during the AD 1000–1300 portion of the Medieval Warm Period.

Noting dust storms are common features adjacent to the Aral Sea, Huang *et al.* (2011) investigated the grain-size distributions of wind-blown sediments found in a core retrieved from that water body while “attempting to trace the variations in atmospheric dynamics in central Asia during the past 2000 years,” They focused on variations observed at the transition from the Medieval Warm Period to the Little Ice Age, since this period, they write, “is the most pronounced climatic transformation during the last millennium,” citing Yang B. *et al.* (2002), Trouet *et al.* (2009), and Chen *et al.* (2010). Their analysis revealed the history of dust deposition in central Asia can be divided into five distinct periods on the basis of their observations: “a remarkably low deposition during AD 1–350, a moderately high value from AD 350–720, a return to a relatively low level between AD 720 and AD 1400 (including the Medieval Warm Period), an exceptionally high deposition from AD 1400 to [the] 1940s and an abnormally low value since [the] 1940s.”

The first of these “distinct periods” coincides with the Roman Warm Period, the second with the Dark Ages Cold Period, the third (as Huang *et al.* note) with the Medieval Warm Period, the fourth with the Little Ice Age, and the fifth with the Current Warm Period. They found the temporal variation in dust deposition they observed was consistent with the “mean atmospheric temperature of the Northern Hemisphere during the past 2000 years, with low/high annual temperature anomalies corresponding to high/low dust supplied in the Aral Sea sediments, respectively.” The four researchers’ graphs of their wind intensity/dust storm data show the minimum values of these inverted measures of annual temperature during the Roman Warm Period, the Medieval Warm Period, and the Current Warm Period were all about the same.

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4.2.4.4.4 Other Asian Countries

In addition to China, Russia, and Japan, the MWP has been identified in several other parts of Asia. Schilman *et al*. (2001), for example, analyzed foraminiferal oxygen and carbon isotopes, together with physical and geochemical properties of sediments, contained in two cores extracted from the bed of the southeastern Mediterranean Sea off the coast of Israel, where they found evidence for the MWP centered on AD 1200. They note there is an abundance of other well-documented evidence for the existence of the MWP in the Eastern Mediterranean, including, they write, "high Saharan lake levels (Schoell, 1978; Nicholson, 1980), high Dead Sea levels (Issar *et al*., 1989, 1991; Issar, 1990, 1998; Issar and Makover-Levin, 1996), and high levels of the Sea of Galilee (Frumkin *et al*., 1991; Issar and Makover-Levin, 1996)," in addition to "a precipitation maximum at the Nile headwaters (Bell and Menzel, 1972; Hassan, 1981; Ambrose and DeNiro, 1989) and in the northeastern Arabian Sea (von Rad *et al*., 1999)."

Schilman *et al*. (2002) analyzed high-resolution δ^{18}O values from a speleothem in Soreq Cave, central Israel (31°45'N, 35°03'E), as well as from planktonic foraminifera in two marine sediment cores retrieved just off the Ashdod coast (31°56.41'N, 34°22.13'E and 31°56.61'N, 34°19.79'E), to obtain a record of climate in this region over the past 3,600 years. The δ^{18}O values of the speleothem and marine cores showed "striking similarity" over the period of study, according to Schilman *et al*., and they were determined to be primarily representative of historic changes in precipitation. Over the 3,600-year record, six major precipitation intervals were noted, three that were relatively wet and three that were relatively dry. The peaks of the humid events occurred at 3,200, 1,300, and 700 yr BP, the latter of which was said by the researchers to be "associated with the global MWP humid event."

Cini Castagnoli *et al*. (2005) extracted a δ^{13}C profile of *Globigerinoides rubber* from a shallow-water core in the Gulf of Taranto (39°45'53"N, 17°53'33"E) to produce a high-precision record of climate variability over the past two millennia, after which it was statistically analyzed, together with a second two-millennia-long tree-ring record obtained from Japanese cedars (Kitagawa and Matsumoto, 1995), for evidence of recurring cycles using Singular Spectrum Analysis and Wavelet Transform. Plots of both records revealed the Dark Ages Cold Period (~400–800 AD), the Medieval Warm Period (~800–1200 AD), the Little Ice Age (~1500–1800 AD), and the Current Warm Period, the roots of which can be traced to an upswing in temperature that began in the depths of the Little Ice Age "about 1700 AD."

Both records were compared with a 300-year record of sunspots Results of the statistical analyses showed a common 11-year oscillation in phase with the Schwabe cycle of solar activity, plus a second multidecadal oscillation (of about 93 years for the shallow-water *G. rubber* series and 87 years for the tree-ring series) in phase with the amplitude modulation of the sunspot number series over the last 300 years. According to the three researchers, the overall phase agreement between the two climate reconstructions and the variations in the sunspot number series "favors the hypothesis that the [multidecadal] oscillation revealed in δ^{13}C from the two different environments is connected to the solar activity," suggesting a solar forcing was at work in both terrestrial and oceanic domains over the past two millennia.

Li *et al*. (2006) conducted palynological analyses of two sediment cores taken from the Song Hong (Red River) Delta, Vietnam (~20.26°N, 106.52°E) to reconstruct climate variations there throughout the Holocene. As indicated by an abundance of taxa well adapted to tropical and subtropical environments, they conclude the Medieval Warm Period (~AD 500–1330) was warmer than the current climate.

Kaniewski *et al*. (2011) write, "according to model-based projections, the northern Arabian Peninsula, a crossroad between Mediterranean, continental and subtropical climates, will be extremely sensitive to greenhouse warming," citing the work of Alpert *et al*. (2008). They also note, "insights into past climate variability during historical periods in such climate hotspots are of major interest to estimate if recent climate trends are atypical or not over the last millennium," but "few palaeo-environmental records span the MCA [Medieval Climate Anomaly] and LIA [Little Ice Age] in the Middle East." Based on an analysis of pollen types and quantities found in a 315-cm sediment core retrieved from alluvial deposits within the floodplain of a spring-fed valley located at 35°22'13.16"N, 35°56'11.36"E in the coastal Syrian lowland, Kaniewski *et al*. converted the pollen data into Plant Functional Types (PFTs) that allowed them to construct pollen-derived Biomes (PdBs) similar to the regional studies of Tarasov *et al*. (1998). They were then able to relate the ratio of PdB warm steppe (WAST) divided by PdB cool steppe (COST) to local temperature, as also had been done a decade earlier by Tarasov *et al*. (1998).

The seven scientists state their WAST/COST record "indicates that temperature changes in coastal Syria are coherent with the widely documented warming during the MCA and cooling during the LIA," assigning the first of these epochs to the period of approximately AD 1000 to 1230 and the latter to approximately AD 1580 to 1850. Regarding the Current Warm Period, they state, "modern warming appears exceptional in the context of the past 1250 years, since only three warm peaks of similar amplitude are registered during the High Middle Ages." However, they conclude, the "three peaks centered on ca. 1115, 1130 and 1170 cal yr AD suggest similar or warmer temperatures compared to AD 2000." The plot of their WAST/COST record (Figure 4.2.4.4.4.1) shows the warmth of the first and last of these peaks was essentially identical to that centered on the end of the last century (AD 2000), and the central peak at AD 1130 was the warmest..

The findings of Kaniewski *et al*. thus reveal recent climate trends in the region of Syria they studied are not atypical over the last millennium, although they do not say so in their study. Earth's current level of warmth need not be attributed to the current high level of the air's CO_2 content; the peak warmth of the MWP was greater than it has been over the past couple of decades yet the air's CO_2 concentration was approximately 100 ppm less than it is today.

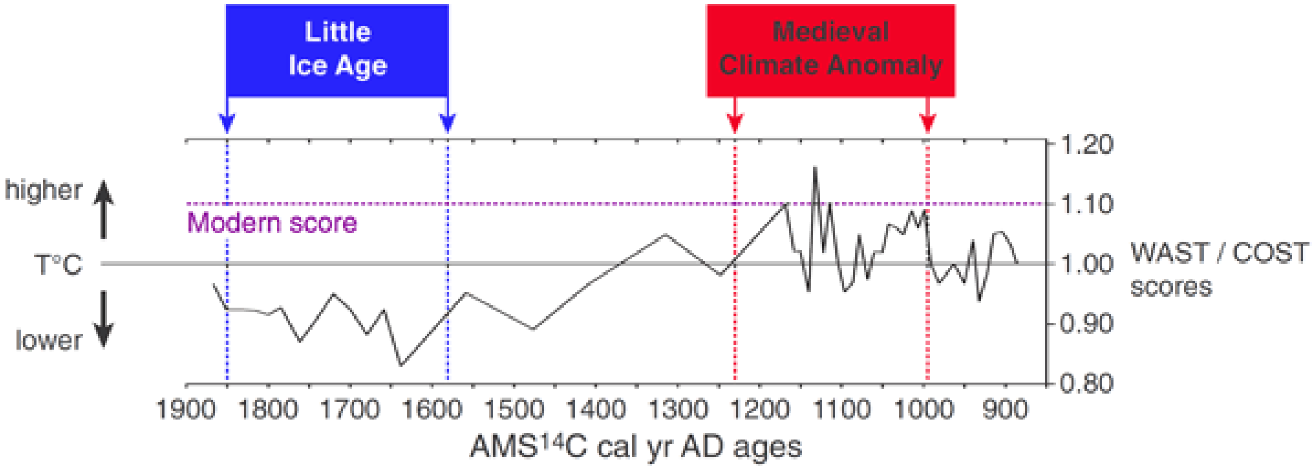

Figure 4.2.4.4.4.1. The 880-1870 cal yr AD warm-cool ratio WAST/COST temperature reconstruction of Kaniewski, D., Van Campo, E., Paulissen, E., Weiss, H., Bakker, J., Rossignol, I., and Van Lerberghe, K. 2011. The medieval climate anomaly and the little Ice Age in coastal Syria inferred from pollen-derived palaeoclimatic patterns. *Global and Planetary Change* **78**: 178–187, Figure 5.

Kar *et al*. (2002) explored the nature of climate change in India as preserved in the sediment profile of an outwash plain two to three km from the snout of the Gangotri Glacier in the Uttarkashi district of Uttranchal, Western Himalaya. Their data reveal a relatively cool climate between 2,000 and 1,700 years ago. From 1,700 to 850 years ago, there was what they called an "amelioration of climate" during the transition from the depth of the Dark Ages Cold Period to the midst of the Medieval Warm Period. After that, Kar *et al*.'s data indicate the climate "became much cooler," indicative of its transition to Little Ice Age conditions, and during the last 200 years there has been a rather steady warming, as shown by Esper *et al*. (2002a) to have been characteristic of the entire Northern Hemisphere.

Feng and Hu (2005) acquired decadal surface air temperatures for the last two millennia from ice core and tree-ring data obtained at five locations on the Tibetan Plateau. These data revealed the late twentieth century was the warmest period in the past two millennia at two of the sites (Dasuopu, ice core; Dunde, ice core), but not at the other three sites (Dulan, tree ring; South Tibetan Plateau, tree ring; Guilya, ice core). At Guilya, for example, the data indicated it was significantly cooler in the final two decades of the twentieth century than for most of the first two centuries of the record, which comprised the latter part of the Roman Warm Period. At the South Tibetan Plateau it was also significantly warmer over a full century near the start of the record, and at Dulan it was significantly warmer for the same portion of the Roman Warm Period plus two near-century-long portions of the Medieval Warm Period. These observations cast doubt on claims late twentieth century temperatures were unprecedented over the past two millennia, and they provide additional evidence for the millennial-scale climatic oscillation that sequentially brought the Roman Warm Period, Dark Ages Cold Period, Medieval Warm Period, Little Ice Age, and Current Warm Period.

Phadtare and Pant (2006) developed a 3,500-year palaeoclimate record of the Late Holocene using a study of pollen and organic matter content and the magnetic susceptibility of radiocarbon-dated samples from a peat deposit in the Kumaon Higher Himalaya of India (30°3'N, 70°56'E). "With an abrupt rise in temperature as well as moisture at ~AD 400," they write, "the climate suddenly turned warm and moist and remained so until ~AD 1260." This period, they note, is "generally referred to as the Medieval Warm Period in the Northern Hemisphere." The climate turned cold and dry over the ensuing century, but then warm and wet again, before turning "cold and moist during ~AD 1540–1730," stating the latter climate episode "represent[s] the Little Ice Age event in the Garhwal-Kumaon Himalaya."

Thereafter, the Indian researchers say, "the climate has been persistently wet with relatively higher temperatures until ca. AD 1940, followed by a cooling trend that continued till the present."

This dramatic modern cooling also is observed in the regional tree-ring record of Yadav *et al.* (2004), who used many long tree-ring series obtained from widely spaced Himalayan cedar (*Cedrus deodara* (Roxb.) G. Don) trees growing on steep slopes with thin soil cover to develop a temperature history of the western Himalayas for the period AD 1226–2000. "Since the 16th century," they write, "the reconstructed temperature shows higher variability as compared to the earlier part of the series (AD 1226–1500), reflecting unstable climate during the Little Ice Age (LIA)."

Yadav *et al.* note similar results have been obtained from juniper tree-ring chronologies from central Tibet (Braeuning, 2001), and "historical records on the frequency of droughts, dust storms and floods in China also show that the climate during the LIA was highly unstable (Zhang and Crowley, 1989)." Yadav *et al.* report 1944–1953 was the warmest 10-year mean of the entire 775-year record, and "thereafter, temperatures decreased." This cooling, they note, "is in agreement with the instrumental records." Also, they state, "tree-ring based temperature reconstructions from other Asian mountain regions like Nepal (Cook *et al.*, 2003), Tibet and central Asia (Briffa *et al.*, 2001) also document cooling during [the] last decades of the 20th century."

The temperatures of the final two decades of Yadav *et al.*'s record appear to be as cold as those of any comparable period over the prior seven-and-a-half centuries, including the coldest periods of the Little Ice Age. This result, they indicate, is radically different from the temperature reconstruction of Mann and Jones (2003), which depicts "unprecedented warming in the 20th century."

Brauning and Griessinger (2006) analyzed $\delta^{13}C$ data obtained from wood cellulose of annual growth rings of long-lived juniper (*Juniperus tibetica*) trees growing at a site in east-central Tibet at approximately 31.8°N, 92.4°E, which were found to be significantly positively correlated with summer temperatures of the surrounding region. The authors found "warm and dry conditions during the Medieval Warm Period between AD 1200 and 1400." Their graph of the data reveals the peak temperature of the MWP to have been greater than the peak temperature of the CWP.

Chauhan (2006) derived abundance distributions of various types of pollen deposited over the past 1,300 years in a one-meter-deep sediment core retrieved from the alpine-region Naychhudwari Bog (77°43'E, 32°30'N) of Himachal Pradesh, northern India. Analyses revealed two broad climatic episodes of warm-moist and cold-dry conditions, the first covering the period AD 650 to 1200 and the second from AD 1500 onwards. "In the global perspective," the Indian scientist writes, the first period "is equivalent to the Medieval Warm Period, which has been witnessed in most parts of the world," while the second period "falls within the time-limit of [the] Little Ice Age."

In the first of these two periods, Chauhan remarks, "the alpine belt of this region experienced warm and moist climate [and] the glaciers receded and the tree-line ascended to higher elevations," suggesting the existence of a prior cooler and drier climate, the Dark Ages Cold Period. From AD 1500 onward, Chauhan writes, "the glaciers advanced and consequently the tree-line descended under the impact of [the] cold and dry climate in the region."

Bhattacharyya *et al.* (2007) developed a relative history of atmospheric warmth and moisture covering the last 1,800 years for the region surrounding Paradise Lake, located in the Northeastern Himalaya at approximately 27°30.324'N, 92°06.269'E, based on pollen and carbon isotopic ($\delta^{13}C$) analyses of a one-meter-long sediment profile obtained from a pit "dug along the dry bed of the lakeshore." Their climatic reconstruction revealed a "warm and moist climate, similar to the prevailing present-day conditions," around AD 240, which would represent the last part of the Roman Warm Period, and another such period "warmer 1100 yrs BP (around AD 985) corresponding to the Medieval Warm Period."

Chauhan and Quamar (2010) analyzed a 2-m-long sediment core retrieved from the Kiktiha Swamp of Central India (~23°N, 84°E) to develop temporal distributions of many types of plants, identifying three major climatic regimes over the past 1,650 years. The first of these regimes was described by the two researchers as "a warm and moist climate," which "supported tropical deciduous Sal forests." This interval "corresponds with the period of the Medieval Warm Period, which is known between AD 740 and 1150 (Lamb, 1977)." The second regime, from about AD 1250 to 1650, was mostly a "period of harsh climate" that "falls within the temporal range of [the] Little Ice Age." It was followed by the third regime, another warm period that has now persisted for three centuries and resulted in "the revival of modern Sal forests." It is not possible to determine from Chauhan and Quamar's paper which of the two warm periods may have been the warmer.

Kotlia and Joshi (2013) examined a 3.55-meter-long sediment core extracted from Badanital Lake (30°29'50"N, 78°55'26"E) in the Garhwal Himalaya of India, finding "the imprints of four major global events"—the "4.2 ka event, Medieval Warm Period (MWP), Little Ice Age (LIA) and modern warming"—based on measurements and analyses of "major oxides and their ratios (CaO/MgO, CaO/TiO2, MgO/TiO2, Na2O/TiO2, TiO2/Al2O3, Na2O/K2O and Fe2O3/TiO2), major elements, chemical index of weathering, chemical index of alteration and loss on ignition." They report the MWP "prevailed around 920–440 years BP," concluding their work "adds to the growing evidence for the global extent of these events."

Esper *et al.* (2002b) used more than 200,000 ring-width measurements obtained from 384 trees at 20 sites ranging from the lower to upper timberline in the Northwest Karakorum of Pakistan (35–37°N, 74–76°E) and Southern Tien Shan of Kirghizia (40°10'N, 72°35'E) to reconstruct regional patterns of climatic variations in Western Central Asia since AD 618. They found the Medieval Warm Period was firmly established and growing warmer by the early seventh century, and between AD 900 and 1000, tree growth was exceptionally rapid, at rates they say "cannot be observed during any other period of the last millennium."

Between AD 1000 and 1200, growing conditions deteriorated, and at about 1500, minimum tree ring-widths were reached that persisted well into the seventeenth century. Toward the end of the twentieth century, ring-widths increased once again, but Esper *et al.* (2002b) report "the twentieth-century trend does not approach the AD 1000 maximum." There is almost no comparison between the two periods, with the Medieval Warm Period being far more conducive to tree growth than the Current Warm Period. As the three researchers note, "growing conditions in the twentieth century exceed the long-term average, but the amplitude of this trend is not comparable to the conditions around AD 1000."

Esper *et al.* (2003) processed several extremely long juniper ring width chronologies for the Alai Range of the western Tien Shan in Kirghizia in such a way as to preserve multi-centennial growth trends typically "lost during the processes of tree ring data standardization and chronology building (Cook and Kairiukstis, 1990; Fritts, 1976)." They used two techniques that maintained low frequency signals: long-term mean standardization (LTM) and regional curve standardization (RCS), as well as the more conventional spline standardization (SPL) technique that obscures (removes) long-term trends.

Carried back a full thousand years, the SPL chronologies depict significant interdecadal variations but no longer-term trends. The LTM and RCS chronologies, on the other hand, show long-term decreasing trends from the start of the record until about AD 1600, broad minima from 1600 to 1800, and long-term increasing trends from about 1800 to the present. Esper *et al.* (2003) report, "the main feature of the LTM and RCS Alai Range chronologies is a multi-centennial wave with high values towards both ends."

This result has essentially the same form as the Northern Hemisphere extratropical temperature history of Esper *et al.* (2002a), depicting the existence of both the Little Ice Age and preceding Medieval Warm Period, which are nowhere to be found in the "hockey stick" temperature reconstructions of Mann *et al.* (1998, 1999) and Mann and Jones (2003). In addition, the work of Esper *et al.* (2002b)—especially the LTM chronology, which has a much smaller variance than the RCS chronology—depicts several periods in the first half of the last millennium that were warmer than any part of the last century. These periods include much of the latter half of the Medieval Warm Period and a good part of the first half of the fifteenth century, which also has been found to have been warmer than it is currently by McIntyre and McKitrick (2003) and by Loehle (2004). Esper *et al*. (2003) remark, "if the tree ring reconstruction had been developed using 'standard' detrending procedures only, it would have been limited to inter-decadal scale variation and would have missed some of the common low frequency signal."

Treydte *et al*. (2009) write "it is still uncertain whether the magnitude and rate of 20th century warming exceeds natural climate variability over the last millennium," citing Esper *et al*. (2002a, 2005a, 2005b), Moberg *et al*. (2005), D'Arrigo *et al*. (2006), Frank *et al*. (2007), and Juckes *et al*. (2007). They developed "a millennium-long (AD 828–1998), annually resolved δ^{13}C tree-ring chronology from high-elevation juniper trees in northern Pakistan [35.74–36.37°N, 74.56–74.99°W] together with three centennial-long (AD 1900–1998) δ^{13}C chronologies from ecologically varying sites," defining an "optimum correction factor" they deemed best-suited to remove non-climatic trends in order to "provide new regional temperature reconstructions derived from tree-ring δ^{13}C, and compare those records with existing regional evidence."

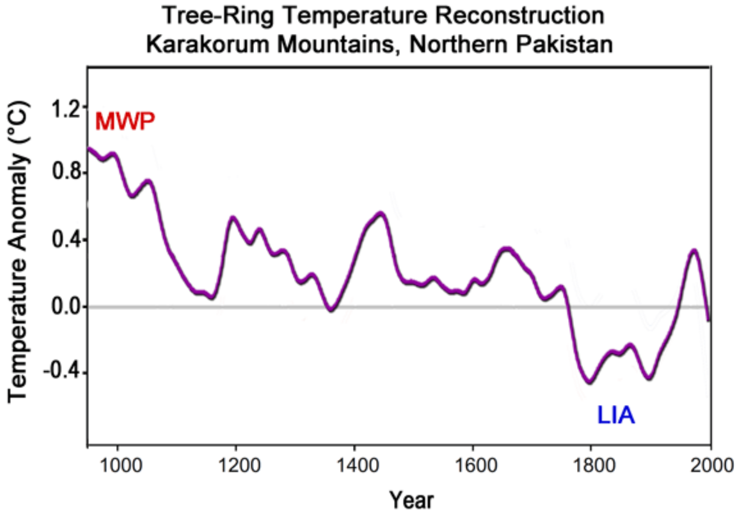

Figure 4.2.4.4.4.2. Proxy tree-ring temperature reconstruction from the Karakorum Mountains, Northern Pakistan. Adapted from Treydte, K.S., Frank, D.C., Saurer, M., Helle, G., Schleser, G.H., and Esper, J. 2009. Impact of climate and CO2 on a millennium-long tree-ring carbon isotope record. *Geochimica et Cosmochimica Acta* **73**: 4635–4647.

This analysis (see Figure 4.2.4.4.4.2) shows the 1990s were "substantially below MWP temperatures," and their reconstruction "provides additional suggestions that High Asian temperatures during the MWP might have exceeded recent conditions," which is also suggested by "ring-width data from living trees (Esper *et al*., 2007)." Thus they "find indications for warmth during the Medieval Warm Period" that imply summer temperatures "higher than today's mean summer temperature."

Yoshioka *et al*. (2001) analyzed the carbon isotopic composition of sediment cores taken from the Dae-Am San high moor (38.22°N, 128.12°E), located on the north-facing slope of Mount Dae-Am, Korean Peninsula. They found upward increases in the δ^{13}C of organic carbon in the sediment core, reaching a maximum at around AD 1100. These findings, according to the authors, suggest the climate of the Korean Peninsula was "warm during the Medieval Warm Period," adding, if their interpretation is correct, the Medieval Warm Period was likely a global event.

Park (2011) writes, "information produced by climate modeling has become progressively more important to understand past climate changes as well as to predict future climates." The Korean researcher also observes, "to evaluate the reliability of such climate model results, quantitative paleoclimate data are essential." In a study designed to obtain such data for a part of the world that has not been intensively studied, Park used modern surface pollen samples from the mountains along the east coast of Korea to derive pollen-temperature transfer functions, which were tested for robustness via detrended correspondence analysis and detrended canonical correspondence analysis, after which the best of these transfer functions was applied to the five fossil pollen records of Jo (1979), Chang and Kim (1982), Chang *et al*. (1987), Fuiki and Yasuda (2004), and Yoon *et al*. (2008), which were derived from four coastal lagoons of Korea's east coast plus one high-altitude peat bog.

Park determined "the 'Medieval Warm Period', 'Little Ice Age' and 'Migration Period' were clearly shown," the first of which was identified as having occurred between AD 700 and 1200, the next between AD 1200 and 1700, and the last as having occurred between AD 350 and 700. The earliest of these periods is commonly referred to as the Dark Ages Cold Period but sometimes described as the Migration Period, as Park reports it was a time "when people migrated southward in Europe because of deteriorating environmental conditions." The graphical representation of Park's temperature reconstruction shows the peak temperature of the Medieval Warm Period was only slightly lower (by about 0.18°C) than the peak temperature of the Current Warm Period, which occurs at the end of the Korean temperature record.

Park's findings imply "the various late-Holocene climate shifts all occurred in the Korean peninsula at the same time as in other regions of the world," and modern-day warming on the Korean peninsula is only slightly greater than what occurred there in the Medieval Warm Period. It is evident from Park's temperature reconstruction that it may have been slightly warmer approximately 2,200 years ago than it was near the end of the twentieth century, suggesting there is nothing unusual or unnatural about Earth's current level of warmth.

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4.2.4.5 Australia and New Zealand

Numerous peer-reviewed studies reveal modern temperatures are not unusual, unnatural, or unprecedented. Earth's climate has both cooled and warmed independent of its atmospheric CO_2 concentration for many millennia. Conditions as warm as, or warmer than, the present have persisted across the Holocene for decades to centuries even though the atmosphere's CO_2 concentration remained at values approximately 30% lower than those of today.

This section highlights evidence from Australia and New Zealand, where much of the material focuses on the most recent millennium of Earth's history, detailing the historical fluctuations of Earth's climate that long ago ushered in the Roman Warm Period, which gave way to the Dark Ages Cold Period, which was followed by the Medieval Warm Period and subsequent Little Ice Age. These natural climate oscillations are the product of a millennial-scale climate forcing; the Current Warm Period is simply a manifestation of its latest phase. Carbon dioxide had little to do with the warmth (or cold) of these prior epochs, and there is no compelling reason to conclude it is having any measurable impact on climate today.

Wilson *et al*. (1979) sought to compare the temperature record from New Zealand, which is "in the Southern Hemisphere and … meteorologically unrelated to Europe," with the climate record of England, where the MWP had been identified. They analyzed the $^{18}O/^{16}O$ profile from the core to the surface of a stalagmite obtained from a cave in New Zealand dated by the ^{14}C method. They found the proxy temperature record provided by the stalagmite was broadly similar to the climate record of England, exhibiting a period in the early part of the past millennium about 0.75°C warmer than it was in the mid-twentieth century (see Figure 4.2.4.5.1). They conclude, "such climatic fluctuations as the Medieval Warm Period and Little Ice Age are not just a local European phenomenon."

Eden and Page (1998) analyzed sediment cores from Lake Tutira, North Island, New Zealand (~39.23°S, 176.9°E) to reconstruct a history of major storms over the past 2,000 years. They found six well-defined and "clearly distinguishable" storm periods of

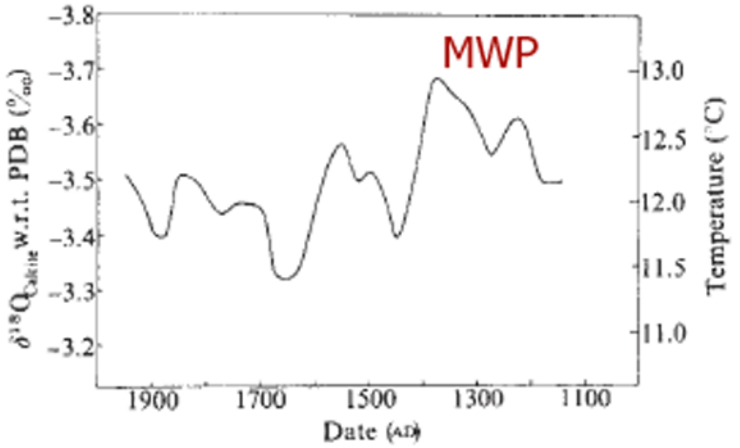

Figure 4.2.4.5.1. Proxy $^{18}O/^{16}O$ temperature reconstruction from a stalagmite in New Zealand. Adapted from Wilson, A.T., Hendy, C.H., and Reynolds, C.P. 1979. Short-term climate change and New Zealand temperatures during the last millennium. *Nature* **279**: 315–317.

the pre-instrumental era, illustrated in Figure 4.2.4.5.2. A seventh period based on data presented in Table 1 of the authors' paper has been added to indicate comparable storms of the modern era.

A comparison of these data with several independent climate proxies throughout the region led the authors to conclude stormy periods occurred during times when the climate was warmer overall. They note, "the Mapara 2 period corresponds to sustained warm temperatures in the Tasmanian and Chilean tree-ring records which might indicate that the period represents a Southern Hemisphere-wide climate anomaly." Additionally, "the Tufa Trig 1 period [AD 864–1014] corresponds to the early part of the Medieval Warm Period suggesting warmer temperatures occurred in New Zealand at this time." Similar correlations were noted among the other storm periods, leading to the inference that given the large number of storm events during the RWP and MWP, as compared to the Current Warm Period (CWP), it is likely the CWP has been neither as warm nor as protracted as these earlier warm periods.

Williams *et al*. (2004) revise and build upon results derived by Williams *et al*. (1999) from stable isotope stratigraphy found in caves at Waitomo, located at 38.3°S latitude about 35 km from the west coast of the central North Island of New Zealand. They enhanced three existing speleothem (stalactite, stalagmite, or flowstone cave deposit) records "by adding another chronology, increasing the subsample resolution of existing

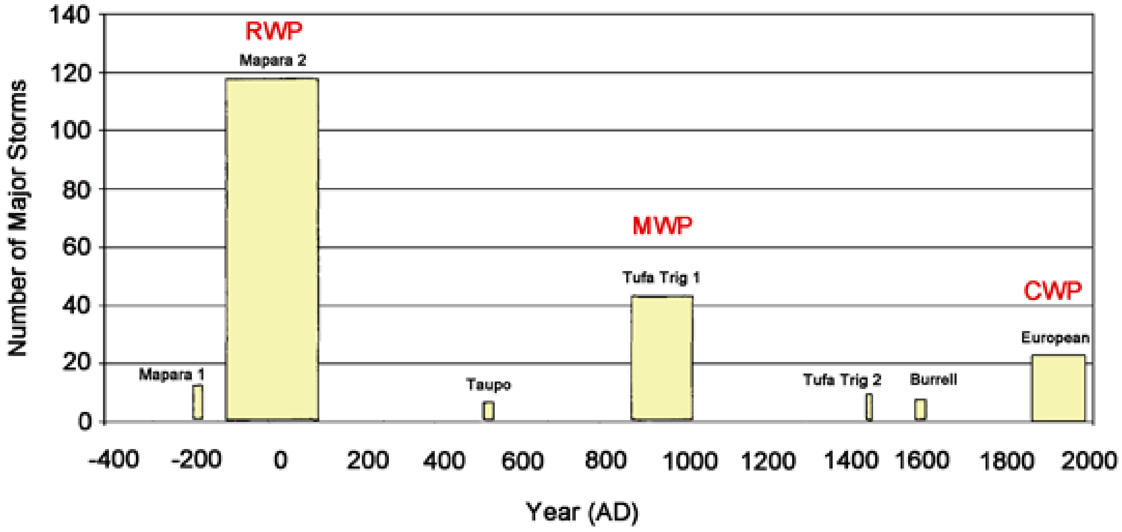

Figure 4.2.4.5.2. Number of major storms as determined from a sediment core from Lake Tutira, North Island, New Zealand. Adapted from Eden, D.N and Page, M.J. 1998. Palaeoclimatic implications of a storm erosion record from late Holocene lake sediments, North Island, New Zealand. *Palaeo-geography, Palaeoclimatology, Palaeoecology* **139**: 37–58.

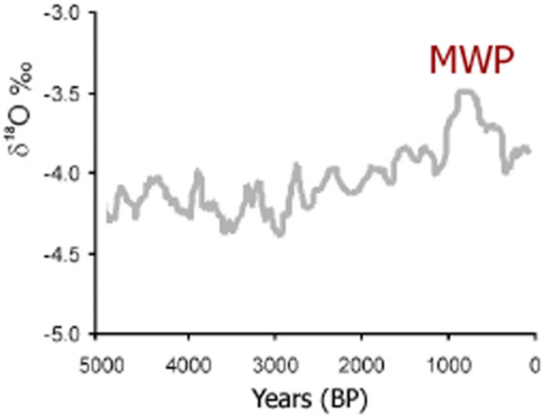

Figure 4.2.4.5.3. Composite δ^{18}O series obtained from four stalagmites found in caves at Waitomo, New Zealand. Adapted from Williams, P.W., King, D.N.T., Zhao, J.-X., and Collerson, K.D. 2004. Speleothem master chronologies: combined Holocene ^{18}O and ^{13}C records from the North Island of New Zealand and their palaeo-environmental interpretation. *The Holocene* **14**: 194–208.

records, and by much improving the temporal control of all chronologies by basing it entirely on uranium series TIMS dating." Williams *et al.*'s improved speleothem master chronologies revealed a warmer-than-present late-Holocene warm peak located between 0.9 and 0.6 ka BP (see Figure 4.2.4.5.3), which they equated with the Medieval Warm Period of Europe, further noting this period "coincided with a period of Polynesian settlement (McGlone and Wilmshurst, 1999)." Thereafter, they report, temperatures "cooled rapidly to a trough about 325 years ago," which they say corresponded to "the culmination of the 'Little Ice Age' in Europe."

Lorrey *et al.* (2008) developed two master speleothem δ^{18}O records for New Zealand's eastern North Island (ENI) and western South Island (WSI) for the period 2000 BC to about AD 1660 and 1825, respectively (see Figure 4.2.4.5.4). The WSI record was a composite chronology composed of data derived from four speleothems from Aurora, Calcite, Doubtful Xanadu, and Waiau caves, while the ENI record was a composite history derived from three speleothems from Disbelief and Te Reinga caves. For both the ENI and WSI δ^{18}O master speleothem histories, their warmest periods fell within the AD 900-1100 time interval of the MWP.

Wirrmann *et al.* (2011) developed a multi-proxy approach to climate in New Caledonia in the southwest tropical Pacific, determining between *ca.* 2,640 and 2,000 cal yr BP, conditions were "drier and cooler," and subsequent observations linked wetter with warmer. They report, "between ca. 1250–500 cal yr BP the higher % of Rhizophoraceae and their peak around ca. 1080–750 cal yr BP underscore a mangrove belt development along the coastline." This episode, they write, must be related to a wetter period and "may be related to a more global phenomenon such as the MWP in the Northern Hemisphere."

The IPCC has rejected the existence of a global MWP, suggesting it was mostly limited in scope to countries surrounding the North Atlantic Ocean. The studies described above are of great importance to the ongoing global warming debate because they provide evidence the the MWP was a global phenomenon in which temperatures around the world were significantly warmer than they have been at any time subsequently. These studies confirm there is nothing unusual or unprecedented about Earth's current level of warmth, with the necessary implication that the temperatures of the present cannot be attributed to the historical increase in the air's CO_2 content.

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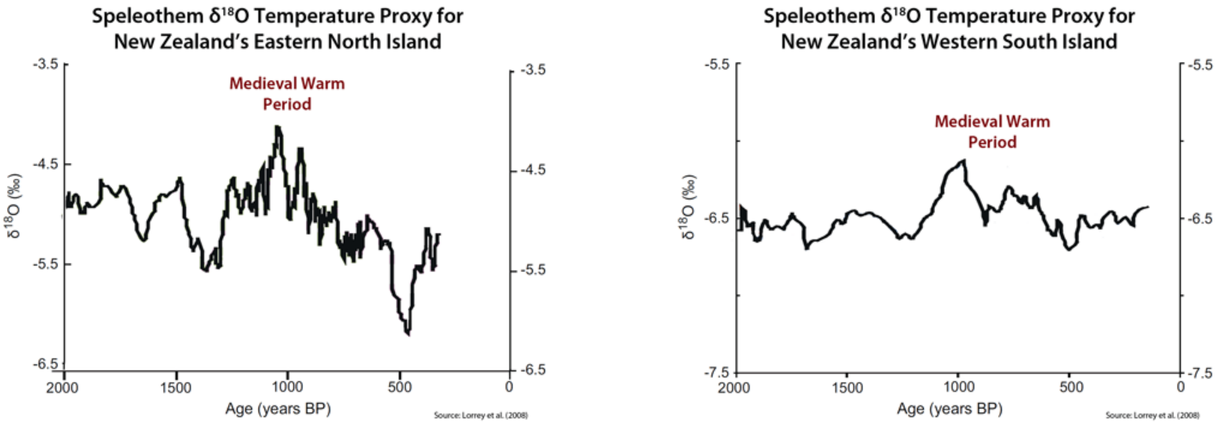

Figure 4.2.4.5.4. Composite speleothem δ^{18}O series obtained for New Zealand's eastern North Island and western South Island. Adapted from Lorrey, A., Williams, P., Salinger, J., Martin, T., Palmer, J., Fowler, A., Zhao, J.-X., and Neil, H. 2008. Speleothem stable isotope records interpreted within a multi-proxy framework and implications for New Zealand palaeoclimate reconstruction. *Quaternary International* **187**: 52–75.

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4.2.4.6 Europe

The following subsections highlight evidence from Europe showing conditions as warm as, or warmer than, the present have persisted across the Holocene for decades to centuries even though the atmosphere's CO2 concentration remained at values approximately 30 percent lower than they are today. Much of the material here focuses on the most recent millennium of Earth's history, detailing the historical fluctuations of Earth's climate that long ago ushered in the Roman Warm Period, which gave way to the Dark Ages Cold Period, which was followed by the Medieval Warm Period and subsequent Little Ice Age. These natural climate oscillations are the product of a millennial-scale climate forcing independent of carbon dioxide levels. The Current Warm Period is simply a manifestation of its latest phase.

4.2.4.6.1 Central

Filippi *et al*. (1999) obtained stable isotope data (delta ^{18}O and delta ^{13}C) from bulk carbonate and ostracode calcite in a radiocarbon-dated sediment core removed from Lake Neuchatel in the western Swiss Lowlands at the foot of the Jura Mountains, which they used to reconstruct the climatic history of that region over the past 1,500 years (Figure 4.2.4.6.1.1). They determined mean annual air temperature dropped by about 1.5°C during the transition from the Medieval Warm Period (MWP) to the Little Ice Age (LIA). In addition, they state, "the warming during the 20th century does not seem to have fully compensated the cooling at the MWP-LIA transition" and during the Medieval Warm Period, mean annual air temperatures were "on average higher than at present."

Bodri and Cermak (1999) derived individual

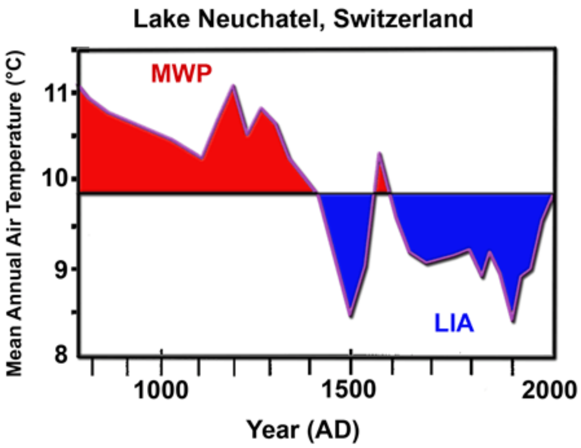

Figure 4.2.4.6.1.1. Temperature reconstruction obtained from sediment core removed from Lake Neuchatel in the western Swiss Lowlands. Adapted from Filippi, M.L., Lambert, P., Hunziker, J., Kubler, B., and Bernasconi, S. 1999. Climatic and anthropogenic influence on the stable isotope record from bulk carbonates and ostracodes in Lake Neuchatel, Switzerland, during the last two millennia. *Journal of Paleolimnology* **21**: 19–34.

ground surface temperature histories from the temperature-depth logs of 98 boreholes in the Czech Republic. This work revealed, they write, "the existence of a medieval warm epoch lasting from 1100–1300 AD," which they describe as "one of the warmest postglacial times." They also note during the main phase of the Little Ice Age, from 1600–1700 AD, "all investigated territory was already subjected to massive cooling," and "the observed recent warming may thus be easily a natural return of climate from the previous colder conditions back to a 'normal.'"

Niggemann *et al*. (2003) studied petrographical and geochemical properties of three stalagmites found in the B7-Cave of Sauerland, Northwest Germany, from which they developed a climate history for the prior 17,600 years. These records, they write, "resemble records from an Irish stalagmite (McDermott *et al*., 1999)," which also has been described by McDermott *et al*. (2001). The four researchers explicitly note their own records provide evidence for the existence of the Little Ice Age, the Medieval Warm Period, and the Roman Warm Period, which also implies the existence of what McDermott *et al*. (2001) called the Dark Ages Cold Period that separated the Medieval and Roman Warm Periods, as well as the unnamed cold period that preceded the Roman Warm Period. The wealth of corroborative information in these records (and many others) clearly suggests there is nothing unusual, unprecedented, or unexpected about the twentieth century warming that ushered in the Current Warm Period.

Bartholy *et al*. (2004) describe the work of Antal Rethly (1879–1975), a meteorologist, professor, and director of the National Meteorological and Earth Magnetism Institute of Hungary, who spent the greater portion of his long professional career collecting more than 14,000 historical records related to the climate of the Carpathian Basin. Rethly published in Hungarian a four-volume set of books, approximately 2,500 pages total, describing those records (Rethly, 1962, 1970; Rethly and Simon, 1999). Building upon this immense foundation, Bartholy *et al*. codified and analyzed the records collected by Rethly, noting, "in order to provide regional climate scenarios for any particular area, past climate tendencies and climatological extremes must be analyzed." The three Hungarian scientists report "the warm peaks of the Medieval Warm Epoch and colder climate of the Little Ice Age followed by the recovery warming period can be detected in the reconstructed temperature index time series."

Mangini *et al*. (2005) developed a highly resolved record of temperature at high elevation, approximately 2,500 meters above sea level, during the past 2,000 years, using a precisely dated δ^{18}O record with better than decadal resolution derived from a stalagmite recovered from Spannagel Cave in the Central Alps of Austria. They applied to the data a transfer function they derived from a comparison of their δ^{18}O data with the reconstructed temperature history of post-1500 Europe developed by Luterbacher *et al*. (2004).

Mangini *et al*. found the lowest temperatures of the past two millennia, according to the new record, occurred during the Little Ice Age (AD 1400–1850), and the highest temperatures were found in the Medieval Warm Period (MWP: AD 800–1300). They write, the highest temperatures of the MWP were "slightly higher than those of the top section of the stalagmite (1950 AD) and higher than the present-day temperature." At three points during the MWP, their data indicate temperature spikes in excess of 1°C above present (1995–1998) temperatures (see Figure 4.2.4.6.1.2).

Mangini *et al*. also report their temperature reconstruction compares well with reconstructions developed from Greenland ice cores (Muller and Gordon, 2000), Bermuda Rise ocean-bottom sediments (Keigwin, 1996), and glacier tongue advances and retreats in the Alps (Holzhauser, 1997; Wanner *et al*., 2000), as well as with the Northern Hemispheric temperature reconstruction of Moberg *et al*. (2005). Considered together, Mangini *et al*. say the datasets "indicate that the MWP was a climatically distinct period in the Northern Hemisphere," emphasizing "this conclusion is in strong contradiction to the temperature reconstruction by the IPCC, which only sees the last 100 years as a period of increased temperature during the last 2000 years."

In a second refutation of an IPCC conclusion, Mangini *et al.* found "a high correlation between δ^{18}O and δ^{14}C, that reflects the amount of radiocarbon in the upper atmosphere," and this correlation "suggests that solar variability was a major driver of climate in Central Europe during the past 2 millennia." They further report, "the maxima of δ^{18}O coincide with solar minima (Dalton, Maunder, Sporer, Wolf, as well as with minima at around AD 700, 500 and 300)," and "the coldest period between 1688 and 1698 coincided with the Maunder Minimum." Also, in a linear-model analysis of the percent of variance of their full temperature reconstruction that is

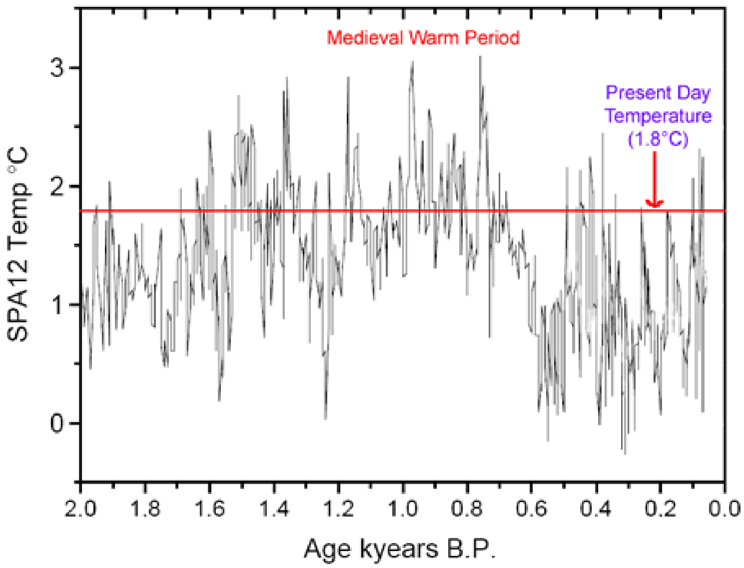

Figure 4.2.4.6.1.2. Temperature reconstruction from Spannagel Cave in the Central Alps of Austria. Adapted from Mangini, A., Spotl, C., and Verdes, P. 2005. Reconstruction of temperature in the Central Alps during the past 2000 yr from a $\delta^{18}O$ stalagmite record. *Earth and Planetary Science Letters* **235**: 741–751.

individually explained by solar and CO_2 forcing, they found the impact of the Sun was fully 279 times greater than that of the air's CO_2 concentration, noting "the flat evolution of CO_2 during the first 19 centuries yields almost vanishing correlation coefficients with the temperature reconstructions."

These findings show the hockey stick temperature reconstruction of Mann *et al.* (1998, 1999), which has long been endorsed by the IPCC, does not reflect the true temperature history of the Northern Hemisphere over the past thousand years, nor does the hockey stick temperature reconstruction of Mann and Jones (2003) reflect the true temperature history of the world over the past two millennia. The Mann studies and the IPCC appear to be focusing on the wrong instigator of climate change over these periods; i.e., CO_2 in lieu of solar activity (see also Chapter 3, this volume).

Using the regional curve standardization technique applied to ring-width measurements from living trees and relict wood, Büntgen *et al.* (2005) developed a 1,052-year summer (June–August) temperature proxy from high-elevation Alpine environments in Switzerland and the western Austrian Alps (between 46°28' to 47°00'N and 7°49' to 11°30'E). This temperature history revealed warm conditions from the beginning of the record in AD 951 to about AD 1350, which the five researchers associated with the Medieval Warm Period. Thereafter, temperatures declined and an extended cold period (the Little Ice Age) ensued, which persisted until approximately 1850, with one brief exception for a few short decades in the mid- to late-1500s, when there was an unusually warm period, the temperatures of which were exceeded only at the beginning and end of the 1,052-year record; i.e., during the Medieval and Current Warm Periods.

Holzhauser *et al.* (2005) presented high-resolution records of variations in glacier size in the Swiss Alps together with lake-level fluctuations in the Jura mountains, the northern French Pre-Alps, and the Swiss Plateau in developing a 3,500-year climate history of west-central Europe, beginning with an in-depth analysis of the Great Aletsch glacier, the largest of all the glaciers in the European Alps.

Near the beginning of the time period studied, the three researchers report, "during the late Bronze Age Optimum from 1350 to 1250 BC, the Great Aletsch glacier was approximately 1000 m shorter than it is today," noting "the period from 1450 to 1250 BC has been recognized as a warm-dry phase in other Alpine and Northern Hemisphere proxies (Tinner *et al*., 2003)." After an intervening unnamed cold-wet phase when the glacier grew in both mass and length, "during the Iron/Roman Age Optimum between c. 200 BC and AD 50," perhaps better known as the Roman Warm Period, the glacier again retreated and "reached today's extent or was even somewhat shorter than today." Next came the Dark Ages Cold Period, which they say was followed by "the Medieval Warm Period, from around AD 800 to the onset of the Little Ice Age around AD 1300." The latter cold-wet phase was "characterized by three successive [glacier length] peaks: a first maximum after 1369 (in the late 1370s), a second between 1670 and 1680, and a third at 1859/60," after which the glacier began its latest and still-ongoing recession in 1865. In addition, they state, documents from the fifteenth century AD indicate at some time during that hundred-year interval "the glacier was of a size similar to that of the 1930s," when many parts of the world were as warm as, or even warmer than, they are today, in harmony with a growing body of evidence suggesting a "Little" Medieval Warm Period occurred during the fifteenth century within the broader expanse of the Little Ice Age.

Data pertaining to the Gorner glacier (the second largest of the Swiss Alps) and the Lower Grindelwald glacier of the Bernese Alps tell much the same story, as Holzhauser *et al*. report these glaciers and the Great Aletsch glacier "experienced nearly synchronous advances" throughout the study period.

The Swiss and French scientists report "glacier maximums coincided with radiocarbon peaks, i.e., periods of weaker solar activity," which in their estimation "suggests a possible solar origin of the climate oscillations punctuating the last 3500 years in west-central Europe, in agreement with previous studies (Denton and Karlen, 1973; Magny, 1993; van Geel *et al*., 1996; Bond *et al*., 2001)." They conclude, "a comparison between the fluctuations of the Great Aletsch glacier and the variations in the atmospheric residual ^{14}C records supports the hypothesis that variations in solar activity were a major forcing factor of climate oscillations in west-central Europe during the late Holocene."

The current warmth of the region Holzhauser *et al*. studied has not yet resulted in a shrinkage of the Great Aletsch glacier equivalent to what it experienced during the Bronze Age Optimum of a little over three thousand years ago, nor what it experienced during the Roman Warm Period of two thousand years ago, suggesting there is nothing unusual or "unprecedented" about the region's current warmth. Our modern warmth is occurring at just about the time one would expect it to occur, in light of the rather consistent time intervals that separated prior warm nodes of the millennial-scale climate oscillation that produced them. This suggests Earth's current warmth, like that of prior Holocene warm periods, is likely solar-induced.

Chapron *et al*. (2005) note "millennial-scale Holocene climate fluctuations have been documented by lake level fluctuations, archaeological and palynological records for many small lakes in the Jura Mountains and several larger peri-alpine lakes." They documented the Holocene evolution of Rhone River clastic sediment supply in Lake Le Bourget via sub-bottom seismic profiling and multidisciplinary analysis of well-dated sediment cores. This revealed, as they describe it, "up to five 'Little Ice Age-like' Holocene cold periods developing enhanced Rhone River flooding activity in Lake Le Bourget documented at *c*. 7200, 5200, 2800, 1600 and 200 cal. yr BP," and "these abrupt climate changes were associated in the NW Alps with Mont Blanc glacier advances, enhanced glaciofluvial regimes and high lake levels." They also note "correlations with European lake level fluctuations and winter precipitation regimes inferred from glacier fluctuations in western Norway suggest that these five Holocene cooling events at 45°N were associated with enhanced westerlies, possibly resulting from a persistent negative mode of the North Atlantic Oscillation."

Situated between these Little Ice Age-like periods would have been Current Warm Period-like conditions. The most recent of these prior warm regimes (the Medieval Warm Period) would have been centered at about AD 1100, while the prior one (the Roman Warm Period) would have been centered in the vicinity of 200 BC, which matches well with what is known about these warm regimes from many other studies.

Robert *et al*. (2006) analyzed assemblages of minerals and microfossils from a sediment core taken from the Berre coastal lagoon in southeast France (~ 43.44°N, 5.10°E) to reconstruct environmental changes in that region over the past 1,500 years. Their analyses revealed three distinct climatic intervals: a cold period that extended from about AD 400 to 900, a warm interval between about AD 980 and 1370, and a cold interval that peaked during the sixteenth and seventeenth centuries. These climatic intervals correspond, respectively, to the Dark Ages Cold Period, Medieval Warm Period (MWP), and Little Ice Age.

The team of eight researchers also found evidence of a higher kaolinite content in the sediment core during the MWP, which suggests, they write, "increased chemical weathering in relation to higher temperatures and/or precipitation." In addition, they discovered the concentration of microfossils of the thermophilic taxon *Spiniferites bentorii* also peaked at this time, and this finding provides additional evidence the temperatures of that period were likely higher than those of the recent past.

Joerin *et al*. (2006) write, "the exceptional trend of warming during the twentieth century in relation to the last 1000 years highlights the importance of assessing natural variability of climate change." The three Swiss researchers examined glacier recessions in the Swiss Alps over the past ten thousand years based on radiocarbon-derived ages of materials found in proglacial fluvial sediments of subglacial origin, focusing on subfossil remains of wood and peat. Combining their results with earlier data of a similar nature, they constructed a master chronology of Swiss glacier fluctuations over the Holocene.

Joerin *et al*. report discovering "alpine glacier recessions occurred at least 12 times during the Holocene," once again demonstrating the reality of the millennial-scale oscillation of climate that has reverberated throughout glacial and interglacial periods alike as far back in time as scientists have searched for the phenomenon. They also determined glacier recessions have been decreasing in frequency since approximately 7,000 years ago, and especially since 3,200 years ago, "culminating in the maximum glacier extent of the 'Little Ice Age.'" Consequently, the warming of the twentieth century cannot be considered strange, since it represents a climatic rebound from the coldest period of the current interglacial, which was the coldest of the last five interglacials, according to Petit *et al*. (1999).

The last of the major glacier recessions in the Swiss Alps occurred between about 1,400 and 1,200 years ago according to Joerin *et al*.'s data, but it took place between 1,200 and 800 years ago, according to the data of Holzhauser *et al*. (2005) for the Great Aletsch Glacier. Joerin *et al*. say the two records need not be considered inconsistent with each other given the uncertainty of the radiocarbon dates. Their presentation of the Great Aletsch Glacier data also indicates the glacier's length at about AD 1000, when there was fully 100 ppm less CO_2 in the air than there is today, was slightly less than its length in 2002, suggesting the peak temperature of the Medieval Warm Period likely was slightly higher than the peak temperature of the twentieth century.

Buntgen *et al*. (2006) developed an annually resolved mean summer (June–September) temperature record for the European Alps, covering the period AD 755–2004 and based on 180 recent and historic larch (*Larix decidua* Mill.) maximum latewood density series, created via the regional curve standardization method that preserves interannual to multi-centennial temperature-related variations. They found in this history the high temperatures of the late tenth, early thirteenth, and twentieth centuries and the prolonged cooling from ~1350 to 1700, or as they describe it, "warmth during medieval and recent times, and cold in between." They report the coldest decade of the record was the 1810s, and even though the record extended through 2004, the warmest decade of the record was the 1940s. In addition, they observe, "warm summers seemed to coincide with periods of high solar activity, and cold summers vice versa." They report comparing their temperature record with other regional- and large-scale reconstructions "reveals similar decadal to longer-term variability," causing them to conclude, "the twentieth-century contribution of anthropogenic greenhouse gases and aerosol remains insecure."

Extending the work of Mangini *et al*. (2005), who had developed a 2,000-year temperature history of the central European Alps based on an analysis of $\delta^{18}O$ data obtained from stalagmite SPA 12 of Austria's Spannagel Cave, Vollweiler *et al*. (2006) used similarly measured $\delta^{18}O$ data obtained from two adjacent stalagmites (SPA 128 and SPA 70) within the same cave to create a master $\delta^{18}O$ history covering the last 9,000 years, which Mangini *et al*. (2007) compared with the Hematite-Stained-Grain (HSG) history of ice-rafted debris in North Atlantic Ocean sediments developed by Bond *et al*. (2001), who had reported "over the last 12,000 years virtually every centennial time-scale increase in drift ice documented in our North Atlantic records was tied to a solar minimum."

Mangini *et al*. found a tight correspondence between the peaks and valleys of their $\delta^{18}O$ curve and the HSG curve of Bond *et al*., concluding "the excellent match between the curves obtained from these two independent data sets gives evidence the $\delta^{18}O$ signal recorded in Spannagel cave reflects the intensity of the warm North Atlantic drift, disproving the assumption that the Spannagel isotope record is merely a local phenomenon," and, therefore, their $\delta^{18}O$ curve "can reasonably be assumed to reflect non-local conditions," implying it has wide regional applicability.

Mangini *et al*. next focus on why their $\delta^{18}O$ curve "displays larger variations for the last 2000 years than the multi-proxy record in Europe, which is mainly derived from tree-ring data" and "from low resolution archives (Mann *et al*., 1998, 1999; Mann and Jones, 2003)." The most likely answer, they write, "is that tree-rings … record the climate conditions during spring and summer," whereas both the HSG and $\delta^{18}O$ curves "mirror winter-like conditions, which are only poorly recorded in tree-rings."

Whereas the Mann *et al*. and Mann and Jones datasets do not reflect the existence of the Medieval Warm Period and Little Ice Age, the Spannagel Cave data do. Applying the calibration curve derived for SPA 12 by Mangini *et al*. (2005) to the new $\delta^{18}O$ curve, it can readily be determined the peak temperature of the Medieval Warm Period was approximately 1.5°C higher than the peak temperature of the Current Warm Period. In addition, the new dataset of Mangini *et al*. (2007) confirms the inference of Bond *et al.*'s finding that over the last 12,000 years virtually every centennial-scale cooling of the North Atlantic region "was tied to a solar minimum," demonstrating the datasets of Mann *et al.* and Mann and Jones fail to capture the full range of temperature variability over the past two millennia. The new dataset clearly depicts the existence of both the Little Ice Age and Medieval Warm Period, the latter of which is seen to have been substantially warmer over periods of centuries than the warmest parts of the twentieth century, almost certainly as a result of enhanced solar activity, and even though the air's CO_2 concentration during the Medieval Warm Period was at least 100 ppm less than it is today.

Schmidt *et al.* (2007) developed a 4,000-year climatic reconstruction by combining spring and autumn temperature anomaly reconstructions based on siliceous algae and pollen tracers found in a sediment core extracted from an Alpine lake (Oberer Landschitzsee; 47°14'52" N, 13°51'40" E) located at the southern slopes of the Austrian Central Alps just slightly above the present tree-line. They compared that reconstructed history with a similar time-scale reconstruction from another lake in the drainage area, local historical records, and other climate proxies on Alpine and Northern Hemispheric scales. They found "spring-temperature anomalies during Roman and Medieval times equaled or slightly exceeded the modern values and paralleled tree-line and glacier fluctuations." They identified "warm phases similar to present between ca. 850–1000 AD and 1200–1300 AD," which they say were "followed by climate deterioration at ca 1300 AD, which culminated during the Little Ice Age."

Schmidt *et al.* (2008) recreated the late-Holocene climate and land-use history for the region around an Austrian alpine lake, Oberer Landschitzsee (47°14'52" N, 13°51'40" E), by analyzing sediment grain size and the concentrations of major and trace elements and minerals in a 4,000-year sediment core recovered from the lake, together with autumn and spring temperature anomalies and ice cover estimated from selected pollen markers and a diatom and chrysophyte cyst thermistor-based regional calibration dataset. Their analysis identified the Roman Warm Period (300 BC to AD 400) and Medieval Warm Period (AD 1000 to AD 1600) and demonstrated "spring temperature anomalies during Roman and Medieval times equaled or slightly exceeded the modern values." They detected two other warm periods—1800 to 1300 BC and 1000 to 500 BC—as well as cooler periods between them, including the Little Ice Age that occurred between the Medieval Warm Period and the Current Warm Period. In addition, they report, "four waves of alpine land use were coupled mainly with warm periods." They found the two warm periods that preceded the Current Warm Period were at least as warm as today.

Millet *et al.* (2009) write, "among biological proxies from lake sediments, chironomid [non-biting midge] assemblages are viewed as one of the most promising climatic indicators," and "the accuracy of chironomid assemblages for the reconstruction of Lateglacial temperatures is now broadly demonstrated." They developed a new chironomid-based temperature record from Lake Anterne (northern French Alps) covering the past two millennia, compared that reconstruction with other late-Holocene temperature records from Central Europe, and addressed the question of whether previously described centennial-scale climate events such as the Medieval Warm Period or Little Ice Age can be detected in this new summer temperature record, noting "at a hemispheric or global scale the existence of the LIA and MWP have been questioned."

The six scientists report they found evidence "of a cold phase at Lake Anterne between AD 400 and 680, a warm episode between AD 680 and 1350, and another cold phase between AD 1350 and 1900," stating these events were "correlated to the so-called 'Dark Age Cold Period' (DACP), the 'Medieval Warm Period' and the 'Little Ice Age.'" They note "many other climate reconstructions across western Europe confirm the existence of several significant climatic changes during the last 1800 years in Central Europe and more specifically the DACP, the MWP and the LIA." They also report the reconstructed temperatures of the twentieth century failed to show a return to MWP levels of warmth, but they attribute that to a breakdown of the chironomid-temperature relationship over the final century of their 1,800-year history.

Corona *et al.* (2010) analyzed tree-ring width data obtained from 548 trees (living and dead) at 34 sites distributed across the French Alps (44°–45°30'N, 6°30'–7°45'E), which they calibrated against monthly homogenized records of temperature obtained from a network of 134 meteorological stations extending back to AD 1760, to develop a summer (June, July, August) temperature history for the period AD 751–2008 using the Regional Curve Standardization technique, which they say "has been shown to be the most appropriate age-related detrending method for preserving multi-centennial climate variability." This work revealed, they write, "most of the 20th century is comparable with the Medieval Warm Period," but "during the last decade of the 20th century, the amplitude and abruptness of the summer temperature increase exceed the warming reconstructed for the Medieval Warm Period." From their graph of the data, that exceedance appears to be about 0.4°C.

Gasiorowski and Sienkiewicz (2010) inferred the thermal conditions of Smreczynski Staw Lake (49°12'N, 19°51'E) in the Tatra Mountains of southern Poland via analyses of the distributions of various cladocera, chironomid, and diatom species they identified and quantified in a sediment core extracted from the center of the lake in the spring of 2003, which contained sediments that had accumulated there over the prior 1,500 years. This work revealed the presence of "a diverse ecosystem at the beginning of [the] record, ca. AD 360–570," which has typically been assigned to the Dark Ages Cold Period. They found from AD 570 to 1220 "environmental conditions were better," and various cold-water taxa were "totally absent." The younger section of this zone—approximately its upper third (AD 850–1150), which contained the highest concentration of warm-water *Chironomus* species—"can be correlated with the Medieval Warm Period," they write. Next came the Little Ice Age, which was the focal point of their study, extending to the start of the twentieth century, after which relative warmth once again returned, persisting to the present. Based on the *Chironomus* concentrations of the Current Warm Period, their data suggest the peak warmth of the CWP and the earlier MWP were about the same.

Sorrel *et al*. (2010) documented "the depositional history of the inner bay coeval to the mid- to late-Holocene transgression in south Brittany," based on "an approach combining AMS ^{14}C [radiocarbon] dating, sedimentological and rock magnetic analyses on sediment cores complemented with seismic data collected in the macrotidal Bay of Vilaine [47°20'–47°35'N, 2°50'–2°30'W]." According to the authors, "the late Holocene component (i.e., the last 2000 years) is best recorded in the most internal sedimentary archives," where they found "an increase in the contribution of riverine inputs occurred during the MWP" at "times of strong fluvial influences in the estuary during ca. 880–1050 AD." They note, "preservation of medieval estuarine flood deposits implies that sediment remobilization by swells considerably waned at that time, and thus that the influence of winter storminess was minimal," in accordance with the findings of Proctor *et al*. (2000) and Meeker and Mayewski (2002). They also note the preservation of fine-grained sediments during the Middle Ages has been reported in other coastal settings, citing the studies of Chaumillon *et al*. (2004) and Billeaud *et al*. (2005). They write, "all sedimentary records from the French and Spanish Atlantic coasts" suggest "the MWP appears to correspond to a period of marked and recurrent increases in soil erosion with enhanced transport of suspended matter to the shelf as a result of a likely accelerated human land-use development." In addition, "milder climatic conditions during ca. 880–1050 AD may have favored the preservation of estuarine flood deposits in estuarine sediments through a waning of winter storminess, and, thus, reduced coastal hydrodynamics at subtidal depths," they write.

The eight researchers state the upper successions of the sediment cores "mark the return to more energetic conditions in the Bay of Vilaine, with coarse sands and shelly sediments sealing the medieval clay intervals," noting "this shift most probably documents the transition from the MWP to the Little Ice Age," which led to the "increased storminess both in the marine and continental ecosystems (Lamb, 1979; Clarke and Rendell, 2009)" associated with "the formation of dune systems over a great variety of coastal environments in northern Europe: Denmark (Aagaard *et al*., 2007; Clemmensen *et al*., 2007, 2009; Matthews and Briffa, 2005), France (Meurisse *et al*., 2005), Netherlands (Jelgersma *et al*., 1995) and Scotland (Dawson *et al*., 2004)." In what they call an even "wider perspective," they note the Medieval Warm Period "is recognized as the warmest period of the last two millennia (Mayewski *et al*., 2004; Moberg *et al*., 2005)."

The French scientists ultimately conclude "the preservation of medieval estuarine flood deposits implies that sediment reworking by marine dynamics was considerably reduced between 880 and 1050 AD," suggesting "climatic conditions were probably mild enough to prevent coastal erosion in northwestern France" during this period.

Larocque-Tobler *et al*. (2010) argue "new records to increase the geographic coverage of paleoclimatic information are needed" to better describe the amplitude of temperature change during the last millennium, and "only by obtaining numerous high-resolution temperature records will it be possible to determine if the 20th century climate change exceeded the natural pre-industrial variability of European climate." They obtained a temperature record spanning the last millennium via an analysis of fossil chironomids (non-biting midges), which they identified and quantified in four sediment cores extracted from the bed of Lake Silvaplana (46°26'56"N, 9°47'33"E) in the Upper Engadine (a high-elevation valley in the eastern Swiss Alps).

This work revealed, "at the beginning of the record, corresponding to the last part of the 'Medieval Climate Anomaly' (here the period between *ca.* AD 1032 and 1262), the chironomid-inferred mean July air temperatures were 1°C warmer than the climate reference period (1961–1990)." Their graphs of 20- and 50-year running means (see Figure 4.2.4.6.1.3) show the peak mean warmth of the Medieval Warm Period exceeded that of the Current Warm Period by about 0.5°C in the case of 20-year averages and 1.2°C in the case of 50-year averages. Thus the five researchers conclude, "based on the chironomid-inferred temperatures, there is no evidence mean-July air temperature exceeded the natural variability recorded during the Medieval Climate Anomaly in the 20th century at Lake Silvaplana," noting similar results "were also obtained in northern Sweden (Grudd, 2008), in Western Europe (Guiot *et al*., 2005), in a composite of Northern Hemisphere tree-ring reconstructions (Esper *et al*., 2002) and a composite of tree rings and other archives (Moberg *et al*., 2005)."

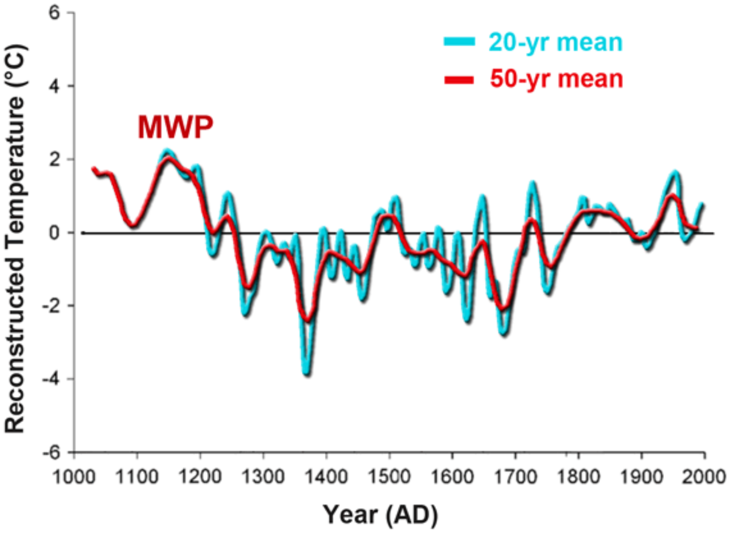

Figure 4.2.4.6.1.3. Temperature reconstruction obtained from sediment cores extracted from the bed of Lake Silvaplana in the eastern Swiss Alps. Adapted from Larocque-Tobler, I., Grosjean, M., Heiri, O., Trachsel, M., and Kamenik, C. 2010. Thousand years of climate change reconstructed from chironomid subfossils preserved in varved lake Silvaplana, Engadine, Switzerland. *Quaternary Science Reviews* **29**: 1940–1949.

Scapozza *et al*. (2010) used radiocarbon dating of the fossil wood remains of eight larch (*Larix decidua*) stem fragments found one meter beneath the surface of the ground at the base of the front of the Piancabella rock glacier (46°27'02" N, 9°00'07" E) in the Southern Swiss Alps in September 2005, determining the wood was formed somewhere between AD 1040 and 1280 with a statistical probability of 95.4 percent. Based on this information and "geomorphological, climatological and geophysical observations," they inferred "the treeline in the Medieval Warm Period was about 200 meters higher than in the middle of the 20th century, which corresponds to a mean summer temperature as much as 1.2°C warmer than in AD 1950." Adjusting for warming between 1950 and the present, it can be estimated the MWP was about 0.5°C warmer than the peak warmth of the CWP.

Magny *et al*. (2011) write, "present-day global warming has provoked an increasing interest in the reconstruction of climate changes over the last millennium (Guiot *et al*., 2005; Jones *et al*., 2009)," which time interval is "characterized by a succession of distinct climatic phases, i.e. a Medieval Warm Period (MWP) followed by a long cooler Little Ice Age (LIA) and finally by a post-industrial rapid increase in temperature," generally referred to as the initial phase of the Current Warm Period (CWP). In a study designed to compare the temperatures of these periods, the six scientists, working at Lake Joux (46°36'N, 6°15'E) at an altitude of 1,006 meters above sea level (a.s.l.) in the Swiss Jura Mountains, employed a multi-proxy approach with pollen and lake-level data to develop a 1,000-year history of the mean temperature of the warmest month of the year (MTWA, which was July at Lake Joux), based on the Modern Analogue Technique. They describe this procedure as "a commonly used and accepted method for the reconstruction of Lateglacial and Holocene climate oscillations from continental and marine sequences," citing Guiot *et al*. (1993), Cheddadi *et al*., (1997), Davis *et al*. (2003), Peyron *et al*. (2005), Kotthoff *et al*. (2008), and Pross *et al*. (2009).

Magny *et al*. report their data "give evidence of the successive climate periods generally recognized within the last 1000 years," which they describe as "a MWP between ca. AD 1100 and 1320, (2) a LIA which, in the Joux Valley, initiated as early as ca. AD 1350 and ended at ca. AD 1870, and (3) a last warmer and drier period," generally referred to as the beginning of the Current Warm Period (CWP).

"Considering the question of present-day global warming on a regional scale," Magny *et al*. write, "the increase in MTWA by ca. 1.6°C observed at Laoura (1100 m a.s.l., near the Joux basin) for the period 1991–2008, when compared to the reference period 1961–1990, still appears to be in the range of the positive temperature anomaly reconstructed at Lake Joux ca. AD 1300 during the late MWP." They note "meteorological data observed at La Brevine (1043 m a.s.l., also near the Joux basin) suggest a similar pattern with an increase in MTWA by 1°C over the period 1991–2008" relative to 1961–1990. Both of these late-twentieth/early twenty-first century temperature increases fall significantly short of that reached during the MWP, when the temperature at Joux Lake exceeded that of the 1961–1990 reference period by fully 2.0°C. The peak warmth of the MWP at Lake Joux appears to have exceeded that of the CWP at that location by 0.4–1.0°C, in harmony with similar findings obtained at other locations around the world.

Swieta-Musznicka *et al*. (2011) analyzed pollen and macrofossils taken from trench walls exposed during archaeological excavations in Gdansk (54°22'N, 18°40'E), northern Poland, as well as with similar materials contained within cores retrieved from sediments lying beneath the trenches, and discovered evidence for a population expansion of *Salvinia natans* (an aquatic fern) in the seventh or eighth century AD, which was similar to a climate-driven population expansion during the last decade. They report, "the co-occurrence of *S. natans* with other aquatic plant species was similar in both the medieval and present-day vegetation," and "the high density of *S. natans* in the medieval population caused impoverishment of the local ecosystems in a way that has been observed in recent water bodies affected by invasive pleustophytes (free-floating plants)." Thus they conclude "the *S. natans* 'blooms' in the Early Middle Ages may be regarded as an extraordinary occurrence that has an analogue in the climate-driven population of this species during the last decade."

The four researchers describe the early period of *S. natans* population expansion as being due to "climate warming similar to the present time." Elsewhere they report, "in the early medieval period, the population density of *S. natans* was similar to or higher than that observed today in shallow waters invaded by this species in the Gdansk region." Their work suggests the medieval warmth of this part of the world was at least equal to, and perhaps warming than, the CWP.

Moschen *et al*. (2011) presented "a high resolution reconstruction of local growing season temperature anomalies at Durres Maar, Germany [50°52'N, 6°53'E], spanning the last two millennia," which was "derived from a stable carbon isotope time series of cellulose chemically extracted from *Sphagnum* leaves (δ^{13}Ccellulose) separated from a kettle-hole peat deposit of several meters thickness," where the temperature reconstruction was based on the temperature dependency of *Sphagnum* δ^{13}Ccellulose observed in calibration studies (Figure 4.2.4.6.1.4). The five researchers identified a cold phase with below-average temperature, lasting from the fourth to the seventh century AD, "in accordance with the so-called European Migration Period," which has come to be known as the Dark Ages Cold Period. Thereafter, they state, "during High Medieval Times above-average temperatures are obvious." The peak warmth of this Medieval Warm Period, which looks from the graph of their data to run from about AD 830 to AD 1150, was approximately 2.8°C greater than the peak warmth of the Current Warm Period in terms of individual anomaly points, and it was approximately 2.7°C greater in terms of 60-year running means. Between these two warm periods, the Little Ice Age could be seen to hold sway.

Expanding upon the work of some of their group two years earlier (Larocque-Tobler *et al*., 2010), Larocque-Tobler *et al*. (2012) note "the climate of the last millennium is still controversial because too few high-resolution paleo-climate recon-structions exist to answer two key research questions"; namely, "Were the 'Medieval Climate Anomaly' (MCA) and the 'Little Ice Age' (LIA) of similar spatial extent and timing in Europe and in the Northern Hemisphere?" and "Does the amplitude of climate change of the last century exceed the natural variability?"

The second Larocque-Tobler team analyzed a lake sediment core extracted from the deepest point of Seebergsee (46°37'N, 7°28'E) in the northern Swiss Alps in AD 2005, employing chironomid head capsules preserved in the sediments to reconstruct mean July air temperatures for the past 1,000 years.

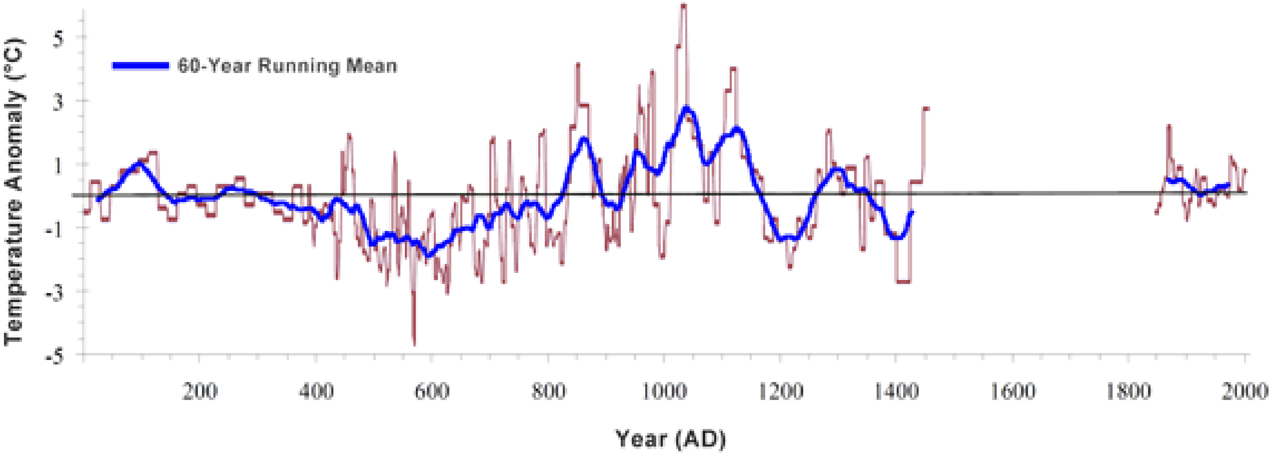

Figure 4.2.4.6.1.4. Temperature reconstruction from Durres Marr, Germany. Adapted from Moschen, R., Kuhl, N., Peters, S., Vos, H., and Lucke, A. 2011. Temperature variability at Durres Maar, Germany during the Migration Period and at High Medieval Times, inferred from stable carbon isotopes of *Sphagnum* cellulose. *Climate of the Past* **7**: 1011–1026.

They compared their results to those of Larocque-Tobler *et al.* (2010) for another Swiss lake (Silvaplana in the eastern Alps) and to regional and European records of early instrumental data (Luterbacher *et al*., 2004; Auer *et al*., 2007; Bohm *et al*., 2010), as well as a composite of paleoclimate reconstructions from the Greater Alpine Region and to millennial scale climate reconstructions of the entire Northern Hemisphere (Mangini *et al*., 2005; Moberg *et al*., 2005; Osborn and Briffa, 2006).

The six scientists' work revealed the peak warmth of the MCA just prior to AD 1200 was approximately 0.9°C greater than the peak warmth near the end of their record, as can be determined from the graph of their data, reproduced here as Figure 4.2.4.6.1.5. The IPCC-endorsed "hockey stick" temperature record of Mann *et al*. (1999), which gives little indication of the existence of the MCA and shows recent temperatures towering over those of that earlier time period, continues to be repudiated by real-world data. Larocque-Tobler *et al*. note their newest temperature history is "mirrored by the chironomid reconstruction from Silvaplana and the Greater Alpine Region composite of reconstructions" and "several other reconstructions from the Northern Hemisphere also show [recent] warm inferred temperatures that were not as warm as the MCA."

Niemann *et al*. (2012) point out, as so many others have, "the assessment of climate variations in Earth's history is of paramount importance for our comprehension of recent and future climate variability." Noting "geological archives containing climate-sensitive proxy indicators are used to reconstruct paleoclimate," Niemann *et al*. employed what they describe as "a novel proxy for continental mean annual air temperature (MAAT) and soil pH" "based on the temperature (T) and pH-dependent distribution of specific bacterial membrane lipids (branched glycerol dialkyl glycerol tetraethers—GDGTs) in soil organic matter." This technique derives from the fact that "microorganisms can modify the composition of their cellular membrane lipids to adapt membrane functionality to specific environmental parameters such as T and pH," as described by Hazel and Williams (1990) and Weijers *et al*. (2007), the latter of whom devised "transfer functions that relate the degree of the GDGT methylation (expressed in the Methylation index—MBT) and cyclisation (expressed in the cyclisation ratio—CBT) to mean annual air temperature."

Niemann *et al*. used sediment cores collected in September 2009 and May 2010 from a small alpine lake (Cadagno) in the Piora Valley of south-central Switzerland, as well as soil samples taken from the surrounding catchment area. The nine Dutch and Swiss researchers report "major climate anomalies recorded by the MBT/CBT-paleothermometer" were "the Little Ice Age (~14th to 19th century) and the Medieval Warm Period (MWP, ~9th to 14th century)," which they say experienced "temperatures similar to the present-day values." They also report, "in addition to the MWP," their "lacustrine paleo T

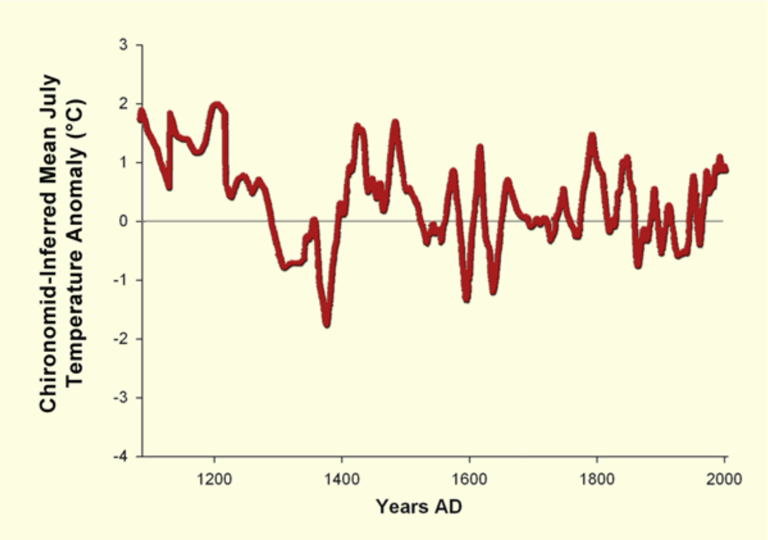

Figure 4.2.4.6.1.5. Reconstruct chironomid-inferred mean July air temperatures for the past 1,000 years, as obtained from a lake sediment core extracted from the deepest point of Seebergsee (46°37'N, 7°28'E) in the northern Swiss Alps. Adapted from Larocque-Tobler, I., Stewart, M.M., Quinlan, R., Traschel, M., Kamenik, C., and Grosjean, M. 2012. A last millennium temperature reconstruction using chironomids preserved in sediments of anoxic Seebergsee (Switzerland): consensus at local, regional and Central European scales. *Quaternary Science Reviews* **41**: 49–56.

record indicates Holocene warm phases at about 3, 5, 7 and 11 kyr before present, which agrees in timing with other records from both the Alps and the sub-polar North-East Atlantic Ocean."

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4.2.4.6.2 Northern

Studying “four well-preserved continuous sediment sequences from the southern flank of the Skagerrak [58.2-58.6°N, 7.6-8.2°E],” which he described as “a current-controlled sedimentary basin between the North and Baltic Seas,” Hass (1996) carried out “granulometric and stable oxygen isotope analyses ... in order to reconstruct climate fluctuations and to evaluate climate impact during the upper Holocene.” He concludes the “Modern Climate Optimum was reached between 1940 and 1950, when temperatures exceeded the present day mean by 0.5°C.” Prior to that was the Little Ice Age, which he placed at about AD 1350–1900, and before that the Medieval Warm Period (AD 800/1000–1350), the climate of which “was characterized by warm summers, mild winters and little storm activity.” Preceding this interval was what has been called the Dark Ages Cold Period, which Hass did not name but placed between AD 400 and 700, and preceding that cold spell was the Roman Warm Period, from approximately 400 BC to AD 400. Preceding these climatic epochs was another pair of cold and warm periods.

Hass’s work adds to the evidence supporting the reality of a repetitive worldwide cycling of climate between Medieval Warm Period- and Little Ice Age-like conditions. In addition, he notes, “at the onset of the Modern Climate Optimum ... conditions change again to a level comparable to the Medieval Warm Period.

Kullman (1998) reviewed “past positional, structural and compositional shifts of tree-limits and upper boreal forests, mainly in the southern Scandes Mountains of Sweden,” based on studies of the elevational location of well-dated subfossil wood remains and the known change in air temperature with change in elevation. Among other things, he discovered "some exceptionally warm and stable centuries, with high tree-limits and dense montane forests, occurred during the Medieval period." He also found "an episode of warmer climate during the first half of the [twentieth] century," but he notes tree limits and high-elevation forests at that time "were far from restored to their medieval levels," which by AD 900–1100 "were situated 80–100 meters higher" than they were about a century ago; i.e., ~1900. He also reports "during the past few decades"—that is, during the latter part of the twentieth century—there was widespread "rapid cold-induced dieback."

The Swedish scientist states, "the slight cooling and associated tree-limit and forest responses since the climate optimum in the late 1930s fit a more general pattern, common to the entire North Atlantic seaboard and adjacent continental areas." He reports "there appear to have been no detectable regional or global tree-limit progression trends over the past 2–3 decades matching the GCM climate projections based on increasing CO_2 levels." He thus concludes "since tree-limits in Scandinavia or elsewhere in the world have not reestablished at their Medieval levels, it is still possible that today's climate, despite centennial net warming, is within its natural limits."

Andren *et al*. (2000) conducted an extensive analysis of changes in siliceous microfossil assemblages and chemical characteristics of various materials found in a well-dated sediment core obtained from the Bornholm Basin in the southwestern Baltic Sea. The data revealed the existence of a period of high primary production at approximately AD 1050, and contemporaneous diatoms were warm water species such as *Pseudosolenia calcar-avis*, which they indicate is "a common tropical and subtropical marine planktonic species" that "cannot be found in the present Baltic Sea." They also note what they call the Recent Baltic Sea Stage, which began about AD 1200, starts "at a point where there is a major decrease in warm water taxa in the diatom assemblage and an increase in cold water taxa, indicating a shift towards a colder climate," which they associate with the Little Ice Age. Andren *et al*.'s data further indicate there was a period of time in the early part of the past millennium when the climate in the area of the southwestern Baltic Sea was warmer than it is today, as the sediment record of that time and vicinity contained several warm water species of diatoms, some of which can no longer be found there. This period of higher temperatures falls within "a period of early Medieval warmth dated to AD 1000–1100," which they note "corresponds to the time when the Vikings succeeded in colonizing Iceland and Greenland."

Hiller *et al*. (2001) analyzed subfossil wood samples from the Khibiny mountains in the Kola Peninsula (67–68°N, 33–34°E) to reconstruct climate change there over the past 1,500 years. They determined between AD 1000 and 1300 the tree-line was located at least 100–140 m above its current elevation, an advance they describe as suggesting mean summer temperatures during this "Medieval climatic optimum" were "at least 0.8°C higher than today." They describe this time period as hosting "the most pronounced warm climate phase on the Kola Peninsula during the last 1500 years,"

Nesje *et al*. (2001) analyzed a 572-cm-long sediment core retrieved from Norway's Lake Atnsjoen to determine the frequency and magnitude of prehistoric floods in the southern part of that country. These efforts revealed several pronounced floods occurred throughout the 4,500-year period. The more recent portion of the record showed a time "of little flood activity around the Medieval period (AD 1000-1400)," correlated with reduced regional glacier activity, and a subsequent period of "the most extensive flood activity in the Atnsjoen catchment," which resulted from the "post-Medieval climate deterioration characterized by lower air temperature, thicker and more long-lasting snow cover, and more frequent storms associated with the 'Little Ice Age.'"

Mikalsen *et al*. (2001) conducted detailed analyses of benthic foraminifera, stable isotopes, and other sedimentary material obtained from a core extracted from a fjord in western Norway, from which they derived a relative temperature history of the region that spanned the last 5,500 years. This work revealed four cold periods characterized by 1.5–2°C reductions in bottom-water temperature—2150 to 1800 BC, 850 to 600 BC, 150 BC to AD 150, AD 500 to 600—and "a cooling that may correspond to the 'Little Ice Age' (AD 1625)." The three researchers also note "there is a good correlation between the cold periods and cold events recorded in other studies." They also identified a warm period from AD 1330 to 1600 that "had the highest bottom-water temperatures in Sulafjorden during the last 5000 years."

Brooks and Birks (2001) were deeply involved in refining protocols for using the larval-stage head capsules of midges to reconstruct temperature histories of various locations, and in this particular paper they report their progress and illustrate the application of their techniques to certain locations in Scotland and Norway. Of particular interest to the

CO_2-climate debate are their findings for Lochan Uaine, in the Cairngorms region of the Scottish Highlands. This lake, they write, "is remote from human habitation and therefore any response of proxy indicators to climatic change [is] unlikely to be masked by the effects of anthropogenic environmental change in its catchment." Reconstructed temperatures for this region peaked at about 11°C, during what they refer to as the "Little Climatic Optimum"—more typically called the Medieval Warm Period—"before cooling by about 1.5°C which may coincide with the 'Little Ice Age.'" These results, say the two scientists, "are in good agreement with a chironomid stratigraphy from Finse, western Norway (Velle, 1998)," where summer temperatures were "about 0.4°C warmer than the present day" during the Medieval Warm Period. The latter observation also appears true for Brooks and Birks' study, since the upper sample of the Lochane Uaine core, collected in 1993, "reconstructs the modern temperature at about 10.5°C" which is 0.5°C less than the 11°C value they obtained from the Medieval Warm Period.

McDermott *et al*. (2001) derived a $\delta^{18}O$ record from a stalagmite discovered in Crag Cave in southwestern Ireland. They compared this record with the $\delta^{18}O$ records from the GRIP and GISP2 ice cores from Greenland. They found "centennial-scale $\delta\ ^{18}O$ variations that correlate with subtle $\delta^{18}O$ changes in the Greenland ice cores, indicating regionally coherent variability in the early Holocene." They also report the Crag Cave data "exhibit variations that are broadly consistent with a Medieval Warm Period at ~1000 ± 200 years ago and a two-stage Little Ice Age, as reconstructed by inverse modeling of temperature profiles in the Greenland Ice Sheet." Also evident in the Crag Cave data were the $\delta^{18}O$ signatures of the earlier Roman Warm Period and Dark Ages Cold Period. The three researchers note the coherent $\delta^{18}O$ variations in the records from both sides of the North Atlantic "indicate that many of the subtle multicentury $\delta^{18}O$ variations in the Greenland ice cores reflect regional North Atlantic margin climate signals rather than local effects." Their data confirm the reality of the Medieval Warm Period/Little Ice Age cycle and the prior and even-more-strongly-expressed Roman Warm Period/Dark Ages Cold Period cycle.

Voronina *et al*. (2001) analyzed dinoflagellate cyst assemblages in two sediment cores from the southeastern Barents Sea—one spanning a period of 8,300 years and one for 4,400 years—obtaining information about sea-surface salinity, temperature, and ice cover throughout the mid- to late-Holocene. The longer of the two cores indicated a warm interval from about 8,000 to 3,000 years before present, followed by cooling pulses coincident with lowered salinity and extended ice cover in the vicinity of 5,000, 3,500, and 2,500 years ago. The shorter of the two cores also revealed cooling pulses at tentative dates of 1,400, 300, and 100 years before present. For the bulk of the past 4,400 years, ice cover lasted only two to three months per year, as opposed to the modern mean of 4.3 months per year, and August temperatures ranged between 6 and 8°C, significantly warmer than the present mean of 4.6°C. This is evidence of considerably warmer temperatures than those of today over much of the past few thousand years—including a period of time coeval with the Medieval Warm Period—in the southeastern Barents Sea, which conditions are said by Voronina *et al*. to be reflective of conditions throughout northwestern Eurasia.

Gunnarson and Linderholm (2002) worked with living and subfossil Scots pine (*Pinus sylvestris* L.) sampled close to the present tree-line in the central Scandinavian Mountains to develop a continuous 1,091-year tree-ring width chronology running from AD 909 to 1998, which they determined to be a good proxy for summer temperatures in the region. They report their data "support evidence for a 'Medieval Warm Period,' where growth conditions were favorable in the tenth and early eleventh centuries." In addition, their data show the warmth of the Medieval Warm Period was both greater and longer-lasting than that of the Current Warm Period, which their data depict as having peaked around 1950.

The two Swedish scientists report their chronology "does not show the continuous temperature decrease from AD 1000 to 1900 followed by a distinct increase during the twentieth century" shown by the hockey stick temperature history of Mann *et al*. (1998, 1999). "On the contrary," they write, their chronology "displays a positive trend from the middle of the seventeenth century, culminating around 1950, followed by strongly decreasing growth."

Berglund (2003) identified several periods of expansion and decline of human cultures in Northwest Europe and compared them with a history of reconstructed climate "based on insolation, glacier activity, lake and sea levels, bog growth, tree line, and tree growth." He found "a positive correlation between human impact/land-use and climate change."

Specifically, in the latter part of the record, where both cultural and climate changes were best defined, there was, in his words, a great "retreat of agriculture" centered on about AD 500, which led to "reforestation in large areas of central Europe and Scandinavia." He additionally notes "this period was one of rapid cooling indicated from tree-ring data (Eronen *et al.*, 1999) as well as sea surface temperatures based on diatom stratigraphy in [the] Norwegian Sea (Jansen and Koc, 2000), which can be correlated with Bond's event 1 in North Atlantic sediments (Bond *et al.*, 1997)."

Next came what Berglund called a "boom period" that covered "several centuries from AD 700 to 1100." This period proved to be "a favorable period for agriculture in marginal areas of Northwest Europe, leading into the so-called Medieval Warm Epoch," when "the climate was warm and dry, with high treelines, glacier retreat, and reduced lake catchment erosion." This period "lasted until around AD 1200, when there was a gradual change to cool/moist climate, the beginning of the Little Ice Age ... with severe consequences for the agrarian society."

Andersson *et al.* (2003) inferred surface conditions of the eastern Norwegian Sea (Voring Plateau) from planktic stable isotopes and planktic foraminiferal assemblage concentrations in two seabed sediment cores obtained in the vicinity of 66.97°N, 7.64°W that covered the last three thousand years. The climate history derived from this study was remarkably similar to that derived by McDermott *et al.* (2001) from a high-resolution speleothem $\delta^{18}O$ record obtained from a stalagmite discovered in a cave in southwestern Ireland. At the beginning of the 3,000-year-long Voring Plateau record, for example, both regions were clearly in the end-stage of the long cold period that preceded the Roman Warm Period. Both records depicted warming from that time to the peak of the Roman Warm Period, which occurred about 2,000 years BP. Both regions then began their descent into the Dark Ages Cold Period, which lasted until the increase in temperature that produced the Medieval Warm Period, which in both records prevailed from about 800 to 550 years BP. Finally, the Little Ice Age was evident, with cold periods centered at approximately 400 and 100 years BP, again in both records.

Interestingly, neither record indicates the existence of what has come to be called the Current Warm Period. Moreover, Andersson *et al.* report, "surface ocean conditions warmer than present were common during the past 3000 years." As time has passed, therefore, evidence for the reality of the solar-induced millennial-scale cycling of climate described by Bond *et al.* (1997, 2001) has continued to mount, while evidence for the "unprecedented" temperature claimed for the present by the IPCC continues to be sought but not found.

Tiljander *et al.* (2003) conducted high-resolution analyses—including varve thickness, relative X-ray density, pollen and diatom assessments, and organic matter loss-on-ignition (LOI)—on a 3,000-year varved sediment sequence obtained from Lake Korttajarvi in central Finland. They compared their results with those of other palaeo-environmental studies conducted in Finland. They found "an organic rich period from AD 980 to 1250" they say "is chronologically comparable with the well-known 'Medieval Warm Period.'" During time period, they report, "the sediment structure changes" and "less mineral material accumulates on the lake bottom than at any other time in the 3000 years sequence analyzed and the sediment is quite organic rich (LOI ~20%)." They conclude, "the winter snow cover must have been negligible, if it existed at all, and spring floods must have been of considerably lower magnitude than during the instrumental period (since AD 1881)," conditions they equate with a winter temperature approximately 2°C warmer than at present.

Tiljander *et al.* cite much corroborative evidence in support of this conclusion. They note, for example, "the relative lack of mineral matter accumulation and high proportion of organic material between AD 950 and 1200 was also noticed in two varved lakes in eastern Finland (Saarinen *et al.*, 2001) as well as in varves of Lake Nautajarvi in central Finland c. AD 1000–1200 (Ojala, 2001)." They also note "a study based on oak barrels, which were used to pay taxes in AD 1250–1300, indicates oak forests grew 150 km north of their present distribution in SW Finland and this latitudinal extension implies a summer temperature 1–2°C higher than today (Hulden, 2001)." And they report "a pollen reconstruction from northern Finland suggests that the July mean temperature was c. 0.8°C warmer than today during the Medieval Climate Anomaly (Seppa, 2001)." In these studies, therefore, the scientists conclude both summer and winter temperatures over much of the Medieval Warm Period throughout many parts of Finland were significantly warmer than they are at present.

Roncaglia (2004) analyzed variations in organic matter deposition from approximately 6,350 cal yr BC to AD 1430 in a sediment core extracted from the

Skalafjord, southern Eysturoy, Faroe Islands to assess climatic conditions in that part of the North Atlantic from the mid- to late-Holocene. She reports an increase in “structured brown phytoclasts, plant tissue and sporomorphs in the sediments dating to ca. AD 830–1090 indicate increased terrestrial influx and inland vegetation supporting the idea of improved climatic conditions,” while also noting “the increase in the amount of structured brown phytoclasts, leaf and membranous tissue and sporomorphs indicated increased inland vegetation probably related to improved climatic conditions and/or the presence of cultivated crops on the islands.” In addition, she found high “total dinoflagellate cyst concentration and increased absolute amount of loricae of tintinnid and planktonic crustacean eggs occurred at ca. AD 830–1090,” concluding these observations “may suggest increased primary productivity in the waters of the fjord,” citing Lewis *et al*. (1990) and Sangiorgi *et al*. (2002).

Roncaglia writes, the “amelioration of climate conditions,” which promoted the enhanced productivity of both land and sea at this time, “may encompass the Medieval Warm Period in the Faroe region.” She also reports an increased concentration of certain other organisms at about AD 1090–1260, which she says “suggests a cooling, which may reflect the beginning of the Little Ice Age.” Thus evidence for both the Medieval Warm Period and Little Ice Age is clear in the sediments of a Faroe Island fjord, demonstrating that even at sea, these major recurring extremes of cyclical Holocene climate make their presence felt to such a degree that they significantly influence both aquatic and terrestrial primary production.

Hormes *et al*. (2004) identified and dated periods of soil formation in moraines in the Kebnekaise mountain region of Swedish Lapland in the foreground of the Nipalsglaciaren (67°58’N, 18°33’E) and compared the climatic implications of their results with those of other proxy climate records derived in other areas of northern and central Scandinavia. Two main periods of soil formation were identified (2750–2000 and 1170–740 cal yr BP), and these time spans coincide nearly perfectly with the Roman and Medieval Warm Periods delineated by McDermott *et al*. (2001) in the high-resolution $\delta^{18}O$ record they developed from a stalagmite in southwestern Ireland’s Crag Cave.

Hormes *et al*. also report the periods during which the soil formation processes took place “represent periods where the Nipalsglacier did not reach the position of the moraine,” and “the glacier was most likely in a position similar to today, and climate conditions were also similar to today.” Comparing their findings with those of other investigators, they report the following with respect to the Medieval Warm Period:

(1) Pollen profiles derived from sediments of Lake Tibetanus in Lapland (Hammarlund *et al*., 2002) “infer increased mean July temperatures ... peaking around 1000 cal yr BP.”

(2) Oxygen isotope studies in nearby Lake 850 “record changes around 1000 cal yr BP towards favorable climate conditions (Shemesh *et al*., 2001).”

(3) At Lake Laihalampi in southern Finland, “pollen-based reconstructions of mean temperatures indicate 0.5°C higher values between 1200 and 1100 cal yr BP (Heikkila and Seppa, 2003).”

(4) Radiocarbon ages of mosses in front of Arjep Ruotesjekna in the Sarek Mountains of Swedish Lapland “support the conclusion that between 1170 and 920 cal yr BP the glaciers had not reached the 1970s limit (Karlen and Denton, 1975).”

(5) Reconstructed temperatures of a pine dendrochronology from northern Fennoscandia “show temperatures between 1100 and 750 cal yr BP to have been around 0.8°C higher than today (Grudd *et al*., 2002).”

(6, 7) At Haugabreen glacier (Matthews, 1980) and Storbreen glacier (Griffey and Matthews, 1978) in southern maritime Norway, “soil formation on moraines was dated between 1060 and 790 cal yr BP.”

(8) Alder trees were melted out from Engabreen glacier (Worsley and Alexander, 1976), “suggesting a smaller extension of this Norwegian glacier between 1180 and 790 cal yr BP supporting warm/dry conditions during that time in central Norway.”

(9) Jostedalsbreen glacier “receded between 1000 and 900 cal yr BP (Nesje *et al*., 2001).”

With respect to their identification of the Roman Warm Period, Hormes *et al*. report prior findings of soil formation at (1) Svartisen glacier between 2,350 and 1,990 cal yr BP by Karlen (1979), (2) Austre Okstindbreen glacier between 2,350 and 1,800 cal yr BP by Griffey and Worsley (1978), and (3) Austre Okstindbreen glacier between 2,750 and 2,150 by Karlen (1979). In addition, they note:

(4) The pine tree-based temperature history of northern Fennoscandia developed by Grudd *et al*. (2002) “discloses a spike +2°C higher than today’s around 2300 cal yr BP.”

(5, 6, 7, 8, 9) “The lacustrine records in Lapland

and Finland are also consistent with supposition of a warmer climate than at present before 2000 cal yr BP and cooler temperatures before 2450 cal yr BP (Rosen *et al*., 2001; Seppa and Birks, 2001; Shemesh *et al*., 2001; Hammarlund *et al*., 2002; Heikkila and Seppa, 2003)."

In view of these many research findings, it is clear both the Medieval and Roman Warm Periods were very real features of Scandinavian climatic history, and they were likely even warmer than the Current Warm Period has been to date.

Blundell and Barber (2005) used plant macrofossils, testate amoebae, and degree of humification as proxies for environmental moisture conditions to develop a 2,800-year "wetness history" from a peat core extracted from Tore Hill Moss, a raised bog in the Strathspey region of Scotland. Based on the results they obtained from the three proxies they studied, they derived a relative wetness history that began 2,800 years ago and extended to AD 2000.

The most clearly defined and longest interval of sustained dryness of this history stretched from about AD 850 to AD 1080, coincident with the well-known Medieval Warm Period, while the most extreme wetness interval occurred during the depths of the last stage of the Little Ice Age. Also evident in the two scientists' wetness history was a period of relative dryness centered on about AD 1550, which corresponded to a period of relative warmth that has previously been documented by several other studies. Preceding the Medieval Warm Period, their hydro-climate reconstruction reveals a highly chaotic period of generally greater wetness that corresponds to the Dark Ages Cold Period, while also evident were dryness peaks representing the Roman Warm Period and two other periods of relative dryness located about 500 years on either side of its center.

The correlation this study demonstrates to exist between relative wetness and warmth in Scotland strongly suggests the temperature of the late twentieth century was nowhere near the highest of the past two millennia in that part of the world, as five other periods over the past 2,800 years were considerably warmer. Blundell and Barber cite many studies that report findings similar to theirs throughout much of the rest of Europe and the North Atlantic Ocean.

Linderholm and Gunnarson (2005) developed what they called the Jämtland multi-millennial tree-ring width chronology, derived from living and subfossil Scots pines (*Pinus sylvestris* L.) sampled close to the present tree-line in the central Scandinavian Mountains. This record spanned 2893 BC to AD 2002, with minor gaps at 1633–1650 BC and AD 887–907. The two researchers focused their analysis on the well-replicated period of 1632 BC to AD 2000, utilizing it as a proxy for summer temperatures.

Several periods of anomalously warm and cold summers were noted throughout the record: 550 to 450 BC (Roman Warm Period), when summer temperatures were the warmest of the entire record, exceeding the 1961–1990 mean by more than 6°C; AD 300 to 400 (Dark Ages Cold Period), which was "the longest period of consecutive cold summers," averaging 1.5°C less than the 1961–1990 mean; AD 900 to 1000, a warm era corresponding to the Medieval Warm Period; and AD 1550 to 1900, a cold period known as the Little Ice Age. With respect to the final section of the tree-ring record, which encompasses the period of modern warming, Linderholm and Gunnarson state this phenomenon "does not stand out as an anomalous feature in the 3600-year record," noting "other periods show more rapid warming and also higher summer temperatures."

Berge *et al*. (2005) describe and discuss the significance of what they refer to as "the first observations of settled blue mussels *Mytilus edulis* L. in the high Arctic Archipelago of Svalbard for the first time since the Viking Age." This discovery of the blue mussel colony was made by divers in August and September 2004 at Sagaskjaeret, Isfjorden, Svalbard (78°13'N, 14°E). Subsequent inferences of the five researchers with regard to pertinent regional climatic and oceanographic conditions over the prior few years led them to conclude "the majority of blue mussels were transported as larvae in unusually warm water by the West Spitsbergen Current from the mainland of Norway to Spitsbergen during the summer of 2002." They write "it is highly probable that the newly established blue mussel population is a direct response to a recent increase in sea surface temperatures."

Berge *et al*. further note the "distribution patterns of blue mussels *Mytilus edulis* L. in the high Arctic indicate that this thermophilous mollusk was abundant along the west coast of Svalbard during warm intervals (Salvigsen *et al*., 1992; Salvigsen, 2002) in the Holocene," but mussels of this species "have not been present at Svalbard for the last 1000 years (Salvigsen, 2002)." In light of these well-documented real-world observations, including the fact that blue mussels only recently had begun to reestablish themselves in this part of the world, they conclude water temperatures there were only beginning to "approach those of the mediaeval warm period."

Weckstrom *et al.* (2006) developed a high-resolution quantitative history of temperature variability over the past 800 years, based on analyses of diatoms found in a sediment core retrieved from a treeline lake—Lake Tsuolbmajavri (68°41'N, 22°05'E)—in Finnish Lapland. The work revealed the "termination phase of the MWP," which they indicate as having occurred between AD 1200 and 1300, was 0.15°C warmer than the peak warmth of the Current Warm Period, which in their history occurred at the conclusion of the twentieth century (see Figure 4.2.4.6.2.1).

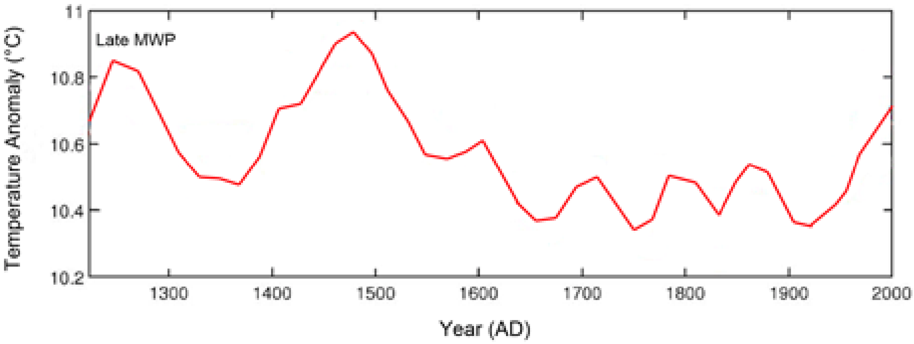

Figure 4.2.4.6.2.1. Decadally smoothed diatom-based temperature reconstruction from Lake Tsuolbmajavri in Finish Lapland. Adapted from Weckstrom, J., Korhola, A., Erasto, P., and Holmstrom, L. 2006. Temperature patterns over the past eight centuries in Northern Fennoscandia inferred from sedimentary diatoms. *Quaternary Research* **66**: 78–86.

Eiriksson *et al.* (2006) reconstructed the near-shore thermal history of the North Atlantic Current along the western coast of Europe over the last two millennia, based on measurements of stable isotopes, benthic and planktonic foraminifera, diatoms, and dinoflagellates, as well as geochemical and sedimentological parameters, which they acquired on the Iberian margin, the West Scotland margin, the Norwegian margin, and the North Icelandic shelf. In addition to identifying the Roman Warm Period (nominally 50 BC–AD 400), which exhibited the warmest sea surface temperatures of the last two millennia on both the Iberian margin and the North Icelandic shelf, and the following Dark Ages Cold Period (AD 400–800), Eiriksson *et al.* report detecting the Medieval Warm Period (AD 800–1300) and Little Ice Age (AD 1300–1900), which was followed in some records by a strong warming to the present. They stated the latter warming "does not appear to be unusual when the proxy records spanning the last two millennia are examined."

The results of Eiriksson *et al.*'s research confirm the millennial-scale climatic oscillation that has been responsible for periodically producing centennial-scale warm and cold periods throughout Earth's history. It also reveals there is nothing unusual or unnatural about the Current Warm Period, which in the case of two of their four sites was found to be somewhat cooler than it was during the Roman Warm Period of 2,000 years ago, when the atmosphere's CO_2 concentration was more than 100 ppm less than it is today.

Haltia-Hovi *et al.* (2007) extracted sediment cores from beneath the 0.7-m-thick ice platform on Lake Lehmilampi (63°37'N, 29°06'E) in North Karelia, eastern Finland, in the springs of 2004 and 2005. They identified and counted the approximately 2,000 annual varves contained in the cores and measured their individual thicknesses and mineral and organic matter contents. They compared these climate-related data with residual $\Delta^{14}C$ data derived from tree rings, which serve as a proxy for solar activity. They report their "comparison of varve parameters (varve thickness, mineral and organic matter accumulation) and the activity of the sun, as reflected in residual $\Delta^{14}C$ [data] appears to coincide remarkably well in Lake Lehmilampi during the last 2000 years, suggesting solar forcing of the climate."

In addition, the Finnish researchers state, "the low deposition rate of mineral matter in AD 1060–1280 possibly implies mild winters with a short ice cover period during that time with minor snow accumulation interrupted by thawing periods." They note the low accumulation of organic matter during this period "suggests a long open water season and a high decomposition rate of organic matter." Consequently, since the AD 1060–1280 period shows by far the lowest levels of both mineral and organic matter content (Figure 4.2.4.6.2.2), and since "the thinnest varves of the last 2000 years were deposited during [the] solar activity maxima in the Middle Ages," it is difficult not to conclude the period was likely the warmest of the past two millennia.

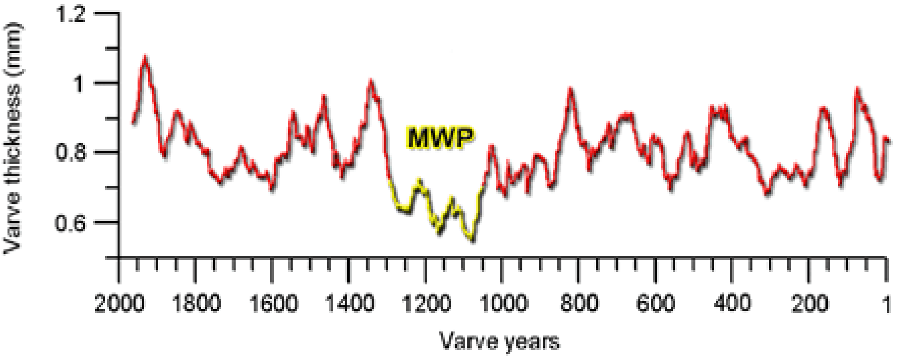

Figure 4.2.4.6.2.2. Varve thickness from sediment cores obtained from Lake Lehmilampi, eastern Finland. Adapted from Haltia-Hovi, E., Saarinen, T., and Kukkonen, M. 2007. A 2000-year record of solar forcing on varved lake sediment in eastern Finland. *Quaternary Science Reviews* **26**: 678–689.

Allen *et al*. (2007) analyzed pollen characteristics within sediment cores retrieved from a small unnamed lake located at 71°02'18"N, 28°10'6.6"E near the coast of Nordkinnhalvoya, Finnmark, Norway and constructed a climatic history of the area. They found "regional vegetation responded to Holocene climatic variability at centennial-millennial time scales" and report, "the most recent widely documented cooling event, the Little Ice Age of ca 450–100 cal BP, also is reflected in our data by a minimum in *Pinus:Betula* [pollen] ratio beginning ca 300 cal BP and ending only in the recent past." They also note, "the Dark Ages cool interval, a period during which various other proxies indicate cooling in Fennoscandia and beyond, is evident too, corresponding to lower values of *Pinus:Betula* [pollen] ratio ca 1600–1100 cal BP." In addition, "the Medieval Warm Period that separated the latter two cool intervals also is strongly reflected in our data, as is the warm period around two millennia ago during which the Roman Empire reached its peak."

Jiang *et al*. (2007) analyzed diatom data they obtained from core MD992271 (66°30'05"N, 19°30'20"W) on the North Icelandic shelf to derive summer sea surface temperatures (SSTs) for that location based on relative abundances of warm and cold water species. They compared the results they obtained with results derived by Jiang *et al*. (2002, 2005) via similar analyses of nearby cores HM107-03 (66°30'N, 19°04'W) and MD992275 (66°33"N, 17°42'W), as well as results derived from GISP2 δ^{18}O data and other marine sediment records obtained from other regions of the North Atlantic.

The data from the new sediment core revealed a gradually decreasing temperature trend over the entire reconstructed 3,000-year SST record, with superimposed centennial- and millennial-scale summer SST fluctuations. In addition, Jiang *et al*. write, "the Medieval Warm Period and the Little Ice Age are identified in the record," with the former period appearing to have prevailed between approximately AD 950 and 1250. The MD992271 record ended in the midst of the Little Ice Age and therefore did not reveal any nineteenth or twentieth century warming. The HM107-03 record, on the other hand, extended to within about 50 years of the present, but it too showed no evidence of any warming at its end. Core MD992275 extended to the nominal present, however, and it suggested the end of the twentieth century was at least three-quarters of a degree Centigrade cooler than the peak temperature of the Medieval Warm Period, about the same qualitative and quantitative difference suggested by the GISP2 δ^{18}O data.

Jiang *et al*. note, "comparison of the data from core MD992271 with those from two other cores, HM107-03 and MD992275, on the North Icelandic shelf shows coherent late Holocene changes in reconstructed summer SST values ... reflecting regional changes in the summer SSTs on the North Icelandic shelf." They conclude, "the consistency between changes in the late Holocene summer SSTs on the North Icelandic shelf and in GISP2 δ^{18}O data, as well as in other marine sediment records from the North Atlantic, further suggests synchronous North Atlantic-wide climate fluctuations."

Justwan *et al*. (2008) reconstructed August sea surface temperatures with a resolution of 40 years over the past 11,000-plus years based on analyses of diatoms found in a sediment core extracted from the northern Icelandic shelf (66°37'53"N, 20°51'16"W). Figure 4.2.4.6.2.3 illustrates the data for the most recent two millennia of this record, showing the peak warmth of the MWP is essentially identical to the peak warmth of the Current Warm Period, albeit the peak warmth of the CWP does not appear at its current endpoint, which would technically make the CWP's current temperature about 0.5°C less than the

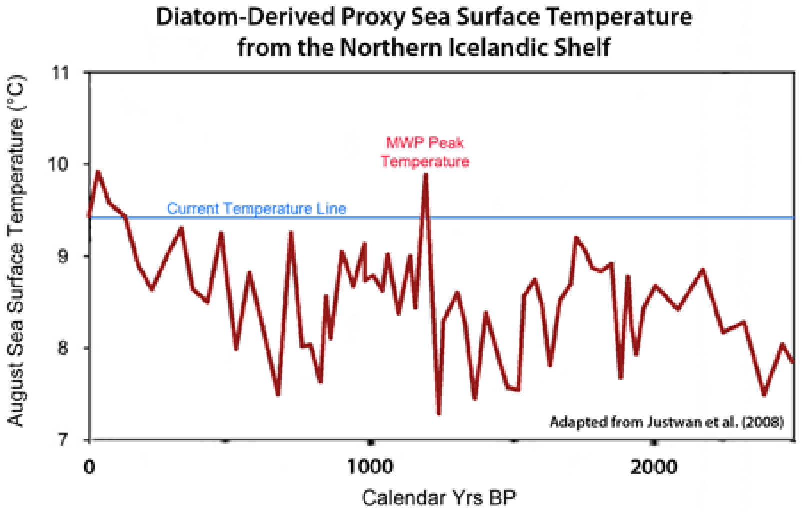

Figure 4.2.4.6.2.3. A diatom-based sea surface temperature reconstruction from the northern Icelandic shelf. Adapted from Justwan, A., Koc, N., and Jennings, A.E. 2008. Evolution of the Irminger and East Icelandic Current systems through the Holocene, revealed by diatom-based sea surface temperature reconstructions. *Quaternary Science Reviews* **27**: 1571–1582.

peak MWP temperature.

Leipe *et al*. (2008) analyzed five 60-cm sediment cores retrieved from the eastern Gotland Basin in the central Baltic Sea (~56°55’–57°15’N, 19°20’–20°00’E) for a variety of physical, chemical, and biological properties. They report, “during the Medieval Warm Period, from about AD 900 to 1250, the hydrographic and environmental conditions were similar to those of the present time.” They note, moreover, analyses of lignin compounds in the sediment cores, which “can be used to characterize terrigenous organic matter from plants,” pointed to the Medieval Warm Period possibly being warmer than the Current Warm Period.

Sicre *et al*. (2008) developed a unique, 2,000-year-long summer sea surface temperature (SST) record with unprecedented temporal resolution (2–5 years) from a sediment core retrieved off North Iceland (66°33’N, 17°42W), based on their analyses of alkenones synthesized primarily in the summer by the marine alga *Emiliania huxleyi* that grew in the overlying ocean’s surface waters, dating the SST data by tephrochronology. Figure 4.2.4.6.2.4 is adapted from the temperature history they derived. Of particular interest is its clear depiction of the millennial-scale oscillation of climate that produced the Roman Warm Period, Dark Ages Cold Period, Medieval Warm Period, Little Ice Age, and Current Warm Period.

In comparing prior temperatures to those of the near-present, the figure shows the SST record peaks at about 8.3°C somewhere around 1940, a particularly warm time in Earth’s modern history. However, the researchers show a “modern temperature” of 9°C they determined from a box-core of nearby surface sediment, which they say “is consistent with the recent compilation produced by Hanna *et al.* (2006).” The latter reported, “since 1874, July and August SSTs measured at Grimsey Island have varied between 6.7 and 9°C,” which suggests Sicre *et al.*’s 9°C value is the *peak* modern temperature observed in the time of Hanna *et al.*’s analysis. It can be concluded the peak temperature of the Medieval Warm Period was fully 1°C warmer than the peak temperature of the Current Warm Period, and the peak temperature of the Roman Warm Period was about 0.5°C warmer than that of the Current Warm Period.

Grudd (2008) notes many tree-ring-based temperature histories terminate far short of the end of the twentieth century, and he states there is thus “an urgent need to update existing tree-ring collections throughout the northern hemisphere,” especially to make valid comparisons of past high-temperature periods, such as the Medieval Warm Period, with the present.

Working with an extensive set of Scots pine (*Pinus sylvestris* L.) tree-ring maximum density (MXD) data from the Torneträsk area of northern Sweden, originally compiled by Schweingruber *et al.* (1988) and covering the period AD 441–1980, Grudd extended the record an additional 24 years to 2004 using new samples obtained from 35 relatively young trees. This had the effect of reducing the mean cambial age of the MXD data in the twentieth century and thus eliminating a disturbing “loss of sensitivity to temperature, apparent in earlier versions of the Torneträsk MXD chronology (Briffa, 2000).” The results are depicted in Figure 4.2.4.6.2.5.

Grudd concluded, as is readily evident from the results presented in the figure above, “the late-twentieth century is not exceptionally warm in the new Torneträsk record,” since “on decadal-to-century timescales, periods around AD 750, 1000, 1400 and 1750 were all equally warm, or warmer.” He states,

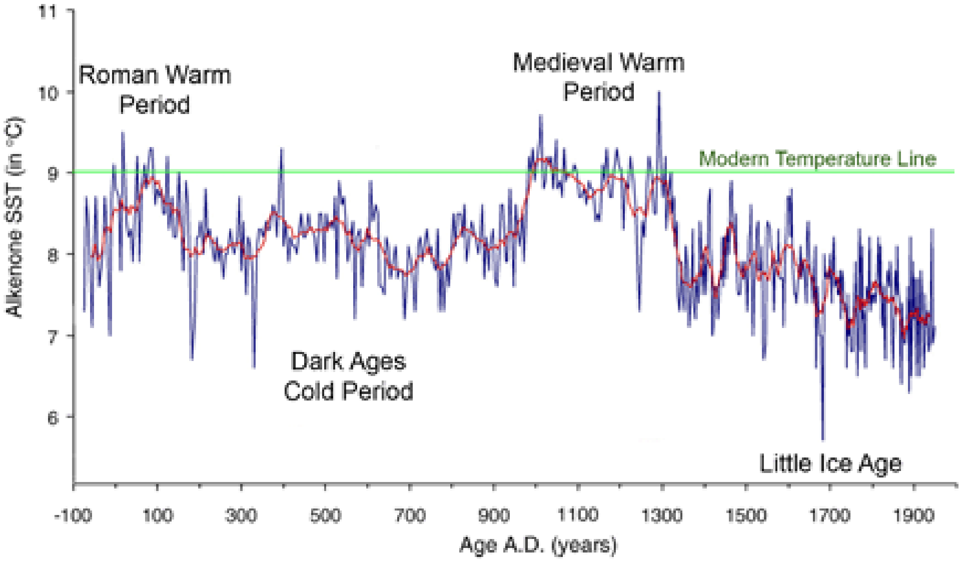

Figure 4.2.4.6.2.4. A 2,000-year summer sea surface temperature record derived from an ocean sediment core off the coast of north Iceland. Adapted from Sicre, M.-A., Jacob, J., Ezat, U., Rousse, S., Kissel, C., Yiou, P., Eiriksson, J., Knudsen, K.L., Jansen, E., and Turon, J.-L. 2008. Decadal variability of sea surface temperatures off North Iceland over the last 2000 years. *Earth and Planetary Science Letters* **268**: 137–142.

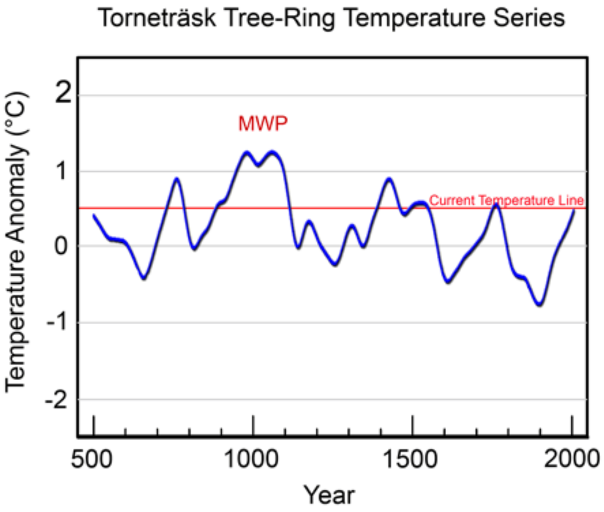

Figure 4.2.4.6.2.5. Tree-ring temperature proxy from Torneträsk, Sweden. Adapted from Sicre, M.-A., Jacob, J., Ezat, U., Rousse, S., Kissel, C., Yiou, P., Eiriksson, J., Knudsen, K.L., Jansen, E., and Turon, J.-L. 2008. Decadal variability of sea surface temperatures off North Iceland over the last 2000 years. *Earth and Planetary Science Letters* **268**: 137–142.

"the warmest summers in this new reconstruction occur in a 200-year period centered on AD 1000," leading him to declare, "Fennoscandia seems to have been significantly warmer during medieval times as compared to the late-twentieth century," and this period "was much warmer than previously recognized." In addition, he notes, "a warm period around AD 1000 is in line with evidence from other proxy indicators from northern Fennoscandia," writing, "pine tree-limit (Shemesh *et al*., 2001; Helama *et al*., 2004; Kulti *et al*., 2006) [and] pollen and diatoms (Korhola *et al*., 2000; Seppa and Birks, 2002; Bigler *et al*., 2006) show indisputable evidence of a 'Medieval Warm Period' that was warmer than the twentieth century climate."

Helama *et al*. (2009) used data obtained from hundreds of moisture-sensitive Scots pine tree-ring records originating in Finland and regional curve standardization (RCS) procedures to develop what they describe as "the first European dendroclimatic precipitation reconstruction," which "covers the classical climatic periods of the Little Ice Age (LIA), the Medieval Climate Anomaly (MCA), and the Dark Ages Cold Period (DACP)," running from AD 670 to AD 1993. These data, they write, indicate "the special feature of this period in climate history is the distinct and persistent drought, from the early ninth century AD to the early thirteenth century AD," which "precisely overlaps the period commonly referred to as the MCA, due to its geographically widespread climatic anomalies both in temperature and moisture." In addition, they report "the reconstruction also agrees well with the general picture of wetter conditions prevailing during the cool periods of the LIA (here, AD 1220–1650) and the DACP (here, AD 720–930)."

The three Finnish scientists note "the global medieval drought that we found occurred in striking temporal synchrony with the multicentennial droughts previously described for North America (Stine, 1994; Cook *et al*., 2004, 2007), eastern South America (Stine, 1994; Rein *et al*., 2004), and equatorial East Africa (Verschuren *et al*., 2000; Russell and Johnson, 2005, 2007; Stager *et al*., 2005) between AD 900 and 1300." Noting further "the global evidence argues for a common force behind the hydrological component of the MCA," they report "previous studies have associated coeval megadroughts during the MCA in various parts of the globe with either solar forcing (Verschuren *et al*., 2000; Stager *et al*., 2005) or the ENSO (Cook *et al*., 2004, 2007; Rein *et al*., 2004; Herweijer *et al*., 2006, 2007; Graham *et al*., 2007, Seager *et al*., 2007)." They conclude, "the evidence so far points to the medieval solar activity maximum (AD 1100–1250), because it is observed in the $\Delta^{14}C$ and ^{10}Be series recovered from the chemistry of tree rings and ice cores, respectively (Solanki *et al*., 2004)."

Bjune *et al*. (2009) used mean July temperature reconstructions based on "pollen-stratigraphical data obtained from eleven small lakes located in the middle boreal, northern boreal, low-alpine, or low-arctic zones of northern Norway, northern Sweden, northern Finland and north-west Russia" to develop a mean quantitative temperature history spanning the past two millennia for this Northern Fennoscandia region (66°25'–70°50'N, 14°03'–35°19'E). They report, "no consistent temperature peak is observed during the 'Medieval Warm Period.'" But a graph of their final result (see Figure 4.2.4.6.2.6) shows what they describe as the present temperature (red vertical line)—derived from the uppermost 1 cm of the sediment cores, which were collected at various times between AD 1994 and 2003—is colder than almost all of the data points obtained by the authors over the past 2,000 years. Focusing on the Medieval Warm Period, it is evident temperatures then were as much as 1.4°C warmer than what they were over the most recent decade or so.

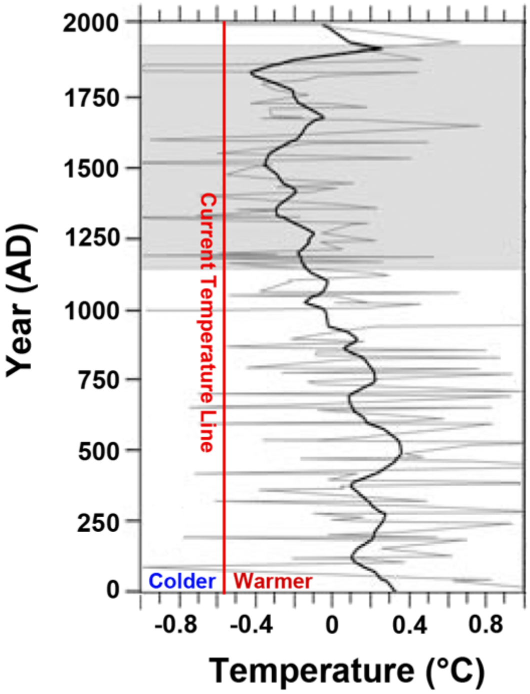

Figure 4.2.4.6.2.6. Mean July temperature reconstruction based on pollen-stratigraphical data obtained from eleven small lakes located in the boreal and alpine low-arctic zones of northern Norway, northern Sweden, northern Finland and north-west Russia. Adapted from Bjune, A.E., Seppa, H., and Birks, H.J.B. 2009. Quantitative summer-temperature reconstructions for the last 2000 years based on pollen-stratigraphical data from northern Fennoscandia. *Journal of Paleolimnology* **41**: 43–56.

Axford *et al*. (2009) write, "the idea of a widespread and spatially coherent 'Medieval Warm Period' (MWP) has come under scrutiny in recent years," but "it remains a viable hypothesis that a period of relative warmth in northwestern Europe and the northern North Atlantic region helped facilitate Norse expansion across the North Atlantic from the ninth to thirteenth centuries, including settlement of Iceland and Greenland," and "subsequent cooling contributed to the demise of the Norse settlements on Greenland." They developed a regional climatic record from a sediment core retrieved from lake Stora Vioarvatn in northeast Iceland (66°14.232'N, 15°50.083'W) in the summer of 2005, based on chironomid assemblage data, which were well correlated with nearby measured temperatures over the 170-year instrumental record, and total organic carbon, nitrogen, and biogenic silica content.

The four researchers report their data indicated "warm temperatures in the tenth and eleventh centuries, with one data point suggesting temperatures slightly warmer than present." They also found "temperatures were higher overall and more consistently high through much of the first millennium AD" (see Figure 4.2.4.6.2.7).

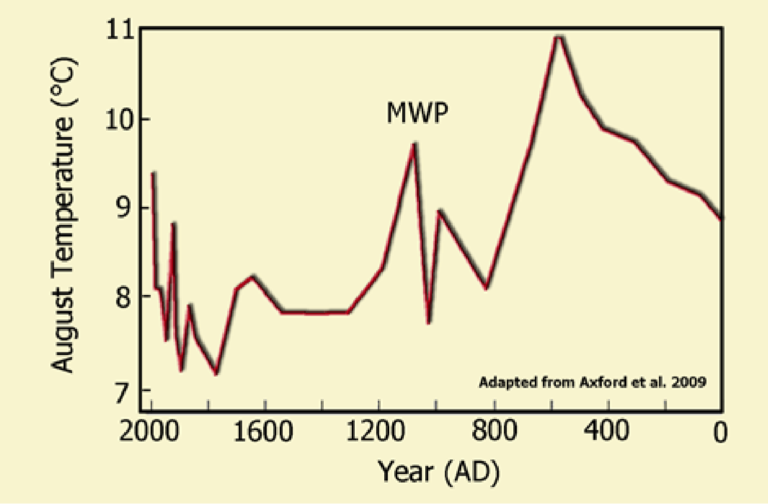

Figure 4.2.4.6.2.7. August temperature reconstruction from Lake Stora Vioarvatn. Adapted from Axford, Y., Geirsdottir, A., Miller, G.H., and Langdon, P.G. 2009. Climate of the Little Ice Age and the past 2000 years in northeast Iceland inferred from chironomids and other lake sediment proxies. *Journal of Paleolimnology* **41**: 7–24.

The Icelandic, UK and U.S. scientists write, "the historical perception of a significant medieval climate anomaly in Iceland may be primarily a reflection of the human perspective," in that "Iceland was settled ca. AD 870, during a period of relative warmth that was followed by many centuries of progressively colder and less hospitable climate." They also note, "had the Norse settled Iceland 1000 years earlier, the MWP might be viewed only as a brief period of climatic amelioration, a respite from a shift to colder temperatures that began in the eighth century," near the end of several centuries of even greater warmth. Viewed from either perspective, it is clear there is nothing unusual or unnatural about the region's present-day temperatures, which the researchers say "do not show much recent warming."

Stancikaite *et al.* (2009) carried out interdisciplinary research at the Impiltis hill fort and settlement area of Northwest Lithuania "to study the climate and the human impact on the landscape, the development of the settlement and the hill fort, the types of agriculture employed there, and changes in the local economy." They determined "the transition from the first to the second millennium AD, also the onset of the 'Medieval Warm Period,' coincided with a period of intensive human activity at the Impiltis hill fort and settlement area."

There was at that time, they discovered, "a high intensity of farming activities, which were supported by favorable climatic conditions and included the existence of permanent agricultural fields as well as the earliest record of rye cultivation in NW Lithuania." The "period of most prominent human activity in the Impiltis," as the eight researchers describe it, "was dated back to about 1050–1250 AD," when they suggest "the favorable climatic conditions of [this] 'Medieval Warm Period' may have supported human activity during its maximum phase." This inference, they write, "correlates well with the chronology of the hill fort and settlement prosperity as represented in data collected from the site." Thereafter, they further suggest, "it is possible that the ensuing gradual regression of human activity was caused, in part, by the climatic deterioration known as the 'Little Ice Age.'"

Bonnet *et al.* (2010) developed a high-resolution record of ocean and climate variations during the late Holocene in the Fram Strait (the major gateway between the Arctic and North Atlantic Oceans, located north of the Greenland Sea), using detailed analyses of a sediment core recovered from a location (78°54.931'N, 6°46.005'E) on the slope of the western continental margin of Svalbard, based on analyses of organic-walled dinoflagellate cysts that permit the reconstruction of sea-surface conditions in both summer and winter. The latter reconstructions, they write, "were made using two different approaches for comparison and to insure the robustness of estimates." These were "the modern analogue technique, which is based on the similarity degree between fossil and modern spectra" and "the artificial neural network technique, which relies on calibration between hydrographical parameters and assemblages."

Bonnet *et al.* discovered the sea surface temperature (SST) histories they developed were "nearly identical and show oscillations between -1°C and 5.5°C in winter and between 2.4°C and 10.0°C in summer." Their graphical results show between 2,500 and 250 years before present (BP), the mean SSTs of summers were warmer than those of the present about 80 percent of the time, and the mean SSTs of winters exceeded those of current winters approximately 75 percent of the time, with the long-term (2,250-year) means of both seasonal periods averaging about 2°C more than current means. In addition, the highest temperatures were recorded around 1,320 cal. years BP, during a warm interval that persisted from about AD 500 to 720 during the very earliest stages of the Medieval Warm Period (MWP), when the peak summer and winter temperatures exceeded the peak summer and winter temperatures of the first several years of the twenty-first century by about 3°C.

Haltia-Hovi *et al*. (2010) write, "lacustrine sediment magnetic assemblages respond sensitively to environmental changes," and "characteristics of magnetic minerals, i.e. their concentration, mineralogy and grain size in sediments, can be studied by making mineral magnetic measurements, which yield large quantities of environmental data rapidly and non-destructively," citing Evans and Heller (2003). Working with two sediment cores taken from Finland's Lake Lehmilampi (63°37'N, 29°06'E), they constructed detailed chronological histories of several magnetic properties of the sediments, as well as a history of their total organic carbon content.

The four researchers discovered a "conspicuous occurrence of fine magnetic particles and high organic concentration" evident around 4,700–4,300 Cal. yrs BP. This period, they note, "is broadly coincident with glacier contraction and treelines higher than present in the Scandinavian mountains according to Denton and Karlen (1973) and Karlen and Kuylenstierna (1996)." From that time on toward the present, there was a "decreasing trend of magnetic concentration, except for the slight localized enhancement in the upper part of the sediment column at ~1,100–900 Cal. yrs BP," where the year zero BP = AD 1950.

Changes of these types have been attributed in prior studies to magnetotactic bacteria (e.g. *Magnetospirillum* spp.), which Haltia-Hovi *et al*. describe as "aquatic organisms that produce internal, small magnetite or greigite grains" that are used "to navigate along the geomagnetic field lines in search of micro or anaerobic conditions in the lake bottom," as described by Blakemore (1982) and Bazylinski and Williams (2007). They further note the studies of Snowball (1994), Kim *et al*. (2005), and Paasche *et al*. (2004) "showed magnetic concentration enhancement, pointing to greater metabolic activity of these aquatic organisms in the presence of abundant organic matter," which is also what Haltia-Hovi *et al*. The latter scientists report the "concentration of organic matter in the sediment is highest, together with fine magnetic grain sizes, in the time period 1,100–900 Cal. years BP," and they say this time interval "is associated with warmer temperatures during the Medieval Climate Anomaly according to the varve parameters of Lake Lehmilampi," citing the precise core-dating by varve-counting work of Haltia-Hovi *et al*. (2007). Taken together, these observations strongly suggest the peak warmth of the Medieval Warm Period (about AD 850–1050) was very likely somewhat greater than that of the Current Warm Period.

Luoto and Helama (2010) analyzed a sediment core extracted in October 2008 from Lake Pieni-Kauro in eastern Finland (64°17'N, 30°07'E), identifying and quantifying midge assemblages dominated by chironomids. They reconstructed a 1,500-year history of mean July air temperature from the Finnish multi-lake calibration model of Luoto (2009). The results, depicted in Figure 4.2.4.6.2.8, delineate a Medieval Warm Period stretching from about AD 580 to 1280, the peak temperature of which was approximately 0.3°C greater than the peak temperature at the end of the record, which concludes near the end of 2008.

Sundqvist *et al*. (2010) developed a 4,000-year δ^{18}O history from a stalagmite (K11) they collected in 2005 from Korallgrottan, a cave in the Caledonian mountain range of Jamtland County, northwest Sweden (64°53'N, 14°E). As shown in Figure 4.2.4.6.2.9, they demonstrated the δ^{18}O history to be well correlated with temperature, even that of the entire Northern Hemisphere.

In describing the δ^{18}O history, Sundqvist *et al*. write, "the stable isotope records show enriched isotopic values during the, for Scandinavia, comparatively cold period AD 1300–1700 [which they equate with the Little Ice Age] and depleted values during the warmer period AD 800–1000 [which they equate with the Medieval Warm Period]." As can clearly be seen from their figure, the two δ^{18}O depletion "peaks" (actually inverted valleys) of the Medieval Warm Period are both more extreme than the "peak" value of the Current Warm Period, which appears at the end of the record.

Gunnarson *et al*. (2011) write, "dendroclimatological sampling of Scots pine (*Pinus sylvestris* L.) has been made in the province of Jamtland, in the west-central Scandinavian mountains, since the 1970s," and "a maximum latewood density (MXD) dataset, covering the period

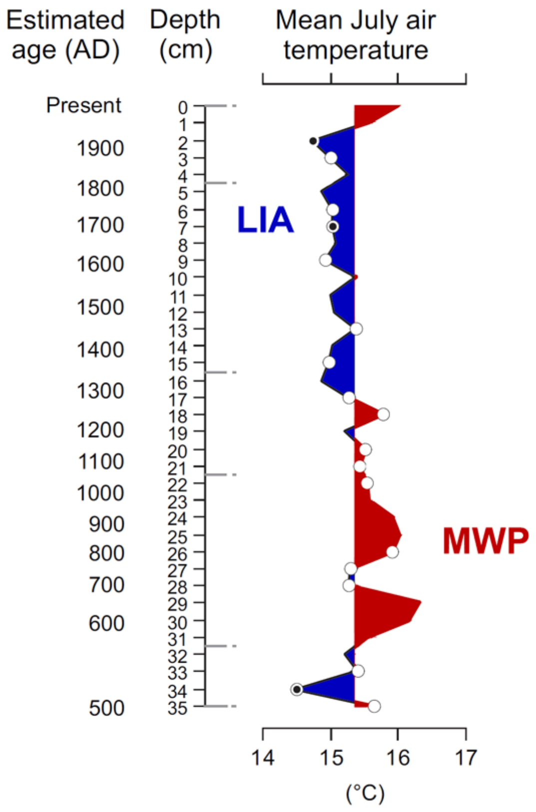

Figure 4.2.4.6.2.8. Reconstructed mean July air temperature from Lake Pieni-Kauro in eastern Finland. Adapted from Luoto, T.P. and Helama, S. 2010. Palaeoclimatological and palaeolimnological records from fossil midges and tree-rings: the role of the North Atlantic Oscillation in eastern Finland through the Medieval Climate Anomaly and Little Ice Age. *Quaternary Science Reviews* **29**: 2411–2423.

AD 1107–1827 (with gap 1292–1315) was presented in the 1980s by Fritz Schweingruber.” Gunnarson *et al*. combined these older historical MXD data with “recently collected MXD data covering AD 1292–2006 into a single reconstruction of April–September temperatures for the period AD 1107–2006,” using regional curve standardization (RCS), which “provides more low-frequency variability than ‘non-RCS’ and stronger correlation with local seasonal temperatures.”

The three researchers found “a steep increase in inferred temperatures at the beginning of the twelfth century, followed by a century of warm temperatures (ca. 1150–1250),” which falls within the temporal confines of the Medieval Warm Period, and they state, “the record ends with a sharp increase in temperatures from around 1910 to the 1940s, followed by decreasing temperatures for a few decades,” after which, they indicate, “another sharp increase in April–September temperature commenced in the late 1990s,” during what is commonly known as the Current Warm Period. They conclude “the two warmest periods are the mid to late twentieth century and the period from AD 1150–1250,” emphasizing the temperatures of both periods have been so similar that “it is not possible to conclude whether the present and relatively recent past are warmer than the 1150–1250 period.”

Divine *et al*. (2011) write, “the recent rapid climate and environmental changes in the Arctic, for instance, sea-ice retreat (e.g., Comiso *et al*., 2008) and ice-sheet melting (e.g., van den Broeke *et al*., 2009), require a focus on long-term variability in this area in order to view these recent changes in the long-term context.” Working with ice cores extracted from Svalbard at Lomonosovfonna in 1997 (Isaksson *et al*., 2001) and at Holtedahlfonna in 2005 (Sjorgren *et al*., 2007), Divine *et al*. used the δ^{18}O data derived from them to reconstruct 1,200-year winter (Dec–Feb) surface air temperature histories for nearby Longyearbyen (78.25°N, 15.47°E) and farther-afield Vardo (70.54°N, 30.61°E, in northern Norway), by calibrating (scaling) the δ^{18}O data to corresponding historically observed tempera-tures at the two locations, which for Longyearbyen were first collected in 1911 and for Vardo have been extended back to 1840 as a result of the work of Polyakov *et al*. (2003).

These efforts resulted in the winter surface air temperature reconstructions depicted in Figure 4.2.4.6.2.10, which begin at the peak warmth of the Medieval Warm Period at a little before AD 800. Temperatures thereafter decline fairly steadily to the coldest period of the Little Ice Age at about AD 1830, after which they rise into the 1930s, decline, and then rise again, terminating just slightly lower than their 1930s peaks near the end of the 1990s. The 11-year running-mean peak winter temperature of the Medieval Warm Period was approximately 9°C greater than the end-of-record 11-year running-mean peak winter temperature at Longyearbyen, whereas it was about 3.3°C warmer at Vardo.

Velle *et al*. (2011) used two short gravity cores and two long piston cores of sediments obtained from the deepest part of Lake Skardtjorna, Spitsbergen (77°57.780’N, 13°48.799’E) in 2008, plus a long core obtained in 2003, to reconstruct histories of chironomid types and concentrations over the past 2,000 years. They translated the chironomid data into mean July air temperatures based on a modern mean July air temperature calibration dataset compiled by Brooks and Birks (2000, 2001), plus additional unpublished data for 2001–2009, utilizing new approaches they developed for their paper. The two researchers write, a “warming that occurred at 1000 to 830 BP,” where BP = 2003, “may correspond to what is known as the ‘Medieval Warm Period.’” Their graphical representation of that record indicates the peak warmth of the MWP can be estimated to be about 0.3°C greater than the peak warmth of the Current Warm Period.

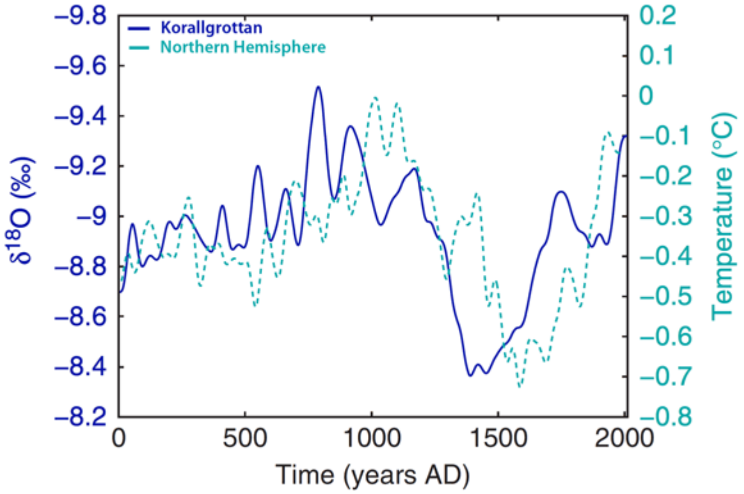

Figure 4.2.4.6.2.9. The 2,000-year Northern Hemispheric temperature reconstruction (dashed line) of Moberg *et al*. (2005) and the last half of the δ^{18}O history (solid line) developed from the K11 stalagmite. Adapted from Sundqvist, H.S., Holmgren, K., Moberg, A., Spotl, C., and Mangini, A. 2010. Stable isotopes in a stalagmite from NW Sweden document environmental changes over the past 4000 years. *Boreas* **39**: 77–86.

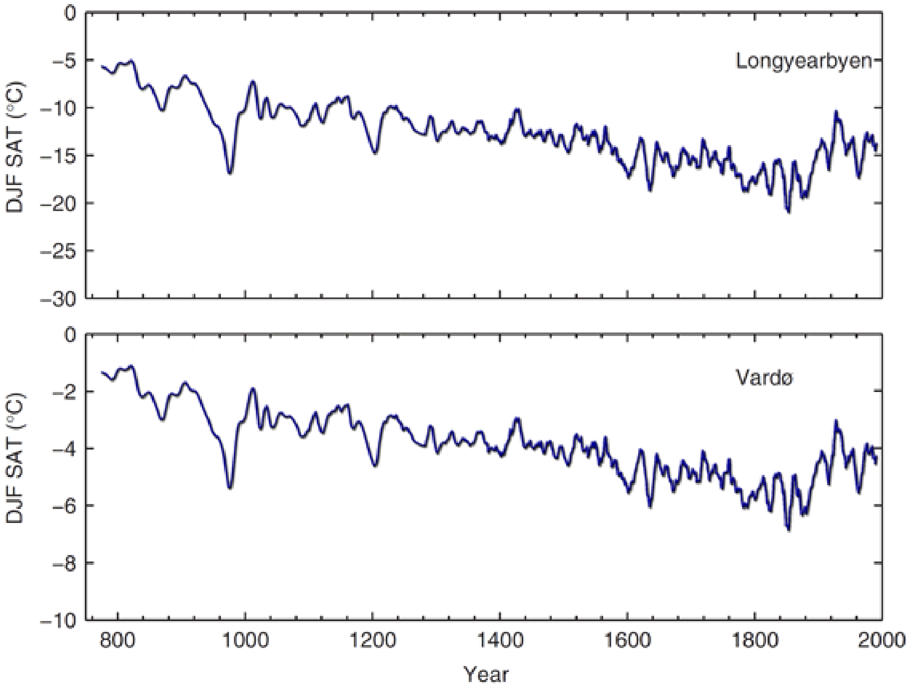

Figure 4.2.4.6.2.10. Reconstructed winter surface air temperature (SAT) for Longyearbyen (top) and Vardo (bottom) vs. time. Adapted from Divine, D., Isaksson, E., Martma, T., Meijer, H.A.J., Moore, J., Pohjola, V., van de Wal, R.S.W., and Godtliebsen, F. 2011. Thousand years of winter surface air temperature variations in Svalbard and northern Norway reconstructed from ice-core data. *Polar Research* **30**: 10.3402/polar.v30i0.7379.

Esper *et al*. (2012) note millennial-length temperature reconstructions have become “an important source of information to benchmark climate models, detect and attribute the role of natural and anthropogenic forcing agents, and quantify the feedback strength of the global carbon cycle.” The four researchers developed 587 high-resolution wood density profiles (Frank and Esper, 2005) from living and sub-fossil *Pinus sylvestris* trees of northern Sweden and Finland to form a long-term maximum latewood density (MXD) record from 138 BC to AD 2006, in which all MXD measurements were derived from high-precision X-ray radiodensitometry, as described by Schweingruber *et al*. (1978), and where biological age trends inherent to the MXD data were removed using regional curve standardization (RCS), as described by Esper *et al*. (2003). The new MXD record was calibrated against mean June–August temperatures obtained from the long-term (1876–2006) instrumental records of Haparanda, Karasjok, and Sodankyla. Comparing their results with the earlier temperature reconstructions of others, they say their MXD-based summer temperature reconstruction "sets a new standard in high-resolution palaeoclimatology," as "the record explains about 60% of the variance of regional temperature data, and is based on more high-precision density series than any other previous reconstruction." The four researchers report their new temperature history "provides evidence for substantial warmth during Roman and Medieval times, larger in extent and longer in duration than 20th century warmth."

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4.2.4.6.3 Southern

Was there a global Medieval Warm Period? The IPCC used to acknowledge there was, but it has long since changed its view on the subject. Mounting evidence suggests it was wrong to do so. This section describes and discusses data from Southern Europe that support the IPCC's original position.

Martinez-Cortizas *et al.* (1999) analyzed a 2.5 meters-long core from the peat bog of Penido Vello in northwest Spain (43°32'N, 7°34'W), sampled at intervals of 2 cm in the upper 1 meter and at intervals of 5 cm below that depth, to derive a record of mercury deposition that extends to 4,000 radiocarbon years before the present. This work revealed "that cold climates promoted an enhanced accumulation and the preservation of mercury with low thermal stability, and warm climates were characterized by a lower accumulation and the predominance of mercury with moderate to high thermal stability." Based on these findings and further analyses, they derived a temperature history for the region standardized to the mean temperature of the most recent 30 years of their record.

As depicted in Figure 4.2.4.6.3.1, the mean temperature of the Medieval Warm Period in northwest Spain was 1.5°C warmer than it was over the period 1968–1998, and the mean temperature of the Roman Warm Period was 2°C warmer. They also found several decadal-scale intervals during the Roman Warm Period were more than 2.5°C warmer

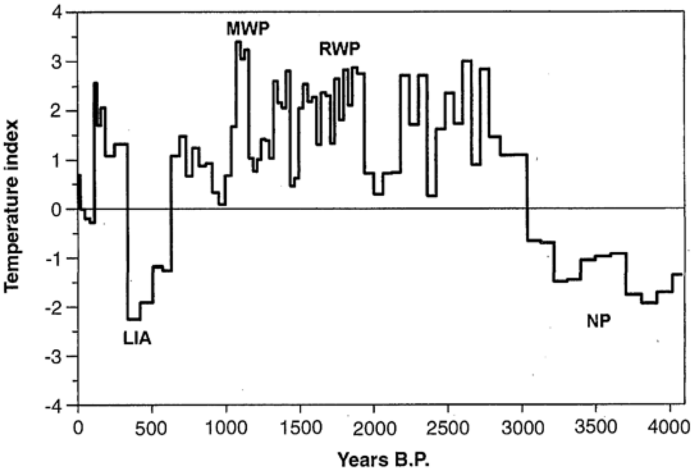

Figure 4.2.4.6.3.1. Temperature proxy for Penido Vello in northwest Spain covering the past 4,000 years. Adapted from Martinez-Cortizas, A., Pontevedra-Pombal, X., Garcia-Rodeja, E., Novoa-Muñoz, J.C., and Shotyk, W. 1999. Mercury in a Spanish peat bog: archive of climate change and atmospheric metal deposition. *Science* **284**: 939–942.

than the 1968–1998 period, and an interval in excess of 80 years during the Medieval Warm Period was more than 3°C warmer. Martinez-Cortizas *et al.* conclude "for the past 4000 years ... the Roman Warm Period and the Medieval Warm Period were the most important warming periods."

Desprat *et al.* (2003) studied the climatic variability of the last three millennia in northwest Iberia via a high-resolution pollen analysis of a sediment core retrieved from the central axis of the Ria de Vigo (42°14.07'N, 8°47.37'W) in the south of Galicia. The results suggest over the past 3,000 years there was "an alternation of three relatively cold periods with three relatively warm episodes." In order of their occurrence, these periods are described by Desprat *et al.* as the "first cold phase of the Subatlantic period (975–250 BC)," which was "followed by the Roman Warm Period (250 BC–450 AD)," and then by "a successive cold period (450–950 AD), the Dark Ages," which "was terminated by the onset of the Medieval Warm Period (950–1400 AD)." That was followed by "the Little Ice Age (1400–1850 AD), including the Maunder Minimum (at around 1700 AD)," which "was succeeded by the recent warming (1850 AD to the present)."

Desprat *et al.* conclude the "solar radiative budget and oceanic circulation seem to be the main mechanisms forcing this cyclicity in NW Iberia," noting "a millennial-scale climatic cyclicity over the last 3,000 years is detected for the first time in NW Iberia paralleling global climatic changes recorded in North Atlantic marine records (Bond *et al.*, 1997; Bianchi and McCave, 1999; Chapman and Shackelton, 2000)."

Silenzi *et al.* (2004) acquired from the northwest coast of Sicily near Capo Gallo promontory new oxygen isotopic data on sea climate trend fluctuations on Vermetid (*Dendropoma petraeum*) reefs that could be interpreted as sea surface temperature (SST) variations. These data clearly depict the Little Ice Age (LIA), with a "temperature variation of about ΔT = 1.99 ± 0.37 °C between the LIA and present day." Of this period, they write, "Watanabe *et al.* (2001) report that 'seawater temperature records from marine biogenic carbonate including coral and foraminifera all indicate that tropical ocean temperatures were lower by anywhere from 0.5° to 5°C during the LIA (Druffel, 1982; Glynn *et al.*, 1983; Dunbar *et al.*, 1994; Linsley *et al.*, 1994; Keigwin, 1996; Winter *et al.*, 2000) with the vast majority of studies indicating a 1–2°C change.'"

Following the LIA, the data of Silenzi *et al.* reveal what they call "the warming trend that characterized the last century." They note, "this rise in temperature ended around the years 1930–1940 AD, and was followed by a relatively cold period between the years 1940 and 1995." Their data also indicate that in the early to mid-1500s, SSTs were warmer than they are currently, as also has been found to be the case by Keigwin (1996) and McIntyre and McKitrick (2003).

Silenzi *et al.*'s results indicate the Little Ice Age was significantly colder than what is shown by the flawed Northern Hemisphere temperature history of Mann *et al.* (1998, 1999). Moreover, Silenzi *et al.* do not show any sign of the dramatic late twentieth century warming claimed by Mann *et al.* And the work of Silenzi *et al.* indicates temperatures in the early to mid-1500s were warmer than they are currently, whereas Mann *et al.* claim it is currently warmer than it has been at any time over the past millennium or two (Mann and Jones, 2003).

Kvavadze and Connor (2005) present "some observations on the ecology, pollen productivity and Holocene history of *Zelkova carpinifolias*," a warmth-loving tree whose pollen "is almost always accompanied by elevated proportions of thermophilous taxa," to refine our understanding of Quaternary climatic trends. The discovery of the tree's fossil remains in Holocene sediments, they write, "can be a good indicator of optimal climatic conditions."

The two researchers report, "Western Georgian pollen spectra of the Subatlantic period show that the period began [about 2580 cal yr BP] in a cold phase, but, by 2200 cal yr BP, climatic amelioration commenced," and "the maximum phase of warming [was] observed in spectra from 1900 cal yr BP," and this interval of warmth was Georgia's contribution to the Roman Warm Period. Thereafter, a cooler phase of climate, during the Dark Ages Cold Period, "occurred in Western Georgia about 1500–1400 cal yr BP," but it too was followed by another warm era "from 1350 to 800 years ago," the Medieval Warm Period. During portions of this time interval, they write, tree lines "migrated upwards and the distribution of *Zelkova* broadened." They also present a history of Holocene oscillations of the upper tree-line in Abkhasia, derived by Kvavadze *et al*. (1992), that depicts slightly greater-than-1950 elevations during a portion of the Medieval Warm Period and much greater extensions above the 1950 tree-line during parts of the Roman Warm Period. After the Medieval Warm Period, they report, "subsequent phases of climatic deterioration (including the Little Ice Age) ... saw an almost complete disappearance of *Zelkova* from Georgian forests."

Thus both the Roman and Medieval Warm Periods have been identified in various parts of European Georgia via studies of *Zelkova carpinifolia* pollen found in local sediments, and portions of these warm climatic intervals were likely even warmer than the conditions there during ~AD 1950, which is the "present" of Kvavadze and Connor's study.

Sea surface temperatures, river discharge, and biological productivity were reconstructed by Abrantes *et al*. (2005) in a multi-proxy analysis of a high-resolution sediment core obtained from the Tagus River estuary near Lisbon, Portugal (~ 38.56°N, 9.35°W). The MWP was identified as occurring between AD 550 and 1300, during which mean sea surface temperatures were between 1.5 and 2°C higher than the mean value of the past century, while peak MWP warmth was about 0.9°C greater than late twentieth century peak warmth.

Pla and Catalan (2005) analyzed chrysophyte cyst data collected from 105 lakes in the Central and Eastern Pyrenees of northeast Spain to produce a history of winter/spring temperatures in this region throughout the Holocene. They found a significant oscillation in the winter/spring temperature reconstruction in which the region's climate alternated between warm and cold phases over the past several thousand years. Of particular note were the Little Ice Age, Medieval Warm Period, Dark Ages Cold Period, and Roman Warm Period, and the warmest of these intervals was the Medieval Warm Period, which started around AD 900 and was about 0.25°C warmer than it is currently (Figure 4.2.4.6.3.2).

After the Medieval Warm Period, temperatures fell to their lowest values of the entire record (about 1.0°C below present), after which they began to warm

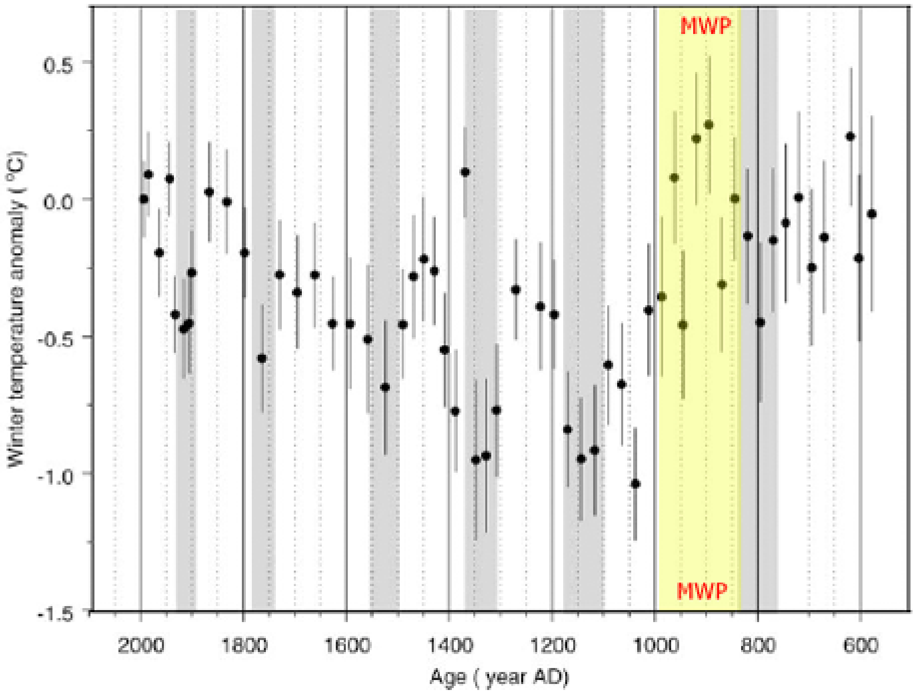

Figure 4.2.4.6.3.2. Altitude anomaly reconstruction from a chrysophyte record converted into winter/spring mean temperatures for the last 1,500 years. Adapted from Pla, S. and Catalan, J. 2005. Chrysophyte cysts from lake sediments reveal the submillennial winter/spring climate variability in the northwestern Mediterranean region throughout the Holocene. *Climate Dynamics* **24**: 263–278.

but remained below present-day values until the early nineteenth and twentieth centuries, with one exception. A significant warming was observed between 1350 and 1400, when temperatures rose a full degree Celsius to a value about 0.15°C warmer than the present. Further examination of Pla and Catalan's data reveals the Current Warm Period is not yet (and may never be) as warm as the Medieval Warm Period, for modern temperatures peaked in the 1970s–1980s and then declined throughout the 1990s.

Giraudi (2005) studied properties of alternating layers of organic-matter-rich soils and alluvial, glacial, and periglacial sediments on higher Apennine massifs in Italy, located at approximately 42°23'N, 13°31'E, reconstructing a history of relative changes in temperature for this region over the past 6,000 years. He determined organic-matter-rich soils formed on slopes currently subject to periglacial and glacial processes around 5740–5590, 1560–1370 and 1300–970 cal yr BP. Based on current relationships between elevation and soil periglacial and glacial processes, Giraudi estimates the mean annual temperature during these three periods "must therefore have been higher than at present," and winter temperatures were at least 0.9-1.2°C higher than those of today.

Cini Castagnoli *et al.* (2005) extracted a $\delta^{13}C$ profile of *Globigerinoides rubber* from a shallow-water core in the Gulf of Taranto off the Italian coast (39°45'53"N, 17°53'33"E), which they used to produce a high-precision record of climate variability over the past two millennia. This record was statistically analyzed, together with a second two-millennia-long tree-ring record obtained from Japanese cedars (Kitagawa and Matsumoto, 1995), for evidence of recurring cycles, using Singular Spectrum Analysis and Wavelet Trans-form, after which both records were compared with a 300-year record of sunspots.

Plots of the pair of two-thousand-year series revealed the existence of the Dark Ages Cold Period (~400–800 AD), Medieval Warm Period (~800–1200 AD), Little Ice Age (~1500–1800 AD), and Current Warm Period. The roots of the latter period can be traced to an upswing in temperature that began in the depths of the Little Ice Age "about 1700 AD." In addition, the statistical analyses showed a common 11-year oscillation in phase with the Schwabe cycle of solar activity, plus a second multidecadal oscillation (of about 93 years for the shallow-water *G. rubber* series and 87 years for the tree-ring series) in phase with the amplitude modulation of the sunspot number series over the past 300 years.

The three researchers state the overall phase agreement between the two climate reconstructions and the variations in the sunspot number series "favors the hypothesis that the [multidecadal] oscillation revealed in $\delta^{13}C$ from the two different environments is connected to the solar activity." This is further evidence for a solar forcing of climate at decadal and multidecadal time scales, as well as for the millennial-scale oscillation of climate that likely has been responsible for the twentieth century warming of the globe that ended the Little Ice Age and ushered in the Current Warm Period.

Frisia *et al.* (2005), working with stalagmite SV1 from Grotta Savi—a cave located at the southeast margin of the European Alps in Italy (45°37'05" N, 13°53'10" E)—developed a 17,000-year record of speleothem calcite $\delta^{18}O$ data, which they calibrated against "a reconstruction of temperature anomalies in the Alps" developed by Luterbacher *et al.* (2004) for the last quarter of the past millennium. This work revealed the occurrence of the Roman Warm Period and a Medieval Warm Period that was broken into two parts by an intervening central cold period. The five researchers state both parts of the Medieval Warm Period were "characterized by temperatures that were similar to the present." As to the Roman Warm Period, they state, its temperatures "were similar to those of today or even slightly warmer."

Garcia *et al.* (2007) note "despite many studies that have pointed to ... the validity of the classical climatic oscillations described for the Late Holocene (Medieval Warm Period, Little Ice Age, etc.), there is a research line that suggests the non-global signature of these periods (IPCC, 2001; Jones and Mann, 2004)." Noting "the best way to solve this controversy would be to increase the number of high-resolution records covering the last millennia and to increase the spatial coverage of these records," they identified five distinct climatic stages: "a cold and arid phase during the Subatlantic (Late Iron Cold Period, < B.C. 150), a warmer and wetter phase (Roman Warm Period, B.C. 150–A.D. 270), a new colder and drier period coinciding with the Dark Ages (A.D. 270–900), the warmer and wetter Medieval Warm Period (A.D. 900–1400), and finally a cooling phase (Little Ice Age, >A.D. 1400)."

Noting "the Iberian Peninsula is unique, as it is located at the intersection between the Mediterranean and the Atlantic, Europe and Africa, and is consequently affected by all of them," Garcia *et al.* suggest "the classical climatic oscillations described for the Late Holocene (Medieval Warm Period, Little Ice Age, etc.)" were both real and global in scope. In addition, the Medieval Warm Period "is identified at about a similar date all around the world (China: Chu *et al*., 2002; Arabia, Fleitmann *et al*., 2004; Africa: Filippi and Talbot, 2005; Iceland: Doner, 2003; central Europe: Filippi *et al*., 1999; New Guinea: Haberle and David, 2004; USA: Cabaniss Pederson *et al*., 2005: Argentina: Mauquoy *et al*., 2004; etc.," the six scientists state, and "comparable changes are described by Desprat *et al*. (2003), Julia *et al*. (1998) and Riera *et al*. (2004) in northwest, central and northeast Spain."

In a paper published in *Science*, Trouet *et al*. (2009) explain how they constructed a 947-year history (AD 1049–1995) of the North Atlantic Oscillation (NAO) using a tree-ring-based drought reconstruction for Morocco (Esper *et al*., 2007) and a speleothem-based precipitation proxy for Scotland (Proctor *et al*., 2000). This history begins in the midst of what they call the Medieval Climate Anomaly (MCA), which they describe as "a period (~AD 800–1300) marked by a wide range of changes in climate globally," and this interval of medieval warmth is "the most recent natural counterpart to modern warmth and can therefore be used to test characteristic patterns of natural versus anthropogenic forcing."

The results of their work are portrayed in Figure 4.2.4.6.3.3, which indicates the peak strength of the NAO during the MCA was essentially equivalent to the peak strength the NAO has so far experienced during the Current Warm Period (CWP), suggesting the peak warmth of the MCA also was likely equivalent to the peak warmth of the CWP.

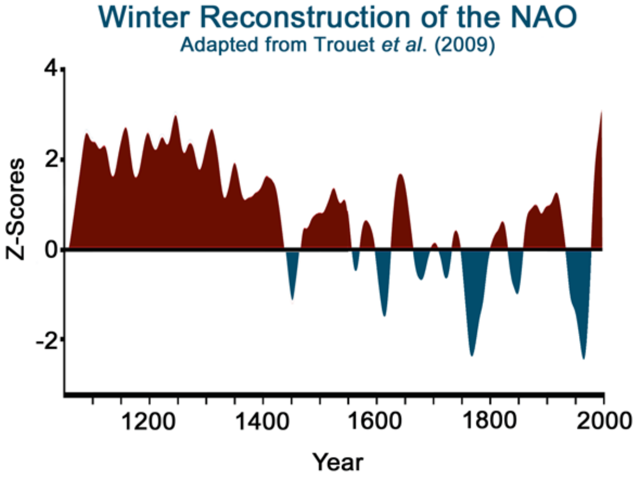

Figure 4.2.4.6.3.3. Winter reconstruction of the NAO over the past 1,000 years. Adapted from Trouet, V., Esper, J., Graham, N.E., Baker, A., Scourse, J.D., and Frank, D.C. 2009. Persistent positive North Atlantic Oscillation mode dominated the Medieval Climate Anomaly. *Science* **324**: 78–80.

With respect to what caused the development of medieval warmth throughout Europe, Trouet *et al.* write "the increased pressure difference between the Azores High and the Icelandic Low during positive NAO phases results in enhanced zonal flow, with stronger westerlies transporting warm air to the European continent," to which they add, "stronger westerlies associated with a positive NAO phase may have enhanced the Atlantic meridional overturning circulation (AMOC)," which in turn may have generated "a related northward migration of the intertropical convergence zone."

As for what might have initiated these phenomena, Trouet *et al.* say "the persistent positive phase [of the NAO] reconstructed for the MCA appears to be associated with prevailing La Niña-like conditions possibly initiated by enhanced solar irradiance and/or reduced volcanic activity and amplified and prolonged by enhanced AMOC." That explanation is highly plausible, especially in light of the many paleoclimate studies that have identified cyclical solar activity as the primary cause of various climate cycles (see Chapter 3, this volume). The six scientists conclude, "the relaxation from this particular ocean-atmosphere state [that of the MCA] into the Little Ice Age appears to be globally contemporaneous and suggests a notable and persistent reorganization of large-scale oceanic and atmospheric circulation patterns." Consequently, it is equally reasonable to suggest the reversal of this process—the reinstatement of the particular ocean-atmosphere state that characterized the MCA—may be what has led to the globally contemporaneous development of the Current Warm Period. This scenario suggests the planet's current level of relative warmth may be due to processes originating in the Sun, which are of course not attributable to man.

Geirsdottir *et al.* (2009) studied biogenic silica (BSi) and total organic carbon (TOC) data obtained from two sediment cores retrieved from Haukadalsvatn (65°03.064'N, 21°37.830'W), a lake in northwest Iceland, and a 170-year instrumental temperature history obtained from Stykkisholmur (50 km distant). They identified "a broad peak in BSI and lack of a trend in TOC between ca. 900 and 1200 AD," which they describe as being indicative of "a broad interval of warmth" "coincident with the Medieval Warm Period," which clearly exhibited greater warmth than was observed at any time during the Current Warm Period (see Figure 4.2.4.6.3.4).

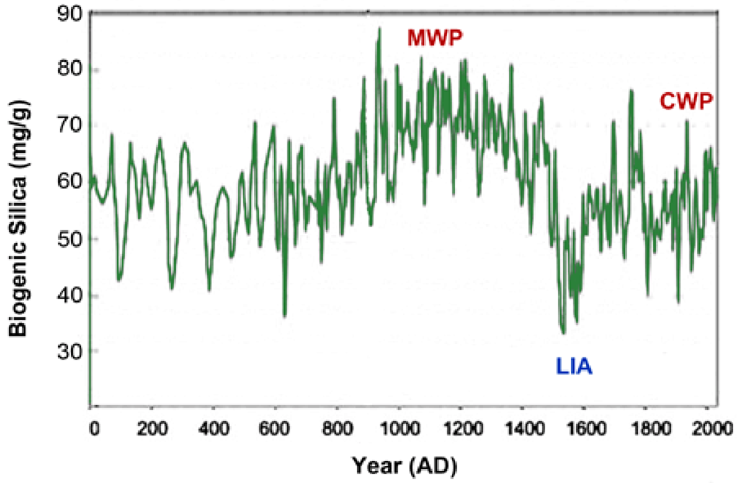

Figure 4.2.4.6.3.4. A 2,000-year record of climate variations reconstructed from Haukadalsvatn, West Iceland. Adapted from Geirsdottir, A., Miller, G.H., Thordarson, T., and Olafsdottir, K.B. 2009. A 2000-year record of climate variations reconstructed from Haukadalsvatn, West Iceland. *Journal of Paleolimnology* **41**: 95–115.

Giraudi (2009) examined "long-term relations among glacial activity, periglacial activity, soil development in northwestern Italy's alpine River Orco headwaters, and down-valley floods on the River Po," based on "studies carried out by means of geological and geomorphologic surveys on the glacial and periglacial features," including a sampling of soils involved in periglacial processes that "provided a basis for development of a chronological framework of late Holocene environmental change" and an analysis of "a stratigraphic sequence exposed in a peat bog along the Rio del Nel" about 1 km from the front edge of the Eastern Nel Glacier.

Giraudi determined between about 200 BC and AD 100—i.e., during the Roman Warm Period—"soils developed in areas at present devoid of vegetation and with permafrost," indicating temperatures at that time "probably reached higher values than those of the present." He also concludes, "analogous conditions likely occurred during the period of [the] 11th–12th centuries AD, when a soil developed on a slope presently characterized by periglacial debris," while noting "in the 11th–12th centuries AD, frost weathering processes were not active and, due to the higher temperatures than at present or the longer duration of a period with high temperatures, vegetation succeeded in colonizing the slope." He also found "the phase of greatest glacial expansion (Little Ice Age) coincides with a period characterized by a large number of floods in the River Po basin," and "phases of glacial retreat [such as occurred during the Roman and Medieval Warm Periods] correlate with periods with relatively few floods in the River Po basin."

Martin-Chivelet *et al.* (2011) developed a 4,000-year temperature history for the northern part of Castilla-Leon in northern Spain based on $\delta^{13}C$ data obtained from stalagmites recovered from three caves, each of which was situated approximately 50 km from a common central point (~42°40'N, 4°W), having found good correlation between the mean annual temperatures of the past 125 years (from a site located 14 km from one of the caves) and corresponding $\delta^{13}C$ data. According to the five researchers, their $\delta^{13}C$ record began with "an initial interval of broad warm conditions between 4000 and 3000 yr BP." Then came "a prolonged time during which thermal conditions become permanently cold," with the coldest conditions occurring between 2,850 and 2,550 yr BP, an interval they describe as "the 'first cold phase' of the Subatlantic period, also called in Europe the Iron Age Cold Period." Next came another warm period when "maximum temperatures were probably reached in the three hundred years interval between 2150 and 1750 yr BP," which corresponds, they write, "to the well-known Roman Warm Period, an interval which has been correlated with a phase of relatively high solar flux."

Thereafter came "another relatively cold episode, which lasted about 250 years and reached its minimum at ~1500 yr BP," which "correlated with the Dark Ages Cold Period described in other areas of Europe." Then, "a rapid trend of warming led to a new, prolonged interval of warmth" that lasted from 1,400 to 700 yr BP. Martin-Chivelet *et al.* state this Medieval Warm Period is "probably the most robust climatic feature in our records, perfectly outlined in the series of the three stalagmites." They also note, "the end of the Medieval Warm Period was marked by a progressive and rapid ... transition into the Little Ice Age, a relatively cold period broadly reported from all Europe and also from other areas in the world as far as South Africa or South America."

A graph of the researchers' data portrays the development of the Current Warm Period, and it suggests temperatures at the end of the twentieth century were about a quarter of a degree Centigrade warmer than the peak warmth of the Medieval Warm Period. They note studies in Northern Spain based on peat bog proxies "suggest that the temperatures during both the Roman Warm Period and the Medieval Warm Period were higher than present-day ones," citing Martinez-Cortizas *et al*. (1999).

Andrade *et al*. (2011) worked with a 2.5-m gravity core and an 18-cm box core taken from the outer area of the Ria de Muros (42°44'N, 9°02'W) on the northwestern coast of the Iberian Peninsula in June 2004 to establish a climate history of the region through "the combined use of textural analysis, magnetic properties and geochemical parameters (total concentrations of diagenetically stable and mobile elements in sediment and pore water)," which "allowed the identification of a current redox front and two palaeosedimentary redox fronts in the sediment record."

These three redox fronts, as the team of Spanish scientists describe them, "originated during periods of high marine/terrestrial organic matter ratio (as inferred from the ratio of total organic carbon to total nitrogen and $\delta^{13}C$)." They state, "sedimentation rates calculated from ^{14}C dating results identify these periods as known periods of increased upwelling and reduced continental input due to colder, drier climate in the NW Iberian Peninsula, namely the Little Ice Age, the Dark Ages, and the first cold period of the Upper Holocene." They also point out the lower proportion of oceanic influence observed between 1,250 and 560 cal. yr BP "coincides with the Medieval Warm Period, during which there was an increase in continental input to both the continental shelf (Mohamed *et al*., 2010) and the Rias of Vigo and Muros (Alvarez *et al*., 2005; Lebreiro *et al*., 2006)." FInally, they note the colder Dark Ages period was preceded by the "Roman Warm Period."

Morellon *et al*. (2011) write, "in the context of present-day global warming, there is increased interest in documenting climate variability during the last millennium," because "it is crucial to reconstruct pre-industrial conditions to discriminate anthropogenic components (i.e., greenhouse gases, land-use changes) from natural forcings (i.e., solar variability, volcanic emissions)." They conducted a multi-proxy study of several short sediment cores recovered from Lake Estanya (42°02'N, 0°32'E) in the Pre-Pyrenean Ranges of northeast Spain, which provide "a detailed record of the complex environmental, hydrological and anthropogenic interactions occurring in the area since medieval times." They report, "the integration of sedimentary facies, elemental and isotopic geochemistry, and biological proxies (diatoms, chironomids and pollen), together with a robust chronological control, provided by AMS radiocarbon dating and ^{210}Pb and ^{137}Cs radiometric techniques, enabled precise reconstruction of the main phases of environmental change, associated with the Medieval Warm Period (MWP), the Little Ice Age (LIA) and the industrial era."

The 13 researchers identified the MWP as occurring in their record from AD 1150 to 1300, noting their pollen data reflect "warmer and drier conditions," in harmony with the higher temperatures of the Iberian Peninsula over the same period that have been documented by Martinez-Cortizas *et al*. (1999), the higher temperatures of the Western Mediterranean region found by Taricco *et al*. (2008), and the global reconstructions of Crowley and Lowery (2000) and Osborn and Briffa (2006), all of which "clearly document warmer conditions from the twelfth to fourteenth centuries." This warmth, Morellon *et al*. state, is "likely related to increased solar irradiance (Bard *et al*., 2000), persistent La Niña-like tropical Pacific conditions, a warm phase of the Atlantic Multidecadal Oscillation, and a more frequent positive phase of the North Atlantic Oscillation (Seager *et al*., 2007)."

Following the MWP was the LIA, which Morellon *et al*. recognize as occurring from AD 1300 to 1850. Lower temperatures (Martinez-Cortizas *et al*., 1999) characterized this period on the Iberian Peninsula, which "coincided with colder North Atlantic (Bond *et al*., 2001) and Mediterranean sea surface temperatures (Taricco *et al*., 2008) and a phase of mountain glacier advance (Wanner *et al*., 2008)," they report. Following the LIA they identified the transition period of AD 1850–2004, which took the region into the Current Warm Period.

Morellon *et al*. write, "a comparison of the main hydrological transitions during the last 800 years in Lake Estanya and solar irradiance (Bard *et al*., 2000) reveals that lower lake levels dominated during periods of enhanced solar activity (MWP and post-1850 AD) and higher lake levels during periods of diminished solar activity (LIA)." Within the LIA, they note periods of higher lake levels or evidence of increased water balance occurred during the solar minima of Wolf (AD 1282–1342), Sporer (AD 1460–

1550), Maunder (AD 1645–1715), and Dalton (AD 1790–1830).

In light of these observations, it appears the multi-centennial climate oscillation uncovered by the 13 researchers has been driven by a similar oscillation in solar activity and by multi-decadal solar activity fluctuations superimposed on that longer-period oscillation. These relationships suggest there is no compelling reason to attribute twentieth century global warming to the concomitant increase in the air's CO_2 content.

As noted in this section, a significant body of research documents the existence of the millennial-scale oscillation of climate that has alternately brought Earth both into and out of the Roman Warm Period, Dark Ages Cold Period, Medieval Warm Period, and Little Ice Age, and, most recently, into the Current Warm Period. During these climatic transitions, except for the most recent one, there have been no significant changes in the atmosphere's CO_2 concentration, which suggests the transition out of the Little Ice Age and into the Current Warm Period likely had nothing at all to do with the concomitant increase in the air's CO_2 content.

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4.2.4.7 North America

As indicated in the introduction of Section 4.2.4, numerous peer-reviewed studies reveal modern temperatures are not unusual. For many millennia, Earth's climate has both cooled and warmed independent of its atmospheric CO_2 concentration. Conditions as warm as, or warmer than, the present have persisted across the Holocene for decades to centuries even though the atmosphere's CO_2 content remained at values approximately 30 percent lower than that of today.

The following subsections highlight evidence from North America, where much of the material focuses on the most recent millennium of Earth's history, detailing the historical fluctuations of Earth's climate that long ago ushered in the Roman Warm Period, which gave way to the Dark Ages Cold Period, then the Medieval Warm Period and subsequent Little Ice Age. These natural climate oscillations are the product of a millennial-scale climate forcing; Current Warm Period is simply a manifestation of its latest phase. Carbon dioxide had little to do with the warmth (or cold) of these prior epochs, and there is no compelling reason to conclude it is having any measurable impact on climate today.

4.2.4.7.1 Alaska and Canada

Arseneault and Payette (1997) analyzed tree-ring and growth-form sequences obtained from more than 300 spruce remains buried in currently treeless peatland located near the tree line in northern Québec to produce a proxy record of climate for this region between AD 690 and 1591. Over this 900-year period, the trees of the region experienced several episodes of both suppressed and rapid growth, indicative of colder and warmer conditions, respectively, than those of the present, the scientists found. Cooler (suppressed growth) conditions prevailed in AD 760–860 and 1025–1400, and warmer (rapid growth) conditions were prevalent in AD 700–750, 860–1000, 1400–1450, and 1500–1570.

Further analysis of the warm period between AD 860 and 1000 led the two researchers to conclude the warmth experienced in northern Quebec during this period coincided with the Medieval Warm Period experienced across the North Atlantic and Northern Europe, which "exceeded in duration and magnitude both the 16th and 20th century warm periods identified previously [by other scientists] using the same methods." Furthermore, on the basis of current annual temperatures at their study site and the northernmost twentieth century location of the forest, which at that time was 130 km south of their site, they conclude, the "Medieval Warm Period was approximately 1°C warmer than the 20th century."

Campbell and Campbell (2000) analyzed pollen and charcoal records obtained from sediment cores retrieved from three small ponds—South Pond (AD 1655–1993), Birch Island Pond (AD 1499–1993), and Pen 5 Pond (400 BC–AD 1993)—located within Canada's Elk Island National Park, which covers close to 200 km^2 of the Beaver Hills region of east-central Alberta. Contrary to the intuitive assumption that there would be an "increase in fire activity with warmer and drier climate," the Canadian researchers found "declining groundwater levels during the Medieval Warm Period [MWP] allowed the replacement of substantial areas of shrub birch with the less fire-prone aspen, causing a decline in fire frequency and/or severity, while increasing carbon storage on the landscape." They conclude this scenario "is likely playing out again today," as all three of the sites they studied "show historic increases in *Populus* pollen and declines in charcoal."

The two researchers note Earth's present climate "is warmer and drier than that of either the Little Ice Age (which followed the MWP) or the early Neoglacial (preceding the MWP)," and we must therefore "consider the present pond levels to be more representative of the MWP than of the time before or after." But since their Pen 5 Pond data indicate sediment charcoal concentrations have not yet dropped to the level characteristic of the MWP—even with what they describe as the help of "active fire suppression in the park combined with what may be thought of as unintentional fire suppression due to agricultural activity around the park"—it appears their study sites and their surroundings have not yet risen to the level of warmth and dryness of the MWP, which they describe as having occurred over the period AD 800–1200.

Calkin *et al*. (2001) reviewed what they called "the most current and comprehensive research of Holocene glaciation" along the northernmost Gulf of Alaska between the Kenai Peninsula and Yakutat Bay, noting several periods of glacial advance and retreat during the past 7,000 years. They describe a general retreat during the Medieval Warm Period that lasted for "at least a few centuries prior to AD 1200." After this Medieval Climatic Optimum, there were three major intervals of Little Ice Age glacial advance: the early fifteenth century, middle seventeenth century, and the last half of the nineteenth century. During these latter periods, glacier equilibrium line altitudes were depressed from 150 to 200 m below present values as Alaskan glaciers "reached their Holocene maximum extensions."

The existence of a Medieval Warm Period and Little Ice Age in Alaska is an obvious reality. Glaciers there reached their maximum Holocene extensions during the Little Ice Age, and it can be inferred Alaskan temperatures reached their Holocene minimum during this period as well. It should therefore come as no surprise that temperatures in Alaska rose significantly above the chill of the Little Ice Age in the region's natural recovery from the coldest period of the Holocene.

Hu *et al*. (2001) "conducted multi-proxy geochemical analyses of a sediment core from Farewell Lake in the northwestern foothills of the Alaska Range," obtaining what they describe as "the first high-resolution quantitative record of Alaskan climate variations that spans the last two millennia." The team of five scientists report their results "suggest that at Farewell Lake SWT [surface water temperature] was as warm as the present at AD 0–300 [during the Roman Warm Period], after which it decreased steadily by ~3.5°C to reach a minimum at AD 600 [during the depths of the Dark Ages Cold Period]." From then, they state, "SWT increased by ~3.0°C during the period AD 600–850 and then [during the Medieval Warm Period] exhibited fluctuations of 0.5–1.0°C until AD 1200." Completing their narrative, they write, "between AD 1200–1700, SWT decreased gradually by 1.25°C [as the world descended into the depths of the Little Ice Age], and from AD 1700 to the present, SWT increased by 1.75C," the latter portion of which warming initiated the Current Warm Period.

Hu *et al*. remark, "the warmth before AD 300 at Farewell Lake coincides with a warm episode extensively documented in northern Europe … whereas the AD 600 cooling is coeval with the European 'Dark Ages.'" They also report, "the relatively warm climate AD 850–1200 at Farewell Lake corresponds to the Medieval Climatic Anomaly, a time of marked climatic departure over much of the planet." They note "these concurrent changes suggest large-scale teleconnections in natural climatic variability during the last two millennia, likely driven by atmospheric controls."

Noting "20th-century climate is a major societal concern in the context of greenhouse warming," Hu *et al*. conclude by reiterating their record "reveals three time intervals of comparable warmth: AD 0–300, 850–1200, and post-1800," and they write, "these data agree with tree-ring evidence from Fennoscandia, indicating that the recent warmth is not atypical of the past 1000 years."

These observations testify to the reality of the non-CO_2-induced millennial-scale oscillation of climate that brought the world, including Alaska, significant periods of warmth some 1,000 years ago, during the Medieval Warm Period, and some 1,000 years before that, during the Roman Warm Period. These earlier periods of warmth were unquestionably not caused by elevated atmospheric CO_2 concentrations, nor were they due to elevated concentrations of any other greenhouse gases. They were caused by something else, and the warmth of today could be due to that same cause.

Gedalof and Smith (2001) compiled a transect of six tree ring-width chronologies from stands of mountain hemlock growing near the treeline that extends from southern Oregon to the Kenai Peninsula, Alaska, analyzing the data in such a way as to "directly relate changes in radial growth to annual variations in the North Pacific ocean-atmosphere system." Over the period of their study (AD 1599–1983), they determined "much of the pre-instrumental record in the Pacific Northwest region of North America [was] characterized by alternating regimes of relatively warmer and cooler SST [sea surface temperature] in the North Pacific, punctuated by abrupt shifts in the mean background state," which were found to be "relatively common occurrences." They found "regime shifts in the North Pacific have occurred 11 times since 1650." Significantly, the abrupt 1976–1977 shift in this Pacific Decadal Oscillation, as it is generally called, was found to be responsible for the vast majority of the past half-century's warming in Alaska.

Kaplan *et al*. (2002) reported on paleolimnological inferences regarding Holocene climatic variability from a small lake in southern Greenland—Qipisarqo Lake (61°00'41"N, 47°45'13"W)—based on lake sediment physical-chemical properties, including magnetic susceptibility, density, water content, and biogenic silica and organic matter concentration. They found "the interval from 6000 to 3000 cal yr B.P. was marked by warmth and stability." Thereafter, however, the climate cooled "until its culmination during the Little Ice Age." From 1,300 to 900 cal yr B.P., there was a partial amelioration during the Medieval Warm Period, which was associated with an approximate 1.5°C rise in temperature. Then, after another brief warming between A.D. 1500 and 1750, the second and more severe portion of the Little Ice Age occurred, which in turn was followed by "naturally initiated post-Little Ice Age warming since A.D. 1850, which is recorded throughout the Arctic" and "has not yet reached peak Holocene warmth."

The three researchers note "colonization around the northwestern North Atlantic occurred during peak Medieval Warm Period conditions that ended in southern Greenland by AD 1100." Norse movements around the region thereafter occurred at what they describe as "perhaps the worst time in the last 10,000 years, in terms of the overall stability of the environment for sustained plant and animal husbandry." The demise of the Norse colonies clearly was the result of "the most environmentally unstable period since deglaciation." They conclude, "current warming, however rapid, has not yet reached peak Holocene warmth."

Campbell (2002) analyzed the grain sizes of sediment cores obtained from Alberta's Pine Lake (52°N, 113.5°W) to provide a non-vegetation-based high-resolution record of climate variability for this part of North America over the past 4,000 years. This effort revealed periods of both increasing and decreasing grain size (moisture availability) throughout the 4,000-year record at decadal, centennial, and millennial time scales, with the most predominant departures including four several-centuries-long epochs that corresponded to the Little Ice Age (about AD 1500–1900), Medieval Warm Period (about AD 700–1300), Dark Ages Cold Period (about 100 BC to AD 700), and Roman Warm Period (about 900–100 BC). A standardized median grain-size history indicated the highest rates of stream discharge during the past 4,000 years occurred during the Little Ice Age at approximately 300–350 years ago, when grain sizes were about 2.5 standard deviations above the 4,000-year mean. In contrast, the lowest rates of streamflow were observed around AD 1100, when median grain sizes were nearly 2 standard deviations below the 4,000-year mean. Most recently, grain size over the past 150 years has generally remained above average.

The Pine Lake sediment record thus convincingly identifies the non-CO_2-induced millennial-scale climate oscillation that brings several-century-long periods of alternating dryness and wetness to the southern Alberta region of North America, during concomitant periods of relative hemispheric warmth and coolness, respectively. It also demonstrates there is nothing unusual about the region's current moisture status, which suggests the planet may still have a bit of warming to do before the Current Warm Period is fully upon us.

Laird *et al*. (2003) studied diatom assemblages in sediment cores taken from three Canadian and three United States lakes situated within the northern prairies of North America. For five of the lakes, diatom-inferred salinity estimates were used to reconstruct relative changes in effective moisture (E/P), where E is evaporation and P is precipitation, with high salinity implying high E/P. For the sixth lake, diatom-inferred total phosphorus was used, and chronologies were based on ^{210}Pb dating of recent sediments and radiocarbon dates for older sediments.

The seven scientists note their data show "shifts in drought conditions on decadal through multicentennial scales have prevailed in this region for at least the last two millennia." In Canada, major shifts occurred near the beginning of the Medieval Warm Period, and in the United States they occurred near its end. The scientists state, "distinct patterns of abrupt change in the Northern Hemisphere are common at or near the termination of the Medieval Warm Period (*ca*. A.D. 800–1300) and the onset of the Little Ice Age (*ca*. A.D. 1300–1850)." They also note "millennial-scale shifts over at least the past 5,500 years, between sustained periods of wetter and drier conditions, occurring approximately every 1,220 years, have been reported from western Canada (Cumming *et al*., 2002)," and "the striking correspondence of these shifts to large changes in fire frequencies, inferred from two sites several hundreds of kilometers to the southwest in the mountain hemlock zone of southern British Columbia (Hallett *et al*., 2003), suggests that these millennial-scale dynamics are linked and operate over wide spatial scales."

Lassen *et al*. (2004) point out "the Norse, under Eric the Red, were able to colonize South Greenland at AD 985, according to the Icelandic Sagas, owing to the mild Medieval Warm Period climate with favorable open-ocean conditions." They also mention the arrival of the Norsemen was "close to the peak of Medieval warming recorded in the GISP2 ice core which was dated at AD 975 (Stuiver *et al*., 1995)," and Esper *et al*. (2002) independently identified the peak warmth of this period throughout North American extratropical latitudes as "occurring around 990." It would appear the window of climatic opportunity provided by the peak warmth of the Medieval Warm Period was a major factor enabling seafaring Scandinavians to establish stable settlements on the coast of Greenland.

As time progressed, however, the glowing promise of the apex of Medieval warmth gave way to the debilitating reality of the depth of Little Ice Age cold. Jensen *et al*. (2004), for example, report the diatom record of Igaliku Fjord "yields evidence of a relatively moist and warm climate at the beginning of settlement, which was crucial for Norse land use," but "a regime of more extreme climatic fluctuations began soon after AD 1000, and after AD c. 1350 cooling became more severe." Lassen *et al*. additionally note, "historical documents on Iceland report the presence of the Norse in South Greenland for the last time in AD 1408," during what they describe as a period of "unprecedented influx of (ice-loaded) East Greenland Current water masses into the innermost parts of Igaliku Fjord." They also report "studies of a Canadian high-Arctic ice core and nearby geothermal data (Koerner and Fisher, 1990) correspondingly showed a significant temperature lowering at AD 1350–1400," when, they write, "the Norse society in Greenland was declining and reaching its final stage probably before the end of the fifteenth century."

Many more details of this incredible saga of five centuries of Nordic survival at the foot of the Greenland Ice Cap also have come to light. Based on a high-resolution record of the fjord's subsurface water-mass properties derived from analyses of benthic foraminifera, Lassen *et al*. conclude stratification of the water column, with Atlantic water masses in its lower reaches, appears to have prevailed throughout the last 3,200 years, except for the Medieval Warm Period. During that period, which they describe as occurring between AD 885 and 1235, the outer part of Igaliku Fjord experienced enhanced vertical mixing (which they attribute to increased wind stress) that would have been expected to increase nutrient availability there. A similar conclusion was reached by Roncaglia and Kuijpers (2004), who found evidence of increased bottom-water ventilation between AD 960 and 1285.

Based on these findings, plus evidence of the presence of *Melonis barleeanus* during the Medieval Warm Period (the distribution of which is mainly controlled by the presence of partly decomposed organic matter), Lassen *et al.* conclude surface productivity in the fjord during this interval of unusual relative warmth was "high and thus could have provided a good supply of marine food for the Norse people."

Shortly thereafter, the cooling that led to the Little Ice Age was accompanied by a gradual re-stratification of the water column, which curtailed nutrient upwelling and the high level of marine productivity that had prevailed throughout the Medieval Warm Period. These linked events, according to Lassen *et al.*, "contributed to the loss of the Norse settlement in Greenland." With deteriorating growing conditions on land and simultaneous reductions in oceanic productivity, it was only a matter of time before the Nordic colonies failed. Lassen *et al.* note, "around AD 1450, the climate further deteriorated with further increasing stratification of the water-column associated with stronger advection of (ice-loaded) East Greenland Current water masses." This led to an even greater "increase of the ice season and a decrease of primary production and marine food supply," which "could also have had a dramatic influence on the local seal population and thus the feeding basis for the Norse population."

Lassen *et al.* conclude "climatic and hydrographic changes in the area of the Eastern Settlement were significant in the crucial period when the Norse disappeared." Also, Jensen *et al.* report, "geomorphological studies in Northeast Greenland have shown evidence of increased winter wind speed, particularly in the period between AD 1420 and 1580 (Christiansen, 1998)," noting "this climatic deterioration coincides with reports of increased sea-ice conditions that caused difficulties in using the old sailing routes from Iceland westbound and further southward along the east coast of Greenland, forcing sailing on more southerly routes when going to Greenland (Seaver, 1996)."

Jensen *et al.* conclude, "life conditions certainly became harsher during the 500 years of Norse colonization," and this severe cooling-induced environmental deterioration "may very likely have hastened the disappearance of the culture." It is also clear the more favorable living conditions associated with the peak warmth of the Medieval Warm Period—which occurred between approximately AD 975 (Stuiver *et al.*, 1995) and AD 990 (Esper *et al.*, 2002)—were what originally enabled the Norse to colonize the region. In the thousand-plus subsequent years, there has never been a sustained period of comparable warmth, nor of comparable terrestrial or marine productivity, either locally or hemispherically (and likely globally, as well).

D'Arrigo *et al.* (2004) sampled trees of white spruce (*Picea glauca* (Moench) Voss) from 14 sites near the elevational treeline on the eastern Seward Peninsula of Alaska, obtaining 46 cores from 38 trees, which they used to develop a maximum latewood density (MXD) chronology for the period AD 1389 to 2001. Calibrating a portion of the latter part of this record (1909–1950) against May–August monthly temperatures obtained from the Nome meteorological station, they converted the entire MXD chronology to warm-season temperatures. This process revealed, they write, "the middle-20th century warming is the warmest 20-year interval since 1640." Their plot of reconstructed temperatures, however, clearly shows a nearly equivalent warm period near the end of the 1600s, as well as a two-decade period of close-to-similar warmth in the mid-1500s. In the latter part of the 1400s there is a decade warmer than that of the mid-twentieth century. This temperature reconstruction, which the five researchers described as "one of the longest density-based records for northern latitudes," thus provides yet another indication twentieth century warmth was by no means unprecedented in the past millennium or two, contrary to the claims of Mann *et al.* (1998, 1999) and Mann and Jones (2003). The study instead supports the findings of Esper *et al.* (2002, 2003), McIntyre and McKitrick (2003), and Loehle (2004), which indicate there were several periods over the past millennium or more when it was as warm as, or even warmer than, it was during the twentieth century.

Luckman and Wilson (2005) used new tree-ring data from the Columbia Icefield area of the Canadian Rockies to present a significant update to a millennial temperature reconstruction published for this region in 1997. The update employed different standardization techniques, such as the regional curve standardization method, to capture a greater degree of low frequency variability (centennial to millennial scale) than reported in the initial study. In addition, the new dataset added more than one hundred years to the chronology that now covers the period 950–1994.

The new tree-ring record was found to explain 53 percent of May–August maximum temperature variation observed in the 1895–1994 data and was thus viewed as a proxy indicator of such temperatures over the past millennium. Based on this relationship, the record showed considerable decadal- and centennial-scale variability, where generally warmer conditions prevailed during the eleventh and twelfth centuries, between about 1350–1450, and from about 1875 through the end of the record. The warmest reconstructed summer occurred in 1434 and was 0.23°C warmer than the next warmest summer, which occurred in 1967, and persistent cold conditions prevailed in 1200–1350, 1450–1550, and 1650–1850, with the 1690s being exceptionally cold (more than 0.4°C colder than other intervals).

The revised Columbia Icefield temperature reconstruction provides further evidence for natural climate fluctuations on centennial-to-millennial time scales and, according to Luckman and Wilson, "appears to indicate a reasonable response of local trees to large-scale forcing of climates, with reconstructed cool conditions comparing well with periods of known low solar activity."

D'Arrigo *et al.* (2005) used a new tree-ring width dataset derived from 14 white spruce chronologies obtained from the Seward Peninsula, Alaska, covering the years 1358–2001, combined with additional tree-ring width chronologies from northwest Alaska, to produce two versions of a much longer data series that extended to AD 978. The first chronology was created using traditional methods of standardization (STD), which do not perform well in capturing multidecadal or longer climate cycles, while the second chronology utilized the regional curve standardization (RCS) method, which better preserves low-frequency variations at multidecadal time scales and longer. The new, improved, and extended final temperature history of this study provided further evidence for natural climate fluctuations on centennial-to-millennial time scales, capturing the temperature oscillations that produced the Medieval Warm Period (eleventh–thirteenth centuries) and Little Ice Age (1500–1700).

Hallett and Hills (2006) reconstructed the Holocene environmental history of Kootenay Valley in the southern Canadian Rockies based on data obtained from the sediments of Dog Lake, British Columbia (50°46'N, 116°06'W). They found in the centuries leading up to AD 800, the area had developed "a more open landscape," and "fire frequencies and summer drought appear to increase," concluding this increased fire activity was "supported by higher dry-open/wet-closed [forest] pollen ratios and indicates a return to dry-open forest conditions around Dog Lake," which lasted about 400 years. Thereafter, they found, "wet-closed forest cover reaches its maximum extent from 700–150 cal years BP [AD 1250–1800]" in what "appears to be a response to Little Ice Age cooling." Finally, they state, "current global warming trends ... may again create the conditions necessary for dry-open ... forest to expand in the Kootenay Valley." The authors say current global warming may recreate climatic conditions similar to those that prevailed in the Kootenay Valley prior to the global chill of the Little Ice Age, which suggests it has not been as warm there yet, nor for as long a time, as it was between AD 800 and 1200.

Loso *et al.* (2006) presented "a varve thickness chronology from glacier-dammed Iceberg Lake [60°46'N, 142°57'W] in the southern Alaska icefields," where "radiogenic evidence confirms that laminations are annual and record continuous sediment deposition from AD 442 to AD 1998" and where "varve thickness increases in warm summers because of higher melt, runoff, and sediment transport." They report the temperatures implied by the varve chronology "were lowest around AD 600, warm between AD 1000 and AD 1300 [which they called "a clear manifestation of the Medieval Warm Period"], cooler between AD 1500 and AD 1850, and have increased dramatically since then."

The four scientists state their varve record "suggests that 20th century warming is more intense ... than the Medieval Warm Period or any other time in the last 1500 years."Their graphical representation of varve thickness suggests the intense warming of the twentieth century peaked around 1965 to 1970, after which it was followed by equally intense cooling, such that by 1998, temperatures are implied to have been less than they were during the Medieval Warm Period. The same story is told by tree ring-width anomalies from the adjacent Wrangell Mountains of Alaska, which Loso *et al.* portray as updated from Davi *et al.* (2003). These two databases show the region's current temperature is lower than it was during the warmest part of the Medieval Warm Period.

Hay *et al.* (2007) analyzed the vertical distributions of diatoms, silicoflagellates, and biogenic silica found in two sediment cores recovered from the inner and outer basins (49°04’N, 125°09’W and 49°02’N, 125°09’W, respectively) of Effingham Inlet, British Columbia, Canada, finding evidence that “a period of warmer and drier climate conditions and possibly increased coastal upwelling offshore occurred ca. 1450–1050 calendar years before present”; i.e., about AD 500–900. Noting “the patterns observed in the diatom record of Effingham Inlet are consistent with regional marine and terrestrial paleoenvironmental records,” they report, “coast range glaciers ... showed a hiatus from 1500 to 1100 calendar years before present,” and this “period of more productive conditions ... was correlative with increased regional primary and marine fish production.” In addition, their data indicated concentrations of *Skeletonema costatum*, which they say “is limited by low temperatures,” were much greater over the AD 550–950 period (which appears to represent the Medieval Warm Period in this part of the world) than in any portion of the following (most recent) millennium.

Zabenskie and Gajewski (2007) extracted sediment cores from Lake JR01 (69°54’N, 95°4.2’W) on the Boothia Peninsula, Nunavut, Canada using a 5-cm diameter Livinstone corer. They note “the uppermost part of the sediment was sampled in a plastic tube with piston to ensure that the sediment-water interface was collected,” and “the upper 20 cm of sediment were sub-sampled into plastic bags at 0.5-cm intervals.” From the fossil pollen assemblages thereby derived, July temperatures were estimated “using the modern analog technique,” as per Sawada (2006). As illustrated in Figure 4.2.4.7.1.1, the two researchers report “maximum estimated July temperatures were reached between 5800 and 3000 cal yr BP, at which time they exceeded present-day values.” Thereafter, temperatures decreased, but with a subsequent “short warming,” which they say “could be interpreted as the Medieval Warm Period,” which they identify as occurring “between 900 and 750 cal yr BP.” After that period of warmth, “temperatures cooled during the Little Ice Age,” as pollen percentages “returned to their values before the [MWP] warming.” During the last 150 years of the record, they observe a “diverse and productive diatom flora,” although “July temperatures reconstructed using the modern analog technique remained stable during this time,” which suggests the Lake JR01 region of the Boothia Peninsula is currently not as warm as it was during the MWP.

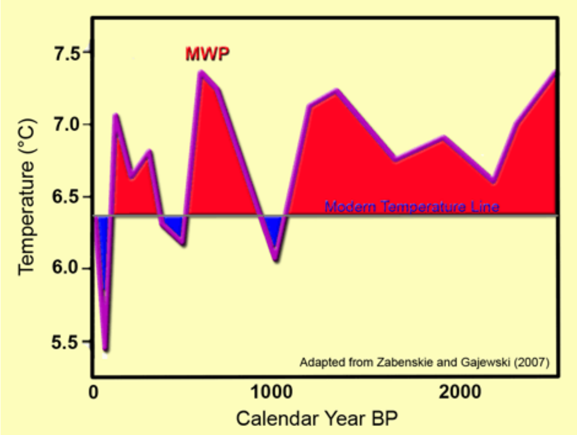

Figure 4.2.4.7.1.1. Reconstructed July mean temperature on the Boothia Peninsula, Nunavut, Canada. Adapted from Zabenskie, S. and Gajewski, K. 2007. Post-glacial climatic change on Boothia Peninsula, Nunavut, Canada. *Quaternary Research* **68**: 261–270.

Podritske and Gajewski (2007) evaluated the relationship between diatoms and temperature by comparing a diatom stratigraphy based on high-resolution sampling with independent paleoclimatic records. They used a high-resolution diatom sequence of the past 9,900 years developed from sediment-core data acquired from a small lake (unofficially named KR02) on Canada’s Victoria Island (located at 71.34°N, 113.78°W) to place recent climatic changes there “in an historical context.” The two researchers report “there is evidence of diatom community response to centennial-scale variations such as the ‘Medieval Warm Period’ (~1000–700 cal yr BP), ‘Little Ice Age’ (~800–150 cal yr BP) and recent warming.” They report the recent warming-induced changes “are not exceptional when placed in the context of diatom community changes over the entire Holocene,” stating, “although recent changes in diatom community composition, productivity, and species richness are apparent, they were surpassed at other periods throughout the Holocene.” The researchers explicitly state the most recent rate of change “was exceeded during the Medieval Warm Period.”

Wiles *et al.* (2008) used “comparisons of temperature sensitive climate proxy records with tree-ring, lichen and radiocarbon dated histories from land-terminating, non-surging glaciers for the last two millennia from southern Alaska” to “identify summer temperature as a primary driver of glacial expansions,” based on “field and laboratory work over the past decade" that yielded "five new or updated glacier histories," one each for Bear Glacier (Kenai Mountains), Marathon Mountain Cirque (Kenai Mountains), Amherst Glacier (Chugach Mountains), Crescent Glacier (Chugach Mountains), and Yakutat Glacier (St. Elias Mountains), all located just above the Gulf of Alaska (about 60°N) between approximately 140 to 150°W.

The four researchers' findings suggest the presence of the Roman Warm Period near the beginning of their 2,000-year record, because of detected "general glacier expansions during the First Millennium AD" that experienced their "strongest advance" at AD 600. The latter cold interval—with ice extent "as extensive as [the] subsequent Little Ice Age"—is typically known as the Dark Ages Cold Period. This cold interval was followed by the Medieval Warm Period (MWP), the evidence for which consisted of "soil formation and forest growth on many forefields in areas that today are only just emerging from beneath retreating termini," which suggests the MWP was likely both warmer and longer-lived than what has been experienced so far in the Current Warm Period. They also report, "tree-ring chronologies [at the Sheridan, Tebenkof, and Princeton glaciers] show that forest growth on these forefields was continuous between the 900s and 1200s."

Noting the alternating warm-cold-warm-cold-warm sequence of the past 2,000 years "is consistent with millennial-scale records of ice-rafted debris flux in the North Atlantic and Northern Hemisphere temperature reconstructions," and "variable Holocene solar irradiance has been proposed as a potential forcing mechanism for millennial-scale climate change," they conclude "this is supported by the Southern Alaskan glacial record."

Besonen *et al*. (2008) derived thousand-year histories of varve thickness and sedimentation accumulation rate for Canada's Lower Murray Lake (81°20'N, 69°30'W), which is typically covered for about 11 months of each year by ice that reaches a thickness of 1.5 to 2 meters at the end of each winter. They note, "field-work on other High Arctic lakes clearly indicates sediment transport and varve thickness are related to temperatures during the short summer season that prevails in this region, and we have no reason to think that this is not the case for Lower Murray Lake." The six scientists report the varve thickness and sediment accumulation rate histories of Lower Murray Lake show "the twelfth and thirteenth centuries were relatively warm." Their data indicate Lower Murray Lake and its environs were often much warmer during this time period (AD 1080–1320) than at any point in the twentieth century, which also has been shown to be the case for Donard Lake (66.25°N, 62°W) by Moore *et al*. (2001).

Payette *et al*. (2008) developed a long-term, spatially explicit fire history of northern boreal forest-tundra in the Riviere Boniface watershed in northeastern Canada (57°45'N, 76°W) based on several years of field investigations designed to exhaustively map and accurately date the occurrences of all fires per each 100-year interval over the last 2,000 years within a 40-km^2 area in that region. They found there was a "70% reduction of forest cover since 1800 yr BP and nearly complete cessation of forest regeneration since 900 yr BP," such that "the northern part of the forest tundra in Eastern Canada has been heavily deforested over the last millennium." They also note "the climate at the tree line was drier and warmer before 900 cal. yr BP."

The three Canadian researchers conclude the chief direct cause of the post-900 yr BP deforestation was "climate deterioration coinciding with the phasing-out of the Medieval Warmth and incidence of the Little Ice Age." In addition, since "the latitudinal position of successful post-fire regeneration of lichen-spruce woodlands is situated approximately 1.5° south of the Boniface area, as a rule of thumb it is probable that a drop of at least 1°C in mean annual temperature occurred after 900 cal. yr BP," they conclude. "Recovery of the boreal forest after a long period of deforestation will require sustained warming," they state, which they add has been occurring only "since the mid-1990s in Eastern subarctic Canada."

Edwards *et al*. (2008) developed a cellulose δ^{13}C dendrochronology "from cross-dated 10-year increments of 16 sub-fossil snags and living-tree ring sequences of *Picea engelmannii* (Englemann spruce) from upper alpine treeline sites near Athabasca Glacier and subfossil material from the forefield of Robson Glacier plus living and snag material of *Pinus albicaulis* (whitebark pine) adjacent to Bennington Glacier, spanning AD 951–1990," as well as from an oxygen isotope (δ^{18}O) dendro-chronology for the same period. They calculated past changes in relative humidity and temperature over Canada's Columbia Icefield in the general vicinity of 53°N, 118°W. They report several "intriguing new discoveries," one of which is "evidence of previously unrecognized winter warmth during the Medieval Climate Anomaly (~AD 11001250)," as illustrated in Figure 4.2.4.7.1.2.

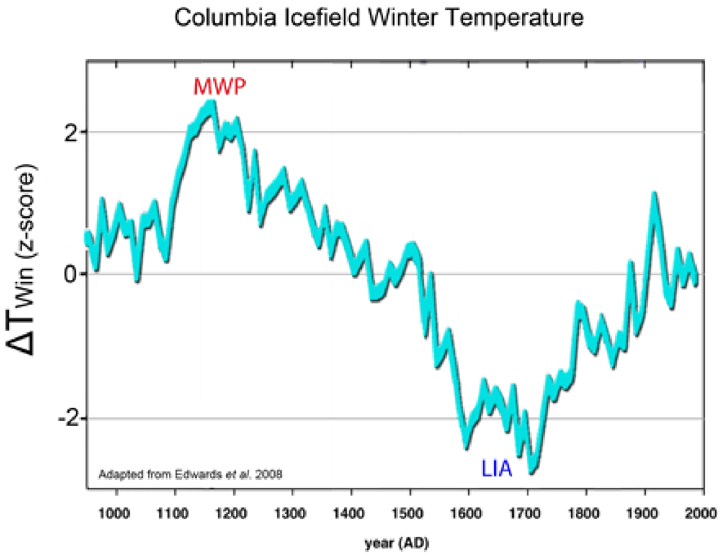

Figure 4.2.4.7.1.2. Columbia Icefield mean winter temperature z-scores relative to that of the period AD 1941-1990. Adapted from Edwards, T.W.D., Birks, S.J., Luckman, B.H., and MacDonald, G.M. 2008. Climatic and hydrologic variability during the past millennium in the eastern Rocky Mountains and northern Great Plains of western Canada. *Quaternary Research* **70**: 188–197.

The four researchers' results show the peak winter temperature of the Medieval Climate Anomaly throughout Canada's Columbia Icefield was warmer than the peak temperature of the Current Warm Period (which appears to have occurred ~1915), and it was even warmer than the mean temperature of the 1941–1990 base period as well as the mean temperature of the last ten years of that period (1980–1990).

Barclay *et al*. (2009) note "tree-ring crossdates of glacially killed logs have provided a precisely dated and detailed picture of Little Ice Age (LIA) glacier fluctuations in southern Alaska," and they extended this history into the First Millennium AD (FMA) by integrating similar data obtained from additional log collections made in 1999 with the prior data to produce a new history of advances and retreats of the Tebenkof Glacier spanning the past two millennia.

Figure 4.2.4.7.1.3 shows between the FMA and LIA extensions of the Tebenkof Glacier terminus, there was a period between about AD 950 and 1230 when the terminus dropped further than two kilometers back from the maximum LIA extension that occurred near the end of the nineteenth century. This warmer/drier period of glacier terminus retreat had to have been much more extreme than what was experienced at any time during the twentieth century, because at the century's end the glacier's terminus had not yet retreated more than two kilometers back from the line of its maximum LIA extension. This 280-year period of likely greater warmth and dryness falls in the middle of the broad peak of maximum warmth during the global Medieval Warm Period.

Based on the data depicted in Figure 4.2.4.7.1.3, it would appear the central portion of the Medieval Warm Period in southern Alaska was likely significantly warmer and drier than at any time during the twentieth century. It can be further concluded there is nothing unprecedented or unusual about that region's current warmth and dryness, which means there is no need to invoke anthropogenic CO_2 emissions as a cause.

Rolland *et al*. (2009) reconstructed the late-Holocene evolution of a Southampton Island lake known as Tasiq Qikitalik (65°05'70'N, 83°47'49'W)

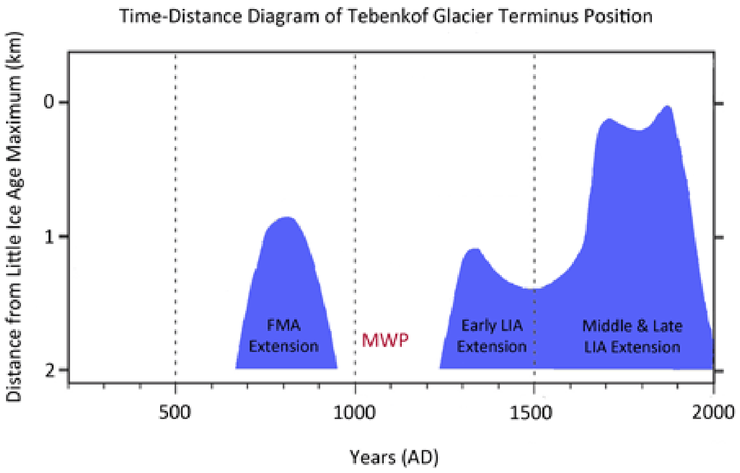

Figure 4.2.4.7.1.3. The temporal history of the distance by which the terminus of the Tebenkof Glacier fell short of its maximum LIA extension over the past two millennia. Adapted from Barclay, D.J., Wiles, G.C., and Calkin, P.E. 2009. Tree-ring crossdates for a first millennium AD advance of Tebenkof Glacier, southern Alaska. *Quaternary Research* **71**: 22–26.

in Nunavut, Canada by studying fossil chironomid distributions along with sedimentological data (X-ray fluorescence, grain size, and C/N ratios) obtained from a sediment core retrieved from the lake's deepest reachable point, deriving in the process a 1,200-year history of inferred August temperatures. They discovered "higher temperatures were recorded from cal yr AD 1160 to AD 1360, which may correspond to the Medieval Warm Period," and "between cal yr AD 1360 and AD 1700, lower temperatures were probably related to a Little Ice Age event," with the latter period exhibiting a minimum August temperature "ca. 2°C colder than the maximum observed during the Medieval Warm Period." The most recent August temperature, which occurred at the end of the record at about 2008, is approximately 0.9°C less than the maximum August temperature of the Medieval Warm Period.

Laird and Cumming (2009) developed a history of changes in the level of Lake 259 (Rawson Lake, 49°40'N, 93°44'W) within the Experimental Lakes Area of northwestern Ontario, Canada based on a suite of near-shore gravity cores they analyzed for diatom species identity and concentration, as well as organic matter content. They discovered "a distinct decline in lake level of ~2.5 to 3.0 m from ~800 to 1130 AD." This interval, they write, "corresponds to an epic drought recorded in many regions of North America from ~800 to 1400 AD," which they say was "often referred to as the Medieval Climatic Anomaly or the Medieval Warm Period," and which also "encompasses 'The Great Drought' of the thirteenth century (Woodhouse and Overpeck, 1998; Woodhouse, 2004; Herweijer *et al.* 2007)." They note the Canadian prairies were at that time "experiencing reductions in surface-water availability due to climate warming and human withdrawals (Schindler and Donahue, 2006)," and many regions in the western U.S. had experienced water supply deficits in reservoir storage with the multi-year drought described by Cook *et al.* (2007). They report "these severe multi-year drought conditions pale in comparison to the many widespread megadroughts that persisted for decades and sometimes centuries in many parts of North America over the last millennium (Woodhouse, 2004)."

Clegg *et al.* (2010) conducted a high-resolution analysis of midge assemblages found in the sediments of Moose Lake (61°22.45'N, 143°35.93'W) in the Wrangell-St. Elias National Park and Preserve of south-central Alaska, based on data obtained from cores removed from the lake bottom in summer 2000 and a midge-to-temperature transfer function that yielded mean July temperatures (T_{July}) for the past six thousand years. Some of the results of this study are portrayed in Figure 4.2.4.7.1.4, which shows, from about 2,600 cal yr BP to the present, a clear multi-centennial oscillation about the declining trend, with peaks and valleys defining the temporal locations of the Roman Warm Period, Dark Ages Cold Period, Medieval Warm Period, Little Ice Age, and the start of the Current Warm Period, which is still not expressed to any significant degree compared to the Medieval and Roman Warm Periods.

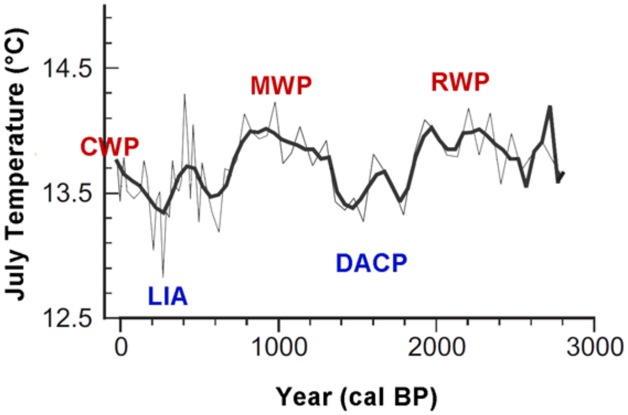

Figure 4.2.4.7.1.4. Mean July near-surface temperature (°C) vs. years before present (cal BP) for south-central Alaska (USA). Adapted from Clegg, B.F., Clarke, G.H., Chipman, M.L., Chou, M., Walker, I.R., Tinner, W., and Hu, F.S. 2010. Six millennia of summer temperature variation based on midge analysis of lake sediments from Alaska. *Quaternary Science Reviews* **29**: 3308–3316.

The seven scientists write, "comparisons of the T_{July} record from Moose Lake with other Alaskan temperature records suggest that the regional coherency observed in instrumental temperature records (e.g., Wiles *et al*., 1998; Gedalof and Smith, 2001; Wilson *et al*., 2007) extends broadly to at least 2000 cal BP." In addition, they note climatic events such as the LIA and the MWP occurred "largely synchronously" between their T_{July} record from Moose Lake and a δ^{18}O-based temperature record from Farewell Lake on the northwestern foothills of the Alaska Range, and "local temperature minima likely associated with First Millennium AD Cooling (centered at 1400 cal BP; Wiles *et al*., 2008) are evident at both Farewell and Hallet lakes (McKay *et al*., 2008)."

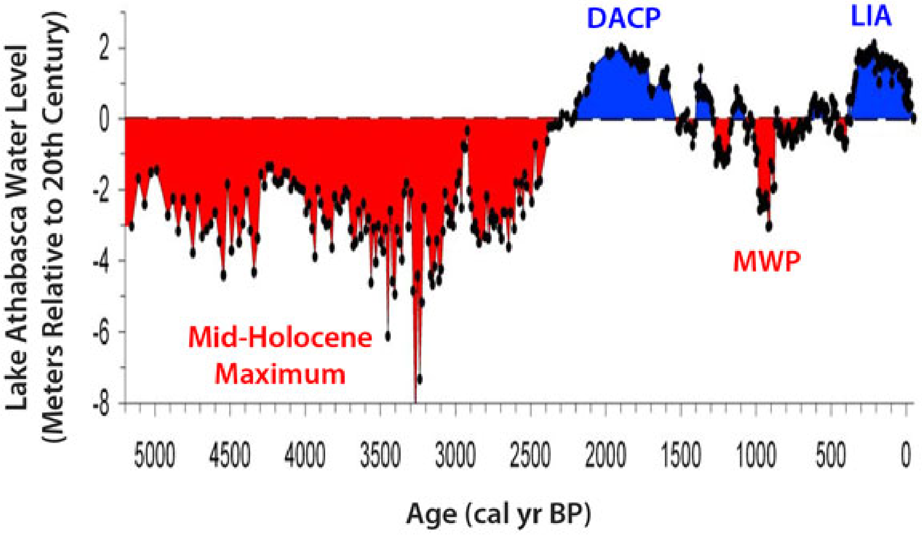

Figure 4.2.4.7.1.5. The Reconstructed water level history of Lake Athabasca. Adapted from Wolfe, B.B., Edwards, T.W.D., Hall, R.I., and Johnston, J.W. 2011. A 5200-year record of freshwater availability for regions in western North America fed by high-elevation runoff. *Geophysical Research Letters* **38**: 10.1029/ 2011GL047599.

Wolfe *et al*. (2011) note the level of Canada's Lake Athabasca—North America's ninth-largest lake, located in the northwest corner of Saskatchewan and the northeast corner of Alberta between 58° and 60° N—"is a sensitive monitor of climate-driven changes in streamflow from alpine catchments draining the eastern slopes of the Rocky Mountains (Wolfe *et al*., 2008; Johnston *et al*., 2010; Sinnatamby *et al*., 2010)." In addition, they write, "paleoenvironmental data indicate that the last millennium was punctuated by multi-decadal episodes of both higher and lower Lake Athabasca levels relative to the 20th century mean, which corresponded with fluctuations in the amount and timing of runoff from glaciers and snowpacks (Wolfe *et al*., 2008)." They also note "the highest levels of the last 1000 years occurred c. 1600–1900 CE [=AD] during the Little Ice Age (LIA), in company with maximum late-Holocene expansion of glaciers in the Canadian Rockies," and the "lowest levels existed at c. 970–1080 CE at a time of low glacier volume," near the midpoint of the global Medieval Warm Period.

In their newest study of the subject, the four Canadian researchers expanded the time span of the lake-level history to the past 5,200 years, based on new analyses of sediment cores they collected in July 2004 from North Pond (a lagoon on Bustard Island located at the western end of Lake Athabasca). They discovered (see Figure 4.2.4.7.1.5) "modern society in western Canada developed during a rare interval of relatively abundant freshwater supply—now a rapidly diminishing by-product of the LIA glacier expansion, which is in agreement with late 20th century decline in Athabasca River discharge identified in hydrometric records (Burn *et al*., 2004; Schindler and Donahue, 2006)." In addition, their data suggest "the transition from water abundance to scarcity can occur within a human lifespan," which, as they caution, "is a very short amount of time for societies to adapt."

Their data suggest the peak warmth of the Medieval Warm Period was likely significantly greater than the peak warmth experienced to date during the Current Warm Period. The rapidly declining water level over the past couple of decades—when Earth's temperature was near its modern peak but exhibited very little trend—suggests lake level could continue its rapid downward course if planetary temperatures merely maintain their current values. Wolfe *et al*. conclude, "as consumption of water from rivers draining the central Rocky Mountain region is on an increasing trend, we must now prepare to deal with continental-scale water-supply reductions well beyond the magnitude and duration of societal memory."

Galloway *et al*. (2011) studied an 11.6-m sediment core they extracted in June 2001 from the deepest point of Felker Lake (51°57.0'N, 121°59.9'W), which sits in the rain shadow generated by Canada's Coast, Cascade, and Columbia Mountains. They analyzed diatom assemblages, together with pollen and spore types and quantities, to produce an 11,670-year record of hydrological change throughout the Holocene, based on a calibration dataset of 219 lakes from British Columbia, including Felker Lake, and select lakes from the Northern Great Plains (Wilson *et al*., 1996). This work provided evidence for what they call a "millennial-scale pacing of climate" throughout the Holocene. They report "the most extreme episode of hydrological change occurred from ca. 1030 cal. year BP to ca. 690 cal. year BP," a period they note was "broadly coeval with the Medieval Warm Period." They say "a coeval warm and dry interval is recognized in numerous paleoclimate studies in western North America," citing the work of Hallett *et al*. (2003), Laird *et al*. (2003), and Bracht *et al*. (2007).

That the warm and dry interval Galloway *et al*. discovered at Felker Lake during the heart of the Medieval Warm Period was the most extreme such period of the entire Holocene indicates just how unusual the Medieval Warm Period was in this regard … and further reveals the *non*-uniqueness of the warmth and dryness experienced in that part of the world during the establishment of the planet's Current Warm Period.

Kobashi *et al*. (2011) write, "Greenland recently incurred record high temperatures and ice loss by melting, adding to concerns that anthropogenic warming is impacting the Greenland ice sheet and in turn accelerating global sea-level rise." They also note "it remains imprecisely known for Greenland how much warming is caused by increasing atmospheric greenhouse gases versus natural variability." They reconstructed Greenland surface snow temperature variability over the past 4,000 years at the GISP2 site (near the Summit of the Greenland ice sheet; hereafter referred to as Greenland temperature) with a new method that utilizes argon and nitrogen isotopic ratios from occluded air bubbles, as described in detail by Kobashi *et al*. (2008a,b).

The eight researchers report "the temperature record starts with a colder period in 'the Bronze Age Cold Epoch,'" which they say was followed by "a warm period in 'the Bronze Age Optimum,'" after which there was a 1,000-year cooling that began "during 'the Iron/Roman Age Optimum,'" followed by "the Dark Ages." That period was followed by "the Medieval Warm Period," after which occurred "the Little Ice Age, which they describe as "the coldest period of the past 4000 years," which was followed, finally, by "the recent warming." They note "the current decadal average surface temperature at the summit is as warm as in the 1930s–1940s, and there was another similarly warm period in the 1140s (Medieval Warm Period)," indicating "the present decade is not outside the envelope of variability of the last 1000 years." They write, "excluding the last millennium," there were fully "72 decades warmer than the present one, in which mean temperatures were 1.0 to 1.5°C warmer," and during two centennial intervals, average temperatures "were nearly 1.0°C warmer than the present decade" (see Figure 4.2.4.7.1.6).

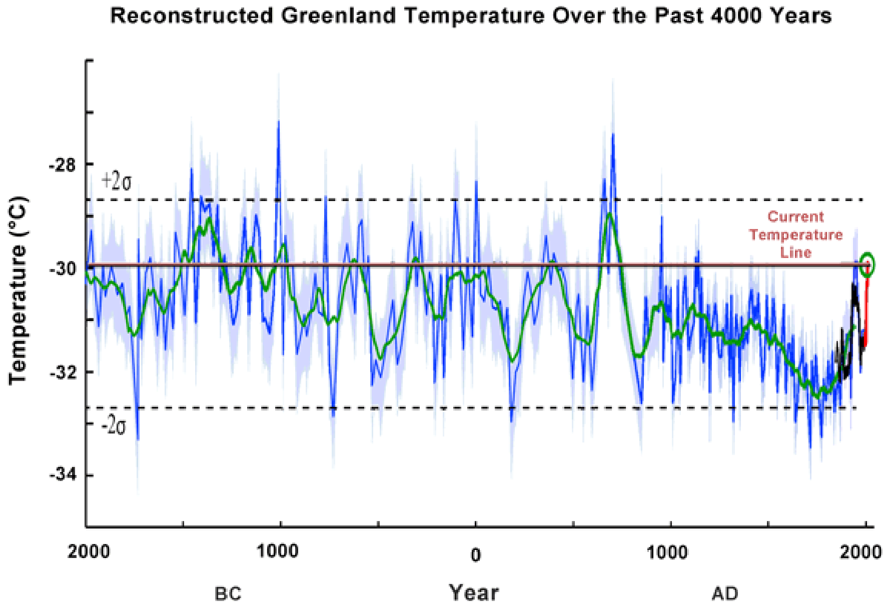

Figure 4.2.4.7.1.6. Reconstructed Greenland snow surface temperatures for the past 4,000 years. The blue line and blue band represent the reconstructed Greenland temperature and 1σ error, respectively. The green line represents a 100-year moving average of the blue line. The black and red lines indicate the Summit and AWS decadal average temperatures, respectively, as calculated by others. Adapted from Kobashi, T., Kawamura, K., Severinghaus, J.P., Barnola, J.-M., Nakaegawa, T., Vinther, B.M., Johnsen, S.J., and Box, J.E. 2011. High variability of Greenland surface temperature over the past 4000 years estimated from trapped air in an ice core. *Geophysical Research Letters* **38**: 10.1029/2011GL049444.

Since the Greenland summit's decadal warmth of the first ten years of the twenty-first century was exceeded fully six dozen times over the prior four millennia, it clearly was in no way unusual, and therefore it is also clear none of Greenland's recent warming has necessarily been caused by increasing concentrations of greenhouse gases. It is far more likely its recent warmth is the next expected phase of the natural oscillation of climate that has produced numerous multi-century periods of alternating warmth and cold over the past four thousand years.

Bunbury and Gajewski (2012) obtained sediment cores from two lakes in the interior southwest of Canada's Yukon Territory—Jenny Lake (61.04°N, 138.36°W) and Upper Fly Lake (61.04°N, 138.09°W)—which, they write, "yielded chironomid records that were used to provide quantitative estimates of mean July air temperature." The two researchers report their chironomid-inferred temperature estimates from the two lakes "compare well with one another and also with other paleoclimate evidence from the region," noting their data suggest "relatively warm conditions during medieval times, centered on AD 1200, followed by a cool Little Ice Age, and warming temperatures over the past 100 years." It can be estimated from the graphical representations of their data that the Medieval Warm Period at both lake sites extended from about AD 1100 to 1350, and it also can be estimated that the most recent (AD 1990) of their temperature determinations were about 0.8°C cooler than the peak warmth of the Medieval Warm Period at Jenny Lake and approximately 0.5°C cooler at Upper Fly Lake.

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4.2.4.7.2 United States

The IPCC claims rising atmospheric CO_2 concentrations due to the burning of fossil fuels such as coal, gasm and oil have raised global air temperatures to their highest level in the past one to two millennia. Therefore, investigating the possibility of a period of equal global warmth within the past one to two thousand years has become a high-priority enterprise, for if such a period can be shown to have existed when the atmosphere's CO_2 concentration was far less than it is today, there will be no compelling reason to attribute the warmth of our day to the CO_2 released into the air by mankind since the beginning of the Industrial Revolution. This section reviews studies of this topic conducted within the confines of the lower 48 contiguous states of the United States of America.

Lloyd and Graumlich (1997) derived 3,500-year histories of treeline elevation fluctuation and tree abundance for five sites in the southern Sierra Nevada (~36.5°N, 108.25°W). They found synchronous increases in treeline elevation from AD 800 to 900 and an episode of high tree abundance above the current treeline between AD 700 and 1200, which implies warmer-than-present temperatures during that period..

Ingram *et al.* (1998) conducted isotopic ($^{18}O/^{16}O$ and $^{13}C/^{12}C$) and elemental chemical analyses (Sr/Ca and Mg/Ca ratios) of sediment cores taken from Petaluma Marsh, San Francisco Bay, Northern California, to develop a record of paleoenvironmental change in this region over the past 700 years. They report high frequency variations in $\delta^{18}O$, $\delta^{13}C$, Mg/Ca, and Sr/Ca were noted throughout the 700-yr record, indicating the presence of oscillations in freshwater inflow, temperature, and evaporation at periods of 35–115 years. Between 150 and 400 cal yr BP, $\delta^{18}O$ and Mg/Ca were relatively low, indicating a period of cold and wet climatic conditions associated with the Little Ice Age. Before that, $\delta^{18}O$ and Mg/Ca were higher from 480 to 650 cal yr BP, indicating, in the words of Ingram *et al.*, "drier and warmer conditions during the end of the Medieval Warm Period." In addition, they note, the record "suggests that the duration of wet and dry periods was greater over the past 700 years than in the twentieth century instrumental record." Ingram *et al.*'s work supports the findings of Graumlich (1990), who found tree-ring evidence in the nearby Sierra Nevada Mountains that the period from 510 to 420 cal yr BP was warmer and wetter than any part of the twentieth century.

Patterson (1998) obtained seasonal temperature variations from $\delta^{18}O(CaCO_3)$ values of late Holocene sagittal fish otoliths recovered from archaeological sites along the southern and western basin of Lake Erie (~41.5°N, 82.75°W). At the turn of the first millennium AD, "both summer maximum and mean annual temperatures in the Great Lakes region were found to be higher than those of the 20th century," whereas winter temperatures at that time were lower, Patterson writes. Summer temperatures at AD 985 were 2 to 6°C warmer than those of 1936–1992, and mean annual temperatures were 0.2°C higher and mean winter temperatures 1.8°C lower. Hence, there was probably no significant difference between the mean annual temperature around AD 985 and the mean annual temperature of the 1980s and 1990s.

Hadley *et al.* (1998) examined body size characteristics of pocket gopher (*Thomomys talpoides*) remains obtained from Lamar Cave, Yellowstone National Park (~45°N, 110°W). During the Medieval Warm Period, pocket gophers had a significantly shorter (89 percent of mean value) diastema (the gap between the animals' molars and incisors) and presumably smaller body size than in colder times, the scientists found. This finding, they write, "accords with Bergmann's rule, which states that animals from warmer parts of a geographic range tend to be smaller." Because modern diastema lengths are not nearly as short as diastema lengths during Medieval times (see Figure 4.2.4.7.2.1), it can be concluded the MWP was likely warmer than the CWP.

Gavin and Brubaker (1999) extracted three 18-cm-deep soil cores from three sites within a subalpine meadow they refer to as Meadow Ridge in Royal Basin (47°49'N, 123°12'30" W), a north-facing glacial valley at the headwaters of Royal Creek in

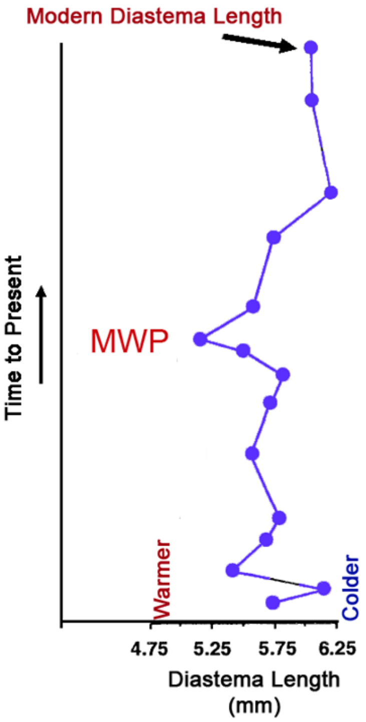

Figure 4.2.4.7.2.1. Diasteme length of pocket gopher remains obtained from Lamar Cave, Yellowstone National Park. Adapted from Hadley, E.A., Kohn, M.H., Leonard, J.A., and Wayne, R.K. 1998. A genetic record of population isolation in pocket gophers during Holocene climatic change. *Proceedings of the National Academy of Sciences, USA* **95**: 6893–6896..

northeastern Olympic National Park in the state of Washington. They constructed depth (= time) profiles of pollen types and abundances over the past six millennia. Based on current associations of the plants that produced the pollen with various climatic parameters, primarily temperature and precipitation, they reconstructed a climatic history of the three sites.

In the part of the soil profiles "corresponding to the Medieval Warm Period (c. 1200–700 BP)," all sites showed an increase in the abundance of *Polygonum bistortoides*, "an indicator of mesic conditions." At one of the sites, it reached a maximum abundance of 50 percent, which they say is "more than three times the value in any modern surface sample at Meadow Ridge." In addition, one of the sites showed "a decline in Cyperaceae (cf. *Carex nigricans*)," which "suggests earlier snow-melt dates." They conclude the observed changes "suggest long and moist growing seasons" during the Medieval Warm Period. In addition, they note the pollen-plant relationship they developed for *P. bistortoides* over this period "corresponds to c. 75% cover," which is "higher than any reported *Polygonum bistortoides* cover in the Olympic Mountains (Schreiner, 1994)," suggesting the MWP of AD 800–1300 was very likely significantly warmer than the Current Warm Period in that part of the world has been to date.

Field and Baumgartner (2000) developed "a robust time series of stable isotope [$\delta^{18}O$ from *Neogloboquadrina dutertrei*] variability over the past millennium from the varved sediments of the Santa Barbara Basin," which they related to observed environmental variability within this part of the California Current over the past half-century, thereby demonstrating "thermal variability dominates the $\delta^{18}O$ signal."

The two researchers report, "an anomalously warm coastal ocean persisted at the multicentennial-scale from roughly AD 1200 to 1450," and this period, as they describe it, "coincides with the age generally assigned to the 'Medieval Warm Period.'" They also report "the period of positive anomalies in the low-frequency series of $\delta^{18}O$ from *N. dutertrei* that continues from ~AD 1450 to ~1800 is consistent with the dates associated with the cooling and neoglaciation of the 'Little Ice Age' in both the Southern and Northern Hemispheres." In addition, they note "the long-term ocean warming and cooling of the California Current region appears to be in phase with the warming and cooling of the midlatitude North Atlantic described by Keigwin (1996)."

Brush (2001) analyzed sediment cores obtained from tributaries, marshes, and the main stem of Chesapeake Bay for paleoecological indicators of regional climate change and land-use variations over the past millennium. They found "the Medieval Climatic Anomaly and the Little Ice Age are recorded in Chesapeake sediments by terrestrial indicators of dry conditions for 200 years, beginning about 1000 years ago, followed by increases in wet indicators from about 800 to 400 years ago." This MCA is what most people refer to as the Medieval Warm Period (MWP), which Brush says is "recognized in many parts of the world from historical and paleoecological evidence." The findings of this paper therefore represent additional evidence for the uniqueness of both the Medieval Warm Period and the Little Ice Age, the two preeminent climatic anomalies of the past thousand years, further suggesting there is nothing unusual about the global warming of the past century or so, as it represents the planet's natural recovery from the global chill of the Little Ice Age and the start of its return to conditions more like those of the Medieval Warm Period.

Viau *et al*. (2002) analyzed a set of 3,076 ^{14}C dates from the North American Pollen Database used to date sequences in more than 700 pollen diagrams across North America. They found nine millennial-scale oscillations during the past 14,000 years in which continent-wide synchronous vegetation changes with a periodicity of roughly 1,650 years were recorded in the pollen records. The most recent of the vegetation transitions was centered at approximately 600 years BP (before present). This event, they write, culminated "in the Little Ice Age, with maximum cooling 300 years ago." Before that event, a major transition that began approximately 1,600 years BP represents the climatic amelioration that culminated "in the maximum warming of the Medieval Warm Period 1000 years ago," they note. And so it goes, back through the Holocene and into the preceding late glacial period, with the times of all major pollen transitions being "consistent with ice and marine records."

According to the five researchers, "the large-scale nature of these transitions and the fact that they are found in different proxies confirms the hypothesis that Holocene and late glacial climate variations of millennial-scale were abrupt transitions between climatic regimes as the atmosphere-ocean system reorganized in response to some forcing." They go on to state, "although several mechanisms for such natural forcing have been advanced, recent evidence points to a potential solar forcing (Bond *et al*., 2001) associated with ocean-atmosphere feedbacks acting as global teleconnections agents." In addition, they note, "these transitions are identifiable across North America and presumably the world."

Willard *et al*. (2003) examined the late Holocene (2,300 yr BP to present) record of Chesapeake Bay, along with the adjacent terrestrial ecosystem in its watershed, through the study of fossil dinoflagellate cysts and pollen derived from sediment cores. They report "several dry periods ranging from decades to centuries in duration are evident in Chesapeake Bay records."

The first of these periods of lower-than-average precipitation, which spanned the period 200 BC–AD 300, occurred during the latter part of the Roman Warm Period, as delineated by McDermott *et al*. (2001) on the basis of a high-resolution speleothem δ^{18}O record from southwest Ireland. The next such period (~AD 800–1200), in the words of the three researchers, "corresponds to the 'Medieval Warm Period,' which has been documented as drier than average by tree-ring (Stahle and Cleaveland, 1994) and pollen (Willard *et al*., 2001) records from the southeastern USA." Other periods consisting of several decadal-scale dry intervals spanned the years AD 1320–1400 and AD 1525–1650.

The researchers also state, "mid-Atlantic dry periods generally correspond to central and southwestern USA 'megadroughts,' described by Woodhouse and Overpeck (1998) as major droughts of decadal or more duration that probably exceeded twentieth-century droughts in severity." In addition, "droughts in the late sixteenth century that lasted several decades, and those in the 'Medieval Warm Period' and between ~AD 50 and AD 350 spanning a century or more have been indicated by Great Plains tree-ring (Stahle *et al*., 1985; Stahle and Cleaveland, 1994), lacustrine diatom and ostracode (Fritz *et al*., 2000; Laird *et al*., 1996a, 1996b) and detrital clastic records (Dean, 1997)."

The work of Willard *et al*. (2003) demonstrates the reality of the millennial-scale hydrologic cycle that accompanies the millennial-scale temperature cycle responsible for producing alternating warm and cold intervals such as the Roman Warm Period, Dark Ages Cold Period, Medieval Warm Period, Little Ice Age, and Current Warm Period. It also confirms the global warming of the twentieth century has not yet produced unusually strong wet and dry periods, contradicting claims that warming will exacerbate extreme climate anomalies.

Cook *et al*. (2004) developed a 1,200-year history of drought for the western half of the United States and adjacent parts of Canada and Mexico (hereafter the "West"), based on annually resolved tree-ring records of summer-season Palmer Drought Severity Index derived for 103 points on a 2.5° x 2.5° grid, 68 of which grid points (66 percent of them) possessed reconstructions that extended back to AD 800. This reconstruction revealed "some remarkable earlier increases in aridity that dwarf the comparatively short-duration current drought in the 'West.'" Also of great interest, "the four driest epochs, centered on AD 936, 1034, 1150 and 1253, all occurred during a ~400 year interval of overall elevated aridity from AD 900 to 1300," which they say was "broadly consistent with the Medieval Warm Period."

The five scientists write, "the overall coincidence between our megadrought epoch and the Medieval Warm Period suggests anomalously warm climate conditions during that time may have contributed to the development of more frequent and persistent droughts in the 'West.'" After citing nine other studies that provide independent evidence of significant drought during this time period for various sub-regions of the "West," they warn, "any trend toward warmer temperatures in the future could lead to a serious long-term increase in aridity over western North America." If the association between warmth and drought in the "West" is robust, as their data suggest, temperatures of the latter part of the twentieth century and the first part of the twenty-first century must still be significantly less than those experienced during large segments of the Medieval Warm Period over much of western North America and the United States in particular.

Carbotte *et al*. (2004) located fossil oyster beds within the Tappan Zee area of the Hudson River estuary (New York, USA) via chirp sub-bottom and side-scan sonar surveys and retrieved sediment cores from the sites that provided shells for radiocarbon dating. The researchers found "oysters flourished during the mid-Holocene warm period," when "summertime temperatures were 2–4°C warmer than today (e.g., Webb *et al*., 1993; Ganopolski *et al*., 1998)." Thereafter, they note, the oysters "disappeared with the onset of cooler climate at 4,000–5,000 cal. years BP," but they "returned during warmer conditions of the late Holocene," which the authors specifically identify as the Roman and Medieval Warm Periods as delineated by Keigwin (1996) and McDermott *et al*. (2001). The authors state, "these warmer periods coincide with the return of oysters in the Tappan Zee." They also report their shell dates suggest a final "major demise at ~500–900 years BP," which they describe as being "consistent with the onset of the Little Ice Age," noting further that in nearby Chesapeake Bay, "Cronin *et al*. (2003) report a sustained period of cooler springtime water temperatures (by ~2–5°C) during the Little Ice Age relative to the earlier Medieval Warm Period." Carbotte *et al.* add, "similar aged fluctuations in oyster presence are observed within shell middens elsewhere along the Atlantic seaboard," citing results obtained from Maine to Florida.

This study of the periodic establishment and demise of oyster beds in the Hudson River estuary and elsewhere along the east coast of the United States paints a clear picture of alternating, multi-century warm and cold intervals over the past two millennia that is vastly different from the 1,000-year-long "hockey stick" temperature history of Mann *et al*. (1998, 1999) and the 2,000-year-long history produced by Mann and Jones (2003), in which Northern Hemispheric and global mean temperatures show essentially no low-frequency variability until the advent of the twentieth century, when temperatures are portrayed as rising dramatically, allowing to the authors to incorrectly claim twentieth century warming was driven by anthropogenic CO_2 emissions.

Sridhar *et al*. (2006) studied the orientation, morphology, and internal structure of dunes in the easternmost (wettest) portion of the Nebraska Sand Hills, where shallow core and outcrop samples indicate the dunes were formed 800 to 1,000 years ago when aridity was widespread and persistent across western North America. In addition, based on wind data obtained from six meteorological stations in and near the Nebraska Sand Hills, they employed a computer program to calculate the sand-drift vectors of dunes that would form today if the sand were free to move and not held in place by prairie grass. They found the current configuration of the Sand Hill dunes could not have been created by the region's current wind regime, in which air currents from the south in the spring and summer bring moist air from the Gulf of Mexico to the U.S. Great Plains. Instead, their work indicates the spring and summer winds that formed the dunes 800 to 1,000 years ago must have come from the southwest, bringing much drier and hotter-than-current air from the deserts of Mexico, with greatly reduced opportunities for rain.

This work clearly suggests much of western North America was likely both drier and hotter during the Medieval Warm Period, 800 to 1,000 years ago, than it is today. As Sridhar *et al*. note, "the dunes record a historically unprecedented large-scale shift of circulation that removed the source of moisture from the region during the growing season." They suggest the resultant drier and warmer conditions may have been further "enhanced and prolonged," as they phrase it, "by reduced soil moisture and related surface-heating effects," which effects are not operative in our day to the degree they were 800 to 1,000 years ago, as was demonstrated by still other of Sridhar *et al.*'s computer analyses.

Rasmussen *et al*. (2006), who had previously demonstrated "speleothems from the Guadalupe Mountains in southeastern New Mexico are annually banded, and variations in band thickness and mineralogy can be used as a record of regional relative moisture (Asmerom and Polyak, 2004)," concentrated on two columnar stalagmites collected from Carlsbad Cavern (BC2) and Hidden Cave (HC1) in the Guadalupe Mountains. Both records suggest periods of dramatic precipitation variability over the last 3,000 years, exhibiting large shifts unlike anything seen in the modern record. They also discovered the period from AD 900–1300 "includes severe drought events, consistent with tree-ring data for the western U.S. (Cook *et al*., 2004)," but the preceding and following centuries (AD 100–750 and AD 1500–1800) "show increased precipitation variability ... coinciding with increased El Niño flooding events."

These findings suggest moisture extremes much greater than those observed in the modern era are neither unusual nor manmade; they are simply a normal part of Earth's natural climatic variability. In addition, Rasmussen *et al*.'s data clearly reveal the occurrence of the Medieval Warm Period, as well as the Dark Ages Cold Period that preceded it and the Little Ice Age that followed it, in terms of available moisture, for in this part of the world, global warmth is typically manifest in terms of low available moisture and global coolness is typically manifest in terms of high available moisture.

Millar *et al*. (2006) studied dead tree trunks located above the current treeline on the tephra-covered slopes of Whitewing Mountain and San Joaquin Ridge south of Mono Lake just east of the Inyo Craters in the eastern Sierra Nevada range of California (USA), identifying the species to which the tree remains belonged, dating them, and (using contemporary distributions of the species in relation to contemporary temperature and precipitation) reconstructing paleoclimate during the time they grew there. They report, "the range of dates for the deadwood samples, AD 815–1350, coincides with the period identified from multiple proxies in the Sierra Nevada and western Great Basin as the Medieval Climate Anomaly," among which were tree-ring reconstructions indicating "increased temperature relative to present (Graumlich, 1993; Scuderi, 1993) and higher treelines (Graumlich and Lloyd, 1996; Lloyd and Graumlich, 1997), and pollen reconstructions [that] show greater abundance of fir in high-elevation communities than at present (Anderson, 1990)."

The five researchers also note "the Medieval forest on Whitewing was growing under mild, favorable conditions (warm with adequate moisture)," as indicated by "extremely low mean sensitivities [to stress] and large average ring widths." They conclude, as reported in their paper's abstract, annual minimum temperatures during the Medieval Climatic Anomaly in the region they studied were "significantly warmer" (+3.2°C) "than present." They say their results "closely compare to climate projections for California in AD 2070–2099 (Hayhoe *et al*., 2004)," in which "average temperature increases of 2.3–5.8°C were projected."

Malamud-Roam *et al*. (2006) conducted an extensive review of "the variety of paleoclimatic resources for the San Francisco Bay and watershed in order to identify major climate variations in the pre-industrial past, and to compare the records from the larger watershed region with the Bay records in order to determine the linkages between climate experienced over the larger watershed region and conditions in the San Francisco Bay." This work revealed "intermittent mega-droughts of the Medieval Climate Anomaly (ca. AD 900–1350) coincided with a period of anomalously warm coastal ocean temperatures in the California Current," and "oxygen isotope compositions of mussel shells from archaeological sites along the central coast also indicate that sea surface temperatures were slightly warmer than present." In contrast, they note, "the Little Ice Age (ca. AD 1450–1800) brought unusually cool and wet conditions to much of the watershed," and "notably stable conditions have prevailed over the instrumental period, i.e., after ca. AD 1850, even including the severe, short-term anomalies experienced during this period," namely, "the severe droughts of the 1930s and the mid-1970s." In this part of the world, therefore, peak Medieval warmth appears to have exceeded peak modern warmth. Also, as the four researchers note, when longer paleoclimate records are considered, "current drought conditions experienced in the US Southwest do not appear out of the range of natural variability."

Benson *et al*. (2007) review and discuss possible impacts of early-eleventh, middle-twelfth, and late-thirteenth century droughts on three Native American cultures that occupied parts of the western United States (Anasazi, Fremont, Lovelock) plus another culture that occupied parts of southwestern Illinois (Cahokia). They found "population declines among the various Native American cultures were documented to have occurred either in the early-11th, middle-12th, or late-13th centuries"—AD 990–1060, 1135–1170, and 1276–1297, respectively—and "really extensive droughts impacted the regions occupied by these prehistoric Native Americans during one or more of these three time periods." In particular, they say the middle-twelfth century drought "had the strongest impact on the Anasazi and

Mississippian Cahokia cultures," noting "by AD 1150, the Anasazi had abandoned 85% of their great houses in the Four Corners region and most of their village sites, and the Cahokians had abandoned one or more of their agricultural support centers, including the large Richland farming complex." In addition, they write, "the sedentary Fremont appear to have abandoned many of their southern area habitation sites in the greater Unita Basin area by AD 1150 as well as the eastern Great Basin and the Southern Colorado Plateau," so "in some sense, the 13th century drought may simply have 'finished off' some cultures that were already in decline." The researchers say these "major reductions in prehistoric Native American habitation sites/population" occurred during a period of "anomalously warm" climate conditions, which characterized the Medieval Warm Period throughout much of the world at that particular time.

Graham *et al*. (2007) conducted an extensive review of Medieval Warm Period–Little Ice Age climatic conditions as revealed in a variety of proxy records obtained throughout western North America. The great balance of this evidence pointed to "generally arid conditions across much of the western and central US from as early as 400 A.D. until about 1300 A.D., followed by a rapid shift towards a wetter regime resembling modern climate." The heart of this Medieval Climate Anomaly (MCA) "lasted from about 800–1250 A.D. and included episodes of severe centennial-scale drought," which "affected regions stretching from northern Mexico, California and central Oregon, eastward through the Great Basin and into the western prairies of the central US." The 11 researchers state, "medieval times witnessed a distinctive pattern of climate change in many regions around the planet," and "as such, the findings suggest the evolution of the concept of an Atlantic-European 'Medieval Warm Period' into a surprisingly sharp instance of Holocene climate change with near-global manifestations." Or as they rephrase it in the final paragraph of their paper, "the near-global scale of MCA climate change seems to be becoming more apparent."

Stahle *et al*. (2007) used "an expanded grid of tree-ring reconstructions of the summer Palmer drought severity indices (PDSI; Cook *et al*., 2004) covering the United States, southern Canada, and most of Mexico to examine the timing, intensity, and spatial distribution of decadal to multidecadal moisture regimes over North America." During the Current Warm Period to date, "the Dust Bowl drought of the 1930s and the Southwestern drought of the 1950s were the two most intense and prolonged droughts to impact North America," the authors found, citing the studies of Worster (1979), Diaz (1983), and Fye *et al*. (2003). During the Little Ice Age, they found three megadroughts, which they defined as "very large-scale drought[s] more severe and sustained than any witnessed during the period of instrumental weather observations (e.g., Stahle *et al*., 2000)." They also note, "much stronger and more persistent droughts have been reconstructed with tree rings and other proxies over North America during the Medieval era (e.g., Stine, 1994; Laird *et al*., 2003; Cook *et al*., 2004)." These megadroughts were so phenomenal the authors refer to them as "no-analog Medieval megadroughts."

Climate models typically project that CO_2-induced global warming will result in more severe droughts. The much more severe and sustained megadroughts of the Little Ice Age appear to render such projections somewhat dubious. On the other hand, the still more severe and sustained no-analog megadroughts of the Medieval Warm Period would appear to bolster their projections. But the incredibly more severe droughts of that earlier period—if they were indeed related to high global air temperatures—would suggest it is not nearly as warm currently as it was during the Medieval Warm Period, when there was much less CO_2 in the air than there is today. These observations undercut the more fundamental claim that the historical rise in the air's CO_2 content has been responsible for unprecedented twentieth century global warming that has taken Earth's mean air temperature to a level unprecedented over the past two millennia.

Carson *et al*. (2007) developed a Holocene history of flood magnitudes in the northern Uinta Mountains of northeastern Utah from reconstructed cross-sectional areas of abandoned channels and relationships relating channel cross-sections to flood magnitudes derived from modern stream guage and channel records. They found over the past 5,000 years the record of bankfull discharge "corresponds well with independent paleoclimate data for the Uinta Mountains," and "during this period, the magnitude of the modal flood is smaller than modern during warm dry intervals and greater than modern during cool wet intervals." They note "the decrease in flood magnitudes following 1000 cal yr B.P. corresponds to numerous local and regional records of warming during the Medieval Climatic Anomaly."

The three researchers' graphical results, as shown in Figure 4.2.4.7.2.2, suggest the three largest negative departures from modern bankfull flood magnitudes (indicating greater than modern warmth) ranged from approximately 15 percent to 22 percent, as best as can be determined from visual inspection of their plotted data. These departures occurred between about 750 and 600 cal yr B.P., as determined from radiocarbon dating of basal channel-fill sediments. In addition to showing the degree of natural variability in northeastern Utah flood magnitudes throughout the Holocene has been much larger (in both positive and negative directions) than what has been observed in modern times, Carson *et al.*'s findings confirm the portion of the Medieval Warm Period between about AD 1250 and 1400 was likely significantly warmer than current conditions.

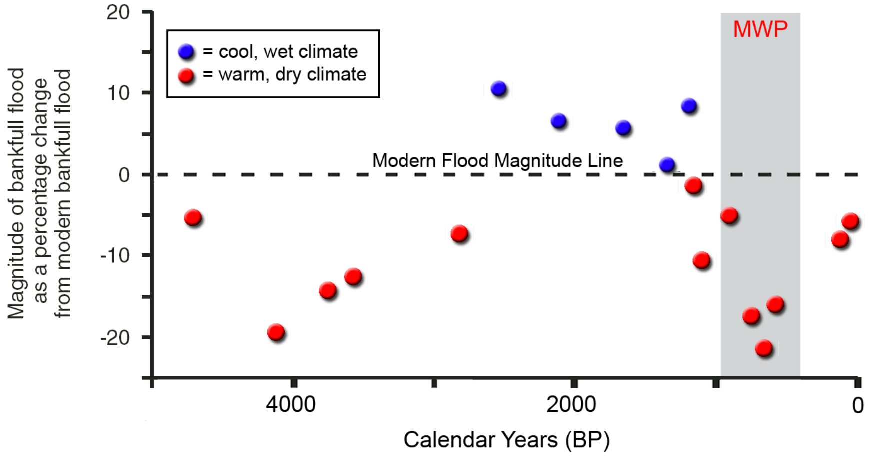

Figure 4.2.4.7.2.2. Uinta Mountains reconstructed climatic history derived from paleoflood chronology. Adapted from Carson, E.C., Knox, J.C., and Mickelson, D.M. 2007. Response of bankfull flood magnitudes to Holocene climate change, Uinta Mountains, northeastern Utah. *Geological Society of America Bulletin* **119**: 1066–1078.

Richey *et al.* (2007) note the variability of the hemispheric temperature reconstructions of Mann and Jones (2003) over the past one to two thousand years are "subdued (≤ 0.5°C)," and their low-amplitude reconstructions are not compatible "with several individual marine records that indicate that centennial-scale sea surface temperature (SST) oscillations of 2–3°C occurred during the past 1–2 k.y. (i.e., Keigwin, 1996; Watanabe *et al.*, 2001; Lund and Curry, 2006; Newton *et al.*, 2006)," just as they also differ from "tree-ring and multi-proxy reconstructions designed to capture multi-centennial-scale variability (e.g., Esper *et al.*, 2002; Moberg *et al.*, 2005)." This suggests "the amplitude of natural climate variability over the past 1 k.y. is >0.5°C," they write.

Richey *et al.* then explain how "a continuous decadal-scale resolution record of climate variability over the past 1400 years in the northern Gulf of Mexico was constructed from a box core recovered in the Pigmy Basin, northern Gulf of Mexico [27°11.61'N, 91°24.54'W]," based on climate proxies derived from "paired analyses of Mg/Ca and δ^{18}O in the white variety of the planktic foraminifer *Globigerinoides ruber* and relative abundance variations of *G. sacculifer* in the foraminifer assemblages." The four researchers report, "two multi-decadal intervals of sustained high Mg/Ca indicate that Gulf of Mexico sea surface temperatures (SSTs) were as warm as, or warmer than, near-modern conditions between 1000 and 1400 yr B.P.," and "foraminiferal Mg/Ca during the coolest interval of the Little Ice Age (ca. 250 yr B.P.) indicate that SST was 2–2.5°C below modern SST" (Figure 4.2.4.7.2.3). In addition, they found "four minima in the Mg/Ca record between 900 and 250 yr. B.P. correspond with the Maunder, Sporer, Wolf, and Oort sunspot minima."

MacDonald *et al.* (2008) define the term "perfect drought" as "a prolonged drought that affects southern California, the Sacramento River basin and the upper Colorado River basin simultaneously," noting the instrumental record indicates the occurrence of such droughts throughout the past century but that they "generally persist for less than five years." That they have occurred at all, however, suggests the possibility of even longer "perfect droughts," that could prove catastrophic for the region. The three researchers explored the likelihood of such droughts occurring in the years to come, based on dendrochronological reconstructions of the winter Palmer Drought Severity Index (PDSI)

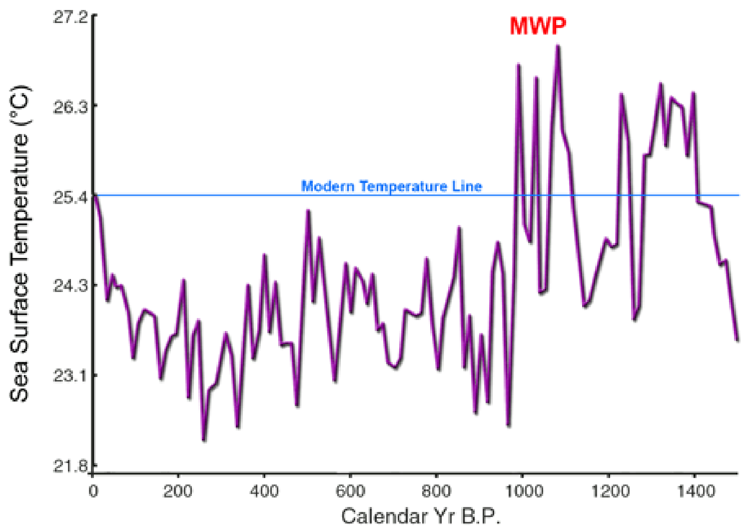

Figure 4.2.4.7.2.3. Annual Mg/Ca-derived SST anomalies for Pigmy Basin, Northern Gulf of Mexico. Adapted from Richey, J.N., Poore, R.Z., Flower, B.P., and Quinn, T.M. 2007. 1400 yr multiproxy record of climate variability from the northern Gulf of Mexico. *Geology* **35**: 423–426.

in southern California over the past thousand years (Figure 4.2.4.7.2.4) and the concomitant annual discharges of the Sacramento and Colorado Rivers (Figure 4.2.4.7.2.5), under the logical assumption that what has occurred before may happen again.

MacDonald *et al.* report finding "prolonged perfect droughts (~30–60 years), which produced arid conditions in all three regions simultaneously, developed in the mid-11th century and the mid-12th century during the period of the so-called 'Medieval Climate Anomaly,'" This leads them to conclude, "prolonged perfect droughts due to natural or anthropogenic changes in radiative forcing, are a clear possibility for the near future."

Another conclusion that can be drawn from MacDonald *et al.*'s findings is that the current warmth of the world is not yet as great as it was during the peak heat of the Medieval Warm Period, or we might have already experienced, or currently be in the process of experiencing, a multidecadal perfect drought. That such has not occurred is encouraging, but it must be remembered that even if the theory of CO_2-induced global warming is incorrect or vastly overstated, further natural warming could push the planet's climate over the "tipping point" that initiates such a drought. That Earth has experienced no net warming over the past decade or so is a good sign in this regard, but there is no guarantee the globe will not begin to warm again, at any time and for whatever reason. Planning for the possibility of a significant perfect drought would appear to be warranted.

McGann (2008) analyzed a sediment core retrieved from the western portion of south bay near San Francisco International Airport (37°37.83'N, 122°21.99'W) for the presence of various foraminifers as well as oxygen and carbon stable isotopes and numerous trace elements found in tests of *Elphidium excavatum*. The U.S. Geological Survey researcher states, "benthic foraminiferal abundances, stable carbon and oxygen isotopes, and Mg/Ca ratios suggest that the climate of south bay has oscillated numerous times between warm and dry, and cool and wet conditions over the past 3870 years." "Both the Medieval Warm Period [MWP] and the Little Ice Age [LIA] are evident," she notes. She identifies the MWP as occurring from AD 743 to 1343 and the LIA as occurring in two stages: AD 1450 to 1530 and AD 1720 to 1850. She states, the timing of the MWP "correlates well with records obtained for Chesapeake Bay (Cronin *et al.*, 2003), Long Island Sound (Thomas *et al.*, 2001; Varekamp *et al.*, 2002), California's Sierra Nevada (Stine, 1994), coastal northernmost California (Barron *et al.*, 2004), and in the San Francisco Bay estuary in north bay at Rush Ranch (Byrne *et al.*, 2001) and south bay at Oyster Point (Ingram *et al.*, 1996)," She notes the cooler and wetter conditions of the LIA have been reported "in Chesapeake Bay (Cronin *et al.*, 2003), Long Island Sound (Thomas *et al.*, 2001; Varekamp *et al.*, 2002), coastal northernmost California (Barron *et al.*, 2004), and in the San Francisco Bay estuary at Rush Ranch (Bryne *et al.*, 2001), Petaluma Marsh (Ingram *et al.*, 1998), and in Richardson Bay (Ingram and DePaolo, 1993)." McGann also notes, "near the top of the core" foraminiferal abundances suggest, "once again, regional warming has taken place." That warming does not appear to have returned the region to the level of sustained warmth it enjoyed during the peak warmth of the MWP.

Analyzing isotopic soil carbon measurements made on 24 modern soils and 30 buried soils scattered between latitudes 48 and 32°N and longitudes 106 and 98°W, Nordt *et al.* (2008) developed a time series of C_4 vs. C_3 plant dynamics for the past 12 ka (ka =

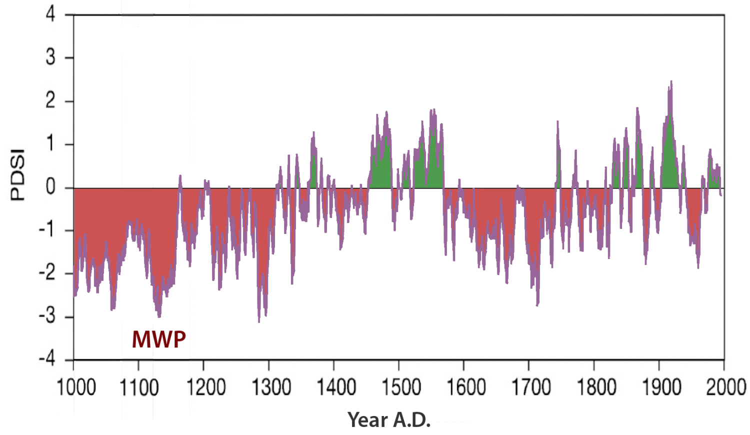

Figure 4.2.4.7.2.4. Reconstructed winter PSDI for Southern California since AD 1100. Adapted from MacDonald, G.M., Kremenetski, K.V., and Hidalgo, H.G. 2008. Southern California and the perfect drought: Simultaneous prolonged drought in Southern California and the Sacramento and Colorado River systems. *Quaternary International* **188**: 11–23.

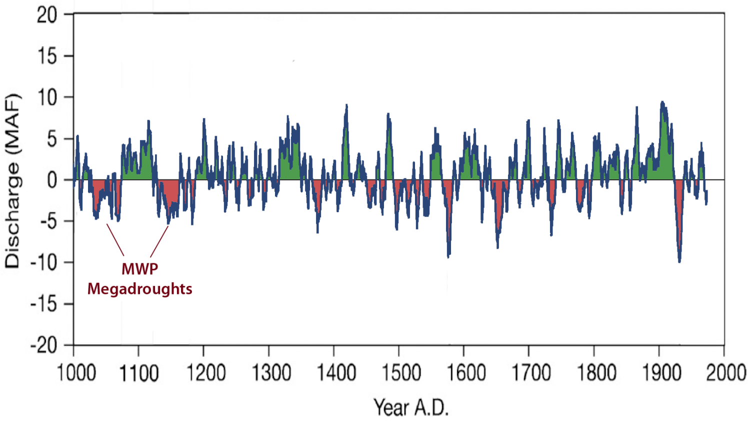

Figure 4.2.4.7.2.5. Five-year moving average of combined annual discharge deviations for the Sacramento and Colorado Rivers since AD 1100. Adapted from MacDonald *et al*. (2008).

1000 ^{14}C yr BP) in the mixed and shortgrass prairie of the U.S. Great Plains. Because the percent of soil carbon derived from C_4 plants "corresponds strongly with summer temperatures as reflected in the soil carbon pool (Nordt *et al*., 2007; von Fischer *et al*., 2008)," they were able to devise a history of the relative warmth of the region over this protracted period (see Figure 4.2.4.7.2.6).

Nordt *et al*.'s data suggest their region of study was slightly warmer during parts of both the Medieval and Roman Warm Periods, and it was significantly warmer during a sizeable portion of the mid-Holocene Thermal Maximum or Climatic Optimum, as it is sometimes called. As to what caused the greater warmth of those earlier periods, Nordt *et al*. observe, "these warm intervals ... exhibit a strong correlation to increases in solar irradiance," as per the irradiance reconstruction of Perry and Hsu (2000).

Whitlock *et al*. (2008) analyzed (at high resolution) geochemical, stable-isotope, pollen, charcoal, and diatom records found in cores obtained from Crevice Lake—located at 45.000°N, 110.578°W—to reconstruct the ecohydrologic, vegetation, and fire history of its watershed for the past 2,650 years and better understand past climate variations at the forest-steppe transition within the canyon of the Yellowstone River in northern Yellowstone National Park (YNP). The seven scientists report their many datasets were "consistent with overall warmer/drier conditions during the Medieval Climate Anomaly," which they note had been variously dated between AD 650 and 1300 in the western United States and Great Plains. They found "the Crevice Lake data suggest a warm interval with dry winters between AD 600 and 850, followed by less dry but still warm conditions between AD 850 and 1100." In addition, they note, "other studies in YNP indicate that trees grew above the present-day treeline and fires were more frequent in the Lamar and Soda Butte drainages between AD 750 and 1150," citing Meyer *et al*. (1995).

Whitlock *et al*. state their data indicate "the last 150 years of environmental history since the formation of YNP have not been anomalous within the range of variability of the last 2650 years, and many of the proxy indicators suggest that 19th and 20th century variability at Crevice Lake was moderate compared with earlier extremes." With the possible exception of the charcoal record, "all of the data show greater variability in the range of ecosystem conditions prior to the establishment of the YNP in 1872." Thus the many parameters measured by Whitlock *et al*. indicate the YNP's twentieth century climate is not unique and suggest much of the Medieval Warm Period was significantly warmer than the Current Warm Period has been to date, given that trees in

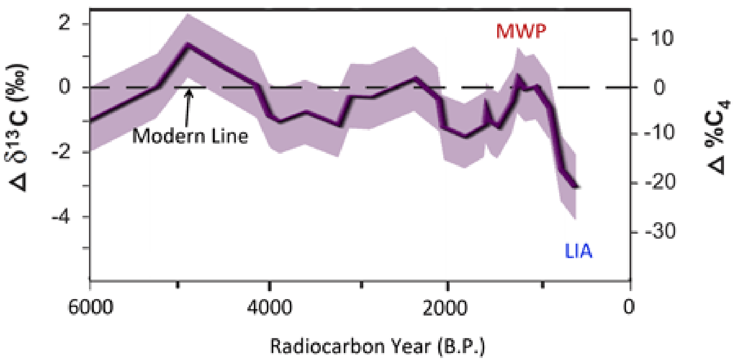

Figure 4.2.4.7.2.6. Buried soil Δδ13C and Δ%C4 from the Great Plains as a proxy for summer temperature. Adapted from Nordt, L., von Fischer, J., Tieszen, L., and Tubbs, J. 2008. Coherent changes in relative C4 plant productivity and climate during the late Quaternary in the North American Great Plains. *Quaternary Science Reviews* **27**: 1600–1611.

some parts of the park grew at higher elevations during the MWP than they do now.

Persico and Meyer (2009) describe their use of "beaver-pond deposits and geomorphic characteristics of small streams to assess long-term effects of beavers and climate change on Holocene fluvial activity in northern Yellowstone National Park," comparing "the distribution of beaver-pond deposit ages to paleoclimatic proxy records in the Yellowstone region." They found "gaps in the beaver-pond deposit record from 2200–1800 and 700–1000 cal yr BP are contemporaneous with increased charcoal accumulation rates in Yellowstone lakes and peaks in fire-related debris-flow activity, inferred to reflect severe drought and warmer temperatures (Meyer *et al*., 1995)." In addition, they note, "the lack of evidence for beaver activity 700–1000 cal yr BP is concurrent with the Medieval Climatic Anomaly, a time of widespread multi-decadal droughts and high climatic variability in Yellowstone National Park (Meyer *et al*., 1995) and the western USA (Cook *et al*., 2004; Stine, 1998; Whitlock *et al*., 2003)." The lack of evidence for beaver activity 2,200–1,800 cal yr BP is concurrent with the Roman Warm Period. The two researchers conclude the severe droughts of these periods "likely caused low to ephemeral discharges in smaller streams, as in modern severe drought," implying the Medieval and Roman Warm Periods were likely to have been at least as dry and warm as it is today.

Mullins *et al*. (2011) studied two sediment cores extracted from the extreme southern end of Cayuga Lake (~42°25'N, 76°35'W) in central New York (USA), finding "paleolimnological evidence for the Medieval Warm Period (~1.4–0.5 ka), which was warmer and wetter than today." This evidence includes weight percent total carbonate (TC), total organic matter (TOM), non-carbonate inorganic terrigenous matter (TT), carbonate stable isotopes (δ^{18}OTC and δ^{13}CTC), carbon isotope values of total organic matter (δ^{13}CTOM), and fossil types (gastropods, ostracods, bivalves, oogonia) and amounts. All were used to interpret past climate based on their relationship to modern climate data for the Finger Lakes region of the state. They conclude, the "data for central New York suggest a warmer, wetter climate than today."

Routson *et al*. (2011) write, "many southwestern United States high-resolution proxy records show numerous droughts over the past millennium, including droughts far more severe than those experienced during the historical period (e.g., Woodhouse and Overpeck, 1998; Cook *et al*., 2004, 2010; Meko *et al*., 2007)." They note, "the medieval interval (ca. AD 900 to 1400), a period with relatively warm Northern Hemisphere temperatures, has been highlighted as a period in western North America with increased drought severity, duration and extent (e.g., Stine, 1994; Cook *et al*., 2004, 2010; Meko *et al*., 2007; Woodhouse *et al*., 2010)," and "the mid-12th century drought associated with dramatic decreases in Colorado River flow (Meko *et al*., 2007), and the 'Great Drought' associated with the abandonment of Ancient Pueblo civilization in the Colorado Plateau region (Douglass, 1929), all occurred during the medieval period."

Routson *et al*. used a new tree-ring record derived from living and remnant bristlecone pine wood from the headwaters region of the Rio Grande River in Colorado (USA), along with other regional records, to evaluate what they describe as "periods of unusually severe drought over the past two millennia (268 BC to AD 2009)." The three researchers report the record they derived "reveals two periods of enhanced drought frequency and severity relative to the rest of the record": "the later period, AD ~1050–1330, corresponds with medieval aridity well documented in other records," and "the earlier period is more persistent (AD ~1–400), and includes the most pronounced event in the ... chronology: a multi-decadal-length drought during the 2nd century." The latter drought "includes the unsmoothed record's driest 25-year interval (AD 148–173) as well as a longer 51-year period, AD 122–172, that has only two years with ring width slightly above the long-term mean." In addition, "the smoothed chronology shows the periods AD 77–282 and AD 301–400 are the longest (206 and 100 years, respectively, below the long-term average) droughts of the entire 2276-year record." This second century drought, they note, "impacted a region that extends from southern New Mexico north and west into Idaho."

The researchers note, "reconstructed Colorado Plateau temperature suggests warmer than average temperature could have influenced both 2nd century and medieval drought severity," and "available data also suggest that the Northern Hemisphere may have been warm during both intervals." Despite these obviously natural occurrences, Routson *et al.* suggest the southwestern United States may experience similar or even more severe megadroughts in the future as a result of greater warming in response to anthropogenic CO_2 emissions.

Sritairat *et al.* (2012) point out "the mid-Hudson region contains freshwater peatland archives that have not been investigated," suggesting "there is a need to identify this base-line information to assess past anthropogenic activities and climatic patterns in relation to projected shifts in climate and vegetation in the Mid-Hudson Valley region." They explored "how climate and human impacts have influenced plant ecology, invasive species expansion, habitat loss, carbon storage, and nutrient dynamics over the past millennium based on the multiproxy analysis of sediment cores using palynology, macrofossil, sedimentological, and geochemical analyses," working with marsh sediment cores obtained at the National Estuarine Research Reserve at Tivoli Bays on the Hudson Estuary, New York, USA.

The six scientists identified a pre-European settlement period (AD 826–1310) with a "high percentage of *Carya*, a warmth-loving species (Fowells, 1965)," a finding that "supports an increase in temperature."At a depth dated to AD 1087 ± 72, they found a charcoal maximum, referring to it as "a feature that is also found in other Hudson river marsh cores at Piermont (Pederson *et al*., 2005) and Iona (Peteet *et al*., 2006)." This represents, they write, "the warm, dry Medieval Warm Period (MWP)," which they further state was "likely a result of a regional Hudson Valley MWP recorded on a larger spatial scale in other parts of North America and the globe."

The substantial body of real-world evidence for a generally warmer-than-present MWP, at a time when the atmosphere's CO_2 concentration was something on the order of 285 ppm, as opposed to the 400 ppm of today, weighs heavily against the claim of higher atmospheric CO_2 concentrations invariably leading to warmer mean global temperatures. This data-grounded fact provides a concrete reason for rejecting the projections of even the very best mathematical models of how Earth's climate is supposed to operate.

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4.2.4.7.3 Central America

Lachniet *et al*. (2004) generated a high-resolution oxygen-isotope rainfall record of the Central American Monsoon for the Isthmus of Panama from a U/Th-dated stalagmite that spanned the period 180 BC to AD 1310. The work revealed pronounced hydrologic anomalies during medieval times, with the driest conditions occurring between AD 900 and 1310, but especially during the AD 1100-–200 "High Medieval" when western European temperatures were reported to be "anomalously high," as Lachniet *et al.* put it. The seven scientists state, "the correspondence between warm medieval temperatures and dry hydrologic anomalies in Panama supports a large-scale Medieval Climatic Anomaly that may have been global in extent, and involved atmospheric circulation reorganizations that are linked to ENSO."

Hodell *et al.* (1995) examined a sediment core retrieved in 1993 from Lake Chichanacanab in the center of the northern Yucatan Peninsula of Mexico (19°50'-19°57'N, 88°45'-88°46'W), finding evidence of a protracted drought during the Terminal Classic Period of Mayan civilization (AD 800–1000). Subsequently, based on two additional sediment cores retrieved from the same location in 2000, Hodell *et al.* (2001) determined the massive drought likely occurred in two distinct phases (750–875 and 1000–1075). Hodell *et al.* (2005) returned to Lake Chichanacanab in March 2004 to retrieve additional sediment cores in some of the deeper parts in the lake, with multiple cores being taken from its deepest point.

Depth profiles of bulk density data were obtained by means of gamma-ray attenuation, as were profiles of reflected red, green, and blue light via a digital color line-scan camera. The researchers report, "the data revealed in great detail the climatic events that comprised the Terminal Classic Drought and coincided with the demise of Classic Maya civilization." They also showed "the Terminal Classic Drought was not a single, two-century-long megadrought, but rather consisted of a series of dry events separated by intervening periods of relatively moister conditions," which "included an early phase (ca 770–870) and late phase (ca 920–1100)." They report, "the bipartite drought history inferred from Chichancanab is supported by oxygen isotope records from nearby Punta Laguna," and "the general pattern is also consistent with findings from the Cariaco Basin off northern Venezuela (Haug *et al*., 2003), suggesting that the Terminal Classic Drought was a widespread phenomenon and not limited to north-central Yucatan." It appears the Terminal Classic Drought that led to the demise of Mayan civilization likely occurred during the climatic transition between the Dark Ages Cold Period and the Medieval Warm Period, when increasing tempera-tures may have exacerbated land water loss via evaporation in the midst of a prolonged period of significantly reduced precip-itation.

Almeida-Lenero *et al.* (2005) analyzed pollen profiles derived from sediment cores retrieved from Lake Zempoala (19°03'N, 99°18'W) and nearby Lake Quila (19°04'N, 99°19'W) in the central Mexican highlands about 65 km southwest of Mexico City. They determined it was generally more humid in the central Mexican highlands during the mid-Holocene than at present. Thereafter, there was a gradual drying of the climate; their data from Lake Zempoala indicate "the interval from 1300 to 1100 cal yr BP was driest and represents an extreme since the mid-Holocene," and this interval of 200 years "coincides with the collapse of the Maya civilization." They report their data from Lake Quila were also "indicative of the most arid period reported during the middle to late Holocene from c. 1300 to 1100 cal yr BP." They state, "climatic aridity during this time was also noted by Metcalfe *et al.* (1991) for the Lerma Basin [central Mexico]," "dry climatic conditions were also reported from Lake Patzcuaro, central Mexico by Watts and Bradbury (1982)," and "dry conditions were also reported for [Mexico's] Zacapu Basin (Metcalfe, 1995) and for [Mexico's] Yucatan Peninsula (Curtis *et al*., 1996, 1998; Hodell *et al*., 1995, 2001)."

Barron and Bukry (2007) analyzed high-resolution records of diatoms and silicoflagellate assemblages spanning the past 2,000 years derived from sediment cores extracted from three sites on the eastern slope of the Gulf of California, comprising core BAM80 E-17 retrieved at 27.92°N, 111.61°W; core NH01-21 retrieved at 26°17.39'N, 109°55.24'W; and core NH01-26 retrieved at 24°16.78'N, 108°11.65W. In all three cores, the relative abundance of *Azpeitia nodulifera* (a tropical diatom whose presence suggests the occurrence of higher sea surface temperatures) was found to be far greater during the Medieval Warm Period than at any other time over the 2,000-year period studied, and during the Current Warm Period its relative abundance was lower than the 2,000-year mean, also in all three of the sediment cores (Figure 4.2.4.7.3.1). In addition, the first of the cores exhibited elevated *A. nodulifera*

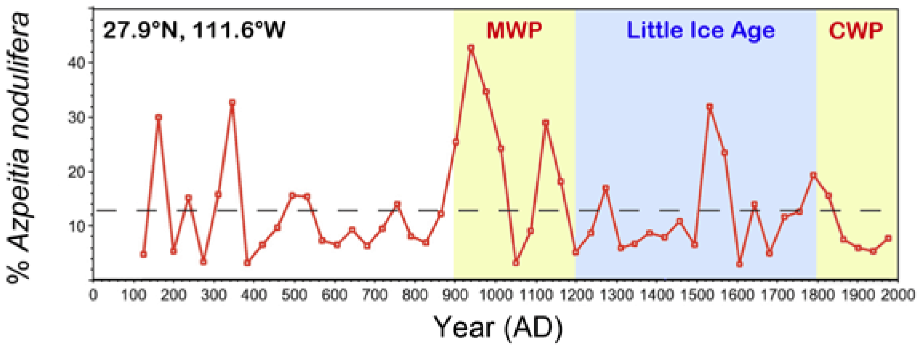

Figure 4.2.4.7.3.1. Relative abundance of Azpeitia nodulifera, a tropical diatom whose presence suggests the occurrence of higher sea surface temperatures, derived from sediment cores extracted from three sites on the eastern slope of the Gulf of California. Adapted from Barron, J.A. and Bukry, D. 2007. Solar forcing of Gulf of California climate during the past 2000 yr suggested by diatoms and silicoflagellates. *Marine Micropaleontology* **62**: 115–139.

abundances from the start of the record to about AD 350, during the latter part of the Roman Warm Period, as well as between AD 1520 and 1560. By analyzing radiocarbon production data, the two researchers found the changes in climate they identified likely were driven by solar forcing.

Metcalfe and Davies (2007) synthesized the findings of a variety of paleoclimate studies based on analyses of the sediment records of several crater lakes and lakes formed by lava dams across the Trans Mexican Volcanic Belt of central Mexico with an absolute chronology provided by radiocarbon dates extending back to 1,500 ^{14}C yr BP. Noting the degree of coherence among the records is “remarkable,” Metcalf and Davis report, “dry conditions, probably the driest of the Holocene, are recorded over the period 1,400 to 800 ^{14}C yr BP (ca. AD 700–1200).” They also observe “the present day climate of central Mexico is typical of most of the country.” The researchers tate their work is “consistent with results from the Yucatan Peninsula (Hodell *et al*., 1995, 2005) … and from the Cariaco basin (Haug *et al*., 2003) and the Isthmus of Panama (Lachniet *et al*., 2004).” In addition, Mayewski *et al*. (2004) have identified the central portion of this period (AD 800 to 1000) as a time of truly global anomalous climate.

Thus, Metcalfe and Davies provide convincing evidence that one of the strongest manifestations of the Medieval Warm Period throughout most of Mexico was a major lack of moisture, which in this particular part of the world delineates the Medieval Warm Period better than the epoch’s primary defining characteristic of elevated temperature.

Hodell *et al*. (2007) inferred “the Holocene paleoclimate history of the northeastern Yucatan Peninsula by comparing physical and chemical properties in two sediment cores from Lake Punta Laguna,” located approximately 20 km NNE of Coba, discussing “the potential implications for Maya cultural transformation.” They report the Terminal Classic Collapse of 750–1050 A.D., which they describe as “the greatest cultural discontinuity prior to Spanish contact,” can “be viewed as a series of transformations, occurring first in the south during the late eighth and ninth centuries A.D., followed by a similar decline in the north in the tenth century A.D.” They also found evidence for “lower lake level and drier climate at about the same time as each major discontinuity in Maya cultural history.”

According to the three researchers, “the fact that both major climatic changes and cultural transformations occurred in the Terminal Classic Period between 750 and 1050 A.D. is probably not coincidental.” Global weather patterns indeed may have changed in such a way over this period that the recurring multi-year dry spells characteristic of the Terminal Classic Period became increasingly severe and difficult for the Maya to bear, likely leading to the civilization’s collapse at the very peak of the global Medieval Warm Period.

Polk *et al*. (2007) analyzed environmental changes on Belize’s Vaca Plateau via “vegetation reconstruction using δ^{13}C values of fulvic acids extracted from cave sediments,” which provide “a proxy record of Maya alteration of the environment through agricultural practices,” in conjunction with “speleothem carbon and oxygen isotope data from another nearby cave in the study area” that “provide information regarding climate variability.”

Starting at approximately AD 500, according to the three U.S. researchers, increasingly negative δ^{13}C values in the sediment record indicate “the declining practice of agriculture,” which they say is “characteristic of a C_3-dominated environment receiving little contribution from the isotopically heavier C_4 agricultural plants." This inference makes sense because the period of initial agricultural decline coincides with the well-known Maya Hiatus of AD 530 to 650, which was driven by an increasing "lack of available water resources needed to sustain agriculture," and the study area "would likely have been among the first sites to be affected by aridity due to its naturally well-drained upland terrain, causing a shift away from agricultural land use that preceded [that of] many other lowland areas."

Polk *et al*. report their $\delta^{13}C$ values indicate that as early as AD 800 the Vaca Plateau "was no longer used for agriculture, coinciding with the Terminal Classic Collapse" of the Maya, which Hodell *et al*. (2007) identified as taking place between AD 750 and 1050, indicating the Ix Chel archaeological site on the Vaca Plateau was one of the first to bear witness to the demise of the Maya people.

These discoveries of Polk *et al*. are just another example of the devastating human consequences of the catastrophic droughts that plagued many parts of North, Central, and northern tropical South America during the global Medieval Warm Period. They also constitute yet another important testament to the reality of the MWP and its global reach.

Dominguez-Vazquez and Islebe (2008) derived a 2,000-year history of regional drought using radiocarbon dating and pollen analyses of a sediment core retrieved from the shore of Naja Lake (16°59'27.6"N, 91°35'29.6"W), located near the Lacandon Forest Region in the state of Chiapas in southeastern Mexico, inhabited by the Maya since the early Formative Period (ca. 1,000 BC). The researchers write, "a marked increase in *Pinus* pollen, together with a reduction in lower montane rain forest taxa, is interpreted as evidence for a strong, protracted drought from 1260 to 730 years BP," which they characterize as "the most severe" of the record. They note, "the drought coincides with the Maya classic collapse and represents the most pronounced dry period of the last 2,000 years in the Lacandon area."

Thus, much as the higher temperatures of the Medieval Warm Period in Greenland benefited the Vikings, its greater dryness in southeastern Mexico cursed the Maya, who had called that region home for close to 2,000 years. This contrast exemplifies how millennial-scale climate change can have vastly different effects on human societies in different parts of the world. It is also equally clear these changes of the past occurred independently of any changes in the air's CO_2 content, and if the world is in the initial stages of a new warming phase of this cycle, both positive and negative impacts can be expected.

Escobar *et al*. (2010) used sediment cores from Lakes Punta Laguna, Chichancanab, and Peten Itza on the Yucatan Peninsula to "(1) investigate 'within-horizon' stable isotope variability ($\delta^{18}O$ and $\delta^{13}C$) measured on multiple, single ostracod valves and gastropod shells, (2) determine the optimum number of individuals required to infer low-frequency climate changes, and (3) evaluate the potential for using intra-sample $\delta^{18}O$ variability in ostracod and gastropod shells as a proxy measure for high-frequency climate variability." The five researchers state the resulting data "allow calculation of mean isotope values and thus provide a rough estimate of the low-frequency variability over the entire sediment sequence." These results indicate "relatively dry periods were persistently dry whereas relatively wet periods were composed of wet and dry times."

These findings "confirm the interpretations of Hodell *et al*. (1995, 2007) and Curtis *et al*. (1996) that there were persistent dry climate episodes associated with the Terminal Classic Maya Period." The scientists determined the Terminal Classic Period from ca. AD 910 to 990 was not only the driest period in the past 3,000 years, but also a persistently dry period. They note, "the core section encompassing the Classic Maya collapse has the lowest sedimentation rate among all layers and the lowest oxygen isotope variability."

Brunelle *et al*. (2010) collected sediments from a cienega (a wet, marshy area where groundwater bubbles to the surface) located at approximately 31.3°N, 109.3°W in the drainage of Black Draw Wash/Rio de San Bernardino of southeastern Arizona (USA) and northeastern Sonora (Mexico) during the summers of 2004 and 2005, sampling the incised channel wall of the Rio de San Bernardino arroyo and the cienega surface of the San Bernardino National Wildlife Refuge "for charcoal analysis to reconstruct fire history," as well as pollen data to infer something about climate. The team of U.S. and Mexican researchers report "preliminary pollen data show taxa that reflect winter-dominated precipitation [which implies summer drought] correspond to times of greater fire activity," and the results from the fire reconstruction "show an increase in fire activity coincident with the onset of ENSO, and an increase in fire frequency during the Medieval Climate Anomaly." During the latter period, from approximately AD 900 to 1260, "background charcoal reaches the highest level of the entire record and fire peaks are frequent," after which, they report "the end of the MCA shows a decline in both background charcoal and fire frequency, likely associated with the end of the MCA-related drought in western North America (Cook *et al*., 2004)."

Figueroa-Rangel *et al.* (2010) constructed a 1,300-year history of the cloud forest vegetation dynamics of the Sierra de Manantlan Biosphere Reserve (SMBR) in west-central Mexico via analyses of fossil pollen, microfossil charcoal, and organic and inorganic sediment data obtained from a 96-cm core of black organic material retrieved from a small forest hollow (19°35'32"N, 104°16'56"W). This reconstruction revealed "during intervals of aridity, cloud forest taxa tend to become reduced," whereas "during intervals of increased humidity, the cloud forest thrives." The three researchers inferred from their reconstruction a major dry period that lasted from approximately AD 750 to 1150 in the SMBR.

They write, "results from this study corroborate the existence of a dry period from 1200 to 800 cal years BP in mountain forests of the region; in central Mexico (Metcalf and Hales, 1994; Metcalfe, 1995; Arnauld *et al*., 1997; O'Hara and Metcalfe, 1997; Almeida-Lenero *et al*., 2005; Ludlow-Wiechers *et al*., 2005; Metcalfe *et al*., 2007); lowlands of the Yucatan Peninsula (Hodell *et al*., 1995, 2001, 2005a,b) and the Cariaco Basin in Venezuela (Haug *et al*., 2003)." They also note "the causes associated to this phase of climate change have been attributed to solar activity (Hodell *et al*., 2001; Haug *et al*., 2003), changes in the latitudinal migration of the Intertropical Convergence Zone (ITCZ, Metcalfe *et al*., 2000; Hodell *et al*., 2005a,b; Berrio *et al*., 2006) and to ENSO variability (Metcalfe, 2006)." The timeframe of this significant dry period coincides well with the broad central portion of the Medieval Warm Period, and this correspondence further harmonizes with the dry period's temporal association with enhanced solar activity and a southward shift of the ITCZ.

Focusing on the North American countries south of the United States southern border, the studies reviewed here clearly demonstrate the existence of a Medieval Warm Period far removed from the North Atlantic Ocean, contrary to the IPCC's dismissal of the MWP as a minor, regional phenomenon. To the contrary, the MWP was global in extent, as demonstrated by data obtained on all of Earth's continents, and it was characterized by temperatures generally higher than those of the recent past and the present, in an atmosphere with a CO_2 concentration of only 285 ppm, compared to the 400 ppm of today.

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4.2.4.8 Oceans

As indicated in the introduction of Section 4.2.4, data presented in numerous peer-reviewed scientific studies reveal the existence of a global Medieval Warm Period (MWP) that occurred approximately 1,000 years ago when atmospheric CO_2 concentrations were approximately 30 percent lower than they are today. This natural fluctuation in climate is likely the product of a millennial-scale oscillation responsible for ushering in the relative warmth of the present day. This subsection highlights work that has documented the MWP, and various characteristics of it, in the world's oceans.

4.2.4.8.1 The Past Several Millennia

Gagan *et al*. (1998) used a double-tracer technique based on Sr/Ca and $^{18}O/^{16}O$ ratios in the skeletal remains of corals from Australia's Great Barrier Reef to infer climatic conditions for that region about 5,350 years ago. Impressed with their use of such coupled data, which allowed them to more accurately determine sea surface temperatures (SSTs) than had been possible in the past, Beck (1998) stated in his commentary on their paper that the new approach "promises to elucidate many important new clues about the dynamics of the coupled ocean-atmosphere-climate system for climate modelers to digest."

Gagan *et al.*'s work indicated the tropical ocean surface some 5,350 years ago, when there was much less CO_2 in the air than there is today, was 1.2°C warmer than the mean that prevailed throughout the early 1990s. This finding accorded well with terrestrial pollen and tree-line elevation records from elsewhere in the tropical Pacific for the entire period from 7,000 to 4,000 years ago. In addition, their work suggests the higher tropical SSTs of that time likely enhanced evaporation from the tropical Pacific, and the extra latent heat and moisture thereby exported to higher latitudes may have helped to maintain the equable climates known to have characterized the extra-tropics during this time.

McManus *et al.* (1999) examined a deep-sea sediment core from the eastern North Atlantic Ocean that included the last five glacial-interglacial cycles. They noted significant temperature oscillations throughout the record, which were of much greater amplitude during glacial as opposed to interglacial periods. SSTs, for example, oscillated between 1° and 2°C during warm interglacials, but varied between 4° and 6°C during colder glacial times. They conclude climatic variability on millennial time scales "has thus been the rule, rather than the exception." It is likely the warming of the last century or so was simply the most recent manifestation of a naturally recurring phenomenon unrelated to the concurrent increase in the atmosphere's CO_2 concentration. In addition, McManus *et al.*'s findings clearly contradict the contention that any future global warming will result in greater, and therefore more harsh, temperature extremes; their half-million-year record clearly indicates temperature variability during warmer times is more muted than it is during colder times.

Adding 50,000 years to the interval investigated by McManus *et al.*, Herbert *et al.* (2001) analyzed proxy SSTs over the past 550,000 years via data obtained from several marine sediment cores taken along the western coast of North America, from 22°N at the southern tip of the Baja Peninsula to 42°N off the coast of Oregon. They found "the previous interglacial produced surface waters several degrees warmer than today," such that "waters as warm as those now at Santa Barbara occurred along the Oregon margin." Their data indicate the peak SSTs of the current interglacial were 1° to 4°C cooler than the peak SSTs of all four of the preceding interglacial periods.

Raymo *et al.* (1998) studied physical and chemical characteristics of an ocean sediment core retrieved from a site south of Iceland. They found millennial-scale oscillations of climate were occurring more than one million years ago in a region of the North Atlantic that has been shown to strongly influence circum-Atlantic, and possibly global, climate. These oscillations appeared to be similar in character and timing to the Dansgaard-Oeschger cycles of the most recent glacial epoch.

Because the climate of the early Pleistocene was too warm to support the growth and development of the large, 100,000-year ice sheets characteristic of the late Pleistocene, and because similar millennial-scale climate oscillations are evident in both time periods, Raymo *et al.* conclude millennial-scale climate oscillations "may be a pervasive and long-term characteristic of Earth's climate, rather than just a feature of the strong glacial-interglacial cycles of the past 800,000 years." Since the millennial-scale climate oscillations of both periods have not been attributed to variations in atmospheric CO_2 concentration, there would appear to be little reason to attribute the warming of the past century or so to the concurrent increase in the atmosphere's CO_2 concentration, or to expect any further rise in CO_2 content to trigger significant warming.

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4.2.4.8.2 The Past Few Centuries

In order to understand the present—and potentially predict the future—it is helpful to have a correct understanding of the past, and nowhere is this more important than in the ongoing debate over the impact of anthropogenic CO_2 emissions on global climate. In this summary, we review what has been learned about this subject based on proxy sea surface temperature data pertaining to the past few centuries.

Fjellsa and Nordberg (1996) derived a history of the Holocene distribution of the dinoflagellate *Gymnodinium catenatum* from an ocean sediment core extracted from the Kattegat region of the North Sea between Sweden and Denmark (56°32'48" N, 12°11'15" E). This work revealed an early abundance of the species at about 4,300–4,500 yr BP. Then, in connection with what they called a "climatic deterioration, the species decreased abruptly and subsequently disappeared." It reestablished its presence some time later and, as they describe it, "occurred in massive 'blooms' during the so-called mediaeval warm epoch round about 700–800 yr BP." They add, "at the time of the so-called Little Ice Age, approximately 300 yr BP, *G. catenatum* again became extinct in the Kattegat area."

Fjellsa and Nordberg report "there appears to be a close relationship between climatic fluctuations and the presence and abundances of *G. catenatum*, which from its present ecology is considered a warmer water species." They conclude the two bloom periods were "characterized as warmer periods with climatic optima correlated to the peak phases," noting "the most massive blooms took place during the so-called 'Medieval warm epoch.'"

The two researchers also report, "cysts from *G. catenatum* have been found in the surface sediments from the Danish coast bordering the Kattegat (Ellegaard *et al*., 1993)," but they say they "do not know if *G. catenatum* has lived as a small part of the plankton since the 'Little Ice Age,' or if the species has been re-introduced by the current system or via ships' ballast tanks." And they note "there is also a possibility that the species has become re-established in conjunction with global warming during the past 80 years." The AD 1996 abundance of the key dinoflagellate was nowhere near that of the "massive blooms" of the Medieval Warm Period. Hence, we date the MWP in the Kattegat region of the North Sea to the period AD 1200–1400, concluding the peak warmth of the MWP was greater than that of the CWP so far.

Keigwin (1996) noted "it is important to document natural climate variability in order to understand the effects of anthropogenic forcing." Working with two subcores of a sediment box core retrieved from 33°41.6'N, 57°36.7'W of the undulating plateau of the northeast Bermuda Rise, he measured the oxygen isotope ratios ($\delta^{18}O$) of the white variety of the planktonic foraminifera *Globigerinoides ruber*, which lives year-round in the upper 25 meters of the northern Sargasso Sea and has a relatively constant annual mass flux and shell flux to the sediments. Calibrating these data against temperature and salinity data obtained at Ocean Station "S" (32°N, 62°30'W) over the prior 42 years, he determined "temperature accounts for about two-thirds of the isotopic signal, whereas salinity accounts for one-third." He then calculated sea surface temperatures (SSTs) of the prior three millennia, after which he "stacked the temperature proxy data from the two subcores by averaging results in 50-year bins," obtaining the results shown in Figure 4.2.4.8.2.1.

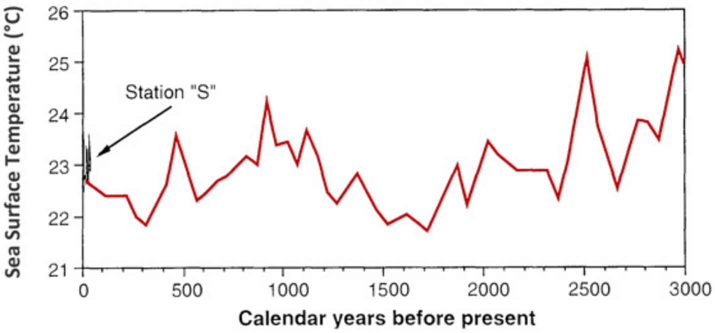

Figure 4.2.4.8.2.1. Fifty-year averages of mean annual sea surface temperature calculated from the $\delta^{18}O$ data of the two Bermuda Rise sediment subcores, together with the mean annual SSTs measured at Ocean Station "S" over the period 1954–1996. Adapted from Keigwin, L. 1996. The Little Ice Age and Medieval Warm Period in the Sargasso Sea. *Science* **274**: 1504–1508.

As can be seen from this figure, and as Keigwin stated, the northern Sargasso Sea SST "was ~1°C cooler than today ~400 years ago (the Little Ice Age) and 1700 years ago [the Dark Ages Cold Period], and ~1°C warmer than today 1000 years ago (the Medieval Warm Period)." He notes "over the course of three millennia, the range of SST variability in the Sargasso Sea is on the order of twice that measured over recent decades" and concludes "at least some of the warming since the Little Ice Age appears to be part of a natural oscillation." In addition, "because the changes described here for surface waters over the Bermuda Rise are probably typical of a large part of the western Sargasso Sea, they most likely reflect climate change on the basin or hemispheric scale."

Andren *et al*. (2000) conducted an extensive analysis of changes over time in siliceous microfossil assemblages and chemical characteristics of various materials found in a well-dated sediment core obtained from the Bornholm Basin in the southwestern Baltic Sea. The data revealed the existence of a period of high primary production at approximately AD 1050. In addition, the diatoms they identified were warm water species such as *Pseudosolenia calcar-avis*, which they describe as "a common tropical and subtropical marine planktonic species" that "cannot be found in the present Baltic Sea." They also note what they call the Recent Baltic Sea Stage, which began about AD 1200, started at a point when there was "a major decrease in warm water taxa in the diatom assemblage and an increase in cold water taxa, indicating a shift towards a colder climate," which they associate with the Little Ice Age.

These data clearly indicate there was a period of time in the early part of the past millennium when the climate in the area of the southwestern Baltic Sea was significantly warmer than it is today, as the sediment record of that time and location contained several warm water species of diatoms, some of which can no longer be found there. This period of higher temperatures, in the words of the three researchers, fell within "a period of early Medieval warmth dated to AD 1000–1100," which "corresponds to the time when the Vikings succeeded in colonizing Iceland and Greenland." This period was one of strikingly high oceanic primary productivity, demonstrating what seems to be the case with both ecosystems and human societies; i.e., warmer is better.

Keigwin and Boyle (2000) discussed the evidence for a climate oscillation with a return period of 1,500 to 2,000 years that is evident in proxy climate data pertaining to the last deglaciation and has continued (with reduced amplitude) through the Holocene, along with its association with contemporaneous changes—demonstrable for the last deglaciation but tenuous for the Holocene—in the thermohaline circulation of the North Atlantic Ocean. The Little Ice Age was the most recent cold phase of this persistent climatic phenomenon that may be induced by variations in the production rate of North Atlantic Deep Water. As the two researchers report, "mounting evidence indicates that the LIA was a global event, and that its onset was synchronous within a few years in both Greenland and Antarctica." In the Northern Hemisphere, for example, they state, it was expressed as a 1°C cooling between approximately 1500 and 1900 AD, with a cooling of approximately 1.7°C in Greenland.

Although the immediate cause or causes of the phenomenon have yet to be definitively identified, there is little question that Earth's climate oscillates globally on a millennial time-scale independent of the activities of man, and the most recent cold phase of that natural oscillation was what we call the Little Ice Age, centered on approximately AD 1700 and lasting until about AD 1900. Thus it was only to be expected that temperatures would have risen over the past century or so, and they may continue to rise even further until a warm epoch analogous to the Medieval Warm Period is reached. It is unjustified to conclude, as the IPCC does, that the majority of any warming that may currently be occurring is due to anthropogenic CO_2 emissions.

Linsley *et al*. (2000) retrieved a core of continuous coral from a massive colony of *Porites lutea* on the southwest side of Rarotonga in the Cook Islands, within which they measured Sr/Ca ratios on 1-mm sections spanning the entire core (representing 271 years of growth), as well as $\delta^{18}O$ values at the same resolution from 1726 to 1770 and from 1950 to 1997. The latter interval was used for calibration purposes and utilized Integrated Global Ocean Service System Products SST data. This analysis revealed a quarter-century period centered on about the year 1745 when SSTs in the vicinity of Rarotonga were at least 1.5°C warmer than they are today.

Winter *et al*. (2000) determined SSTs for the periods 1700–1705, 1780–1785, and 1810–1815 from a study of oxygen isotope data obtained from coral skeletons of *Montastrea faveolata* located on the southwestern shore of Puerto Rico. Similar isotope data obtained for the period 1983–1989 and contemporary SSTs directly measured at the University of Puerto Rico's marine station at La Parguera were used to calibrate the temperature reconstruction technique and provide a current baseline against which to compare the researchers' Little Ice Age results. The SSTs they derived were significantly cooler during the three Little Ice Age periods than they were at the time of their study. They report their results indicate "the Caribbean experienced cooling during the Little Ice Age with temperature estimated to be at least 2°–3° cooler than found during the present decade."

The data presented by Winter *et al*., as well as the data contained in several papers they cite, led them to conclude "the Little Ice Age may have been more global in extent than previously expected." It also may have been much colder than previously believed, for they point out the cooling suggested by their data "represents about half of the sea surface temperature cooling recorded in Barbados corals during the Last Glacial Maximum."

Doose-Rolinski *et al*. (2001) analyzed a complete and annually laminated sediment core extracted from the bed of the northeastern Arabian Sea just south southeast of Karachi, Pakistan, using oxygen isotopes of planktonic foraminifera and measurements of long-chain alkenones to derive a detailed sea surface temperature and evaporation history of the area. They found the greatest temperature fluctuations of the 5,000-year record occurred between 4,600 and 3,300 years ago and between 500 and 200 years ago, which were also the coldest periods of the record. Of the latter interval, they note, "in northern and central Europe this period is known as the 'Little Ice Age.'" They state their results confirm the "global effects" of this unique climatic change. Also apparent in their temperature history is a period of sustained warmth that prevailed between about 1,250 and 950 years ago, corresponding with the Medieval Warm Period of northern and central Europe.

de Garidel-Thoron and Beaufort (2001) reconstructed a 200,000-year history of primary productivity (PP) in the Sulu Sea north of Borneo, based on abundances of the coccolithophore *Florisphaera profunda*, which was measured in a 36-meter giant piston core retrieved from a depth of 3,600 meters. Three time-slices were explored in detail in order to determine high-frequency cycles in the PP record: one from 160 to 130 ka, one from 60 to 30 ka, and one from 22 to 4.1 ka. The finest-scale repeatable feature observed in all three time-slices was a climate-driven PP oscillation with a mean period of approximately 1,500 years.

The two researchers state they cycle's occurrence in the three different time-slices suggests "a common origin and an almost stationary signal across different climatic conditions." They also note the PP cycle's similarity to the 1,470-year temperature cycle observed by Dansgaard *et al*. (1984) in the Camp Century δ^{18}O ice core record, the ~1500-year δ^{18}O and chemical markers cycles observed by Mayewski *et al*. (1997) in the Summit ice core, the 1,470-year climate cycle found by Bond *et al*. (1997, 2001) in North Atlantic deep-sea cores, and the 1500-year climate cycle found by Campbell *et al*. (1998) in an Alaskan lake. These observations led them to suggest there was "a common origin" for the documented cyclicity in the climate of both high and low latitudes.

Hendy *et al*. (2002) reconstructed a 420-year SST history based on Sr/Ca measurements of several coral cores taken from massive *Porites* colonies in the central portion of Australia's Great Barrier Reef. The earliest portion of this region's reconstructed temperature history, from 1565 to about 1700, corresponds to the coldest period of the Little Ice Age as recorded in the Northern Hemisphere. Five-year blocks of mean Great Barrier Reef SSTs during this cold period were sometimes 0.5 to 1.0°C or more below the region's long-term mean. Over the following century, however, South Pacific SSTs were much warmer, as were temperatures in the Northern Hemisphere. In the South Pacific, in fact, SSTs during this period were consistently as warm as—and many times even warmer than—those of the early 1980s, where the coral record ended. During the late 1800s, the South Pacific once again experienced colder conditions that coincided with the "last gasp" of the Little Ice Age in the Northern Hemisphere, after which the Current Warm Period made its presence felt in both regions. That Hendy *et al*. found mid-eighteenth century South Pacific SSTs to be as warm as or even warmer than the final years of the twentieth century suggests the climate of the modern world is in no way unusual, unnatural, or unprecedented.

The mid-eighteenth century warmth of the tropical and subtropical South Pacific Ocean occurred at essentially the same time as the significant peak in Northern Hemispheric temperature that is strikingly evident in the data of Jones *et al*. (1998) and reproduced in the paper of Hendy *et al*. Thus if the data of Hendy *et al*. and Linsley *et al*. (2000 cited earlier) are representative of the great expanse of Southern Hemispheric ocean, the mid-eightreenth century mean temperature of the entire globe may have been about the same as it is now.

Roncaglia (2004) analyzed variations in organic matter deposition from approximately 6,350 cal yr BC to AD 1,430 in a sediment core extracted from the Skalafjord, southern Eysturoy, Faroe Islands to assess climatic conditions in that part of the North Atlantic in the mid- to late-Holocene. She discovered an increase in structured brown phytoclasts, plant tissue, and sporomorphs in sediments dating to ca. AD 830–1090, which she considered indicative of "increased terrestrial influx and inland vegetation supporting the idea of improved climatic conditions." In addition, she reports high "total dinoflagellate cyst concentration and increased absolute amount of loricae of tintinnid and planktonic crustacean eggs occurred at ca. AD 830–1090." She concludes these observations "may suggest increased primary productivity in the waters of the fjord," citing Lewis *et al.* (1990) and Sangiorgi *et al.* (2002). She reports the "amelioration of climate conditions" that promoted the enhanced productivity of both land and sea at this time "may encompass the Medieval Warm Period in the Faroe region."

Providing a longer and different proxy temperature record from the Northern Hemisphere, Jacoby *et al.* (2004) extracted cores from century-old oak trees growing within one km of the Pacific Ocean on Kunashir Island (the southernmost large island in the Kurile Island chain belonging to Russia, located between the Sea of Okhotsk and the northwest Pacific Ocean) and developed them into a four-century tree-ring width index series that was correlated strongly with island summer air temperature. The scientists report, "the recorded temperature data and the tree-ring data show similar correlation patterns with sea-surface temperatures of the North Pacific." They found "the tree-ring series explains more than 33% of the variance of the July–September Pacific Decadal Oscillation and has similar spectral properties, further supporting the concept of multidecadal variation or shifts in North Pacific climate, for four centuries."

The Kunashir June–September mean maximum temperature reconstruction exhibited no long-term trend (neither cooling nor warming) over the entire period from 1600 to 2000, nor did it show any net temperature change over the twentieth century. The peak warmth of the past hundred years occurred right at the mid-century mark, after which temperatures decreased considerably and ended up right about where they started the century.

Lund and Curry (2004) write, "while the Florida Current-Gulf Stream system is arguably one of the most studied features in modern oceanography, almost nothing is known about its behavior on centennial to millennial timescales." Two researchers analyzed planktonic foraminiferal δ^{18}O time series obtained from three well-dated sediment cores retrieved from the seabed near the Florida Keys (24.4°N, 83.3°W) that covered the past 5,200 years. They report the isotopic data from the three cores indicate "the surface Florida Current was denser (colder, saltier or both) during the Little Ice Age than either the Medieval Warm Period or today," and "when considered with other published results (Keigwin, 1996; deMenocal *et al.*, 2000), it is possible that the entire subtropical gyre of the North Atlantic cooled during the Little Ice Age ... perhaps consistent with the simulated effects of reduced solar irradiance (Rind and Overpeck, 1993; Shindell *et al.*, 2001)." In addition, they note, "the coherence and phasing of atmospheric ^{14}C production and Florida Current δ^{18}O during the Late Holocene implies that solar variability may influence Florida Current surface density at frequencies between 1/300 and 1/100 years." This evidence confirms centennial- and millennial-scale climatic variability is explained by similar-scale variability in solar activity, much as Bond *et al.* (2001) found for ice-rafting variability in the subpolar North Atlantic, further suggesting there is no need to use the historical increase in the air's CO_2 content to explain the increase in temperature that marked Earth's transition from the Little Ice Age to the Current Warm Period.

Asami *et al.* (2005) developed a 213-year (1787–2000) monthly resolved time series of carbon and oxygen isotope data obtained from a coral core retrieved from a *Porites labata* colony located on the northwestern coast of Guam, where the colony had been exposed to open sea surface conditions over the entire period of its development. They determined "the early 19th century (1801–1820) was the coolest in the past 210 years, which is consistent with sea surface temperature [SST] reconstructions derived from a δ^{18}O coral record from New Caledonia (Crowley *et al.*, 1997)." This period, they write, "was characterized by a decrease in solar irradiance (Lean *et al.*, 1995; Crowley and Kim, 1996) and by a series of large volcanic eruptions in 1808–1809 and 1818–1822 (Crowley *et al.*, 1997)." From that point on, they report, "the long-term δ^{18}O coral trend is characterized by its overall depletion throughout the period," indicative of a gradual warming of approximately 0.75°C.

This temperature history from a tropical region of the globe is essentially identical to the extratropical Northern Hemispheric temperature record of Esper *et al.* (2002), which stands in stark contrast to temperature reconstructions of Mann *et al.* (1998, 1999), which do not depict the existence of the Little Ice Age. The latter multi-century cool period is clearly manifest at the beginning of the Guam record, and it is evident at about the same time in the New

Caledonia record. The Guam SST history also differs from the Mann *et al*. temperature history depicting close to continuous warming from about 1815, just as the Esper *et al*. record does, whereas the Mann *et al*. record does not depict any warming until after 1910, about a century later. The 0.75°C rise in temperature from the start of the warming until the end of the twentieth century observed in the Guam record is not at all unusual, since it begins at one of the coldest points of the coldest multi-century period of the entire Holocene, the current inter-glacial.

Dima *et al*. (2005) note previous investigations of a Rarotonga coral-based SST reconstruction from the Cook Islands in the South Pacific Ocean focused on documenting and interpreting decadal and interdecadal variability without separating distinct modes of variability within this frequency band (Linsley *et al*. 2000, 2004; Evans *et al*. 2001). They reanalyzed the original coral record using Singular Spectrum Analysis to determine the dominant periods of multi-decadal variability in the series over the period 1727–1996. Their analysis revealed two dominant multi-decadal cycles, with periods of about 25 and 80 years. These modes of variability were found to be similar to multi-decadal modes observed in the global SST field of Kaplan *et al*. (1998) for the period 1856–1996. The ~25-year cycle was found to be associated with the Pacific Decadal Oscillation, whereas the ~80-year cycle was determined to be "almost identical" to a pattern of solar forcing found by Lohmann *et al*. (2004), which, according to Dima *et al*., "points to a possible solar origin" of this mode of SST variability. The results of their study provide an intriguing glimpse into the cyclical world of oceanic climatic change, demonstrating the existence of two strong multi-decadal modes of SST variability that are clearly natural in origin. Before SST trends can be attributed to anthropogenic activities, they must have all known modes of natural variability removed from them.

Newton *et al*. (2006) analyzed a sediment core collected at 5°12.07'S, 117°29.20'E in the Indo-Pacific Warm Pool (one of the warmest regions in the modern oceans) for planktonic foraminiferal (*Globigerinoides ruber*) Mg/Ca and δ^{18}O data to derive high-resolution summer sea surface temperature (SST) and salinity histories extending back about a thousand years. They report, "the warmest temperatures and highest salinities occurred during the Medieval Warm Period," which lasted from about AD 1020 to1260. Over this period, summer SSTs averaged about 29.7°C, as best as can be determined from their graph of the data (Figure 4.2.4.8.2.2), with a peak of about 30.9°C in the vicinity of AD 1080. These values are to be compared with the region's average modern summer SST of 29.0°C, significantly lower than that of the Medieval Warm Period. They also found "the coolest temperatures and lowest salinities occurred during the Little Ice Age," the lowest temperatures of which occurred "around AD 1700, during the period of reduced solar intensity known as the Maunder Minimum," when summer SSTs "were 1.0–1.5°C cooler than present," presumably due to the lower solar activity of that period. Newton *et al*. state their data from the Makassar Strait of Indonesia clearly indicates "climate changes during the Medieval Warm Period and Little Ice Age were not confined to the high latitudes" nor to countries bordering the North Atlantic Ocean.

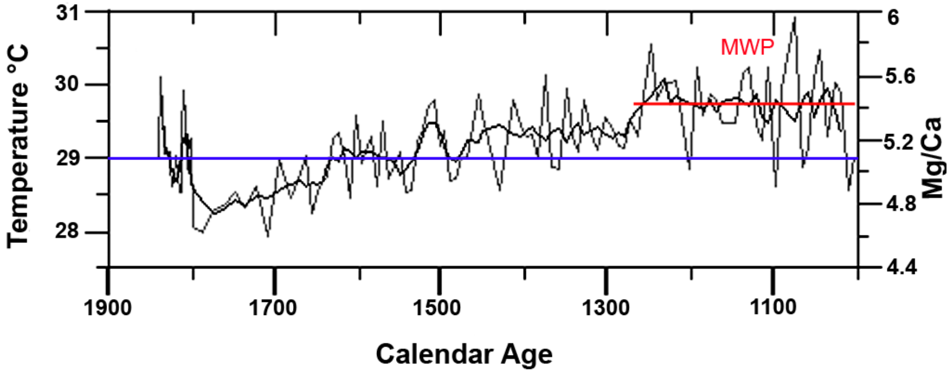

Figure 4.2.4.8.2.2. Mg/Ca-derived summer sea surface temperatures (SST) in the Indo-Pacific Warm Pool. The blue line represents the modern average SST value of 29°C. Adapted from Newton, A., Thunell, R., and Stott, L. 2006. Climate and hydrographic variability in the Indo-Pacific Warm Pool during the last millennium. *Geophysical Research Letters* **33**: 10.1029/2006GL027234.

Richey *et al*. (2007) note the variability of the hemispheric temperature reconstructions of Mann and Jones (2003) over the past one to two thousand years were "subdued (≤0.5°C)" and their low-amplitude reconstructions contrast "with several individual marine records that indicate that centennial-scale sea surface temperature (SST) oscillations of 2–3°C occurred during the past 1-2 k.y. (i.e., Keigwin, 1996; Watanabe *et al*., 2001; Lund and Curry, 2006; Newton *et al*., 2006)." They also contrast with "tree-ring and multiproxy reconstructions designed to capture multicentennial-scale variability (e.g., Esper *et al*., 2002; Moberg *et al*., 2005)," which further suggests "the amplitude of natural climate variability over the past 1 k.y. is >0.5°C," the scientists state. They constructed a continuous decadal-scale-resolution record of climate variability over the past 1,400 years in the northern Gulf of Mexico from a box core recovered in the Pigmy Basin, northern Gulf of Mexico (27°11.61'N, 91°24.54'W), based on climate proxies derived from paired analyses of Mg/Ca and $\delta^{18}O$ in the white variety of the planktic foraminifer *Globigerinoides ruber* and relative abundance variations of *G. sacculifer* in the foraminifer assemblages.

The four researchers report two multi-decadal intervals of sustained high Mg/Ca indicated Gulf of Mexico sea surface temperatures (SSTs) were as warm as, or warmer than, near-modern conditions between 1,000 and 1,400 yr BP (during the MWP), and foraminiferal Mg/Ca during the coolest interval of the Little Ice Age (ca. 250 yr BP) indicated SSTs were 2–2.5°C below modern SSTs. In addition, they found the four minima in the Mg/Ca record between 900 and 250 yr. B.P. corresponded in time with the Maunder, Sporer, Wolf, and Oort sunspot minima.

Barron and Bukry (2007) developed high-resolution records of diatoms and silicoflagellate assemblages spanning the past 2,000 years, from analyses of a sediment core extracted from the Carmen (26°17.39'N, 109°55.24'W), Guaymas (27.92°N, 111.61°W), and Pescadero Basins (24°16.78'N, 108°11.65W) of the Gulf of California. The relative abundance of *Azpeitia nodulifera*, a tropical diatom whose presence suggests the occurrence of higher sea surface temperatures, was found to be far greater during the Medieval Warm Period than at any other time in the 2,000-year period studied. During the Current Warm Period, its relative abundance was lower than the 2,000-year mean.

Matul *et al*. (2007) studied the distributions of different species of siliceous microflora (diatoms), calcareous microfauna (foraminifers), and spore-pollen assemblages in sediment cores retrieved from 21 sites on the inner shelf of the southern and eastern Laptev Sea, starting from the Lena River delta and moving seaward between about 130 and 134°E and stretching from approximately 71 to 78°N. The cores were acquired by a Russian-French Expedition during the cruise of R/V *Yakov Smirnitsky* in 1991. The analysis indicated the existence of "the Medieval Warm Period, ~600–1100 years BP; the Little Ice Age, ~100–600 years BP, with the cooling maximum, ~150–450 years BP, and the 'industrial' warming during the last 100 years." In addition, "judging from the increased diversity and abundance of the benthic foraminifers, the appearance of moderately thermophilic diatom species, and the presence of forest tundra (instead of tundra) pollen," they conclude, "the Medieval warming exceeded the recent 'industrial' one."

Using a well-established radiolarian-based transfer function, Fengming *et al*. (2008) developed a mean annual sea surface temperature (SST) history of the last 10,500 years based on data derived from the top 390 cm of a gravity core recovered from the western slope of the northern Okinawa Trough (29°13.93'N, 128°53'E) of the East China Sea. This record revealed that early in the Holocene, between 10,500 and 8,500 calendar years before present (cal. yr BP), mean annual SST gradually rose from ~23.5 to ~25.2°C, but it then declined abruptly to ~24.0°C at about 8,200 cal. yr BP. The middle portion of the Holocene that followed was relatively stable, with a mean SST of ~24.7°C, after which a dramatic cooling to ~23.6°C occurred at about 3,100 cal. yr BP that lasted until about 2,600 cal. yr BP, largely coincident with what is known as the "third Neoglaciation" of Europe.

This cold interval was followed by the Roman Warm Period (~2,600–1,700 cal. yr BP), when SSTs rose to ~24.8°C. Then came the Dark Ages Cold Period, when SSTs dropped to ~23.8°C, after which temperatures during the Medieval Warm Period (~1,250–750 cal. yr BP) returned to ~24.8°C, only to decline to ~24.2°C during the Little Ice Age (~600–300 cal. yr BP). Thereafter, it began to warm once again, but the warming was short-lived, with the temperature reversing course and falling slightly below the Little Ice Age minimum value of ~24.2°C at about AD 1950, where the SST history terminates.

This SST record from the East China Sea clearly reveals the millennial-scale cycling of climate seen in numerous paleoclimatic proxies throughout the world (see Figure 4.2.4.8.2.3), and it suggests the near-identical peak SSTs of the East China Sea during both the Medieval and Roman Warm Periods were

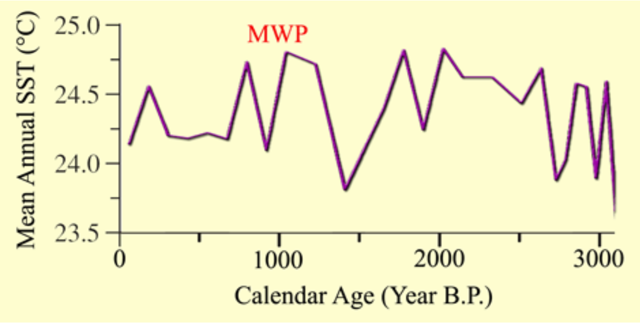

Figure 4.2.4.8.2.3. Sea surface temperature proxy derived from a gravity core recovered from the East China Sea. Adapted from Fengming, C., Tiegang, L., Lihua, Z., and Jun, Y. 2008. A Holocene paleotemperature record based on radiolaria from the northern Okinawa Trough (East China Sea). *Quaternary International* **183**: 115–122.

probably significantly greater than those of today, which likely have had insufficient time to reverse course and warm to such an elevated level from their lowest level of the past 1,300 years.

In reference to the claims of Jansen *et al*. (2007) and Mann *et al*. (2008) that Northern Hemisphere surface temperature reconstructions indicate "the late twentieth century was warmer than any other time during the past 500 years and possibly any time during the past 1,300 years," Oppo *et al*. (2009) state these temperature reconstructions may not be as representative of the planet as a whole as they are typically made out to be, because they "are based largely on terrestrial records from extra-tropical or high-elevation sites," whereas "global average surface temperature changes closely follow those of the global tropics, which are 75% ocean." The three researchers derived a "continuous sea surface temperature (SST) reconstruction from the IPWP [Indo-Pacific Warm Pool]," which they describe as "the largest reservoir of warm surface water on the Earth and the main source of heat for the global atmosphere." This temperature history, based on δ^{18}O and Mg/Ca data obtained from samples of the planktonic foraminifera *Globigerinoides ruber* found in two gravity cores, a nearby multi-core (all at 3°53'S, 119°27'E), and a piston core (at 5°12'S, 117°29'E) recovered from the Makassar Strait on the Sulawesi margin, spans the past two millennia (see Figure 4.2.4.8.2.4) and "overlaps the instrumental record, enabling both a direct comparison of proxy data to the instrumental record and an evaluation of past changes in the context of twentieth century trends."

They report the SST reconstruction "shows cooler temperatures between about AD 400 and AD 950 [the Dark Ages Cold Period] than during much of the so-called Medieval Warm Period (about AD 900–1300)." Of the latter period, they state, "reconstructed SSTs were warmest from AD 1000 to AD 1250," when "SSTs within error of modern SSTs occurred in the IPWP," as also was the case "during brief periods of the first millennium AD," during the Roman Warm Period. Thus a globally significant SST history, "enabling both a direct comparison of proxy data to the instrumental record and an evaluation of past changes in the context of twentieth century trends," shows substantial evidence that throughout portions of both the Roman and Medieval Warm Periods, SSTs in the Indo-Pacific Warm Pool were essentially equivalent to those of "the late twentieth century," once again indicating current air temperatures in this critically important region of the globe are not out of

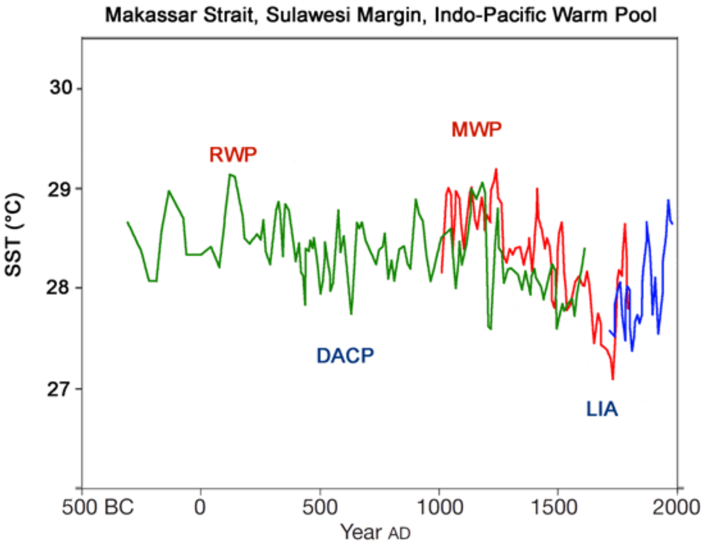

Figure 4.2.4.8.2.4. A 2,000-year temperature history, based on δ^{18}O and Mg/Ca data obtained from samples of a planktonic foraminifera found in ocean sediment cores recovered from the Makassar Strait on the Sulawesi margin of the Indo-Pacific Warm Pool. Adapted from Oppo, D.W., Rosenthal, Y., and Linsley, B.K. 2009. 2,000-year-long temperature and hydrology reconstructions from the Indo-Pacific warm pool. *Nature* **460**: 1113–1116.

the ordinary.

Isono *et al.* (2009) studied three sediment cores retrieved off the coast of central Japan in the northwestern Pacific Ocean (36°02'N, 141°47'E) to generate a multi-decadal-resolution record of alkenone-derived sea surface temperature (SST) that covers the full expanse of the Holocene. This record, they write, "showed centennial and millennial variability with an amplitude of ~1°C throughout the entire Holocene," and they state, "spectral analysis for SST variation revealed a statistically significant peak with 1470-year periodicity." At the end of the record, Isono *et al.* report, "SST minima centered at ca. 0.3 ka and ca. 1.5 ka are correlated with the Little Ice Age and the Dark Ages Cold Period in Europe, respectively, whereas the SST maximum centered at ca. 1.0 ka is correlated with the Medieval Warm Period." From data presented in the authors' Figure 2, it can be estimated the MWP was about 1°C warmer than the Current Warm Period.

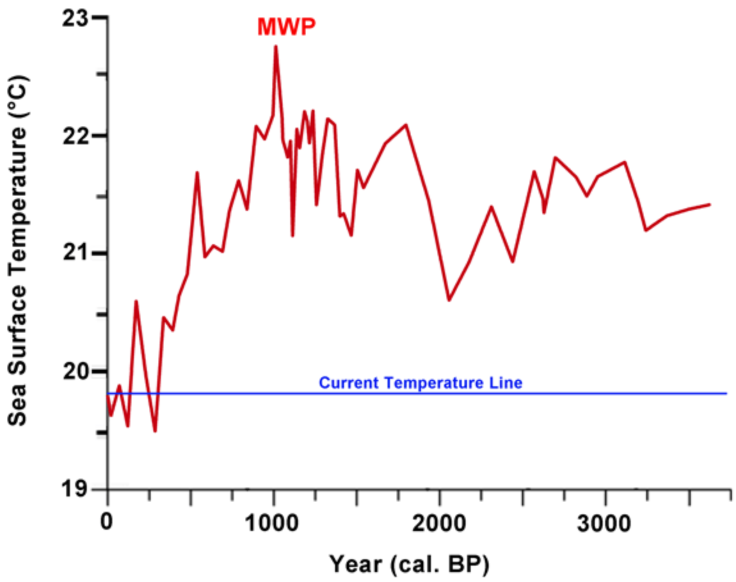

Figure 4.2.4.8.2.5. A 3,600-year proxy sea surface temperature record from the northern East China Sea. Adapted from Li, G.X., Sun, X.Y., Liu, Y., Bickert, T., and Ma, Y.Y. 2009. Sea surface temperature record from the north of the East China Sea since late Holocene. *Chinese Science Bulletin* **54**: 4507–4513.

Li *et al.* (2009) analyzed a sediment core extracted from the northern East China Sea (31.68°N, 125.81°E) in June 2006, employing the alkenone paleotemperature index $U^{k'}37$ together with the Muller *et al.* (1998) calibration equation to construct a sea surface temperature history of that region covering the past 3,600 years (Figure 4.2.4.8.2.5). They report "the highest temperature was 22.7°C which was recorded at 1.01 cal ka BP," about three-fifths of the way through the Medieval Warm Period. They also note cooling prevailed "from 0.85 cal. ka BP to present," with the latter point indicating a temperature of 19.78°C. We calculate, based on their work, the peak warmth of the MWP was 2.9°C greater than the mean warmth of the first decade of the twenty-first century, which is often characterized as the warmest decade of the instrumental period.

Richter *et al.* (2009) obtained high-resolution (22-year average) planktonic foraminiferal Mg/Ca and stable oxygen isotope (δ^{18}O) data from a pair of sediment cores retrieved from the northeast Atlantic Ocean's Feni Drift, Rockall Trough region (55°39.02'N, 13°59.10'W and 55°39.10'N, 13°59.13'W), from which they derived late Holocene (0–2.4 ka BP) sea surface temperatures (SSTs). These data revealed "a general long-term cooling trend," but "superimposed on this overall trend" were "partly higher temperatures and salinities from 180 to 560 AD and 750–1160 AD," which the three researchers say "may be ascribed to the Roman and Medieval Warm Periods, respectively." The latter was followed by the Little Ice Age (LIA) and what they describe as the "post-LIA recovery and, possibly, (late) 20th century anthropogenic warming."

The twentieth century warming, they write, "concurs with distinct continental-scale warming, consistently reaching unprecedented maximum temperatures after ~1990 AD." Their use of the word "unprecedented" is a bit misleading, for they subsequently write, "the SST increase over the last three decades does not, or not 'yet', appear unusual compared to the entire 0–2.4 ka record," and "the warming trend over the second half of the 20th century has not yet reverted the late Holocene millennial-scale cooling." Their data clearly indicate the peak temperature of the Medieval Warm Period was approximately 2.2°C greater than the peak temperature of the late twentieth century, and the peak temperature of the Roman Warm Period was about 2.7°C greater than that of the late twentieth century.

That the warmest portions of the Roman and Medieval Warm Periods in the vicinity of the northeast Atlantic were so much warmer than the warmest of the Current Warm Period, and at times when the air's CO_2 content was much less than it is currently, strongly suggests the atmosphere's CO_2 concentration had little or no impact on the late-Holocene climatic history of that part of the planet. The three Dutch researchers state, “pervasive multidecadal- to centennial-scale variability throughout the sedimentary proxy records can be partly attributed to solar forcing and/or variable heat extraction from the surface ocean caused by shifts in the prevailing state of the North Atlantic Oscillation,” as well as to “internal (unforced) fluctuations.”

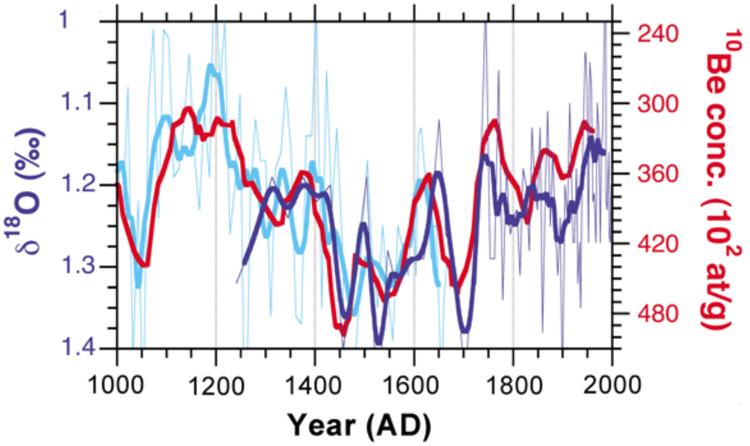

Figure 4.2.4.8.2.6. A 1,000-year proxy temperature record based on measurements of $\delta^{18}O$ in a planktonic foraminifer obtained from two sediment cores in the eastern Norwegian Sea. Adapted from Sejrup, H.P., Lehman, S.J., Haflidason, H., Noone, D., Muscheler, R., Berstad, I.M., and Andrews, J.T. 2010. Response of Norwegian Sea temperature to solar forcing since 1000 A.D. *Journal of Geophysical Research* **115**: 10.1029/2010JC006264.

Sejrup *et al*. (2010) developed a 1,000-year-long proxy temperature record from two sediment cores extracted from the seabed of the eastern Norwegian Sea (~64°N, 3°E), “based on measurements of $\delta^{18}O$ in *Neogloboquadrina pachyderma*, a planktonic foraminifer that calcifies at relatively shallow depths within the Atlantic waters of the eastern Norwegian Sea during late summer.” They found “the lowest isotope values (highest temperatures) of the last millennium are seen ~1100–1300 A.D., during the Medieval Climate Anomaly, and again after ~1950 A.D.” By applying “relatively conservative isotopic estimates of temperature change” utilized by the authors of -0.25‰/°C, from the graphs of their data, it can be estimated the most extreme minimum $\delta^{18}O$ values of the 1100–1300 period yield temperatures at least 0.35°C warmer than those of the post-1950 period (see Figure 4.2.4.8.2.6).

Combining use of ^{210}Pb dates, identification of Icelandic tephras of known age, and wiggle matching of ^{14}C radiocarbon dates, Sejrup *et al*. (2011) established exceptionally accurate chronologies for two marine sediment cores raised from the same location on the Norwegian continental margin (63°45'44"N, 05°15'19"E) in 1998. They evaluated $\delta^{18}O$ values of the planktonic foram *Neogloboquadrina pachyderma* (dex), a parameter influenced by the temperature and salinity of the seawater in which the foram lives, over the 8,000-year period spanned by the retrieved cores. After noting the work of Berstad *et al.* (2003) suggests salinity should have a relatively small influence on the isotope values of *N. Pachy.* (dex) at the site of their study, they developed the $\delta^{18}O$ history depicted in Figure 4.2.4.8.2.7, which they use as a proxy for what they call “near surface water summer temperature.” This history clearly shows the peak warmth of the Medieval Warm Period was significantly greater than the peak warmth of the Current Warm Period to date.

Ran *et al*. (2011) reconstructed summer sea surface temperature (SST) on the North Icelandic shelf for the period AD 940–2006, based on high-resolution and precisely dated diatom records and “a modern diatom-environmental dataset from around Iceland … established as a basis for quantitative reconstruction of palaeoceanographic conditions on the North Icelandic shelf (Jiang *et al*., 2001, 2002).” The four researchers find the sea surface on the North Icelandic shelf “was not as warm during the last century as during the Medieval Warm Period (MWP).” They also state, “warm and stable conditions with relatively strong influence of the Irminger Current on the North Icelandic shelf are indicated during the interval AD 940–1300, corresponding in time to the MWP,” and “a considerable cooling at ~AD 1300 indicates the transition to the Little Ice Age (LIA) with increased influence of Polar and Arctic water masses deriving from the East Greenland and East Icelandic currents.” After that came “an extended cooling period between AD 1300 and 1910,” followed by “a two-step warming during the last 100 years” that was “interrupted by three cool events around AD 1920, in the AD 1960s and in the late AD 1990s.”

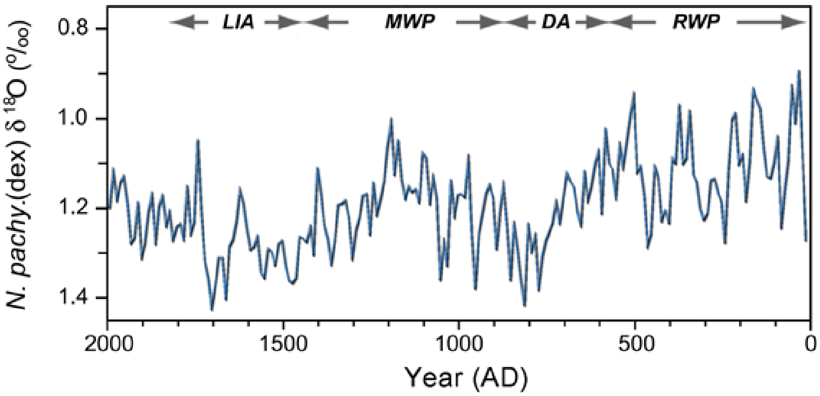

Figure 4.2.4.8.2.7. Proxy temperature reconstruction of *N. pachyderma* (dex) δ^{18}O vs. time. Adapted from Sejrup, H.P., Haflidason, H., and Andrews, J.T. 2011. A Holocene North Atlantic SST record and regional climate variability. *Quaternary Science Reviews* **30**: 3181–3195.

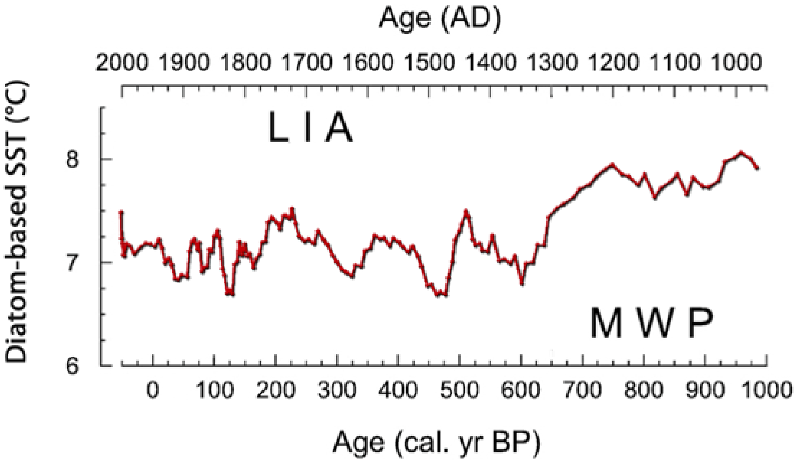

Figure 4.2.4.8.2.8. Reconstructed summer sea surface temperature (SST) on the North Icelandic shelf for the period AD 940–2006. Adapted from Ran, L., Jiang, H., Knudsen, K.L., and Eiriksson, J. 2011. Diatom-based reconstruction of palaeoceanographic changes on the North Icelandic shelf during the last millennium. *Palaeogeography, Palaeoclimatology, Palaeo-ecology* **302**: 109–119.

Ran *et al*. thus present another proxy record indicating the warmth of the more distant past clearly exceeded that of the recent past, with the peak temperature of the MWP exceeding that of the Current Warm Period at this location by about 0.6°C, as best as can be determined from the graphical representation of Ran *et al*.'s data presented in Figure 4.2.4.8.2.8. They conclude, "the data suggest that solar radiation may be one of the important forcing mechanisms behind the palae-oceanographic changes."

Saenger *et al*. (2011) analyzed seabed sediment sub-cores taken from a giant gravity core (59GGC) and a multicore (MC22) separated from each other by 22 km along the Carolina Slope of the western North Atlantic Ocean near the southern flank of the Gulf Stream at 32.977°N, 76.316°W and 32.784°N, 76.276°W, respectively, developed two sets of 2,000-year sea surface temperature (SST) histories based on Mg/Ca ratios of the shells of the planktic foraminifera *Globigerinoides ruber*, using two Mg/Ca-SST calibrations: that of Anand *et al*. (2003) for both cores and that of Arbuszewski *et al*. (2010) for the 59GGC core only.

Using the calibration of Anand *et al*. (2003), the peak warmth of the MWP is seen to have been about 0.1°C less than that of the CWP based on both the 59GGC and MC22 core data. When using the calibration of Arbuszewski *et al*. (2010), the peak warmth of the MWP is seen to have been about 0.7°C greater than that of the CWP based on the data from the 59GGC core. Thus Saenger *et al*.'s study suggests the peak warmth of the MWP was 0.1°C less than that of the CWP, and it also suggests the peak warmth of the MWP was 0.7°C greater than that of the CWP at the 59GGC site, with the MWP of both sites falling in the range of about AD 700–1300. Whichever calibration creates the more accurate record, it is clear temperatures in the region are hardly unusual or unnatural.

Copard *et al*. (2012) extracted the rare earth element *neodymium* (Nd) from pristine aragonite fragments of fossil deep-sea corals of the species *Lophelia pertusa* taken by gravity core from the southwestern flank of Rockall Trough in the Northeast Atlantic Ocean (55°31.17'–55°32' N, 15°39.08'–15°40'W). They calcu-lated iso-topic composition (εNd) according to the relationship εNd =([(^{143}Nd/^{144}Nd)sample/0.512638]-1) x 10,000, as per Jacobsen and Wasserberg (1980). Copard *et al.* state,

"the warm Medieval Climate Anomaly (1,000–1250 AD) was characterized by low εNd values (-13.9 to -14.5) ... while the Little Ice Age (around 1350–1850 AD) was marked by higher εNd values." After the end of the LIA, εNd once again declines, but according to the author's Figure 5d, it never quite reaches the -13.9 value that defines the boundary condition (εNd = -13.9) of the beginning and end of the MWP. Because the εNd value of modern seawater recirculating in the northern North Atlantic at surface and intermediate depths is only -13.1, it can be cautiously concluded ocean temperatures during the Current Warm Period have not eclipsed those experienced during Medieval times.

Wu *et al.* (2012) write, "one of the key questions in the reconstruction of late Holocene climate is whether or not the 20th-century warming is unusual over the past two millennia," noting "a clear answer to this question is crucial for the assessment of the relative contribution of human activities and natural processes to the observed warming." They developed a bi-decadal-resolution record of sea surface temperature (SST) in the Southern Okinawa Trough covering the past 2,700 years by analyzing tetraether lipids of planktonic archaea in the ODP Hole 1202B (24°48'N, 122°30'E), which they describe as "a site under the strong influence of the Kuroshio Current and East Asian monsoon."

The five Chinese researchers report finding SST anomalies that "generally coincided with previously reported late Holocene climate events, including the Roman Warm Period [120 BC–AD 400], Sui-Tang Dynasty Warm Period [AD 550–790], Medieval Warm Period [AD 900–1300], Current Warm Period [AD 1850–present], Dark Age Cold Period [AD 400–550] and Little Ice Age [AD 1300–1850]." They note, "despite an increase since AD 1850, the mean SST in the 20th century is still within the range of natural variability during the past 2700 years." In addition, they note climate records from East China (Ge *et al.*, 2004), the North Icelandic Shelf (Patterson *et al.*, 2010), and Greenland (Kobashi *et al.*, 2011) also exhibit "centennial-scale warm periods during the first millennia AD, comparable to or even warmer than mean 20th-century conditions."

Moros *et al.* (2012) inferred late-Holocene trends and variability of the East Greenland Current's influence on the Sub-Arctic Front, based on new oxygen isotope data of three planktonic foraminiferal species, Mg/Ca-derived sea-surface temperature data, alkenone biomarker paleothermometry, coccolith abundance, species counts, and diatom census data derived from a sediment core extracted from Reykjanes Ridge at 58°56.327'N, 30°24.590'W in the North Atlantic Ocean. They found "increasingly colder millennial-scale cooling events" centered on 5.6, 3.8, 2.7, 1.3, and 0.3 ka, the latter and coldest of which was the Little Ice Age. Between the third and fourth of these cold events was the Roman Warm Period, which they describe as the warmest period of the late Holocene.

Climate change is real. In fact, it's the *norm*. And in the several oceanic studies briefly reviewed above, as well as studies pertaining to the terrestrial surface of the planet reported on elsewhere in this Section 4.2, Earth's climate has been recognized as having shifted over the past century or so from the coldest period of the current interglacial to a significantly warmer state, but one that appears not yet to have achieved the level of warmth characteristic of the prior Medieval Warm Period or the earlier Roman Warm Period. Since none of these warming periods was driven by increases in the air's CO_2 concentration, there is no compelling reason to conclude—especially with the level of certainty expressed by the IPCC—that the twentieth century warming of the globe was driven by concurrent anthropogenic CO_2 emissions.

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4.2.4.8.3 Past Century

Dippner and Ottersen (2001) produced a twentieth century (1900–1995) history of mean sea water temperature from the surface to a depth of 200 meters for the Kola Section of the Barents Sea, which stretches from 70°30’N to 72°30’N along the 33°30’ E meridian. The record they developed indicates the mean temperature of the upper 200 meters of water rose by approximately 1°C from 1900 to 1940, after which it declined until about 1980 and then rose to the end of the record. The latter increase was not great enough to bring water temperatures back to the highs they experienced in the 1940s and early 1950s, and a linear regression from 1940 onward (or even 1930 onward) would produce a negative slope indicative of an overall cooling trend over the final 55 (or 65) years of the record.

Bratcher and Giese (2002) note the general trend of global surface air temperature was one of warming, but they caution there was “considerable variation in the upward trend,” and “how much of this variability is attributable to natural variations and how much is due to anthropogenic contributions to atmospheric greenhouse gases has not yet been resolved.” They add, “the possibility exists that some portion of the recent increase in global surface air temperature is part of a naturally oscillating system.” Hence, they explore “the recent record of Southern Hemisphere subsurface [ocean water] temperature anomalies and whether they may be an indicator of future global surface air temperature trends.”

The two researchers found “low frequency changes of tropical Pacific temperature lead global surface air temperature changes by about four years,” and "anomalies of tropical Pacific surface temperature are in turn preceded by subsurface temperature anomalies in the southern tropical Pacific by approximately seven years." In addition, they document a distinct cooling of the southern tropical Pacific over the prior eight years, leading them to conclude "the warming trend in global surface air temperature observed since the late 1970s may soon weaken." They proved correct, as the previous upward trend in the globe's mean surface air temperature—from the time of their writing—not only weakened but reversed course and began to trend downward.

Chavez *et al*. (2003) analyzed "physical and biological fluctuations with periods of about 50 years that are particularly prominent in the Pacific Ocean," including air and ocean temperatures, atmospheric CO_2 concentration, landings of anchovies and sardines, and the productivity of coastal and open ocean ecosystems. They found "sardine and anchovy fluctuations are associated with large-scale changes in ocean temperatures: for 25 years, the Pacific is warmer than average (the warm, sardine regime) and then switches to cooler than average for the next 25 years (the cool, anchovy regime)." They also found "instrumental data provide evidence for two full cycles: cool phases from about 1900 to 1925 and 1950 to 1975 and warm phases from about 1925 to 1950 and 1975 to the mid-1990s." These warm and cool regimes, which they respectively called El Viejo ("the old man") and La Vieja ("the old woman"), were manifest in myriad similar-scale biological fluctuations that may be even better indicators of climate change than climate data themselves, in the researchers' estimation.

The findings of this unique study have many ramifications, especially the challenge they present for the detection of CO_2-induced global warming. Chavez *et al*. note, for example, data used in climate change projections are "strongly influenced by multidecadal variability of the sort described here, creating an interpretive problem." They conclude "these large-scale, naturally occurring variations must be taken into account when considering human-induced climate change." The warming of the late 1970s to late 1990s, which returned much of the world to the level of warmth experienced during the 1930s and 1940s, has ended and reversed course. Chavez *et al*. cite evidence that indicates a change from El Viejo to La Vieja conditions was already in progress at the time of their writing.

Breaker (2005) performed statistical analyses on a daily sea-surface temperature (SST) record from the Hopkins Marine Station in Pacific Grove, California (USA), located at the southern end of Monterey Bay, for the period 1920–2001, to identify and estimate the relative importance of atmospheric and oceanic processes that contribute to the variability in the SST record on seasonal to interdecadal time scales. Based on monthly averages, Breaker found approximately 44 percent of the variability in the Pacific Grove data came from the annual cycle, 18 percent from El Niño warming episodes, 6 percent from the Pacific Decadal Oscillation (PDO), 4 percent from the long-term trend, and 3 percent from the semiannual cycle. Linear analysis of the 82-year record revealed a statistically significant SST increase of 0.01°C per year, and this trend is similar to the findings of other researchers who have attributed the trend to CO_2-induced global warming. Further analyses by Breaker suggest this attribution may have been premature.

Breaker discovered two major regime shifts associated with the PDO over the course of the record, one at about 1930 and one in 1976, which could explain most of the 82-year warming. Prior to the regime shift around 1930, for example, the waters of Monterey Bay were, in Breaker's words, "much colder than at any time since then." And if one computes the linear SST trend subsequent to this regime shift, which Breaker did, the resulting 72-year trend is a non-statistically significant +0.0042°C. Breaker concludes, "although the long-term increase in SST at Pacific Grove appears to be consistent with global warming, the integrated anomaly suggests that temperature increases in Monterey Bay have occurred rather abruptly and thus it becomes more difficult to invoke the global warming scenario."

Breaker's study clearly demonstrates decadal-scale regime shifts can dwarf any potential "fingerprint" of CO_2-induced global warming that might be present in twentieth century SST datasets. Also, it is clear the regime shift around 1930 was not the product of anthropogenic-induced global warming, because so little of the current burden of anthropogenic greenhouse gases had been released to the atmosphere prior to that time compared to what was subsequently released.

Hobson *et al*. (2008) used SST data from the International Comprehensive Ocean-Atmosphere Data Set to calculate, in annual time steps, the mean August–September positions of the 12, 15, and 18°C isotherms in the North Atlantic Ocean from 1854 to 2005 at 2-degree longitudinal intervals. They found the three isotherms "have tended to move northwards during two distinct periods: in the 1930s–1940s and then again at the end of the 20th century"; "the chances of this occurring randomly are negligible"; the 15°C isotherm "reached a maximum latitude of 52.0°N in 1932, and a latitude of 51.7°N in 2005, a difference of approximately 33 km"; and "of the 10 most extreme years, 4 have occurred in the 1992–2005 warm era and 3 have occurred in the 1926-1939 era."

The UK and Australian researchers conclude, "current 'warm era conditions' do not eclipse prior 'warm' conditions during the instrumental record," indicating the period of most significant greenhouse gas buildup over the past century (1930 and onward) brought little or no net increase in SSTs throughout this large sector of the North Atlantic Ocean.

DeCastro *et al*. (2009) employed two sea surface temperature (SST) datasets to reconstruct the SST history of the Bay of Biscay for the period 1854–2007: an extended reconstructed SST history obtained from NOAA/OAR/ESRL PSD of Boulder, Colorado, USA, for the period 1854–1997; and weekly mean SST data obtained from nighttime measurements made by Advanced Very-High Resolution Radiometers onboard NOAA satellites for the period 1985–2006. They did so, they write, "to put the intensity of the present warming trend within the context of the last two centuries."

The authors report, "two consecutive warming-cooling cycles were detected during the period 1854–2007: cooling from 1867 to 1910 (-0.14°C per decade); warming from 1910 to 1945 (0.17°C per decade); cooling from 1945 to 1974 (-0.10°C per decade); and warming from 1974 to 2007 (0.22°C per decade)." The four Spanish scientists state, "the present warming period (1974–2007) is on the same order of magnitude although slightly more intense than the one observed from 1910 to 1945." They conclude, "this fact does not permit elucidating the possible anthropogenic influence on the present day warming, which still remains an open question." This conclusion, they write, "is consistent with the analysis carried out by Hobson *et al*. (2008) for the North Atlantic," who also conclude "current 'warm era conditions' do not eclipse prior 'warm' conditions during the instrumental record." With respect to sea surface temperature, they observe, "the North Atlantic remains within the envelope of previous recorded conditions."

Halfar *et al*. (2011) state, "mid- and high-latitude crustose coralline algae are an emerging extra-tropical marine climate archive," as was demonstrated during a field calibration study (Halfar *et al*., 2008), because "they are amongst the longest-lived shallow marine organisms (Frantz *et al*., 2005)," and "they show constant growth over their lifespan and are not subject to an ontogenetic growth trend with skeletal age." Using "a regional network of specimens of the coralline alga *Clathromorphum compactum* spanning portions of the Labrador Current inshore branch from the Gulf of St. Lawrence to both latitudinal extremes of the eastern Newfoundland shelf," the authors generated "a 115-year-long growth-increment-width based record of subarctic northwest Atlantic surface temperatures."

The new temperature reconstruction reveals "the well-documented regime shift and warming in the northwestern Atlantic during the 1990s." The eight researchers further report, "large positive changes in algal growth anomalies were also present in the 1920s and 1930s, indicating the impact of a concurrent large-scale regime shift throughout the North Atlantic was more strongly felt in the subarctic Northwestern Atlantic than previously thought." They state this regime shift "may have even exceeded the 1990s event with respect to the magnitude of the warming," as "has recently been suggested for the central and eastern North Atlantic," citing Drinkwater (2006).

This study adds to a large body of evidence documenting warmer temperatures in the 1920s and 1930s than in the late 1990s/early 2000s, an observation at odds with the IPCC's claims the warming of the past two decades is unprecedented over the past millennium or more. The air's CO_2 concentration in the 1920s and 1930s was roughly 300–305 ppm; today's atmosphereic CO_2 concentration is about 400 ppm, some 30 percent greater than during those warmer times.

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4.2.8.4.4 Past Few Decades

What do ocean temperatures tell us about the theory of CO_2-induced global warming? This section considers what can and cannot be inferred from studies of the past few decades.

In a *Science* news story highlighting the work of Levitus *et al*. (2000), Richard Kerr's title all but announced the finding of climatology's Holy Grail: "Globe's 'Missing Warming' Found in the Ocean." Was that really the case? Before considering this question, it is instructive to note Kerr clearly acknowledges much of the warming that had long been predicted to occur as a consequence of the historical rise in the atmosphere's CO_2 concentration had indeed been missing. That is to say, his choice of words was admissive of the fact that Earth's atmosphere had not warmed by the amount that had long been predicted.

So how much of the missing warming was supposedly found? In a detailed analysis of a vast array of oceanic temperatures spanning the globe and extending from the surface down to a depth of 3,000 meters, Levitus *et al*. detected an incredibly small 0.06°C temperature increase between the mid-1950s and mid-1990s. Because the world's oceans have a combined mass 2,500 times greater than that of the atmosphere, this figure, as small as it seems, was truly significant. But was it correct?

Although their data extended back in time several years beyond the point at which they specified the warming to begin, Levitus *et al*. computed the linear trend in temperature between the lowest valley of their oscillating time series and its highest peak, ensuring they would obtain the largest warming possible. Over a moderately longer time period, global ocean warming would have been computed to be much less than what Levitus *et al*. reported, and the extended record would make the rate of warming smaller still. Nevertheless, NASA's James Hansen was quoted by Kerr as saying the new ocean-warming data "imply that climate sensitivity is not at the low end of the spectrum" that had typically been considered plausible.

But scientists were not interested only in the magnitude of the warming; they also wondered about cause. Climate modeler Jerry Mahlman, for example, stated, according to Kerr, that the study of Levitus *et al*. "adds credibility to the belief that most of the warming in the 20th century is anthropogenic." Yet Levitus *et al*. had clearly stated in their *Science* paper, "we cannot partition the observed warming to an anthropogenic component or a component associated with natural variability," which brings us to the subject of climate sensitivity. To calculate such a parameter one must have values for both a climate forcing and a climate response. If one cannot identify the source of the forcing, much less its magnitude, it is clearly impossible to calculate a sensitivity.

Levitus *et al*. (2001) and Barnett *et al*. (2001) added to the documentation of the modest warming of the planet's deep oceans. With respect to this accomplishment, Lindzen (2002) wrote, "the fact that models forced by increasing CO_2 and tuned by nominal inclusion of aerosol effects to simulate the global mean temperature record for the past century roughly matched the observed deep ocean record was taken as evidence of the correctness of the models and of the anthropogenic origin of the deep ocean warming." However, he took strong exception to this conclusion.

Assuming the deep-ocean temperature measurements and their analysis were correct, Lindzen used a coupled climate model (an energy balance model with a mixed layer diffusive ocean) "to examine whether deep ocean temperature behavior from 1950 to 2000 actually distinguishes between models of radically different sensitivity to doubled

CO_2." This revealed the warming of the deep oceans, in Lindzen's words, "is largely independent of model sensitivity," which led him to conclude "the behavior of deep ocean temperatures is not a test of model sensitivity, but rather a consequence of having the correct global mean surface temperature time history." He notes, "we are dealing with observed surface warming that has been going on for over a century" and "the oceanic temperature change over the period 1950–2000 reflects earlier temperature changes at the surface."

Further to this point, it should be noted according to the data of Esper *et al*. (2002), the Earth began to warm in the early 1800s, and the warming of the twentieth century, according to Briffa and Osborn (2002), was "a continuation of a trend that began at the start of the 19th century." Earth had completed the bulk of its post-Little Ice Age temperature rebound well before much of the Industrial Revolution's CO_2 emissions entered the atmosphere; i.e., by about 1930. As a result, the modest rise in deep-water temperatures over the past half-century or so tells us nothing about the sensitivity of Earth's climate to atmospheric CO_2 enrichment, nor does it link the warming to anthropogenic CO_2 emissions.

He *et al*. (2002) used stable oxygen isotope data acquired from a core of *Porites lutea* coral on the east of Hainan Island in the South China Sea to develop a 56-year (1943–1998) history of sea surface temperature in that region. They report the sea surface temperature in the 1940s "was warmer than that in the 1980s–1990s," by as much as 1.5°C.

Motivated by reports of "extraordinary change in the Arctic Ocean observed in recent decades," Polyakov *et al*. (2003) began their study by referencing the work of Carmack *et al*. (1995) and Woodgate *et al*. (2001), who had reported evidence of positive Atlantic Layer Core Temperature (ALCT) anomalies of up to 1°C in the 150- to 800-meter depth interval. Polyakov *et al*. note, however, an evaluation of the significance of these anomalies "requires an understanding of the underlying long-term variability" of the pertinent measurements.

The data employed by Polyakov *et al*. included temperature and salinity measurements from Russian winter surveys of the central Arctic Ocean carried out over the period 1973–1979, derived from 1034 oceanographic stations and constituting "the most complete set of arctic observations." In addition, they utilized 40 years of summer and winter observations from the Laptev Sea. Based on these comprehensive measurements, they determined new statistical estimates of long-term variability in both ALCT and sea-surface salinity (SSS). This work demonstrates the standard dataset that had been used to suggest the existence of the apparent 1°C temperature anomalies of the 1990s "considerably underestimates variability," as the observed ALCT anomalies in the late 1970s were fully as great as those of the 1990s.

Polyakov *et al*. state their new statistical analyses placed "strong constraints on our ability to define long-term means," as well as the magnitudes of ALCT and SSS anomalies computed using synoptic measurements from the 1990s referenced to means from earlier climatologies. Consequently, what some had described as "the extraordinary change in the Arctic Ocean observed in recent decades" turned out to be not extraordinary at all; it was merely a reappearance of conditions that had prevailed a few years earlier.

Freeland *et al*. (2003) analyzed water temperature and salinity measurements made at a number of depths over a period of several years along two lines emanating from central Oregon and Vancouver Island westward into the Pacific Ocean. The data indicate subsurface waters in an approximate 100-meter-thick layer located between 30 and 150 meters depth off central Oregon were, in the words of the researchers, "unexpectedly cool in July 2002." Mid-depth temperatures over the outer continental shelf and upper slope were more than 0.5°C colder than the historical summer average calculated by Smith *et al*. (2001) for the period 1961–2000, which Freeland *et al*. state, "might be cooler than a longer-term mean because the 1961–71 decade coincided with a cool phase of the Pacific Decadal Oscillation (Mantua *et al*., 1997)." At the most offshore station, they report "the upper halocline [was] >1°C colder than normal and about 0.5°C colder than any prior observation." In addition to being substantially cooler, the anomalous water was also much fresher, and the combined effects of these two phenomena made the water less "spicy," as Freeland *et al*. describe it—so much so that they refer to the intensity of the spiciness anomaly as "remarkable."

Along the line that runs from the mouth of Juan de Fuca Strait to Station Papa at 50°N, 145°W in the Gulf of Alaska, which was sampled regularly between 1959 and 1981 and irregularly thereafter, similarly low spiciness was observed, which in the researchers' opinion is the same feature as detected off the coast of central Oregon. They report "conditions in June 2002 [were] well outside the bounds of all previous experience," and "in summer 2001 the spiciness of this layer was already at the lower bound of previous experience."

Freeland *et al*. conclude their data implies "the waters off Vancouver Island and Oregon in July 2002 were displaced about 500 km south of their normal summer position." Was this observation an indication the Pacific Ocean was beginning to experience a shift from what Chavez *et al*. (2003) called a "warm, sardine regime" to a "cool, anchovy regime"? It is tempting to suggest it was. Freeland *et al*. cautioned against jumping to such a conclusion, saying there were no obvious signals of such a regime shift in several standard climate indices and that without evidence of a large-scale climate perturbation, the spiciness anomaly might have been simply anomalous. Consequently, although the pattern of Pacific Ocean regime shifts documented by Chavez *et al*. suggest a change from warmer to cooler conditions might have been imminent, there was not at that time sufficient climatic evidence to conclude such a shift was occurring.

In reference to the 1976–1977 regime shift in the Pacific, Chavez *et al*. note, "it took well over a decade to determine that a regime shift had occurred in the mid-1970s" and hence, "a regime or climate shift may even be best determined by monitoring marine organisms rather than climate," as suggested by Hare and Mantua (2000). Chavez *et al.* cite several studies that appeared to provide such evidence, including "a dramatic increase in ocean chlorophyll off California," which would seem a logical response to what Freeland *et al.* described as "an invasion of nutrient-rich Subarctic waters." Other pertinent evidence cited by Chavez *et al.* includes "dramatic increases in baitfish (including northern anchovy) and salmon abundance off Oregon and Washington" and "increases in zooplankton abundance and changes in community structure from California to Oregon and British Columbia, with dramatic increases in northern or cooler species."

McPhaden and Zhang (2004) report between the mid-1970s and mid-1990s sea surface temperatures in the eastern and central equatorial Pacific Ocean rose by about 0.7°C in response to a slowdown of the shallow meridional overturning circulation, and some scientists had suggested these phenomena were the result of greenhouse gas forcing. They also note the existence of evidence for a late 1990s "regime shift" in the North Pacific (Chavez *et al*., 2003; Peterson and Schwing, 2003) that could temper or even refute the other interpretation of the data.

Since year-to-year fluctuations associated with El Niño and La Niña conditions can greatly influence Earth's climate system, the two researchers compared mean conditions in the eastern and central equatorial Pacific Ocean for the six-year period July 1992–June 1998 with the more recent five-year period July 1998–June 2003, both of which intervals spanned at least one complete ENSO warm and cold phase cycle. In addition to sea surface temperatures, their investigation utilized hydrographic and wind data spanning the period 1992–2003 to calculate geostrophic meridional volume transports in the upper pycnocline of the tropical Pacific.

These data and analyses indicated "the shallow meridianal overturning circulation in the tropical Pacific Ocean has rebounded since 1998, after 25 years of significantly weaker flow." McPhaden and Zhang determined it had "recently rebounded to levels almost as high as in the 1970s." Likewise, the area-averaged sea surface temperature in the eastern and central equatorial Pacific Ocean concurrently dropped approximately 0.6°C to almost equal the low of the mid-1970s and match the low of the previous regime in the mid-1950s.

McPhaden and Zhang conclude the "precise magnitude of anthropogenic influences [on tropical Pacific sea surface temperatures] will be difficult to extract with confidence from the instrumental record given the rapidity with which observed warming trends can be reversed by natural variations."

Lyman *et al*. (2006) note, "with over 1000 times the heat capacity of the atmosphere, the World Ocean is the largest repository for changes in global heat content," and "monitoring ocean heat content is therefore fundamental to detecting and understanding changes in the Earth's heat balance." Consequently, "using a broad array of in situ temperature data from expendable bathythermographs, ship board conductivity-temperature-depth sensors, moored buoy thermistor records, and autonomous profiling conductivity-temperature-depth floats," they estimated the global integral of ocean heat content anomaly of the upper 750 meters from the start of 1993 through the end of 2005.

This undertaking revealed that from 1993 to 2003 the heat content of the upper 750 meters of the world ocean increased by 8.1 (±1.4) x 10^{22} J, but "this increase was followed by a decrease of 3.2 (±1.1) x 10^{22} J between 2003 and 2005." This decrease, they write, "represents a substantial loss of heat over a 2-year period, amounting to about one fifth of the long-term upper-ocean heat gain between 1955 and 2003 reported by Levitus *et al*. (2005)." They also found "the maximum cooling occurs at about 400 m," and "the cooling signal is still strong at 750 m and appears to extend deeper." They report preliminary estimates "show that additional cooling occurred between depths of 750 and 1400 m." As for the source of the cooling, they say it "could be the result of a net loss of heat from the Earth to space."

Lyman *et al*. note the physical causes of the type of variability they discovered "are not yet well understood," and "this variability is not adequately simulated in the current generation of coupled climate models used to study the impact of anthropogenic influences on climate," which "may complicate detection and attribution of human-induced climate influences." This statement suggests there has not yet been an adequate demonstration of human-induced influences on world ocean temperatures. It also would appear there currently is little hope of finding such a connection in subsets of world ocean data any time soon, for "the relatively small magnitude of the globally averaged signal is dwarfed by much larger regional variations in ocean heat content anomaly." Whereas "the recent decrease in heat content amounts to an average cooling rate of -1.0 ± 0.3 Wm^{-2} (of the Earth's total surface area) from 2003 to 2005," regional variations "sometimes exceed the equivalent of a local air-sea heat flux anomaly of 50 Wm^{-2} applied continuously over 2 years."

Noting the global-scale study of the world's oceans conducted by Levitus *et al*. (2005) suggested a significant increase in the heat content of the upper 3-km layer between 1957 and 1997, Gouretski and Koltermann (2007) contend Levitus *et al*. did not take into account "possible temperature biases associated with differing instrumentation." The large database employed by Levitus *et al.* was derived from five types of instruments—mechanical and expandable bathythermographs (MBTs and XBTs), hydrographic bottles (Nansen and Rosette), conductivity-temperature-depth (CTD) instruments, and profiling floats—and they analyzed temperature offsets among them and applied their findings to temporal trends in the degree of each type of instrument's usage over the period in question.

Gouretski and Koltermann note XBT data comprised the largest proportion of the total database, and "with XBT temperatures being positively biased by 0.2-0.4°C on average," this bias resulted in "a significant World Ocean warming artifact when time periods before and after introduction of XBTs [were] compared." When Gouretski and Koltermann used the bias-correction techniques they developed, the ocean heat content increase since the 1950s was reduced by a factor of 0.62. They write, "such corrections if applied would correspondingly reduce the estimate of the ocean warming in Levitus *et al*. (2005) calculations." Gouretski and Koltermann's work indicates the warming of the global ocean over the last half of the twentieth century as calculated by Levitus *et al*. (2005) was seriously overestimated.

Harrison and Carson (2007) sorted individual temperature observations in the World Ocean Database 2001 into 1°x1° and 2°x2 ° bins, after which, working only with bins having at least five observations per decade for four of the five decades since 1950, they calculated 51-year temperature trends for depths of 100, 300, and 500 meters, as well as sequential 20-year trends—i.e., 1950-1970, 1955–1975, 1960–1980, and 1980–2000—for the same depths. Based on the results, which were statistically significant at the 90% confidence level, they determined the upper ocean "is replete with variability in space and time, and multi-decadal variability is quite energetic almost everywhere." They found 95 percent of the 2°x2° regions they studied "had both warming and cooling trends over sequential 20-year periods," and "the 51-year trends are determined in a number of regions by large trends over 20- to 25-year sub-periods." They conclude, "trends based on records of one or two decades in length are unlikely to represent accurately longer-term trends," and, therefore, "it is unwise to attempt to infer long-term trends based on data from only one or two decades." In addition, they note, "the magnitude of the 20-year trend variability is great enough to call into question how well even the statistically significant 51-year trends ... represent longer-term trends."

Carson and Harrison (2008) derived and analyzed ocean temperature trends over the period 1955–2003 at depths ranging from 50 to 1,000 meters to "test the sensitivity of trends to various data processing methods." They used the *World Ocean Database 2005* (Boyer *et al*., 2006), employed the analytical approach of Harrison and Carson (2007), and compared their results with those of Levitus *et al.* (2005). They find, "most of the ocean does not have significant 50-year trends at the 90% confidence level (CL)." They state, "only 30% of the ocean at 50 meters has 90% CL trends, and the percentage decreases significantly with increasing depth." In comparison with prior calculated trends, they also report the results "can differ substantially, even in the areas with statistically significant trends," noting, "trends based on the more interpolated analyses," such as those of Levitus *et al*. (2005), "show more warming." Thus the two researchers conclude, "ocean heat content integrals and integral trends may be substantially more uncertain than has yet been acknowledged."

In concluding this summary of the global ocean's thermal behavior over the past few decades, we discuss two papers that deal more with processes than with history. The first of these papers is that of Kleypas *et al*. (2008), who looked for evidence of an ocean thermostat by analyzing patterns of sea surface temperature (SST) increases in the tropics over the past five decades. They focused their attention on the western Pacific warm pool (WPWP), because, they write, "this is a region where maximum SSTs are thought to be limited by negative feedbacks," as described in the writings of Reginald Newell (1979), whom they cite and who in collaboration with Thomas Dopplick demonstrated, nearly three decades ago, that the degree of CO_2-induced global warming predicted by the climate models of that day was far greater (and is greater still today) than what is allowed by the real world (Newell and Dopplick, 1979), as further described in the historical narrative of Idso (1982).

Kleypas *et al*. say their analysis indicates "the warmest parts of the WPWP have warmed less than elsewhere in the tropical oceans," which "supports the existence of thermostat mechanisms that act to depress warming beyond certain temperature thresholds." In addition, they report "coral reefs within or near the WPWP have had fewer reported bleaching events relative to reefs in other regions," which is also indicative of the existence of an upper-limiting temperature above which SSTs typically do not rise, presumably because the oceanic thermostat kicks in when they approach 30°C in the region the three researchers describe as "the center of coral reef biodiversity."

These findings support the thesis put forward years ago by both Newell and Dopplick (1979) and Idso (1980, 1982, 1989): that rather than Earth possessing some thermal "tipping point" above which global warming dramatically accelerates, the planet's climatic system does just the opposite and greatly attenuates warming above a certain level.

Shaviv (2008) begins by noting "climatic variations synchronized with solar variations do exist, whether over the solar cycle or over longer time-scales," citing numerous references, many more of which can be found in Chapter 3 of this volume. Nevertheless, it is difficult for some to accept the logical derivative of this fact—that solar variations are driving major climate changes—their prime objection being that measured or reconstructed variations in total solar irradiance seem far too small to be able to produce the observed climatic changes.

One potential way to resolve this dilemma would be to discover some amplification mechanism, but most attempts have been fraught with difficulty and met with much criticism. Shaviv, however, makes a good case for at least the existence of such an amplifier, and he points us in the direction of a sensible candidate to fill this role.

Shaviv used "the oceans as a calorimeter to measure the radiative forcing variations associated with the solar cycle" via "the study of three independent records: the net heat flux into the oceans over 5 decades, the sea-level change rate based on tide gauge records over the 20th century, and the sea-surface temperature variations," each of which can be used, in his words, "to consistently derive the same oceanic heat flux."

Shaviv demonstrates "there are large variations in the oceanic heat content together with the 11-year solar cycle." In addition, he reports the three independent datasets "consistently show that the oceans absorb and emit an order of magnitude more heat than could be expected from just the variations in the total solar irradiance," thus "implying," as he describes it, "the necessary existence of an amplification mechanism, although without pointing to which one."

Shaviv nonetheless acknowledges his affinity for the solar-wind modulated cosmic ray flux (CRF) hypothesis suggested by Ney (1959), discussed by Dickenson (1975), and championed by Svensmark (1998). Based on "correlations between CRF variations and cloud cover, correlations between non-solar CRF variations and temperature over geological timescales, as well as experimental results showing that the formation of small condensation nuclei could be bottlenecked by the number density of atmospheric ions," this concept, according to Shaviv, "predicts the correct radiation imbalance observed in the cloud cover variations" needed to produce the magnitude of the net heat flux into the oceans associated with the 11-year solar cycle.

Shaviv thus concludes the solar-wind modulated CRF hypothesis is "a favorable candidate" for primary instigator of the many climatic phenomena described in this volume.

Even with all the data that have been acquired over the past half-century, it remains difficult to state with much confidence exactly what the world's oceans are doing in terms of the storage and loss of heat. To state precisely *why* they are doing whatever it is they are doing is even more difficult.

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4.2.4.9 South America

As indicated in the introduction of Section 4.2.4, data presented in numerous peer-reviewed studies reveal modern temperatures are not unnatural. For many millennia, Earth's climate has both cooled and warmed independent of its atmospheric CO_2 concentration. Conditions as warm as or warmer than the present have persisted across the Holocene for decades to centuries even though the atmosphere's CO_2 concentration remained at values approximately 30 percent lower than today's.

The following subsections highlight studies addressing this topic in South America. Much of the material focuses on the most recent millennium of Earth's history, detailing the historical fluctuations of Earth's climate that long ago ushered in the Roman Warm Period, which gave way to the Dark Ages Cold Period, which was followed by the Medieval Warm Period and subsequent Little Ice Age. These natural climate oscillations are the product of a millennial-scale climate forcing; the Current Warm Period is simply the latest manifestation. Carbon dioxide had little to do with the warmth (or cold) of these prior epochs, and there is no compelling reason to conclude it is having any measurable impact on climate today.

4.2.4.9.1 Argentina

Cioccale (1999) assembled what was known at the time about the climatic history of the central region of Argentia over the past 1,400 years, highlighting a climatic "improvement" that began 400 years before the start of the last millennium, which ultimately came to be characterized by "a marked increase of environmental suitability, under a relatively homogeneous climate." As a result of this climatic amelioration that marked the transition of the region from the Dark Ages Cold Period to the Medieval Warm Period, Cioccale reports "the population located in the lower valleys ascended to higher areas in the Andes," where they remained until around AD 1320, when the transition to the stressful and extreme climate of the Little Ice Age began.

At the southern tip of the country, in Tierra del Fuego, Mauquoy *et al.* (2004) inferred similar changes in temperature and/or precipitation from plant macrofossils, pollen, fungal spores, testate amebae, and humification associated with peat monoliths collected from the Valle de Andorra. These new chronologies were compared with other chronologies from both the Southern and Northern Hemispheres, and the analysis showed evidence for a period of warming-induced drier conditions in AD 960–1020, which, they write, "seems to correspond to the Medieval Warm Period (MWP, as derived in the Northern Hemisphere)." They also note, "this interval compares well to the date range of AD 950–1045 based on Northern Hemisphere extratropical tree-ring data (Esper *et al.*, 2002)." They conclude this correspondence "shows that the MWP was possibly synchronous in both hemispheres, as suggested by Villalba (1994)."

Haberzettl *et al.* (2005) worked with five sediment cores extracted from Laguna Potrok Aike (51°58'S, 70°23'W), one of the few permanently water-filled lakes in the dry-lands of southern Patagonia. They analyzed a host of proxy climate indicators, finding "the sediment record of Laguna Potrok Aike reveals an unprecedented sensitive continuous high resolution lake level, vegetation and climate record for southern Patagonia since AD 400." This history indicates the climate of the region fluctuated rapidly from the beginning of the record up to the start of the Medieval Climatic Anomaly (MCA), which Stine (1998) proposed as having begun at about AD 870. This earlier time interval corresponds with the Dark Ages Cold Period of Europe, and it was followed by the MCA, or what

Europeans call the Medieval Warm Period. The latter was most strongly expressed in the Laguna Potrok Aike data from AD 1240 to 1410, during which period maxima of total inorganic carbon (TIC), total organic carbon (TOC), total nitrogen (TN), carbon/nitrogen ratio (C/N) and δ^{13}Corg indicate, in the words of the ten researchers, "low lake levels and warm and dry climate."

Thereafter, the scientists continue, "the MCA ends during the 15th century" and was "followed by the so called 'Little Ice Age.'" Finally, they write, "in the course of the 20th century, Laguna Potrok Aike reacted like many other Patagonian lakes with a lake level lowering after 1940, culminating in 1990, and followed by a subsequent rise and recession."

As to whether it was warmer during the MCA than during the twentieth century, Haberzettl *et al*. state, "there is evidence for lower lake levels during the MCA than today in every proxy," and "the existence of lower lake levels in former times was demonstrated by seismic studies which revealed hitherto undated fossil lake level terraces ca. 30 m below the present lake level (Zolitschka *et al*, 2004)." In addition, "TOC and TN as proxies reflecting productivity also show higher values during the MCA than today," even though "present TOC and TN values are elevated due to anthropogenic eutrophication." They conclude, "this altogether implies that it might have been warmer during [AD 1240 to 1410] than today."

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4.2.4.9.2 Brazil

Vuille *et al*. (2012) reviewed the history of the South American summer monsoon (SASM) over the past two millennia, using information obtained from high-resolution stable isotopes derived from speleothems, ice cores, and lake sediments acquired from the monsoon belt of the tropical Andes and Southeast Brazil. This work reveals "a very coherent behavior over the past two millennia with significant decadal to multidecadal variability superimposed on large excursions during three key periods: the Medieval Climate Anomaly (MCA), the Little Ice Age (LIA) and the current warm period (CWP)," which they interpret as "times when the SASM's mean state was significantly weakened (MCA and CWP) and strengthened (LIA), respectively."

The nine researchers hypothesize, "these centennial-scale climate anomalies were at least partially driven by temperature changes in the Northern Hemisphere and in particular over the North Atlantic, leading to a latitudinal displacement of the Intertropical Convergence Zone and a change in monsoon intensity (amount of rainfall upstream over the Amazon Basin)." As they note the intensity of the SASM "today appears on par with conditions during the MCA," it can be concluded the peak temperatures of the MCA and the CWP over the North Atlantic Ocean are likely on par as well, suggesting there is nothing unusual about today's current level of warmth over the North Atlantic and today's global level of warmth need not have been caused by the concurrent 40 percent greater atmospheric CO_2 concentration.

Reference

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4.2.4.9.3 Chile

Lamy *et al.* (2001) used the iron content from an ocean sediment core taken from the Chilean continental slope (41°S, 74.45°W) as a proxy for historic rainfall in this region during the Holocene. Results indicate several centennial and millennial-scale phases of rainfall throughout this period, including an era of decreased rainfall “coinciding with the Medieval Warm Period,” which was followed by an era of increased rainfall during the Little Ice Age (see Figure 4.2.4.9.3.1). They conclude their data “provide further indications that both the LIA and MWP were global climate events.”

Jenny *et al.* (2002) studied geochemical, sedimentological, and diatom-assemblage data derived from sediment cores extracted from one of the largest natural lakes (Laguna Aculeo) in the central part of Chile. From 200 BC, when the record began, until AD 200, conditions there were primarily dry, during the latter stages of the Roman Warm Period. Subsequently, from AD 200–700, with a slight respite in the central hundred years of that period, there was a high frequency of flood events, during the Dark Ages Cold Period. Then came a several-hundred-year period of less flooding that was coeval with the Medieval Warm Period. This more benign period was followed by another period of frequent flooding from 1300–1700 coincident with the Little Ice Age, after which flooding picked up again after 1850.

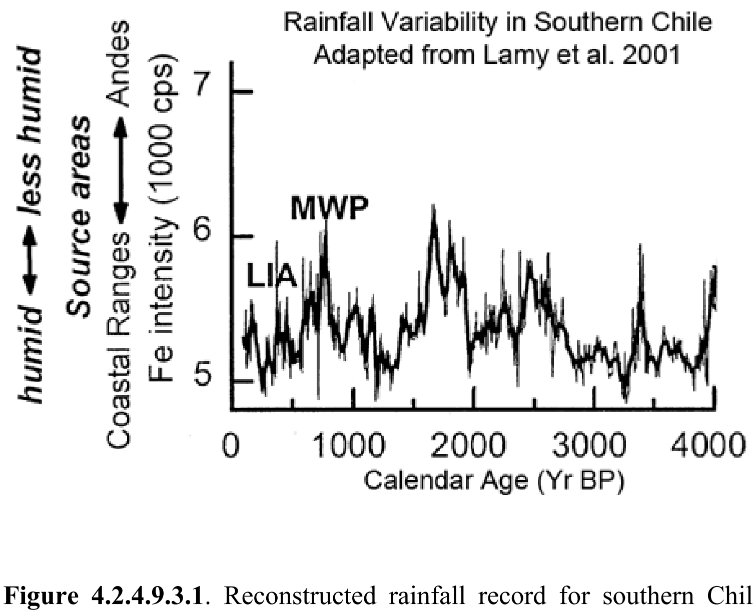

Figure 4.2.4.9.3.1. Reconstructed rainfall record for southern Chile. Adapted from Lamy, F., Hebbeln, D., Röhl, U., and Wefer, G. 2001. Holocene rainfall variability in southern Chile: a marine record of latitudinal shifts of the Southern Westerlies. *Earth and Planetary Science Letters* **185**: 369–382.

Nester *et al.* (2007) studied fluvial terraces in the Pampa del Tamarugal (PdT) basin of the Atacama Desert of northern Chile, which contains widespread fossil wood, *in situ* roots, and well-preserved leaf litter deposits indicative of perennial surface flow in now-dry channels where streams once cut canyons in the desert’s currently hyper-arid core. In this challenging environment, and based on radiocarbon dating, the five researchers determined the approximate dates of the most important recharge events of these channels of the last 18,000 years, demonstrating “there was enhanced stream discharge into the PdT during the time intervals of 17,750–13,750, 11,750, and 1,100–700 cal yr BP,” while noting “groundwater must have been near the surface (<10 m) for *Prosopis* stands to have lived [there] between 1,100–700 cal yr BP.” The latter Chilean “Medieval Climatic Anomaly (MCA),” as they describe it, “is of opposite hydrological impact (wet) to that of coastal Peru (dry), where lithic concentrations in a marine core document diminished strength of El Niño events during the MCA (Rein *et al*., 2004).”

This wettest interval of the past 11,000-plus years in the hyper-arid core of the Atacama Desert (~AD 900–1300) coincides nicely with the central portion of the mean timeframe of the MWP as experienced around the globe. This unique set of regional circumstances—wet in the Atacama Desert of Chile and dry along coastal Peru—is a strong indication of the dramatic but varied effects of the global Medieval Warm Period in this particular part of the world.

Rebolledo *et al.* (2008) analyzed changes in marine productivity and contemporaneous terrestrial input in a study of sediment cores retrieved from the Jacaf Channel (44°S, 72°W) of Chilean Northern Patagonia that contained data pertaining to the past 1,800 years, using biogenic opal, siliceous microorganisms, alkenones, and organic (Corg content, molar C/N) and inorganic (Cinorg, Fe, Ti, Ca) elements as proxies for terrestrial input and/or carbonate productivity. They compared their findings with those of other researchers who had conducted similar paleoclimatic studies in various parts of South America and Antarctica.

The seven scientists reported, "the down-core record clearly shows two productivity/climate modes." As they describe it, the first period—prior to 900 cal yr BP and including the Medieval Warm Period (MWP)—is characterized by "decreased marine productivity and a reduced continental signal, pointing to diminished precipitation and runoff." The second period—between 750 cal yr BP and the late 1800s, and including the Little Ice Age (LIA)—is characterized by "elevated productivity and an increased continental signal, suggesting higher precipitation and runoff." In addition, their data clearly show the MWP and LIA were "separated by a relatively abrupt transition of ~150 years." In addition to providing another demonstration of the reality of the MWP and LIA in South America, the Chilean, German, and U.S. scientists conclude the good correspondence between their record and various "other paleoclimate studies carried out in South America and Antarctica demonstrates that the Chilean fjord area of Northern Patagonia is not just sensitive to local climatic variability but also to regional and possibly global variability."

von Gunten *et al.* (2009) write, "quantitative high-resolution global, hemispherical and regional climate reconstructions covering the last millennium are fundamental in placing modern climate warming into a long-term context," in order to "assess the sensitivity of the climate system to natural and anthropogenic forcings, and thus to reduce uncertainty about the magnitude and impact of future global climate change." They note, for the entire Southern Hemisphere, "Mann and Jones (2003) considered only five data sets suitable for their work on surface temperature reconstructions for the past two millennia," and "only two of these data series are from South America," one of which is a tree-ring record "with unknown preservation of the low-frequency component of climate variability" and the other a $\delta^{18}O$ ice core record they describe as "arguably putative at best" in terms of its temperature signal.

von Gunten *et al.* developed a continuous high-resolution (1–3 years sampling interval, five-year filtered reconstruction) austral summer (December to February) temperature reconstruction based on chloro-pigments derived from algae and phototrophic bacteria found in sediment cores retrieved from Central Chile's Laguna Aculeo (33°50'S, 70°54'W) in 2005 that extended back to AD 850, which they describe as "the first quantitative temperature reconstruction for Central Chile for the last millennium." The Swiss, German, and UK scientists report their data provided "quantitative evidence for the presence of a Medieval Climate Anomaly (in this case, warm summers between AD 1150 and 1350; $\Delta T = +0.27$ to $+0.37$°C with respect to (wrt) twentieth century) and a very cool period synchronous to the 'Little Ice Age' starting with a sharp drop between AD 1350 and AD 1400 (-0.3°C/10 years, decadal trend) followed by constantly cool ($\Delta T = -0.70$ to -0.90°C wrt twentieth century) summers until AD 1750."

The graph of their data, as presented in Figure 4.2.4.9.3.2, indicates the peak warmth of the Medieval Climate Anomaly was about 0.7°C warmer than the last decade or so of the twentieth century, but only about 0.25°C warmer than the peak warmth of the twentieth century, which occurred in the late 1940s in their reconstructed temperatures and their instrumental data, which are essentially identical over most of the 1900s. In addition, they note, the "structure of variability" shown in their data "is consistent in great detail with annually resolved tree-ring-based warm-season temperature and river discharge reconstructions from northern Patagonia for the past 400 years, with qualitative climate reconstructions from Andean glacier fluctuations, and with hydrological changes in Patagonian lake sediment records."

The work of the five researchers thus clearly demonstrates the existence of both the Medieval Warm Period (MWP) and Little Ice Age in the Southern Hemisphere, as well as the fact that the MWP was warmer (and for much longer) than the Current Warm Period has been to date. This suggests there is nothing unnatural about the planet's current level of warmth, or the rate at which it was reached, and thus removes any need to invoke current higher concentrations of atmospheric CO_2 as the cause of these nondescript features of our current climate.

Sepulveda *et al.* (2009) write, "deciphering climate variability in the Southern Hemisphere and particularly from southern South America—the only continental land mass lying between 38°S and the Antarctic Circle—is crucial for documenting the inter-hemispheric synchronicity of recent abrupt

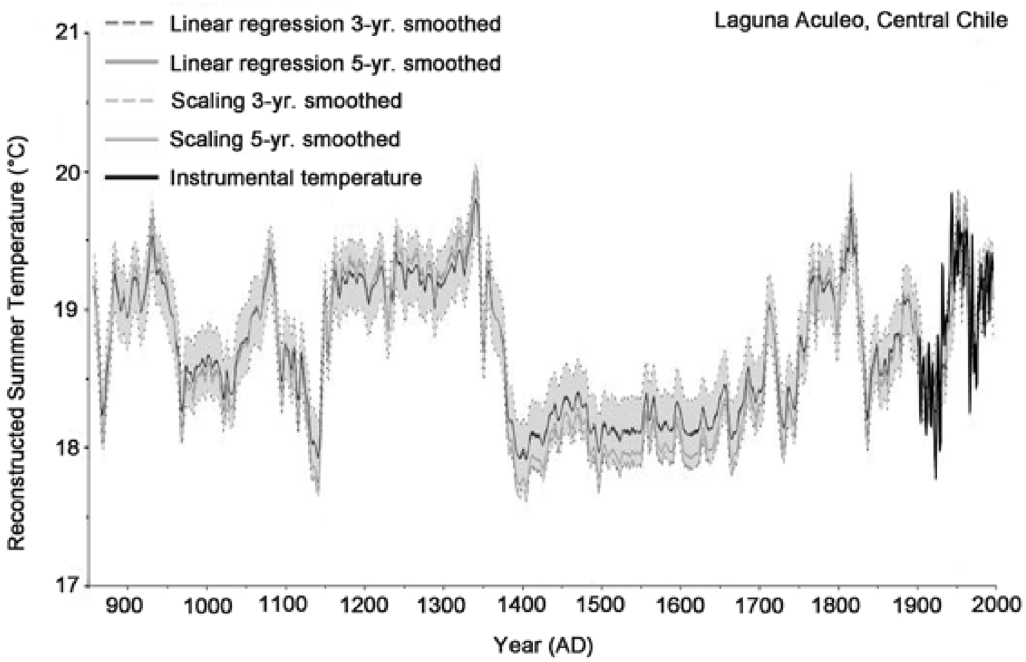

Figure 4.2.4.9.3.2. Proxy temperature reconstruction since AD 850 based on sedimentary pigments from a lake in central Chile. Adapted from von Gunten, L., Grosjean, M., Rein, B., Urrutia, R., and Appleby, P. 2009. A quantitative high-resolution summer temperature reconstruction based on sedimentary pigments from Laguna Aculeo, central Chile, back to AD 850. *The Holocene* **19**: 873–881.

climate changes and thereby determining their ultimate cause(s),” as well as for “predicting future abrupt climate changes.” The eight researchers conducted “a high-resolution multi-proxy study including the elemental and isotopic composition of bulk organic matter, land plant-derived biomarkers, and alkenone-based sea-surface temperature (SST) [derived] from a marine sedimentary record obtained from the Jacaf Fjord in northern Chilean Patagonia [44°20.00’S, 72°58.15’W]” to provide “a detailed reconstruction of continental runoff, precipitation and summer SST spanning the last 1750 years.”

The Chilean, German, and U.S. scientists report they “observed two different regimes of climate variability in [the] record: a relatively dry/warm period before 900 cal yr BP (higher runoff and average SST 1°C warmer than present day) and a wet/cold period after 750 cal yr BP (higher runoff and average SST 1°C colder than present day),” which they associate with the Medieval Warm Period and Little Ice Age, respectively. They conclude, “the reasonably good correlation between our results (particularly SST) and other continental and marine archives from central-south Chile, Peru, and Antarctica ... confirms the occurrence of globally important climatic anomalies such as the Medieval Warm Period and the Little Ice Age.”

Solari *et al*. (2010) obtained a δ^{18}O record stretching back in time about 1,200 years from the shore of Lago Sarmiento (51°03’00”S, 72°45’01”W) in southern Chile, where massive dead carbonate microbialites are exposed, to which they applied a “well-established, temperature-dependent oxygen isotope equilibrium fractionation equation between calcite and water” that yielded values of surface water temperature at a number of dates, the two oldest of which (AD 800 and 1100) bracketed the MWP at that location. The warmest of these values was 9.5°C, which was 1.26°C greater than the mean surface water temperature of 8.24°C they calculated from actual temperature measurements made every 20 minutes from April 1, 2003 to March 15, 2004. A δ^{18}O-based surface water temperature of 8.9°C is indicated fairly close to the present. Calculated conservatively, the peak temperature of the MWP was likely 0.6°C greater than the peak of the CWP.

Fletcher and Moreno (2012) "sampled and analyzed sediment cores from Laguna San Pedro (38°26'S, 71°19'W)," which they describe as "a small closed-basin lake located within the present-day distribution of *Araucaria-Nothofagus* forest in the Temperate-Mediterranean Transition zone in the Andes of Chile," where they reconstructed the vegetation, climate, and fire regime histories of the past 1,500 years. They found evidence of "persistent cool/La Nina ENSO states" during the periods 1300–1000 and 725–121 cal yr BP, which they identify as the "Dark Ages Cold Period and Little Ice Age, respectively." In addition, they report finding evidence of "low relative growing season moisture and warmer temperature that correspond well with evidence for persistent warm/El Nino ENSO states (1500–1300 and 1000–725 cal yr BP)," which they respectively associate with the Roman Warm Period and Medieval Climate Anomaly. Regarding the transition from the Little Ice Age to the Current Warm Period, which occurred from 121 cal yr BP (AD 1829) to the present, they found evidence for "a dramatic landscape alteration associated with the arrival of exotic taxa and an increase in burning," which they attribute to European colonization of the area. Fletcher and Moreno also state, "the palaeo-environmental history inferred from Laguna San Pedro provides important palaeo-climatic information for this part of southern South America that is poorly represented in the palaeo-climate literature."

Elbert *et al*. (2013) analyzed sediment cores from Laguna Escondida (45°31'S, 71°49'W) in Northern Chile for biogenic silica (bSi) concentrations, which they compared with modern meteorological data from the CRU TS 3.0 reanalysis data set (Mitchell and Jones, 2005; 0.5°x0.5° grid cell 45°S/72°W), while using radiometric dating (^{210}Pb, ^{137}Cs, ^{14}C-MS) to place the entire set of results in a temporally correct perspective. The result is depicted in Figure 4.2.4.9.3.3, showing the peak warmth of the Medieval Warm Period (~AD 920–1180) was about 2.9°C greater than the most recent sediment-derived Current Warm Period temperatures.

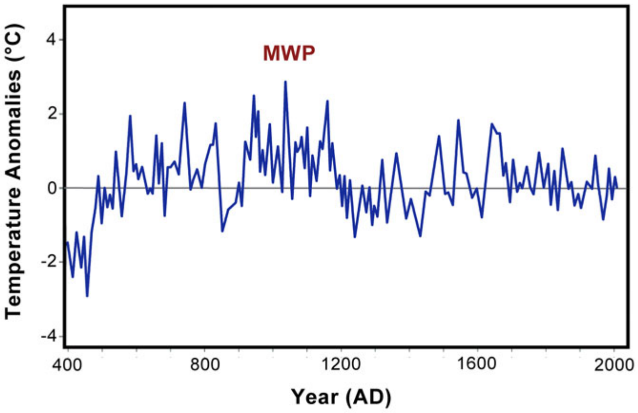

Figure 4.2.4.9.3.3. Proxy temperature reconstruction since AD 400 from a lake in northern Chile. Adapted from Elbert, J., Wartenburger, R., von Gunten, L., Urrutia, R., Fischer, D, Fujak, M., Hamann, Y., Greber, N.D., and Grosjean, M. 2013. Late Holocene air temperature variability reconstructed from the sediments of Laguna Escondida, Patagonia, Chile (45°30'S). *Palaeogeography, Palaeoclimatology, Palaeoecology* **369**: 482–492.

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Sepulveda, J., Pantoja, S., Hughen, K.A., Bertrand, S., Figueroa, D., Leon, T., Drenzek, N.J., and Lange, C. 2009. Late Holocene sea-surface temperature and precipitation variability in northern Patagonia, Chile (Jacaf Fjord, 44°S). *Quaternary Research* **72**: 400–409.

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von Gunten, L., Grosjean, M., Rein, B., Urrutia, R., and Appleby, P. 2009. A quantitative high-resolution summer temperature reconstruction based on sedimentary pigments from Laguna Aculeo, central Chile, back to AD 850. *The Holocene* **19**: 873–881.

4.2.4.9.4 Peru

Chepstow-Lusty *et al*. (1998) derived a 4,000-year climate history from a study of pollen in sediment cores obtained from a recently in-filled lake in the Patacancha Valley near Marcacocha. Their data indicate a several-century decline in pollen content after AD 100, as the Roman Warm Period gave way to the Dark Ages Cold Period. A "more optimum climate," as they describe it, with warmer temperatures and drier conditions, prevailed for several centuries after about AD 900, the Medieval Warm Period, followed by the Little Ice Age. These climatic periods are in nearly perfect temporal agreement with the climate history derived by McDermott *et al*. (2001) from a study of a stalagmite recovered from a cave nearly half the world away in Ireland.

Subsequent work in this area was conducted by Chepstow-Lusty and Winfield (2000). They identify "the warm global climatic interval frequently referred to as the Medieval Warm Epoch" centered on approximately 1,000 years ago. This extremely arid interval in this part of South America, in their opinion, may have played a significant role in the collapse of the Tiwanaku civilization further south, where a contemporaneous prolonged drought occurred in and around the area of Lake Titicaca (Binford *et al*., 1997; Abbott *et al*., 1997).

Near the start of this extended dry period, which established itself gradually between about AD 700 and 1000, Chepstow-Lusty and Winfield report, "temperatures were beginning to increase after a sustained cold period that had precluded agricultural activity at these altitudes." This earlier colder and wetter interval was coeval with the Dark Ages Cold Period of the North Atlantic region, which in the Peruvian Andes prevailed for much of the millennium preceding AD 1000, as revealed by a series of climatic records developed from sediment cores extracted from other lakes in the Central Peruvian Andes (Hansen *et al*., 1994) and by proxy evidence of concomitant Peruvian glacial expansion (Wright, 1984; Seltzer and Hastorf, 1990).

Preceding the Dark Ages Cold Period in both parts of the world was what in the North Atlantic region is called the Roman Warm Period. This well-defined climatic epoch is also strikingly evident in the pollen records of Chepstow-Lusty *et al*. (2003), straddling the BC/AD calendar break with one to two hundred years of relative warmth and significant aridity on both sides of it.

Data compiled by Chepstow-Lusty *et al*. (2003) reveal the occurrence of the Little Ice Age, which in the Central Peruvian Andes was characterized by relative coolness and wetness. These characteristics of that climatic interval are also evident in ice cores retrieved from the Quelccaya ice cap in southern Peru, the summit of which extends 5,670 meters above mean sea level (Thompson *et al*., 1986, 1988). Both the Quelccaya ice core data and the Marcacocha pollen data indicate the transition to the drier Current Warm Period that occurred over the past 100-plus years.

Rein *et al*. (2004) derived a high-resolution flood record of the entire Holocene from an analysis of the sediments in a 20-meter core retrieved from a sheltered basin situated on the edge of the Peruvian shelf about 80 km west of Lima. They found a major Holocene anomaly in the flux of lithic components from the continent onto the Peruvian shelf during the Medieval period. They report, "lithic concentrations were very low for about 450 years during the Medieval climatic anomaly from A.D. 800 to 1250" (see Figure 4.2.4.9.4.1). They write, "all known terrestrial deposits of El Niño mega-floods (Magillian and Goldstein, 2001; Wells, 1990) precede or follow the medieval anomaly in our marine records and none of the El Niño mega-floods known from the continent date within the marine anomaly." In addition, "this precipitation anomaly also occurred in other high-resolution records throughout the ENSO domain," citing 11 references in support of this statement.

Consequently, because heavy winter rainfalls

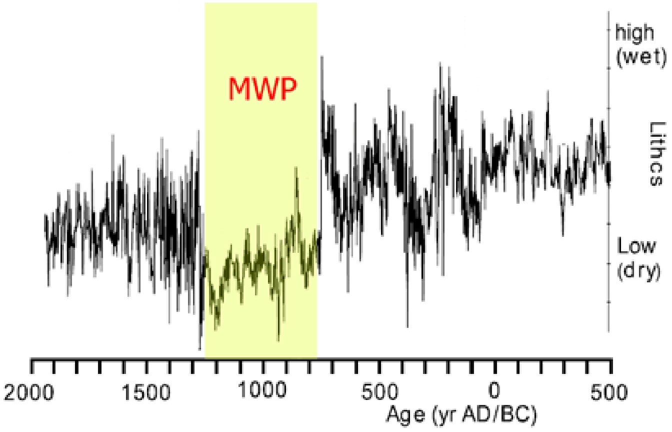

Figure 4.2.4.9.4.1. Marine record of El Niño flood sediments off Peru, as derived from lithic concentrations. Adapted from Rein B., Lückge, A., and Sirocko, F. 2004. A major Holocene ENSO anomaly during the Medieval period. *Geophysical Research Letters* **31**: 10.1029/2004GL020161.

along and off coastal Peru occur only during times of maximum El Niño strength, and because El Niños are typically more prevalent and stronger during cooler as opposed to warmer periods, the lack of strong El Niños from A.D. 800 to 1250 suggests this period was truly a Medieval Warm Period. The significance of this observation was not lost on Rein *et al.* In the introduction to their paper, for example, they observe, "discrepancies exist between the Mann curve and alternative time series for the Medieval period." Most notably, they write, "the global Mann curve has no temperature optimum, whereas the Esper *et al.* (2002) reconstruction shows northern hemisphere temperatures almost as high as those of the 20th century" during the Medieval Warm Period. Rein *et al.* conclude, "the occurrence of a Medieval climatic anomaly (A.D. 800–1250) with persistently weak El Niños may therefore assist the interpretation of some of the regional discrepancies in thermal reconstructions of Medieval times," a polite way of suggesting the Mann *et al.* (1998, 1999) hockey stick temperature history is deficient in failing to identify a true Medieval Warm Period.

Rein *et al.* (2005) derived sea surface temperatures from alkenones extracted from a high-resolution marine sediment core retrieved off the coast of Peru (12.05°S, 77.66°W), spanning the past 20,000 years and ending in the 1960s. Their Figure 11, reproduced here as Figure 4.2.4.9.4.2, shows the warmest temperatures of this 20,000 year period (~23.2°C) occurred during the late Medieval time (AD 800–1250). Taking this value, 23.2°C, and comparing it with the modern monthly long-term means in sea surface temperature, which the authors characterize as between 15°C and 22°C, the peak warmth of the Medieval Warm Period for this region was about 1.2°C above that of the Current Warm Period.

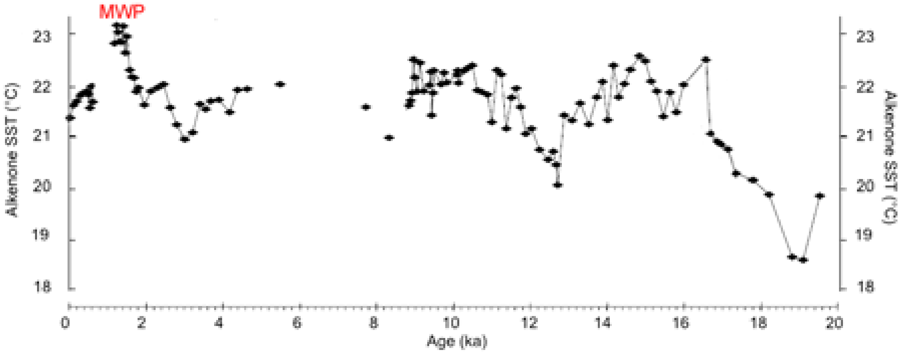

Figure 4.2.4.9.4.2. Coastal Peru proxy sea surface temperatures. Adapted from Rein B., Lückge, A., Reinhardt, L., Sirocko, F., Wolf, A., and Dullo, W.-C. 2005. El Niño variability off Peru during the last 20,000 years. *Paleoceanography* **20**: 10.1029/ 2004PA001099.

Sterken *et al.* (2006) conducted a quantitative diatom analysis on a sediment core obtained from the small infilled lake basin of Marcacocha, in the Cuzco region of the south central Andes mountains of Peru (13.22°S, 72.2°W) to reconstruct environmental changes during the past 1,200 years. The data indicated a major climate transition around AD 1070, representing "the most prominent change in the diatom record with a marked shift towards higher temperatures."

Unkel *et al*. (2007) employed “geomorphological field-work” and “chronometric analyses”—consisting of conventional ^{14}C-dating of charcoal, wood and root samples and optical-stimulated luminescence dating of feldspar and quartz—while investigating “alluvial archives and debris flow deposits” in the hyper-arid zone of the northern Atacama Desert of Peru between Pisco/Ica and Nazca/San Juan (~14.3°S, 75.3°W). This work, together with others’, indicates the existence of a period of “fluvial silence” for “the time of the 9th-13th centuries,” due to “increased aridification,” which they associated with the Medieval Warm Period (~AD 800–1250).

Bird *et al*. (2011) developed a 2,300-year history of the South American Summer Monsoon (SASM) from an annually resolved authigenic calcite record of precipitation δ^{18}O obtained from a varved lake in the Central Peruvian Andes—Laguna Pumacocha (10.70°S, 76.06°W, 4300 m asl). Their history shows, they write, “δ^{18}O peaked during the Medieval Climate Anomaly (MCA) from AD 900 to 1100, providing evidence the SASM weakened considerably during this period.” Thereafter, they found, “minimum δ^{18}O values occurred during the Little Ice Age (LIA) between AD 1400 and 1820, reflecting a prolonged intensi-fication of the SASM,” after which “δ^{18}O increased rapid-ly, particularly during the Current Warm Period (CWP; AD 1900 to present), indi-cating a return to reduced SASM precipitation.”

The six scientists also note the Pumacocha record tracks the 900-year-long Cascayunga Cave δ^{18}O record (6.09°S, 77.23°W, 930 m asl), which they say “is interpreted as a record of South American rainfall (Reuter *et al*., 2009).” They report it shares many features with the annually resolved Quelccaya Ice Cap δ^{18}O record (13.93°S, 70.83°W, 5670 m asl) derived by Thompson *et al*. (1986). They state, “the close agreement in the timing, direction, and magnitude of mean state changes in δ^{18}O during the MCA, LIA, and CWP from lake sediment, speleothem, and ice core records supports the idea that a common large-scale mechanism influenced δ^{18}O reaching these central Andean sites spanning 11° latitude and 4,740 meters of elevation.” They conclude, “the most likely cause of these documented shifts in δ^{18}Oprecip is a change in SASM intensity, as all three sites receive the majority of their annual precipitation during the monsoon season.”

Bird *et al*. also describe the “remarkable correspondence” that exists between the Pumacocha δ^{18}O record of SASM rainfall and the 2,000-year Northern Hemispheric temperature reconstruction of Moberg *et al*. (2005), plus the similar relationship both records share with the somewhat-shorter North Atlantic temperature reconstruction of Mann *et al*. (2009). Specifically, they indicate “the two greatest reductions in SASM intensity in the Pumacocha δ^{18}O record were coincident with Northern Hemisphere temperature maxima during the MCA and CWP,” and “the SASM was stronger than at any other point in the last 2,300 years when Northern Hemisphere temperatures were at a 2,000-year low during the LIA.” As noted above, their data show the same relationships exist between the Pumacocha δ^{18}O history and the North Atlantic temperature history.

Especially interesting about these observations is that Bird *et al.*’s graphical representations of the Northern Hemisphere and North Atlantic temperature histories of Moberg *et al*. and Mann *et al*. both show the peak warmth of the MCA to be at least as great as, and possibly even a little greater than, the peak warmth of the CWP, plus the fact that the δ^{18}O data of Bird *et al*. suggest much the same thing, based upon what they call the “remarkable correspondence” among the three datasets, which can be seen in Figure 4.2.4.9.4.3.

As illustrated in this figure, the correspondence among the four datasets is nothing short of astounding. The equivalent or slightly greater warmth of the MCA (known also as the Medieval Warm Period or MWP) compared to the CWP would appear to be well-established for the North Atlantic Ocean, the Northern Hemisphere, and a good portion of South America. In support of this conclusion, Bird *et al.* note the diminished SASM precipitation (higher δ^{18}O data) during the MWP and CWP also tracks the northward migration of the Intertropical Convergence Zone over the Atlantic, since “the Pumacocha record shows that the SASM was considerably reduced during the MCA when peak %Ti in the Cariaco Basin record indicates that the Intertropical Convergence Zone was persistently northward,” as demonstrated by Haug *et al.* (2001).

A growing body of evidence suggests the Medieval Warm Period of a thousand or so years ago was as warm as or warmer than the Current Warm Period to date. And with the air’s CO_2 concentration having risen by some 40 percent since the days of the MWP, without any net increase in temperature, it is unlikely Earth’s current warmth is being provided by that increase in the atmosphere’s CO_2 content.

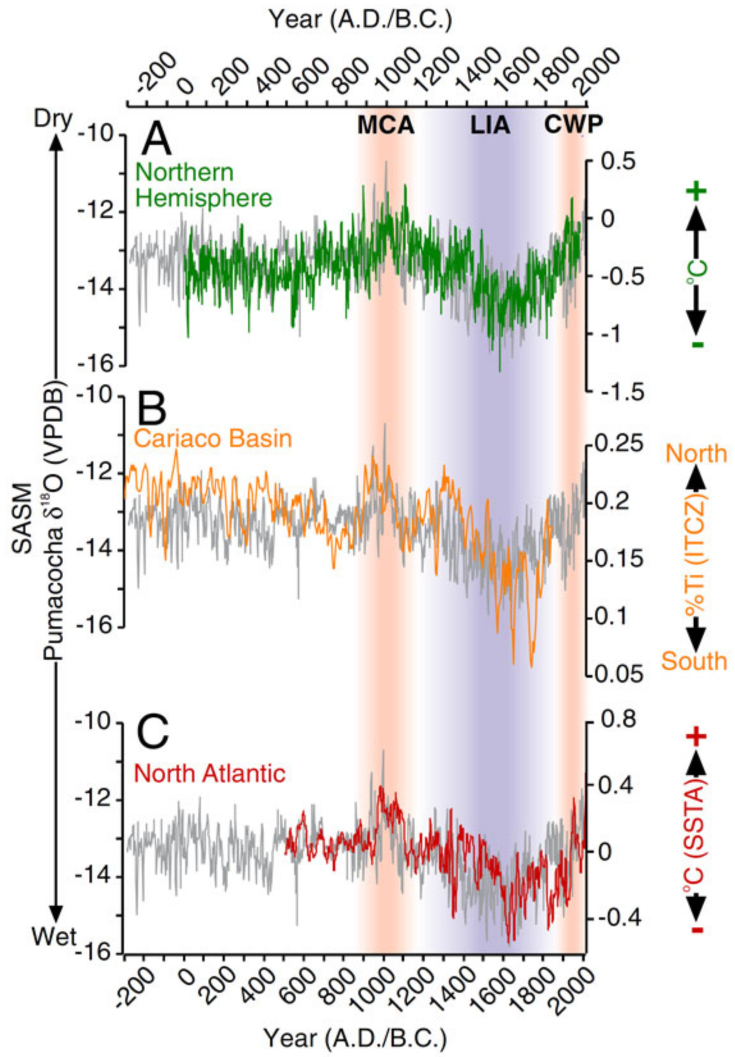

Figure 4.2.4.9.4.3. (A) The reconstructed Northern Hemispheric temperature history of Moberg, A., Sonechkin, D.M., Holmgren, K., Datsenko, N.M., and Karlen, W. 2005. Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data. *Nature* **433**: 613–617; (B) the reconstructed North Atlantic temperature history of Mann, M.E., Zhang, Z., Rutherford, S., Bradley, R.S., Hughes, M.K., Shindell, D., Ammann, C., Faluvegi, G., and Ni, F. 2009. Global signatures and dynamical origins of the Little Ice Age and Medieval Climate Anomaly. *Science* **326**: 1256–1260; and (C) the Cariaco Basin %Ti data of Haug, G.H., Hughen, K.A., Sigman, D.M., Peterson, L.C., and Rohl, U. 2001. Southward migration of the intertropical convergence zone through the Holocene. *Science* **293**: 1304–1308, which represent the degree of northward migration of the Intertropical Convergence Zone, each plotted together with the δ^{18}O data (gray lines) of Bird *et al*. (2011). Figure adapted from Bird, B.W., Abbott, M.B., Vuille, M., Rodbell, D.T., Stansell, N.D., and Rosenmeier, M.F. 2011. A 2,300-year-long annually resolved record of the South American summer monsoon from the Peruvian Andes. *Proceedings of the National Academy of Sciences USA* **108**: 8583–8588.

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4.2.4.9.5 Venezuela

Haug *et al.* (2001) found a temperature/precipitation relationship for Venezuela different from that of the rest of the continent. In examining the titanium and iron concentrations of an ocean sediment core taken from the Cariaco Basin on the country's northern shelf, they determined the concentrations of these elements were lower during the Younger Dryas cold period between 12.6 and 11.5 thousand years ago, corresponding to a weakened hydrologic cycle with less precipitation and runoff. During the warmth of the Holocene Optimum of 10.5 to 5.4 thousand years ago, they found, titanium and iron concentrations remained at or near their highest values, suggesting wet conditions and an enhanced hydrologic cycle. Closer to the present, higher precipitation also was noted during the Medieval Warm Period from 1.05 to 0.7 thousand years ago, followed by drier conditions associated with the Little Ice Age between 550 and 200 years ago.

Haug *et al.* (2003) developed a hydrologic history of pertinent portions of the record, which yielded "roughly bi-monthly resolution and clear resolution of the annual signal." According to this record, "before about 150 A.D.," which the climate history of McDermott *et al.* (2001) shows as corresponding to the latter portion of the Roman Warm Period (RWP), Mayan civilization flourished. During the transition to the Dark Ages Cold Period (DACP), which was accompanied by a slow but long decline in precipitation, "the first documented historical crisis hit the lowlands, which led to the 'Pre-Classic abandonment' (Webster, 2002) of major cities," Haug *et al.* report.

This crisis occurred during the first intense multi-year drought of the RWP-to-DACP transition, which was centered on about the year 250 AD Although the drought was devastating to the Maya, when it was over, "populations recovered, cities were reoccupied, and Maya culture blossomed in the following centuries during the so-called Classic period,” Haug *et al.* report. Between about 750 and 950 AD, during what Haug *et al.* determined was the driest interval of the entire Dark Ages Cold Period, “the Maya experienced a demographic disaster as profound as any other in human history” in response to a number of intense multi-year droughts. During this Terminal Classic Collapse, as it is called, “many of the densely populated urban centers were abandoned permanently, and Classic Maya civilization came to an end.”

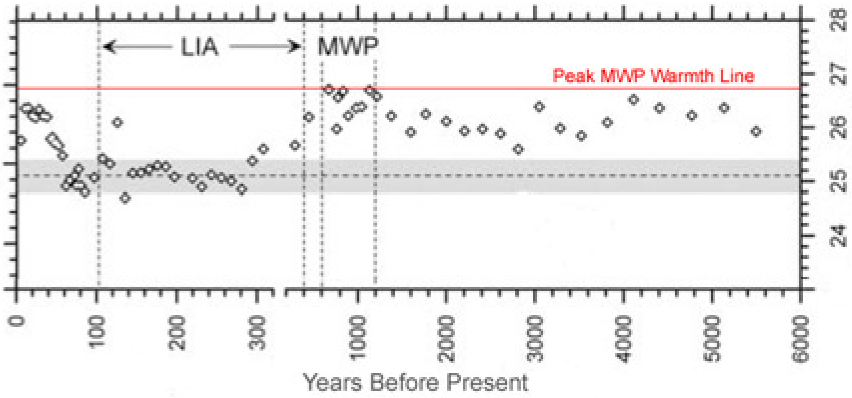

Figure 4.2.4.9.5.1. Alkenone-based SST reconstruction for the Cariaco Basin, Venezuela. Adapted from Goni, M.A., Woodworth, M.P., Aceves, H.L., Thunell, R.C., Tappa, E., Black, D., Muller-Karger, F., Astor, Y., and Varela, R. 2004. Generation, transport, and preservation of the alkenone-based $U37^{K'}$ sea surface temperature index in the water column and sediments of the Cariaco Basin (Venezuela). *Global Biogeochemical Cycles* **18**: 10.1029/2003GB002132.

Haug *et al.* conclude the latter droughts “were the most severe to affect this region in the first millennium A.D.” Although some of these spectacular droughts were “brief,” lasting “only” between three and nine years, Haug *et al.* report “they occurred during an extended period of reduced overall precipitation that may have already pushed the Maya system to the verge of collapse.

Although the Mayan civilization thus faded away, Haug *et al.*’s data soon thereafter depict the development of the Medieval Warm Period, when the Vikings established their historic settlement on Greenland. Then came the Little Ice Age, which just as quickly led to the Vikings’ demise in that part of the world. This distinctive cold interval of the planet’s millennial-scale climatic oscillation must have also led to hard times for the people of Mesoamerica and northern tropical South America, for the data of Haug *et al.* indicate the Little Ice Age produced by far the lowest precipitation regime (of several hundred years duration) of the last two millennia in that part of the world.

Goni *et al.* (2004) reconstructed a history of sea surface temperatures covering the past 6,000 years for the Cariaco Basin (20°30’N, 64°40’W) on the continental shelf off the central coast of Venezuela, based on the degree of un-saturation of certain long-chain alkenones synthesized by haptophyte algae contained in a sediment core retrieved from the eastern sub-basin.

Figure 4.2.4.9.5.1 shows the highest alkenone-derived sea surface temperatures “were measured during the Medieval Warm Period (MWP),” which Goni *et al.* identify as occurring between AD 800 and 1400. It is also evident peak MWP temperatures were approximately 0.35°C warmer than peak Current Warm Period (CWP) temperatures and fully 0.95°C warmer than the mean temperature of the last decade of the twentieth century.

Rein (2004) obtained high-resolution $\delta^{18}O$ records generated from seasonally representative planktic foraminifera from two ocean sediment cores extracted from the Cariaco Basin off the coast of Venezuela (~10.65°N, 64.66°W) to produce a temperature/salinity reconstruction in this region of the Caribbean/tropical North Atlantic over the last 2,000 years. A general trend toward cooler and perhaps more saline waters over the length of the record was observed. The authors describe discussion of the Medieval Warm Period and Little Ice Age as “complicated,” but they acknowledge their record reveals “an interval of warmer [sea surface temperatures] prior to ~ A.D. 1600–1900” where the $\delta^{18}O$ data “correctly sequence the relative temperature change between the so-called MWP and LIA.”

According to the authors’ graph of *G. bulloides* $\delta^{18}O$ (25-year mean, reproduced here as Figure 4.2.4.9.5.2), along with their stated relationship that a $\delta^{18}O$ change of 1.0‰ is equivalent to a 4.2°C change in temperature, the difference in peak warmth between the MWP and CWP can be calculated as 1.05°C, with the MWP being the warmer of the two

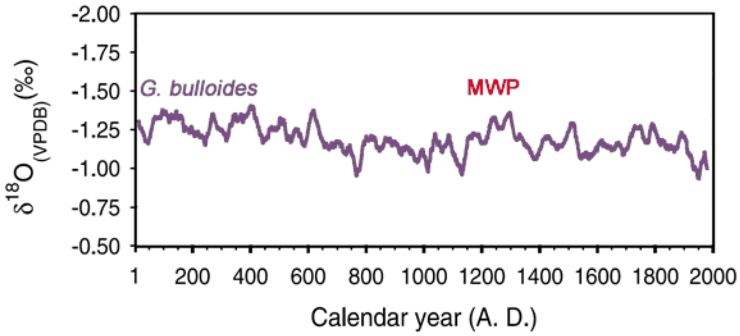

Figure 4.2.4.9.5.2. A high-resolution $\delta^{18}O$ temperature/salinity reconstruction from two ocean sediment cores extracted from the Cariaco Basin off the coast of Venezuela. Adapted from Black, D.E., Thunell, R.C., Kaplan, A., Peterson, L.C., and Tappa, E. J. 2004. A 2000-year record of Caribbean and tropical North Atlantic hydrographic variability. *Paleoceanography* **19**, PA2022, doi:10.1029/ 2003PA000982.

periods.

Polissar *et al*. (2006) derived continuous decadal-scale records of two climate-relevant parameters related to precipitation/ evaporation balance and, hence, glacier activity, from sediment cores extracted from Laguna Blanca (8°20'N, 71°47'W) and Laguna Mucubaji (8°47'N, 70°50'W). Data they obtained from the nearby Piedras Blancas peat bog yielded a third parameter—"pollen histories that chronicle vegetation change in response to climate." All three parameters suggest the MWP was warmer than the CWP.

In the case of Laguna Blanca magnetic susceptibility, the MWP's greater warmth extended from before the start of the record (sometime prior to AD 500) to approximately AD 1300. In the case of the abundance of sedge pollen from the Piedras Blancas peat bog, it extended from about AD 550 to 1020, and in the case of altitudinal shifts in ecological zones derived from the Piedras Blancas data, it extended from sometime before the start of the record to about AD 1000. All three datasets thus suggest the MWP, during the period AD 550–1000, was warmer than the CWP.

The Polissar *et al*. study also clearly implicated solar variability as the cause of the climatic variations they observed. The six scientists note, for example, "four glacial advances occurred between AD 1250 and 1810, coincident with solar-activity minima," and they note the data they presented "suggest that solar activity has exerted a strong influence on century-scale tropical climate variability during the late Holocene, modulating both precipitation and tempera-ture," in addition to demonstrating the "considerable sensitivity of tropical climate to small changes in radiative forcing from solar irradiance variability."

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Goni, M.A., Woodworth, M.P., Aceves, H.L., Thunell, R.C., Tappa, E., Black, D., Muller-Karger, F., Astor, Y., and Varela, R. 2004. Generation, transport, and preservation of the alkenone-based $U37^{K'}$ sea surface temperature index in the water column and sediments of the Cariaco Basin (Venezuela). *Global Biogeochemical Cycles* **18**: 10.1029/2003GB002132.

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4.2.4.9.6 Other/Multiple Regions

Kellerhals *et al*. (2010) write, "to place recent global warming into a longer-term perspective and to understand the mechanisms and causes of climate change, proxy-derived temperature estimates are needed for time periods prior to instrumental records and regions outside instrumental coverage." They also note "for tropical regions and the Southern

Hemisphere ... proxy information is very fragmentary."

Kellerhals *et al.* developed "a reconstruction of tropical South American temperature anomalies over the last ~1600 years ... based on a highly resolved and carefully dated ammonium record from an ice core that was drilled in 1999 on Nevado Illimani [16°37'S, 67°46'W] in the eastern Bolivian Andes." The researchers note "studies from other remote ice core sites have found significant correlations between $NH4^+$ concentration and temperature for Siberia and the Indian subcontinent for preindustrial time periods," citing the work of Kang *et al.* (2002) and Eichler *et al.* (2009). In calibrating and validating the $NH4^+$-to-°C transfer function, they say they used "the Amazon Basin subset of the gridded HadCRUT3 temperature data set," described by Brohan *et al.* (2006).

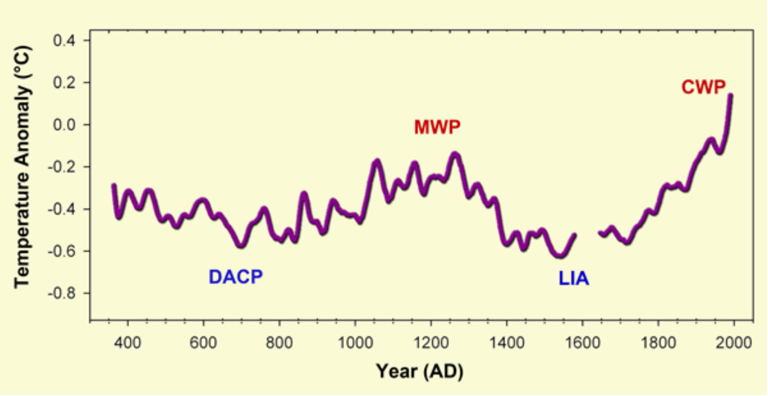

Figure 4.2.4.9.6.1. Reconstructed tropical South American temperature anomalies normalized to the AD 1961–1990 average and smoothed with a 39-year Gaussian filter. Adapted from Kellerhals, T., Brutsch, S., Sigl, M., Knusel, S., Gaggeler, H.W., and Schwikowski, M. 2010. Ammonium concentration in ice cores: a new proxy for regional temperature reconstruction? *Journal of Geophysical Research* **115**: 10.1029/2009JD012603.

The results of this analysis are depicted in Figure 4.2.4.9.6.1. The scientists report, "the most striking features in the reconstruction are [1] the warm temperatures from ~1050 to ~1300 AD [the Medieval Warm Period] compared to the preceding and following centuries, [2] the persistent cooler temperatures from ~1400 to ~1800 AD [the Little Ice Age], and [3] the subsequent rise to warmer temperatures [the Current Warm Period] which eventually seem to exceed, in the last decades of the 20th century, the range of past variation." In regard to this last observation—as best as can be determined from their graph of the data—the peak warmth of the Current Warm Period was ~0.27°C greater than the peak warmth of the Medieval Warm Period.

Kellerhals *et al.* note the terms Little Ice Age (LIA) and Medieval Warm Period (MWP) can be validly employed to describe the "extensive advances of alpine glaciers in Europe from the 16th to the 19th century and the comparatively warm conditions in Europe from the 10th to the 13th century." However, they add, the implication that these terms represent "globally synchronous cold and warm periods" has been dismissed by the IPCC and others. Kellerhals *et al.* conclude the "relatively warm temperatures during the first centuries of the past millennium and subsequent cold conditions from the 15th to the 18th century suggest that the MWP and the LIA are not confined to high northern latitudes," and they "also have a tropical signature." These observations add to the growing body of evidence demonstrating the global extent of the millennial-scale oscillation of climate that produced both the MWP and the LIA, and which has likely been responsible for the bulk of the warming that led to the establishment of the Current Warm Period.

Neukom *et al.* (2011) reconstructed a mean austral summer (December–February) temperature history for the period AD 900–1995 for the terrestrial area of the planet located between 20°S and 55°S and between 30°W and 80°W—a region they call Southern South America (SSA)—using 22 of the best climate proxies they could find that stretched far enough back in time. Their results, they note, "represent the first seasonal sub-continental-scale climate field reconstructions of the Southern Hemisphere going so far back in time." Such an analysis, the authors state, was necessary "to put the recent warming into a larger temporal and spatial context."

According to the international research team—composed of scientists from Argentina, Chile, Germany, Switzerland, The Netherlands, the United Kingdom, and the United States—their summer temperature reconstruction indicates "a warm period extended in SSA from 900 (or even earlier) to the mid-fourteenth century," which they describe as having been "towards the end of the Medieval Climate Anomaly as concluded from Northern Hemisphere temperature reconstructions." As depicted in Figure 4.2.4.9.6.2, their calculations show

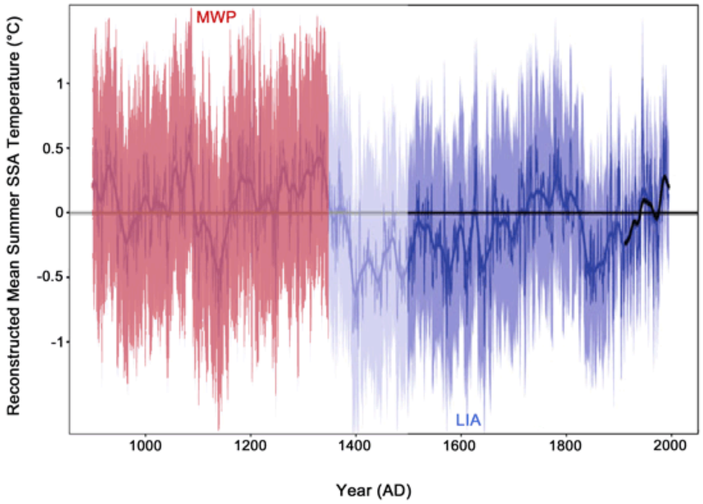

Figure 4.2.4.9.6.2. Reconstructed mean summer SSA temperatures. Adapted from Neukom, R., Luterbacher, J., Villalba, R., Kuttel, M., Frank, D., Jones, P.D., Grosjean, M., Wanner, H., Aravena, J.-C., Black, D.E., Christie, D.A., D'Arrigo, R., Lara, A., Morales, M., Soliz-Gamboa, C., Srur, A., Urritia, R., and von Gunten, L. 2011. Multiproxy summer and winter surface air temperature field reconstructions for southern South America covering the past centuries. *Climate Dynamics* **37**: 35–51.

the warmest decade of this Medieval Warm Period was AD 1079–1088, which, as best as can be determined from their graph, is about 0.17°C warmer than the peak warmth of the Current Warm Period.

Bracco *et al*. (2011) studied the emergence and development of prehistoric mound building in southeast Uruguay, employing paleoclimatic data to obtain a picture of how the climate of the region changed in the past 7,000 years. Focusing on the coastal lagoons within the Merin Lagoon basin, located between 31–34°S and 52–54°W in the easternmost part of the South American plains, Bracco *et al*. say paleolimnological investigations were initiated there in AD 2000 by a multidisciplinary group of researchers who studied past climate conditions via "multiproxy analyses (i.e., diatoms, opal phytoliths, pollen, molluscs, sediments, geochemistry, thin sections), together with radiocarbon dating." Working predominantly with phytoliths found in various sediment cores, they derived 7,000-year histories of both temperature and a humidity index.

The South American scientists found a period (AD 750–1350) "characterized by warmer and wetter conditions than those of the present," which matches well with the timeframe of the Medieval Warm Period. Within this period, they write, "there are two peaks of extreme humid and warm events," the second of which "fits chronologically into the 'Warm Period' (Broecker, 2001; Roberts, 2009), whose occurrence has been already pointed out by Iriondo and Garcia (1993) and Prevosti *et al*. (2004) in this region."

These findings help confirm the global nature of the Medieval Warm Period. Bracco *et al*. also note their results "are consistent with other paleoclimatic reconstructions (Bracco *et al*., 2005; Garcia-Rodriguez *et al*., 2009) and the synthesis presented by Mancini *et al*. (2005), and they are partially consistent with other regional studies (Iriondo and Garcia, 1993; Prieto, 1996, 2000; Iriondo, 1999; Panario and Gutierrez, 1999; Tonni *et al*., 1999; Zarate *et al*., 2000; Prieto *et al*., 2004; Quattrocchio *et al*., 2008; Piovano *et al*., 2009, in Argentina; Behling, 1995, 2002, 2007; Melo *et al*., 2003; Moro *et al*., 2004, in Brazil." This growing body of empirical findings is evidence of the millennial-scale cycling of our planet's climate, which after the passing of the Little Ice Age that followed the Medieval Warm Period is likely what has most recently ushered us into the Current Warm Period.

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4.3 Predicted vs. Observed Global Warming Effects on ENSO

Computer model simulations have given rise to three claims regarding the influence of global warming on ENSO events: (1) global warming will increase the frequency of ENSO events, (2) global warming will increase the intensity of ENSO events, and (3) weather-related disasters will be exacerbated under El Niño conditions (see, for example, Timmermann *et al.*, 1999; Collins 2000a,b; Cubasch *et al.*, 2001). However, as outlined in the following two subsections, this is generally not what observational data show. The data for nearly all historical records show frequent and strong El Niño activity increases during periods of colder temperatures (e.g., the Little Ice Age) and decreases during warm ones (e.g., Medieval Warm Period, Current Warm Period).

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4.3.1 Frequency and Intensity

Mendelssohn *et al.* (2005) performed a statistical analysis known as state-space decomposition on three El Niño-related indices (Southern Oscillation Index, its component sea level pressure series, and the NINO3 index) for the twentieth century. The stochastic cycles produced by the state-space models were all relatively stationary, which, in the words of the investigative scientists, does “not support the idea that El Niños have become more frequent.” As to the magnitude of ENSO events, they say there were some “outlier events” in the later portion of the record, which may suggest ENSO magnitudes have increased in recent years, but they conclude “it is premature to tell.”

Lee and McPhaden (2010) used satellite observations of sea surface temperature (SST) in the past three decades “to examine SST in the CP region, distinguishing between the increases in El Niño intensity and changes in background SST.” The two U.S. researchers discovered the SSTs in the CP region during El Niño years are “getting significantly higher while those during La Niña and neutral years are not.” Therefore, they reason, “the increasing intensity of El Niño events in the CP region is not simply the result of the well-documented background warming trend in the western-Pacific warm pool,” but instead “it is the increasing amplitude of El Niño events that causes a net warming trend of SST in the CP region.”

Lee and McPhaden conclude their results “suggest that, at least for the past three decades, the warming of the warm pool in the CP region is primarily because of more intense El Niño events in that region.” In addition, they report, “in contrast to the CP region, the intensity of El Niño events in the EP region does not have a warming trend, and even has a cooling trend (though not significant at the 90% level of confidence) over the three-decade period.” They write, “further investigation is therefore needed to understand these issues better, given the uncertainty surrounding causal mechanisms and the implications the observed changes have for global climate and societal impacts.”

Noting DelSole and Tippett (2009) had recently demonstrated relatively short meteorological records, on the order of 50 years or less, “are not sufficient to detect trends in a mode of variability such as ENSO,” Ray and Giese (2012) explored the postulated global warming-ENSO connection by comparing sea surface temperatures (SSTs) derived from an ocean reanalysis with three widely used SST reconstructions. They used the reanalysis data to evaluate potential changes in ENSO characteristics over the period 1871–2008. The two researchers conclude, “there is no evidence that there are changes in the [1] strength, [2] frequency, [3]duration, [4] location or [5] direction of propagation of El Niño and La Niña anomalies caused by global warming during the period from 1871 to 2008.”

Yeh *et al*. (2011) state there is an "expectation that ENSO [El Niño-Southern Oscillation] statistics would change under global warming, although the details remain uncertain because of the large spread of model projections for the 21st century (Guilyardi *et al*., 2009)." In addition, they note there is evidence of "increasing intensity as well as occurrence frequency of the so-called Central Pacific (CP) El Niño events since the 1990s." This brings up the question of whether the latter is a consequence of global warming.

In exploring this highly unsettled (Collins *et al*., 2010) situation, Yeh *et al*. ran a multi-millennial CGCM (coupled general circulation model) simulation "to assess whether the natural changes in the frequency of CP El Niño occurrence simulated by the model are comparable to the observed changes over the last few decades," suggesting, "if the changes are similar then we cannot rule out the possibility that the recent changes are simply natural variability."

The five researchers report their control simulation—run for 4.200 years of data with the present values of greenhouse gases—"exhibits large variations of the occurrence frequency of the CP El Niño versus the eastern Pacific (EP) El Niño" and "simulates to some extent changes in the occurrence ratio of CP and EP El Niño in comparison with the observations." Therefore, they conclude, "we cannot exclude the possibility that an increasing of occurrence frequency of CP El Niño during recent decades in the observation could be a part of natural variability in the tropical climate system," providing more evidence for the likely cyclical origin of recent global warming.

Nicholls (2008) notes there has been a "long-running debate as to how the El Niño-Southern Oscillation (ENSO) might react to global warming," and "the focus in most model studies on ENSO and climate change has been on whether the Pacific will tend to a more permanent El Niño state as the world warms due to an enhanced greenhouse effect." Nicholls examined "trends in the seasonal and temporal behaviour of ENSO, specifically its phase-locking to the annual cycle over the past 50 years," where phase-locking "means that El Niño and La Niña events tend to start about April–May and reach a maximum amplitude about December–February," which is why he examined trends in ENSO indices for each month of the year.

The Australian researcher thus determined "there has been no substantial modulation of the temporal/seasonal behaviour of the El Niño-Southern Oscillation"—as measured by the sea surface temperature averaged across the region 5°S–5°N by 120°W–170°W, and the Southern Oscillation Index (the non-standardized difference between sea level pressures at Tahiti and Darwin)—over the past 50 years, during what he describes as "a period of substantial growth in the atmospheric concentrations of greenhouse gases and of global warming." Nicholls reports "the temporal/seasonal nature of the El Niño-Southern Oscillation has been remarkably consistent through a period of strong global warming," clearly repudiating climate-model-derived inferences of global warming increasing both the frequency and intensity of ENSO events.

In a paper addressing "the need for a reliable ENSO index that allows for the historical definition of ENSO events in the instrumental record back to 1871," Wolter and Timlin (2011) state their Multivariate ENSO Index (MEI) was originally defined by them (Wolter and Timlin, 1993, 1998) as "the first seasonally varying principal component of six atmosphere-ocean variable fields in the tropical Pacific basin." This index, they note, "provides for a more complete and flexible description of the ENSO phenomenon than single variable ENSO indices."

To improve even further on their earlier refinement, the two U.S. researchers describe their efforts "to boil the MEI concept down to its most essential components (based on sea level pressure and sea surface temperature) to enable historical analyses that more than double its period of record." Their efforts, they note, were "designed to help with the assessment of ENSO conditions through as long a record as possible to be able to differentiate between 'natural' ENSO behavior in all its rich facets, and the 'Brave New World' of this phenomenon under evolving greenhouse gas-related climate conditions."

Wolter and Timlin report, "the new MEI.ext confirms that ENSO activity went through a lull in the early- to mid-20th century, but was just about as prevalent one century ago as in recent decades." They write, "so far, none of the behavior of recent ENSO events appears unprecedented, including duration, onset timing, and spacing in the last few decades compared to a full century before then."

Evans *et al*. (2002) reconstructed gridded Pacific Ocean sea surface temperatures from coral stable isotope ($\delta^{18}O$) data, from which they assessed ENSO activity over the period 1607–1990. The results of their analysis show a period of relatively vigorous ENSO activity over the colder-than-present period of

1820–1860 was "similar to [that] observed in the past two decades." Similarly, in a study partly based on the instrumental temperature record for the period 1876–1996, Allan and D'Arrigo (1999) found four persistent El Niño sequences similar to that of the 1990s, and using tree-ring proxy data covering the period 1706 to 1977, they found several other ENSO events of prolonged duration. There were four or five persistent El Niño sequences in each of the eighteenth and nineteenth centuries, and both these centuries were significantly colder than the final two decades of the twentieth century. This led them to conclude there is "no evidence for an enhanced greenhouse influence in the frequency or duration of 'persistent' ENSO event sequences."

Brook *et al.* (1999) analyzed the layering of couplets of inclusion-rich calcite over inclusion-free calcite, and darker aragonite over clear aragonite, in two stalagmites from Anjohibe Cave in Madagascar, comparing their results with historical records of El Niño events and proxy records of El Niño events and sea surface temperatures derived from ice core and coral data. The cave-derived record of El Niño events compared well with the historical and proxy ice core and coral records, and these data indicated, Brook *et al.* report, "the period 1700–50 possibly witnessed the highest frequency of El Niño events in the last four and a half centuries while the period 1780–1930 was the longest period of consistently high El Niño occurrences." Both of these periods were considerably cooler than the 1980s and 1990s.

Braganza *et al.* (2009) developed an annually resolved Pacific-basin-wide ENSO index for the period AD 1525–1982 based on tree-ring, coral, and ice-core data obtained from the western equatorial Pacific, New Zealand, the central Pacific, and subtropical North America—which constitute, they write, "a set of multiproxy indicators from locations that span a broader area of the Pacific basin than has been attempted previously." According to the five researchers, "the proxy ENSO index over the last 450 years shows considerable amplitude and frequency modulation in the 3–10 year band on multidecadal time scales." They further state, "in the context of the entire record, we find no pronounced signal of twentieth century climate change in ENSO variability."

Meyerson *et al.* (2003) analyzed an annually dated ice core from the South Pole for the period 1487–1992, focusing on the marine biogenic sulfur species methanesulfonate (MS). They used orthogonal function analysis to calibrate the high-resolution MS series with associated environmental series for the period of overlap (1973–1992). This procedure allowed them to derive a five-century history of ENSO activity and southeastern Pacific sea-ice extent; the latter parameter "is indicative of regional temperatures within the Little Ice Age period in the southeastern Pacific sea-ice sector."

Meyerson *et al.* found a shift toward generally cooler conditions at about 1800 AD. This shift was concurrent with an increase in the frequency of El Niño events in the ice core proxy record, which contradicts what climate models generally predict. Their findings are, by contrast, harmonious with the historical El Niño chronologies of both South America (Quinn and Neal, 1992) and the Nile region (Quinn, 1992; Diaz and Pulwarty, 1994). These records depict, they note, "increased El Niño activity during the period of the Little Ice Age (nominally 1400–1900) and decreased El Niño activity during the Medieval Warm Period (nominally 950–1250)," as per Anderson (1992) and de Putter *et al.* (1998).

Wang *et al.* (2004) evaluated all ENSO events they could identify in existing records of the past 500 years to see if there was any significant increase in their frequency of their occurrence over the twentieth century. Although Wang *et al.* note El Niño frequency was a little higher in the twentieth century, and La Niña frequency was somewhat higher during the Little Ice Age, they report "ENSO frequency [was] relatively stationary during the last 500 years, including the Little Ice Age (1550–1850) and Modern Warming Period (the 20th century)." They note Diaz and Pulwarty (1994) found "the frequency of ENSO during the Little Ice Age does not differ greatly from that found in the 20th century based on singular spectrum analysis and evolutive spectral analysis."

Herweijer *et al.* (2007) put into longer perspective "the famous droughts of the instrumental record (i.e., the 1930s Dust Bowl and the 1950s Southwest droughts)," using Palmer Drought Severity Index data found in the North American Drought Atlas prepared by Cook and Krusic (2004), which were derived from a network of drought-sensitive tree-ring chronologies (some stretching back to AD 800 and encompassing the Medieval Warm Period). The authors found "medieval megadroughts were forced by protracted La Niña-like tropical Pacific sea surface temperatures." In addition, the data identify "a global hydroclimatic 'footprint' of the medieval era revealed by existing paleoclimatic archives from the tropical Pacific and ENSO-sensitive tropical and extratropical land regions." The authors state, "this global pattern matches that observed for modern-day persistent North American drought," namely, "a La Niña-like tropical Pacific."

Khider *et al.* (2011) developed a history of ENSO variability over a period of time that included both the Medieval Climate Anomaly (MCA, AD 800–1300) and the Little Ice Age (LIA, AD 1500–1850) "by comparing the spread and symmetry of $\delta^{18}O$ values of individual specimens of the thermocline-dwelling planktonic foraminifer *Pulleniatina obliquiloculata* extracted from discrete time horizons of a sediment core collected in the Sulawesi Sea, at the edge of the western tropical Pacific warm pool," and by interpreting the spread of individual $\delta^{18}O$ values "to be a measure of the strength of both phases of ENSO." The five researchers used the symmetry of the $\delta^{18}O$ distributions "to evaluate the relative strength/frequency of El Niño and La Niña events." They report "the strength/frequency of ENSO, as inferred from the spread of the $\delta^{18}O$ distributions, during the MCA and during the LIA was not statistically distinguishable and was comparable to that of the 20th century." They write, their results suggest "ENSO during the MCA was skewed toward stronger/more frequent La Niña than El Niño," an observation they note is "consistent with the medieval megadroughts documented from sites in western North America."

Cobb *et al.* (2003) generated multi-century, monthly-resolved records of tropical Pacific climate variability over the last millennium by splicing together overlapping fossil-coral records from the central tropical Pacific. This allowed them "to characterize the range of natural variability in the tropical Pacific climate system with unprecedented fidelity and detail." They discovered "ENSO activity in the seventeenth-century sequence [was] not only stronger, but more frequent than ENSO activity in the late twentieth century." They also found "there [were] 30-yr intervals during both the twelfth and fourteenth centuries when ENSO activity [was] greatly reduced relative to twentieth-century observations." Once again, ENSO activity is shown to have been much greater and more intense during the cold of the Little Ice Age than the warmth of the late twentieth century.

Eltahir and Wang (1999) used water-level records of the Nile River as a proxy for El Niño episodes over the past 14 centuries. Although the frequency of El Niño events over the 1980s and 1990s was high, they found it was not without precedent, being similar to values observed near the start of the twentieth century and much the same as those "experienced during the last three centuries of the first millennium." The latter period, according to Esper *et al.* (2002), was also significantly cooler than the latter part of the twentieth century.

Langton *et al.* (2008) used geochemical data obtained by analysis of a sediment core extracted from the shallow-silled and intermittently dysoxic Kau Bay in Halmahera, Indonesia (1°N, 127.5°E) to reconstruct century-scale climate variability within the Western Pacific Warm Pool over the past 3,500 years. Langton *et al.* report, "basin stagnation, signaling less El Niño-like conditions, occurred during the time frame of the Medieval Warm Period (MWP), from ca. 1000 to 750 years BP," which was "followed by an increase in El Niño activity that culminated at the beginning of the Little Ice Age ca. 700 years BP." Thereafter, their record suggests, "the remainder of the Little Ice Age was characterized by a steady decrease in El Niño activity with warming and freshening of the surface water that continued to the present." In addition, they state, "the chronology of flood deposits in Laguna Pallcacocha, Ecuador (Moy *et al.*, 2002; Rodbell *et al.*, 1999), attributed to intense El Niño events, shows similar century-scale periods of increased [and decreased] El Niño frequency."

The nine researchers conclude "the finding of similar century-scale variability in climate archives from two El Niño-sensitive regions on opposite sides of the tropical Pacific strongly suggests they are dominated by the low-frequency variability of ENSO-related changes in the mean state of the surface ocean in [the] equatorial Pacific," and the "century-scale variability," as they describe it, suggests global warming typically tends to retard El Nino activity and global cooling tends to promote it.

Woodroffe *et al.* (2003) confirmed this finding applied over an even longer period of time. Using oxygen isotope ratios obtained from *Porites* microatolls at Christmas Island in the central Pacific to provide high-resolution proxy records of ENSO variability since 3.8 thousand years ago (ka), they found, "individual ENSO events in the late Holocene [3.8–2.8 ka] appear at least as intense as those experienced in the past two decades." In addition, "geoarcheological evidence from South America (Sandweiss *et al.*, 1996), Ecuadorian varved lake sediments (Rodbell *et al.*, 1999), and corals from Papua New Guinea (Tudhope *et al.*, 2001) indicate that ENSO events were considerably weaker or absent between 8.8 and 5.8 ka," the warmest period of the Holocene. They report, "faunal remains from archeological sites in Peru (Sandweiss *et al.*, 2001) indicate that the onset of modern, rapid ENSO recurrence intervals was achieved only after ~4-3 ka," or during the long cold interlude that preceded the Roman Warm Period (McDermott *et al*., 2001).

Wei *et al*. (2007) reconstructed three mid-Holocene sea surface temperature (SST) records spanning more than 30 years using Sr/Ca ratios derived from cores of three *Porites lutea* colonies in the fringe reef at Dadonghai, Sanya in southern Hainan Island, which lived about 6,000 years ago at a water depth similar to that of modern coral at that location (approximately 18°12'N, 109°33'E). According to the six researchers, "the results indicate warmer than present climates between circa 6100 yr B.P. and circa 6500 yr B.P. with the mid-Holocene average minimum monthly winter SSTs, the average maximum monthly summer SSTs, and the average annual SSTs being about 0.5°–1.4°C, 0°–2.0°C, and 0.2°–1.5°C higher, respectively, than they were during 1970–1994." In addition, they report, "ENSO variability in the mid-Holocene SSTs was weaker than that in the modern record, and the SST record with the highest summer temperatures from circa 6460 yr B.P. to 6496 yr B.P. shows no robust ENSO cycle."

McGregor and Gagan (2004) used several annually resolved fossil *Porites* coral δ^{18}O records to investigate the characteristics of ENSO events over a period of time in which Earth cooled substantially. For comparison, study of a modern coral core provided evidence of ENSO events for the period 1950–1997, the results of which analysis suggest they occurred at a rate of 19 events/century. The mid-Holocene coral δ^{18}O records, by contrast, showed reduced rates of ENSO occurrence: 12 events/century for the period 7.6–7.1 ka, eight events/century for the period 6.1–5.4 ka, and six events/century at 6.5 ka. For the period 2.5–1.7 ka, the results were quite different, with all of the coral records revealing "large and protracted δ^{18}O anomalies indicative of particularly severe El Niño events." They note, for example, "the 2.5 ka Madang PNG coral records a protracted 4-year El Niño, like the 1991–1994 event, but almost twice the amplitude of [the] 1997–1998 event (Tudhope *et al*., 2001)." In addition, "the 2 ka Muschu Island coral δ^{18}O record shows a severe 7-year El Niño, longer than any recorded Holocene or modern event." And they add, "the 1.7 ka *Porites* microatoll of Woodroffe *et al*. (2003) also records an extreme El Niño that was twice the amplitude of the 1997–1998 event." Taken together, these results portray a "mid-Holocene El Niño suppression and late Holocene amplification."

That there tend to be fewer and weaker ENSO events during warm periods is documented further by Riedinger *et al*. (2002). In a 7,000-year study of ENSO activity in the vicinity of the Galapagos Islands, they determined "mid-Holocene [7130 to 4600 yr BP] El Niño activity was infrequent," when global air temperature was significantly warmer than it is now, but both the "frequency and intensity of events increased at about 3100 yr BP," when the world cooled below today's temperatures. Throughout the former 2,530-year warm period, there were only 23 strong to very strong El Niños and 56 moderate events, according to their data, whereas throughout the most recent (and significantly colder) 3,100-year period, they identified 80 strong to very strong El Niños and 186 moderate events. These numbers correspond to rates of 0.9 strong and 2.2 moderate occurrences per century in the earlier, warm period and 2.7 strong and 6.0 moderate occurrences per century in the latter, cool period, an approximate tripling of the rate of occurrence of both strong and moderate El Niños in going from the warmth of the Holocene "Climatic Optimum" to the colder conditions of the past three millennia.

Similar results have been reported by Andrus *et al*. (2002), who found sea surface temperatures off the coast of Peru were 3 to 4°C warmer 6,000 years ago than in the 1990s and provided little evidence of El Niño activity.

Moy *et al*. (2002) analyzed a sediment core from lake Laguna Pallcacocha in the southern Ecuadorian Andes, producing a proxy measure of ENSO over the past 12,000 years. For the moderate and strong ENSO events detected by their analytical techniques (weaker events are not registered), "the overall trend exhibited in the Pallcacocha record includes a low concentration of events in the early Holocene, followed by increasing occurrence after 7,000 cal. yr BP, with peak event frequency occurring at ~1,200 cal. yr BP," after which the frequency of events declines dramatically to the present, they write.

In the last 1,200 years of this record, the decline in the frequency of ENSO events is anything but smooth. In coming out of the Dark Ages Cold Period, one of the coldest intervals of the Holocene (McDermott *et al*., 2001), the number of ENSO events drops by an order of magnitude, from a high of approximately 33 events per 100 yr to a low of about three events per 100 yr, centered approximately on the year AD 1000, right in the middle of the Medieval Warm Period as delineated by the work of Esper *et al*.

(2002). At approximately AD 1250, the frequency of ENSO events exhibits a new peak of approximately 27 events per century in the midst of the longest sustained cold period of the Little Ice Age, again as delineated by the work of Esper *et al*. Finally, ENSO event frequency declines in zigzag fashion to a low on the order of four to five events per century at the start of the Current Warm Period, which according to the temperature history of Esper *et al*. begins at about 1940.

A similar decline in ENSO events during the Medieval Warm Period is noted by Rein *et al*. (2004), who derived a high-resolution flood record of the entire Holocene from an analysis of the sediments in a 20-meter core retrieved from a sheltered basin on the edge of the Peruvian shelf about 80 km west of Lima, Peru. Rein *et al*. found a major Holocene anomaly in the flux of lithic components from the continent onto the Peruvian shelf during the late Medieval period. They report "lithic concentrations were very low for about 450 years during the Medieval climatic anomaly from A.D. 800 to 1250." They write, "all known terrestrial deposits of El Niño mega-floods (Magillian and Goldstein, 2001; Wells, 1990) precede or follow the medieval anomaly in our marine records and none of the El Niño mega-floods known from the continent date within the marine anomaly."

In addition, they report, "this precipitation anomaly also occurred in other high-resolution records throughout the ENSO domain." Rein *et al*. note, for example, "from an Ecuadorian lake record where moderate to strong El Niño floods are recorded (Moy *et al*., 2002), a minimum of such events is reported during the upper Medieval period." They also note the oldest (A.D. 928–961) of the five "time windows" on central Pacific El Niño activity provided by the corals investigated by Cobb *et al*. (2003) exhibits evidence for weaker El Niños than all subsequent time windows extending to 1998. In addition, they note, "extreme long-lasting droughts that peaked coincident with those in the Peru record around A.D. 1160, are reported from several archives in the western USA and Southern Patagonia (Stine, 1994)," and near-contemporaneous dry periods "also occurred in the tropical Andes (Abbot *et al*., 1997; Binford *et al*., 1997), Oman (Fleitmann *et al*., 2003) and eastern Africa (De Putter *et al*., 1998; Verschuren *et al*., 2000)." They conclude, "hints that these droughts are not only coinciding events but related to El Niño anomalies come from the high-resolution Moon Lake (North Dakota, USA) salinity record (Laird *et al*., 1996)."

Rittenour *et al*. (2000) studied a recently revised New England varve chronology derived from proglacial lakes formed during the recession of the Laurentide ice sheet some 17,500 to 13,500 years ago, finding "the chronology shows a distinct interannual band of enhanced variability suggestive of El Niño-Southern Oscillation (ENSO) teleconnections into North America during the late Pleistocene, when the Laurentide ice sheet was near its maximum extent ... during near-peak glacial conditions." But during the middle of the Holocene, when it was considerably warmer, Overpeck and Webb (2000) report data from corals suggest "interannual ENSO variability, as we now know it, was substantially reduced, or perhaps even absent."

Nederbragt and Thurow (2005) analyzed the varve thickness profiles of two sediment cores retrieved from the Santa Barbara Basin off the coast of California, USA, to determine how the strength of the El Niño/Southern Oscillation (ENSO) phenomenon has varied there over the past 15,000 years. The records show the strength of the ENSO signal fluctuated on multidecadal to centennial timescales. In spite of this variability, Nederbragt and Thurow note power spectra analysis gave no indication of a unidirectional trend in either the frequency or amplitude of ENSO events. The ENSO signal at millennial timescales was reported to be "more or less constant."

In a follow-up to their 2004 work (Rein *et al*., 2004), Rein *et al*. (2005) developed high-resolution marine proxy data for El Niño variability over the last 20,000 years, obtained by analyzing a sediment core retrieved from a sheltered basin on the edge of the Peruvian shelf (12°03'S, 77°39.8'W) about 80 km west of Lima. The most well-defined feature of the record was a dramatic depression of El Niño activity between about 5.6 and 8 thousand years ago, which coincided with the major warmth of the Holocene Climatic Optimum. The next-most significant feature was "the medieval period of low El Niño activity," which the researchers describe as "the major anomaly during the late Holocene"—i.e., the Medieval Warm Period—as their data indicate "El Niños were persistently weak between 800 and 1250 AD."

Studying the past millennium in more detail, Rein *et al*. found signs of just the opposite behavior, though on a much shorter timescale: On average, they note, "temperature reconstructions show higher temperatures with increased El Niño activity." That finding was to be expected, however, for that is what El Niños do—they create significant spikes in mean global air temperature, as was dramatically demonstrated by the 1997–1998 El Niño that produced the highest mean annual temperature (1998) of the entire satellite record and gave the record its slightly upward-trending slope. Although El Niños may significantly impact short-term climate, periodically nudging global temperatures upward, they in turn are even more strongly affected by long-term climate, as demonstrated by the findings discussed in the preceding paragraphs of this section, where it is readily seen long-term warmth depresses El Niño activity.

In providing some additional examples of this phenomenon—the overriding power of centennial- to millennial-scale climate variability compared to decadal to multidecadal variability (in terms of what drives what when it comes to changes in temperature and El Niño activity)—Rein *et al*. report, during the Medieval Warm Period, when "Northern Hemisphere temperatures peaked," there was "extraordinarily weak El Niño activity"; in the late thirteenth and early seventeenth centuries, "temperatures in the Northern Hemisphere were rather cool but El Niño activity was high"; and during the nineteenth century, when the Northern Hemisphere began to warm as the planet commenced its recovery from the global chill of the Little Ice Age, El Niño activity began to decline, as Medieval-Warm-Period-like conditions were once again being established as the Current Warm Period was coming into existence.

In light of these observations, it is quite likely the slight global warming evident in the satellite record of the past three decades was simply a natural consequence of El Niño activity, which will likely subside somewhat as the Current Warm Period (which we contend to be primarily a product of Earth's natural millennial-scale oscillation of climate) becomes more firmly entrenched at a slightly higher temperature commensurate with that of the Medieval Warm Period.

Another explanation may rest in the work of Verdon and Franks (2006), who used "proxy climate records derived from paleoclimate data to investigate the long-term behavior of the Pacific Decadal Oscillation (PDO) and the El Niño Southern Oscillation (ENSO)" over the past 400 years. The pair of researchers found climate shifts associated with changes in the PDO "occurred with a similar frequency to those documented in the 20th century." In addition, and more importantly, they find "phase changes in the PDO have a propensity to coincide with changes in the relative frequency of ENSO events, where the positive phase of the PDO is associated with an enhanced frequency of El Niño events, while the negative phase is shown to be more favourable for the development of La Niña events."

The two Australian scientists note the numerous El Niño events of the recent past "have been reported as unusual, and have even been suggested to be possible evidence of anthropogenic climate change [e.g., Trenberth and Hoar, 1996]." However, they continue, "the paleo records suggest that the apparent lack of La Niña events and high frequency of El Niño events over the past two decades may not be abnormal and could be attributed to the fact that during this time the PDO has been in a positive phase," such that "when the PDO switches back to a negatively dominated phase, it is quite likely that the frequency of La Niña events will increase once again." Consequently, there is no compelling reason to conclude the recent preponderance of El Niño events over La Niña events is a "fingerprint" of CO_2-induced global warming, especially in light of the evidence highlighted in this section.

Davies *et al*. (2012) note, "variations in the frequency and amplitude of the El Niño-Southern Oscillation (ENSO) recorded in both instrumental and paleoclimate archives have led to speculation that global warming may cause fundamental changes in this preeminent mode of global interannual climate variability (Fedorov and Philander, 2000)." They note there is speculation "warmer climates may promote a permanent El Niño state (Wara *et al*., 2005; Fedorov *et al*., 2006)." In a study designed to explore this possibility further, Davies *et al*. analyzed the latest Cretaceous laminated Marca Shale of California, which permits "a seasonal-scale reconstruction of water column flux events and, hence, interannual paleoclimate variability," during what is known to have been a "past 'greenhouse' climate state."

The four researchers report "significant spectral peaks obtained from lamina-derived time series analysis of the Marca Shale closely resemble those of modern and historical ENSO variability." In addition, "the parameters from which the time series are derived (biogenic- and terrigenous-lamina thickness and bioturbation index) appear directly related to the marine production and flux, incursion of oxygenated waters, and input of terrigenous sediment that would be influenced by ENSO-type mechanisms of inter-annual variability." Davies *et al*. say there is "little support for the existence of a 'permanent El Niño' in the Late Cretaceous, in the sense of the continual El Niño state depicted by Fedorov *et al*. (2006)." They say this evidence "builds on results from the Cretaceous Arctic (Davies *et al*., 2011) and from younger Eocene and Miocene warm periods (Huber and Caballero, 2003; Galeotti *et al*., 2010; Lenz *et al*., 2010) to emphasize that there was robust ENSO variability in past 'greenhouse' episodes and that future warming will be unlikely to promote a permanent El Niño state."

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4.3.2 Influence on Extreme Weather Events

Computer model simulations have given rise to concerns that weather-related disasters will be exacerbated under warm, El Niño conditions. The validity of this assertion is challenged by the studies reported in this section, which demonstrate ENSO events generally do not lead to greater frequency or severity of extreme weather events.

Changnon (1999) determined adverse weather events attributed to the El Niño of 1997–1998 cost the United States economy $4.5 billion and contributed to the loss of 189 lives, which is serious indeed. On the other hand, he determined El Niño-related benefits amounted to approximately $19.5 billion—resulting primarily from reduced energy costs, industry sales, and reduction in hurricane damage—and a total of 850 lives were saved, thanks to the reduction of bad winter weather. Thus the net impact of the 1997–1998 El Niño on the United States, Changnon writes, was "surprisingly positive," in stark contrast to what was often reported in the media and by climate alarmists, who tended, in his words, "to focus only on the negative outcomes."

Another "surprisingly positive" consequence of El Niños is their tendency to moderate the frequency and intensity of Atlantic hurricanes. Working with data for 1950–1998, Wilson (1999) determined the probability of having three or more intense hurricanes during a warmer El Niño year was approximately 14 percent, and during a cooler non-El Niño year the probability jumped to 53 percent. Similarly, in a study of tropical storm and hurricane strikes along the southeast coast of the United States over the entire last century, Muller and Stone (2001) determined "more tropical storm and hurricane events can be anticipated during La Niña seasons [3.3 per season] and fewer during El Niño seasons [1.7 per season]."

In another study of Atlantic basin hurricanes, this one considering the period 1925 to 1997, Pielke and Landsea (1999) report average hurricane wind speeds during warmer El Niño years were about six meters per second lower than during cooler La Niña years. In addition, they report hurricane damage during cooler La Niña years was twice as great as during warmer El Niño years. These year-to-year variations indicate hurricane frequency and intensity—as well as damage—tend to decline under warmer El Niño conditions, just the opposite of the impression typically conveyed to the public.

In the North Indian Ocean, Singh *et al*. (2000) studied tropical cyclone data pertaining to the period 1877–1998, finding tropical cyclone frequency declined there during the months of most severe cyclone formation (November and May), when ENSO was in a warm phase. Similarly, De Lange and Gibb (2000) studied New Zealand storm surges recorded by several tide gauges in Tauranga Harbor over the period 1960–1998, finding a considerable decline in both the annual number of such events and their magnitude in the latter (warmer) half of the nearly four-decade record, noting La Niña seasons typically experienced more storm surge days than El Niño seasons. Regarding Australia, Kuhnel and Coates (2000) found yearly fatality event-days due to floods, bushfires, and heatwaves in 1876–1991were greater in cooler La Niña years than in warmer El Niño years.

In a study of breeding populations of Cory's Shearwaters on the Tremiti Islands of Italy, Brichetti *et al*. (2000) found survival rates of the birds during El Niño years were greater than during La Niña years, which they attribute to the calming influence of El Niño on Atlantic hurricanes.

Elsner *et al*. (2001) used annual U.S. hurricane data obtained from the U.S. National Oceanic and Atmospheric Administration, plus data obtained from the Joint Institute for the Study of the Atmosphere and the Oceans for average sea surface temperature (SST) anomalies for the region bounded by 6°N to 6°S latitude and 90°W to 180°W longitude (the "cold tongue index" or CTI) to discover whether there was a connection between the number of hurricanes that hit the eastern coast of the United States each year and the presence or absence of El Niño conditions. Based on data for the period 1901–2000, they found "when CTI values indicate below normal equatorial SSTs, the probability of a U.S. hurricane increases." Or as they describe the relationship in another place, "the annual count of hurricanes is higher when values of the CTI are lower (La Niña events)." Thus the entire past century of real-world hurricane experience indicates the yearly number of U.S. land-falling hurricanes has tended to decrease during El Niño conditions, as has the overall occurrence of hurricanes in the Atlantic basin.

Schwartz and Schmidlin (2002) examined past issues of *Storm Data*—a publication of the U.S. National Weather Service (NWS)—to compile a blizzard database for the years 1959–2000 for the conterminous United States. They analyzed the data to determine temporal trends and spatial patters of U.S. blizzards, as well as their relationship to ENSO. Over the 41-year period of their study, they identified 438 blizzards, an average of 10.7 blizzards per year. Year-to-year blizzard variability was significant, however, with the number of annual blizzards ranging from a low of one in the winter of 1980–1981 to a high of 27 during the 1996–1997 winter. In addition, a weak but marginally significant relationship with ENSO was noted, with a tendency for two to three more blizzards to occur during La Niña winters than during El Niño winters.

Hudak and Young (2002) used an objective method of identifying June through November storms in the southern Beaufort Sea based on surface wind speed over the period 1970–1995, finding considerable year-to-year variation in the number of storms but no discernible trend. They also observed a small increase in the number of storms during El Niño vs. La Niña years, but they report "due to the relatively small number of cases, no statistical significance can be associated with this difference." Thus, in a region of the world where climate models predict the effects of CO_2-induced global warming should be most evident, the past quarter-century has seen no change in the number of June-November storms.

Higgins *et al*. (2002) examined the influence of two important sources of Northern Hemispheric climate variability—ENSO and the Arctic Oscillation (AO)—on winter (Jan–Mar) daily temperature extremes throughout the conterminous United States over the 50-year period 1950–1999. This work revealed considerable decadal variability in surface air temperatures. Nevertheless, during El Niño years the number of extreme temperature days was found to decrease by around 10 percent, and during La Niña years they increased by around 5 percent. They found little or no difference in the number of extreme temperature days between the AO's positive and negative phases.

Goddard and Dilley (2005) state the huge reported "cost" of El Niño events "contributes greatly to misconceptions about the global climate effects and socioeconomic impacts of El Niño and La Niña." They note the monetary figures typically bandied about represent a gross estimate of all hydro-meteorological impacts worldwide in specific El Niño years, but they note "how these losses compare with those during ENSO-neutral periods has not been established," adding, "during El Niño events, El Niño is implicitly assumed to be associated with all climate-related losses." They thus embarked on a study intended to provide the missing information.

Goddard and Dilley arrive at three major conclusions. First, they conclude "perturbation to precipitation over land areas is only weakly affected by ENSO extremes," as they found "the risk of widespread extreme precipitation anomalies during ENSO extremes is comparable to that during neutral conditions" and "the highest values of integrated rainfall perturbation are not greater during ENSO extremes than during neutral conditions." Second, they found "the frequency of reported climate-related disasters does not increase during El Niño/La Niña years relative to neutral years." And third, they found seasonal rainfall forecast skill increases "in magnitude and coverage, during ENSO extremes," such that "the prudent use of climate forecasts could mitigate adverse impacts and lead instead to increased beneficial impacts, which could transform years of ENSO extremes into the least costly to life and property."

Among the beneficial impacts of ENSO extremes Goddard and Dilley say could yield a more complete appreciation of the differing socioeconomic impacts of El Niño and La Niña events is the well-established fact that "tropical Atlantic hurricanes that threaten the southeastern United States, the Caribbean, and eastern Central America occur less frequently during El Niño years (Gray, 1984)." Moreover, "warmer winter temperatures commonly are observed in the northern United States during El Niño, leading to less energy use and, therefore, lower energy prices (Chagnon, 1999)."

Goddard and Dilley conclude, "between mitigating adverse climate effects and taking advantage of beneficial ones through the prudent use of climate forecasts, El Niño and La Niña years may eventually result in substantially lower socioeconomic losses, globally, than are realized in other years." Even in the absence of such actions, their work (and that of many other researchers) reveals there is little to fear during extreme ENSO years as compared to ENSO-neutral years.

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