Met Office
Hadley Centre

defra
Department for Environment
Food and Rural Affairs

New science for managing climate risks

It has been demonstrated beyond reasonable doubt that the climate is changing due to man-made greenhouse gases.

We are already committed to further substantial change over the next 30 years and change is likely to accelerate over the rest of the 21st century. If no action is taken on climate change the costs of adaptation are potentially huge, both economically and socially. The best possible scientific advice is a key element in planning the most effective ways to minimise future climate change impacts.

“Warming of the climate system is unequivocal…”

“Most of the observed increase in global average temperatures since the mid-20th century is very likely [more than 90%] due to the observed increase in anthropogenic greenhouse gas concentrations.”

IPCC[3] AR4 WG1[4] SPM[5] – February 2007

The new Integrated Climate Programme (ICP) of the Met Office Hadley Centre is designed to meet the core requirements of the UK Government for information on climate change, through the main funding departments, Defra[1] and MoD[2]. It provides the science that will be required to help policymakers and other stakeholders in the UK and internationally to deal with climate change in the future. This brochure presents recent science highlights and outlines future work to underpin government policy and planning.

KEY QUESTIONS ARE:

- How will climate change regionally in the near future?
- What are the risks of dangerous climate change?
- Can we avoid dangerous climate change?
- What are the potential impacts of climate change with different degrees of mitigation and adaptation?

A key focus of the ICP is to quantify and reduce the uncertainties in climate predictions and in our assessment of past climate change in order to improve the information we provide. Increasingly, our focus is on regional scales and on providing information in ways most relevant to stakeholders.

[1] Defra is the UK Government’s Department for Environment Food and Rural Affairs.
[2] MoD is the UK Government’s Ministry of Defence.
[3] Intergovernmental Panel on Climate Change.
[4] 4th Assessment Report Working Group 1.
[5] Summary for Policymakers.

Observing the changing climate

The evidence for significant climate change in the recent past is now overwhelming. However, as policies and impacts start to have a direct effect on individuals, the evidence will be questioned again and again. Further monitoring of the natural environment will provide confirmation of continuing changes and an improved assessment of current natural climate variability. Observational monitoring will also offer the first warning of abrupt changes or climate surprises, which will be vital for effective adaptation.

The Met Office Hadley Centre plays a key role in monitoring changes in global temperature and found that 2006 was the sixth warmest year in the instrument record, which dates back to the middle of the nineteenth century. The figure below shows that the ten warmest years have all occurred since 1995. Early indications suggest that while 2007 is unlikely to become the warmest year on record, it will almost certainly take its place amongst the top ten.

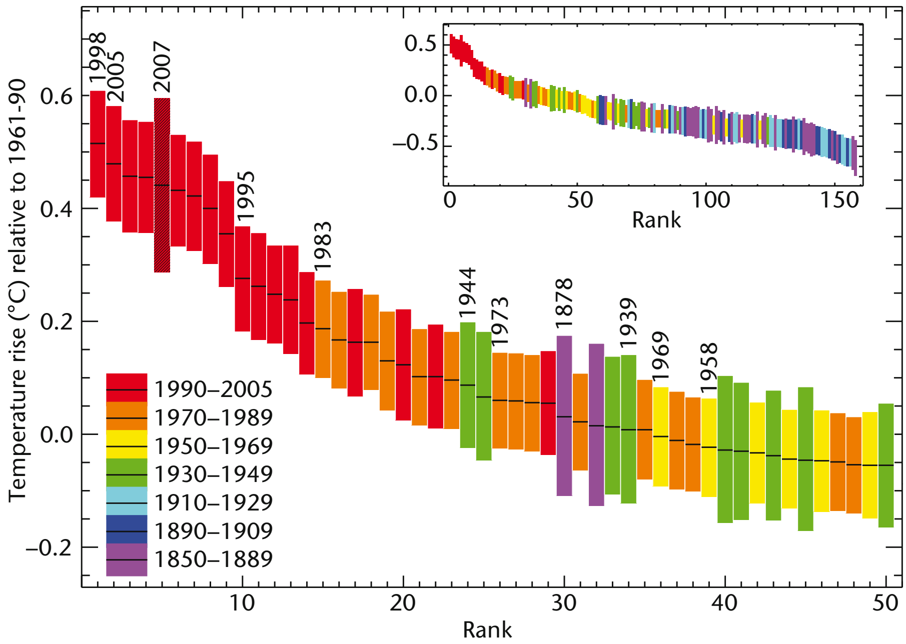


Figure: Observed global average surface temperature differences (black lines) from the average for 1961 to 1990. Vertical coloured bars represent the temperature uncertainty range. The warmest years in each decade are labelled. The data are from the HadCRUT3 dataset. More information is available at www.metoffice.gov.uk/hadobs (see the link to HadCRUT3)

RECORD BREAKING EVENTS IN 2007

Reductions in sea ice

Polar regions are expected to warm faster than many other areas, making observations from high latitudes especially valuable. The extent of summer sea ice has consistently decreased by around 10% per decade (figure below) since the mid 1970s, when satellite monitoring of Arctic sea ice began. However, there are also large natural year-to-year variations around this trend.

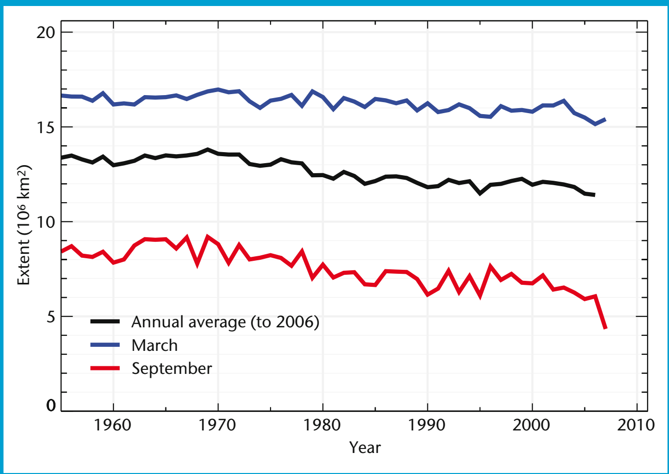


Figure: Observed Artic sea ice extent for March and September, and the annual average. The data are from the HadISST dataset. More information is available at www.metoffice.gov.uk/hadobs (see the link to HadISST)

In 2007 the September sea ice extent in the Arctic fell to its lowest level since these records began with a very noticeable and significant consequence. The Northwest Passage became navigable by ship without an ice breaker for the first time in decades. In future, this route is likely to be opened more frequently and for longer with enormous implications for international trade.

At present it is not possible to say with any certainty whether the large reduction in summer sea ice in 2007 is evidence of an acceleration of the long-term trend, because of the natural year-to-year variations. Further monitoring and analysis of the processes driving the changes is vital.

Flooding in the UK

Flooding in the UK this summer was widespread and severe, contributing to several deaths and reported loses of up to £5 billion. The exceptionally large amounts of rainfall were caused by naturally occurring weather systems and unusually warm sea surface temperatures which, in part, may be a result of global warming.

In general we expect heavy rainfall to increase across the UK in winter, but projections for summer are less robust.

The jet stream – a band of strong winds high in the atmosphere which affects weather systems across the Atlantic – was unusually far south in summer 2007. This brought more weather systems, with persistent rain across the UK, than we would normally expect at this time of year. The southward shift of the jet stream is typical in La Niña years, such as this year (and not associated with climate change), but was unusual in that the weather systems were further south than normal. The amount of rainfall was increased by warm sea surface temperatures leading to more evaporation of water into the weather systems. These warm seas are probably the result of the exceptionally warm weather in north-west Europe over the last year. The warm sea temperatures cannot be directly linked to climate change but previous work at the Met Office Hadley Centre has shown that such warm temperatures in the region are occurring more frequently now than they were before the industrial revolution. Whilst we cannot yet be sure how rainfall will change in summer in the UK it is likely that, when weather conditions similar to this year occur naturally in the future, even more extreme rainfall will result due to higher sea surface temperatures with further global warming.

The United Kingdom experienced exceptionally wet weather during June and July 2007. The combined June – July rainfall total is the largest of any equivalent period in the 242-year England and Wales precipitation record.

What are the risks of dangerous climate change?

"The ultimate objective of this Convention ...is to achieve ...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

UNFCCC[1] Article 2

Climate science can predict many of the implications and potential dangers associated with various amounts of climate change. The Met Office Hadley Centre has made considerable progress in understanding integrated dangers, where the temperature rise is only one of the environmental stresses leading to local impacts.

Ice sheets
Improved modelling of ice sheets and inclusion of Antarctica as well as Greenland will enable better predictions of sea-level rise and at what stage changes are likely to become irreversible.

Ecosystems
Improved modelling of the interaction between climate and the biosphere will reduce uncertainty in predictions of climate change and consequent changes to the biosphere.

Ocean circulation
The risks will be quantified of a shutdown of the major overturning circulation in the Atlantic which would cause widespread cooling in Europe.

Methane clathrates and permafrost
The likelihood will be assessed of release of methane from vast undersea stores and from thawing permafrost, both of which could greatly enhance climate change.

[1] United Nations Framework Convention on Climate Change

Risk of large changes in ocean circulation and the release of methane clathrates.

+?°C

Risk of significant loss of Amazon rainforest. Globally few ecosystems can adapt, consequent reductions in food supply and further damage to the climate system.

+3°C

Melting of Greenland ice sheet may become irreversible.

+2°C

Some marine ecosystems suffer irreversible change. Ocean acidification is already a risk.

+1°C

Can we avoid dangerous climate change?

The Kyoto Protocol prescribes limits to emissions of greenhouse gases for some of the world's emitters up to the year 2012. The UNFCCC provides a framework for discussing the further reductions that would be needed to avoid the most significant impacts of climate change. The European Union currently supports the aim of keeping global average warming to less than 2 °C above pre-industrial temperatures.

The Met Office Hadley Centre provides advice on the consequences of a range of future emissions scenarios. The figure opposite shows two future scenarios in which greenhouse gas emissions, initially following the IPCC SRES A2 scenario[1], are reduced in the future over 50 years, starting in either 2013 or 2036. These years correspond to equivalent carbon dioxide (CO_2) concentration[2] reaching 450ppm[3] and 550ppm, respectively. The scenarios include the effect of greenhouse gases and sulphate aerosols. The 2036 scenario eventually brings the projected future warming well below that of 'business as usual[4]' but earlier action avoids a further 1 °C of potential warming.

By including our latest estimates of uncertainty in climate response, we have estimated the likelihood of temperature increases of 2 °C and 3 °C above pre-industrial levels for a range of potential greenhouse gas stabilisation levels. These represent the eventual temperatures which will take at least several decades to achieve after atmospheric greenhouse gas concentrations are stabilised. This is a consequence of the ocean adjusting slowly to the atmospheric greenhouse gas changes.

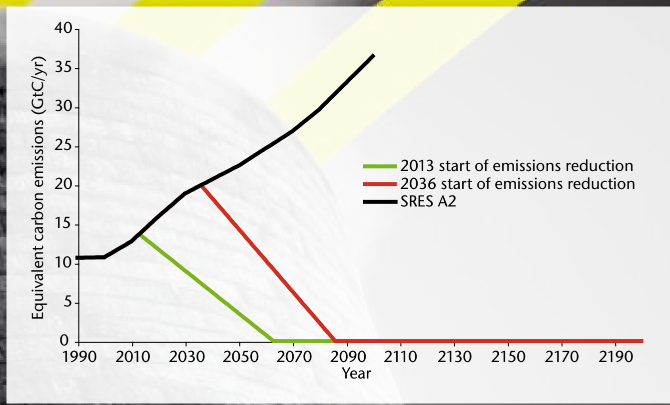
If greenhouse gases and aerosols were fixed at today's concentrations then temperatures would continue to rise by between 0.25 °C and 0.75 °C by the end of the century.

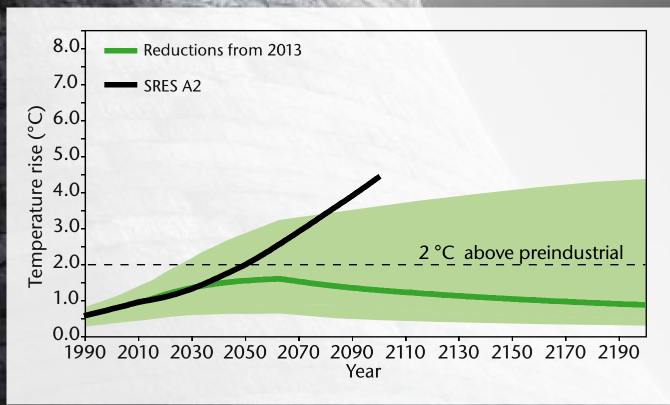
We are now investigating a wide range of future scenarios which include uncertainties from both the climate system and natural ecosystems.

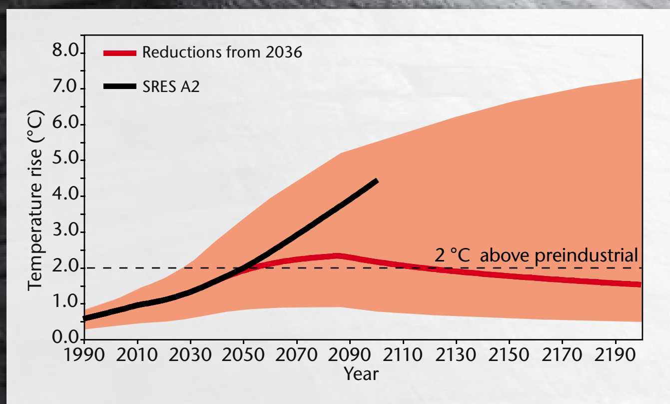
We are also examining the ease with which the climate system and associated impacts can recover if temperature targets are exceeded. Eventually, the results will form part of a new integrated assessment of the effect of mitigation action on climate and resulting impacts.

CO_2 equiv stabilisation level	For 2 °C target	For 3 °C target
430	63	10
450	77	18
550	99	69
650	99	94

Percentage likelihood of eventual warming exceeding 2 °C and 3 °C temperature thresholds above pre-industrial levels







The upper panel shows the emissions for three major greenhouse gases (CO_2, CH_4 and N_2O) combined into a carbon equivalent. The middle panel shows the predicted temperature rise for the idealised scenario in which emissions are reduced from 2013. The median projection is the solid line and the range of possible temperatures is represented by the shading. The lower panel shows the same but for reductions from 2036.

[1] SRES A2 is a business as usual scenario with medium to high emissions of greenhouse gases and aerosols.

[2] Equivalent CO_2 concentration provides a way to combine the effects of a range of greenhouse gases into a single measure. Some authors also include the effects of aerosol particles. While these are included in our simulations they are not included in our reported equivalent CO_2 concentrations.

[3] Parts per million.

[4] 'Business as usual' means that emissions of greenhouse gases are not controlled, but continue to grow as economies and populations grow.

Adaptation and planning

Climate variability already poses a substantial challenge for society and further changes in climate are now unavoidable, even assuming a future international agreement and implementation of mitigation policies. This makes the development of adaptation strategies imperative. We are providing a wide range of scientific information to support these activities.

Adaptation and planning requires good quality information on the risks of climate change and its impacts in a form that is relevant to users. The new Integrated Climate Programme will put the Met Office Hadley Centre in a unique position to integrate climate change information into planning and decision-making processes in government and industry and to integrate weather and climate information into contingency planning. Results will cover a range of timescales from seasons through decades to more than a century, and a range of spatial scales from global down to continental and regional scales (for example to give useful information for the UK regions). A particular aim will be to present many of the results probabilistically in order to enable quantified risk assessment as a basis for planning and policy decisions.

It is not just the change in temperature and rainfall that are important, but also more complex effects on the physical and biological environment and on human systems. The Met Office Hadley Centre will work with other providers to supply consistent information on the impacts of climate change. Examples of the output will include predictions of extreme events, water availability, coastal flooding and heat-stress.
One of our main customers, MoD, has commissioned work as part of the programme to assess which sensitive regions of the world are likely to reach crisis point as a result of increased environmental stresses. We will also be able to inform MoD about the climate impacts most relevant to its operations.

The Met Office Hadley Centre climate models already produce a wide range of impact-relevant quantities, including:
- Air temperature
- Rainfall
- Snowfall
- River flow
- Soil moisture and temperature
- Wind speed and direction
- Surface sunlight amount
- Cloud amount
- Ecosystem productivity
- Sea-ice amount
- Ocean temperature and salinity

In addition we now routinely produce many derived quantities including:
- Sea-level rise
- Heat stress
- Water stress
- Air quality

Two major initiatives currently being undertaken are the production of a new set of climate scenarios for the UK Climate Impacts Programme in 2008 (UKCIP08), and making available the regional climate modelling system PRECIS (Providing Regional Climates for Impacts Studies) to scientists from developing countries. These will enable stakeholders to obtain the climate information they need in order to understand how changes will affect their interests on a local scale, and to form relevant adaptation plans.

How will climate change in the near future?

Man-made climate change means that the past will not be a good indicator for the future. Forecasts for the next season, year and decade will take on a higher priority. In particular, our ability to forecast extreme climate events a season ahead will enable vital short-term actions to be taken.

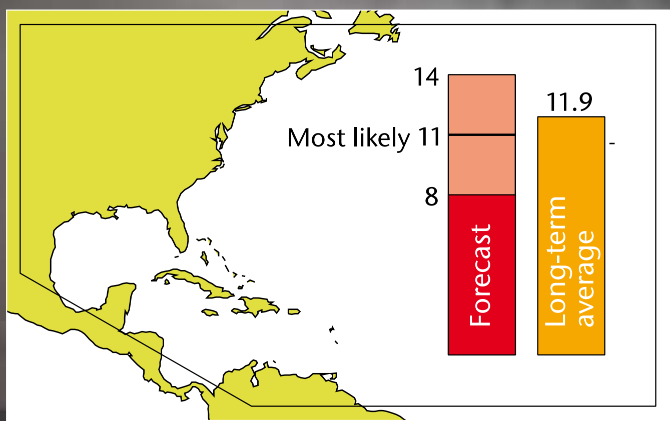
Planners and other users also require information on annual and decadal timescales. The Met Office is unique in providing predictions from daily through seasonal to decadal and centennial timescales using the Unified Model framework.

Forecasting for the next season

Met Office seasonal predictions are provided to government departments, public websites and meteorological services worldwide. The Met Office was one of the first centres to be awarded World Meteorological Organization status as a Global Producing Centre for long-range forecasts. These are issued routinely for Europe and the Regional Climate Outlook Forums of Africa and East Asia. Meetings are held in advance of each region's rainy season at which local and international experts input forecasts from numerous sources to form a consensus on the outlook for the region for the season ahead.

Tropical storm forecast for the North Atlantic basin July to November 2006. The forecast indicated a 70% chance that the number of tropical storms would be in the range eight to 14, with 11 the most likely number.

This represented slightly below normal activity relative to the 1987–2005 long-term average of 11.9. Observed activity for the 2006 season was indeed below normal with nine tropical storms observed in the July to November period.



One feature of our modelling system is that it has considerable skill predicting the number of tropical storms in the North Atlantic season (usually June to November). For example, the change from the exceptionally active season of 2005 to the below-normal activity of the 2006 season was well predicted.

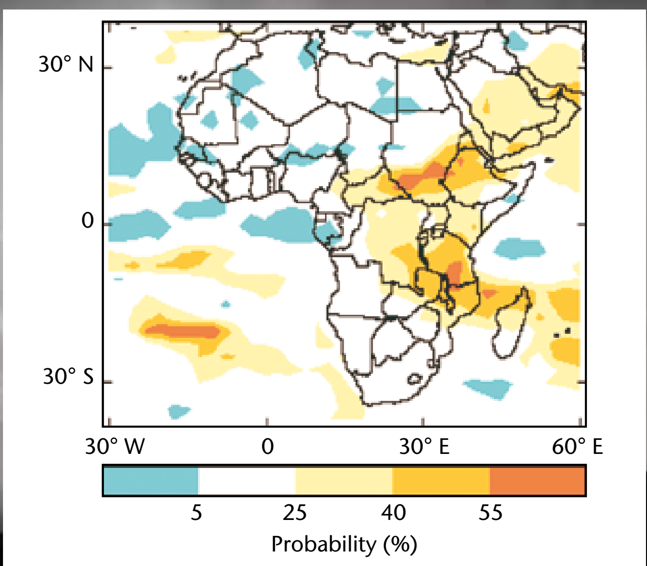
This marked difference between seasons was missed by a number of statistical prediction methods, which have traditionally formed the basis of most published forecasts. Our short-range weather forecasts also produced one of the most accurate predictions of the path of hurricane Katrina in 2005. The figure opposite shows a trial seasonal prediction for July to November 2006. Our first operational prediction was issued on 19 June 2007 for July to November 2007. (www.metoffice.gov.uk)

Other key forecasts, with users from around the world, include:

- Seasonal probability forecasts for the UK and Europe issued to the public and planners.
- Regional precipitation for tropical NW Africa, E Africa and NE Brazil – regions with high climate vulnerability but also with relatively high forecast skill.
- Specialised forecasts to support MoD operations in Iraq, Afghanistan, Yugoslavia and the Falkland Islands.
- Prototype monthly forecasts of Environmental Stress Index, designed for direct use by MoD personnel, have been trialled for operations in Iraq and Afghanistan and for training activities in the UK.

Predictions will be improved by:

- Using the most up to date models and understanding of climate processes.
- Improving the initial conditions for the ocean using new technical developments and more extensive observations.
- New dissemination techniques to provide information in a form useful to users.



Forecast of low rainfall for October to December, East Africa short rains period, issued in September 2005 from the Met Office seasonal forecast. This low rainfall category has an historic average probability of 20%. The forecast indicated more than 25% probability (yellow/orange shading) over a wide area and more than 40% in some regions (e.g. Tanzania). This provided useful guidance enabling the authorities to avoid the worst consequences of food and water scarcity and disruption to power supply.

Forecasting the next decade

On a timescale of several decades the prediction of global warming is now robust. However, over the next few years natural variations may either amplify or offset some of the warming. Whilst having predictions of the state of the climate a season ahead allows for some types of adaptation measures to be put in place – such as stockpiling food or sandbags – having skilful predictions up to a decade in advance allows for a greater range of actions including major infrastructure changes such as improved building ventilation or flood protection. The five to 10-year period is also the length of the planning cycle for many businesses.

The Met Office Hadley Centre has pioneered a new system to predict the climate a decade ahead. The system simulates both the human-driven climate change and the evolution of slow natural variations already locked into the system. This is possible because the climate takes a long time to respond to some variations. In particular, the state of the ocean has an impact on climate for months and years into the future. In part, this is because it takes a long time for the ocean to heat up and cool down.

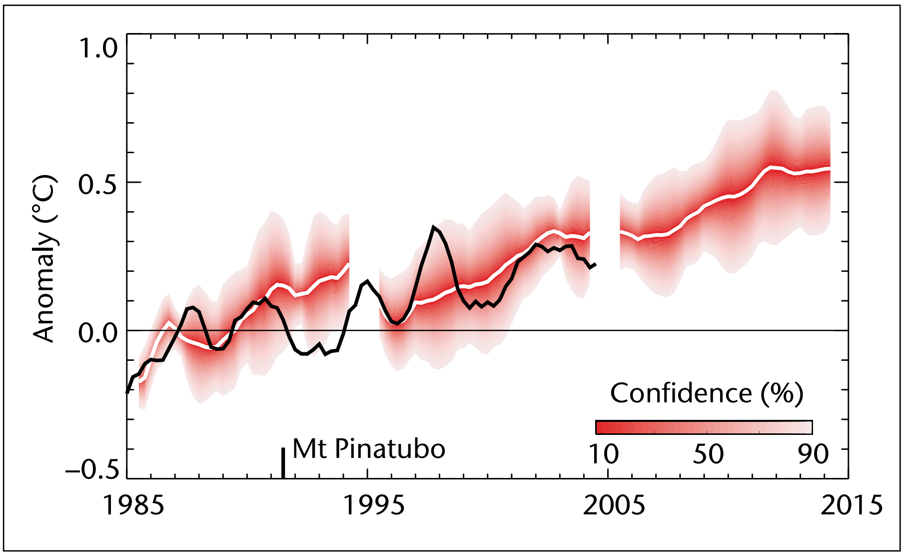
By starting this system in the 1980s and comparing the results with observations from the 1990s we have already demonstrated its skill at predicting the global climate. However, a major effect it cannot predict is volcanic eruptions, so the biggest differences between the model and the observations occur following the major eruption of Mount Pinatubo in June 1991.

We are now using the system to predict changes out to 2014. By the end of this period, the global average temperature is expected to have risen by around 0.3 °C compared to 2004, and half of the years after 2009 are predicted to be hotter than the current record hot year, 1998.

The current system captures some aspects of regional change but there are some limitations, for instance, our ability to simulate the North Atlantic Oscillation which affects the European weather and climate. A key aim of our next generation computer model is to improve regional predictions.

Future work will extend the range of outputs, for example, by providing information on changes in extremes, so that stakeholders can obtain maximum benefit from this new type of prediction.

The recent drought in Australia has impacted on farming. It has also affected the indigenous animal population.



Observations of global average temperature (black line) compared with decadal 'hindcasts' (10-year model simulations of the past, white lines and red shading), plus the first decadal prediction for the 10 years from 2005. Temperatures are plotted as anomalies (relative to 1979–2001). As with short-term weather forecasts there remains some uncertainty in our predictions of temperature over a decade. The red shading shows our confidence in predictions of temperature in any given year. If there are no volcanic eruptions during the forecast period, there is a 90% likelihood of the temperature being within the shaded area.

PRECIS (Providing Regional Climates for Impact Studies)

PRECIS has over 250 users worldwide organised into the following regional user groups:

- southern and central Africa;
- south and south-east Asia;
- Caribbean/Central America and South America;
- Middle East/Central Asia; and
- a few users in Europe and North America

PRECIS forms the core of a capacity building and technology transfer programme which enables scientists in developing countries to have access to the latest climate modelling tools and training in order to produce spatially detailed information on climate change. Many developing countries previously had little or no access to such technology and often have significant vulnerability to climate change.

Scientists and stakeholders can gain direct experience in analysing and applying climate information. Local ownership of the climate change projections not only builds confidence in their value but raises awareness of our changing climate and related issues within the region.

The value of PRECIS arises because it is easy to use as well as containing the latest science:

- It operates on readily available Personal Computers.

- It includes a graphical user interface to set up experiments.

- It includes the latest Met Office Hadley Centre regional climate model, which can be run at 50 km or 25 km resolutions. This adds skilful local detail, including simulating realistic extreme weather events to the broad-scale projections available from global climate models.

- It comes with boundary conditions from global climate models and observations.

- It contains a suite of data analysis and display tools.

- It is simple to set up for any region of the world.

- Climate change scenarios can be run for the last 50 years (to evaluate the model) and for the next 100 years using well established methods[1].

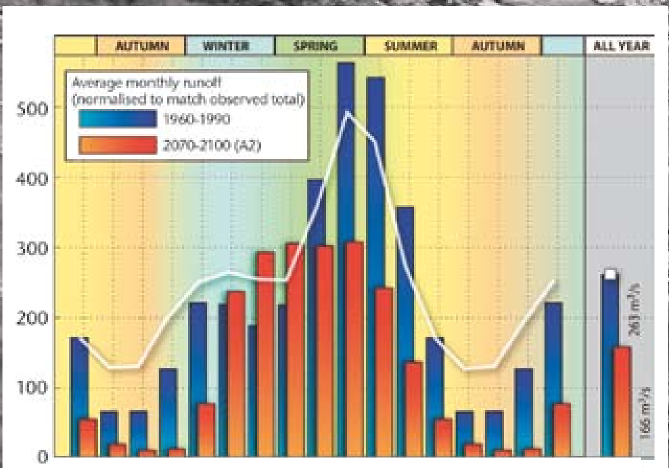
- Users attend a workshop to learn how to use the system and have access to follow up workshops, a website, mailing lists and technical scientific advice to promote technology transfer and capacity building.

The Met Office Hadley Centre aims to continue to improve PRECIS and the support it provides[2]. Ongoing improvements are aimed at giving users more information about uncertainty in their climate projections by using boundary conditions from different global models. Data processing and the display utilities have also been improved.

Climate change case study: Chile

PRECIS has been used to assess possible impacts of climate change on water availability in the Rio Maule watershed in Chile. The PRECIS simulation of present day (blue bars) compares well with observations (white line).

The PRECIS projection for the end of the century (red bars) shows considerable reductions in total water, because precipitation is reduced. Also, the peak in water occurs earlier in the annual cycle, as more precipitation falls as rain rather than snow. These changes may have significant implications for water availability in the region.



Department of Geophysics, University of Chile.

[1] The methodology is based on that used in the last major assessment over the UK published in 2002 and allows users to assess national or regional vulnerability.

[2] Over the past five years this activity has been supported by funding from the Department for Environment, Food and Rural Affairs (Defra), the Department For International Development (DFID) and the Foreign and Commonwealth Office (FCO).

Water - drought and flooding

According to the United Nations Environment Programme, in the mid-1990s about 1.7 billion people lived in water-stressed countries and 20% of these lacked access to safe drinking water. By 2030, assuming a 'business as usual' scenario, population growth alone could almost double this number. In many regions climate change is likely to exacerbate such stresses.

RIVER, COUNTRY	% change in flow
Congo, Zaire	30.6
Changjiang/Yangtze, China	19.0
Brahmaputra, Bangladesh	23.3
Ganges, Bangladesh	30.7
Amazon, Brazil	-13.4
Magdalena, Colombia	-23.8
Orinoco, Venezuela	-18.7
Zambezi, Mozambique	-34.9

Over half of the world's drinking water is extracted directly from rivers or reservoirs. Our climate model predictions indicate large reductions in river flow across southern Europe, the Middle East, the Amazon Basin, and the Danube for the 21st century under a 'business as usual' emissions scenario. Clearly, changes of this magnitude could significantly exacerbate water stress in affected regions and, where rivers flow across national borders, foster international conflict. Our current challenge is reducing the uncertainty in these regional predictions.

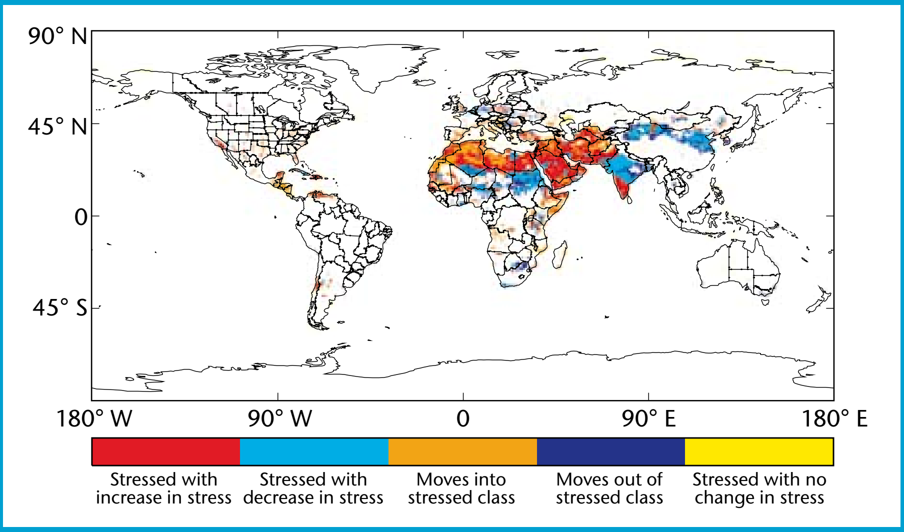
Increases in global temperature are expected to increase evaporation and intensify the water cycle. While this will drive the increase in drought in some locations at certain times, it is likely to increase rainfall in others.

Furthermore, a greater fraction of the rain may fall in very intense events, increasing run-off and flooding in some areas. Recent work at the Met Office Hadley Centre showed that our models are able to reproduce observed changes in drought. The same models project that an additional 30% of the global land mass is likely to experience drought by the end of the 21st century under 'business as usual' conditions. However, the regional details are still very uncertain.

Work is now focusing on estimating the risk of drought and flood events and linking the climate changes to the vulnerability of populations in different parts of the world. This will include accounting for local conditions and water management practices.

We are also planning to estimate the change in water supply from mountain glaciers, on which around one-sixth of the world's population currently depend.

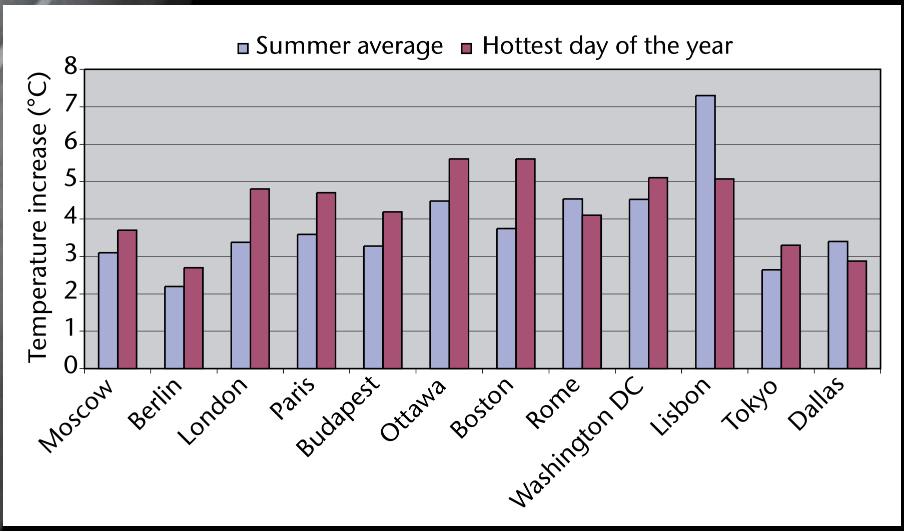
Over half of the world's drinking water is extracted directly from rivers or reservoirs.



The change in water stress between today and the end of the 21st century for a 'business as usual' scenario. Water stress is defined as occurring when the water availability, in this case river flow, divided by the population is less than 1700 cubic metres per year.

Changing temperature extremes and health impacts

Night-time temperature extremes have already risen as a result of human emissions of greenhouse gases. In the future, this trend is predicted to continue and daytime extreme temperatures are also expected to rise significantly (see figure below).



Projected increases in the summer average temperature and that of the hottest day of the year from a Met Office Hadley Centre global climate model for a range of world cities when the global average temperature increases by 2 °C. In all cases the cities warm by more than the global average temperature.

Temperatures within cities are typically higher than those of the surrounding rural areas due to the release of heat from local power consumption and the way that the urban environment alters the transfer of heat and moisture between the ground and atmosphere. How this urban heat island effect will change in the future is uncertain and will depend on the future size and design of cities.

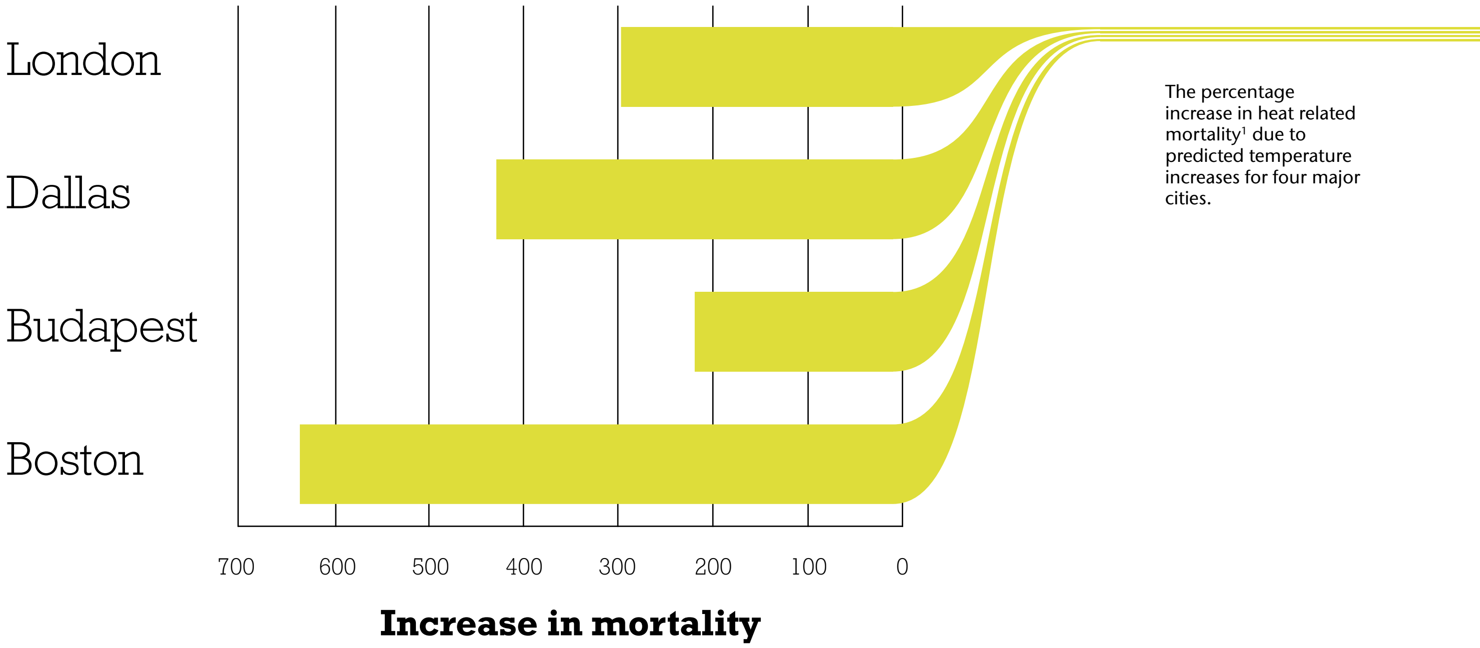
Without adaptation, future extremes of temperature are expected to increase human mortality, especially when they are sustained for an extended period. Using relationships between past changes in mortality and observed temperature, an estimate of future heat-related mortality can be made (figure below). By adapting infrastructures and behaviour to better cope with higher temperatures it should be possible to reduce these potential casualties.

A key aim of this work is to provide an early warning system of future casualties for health planners. The Met Office already produces short-term health warnings based on weather forecasts and new work will extend the advanced warning time using seasonal and climate change predictions. Long-term predictions including the impact of adaptation measures will be especially useful to planners involved in developing the future health infrastructure.

The Met Office Hadley Centre will also examine the effect of other factors, such as air quality, on human and animal health. We already predict changes in low-level ozone and particulates and this will form a starting point for the new research.

"[The] probability of European mean summer temperatures exceeding those of 2003 increases rapidly under the SRES A2 scenario, with more than half of years warmer than 2003 by the 2040s."

Stott et al., Nature, 2004



The percentage increase in heat related mortality[1] due to predicted temperature increases for four major cities.

[1] The temperature-mortality relationships were derived by a Met Office CASE student, S. Gosling, working at King's College, London.

Leaders of science at the Met Office Hadley Centre

John Mitchell
Director of Climate Science

Chris Gordon
Deputy Director of Climate Science - with particular responsibility for developing science and collaboration strategy

Vicky Pope
responsible for negotiating the research agreement with Defra and MoD and ensuring it is delivered to a high standard

Derrick Ryall
responsible for the day to day management of the climate programme

Olivier Boucher
leads earth system science and modelling

Chris Folland
leads climate monitoring and detection and seasonal forecasting

James Murphy
leads climate prediction including quantifying uncertainty

Cath Senior
leads climate model development and understanding climate change

Richard Wood
leads climate, cryosphere and ocean research

Jean Palutikof
Head of the Technical Support Unit for IPCC WGII

Jonathan Gregory
Met Office Fellow in climate change

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