Met Office
Hadley Centre

Evidence

The state of the climate

Evidence of global warming has continued to grow in the three years since the last IPCC[1] report — and during 2010 in particular.

Climate change evidence

2010 has seen the publication of more evidence that the world is warming and that man has contributed to that warming.

Changes have now been observed in many different climate variables, in addition to temperature. Other key changes include an increase in the amount of moisture in the atmosphere, continuing sea-level rise and a decreasing Arctic sea-ice extent. All are consistent with a long-term warming trend.

Short-term climate variations are also seen in observations, which temporarily increase or decrease the rate of change away from the long-term trends. Here, we investigate some contributory factors to shorter term variations in the rate of global warming and in the rate of Arctic sea-ice loss.

Against this background of long-term climate change and shorter term natural variability, we find that 2010 is one of the warmest years on record (based on the 12-month average up to September 2010). There has also been a number of noteworthy extreme weather events around the world. The impacts of these highlight the vulnerability of the human and natural worlds to changes in climate. Events of this type may be exacerbated by global warming.

Controversy over this past year has led some to question the evidence for climate change and man's involvement in that change. In fact, the evidence of a rapid long-term change in climate, driven by mankind's activities, is becoming even stronger. That's why we are now presenting the evidence — focusing mainly on the work of the Met Office Hadley Centre, but often conducted in collaboration with other groups around the world.

The evidence continues to accumulate, strengthening the link between man's activity and a wide range of indicators of a changing climate, both globally and regionally.

[1] Intergovernmental Panel on Climate Change

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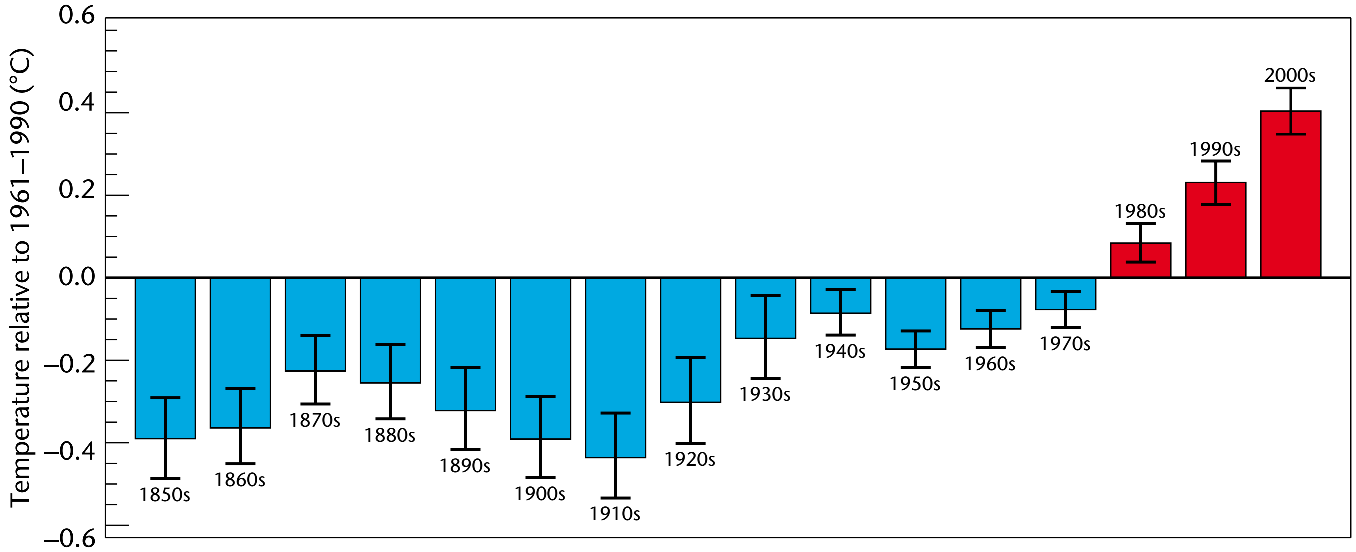
DEPARTMENT OF ENERGY & CLIMATE CHANGE

defra
Department for Environment Food and Rural Affairs

Tidal flood waters, Satkhira District, Bangladesh, May 2009
Photo: Panos

2000–2009: warmest decade in the instrumental record.

Long-term climate change



Observed global average temperature for each decade from 1850 to 2009 relative to 1961–90.
Whiskers show the uncertainty range in the temperature data.

GLOBAL WARMING

The average temperature over the first decade of the 21st century was significantly warmer than any preceding decade in the instrumental record, stretching back over 160 years.
It measured 0.4 °C above the 1961–90 climatological average (0.69 °C above the pre-industrial average). The period 2000–2009 was warmer than the 1990s that, in turn, were warmer than the 1980s. Despite variability from year to year — which sees some years warmer and others cooler — a clear underlying trend of increasing global temperature can be seen from the late 1970s onwards at about 0.16 °C per decade.

These findings are in line with the other independent analyses of global temperatures carried out by NOAA's National Climatic Data Center (NCDC) and NASA's Goddard Institute for Space Studies (GISS). All show the same decadal rankings.

It's not just global average temperature that has increased — virtually all land areas across the globe warmed over at least the last three decades, with the greatest warming taking place in high northern latitudes, large parts of Asia and the African interior. A minority of areas that cooled in this period include the Southern Ocean around Antarctica.

Met Office findings that the world is warming are in line with independent analyses of decadal temperatures conducted by NOAA's National Climatic Data Center and NASA's Goddard Institute for Space Studies.

The Met Office Hadley Centre compiled evidence from diverse sources ranging from high in the atmosphere to the depths of the ocean.

Upsala Glacier, Argentina in 1928 (left) and today (right).
Photo left: ©Archivo Museo Salesiano/De Agostini. Photo right: © Daniel Beltr / Archivo Museo Salesiano / Greenpeace

Other indicators of warming

Although we normally use temperature at the surface of the Earth as the primary indicator of climate change, there are other key observations that add to the evidence of a warming world.

Drawing from the work of more than 20 institutions worldwide, the Met Office Hadley Centre compiled results for a number of climate indicators. The multiple datasets used for each indicator are from diverse sources such as satellites, weather balloons, weather stations, ships, ocean buoys and field surveys. In addition, the datasets went through several independent analyses.

We found changes in a number of indicators that are consistent with a warming world:

- A discernable increase in **air temperature** observed above both the land and sea.
- Increases in **water temperature** at the sea surface down to hundreds of metres below the surface.
- An increase in **humidity** as a warmer atmosphere holds more moisture.
- Increases in **sea-level** as warmer waters expand and land-based ice melts.
- Shrinking of **Arctic sea-ice, glaciers** and Northern Hemisphere **spring snow cover**.

Antarctic sea-ice has increased since satellite records began (at a rate of 0.1 million km^2 per decade) but these changes are much smaller than those in the Arctic (a decrease of 0.8 million km^2 per decade).

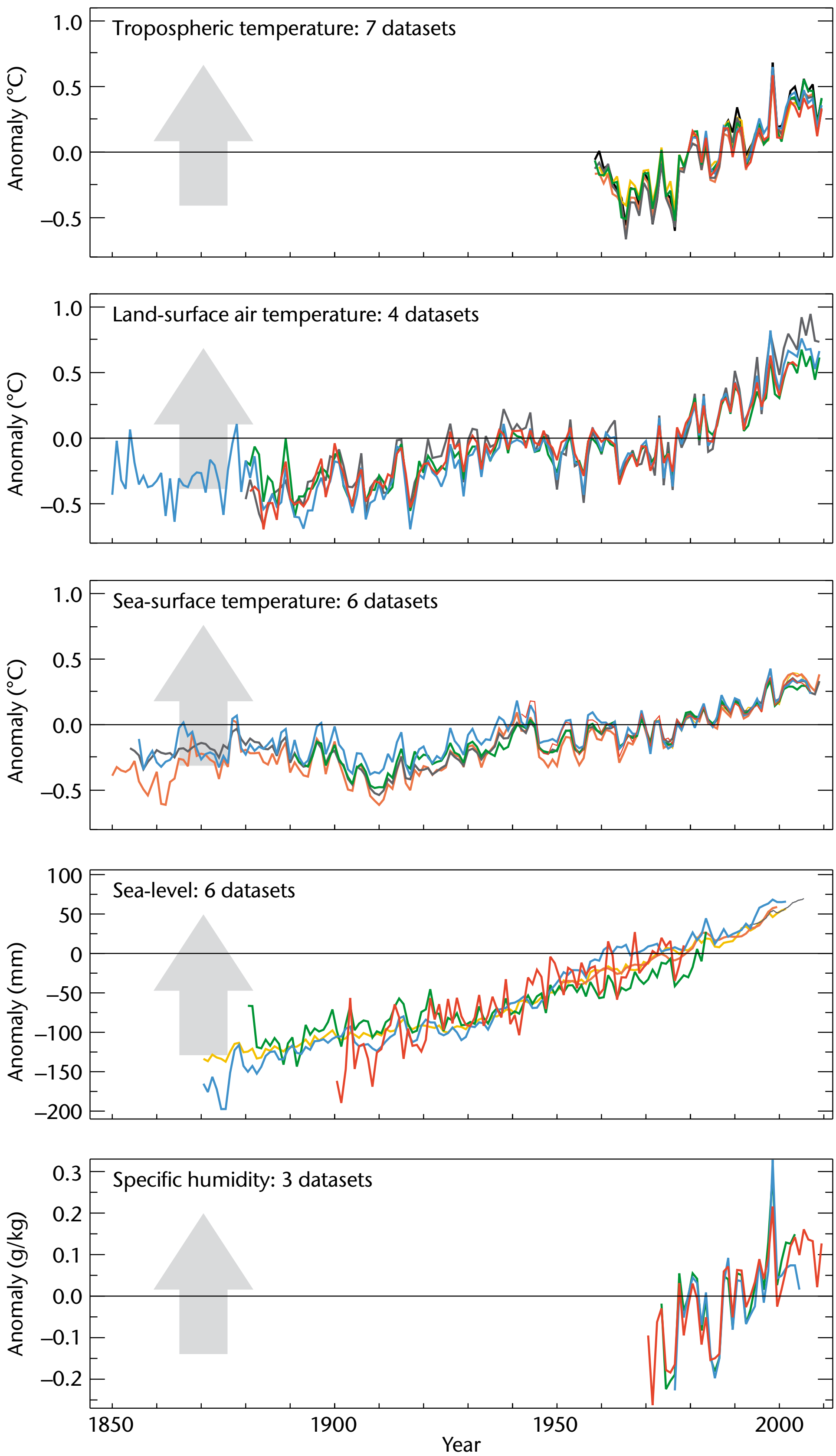
MULTIPLE DATASETS AND INDEPENDENT ANALYSES HIGHLIGHT LONG-TERM WARMING

Although there are noticeable highs and lows in year to year data — due to natural variability in the Earth's climate — over longer periods of time there are discernable trends in these indicators, as shown by multiple and independently corroborated analyses. These clear and unmistakable signs of a warming world highlight the necessity of looking at the longer term record when understanding climate change.

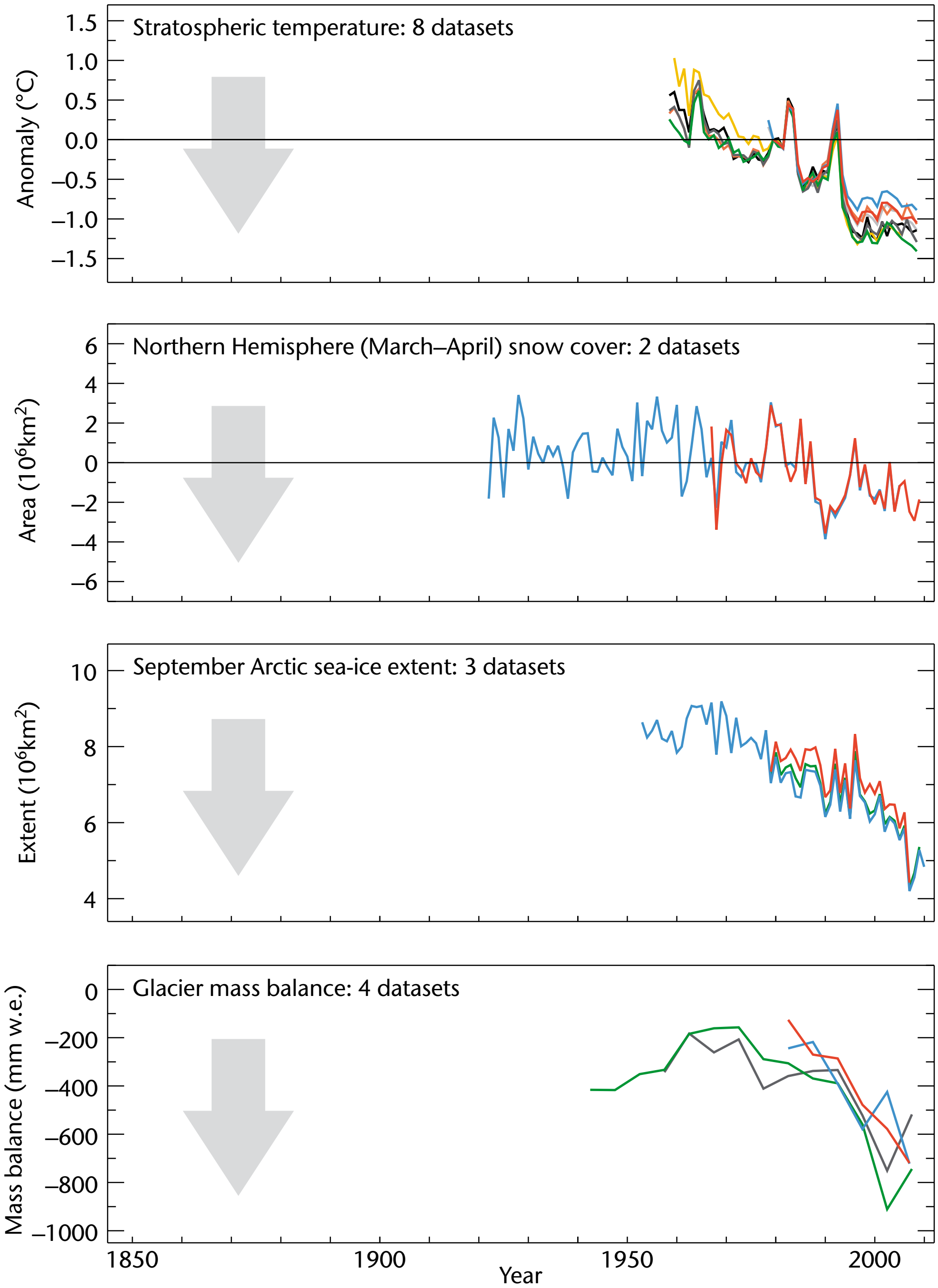
Multiple analyses indicate that each climate indicator is relatively mature and robust.

INCREASING — Observations consistent with a warming world

Nine indicators of climate change as apparent from multiple datasets. Changes in all the indicators over time are consistent with a warming world.



DECREASING — Observations consistent with a warming world



The temperature rise is inexorable — despite short-term variations.

Maize crop suffering drought

Short-term trends in climate

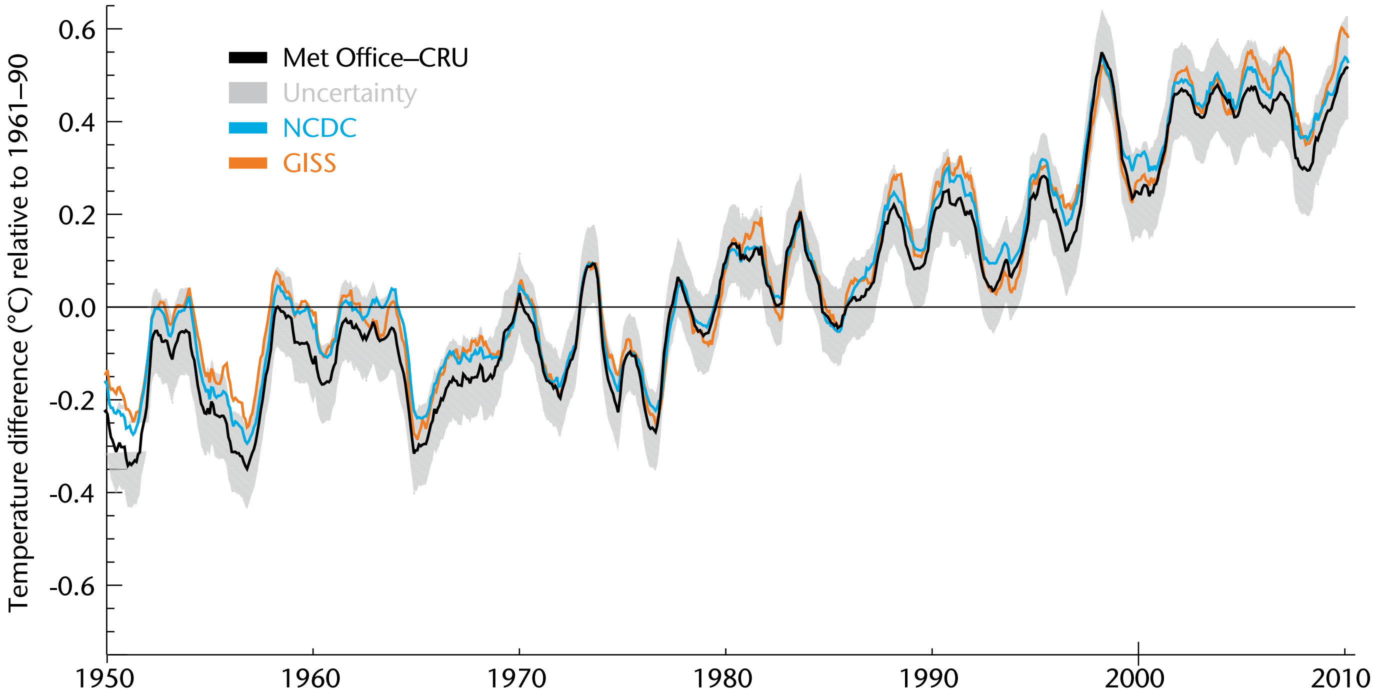
Many factors drive short-term variations in climate, causing some decades to warm more quickly than the long-term trend, whilst others warm more slowly. In addition, the various indicators of global warming can behave differently in the short-term. We highlight two examples from the last decade — surface temperature, where a recent decrease in the rate of warming may be explained by natural variability, and Arctic summer sea-ice, where the rate of loss in ice extent has increased above the long-term trend but the causes are less clear.

TEMPERATURE

Since the late 1970s the long-term rate of surface warming has been about 0.16 °C per decade. However, the observed rate of warming has decreased slightly in the last 10 years to 0.05–0.13 °C per decade — depending on whether you use the Met Office–CRU[2] observational dataset, that of NASA's Goddard Institute for Space Studies (GISS) or NOAA's National Climatic Data Center (NCDC).

The recent decrease in rate of temperature rise has been independently observed in both land and sea-surface temperature records. There is also evidence of a slower accumulation of heat in the ocean down to 700 m depth since 2003.

2 Met Office Hadley Centre in collaboration with the Climatic Research Unit, University of East Anglia



12-month running mean of global average temperatures from three datasets. HadCRUT3 (black and grey area) produced by the Met Office–CRU; NCDC (blue) produced by the National Climate Data Center; and GISS (orange) produced by the Goddard Institute for Space Studies at NASA. The grey shaded area shows the approximate 95% confidence range for the HadCRUT3 data. The true global average is expected to lie outside this range around 5% of the time.

Factors contributing to short-term trends

Concentrations of man-made greenhouse gases have continued to increase over the last decade at a more or less constant rate. So, a slowdown in emissions due to the recent recession cannot account for the short-term trends.

We are already familiar with the concept of natural variability, seeing the weather vary from hour to hour and day to day. Similarly, the climate varies naturally from year to year and decade to decade. Climate model simulations suggest internal variability of the climate system could be responsible for all of the recent decrease in the rate of warming.

Peruvian vessel fishing for anchovies in the Pacific Ocean.
Photo: ©IRD/Arnaud Bertrand

EL NIÑO

El Niño occurs every few years across the tropical Pacific Ocean and lasts about 12–18 months. The water warms and spreads from the West Pacific and Indian Oceans to the East Pacific. Its counterpart La Niña has the opposite effect — with temperatures cooler than normal.

El Niño raises the global average temperature and affects weather patterns around the world, but particularly in the Tropics. For example, it affects the trade winds and the location of the strongest rainfall in the Pacific region.

Natural variability within the climate system could explain all of the recent slowdown, but other factors could have contributed.

It is possible that more heat is being transported to the deep ocean, leading to less warming at the surface. The deep ocean temperature remains a major uncertainty. We have only been able to monitor the ocean (average depth about 4000 m) to about 2000 m to any extent since 2002 with the deployment of Argo floats. Prior to that, data below 700 m are limited.

Two natural factors that have been important in previous decades, however, have not contributed to the recent slowdown. El Niño/La Niña (ENSO) variability has contributed a net warming effect over the last decade. There have also been very few climatically significant volcanic eruptions in the same period (particles emitted by volcanoes tend to cool the climate).

Other possible factors may have contributed to short-term trends:

- **Changes in solar activity[3]**
  A natural downturn in the radiation from the Sun occurred during some of the last decade as part of the well-known 11-year solar cycle, possibly cooling the Earth's surface. However, one recent research paper[4] suggests that this could have led to temporary warming rather than cooling.

The Sun during a period of active sunspots

- **Changes in stratospheric water vapour[5]**
  In the last decade there has been a small reduction in stratospheric water vapour — also a greenhouse gas. The reasons for this reduction are not known, but may relate to natural internal variability controlling the amount of moisture reaching the stratosphere.

- **Increased aerosol emissions from Asia**
  A possible increase in aerosol emissions from Asia in the last decade may have contributed substantially to the recent slowdown. Aerosols cool the climate by reflecting sunlight. Difficulties in monitoring aerosol pollution, however, mean the impact is uncertain.

The rate of warming in the last decade has been underestimated because of changes in ocean measurements and poor data coverage in the Arctic.

- **Changes to sea-surface temperature measurement practices[6]**
  Changes in the way sea-surface temperatures were measured over the last decade have introduced a small artificial cooling of up to 0.03 °C over the last decade. This is being corrected in a new version of the Met Office dataset.

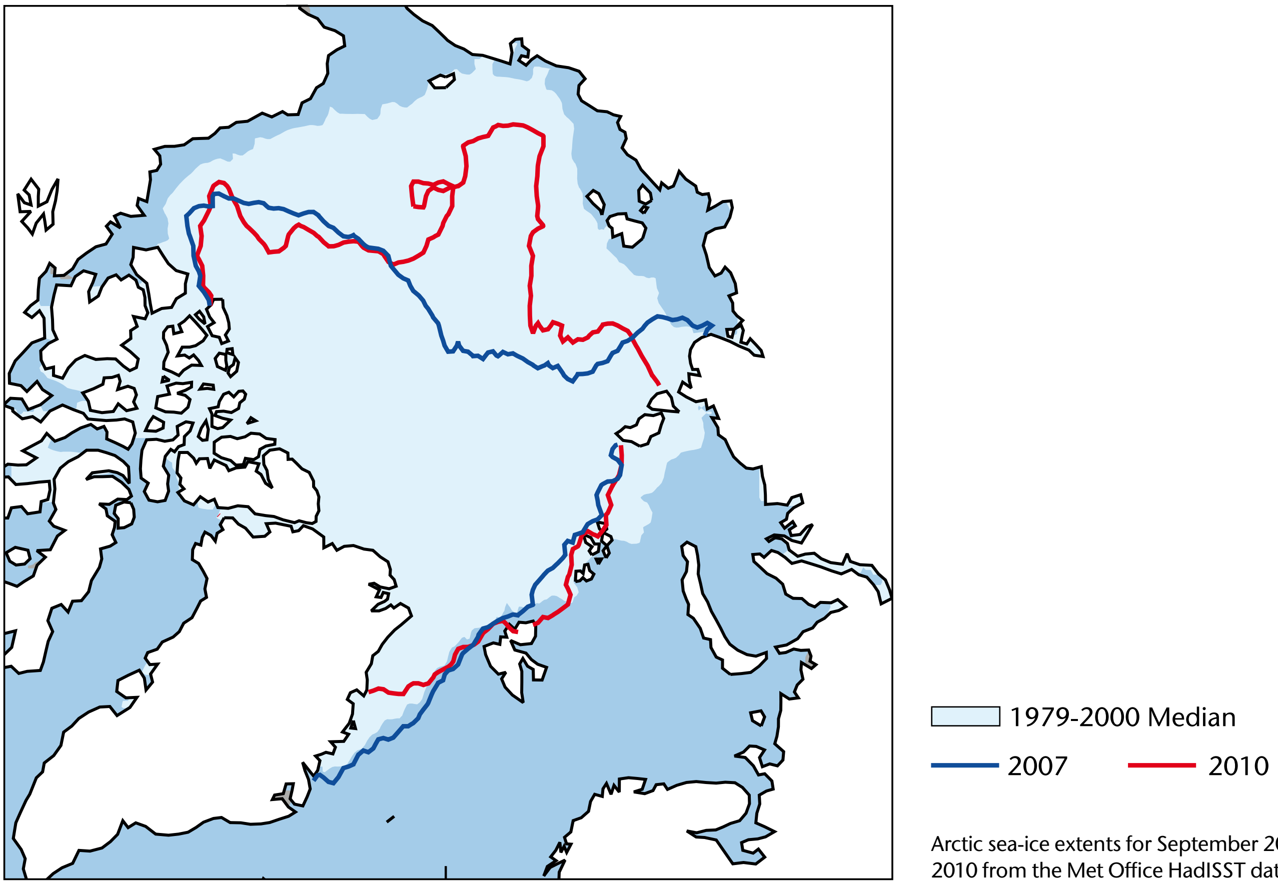
- **Strong warming in the Arctic is poorly represented**
  Satellite measurements and other evidence indicate that temperatures in the Arctic have increased at a faster rate in the last 10 years. This region is poorly represented in the surface temperature datasets because there are very few observing stations. The recent shift in the pattern of warming means that understanding the implications of poor sampling of the Arctic has become more important. This has contributed to the apparent slowdown in some datasets.

[3] Chapter 10, IPCC Fourth Assessment Report 2007; J. Lean, 2009. Cycles and trends in solar irradiance and climate. WIREs: Climate Change, Vol. 1, 111–122.
[4] J. D. Haigh, A.R. Winning, R. Toumi and J.W. Harder, 2010. An influence of solar spectral variations on radiative forcing of climate, Nature Vol. 467, 696–699.
[5] S. Solomon, K. H. Rosenlof, R. W. Portmann, J. S. Daniel, S. M. Davis, T. J. Sanford and G.K. Plattner, 2010. Contributions of stratospheric water vapor to decadal changes in the rate of global warming, Science Vol. 327, 1219–1223.
[6] J. J. Kennedy, R. O. Smith and N. A. Rayner, 2011. Using AATSR data to assess the quality of in situ SST observations for climate studies, in press Remote Sensing of Environment.

The four lowest sea-ice extents have occurred in the last four years.

Short-term trends:

Arctic summer sea-ice



Arctic sea-ice extents for September 2007 and 2010 from the Met Office HadISST dataset

Since the late 1970s, when systematic satellite monitoring of Arctic sea-ice began, there has been a marked decline in the extent of the ice, but with significant variations from year to year. The minima for the last four years are the four lowest recorded during the satellite era. There was a dramatic loss in 2007 followed by a partial recovery. 2008, 2010 and 2009 rank second, third and fourth lowest, respectively. In 2010 the minimum was 4.6 million km^2 on 19th September. Ice cover remained in the East Siberian Sea, but both the Northwest Passage and the Northern Sea Route were open at the time of the minimum, in contrast to 2007 when the Northern Sea Route remained blocked by ice.

There has been a decline of around 2.4 million km^2 of Arctic summer sea-ice since the late 1970s — an area larger than Greenland.

Sea-ice at Spitsbergen, Arctic Circle

In contrast with temperature, there is now some statistical evidence that sea-ice is declining at a faster rate on average. It is too early to tell whether this will be sustained.

It is not clear what, if anything, might be causing a change in the rate of decline. However, it is clear that natural variability plays a major role in determining the ice extent in individual years. In particular, highly variable atmospheric circulation in the Arctic summer plays an important part in sudden changes to sea-ice and can explain the dramatic drop which led to a minimum in Arctic sea-ice extent in summer 2007 and the low sea-ice in subsequent years.

Man-made climate change has been shown to have affected the long-term trend, which has seen a summer decline of around 0.8 million km^2 per decade since the late 1970s. Climate models can only explain the decrease in ice extent if they take account of man-made factors as well as natural variations, strongly suggesting that human activity has contributed to the decline.

Short-term trends:
Summary

The long-term trend in Arctic summer sea-ice extent is consistent with the long-term warming trend. However, the short-term trends in temperature and sea-ice appear to be at odds with each other — with the former decreasing in rate over the last 10 years and the latter increasing in rate. The factors affecting short-term trends vary for different climate indicators which can lead to apparently contradictory signals, as we have seen here. Sustained monitoring plays a critical role in distinguishing short- and long-term trends and identifying any change in the long-term rate of global climate change.

ARE SHORT-TERM TRENDS CONSISTENT WITH A WARMING WORLD?

They are consistent with the models

A 10-year decreased (or, indeed, increased) rate of global temperature rise is frequently seen in climate model predictions of global warming — driven by increasing greenhouse gases. Equally, rapid sea-ice loss is often seen for a few years followed by a partial recovery to the long-term trend. Recent trends therefore remain entirely consistent with predicted man-made climate change.

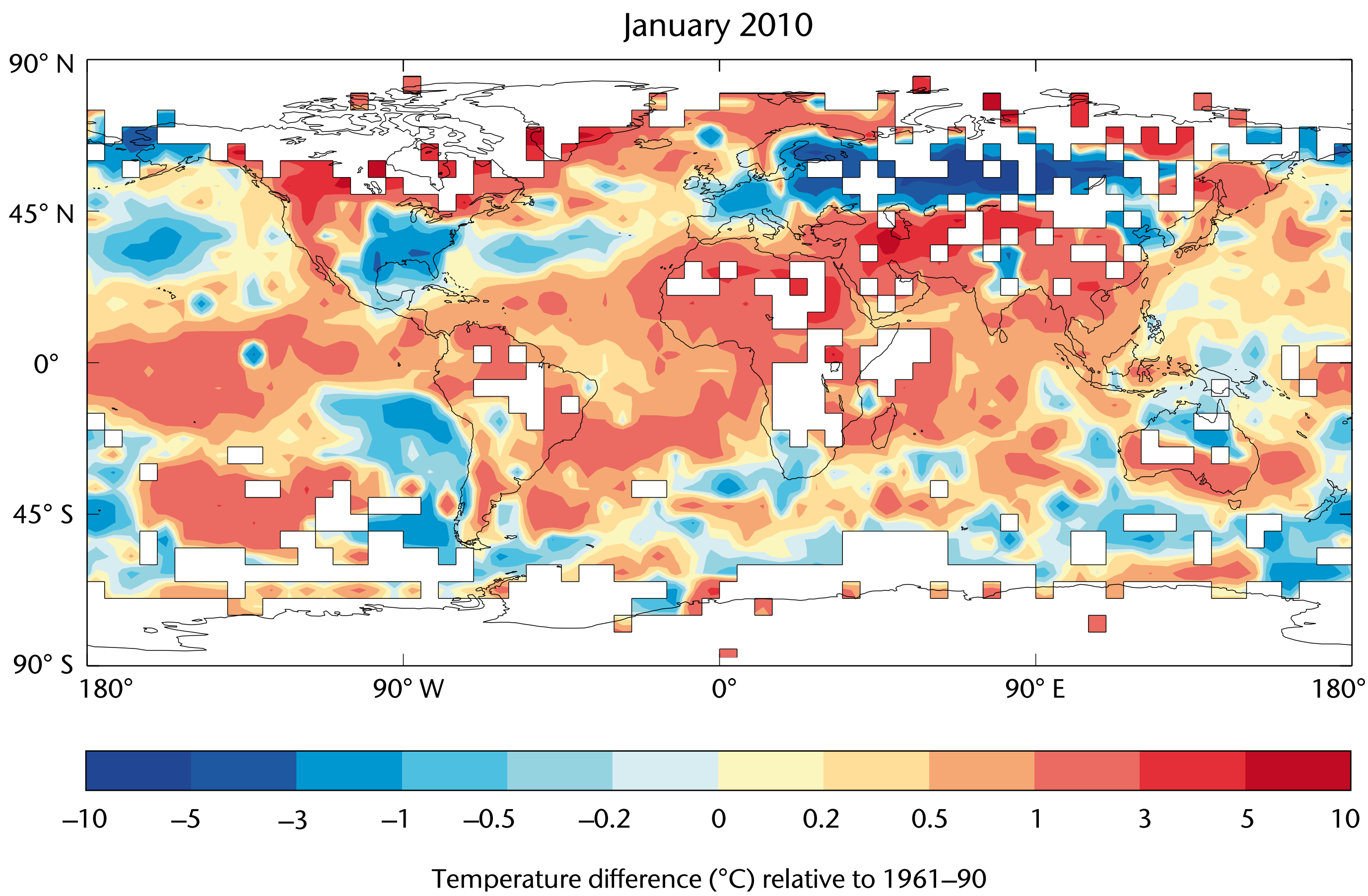
Further warming increase is expected

We expect warming to increase in the next few years. This is consistent with Met Office decadal forecasts and based on our expectation that internal variability is a major contributor to the recent decrease. However, other future external factors — such as volcanic eruptions or changes in solar activity — could prolong the current reduction in warming.

More research still needed

Some of the factors that contribute to short-term variations, such as stratospheric water vapour changes, are not fully understood or well represented in current climate models. More research is needed to improve the modelling of relevant physical processes and the monitoring of our evolving climate.

Despite cold temperatures in northern Europe, Asia and the eastern USA in January 2010, globally it was one of the warmest Januarys on record.

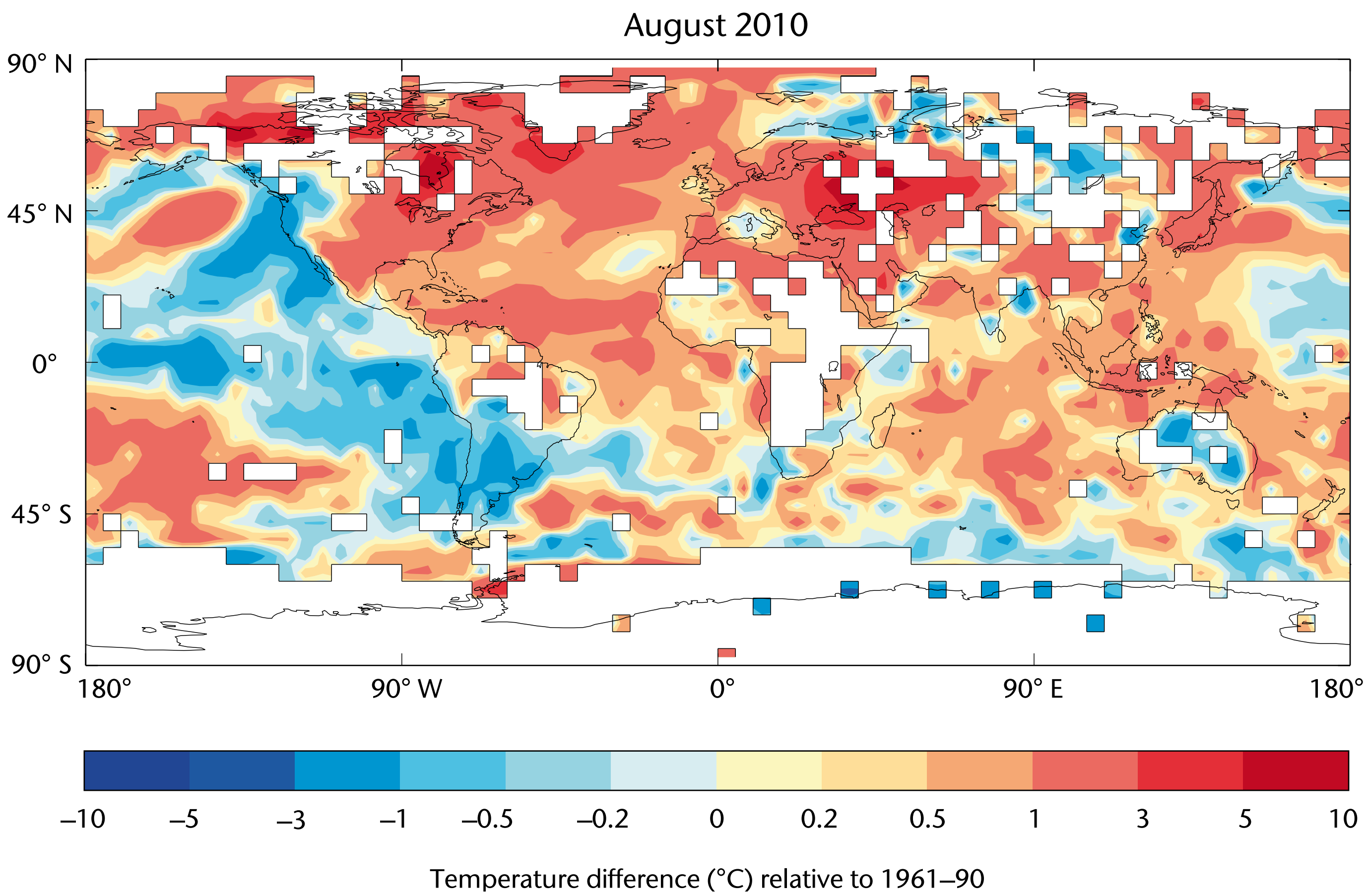


The Met Office–CRU global dataset highlights January 2010 as one of the warmest Januarys on record. The plot shows near-surface temperatures for January 2010 (above) and August 2010 (opposite page) compared to the climatological average for 1961–90.

The climate in 2010

The Met Office Hadley Centre has calculated that the global surface temperature in 2009 was 0.44 °C above the 1961–90 climatological average (0.73 °C above the pre-industrial average) — the fifth warmest in the instrumental record stretching back to 1850. Despite cold end of year temperatures in parts of the Northern Hemisphere, this was an increase on the 2008 ranking (see page 9). Based on data to September, 2010 is even warmer than 2009 and one of the warmest on record. The global temperature for the twelve months to September 2010 was 0.52 °C above the 1961–90 average (0.81 °C above the pre-industrial average).

An El Niño peaked in late December 2009 and continued to raise global temperatures for the first few months of 2010. However, this El Niño was considerably weaker than that which led to record-breaking global temperatures in 1998. La Niña, which brings cooler global temperatures, then became well established during the second half of 2010. Despite the weaker El Niño in 2010, this year is one of the warmest in the instrumental record. Man-made warming is likely to be a contributory factor.



January 2010. A man attempts to clear deep snowdrifts near Oldham, as heavy snowfalls continue across many parts of the UK. Photo: PAPhotos

July 2010. Moscow experienced a heatwave where for several weeks the air temperature did not drop below 30 °C.

There is a tendency for people to interpret their own experiences of day to day weather in terms of climate change. Although temperatures plummeted in January 2010 in northern Europe, Asia and the eastern USA, globally the month was one of the warmest Januarys on record. In fact, in large areas, including western Canada and the eastern Mediterranean, January was unusually warm. This illustrates that the global picture was very different from the regional. Equally, one warm or cold month does not indicate a trend. Rather, we must look at long-term trends.

Extremes in 2010

Air in Moscow full of smoke due to raging wildfires in July, 2010.

Although we can't attribute individual extreme weather events to climate change, the risk of some types of events may have already increased.

2010 saw a number of extreme events across the world, including record-breaking temperatures and widespread monsoon flooding in Pakistan; heatwaves and wildfires in Russia; flash flooding and mudslides in China; and drought, followed by flash floods, in Niger.

The events in Russia and Pakistan are of special interest as they were linked by an unusual meteorological pattern across Eurasia (for more on this see panel opposite).

MOSCOW TAKES THE HEAT

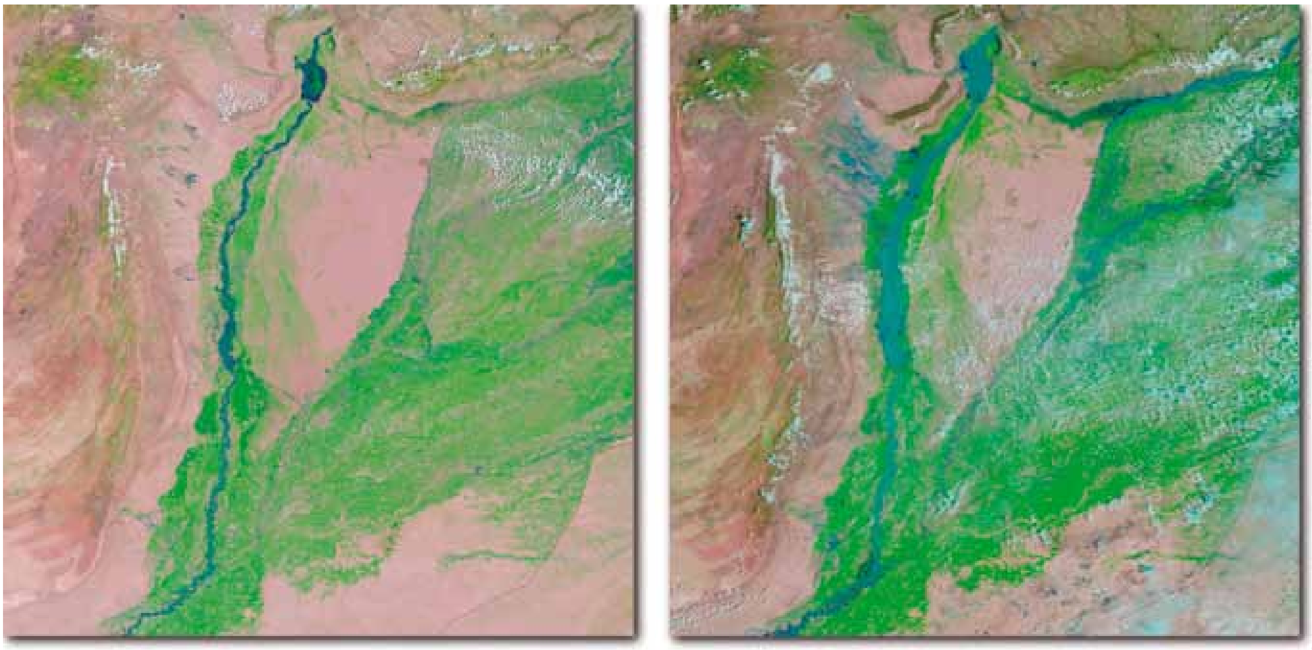
On Monday 26 July 2010, Moscow endured its hottest day in 130 years of records. The temperature reached 37.5 °C, breaking the previous record of 36.8 °C set on 7 August 1920. This record was again broken a few days later on 29 July, with a maximum temperature of 38.2 °C.

July was the warmest month ever recorded in Moscow, with an average temperature exceeding the long-term average by over 7 °C. Crops failed, and forest and peat fires burned around the Russian capital, shrouding it in smoke.

PAKISTAN SWELTERS THEN FLOODS

On 26 May 2010, Pakistan experienced its highest recorded temperature of 52.5 °C in Pad Idan.

In late July, an active low pressure system moved south into Pakistan to combine with the monsoon. Over the two days 28–29 July 333 mm of rain fell in Peshawar province. This intense rainfall caused severe flooding and landslides, sweeping thousands of villages away and affecting tens of millions of Pakistan's population.



Flooding of the Indus River in north-west Pakistan as seen from the MODIS satellite instrument. The image on the left shows the river in its normal state (1 August 2009); the image on the right, taken almost exactly one year later, shows the river in a flooded state (31 July 2010). Courtesy NASA.

AN UNUSUAL METEOROLOGICAL PATTERN

The jet stream — a fast-flowing air current a few kilometres up in the atmosphere — normally brings weather systems from west to east. In July 2010 the jet stream became fixed in a static 'blocking' pattern creating high surface-pressure over western Russia; this resulted in the heatwave. Another element of this persistent large-scale pattern simultaneously caused mid-latitude weather systems to penetrate further south towards Pakistan. These engaged with the warm, humid monsoon airflow and produced unusually large amounts of rainfall.

CAN WE LINK SUMMER 2010 EXTREMES TO GLOBAL WARMING?

We cannot readily attribute any individual extreme weather event — such as those that occurred in summer 2010 in Pakistan, Russia and China — to man-made climate change. However, climate change is 'loading the dice'— heatwaves and heavy rainfall events are likely to occur with increasing frequency globally. Indeed, we may be already seeing this. For example, there is evidence that heavy rainfall events are getting heavier, including in India[7] and China[8]. This is entirely consistent with our understanding of the physics of the atmosphere — that warmer air holds more moisture, with the potential for heavier downpours.

Our climate change predictions support the emerging trend in observations and show a clear intensification of extreme rainfall events in a warmer world. So, although climate change is very unlikely to have been solely responsible for the Pakistan floods, it is possible that it may have played a role in exacerbating an unfortunate conjunction of weather patterns which led to this event. Further research is needed to understand how climate change may have altered the risk of such an event occurring.

More heat, more heatwaves

In the case of heatwaves, there is a fairly direct link between the global and regional average warming attributable to human influence and the increasing frequency of extreme temperatures that has been observed worldwide. As the average global temperature increases, there is an increased risk of major and long-lasting heatwaves like the one in Moscow.

[7] S. K. Dash, M. A. Kulkarni, U. C. Mohanty and K. Prasad, 2009: Changes in the characteristics of rain events in India. Journal of Geophysical Research, Vol. 114.

[8] B. Liu, M. Xu, M. Henderson and Y. Qi, 2005: Observed trends of precipitation amount, frequency and intensity in China, 1960–2000. Journal of Geophysical Research, Vol. 110.

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