



Met Office
Hadley Centre

The changing climate: past changes and future projections

September 2013



GUIDE TO CLIMATE CHANGE SCIENCE

The science of climate change will be a focus for global attention over the next year as the Intergovernmental Panel on Climate Change (IPCC) begins publication of its Fifth Assessment Report (AR5). AR5 will provide a clear scientific view on the current state of knowledge on climate change and its potential impacts. It is the first comprehensive update on the science since the Fourth Assessment Report (AR4) was published in 2007.

As an authoritative document, AR5's contents will form the evidence basis for decision makers in government, business and organisations around the world over the coming years.

The Met Office Hadley Centre, as one of the world's leading climate research centres, has been a key contributor to the IPCC process and AR5. This contribution draws on the breadth of the UK's national climate capability and our partnerships with research establishments across the UK, and around the world. Several of our scientists are lead authors on the report, and extensive use is made of our science, models and datasets.

Over the coming months our advice can help you understand and interpret the key findings in the report documents as they are published between September 2013 and November 2014. The first volume will focus on climate science, while later volumes will provide updates on climate impacts and mitigation issues.

In the run-up to the start of that process, this guide looks at some of the elements of climate change science.

CURRENT STATE OF THE CLIMATE

Weather and climate science is founded on observing and understanding our environment. A global network of observation and monitoring systems helps build a picture of current and past climate. This is the basis on which science can advance and underpin advice required by users.

Established science tells us that greenhouse gases play a key role in our atmosphere by trapping some of the heat which is generated by incoming energy from the sun. Without this effect the Earth would be much cooler.

Human activity has increased the concentration of greenhouse gases in the atmosphere, which increases the amount of heat they trap which is altering the Earth's energy balance. Figure 1 shows the measured concentration of one of the most important greenhouse gases, carbon dioxide (CO₂), over the past few years. Since the industrial revolution began more than 150 years ago, concentrations have increased by around 40% from 280–290 parts per million (ppm) to present levels, largely due to burning of fossil fuels, industrial activity and changes in land use. This year, levels briefly exceeded 400 ppm for the first time in the Mauna Loa record.



Atmospheric CO₂ at Mauna Loa Observatory

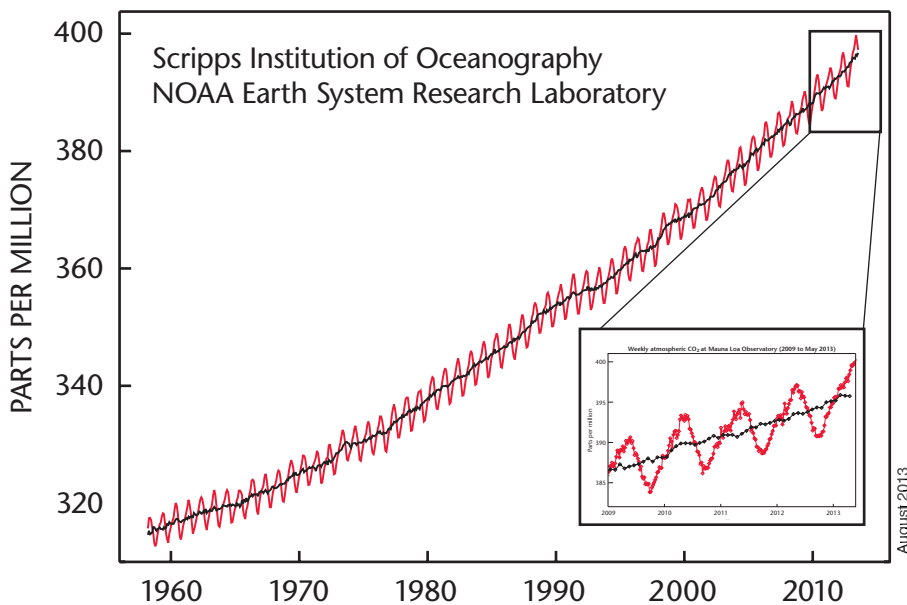


Figure 1. The carbon dioxide data (red curve), measured as the mole fraction in dry air, on Mauna Loa, Hawaii constitutes the longest record of direct measurements of CO₂ in the atmosphere. The black curve represents the seasonally corrected data. Source: National Ocean and Atmospheric Administration (NOAA).

Inset shows the most recent weekly values of atmospheric carbon dioxide at Mauna Loa Observatory between 2009 and 2013.

August 2013

A SLOWER RATE OF WARMING IN RECENT YEARS HAS SEEN TEMPERATURES REMAIN AT NEAR-RECORD LEVELS

The rate of global temperature rise has slowed in the last decade or so. This has seen temperatures remain at near record levels – with the last decade (2000–2009) being the warmest on record. There have been previous periods of little or no warming in the observational record (figure 6), and climate model projections also show such periods. These have a variety of causes.

The recent slowdown could be due to long-term ocean cycles, which alter the way the oceans take up and store heat, and changes in the radiative forcing (i.e. energy coming in and going out) of the planet. Research is ongoing to understand these changes.

Based on our current understanding, we expect warming to resume in line with projections for the current and increasing levels of greenhouse gas concentrations.

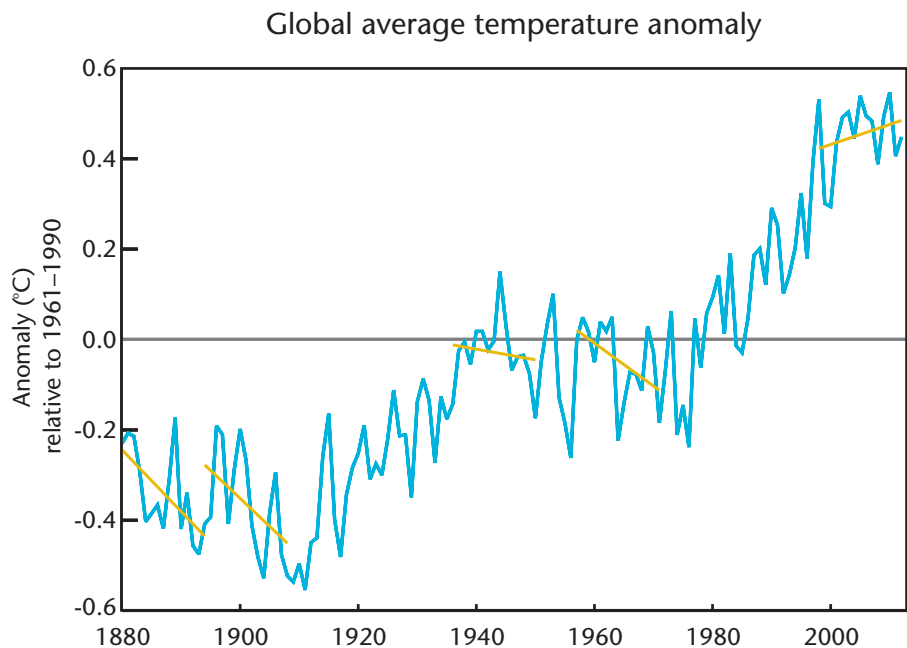


Figure 6. Global average near surface temperature difference relative to 1961–1990 using Met Office observations (HadCRUT4).

Straight lines show 15-year periods in the time series where there has been a slower rate of warming, for example 1880–1894, 1936–1950, 1998–2012, as well as periods of rapid warming, for example around 1910 and late 1970s.

MANY ASPECTS OF GLOBAL WEATHER ARE CHANGING

The changes we have observed in the climate have had an impact on weather patterns. Research is showing how human activity has changed the odds of certain extreme weather events or seasons happening. For example, human emissions of greenhouse gases mean that the chances of experiencing a summer as hot as the European heatwave of 2003 were found to have at least doubled.

Not all extreme weather events are influenced by human activity. For example, the damage caused by the 2011 floods on the Chao Phraya river in Thailand was unprecedented, but the available data show the amount of rain that fell in the catchment area was not very unusual. Other factors such as land use changes were important in setting the scale of the disaster.

New research suggests that long-term cycles in the ocean lasting tens of years affect the position of the jet stream and contribute to the run of unusual seasons seen recently in the UK. This is a new area of research and we do not yet know whether greenhouse gases have changed these cycles.

EVENT IN 2011	HAVE HUMANS CHANGED THE ODDS OF OCCURRENCE?	COMMENTS
Texas heatwave	Increased	During La Niña years only
Unusually warm November in UK	Increased	About 60 times more likely than during the 1960s
East African drought	Inconclusive	Both La Niña and humans could have increased the odds
Cold December 2010 and January 2011 in UK	Decreased	Natural variability could still result in cold winters
Thailand floods	Insufficient evidence	Factors other than climate change at play
Warm European spring and autumn	Increased	Takes into account weather patterns

The Met Office Hadley Centre, along with colleagues in the US National Oceanic and Atmospheric Administration, trialled the attribution of recent extreme weather in the Bulletin of the American Meteorological Society (BAMS) in July 2012. Attribution studies on six extreme weather events of 2011 were presented*

*Peterson, T.C., Stott, P.A., Herring, S. (Eds) 2012. *Explaining Extreme Events of 2011 from a Climate Perspective*. BAMS. 10.1175/BAMS-D-12-00021.1

PROJECTING THE FUTURE

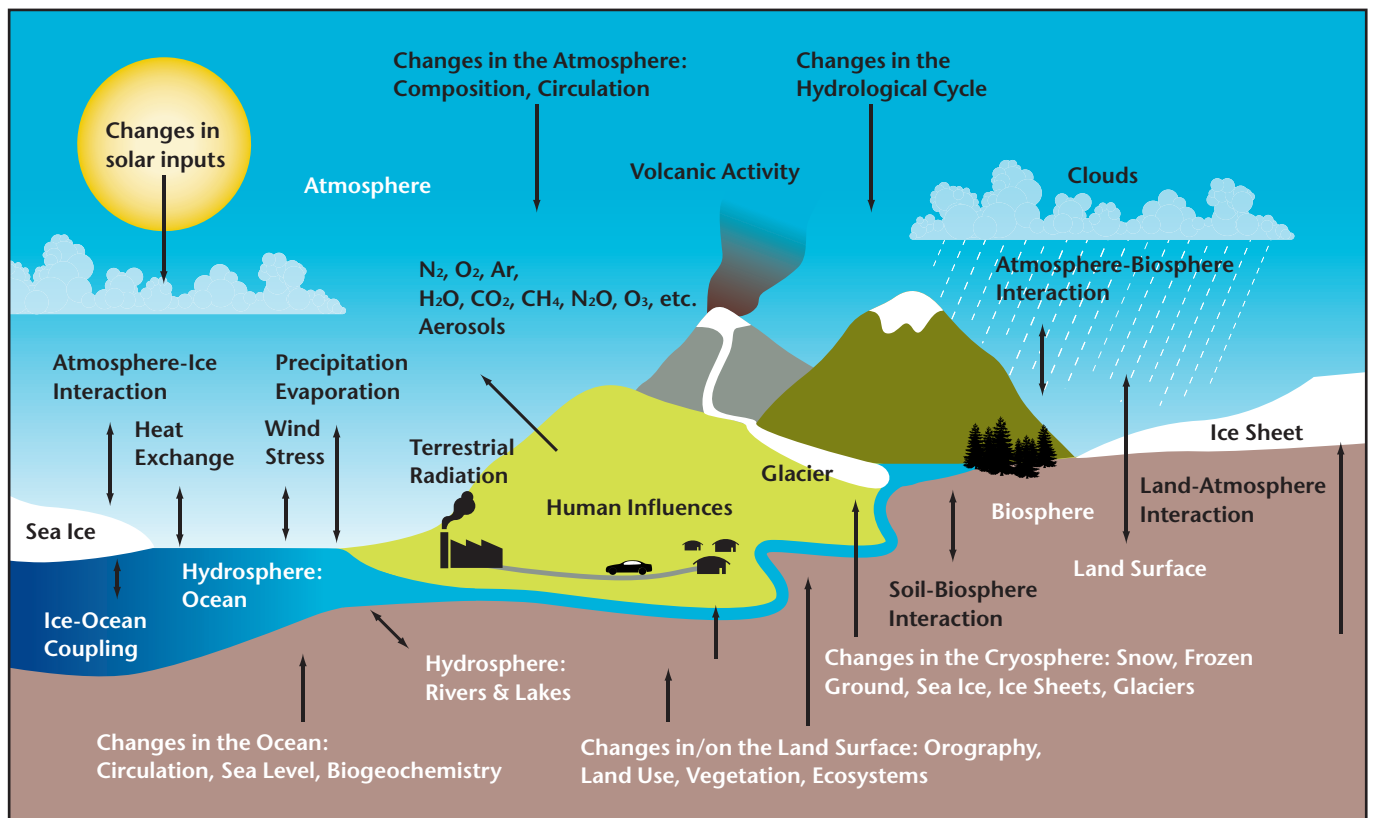


Figure 7. The various processes that are generally represented in Earth system climate models to obtain a picture of how these processes affect climate.

To project changes in climate, research centres use computer models which simulate the Earth's climate system using the laws of physics and our current understanding of the ocean and atmosphere. The models are evaluated by comparing them to past climate, past trends and the ability to reproduce particular types of extreme seasons, giving confidence in the models and our understanding of the physics and chemistry of global warming.

Climate models are becoming increasingly sophisticated and now allow for many, but not all, of the complex processes that control the climate. The further into the future a model is used to project change, the less confident we can be in a single value. Therefore when using models to project changes several decades ahead, a certainty range is typically used to show the spread we are confident of. Ranges can be used in risk-based planning.

Climate feedbacks will play a role

Climate change resulting directly from radiative forcing by greenhouse gases can lead to responses in other parts of the climate system which may either accelerate warming (known as positive feedbacks) or slow it (negative feedbacks).

Some feedbacks respond very rapidly, such as warmer temperatures leading to increased water vapour in the atmosphere, which increases the greenhouse effect (positive), or changes in cloud cover, which could retain more heat but also reflect more of the sun's energy back into space (positive and negative). Other feedbacks involve changes on longer timescales, such as many of those related to the carbon cycle. A key area of interest in the forthcoming IPCC AR5 will be the improved understanding and quantification of many feedback processes.

GLOBAL TEMPERATURE SHOULD RISE IN FUTURE, BUT NOT AT A CONSTANT RATE

Global temperatures are expected to rise in the future, although the rate of warming will not be continuous as natural variability is superimposed upon long term changes. The amount of warming will also depend on emissions of greenhouse gases, changes in land use, and other factors – such as emissions of aerosols, which can have temporary cooling effects.

Different emission levels can be input into climate models which enable researchers to assess scenarios of future emissions and the projected changes to the climate. This is used in providing guidance on the emissions levels that are likely to avoid potentially dangerous climate change and informing adaptation on global, regional and local scales.

One of the most effective ways to use models is to combine them with observations. When this approach is used with the latest climate models the projection range over the next several decades is slightly smaller than from the models alone (figure 8).

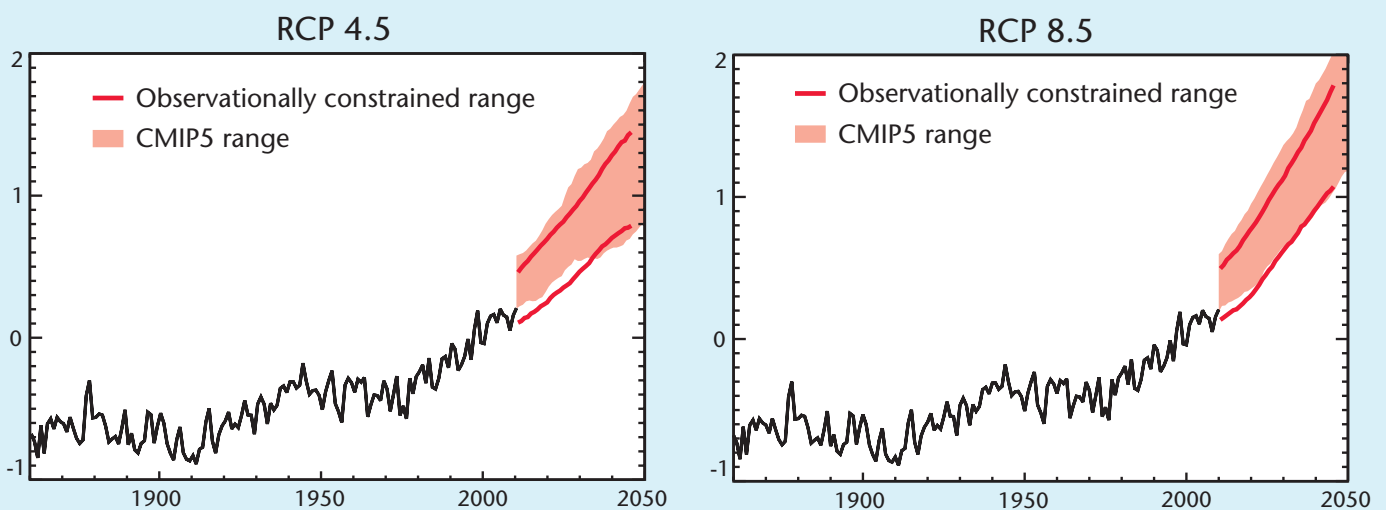


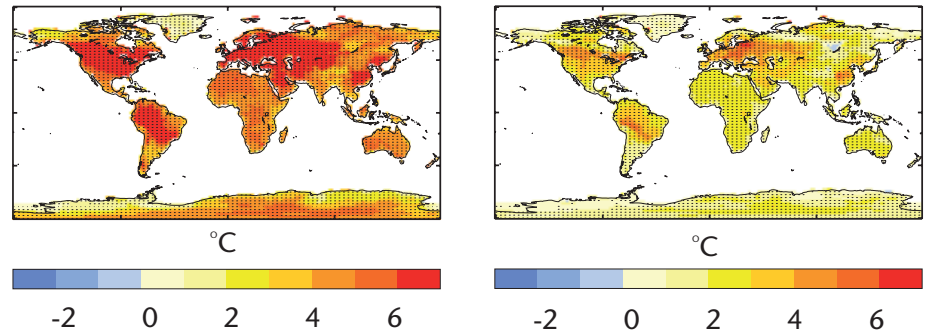
Figure 8. Global mean temperature projections from the Met Office Hadley Centre Earth system model, HadGEM2-ES constrained with observations, and the climate models from other modelling centres (CMIP5 range) for two IPCC Representative Concentration Pathway (RCP) scenarios. These are a set of scenarios based on varying future emissions of greenhouse gases leading to different levels of temperature rise. In this instance RCP 4.5 results in a lower temperature rise than RCP 8.5.

MODELS HELP TO UNDERSTAND THE POTENTIAL IMPACTS OF CLIMATE CHANGE AT A REGIONAL LEVEL

Increasing temperatures and other related impacts are likely to cause changes in the winds in the atmosphere and rainfall patterns. This could affect weather at regional and local levels. The increasing sophistication of climate models and increases in computer power both contribute towards scientists being able to make more robust projections about regional changes and the impacts those changes may have on factors such as food, water availability, and flooding.

Figure 9. Projected global changes in annual maximum temperature, demonstrating that with no change to current emission levels, temperatures are projected to increase by up to 6 °C relative to the 1961–1990 average (left panel), whereas with mitigation warming could be kept to 2 °C across most areas (right panel).

Changes are shown for the period 2070–2099 relative to 1961–1990. Changes are shown for a business as usual scenario (left panel) and a mitigation scenario (right panel), in which emissions are reduced rapidly during the 21st century. Dots indicate regions where changes between the two periods are significant at the 5% level (using a Student’s t-test). Model used was HadGEM1.



EARLY ACTION IS LIKELY TO REDUCE THE CHANCES OF DANGEROUS CLIMATE CHANGE

The United Nations has agreed that a rise in global temperature of more than 2 °C above pre-industrial levels could be dangerous, leading to ‘unacceptable’ levels of climate impacts and being more likely to trigger accelerated or irreversible environmental change. Research using climate models suggests early global action to reduce greenhouse gas emissions increases the chance of remaining below this level.

If greenhouse gas emissions peak in the next few years and then reduce by between 3 and 5% per year there is still a significant chance of limiting global average warming to no more than 2 °C (figure 10).

However, even for a 2 °C warming above pre-industrial levels there will be regional changes in climate and weather. Significant damage or adaptation will still be an issue but they will be much reduced compared to projected warming of 4 °C by the end of the century under no mitigation scenarios.

Climate research conducted by the Met Office Hadley Centre can also help to assess the effectiveness and potential environmental impacts of attempts to manipulate the Earth’s climate (so called “geo engineering”). At present there is limited understanding of the effectiveness or side effects of such techniques and a precautionary approach has been recommended by many researchers. Furthermore, there are many other political, moral and practical factors to consider alongside the science.

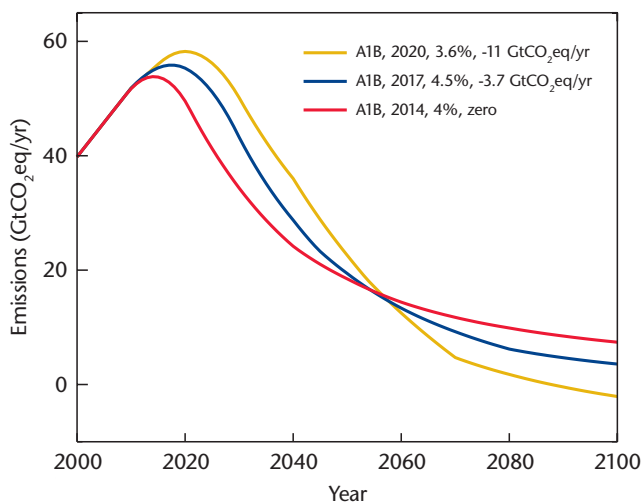


Figure 10. Keeping emissions on a pathway to limit global warming to 2 °C above pre-industrial levels is feasible but challenging. In these example scenarios some different options to achieve this target are shown. The yellow and blue curves ultimately require negative emissions through a combination of factors such as carbon capture and storage and bio-energy. By peaking emissions in 2014 and then reducing them by 4% per year (the red curve) the 2 °C target could be achieved with zero emissions.

CLIMATE SERVICE UK: CLIMATE AND WEATHER SCIENCE HELPS PLAN FOR THE FUTURE

Climate science continues to evolve, and the UK remains at the forefront of cutting edge science. This science, and the Met Office's role in delivering the national climate capability, underpins the support we can offer for decisions on how to manage the risk and opportunities associated with a changing climate. These climate services integrate current climate science into decision-making and can help society navigate the challenges of a changing climate.

For more information on the Climate Service UK see:
www.metoffice.gov.uk/climate-service-uk



Key issues in climate science ahead of AR5

AR5 will provide an authoritative and detailed assessment of climate science. As the report is based primarily on peer-reviewed research, much of which is already published, it is possible to identify some of the key issues in current climate science which are likely to be of interest and where there have been significant updates since AR4. The Met Office will be in a position to help interpret the new developments in these topics of interest when the new IPCC report is published:

- How recent extreme weather events may have been influenced by man-made climate change.
- Discussion of the causes and implications of the recent slowdown in global warming.
- Estimates of how sensitive the Earth's climate is to greenhouse gases, which are central to producing climate projections using models.
- Estimates of sea level rise over timescales out to 2100, including the latest understanding of the role of ice sheets.
- Improved understanding of how earth system processes, such as changes in vegetation or the thawing of permafrost coverage, affect the amount of future climate change expected.