Our changing climate – the current science

November 2015

Our climate is changing and the scientific evidence that man is contributing to this is stronger than ever before. The United Nation's 21st Conference of the Parties in Paris (COP21) will bring together representatives from 195 countries to take forward the political response to this challenge. Members will attempt to come to legally binding agreements with the aim of limiting global warming to around 2 °C above the levels before the world's industrial revolution.

Understanding how the climate has already changed and how it could change in future are vital to guiding these discussions. In 2013 the Intergovernmental Panel on Climate Change (IPCC) published its Fifth Assessment Report on Climate Change (AR5), the most comprehensive appraisal of the science published to date. Its headline conclusions cover many aspects of the subject – from the warming we have seen, to future impacts on issues like extreme weather and sea-level rise, as well as guidance on how we can avoid the most dangerous levels of climate change.

Since the publication of AR5, the global science community continues to build and refine this vital evidence base. 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 continues to work alongside research centres around the world to push forward understanding and to help people manage the risks of the changing climate.

Here we present the latest view on the key science around climate change.

CURRENT STATE OF THE CLIMATE

Greenhouse gases play a key role in our atmosphere by trapping some of the heat which is generated by incoming energy from the sun. This effect is vital to life on our planet – without it the Earth could be more than 20 °C cooler. While all greenhouse gases contribute to this effect, much attention is focused on carbon dioxide (CO_2) because it is being directly altered by human activity, has a relatively potent greenhouse effect, and stays in the atmosphere for a long time (50 to 200 years).

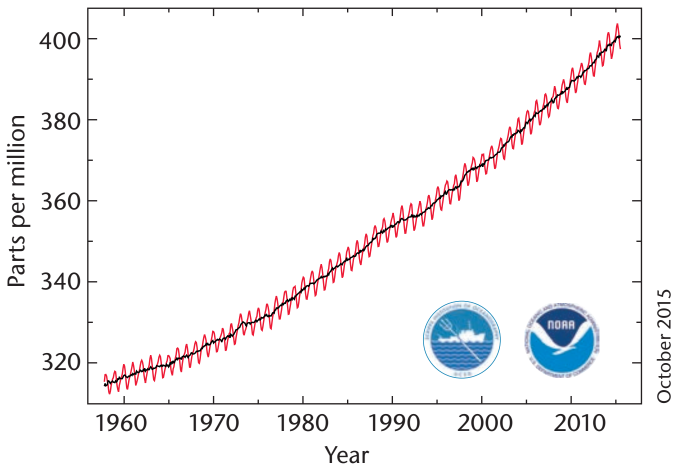

Figure 1. The carbon dioxide data (red curve) on Mauna Loa, Hawaii constitutes the longest record of direct measurements of CO_2 in the atmosphere. The black curve represents the seasonally corrected data. Source: National Ocean and Atmospheric Administration (NOAA).

Since the industrial revolution began more than 150 years ago the concentration of CO_2 in our atmosphere has increased by around 40%, from around 280–290 parts per million (ppm) to present levels. Monthly global average CO_2 concentrations passed 400ppm for the first time in March 2015. Evidence from ice-cores, which give an insight into CO_2 levels going back for hundreds of thousands of years, show that concentrations are higher now than at any point in the last 800,000 years. Levels of other greenhouse gases, such as methane, have also been rapidly rising. This long-term increase has been largely due to burning of fossil fuels, industrial activity and changes in land use.

> "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen."
>
> IPCC AR5 Synthesis Report

MANY INDICATORS SHOW OUR PLANET HAS WARMED

Increases in the atmospheric concentration of greenhouse gases have led to more energy entering the Earth's atmosphere. This is very likely to have contributed to changes across the planet. These include:

- **Increased air temperatures over land and sea.** In 2015, surface global temperature reached around 1 °C above levels around the industrial revolution for the first time. This marks a significant milestone as governments aim to limit long-term warming to around 2 °C to avoid the most dangerous impacts of climate change.

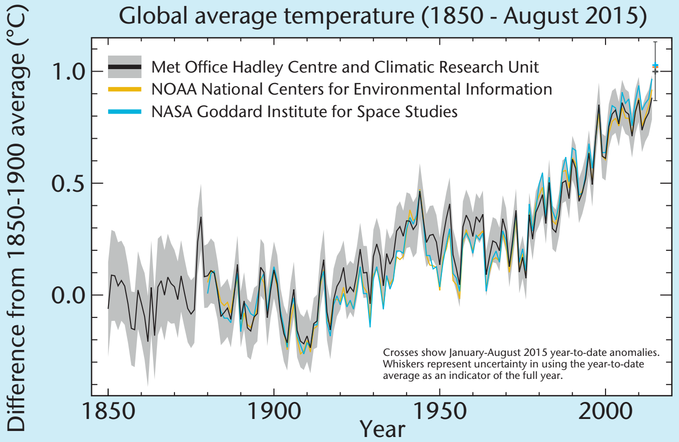

Figure 2. Shows the HadCRUT4 global mean temperature record (black line) with its uncertainty range (grey shaded area) alongside data from the two other main datasets compiled by NOAA and NASA.

- **Global sea levels have risen** by around 1.7 mm per year over the last century and increasing to 3.2 mm per year since around the early 1990s. Our understanding of the components of sea-level rise has improved significantly over recent years, with the main contributors being thermal expansion (oceans expanding as they warm) and melting of glaciers.

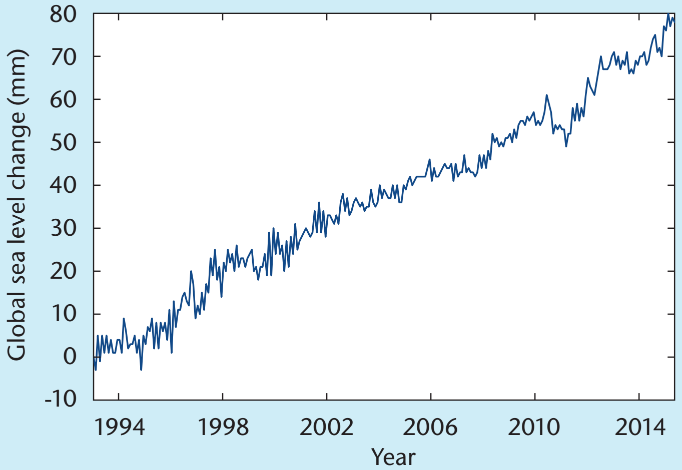

Figure 3. Observed change in global mean sea level relative to January 1993 based on satellite altimeter data. Data source: Commonwealth Scientific and Industrial Research Organisation (CSIRO).

- **Shrinking of Arctic sea-ice, most mountain glaciers and snow cover in the Northern Hemisphere.** Arctic sea-ice September extent has been decreasing at around 0.85 million km² per decade over the period 1979-2015, according to the Met Office's HadISST dataset. This represents a decline of 13.3% per decade, relative to the 1981 to 2010 mean extent (6.38 million km²). Antarctic sea ice, however, has seen record extent in recent years. There is some evidence to suggest this could be due to changing wind patterns which are linked to climate change.

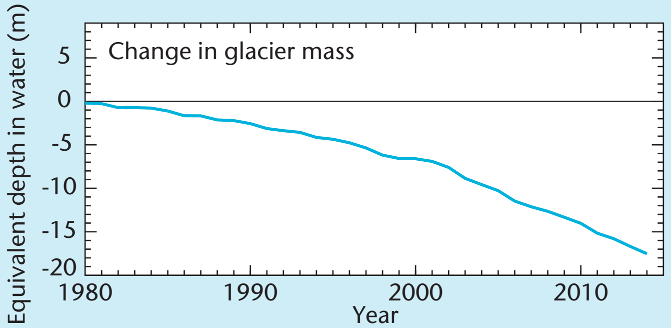

Figure 4. Total change in glacier mass balance since 1980 for 37 reference glaciers across the globe. Note that 2014 values are preliminary. A negative mass balance means glaciers overall are shrinking. Source: World Glacier Monitoring Service.

- **Increases in some types of extreme weather,** such as heatwaves and heavy rainfall, have also been observed globally – although trends vary regionally.

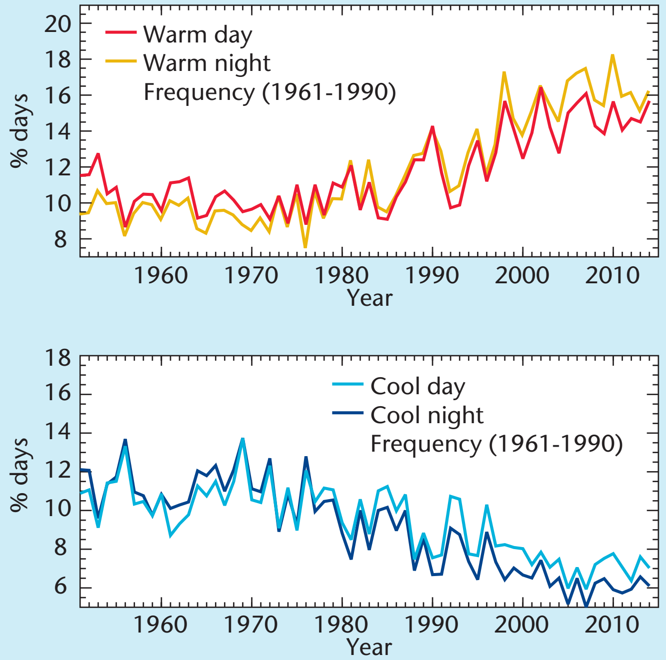

Figure 5. Frequency of global average daily temperature extremes in percent of days per year. Cool extremes are defined as days/nights in the bottom 10% of temperatures over a 30-year-period between 1981-2010, while warm days/nights are in the top 10%.

EXTREME WEATHER EVENTS ARE CHANGING

Global observations show an increase in certain types of extreme weather since 1950. There is a growing body of evidence which shows that human influence on our climate is increasing the risk of certain types of extremes, notably heatwaves. For example, Met Office research published in 2014 found that the chances of Europe experiencing a heatwave as extreme as seen in 2003 have increased from about 1-in-1000 to about 1-in-100 years. Such extremes are projected to increase further in the future but the exact changes will depend on emissions of greenhouse gases. Each year the Met Office contributes to a report in the Bulletin of the American Meteorological Society (BAMS) called 'Explaining Extreme Events from a Climate Perspective'. The report presents a number of studies, carried out by researchers around the world, which look at whether human influence on the climate changed the risk of specific extreme events in the past year. As this area of research develops, the number of studies is steadily increasing and looking at a more globally diverse set of locations. Selected findings from the report issued in 2015 are in the table opposite.

EVENT	FINDINGS
UK winter rainfall 2013/14 – the wettest winter in UK observational records.	Under the same weather pattern experienced in winter 2013/14 (a persistent westerly flow), extreme rainfall over 10 consecutive winter days is now seven times more likely than in a world without man-made greenhouse gas emissions.
Northern China hot spring in 2014 – third warmest spring since reliable observations began in late 1950s.	Anthropogenic forcing may have contributed to an 11-fold increase in the chance of the 2014 hot spring in Northern China.
Nepal snowstorm in October 2014 – severe snowstorms and related avalanches led to the deaths of dozens of people.	The Himalayan snowstorm resulted from the unusual merger of a tropical cyclone with an upper trough, and their collective changes under climate warming have increased the odds for similar events.
Southeast Brazil water shortage in 2014/15 – profound water shortages after one of the worst droughts in decades.	Anthropogenic climate change is not found to be a major influence on the water shortage whereas increasing population and water consumption increased vulnerability.
Hawaiian hurricane season 2014 – the 2014 Pacific hurricane season was the fourth most active since reliable records began in 1949.	New climate simulations suggest that the extremely active 2014 Hawaiian hurricane season was made substantially more likely by anthropogenic forcing, but that natural variability of El Niño was also partially involved.
Canada extreme flood – more than 200 mm of rain fell within 48 hours in the southeastern Canadian Prairies, leading to flash floods.	The collective effects of anthropogenic climate change and artificial pond drainage may have played an important role.

RECENT WARMING RATES

The rate of global surface temperature rise has varied greatly over the past century due to natural variability and other factors, but there has been a clear and ongoing warming trend. In the last decade or so we have gone through a spell of slower warming at the surface, similar to previous periods, despite the Earth continuing to accumulate energy due to increased greenhouse gases in the atmosphere.

Understanding the exact cause of the recent slowdown in surface warming is an area of continued research. It may be due to variability within our climate system, such as changes in long-term ocean cycles, or there may be a contribution from external factors such as changes in solar output or aerosols.

Although we can't say for sure the current pause is over, global temperatures are on the rise again. 2014 was nominally the warmest year in records dating back to 1850 while observations suggest 2015 is on course to be warmer still. Early projections for 2016 also indicate it could be another record or near-record year. It's more difficult to say what will happen in the years immediately after that, but in the longer-term we expect the warming trend to continue.

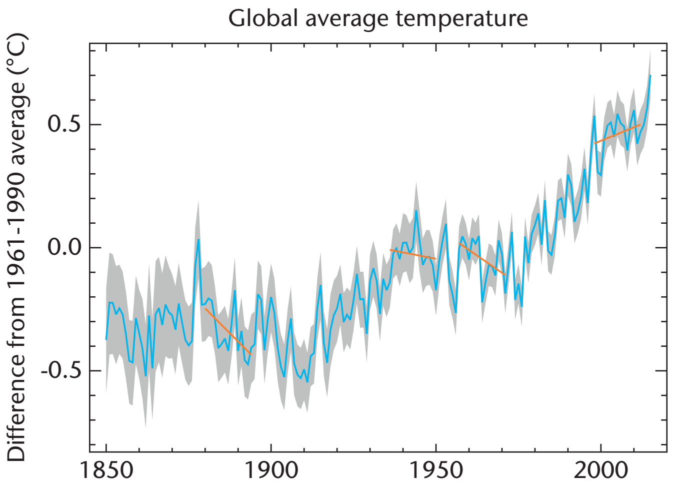

Figure 6. Global average near surface temperature difference relative to 1961-1990 using Met Office observations (HadCRUT4). Straight lines show 15-year periods in the time series where there has been a slower rate of warming, for example 1880-1894, 1936-1950, 1998-2012, as well as periods of rapid warming, for example around 1910 and late 1970s.

PROJECTING FUTURE CHANGE

Models

To project future changes in climate, research centres use computer models which simulate the Earth's climate system. These are based on the laws of physics, our latest understanding of the ocean and atmosphere, and they increasingly take into account complex processes in the Earth system – such as the way plants intake CO_2 emissions. The models are rigorously tested, for instance by simulating the past and comparing the results with measurements from the real world.

Increasing computing power also means models can be run with more spatial detail. This means smaller-scale atmospheric processes, such as the formation of thunderstorms, can be captured in models and impacts can be assessed in more detail at a local level. Progress in this area will enable climate science to give more guidance on how future changes will affect the lives of people around the world.

These advances make it possible for scientists to present ever more robust projections of the range of changes in the future and what impact these may have on diverse factors such as food and water availability, drought and flooding.

Some uncertainties remain – particularly around natural responses in the climate system which could either speed up or slow down future warming. Examples include:

- how cloud cover may respond to increasing temperatures – more clouds could help cool the planet, while less could increase warming,
- melting permafrost, which could release large amounts of greenhouse gases into the atmosphere as it melts in response to global warming.

Understanding of these feedbacks is increasing all the time, which is helping to further enhance confidence in the projections of future changes.

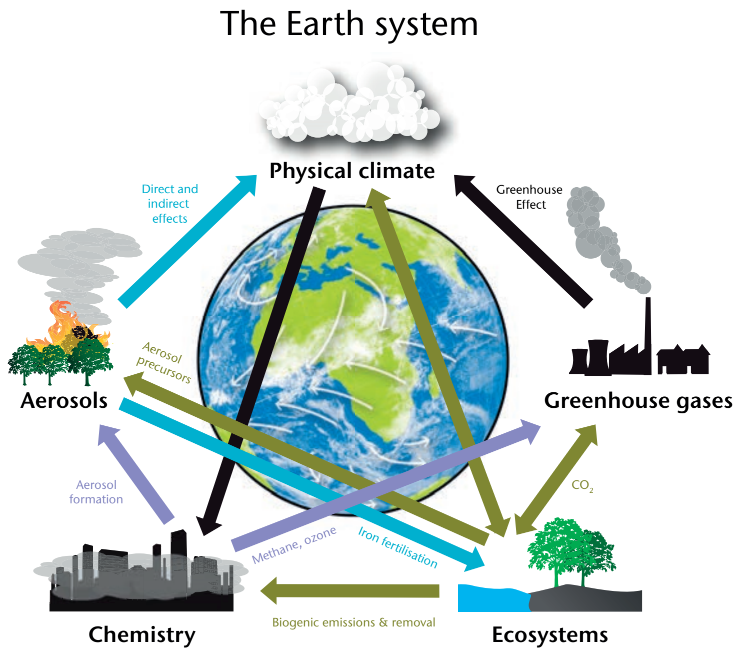

Figure 7. One thing changes everything. Human activities like burning coal, oil and gas to power our homes, factories and transport have released huge quantities of carbon dioxide into the atmosphere, causing an enhanced greenhouse effect. This causes an imbalance in the energy cycle that, in turn, impacts the water cycle, atmospheric circulation and ocean currents, leading to changes in weather and climate.

EMISSIONS

The amount of warming we see will depends on emissions of greenhouse gases, changes in land use, and other factors – such as emissions of aerosols, which can have either a temporary cooling or a warming effect on the climate depending on their type. These alternative views of future forcings must be accounted for when making projections of the future. This is often done using what are known as representative concentration pathways (RCPs). At one end of the scale, RCP 8.5 represents a world with high greenhouse gas emissions, while RCP2.6 represents significant activity to reduce them. Studying potential future change using these scenarios helps guide our understanding of the emissions levels that are likely to avoid potentially dangerous climate change and informing adaptation on global, regional and local scales.

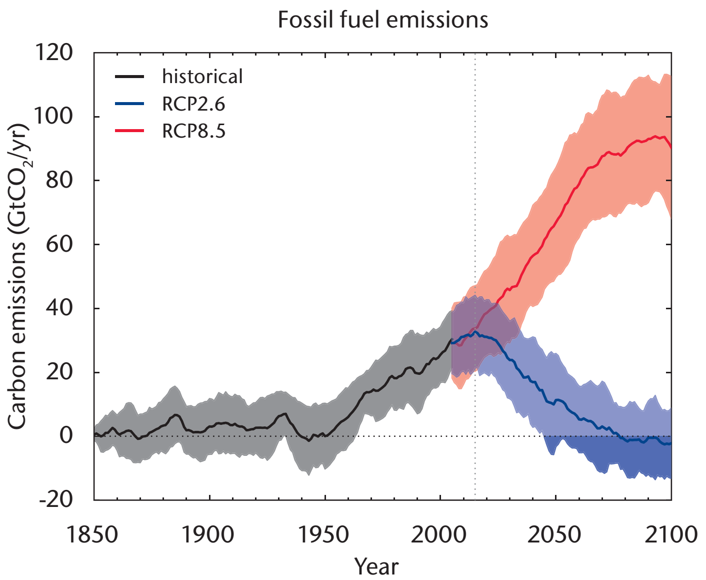

Figure 8. Emissions profiles over the 20th and 21st century for RCP2.6 and RCP8.5 CO_2 concentration pathways, with the shaded area showing model range and the dark line representing the central estimate. For scenarios that give a likely chance of keeping global temperatures below 2 °C above pre-industrial levels, many models suggest a need to artificially remove some CO_2 from the atmosphere. This might be achieved by combining biofuels with use of carbon capture and storage (CCS) technology – but the feasibility of this on a large-scale remains somewhat uncertain.

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.

The amount of eventual global warming the world will experience depends on both the past and future emissions of greenhouse gases. In particular, most of the warming is likely to be linked to carbon emissions and it is now understood that the amount of warming will depend on the cumulative emissions of CO_2 since the start of the industrial revolution. It is estimated that about 2,900 Gigatonnes of CO_2 ($GtCO_2$) can be emitted to stay within a likely (more than 66%) chance of limiting warming to below the 2 °C level. As of 2014, about 2,000 $GtCO_2$ had already been emitted – meaning society has already used more than half of the 2 °C budget. In addition to limiting carbon emissions, other GHG emissions will also need to be reduced to limit warming to the 2 °C level.

Whilst there are challenges in limiting warming to 2 °C, current understanding of the climate system and emission reduction technologies suggest that it is possible to do so. However, the later that global CO_2 emissions peak – the faster subsequent emissions cuts would need to be in order to keep global temperature rise below 2 °C. Simulations show that beginning emission reductions earlier reduces reliance on as-yet undeveloped and unproven technologies.

It is also now evident that whilst mitigation will significantly reduce the potential impacts of climate change, and will likely to lead to co-benefits such as improved air quality, there will still need to be adaptation. However, adapting to a world that has warmed by 2 °C is much more feasible than one with warming of 4 °C or more.

How emissions could affect our future climate

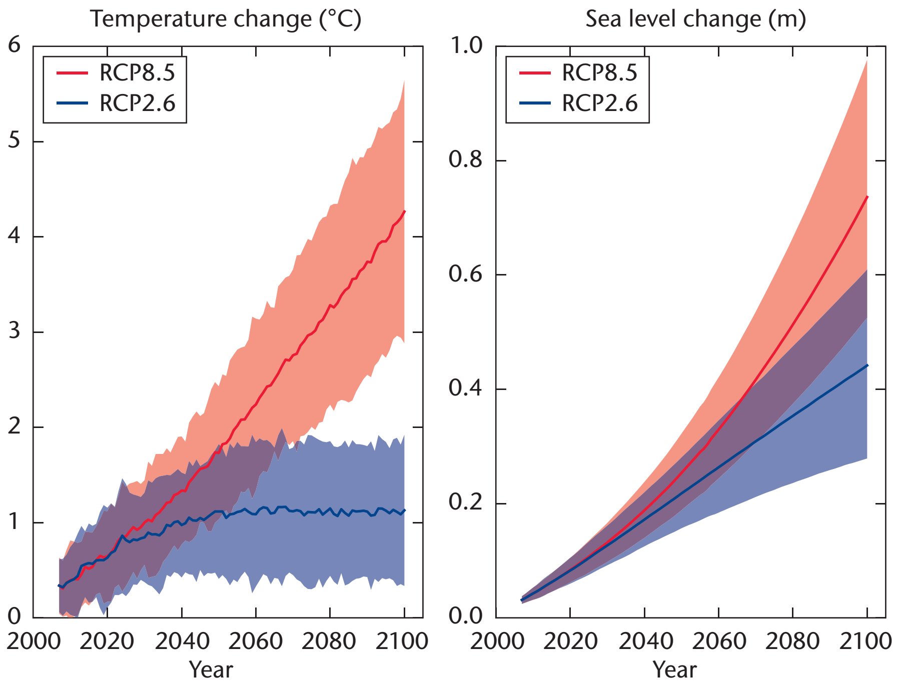

Figure 9. Climate model projections of global mean surface temperature and sea level change relative to the period 1986-2005. Data source: IPCC AR5.

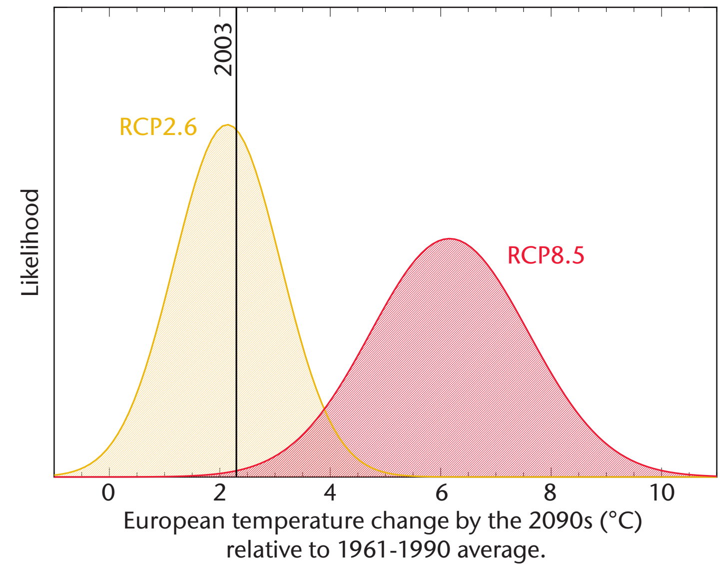

Figure 10. Met Office research shows that by the end of the 21st Century, European summer temperatures comparable with the 2003 heatwave are likley to occur more often than not under the low-end emissions scenario (RCP2.6). Under the higher emissions scenario (RCP8.5), such summers would be unusually cool.

Research challenges for the future: A new era in climate science

Evidence continues to mount that the world is warming and that human activity is the dominant cause. We know that the climate system is already committed to a certain level of future warming as a result of current cumulative emissions. Now is the time for climate science to deal with new challenges as advances in technology and understanding enable us to look in ever greater detail at what future changes mean for communities and what we can do to adapt.

The Met Office Hadley Centre's combination of expertise in observations and monitoring, physical and Earth system modelling, computing power and science expertise, working together with organisations across the world, means we are at the forefront of the global challenge to create a more resilient and sustainable future.

UK CLIMATE SCIENCE FOR CLIMATE SERVICES: 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.

Having climate and weather science expertise unified in the Met Office, enables the UK to access the best weather and climate information across timescales. This expertise helps people to plan for the future, and manage weather and climate risks from hours to centuries ahead.

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

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