Met Office

Big Changes Underway in the Climate System?

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Introduction

The Earth's *global average* surface climate is primarily determined by the exchange of energy between the atmosphere, the oceans and space. However, changes in *regional* climate are often governed by changes in the circulation of the atmosphere and ocean. These form coherent patterns like the El Niño Southern Oscillation (ENSO) fluctuations in tropical East Pacific sea surface temperature and sea level pressure, or the North Atlantic Oscillation variations in the strength of the westerlies over the North Atlantic. A fluctuation in any one of these can temporarily exacerbate or counter the effects of global climate change in affected regions. Some of these patterns of climate variability fluctuate over years and decades and can even affect global average surface temperature, as appears to have occurred in recent years with changes in the Pacific implicated in the slowdown in the rate of global surface warming.

Here we examine the latest behaviour of some of these key climate patterns. We begin with the year-to-year changes in the El Niño Southern Oscillation and look across timescales to potential multi-decadal changes in the Atlantic and Pacific. We use our latest global observations and initialised climate predictions from months to years ahead to assess whether rapid shifts are imminent or already underway. Changes in these key climate patterns could have pronounced effects on regional climate worldwide and temporarily alter the rate of global warming.

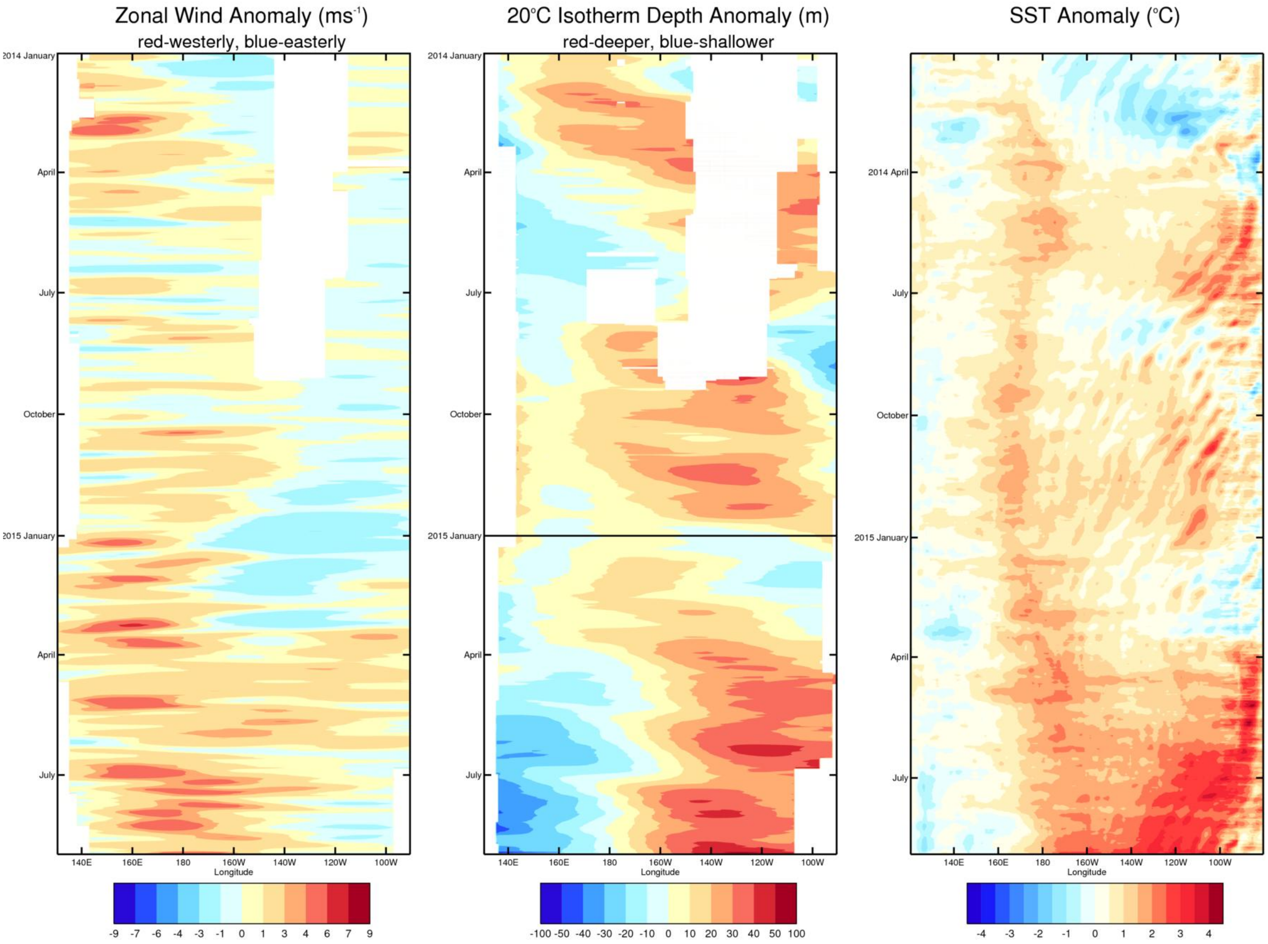
El Niño well underway

Background:

An El Niño event is a temporary natural warming of the surface waters of the tropical East Pacific substantially above usual levels. It spreads across the equatorial Pacific, lasting for months, and is accompanied by a reduction in equatorial trade winds that reinforce the warming. Such events occur every few years, and are a major part of the natural year-to-year changes in the climate system (Diaz and Markgraf, 2000). Their growth and decay are caused by interactions between the ocean and atmosphere where slow processes in the ocean set the timescale. El Niño events, and their cold counterparts called La Niña events, tend to peak in the Northern Hemisphere winter. Both El Niño and La Niña cause shifts in rainfall, temperature and wind patterns worldwide and these have important impacts on society and economies (Glantz 2000). For example, El Niño affects tropical storms, with a tendency for fewer North Atlantic hurricanes but more intense West Pacific typhoons.

The tropical Pacific in recent years and months

Buoys and satellite instruments provide observations of the tropical Pacific Ocean and atmosphere. In particular, surface and subsurface ocean temperatures, surface winds and rainfall patterns in the tropical Pacific are key indicators for ENSO. Figure 1 shows the recent behaviour of eastward wind speed (left), sea-surface temperature (SST, right), and the depth at which the ocean temperature is 20˚C (middle, referred to as the 20˚C isotherm), a measure of upper ocean heat content along the equator. The heat content is a sensitive indicator of the oceanic response to surface winds, and positive values in the central-east Pacific are associated with a tendency for warming there.



Data from TAO Project Office of NOAA/PMEL

Data from TAO Project Office of NOAA/PMEL

Data from OSTIA

Figure 1. The state of El Niño: equatorial Pacific eastward wind speed (left, m/s), depth of the 20˚ C isotherm (middle, m) and sea surface temperatures (right, ˚C). Differences from normal conditions are plotted. Data are from http://www.pmel.noaa.gov/tao and the Met Office OSTIA analysis (Donlon et al. 2012) referenced to the 1961-1990 period (Rayner et al. 2003).

Early in 2014 the 20˚C isotherm was deeper than usual in the central sector (180W-140W). This indicates an accumulation of heat in the West Pacific, which is a typical precursor to an El Niño event. Bursts of strong eastward (westerly) wind anomalies occurred in the West Pacific early in 2014, and these can act as a catalyst for El Niño. This weakening of the usual westward (easterly) trade winds induces downward motion in the ocean, deepening the 20˚C isotherm and initiating an ocean wave that takes typically two months to cross the equatorial Pacific from west to east. Examples of these waves can be seen as diagonal orange strips in the heat content anomaly (Fig.1, middle).

These events were picked up by climate prediction systems, and the forecast likelihood of an El Niño in 2014 increased. Ocean temperatures did indeed increase a little in the equatorial East Pacific (Fig.1, right). Nevertheless, temperatures were also above normal in the West Pacific, and as further strong eastward wind episodes were absent, the atmospheric response was muted. Compared to some other forecast systems the Met Office forecasts made through spring and summer 2014 showed relatively modest warming and were consistent with the observed weak development (see the 2014 forecasts at http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/gpc-outlooks/el-nino-la-nina). A fuller description of El Niño and its behaviour in 2014 can be found in http://www.metoffice.gov.uk/media/pdf/l/g/El_Nino_Briefing_July25_Update.pdf

El Niño onset and outlook in 2015

The equatorial Pacific SST remained warmer than usual through to 2015, particularly in the region to the west of the International Dateline. Eastward wind bursts in February and March (Fig.1, left panel) again raised the odds for El Niño onset earlier this year. Other bursts have led to sub-surface changes in the ocean that raised SST further in the central-east Pacific, and in contrast to 2014 ocean-atmosphere interactions caused further warming, establishing the first El Niño event since 2010. Recent further bursts of eastward wind anomalies have led to further El Niño growth and this is expected to continue.

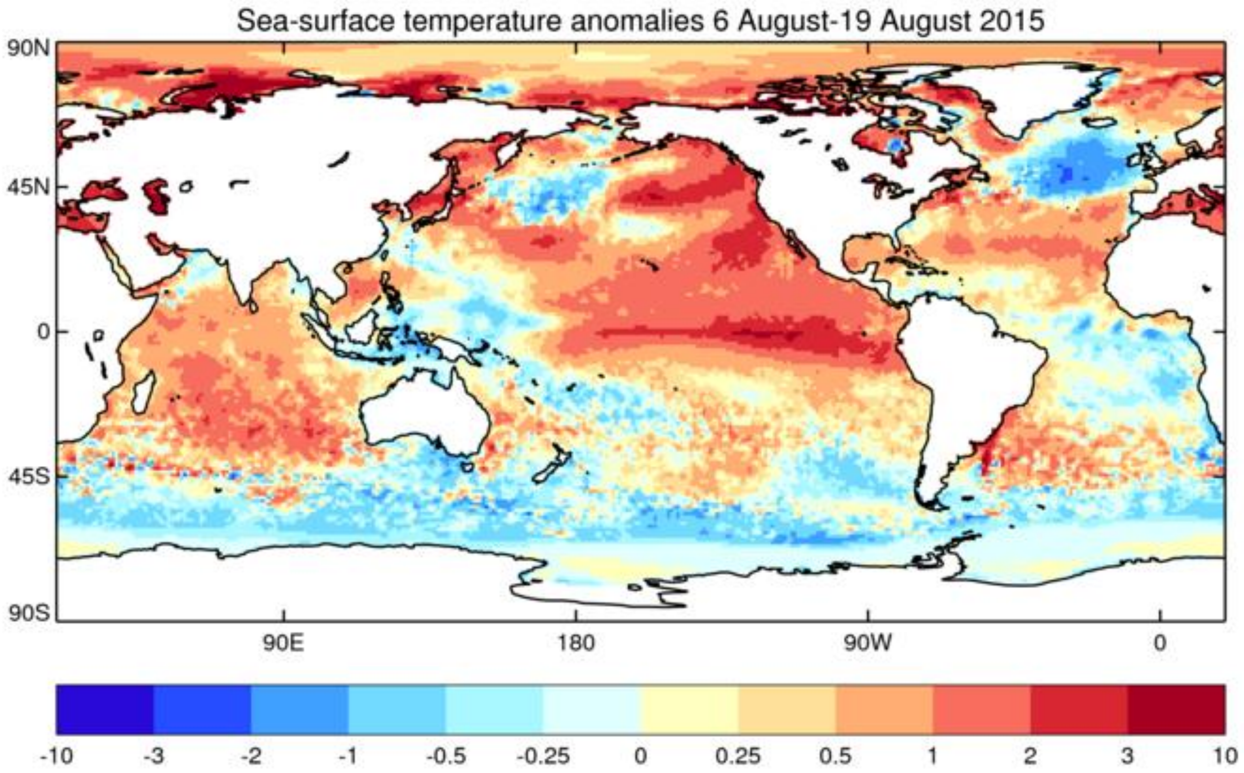


Figure 2: Recent sea surface temperatures. Differences from normal are shown, taken from the from the OSTIA data set (Donlon et al. 2012) and the climatology is from HadISST. Units are °C.

The recent sea surface temperature anomalies shown in Figure 2 indicate raised temperatures in the central-east equatorial Pacific, highest near South America, in a pattern typical of a classic East Pacific El Niño event.

With input from seasonal forecasting centres worldwide, including the Met Office, the World Meteorological Organization issues updates on the state of ENSO and an outlook for the coming months (http://www.wmo.int/pages/prog/wcp/wcasp/enso_updates.html). In the September issue it is stated that "temperatures in the east-central tropical Pacific Ocean are likely to exceed 2° Celsius above average, potentially placing this El Niño event among the four strongest events since 1950".

The Met Office makes use of a state-of-the-art climate model to provide near term climate predictions (http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal). The outlooks for tropical Pacific SST produced in August 2015 are shown in Figure 3 below. The El Niño event is likely to continue to grow in the coming months. So far the evolution of the 2015 El Nino is similar in many respects to that of the major El Nino of 1997/98.

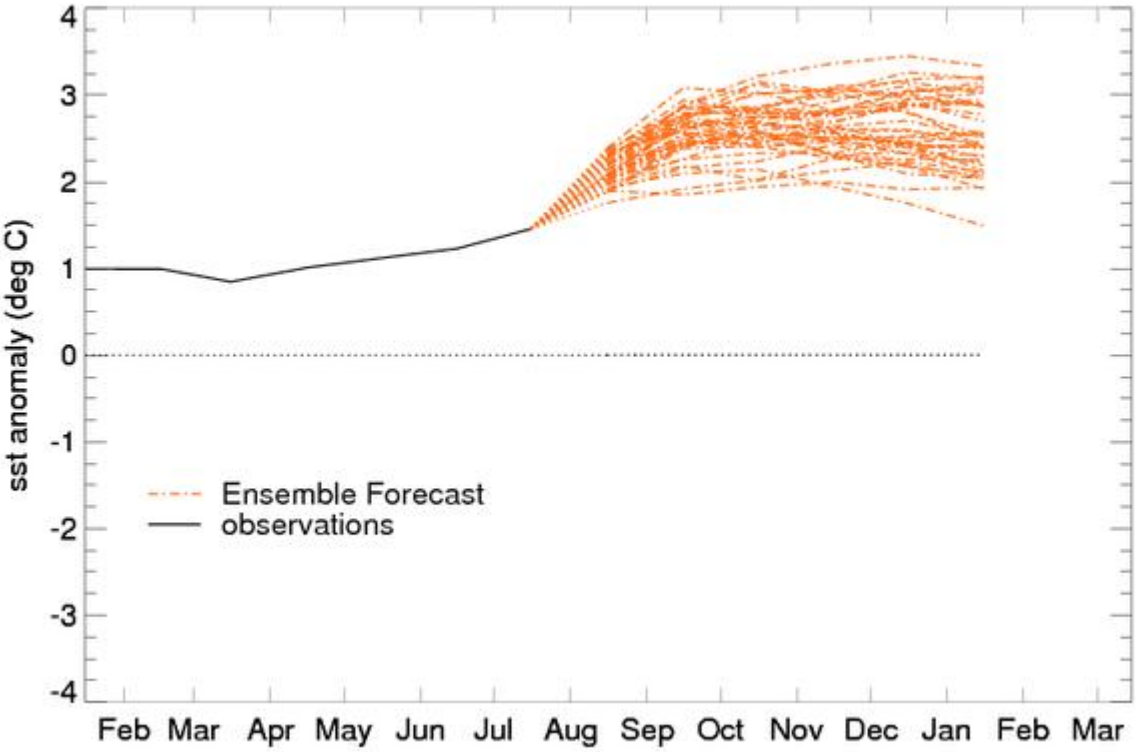


Figure 3: Forecasts of a growing El Niño. Predictions of sea surface temperature anomalies in the tropical Pacific (Niño3.4, central-east equatorial Pacific region) from the Met Office issued in August 2015. Black lines are observed values and dashed orange lines show the uncertainty between different forecasts. Differences from normal are plotted.

El Niño impacts

The range of likely impacts from El Niño can be inferred from observations of past events, although there is no guarantee of a specific outcome as other factors also influence regional climate. Instead, an El Niño event substantially shifts the likelihood of particular conditions (Davey et al., 2014). Figure 4 shows some of the likely effects on rainfall. For example, an El Niño event typically raises the chances of dry conditions in parts of Asia, Australia, southern and sub-Saharan North Africa and Central America, but brings a tendency for wetter conditions in equatorial East Africa and southern USA. The specific seasons in which these impacts are felt vary from region-to-region and summary maps of thee historical impacts can be found at: http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/gpc-outlooks/el-nino-la-nina/ENSO-impacts.

In May and June 2015 there has been reduced rainfall in Southeast Asia, Central America and northeastern South America, which are typical effects of El Niño (Fig. 4). Global mean temperatures are also very high in 2015, as discussed below. The near-El Niño conditions earlier this year were also consistent with the below-normal rains in North East Brazil and north-eastern Australia in early 2015.

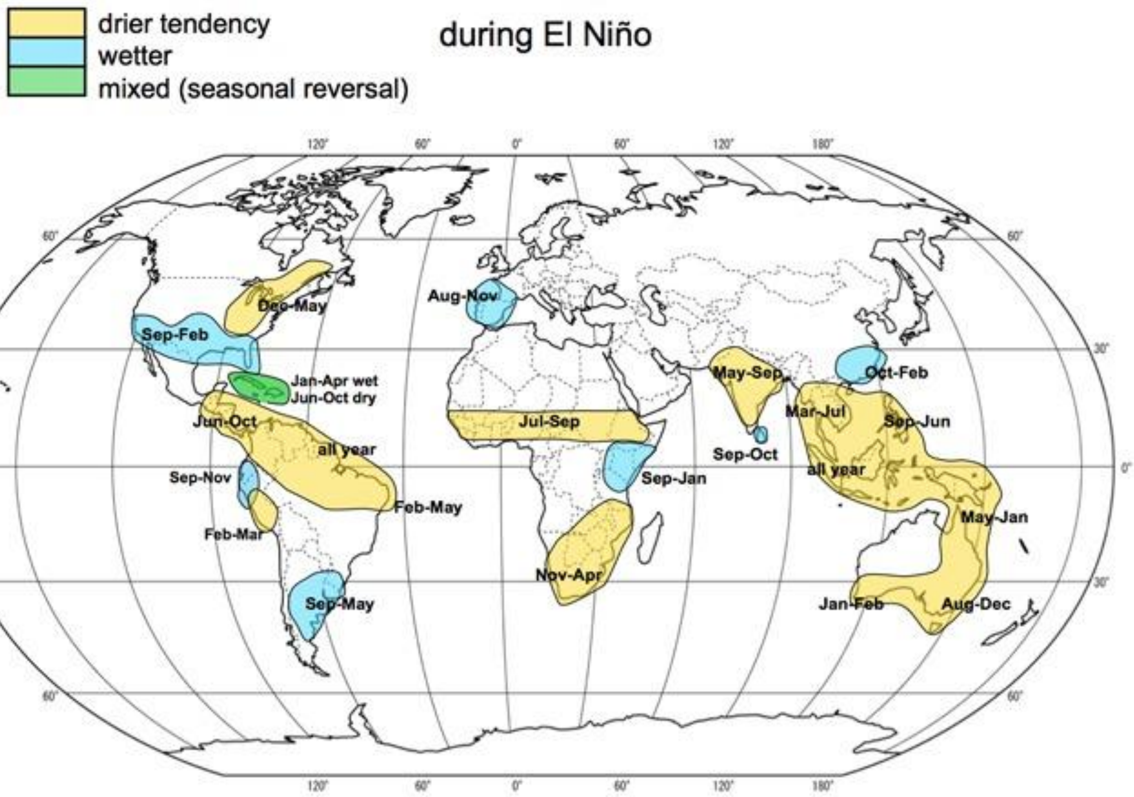


Figure 4: Schematic map of the typical precipitation effects over land favoured during El Niño events. Impacts are calculated according to the rate of occurrence in historical analyses.

Predictions that take into account the latest observations can be found in the outlooks from Met Office climate prediction systems, available at: http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal .

The precipitation outlook from our global climate prediction (Fig. 5) shows that many of the typical impacts of El Niño currently have enhanced forecast probabilities with increased likelihood of drier than normal conditions for much of maritime Southeast Asia, India, Central America and northern Brazil. The Indian summer monsoon rainfall is currently running at a deficit of over 10%. There is also an increased likelihood of wetter than normal conditions for the south western U.S. and southern South America. The increased chance of enhanced rainfall for California later this year could be important in helping to alleviate the long-standing drought in this region (http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CA)

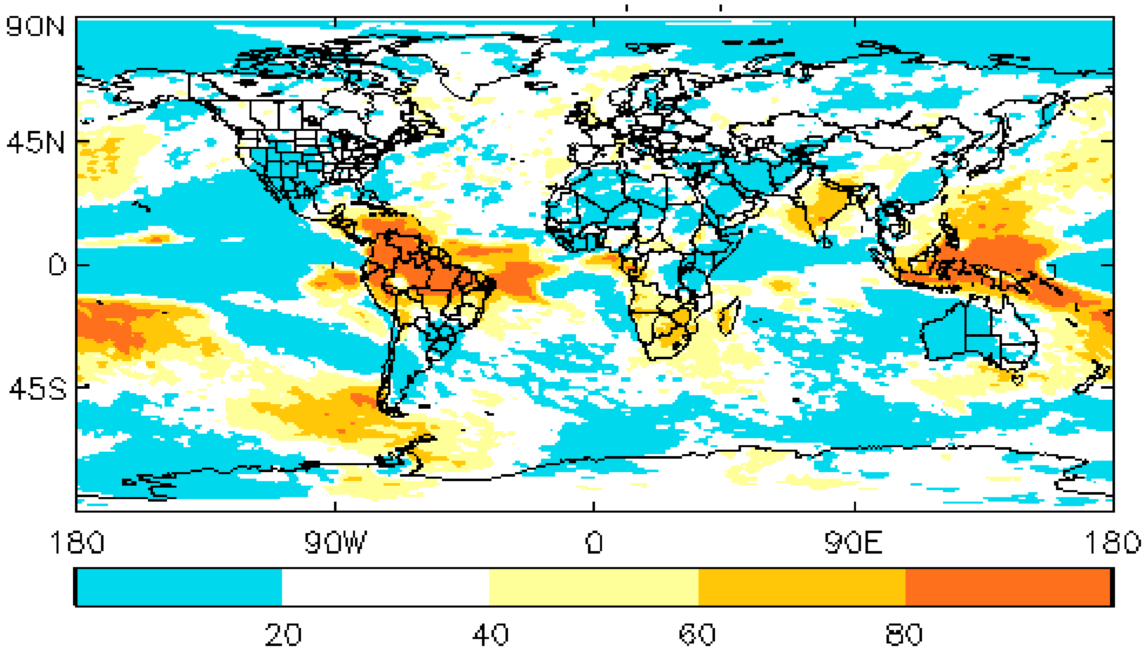


Figure 5: Forecast probability of below-normal precipitation (lower tercile) for September-November 2015. Data are from the Met Office GloSea5 forecast system and issued in August 2015. GloSea5 is an ensemble forecast system based on fundamental laws of physics (MacLachlan et al 2014)

A longer term shift in the Pacific?

Background

Although the year-to-year climate of the Pacific is dominated by ENSO, there are also slower variations that are important for understanding climate changes over longer periods. The Pacific Decadal Oscillation (PDO) is chief amongst these after allowing for trends due to global warming (Zhang et al., 1997). It has a strong characteristic imprint on Pacific SST (Fig. 6, left) and is part of a global pattern extending far into the Southern Hemisphere (Folland et al., 2002). Figure 6 (right) shows that a similar pattern is simulated in climate models. The modelled pattern is remarkably similar over the oceans.

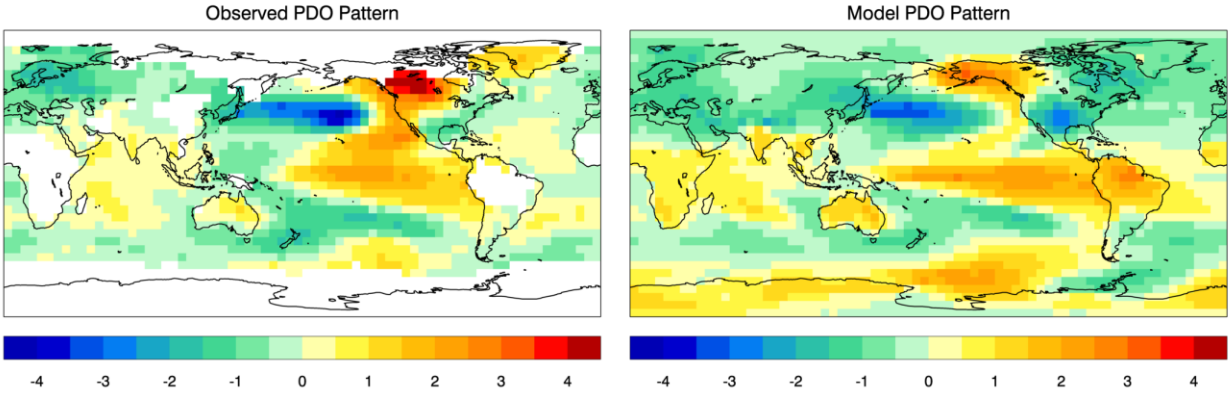


Figure 6. The Pacific Decadal Oscillation. Observed (left) and modelled (right) surface temperature anomalies during positive PDO phases. Model simulations contained historical external forcing. The scale is in ^{o}C per unit change in the PDO index, after Zhang et al., 1997.

The PDO is regularly monitored from month to month http://www.cpc.ncep.noaa.gov/products/people/yxue/ocean_briefing_new/mnth_pdo_4yr.gif) but on timescales of a year or two the PDO can be difficult to distinguish from ENSO. Although the PDO has more variability in the extratropics and from decade-to-decade than ENSO this makes it difficult to identify the current state of the PDO.

The near-global pattern of SST variability exhibited by the PDO affects regional and global climate (Christensen et al 2014). England et al (2014) and references therein provide good evidence that the recent predominantly negative phase of the PDO has also contributed to the recent slowdown in long-term surface warming. This is discussed further in the last section of this report.

Recent decades

Figure 7 shows the evolution of the PDO. This suggests that the PDO has been in a mostly negative state over the last decade but the index has increased rapidly and is currently in a positive state. The thick curves show longer term behaviour of the PDO. The curves on the extreme right do show an increase but the current state of this smoothed PDO is still uncertain until more data are available.

Evidence that the PDO may be moving towards a more persistently positive state is indicated by the exceptionally warm current conditions off the North American coast and other regional changes in the Southern Hemisphere (see Figure 2). These developed during 2014, ahead of the current El Nino suggesting that changes occurring in the North Pacific could be independent of the current warming of the equatorial Pacific.

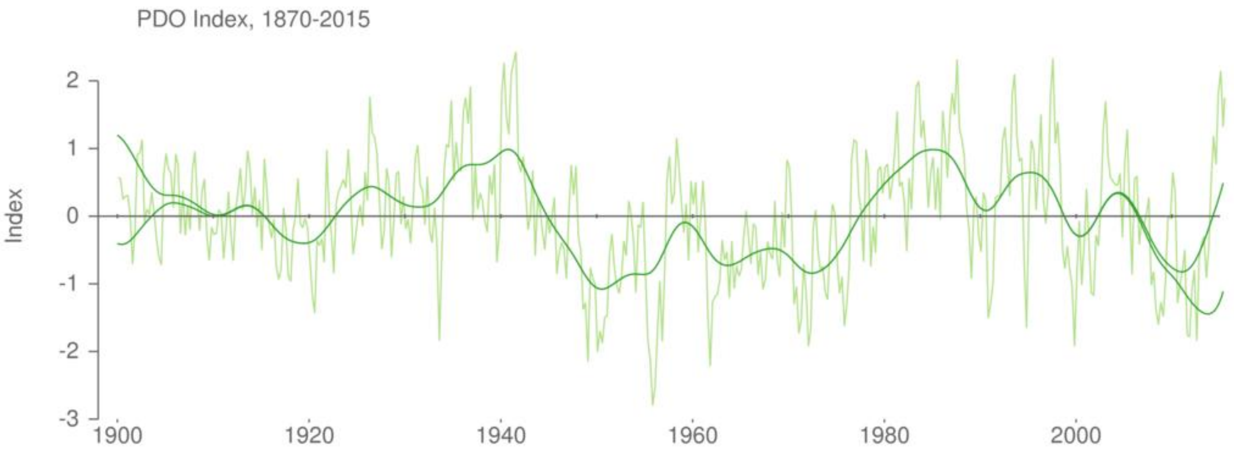


Figure 7. Pacific Decadal Oscillation. Three-month averages of the monthly PDO index of Zhang et al. (1997) from 1900 to 2015. The same series after smoothing to retain decadal and longer variations is overlaid. The pair of curves at each end illustrate large uncertainty due to lack of data before and after the series.

Outlook

Changes in the climate system from year-to-year and decade-to-decade can be driven by both internal climate variability related to ocean-atmosphere dynamics and external forcing from greenhouse gases, atmospheric aerosols, solar variability and volcanic eruptions. In principle, climate predictions initialised with observations are therefore a very good tool for predicting the PDO because they include all of these sources of predictability (e.g. Dong et al., 2014, Chikamoto et al., 2015). However, while models produce fluctuations in the PDO that are similar to the observed pattern (Fig. 6), they do not generally reproduce the observed sequence of long-term PDO variability. Apart from occasional reports of successful predictions from close to major PDO shifts (Ding et al., 2013), it is possible that much of the historical PDO variability in Figure 7 could simply be inherently unpredictable beyond a year or two (Wittenberg et al 2014).

The PDO does not change from negative to positive in a regular way (Folland et al., 1999). So although the negative phase has so far lasted about 15 years this does not necessarily indicate that a positive shift is imminent. Measured from month to month, the PDO is likely to be positive in the coming year as El Niño develops. However, even a strong El Niño does not by itself guarantee that the PDO will remain positive. For example, the exceptionally strong El Niño of 1997-1998 occurred during a period when the PDO was soon to become strongly negative.

We conclude that current developments in the worldwide pattern of sea surface temperatures are consistent with an emerging positive shift in the PDO but that it is too early to be confident that this will outlast the current El Niño.

A longer term shift in the Atlantic?

Background

Climate records show that the North Atlantic Ocean surface temperature has alternated between relatively warm and cool periods over at least the last 100 years (Parker et al., 2007), with each phase lasting a few decades. This phenomenon has been named the ‘Atlantic Multidecadal Oscillation’ (AMO). Relative to global mean surface temperature, the North Atlantic was cool in the periods 1900-1925 and 1960-1995, and warm in the period before 1900, between 1925 and 1965, and after 1995 (Fig. 8). The current warm phase is now 20 years long and historical precedent suggests a return to relatively cool conditions could occur within a few years (Knight et al., 2005). However, the short observational record precludes a confident prediction based on observations alone.

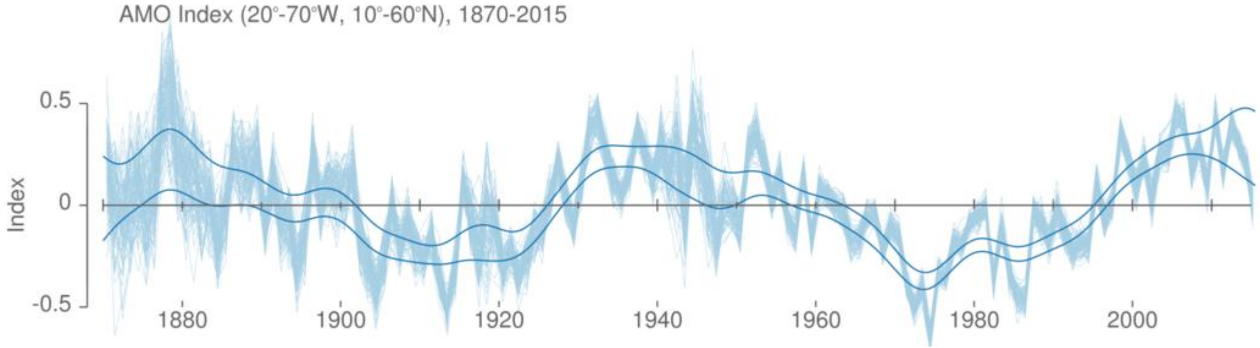


Figure 8: Atlantic Multidecadal Oscillation. Values are annual average, area average North Atlantic sea surface temperature *with the long-term linear warming trend removed* (˚C), derived from the HadSST3 dataset (Kennedy et al., 2011a,b). The spread of values is a measure of the uncertainty arising from sampling and measurement errors. The solid lines show the low frequency AMO component.

AMO variability is thought to be associated with the flow of water that carries heat northward within the North Atlantic Ocean, known as the Atlantic Meridional Overturning

Circulation (AMOC; Knight et al. 2005). Variability in AMOC strength alters the amount of heat that is transported, in turn changing the average surface temperature of the North Atlantic Ocean (Gulev et al., 2013). North Atlantic temperatures are also affected by industrial aerosol particles from Europe and North America. These particles interact with cloud droplets to make clouds more reflective; so changing concentrations of these aerosol particles over the decades may have significantly altered the amount of sunshine available to warm the sea surface (Booth et al. 2012), although there is still large uncertainty about this mechanism (Zhang et al 2013).

Recent decades

The AMO index shows that the current warm North Atlantic phase reached maturity in about 2005, after which there has been no additional warming. The very end of the series hints at the start of a downturn. Latest observations also show that cool anomalies have developed over parts of the North Atlantic Ocean (see Figure 2). This also suggests the start of a decline in the AMO index, although its substantial year-to-year variations make it less certain that this decline will be sustained.

The long duration of AMO phases means that large shifts in the AMO have only happened three times in the last 100 years, so our knowledge of how they develop is limited. Nevertheless, observations of past shifts in the AMO suggest possible precursors. In the lead up to the 1990s shift, a body of relatively warm, dense water formed below 1000m depth off the east coast of North America, contrasting with relatively less dense waters in the eastern North Atlantic (Robson et al., 2012). Opposite anomalies have been observed in recent years (Robson et al 2014a, Hermanson et al. 2014) and may also have occurred before the 1960s shift (Robson et al 2014b). These density changes are thought to be dynamically linked to variations in the AMOC, which has an influence down to about 3000m depth.

Consistent with the recent deep density changes, the AMOC strength derived from ocean measurements at 26˚N (Smeed et al. 2014) shows a persistent decrease since 2004 (Fig. 9). While the continuation of the decline is uncertain, the median estimate corresponds to a reduction in strength of about 20%. This implies reduced northward heat transport that should lead to cooling of the North Atlantic over several years. Furthermore, decadal-length climate forecasts predict that these density changes are likely to continue and are likely to lead to a cooling influence on Atlantic SSTs (Hermanson et al. 2014).

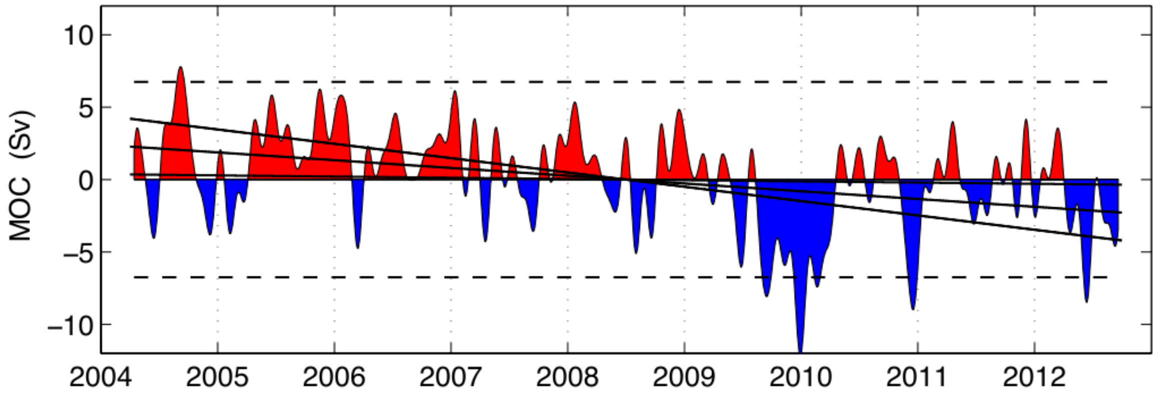


Figure 9: The Atlantic Ocean Meridional Overturning Circulation (AMOC) transport as measured by the RAPID-MOCHA array at 26^{o}N. Units are Sverdrups (1Sv=10^6 m^3s^{-1}). Figure modified from Smeed et al, 2014.

Outlook and impacts

Despite these signals it is not certain that there will be a shift towards cooler Atlantic conditions over the next few years. Temporary cooling has occurred in the past without leading to a sustained AMO shift. However, the current trends suggest that the chances of a shift in the next few years have increased.

What would a shift towards relatively cooler North Atlantic conditions mean for our climate? Historically, the AMO has shown an impact on temperature and precipitation in Northern Hemisphere summer (Fig. 10). In cold AMO phases, the continents surrounding the North Atlantic generally have cooler summers (Knight et al. 2006). Summertime precipitation in Northern Europe tends to decrease as a result of a northward shift in the path of low pressure centres that bring clouds and rain (Folland et al. 2009, Sutton and Dong 2012). In contrast, summer rainfall over the United States is increased by cold Atlantic conditions (Enfield et al. 2001, Sutton and Hodson 2005). Rainfall in the African Sahel region is also reduced because cold North Atlantic conditions favour a southward displacement of the tropical rainfall zone that brings this region its seasonal rains (Giannini et al. 2003). In addition, this shift modifies wind patterns, which is one of the factors inhibiting the development of strong Atlantic hurricanes (Knight et al. 2006). Observational (Folland et al. 2013) and model (Knight et al. 2005) estimates further suggest AMO shifts have an effect on global mean near-surface temperatures of about 0.1˚C. A rapid AMO decline could therefore maintain the current slowdown in global warming longer than would otherwise be the case.

The AMO could be a mixture of internal and externally forced effects and so global warming and other effects must be factored in to future predictions. Nevertheless a decrease in the AMO would increase the chances of dry Northern European summers compared to the last decade, while the US would likely become wetter. Droughts in the African Sahel similar to those experienced in the 1980s would also be more likely.

Although conditions in the Pacific also matter, should the North Atlantic cool this could also lead to fewer hurricanes than experienced in the recent active decades since the mid 1990s. The increasingly likely prospect of a shift in North Atlantic conditions during the next few years implies a risk of some marked changes in regional climate over this timescale (Srokosz and Bryden 2015).

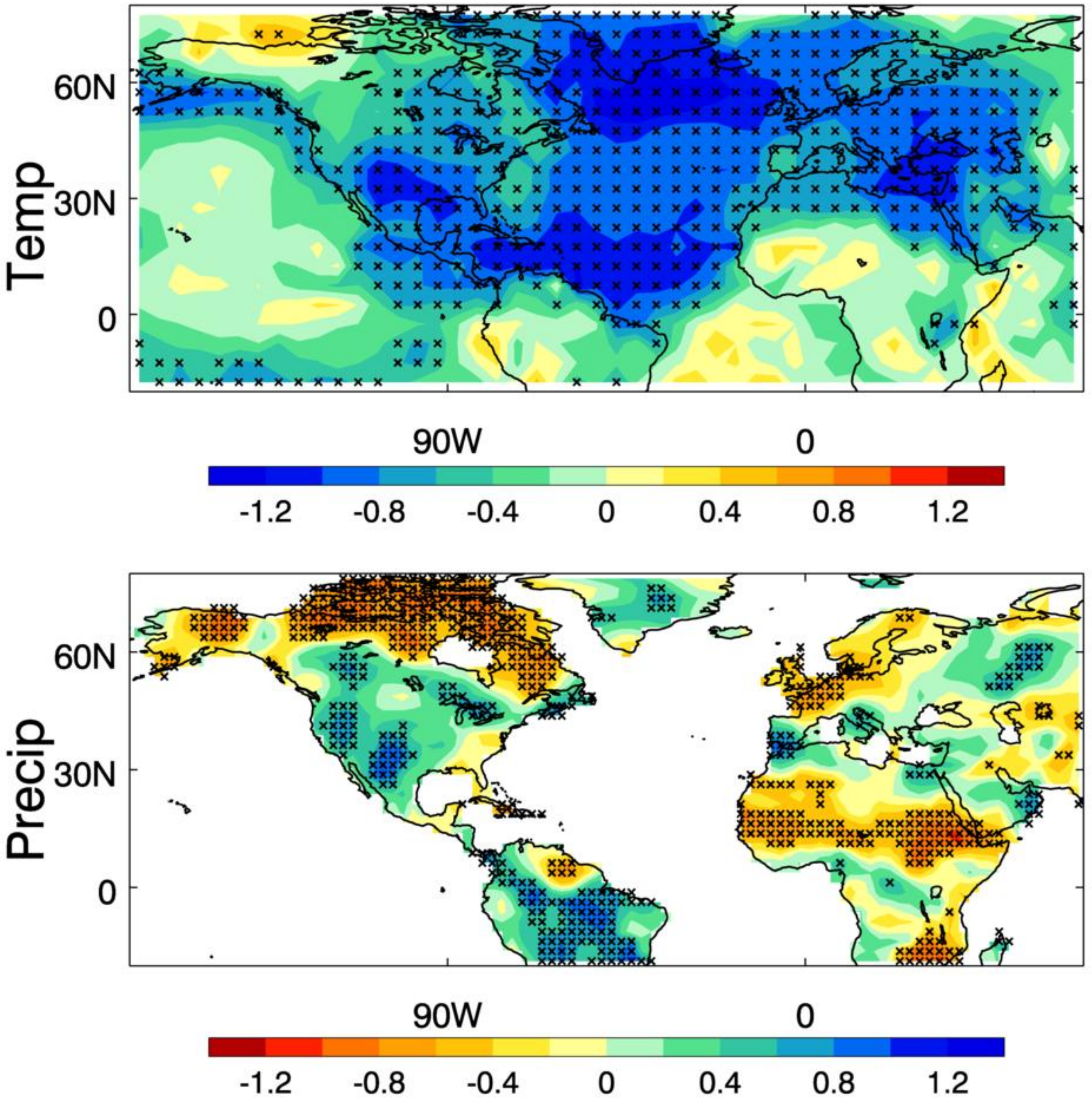


Figure 10: Impacts of a cold Atlantic on Northern Hemisphere summer surface temperature and precipitation. The figure shows half the difference between observed warm (1930–1940, 1954–1956, 1999–2005) and cold (1921–1923, 1969–1976, 1982, 1985–1992) decades. Units are standard deviations of 9 year rolling window smoothed fields. Crosses show locations where the differences are considered unlikely to have occurred by chance alone. Adapted from Figure 3 of Hermanson et al. 2014.

What is happening to global average temperature?

Background

Global mean surface temperature rose rapidly from the 1970s, but the rate of warming has slowed over the most recent 15 years or so (Fig. 11, grey shading). Understanding the cause of the recent slowdown in global surface temperature warming and predicting when it will end is an active topic of research (Trenberth et al 2015).

It is well established that trace gases such as carbon dioxide warm our planet through the "greenhouse effect". These gases are relatively transparent to incoming sunlight, but trap some of the longer-wavelength radiation emitted by the Earth. However, other factors, both natural and man-made, can also change global temperatures. For example, a cooling could be caused by a downturn of the amount of energy received from the sun, or an increase in the sunlight reflected back to space by aerosol particles in the atmosphere. Aerosols increase temporarily after volcanic eruptions, but are also generated by pollution such as sulphur dioxide from factories.

These "external" factors are imposed on the climate system and may also affect the ENSO, PDO and AMO variations discussed above and in earlier studies (e.g. Smith et al 2007, Keenleyside et al 2008, Pohlmann et al 2009). However, the patterns of climate variability discussed in this report can also vary without any change in "external" forcing. Long-term forced changes, like global warming, will therefore not proceed smoothly with every year being warmer than its predecessor. Indeed, the historical record (Fig. 11) shows periods where temperatures rose rapidly, such as the 1920s to 1940s and 1970s to 1990s, as well as periods with little warming or even cooling, such as the 1880s, 1900s, 1940s, 1960s and the most recent period starting around 2000. Many of these short lived historical periods with little warming can be explained by major volcanic eruptions (marked with vertical grey lines in Figure 11). Although there has not been a major volcanic eruption since Mount Pinatubo in 1991 there have been several minor eruptions that may have contributed to the slowdown in warming (Solomon et al 2011, Fyfe et al 2013, Haywood et al 2014, Santer et al 2014). Solar activity has also decreased recently (Lean 2009, Kaufmann et al 2011) and there is uncertainty about the degree of cooling from aerosols (Shindell et al 2013, Bellouin et al 2011). These external factors, along with observational uncertainty, potentially reconcile some of the apparent difference in global mean temperatures between observations and model simulations (Schmidt et al 2014, Huber and Knutti 2014, IPCC 2013, Cowtan et al 2015).

Many studies have also highlighted the importance of temperature trends in the Pacific in the recent warming slowdown (Kosaka and Xie 2013, England et al 2014, Watanabe et al 2014), and there is some evidence that trends in the North Atlantic may have played a role (McGregor et al 2014). Trends in these regions are consistent with natural internal variability in model simulations (Meehl et al 2013, Risbey et al 2014, Roberts et al 2015). However, an increase in Pacific trade winds that may be much larger than expected from internal variability may also be important (England et al 2014). This increase in trade winds could simply be a rare natural event, but there could also be a forced component that is not simulated correctly by the models. The relative roles of external factors and internal variability in driving global temperatures from one decade to the next are therefore still not fully understood.

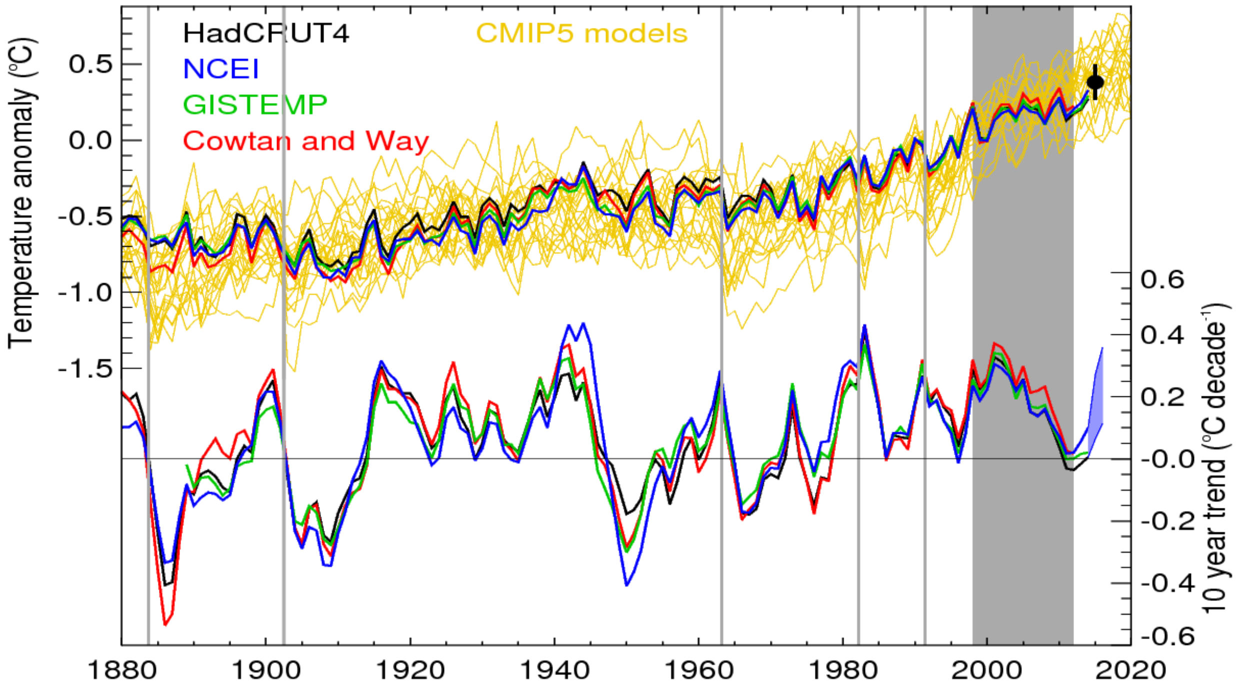


Figure 11: The recent slowdown in surface warming in context. Observed global mean temperature difference from the 1981-2010 mean (°C) from four observational datasets and 22 model simulations from the 5th Coupled Model Intercomparison Project (upper). Observed 10-year temperature trends (°C per decade, lower). Observed datasets are HadCRUT4 (Morice et al 2012), NCEI (Karl et al 2015), GISTEMP (Hansen et al 2010) and Cowtan and Way (2013). Temperatures relative to 1961 to 1990 can be obtained by adding 0.3°C. Vertical grey lines indicate major volcanic eruptions, and grey shading highlights the recent slowdown in surface warming. The black circle in the upper panel shows global average temperature for 2015 so far. The projected values indicated by blue shading in the lower panel assume that current global temperatures (and the observational uncertainty estimated by the difference between datasets) persist for the next 2 years.

Outlook

A better understanding of the cause of the global warming slowdown is needed in order to confidently predict its end. However, there are signs in the observations and near term climate predictions that are consistent with a resumption of warming. 2014 was nominally the warmest year on record (though observational uncertainties mean we cannot be certain of the precise ranking) and Met Office forecasts made in advance of 2015 suggest it could be similar or even warmer this year (http://www.metoffice.gov.uk/news/releases/archive/2014/2015-global-temp-forecast). Currently this is being borne out, with near-record global temperatures in each month. This is consistent with past climate change and the growth of the current El Niño, which is already having a warming effect and is predicted to continue over the coming months (http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/gpc-outlooks/el-nino-la-nina).

Global mean surface temperature for 2015 so far is 0.38±0.14°C above the 1981-2010 average (0.68±0.14°C above the 1961-1990 average). If this continues, 2015 will likely be warmer than any other year in the observational record. Given that global average temperature responds to El Niño with a lag of a few months (Trenberth et al 2002) and that El Niño is predicted to develop further, it is reasonable to assume that both 2015 and

2016 will show similar warmth to the current value for 2015. If this were to happen then ten year global temperature trends would increase to a value of around 0.2°C per decade by 2016, as often occurred in the late 20th century (Fig. 11, lower graph). Note however, that a large volcanic eruption or a sudden shift to a cool phase of the AMO would alter this and that trends over longer periods of 15 years would take longer to respond.

Summary

Changes are occurring in some of the leading patterns of global climate variability, altering the risk of regional climate impacts worldwide and affecting decadal rates of global warming.

El Niño is now well underway and is growing in strength. This is likely to have widespread regional impacts and to continue to contribute to raised global average temperatures this year and next year.

On longer timescales, the Pacific Decadal Oscillation has been negative in recent years and this has been linked to a slowing of the rate of global warming. Changes in the North Pacific suggest that the PDO may now be entering its positive phase, but because understanding of what drives the low frequency behaviour of the PDO is limited and its predictability appears to be low, a definitive statement on its future state is not yet possible.

The Atlantic Ocean has been warm in recent years but is now showing the first signs of a switch to cooler conditions, consistent with observed changes in the deeper ocean circulation. Widespread impacts around the Atlantic basin are likely if this continues.

While global surface warming slowed from the end of the 20th century, our best estimates of global mean temperature for 2015 are at or near record levels, and this is consistent with climate predictions for similarly high values that we made last year (http://www.metoffice.gov.uk/news/releases/archive/2014/2015-global-temp-forecast). Record or near record temperatures last year and so far this year, along with the expected warming effects of El Niño, mean that decadal temperature trends are likely to increase. Barring a large volcanic eruption or a very sudden return to La Niña or negative AMO conditions which could temporarily cool climate, ten year global average warming rates are likely to return to late 20th century levels within the next two years. Nevertheless, the slowdown in warming is still an active research topic and trends over a longer (15 year) period will take longer to respond.

Further long-term global warming is expected over the coming decades but variations of climate worldwide from year to year or decade to decade will always depend on the subsequent variations in the patterns of climate variability described in this report.

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