

with climate. The occasional tiny snippets of real information about global warming have been drowned in an ocean of sensational claims and counter-claims. The result is hardly surprising: scepticism and disbelief – but who is responsible for this climate-change confusion?

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Global and regional climate in 2014

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Global annual overview

The global average near-surface temperature for 2014 was 0.56 ± 0.10 degC above the 1961–1990 average (Figure 1) according to the HadCRUT.4.3.0.0 data set produced by the Met Office Hadley Centre and the University of East Anglia Climatic Research Unit. 2014 ranks as the joint warmest year on record, tied with 2010. This estimate is

based on observations from around 1200 land stations, 4000 voluntary observing ships, 1500 drifting buoys and around 440 moored buoys. The estimated uncertainty of 0.1 degC in the global average temperature arises from the combined effects of measurement error and incomplete global coverage of observations. Accounting for uncertainty in observational estimates of globally averaged temperatures, 2014 is very likely to lie within the top 10 warmest years on record.

The uncertainty in the ranking of global temperatures is highlighted by differences between the estimates produced by other

groups. Global temperature estimates produced by the National Aeronautic and Space Administration's Goddard Institute for Space Studies (NASA GISS; Hansen *et al.*, 2010) and the National Oceanic and Atmospheric Administration's National Climatic Data Center (NOAA NCDC; Smith *et al.*, 2008) also indicate that 2014 was an exceptionally warm year, with both data sets placing 2014 as nominally the warmest on record. In both cases the uncertainties are such that a definitive ranking is not possible. The Japanese Meteorological Agency (JMA) also produces an estimate of global temperature which places 2014 as nominally warmest on record.

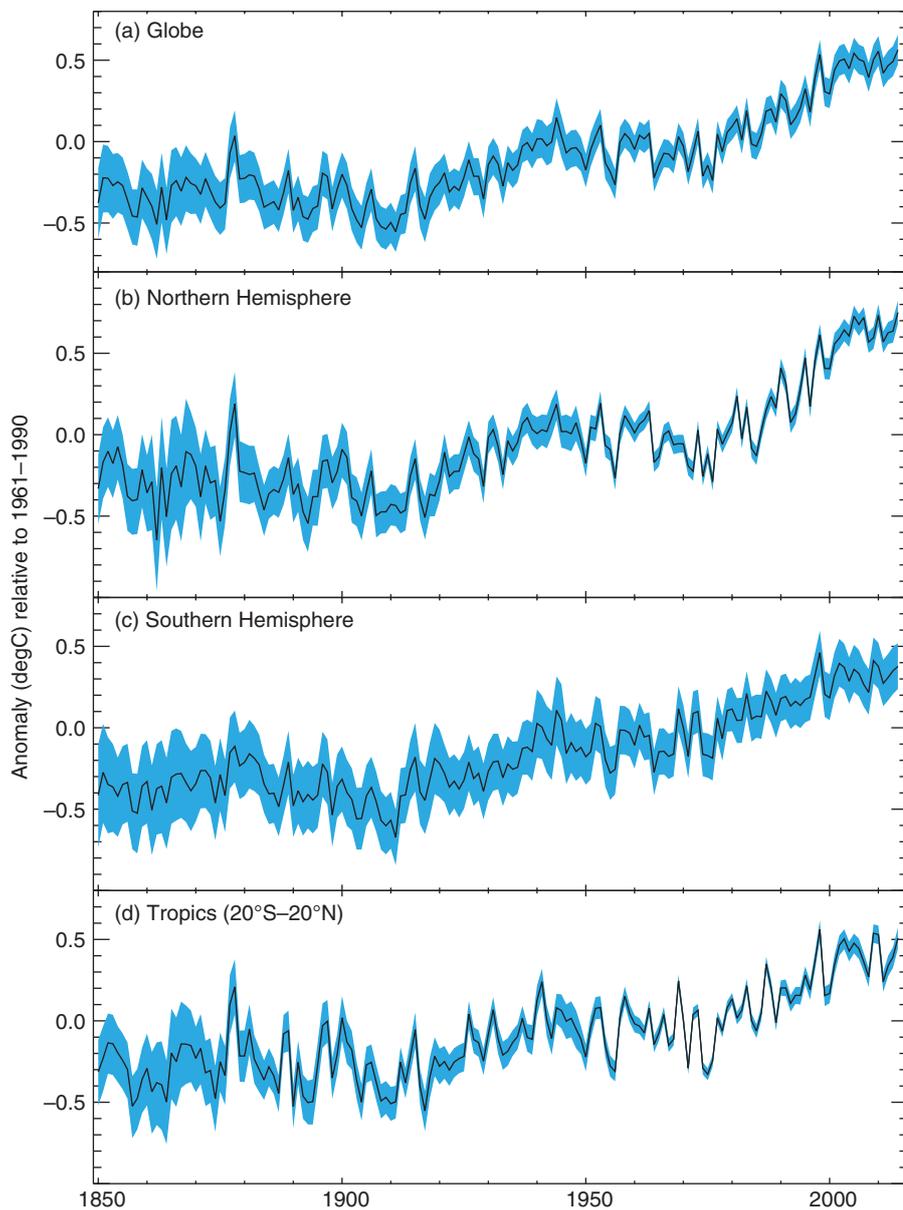


Figure 1. Annual average temperature anomalies (relative to 1961–1990) from 1850 to 2014 for (a) the globe, (b) the Northern Hemisphere, (c) the Southern Hemisphere and (d) the Tropics (20°S–20°N). The solid black line is the best estimate and the blue shaded area indicates the 95% confidence range on the estimate. Data are from HadCRUT.4.3.0.0 (Morice *et al.*, 2012).

An update of the Berkeley Earth data set (an update of Rohde *et al.*, 2013) places 2014 as warmest, tied with 2010 and 2005. An estimate based on HadCRUT4, which uses statistical methods to estimate temperature anomalies in areas with no measurements (an update of Cowtan and Way, 2014), places 2014 as the second warmest year on record. The reanalysis produced by the European Centre for Medium-range Weather Forecasts (ECMWF), which is somewhat independent of the surface temperature data sets, has 2014 in joint third place after 2010 and 2005 and very similar to 2006.

The period 1961–1990 is used as a baseline where possible as this is the period recommended as a climate normal by the World Meteorological Organisation (WMO). It was also used by Working

Group 1 of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. However, for some geophysical indicators, particularly those such as sea-ice extent that are more reliably measured by satellite instruments, a more modern period has been used.

The average temperature for the Northern Hemisphere in 2014 was 0.75 ± 0.07 degC above the 1961–1990 average, nominally the warmest year on record, but, given the uncertainties, not measurably different from any of the other four warmest years. The average temperature for the Southern Hemisphere was 0.38 ± 0.14 degC above the long-term mean. Uncertainties in estimates of Southern Hemisphere average temperatures are generally higher than for the Northern Hemisphere due to a relative

paucity of observations. Even so, it is possible to say that 2014 was one of the 20 warmest years on record for the Southern Hemisphere.

On average during 2014, most land regions experienced warmer than average conditions. The global annual average temperature across land areas was 0.84 ± 0.14 degC above the 1961–1990 average (based on CRUTEM4, Jones *et al.*, 2012). Notably warm conditions were experienced across western North America, Europe, western Asia, eastern Asia, northern and eastern South America, much of Africa, and southern and western Australia (Figure 2). Conditions were cooler than average across a large area of central and eastern North America.

Sea-surface temperatures (SSTs) for 2014 were warmer than average in most regions (Figure 2). The global average SST for the year was 0.48 ± 0.07 degC above the 1961–1990 average, likely the warmest year on record at the sea-surface. Notably warmer than average SSTs, in excess of the 90th percentile of occurrence, were recorded in the western tropical Pacific, northern and north-eastern Pacific, much of the Indian Ocean, large areas of the North Atlantic outside the tropics, the southwest Atlantic and the southwest Pacific. Cooler than average SSTs were present in the eastern South Pacific, a region of the central North Atlantic at around 45°N, the western north Pacific and the Southern Ocean. Regions of unusually cool SSTs were few and localised.

Figure 3 shows annual total precipitation expressed as a percentage of the 1961–1990 average. There was unusually low rainfall in eastern Brazil, with some areas ending the year in severe drought. São Paulo was particularly badly affected. Other parts of South America were unusually wet. Argentina had well-above-average precipitation totals. Rainfall deficits in western parts of the USA meant that large areas remained in moderate to severe drought. California was not only dry but exceptionally warm during 2014. Flooding associated with heavy rainfall occurred in the Balkans in May, in Pakistan and northwest India in September, in Bangladesh in late August and September and in Morocco in November. Mexico also saw high rainfall totals in some months associated with tropical storms.

Global seasonal climate

During Northern Hemisphere (NH) winter 2013/2014, unusually high air temperatures were measured in western USA (Figure 4; which was also dry, Figure 5), Central America, western and northern Europe (also wet), eastern regions of northern Asia and northern East Asia, southern South America (also dry), much of Africa, and southeastern Australia (also dry). Notably cool conditions were reported for central and eastern North

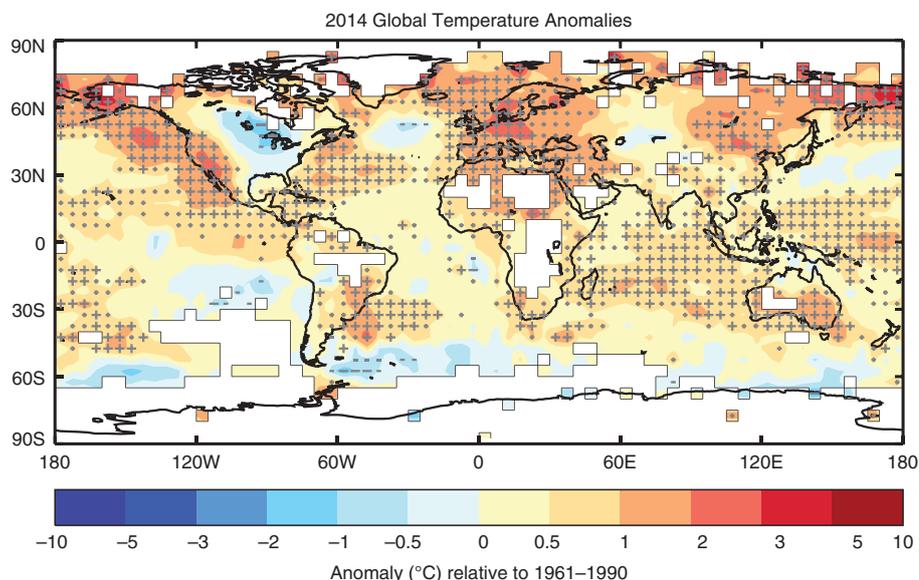


Figure 2. Annual average land-surface air and sea-surface temperature anomalies (degC relative to 1961–1990) for 2014. A temperature anomaly is calculated for a grid cell if at least 1 month's data is available for the grid cell. Data are from HadCRUT.4.3.0.0, an update of Morice *et al.* (2012). The crosses indicate where temperatures exceed the 90th (small crosses) and 98th (large crosses) percentiles of the 1961–1990 distribution of annual temperatures calculated by the method of Horton *et al.* (2001). Dashes indicate where temperatures were below the 10th (small dashes) and 2nd (large dashes) percentiles of the 1961–1990 distribution.

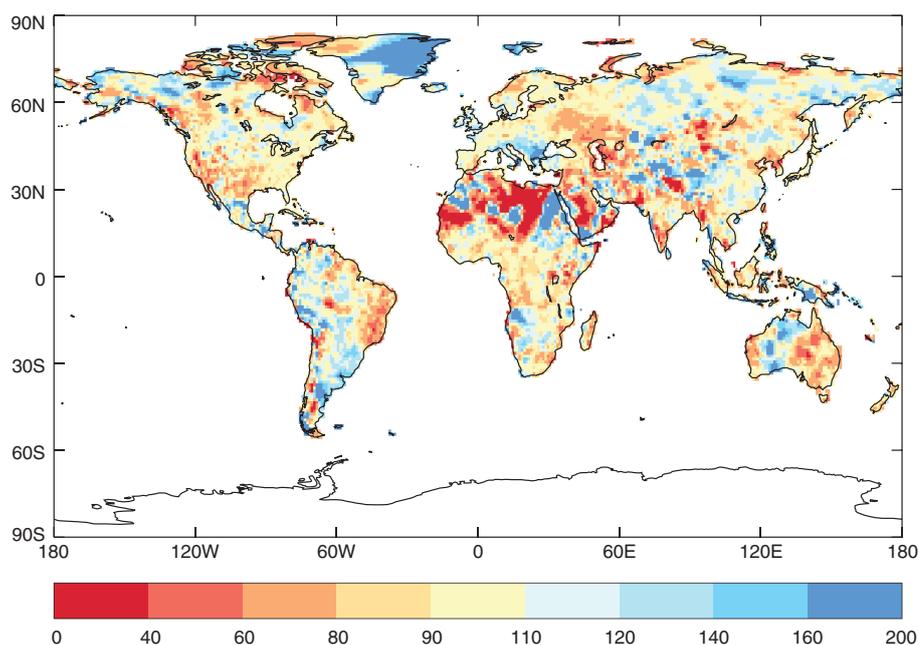


Figure 3. Annual total precipitation anomalies for 2014, expressed as percentages of the 1961–1990 normal. Data are from the Global Precipitation Climatology Centre (GPCC) Monitoring product (Becker *et al.*, 2013).

America. Notably warm SSTs were present in the western tropical Pacific, the north-eastern Pacific, in bands across the central North Atlantic and central South Atlantic, in the eastern South Atlantic and central Indian Ocean. Unusually cool SSTs were present in the far southwestern Atlantic close to Drake's Passage, the central equatorial Pacific, the southeastern Pacific and the south of the Indian Ocean.

In NH spring 2014, much of Eurasia was unusually warm, except for a region of cooler than average temperatures centred on India and a region of less significant above-average temperatures extending in a band from India to northwest Russia. The pattern of temperatures over North America was similar to that seen in the winter, with below-average temperatures dominating in the east and above-average

temperatures and continuing drought in the west. Eastern Australia was also unusually warm. The pattern of warmer and cooler areas of the oceans was similar to that seen during the previous season. In the North Pacific, the area of pronounced warm anomalies in the northeast moved closer to the west coast of North America, and the area experiencing unusually high SSTs in the Indian Ocean increased.

In the NH summer, unusual warmth was observed in western North America, Central America, northern Europe, a region stretching from central Europe through to Southern Asia, northeastern Asia, much of Africa and Southeast Asia. Regions of cooler than normal air temperatures, although not unusually cool, were observed in central North America, western North Asia, East Asia and northern Australia. Much of Brazil was unusually dry. Unusually warmer-than-normal SSTs were present in the east and west of the tropical Pacific and much of the Indian Ocean. Few areas at sea were notably cooler than average. During the NH Summer, SSTs averaged across the Northern Hemisphere reached record levels. Large areas of both the North Pacific and North Atlantic were unusually warm, as were waters between Canada and Greenland and between Greenland and northern Europe. High temperatures in the far north of the Atlantic were associated with unusually settled and hence sunny conditions.

Northern Hemisphere autumn saw a return to the warm west/cold east pattern across North America. Much of Europe and North Africa was unusually warm, as were scattered areas from India to northeast Russia. Australia recorded its warmest spring on record, with diminished rainfall except in the west, and large areas of South America were also unusually warm. Below-average temperatures were observed across large areas of central Asia. As in NH summer, large areas of the north Atlantic and North Pacific, as well as large areas of the Indian Ocean and the western tropical Pacific, were unusually warm. The southeast Pacific, a small area in the central North Pacific and an area to the south of Greenland were unusually cool.

The hurricane season in the North Atlantic was less active than the 1981–2010 average. A total of eight named storms formed compared with the long-term average of twelve. Six of the storms became hurricanes and two of those became major hurricanes. In total the Accumulated Cyclone Energy was only 67% of the 1981–2010 average. Hurricane Arthur was the first hurricane to make landfall in the US since August 2012.

Arctic sea ice typically reaches its maximum extent in March and its minimum extent in September (Figure 6). According to the HadISST1.2 data set (an update of Rayner *et al.*, 2003), the average ice extent for March 2014 was 15.3 million km², the

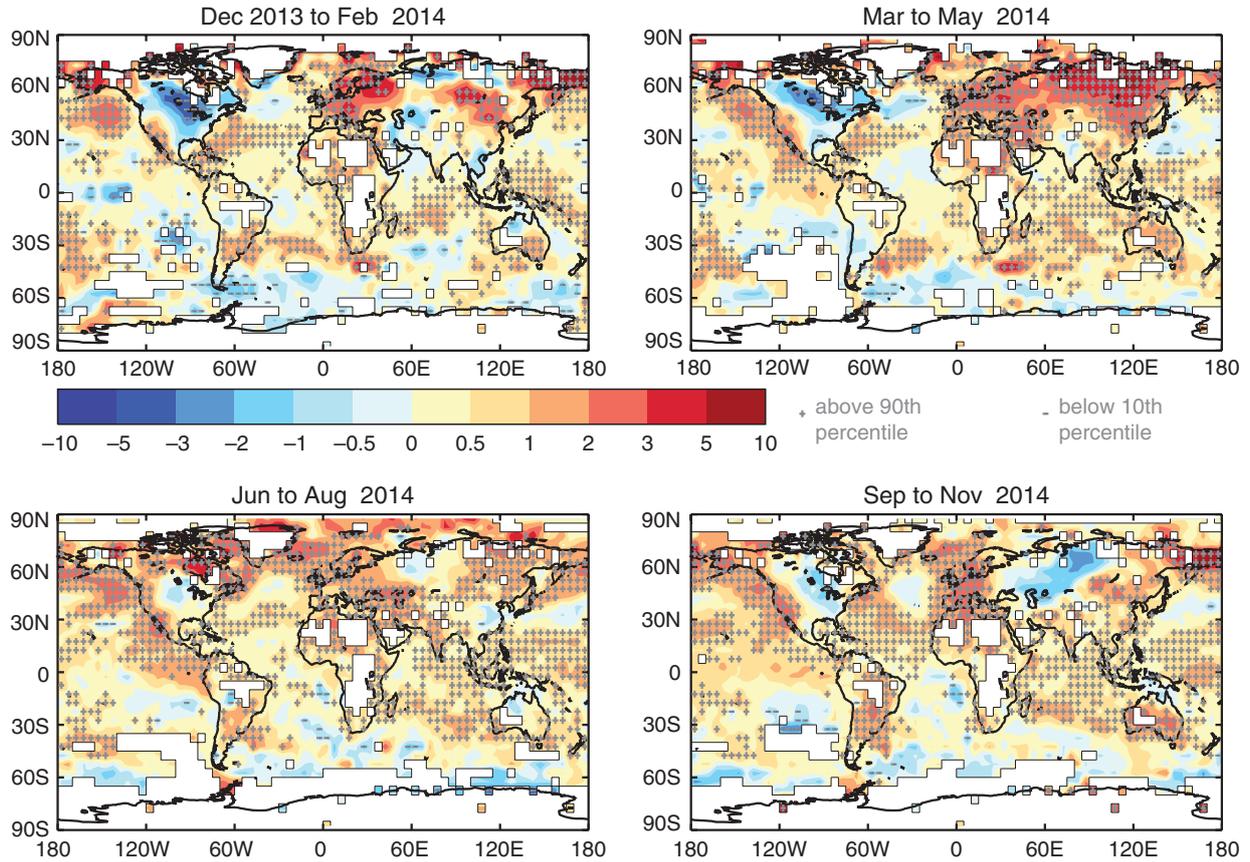


Figure 4. Land-surface air and sea-surface temperature anomalies (degC, relative to 1961–1990) for December 2013 to February 2014, March to May 2014, June to August 2014, and September to November 2014. Data are from HadCRUT.4.3.0.0, an update of Morice et al. (2012). The crosses and dashes show the extreme seasonal anomalies in the same style as in Figure 2.

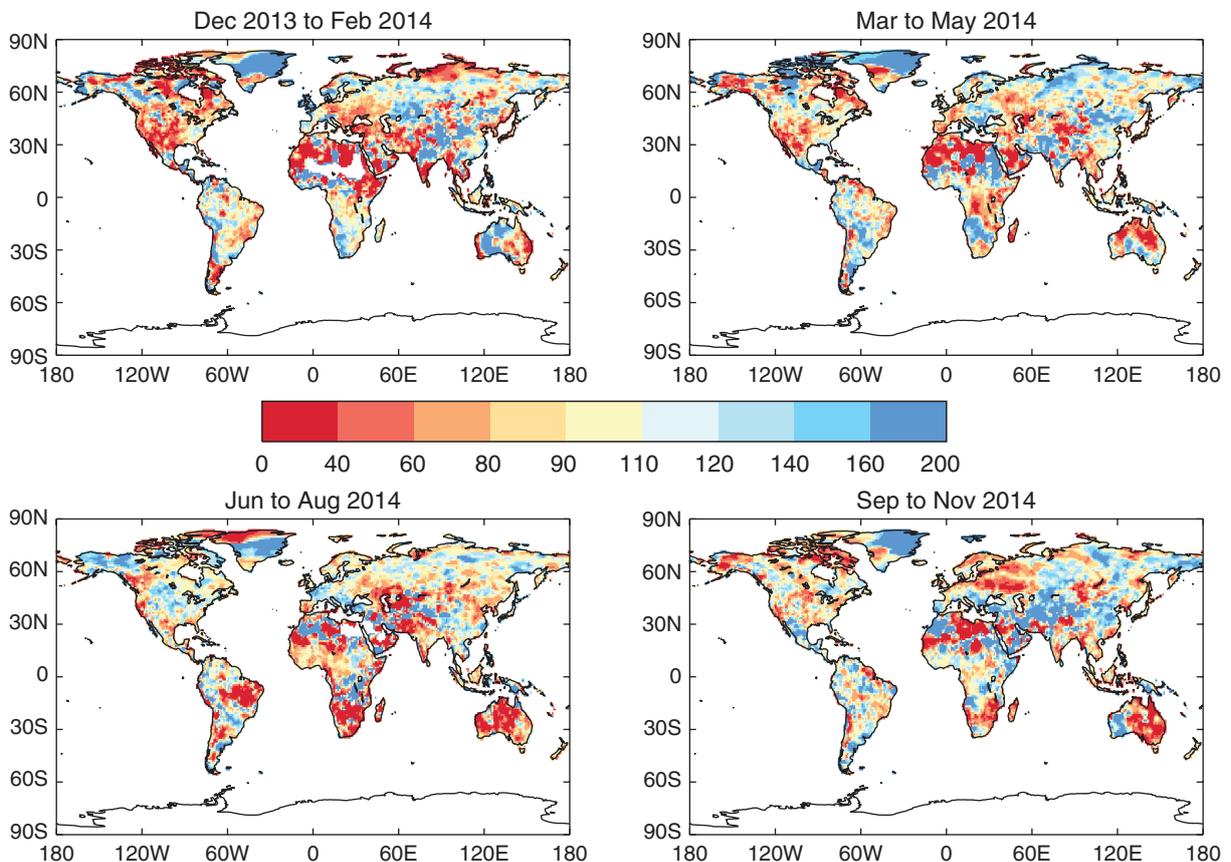


Figure 5. Seasonal total precipitation anomalies expressed as a percentage of the 1961–1990 normal. Data are from the GPCP Monitoring Product (Becker et al., 2013).

fifth lowest on record. The average ice extent for September 2014 was 5.2 million km², the joint sixth lowest extent on record. Antarctic sea ice extent was at or near record levels for much of 2014. The annual peak of Antarctic sea ice extent usually occurs in September or early October. In 2014, according to the US National Snow and Ice Data Center (NSIDC), Antarctic sea ice extent reached a new record maximum, with an area of 20.11 million km² on 22 September. This was the third year in a row that a new record Antarctic sea ice extent has been reached.

The Sahel region of Africa, the semi-arid region on the southern edge of the Sahara, saw precipitation totals similar to those recorded in 2013 (Figure 7). The rainfall total for 2014 was below the levels typical of the wetter period before 1970, but above the average for the drier period, marked by severe droughts, which affected the region between 1970 and 1990. The update for 2014 is based on a new analysis which uses CRU data from 1901 to 1978 and is updated using GPCP2.2 for 1979–2014 (Adler *et al.*, 2003). The comparison with the version used in earlier annual papers appearing in *Weather* on Global and Regional Climate indicates the overall reliability of the long-term trends and interannual variability (Kennedy *et al.*, 2014), but also highlights (by the many small differences) the uncertainty in the record. The offset arises because the CRU record is expressed as anomalies relative to the average for 1961–1990, which was drier than the reference period used by Nicholson (1985).

European and UK climate

2014 was an unusually warm year for the UK and much of Europe (Figures 8 and 10). The annual average temperature across Europe was the highest on record and a number of European countries including the UK also reported record temperatures. In the Central England Temperature series, 2014 was the warmest year on record by a narrow margin. In the UK, monthly average temperatures were not individually exceptional, but a series of 'quite warm' months combined to give a record annual average (Table 1).

Winter 2013/2014 was exceptionally wet and stormy across the UK and some nearby parts of Europe (Figure 9). On 5/6 December 2013 the most significant storm surge to affect the east coast of the UK for 60 years was observed. The UK's winter rainfall total was 177% of the 1961–1990 average, making this the wettest winter in the UK series from 1910. It was also the wettest winter in the near 250-year England and Wales precipitation series from 1766. Some parts of southern England received well over 250% of average. In general, it was the persistence of the storms, rather than any individual event, which led to the high

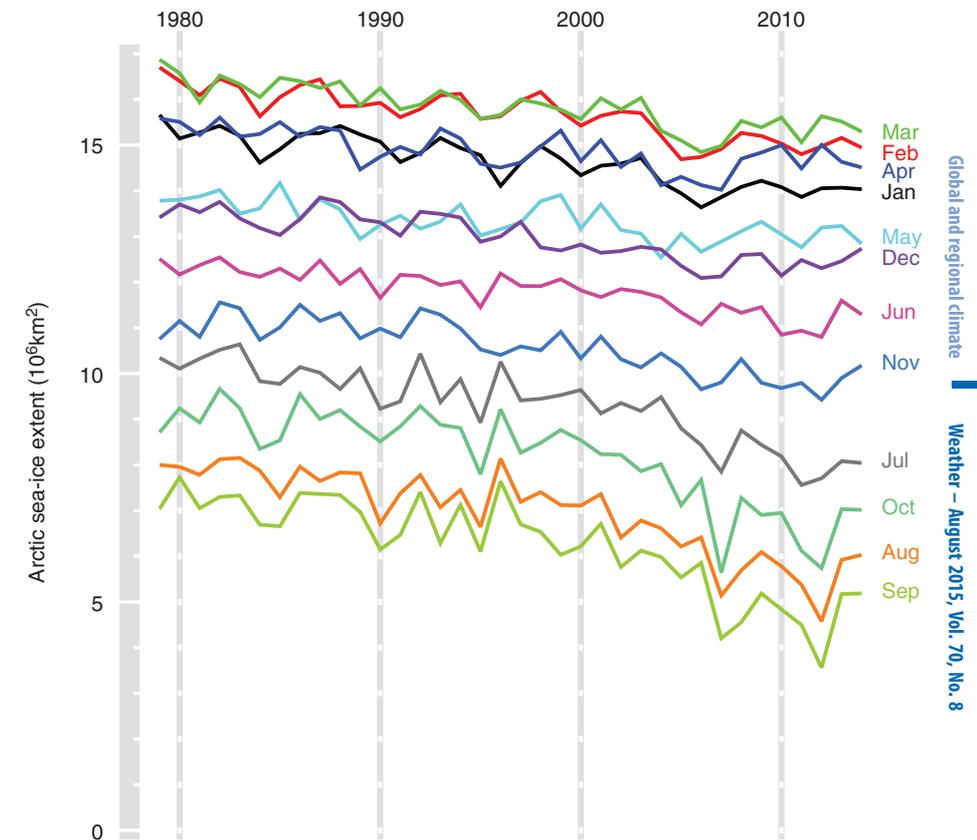


Figure 6. Monthly Arctic sea ice extent (million km²) 1979–2014. Time series are based on an update of Rayner *et al.* (2003). See also Titchner and Rayner (2014).

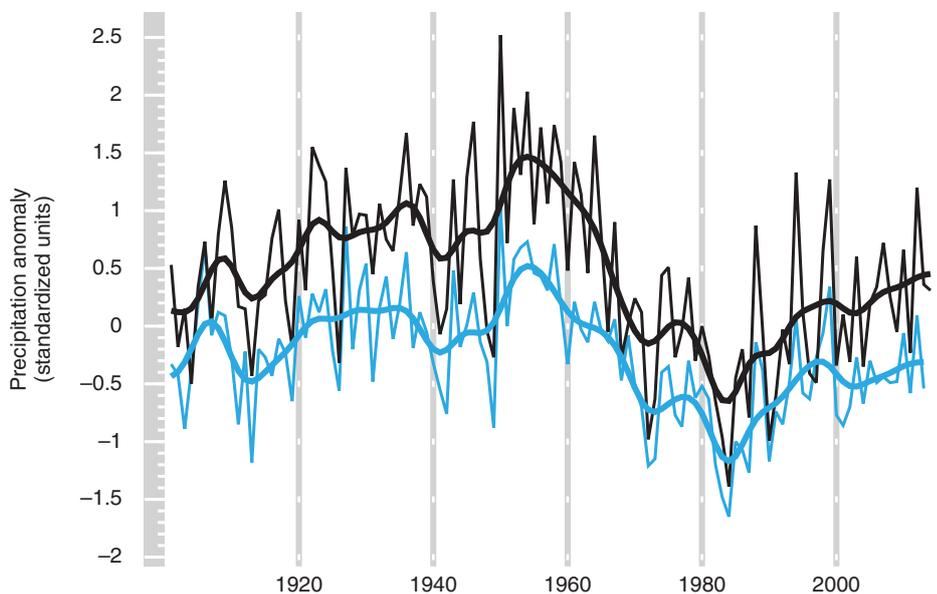


Figure 7. Annual rainfall anomalies (in standardised units) for the Sahel during 1901–2014. The blue line shows standardised data based on averages and standard deviations of stations' data for generally around 50 years ending in 1973 (Nicholson, 1985). The values from 1901 to 1984 are from Nicholson (1985); from 1985–2000 they are calculated from internationally transmitted monthly climate data, whilst those for 2001–2013 are based on NCEP gridded gauge data (Chen *et al.*, 2002). The black line shows standardised data relative to 1961–1990 based on CRU precipitation data set from 1901 to 1978 and GPCP2.2 (Adler *et al.*, 2003) from 1979 to 2014.

seasonal rainfall totals. During two spells of stormy weather from mid-December to early January, and from late-January to mid-February, at least 12 major Atlantic storms affected the UK. This was the stormiest

period of weather for at least 20 years, with the conditions linked to an unusually strong Atlantic jet stream, in turn linked to strong upstream temperature contrasts across the eastern US.

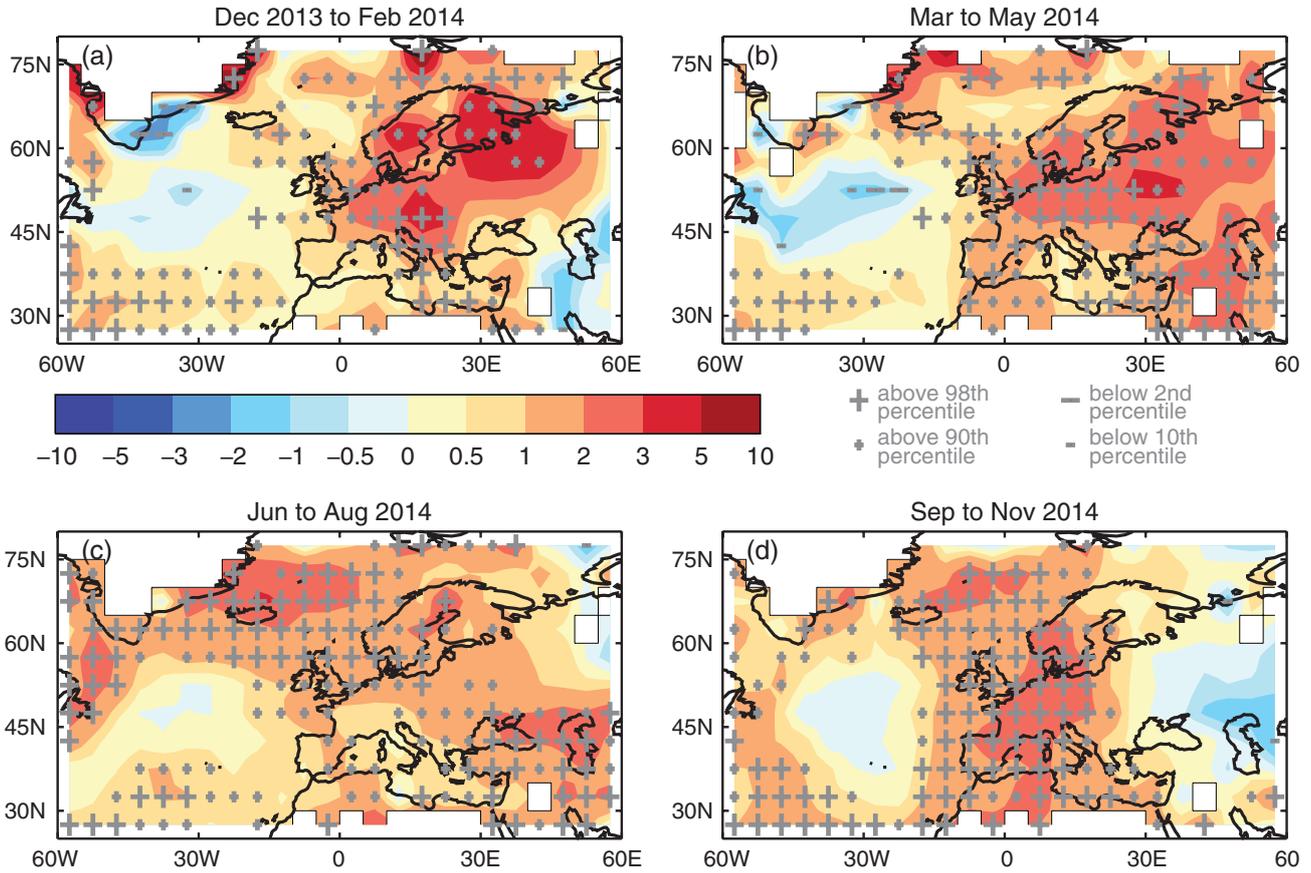


Figure 8. Surface air-temperature anomalies for Europe and sea-surface temperature anomalies for neighbouring waters (degC, relative to 1961–1990) for December 2013 to February 2014, March to May 2014, June to August 2014, and September to November 2014. Data are from HadCRUT.4.3.0.0, an update of Morice et al. (2012). The crosses and dashes show the extreme seasonal anomalies in the same style as in Figures 2 and 4.

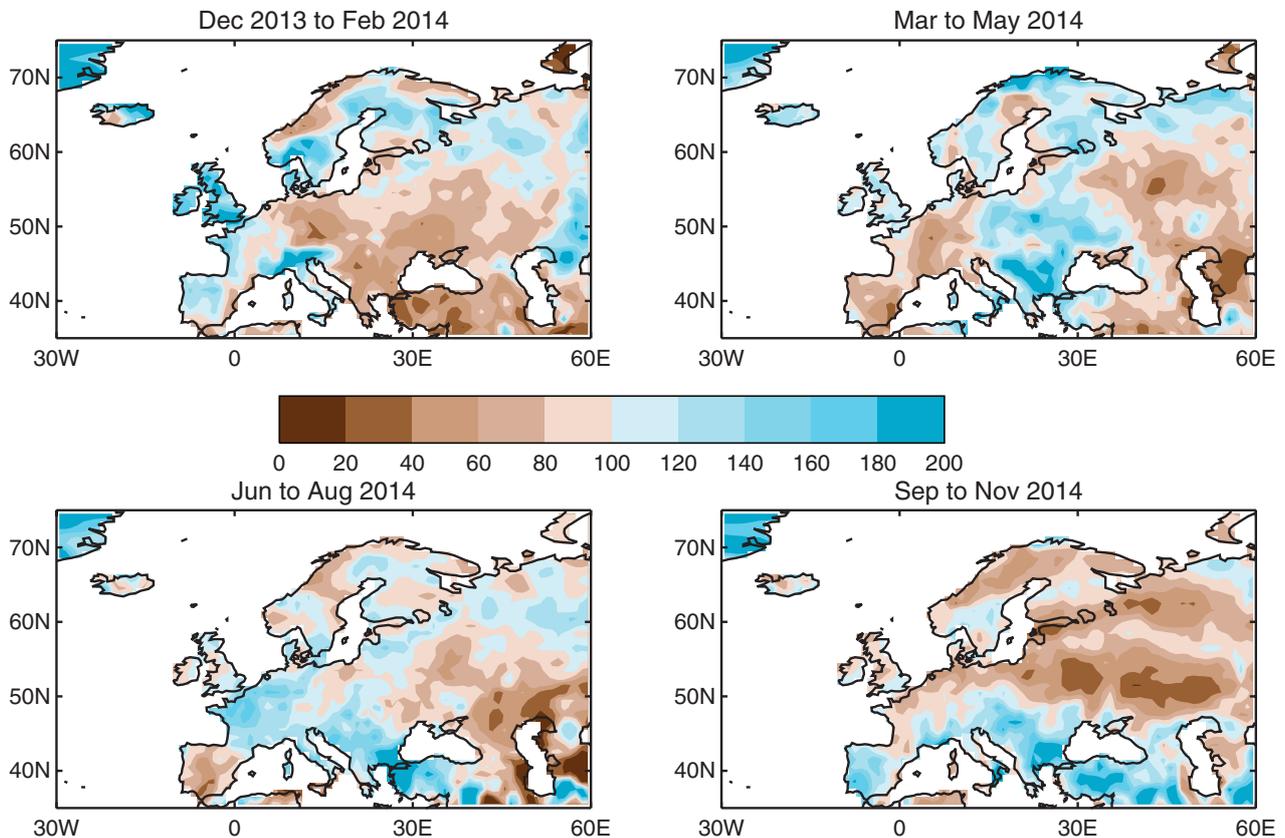


Figure 9. Seasonal precipitation totals expressed as a percentage of the 1961–1990 average. Data are from the GPCP monitoring product (Becker et al., 2013).

Table 1

Monthly and annual mean Central England Temperature (Parker et al., 1992), total England and Wales Precipitation (Alexander and Jones, 2000) and UK temperature for 2014 (Perry and Hollis, 2005a; 2005b).

	CET 2014, °C (anomaly, degC)	EWP 2014, mm (% of normal)	UK 2014, °C (anomaly, degC)
January	5.7 (1.9)	185 (203)	4.8 (1.8)
February	6.2 (2.4)	137 (209)	5.2 (2.2)
March	7.6 (2.0)	56 (75)	6.7 (2.0)
April	10.2 (2.3)	64 (104)	9.2 (2.5)
May	12.2 (1.1)	103 (158)	11.2 (1.5)
June	15.1 (1.0)	50 (76)	14.2 (1.5)
July	17.7 (1.7)	55 (88)	16.3 (1.9)
August	14.9 (-0.8)	119 (154)	13.9 (-0.3)
September	15.1 (1.5)	16 (21)	13.9 (1.7)
October	12.5 (1.9)	118 (136)	11.1 (1.6)
November	8.6 (2.0)	127 (137)	7.6 (2.0)
December	5.2 (0.5)	78 (81)	4.4 (0.6)
Annual	10.95 (1.44)	1106 (121)	9.9 (1.6)

There were several fatalities and over 7000 homes and businesses flooded, with the Somerset Levels inundated for many weeks and the Thames Valley also badly affected. However, the flooding was not on the same scale as that of summer 2007 when 55 000 properties were affected. The storms also resulted in very high waves affecting coastal communities in Wales and southwest England, causing some damage to coastal infrastructure. In Dawlish, Devon, the main-line railway link to southwest England was damaged, severing a key transport link for many weeks.

Parts of the Balkan Peninsula received above-average rainfall totals from March to October (Figure 9). Heavy rain between 12 and 18 May fell on already saturated surfaces and caused severe flooding and landslides in Serbia, Bosnia-Herzegovina and Croatia.

The remnants of ex-hurricane Bertha brought windy and wet weather to the

UK on 10/11 August. Northeast Scotland was worst affected, with an area from Ullapool to Aberdeen receiving a whole month's average rain in only 2 days. In the Lossiemouth to Inverness area 2-day totals reached twice the monthly average. There was a significant orographic component to this heavy rain from a northeasterly airflow, in a reversal of the normal rain-shadow effect. Flooding, fallen trees, and landslips caused disruption to rail and road transport links and 200 properties were evacuated in Elgin. A very similar event also affected this part of Scotland on 3/4 September 2009. August overall was a very wet month across northern Scotland, which received more than twice the monthly average rainfall widely. The climate district of Northern Scotland recorded 198% of the 1961–1990 August average rainfall, making this the wettest August here in a series from 1910.

September was dominated by high pressure, bringing settled weather to the UK. Large swathes of the country received less than 20% of September's normal rainfall, and the UK overall received only 22% of the 1961–1990 September average. This was the driest September for the UK in a series from 1910, and the driest calendar month since August 1995. September was also warmer than average, although not exceptionally so, but, unusually, it was only the fifth time since 1910 that the UK's mean temperature for September has equalled or exceeded that for August. The 'Indian Summer' was welcome for many following a rather cool and wet August. There were no significant adverse weather impacts from the dryness.

More detail on the climate in 2014 can be found in the World Meteorological Organization's (WMO's) statement on the status of global climate in 2014 on <http://www.wmo.int> and in the *State of the Climate* report published in the July 2015 issue of the *Bulletin of the American Meteorological Society* and also online at <http://www.ncdc.noaa.gov/bams-state-of-the-climate/>. A more complete summary of European climate will be published by WMO in its *annual bulletin on the climate in WMO region VI – Europe and the Middle East*, 2014. Selected global and UK data sets can be accessed from <http://www.metoffice.gov.uk/hadobs>.

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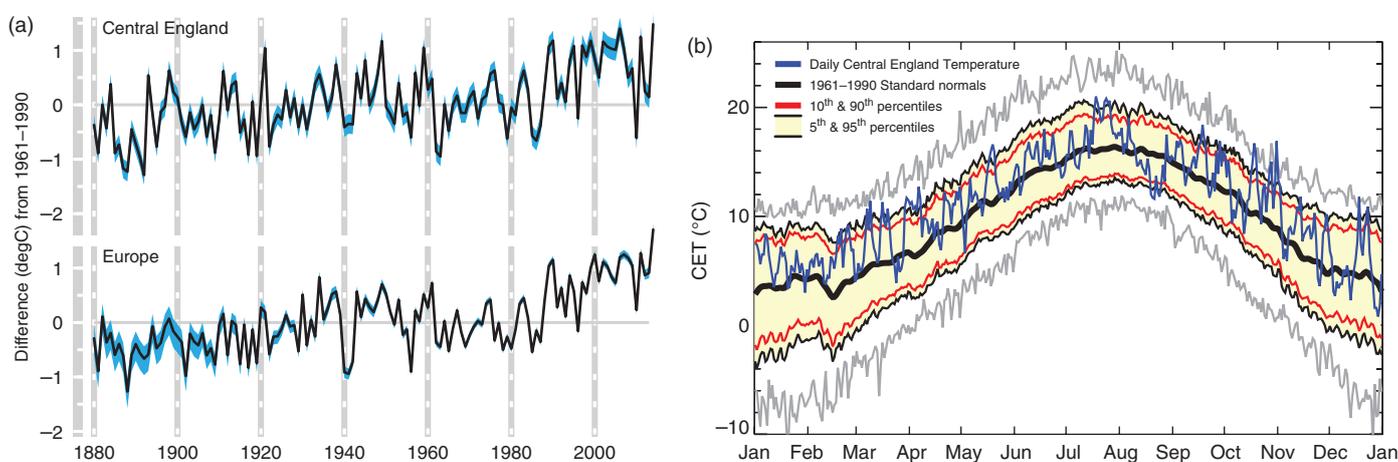


Figure 10. (a) Annual average mean Central England (Parker and Horton, 2005, updated) and European (Jones et al., 2012, updated) temperature anomalies (degC relative to 1961–1990) from 1880 to 2014 and two-standard-deviation uncertainties (blue shading). (b) Mean daily Central England Temperature (°C, CET) for 2014 (dark blue line). The heavy black line shows the normal for 1961–1990 after smoothing, and the red lines are the corresponding 10th and 90th percentiles for each day of the year. The yellow band is the interval between the 5th and 95th percentiles. The light grey lines represent the highest and lowest values of mean CET in the daily record since 1772 (Parker et al., 1992).

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Meeting report

Stratosphere–troposphere coupling in the Earth system: Where next?

Over the past few decades, the importance of the stratosphere for weather and climate has become a strong focus of research. The research has shown that the stratosphere has a key role in affecting surface variability and predictability. For example, the recent World Meteorological Organization (WMO)/United Nations Environmental Programme (UNEP) Ozone Assessment Report (2014) described how stratospheric ozone depletion is likely to have been the main driver of changes in the Southern Hemispheric surface climate in recent decades. Most weather and climate models now aim to represent the stratosphere better.

Many outstanding issues remain around the ways in which the stratosphere can affect the troposphere. The above-titled meeting, held at the University of Reading on the afternoon of 21 January 2015, aimed to discuss these issues. Five main talks by experts were followed by a discussion session led by meeting chair *Peter Haynes*, and preceded by an introduction from meeting

organiser *Amanda Maycock* (both from the University of Cambridge).

The meeting was popular and fully subscribed for people attending in person and remotely via a new webcast system. This is the second time the Royal Meteorological Society has trialled a web conferencing service for those unable to travel to the meeting. The online chat feature and Twitter (via the hashtag #RMetSMeet) allowed remote participants to ask questions.

Amanda's introduction reminded us that a cold cyclonic polar vortex forms in the stratosphere every winter and that it is disturbed by breaking planetary-scale Rossby waves propagating up from the troposphere. In about two-thirds of Northern Hemispheric winters, the waves disturb the polar vortex so violently that the zonal-mean winds reverse and polar temperatures rise by several tens of degC. Such events are called stratospheric sudden warmings (SSWs) and account for the dominant mode of variability of the zonal mean circulation,

as measured for instance by the Northern Annular Mode (NAM) index. Figure 1 is the well known Baldwin–Dunkerton 'dripping paint plot', a time–height cross-section of the NAM index composited with respect to the onset of many SSWs. The plot suggests, but does not prove, downward influence from stratosphere to troposphere, affecting the weather over the next few months. More recently, however, numerical experiments with stratospheric nudging have confirmed such influence.

Adam Scaife (Met Office) spoke on climate and seasonal forecasting. Research has shown that the responses to different drivers of Atlantic winter climate often exhibit the same large-scale surface pressure pattern, that of the North Atlantic Oscillation (NAO). Several participants likened the NAO to a nonlinear 'bell' waiting to be rung by the stratosphere or by another driver. Adam showed that with the Met Office's new Global Seasonal Forecasting System (GloSea5) significant progress has