Why was the start to spring 2013 so cold?

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Summary

March 2013 was the second coldest March in the UK record since 1910, and was associated with a negative phase of the North Atlantic Oscillation. A number of potential drivers may predispose the climate system to a state which accounts for these conditions.

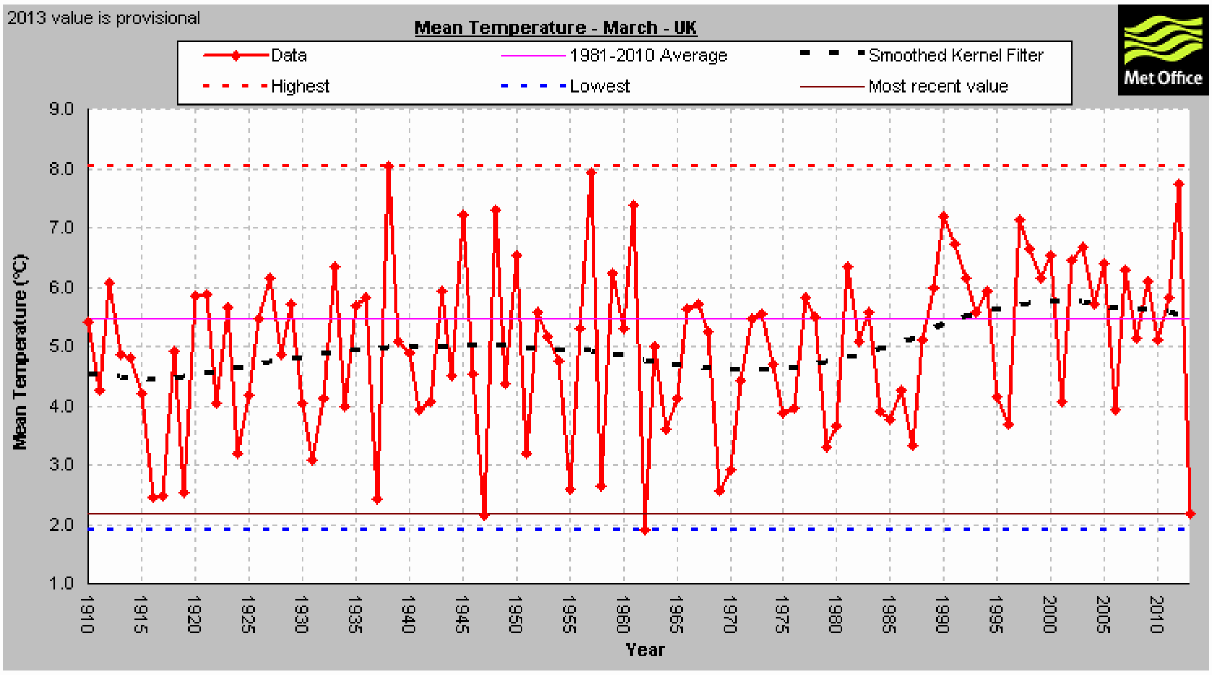
- The cold temperatures were part of a larger-scale weather pattern in the Northern Hemisphere.
- This pattern was associated with the negative phase of the North Atlantic Oscillation, which leads to the prevalence of easterly winds and cold conditions over the UK.
- There are a number of similarities between the climatological context of the March 2013 cold weather and that observed in 1962 (the coldest March on record).
- A number of potential drivers may predispose the climate system to negative NAO states in early spring. These include:
    - weather in the Tropics
    - the Stratosphere
    - conditions in the North Atlantic
    - the state of the Arctic
- These drivers are not necessarily independent, and no single explanation can account for the cold conditions observed.

Introduction

This March has been the coldest since 1962 in the UK in the national record dating back to 1910 (Figure 1). Provisional figures indicate that the UK mean temperature was 2.2°C, which is 3.3°C below the long term 1981-2010 average. Figure 1 also illustrates that the whole of the UK was colder than normal.

This ranks March 2013 as joint second (tied with 1947) coldest in the records. Unusually, this March was also colder than the preceding winter months of December (3.8°C), January (3.3°C) and February (2.8°C). This last happened in 1975.

As well as being very cold, March has also been very snowy and joins 2006, 2001, 1995, 1987, 1979, 1970 and 1962 as years when March saw some significant snowfall.



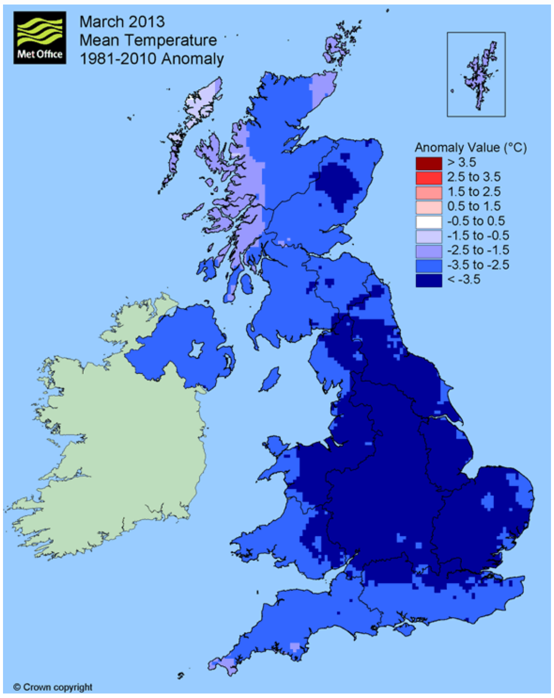


***Figure 1**: Time series of UK temperatures for March since 1910 (above) and the distribution of temperature anomalies over the UK from the climatology for 1981-2010 (right panel).*

Global Context

The cold temperatures during March were part of a hemisphere-scale pattern of temperature anomalies (Figure 2). This was orientated across the pole with large anomalies over North America and across Asia. Extreme cold and snow has affected Russia and the Ukraine, and over the eastern and northern USA temperatures were more than 3°C colder than normal over very large areas. Among the hardest hit areas were in northern France, Germany and Ukraine, where maximum snow accumulations exceeded 50 cm. There were at least 30 fatalities reported, and total economic losses were estimated at $1.8bn, including $914M in France alone[1].

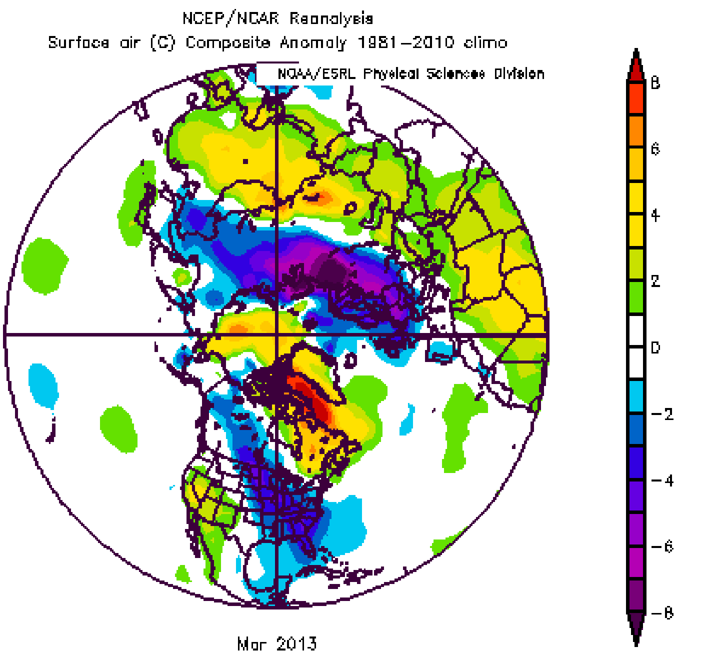


Figure 2: Surface air temperature anomalies over the northern hemisphere for March 2013.

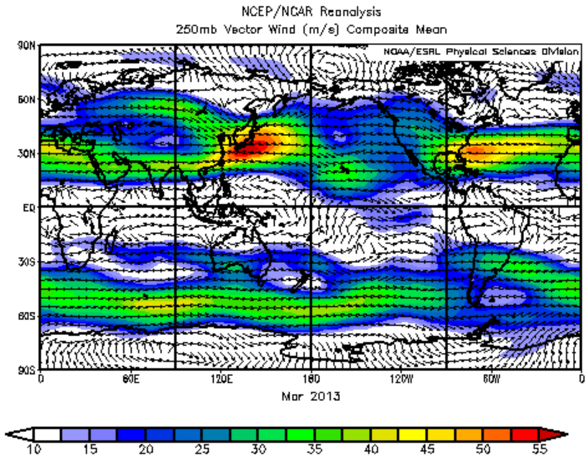
As expected from the pattern of temperature anomalies in Figure 2, the atmospheric circulation was very perturbed throughout March 2013 (Figure 3). The mean sea level pressure pattern (Figure 3, right panel) shows higher pressure than normal over the Arctic and much lower pressure than normal over the Azores, characteristic of the negative phase of the North Atlantic Oscillation (NAO)[2]. Consequently the UK has been dominated by persistent easterly and north-easterly winds bringing very cold air over the country from northern Europe and Russia (Figure 2).

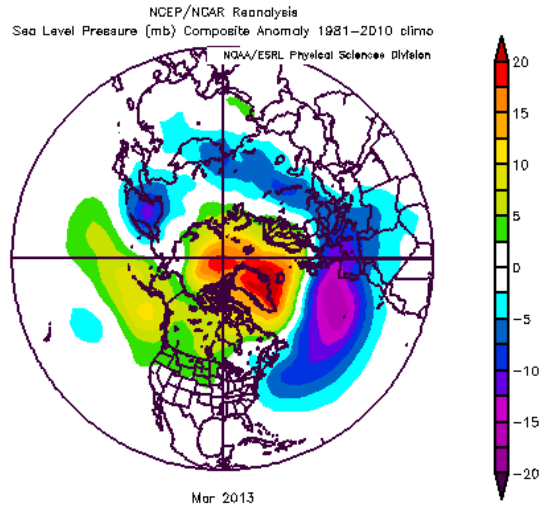
An integral part of the negative phase of the NAO is a southwards shift of the North Atlantic jet stream (Figure 3, upper left panel), which acts to steer the storm track across southern Europe and the Mediterranean, away from its usual trajectory over the UK (Figure 3, lower left panel).

As Figure 3 shows, the jet stream was also perturbed over the North Pacific with a large southerly excursion in the central Pacific. This is likely to be part of the global response to variations in tropical weather patterns, which were again quite large during March.

[1] AON Benfield, Impact Forecasting, March 2013 Global Catastrophe Recap

[2] The **North Atlantic Oscillation** (**NAO)** is the dominant mode of winter climate variability in the North Atlantic region ranging from central North America to Europe and much into Northern Asia. The NAO is a large scale fluctuation in atmospheric mass between the subtropical and the polar low. Through east-west oscillation of the Icelandic low and Azores high, it influences the strength and direction of storm tracks across the North Atlantic. The corresponding index varies from year to year, but also exhibits a tendency to remain in one phase for intervals lasting several years.





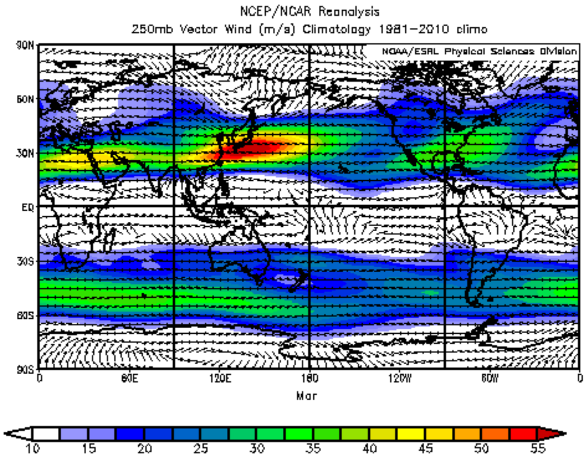


***Figure 3**: Mean sea level pressure anomalies for March 2013 (right panel) against the climatology for 1981-2010. Upper tropospheric winds for March 2013 (upper left panel) and the climatology (1981-2010) for March. The arrows depict the direction of the wind and the colour shading shows the wind strength. The major jet streams of the northern and southern hemispheres are identified by the regions of strongest winds.*

The rainfall anomalies shown in Figure 4 (left panel) indicate a continuation of the disturbed weather over the West Pacific and northern Australia that has been a feature of recent years, related to La Nina[3] conditions in the equatorial Pacific. Although the recent La Nina event has dissipated and equatorial East Pacific ocean temperatures have returned to near neutral conditions, the West Pacific continues to be warmer than normal (Figure 4, right panel). In addition, the Madden Julian Oscillation[4] (MJO) has again been active through the Indian Ocean and into the West Pacific during late February into mid-March, contributing

[3] **La Nina** corresponds to the cold phase of El Nino Southern Oscillation (ENSO) cycle in which sea surface temperatures along the Peruvian coast and across the equatorial East Pacific are colder than normal; concurrently sea surface temperatures in the West Pacific tend to be warmer than normal. This change in the pattern of sea surface temperatures drives more rainfall and active weather systems over the warm waters of the West Pacific and Indonesian seas, and the global effects are felt as far as the UK through changes in the planetary waves and hence the position of the jet stream.

[4] The **Madden–Julian oscillation (MJO)** dominates the intraseasonal (30–90 days) variability in the tropical atmosphere. It involves a large-scale coupling between the atmospheric circulation and tropical deep convection, which is characterized by a travelling pattern, propagating eastwards at approximately 4 to 8 m/s, through the atmosphere, above the warm parts of the Indian and Pacific oceans. This overall circulation pattern manifests itself in various ways, most clearly as anomalous rainfall. The MJO can be seen as an eastward progression of large regions of both enhanced and suppressed tropical rainfall. The anomalous rainfall is usually first evident over the western Indian Ocean, and remains evident as it propagates over the very warm ocean waters of the western and central tropical Pacific. This pattern of tropical rainfall then generally becomes nondescript as it moves over the cooler ocean waters of the eastern Pacific but occasionally reappears at lower amplitude over South America, the tropical Atlantic and Africa. The wet phase of enhanced convection and rainfall is followed by a dry phase where cloudiness and thunderstorm activity is suppressed. Each cycle lasts approximately 30–60 days.

substantially to the increased rainfall over the West Pacific in the monthly mean pattern (Figure 4, left panel).

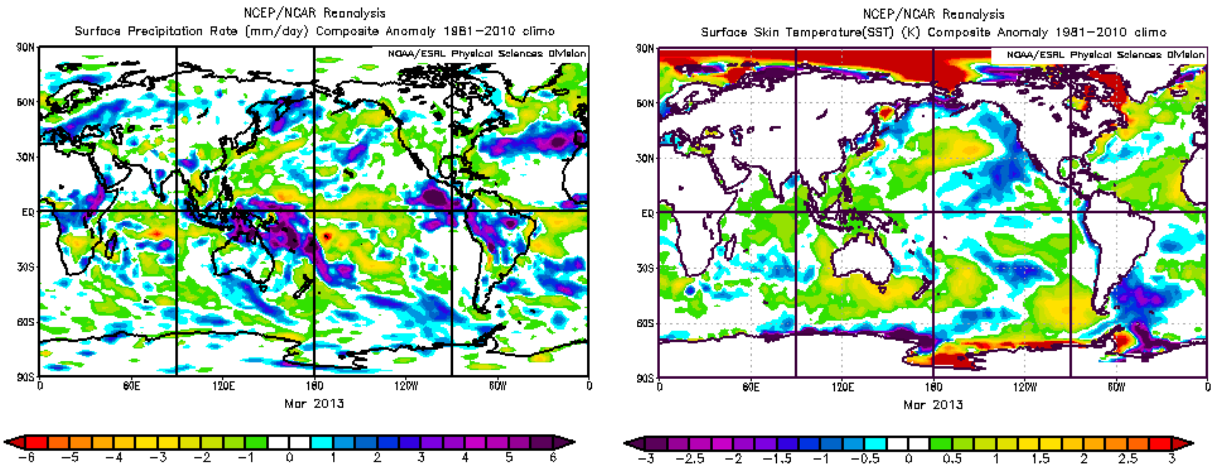
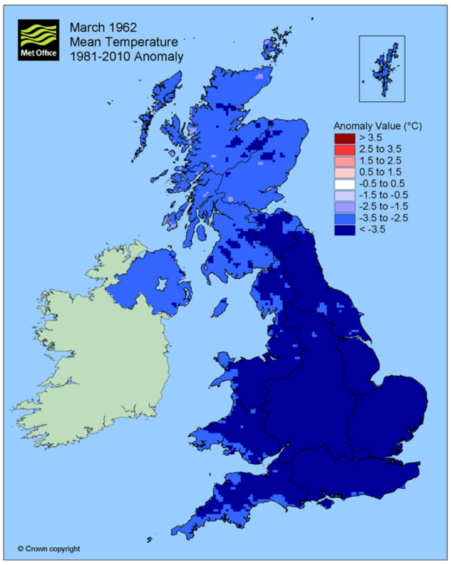


Figure 4*: Global rainfall anomalies (left panel) and Sea surface temperature anomalies (right panel) for March 2013 against the climatology for 1981-2010.*

Looking closer to home, the displacement of the North Atlantic storm track to the south is very evident in the increased rainfall relative to normal in southern Europe, with drier conditions further north (Figure 4, left panel). Sea surface temperatures in the North Pacific and North Atlantic continue to be perturbed, consistent with changes in the atmospheric circulation. A notable feature of the ocean temperature anomalies in Figure 4 (right panel) is the extremely warm water in the Labrador Sea and down the coast of Newfoundland. Likewise the Arctic is mostly warmer than normal. The pattern of ocean temperatures in the Atlantic is consistent with the known effects of the winds associated with the negative NAO, implying an atmospheric signature in the ocean. There is also likely to be an (albeit weaker) effect from this oceanic pattern on the atmosphere, implying the possibility of a feedback which predisposes the winter circulation to negative phases of the NAO and is likely a contributory factor to this year's cold start to spring.

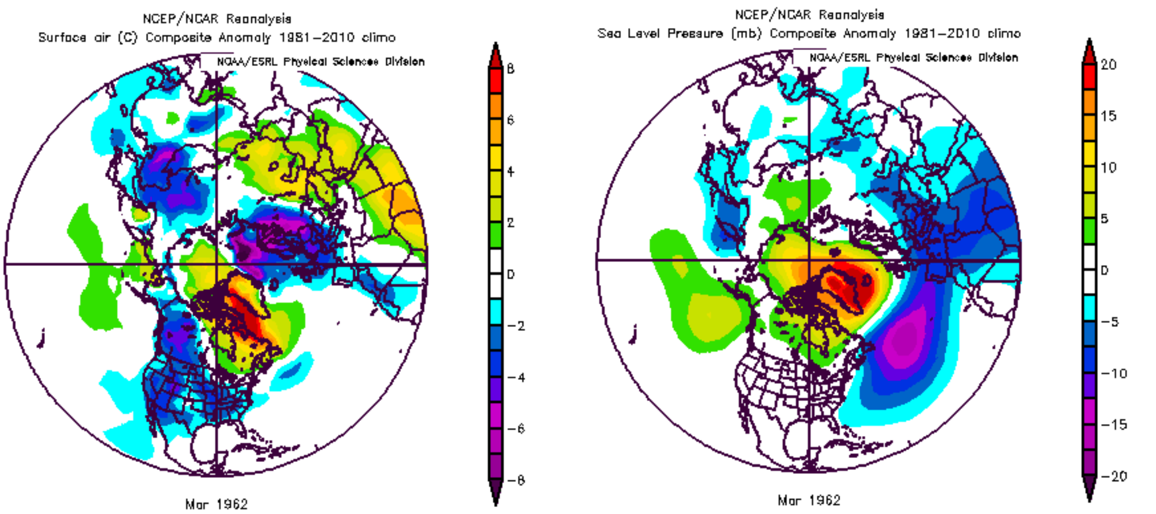
Comparison with 1962

As Figure 1 (left panel) shows, very cold conditions in March have not been a feature of recent decades; indeed the general trend has been one of warmer and earlier springs. The last time the UK experienced a very cold March was in 1962 and, again, it was a countrywide event (Figure 5).



It is informative to consider whether there are similarities in the global climate system in 1962 (Figure 6) to this year's situation (Figure 3). Comparison with the equivalent figures for 2013 shows a remarkable resemblance. The hemispheric pattern of the surface air temperature anomalies is almost identical, as is the hemispheric pattern of mean sea level pressure anomalies. Again the negative phase of the NAO dominated the Euro-Atlantic sector in 1962, with the same southwards shift in the jet stream taking the weather systems into southern Europe and the Mediterranean.

***Figure 5**: UK temperature anomalies for March 1962 against the climatology for 1981-2010.*



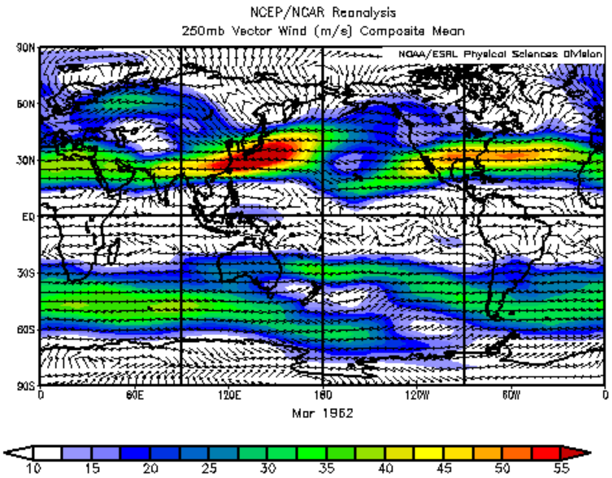


***Figure 6**: Surface air temperature (upper left panel) and mean sea level pressure right panel) anomalies for March 1962 versus the long-term climatology for 1981-2010. Upper tropospheric winds for March 1962 (lower left panel).*

The related global rainfall and sea surface temperature anomalies are shown in Figure 7 and can be compared with those for 2013 (Figure 4). Again the southwards displacement of the North Atlantic storm track is very evident in the rainfall anomalies, particularly over the Atlantic. However, the tropical rainfall patterns are quite different (with the caveat that there are uncertainties in these data due to the paucity of observations 50 years ago).

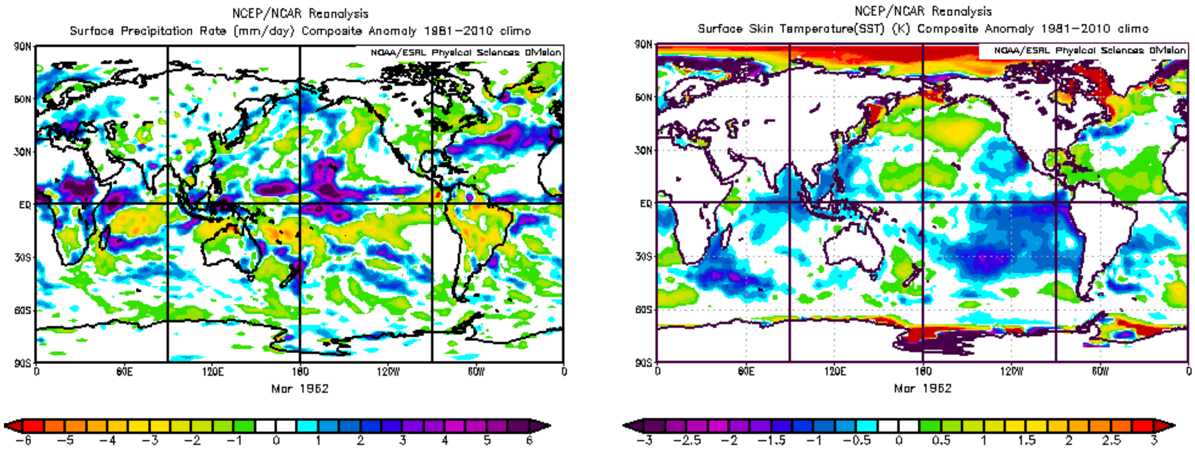


Figure 7*: Global rainfall anomalies (left panel) and surface air temperature anomalies (right panel) for March 1962 against the climatology for 1981-2010.*

In terms of sea surface temperature anomalies (Figure 7, right panel) there are some differences which are due in part to the signals of global warming that have emerged over the past 50 years. Even taking those into account, however, there is some evidence of La Nina conditions in the equatorial Pacific and similarities in the pattern of temperature anomalies in the North Atlantic.

What is particularly notable are the warmer than normal sea surface temperatures in the Labrador Sea and down the coast of Newfoundland, which are remarkably similar to this year. Likewise the Arctic basin is warmer than the current climatology for 1981-2010, even allowing for the substantial warming trend in the Arctic during recent years.

Potential drivers of the 2013 cold start to spring

There are a number of factors that may predispose the climate system to negative NAO states in early spring and the prevalence of easterly winds over the UK, leading to anomalously cold conditions. Several of these were in force during the 2013 spring (and also in 1962).

(i) The Tropics

The influence of weather patterns in the tropical Pacific on the phase of the NAO in winter is well known. Particularly relevant for this year is the behaviour of the Madden Julian Oscillation (MJO; Figure 8).

When the MJO is in its active phase over Indonesia (Maritime Continent) and the West Pacific, it tends to drive negative NAO conditions 2-3 weeks later[5]. As already noted the MJO entered its active phase over Indonesia in late February, propagating eastwards into the West Pacific in early March where it stagnated for two weeks before continuing its eastwards progression and weakening substantially.

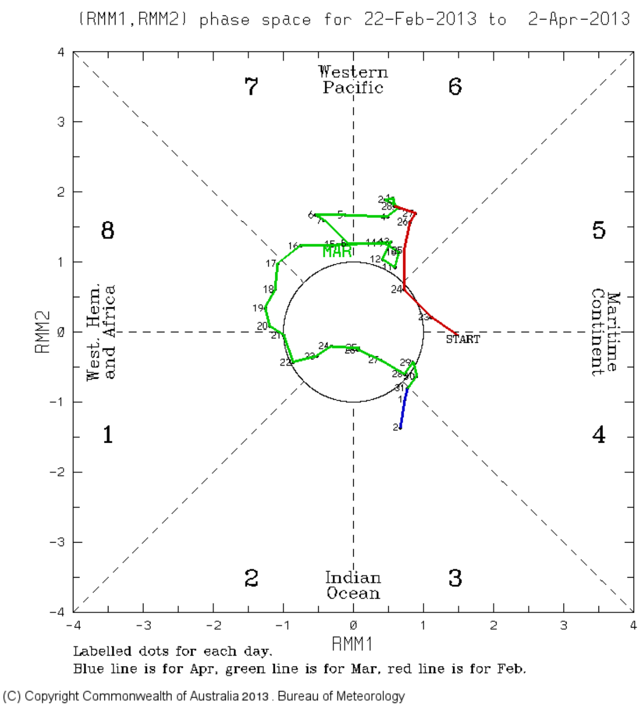


***Figure 8**: Time-space phase diagram showing the trajectory and strength of the MJO during February and March 2013. The coloured lines with numbers show the day-by-day movement across the sectors and the distance from the inner circle depicts the strength of the MJO.*

The MJO moves progressively eastwards from the Indonesian region (Maritime Continent) during late February (red line) and enters the West Pacific at the beginning of March (green line). It then stagnates over the West Pacific, but remains strong, before continuing its eastward progress reaching the East Pacific and South America around 20 March when it weakens considerably. At the beginning of April the MJO is just re-emerging over the Indian Ocean.

During its time over the West Pacific the MJO was particularly strong, accounting for the large rainfall anomaly seen in Figure 4 (left panel), and probably having a significant impact on the northern hemisphere circulation. It is very likely therefore that the MJO played a role in this year's cold spring, just as it probably did, but for different reasons, in the remarkable transition from dry to wet conditions over the UK in spring 2012.

[5] Cassou C (2008) Intraseasonal interaction between the Madden– Julian Oscillation and the North Atlantic Oscillation. Nature 455:523–527.

(ii) The Stratosphere

The stratosphere is the atmospheric layer above the troposphere, between 10km and 50km. We now know that interactions between the stratosphere and the troposphere are fundamental components of the Earth's climate. Of particular relevance to this year's cold weather is the sudden stratospheric warming which took place in early January. A sudden stratospheric warming describes the displacement of the cold vortex over the winter pole, with a rapid warming (up to about 50°C in just a couple of days) in the middle stratosphere. This is accompanied by a substantial weakening of the high altitude westerly winds around the polar vortex or even a reversal to easterly winds.

There is now a substantial body of evidence to show that during winter and early spring, sudden stratospheric warming events in the upper stratosphere over the North Pole can influence surface weather conditions over the UK some 2-3 weeks later[6]. The easterly winds in the upper stratosphere 'burrow' down through the atmosphere to affect the jet stream and surface climate. The result is a switch from a mild westerly Atlantic flow over Europe to easterly winds with an increased risk of cold extremes. The appearance of a sudden stratospheric warming provides a 'window of opportunity' for monthly forecasts to warn of increased risk of blocking weather patterns and the development of cold, easterly conditions over the UK.

As Figure 9 shows, a significant stratospheric warming event developed at the beginning of January 2013, with the reversal of the normal westerly winds to easterly winds in the upper stratosphere. Based on this understanding, the Met Office 16 to 30-day forecast correctly reflected the increasing risk of cold conditions since mid-January this year.

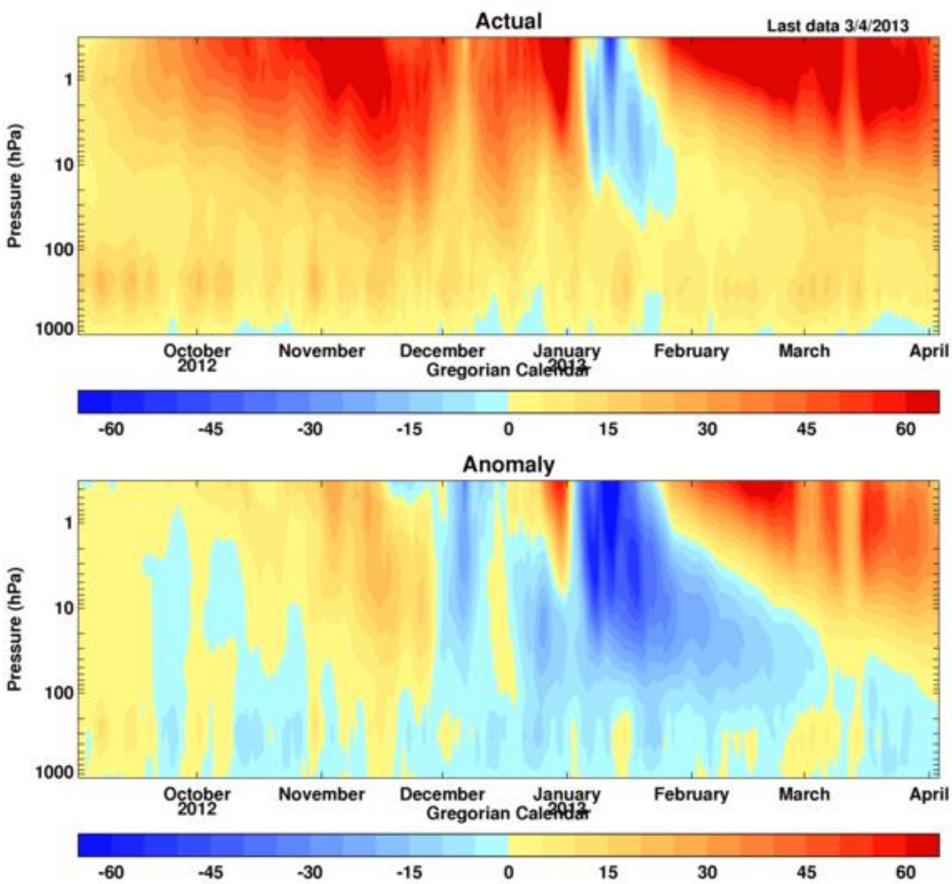


***Figure 9**: Time series of the vertical profile of the daily mean winds at 60^0N from the surface to the upper stratosphere, through the winter of 2012/2013. The upper panel shows the actual mean wind and the lower panel shows the anomalous wind. Yellow/red colours depict westerly winds and blue colours depict easterly winds.*

[6] http://metofficenews.wordpress.com/2013/01/08/what-is-a-sudden-stratospheric-warming-ssw/

The rapid descent of the easterly anomalies to the surface by the middle of January is clearly seen in the lower panel of Figure 9, initiating the development of negative NAO weather patterns over the Euro-Atlantic sector. Thereafter the upper stratospheric westerly winds began to re-establish themselves, gradually descending over the next two months to reach the tropopause (near 100mb) by the beginning of April. This ‘healing’ process is well understood and means that for at least 60 days after the onset of a sudden stratospheric warming, average surface pressure maps resemble closely the negative Arctic Oscillation pattern (Figure 10, right panel).

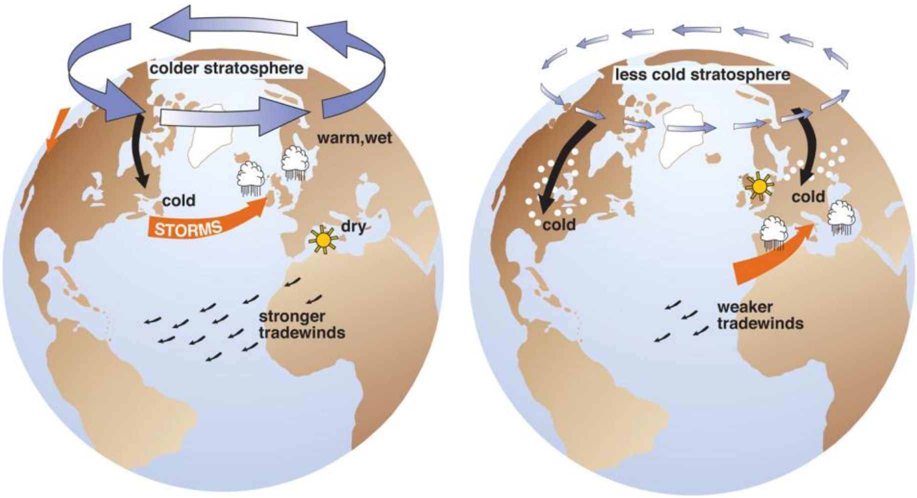


***Figure 10**: Schematic of the positive (left panel) and negative (right panel) of the Arctic Oscillation, which is strongly linked to the circulation of the stratosphere.*

Credit: J. Wallace, University of Washington.

The weather patterns experienced at the start of this spring are very consistent with the negative phase of the Arctic Oscillation, with a warmer stratosphere and weakened westerly winds. It is likely therefore that the behaviour of the stratosphere has been an important factor in driving the persistent cold easterly weather regime that has characterised this spring.

(iii) The North Atlantic

The climate of the North Atlantic and Europe continues to be influenced by the positive phase of the Atlantic Multi-decadal Oscillation (AMO; Figure 11), which describes long period fluctuations in the basin-wide sea surface temperatures of the North Atlantic. The warm phase of the AMO is characterised by above normal temperatures across the North Atlantic, but with a pattern of particularly warm water down the Labrador Sea and south of Greenland. This pattern was observed in 1962 and 2013 (Figures 4 and 7), and both years lie within the positive phase of the AMO.

Whilst the AMO has been linked to large-scale precipitation changes, most notably over the Sahel, the USA and Brazil, and to the activity of the Atlantic hurricane season, its influence on our winter climate is unclear. This is because variability in the North Atlantic Oscillation dominates and tends to imprint itself on the pattern of North Atlantic sea surface temperatures. However, there is some evidence that the changes in Atlantic sea surface temperatures associated with the AMO, dispose the circulation to give drier than normal spring conditions over the UK and northern Europe[7].

[7] R. Sutton and B. Dong, Atlantic Ocean influence on a shift in European climate in the 1990s. *Nature Geoscience,* **5**, 788–792 (2012) doi:10.1038/ngeo1595

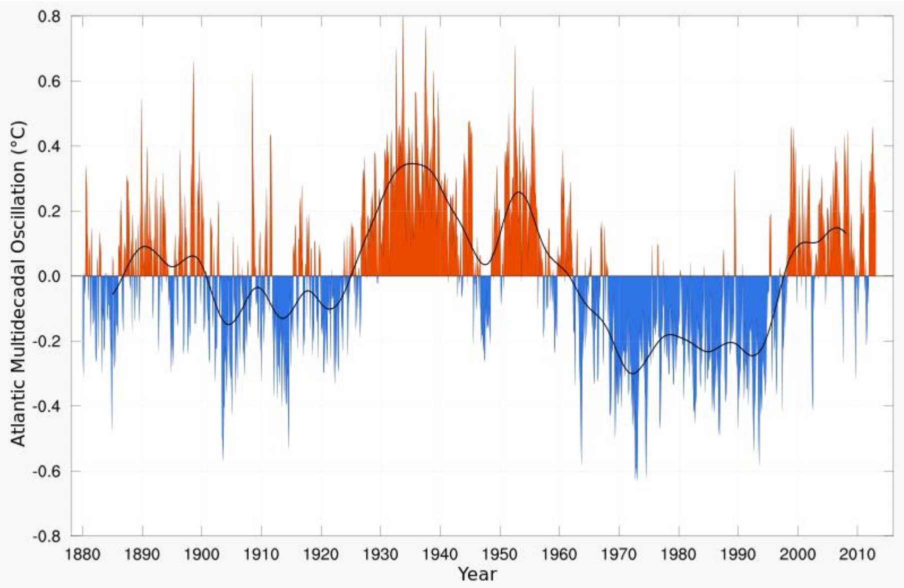


***Figure 11**: Time series of the index describing the phase of the Atlantic Multidecadal Oscillation.*

(iv) The Arctic

There is no doubt that the climate of the Arctic is changing and this can be seen in the seasonal cycle of sea-ice extent (Figure 12). Since 2007 and the unprecedented loss of sea ice extent that summer, the Arctic appears to have entered a new regime where although the ice fills in each winter, it is lost again very rapidly in summer. This is because increasingly the Arctic is covered by first year ice, which is thin and easily melted. This also means that during winter there is potential for a greater heat flux through the ice from the warmer ocean below.

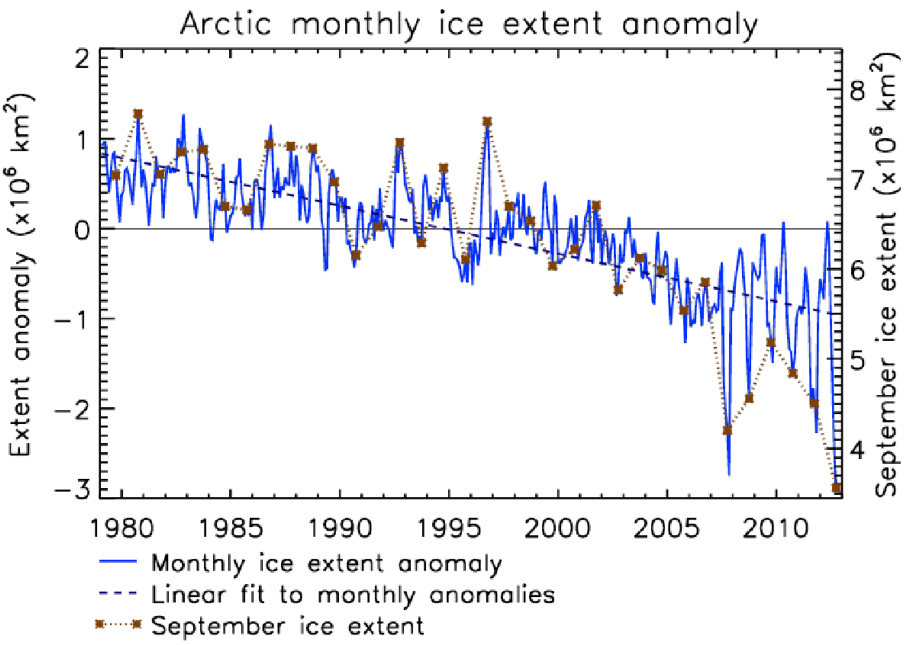


***Figure 12**: Anomalies in monthly Arctic sea ice extent (blue line) and actual September sea ice extents (brown stars) from 1979 to present.*

Preliminary and ongoing research at the Met Office Hadley Centre is providing increasing evidence that the loss and thinning of Arctic sea ice predisposes the winter and spring atmospheric circulation over the North Atlantic and Europe to negative NAO regimes, as was experienced at the start of this spring.

There have been some suggestions that the rapid decline of Arctic sea ice, especially during summer, is responsible for this year's cold spring. It is argued[8] that amplification of global warming over the Arctic is reducing the equator to pole temperature gradient, thereby weakening the strength of the mid-latitude jet streams. In turn this may lead to slower progression of upper-level waves and would cause associated weather patterns in mid-latitudes to be more persistent, potentially leading to an increased probability of extreme weather events that result from prolonged conditions, such as drought, flooding, cold spells, and heat waves.

This hypothesis remains contentious[9], however, and there is little evidence from the comparison between the cold spring of 1962 and this year that the Arctic has been a contributory factor in terms of the hypothesis proposed above. Figure 13 shows the mid-troposphere temperature anomalies for 1962 and 2013; over the Arctic they are almost identical and reflect the negative NAO pattern. It is hard to argue that Arctic amplification had changed the equator to pole temperature in a systematic way to affect the circulation this spring.

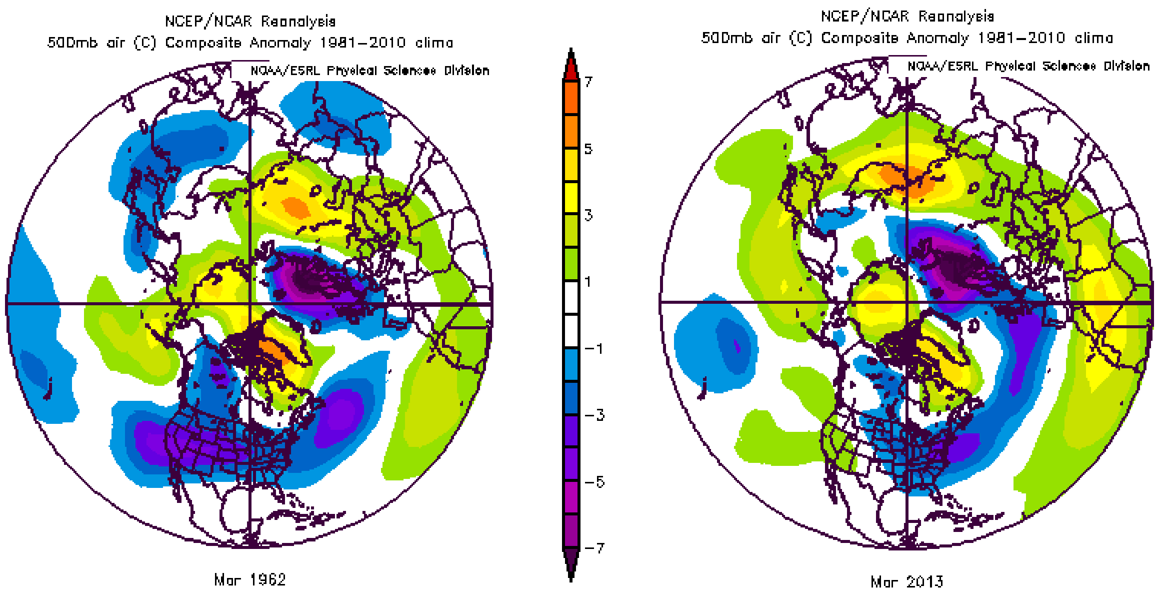


Figure 13: *Temperature anomalies in the middle troposphere (500mb) for March 1962 (left panel) and March 2013 (right panel) against the climatology for 1981-2010.*

[8] Francis, J. A. and S. J. Vavrus, 2012: Evidence Linking Arctic Amplification to Extreme Weather in Mid-Latitudes, Geophys. Res. Lett., Vol. 39, L06801, doi:10.1029/2012GL051000
[9] Screen, J.A. & I. Simmonds, 2013: Exploring links between Arctic amplification and mid-latitude weather, Geophys. Res. Lett., accepted

Concluding Remarks

March 2013 was exceptionally cold in the UK, as well as the North Atlantic and European region more generally, in the context of the last 50 years. Such climate ‘events’ lead to increased interest from the public, media, government and businesses in both the impacts of the weather on our livelihoods and infrastructure, and in the drivers of significant weather.

As is ever the case, the conditions that led to a cold March are linked to a number of different and often inter-related factors. This can also be said of the cold winter of 2010/11, the UK drought in 2010/12 and extreme summer rainfall in 2012. This makes it difficult to definitively attribute a particular ‘event’ to one simple explanation, which can make communicating the science drivers more complicated and nuanced than some audiences may wish. On the other hand, this simply reflects the richness and complexity of our climate system, which drives the weather that we experience on a daily basis.

This report has shown remarkable similarities between the climatological context of the March 2013 cold weather and the coldest UK March on record in 1962. These have been associated with a negative phase of the NAO and a southwards shift in the jet stream and North Atlantic storm track. Other similarities include notably warm sea temperatures in the Labrador Sea and down the coast of Newfoundland, a warm Arctic, and evidence of warmer than average conditions in the equatorial West Pacific, characteristic of La Nina. The influence of an active MJO in February/March 2013 through the Indian Ocean and into the West Pacific is also noted.

A number of potential drivers of the cold weather have been discussed, including

i) weather patterns in the Tropics
ii) the Stratosphere
iii) conditions in the North Atlantic
iv) the state of the Arctic

These are all active areas of research, with new understanding emerging from observations and modelling studies.

Whilst the cold March weather is certainly unusual, it is not unprecedented or outside the expected natural variability of our climate. There is particularly heightened interest in the role of the Arctic on the UK’s weather, given rapid changes in Arctic sea ice, and on the likely changes we may observe given future decline. It is worth re-emphasising, however, that while changes in the Arctic are consistent with predisposing the climate system to cold weather in northern Europe, this is only one possible driver among several potential factors which could account for the cold March weather. What we have still to understand is the degree to which our changing climate may alter the likelihood and intensity of extreme events. With the rapidly changing Arctic, this is now high on the research agenda.

Recent weather (including notably cold winters, droughts and flooding in recent years) has highlighted the need for higher resolution climate models to provide more robust estimates of the future risk of major extreme climate events and to provide more reliable longer range forecasts. The recent increase in computer capacity at the Met Office should contribute to this aim. A priority will be the development of climate scenarios for the next 20-30 years to aid decision-making, as well as addressing important questions around the role of the changing Arctic on UK weather patterns.

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