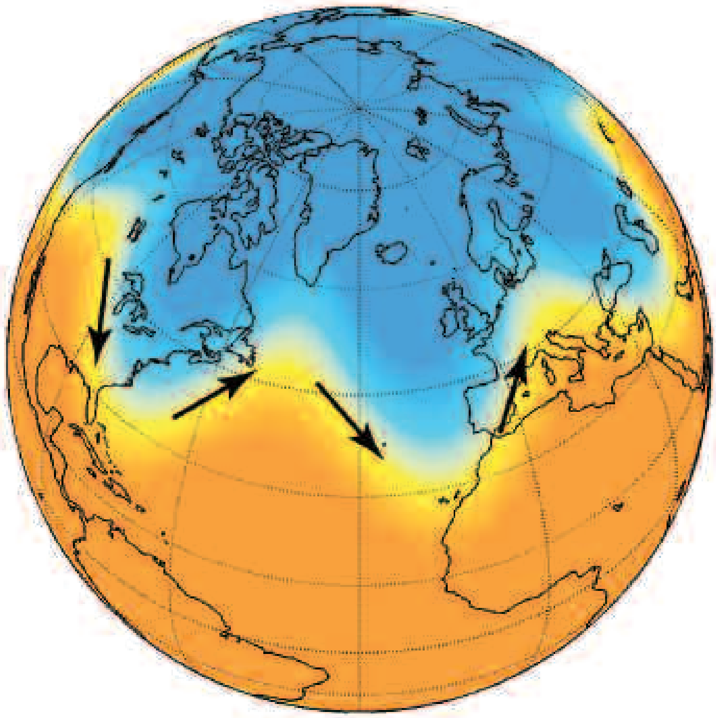
The answer is blowing in the wind

Wet and warm or cold and dry, the North Atlantic Oscillation has a large part to play in UK weather. **Tim Woollings** and colleagues have suggested a new explanation for its existence that could help to explain the recent warm winters.



The jet stream winds (arrows) follow the boundary between cold polar air (blue) and warm tropical air (red). In a Rossby wave the jet meanders north and south.

The average UK winter temperature increased from 3.2°C in the 1960s to 4.5°C in the 1990s. This may seem like a small change, but it means that UK winters have warmed at over twice the global average rate. While human-induced climate change is undoubtedly playing a part in this, about half of the UK warming is linked to a dramatic trend in a pattern of natural climate variability known as the North Atlantic Oscillation, or NAO.

The NAO describes variations in both the strength and orientation of the Atlantic jetstream – a band of intense westerly wind blowing across the Atlantic from North America at about the level that aircraft fly (11 kilometres). Europe's winter climate is largely determined by the jetstream and the associated storm track beneath it. The east coast of North America is a major breeding ground for storms, as cold continental air meets the relatively warm ocean. The jetstream steers these storms towards Europe, forming the North Atlantic storm track.

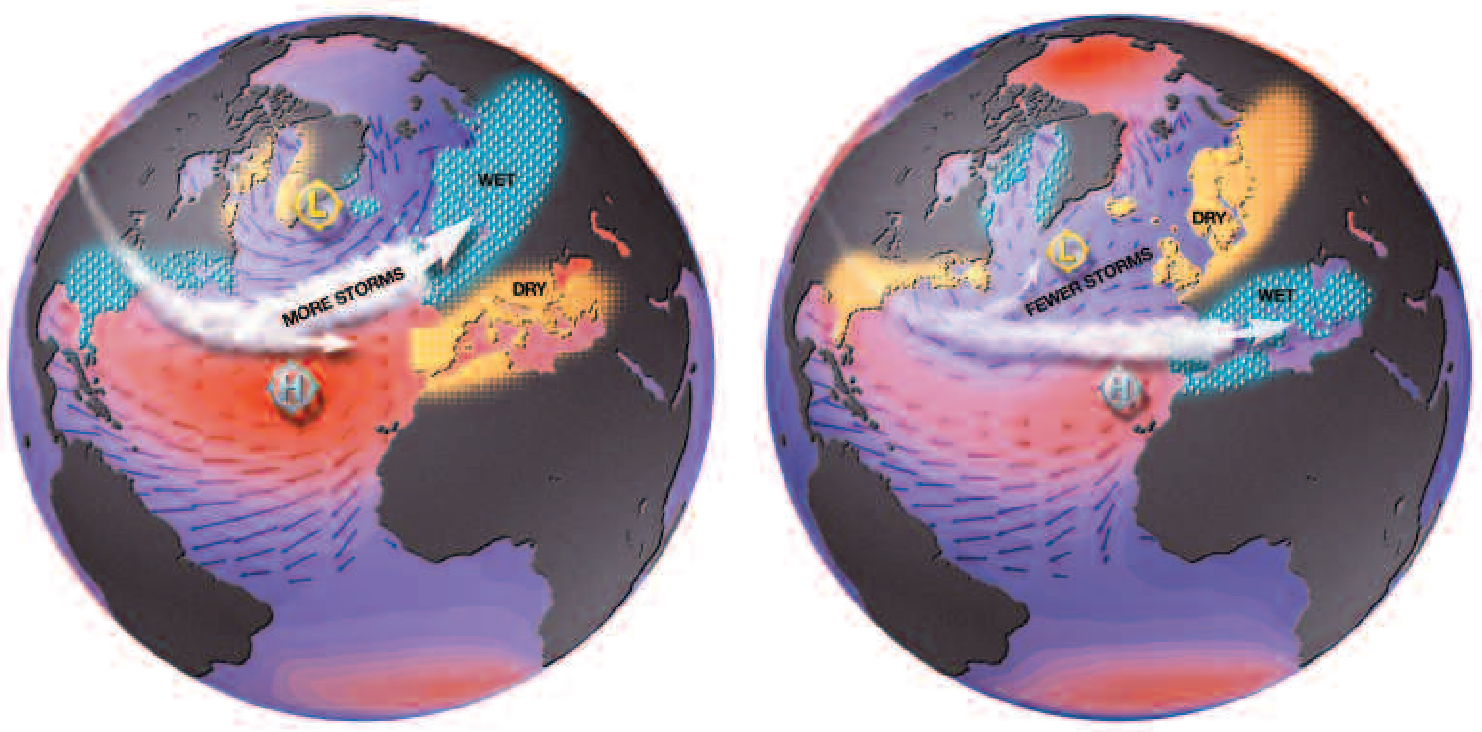
Some winters the jetstream is weak and angled almost directly eastward across the Atlantic towards France and Spain. This makes the storm track weak as well, and storms tend to pass south of the UK towards the Mediterranean. What the UK feels is a weakening of the normal, mild maritime influence, leading to a cold, drier, more continental climate. At other times the jetstream and storm track are stronger than usual and angled to the north towards northern Europe, so the UK is wetter and, in the winter, milder than usual.

These two situations are effectively a weakening or strengthening of the normal climate features, so are referred to as the negative and positive phases of the NAO respectively. The word 'oscillation' gives the impression that we are bouncing back and forth between these two extreme climates. This is somewhat misleading as many winters lie in between and are characterised by neither extreme. The NAO affects other seasons but to a lesser extent.

The strong UK warming is partly linked to an unprecedented trend in the NAO: from lots of very negative (cold) winters in the 1960s to very positive (warm) winters in the 1990s. This has had a profound impact on our climate, but as yet the reasons for this trend are unknown. Is it a purely natural variation or a complex effect of human-induced climate change?

The good news is that we have made some progress recently into understanding why the NAO exists. Several different studies suggest that changes in the NAO happen when large-scale waves break in the upper atmosphere. These waves, called Rossby waves, are similar to waves on the ocean surface, but instead of water moving up and down, they consist of air masses undulating north and south. The jet streams heave and swell with the Rossby waves. These waves are large – each peak or trough is typically a few thousand kilometres across. So what does it mean for a Rossby wave to break? As in the ocean, this happens when the amplitude of the wave gets large. Then the smooth, gentle wave shape becomes distorted and collapses into a very turbulent flow. When this happens over the Atlantic, the turbulent breaking can disturb the steady jetstream, pushing it to the north or the south. This, according to the recent studies, is the mechanism behind the NAO.

Here at the University of Reading, a chance coincidence led us to suggest a new interpretation of this theory. As part of a climate change project, I have been using a very detailed Met Office computer model to simulate weather and climate over the Atlantic. It seemed that the model had difficulty in simulating a particular kind of weather regime, namely a blocking high



Schematics of the positive (left) and negative (right) phases of the North Atlantic Oscillation. Martin Visbec, Leibniz-Institut für Meereswissenschaften, Kiel, Germany.

pressure area located over or near Greenland. Blocking is a very dramatic event, in which a large high pressure centre develops and persists for many days or even weeks, blocking the normal westerly winds and storms. Coincidentally, Paul Berrisford, another scientist at Reading, was studying the Southern Hemisphere and found lots of blocking-like events further south than expected, near Antarctica. This led him to look for Northern Hemisphere blocking further north than usual, and he discovered that these 'Greenland blocking' events also happen much more often than we'd previously thought, so we decided to investigate further.

Why is this relevant to the NAO? Well, the process responsible for blocking also turns out to be Rossby wave-breaking. In a Rossby wave, air from the south is moved north, and vice-versa. The breaking of the wave over the Atlantic often results in a large mass of warm air from the subtropics being pulled north towards the pole and separated from the main subtropical air mass. Because of the curvature of the Earth, air from the south spins slower about the Earth's axis than northern air. When it moves north it conserves its total amount of spin, and so relative to the surface it spins the other way, that is, against the spin of the Earth or anti-cyclonically. The result is a blocking high or anticyclone. When this lies over Europe it really does tend to block the westerly jetstream and the storm track, but when it lies over Greenland the jetstream winds and the storms pass to the south of the anticyclone, so that it's more of a diversion than a block.

This situation, with the jetstream diverted to the south, clearly resembles the negative NAO phase (and in fact Paul had noticed similar jet shifts linked to the Antarctic events). We then looked closer and discovered a very strong correlation between the NAO and how often Greenland blocking occurs. This led us to suggest a new hypothesis: the NAO is a signal of variations in Greenland blocking. Suppose that in one winter there is a lot of Greenland blocking. Then that winter will measure as a negative (cold, dry) NAO winter. In the same way a positive (warm, wet) NAO winter is simply one in which there is little Greenland blocking. This is a subtly different, and simpler, theory than those proposed before, which see the positive NAO as a separate entity, arising from a different process.

If our theory is correct, it could help unlock the secret behind the recent NAO trend. As seen from this viewpoint, the trend represents less Greenland blocking in recent winters. We now need to improve our understanding of why blocking happens, to see how gradual changes in the atmosphere or oceans could be affecting how often Greenland blocking occurs. This work also has potential to help improve long-range weather forecasts, since in many cases a particular Rossby wave pattern is seen over North America over a week before the Greenland blocking begins.

And what, then, does the future hold for the NAO? The effect of global warming will be to subtly change the atmosphere, perhaps by moving the Atlantic jetstream a little to the north, as many climate models now predict. If these changes act to load the dice, so that Greenland blocking happens more or less often, then we might expect further changes in the NAO to come. ❖

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