The winter North Atlantic Oscillation

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1. What is the NAO?

The North Atlantic Oscillation (NAO) is one of a number of preferred modes of behaviour of the coupled atmosphere/ocean system, characterising atmospheric variability at time scales from months to decades. It is especially strong during the Northern Hemisphere winter, both in its atmospheric circulation signature, and also in terms of its influence on surface climate (see section 2). It is most commonly represented (Figure 1a) by a shift in atmospheric mass from the region of the Azores High to the Iceland Low ("low" NAO conditions), or vice versa ("high" NAO conditions). [As such, it can be seen as a slightly regionalised version of the Arctic Oscillation (Thompson and Wallace, 1998), with which it is correlated.] In the extra-tropics it is the transient motions of the atmosphere that are the key to explaining the seasonal pressure fields, and so the NAO can also be represented by a meridional shift in the tracks of synoptic disturbances (Figure 1b) or in the storm tracks (Serreze et al., 1997).

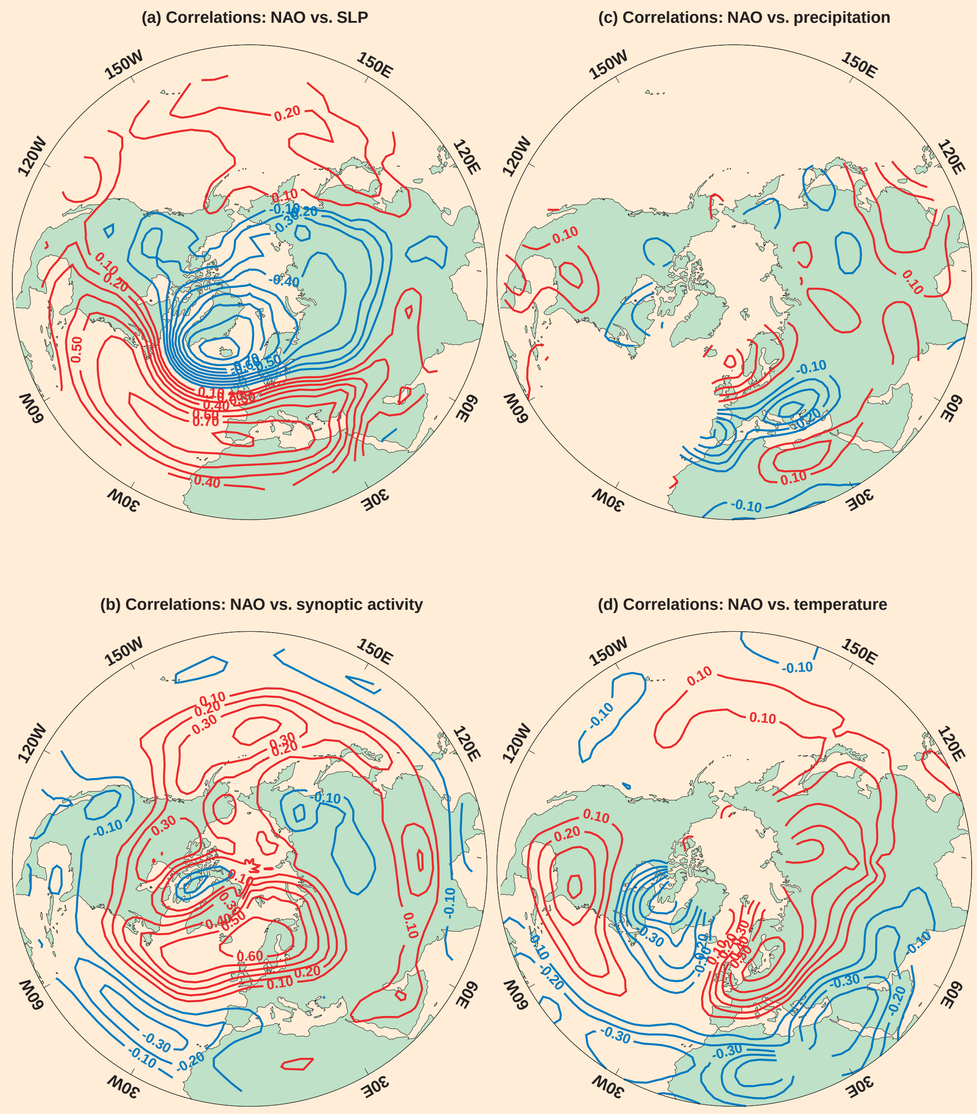

Figure 1: Correlations between the winter NAO index and (a) winter sea level pressure, (b) winter synoptic-scale variability, (c) winter terrestrial precipitation, and (d) winter temperature. Positive correlations are red, negative are blue.

2. Why is the NAO interesting?

The NAO exerts a strong control on surface climate, particularly in the Atlantic and European sectors, but also further afield. In addition to the changes in the mean wind speed/direction and storm climatology implied by Figure 1a and 1b, the NAO is also associated with large changes in European winter precipitation (Figure 1c) and four centres of temperature response (Figure 1d). The resulting impact of these variations is large and widespread, including influences on fisheries, wave climate, agriculture, hydroelectric potential, snow skiing season, and water resources. The NAO also drives large changes in air-sea fluxes (Cayan, 1992), and therefore impacts upon the wind-driven and thermohaline circulations of the ocean (Dickson et al., 1996).

The ability to forecast the NAO a season or more in advance would be greatly beneficial (see the work of Rodwell et al., 1999, for an indication of its potential predictability). The longer-term behaviour of the NAO is of even more interest, especially because the recent multi-decadal trend in the NAO index (from the 1960s to the early 1990s, see Figure 2) coincides with winter warming of the Northern Hemisphere land masses (Hurrell, 1996). This raises some important questions. How much of the recent winter warming is due to a natural climate variation? Is a global warming signal manifesting itself by amplifying a natural mode of the climate system? How unusual is the recent dominance and strength of the positive phase of the oscillation?

Some of these questions have been answered by making use of numerical models of the climate system. For example, Osborn et al. (1999) show that the trend in the NAO from the 1960s to the early 1990s is outside the range of earlier variability in the instrumental record, and is also outside the range of variability simulated during a 1400-year integration of the UK Hadley Centre's coupled climate model. This implies that either the recent changes are externally forced (e.g., by anthropogenic forcing), or that the model is deficient in its simulation of multi-decadal climate variability. This is where paleoclimatic reconstructions might provide some insight.

Figure 2: Winter NAO index from 1822/3, **updated to 1998/9**, using instrumental pressure observations over Gibraltar and Iceland (Jones et al., 1997). Values are averages over each December to March, expressed as standardised anomalies from the 1951-80 mean.

3. The role of paleoclimate research

Paleoclimate research will help us to answer some of the questions raised in section 2, and to evaluate the climate models used for simulating multi-decadal (and longer) climate variability. Recovery, digitisation and homogenisation of early instrumental measurements enables an extension of the NAO record back to the 1820s (Jones et al., 1997, shown in Figure 2), with the potential for a record back to the 18th century (Luterbacher et al., 1999).

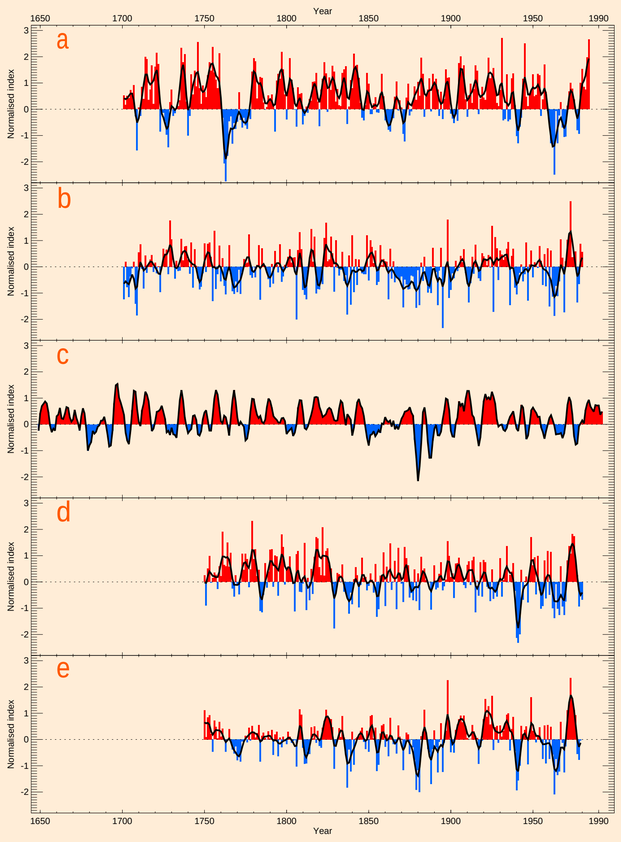

Figure 3: Reconstructions of the NAO index using paleodata (the target index and/or season are different in each case), by (a) Stockton and Glueck (1999), (b) Cook et al. (1998), (c) Appenzeller et al. (1998), (d) Mann (1999), and (e) Cullen et al. (1999).

A range of preliminary reconstructions using non-instrumental data have been produced recently (Figure 3). Stockton and Glueck (1999) use a combination of Moroccan tree-rings (sensitive to winter precipitation in a region where the NAO is quite strongly related to winter rainfall - see Figure 1c), and other proxies, to produce a reconstruction of the winter NAO back to 1700 AD (Figure 3a). Cook et al. (1998) use tree-ring width chronologies from the eastern US and north-western Europe to produce a reconstruction back to 1700 AD (Figure 3b). Appenzeller et al. (1998) use ice core accumulation from western Greenland, capturing the annual-mean NAO at multi-annual and longer time scales (Figure 3c). Mann (1999) uses a combination of proxy types to reconstruct annual temperature patterns, which are then related to a mode of temperature variability that varies in a similar way to the winter NAO (Figure 3d). Cullen et al. (1999) combine four reconstructions in a way that optimally represents the NAO during the winter (Figure 3e).

Correlations between each reconstruction and its target index (which is different in each case) vary from 0.56 to 0.87 (for the calibration period). The skill may deteriorate during the early parts of the reconstructions if the quality and/or availability of the paleo records is reduced. We note here that the correlations between the various reconstructions are lower during the pre-calibration (i.e., pre-instrumental) period. All of these reconstructions should, therefore, be viewed in some sense as experimental. It is clear that this area will be one of increasing focus and collaborative research. It has been highlighted as one of the key questions to be addressed in Time Stream 1 PEP III research (www.geog.ucl.ac.uk/ecrc/p3planov.htm).

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