North Atlantic Oscillation

• General features

• 2009-2010 case study

• Links to other circulation indices

• Internal variability vs. external forcing (predictability)
Figure 1

Vector Winds

Hurrell et al., 2003
Vector Winds

Hurrell et al., 2003

Figure 2
Strong Icelandic Low/Azores High Pressure Gradient

Weak Pressure Gradient
Hurrell et al., 2003, Figure 6
Figure 7. The difference in boreal winter (December-February) mean sea level pressure and 1000 hPa vector winds between positive (hi) and negative (lo) index phases of the NAO. The composites are constructed from winter data (the NCEP/NCAR reanalyses over 1958-2001) when the magnitude of the NAO index (defined as the principal component time series of the leading empirical orthogonal function of Atlantic-sector sea level pressure, as in Figures 6 and 10) exceeds one standard deviation. Nine winters are included in each composite. The contour increment for sea level pressure is 2 hPa, negative val-
1958-1998 storm track shifts

Hurrell et al., 2003

Figure 15
Figure 16. Difference in mean winter (December-March) evaporation (E) minus precipitation (P) between years when the NAO index exceeds one standard deviation. The NAO index is defined as in the middle panel of Figure 10, and nine winters enter into both the high index and the low index composites. The E-P field is obtained as a residual of the atmospheric moisture budget [see Hurrell, 1995a]. The calculation was based on the NCEP/NCAR reanalyses over 1958-2001, and truncated to 21 wavenumbers. The contour increment is 0.3 mm day$^{-1}$, differences greater than 0.3 mm day$^{-1}$ (E exceeds P) are indicated by dark shading, and differences less than -0.3 mm day$^{-1}$ (P exceeds E) are indicated by light shading.
The maps at left show the relationship between a strong positive NAO and precipitation and temperature. Positive correlation means that an area is wetter or warmer than normal, negative correlation means an area is drier or colder than normal, and no correlation means the area is unaffected by the NAO. (Images courtesy Lamont-Doherty Earth Observatory)
Northern Hemisphere Annular Mode

North Atlantic Oscillation

Hurrell et al., 2003

Figure 8
2009-2010 Case Study

http://www.esrl.noaa.gov/psd/data/climateindices/

Jung et al, 2011.
North Atlantic Oscillation (NAO): from NOAA/CPC and Pacific North American Index (PNA) from NOAA/CPC
Dec to Feb averaged: 1948 to 2013

http://www.esrl.noaa.gov/psd/data/climateindices/
Wang et al 2010

http://www.esrl.noaa.gov/psd/data/composites/day/
Dec 2009 - Feb 2010 Divisional Ranks
National Climatic Data Center/NESDIS/NOAA

Temperature

Precipitation

References


<table>
<thead>
<tr>
<th>acronym</th>
<th>large-scale climate pattern</th>
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<td>AAO</td>
<td>Antarctic Oscillation</td>
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<td>AO</td>
<td>Arctic Oscillation</td>
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<tr>
<td>EA</td>
<td>East Atlantic pattern</td>
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<td>EAWR</td>
<td>East Atlantic/Western Russia pattern</td>
</tr>
<tr>
<td>ENSO</td>
<td>El Niño Southern Oscillation</td>
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<tr>
<td>EP</td>
<td>East Pacific pattern</td>
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<tr>
<td>NAM</td>
<td>Northern Annular mode (identical to AO)</td>
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<tr>
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<td>PSA</td>
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<td>SAM</td>
<td>Southern Annular mode (as AAO, but opposite sign)</td>
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<td>Southern Oscillation</td>
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<td>Tropical/Northern Hemisphere pattern</td>
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<tr>
<td>WP</td>
<td>West Pacific pattern</td>
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Much of the structure of N.Hemisphere winter circulation, temperature, and precipitation can be represented by two planetary-scale patterns.
“True hemisphere ‘teleconnection patterns’ are more limited in number than the acronyms used to label them.”

NAO doesn’t vary at any preferred time scale

NAO has some persistence

*Figure 10.* Normalized indices of the mean winter (December-March) NAO constructed from sea level pressure data. In the top panel, the index is based on the difference of normalized sea level pressure between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland from 1864 through 2002. The average winter sea level pressure data at each station were normalized by division of each seasonal pressure by the long-term mean (1864-1983) standard deviation. In the middle panel, the index is the principal component time series of the leading empirical orthogonal function (EOF) of Atlantic-sector sea level pressure (bottom panel of Figure 8). In the lower panel, the index is the principal component time series of the leading EOF of Northern Hemisphere sea level pressure (top panel of Figure 8). The heavy solid lines represent the indices smoothed to remove fluctuations with periods less than 4 years. The indicated year corresponds to the January of the winter season (e.g., 1990 is the winter of 1989/1990). See http://www.cgd.ucar.edu/~jhurrell/nao.html
Fig 2. NAO Spectrum (1866-2000).
Table 2. Dominant periods and explained variance.

<table>
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<th>Index</th>
<th>Period (years)</th>
<th>Explained variance (%)</th>
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<td>NAO</td>
<td>8.2</td>
<td>17.9</td>
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<td></td>
<td>2.9</td>
<td>16.1</td>
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<td></td>
<td>5.0</td>
<td>12.1</td>
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<td></td>
<td>13.0</td>
<td>10.8</td>
</tr>
<tr>
<td>SOI</td>
<td>6.4</td>
<td>20.8</td>
</tr>
<tr>
<td></td>
<td>3.5</td>
<td>17.4</td>
</tr>
<tr>
<td></td>
<td>4.7</td>
<td>13.0</td>
</tr>
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</table>

- No cycles significant at 95% confidence level
- No coincidence between SOI and NAO periodicity
Figure 11. The time history of occurrence of the NAO regimes (panels a and b of Figure 9) over 1900-2000. The vertical bars give the number of months in each winter (December-March) season that the given regime is present. The indicated year corresponds to the January of the winter season (e.g., 1990 is the winter of 1989/1990).
Since the mechanisms driving NAO variability include internal atmospheric variability....

Can models simulate the NAO?
NCAR CCM

NAO    DJFM

45.01% total variance explained

Hurrell et al., 2003  Figure 19
external forcing, or all models fail to simulate interdecadal variability
External forcing:

oceans extratropical SST anomalies force NAO SLP

What portion of the world’s oceans is driving N. Atlantic atmosphere?

Indo-Pacific warming related to positive NAO

°C per standardized change in NAO
500-mb height anomalies

observed

Simulated

w/ **global** SSTs prescribed

w/ **tropical** SSTs prescribed

Predictability??

NAO: stochastic interactions b/t storms and mean Rossby waves

Possible external nudges:
• Oceans
• Stratospheric winds
Reasons to predict...

Figure 18. a) Monthly hydroelectric energy production in TWh per month for Norway (thin line). The heavy line denotes the annual average. b) Difference between hydroelectric energy production and electric energy consumption in Norway. Positive values represent times when Norway is able to export energy to Sweden and negative values indicate a shortage in hydropower production. The heavy gray bars in the background show the winter mean NAO index for this and all of the following graphs. c) Monthly time series of the first empirical orthogonal function of rainfall obtained from the Norwegian East coast stations and the Norwegian North-west coast stations. d) Reservoir level. e) Spot Market Price.
Trends?

Winter (DJFM) NAO index updated to winter 2012/2013

NAO index

Year

1850 1900 1950 2000
Future Projections

Figure 10.9. Multi-model mean changes in surface air temperature (°C, left), precipitation (mm day⁻¹, middle) and sea level pressure (hPa, right) for boreal winter (DJF, top) and summer (JJA, bottom). Changes are given for the SRES A1B scenario, for the period 2080 to 2099 relative to 1980 to 1999. Stippling denotes areas where the magnitude of the multi-model ensemble mean exceeds the inter-model standard deviation. Results for individual models can be seen in the Supplementary Material for this chapter.
Future Projections

• NAO barely sensitive in most models.

• Mostly a northward shift of the centres of action rather than intensification of the pressure gradient.

• Changes reliant on accurate prediction of SST variations

AR5: “Model agreement in projections indicate that future boreal wintertime North Atlantic Oscillation is very likely to exhibit large natural variations and trends of similar magnitude to those observed in the past and is likely to become slightly more positive on average, with some, but not well documented, implications for winter conditions in the Arctic, North America and Eurasia.”
External forcing:

- cooling stratosphere
- ozone loss
- increasing GHGs
- stronger lower stratospheric winds

unclear how stratospheric circulation affects tropospheric circulation
Predictability?

Some model success
- forced with SSTs