Potential Predictability of the NAO: From Days to Decades

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- Predictability of NAO or AO?
- Short-range predictability
- Long-range predictability

Role of the Stratosphere in the Troposphere workshop,
Whistler Resort, Canada, 29 April – 2 May 2003.
North Atlantic Oscillation or Arctic Oscillation?

Correlation of SLP with NAO

Correlation of SLP with AO

Correlation maps of winter (DJF) NCAR/NCEP reanalyses 1958-98
Produced using the Climate Explorer at http://climexp.knmi.nl

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And what about these two phenomena?

Correlation of $r=0.56$ (n=150x110=16500 pixels)
Highly significant ($p<0.001$)
Which is more dynamical??

Example kindly prepared by Matt Sapiano
Daily AO index from Sep 1999 - 2002
Persistence in the daily AO index
Heteroskedasticity

Almost 10 times the variance in winter than in summer
Autocorrelation of daily AO index

Strange weak correlation winter to following August

Maximum persistence in Dec-March
Autocorrelation of daily AO series

- Rapid drop-off
- The "shoulder"
- The "moghul"
- The "tail"
AR1 time series modelling of daily AO

\[ x(t+1) = r x(t) + \varepsilon(t) \]
\[ \hat{r} = 0.945 \pm 0.0026 \]
\[ T = -\frac{1}{\log(\hat{r})} = 17.8 \text{days} \]

→ AR(1) provides a rough fit to the short-range features
Power spectrum: Daily AO index

AR1 $r_1 = 0.945$

$P(f) \sim f^{-0.22}$

Wunsch (2000)

Stephenson et al. (2000)

bandwidth= 0.00011037 , 95% C.I. is (-2.9209 , 4.42728) dB
Quantifying the size of a Stratosphere-Troposphere connection in the Arctic Oscillation

\[ AO(t + \tau) = \beta \ AO(t) + \beta_1 NAM(t) + \varepsilon(t) \]

\[ \Rightarrow r_\tau = r(AO(t + \tau), AO(t)) = \beta_0 + \beta_1 r(AO(t), NAM(t)) \]
Example: NAM 150mb and AO to predict AO 20 days later

\[ \rho( y_Z^t, x_Z^t ) = 0.72 \]

\[ \beta_1 = 0.31 \]

\[ \beta_0 = 0.08 \]

\[ 20\text{-day AO autocorrelation} = 0.30 = 0.08 + 0.72 \times 0.31 \]
Effect of NAM at 70mb on AO

Direct stratospheric effect important for AO 10-60day ahead
Direct and indirect effects for all NAM
Out of sample gain in MSE forecast skill

→ 5% gain in MSE skill by using stratosphere as predictor of AO in 10-40 day ahead forecast range
Long-range correlation of daily AO

b) Autocorrelations for Dec-Mar AO daily values

→ long-range dependence in daily AO values
Potential predictability

Given knowledge of the daily AO index $X(t)$ at time $t$, we would like to predict the following $k$-day mean:

$$\overline{X}_k(t) = \frac{1}{n} \sum_{k=1}^{n} X(t + k)$$

Consider AO to be the sum of a potentially predictable signal component and a “weather noise” component:

$$X(t) = T(t) + W(t)$$

$$\Rightarrow \text{Var}(\overline{X}_k) = \text{Var}(\overline{T}_k) + \text{Var}(\overline{W}_k)$$

**Potential predictability** is then defined as the ratio

$$F = \frac{\text{Var}(\overline{X}_k)}{\text{Var}(\overline{W}_k)}$$

$F > 1$ indicates more than short-range weather noise and hence some potentially predictable component.
Aggregated variance of AO

Daily AO series
Falls off more slowly than $1/n$.
Power law scaling from 16-4096+ days with exponent $-0.64$

AR1 simulation
N.B. falls off as $1/n$ for large $n$. 

$$Var\bar{X}_k = \sigma^2 \left( 1 + \frac{2}{k} \sum_{j=1}^{k-1} (k - j)r_j \right)$$

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Potential predictability

\[ F = \frac{\text{Var}(\overline{X}_k)}{\text{Var}(\overline{W}_k)} \]

\( F > 1 \) more variance than expected from weather noise
Accumulated daily AO from 1958-2002

\[
\bar{X}_k(t) = \frac{1}{k} (S(t+k) - S(t))
\]

where \( S(t) = \sum_{t'=0}^{t} X(t') \)

→ Accumulated AO may be a good measure of climate state
Accumulated AO and NAM indices

→ Similar behaviour in troposphere and stratosphere??
Summary

- AO has both short and long-range dependence that can lead to predictability ("windows of opportunity")
- Short-range AO weather noise is not just AR1
- Stratosphere important for 10-60 day range
- Potential predictability on longer time-scales (more variability than just weather noise)
- Potential predictability increases with increasing time scale (long-range dependence)
- Strange co-varying long-term behaviour in troposphere and stratosphere.