Predictability and prediction of the North Atlantic Oscillation

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Acknowledgements:
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Outlines

• Brief introduction on NAO and its impact
• **NAO prediction on intraseasonal time scale**
  MJO contribution;
  intraseasonal hindcast
• **NAO seasonal prediction**
  possible signal sources;
  potential predictability;
  skill in four Canadian AGCMs
  hindcast with a simple GCM
The NAO

- The NAO is one of the most important modes of atmospheric variability in the northern hemisphere.
- The NAO has a larger amplitude in winter than in summer.
- The NAO accounts for 31% of the variance in winter surface air temperature north of 20°N (Hurrell, 1995).
The NAO index

- a measure of phase and amplitude

- Station-based index: difference between normalized mean winter SLP anomalies at Lisbon, Portugal and Stykkisholmur, Iceland (e.g., Hurrell, 1996)

- Principal component (PC) based
s = P2* – P1* 

Station Based Indices

(Hurrell, 1996)
Impact of an extreme positive NAO

- A stronger than normal subtropical high pressure centre and a deeper than usual Icelandic low
- Stronger westerly winds and storm activity across the Atlantic Ocean
- Warmer and wetter winter in Europe, colder and drier conditions in northeastern Canada and Greenland
- Influence on global warming
How is the NAO variability generated?

- Causes within the atmosphere: interactions among different scales and frequencies in the atmosphere

- Causes external to the atmosphere:
  - Sea surface temperature (SST) anomaly in the North Atlantic
  - Changes in ice and snow cover
  - SST anomaly in the tropics
NAO forecasts

- Intraseasonal time scale
  impact of the MJO
The Madden-Julian Oscillation (MJO)

- Discovered by Madden and Julian (1971). Spectrum analysis of 10 year record of SLP at Canton, and upper level zonal wind at Singapore. Peak at 40-50 days.
- Dominant tropical wave on intraseasonal time scale
- 30-60 day period, wavenumber 1~3
- Propagates eastward along the equator (~5 m/s in eastern Hemisphere, and ~10 m/s in western Hemisphere)
- Organizes convection and precipitation
Composites of tropical Precipitation rate for 8 MJO phases, according to Wheeler and Hendon index.

Xie and Arkin pentad data, 1979-2003
Lagged composites of NAO index for each MJO phase

Lin et al. JCLIM, 2009
NAO

Definition of the NAO: 2\textsuperscript{nd} REOF of monthly Z500

NAO index: projection of pentad Z500 anomaly onto this pattern

Period: 1979-2003

Extended winter, November to April (36 pentads each winter)
### Lagged probability of the NAO index

**Positive:** upper tercile; **Negative:** low tercile

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Lin et al. (2009)
Tropical influence

Lin et al. (2009)
Correlation when PC2 leads PC1 by 2 pentads: 0.66

Similar to phases 2 + 3
Normalized Z500 regression to PC2
ISO hindscast with GEM

- GEM clim of Canadian Meteorological Centre (CMC)--
  GEMCLIM 3.2.2, 50 vertical levels and 2° of horizontal resolution
- 1985-2008
- 3 times a month (1st, 11th and 21st)
- 10-member ensemble (balanced perturbation to NCEP reanalysis)
- NCEP SST, SMIP and CMC Sea ice, Snow cover: Dewey-Heim (Steve Lambert) and CMC
- 45-day integrations
NAO forecast skill
extended winter – Nov – March
tropical influence
NAO forecast skill

- Blue line: phase8145, 119 cases
- Red line: phase2367, 135 cases

Pentads:
- 0
- 0.1
- 0.2
- 0.3
- 0.4
- 0.5
- 0.6
- 0.7
- 0.8
- 0.9
- 1
Correlation skill: averaged for pentads 3 and 4
Correlation skill: averaged for pentads 3 and 4
NAO seasonal forecasts

Possible signal sources:

• Sea surface temperature (SST) anomaly in the North Atlantic (e.g., Rodwell et al. 1999)
• Changes in ice and snow cover (e.g., Cohen and Entekhabi 1999)
• SST anomaly in the tropics (e.g., Jia et al. 2008)
Potential predictability

- GEM-CLIM
- Two 20-year integrations
  1) AMIP-type: observed SST
  2) climatological SST (only annual cycle)
- Compare variances of these two runs
Elisabeth Viktor, personal communication
Historical forecast (HFP2)

• 4 global models
  GEM: 2°x2°, 50 levels
  AGCM2: 625 km (T32), 10 levels
  AGCM3: 315 km (T63), 32 levels
  SEF: 210 km (T95), 27 levels
• Once a month (beginning of each month)
• 4-month integrations
• 10 members each model
• Persistent SST anomaly
• Sea ice and snow cover anomalies relaxed to climatology
• 1969-2003
NAO seasonal forecast skill

- Lead=0: skill in late winter to spring
- Four models have similar performance
- Lead=1 month: skill drops significantly

Possible explanation:
- skill comes from initial condition
- models do not have a correct response pattern in the NAO
Identify dominant forced patterns

For the DJFM run:

SVD analysis between November tropical Pacific SST and DJF or JFM ensemble mean Z500

The expansion coefficient of SVD2 (Z500) is significantly correlated with the observed NAO index
Leading pairs of SVD in observations

November SST vs JFM z500

*obs-djfm-mois234 SVD1*

*obs-djfm-mois234 SVD2*
Leading pairs of SVD in GEM ensemble mean

November SST vs JFM z500
Leading pairs of SVD in GCM3 ensemble mean

November SST vs JFM z500
NAO skill of ensemble forecast

Temporal correlation with DJF observed NAO index

<table>
<thead>
<tr>
<th></th>
<th>Forecast NAO index</th>
<th>Forced SVD2</th>
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<tbody>
<tr>
<td>GCM2</td>
<td>-0.13</td>
<td>0.30</td>
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<tr>
<td>GCM3</td>
<td>0.26</td>
<td>0.57</td>
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<tr>
<td>SEF</td>
<td>0.33</td>
<td>0.47</td>
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<tr>
<td>GEM</td>
<td>0.25</td>
<td>0.39</td>
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Lead = 0
NAO skill of ensemble forecast

Temporal correlation with JFM observed NAO index

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<td>GCM3</td>
<td>0.27</td>
<td>0.43</td>
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<td>SEF</td>
<td>0.12</td>
<td>0.42</td>
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<tr>
<td>GEM</td>
<td>0.20</td>
<td>0.31</td>
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Lead = 1 month
NAO skill of ensemble forecast

- Model has a biased NAO pattern
- The forced SVD2 pattern has a time evolution that matches well the observed NAO index → can be used as a skillful forecast of the NAO index
The NAO hindcast with a simple GCM

To test if a numerical model with intermediate complexity has skill in NAO seasonal forecasting
Model and experiment

- Primitive equation AGCM (Hall 2000)
- T31, 10 levels
- Time-independent forcing – similar configuration of model forcing as in the Marshall-Molteni model, but not Q-G.
- No moisture equation, no interactive convection
The model forcing

\[ \frac{d\Phi}{dt} = N(\Phi) + F \]

Time average and get

\[ 0 = \overline{N(\Phi)} + \overline{F} \]

Use \( \overline{F} \) in model

\[ \frac{d\Psi}{dt} = N(\Psi) + \overline{F} \]
The Model Forcing

- Forcing calculated from NCEP/NCAR reanalyses for each November and DJF of 1948-1998.

- Includes synthesis of all physical forcings: SST, sea-ice, land-surface conditions, etc.
The Experimental Protocol


• 24-member ensembles
  – Initial conditions
    ▪ Dec. 1. Observations plus small-amplitude perturbations (scaled anomalies from random days in the season)

• Forcing
  – Compute forcing anomaly for November.
  – Add it to the forcing climatology of DJF.
  – Constant through the season.
Correlation between observed and model ensemble mean indices

<table>
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<tr>
<th>DJF</th>
<th>NAO</th>
<th>PNA</th>
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<tbody>
<tr>
<td>51 DJFs</td>
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<tr>
<td>16 EPSO</td>
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<td>35 NEPSO</td>
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Lead = 0

Numbers shown are those passing 0.1 significance level, and those in red passing 0.05 significance level.
Comparison with GCM2 for DJF  

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<td>26 DJFs</td>
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Lead = 0
Correlation between observed and model ensemble mean indices

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Lead = 1 month
## Comparison with GCM2 for JF

**Lead = 1 month**

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SGCM has better NAO skill than GCM2, possibly because of more realistic climatology, and forcing anomaly (more factors than GCM2)
Summary

- NAO intraseasonal forecast skill influenced by the MJO
- Some skillful NAO seasonal forecast possible in late winter and spring
- Seasonal forecast of NAO has biased spatial pattern, some statistical post-processing procedure can improve the skill
- A simple GCM has a NAO seasonal forecast skill comparable to an operational GEM forecast: importance of model climatology and representation of forcing.
References:

Thank you!
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