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Predictability and prediction of the North Atlantic Oscillation

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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

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The NAO

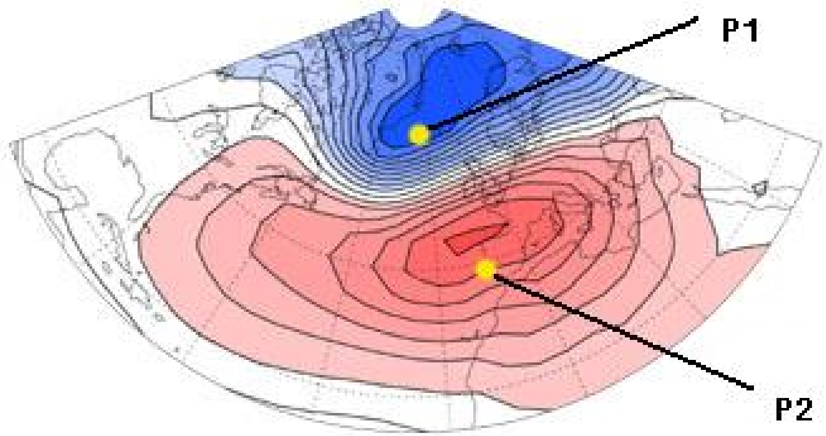
- The NAO is one of the most important modes of atmospheric variability in the northern hemisphere
- The NAO has a larger amplitude in winter than in summer
- The NAO accounts for 31% of the variance in winter surface air temperature north of 20°N (Hurrell, 1995)

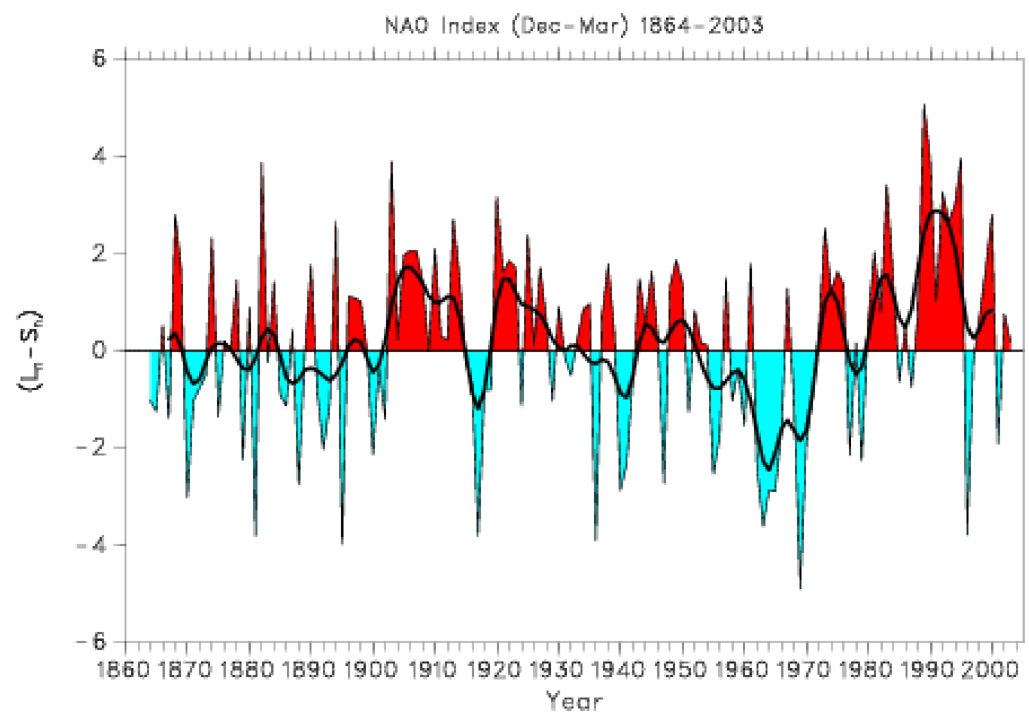
The NAO index

– 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

Station Based Indices





(Hurrell, 1996)

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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

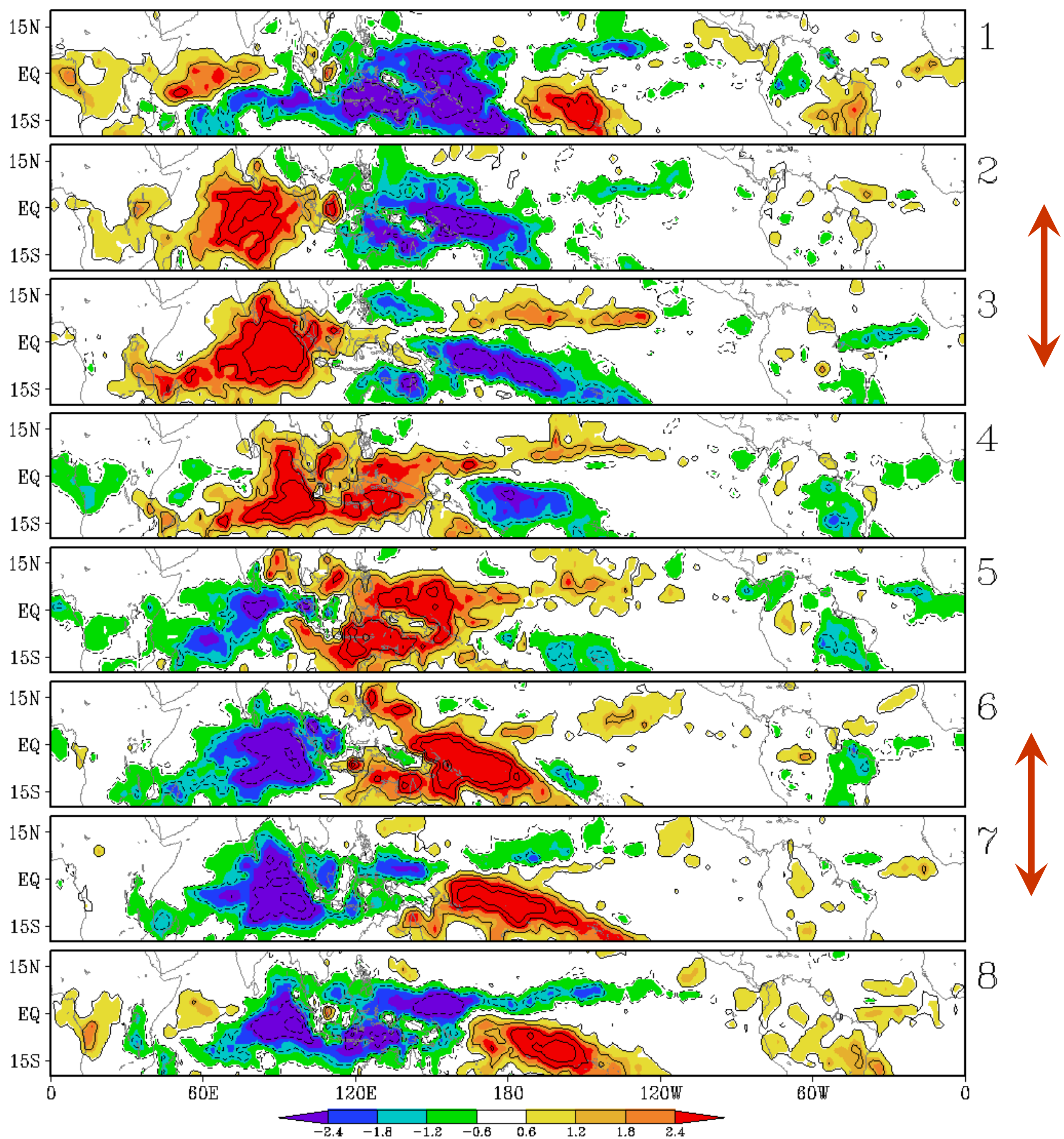
  impact of the MJO

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.



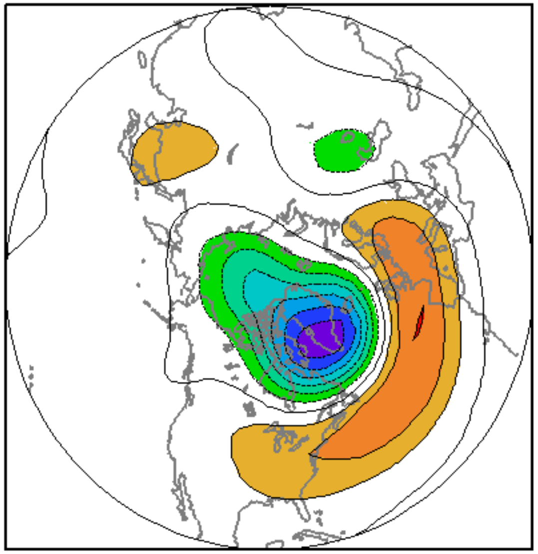
Xie and Arkin pentad data, 1979-2003

Lagged composites of NAO index for each MJO phase

Lin et al. JCLIM, 2009

NAO

Definition of the NAO: 2nd 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)

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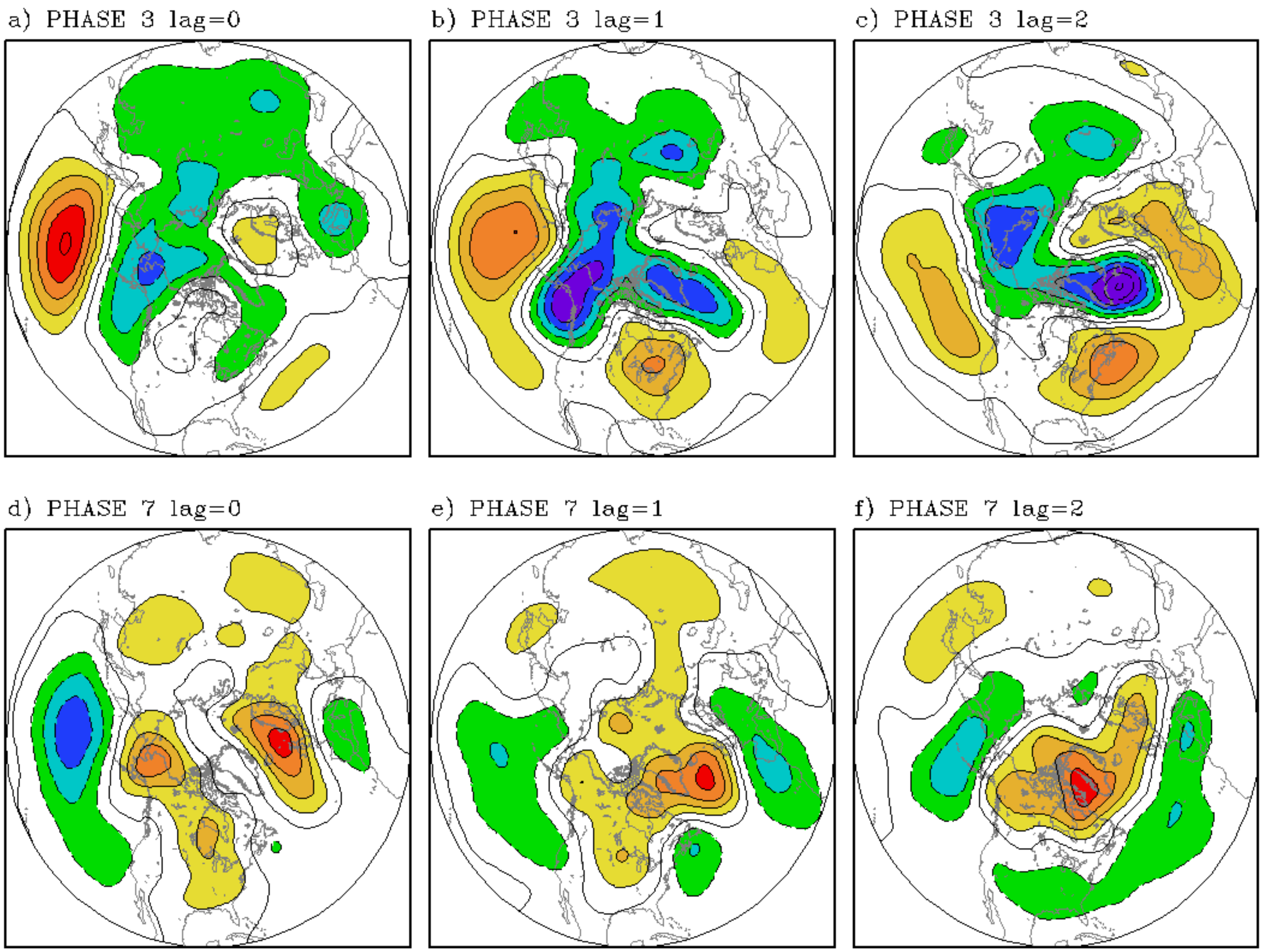
Lagged probability of the NAO index

Positive: upper tercile; Negative: low tercile

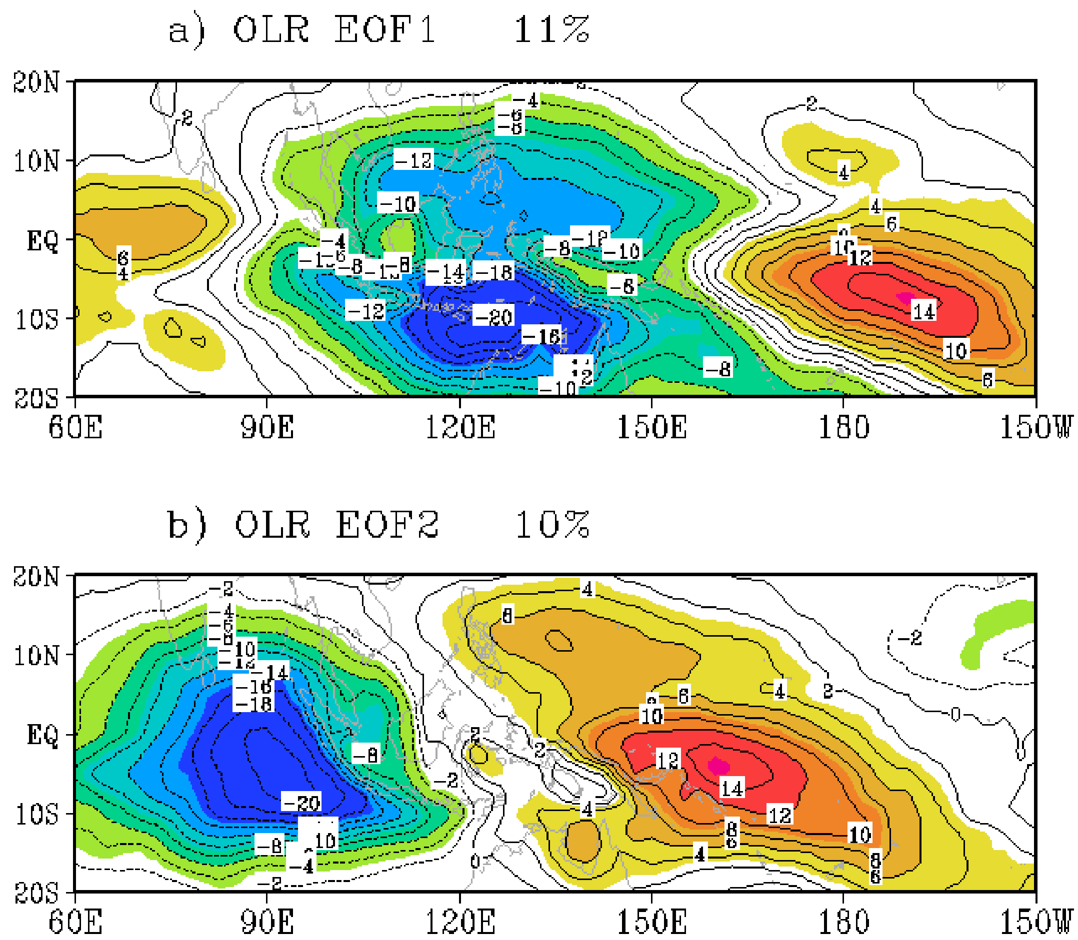
Phase	1	2	3	4	5	6	7	8
Lag −5		−35%	−40%			+49%	+49%	
Lag −4						+52%	+46%	
Lag −3		−40%					+46%	
Lag −2						+50%		
Lag −1								
Lag 0				+45%				−42%
Lag +1			+47%	+45%				−46%
Lag +2		+47%	+50%	+42%		−41%	−41%	−42%
Lag +3		+48%				−41%	−48%	
Lag +4						−39%	−48%	
Lag +5				−41%				

Lin et al. (2009)

Tropical influence



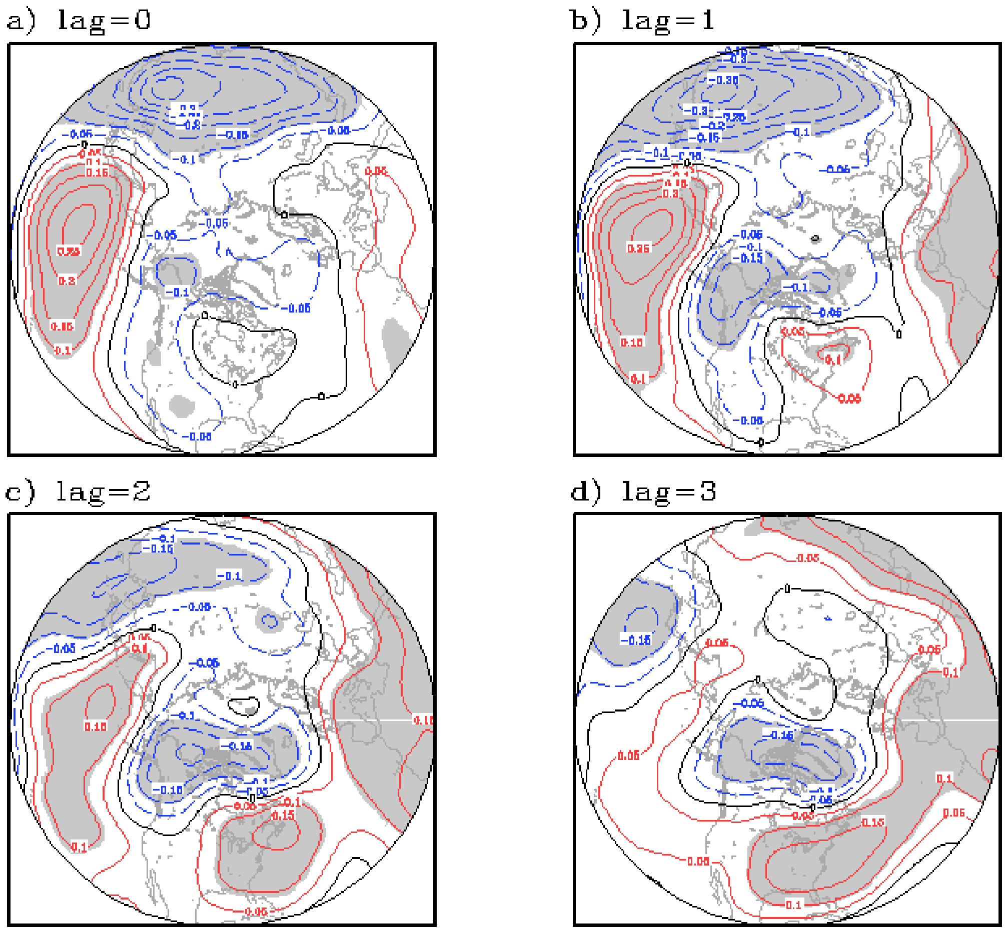
Lin et al. (2009)



Similar to

phases 2 + 3

Correlation when PC2 leads PC1 by 2 pentads: 0.66



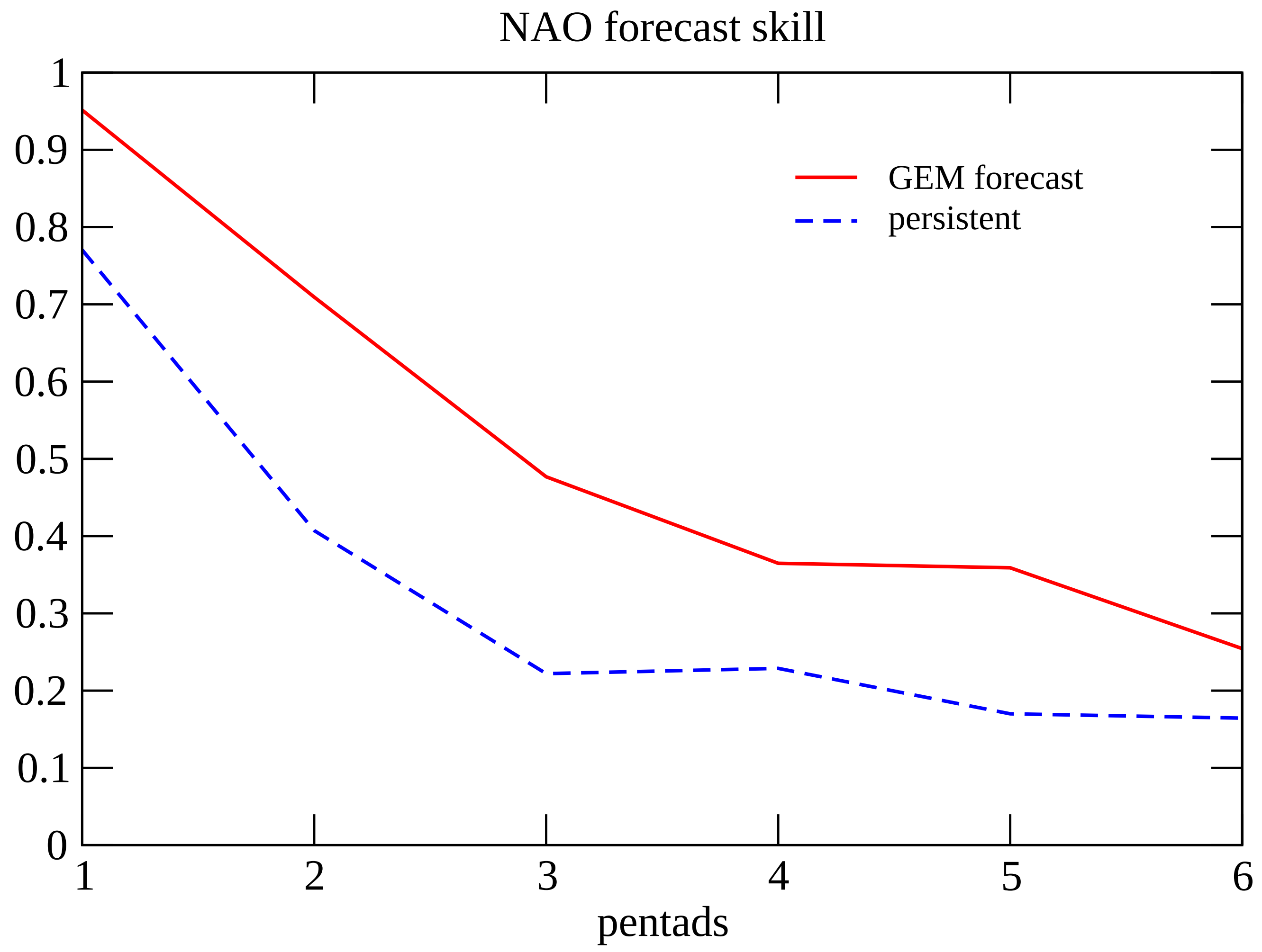
Normalized Z500 regression to PC2

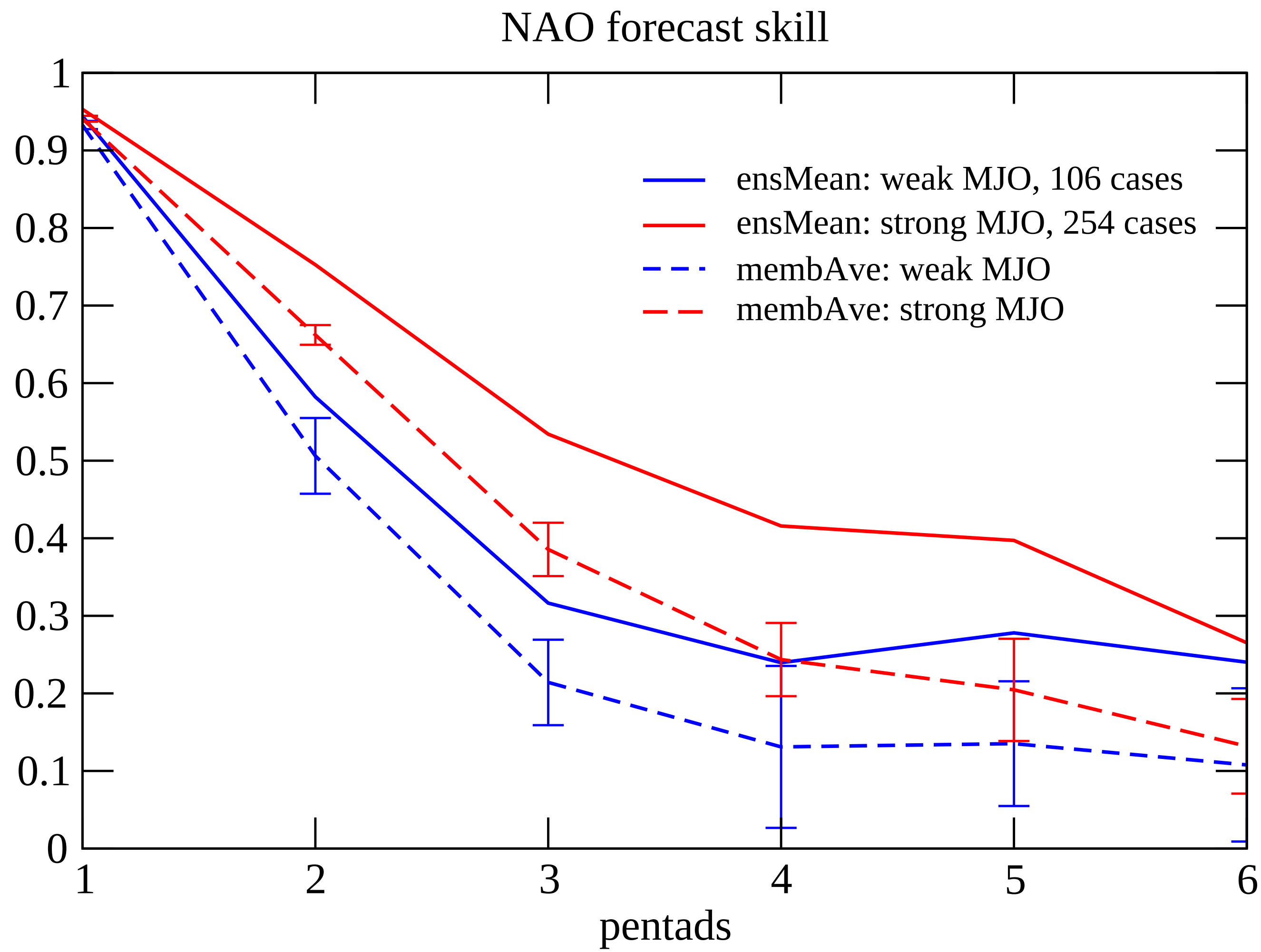
ISO hindscast with GEM

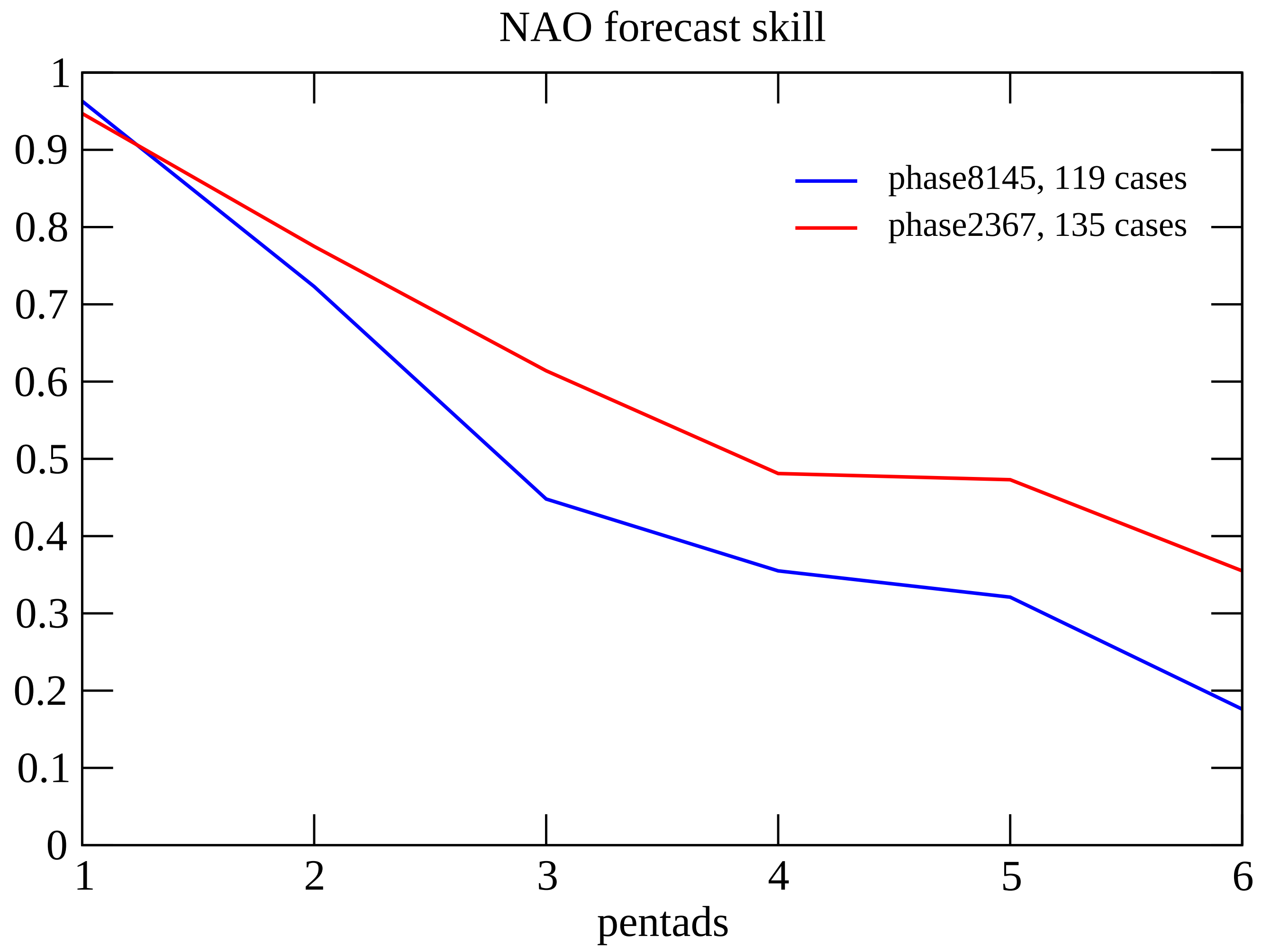
- GEM clim of Canadian Meteorological Centre (CMC)--

  GEMCLIM 3.2.2, 50 vertical levels and 2^o 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

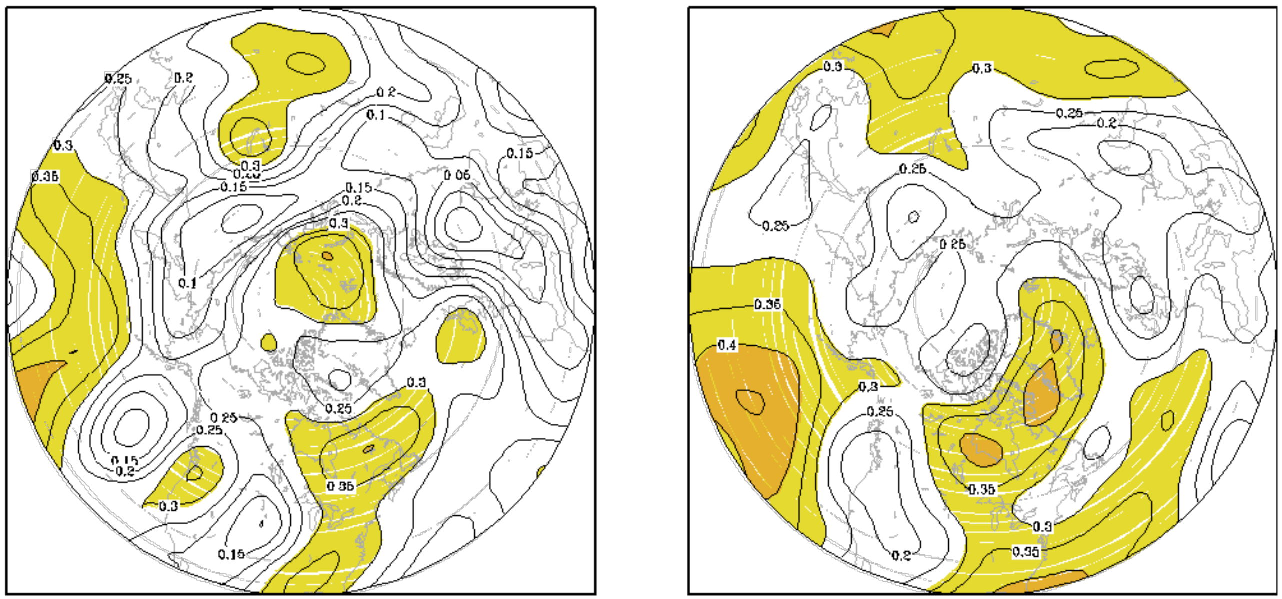
NAO forecast skill
extended winter – Nov – March
tropical influence


NAO forecast skill
GEM forecast
persistent
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
pentads


NAO forecast skill
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
pentads
ensMean: weak MJO, 106 cases
ensMean: strong MJO, 254 cases
membAve: weak MJO
membAve: strong MJO

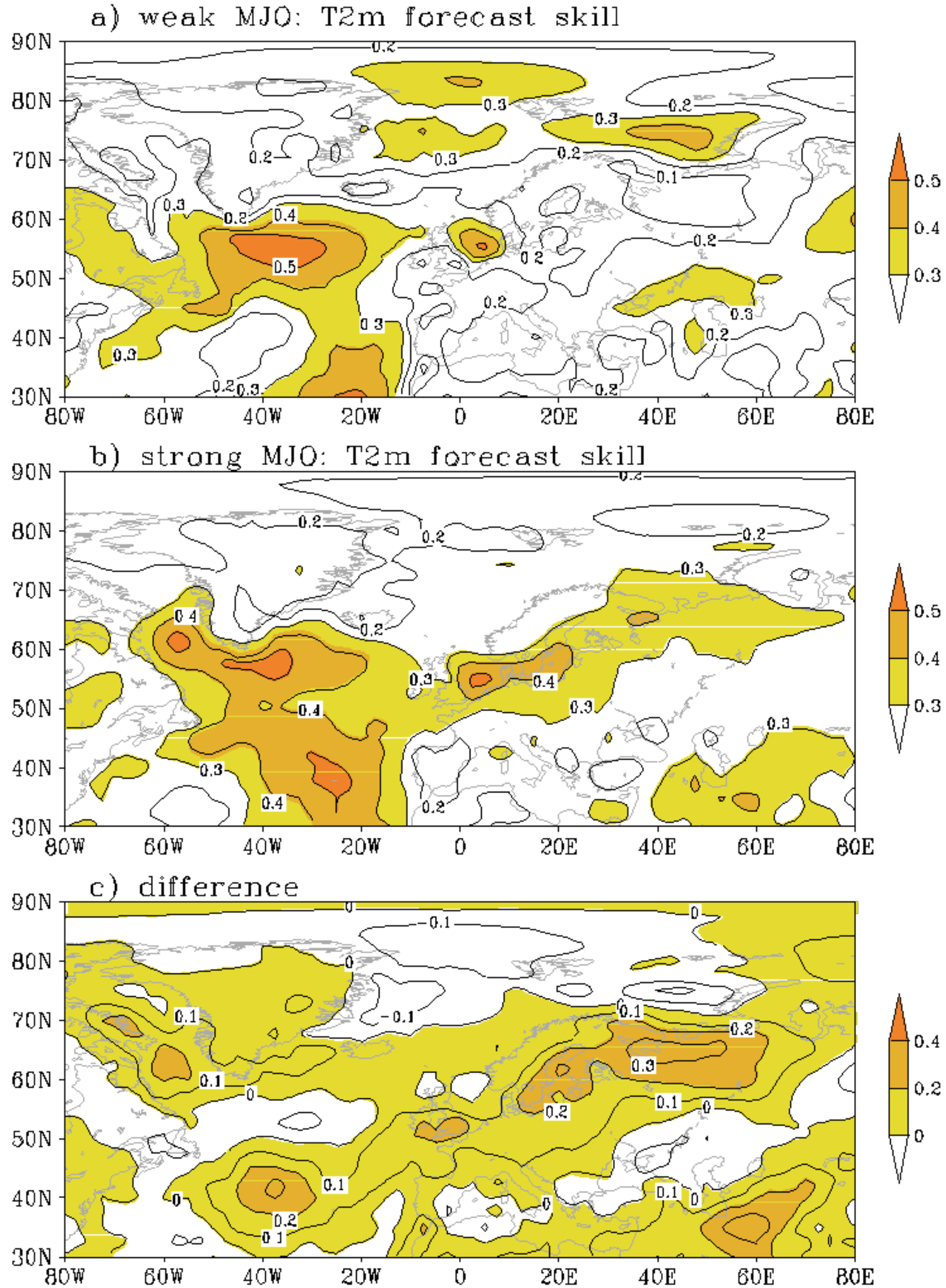

NAO forecast skill
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
pentads
phase8145, 119 cases
phase2367, 135 cases

a) weak MJO: Z500 skill   b) strong MJO: Z500 skill



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

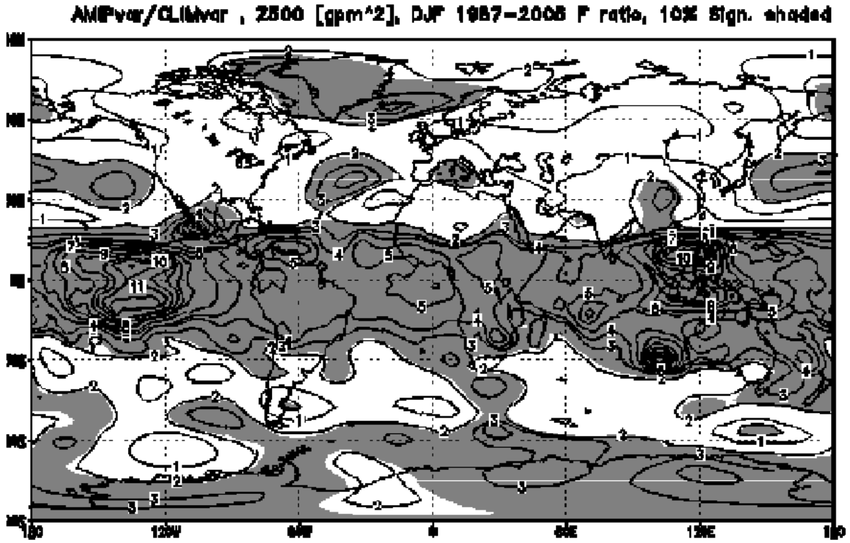
- GEM-CLIM
- Two 20-year integrations

  1) AMIP-type: observed SST

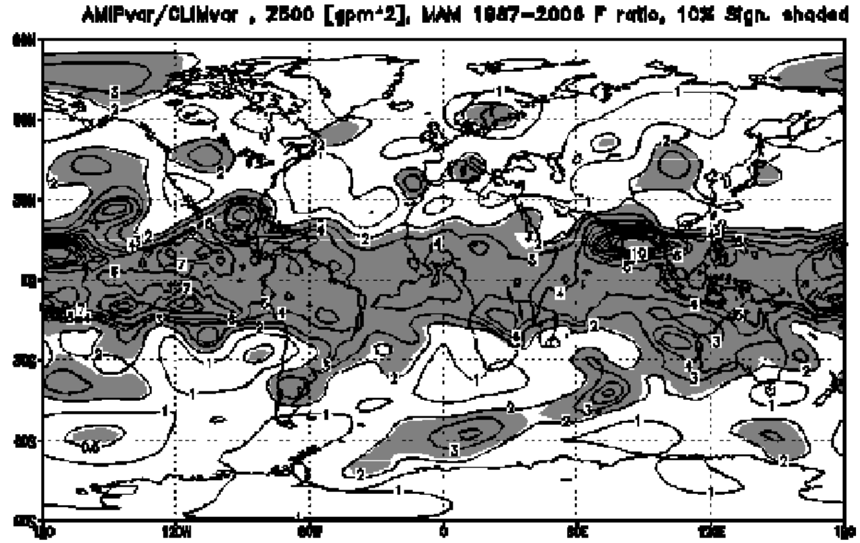
  2) climatological SST (only annual cycle)
- Compare variances of these two runs

Z500

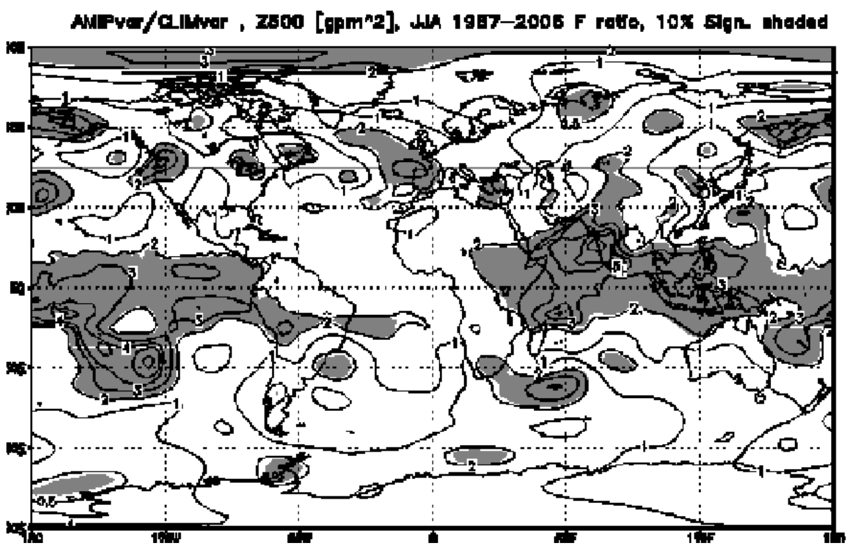
DJF



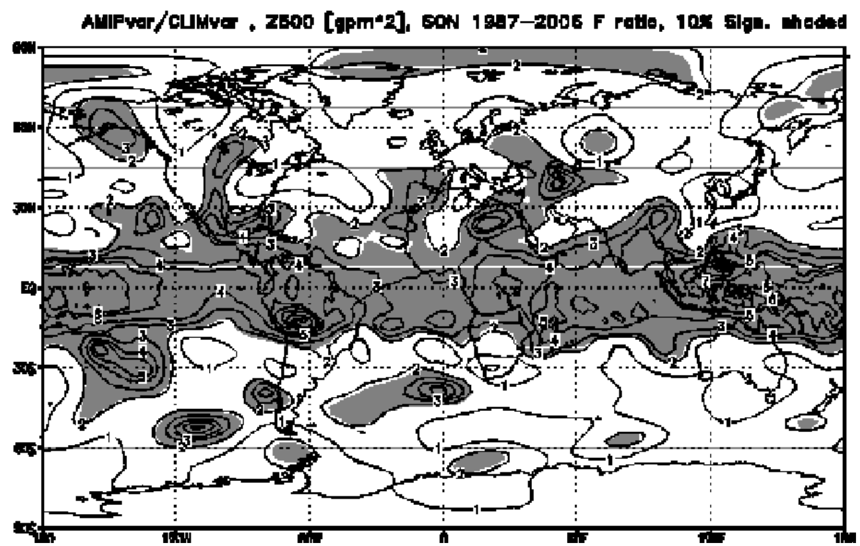
MAM



JJA



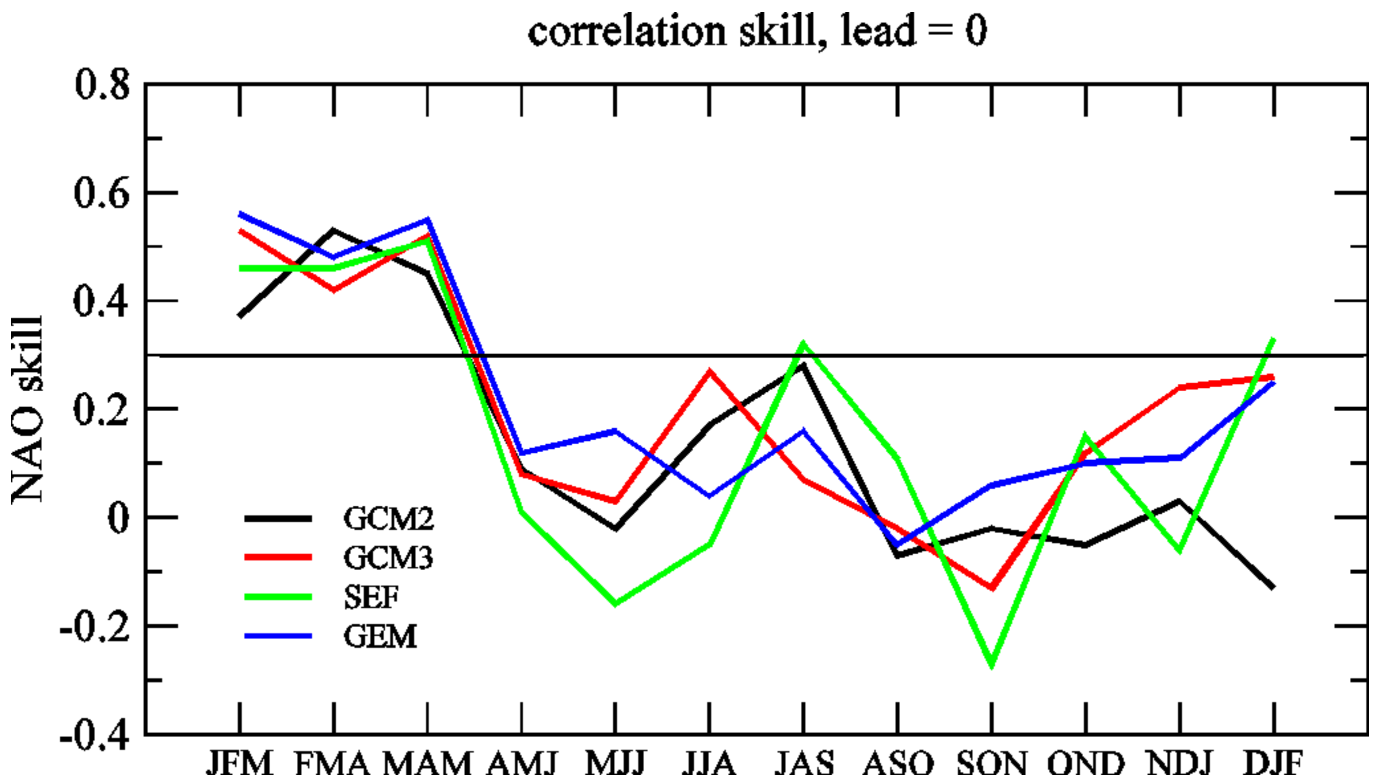
SON

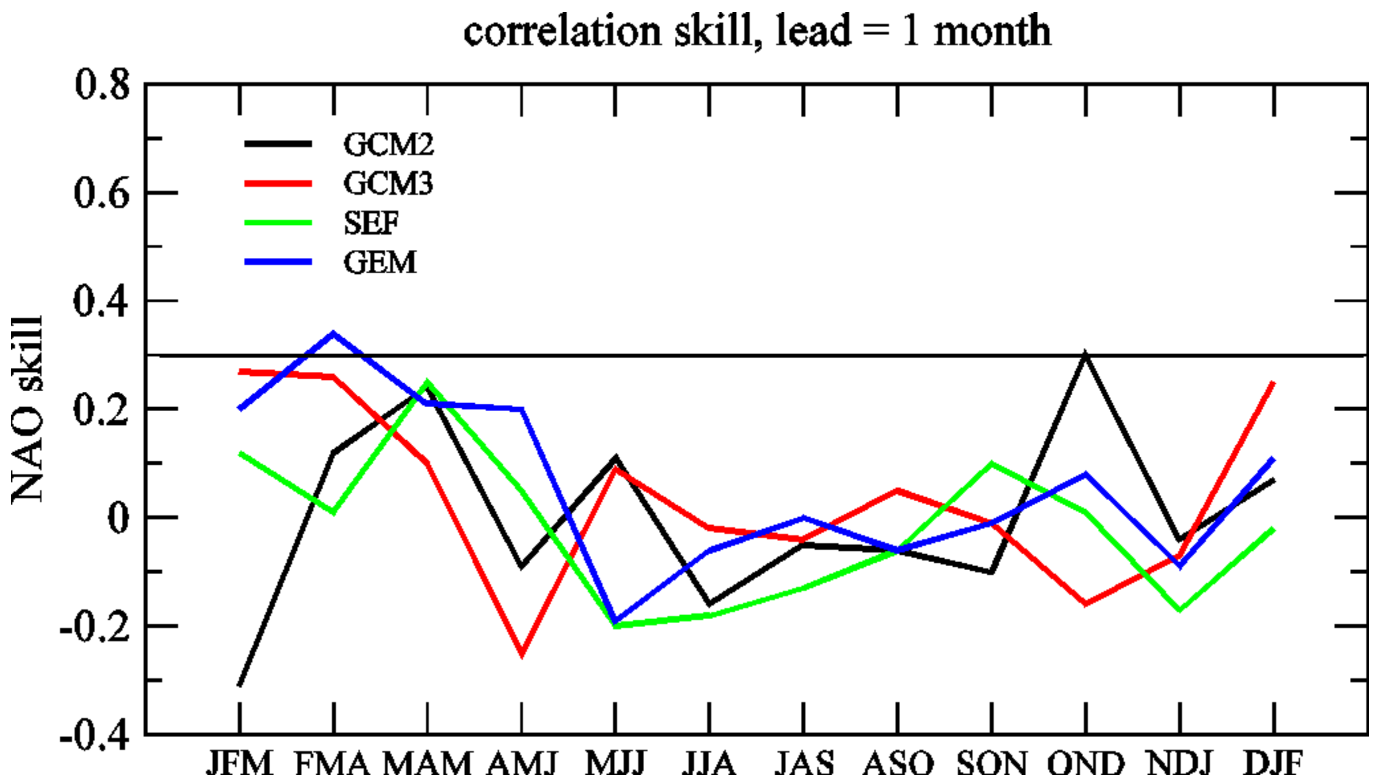


Elisabeth Viktor, personal communication

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


correlation skill, lead = 0
NAO skill
0.8
0.6
0.4
0.2
0
-0.2
-0.4
JFM FMA MAM AMJ MJJ JJA JAS ASO SON OND NDJ DJF
GCM2
GCM3
SEF
GEM


correlation skill, lead = 1 month
NAO skill
0.8
0.6
0.4
0.2
0
-0.2
-0.4
GCM2
GCM3
SEF
GEM
JFM
FMA
MAM
AMJ
MJJ
JJA
JAS
ASO
SON
OND
NDJ
DJF

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

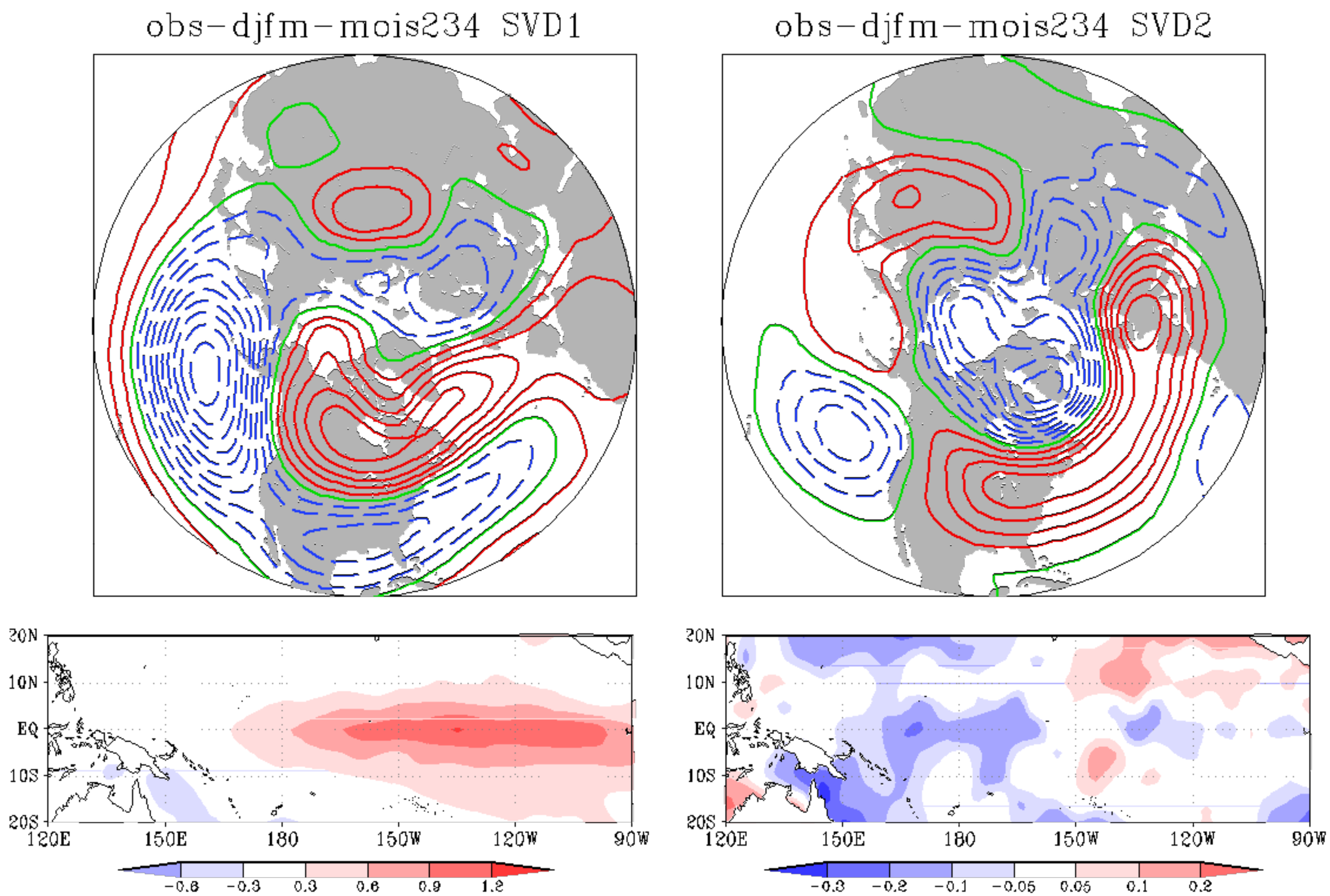
For the DJFM run:

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

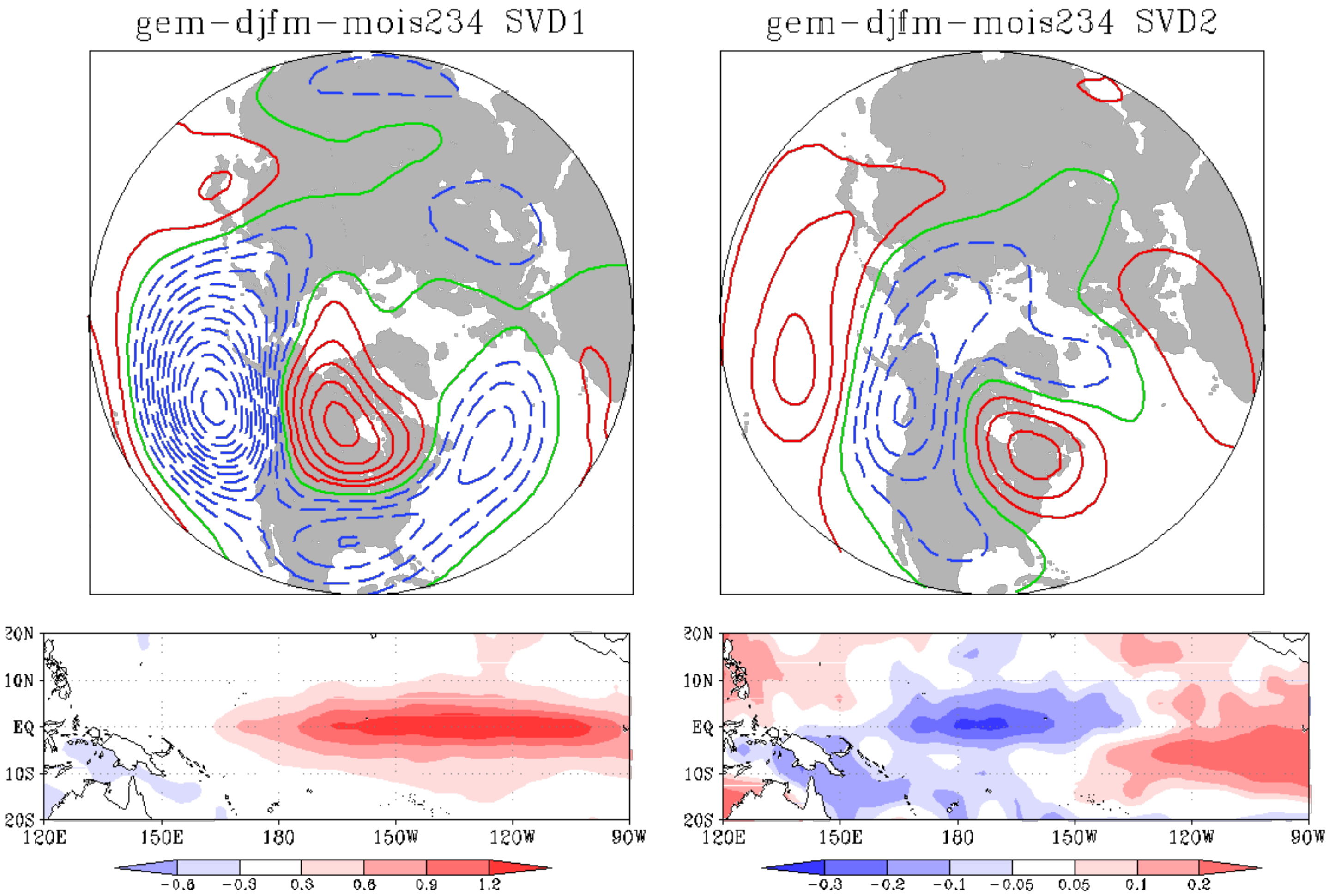
Leading pairs of SVD in observations

November SST vs JFM z500



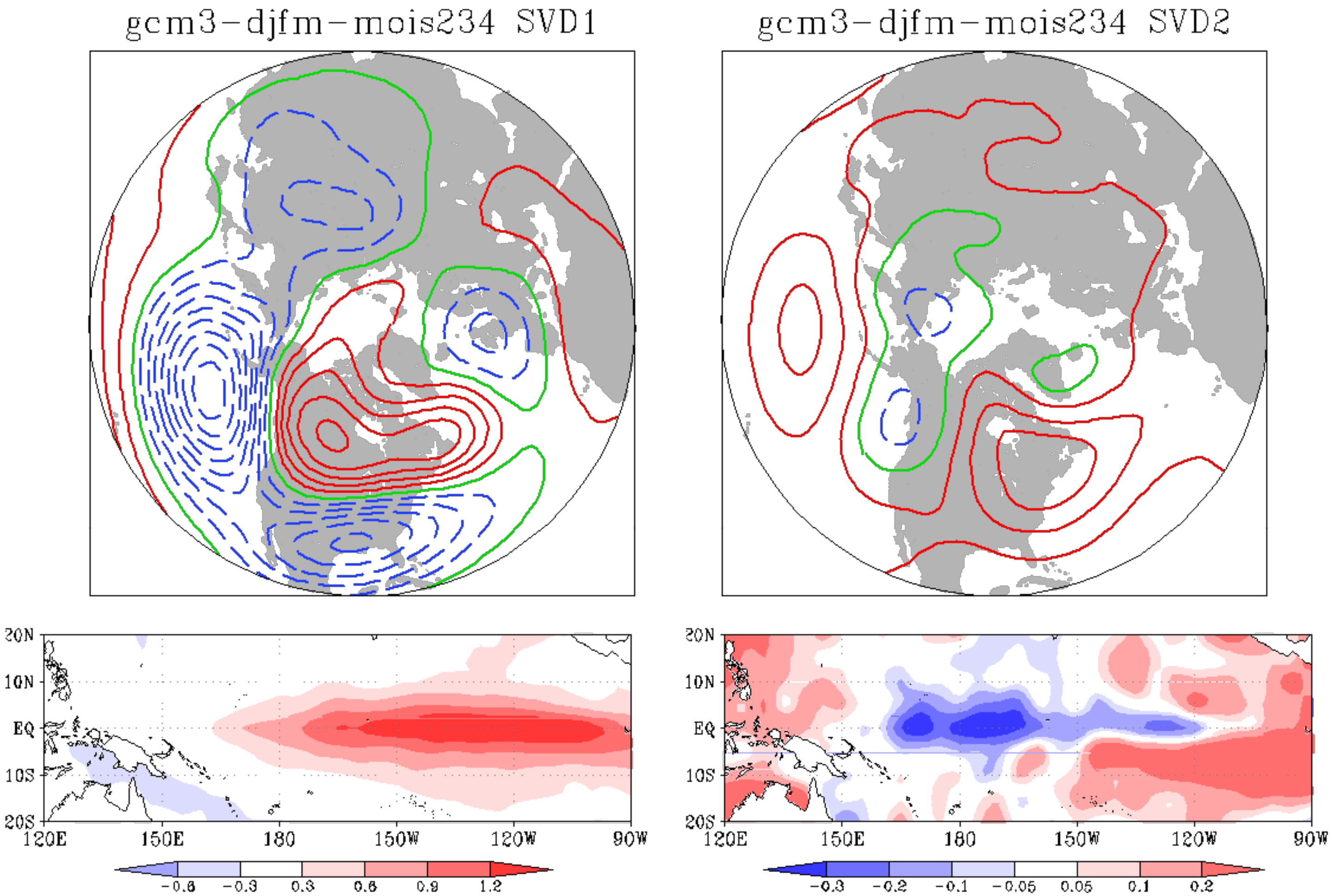
Leading pairs of SVD in GEM ensemble mean

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

	Forecast NAO index	Forced SVD2
GCM2	-0.13	**0.30**
GCM3	0.26	**0.57**
SEF	**0.33**	**0.47**
GEM	0.25	**0.39**

Lead = 0

NAO skill of ensemble forecast

Temporal correlation with JFM observed NAO index

	Forecast NAO index	Forced SVD2
GCM2	-0.31	**0.35**
GCM3	0.27	**0.43**
SEF	0.12	**0.42**
GEM	0.20	**0.31**

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

$$0 = \overline{N(\Phi)} + \bar{F}$$

Use $\bar{F}$ in model

$$\frac{d\Psi}{dt} = N(\Psi) + \bar{F}$$

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

- Perform 3-month forecasts for 51 DJFs 1948/49-1998/99.
- 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

DJF	NAO	PNA
51 DJFs	**0.44**	0.26
16 EPSO		**0.68**
35 NEPSO	**0.46**	

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

Lead = 0

SGCM	NAO	PNA
26 DJFs	**0.66**	0.39
9 EPSO		**0.70**
17 NEPSO	**0.65**	

GCM2	NAO	PNA
26 DJFs	**0.47**	0.34
9 EPSO		**0.67**
17 NEPSO	**0.58**	

Correlation between observed and model ensemble mean indices

JF	NAO	PNA
51 JFs	**0.34**	
16 EPSO		**0.59**
35 NEPSO	**0.39**	

Lead = 1 month

Comparison with GCM2 for JF

Lead = 1 month

SGCM	NAO	PNA
26 JFs	**0.58**	**0.43**
9 EPSO		**0.66**
17 NEPSO	**0.55**	

GCM2	NAO	PNA
26 JFs		**0.43**
9 EPSO		**0.84**
17 NEPSO		

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:

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- Lin, H., J. Derome and G. Brunet, 2005: Correction of atmospheric dynamical seasonal forecasts using the leading ocean-forced spatial patterns. *Geophys. Res. Lett*., 32, L14804, doi:10.1029/2005GL023060.
- Lin, H., G. Brunet, and J. Derome, 2009, An observed connection between the North Atlantic Oscillation and the Madden-Julian Oscillation. *J. Climate*, 22, 364-380.
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Thank you!

Lagged composites of the NAO index

Phase	1	2	3	4	5	6	7	8
Lag −5			−0.39				0.28	
Lag −4		−0.26				0.28		
Lag −3		−0.29						
Lag −2						0.26		
Lag −1								
Lag 0								−0.41
Lag +1		0.26	0.27	0.26			−0.25	−0.35
Lag +2		0.34	0.36			−0.31	−0.33	−0.29
Lag +3		0.35				−0.35	−0.41	
Lag +4						−0.35	−0.31	
Lag +5				−0.27				

Lin et al. (2009)