Recent understanding of AO and its predictability in the NWP models

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Contents

- Introduction
  - AO pattern
  - Dynamical aspect
  - Upward trend relating with global warming
- Predictability of the AO in the NWP models
- Overview of some recent studies on the AO
  - Studies about the NAO (as a part of the AO)
  - Predictability
    - Relation with the preceding snow coverage in the Eastern Siberia
    - Relation with the stratosphere
- Prediction of the AO for 2008/09 winter by the JMA's seasonal EPS

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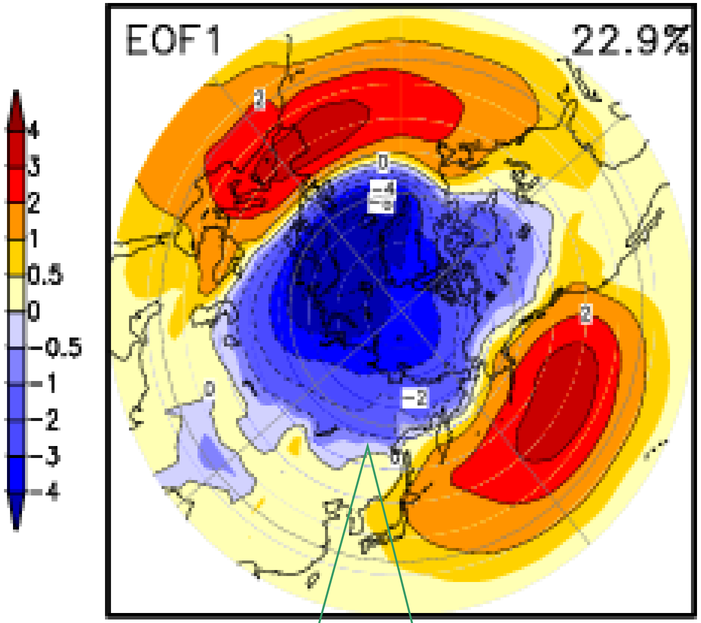
AO pattern

- The AO is the most dominant variations in the boreal winter.
  - For the first time, the AO is defined as the leading mode of Empirical Orthogonal Function (EOF) analysis of sea level pressure (SLP) (Thompson and Wallace 1998)
- Meridionally asymmetric anomalies pattern
  - contrast of anomalies between the Arctic and mid-latitudes
- Positive phase:
  - Negative anomalies in the Arctic
  - Positive anomalies in the mid-latitudes

EOF-1 of SLP in DJF
(JRA-25/JCDAS 1979-2007)

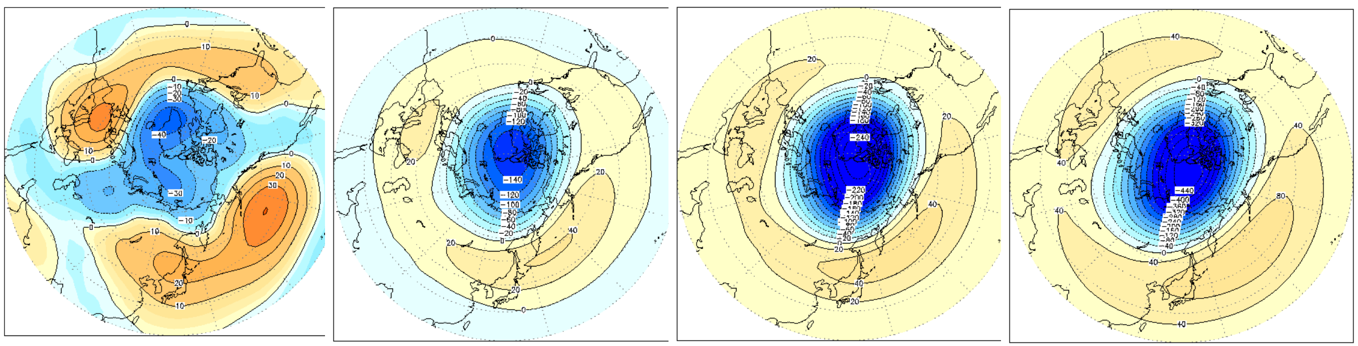


AO positive;
- the Arctic
+ mid-latitudes

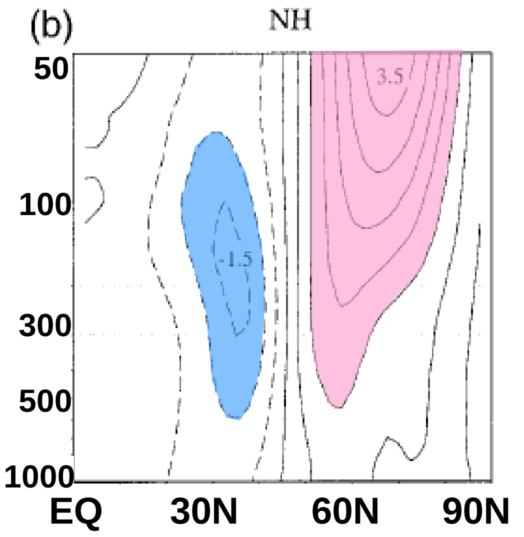
Barotropic structure of the AO

Leading EOF of height anomalies in DJF at various level
(JRA-25/JCDAS 1979-2007)

500hPa **100hPa** **50hPa** **10hPa**



Zonal mean wind regressed on the AO index
(by the NCEP-NCAR reanalyses)
(Thompson and Wallace 2000)



- Such asymmetric pattern can be found from the troposphere to the lower stratosphere in winter

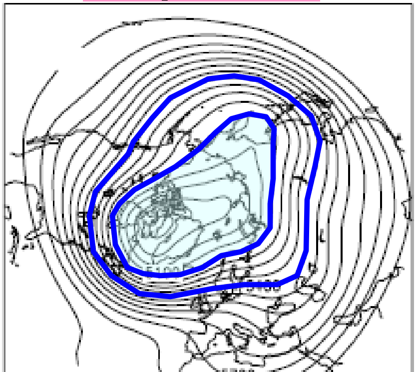
--> Barotropic structure of the AO

- often called “Northern (Hemisphere) Annular Mode; NAM”

Correlation between the AO index and lower troposphere temperatures

Z500 in case of AO positive and negative (AO index = +2, -2) in DJF
(from Yamasaki 2004)

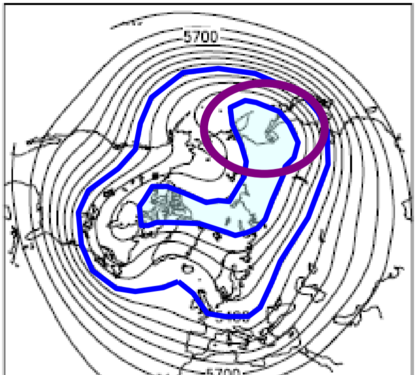
AO positive



Contours: 5400 and 5160

- The polar vortex shrinks and strengthens.
- The westerlies tend to flow zonally.

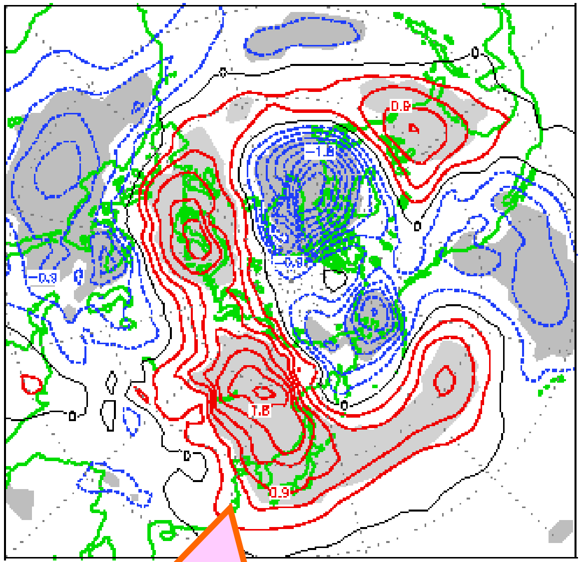
AO negative



Contours: 5400 and 5160

- The westerlies tend to meander.
- The polar vortex extends to the Sea of Okhotsk.

Regression of 850hPa temperature upon the AO index in DJF (by JRA-25 1979-2004)



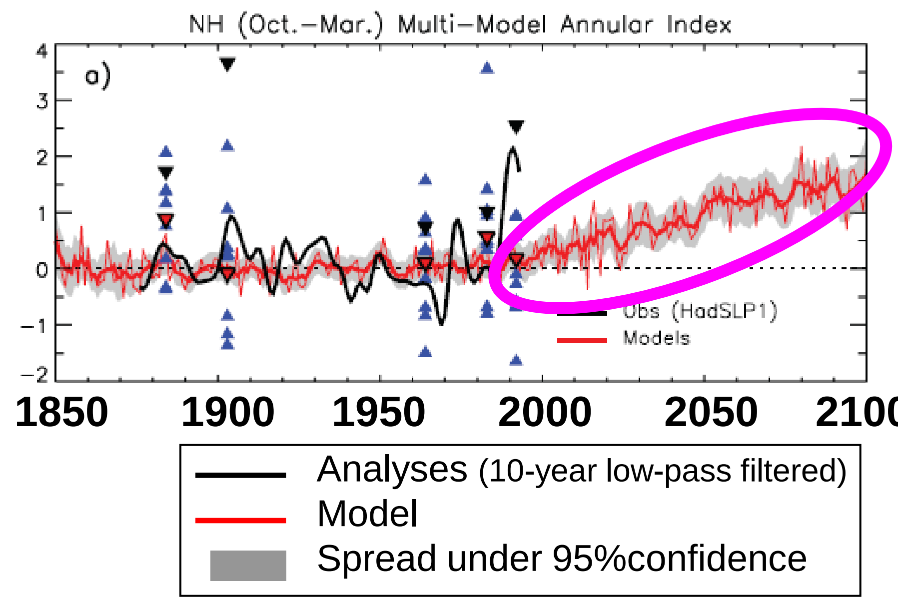
AO positive;
tends to be warm in the East Asia

IPCC's View of the relation between global warming and the AO

- According to the IPCC/AR4/WG1
  (The Physical Science Basis)
  – /chapter-10(Global Climate Projections)
  – **Executive summary on SLP**

- **Sea level pressure is projected to increase over the subtropics and mid-latitudes, and decrease over high latitudes** (order several millibars by the end of the 21st century) associated with a poleward expansion and weakening of the Hadley Circulation and a poleward shift of the storm tracks of several degrees latitude with a consequent increase in cyclonic circulation patterns over the high-latitude arctic and antarctic regions.
- **Thus, there is a projected <u>positive trend</u> of the Northern Annular Mode (NAM)** and the closely related North Atlantic Oscillation (NAO) as well as the Southern Annular Mode (SAM).
- There is considerable spread among the models for the NAO, but the magnitude of the increase for the SAM is generally more consistent across models.

10-year low-pass filtered predicted the AO index averaged multi models for IPCC-AR4 simulations



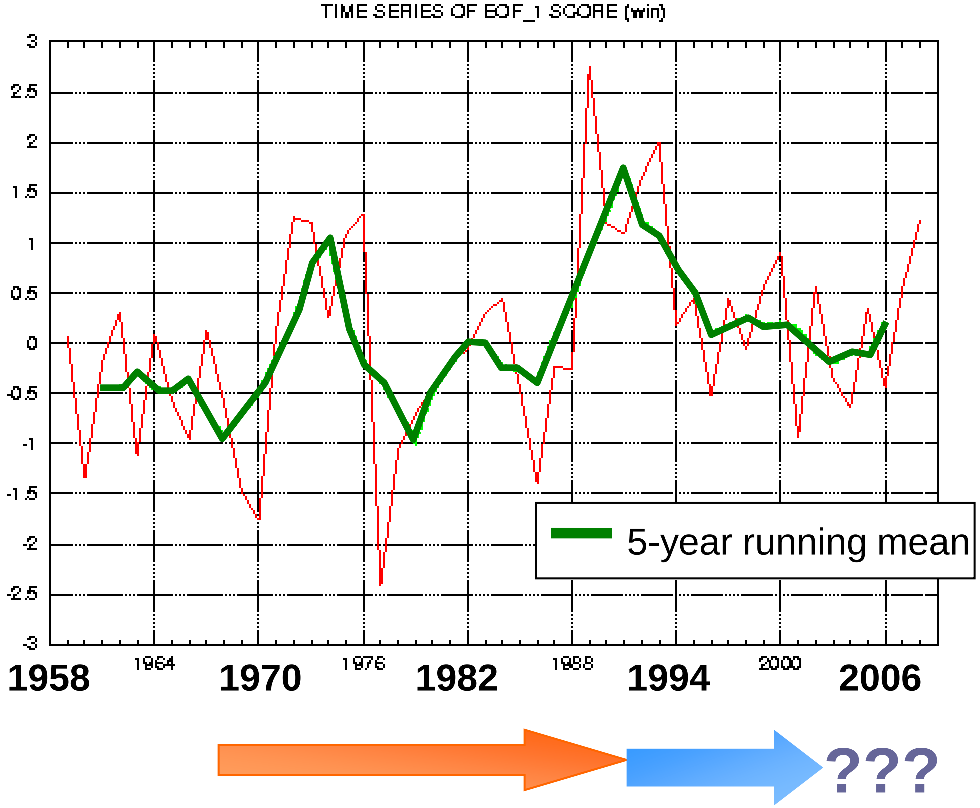
(figure 10.17 in the IPCC-AR4/WG1/chapter-10)

Recent variation of the AO index

- Upward trend from the late 1960s
- However, it is unclear in the recent years.

- Relation between the AO and global warming will be discussed as a future issue.

Recent variation of the AO index (DJF mean)



Why does the AO-like pattern dominant?

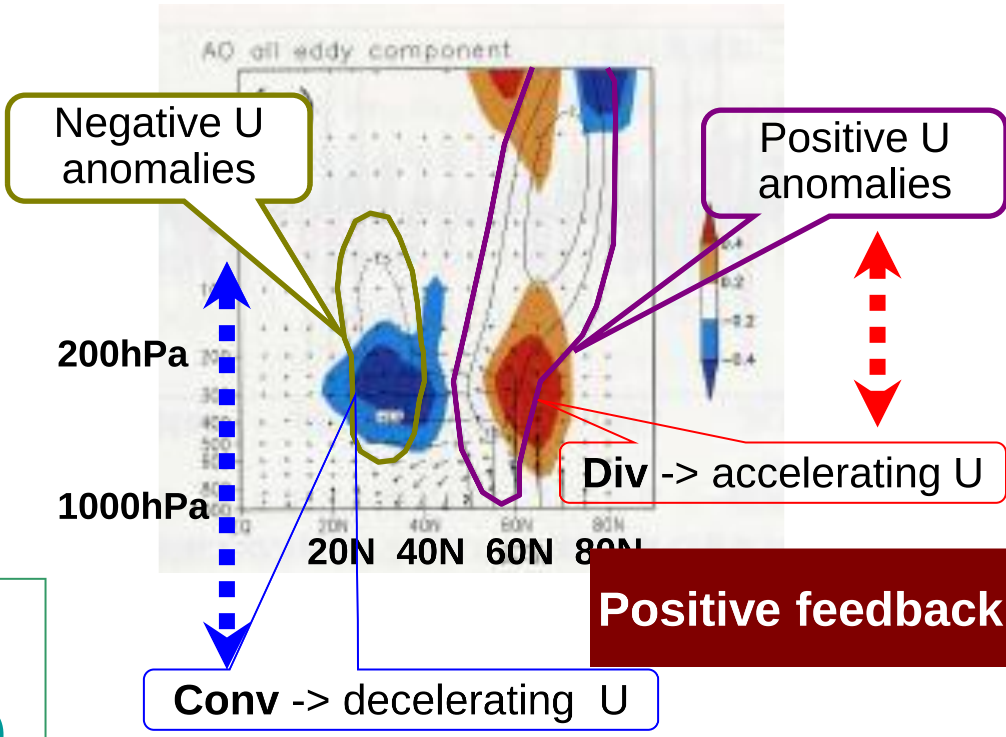
- Positive feedback of the AO-like pattern by zonal-eddy coupling

- Zonally asymmetric wind anomalies forces its anomalies.

⬇

- The AO is sustained mainly by the interaction between zonally asymmetric wind anomalies and zonal averaged flow; (zonal-eddy coupling).

Anomalies of EP flux (vector), its convergence (shade) and zonal wind (contour) associated with the AO (from in the Kimoto et al. 2004)



Divergence of the meridional component of EP-flux
--> acceleration of zonal wind)

AO as the least dumped mode in the NH winter
(from Kimoto et al. 2001)

- **(Experiments)**
  - Linearized model considered only zonal averaged component and zonal-eddy coupling

  (omit non-stationary waves (wave-wave interaction)
- **(Results)**
  - Linearized model reproduces the AO-like pattern as the EOF-1.

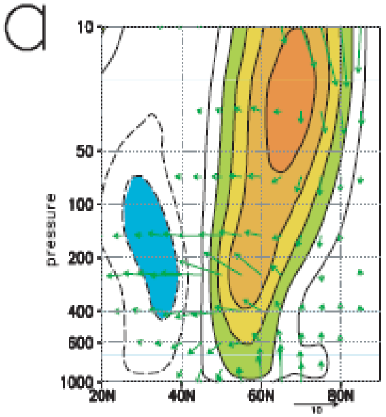
  = Even if only zonal-eddy coupling is considered, (without any effect, such as external forcing as SST or wave-wave interaction), the AO-like pattern sustains.

The AO is
- internal variability of the atmosphere
- the least dumped mode

(=If once the AO occurs, this pattern is easy to remain.)

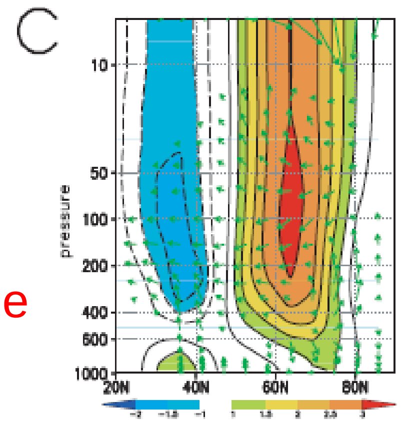
Anomalies of zonal wind and EP flux associated with stationary waves

EOF-1 in the **analysis**



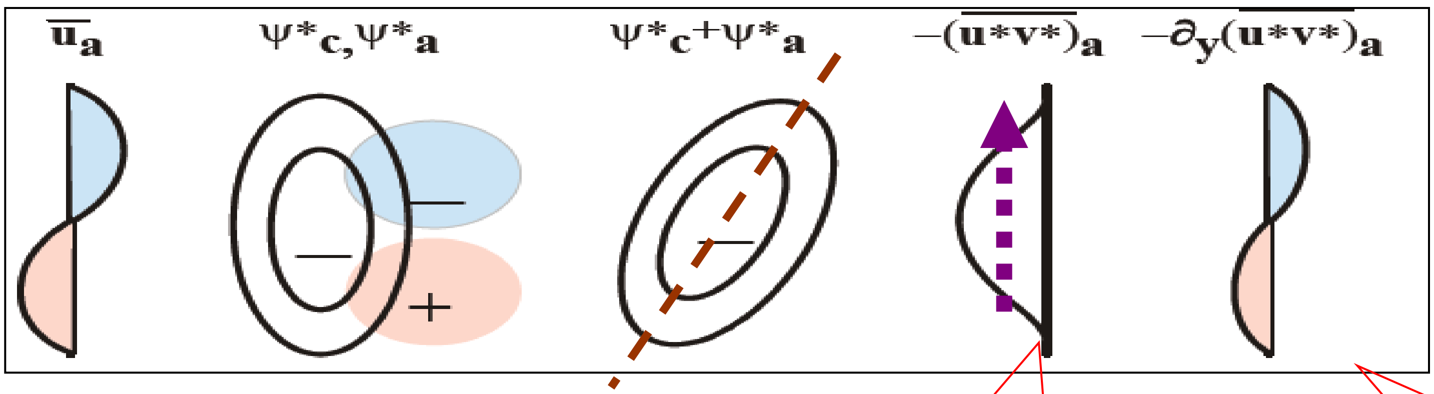
EOF-1 in the **linearized model**

->similar to the EOF1 in the analysis



Tilted-trough mechanism

- a concept of the positive feedback of the AO-like pattern by the “zonal-eddy coupling”;
  “tilted-trough mechanism” (Kimoto et al. 2001)



Suppose the AO like anomalies of zonal flow.

Considering the momentum advection, the trough tilted along NE-SW.

northwardly transport of momentum flux is given.

The AO-like anomalies are enhanced.

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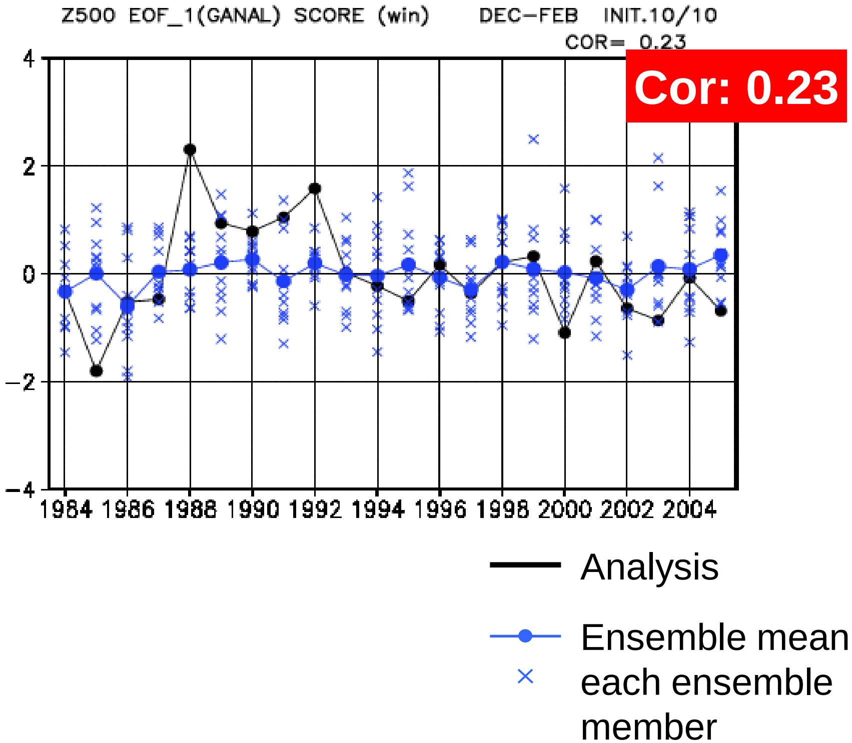
Difficulty of the forecast of the AO for seasonal timescale (hindcast with the JMA's seasonal EPS)

Verification of the AO index in DJF with the initial month of **October**.

(from the hindcast of 1984-2005 (22years).



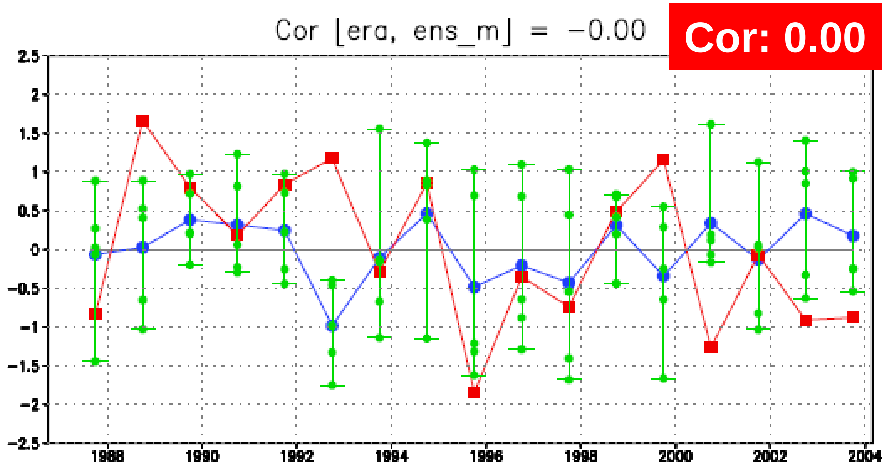
Anomaly correlation of the AO index in DJF for the seasonal EPS

Initial month	
September	-0.02
October	0.23
November	0.35
December	0.58 (for JFM)

In case of the System 3 of ECMWF…

(From the figure 28 in the ECMWF Technical Memorandum No. 503)

Verification of the NAO index for DJF with the initial month of Sep by the system-3 of ECMWF. **(from the Preliminary hindcast experiment for 1987-2005)**



Difficulty of predicting the AO(/NAO) is common to all of the NWP models.

•The AO is an internal variability of the atmosphere in the mid-high latitudes.
-->Forecast of the AO(/NAO) is difficult for the seasonal timescale
,although some forecast skill is found for one-month timescale.

➢Nevertheless, there are some studies concerning with the predictability of the AO(/NAO).

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North Atlantic Oscillation (NAO)

(Concerning with the North Atlantic, “NAO” has been studied since much before the AO was proposed.)

- Dominant mode of winter climate variability in the North Atlantic
  - seesaw between the Icelandic Low and the Azores High
- Anomalies pattern of the NAO is similar to that of the AO in the North Atlantic.
  - The NAO index highly correlated with the AO index.

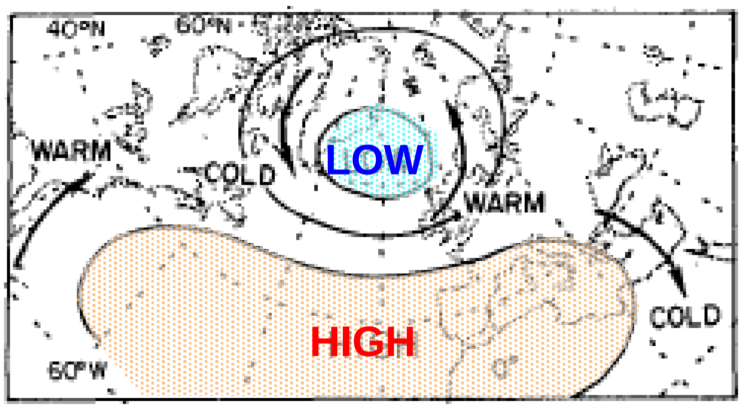
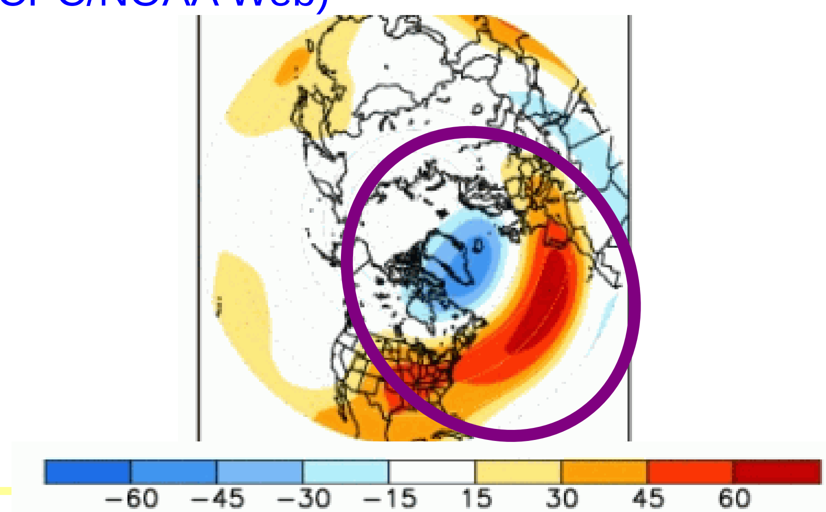


Fig. 1. Idealized relationships between pressure and temperature anomalies associated with the North Atlantic Oscillation.

(from Wallace and Gutzler 1981)

Regression of 500hPa height upon the NAO index in January (from the CPC/NOAA Web)

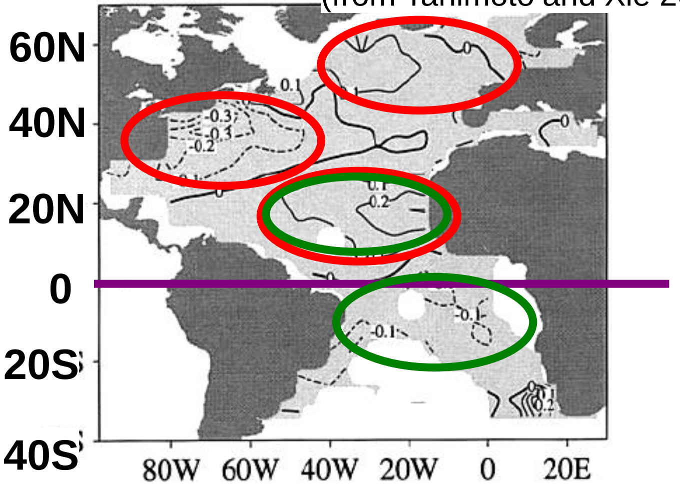


http://www.cpc.ncep.noaa.gov/data/teledoc/nao_map.shtml

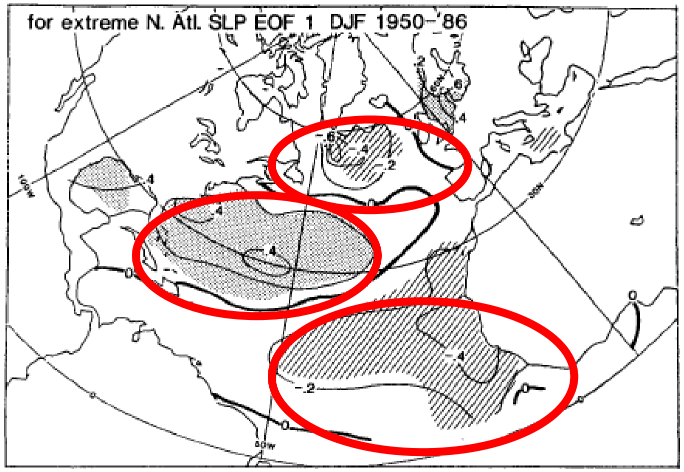
"Atlantic dipole" and "Atlantic tripole" patterns

EOF-1 of SST anomalies for the North Atlantic (and regression of SST anomalies in the South Atlantic)

(from Tanimoto and Xie 2002)



Regression of heating rate of SSTs (K/month) **upon the NAO index**



- North Atlantic; "**Atlantic tripole**"
  - Subtropical North Atlantic
  - East of U.S.
  - High-latitude
- Tropical Atlantic; "**Atlantic dipole**"
  - Dipole anomalies across EQ

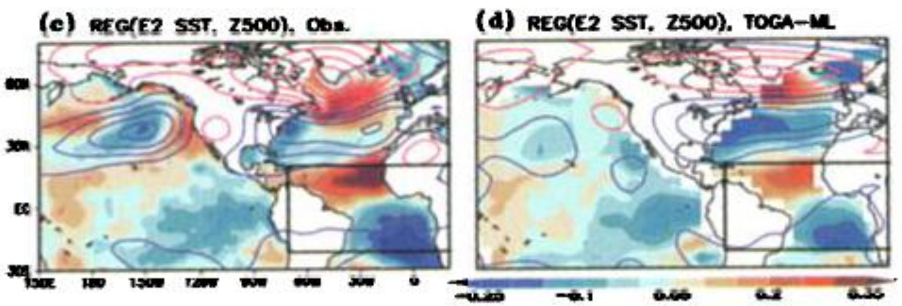
(Subtropical North Pacific region is shared)

•Similar to the "Atlantic tripole"

--> SST anomalies relating with the NAO is similar to the dominant pattern of SST variations in the North Atlantic.

Tropical SST anomalies forcing of the NAO
(Watanabe and Kimoto 1999)

SST and 500hPa height anomalies regressed upon EOF-2 of SST anomalies in the tropical Atlantic



NAO-like Z500 and tripole

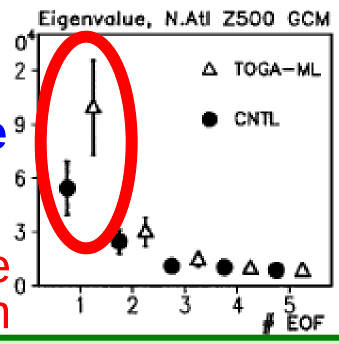
Dipole pattern of SST anom.

Analysis

Model (MGCM with TOGA_ML)

Eigenvalue for Z500 anomalies pattern (in the North Atlantic) **in the CNTL and TOGA-ML**

EOF1=NAO-like pattern



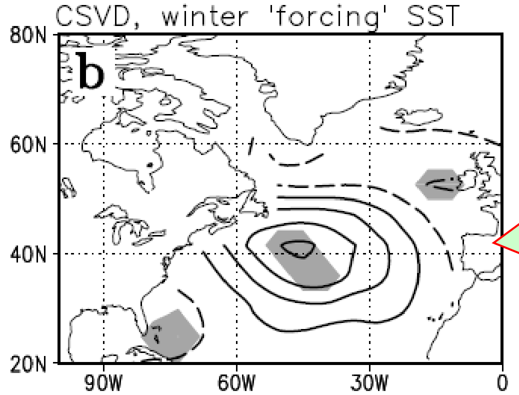
- **CNTL**: free run
- **TOGA-ML**: **only <u>tropical SSTs</u>** are prescribed to the observations

- Long-range integration experiments (60-yr)
- Similar EOF patterns of Z500 and SST anomalies between model and analysis.
- EOF-1 of SST anom.;
  - Monopole pattern
  - forces PNA-like 500hPa height anomalies (not shown)
- EOF-2 of SST anom.;
  - Similar to the “Atlantic dipole” in the tropical Atlantic
  - forces NAO-like pattern of Z500 anomalies
  - Induces tripole pattern of SST anomalies in the North Atlantic

- “Atlantic dipole” can forces the NAO-like pattern of 500hPa height anomalies.
- ,and it induces the Atlantic tripole in the North Atlantic.

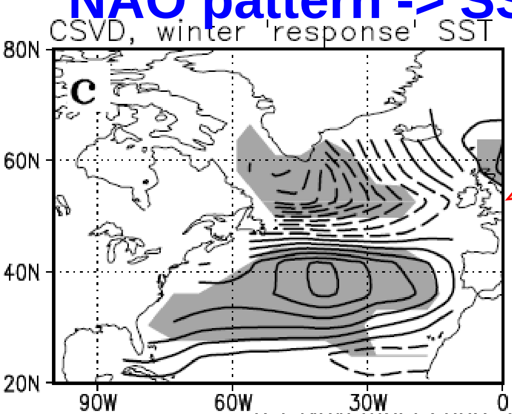
Positive feedback between Atlantic tripole - NAO
(Watanabe and Kimoto 2000, Czaja and Freankignoul 2002)

Forcing of SST (associating with SST-> NAO pattern)



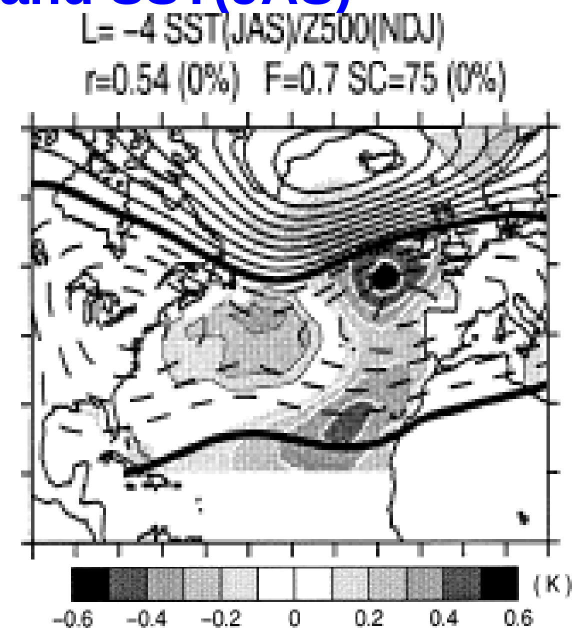
Positive SST anomalies around 40N and surrounding negative anomalies are most effective for the NAO.

Response of SST (associating with NAO pattern -> SST)



Response of SST anomalies is similar to the “Atlantic tripole”.

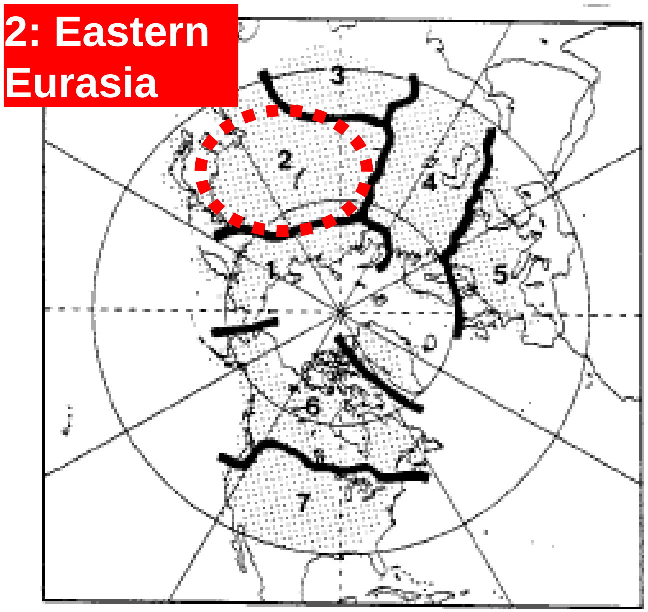
Lag correlations between Z500 (NDJ) and SST(JAS)



SST tripole pattern precedes the NAO, that is the clearest in NDJ of Z500.

Inverse relationship between snow coverage in the eastern Eurasia in fall and AO in the subsequent winter
(from Watanabe and Nitta 1999)

Division



Lag correlation between snow coverage anomalies during SON in the division-2 and Z500 anomalies during the subsequent DJF (1972-1991)

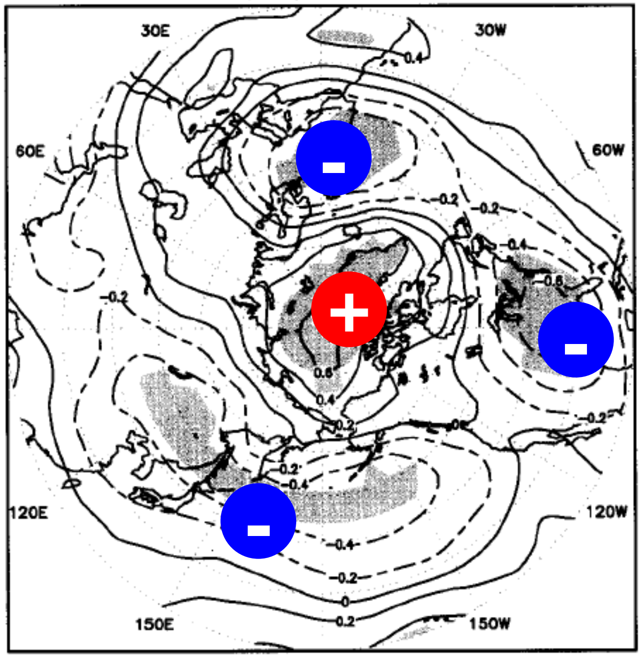


FIG. 11. Correlation of September–November SE over eastern Eurasia with 500-hPa heights in the succeeding winter for 1972 to 1991. Contour interval is 0.2, and negative values are dashed. Values significant at the 5% level using *t* test are shaded.

Model experiment of the snow anomalies impact on the AO
(from Gong and Entekhabi 2003)

Snow forcing region

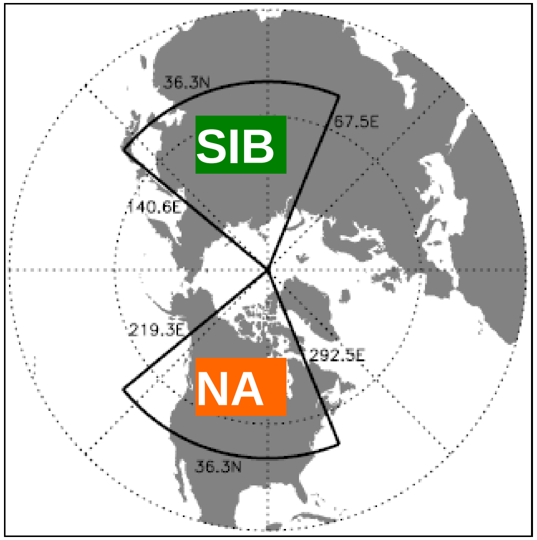
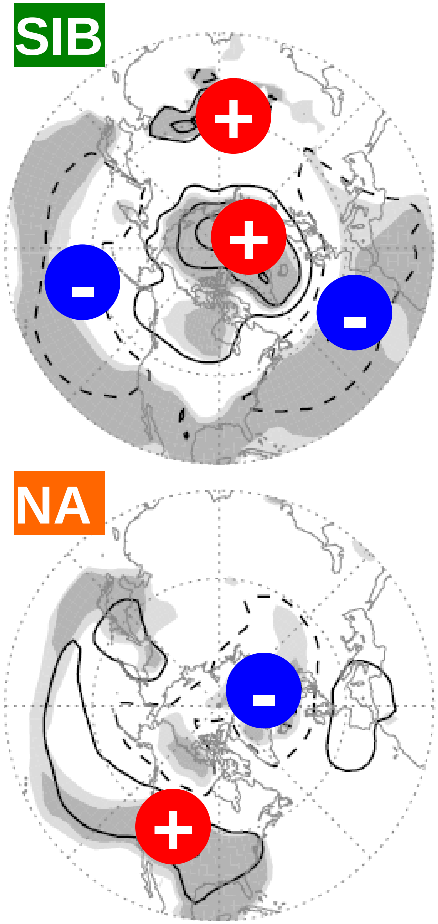


Figure 1. Snow forcing regions applied for the Siberia (SIB) and North America (NA) GCM experiments.

Impact on SLP of a **positive snow perturbation** (DJF)



•Contour: (+,-)1,3,5 hPa
(Dushed line: negative)
•Shade: 90,95 % significance

Large snow forced in the Eastern Siberia promotes negative phase of the AO.

(future issue)
•Why in eastern Siberia?
•In case of negative forced of snow

Relationship between the PJO and the AO

Zonal mean of zonal wind (U) anomalies at 60N (31days running mean)

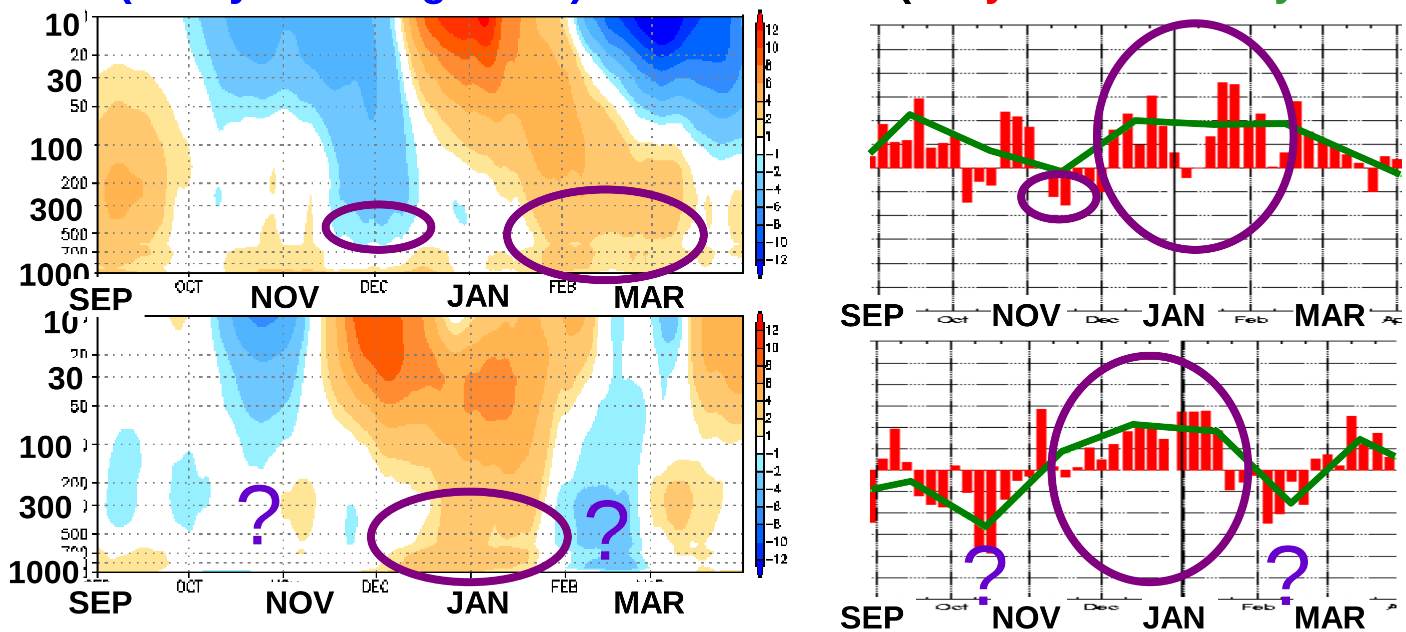
AO index (5days and monthly mean)

2007/08 winter

(Sep-Mar)

2006/07 winter

(Sep-Mar)

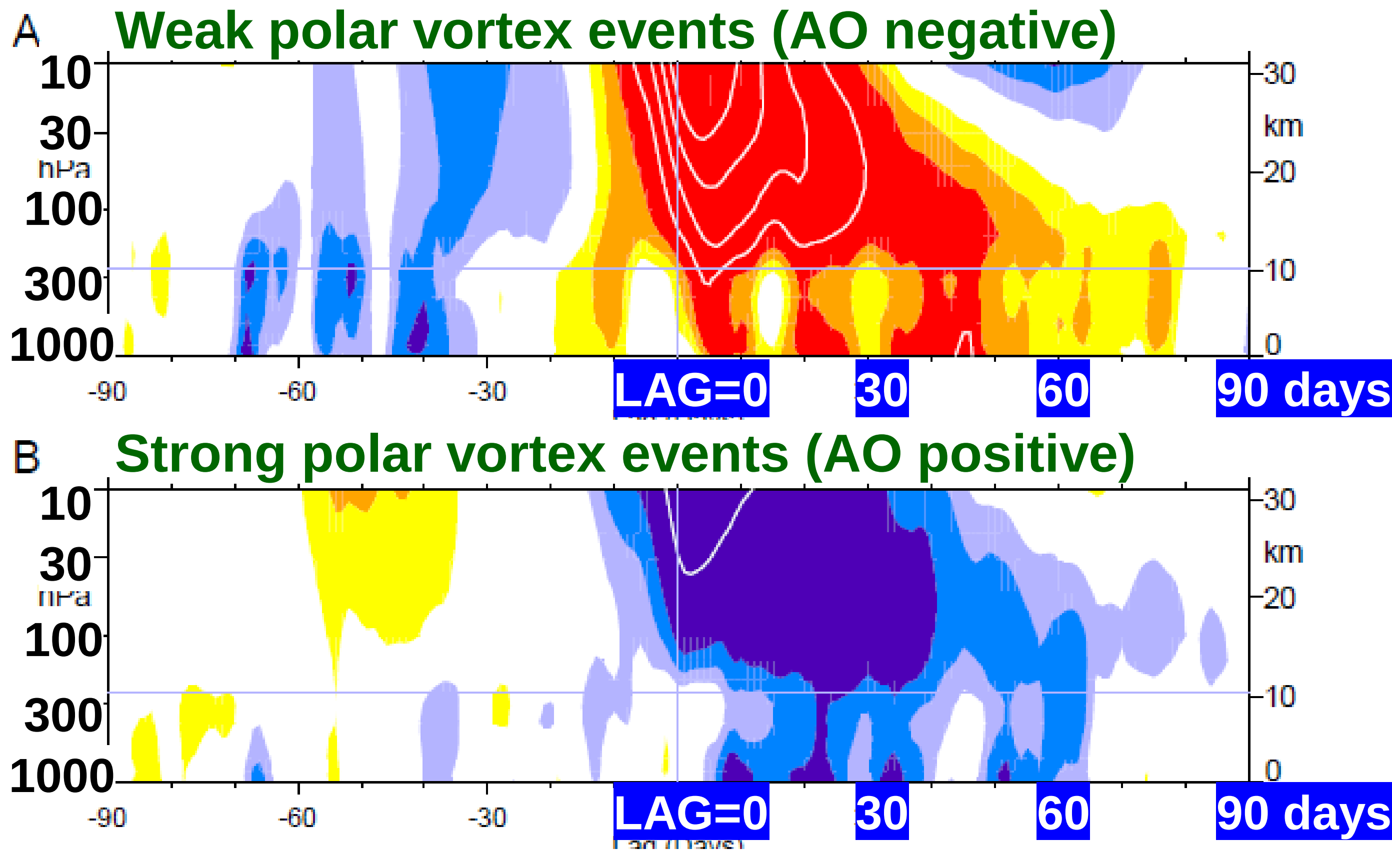


- **PJO** (Polar-night Jet Oscillation): a prominent mode especially in the winter stratosphere, downwardly propagating zonal wind anomalies
  - often propagates into troposphere, but does not always occur.

Composite of magnitude of the pattern associated with the NAM

Baldwin, M. P. and T. J. Dunkerton, 2001

The AO in the troposphere lags behind that at the 10hPa (by 1-2 months).



LAG=0 is defined as a date when index at 10hPa=-3.0 or +1.5.

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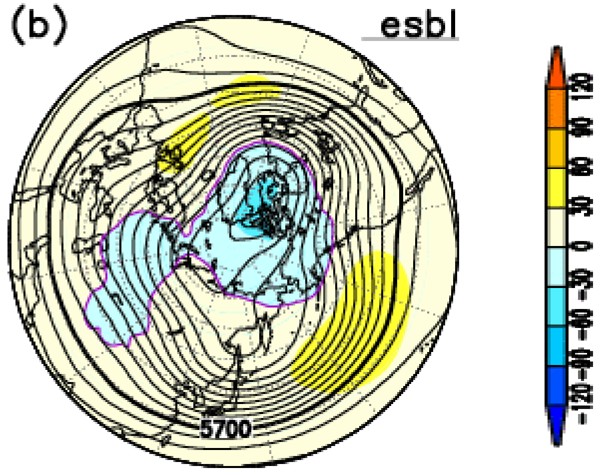
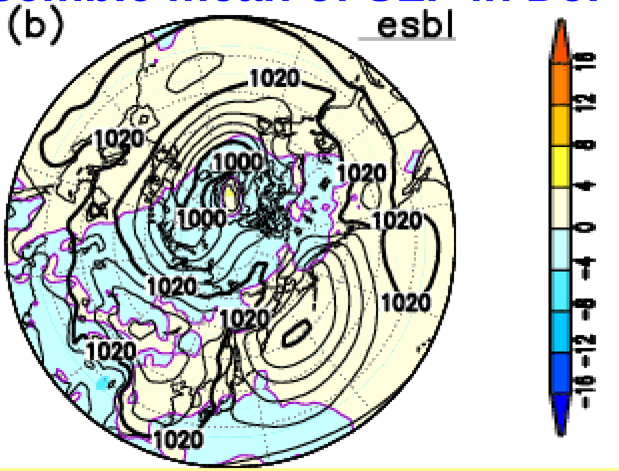
Prediction of the AO for 2008/09 DJF (by the JMA's seasonal EPS) (1)

- Initial date: 17 Oct 2008
- Resolution of the model: TL95L40M51

Ensemble mean of Z500 in DJF



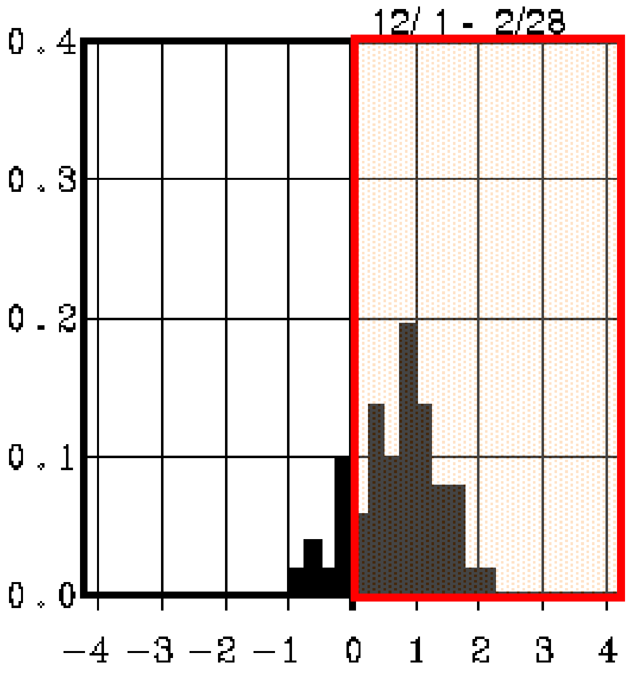
Ensemble mean of SLP in DJF



- **Predicted pattern is similar to the AO positive.**
  - Predicted 500 hPa height anomalies are generally positive in mid latitudes, while negative in high latitude.
  - Inactive of the Aleutian low (positive anomalies of SLP) and active of the Icelandic low (negative anomalies of SLP) are predicted.

Prediction about the AO for 2008/09 DJF (by the JMA's seasonal EPS) (2)

Histogram of the predicted AO index (DJF) by each ensemble member



About 80% of the members predict AO positive.

However,

It is a matter how mach taking into consideration a poor skill of the numerical model in the mid-high latitudes, such as the AO.

Summary

- AO pattern
  - Annear pattern with dipole between the arctic and mid-latitudes
  - Leading mode of the EOF analyses
  - Barotropic structure from troposphere to lower-stratosphere (in winter)
  - Recent variations
    - Upward trend from 1960s (However, it is unclear recently.)
    - IPCC/AR4 refers to the relation between the AO and global warming
- Study on a dynamical aspect
  - The AO pattern is the least dumped mode in the atmosphere
  - Sustained mainly by the zonal-eddy coupling
- Forecast skill by an numerical model
  - Very difficult for the seasonal timescale

Summary

- Studies on predictability
  - Study about the NAO
    - Tropical Atlantic SST forcing of the NAO
    - Positive feedback between Atlantic tripole and the NAO
  - Relationship between the snow coverage over eastern Eurasia in fall and the AO in subsequent winter
  - Relation between the PJO and the AO

- Outlook of the AO in this winter…
  - Positive phase of the AO is predicted by the JMA's seasonal EPS, while forecast skill is low.

--> Forecasters conclude that the AO in this winter will be … ???

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