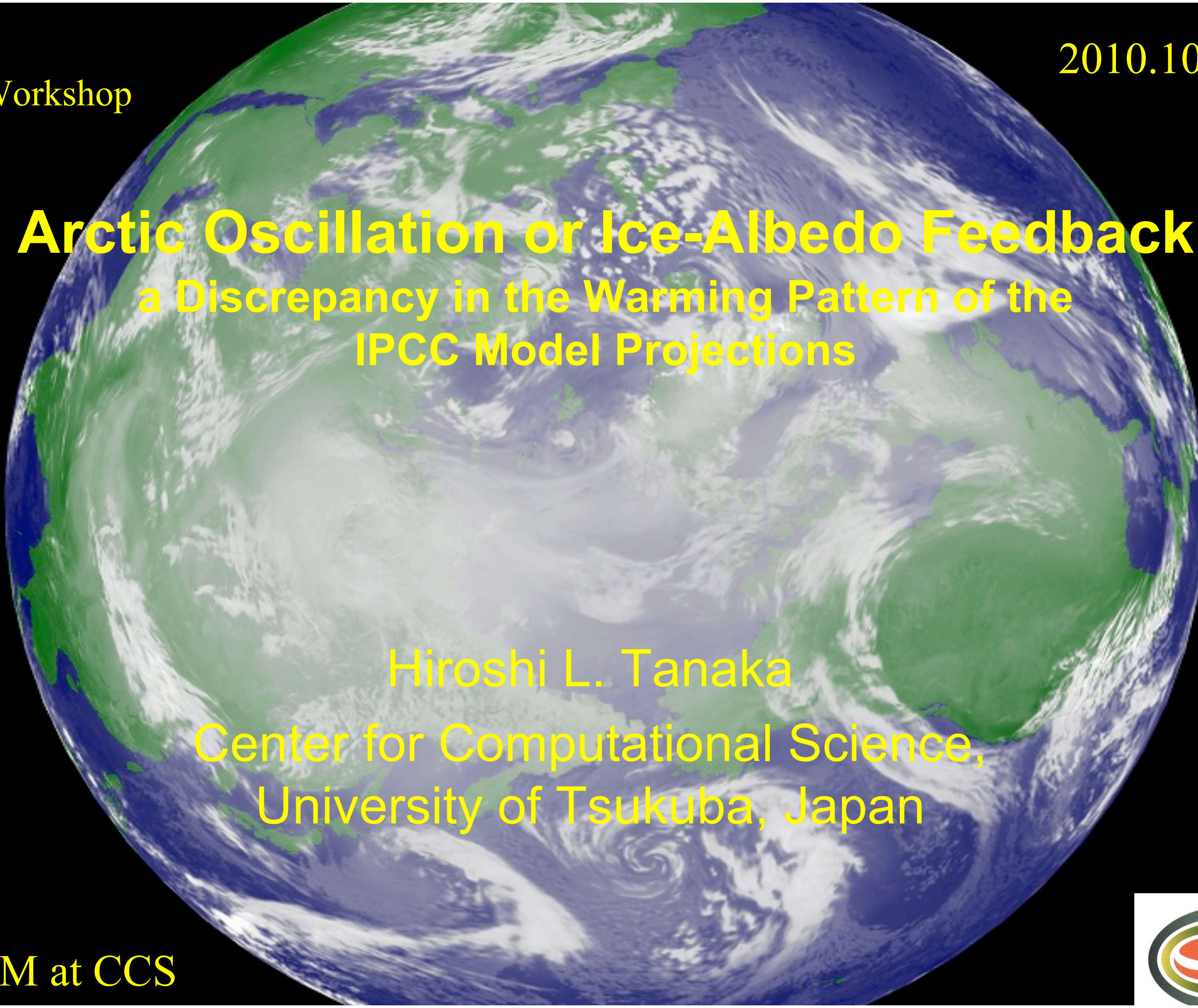
WCRP
Polar Workshop

2010.10.27



Arctic Oscillation or Ice-Albedo Feedback:

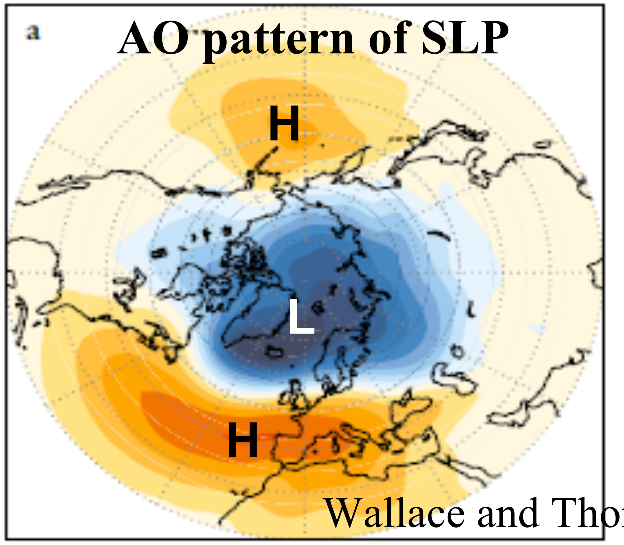
a Discrepancy in the Warming Pattern of the IPCC Model Projections

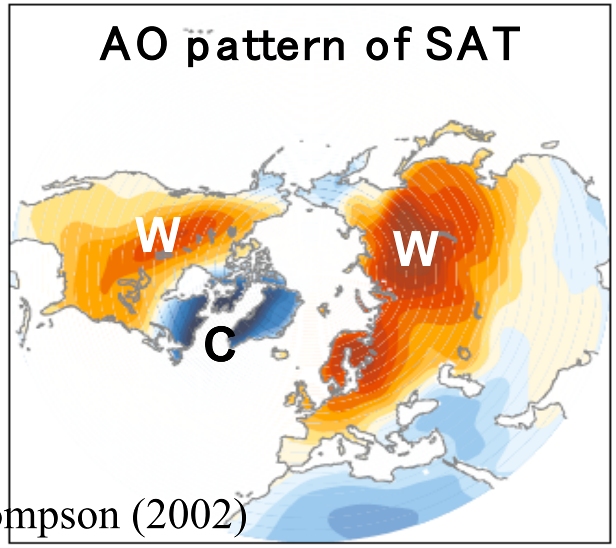
Hiroshi L. Tanaka

Center for Computational Science,
University of Tsukuba, Japan

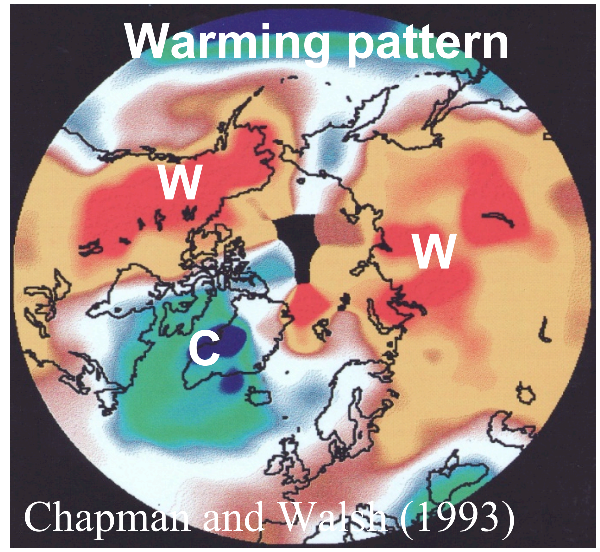
NICAM at CCS

Arctic Oscillation and Global Warming





Wallace and Thompson (2002)

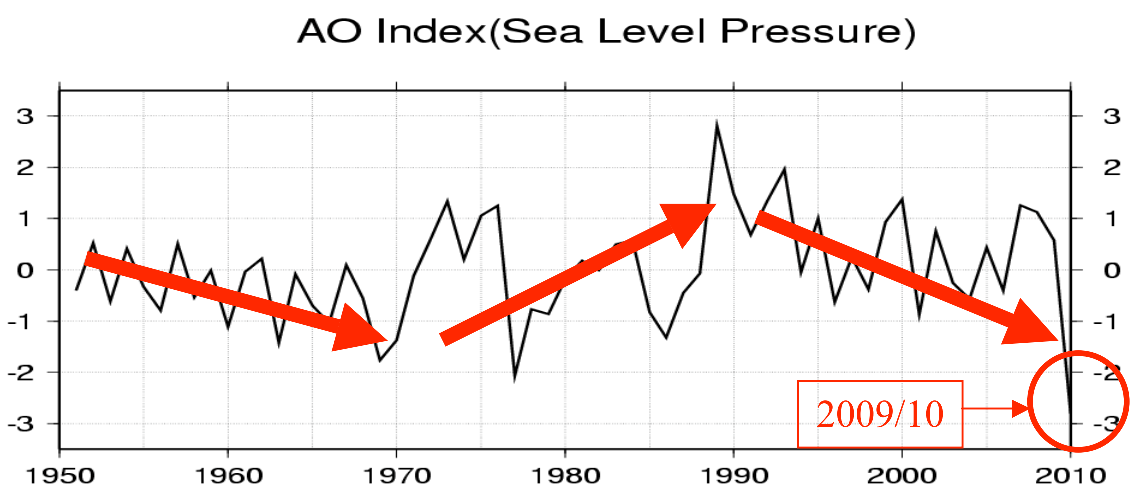


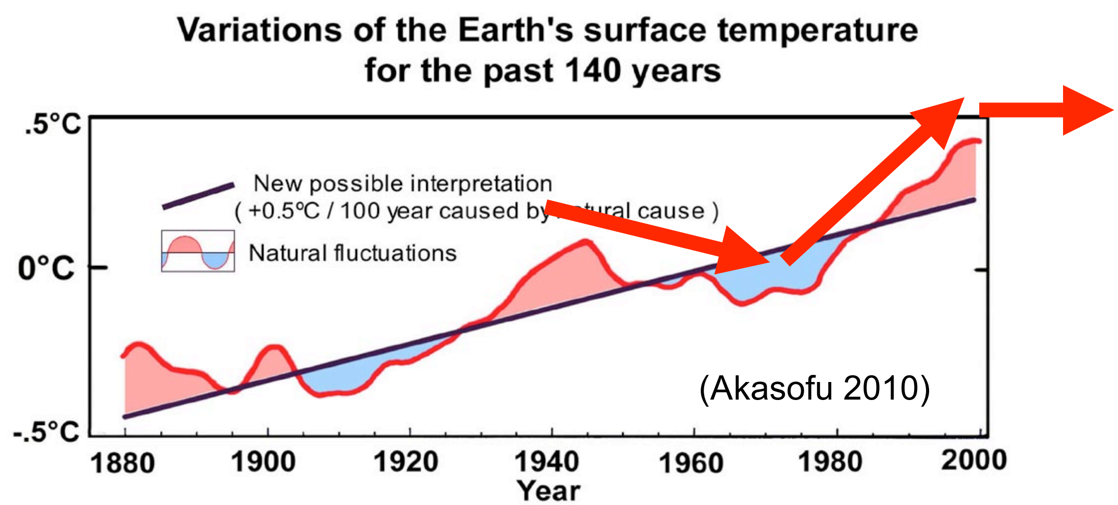
Chapman and Walsh (1993)

- AO is defined by EOF-1 of SLP (Thompson and Wallace 1998).
- AO pattern of SAT shows warming at Siberia and North America and cooling at Greenland (Thompson et al. 2002).

→ About half of the variance of the observed warming pattern is explained by AO (Thompson et al. 2002).

AO Index (AOI) and SAT



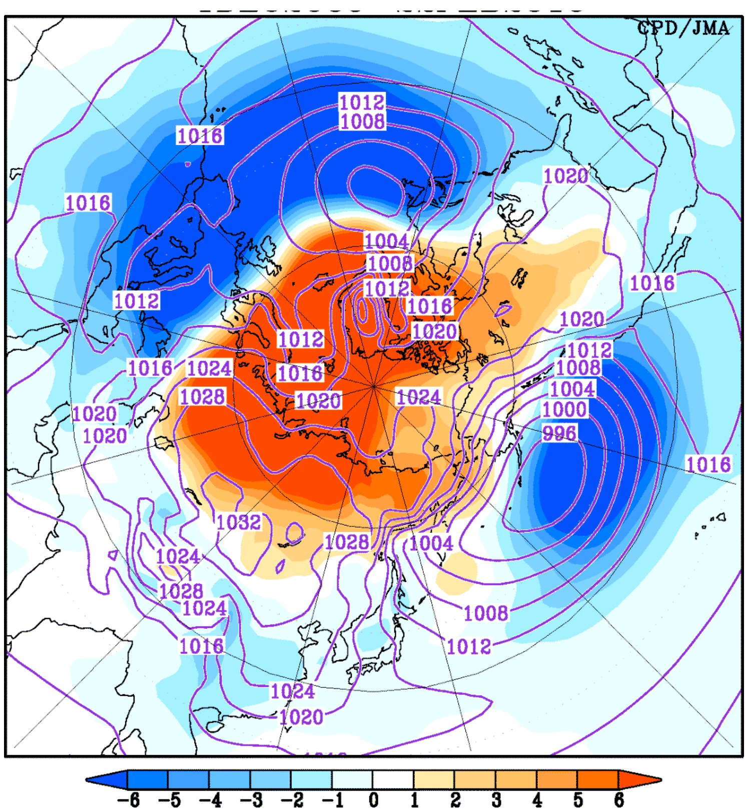


- **Decadal variation of AOI coincides with**
- **Cooling for 1940-1970, warming for 1970-1990,**
- **warming stopped for**
- **2000-**

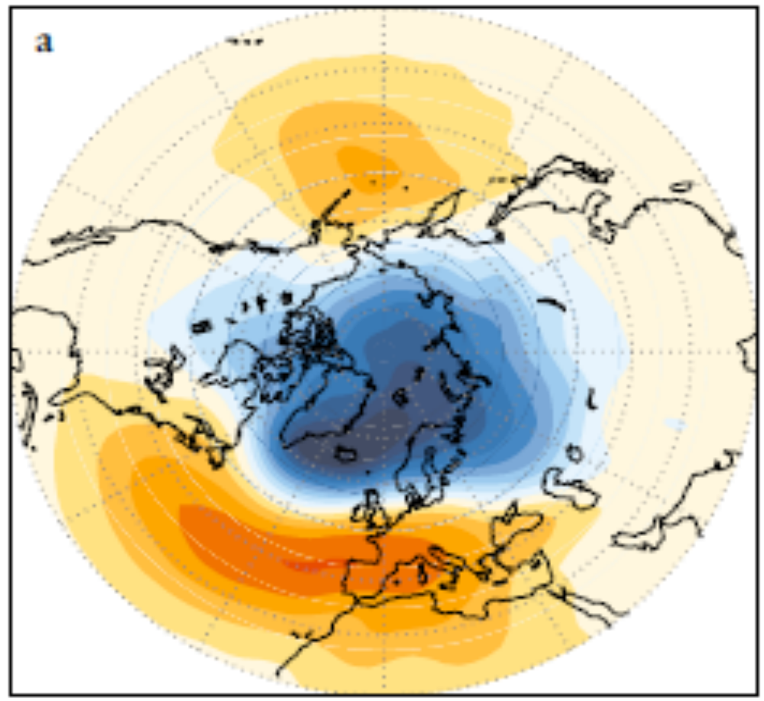
big AO minus for 2009/10

AO pattern of SLP and anomaly for 2009/10

2009/10



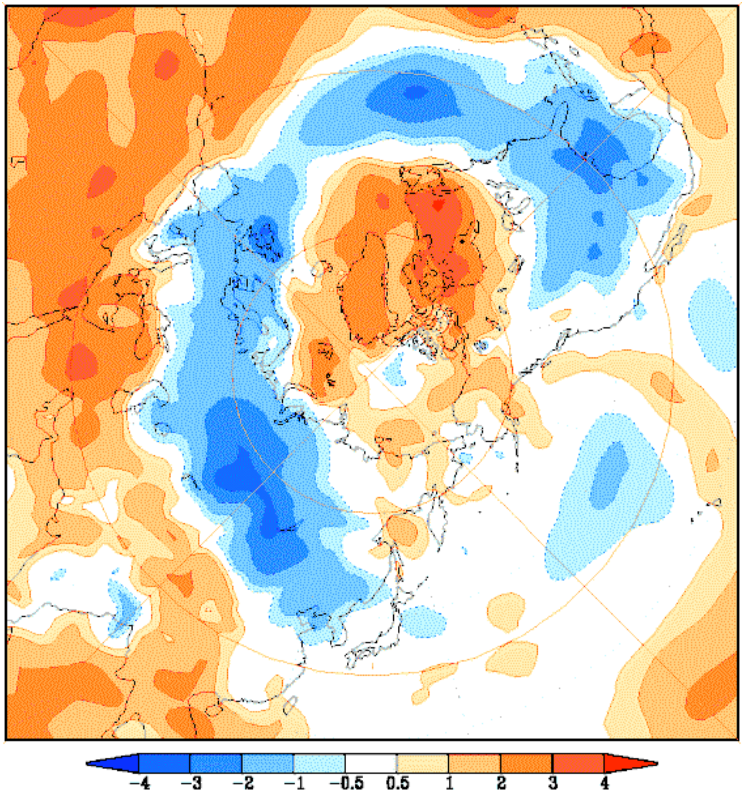
The anomaly shows AO negative pattern

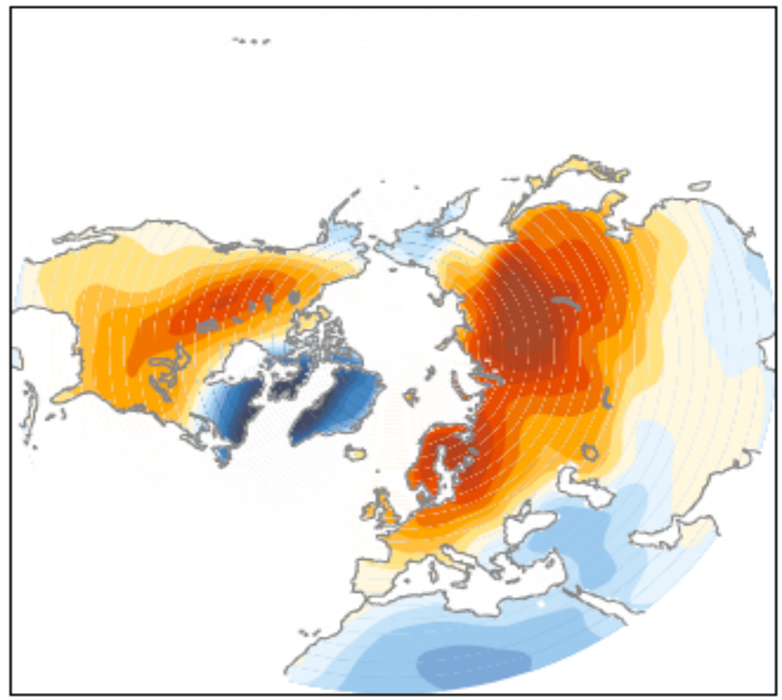


AO pattern of SAT and anomaly for 2009/10

2009/10

The anomaly shows AO negative pattern



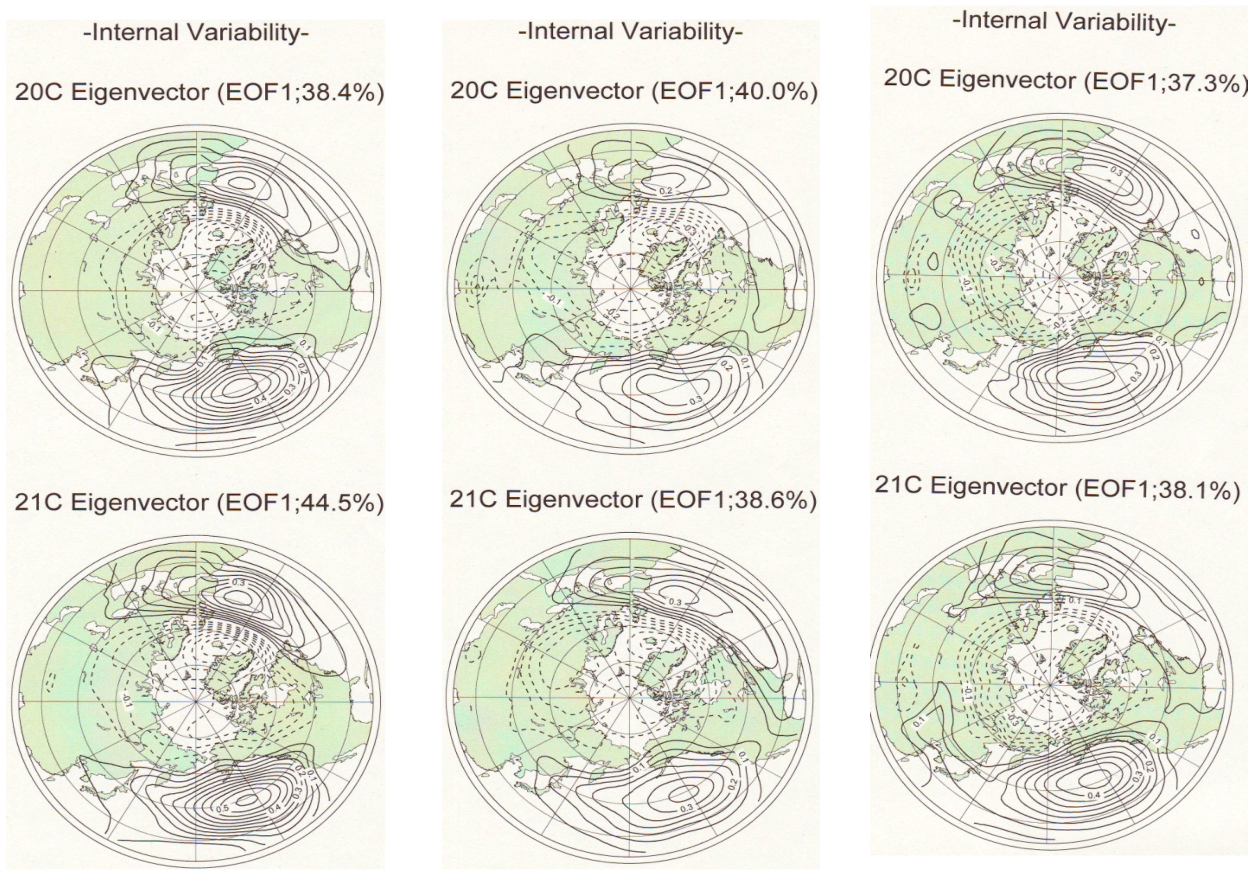


AO analyzed in IPCC-AR4 models

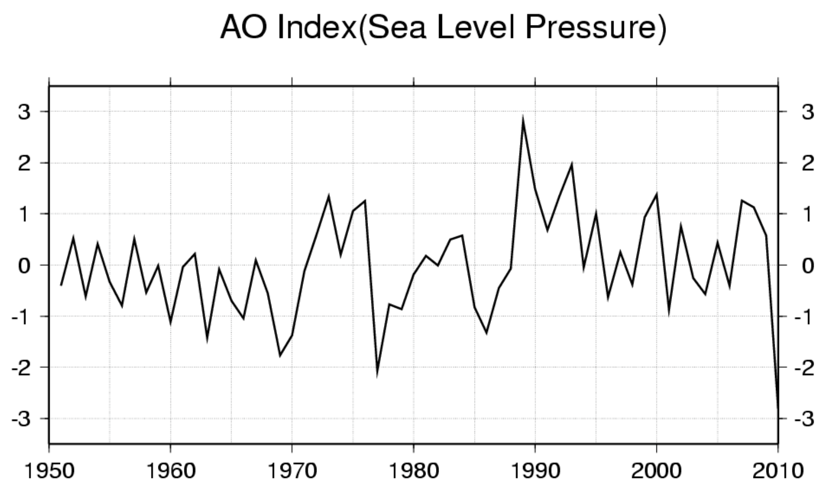
Internal variability shows AO pattern.

(Ohashi and Tanaka 2009)

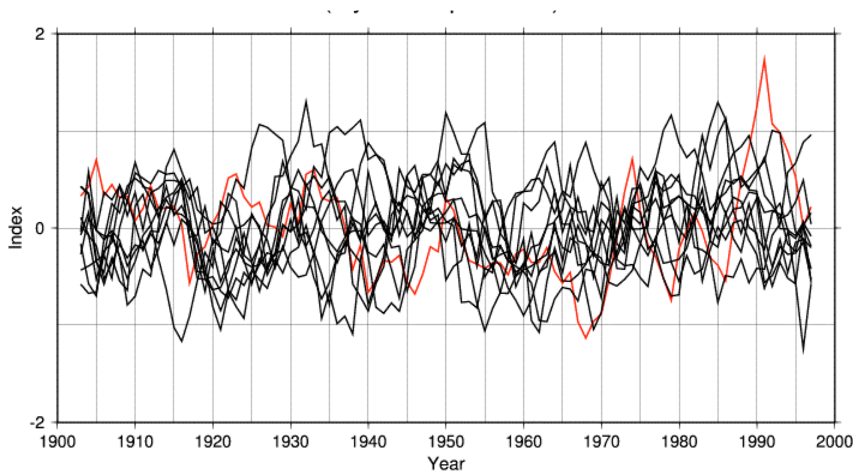
MRI MIROC NCAR

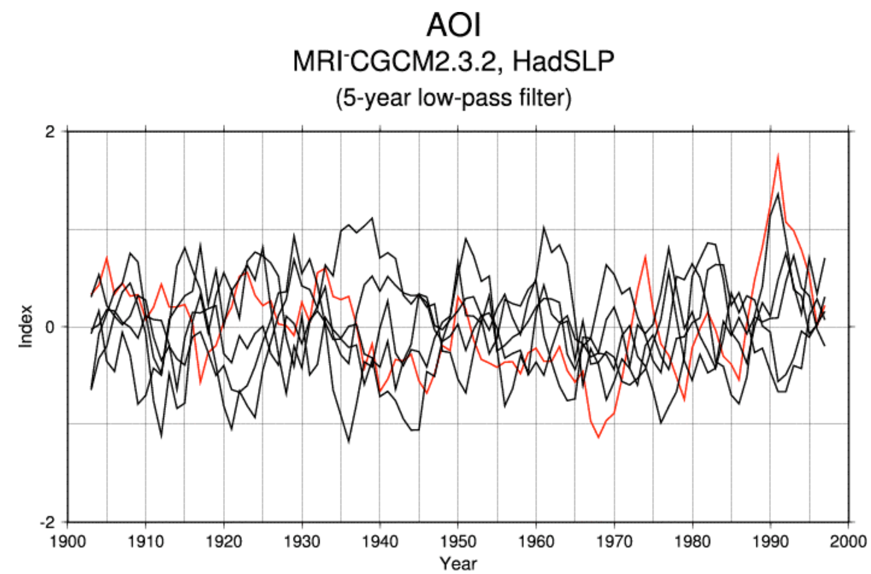


Observation



AO may be a realization of stochastic process.

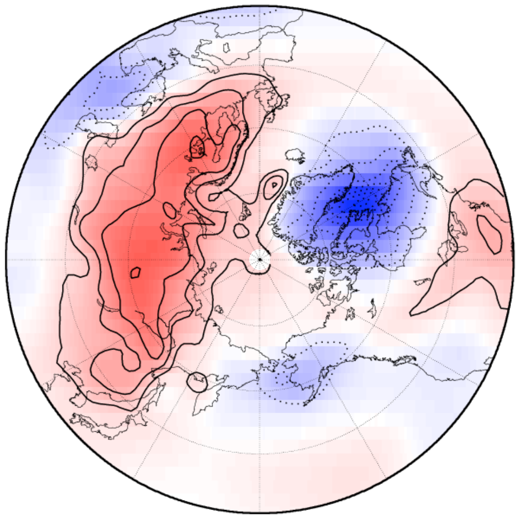




AOI by 10 IPCC-AR4 models

AOI by MRI ensemble projection

AOI vs SAT
NCEP/NCAR reanalysis
(1951-2010 DJF in K)
(Sea Level Pressure)

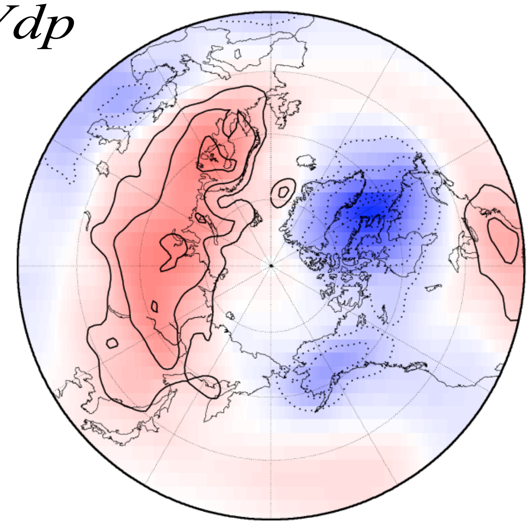


$$\frac{\partial p_s}{\partial t} \approx -\int_0^{p_s} \nabla \cdot V dp$$

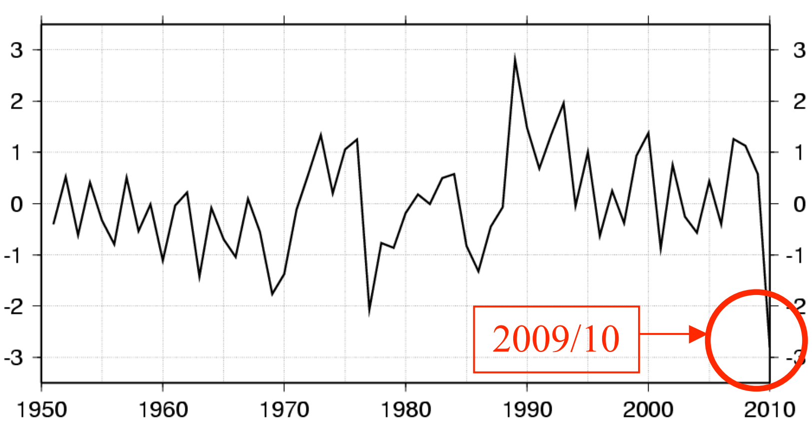
$$\approx \frac{p_s}{g h_0} \frac{\partial \phi_0}{\partial t}$$

SAT regressed with the AOI

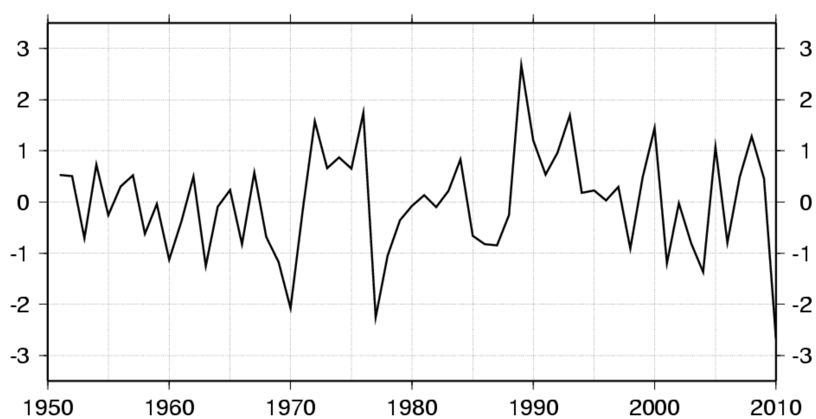
AOI vs SAT
NCEP/NCAR reanalysis
(1951-2010 DJF in K)
(Barotropic Component)



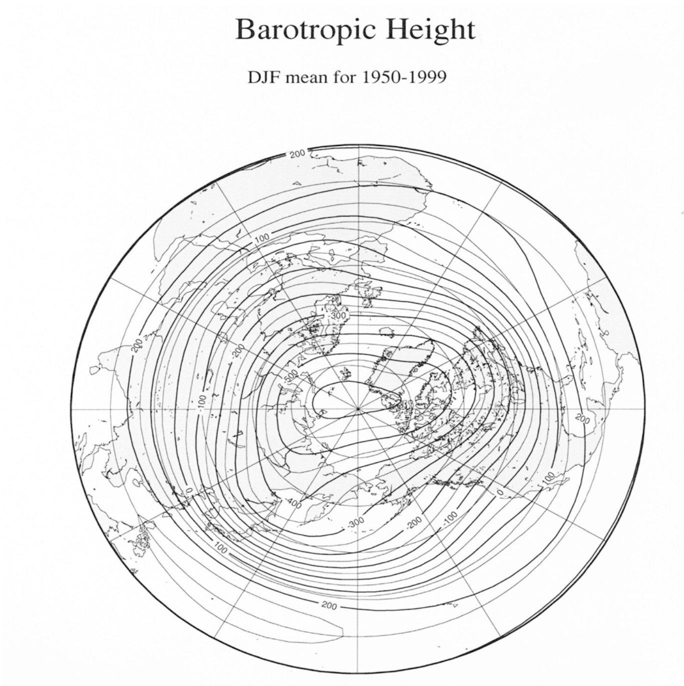
AO Index(Sea Level Pressure)



AO Index(Barotropic Component)



Singular Eigenmode Theory of AO



Climate basic state

$$w_i = \overline{w_i} + w_i'$$

EVP and SVD analysis

$U = (u, v, \phi')$, ϕ' : Deviation from global mean

$$M\frac{dU}{dt} + LU = N + F \qquad \text{Primitive equations}$$

$$\frac{dw_i}{d\tau} + i\sigma_i w_i = -i\sum_{jk} r_{ijk} w_j w_k + f_i \qquad \text{3D spectral model}$$

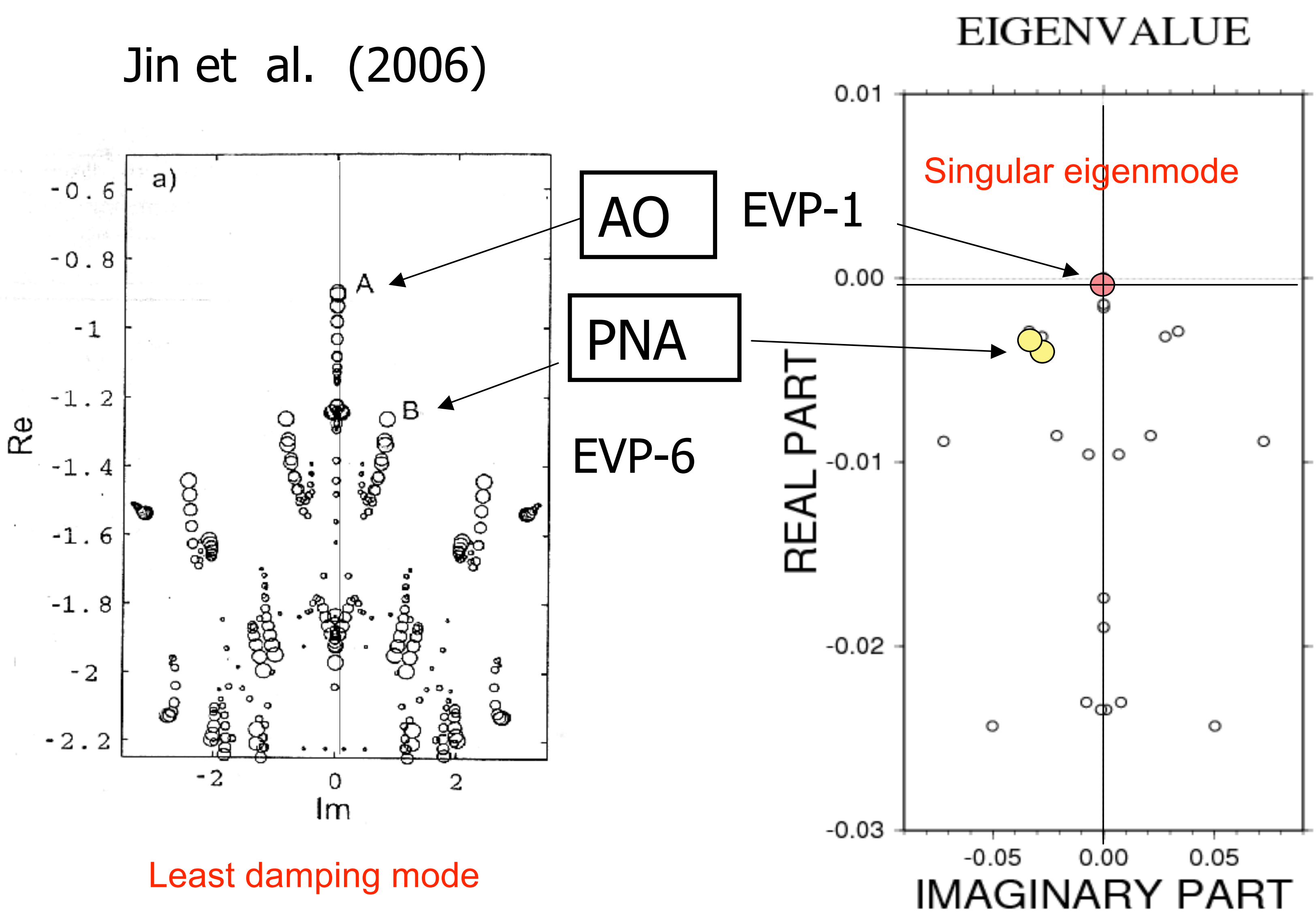
Construct a barotropic model from 3D model

$$\frac{dx}{dt} = Ax + f \qquad \text{Linearized by a basic state}$$

$$\frac{dx}{dt} = Ax \xrightarrow{EVP} \nu x = Ax$$

$$x = -A^{-1} f \xrightarrow{SVD} x = -V\Sigma^{-1}U^T f$$

(Tanaka and Matsueda 2005)


Jin et al. (2006)
a)
A
B
Re
Im
AO
PNA
EVP-1
EVP-6
EIGENVALUE
Singular eigenmode
REAL PART
IMAGINARY PART
Least damping mode

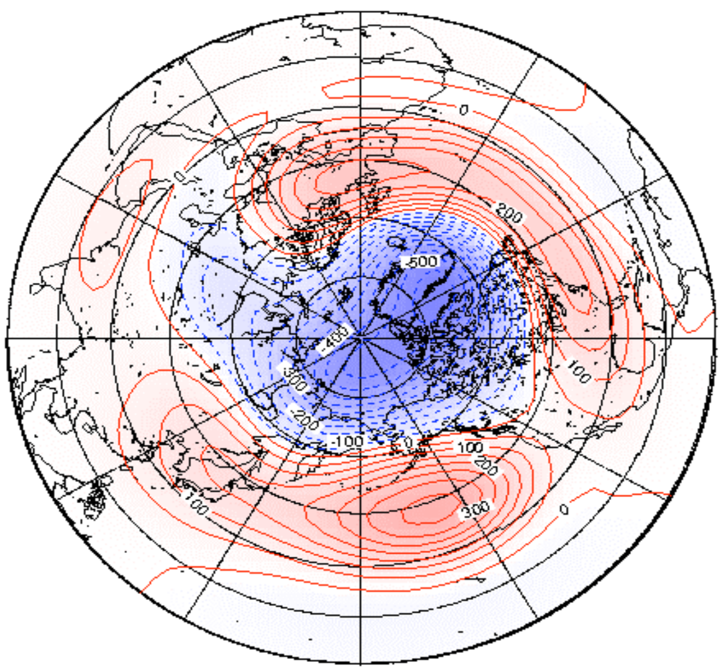
Singular Eigenmode Theory of AO

Observation

Barotropic Height

Arctic Oscillation (DJF)

EOF-1

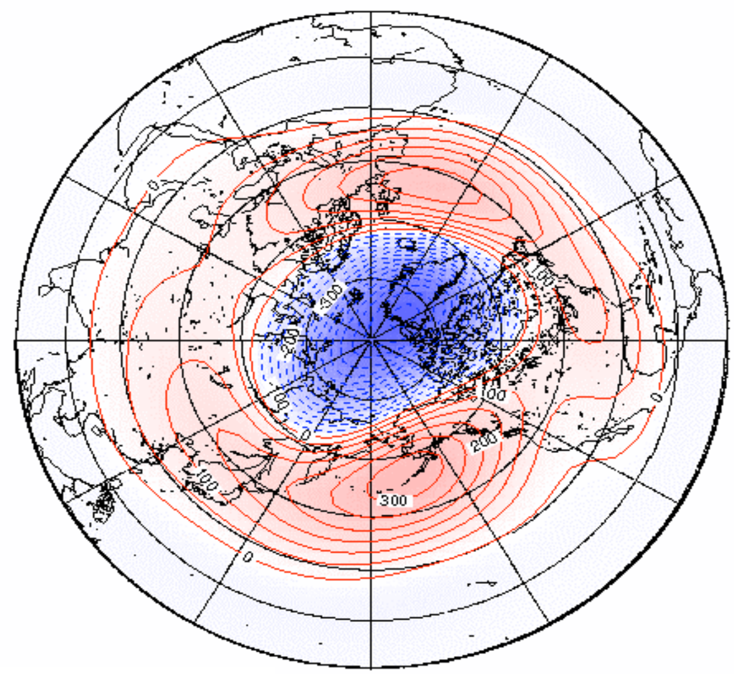


Theory

Barotropic Height

Standing eigenmode EVP-1

EVP-1

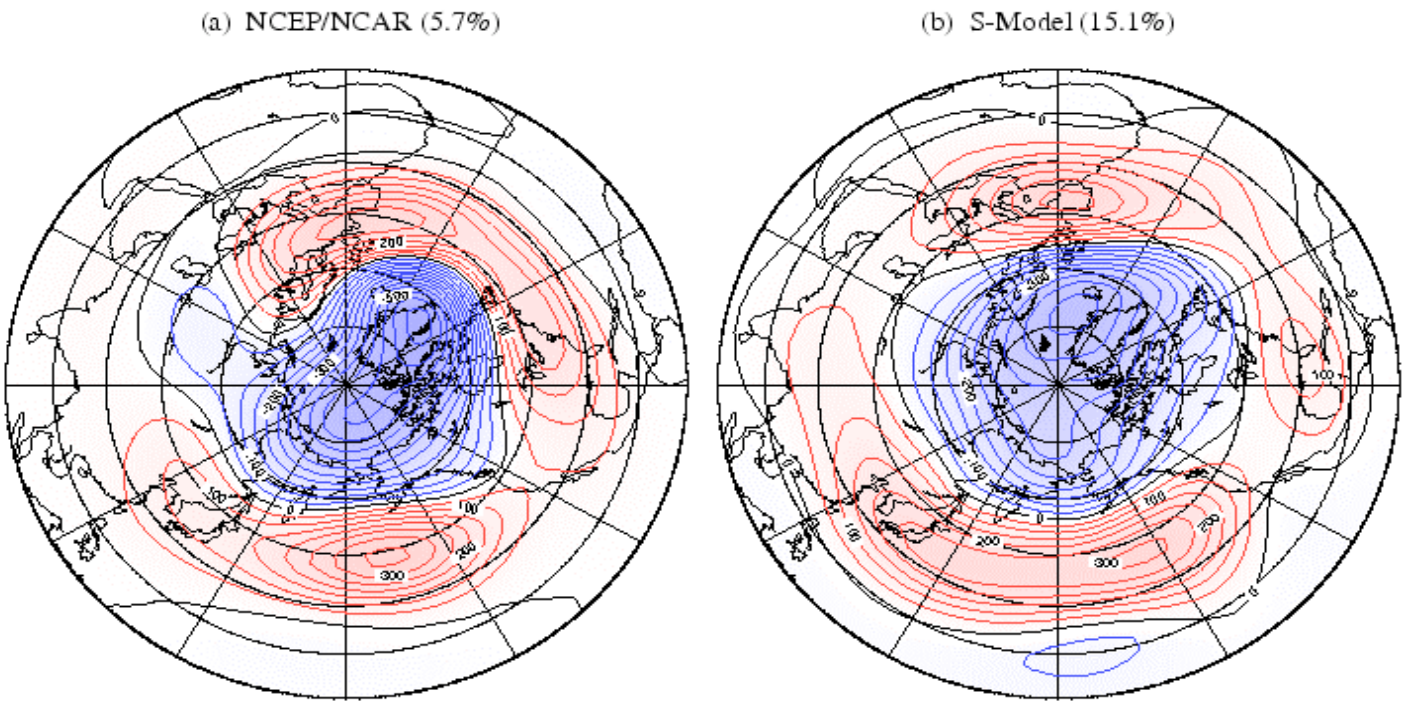


(Tanaka and Matsueda 2005, JMSJ)

AO in Observation and S-model

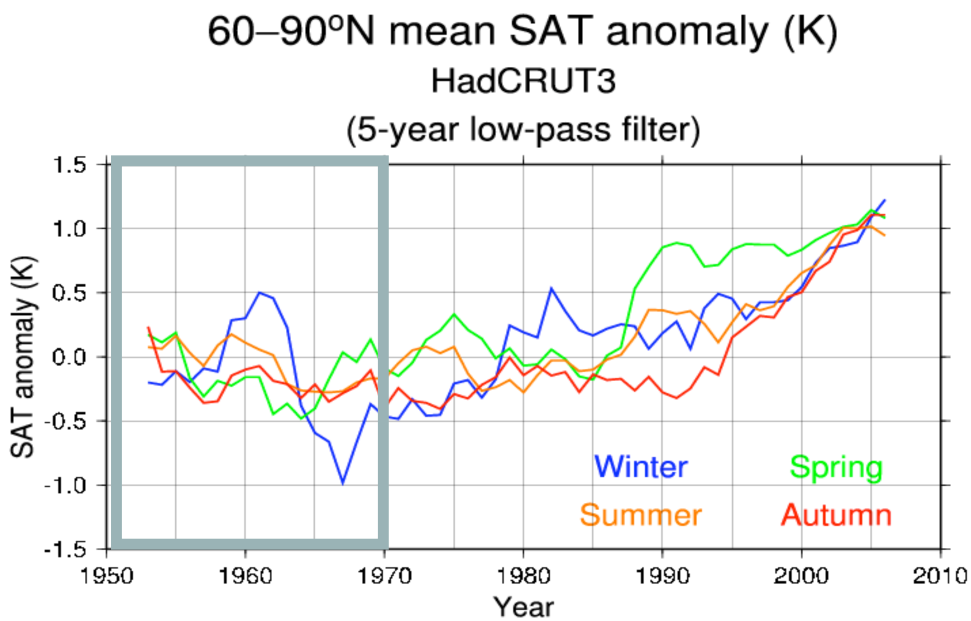
Barotropic Height
EOF-1
1950-2000

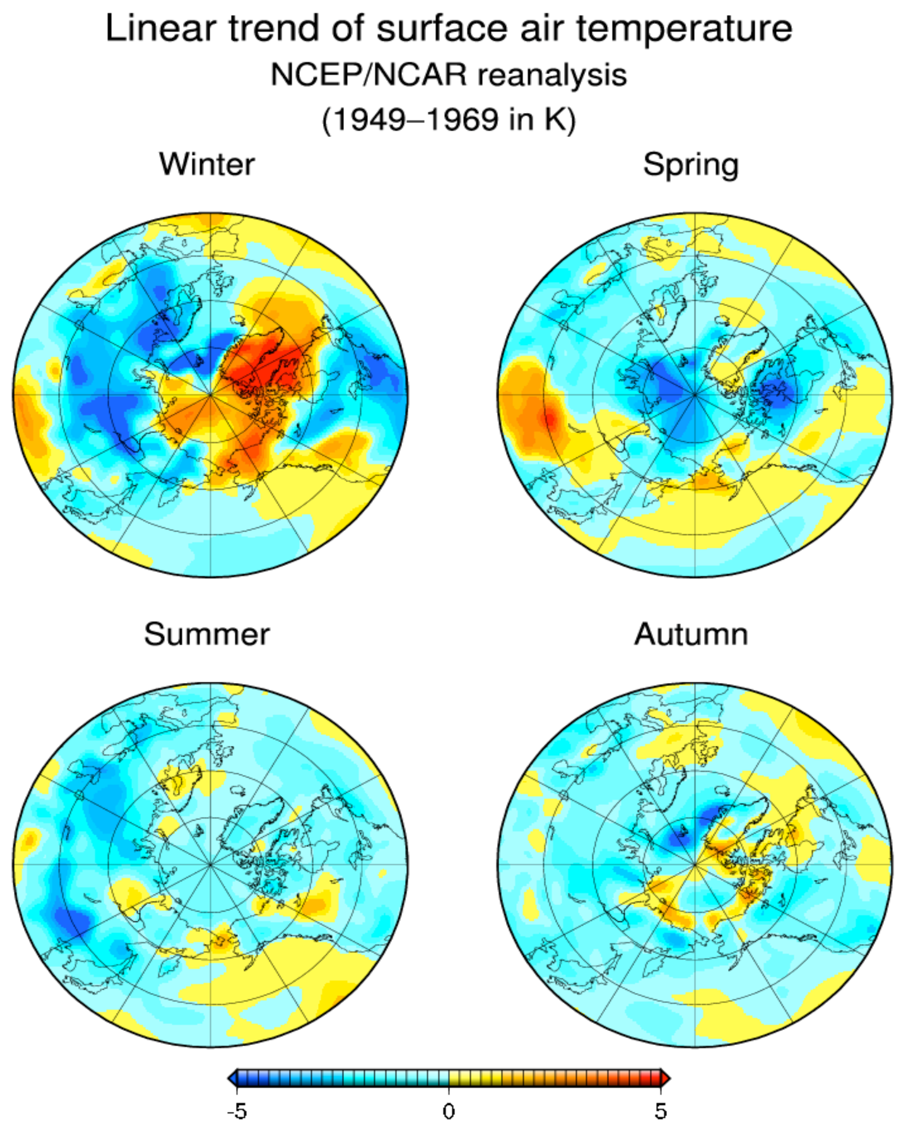
(Tanaka 2003, JAS)



$$\frac{dw_i}{d\tau} + i\sigma_i w_i = -i\sum_{jk} r_{ijk} w_j w_k + f_i \quad \text{Barotropic S-model}$$

Observed SAT Trend (1949-1969)

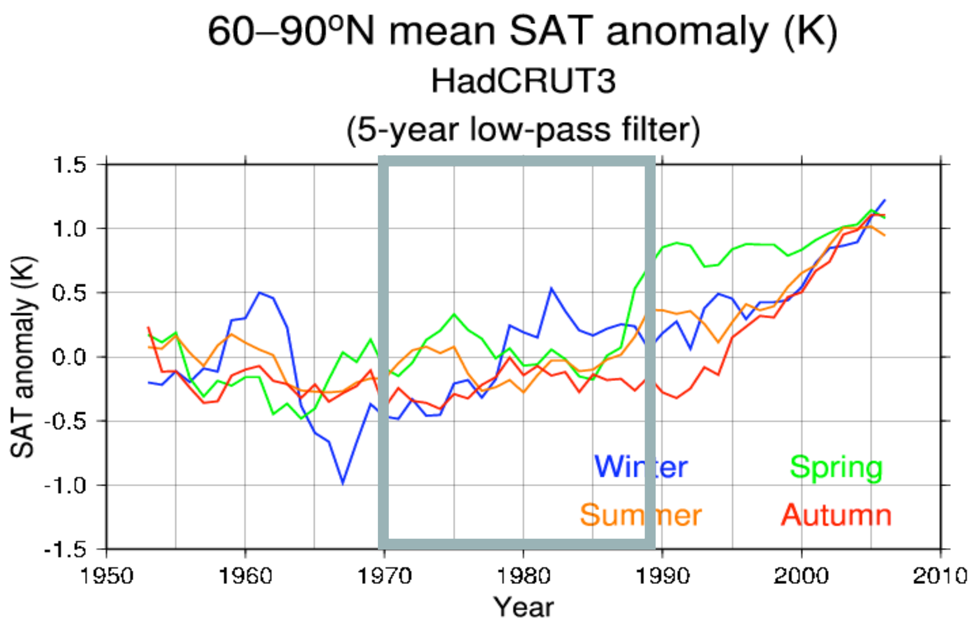


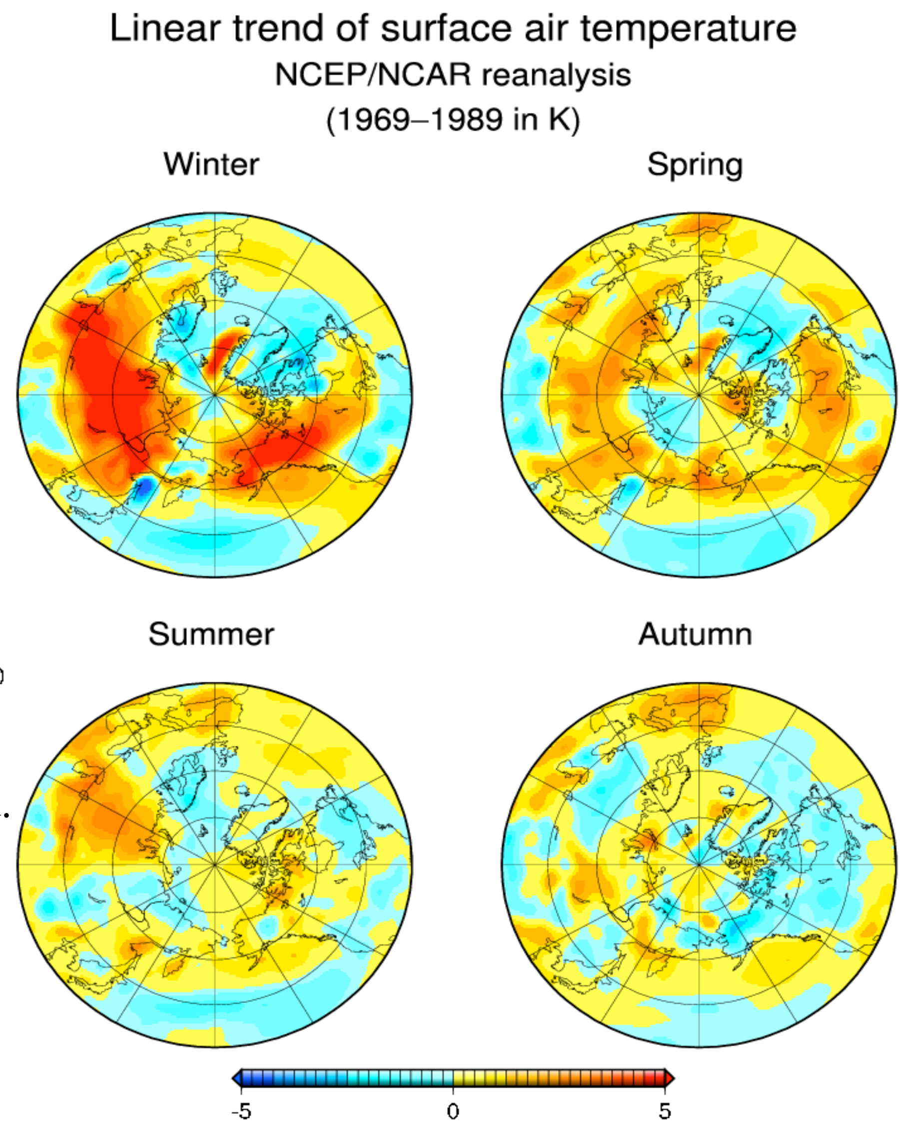


- Moderate cooling when AOI shows negative trend.
- Cooling pattern is similar to AO negative pattern
- No clear trend in spring to fall

(Ohashi and Tanaka 2010)

Observed SAT Trend (1969-1989)

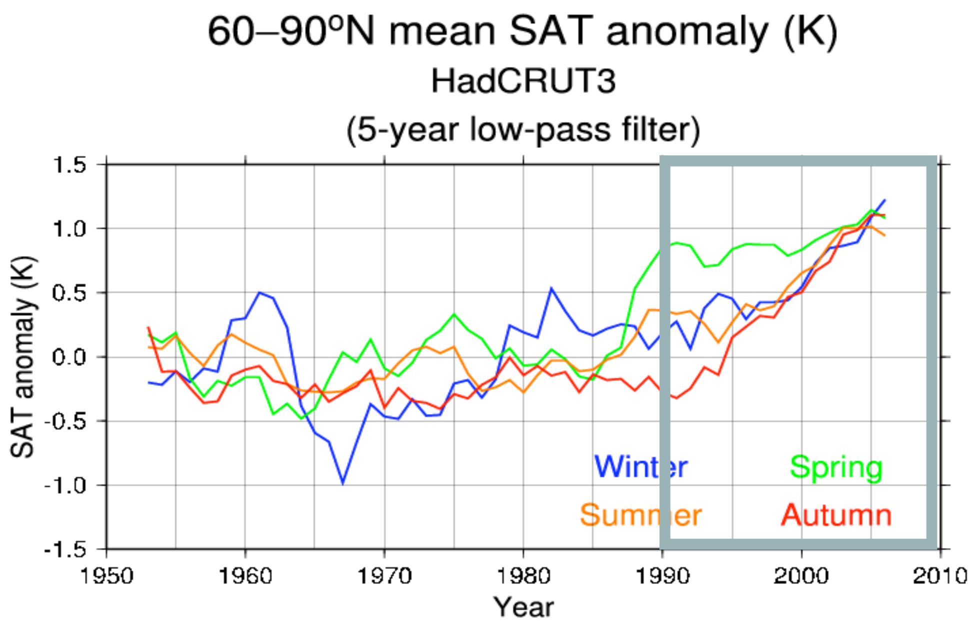


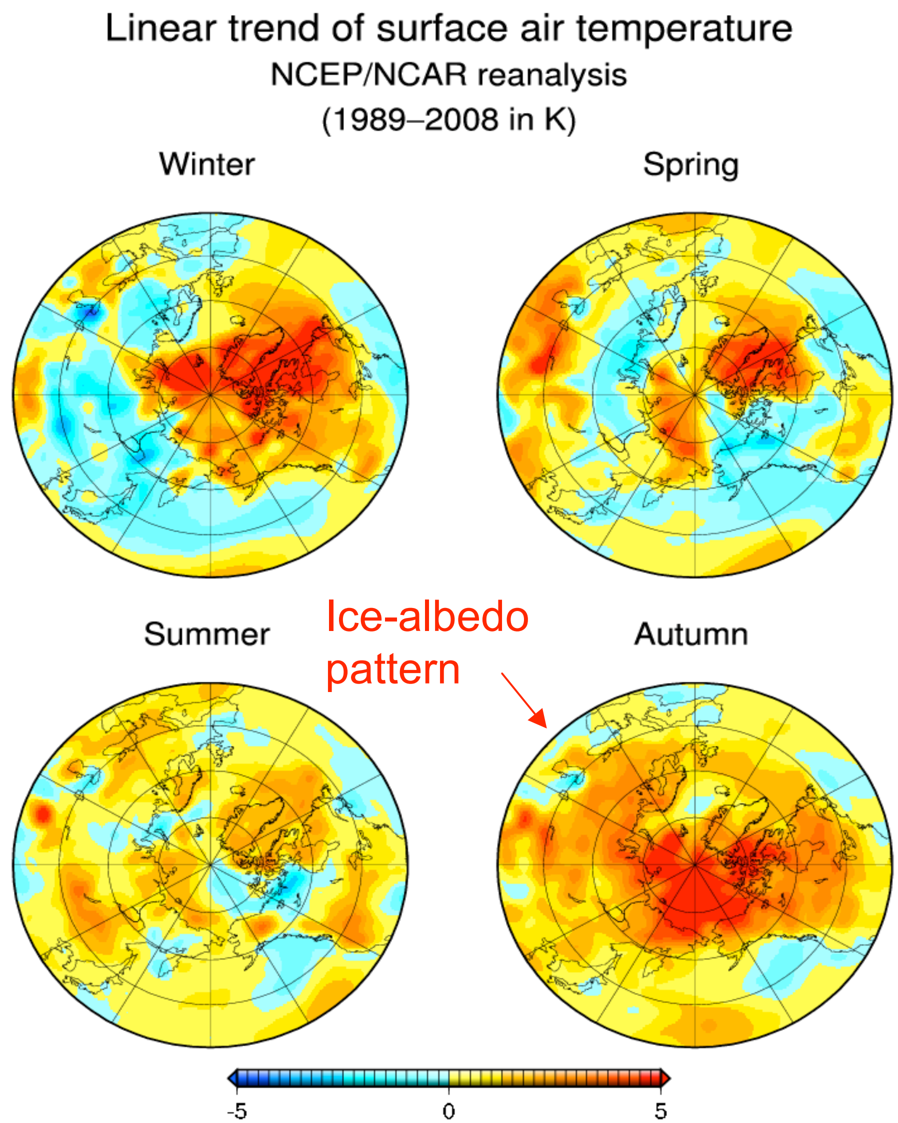


- Clear warming trend in winter when AOI increased.
- The warming pattern is recognized as AO positive.
- No clear trend in spring to fall

(Ohashi and Tanaka 2010)

Observed SAT Trend (1989-2008)

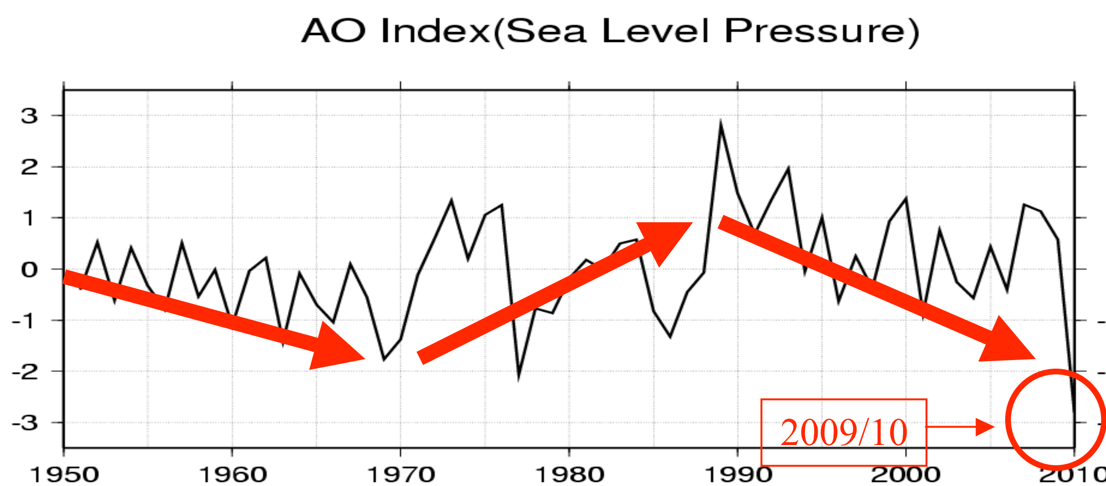




- Warming trend is AO negative pattern in winter when AOI shows negative trend
- Warming trend is Ice-albedo pattern in fall .

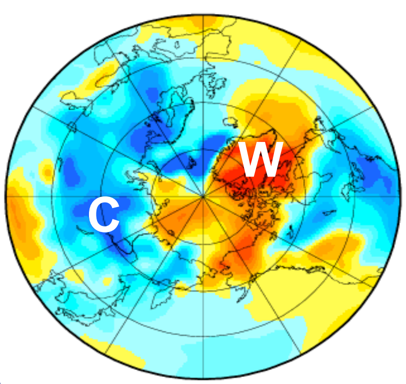
(Ohashi and Tanaka 2010)

Long-term variation of AOI and SAT



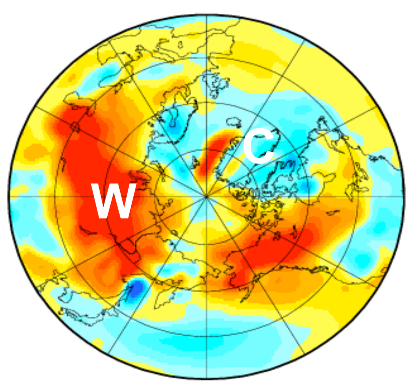
AO is an unpredictable natural variability, which controls the decadal trends of SAT.

Winter



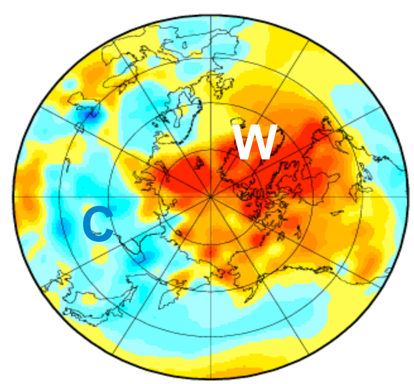
AO negative

Winter



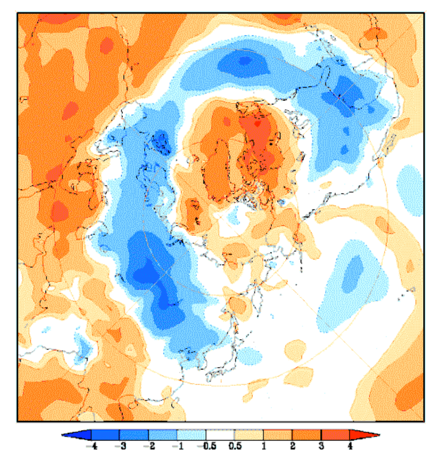
AO positive

Winter



AO negative

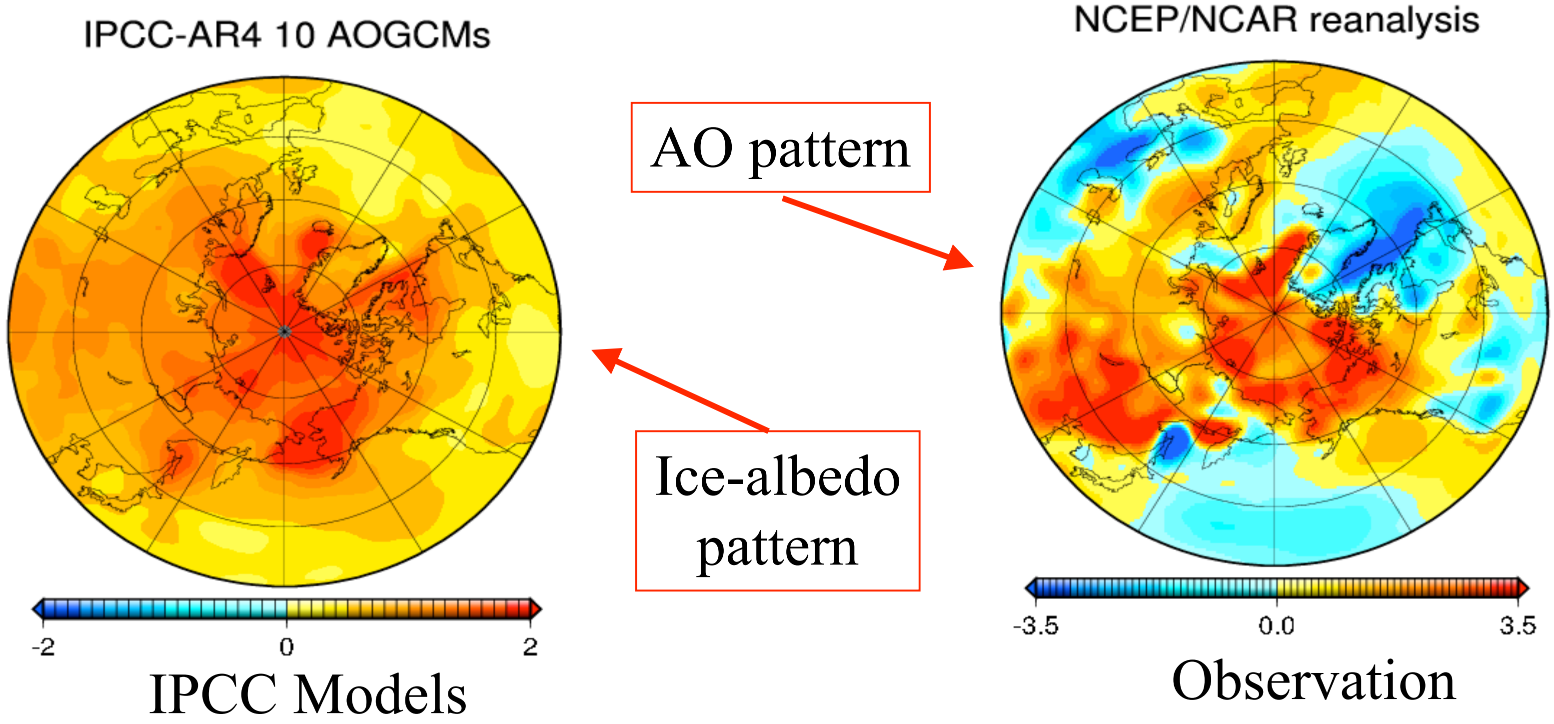
2009/2010



Trend of Surface Air Temperature

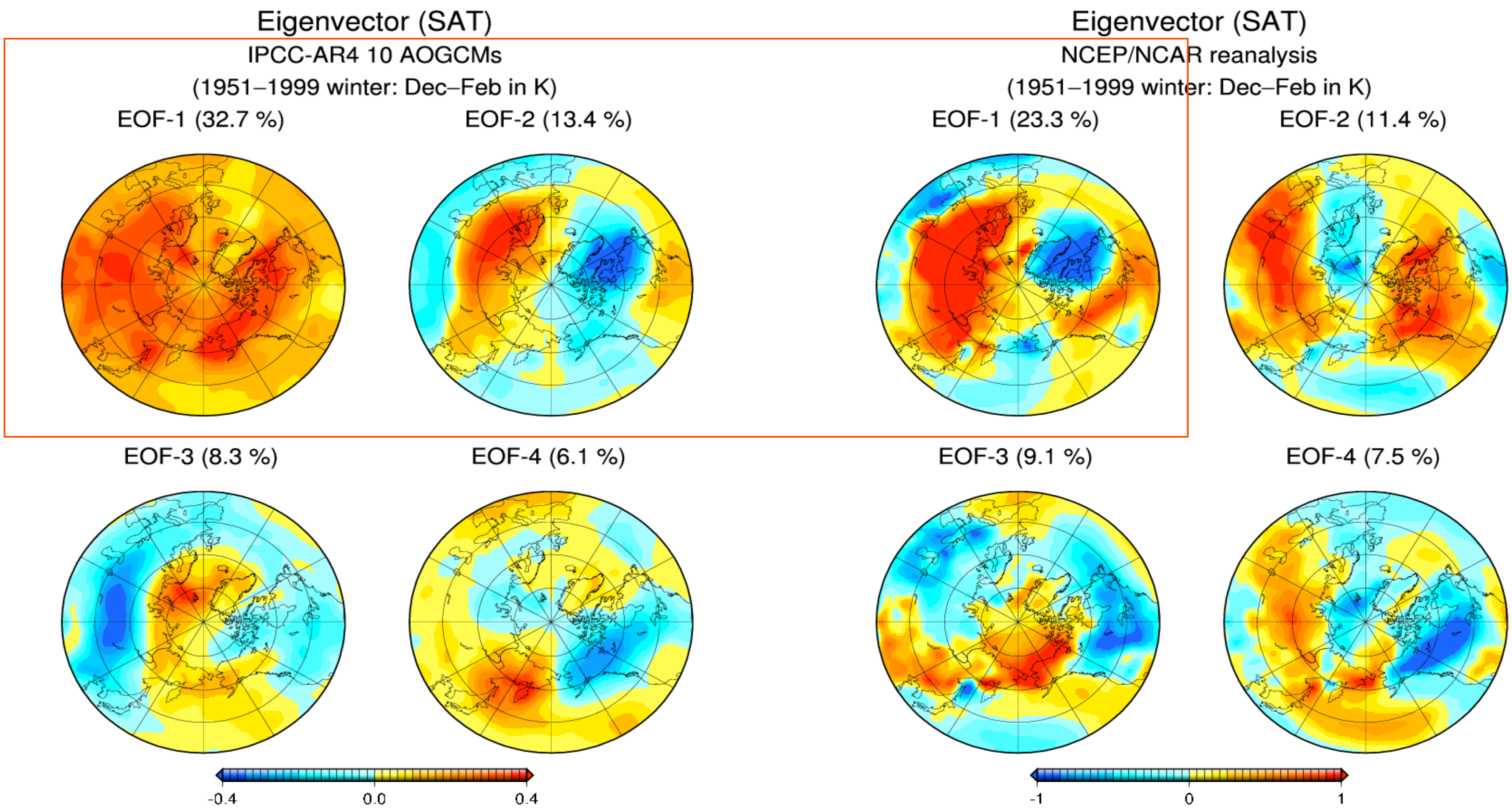
Linear trend of surface air temperature

(1951–1999 winter: Dec–Feb in K)



- **Observation shows that the warming is AO pattern (natural variability), but the IPCC models show that the warming is Ice-albedo pattern (anthropogenic forcing).**

EOF Analyses of IPCC Models and Observation



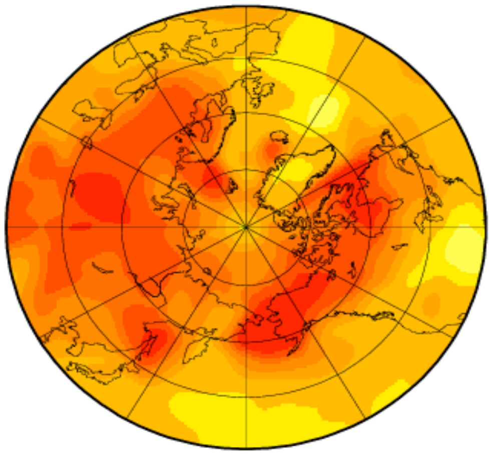
- **In the IPCC models the warming occurs by the anthropogenic forcing, which is not seen in the observation, and AO appears as EOF-2 in the model.**

Inconvenient truth of IPCC Models

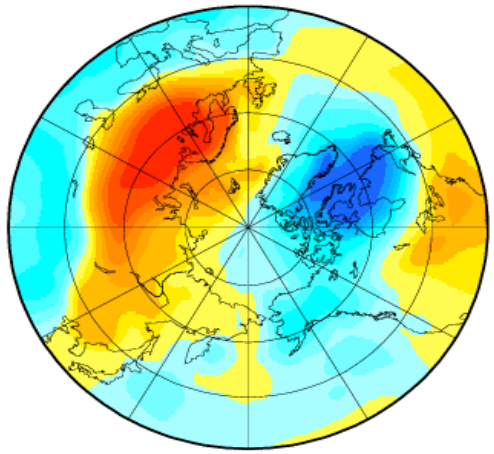
10 IPCC Model Mean

Observation

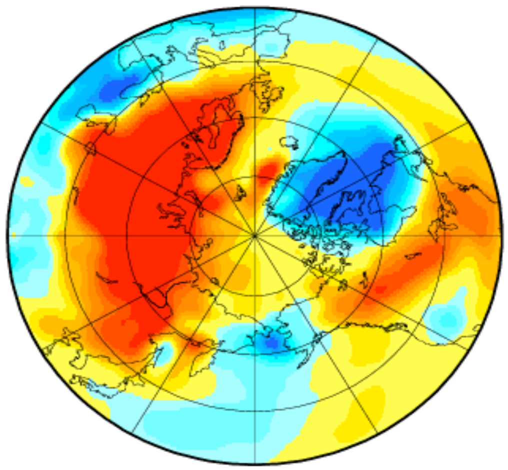
EOF-1 (32.7 %)



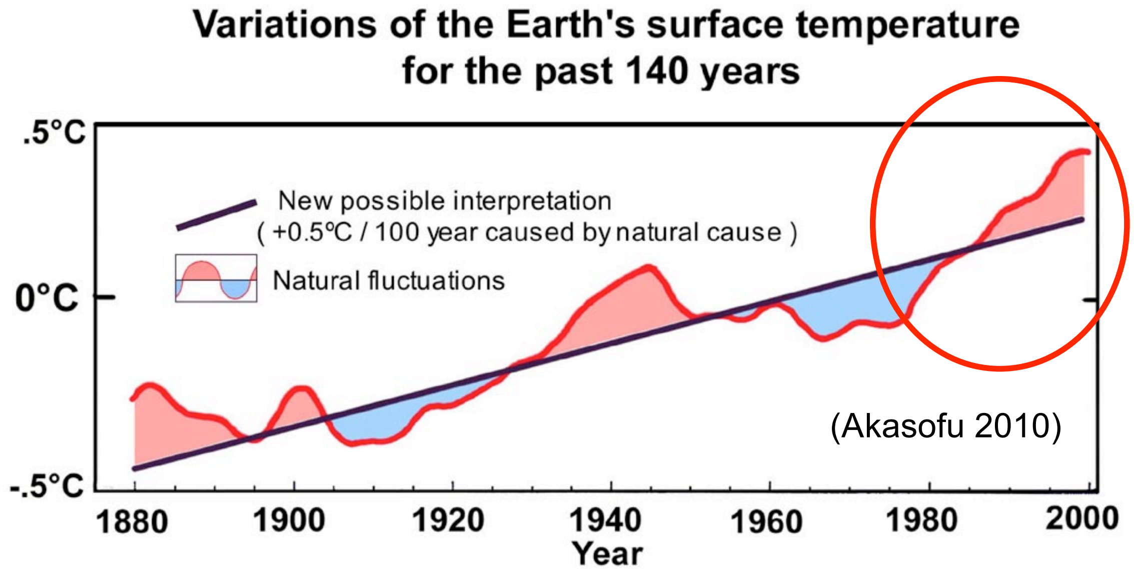
EOF-2 (13.4 %)



EOF-1 (23.3 %)

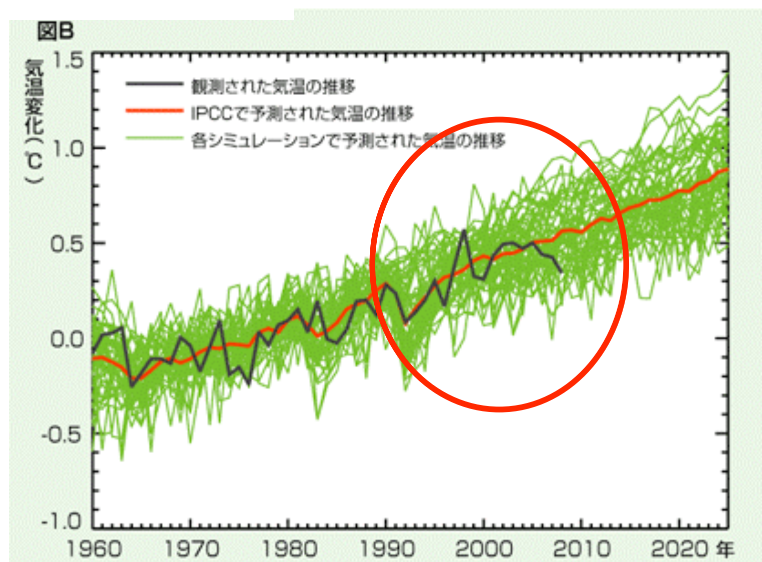


- **In observation, the warming occurs by natural variavility as AO pattern, while it occurs by Ice-albedo pattern in the IPCC models due to the anthropogenic forcing: a discrepancy in the IPCC models.**
- **The AO pattern appears in EOF-2 in the IPCC models with variance ratio of 32.7:13.4 (i.e. 5:2) for the 10 model mean: i.e. 5:20 in theory for one model.**



- **The long-term trend may be anthropogenic.**
- **Natural variability of AO is superimposed on the recent global warming.**

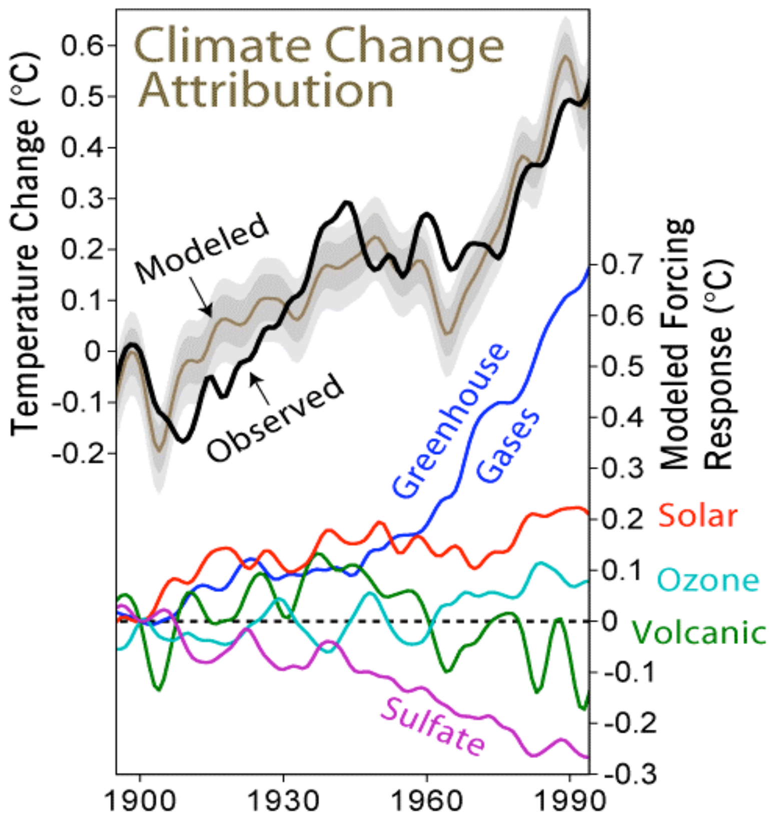
- **The warming has stopped in the 21th Century by natural variability.**
- **Rapid warming after 1970s contains large fraction of unpredictable natural variability of AO.**
- **Hence, the models should not fit with that rapid warming.**



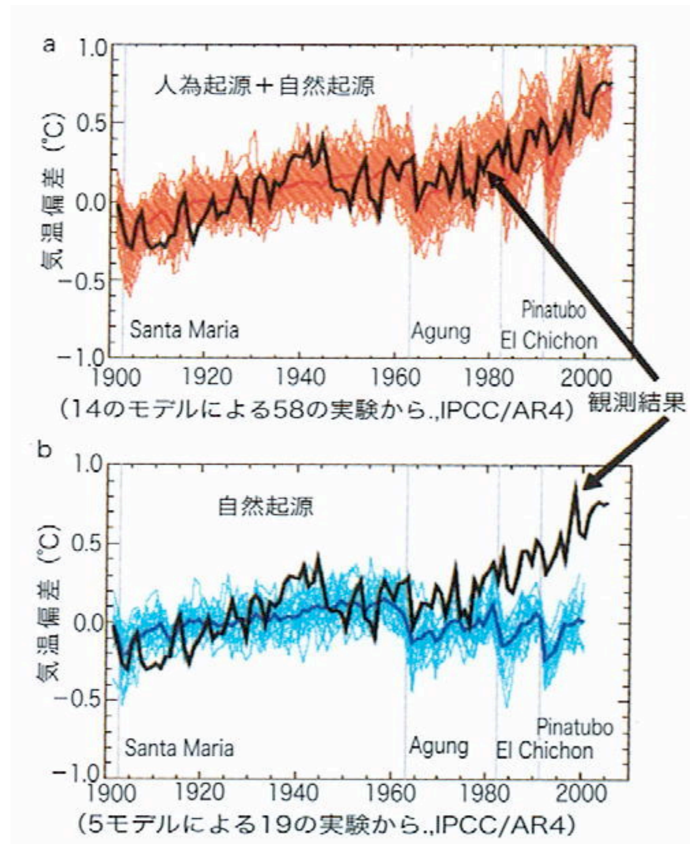
(Emori 2009)

Warming by anthropogenic GHG

Warming is separated in every contributions

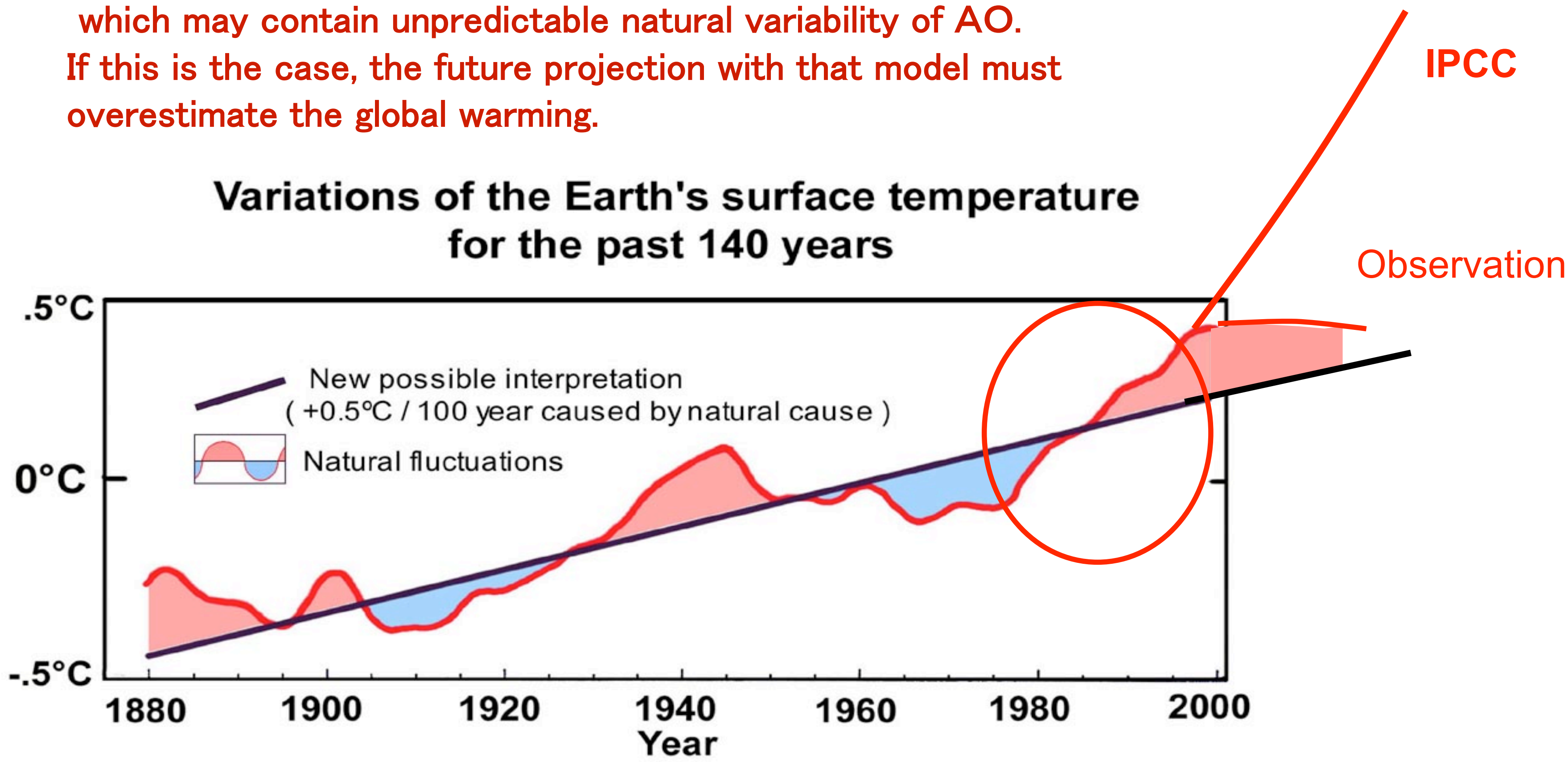


IPCC-AR4 models are justified



- Natural variability and warming trend

IPCC models are developed (tuned) to fit the rapid warming for 1970–1990, which may contain unpredictable natural variability of AO.
If this is the case, the future projection with that model must overestimate the global warming.



Ohashi and Tanaka (2010, SOLA)

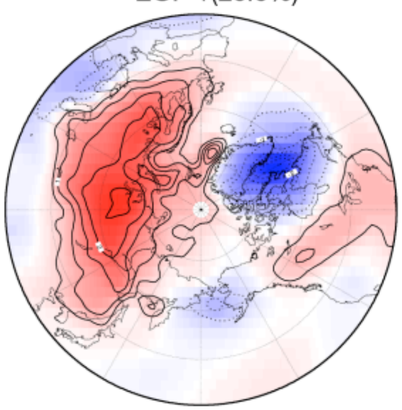
We attempt to exclude the AO from global warming

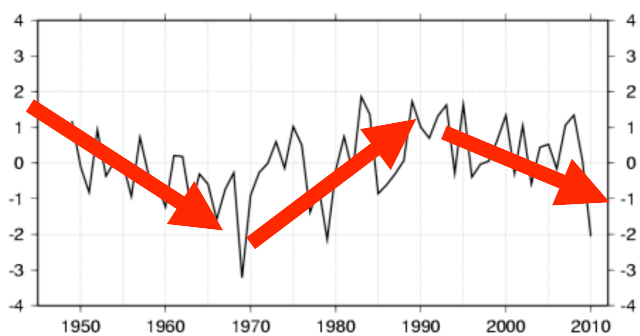
$$\overline{T(x,t)} = \overline{a_1(t)T_1(x)} + \overline{a_2(t)T_2(x)} + \ldots + \overline{a_N(t)T_N(x)} \quad \text{EOF}$$

$$\overline{T(x,t)} = \overline{a_2(t)T_2(x)} + \ldots + \overline{a_N(t)T_N(x)} \quad \text{without EOF-1}$$

Eigenvector (SAT)
NCEP/NCAR reanalysis
(48/49 - 09/10 DJF in K)

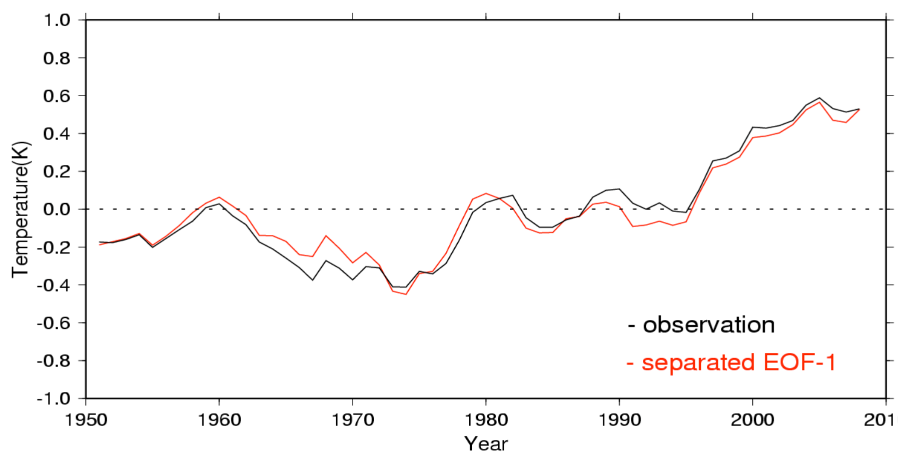
EOF-1(20.0%)





AO has the largest amplitude, but it is almost orthogonal to the global warming trend

NCEP/NCAR reanalysis
5-Year Low Pass Filter

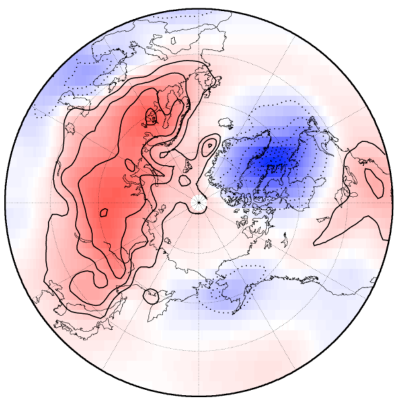


We attempt to exclude the AO from global warming

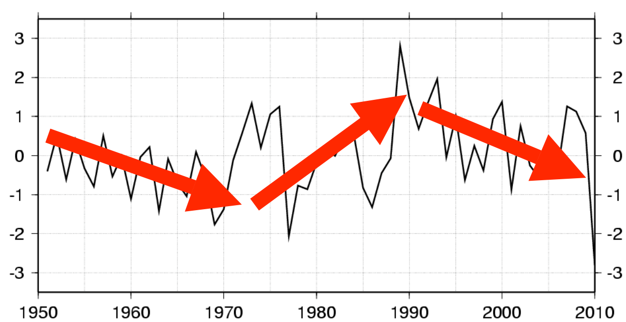
$$\overline{T(x,t)} = \overline{a_1(t)T_1(x)} + \overline{a_2(t)T_2(x)} + \ldots + \overline{a_N(t)T_N(x)}$$ Orthogonal Projection

$$\overline{T(x,t)} = \overline{a_2(t)T_2(x)} + \ldots + \overline{a_N(t)T_N(x)}$$ without AO (SLP)

AOI vs SAT
NCEP/NCAR reanalysis
(1951-2010 DJF in K)
(Sea Level Pressure)

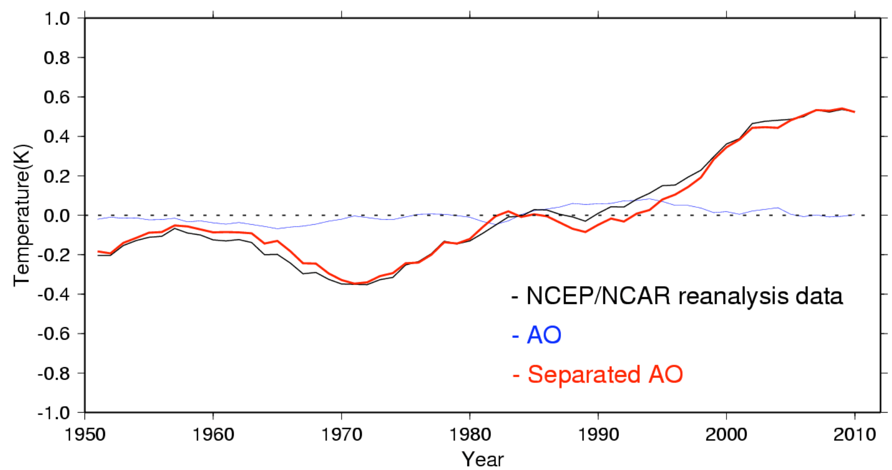


AO Index(Sea Level Pressure)



AO has the largest amplitude, but it is almost orthogonal to the global warming trend

NCEP/NCAR reanalysis(Northern Hemisphere)
AOI(Sea Level Pressure) vs SAT
11-Year Low Pass Filter



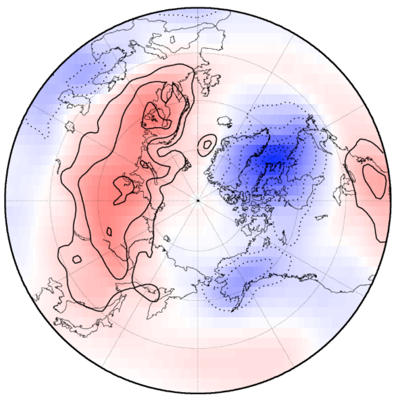
Another inconvenient truth of AO in global warming

$U = (u, v, \phi')$, ϕ' : Deviation from global mean

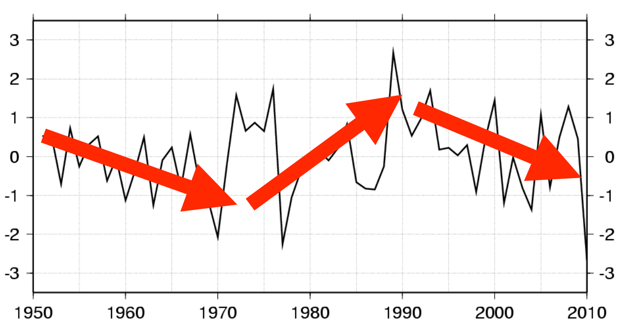
$$M \frac{dU}{dt} + LU = N + F$$ Primitive equations

$\overline{T'} = \overline{\phi_z'} = 0$: Dynamical model conserving availabl potential energy is orthogonal to the variation in global mean $\overline{T}$.

AOI vs SAT
NCEP/NCAR reanalysis
(1951-2010 DJF in K)
(Barotropic Component)

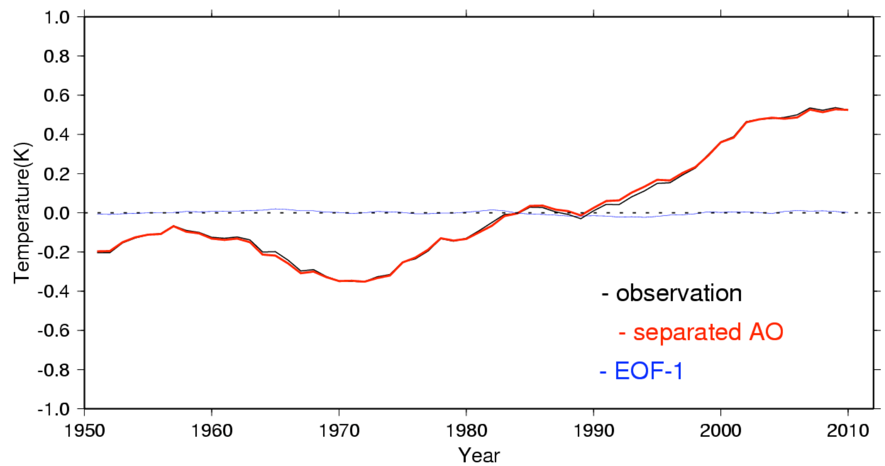


AO Index(Barotropic Component)



AO has the largest amplitude, but it is almost orthogonal to the global warming trend

NCEP/NCAR reanalysis(Northern Hemisphere)
AOI(Barotropic Component) vs SAT
11-Year Low Pass Filter

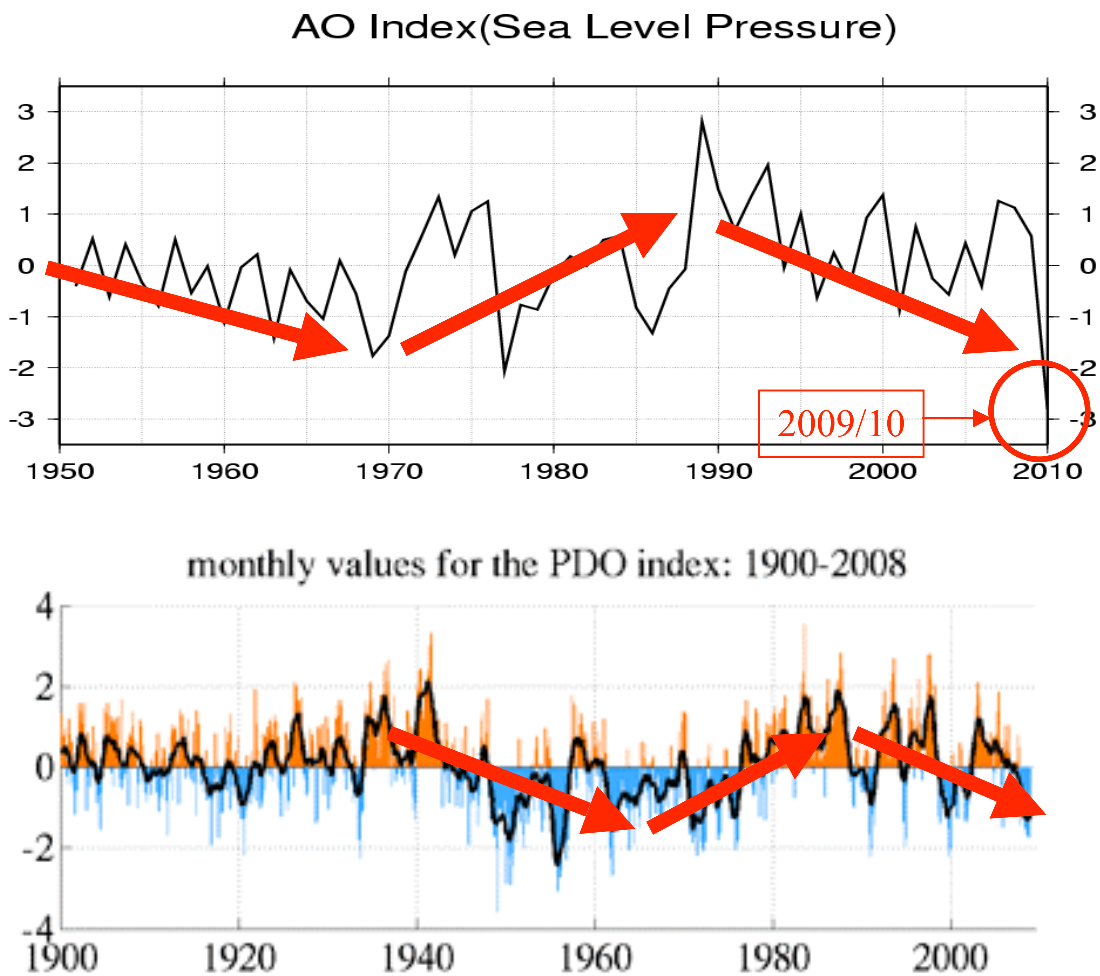


Summary

- AO is the most dominant natural variability in the Northern Hemisphere.
- AO may be understood as dynamical eigenmode of the atmosphere with zero eigenvalue.
- AO controls most of the local temperature variability in the Northern Hemisphere.
- However, it is found that the large variability of the AO is dynamically orthogonal to the global warming trend and the decadal variability.
- If the AO influences the global warming, it must be the indirect effect through climate subsystem.

Thank you.

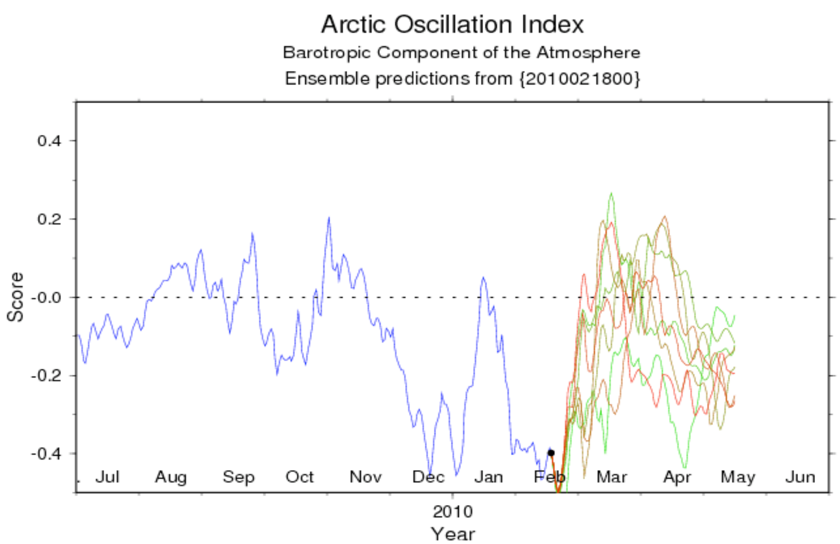
AOI and PDO

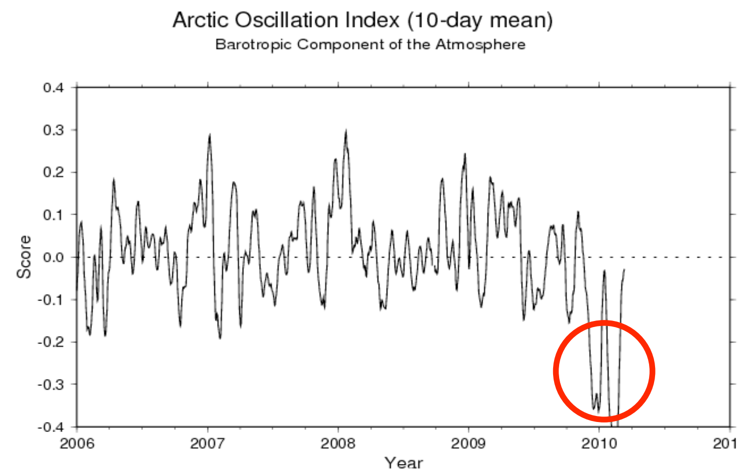


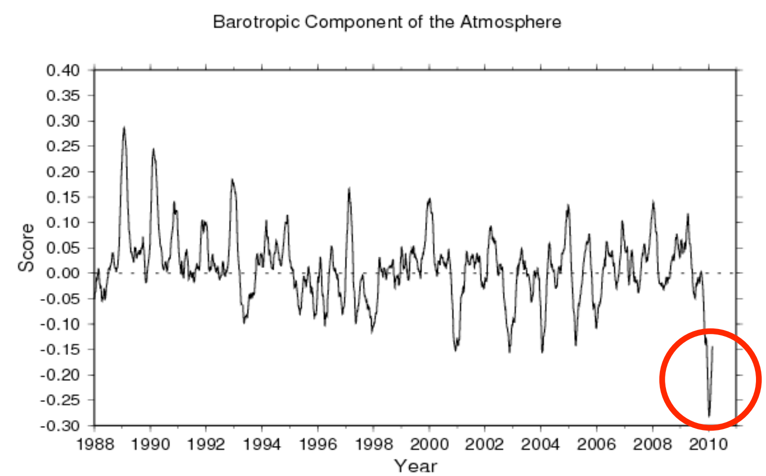
AOI and PDO show multi-decadal variability

Unprecedented negative AO in 2009/10.

AOI for 2009/2010 and the 90-day ensemble prediction



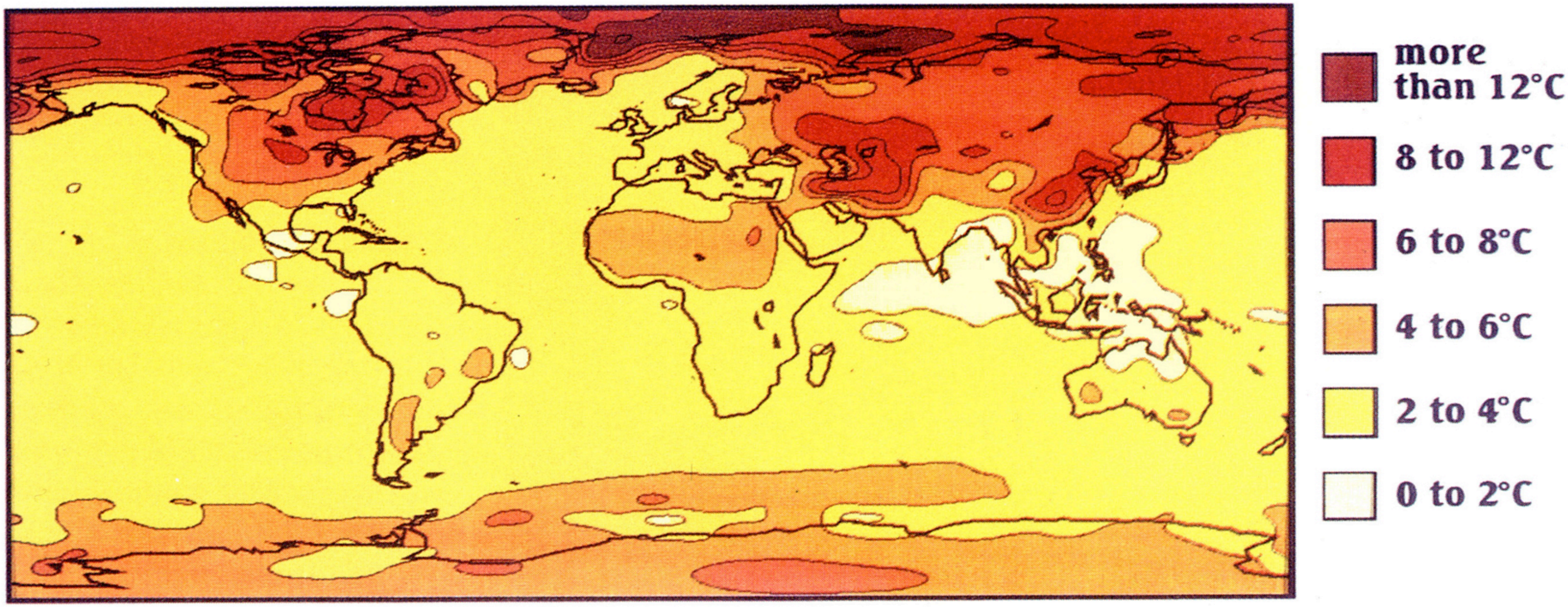




The negative AOI for 2009/10 exceeds 3 standard deviations.

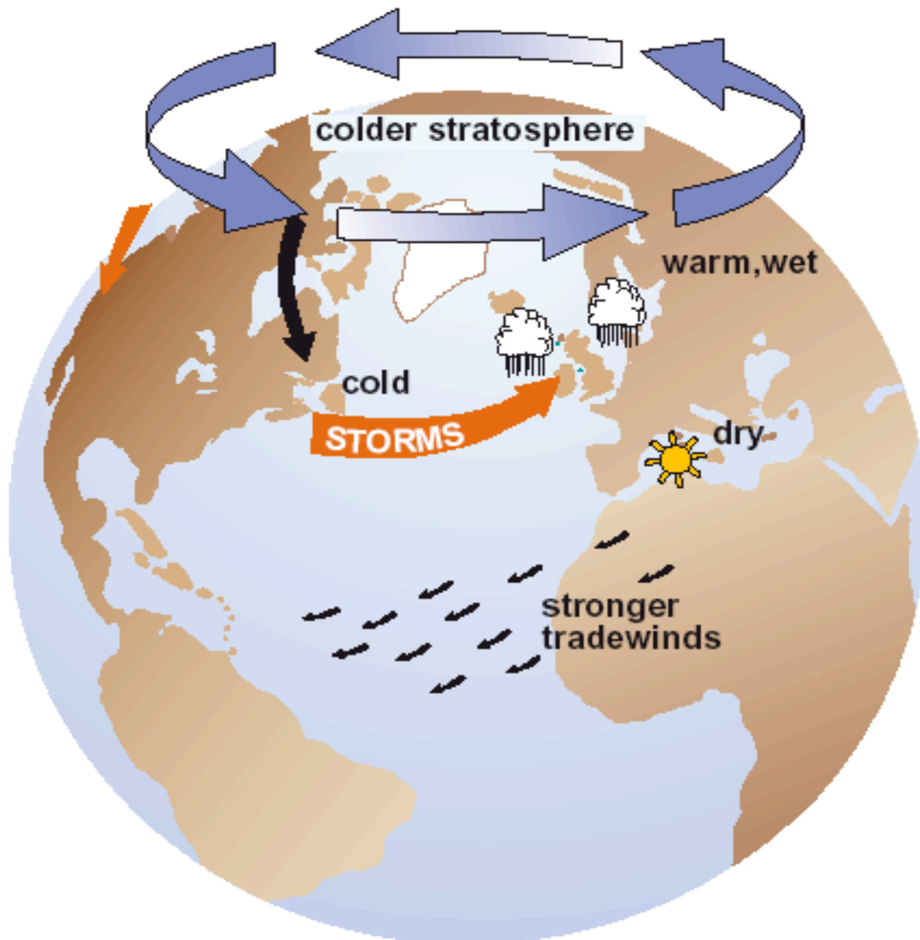
Anthropogenic global warming

IPCC, CAMBRIDGE UNIVERSITY PRESS



Projections from computer models predict large temperature increases in future arctic winters (Dec., Jan., Feb.) after CO_2 has doubled in the atmosphere.

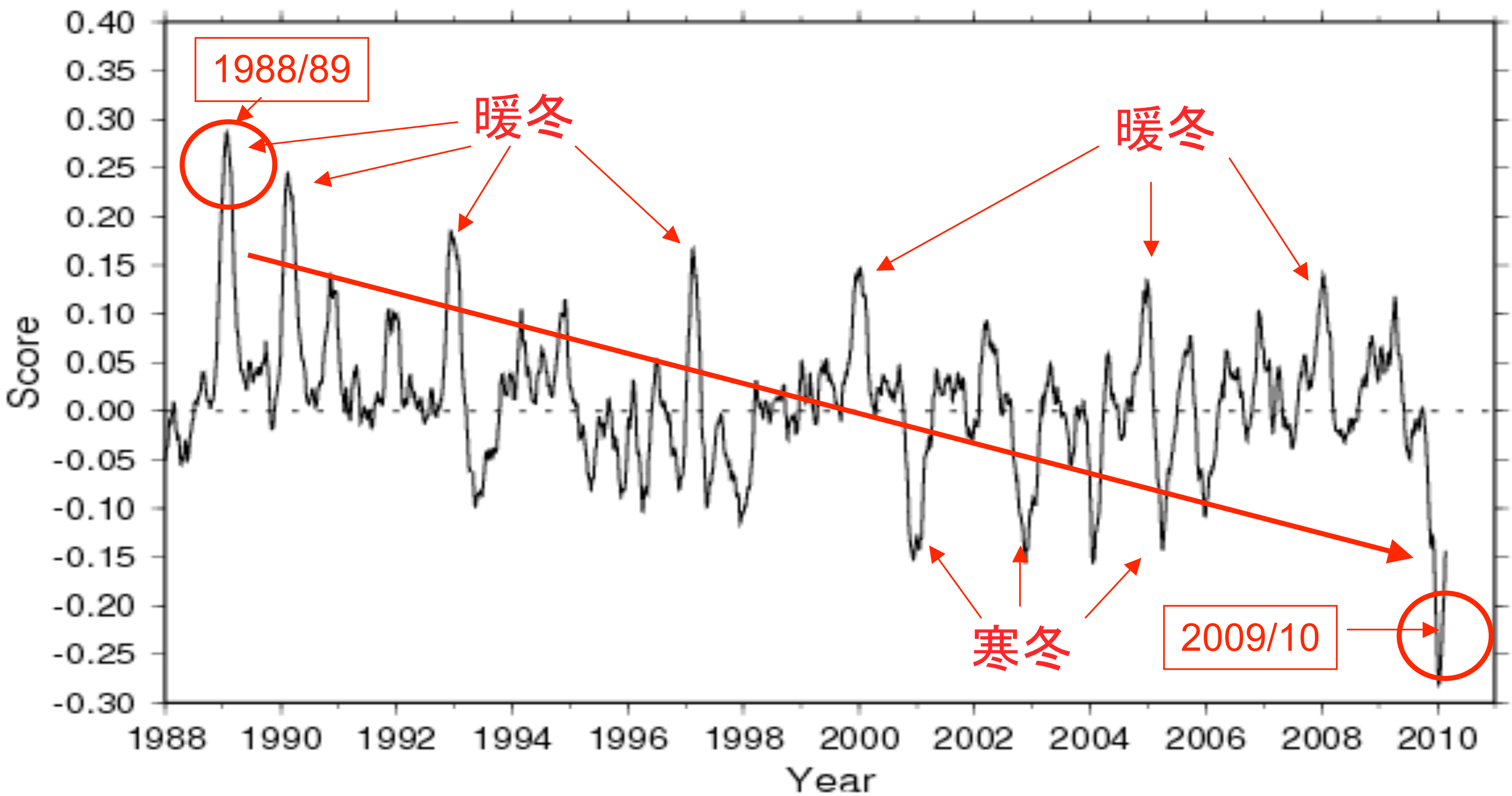
Arctic Oscillation



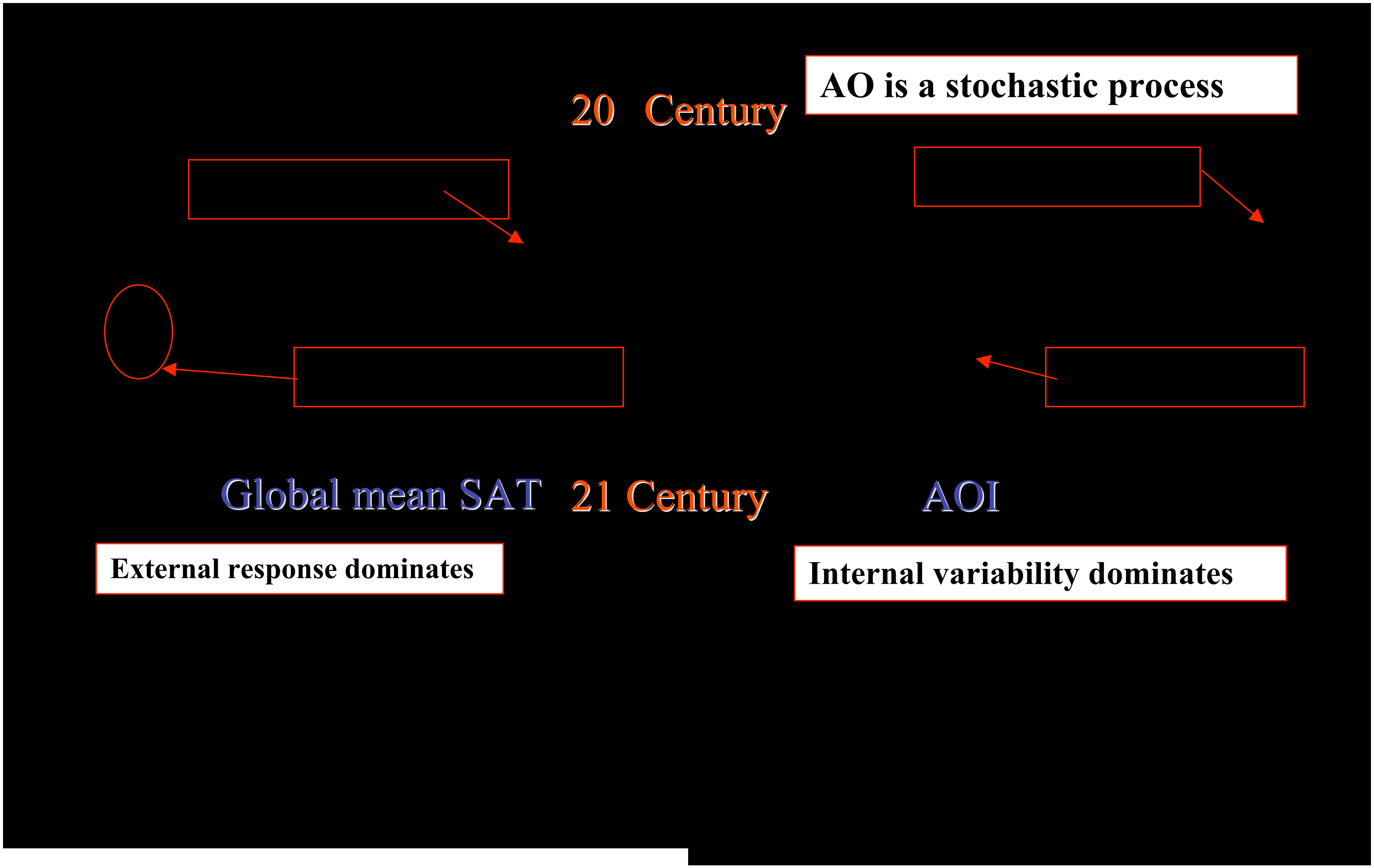
1988年以降の北極振動指数

Arctic Oscillation Index (90-day mean)

Barotropic Component of the Atmosphere



Ensemble projections by models



Numerical simulations of AO

Barotropic Component of the Atmosphere

○ Vertical Transform

$$(u, v, \phi')^T_0 = \frac{1}{p_s}\int_0^{p_s} (u, v, \phi')^T G_0 dp \qquad (1)$$

○ Barotropic Model

$$\frac{\partial u}{\partial t} = -\vec{v}\cdot\nabla u + fv - \frac{\partial \phi}{\partial x} + F_x \qquad (2)$$

$$\frac{\partial v}{\partial t} = -\vec{v}\cdot\nabla v - fu - \frac{\partial \phi}{\partial y} + F_y \qquad (3)$$

$$\frac{\partial \phi}{\partial t} = -\vec{v}\cdot\nabla \phi - \bar{\phi}\nabla\cdot\vec{v} + F_z \qquad (4)$$

○ 3-D Spectral Transform

$$U(\lambda, \theta, p, t) = \sum_{nlm} w_{nlm}(t) X_m \Pi_{nlm}(\lambda, \theta, p), \qquad (5)$$

$$w_{nlm}(t) = < U(\lambda, \theta, p, t), X_m^{-1}\Pi_{nlm} > \qquad (6)$$

where $U(\lambda, \theta, p, t) = (u, v, \phi')^T$, $w_{nlm}(t)$ is the spectral expansion coefficient, $X_m = diag(c_m, c_m, c_m^2)$, and Π_{nlm} is the 3-D NMF.

3D spectral model

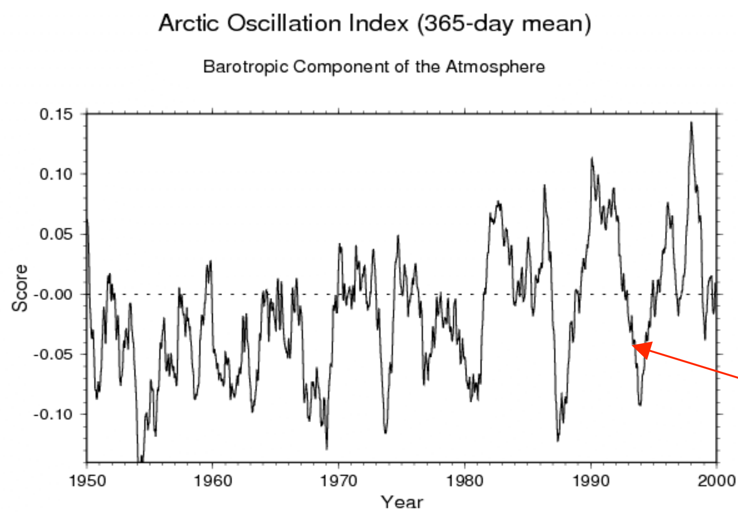
$$\frac{dw_i}{d\tau} = -i\sigma_i w_i - i\sum_{jk} r_{ijk} w_j w_k + f_i,$$

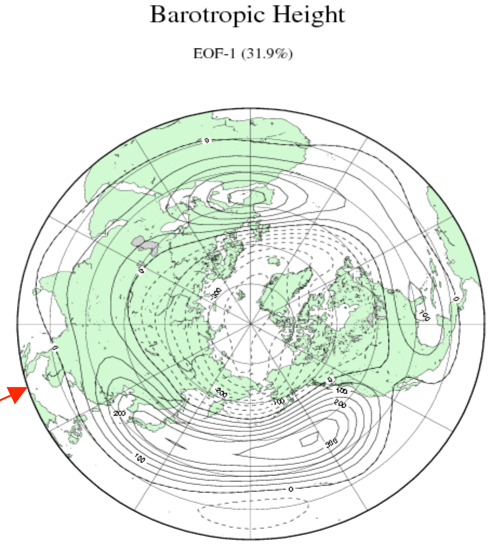
$$f_i = f_{AB} + f_{BC} + f_{DE} + f_{DZ} + f_{DF}$$

Physical process contains large error (20%)

Barotropic S-Model
(Tanaka 1998, JMSJ)

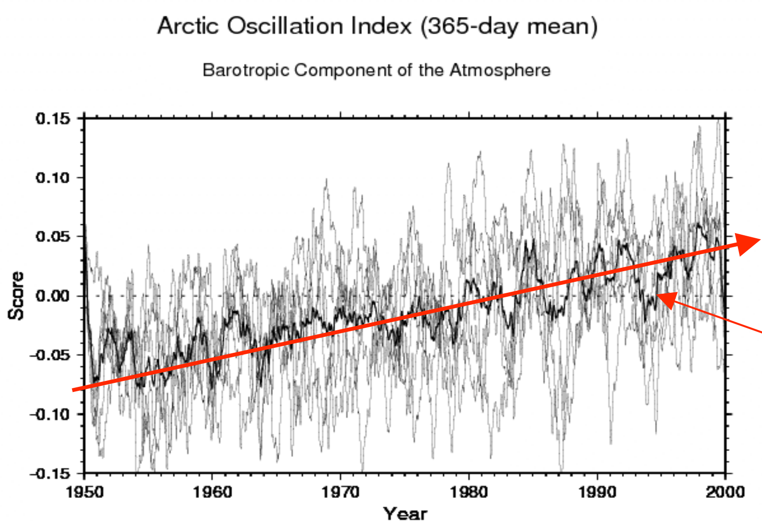
Ensemble prediction of AOI by S-model

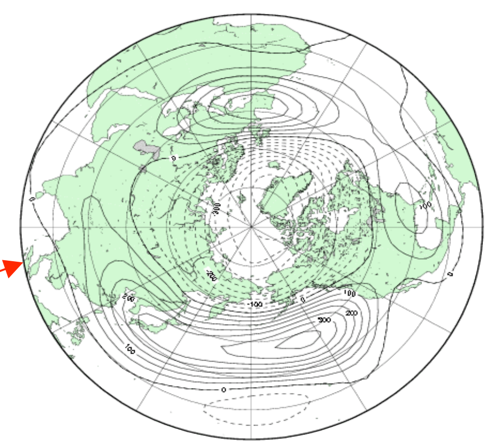




Internal variability

AO is realized as internal variability

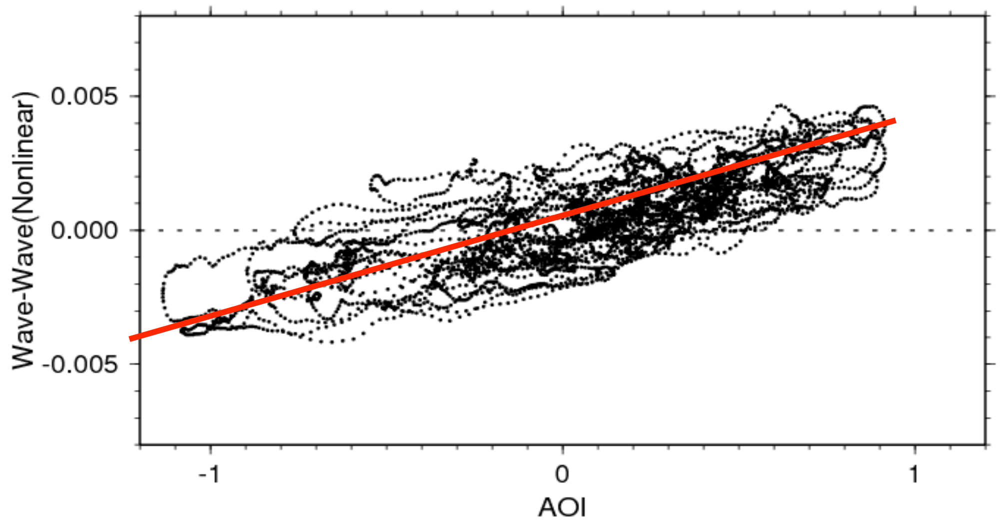




External forcing

AOI and Wave-Wave

3-Months Running Mean



Charney mode and Polar mode

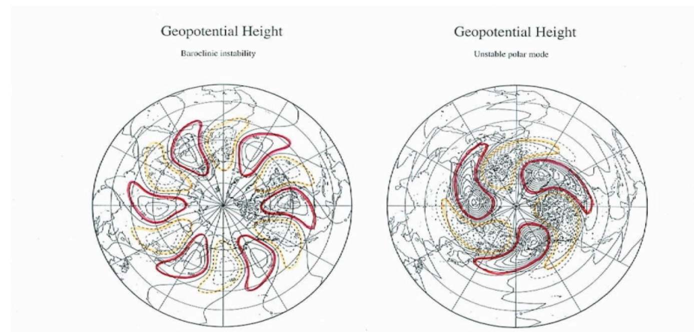


Fig. 15 Geopotential height structures of the parameterized baroclinic instability for (a) Charney mode of zonal wavenumber 6 associated with the linear matrix $(BC)_{ij}$ in (12), and (b) that for the polar mode of zonal wavenumber 3 induced by the baroclinicity of the polar jet discussed by Tanaka and Tokinaga (2002).

$$\frac{dw_i}{d\tau} = -i\sigma_i w_i - i\sum_{jk} r_{ijk} w_j w_k + f_i$$

Transient eddy and AOI

$$< -i\sum_{jk} r_{ijk} w'_j w'_k \, , \; V_i > = a < w'_i \, , \; V_i >$$

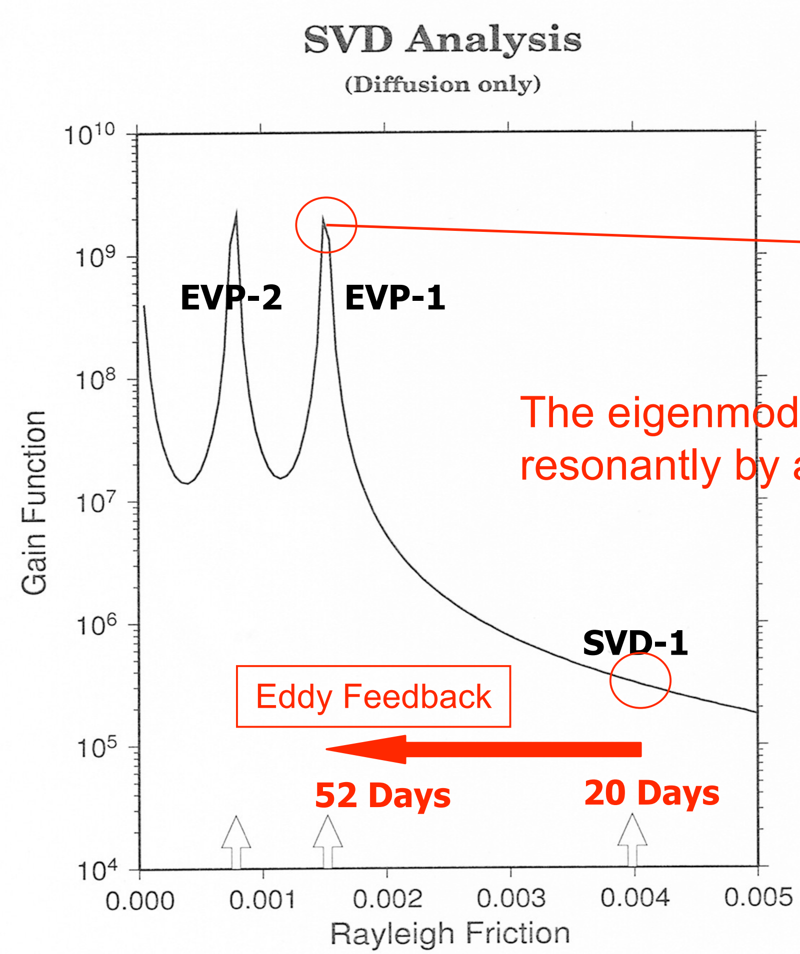
Positive feedback

Trangient eddy

AOI

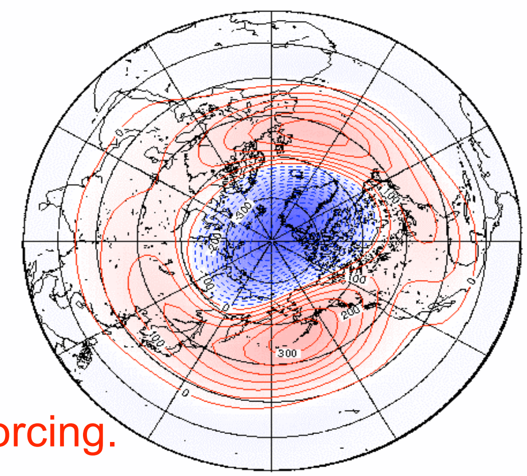
V_i is the vector of AO

Singular Eigenmode Theory



EVP-1

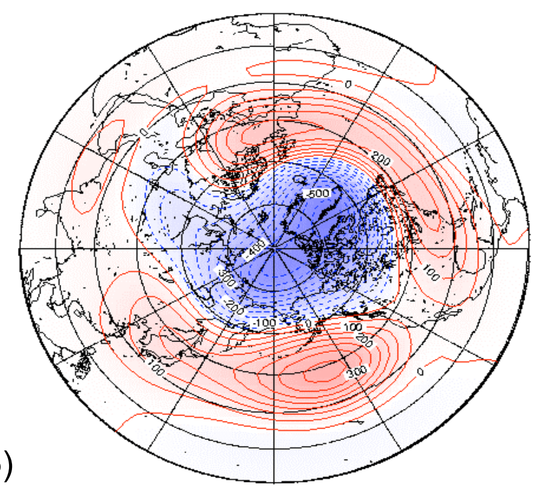
Singular eigenmode



The eigenmode can be excited resonantly by arbitrary steady forcing.

EOF-1

AO mode



(Tanaka and Matsueda 2005)

Summary

- **Statement1 by ICSU on the controversy around the 4th IPCC Assessment (23 Feb. 2010)**

- the IPCC 4th Assessment Report represents the most comprehensive international scientific assessment ever conducted.
- The IPCC processes are tried and tested but they are not infallible (and have never been presented as such by the scientific community).
- In any area of science it is important that errors, or previous assumptions that change in the light of new evidence, are openly admitted and corrected.