The Arctic Oscillation. Phenomenon and Possible Mechanisms

Vladimir Kryjov

Outline

Background: Polar Vortex and Polar Night Jet

Definition

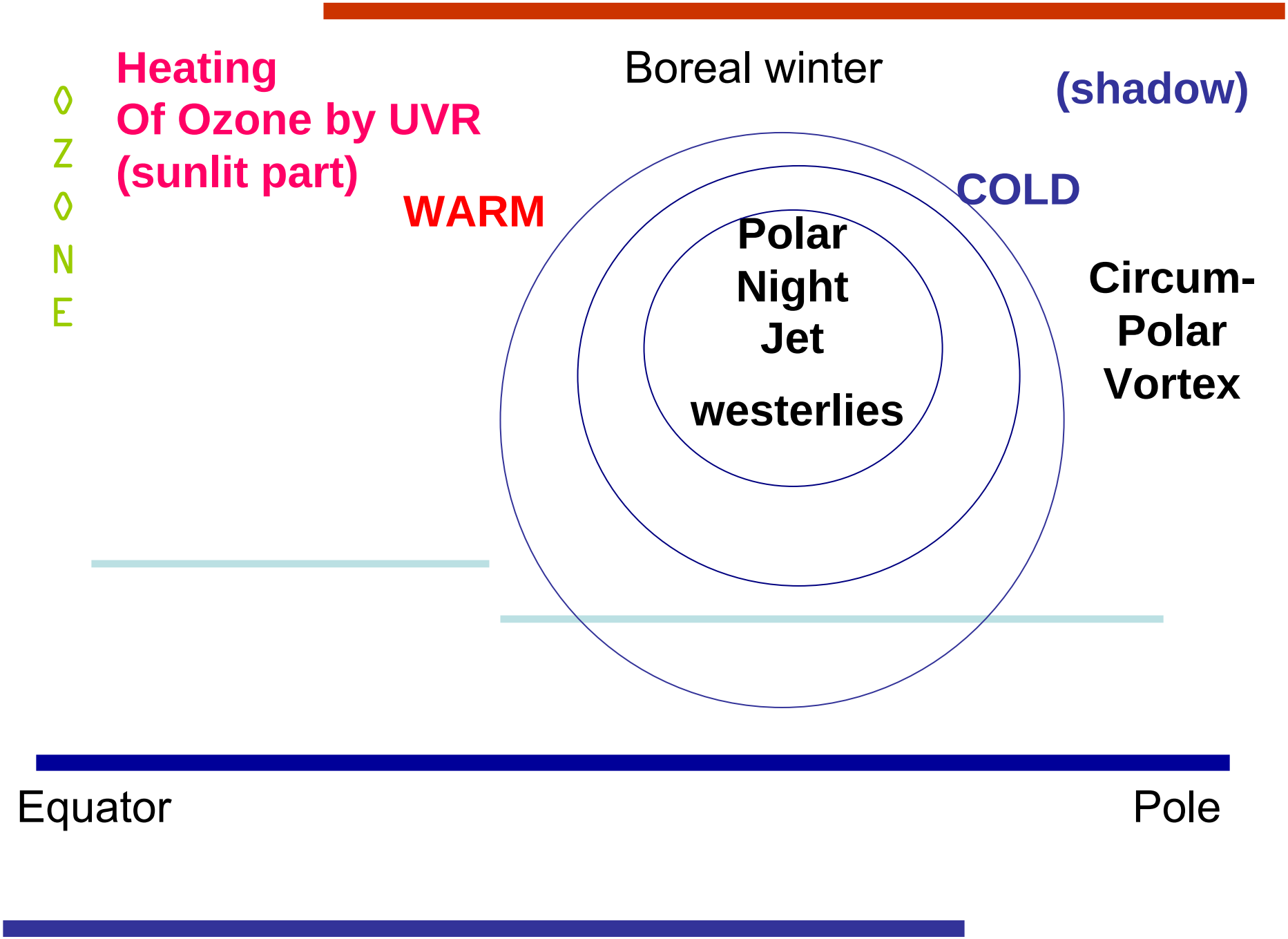
Impacts

Downward propagation

Possible mechanisms

Summary

Background:
Polar Vortex and Polar Night Jet


Heating
Of Ozone by UVR
(sunlit part)
OZONE
Boreal winter
(shadow)
WARM
COLD
Polar
Night
Jet
westerlies
Circum-
Polar
Vortex
Equator
Pole

Boreal winter

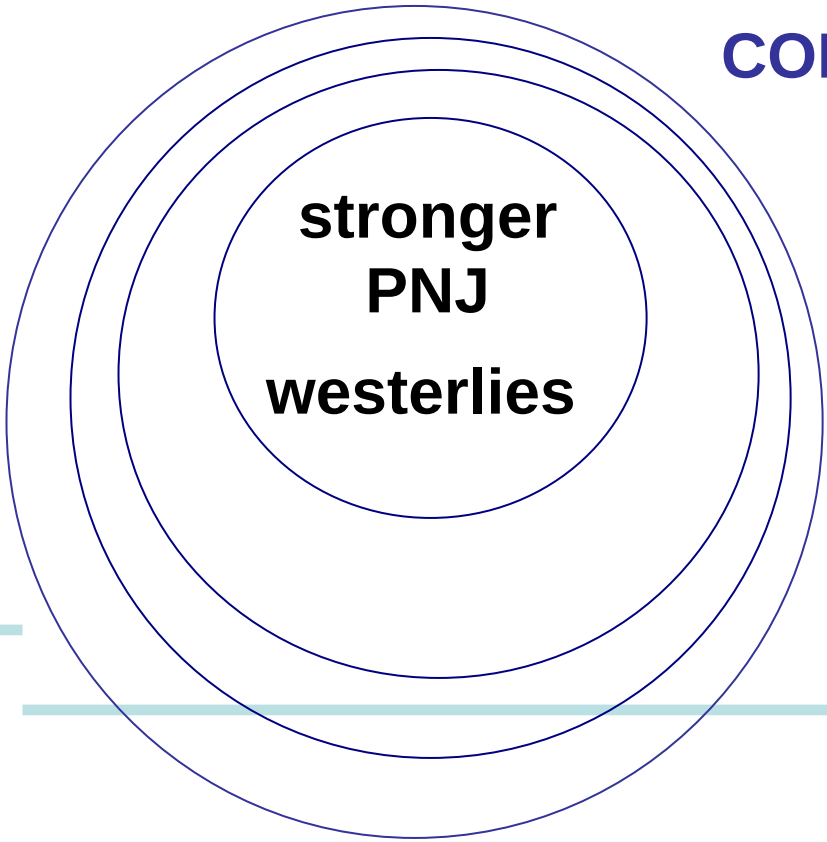
OZONE

More Ozone
and/or
More Heating
Of Ozone by UVR
(sunlit part)

WARMER

(shadow)

COLDER



stronger
CPV

Equator

Pole

OZONE

Less Ozone and/or Less Heating Of Ozone by UVR (sunlit part)

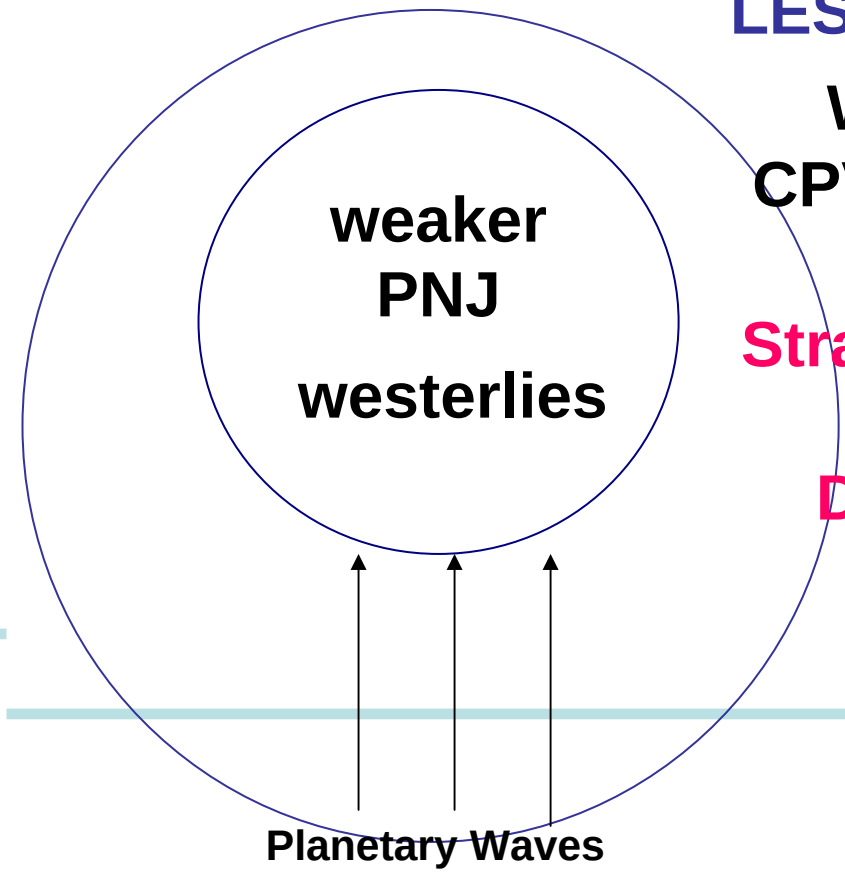
LESS WARM

Boreal winter

(shadow)

LESS COLD

Weaker CPV or even Sudden Stratospheric Warming Distruction of CPV

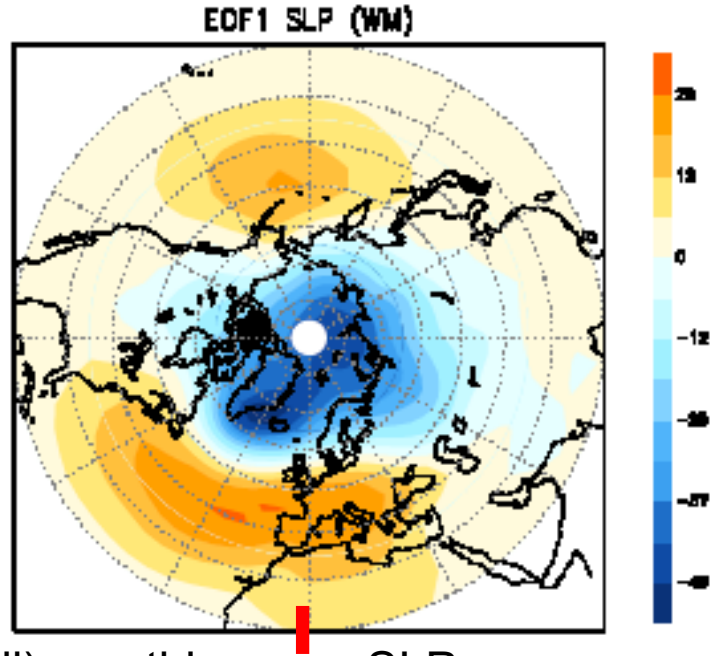


Equator

Pole

Definition of the AO

Definition

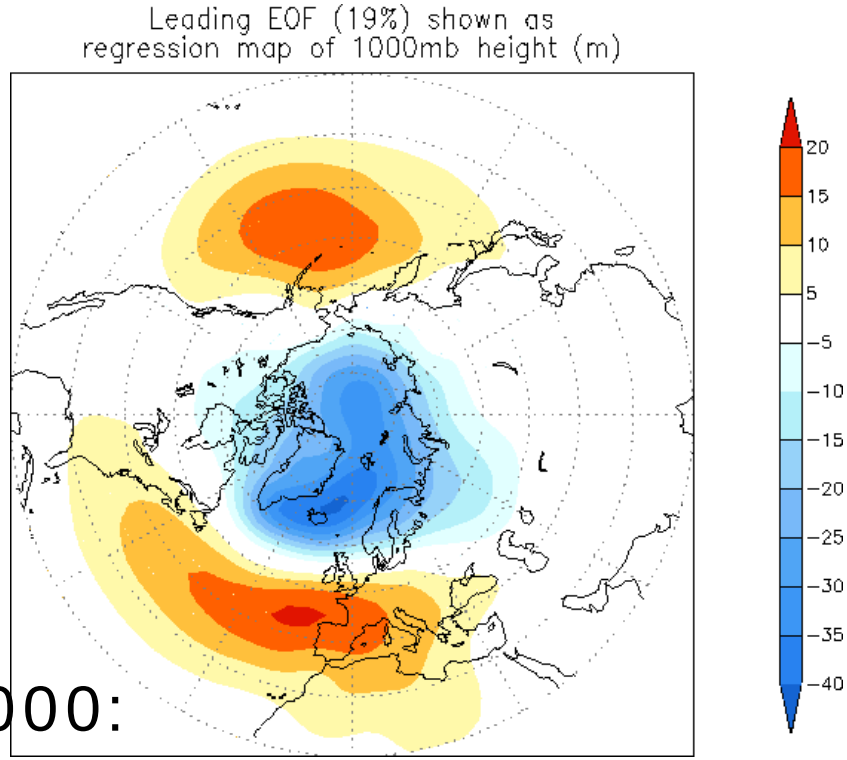


1998:

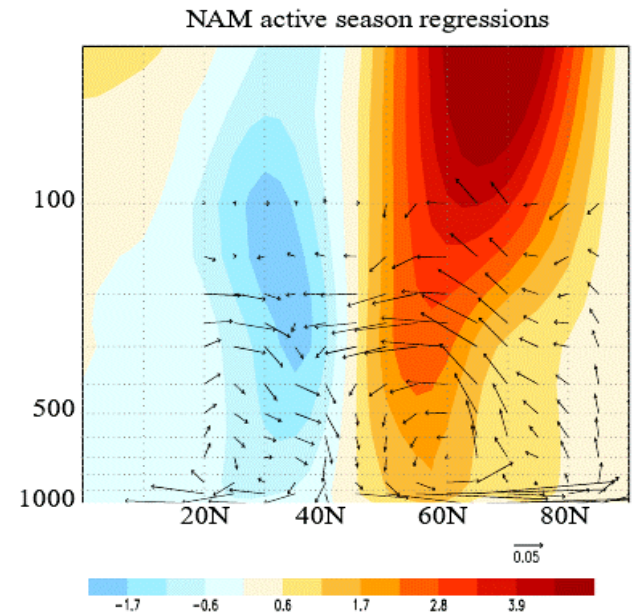
"… As the reference variable we use the leading principal component of the wintertime (November-April) monthly mean SLP anomaly field over the domain poleward of 20°N, which accounts for 22% of the variance …"

Thompson, D. W. J, and J. M. Wallace, 1998:
The Arctic Oscillation signature in the wintertime geopotential height and temperature fields.
Geophys. Res. Lett., **25,** 1297–1300.

Predecessors: *Lorenz* (1951)
Kutzbach (1970)
Wallace and Gutzler (1981)
Trenberth and Paolino (1981)



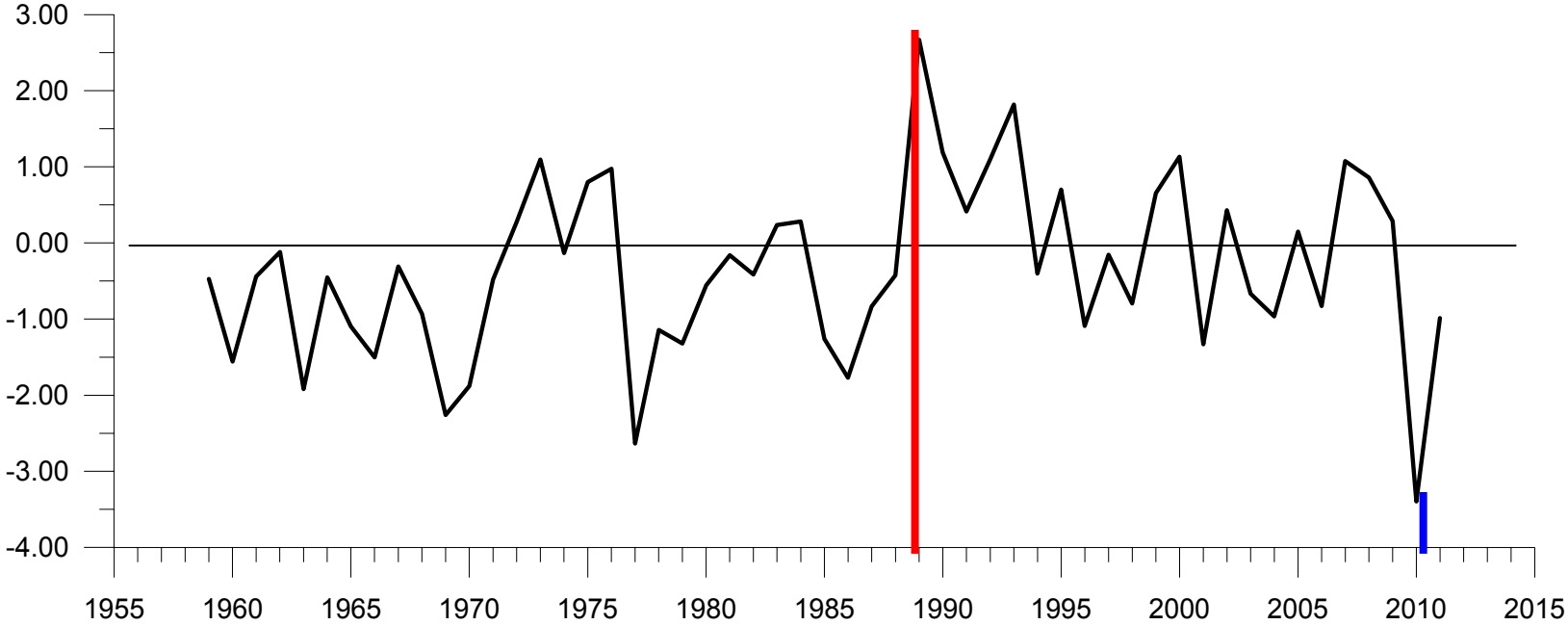
2000:

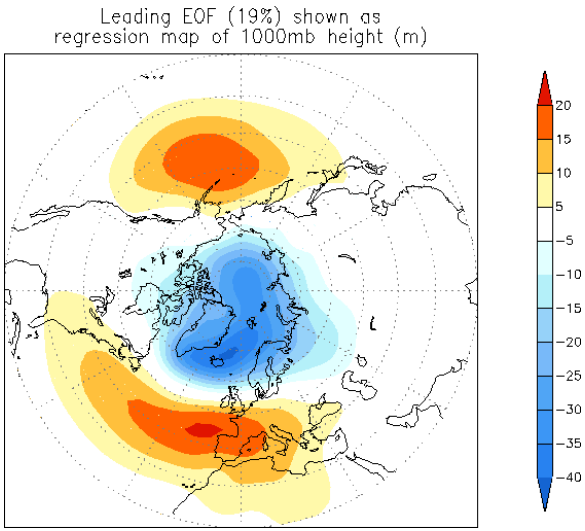


Zonal wind (m/s) and mean meridional circulation anomalies (m/s; cm/s) regressed on January-March values of the NAM index.

The loading pattern of the AO:
the leading EOF of *year-round* monthly mean 1000 mb height anomaly during 1979-2000.

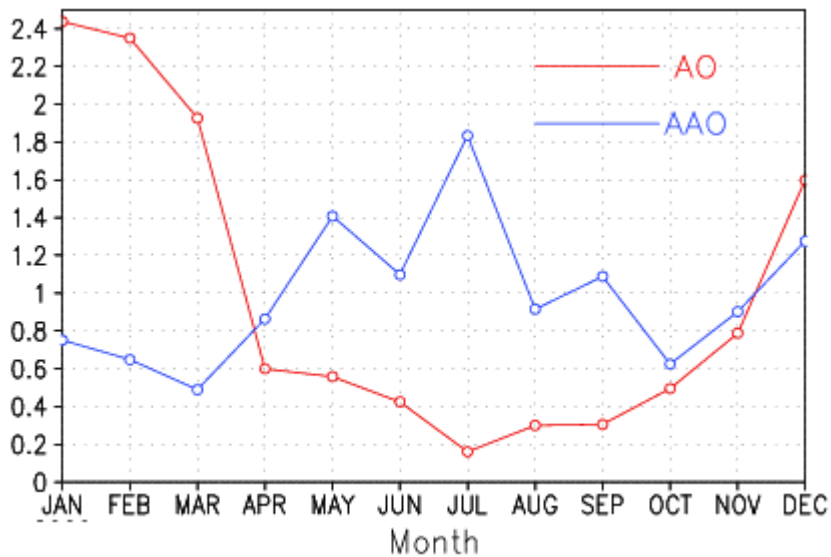
Data: the NCEP/NCAR 1000 (700) mb height anomalies on 2.5°x2.5° mesh.
The covariance matrix. Weighted by the square root of the cosine of latitude.
Monthly AO (AAO) indices are constructed by projecting the monthly mean 1000 (700) mb height anomalies onto the leading EOF mode. Time series are normalized by the standard deviation of the *monthly* index (1979-2000 base period).
(CPC web-site)





Time series of the wintertime (DJF) AO index

(year mark as of January)

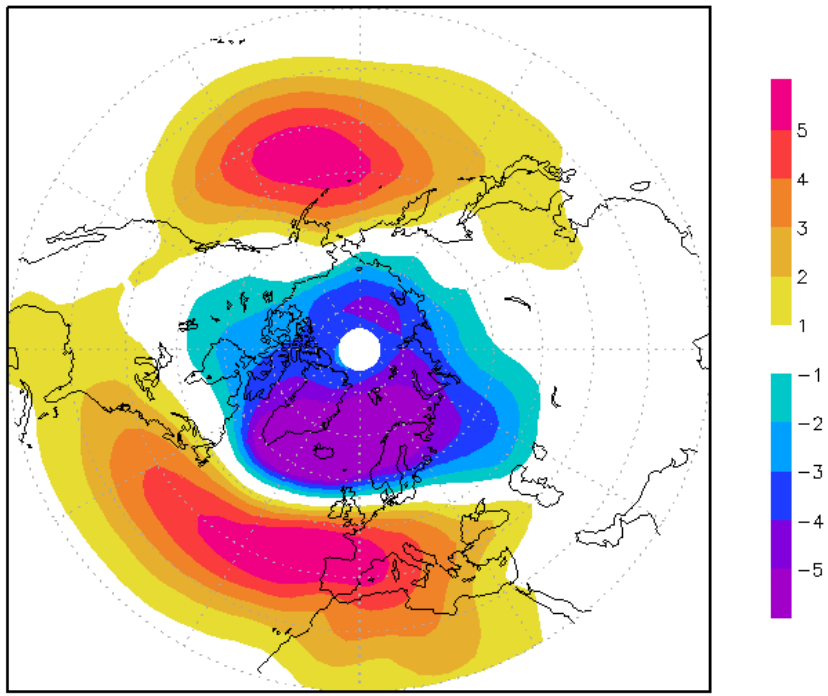


Variance of the NCEP CPC's monthly indices prior to normalization.

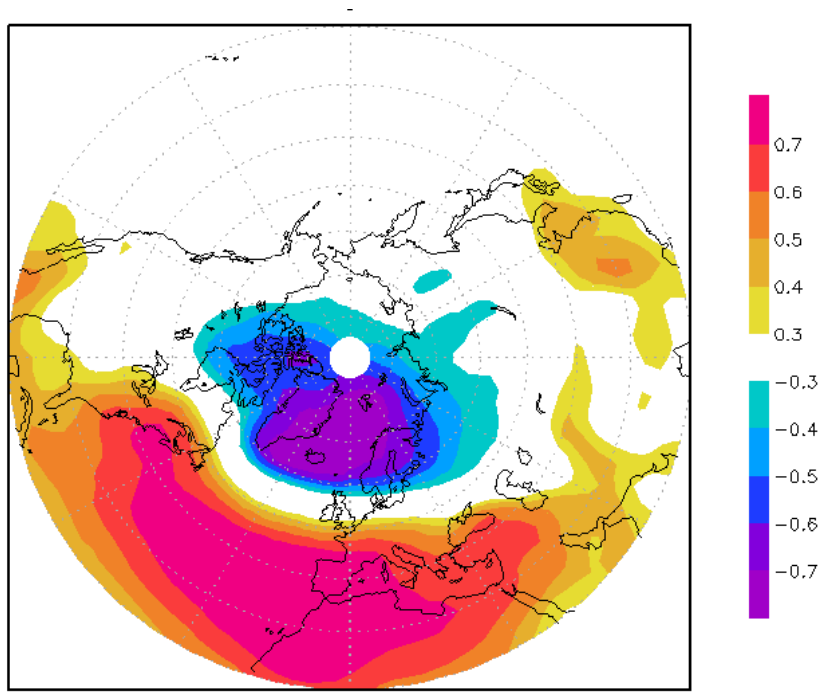
www.cpc.ncep.noaa.gov/products/precip/CWlink/ao_aao.htm

It should be taken into account when averaging over several months!

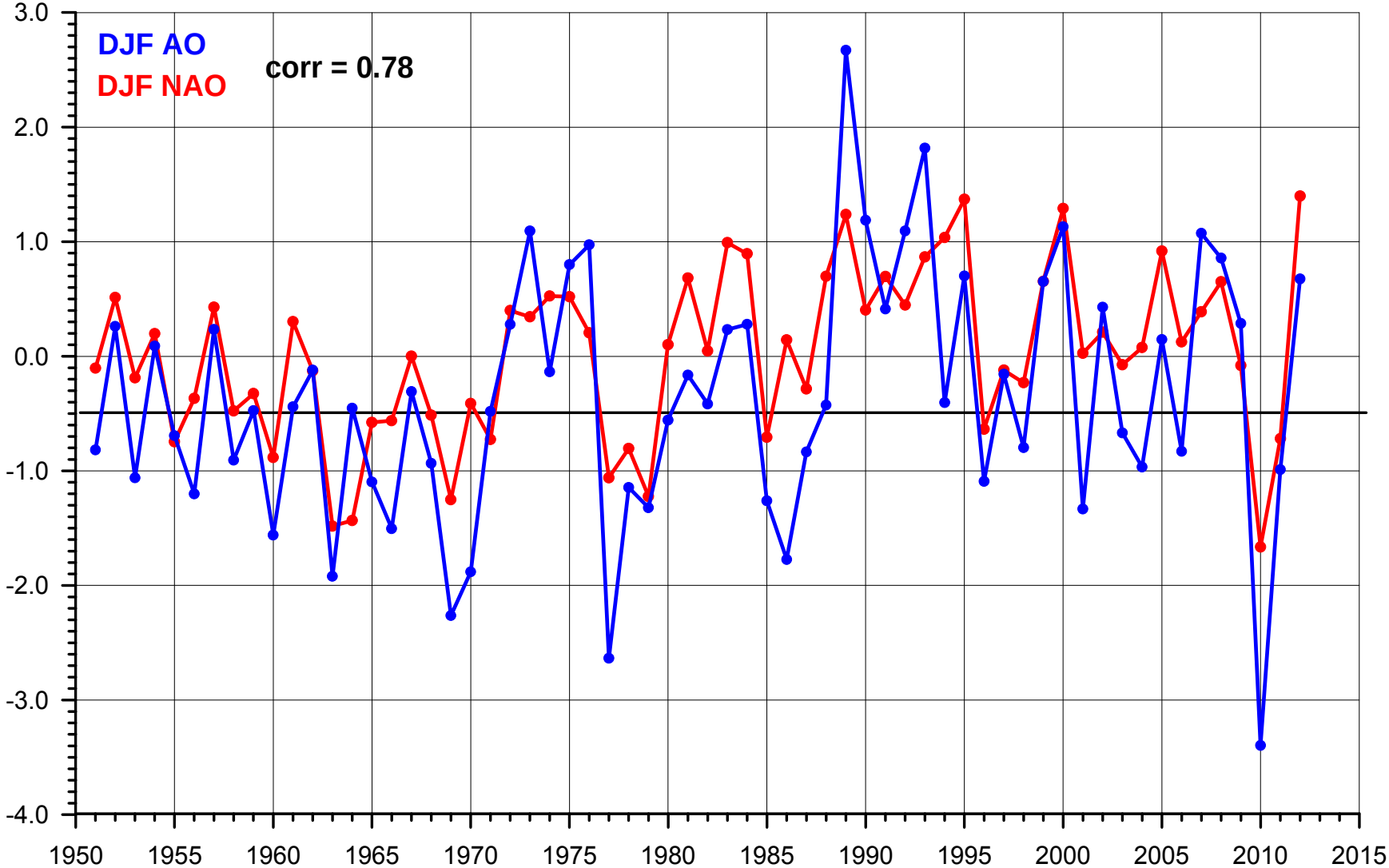
The AO and the NAO



The DJF AO
As The EOF-1 of Z1000
over the Northern Hemisphere



The DJF NAO
As EOF-1 of SLP
in North Atlantic sector



Time series of the wintertime AO and NAO

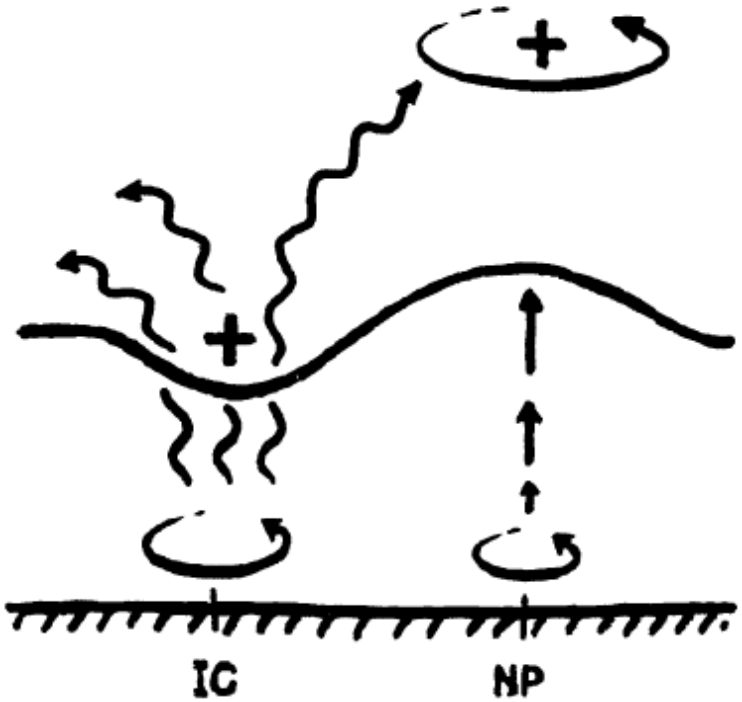
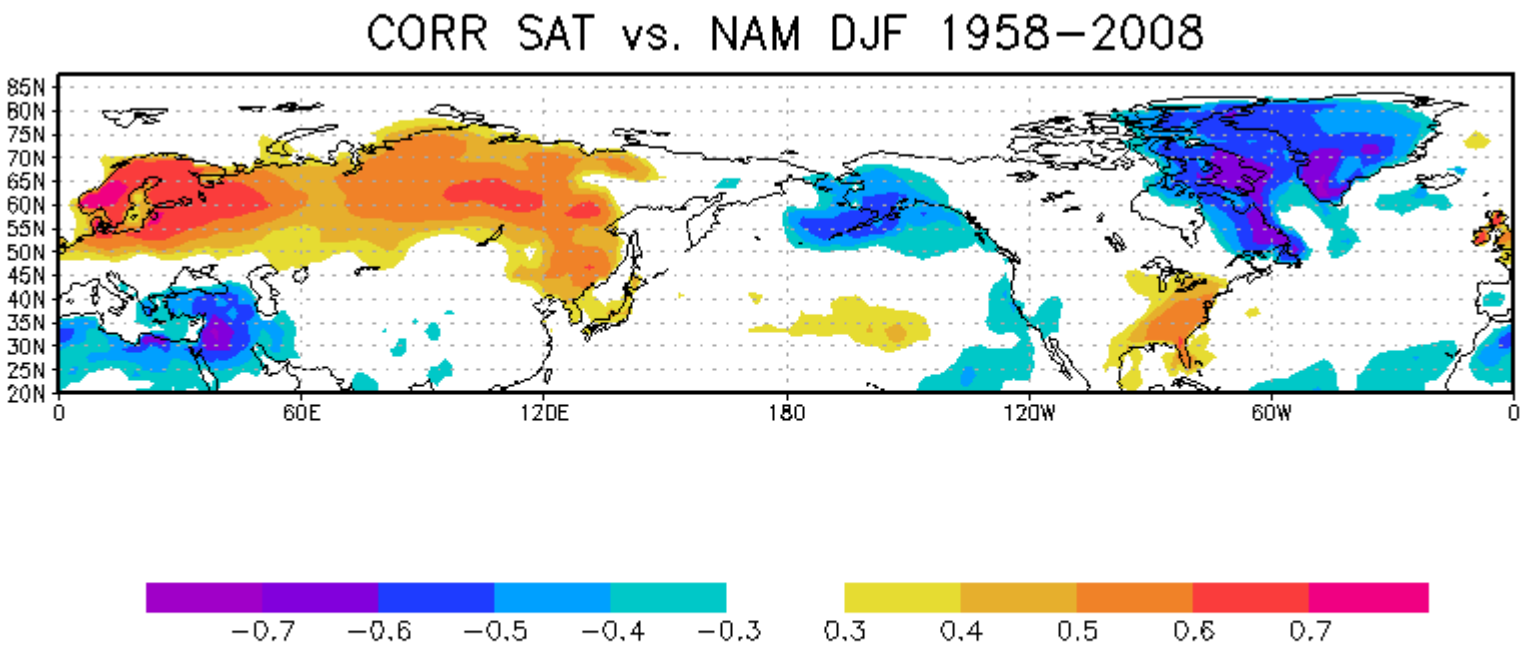


FIG. 1. Schematic of the connections between modulations in the NAO, the height of the tropopause, and the strength of the stratospheric jet. If the NAO index increases, associated with it the cyclonic circulation over Iceland (IC) enhances (circular arrow at IC) and the tropopause (thick solid line) lowers with associated positive potential vorticity anomaly (+); upward-propagating Rossby waves (wavy lines) refract more toward the equator and break less in the stratospheric jet; the stratospheric jet enhances (large circular arrow) with associated positive potential vorticity anomaly (+); the tropopause below this anomaly rises and stretches (vertical arrows) the tropospheric column leading to an enhanced cyclonic circulation over the North Pole (circular arrow at NP).

(From Ambaum and Hoskins, 2002)

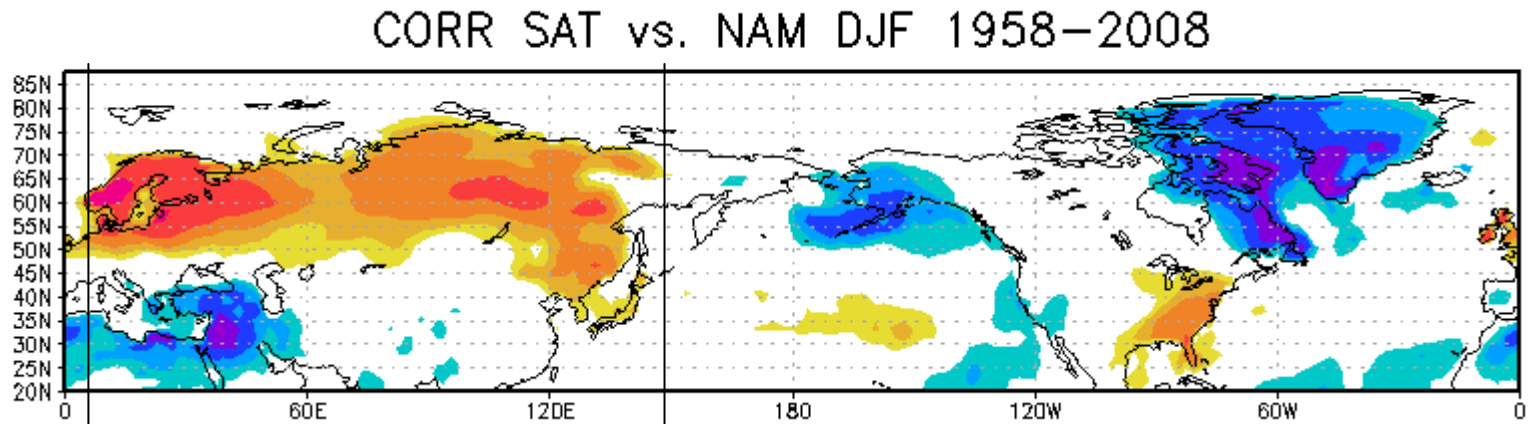
Impacts

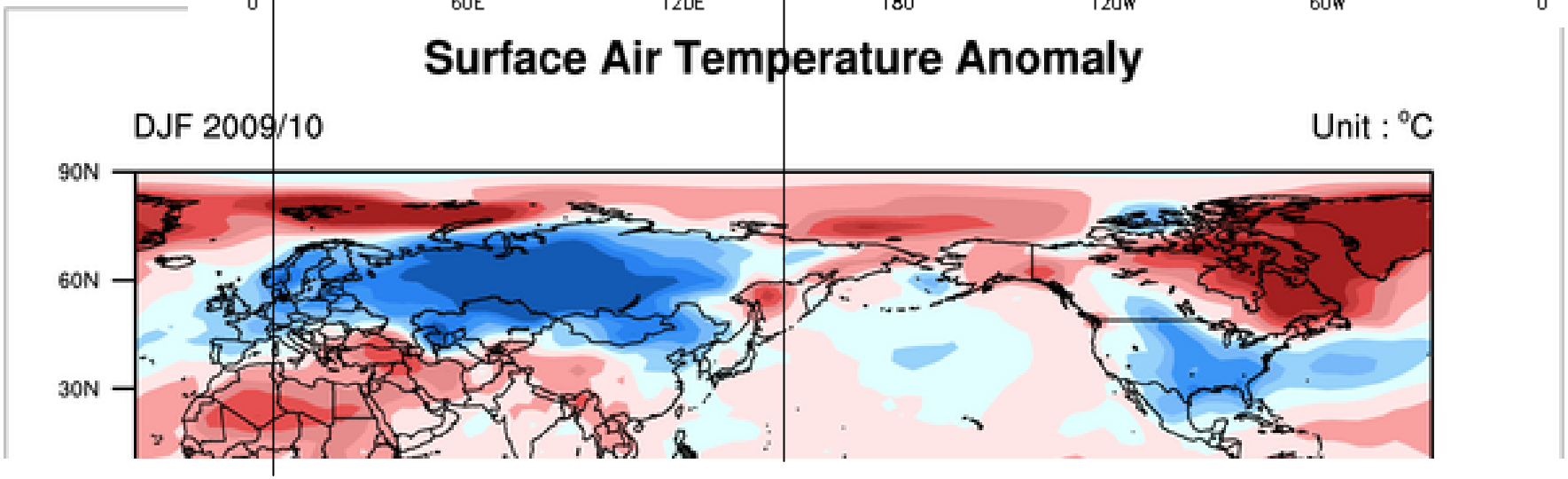
Linear impact on concurrent wintertime temperature



Correlation map between DJF temperature and the AO

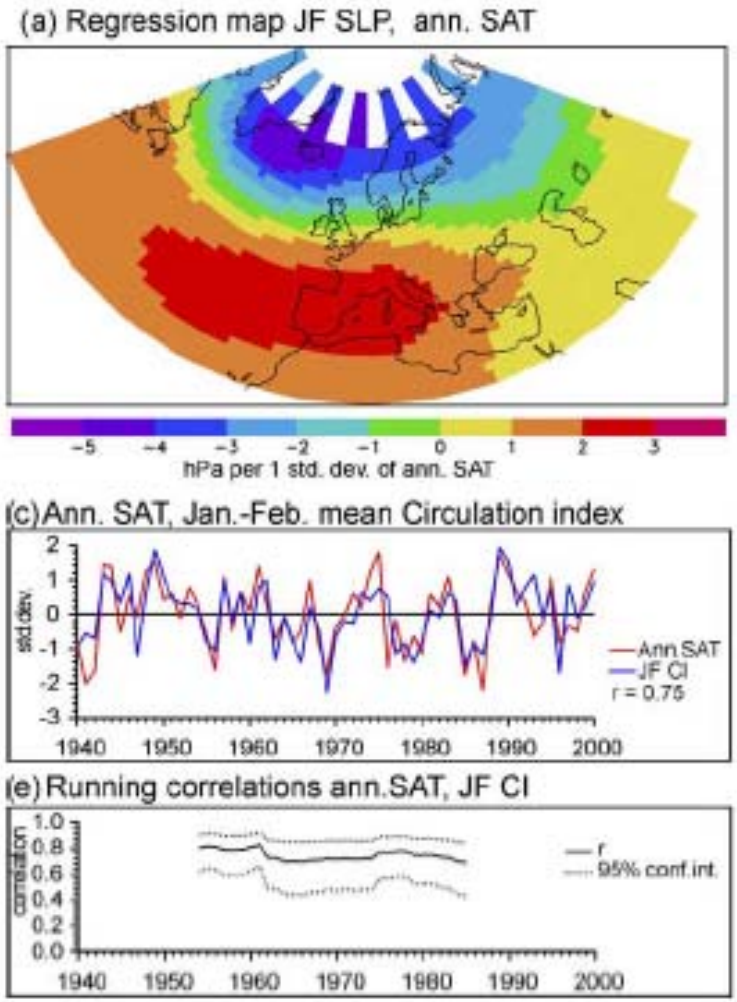
Linear impact on concurrent wintertime temperature

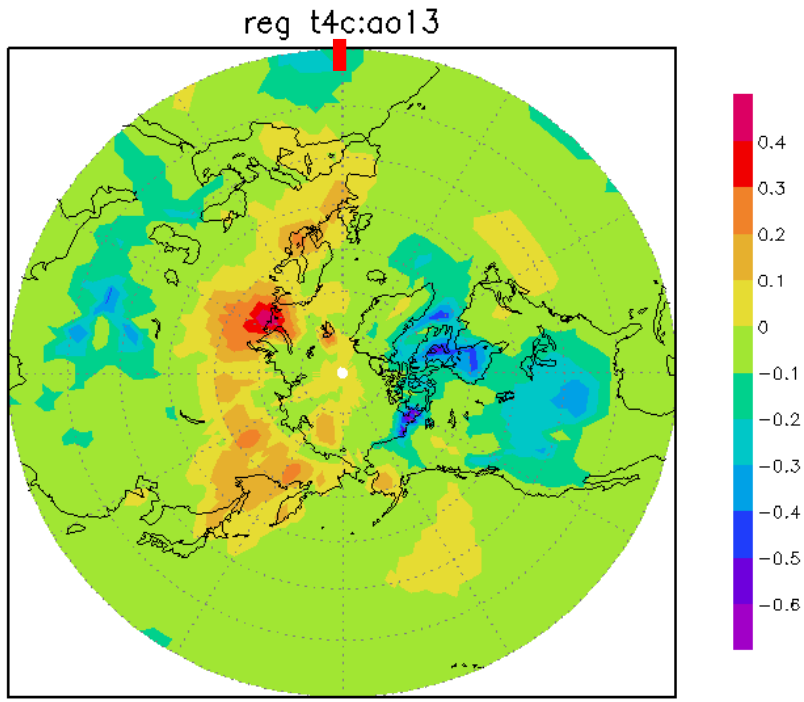




Consistency between the temperature anomaly pattern in DJF 2009/10 and the negative AO impact

Impact
on annual mean temperature

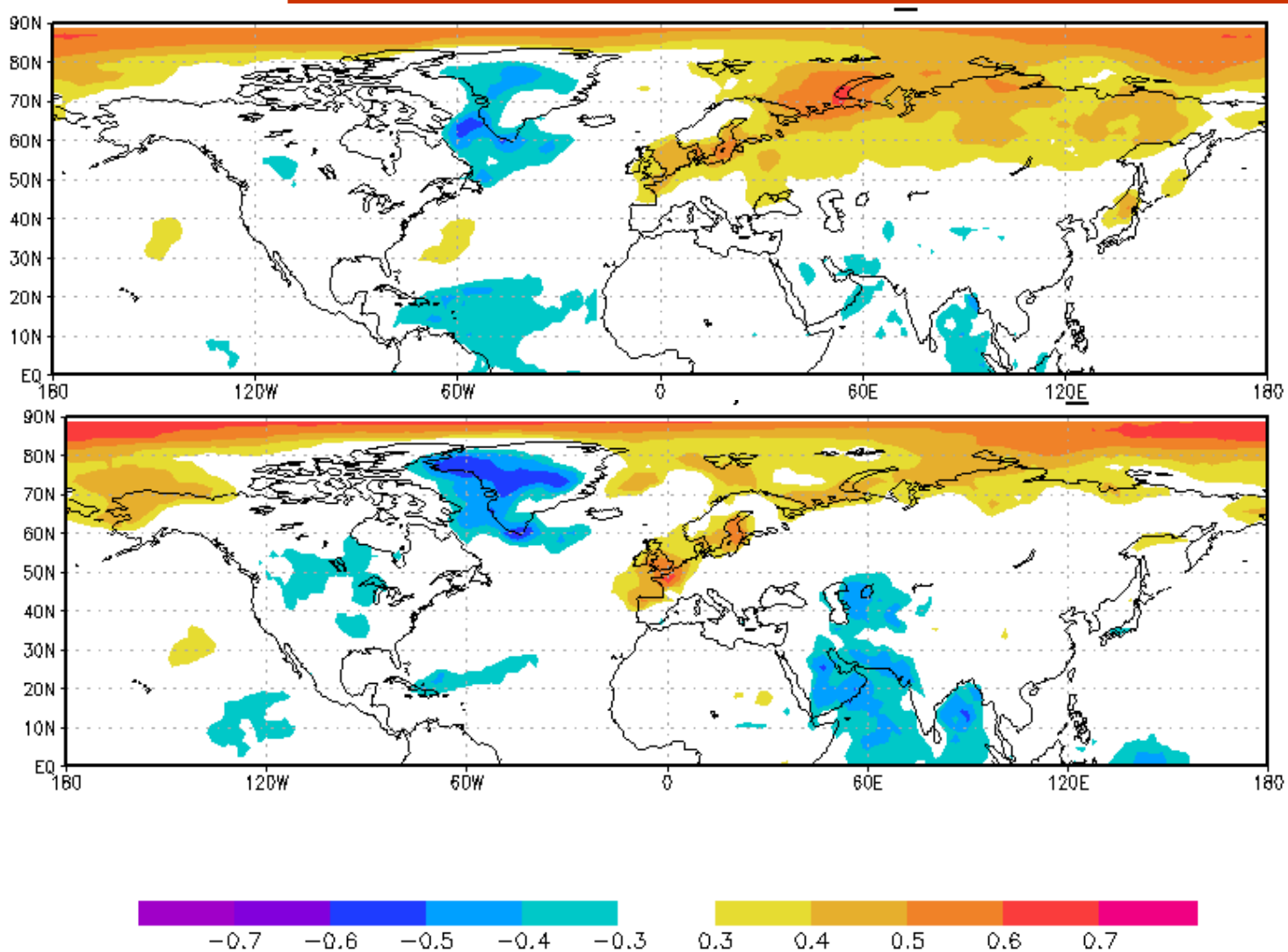




April-December Temperature regressed on the January-March AO index

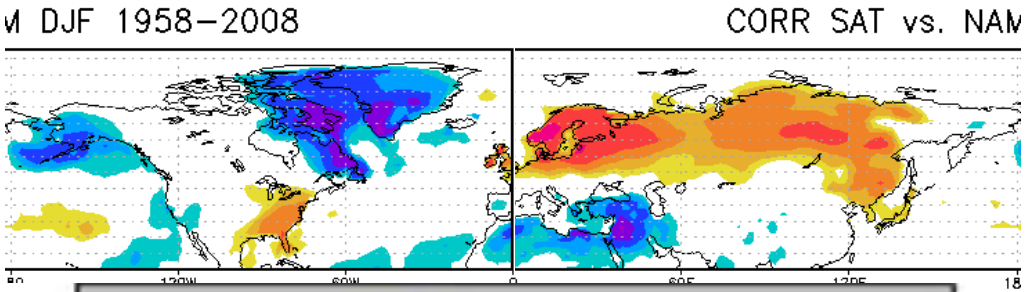
JF SLP regressed on Northern Europe annual mean temperature. Correlation between the circulation index of the map (SLP projected on the correlation map) and the AO is 0.94
From V. Kryjov (2004)

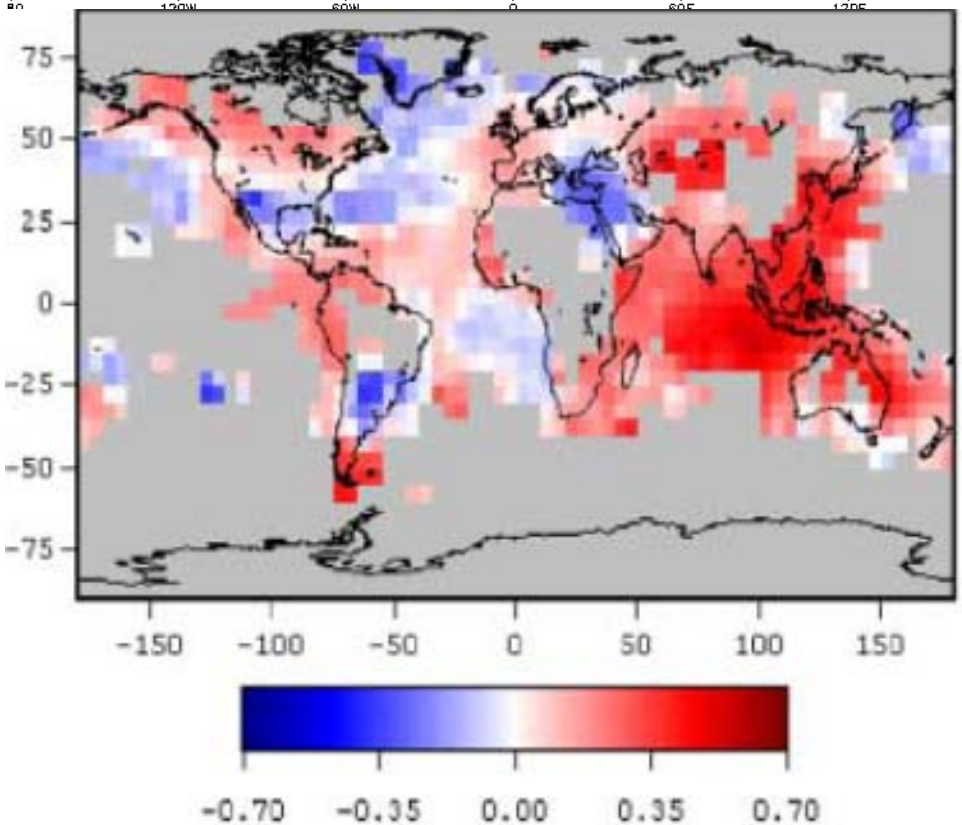
See also
Kryjov (2002),
Rigor et al. (2002)



(top) Correlation between March–June temperature and JF AO index and (bottom) Partial correlation between the same variables, with snow extent influence being removed

Reconstructions and Projections



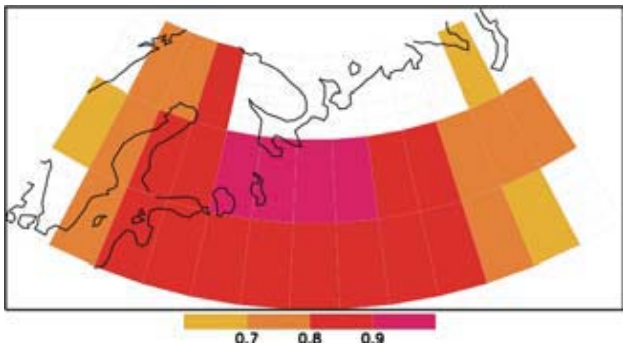


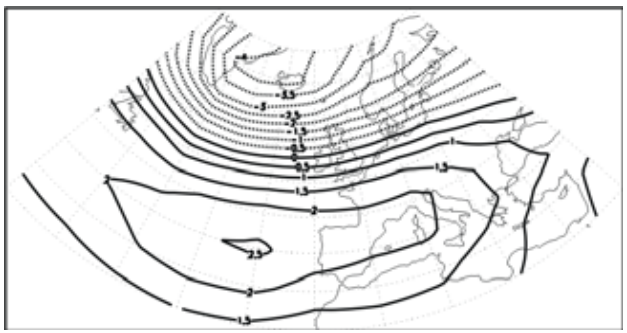
1650 – 1850
temperature change pattern
is close to temperature
response to the AO

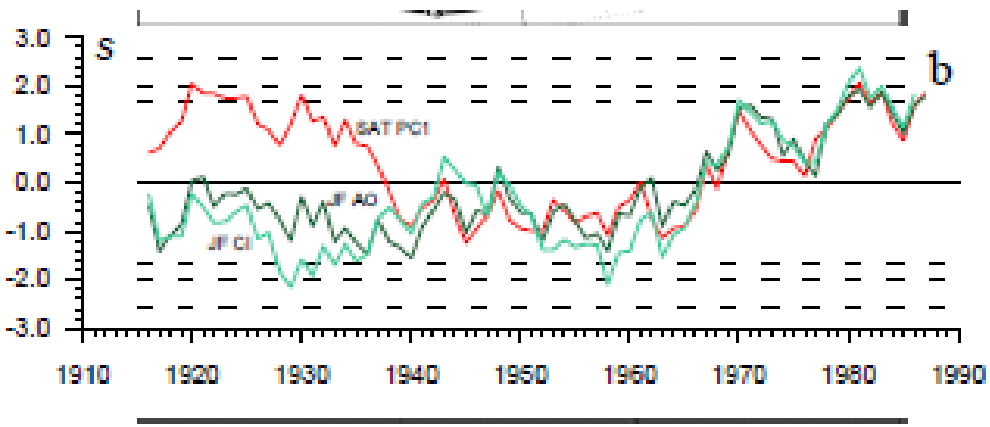
(Waple et al., CD, 2002)

Fig. 2A–C. Correlation pattern between Mann et al. (1998) proxy-reconstructed surface temperature patterns and Lean et al. (1995) solar irradiance reconstruction for the period 1650-1850. Signifi-

Longer range influences







Upper: Annual SAT EOF1

Middle: Regression of the JF SLP fields on annual SAT PC1;

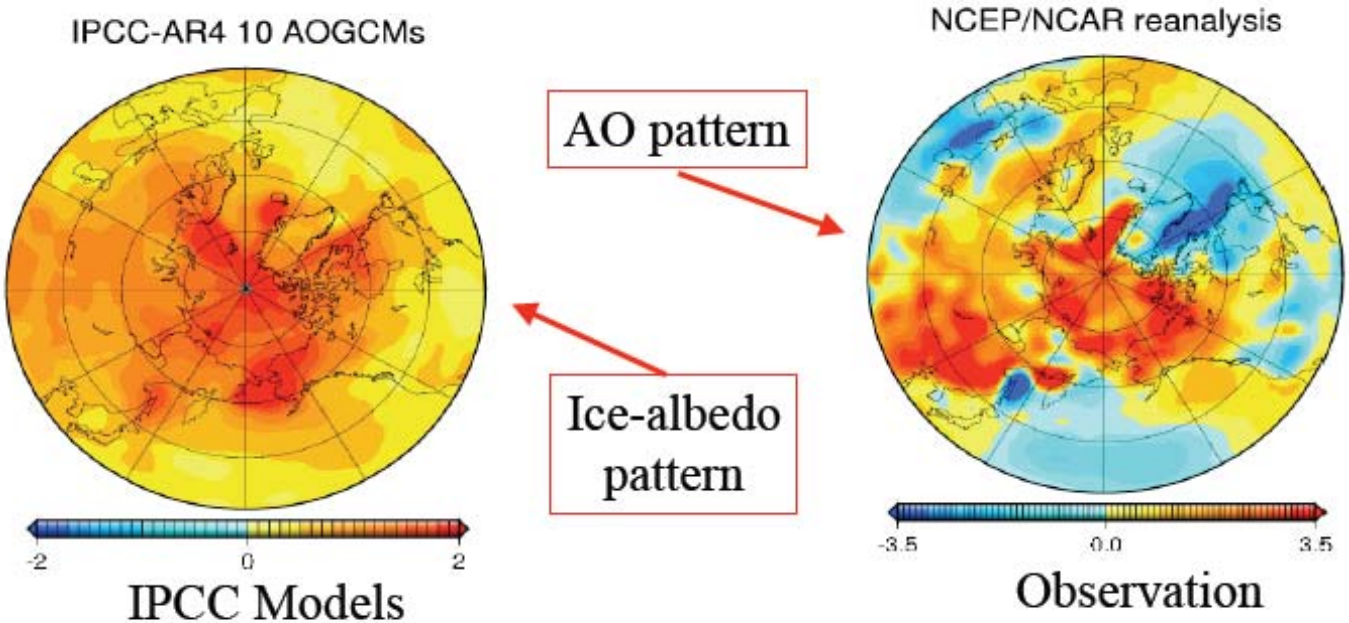
Bottom: Normalised Mann-Whitney statistic *S f*or annual SAT PC1 (red), JF AO (forest green), the JF CI based on the annual SAT PC1 (navy green);

Units of the regression maps are hPa per 1 std.dev. of the PC1 (a) and PC2 (b)

From Kryjov (2004)

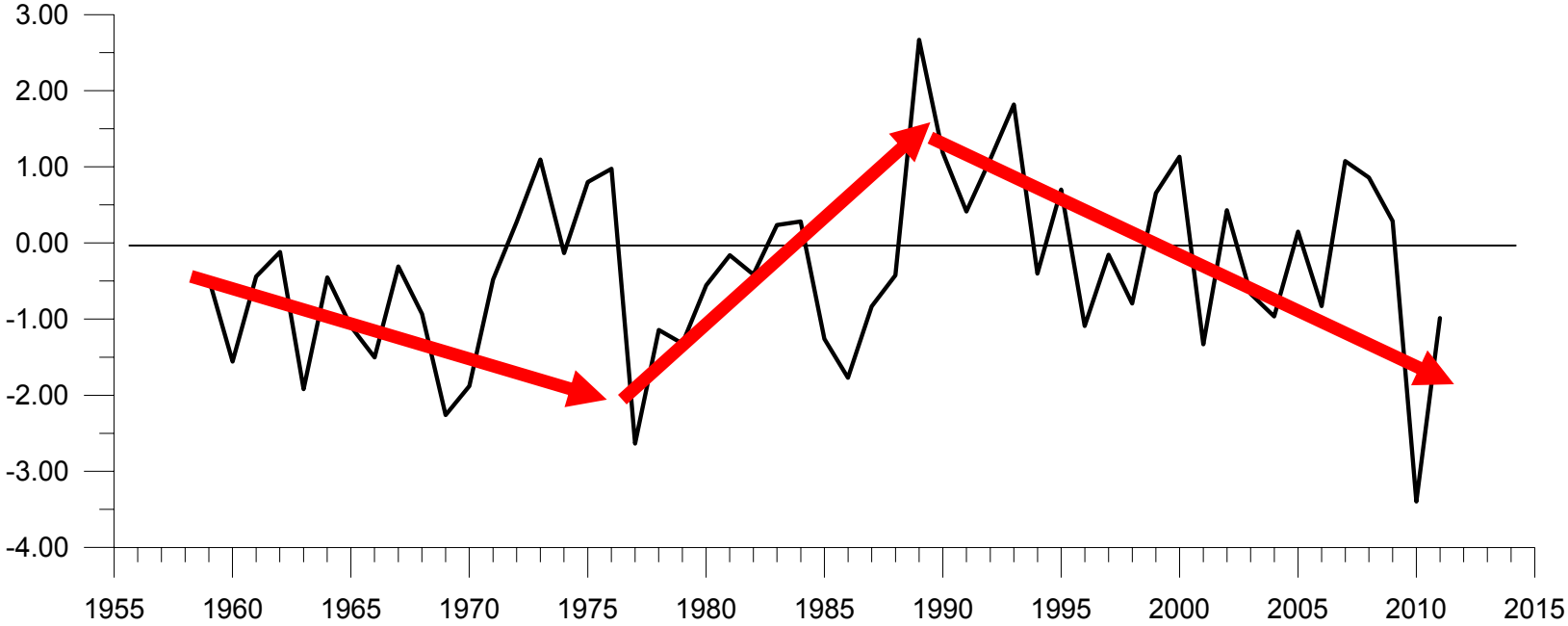
Trend of Surface Air Temperature

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).**

From Hiroshi Tanaka's Bergen (2010) presentation



Time series of the wintertime (DJF) AO index
(year mark as of January)

PREDICTABILITY
Downward propagation

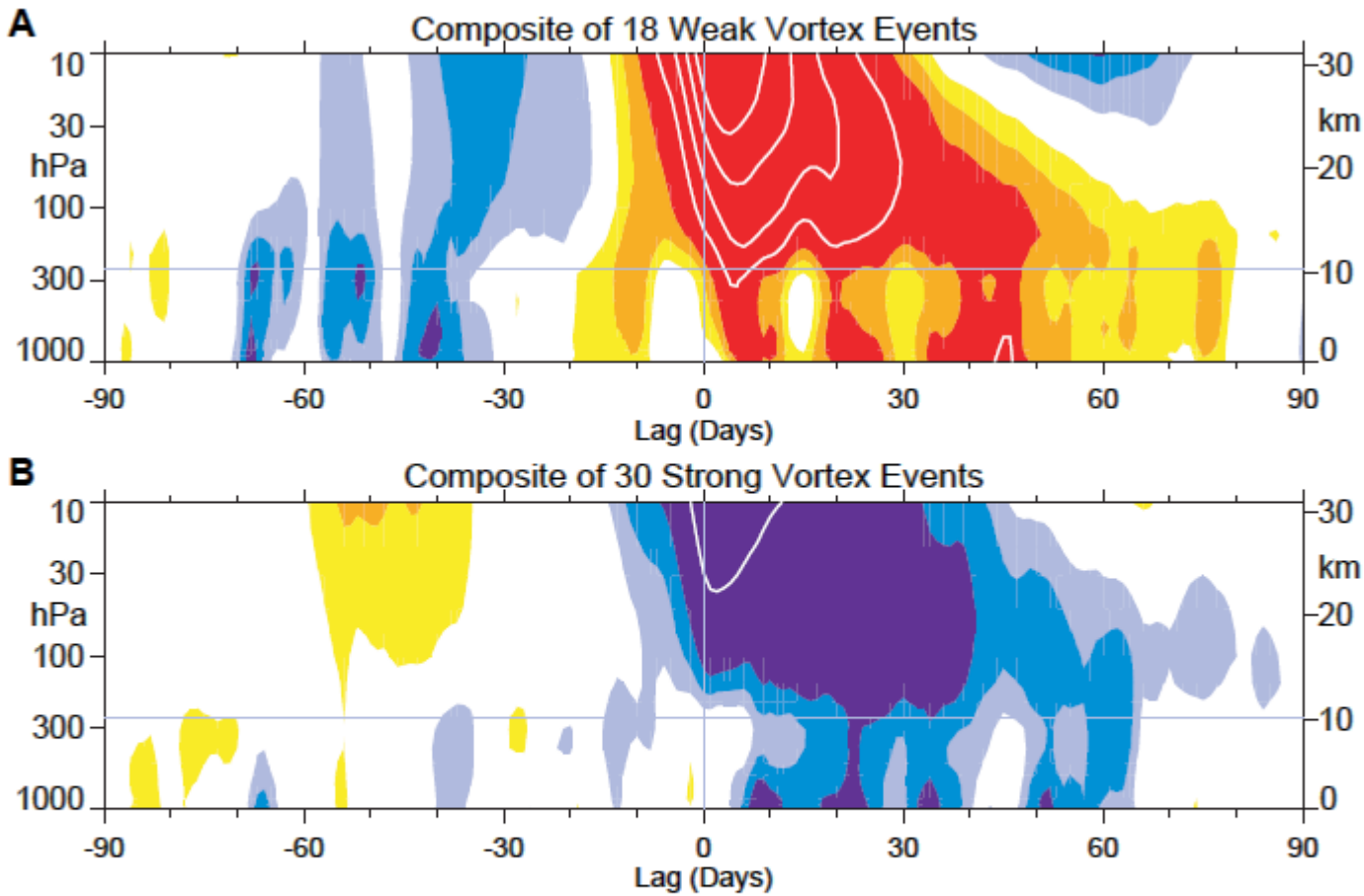
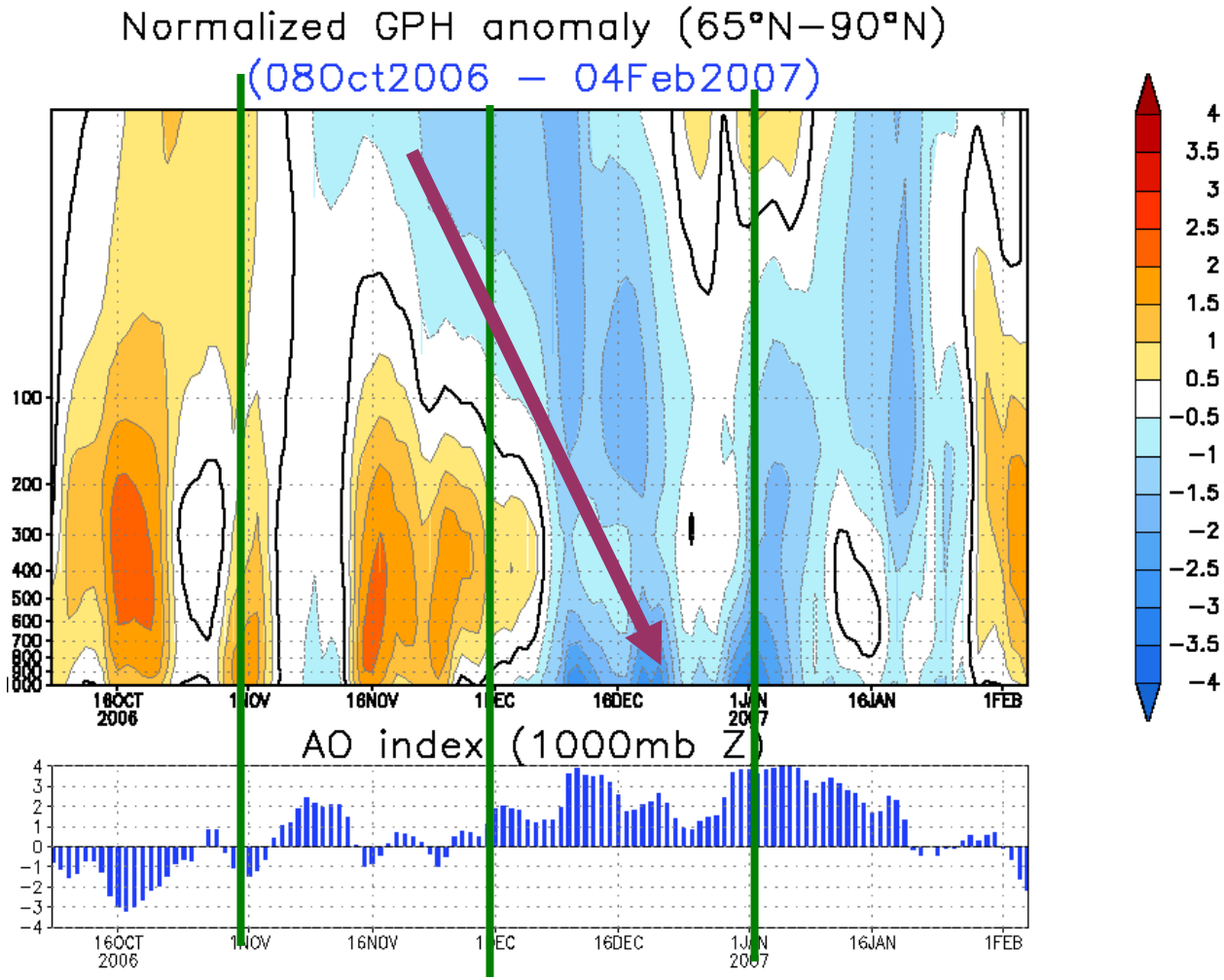


Fig. 2. Composites of time-height development of the northern annular mode for **(A)** 18 weak vortex events and **(B)** 30 strong vortex events. The events are determined by the dates on which the 10-hPa annular mode values cross −3.0 and +1.5, respectively. The indices are nondimensional; the contour interval for the color shading is 0.25, and 0.5 for the white contours. Values between −0.25 and 0.25 are unshaded. The thin horizontal lines indicate the approximate boundary between the troposphere and the stratosphere.

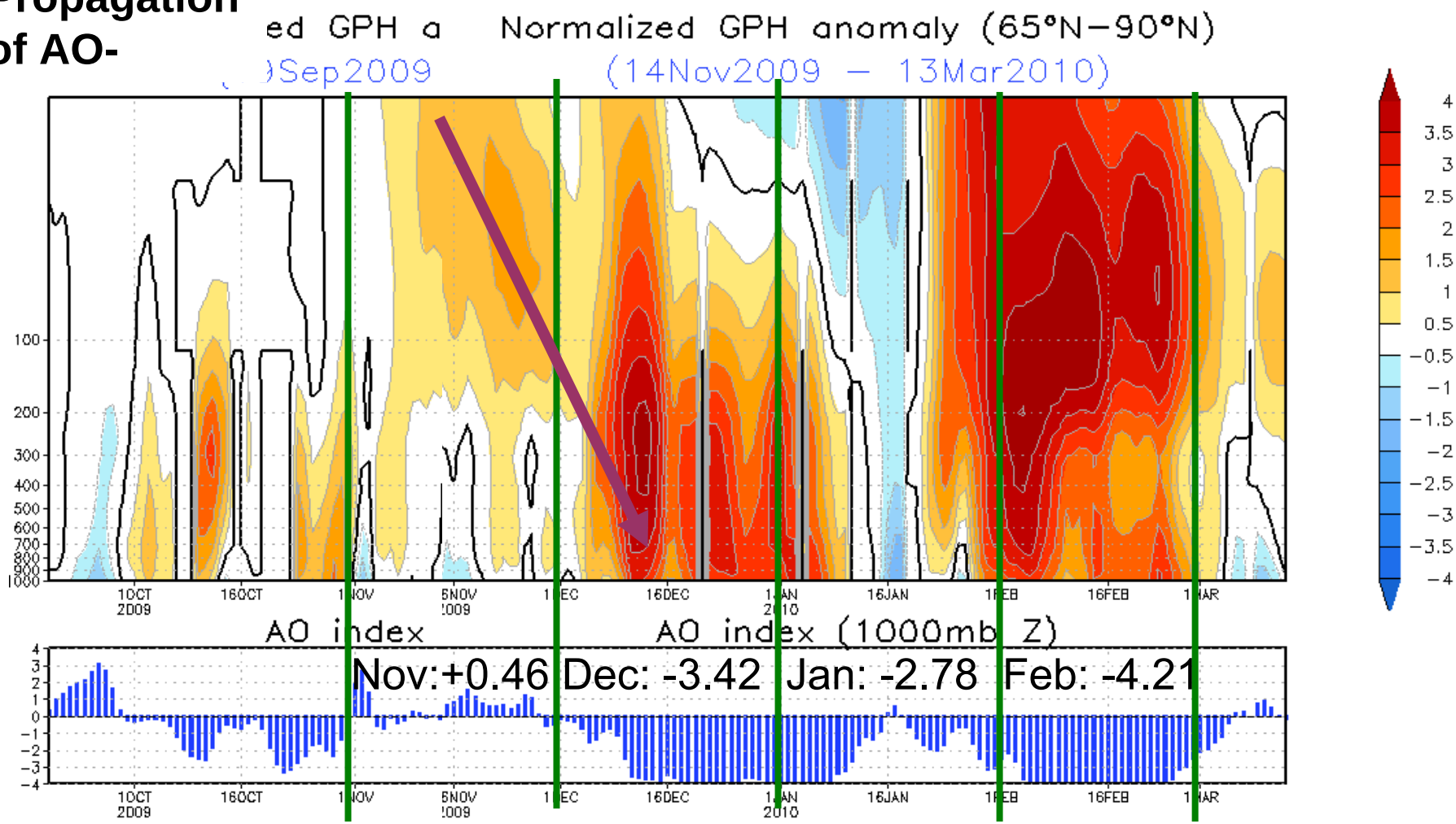
From M.P.Baldwin and T.J.Dunkerton (2001)

Downward Propagation of AO+

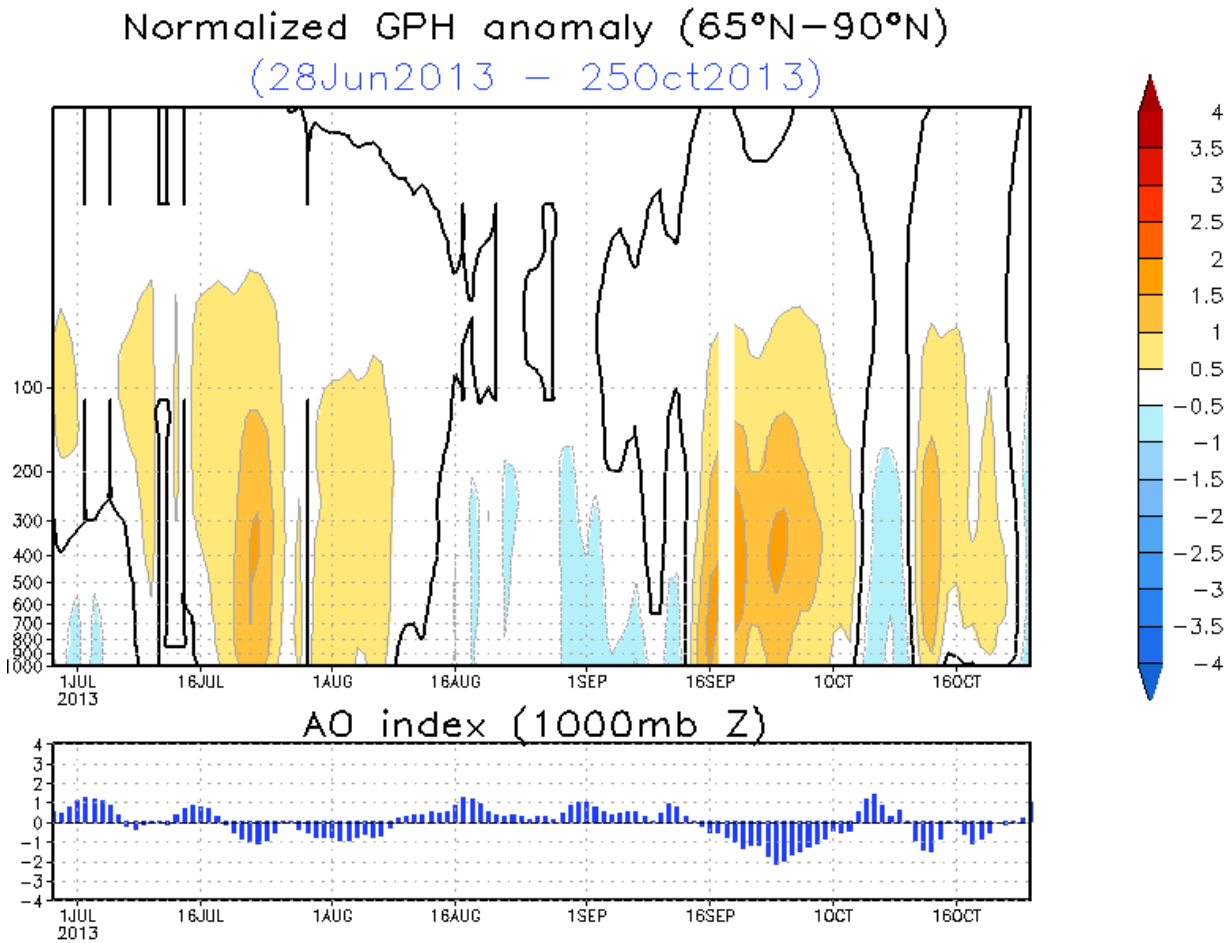


The daily geopotential height (GPH) anomalies at 17 pressure levels are shown for the previous 120 days as indicated, and they are normalized by standard deviation using 1979-2000 base period. The anomalies are calculated by subtracting 1979-2000 daily climatology, and then averaged over the polar cap poleward of 65ºN. The blue (red) colors represent a strong (weak) polar vortex. The black solid lines show the zero anomalies (From the NOAA NCEP CPC web site).

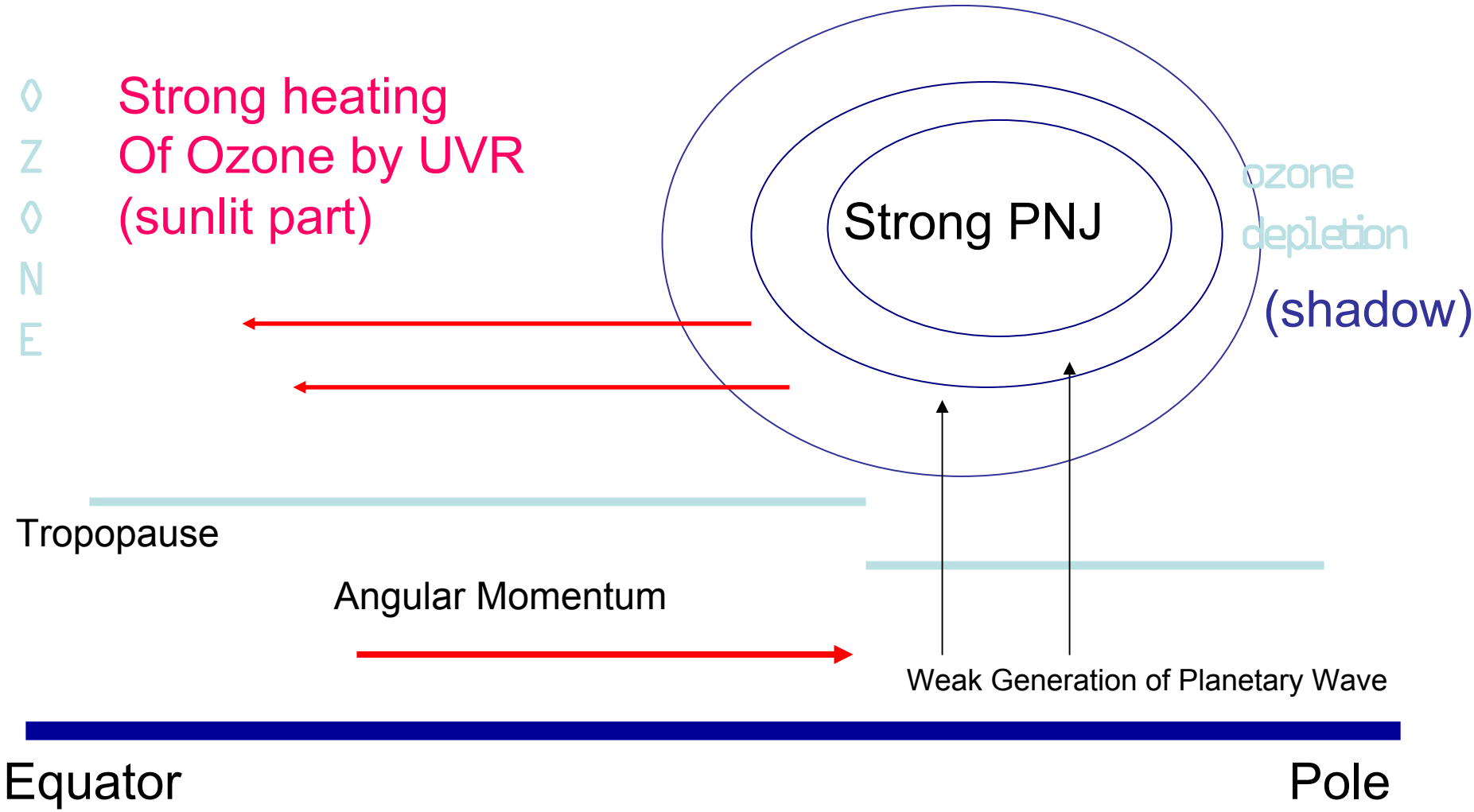
Downward Propagation of AO-



The daily geopotential height (GPH) anomalies at 17 pressure levels are shown for the previous 120 days as indicated, and they are normalized by standard deviation using 1979-2000 base period. The anomalies are calculated by subtracting 1979-2000 daily climatology, and then averaged over the polar cap poleward of 65ºN. The blue (red) colors represent a strong (weak) polar vortex. The black solid lines show the zero anomalies (From the NOAA NCEP CPC web site).

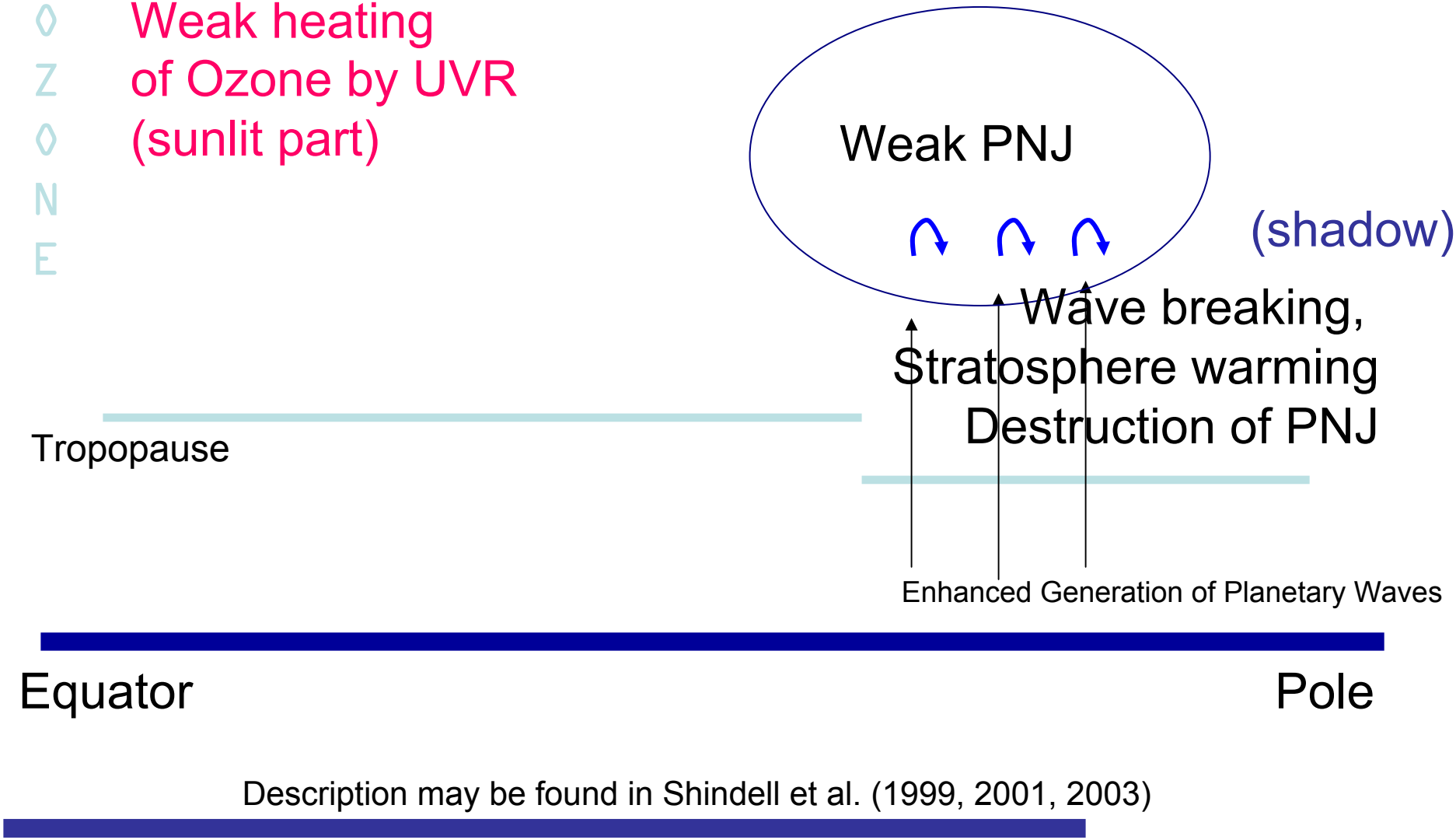

Normalized GPH anomaly (65°N–90°N)
(28Jun2013 – 25Oct2013)
100
200
300
400
500
600
700
800
900
1000
1JUL 2013
16JUL
1AUG
16AUG
1SEP
16SEP
1OCT
16OCT
4
3.5
3
2.5
2
1.5
1
0.5
−0.5
−1
−1.5
−2
−2.5
−3
−3.5
−4
AO index (1000mb Z)
4
3
2
1
0
−1
−2
−3
−4
1JUL 2013
16JUL
1AUG
16AUG
1SEP
16SEP
1OCT
16OCT

For positive AO are favourable:



Description may be found in Shindell et al. (1999, 2001, 2003)

For negative AO are favourable:

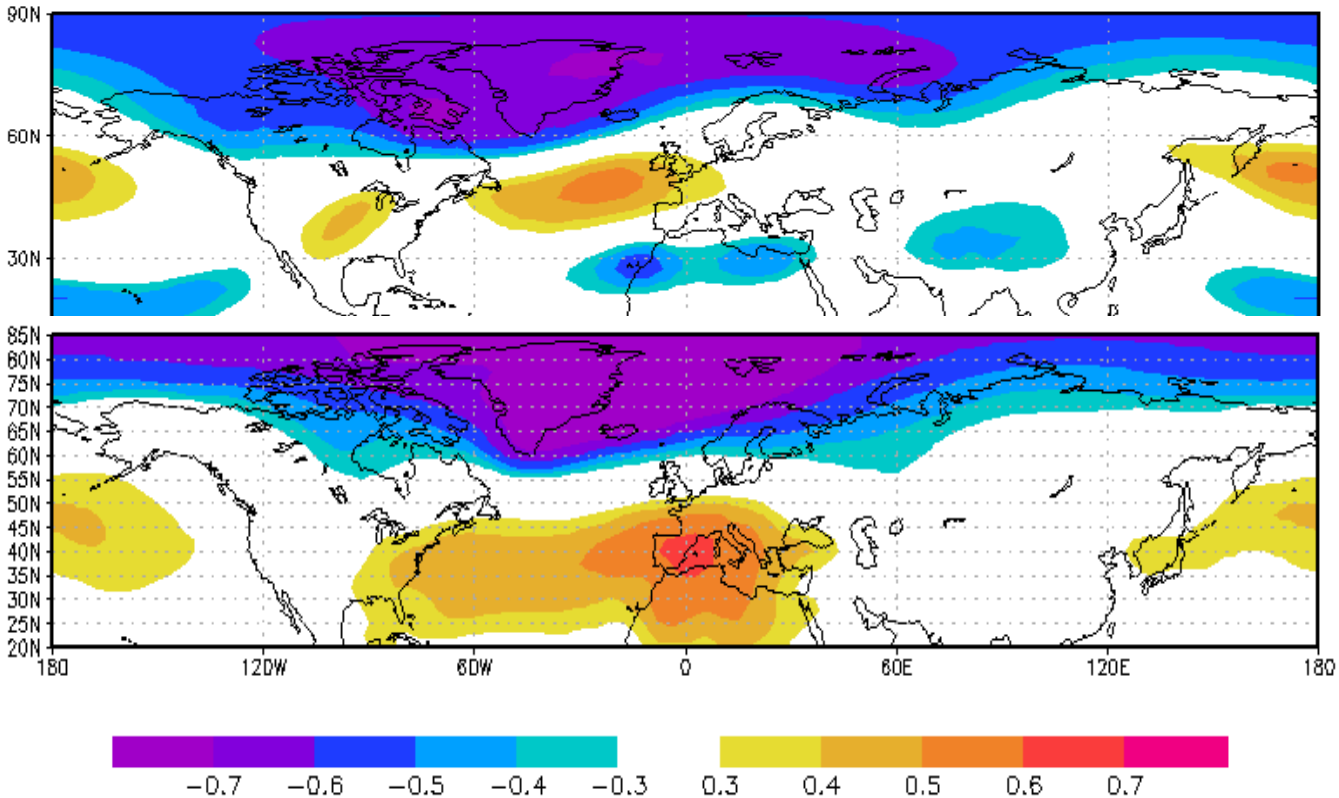


Description may be found in Shindell et al. (1999, 2001, 2003)

PREDICTABILITY
Some model predictions

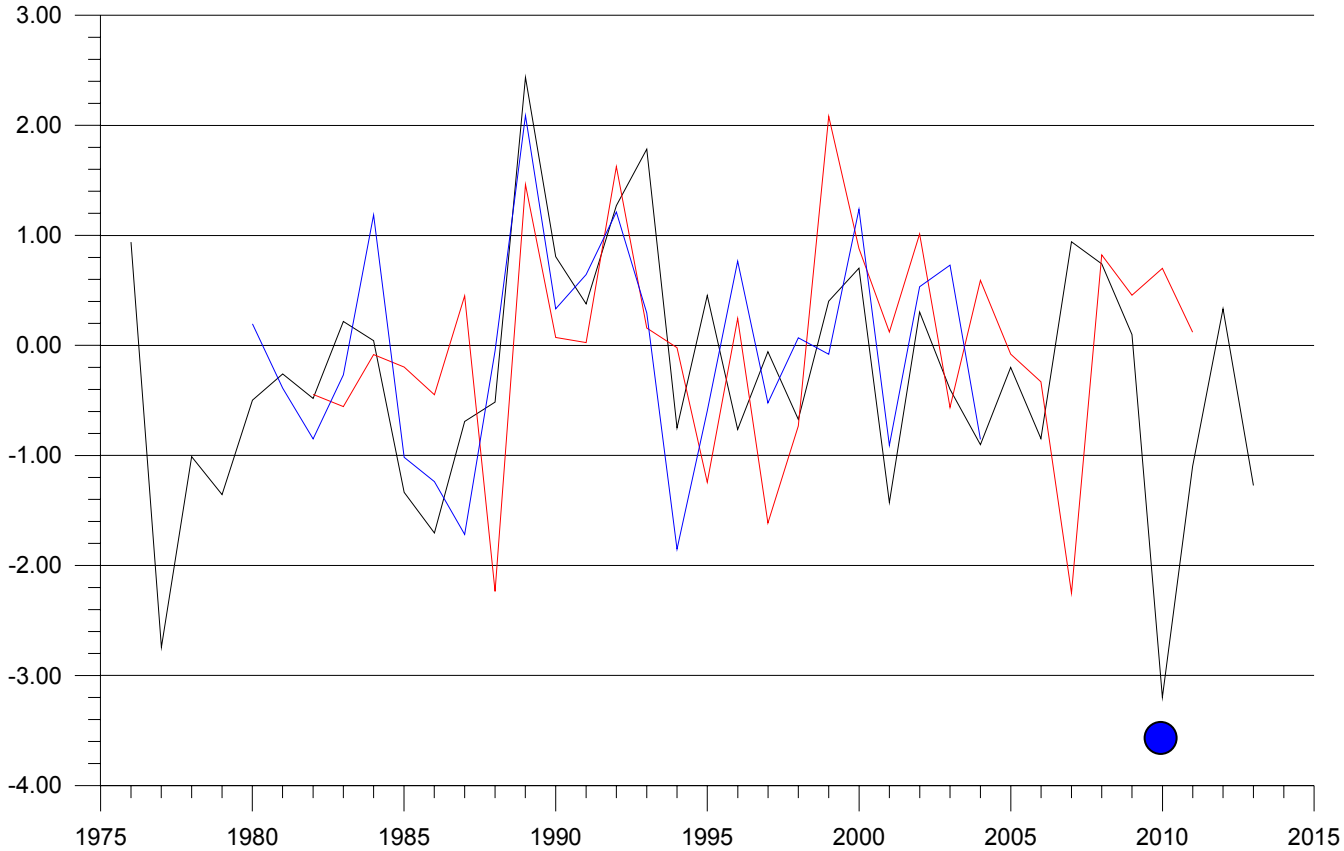
a.

b.

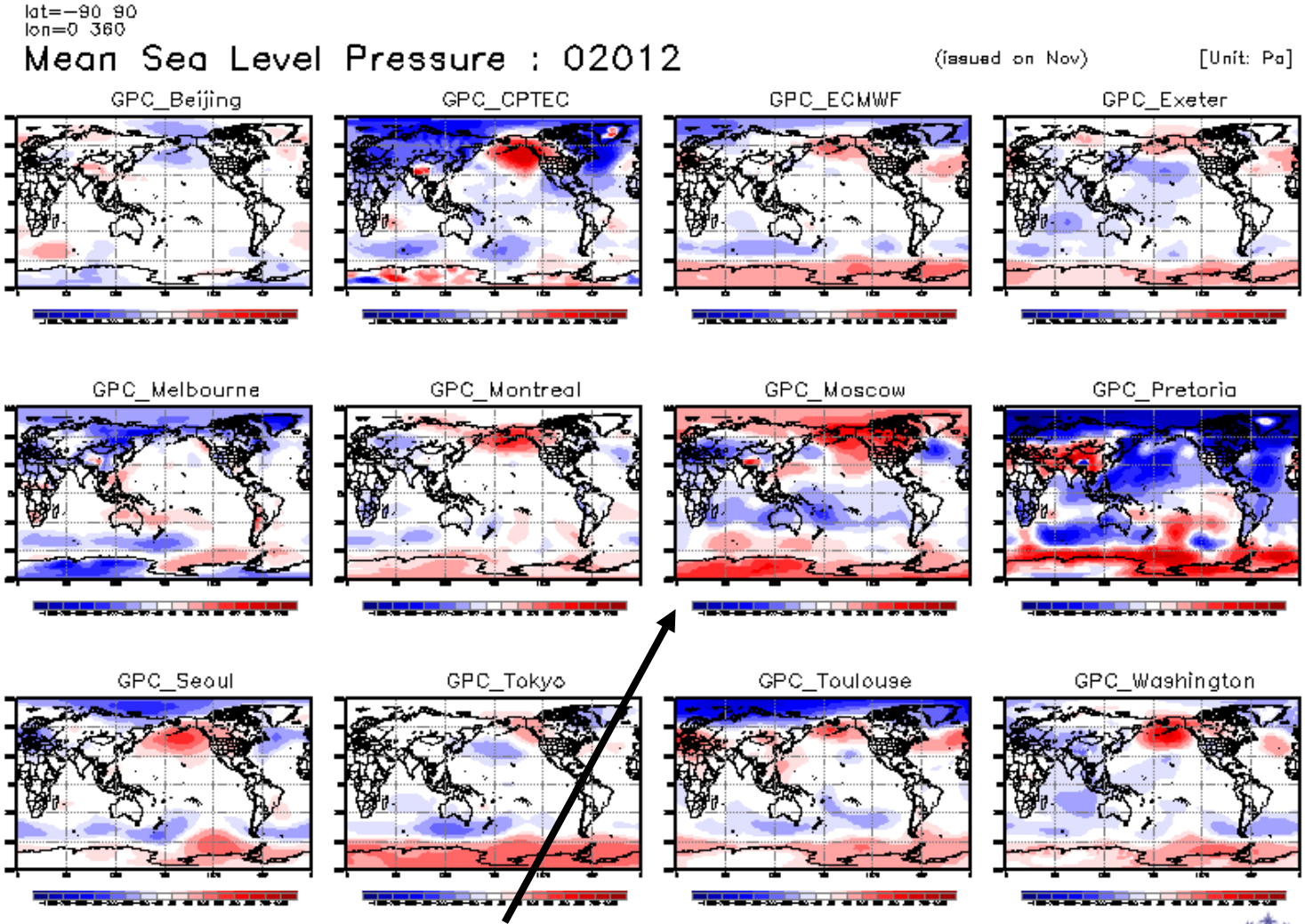


Correlations between the observed wintertime (DJF) AO index
- and wintertime (DJF) SLP predictions by GPC-Moscow (a),
- and observed wintertime (DJF) SLP (b).

1979 – 2003 (25 yrs.)



Time series of observed (black) and predicted DJF AO index. SL-AV model. Blue – version of 2004, red – version of 2011.



Distinct negative phase of the AO

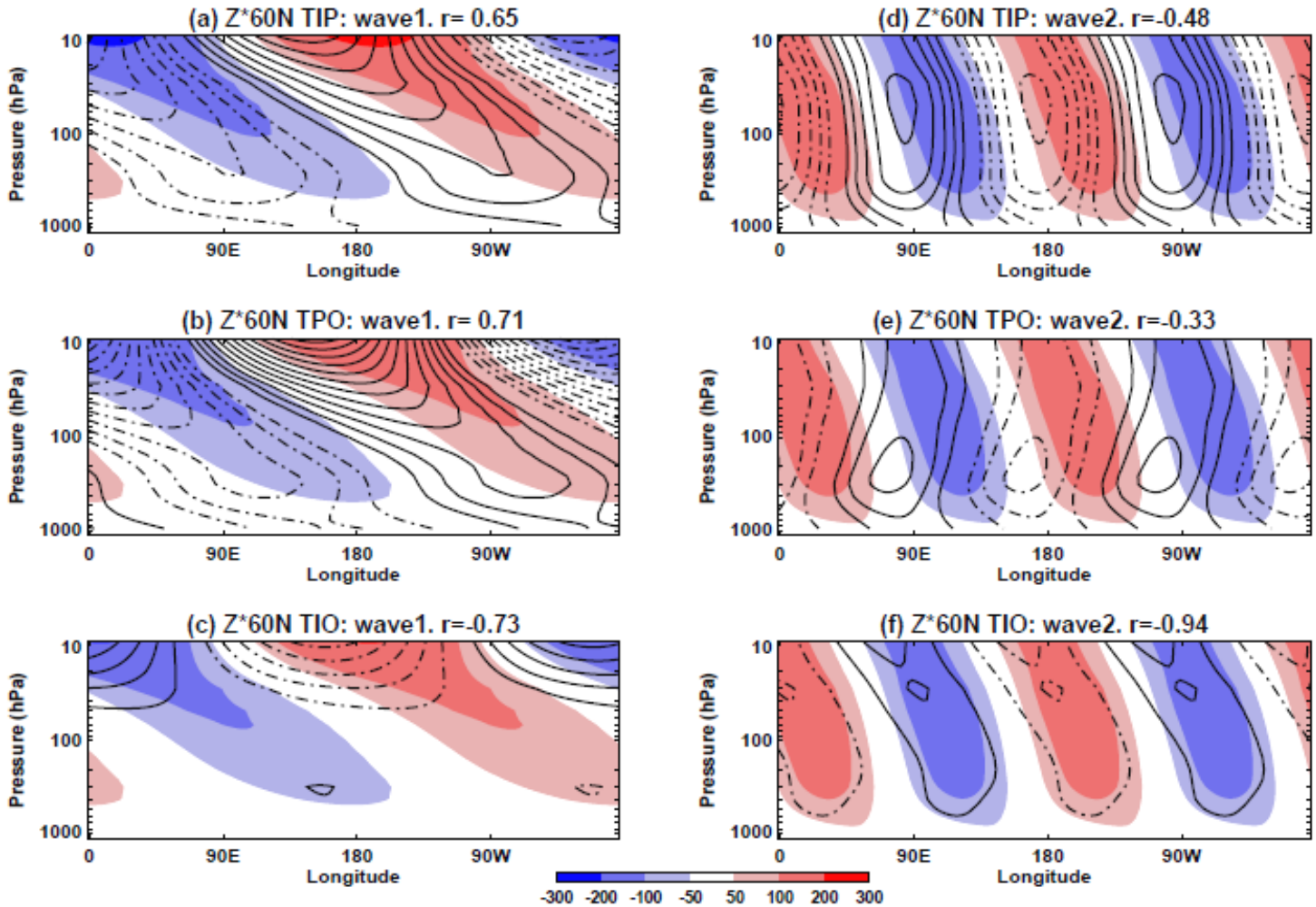
GPC predictions of DJF'12-13 mean SLP (from WMO LC LRF-MME)

Nowadays, it is believed that the AO is a result from the interaction between the zonal mean zonal flow and planetary waves in the Stratosphere.

Possible mechanisms

The ENSO and the AO

Wave generation. Influence from the tropics



Indian+Pacific

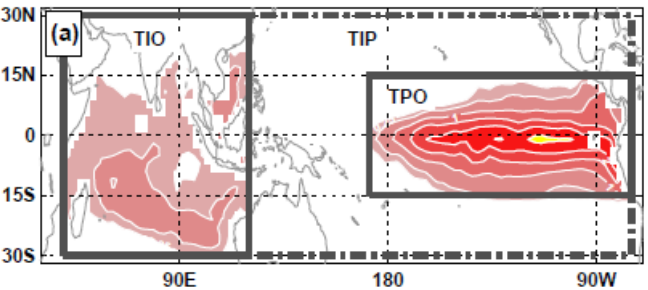
Pacific Ocean Enhancement Of wave 1 AO-

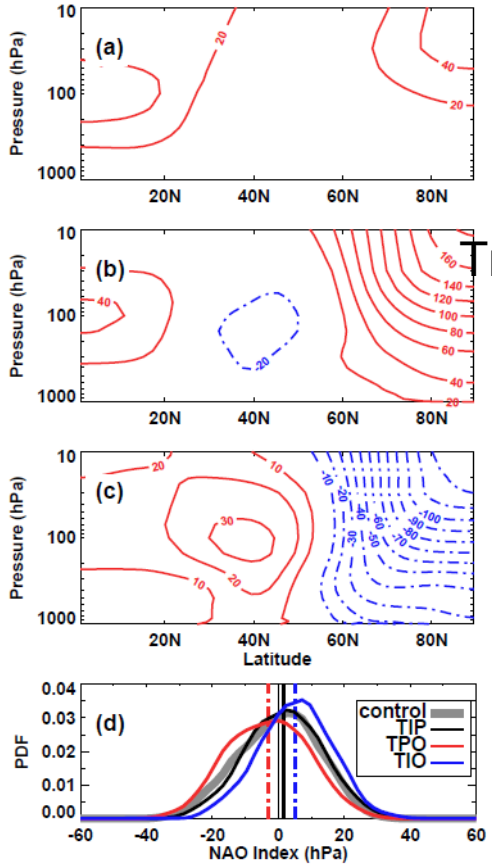
Indian Ocean Weakening of both Wave 1 and wave 1 AO+

FIG. 7. As Fig. 5 except for longitude-pressure sections of the eddy geopotential height at 60°N (Z*60N). Contours show the Z*60N (interval 20 m). Shading shows the climatological (stationary) wave field from the control simulation.

(from Fletcher & Kushner, 2010)

Wave generation. Influence from the tropics





Tropical Indo-Pacific (TIP)

Tropical Pacific Ocean (TPO)+
AO-

Tropical Indian Ocean (TIO)+
AO+

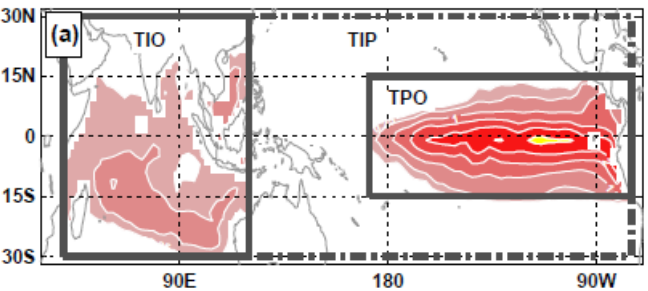
NAO

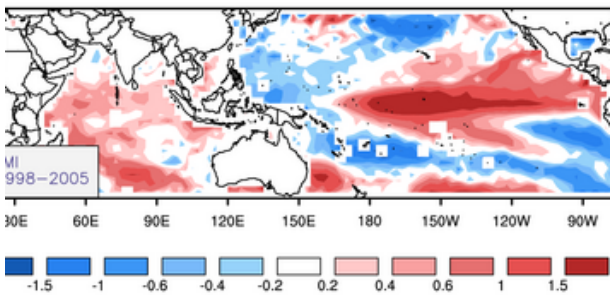
Geopotential Heigh Response to the five strongest El-Nino (1950-2001)

FIG. 5. Panels (a)-(c) are as Figs. 2a-c except for the zonal mean geopotential height response as a function of latitude and pressure. The contour interval is 20 m in (a),(c) and 10 m in (b). Panel (d) shows probability density functions (PDF) for the NAO index response (units hPa) computed using a dipole index of daily (Jan 1st - Feb 28th) SLP anomalies from all ensemble members at grid cells over Iceland and the Azores. The vertical lines show the ensemble mean NAO response. The thicker grey line is the PDF of the daily NAO index from the unforced control simulation.

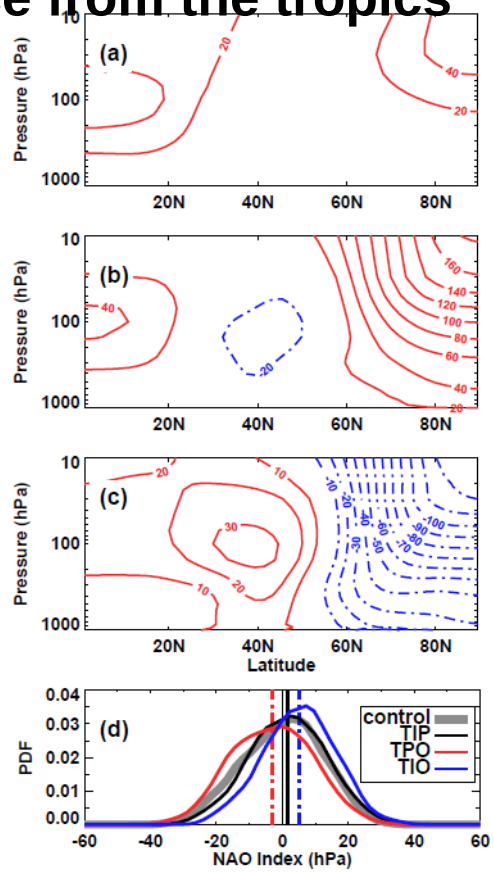
From Fletcher and Kushner (2011)
The role of linear interference in the Annular Mode response to Tropical SST forcing

Wave generation. Influence from the tropics





SST anomaly, DJF 2009-10



Tropical Indo-Pacific (TIP)

Tropical Pacific Ocean (TPO)+ AO-

Tropical Indian Ocean (TIO)+ AO+

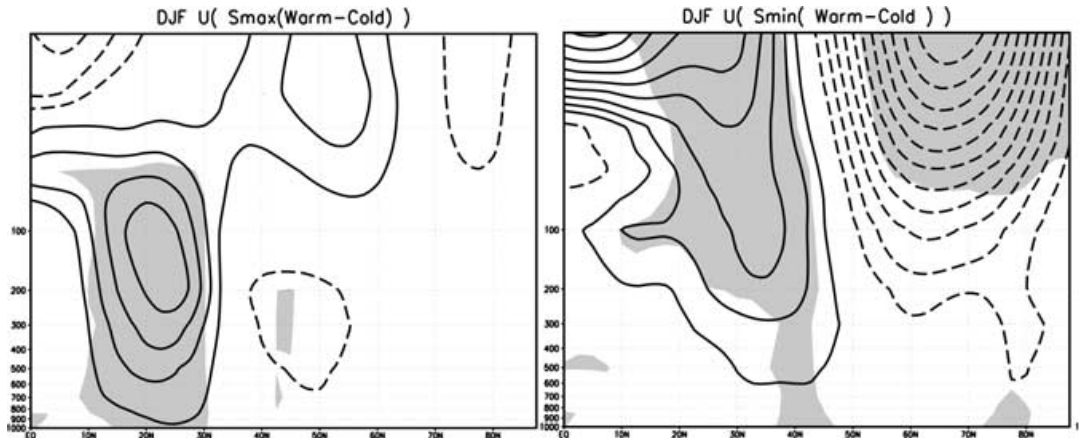
NAO

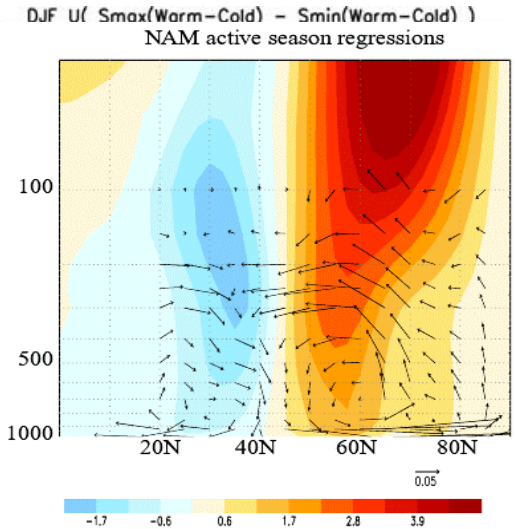
Geopotential Heigh Response to the five strongest El-Nino (1950-2001)

FIG. 5. Panels (a)-(c) are as Figs. 2a-c except for the zonal mean geopotential height response as a function of latitude and pressure. The contour interval is 20 m in (a),(c) and 10 m in (b). Panel (d) shows probability density functions (PDF) for the NAO index response (units hPa) computed using a dipole index of daily (Jan 1st - Feb 28th) SLP anomalies from all ensemble members at grid cells over Iceland and the Azores. The vertical lines show the ensemble mean NAO response. The thicker grey line is the PDF of the daily NAO index from the unforced control simulation.

From Fletcher and Kushner (2011)
The role of linear interference in the Annular Mode response to Tropical SST forcing

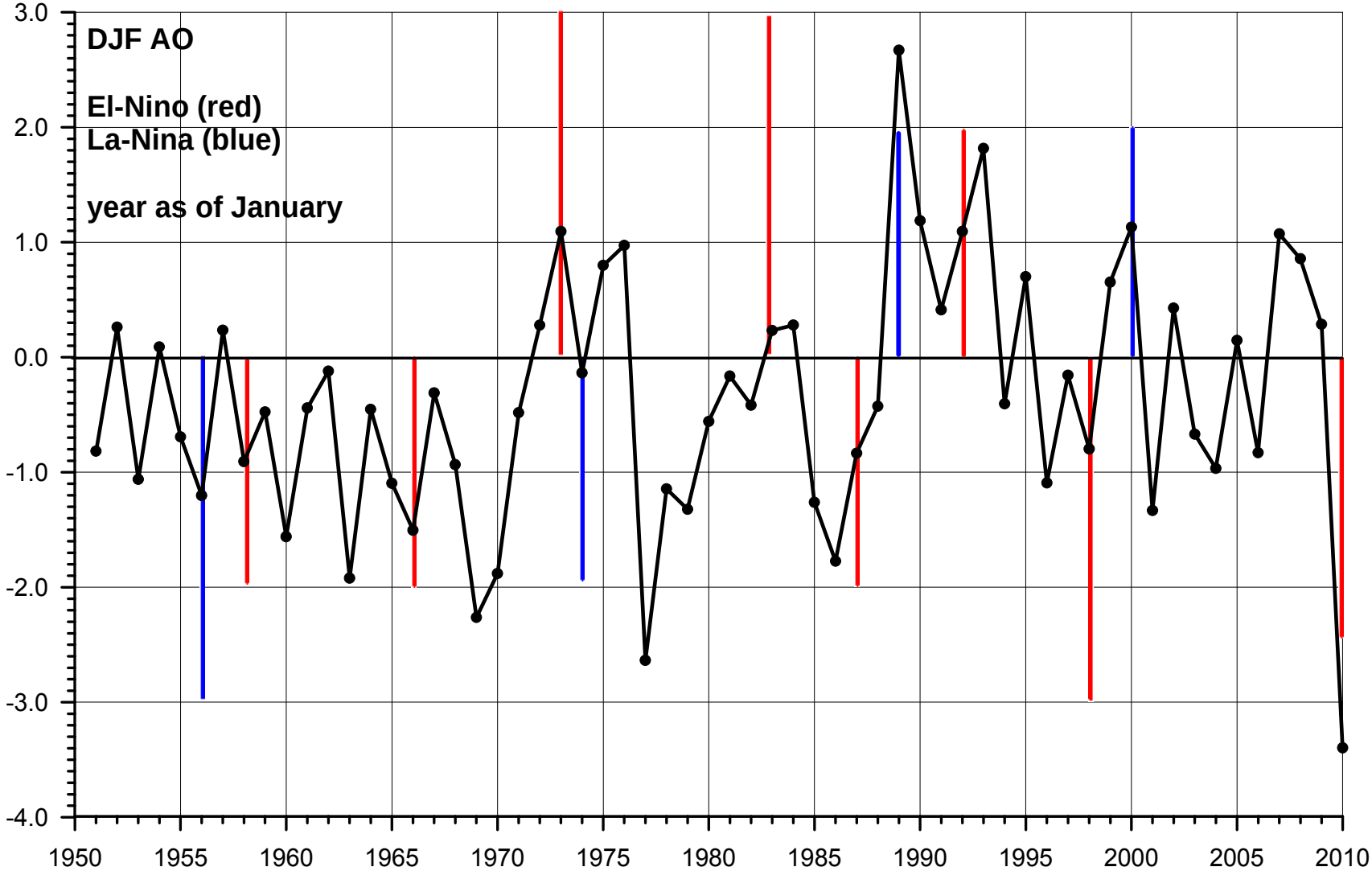
Stratosphere





Zonal wind (m/s) and mean meridional circulation anomalies (m/s; cm/s) regressed on January-March values of the NAM index.

Difference between the Sep.–Jan. cold and warm ENSO composites of DJF zonal mean zonal wind during (left) solar maxima, (middle) solar minima, and (right) the difference between them. Contour interval is 1 m/s, negative values are dashed, the 0 value is omitted. The area where the difference is significant at the 2.5% level is shaded (From Kryjov and Park, 2007).


DJF AO
El-Nino (red)
La-Nina (blue)
year as of January
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

Summary

The AO is the dominant mode of atmospheric variability of boreal winter

The wintertime AO strongly impacts the whole climate system
on a wide range of time scales from days to decades

Effect of the wintertime AO impact is noticeable throughout the whole year

The AO is believed to be a result
from the zonal mean flow – planetary wave interaction

Improvement of the wintertime AO prediction is believed
to come from the better simulation of the wave generation
and stratospheric processes

Thank You