The Arctic Oscillation. Phenomenon and Possible Mechanisms

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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)

Polar Night

Jet westerlies

Boreal winter

Circum-Polar Vortex

Equator Pole

Warm (shadow)
More Ozone and/or More Heating Of Ozone by UVR (sunlit part)
Less Ozone and/or Less Heating Of Ozone by UVR (sunlit part) weaker PNJ westerlies

Boreal winter

Weaker CPV or even LESS COLD
Sudden Stratospheric Warming Destruction of CPV

Planetary Waves

Equator Pole

LESS WARM
Definition of the AO
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 …”


Predecessors: Lorenz (1951)
Kutzbach (1970)
Wallace and Gutzler (1981)
Trenberth and Paolino (1981)
The loading pattern of the AO:
the leading EOF of \textit{year-round} monthly mean 1000 mb height anomaly

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 \textit{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

djf ao
djf nao
corr = 0.78


-4.0 -3.0 -2.0 -1.0 0.0 1.0 2.0 3.0
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
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)
Longer range influences

Upper: Annual SAT EOF1

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

Bottom: Normalised Mann-Whitney statistic $S$ for 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.
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 65°N. 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 65° N. 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)
For positive AO are favourable:

- Strong heating of ozone by UVR (sunlit part)
- Strong PNJ
- Weak generation of planetary wave

Description may be found in Shindell et al. (1999, 2001, 2003)
For negative AO are favourable:

- Weak heating of Ozone by UVR (sunlit part)
- Weak PNJ
- Wave breaking, Stratosphere warming, Destruction of PNJ
- Enhanced Generation of Planetary Waves

Description may be found in Shindell et al. (1999, 2001, 2003)
PREDICTABILITY
Some model predictions
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+

From Fletcher & Kushner, 2010

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.
Wave generation. Influence from the tropics

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

Tropical Indo-Pacific (TIP)

Tropical Pacific Ocean (TPO)+
AO-

Tropical Indian Ocean (TIO)+
AO+

NAO

Geopotential Height 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.
Wave generation. Influence from the tropics

Tropical Indo-Pacific (TIP)
Tropical Pacific Ocean (TPO)+ AO-
Tropical Indian Ocean (TIO)+ AO+

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

SST anomaly, DJF 2009-10

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