Arctic Oscillation and the East Asian Climate

By Daoyi Gong

Introduction

Many surface climate anomalies are directly brought on by fluctuations in the atmospheric circulation. Variability in temperature and precipitation on the local and regional scales are closely related to the atmospheric condition in the region of the target area as well as the global scale atmospheric variations. A number of studies have shown that the Arctic Oscillation (AO) is strongly coupled to surface air temperature fluctuations over the Eurasian continent.[1] AO's influence on the global and regional climate changes is currently the subject of much interest (Thompson and Wallace, 2001; Kerr 1999). The focus of this study is to investigate the AO's influence on variations of the climate over the eastern Asian region.

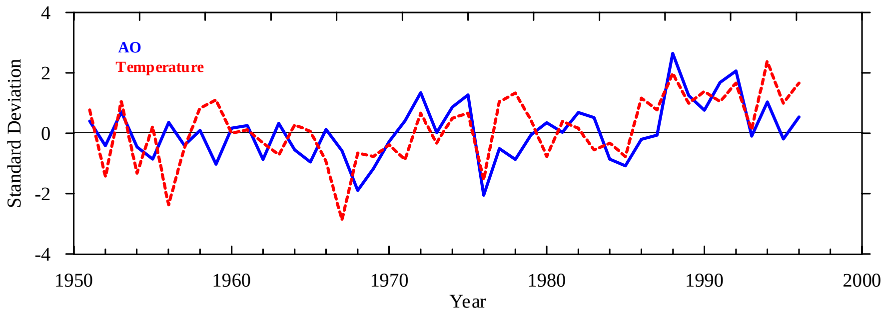
AO and the surface climate changes on the inter-annual time scale

The correlation coefficients between the AO index and temperatures over China are computated for wintertime (January-February-March: JFM) for 1958/59 and 1998/99. These results indicate that a positive relationship exists everywhere in China, except in the small regions over the southwestern Tibetan Plateau where the correlation coefficients vary from 0 to -0.2. The most significant areas cover the northern territory of China, north of 30°N-40°N, namely the northwestern, the northeastern, and the coastal regions (Figure 1). In these regions the correlation coefficients are above 0.3. This means that 16%~36% of the variance is associated with the AO. Thompson and Wallace (1998, 2000) have regressed northern hemispheric surface air temperature anomalies onto the standardized AO for JFM. They found that the positive phase of the winter AO is associated with positive surface air temperature anomalies throughout high latitudes of Eurasia. Regression coefficients vary from about 0.25 to 0.5 per standard deviation of the AO index over northern China. The results presented here are generally consistent with the previous findings but reveal more regional details.

The correlation coefficients between the AO index and precipitation are also calculated for the same period. It is interesting to note that the positive phase of the AO is generally associated with the positive precipitation anomalies, except for the small region in the northwest. The most significant relationship arises from two regions with values varying between 0.3 and 0.4. The larger area covers the central region of China between 30° to 40°N (east of 100°E) and a small area in the southern region of China close to the South China Sea. This means that about 10%-15% of the winter precipitation variance can be explained by the AO. The averaged precipitation over the entire inland

[1] Thompson and Wallace (1998) pointed out that the leading empirical orthogonal function of the wintertime northern hemisphere pressure field resembles the North Atlantic Oscillation but with more zonally symmetric appearance. This annular-like mode in the northern extratropical circulation is called Arctic Oscillation (AO). The AO has an equivalent barotropic structure from the surface to the lower stratosphere. Fluctuations in the AO create a seesaw pattern in which atmospheric pressure at the northern polar and middle latitudes alternates between positive and negative phase.

Figure 1. Time series of AO and the mean surface air temperature of 160-station in China during wintertime. To facilitate comparison all series are standardized regarding to 1961-90. The two curves correlate at 0.49, significant at 95% confidence level.



China also correlates with the AO at 0.47, this value is above the 95% confidence level.

Long-term climate variations

In this section the long-term variations of the AO and its connections to climate in China are analyzed by employing low-pass filtering techniques. Figure 2 shows the long-term time series of winter precipitation and temperature in China. Precipitation is computed from the mean of 33 stations over eastern China. All stations are located east of 100°E (Wang et al., 2000). This 33-station-mean series correlates to the 160-station-mean at 0.99 for the period 1951-1999. Temperature is the mean of Shanghai and Beijing. There is good spatial consistency in the temperature changes over China in winter as revealed by the empirical orthogonal function analysis (Wang et al., 1999), thus several typical stations may be enough for analysis. Here we chose only Beijing and Shanghai, this 2-station-mean series correlates to the 160-station-mean at 0.92 for the period 1951-1998.

A number of studies have demonstrated that there are interdecadal climatic variations in China. In order to compare the correlation between the climate and atmospheric indices on the interdecadal scale, a 10-40yr band-pass filter is applied to these long-term time series. The filtered low frequency components for these series are shown in Figure 2. To facilitate comparison, all series are normalized before filtering. Only the period from 1899 to1994 is shown here, due to the limit of data availability. In the above analysis it is found that there are good relationships between the AO, precipitation and temperature. As shown in Figure 2, these relationships are still evident, the correlation coefficients suggest that the AO plays a more significant role in both temperature and precipitation on the interdecadal time scale than on interannual time scale. The correlation between the AO and temperature is 0.68, for precipitation the correlation is even higher with a value of 0.72.

AO and the East Asian monsoon

Plenty of scientific evidence has indicated that the most important regional factor affecting winter climate in China is the Siberian High. An intensified Siberian High leads to a strong East Asian winter monsoon, which would give rise to a dramatic temperature changes over eastern Asia. Gong et al. (2001) reported that there is a significant out-of-phase relationship between the AO and Siberian High intensity. The Siberian High intensity is measured as the mean sea level pressure over the central region of the anticyclone. The correlation coefficient between these two indices is –0.48 for December-January-February (DJF) for the period 1958-98. It was found that the negative phase of the AO is concurrent with a stronger East Asian Trough and an anomalous anticyclonic flow over the Urals at the middle troposphere (500hPa). This anomalous circulation pattern could bring stronger northwesterlies and may enhance the upper-level airflow convergence in the rear of the trough. That means a weaker AO can be helpful to dynamically strengthen the Siberian High and winter monsoon, and vice versa.

The AO's influence on the East Asian winter monsoon and surface climate is evident over most of the continental Asia. Mean temperature averaged over middle to high latitude Asia (30°E-140°E, 30°N-70°N) is correlated to the Siberian High central intensity with correlation coefficient of -0.58 (1922-1999), and for precipitation, the correlation

Figure 2. Low frequent variations of AO (in black), temperature (in red) and precipitation (in blue). Shown as the results from a 10-40yr band-pass filter.

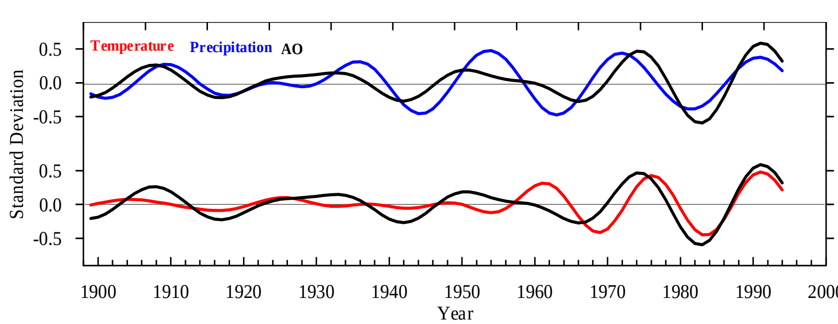


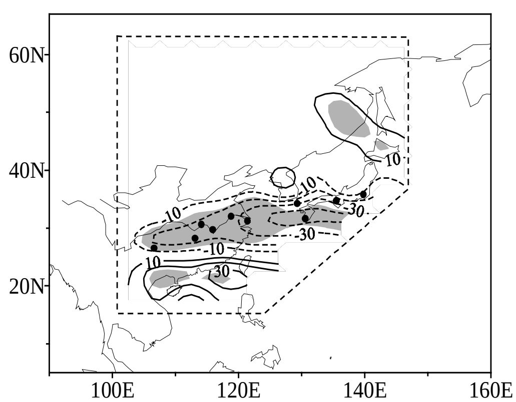
Table 1. Summary of correlation statistics for winter (JFM). * Significant at 95% confidence level. Shown in parentheses are sample numbers used to compute the correlation. The sample numbers are variable due to the data availability. Precipitation and temperature are means for continental Asia averaged over middle to high latitude Asia (30°E-140°E, 30°N-70°N).

	AO	EU	SO	Precipitation	Temperature
Siberian High	-0.52*(76)	0.30*(52)	0.14(79)	-0.44*(77)	-0.58*(78)
AO	1	-0.37*(49)	0.12(76)	0.14(76)	0.53*(76)
EU		1	-0.07(52)	-0.28*(50)	0.21(51)
SO			1	-0.38*(77)	-0.28*(78)

coefficient is -0.44 (1922-1998). Of course, some other circulation systems such as Southern Oscillation Index (SOI) and Eurasian teleconnection pattern (EU) are also found to be responsible for the climatic changes over mid to high latitudes to some extent (Hurrell, 1996, Zhu et al, 1997). Co-variability values among some components are listed in Table 1. To check the contribution by these elements, a multiple regression analysis is applied to these indices. For the sake of establishing equal record length among the indices, all data are adjusted to the period from 1949 to 1997. The Siberian High, AO, EU and SO all together can explain 72 percent of the variance in temperature. The isolated variance reveals that the AO-related change is the most important, with a contribution of 30%. The Siberian High explains 24% of the variance in temperature. The fractions related to EU and SO are 11% and 7%, respectively. The precipitation variance explained by the AO and Siberian High is relatively low, both less than 10%.

Given the evidence of strong influence of winter-half-year AO on the surface conditions (snow, temperature, sea-ice, sea surface temperature, etc.), one can propose that the AO may not impact only the wintertime climate, but also the summer condition. A recent study shows that the AO also exerts significant influences on year-to-year variations in the East Asian summer monsoon rainfall (Gong and Ho, 2002). The correlation between late spring AO and precipitation shows well-defined features over East Asia (Figure 3). Mean summer precipitation averaged over ten stations located at southern Japan and middle China (along the famous *Meiyu-Baiu* rainfall belt) is used to measure the summer monsoon rainfall. When the AO leads by one month, the correlation between the May-July AO and summer monsoon rainfall is -0.44. When AO leads by two months, the correlation becomes -0.32. The May AO index shows the strongest connection to the summer monsoon rainfall, with correlation coefficient of -0.45. Large-scale atmospheric circulation patterns in East Asia in association with the AO are also evident. A positive phase of the AO

Figure 3. Changes in summer precipitation (mm) corresponding to a one standard deviation of the May AO index for the period 1900-1998. Regions above 95% confidence level are shaded. The contour interval is 10 mm. Zero contours are omitted. Filled circles are ten stations with data available for the entire period of 1899-



in late spring is found to lead to a northward shift in the summertime upper tropospheric jet stream over East Asia. This northward shift of the jet stream is closely related to an anomalous sinking motion in 20º-40ºN and a rising motion in surrounding regions. These changes give rise to drier conditions over the region extending from the Yangtze River valley to southern Japan and wetter conditions in southern China. Possible mechanisms connecting the late spring AO and summer monsoon rainfall remain to be addressed.

Conclusion

AO has a strong influence on the climate in East Asia. During the high-AO years, warmer than normal temperature and precipitation are observed over most of China in winter. On the interdecadal time scale, the AO also shows significant influences on both temperature and precipitation.

It is also revealed that the AO significantly impacts the East Asian winter monsoon through the Siberian High. A weak AO gives rise to the strong Siberian High and winter monsoon. Evidence also shows that there are significant connections between the late spring AO and East Asian summer monsoon and monsoon rainfall; a positive-strong-AO usually leads to less summer monsoon rainfall along the Yangtze River and southern Japan.

Suggested references and web sites

- For more information on AO and its definition see:

Thompson, D. W. J., and J. M. Wallace, 1998: The Arctic Oscillation signature in the wintertime geopotential height and temperature fields, *Geophysical Research Letters*, **25**, 1297-1300.

- For more information on AO's climatic influence see:

Gong, D.Y., S.W. Wang, and J.H. Zhu, 2001: East Asian winter monsoon and Arctic Oscillation. *Geophysical Research Letters*, **28**(10), 2073-2076.

Gong, D. Y., and C. H. Ho. Arctic Oscillation Signals in the East Asian Summer Monsoon, 2002: *Journal Geophysical Research - Atmosphere*, in press.

Kerr R. A., 1999: A new force in high-latitude climate. *Science*, **284**,241-242.

Thompson, D. W. J., and J. M. Wallace, Annular modes in the extratropical circulation, Part I: Month-to-month variability. *Journal of Climate*, **13**(5), 1000-1016.

Thompson, D. W. J., and J. M. Wallace, Regional climate impacts of the Northern Hemisphere annular mode. *Science*, **293**,85-89.

Thompson, D. W. J., J. M. Wallace, and C. Gabriele, Annular modes in the extratropical circulation, Part II: Trends. *Journal of Climate*, **13**(5), 1018-1036.

- Information on AO can also be obtained at:

http://nsidc.org/arcticmet/patterns/arctic_oscillation.html

http://tao.atmos.washington.edu/wallace/ncar_notes/

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Upcoming Events

NOAA 27th Annual Climate Diagnostics and Prediction Workshop
October 21-25, 2002
Fairfax, Virginia
http://www.cpc.noaa.gov

Climate Prediction Assessments Workshop: Research and Applications on Use and Impacts
October 28-30, 2002
Washington, DC
http://www.ogp.noaa.gov/

83rd Annual conference of the American Meteorological Society
February 9-13, 2003
Long Beach, CA
http://www.ametsoc.org/

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