

# East Asian winter monsoon and Arctic Oscillation

Dao-Yi Gong

Key Laboratory of Environmental Change and Natural Disaster  
Institute of Resources Science, Beijing Normal University, Beijing, 100875, China

Shao-Wu Wang, Jin-Hong Zhu

Department of Geophysics, Peking University, Beijing, 100871, China

**Abstract.** In this study, the connection between Arctic Oscillation (AO) and variability of East Asian winter monsoon is investigated. Two indices are chosen to describe the winter monsoon. One is the intensity of the Siberian High, defined as the average SLP over the center region, and the other is the temperature of eastern China, averaged over 76 surface stations. These are two tightly related components, correlate at -0.62 for period 1951-99. Temperature drops by 0.64 degrees Celsius in association with a one standard deviation increase in Siberian High intensity. It is found that there are significant out-of-phase relationships between the AO and the East Asian winter monsoon. The correlation coefficient between the AO and the Siberian High intensity index is -0.48 for period 1958-98. AO is also significantly correlated with the temperature of eastern China at 0.34. However, when the linear trend is removed, the correlation between AO and temperature is no longer significant. But the strong connection between the AO and Siberian High, and between the Siberian High and temperature are still significant. These results reveal that the AO influences the East Asian winter monsoon through the impact on the Siberian High. Negative phase of the AO is concurrent with a stronger East Asian Trough and an anomalous anticyclonic flow over Urals at the middle troposphere (500hPa). Both the AO and the Eurasian pattern play important roles in changes of the Siberian High and/or East Asian winter monsoon. They account for 13.0% and 36.0% of the variance in the Siberian High respectively.

## Introduction

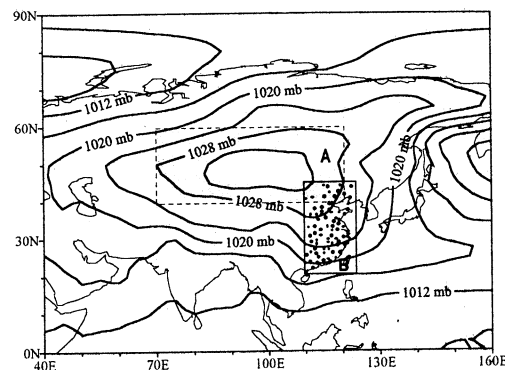
Thompson and Wallace [1998] pointed out that the leading empirical orthogonal function of the wintertime Northern Hemisphere sea level pressure field resembles the North Atlantic Oscillation but has a more zonally symmetric appearance. This annular-like mode in the northern extratropical circulation, which has an equivalent barotropic structure from the surface to the lower stratosphere, is called "Arctic Oscillation (AO)" [Thompson and Wallace, 1998]. This mode is found to exist in both hemispheres [Thompson and Wallace, 2000; Gong and Wang, 1998; Gong and Wang, 1999a]. Fluctuations in the AO create a seesaw pattern in which atmospheric pressure at northern polar and middle latitudes alternates between positive and negative phase. This kind of variation generally resembles the zonal index cycle [Wallace, 2000]. A growing body of evidence indicates that the AO has wide-ranging effects over the Northern Hemisphere. It is found that AO is strongly coupled to surface air temperature fluctuations over the Eurasian continent [Thompson and Wallace, 1998; Thompson and Wallace, 2000; Kerr, 1999]. Some regional climate associations with AO are highlighted recently, for example, Wang and Ikeda [2000] demonstrated that there is a significant

relationship between the sea-ice cover in the Arctic and sub-polar regions and the AO. Surface air temperature changes over the Arctic Ocean are strongly related to the AO too, which accounts for more than half of the surface air temperature trends over Alaska, Eurasia and the eastern Arctic Ocean during the past two decades [Rigor et al., 2000]. Cavazos [2000] reported that wintertime extreme precipitation events in Balkans are modulated by changes in the circulation associated with the AO. The variability of some regional circulation systems such as Aleutian Low also shows an apparent relation to the AO [Overland et al., 1999].

Given the previous results regarding obvious association of the inner Eurasian continental temperature with the AO, we will investigate the possible connection between the AO and the East Asian winter monsoon in this manuscript.

## Data

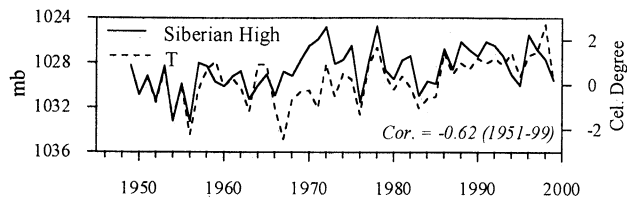
The main surface climate data sets for this study include the monthly mean air temperature data of 160 stations in China compiled by the China Meteorological Administration. In this study only 76 stations in eastern China, as shown in Figure 1, are used. These data cover the period from 1951 to present. Monthly mean sea level pressure (SLP) data and 500 hPa geopotential heights for Northern Hemisphere are taken from National Center for Environmental Prediction / National Center for Atmospheric Research (NCEP/NCAR) Reanalysis data set [Kalnay et al., 1996], and have downloaded through the internet at <http://ingrid.ldeo.columbia.edu/>. To reduce the downloading time, we extracted subsets of the data on a 5°×5° mesh for both the SLP and 500 hPa height. This spatial resolution for these two fields is sufficient for the purposes of this research.



**Figure 1.** Climatology of winter sea level pressure over Eurasia. Sea level pressure for grids in Region A are averaged to define the intensity of Siberian High. Seventy-six stations (shown as black dots) in Region B, over which the East Asian winter monsoon is manifest, are averaged to obtain the mean temperature of eastern China.

Copyright 2001 by the American Geophysical Union.

Paper number 2000GL012311.  
0094-8276/01/2000GL012311\$05.00



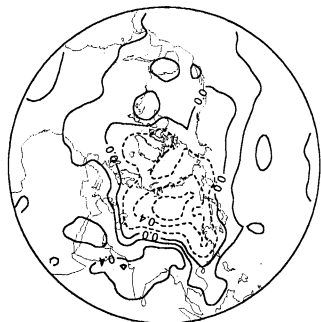
**Figure 2.** Time series of Siberian High intensity and temperature of eastern China. Temperature is shown as the departure with respect to 1961-90. The axis of Siberian High graph is inverted to facilitate comparison.

The Arctic Oscillation indices used here are kindly provided by Dr. David Thompson [Thompson and Wallace, 1998]. There are two kinds of AO indices. One is derived from the long-term historical sea level pressure fields since 1899, and the other is as same as the previous one but based on the NCEP/NCAR Reanalysis sea level pressure field. The shorter monthly AO records are available over the 1958 to 1999 period. These two AO indices correlate at 0.99 for the period 1958-1997 for all four seasons. Both AO indices are prepared by Dr. David Thompson, and can be accessed via internet at <ftp://ftp.atmos.washington.edu/>. In this research only the indices derived from the NCEP/NCAR Reanalysis data are used. All above-mentioned data are averaged for three wintertime months (December, January and February).

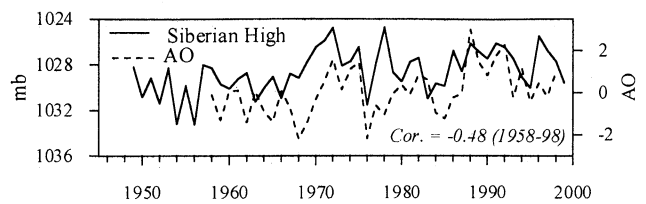
## Results

In the large-scale mean circulation, the surface circulation over Asia is dominated by the huge atmospheric center of action, namely the Siberian High. This anticyclonic circulation system is centered over the inner territory, and controls almost the entire region of continental Asia and brings strong northerly and northeasterly winds over the northern and central China and the South China Sea. These winter monsoon winds influence the climate of underlying regions directly. Strong northerly winds bring intense cold air masses from the inner land to lower latitude coastal regions, the associated cold waves or cold surges over the East Asia result in the dramatic changes in air temperature [Wang, 1962]. Gong and Wang [1999b] pointed out that the Siberian High account for about 43.6% variance of the winter temperature for China on average.

In this manuscript two indices are chosen to describe the winter monsoon. One is the Intensity of Siberian High, and the other is the temperature of eastern China. The Intensity of Siberian High is defined as the mean SLP averaged



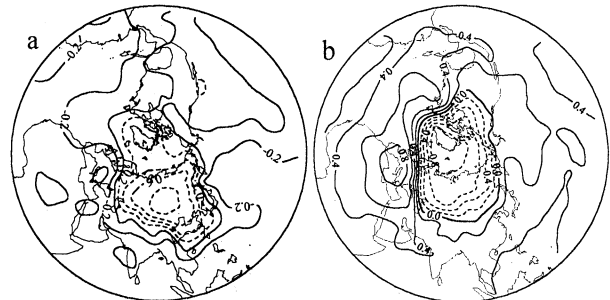
**Figure 3.** Correlation between the temperature of eastern China and SLP during Northern Hemisphere winter for the period 1951-99. Note that the limits for 95% and 99% confidence levels are approximately  $\pm 0.28$  and  $\pm 0.37$  respectively. Contour interval: 0.2.



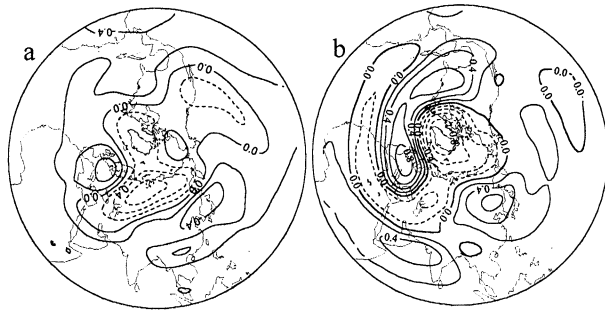
**Figure 4.** Time series of Siberian High intensity and the Arctic Oscillation index. The axis of Siberian High graph is inverted to facilitate comparison.

over the center of the anticyclone ( $70^{\circ}\text{E}$ - $120^{\circ}\text{E}$ ,  $40^{\circ}\text{N}$ - $60^{\circ}\text{N}$ ). The temperature of eastern China is averaged over 76 stations within the rectangular domain  $110^{\circ}\text{E}$ - $123^{\circ}\text{E}$ ,  $20^{\circ}\text{N}$ - $45^{\circ}\text{N}$ . These two regions are shown in Figure 1. Figure 2 shows the corresponding time series. They correlate at -0.62 for period 1951-1999. This value is much above the 95% confidence level. Obviously, the intensified East Asian winter monsoon cools the monsoon regions significantly during the strong Siberian High years. Temperature would drop by 0.64 degrees Celsius for each one standard deviation increase in Siberian High, and vice versa. Their close relationship can also be confirmed in Figure 3, in which the correlation between the temperature and the SLP over Northern Hemisphere are shown. It reveals that the winter temperature over eastern China is strongly connected to the SLP variations over high latitudes of the Eurasian continent. Mostly significant negative coefficients are centered over Siberia with values lower than -0.6.

The correlation coefficient between the AO and the Siberian High intensity index is -0.48, significant at the 99% confidence level. Figure 4 shows the plots of these two series. The correlation between AO and temperature of eastern China is 0.34, also above the 95% confidence limit. Some previous studies have pointed out that the positive phase of AO is associated with the lower SLP over the polar region and much of the Eurasian continent. For example, SLP over Siberia tends to be lower by 1-3hPa when the AO index increases by a single standard deviation [Thompson et al., 2000]. The evidence suggests a substantial out-of-phase relationship between the AO and Siberian SLP. Given the significant correlation between AO and the Siberian High, we can expect the similar spatial patterns of changes in SLP associated with the AO and Siberian High intensity, at least over the middle to higher latitude continental Asia. Figure 5(a) and 5(b) display similar structures, the north polar region and the interior of Asia share the same signs, and other areas, mostly



**Figure 5.** (a) Correlation between the Siberian High intensity and the SLP over the Northern Hemisphere in wintertime. The sign of the Siberian High index has been reversed and therefore the correlation correspond to the situation where the high is weaker than normal. (b) as in (a) but for the AO and the SLP. Analysis periods for (a) and (b) are 1949-99 and 1958-98 respectively. Positive contours in (a) are shown as dashed lines. Contour interval: 0.2.



**Figure 6.** (a) Correlation between the Siberian High intensity and the 500 hPa heights over the Northern Hemisphere in wintertime. The sign of the Siberian High index has been reversed and therefore the correlation correspond to the situation where the high is weaker than normal. (b) as in (a) but for the AO and the heights. Analysis periods for (a) and (b) are 1949-99 and 1958-98 respectively. Positive contours in (a) are shown as dashed lines. Contour interval: 0.2.

in the lower latitudes display the opposite sign. The high values over Arctic and inland Asia in both figures are particularly impressive. An anomalous pattern emerges in middle troposphere too. Figure 6(a) and (b) show results analogous to those in Figure 5 but for the 500hPa heights. The spatial patterns do not resemble one another as much as the patterns for SLP. However, in continental Eurasia there show similar anomaly centers. Two centers in Europe and Japan-Northeastern China display the same signs, and one center over the Urals shows the opposite sign. This means that a negative phase of the AO is associated with a deeper East Asian Trough and a strong anticyclone over Urals. This pattern is also concurrent with a strong Siberian High. Thus, a deeper downstream trough, a stronger upstream anticyclone and an intensified Siberian High would tend to bring strong cold waves or surges blowing over the eastern China frequently and cause a notable decrease in temperature over eastern Asia.

Thompson and Wallace [2000] argued that the near-surface temperature anomalies associated with the AO over the most of the Eurasian continent are generated primarily through the advection of temperature by the AO-related zonally-symmetric component of the zonal wind anomalies. As their results show (see their Figure 10), warm advection is found over Siberia. However, cold advection over the eastern China is not consistent with the observed in-phase relationship between the AO and temperature. If only the AO's zonal-component is taken into account, the temperature would decrease. The observed increase must result from some other reasons. The meridional component of the anomalously cold flow induced by the high pressure would play a more important role in the dramatic drops in temperature over this region [Wu and Chan, 1995; Zhang et al., 1997]. The correlation between the Siberian High and meridional wind at 850hPa show that there are strong negative relationship over the most East Asia (110°E-130°E). Strong northerly flow in association with a strong Siberian High is manifested in this region. Whereas the correlation coefficients between the AO and meridional wind display that there is very low correlation in the eastern Asia. (Figures not shown).

It should be noted that the time series of AO, Siberian High and surface temperature show apparent low-frequency variability. This may influence the significance level of correlation coefficients among them since the actual degrees of freedom must be less than the number used here. When the linear trend is removed, the coefficient between the AO index and surface temperature over the eastern China is only 0.17, which is no longer significant. With this statistic taken into account, an attempt to address any direct relationship between the AO and East Asian winter monsoon may not be relevant on interannual time scales. It

**Table 1.** Summary of correlation statistics for winter.

	Siberian High	Temperature
AO	-0.48*	0.34*
WP	0.28*	-0.30*
EU	0.51*	-0.32*
Cor.(AO,EU)=	-0.38*	
Cor.(AO,WP)=	-0.13	

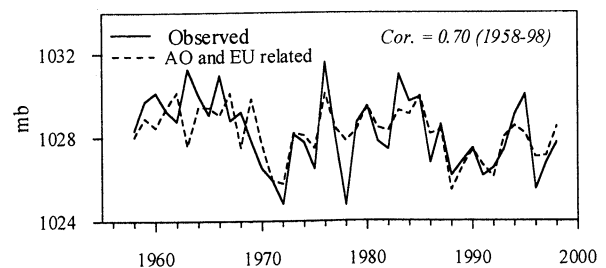
\*Significant at 95% confidence level. All correlation are computed for period 1951-99, except these regarding to AO, which is for 1958-98. WP, Western Pacific pattern, EU, Eurasian pattern. WP and EU indices are after the definition of Wallace and Gutzler [1981] but based on the NCEP/NCAR reanalysis 500hPa height.

may be the case that the AO tends to influence SLP only in the northern part of the Siberia as indicated in Fig.5b, and therefore its significant influence may not extends into as far south as eastern China. However, the residual series of the AO and Siberian High correlate at -0.39, correlation between the Siberian High and temperature also remains a much low value of -0.52, both significant. This implies that the Siberian High may play an important role in connecting the AO and surface temperature over the eastern China.

## Discussion and conclusions

Deser [2000] showed that the temporal coherence between the Arctic and mid-latitudes is strongest over the Atlantic sector. The influence of the AO on the climate over North Atlantic should be more powerful and direct. Our results reveal that the AO also significantly influences the East Asian winter monsoon through the impact on the Siberian High.

In addition to the Siberian High, some other regional atmospheric teleconnections such as the Eurasian pattern (EU) and the Western Pacific pattern (WP) may play notable roles in the East Asian winter monsoon and regional climate [Shi, 1996; Wu and Huang, 1999]. Their relationships with the AO and the Siberian High need be analyzed. Table 1 gives the correlation coefficients among the AO, the Siberian High, the EU, the WP and the temperature of eastern China. The EU is correlated with the AO, the Siberian High and the temperature significantly, it is really important for understanding the variability of the winter monsoon. The WP is significantly correlated with the Siberian High and the temperature with lower values, but has a much weaker correlation with the AO, only -0.13. Taking the AO, EU and WP all into account, 49.0% of the variance in the Siberian High can be explained. After removal of the shared variance, only the contributions of the AO and EU remain 13.0% and 36.0% respectively, whereas the portion by WP is nearly zero. As indicated in Figure 7, contributions from the AO and EU pattern explain a major portion of the observed fluctuations in the Siberian High intensity on interannual and longer time scales. Thus, both the AO and EU pattern play important roles in changes of the Siberian High and the East Asian winter monsoon.



**Figure 7.** Intensity of Siberian High related to the AO and the EU, shown in dashed line.

Although the significant coupling between the AO and the East Asian winter monsoon and Siberian High is documented in this study, the possible dynamical processes may be complicated. For example, previous studies have revealed that both stationary and transient waves strongly evolve with the fluctuations of westerly flow [Rossby, 1939; Limpasuvan et al., 1999]. Using a simple two-layer general circulation model, Robinson [1994] clearly demonstrated the presence of a positive eddy feedback upon the zonal index. Ohhashi and Yamazaki [1999] recently pointed out that the positive feedback between the wave activity and the zonal wind is responsible for the dominance EU mode. Thompson and Wallace [2000] indicated that the temperature advection associated with the AO-related zonal component of the anomalous flow plays an important role in establishing and maintaining the stationary wave pattern. Some previous studies showed the genesis and development of the Siberian High result from the combined effects of the mass convergence at middle and upper-levels and radiative cooling [Ding and Krishnamurti, 1987; Ding, 1990]. Thus, the dynamical mechanisms responsible for the connections and feedbacks among the AO, teleconnections, the Siberian High and the winter monsoon need further research.

**Acknowledgments.** This research is supported by the Natural Science Foundation of China Grant to the Beijing Normal University, and by the National Key Developing Program for Basic Sciences under Grant G1998040900(I). We are thankful to Dr. David W. J. Thompson for providing AO indices, to Prof. Yihui Ding of National Climate Center of China for helpful discussion. We are indebted to one anonymous reviewer for the insightful comments. We particularly thank Prof. John M. Wallace for valuable suggestions and the editorial corrections that improve this manuscript greatly.

## References

- Cavazos, T., Using self-organizing maps to investigate extreme climate events: An application to wintertime precipitation in the Balkans, *J. Climate*, *13*, 1718-1732, 2000.
- Deser, C., On the teleconnectivity of the Arctic Oscillation, *Geophys. Res. Lett.*, *27*(6), 779-782, 2000.
- Ding, Y.H., and T. N. Krishnamurti, Heat Budget of the Siberian High and the winter monsoon. *Mon. Wea. Rev.*, *115*, 2428-2449, 1987.
- Ding, Y.H., Buildup, air-mass transformation and propagation of Siberian High and its relations to cold surge in East Asia. *Meteor. Atmo. Physics*, *44*, 281-292, 1990.
- Gong, D. Y., and S. W. Wang, Antarctic oscillation: concept and applications, *Chinese Science Bulletin*, *43*(9), 734-738, 1998.
- Gong, D. Y., and S. W. Wang, Definition of Antarctic Oscillation Index, *Geophys. Res. Lett.*, *26*, 459-462, 1999a.
- Gong, D. Y., and S. W. Wang, Long-term variability of the Siberian High and the possible influence of global warming, *Acta Geographica Sinica*, *54*(2), 125-133, 1999b. (In Chinese).
- Kalnay, E., and Co-authors, The NCEP/NCAR 40-year Reanalysis Project, *Bull. Am. Meteorol. Soc.*, *77*, 437-471, 1996.
- Kerr, R. A., A new force in high-latitude climate, *Science*, *284*, 241-242, 1999.
- Limpasuvan, V., and D. L. Hartmann, Eddies and the annular modes of climate variability, *Geophys. Res. Lett.*, *26*(20), 3133-3136, 1999.
- Ohhashi, Y., and K. Yamazaki, Variability of the Eurasian pattern and its interpretation by wave activity flux, *J. Meteor. Soc. Japan*, *77*, 495-511, 1999.
- Overland, J. E., J. M. Adams, and N. A. Bond, Decadal variability of the Aleutian low and its relation to high-latitude circulation, *J. Climate*, *12*(5), 1542-1548, 1999.
- Rigor, I. G., R. L. Colony, and S. Martin, Variations in surface air temperature observations in the Arctic, 1979-97, *J. Climate*, *13*(5), 896-914, 2000.
- Robinson, W. A., Eddy feed-backs on the zonal index and eddy-zonal flow interactions induced by zonal flow transience, *J. Atmos. Sci.*, *51*, 2553-2562, 1994.
- Rossby, C. G., Relationship between variations in the intensity of the zonal variation and the displacement of the semi-permanent centers of action, *J. Marine. Res.*, *2*, 38-55, 1939.
- Shi, N., Secular variability of winter atmospheric teleconnection pattern in the northern hemisphere and its relation with China's climate change, *Acta Meteorol. Sinica*, *54*(6), 676-683, 1996. (In Chinese).
- Thompson, D. W. J., and J. M. Wallace, Annular modes in the extratropical circulation, Part I: Month-to-month variability. *J. Climate*, *13*(5), 1000-1016, 2000.
- Thompson, D. W. J., and J. M. Wallace, The Arctic Oscillation signature in the wintertime geopotential height and temperature fields, *Geophys. Res. Lett.*, *25*, 1297-1300, 1998.
- Thompson, D. W. J., J. M. Wallace, and C. Gabriele, Annular modes in the extratropical circulation, Part II: Trends. *J. Climate*, *13*(5), 1018-1036, 2000.
- Wallace, J. M., and D. S. Gutzler, Teleconnections in the geopotential height field during the Northern Hemisphere winter, *Mon. Wea. Rev.*, *109*, 784-812, 1981.
- Wallace, J. M., North Atlantic Oscillation/Annular Mode: two paradigms-one phenomenon, *Quart. J. Royal Met. Soc.*, *126*(564), 791-805, 2000.
- Wang, J., and M. Ikeda, Arctic Oscillation and Arctic sea-ice oscillation, *Geophys. Res. Lett.*, *27*(9), 1287-1290, 2000.
- Wang, S. W., Fluctuation of East Asian ACAs and climate change in China, *Acta Meteorologica Sinica*, *32*, 20-36, 1962. (In Chinese)
- Wu, B. Y., and R. H. Huang, Effect of the extremes in the North Atlantic Oscillation on East Asian winter monsoon, *Chinese J. Atmospheric Sciences*, *23*(6), 641-651, 1999 (In Chinese).
- Wu, M.C., and J.C.L. Chan, Surface-features of winter monsoon surges over South China. *Mon. Wea. Rev.*, *123*, 662-680, 1995.
- Zhang, Y., K.R., Sperber, and J. S., Boyle, Climatology and interannual variation of the East Asian winter monsoon: Results from the 1979-95 NCEP/NCAR reanalysis. *Mon. Wea. Rev.*, *125*(10), 2605-2619, 1997.

D.Y. Gong, Institute of Resources Science, Beijing Normal University, Beijing, 100875, China. (e-mail: gdy@pku.edu.cn, gdy@irs.bnu.edu.cn)

S.W. Wang and J.H. Zhu, Department of Geophysics, Peking University, Beijing, 100871, China (e-mail: swwang@pku.edu.cn, zjh@pku.edu.cn)

(Received September 8, 2000; revised February 10, 2001; accepted March 7, 2001.)