Winter Arctic Oscillation, Siberian High and East Asian Winter Monsoon

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Received 23 April 2002; revised 28 June 2002; accepted 10 July 2002; published 1 October 2002.

[1] In this note, we investigate the impacts of the winter Arctic Oscillation (AO) and Siberian High (SH) on the East Asia winter monsoon (EAWM). It is found that the winter AO and the SH are relatively independent of each other in influencing the EAWM. The winter AO influences directly surface air temperature (SAT), sea level pressure (SLP) and the East Asian Trough at 500 hPa over the region northwards of 35°N in East Asia rather than through its impact on the SH. Compared with influences of the winter AO, the SH shows more direct and significant influences on the EAWM, particularly on SLP and northerly wind along the East Asian Coast. Impacts of the SH on the SAT occur primarily in the southwards of 50°N over East Asia, the northwestern Pacific and the South China Sea, because the AO suppresses the SH's influences in high latitudes of Asian Continent and the some subarctic regions. *INDEX TERMS:* 1704 History of Geophysics: Atmospheric sciences; 1610 Global Change: Atmosphere (0315, 0325); 1620 Global Change: Climate dynamics (3309). **Citation:** Wu, B., and J. Wang, Winter Arctic Oscillation, Siberian High and East Asian Winter Monsoon, *Geophys. Res. Lett.*, *29*(19), 1897, doi:10.1029/2002GL015373, 2002.

1. Introduction

[2] The Arctic Oscillation (AO) represents the leading empirical orthogonal function of winter sea level pressure (SLP) fields, and which resembles North Atlantic Oscillation, but has a more zonally symmetric structure [*Thompson and Wallace*, 1998; *Wallace*, 2000]. The previous Studies revealed that the winter AO bears a close relation to surface air temperature (SAT) in the Arctic and Eurasian Continent [*Thompson and Wallace*, 1998; *Thompson and Wallace*, 2000; *Wang and Ikeda*, 2000].

[3] The East Asian winter monsoon (EAWM) system is one of the most active components of the global climate system. Climate variability in East Asia has notable impacts on both adjacent regions and the regions far away [*Lau and Li*, 1984; *Zhang et al.*, 1997; *Ji et al.*, 1997; *Wang et al.*, 2000]. In winter, the robust Siberian High (SH) appears in Asian Continent with a strong Aleutian Low (AL) to its east. The most prominent surface feature of the EAWM is characterized by strong northwesterlies along the east flank of the SH and the East Asia Coast except for the South China Sea where northeasterlies prevail [*Chen et al.*, 2000]. *Gong et al.* [2001] first investigated the connection between the AO and the EAWM, and pointed out that the AO influences the EAWM through the impacts on the winter SH. Although the winter AO may influence the SH, the AO accounts for only 13.0% of the variance in the SH. As two independent action centers in boreal winter, the AO and the SH would play a relatively independent role in influencing climate variability over East Asia. The purpose of the present study is to investigate different roles of the winter AO and the SH in influencing the EAWM.

2. Data

[4] The dataset used here, including monthly SLP, SAT (2-m), 500 hPa geopotential height for the years 1958–2000, is taken from the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Re-analysis dataset [*Kalnay et al.*, 1996]. Dr. David Thompson kindly provided the AO index for the present study. All the data are averages of three winter months (December, January and February).

3. Results

[5] As described in the introduction, strong northwesterlies prevail over the coast of East Asia during winter, while southwesterlies in summer. Therefore, the intensity of winter or summer monsoon of East Asia is closely tied with meridional winds, then with air temperature and rainfall. In this note, based on the literature of *Shi et al.* [1996], an intensity index of the EAWM (hereinafter EAWM index), which roughly represents meridional wind intensity over the coast of East Asia, is defined as the sum of zonal SLP differences (110°E minus 160°E) over 20–70°N with a 2.5°×2.5° interval in latitude and longitude. Compared with their definition, in which the defined area is limited in 20–50°N, the area of the present study extends northwards to 70°N. Because of a northeastward extension of the SH (Figure 1) northeastlies are actually predominant over the high latitude in East Asia. We calculated a regionally averaged SLP (40–60°N, 80–120°E) as an intensity index of the SH (Figure 1, hereinafter SH index). This definition also shows a little difference with that by *Gong et al.* [2001] wherein their definition region is 40–60°N, 70–120°E with a interval 5°×5° in latitude and longitude. The calculations indicate that the intensity index of the present study is more

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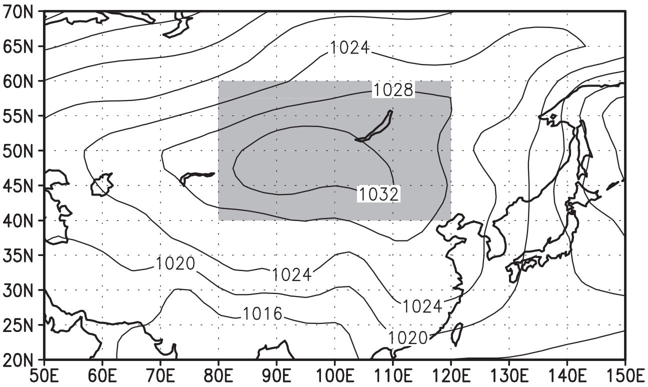

Figure 1. Winter (Dec.–Feb.) mean SLP for 1958–1999. The grid values of SLP for the shading region are averaged to define the intensity index of the winter Siberian High.

suitable than the previous definition in describing the impacts of the SH on the EAWM. Figure 2 shows interannual variations of the SH, the AO and the EAWM index. Correlation coefficient (hereinafter CC) of the SH index and the EAWM index is 0.8. This high correlation implies that the SH index can express the intensity of the EAWM. However, CC of the SH index and the AO index is -0.36, much lower than that with the EAWM. This means that relationship between the two time series is not as close as what we expected. Although *Gong et al.* [2001] suggested that the winter SH variation is closely related with the AO ($r = -0.48$), sometimes the two time series vary out of phase, particularly during the winters in 1972–1977 and in 1987–1995 (see their Figure 4). Such phenomenon indicates that the relation between the winter SH and the AO is complicated, and closely depends on the selected region for calculating the intensity index of the SH. As the definition region extends westwards, the relation tends to be closer. However, impact of the SH on the EAWM becomes weaker. In order to reveal different influences from the winter SH and the AO on the EAWM, we made a composite analysis. Those cases selected for the winter SH and the AO are listed in Table 1.

[6] In SLP fields, the differences resemble the NAO pattern with a positive phase (Figure 3a). In East Asia, significant variations only appear in the south of the Okhotsk Sea and the east of Japan, which implies that the AO directly affects SLP variations over the region. Figure 3b shows that positive SLP anomalies almost cover the entire Arctic, Eurasian Continent and East Asia with a maximum anomaly appearing in the south to the Lake Baikal. Meanwhile, the northern Pacific has negative SLP anomalies, which indicates a deepened AL. Consequently, northerliers between the stronger SH and the deepened AL would become robust along the East Asian Coast. Corresponding to extremes in the winter AO and the SH, SLP variations show obvious differences, particularly in their influences on East Asia. Those demonstrate that the winter AO and the SH are relatively independent of each other in influencing the EAWM. Certainly, the winter AO may influence the SH, as shown in Figure 3a. Negative SLP anomalies in the high latitudes of Asian Continent would be favorable for weakening the winter SH. Figure 3b also shows that the winter SH has no significant effects on SLP variations in the entire Arctic and the North Atlantic sector. We also notice that a

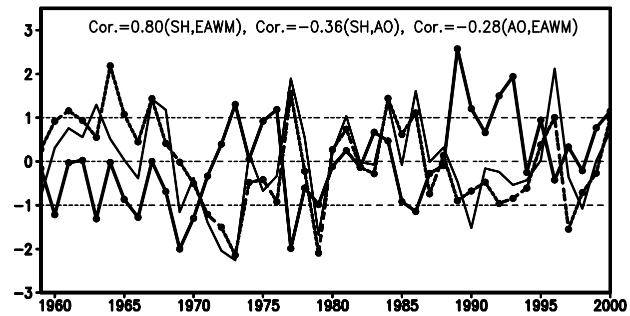

Figure 2. Interannual variations of the normalized winter AO (solid line), SH index (dashed line) and EAWM intensity index (thin solid line). The year refers to winter (Dec.–Feb.) season, taken as the year of Jan. and Feb.

Table 1. List of the Selected Cases Used in the Composite Analysis

AO		SH	
Standard deviations			
>1.0 (H)	<−1.0 (L)	>1.0 (H)	<−1.0 (L)
1972/1973	1959/1960	1960/1961	1970/1971
1975/1976	1962/1963	1963/1964	1971/1972
1988/1989	1965/1966	1964/1965	1972/1973
1989/1990	1968/1969	1966/1967	1978/1979
1991/1992	1969/1970	1976/1977	1996/1997
1992/1993	1976/1977	1983/1984	
1999/2000	1985/1986	1985/1986	
		1995/1996	

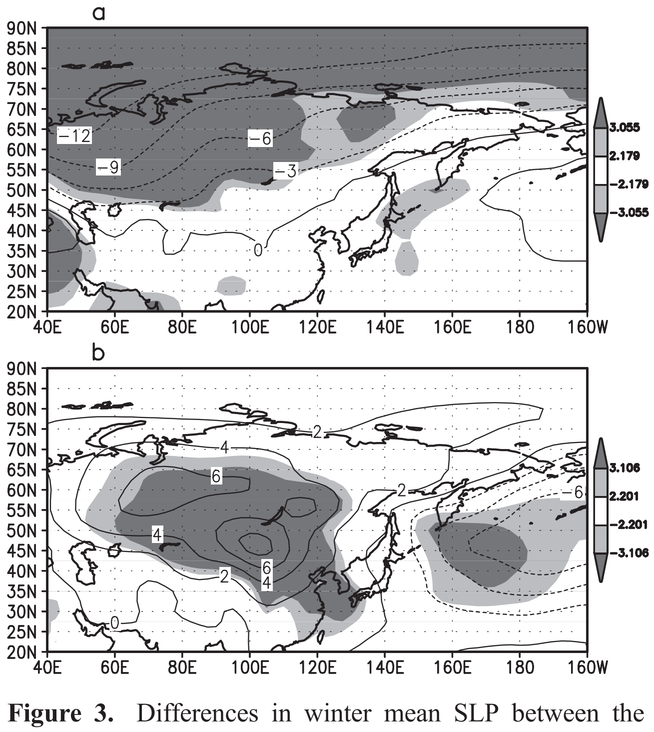

Figure 3. Differences in winter mean SLP between the positive and the negative index phases in (a) the winter AO, (b) the winter SH (the positive minus the negative). The gray and dark area represent that the differences of SLP exceed 95% and 99% confidence level, respectively.

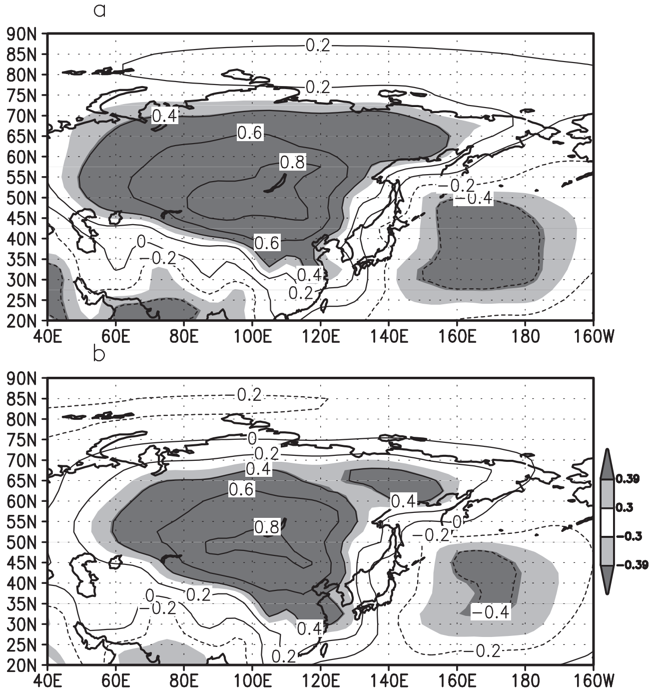

Figure 4. Correlations of the winter SH index with (a) the original SLP and (b) the residual SLP after the AO-related SLP variations are removed by means of a linear regression. The gray and dark area represent that the correlations exceed 95% and 99% confidence level, respectively.

positive (negative) index phase in the winter AO results in the weakened (strengthened) East Asian Trough at 500 hPa (not shown), which is favorable for producing the weaker (stronger) EAWM.

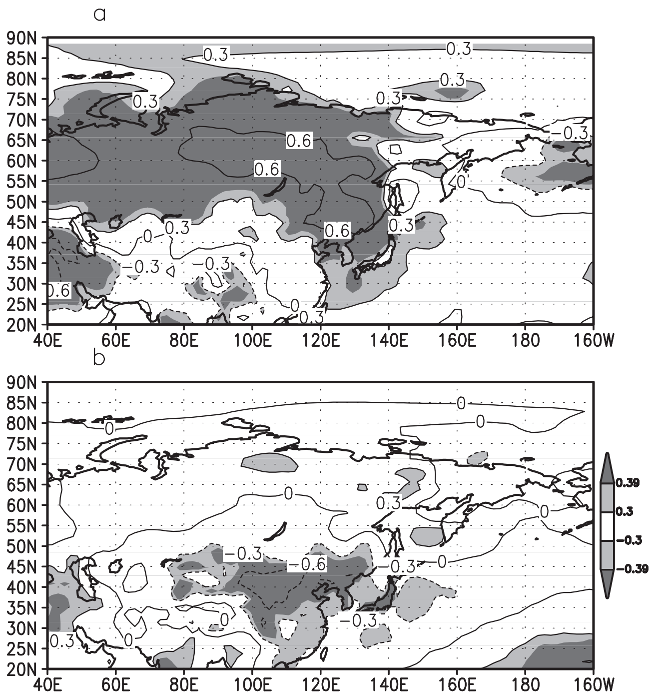

Figure 5. Correlations of surface air temperature with (a) the winter AO and (b) the SH index. The meaning of the shading is the same as in Figure 4.

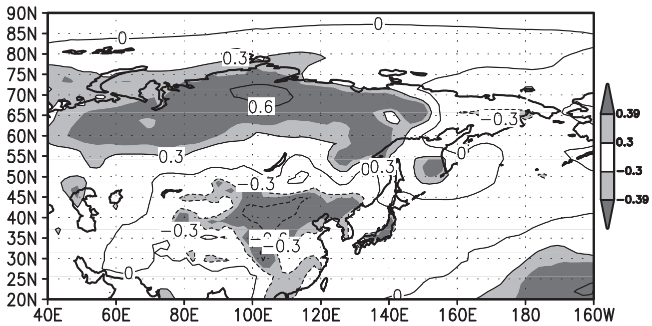

Figure 6. Same as in Figure 5b except for the residual surface air temperature after removing the possible influences of the winter AO.

[7] In order to remove the possible linear influences from the winter AO, we made a linear regression analysis to SLP variations using the AO time series, then we calculate CCs of the winter SH index and the original SLP (Figure 4a) and the residual SLP (Figure 4b), respectively. Compared with Figure 4a, Figure 4b shows that influences from the SH become more clear and obvious over East Asia. This means that the AO suppresses the SH's influences over East Asia, particularly south of 40°N.

[8] We also calculate CCs between the SAT and the winter AO (Figure 5a) and the SH index (Figure 5b), respectively. The most significant correlations appear in the north side of 35°N over East Asia (Figure 5a). As indicated in Figure 5b, significant correlations cover the south side of 50°N over East Asia, including central and eastern China, Korea Peninsula, most parts of Japan and the partly northwestern Pacific. It is clear that the winter SH plays a more important role in influencing air temperatures over East Asia. Removing the possible influences from the winter AO, Figure 6 indicates that the winter SH still shows a stronger influence on the SAT in the regions including the low-middle latitudes of Asian Continent and southern Japan. Compared with Figure 5b, we also notice that correlations become significant in the high latitudes of Asian Continent, the Kara, the Barents and part of Laptev Seas. This phenomenon demonstrates clearly that impacts of the winter SH on the SAT are obviously suppressed in above regions because of the existence of the winter AO. Therefore, the SAT variations may be due to the combined effects of the winter AO and the SH in the high latitudes of Asian Continent and some subarctic ocean.

4. Conclusions and Discussion

[9] This note indicates that the winter AO and the SH are parts of a coupled system in which the winter AO may sometimes affect the SH, while at other times, these two events are relatively independent of each other. The winter AO influences directly the SAT, SLP and the East Asian Trough at 500 hPa over the northwards of 35°N in East Asia rather than through impacts on the winter SH. The winter SH shows more direct and significant influences on the EAWM than the winter AO, particularly on SLP and northerlies along the East Asia Coast. Impacts of the SH on the SAT occur primarily on the south side of 50°N over East Asia, the northwestern Pacific and the South China

Sea, because the AO suppresses the SH's influences in the high latitudes of Asian Continent. Therefore, the winter AO and the SH are relatively independent of each other in influencing the EAWM.

[10] As indicated in Figure 2, the SH determines the intensity of the EAWM, and the EAWM then directly influences climate variations over East Asia. With respect to the impacts of the AO on the EAWM, on one hand, the AO indirectly affects the EAWM (sometimes) through influencing the SH; on the other hand, the AO directly influences the EAWM. During the high index state of the AO, westerly winds are stronger than normal over the northern Eurasian Continent, which results in the weakened East Asian Trough at 500 hPa. Under this circulation condition, meridional winds in the low troposphere over East Asia tend to be weaker due to the strong zonal steering flow aloft. Consequently, temperature is higher than normal over East Asia, and the EAWM is weaker. The reverse conditions are applicable for the low index state. As shown in Figure 2, CC between the AO and the EAWM is −0.28, which is marginally significant for 42 samples. It should be pointed out that the advection of temperature associated with the AO is not important for temperature variations over East Asia.

[11] **Acknowledgments.** We would like to thank Dr. David W. J. Thompson for kindly providing the AO indices. Thanks also to two anonymous reviewers and the editors for their helpful comments and suggestions. We are thankful to the National Key Developing Program (Grant G1998040900), the Frontier Research System for Global Change of Japan and the National Natural Foundation of China (Grant No. 49905003) for financial support.

References

Chen, W., H.-F. Graf, and R.-H. Huang, The interannual variability of East Asian Winter Monsoon and its relation to the summer monsoon, *Adv. Atmos. Sci.*, *17*(1), 48–60, 2000.

Gong, D. Y., S. W. Wang, and J. H. Zhu, East Asian winter monsoon and Arctic Oscillation, *Geophy. Res. Lett.*, *28*(10), 2073–2076, 2001.

Ji, L., S. Sun, and K. Arpe, Model study on the interannual variability of Asian winter monsoon and its influence, *Adv. Atmos. Sci.*, *14*, 1–22, 1997.

Kalnay, E., et al., The NCEP/NCAR 40-year Reanalysis Project, *Bull. Am. Meteorol. Soc.*, *77*, 437–471, 1996.

Lau, K.-M., and M. Li, Monsoon of East Asia and its global associations: a survey, *Bull. Amer. Meteor. Soc.*, *65*, 114–125, 1984.

Shi, N., J. Lu, and Q. Zhu, East Asian winter/summer monsoon intensity indices with their climatic change in 1873–1989, *J. Nanjing Institute of Meteor.*, *19*(2), 168–176 (in Chinese) 1996.

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

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.

Wallace, J. M., North Atlantic Oscillation/annual Mode: Two paradigms-one phenomenon, *Quart. J. Royal Met. Soc.*, *126*(564), 791–805, 2000.

Wang, B., R. Wu, and X. Fu, Pacific-East Asian Teleconnection: How Does ENSO affect Asian Climate?, *J. Climate*, *13*, 1517–1536, 2000.

Wang, J., and M. Ikeda, Arctic Oscillation and Arctic sea ice oscillation, *Geophys. Res. Lett.*, *27*(9), 1287–1290, 2000.

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.

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