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Zonal asymmetry of the Antarctic Oscillation

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[1] In this research, the zonal asymmetry of the southern annular mode, or the Antarctic Oscillation (AAO), is studied. It is indicated that apparent zonal asymmetry exists in the normalized sea level pressure differences between the middle and high latitudes during the boreal summer, among different longitudes, especially between the Western and Eastern Hemispheres. Results show that the Southern Oscillation (SO) is responsible for part of the zonal asymmetry in AAO. The Western Hemisphere and the Eastern Hemisphere parts of AAO are correlated at 0.23 and 0.52 respectively for the period of 1959–1998 before and after the linear regressions on the Southern Oscillation Index (SOI) have been removed from the time series. The paper also discusses the relationship between the precipitation in the East Asia and the AAO before and after removing the linear regressions on SO index (SOI), indicating the stable relationship between the East Asian precipitation and the zonal symmetric component of AAO. **Citation:** Fan, K. (2007), Zonal asymmetry of the Antarctic Oscillation, *Geophys. Res. Lett.*, *34*, L02706, doi:10.1029/2006GL028045.

1. Introduction

[2] The Antarctic Oscillation (AAO), or Southern annular mode (SAM), has been identified as the major mode in the interannual variability of the low troposphere in the Southern Hemisphere (SH). *Walker* [1928] noted the seesaw pattern of the high pressure belt across Chile and the Argentine and the low pressure area of Weddell Sea and the Bellingshausen Sea. The AAO has been identified as the leading mode in the interannual variability of the low-level atmosphere in SH and can be defined as the leading principal component of the SH sea level pressure (SLP) anomalies poleward of 20°S [*Thompson and Wallace*, 2000], or as the zonal mean normalized SLP difference between the middle and high latitudes in the SH [*Gong and Wang*, 1999].

[3] Studies revealed that AAO is associated with the climate in not only the Southern Hemisphere but also the Northern Hemisphere. The AAO has been found to be correlated with the total column ozone [*Sexton*, 2001; *Thompson and Solomon*, 2002], tropopause height over middle and high latitudes, the strength of trade winds [*Thompson and Wallace*, 2000], Antarctic surface temperature [*Kwok and Comiso*, 2002], sea ice and ocean conditions [*Hall and Visbeck*, 2002] in the Southern Hemisphere, as well as the precipitation of the southeastern South America [*Silvestri and Vera*, 2003]. Recent research identified the influences of AAO in the Northern Hemisphere climate, including the summer precipitation in China [*Wang and Fan*, 2005], the dust weather frequency in North China [*Fan and Wang*, 2004], and the western African rainfall [*Reason and Rouault*, 2005].

[4] Regarding the zonal features in the SH high latitudes, *Yuan and Martinson* [2000, 2001] indicated the Antarctic Dipole Pattern (ADP) characterized by a seesaw in surface air temperature, sea ice, and SLP between the eastern Pacific and the Atlantic sectors of the Antarctic. They also suggest that the ADP is closely associated with ENSO. *Liu et al.* [2002] proposed a mechanism-the regional mean meridional atmospheric circulation to explain the ENSO-ADP linkage. Based on these results, this research will discuss the zonal asymmetry of the AAO, including the facts, association with ENSO and implication for the relationship between the AAO and the East Asian rainfall.

2. Data

[5] The data sets employed in this research include the monthly reanalysis data (1949–1998) at 17 vertical levels with a horizontal resolution of 2.5° × 2.5° of the National Center for Atmospheric Research (NCAR) and National Center for Environmental Prediction (NCEP) [*Kalnay et al.*, 1996], the analyzed monthly sea level pressure data for 1871–1998 with 5° × 5° horizontal resolution from the Hadley Center for Climate Prediction and Research (HC) [*Basnett and Parker*, 1997], and the Southern Oscillation index (SOI). The SOI is defined as the normalized pressure difference between Tahiti and Darwin and was calculated based on the method given by *Ropelewski and Jones* [1987]. The monthly precipitation on a 2.5° × 2.5° latitude/longitude grid from the Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP) is also employed in this research [*Xie and Arkin*, 1997]. All the correlations in this paper are computed based on the interannual variability from the de-trended temporal series.

3. Asymmetry of the AAO

[6] First we compute the normalized SLP difference between 40°S and 60°S averaged in 180°W–0°W, which could be referred to as the Antarctic Oscillation in the Western Hemisphere (AAOWH). Similarly, we could also define and compute the Antarctic Oscillation in the Eastern Hemisphere (AAOEH). The AAOWH and AAOEH are correlated at 0.23 for the boreal summer season (June to September, JJAS for brief hereafter) in 1959–1998. Therefore, they are only marginally correlated, indicating the existence of zonal asymmetry of the Antarctic Oscillation.

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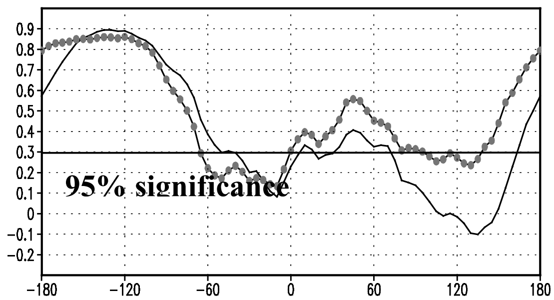

Figure 1. The correlation coefficients between AAOWH and the normalized SLP differences between 40°S and 60°S in different longitudes for JJAS in 1959–1998. The solid line and the dotted solid line represent the results before and after, respectively, the linear regressions on the SOI have been removed from the time series. The abscissa are the longitude, with negative values denoting the Western Hemisphere.

[7] We then compute and depict the correlation coefficients between the AAOWH and the normalized SLP differences between 40°S and 60°S along the longitudes for the period of 1959–1998 (the solid line in Figure 1). The correlation coefficients are all positive in the Western Hemisphere, significant at 95% level, indicating a good zonal symmetry within the Western Hemisphere (WH). However, there is an apparent asymmetry between the Western Hemisphere and the Eastern Hemisphere (EH), with much smaller correlation coefficients in EH. In many longitudes, the correlation coefficients are not significant in 95% significance level. It is even more pronounced that the correlation coefficients at the longitudes near 120°E–150°E are close to zero, showing the apparent asymmetry between the EH and WH.

[8] Therefore, it is found that there are significant zonal asymmetry between the WH and EH with respect to the Antarctic Oscillation. Since that the El Nino and Southern Oscillation (ENSO) is the strongest signal in the interannual variability of the tropical ocean-atmosphere and that the SO is a zonal circulation cell (see Figure 2), we speculate that the SOI maybe an important factor for the zonal asymmetry of AAO. In order to demonstrate this hypothesis, we first removed the linear regression on SOI in the SLP fields and then re-draw the correlation coefficient between the AAOWH and the normalized SLP differences between 40°S and 60°S in all longitudes (the dotted solid line in Figure 1). We can see that the zonal asymmetry between the WH and EH is substantially weakened, although the correlation coefficients in WH remain almost unchanged. We re-compute the AAOWH and AAOEH, and the correlation coefficient in 1959–1998 is 0.52 which is much larger than 0.23 (for the correlation coefficient before the linear regression on SOI is removed in the SLP fields). Therefore, the zonal asymmetry between the WH and EH is largely associated with SOI.

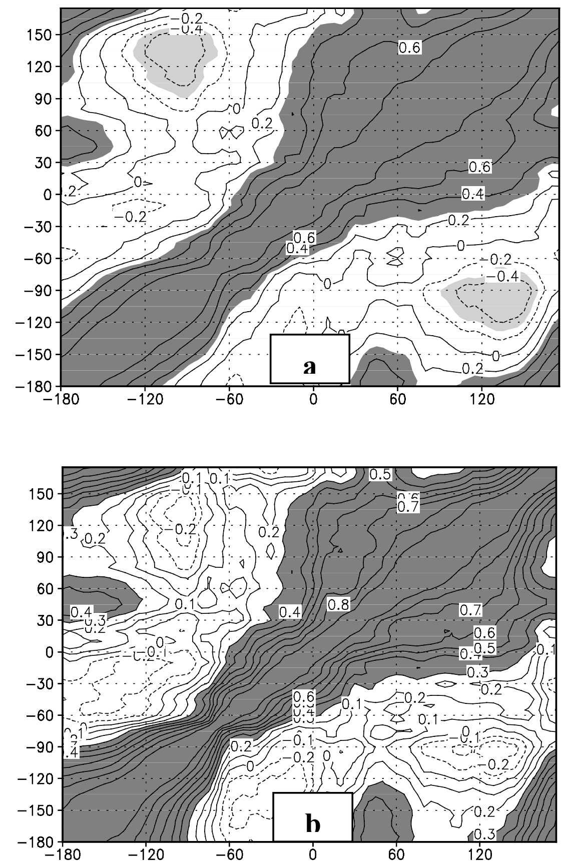

Figure 3. The correlation coefficients of the normalized SLP differences between 40°S and 60°S among different longitudes for JJAS in 1959–1998. Results before (a) and after (b) the linear regressions on SOI have been removed. Shaded areas indicate significant correlations at the 95% level, estimated by a local student t-test.

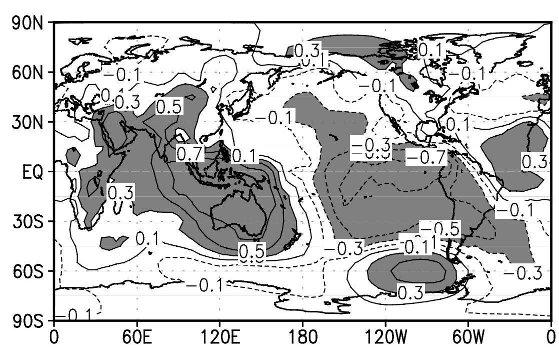

Figure 2. The correlation coefficients between the SOI and SLP for JJAS in 1959–1998. Shaded areas indicate significant correlations at the 95% level, estimated by a local student t-test.

[9] Now we discuss the correlation coefficients of the normalized SLP differences between 40°S and 60°S among different longitudes for JJAS in 1959–1998 (Figure 3). More details regarding the zonal asymmetry of the AAO can be found in this figure. As shown in Figure 3a, which is the result before the linear regressions on SOI have been removed, the zonal asymmetry exhibits two pronounced seesaws. One is the characterized by the negative correlation coefficient between the Atlantic and the eastern Pacific sectors, which has been known as the ADP (AS1 hereafter) previously by *Yuan and Martinson* [2000, 2001] and later explained by *Liu et al.* [2002]. However, another seesaw is between the western Pacific and the eastern Pacific sectors

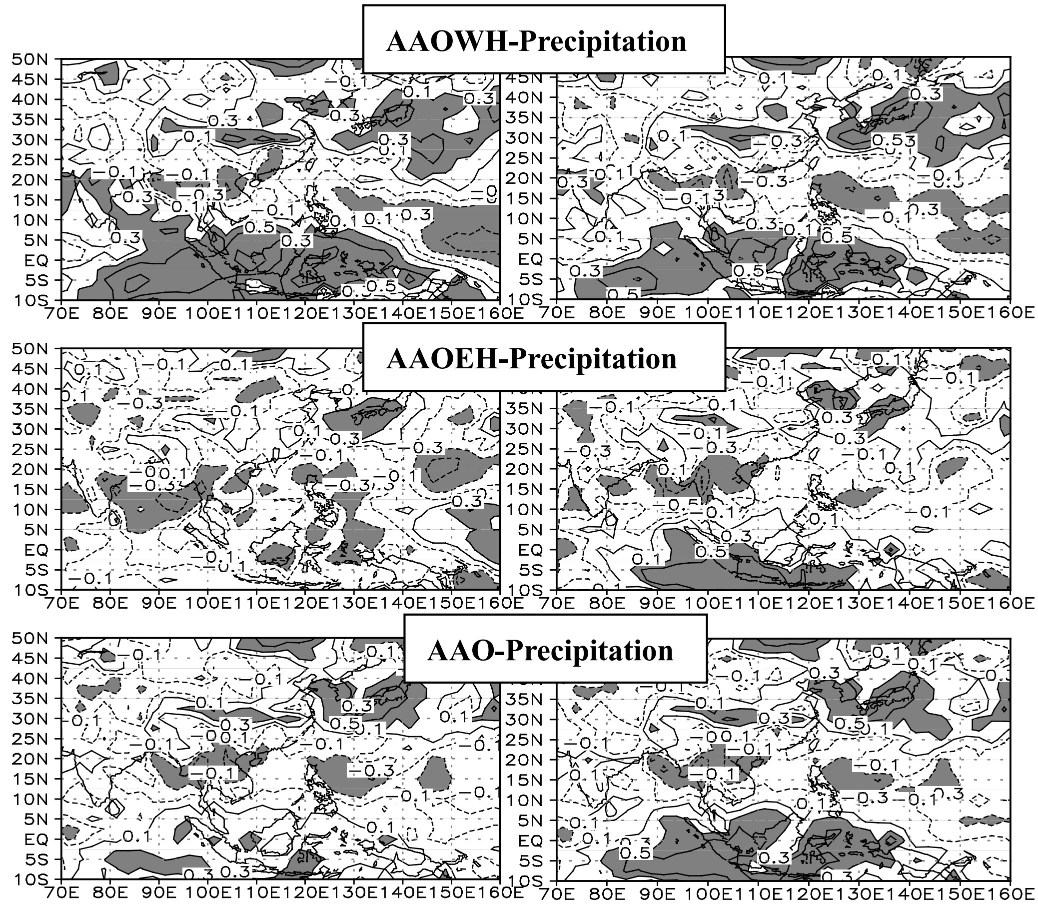

Figure 4. The correlation coefficients between precipitation and AAOWH, AAOEH, and AAO for JJAS in 1979–1998. Shaded areas indicate larger values than 0.30. Results before (left) and after (right) the linear regressions on the SOI are removed.

(AS2 hereafter). The AS2 is stronger than AS1, which can be seen clearly in Figure 3a.

[10] Then, how about the results after removing the linear regressions on SOI? Figure 3b shows that the AS2 is greatly reduced, and the significant negative correlation coefficients disappear. Therefore, the asymmetry between the western Pacific and the eastern Pacific is closely linked with the ENSO cycle. However, the asymmetry between the Atlantic and the eastern Pacific (AS1) does not correlate significantly with SOI. The negative correlation coefficients between the Atlantic and the eastern pacific (not significant at 95% level) remain little changed after the linear regressions on the SOI have been removed.

[11] Therefore, the above results suggest that the ENSO cycle can only explain part of the zonal asymmetry of AAO.

4. Implication for the AAO-East Asian Precipitation Relationship

[12] The above preliminary analysis indicates the zonal asymmetry of the Southern Hemisphere Oscillation between middle and high latitudes during the boreal summer. Such asymmetry has been found to be essentially associated with the SOI. The correlation coefficients between AAOWH and AAOEH are respectively 0.23 and 0.52 before and after the linear regressions on SOI are removed, demonstrating the significant role of SOI in the zonal asymmetry of the AAO. The geographical patterns of the correlations between SLP and AAOWH as well as AAOEH clearly show the impacts of SOI. Similar results could be obtained for the boreal winter, but the impacts of the SOI on the zonal asymmetry of AAO are less significant for the boreal winter (figures not shown).

[13] Now we discuss the relationships between China Yangtze River Valley precipitation (YZP) and the Antarctic Oscillation, in the context of the zonal asymmetry of AAO. The positive correlation between the YZP and AAO was revealed previously by *Gao et al.* [2003], as can be seen in Figure 4 as well. However, the AAOWH-precipitation correlation pattern is substantially different from the AAOEH-precipitation correlation pattern in the Yangtze River Valley and the tropical Indian and western Pacific regions (see Figure 4, left). The correlation coefficient between AAOWH and precipitation is positive in the Yangtze River Valley and the tropical Indian and western Pacific regions, while correlation coefficient between AAOEH and precipitation is very small in the Yangtze River Valley and is negative in the tropical Indian and western Pacific regions.

[14] After removing the linear regressions on SOI in the AAOWH, AAOEH and AAO, we re-draw the correlation coefficients chart (see Figure 4, right). This time, we find

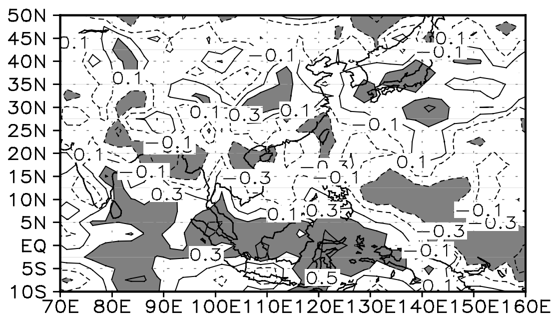

Figure 5. The correlation coefficients between JJAS precipitation and AAO for April–May in 1979–1998, after the linear regressions on the SOI are removed. Shaded areas indicate larger values than 0.30.

that the spatial patterns in the three diagrams are all well-organized and similar to each other, with positive values in the Yangtze River Valley, Japan and the tropical Indian and western Pacific regions and negative values in the Indo-China Peninsula and the South China. Therefore, it is very important to recognize the zonal asymmetry of the AAO. Only when the zonal asymmetric part of AAO, which is highly dependent on the Southern Oscillation, is removed, can we obtain the quasi-symmetric part of AAO and its relationship to the precipitation in the East Asia, tropical Indian and western Pacific.

[15] Interestingly, the changes of AAO also lead the Asian precipitation variability. Figure 5 depicts the correlation coefficient between the AAO in April-May and the JJAS precipitation after the linear regression on the SOI removed, in which substantial correlation could be found in the large areas of tropical and subtropical regions of Asia. Thus the signal of the AAO is potentially applicable in the seasonal prediction of Asian summer rainfall.

[16] Therefore, recognizing the zonal asymmetry of AAO has important implications in realizing the characteristics and variability of AAO, as well as identifying the atmospheric responses to AAO. This paper identified the significant role of SO in the zonal asymmetry of AAO. However, this is only a part of the story. Even though the linear regressions on SOI are removed, the zonal asymmetry of AAO still remains. Thus, other factors or processes must be responsible for the remaining parts of the zonal asymmetry of AAO.

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