GEOPHYSICAL RESEARCH LETTERS, VOL. 26, NO.4, PAGES 459-462, FEBRUARY 15, 1999

Definition of Antarctic oscillation index

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Abstract. Following Walker's work about his famous three oscillations published during the 1920-30s, many papers were written about atmospheric oscillations A fourth atmospheric oscillation in the middle and high southern latitudes was found, and named the Antarctic Oscillation (AO) AO refers to a large scale alternation of atmospheric mass between the mid-latitudes and high latitudes surface pressure In order to understand the spatial structure of sea level pressure variation in detail, empirical orthogonal function analysis is applied An objective index of the Antarctic Oscillation Index (AOI) is defined as the difference of zonal mean sea level pressure between 40°S and 65°S. The AOI has the potential for clarifying climate regimes in the southern hemisphere, similar to how the NAO and the NPO has been used in the northern hemisphere.

Introduction

During the past one hundred years, much attention has been given to low-level atmospheric circulation for understanding the local to planetary scale climatic anomalies During the 1920-1930s, a comprehensive study on atmospheric oscillations was carried out by Sir Gilbert Walker Three oscillations were revealed and named as "North Atlantic Oscillation (NAO)", "North Pacific Oscillation (NPO)" and "Southern Oscillation (SO)". Numerical definitions of the three oscillations were also given by Walker [*Montgomery*, 1940] A large number of papers about these oscillations were published after Walker, and more details were also revealed.

Were there other oscillation(s) besides NAO, NPO and SO, especially in the southern hemisphere? It had been supposed that there might be other atmospheric oscillation(s) in the high southern latitudes. Although as early as in the first quarter of this century *Walker* [1928] had stated that: "Just as in the North Atlantic there is a pressure opposition between the Azores and Iceland,...,there is an opposition between the high pressure belt across Chile and the Argentine on the one hand , and the low pressure area of Weddell Sea and the Bellingshausen Sea on the other.", the scarcity of data in the southern hemisphere hindered the search for new oscillation(s). During the last two decades, more comprehensive data over the southern hemisphere became available, and more analyses were carried out [see *Kidson* 1975; *Rogers and van Loon* 1982;*Mo and White* 1985; *Mo* 1986; *Connolley* 1997; *Gong and Wang* 1998]. A fourth atmospheric oscillation in the middle and high southern latitudes was found, and named as the Antarctic Oscillation(AO) [*Wang* 1992; *Gong and Wang* 1998] . The term AO refers to a large scale alternation of atmospheric mass between the mid-latitude surface pressure and high latitudes surface pressure. The result of coupled general circulation models(CGCM) also showed the AO was an inherent characteristic of the climate system [*Schneider and Kinter III*,1994; *Connolley* 1997; *Gong* 1997].

In order to understand the variability of AO and its possible connection with southern climatic anomalies in detail, it's necessary and useful to define an objective index of the AO (i.e. Antarctic Oscillation Index: AOI) Here we demonstrate the prominent features of AO revealed by empirical orthogonal function analysis, and then a numerical definition of AOI is given.

Data and Analysis

This study uses the NCEP/NCAR reanalysis [*Kalnay et al.*, 1996] monthly mean sea level pressure (SLP) from January of 1958 to December of 1997 in 10°×5° longitude-latitude grid.

In order to investigate the spatial structure of SLP variation, empirical orthogonal function(EOF) analysis is applied. EOF analysis of southern hemispheric area weighted SLP anomaly (×cosφ) for each month of annual cycle shows that the 12 EOF-1s have similar patterns: Antarctica and the vicinity is a center of same sign with another center of opposite sign covering 40-50°S latitudes. This suggests that the Antarctic Oscillation pattern is stable in all 12 months. And the Antarctic Oscillation mode is also prominent. The first EOF accounts for 22.5% of the covariance matrix variance on average. The lowest variance explained by EOF-1 is 17.2% (of March), and the highest is 33.1% (of December).

To extract the more representative modes, all 480 months are used as continuous time series for EOF analysis. The EOF-1 pattern is illustrated in Figure 1. This mode accounts for 18.4% variance The zonally symmetrical pattern is predominant in

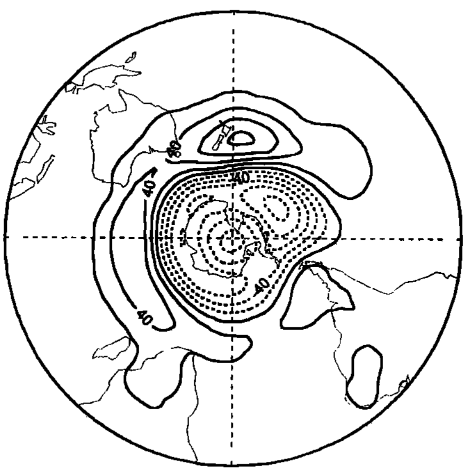

Figure 1. EOF-1 from the covariance matrix for monthly mean SLP. The scaling is arbitrary. Negative contours dashed, zero contour bold

Paper number 1999GL900003.
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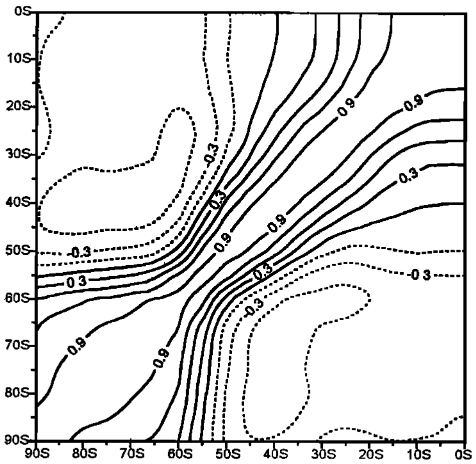

Figure 2. Correlation coefficients among zonally mean SLP in southern hemisphere.

general. And also the alternation of SLP between mid-latitudes and Antarctica is most striking.

Correlation analysis also supports the result of EOF analysis. The important feature is the strong negative relationship between the 40°S and 60°-70°S zonally mean SLP Correlation coefficient is -0.46 between 40°S and 60°S, -0 59 between 40°S and 65°S and between 40°S and 70°S, all significant above 1% confidence level. See figure 2.

It is reasonable to conclude that the SLP seesaw between 40°-50°S latitudes and regions over Antarctica and its vicinity is stable and significant. And like NAO and NPO, the AO also bear out the feature of standing wave with node along about 55°S When the SLP of 40°S is high, the SLP of 60°-70°S become low, and vice versa

Definition of AOI

The above analysis suggests that the zonally averaged SLP of 40°S and 65°S are the important components of the extratropical southern hemispheric surface pressure system. The variability of AO can be objectively expressed just by the two components satisfactorily. Then in the light of definition of other oscillations, the numerical definitions of Antarctic Oscillation Index(AOI) is given as follows:

$$AOI=P^*_{40°S} - P^*_{65°S} \quad (1)$$

$P^*_{40°S}$ and $P^*_{65°S}$ stands for normalized zonally mean SLP of 40°S and 65°S for every month respectively.

Figure 3 shows the percentage of SLP variance explained by the Antarctic Oscillation Index. In the middle and high latitudes much variance is explained: the highest is above 50% in Antarctica. It is reasonable and acceptable for using AOI as an objective index to monitor and measure the atmospheric circulation condition in high southern latitudes.

Semi-annual oscillation is a general phenomenon in the surface pressure variation over the middle and high southern hemisphere[*Schwerdtfeger*, 1967] The amplitude of the semi-annual oscillation peaks from 45°S to 50°S, reaches a minimum near 55-60°S, and reaches a second peak over Antarctica, but the phase of the two peaks is reversed [*Hurrell and van Loon*, 1994]. The spatial feature of semi-annual oscillation is similar to the spatial structure of AO. But the power spectra of AOI shows that there is no significant semi-annual oscillation signal in the time series of AOI, but the period of 4.2 months and 2.7 months exceeds 0.05 red noise confidence level, and the period of 45.7 months is close to the confidence level. *Hameed et al.* [1995] also described the similar spectrum of SLP at 74°S in the ocean-atmosphere GCMs. This suggests that the semi-annual oscillation is much a regularly seasonal cycle, but the definition of AOI removed the semi-annual oscillation and it can depict the anomalous variation of large-scale sea level pressure.

The AOI is low during the 1960s to early 1970s and much high during the 1980s as showed in Figure 4. We should pay more attention to the decadal variability of AOI and its association with the southern climatic change in the further research.

Discussions

Various atmospheric circulation indices have been designed and related to climate variation in the southern mid-high latitudes. But most of these zonal and meridional circulation indices are regional in scale focused on New Zealand and the Antarctic region [*Trenberth*, 1976; *King*, 1994]. A more commonly used tele-connection index is the Trans-Polar Index (TPI) which is defined as the difference in sea level pressure between Hobart, Tasmania(43°S 147°E) and Stanley, South Atlantic Ocean (52°S 58°W) [*Pittock*, 1980].*Karoly et al.*[1996] found TPI to be well correlated with their EOF-2, and *Connolley*'s[1997] EOF-2 is very similar to TPI [*c.f. Figure3a,b of Villalba et al.*, 1997]. But TPI and AOI are different things, and may well have different applications.

In *Connolley*'s[1997] analysis, the EOF-1 showed strong wave-3 pattern in middle latitudes[see *Fig.4b of Connolley* 1997], and *Mo and White*[1985] also found similar wavenumber 3 pattern in Southern Ocean by calculating the correlation coefficients of winter SLP field. Our EOF-1 pattern (AO mode) is similar to the result of EOF-1 of Australian Bureau of Meteorology analyses, but the wave 3 pattern in middle latitudes is weak. In figure 1, all mid-latitudes values are in the same sign, it is in general a zonally-symmetric oscillation

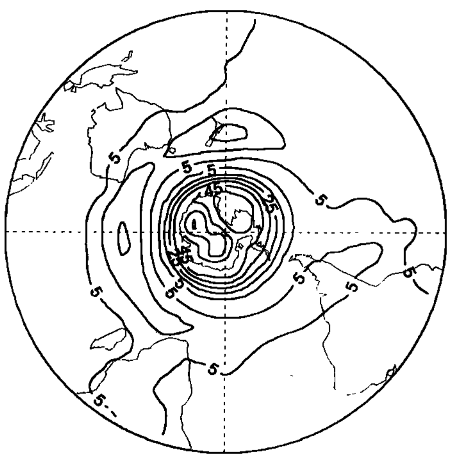

Figure 3. Percentage variance explained of the sea-level pressure.

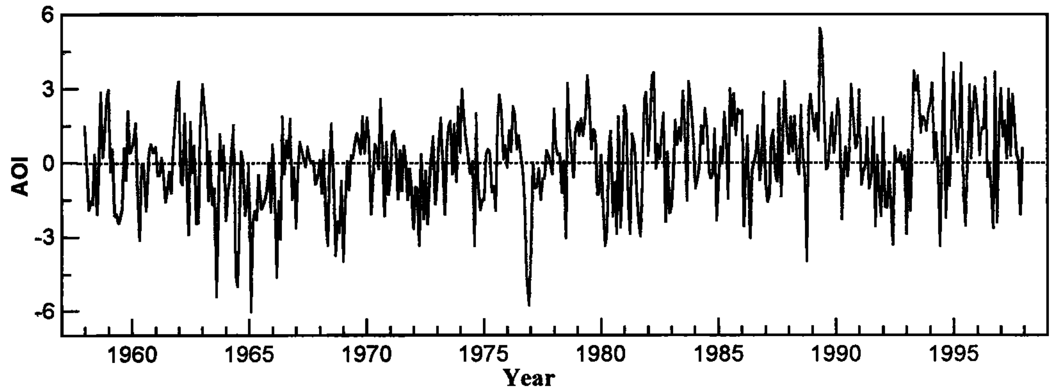

Figure 4. AOI time series

Zonally-symmetric seesaw in sea-level pressure between high and middle latitudes exists in both hemisphere. The fluctuation of this seesaw reflects the alternation of atmospheric mass between the middle and high latitudes. Zonal circulation index was usually defined as the difference of zonally averaged sea level pressure (or geopotential heights) between 35°N and 55°N(or between 40°N and 60°N) to measure the strength of zonal westerlies in northern hemisphere during 1940s. In the high index state the subtropical highs develop stronger, the subpolar lows develop deeper, and vice versa [*Lorenz,*1951]. By subtracting the 10 low-index composite SLP fields from their 10 high-index counterparts, we have produced the figure 5. Ten highest index years are 1990, 1928, 1921, 1988, 1989, 1948, 1899, 1986, 1983 and 1932, ten 10 lowest index years are 1963, 1940, 1893, 1969, 1956, 1907, 1897, 1954, 1980 and 1929. The SLP data set covers 1873 through 1994. It shows evidence of the signatures of the North Atlantic Oscillation and the North Pacific Oscillation. Same features appear again when only reanalysis data used for composite. This also agrees well with the results of *Wallace and Hsu*[1985, *c.f. Figure 2*]. Similarly, the AOI can also measure the states of the index cycle and represent the oscillation between the middle and high southern latitudes. And the AOI has the potential for clarifying climate regimes in the southern hemisphere, similar to how the NAO and the NPO has been used in the northern hemisphere.

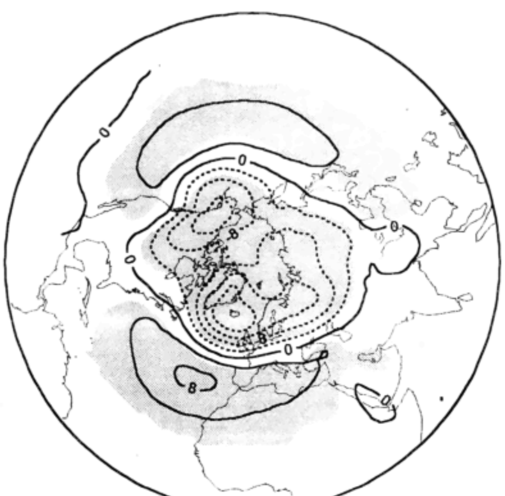

Figure 5. Mean difference of January SLP between 10 highest and 10 lowest index years in northern hemisphere. Contour interval is 4hPa, negative contours dashed, zero contour bold. Areas with confidence limit of 0.05 using a t-test are shaded. The SLP data set covers 1873 through 1994, is obtained from Climatic Research Unit/University of East Anglia, UK; and is carefully checked and interpolated using the historical SLP map dataset compiled by the Long-range Forecasting Group of Peking University, P.R.China.

Acknowledgments. We acknowledge NCEP/NCAR for making the reanalysis data available. We would like to thank two referees for helpful suggestions and comments. This work was supported in part by NSFC(No.49635190).

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(Received July 9, 1998; revised November 4, 1998, accepted: December 14, 1998.)