1.7 Evidences of Dominant Atmospheric Circulation Variability in the Context of Global Warming

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1. Introduction

Recent studies show dramatic changes of atmospheric circulation during last decades. For example, the Annular Mode or Arctic Oscillation (AO) and Antarctic Oscillation (AAO) recognized by Thompson and Wallace (1998) and Gong and Wang (1998) indicate persistent negative anomalies of sea level pressure (SLP) in both Polar Regions since late 1980s up to present.

In terms of zonal symmetry of these leading modes and their similarity in both hemispheres, we investigated interhemisphere coherent variability of zonally mean geopotential height extending from north pole to south pole and from 1000mb to 100mb, its seasonality, associated mid-latitude westerlies and their relationship to global warming.

2. Data

The monthly geopotential height during 1948 through 2001 from the NCAR/NCEP Reanalysis (Kalnay et al. 1996) and the long-term observation of global surface air temperature (Jones 1994) data are used to explore characteristics of predominant variability of atmospheric circulation in the context of global warming in this study.

3. Zonally symmetric leading mode and its seasonality

In order to see potential relations of atmospheric circulation in both hemispheres, we check correlations of geopotential height in both hemispheres. Figure 1 shows the correlation efficient of zonal mean geopotential height at 500hpa. Variations of geopotential height are out of phase between polar and extratropical regions. The north hemisphere and south hemisphere show symmetric to a great degree. Maximum negative correlation happens around $60^o N$ and $45^o S$, respectively.

EOF/PC analysis was further performed to investigate coherent variability in both hemispheres with zonal mean geopotential height from 1000hpa to 100hpa. The first EOF with annual mean data explains almost 70% of total variance, revealing opposite pattern between tropical and high latitudes in both hemispheres, the same as the fact revealed by figure 1.

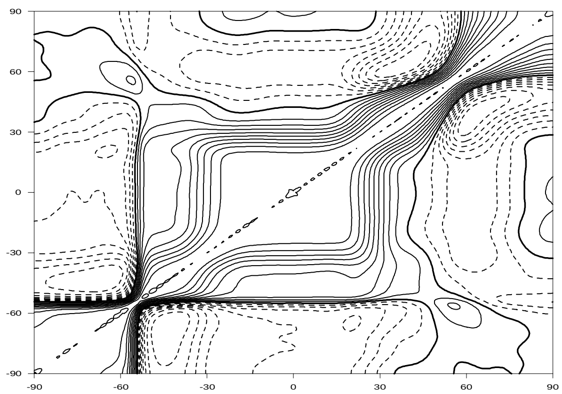

Fig. 1 The cross correlation coefficients between different latitudes of averaged 500hPa height. The contour interval is 0.1. Dashed line: negative values; solid line: positive values.

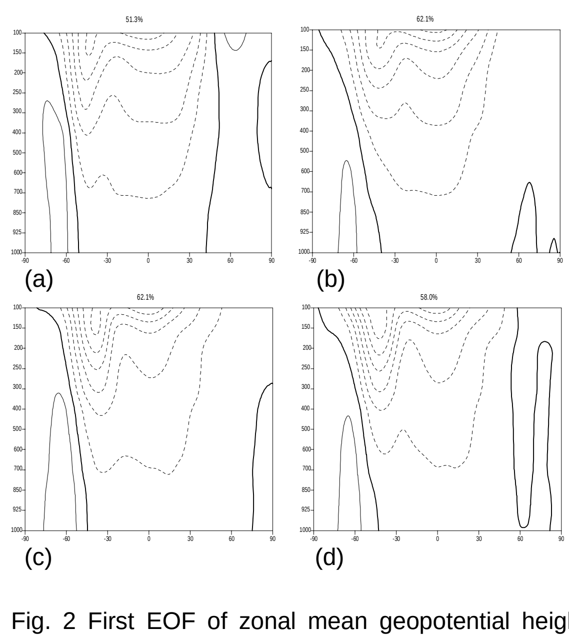

Fig. 2 First EOF of zonal mean geopotential height from 1000hpa to 100hpa for four seasons defined during (a) Dec.-Feb.; (b) Mar.-May; (c) Jun.-Aug.; and (d) Sept.-Nov.

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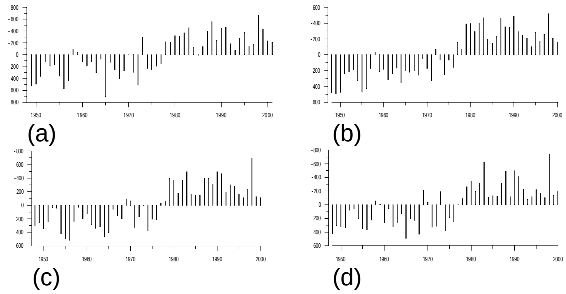

Fig. 3 The same as Fig. 1, but for principal component.

Figure 2 and 3 show EOFs and associated principal components for four seasons. The leading mode is pretty robust and stable in the seasonal cycle. Their contributions to total variances range from 46% to 62% with maximum for summer data, as indicated in Table 1. Although the AO shows annular characteristics, its principal component differs from those showed in figure 3. Figure 3 indicates dramatic changes in later 1970s from negative phase to positive phase, which agrees very well with global surface temperature variations (Jones et al. 1999).

Table 1 Variance explained by EOF1

	Dec-Feb	Mar-May	Jun-Aug	Sept-Nov
Variance	51.3	56.6	62.1	58.0

Thompson and Wallace (1998, 1999) indicated that the AO is closely associated with surface air temperature. Regression analysis demonstrates that the surface air temperature increase in the Eurasia could be accounted for by AO. In order to see the relationship of the leading mode defined in this paper to the global warming, we calculated correlative efficient between the leading mode and global surface air temperature and list them in Table 2. They show a close correlation and the maximum value can arrive at –0.84 for winter season.

Table 2 Correlation efficient of global mean surface air temperature with first principal component of four seasons

	Dec-Feb	Mar-May	Jun-Aug	Sept-Nov
Correlation	-0.84	-0.82	-0.72	-0.74

4. Variability and trend of westerlies

The leading mode shows opposite variability and trend between polar and extratropical regions. It should be manifested by extratropical westerlies. As Limpasuvan and Hartmann (1999) stated, the leading mode reflects anomalous westerlies vacillation. We check the westerly intensity as measured by the difference of geopotential height between $60^o N$ and $40^o N$ and $60^o S$ and $45^o S$, respectively. The westerly index is defined as:

NWI=$[H]_{40N}$-$[H]_{60N}$ for north hemisphere
SWI=$[H]_{45S}$-$[H]_{65S}$ for south hemisphere

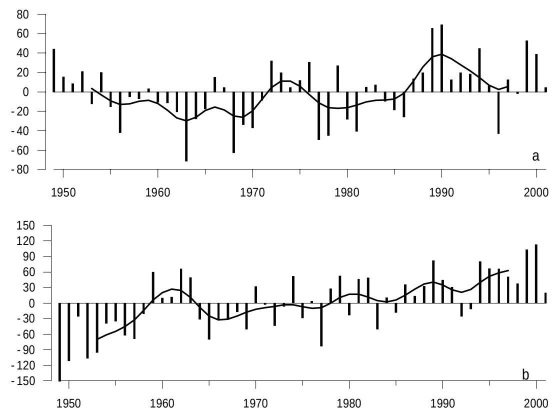

Fig. 4 Annual mean (a) NWI and (b) SWI at 500hPa. The solid line is for filtered results.

Figure 4 depicts the westerly indices. They show decadal variability of westerlies in both hemispheres. Westerlies obviously intensify in the last decades. The westerlies significantly strengthen since later 1980s in the north hemisphere while the similar phenomena happened earlier back to 1970s in the southern hemisphere.

Table 3 Classification of westerly anomalies in both hemispheres and number of occurrence

Pattern	NWI	SWI	Number
1	+	+	16
2	+	-	13
3	-	+	11
4	-	-	13

Pattern / Decade	1	2	3	4
1950s	1	4	0	5
1960s	0	2	4	4
1970s	3	3	2	2
1980s	4	1	3	2
1990s	6	2	2	0

In Table 3, we classify four types of pattern to classify variability of westerly intensity in both hemispheres. The table shows number of occurrence of each type of patter during entire period and respective five decades. The increasing trends of intensified westerlies happened in both hemispheres are very clear. In 1990s, the number of positive sign simultaneously occurring in the both hemispheres arrives at 6, much higher than those in 1950s and 1960s.

5. Concluding remarks

Thompson and Wallace (1998, 1999) recognized the annular modes in both the northern and southern hemispheres, which are characterized by zonally symmetric and barotropical structures. Considering these basic features, we examine zonal mean geopotential height data from 1948 upto present to investigate coherent variability of atmospheric circulation from the north pole to south pole and from surface to stratosphere.

The first EOF pattern shows opposite sign between polar and extratropical regions, indicating out of phase variations of geopotential height. Although the AO and AAO have symmetric characteristics, their principal component is different from that defined in this paper. For the mode in this paper, positive trends happen since later 1970s, coincide with the changes of global surface air temperature (Jones et al. 1999). Correlation analysis also shows strong relationship of the leading mode to the global warming.

Variability of westerlies intensity could be a manifestation of the leading mode. In recent decades, westerlies in both hemispheres tend to strengthen simultaneously. The number that westerlies intensify in both hemispheres reaches 6, much higher than 1950s and 1960s. This perhaps could be accounted for by global warming.

6. References

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