Article ID: 1006-8775(2010) 02-0035-07

THE RELATIONSHIP BETWEEN EXTREME PRECIPITATION ANOMALY IN SOUTH OF CHINA AND ATMOSPHERIC CIRCULATION IN THE SOUTHERN HEMISPHERE

MIN Shen (闵 屾)[1, 2], QIAN Yong-fu (钱永甫)[1]

(1. School of Atmospheric Sciences, Institute of Severe Weather and Climate, Nanjing University, Nanjing 210093 China; 2. State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing China 210008)

Abstract: Based on the daily rainfall datasets of 743 stations in China and the NCEP/NCAR monthly reanalysis data during the period of 1960–2003, the relationship between the anomalous extreme precipitation (EP) in the south of China and atmospheric circulation in the Southern Hemisphere is analyzed. The phenomenon of opposite changes in the sea level pressure and geopotential height anomalies over the Ross Sea and New Zealand is defined as RN, and the index which describes this phenomenon is expressed as RNI. The results show that the RN has barotropic structure and the RNI in May is closely related to the June EP amount in the south of China (SCEP) and the East Asian summer monsoon (EASM). The positive correlations between the May RNI at each level and the June SCEP are significant, and the related simultaneous correlations between the RNI and the June SCEP are also positive, suggesting that the potential impact of RN on the SCEP persists from May to June. Therefore, RN in May can be taken as one of the predictive factors for the June SCEP. Furthermore, one possible physical mechanism by which the RN affects the June SCEP is a barotropic meridional teleconnection emanating from the Southern Hemisphere to the western North Pacific.

Key words: south of China; extreme precipitation; anomaly; Ross Sea-New Zealand

CLC number: P461 **Document code:** A **doi:** 10.3969/j.issn.1006-8775.2010.01.005

1 INTRODUCTION

Previous studies have shown that the Southern Hemisphere atmospheric circulation may be related to East Asian climate. He et al. [1] studied the relationship between circulation anomalies in the Southern Hemisphere and summer precipitation distribution in China, and showed that when the ridge of Australian High is stronger than normal and the zonal wind shear anomaly in the tropical southwest Pacific is negative, the rain belt is located in the southern part of China. Xue et al. [2-4] investigated the interannual variability of the Mascarene high and Australian High and their influence on the East Asian Summer Monsoon (EASM). The results show that due to seasonal persistence, the related Mascarene high and Australian High in boreal spring may provide some useful information for the EASM prediction.

Antarctic Oscillation (AAO), which is also known as Southern Hemisphere annular mode, has zonal symmetry and barotropic structure as a major mode of the Southern Hemisphere extratropical atmospheric circulation. Lu et al. [5] focused on the interannual variability of AAO, which is dominated by internal atmospheric variability. Fan et al. [6, 7] found that there exists a meridional teleconnection pattern from the Antarctic to Arctic during the abnormal years of AAO and this meridional teleconnection has been demonstrated through simulations. Gao et al. [8] pointed out that the influence of interannual variability of AAO on Meiyu is important. Fan [9] and Nan et al. [10] suggested that there are significant positive correlations between the boreal spring Southern Hemisphere annular mode and the following summer precipitation over the Yangtze River Valley, and the boreal spring

Received date: 2009-07-27; **revised date:** 2009-10-08
Foundation item: National Basic Research Program of China (2004CB418300, 2010CB833406) and National Natural Science Foundation of China (40675042, 40890054, 40871007)
Biography: MIN Shen, Ph.D. candidate, mainly undertaking the analysis of regional climate change.
E-mail for correspondence author: qianzh2@nju.edu.cn

Southern Hemisphere circulation anomaly is one of the important climate predictors for summer rainfall over the Yangtze River valley. Furthermore, Nan et al. [11] indicated that the SSTA in the Indian Ocean and the South China Sea is a bridge between the boreal spring Southern Hemisphere annular mode and summer precipitation in the Yangtze River valley.

The aforementioned studies have fostered much effort on searching for the impact of the Southern Hemisphere circulation anomaly on East Asian climate, especially the influence of the Southern Hemisphere circulation anomaly on summer rainfall over the Yangtze River valley. However, the precipitation intensity in the south of China is stronger, and the extreme precipitation (EP) in the south of China happens more frequently than in the Yangtze River valley. Therefore we will focus on the south of China and study how the changes in the Southern Hemisphere circulation could lead to the EP anomalies in the south of China. The previous studies dealt with seasonal mean anomalies, while here we will focus on subseasonal variation, especially on June rainfall variation in the south of China, because June is the peak rainy season there. We found a statistically significant lead-lag correlation on the monthly time scale between the south of China extreme precipitation in June and a dipole pressure anomaly over the Ross Sea (High)-New Zeeland (Low) in May. We will discuss how the Ross Sea-New Zealand dipole anomaly can lead to anomalous EP in the south of China.

2 DATA AND METHODS

Daily rainfall dataset of 743 weather stations in China and the NCEP/NCAR monthly reanalysis data of geopotential height (GH), sea level pressure (SLP), and u, v and ω fields during the period of 1960－2003 were used in this study.

Seventy-eight stations in the south of China are selected to define the rainfall there. These stations distribute quite uniformly in Guangxi, Guangdong, Fujian, Hainan, and southern Jiangxi and southern Hunan (south of 28°N). In order to increase the spatial comparability between the rainy regions and the less rainy areas, and the temporal comparability between the pluvial period and the less rainfall seasons, each station is assigned a month-dependent EP threshold defined by Min et al. [12], and the daily precipitation with the amount exceeding the specified threshold is defined as an EP event. Finally, the monthly EP amount is calculated as the total rainfall of all EP events during that month. The area-mean EP amount over the south of China is designated as SCEP.

According to the definition of the precipitation-concentration period (PCP) by Li et al. [13], the extreme PCPs at 47 stations, which account for 60.3% of all stations, occur in June, and the extreme PCPs at the other stations occur in May, July and August. Therefore, June is the month of peak heavy precipitation. The month-by-month distribution of the climatic mean SCEP is shown in Fig. 1a, and we can see that the climatological mean of June SCEP is 123.6 mm, which is the maximum value. For this reason, our attention will focus on the June SCEP and examine its linkage with anomalous atmospheric circulation in the previous month, May. This means that we examine the subseasonal lead-lag teleconnection rather than the seasonal mean one.

The normalized anomalies and the 11-year running average of the June SCEP are shown in Fig. 1b. The June SCEP anomalies are generally negative from 1975 to 1990, and they are mostly positive afterwards. The years with standard deviation of the ≥ 1 June SCEP from Fig. 1b was used to define as abundant June SCEP years and those as deficient years if the June SCEP ≤ –1. Note that here we do not distinguish interannual and interdecadal variations. We use the lead-lag correlation and composite analysis techniques to study the relationship between the June SCEP anomalies and atmospheric circulation in the Southern Hemisphere. Furthermore, the Student t-test was utilized to examine the statistical significance.

3 LEAD-LAG RELATIONSHIP BETWEEN THE SOUTH OF CHINA EXTREME PRECIPITATION AND ROSS SEA-NEW ZEALAND DIPOLE PRESSURE ANOMALY

3.1 *Definition of RN index*

The composite difference in the SLP field of May between the abundant and deficient June SCEP years shows a pronounced dipole pressure anomaly with a high centered at 60°S and the dateline and a low centered at New Zealand (Fig. 2). This "seesaw" pattern is not the AAO mode but may be related to it. According to the AAO index (AAOI) defined by Gong et al. [14], Gao et al. [8] and Nan et al. [10-11], respectively, the correlations between the May AAOI and the June SCEP are negative, but the correlations cannot exceed the 90% confidence level. There are pronounced zonal asymmetric structures as seen from Fig. 2 and such a zonal nonuniformity may be one of the factors that have important impact on the June SCEP. For this reason, we emphasize the Ross Sea-New Zealand (RN) dipole rather than AAO.

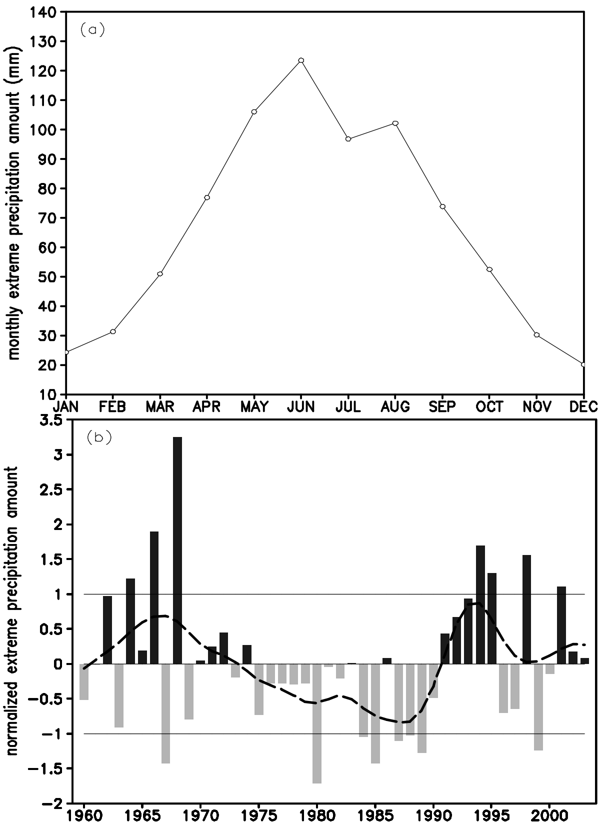


Fig.1 (a) The seasonal distribution of the climatological extreme precipitation amount in the south of China (SCEP); (b) The time series of the normalized June SCEP anomalies (bars) and their 11-year running average (dashed line).

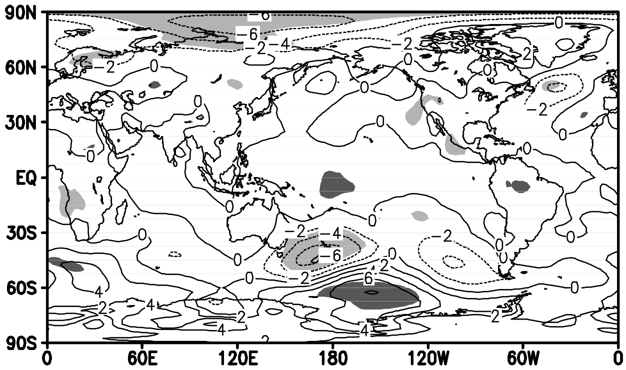


Fig.2 Composite differences in May sea level pressure field between the abundant and deficient June SCEP years. Regions where the correlation is significant above the 95% confidence level are shaded. (Unit: hPa)

To characterize this RN dipole feature, we use a new index called as RN index (RNI). The RNI is defined as the normalized area-mean anomalous SLP difference between the Ross Sea (60°S－75°S, 130°W－160°W) and New Zealand (30°S－45°S, 160°E－170°W). In May, the normalized area-mean SLP anomalies in these two areas have a negative correlation coefficient of –0.54, which is significant at the confidence level above 99.9%. The correlations between the pressure at each pole and the RNI are more remarkable. Therefore, the definition of RNI is reasonable and the positive (negative) index corresponds to the positive (negative) RN mode.

Figure 3 shows the time series of normalized anomalies of RNI in May during 1960 to 2003. The interdecadal variation of the RNI in May is similar to the June SCEP before the mid-1990s, and the correlation between the May RNI and the June SCEP is 0.45, which is significant above the 99% confidence level. The abundant June SCEP years, 1964, 1966, 1968, 1994, and 2001, correspond to the positive RNI anomalies in May, and the deficient June SCEP years, 1967, 1980, 1984, 1985, 1987, 1988, 1989, and 1999, all correspond to the negative RNI anomalies in May. The years with standard deviation of the May RNI ≥ 1 (≤–1) from Fig. 3 can be defined as strong positive (negative) RNI years. There are six strong positive RNI years (1961, 1965, 1966, 1968, 1992, and 1994), which accounts for 66.7% of the total and correspond to positive June SCEP anomalies. On the other hand, the seven strong negative RNI years (1980, 1985, 1987, 1989, 1997, 1999, and 2000)—accounting for 77.8% of the total—correspond to the negative June SCEP anomalies. These results suggest that when the equatorward pressure gradient decreases (increases) at mid- and high-latitudes over the Southern Hemisphere in May, the June SCEP tends to be above (below) normal.

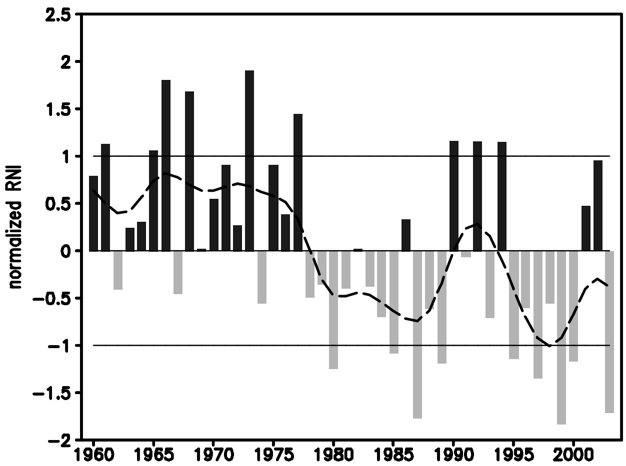


Fig.3 The same as Fig. 2b, but for the Ross Sea-New Zealand dipole index (RNI) in May.

Moreover, EASM is closely related to precipitation in the south of China and the EASM circulation links the circulation of both hemispheres. The correlation between the May RNI and the June EASM index (EASMI) defined by Wang et al. [15] is 0.35 (above the 95% confidence level), which implies that when the pressure gradient decreases at mid- and high-latitudes over the Southern Hemisphere in May, the June EASM would be stronger. Moreover, the related simultaneous correlation between the EASMI and the June SCEP is positive, indicating that the EASM circulation becomes stronger and then heavy SCEP takes place.

The composite difference pattern of the June SLP field between the abundant and deficient June SCEP years is similar to that in May (not shown). The simultaneous correlation between the RNI and the June SCEP is also positive, but the correlation coefficient is smaller than that between the May RNI and the June SCEP. The linkage of the Southern Hemisphere circulation anomalies and the June SCEP has good seasonal persistence from May to June, and the leading correlation between May RNI and the June SCEP is more remarkable than the corresponding simultaneous correlation in June.

3.2 *RN index related to geopotential height*

The composite difference in the May 500-hPa Geopotential Height (GH) field between the abundant and deficient June SCEP years shows significant negative anomaly around New Zealand and outstanding positive anomaly over the Ross Sea (Fig. 4a), which is similar to the anomalous dipole shown in Fig. 2. This implies that the dipole anomaly between Ross Sea high and New Zealand low has an equivalent barotropic structure. Thus, the RNI can also be defined by the normalized GH anomaly difference between the Ross Sea and New Zealand. In May, the normalized area-mean GH anomalies at 500 hPa between these two areas are significantly opposite with a significant correlation coefficient of –0.63. In addition, the May RNI is positively correlated with the June SCEP (above the 99% confidence level).

The composite difference of 500-hPa GH field between the abundant and deficient June SCEP years in related simultaneous periods shows that the GH anomalies over the Ross Sea are out of phase with those over New Zealand, but the difference is less significant than that in May (Fig. 4b). Furthermore, there are remarkable positive anomalies over the northeast part of Australia.

From May to June, normalized anomalies of area-mean GH over the Ross Sea and New Zealand are oppositely correlated at large margins throughout the troposphere at all levels but 100 hPa (Fig. 5a). Moreover, in the area of 30°S – 75°S, 160°E – 130°W, the correlation coefficients between the composite GH differences at each level are over 0.9 in May and over 0.6 in June. The positive correlations between the May RNI and the June SCEP are statistically significant at the 95% confidence level, while the related simultaneous correlations between the RNI and the June SCEP are positive, too, though the coefficients are smaller than that in May (Fig. 5b). Therefore, from May to June, heavy June SCEP always corresponds to a positive RN mode at each level.

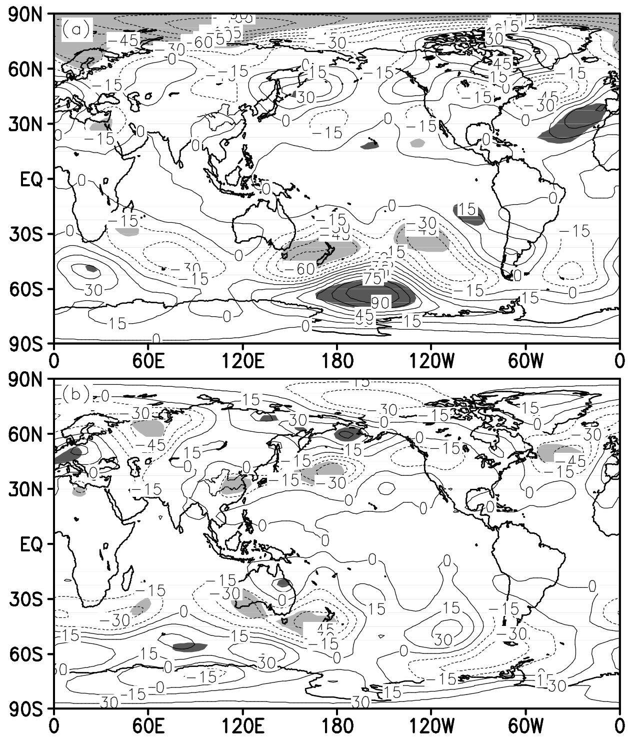


Fig.4 Composite differences of the 500-hPa GH field between the abundant and deficient June SCEP years in May (a) and in June (b). Regions where the correlation is significant above the 95% confidence level are shaded. (Unit: gpm)

4 POSSIBLE MECHANISMS

To understand what links the May Southern Hemisphere atmospheric circulation anomalies with the June SCEP anomalies, we show that the wind difference at 500 hPa between the abundant and deficient June SCEP years (see Fig. 6). In May, the most striking feature is an anti-cyclonic circulation anomaly over the Ross Sea and a cyclonic circulation anomaly over New Zealand. Moreover, there is a weak anomalous anticyclone at the northeast of Australia (Fig. 6a). Meanwhile, an anti-cyclonic circulation anomaly appears over the western North Pacific region (near 140°E) and the Yangtze River valley, and a cyclonic circulation anomaly covers the region from Indochina Peninsula extending eastward to the Philippines. In June, prominent anomalies are seen in the areas as marked by bold parallelogram in Fig. 6b. The anomalous anticyclone over the Ross Sea becomes less significant, but the cyclonic circulation anomaly over New Zealand and the anomalous anticyclone in the northeast Australia become evident, suggesting an equatorward propagation of the stationary wave train. The enhanced northeast Australian High yields significant anomalous easterlies over the maritime continent. At the same time, significant anticyclonic circulation anomaly can be observed over the northern part of South China Sea and Philippine Sea with a notable cyclonic circulation anomaly over the southeast China. Figures 6a & 6b show an obviously meridional teleconnection pattern, which persists, propagates northward from May to June.

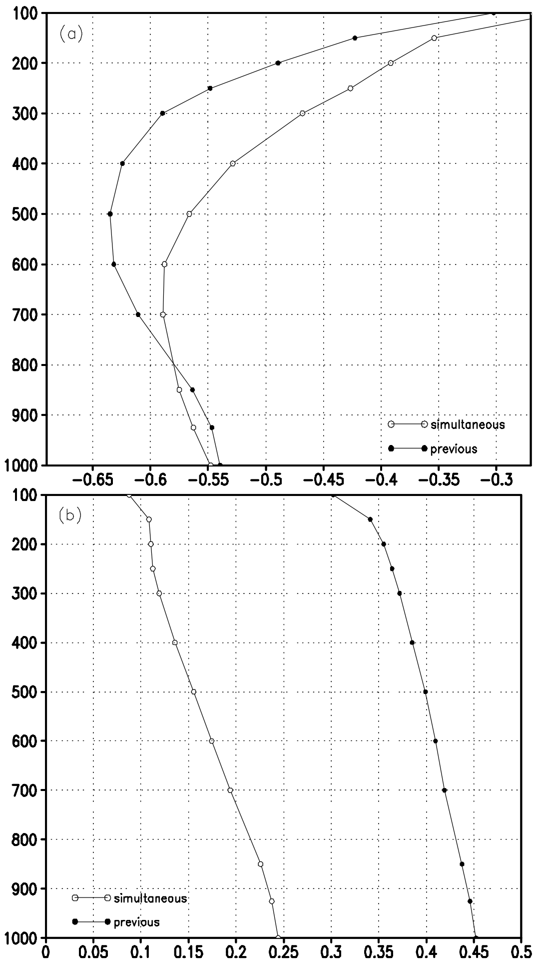
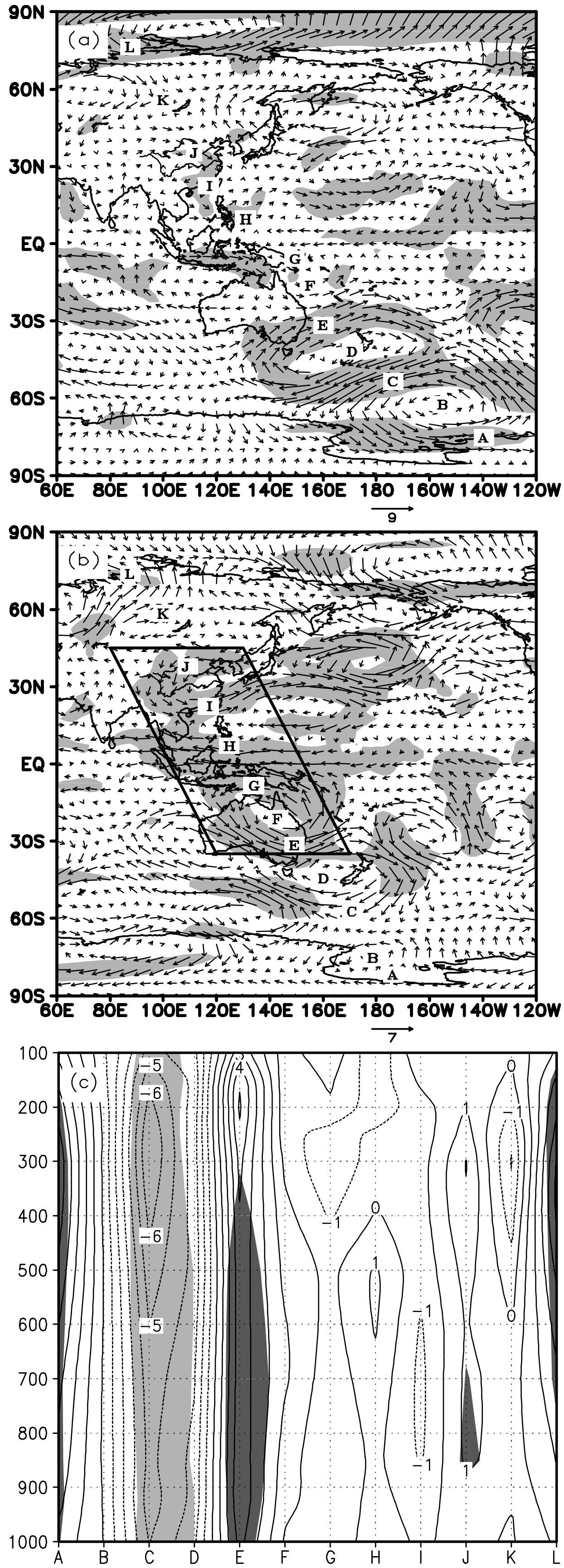


Fig.5 Distributions of correlation coefficients with height between the normalized anomalies of area-mean GH over the Ross Sea and New Zealand (a) and between the RNI and the June SCEP (b).

The cross section of zonal wind differences, made with the winds at 12 spots selected from the meridional teleconnection pattern, displays the barotropic meridional teleconnection from the Southern Hemisphere to the Northern Hemisphere. This teleconnection pattern of May is prominent in the mid- and high-latitudes over the Southern Hemisphere (Fig. 6c) and well established in June from the Southern Hemisphere mid-latitudes to the Northern Hemisphere mid-latitudes (Fig. 6d). He et al. [16] studied the impact of cold air activity in Australia on the intensification and northward advancement of the East Asian summer monsoon, and pointed out that meridional wind disturbance propagated from south to north in this process, which is similar to our meridional teleconnection pattern.



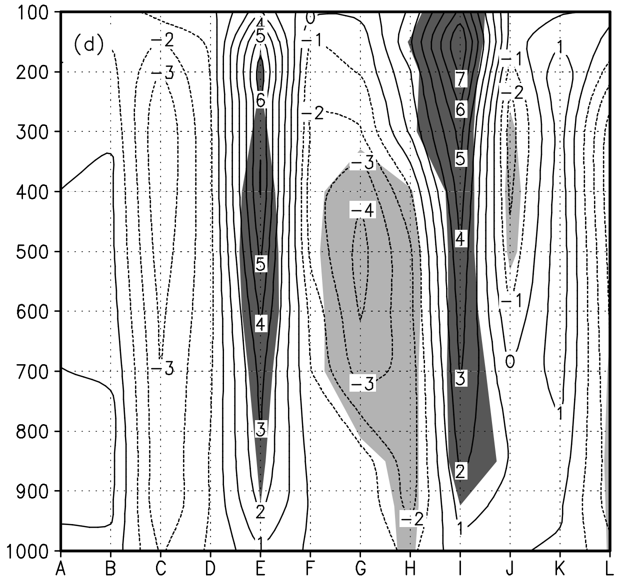


Fig.6 Composite wind differences at 500 hPa between the abundant and deficient June SCEP years in May (a) and in June (b). Panels (c) and (d) show the cross sections of the corresponding composite zonal wind differences made along the teleconnection path (12 spots as shown in Fig. 6b) for May (c) and June (d). The capital letters in (a) and (b) denote the meridional teleconnection along which the cross sections (c and d) are made. Regions above the 95% confidence level are shaded. (Unit: m s^{-1})

The aforementioned teleconnection pattern explains the physical linkage between RN and the SCEP. The SLP (GH) anomalies over the Ross Sea and New Zealand would lead to an abnormal northeast Australian High through equatorward mass/energy propagation. The anomalous Australian High further results in enhanced easterly winter monsoon over Indonesia. The convection is thus enhanced in the maritime continent. As a result, the ascending branch of the meridional overturning circulation over the maritime continent was strengthened and the corresponding descending branch of the meridional circulation also enhanced over the northern South China Sea and Philippine Sea, thereby enhancing the Western Pacific subtropical high over the northern South China Sea and Philippine Sea. The latter is largely responsible for the increased SCEP.

To support the aforementioned hypothesis, the meridional circulation along the teleconnection path is investigated. Fig. 7 presents a cross section of zonal mean meridional circulation difference between the abundant and deficient June SCEP years. The meridional cross section was made along the teleconnection path marked by the bold parallelogram in Fig. 6b. As shown in Fig. 7, the updraft occurs over the equatorial areas and the strong descending motion occurs over the Philippine Sea between 10°N and 20°N. These ascending and descending branches constitute a Hadley-type meridional circulation. Positive ascending flow anomalies are dominant near 25°N, corresponding to the enhanced SCEP. It is suggested that the enhanced Australian High strengthens easterly winter monsoon and precipitation over the maritime continent to enhance the upward draft branch of the meridional circulation, which further enhances the downward sinking motion over the Philippine Sea and the western Pacific subtropical high, thereby inducing more June SCEP.

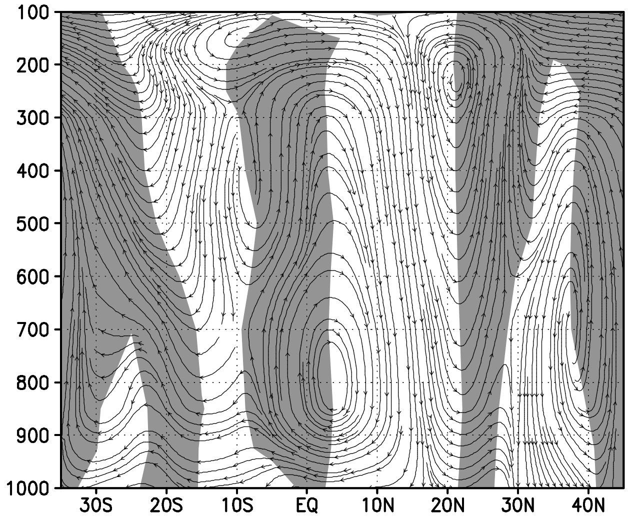


Fig.7 Cross section of zonal mean meridional circulation along the teleconnection path (the areas marked by bold parallelogram in Fig. 6b). The meridional circulation is made with the composite difference between the abundant and deficient June SCEP years. Regions where the anomaly is upward are shaded.

5 CONCLUSION AND DISCUSSION

The June Extreme Precipitation (SCEP) for the south of China is shown to be significantly expressed by the Ross Sea (High)-New Zealand (Low), or RN dipole in May (Fig. 2 and Fig. 4a) as well as in June. For this reason, RN in previous periods can be taken as one of the impacting and predictive factors for the June SCEP.

This RN dipole occurs in the southwest Pacific. How can it be related to SCEP? Our analysis shows that the enhanced June SCEP depends on the enhanced western North Pacific Subtropical High (WNPSH) over the northern Philippine Sea and South China Sea, while the WNPSH is linked to the RN dipole via a meridional teleconnection from Southern Hemisphere to Northern Hemisphere. The simultaneous correlation between WNPSH and RN dipole was shown to arise from a teleconnection pattern that emanates primarily from New Zealand to the Philippine Sea (Fig. 6b). This teleconnection pattern has a barotropic structure. The May RN dipole appears to propagate equatorward, and by June the Ross Sea High weakens but the New Zealand Low and Australian High are enhanced. When the Australian High intensifies, the associated Indonesian winter easterly monsoon enhances the equatorial convection and the in situ updraft, resulting in an enhanced local Hadley-type overturning cell, so that sinking motion over the Philippine Sea－South China Sea is strengthened (Fig. 7), which causes enhanced WNPSH over the northern South China Sea and Philippine Sea and the June SCEP. Note that the AAO is a zonal symmetric mode while the RN dipole is largely a zonal asymmetric feature. Furthermore, the Subtropical High in the Southern Hemisphere associated with the AAO is different from the Australian High defined in our paper.

A number of questions remain unanswered. For instance, how does the RN dipole propagate energy equatorward? What is the exact time scale for this equatorward propagation? What is the subseasonal variation of the meridional teleconnection and how does it relate to the mean flows? Further studies are needed to fully understand the dynamics of the meridional teleconnection.

REFERENCES:

[1] HE Min, SUN Lin-hai, AI Xiu. The relationship and influence mechanism between circulation anomaly in southern hemisphere and summer precipitation distribution in China [J]. J. Appl. Meteor. Sci. (in Chinese), 2006, 17(4): 394-402.

[2] XUE Feng, WANG Hui-jun, HE Jin-hai. Interannual variability of Mascarene high and Australian High and their influence on summer rainfall over East Asia [J]. Chin. Sci. Bull., 2003, 48(5): 492-497.

[3] XUE Feng, JIANG Da-bang, LANG Xian-mei, et al. Influence of the Mascarene high and Australian High on the summer monsoon in East Asian: Ensemble simulation [J]. Adv. Atmos. Sci., 2003, 20(5): 799-809.

[4] XUE, Feng, WANG Hui-Jun, HE Jin-hai. Interannual variability of Mascarene high and Australian High and their influences on East Asian summer monsoon [J]. J. Meteor. Soc. Japan, 2004, 82(4), 1173-1186.

[5] LU Ri-yu, LI Ying, BUWEN D. Arctic Oscillation and Antarctic Oscillation in internal atmospheric variability with an ensemble AGCM simulation [J]. Adv. Atmos. Sci., 2007, 24(1): 152-162.

[6] FAN Ke, WANG Hui-jun. Interannual variability of Antarctic Oscillation and its influence on East Asian climate during boreal winter and spring [J]. Sci. China: (Ser. D: Earth Sci.), 2006, 46(5): 554-560.

[7] FAN Ke, WANG Hui-jun. Simulation of the AAO anomaly and its influence on the northern hemispheric circulation in boreal winter and spring [J]. Chin. J. Geophys. (in Chinese), 2007, 50(2): 397-403.

[8] GAO Hui, XUE Feng, WANG Hui-jun. Influence of interannual variability of Antarctic Oscillation on Meiyu along the Yangtze and Huaihe River Valley and its importance to prediction [J]. Chin. Sci. Bull., 2003, 48(suppl.): 61-67.

[9] FAN Ke. Atmospheric circulation anomalies in the Southern Hemisphere and summer rainfall over Yangtze River Valley [J]. Chin. J. Geophys. (in Chinese), 2006, 49(3): 672-679.

[10] NAN Su-lan, LI Jian-ping. The relationship between the summer precipitation in the Yangtze River Valley and the boreal spring southern hemisphere annular mode: I Basic facts [J]. Acta Meteor. Sinica (in Chinese), 2005, 63(6): 837-846.

[11] NAN Su-lan, LI Jian-ping. The relationship between the summer precipitation in the Yangtze River Valley and the boreal spring southern hemisphere annular mode: II The role of the Indian ocean and the south of China sea as an "oceanic bridge" [J]. Acta Meteor. Sinica (in Chinese), 2005, 63(6): 837-842.

[12] MIN Shen, QIAN Yong-fu. Trends in all kinds of precipitation events in China over the past 40 years [J]. Acta Sci. Nat. Uni. Sunyatseni (in Chinese), 2008, 47(3): 105-111.

[13] LI Shao-juan, QIAN Yong-fu. New methods to research the general features of precipitation in China [J]. J. Nanjing Inst. Meteor. (in Chinese), 2006, 29(6): 341-321.

[14] GONG Dao-yi, WANG Shao-wu. Definition of Antarctic oscillation index [J]. Geophy. Res. Lett., 1999, 26: 459-462.

[15] WANG Hui-jun. Instability of the East Asian Summer monsoon – ENSO relations [J]. Adv. Atmos. Sci., 2002, 19(1): 1-11.

[16] HE Jin-hai, LI Jun, LI Yong-ping. Numerical experiment with processes for effect of Australian cold air activity on East-Asian summer monsoon [J]. Acta Meteor. Sinica (in Chinese), 1991, 49(02): 162-169.

Citation: MIN Shen and QIAN Yong-fu. The relationship between extreme precipitation anomaly in south of China and atmospheric circulation in the Southern Hemisphere. *J. Trop. Meteor.*, 2010, 16(1): 35-41.