The Spring Monsoon in South China and Its Relationship to Large–Scale Circulation Features

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ABSTRACT

In this paper, the authors define the spring monsoon in South China, and study the climatology and the interannual variation through analysis of the precipitation and the related atmospheric circulation, as revealed by the NCEP / NCAR reanalysis data. The results indicate that the spring monsoon season in South China occurs climatologically in April and May, which is supported by both seasonal and interannual variation of the atmospheric circulation and precipitation. The related atmospheric circulation is different from that during the East Asian summer or winter monsoon season. The interannual variation of the spring monsoon rainfall in South China relates primarily to the anomalous circulation over the North Pacific, which is linked with the westerly jet over North Asia and with the polar vortex. It is also connected with sea surface temperature anomalies in the Pacific. Changes in the Asian tropical atmospheric circulation has little influence on the spring monsoon in South China according to this research.

Key words: spring monsoon, seasonal variation, interannual variation

1. Introduction

In South China (south of the Yangtze River), the rainy season lasts about six months (from March to September) due to its low latitude geographical location. This long period is usually categorized into two sub–rainy seasons, namely, the springtime season (the period of the atmospheric circulation in transition from the winter monsoon state to the summer monsoon state in spring) and the summer monsoon season. The summer monsoon season is the rainy period for the mainland of China, and has attracted many studies. During the summer monsoon season, Meiyu over the Yangtze River Valley happens climatologically from mid–June to mid–July, characterized by persistent rainfall associated with the quasi–stationary Meiyu front in the synoptic chart (Tao et al. 1958; Tao and Chen 1987; Tao et al. 1988). The wind components of the Meiyu front consist of the southwest monsoon flow originating from the Indian Ocean, the southeast monsoon flow associated with the subtropical high in the western Pacific, and the westerly in middle latitudes of the lower troposphere. In spring, concentrated precipitation falls only in South China while other regions in the mainland are still in the dry season. The springtime precipitation brings about the rainwater for agriculture and, sometimes when the spring monsoon is in an anomalous state, disasters due to heavy rain or drought in South China. Therefore, the springtime precipitation and the circulation are very important in South China, both scientifically and economically.

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In the past the seasonal variation of rainfall in eastern China used to be described as a process of the meridional movement of the rainbelt. This is true in phenomenon, but not accurate in nature, because there are two mechanisms relating to the rainbelt in eastern China: one is the subtropical rainbelt linked to the subtropical high pressure system over the western Pacific; and the other is the tropical Asian monsoon rainbelt which is associated with the tropical Asian monsoon flow originating from the Indian Ocean and Indo–China Peninsula. Since the mechanisms of the two sub–rainy seasons in South China are physically different, it is worth defining the exact period for each sub–rainy season based on physical considerations, and studying the springtime circulation and its interannual variability. These are of great importance for seeking reasonable and effective methods for seasonal prediction of the precipitation anomalies.

There have been some studies on the synoptic analysis of the premonsoon season –the season before the summer monsoon (some collective results can be found in the book edited by Huang et al. 1986). However, there are comparatively less studies on the springtime circulation from the views of seasonal and interannual climate variation. The averages of April to June, or of May / June are usually used to represent a so–called ' premonsoon' season over South China (Gao et al. 1999; Guo and Sha 1983; Wu and Liang 1992), but no physical mechanisms are given to support such a definition.

In this study, we propose the concept of ' spring monsoon' and try to accurately define the period of the spring monsoon season through diagnosis of the precipitation and atmospheric circulation. We also analyze the relationship between the spring monsoon precipitation and the atmospheric circulation. Evidence from the seasonal cycle for rainfall and the related atmospheric circulation is presented in section 2, whereas section 3 discusses the interannual variation of the spring monsoon in South China.

Covering the years 1979–1998, the data sets adopted in this study include the OI (Optimum Interpolation) monthly mean sea surface temperature (SST) and the monthly atmospheric reanalysis data from the National Centers for Environmental Prediction / National Center for Atmospheric Research (NCEP / NCAR), and the analyzed monthly global precipitation of Xie and Arkin (1997).

2. The climatology of the spring monsoon in South China

As shown in Fig. 1 of the climatology of the monthly mean precipitation, large precipitation appears in June–July–August (JJA) over the Yangtze River and the Yellow River valleys in China, while the rainbelt related to the spring monsoon rainfall in the region south of the Yangtze River (South China) is located primarily in the Pacific Ocean during winter. Beginning from March, the subtropical rainbelt (SR) over the Pacific Ocean gradually moves westward and occupies the region of South China. From June, the tropical rainbelt (TR) moves northward to combine with the SR to bring the largest rainfall until August over the region. Then, gradually, the SR retreats eastward to the subtropical western Pacific and the TR moves southward to the tropical area after August. Physically, the June precipitation over South China is a combination of the subtropical and tropical rainbelts (or, the combined results of the so–called southwest monsoon flow and the southeast monsoon flow). Therefore, the mechanism of the June precipitation over South China is similar to that in July and August, and hence it should not be categorized as belonging to the spring monsoon season, although largest precipitation over South China (111.25°–121.25°E, 23.5°–32.5°N) appears in June (Fig. 2). March should not be included in the spring monsoon period either, because the

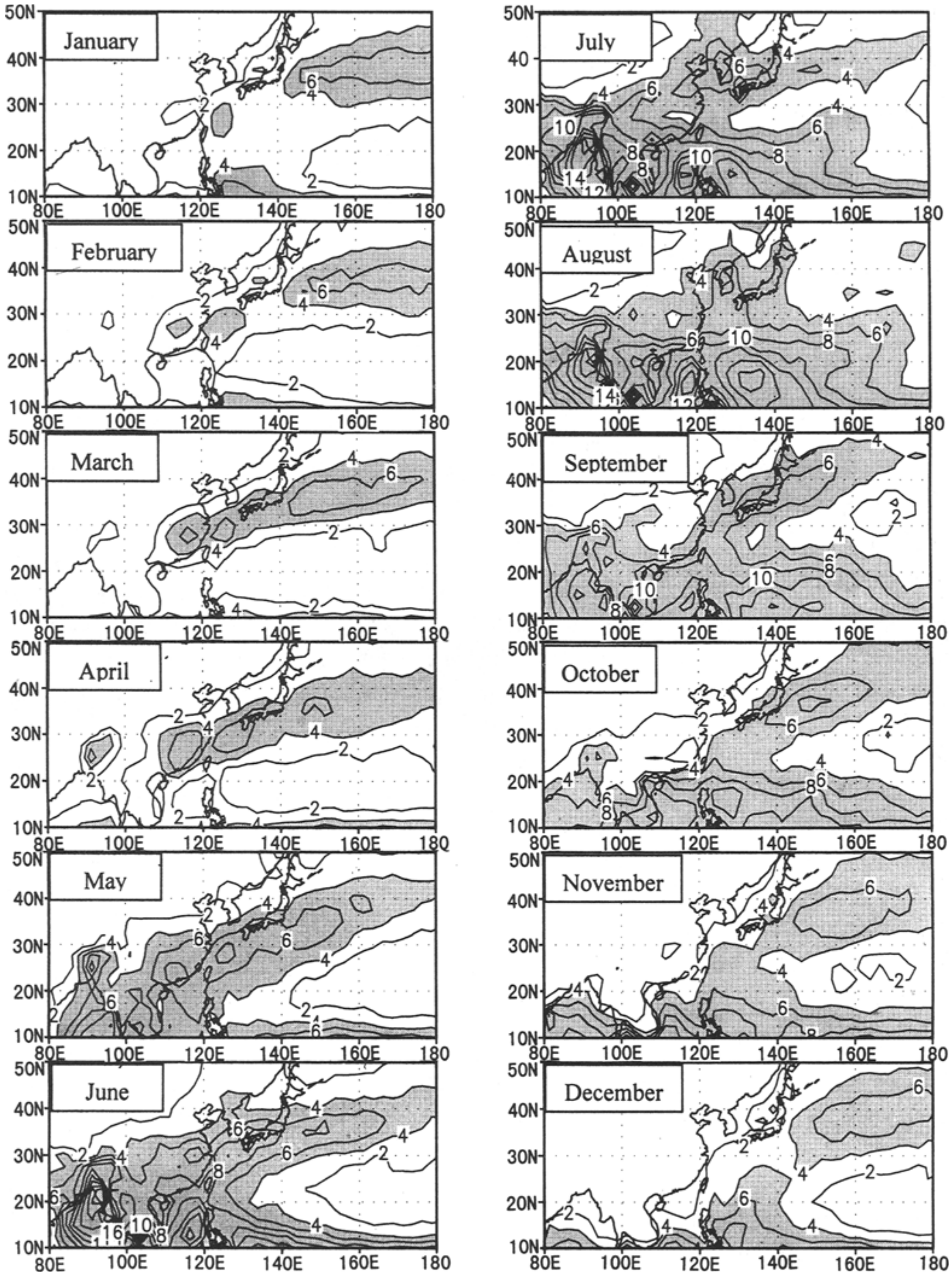

Fig. 1. The monthly precipitation over South China. Areas with values larger than 4 mm d^{-1} are shaded. The abscissa is the longitude in the Eastern Hemisphere, whereas the scale is the latitude in the Northern Hemisphere.

rainfall amount is comparatively smaller. So then, looking at the seasonal variation of the monthly means, April / May is the precise period of the spring monsoon over South China in

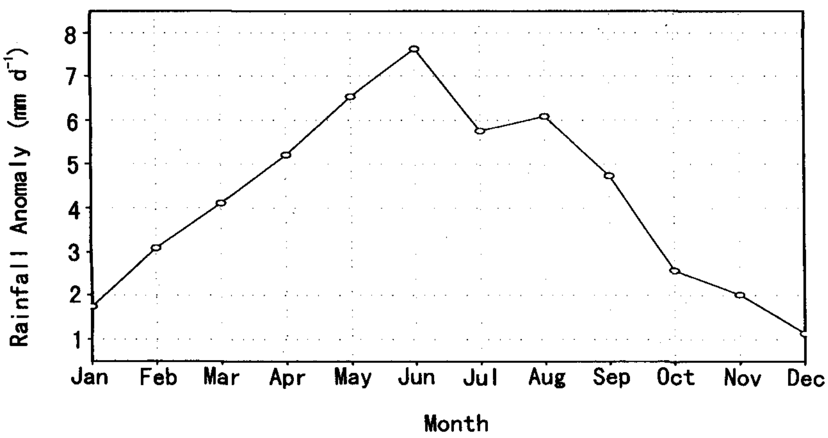

Fig. 2. The South China (111.25°–121.25°E, 23.5°–32.5°N) average rainfall anomalies (in mm d^{-1}) changing with months.

which the wind flow associated with the subtropical high over the western Pacific is dominant.

There is further strong evidence for defining April/ May as the period of the spring monsoon season. Table 1 gives the correlation coefficients between the monthly rainfall in April and that in each of the other months during 1979–1998, indicating that only the rainfall between April and May are highly correlated (0.61). The correlation coefficient between the rainfall in March and that in April is much smaller (0.1, and insignificant). Therefore, the spring monsoon season in South China should include April and May only, and the mean precipitation over the South China region for April and May can be used as an index to represent the strength of the spring monsoon.

Table 1. Correlation coefficients between the climatological precipitation in April and that in other months for 1979–1998

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.380	0.049	0.098	1.000	0.610	–0.187	–0.158	0.062	0.284	0.151	0.049	–0.196

Now we consider the atmospheric circulation related to the spring monsoon climate by comparing the April/ May (AM) average to the June average and January/ February (JF) average. Fig. 3 depicts the climatological wind distribution at 850 hPa, showing clearly the substantial differences between AM and June or JF. During JF, a strong westerly is located over North Asia and the North Pacific, and an easterly exists in the tropical Indian Ocean and western Pacific (characterizing the East Asian tropical winter monsoon). In June, the East Asian climate is characterized by the so–called southwest monsoon (the tropical monsoon component) and the southeast monsoon (the subtropical monsoon component). The flow pattern in April/ May is between theses states, namely the southeast flow related to the subtropical high over the western Pacific is strong enough but the southwest wind over tropical Asia is very weak, and the summer monsoon over India, Southeast Asia, and the Yangtze River valley has not yet established itself. At the same time, the westerly over North Asia and the North Pacific is weakened dramatically compared to the winter case (JF). Therefore, it

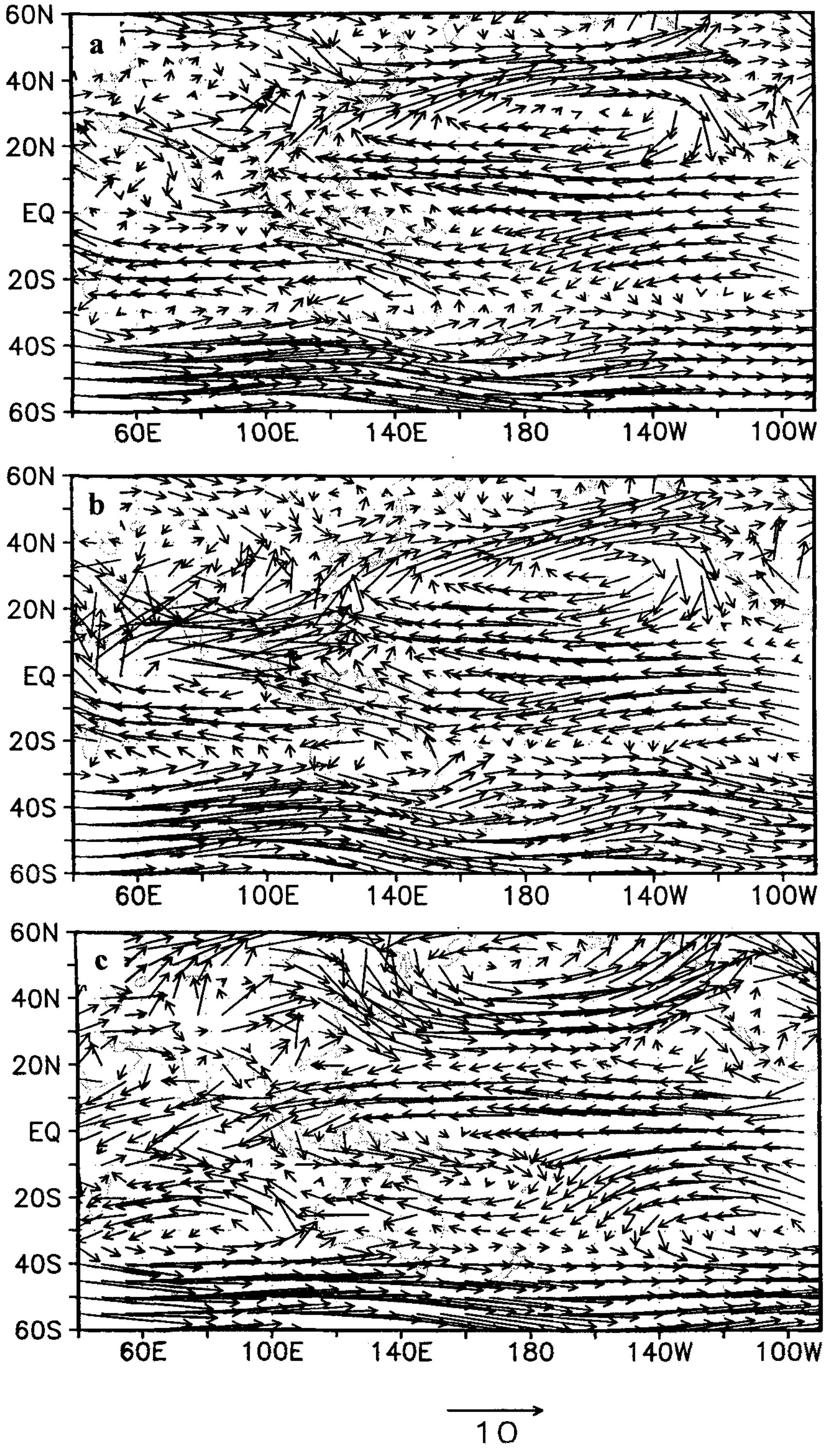

Fig. 3. The geographical distribution of the monthly 850 hPa winds (in m s^{-1}) for (a) April / May, (b) June, (c) January–February, (d) April / May minus June, and (e) April / May minus January–February.

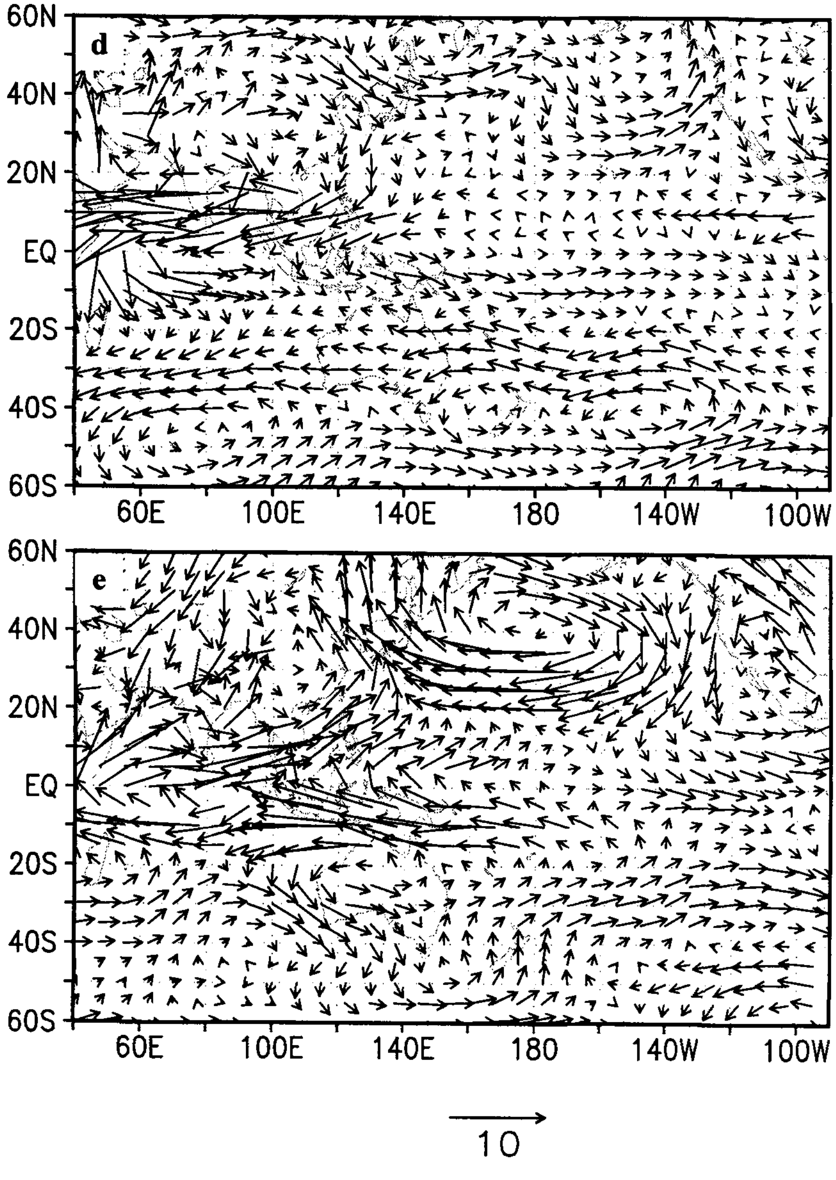

Fig. 3. (Continued).

seems that the spring monsoon rainfall is tightly linked with the subtropical high over the Pacific, and it is not very related to the tropical monsoon flow as it is in the summer case. The high pressure system in the sea level pressures over the Pacific occupies the East Asian coast during AM, which is similar to the summer case, while the system is confined to the eastern Pacific in JF (figure not shown).

At 500 hPa, the meridional gradient of the geopotential height (in units of 10 m) is much larger in JF than in June over Asia, so that the shaded belt between the two contours (552 and 580) is much wider and there is a ridge over North Asia in June. In AM, there is no ridge as in June, and the meridional gradient is not as large as in JF (Fig. 4). Therefore, in view of the

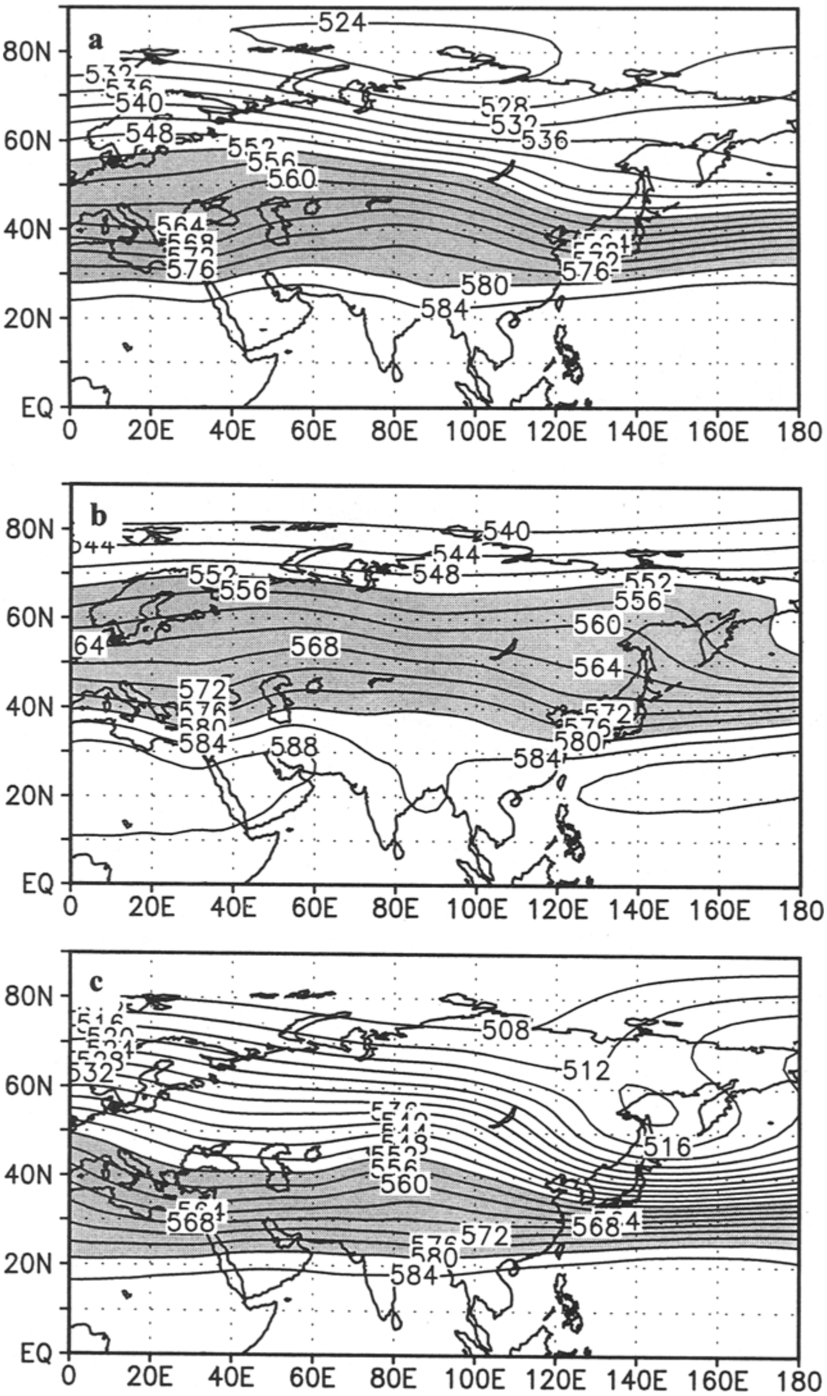

Fig. 4. The geographical distribution of the average 500 hPa geopotential height (in units of 10 m) for (a) April / May, (b) June, and (c) January–February. Areas with values larger than 552 and smaller than 580 are shaded.

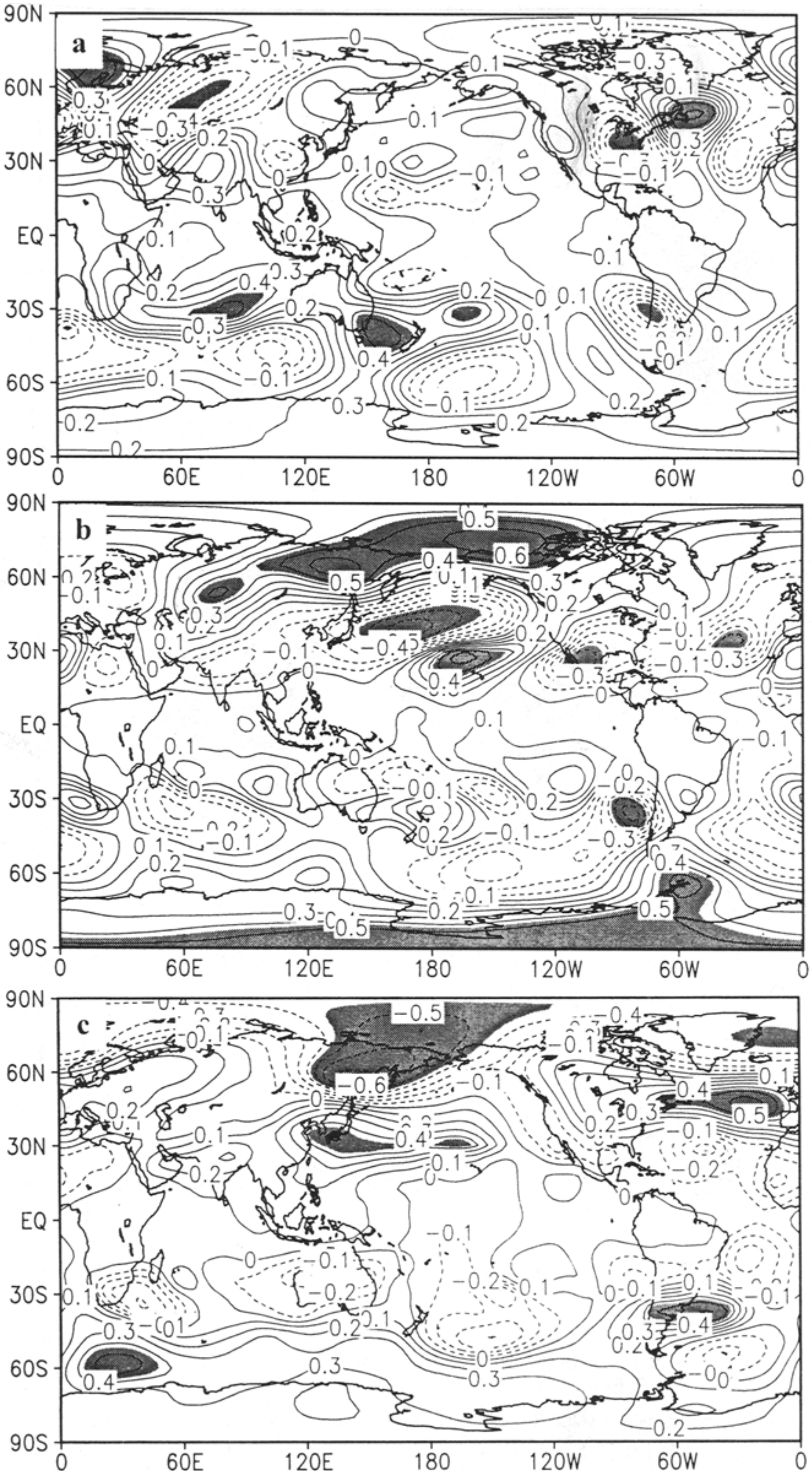

Fig. 5. The correlation coefficient between SPMR and the geopotential height at 200 hPa of (a) April / May, (b) June, and (c) January–February. Shaded areas indicate significant differences at the 95% level, estimated by a local student t–test.

global atmospheric circulation, the circulation for the spring monsoon is quite different from that in the winter and the summer seasons.

3. The interannual variation of the spring monsoon circulation

Following Zeng and Zhang (1998) and Xue and Zeng (1999), the spring–to–summer seasonal transition of the Asian–Pacific atmospheric circulation occurs most early in the high–level troposphere and the low–level stratosphere. Therefore, we first analyze the correlation between AM spring monsoon rainfall in South China (SPMR) and the geopotential height at 200 hPa in AM, March, and JF, respectively (Fig. 5). The simultaneous correlation is generally weak, but it seems that SPMR is correlated with EUP (Europe–Pacific) teleconnection patterns whose centers are located in Europe, Siberia, and Japan, respectively (Fig. 5a). While in the preceding March (Fig. 5b), the pattern for the correlation coefficient is shaped like the western Pacific teleconnection pattern (WP) which is related to the North Pacific Oscillation (NPO) in the sea level pressure field (Wallace and Gutzler 1981). Therefore, a stronger SPMR is related to a weaker polar vortex in the preceding March, but to a stronger polar vortex in the preceding JF (Fig. 5c). It seems that the SPMR–related geopotential height pattern in JF is opposite to that in March over the North Pacific. These lag–correlations between SPMR and the preceding 200 hPa circulation shows that the winter and spring atmospheric circulation at high levels may have substantial impacts on the summer climate, as suggested by Zeng and Zhang (1998) and Xue and Zeng (1999).

The interannual variation of SPMR is given in Fig. 6, indicating a large variability among different years. We make a composite analysis on the differences of the atmospheric circulation and SST between positive and negative SPMR years so as to give a clearer picture.

Figure 7 depicts the composite differences of the preceding March geopotential height at 200, 500, and 850 hPa between positive (1980, 1981, 1983, 1984, and 1989) and negative (1982, 1985, 1991, 1994, and 1995) SPMR years. Shaded areas indicate significant differences at the 95% significance level, estimated by a local student t–test. Clearly, the polar vortex is

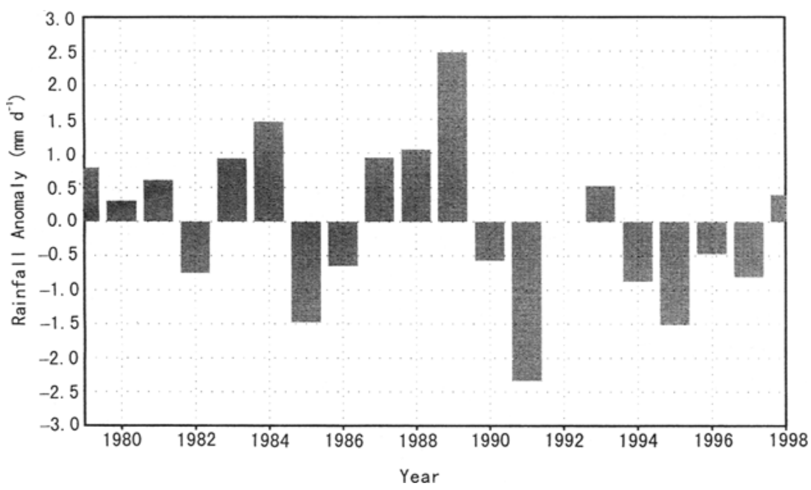

Fig. 6. The interannual variation of the spring monsoon rainfall anomalies in April / May for South China (111.25°–121.25°E, 23.5°–32.5°N) (in mm d^{-1}).

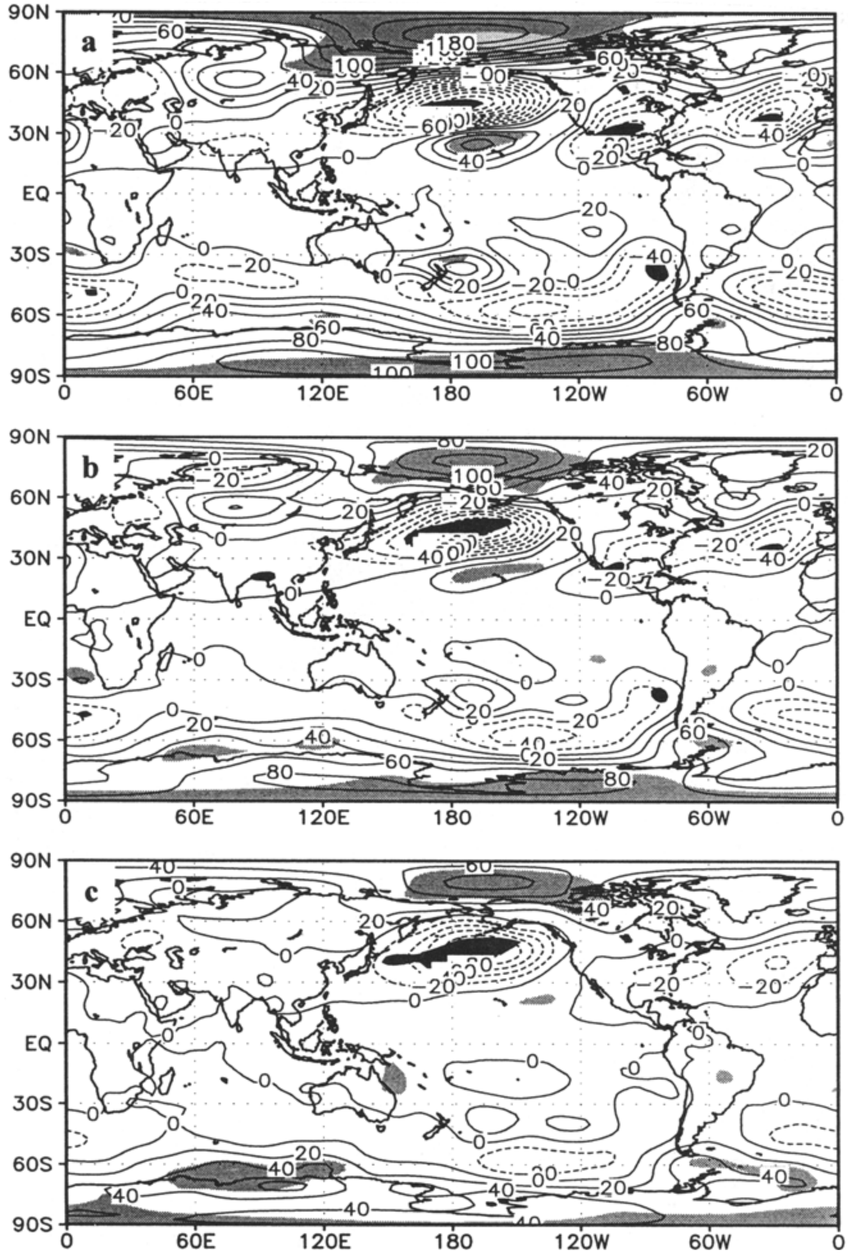

Fig. 7. Differences of geopotential height at (a) 200 hPa, (b) 500 hPa, and (c) 850 hPa in the preceding March between positive and negative years of SPMR anomalies. Shaded areas indicate significant differences at the 95% level, estimated by a local student t-test.

significantly weakened at 200 hPa in positive SPMR years compared to negative SPMR years, and the mid-latitude Pacific is covered with negative differences (Fig. 7a). This pattern remains at 500 hPa and 850 hPa as well, but with smaller magnitudes for the differences. This means that the anomalies in geopotential height have a relative barotropic structure. Accordingly, there is a large area of negative differences in the sea level pressure field over the

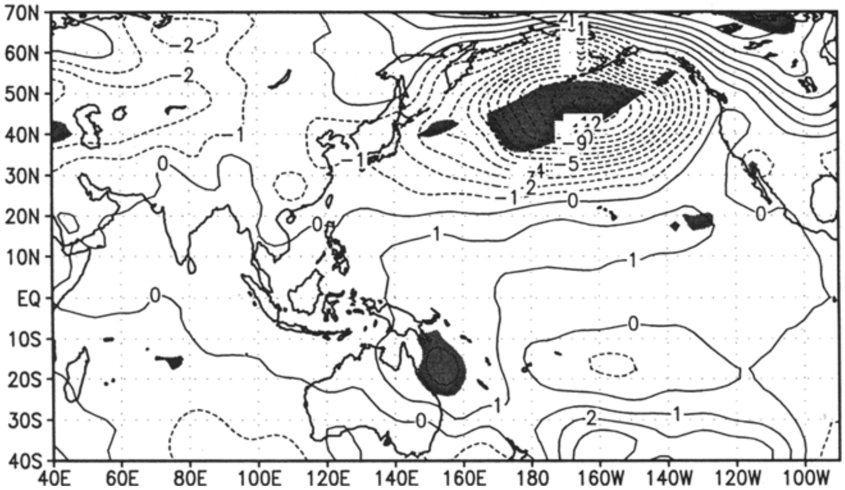

Fig. 8. Same as Fig. 7(a), but for the sea level pressure (in units of hPa).

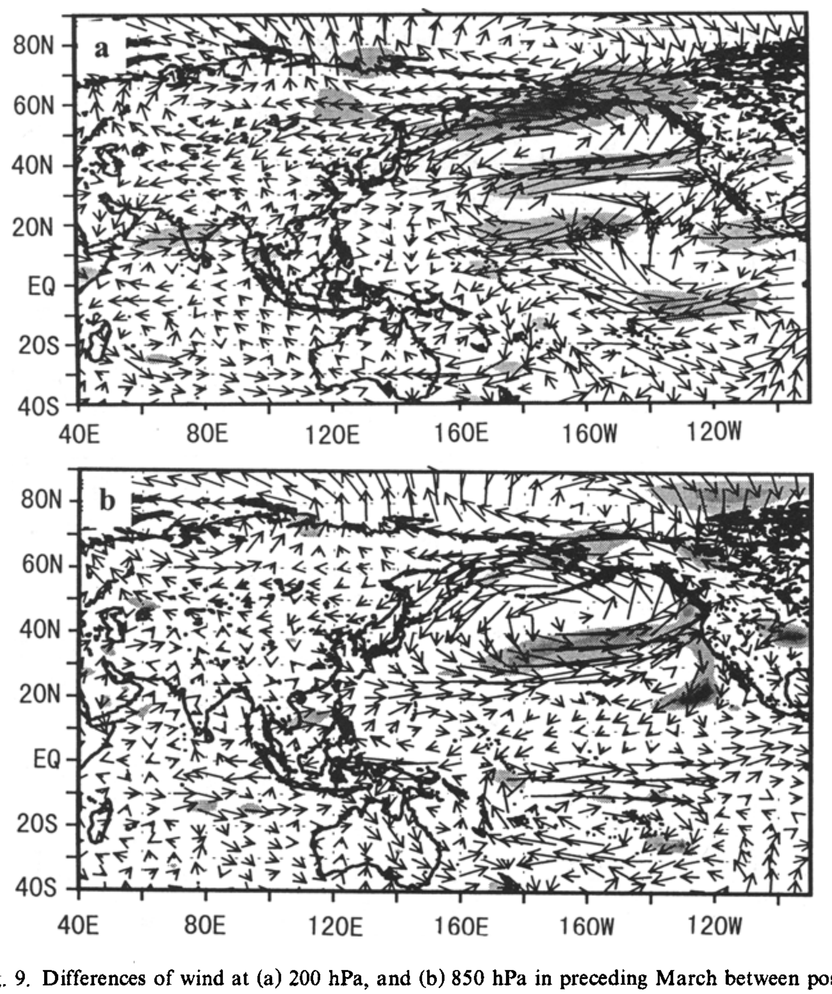

Fig. 9. Differences of wind at (a) 200 hPa, and (b) 850 hPa in preceding March between positive and negative years of SPMR anomalies. Shaded areas indicate significant differences at the 95% level, estimated by a local student *t*–test.

North Pacific in the preceding March (Fig. 8), while differences over the Eurasian continent are much smaller and insignificant.

Therefore, the SPMR is significantly correlated with the preceding March atmospheric circulation over the North Pacific and the Arctic. The scenario for the positive SPMR years is like this: the polar vortex is weakened, the westerly jet over North Asia and the North Pacific is also weakened, and there is a cyclonic anomalous circulation with barotropic structure over the North Pacific in the troposphere which can be clearly seen in the distribution of the velocity differences at 200 hPa (Fig. 9). This scenario indicates that SPMR is closely linked with the atmospheric circulation over the northern Pacific and that it is influenced little by the tropical Asian monsoon flow originating in the Indian Ocean, although the equatorial flow in the Indian Ocean and the tropical zonal wind plays some roles as well.

The SST over the North Pacific and the tropical eastern Pacific in the preceding March and AM for positive SPMR years is lower compared to negative SPMR years, while in the northern subtropical Pacific there exist positive differences of SST. Differences of SST

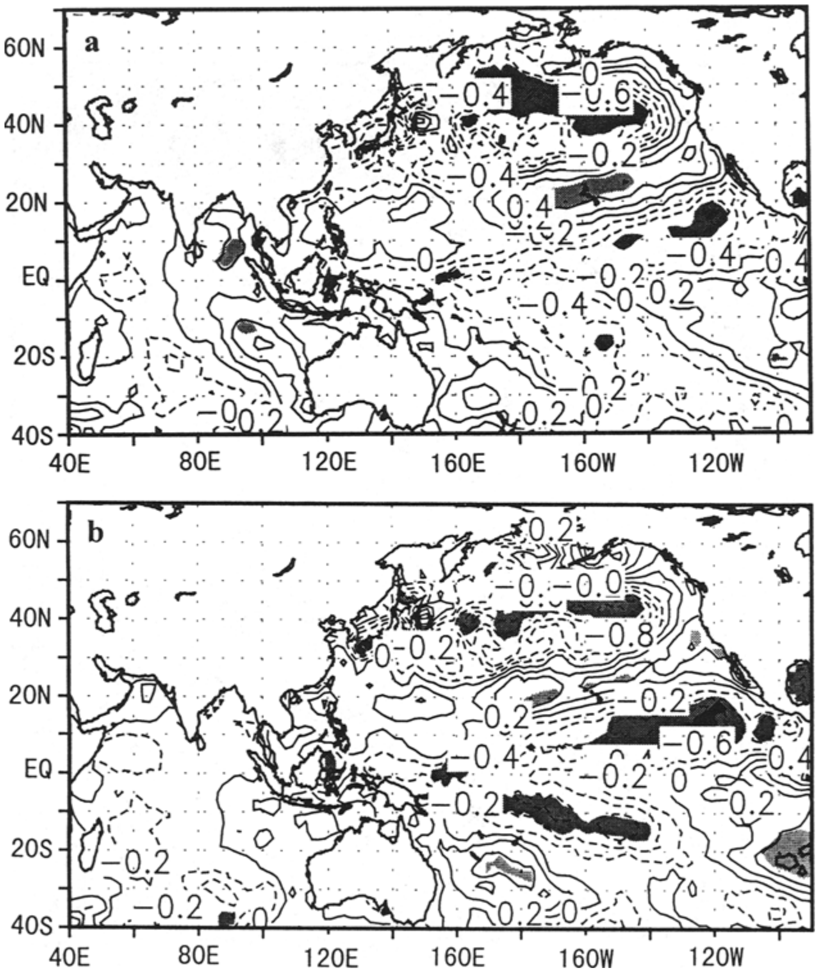

Fig. 10. Differences of SST (in °C) in (a) the preceding March, and (b) April / May between positive and negative years of SPMR anomalies. Shaded areas indicate significant differences at the 95% level, estimated by a local student t-test.

between positive and negative SPMR years are much smaller and insignificant over the Indian Ocean, compared to those over the Pacific (Fig. 10).

4. Summary

In this research, we define and prove the spring monsoon season over South China to be in April and May in view of the atmospheric circulation. This conclusion is supported by the seasonal variations of the Asian–Pacific atmospheric circulation and precipitation. The spring monsoon is connected primarily with the subtropical high in the low troposphere over the Northern Hemisphere Pacific during the April / May period. Therefore, the wind component over South China connected with the subtropical high dominates the spring monsoon flow, although the wind component from India and the Indo–China Peninsula is also of some importance.

The interannual variability of the spring monsoon rainfall in South China is primarily connected with the anomalous circulation in the troposphere over the mid–latitude Pacific in the preceding March. This anomalous circulation is linked, in turn, with the weakening (enhancement) of the westerly jet in North Asia and the North Pacific, and with the weakening (enhancement) of the polar vortex as well. The geographical pattern of the geopotential height differences between positive and negative SPMR years resembles the WP teleconnection pattern as indicated in Wallace and Gutzler (1981).

The positive SPMR anomaly is correlated with April / May and preceding March SST anomalies over the Pacific, especially, with the negative SST anomalies over the North Pacific and tropical eastern Pacific, and with the positive SST anomalies over the subtropical Pacific. Therefore, it seems that SPMR is connected with SST mainly over the Pacific, rather than over the Indian Ocean. In addition, from Fig. 10, we note that the SPMR–related SST anomalies are significant primarily over the central and eastern part of the Pacific, rather than the western part. However, the mechanisms behind these kinds of correlations are unclear and need to be addressed in future research.

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中国华南春季季风及其与大尺度环流特征的关系

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摘　要

定义了中国华南春季季风，并用 NCEP／NCAR 再分析资料研究了春季风的气候特征以及春季风降水和大尺度环流在年际变化上的关系。结果表明，从降水和大气环流的变化来看，华南春季风在气候上发生于 4 月和 5 月；与华南春季风相联系的大气环流特征与夏季风和冬季风所对应的大气环流特征完全不同。华南春季风降水的年际变化主要与太平洋北部的异常环流相关联，而这种异常环流又与亚洲北部的西风急流和极地涡旋有联系；华南春季风降水的年际变化还与太平洋的海表温度异常有关；而亚洲热带大气环流的年际变化与华南春季风降水的变化关系不大。

关键词: 春季风，季节变化，年际变化