ADVANCES IN ATMOSPHERIC SCIENCES, VOL. 25, NO. 1, 2008, 117–125

Interannual Variability of Autumn Precipitation over South China and its Relation to Atmospheric Circulation and SST Anomalies

NIU Ning[1,2,3] (牛 宁) and LI Jianping*[2] (李建平)

[1] *College of Atmospheric Sciences, Lanzhou University, Lanzhou* 730000

[2] *State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing* 100029

[3] *China Meteorological Administration Training Center, Beijing* 100081

(Received 5 January 2007; revised 18 May 2007)

ABSTRACT

The interannual variability of autumn precipitation over South China and its relationship with atmospheric circulation and SST anomalies are examined using the autumn precipitation data of 160 stations in China and the NCEP-NCAR reanalysis dataset from 1951 to 2004. Results indicate a strong interannual variability of autumn precipitation over South China and its positive correlation with the autumn western Pacific subtropical high (WPSH). In the flood years, the WPSH ridge line lies over the south of South China and the strengthened ridge over North Asia triggers cold air to move southward. Furthermore, there exists a significantly anomalous updraft and cyclone with the northward stream strengthened at 850 hPa and a positive anomaly center of meridional moisture transport strengthening the northward warm and humid water transport over South China. These display the reverse feature in drought years. The autumn precipitation interannual variability over South China correlates positively with SST in the western Pacific and North Pacific, whereas a negative correlation occurs in the South Indian Ocean in July. The time of the strongest lag-correlation coefficients between SST and autumn precipitation over South China is about two months, implying that the SST of the three ocean areas in July might be one of the predictors for autumn precipitation interannual variability over South China. Discussion about the linkage among July SSTs in the western Pacific, the autumn WPSH and autumn precipitation over South China suggests that SST anomalies might contribute to autumn precipitation through its close relation to the autumn WPSH.

Key words: interannual variability, autumn precipitation, South China, circulation anomaly, sea surface temperature

DOI: 10.1007/s00376-008-0117-2

1. Introduction

In China, variation of precipitation is considered to be spatial and temporal. The interannual variability of summer precipitation in China attracts more and more attention. Yang and Liu (1987) studied interannual and interdecadal variabilities of precipitation over East Asia, Southeast Asia and South Asia during the months from April to September. Lau and Yang (1997) investigated interannual variability of summer precipitation over Southeast Asia. Lu (2005) examined atmospheric circulation and the SSTs associated with the JA (July and August) interannual variability of North China precipitation and found that it is associated with the SST anomalies of the equatorial eastern Pacific. Duan et al. (2005) analyzed the interannual variability of summer precipitation over South China, North China and the Changjiang-Huaihe valley and the results suggested that the interannual changes of summer precipitation are independent in these three regions. In addition, the interannual variability of summer precipitation has also been studied

*Corresponding author: LI Jianping, ljp@lasg.iap.ac.cn

by defining an index of summer monsoon (Zhang et al., 2003; Li and Zeng, 2005). Some researchers have investigated the interannual variability of winter precipitation (Chen et al., 2000; Xu and Chan, 2002). South China precipitation is the concern of many researchers (Yu et al., 2001; Wang et al., 2002; Yang and Li, 2003; Niu and Li, 2007). Yu et al. (2001) investigated the correlation between rainfall over the Yangtze River valley and global SSTs. Wang et al. (2002) reviewed the features of precipitation and large-scale circulation and its relation to the spring monsoon over South China. Yang and Li (2003) studied the features of the Intraseasonal Oscillation during the serious flood and drought years in the Changjiang-Huaihe River basin. The autumn drought in 2004 over South China is discussed by Niu and Li (2007). However, few researchers have focused on the interannual variability of autumn precipitation over South China.

Floods and droughts in autumn always bring about serious economic loss, so it is significant to study the interannual variability of autumn precipitation over South China. For example, the autumn drought in 2004 over South China was the most severe drought since 1951. The size of the stricken area was 3.18 million hectares, with around 22 million people affected, and the loss due to the drought amounted to 46 billion RMB (see http://www.hwcc.com.cn/newsdisplay/newsdisplay.asp?Id=114515). Furthermore, the ratio of autumn precipitation over South China to the whole year for the long-term mean is about 15%, and therefore the contribution of autumn precipitation to the total cannot be ignored over South China. In order to find the predictors for autumn precipitation over South China, the interannual variability of autumn precipitation in the area should be studied further.

It is necessary to understand the features of autumn precipitation and the background of atmospheric circulation during drought and flood years. In this study, atmospheric circulation anomalies in autumn over South China and global summer SST anomalies are investigated to probe the regularities of precipitation variability and to find its predictors. Section 2 describes the data. The interannual variability of autumn precipitation over South China is analyzed and the definition of flood and drought years is given in section 3. The distinct characteristics of atmospheric circulation in flood and drought years are presented in section 4. The concurrent relationship between autumn precipitation over South China and the July SST anomalies in the western Pacific, North Pacific and the South Indian Ocean is studied in section 5. Finally, conclusions are drawn in section 6.

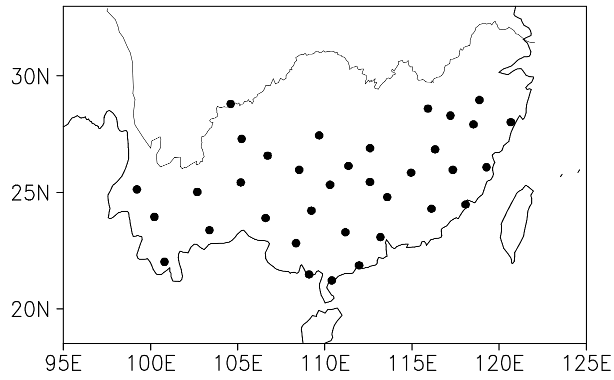

Fig. 1. Distribution of the stations used in this study.

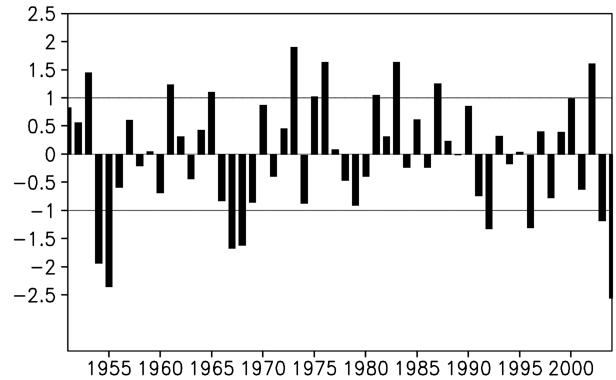

Fig. 2. Standardized deviation of precipitation removed linear trend in autumn (September and October) from 1951 to 2004 over South China. The lines represent the standard deviation.

2. Data description

The major data used in this work are the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis dataset (Kalnay et al., 1996) in 2.5° × 2.5° grids and global SST data in 2.0° × 2.0° grids. In addition, monthly mean precipitation data from 160 stations across China from 1951 to 2004 compiled by the China Meteorological Administration are also employed in this study. It is found that large variability of autumn precipitation over South China often occurs in September and October. Therefore, data for these two months are used in this study. In the analysis of interannual variability of autumn precipitation over South China, these data have been removed in the linear trend to eliminate the influence of long-term change. Precipitation data from 42 stations across South China are used in this paper, and the distribution of these stations is showed in Fig. 1.

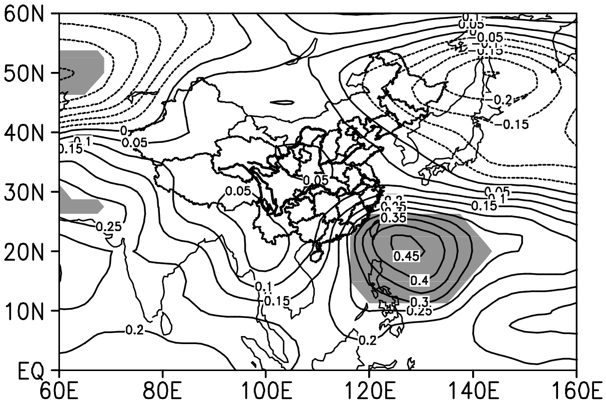

Fig. 3. Correlation coefficients between geopotential height at 500 hPa removed linear trend and autumn precipitation removed linear trend over South China. The shading indicates significance at the 95% Student's t-test confidence level. The contour interval is 0.05.

3. Interannual variability of autumn precipitation over South China

Figure 2 shows the standardized amplitudes of autumn precipitation over South China. It can be seen that there exists a clear interannual variability in autumn precipitation over South China. The years when the standardized amplitude of precipitation is greater than 1.0 are defined as those with strong autumn precipitation over South China, and the years with weak autumn precipitation over South China are defined by the standardized amplitude of precipitation being less than −1.0. It can be seen from Fig. 2 that ten years (1953, 1961, 1965, 1973, 1975, 1976, 1981, 1983, 1987, 2002) are selected as flood years. Eight years (1954, 1955, 1967, 1968, 1992, 1996, 2003, 2004) are chosen as drought years. It is obvious that the frequency of flooding is equivalent to that of droughts during the period (1950s–1960s). Only flood years are found from the 1970s to the 1980s. After the 1990s, the frequency of droughts is much greater than that of floods. Obviously, the autumn drought is dominant in recent years over South China.

4. Atmospheric circulation anomalies

Droughts and floods are often related to atmospheric circulation. In this section, the composite charts of variables have been constructed in order to reveal the relationship between atmospheric circulation anomalies and autumn precipitation anomalies over South China.

Figure 3 shows the correlation coefficients between the geopotential height at 500 hPa and autumn precipitation over South China. It can be seen that autumn precipitation over South China is significantly correlated with the western Pacific subtropical high (WPSH), with the maximum correlation coefficient exceeding 0.45. More (less) precipitation corresponds to a stronger (weaker) WPSH. Autumn precipitation over South China is greatly affected by the WPSH.

Figure 4 gives the results of the composite geopotential height at 500 hPa in the flood and drought years over East Asia. During the flood years (Fig. 4a), the domain around 588 contour lies over the western Pacific, and the WPSH ridge line lies over the south of South China. The strengthened ridge over North Asia triggers the southward movement of cold air and the convergence between cold air and warm air. The tendency is for rain, but the position in the drought years is quite different from that in the flood years. In view of the geopotential height at 500 hPa in the drought years (Fig. 4b), the WPSH ridge line is split into two

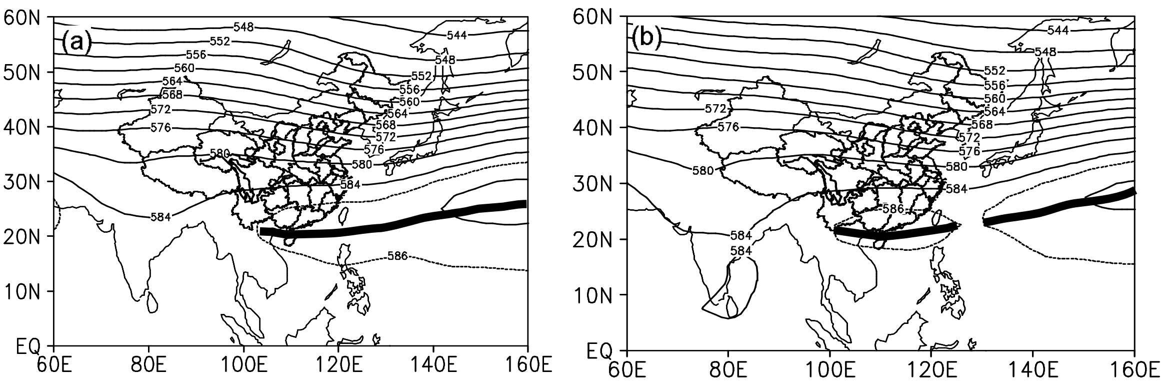

Fig. 4. Composite geopotential height at 500 hPa in (a) flood and (b) drought years. Units: 10 gpm. Contour interval is 40 gpm, but the dashed line is 586×10 gpm contour, and the thick solid line represents the western Pacific subtropical high ridge.

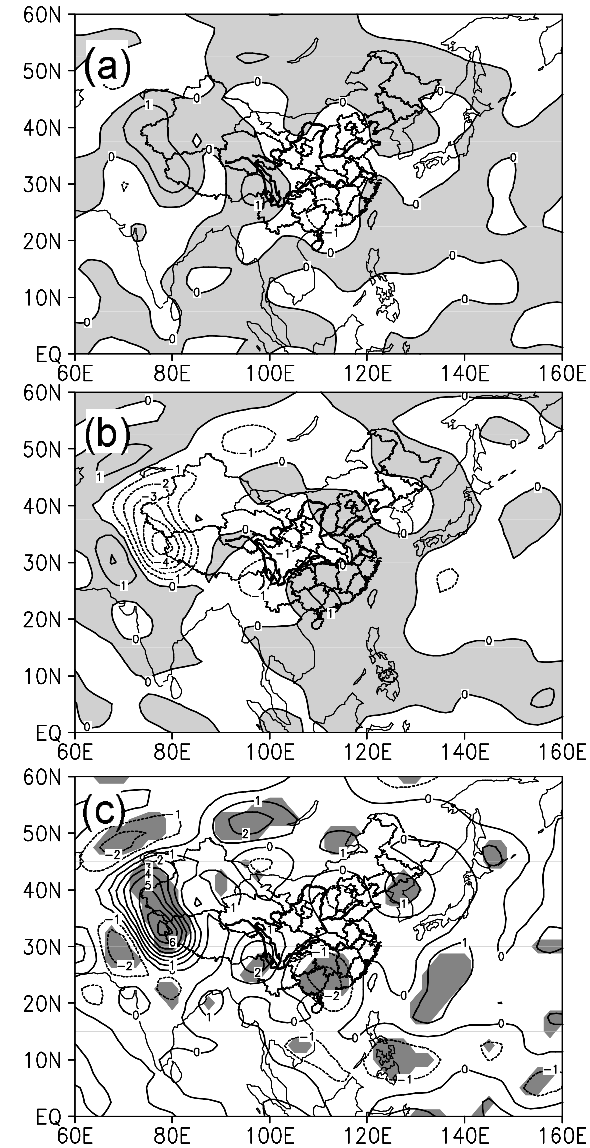

Fig. 5. Composite vertical velocity anomalies at 850 hPa for (a) flood and (b) drought years, and (c) the composite difference between the flood and drought years. Units: 10^{-2} Pa s^{-1}. The interval contour is 1×10^{-2} kg s^{-1} m^{-1}. Shaded areas in (a) and (b) indicate sinking flow, and shaded areas in (c) are the statistically significant areas exceeding the 95% Student's t-test confidence level.

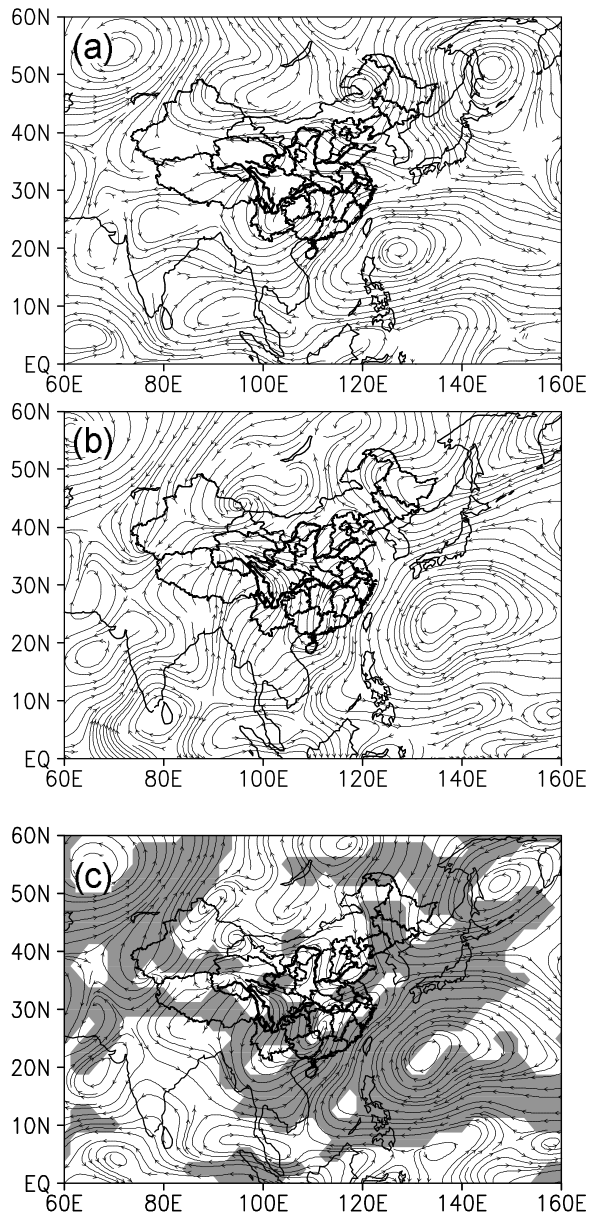

Fig. 6. Same as Fig. 5 except for the stream at 850 hPa. Shaded areas in (c) are the statistically significant areas exceeding the 95% Student's t-test confidence level.

parts. One of them is over South China, and South China is covered by the subtropical high cell. Comparing with Fig. 4a, the location of the WPSH shifts eastward in drought years. This is unfavorable for precipitation in this region.

The composite anomalies of the vertical velocity at 850 hPa in flood and drought years and the composite difference between them are shown in Fig. 5. In the flood years (Fig. 5a), the pattern (+ − +) is obvious along about 30°N over East Asia, and the anomalous updraft dominates over South China. This kind of distribution of vertical velocity at 850 hPa favors precipitation. In the drought years (Fig. 5b), the distribution of vertical velocity at 850 hPa displays the reverse characteristics compared to severe flood years. The pattern (− + −) is presented and the anomalous downdraft dominates over the area, which is unfavorable for precipitation. The large difference between flood and drought years over South China is statistically significant and exceeds the 95% confidence level (Fig. 5c), determined from the Student's t-test. The

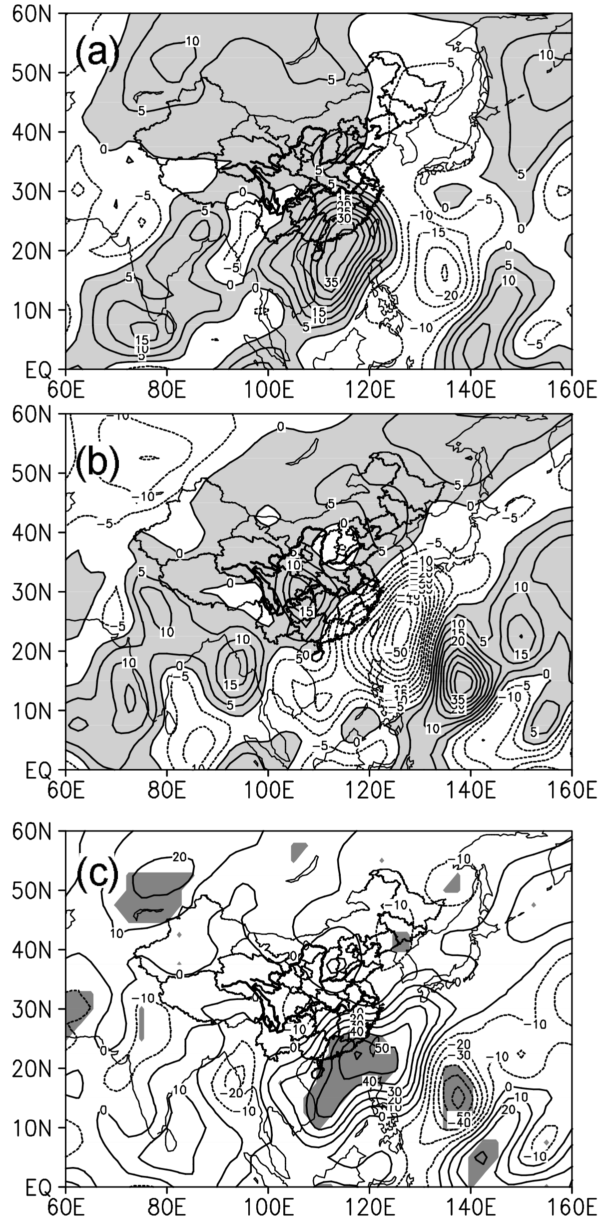

Fig. 7. Same as Fig. 5 except for meridional moisture transport. Units: 10^{-6} kg s^{-1} m^{-1}. Shaded areas in (a) and (b) indicate northward water transport, and the interval contour is 10×10^{-6} kg s^{-1} m^{-1}. Shaded areas in (c) are the statistically significant areas exceeding the 95% Student's t-test confidence level.

distribution of vertical velocity at 850 hPa is responsible for the floods and droughts over South China.

Composite anomalies of the stream at 850 hPa in both flood and drought years and the composite difference of the stream at 850 hPa between them are shown in Fig. 6. In the flood years (Fig. 6a), an anticyclonic anomaly centers over the western Pacific and a cyclonic anomaly center is over South China which strengthens the northward water transport over this region. This is the advantage of precipitation. In the severe drought years (Fig. 6b), the distribution of the stream at 850 hPa shows a reverse characteristic. An anticyclonic anomaly center is over South China and the dominant flow is the southward motion. This position of the stream weakens the water transport and it is not in favor of precipitation. Besides, it can be seen from Fig. 6c that the difference of the stream at 850 hPa between the floods and droughts is significant, exceeding the 95% confidence level determined by the Student's t-test.

Water vapor transport plays an important role in precipitation. Zhang (2001) studied the relations between water vapor transport from the Indian monsoon and that over East Asia and summer precipitation in China. Zhou and Yu (2005) revealed that atmospheric water vapor transports are associated with typical anomalous summer precipitation patterns in China. In this section, water transport is studied as a factor in precipitation over South China. In Fig. 7, the meridional moisture transport anomalies in flood and drought years and the composite difference between them are shown. From Fig. 7a, it can be seen that the pattern (− + −) occurs over Southeast Asia. A positive anomaly center occurs over South China, which means that the northward warm and humid water transport is obvious over South China. This kind of position is advantageous for precipitation. However, in drought years (Fig. 7b), the pattern (+ − +) occurs over Southeast Asia and there exists a negative anomaly over South China, indicating that cold and dry water transport from the north is dominant. This is unfavorable for precipitation. As seen from Fig. 7c, the difference of the meridional moisture over South China between floods and droughts is statistically significant and exceeds the 95% confidence level determined by the Student's t-test.

5. The relation between SST and autumn precipitation over South China

In order to investigate the relationship between global SST and autumn precipitation over South China, a correlation analysis between autumn precipitation and global SST in June, July, August, September and October is carried out, respectively. It is found that the most remarkable area of statistical significance is mostly located in the North Pacific, the western Pacific and the South Indian Ocean. In particular, the most statistically significant areas appear in July (Fig. 8). As seen from Fig. 8, the inverse correlation coefficients between autumn precipitation over South China and SSTs in the western Pacific and North

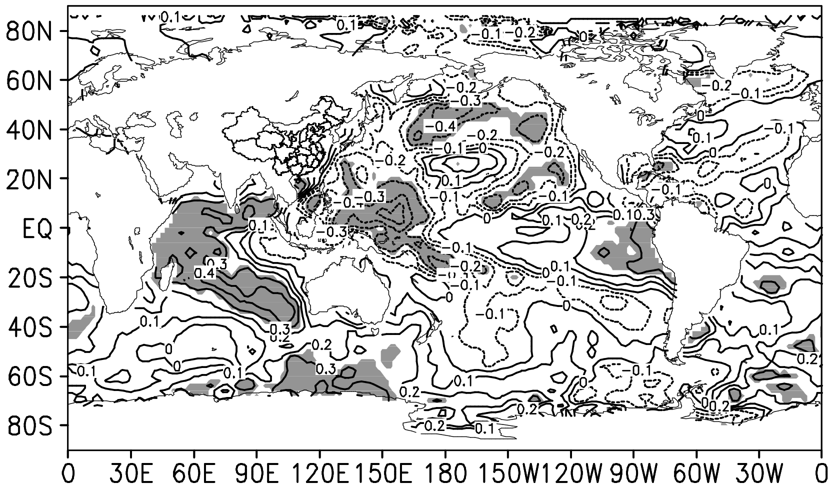

Fig. 8. Correlation coefficients between autumn precipitation over South China and global SST in July. Regions above the 95% Student's t-test confidence level are shaded. The contour interval is 0.10.

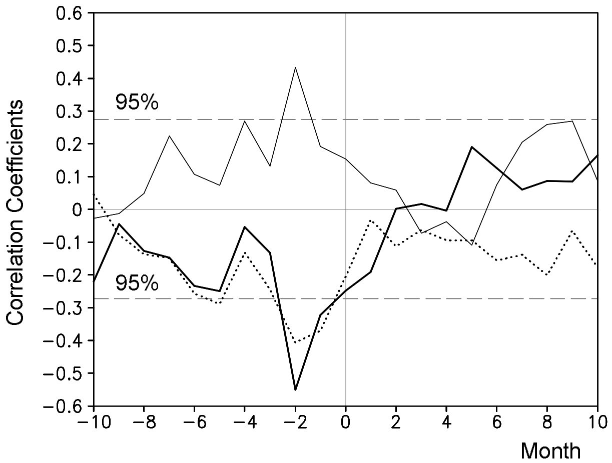

Fig. 9. Lag-correlation between autumn precipitation over South China and monthly SST anomalies in the western Pacific (thick solid curve), the North Pacific Ocean (dotted curve) and the South Indian Ocean (thin solid curve). The negative (positive) numbers on the x-axis represent the length of time the monthly SST anomalies lead (lag behind) autumn precipitation over South China. Dashed lines represent the 95% Student's t-test confidence level.

Pacific are less than −0.40, and the correlation coefficients between autumn precipitation over South China and SST in the South Indian Ocean are all positive, with the maximum exceeding 0.40.

The western Pacific (0°–16°N, 140°–166°E), the North Pacific (166°W–178°E) and the South Indian Ocean (38°–32°S, 90°–110°E) are selected as the key ocean areas to study the influence of SST on autumn precipitation.

In order to contrast the relationship between SST of these three ocean areas and autumn precipitation over South China, a lag-correlation between autumn precipitation and July SST anomalies in the three key ocean areas is carried out, respectively. The lag-correlation between precipitation and SST anomalies means the SST anomalies leads autumn precipitation over South China. As shown in Fig. 9, in the months leading up to autumn, the related coefficients between autumn precipitation over South China and SST anomalies in the western Pacific and North Pacific are both negative. However, this is the reverse of the correlation coefficients in the South Indian Ocean. The time of the strongest lag-correlation coefficients between SST and autumn precipitation over South China is two months, i.e. the SST anomaly leads the autumn precipitation over South China by about two months. It is suggested that SST in the western Pacific, North Pacific and South Indian Ocean in July may be one of the predictors for autumn precipitation over South China. Besides, the correlated relationship of SST anomalies in the three different ocean areas is remarkable, and the SSTA in the western Pacific may be a major factor impacting on autumn precipitation over South China because of its strongest correlations (−0.55 vs ±0.4).

The thermal state, including atmospheric convection and SST of the western Pacific, plays an important role in the variations of atmospheric circulation and summer precipitation over East Asia (Nitta, 1987; Huang and Li, 1987; Huang and Sun, 1994; Lu, 2001). In this section, the relationship between SST anomalies and autumn precipitation is discussed. Figure 10 shows the correlation coefficients between July SST

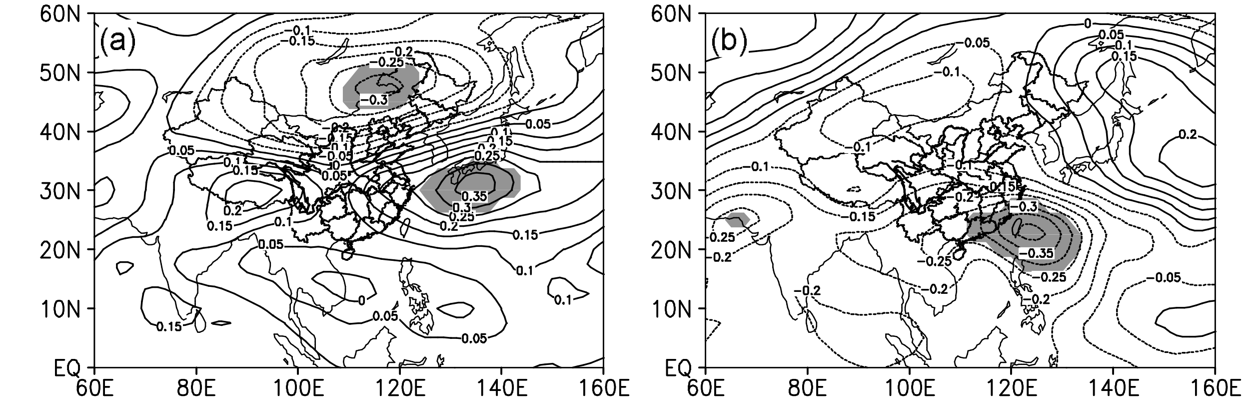

Fig. 10. Correlation coefficients between averaged SST in the western Pacific (0°–16°N, 140°–166°E) in July and the geopotential height at 500 hPa in (a) summer and (b) autumn. Regions above the 95% Student's t-test confidence level are shaded. The contour interval is 0.05.

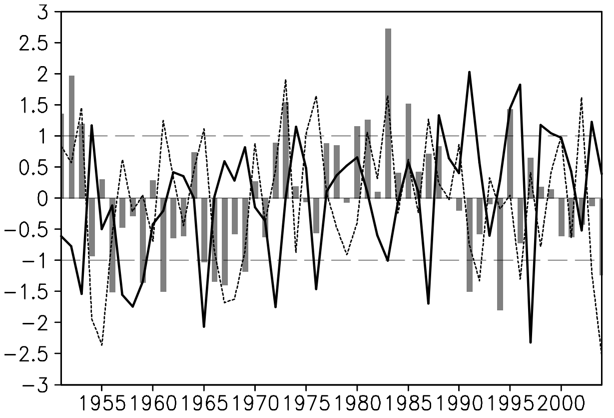

Fig. 11. Normalized time series of SST averaged in the western Pacific (0°–16°N, 140°–166°E) (thick solid curve), autumn precipitation over South China (short dashed curve) and the geopotential height at 500 hPa averaged over the area (17.5°–25°N, 117.56°–130°E) (bar). Long dashed lines represent the standard deviation.

anomalies in the western Pacific (0°–16°N, 140°–166°E) and geopotential height at 500 hPa in summer (Fig. 10a) and autumn (Fig. 10b). Comparing with Fig. 10a and Fig. 10b, it can be found that the WPSH in autumn shifts southward, which leads to less precipitation over South China. Figure 10 also shows that July SST in the western Pacific is positively correlated with geopotential height at 500 hPa in summer, whereas a negative correlation occurs in autumn. Combining with Fig. 3, while July SST in the western Pacific is warmer, the autumn WPSH weakens and autumn precipitation decreases. The above result means that there exists a close relationship between July SST in the western Pacific and the autumn WPSH.

In order to further investigate the relationship of July SST in the western Pacific, the autumn WPSH and autumn precipitation over South China, Fig. 11 shows the normalized time series of SST averaged in the western Pacific (0°–16°N, 140°–166°E), autumn precipitation over South China and the autumn geopotential height at 500 hPa averaged over the area (17.5°–25°N, 117.5°–130°E). Here we can see that when SST in the western Pacific is warmer (colder), the autumn WPSH becomes weaker and autumn precipitation decreases (increases). The WPSH is significantly negatively correlated with SST in the western Pacific (correlation coefficient of −0.36) and positively correlated with autumn precipitation (correlation coefficient of 0.42). It is suggested that July SST in the western Pacific might contribute to autumn precipitation over South China through its close relation to the autumn WPSH.

6. Conclusions

In this paper, the interannual variability of autumn precipitation in South China and its relation to atmospheric circulation and SST anomalies have been studied. Autumn precipitation over South China exhibits a strong interannual variability, and the results suggest that the frequency of flooding is as much as that of droughts from the 1950s to the 1970s, and then the former is greater than the latter during the period (1970s–1990s). After the 1990s, the frequency of flooding is less than that of droughts. Obviously, autumn droughts are dominant in recent years over South China.

The interannual variability of autumn precipitation over South China is significantly correlated with the WPSH. More (less) precipitation corresponds to a stronger (weaker) subtropical high. In flood years, the domain surrounded by 588 contour is over the western Pacific, and the WPSH ridge lies over the south of South China. The strengthened ridge over North Asia triggers the southward movement of cold air and the convergence between cold air and warm air. This is favorable for precipitation. The pattern of vertical velocity at 850 hPa is characterized by a significantly anomalous updraft over South China. It is remarkable of the stream at 850 hPa that a significantly anomalous cyclone over South China strengthens the northward stream. Meanwhile, the feature of meridional moisture transport is that a positive anomaly center occurs over South China, and the northward warm and humid water transport is dominant over South China. These features are advantageous for precipitation. In drought years, the reverse is found.

Correlation between the interannual variability of autumn precipitation over South China and global SST in July shows that significant areas mostly locate in three key ocean areas (the western Pacific, North Pacific, and the South Indian Ocean). Autumn precipitation over South China is positively correlated with July SST in the western Pacific and North Pacific, whereas a negative correlation occurs in the South Indian Ocean. Besides, the correlation in the western Pacific is the strongest among the three ocean areas. The time of the maximum lag-correlation coefficients between SST and autumn precipitation over South China is about two months, implying that July SSTs in the three key ocean areas might be one of the predictors for autumn precipitation interannual variability over South China. The SSTA in the western Pacific may be the major factor impacting on autumn precipitation over South China because of its strongest correlations (-0.55 vs ± 0.4). Further discussion about the linkage among July SSTs in the western Pacific, the autumn WPSH and autumn precipitation over South China, showed that the WPSH is significantly negatively correlated with SST in the western Pacific (correlation coefficient of -0.36) and positively correlated with autumn precipitation (correlation coefficient of 0.42), which implies that July SST anomalies in the western Pacific might contribute to autumn precipitation over South China through its close relation to the autumn WPSH.

Acknowledgements. The authors would like to thank the anonymous reviewers for their helpful comments and suggestions. This work was supported by the 973 Program (Grant No. 2006CB403600) and the National Science Foundation of China (Grant No. 40523001).

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