Vol. 16 No. 2 Advances in Atmospheric Sciences May 1999

# A Diagnostic Study of the Impact of El Niño on the Precipitation in China①

Zhang Renhe (张人禾),
*LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100080*
Akimasa Sumi and Masahide Kimoto
*Center for Climate System Research, University of Tokyo, Tokyo 153, Japan*

(Received March 20, 1998; revised May 5, 1998)

## ABSTRACT

The impact of El Niño on the precipitation in China for different seasons are investigated diagnostically. It is found that El Niño can influence the precipitation in China significantly during its mature phase. In the Northern winter, spring and autumn, the positive precipitation anomalies are found in the southern part of China during the El Niño mature phase. In the Northern summer, the patterns of the precipitation anomalies in the El Niño mature phase are different from those in the other seasons. The negative precipitation anomalies appear in both southern and northern parts of China, while in between around the lower reaches of the Yangtze River and the Huaihe River valleys the precipitation anomalies tend to be positive.

In the Northern winter, spring and autumn, the physical process by which El Niño affects the precipitation in the southern part of China can be explained by the features of the circulation anomalies over East Asia during the El Niño mature phase (Zhang et al., 1996). The appearance of an anticyclonic anomaly to the north of the maritime continent in the lower troposphere during the El Niño mature phase intensifies the subtropical high in the western Pacific and makes it shift westward. The associated southwesterly flow is responsible for the positive precipitation anomalies in the southern part of China. In the Northern summer, the intensified western Pacific subtropical high covers the southeastern periphery of China so that the precipitation there becomes less. In addition, the weakening of the Indian monsoon provides less moisture inflow to the northern part of China.

**Key words:** El Niño, Precipitation in China, East Asian monsoon

## 1. Introduction

El Niño is the most outstanding interannual variability in the ocean. It is well known that the heat source driving the atmospheric general circulation is mainly within the tropics. El Niño occurs in the tropical Pacific and the warming of the ocean during the El Niño can cover a large area in the tropical Pacific (Rasmusson and Carpenter, 1982). The occurrence of El Niño changes greatly the pattern of the thermal heating of the atmosphere, which brings large circulation anomalies. Numerous researches have been done on the impact of El Niño on variations of the worldwide weather and climate. The results showed that El Niño has significant effects not only in the tropical region (Rasmusson and Carpenter, 1982) but also in the

---

①This work was partly supported by the National Key Project of China 96–908–04–02 and the Key Project of Chinese Academy of Sciences KZ951–S1–404.

extratropics, which have been demonstrated both by observational studies (e.g., Horel and Wallace, 1981; Van Loon and Madden, 1981; Hamilton, 1988; Fraedrich, 1994) and by modeling studies (e.g., Shukla and Wallace, 1983; Lau, 1985; Held et al., 1989). Moreover, some studies with the atmospheric general circulation models (AGCMs) forced by the observed sea surface temperature (SST) even showed some predictive skill for the El Niño–related climate anomalies (Bengtsson et al., 1993; Barnett et al., 1994; Palmer and Anderson, 1994).

The Asian monsoon system is one of the most important circulation systems in the general circulation of the global atmosphere (Krishnamurti, 1971; Krishnamurti et al., 1973). As reviewed by Lau and Li (1984) and by Tao and Chen (1987), the Asian monsoon is divided into two subsystems, i.e., East Asian and Indian monsoons because of their different large–scale structures. The impact of El Niño on the Indian monsoon has been studied by many researchers and it is pointed out that a poor Indian monsoon is usually accompanied with an El Niño event (e.g., Mooley and Parthasarathy, 1983; Rasmusson and Carpenter, 1983; Khandekar and Neralla, 1984). The influence of El Niño on the summer climate over the East Asia has been studied by some investigators. It has been found that a teleconnection between the western tropical Pacific and the East Asian region has significant impact on the East Asian summer climate (Nitta, 1986; 1987; Huang et al., 1993). Nitta (1987) described that in most of the El Niño years, the cold SST anomalies around the Philippine Islands appeared and the convection there was inactive, so that the mid–latitude East Asia experienced a relatively cold summer through this teleconnection. It was also pointed out that El Niño may affect the summer precipitation in China (Huang and Wu, 1989; Li, 1990). Zhang et al. (1996) (hereafter referred to as ZSK) found that the impact of El Niño on the East Asian monsoon circulation is significant during the El Niño mature phase. When the mature phase is in boreal summer, the East Asian summer monsoon is intensified. On the contrary, when boreal winter is within the mature phase, the East Asian winter monsoon is weakened.

As for the physical process by which El Niño affects the circulation in the extratropics, it has been demonstrated that the stationary Rossby wave propagation is responsible for the atmospheric response over the northern Pacific and North America particularly in the Northern winter (e.g., Hoskins and Karoly, 1981; Webster, 1981; Horel and Wallace, 1981). As pointed out by ZSK, the physical process by which El Niño affects the circulation over East Asia is different from the aforementioned one. In contrast to the strong heating of the atmosphere over the eastern equatorial Pacific, during the El Niño mature phase the cooling anomaly is the strongest over the maritime continent in the equatorial western Pacific. The Rossby wave response to this cooling anomaly and the Hadley circulation anomaly over the western Pacific and East Asia related to this cooling anomaly affect the East Asian monsoon circulation.

In the study of ZSK, the impact of El Niño on the East Asian circulation was investigated. The precipitation is one of the most important components in the monsoon Asia. Its anomaly can cause droughts and floods in the East Asian country, which often exerts a heavy toll in human life and in economics. However, it is not clear to what extent and how the East Asian precipitation is affected by El Niño. As a continuation to ZSK, in this paper the impact of El Niño on the precipitation in China is investigated, especially during the El Niño mature phase. Section 2 describes the data. The El Niño mature phases are defined in Section 3 based on the sea surface temperature anomaly (SSTA) in the equatorial eastern Pacific. In Section 4, the relationship between the precipitation in China and El Niño events is investigated. Section 5 discusses the connection mechanisms between El Niño and the precipitation anomalies in China. A summary and concluding remarks follow in Section 6.

## 2. Data

The datasets used in the present study are as follows:

(1) the monthly precipitation dataset of 160 stations in China from January 1951 to December 1994 compiled by China Meteorological Administration, whose station distribution in Fig. 1 shows that it mainly represents the eastern half of China,

(2) the monthly SSTA data on a 2° × 2° grid from January 1951 to September 1993 provided by the Japan Meteorological Agency (JMA),

(3) the monthly climatology and anomaly of the 850 hPa wind and the 500 hPa geopotential height computed over the period from January 1980 to December 1994, based on the analyses by European Center for Medium-Range Weather Forecasts (ECMWF) for years from 1980 to 1992 and those by JMA from 1993 to 1994, and

(4) the all-India summer monsoon (June-September) rainfall data (Sontakke et al., 1992, 1993) for the period between 1951 and 1994, over which the climatology and anomaly are calculated.

## 3. The evolution of NINO3 SSTA and El Niño

In ZSK and in the present study, El Niño is defined by a standard index over a region called NINO3 (5°S-5°N, 90°W- 150°W). We average the monthly NINO3 SSTA to be the seasonal mean for four seasons, i.e., winter (December-February), spring (March-May), summer (June-August) and autumn (September-November). We define an El Niño event to be the period when the seasonal NINO3 SSTA is greater than 0.5°C. In order to investigate the features of precipitation in China during the El Niño mature phase, we define the El Niño mature phase as follows. For the strong El Niño events, the seasons when seasonal NINO3

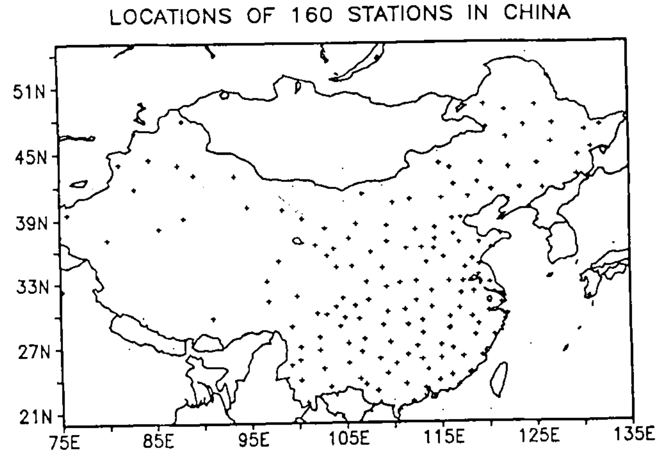


Fig. 1. Locations (crosses) of the 160 stations for precipitation dataset in China.

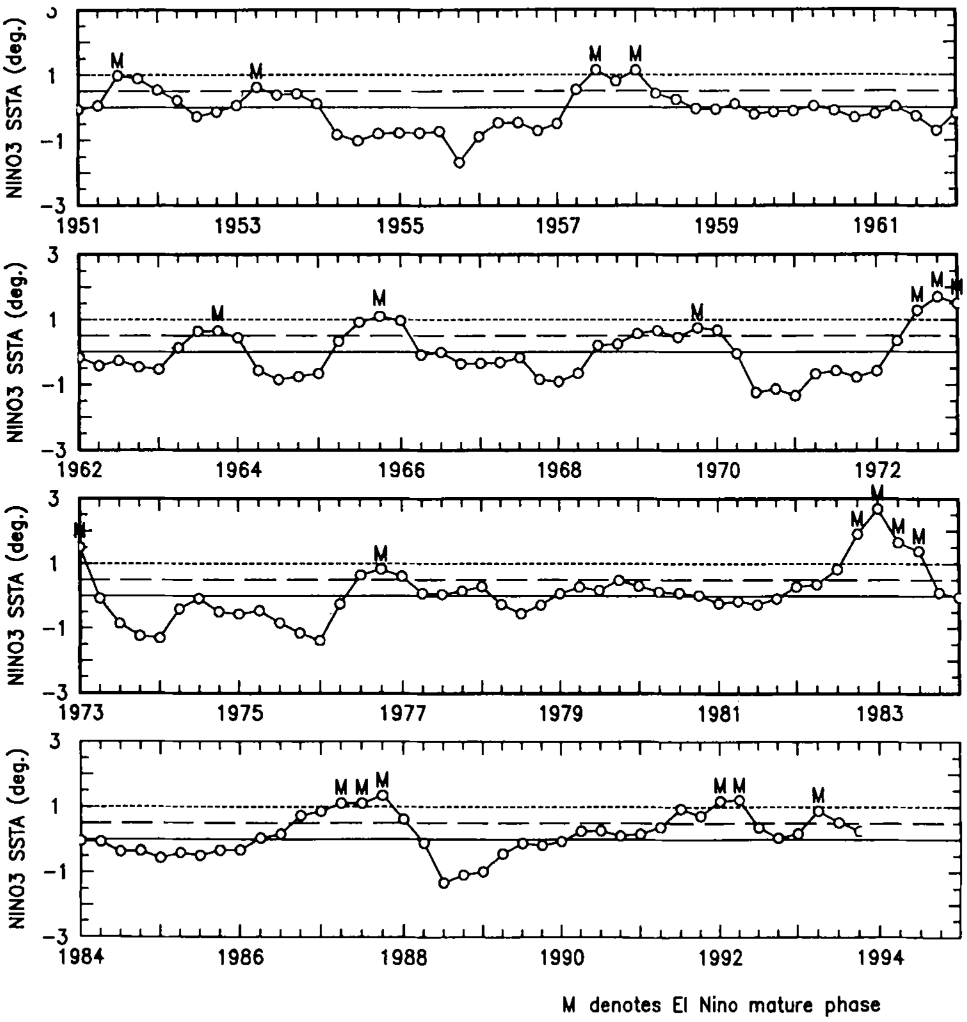


Fig. 2. Evolution of the seasonal mean SSTA at NINO3 (Unit:°C). M stands for the mature phase of each El Niño event.

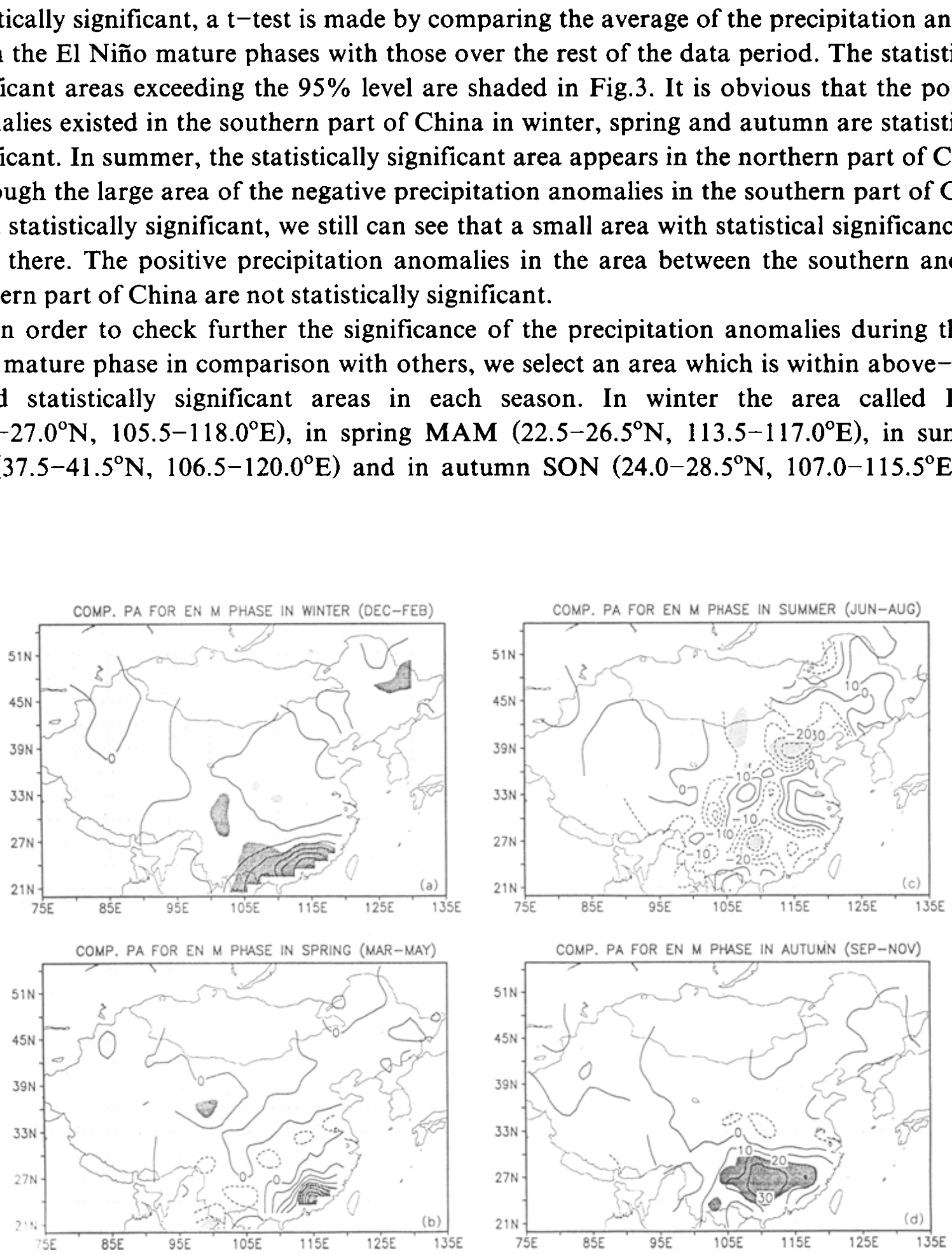
SSTA is greater than 1.0°C are taken to be the mature phase of these El Niños. For the weak El Niño events with seasonal NINO3 SSTA less than 1.0°C, we then choose the season with the highest NINO3 SSTA to be the El Niño mature phase. Fig. 2 shows the evolution of the seasonal NINO3 SSTA with the marking of the mature phase for each El Niño event. We can see that there are 11 El Niño events during this period. Based on our definition, there are 4 winters, 5 springs, 5 summers and 7 autumns within the El Niño mature phases, respectively.

## 4. Precipitation anomalies in China during the El Niño mature phase

As pointed out by ZSK, the lower tropospheric circulation anomalies along the coast of East Asia during the El Niño mature phases are significantly different from those during the other phases. Composites of the precipitation anomalies during the El Niño mature phase for different seasons are shown in Fig. 3. It can be seen that in winter (Fig.3a), spring (Fig.3b) and autumn (Fig.3d), the positive anomalies appear in the southern part of China. The pattern in summer (Fig.3c) is different from those in the other three seasons. There exist negative precipitation anomalies in both the southern and northern parts of China, while in the area between the north and the south the positive anomalies appear.

In order to check if these precipitation anomalies during the El Niño mature phases are statistically significant, a t–test is made by comparing the average of the precipitation anomalies in the El Niño mature phases with those over the rest of the data period. The statistically significant areas exceeding the 95% level are shaded in Fig.3. It is obvious that the positive anomalies existed in the southern part of China in winter, spring and autumn are statistically significant. In summer, the statistically significant area appears in the northern part of China. Although the large area of the negative precipitation anomalies in the southern part of China is not statistically significant, we still can see that a small area with statistical significance appears there. The positive precipitation anomalies in the area between the southern and the northern part of China are not statistically significant.

In order to check further the significance of the precipitation anomalies during the El Niño mature phase in comparison with others, we select an area which is within above–mentioned statistically significant areas in each season. In winter the area called DJF (21.5–27.0°N, 105.5–118.0°E), in spring MAM (22.5–26.5°N, 113.5–117.0°E), in summer JJA (37.5–41.5°N, 106.5–120.0°E) and in autumn SON (24.0–28.5°N, 107.0–115.5°E) are


COMP. PA FOR EN M PHASE IN WINTER (DEC–FEB)

COMP. PA FOR EN M PHASE IN SUMMER (JUN–AUG)

COMP. PA FOR EN M PHASE IN SPRING (MAR–MAY)

COMP. PA FOR EN M PHASE IN AUTUMN (SEP–NOV)

Fig. 3. Composites of precipitation anomalies (Unit: mm / month) during the El Niño mature phase for winter (a), spring (b), summer (c) and Autumn (d). The contour interval is 10 mm / month. The heavy and light shadings are the statistically significant areas exceeding the 95% level for positive and negative values, respectively.

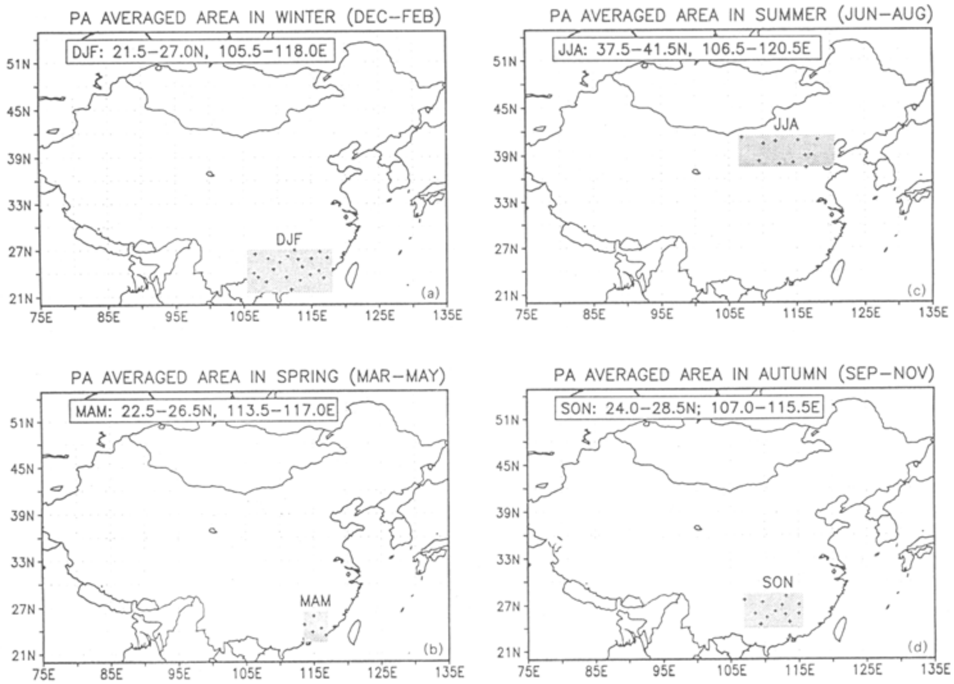
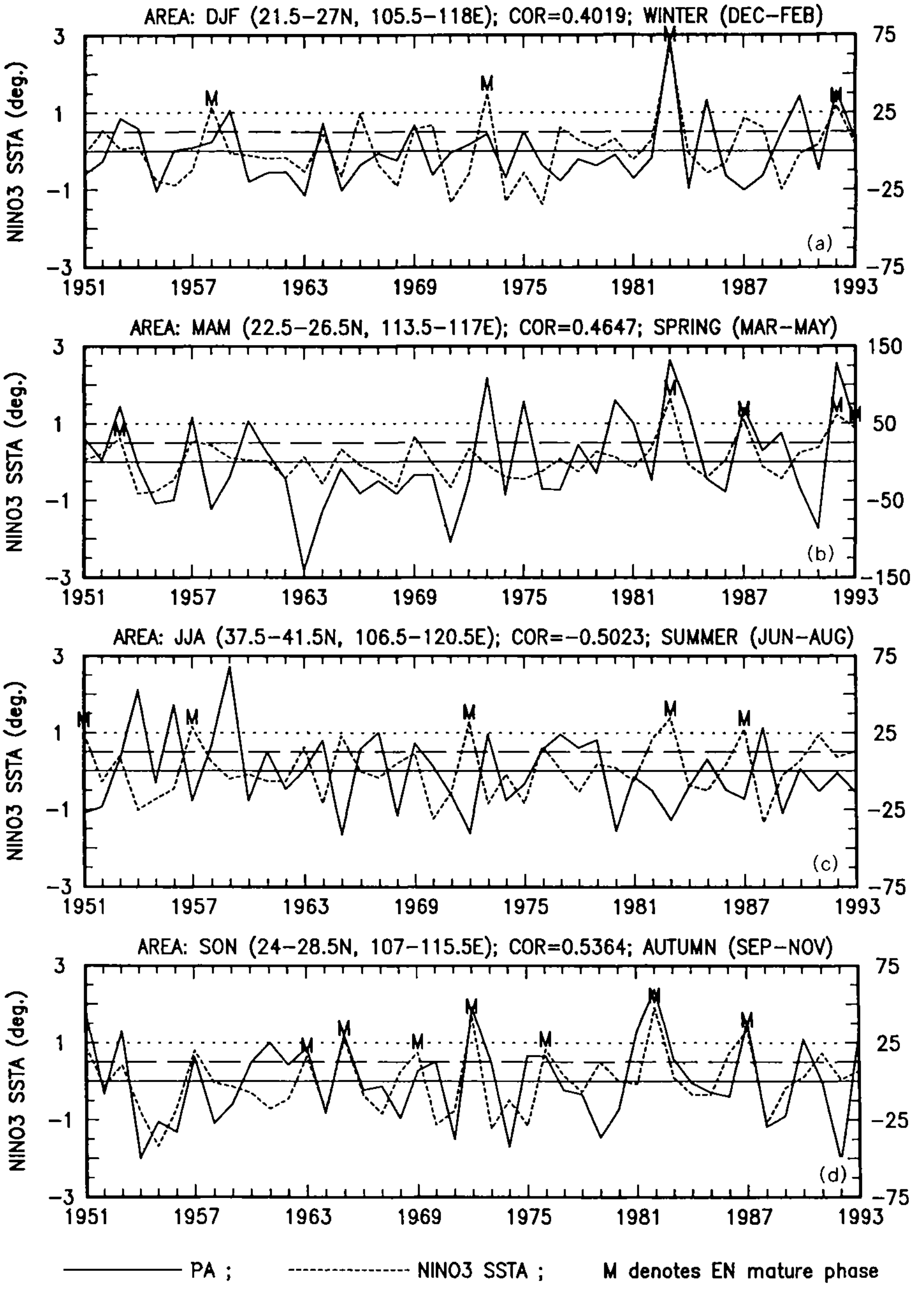


Fig. 4. Locations of area DJF in winter (a), MAM in spring (b), JJA in summer (c) and SON in autumn (d) (shaded areas). The crosses within the shadings are the station locations.

chosen. The locations of these areas and the station points within these areas are shown in Fig. 4. The area DJF (Fig.4a), MAM (Fig.4b) and SON (Fig.4d) are in the southern part of China, while the area JJA (Fig.4c) is in the northern part of China.

The time series of the precipitation anomalies averaged in these areas for different seasons are shown in Fig. 5, together with the evolutions of the seasonal NINO3 SSTA in the corresponding season. To calculate the correlation coefficients between the area mean seasonal precipitation anomalies and the corresponding seasonal NINO3 SSTA for different seasons, we can get their values to be 0.4019 in winter, 0.4647 in spring, −0.5023 in summer and 0.5364 in autumn. They are all statistically significant exceeding the 99% level. To examine Fig. 5 carefully, we can find that the correlation during the El Niño mature phases makes a great contribution to these positive correlations in winter (Fig.5a), spring (Fig.5b) and autumn (Fig.5d). In order to prove this, we calculated the contributions with the data during the El Niño mature phases to these correlation coefficients, which are listed in Table 1. From Table 1 we can see that in winter, spring and autumn, the contributions from the El Niño mature phase account for 93.97%, 84.85% and 62.73% of the positive correlations in the southern part of China, respectively. Thus, the importance of the mutual connection during the El Niño mature phase is reconfirmed except for summer. In summer, although the negative precipitation anomalies in the northern part of China during the El Niño mature phase are statistically significant, Table 1 shows only less than a half contribution from the mature phase to the correlation. The reasons of how the precipitation anomalies in different seasons are connected with El Niño will be discussed in the next section.


AREA: DJF (21.5–27N, 105.5–118E); COR=0.4019; WINTER (DEC–FEB)

AREA: MAM (22.5–26.5N, 113.5–117E); COR=0.4647; SPRING (MAR–MAY)

AREA: JJA (37.5–41.5N, 106.5–120.5E); COR=–0.5023; SUMMER (JUN–AUG)

AREA: SON (24–28.5N, 107–115.5E); COR=0.5364; AUTUMN (SEP–NOV)

Fig. 5. Evolutions of the seasonal precipitation anomalies (PA; Unit: mm / month) (solid lines) averaged on the area DJF for winter (a), MAM for spring (b), JJA for summer (c) and SON for autumn (d). The dashed lines are the seasonal NINO3 SSTA (Unit:°C) in the corresponding season. M denotes the El Niño mature phase.

We also make the composites of the seasonal precipitation anomalies in China for the other phases of El Niño and those for La Niña in different seasons, respectively (figures not shown). La Niña is defined as the periods when the seasonal NINO3 SSTA is lower than

−0.5°C. We repeat the same t−test mentioned above. For the composite seasonal precipitation anomalies in China during the other phases of El Niño, no clear area of statistical significance can be found. For La Niña, we also do not find a reversed pattern of the seasonal precipitation anomalies which is statistically significant.

**Table 1.** Correlation coefficients between the area mean precipitation anomalies and NINO3 SSTA for different seasons and the contributions from the El Niño mature phase

| area | season | correlation coefficient | contribution from the El Niño mature phase | ratio (mature phase / the total) |
|---|---|---|---|---|
| DJF | winter | 0.4019 | 0.3777 | 93.97% |
| MAM | spring | 0.4647 | 0.3943 | 84.85% |
| JJA | summer | −0.5023 | −0.2307 | 45.92% |
| SON | autumn | 0.5364 | 0.3365 | 62.73% |

## 5. Connection mechanisms between precipitation anomalies and El Niño

The precipitation over the East Asian region is greatly affected by the western Pacific subtropical high. The rainfall area generally appears along its northwestern edge where the warm and humid flow from the south meets the cold and dry flow from the north. In China and in Japan, the extent of the western Pacific subtropical high is usually defined by the area enclosed by the 5880 gpm contour of the 500 hPa geopotential height field. In order to investigate the physical reasons for the explanation of the seasonal precipitation anomaly pattern during the El Niño mature phases, we examine the corresponding composites of the 5880 gpm contour shown in Fig. 6. The climatological 5880 gpm contour for each season is also shown in Fig. 6. It is clearly seen that the subtropical high is strengthened and shifted westward during the El Niño mature phases for all the four seasons. In winter (Fig.6a), spring (Fig.6b) and autumn (Fig.6d), the subtropical high moves to the south of the mainland of China in the El Niño mature phases. Therefore, there is more precipitation in the southern part of China (Figs.3a, 3b and 3d). In summer (Fig.6c), since the subtropical high moves further west into the southeastern periphery of the mainland of China, the negative precipitation anomalies appear in the southern part of China and the positive anomalies to the north of the northern edge of the subtropical high, as has been seen in Fig.3c.

The behavior of the western Pacific subtropical high during the El Niño mature phase is associated with the circulation anomalies in the lower troposphere over the western tropical Pacific. Fig. 7 shows the composite wind anomalies at 850 hPa during the mature phase for different seasons. An anticyclonic anomaly over the tropical western Pacific to the north of the maritime continent appears in all the four seasons, which is associated with the strengthening and westward shifting of the subtropical high. The formation of this anticyclonic anomaly during the El Niño mature phase was discussed by ZSK. It was pointed out that the strong positive anomalies of the outgoing longwave radiation (OLR) over the maritime continent during the mature phase imply the strong cooling anomaly of the atmosphere there. An associated Rossby wave response to this cooling anomaly can make the anticyclonic anomaly appear to the north of the maritime continent. This anticyclonic anomaly affects the East Asian monsoon circulation and the western Pacific subtropical high, which exerts significant effect on the precipitation in China.

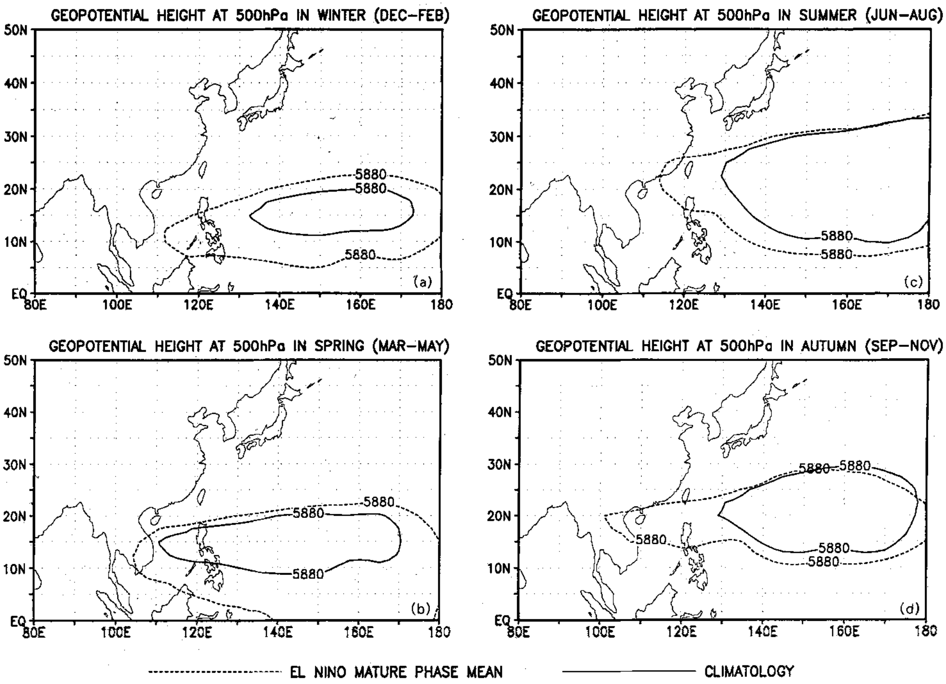


Fig. 6. Climatological (solid lines) and the El Niño mature phase composites (dashed lines) of the 5880 gpm contour of the geopotential height at 500 hPa for winter (a), spring (b), summer (c) and autumn (d).

The summer climate in East Asia is affected by the moisture transportation across the Bay of Bengal associated with the Indian monsoon ( Tao and Chen, 1987). In summer, the negative precipitation anomalies in the northern part of China have a negative significant correlation with the NINO3 SSTA (Fig.5c), which is the same as the relationship between Indian monsoon and El Niño. In the following we will make a preliminary investigation to see if the impact of El Niño on the northern part of China is through the Indian monsoon.

The correlation coefficients between the all-Indian rainfall (June-September) and summer precipitation (June-August) in China for the period from 1951 to 1994 are shown in Fig. 8. We can see that the area of the significant positive correlation exceeding the 95% level appears in the northern part of China. This feature has also been mentioned by Guo and Wang (1988). Time series of NINO3 SSTA, all-Indian summer monsoon rainfall anomalies and the summer precipitation anomalies in the northern part of China are shown in Fig. 9. The correlation coefficient between the summer-time NINO3 SSTA and the all-Indian monsoon rainfall is −0.59 and that between the Indian monsoon rainfall and the precipitation anomalies averaged on the area JJA is 0.48. Both of them are statistically significant at a 99% level. The composite wind anomalies in summer at 850 hPa during the El Niño mature phase (Fig.7c) show the easterly anomalies over the Bay of Bengal, a sign of weak Indian monsoon. It is likely that the weak Indian monsoon westerlies across the Bay of Bengal is associated with the reduction of the moisture transportation from India northeastward to China.

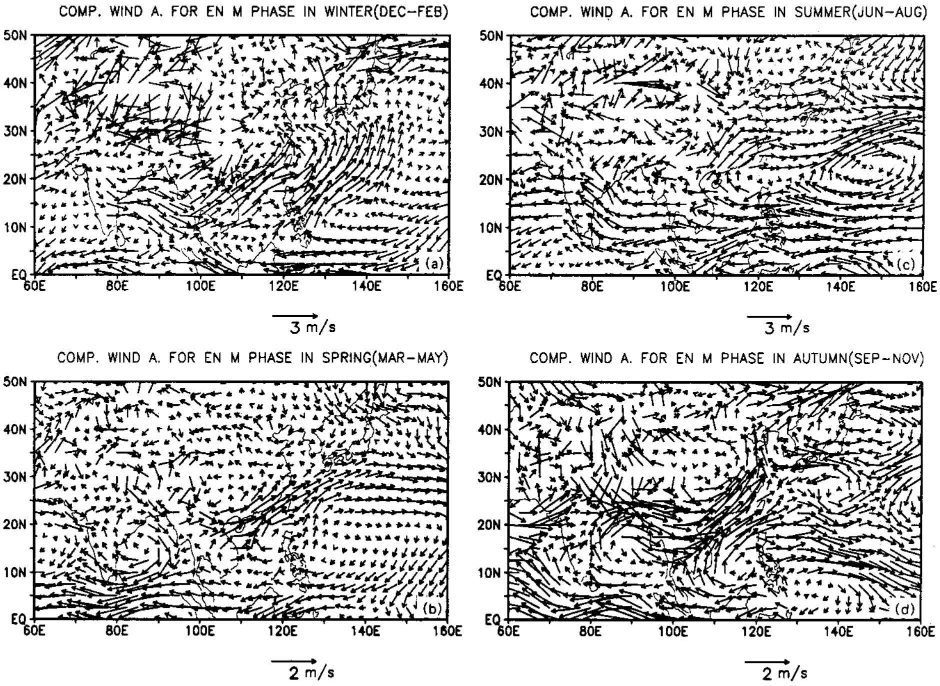


Fig. 7. Composites of wind anomalies in the El Niño mature phase at 850 hPa in winter (a), spring (b), summer (c) and autumn (d).

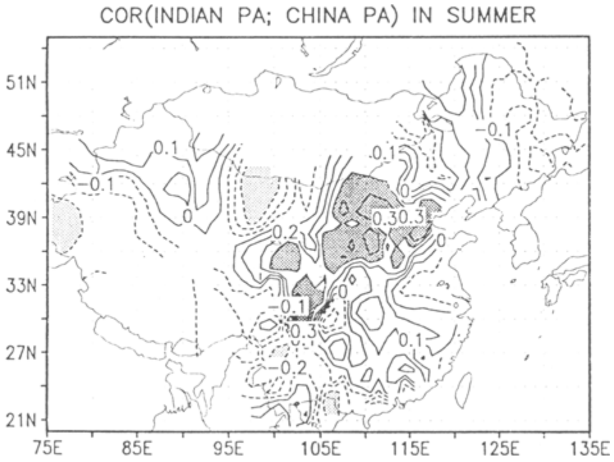


Fig. 8. Distribution of correlation coefficients of all-India summer (June-September) monsoon rainfall with the summer (June-August) precipitation in China. (Shadings are the area with statistical significance exceeding the 95% level)

## 6. Summary and concluding remarks

The present study reveals that El Niño in its mature phase has significant impacts on the

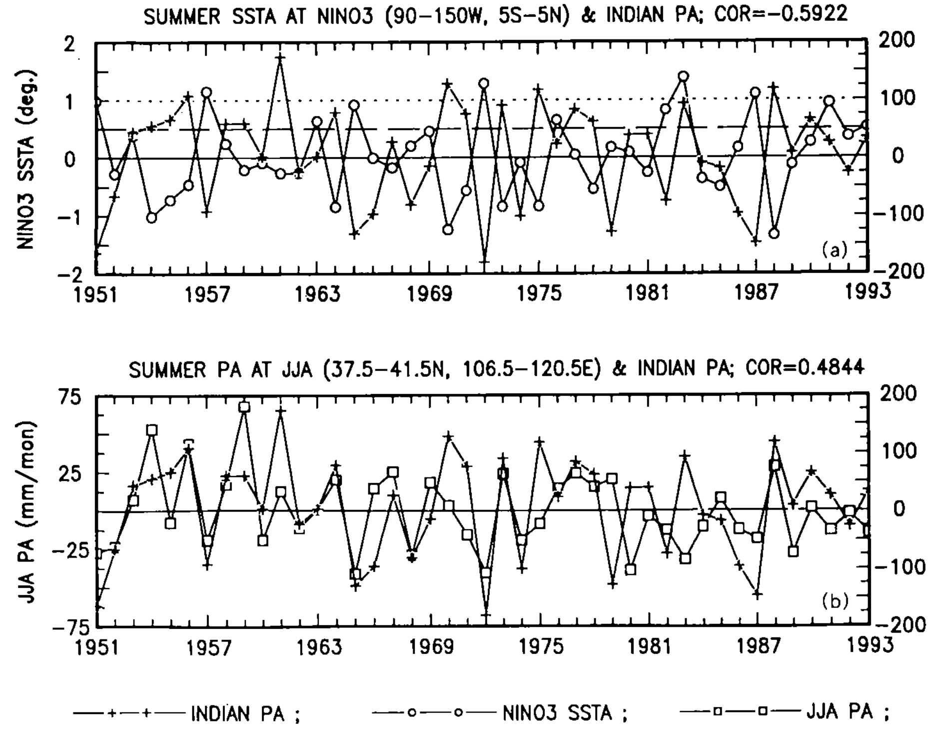


Fig. 9. Evolutions of summer-time NINO3 SSTA (Unit:°C), all-India summer (June-September) monsoon rainfall anomalies (Unit: mm) and summer (June-August) precipitation anomalies (Unit: mm / month) averaged on the area JJA in the northern part of China.

precipitation in China. In the Northern winter, spring and autumn, the positive precipitation anomalies occur in the southern part of China. In the Northern summer, the pattern of the precipitation anomalies in the El Niño mature phase is different from those of the other seasons. The negative precipitation anomalies appear in both the southern and northern parts of China, and the positive anomalies in between.

The physical process by which El Niño affects the precipitation in China is considered. In the Northern winter, spring and autumn, the precipitation anomalies in the southern part of China can be explained by the circulation anomalies over the East Asian region during the El Niño mature phase, as has been described by ZSK. The appearance of the anticyclonic anomaly to the north of the maritime continent in the lower troposphere at 850 hPa during the El Niño mature phase is associated with an intensified and westward shifted subtropical high over the western Pacific, which was responsible for the positive precipitation anomalies in the southern part of China.

In the Northern summer, the intensified western Pacific subtropical high moves westward into the southeastern periphery of China so that the precipitation there is less, and in the area to the north edge of the subtropical high the precipitation becomes more. In addition, the Indian summer monsoon has a negative correlation with El Niño as well as a positive correlation with the precipitation in the northern part of China. Therefore, the impact of El Niño on the precipitation in the northern part of China is likely to be influenced by the variation of the

Indian monsoon. Because the summer climate in East Asia is greatly influenced by the moisture transported by the monsoon flow across the Bay of Bengal in the lower troposphere, the weakening of the Indian monsoon may lead to a weakening of the moisture transportation accompanied with the weakened monsoon flow across the Bay of Bengal. Thus, less precipitation may occur in the northern part of China.

This paper provides further evidence of the results in the previous study in ZSK, i.e., the impact of El Niño on the East Asian monsoon is significant in the El Niño mature phase. The East Asian monsoon is mainly maintained by the huge contrast between the heating of the atmosphere over the land and that over its surrounding oceans. As pointed by ZSK, the El Niño mature phase is characterized by the significant changes of the heating field over the maritime continent. Therefore, during this period the huge East Asian monsoon system can be significantly modulated.

Although some possible physical explanations for the precipitation anomalies in China during the El Niño mature phase are given in the paper, for fully understanding the physical reasons the moisture circulations have to be studied with more extensive datasets. The summer–time precipitation in East Asia strongly depends on the synoptic–scale and mesoscale fluctuations in the monsoon trough, known as Mei–Yu in Chinese or Baiu in Japanese. Our study provides the large–scale and seasonal mean features of the precipitation anomalies. It is also necessary in particular to investigate the El Niño–related behaviors of the synoptic–scale and mesoscale fluctuations in the monsoon trough for understanding the variabilities of the summer–time precipitation in East Asia.

The authors wish to thank Dr. Shen X. for discussions and computational assistance, Prof. Wang S. W. and Dr. Zhai P. M. for providing the precipitation dataset. One of the authors (Zhang R.) acknowledges the financial support from the Center for Climate System Research (CCSR), University of Tokyo during his stay at CCSR. Zhang R. would also like to thank Prof. Huang R. H. for his helpful discussions.

## REFERENCES

Barnett, T. P., L. Bengtsson, K. Arpe, M. Flugel, N. E. Graham, M. Latif, J. Ritchie, E. Roeckner, U. Schulzweida and M. Tyree, 1994: Forecasting global ENSO–related climate anomalies. *Tellus*, **46A**, 381–397.

Bengtsson, L., U. Schlese, E. Roeckner, M. Latif, T. P. Barnett and N. E. Graham, 1993: A two tiered approach to long–range climate forecasting. *Science*, **261**, 1026–1029.

Cane, M. A., S. E. Zabiak and S. C. Dolan, 1986: Experimental forecasts of El Niño. *Nature*, **321**, 827–832.

Fraedrich, K., 1994: An ENSO impact on Europe? A Review. *Tellus*, **46A**, 541–552.

Guo, Q. and J. Wang, 1988: A comparison of the summer precipitation in India with that in China. *J. Tropical Meteorology*, **4**, 53–59. (in Chinese).

Hamilton, K., 1988: A detailed examination of the extratropical response to tropical El Niño / Southern Oscillation. *J. Climatol.*, **8**, 67–86.

Held, I. M., S. W. Lyons and S. Nigam, 1989: Transients and the extratropical response to El Niño. *J. Atmos. Sci.*, **46**, 163–174.

Horel, J. D. and J. M. Wallace, 1981: Planetary–scale atmospheric phenomena associated with the Southern Oscillation. *Mon. Wea. Rev.*, **109**, 813–829.

Hoskins, B. J. and D. J. Karoly, 1981: The steady linear response on a spherical atmosphere to thermal and orographic forcing. *J. Atmos. Sci.*, **38**, 1179–1196.

Huang, R and Y. Wu, 1989: The influence of ENSO on the summer climate change in China and its mechanisms. *Adv. Atmos. Sci.*, **6**, 21–32.

Huang, R., B. Yin and A. Liu, 1993: Intraseasonal variability of the East Asian summer monsoon and its association with the convective activities in the tropical western Pacific. *Climate Variability*, Ye et al., Eds., China Meteorological Press, Beijing, 139–155.

Khandekar, M. L. and V. R. Neralla, 1984: On the relationship between the sea surface temperature in the equatorial Pacific and the Indian monsoon rainfall. *Geophy. Res. Let.*, **11**, 1137–1140.

Krishnamurti, T. N., 1971: Tropical east-west circulations during the northern summer. *J. Atmos. Sci.*, **28**, 1342–1347.

Krishnamurti, T. N., W. J. Koss and J. D. Lee, 1973: Tropical east–west circulations during the northern winter. *J. Atmos. Sci.*, **30**, 780–787.

Lau, K. M. and M. T. Li, 1984: The monsoon of East Asia and its global association – A survey. *Bull. Amer. Meteor. Soc.*, **65**, 114–125.

Lau, N. C., 1985: Modeling the seasonal dependence of the atmospheric response to observed El Niño in 1962–76. *Mon. Wea. Rev.*, **113**, 1970–1996.

Li, Chongying, 1990: On interaction between anomalous circulation / climate in East Asia and El Niño event. In: Climate Change, Dynamics and Modelling, Zeng et al., Eds., China Meteorological Press, Beijing, 101–126.

Mooley, D. and B. Parthasarathy, 1983: Variability of the Indian summer monsoon and tropical circulation features. *Mon. Wea.. Rev.*, **111**, 967–978.

Nitta, T., 1986: Long term variations of cloud amount in the western Pacific region. *J. Meteor. Soc. Japan*, **64**, 373–390.

Nitta, T., 1987: Convective activities in the tropical western Pacific and their impact on the Northern Hemisphere summer circulation. *J. Meteor. Soc. Japan*, **65**, 373–390.

Palmer, T. N. and D. L. T. Anderson, 1994: The prospects for seasonal forecasting. *Q. J. R. Meteor. Soc.*, **120**, 755–793.

Rasmusson, E. M. and T. Carpenter, 1982: Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation / El Niño. *Mon. Wea. Rev.*, **110**, 354–384.

Rasmusson, E. M. and T. Carpenter, 1983: The relationship between eastern equatorial sea surface temperature and rainfall over India and Sri Lanka. *Mon. Wea. Rev.*, **111**, 517–527.

Rasmusson, E. M. and J. M. Wallace, 1983: Meteorological aspects of the El Niño / Southern Oscillation. *Science*, **222**, 1195–1202.

Shukla, J. and J. M. Wallace, 1983: Numerical simulation of the atmospheric response to equatorial Pacific sea surface temperature anomalies. *J. Atmos. Sci.*, **40**, 1613–1630.

Sontakke, N. A., G. B. Pant and N. Singh, 1992: Construction and analysis of all-India summer monsoon rainfall series for the longest instrumental period: 1813–1991. Indian Institute of Tropical Meteorology Research Report, No. RR- 053, 20pp.

Sontakke, N. A., G. B. Pant and N. Singh, 1993: Construction of all–Indian summer monsoon rainfall series for the period 1844–1991. *J. Climate*, **6**, 1807– 1811.

Tao, S. Y. and L. X. Chen, 1987: A review of recent research on the East Asia summer monsoon in China. Monsoon Meteorology, C. P. Chang and T. N. Krishnamurti, Eds., Oxford University Press, 60–92.

Van Loon, H. and R. A. Madden, 1981: The Southern Oscillation. Part I: Global association with pressure and temperature in northern winter. *Mon. Wea. Rev.*, **109**, 1150–1162.

Webster, P. J., 1981: Seasonality in the local and remote atmospheric response to sea surface temperature anomalies. *J. Atmos. Sci.*, **39**, 41–52.

Zhang, Renhe, A Sumi and M. Kimoto, 1996: Impact of El Niño on the East Asian monsoon: A diagnostic study of the '86 / 87 and '91 / 92 events. *J. Meteor. Soc. Japan*, **74**, 49–62.