Numerical Simulation of the Relationships between the 1998 Yangtze River Valley Floods and SST Anomalies

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ABSTRACT

With the IAP / LASG GOALS model, the relationships between the floods in the Yangtze River valley and sea surface temperature anomalies (SSTA) in the Pacific and Indian Oceans in 1998 have been studied. The results show that the model can reproduce the heavy rainfall over the Yangtze River valley in the summer of 1998 forced by global observational sea surface temperatures (SST). The model can also reproduce the observed principal features of the subtropical high anomalies over the western Pacific. The experiments with the observed SST in different ocean areas and different periods have been made. By comparing the effects of SSTA of different ocean areas on the floods, it is found that the SSTA in the Indian Ocean are a major contributor to the floods, and the results also show that the SSTA in the Indian Ocean and the western Pacific have a much closer relationship with the strong anomalies of the subtropical high over the western Pacific than the SSTA in other concerned areas. The study also indicates that the floods and subtropical high anomalies in the summer of 1998 are more controlled by the simultaneous summertime SSTA than by SSTA in the preceding winter and spring seasons.

Key words: The Yangtze River valley floods, SST anomalies, Numerical simulation

1. Introduction

During the summer of 1998, continuous rainstorms occurred in the Yangtze River valley of China and caused another entire valley flood disaster since 1954 (National Climate Center 1998). The positive center of June, July and August (JJA) seasonal mean precipitation anomalies in the middle Yangtze River valley reached more than 100%. There are several papers that analyze the climatic background of the 1998 summer floods and show that the El Niño event during 1997–1998 may be an important cause for the floods (Tao et al. 1998; Huang et al. 1998). Tao et al. (1998) indicated that there would be much more precipitation in the Yangtze River valley in the summer season, following the winter of an El Niño event.

Firstly, from a SSTA composite chart of several El Niño events (figure omitted), we can notice that during an El Niño event, SSTA occur not only in the equatorial eastern Pacific, but also in other oceanic areas. There are very strong positive SSTA in the equatorial central and eastern Pacific and negative SSTA from the equatorial western Pacific to the northeast Pacific in the winter season. Positive SSTA can also be found in the northwest Pacific, the South China Sea and in most parts of the Indian Ocean. In the composite chart of SSTA of several La Niña events (figure also omitted), we can find almost opposite distributions of SSTA. In fact, the SSTA in different regional oceans have some connections with each other

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(Lau and Nath 1996; Wu and Meng 1998). So when we discuss the relationship of weather and climate in China with respect to SSTA, we can find many relationships between weather and climate in China and SSTA of different regional oceans. Indeed, there have been many diagnostic studies on relationships between summer rainfall over the Yangtze River valley and SSTA of different regional oceans (Chen 1977; Gui et al. 1978; Huang and Wu, 1989; Deng et al. 1989; Mao and Wu 2000; Sun and Gao 2000). Most of these studies indicated that the SSTA of the equatorial eastern Pacific, the northwest Pacific and the Indian Ocean in spring have positive correlation with the summer rainfall over the Yangtze River valley. Now the first question posed is which regional ocean SSTA may be a major contributor if the SSTA are indeed a factor in the flooding of the Yangtze River valley? Wu and Liu (1995) verified the sensitivity of atmospheric rainfall in response to the tropical SSTA at different regions of the Pacific and Indian Oceans with the GFDL atmospheric general circulation model (AGCM) and indicated that the rainfall anomalies occur only in the region of SSTA and their surroundings. Their numerical experiments were made only for the month of August. In this paper, the relationships between the whole summer rainfall of the Yangtze River valley in 1998 and SSTA at different regions of the Pacific and Indian Oceans will be discussed in detail.

Secondly, it is found that the El Niño event of 1997 / 98 decayed very rapidly from February 1998 to the summer. The averaged SSTA from January to May 1998 was still in a very strong El Niño phase with the positive SSTA more than 3°C in the equatorial eastern Pacific (figure omitted) while the JJA seasonal mean SSTA were less than −2°C in the equatorial eastern Pacific and were positive in the tropical western Pacific. Here another question is put forth whether the different SSTA during different periods would have different impacts on the flood?

This study is organized as follows: In section 2, a description of the model and experimental design is given. Section 3 and section 4 deal with the simulation of heavy rainfall and the western Pacific subtropical high, respectively. A sensitive experiment to further explore the relationship between rainfall in the Yangtze River Valley and SST in the Indian Ocean is made in Section 5 and a summary is given in the final section.

2. Model and experimental design

The model used in this study is the atmospheric component of the IAP / LASG GOALS model, which is a global coupled ocean−atmosphere−sea ice−land system model. The atmospheric component is a nine−layer spectral R15 AGCM (which has an equivalent grid spacing of roughly $7.5^\circ \times 4.5^\circ$) (Wu et al. 1996). More details can be found in Wu et al. (1997) and Zhang et al. (2000).

First the model is integrated for ten years, forced by the observed climatic sea surface temperature (SST) of 1990−1997. The average of the last five years is regarded as a model climate, referred to as the control run.

Then the model is integrated with the observed SST of 1998 from January 1 to August 31 and initialized from five different atmospheric conditions (January 1 of the sixth, seventh, eighth, ninth and tenth model year). We do the ensemble of integration and obtain the seasonal mean results for June, July and August. We call this basic experiment E00. We will compare the differences between E00 and the control run with observations and verify the model's ability to reproduce the observed climatic anomalies in 1998.

A set of experiments is performed to investigate the impacts of SSTA in different oceanic regions on the floods. Four regions are chosen: 01— the tropical eastern Pacific

(180°E–82.5°W, 11.3°S–11.3°N), 02—the northwest Pacific (120°E–180°, 20.3°–42.8°N), 03—the tropical western Pacific (120°–150°E, 15.8°S–15.8°N), and 04—the Indian Ocean (52.5°–112.5°E, 20.3°S–20.3°N). In each experiment the observed 1998 SST is used within a selected region and the climatic SST out of the region. In this way we are able to set different regional ocean experiments: E01, E02, E03 and E04. Comparing them with each other and with E00, it is easy to discuss the impacts of different oceanic regions on the floods. In the same way, experiments for combined oceanic regions are made. For example, E40 is a combined experiment for the 01, 02, 03 and 04 regions, E30 for the 01, 02 and 03 regions, and E34 for the 03 and 04 regions.

In order to investigate the effects of SSTA of different periods on the floods, another two sets of experiments, F and G, are designed. In the F experiments, the observed 1998 SST is used from January to May and the climatic SST is used for June, July and August in model integration. In the G experiments, the climatic SST is used from January to May and the observed 1998 SST is used for June, July and August. Of course, we can do different period SSTA experiments for different regional oceans.

Table 1 lists all experiments. These are the ensemble of five different initial integrations from January to August. The five initial atmospheric conditions in the runs are the same as those in E00. The JJA seasonal mean of precipitation and some other variables of atmospheric general circulation are calculated. All figures in the paper show only the differences between the experiments and the control run unless stated otherwise.

Table 1. The basic experiment and experiments of different regional oceans and different periods

E	E00	E01	E02	E03	E04	E30	E40	E34
F	F00	F01	F02	F03	F04	F30	F40	F34
G	G00	G01	G02	G03	G04	G30	G40	G34

3. The simulation of heavy rainfall

3.1 *Basic experiment*

Fig.1 shows the simulated precipitation anomalies (%) of JJA 1998 for the basic experiment E00. Two large positive anomalies are located at the Yangtze River valley and in northeast China respectively. In the observed data of the summer season of 1998 (figure omitted), there are very strong rainfall events in these two areas and their anomalies are more than 100%. The simulated anomaly at the Yangtze River valley is more than 80%, a little less than the observed one. In the observation there are also two negative precipitation anomalies in South China and in some parts of North China. The simulated precipitation anomaly pattern is very similar to the observed in eastern China, even if there are some differences between them, namely the positions of anomaly centers, because of the coarse resolution of the model. This means that the model can reproduce the observed heavy rainfall in the Yangtze River valley in a rather realistic way. From simulated moisture anomalies and moisture flux anomalies at 850 hPa (figure omitted), there are positive anomalies of moisture in most parts of China and strong moisture transport from the South China Sea to the Yangtze River valley. This forms a strong moisture convergence in the middle reaches of the Yangtze River valley, which provides a very important physical condition for the floods. The simulated strong moisture transport anomalies and convergence are consistent with the diagnostic analyses (see

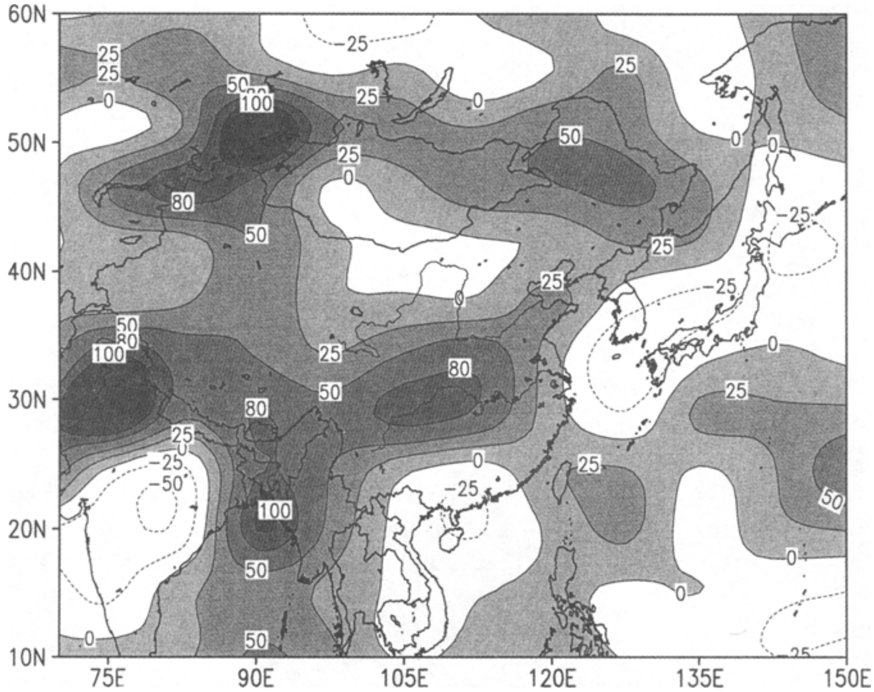

Fig. 1. Simulated precipitation anomalies (%) in JJA 1998 for experiment E00.

the Figs. 8 and 9 of Tao et al. 1998).

3.2 *Different regional oceans experiments*

Fig. 2 shows the simulated precipitation anomalies (%) in JJA 1998 for experiments E01, E02, E03 and E04. Firstly, it is found that the response of precipitation to tropical SST is not only limited to tropical regions. A possible explanation is that the tropical SSTA impact the atmospheric general circulation of middle–high latitudes through an " atmospheric bridge" and in turn the anomalies of atmospheric general circulation impact the precipitation pattern in the middle–high latitudes through a long integration. It is also found that SSTA of all four regions have some positive contributions to the heavy rainfall over the Yangtze River valley, and yet the SSTA in the Indian Ocean are a major contributor to the floods. In experiment E04, the strong precipitation anomalies are located from Bengal to the Yangtze River valley and the maximum of the simulated precipitation anomaly is more than 100%, which is close to the observed value. In the simulated moisture field of E04 (see Fig. 3), there is a very strong moisture transport band from Bengal to the Yangtze River valley, which is related to the heavy rainfall there. We notice that in the spring and summer of 1998 there were positive SSTA in most parts of the Indian Ocean. Deng et al. (1989) indicated that summer rainfall of the Yangtze River valley has a two–month lagged positive correlation with the SST in the Arabian Sea. Recently, Mao and Wu (2000) indicated that SSTA in the equatorial Indian Ocean in May have an obvious positive correlation with the precipitation in the Yangtze River valley in July and could be used as a predictor for the precipitation. The simulated results in experiment E04 are consistent with these other diagnostic studies.

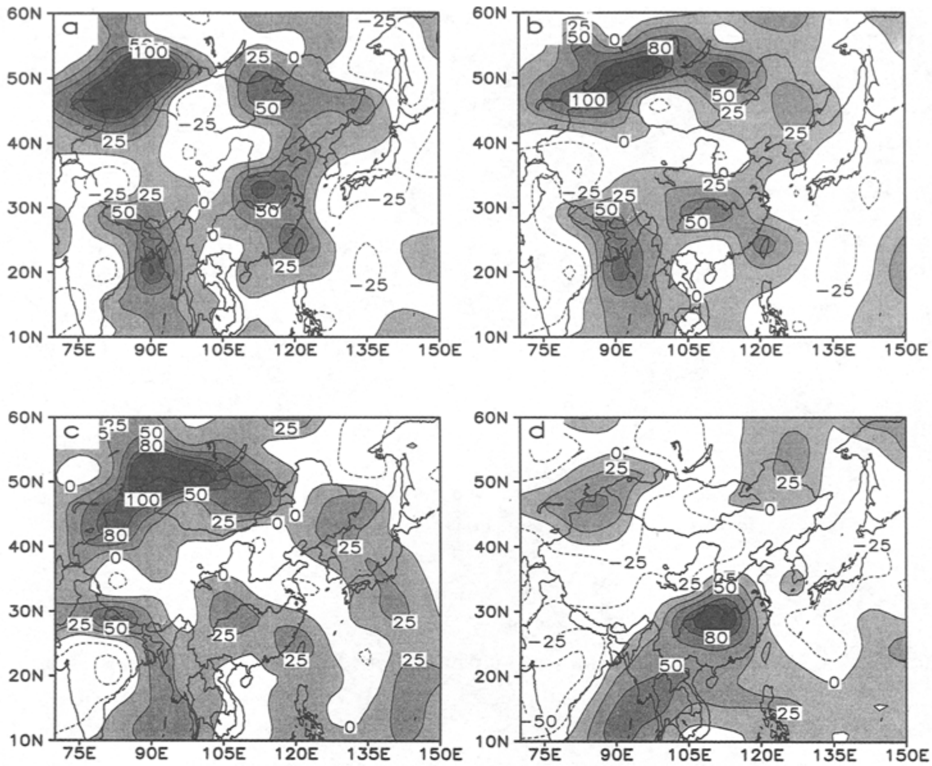

Fig. 2. Simulated precipitation anomalies (%) in JJA 1998: (a) in E01, (b) in E02, (c) in E03 and (d) in E04.

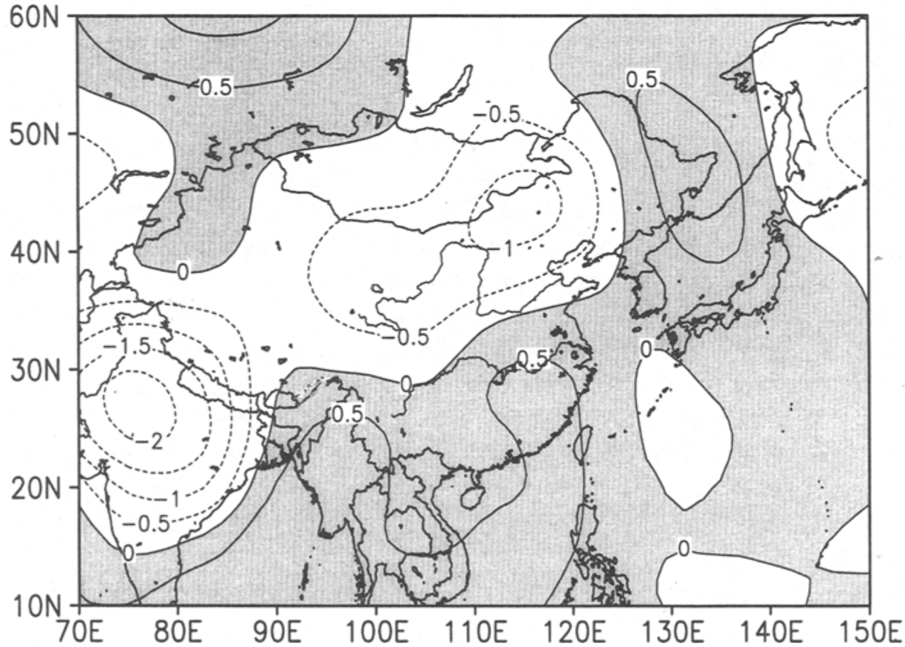

Fig. 3. Simulated moisture field of 850 hPa in JJA 1998 for experiment E04 (units: 10 g kg^{-1}).

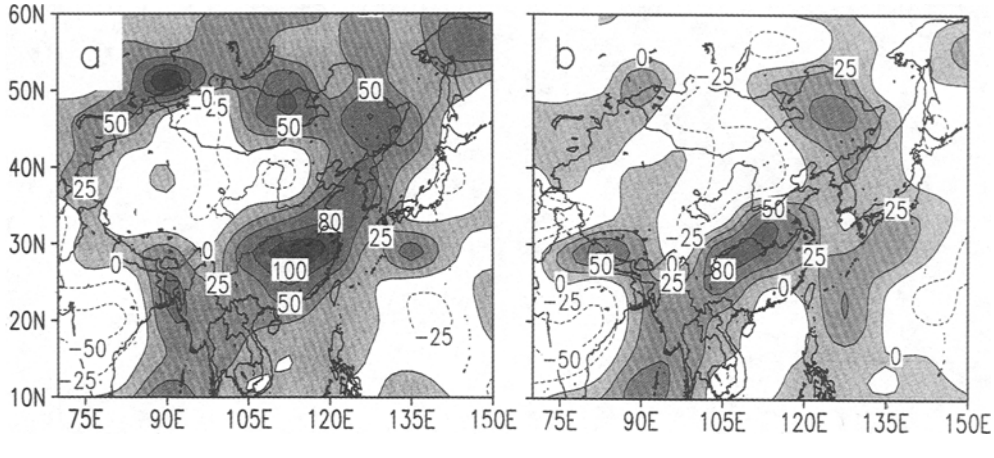

Fig. 4. Simulated precipitation anomalies (%) in JJA 1998: (a) in E40, (b) in E34.

Because of the importance of the Indian Ocean SSTA, two combined experiments of different regional oceans with the Indian Ocean included are shown here (Fig. 4). Experiment E40 shows the best simulation for the summer heavy rainfall over the Yangtze River valley in 1998, both in intensity and location of precipitation. It confirms that SSTA of the four regions have some positive contribution to heavy rainfall over the Yangtze River valley. Experiment E34 also shows a good simulation for the heavy summer rainfall there. We notice that there is a poor simulation for the heavy summer rainfall for combined experiment E30 (figure omitted). The above descriptions indicate that the pattern of SSTA may be more important to the precipitation anomalies than SSTA of an individual region (Lin 1999).

3.3 *Different period experiments*

Fig. 5 shows three pairs of different period SSTA experiments. Comparing the G experiments with the F experiments, the simulated precipitation anomalies over the Yangtze River valley in the G experiments are much stronger than those in corresponding F experiments for all three pairs of experiments. This obviously indicates that the SSTA in June, July and August have much stronger impacts on the heavy summer rainfall over the Yangtze River valley than SSTA from January to May. The same results can be found in two other pairs of experiments, F00 and G00, F01 and G01 (figure omitted). However, in the experiments F02 and G02, F03 and G03 (figure omitted), the differences between the sets of experiment G and experiment F are not obvious. The result may indicate that in the experiments with SSTA in the Indian Ocean included, the SSTA in the summer season have a greater impact on the summer rainfall over the Yangtze River valley than SSTA in the preceding winter and spring. Fig. 6 shows the moisture differences of two sets of experiments (G−F). It is found that the moisture obviously increases in all G experiments in the eastern part of China, especially over the Yangtze River valley in G40 and G04. This indicates that the summer SSTA in the Indian Ocean may have an impact on the moisture transport from Bengal to eastern China first and then on the precipitation distribution in eastern China in the summer. Sun and Gao (2000) indicated that there are positive (negative) SSTA in summer in the Indian Ocean for the summer flood (drought) season in the middle and lower reaches of the Yangtze River. That diagnostic study supports the simulated results here.

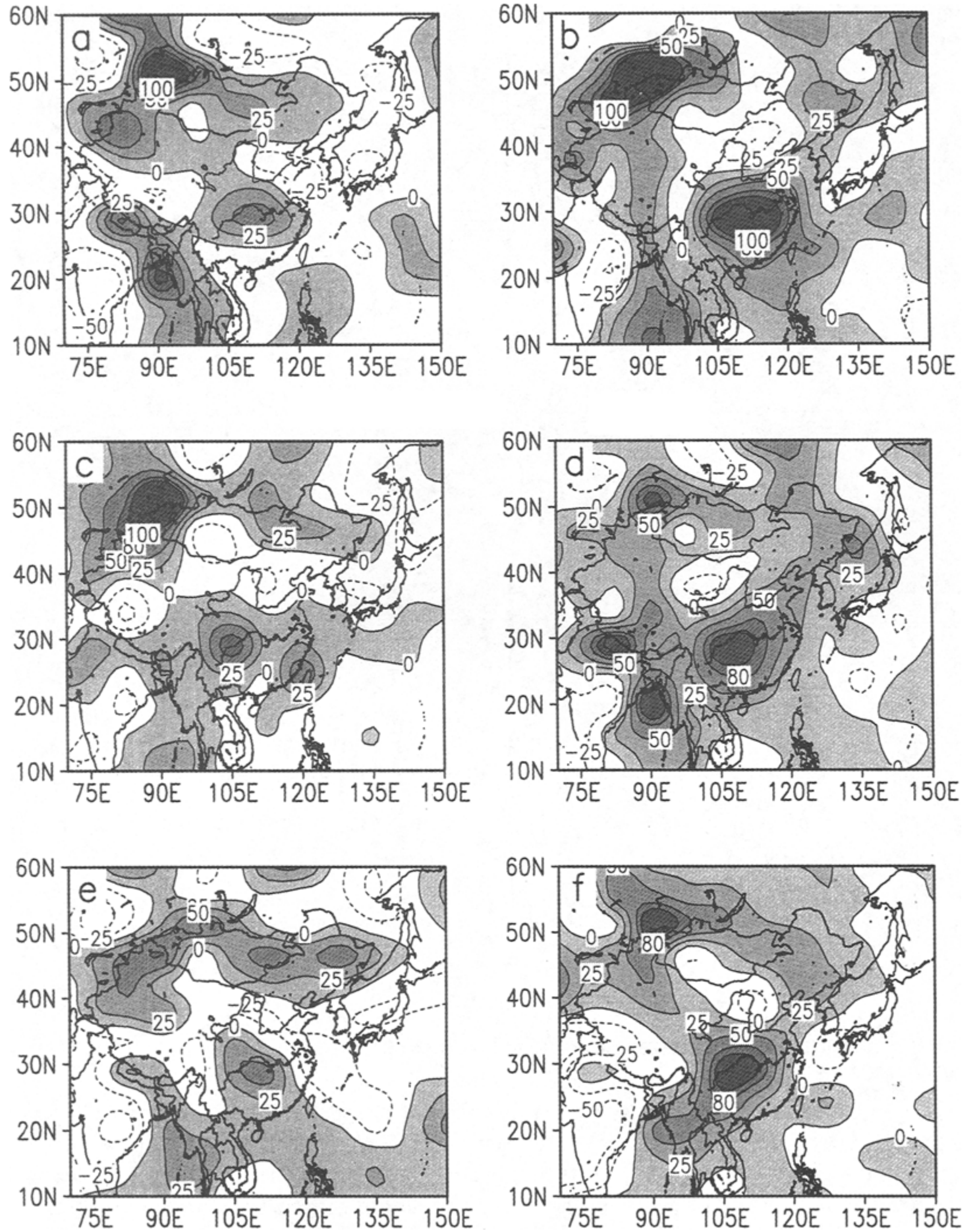

Fig. 5. Simulated precipitation anomaly (%) in JJA 1998: (a) F40 and (b) G40; (c) F34 and (d) G34; (e) F04 and (f) G04, respectively.

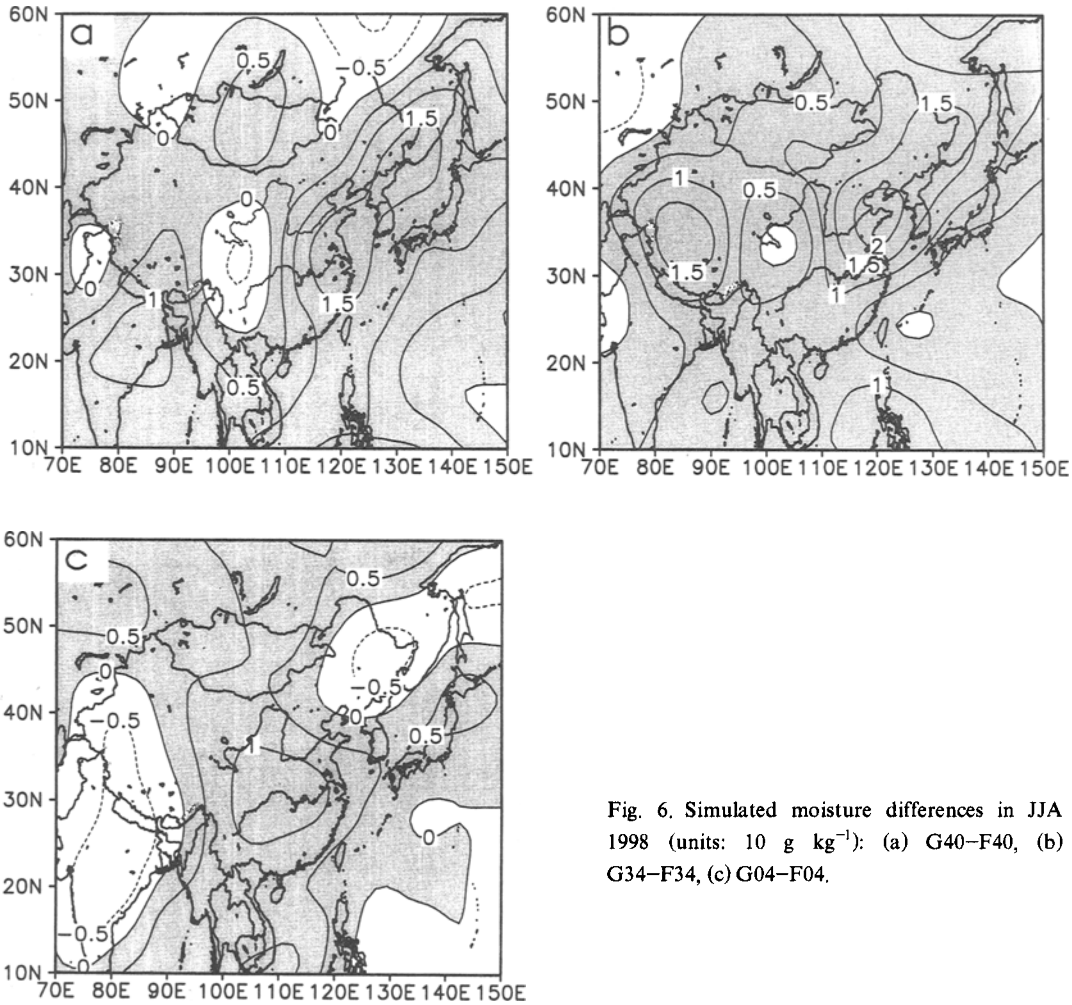

Fig. 6. Simulated moisture differences in JJA 1998 (units: 10 g kg^{-1}): (a) G40−F40, (b) G34−F34, (c) G04−F04.

4. The simulation of the western Pacific subtropical high

The subtropical high over the western Pacific has a very close relationship with the precipitation in eastern China. There have also been many papers on the relationship between the subtropical high and the SST. One of the main conclusions from these is that the subtropical high over the north Pacific has a lagged positive correlation with SST variation in the tropical eastern Pacific (Angell 1981; Chen 1982; Zhang and Wang 1984; Gong and Wang 1998). As to the subtropical high over the western Pacific, the relationship seems to be more complicated. Chen (1977) indicated that when SSTA in the tropical eastern Pacific are negative, the subtropical high over the western Pacific spreads further west with more intensity. Liu (1999) indicated that the intensity and position of the subtropical high over the western Pacific depend on the distributions of the SSTA. In this paper we first validate the model's ability to simulate the subtropical high over the western Pacific in the summer of 1998 and then discuss the relationship between the subtropical high and the SST further.

4.1 *Control run and basic experiment*

Fig. 7 shows the simulated geopotential height field of 500 hPa during the summer season for the control run and the basic experiment E00. Results from the control run show that the model can reasonably reproduce the northward shift of the subtropical high from June to August despite a weaker simulated subtropical high than the observed one. From experiment E00 it is found that the simulated subtropical high with the observed 1998 SST forcing is much stronger and spreads further west in E00 than in the control run, which is in very good agreement with observation (National Climate Center 1998).

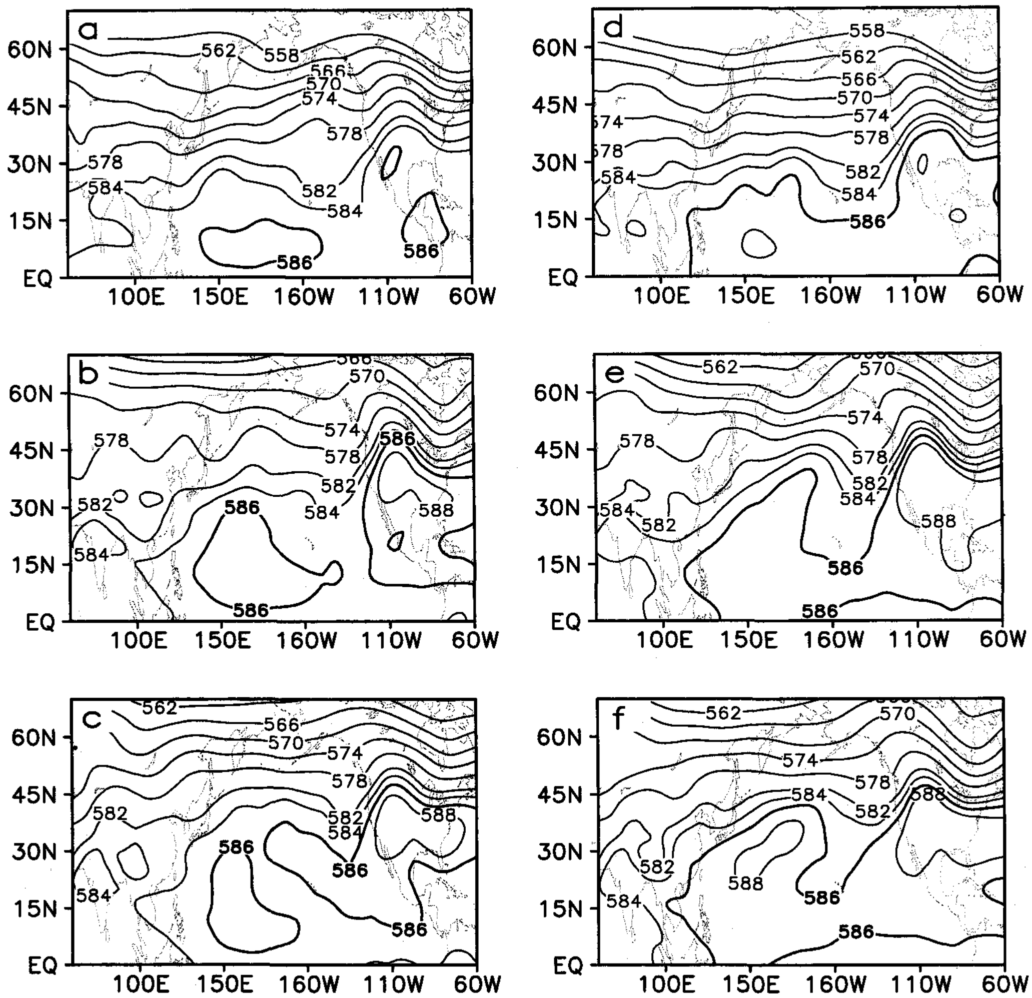

Fig. 7. Simulated geopotential height field of 500 hPa in the summer of 1998 (Units: 10 gpm): Left is control run, right is E00; upper is June, middle is July and lower is August.

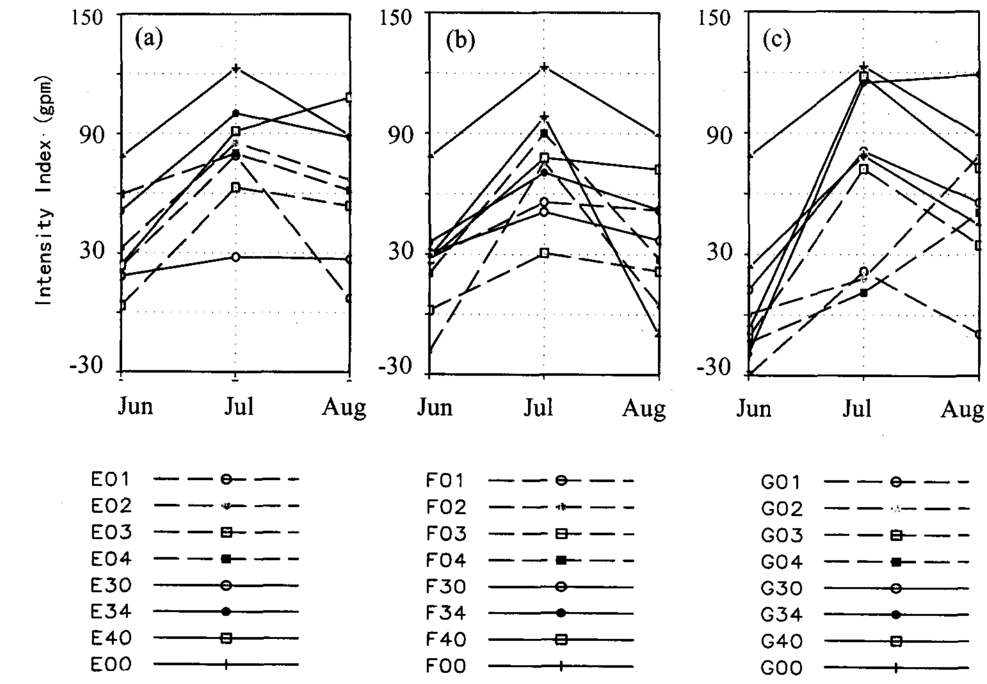

Fig. 8. Simulated evolution of the intensity indices of the western Pacific subtropical high in the summer of 1998 (units: 10 gpm): (a) in E experiments, (b) in F experiments, (c) in G experiments.

4.2 *Experiments of different regional oceans and of different periods*

The evolution of the simulated intensity indices of the western Pacific subtropical high (500 hPa) in the summer of 1998 for different regional oceans in experiments E, F and G is shown in Figure 8. The simulated evolution of the intensity indices for experiment E00 is shown in all three individual figures (see Figs. 8a, b, c.). The E experiments (Fig. 8a) show that every individual regional ocean SST has some positive contribution to the anomalous intensities of the subtropical high over the western Pacific. For the F experiments (Fig. 8b), the SSTA of the Indian Ocean in early winter and spring have a greater effect on the intensities of the subtropical high of the western Pacific in summer than the SSTA of other regions. In the G experiments (Fig. 8c), the simulated intensities in combined experiments G34 and G40 are much closer to those in E00 than those in the F experiments. This indicates that the SSTA of the Indian Ocean and the tropical western Pacific in summer may have a much greater impact on the intensities of the subtropical high of the western Pacific in the summer.

5. The sensitive experiment

The above experiments show the great importance of SSTA in the Indian Ocean to the simulations of both heavy rainfall over the Yangtze River valley and the subtropical high over the western Pacific. In order to verify this conclusion further, a sensitive experiment XG04 is designed. In XG04, the SST is the difference between the observed SST of 1998 (SST_{98}) and 2 $\times$ ($SST_{98}$$-$$SST_{cli}$) in the Indian Ocean instead of the observed 1998 SST in G04. SST_{cli} is the

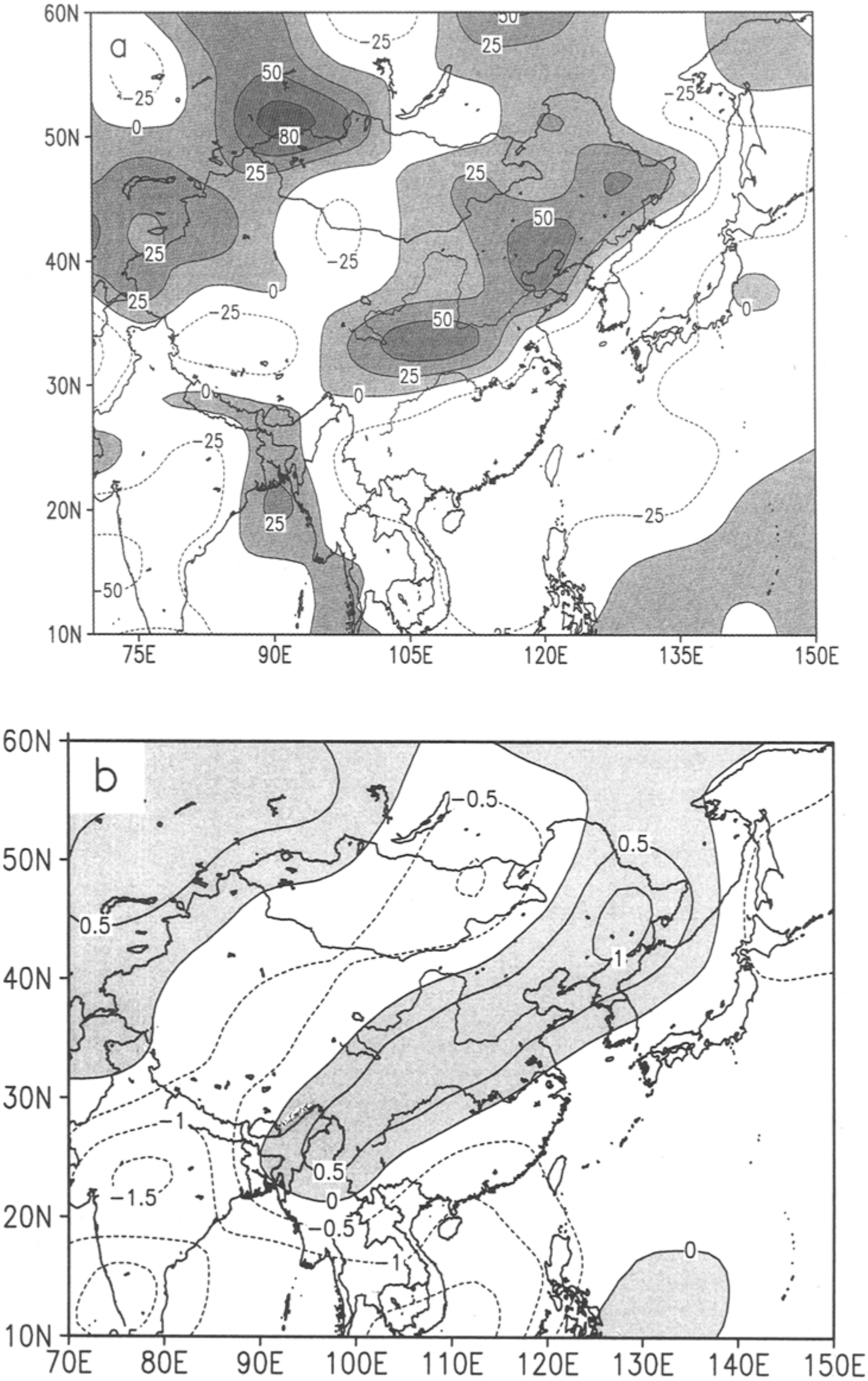

Fig. 9. Simulations in experiment XG04 for JJA 1998: (a) precipitation anomalies (%), (b) moisture anomaly field at 850 hPa (units: 10 g kg^{-1}).

observed climatic SST of 1990–1997 used in the control run integration. Fig. 9 shows the anomalies of the simulated precipitation and moisture field of 850 hPa for JJA in XG04. As in the description in section 2, the anomaly is also defined as the difference between XG04 and the control run. Comparing XG04 in Fig. 9a with G04 in Fig. 5f, there is much less precipitation to the south of the Yangtze River valley and much more precipitation over the middle reaches of the Yellow River in XG04, which is very different from G04. Fig. 9b shows that the moisture zone shifts from the south to the Yangtze River valley (Fig. 3) to the middle reaches of the Yellow River. Experiment XG04 shows that lower SST in the Indian Ocean may be connected with less precipitation over the Yangtze River valley.

6. Summary and discussion

Comparing IAP / LASG GOALS model simulations with observations, the GOALS model is able to simulate the observed precipitation pattern in East China in the summer of 1998, especially the heavy rainfall over the Yangtze River valley using the observed SST. The simulated moisture flux convergence zone over the Yangtze River valley and a much stronger western Pacific subtropical high with a position further west are also in good agreement with observations. This provides a good basis to investigate the effects of SSTA of different ocean areas and different periods on the heavy rainfall over the Yangtze River valley in the summer of 1998.

By comparing the effects of SST of different ocean areas on the heavy rainfall, the SST of all four selected regional oceans have some positive contributions to the heavy rainfall over the Yangtze River Valley. The combined regions experiment (E40) has the best simulation, which indicates that the SST pattern is very important to climatic simulation and prediction. It is interesting to note that the SST in the Indian Ocean is a major contributor to the flooding. Comparing G04 with XG04 shows that warmer SST in the Indian Ocean are beneficial to heavy rainfalls over the Yangtze River valley while lower SST may move the rainfall band to North China. It is also interesting to note that the SSTA of the Indian Ocean and the western Pacific have a closer relationship with the strong anomalies of the subtropical high over the western Pacific in the summer of 1998 than the SSTA of other regions.

Comparing the G experiments with the F experiments, the heavy rainfall over the Yangtze River Valley and the anomalies of the subtropical high over the western Pacific in the summer of 1998 are much more controlled by SSTA during June, July and August, than by SSTA during the preceding winter and spring. This conclusion is significant to short–range climate prediction. More numerical simulations for other years are needed to verify this conclusion.

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1998 年长江流域洪水与海温异常关系的数值模拟研究

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摘　要

用 IAP／LASG GOALS 模式对 1998 年长江流域洪水与太平洋和印度洋海表温度异常之间的关系进行了数值模拟研究。利用观测的全球海表温度，模式能再现 1998 年夏季长江流域的暴雨，模式也能再现观测的 1998 年夏季西太平洋副高异常的基本特征。设计了一系列不同海区和不同时段的海温异常的敏感性试验。试验结果表明：印度洋海温异常是造成 1998 年长江流域洪水的主要因子；印度洋和西太平洋海温异常与西太副高的异常有更紧密的关系；夏季海表温度异常对 1998 年长江流域暴雨和西太副高异常的作用与冬春海温异常的的作用相比要大得多。

关键词：长江暴雨，海温异常，数值模拟