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SIMULATION OF SUMMER CLIMATE IN CHINA DURING 1997 AND 1998 USING A REGIONAL AIR-SEA COUPLED MODEL

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Abstract: Using the regional air-sea coupled climate model RegCM3-POM, a series of numerical experiments are performed to simulate the summer climate in 1997 and 1998 with different coupling time steps. The results show that the coupled model has good performance on the simulation of the summer sea surface temperature (SST) in 1997 and 1998, and the simulation results of CPL1 (with the coupling time step at 1 hour) are similar to those of CPL6 (with the coupling time step at 6 hours). The coupled model can well simulate SST differences between 1997 and 1998. As for the simulation of the drought in 1997 and the flood in 1998, the results of CPL6 are more accurate. The coupled model can well simulate the drought in 1997 over North China, and compared with the results of the atmosphere model RegCM3, the simulation ability of the coupled model is improved. The coupling model has better ability in the simulation of the circulation in the middle and low levels, and the water vapor transportation in the coupling model is reasonable in both 1997 and 1998. RegCM3 (an uncoupled model) cannot correctly simulate the transportation path differences between 1997 and 1998, but the coupled model can simulate the differences well.

Key words: regional air-sea coupled model; precipitation; numerical simulation

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1 INTRODUCTION

RegCM, a regional climate model with high resolution, has been rapidly developed since the late 1980s, which is time-saving and can better represent the atmospheric dynamics and mesoscale forcing[1-2]. This high resolution model was developed by the International Centre for Theoretical Physics[3-5]. It is a powerful tool and has been widely applied to the climate simulation in East Asia[6-10]. The RegCM can well simulate the average climate status, extreme climate events and climate variations. However, the simulation results always have some deficiencies[11-13], and the RegCM often takes the observed (given) sea surface feature as its bottom boundary condition, so it cannot reflect the air-sea interaction correctly[14]. The research shows that the air-sea interaction in the East Asia region is very strong, and sea surface temperatures (SSTs) in South China Sea, Bay of Bengal, and Western Pacific have significant influences on the weather and climate in East Asia[15]. East Asia is marked by a complex topography, land-sea distribution, and monsoon climate, so the dynamic process and physical mechanism are very complicated. Some high resolution air-sea coupled models abroad, which are not designed for East Asia, may not be suitable for China[16, 17]. In this paper, a regional air-sea coupled model is developed based on RegCM3 and the Princeton Ocean Model (POM) and the extreme climate events in 1997 and 1998 are simulated. 1997 is the drought year in North China and 1998 is the flood year in Yangtze River Basin[18, 19].

2 MODEL DESCRIPTION AND DATA

In this work, the air-sea coupled model RegCM3-POM is based on RegCM3 and POM (Version 2K). A flux coupling scheme is chosen and the detailed methods and processes can be found in

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Yao and Zhang[20].

The experiment designs are as follows: Before running the coupled model RegCM3-POM, the ocean model integrates for a year first as spin-up and the stationary ocean is then equilibrated to the climate status. Then the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR, USA) wind data in 1997/1998 are used to force the POM model from January 1 and April 25, and the simulated ocean will then be used as the initial ocean condition of the coupled model. And then, RegCM3-POM is used to simulate the summer climate in 1997 and 1998. Here, two experiments (CPL1 and CPL2) are designed for different coupling time steps, 1 hour for the former and 6 hours for the latter, and the same experiments are performed using the uncoupled model RegCM3 as the control experiments (ATM). The spin-up time of the coupled model is from April 25 to May 31 and the simulation results from June to August are analyzed.

Lambert conformal projection is chosen for the atmosphere module of the coupled model system and RegCM3 and the grid number is 149×107, with the center located in 19.5°N, 110°E. The horizontal resolution in this module is 60 km×60 km and there are 18 layers in the vertical, with the top-layer pressure at 5 hPa. The planetary boundary layer scheme developed by Holtslag and the modified Kuo convective parameterization are chosen. Zeng's scheme is chosen for ocean flux in the ocean surface. The system uses the radiation method of the NCAR CCM3. For the ocean module of the coupled model and the ocean model POM, the horizontal resolution is 0.5°×0.5° and the σ coordinate is chosen in the vertical with 16 levels. The simulated ocean area is from 5° to 45°N and from 80° to 140°E, so Western Pacific, Bay of Bengal, and South China Sea are all included.

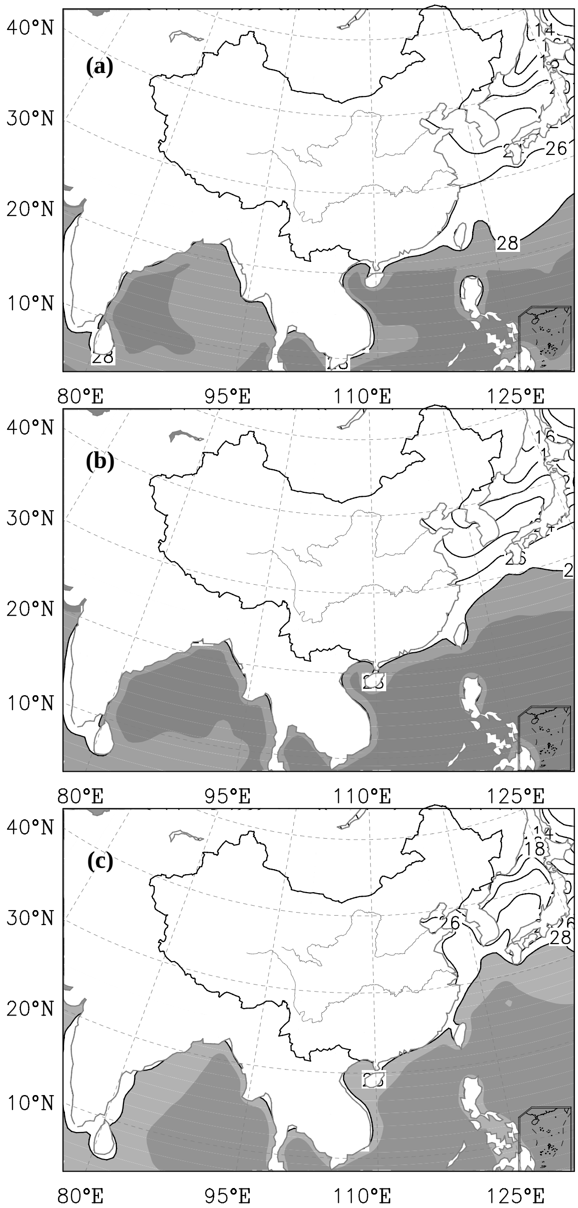
The 1994 Levitus salt and temperature data and NCEP/NCAR reanalysis wind data are used for POM. The initial and boundary conditions of ATM and CPL are provided by NOAA/NCEP Reanalysis Project 2 and global sea ice and temperature (GISST). Observed precipitation data are used to test the simulation results.

3 ANALYSIS OF THE SIMULATION RESULTS

3.1 *Sea surface temperature*

The ocean is the major source of atmospheric moisture and the atmosphere of the surface layer influences the SST by driving the ocean currents and controlling the heating flux exchange. As for the air-sea coupled model, the first test indicator is the simulation ability of the SST. Because the SST anomaly is closely related to atmospheric circulation and precipitation, the simulated SSTs are analyzed first.

Figures 1a and 1b show the summer SST pattern of GISST data in 1997 and 1998. Figures 1c and 1d show the simulated SST by RegCM3-POM in 1997 and 1998 with the 6-hour coupling time step, and Figures 1e and 1f show the differences between CPL6 and CPL1. The simulated SST distribution is consistent with the GISST data and there are no significant SST differences between CPL6 and CPL1 in the Bay of Bengal and the South China Sea. In the Yellow Sea, Bohai Sea and the Sea of Japan, the differences between CPL6 and CPL1 are about 0.2 to 0.6°C. The simulated SSTs are accurate in both CPL6 and CPL1.



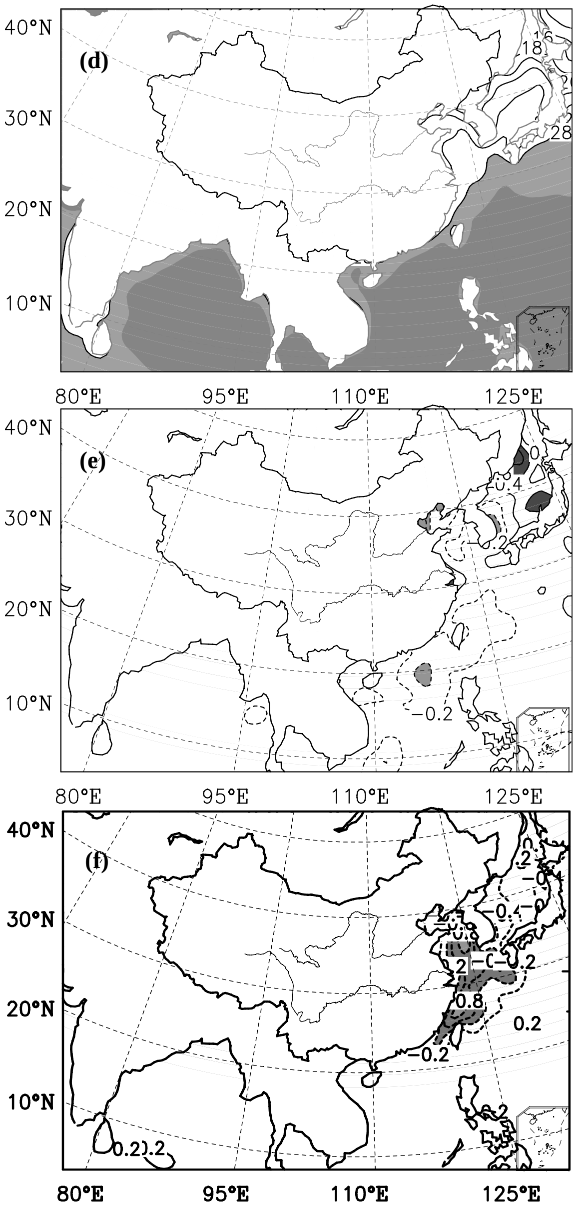


Figure 1. The summer SST in 1997 and 1998 (a: GISST in 1997; b: GISST in 1998; c: SST in CPL6 in 1997; d: SST in CPL6 in 1998; e: differences between CPL1 and CPL6 in 1997; f: differences between CPL1 and CPL6 in 1998. Values in shaded areas are higher than 28 in panels a to d, and 0.5 in panels e and f. Units: °C).

SST anomalies affect the precipitation and it is necessary to analyze the simulated interannual variations of SST between 1997 and 1998. The SST differences between the two years are shown in Figure 2 and the values of shaded areas are greater than 0.5°C. Compared with 1997, the SSTs in 1998 are 0.5°C higher than the SSTs in most oceans. The most abnormal area is the Kuroshio area, with 2°C anomaly, and the anomalous SSTs in South China Sea and Bay of Bengal are greater than 1°C. The analysis of the simulated SSTs by RegCM3-POM shows that the coupled model has good performance in reflecting the SST differences between 1997 and 1998 in the Bay of Bengal, South China Sea and eastern coastal region.

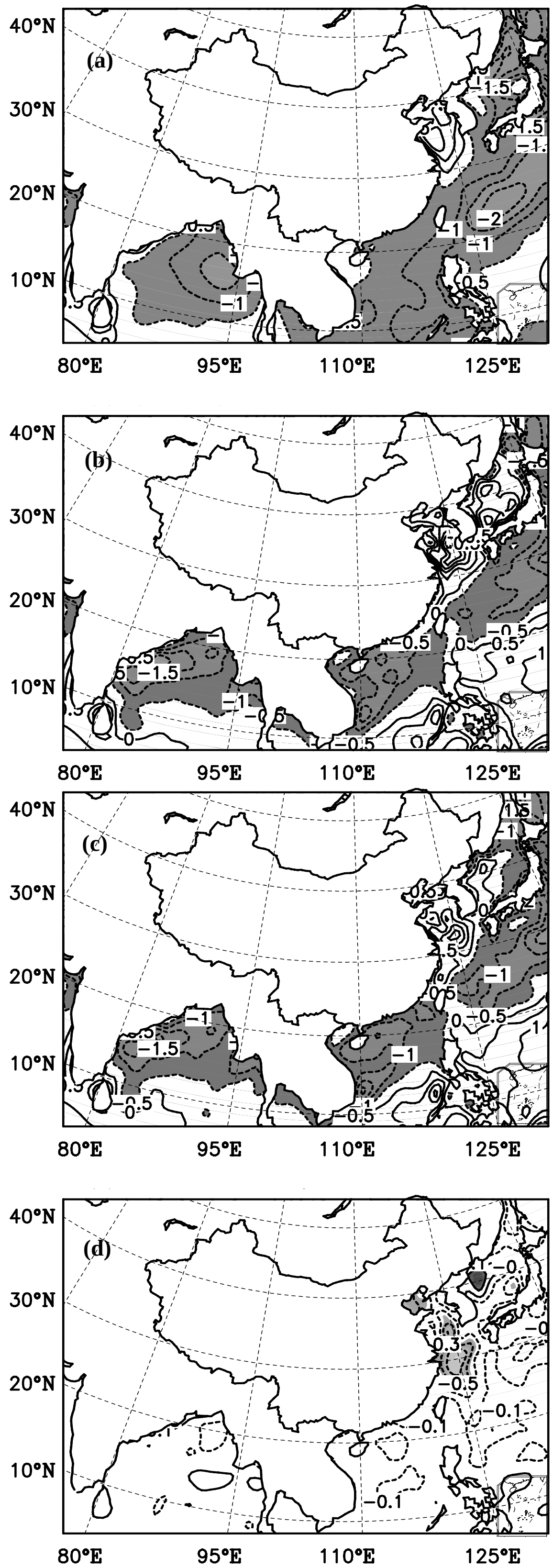
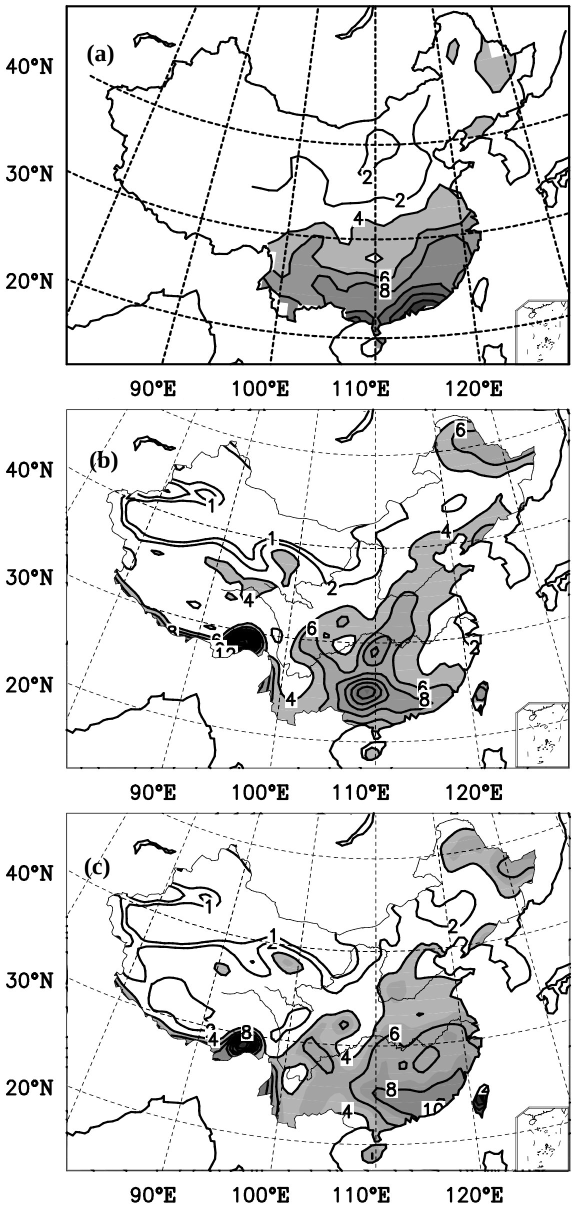


Figure 2. SST differences in June between 1997 and 1998 (a: GISST; b: CPL1; c: CPL6; d: CPL1-CPL6. The values in shaded areas are higher than 0.5. Units: °C).

3.2 *Precipitation*

Figure 3a shows that 1997 is a year of more precipitation in South China but a typical drought year in North China. The observations indicate that the rainfall is about 2 mm d^{-1} in North China and the rainfall center is in South China. The simulation results in ATM (Figure 3b) shows that the rainfall belts are mainly located in the west of South China, and the model overvalues the precipitation in North China, especially in the east of North China. There are some differences between the simulation results of CPL1 (Figure 3c) and CPL6 (Figure 3d). The simulated precipitation in CPL1 is above the observation in eastern North China and the experiment CPL6 accurately simulates the precipitation in North China. Compared with the results in ATM and CPL1, the coupled model with the 6-hour coupling time step is more suitable for the precipitation simulation in 1997.



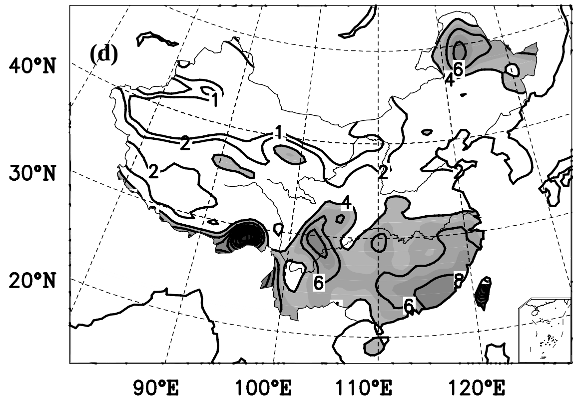
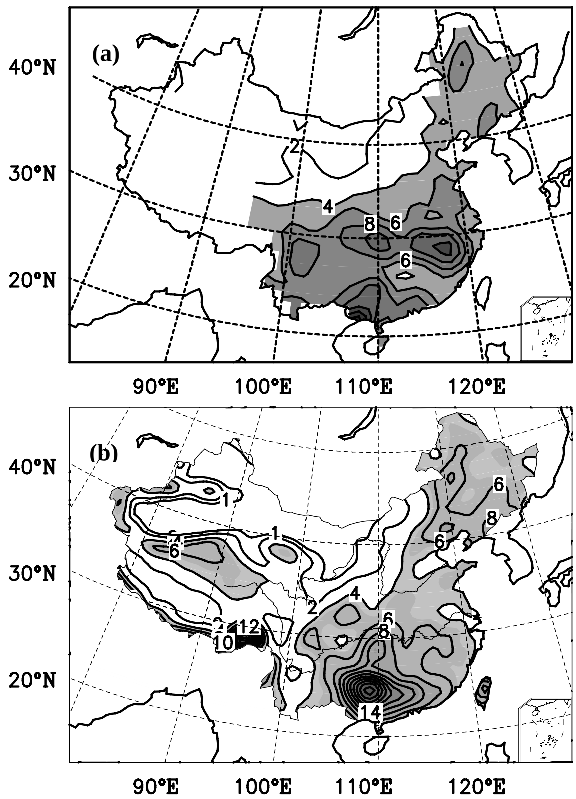


Figure 3. Precipitation in 1997 (a: observation; b: ATM; c: CPL1; d: CPL6. The values of the shaded area are greater than 4. Units: mm d^{-1}).

It is a severe flooding year in 1998 in the Yangtze River Basin. The observation (Figure 4a) indicates that it is above normal precipitation in all regions of the Yangtze River Basin and another rainfall center is South China. The simulation results in ATM are shown in Figure 4b. The rainfall in lower Yangtze River Basin is less than the observation, and the model overestimates the rainfall in South China. The results of the coupled model are given in Figures 4c and 4d. Neither the coupled model nor the uncoupled model can well simulate the rainfall in lower Yangtze River Basin and South China. However, compared with CPL1 and ATM, CPL6 gives results that are more consistent with the observation.



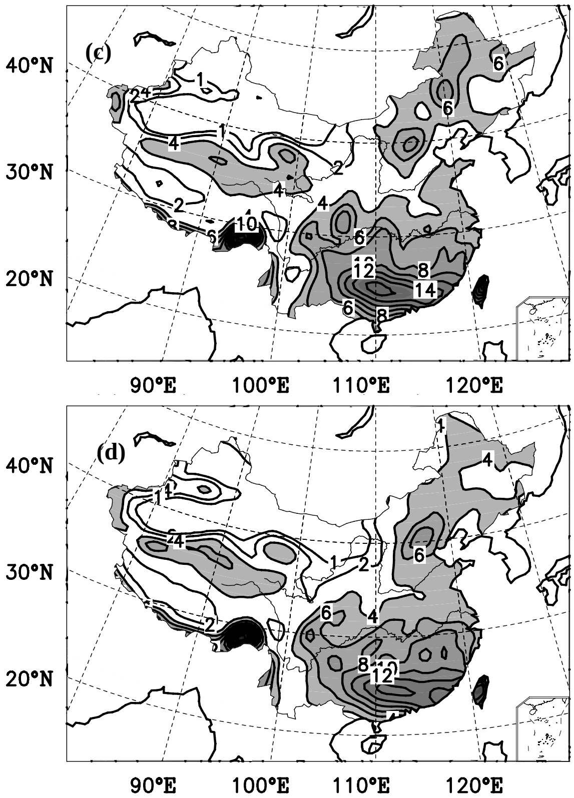


Figure 4. Same as Figure 3 but for 1998.

The analysis above shows that the coupled model shows good performance in simulating the summer precipitation in 1997 and 1998. Compared to the two groups of coupled experiments, the simulations with the 6-hour coupling time step are more reasonable. Therefore, the simulations in CPL6 are analyzed further in the following analysis.

3.3 *Circulation*

Figure 5 shows the geopotential height at 850 hPa in the summer of 1997 and 1998 and their differences. The western Pacific subtropical high of the NCEP/NCAR data is more westward in 1998 (Figure 5c) than that in 1997 (Figure 5f). The differences between them (Figure 5i) indicate that there are positive anomalies of southwest airstreams in the Yangtze River Basin, which may be one of the causes for the flood there. The simulation results of the uncoupled model RegCM3 (Figures 5b, 5e and 5h) show that the geopotential height is stronger than that of NCEP/NCAR data and the entire southeast region of China is controlled by the subtropical high, which may cause weaker precipitation in the southeast coast in ATM than in the observation. The coupled model can well simulate the spatial distribution of geopotential height in 1997 and 1998 (Figures 5a and 5d). In addition, it also can well simulate the geopotential height differences between 1997 and 1998, and their intensity and distribution in CPL6 are more accurate than those in ATM, and the results in ATM is not consistent with that of the NCEP/NCAR data. Analysis of the circulation (wind, geopotential height) at other levels (figures omitted) indicates that the coupled model can effectively improve the simulation of atmospheric circulation in the middle and low troposphere (the levels 1000 to 500 hPa).

3.4 *Water vapor transport*

The analysis of precipitation and circulation indicates that the coupled model RegCM3-POM performs well in the simulation of climate in East Asia. Monsoons in East Asia are very strong and the water vapor transport carried by the monsoon flow is closely related to the summer precipitation in China. Therefore, the vertically integrated moisture flux in summer is further analyzed to study the simulated vapor transport differences between the coupled model and the uncoupled model. The formula of the vapor transport is as follows:

$$Q = \frac{1}{g}\int_{p}^{p_s} \vec{V} q dp$$

Here, $\vec{V}$ is the wind speed, q the specific humidity, g the acceleration of gravity, p the top pressure, and p_s the surface pressure.

The specific humidity and wind speed outputs at levels 1000-300 hPa are analyzed. First, the daily water vapor flux is calculated and then the vertical integration is performed to determine the water vapor flux in the atmosphere column. The vapor transport distributions in the summers of 1997 and 1998 are shown in Figure 6. The lateral boundary conditions in the uncoupled model are the same as in the coupled model, so the water vapor from the lateral boundary in the two models is the same. Therefore, the differences of the vapor between the RegCM3 and RegCM3-POM are closely related to the air-sea interaction in the air-sea interface.

The water vapor from Bay of Bengal, South China Sea and Western Pacific is transported to eastern China in 1997 (Figure 6c) and the coupled model can well simulate the transport paths (Figure 6a). The NCEP/NCAR data (Figure 6f) and the results of the coupled model (Figure 6d) show that the Western Pacific subtropical high is more southward and westward in 1998 than in 1997. However, the uncoupled model RegCM3 (Figures 6b and 6e) fails in the simulation of the vapor transport paths. In addition, the coupled model can well reflect the water vapor differences between 1997 and 1998 (Figures 6g and 6i) and the results in ATM are not satisfactory (Figure 6h).

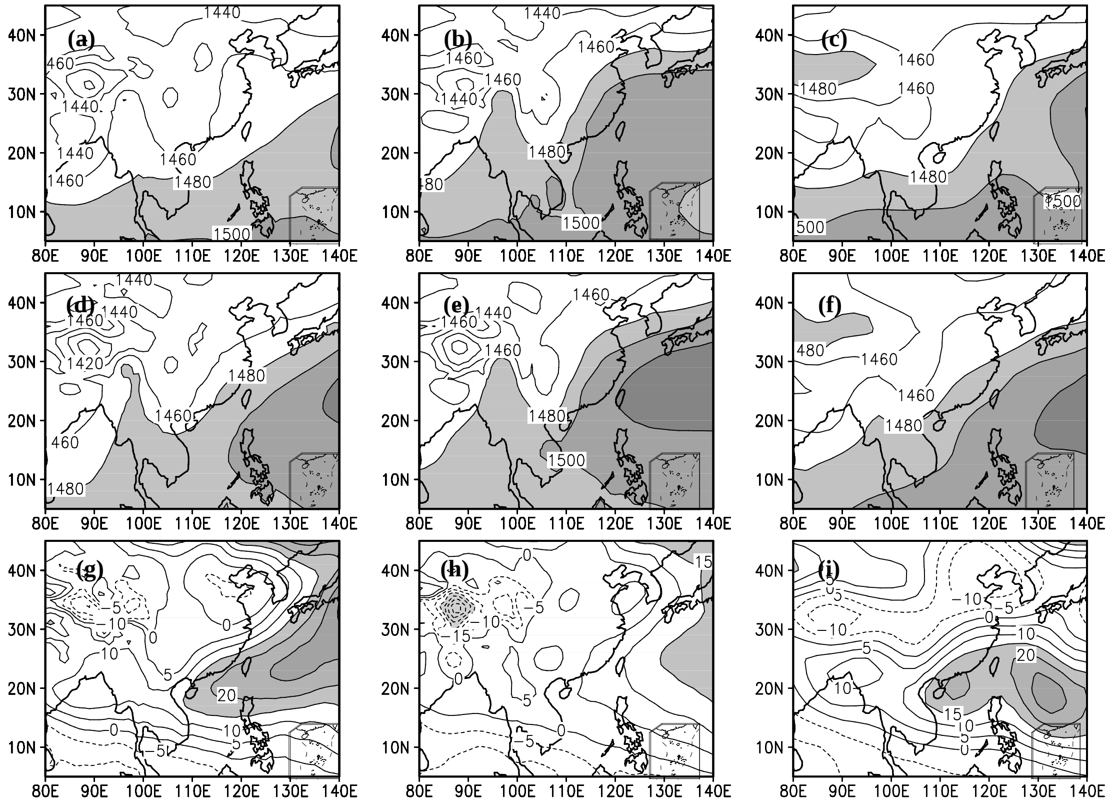


Figure 5. The summer geopotential height at 850 hPa level in 1997 and 1998 and their differences (a: geopotential height in CPL6 in 1997; b: in ATM in 1997; c: NCEP/NCAR data in 1997; d: in CPL6 in 1998; e: in ATM in 1998; f: NCEP/NCAR data in 1998; g: differences between 1997 and 1998 in CPL6; h: differences in ATM; i: differences in NCEP/NCAR data. The values in shaded areas are greater than 1480 in panels a to f and greater than 15 in panels g to i. Units: gpm).

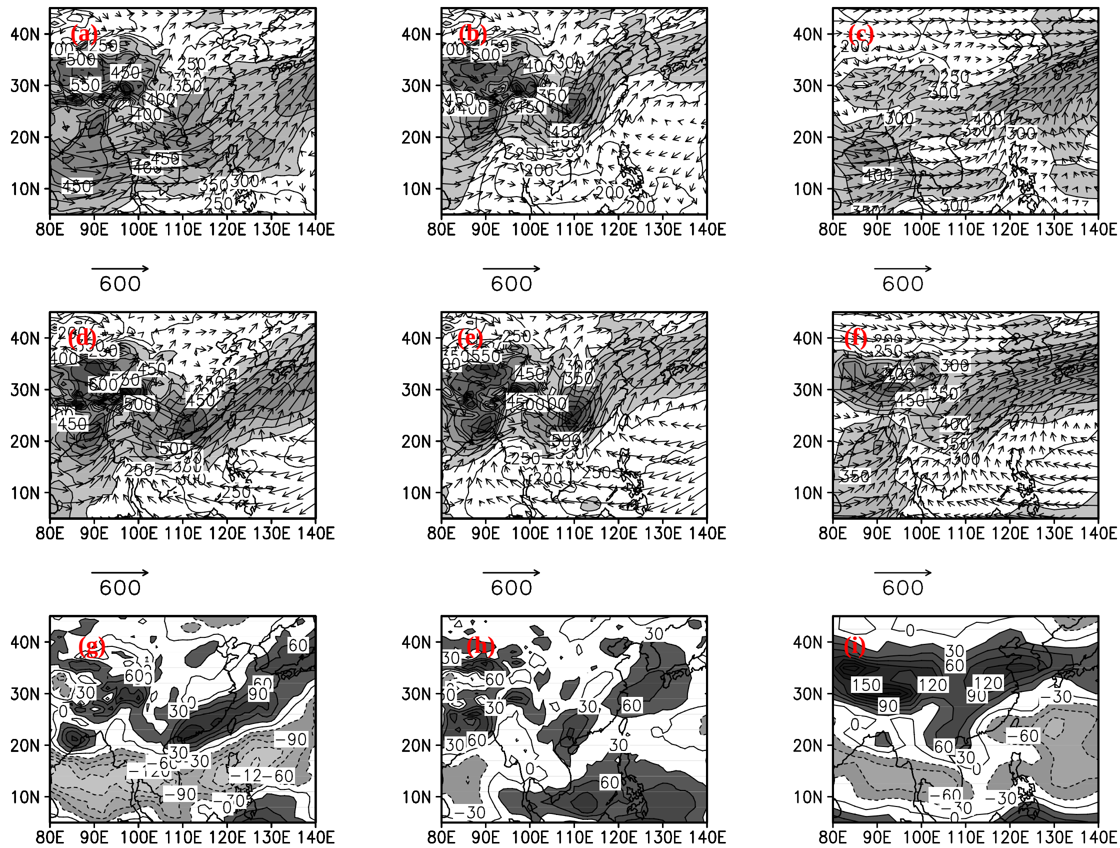


Figure 6. Same as Figure 5, but for vertical moisture flux (The values in shaded areas are greater than 300 in panels a to f and greater than 40 in panels g to i. Units: kg m^{-1} s^{-1}).

4 CONCLUSION

(1) The coupled models with different coupling time steps can well simulate the sea surface temperature distribution in 1997 and 1998 and the SST differences between 1997 and 1998 also are consistent with that of GISST data.

(2) The coupled model with 6-hour coupling time steps has better performance in the simulation of the drought in North China in 1997 and the results in ATM are not accurate. Neither the uncoupled model nor the coupled model can well simulate the precipitation in 1998, in contrast with the results in CPL1 and ATM. The results in CPL6 are slightly reasonable.

(3) The coupled model can effectively enhance the ability of simulating the circulation in low and middle troposphere. Analysis of water vapor transport indicates that the source regions of water vapor in 1998 are the South China Sea, Bay of Bengal and Western Pacific, and in 1997, the main source region is the Bay of Bengal. The coupled model can well simulate the water vapor differences between 1997 and 1998 and the results of the uncoupled model RegCM3 are not accurate.

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