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Simulation of regional temperature and precipitation in the past 50 years and the next 30 years over China

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ABSTRACT

Climate change was simulated based on greenhouse gas concentrations using IAP/LASG GOLAS 4.0. In the various regions of China, climate change was detected over the past 50 years of the 20th century and its trend was projected for 30 years into the future. The results show that the simulation is reasonable for the regions of China over the past 50 years. There were obvious warming trends of about 0.84 °C/50a in China, with maximum 1.05 °C/50a and minimum 0.63 °C/50a rates recorded in western and southern regions respectively, based on the greenhouse gas experiments within GOALS. The correlation between observed and simulated values greatly exceeds the 99% confidence level. Of particular note were clearly increased winter temperatures. Winter warming of 0.985 °C/50a across China, bounded by a maximum of 1.11 °C/50a in the Qinghai-Tibet Plateau and a minimum of 0.96 °C/50a in North China, calculated by GOALS, were only slightly different from recorded observations. In the future 30 years, annual mean temperatures will continue to rise (0.71 °C/30a) across the Chinese Mainland. Maximum increases will be in the northeastern region (1.0 °C/30a) and minimum increases in southern parts (0.36 °C/30a). Precipitation projections are more complex than those for temperature. In western China and North China, the precipitation will increase. An upward trend is also forecast for the Tibetan Plateau.

1. Introduction

Global warming has caused serious ecological and environmental deterioration, extreme climate events, such as flooding, drought, and other disasters, result in increasing social and economic losses. The Fourth Assessment report of the Intergovernmental Panel on Climate Change (IPCC) indicated that temperature change was very likely caused by increasing Greenhouse gases due to human activities (IPCC, 2007). The average air surface temperature increased in China in the past century, and the rate of warming is about 0.5–0.8 °C/100a. It is slightly higher than the global rate (0.6 °C ± 0.2). In the recent 50 years, the annual average surface air temperature increase of 1.1 °C in China, and warming rate of 0.22 °C/10a, were significantly higher than the Northern Hemisphere's and global average rate of warming in the same period (Ding et al., 2006).

Chinese scientists have researched the detection and attribution of climate change over China (Ding and Shi, 1997; Zhao et al., 2000; Gao et al., 2001; Guo et al., 2001; Zhao et al., 2005a, 2005b; Ding et al., 2007). The warming in northern China and the Qinghai-Tibet Plateau is more evident than in other areas. The annual precipitation trends did not change significantly in the past 100 years, but decadal variability is larger and precipitation trends show an obvious regional difference.

Human activity in different regions of China and the impact of climate change varies. Zhao et al. (2003) have detected climate change in Northwest China in the 20th century by using 7 global climate system models from the IPCC (2001). The increased greenhouse gas sulfate aerosol emissions in the 20th century, were accompanied by an average warming of 0.34–1.57 °C/100a and 0.90–1.86 °C/50a in Northwest China. From the mid-1980s, the eastern region of Northwest China, North China and Northeast China with relatively cool–wet climates have shown a transition to warmer, drier conditions, with different patterns in southeastern China and the western region of northwestern China (Su and Wang, 2007). Simultaneously, the temperature in northwest region began to rise rapidly, more than 0.6 °C, much higher than the national average. Summer precipitation in the western region is predicted to increase, but will decrease in the eastern part of Northwest China with doubled CO_2 (Zhang et al., 2003). Over the past 10 years in China's western region, 82.2% of the glaciers are in retreat, and the

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area of glaciers shrank by 4.5% (Liu et al., 2006), In Xinjiang, glacier runoff shows a clear trend of increase. Drought in Northeast China is more serious under climate change. If the global average temperature increases 1 degree, drought extent would increase 5–20%, to 22% in the Northeast (Xie et al., 2003). Beginning in the mid-1980s, the temperature in North China has continued to warm and precipitation decreased. The temperature increasing trend is predicted to continue into 2030 and the rate of warming could reach +2.5 °C. In 2030, North China's precipitation will also increase, with a simultaneous decrease in southern China (Liu et al., 2007).

However, due to the complex terrain and complex climate change across the different regions of China, the projected climate change trends differ. Simulation researches of climate change trends have not been extensively conducted for the different regions in China, except Western and North China. Therefore, this paper simulated the climate change trends in various regions of China using the IPCC (2001) greenhouse gases scenario and explored the initial mechanisms of climate change. Section 2 introduces the climate model and designs. Sections 3 and 4 show the influences of human activities on temperature and precipitation in various regions, which include the detection for the past 50 years of the 20th century and projections into the next 30 years of the 21st century, respectively. Section 5 explores a preliminary mechanism.

2. Model, experiment design and data

The IAP/LASG GOALS model is a Global Ocean–Atmosphere–Land system coupled model, which was developed by the State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics (IAP), and the Chinese Academy of Sciences (CAS). The model details were described in Wu et al. (1996) and Zhang et al. (2000). The atmospheric component of the coupled model is a spectral model with a rhomboidal truncation at a zonal 15 wave (R15), an equivalent grid spacing of horizontal resolution roughly 7.5° × 4.5°. There are nine levels in the vertical direction. The ocean component of the model is a global ocean general circulation model (OGCM) with the horizontal resolution 4° × 5° and 20 levels in depth (ML20-2). The land process model is a simplified version of the SSiB model with three soil layers, one vegetation layer, and eleven types of vegetation. A simple thermal dynamics sea ice model is coupled with the OGCM. The coupling scheme between atmospheric component and ocean component used is daily flux anomaly exchange (DFA) (Yu and Zhang, 1998).

The experiments included two integration runs, one a control run (CTL) and the other a forcing run (FORC), which includes three integrations with different initial conditions in each run for ensemble prediction. For the CTL run, the greenhouse gas concentrations remain set at a 1951 constant: CO_2 ~310 ppm, CH_4 ~ 1.147 ppm, N_2O ~ 0.289 ppm, CFC11 ~ 0.0007, CFC12 ~ 0.0093. For the FORC run, the real greenhouse gases concentration during 1951–2000 and scenario emission concentration during 2001–2030 were provided by the IPCC (2001). The period of integration spans 80 years from Jan. 1, 1950 to Dec. 31, 2030. Climate change in China was detected in the last 50 years of the 20th century and predicted into the future.

In this paper, the observational data, temperature and precipitation, at 160 stations, were provided by the China Meteorological Administration. The mean temperature during 1951–2000 for the Globe and Northern Hemisphere came from the British CRU. The average climate value was from 1961 to 1990. In order to better understand climate change in China, the area was divided into 5 regions: I northeastern region (40–55°N, 115–135°E), II North China region (30–42.5°N, 100–120°E), III Southern region (20–30°N, 100–120°E), IV Western region (27.5–50°N, 75–100°E) and V Plateau region (27.5–37.5°N, 80–100°E).

3. Detection of climate change in the last 50 years of 20th century

3.1. Climate change in China

3.1.1. Temperature

In order to explore the temperature component over the last 50 years of the 20th century over China and various regions of China, the temperature trend was calculated using GOALS. The

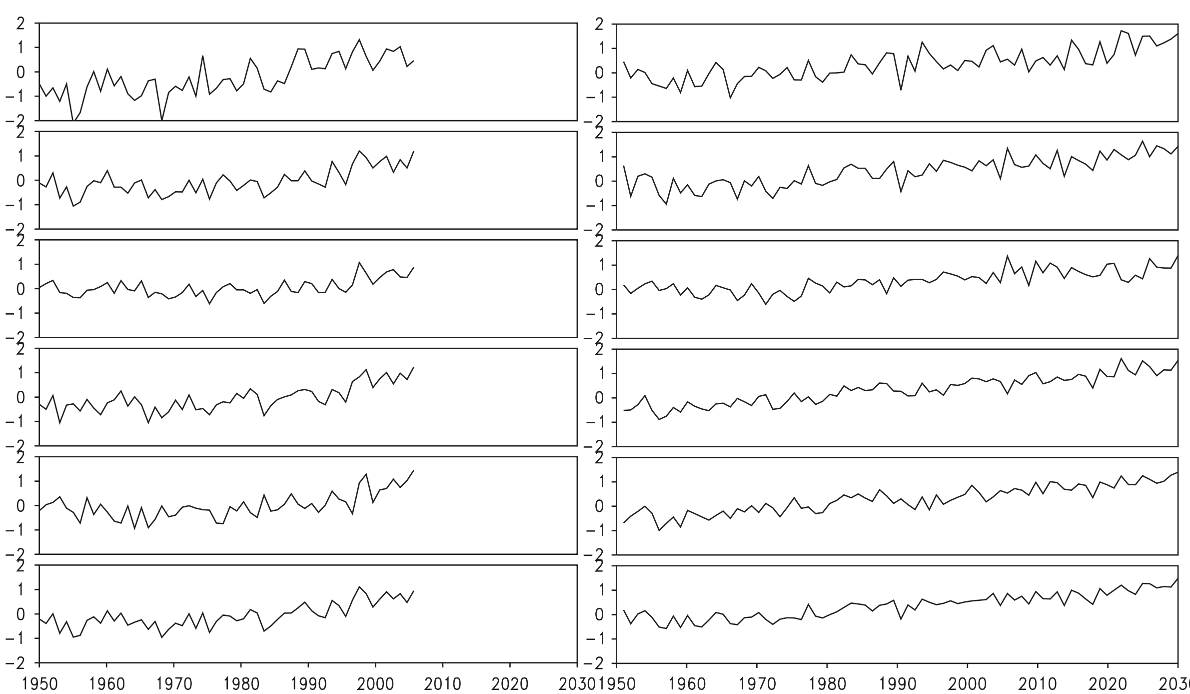

Fig. 1. Annual mean temperature time series of observation (left) and simulation (right) in the regions of China (°C); (note: from top to bottom I, II, III, IV, V, China).

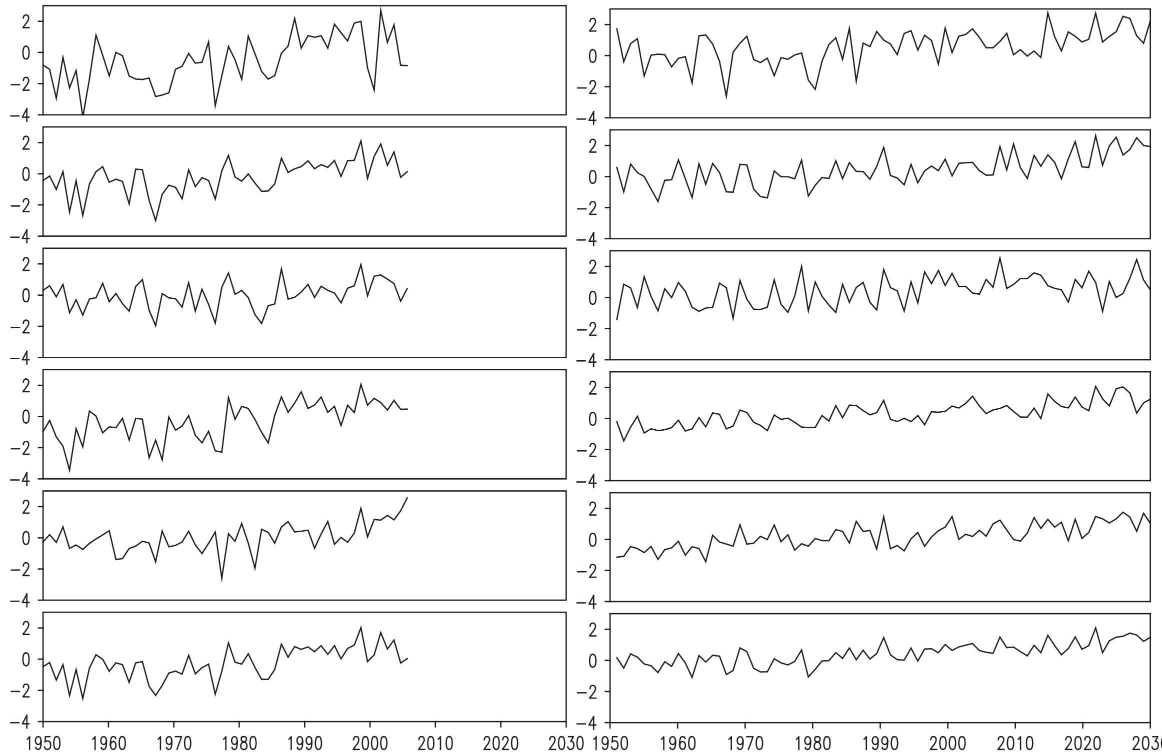

Fig. 2. DJF mean temperature time series of observation (left) and simulation (right) in the regions of China (°C) (note: same as above).

results show that there were two obvious periods of climate change in China. Before the 1980s, the annual average temperature was lower than normal in the regions and across China. From the mid-1980s, China's average temperature began to increase. This warming tendency was not evident in the CTL run. Fig. 1 shows the annual temperature change in China and across the regions. From observational data of the last 50 years (1951–2000), the linear trend is 0.92 °C/50a across the whole of China, which is greater than the GOALS projection. In the regions, the observed temperature linear trend is less than that of the simulation except for region I. The maximum warming rate is 1.71 °C/50a in region I, followed by region IV (western China,

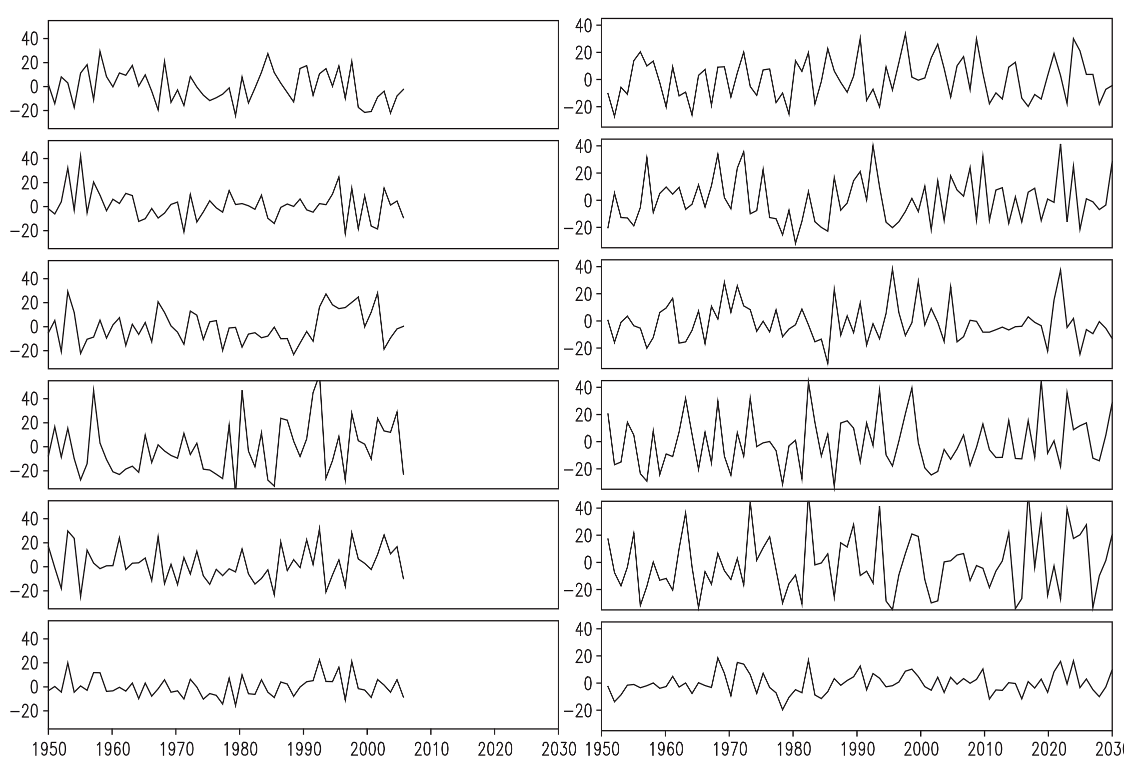

Fig. 3. Summer precipitation change trends in each region (%) (note: same as above).

Table 1
Temperature (°C/30a) and precipitation (mm/30a) linear trend from 2001 to 2003.

		I	II	III	IV	V	China
Temperature	Annual mean	1.00	0.76	0.36	0.71	0.71	0.71
	DJF	0.90	1.53	−0.12	0.77	0.80	0.77
Precipitation	Annual mean	−1.30	6.80	2.88	8.38	3.75	4.19
	JJA	−8.66	2.29	−9.07	24.41	16.43	2.24

0.885 °C/50a), region II (northern China, 0.83 °C/50a) and region V (Plateau, 0.59 °C/50a). The minimum rate is in region III where a change of 0.255 °C/50a is evident. However, the warmest, simulated rate of warming is in region IV (1.05 °C/50a), within the 0.90–1.86 °C/50a value obtained in northwestern China used by 7 models from IPCC (2001) (Zhao et al., 2003). Furthermore, the correlation between simulation and observation far exceeds the 99% confidence level in all regions of China and across the whole of China.

In the past 50 years, especially since the 1980s, there exists an obvious temperature increase in winter. Fig. 2 shows a DJF temperature change trend with observation and simulation in the regions. The warming is very evident from both observation and simulation data in the northern parts of China, such as northeastern, northwestern China and North China. However, the simulated change is slightly less than that observed except in the Plateau area and in southern China. For DJF temperatures in the regions of China, although the temperature dropped slightly in the early 1990s, after a short period it increased quickly. Correlation exceeds the 95% confidence level.

3.1.2. Precipitation

Observed and simulated annual and summer precipitation were compared. In this instance correlation was not apparent in most regions. The correlation coefficient was small or negative, except for the northeastern region (0.29). On the basis of observations over the last 50 years of the 20th century, the annual precipitation trend in northeastern China and North China is decreasing. In particular, North China's decline is obvious with a linear trend of −8 mm/50a. Precipitation in other regions is increasing slightly, especially in the western region, with a linear trend of 16 mm/50a. The trend of annual precipitation increase in the regions was simulated well, except in northeastern and North China.

Fig. 3 compares the observed and simulated JJA precipitation variation in the regions. For the various regions in each period, the observed precipitation trend was comparable to the GOALS simulation. For example, the climate was dry before the 1980s and wet after the 1980s in western China. There were four periods with two dry (before the mid-1960s, from the mid-1970s to the mid-1990s) and two wet phases (from the mid-1960s to the mid-1970s, from the mid-1990s to soon after 2000) in southern China. In most regions, simulations compare well with observations, although differences exist over some periods and in some regions. Overall, the precipitation trend is not as clear as that for temperature using the GOALS simulation, likely because the causal factors for precipitation are diverse and complicated. This evidence suggests that human activities may have impacted precipitation change, and the detectable effect is limited to the current global climate model at the regional level of simulation. This may remain the case as it is difficult to develop better simulations.

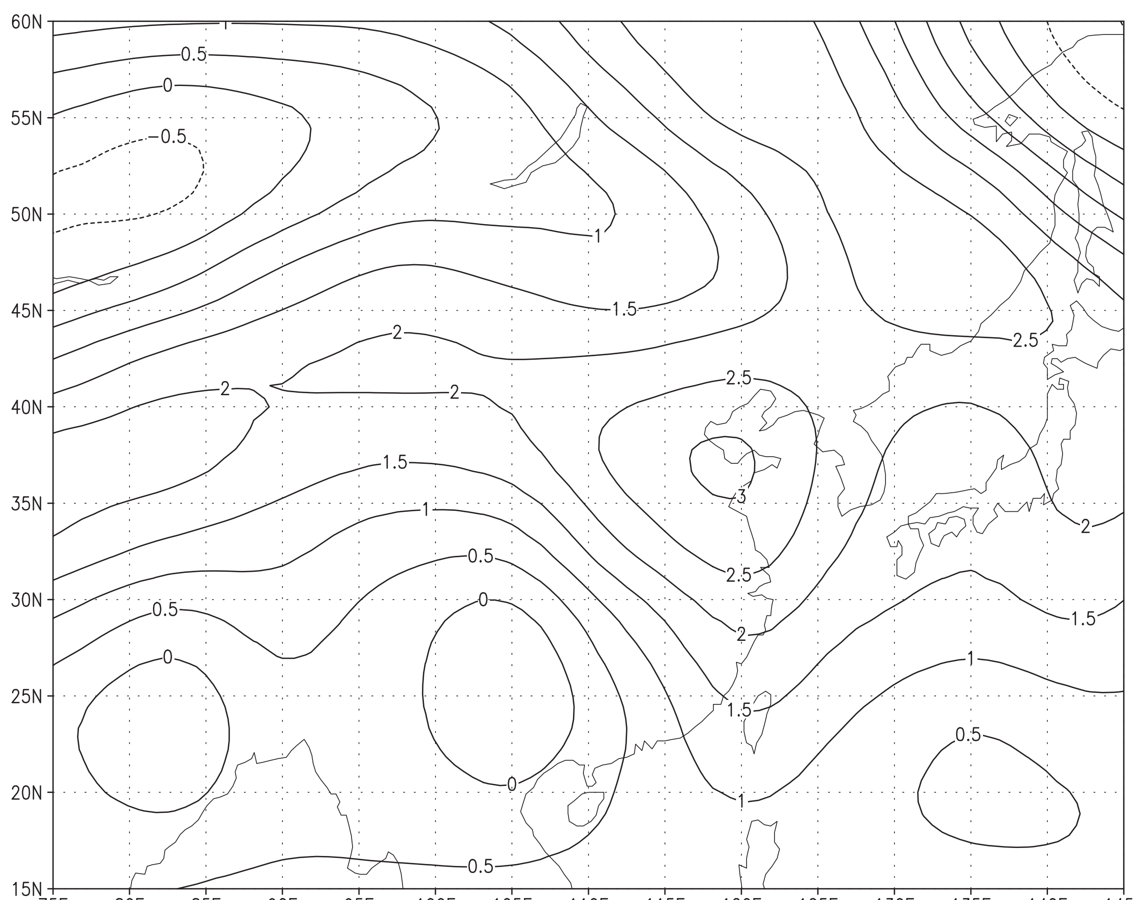

Fig. 4. DJF temperature anomaly over China in 2030 (°C).

4. Climate change trends in the next 30 years

4.1. Temperature

Over the next 30 years, temperatures across China are predicted to continue warming (see Figs. 1 and 2). The linear temperature trend in various regions in the next 30 years is shown in Table 1. Across China the annual temperature trend is 0.71 °C/30a, with the increase in the northern region projected to be 1.00 °C/30a and that in the southern region at least 0.36 °C/30a. To 2030, the annual temperature in China is predicted to increase about 1.49 °C above the mean, with the northeastern region increase of 1.61 °C being the greatest and that in the southern region (1.39 °C), the least. In winter however, the greatest temperature increases could appear in North China with an increase of 2.24 °C and a linear trend of 1.53 °C/30a by 2030. In contrast, the increase in the southern region will be slower with a linear trend of −0.12 °C/30a, thereby only increasing by 0.5 °C in 2030, representing the smallest rise for any region across China. In general, the predicted warming rate will be substantial in northern China and relatively small in the southern region over the next 30 years (see Fig. 4).

4.2. Precipitation

The precipitation trend is complex in regions of China, differing in each region. For the next 30 years, in the Northeastern region, both annual precipitation and summer rainfall are predicted to decline, with linear trends of −1.3 mm/30a and −8.7 mm/30a, respectively Fig. 5. For the remaining regions, the annual precipitation will increase. Summer rainfall is predicted to decrease by −9.1 mm/30a in the southern region. In the next 30 years, precipitation could increase most notably in western China, and the average summer linear trend is 24.4 mm/30a, and the annual precipitation linear trend is 8.4 mm/30a. For the Tibetan plateau, the JJA precipitation increase will be obvious with a linear trend of 16.4 mm/30a. JJA precipitation in the Tibetan plateau is expected to show an upward trend in the future. Fig. 6 shows the distribution of JJA precipitation anomaly percentage in 2030. Summer precipitation is predicted to increase in northern and decrease in southern China.

5. Preliminary exploration of climate change mechanisms

After the 1980s, the mid-high latitude geopotential height at 500 hPa has been rising. The simulation shows that this rise will be more obvious in the Chinese mainland in the early 21st century. North China will show the greatest increase at mid-latitude. The warming rate will be relatively small in the southern region with only a slow rise at 500 hPa. Due to the extra-forcing from human activities, surface temperatures will rise and sensible heat will increase, thereby raising the geopotential height. Inversely, this rise will enhance the ground temperature increase in a positive feedback process.

For the JJA height difference at 500 hPa, between the periods of 2001–2030 and 1977–2000, it is clear that the height will decrease in northern China and will increase in southern China. This is a key component of the circulation which would result in an increase in the JJA precipitation in North China and coincident decrease in southern China, over the next 30 years.

Simultaneously, for the JJA vortex difference at 500 hPa between 2001–2030 and 1977–2000, the positive vortex in northern China indicates a strengthening of the convergent, ascending motion resulting in an increase in precipitation. Conversely, in southern

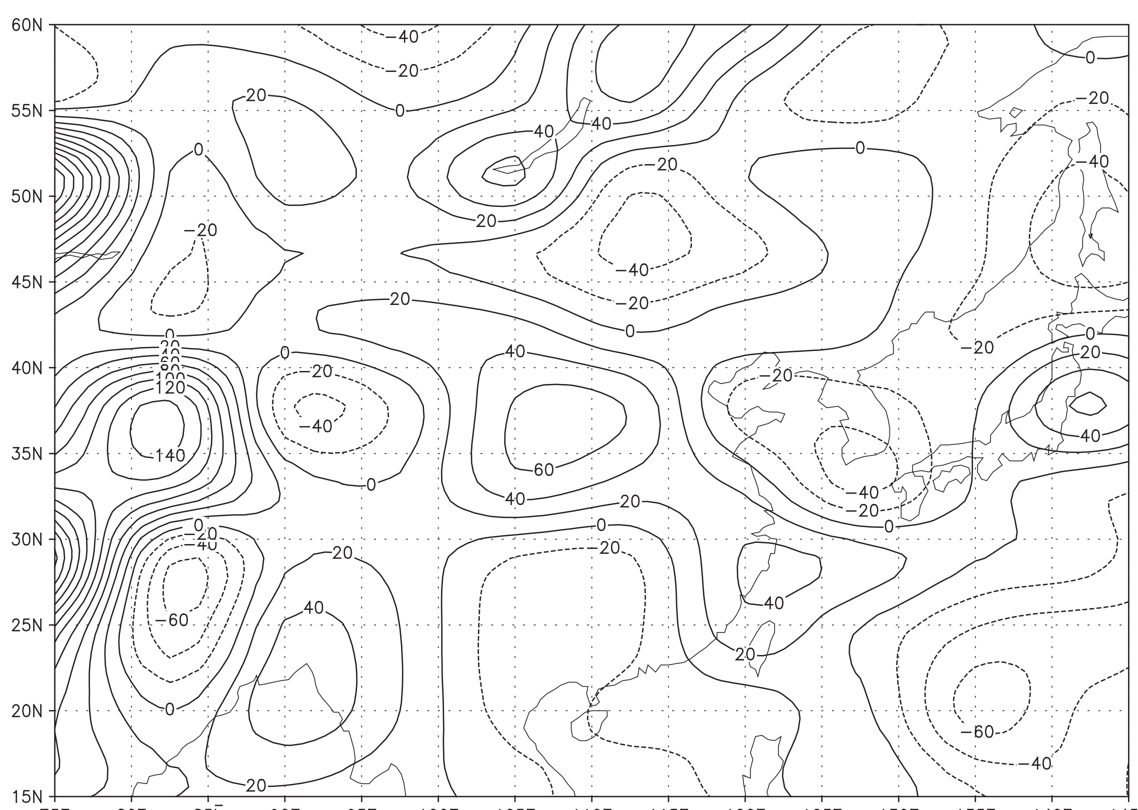

Fig. 5. Precipitation anomaly percentage in summer 2030 (%).

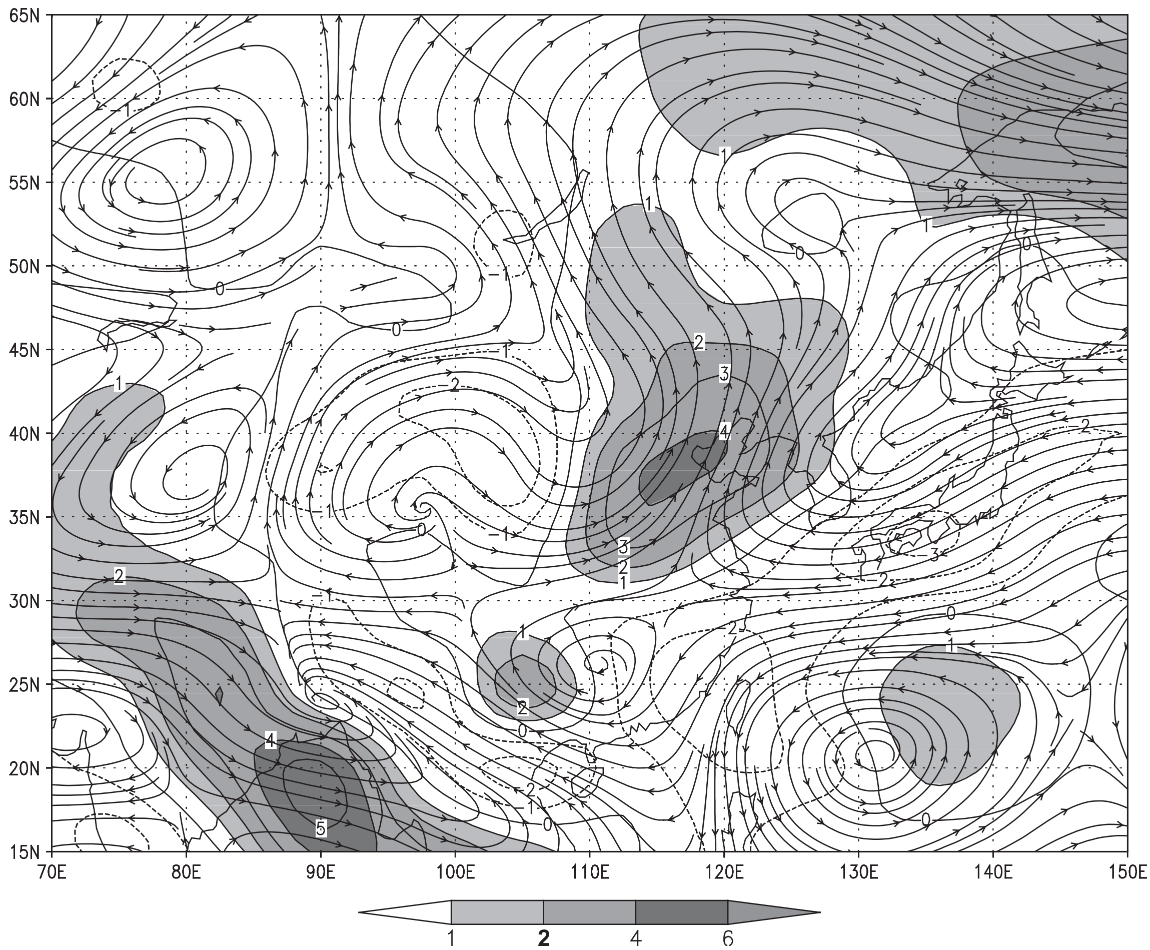

Fig. 6. Difference of JJA water vapor flux at 700 hPa in China between 2001–2030 and 1977–2000 (unit: 10^{-5} kg/m^2 s) (note: shaded area express water vapor flux greater than 1×10^{-5} kg/m^2 s, solid illustrates stream line, and broken line indicates less than -1×10^{-5} kg/m^2 s).

China, the negative vortex shows strong descending divergence resulting in a decrease in precipitation.

Fig. 6 demonstrates the difference in the distribution of water vapor flux between 2001–2030 and 1977–2000 at 700 hPa. An obvious water vapor convergence area comes from the south and the Yellow Sea, providing the water vapor necessary for precipitation, so an increase in precipitation is highly probable in regions I and II. Southern China however, is an area of water vapor divergence and so the precipitation would decrease. In West China, divergence is in the eastern part and convergence in the west, resulting in dry conditions in the east and wet in the west (the most parts of West China).

6. Conclusions

The GOALS model simulated climate change in the past 50 years of the 20th century and predicted climate change trends in the next 30 years in the regions of China with real greenhouse gases concentration and an emission scenario concentration provided by the IPCC (2001).

The detection of climate change in the regions of China in the past 50 years of the 20th century indicated an obvious warming of 0.92 °C/50a in the Chinese mainland, a maximum warming of 1.71 °C/50a in northeastern China, and a minimum rate of 0.26 °C/50a in southern China as computed from the observed data. The control run did not provide equivalent warming trends. There were obvious warming trends, by about 0.84 °C/50a, in the Chinese mainland with maximum and minimum values of 1.05 °C/50a and 0.63 °C/50a respectively, under the greenhouse gases experiments of GOALS. The correlation between observation and simulation far exceeds the 99% confidence level. So, climate warming in the regions of China can be attributed to greenhouse gases. The most obvious warming occurred in winter. Over the past 50 years of the 20th century, analysis of observed data reveals a warming of 1.90 °C/50a in the Chinese mainland and a maximum warming of 2.94 °C/50a the northeastern and a minimum 0.555 °C/50a in southern China. However, the warming calculated from GOALS is of 0.985 °C/50a in the Chinese mainland with a maximum of 1.11 °C/50a in the Plateau region and a minimum 0.955 °C/50a in North China.

Over the next 30 years, the annual mean temperature will continue to increase (0.71 °C/30a) in the Chinese mainland with maximum increases in northeastern area (1.0 °C/30a) and minimum in the southern (0.36 °C/30a) areas. In winter, the linear warming trend is 0.768 °C/30a for the mainland. However, the biggest projected increase is for the northeast region and not in North China with a linear trend of 1.527 °C/30a. In contrast, the southern region is predicted to experience a slight cooling (−0.12 °C/30a).

Projections for precipitation are more complex than those for temperature. Over the next 30 years, annual precipitation is predicted to increase except for the northeastern region (−1.3 mm/30a). Summer precipitation however, will apparently decline in northeastern and southern China, with linear trends of −8.7 mm/30a and −9.1 mm/30a respectively. Precipitation is predicted to increase in the remaining regions of China, and the most obvious increase will occur in west with a linear trend of 24.4 mm/30a. An upward trend will also appear in the Tibet Plateau. The GOALS model was successful in simulating basic climate change patterns across the regions of China over the last 50 years of the 20th century, but, because of the coarse resolution of the model and the influence of other, more complex factors, the prediction of climate change trends into the future 30 years requires further research.

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