Prediction Research of Climate Change Trends over North China in the Future 30 Years*

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ABSTRACT

A simulation of climate change trends over North China in the past 50 years and future 30 years was performed with the actual greenhouse gas concentration and IPCC SRES B2 scenario concentration by IAP/LASG GOALS 4.0 (Global Ocean-Atmosphere-Land system coupled model), developed by the State Key Laboratory of Numerical Modelling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (CAS). In order to validate the model, the modern climate during 1951–2000 was first simulated by the GOALS model with the actual greenhouse gas concentration, and the simulation results were compared with observed data. The simulation results basically reproduce the lower temperature from the 1960s to mid-1970s and the warming from the 1980s for the globe and Northern Hemisphere, and better the important cold (1950–1976) and warm (1977–2000) periods in the past 50 years over North China. The correlation coefficient is 0.34 between simulations and observations (significant at a more than 0.05 confidence level). The range of winter temperature departures for North China is between those for the eastern and western China's Mainland. Meanwhile, the summer precipitation trend turning around the 1980s is also successfully simulated. The climate change trends in the future 30 years were simulated with the CO_2 concentration under IPCC SRES-B2 emission scenario. The results show that, in the future 30 years, winter temperature will keep a warming trend in North China and increase by about 2.5°C relative to climate mean (1960–1990). Meanwhile, summer precipitation will obviously increase in North China and decrease in South China, displaying a south-deficit-north-excessive pattern of precipitation.

Key words: GOALS 4.0, North China, CO_2 concentration of B2 emission scenario, climate change projection

1. Introduction

Because of the temperature rising and precipitation decreasing, the drought over North China has become increasingly serious since the 1980s. The analysis of the 160-station climate data over China (Chen et al., 1991) indicated that the temperature over North China in the 1980s increased by 0.54°C comparing with the 1950s. While Huang et al. (1999) discussed the drought trends over North China with the 336-station dekad precipitation over China from June to August, and pointed out that the precipitation in the 1980s was less than that in the 1970s and the drought trend aggravated and that the total area-mean precipitation in the 1980s was 30% less than that in the 1950s. Meteorologists and climatologists have made lots of research about the problems of high temperature, less precipitation, and serious drought trend over North China. Yang et al. (2005) and Zhu and Yang (2003) researched the relationship between the decadal change of global air-sea interaction and the precipitation over North China, and pointed out that there

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existed an abnormal correlation between the precipitation over North China and the PDO (Pacific decadal oscillation): if the sea temperature over the tropical mid-eastern Pacific rises and the sea temperature over the central part of northern Pacific is less than normal, which means that the Pacific is in warm phase, and then the North China areas are controlled by high pressure and precipitation decreases. Similarly, Huang and Wu (1989, 1999) discussed the mechanism of the drought over North China with the air-sea interaction. Zhang et al. (2003) analyzed the causes of the North China drought from the abnormal characters of the atmospheric circulation and pointed out that the main reason resulting in the less precipitation over North China was that the southerly was weaker than normal causing less water vapor to reach there. Liu and Guo (2005) also pointed out that the abnormality of pressure system in mid-high latitudes affected the strength of East Asian monsoon and that the weakening of East Asian monsoon since the end of 1970s was caused by the positive pressure abnormality in the China-Mongolia area, whose northerly abnormal wind in the east prevented the water vapor from being transported northward, so that the East Asian monsoon was weakened and the precipitation in North China decreased. With the research about the surface moisture of North China, Ma and Fu (2001) pointed out that the index of surface moisture in North China has decreased and the aridity increased since the 1980s.

Now, it is generally acknowledged by IPCC that the concentration of CO_2 in the atmosphere is one of the main reasons that cause the global climate warming (2001). Guo et al. (2001) simulated and concluded that the climate of East Asia obviously responds to the 1% increment per year of the CO_2 concentration, especially the temperature over the mid-high latitude continents increased more notably. Are the temperature rising and the precipitation decreasing over North China related to the increment of the CO_2 concentration? There is no similar work in China now. Using the real greenhouse gases emission and the emission change in the future provided by IPCC, we simulated the possible affection of the CO_2 emission to the current climate change over North China and the climate change trend over North China in the future 30 years, with the IAP/LASG GOALS 4.0 (Global Ocean-Atmosphere-Land system coupled model) developed by the State Key Laboratory of Numerical for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (CAS).

2. Model and experiment

GOALS 4.0 model is a Global Ocean-Atmosphere-Land system coupled model developed by the LASG. The atmospheric general circulation model (AGCM) is a spectral model truncated at R15 (approximately 7.5°lon.×4.5°lat.) resolution with nine vertical levels (hereafter R15L9). The ocean general circulation model (OGCM) is a model with the resolution 4°lon.×5°lat. in horizon and 20 levels in vertical. We also used a simple thermodynamics sea ice model and a simplified simple biosphere model (SSiB). The SSiB has 3 soil layers, 1 canopy layer, and 11 biomes. The OGCM and AGCM were coupled in daily flux anomaly (DFA) exchange (Yu and Zhang, 1998).

The experiments included two integration runs, one is the control run (CTL) which remains greenhouse gases concentration constant in 1951, such as CO_2–310 ppm, CH_4–1.147 ppm, N_2O–0.289 ppm, CFC11–0.0007 ppm, and CFC12–0.0093 ppm, and the other is the forcing run (FORC) which includes 3 integrations with different initial conditions in each run for ensemble. But for FORC run, the real greenhouse gases concentration during 1951–2000 and scenario emission concentration during 2001–2030 were provided by IPCC (2001). The period of integration is the total 80 years from 1 January 1950 to 31 December 2030. Climate change in China was detected in the last 50 years of 20th century and predicted in the future 30 years.

In this paper, temperature and precipitation at 160 stations were from China Meteorological Administration. The mean temperature data during 1951–2000 in the globe and Northern Hemisphere were taken from CRU, British. The North China region is 34°–42°N, 112°–121°E in this paper, which includes 17 stations prescriptive in the Project of "Research of Short-term Climate Prediction in China".

3. The background simulation of the climate change in the past 50 years

3.1 Global climate change

With the observation data of the greenhouse gas in the atmosphere during 1950–2000 and the prediction data released from 2000 to 2030-B2 condition (Fig.1), provided by IPCC assessment report, we simulated the global climate change resulting from the increasing density of CO_2. Figure 2 shows the variations of annual temperatures for the global and Northern Hemisphere by use of the GOALS 4.0 model and the actual observation, respectively. In the control experiment, which means that the density of the greenhouse gas remains constant, only the inter-decadal and inter-annual variations exist inside the air-sea coupled system, which means that it cannot reflect the global climate warming trend in the mid-term and the beginning of the later stage of the 20th century. However, after considering the real greenhouse gas emission in the atmosphere, the model can preferably reproduce the global climate variation trend in the recent 50 year. The negative abnormality of the temperature over the globe and the Northern Hemisphere during the 1960s and 1970s and the calefaction during the 1980s can be embodied in the result. All above fully show the close

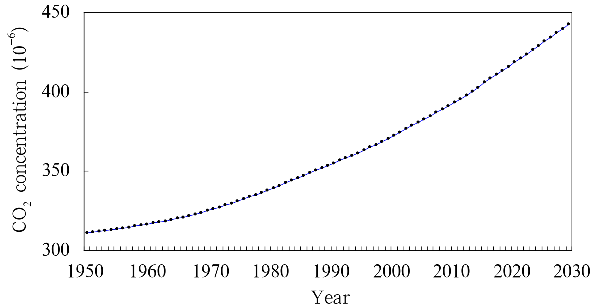

Fig.1. Temporal variation of CO_2 scenario emission concentration (from IPCC) (unit: ppm).

relationship between the global warming and the increasing density of the greenhouse gas caused by the human activities. At the same time, they also prove the ability of the GOALS 4.0 model to simulate the global climate variations, which can be seen in Ma (2002) for more details.

In order to compare with other studies expediently, we divided global climate variations in the second half of 20th century into two more apparently cold or warm periods, i.e., the colder period from 1950 to 1976 and the warmer period from 1976 to 2000, and further discussed the climate variations over North China and its possible mechanism. The climate equilibrium state used in this article is the 30-yr mean between 1961 and 1990. All anomalies in this article were made relative to this mean.

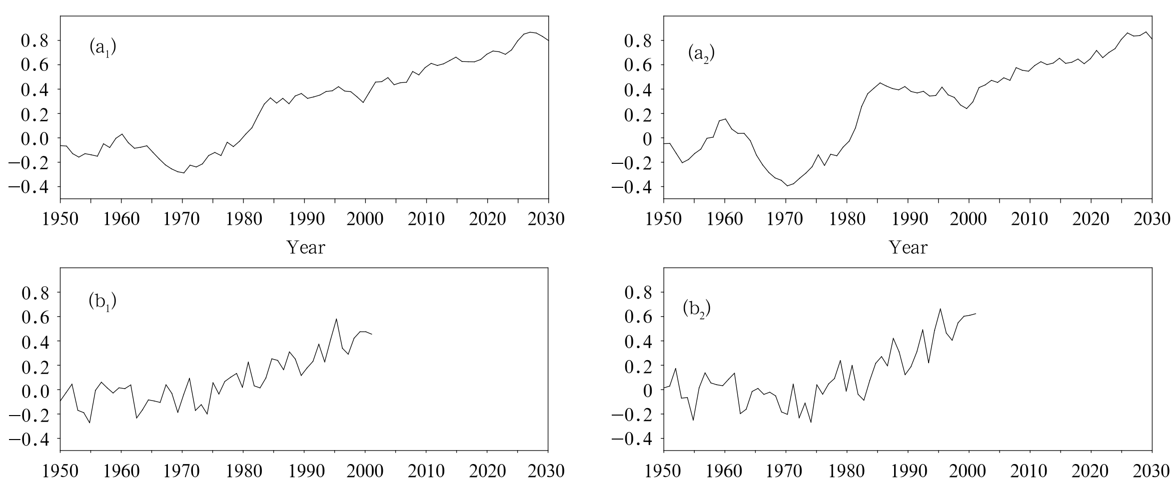

Fig.2. Simulated (a) and observed (b) variations of annual temperature in the globe (a_1,b_1) and Northern Hemisphere (a_2, b_2) (unit: °C).

3.2 Climate change over North China

3.2.1 Winter temperature

The climate change trend of North China is consistent with that of the global climate change trend. The comparisons between the inter-annual variations of the winter temperature over North China since 1950 simulated in GOALS 4.0 model and the real observation results are shown in Fig.3. The observation results show there are two apparent stages of the winter temperature over North China in the 50-yr period in the 20th century: the temperature was relatively lower than normal from 1950s to the mid and later stage of 1970s and North China is in a cold period, while the temperature rises apparently from the mid and later stage of 1970s to the end of 1990s and North China is in a warm period. As a result of the simulation considering the density of CO_2 in the real atmosphere, there are two apparent cold or warm periods in the climate variation of the winter in North China, which are the cold period before 1980s and the warm period later. The correlation between the simulation and the real observation is 0.34, which satisfies the confidence level of 0.05, meaning that the variations of CO_2 density have significant effect on the variation of the temperature in winter over North China (while there is no this feature in the control experiment).

The observation data show that the temperature rising in the mid-high latitudes of the Northern Hemisphere in winter is more apparent than that in mid-low latitudes, while the temperature rising in the continents is more apparent than in the oceans (IPCC, 2001). The simulation result of the GOALS 4.0 model can also reproduce these features (Fig.4), i.e., there is a greater temperature rising range over the mid-high latitude of the Eurasia Continent and a slightly less temperature rising range over the China's Mainland. But the China's Mainland is totally in calefacient mode, which means that the temperature rising range is most significant over most of Northeast China, eastern Inner-Mongolia, and South China (>0.4°C), relatively small over most of western China (about 0.2°C) and about 0.2–0.4°C over North China, which is in the two areas.

Considering the effect of the variation of CO_2 density, GOALS 4.0 model can not only simulate the temperature rising trend since the beginning of 1980s, but also get better results of the cold period from 1950 to 1975. For example, in the cold period, the temperatures over the China's Mainland are generally lower than normal, with temperature variations less than –0.4°C, and the negative center of temperature variation is mainly in the central part of China.

Similarly, the effects of the variation of CO_2 density in the atmosphere on the temperature in summer are clear, in which the temperature rising range is apparent less than that in winter, but the areas with significant temperature rising are still in the mid-high latitudes. The areas with significant temperature rising in China's Mainland are the northern Northeast China and coasts of eastern China (>0.3°C), only 0.1–0.2°C in Xinjiang and 0.2–0.3°C in North China.

3.2.2 Summer precipitation

In the second half of 20th century, the precipitation in summer over North China underwent two wet or dry periods. There is more precipitation over North China before the 1980s, which is the relative wet period, while there is less precipitation over North

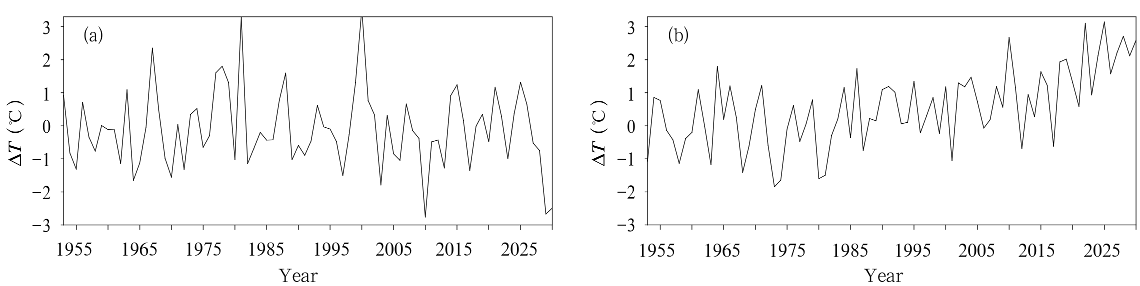

Fig.3. Winter (DJF) temperature change trends in North China. (a) Simulation by GOALS and (b) observations.

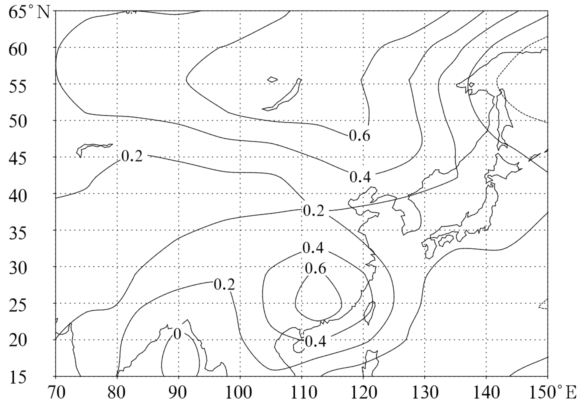

Fig.4. Winter (DJF) average temperature change during 1977–2000 in North China (unit: °C). Contours are plotted at intervals of 0.2°C, with solid lines for ⩾0°C and dashed for <0°C.

China after the 1980s, which results in serious drought. GOALS 4.0 model simulates the variation trend of the precipitation percentage anomalies in summer over North China (Fig.5a). The simulation of wet or dry period of the precipitation trend over North China in the past 50 years of 20th century is similar to the observation result, such as the abundant precipitation period before the 1980s, the rainless period after the 1980s, and the relative humid short-term period in the beginning of 1990s. Therefore, the simulation of the GOALS 4.0 for the variation of summer precipitation over North China is reliable.

With all the mentioned above, after considering the effect of the variation of CO_2 density in the real atmosphere, GOALS 4.0 model has better ability to simulate the climate change of North China. No matter winter or summer, it can well simulate the climate change of North China in the past 50 years of 20th century, the two apparent cold or warm periods and two apparent rainy or rainless periods in summer. All these manifest that the variations of the emission density of the greenhouse gases in the atmosphere are main causes for the climate change over North China.

4. The climate change trends of North China in the future 30 years

4.1 Winter

It can be seen from all the analyses mentioned above that, after the density of CO_2 in the atmosphere is considered, the GOALS 4.0 model has better ability to simulate the climate change over North China. In Figs.2 and 3, we can see that the warming trend since the mid-term of 1980s will extend to 2030, which means that the climate change of the world and North China will continue to remain in warming mode.

In the difference of the mean winter temperature between 2001–2030 and 1977–2000 (Fig.6), there is a warming band from east to west across China's Mainland and the warming mode still remains in the eastern China, with the warming center in North China, which is the most significant area in magnitude and variation range, with the mean greatest warming range above 1.1°C, while there is a smaller warming range in the north side of Eurasia Continent, which means that the warming range will slow down in the future 30 years in these regions. The southern Southwest China is the region with the least warming range, even with

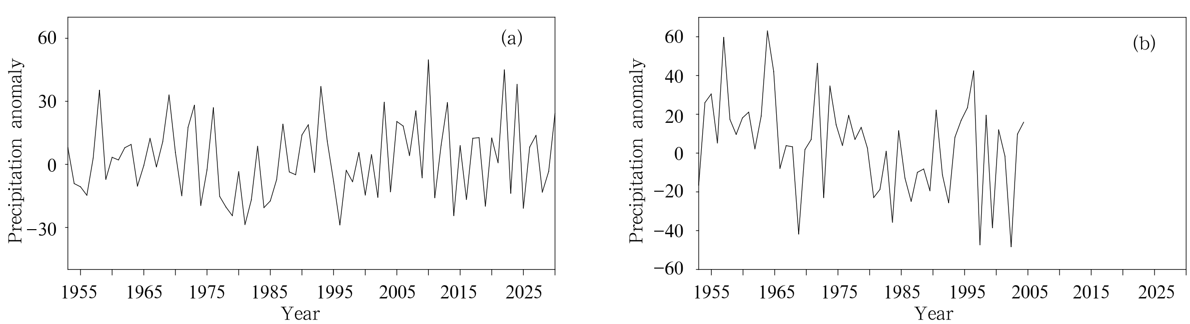

Fig.5. Summer (JJA) precipitation anomaly percentage in North China. (a) Simulation by GOALS and (b) observations.

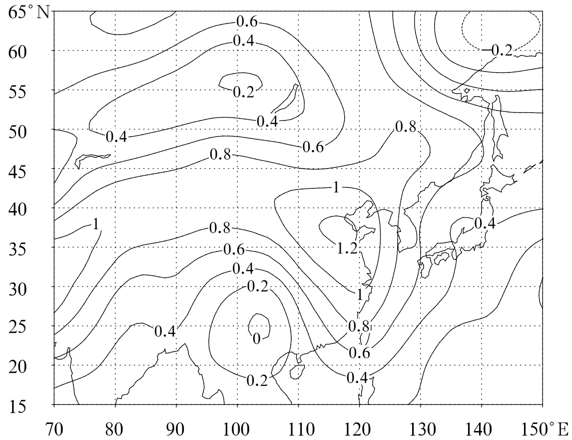

Fig.6. Difference distributions of winter (DJF) temperature between 2001–2030 and 1977–2000 in North China (unit: °C). Contours are plotted at intervals of 0.2°C, with solid lines for ⩾0°C and dashed for <0°C.

negative warming range in parts. It is anticipated that the warming range of North China in winter will ascend step by step in the future 30 years of 21st century and the warming center will be about 2.5°C in 2030. In the winter of 2030, the distribution of precipitation in China will be wetter in north and drier in south, and there is relative less precipitation in central China, while there will be more precipitation in North China.

4.2 Summer

It is remarkable that with the more warming of the global climate, the precipitation of North China in the future 30 years will increase. In Fig.7, we can get that there is an increasing trend of precipitation in most areas of northern China (except Northwest China) and North China will be the most significant area with increasing precipitation and Northeast China and southern Southwest China will be the next, while there will be less precipitation in the areas south to the Yangtze River, including Jiangnan and South China. All these mean that the precipitation distribution of China in summer will change significantly, i.e., there will be more precipitation in northern areas and less precipitation in southern areas. It is very interesting that the global air-sea coupled model in the National Climate Center (NCC-CGCM) also gets the similar result. At the same time, the temperature of North China in summer will persist in increasing.

With the increasing of human activities and the global warming, the temperatures over North China will continuously ascend. However, in surveying the current climate change of North China, the changes over North China do not ascend due to the increasing density of greenhouse gases, which means that the variation of the precipitation is nonlinear and the

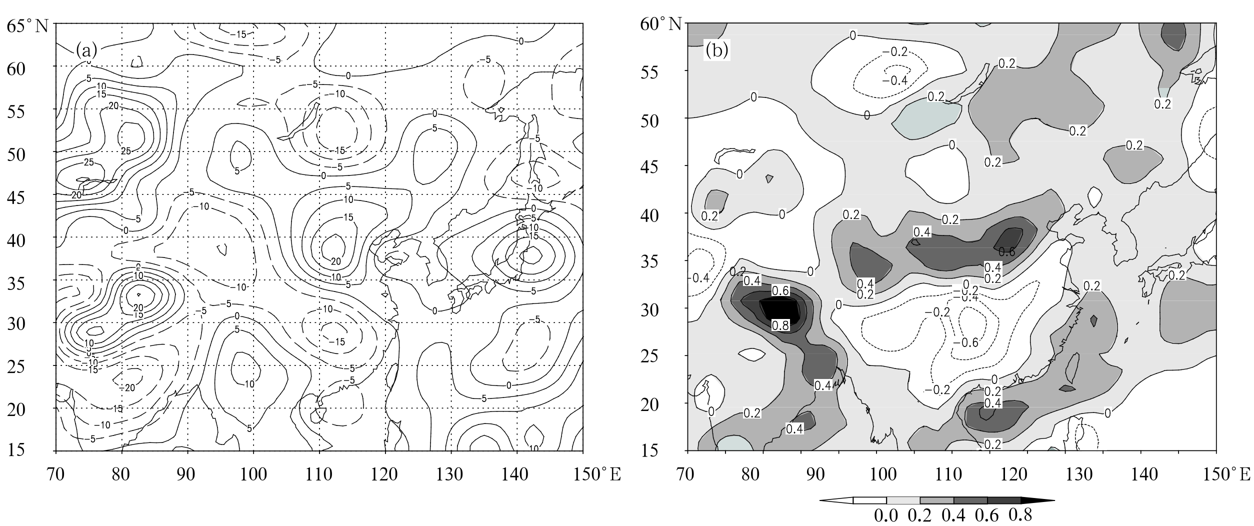

Fig.7. Simulation of summer (JJA) precipitation anomalies in 2030 over North China by (a) GOALS (unit: mm) and (b) NCC-CGCM (unit: mm day^{-1}). Solid lines are for ⩾0°C and dashed lines for <0°C.

climate changes are not fully controlled by the variation of the greenhouse gases' density. It is unknown whether the climate changes are controlled by the laws of atmospheric intrinsic activity or by other forcing factors, which need further studying.

4.3 Causation analysis

The 500-hPa geopotential height field over North China has been in the ascending mode since the mid-later stage of 1970s. The mean 500-hPa geopotential height field from 1977 to 2000 is apparently higher than that from 1950 to 1976, and will be ascending in the future 30 years. In the future 30 years, the ascent of the geopotential height field in winter over China is more apparent as shown in Fig.8, indicating that the ascending range over North China is the most significant and North China is the area with the highest ascending range of geopotential height in the mid-high latitudes of Asia. The ascending range of potential height field over southern China is relatively small. Because of effect of the human activities, the surface temperatures ascend, which made the sensible heat enhancing, and elevated the geopotential height field at the same time, while the strengthening of the geopotential height will intensify the surface temperature. This is a positive feedback process.

Unlike the winter, in the past 50 years, the 500-hPa geopotential height anomalies over North China are controlled by cyclone anomalies when the precipitation in summer over North China is in wet period, while the 500-hPa geopotential height anomalies over North China are controlled by anticyclone anomalies when the precipitation in summer over North China is in dry period. It is because that there will be less sensible heating and more latent heating in the period with more precipitation, which will make the 500-hPa geopotential height field descending. The difference of the geopotential height field between 2001–2030 and 1977–2000 is presented in Fig.9, which shows clearly that the height field over the northern mainland of China descends and the height field over the southern mainland of China ascends. This is one of the main circulation factors that there will be more precipitation in the summer over North China and less precipitation in South China.

Zhang et al. (2003) pointed out that the reason for the dryness and less precipitation in North China from the 1980s is the strengthening of northerly and weakening of southerly over North China, which restrains the transportation of the water vapor to the north. The difference distribution of the vapor transportation on 850 hPa in summer over North China between 2001–2030 and 1977–2000 is shown in Fig.10. There will be much stronger southerly flows over North China in the future 30 years than in the early period. North China is an apparent vapor convergence area and with the increasing of vapor condition, which will supply the necessary vapor condition for the increasing of the precipitation over North China.

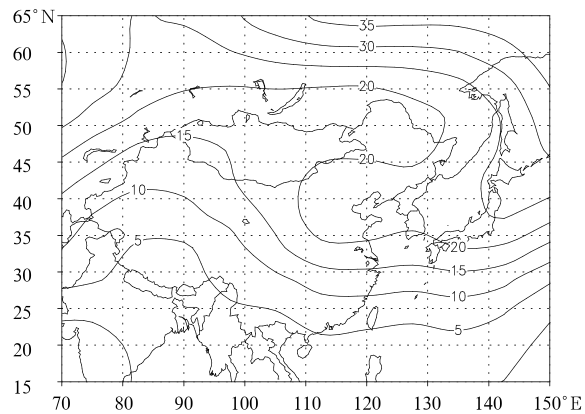

Fig.8. Summer (JJA) height anomalies at 500 hPa over North China in the future 30 years (unit: gpm).

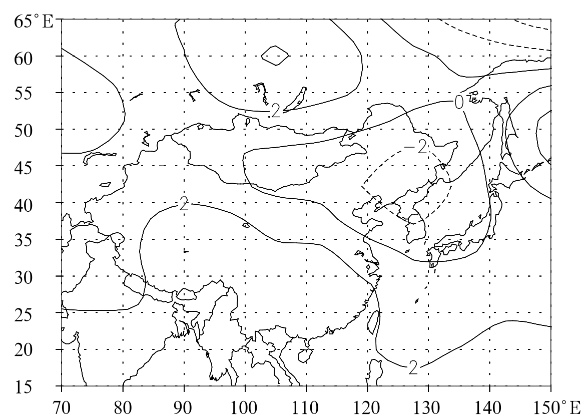

Fig.9. Winter (DJF) difference of height at 500 hPa over North China between 2001–2030 and 1977–2000 (unit: gpm).

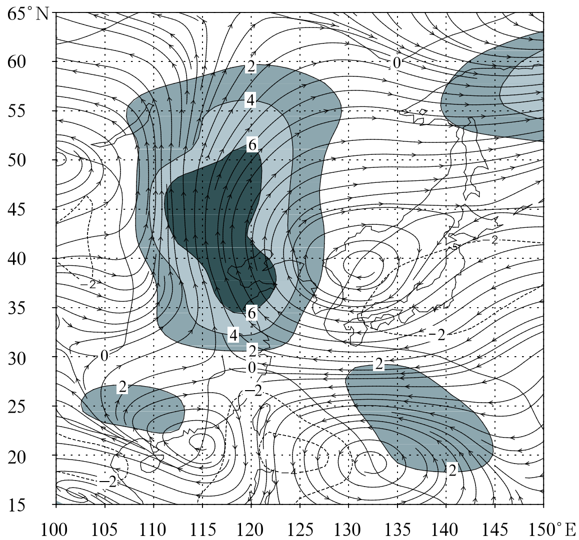

Fig.10. Summer (JJA) difference of water vapor flux at 850 hPa over North China between 2001–2030 and 1977–2000 (unit: 10^{-5} kg m^{-2}s^{-1}).

5. Conclusions

Using the GOALS 4.0 model and considering the effect of the real greenhouse gases density in the atmosphere and its emission in the future, we have simulated the climate changes in the past 50 years of 20th century over the North China area and predicated the climate change trend in the future 30 years, and obtained the following conclusions:

(1) After the real emission of the greenhouse gases in the atmosphere was considered, GOALS 4.0 model could well simulate the climate change over North China during the second half of 20th century, and reproduced the cold or warm periods in winter and the flood or drought periods in summer around the 1970s, which demonstrated that GOALS 4.0 model has better ability to simulate the climate change over North China.

(2) In the future 30 years, the temperature over China's Mainland appears to be in ascending tendency and the North China area would be the most significant areas with the greatest temperature rising range in the China's Mainland and the temperature rising range would reach 2.5°C in 2030, while there would be the least temperature rising range and the least temperature rising range in the southern Southwest China, even there would be temperature decreasing in parts of above areas.

(3) During 2001–2030, the more precipitation in the north and less precipitation in the south except Northwest China would be the precipitation distribution pattern over the eastern China in summer, i.e., there would be more precipitation in North China while there would be less precipitation in the southern China.

(4) The 500-hPa height field over the China's Mainland in winter would continue to ascend, and the North China would be the most significant areas. While the 500-hPa height field of North China in summer would decrease, and the southerly in 850 hPa would strengthen. This is the main circulation factor repondsible for the trend that the temperature in winter would ascend and the precipitation in summer would increase over North China in the future 30 years.

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