Climate Change Projections for the 21st Century by the NCC/IAP T63 Model with SRES Scenarios *

XU Ying (徐 影), ZHAO Zongci (赵宗慈), LUO Yong (罗 勇), and GAO Xuejie (高学杰)

Laboratory for Climate Studies of China Meteorological Administration, National Climate Center, Beijing 100081

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ABSTRACT

The projections of climate change in the globe and East Asia by the NCC/IAP T63 model with the SRES A2 and A1B scenarios have been investigated in this paper. The results pointed out a global warming of 3.6°C/100 yr and 2.5°C/100 yr for A2 and A1B during the 21st century, respectively. The warming in high and middle latitudes will be more obvious than that in low latitudes, especially in the winter hemisphere. The warming of 5.1°C/100 yr for A2 and 3.6°C /100 yr for A1B over East Asia in the 21st century will be much higher than that in the globe. The global mean precipitation will increase by about 4.3%/100 yr for A2 and 3.4%/100 yr for A1B in the 21st century, respectively. The precipitation will increase in most parts of the low and high latitudes and decrease in some regions of the subtropical latitudes. The linear trends of the annual mean precipitation anomalies over East Asia will be 9.8%/100 yr for A2 and 5.2%/100 yr for A1B, respectively. The drier situations will occur over the northwestern and southeastern parts of East Asia.

The changes of the annual mean temperature and precipitation in the globe for the 21st century by the NCC/IAP T63 model with SRES A2 and A1B scenarios are in agreement with a number of the model projections.

Key words: globe, East Asia, 21st century, projection, climate change

1. Introduction

For the latest 15 years, the climate change has been paid more attention by the policy-makers, scientists, and the public. The global warming of 0.4-0.8°C for the 20th century has been measured by the instrumental observations. The atmospheric concentration of CO_2 increased from 280 ppm for the period 1000-1750 to 368 ppm in the year 2000 with an increase of 27%-35%. In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely due to the increase in greenhouse gas concentrations (IPCC, 2001).

Many global and regional climate models with the different scenarios have investigated the climate change in future. Since the end of the 20th century, a number of the new Atmosphere-Ocean General Circulation Models (AOGCMs) with the SRES A2 and B2 scenarios have investigated the projections of the climate change for the 21st century. The atmospheric concentration of CO_2 might increase to about 540-970 ppm by 2100 (IPCC, 2001). The projections by the models with SRES scenarios pointed out the obvious warming of 1.4-5.8°C in the globe during the period 1990-2100 (Gordon and O'Farrell, 1997; Haywood et al., 1997; Mitchell and Johns, 1997; Roeckner et al., 1999; Emori et al., 1999; Meehl et al., 2000; Cubasch et al., 2001; Boer, 2004).

Chinese scientists have developed an atmosphere-ocean-land general circulation model with a high resolution of T63 (named NCC/IAP T63) at the end of the 20th century. The control run of the NCC/IAP T63 indicated that the model had a reasonable simulation on several key variables such as temperature, precipitation, sea level pressure, atmospheric circulation, and sea surface temperature anomalies in the globe and East Asia. The model had a capability to simulate several important phenomena such as East Asian monsoon, ENSO, and the thermohaline

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circulation (Zhang et al., 2000; Ding et al., 2000; Zhao et al., 2004; Xu, 2002).

In the recent years, the NCC/IAP T63 model has been employed to the seasonal and annual predictions over East Asia and the Pacific Ocean that was joined by the China and East Asian Prediction Workshop each year since 2001, the sensitivity experiments of the physical mechanisms of East Asian monsoon, and the impacts of human activities on climate change in the globe and East Asia (Li and Zhao, 2002; Xu, 2002; Ding et al., 2004a; Li et al., 2004; Zhao et al., 2004; Ding et al., 2004b).

The IPCC Working Group 1 (WG1) Fourth report will be published in 2007. For contributing to the report, in this research, the projections of climate change by the NCC/IAP T63 with SRES A2 and A1B will be presented in the following sections. Section 2 is going to introduce the brief description of the model and the design of the scenarios. Sections 3 and 4 will provide the projections for the 21st century in both globe and East Asia, respectively. The last section will give conclusions and discussions.

2. Brief description of the NCC/IAP T63 model and design of human emissions

The atmospheric and oceanic components of the NCC/IAP T63 model were created and developed by National Climate Center, China Meteorological Administration and Institute of Atmospheric Physics, Chinese Academy of Sciences, respectively. The atmospheric and oceanic models have 16 and 30 vertical layers with a horizontal resolution of 1.875° latitudinal and longitudinal grids (T63), respectively.

The atmospheric model was based on the medium-range weather forecast model of Numerical Forecast Division of National Meteorological Center (China), which could be traced back to ECMWF Cray-based model. A number of changes were made and developed in the atmospheric component to improve its performance. They were the dynamic networks and several physical processes such as introducing a reference-atmospheric scheme, atmospheric mass-conservation scheme, the semi-implicit scheme in cell-integrated semi-Lagrangian mode, reduced truncation error, radiation-clouds-trace gases scheme, convective parameterization, land-vegetation model with three layers, boundary layer process, and seasonal snow model. A complicated scheme of cloud and radiation (Morcrette scheme and k-distributive radiation scheme) has been selected. The scheme allowed the cloud-covers occurring at any level of the model partly. With another way, the scattering process of cloud was considered in the radiative scheme. The gaseous absorbers included H_2O, CO_2, and O_3, as well as aerosols were prescribed (Dong et al., 2000; Ding et al., 2000; Climate System Modeling Division, 2005).

The oceanic model was based on the original LASG OGCM (20-layer with a $4°\times5°$ resolution) and developed as a model with the higher resolutions (L30 T63) including 10 layers within top 250 m, another 10 layers between 250 to 1000 m, and the rest 10 layers between 1000 and 5600 m, and the better physical parameterizations such as introduced Gent and McWilliam mixing skill and Pakanowski and Philander mixing scheme for the upper ocean (Zhang et al., 2000), as well as the "flux adjustment" term that was added to the surface fluxes of heat, water, and momentum which were passed from the atmosphere to the ocean model. No "rigidity" approximation was applied in the model. Therefore, the sea level was a predictand (Yu and Zhang, 2000). For a reasonable simulating of the thermohaline and salt cycle, some relative parameters have been improved (Yu, personal communication). In this research, a thermodynamic sea ice model was coupled to the ocean model.

The control run of NCC/IAP T63 model in our research was arranged as follows: Before the coupling, the atmospheric model ran for more than 100 yr, and the oceanic model ran for more than 3000 yr, separately. After the coupling, the coupled model ran for more than 100 yr for the spin up. Then, the coupled model carried out the run from 1900 to 2100.

The IPCC SRES scenarios A2 (high emission) and A1B (medium emission) for both the 20th and 21st centuries have been selected as the designs of human activities. Those data were obtained from IPCC website.

Several major climate variables such as annual

and seasonal surface air temperature, sea surface temperature, sea level pressure, 500 hPa height, precipitation, and wind velocity in the globe and East Asia (15°-60°N, 70°-140°E) have been projected in the research. Due to the limited pages, surface air temperature and precipitation will be presented in this paper. The anomalies of the annual and seasonal mean temperature and precipitation in the 21st century relative to the present 30 yr of 1961-1990 were calculated.

3. Projections of global climate change

3.1 *Surface air temperature*

Figure 1 shows the time evolution of the anomalies of the global and hemispheric mean temperature for the 21st century relative to 1961-1990 as projected by the NCC/IAP T63. A global warming of 4.4°C and 3.3°C by 2100 is projected by the NCC/IAP T63 with SRES A2 and A1B, respectively. The linear trends of the global mean temperature in the 21st century will be 3.6°C/100 yr and 2.5°C/100 yr for A2 and A1B, respectively. The temperature over the Northern Hemisphere will be warmer than the Southern Hemisphere (Fig.1). The range of the temperature change by the NCC/IAP T63 is similar to most coupled model projections as mentioned in the report of IPCC 2001.

The geographical distributions of the annual and seasonal mean surface air temperature anomalies for 2071-2100 relative to 1961-1990 are presented in Figs.2 and 3, respectively. The annual mean temperature will increase everywhere as a result of the NCC/IAP T63 with SRES scenarios, except for some parts of Antarctic region. The obvious warming of 4.0-6.0°C for A2 and 4.0-5.0°C for A1B will appear in the middle and high latitudes of the Northern Hemisphere for 2071-2100 relative to 1961-1990. There will be a less warming of 0.5-1.5°C in the low latitudes (Fig.2). The warming of 12.0-16.0°C in some parts of high latitudes of the Northern Hemisphere in winter (DJF) will be much larger than the annual and summer (JJA)

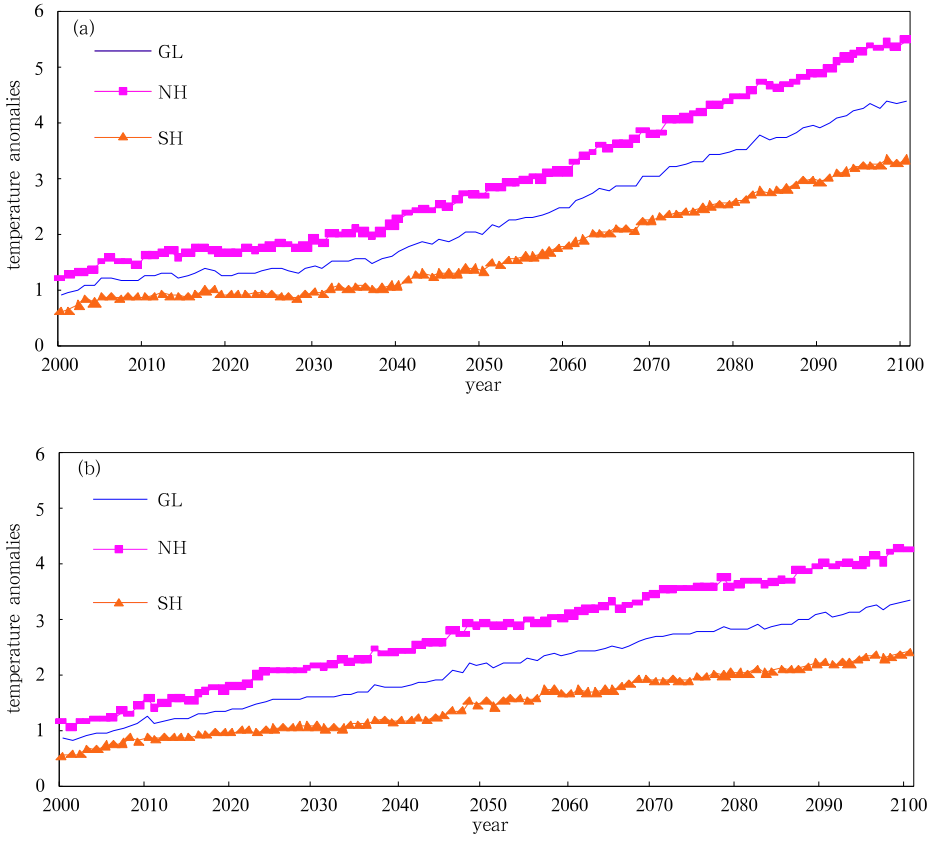

Fig.1. Time evolution of the global and hemispheric mean temperature anomalies for the 21st century relative to 1961-1990 as projected by the NCC/IAP T63 with SRES A2 (a) and A1B (b) (unit: °C).

warming (Fig.3).

3.2 *Precipitation*

The time evolutions of the anomalies of the annual mean precipitation in the globe and both hemispheres for the 21st century relative to 1961-1990 are depicted in Fig.4. It is indicated that the global and hemispheric mean precipitation will increase in the 21st century as projected by the NCC/IAP T63 with the SRES scenarios. The linear trends will be about 4.3%/100 yr and 3.4%/100 yr as projected by the NCC/IAP T63 with SRES A2 and A1B, respectively. The SRES A2 will cause the wetter situation than that for the SRES A1B. For example, it will be 6.0% for A2 and 4.7% for A1B by 2100, respectively (Fig.4).

Figures 5 and 6 respectively give the geographical distributions of the annual and seasonal mean precipitation for 2071-2100 relative to 1961-1990 as projected by the NCC/IAP T63 with SRES A2 and A1B. The annual mean precipitation will increase by about 10%-30% and 30%-70% over some parts of the tropical, middle and high latitudes of both hemispheres, respectively. In contrast to the wetter regions, some parts of the subtropical latitudes will become drier by about -10%-30% (Fig.5). The seasonal distributions indicate that the summer mean rainfall will increase by about 30%-70% over the warm pool of the western Pacific Ocean and by about 100%-300% over the Sahara regions for 2071-2100 in comparison with that of 1961-1990 (Fig.6).

By summarizing the projections of the global changes by NCC/IAP T63 and comparing with other model results, Fig.7 indicates a scatter diagram of the projections of the global mean temperature and precipitation changes by a number of global models for 2100. A global warming of 3.1°C with a range of 0.7°C to 5.5°C and wetting of about 4% with a range of 0.4% to 8.8% as projected by 8 models with A2 and B2 (or A1B) for 2100 are noticed in Fig.7. The simulations by the NCC/IAP T63 belonged to the larger warming

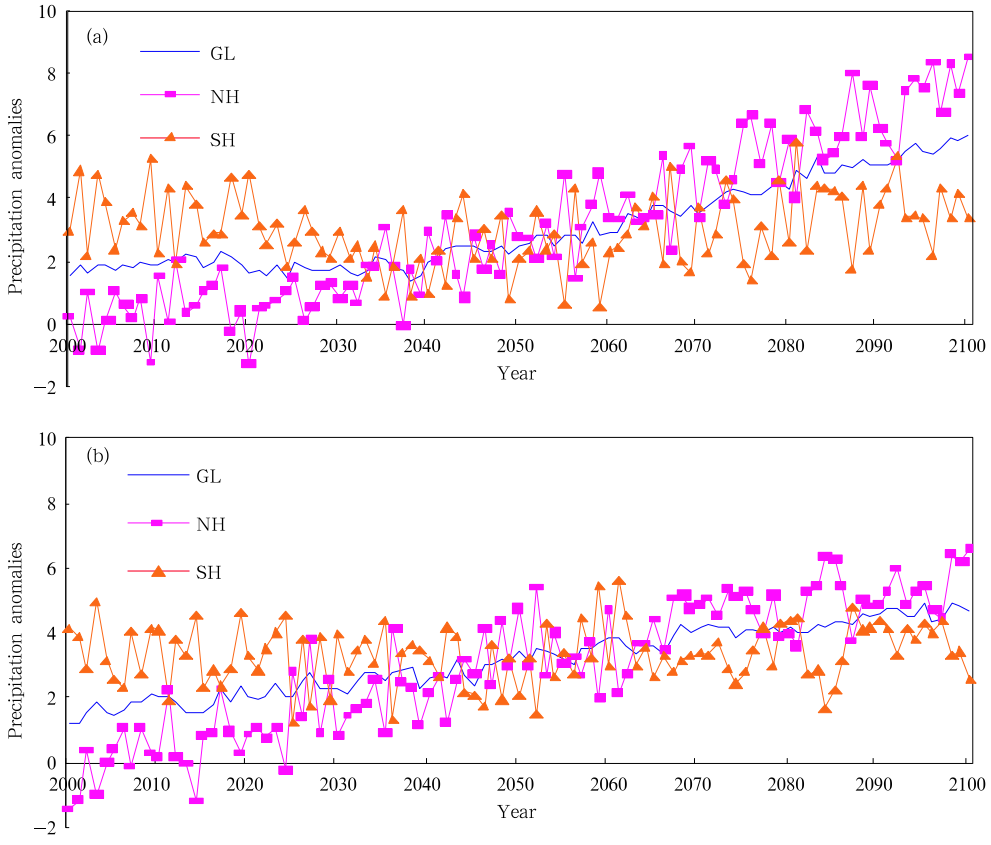

Fig.4. Time evolution of the global and hemispheric mean precipitation anomalies for the 21st century relative to 1961-1990 as projected by the NCC/IAP T63 with SRES A2 (a) and A1B (b) (unit: %).

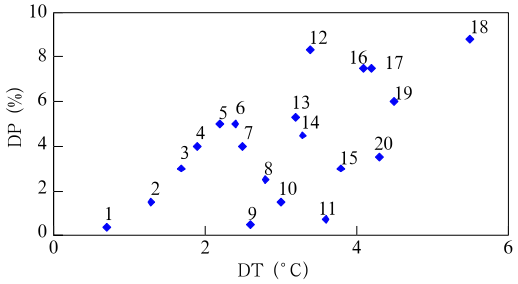

Fig.7. Scatter diagram of changes of the global mean temperature (DT) and precipitation (DP) in 2100 as projected by eight AOGCM models with SRES A2 and B2 (1:MRIB2, 2:MRIA2, 3:CSMB2, 4:DOEB2, 5:GFDLB2, 6:DOEA2, 7:CSMA2, 8:HADLB2, 9:ECHAMB2, 10:CCCB2, 11:ECHAMA2, 12:GFDLA2, 13:CSIROB2, 14:NCCA1B, 15:HADLA2, 16:CSIROA2, 17:CCSRB2, 18:CCSRA2, 19:NCCA2, and 20:CCCA2; other 7 model results were from IPCC 2001).

projections among the model groups (Fig.7).

4. Projections of climate change over East Asia

We pay more attention to East Asia where it is a monsoon region with a vast population. The projections of climate change over East Asia for the 21st century due to the SRES scenarios A2 and A1B are going to be provided in the following section.

4.1 *Temperature*

The linear trends of temperature change over East Asia will be 5.1°C/100 yr for A2 and 3.6°C/100 yr for A1B, respectively. The warming of 6.9°C and 5.6°C by 2100 was projected by the model (Fig.8). It means that the warming over East Asia for the 21st century will be much larger than that in the globe due to the SRES scenarios.

For the change of the annual mean temperature in 2071-2100 relative to 1961-1990, the significant warming of 5-7°C for A2 and 4-6°C for A1B over the northwest and northeast regions of East Asia will occur, respectively. The lower warming of 2-4°C over other regions was projected (Fig.9). The obvious warming of 8-12°C over the northwestern and northeastern parts of East Asia in winter will be much higher than that in summer for both scenarios (Fig.10).

4.2 *Precipitation*

The NCC/IAP T63 with the SRES scenarios

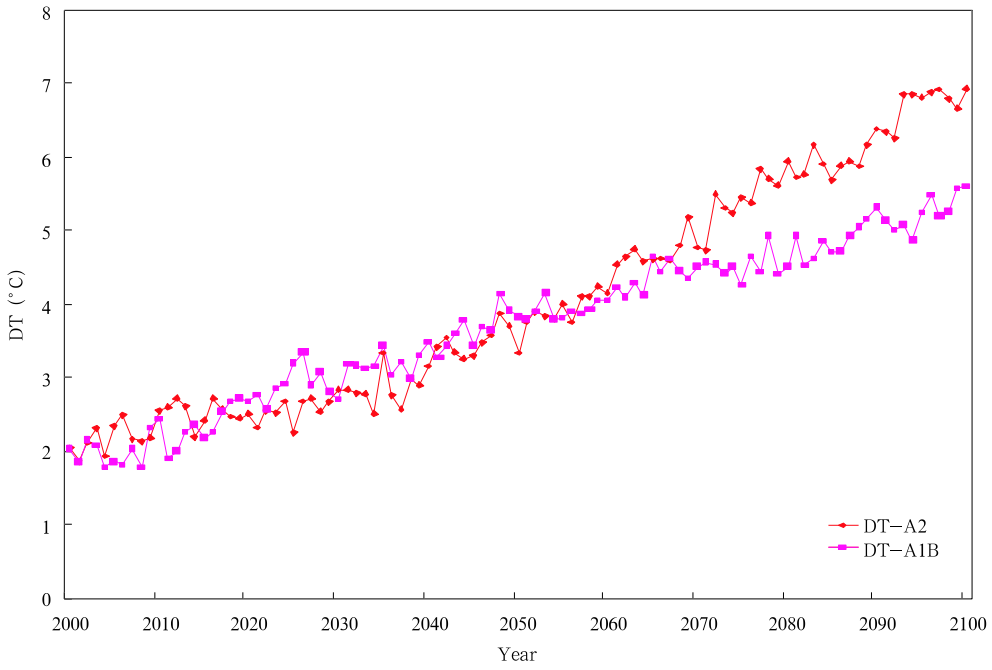

Fig.8. Time evolutions of annual mean temperature anomalies over East Asia as projected by the NCC/IAP T63 with SRES A2 and A1B (unit: °C).

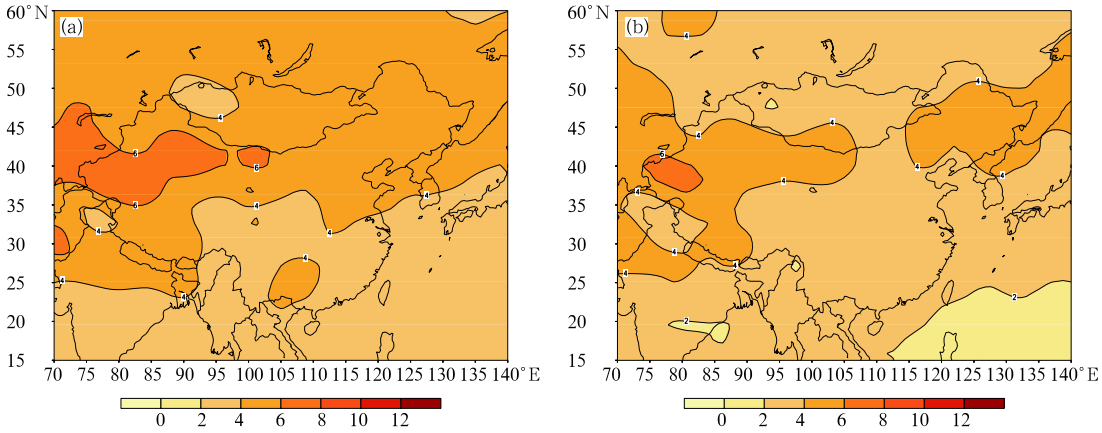

Fig.9. Geographical distributions of annual mean temperature anomalies over East Asia as projected by the NCC/IAP T63 with SRES A2 (a) and A1B (b) (unit: °C).

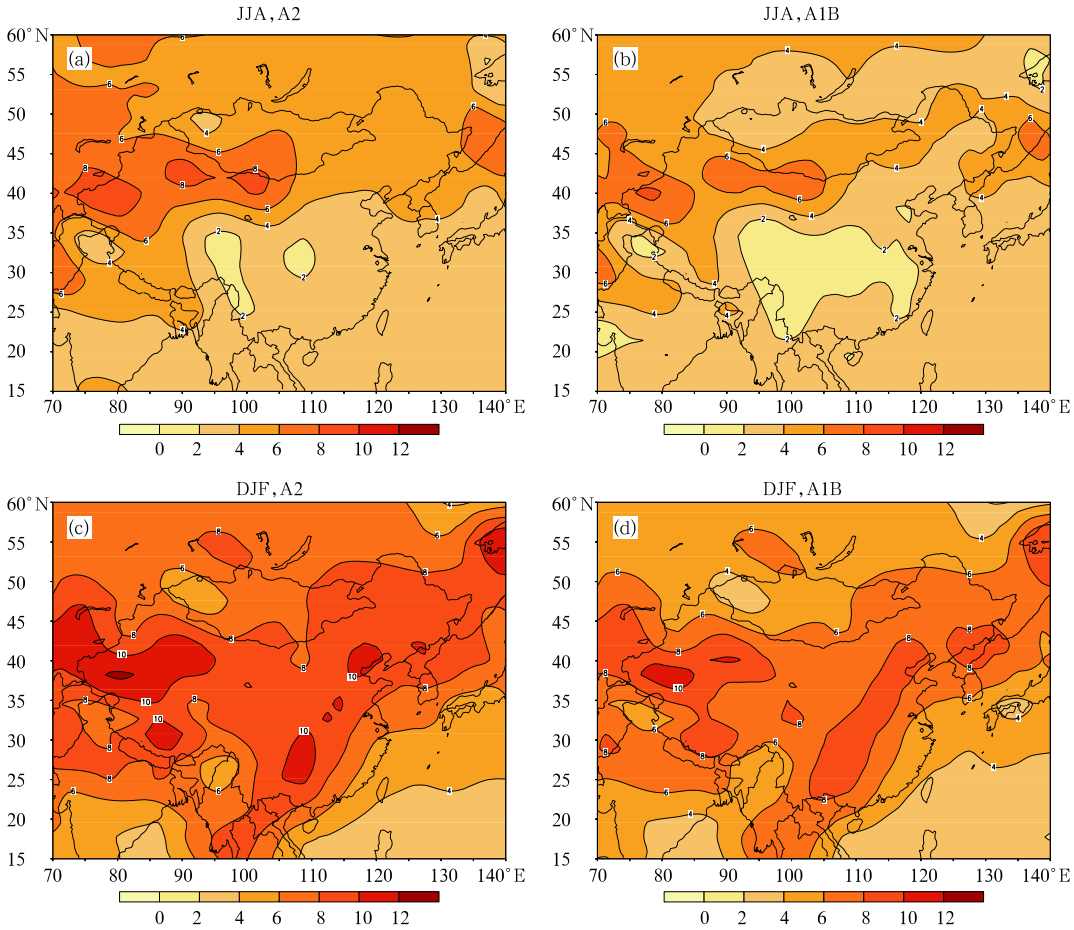

Fig.10. Geographical distributions of the seasonal mean temperature anomalies over East Asia for December-January-February (bottom), and June-July-August (top) of 2071-2100 relative to 1961-1990 as projected by the NCC/IAP T63 with SRES A2 (left) and A1B (right) (unit: °C).

projected the drier situations before 2065 and the wetter situations for A2 after 2065. The linear trends of annual mean precipitation will be 9.8%/100 yr for A2 and 5.2%/100 yr for A1B, respectively. It will be 0.9% for A2 and -1.1% for A1B over the mean of the whole East Asia by the last 5 years (Fig.11).

The annual mean precipitation for 2071-2100 relative to 1961-1990 will become drier by about -10%-30% over the Northwest and Southeast China and wetter by about 5%-20% over the middle and southwestern China, as well as northeast parts of East Asia (Fig.12). The patterns of precipitation anomalies in summer will be similar to the annual distributions. It will become wetter in most parts of East Asia in winter (Fig.13).

The intercomparisons of the projections of both temperature and precipitation among the models included the NCC/IAP T63 in East Asia and China for the 21st century have been presented in another paper (Luo et al., 2005).

5. Conclusions and discussions

In this research, a high resolution model NCC /IAP T63 with the new IPCC emission scenarios

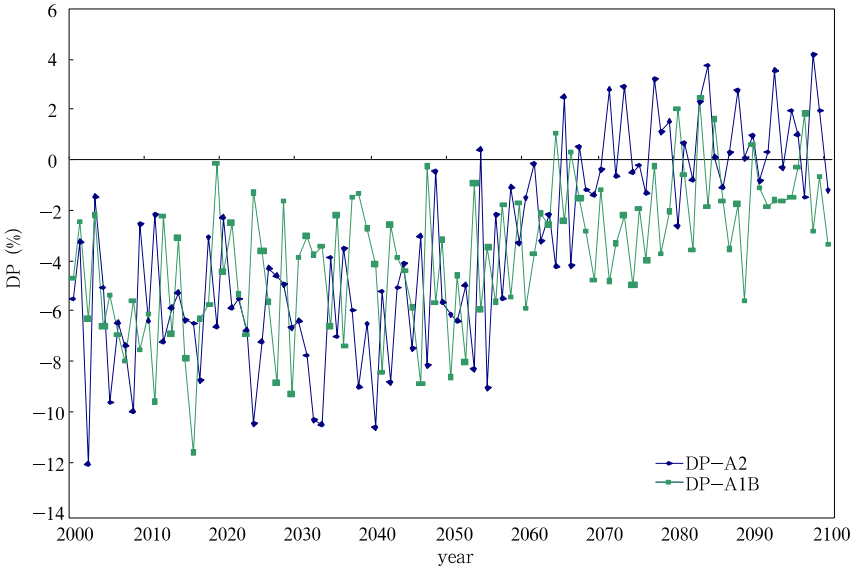

Fig.11. Time evolutions of annual mean precipitation anomalies over East Asia as projected by the NCC/IAP T63 with SRES A2 and A1B (unit: %).

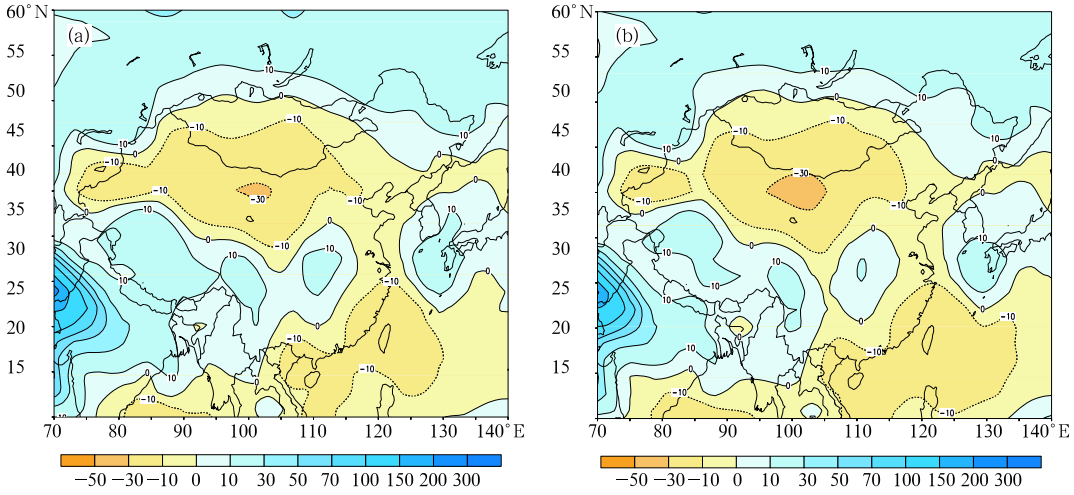

Fig.12. Geographical distributions of annual mean precipitation anomalies over East Asia as projected by the NCC/IAP T63 with SRES A2 (a) and A1B (b) (unit: %).

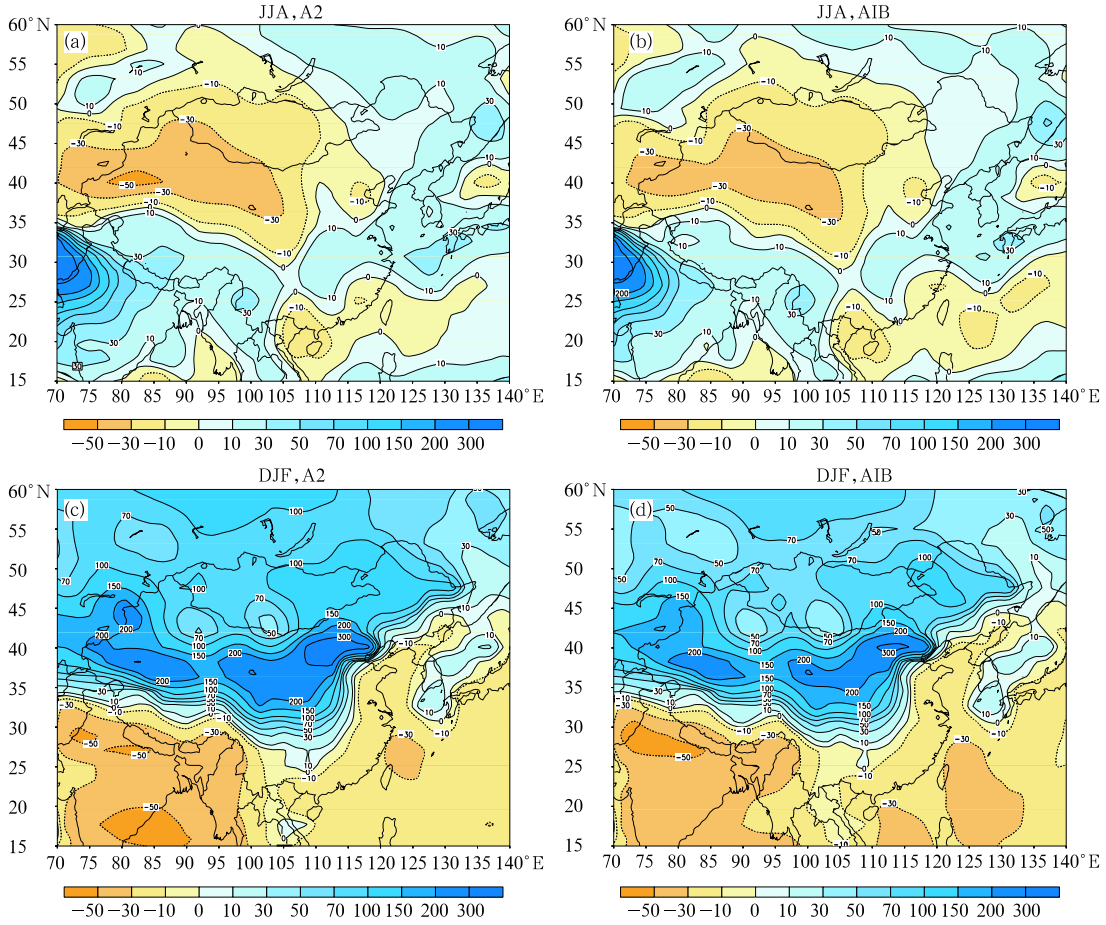

Fig.13. Geographical distributions of the seasonal mean precipitation anomalies over East Asia for December-January-February (bottom), and June-July-August (top) of 2071-2100 relative to 1961-1990 as projected by the NCC/IAP T63 with SRES A2 (left) and A1B (right) (unit: %).

SRES A2 (high emission) and A1B (medium emission) has been used to project the climate change in the globe and East Asia.

A global warming of 3.6°C/100 yr and 2.5°C/100 yr for A2 and A1B during the 21st century was projected, respectively. The warming in the high and middle latitudes will be higher than that in low latitudes, especially in the winter hemisphere. A significant warming of 5.1°C/100 yr for A2 and 3.6°C/100 yr for A1B over East Asia was noticed. The projections indicated that the warming over East Asia in the 21st century will be much more obvious than that in the globe.

The global mean precipitation will increase by about 4.3%/100 yr for A2 and 3.4%/100 yr for A1B in the 21st century, respectively. The precipitation will increase in most parts of the low and high latitudes and decrease in some regions of the subtropical latitudes. The linear trends of the annual mean precipitation anomalies over East Asia will be 9.7%/100 yr for A2 and 5.2%/100 yr for A1B, respectively. The drier situations will occur over the northwestern and southeastern parts of East Asia.

The IPCC SRES provides a number of the SRES scenarios. The further research will be concentrated on the more emission scenarios and the projections of the climate extreme events. The ensemble projections will be conducted in future.

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