

# Projections of Climate Change over China for the 21st Century \*

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## ABSTRACT

The projections of climate changes in China for the 21st century by about 40 climate scenarios and multi-model ensembles have been investigated in this research. All the models with the different scenarios project a warming of 1.2°C to 9.2°C in China by the end of 21st century. Most of the projections point show the increasing of precipitation in China for the 21st century.

**Key words:** climate change, projections, China, 21st century, climate models

## 1. Introduction

Under the background of global warming in the 20th century, it was also getting warmer of 0.2-0.7°C/100 yr over China for the last 100 years, especially for the last 50 years (0.6-0.9°C/50 yr) based on the instrumental observations (Wang and Gong, 2000; Ren et al., 2004; Zhao et al., 2004). In another way, it was noticed that the concentration of greenhouse gases and sulfate aerosols in the atmosphere increased by the human emissions. Some new evidences indicated that the greenhouse gases due to the human emissions play an important role in the observed climate warming (Cubasch et al., 2001).

The governments and public have paid more and more attentions to the climate change. An important issue is to project the climate change caused by the greenhouse gases and sulfate aerosols in the globe for the 21st century. A number of climate models with the various scenarios have projected the climate change in the globe and some regions for the 21st century. The obvious warming and wetting in the globe for the 21st century due to the different scenarios have been pointed out (Cubasch et al., 2001; Giorgi et al., 2001). Some researches indicated that the climate models have the certain capabilities to simulate the climate change in the global and large-scale regions (McAvaney et al., 2001; Giorgi et al., 2001).

In this research, we focus on the projections of

climate change over China for the 21st century. The second section is going to introduce the climate models and designs of greenhouse gases, sulfate aerosols, and others briefly. The changes of the annual surface air temperature and precipitation over China for the 21st century as projected by about 40 climate models with the various scenarios will be presented at the following sections. Summary will be given in the end of the paper.

## 2. Brief descriptions of climate models and human emission scenarios

A couple of researches indicated that the climate changes over China as simulated by multi-model ensembles were better than by single model to compare with the observations (Zhao and Xu, 2002; Zhao et al., 2004). In our research, about 40 climate scenarios and their ensembles have been selected and calculated. Most of them were provided by the DDC of IPCC such as CCC-Canada, CCSR/NIES-Japan, CSIRO-Australia, ECHAM-Germany, GFDL-USA, HADL-UK, and NCAR-USA with greenhouse gases (GG) increasing, both greenhouse gases and sulfate aerosols (GS) increasing, the IPCC SRES A2 (highest emission) and B2 (middle emission) (Cubasch et al., 2001). For adding more East Asian information, several other climate models such as CCSR/NIES2-Japan, GOALS/LASG-China, IAP-China, NCC/IAP T63-

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China, RegCM/CN-China, and YONU-Korea with the different scenarios such as 1% increasing greenhouse gases, GG, GS, SRES A1 (middle emission), A2, B1 (lowest emission), and B2 have been employed and computed (Ding et al., 2001; Gao et al., 2001; Guo et al., 2001; Ma, 2002; Xu, 2002; Zhao and Xu, 2002; Ding et al., 2004; Zhao et al., 2004).

### 3. Change of annual mean surface air temperature

Some research presented the warming of 0.0-3.1°C/100 yr and 0.0-2.9°C/50 yr for the 20th century as simulated by the climate models with the different scenarios, respectively. The correlation coefficients between the simulations and observations were 0.1-0.6 for the 100 yr (1900-1999) and 0.2-0.6 for the last 50 yr (1950-1999), respectively (Zhao and Xu, 2002; Zhao et al., 2004).

The scientists are interested in the changes of the surface air temperature in China for the 21st century. Figure 1 provides the evolutions of surface air tem-

perature anomalies relative to the years of 1961-1990 in China for the 20th and 21st centuries. Table 1 indicates the linear trends of temperature changes in China for the 21st century as projected by the climate models with the different scenarios.

Based on the multi-model ensembles, the linear trends of temperature changes in the 21st century will be 5.2°C/100 yr with a range of 3.0°C/100 yr to 9.2°C/100 yr for GG, 4.2°C/100 yr with a range of 0.0°C/100 yr to 6.9°C/100 yr for GS, 5.1°C/100 yr with a range of 2.5°C/100 yr to 8.9°C/100 yr for A2, and 3.3°C/100 yr with a range of 1.2°C/100 yr to 5.4°C/100 yr for B2, respectively (Fig.1 and Table 1). It will be very likely much warmer in China for the 21st century than the 20th century.

It is also noticed in the patterns of temperature changes for the 21st century that there will be an obvious warming in North China and a slight warming in South China. For four seasons, the warming in winter will be larger than other seasons (figures not shown).

**Table 1.** Linear trends of temperature change in China for 2000-2099 as projected by the AOGCMs with the different scenarios (unit: °C/100 yr) (updated from Zhao and Xu, 2002; Xu, 2002; Zhao et al., 2003; Ding et al., 2004)

GCMs	GG or A2	GS or B2
CCC	9.22	6.89
CCSR	5.11	3.85
CSIRO	3.88	3.5
DKRZ	4.71	0.69
GFDL	2.95	2.46
HADL	4.08	3.14
NCAR	4.01	-0.28
Mean of the above models	4.85	2.89
GCM7 (above model ensembles)	5.16	4.15
NCC/IAP T63	1.30	0.94
CCSR/NIES2	A1 7.72; A2 8.85	B1 4.65; B2 5.35
CCC-SRES	5.36	2.87
CSIRO-SRES	5.12	3.31
ECHAM4-OPYC-SRES	2.45	1.20
GFDL-SRES	3.82	2.54
HADL3-SRES	5.20	2.94
GCMs-SRES mean	5.50	3.27
Mean	4.96	2.97

### 4. Change of annual precipitation

The impacts of rainfall on economy in China located in the monsoon region are significant. As we know, the precipitation in China depends on many

natural factors, such as atmospheric circulation and its index, decadal and interdecadal variabilities, periodicity and oscillations, sea surface temperature anomalies over the key regions, including El Niño, snow covers, and sudden climate change. In this research, we



paid more attentions to the effects of human activities such as greenhouse gases, sulfate aerosols, black carbon, and land-use changes on precipitation in China for the 21st century.

Precipitation changes for the 21st century as projected by the climate models with various scenarios are more complicated than the temperature changes. Most modelling scenarios projected the wetter situations in China for the 21st century (see Fig.2). The linear trends of precipitation changes will be 47 mm/100 yr with a range of -78 mm/100 yr to 144 mm/100 yr for GG, 48 mm/100 yr with a range of -72 mm/100 yr to 120 mm/100 yr for GS, 135 mm/100 yr with a

range of -56 mm/100 yr to 286 mm/100 yr for A2, and 77 mm/100 yr with a range of -38 to 187 mm/100 yr for B2, respectively (see Table 2).

The calculations projected the increasing of precipitation over most parts of China, especially in North China. There will be the decreasing in precipitation in the central parts of China. Because China is a monsoon prevailing country, and most rainfall concentrates on the summer half years. Therefore, the characteristics of the summer precipitation changes for the 21st century will be similar to the annual patterns (figures not shown).

**Table 2.** Linear trends of precipitation changes in China for 2000-2099 as projected by the AOGCMs with the different scenarios (unit: mm/100 yr) (updated from Zhao and Xu, 2002; Xu et al., 2002; Zhao et al., 2003; Ding et al., 2004)

GCMs	GG or A2	GS or B2
CCC	-78	-72
CCSR	144	84
CSIRO	36	12
DKRZ	84	48
GFDL	72	36
HADL	120	120
NCAR	-48	108
Mean of above seven GCMs	48	48
GCM7 (seven GCMs' ensembles)	48	60
NCC/IAP T63	24	-60
CCSR/NIES2	A1 185; A2 153	B1 88; B2 107
CCC-SRES	55	8
CSIRO-SRES	91	75
ECHAM4/OPYC-SRES	-56	-38
GFDL-SRES	231	115
HADL-SRES	286	187
GCMs-SRES mean	135	77
Mean	85	56

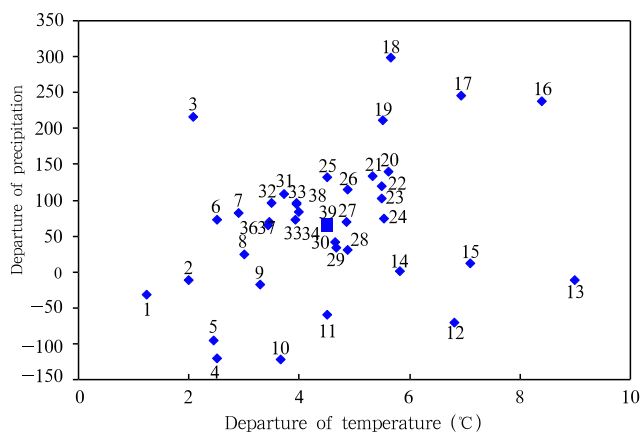
## 5. Assessments of reliability

The reliability of the projections of the temperature and precipitation changes in China for the 21st century has been assessed.

As an example, Fig.3 shows the projections of both annual mean temperature and precipitation changes in China by the end of the 21st century. About 40 models and scenarios projected the warming over China by the end of the 21st century. The calculations indicated that 85% of total models pro-

jected a warming of 2.0-6.0°C. It is noticed the mean warming of 4.5°C with a large range of temperature changes from 1.2°C to 9.2°C as projected by the climate models and scenarios. Among them, about 32% of total models and scenarios projected the warming of 5°C and higher.

Percentage 76 of total models and scenarios projected an increasing precipitation in China by the end of 21st century. The precipitation will probably increase by 67 mm in average with a large range from -122 mm to 298 mm. Among them, about 24% of total



**Fig.3.** Scatter diagram of annual mean temperature and precipitation changes relative to the years of 1961-1990 in East Asia and China by the end of 21st century as projected by the climate models and scenarios (1: ECHAMB2, 2: IAP2GS, 3: GFDLB2, 4: DKRZGS, 5: ECHAMA2, 6: YONUGG, 7: GFDLA2, 8: IAP2GG, 9: HADLGS, 10: CCCB2, 11: NCARGS, 12: CCCGS, 13: NCARGG, 14: CCCA2, 15: CCCGG, 16: CCSRA2, 17: CCSRA1, 18: HADLA2, 19: CCSRGG, 20: CCSRB2, 21: CCSRB1, 22: DKRZGG, 23: CSIROA2, 24: NCCGG, 25: GFDLGG, 26: CCSRGS, 27: M26, 28: HADLGG, 29: NCCGS, 30: CSIROGG, 31: CSIROGS, 32: IAPGG, 33: CSIROB2, 34: GFDLGS, 35: RCMGS, 36: Ms, 37: HADLB2, 38: RCMGG, and 39: total mean).

models and scenarios projected the decreasing and 32% of total models and scenarios projected the increasing by 20% and more (see Fig.3).

It means that the obvious warming will occur very likely in China by the end of the 21st century. The uncertainties of the precipitation change are larger than that of temperature.

## 6. Summary

Most results of the major Chinese and foreign model groups have been involved in this research. As the global warming of the 21st centuries, it will be warming in China from all the model projections. The warming of 4.5°C with a large range from 1.2°C to 9.2°C in China by the end of the 21st century was projected by the climate models with various scenarios. The precipitation change in future will be more complicated than the temperature. Most models pro-

jected the wetter situation in China for the 21st century.

The further researches will be expected to reduce the uncertainties.

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