A Modeling Study of Climatic Change and Its Implication for Agriculture in China
Part I: Climatic Change in China

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ABSTRACT

The trends and features of China's climatic change in the past and future are analysed by applying station observations and GCM simulation results. Nationally, the country has warmed by 0.3°C in annual mean air temperature and decreased by 5% in annual precipitation over 1951–1990. Regionally, temperature change has varied from a cooling of 0.3°C in Southwest China to a warming of 1.0°C in Northeast China. With the exception of South China, all regions of China have shown a declination in precipitation. Climatic change has the features of increasing remarkably in winter temperature and decreasing obviously in summer precipitation. Under doubled CO_2 concentration, climatic change in China will tend to be warmer and moister, with increases of 4.5°C in annual mean air temperature and 11% in annual precipitation on the national scale. Future climatic change will reduce the temporal and spatial differences of climatic factors.

Key words: Climatic change, Carbon dioxide concentration, Regional climate

I. INTRODUCTION

The global climatic change due to the greenhouse effect has been greatly concerned by the government and people of various nations of the world today. Scientists are studying this important environmental problem extensively and thoroughly. Research results indicate that the expected global temperature would rise by between 1.5°C and 4.5°C for a doubling CO_2concentration that may occur in the future several decades. This warming would be larger in polar and high–latitudinal zones than in equatorial and low–latitudinal zones and larger in winter half year than in summer half year. In addition, the global precipitation would increase by between 3% and 15% and changes would occur in precipitation intensity and distribution (Houghton, et al., 1990). For a specific region of the world (e.g., China), however, the trends of future changes of temperature and precipitation are considerably different from the global trends. They have local features of temporal and spatial variations that are influenced by various factors such as geography (latitude, altitude, the distance off the coast, etc.), topography (mountains, hills, plains, etc.), climatic characteristics (continental climate, ocean climate, etc.), and the degree of economic development of the region (Gullett, et al., 1992). Many researchers have studied the actual and future trends of climatic change in China under the background of the global warming (Chen Longxun et al., 1990; Chen Longxun et al., 1991; Zhao Zongci, 1989). This paper will analyse China's climatic change trends in the past and future by applying meteorological observations and GCMs outputs so as to provide necessary climatic background for subsequent impact study.

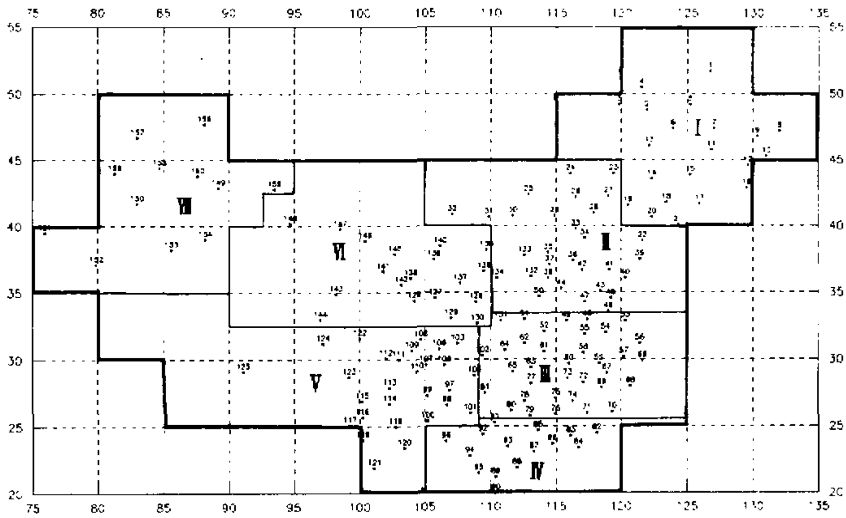


Fig. 1. The schematic diagram of station distribution and climatic regions.

II. ANALYSIS METHOD

First, the features of climatic change in China for the past 40 years are analysed by applying observations on monthly mean surface air temperature and monthly precipitation at 160 stations in the period of January 1951—December 1990 from National Meteorological Center of China. The analysis for past trends is the basis of testing simulation results of models and verifying prediction for future climatic change.

Table 1. Some Characteristics of 7 GCMs

Model	Resolution		Vertical layers	Ocean model	ΔTeq (℃)	ΔPeq (%)
	Longitude	Latitude				
UKMO–L	7.5	5	11	mixed–layer	5.2	15
UKMO–H	3.75	2.5	11	mixed–layer	3.5	11
GFDL	7.5	4.5	9	mixed–layer	4.0	9
GISS	10	7.8	9	mixed–layer	4.2	11
OSU	5	4	2	mixed–layer	2.8	8
LLNL	5	4	2	2–layer ocean	3.8	11
MPI	5.6	5.6	19	11–layer ocean	1.6	3

Note: ΔTeq and ΔPeq are the global mean differences of temperature and precipitation between disturbed and controlled values under doubled CO_2 concentration except MPI GCM, where they refer to 10–year mean of ($2\times CO_2 - 1\times CO_2$) of simulated temperature and precipitation during 61st–70th model year (i.e., 2045–2054).

Second, the trends of future climatic change in China are analysed by applying $1\times CO_2$ and $2\times CO_2$ outputs of 7 GCMs. Seven GCMs are referred to as UKMO–low resolution (UKMO–L), UKMO–high resolution (UKMO–H), GFDL, GISS, OSU, LLNL and

MPI GCM, their relevant characteristics are given in Table 1. In order to compare simulation results of every model, all outputs are interpolated on the same space mesh ($5^\circ \times 5^\circ$).

Fig. 1 gives the distribution of 160 stations and climatic regionalization applied in analysis over gridded Chinese regions. In Fig. 1, abscissa is the longitude (east) and ordinate is the latitude (north); dots represent stations and numbers above dots refer to station indexes from 1 to 160; thick solid lines represent the bounds of climatic regions which correspond to Northeast China (I), North China (II), the middle and lower reaches of the Yangtze River (III), South China (IV), Southwest China (V), Northwest China (VI) and Xinjiang (VII). Obviously, this is a simplified schematic diagram in which the bounds of the country and climatic regions are represented approximately to facilitate computing and analyzing.

III. RESULTS

1. *Climatic Change in China over Past 40 Years*

(1) *Nation–wide changes*

Figs. 2 and 3 show the trends of air temperature and precipitation from 1951 to 1990 nationally where dotted lines represent the annual departures of temperature or precipitation from long–term climate mean (i.e., average over past 30 years from 1951 to 1980 in this analysis). Using departures rather than actual temperature or precipitation makes it possible to relate all of the station data to the same reference point (e.g., normal climate conditions). This technique greatly reduces the effect of local influences on a single dataset. Thin solid lines represent 10–year running mean variations corresponding to the departures mentioned above. Thick solid lines represent the best–fit linear trends for the series of departures.

As Fig. 2 shows, the trend of temperature change in China over recent 40 years is warming with an increase of 0.3°C based on national annual mean temperature. But fluctuations also occurred in the context of general trend of warming. Since the 1950s, annual mean air temperature has shown an upward trend that persisted to the early 1960s with a peak value. Then temperature began cooling until the mid–1970s and rose gradually again to reach maximum temperature during the 1980s. As Fig. 3 shows, the trend of precipitation change on the national scale is decreasing with a percentage of 5 in annual precipitation over past 40 years. The feature of precipitation change is that the 1950s was above–normal precipitation period and precipitation began to decrease to enter a dry period in the 1960s. During the 1970s, precipitation increased somewhat. Since the late 1970s to the 1980s, precipitation began to decrease again.

The patterns of the seasonal mean temperature and seasonal precipitation indicate that climatic change has seasonal differences. Temperature change ranges of various seasons are 0.8°C (winter), 0.3°C (spring), −0.2°C (summer) and 0.2°C (autumn) and precipitation change ranges are −2% (winter), −4% (spring), −10% (summer) and 3% (autumn). Therefore, winter mean temperature greatly contributes to temperature change (i.e., warming) and summer precipitation considerably contributes to precipitation change (i.e., drying).

(2) *Regional changes*

This paper also analyses climatic changes of various regions according to China's climatic regionalization in order to identify spatial differences in climatic change.

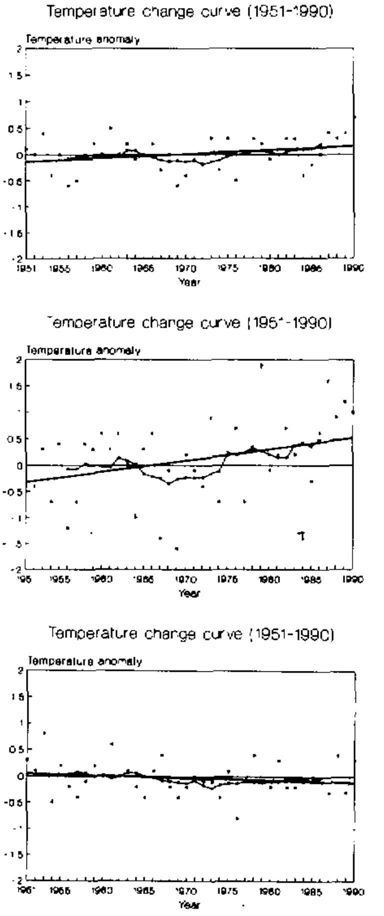


Fig. 2. National trends of annual (top), winter (middle) and summer (bottom) mean air temperature.

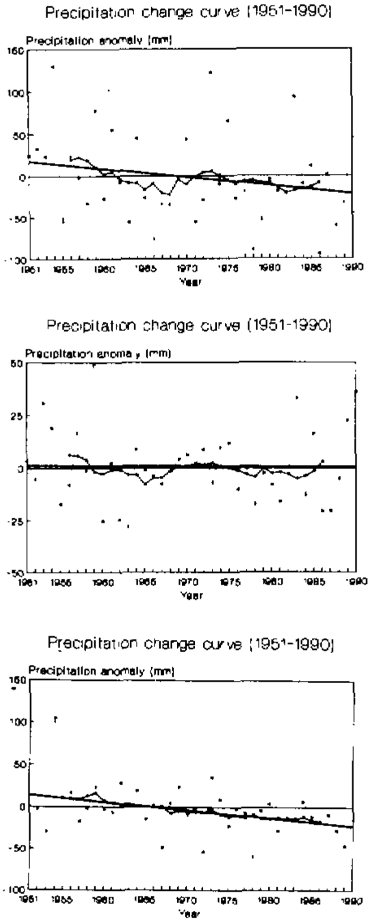
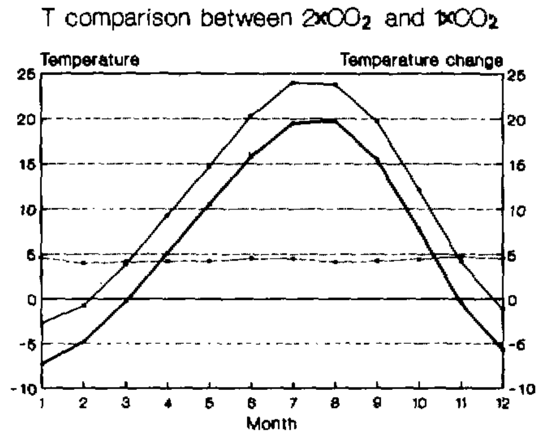


Fig. 3. National trends of annual (top), winter (middle) and summer (bottom) precipitation.

Table 2. The Trends of Temperatures and Precipitations of Various Regions (1951–1990)

Climatic regions	Temperature changes (℃)			Precipitation changes (%)		
	Annual	Winter	Summer	Annual	Winter	Summer
I	1.0	1.6	0.3	−7	−12	−4
II	0.8	1.5	−0.1	−17	1	−21
III	0	0.3	−0.4	−4	−4	−4
IV	0	0	0.3	2	16	−12
V	−0.3	−0.2	−0.2	−5	−2	−9
VI	0.1	1.1	−0.8	2	−12	3
VII	0.7	2.3	−0.3	1	−19	−1



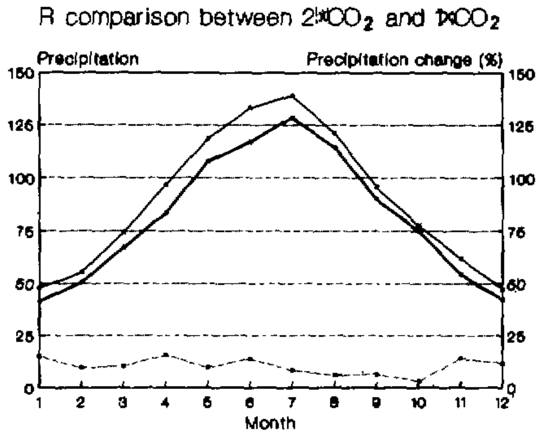


Fig. 4. National average simulation results of the composite GCM. (Top map is temperature change curve; bottom map is precipitation change curve. Thick solid lines represent 1 × CO_2 simulations; thin solid lines represent 2 × CO_2 simulations. Dotted lines represent change amounts which are the absolute differences between the 2 × CO_2 and 1 × CO_2 outputs for temperature and the percentage changes of the absolute differences between the 2 × CO_2 and 1 × CO_2 outputs divided by the 1 × CO_2 outputs for precipitation.)

Table 2 lists trend values of temperature and precipitation of 7 climatic regions over past 40 years from 1951 to 1990. As for temperature, temperature changes of various regions tended to be warming except Southwest China, where a cooling of 0.3°C was observed, particularly in Northeast China, North China and Xinjiang with an increase of 1.0°, 0.8° and 0.7°C in annual mean air temperature respectively. In addition, winter temperature increased remarkably and summer temperature had a downward trend in most regions. As for precipitation, annual precipitation decreased by 7%, 17%, 4% and 5% in Northeast China, North China, the middle and lower reaches of the Yangtze River, and Southwest China, respectively and increased somewhat in other regions. Seasonal precipitations of various regions had a general downward trend. Obviously, there are considerable spatial differences in changes of temperature and precipitation. The trends of temperatures and precipitations of various regions are much more complicated than those of national average.

From the above analyses for the changing trends of temperature and precipitation over past 40 years in China, we came to the conclusion that regional climatic anomalies do not occur consistently across the country, although there exists a general warming trend in higher latitude zones. In other words, there are significant temporal and spatial variations in climatic change, even in the China's region.

2. *Climatic Change in China for the Future*

This analysis shows possibly changing trends of temperature and precipitation fields for a doubling CO_2 concentration by comparing $2\times$ CO_2 simulation values with $1\times$ CO_2 simulation values of GCM.

(1) *Nation–wide changes*

Fig. 4 shows $2\times CO_2$ and $1\times CO_2$ simulation results of the composite GCM generated by the average of seven GCM experiments. As Fig. 4 shows, when CO_2 concentration in the atmosphere is doubled, the general trends of climatic change in China would tend to be warmer and moister with a warming of 4.5°C in monthly mean temperature and an increase of 11% in monthly precipitation.

Fig. 4 shows national distribution of contour lines of future changes for temperature and precipitation simulated by GCM (results shown in the Fig. 5 being simulations of the composite GCM). As Fig. 4 shows, temperature will increase by between 2.8°C and 5.3°C. Contour lines of temperature exhibit the variations from east to west and from southeast to northwest. Temperature change in Southeast China is smaller with a minimum warming of 2.8°C; warming in Northwest and Northeast China is most striking with a maximum of 5.3°C in Xinjiang. Generally, temperatures in all regions over the country tend to increase. But there are regional differences in warming ranges. For precipitation, the range of future change is between −1.9% and 19.7%. Precipitations in most regions tend to increase except part of South China, where the precipitation has a downward trend (less than 2%), particularly in Tibet and Xinjiang with a maximum increase of 19.7%. Second maximum values occur in Northeast China with an increase range of 10%. Contour lines of precipitation change exhibit the variation from south to north. Precipitation change tends to increase from east to west.

(2) *Regional changes*

Table 3 lists possible future changes of temperatures and precipitations of various regions simulated by seven GCMs (results shown in Table 3 being simulations of the composite GCM). From Table 3, when CO_2 concentration in the atmosphere is doubled, temperatures of various regions tend to increase and precipitations have also an upward trend except individual months. Similar to climatic change over past 40 years, there are regional differences in future climatic change. For temperature, warming ranges (annual average) of various regions are 4.6°C in Northeast China, 4.5°C in North China, 3.8°C in the middle and lower reaches of the Yangtze River, 3.2°C in South China, 4.3°C in Southwest China, 4.6°C in Northwest China, and 4.8°C in Xinjiang. Obviously, warming ranges in higher latitudes (e.g., Northeast China, North China, Northwest China, Xinjiang) are greater than those in lower latitudes (e.g., the middle and lower reaches of the Yangtze River, South China, Southwest China). In addition, warming ranges of most regions in winter are greater than those in summer except Northwest China and Xinjiang. The results are generally consistent with the global simulation results. For precipitation, precipitations of various regions tend to increase (except individual months) except South China. And increase ranges of precipitations in most regions in winter are greater than those in summer except Southwest China. In South China, precipitations in spring and autumn have a downward trend and those in winter and summer have an upward trend. Similar to temperature changes, precipitation changes in higher latitudes are greater than those in lower latitudes.

Table 3. Future Climatic Changes of Various Regions Simulated by GCM

Climatic regions	temperature changes (℃)											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
I	5.1	4.7	4.3	4.6	4.7	4.7	3.9	3.9	4.2	4.8	5.3	4.7
II	4.6	4.0	4.5	4.6	4.4	4.6	4.6	4.2	4.2	4.6	5.0	4.7
III	3.7	3.8	4.0	3.8	3.7	4.0	3.6	3.3	3.4	3.7	4.1	4.4
IV	3.3	3.5	3.1	3.1	3.2	3.0	2.4	2.3	2.7	3.3	3.8	3.9
V	4.8	3.9	3.8	3.9	4.3	4.5	4.7	3.8	4.2	4.4	4.7	4.3
VI	4.8	3.6	4.0	4.4	4.2	4.5	5.4	4.7	4.8	4.7	4.9	4.6
VII	4.7	4.1	4.4	4.8	4.4	4.9	5.3	5.2	5.1	4.7	4.6	4.5
Climatic regions	precipitation changes (℃)											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
I	25.2	17.4	11.8	17.2	12.2	8.0	11.3	2.2	14.1	10.0	17.5	10.7
II	16.5	18.9	10.1	28.7	4.3	4.8	2.1	−1.4	5.2	0.4	20.9	11.9
III	15.1	0.6	6.1	11.9	2.9	13.0	1.1	0.4	7.7	3.4	10.5	2.7
IV	4.5	−18.0	−11.3	−6.2	9.7	41.1	13.3	8.1	−5.3	−1.8	10.7	3.2
V	7.9	9.1	13.7	12.3	11.8	14.1	13.0	14.7	6.2	1.5	6.0	9.6
VI	21.4	20.4	22.2	29.4	21.0	12.2	6.6	5.6	2.4	4.9	24.8	22.7
VII	21.2	27.4	17.8	24.9	10.9	13.9	0.0	−4.7	7.6	8.1	19.3	24.1

Synthesizing future change trends of temperature and precipitation, one can draw the conclusion that future climatic change shows not only obvious regional and seasonal differences but also a kind of characteristic feature, that is, the ranges of temperature change in existing lower temperature regions (e.g., higher latitudes such as Northeast China, North China) or seasons (e.g., winter) are greater than those in existing higher temperature regions (e.g.,

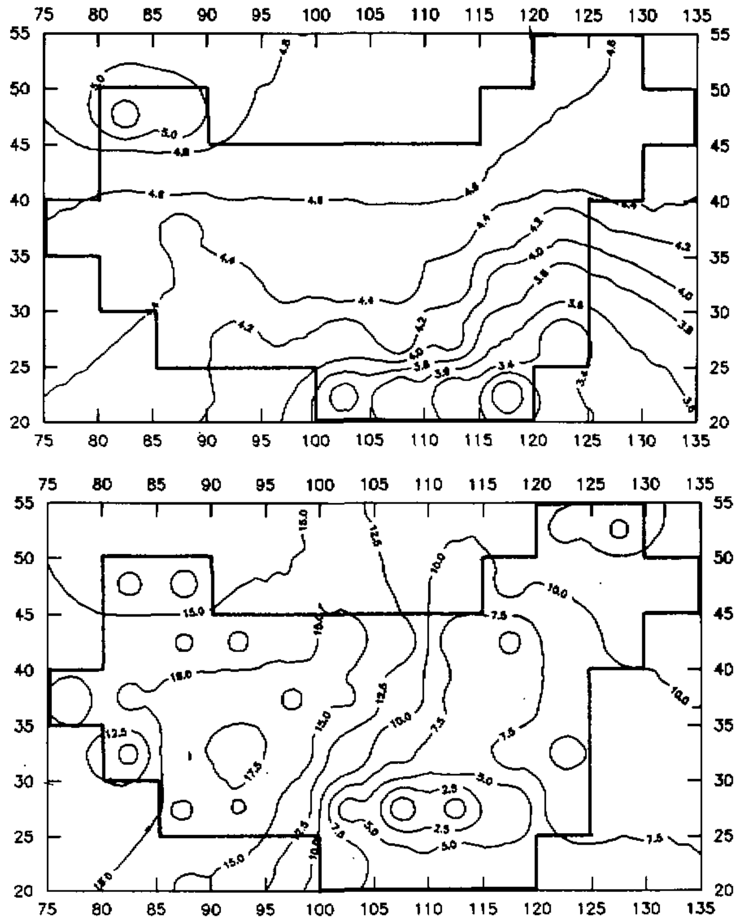


Fig. 5. Contour lines of future changes of temperature and precipitation. (Top map is temperature change, the interval of contour lines is 0.2°C; bottom map is precipitation change, the interval of contour lines is 2.5%.)

lower latitudes such as South China) or seasons (e.g., summer) and the ranges of precipitation change in existing less precipitation regions (e.g., Northwest China) or seasons (e.g., winter) have a greater trend than those in existing more precipitation regions (e.g., South China) or seasons (e.g., summer). In other words, the greater ranges of future climatic change occur in regions or seasons with higher values of climate factors; the relatively smaller ranges of future climatic change occur in regions or seasons with lower values of climate factors. Therefore, future climatic change will reduce spatial and seasonal differences in climate factors.

IV. CONCLUSION AND DISCUSSION

According to the above analyses, air temperature of national average warmed by 0.3°C over 1951–1990, with a most remarkable increase of 0.8°C in winter temperature and a decrease of 0.2°C in summer temperature. Precipitation decreased by 5%, particularly with a decrease by 10% in summer precipitation. Regionally, temperature changes have varied from a moderate cooling of 0.3°C in Southwest China to no obvious changes in the middle and lower reaches of the Yangtze River and South China to a substantial warming of 1.0°C and 0.8°C in Northeast and North China, respectively. Precipitation changes have varied from an increase of 2% in South China to no obvious changes in Northwest China and Xinjiang to a downward trend in other regions with decrease ranges of 7% in Northeast China, 17% in North China, 4% in the middle and lower reaches of the Yangtze River, and 5% in Southwest China. Like national changes, regional changes exhibit the features of increasing remarkably in winter temperature and decreasing obviously in summer precipitation.

When CO_2 concentration is doubled, the general trends of China's climatic change show increases in temperature and precipitation and China's climate tends to be warmer and moister, with increase ranges of 4.5°C in annual mean air temperature and 11% in annual precipitation. There are regional differences in future climatic change. Warming ranges in higher latitudes (warmed by 4.6°C in Northeast China, 4.5°C in North China, 4.6°C in Northwest China, 4.8°C in Xinjiang) are greater than those in lower latitudes (3.8°C in the middle and lower reaches of the Yangtze River, 3.2°C in South China, 4.3°C in Southwest China); precipitation changes in higher latitudes (increased by 11.2% in Northeast China, 7.1% in North China, 13.8% in Northwest China, 14.3% in Xinjiang) are also greater than those in lower latitudes (6.1% in the middle and lower reaches of the Yangtze River, 6.4% in South China, 10.8% in Southwest China). Moreover, future climatic change tends to reduce seasonal differences. This is due to the fact that warming ranges in winter are greater than those in summer and increase ranges in winter precipitation are often greater than those in summer precipitation. Therefore, future climatic change will tend to reduce temporal and spatial differences in climate.

Because there are considerable spatial and seasonal differences in the past and future climatic change, it should consider seasonal and regioal variations in analysing climatic change and carrying out related research. But it must be pointed out that the application of regional results of GCM is limited by less reliable GCM outputs in limited area due to the limitation and uncertainties of GCM simulation. In addition, the future research should go further into how to carry out the regionalization reasonably. From the viewpoint of climatic impact study, the trends of climatic change in smaller regions are more important than those of the global scale or in larger regions. This will be demonstrated clearly in impact studies which will be reported in Part II of the present paper.

REFERENCES

Chen Longxun, Gao Suhua, Zhao Zongci, Ren Zhenhai and Tian Guangsheng (1990), Change of climate and its influence on the cropping system in China, *Acta Meteorologica Sinica*, **4**: 464–474.

Chen Longxun, Shao Yongning, Zhang Qinfen, Ren Zhenhai, Tian Guangsheng (1991), Preliminary analysis of climatic change during the last 39 years in China, *Quarterly Journal of Applied Meteorology*, **2**: 164–174 (in Chinese).

Houghton, J.T., G.J. Jenkins and J.J. Ephraums (eds.) (1990), *Climate change: the IPCC scientific assessment*, Cambridge University Press, 365 pp.

Gullett, D.W. and W.R. Skinner (1992), The state of Canada's climate: temperature change in Canada 1895–1991, Atmospheric Environment Service, Environment Canada. SOE Report No.92–2, 36 pp.

Zhao Zongci (1989), Climatic change in China as simulated due to greenhouse effect, *Meteorological Monthly*, 3: 10–14 (in Chinese).