CHANGE OF CLIMATE AND ITS INFLUENCE ON THE CROPPING SYSTEM IN CHINA

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ABSTRACT

The global change of climate and its influence on the cropping system in China have been investigated in this paper. It is found that the temperature was increased during the last decade and the precipitation decreased in northern China and increased in southern China during the last 30 years. The sea level has been rising by about 21—26 cm in the coastal areas south of 30°N in China during the last 100 years.

The most of results as simulated by the general circulation models (GCMs)show that the temperature increase would amount to about 2°—4°C in the most parts of China and precipitation and soil moisture might be decreased in northern China and increased in sourthern China due to doubling of carbon dioxide (CO_2).

The effects of doubled CO_2 on growth period and climatic yield capability in China have been estimated roughly. It is shown that the regions of the growth period in China would be moved northward about five degrees latitude and the climatic yield capability might be increased by about 10% in the most parts of China.

I. INTRODUCTION

Since the 1970s, the global warming of climate has been pointed out by many meteorologists. Most of them believe that the greenhouse effect is the main mechanism of warming. The warming has also been concerned by Chinese meteorologists. They may have asked, "Does the warming occur in China?" "Does the greenhouse effect influence the cropping system in China greatly?" In this paper, we have tentatively discussed these problems with the observational data in China, and shown the results of numerical experiments and computation of yield change due to warming.

II. FEATURES OF CLIMATIC CHANGE DURING THE LAST 100 YEARS IN CHINA

According to the historical records since 1400, Chinese scientists have pointed out that there are three cold periods (1470—1520, 1620—1750 and 1840—1890) and two warm periods (1550—1600 and 1770—1830) in the last 500 years. The amplitude of temperature between cold and warm periods is about 0.5°—1.0°C. The time interval is about 100 years and the maintenance of each period is roughly 50 years.

In the last 100 years, it was a warm period before the middle 1940s and was a cooling period between the middle 1940s and 1970s. The minimum temperature occurred in the late 1950s. Fig. 1 shows the five-year running mean curves of annual mean surface temperature during the last 100 years in Shenyang, Beijing, Shanghai and Guangzhou, respectively.

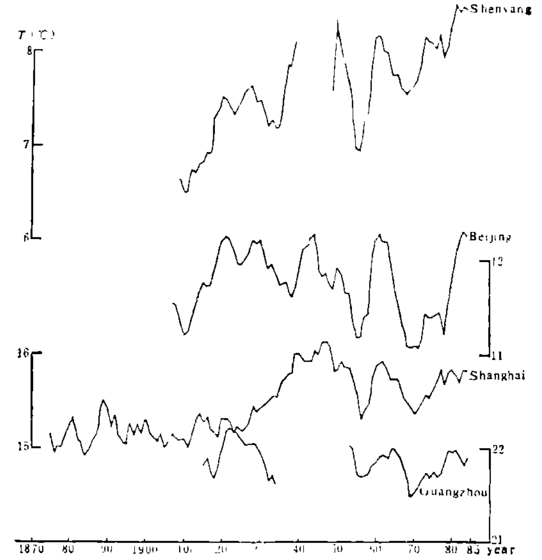

Fig. 1. 5-year running mean curves of annual mean surface temperature for Shenyang, Beijing, Shanghai and Guangzhou.

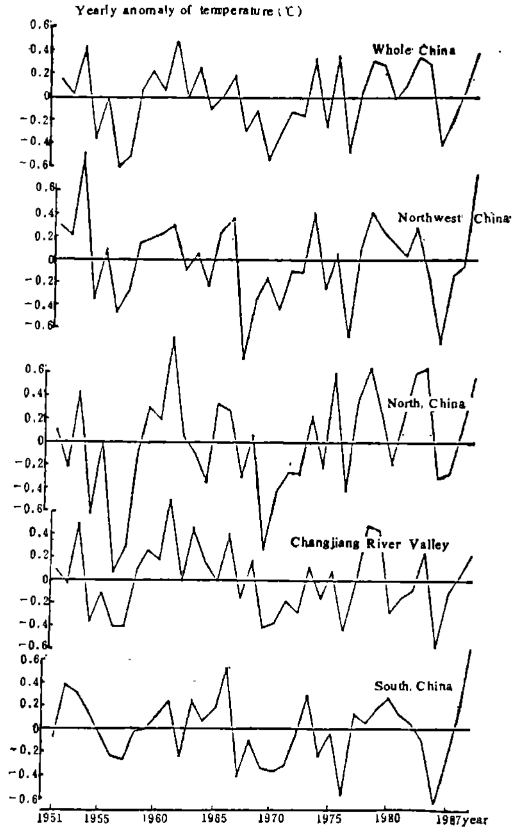

Fig. 2. Yearly anomaly of temperature in China.

Fig. 1 indicates some oscillations. A warm period was found during the early 1940s and a cooling period occurred rapidly after the middle 1940s. For a latest oscillation, it is warming since the 1970s, but the maximum temperature of this oscillation is not higher than that of the normal oscillations. Therefore, we can not say the change of temperature is already influenced by the greenhouse effect.

For more details, we have prepared a monthly data set of temperature (T) and precipitation (P) covering 180 stations in China over the period from Jan. 1951 to June 1988. The anomalies of the regional yearly mean temperatures in whole China and different regions were computed and shown in Fig. 2. Similar to Fig. 2, Figs. 3 and 4 show the yearly winter (Dec.—Feb.) and summer (June—Aug.) anomalies of temperature (T) in the same regions, respectively. For yearly anomaly, Fig. 2 indicates that there are three warm periods (before 1953, 1958—1967 and after 1972) for the curve of whole China. The features of T change in different regions are very similar to those of whole China. The last warming began after 1972. Up to 1988, the amplitudes for the whole country, north China and the Changjiang River Valley were not higher than that of the normal oscillation. However, it is higher than before in the northwest and south China. For winter anomaly of T (Fig. 3), the temperature rose after 1982-in whole China, especially in the south part of China. For summer (Fig. 4), tne warming began after 1981, but it did not increase too much. From the above

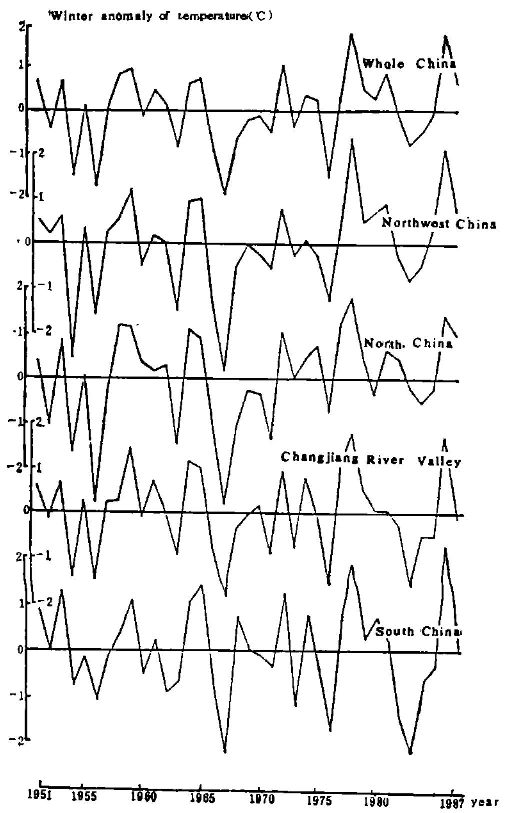

Fig. 3. Winter anomaly of temperature in China.

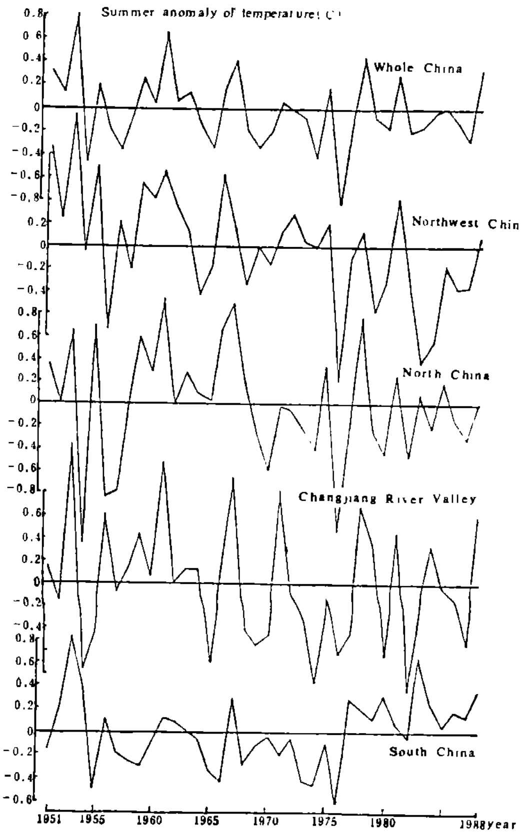

Fig. 4. Summer anomaly of temperature in China.

facts, we can conclude that the warming appeared during tne last 10 years, but the temperature was not higher than that of the amplitude of tne normal oscillation yet. Therefore, we can not conclude that the greenhouse effect has already influenced the temperature in China greatly.

The precipitation will change much according to the theory of greenhouse effect. Fig. 5 shows the five-year running mean curves of annual precipitation in Shenyang, Beijing, Shanghai and Guangzhou since 1730. There appeared five periods of light precipitation (1728—1777, 493mm; 1812—1839, 548mm; 1854—1870, 501mm; 1895—1945, 528mm and 1960—1979, 612mm) and four periods of heavy precipitation (1778—1811, 868mm; 1840—1853, 690mm; 1871—1894, 753 mm and 1946—1959, 711mm) in Beijing. The precipitation in Beijing markedly oscillated and decreased much after the 1950s. In fact, a drought period has appeared in the north China since 1950. This fact might be the evidence supporting the theory of greenhouse effect. The precipitations in Shenyang, Shanghai and Guangzhou also markedly fluctuated, but increased since the 1970s. For more details, we also prepared the curves of yearly anomaly of precipitation in whole China and the different regions (Fig. 6). The period of light precipitation since 1970 has been noticed, especially in the north and northwest China. We still can not decide whether the decrease of precipitation since 1950 is due to the greenhouse effect.

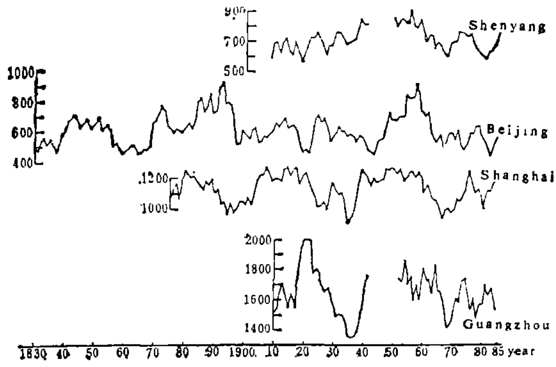

Fig. 5. 5-year running mean curves of annual precipitation for Shenyang, Beijing, Shanghai and Guangzhou.

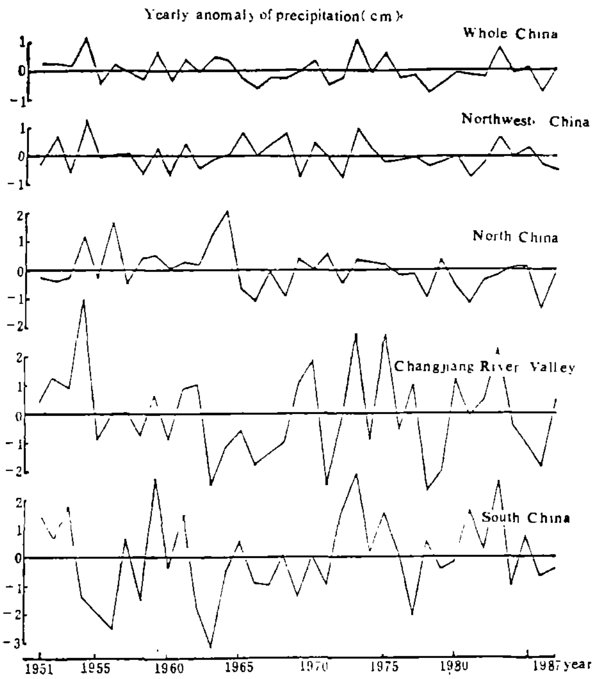

Fig. 6. Yearly anomaly of precipitation in China.

The rising of sea level is an important result of the greenhouse effect. In China, the sea level rose in the coastal areas south of 30°N, i.e., the Changjiang River Valley and decreased slightly in the coastal areas north of 30°N. The mean rising of the sea level in south of 30°N is about 21—26 cm and the decrease in north of 30°N is approximately 10 cm during the last 100 years.

The above mentioned features of climate indicate that the climate in China has been warming slightly since 1970 and changing to dry in the northern China since 1950 and to wet in the southern China since 1963. Besides, the sea level of the Chinese coast areas south of 30°N has been rising in the recent 100 years. Either for warming or for dry/wet, the amplitude is still lower than that of the normal oscillation.

III. CLIMATIC CHANGE IN CHINA DUE TO THE GREENHOUSE EFFECT

Up to now, the best method for studying the climatic change due to greenhouse effect is the numerical simulated experiments.

The global simulations of the Geophysical Fluid Dynamics Laboratory (GFDL) (Manabe and Wetherald, 1987), the Goddard Institute for Space Studies (GISS) (Hansen et al., 1984), the National Center for Atmospheric Research (NCAR) (Washington and Meehl, 1984). Oregon State University (OSU) (Schlesinger and Zhao, 1989) and the United Kingdom Meteorological Office (UKMO) (Wilson and Mitchell, 1986) general circulation models (GCMs) have been investigated for doubled CO_2 ($2\times CO_2$) and control ($1\times CO_2$) experiments. Our work

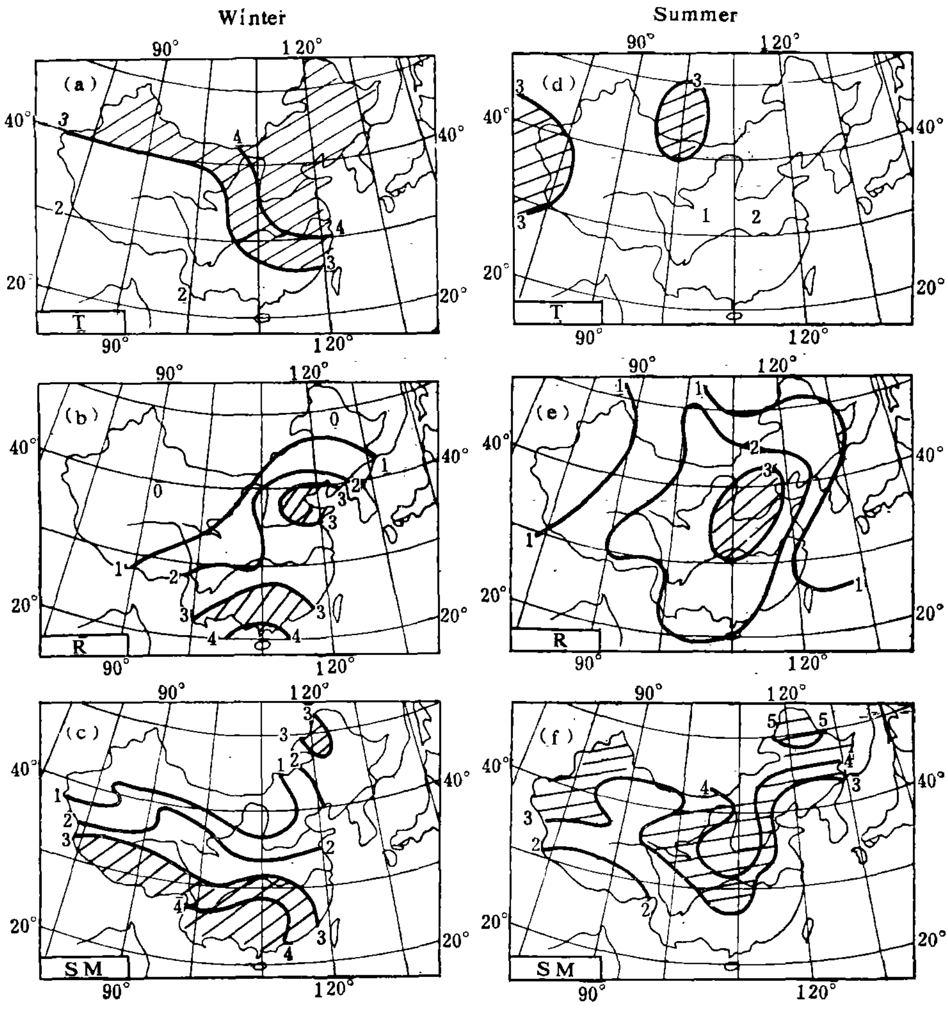

Fig. 7. Summarized map as simulated by five models (GFDL, GISS, NCAR, OSU and UKMO) for $2\times CO_2$ and $1\times CO_2$ in winter (left) and summer (right) for temperature (a), (d), precipitation (b), (e) and soil moisture (c), (f). Hatched areas in (a) and (d) express that three or more of the models agree on a warming by about 4°C or more; and those in (b), (c), (e) and (f) express that three or more of the models agree on the decrease of precipitation and soil moisture. The labeled numbers show how many models agree on this characteristic.

is to analyse their results of temperature, precipitation and soil moisture in summer and winter in the parts of China for $2\times CO_2$ and $1\times CO_2$.

Similar to Zhao and Kellogg (1988) and Zhao (1989), Fig. 7 summarizes the results induced by doubled CO_2 as simulated by the GFDL, GISS, NCAR, OSU and UKMO models for temperature, precipitation and soil moisture in winter (left) and summer (right) in China.

It is interesting to notice from Fig.s 7c and 7f that the soil moisture will be decreased in the southern and southwestern China in winter and in the northern and central China in summer. An obvious warming of about 4°C in winter and 2°C—3°C in summer was simulated in the most parts of China. It is found in Fig. 7b that the wet areas in the western, northwestern and northeastern China and dry areas in the most parts of the northern and southern China in winter appear as simulated by the most of models. The most models show that climate is getting wetter in the northeastern and northwestern China and drier in the northern and central China in summer due to doubling of CO_2 (see Fig. 7e).

Table 1 shows the tendency of temperature, precipitation and soil moisture in the different parts of China for $2\times CO$ minus $1\times CO_2$ as simulated by the most of five models.

Table 1. Tendency of Temperature (*T*), Precipitation (*P*) and Soil Moisture (*SM*) for $2\times CO_2$ minus $1\times CO_2$ in China

	Winter			Summer			
	T	*P*	*SM*	*T*	*P*	*SM*	
Northeast	+	+	+	+	+	−	Warm/Wet
Northwest	+	+	+	+	+	−	Slightly warm/Dry?
					?		
North	+	−	+	+	−	−	Warm/Dry
Central	+	−	+	+	−	−	Warm/Dry
		?	?				
East	+	?	?	+	+	?	Warm/Wet
Southwest	+	?	−	+	+	+	Warm/Wet?
					?	?	
South	+	−	−	+	+	+	Warm/?
					?	?	

According to Table 1, the greenhouse effect might be useful for agriculture in the northeastern China and would decrease the output of grains in the northwestern, central and northern China. If the warming caused by increasing CO_2 as simulated by experiments is true, the climate in the Huanghe River Valley might be as warm as that in the Changjiang River Valley.

The results of five models show that the warming in China induced by doubled CO_2 is consistent. The OSU AGCM coupled to a mixed-layer ocean model (Schlesinger and Zhao, 1989) is used in Chinese cropping experiments. The annual mean temperature for $2\times CO_2$ in China as simulated by the OSU AGCM/mixed-layer ocean model is shown in Fig.8. A warming of about 3°C for the annual mean temperature in the most parts of China is noted.

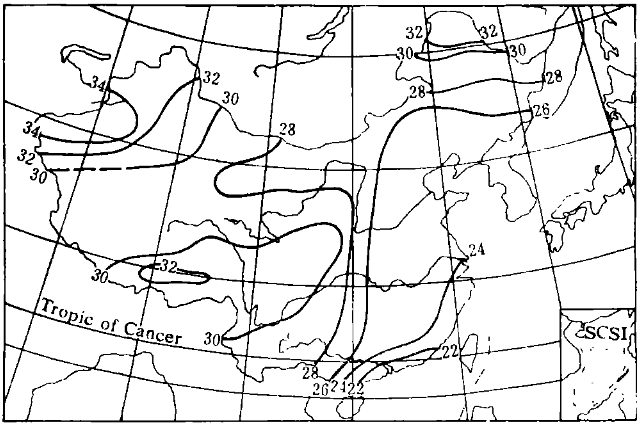

Fig. 8. Anuual mean temperature for $2\times CO_2$ in China as simulated by the OSU AGCM/mixed layer ocean model (unit:°C).

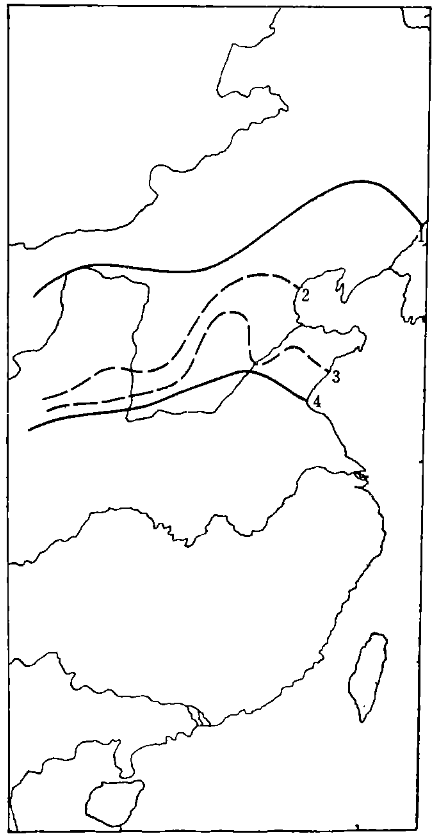

Fig. 10. Change of cropping system in China when YMT rises by 3°C.

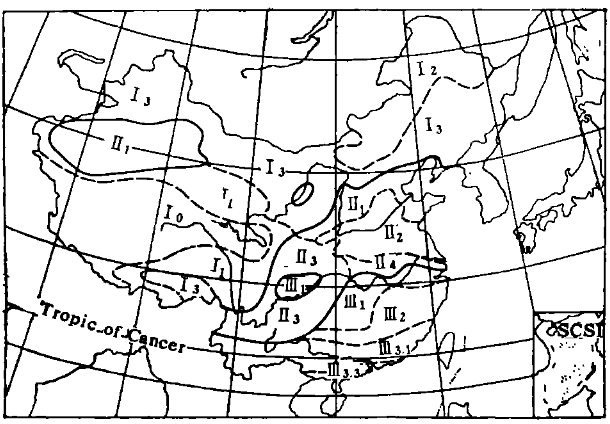

Fig. 9. The map of agroclimatic regionalization in China.

IV. INFLUENCE OF THE GREENHOUSE EFFECT ON THE CROPPING SYSTEM IN CHINA

The reasonable agroclimatic regionalization is very useful for using agroclimatic resources, increasing the output of grains and improving the ecological equilibrium. For discussing the influence of climatic change on the cropping system, the work of agroclimatic regionalization in China should be described. Fig. 9 shows the map of agroclimatic regionalization of China (AMS, 1981). The planting regions in China were divided into three types. Type I dominates the single cropping system, Type II the twice cropping system, and Type III the triple cropping system.

The agroclimatic region of the eastern Asian monsoon occupies 46.21% of the whole country and has 80% of arable land in China. The total value of agroproduct accounts for almost 90% in China. So eastern part is very important for China. We need to increase the output of grain in the regions of Huang-Huai-Hai and the hilly land in subtropics.

Northwest China is an arid or semi-arid region. The development of agriculture and industry in the region mostly depends on the water resources. Due to the rapid increase of population in Northwest China, the water resources are decreased year by year. Therefore, people need carefully planning the development of industry and need controlling the growth of population.

As mentioned above, the precipitation in North China has been decreasing year by year since 1950. At present, the water resources are very lack in the region. We need develop a "water-saving" cropping system.

As mentioned earlier, the greenhouse effect would cause warming and dry/wet in China. It is interesting to investigate the relation between the greenhouse effect, climatic change and cropping system. As we know, it is a complex problem. Here, we try to estimate roughly the changes of cropping system due to the changes of temperature. The warming would cause the changes of accumulated temperature (AT, $T>0°C$ or 10°C) and the growth period and total thermal condition. We have analysed the value of AT for $T>0°C$ or 10°C if the yearly mean temperature (YMT) rises by 1°C, 2°C and 3°C using the data of 120 stations in the main region of agriculture from 1951 to 1986 (see Table 2). On the average, increase of AT of 5% to 6% will be achieved if YMT rises by 1°C in the region from 35°N to 25°N.

Table 2. Change of AT for $T>10°C$ when YMT Rises (°C)

Rising of YMT	Beijing 39°48′	Luoyang 34°40′	Hangzhou 30°14′	Guilin 25°25′	Zhanjiang 21°13′
1°C	166	257	218	354	506
2°C	332	514	436	709	1012
3°C	499	777	654	1063	1518

On the average, line of AT 4000°C is the southern boundary of single cropping system. Region with AT ranging from 4800° to 5500°C is good for growing wheat-rice double cropping system, AT 5500°—5800°C for rice-rice double cropping system, and AT 5800°C for triple cropping system. If we only consider the rise of YMT, the accumulated temperature would be larger than 4000°C in the eastern main agricultural region except the northeast China and Innermongolia. That is to say, the most part of this region is able to grow twice per year, i.e., it becomes a region of double cropping system if YMT rises by 3°C, as simulated by the OSU AGCM/mixed-layer ocean model for $2\times CO_2$ (see Fig. 8). Besides, the northern boundary of triple cropping system might move northward about five latitudes from the Changjiang River Valley to the Huanghe River Valley if CO_2 is doubled (i.e. YMT rises by 3°C). Fig. 10 shows the change of cropping system in this case.

The warming could also extend the growth period. The meaning of the growth period has been given in Appendix. Table 3 shows the change of growth period (days) when YMT rises by 1°C, 2°C and 3°C.

Table 3. Change of Growth Period (Days) when YMP Rises by 1°C, 2°C and 3°C

Increase of YMT (°C)	Datong 40°06′	Linyi 35°04′	Hangzhou 30°14′	Kunming 25°01′	Zhanjiang 21°13′
+0°C	153	210	233	258	347
+1°C	+10	+11	+10	+28	+22
+2°C	+20	+22	+20	+56	+44
+3°C	+30	+33	+30	+84	+66

Considering the changes of AT and growth period due to the rise of YMT, we can compute the yield increases (Table 4). It is shown in Table 4 that when YMT rises by 3°C, the 10—20% yield increases will be produced. This is a result only considering the thermal effect of increased CO_2. In fact, the increase of CO_2 would make the climate dry or wet. This is an important fact for yield. Now, we are computing the yield considering both the thermal and the dry/wet conditions. It will be finished very soon.

Table 4. Change of Yield (%) in Some Areas when YMT Rises

Rising of YMT	Datong	Linyi	Hangzhou	Kunming	Lian County
+1℃	7	5	4	5	3
+2℃	15	11	9	10	7
+3℃	21	16	13	14	10

If we only take into consideration the thermal effect of doubled CO_2 on the cropping system in China, the increasing rate of the climatic yield capability is shown in Fig. 11. The method of the estimating climatic yield capability is given in Appendix. It is shown in Fig. 11 that normally, the climatic yield capability might be increased by about 10% because of the doubled CO_2. An increase of about 15%—20% would be found in the central and southern China.

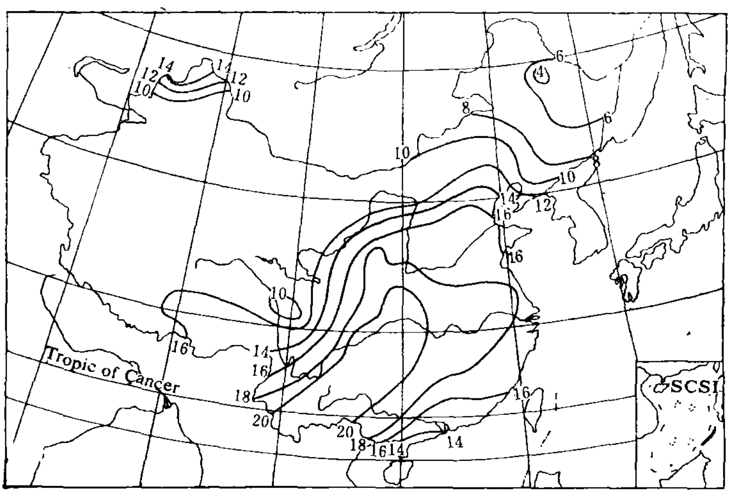

Fig. 11. Climatic yield capability in China (unit: %).

V. CONCLUSION AND DISCUSSION

As mentioned above, an apparent tendency of the temperature increase and precipitation decrease in China during the last 100 years is not found. But it is noticed that the temperature in China is increased during the last ten years and the precipitation is decreased in the northern part of China and increased in the southern part of China during the last 30 years. The sea level in the coastal areas south of 30°N in China has been rising during the last 100 years.

The changes of temperature, precipitation and soil moisture in China as simulated by several GCMs for doubled CO_2 are analysed. It is shown from all results of GCMs that the temperature would be increased by about 2°—4°C in the most parts of China. The precipitation and soil moisture might be decreased in the northern part of China and increased in the southern part of China, which is in agreement with the most results of the GCMs.

It is a difficult problem to estimate the influence of greenhouse effect on the cropping system. The changes of growth period and climate yield capability in China induced by doubled CO_2 have been estimated roughly. It is noted that the regions of the growth period in China might be moved northward about five latitudes and the climatic yield capability would be increased by about 10% in the most parts of China, especially in the central and southern parts of China.

It is not enough only to estimate thermal effect of the doubled CO_2 on the cropping system. It is a very difficult and complex problem about the relation between greenhouse effect, climatic change and cropping system. Here, we just begin to investigate this field. We hope that more research will be done and some useful results would be got in future.

APPENDIX

1. *Change of the Growth Period*

Tne growth period is the days during which the temperatures reach or exceed 10°C. The accumulated temperatures (≥10°C) have been calculated for each station. For example, the accumulated temperature (≥10°C) in Beijing is 4163°C and the growth period is 199 days. If the annual mean temperatures rise by 1°C, 2°C and 3°C, the accumulated temperatures increase by 166°C, 332°C and 499°C and the growth periods increase by 8 days, 16 days and 24 days, respectively.

2. *Estimation of the Climatic Yield Capability*

The Thornthwaite-Memoriao mode (shao and He, 1988) was used in this paper for estimating the climatic yield capability. The formula is

$$TSPr=3000[1-\exp(-0.000635(r-20))],$$

where $TSPr$ is the dry material yield of plant (unit:$gm^{-2}\ yr^{-1}$), and it is estimated by the real evapotranspiration. r is the annual mean evapotraspiration, which is estimated by

$$r=\frac{1.05N}{\sqrt{1+\left(\frac{1.05N}{L}\right)^2}},$$

where N is the annual mean precipitation, L is a function of temperature, and

$$L=300+25T+0.05T^3,$$

where T is the annual mean air temperature.

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