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The Influence of Climate Change on Rice in China from 1961 to 2009

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1. Introduction

At present, 40% of the Earth's land surface is managed for cropland and pasture (Foley et al., 2005). In developing countries, nearly 70% of people live in rural areas where agriculture is the largest supporter of livelihoods. For China, as such large developing country, the total population accounted to 13 billion with 73% of them pursuing agriculture, and the cropland was 1.3 billion ha in 2006 (CAY, 2007). About 20% of the global population lives in China supported only by 7% of the world's cultivated land. Although Chinese agriculture has undergone tremendous structural changes over the last decades, the average staple crop productivity has doubled in 25 years while the population increased by 25 % (CSY, 2003), until now, agriculture is still the most important industry for China which can affect food supplies of 13 billion populations.

Rice is one of China's most important staple food crops, and its planting area amounted to 27.4% of all food crop area, and its production was 37.1% of total food production in China (CAY, 2007). Meanwhile, the production of rice was influenced strongly by climate (Olesen, 2002), so its confirmed that the agriculture will be affected greatly by climate change.

2. Indexes

2.1 Rice planting regions

The triple-cropping rice can be planted in southern China when the accumulated temperature amounted to 7000 °C (daily temperature >10 °C), while when the accumulated temperature changed during 5300 - 7000 °C accumulated temperature amounted to, the double-cropping rice can growth (Cheng and Li, 2007).

2.2 The growing season length

Cheng and Li (2007) gave the indexes of the growing length of rice in southern China, the start of growing length was defied by the daily temperature more than 10 °C stably, and the end of growing season was defied by the daily temperature more than 20 °C.

2.3 High temperature

The production of rice was influenced strongly when the daily temperature was more than 35 °C in southern China, so 35 °C was defied as high temperature.

3. Results

3.1 Air temperature and precipitation variation in China, 1961-2009

The high quality data collected by 511 weather stations (selected from 748 CMA baseline or basic stations in line with the criteria of continuity and integrity) were employed to analyze and understand the temperature and precipitation variation trends in China during the period of 1961-2009. Anomalies were calculated based on the benchmark values of meteorological elements. Meanwhile, temperature and precipitation anomalies were calculated in grids ($5^\circ \times 5^\circ$, longitude \times latitude). The averaged nationwide series were obtained through an area-weighted process. The benchmark values of meteorological elements were derived from the averages of 1971-2000.

3.1.1 Temperature variation trends, 1961-2009

Fig. 1 depicts the averaged temperature anomalies in China during the period of 1961-2009. It is apparent that in a period of 49 years, China has witnessed an ascending mean temperature trend across the country, or 1.5°C up for the period of 1961-2009. The mean temperature in most years has registered a positive anomaly since the 1990s, with 2007 being the warmest.

Most parts of China enjoyed an ascending trend of air temperature, as shown by the spatial distribution of air temperature variation in Fig. 2, with the northern part sitting in a noticeably warming range between $0.3\text{-}0.6^\circ\text{C}/10\text{a}$. The northeast part of the northeast region, the central part of Inner Mongolia, and the east part of Xinjiang also saw a temperature rise up to $0.6\text{-}0.9^\circ\text{C}/10\text{a}$. Most part of the Yellow River in the south came up with a universal small rise of temperature, basically under $0.3^\circ\text{C}/10\text{a}$.

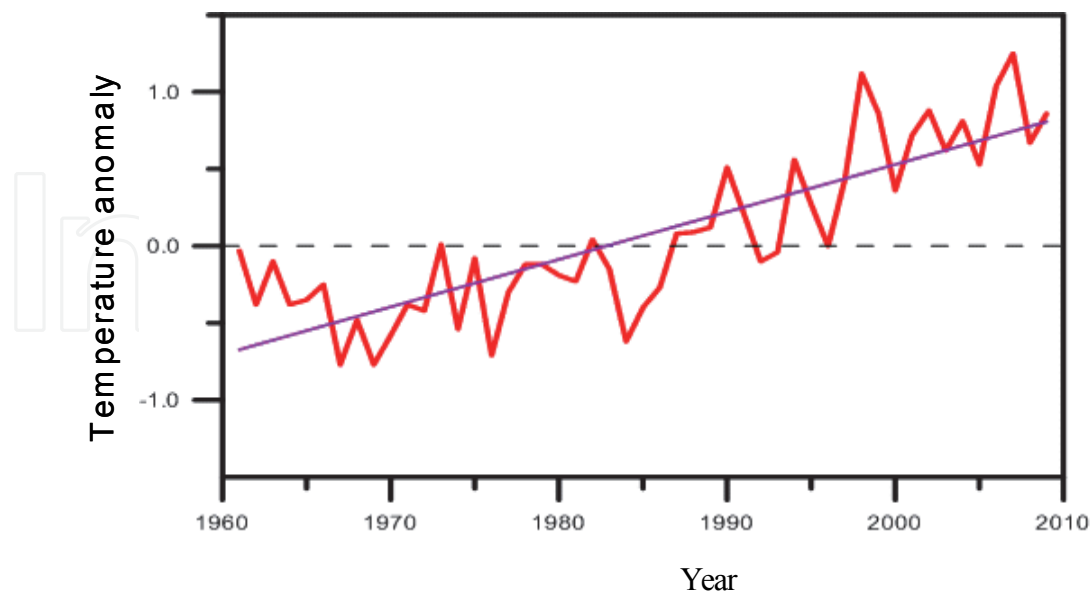


Fig. 1. Averaged temperature anomalies, 1961-2009 ($^\circ\text{C}$).

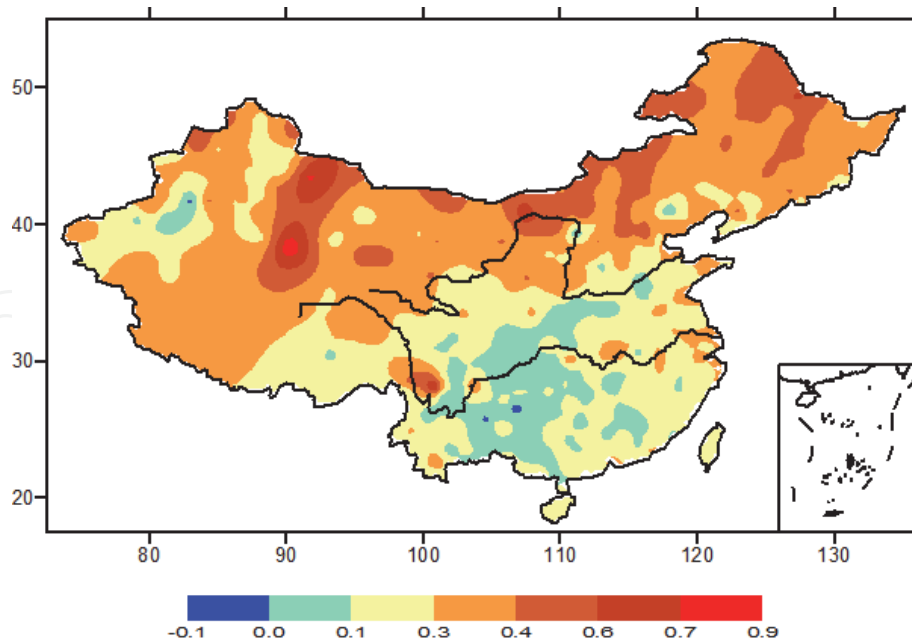


Fig. 2. Spatial distribution of temperature variation across the country, 1961-2009 ($^{\circ}\text{C}/10\text{a}$).

3.1.2 Precipitation variation, 1961-2009

China had not registered a noticeable trendy variation of averaged precipitation during the period of 1961-2009, with a slight increase of 12.86mm (Fig. 3), though the curve went down in the latest 10 years. Fig. 4 shows the spatial distribution of precipitation trends across the country, suggesting a decline in most parts of East China, noticeably in most parts of North China, the Pan-Bohai Sea region, and the central and east part of the southwest region. During the same period of time, the lower and middle streams of the Yangtze River, the southeast coastal areas, and Hainan saw increased rainfall. On the other hand, most parts of China west of 105°E tended to have an increased precipitation, noticeably in the southeast part of Tibet.

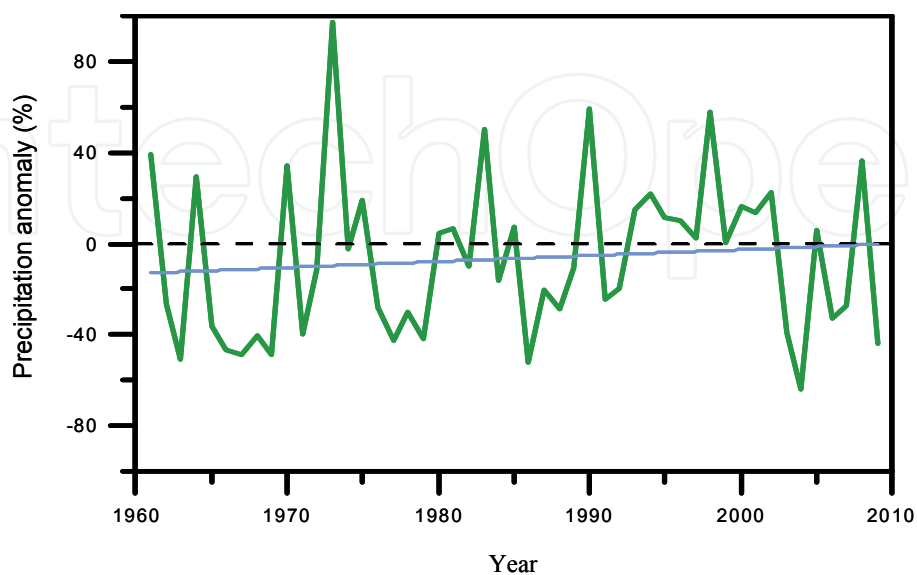


Fig. 3. Averaged precipitation anomalies, 1961-2009 (mm).

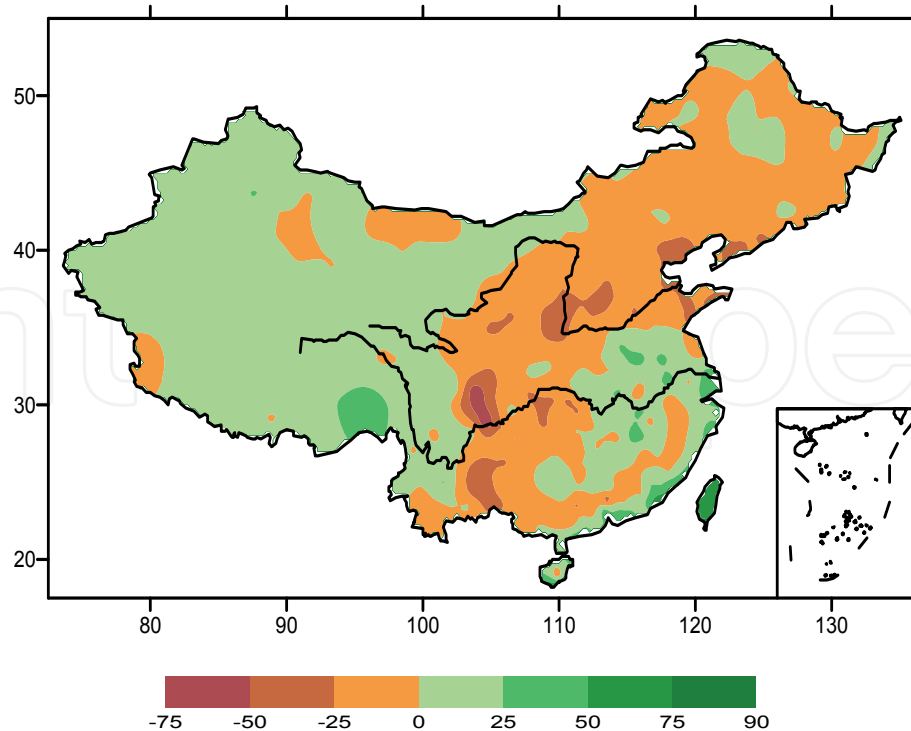


Fig. 4. Spatial distribution of precipitation variation, 1961-2009 (mm/10a).

3.2. Climate change impact on the northward shift of double rice cropping in South China

3.2.1 Active accumulated temperature variation across the southern rice growing areas

Paddy rice is a short-day plant which needs the warm and wet environment. Rice growing activities have to be defined in line with a range of ecological and environmental elements, including heat, growing season, water, sunshine, elevation, soil, production condition, and cropping system (Cheng, 2007). Heat resource makes a pivotal element in defining the distribution of rice growing areas. Theoretically, the heat resource defined for paddy rice is technically expressed in an active accumulated temperature $\geq 10^{\circ}\text{C}$. Active accumulated temperature is the sum total of the temperatures that are above the lowest biological temperature a plant has had during the entire growth season in a year, or the sum total of the averaged daily temperatures that are above a given threshold value. In southern China, triple cropping rice can be planted when the active accumulated temperature was more than 7000°C , and double cropping rice can grow when the active accumulated temperature was more than 5300°C (Cheng, 2007).

Previous studies show that most parts of China have registered an increased heat resource against the background of global warming, which extends crops' growing season and allows thermophilic crops to move further north, changing the pattern of cropping systems. During the period of 1961-2009, the southern rice growing areas witnessed a noticeably increased active accumulated temperature ($\geq 10^{\circ}\text{C}$), with an averaged active accumulated temperature at 5712.8°C in the 60's, and 5686.3°C and 5677.0°C in the 70's and 80's, respectively. The same indicator rose to 5809.8°C in the 1990's, or 97.0°C up compared with the 60's. During the period of 2001-2009, the averaged active accumulated temperature hit 5980.8°C , or 268.0°C higher compared with the 60's, or 303.8°C up against the 80's. During

the 19 years running from 1991 to 2009, 16 years reported an active accumulated temperature that was higher than it from 1971 to 2000, with 1998 being the warmest at 6144.9 °C, or 420.6 °C higher than what would have been in a normal year. The same indicator appeared at 6011.1 °C in 2009, or 286.8 °C higher compared with a normal year (Fig. 5).

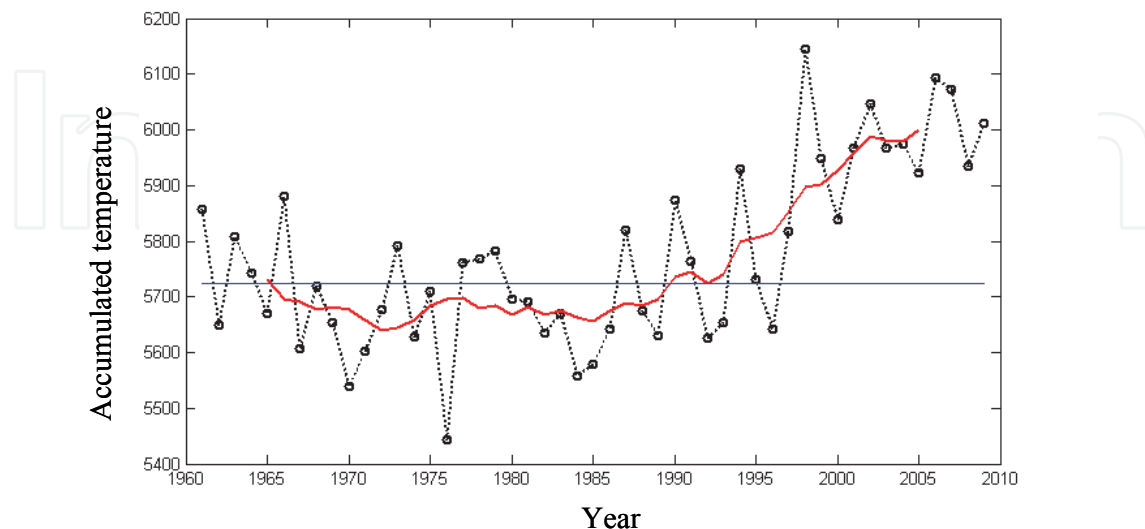


Fig. 5. Active accumulated temperature variation in the southern rice growing areas, 1961-2009 (°C).

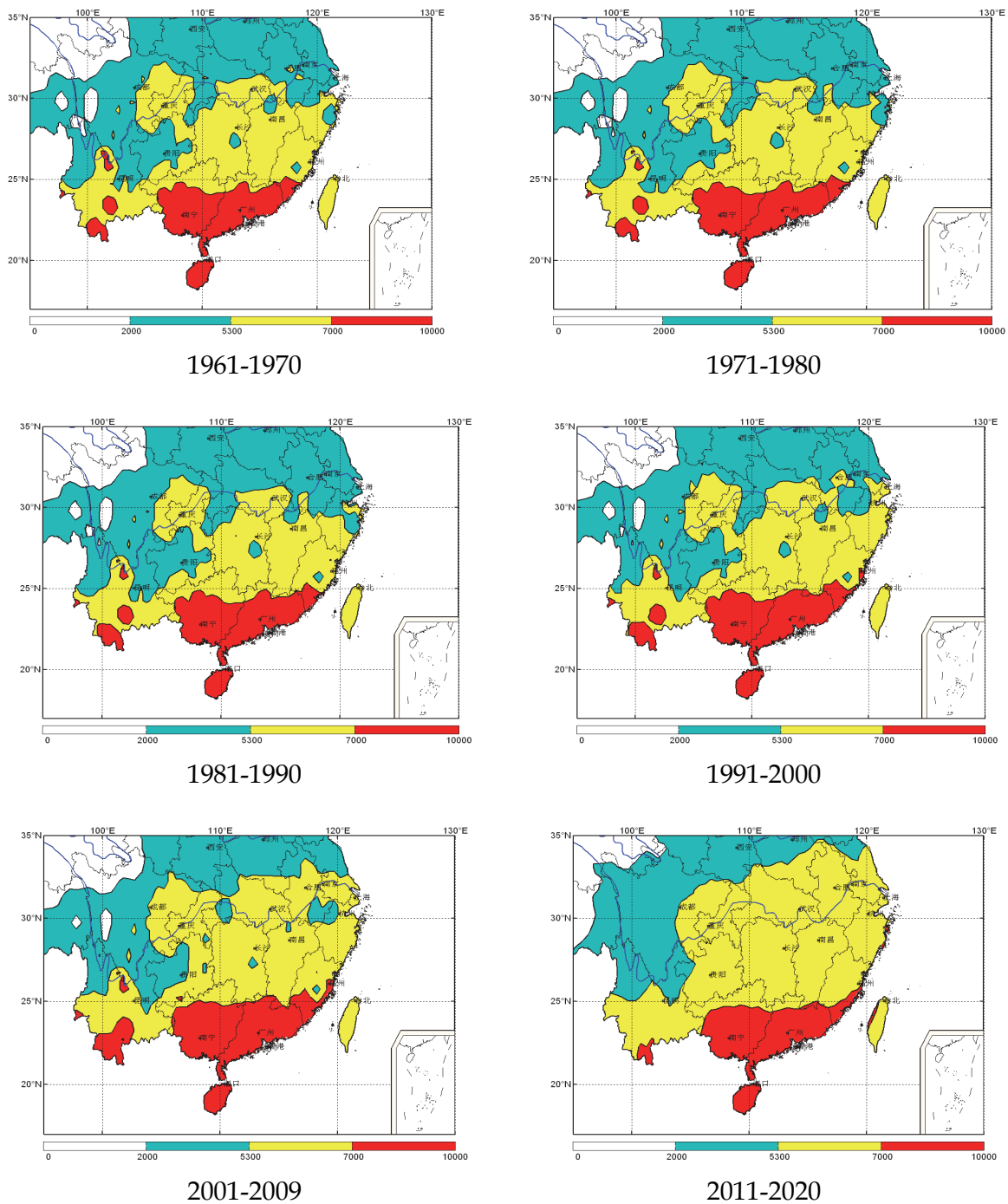
Rice is a staple food crop in China. In 2000, the rice sown area reached 29.962 million hectares, accounting for 27.6% of the grain sown area in the country, with a yield of 187.91 million tons, or 40.7% of the total food crop yield in the country (CSY, 2001). Heat resource defines the distribution and cropping of rice growing. For example, an area having an accumulated temperature at 2000-5300°C (≥ 10 °C) is desirable for the one-cropping system, while the one at 5300-7000°C may enjoy a double cropping practice. An area with an accumulated temperature at 7000°C or above is allowed to grow three cropping.

During the period of the 1960's-1980's, China saw limited variations in heat distribution. The areas having an annual active accumulated temperature (≥ 10 °C) at 7000°C or above sat mostly in the central and southern part of South China, practicing a three cropping system. The areas with an annual active accumulated temperature (≥ 10 °C) between 5300°C and 7000°C have included most parts of Hunan, Jiangxi, the central and southern part of Zhejiang, most parts of Fujian, the southeast part of Hubei, some parts of Sichuan and Chongqing, and the southern part of Yunnan (Figs. 6).

During the period from the 1990s to 2009, the safe threshold for double cropping (5300°C) and triple cropping (7000°C) moved further north. For example, the northern boundary of double cropping moved up for more than 2 degrees, or some 300 km (Figs. 6). As a result, a range of areas, including the east part of Sichuan, most parts of Chongqing, the east part of Guizhou, most parts of Hubei, most parts of Anhui, and the southern part of Jiangsu, became desirable for double cropping.

China National Climate Center predicts that China will see a further warming climate during the period of 2011-2020 (Ding et al., 2007). Most parts of the country will have a sustained rise of active accumulated temperature. The trend may further increase the heat resource for the newly added double cropping areas. As a result, the northern boundary of

double cropping may move further north (Fig.6). These areas apparently need to readjust the cropping system in a scientific manner, in line with the local conditions, adapting to the changed climate resource and environment, and enhancing the utilization of climate resources.



(the data during 1961-2009 from observed meteorological stations, and the data during 2011-2020 projected by RegCM3)

Fig. 6. Distribution of active accumulated temperature (≥ 10 °C) in the southern rice growing areas. Note: the red color represents the areas desirable for triple cropping, and the yellow one for double cropping.

3.2.2 Changed duration of the growing season

The growing season duration is also an element that defines the distribution of rice growing areas. For example, early rice is sown in the late February in the southern part of China, with late rice being harvested in the early November. The sowing could be later, starting from the mid-March in the south of the Yangtze River, with late rice becoming ripened in the mid-October. In southern China, triple cropping rice can be planted when the growing season length was longer than 270 days, and double cropping rice can grow when the growing season length was longer than 200 days (Cheng, 2007).

During the period of 1961-2009, the duration of rice growing season (the days with an averaged temperature passing the threshold of $\geq 10\text{ }^{\circ}\text{C}$ in the beginning of the growing season and $\geq 20\text{ }^{\circ}\text{C}$ at the end of it) in the southern part of the country was noticeably prolonged (Fig. 7). For example, the duration of rice growing season lasted for 214.9 days in the 60's, with 221.9 days and 211.7 days in the 1970's and 1980's, respectively. In the 90's, an averaged rice growing season would last for 220.3 days, a bit longer compared with the 60's and 80's, though slightly shorter against the 70's. During the period of 2000-2009, the rice growing season rose to 231.4 days in the southern rice growing areas, or 16.5 days longer compared with the 60's, or 19.7 days longer against the 80's. Apparently, the duration of rice growing season has become noticeably longer in the southern part of China since the 21st century.

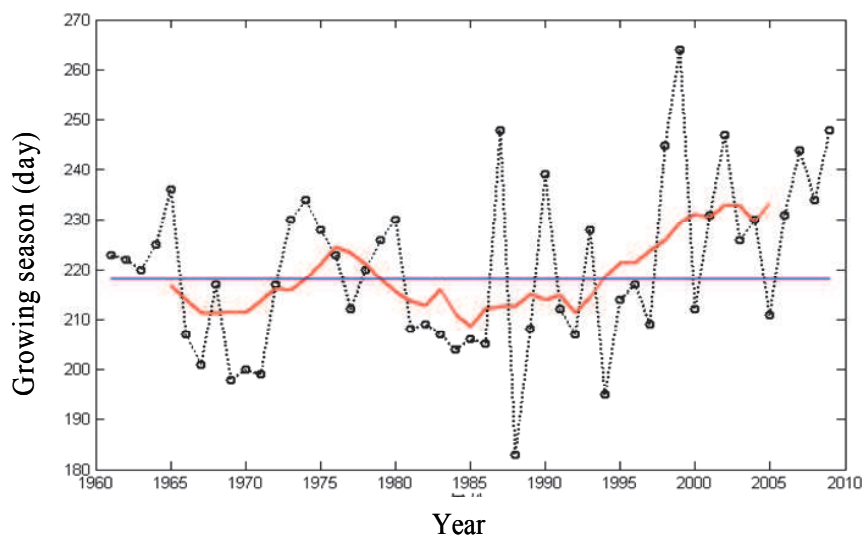
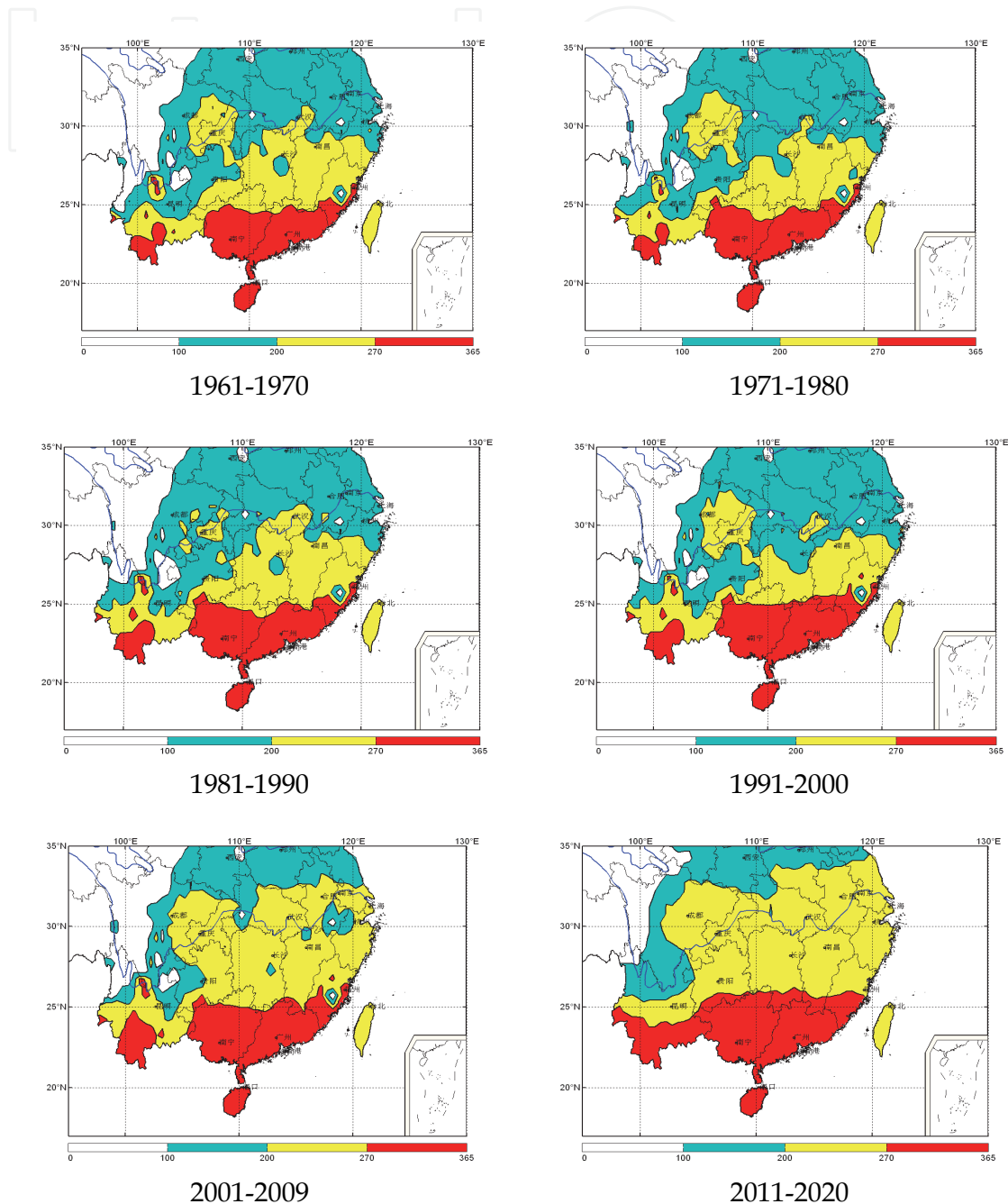


Fig. 7. Changed duration of rice growing season in the southern rice growing areas, 1961-2009 (day).

In China, the safe rice growing season would last for some 270 days under a triple cropping system, or some 200 days for a double cropping system. In other words, the 270-day growing season is desirable for triple cropping, and the 200-day for double cropping.

Figs. 8 show that as far as the safe rice growing season is concerned, climate warming has imposed no significant impacts on the scope of the areas desirable for triple cropping. However, climate warming have noticeably pushed the northern boundary of double cropping further north. Such northward shift has become increasingly noticeable since the 21st century. In the period from the 60s to the 90s, the double cropping system was mainly practiced in the south of the Yangtze River Valley. However, the northern boundary of double cropping has gone further to the north of the Yangtze River since the 21st century, including the northeast part of Sichuan, the east part of Guizhou, Chongqing, most parts of Hubei, the central and southern part of Anhui, and the southern part of Jiangsu. Apparently, the northern boundary of double cropping has gone further north, compared with the 90's.

According to the analysis and prediction made by China National Climate Center, the period of 2011-2020 will see a further intensified climate warming trend in China, with a prolonged rice growing season in the southern part of the country, and a further northward shift of the double cropping boundary. The conclusion agrees with the northward shift of the double cropping boundary depicted by the results of active accumulated temperature calculation.



(the data during 1961-2009 from observed meteorological stations, and the data during 2011-2020 projected by RegCM3)

Fig. 8. Changed duration of rice growing season in the southern rice growing areas (day). Note: the red color represents the areas desirable for triple cropping, and the yellow one for double cropping.

3.2.3 Annual precipitation variation

Precipitation is also in a position to affect the distribution of rice growing areas. In China, both double and triple cropping need an annual rainfall no less than 1,000 mm. Fig. 19 shows that climate warming has produced limited impacts on the rainfall in the southern part of China. In the 60's, the southern part of the country where paddy rice was grown registered an averaged annual precipitation of 1379mm. The 1970's, 1980's, and 1990's recorded a sustained increase of precipitation at 1412 mm, 1435mm, and 1491 mm respectively (Fig. 9). China, however, has seen a slightly decreased precipitation to 1431 mm starting from the 21st century.

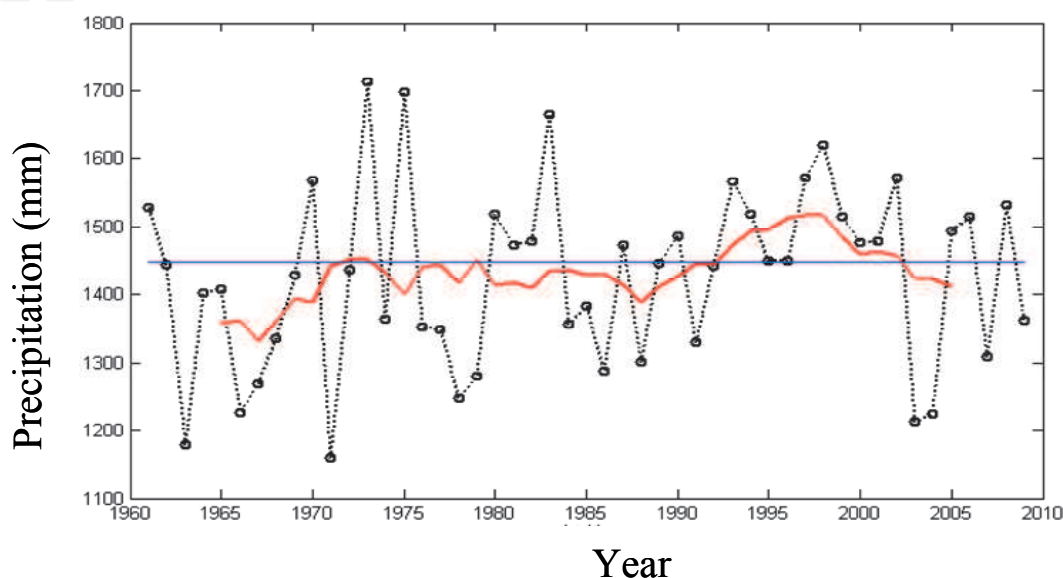
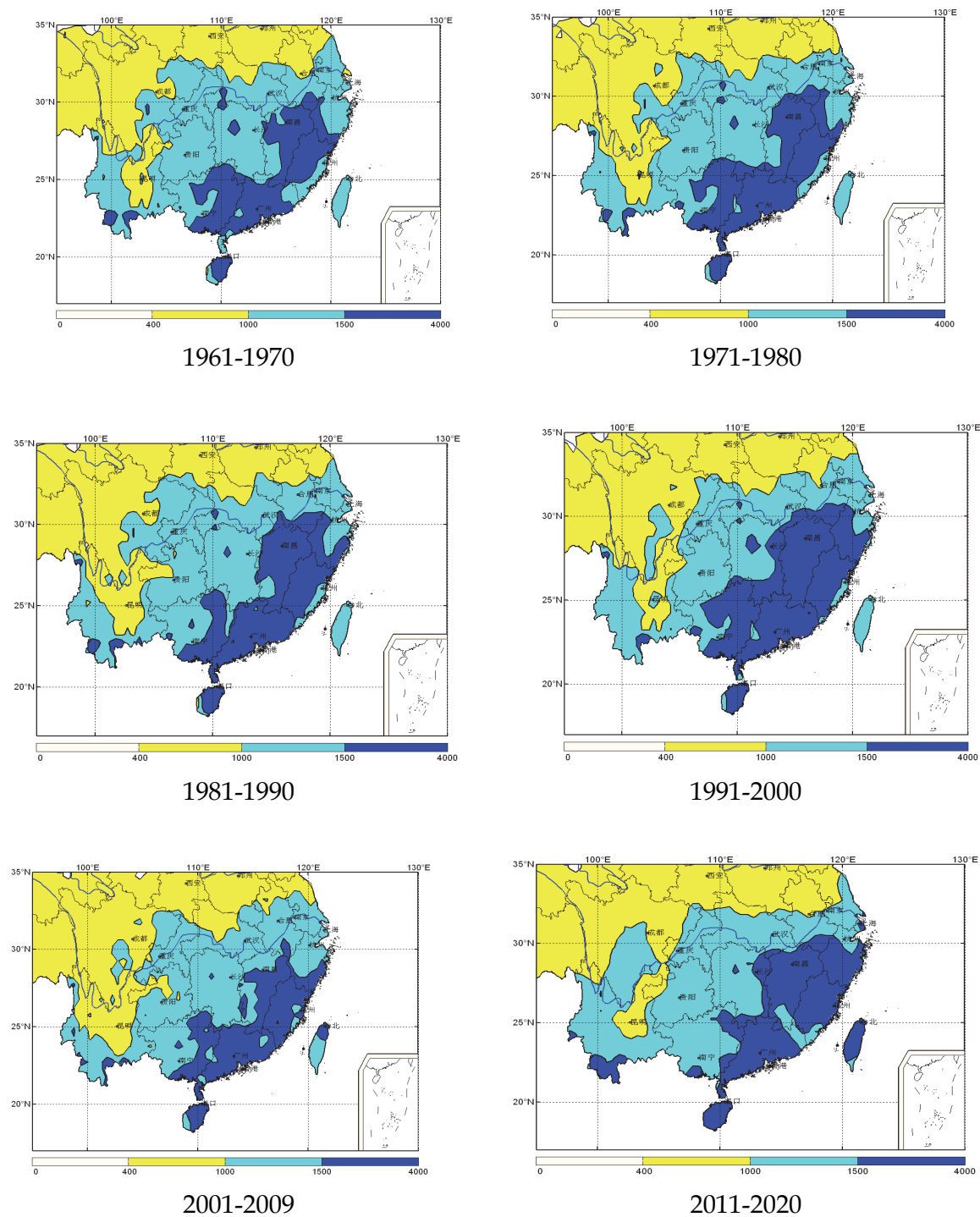


Fig. 9. Annual precipitation variation in the southern rice growing areas, 1961-2009 (mm).

In addition, most parts of Hainan Province, the east part of Guangxi, Guangdong, Fujian, and Jiangxi reported an annual precipitation of 1,500 mm or above in the 60's, with the rest of rice growing areas in the south sitting between 1,000mm and 1,500 mm (Fig. 10). In the 70's, the areas enjoying an annual precipitation of 1,500 mm or above did not see much change in number, though the areas sitting between 1,000mm and 1,500 mm in both Sichuan and Jiangsu reported a slight drop in number. In the 80's, the areas having an annual precipitation of 1,500 mm or above in Guangxi saw a slight drop in number, with little change of the areas sitting between 1,000mm and 1,500 mm. In the 90's, the areas having an annual precipitation of 1,500 mm or above in Guangxi reported some increase in number, though the areas sitting between 1,000mm and 1,500 mm in Sichuan suffered a noticeable drop in number. Zhejiang, Anhui, and Jiangxi have reported a noticeably declined number of the areas having an annual precipitation of 1,500 mm or above since the 21st century, with a slight drop of the areas sitting between 1,000mm and 1,500 mm in both Sichuan and Yunnan.

Overall speaking, the southern paddy rice growing areas in China didn't see much change in precipitation during the period of 1961-2009, though a number of provinces, including Jiangsu, Hubei, and Sichuan, had reported a declined number of the areas sitting between 1,000mm and 1,500 mm since the 21st century, which deserves further attention.

China National Climate Center predicts that the southern part of China will not see a large variation in precipitation during the period of 2011-2020 (Ding et al., 2007). As a result, precipitation will produce no significant impacts on the southern rice growing areas in the coming decade if the precipitation change slightly.



(the data during 1961-2009 from observed meteorological stations, and the data during 2011-2020 projected by RegCM3)

Fig. 10. Distribution of annual precipitation in the southern rice growing areas (mm).

3.2.4 High temperature day trends in the southern rice growing areas

The Jiangnan region

In the most part of the Jiangnan of China, rice would enter the heading, flowering, and filling stages in June and July. In the Jiangnan, the first cropping rice enters the heading and flowering stage in August. This period of time is featured with the positive dominance of subtropical highs, claiming more high temperature days. The abnormal frequency of hot days would result in a shortened period for heading, flowering, and filling, reducing the leaf assimilation on the one hand, and causing the surge of blighted rice and a reduced yield and quality on the other (Zhang and Wang, 1998).

In June, hot weather ($\geq 35\text{ }^{\circ}\text{C}$) starts to affect the lower and middle reaches of the Yangtze River. In the early June, this part of the Jiangnan would have 0.3 hot days in a normal year, with 0.5 hot days for the period of 2001-2009. In the mid-June, 0.4 hot days would appear in a normal year, with 0.8 days in the period of 2001-2009. In the late June, 0.6 hot days is a common place, with 1.7 days for the period of 2001-2009. It is noteworthy that the lower and middle reaches of the Jiangnan has witnessed a noticeably raised number of hot days at 2.1 days during the period of 2005-2009 since 2005 (Table 1).

July is a month featured with a noticeably raised number of hot days in the lower and middle reaches of the Yangtze River. In the early July, hot days would reach 1.9 in number in a normal year, with 2.6 days for the years since 2000. The mid-July would produce 2.7 hot days, though 3.5 days since 2000. In the late July, high temperature days would go up to 3.2 days on an average, with 4.5 days for the period of 2000-2009. Technically, the late July claims the most hot days in the lower and middle reaches of the Jiangnan with a noticeably raised number of hot days in the past 20 years (Table 1).

August starts to see a declined number of hot days in the Jiangnan. In the early August, high temperature days reach 2.9 on an average, though with a slightly descending trend in the past 10 or 20 years. The mid-August would have 1.5 hot days, expecting no ascending trend. In the late August, high temperature days are averaged at 1.2 days. Technically, the early August would have a slightly increased number of high temperature days, and the mid-August a steadily decreased number of hot days since that time on.

Overall, the Jiangnan would have 14.7 hot days for the summer (June-August). The number of high temperature days has witnessed a noticeable rise, especially in the late June and late July, since 2000.

South China

The South China starts to have hot days ($\geq 35\text{ }^{\circ}\text{C}$) in June. In the early June, this part of the country would have 0.5 hot days on an average (Table 1), with 0.6 days for the mid-June, and 0.8 days for the late part of the month. This part of the country has registered a noticeably increased number of hot days in the late June since 2000.

July is featured with a noticeably raised number of hot days, with 1.5 hot days for the early July (Table 1). The mid-July would have 1.9 hot days on an average, though 2-5 days for the years since 2000. The late July has registered a pattern similar to the mid-July, with 2.2 hot days on an average, and a noticeably increased number of hot days to 2-5 days since 2000.

In August, the lower and middle reaches of the Yangtze River start to see fewer hot days. The early August is averaged with 1.7 hot days, witnessed a noticeably increased number of hot days in a 10-year period. The mid-August would have 1.4 hot days, and the late August 1.2 hot days. Overall speaking, the early August has slightly more high temperature days,

with an ascending trend in the past decade. The number of hot days steadily declines starting from the mid-August (Table 1).

		1961-1970	1971-1980	1981-1990	1991-2000	2001-2009
Jiangnan	Jun 1-10	0.3	0.2	0.4	0.3	0.3
	Jun 11-20	0.5	0.6	0.4	0.3	0.8
	Jun 21-30	0.8	0.7	0.6	0.7	1.7
	July 1-10	1.4	2.5	1.8	1.4	2.8
	July 11-20	3.6	2.1	3.3	2.8	3.4
	July 21-31	4.3	3.1	2.5	3.8	4.5
	Aug 1-10	3.1	3.3	2.6	2.8	2.9
	Aug 11-20	2.6	1.4	1.8	1.4	1.8
	Aug 21-31	2.7	1.4	1.0	1.1	2.1
South China	Jun 1-10	0.3	0.2	0.3	0.9	0.4
	Jun 11-20	0.4	0.7	0.6	0.5	0.5
	Jun 21-30	0.8	0.7	1.0	0.7	1.5
	July 1-10	1.1	1.7	1.5	1.2	2.1
	July 11-20	1.8	1.9	2.2	1.6	3.0
	July 21-31	2.5	1.9	2.1	2.4	3.1
	Aug 1-10	1.4	1.2	2.1	1.9	2.7
	Aug 11-20	1.4	0.9	1.9	1.4	1.8
	Aug 21-31	1.7	0.8	1.2	1.5	1.8

Table 1. The high temperature days ($\geq 35^\circ\text{C}$) for every 10 days over Jiangnan and South China regions during 1961-2009.

In summary, the South China has, on an average, 11.8 hot days in the summer, though with a noticeably raised number of hot days since 2000, especially from the late June to the early August. In the past decade, the southern rice growing areas have witnessed a noticeably increased number of hot days in the summer, which may cause heat injury to the rice plants in their filling stage, compromising both the yield and quality of rice. In this context, one has to breed heat resistant rice varieties and develop technical measures to ease the damages caused by high temperature.

4. Conclusion

Rice is one of China's most important staple food crops, and the climate change have already influenced the growth of rice in China. All the above studies showed that the climate change were influenced the rice planting in southern China. For recent two decades, as the active accumulated temperature increases in the southern China, the rice growth period extended, with the double-cropping rice growing boundaries being apparently pushed northward, even showing a slight northward shift of triple-cropping rice boundaries. From 1960s to 1980s, the double-cropping rice only grew in the areas to the south of the Yangtze River. However, for the recent 10 years, its growth areas had shifted to those to the north of the Yangtze, with their northern boundaries having been pushed approximately 300 km to the north, extending to northeastern part of the Sichuan, eastern Guizhou, Chongqing, most Hubei, central and southern Anhui, as well as southern Jiangsu (Fig.11). Although climate warming increased the thermal resources for rice growth areas over the region, creating favorable conditions for making use the thermal resources, and for

increasing the multi-cropping index, farmers may face challenges as how to better address the issues related to availability of additional farming machinery required for the enlarged double-cropping rice production. On the other side, as climate will continue to warm, the early rice may be negatively affected by high temperature ($\geq 35^\circ\text{C}$) on filling stage of rice, and therefore it is imperative to develop and use heat-resistant rice varieties to mitigate the high temperature-induced crop damages.

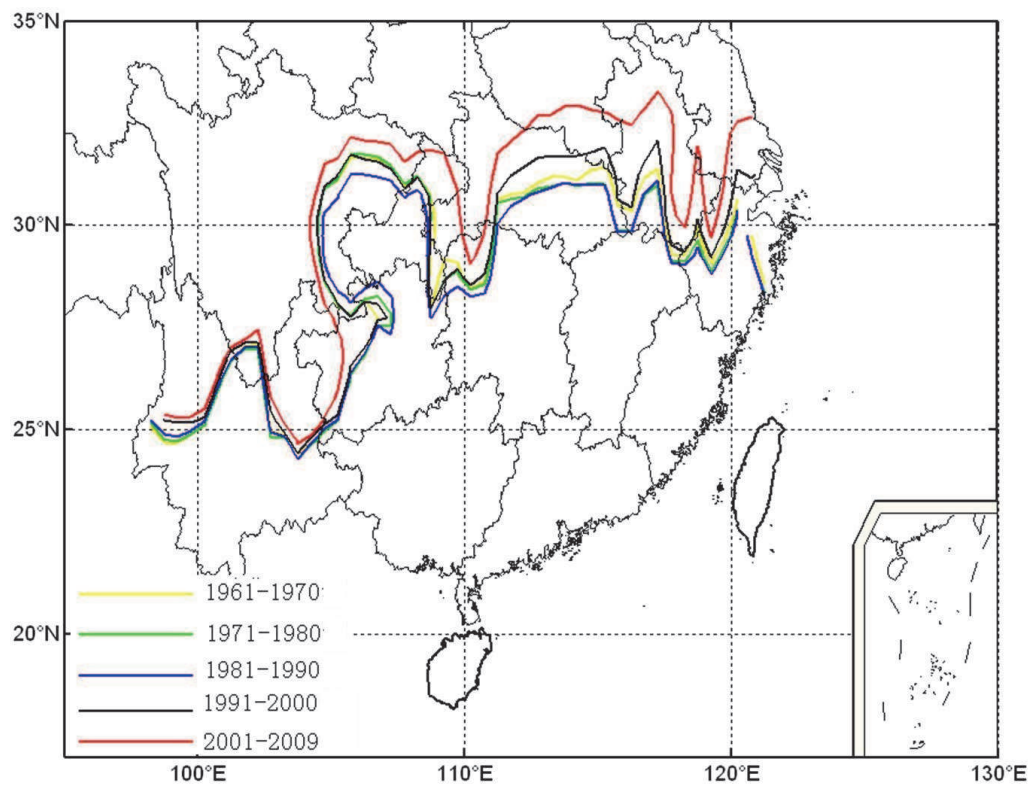


Fig. 11. The influence of climate change on growing northern boundaries of double-cropping rice in China from 1961 to 2009.

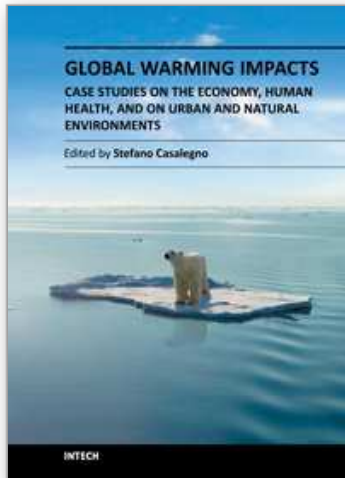
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This book addresses the theme of the impacts of global warming on different specific fields, ranging from the regional and global economy, to agriculture, human health, urban areas, land vegetation, marine areas and mangroves. Despite the volume of scientific work that has been undertaken in relation to each of each of these issues, the study of the impacts of global warming upon them is a relatively recent and unexplored topic. The chapters of this book offer a broad overview of potential applications of global warming science. As this science continues to evolve, confirm and reject study hypotheses, it is hoped that this book will stimulate further developments in relation to the impacts of changes in the global climate.

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