The Impacts of Climate Change on Chinese Agriculture – Phase II

Climate Change in Ningxia: Scenarios and Impacts

Technical Report

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Project Background

The project *Impacts of Climate Change on Chinese Agriculture* (ICCCA) was funded by the UK Government's Department for Environment, Food and Rural Affairs (Defra – transferred to the Department of Energy and Climate Change, DECC, in October 2008) and Department for International Development (DfID), conducted in partnership with China's Ministry of Science and Technology (MOST).

Since 2001, the project has led the way in understanding how climate change can be expected to affect rural China.

The project was rolled out in two phases: Phase I (2001 to 2004) applied regional climate modelling to construct several possible future climate scenarios for China. These were subsequently fed into a suite of regional crop models adapted by the Institute of Environment and Sustainable Development in Agriculture (previously the Agrometeorology Institute) of the Chinese Academy of Agricultural Sciences (CAAS), in collaboration with UK climate-change researchers, to determine the potential impacts of climate change on crop yields in China up to 2100.

Building on Phase I, Phase II (2005 to 2008) refined and widened the national level analysis. CAAS also worked in collaboration with major regional implementers such as the Clean Development Mechanism Service Centre (Ningxia) and Meteorological Study Institute (Ningxia), and engaged a range of stakeholders to assess the impact of climate change on rural livelihoods. This led to the development of the first regional adaptation framework in China – for the northern province of Ningxia.

The key findings and approaches for the project are summarised in six pamphlets. These are:

- *Overall summary of results*
- *Understanding how China's climate may change in the future*
- *Modelling the impacts of climate change on cereal production in China*
- *Modelling the interaction of climate change - water availability and socio-economic scenarios on cereal production*
- *Rural livelihoods and vulnerability to climate hazards in Ningxia*
- *An adaptation framework and strategy for Ningxia*

The full technical reports from the project can be found at www.china-climate-adapt.org. These are:

- *National Level Study: The Impacts of Climate Change on Cereal Production in China*
- *Future Cereal Production in China: Modelling the Interaction of Climate Change,Water Availability and Socio-Economic Scenarios*
- *Climate and Livelihoods in Rural Ningxia*
- *Climate Change in Ningxia: Scenarios and Impacts. Technical Report.*
- *Adaptation Framework and Strategy:*
    - *Part 1 – A Framework for Adaptation*
    - *Part 2 – Application of the Adaptation Framework: A Case Study of Ningxia, Northwest China*
    - *Part 3 – An Adaptation Strategy for Agriculture in Ningxia, Northwest China*

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The project team comprised the Institute of Environment and Sustainable Development in Agriculture of the Chinese Academy of Agricultural Sciences (CAAS), AEA Group, who managed the project and provided technical input, and Dr. Declan Conway of the University of East Anglia as Scientific Advisor. The project has benefited from the contribution of numerous partners and stakeholders in both China and the UK. Collaborative research links have been forged resulting in new insights into the scientific and policy challenges posed by climate change in China over the next century.

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Key collaborators

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- Chinese Ministry of Science and Technology
- National Development and Reform Commission
- China Meteorology Administration
- Chinese Ministry of Agriculture
- Chinese Academy of Social Sciences
- Ningxia Department of Science and Technology
- Ningxia Bureau of Meteorology
- Ningxia Agriculture and Livestock Department
- Office of Environmental Protection, Ningxia
- Office for Poverty Alleviation, Ningxia
- Clean Development Mechanism Centre, Ningxia

UK

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- School of Earth, Environmental and Geographical Sciences, University of Edinburgh, UK
- Unit for Landscape Modelling, Cambridge University, UK

www.china-climate-adapt.org

Executive summary

The first stage of the consultation process leading to an assessment of the impact of climate change on rural livelihoods and the development of an adaptation strategy for the agriculture sector in Ningxia entailed familiarising stakeholders in Ningxia with projections of what the future climate may be like in the region, and its potential impact on agricultural production.

This report outlines the research in climate modelling and crop modelling underpinning this key first stage. On climate modelling, it presents the high-resolution climate scenarios for Ningxia out to 2100 produced by ICCCA Phase II with the PRECIS regional climate model under Intergovernmental Panel of Climate Change SRES emissions scenarios A2 (medium-high emissions) and B2 (medium-low emissions). On crop modelling, crop production under the PRECIS climate scenarios was simulated for four staple crops in the region – maize, wheat, rice, potato.

The findings are as follows:

Future climate in Ningxia

Table ES. 1 below summarises the changes in maximum and minimum temperature, and precipitation projected by PRECIS.

Overall:

- The warming registered in recent years is projected to continue and accelerate, reaching up to 6.4℃ by the 2080s under the A2 (medium-high) emissi ons scenario.
- Overall precipitation is projected to increase by 12% in the 2080s under A2 emissions. Seasonal trends suggest marked decreases in summer precipitation (June to August), namely -23% by the 2080s under A2 emissions.
- Precipitation projections also display differing geographically across the region: whilst moderately drier conditions occur in the north, in the south precipitation is projected to increase.

Table ES. 1 Changes in future annual maximum and minimum temperature (℃) and precipitation (%) for Ningxia projected by PRECIS under SRES A2 (medium-high) and B2 (medium low) emissions scenarios.

Changes relative to the baseline (1961-1990)	T_{max} (℃)		T_{min}(℃)		Precipitation (%)	
	B2	A2	B2	A2	B2	A2
2011-2040	1.6	1.8	1.6	1.8	+3	+5
2041-2070	2.6	3.6	2.7	3.7	+4	+8
2071-2100	3.5	6.0	3.7	6.4	+6	+12

A range of other climate models have produced climate scenarios for China under the IPCC SRES A2 and B1 emissions scenarios; these climate scenarios were made available for the IPCC Fourth Assessment Report. Multi-model climate scenario averages were also taken across different models, and PRECIS scenarios were then compared to these multi-model averages to assess PRECIS' performance against other established models. The features of the multi-model averages are presented in Table ES.2 below.

Table ES. 2 Summary of main changes in temperature and precipitation in Ningxia based on results of IPCC Fourth Assessment Report multi-model output, extracted for Northern China, including Ningxia.

Temperature
High confidence
• Warming in all seasons and all periods with A2 and B1. • 2020s Annual warming: A2 1.3℃; B1 1.2℃. • 2050s Annual warming: A2 2.5℃; B1 1.9℃.
Precipitation
Medium confidence
• Annual precipitation increases in all seasons and all periods with A2 and B1. • 2020s Annual increase with A2 +3%; B1 +7%. • 2050s Annual increase with A2 +9%; B1 +8%. • Annual changes mask significant seasonal changes in precipitation. • For the key season for precipitation, summer (JJA), models show some divergence with nearly half the sample projecting drier conditions. Extreme results range from roughly -25% to +40% changes in summer precipitation.

Effects of climate change on crop yields

Ningxia Meteorological Bureau applied a set of crop models to simulate the effects of climate change on four key crops in the region: maize, rice, wheat and potato. This work formed part of a collaborative capacity building exercise to develop the ability to run crop models in Ningxia Meteorological Bureau. Preliminary results of this ongoing work are presented here.

For rice, maize and wheat, the impacts of climate change on production was simulated using the CERES model calibrated so as to simulate the growth of the crop varieties that are typically grown in Ningxia as well as the historical record; changes in potato yields were simulated with the SUBSTOR model, calibrated to match the features of local varieties and the historical record of the last 20 years.

Table ES. 3 below sets out the overall results of the simulations for rice, maize and spring wheat in the region, whilst Table ES. 4 presents the results for potato crops. Note that whereas rice and maize yields are projected to increase throughout the century (relative to the baseline period), wheat and potato production are expected to decrease and, in the case of potato, the decreases are projected to become rather significant as the century progresses.

Table ES. 3 Future climate change and irrigated crop production in Ningxia

Crop type	Key impacts, short term and long term		2020s	2050s	2080s
Rice (irrigated)	Yield change Time to heading and maturity declines in future	A2	+7%	+10%	+9%
		B2	+4%	+9%	+9%
Maize (irrigated)	Yield change	A2	+18%	+1%	-7%
		B2	+21%	+4%	-5%
Spring Wheat (irrigated)	Yield change	A2	-3%	-9%	-18%
		B2	-3%	-7%	-11%

Table ES. 4 Future climate change and rainfed potato production in Ningxia

	2020s			2050s			2080s		
	Whole average	South section	Middle section	Whole average	South section	Middle section	Whole average	South section	Middle section
A2	-13.1	-12.6	-14.6	-21.1	-20.1	-23.8	-41.3	-40.9	-42.4
B2	-8.7	-9.5	-6.3	-11.1	-11.2	-10.6	-15.3	-14.9	-16.3

Socio-economic scenarios for Ningxia

ICCCA Phase II also developed socio-economic scenarios for Ningxia to 2050. These were fed into the stakeholder consultation with a view to providing an insight into the socio-economic significance of the changes in staple crop production projected by the modelling research.

The key features of Ningxia's socio-economic future as obtained by applying the same methodology that ICCCA Phase II used for its national level analysis are as follows:

- **Ningxia's population is projected to increase** from 5.96 million people in 2005 to 6.84, 6.54 and 6.79 in 2020 under, respectively, the A2, B2 and NP scenarios. In 2050, the population is projected to reach 8.66 million under the A2 scenario, 6.84 under the B2 scenario and 7.02 under the NP scenario.
- **GDP per capita in Ningxia is projected to increase five to tenfold between 2005 and 2050 depending on the emissions scenario used:** from $49.4x10^9$ RMB in 2005 to $264.4\ x10^9$ under the A2 scenario and $512.9\ x10^9$ RMB under the NP scenario (The B2 scenario yields similar projections to NP). Ningxia's economy, however, is projected to remain slightly below national average levels.
- **Overall agricultural land use is projected to decrease** in Ningxia, along with the trends elsewhere in China. The rates of change and areal estimates are subject to large uncertainties due to data availability and the crucial role of policy interventions. Changes range from large decreases under A2 (A2 sustains the high contemporary rates) to no change at all under B2 (as B2 assumes that government policy interventions to halt the decline in agricultural land area are successful).
- **Simulations suggest increases in water demand** which are accompanied by a shift in the proportional use of water by sector, primarily away from agriculture and towards industrial, urban and environmental uses where demand is expected to increase.

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1 Introduction

Phase II of the project *Impacts of Climate Change on Chinese Agriculture* (ICCCA), launched in September 2005, comprised an innovative case study that combined scientific research with practical policy perspectives on integrating climate change concerns into regional development planning. This case study centred on Ningxia Autonomous Hui Region in northwest China and ran between 2005 and 2008; it focused primarily on the impacts of climate change on agriculture.

The research concerning this case study was led by the Chinese Academy of Agricultural Sciences in collaboration with regional institutions in Ningxia: the Clean Development Mechanism Centre, Ningxia Meteorological Institute, Ningxia's Department of Science and Technology, Ningxia's Academy of Social Sciences, Office for Poverty Alleviation, Ningxia Development and Reform Commission, and Ningxia Department of Water Resources – and climate change researchers from the UK.

The study integrated biophysical dimensions of climate change (using high resolution climate scenarios, impacts modelling of crop growth and water availability) within a detailed understanding of socio-economic, institutional and policy contexts. It also included extensive stakeholder dialogue with government institutions, as well as a rural livelihoods approach to understanding vulnerability and adaptive capacity in rural communities. The results were fed into the development of a flexible generic framework for integrating adaptation into planning and management operations to develop an adaptation strategy for the agricultural sector in Ningxia. The approach was intended to lay the foundation for future adaptation policies in other Chinese regions and to identify lessons for similar exercises in other countries.

This report focuses on the climate modelling and crop modelling exclusively. The technical research results presented here fed directly into the development of an adaptation policy framework and strategy through a detailed consultation process in Ningxia. Specifically, the information presented in this report was used to inform participants at project workshops about the potential changes to the region's climate, and their effects on crops. Stakeholders were thus encouraged to start identifying the needs and opportunities opened up by climate change, and devise, assess and prioritise adaptation actions, i.e. actions and activities whose aim is to reduce the vulnerability that arises as a result of changes in the climate, and capitalise on new opportunities. The case study culminated with the formulation of an adaptation strategy for the agriculture in Ningxia and the establishment of the Ningxia Climate Change Response Office. ICCCA Phase II research in adaptation, including the consultation process and the development of an adaptation framework and strategy for Ningxia's agriculture sector as well as ICCCA's work on livelihoods can be found in four separate reports, namely: *Adaptation Framework and Strategy: Part 1, Part 2 and Part 3* (Ju Hui *et al*., 2008a, Ju Hui *et al*., 2008b and Ju Hui *et al*., 2008c) and *Climate and Livelihoods in Rural Ningxia* (Li Yue et al., 2008).

This report is structured as follows: Section 2 reviews recent climate variability and extreme events in Ningixa, as well as their economic impacts on the region. Section 3 presents the results of climate modelling. This includes, on the one hand, high-resolution climate scenarios for Ningxia out to 2100 computed with the PRECIS regional climate model and, on the other, multi-model average climate scenarios produced on the basis of a range of global climate models. The latter multi-model averages are used as a benchmark to assess PRECIS' performance relative to the existing suite of climate models. Section 4 sets out socio-economic scenarios for Ningxia to 2050 following the same methodology used by ICCCA to construct socio-economic scenarios for China as a whole (see *National Level Study: The Impacts of Climate Change on Cereal Production in China* for further details, Xiong *et al*. 2008). Finally, Section 5 briefly summarises the impacts of climate change on four staple crops in Ningxia – rice, wheat, maize and potato – using PRECIS climate scenarios. Details of the modelling specific to each crop can be found in Appendices A1 to A4. The appendices are intended as preliminary work, and are included here to provide an insight into the crop modelling capacity building undertaken within Ningxia Meteorological Bureau as part of ICCCA.

The results of ICCCA Phase II are summarised in brochures available on the project website: www.china-climate-adapt.org .

2 Recent climate variability, extreme events and economic impacts in Ningxia

Authors: Chen Xiaoguang, Declan Conway, Li Yue and Wan Yunfan

2.1 Introduction to the climate of Ningxia

Ningxia Hui Autonomous Region is located in the eastern part of northwest China (N35°14' to N39°23', E104°17' to E107°39'), in the upper reaches of the Y ellow River and has an area of 66,000 km^2. Ningxia is largely arid and semi–arid and narrow from east to west and long from south to north. The topography is higher in the south and lower in the northern plains region, through which a 399 km stretch of the Yellow River runs. Central Ningxia is flat and the southern parts are hilly and mountainous with elevations ranging from 1100m to 2700m above sea level. The southwest of Ningxia is located in the transitional zone of three climatic regions and is influenced by the Qinghai-Tibet Plateau, a high, cold region of China. Ningxia straddles the eastern monsoon and northwest arid regions of China, where annual mean temperature ranges from 5.4-10.0℃; the mountainous area to the south of the region records annual precipitation of 693mm. This decreases as one heads north, to where precipitation is only 162mmin the most northerly area. The annual precipitation average across all of Ningxia is 262mm. Ningxia is influenced by the Siberian winter monsoon in winter, and the Indian monsoon, East Asian monsoon and Siberian summer monsoon in summer. Precipitation from October to April accounts for 19% of the annual total, whilst precipitation from May to September accounts for 81% of the annual total.

2.1.1 Background studies of climate variability in the region

By analysing annual and seasonal precipitation in Ningxia using 43 years of observed data in Ningxia Chen *et al.* (2005) found a decreasing trend in annual precipitation. They also found annual mean temperature in Ningxia increased with fluctuations during this period, especially in the central arid area and regions north of Yinchuan. It was also noted that frost damage had significantly increased during the period studied. Using annual ring data of trees growing in Helan Mountain, Li Yanchun *et al.* (2001) analyzed the climate during the last 100 years in Ningxia and found there was a trend of temperature increasing, especially in the 1940s and late 1980s.

According to observations during the last 43 years, evaporation in Ningxia has been falling. Yang Jianping *et al.* (2003) pointed out that there was a decreasing trend in evaporation in arid and semiarid regions during the past 40 years. Chen Xiaoguang *et al*. (2006) found that annual evaporation in Ningxia has decreased since the 1960s. In the irrigation region of northern Ningxia, evaporation has decreased continuously from a maximum of 2029mm recorded in the 1960s. In the central arid zone, the highest evaporation occurred in the 1970s.

By analyzing the character of clouds Chen Shaoyong *et al.* (2006) derived that the general cloud cover in the east of northwestern China has decreased. Chen Nan *et al.* (2008) obtained similar trends in Ningxia, namely gradually decreasing annual cloud cover. From analysis of the humidity changes in Ningxia, Chen Xiaoguang *et al*. (2006) found there was relatively high humidity in the 1960s, which fell in the 1970s and which since the 1980s has been continually increasing to a maximum which was recorded between 2001 and 2003, especially during autumn and winter of these years. In the last 20 years soil moisture conditions as measured at weather stations in Ningxia have decreased, especially in the central arid zone.

In the last 50 years the crop area damaged by hail increased with a linear trend of 0.29 ha per decade in Ningxia. Hail on 14 June 2004 caused an estimated agricultural loss up to 44 million RMB. The hail-prone areas in Ningxia can be separated into northern and southern areas. In the north, where climate is influenced by the Helan Mountains, the hail tracks from north to south or from northwest to southeast; in the south it is influenced by the Xiang, Nanhua, Liupan and other mountains and usually tracks from northwest to southeast, mainly along the mountain ridge. Finally, the length of the growing season in Ningxia has increased from 1970 to 2004 by about 3-5 days across the region, with only small differences recorded between stations.

2.1.2 The role of Ningxia Meteorological Bureau in monitoring and reducing weather-related risks

The Ningxia Meteorological Bureau has a number of responsibilities in relation to the impacts of climate change:

- Conduct weather observation, forecast and prediction services;
- Provide specific weather forecasts, weather records and climate assessment, and offer weather guarantee for key project implementation;
- Provide disaster weather warning and agro-meteorology service to the public;
- Support the scientific base and evidence for the utilization of agricultural climate resources;
- Organise and implement artificial weather modification and mitigation work such as drought resistance, hail prevention and water collection in order to boost agricultural development;
- Disseminate and apply climate research achievement.

Since 2002, the area in which artificial rainfall stimulation by aeroplane is carried out in Ningxia has been enlarged from originally just the southern mountainous area to covering the whole autonomous region. The work period has also been extended from early April to the end of September, whereas originally it finished in early July. The programme has been extended to cover hail defence and artificial rainfall stimulation by the use of antiaircraft artillery in the southern mountainous area. The weather modification is an effective method of avoiding the hazard of hailstorms and heavy precipitation. In 1974 Ningxia started artificial precipitation stimulation by cloud seeding using palladium deposited by aeroplane, and hail suppression using antiaircraft artillery. Since 2003 a new type of weather modification system has been in use in Ningxia involving the use of 73 rockets and 61 anti-aircraft artilleries. Aeroplanes are used for weather modification during the spring, summer and autumn, and rockets and antiaircraft artilleries all year round. According to statistics, the average precipitation increase as a result of artificial precipitation stimulation using aeroplanes was 400 million tons each year from 1984 to 2002, and the total precipitation increased by 1050 and 860 million tons in 2003 and 2004 respectively. Artificial weather modification has become a very important approach in disaster prevention, agricultural production and improvement of urban environments.

2.2 Seasonality and long term climate trends in Ningxia

2.2.1 Methods and data

We use daily precipitation and maximum and minimum temperature observations from 22 stations in Ningxia obtained from the Ningxia Meteorological Archives, covering the period of 1961 to 2007. Regional averages are presented in Table 2.1 below for the whole of Ningxia and for three sub-regions; north, central and southern. This table lists the names of the stations and their seasonal and annual mean precipitation and temperature. For temporal analysis we divide temperature into 2℃ intervals for temperatures below 34℃, and into 1℃ intervals for temperatures over and above 34℃. Daily precipitation is divided into no rainfall, 0-2mm, 2.1-5mm, 5.1-10mm, 10.1-15mm, 15.1-20mm, 20.1-25mm, 25.1-50mm, and over 50mm of rainfall. We calculate the regional average daily frequency in each interval to identify detailed changes in frequency and magnitude. We use the 30 year period from 1961 to 1990 to calculate climate averages and the Kruskal–Wallis test for statistical significance.

Table 2.1 Climate stations in Ningxia: seasonal and annual mean precipitation and temperature (1961-2007)[2]

Station	Mean temperature					Mean precipitation				
	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
North										
Shitanjing	-6.0	9.5	22.1	8.2	8.5	3.5	28.1	112.5	31.6	175.8
Dawukou	-5.1	11.6	23.6	9.6	10.0	3.4	22.1	110.5	31.8	167.9
Huinong	-6.5	10.3	22.6	8.8	8.9	2.4	23.9	104.0	31.3	161.7
Helan	-6.2	10.6	22.4	8.9	9.0	3.4	32.3	105.5	40.1	181.3
Pingluo	-6.3	10.5	22.4	8.9	8.9	3.0	27.8	113.5	35.7	179.9
Wuzhong	-4.9	10.9	22.0	9.2	9.3	3.2	34.2	103.4	41.4	182.2
Yinchuan	-6.0	10.7	22.3	9.0	9.1	3.7	35.1	99.4	36.4	174.7
Taole	-7.2	10.3	22.7	8.4	8.6	2.7	30.0	105.8	35.4	173.9
Qingtongxia	-5.0	10.9	22.0	9.2	9.4	3.2	31.8	104.3	41.7	181.0
Yongning	-5.6	10.6	21.9	9.1	9.1	3.6	34.4	105.3	41.3	184.5
Lingwu	-5.6	10.7	22.1	8.8	9.1	3.8	35.6	113.6	44.0	197.0
Zhongwei	-5.6	10.6	21.4	8.8	8.9	3.1	32.2	109.5	42.0	186.7
Zhongning	-4.9	11.3	22.2	9.4	9.6	2.9	31.1	97.8	36.8	168.6
Central										
Xingrenpu	-7.6	8.4	19.8	6.7	6.9	4.0	46.0	145.1	56.5	251.5
Yanchi	-6.5	9.6	21.4	8.0	8.2	6.1	49.7	154.1	60.4	270.2
Mahuangshan	-6.2	7.9	19.1	7.0	7.0	7.3	61.4	193.2	82.1	343.9
Tongxin	-5.5	10.6	21.9	8.9	9.1	5.9	51.3	148.2	62.6	268.0
South										
Haiyuan	-5.1	8.2	18.8	7.3	7.4	8.3	63.3	186.6	80.4	338.6
Guyuan	-6.3	7.7	18.1	6.5	6.6	8.4	73.6	226.4	93.7	402.0
Xiji	-7.2	6.6	17.0	5.6	5.6	7.6	72.8	224.2	101.9	406.5
Longde	-6.6	6.2	16.1	5.5	5.4	13.1	85.4	291.7	125.5	515.7
Jingyuan	-5.4	6.6	16.6	6.1	6.0	15.2	103.2	322.5	152.1	593.0

2.2.2 Temperature: annual and seasonal patterns

Figure 2.1 below shows the mean monthly temperatures and trends in temperature over three different timescales: the full period (1961-2007) and more recent periods (1981-2007 and 1991-2007) to highlight any strong recent trends. Time series of annual and seasonal temperature for the whole region are shown in Figure 2.2. Ningxia experiences a strongly seasonal temperature regime, with very cold winters and hot summers. Seasonal patterns are similar across the region but summer temperatures are slightly lower in the south. Temperatures in most winter months in all three periods show an increasing trend (higher than 0.5℃/decade fo r 1961-2007) which has increased in the most recent years (in the range of 0.6-1.5℃/decade during 1991-2007), especially between January and June.

These temporal trends are similar in the north and central sub-regions, but in the south the long-term trend has been one of cooling, albeit with marked warming in most recent years between January and June.

[2] DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November.

Figure 2.1 Mean monthly temperature and trend in temperature over three different periods: the full record (1961-2007, black line) and more recent periods (1981-2007: yellow line; and 1991-2007: light blue line).

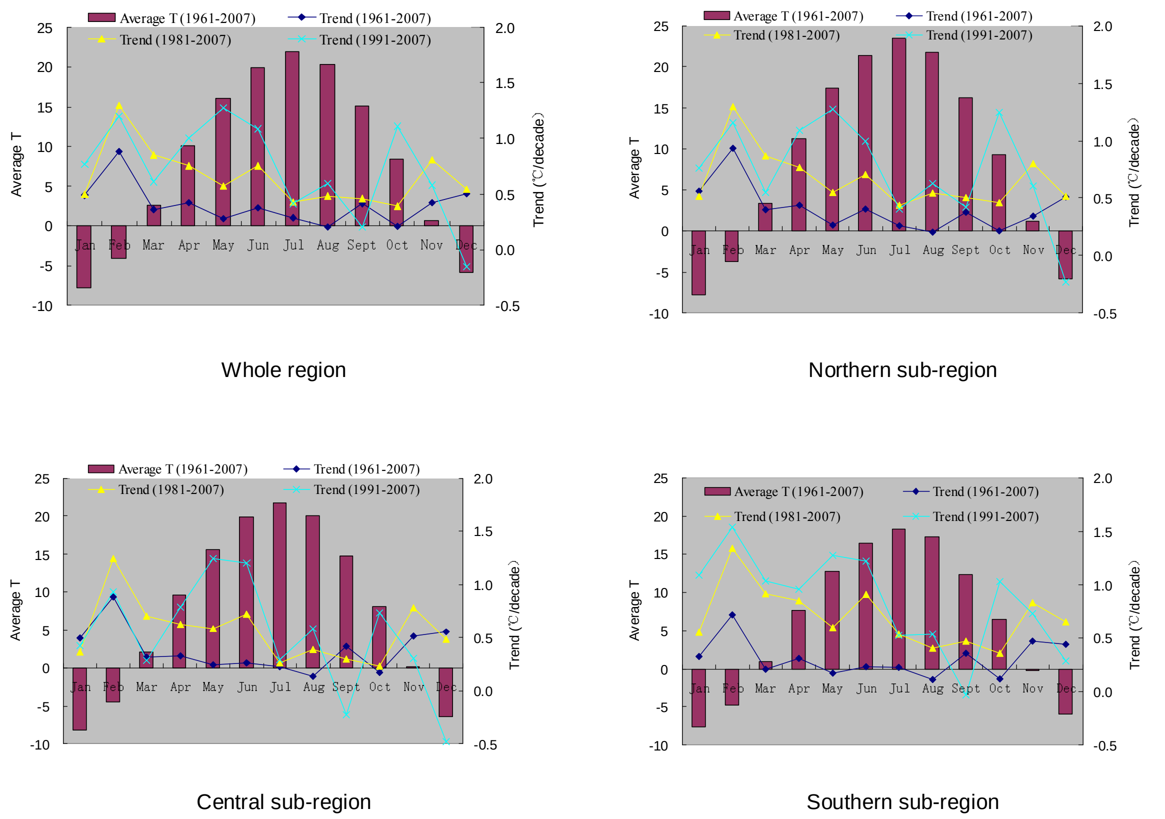
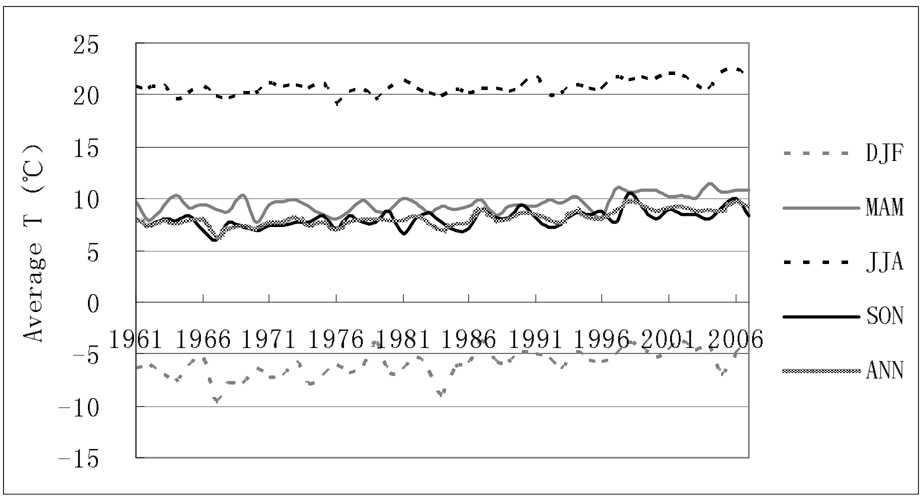


Figure 2.2 Seasonal and annual temperature series for the whole of Ningxia, 1961-2007



Note: DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November. Ann = Annual average.

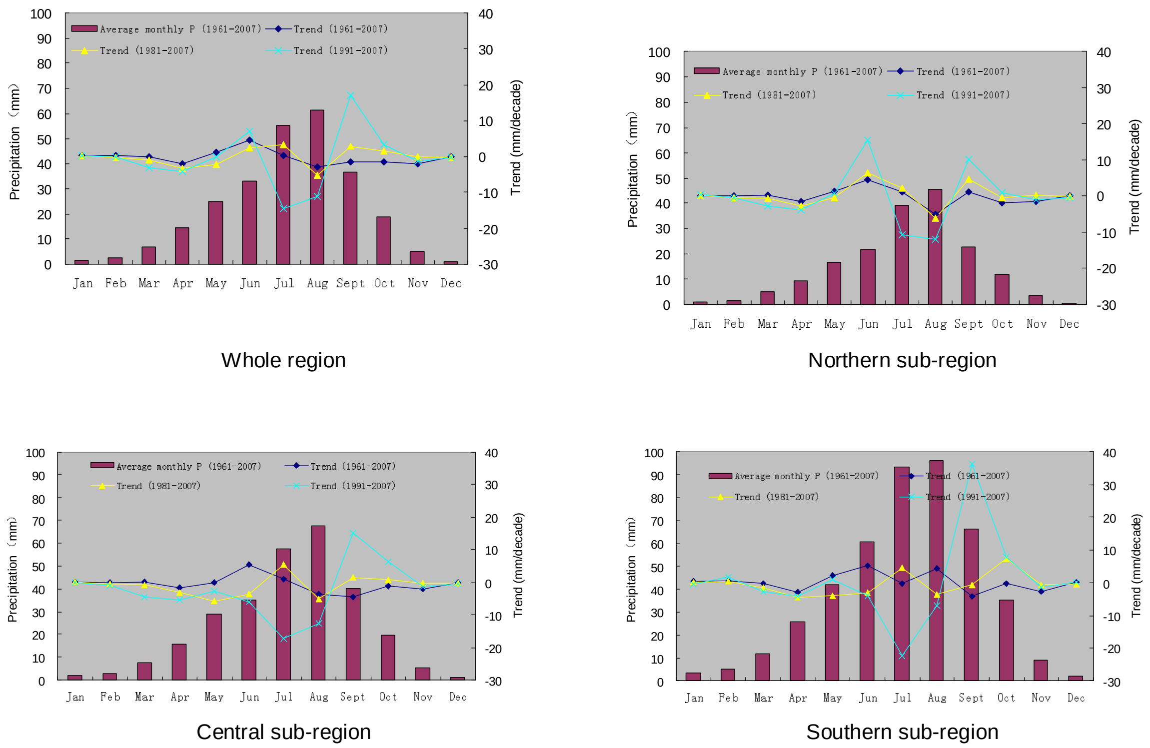
2.2.3 Precipitation: annual and seasonal patterns

Figure 2.3 shows the mean monthly precipitation and trends in precipitation over the same three periods as above (1961-2007, 1981-2007 and 1991-2007). Time series of annual and seasonal precipitation for the whole region are shown in Figure 2.4. Ningxia experiences a strongly seasonal precipitation regime, with dry winters (October to April monthly precipitation is less than 20mm) and short wet summers (just two months, July and August, receive over and above 50mm precipitation). Seasonal patterns are similar across the region with precipitation amounts increasing from North to South.

Precipitation in most months in all three periods shows very modest evidence of slightly increasing trends in June/July (roughly 1.0-5.4mm/decade over the full period) and slight decrease between August and November (roughly 1.5-2.9mm/decade over the full period). Over more recent periods stronger trends emerge: during the 1981–2007 period, July shows an increase (roughly 2-3.5mm/decade) in the central and southern sub-regions. During 1991-2007 some quite marked monthly trends have occurred with March, July and August showing decreases in precipitation (roughly 7-22mm/decade) and September showing an increase (roughly 10-36mm/decade) in all three sub-regions. 1964 was the wettest year, and 1982 the driest.

A marked feature of the series are the three dry years from 2004-2006. In 2005 the average rainfall in Ningxia was abnormally low at only 182mm, giving that year the second lowest precipitation over the period under consideration (the lowest precipitation occurred in 1982, when it was 155mm). Figure 2.5 below shows the long-term trends using a 5-year moving average for the whole of Ningxia as well as its three sub-regions. Decadal variability has been fairly modest and is similar across the whole region: slightly drier conditions were experienced during the 1970s, the late 1980s and early 1990s were wetter, and there was a modest decrease in precipitation from the mid-1990s to the present.

Figure 2.3 Mean monthly precipitation and trend in precipitation over three different periods: the full record (1961-2007, black line) and more recent periods (1981-2007: yellow line; and 1991-2007: light blue line)



Whole region

Northern sub-region

Central sub-region

Southern sub-region

Figure 2.4 Seasonal and annual precipitation series for the whole of Ningxia, 1961-2007 (DJF not shown as precipitation <10mm)

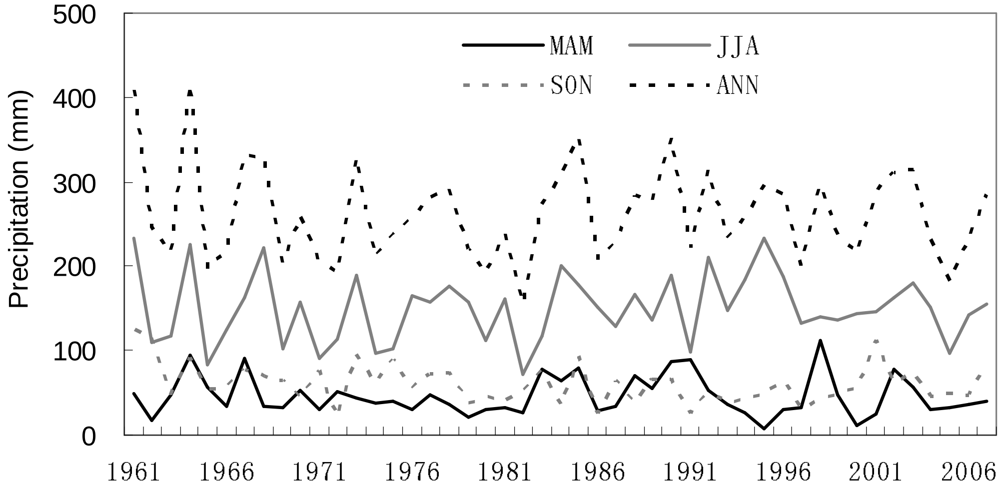


Figure 2.5 Five year moving average precipitation series for the whole of Ningxia and its three sub-regions, 1961-2007

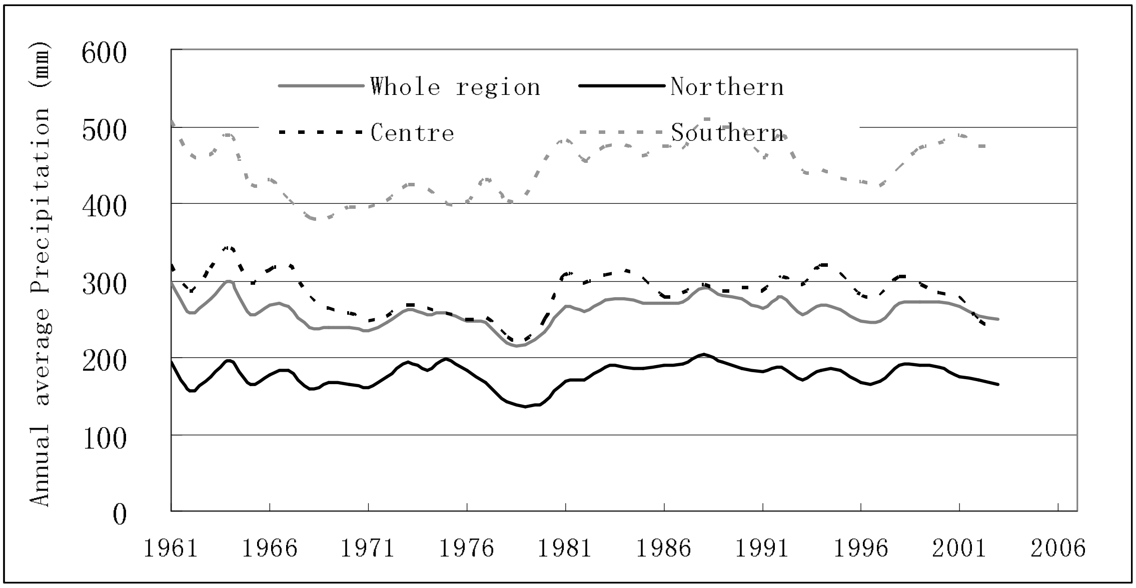


Table 2.2 lists summary trends by season and sub-region for the three periods considered. The key features to note are the consistent warming across the whole region, which has increased since the 1980s and is highest in winter. Precipitation patterns are more complex. Over the full period modest decreases in precipitation have occurred in the central sub-region (most marked during the autumn – SON), while wetter conditions have been recorded (during JJA) in the southern and central sub-regions. During the most recent period (1991-2007) some quite marked trends emerge: greater decreases in precipitation (during SON) and wetter conditions (JJA) in the southern and central sub-regions have been observed. All three sub-regions were drier during JJA and experienced increased precipitation.

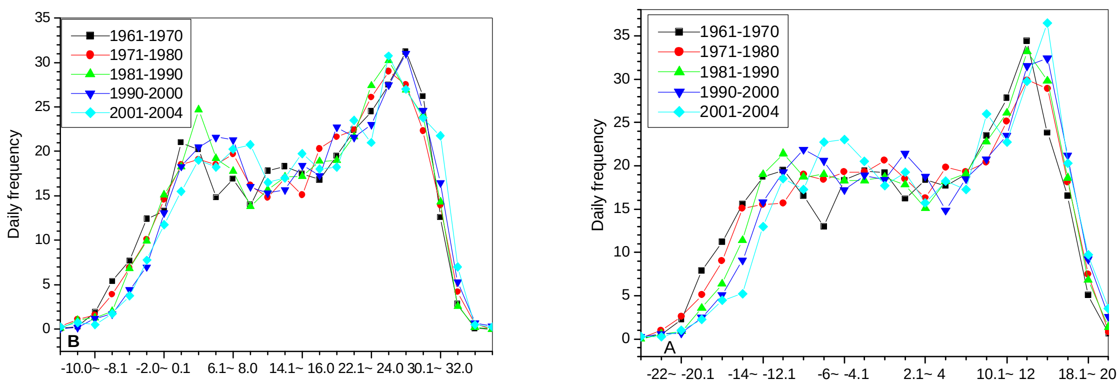
Table 2.2 Seasonal and annual trends in temperature and precipitation for the three sub-regions and three different periods

Sub-region	Temperature trend (℃/decade)					Precipitation trend (mm/decade)				
	DJF	MAM	JJA	SON	ANN	DJF	MAM	JJA	SON	ANN
	Trend 1961-2007									
Northern	0.66	0.37	0.29	0.31	0.41	0.29	0.14	0.77	-2.12	-0.93
Central	0.64	0.30	0.20	0.37	0.38	0.33	-1.54	2.80	-7.76	-6.17
Southern	0.49	0.23	0.19	0.32	0.31	1.41	-0.88	9.31	-7.09	2.74
	Trend 1981-2007									
Northern	0.76	0.73	0.56	0.59	0.68	-0.29	-3.80	2.75	4.62	3.29
Central	0.68	0.63	0.46	0.43	0.57	-0.65	-9.68	-3.30	1.99	-11.66
Southern	0.83	0.79	0.62	0.55	0.71	0.25	-9.98	-1.89	6.04	-5.58
	Trend 1991-2007									
Northern	0.51	0.97	0.68	0.76	0.77	-0.17	-5.84	-7.33	10.01	-3.32
Central	0.24	0.77	0.69	0.27	0.54	-1.31	-12.44	-35.85	19.84	-29.76
Southern	0.93	1.09	0.77	0.58	0.87	1.30	-5.83	-33.26	42.55	4.77

2.2.4 Temperature and precipitation extremes

Figure 2.6 shows the daily frequency of maximum temperature at different intervals. This shows that the frequency of days with a maximum temperature of less than 0℃ decreased in Ningxia, while days with maximum temperatures exceeding 32℃ became more frequent. The frequency of days above 4℃ has increased, particularly that of very hot days over 30℃. The mean annual minimum temperature in Ningxia is 1.8℃, but the monthly range is from –26 to 22℃. Overall the differences between decades are fairly modest and no clear trends emerge from the analysis.

Figure 2.6 Average frequency of maximum (left) and minimum (right) temperatures in different intervals by decade.



For most parts of Ningxia rainfall with daily precipitation less than 2mm in summer is generally ineffective rainfall, and rainfall between 2 to 20mm should be effective rainfall. Runoff, even floods, may appear if the daily precipitation is more than 20mm. Table 2.3 shows that the average frequencies of days with precipitation less than 2mm and events with precipitation levels of 10–20 mm and over 50mm showed little change. Days with precipitation levels of 2.1–10 mm decreased and those with 20–50 mm increased very slightly.

Table 2.3 Mean frequency of daily precipitation events in different intervals by decade.

Decade	<2 mm	2 – 10 mm	10–20 mm	20 – 50 mm	> 50mm
1961-1970	336	22.3	5.0	2.0	0.2
1971-1980	336	22.8	4.5	1.6	0.2
1981-1990	336	21.7	5.7	2.1	0.1
1991-2000	338	19.6	4.8	2.4	0.2
2001-2005	338	19.4	5.1	2.2	0.2

2.3 The 2004-2006 drought: climatology and impacts

In 2005, Ningxia suffered a sustained decrease in precipitation in most parts of the region. The irrigation area using water diverted from the Yellow River and the middle part of the region experienced severe droughts. The total rainfall in Ningxia from December 2004 to November 2005 ranged from 57mm to 688mm. The rainfall in southern Ningxia ranged from 376mm to 688mm, which was about 10% lower than the long-term average for the area. Within southern Ningxia the severity of the drought varied: in Xiji and Liupan Mountain rainfall was close to the long-term average; in Longde and Jingyuan it was roughly 10-20% greater than the long-term average. The 2005 drought in other parts in Ningxia was more severe, with rainfall ranging from 57mm to 287mm; roughly 20%-70% lower than the long-term average. Drought and severe drought occurred in most parts of the Yellow River irrigation region and the central arid zone. For some parts of Ningxia this was the driest year in the meteorological records.

During this period it was difficult to plant crops in summer and autumn in areas within the region including Haiyuan, Yanchi and Tongxin. In the central arid zone, 289,000 ha of crops were damaged by drought, and the drought in the middle part of the region destroyed crops over 421,000 ha and affected 720,000 people, making it difficult for 463,000 of them to obtain drinking water. Drought also brought down both the quality and yield of grazing grass, which in turn affected the number and quality of livestock. In general, there were insufficient quantities of water to adequately sustain people and livestock and according to the Civil Affairs Department the direct economic loss caused by the drought in Ningxia was 1.27 billion RMB.

In the summer of 2006, further severe drought affected 184 natural villages in 26 townships within 12 counties in Central Ningxia. This included Zhong Ning, Tong Xin, and Hai Yuan, which experienced reduced yields for some 547,000 ha of arable land. Drought also led to drinking water shortages for 416,000 people and 1.8 million animals. The drought led to a direct economic loss of as much as RMB 1.58 billion, and was more serious in 2006 than in the previous year. However, rainstorms were also very frequent in some areas of Ningxia especially on the 14th of July. On that day the northern region of Ningxia experienced a heavy rainstorm, and precipitation in Yinchuan for a 10-hour period on that day was up to 99.8mm, which is more than half of the annual total for the region and has broken the record for daily precipitation. The event not only caused serious flooding in northern Ningxia but also caused serious losses to agriculture, industry and transportation industry.

2.4 Economic impacts of extreme weather events in Ningxia

Between 1994 and 2006 the direct agricultural economic loss caused by meteorological disasters exceeded RMB 660 million, with 479,000 ha of arable land affected by disasters and annual yields reduced by 480,000 tons. Ningxia sits in a belt where moderate semi-arid climate prevails and the region has long been affected by various meteorological extremes. Each year in the region approximately 24,000 sheep and 4000 cattle are lost due to meteorological disasters. Since 2000 the average annual direct economic loss to the agricultural sector due to meteorological hazards has been roughly RMB 910 million (see Figure 2.7 – left), with nearly 584,000 ha of arable land affected by disasters and a reduced annual food yield of roughly 793,000 tons (see Figure 2.7 – right).

In 2000, the region had 620,000 ha of arable land affected by disasters, of which 413,000 ha produced no yield, thereby reducing food production by 600,000 tons (Figure 2.7 – right). Roughly 2.51 million people were affected by disasters including some 928,000 who, together with 300,000 cattle and 1.29 million sheep, experienced drinking water shortages. Using a poverty threshold of RMB 625 annual income, the region had a poverty rate of 18%, 5% higher than the preceding year, and a poverty-stricken population of 687,000 people (194,800 more than the previous year).

In Ningxia farming activities are greatly affected by natural disasters including drought, floods, sandstorms, hail, frost, gales, torrential rain and high and low temperature stress. The occurrence and spread of some crop pests and diseases is also associated with meteorological conditions, and meteorological disasters have become a significant obstacle restricting the development of farming activities. During the period 1949-2000, 23% of the region's arable land was affected and 17% was

Figure 2.7 Agricultural economic loss caused by meteorological disasters in Ningxia (left) and grain loss caused by meteorological disasters in Ningxia (1000 tonne)

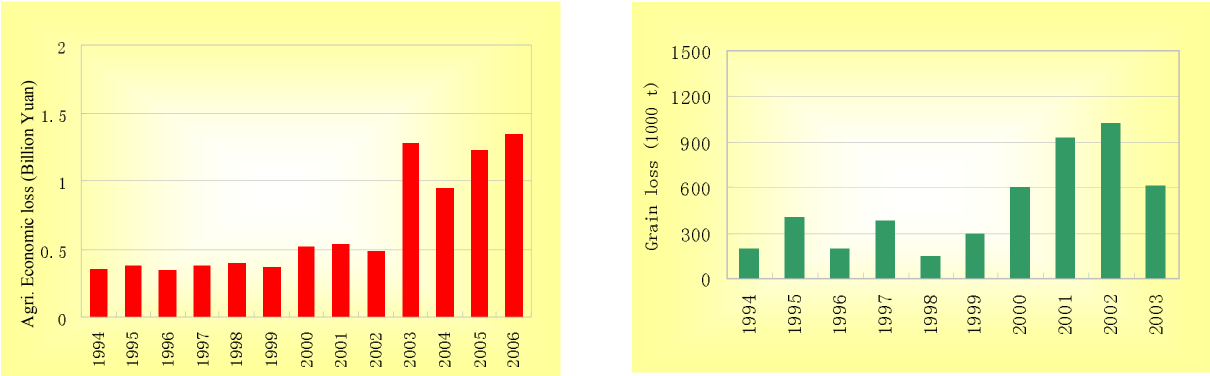
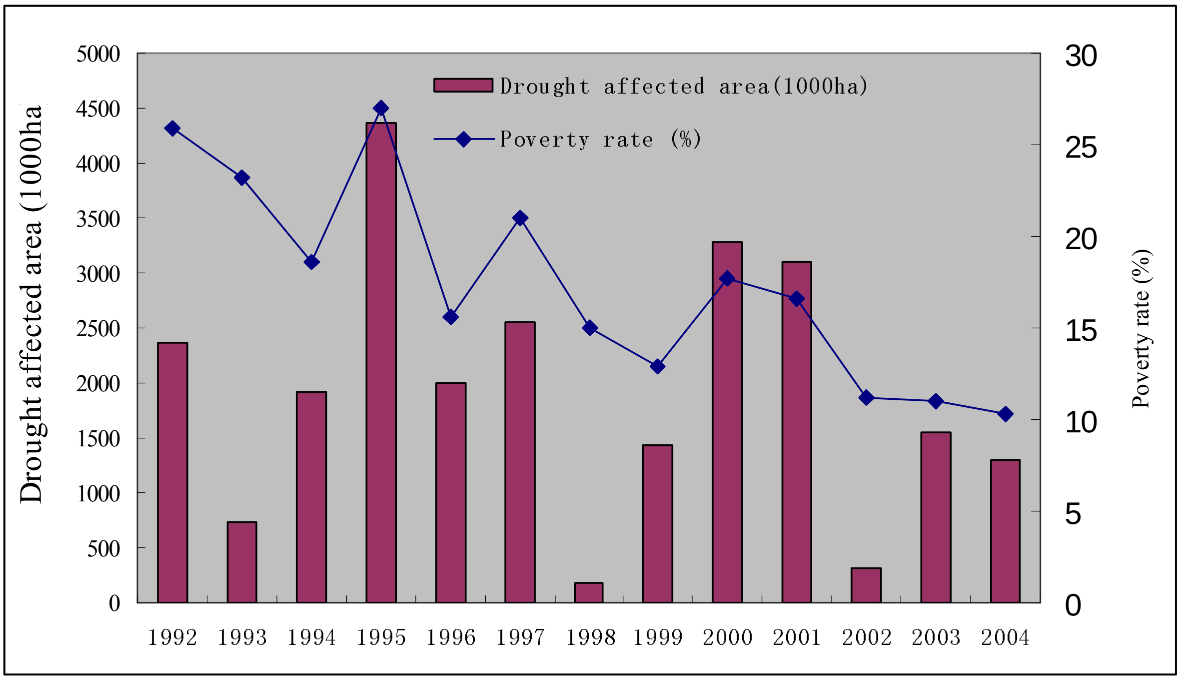


Figure 2.8 Drought affected area and poverty rate



destroyed by meteorological disasters. On average each year in Ningxia 193,500 ha of arable land is affected by meteorological disasters, and 142,300 ha is destroyed. Of the disasters that affected the arable land, drought, hail, and frost caused the most damage at 55%, 21%, and 10% respectively by area.

Table 2.4 above summarises the main meteorological hazards that occur in Ningxia and provides some examples of their impacts on agricultural production. Information on the specific impacts on livelihoods is provided in greater detail in another ICCCA Phase II report entitled *Climate and Livelihoods in Rural Ningxia* (Li Yue *et al*., 2008).

Figure 2.9 Damage caused by different meteorological hazards

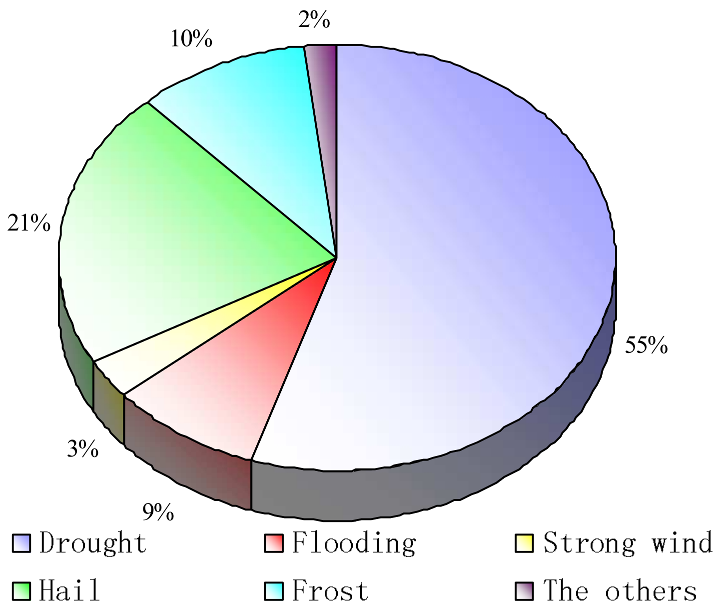


Table 2.4 A summary of the main meteorological hazards in Ningxia and their impacts. *Statistics published by Ningxia Meteorological Bureau and Ningxia Civil Affairs.

Hazard and distribution	Examples of impacts*
Floods are usually mountain floods caused by torrential rain and have limited impacts. They usually occur between June and September, mainly in the south of the region. In the last 50 years, floods have become an annual phenomenon with an average of 10 a year. In the last 5 years, the frequency has risen to 10-15 a year.	In the intense rain of 14 July 2006,.104.8 mm fell in Yinchuan, and 92.5 mm in Huinong, which was the heaviest rainfall ever recorded by the two cities. 200,000 people in 246 villages in 18 counties in Ningxia were affected and 2,289 people were evacuated, with 3 people and 196 animals being killed by the disaster. Torrential rains and floods also damaged 159 water-related facilities, 34 km of rural roads, and 16,675 ha of arable land. The events caused a direct economic loss worth RMB 250 million. Intense precipitation in July through September can affect the growth, ripening, and harvest of crops.
Frost is a common natural disaster affecting Ningxia every year. The dangerous period of spring frostbite is mid-April and early May for the plain area, and early and mid May for the mountainous areas.	This period is a vulnerable time for seedlings of flax, hemp, rape, and squash, as well as some blossoming fruit trees. Temperatures below 0℃ may cause damage to crops and fruit trees. Autumn frostbite may damage crops in early September in mountainous areas, and in late September in the plain area.
Hail is a common natural disaster in Ningxia, mostly occurring in the southern mountainous areas.	In the last 50 years, the arable land area affected by hail has seen a linear increase at a rate of 2,900 ha every 10 years, and heavy damage is often caused by hail. For example, hail on 14 June 2004 caused damage worth RMB 44 million and in the summer of 2006 the region was subject to eight local hail attacks, causing a direct economic loss of RMB 4.37 million.
Low temperature is a temperature persistently lower than the required temperature for the growth of crops, which may retard their development. To some crops that are sensitive to low temperature, three consecutive days of low temperature may cause physical damages to the crop, resulting in a reduced yield.	In Ningxia, paddy rice usually suffers cold injuries in the seedling, flowering, and ear development phases. During the seedling phase, low temperature may lead to frost damage affecting seedlings, retarding the development of rice, and resulting in a reduced yield. Low temperatures can also severely affect rice in flower. In 1976 Ningxia was hit very hard by low temperatures, with 37% of the arable land in the region affected by this disaster. Some 51,900 ha of rice failed to reach full development, with a dead kernel rate of 55%, and yields reduced by 59%. Low temperature also caused large number of pregnant livestock to miscarry.
High temperatures are usually associated with low humidity and are often accompanied by hot, drying winds. For example, a dry hot wind that occurred on 11 June 1961 (during flowering) brought down the wheat yield by 12%.	High temperatures affect spring wheat yields in Ningxia by 5%-10%, or sometimes by as much as 20%. During both the flowering and ripening phases, hot drying winds may hamper seed development and reduce the weight of the grain. During late June the Chinese Wolfberry is most sensitive to environmental and meteorological factors. Dry hot winds may shorten the growth period of young seeds by stopping the growth of fruit-bearing branches. Such winds increase the nutritional needs of the plant itself, which in turn decreases the size of seeds, affecting both yield and quality.

2.5 Conclusions

This chapter reviewed climate variability in Ningxia, the activities of the region's Meteorological Bureau and past economic impacts of extreme weather events in the region. Meteorological observations were used to analyse recent variability and trends in seasonal and annual temperature, precipitation and other climate parameters in Ningxia.

On the basis of observations of rainfall and temperature from 22 weather stations in Ningxia for the period between 1961 and 2007, Ningxia's climate is dry and highly seasonal. Specifically:

- Mean annual rainfall ranges from 593mm in the mountainous south to 162mm in the arid north.
- Its temperature regime is highly seasonal, with very cold winters and hot summers. Seasonal patterns are similar across the region but summer temperatures are slightly lower in the south.
- Its precipitation regime is also highly seasonal, with dry winters (October to April monthly precipitation <20mm) and short wet summers (precipitation in July and August is over 50mm). Precipitation levels increase from north to south.

In addition, the following trends in Ningxia's climate were identified:

- The mean annual temperature of Ningxia was fairly stable from the early 1950s to the 1980s but then developed a modest positive trend.
- Temperatures in winter months show an increasing trend (roughly 0.5℃/decade) which for 1991-2007 increased to 0.6-1.2℃/per decade.
- Precipitation in most months has shown a slight upward trend in the full period studies (1961-2007) with additional increases in June/July (an increase of roughly 1.0-5.4mm/decade) and slight decreases between August and November (falls of roughly 1.0-4.5mm/decade).
- A recent marked feature has been three very dry years in 2004-2006. In 2005 the average rainfall in Ningxia was abnormally low, making it the second lowest year since 1961.
- Decadal variability has been fairly modest and is similar across the whole region; slightly drier conditions were experienced during the 1970s, it was wetter in the late 1980s and early 1990s and there was a modest decrease from the mid-1990s to the present.
- Sub-regional analysis highlights differences in precipitation variability and trends and more spatially coherent patterns of warming in all seasons.

Finally, we conclude that the meteorological hazards experienced in Ningxia in the period under consideration have had considerable economic impacts in the region:

- A review of meteorological hazards in the region demonstrates their economic importance. Farming activities are greatly affected by drought, floods, sandstorms, hail, frost, gales, torrential rain, and high and low temperature stress.
- Before 2000, the direct economic loss in the agricultural sector caused by meteorological hazards was roughly RMB 910 million a year, with the area of cropland affected by disasters approaching 584,000 ha and a reduced annual food yield of roughly 793,000 tons.
- Since 2000 economic losses have increased to an average RMB 1.27 billion/year.

3 The future climate of Ningxia: High resolution climate change scenarios

Authors: Xu Yinlong, Chen Nan, Declan Conway, Zhang Yingxian, Xu Bin, Yang Kan

3.1 Introduction and methods

This section describes the development of high-resolution scenarios for Ningxia. Regional climate scenarios were generated following the methodology described by the UK Climate Impacts Programme (UKCIP) (UKCIP, 2002). This uses a nested climate model, with output from a coupled ocean-atmosphere global climate model (GCM), namely HadCM3H (~300 km grid interval) to drive a high-resolution (~50 km grid interval) atmospheric regional model (PRECIS – Jones *et al.,* 2004) for China. PRECIS can provide finer spatial resolution (typically 50 km) and time resolution (e.g. daily weather data) out to 2100, better spatial detail (i.e. topography), and better simulation of extreme weather events. The study presents results based on 30-year means for the periods: 1961-1990 (baseline period), 2011-2040 (2020s), 2041-2070 (2050s), and 2071-2100 (2080s). Full detail on methods is presented in a separate ICCCA Phase II report entitled Xiong *National Level Study: The Impacts of Climate Change on Cereal Production in China* (Xiong *et al*., 2008).

3.1.1 Data structure

In the Ningxia case study, the climate scenarios were generated following the steps listed in Table 3.1.

Table 3.1 Details of the regional climate model simulations and scenarios for Ningxia

Timeslice	Boundary Data	Scenarios	Comments
1979-1993	ECMWF reanalysis data	Observation	Direct simulation
1961-1990	HadAM3P (global climate model output used to drive PRECIS)	Baseline	Direct simulation
2011-2040	-	SRES A2/B2	Pattern-scaling
2041-2070	-	SRES A2/B2	Pattern-scaling
2071-2100	HadAM3P	SRES A2/B2	Direct simulation

Note: SRES A2 is the IPCC emissions scenario (storyline) representing a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines. SRES B2, meanwhile, is a storyline representing a heterogeneous world with local emphasis, which gives priority to the environment and implements clean and efficient technologies. (see Nakicenovic et al., 2000).
ECMWF = European Centre for Medium-Range Weather Forecasts.

3.1.2 Interpolation of PRECIS data

Table 3.1 shows that climate change in the 2080s is directly simulated with GCM-HadAM3P boundary data and the method of pattern-scaling (Hulme *et al.,* 2002 please add full ref to reference list) is used to interpolate the direct simulation results from the 2080s to the 2020s and 2050s. This approach (usually) involves normalising GCM response patterns according to the respective GCM global mean temperature change. These normalised patterns are then rescaled using a scalar (global temperature change) derived from simple climate models and representing the SRES A2/B2 scenarios.

3.2 Comparison with ECMWF reanalysis data for the climate in the baseline period (1961-1990)

We first assess PRECIS' capacity to simulate the present climate. We use ECMWF reanalysis data for 1979-1993 as quasi-observational lateral conditions to drive PRECIS. We then compare the simulation in Ningxia with experimental data for the same period.

PRECIS simulates quite well the spatial distribution of annual and seasonal mean temperatures in Ningxia. The observed average maximum temperature trend is 0.51℃ (over the full record), and PRECIS correctly simulates the trend of rising monthly mean temperatures, especially the large increases seen in recent years and the decrease in daily temperature range (Figure 3.1). There is a systematic shift in daily mean, maximum and minimum temperatures. PRECIS can reasonably simulate monthly, seasonal and yearly precipitation but produces rather large errors in the simulation of daily precipitation (Figure 3.2 and Figure 3.3). Due to bias in the simulation of temperature and precipitation, the daily PRECIS data were adjusted using the difference (actual for temperature and proportional for precipitation) between the observations and PRECIS output.

Figure 3.1 Comparison of the simulated and observed frequency distributions of daily minimum and maximum temperatures. The blue line represents observed data; the pink line provides the results of the simulations.

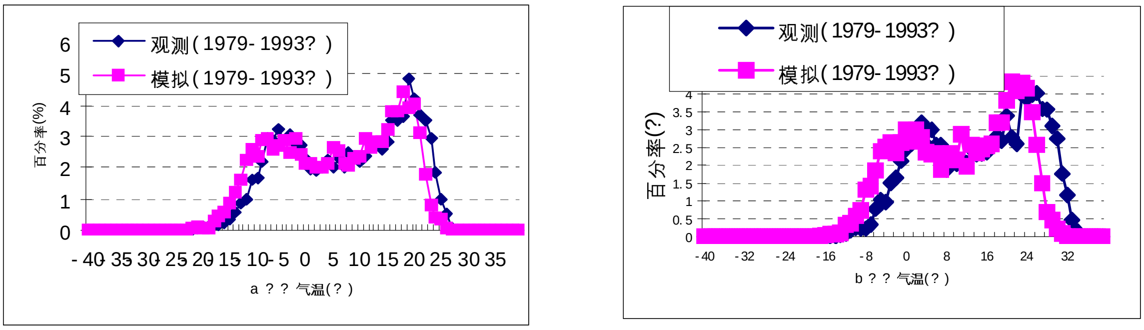


Figure 3.2 Comparison of the simulated (pink) and observed (blue) monthly precipitation during 1979—1993 in Ningxia

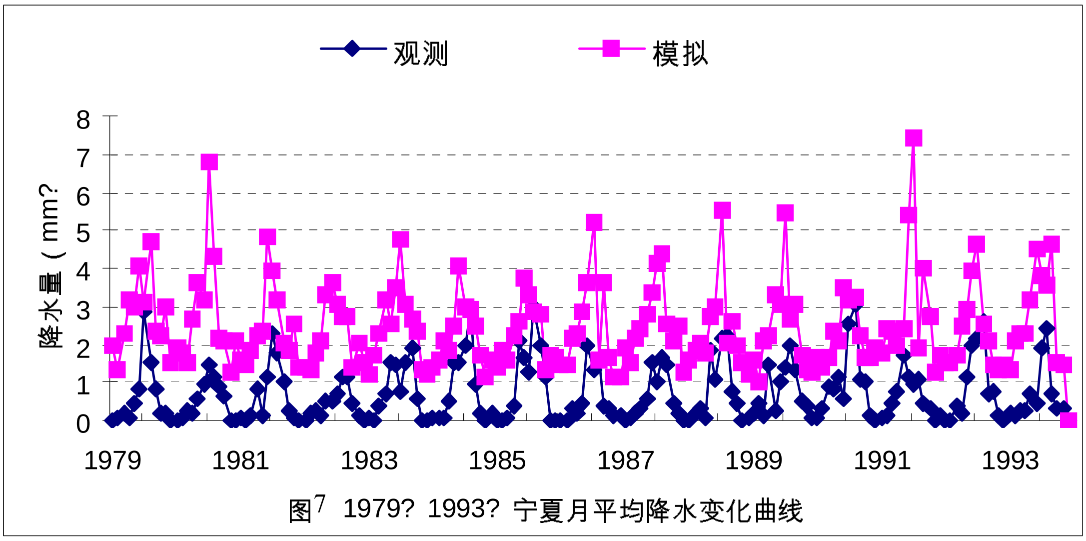
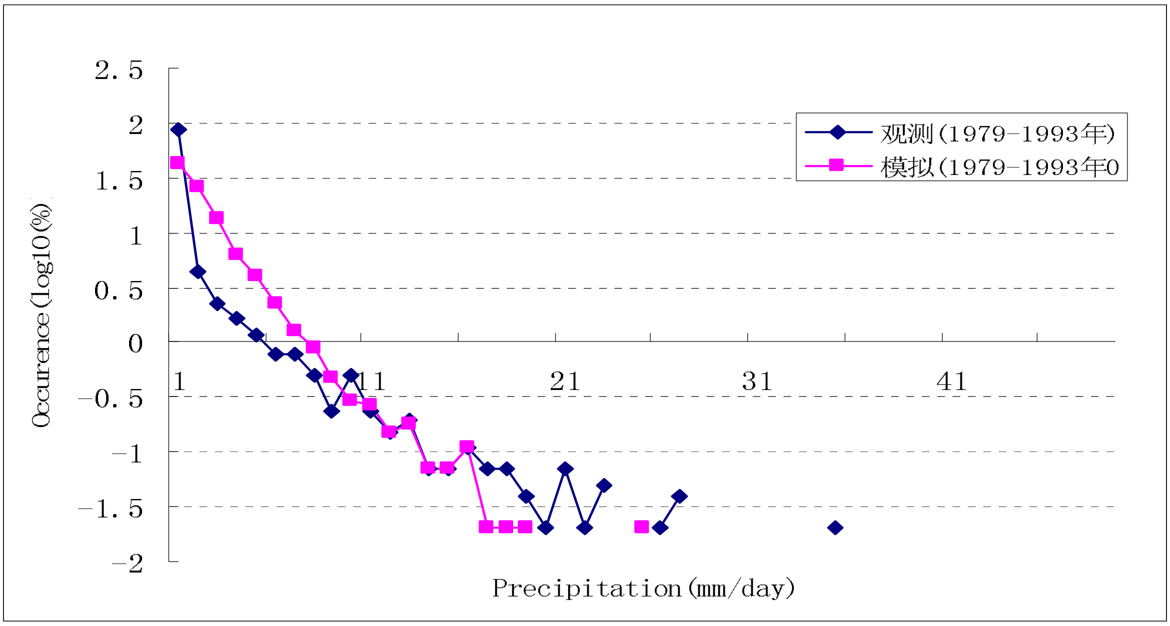


Figure 3.3 Probability of daily precipitation (blue – observed, pink – simulated) for 1979—1993 in Ningxia



Validation of PRECIS' simulation of temperature and precipitation in Ningxia was presented in Chen Nan *et al.* (2007).

3.3 PRECIS climate change scenarios for Ningxia

3.3.1 Temperature

The average changes in seasonal and annual temperature and precipitation for three future time slices are presented in Table 3.2 – Table 3.4. Figure 3.4 shows the temporal evolution of seasonal and annual average temperatures under the SRES A2 and B2 emissions scenarios. The summer increase in maximum temperature is highest, followed by autumn, and spring increases are lowest under B2. Forecasts under A2 are similar to those under B2. The increase in minimum temperature (time series not shown) is slightly different between the two; the largest increases occur in summer and winter, and the lowest in spring under B2. Under A2, the highest increase is summer, then winter, with the smallest occurring in spring. Warming is slightly higher in the south than in the north (not shown).

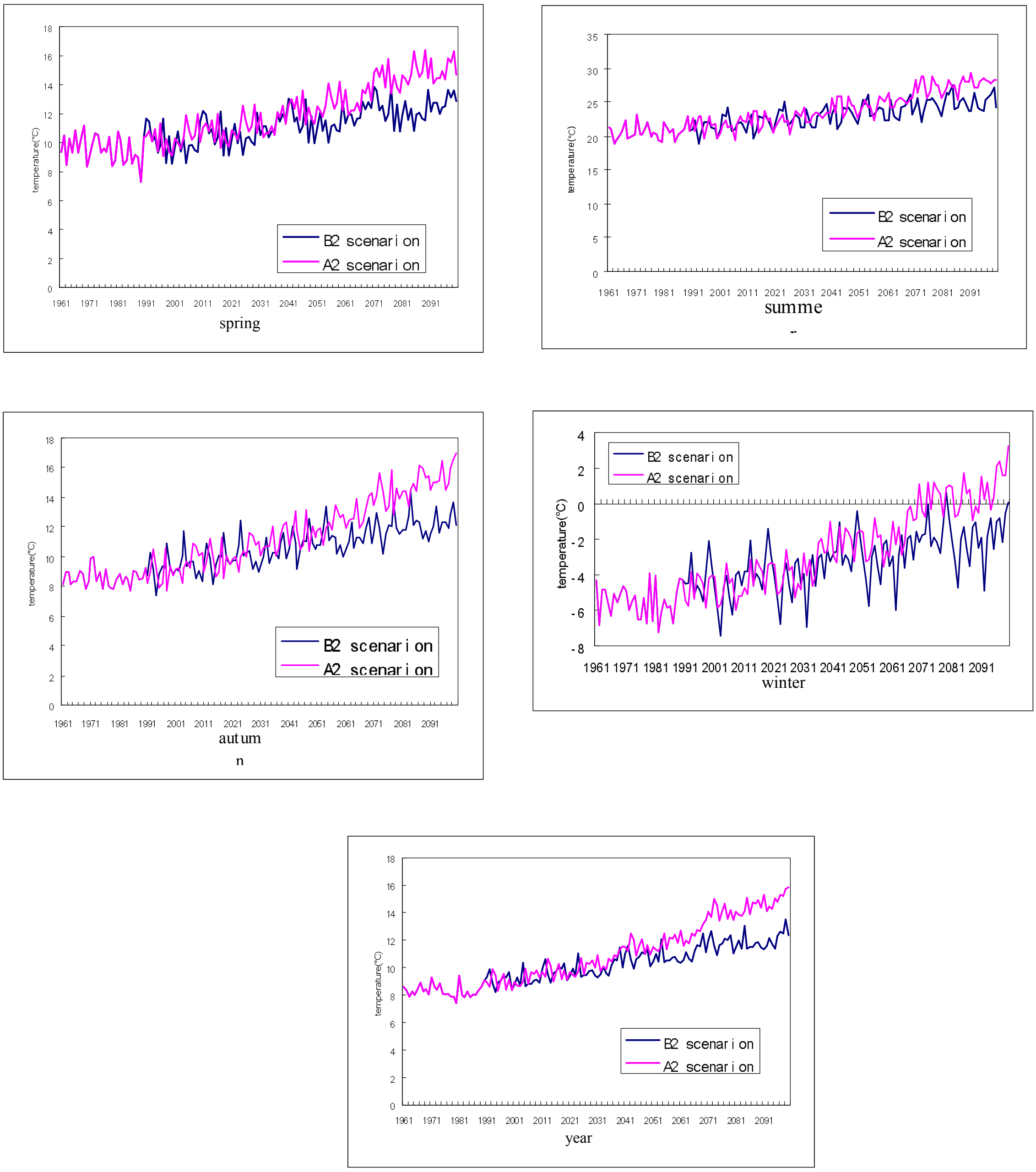
Table 3.2 Increase in future maximum temperature using PRECIS with A2 and B2 for Ningxia

Temperature difference relative to the baseline period (℃)	Spring		Summer		Autumn		Winter		Year	
	B2	A2	B2	A2	B2	A2	B2	A2	B2	A2
2011-2040	1.2	1.6	1.9	2.1	1.7	1.9	1.4	1.8	1.6	1.8
2041-2070	2.0	3.1	3.2	4.3	2.7	3.7	2.3	3.4	2.6	3.6
2071-2100	2.6	5.1	4.5	7.3	3.7	6.2	3.2	5.7	3.5	6.0

Table 3.3 Increase in future minimum temperature using PRECIS with A2 and B2 for Ningxia

Temperature difference relative to the baseline period (℃)	Spring		Summer		Autumn		Winter		Year	
	B2	A2	B2	A2	B2	A2	B2	A2	B2	A2
2011-2040	1.3	1.6	1.7	1.9	1.5	1.8	1.7	1.9	1.6	1.8
2041-2070	2.3	3.2	2.9	4.0	2.5	3.8	3.0	3.9	2.7	3.7
2071-2100	3.2	5.5	4.0	6.8	3.5	6.5	4.3	6.7	3.7	6.4

Figure 3.4 Seasonal and annual temperatures with A2 and B2, 1961-2100



3.3.2 Precipitation

Figure 3.5 shows annual and seasonal precipitation under SRES A2 and B2 emissions scenarios from 1961 to 2100. Under scenario A2, the amplitude of annual precipitation variation is relatively high, with an increasing trend, whereas with scenario B2 the amplitude is lower and the increasing trend is less. Table 3.4 shows that precipitation across the region increases, on annual timescales and in all seasons, except during summer (and autumn with B2). There are quite substantial decreases in summer precipitation. Figure 3.6 Figure 3.7 show the spatial patterns of annual precipitation change under the A2 and B2 scenarios respectively. There is a gradient of change from north to south under both scenarios, with moderately dryer conditions in more northerly areas and increasingly higher increases in precipitation in the south.

Figure 3.5 Seasonal and annual precipitation under SRES A2 and B2 emissions scenarios

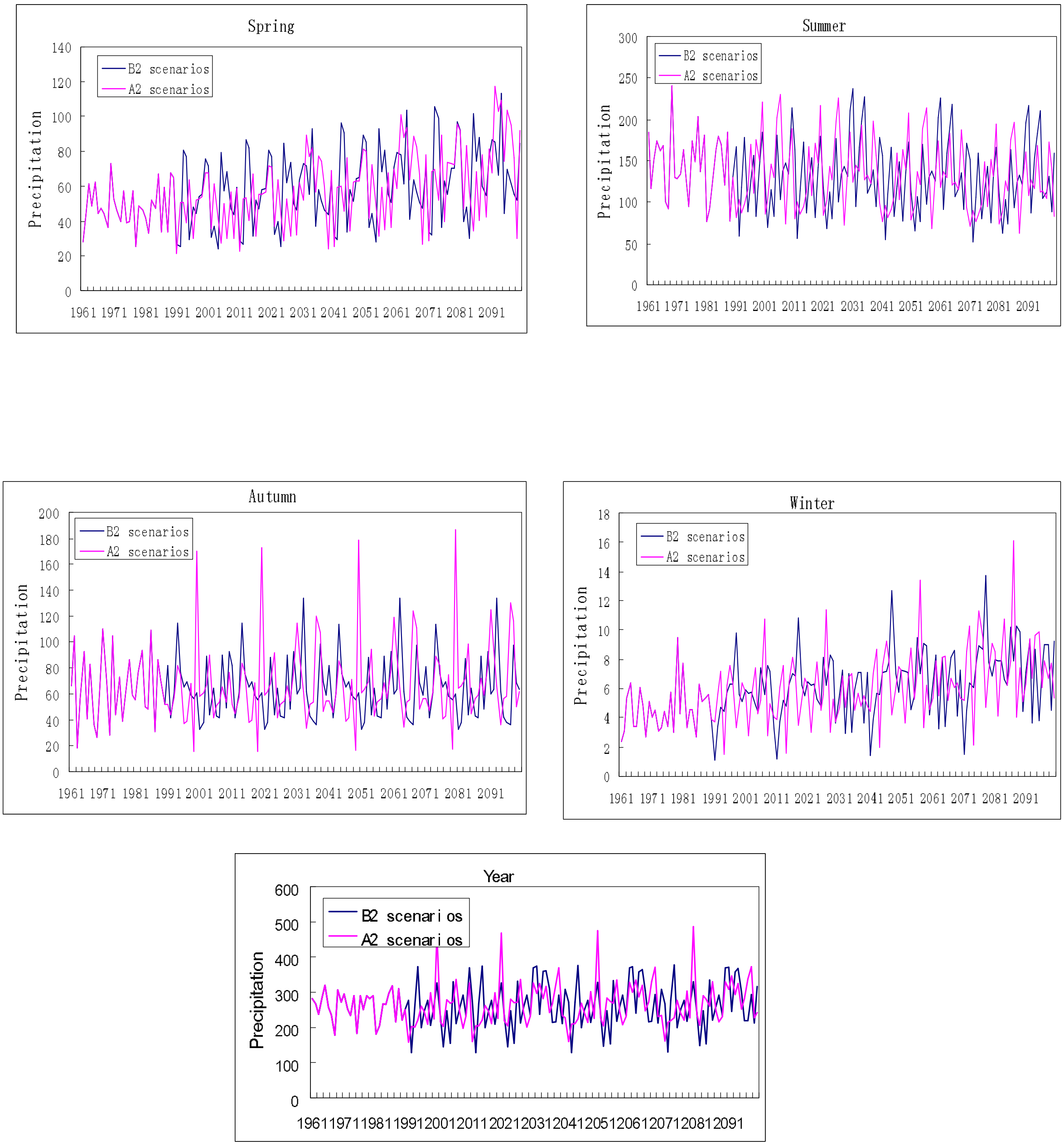


Table 3.4 Percent seasonal and annual changes in future precipitation using PRECIS with A2 and B2 for Ningxia (changes in per cent)

Period	Annual		Spring		Summer		Autumn		Winter	
	B2	A2	B2	A2	B2	A2	B2	A2	B2	A2
2020s	3	5	9	7	-7	-6	0	2	1	1
2050s	4	8	14	14	-12	-13	0	5	2	2
2080s	6	12	20	24	-17	-23	0	8	3	3

Figure 3.6 Climate scenarios for Ningxia from PRECIS. Annual precipitation change for the 2020s, 2050s and 2080s under SRES A2 emissions scenario

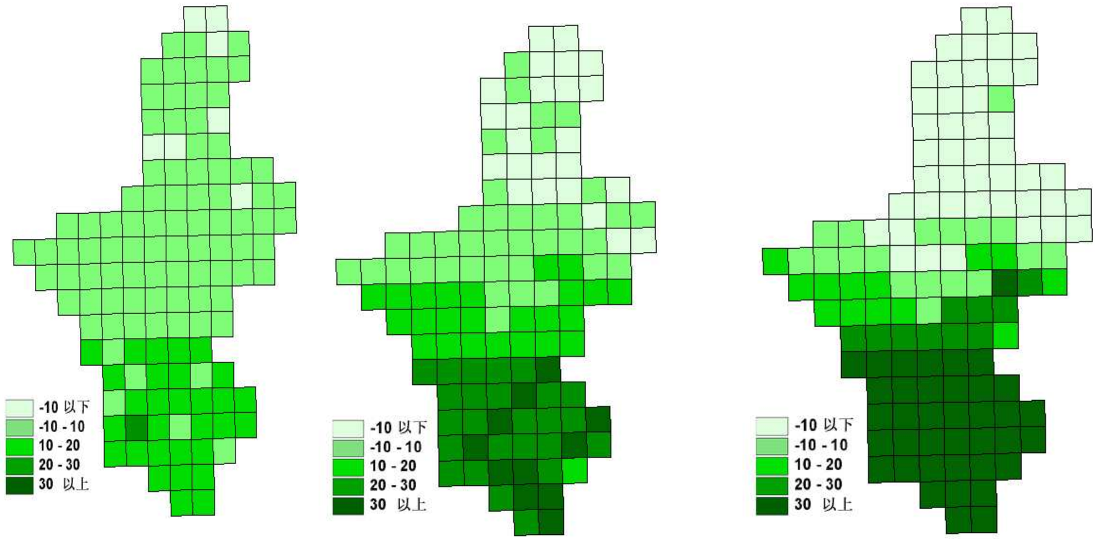
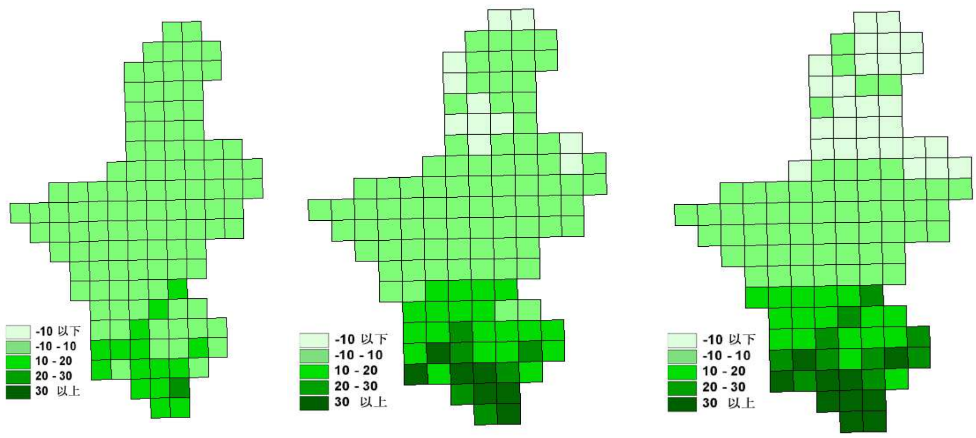


Figure 3.7 Climate scenarios for Ningxia from PRECIS. Annual precipitation change for the 2020s, 2050s and 2080s under SRES B2 emissions scenario



3.4 Results from other GCMs used for the IPCC Fourth Assessment Report

A range of recent climate change scenarios are presented for Ningxia based on climate model results made available through the Programme for Climate Model Diagnosis and Intercomparison (PCMDI) for the IPCC Fourth Assessment Report (Meehl *et al.,*2007). Full details are described in another ICCCA Phase II report: *National Level Study: The Impacts of Climate Change on Cereal Production in China* (Xiong *et al*., 2008). A large scale window was extracted for China (20°N-55°N, 72°E-136°E) and then split into a number of geographically distinct smaller sub-regions. Table 3.5 highlights the main changes in temperature and precipitation from the set of models.

Table 3.5 Summary of the main changes suggested by IPPC Fourth Assessment Report multi-model averages for a region of China that comprises all of Ningxia

Temperature
High confidence
• Warming in all seasons and all periods with A2 and B1.
• 2020s Annual warming: A2 1.3°C; B1 1.2°C.
• 2050s Annual warming: A2 2.5°C; B1 1.9°C.
Precipitation
Medium confidence
• Annual precipitation increases in all seasons and all periods with A2 and B1.
• 2020s Annual increase with A2 +3%; B1 +7%.
• 2050s Annual increase with A2 +9%; B1 +8%.
• Annual changes mask significant seasonal changes in precipitation.
• For the key season for precipitation, summer (JJA), models show some divergence with nearly half the sample projecting drier conditions. Extreme results range from roughly -25% to +40% changes in summer precipitation.

Table 3.6 and Table 3.7 show the model average and extreme ranges (from all models) in temperature and precipitation change, for annual, spring and summer periods in the whole of China and the north China.

Table 3.6 Average change in temperature for China and North China (similar region to Ningxia) by the 2020s and 2050s (compared to the 1961-1990 mean) under A2 (average across 17 GCMs) and B1 (average across 19 GCMs) scenarios

Absolute Temperature change (°C)	A2 SCENARIO						B1 SCENARIO					
	Annual		MAM		JJA		Annual		MAM		JJA	
	2020s	2050s	2020s	2050s	2020s	2050s	2020s	2050s	2020s	2050s	2020s	2050s
North	1.3	2.5	1.3	2.2	1.3	2.5	1.2	1.9	1.1	1.8	1.2	2.0
China	1.2	2.4	1.2	2.3	1.1	2.2	1.2	1.9	1.1	1.8	1.1	1.8

Table 3.7 Average % change in rainfall for China and North China (similar region to Ningxia) by the 2020s and 2050s (compared to the 1961-1990 mean) under A2 (average across 17 GCMs) and B1 (average across 19 GCMs) scenarios

% Rainfall Change	A2 SCENARIO						B1 SCENARIO					
	Annual		MAM		JJA		Annual		MAM		JJA	
	2020s	2050s	2020s	2050s	2020s	2050s	2020s	2050s	2020s	2050s	2020s	2050s
North	+3	+9	+6	+12	+1	+3	+7	+8	+8	+12	+5	+4
China	+1	+4	+1	+5	+2	+6	+2	-1	+2	+5	+3	+4

Figure 3.8 and Figure 3.9 summarise the main results by showing precipitation (per cent change) against temperature (absolute change, °C) for all models and the three periods in the future. A progressive warming is clear, as is a very progressive shift to wetter conditions across the majority of models (although some seasons and regions have moderately drier conditions in the 2020s and 2050s). By the 2080s all models show an increase in annual precipitation. These results support medium to high confidence in the broad-scale precipitation changes predicted across Ningxia, namely that annual precipitation is to increase. Seasonal and regional patterns differ somewhat: for example,

in summer (JJA), which corresponds to the main season for precipitation, models show some divergence with nearly half the sample projecting drier conditions.

Figure 3.8 Annual changes in temperature and precipitation by the 2020s, 2050s, and 2080s with 17 GCMs (A2 scenario).

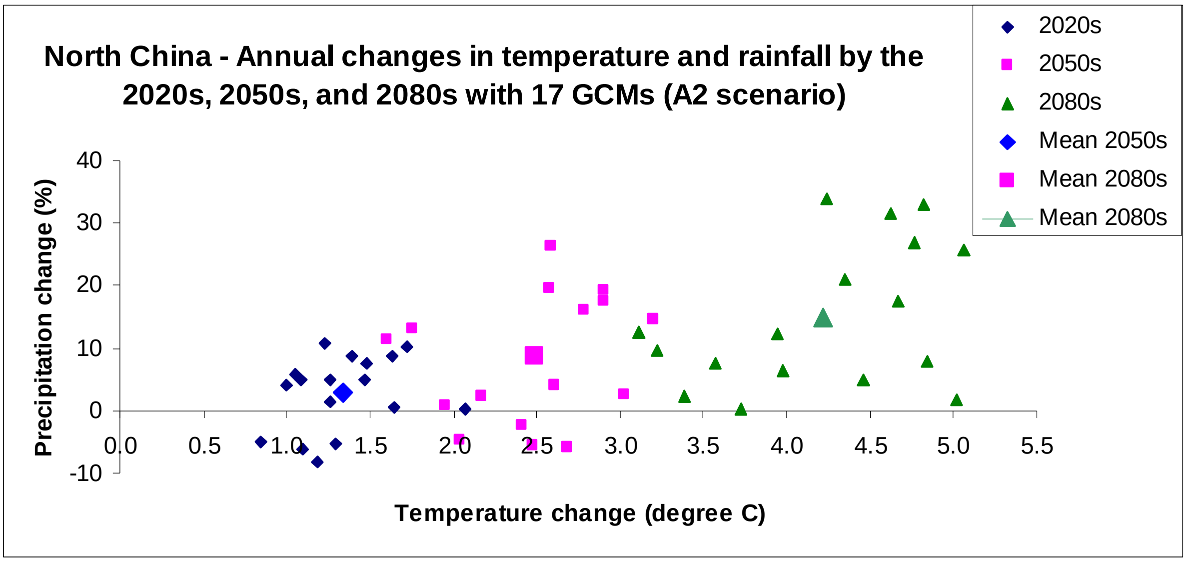


Figure 3.9 Summer (JJA, wet season) changes in temperature and precipitation by the 2020s, 2050s, and 2080s with 17 GCMs.

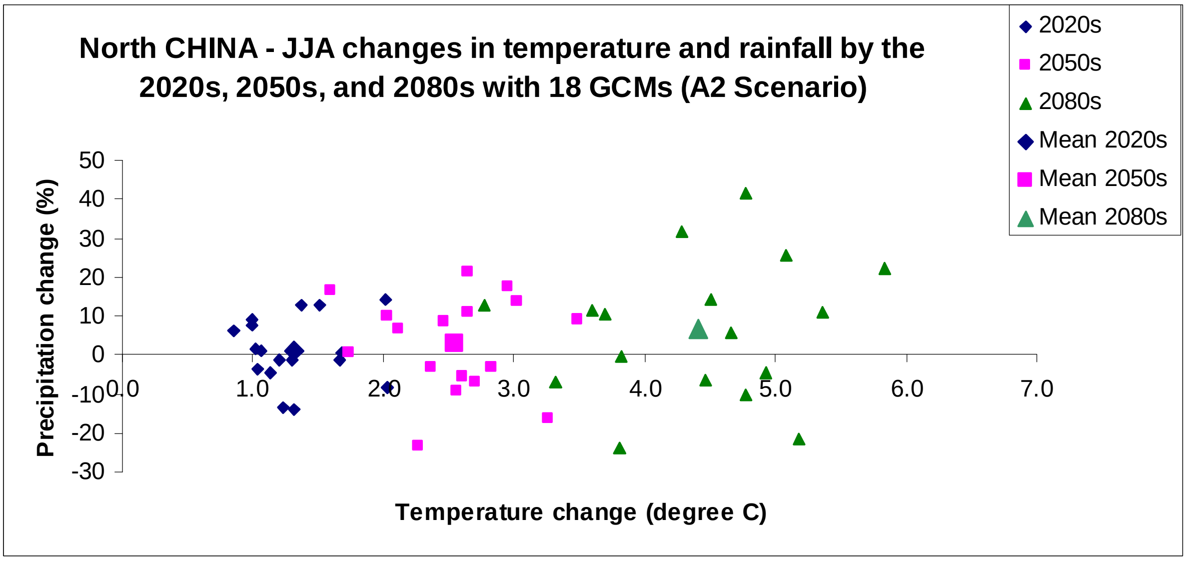


Table 3.8 and Table 3.9 list the range of seasonal changes in temperature and precipitation respectively, and in nearly all cases these include some very extreme results, particularly for precipitation.

Table 3.8 Average and range between models in temperature change for for sub-region of North China by 2020s and 2050s (compared to the 1961-1990 mean) under A2 (average across 17 GCMs) and B1 (average across 19 GCMs) scenarios.

Emissions Scenario	Time Period	Absolute Temperature Change	Annual	DJF	MAM	JJA	SON
A2	2020s	Cool	0.8	0.8	0.8	0.8	0.6
		Average	**1.4**	**1.4**	**1.2**	**1.5**	**1.4**
		Warm	2.7	2.7	1.9	4.0	2.9
	2050s	Cool	1.6	1.6	1.0	1.6	1.3
		Average	**2.5**	**2.5**	**2.1**	**2.6**	**2.5**
		Warm	3.2	3.2	3.0	4.0	3.4
B1	2020s	Cool	0.5	0.5	0.4	0.4	0.4
		Average	**1.3**	**1.3**	**1.1**	**1.3**	**1.3**
		Warm	3.1	3.1	2.0	4.8	3.4
	2050s	Cool	1.1	1.1	0.8	1.0	0.9
		Average	**2.0**	**2.0**	**1.7**	**2.1**	**2.0**
		Warm	3.1	3.1	2.8	4.5	3.2

Table 3.9 Average and range between models in precipitation change for sub-region of North China by 2020s and 2050s (compared to the 1961-1990 mean) under A2 (average across 17 GCMs) and B1 (average across 19 GCMs) scenarios

Emissions Scenario	Time Period	Per cent Precipitation Change	Annual	DJF	MAM	JJA	SON
A2	2020s	**Dry**	-88	-88	-48	-89	-95
		Average	**-2**	**-3**	**+3**	**-4**	**-4**
		Wet	+11	+10	+28	+14	+49
	2050s	**Dry**	-88	-88	-48	-90	-96
		Average	**+3**	**+3**	**+9**	**-2**	**+6**
		Wet	+26	+26	+29	+21	+61
B1	2020s	**Dry**	-81	-81	-17	-83	-92
		Average	**+2**	**+2**	**+7**	**+0.3**	**+3**
		Wet	+16	+15	+23	+17	+43
	2050s	**Dry**	-81	-81	-12	-83	-95
		Average	**+4**	**+4**	**+11**	**0**	**+3**
		Wet	+19	+19	+28	+23	+32

3.5 Conclusions

High-resolution future climate change scenarios for China have been used to provide detailed scenarios for Ningxia using two IPCC SRES greenhouse gas emissions scenarios (A2, corresponding to medium-high emissions, and B2, corresponding to medium-low emissions) for the 2020s, 2050s and 2080s.

The PRECIS scenarios show continued and faster warming in Ningxia, with an average increase of up to 6.4℃ under SRES A2 by the 2080s. Precipitation increases by 12% overall under the A2 scenario by the 2080s, but quite marked decreases occur in summer (June to August) with a 23% fall under A2 by the 2080s. Drier conditions occur in more northerly areas whereas in the south precipitation levels increase.

Table 3.10 below shows changes in future annual maximum and minimum temperature and precipitation (in ℃ and %.) in Ningxia using PRECIS (Providing REgional Climates for Impacts Studies) under the A2 and B2 scenarios.

A range of climate change scenarios for China from other global climate models based on results made available for the IPCC Fourth Assessment Report were also used to evaluate potential future changes in temperature and precipitation for Ningxia. These scenarios were also compared with those produced by PRECIS.

Our findings support medium to high confidence that the broad-scale precipitation changes across Ningxia will lead to increases in annual precipitation. Models display some divergence in their projections for the main precipitation season (JJA – summer) with nearly half of the models sampled projecting drier conditions than the baseline for the summer season.

Table 3.10 Summary changes in average maximum and minimum temperature, and in precipitation under A2 and B2 emissions scenarios, for the 2020s, 2050s and 2080s with PRECIS

Difference relative to the baseline period	T_{max} (℃)		T_{min} (℃)		Precipitation (%)	
	B2	A2	B2	A2	B2	A2
2011-2040	1.6	1.8	1.6	1.8	+3	+5
2041-2070	2.6	3.6	2.7	3.7	+4	+8
2071-2100	3.5	6.0	3.7	6.4	+6	+12

4 Socio-economic scenarios for Ningxia

Authors: Jiang Jinhe, Duan Qinglin

4.1 Introduction

For the regional analysis, we use the same scenarios – National Planning (NP), SRES A2 and SRES B2 – and the main driving forces as those we used for the national level analysis carried out under ICCCA Phase II and presented in the report *National Level Study: The Integrated Impacts of Climate Change on Cereal Production in China* (Xiong et al., 2008). Regional socio-economic scenarios for GDP and population are developed using the same methodology as in the national level work (see Chapter 5 in the *National Level Study*, Xiong *et al*., 2008). Our approach downscales both the aggregated population and GDP data for China to the regional level using a simple linear downscaling methodology based on the base year 2005. Regional annual population and GDP growth rates were set equal to national rates. This is equivalent to keeping the fractional share of each regional population or GDP constant relative to the national level (at the base year value), for the whole period under study.

For regional GDP and population dynamics under the NP scenario, we considered the regional development programming issued by local government from 2005 to 2020 and also used the same downscaling method based on national level scenarios between 2020 and 2050.

For regional agricultural land use scenarios, we adopted a simple statistical method based on recent relationships between regional scale GDP and changes in arable land area. Underpinning this is the hypothesis that urbanisation and industrial growth are the main drivers of decline in arable land area (detailed methods for each scenario are presented in the *National Level Study*).

For regional water demand scenarios we considered the total water consumption data on the basis of four sectors, namely; agricultural, industrial, domestic, and environmental. The data were obtained from the Water Report by the Ministry of Water Resources of China. Different methods are required for each sector at province level, and these can be aggregated to form total water demand by sector. Finally, total water demand for China was considered. The methods for each of the different sectors can be found in ICCCA's *National Level Study* (Xiong *et al*., 2008).

4.1.1 The current socio-economic situation in Ningxia

Ningxia Hui Autonomous Region is located in northern China on the middle part of the upper stream of Yellow River, at longitude E104º17´to E107º39´ and latitude N35º14´to N39º23´. The topography in Ningxia is low in the north and high in the south (Figure 4.1). The region's area totals about 66401.9 km^2, which accounts for 0.69% of national land area. In 2006 the regional GDP was 71.1 billion RMB, in which primary, secondary and tertiary industries accounted for 11.2%, 49.2% and 39.6% of GDP respectively. The energy industry and agricultural sector in Ningxia have traditionally been strong in Ningxia, and the proportion of heavy industry output accounted for 82.3% of gross output value of all industrial sectors in the region. At the end of 2006, the total population was 6.04 million. In 2006 Ningxia had an economic output accounting for 0.34% of China's GDP and a population accounting for 0.46% of China's population.

4.1.2 Population

The population in Ningxia increased from 4.66 million in 1990 to 5.96 million in 2005, corresponding to an average 16.5% annual growth rate (Figure 4.2). The populations's natural growth rate decreased from 18.8% in 1990 to 11.0% in 2005. Notwithstanding, it is still 5.1 points higher than the national average in 2005. The percentage of total population aged between 15 and 64 in 2004 was 68.5%, which reflects the abundant Ningxia workforce. Illiteracy rates amongst the population aged over 15 decreased from 33.5% in 1990 to 15.7% in 2004. From 1990 to 2005, the proportion of rural population decreased from 76.1% to 64.5%. For reference, this index for all of China in 2005 was 56.1%.

Figure 4.1 Land topography structure in Ningxia

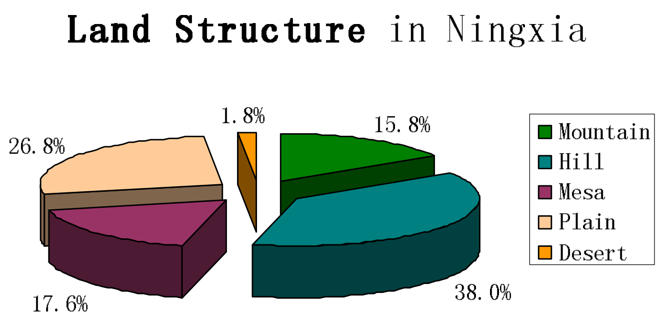
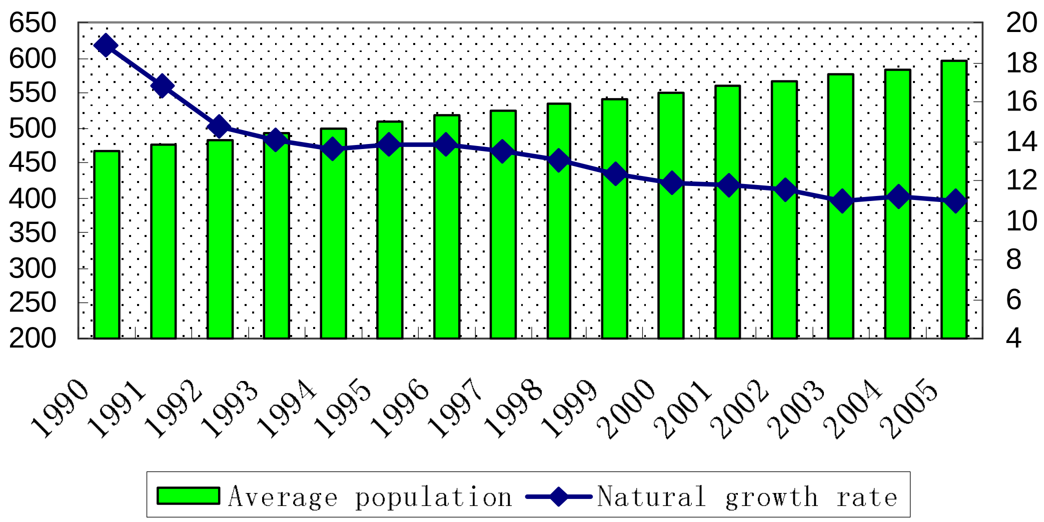


Figure 4.2 Population and Natural growth rate in Ningxia from 1990 to 2005[3]



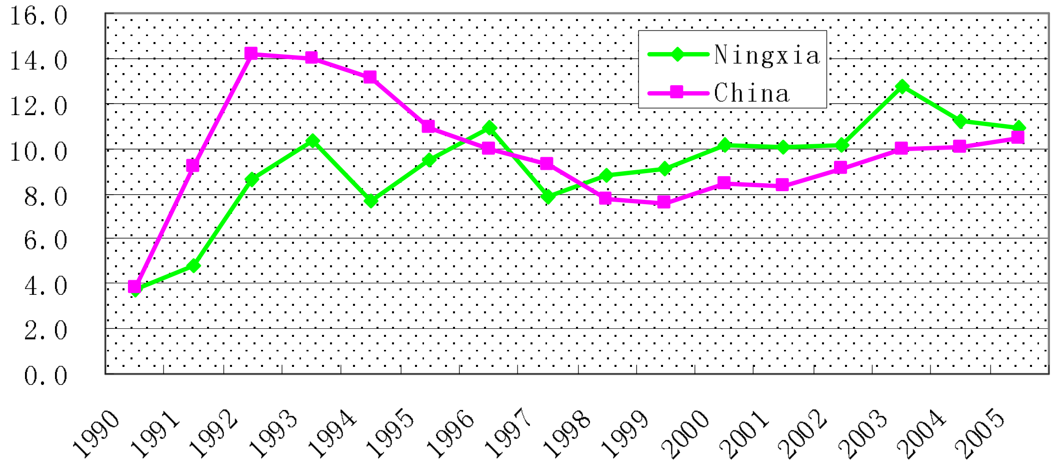
4.1.3 Economy

From 1990 to 2005, the annual GDP growth rate in Ningxia was 9.5% at constant prices which was lower than the 10.1% national average (Figure 4.3). Nevertheless, from 1998 onwards the GDP growth rate in Ningxia has been higher than the national average, especially in 2005 when the growth rate reached 12.7% in Ningxia, 2.7 points over and above than the national average. In 2005 the per capita GDP was 10,240 yuan which amounts to only 72.8% of the national average. The value-added proportion of primary industry to Ningxia GDP decreased from 26.0% in 1990 to 11.9% in 2005; the

[3] Data source: Ningxia Statistic Yearbook, China Statistic Yearbook.

national average in 2005 is 12.5%. Looking at economic development in China as a whole, Ningxia still remains at a lower economic level than the national average. However, development and growth trends are higher than average.

Figure 4.3 GDP growth rate in Ningxia (green) and China (pink) (1990 – 2005)



4.1.4 Agricultural land use

From 1998 to 2005 the arable land area in Ningxia decreased by 170,000 ha, mainly due to the Grain-for-Green Programme in mountainous areas. In 2004 the area of cultivated land in the plain area of Ningxia was only 323,000 ha, comprising about 50 % paddy fields and 50 % irrigated arable land. The area of cultivated land in the mountainous area was 621,400 ha; the irrigated land area amounts to 97,200 ha because of the expensive irrigation cost of introducing water from the Yellow River. In response to climate change in mountainous areas in recent years, the planting area for summer crops has decreased and the area of autumn-sown crops has increased accordingly.

4.1.5 Water use

Because of changes in allocation of Yellow River water and other constraints on water use due to Ningxia's arid conditions, total water use in Ningxia decreased from 1997 to 2005 (Table 4.1). Ningxia's proportion of national water consumption also decreased from 1.7% in 1997 to 1.4% in 2005. The annual per-capita water use in Ningxia is very high: 1314 m^3 in 2005 compared to 432 m^3 in China as a whole, but per-capita domestic water use in Ningxia is lower than the national average (30 m^3 in Ningxia as compared with the Chinese average of 52 m^3). The reason is that the proportion of agriculture water use amounts to more than 90% of total water consumed in Ningxia. In future, regional planning objectives aim to decrease the proportion of water used for agriculture and increase the proportion of water for non-agricultural production sectors in Ningxia. Improvements in water use efficiency in the agricultural sector are very important to help conserve water resources in Ningxia.

Table 4.1 Water use and structure in Ningxia from 1997 to 2005

	Total (100 M m^3)	Agriculture (%)	Production (%)	Domestic (%)	Environment (%)	Per capita domestic (m^3)
1997	94.48	91.8	6.6	1.5		28
2000	87.23	92.6	5.5	1.9		31
2004	74.05	92.7	4.3	2.4	0.6	31
2005	78.09	92.5	4.4	2.2	0.8	30

Note: domestic water use includes household and services water use.
Data source: Report of Water Resources in China (yearly report)

4.2 Results for Ningxia

4.2.1 Population and economy (GDP)

Because of statistical issues, the totals of population and regional GDP at province level in China show discrepancies with the national population and GDP statistics. The residuals of population and GDP between aggregated provinces and national statistics accounted for -1.9% and 6.2% in 2005 respectively. Thus, all projections under the three scenarios conserve the same residual proportion as the base year according to the downscaling method.

Table 4.2 shows the population projection under the three scenarios considered: A2, B2 and NP. Scenario B2 is similar to NP; at the national level the population projection under B2 is less than NP, but at the regional level, some provincial populations under B2 are larger than under the NP scenario. The same population trends apply for regional and the national simulations.

Table 4.2 Ningxia population projections in the three SES

	2000	2005	2020			2050		
			A2	B2	NP	A2	B2	NP
Ningxia	5.54	5.96	6.84	6.54	6.79	8.66	6.84	7.02
China	1267	1308	1533	1439	1470	1941	1506	1520

Note: Population expressed in millions of people.
Data source: statistical yearbook for 2000 and 2005, and local development programming from regional government website; others are the result of this project.

Under the B2 scenario, GDP projections are, for all provinces, higher than the NP projections (Table 4.3). Ningxia's GDP increases from 2005's value of 49.4×10^9 RMB to 264.4×10^9 under A2 and 512.9×10^9 RMB with the NP scenario. Ningxia's economy remains slightly below national average levels.

Table 4.3 Ningxia GDP projections in the three SES

	2005	GDP per capita (NP in 2020)	2020			2050		
			A2	B2	NP	A2	B2	NP
Ningxia	494	3000	952	1519	1693	2644	4593	5129
China	156750	3400	301,000	481,000	413,000	837,000	1,450,000	1,301,000

Note: GDP in 100 M RMB at comparable price in 2000; GDP per capita unit (3rd column only): USD at exchange rate in 2000 100USD = 827RMB; figures for per-capita GDP are rounded to nearest 50.
Data source: statistical yearbook for 2000 and 2005, and local development programming from regional government website; others are the result of this project.

4.2.2 Changes in agricultural land use

Three agricultural land use scenarios derived from A2, B2 and NP scenarios were used in Ningxia and China as a whole. The detailed method for establishing forecasts can be found in ICCCA's *National Level Study* (Xiong et al. 2008). The agricultural land use projection under B2 is assumed to remain at a constant value (using the area from 2005 statistics), and the NP scenario assumes no change in land use from 2020 onwards. According to China's recent policies for the protection of arable land, the total agricultural land area in Ningxia is expected to remain at a constant 1.333 M ha until 2020. Table 4.4 shows the results for scenarios A2-high emissions, B2-low emissions and NP in 2050. The average arable area per capita in China is about 40% of the global average in 2005. Although the amount of arable area in 2020 under the NP scenario is the same as in 2005, the arable area per capita in 2020 under NP is less than in 2005.

Table 4.4 Ningxia agricultural land use projections in the three Socio-economic scenarios (ha per capita)

	2005	Per capita in 2005	2020			2050		
			A2 High	B2 Low	NP	A2 High	B2 Low	NP
Ningxia	1333	0.22	1082	1131	0.20	715	772	1102
China	121471	0.09	153300	115039	0.08	194089	108853	117525

Note: agricultural land use figures are in 1000 ha. Per-capita land unit is in ha/person (3rd column only); the land area under NP scenario in 2020 is set to be the same as that in 2005.
Data source: Report of the Ministry of Land and Resources for 2005; others are the result of this project.

4.2.3 Changes in demand for water

The total water demand for each province comprises usage by the four main sectors: agriculture, industrial, urban/domestic, and environmental. In 2005, average per-capita domestic water use in China was 52m^3/year; in Ningxia it was only 30 m^3/year.

Table 4.5 Ningxia water demand projections under the A2, B2 and NP scenarios

	2005	Domestic water / capita in 2005	2020			2050		
			A2 High	B2	NP	A2 High	B2	NP
Ningxia	78	30	71	85	86	68	99	87
China	5633	52	6161	6196	6204	7470	6914	6757

Note: water use in 100 M m^3; per capita domestic (non-production) water use unit: m^3/person.
Data source: Water Report of the Ministry of Water Resources for 2005 and project results.

Table 4.6 shows the predicted future water demand by sector under the three scenarios in Ningxia. For all scenarios the proportion allocated to the agricultural sector decreases while the proportion of water allocated to the urban/domestic sectors or environment increases.

Table 4.6 Ningxia water demand structure in 2020 and 2050 in the three SES (%)

		Agriculture	Production	Domestic	Environment
2005		93	4	2	0.8
2020	A2	82.4	10.2	4.3	3.2
	B2	84.8	8.1	3.2	3.8
	NP	84.6	8.4	3.5	3.8
2050	A2	57.2	25.5	9.1	8.2
	B2	73	13.8	4.5	8.6
	NP	72.8	16.1	5.6	9.8

Note: Agriculture water demand structure under A2 refers to A2-high scenario.
Data source: Water Report of the Ministry of Water Resources for 2005; others are the result of this project

4.3 Conclusions

The method that we used to develop regional socio-economic scenarios (SES), essentially GDP and population, was the same as the one we used to develop national socio-economic scenarios. The latter is outlined in detail in ICCCA's *National Level Study* (Xiong *et al*. 2008). Our approach downscales both the aggregated population and GDP data for China to the regional level, using a simple linear downscaling methodology.

IPCC A2 and B2 emissions scenarios are used so as to preserve consistency with the PRECIS climate change scenarios; a third scenario – the National Planning (NP) scenario – was also developed. This uses Chinese government plans to 2020 and expert interpretation to extrapolate socio-economic trends and emissions forecasts beyond 2020, and to 2050.

Recent national and provincial level statistics on agricultural land use and water use were used to generate projections of agricultural land use change and future water demand by sector.

The results show the following key changes:

- Ningxia's population is projected to increase from 5.96 (2005) to 6.84 (A2), 6.54 (B2) and 6.79 (NP) in 2020 and to 8.66 (A2), 6.84 (B2) and 7.02 (NP) in 2050 (in million persons).
- Ningxia's total GDP is projected to increase from 49.4x10^9 RMB in 2005 to 264.4 x10^9 in 2050 under A2, and 512.9 x10^9 RMB under NP; the results under B2 mirror those under NP. The value of Ningxia's economy remains slightly below national average levels.
- Per capita GDP is projected to increase from present level of 494 to 952 (A2) 1519 (B2) by 2020 and to 2644 (A2) 4593 (B2) by 2050 (US$ per capita).
- Extrapolation of recent trends across China on agricultural land use suggests that there will be a reduction in agricultural land use in Ningxia. The rates of change and areal estimates are subject to large uncertainties due to problems with observed data and the crucial role of policy interventions. Changes range from large decreases under A2 (due to high contemporary rates) to no change

under B2 (largely due to the fact that B2 assumes that government policy interventions to halt decline in agricultural land area are successful).
- Water demand increases accompanied by a shift in the proportional use of water by sector, primarily away from agriculture in response to greater demand from industrial, urban and environmental uses (based on existing local government policy objectives).

5 The impacts of climate change on crop yields in Ningxia

Authors: Li Jianping (Potato), Liu Yulan (Maize), Yang Qin (Wheat), Liu Jing and Ma Liwen (Rice), Chen Xiaojuan, Su Zansheng, and Wang Lianxi.

Ningxia Meteorological Bureau applied a set of crop models to simulate the effects of climate change on four key crops in the region: maize, rice, wheat and potato.

For each crop either CERES (Maize, rice and wheat) or SUBSTOR (Potato) models have been calibrated to simulate growth of typical varieties grown in Ningxia. The work involved extensive collection of agrometeorological data, such as cultivar characteristics and historical crop yields. Separate reports are appended detailing the methods and results of each of the crop studies (See Appendices 1 to 4).

The models were calibrated to produce a good simulation of historical yields, taking into consideration the substantial increases in yield that have occurred due to changes in agricultural technology and management during the last 20 years.

In each case the crop models were applied to grid cells in Ningxia where the relevant crops are grown, i.e. irrigated areas for maize, rice and wheat and rainfed areas in the south for potato.

The table below lists examples of how some of the key crops in Ningxia may be affected by the combined effects of warmer temperatures and increasing concentrations of atmospheric carbon dioxide (CO_2 tends to have a fertilizing effect on crop growth).

Table 5.1 Future climate change and irrigated crop production in Ningxia

Crop type	Key impacts, short and long term		2020s	2050s	2080s
Rice (irrigated)	Yield change	A2	+7%	+10%	+9%
	Time to maturity declines in future	B2	+4%	+9%	+9%
Maize (irrigated)	Yield change	A2	+18%	+1%	-7%
		B2	+21%	+4%	-5%
Spring Wheat (irrigated)	Yield change	A2	-3%	-9%	-18%,
		B2	-3%	-7%	-11%

Crop yields in Ningxia show a mixed response to climate change: rice yields increase modestly, maize yields increase significantly in the short-term changing but then decline (relative to current levels?) beyond the 2050s. Meanwhile, we project modest to large decreases in spring wheat yields.

The effects on crop water requirements, where simulated, were generally quite modest (around 5-10mm, or within 10%) relative to the overall requirements, possibly due to the offsetting effects of increased CO_2 concentrations.

The effects on potato yields were negative in all cases and generally produced quite large changes as shown in the table below.

Table 5.2 Future per cent changes in rainfed potato production in Ningxia

	2020s			2050s			2080s		
	All Ningxia	Southern Ningxia	Central Ningxia	All Ningxia	Southern Ningxia	Central Ningxia	All Ningxia	Southern Ningxia	Central Ningxia
A2	-13.1	-12.6	-14.6	-21.1	-20.1	-23.8	-41.3	-40.9	-42.4
B2	-8.7	-9.5	-6.3	-11.1	-11.2	-10.6	-15.3	-14.9	-16.3

Appendices 1 to 4 provide full details of the research undertaken for each of the four crops considered: maize, wheat, rice, and potato.

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Appendices

Appendix 1: Impacts of Climate Change on Maize Yields in Ningxia's Irrigation Area

Appendix 2: Impacts of Climate Change on wheat yields in Ningxia

Appendix 3: Impacts of Climate Change on Rice Yields in Ningxia

Appendix 4: Impacts of Climate Change on Potato Yields in Ningxia

These appendices are included here to bear witness to the crop modelling capacity developed within Ningxia Meteorological Bureau as part of ICCCA Phase II. They are intended as preliminary work which, at the time Phase II finished, was being further refined.

Appendix 1

The Impacts of Climate Change on Maize in Ningxia’s Irrigation Area

Author: Liu Yulan

Temperature change during maize growing periods in Ningxia Irrigation Area

The climate in Ningxia’s irrigation area has been warming since the 1980s. The curve of mean daily temperature in maize’s growing season (late April to mid-September) can be divided into two distinct periods: up to 1993, and 1994 and after. The T-test showed that the temperature during maize’s growing season lept in 1993, with the average temperature during maize’s growing season for 1994-2004 about 0.7℃ higher than that for 1981-1993 (0. 01 significance test). The temperatures in the relatively lower temperature years of 1990s are similar to the temperatures in the relative higher temperature year in 1980s. Clearly, the average temperature during the growing season after 1990s increased relative to the 1980s.

Figure A1. 1 Average temperature during maize's growing season

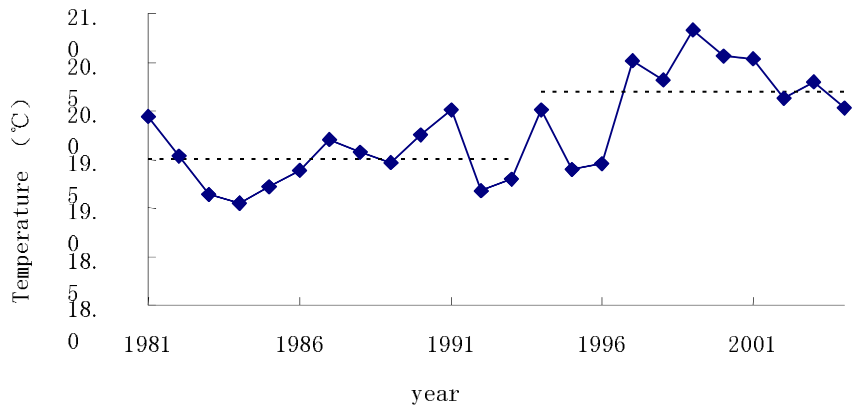


Table A1. 1 shows that the temperature increased in every period of maize. Comparing the mean temperature in 1994-2004 and that in 1981-1993, the results show that the mean temperature increased by 0.8℃ at the seedling, the jointing-spik e formation and the heading-flowering-silking stages; and by 0.9℃ at grain filling phase. The mea n maximum temperature increased by 0.6℃ at the seedling stage, 0.9℃ at jointing-spike formation st age, 0.5℃ at the heading-flowering-silking stage and 0.6℃ at the grain filling phase. Overall, howev er, the temperature did not exceed the scope of appropriate temperature for maize in Ningxia’s irrigation area.

Table A1. 1 The temperature in every period of maize and change

growth stage	period	appropriate temperature (℃)	mean temperature (℃)		mean maximum temperature (℃)	
seedling stage	May	16-18	17.1	17.9	22.6	23.2
jointing-spike formation	June	24-26	20.3	22.1	25.8	26.7
heading-flowering-silking	July	25-27	23.2	24.0	27.9	28.4
grain filling phase	August – mid September	20-25	19.6	20.5	25.3	25.9

The impact of climate warming on maize yields in Ningxia's irrigation area

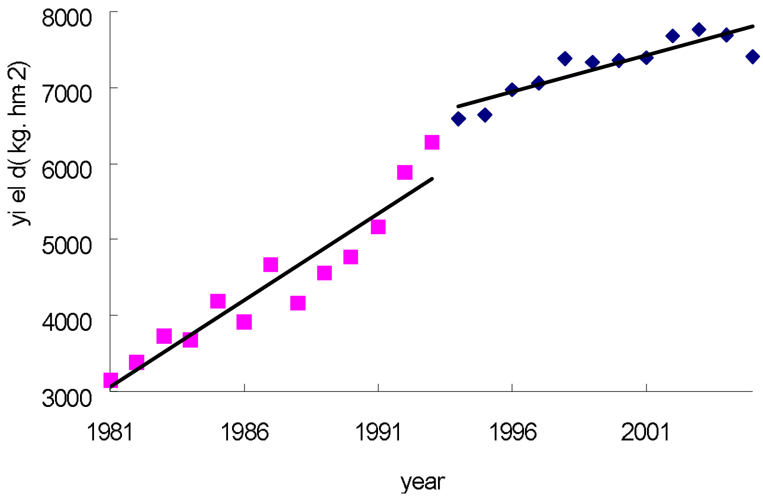
The maize yield data was divided into two parts from 1993 for the sector in Ningxia irrigation area. Respectively, the yield trend was simulated:

1981-1993 : $\hat{Y}_{t1} = 2835.7 + 227.35t$ （t=1，2，……，13） R^2=0.8963

1994-2004 : $\hat{Y}_{t2} = 6561.8 + 116.52t$ （t=1，2，……，11） R^2=0.9154

They all adopted the 0.01 significance test.

Figure A1. 2 The change of maize yield per acreage in irrigation area of Ningxia



The temperature coefficient is the quantitative indicator of the warming effect on the maize yield. Calculating the correlation coefficient between the temperature departure and the percentage of the climate yield to the trend yield, the result showed that the correlation coefficient was -0.312 in 1981-1994, 0.48 in 1994 to 2004. The equations could be established respectively in 1981-1993 and 1994-2004:

$$\alpha_1(\Delta T) = 0.0049 - 0.1738\Delta T - 0.0827\Delta T^2 + 0.6183\Delta T^3 \quad R^2=0.194$$

$$\alpha_2(\Delta T) = 0.0094 - 0.0478\Delta T - 0.03\Delta T^2 + 0.824T^3 \quad R^2=0.207$$

Using the temperature departure of Ningxia's irrigation area before and after the leap, the temperature coefficients are 0.0329 for 1981-1993 and 0.0382 for 1994-2004. Based on the actual yield of the corresponding period, the climate yields are 141.02 and 260.94. Thus, the warming effect on the maize yield was 4.5% (Table A1. 2).

Table A1. 2 The contribution of climate warming to maize yield in Ningxia's irrigated area

	1981-1993年	1994-2004年
mean temperature departure（℃）	-0.3	0.4
temperature influencing index	0.0329	0.0382
practical mean yield（Kg/ha）	4427	7089
practical increase production（Kg/ha）		2662
climatic yield（Kg/ha)	141.02	260.94
climatic increase production（Kg/ha）		119.92
the contributing rate of climate warming（%）		4.5

The impacts of warming on maize's yield in Ningxia's irrigated area

Under future climate scenarios, and providing that the varieties of the current ecological types area of maize are kept constant and full irrigation is guaranteed, relative to the baseline average (1961-1990) maize yields increase about 20% in the 2020s and 1-4% in 2050s. As the temperature continue to increase, yields will decrease by 5-7% in 2080s. In the 2020s and 2050s, yield increases under the B2 scenario are slightly larger than under A2, and projected decreases in the 2080s under B2 are projected to be less significant than those under A2.

Table A1. 3 Maize yield change in Ningxia's irrigated area under A2 and B2 emissions scenarios

climate scenario	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
A2	18	1	-7
B2	21	4	-5

Figure A1. 3 Spatial patterns of change in Maize yield.

Appendix 2

The Impacts of Climate Change on Wheat in Ningxia

Author: Yang Qin

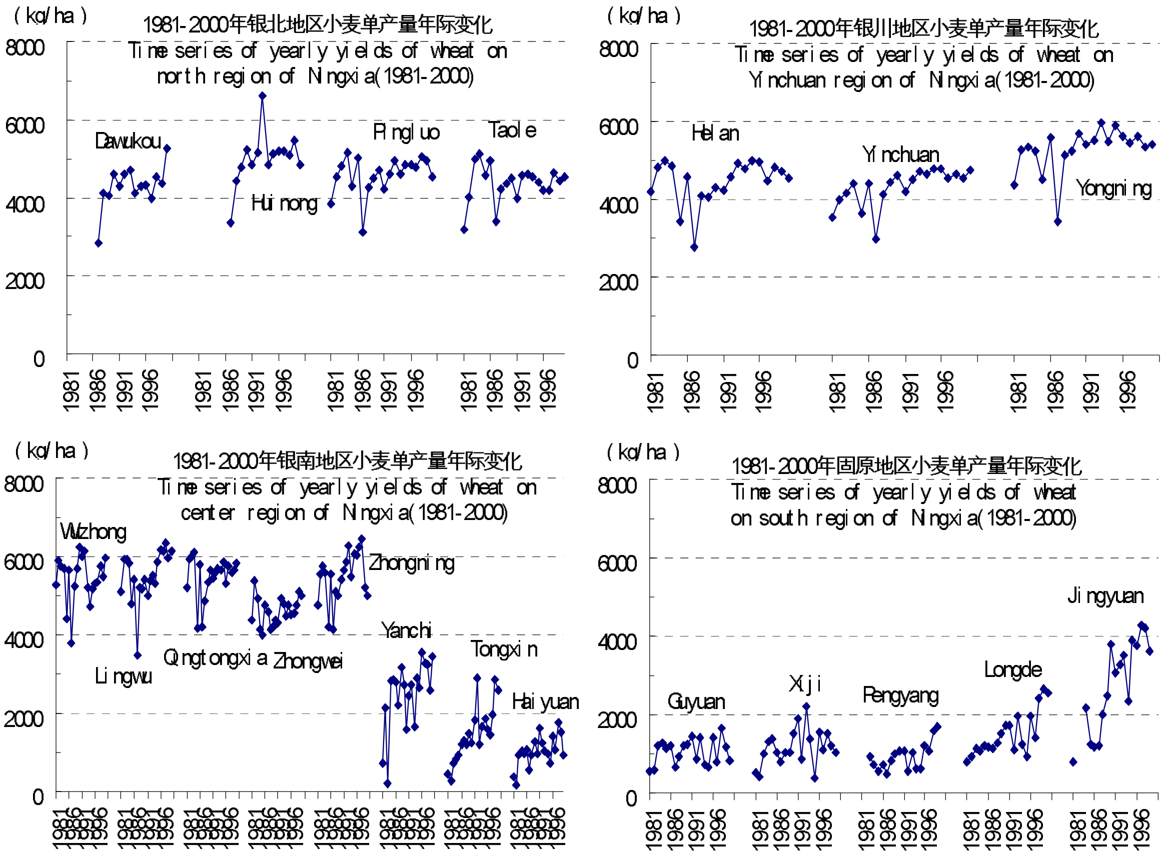
Abstract

Under the condition that insect pest and diseases were not considered, the CERES-Wheat model in DSSAT crop modelling was applied. Byh adjusting Yongliang 4 spring wheat cultivar coefficient and validating the model on Ningxia's Yongning county, seven appropriate cultivar coefficients were obtained. These coefficients were then used to simulate growth performance and potential yields were on the same cultivar type for 15 years (1986-2000) on Pingluo county of Ningxia. The results for potential yields and flowering dates showed that the simulations replicated well observation values. Larger differences (errors) resulted between simulated and observed physiology maturity dates. Potential yields for 59 grids (25km x25km) in Huanghe (Ningxia) were simulated for 100 years divided three periods (2020s: 2011-2040; 2050s: 2041-2070; 2080s:2071-2100) under two different climate scenarios (SRES A2 and B2) and compared to the average yields during the baseline period (1961-1990).The results showed that under both climate scenarios, potential yields would decrease relative to the baseline average. Specifically, under A2 decreases of 3%、8.6%, 7.7% were projected respectively for the 2020s, 2050s and 2080s; under B2 these would be 3.1%、6.9%, 10.5%.

Historical yields

Figure A2. 1 shows a time series of yearly yield of spring wheat for 20 counties in Ningxia for 1981-2000. In a year yearly yield was not recorded down, so average yield was in which yields were recorded each year. In the figure yearly yields is different in different regions divided north, Yinchuan, center, south region of Ningxia. In north, Yinchuan, and most regions included the Yellow River irrigation areas of the center, yearly average yield is higher than in south region. Most regions included the Yellow River irrigation of the center yearly average yield for twenty years was the highest in all regions of Ningxia, the lowest and the highest yield was 4605 kg/ha ~5507kg/ha,in Yinchuan region, it was 4316 kg/ha ~5267kg/ha, in the northern region, it was 4297 kg/ha ~5018kg/ha. In south region it was 927 kg/ha ~2754kg/ha.

Figure A2. 1 Yearly yield of spring wheat in four regions of Ningxia (North, Yinchuan、Center、South) from 1981 to 2000 for 20 counties



Methodology: Model description, Validation/calibration

Data

Our main aim is to simulate the variability of wheat yield for the past twenty years, so we investigate the relationship between potential simulated yields and measured yields. We choose Yongning county as the test site. During 1981-2000 crop cultivar in this county has changed four times. In 1981 and 1982 the wheat cultivar MoKa was planted; from 1983 to 1985 W3 was used; from 1986 to 1991 this was replaced with Yongliang No.4; from 1992 to 1993 a new cultivar called Yongliang No.12 was planted instead. From 1994 to 2000 the same crop cultivar as in 1986 to 1991, Yongliang No.4, was reinstated.

In order to calibrate the CERES-Wheat model we choose the wheat cultivar Yongliang No.4 planted for the longest time, namely in 1986-1991 and 1996-2000, and identified the crop coefficients for this wheat to use in the model.

We collected most data associated with model, including experiment details to simulate potential yearly yield for eleven years from 1986-1991 and 1996-2000.

The following inputs were prepared: experiment details, cultivar coefficients, weather data, soil data and observed plant growth data.

Adjusting crop coefficients

Identifying the cultivar coefficient of each year, we used minimization of the sum of square of errors (Hoogenboom,G. et al.1999) to identify coefficients. We calculated the sum of squares (SS) of seven basic variables (flowering date, maturity date, grain yield, biomass at maturity, grain number, grain number per spike, grain weight). We identified a set of optimal coefficients when SS reached the minimum value. SS is given by Equation 1 below:

$$SS = (simY1-obsY1)^2 + . . . + (simY_i-obsY_i)^2 \qquad (1)$$

Where Y_i is one of the seven variables, sim is simulation value, obs is observation value.

Rather than randomly changing various parameters, we sought to reduce the number of degrees of freedom by knowing the expected range of parameter values, as well as which parameters are really the most important to change.

By iterative calculation and calculating sum of squares of minimum of seven basic variables, we obtained the coefficient of the past eight years.

We chose the same crop cultivar that was planted for the longest period: Yongliang No.4, used from 1986 to 2000.

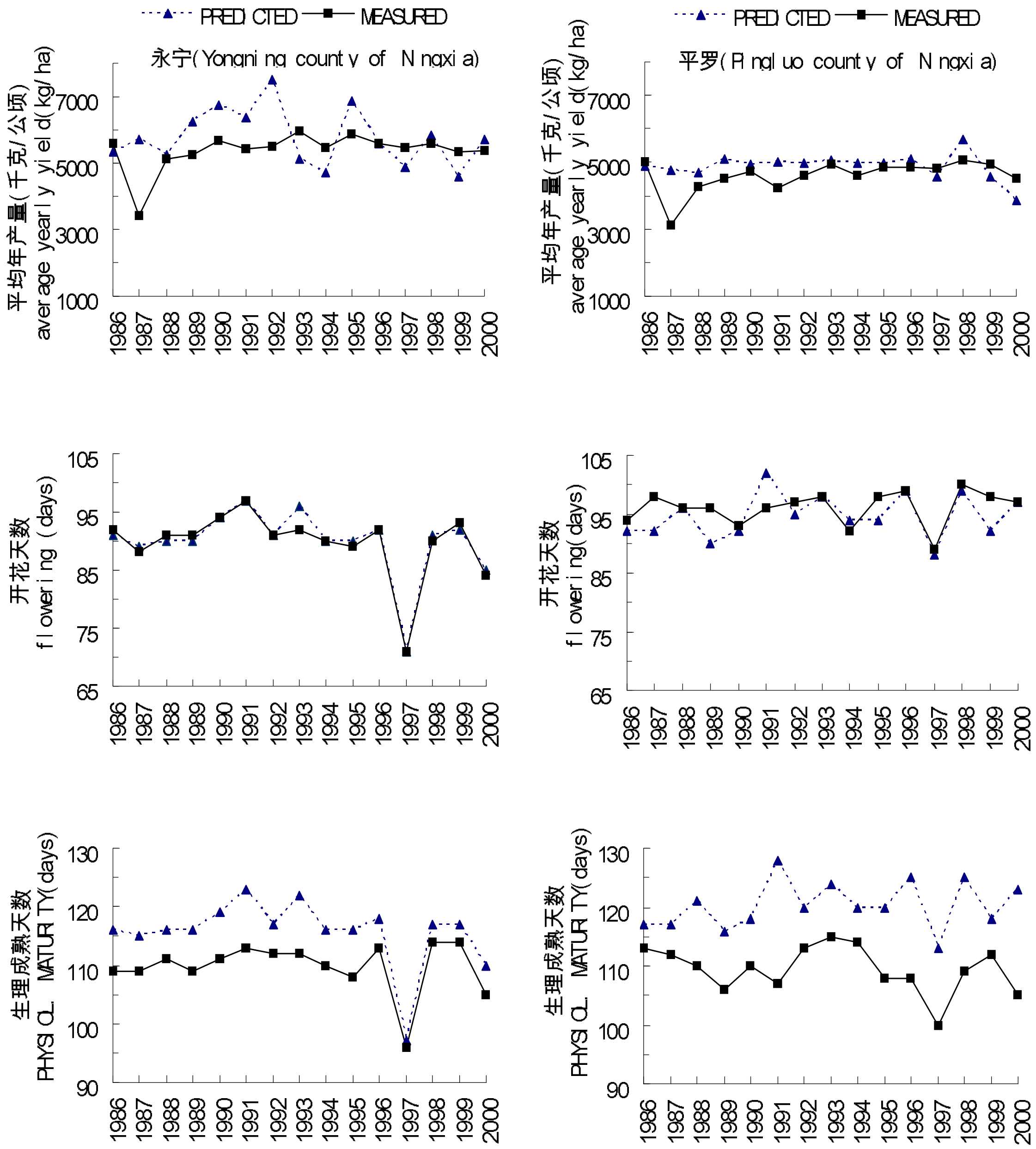
The results of our simulations were very good for flowering date, grain number(/m2), but not so good for other ones including potential yield in some years. Especially in 1987 most counties in Ningxia produced the lowest yield in the period 1981 to 2000. This was because of the impact of extreme weather.

Spatial adjustment for coefficients

Once the model coefficients were determined on the basis of experiments in Yinchuan, we used them for a different county – Pingluo county – on same cultivar Yongliang 4 spring wheat for some historical experiments to test yield. Firstly, by iterative calculation program, searched its appropriate coefficients in order to keep the best approach during real yields and simulated potential yields, and then compared with Yinchuan's coefficients, adjusted to approach real yield as possible. The rule that coefficients were decided was to accord formular (1), choose minimum value SS through many times tests, and then simulated other years of Pingluo county.

Figure A2. 2 shows simulation results of potential yields on Yinchuan and Pingluo counties for 15 years(1986-2000). Using the method, we simulated potential yield in the Yellow River irrigation grids (25km×25km) for the baseline period (1961-1990), and under the SRES A2 and B2 climate scenarios to 2100.

Figure A2. 2 Observed (black) and simulated (blue) growth stage characters and potential yields on No.4 Yongliang spring-wheat in two different counties in Ningxia (Yongning – left; and Pingluo – right)



Error analysis

Calculating the mean percentage error (MPE), a root mean square difference (RMSD), mean bias error (MBE), we analyzed error above simulation results as showed in Table A2. 1. Predicted average potential yields for 15 years were higher than real yields in two counties, namely 400kg/ha and 271kg/ha in Yongning and Pingluo counties respectively. The simulated anthesis date was one day later than the real date in Pingluo; the simulated date coincided with the real date in Yongning. The simulated maturity date (physiological) was 6-11 days later than the real date in both counties. According to MPE error analyses, average errors were lower than 20% for prediction results of three types for 15 years. This was considered to be an acceptable error range.

Table A2. 1 Comparison of observation and simulation error about potential yields and following days and physiological maturity days for Yongning and Pingluo counties for 1986-2000.

county name		predicted	measured	MPE(%)	RMSD	MBE
Yongning	potential yield(kg/ha)	5770	5375	16.5	1029.3	388.4
	flowering(days)	90	90	0.9	1.3	0.7
	Physiol. maturity(days)	116	110	5.4	6.4	6.0
Pingluo	potential yield(kg/ha)	4872	4601	11.2	599.2	245.2
	flowering(days)	95	96	2.6	3.4	-1.5
	Physiol. maturity(days)	120	109	10.0	12.0	10.5

Control level of irrigation and fertilizer in experiments

After crop coefficients were decided and used in yield simulation of the future 100 years, control level of irrigation and fertilizer was applied (Table A2. 2).

Table A2. 2 Fertilization application and irrigation control level in experiment file

control lever of irrigation and fertilizer in experiment			
irrigation times	irrigation date	fertilizer times	fertilizer date
1	tillering irrigation(26 Apr.)	1	the end of Feb.or the first of Mar.
2	node irrigation(12 May)	2	the end of Apr.or the first of May
3	anthesis irrigation(1 Jue.)		
4	ripening irrigation(24 Jue.)		

Impacts: Simulation results of the Yellow River irrigation region of Ningxia for 59 grids (25km×25km)

Change of yield and variability on the Yellow River irrigation region

Potential yields were simulated on the Yellow River irrigation region of Ningxia for 59 grids (25km×25km) by applying CERES-wheat model under three climate scenarios, called BS (baseline)、A2 (medium-high emissions, radiation about 1%)、B2 (medium-low emissions, radiation about 0.5%). Simulated yields under the A2 and B2 scenarios for the 2020s, 2050s and 2080s were compared to the average over the period 1961-1990. The simulations project a markedly decreasing trend in yields: whilst the average yield in the baseline period (1961-1990) was 6234kg/ha, under the A2 scenario, the average yields projected are 6045kg/ha (2020s)、5697kg/ha (2050s) and 5128kg/ha (2080s); under the B2 scenario, these are 6038kg/ha (2020s)、5803kg/ha (2050s)、5577kg/ha (2080s). These correspond to decreases of 3%、8.6%、17.7% under A2, and of 3.1%、6.9%、10.5% under B2. Simulation results of potential yields are shown in Figure A2. 3、Figure A2. 4 and Figure A2. 5. Figure A2. 6 and Figure A2. 7 show the mean percentage error in potential yield under the A2 and the B2 climate scenarios respectively, for the 2020s, 2050s and 2080s.

Figure A2. 3 Potential yields of 59 grids (25km×25km) in Huanghe irrigation region of Ningxia for the baseline period (1961-1990)

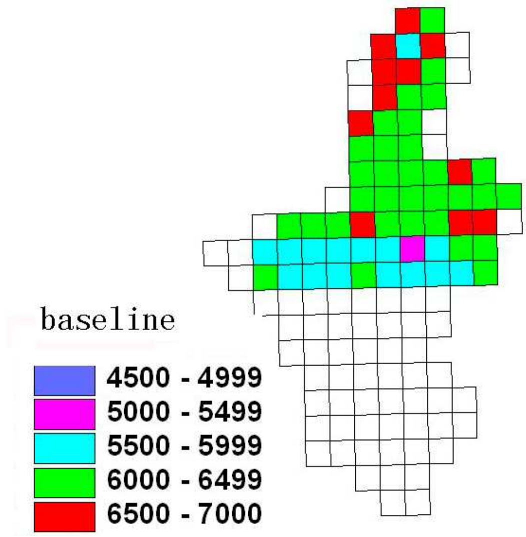


Figure A2. 4 Potential yields of 59 grids (25km×25km) in Huanghe irrigation region of Ningxia under A2 (left: 2020s; centre: 2050s; right: 2080s)

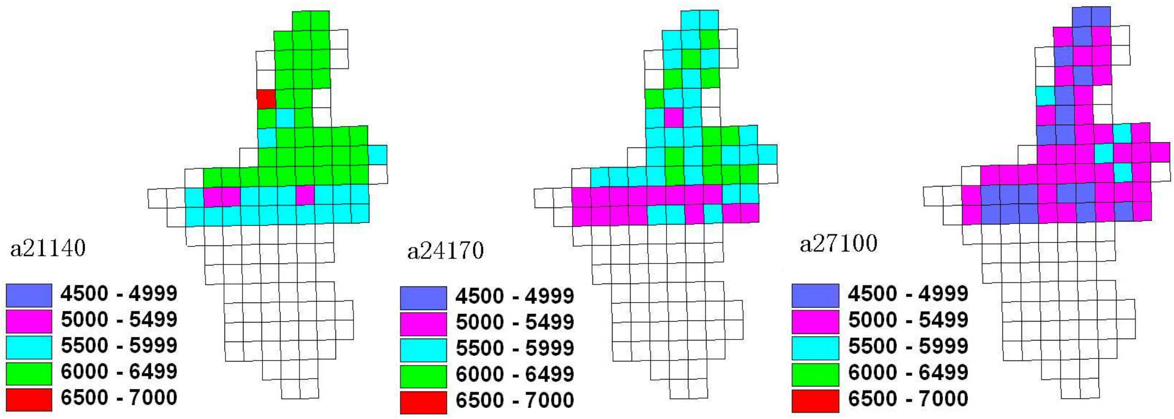


Figure A2. 5 Potential yields of 59 grids (25km×25km) in Huanghe irrigation region of Ningxia under B2 (left: 2020s; centre: 2050s; right: 2080s)

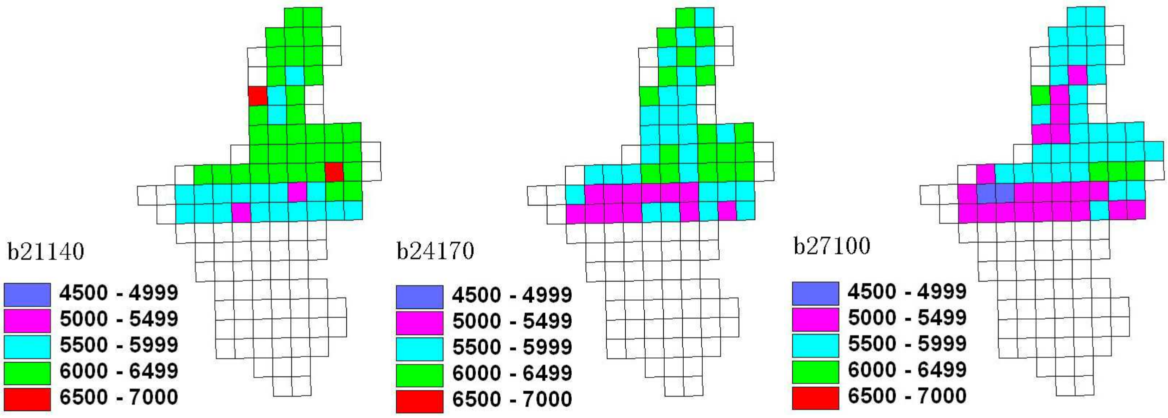


Figure A2. 6 Mean percentage error of potential yields of 59 grids (25km×25km) on Huanghe irrigation region of Ningxia under A2 (left: 2020s; centre: 2050s; right: 2080s)

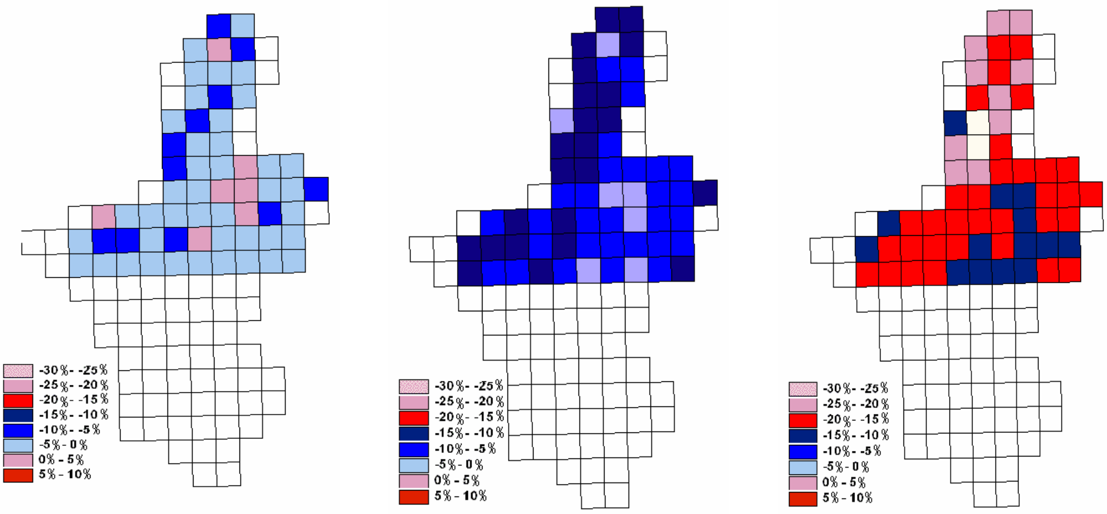


Figure A2. 7 Mean percentage error of potential yields of 59 grids (25km×25km) in Huanghe irrigation region of Ningxia under B2 (left: 2020s; centre: 2050s; right: 2080s)

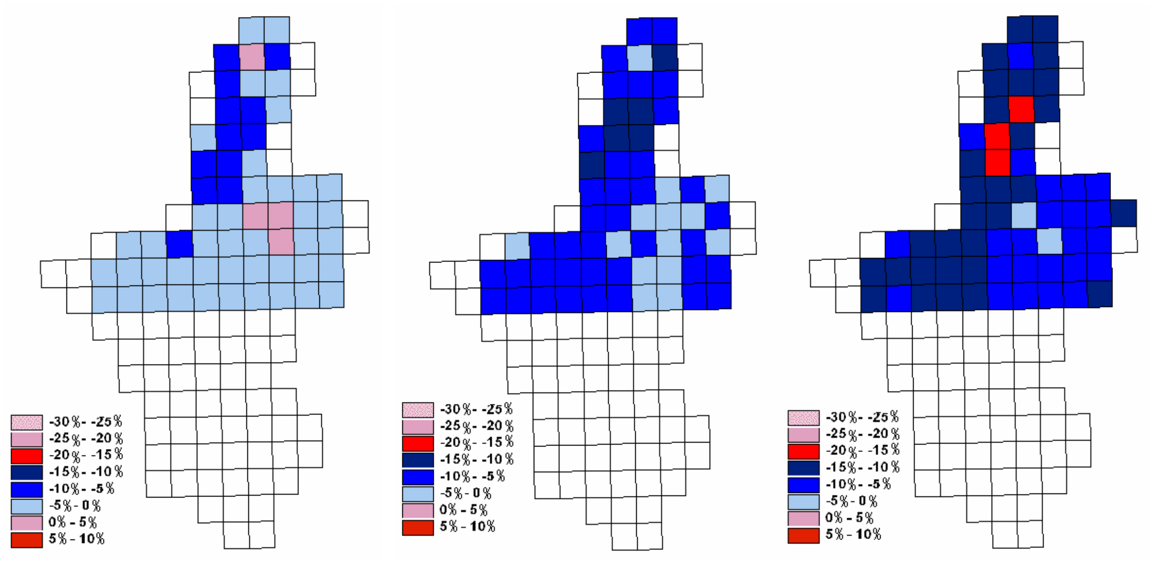


Figure A2. 8 and Figure A2. 9 show the variability rate of potential yields under the SRES A2 and B2 climate scenarios for the 2020s, 2050s and 2080s. The variability rate in any one year *n* is computed as the difference between the yearly yield in that year (Y_n) and the average yearly yield in 1961-1990 (Y_{BS}), divided by the mean yield in the baseline period. In mathematical form, this is:

$$VR = \left(\frac{Y_n - Y_{BS}}{Y_{BS}} \right)$$

Positive variability rate indicates that future yields are projected to be over and above the average yearly yield in the period 1961-1990; negative variability means that future yields are projected to be below the baseline average.

Grid cells for which the average yield for 1961-1990 was not available are left uncoloured in Figure A2. 4 to Figure A2. 9.

Figure A2. 8 Variability rate of potential yields of 59 grids (25km×25km) on Huanghe irrigation region of Ningxia under A2 (left: 2020s; centre: 2050s; right: 2080s)

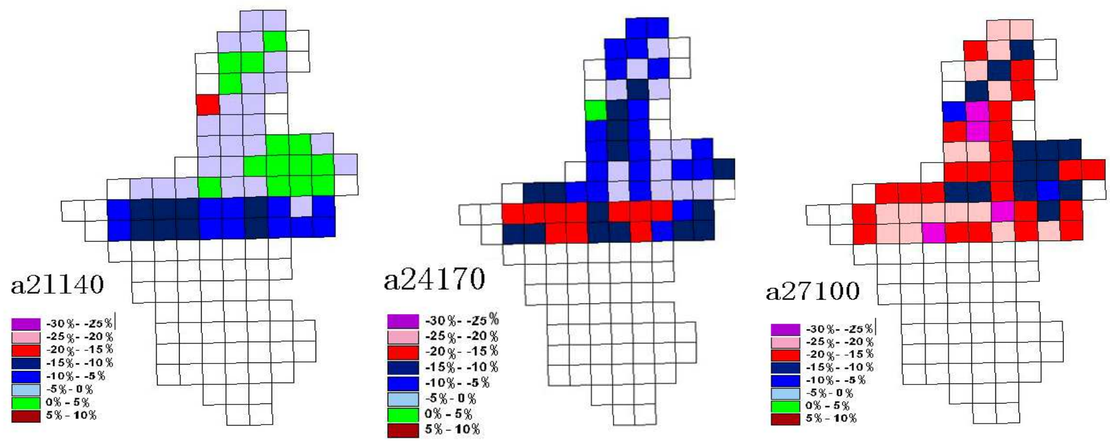
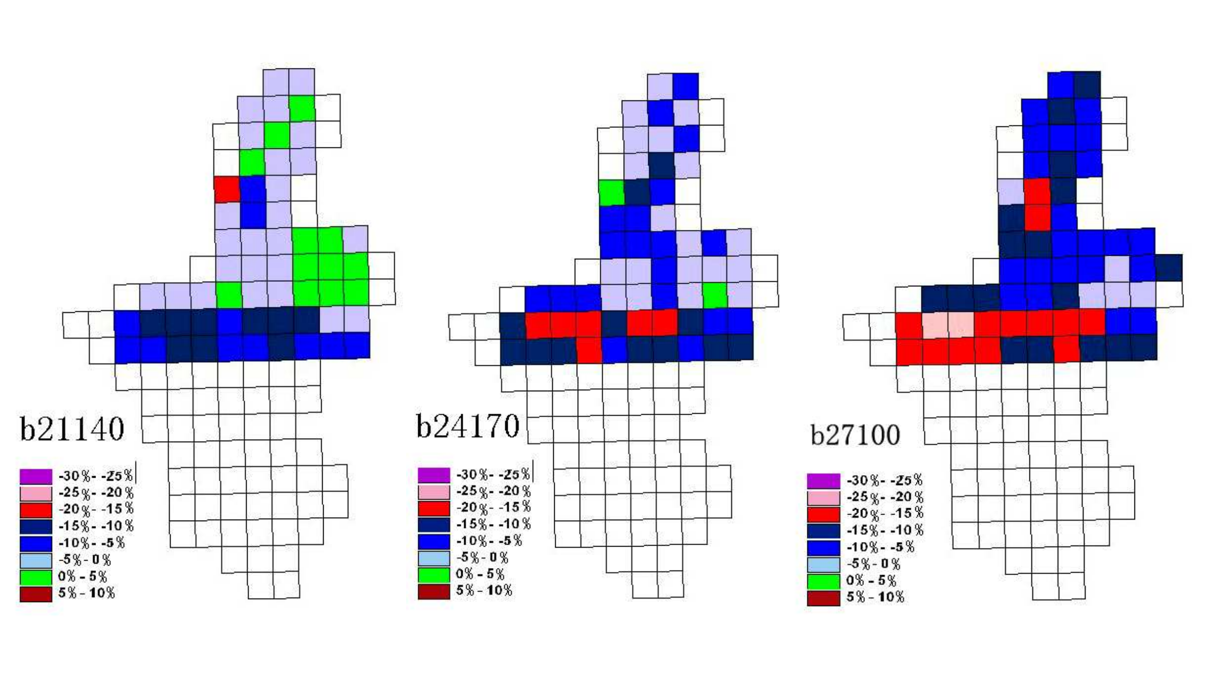


Figure A2. 9 Variability rate of potential yields of 59 grids (25km×25km)on Huanghe irrigation region of Ningxia under B2 (left:2020s; centre: 2050s; right: 2080s)



Change in growth stage and evapotranspiration

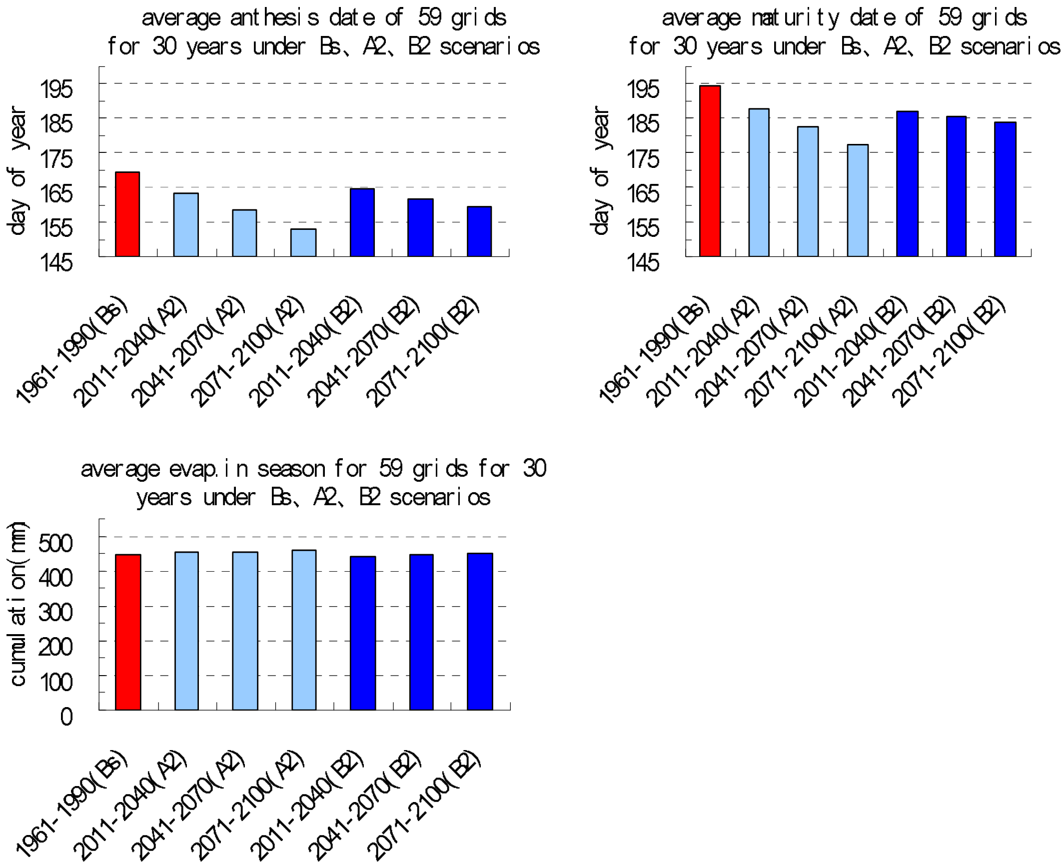
We simulate anthesis and maturity date and total evapotranspiration in season for the baseline period (1961-1990) and two future scenarios (A2 and B2) for the Yellow River irrigation region of Ningxia for 59 grids (25km×25km). The results show that under the three climate scenarios growth length range is 22-25 days from anthesis to maturity (physiological) date. For the baseline period (1961-1990) the growth length period was 25 days; under the A2 scenario, the growth length period is projected to remain unchanged in the 2020s and 2050s, and to decrease to 24 days for the 2080s. In contrast, under B2 the growth length is projected to be 22 days for the 2020s, 24 days for the 2050s and 25 days for the 2080s. Under the A2 scenario, the anthesis date occurs 6, 11 and 16 days earlier than during the baseline period for the 2020s, 2050s and 2080s respectively; and the maturity (physiological) date is projected to occur 6, 11, 17 days earlier for the 2020s, 2050s and 2080s respectively. Under B2, the anthesis date is projected to occur 4, 7, 10 days earlier than during the baseline period, and the maturity date is projected to be brought forward by 7, 8, 10 days in the 2020s, 2050s and 2080s respectively.

The average total evapotranspiration in season in 59 grids in 1961-1990 was 446mm. Under the A2 scenario, evapotranspiration in season is projected to increase by 7mm (2020s), 10mm (2050s) and 13mm (2080s). Accordingly, there is a slight increasing trend. Under the B2 scenario, virtually no changes occur in the 2020s and 2050s relative to the baseline period, with evapotranspiration totalling about 444mm-446mm. In the 2080s, evapotranspiration increases marginally relative to the 1961-1990 average, reaching up to 450mm for the whole season. Table A2. 3 and Figure A2. 10 reflect these results.

Table A2. 3 Average value of anthesis and maturity date and evapotranspiration in season for the baseline period (1961-1990) and under the A2 and B2 scenarios for 59 grids in the Yellow River irrigation region of Ningxia

	Baseline	A2 scenario			B2 scenario		
	1961-1990	2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100
anthesis date	169(18 Jun)	163(12 Jun)	158(7 Jun)	153(2 Jun)	165(14 Jun)	162(11 Jun)	159(8 Jun)
maturity date	194(13 Jul.)	188(7 Jul.)	183(2 Jul.)	177(26 Jun)	187(6 Jul.)	186(5 Jul.)	184(3 Jul.)
evapotranspiration(mm)	446	453	456	459	444	445	450

Figure A2. 10 Simulated anthesis and maturity date and evapotranspiration in season for the baseline period (1961-1990) and under the A2 and the B2 scenario for 59 grids in the Yellow River irrigation region of Ningxia



Conclusions

Potential yield of spring wheat was simulated with CERES-wheat model in DSSAT3.5 crop model. The simulation results indicate a decreasing trend in spring wheat yields in the Yellow River irrigation region of Ningxia province under both the A2 (medium-high emissions) and the B2 (medium-low emissions) climate scenarios relative to the average yields in 1961-1990. The reductions in yields are more acute/rapid under A2 than under B2. Anthesis and maturity (physiological) date under A2、B2 are projected to occur earlier than in the baseline period. Growth length period (from anthesis date to maturity (physiological) date) was 22-25 days. Under the B2 scenario, the growth length period is shortened by 1-3 days relative to the average 25 days in 1961-1990. Average total evapotranspiration in season is projected to increase, albeit little, in the 2020s, 2050s and 2080s under A2. Under B2, meanwhile, average total evapotranspiration is mostly projected to remain unchanged, with the most significant increase, for the 2080s, totalling only 5mm over and above the baseline level of 446mm.

None of the above results include the potentially devastating effects of disease and pests during the growth stages. Furthering the understanding of these factors, and incorporating them into crop models will be essential for an improved understanding of future conditions.

Appendix 3

The Impacts of Climate Change on Rice Yields in Ningxia

Authors: Liu Jing (Ningxia Meteorological Institute. Yinchuan, Ningxia, China. 750002) and Ma Liwen (Ningxia observatory. Yinchuan, Ningxia, China. 750002)

Debugging the genotype

Based on the rice agrometeorological data observed from 1981 to 2000 in Yongning, the local rice genotype parameters are debugged. Aimed at the rice yield, growing stage, spica and grain proportion and LAI, all the parameters of different varieties are adjusted under the recorded data of water management, fertilizer and planting details. Among those eight varieties, the best genotypes are Jingyin 39, Ningjing 9 and Ningjing 16 which have been planted for many years. Besides reflecting normal climate conditions, the high accordance between yield simulation and observation is showed in Figure A3. 1 on that yearly simulation of extra high and low yield are reappeared on high temperature and cool damage respectively. The average error, showed in Figure A3.2, is only 0.19% that average yield simulated from 1981-2000 is 9134kg/ha and the average yield in the same period is 9117kg/ha. The heading date simulated is also accordance with observation which is showed in Figure A3. 3 that the average and maximum error are 0 and 4 days respectively.

In order to verify the simulation's accuracy, the yield series of Zhongwei from 1981-2000 was also simulated by the same genotype. The results show that both the tendency of simulated yield and the heading date are coped with the observation data. In addition, those genotypes are suitable for simulating rice growing stage, maximum LAI, panicle and grain number, leaf number etc.

Figure A3. 1 The simulation of rice yield by genotype tests using experimental data in Yongning from 1981-2000

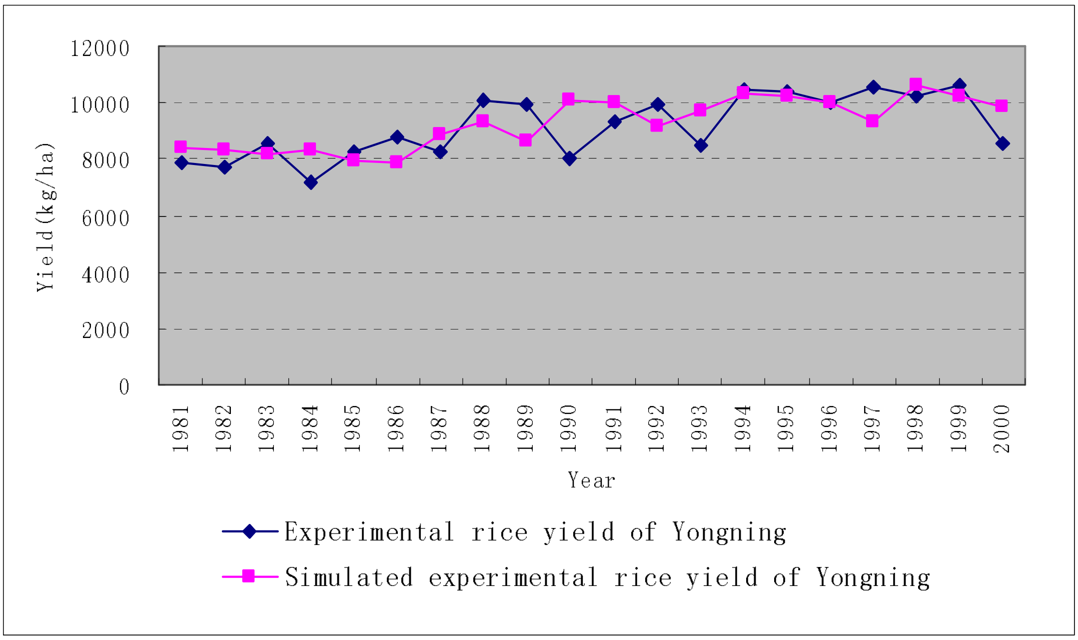


Figure A3. 2 The simulation of rice yield by genotype tests using authoritative statistical data in Yongning from 1981-2000

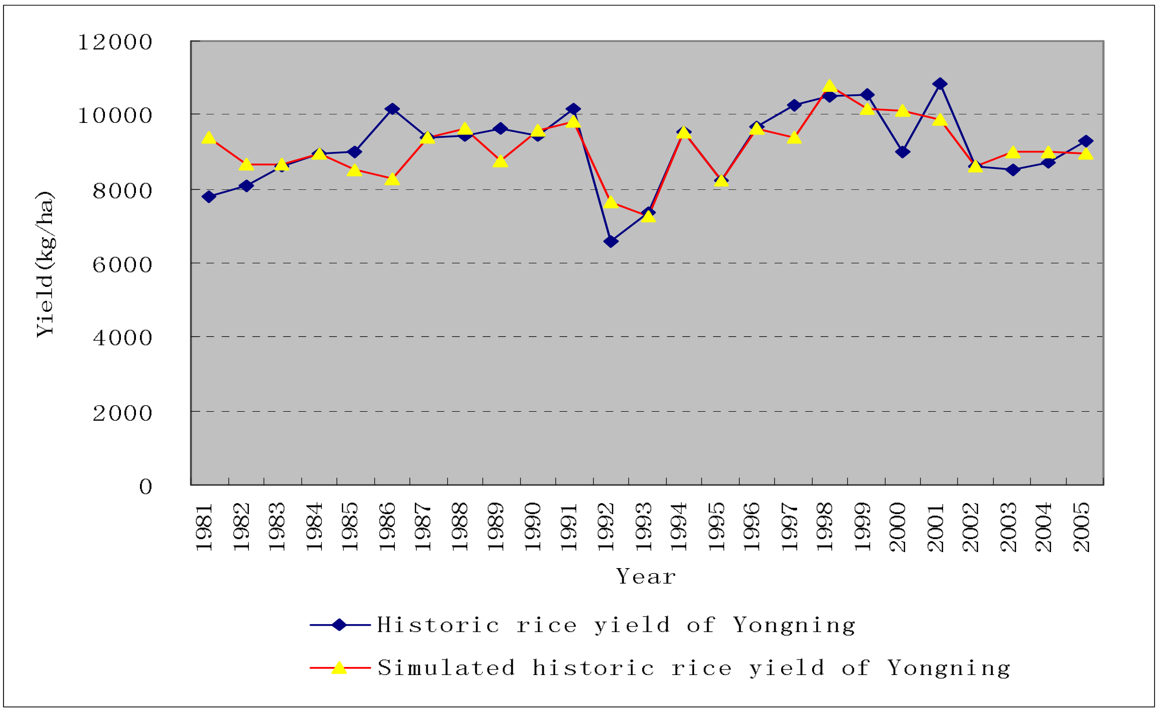
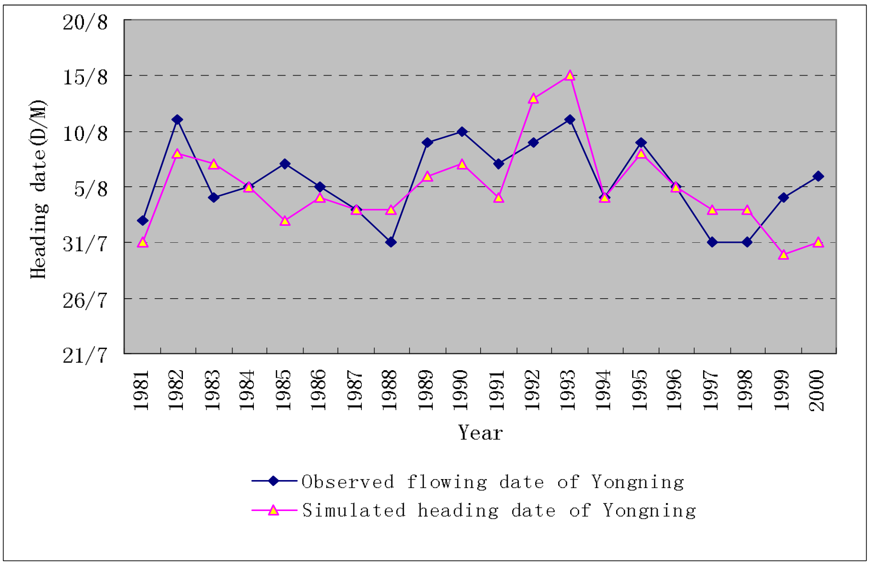


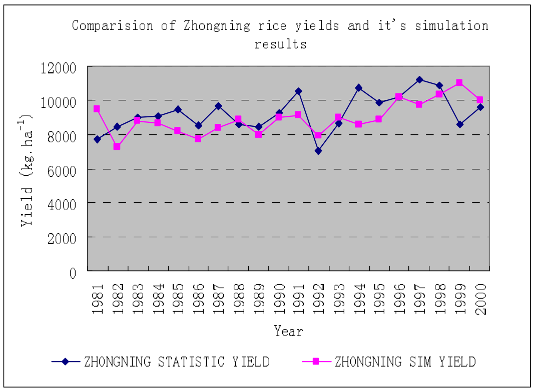
Figure A3. 3 The annual heading date simulation from 1981-2000 in Yongning



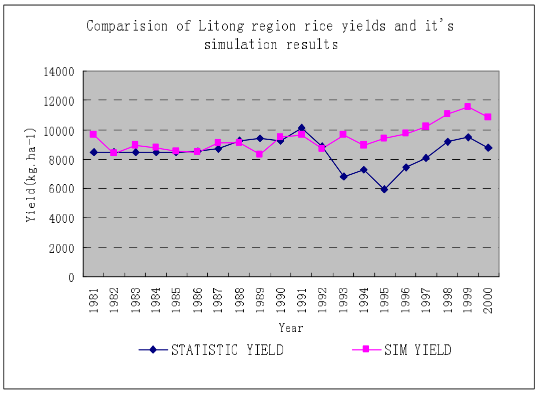
Historic rice yield simulation results

In the interest of the suitability and feasibility of genotype parameters on rice yield regional simulation influenced by the climate change, the Ningxia regional rice growth, shown in Figure A3. 4, is simulated by parameters of genotype selected. In the traditional rice transplanting areas such as Zhongning, Qingtongxia, Yongning and Lingwu, the simulated yield curves are highly coherent with that of the statistical data except Wuzhong from 1993 due to changes to this administrative region and lower fertilised field was transplanted in southern area. The rice yields simulated in Yinchuan, Helan, Pingluo and Huinong are higher than statistical yield because those cities and counties are planted both in the way of transplanting and seeding by which the seeding yields are lower than transplanting one. But the tendency is the same. All the results indicated that those genotype parameters meet the requirement in simulating the influence on regional rice production under climate change.

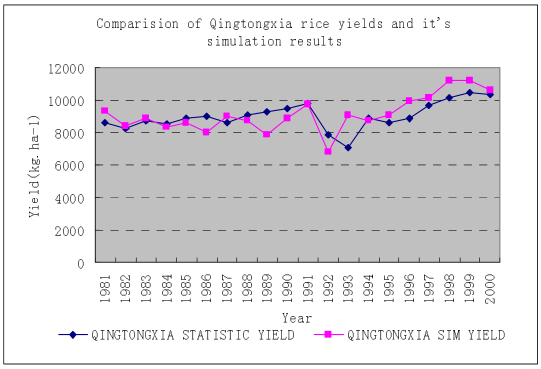
Figure A3. 4 Comparison of rice yield simulated and statistic in different regions of Ningxia



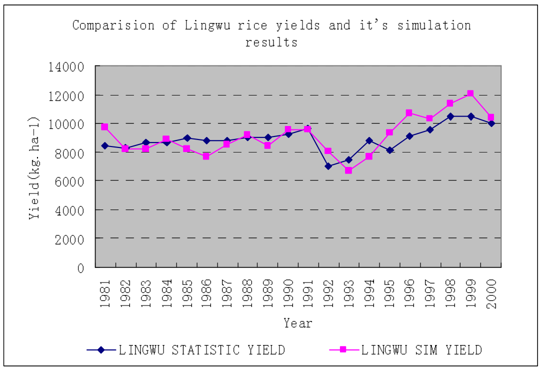
a. Zhongning



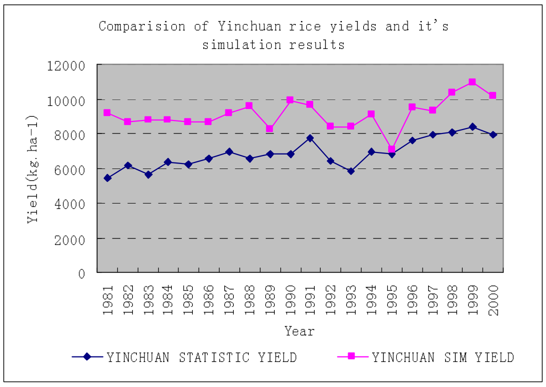
b. Litong



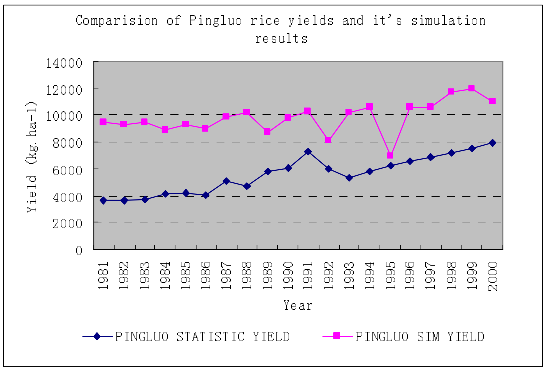
c. Qinggtongxia



d. Lingwu



d. Yinchuan



f. Pingluo

Rice yields during the baseline period (1961-1990)

Considering the CO_2 change in the atmosphere from 1961-1990, the CO_2 in each year is introduced in every experiment file, and the rice model is run assuming normal management, including the same water irrigation, fertilizer schedule, transplanting date and population etc. The average regional rice yields in baseline years are shown in Figure A3. 5. Since the advance of agricultural technology, e.g. in fertility level, variety updating, technological progress, fertilisation and irrigation improvement, the regional rice yield has increased from 2000-3000kg/ha in the 1960s, to 4000-6500kg/ha in the 1970s and 8000-9000kg/ha in 1980s respectively. Thus, it is not comparable to simulated yield in mono variety, with same management, but the latter can reflect the yield loss in lower temperature years such as 1976 and 1979. After the yields are filtered by orthogonal polynomial, the adjusted yields are obtained by adding the difference between yields, and yield tends to the average yield from 1981-1990. Thus, the regional rice yield is adjusted to average level so as to smooth yield tends with time went by. The adjusted yield curve corresponds to the simulated yields both in observation weather data and in predicted weather data by PRECIS, especially in lower or higher temperature years which cause yield decrease or increase. There is no doubt that the modelling on baseline years is reasonable. It meets the requirement for estimating the influence of future climate change on rice production.

Figure A3. 5 Comparison of average rice yield in Ningxia simulated and statistic one in baseline years.

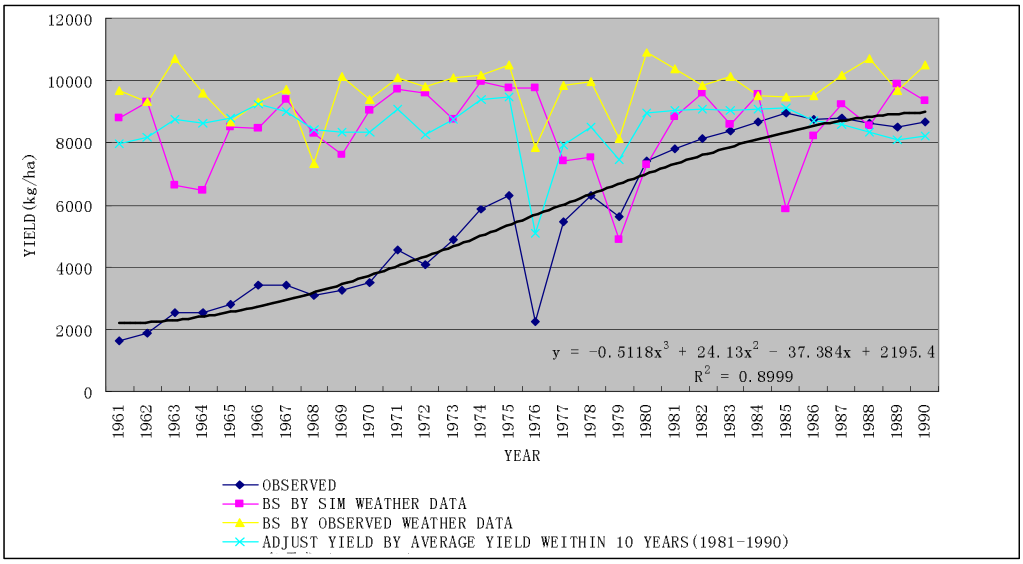


Figure A3. 6 Simulating the rice regional average heading and mature days from transplanting date during the baseline period (1961-1990)

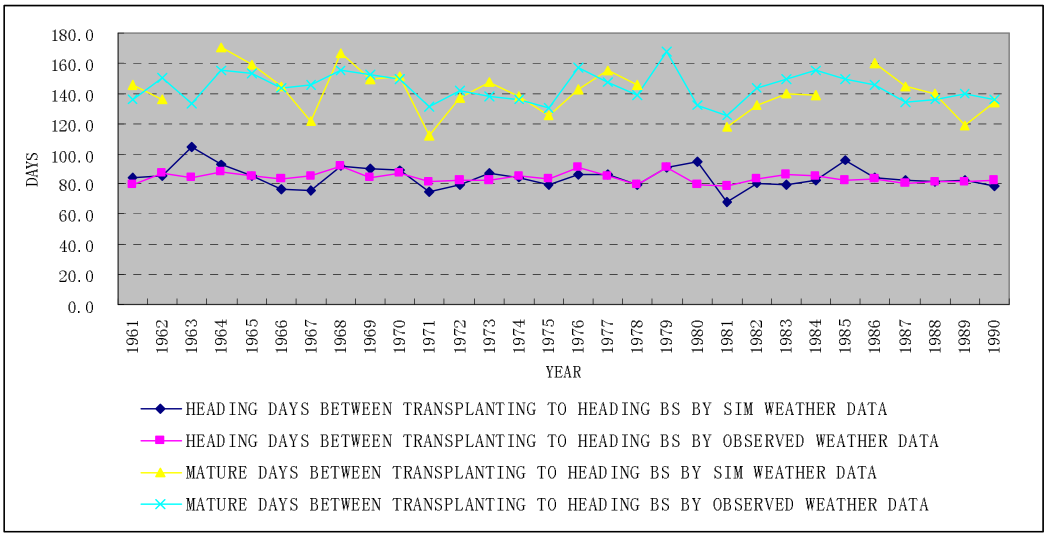


Figure A3. 6 shows the observed and simulated days from transplanting date to heading and mature date for the baseline period. Simulations are adjusted to PRECIS weather data in baseline years. As the climate warms, both heading and maturing occur at an earlier date, and there is good accordance between the results of the simulation and experimental data in 1981-1990.

Future rice yields under the A2 and B2 climate scenarios

According to geography factors, the weather prediction of PRECIS in A2 and B2 CO_2 discharged situation from 2001-2100 is adjusted to every weather station in Ningxia. Considering soil type, nutrition in each spot and regular management, such as transplant population, date, water irrigation management, fertilizer, as well as considering the photosynthesis efficiency by CO_2 discharge in each experiment every year, the predicted rice yields and growing stage of Ningjing16 variety are simulated in A2, B2 situation from 2001-2100 in each county of Ningxia. The results are divided to 1991-2010, 2011-2040, 2041-2070 and 2071-2100 to compare with the baseline years. (Shown in Table A3. 1).

Table A3. 1 Regional rice yields under the SRES A2 and B2 scenarios to 2100

YEAR	P-A DAYS		P-M DAYS		YIELD(kg/ha)	
	A2	B2	A2	B2	A2	B2
1961-1990	84.1	84.1	142.9	142.9	9707	9707
1991-2010	78.5	79.5	129.9	132.3	10369	10102
2011-2040	74.1	75.0	120.8	125.1	10789	10556
2041-2070	66.8	69.8	104.8	111.7	10695	10620
2071-2100	58.9	65.8	92.6	104.2	10566	10565
PERCENTAGE(%)						
1961-1990	0	0	0	0	0	0
1991-2010	-6.7	-5.4	-9.1	-7.4	6.8	4.1
2011-2040	-11.8	-10.8	-15.5	-12.4	11.2	8.7
2041-2070	-20.6	-17.0	-26.7	-21.8	10.2	9.4
2071-2100	-29.9	-21.8	-35.2	-27.1	8.9	8.8

Conclusions

The results under the SRES A2 and B2 scenarios show that the average regional yield is projected to increase to 10,000kg/ha from current levels. Further, the growth length period is projected to decrease as compared to current. Compare with baseline years (1961-1990), under the A2 emissions scenario, the average regional rice yield is projected to reach 10,789kg/ha in the 2020s (representing a +11.2% increase relative to current levels), 10,695kg/ha in the 2050s (an increase of +10.2% relative to today), and to 10,566kg/ha in the 2080s (an increase of 8.9% relative to today). In contrast, the increases in rice yield under the B2 emissions scenario are projected to be smaller than those under A2: namely 10,566kg/ha in the 2020s (representing a +8.7% increase), 10,620kg/ha in the 2050s (representing an increase of +9.4% relative to today's levels), and 10,565kg/ha in the 2080s (+ 8.8% increase relative to today).

Under the A2 scenario, the average heading days will change from 74.1 on average in 1961-1990 to 84.1 days in 2011-2040 (2020s). The mature days in this period is projected to total 120.8 days, 22.1 days less than the average during the baseline period. In the 2050s (2041-2070), the heading and mature days are projected to be 66.8 and 104.8 days respectively, i.e. 17.3 and 38.1 days shorter than they were, on average, during the baseline period. In the 2080s (2071-2100), the heading and mature days will be 58.9 and 92.6 days respectively, 25.2 and 50.3 days shorter than in the average year in 1961-1990.

Under the B2 scenario, in the 2020s (2011-2040), the average heading and mature days will shorten to 79.5 and 125.1 days respectively, 4.6 and 17.8 days ahead than that in baseline years. In the 2050s (2041-2070), the heading and mature days will be 69.8 and 31.2 days, 14.3 and 31.2 days shorter than baseline years respectively. And in the 2080s (2071-2100), the heading and mature days are projected to be 65.8 and 104.2 days, 18.3 and 38.7 days before the days in baseline years.

Appendix 4

The Impacts of Climate Change on Potato Yields in Ningxia

Author: Li Jianping

Abstract

We combine the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) emissions scenarios A2 and B2 with PRECIS and the SUBSTOR-POTATO model to model changes in potato yield in Ningxia in the 2020s (2011-2040), 2050s (2041-2070), 2080s (2071-2100). Our results show that total potato yields in Ningxia are projected to decrease under both the A2 and the B2 scenarios.

Key words: climatic change; Ningxia; potato; simulation

Introduction

Potato is grown essentially in central and southern in Ningxia (Figure A4. 1).

Figure A4. 1 Proportional distribution of county potato cultivation areas across Ningxia before and after 2000.

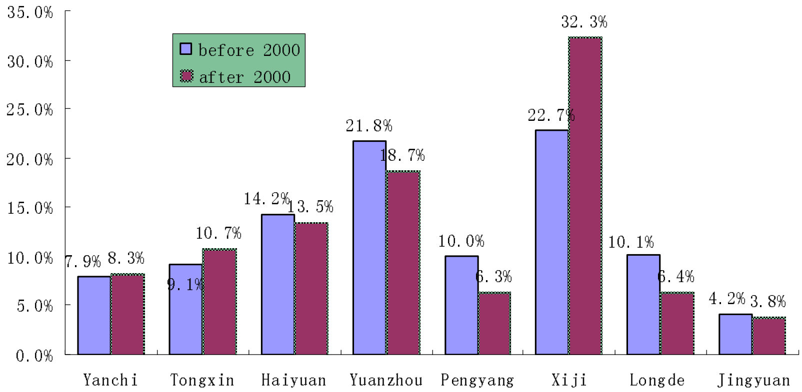


Figure A4. 2 The proportions of potato areas of the food crops

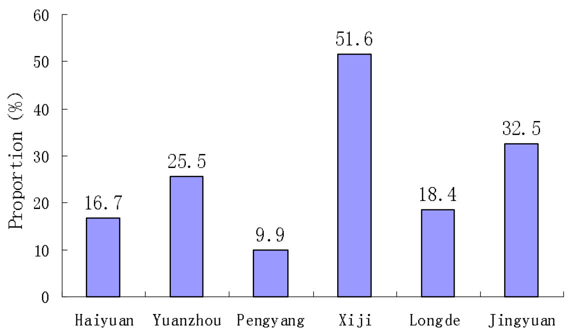
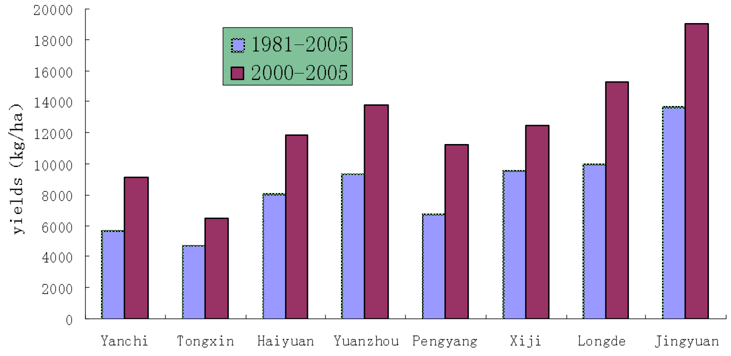
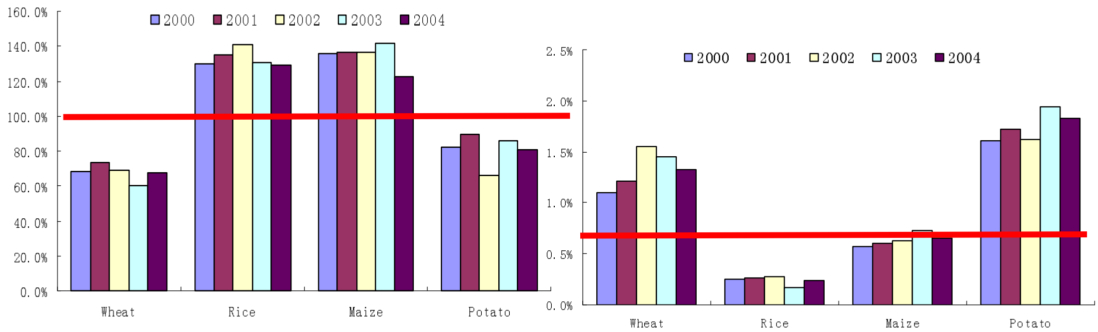


Figure A4. 3 Average potato yields in different counties 1981-2005 (blue) and 2000-2005 (purple)



Ningxia potato yield is 60% - 80% of Chinese average. Comparing wheat and potato yield of Ningxia mountain region, potato yield is five times beyond wheat's.

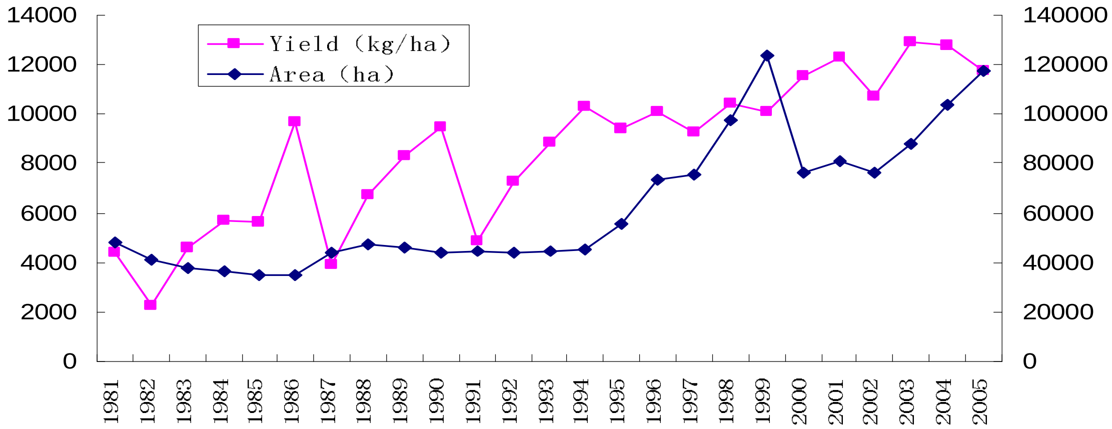
Figure A4. 4 Left: Potato yield in Ningxia as compared with China's average yield (the latter in red); and right: potato area level in Ningxia as compared to the national level (the latter in red)



Ningxia potato yield increased between 1981 and 2005, with an average annual increment of 362kg/hm.

Potato area variability is 36.8% and yield's is 29.6% for 25 years. So potato yield is more stable than area.

Figure A4. 5 Potato Yield and Area Change from 1981 to 2005 in Ningxia



Methodology: model description, validation, calibration)

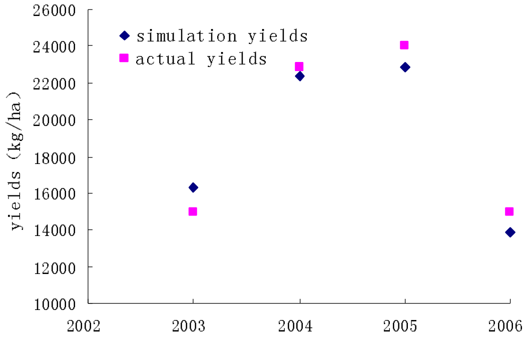
SUBSTOR potato model

The SUBSTOR potato model integrates empirical and mechanistic sub-models to predict potato growth, development, and yield as a function of climate, field, management, and genetic factors. Five cultivar–specific genetic coefficients affect development rates, organ growth, and plant ontology: TC, P2, PD,G3, and G2.TC is a genetic coefficient for vegetative growth sensitivity to air temperature (unitless, 0 to 1), P2 is for cultivar sensitivity to of photoperiod (unitless, 0 to 1), PD is for determinacy (unitless, 0 to 1), G2 is for leaf expansion rate (cm^2 m–2 d–1) and G3 is for maximum tuber–bulking growth rate (g plant–1 d–1).

Calibration and validation of SUBSTOR using experimental data

Using experimental data, meteorology data and soil data of Yuan Zhou County from 2003 to 2006, we calibrate the genetic coefficients by trial and error method.

Figure A4. 6 Left: Simulated (blue) and actual (pink) yield; Right: Simulated (blue) and actual (pink) mature date



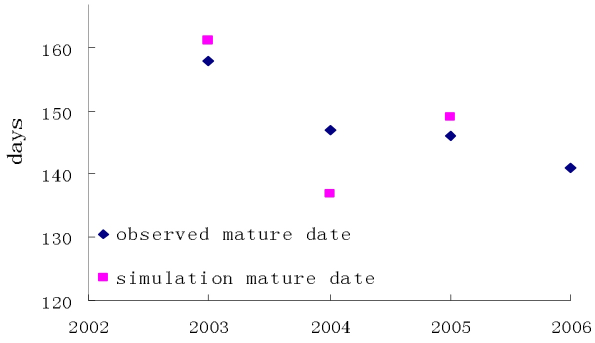
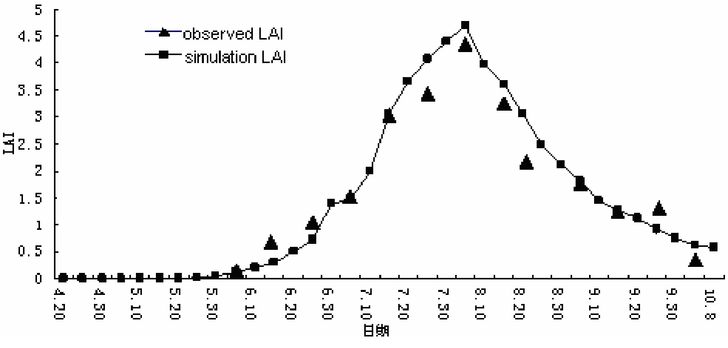
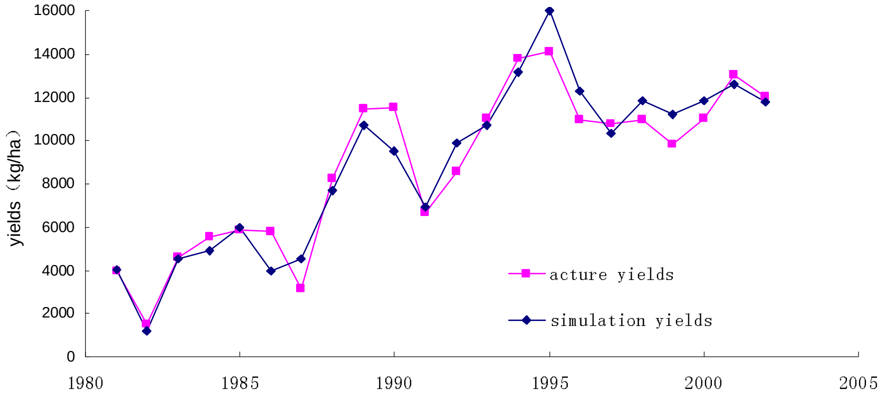


Figure A4. 7 Simulation LAI and Observed LAI



Interval is 56 to 69 days from planting to tuber initial growth and 129 to 171 from planting to mature. This conform to actual situation of Ningxia

Figure A4. 8 Simulation and actual yield from 1981-2005



Climate change impacts

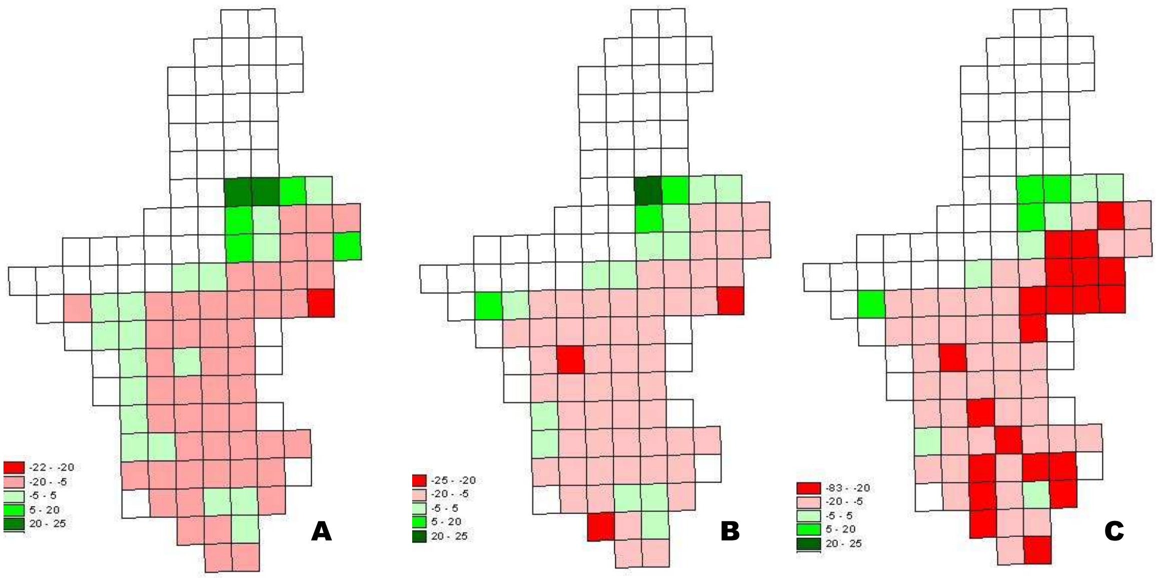
Climate change impacts on potato single yield by modelling

The SUBSTOR was driven by PRECIS output to predict changes in yields of potato on a desktop PC; these changes were then applied to all sowing areas of Ningxia to generate detailed crop predictions on a 25×25 km grid scale. Select 75 grids in main region of potato planting in Ningxia to study climate change impacts on potato. The modelling results show that, if current planting and field management practices remain unchanged, potato yield in Ningxia will decrease under the B2 scenario. Reductions in the 2020s will be small, but will be more significant in the 2050s, and largest in the 2080s. Under the A2 scenario, the reductions in potato yield are projected to be more significant than under the B2 scenario. The reductions in yield in Ningxia's southern area are projected to be larger than in the central area.

Table A4. 1 Changes potato yields under SRES A2 and B2 in Ningxia compared to average yield during the baseline period (1961-1990)

SRES	2020s			2050s			2080s		
	Whole average	South section	Middle section	Whole average	South section	Middle section	Whole average	South section	Middle section
A2	-13.1	-12.6	-14.6	-21.1	-20.1	-23.8	-41.3	-40.9	-42.4
B2	-8.7	-9.5	-6.3	-11.1	-11.2	-10.6	-15.3	-14.9	-16.3

Figure A4. 9 Change in potato yield under SRES B2 in Ningxia comparing to average yield in 1961-1990



Climate change impacts on potato evapotranspiration

If current planting and field management practices remain unchanged, potato evapotranspiration in Ningxia will decrease under the A2 and B2 scenarios. Deductions in the 2020s will be minimal; they will be larger in the 2050s and largest in the 2080s. Under the A2 scenario, potato evapotranspiration will decrease more than under B2.

Table A4. 2 Change in potato evapotranspiration under SRES A2 and B2 in Ningxia compared to average evapotranspiration in 1961-1990.

SRES	2020s			2050s		
	Whole average	South section	Middle section	Whole average	South section	Middle section
A2	-6.7	-6.9	-6.5	-9.3	-11.2	-7.6
B2	-5.2	-4.8	-5.5	-9.9	-8.8	-10.9

Climate change impacts on total potato yield

In 2006, total potato yields in Ningxia were 3,246,000 tonnes and the total planting area was 186,905 ha. If current planting and field management practices remain unchanged, total potato yields in Ningxia are projected to decrease under both the A2 and the B2 scenarios.

Effects of adaptation measures

- Mulching through the impact of experimental studies shows that: mulching has good water, warming and yield results. The same conditions of film processing and control open field, the plastic potato vegetative growth stage than the control topsoil moisture increased 5-10%; 5 cm temperature increase 2-3 ℃, 10 cm temperature increase nearly 2 ℃, yield increased by 20 – 40%.
- Sowing period adjustments to maintain the current level of fertilization, the same species, A2 scenario under the 2020s will be broadcast early period of 30 to 40 days, 2050s will be broadcast early period of 40 to 50 days, 2080s will be broadcast early period of 50 to 60 days. In some areas potato production will increase by 10 to 15 percent, the highest regional up to 60 percent, to the south of the greater production increases, but the 2080s with the sowing period ahead, potato increased the probability of damage.
- Fertilizer affected by SUBSTOR model to simulate different developmental stages of fertilizer to increase the impact of potato production, the results showed that the amount of fertilizer to increase potato production impact was not obvious, not to increase the basic production.

Conclusions

- Since the 1980s, Ningxia potato production yields and area have increased.
- Maintaining the current planting and field management measures with A2 and B2 climate change scenarios Ningxia potato yields show downward trends.
- Adjusting the sowing time increases by about 15 percent potato output. Mulching can increase production about 20 percent. Therefore potential exists to adopt appropriate measures to offset climate change impacts on potato production.

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