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Chinese Food Security and Climate Change: Agriculture Futures

*Liming Ye, Huajun Tang, Wenbin Wu, Peng Yang, Gerald C. Nelson,
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Abstract

Food security in China affects the livelihood and well-being of one-fifth of the world population. Climate change is now affecting agriculture and food production in every country of the world. Here the authors present the IMPACT model results on yield, production, and net trade of major crops (wheat, rice, and maize) in China, and on daily calorie availability as an overall indicator of food security under climate change scenarios and socio-economic pathways in 2050. The obtained results show that wheat, maize, and rice yields will increase by 17%, 45%, and 15%, alongside price increases of 60%, 100%, and 40%, respectively, during 2010–2050. Crop production is projected to increase by 23%, 70%, and 3% reaching 123, 240, and 125 million tons for wheat, maize, and rice, respectively, in 2050. The results also show that China will remain a major importer of maize at 20 million tons per year, but turn from a net importer of rice (5 million tons per year in 2010) to a net exporter in 2020 (5–9 million tons per year by 2050), while becoming a self-sufficient consumer of wheat by 2050. The outcomes of calorie availability suggest that China will be able to maintain a level of at least 3,000 kilocalories per day through 2010–2050. Climate change has relatively little effect on calorie availability within a pathway scenario. The authors conclude that Chinese agriculture is relatively resilient to climate change. Chinese food security by 2050 will unlikely be compromised in the context of climate change. The major challenge to food security, however, will rise from increasing demand coupled with regional disparities in the adaptive capacity to climate change.

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Contents

Abstract.....	1
Contents.....	2
Table of Tables	3
Table of Figures.....	4
1 Introduction.....	6
1.1 Regional Impacts of Climate Change	7
2 Agriculture, Food Security and Chinese Development	10
2.1 Review of the Current Situation.....	10
2.1.1 Population.....	10
2.1.2 Income	12
2.1.3 Vulnerability.....	13
2.2 Review of Land Use and Agriculture	14
2.2.1 Land use overview	14
2.2.2 Agriculture overview	16
3 Scenarios for Adaptation.....	20
3.1 Biophysical Scenarios.....	20
3.1.1 Climate scenarios	20
3.1.2 Crop physiological response to climate change.....	23
3.1.3 From biophysical scenarios to socioeconomic consequences: the IMPACT model	30
3.2 Income and Demographic Scenarios	31
3.3 Crop-specific Agricultural Vulnerability Scenarios	33
3.4 Human Vulnerability Scenarios.....	38
4 Agriculture and Greenhouse Gas Mitigation.....	39
4.1 Agricultural Emissions History	39
4.2 Agricultural Mitigation Potential	40
4.3 Adaptation and Mitigation Synergies	41
5 Conclusions.....	42
Acknowledgements.....	43
References	44
Appendix	49

Table of Tables

Table 1. Population growth rates, 1960-2008 (%)	10
Table 2. Education and labor statistics	14
Table 3. Harvest area of leading agricultural commodities, 2006-2008 average	16
Table 4. Value of production for leading agricultural commodities, 2006-2008 average	16
Table 5. Yield change under climate change scenarios in 2050 over 2000, %.....	23
Table 6. GDP and population choices for the three overall socio-economic pathway scenarios	31
Table 7. Average scenario per capita GDP growth rates (percent per year)	32
Table 8. China and U.S. per capita income scenario outcomes for 2010, 2030, and 2050 (2000US\$ per person)	33

Table of Figures

Figure 1. Changes in mean annual precipitation between 2000 and 2050 using the A1B scenario (mm per year)	8
Figure 2. Changes in annual maximum temperature between 2000 and 2050 using the A1B scenario (°C)	9
Figure 3. Population trends: total population, rural population, and percent urban, 1960-2008	11
Figure 4. Population distribution (persons per square kilometer)	11
Figure 5. Population scenarios for 2010 to 2050	12
Figure 6. Per capita GDP (constant 2000 US\$) and share of GDP from agriculture	12
Figure 7. Poverty as measured by population share (%) living on US\$2 per day or less	13
Figure 8. Well-being indicators: life expectancy at birth and under-5 mortality rate	14
Figure 9. Land cover inventory as in year 2000	15
Figure 10. Protected areas	15
Figure 11. Yield and harvest area density of irrigated wheat in year 2000	17
Figure 12. Yield and harvest area density of rainfed wheat in year 2000	17
Figure 13. Yield and harvest area density of irrigated maize in year 2000	18
Figure 14. Yield and harvest area density of rainfed maize in year 2000	18
Figure 15. Yield and harvest area density of irrigated rice in year 2000	19
Figure 16. Yield and harvest area density of rainfed rice in year 2000	19
Figure 17. Changes in mean annual precipitation for China between 2000 and 2050 using the A1B scenario (millimeters)	21
Figure 18. Changes in normal annual maximum temperature for China between 2000 and 2050 using the A1B scenario (°C)	22
Figure 19. Yield change between 2000 and 2050 under four climate change scenarios: irrigated wheat	24
Figure 20. Yield change between 2000 and 2050 under four climate change scenarios: rainfed wheat...	25
Figure 21. Yield change between 2000 and 2050 under four climate change scenarios: irrigated maize	26
Figure 22. Yield change between 2000 and 2050 under four climate change scenarios: rainfed maize ...	27

Figure 23. Yield change between 2000 and 2050 under four climate change scenarios: irrigated rice.....	28
Figure 24. Yield change between 2000 and 2050 under four climate change scenarios: rainfed rice	29
Figure 25. The IMPACT modeling framework	30
Figure 26. The 281 FPU's adopted by the IMPACT model	31
Figure 27. GDP per capita scenarios	32
Figure 28. Scenario outcomes for wheat production, yield, area, net export, and price.....	35
Figure 29. Scenario outcomes for maize production, yield, area, net export, and price	36
Figure 30. Scenario outcomes for rice production, yield, area, net export, and price.....	37
Figure 31. Average daily kilocalories availability under multiple income and climate scenarios (kilocalories per person per day)	38
Figure 32. Number of malnourished children under 5 years of age under multiple income and climate scenarios	39
Figure 33. GHG emissions (CO ₂ , CH ₄ , N ₂ O, PFCs, HFCs, SF ₆) in China by sector, million ton	40

1 Introduction

The world faces multiple challenges to food security ranging from continuous population growth and rapid diet transition to decreasing cropland area and insufficient production practices (Beddington et al., 2012). The world's population, for example, has increased from 1.65 billion in 1900 to over 6 billion in 2000 and further to 7 billion in 2011 (Smith, 2011). Overall, food production per capita has remained stable during the twentieth century, largely due to technological advances. Breakthroughs in wheat and rice production, which have been known as the Green Revolution (Evenson and Gollin, 2003), have greatly contributed to the ease of the population burden in various parts of the world. However, some 800 million to 1 billion people still experience chronic and transitory hunger at present, partly due to the rapid rise in food price (Sanchez and Swaminathan, 2005; Borlaug, 2007). Global food prices have risen dramatically in the past few years and are forecast to rise further and become more volatile, disrupting assumptions that stable and declining food prices and assured supplies can be taken for granted (Beddington et al., 2012). The food system faces additional pressure as the dominant diet pattern is shifting towards higher consumption of calories, fats and animal products. Moreover, as the dominant source of the human food supply, the per capita availability of world cropland has been decreasing at a rate of 0.8% per year during the twentieth century (Ramankutty et al., 2008) and will continue to decrease at the foreseeable future. The demand for cereals will probably grow by 50% until 2030 and even higher production will have to be achieved through agricultural intensification for a world of 9 billion people in 2050 (Tilman et al., 2002; Schmidhuber and Tubiello, 2007).

Climate change will further exacerbate the already-fragile global food production system and the natural resource base. Global surface temperature has increased 0.8°C during the twentieth century; four thirds of this increase occurred in the last three decades (Hansen et al., 2006). The acceleration in global warming and its associated changes in precipitation have already affected global agriculture and the food production system in many ways (Godfray et al. 2011). Crop production is affected by climatic variables such as rising temperatures, changing precipitation regimes and increased atmospheric CO₂ levels (Long, 2012); it is also affected by biological variables such as the lengths of the crop growth periods and the crop cycle (Ye et al., 2012). Experimental findings on wheat and rice under managed environments, for instance, indicated decreased crop duration (and hence yield) of wheat as a consequence of warming and reductions in yield of rice of ~5% °C⁻¹ rise above 32°C (Gregory et al., 2005). These effects of temperature were considered sufficiently detrimental that they would largely offset any increase in yield as a consequence of increased atmospheric CO₂ concentration.

The focus of this paper is the projected impact of climate change on Chinese food security through 2050. The paper consists of three parts. The first part is an overview of the current food security situation, the underlying natural resources available in China and the drivers that lead to the current state, focusing on income and population growth. The second part reviews the China-specific outcomes of a set of scenarios for the future of global food security in the context of climate change. These country-specific outcomes are based on IMPACT model results obtained in July 2011. The third part examines available adaptation and mitigation options that are suitable and technically implementable in China.

In the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Working Group 1 reports that "climate is often defined as 'average weather'. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 years)" (Le Treut et al., 2007).

Agriculture is vulnerable to climate change in a number of dimensions. Higher temperatures eventually reduce yields of desirable crops and tend to encourage weed and pest proliferation. Greater variations in precipitation patterns increase the likelihood of short-run crop failures and

long-run production declines. Although there might be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security. The impacts are

- Direct, on crops and livestock productivity domestically
- Indirect, on availability/prices of food domestically and in international markets
- Indirect, on income from agricultural production both at the farm and country levels

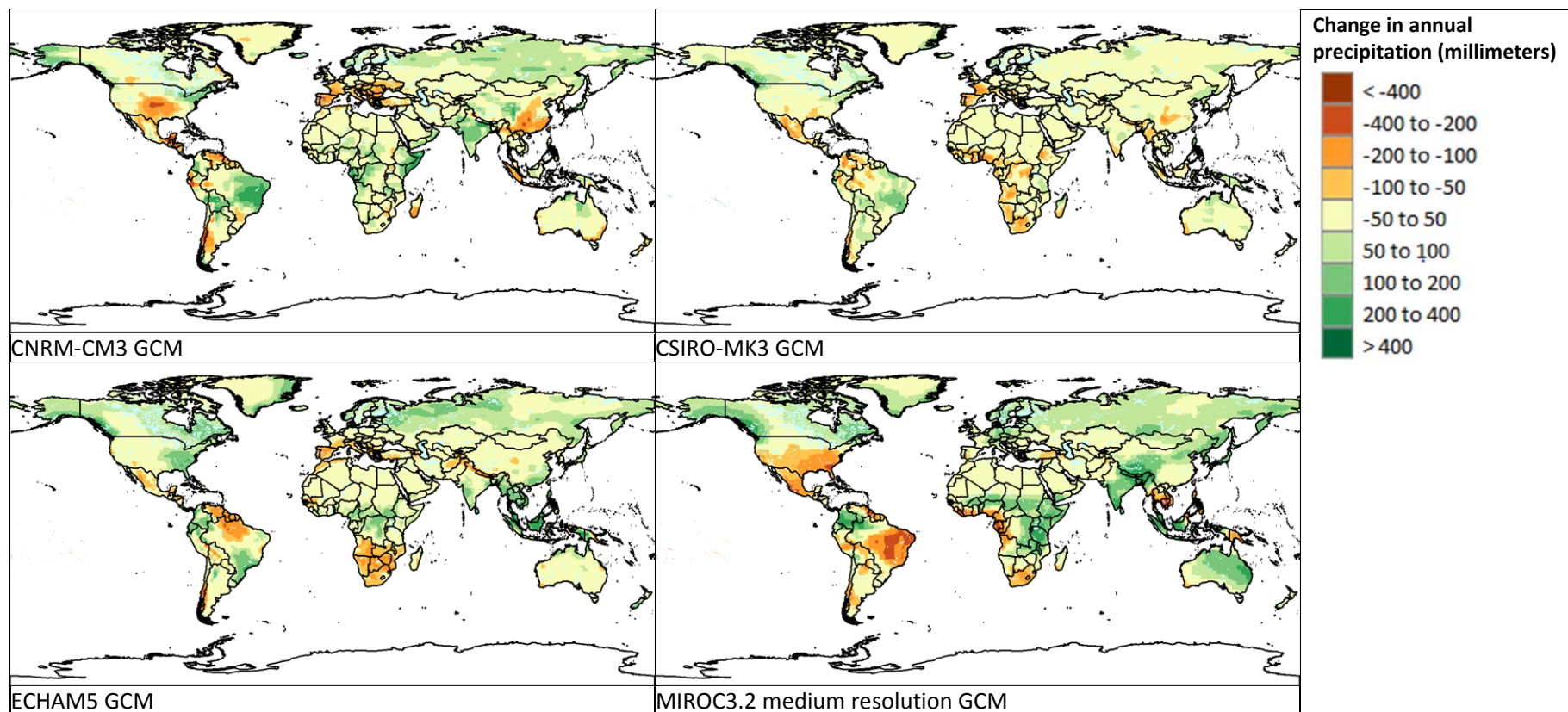
1.1 Regional Impacts of Climate Change

While the general consequences of climate change are becoming increasingly well known, great uncertainty remains about how climate change effects will play out in specific locations¹. Figure 1 shows changes in average precipitation globally between 2000 and 2050 for four General Circulation Models (GCMs), each using the A1B emission scenario. Figure 2 shows the change in average maximum temperature. In each set of figures, the legend colors are identical; a specific color represents the same change in temperature or precipitation across the models.

A quick glance at these figures shows that substantial differences exist. For example, in Figure 1 the MIROC GCM predicts that Southeast Asia will be much drier, while the ECHAM model has the same region getting wetter. In South Asia, the MIROC GCM has an increase in precipitation, especially in the northeast, while the CSIRO GCM has a drier South Asia. In northeast Brazil, the CNRM GCM shows significant drying while the MIROC scenario has a sizeable increase in precipitation. In Figure 2, we see that the MIROC and ECHAM GCMs predict very big temperature increases for northeast South Asia, but they differ on whether northwest South Asia will also experience such a severe temperature increase. These figures illustrate qualitatively the range of potential climate outcomes using current modeling capabilities and provide an indication of the uncertainty in climate-change impacts. The differences across models are why policymakers must avoid seeking specific solutions for specific locations - unless there is significant agreement across models. Rather, it is important to note general trends and to consider policies that are helpful and robust across the range of climate outcomes.

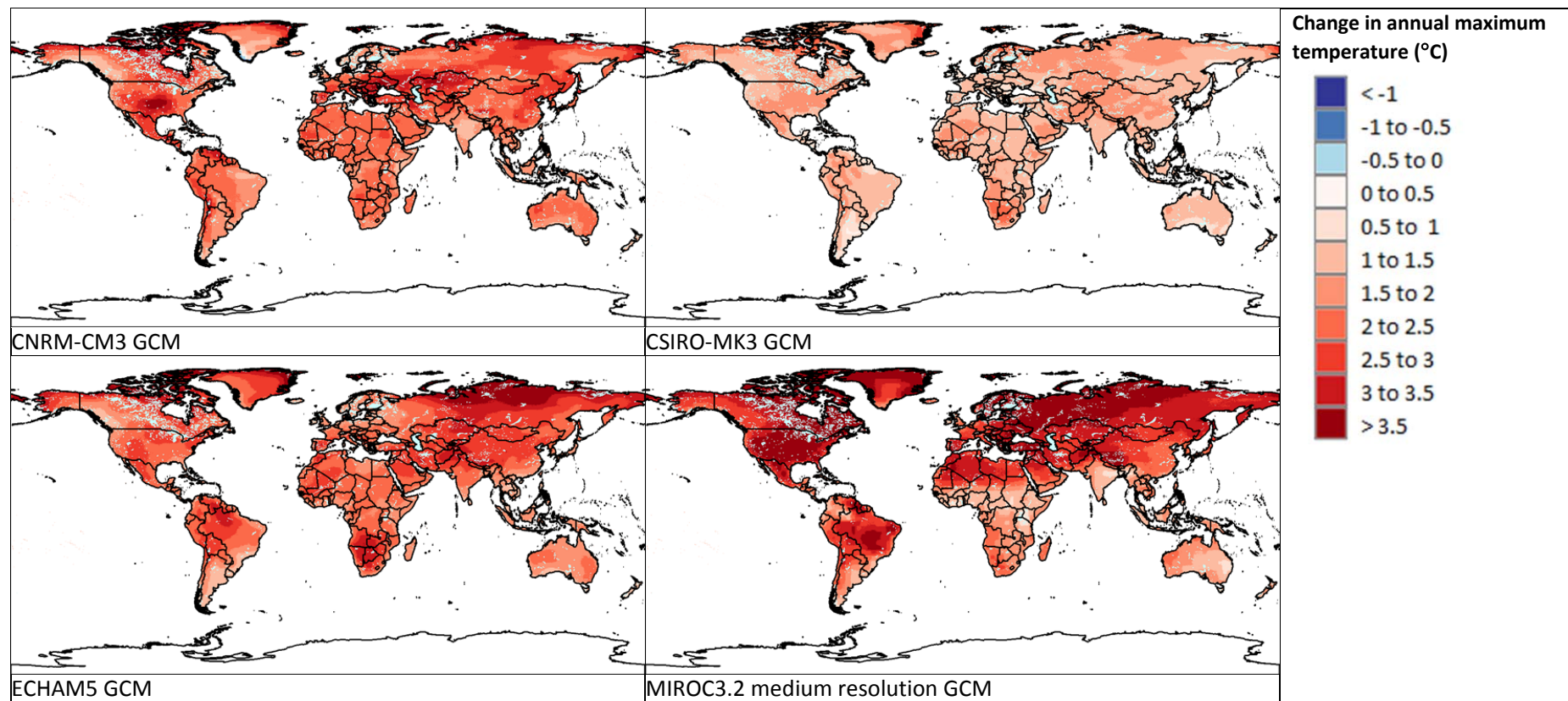
¹ To understand the significant uncertainty in how these effects play out over the surface of the earth it is useful to describe briefly the process by which the results depicted in the figures are derived. They start with global (or general) circulation models (GCMs) that model the physics and chemistry of the atmosphere and its interactions with oceans and the land surface. Several GCMs have been developed independently around the world. Next, integrated assessment models (IAMs) simulate the interactions between humans and their surroundings, including industrial activities, transportation, agriculture and other land uses and estimate the emissions of the various greenhouse gasses (carbon dioxide, methane and nitrous oxide are the most important). Several independent IAMs exist as well. The emissions simulation results of the IAMs are made available to the GCM models as inputs that alter atmospheric chemistry. The end result is a set of estimates of precipitation and temperature values around the globe often at 2 degree intervals (about 200 km at the equator) for most models. Periodically, the Intergovernmental Panel on Climate Change (IPCC) issues assessment reports on the state of our understanding of climate science and interactions with the oceans, land and human activities.

Figure 1. Changes in mean annual precipitation between 2000 and 2050 using the A1B scenario (mm per year).



Source: IFPRI calculations based on downscaled climate data available at <http://ccafs-climate.org>.

Figure 2. Changes in annual maximum temperature between 2000 and 2050 using the A1B scenario (°C)



Source: IFPRI calculations based on downscaled climate data available at <http://ccaifs-climate.org/>.

2 Agriculture, Food Security and Chinese Development

China embarked on economic reform more than three decades ago when the government introduced the household responsibility system (HRS) in agriculture. Price distortions were reduced, and key land rights were reallocated from collective farms to individual households. Bold policies and institutional reforms motivated higher grain production and dramatically improved food security, which resulted in what was considered as “the greatest increase in economic wellbeing within a 15-year period in all of human history” (Sachs et al., 1994). During the past few decades, agricultural productivity rose steadily, and per capita grain output reached a level similar to that in developed countries. With sustained growth in agriculture, rural incomes rose significantly, permanently lifting millions of people out of poverty (Ye and Van Ranst, 2009). The Chinese population has increased over 30% since 1980, reaching 1.34 billion in 2010. The production of staple grains has generally come up with the population growth, enabling China to feed approximately 20% of the world’s population on less than 7% of the world’s cropland. As the world’s biggest grain producer, China produced ~550 million tons of staple grains in 2010, renewing the harvest record for yet another time in seven consecutive years since 2004.

2.1 Review of the Current Situation

This section reviews China’s economic performance since the beginning of reforms in early 1980s using population and income as indicators.

2.1.1 Population

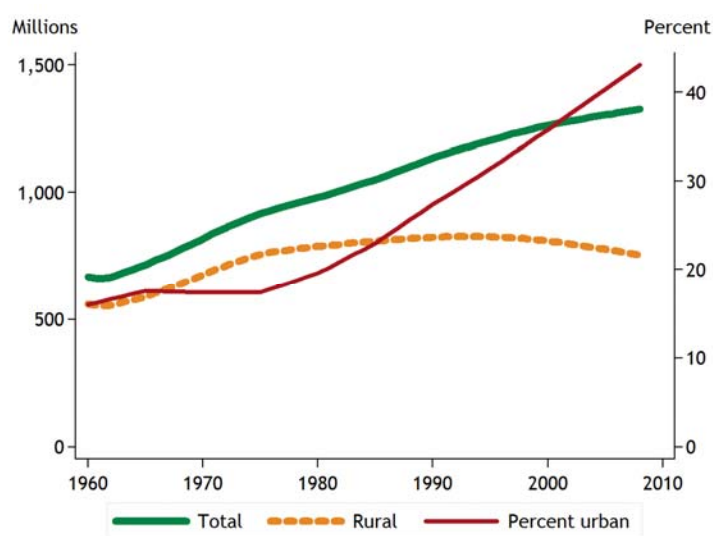
The population size and its associated growth rate are key parameters to determine food demand and to predict the future trends of it. Figure 3 shows total and rural population and counts (left axis) and the share of urban population (right axis), and Table 1 provides additional information on rates of population growth. China adopted the so-called “one-child” population control policy in late 1970s. As a result, total population growth fell sharply over the second half of the 20th century, reaching a level of 0.6 percent per year in the first decade of the 21st century. In the meanwhile, the share of the urban population increased sharply, with an average acceleration of nearly 1 percent per year since early 1980s. The rapid urbanization will, on one hand, hopefully propel further economic growth since urbanization plays a central role in China’s national development strategy (Change and Brada, 2006). But on the other hand, urban expansion will likely cause more cropland to be taken away from food production, casting negative impacts on China’s ability to maintain a stable food self-sufficiency level.

Table 1. Population growth rates, 1960-2008 (%)

Decade	Total Growth Rate	Rural Growth Rate	Urban Growth Rate
1960-1969	0.02	0.02	0.02
1970-1979	0.02	0.02	0.03
1980-1989	0.01	0.00	0.05
1990-1999	0.01	0.00	0.00
2000-2008	0.01	-0.01	0.03

Source: IFPRI calculations, based on World Development Indicators (World Bank, 2009)

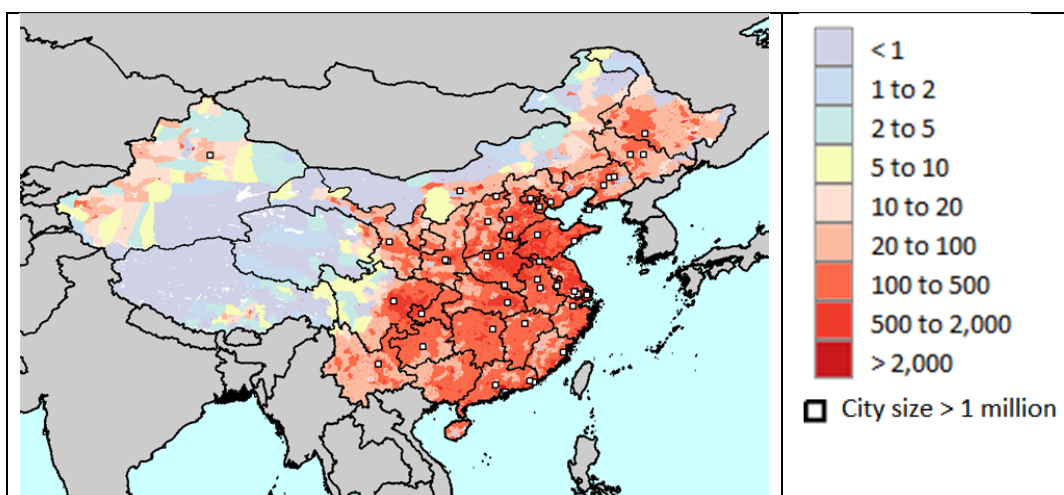
Figure 3. Population trends: total population, rural population, and percent urban, 1960-2008



Source: World Development Indicators (World Bank, 2009)

Figure 4 shows the geographic distribution of population within China, based on census data and other sources compiled by CIESIN (2004). It clearly shows that China is densely populated in the eastern seaboard, overlapping with the socio-economic development centers of the Bohai Economic Rim around Beijing, the Yangtze River Delta around Shanghai and the Pearl River Delta around Guangzhou and Hong Kong. The region along the border with Mongolia and the Tarim Basin in the west are extremely sparsely populated. This regional disparity in population distribution has importance consequences for regional food security.

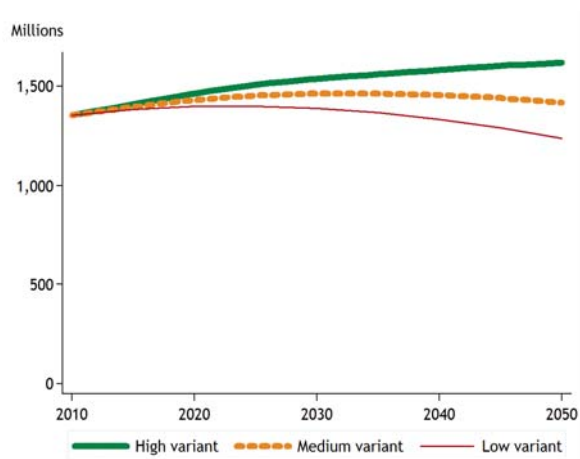
Figure 4. Population distribution (persons per square kilometer)



Source: IFPRI estimates from GRUMP for the year 2000 (CIESIN, 2004).

Figure 5 shows population projections by the UN Population office through 2050. Under the medium variant, Chinese population is expected to plateau around 2030 and then declines. The low variant has the decline starting sooner, while the high variant has population growth continuing beyond 2050.

Figure 5. Population scenarios for 2010 to 2050

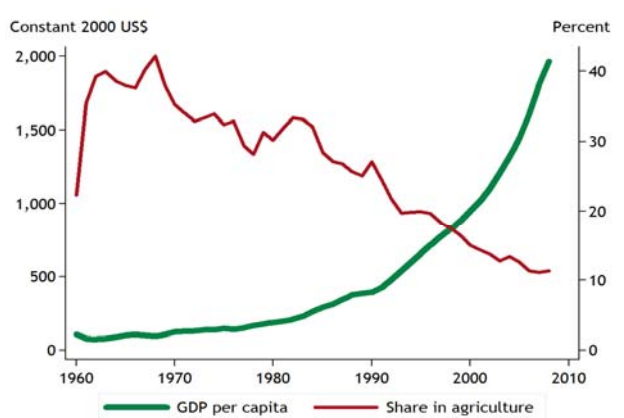


Source: UN Population Projections (United Nations, 2008).

2.1.2 Income

The income available to an individual is the single best indicator of their resilience to stresses. Figure 6 shows trends in GDP per capita and proportion of GDP from agriculture. The agricultural share is included both because of its vulnerability to climate change impacts and as an indicator of the national development level. As development increases, the importance of agriculture in GDP tends to decline. The figure indicates both the enormous growth of the Chinese economy since late 1970s and the corresponding reduction in the size of the agricultural sector relative to the rest of the economy.

Figure 6. Per capita GDP (constant 2000 US\$) and share of GDP from agriculture



Source: World Development Indicators (World Bank, 2009).

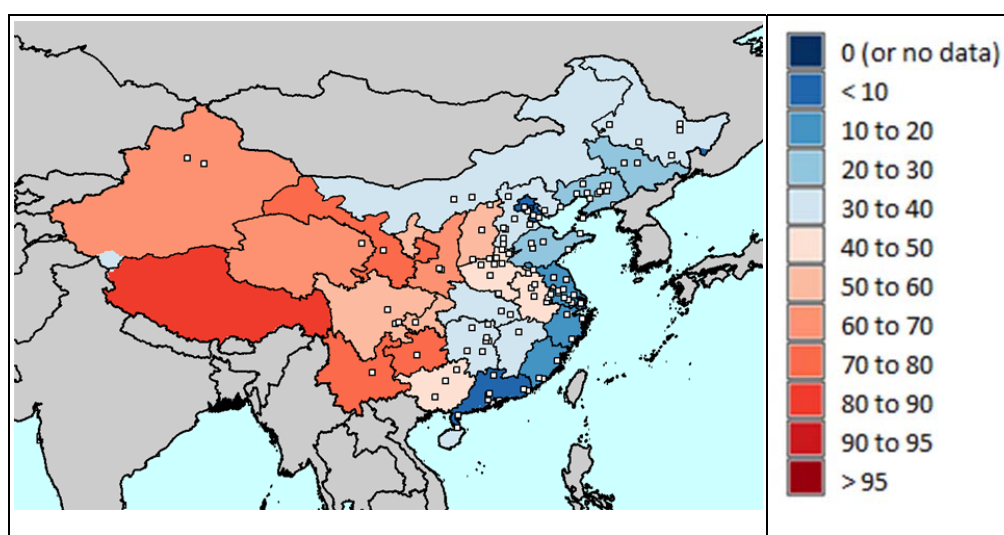
2.1.3 Vulnerability

Vulnerability is the lack of ability to recover from stress. Poor people are vulnerable to many different kinds of stresses because they lack the financial resources to respond. In agriculture, poor people are particularly vulnerable to the stresses of an uncertain climate. This paper focuses on income, both level and sources. At the national level, vulnerability arises in the interactions among population and income growth and the availability of natural and manufactured resources. National per capita income statistics reported above show averages but potentially conceal large variations across sectors or regions.

Although the average figures show substantial improvements in economic performance, improvement in resilience and human well-being, substantial regional differences remain.

Figure 7 shows the distribution of the proportion of the population living on less than \$2.00 per day. Regional disparities are clearly shown. The poverty rates of the densely populated provinces on the eastern seaboard, shaded in blue colors, are mostly lower than 20 percent of the population, while in the western provinces, shaded in red colors on map, the poverty rate is much higher; 60 to 90 percent of the population there earn less than the equivalent of US\$2 per day.

Figure 7. Poverty as measured by population share (%) living on US\$2 per day or less



Source: Wood et al. (2010) available at labs.harvestchoice.org/2010/08/poverty-maps

Table 2 provides additional indicators of vulnerability and resilience to economic shocks including the level of school education, adult literacy, concentration of labor in agriculture, and malnutrition.

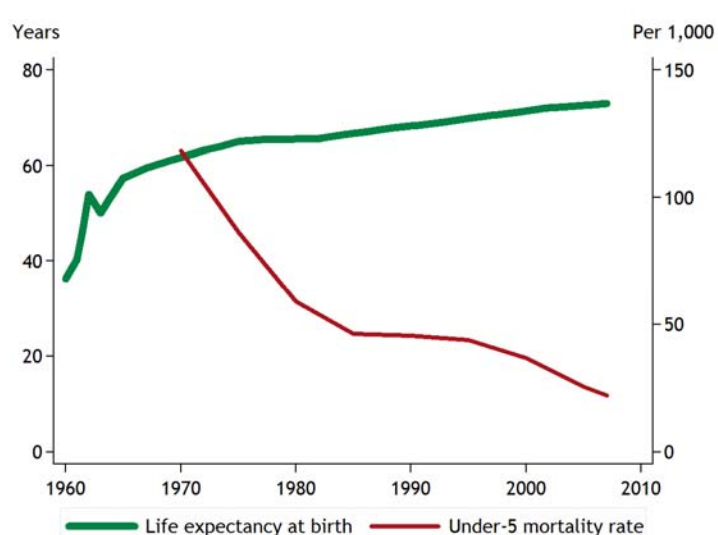
Table 2. Education and labor statistics

Indicator	Year	Value
Primary school enrollment: Percent gross (3-year average)	2007	112.3
Secondary school enrollment: Percent gross (3-year average)	2007	77.3
Adult literacy rate	2007	93.3
Percent employed in agriculture	2002	44.1
Under-5 malnutrition (weight for age)	2002	6.8

Source: World Development Indicators (World Bank 2009).

The outcomes of significant vulnerability include low life expectancy and high infant mortality. Figure 8 shows the trajectories of these two parameters during the past 50 years. China has made remarkable progress in vulnerability reduction. The life expectancy at birth jumped from less than 40 years in early 1960s to over 60 years in early 1970s and then increased steadily to over 70 years in 2008. China also made significant progress in child malnutrition control. The under-5 mortality rate was measured at 6% in early 1970s, the number declined to 2% by the early 2000s.

Figure 8. Well-being indicators: life expectancy at birth and under-5 mortality rate



Source: World Development Indicators (World Bank, 2009)

2.2 Review of Land Use and Agriculture

Agricultural production is dependent on the availability of land with sufficient water, soil quality and an adequate growing season.

2.2.1 Land use overview

Satellite-based land cover inventory in year 2000, as mapped in Figure 9, shows that crop production is largely limited to the Three River Plain in the northeast, the North China Plain, the Loess Plateau, the lower Yangtze River Basin, and the Sichuan Basin as indicated by the “cultivated

and managed areas” land cover type. Croplands in southeast, south, and southwest China are much fragmented, as indicated by the two “mosaic” land cover types, and are thus of secondary importance to agriculture. Aggregate, cropland is accounted for only 14% of the total land mass, which is equivalent to 0.1 hectares per capita.

Figure 9. Land cover inventory as in year 2000

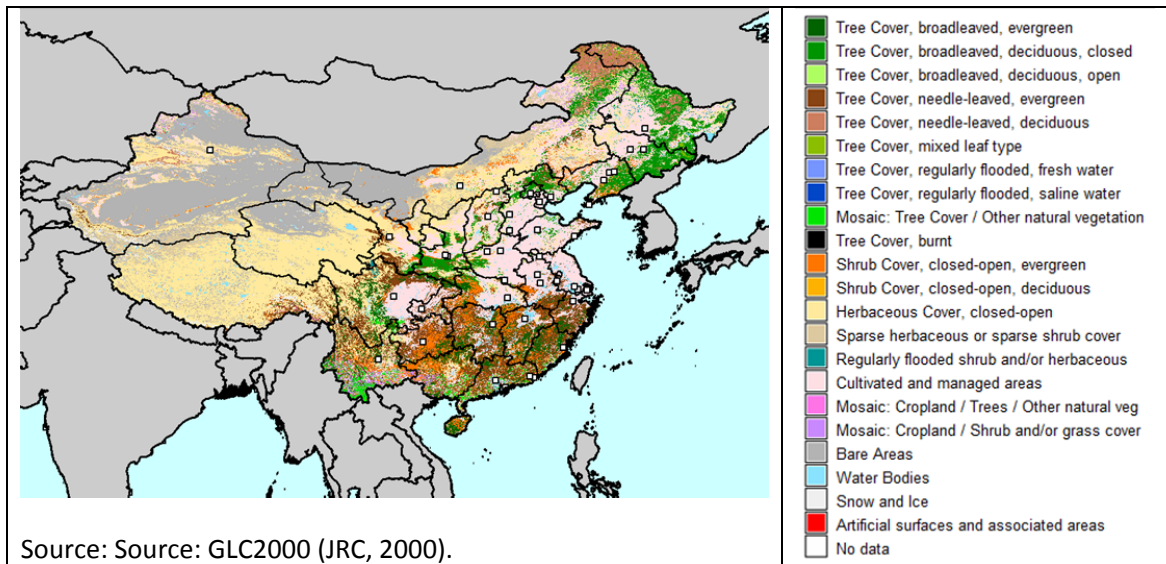
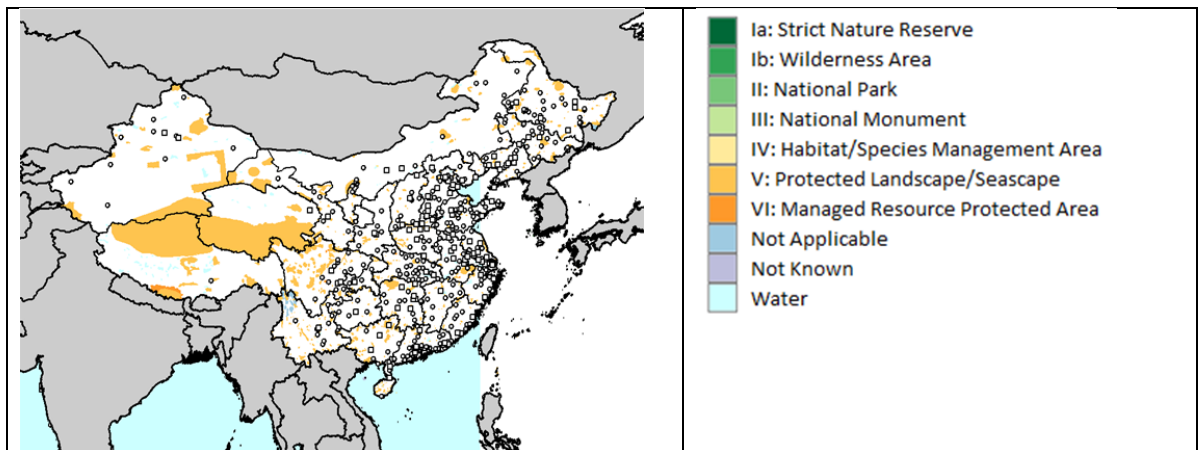


Figure 10 shows the locations of protected areas, including parks and natural reserves. These locations provide important protection of environmentally fragile regions.

Figure 10. Protected areas



Source: World Database on Protected Areas (UNEP, 2009). Water is from Global Lakes and Wetlands Database (WWF) (Lehner and Döll, 2004).

2.2.2 Agriculture overview

Tables 3 and 4 give key agricultural commodities in terms of area harvested and value for the period of 2006-2008, respectively. Rice, maize and wheat are traditionally the most important crops in China. They take nearly half of the total area of major agricultural harvests. In monetary terms, these big three plus cotton account for 47% of the total value of key agricultural commodities listed in Table 4. Rice and maize are still in the top two positions, while cotton is in the third position with wheat ranking the fourth.

Table 3. Harvest area of leading agricultural commodities, 2006-2008 average

Rank	Crop	% of total	Area harvested (000 hectares)
1	Paddy rice	17.7%	29,291
2	Maize	17.7%	29,288
3	Wheat	14.3%	23,650
4	Soybeans	5.5%	9,062
5	Fresh vegetables	5.2%	8,532
6	Rapeseed	3.7%	6,073
7	Seed cotton	3.5%	5,834
8	Potatoes	2.6%	4,367
9	Groundnuts with shell	2.5%	4,190
10	Sweet potatoes	2.2%	3,673
	Total	100.0%	165,072

Source: FAOSTAT (FAO, 2010)

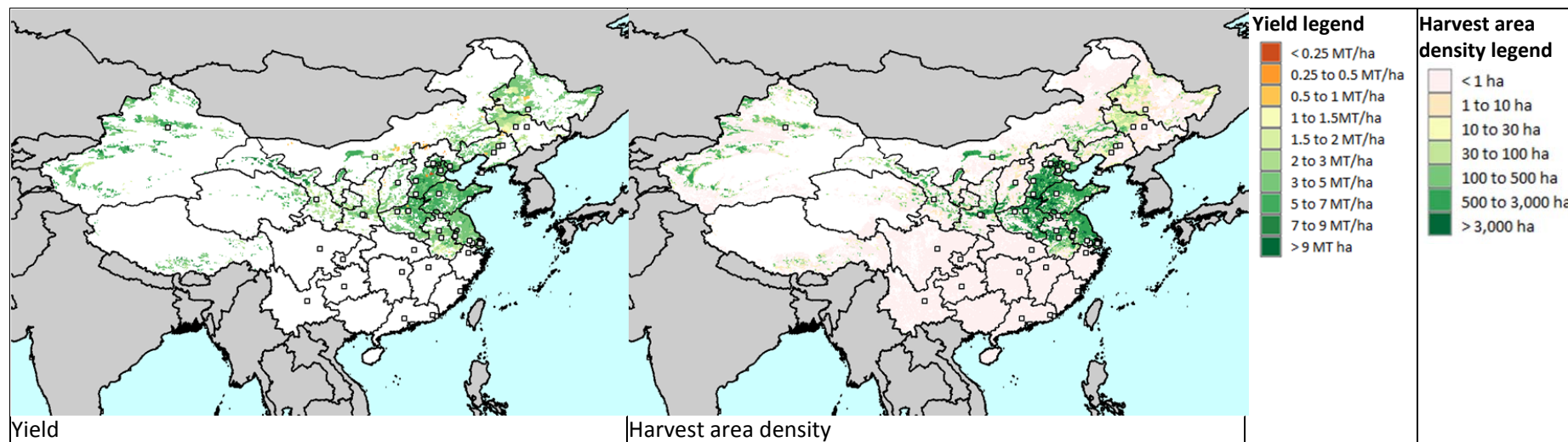
Table 4. Value of production for leading agricultural commodities, 2006-2008 average

Rank	Crop	% of total	Value of Production (million US\$)
1	Paddy rice	20.7%	65,377
2	Maize	11.6%	36,573
3	Seed cotton	7.3%	22,988
4	Wheat	7.2%	22,713
5	Fresh vegetables	6.4%	20,049
6	Apples	4.9%	15,306
7	Asparagus	3.1%	9,747
8	Groundnuts with shell	2.3%	7,222
9	Lettuce and chicory	2.2%	7,065
10	Soybeans	2.0%	6,367
	Total	100.0%	315,479

Source: FAOSTAT (FAO, 2010)

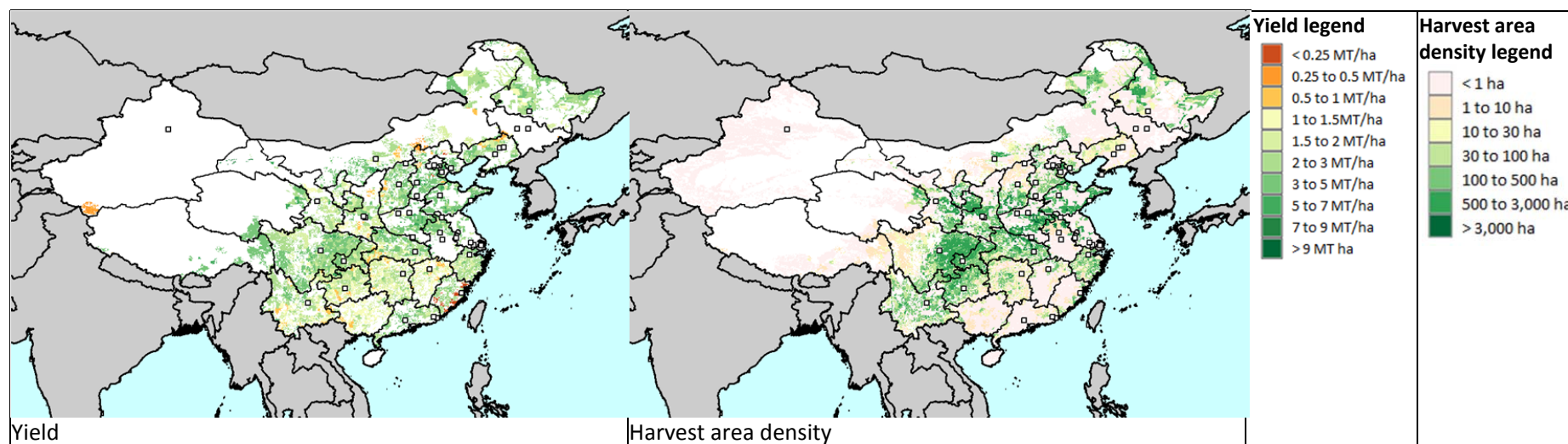
Figure 11 to Figure 16 show the spatial-explicit maps of the irrigated and rainfed production of major food crops of wheat, maize and rice in terms of estimated yield and harvest area. These figures are based on the SPAM dataset (You et al., 2009), a plausible allocation of crop production both at the national and the subnational scales. The agricultural important regions can be more easily identified in these figures than in Figure 9.

Figure 11. Yield and harvest area density of irrigated wheat in year 2000



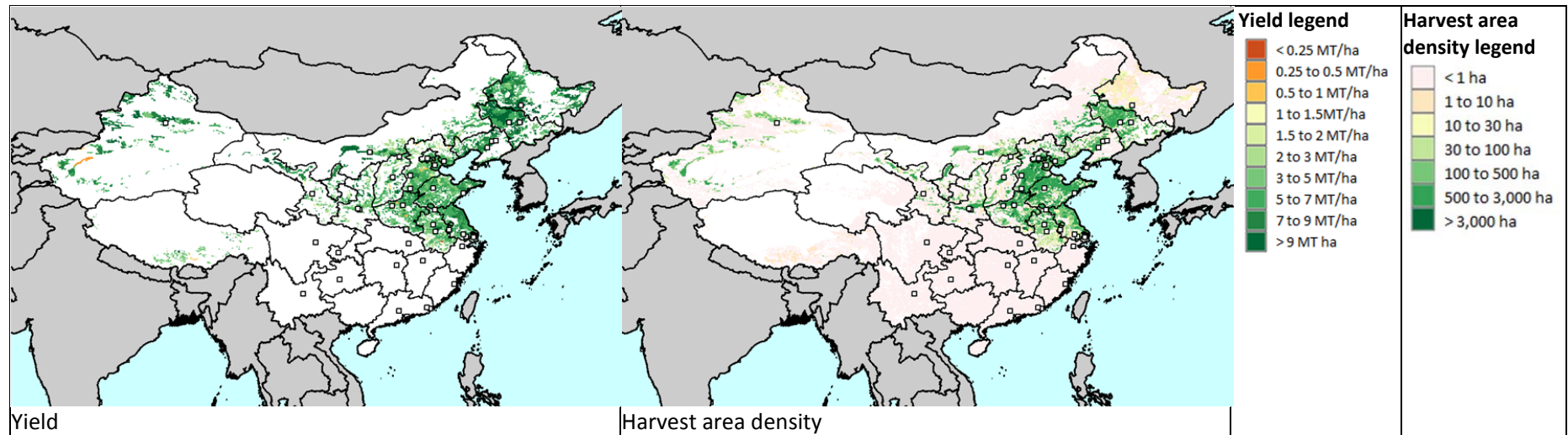
Source: SPAM Dataset (You et al., 2009)

Figure 12. Yield and harvest area density of rainfed wheat in year 2000



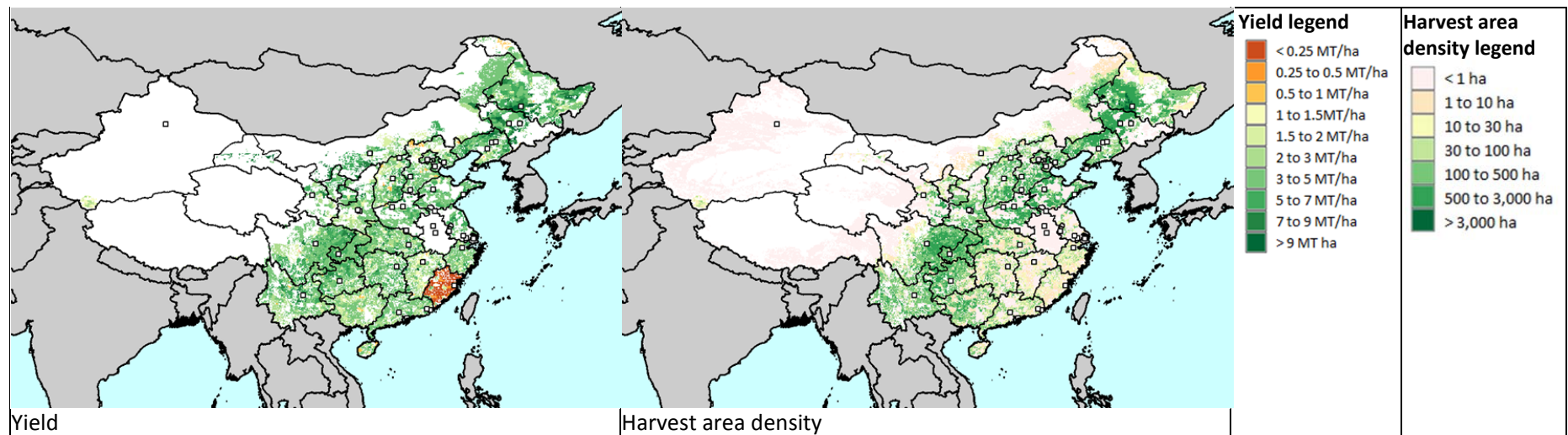
Source: SPAM Dataset (You et al., 2009)

Figure 13. Yield and harvest area density of irrigated maize in year 2000



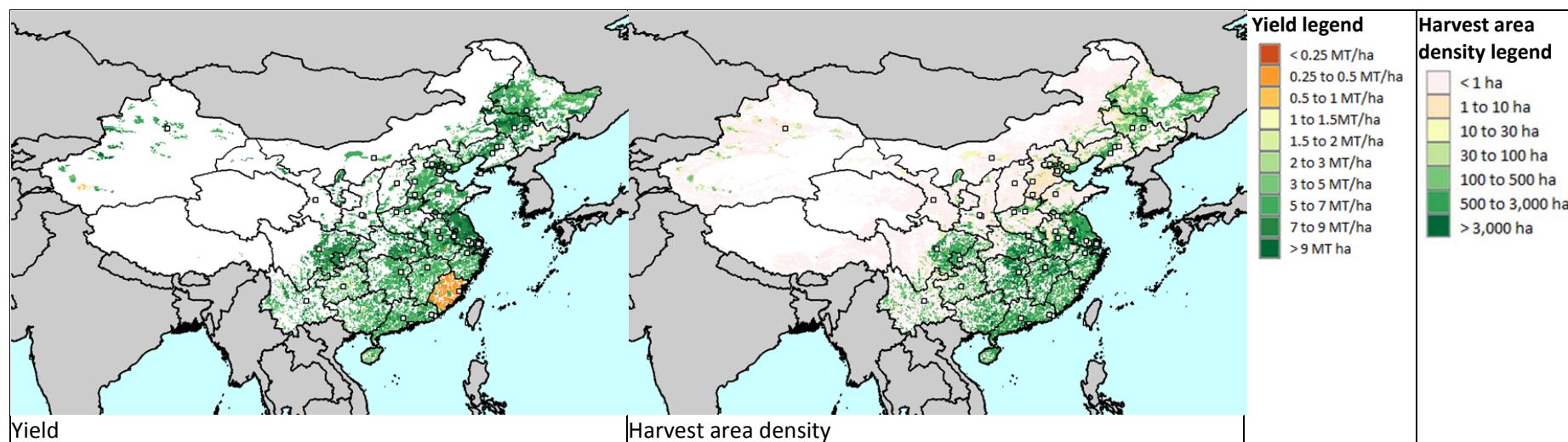
Source: SPAM Dataset (You et al., 2009)

Figure 14. Yield and harvest area density of rainfed maize in year 2000



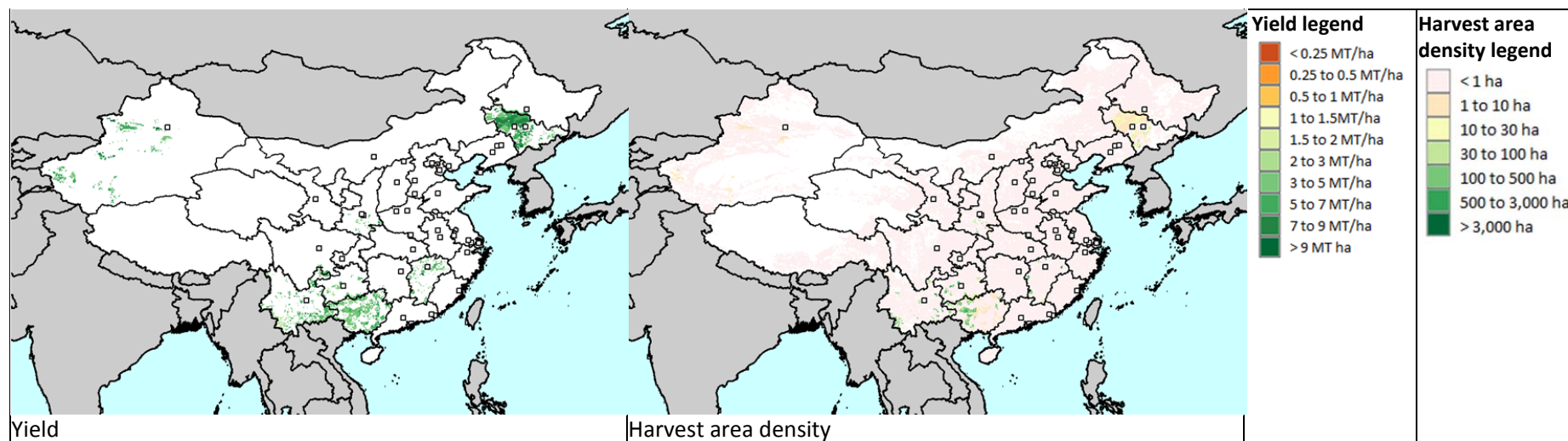
Source: SPAM Dataset (You et al., 2009)

Figure 15. Yield and harvest area density of irrigated rice in year 2000



Source: SPAM Dataset (You et al., 2009)

Figure 16. Yield and harvest area density of rainfed rice in year 2000



Source: SPAM Dataset (You et al., 2009)

3 Scenarios for Adaptation

The current status of the country with respect to vulnerability is reviewed in this section. This includes a brief overview of current population trends, per capita income growth and its distribution, and the state of agriculture.

To better understand the possible vulnerability to climate change, it is necessary to develop plausible scenarios. Scenarios are defined by Raskin et al. (2005) as “plausible, challenging, and relevant stories about how the future might unfold, which can be told in both words and numbers. Scenarios are not forecasts, projections, predictions, or recommendations. They are about envisioning future pathways and accounting for critical uncertainties”.

In this paper, combinations of economic and demographic drivers have been selected that collectively result in three pathways - a baseline scenario that is “middle of the road”, a pessimistic scenario that chooses driver combinations that, while plausible, are likely to result in more negative outcomes for human well-being, and an optimistic scenario that is likely to result in improved outcomes relative to the baseline. These three overall scenarios are further qualified by four climate scenarios: plausible changes in climate conditions based on scenarios of greenhouse gas emissions.

3.1 Biophysical Scenarios

This section presents the climate scenarios used in the analysis and the crop physiological response to the changes in climate between 2000 and 2050.

3.1.1 Climate scenarios

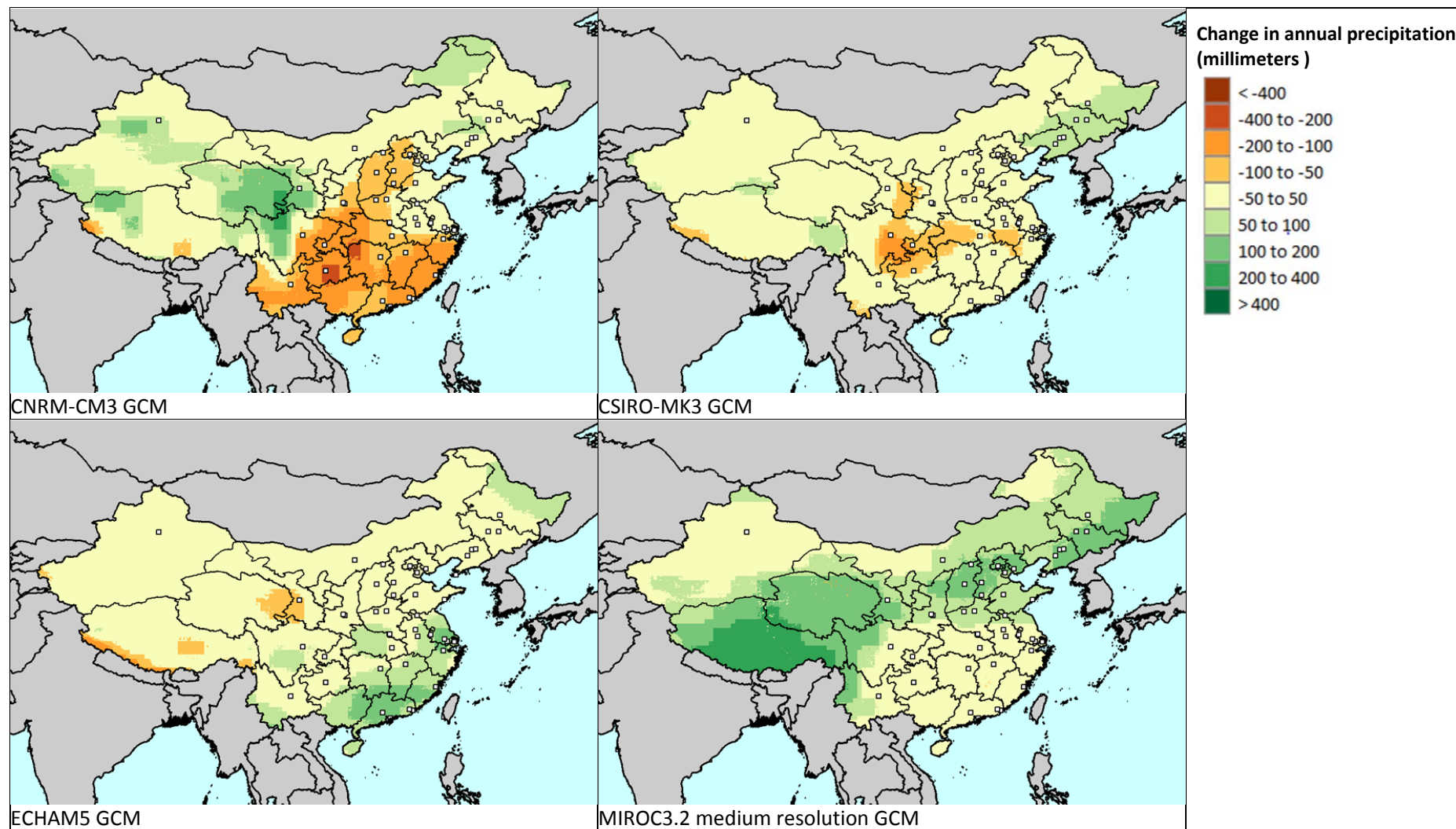
Four climate scenarios, downscaled from 4 GCMs - CNRM, CSIRO, ECHAM, and MIROC - driven by SRES emission scenario A1B or B1, were used to accommodate the likely ranges of future temperature and precipitation changes. The CSIRO scenario, for example, represents a dry and relatively cool future, while the MIROC scenario represents a wet and warmer future. The scenario-based temperature and precipitation were then utilized for crop modeling analysis.

Figure 17 shows precipitation changes between 2010 and 2050 for China from 4 downscaled GCMs driven by the A1B emission scenario; Figure 18 shows changes in maximum temperature for the month with the highest mean daily maximum temperature between 2010 and 2050 for China from the same GCMs.

In one of the major agricultural regions in China, the North China Plain, for example, climate is expected to be drier according to the CNRM scenario; the annual precipitation can decrease by 100 mm (Figure 17). To the contrary, the MIROC GCM depicts a much wetter future in the same region - annual precipitation can be 100 mm higher in 2050 than in 2010. The same amount of precipitation can be expected in the North China Plain by 2050 under the other two GCMs - CSIRO and ECHAM. The disparity among GCM results explains why the multi-model ensemble approach is used to deal simulated crop yields under climate change scenarios.

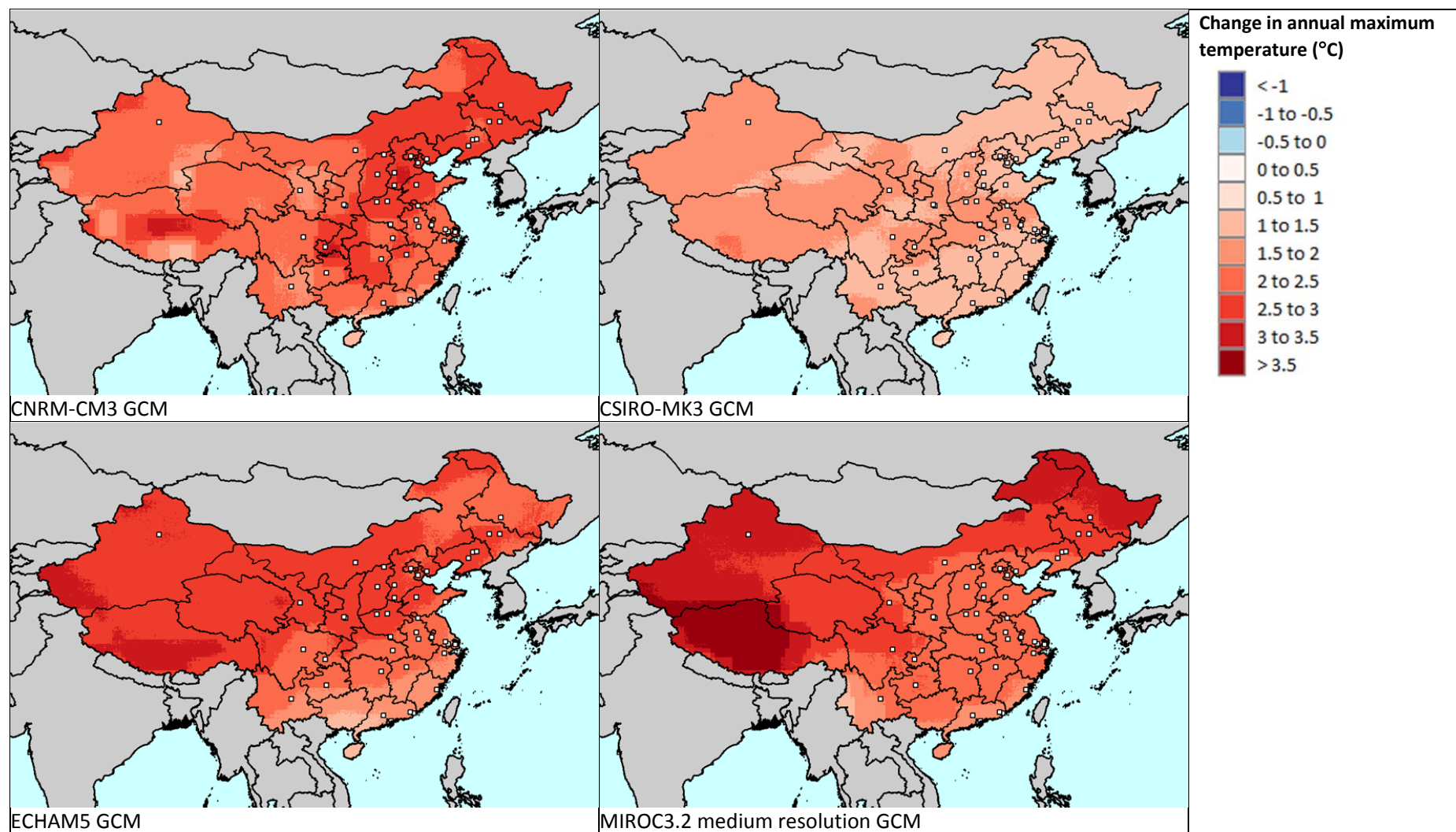
The GCM results are more unanimous on temperature change. They all depict a warmer future (Figure 18). The disagreement on temperature is much smaller than on precipitation. In North China Plain, temperature will increase 1-2°C under CNRM, ECHAM, and MIROC, while the CSIRO GCM predicts a less warmer future of less than 1°C. The general picture is that the higher latitudinal (e.g., Northeast) and higher altitudinal regions (e.g., Tibetan Plateau) are expected to receive higher warming, compared to the lower latitudinal/altitudinal regions.

Figure 17. Changes in mean annual precipitation for China between 2000 and 2050 using the A1B scenario (millimeters)



Source: IFPRI calculations based on downscaled climate data available at <http://ccafs-climate.org/>.

Figure 18. Changes in normal annual maximum temperature for China between 2000 and 2050 using the A1B scenario (°C)



Source: IFPRI calculations based on downscaled climate data available at <http://ccafs-climate.org/>.

3.1.2 Crop physiological response to climate change

The crop-specific CERES models of the DSSAT crop modeling system (Jones et al., 2003) were used to simulate responses of major crops (rice, wheat, maize, soybeans, and groundnuts) to climate, soil, and nutrient availability at the current locations based on the SPAM dataset of crop location and management techniques (You and Wood, 2006). In addition to temperature and precipitation, we also used soil data, assumptions about fertilizer application and planting month, and additional climatic parameters such as the length of sunshine duration.

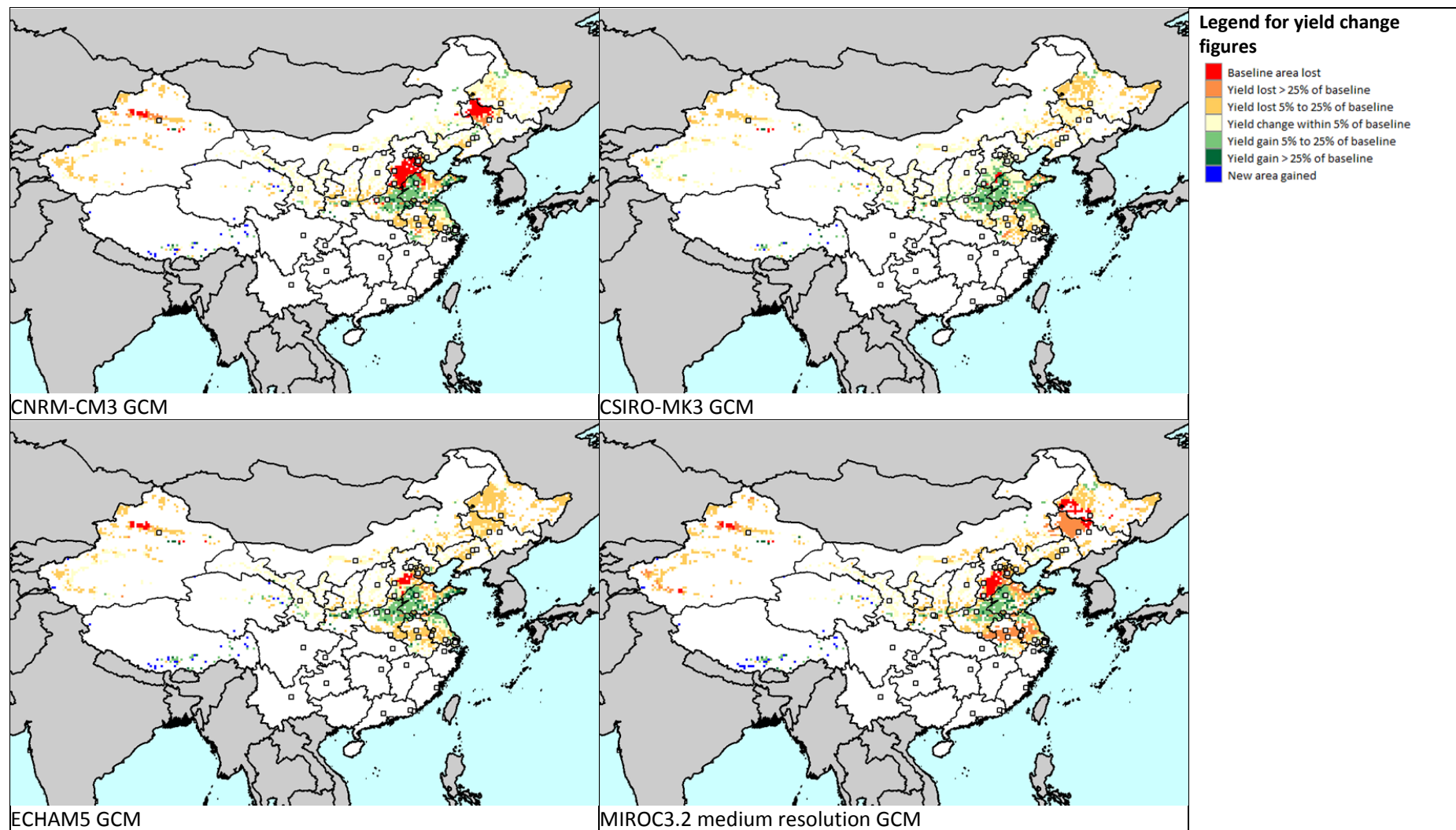
We then repeated the exercise for each of the 4 future scenarios through 2050. For all locations, variety, soil and management practices were held constant. The simulated future yields were subsequently compared to the current or baseline yields - which were also simulated using DSSAT - to drive the yield differences. The obtained results for wheat, maize, and rice - under both irrigated and rainfed farming - were mapped in Figure 19 to Figure 24, respectively, for qualitative evaluation of climate change impact on crop yield in 2050 relative to yield under current climate in 2000. The legends of these figures were intentionally kept identical. Yield loss was mapped in yellowish/brownish colors and yield gain was mapped in greenish/bluish colors.

The changes of the yields of maize, rice, and wheat under two typical GCMs - CSIRO and MIROC - cross-driven by the A1B and B1 emission scenarios, respectively, in 2050 over 2000 were summarized in Table 5. Chinese crops respond mildly to climate change. Irrigated yields tend to decrease, as in the case of maize in particular (Figure 21). This decrease would probably be caused by the decreasing availability of irrigation water due to more intense competition of water use from urban sprawl and due to groundwater depletion in major maize regions such as the North China Plain. Rainfed yields tend to increase because the expected warmer and wetter climates under both CSIRO and MIROC scenarios are favorable to these rainfed varieties (Figure 17). Overall, the yields of maize and rice will increase slightly, but the yield of wheat will decrease only marginally, by 2050 under the climate change scenarios considered.

Table 5. Yield change under climate change scenarios in 2050 over 2000, %

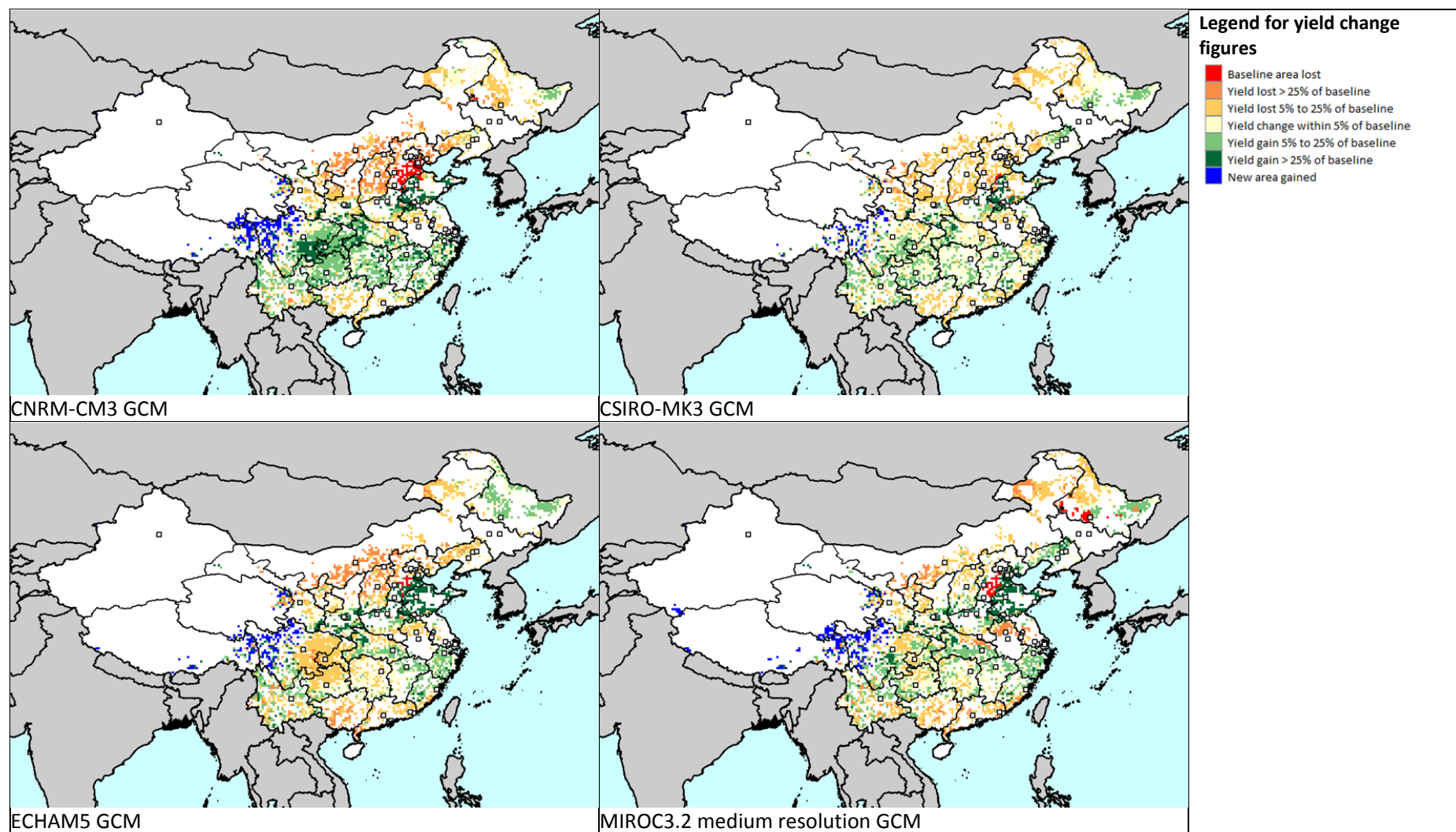
Scenario	Maize	Rice	Wheat
Irrigated			
CSIRO A1B	-3.49	0.44	2.96
CSIRO B1	-4.08	0.02	1.39
MIROC A1B	-4.18	-5.09	-9.81
MIROC B1	-3.96	-1.92	-4.53
Rainfed			
CSIRO A1B	3.75	12.38	2.01
CSIRO B1	3.7	3.46	-2.11
MIROC A1B	2.51	14.32	2.89
MIROC B1	1.93	12.08	2.97
Average			
CSIRO A1B	0.85	2.83	2.37
CSIRO B1	0.59	0.71	-0.78
MIROC A1B	-0.17	-1.21	-1.94
MIROC B1	-0.43	0.88	0.12
All scenarios	0.21	0.80	-0.06

Figure 19. Yield change between 2000 and 2050 under four climate change scenarios: irrigated wheat



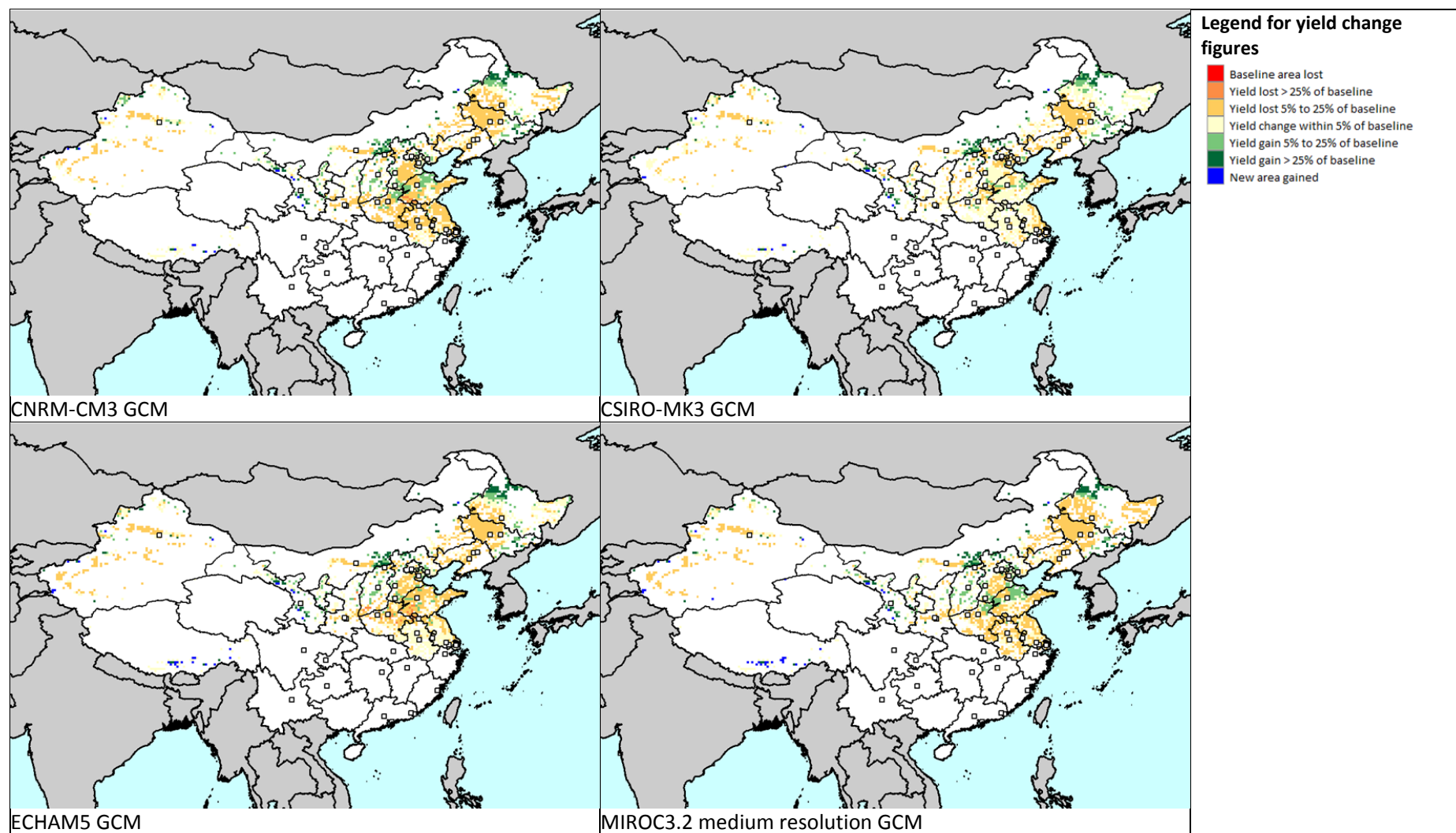
Source: IFPRI calculations based on downscaled climate data and DSSAT model runs

Figure 20. Yield change between 2000 and 2050 under four climate change scenarios: rainfed wheat



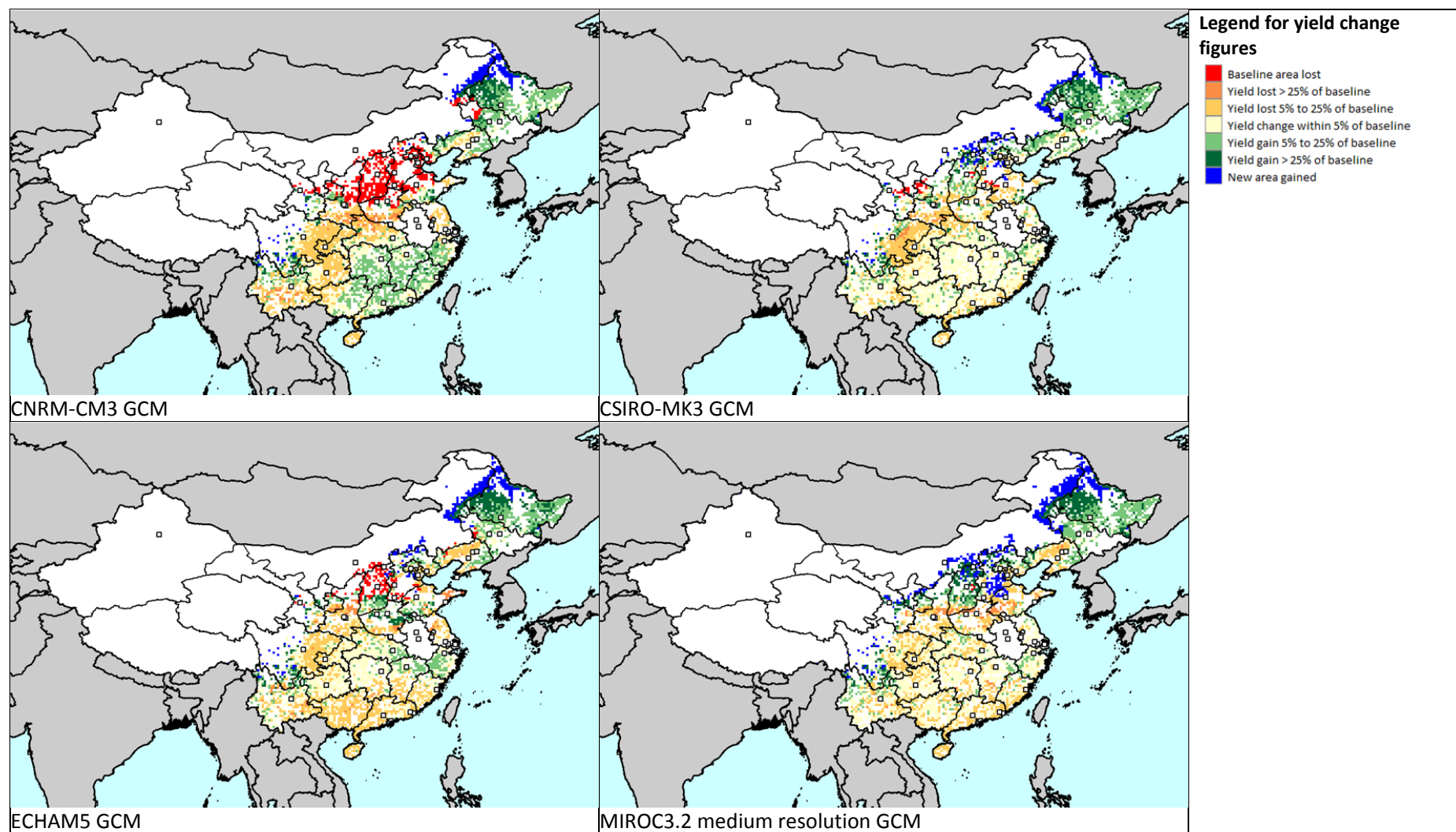
Source: IFPRI calculations based on downscaled climate data and DSSAT model runs

Figure 21. Yield change between 2000 and 2050 under four climate change scenarios: irrigated maize



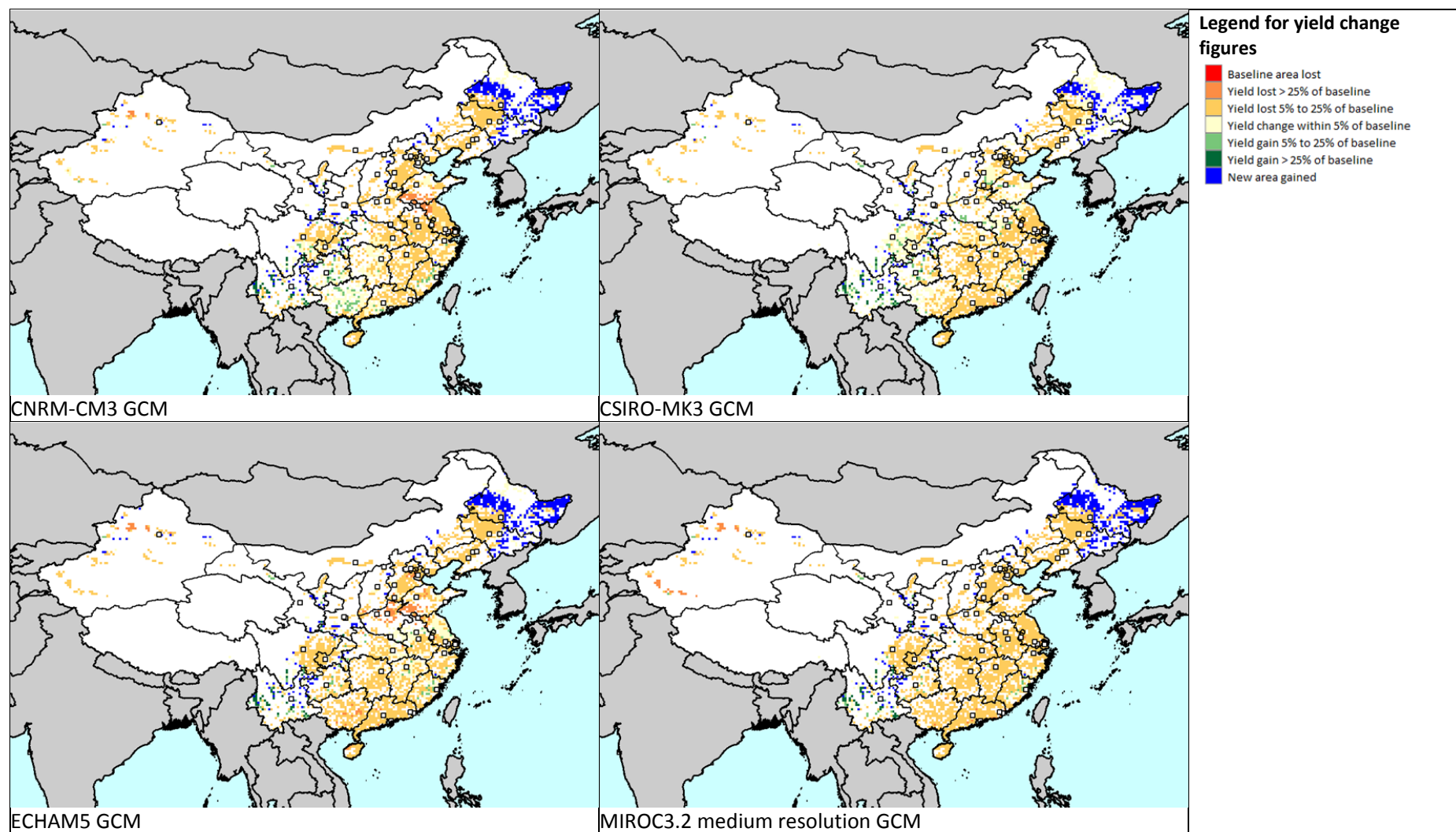
Source: IFPRI calculations based on downscaled climate data and DSSAT model runs

Figure 22. Yield change between 2000 and 2050 under four climate change scenarios: rainfed maize



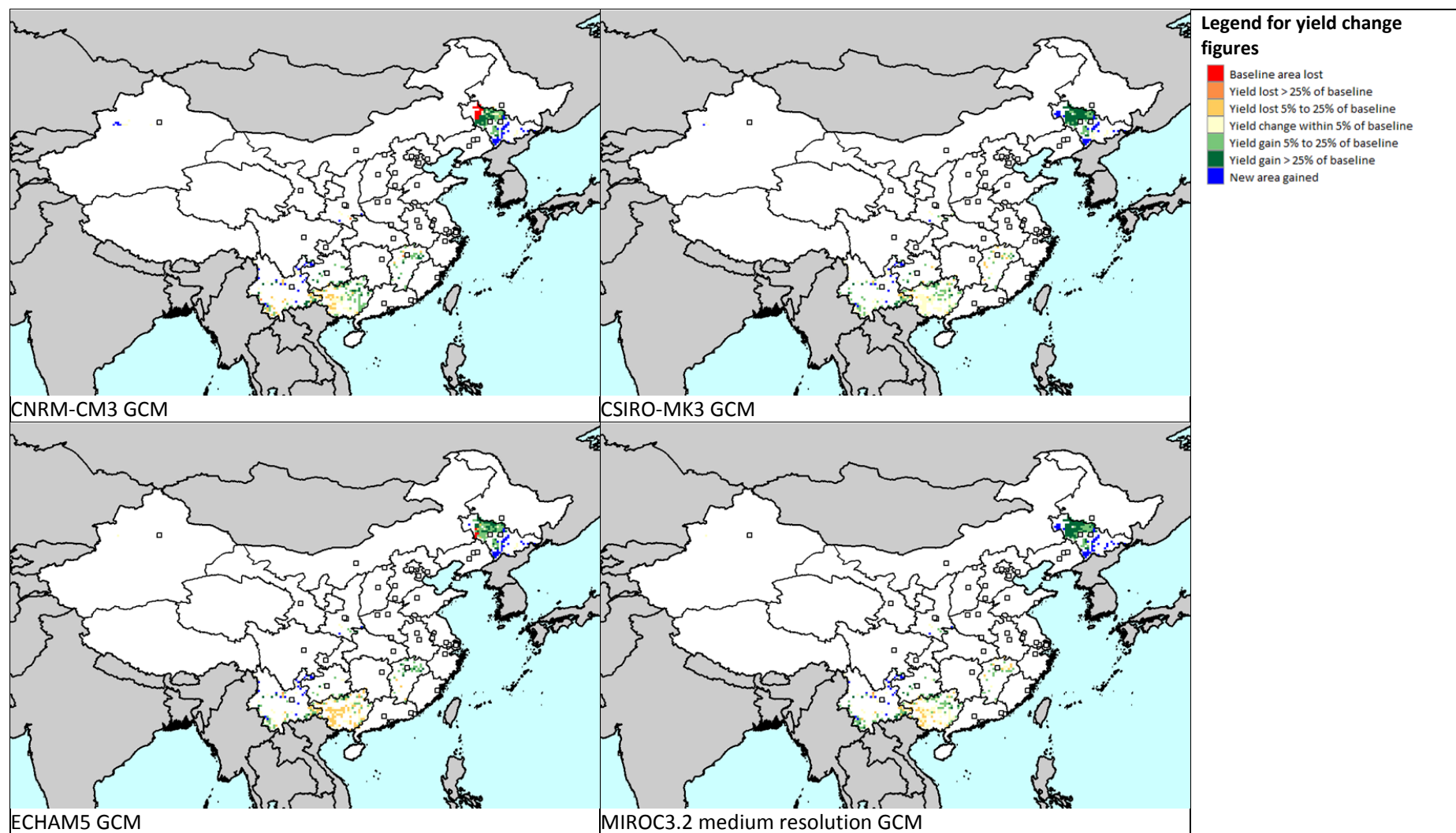
Source: IFPRI calculations based on downscaled climate data and DSSAT model runs

Figure 23. Yield change between 2000 and 2050 under four climate change scenarios: irrigated rice



Source: IFPRI calculations based on downscaled climate data and DSSAT model runs

Figure 24. Yield change between 2000 and 2050 under four climate change scenarios: rainfed rice

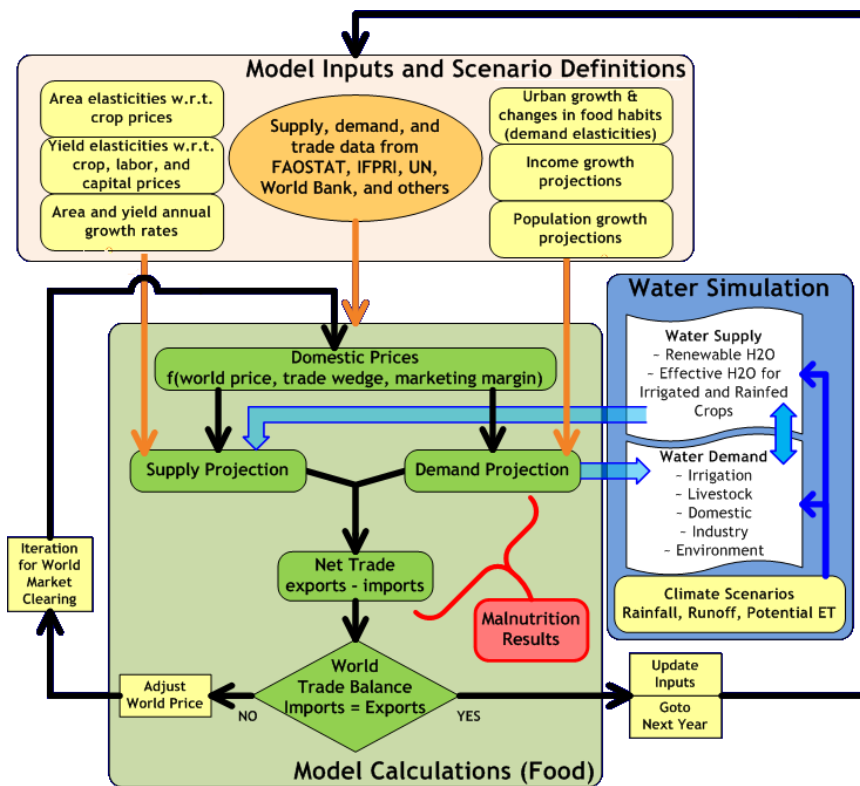


Source: IFPRI calculations based on downscaled climate data and DSSAT model runs

3.1.3 From biophysical scenarios to socioeconomic consequences: the IMPACT model

Figure 25 provides a diagram of the links among the three models used in this analysis: IFPRI's IMPACT model (Cline and Zhu, 2008), a partial equilibrium agriculture model that emphasizes policy simulations; a hydrology model and an associated water-supply demand model incorporated into IMPACT; and the DSSAT crop modeling suite (Jones et al., 2003) that estimates yields of selected crops under varying management systems and climate change scenarios. The modeling methodology reconciles the limited spatial resolution of macro-level economic models that operate through equilibrium-driven relationships at a national level with detailed models of biophysical processes at high spatial resolution. The DSSAT system is used to simulate responses of five important crops (rice, wheat, maize, soybeans, and groundnuts) to climate, soil, and nutrient availability, at current locations based on the SPAM dataset of crop location and management techniques. This analysis is done at a spatial resolution of 15 arc minutes, or about 30 km at the equator. These results are aggregated up to the IMPACT model's 281 spatial units, called food production units (FPUs, Figure 26). The FPUs are defined by political boundaries at the river basin scale (See Appendix for FPUs in China).

Figure 25. The IMPACT modeling framework



Source: Nelson et al. (2010).

Figure 26. The 281 FPUUs adopted by the IMPACT model



Source: Nelson et al. (2010)

3.2 Income and Demographic Scenarios

IFPRI's IMPACT model has a wide variety of options for exploring plausible scenarios. The drivers used for simulations include: population, GDP, climate scenarios, rainfed and irrigated exogenous productivity and crop-specific area growth rates, and irrigation efficiency. In all cases except climate, the country-specific (or more disaggregated) values can be adjusted individually. Differences in GDP and population growth define the overall scenarios analyzed here, with all other driver values remaining the same across all the three socio-economic pathway scenarios.

Table 6 documents the GDP and population growth choices for these three overall scenarios adopted in this analysis.

Table 6. GDP and population choices for the three overall socio-economic pathway scenarios

Parameter	Pessimistic	Baseline	Optimistic
GDP, constant 2000 US\$	Lowest of the four GDP growth rate scenarios from the Millennium Ecosystem Assessment GDP scenarios (Millennium Ecosystem Assessment, 2005) <i>and</i> the rate used in the baseline (next column)	Based on rates from World Bank EACC study (World Bank, 2010), updated for Sub-Saharan Africa and South Asian countries	Highest of the four GDP growth rates from the Millennium Ecosystem Assessment GDP scenarios <i>and</i> the rate used in the baseline (previous column)
Population	UN High variant, 2008 revision	UN medium variant, 2008 revision	UN low variant, 2008 revision

Source: Based on analysis conducted for Nelson et al. (2010).

The IMPACT modeling suite was run with four climate model and scenario combinations; the CSIRO and the MIROC GCMs with the A1B and the B1 scenarios. Those four outputs were used with each of the three GDP per capita scenarios. Table 7 shows the annual growth rates for different regional groupings as well as for China. Figure 27 illustrates the pathways of per-capita income growth for China under these scenarios. In all scenarios, China's income growth exceeds those of the developed group of countries and most developing countries, although it is expected to slow from the current rapid pace.

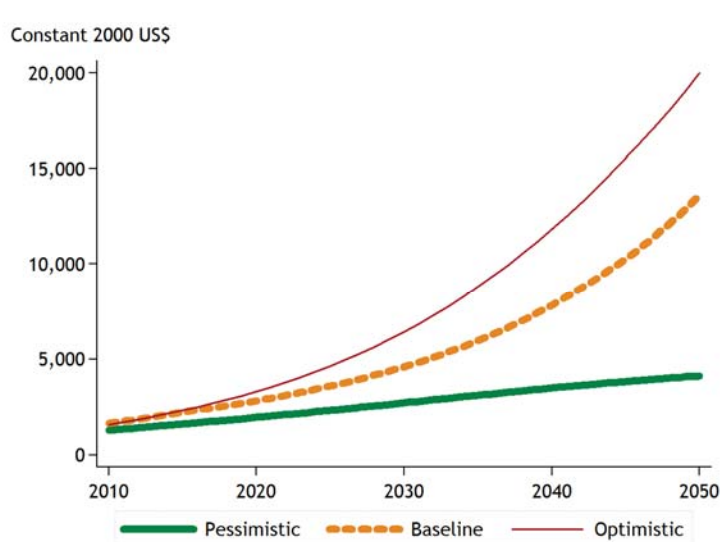
Table 7. Average scenario per capita GDP growth rates (percent per year)

Category	1990–2000	2010–2050		
		Pessimistic	Baseline	Optimistic
China	8.09	3.65	5.18	6.24
Developed	2.7	0.74	2.17	2.56
Developing	3.9	2.09	3.86	5
Low-income developing	4.7	2.6	3.6	4.94
Middle-income developing	3.8	2.21	4.01	5.11
World	2.9	0.86	2.49	3.22

Source: World Development Indicators for 1990–2000 and authors' calculations for 2010–2050.

Figure 27 graphs the three GDP per capita scenario pathways, derived from the three GDP projections and the three population projections obtained from the United Nations Population office. The "optimistic scenario" combines high GDP with low population. The "baseline scenario" combines the medium GDP projection with the medium population projection. Finally, the "pessimistic scenario" combines the low GDP projection with the high population projection.

Figure 27. GDP per capita scenarios



Source: Based on IMPACT results of July 2011, computed from World Bank and United Nations population estimates (2008 revision).

Note that the scenarios used apply to all countries; that is, in the optimistic scenario, every country in the world is assumed to experience high GDP growth and low population growth.

The GDP per capita scenario results for China and the U.S. are summarized in Table 8. In the pessimistic scenario, U.S. per capita income increases less than 2 times while in the optimistic scenario, it almost triples between 2010 and 2050. The Chinese per capita income triples in the pessimistic scenario and increases almost 12 times in the optimistic scenario. However, despite China's much more rapid growth than in the U.S. its per capita income in 2050 is still only one-fifth of that in the U.S.

Table 8. China and U.S. per capita income scenario outcomes for 2010, 2030, and 2050 (2000US\$ per person)

	2010	2030	2050
Pessimistic			
China	1,264	2,699	5,640
U.S.	37,504	51,132	58,291
Baseline			
China	1,627	4,590	13,584
U.S.	37,723	56,517	88,841
Optimistic			
China	1,551	6,433	20,000
U.S.	39,218	67,531	101,853

3.3 Crop-specific Agricultural Vulnerability Scenarios

Figure 28 to Figure 30 show simulation results from the IMPACT model for wheat, maize, and rice. Each crop has five graphs, showing production, yield, area, net export, and world price, respectively.

Several of the figures below use box and whisker plots to present the effects of climate change modeled by the MIROC and CSIRO GCMs under the A1B and B1 emission scenarios in the context of each of the economic and demographic pathways (optimistic, baseline, and pessimistic). Each box has 3 lines. The top line represents the 75th percentile, the middle line represents the median, and the bottom line represents the 25th percentile.²

Wheat yield in China will increase steadily from 2010 to 2050 by 17%, partly due to the increase in factor inputs stimulated by the significant increase of world wheat price by 60% (Figure 28). Accordingly, wheat production will increase from 100 million tons in 2010 to 123 million tons in 2050, although the wheat area remains constant at 24–25 million hectares during 2010–2050 under all scenarios.

World maize price is projected to increase more than other cereals in percentage terms. Maize price doubles from about US\$100 in 2010 to US\$200 in 2050 under all scenarios (Figure 29). As a result, the maize yield will jump by 45% from 5.1 tons per hectare in 2010 to 7.4 tons per hectare in 2050, despite the marginal effect of climate change on maize yield (Table 5). In line with the price crease, maize area will expand by 18% from 28 million hectares in 2010 to 33 million hectares in 2050. Consequently, maize production will increase significantly by 70%, from 140 million tons in 2010 to 240 million tons in 2050.

Although world prices of key commodities are all expected to rise under all scenarios, the pattern of rice price increase is more distinct. The rice price pathways diverge significantly depending on the overall scenario, with the pessimistic scenario leading to the highest prices (Figure 30) – a consequence of higher population and lower income in countries where rice is a staple for the poor. Even under the optimistic scenario, rice price will still rise by 40% during 2010–2050. Despite price increases, rice yield is expected to increase only slightly from 4.1 tons per hectare in 2010 to 4.7 tons per hectare in 2050. Rice production remains roughly constant until 2025 at 125 million tons, or a 3% increase over 2010, and then declines to 90% of current levels in 2050 as area devoted to rice declines from around 30 million hectares in 2010 to 23 million hectares in 2050.

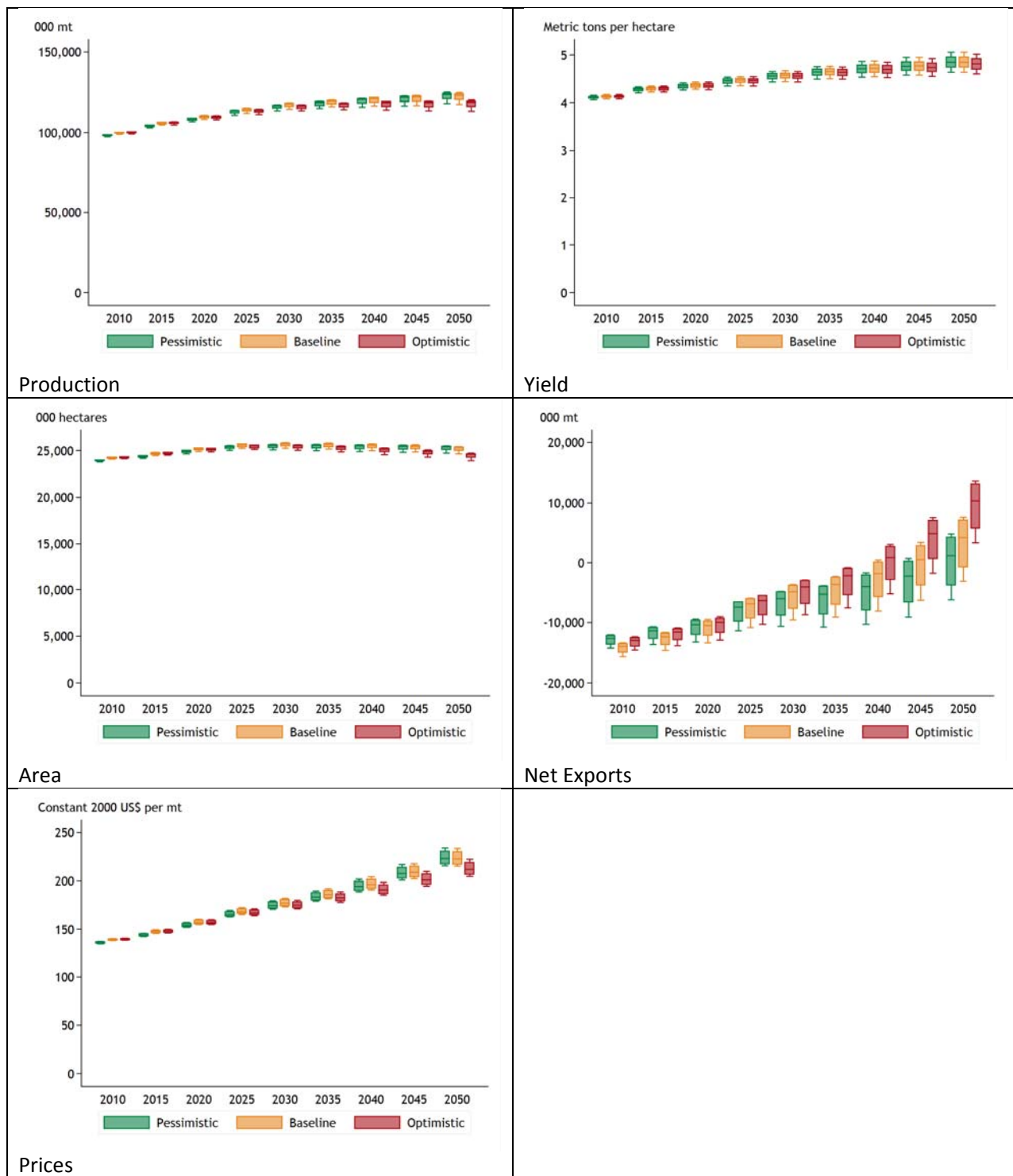
The discrepancy between price increase and area decrease reflects the fact that demand for rice tends to decrease as income increases due to the effect of higher income on rice consumption and diet pattern change (Chern et al., 2003; Kearney, 2010). It is interesting to observe that China will probably turn from a net importer of rice (slightly less than 5 million tons in 2010) to a net exporter by 2020 (Figure 30). Under the baseline and the optimistic overall scenarios in 2050, China is expected to have a surplus of 5–9 million tons of rice for export. Under the pessimistic scenario, China remains a net importer of rice by 2050 but with a much smaller volume of 1 million tons.

² These graphs were generated using Stata with Tukey's (Tukey, 1977) formula for setting the whisker values. If the interquartile range (IQR) is defined as the difference between the 75th and 25th percentiles, the top whisker is equal to the 75th percentile plus 1.5 times the IQR. The bottom whisker is equal to the 25th percentile minus 1.5 times the IQR (StataCorp, 2009).

Perhaps the most promising scenario result is that China will remain a major importer of maize from the world food market at the scale of ~20 million tons per year, although the domestic production capacity is expected to grow constantly during 2010–2050, resulted from yield improvements and area expansions (Figure 29). Obviously, the imported maize will be overwhelmingly used as feed to meet the domestic demands of animal products (Chern et al., 2003).

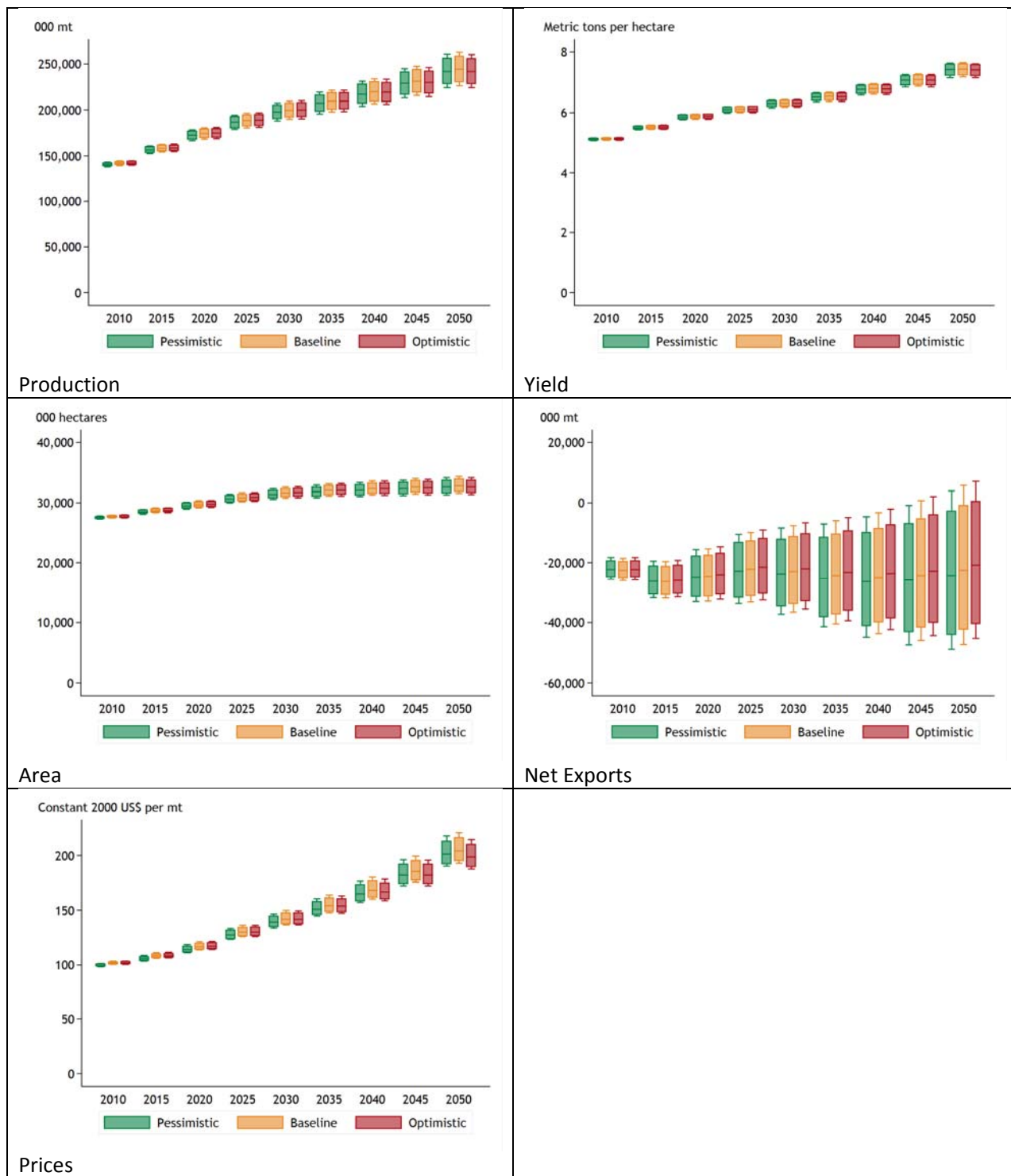
China is expected to become a smaller and smaller importer of wheat (Figure 28). The wheat self-sufficiency level will approach 100% by 2050 under all scenarios.

Figure 28. Scenario outcomes for wheat production, yield, area, net export, and price



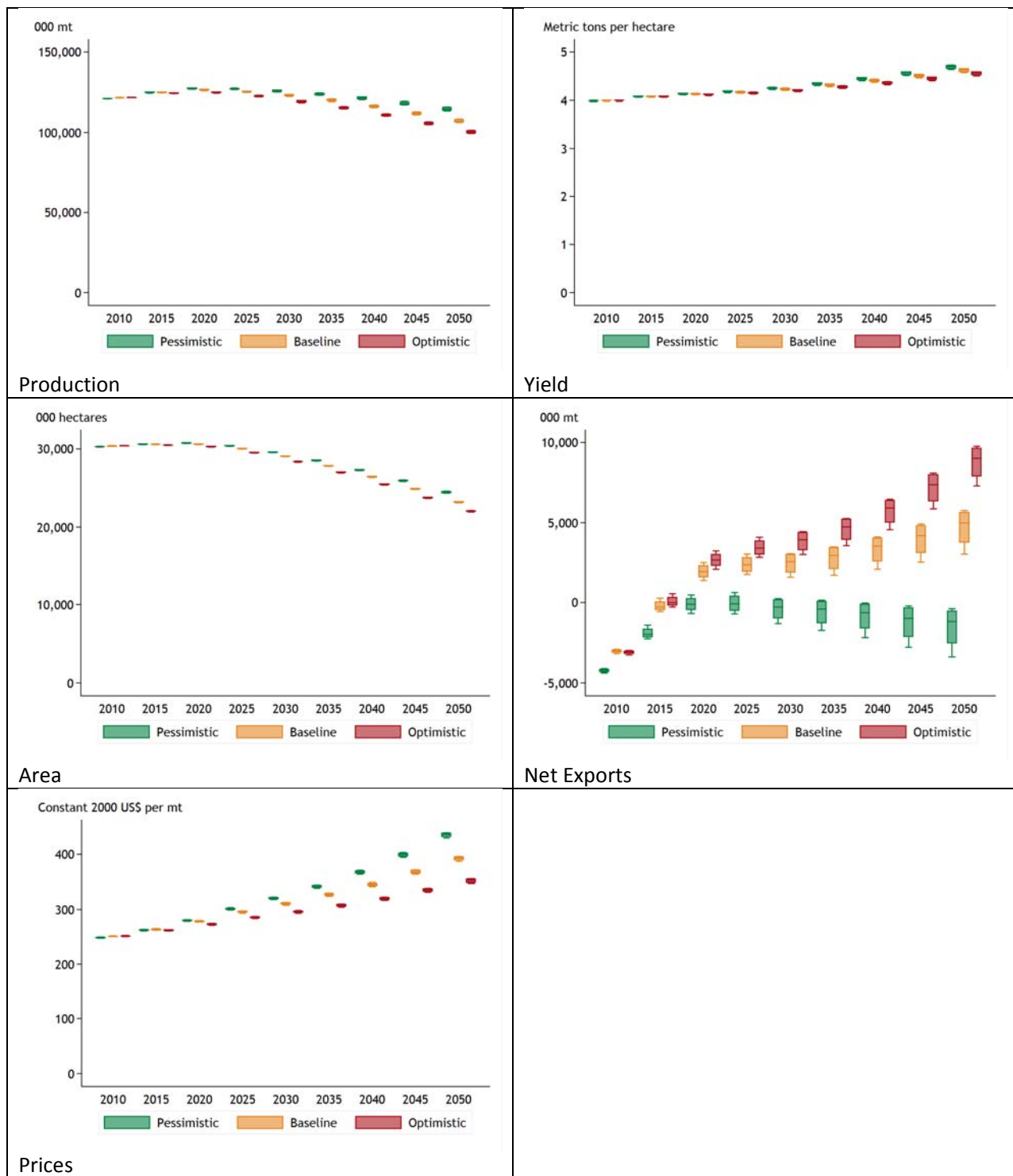
Source: Based on IMPACT results of July 2011.

Figure 29. Scenario outcomes for maize production, yield, area, net export, and price



Source: Based on IMPACT results of July 2011.

Figure 30. Scenario outcomes for rice production, yield, area, net export, and price



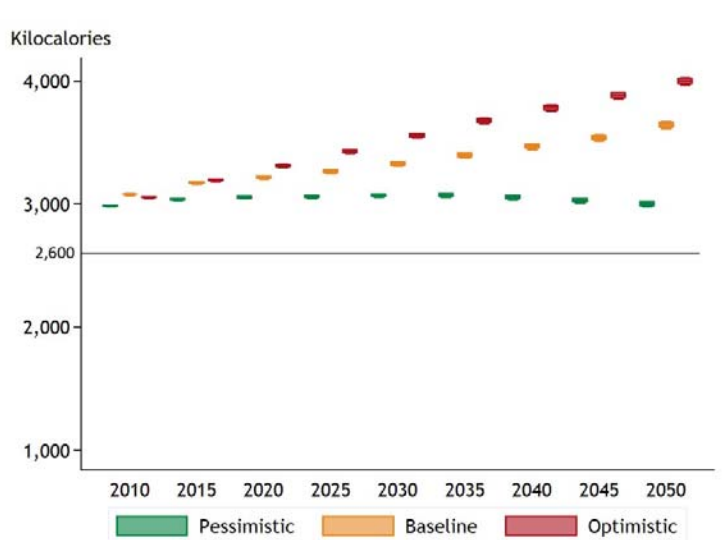
Source: Based on IMPACT results of July 2011.

3.4 Human Vulnerability Scenarios

Figure 31 shows scenario outcomes for the average daily kilocalories per capita and Figure 32 the number of malnourished children under five. The story is much the same in both figures in qualitative terms. The baseline and optimistic scenarios show increases in calorie availability. The pessimistic scenario shows no increase but a stable level at about 3,000 kilocalories per day across the period 2010–2050. Climate change has relatively little effect within an overall scenario.

These scenario levels of calorie availability are well above the 2020 goal of 2,600 kilocalories per day stipulated by the Chinese Food and Nutrition Development Strategy (MOA, 2002; Xu, 2011). These levels allow sufficient development rooms to meet higher nutrition requirements in China by 2050. The Chinese food security in terms of per capita calorie availability will be unlikely compromised by 2050.

Figure 31. Average daily kilocalories availability under multiple income and climate scenarios (kilocalories per person per day)

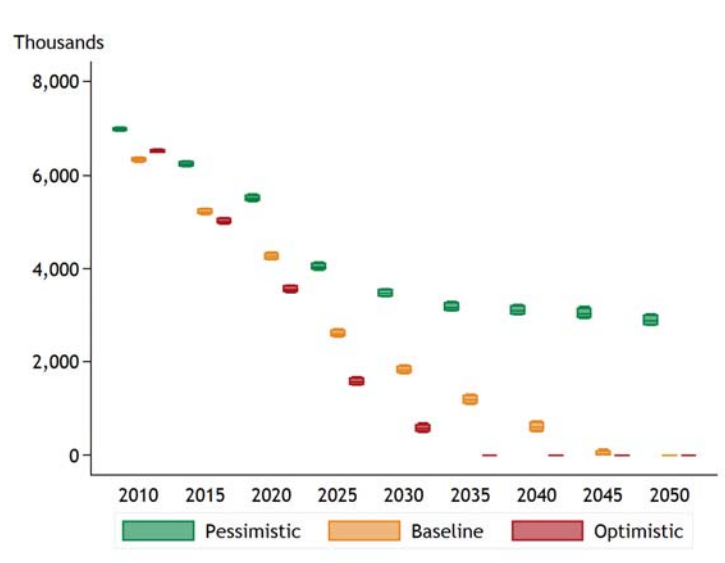


Source: Based on IMPACT results of July 2011.

As expected, the baseline and optimistic scenarios do best in reducing malnourished children. In the optimistic scenario the count drops close to zero, while with the baseline it falls from about 8 million children in 2010 to about 2 million in 2050. The pessimistic scenario is also the least desirable from the perspective of reducing malnourished children. After a slow decline to just below 6 million by the mid-2020s, the decline stops and the number increases slightly.

As the box and whiskers plots indicate, within a particular overall scenario climate change has relatively little impact on the number of malnourished children. The range in 2050 from the different climate scenarios is typically less than 1 million children malnourished. The reason, as discussed above, is the function of trade to buffer the impact of climate change on domestic food production.

Figure 32. Number of malnourished children under 5 years of age under multiple income and climate scenarios



Source: Based on IMPACT results of July 2011.

4 Agriculture and Greenhouse Gas Mitigation

4.1 Agricultural Emissions History

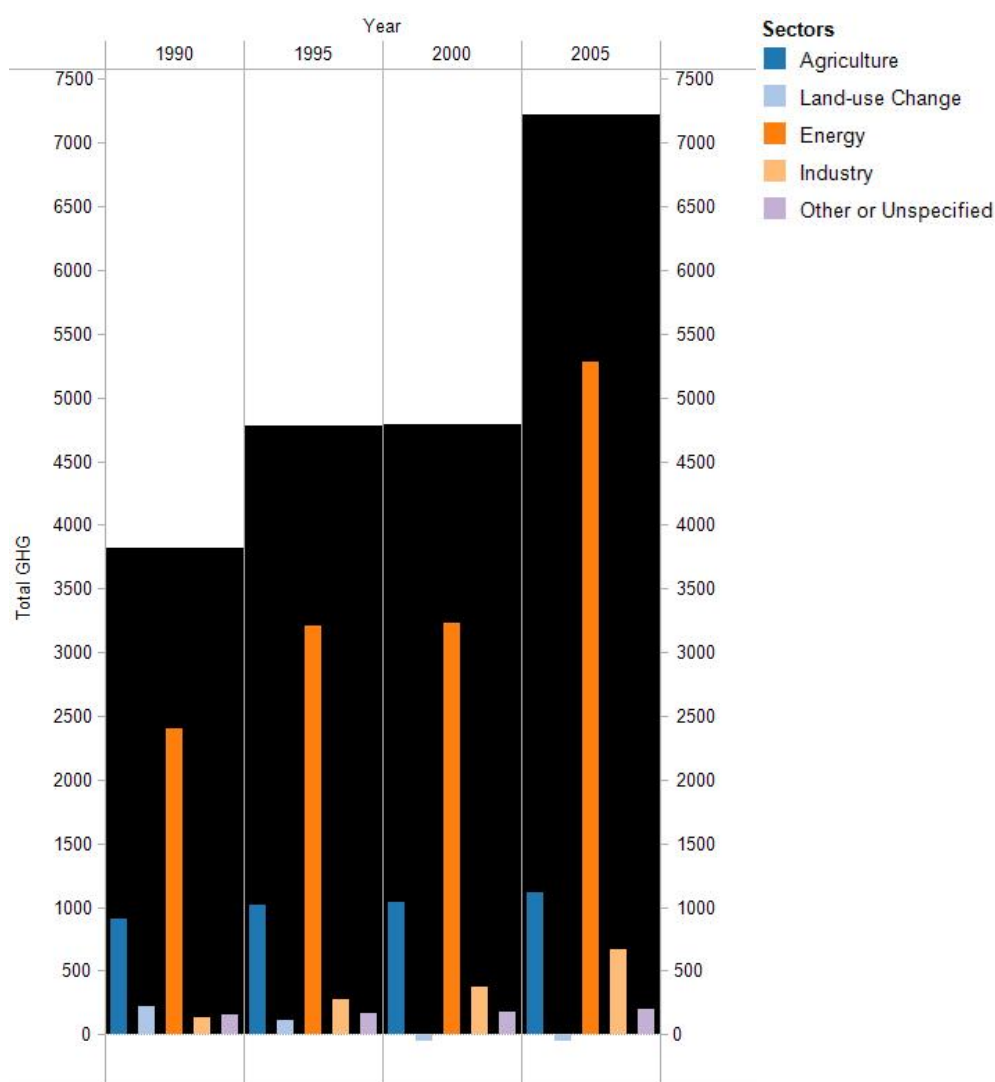
Global atmospheric concentrations of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in CO₂ concentration are due primarily to fossil fuel use and land use change, while those of CH₄ and N₂O are primarily due to agriculture. A wide range of direct and indirect measurements confirm that the atmospheric mixing ratio of CO₂ has increased globally by about 100 ppm (36%) over the last 250 years, from a range of 275 to 285 ppm in the pre-industrial era (1000-1750 CE) to 379 ppm in 2005. The global average abundance of CH₄ was measured at 1,774 ppb in 2005, unprecedented in at least the last 650,000 years. Ice core data for N₂O have shown relatively little changes over the first 1,800 years of this record extending back 2,000 years. Since 1750, atmospheric N₂O levels have risen rapidly from 270 ppb to 319 ppb in 2005 (Forster et al., 2007).

Agriculture is known as one of the major sources of greenhouse has (GHG) emissions. CO₂ is released largely from microbial decay or burning of plant litter and soil organic matter. Methane is produced when organic materials decompose under anoxic conditions, notably from fermentative digestion by ruminant livestock, stored manures and rice grown under flooded conditions. N₂O is produced by the microbial transformations of nitrogen (N) in soils and manures, and is often enhanced where available N exceeds plant requirements, especially under wet conditions (Smith and Olesen, 2010).

Systematic researches (WRI, 2011) showed that Chinese agriculture emitted 1,136 million tons of CO₂ equivalent (CO₂-eq) in 2005, increasing by 12% from 1,015 million tons in 1995 (Figure 33), measured in terms of the commonly referred IPCC global warming potential. The results from an independent Chinese inventory in 1994 (Dong et al., 2008) revealed that CH₄ from agriculture accounted for 50% of China's total CH₄ emission, and that at least 90% N₂O emission in China was released from agriculture.

Agriculture has been the second largest GHG emitter in China, only next to the energy sector at least for the past two decades (Figure 33). In 2005, agricultural emissions contributed 16% -- while emissions from energy production contributed 72% -- to China's total GHG emission of ~7,200 million tons CO₂-eq as similarly reported by Chen and Zhang (2010).

Figure 33. GHG emissions (CO₂, CH₄, N₂O, PFCs, HFCs, SF₆) in China by sector, million ton



Source: Climate Analysis Indicators Tool (CAIT) Version 8.0. (WRI, 2011)

4.2 Agricultural Mitigation Potential

There is a significant potential for GHG mitigation in agriculture through active management of agricultural systems. Integrated assessment (Smith et al., 2008) indicated that the technical potential of global agricultural mitigation would be in the range of 5,500–6,000 million tons CO₂-eq per year by 2030 for all gases. However, this biophysical potential can never be fully achieved due to institutional, educational, social, and political constraints (Freibauer et al., 2004). In other words, the full implementation of the biophysical mitigation potential will have exceptionally high costs at e.g., 5,000 US\$ per ton of CO₂-eq. Economic evaluation suggested that much lower prices of 20, 50, and 100 US\$ per ton of CO₂-eq would deliver 35%, 43%, and 56% of total mitigation potential by 2030, respectively. Therefore, global agricultural mitigation potential achievable at carbon prices of 20, 50, and 100 US\$ per ton of CO₂-eq is evaluated as 1,900–2,100, 2,400–2,500, and 3,100–3,300 million tons of CO₂-eq per year, respectively (Smith et al., 2008).

In 2010, China produced 550 million tons of staple grains on 110 million hectares of cropland, of which 27% was rice. As the world's biggest producer and applicator of chemical fertilizers (Jin, 2012), China consumed 56 million tons of fertilizers in 2010, of which 43% was nitrogen (N) fertilizers. A recent national assessment (Editorial Board, 2011) showed that improved agronomic practices associated with rice management could mitigate 30–40% of CH₄ from the Chinese rice field, equivalent to 130–170 million tons of CO₂-eq. Intermittent irrigation, a practice of draining the wetland rice once or several times during the rice growing season, for example, can effectively reduce CH₄ emissions (Yan et al., 2003). In the off-rice season, CH₄ emissions can be reduced by keeping the soil as dry as possible to avoid

waterlogging. Animal waste management also has the potential to reduce CH₄ and N₂O emissions. Anaerobic digestion, composting, proper temperature of storage tanks, compacting, and coverage were identified as approaches with the potential of 40–60% GHG emission reduction compared to traditional handling and use of farmyard manure (Bellarby et al., 2013). Fertilizer optimization practices, such as precision fertilization (placing N more precisely into the soil to make it more accessible to crop roots), fertilizer prescription (adjusting application rates on precise estimation of crop needs; avoiding overdose), slow-release fertilizer forms, and nitrification inhibitor use, all have the potential to reduce cropland N₂O emissions (Venterea et al., 2012). Moreover, cropland carbon management measures have the potential of soil carbon sequestration at 47–96 ton C per km² per year. The number of household biogas tank users in rural China is expected to reach 60 million by 2015, offering a capacity of 23.3 billion m³ in biogas production; 8,000 centralized biogas facilities are planned to be built by 2015, with an additional capacity of 670 million m³. Household tanks and centralized facilities will jointly deliver a mitigation potential of 81–123 million tons of CO₂-eq per year through reduction of CH₄ emissions from animal wastes and displacement of CO₂ emissions from fossil fuels.

4.3 Adaptation and Mitigation Synergies

The challenges facing the Chinese agriculture within the climate change context are to ensure food security and to adapt to a changing and more variable climate while reducing emissions. As already discussed above, mitigation options are basically practices engaged to reduce methane or nitrous oxide emissions or to increase soil carbon stocks. Essentially, all mitigation options affect the carbon and/or nitrogen cycle of the agroecosystem (Smith and Olesen, 2010). Adaptation measures involve enhancing the resilience of the production systems through improved management. Most categories of adaptation measures for climate change have positive impacts on mitigation, although some mitigation measures may have negative impact on the adaptive capacity of farming systems. Priorities should be given to the following measures:

- *Cropland management.* The aim of cropland management in the context of climate change is two-fold, both to mitigate GHG emissions and to increase soil C storage. The most important GHGs from dry croplands are N₂O and CO₂, while the dominant gas from rice wetlands is CH₄. Agronomic practices thus focus on enhancing C input and retention in soils and at the same time aim to reduce N₂O by avoiding periods of excessive N contents in soils and by minimizing N losses from the agroecosystem (Jin, 2012). For paddy rice, innovative water management schemes, such as intermittent irrigation in combination with prolonged off-rice drainage, are practiced to reduce CH₄ and N₂O emissions (Yan et al., 2003). Adding organic matter in soil, primarily a mitigation option, can enhance crop yield and improve yield stability (Ye et al., 2008; Pan et al., 2009) and at the same time strengthen the adaptive capacity of soils; it is thus a “win-win-win” option (Smith and Olesen, 2010) which is almost always desirable (Powelson et al., 2011). The common practice of adding cereal straw to soil usually leads to an increase in soil C content. Typically under temperate climate, about one-third of plant material added to soil is returned after one year, with two-thirds being emitted; under tropical conditions less is retained in soil. Some of the organic materials such as animal manures, composts or residue from biogas production have the additional benefit of nutrient recycling which could in turn decrease fertilizer dependency. However, care has to be taken in managing these nutrients, especially N and P, to avoid excess inputs and/or availability at times of small crop uptake and large risks of losses (Jordan-Meille et al., 2012). Adoption of conservation tillage (Baker et al., 2007) but under suitable soil and climatic conditions (Antle and Ogle, 2012), agroforestry (Mutuo et al., 2005), and reversion of marginal or degraded croplands to native vegetation (Yin and Yin, 2010) are also good examples of adaptation and mitigation synergies;
- *Farming system design.* Intensive farming systems in China generally have a low sensitivity to climate change, given the magnitude of yield change under future scenarios (Table 5). However, there is a large variation across China in climatic, soil, land use and economic conditions which are expected to influence the adaptive capacity of farming systems (Olesen et al., 2011). Adaptation to increased variability of temperature and rainfall involves increasing the resilience of the farming systems. This may be done by improving soil water holding capacity through adding organic materials into arable soils (see above) or by adding diversity to crop rotations (Mäder et al., 2002) by, e.g., selecting crops or varieties that follow better in a rotation and adding legumes to cereal-based systems, the latter of which reduces reliance on N inputs and thus limits N₂O emissions. The effects of extremely high temperatures on crops may be reduced through modifying the microclimate, e.g. by adding shade and shelter as in agroforestry systems (Lin et al., 2008). Farming systems

can be fine-tuned to a changed climate by e.g. providing temporary vegetative cover between conventional crops. These “catch” or “cover” crops conserve soil moisture, add C to soils (Freibauer et al., 2004) and may also extract plant-available N left over by the preceding crop, thereby reducing N₂O emissions. Farming systems can also be more actively modified by shifting the planting dates of crops either to maximize the utilization of climatic resources or to minimize the impacts of unfavorable conditions (Jalota et al., 2012). These adaptation options will in general, if properly applied, reduce GHG emissions by improving N use efficiency and enhancing soil C storage;

- *Water management.* About 18% of the world’s croplands receive supplementary water through irrigation (Millennium Ecosystem Assessment, 2005). This number is even higher in China. The average irrigation rates for two of the key crops in China, maize and wheat, are evaluated at 52% and 38%, respectively, using satellite remote sensing (Ye et al., 2012). Irrigation can enhance C storage in soil through improved yields and residue returns. But some of these gains may be offset by CO₂ from energy use or from N₂O from higher moisture and N inputs. Drainage of croplands in humid environments can promote productivity and perhaps suppress N₂O emissions by improving aeration (Monteny et al., 2006). Any N lost through drainage, however, is susceptible to loss as N₂O. Therefore, altering amounts and timing of irrigation (or drainage as in the case of rice) forms the basis for valid adaptation options (Howden et al., 2007). In regions receiving more rainfall, water management should focus on the prevention of water logging, erosion, and nutrient leaching; in areas expecting less rainfall, attention should be given to wider use of technologies to harvest water, conserve soil moisture, and use and transport water more effectively. As a newly developed adaptation option in China’s erosion-prone Loess Plateau, for example, bio-fencing, that is, using shrubs such as *amorpha* and *Korshinsk* peashrub around straw-mulched fields as a biological fence, produces additional benefits (extra 10 mm water storage over 1 m soil depth; and nearly 20% higher yield for spring wheat) if used in combination with terracing and straw mulching on soil water storage (e.g. additional 26 mm over 1 m soil depth under straw mulching) and yield (15% higher spring wheat yield under mulching) and erosion control (Bindraban et al., 2012);
- *Bioenergy.* Agricultural crops and residues are seen as sources of feedstock for bioenergy to displace fossil fuels. Biofuels release CO₂ when burned, but this CO₂ is of recent atmospheric origin and displaces CO₂ which otherwise would have come from fossil C. The net benefit to atmospheric CO₂, however, depends on energy used in growing and processing the bioenergy feedstock, and on emissions from land use change in case, e.g., if forest is cleared to grow energy crops (Smith et al., 2008). As the third largest producer of bio-ethanol, China used some 5 million tons of maize and wheat, or 1% of its total grain harvest, to produce 1.6 million tons of ethanol in 2005. The Chinese ethanol output is expected to rise to 10 million tons in 2020 and to 13 million tons in 2030, threatening future Chinese food security (Ye and Van Ranst, 2009). There is a particularly high risk of negative effects of mitigation measures related to the increased removal of crop residues from cropping systems for use in bioenergy, if this means that soil C contents are being depleted (Smith and Olesen, 2010). The outlook for bioenergy in China and elsewhere is to grow energy crops – preferably innovative perennials which have low water demand – on suitable wasteland. Turning this outlook into a plausible option needs coordinated efforts through international cooperation on research and development in this particular field and beyond.

5 Conclusions

China has been extraordinarily successful in transforming its highly planned economy into a free market-based system within a considerably short period of a few decades, especially in the agricultural sector which enables China to feed approximately 20% of the world’s population on less than 7% of the world’s cropland. The analysis of the IMPACT model results presented in this paper suggests that Chinese agriculture is relatively resilient to climate change compared to other parts of the world. In light of the slowing in population growth before ~2030 and of the outlook of a decreasing population size thereafter, the overall status of the Chinese food security by the middle of the twenty-first century will unlikely be substantially compromised in the context of climate change. The human vulnerability outcomes shows that the daily calorie availability will be well above the officially stipulated level of 2,600 kilocalories per day, and that the mortality count of children under five years due to malnutrition will be continuously decreasing from the current levels, even under the most pessimistic scenario by 2050. The major challenges, however, will rise from the increasing

demand of a richer diet – driven by the rapid growth in income levels which are expected to double against the current levels in 2020 – coupled with regional disparities in the adaptive capacity to climate change. There is a particularly high level of uncertainty as to how climate change will play out in specific locations. The immediate implication of this point is that the grain handling and transportation facilities need to be reexamined, and repositioned if necessary, to ensure a fair spatial distribution. Smooth and timely shipments of large quantities of grains across regions should be considered as one of the first steps in China's adaptive capacity building.

The scenario outcomes of grain production, derived from the IMPACT results and shown in Figure 28 to Figure 30, depict a relatively optimistic outlook on yield, production and trade toward 2050. The maize yield, for example, is predicted to jump by 45% during 2010–2050, contrasting with the simulated effect of climate change on maize yield using the DSSAT crop model (Table 5). DSSAT simulation shows that climate change can cause max. 4% change in maize yield, either increase or decrease, between 2010 and 2050. The multi-scenario ensemble effect of 0.2% (Table 5) suggests that overall effect of climate change can even be neutral over a large country like China in this particular case. The fundamental drivers behind these two differential rates of yield change, 45% versus 4%, are technology and trade. Technology development in terms of varietal performance and input use efficiency has been a major driver of yield improvements globally, as in the case of Green Revolution (Evenson and Gollin, 2003). But over a shorter period of time, food price may play a more important role on raising crop yield by means of higher inputs. The jump of maize yield by 45%, as predicted by the IMPACT model, was associated with a sharp price increase by 100% during 2010–2050. These two important processes of yield change, either biophysical or economic, were both considered by the IMPACT model but not by DSSAT. This simple observation of yield change drivers has profound implications on future food security.

The first implication is on the importance of crop breeding for food security under climate change. Breeding and agronomic improvements have, on average, achieved a linear increase in global food production, at an average rate of 32 million tons per year (Tester and Langridge, 2010). This rate has been sustained for more than 40 years. An even higher rate is needed for a growing population with a richer diet. This requires substantial changes for methods in agronomic processes and management practices. In China, production growth can only be realized through higher yields, given the decreasing trend and outlook in crop areas. As a recent study (Ye et al., 2012) suggested, maintaining yield growth rate on a yearly basis has great significance in ensuring food security in China. Therefore, continued investment in enhancing agriculture productivity should remain a key policy element in managing climate risks facing Chinese agriculture. Joint efforts on crop breeding are needed to produce innovative varieties that maintain yields but tolerate drought, salinity, pests and diseases, and other climate shocks (Trethowan et al., 2010). The second implication is on the role of international trade in climate change adaptation, which is notably missing in the current thinking of climate change in China. As the IMPACT results show, open international trade is key to buffer the impact of climate change on domestic production and thus to maintain a stable supply through price and market effects. This illustrates the importance of keeping international trade open for Chinese food security; it also indicates the importance of vulnerability alleviation for the rural poor in designing adaptation strategies to cope with climate change.

In a broader context, challenges of ensuring food security under climate change require urgent and substantial increase in the focus of research, innovation, transformation of knowledge, and education at all levels across all sectors related to agriculture (Smith and Olesen, 2010). This is only possible through capacity building actions toward a harmonized system of climate change adaptation and mitigation through agricultural intensification for food security. Such actions involve not only national and local governments but also international organizations and the international research community. It is important to note that investment in agricultural research is an efficient long-term mitigation strategy since investment in yield improvements compares favorably with other commonly proposed mitigation strategies (Burney et al., 2010). It is also important to note that reforms in the governing scheme of the intellectual property rights are much needed to facilitate effective transfer of climate change- and food security-related knowledge.

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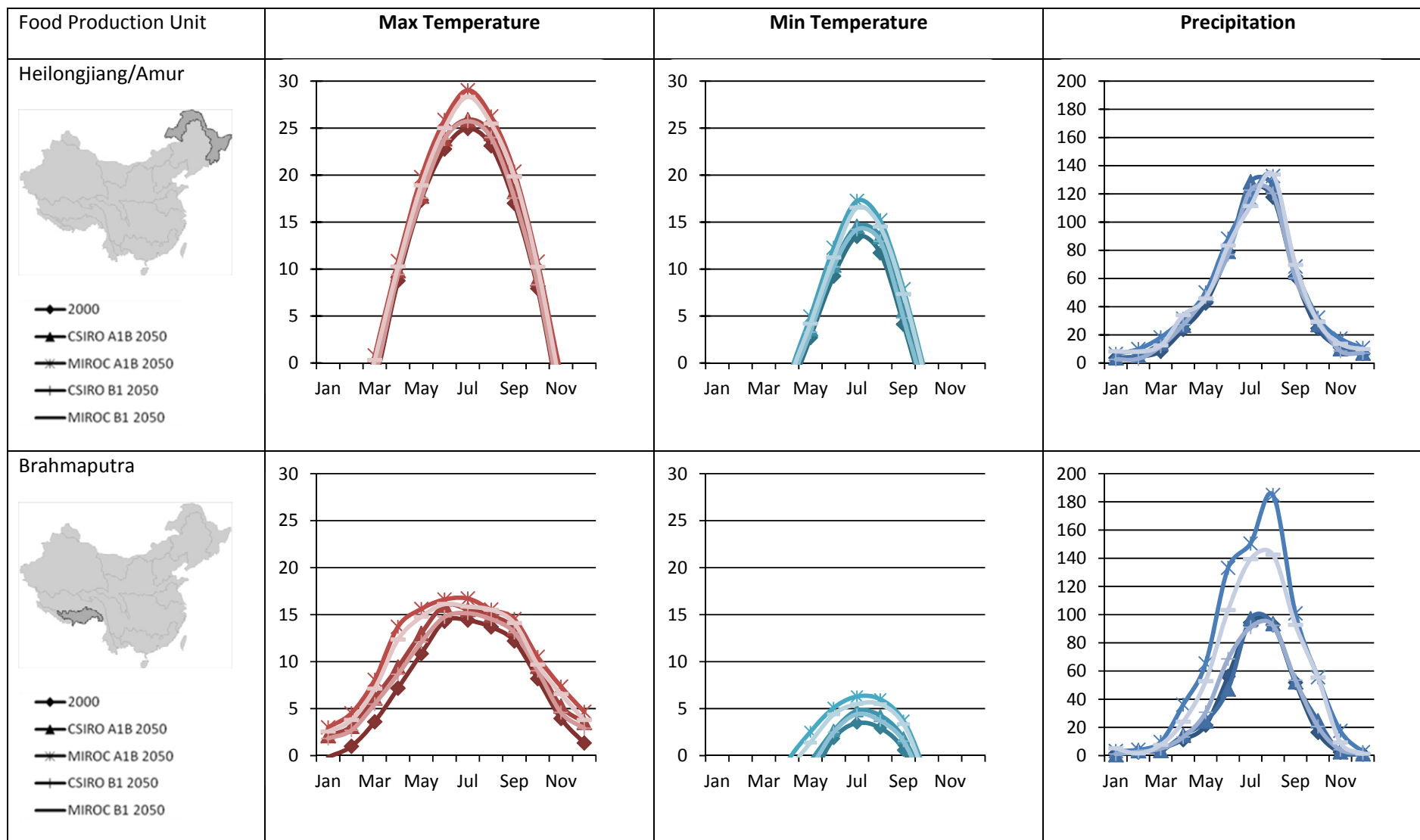
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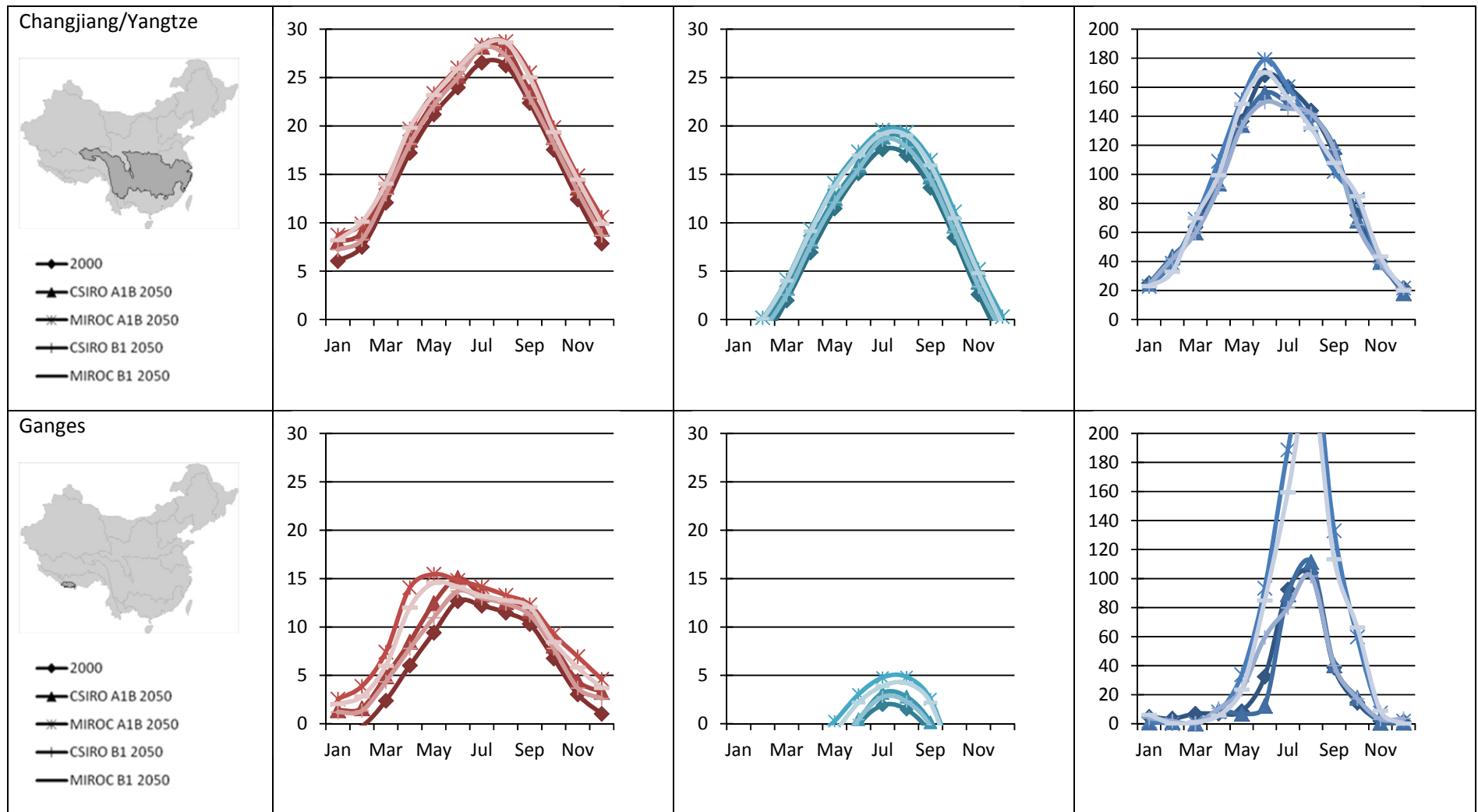
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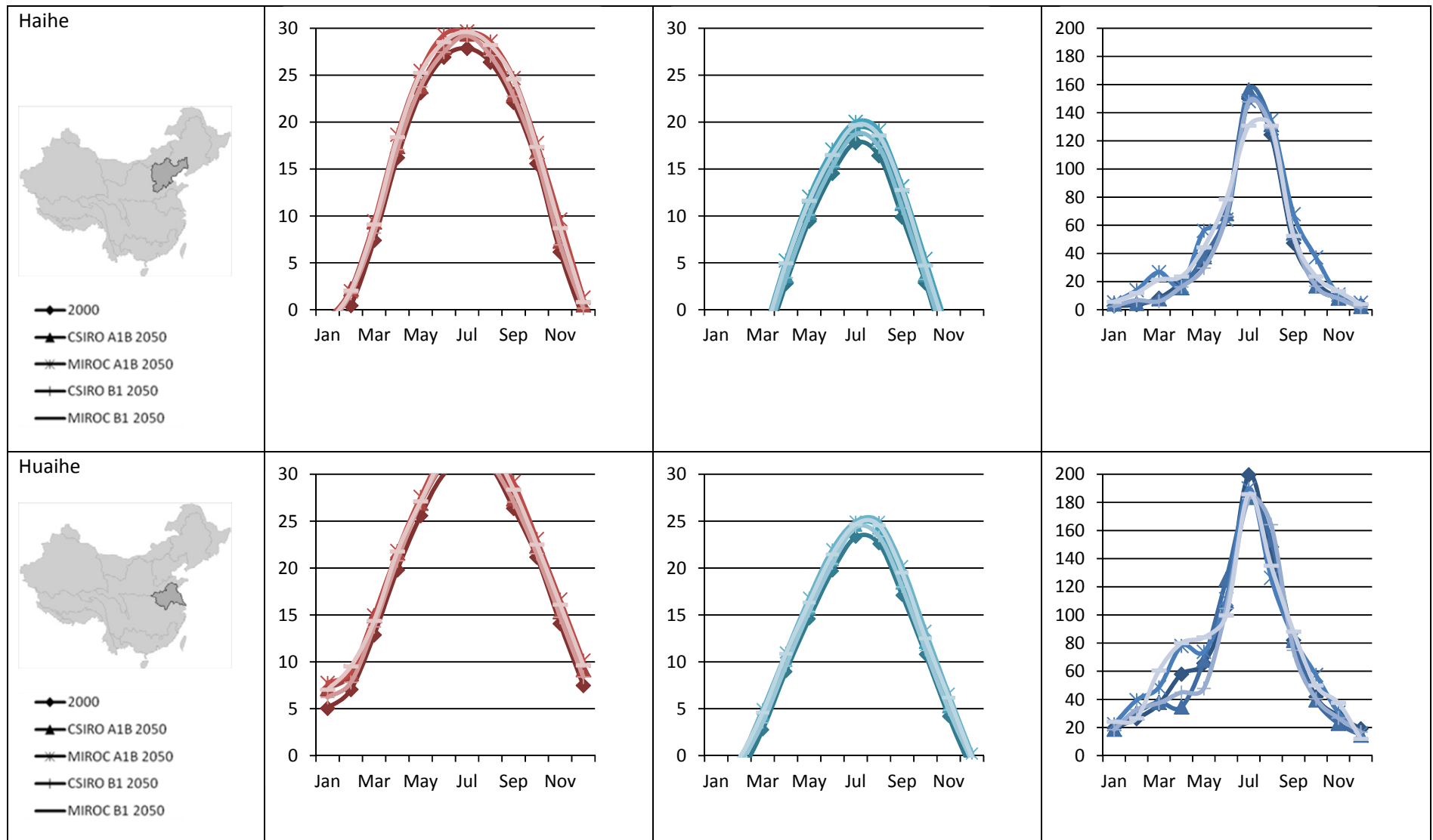
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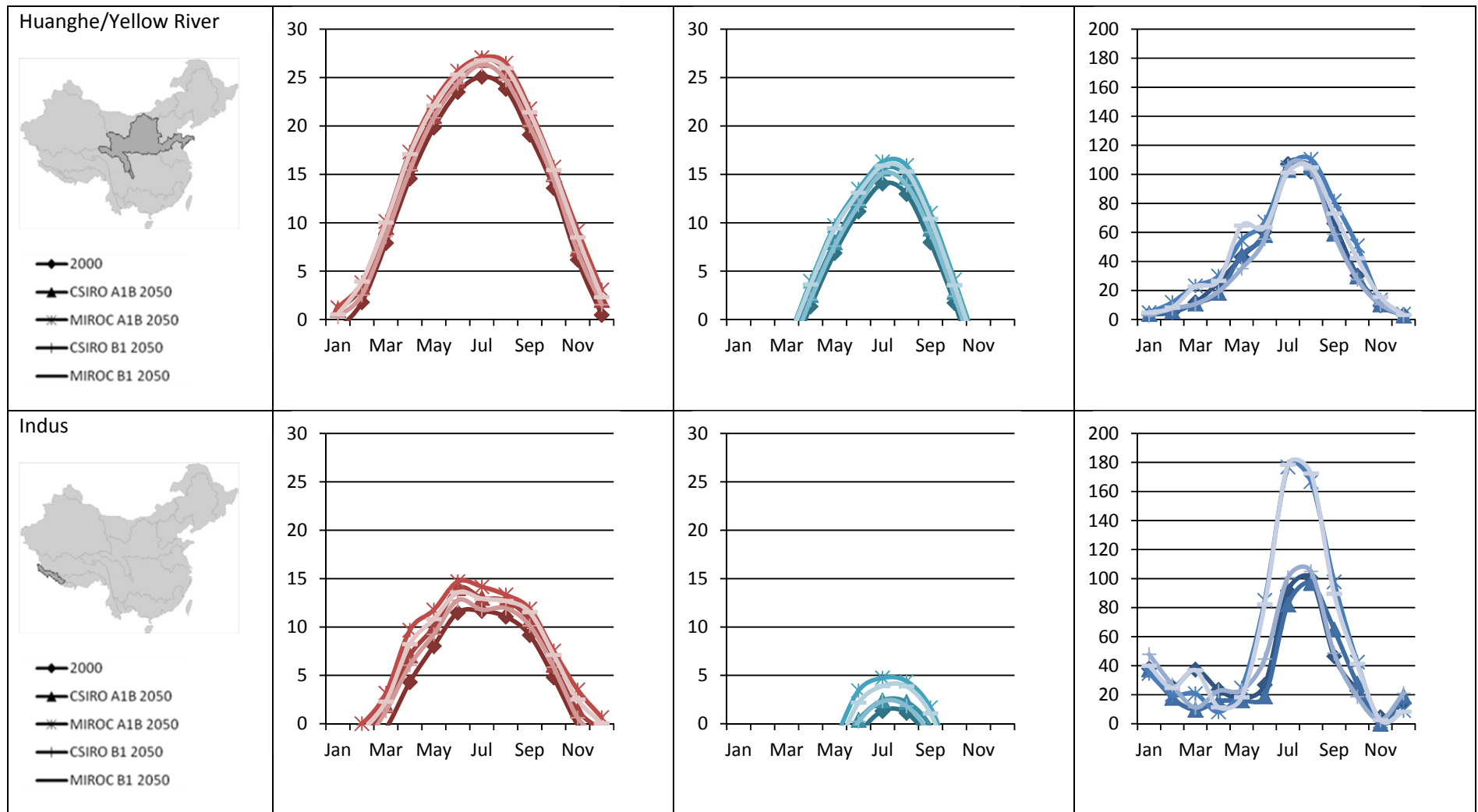
Appendix

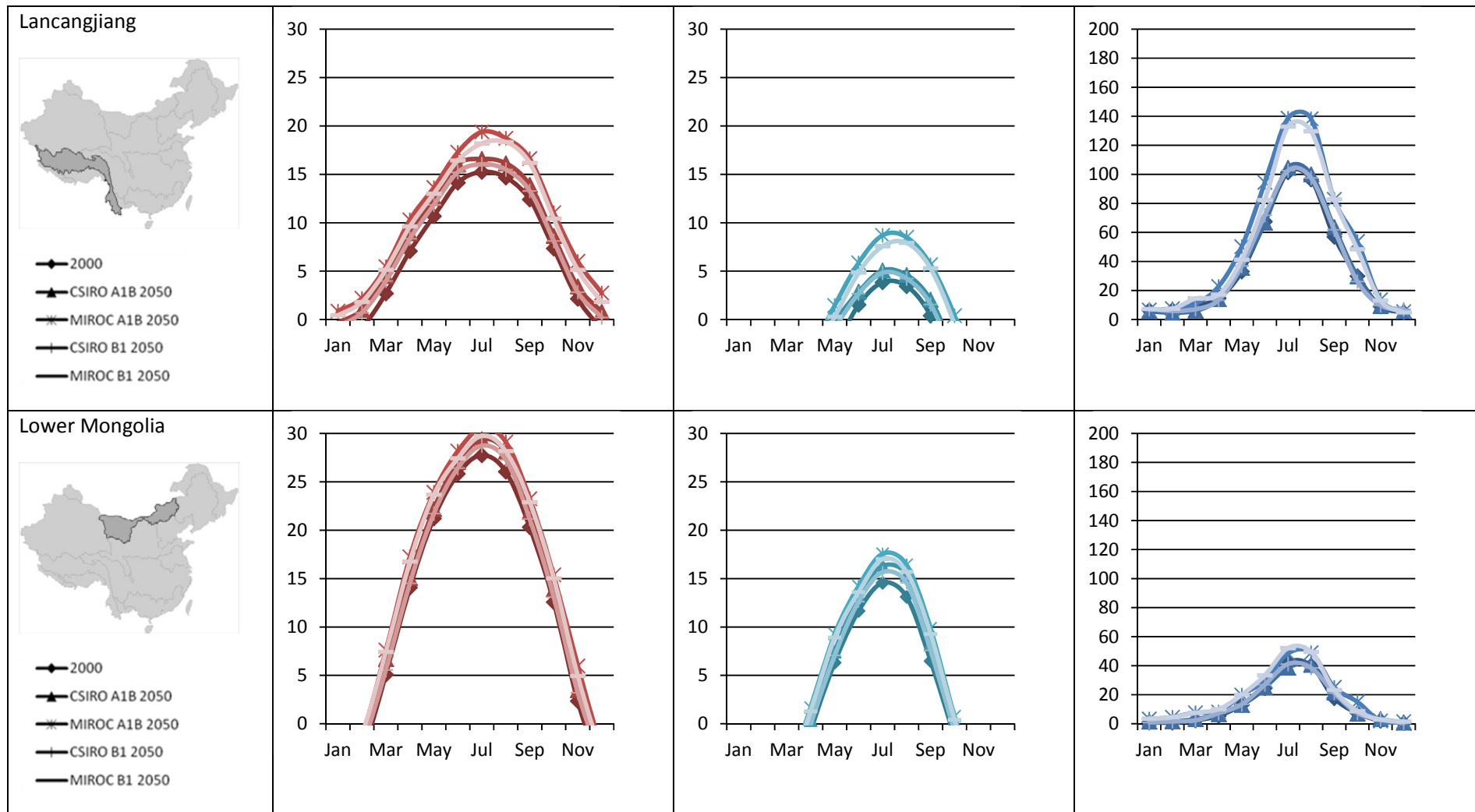
This appendix presents figures for each food production unit (FPU) in China of monthly average precipitation, minimum temperature and maximum temperature for 2000 and in 2050 for 5 climate scenarios.

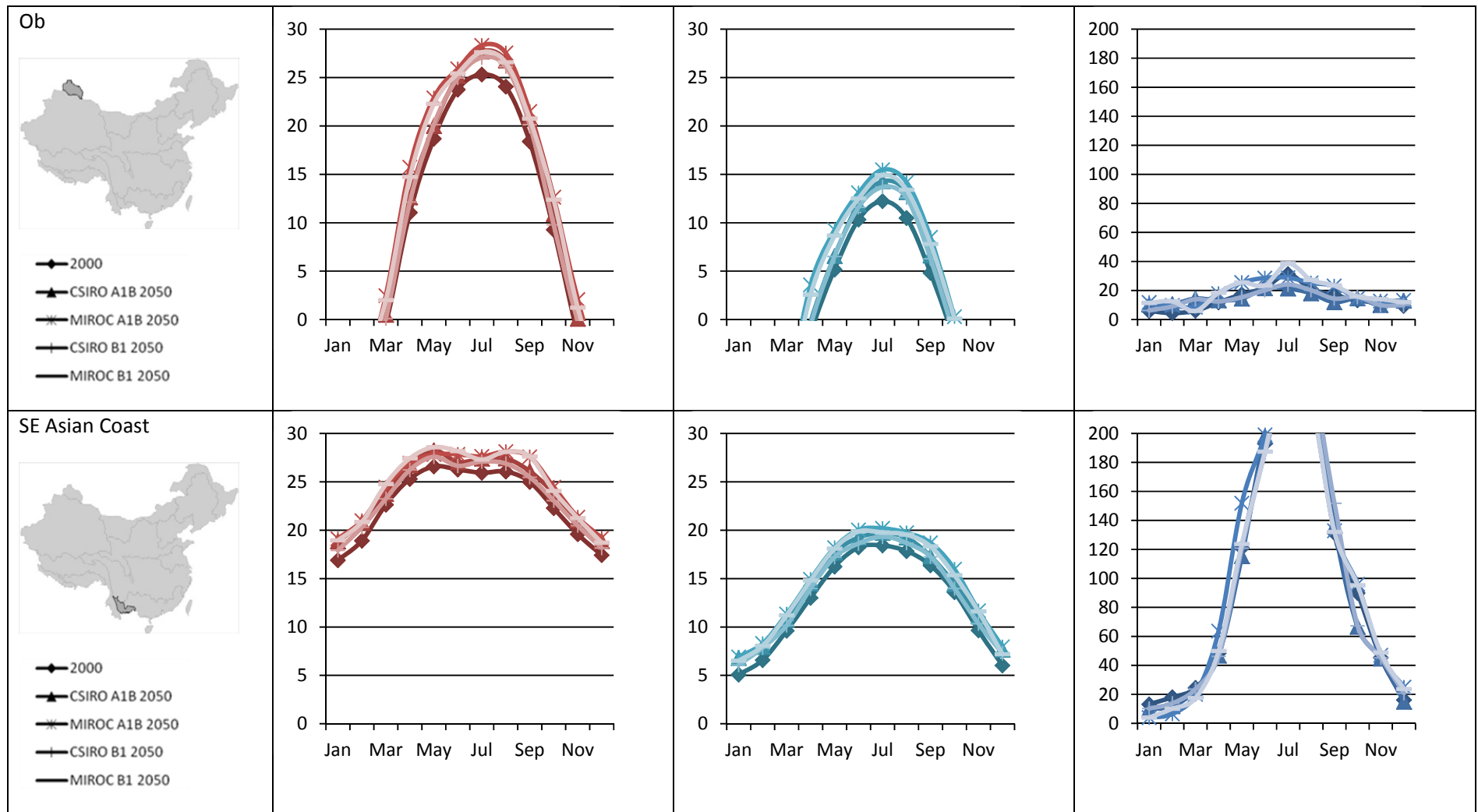


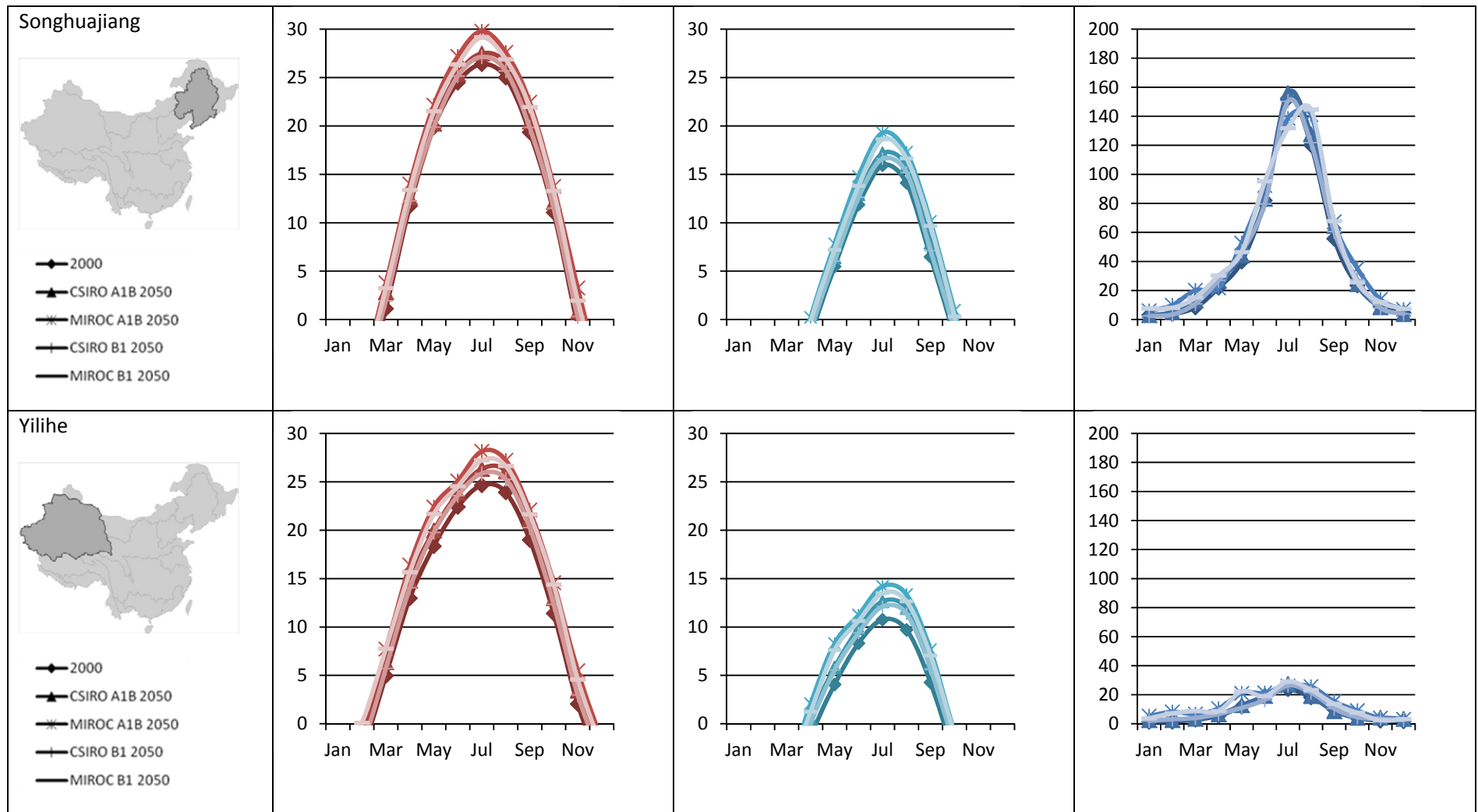








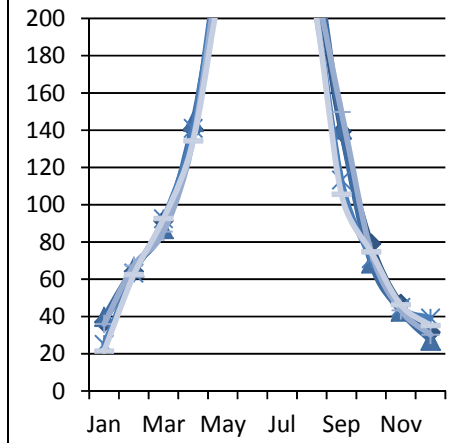
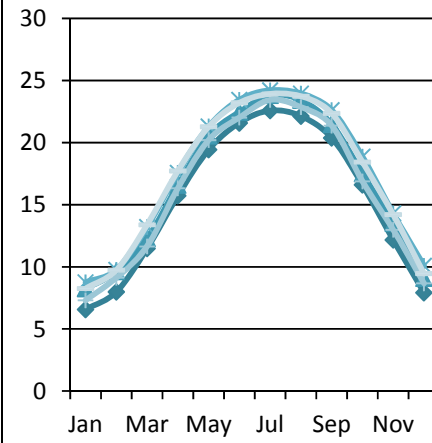
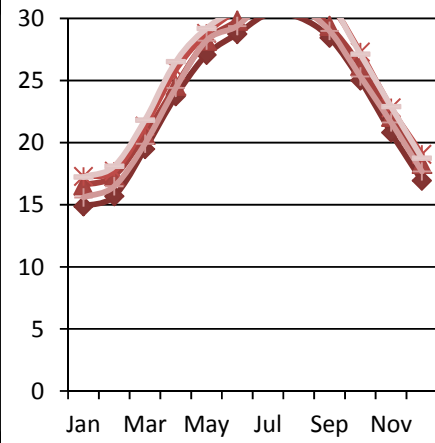




Zhujiang/Pearl River



- 2000
- CSIRO A1B 2050
- MIROC A1B 2050
- CSIRO B1 2050
- MIROC B1 2050



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