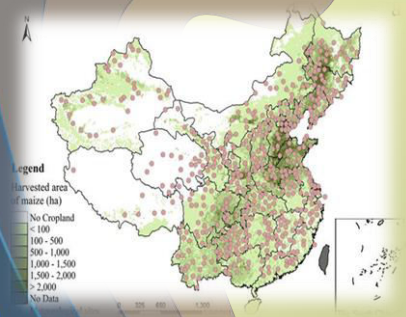
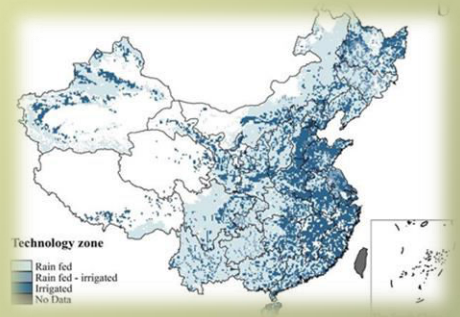
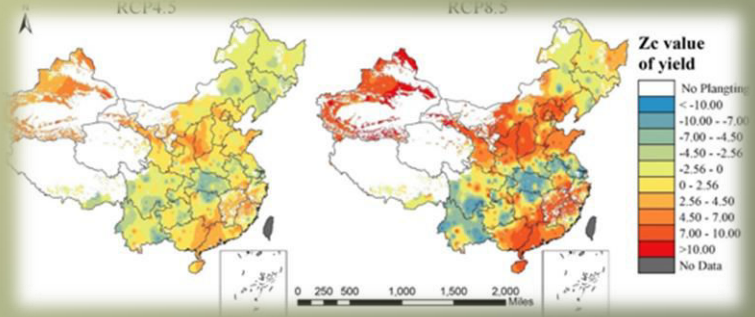
Impacts of Future Climate Change on Water Footprint of Maize in Different Agricultural Production System in China







Shikun Sun

Northwest A&F University

XVIII World Water Congress
International Water Resources Association (IWRA)

XVIII WORLD WATER CONGRESS
Water for All
Harmony between Humans and Nature

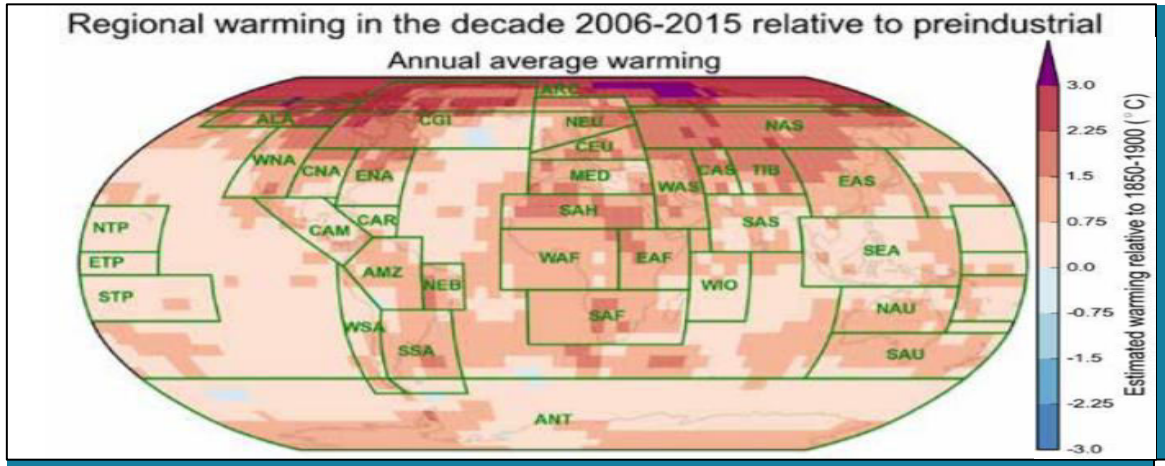
第18届 世界水资源大会
水与万物:
人与自然和谐共生

XVIII World Water Congress
International Water Resources Association (IWRA)

Content

- BACKGROUND
- METHODS
- RESULTS
- DISCUSSIONS
- CONCLUTIONS

1 BACKGROUND

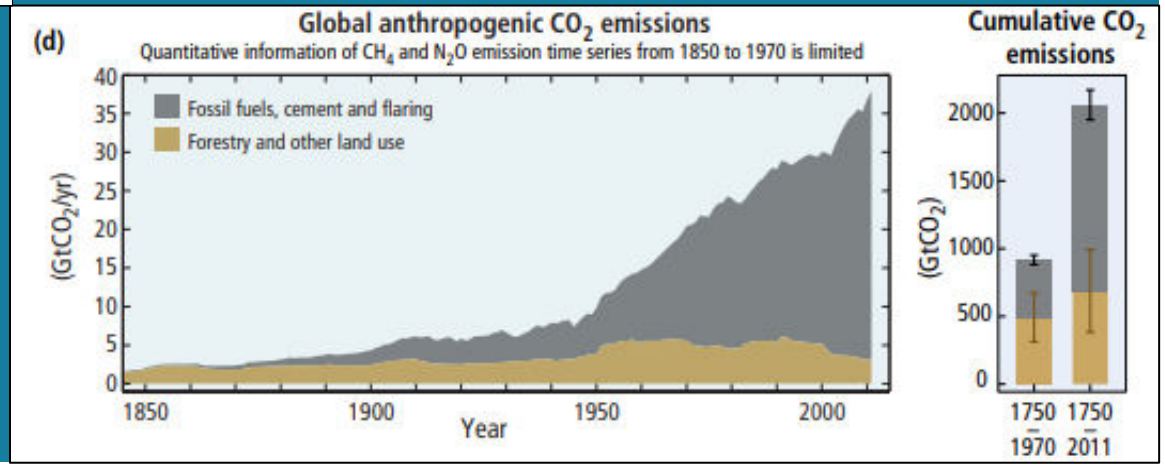


Anthropogenic greenhouse gas (GHG) :

About **half** of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred **in the last 40 years** (high confidence).

Climate warming:

Human-induced warming reached approximately **1°C (likely between 0.8°C and 1.2°C)** above pre-industrial levels in 2017, increasing at 0.2°C (likely between 0.1°C and 0.3°C) per decade.



Reference:

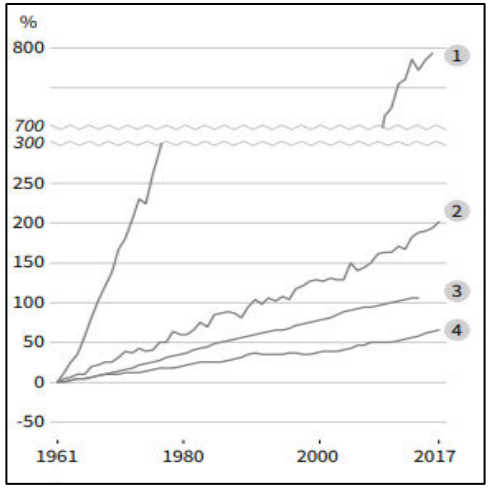
1. IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner (eds.)].
2. IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

1 BACKGROUND

XVIII World Water Congress
International Water Resources Association (IWRA)

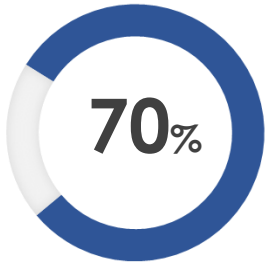
Agricultural production:

Global population growth and changes in per capita consumption of food and energy have caused substantial increase in land and freshwater use with agriculture currently accounting for **70%** of global fresh-water use[1]



CHANGE in % rel. to 1961

1. Inorganic N fertiliser use
2. Cereal yields
3. Irrigation water volume
4. Total number of ruminant livestock



China maize production and irrigation:

China's irrigated areas produce about **75%** of the country's grain and more than **90%** of cash crops[2].

China has the **second-largest** planting area and maize yield in the world[3].

Reference:

1. IPCC, 2019: Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, et al., (eds.)].
2. Department of rural water resources, Ministry of Water Resources of the people's Republic of China. 2009. Water-saving Irrigation in China. China Water Resources and Hydropower Press.
3. FAO., 2016. Food and Agriculture Organization of the United Nation. http://faostat.fao.org.

1 BACKGROUND

XVIII World Water Congress
International Water Resources Association (IWRA)

Purpose of research:

- Agriculture is the most **vulnerable** production sector to climate change, and the climate warming may result in larger water demand for maintaining sustainable supply of agricultural products.

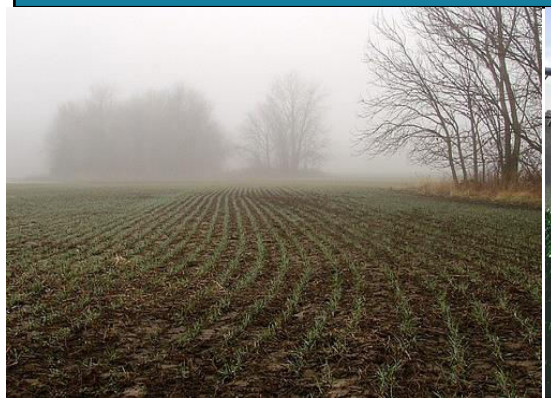
- In this study, **maize** was taken as the research object and the **water footprint** was used as the evaluation index to evaluate the vulnerability of crop production and water use in different agricultural production systems under the future climate change scenarios.

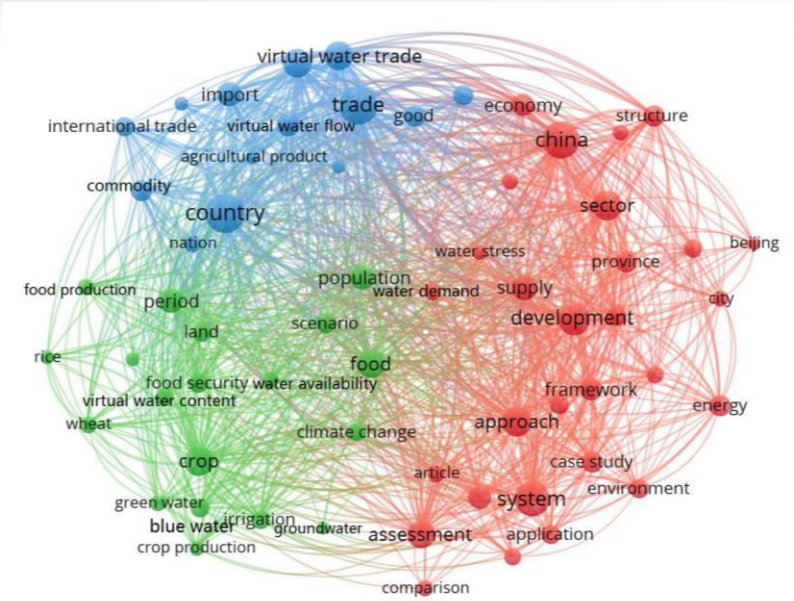


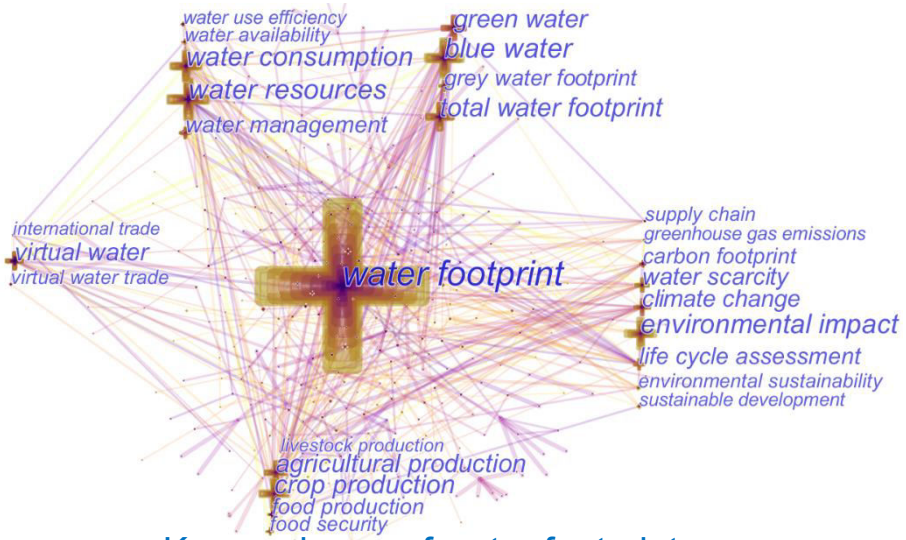

1 BACKGROUND

► **W**ater footprint is a measure of humanity's appropriation of fresh water in volumes of water consumed and polluted.

WF of crop: the volume of fresh water (green and blue water) used to produce the unit crop product (m^3/kg or m^3/ton).







Keyword map of water footprint papers

METHODS

Data

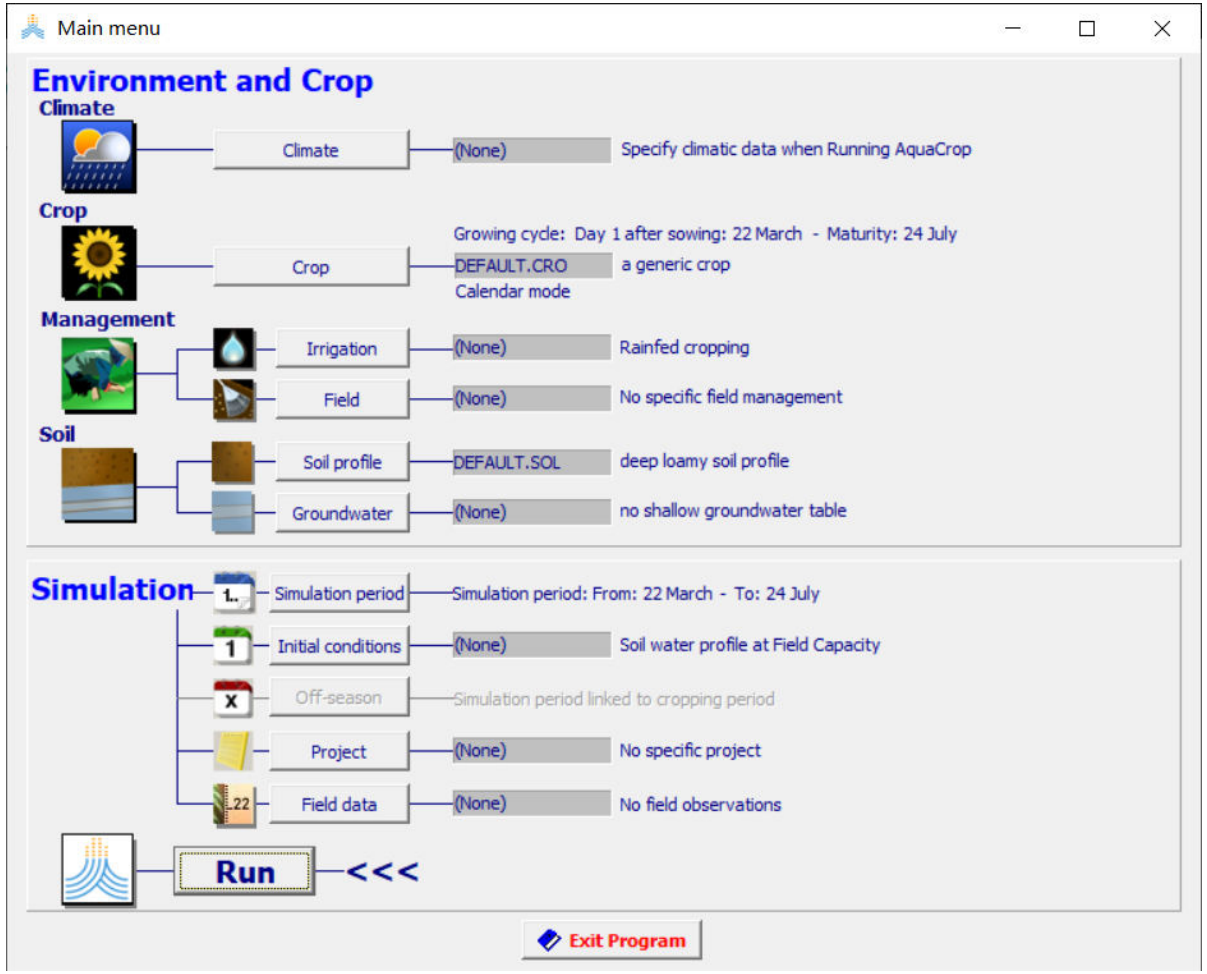
The data used in this study mainly include climate, crop, soil, field and irrigation management data.

The future climate data, under two Representative Concentration Pathways (RCPs) scenarios (RCP4.5 and RCP8.5), required for this study were statistically downscaled from **31 GCMs** of the Coupled Model Inter-comparison Project phase 5 (CMIP5).

List of GCM projections in this study

No.	Model Name	Institute	No.	Model Name	Institute	Country
1	ACCESS1-0	Commonwealth Scientific and Industrial Research Orgar	17	GISS-E2-R		USA
2	ACCESS1-3	(CSIRO) and Bureau of Meteorology (BOM)	18	GFDL-CM3	Geophysical Fluid Dynamics Laboratory	USA
3	BCC-CSM1-1	Beijing Climate Center	19	GFDL-ESM2G	Beijing Climate Center	USA
4	BCC-CSM1-1-m		20	GFDL-ESM2M		USA
5	BNU-ESM	Beijing Normal University	21	HadGEM2-AO	National Institute of Meteorological Research, Korea	South K
6	CCSM4	National Center for Atmospheric Research			Meteorological Administration	
7	CESM1-BGC	National Center for Atmospheric Research	22	INM-CM4	Institute for Numerical Mathematics	Russia
8	CESM1-CAM5		23	IPSL-CM5A-MR	Institute Pierre-Simon Laplace	France
9	CESM1-WACCM		24	IPSL-CM5B-LR	Atmosphere and Ocean Research Institute, National Institute	France
10	CMCC-CM	Euro-Mediterraneo sui Cambiamenti Climatici	25	MIROC5	for Environmental Studies, and Japan Agency for Marine -	Japan
11	CMCC-CMS				Earth Science and Technology	
12	CNRM-CM5	Centre National de Recherches Meteorologiques, Meteo	26	MIROC-ESM	Euro-Mediterraneo sui Cambiamenti Climatici	Japan
13	EC-EARTH	EC-EARTH consortium published at Irish Centre for Hi	27	MIROC-ESM-CHEM		Japan
		Computing	28	MPI-ESM-LR	Max Planck Institute for Meteorology	Germar
14	FIO-ESM	The First Institute of Oceanography	29	MRI-CGCM3	Meteorological Research Institute	Japan
15	GISS-E2-H	NASA/GISS Goddard Institute for Space Studies	30	NorESM1-M	Norwegian Climate Centre	Norway
16	GISS-E2-H-CC		31	NorESM1-ME	NASA/GISS Goddard Institute for Space Studies	Norway

Crop model — AquaCrop



AquaCrop model interface

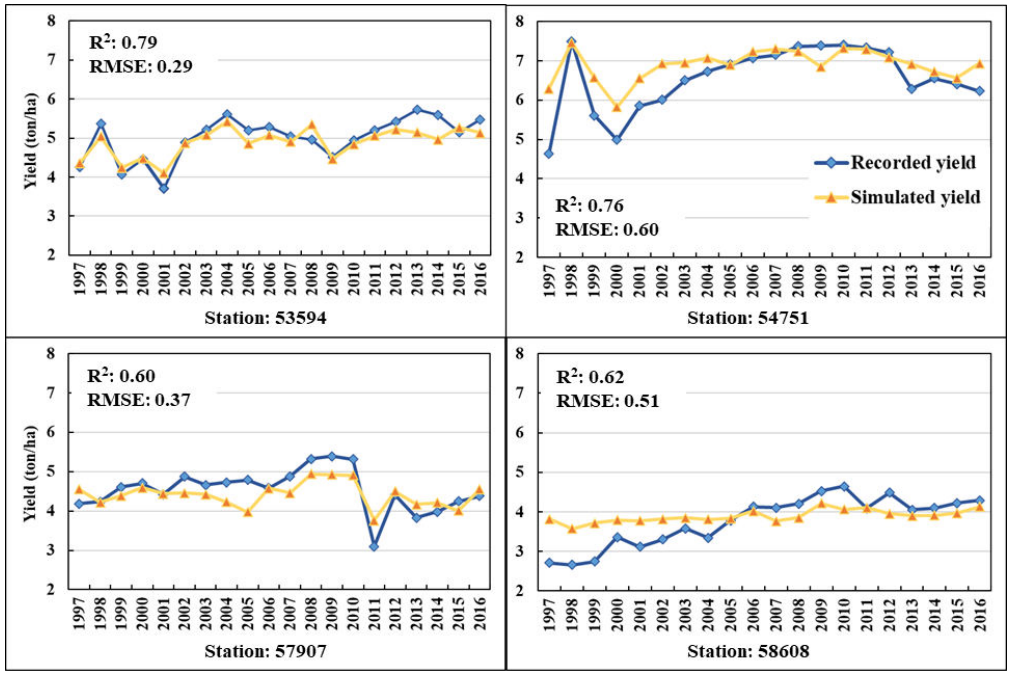
AquaCrop:

AquaCrop is a **water-driven** model designed for planning, agricultural management and scenario simulations.

AquaCrop successfully realizes the balance among accuracy, simplicity and robustness.

To run the AquaCrop model, the required data include **climate, crop, soil, field and irrigation management parameters**.

Model calibration and validation



Recorded and simulated yield

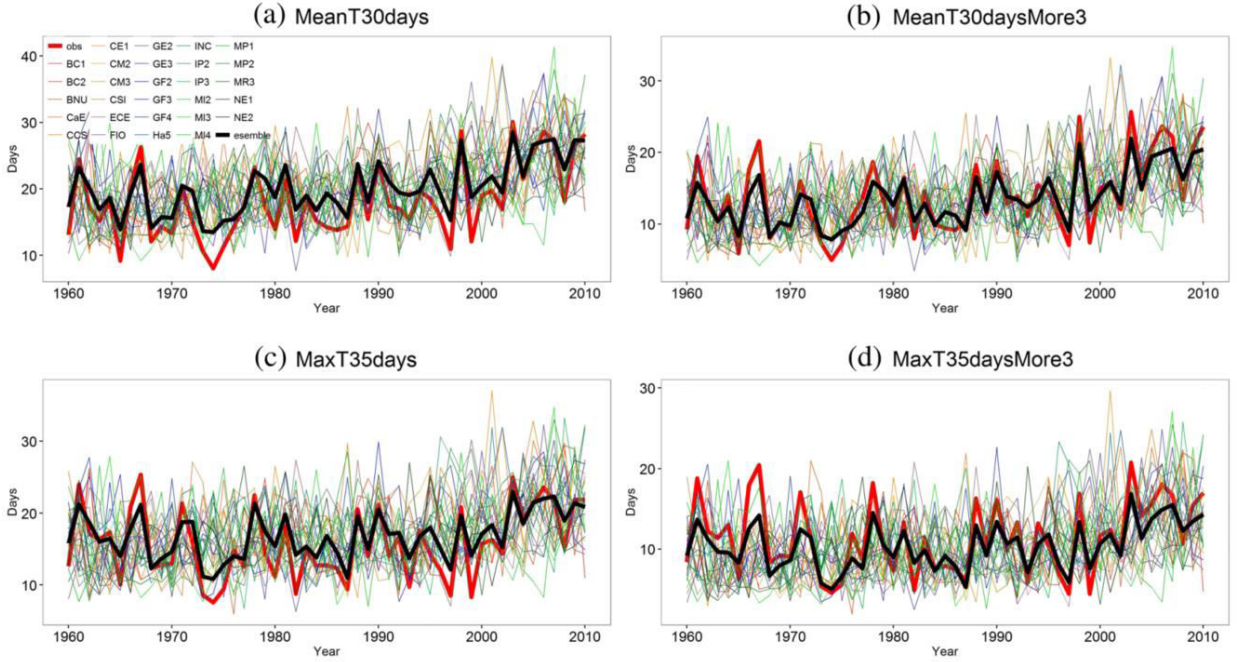


Fig. 3 Observed and simulated heat stress indices from individual models and the ensemble multi-model independence weight mean (IWM). Values are averaged across the rice-planting region of southern China

Downscaled and historical climate data

Calibration and validation of AquaCrop model:

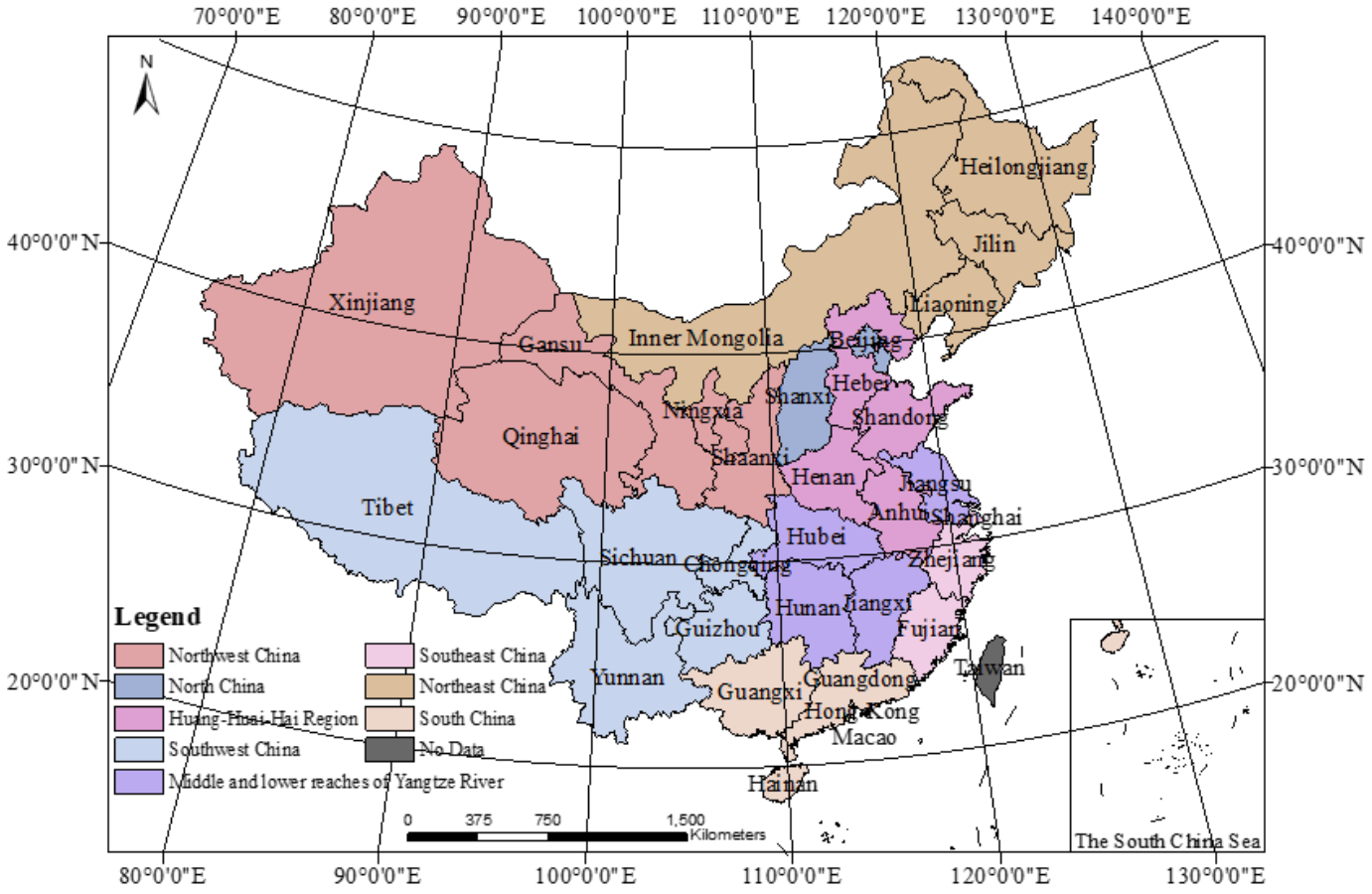
The RMSE for maize yield during validation was **0.54 ton/ha**. It has a good performance in crop yield modelling.

Calibration and validation of GCMs data:

References indicated that downscaled daily climate data are generally **consistent with the observed daily data** for the GCMs.

1. He L., Cleverly J., Wang B., et al. 2018. Multi-model ensemble projections of future extreme heat stress on rice across southern China. *Theor. Appl. Climatol.*133(3-4):1107-1118.

Study area description



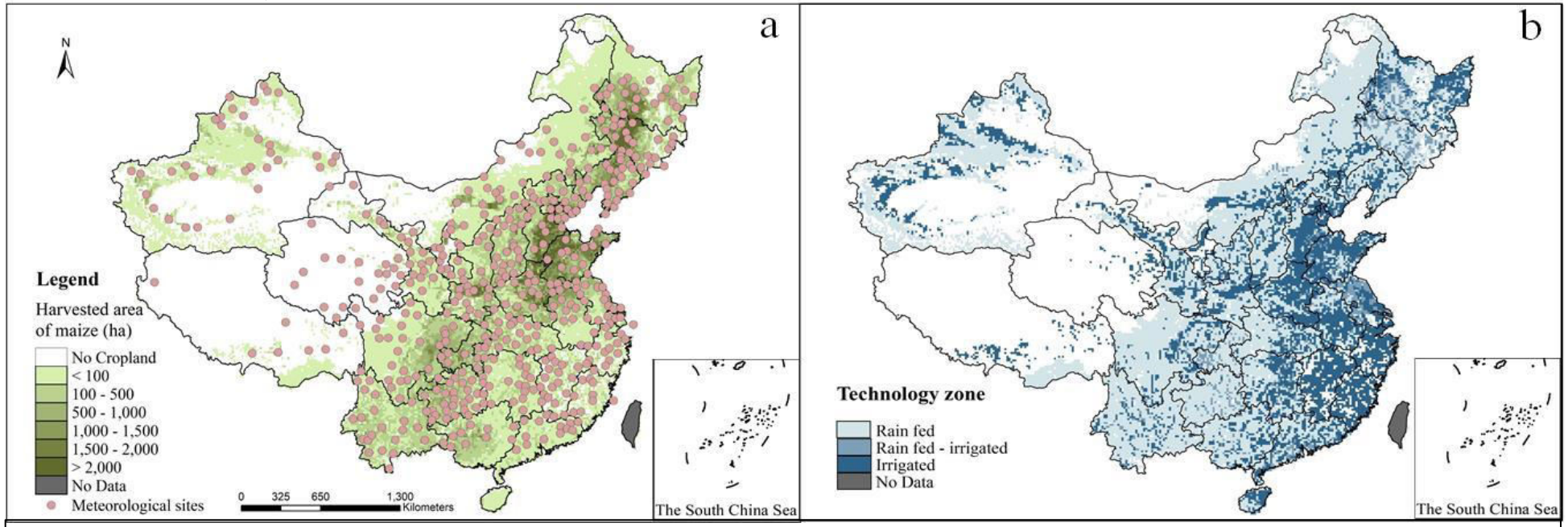
Sub-zones description

Sub-zones:

According to geographic location, natural conditions and similar characteristics of agricultural production, Mainland China is divided into **eight sub-zones** including Northwest China, North China, Northeast China, Huang-Huai-Hai Region, Southwest China, Middle and lower reaches of Yangtze River, Southeast China and South China.

METHODS

Study area description



Overview of the study area. (a) Distribution of planting area and weather station.(b) Distribution of different irrigation

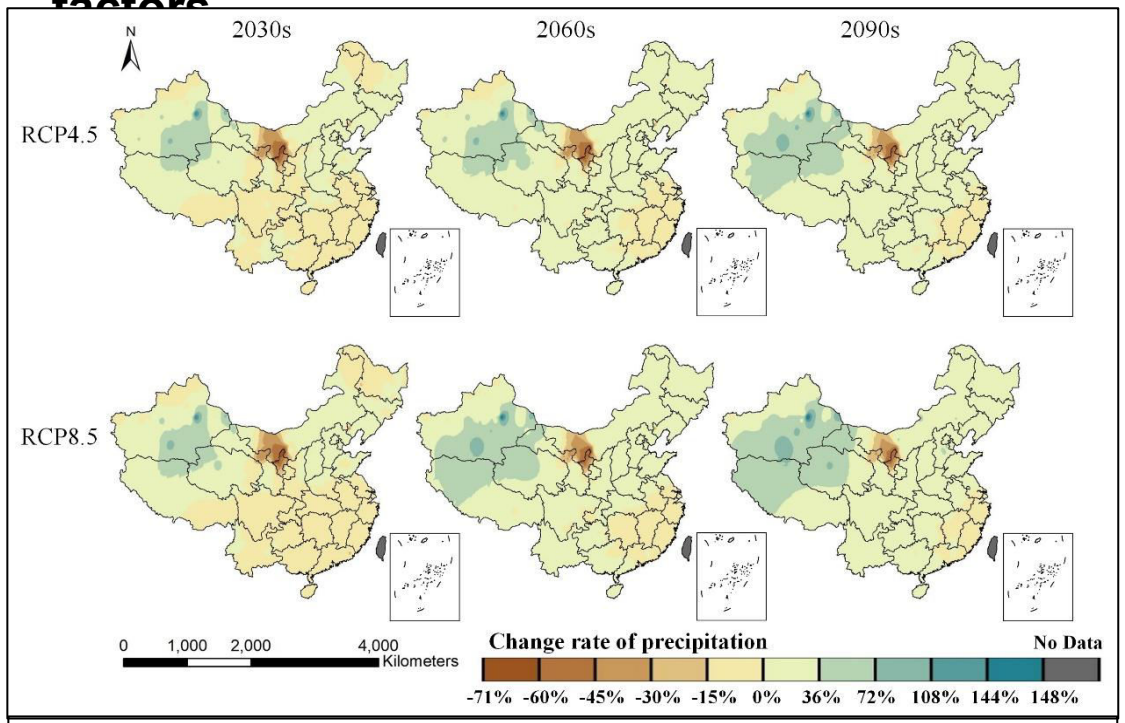
619 meteorological stations in China were selected in this study, which covered the year 1997-2016 as the historical baseline.

We classified this grid **into rain-fed areas, irrigated areas, combined rain-fed and irrigated areas**.

Global Monthly Irrigated and Rainfed Crop Areas(Portmann et al., 2010)

RESULTS

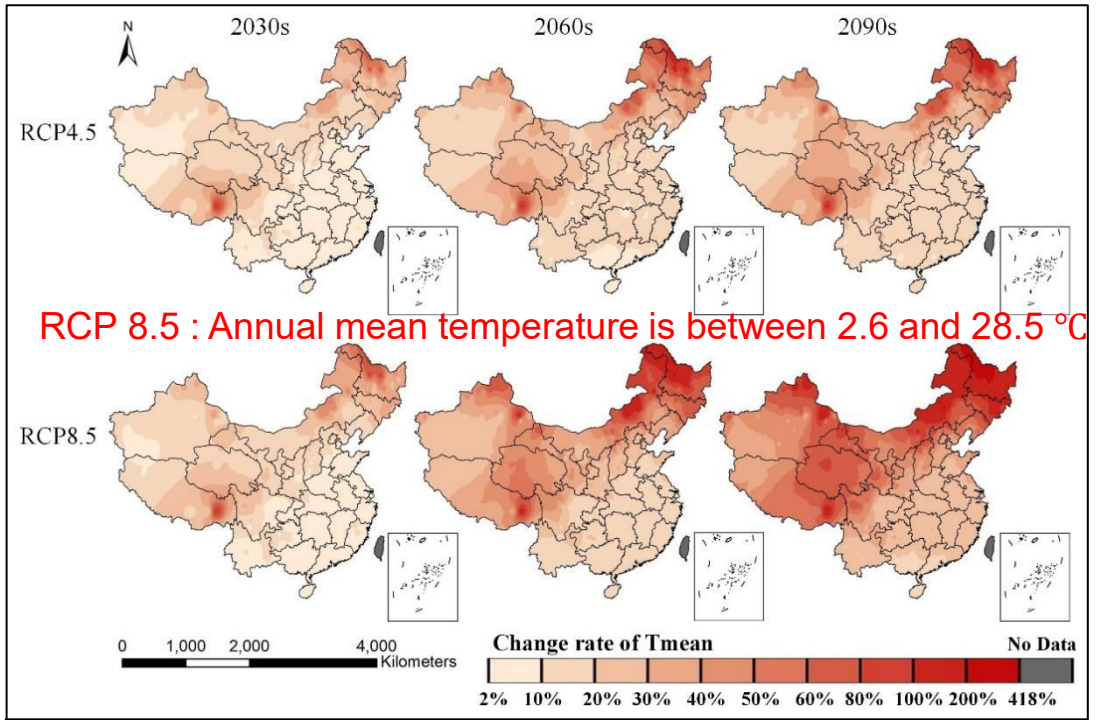
Temporal and spatial variation of major meteorological factors



Distribution of change rate of precipitation in China under future climate scenarios

RCP 4.5: Annual mean temperature is between 2.3 and 26.7 ℃

RCP 8.5 : Annual mean temperature is between 2.6 and 28.5 ℃



Distribution of change rate of mean temperature under future climate scenarios

Precipitation:

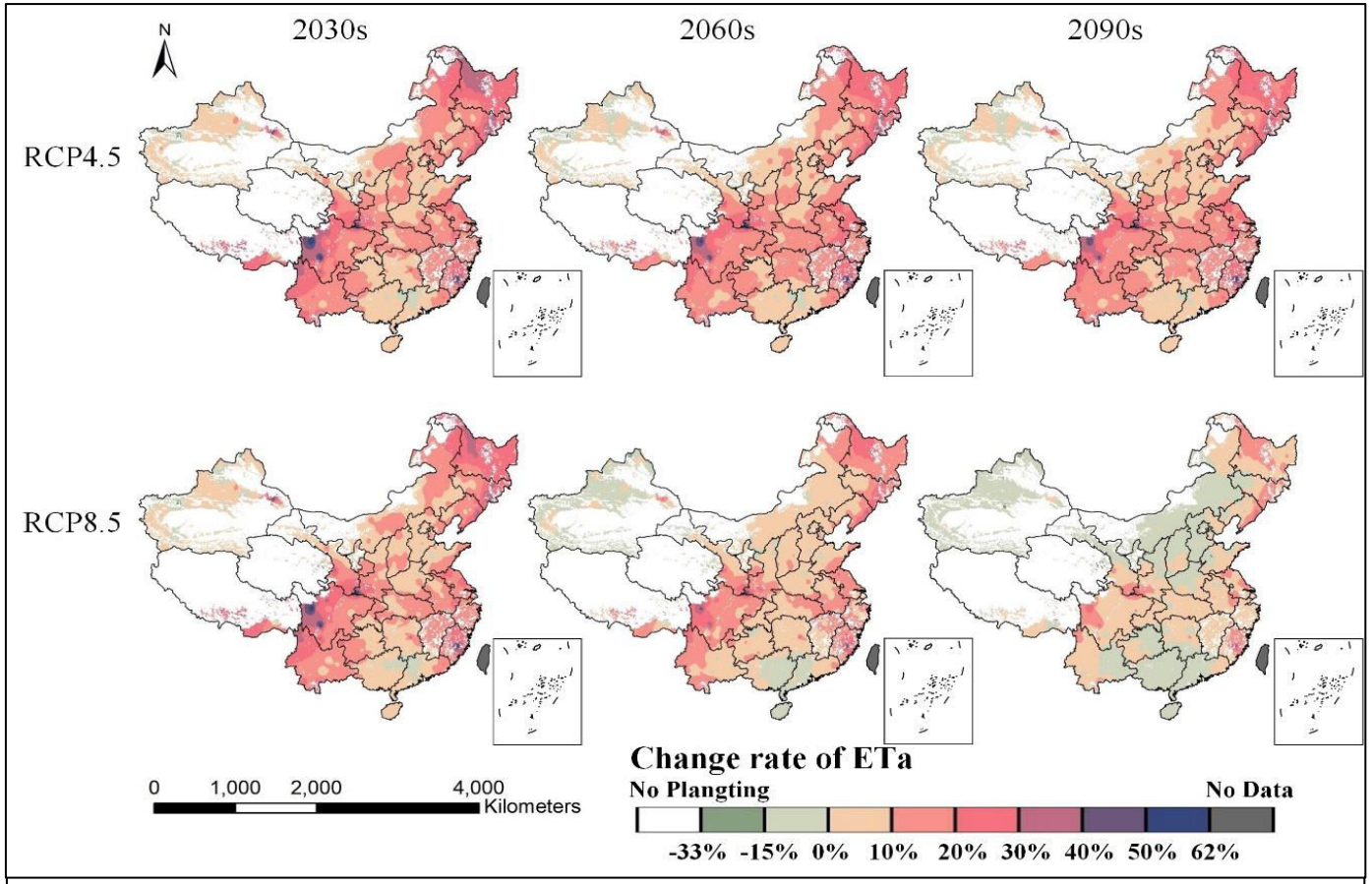
Precipitation in most regions will be increased under future climate scenario. **The precipitation would have a larger increase in Northwest China**.

Temperature:

Most regions would experience increasing temperatures under future climate scenarios. A larger increase in temperature would be detected in west and

RESULTS

Spatiotemporal variation of crop evapotranspiration (ET_c) for maize under future climate scenarios



Change rate of ETc for maize under future climate scenarios compared to baseline

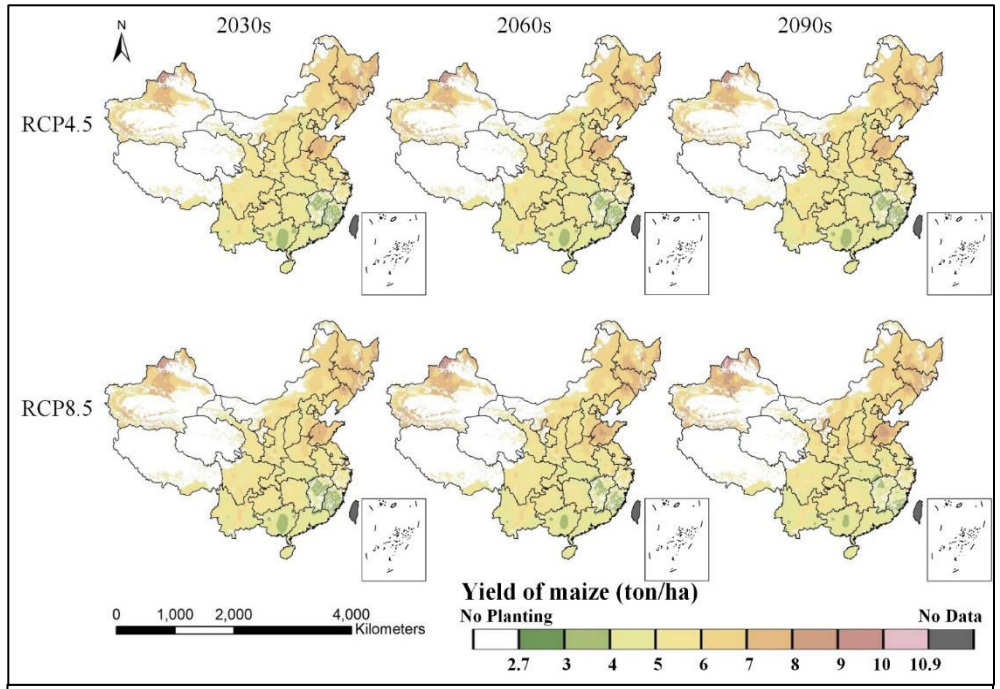
ET_c:

In the RCP 4.5 scenario, ET_c would be higher than that of baseline in most areas of China, and most regions would **have an increasement of 10%-20%** compared to the baseline.

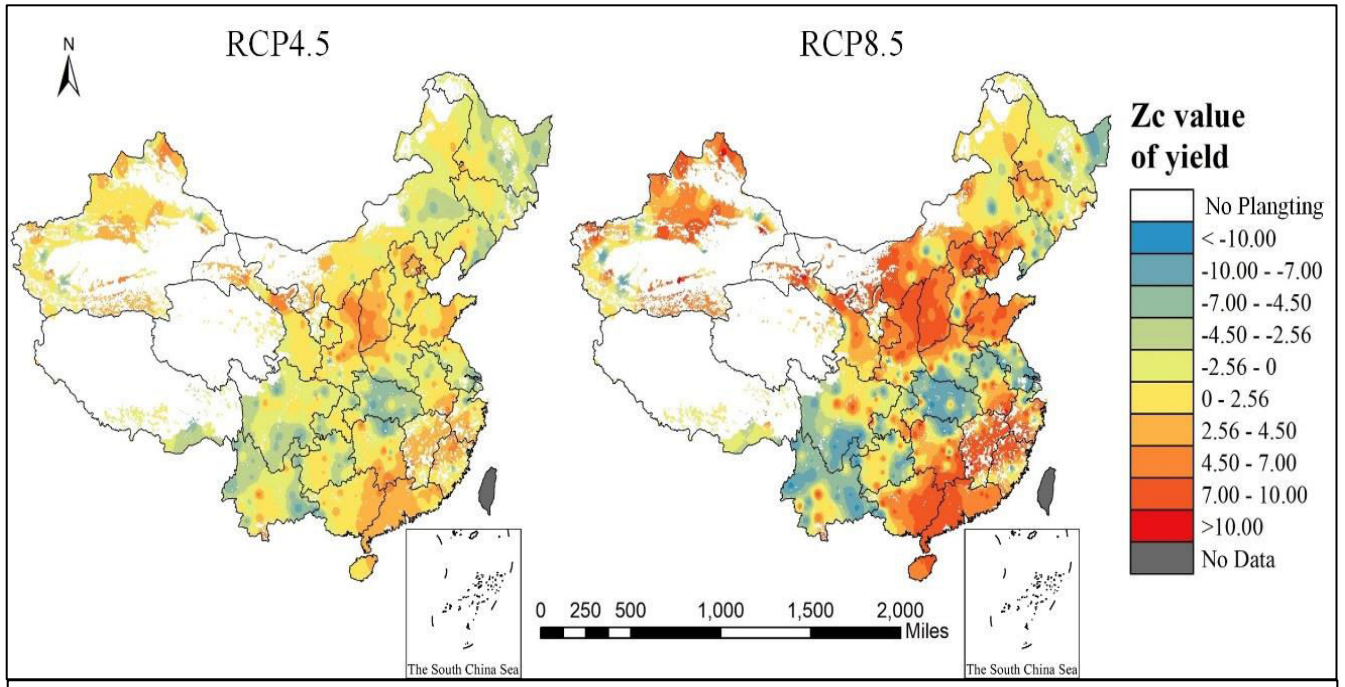
In the RCP 8.5 scenario, the general change rate of ET_c would be smaller than that in the RCP 4.5 scenario.

RESULTS

Spatiotemporal variation of maize yield per unit area under future climate scenarios



Distribution of yield of maize under actual irrigation scenario



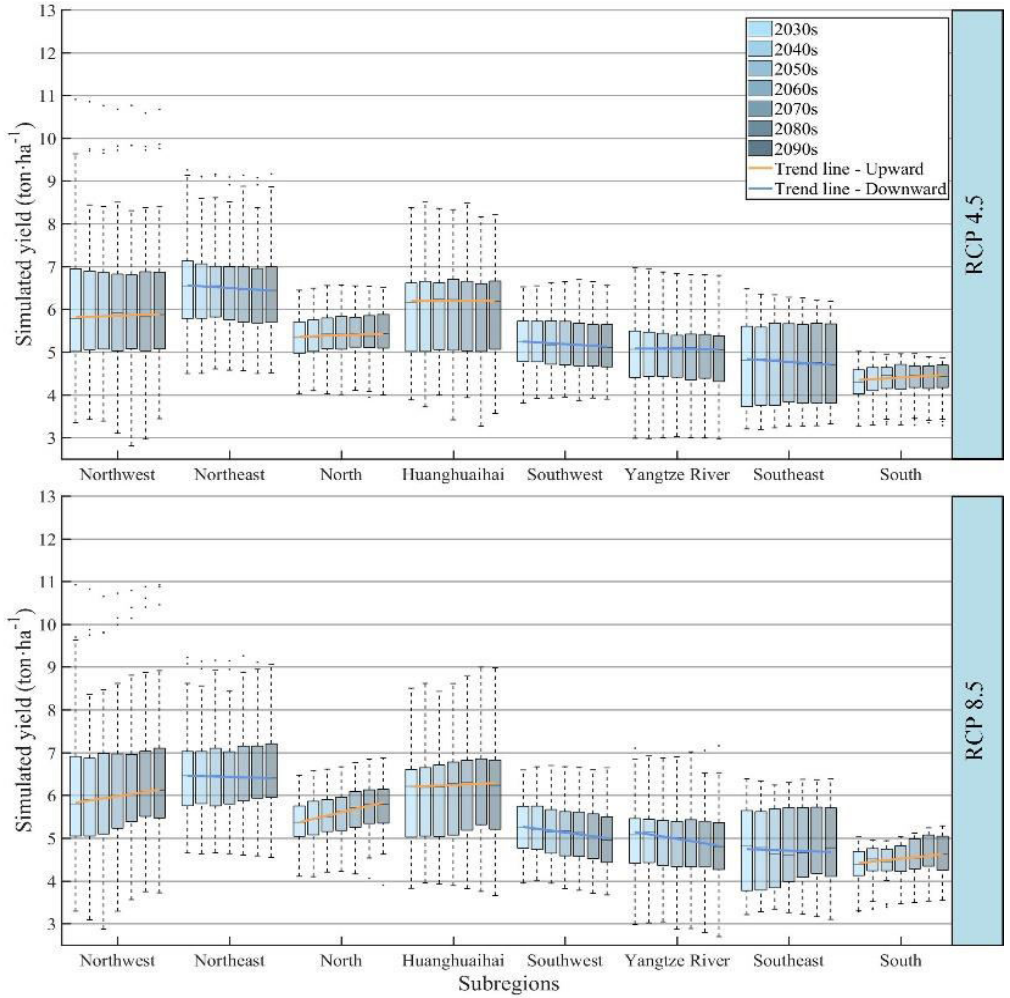
Zc values of maize yield in China under future climate scenarios

There will be a significant increasing trend of maize yield in parts of Northwest China, North China and South China under the RCP 4.5 scenario, and in Northwest China, South China and Southeast China under the RCP 8.5 scenario.

In general, **maize yield per unit area would be higher in the northern areas than in the southern areas**

RESULTS

Spatiotemporal variation of maize yield per unit area in different subregions under future climate scenarios



Maize yield per unit area in different subregions

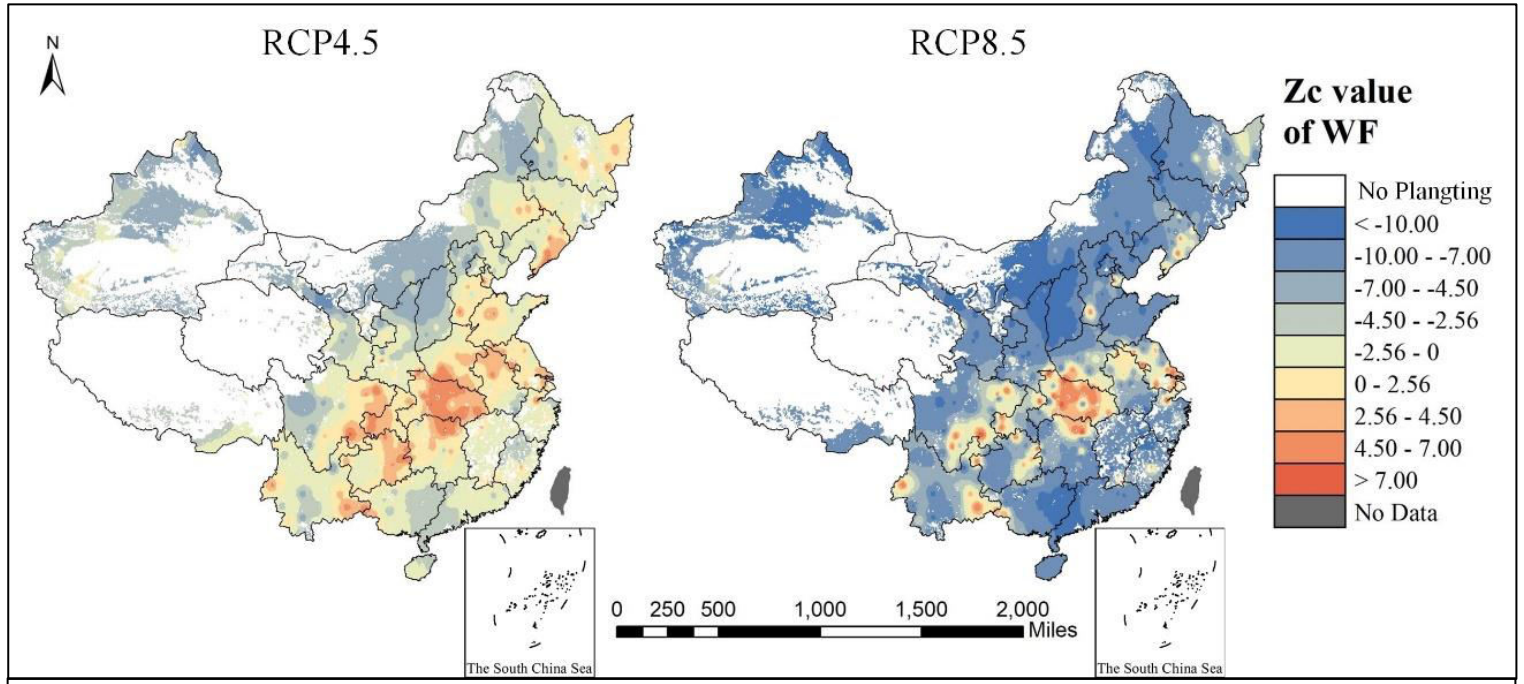
Different subregions

An increasing trend of maize yield would occur in Northwest China, North China, Huang-Huai-Hai Region and South China, while a decreasing trend would be observed in other regions.

The changing trends were the **same** for the RCP 4.5 and RCP 8.5 scenarios, but those of RCP 8.5 were more obvious.

RESULTS

Spatiotemporal variation of the water footprint of maize under future climate scenarios



Manner-Kendall trend test of water footprint of maize under future climate scenarios

0.63 m^3/kg in the RCP 4.5 scenario

0.60 m^3/kg in the RCP 8.5 scenario

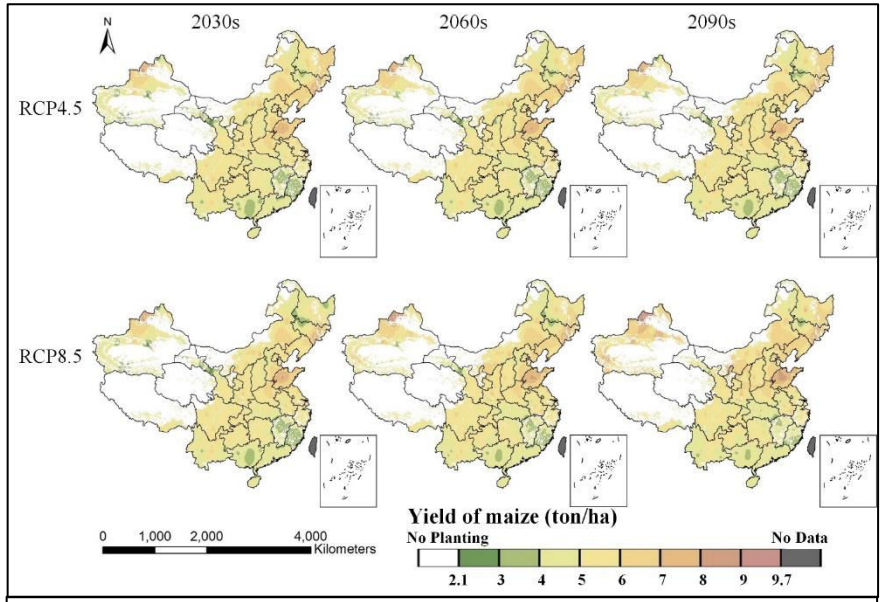
Water footprint of maize under current irrigation scenario:

A significant increasing trend would occur in the Middle and lower reaches of the Yangtze River and the eastern part of Southwest China in the RCP 4.5 scenario and in the Middle and lower reaches of the Yangtze River in the RCP 8.5 scenario.

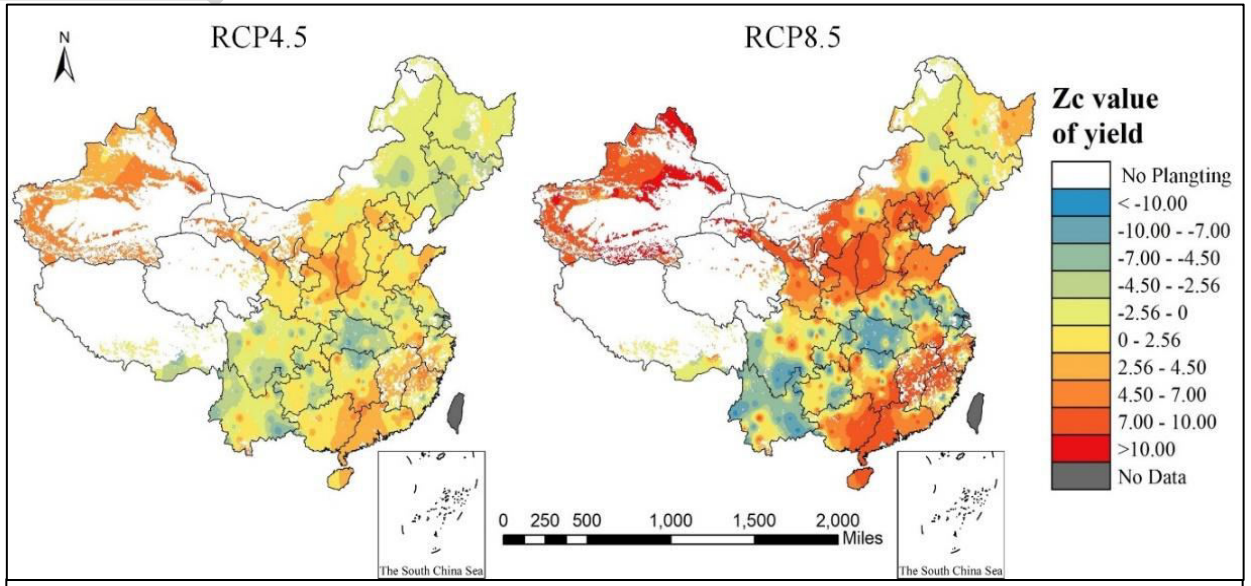
4 DISCUSSIONS

XVIII World Water Congress
International Water Resources Association (IWRA)

Effects of climate change on maize yield under rain-fed scenario



Distribution of maize yield under rain-fed scenario



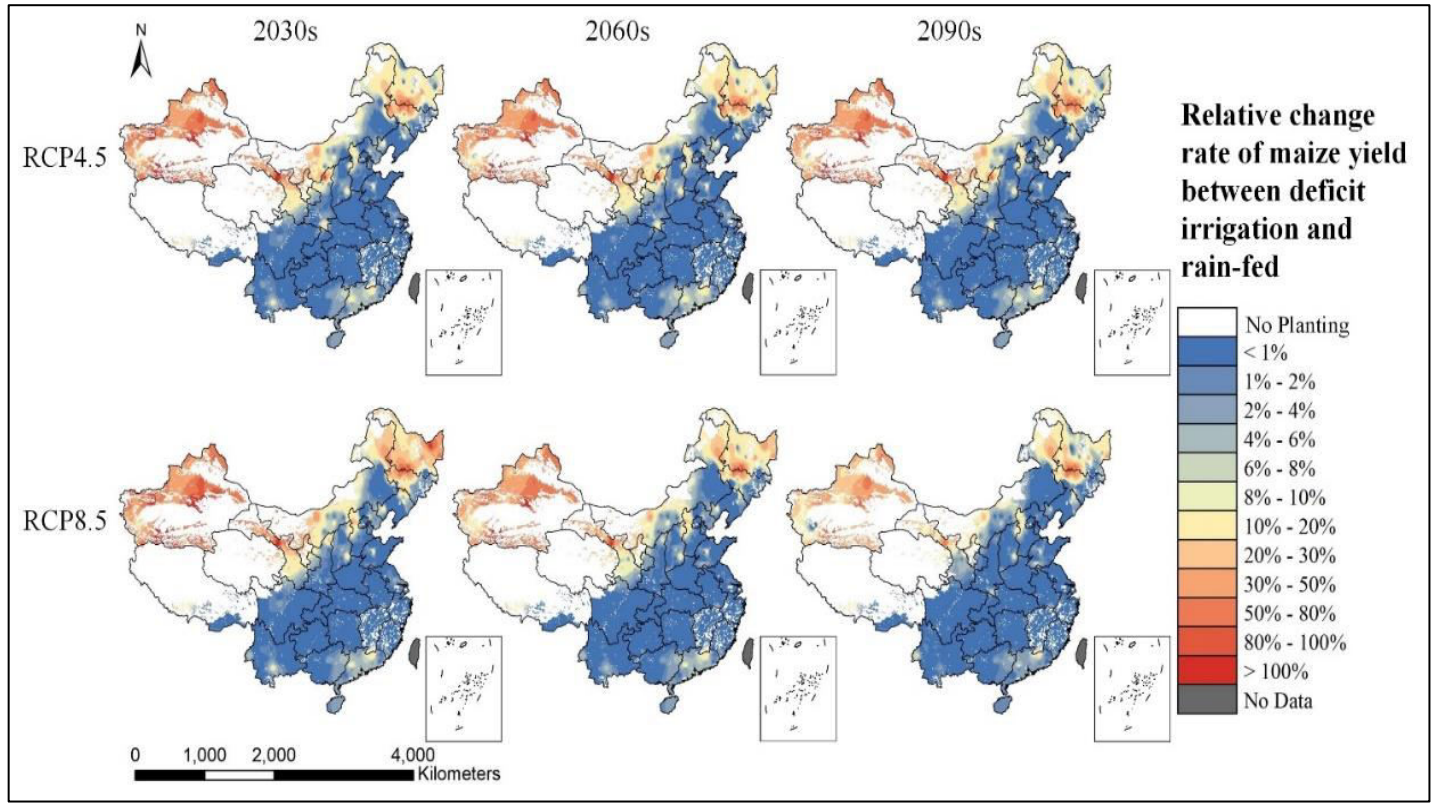
Zc values of maize yield in China under rain-fed in future climate scenarios

Effects of climate change on maize production have obvious regional differences:

The increase in the maize yield in Northwest China, north China was probably caused by the increasing precipitation would alleviate the drought condition in these areas.

The reduced maize yield in Southwest China, Middle and lower reaches of the Yangtze River was probably attributed to precipitation could not achieving a balance with the increasing water demand.

Effects of different irrigation strategies on maize yield

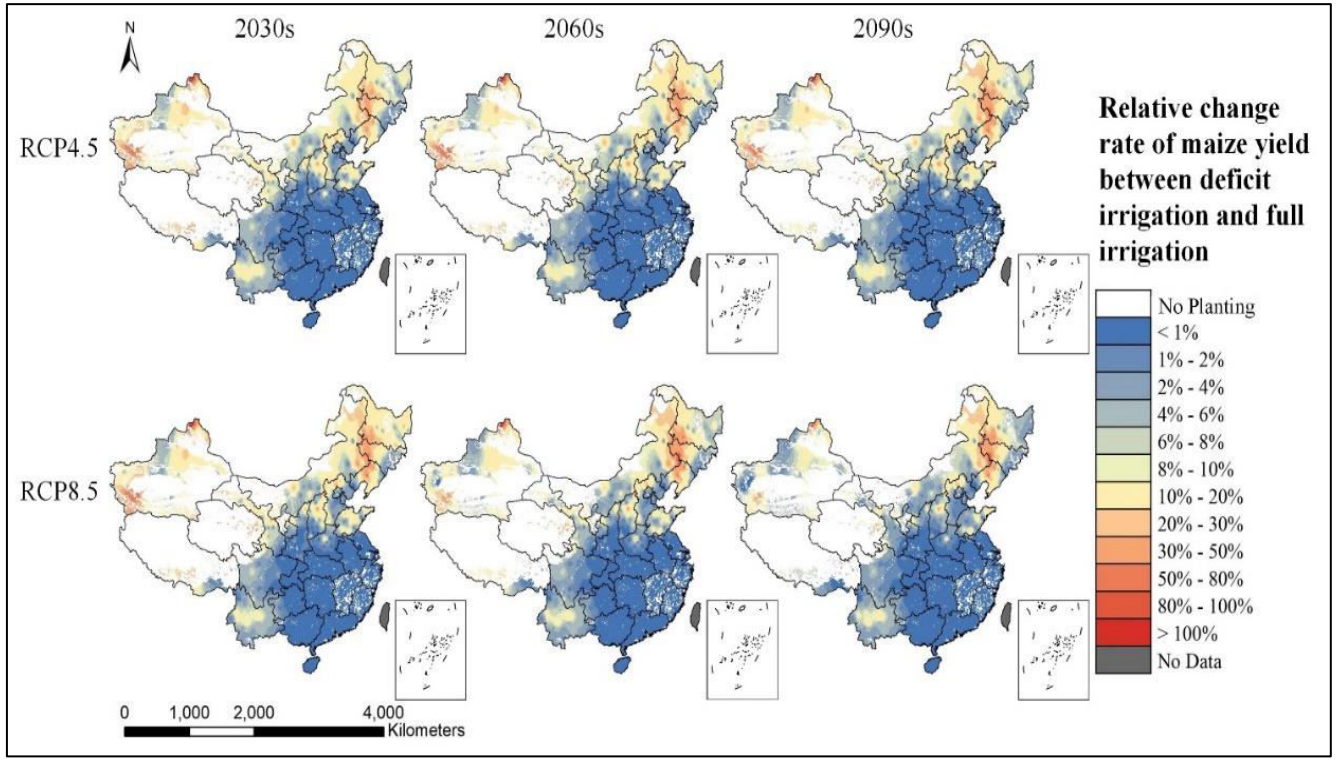


Relative change rate of maize yield between rain-fed and deficit irrigation scenarios

Results show that even in the deficit irrigation scenario, it could **benefit maize production in arid regions**, especially in Northwest China and Northeast China.

The increase in the maize yield in most regions of China in the RCP 4.5 scenario was generally larger than that in the RCP 8.5 scenario.

Effects of different irrigation strategies on maize yield



Relative change rate of maize yield between deficit irrigation and full irrigation scenarios

Under the full irrigation scenario, the maize yield would witness a large increase, which proved that **full irrigation could offset the reduced maize yield in water deficit regions.**

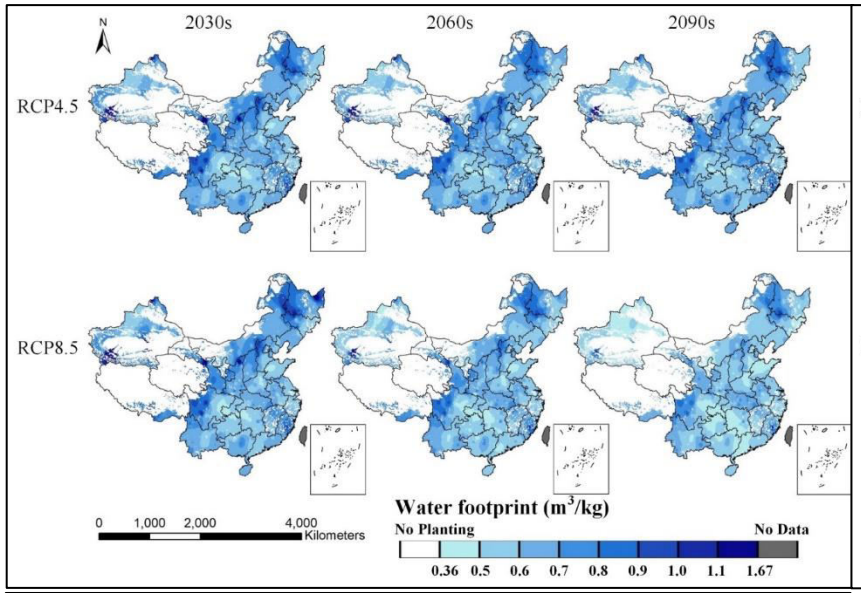
A larger increase in the maize yield was mainly observed in Northwest China, Southwest China, and Northeast China, and the values were mostly between 5%

4 DISCUSSIONS

XVIII World Water Congress
International Water Resources Association (IWRA)

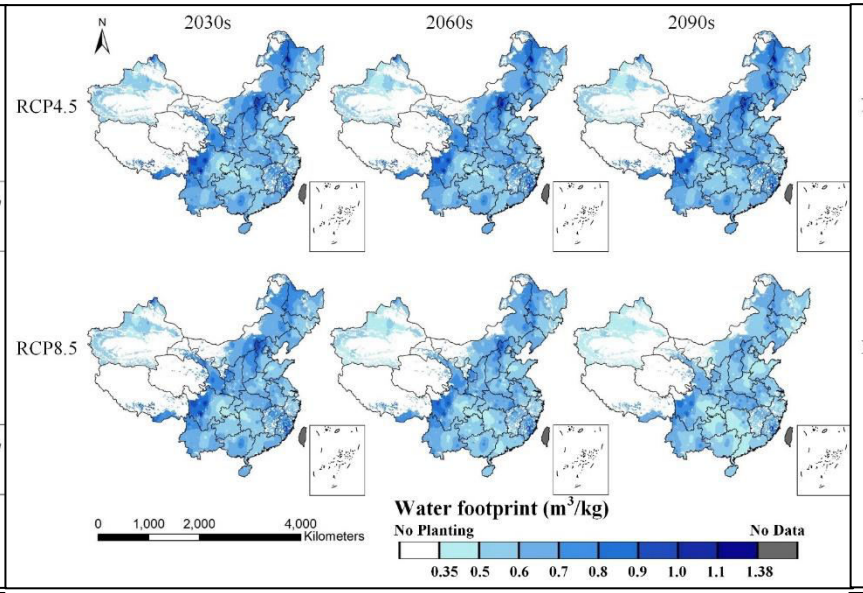
Water footprint of maize under different water supply scenarios

RCP4.5-- 0.42 and 1.64 m^3/kg
RCP8.5-- 0.36 and 1.93 m^3/kg



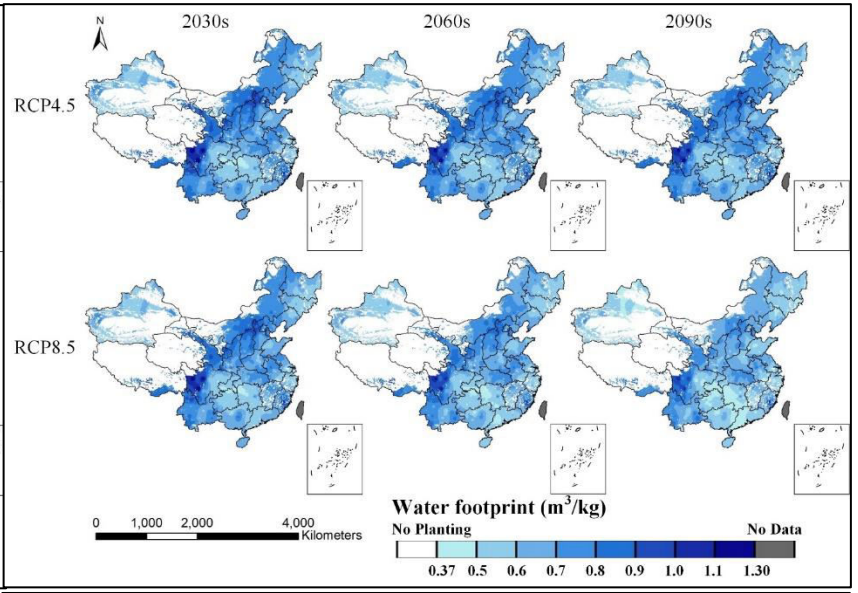
WF of maize under rain-fed scenario

RCP4.5-- 0.40 and 1.38 m^3/kg
RCP8.5-- 0.35 and 1.11 m^3/kg



WF of maize under deficit irrigation scenario

RCP4.5-- 0.43 and 1.30 m^3/kg
RCP8.5-- 0.36 and 1.28 m^3/kg



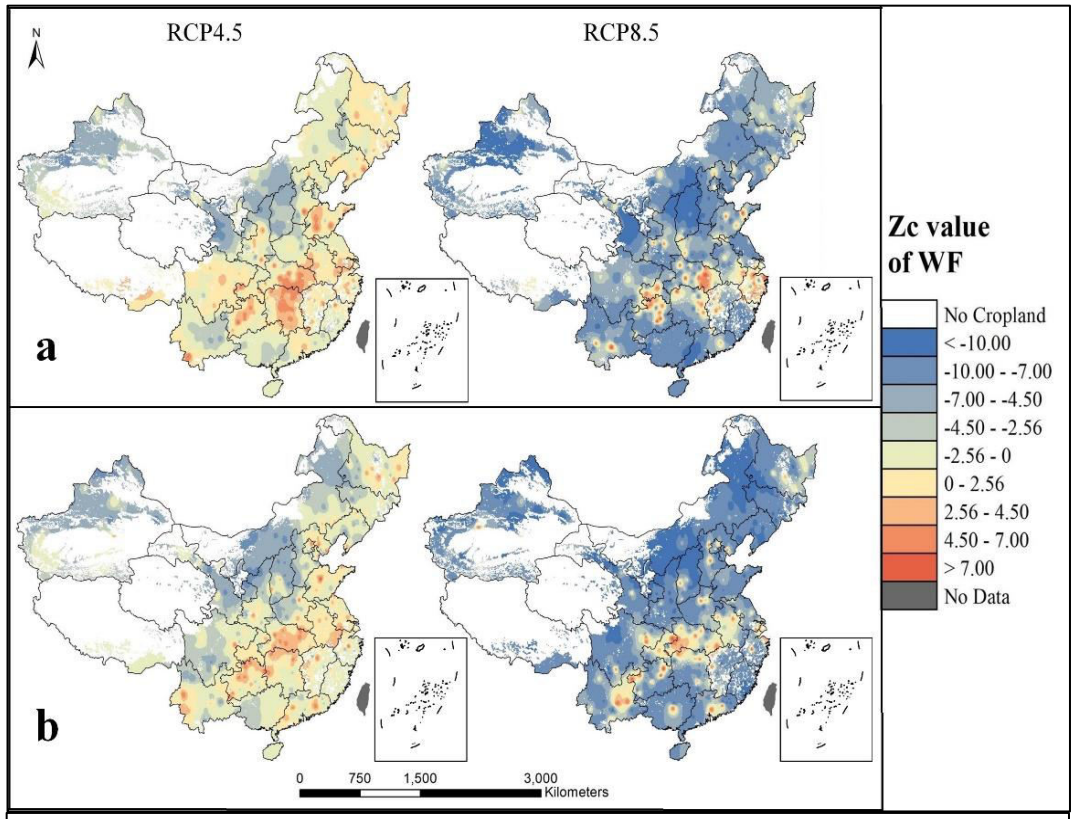
WF of maize under full irrigation scenario

In general, the WF of maize under deficit irrigation conditions was relatively lower than that of other scenarios, which indicates that the deficit irrigation has the WUE advantage over other

4 DISCUSSIONS

XVIII World Water Congress
International Water Resources Association (IWRA)

Effects of irrigation on water footprint of maize



Zc values of WF of maize under deficit irrigation and full irrigation scenario (a. deficit irrigation; b. full irrigation)

The increase in irrigation would reduce the WF in regions with high WF values under rain-fed scenarios.

Increased irrigation could greatly increase the maize yield and then reduce its WF.

However, for the southern part of China, sufficient precipitation has already met the water demand for crop growth; therefore, irrigation would have fewer benefits for reducing WF.

5 CONCLUTIONS

- In most regions of China, precipitation and annual mean temperature would increase over time, and this trend was more obvious in the RCP 8.5 scenario.
- The ET_c and yield of maize in the northern areas would be generally higher than those in the southern areas. The increase in temperature and CO_2 concentration would contribute to a higher maize yield per unit area.
- Deficit irrigation could result in high water use efficiency and increase the maize yield in Northwest China while more irrigation would greatly benefit the maize yield in arid and semi-arid areas.
- Irrigation could alleviate the adverse effects of climate change on the water footprint of maize in arid regions, which also demonstrated regional differences.

XVIII World Water Congress
International Water Resources Association (IWRA)

NORTHWEST A&F UNIVERSITY

Thank you for your attention!