Potential effects of expanding irrigation on crop production under climate change

Masashi OKADA

NIES, Japan

Background

- Replacing rainfed cropping systems with irrigated systems has been deemed an effective agricultural adaptation measure under climate change.

- However, few agricultural impact assessments have considered changes in the water availability because of climate change and water-use competition among crops.

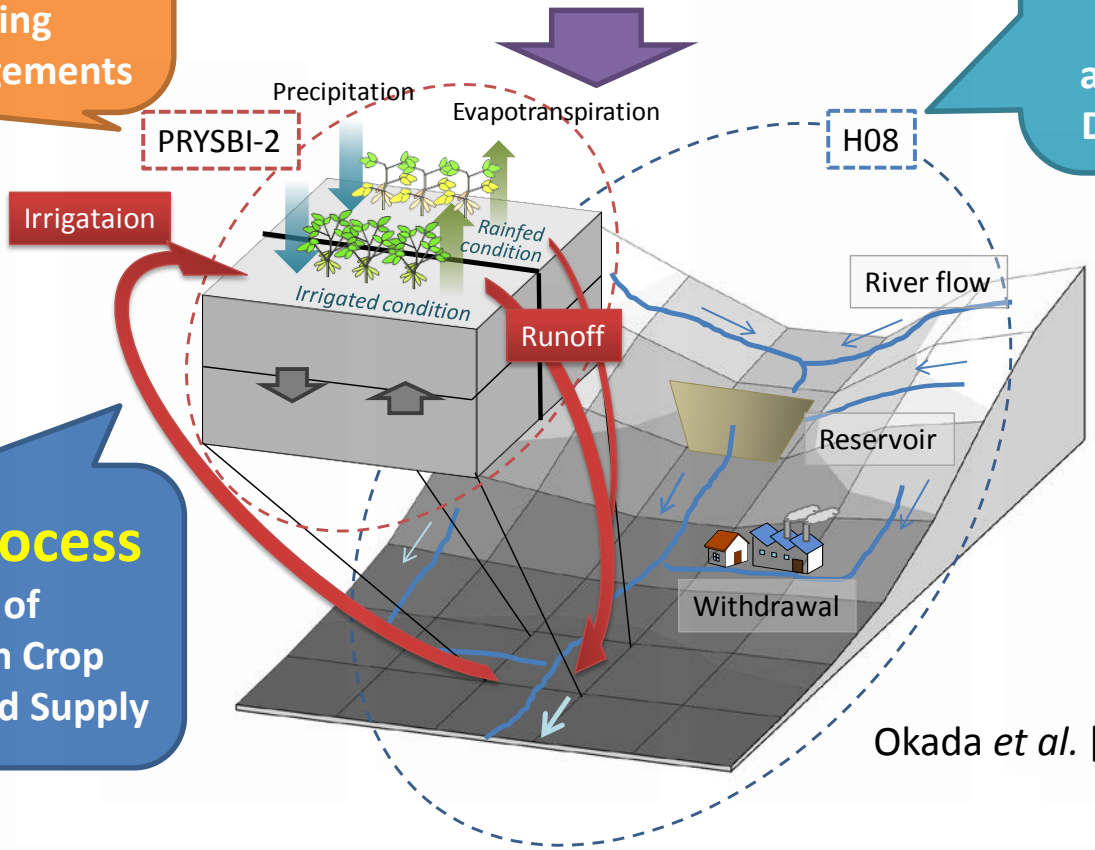
- Here, we assessed future global crop production under a changing climate and expanded irrigation using the large-scale crop-river coupled model CROVER.

CROVER model

Crop Growth and Yield Formation
Crop Growth Simulation with considering Cultivation Managements

Climate Data
(Temp, Precip., Solar Rad., Humidity, Wind Speed)

Water Resource
Natural Water Circulation and Human Activities (Industrial and Domestic Waters, Dam Operations etc.)

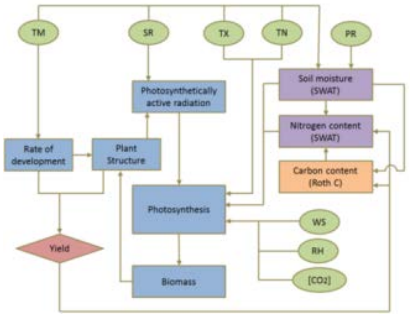


Irrigation Process
Considering of Equilibrium with Crop Water Demand and Supply

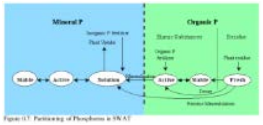
Okada *et al.* [2015] *JAMES*

- The coupled model CROVER was created by embedding the PRYSBI-2 large-area crop model into the global water resources model H08.

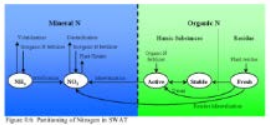
PRYSBI-2 large-area crop model

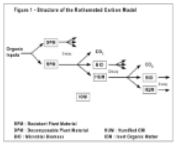


PRYSBI2



SWAT Soil & Water Assessment Tool





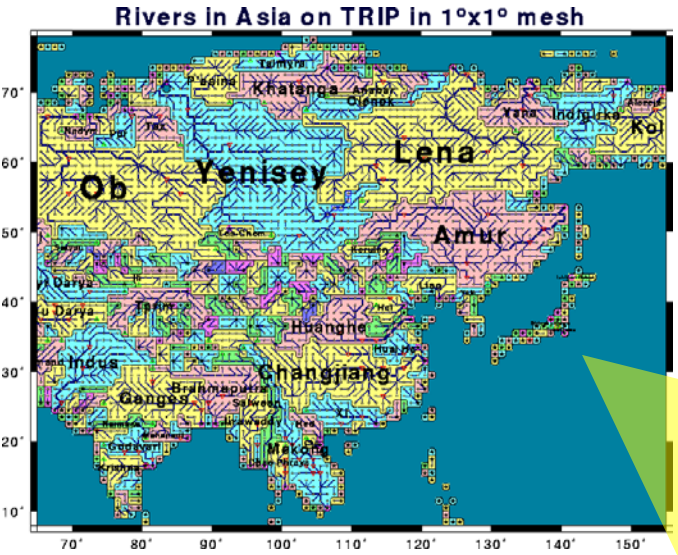
RothC

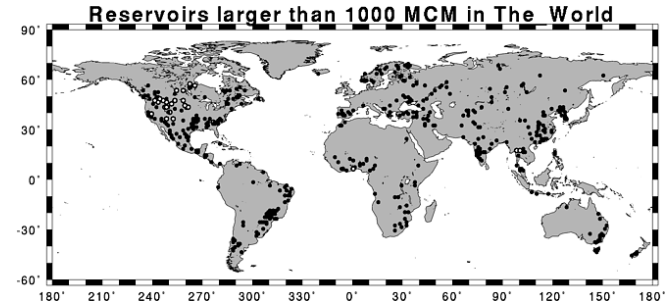
Sakurai *et al.* [2014] *Sci. Rep.*

- PRYSBI-2 has 3 major components:
  - (1) Crop growth was based on basic process-based models,
  - (2) Land-surface hydrological dynamics (SWAT) and
  - (3) Soil carbon dynamics (RothC).
- PRYSBI-2 can address 5 crops (maize, rice, soybean, spring wheat and winter wheat)

- The parameter values were calibrated by using a Bayesian method for each crop in individual grid cells.
  - the spatial uncertainties of the model parameters was considered by estimating the posterior distribution of the parameters from the historical agricultural data.

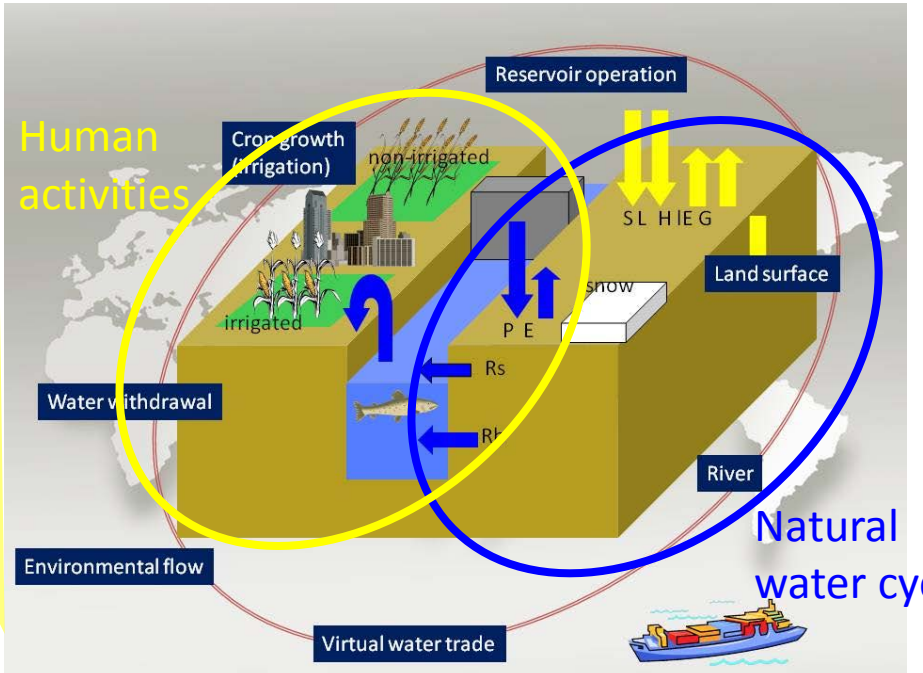
H08 global hydrological model





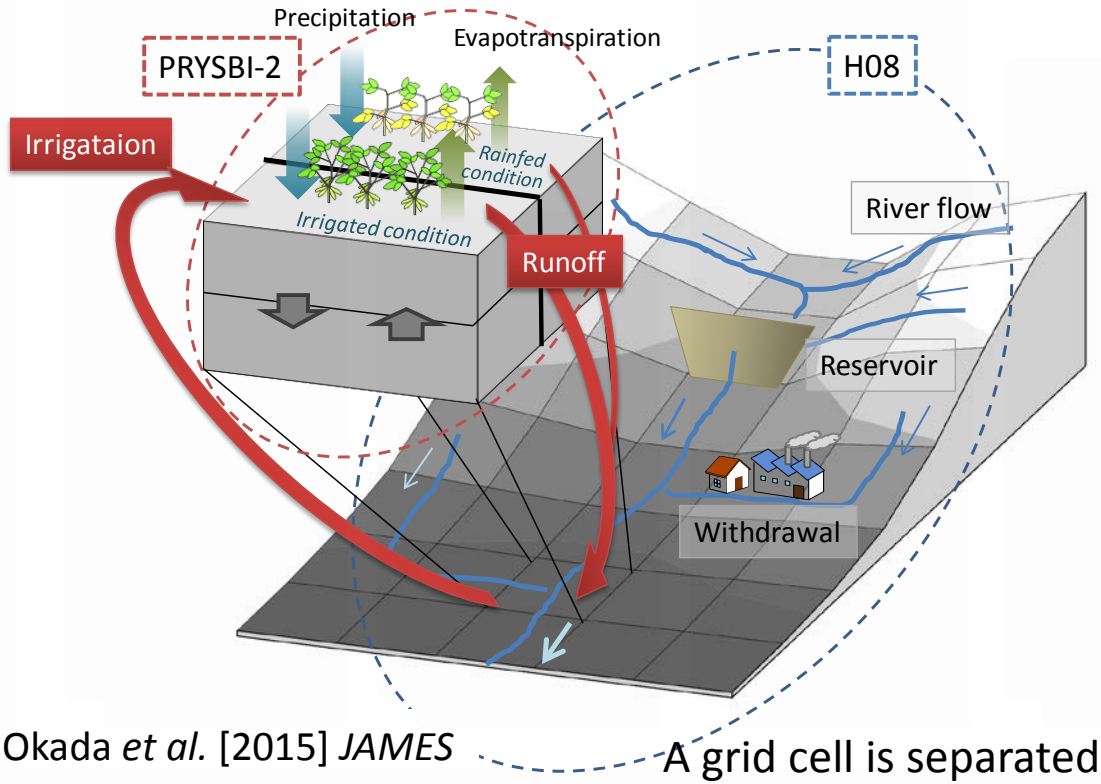
452 large reservoirs（4,140 km^3）

- H08 model can simulate both natural and anthropogenic water flow globally on a daily basis.
- H08 has 6 components:
  (1) Land surface hydrology,
  (2) River routing,
  (3) Crop growth,
  (4) Reservoir operation,
  (5) Environmental flow requirement estimation and
  (6) Anthropogenic water withdrawal.



Hanasaki *et al.* [2006] *JH*
Hanasaki *et al.* [2008a,b] *HESS*

CROVER model



Okada *et al.* [2015] *JAMES*

- The CROVER model was developed by combining 3 components from PRYSBI-2:
  - (1) Crop growth,
  - (2) Land surface hydrology,
  - (3) Soil carbon dynamics

  and 3 components from H08:
  - (1) River routing,
  - (2) Reservoir operation,
  - (3) Anthropogenic water withdrawal.
- It operates at a 1.125-degree resolution at a daily time step.

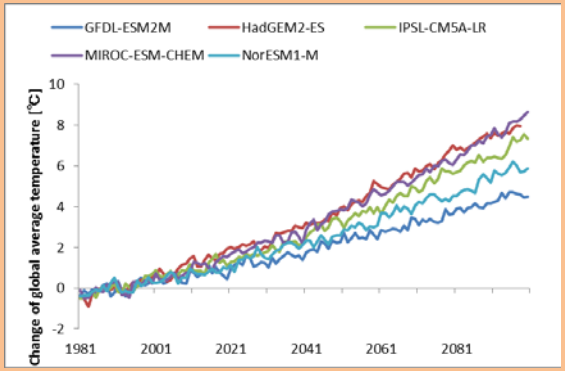
A grid cell is separated into 11 land-use categories
- -5 crops (maize, rice, soybean, spring wheat, winter wheat)
- - 2 conditions (irrigated, rainfed)
- - 1 vegetation

- It simulates the large-scale terrestrial hydrological cycle and crop growth depending on climate, soil properties, landuse, crop cultivation management, socio-economic water demand, and reservoir operation management.

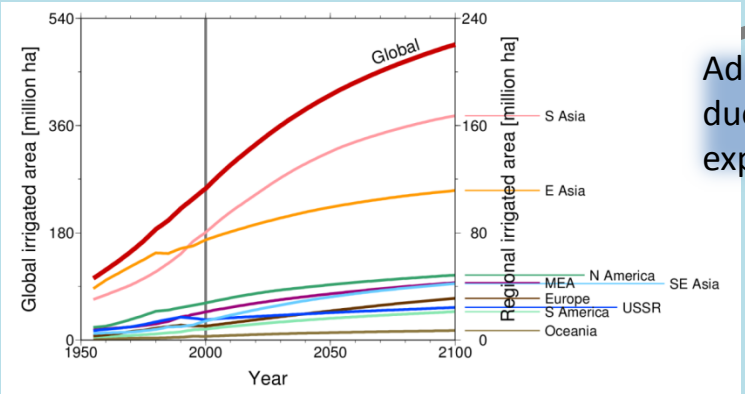
Simulation setting

- This study applied three types of future scenarios (climate change, irrigation area expansion and fertilizer scenarios) to the CROVER model.
- The simulation operated at a 1.125-degree resolution and on a daily time step.

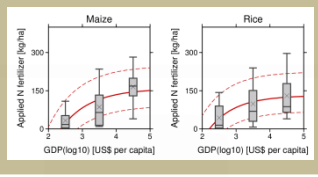
Climate change scenario

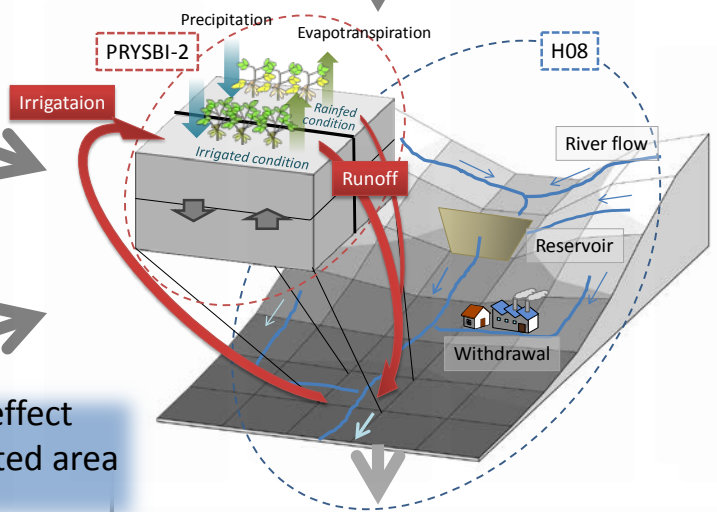


Irrigation area expansion scenario

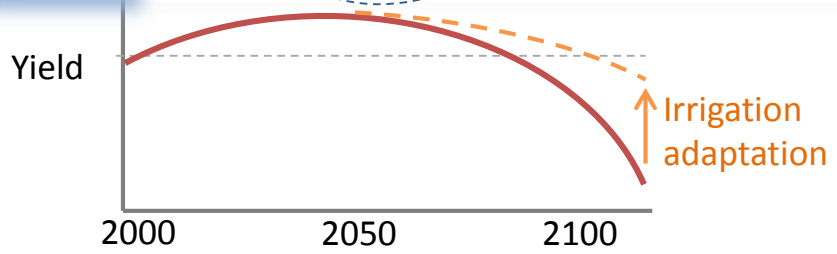


Fertilizer scenario

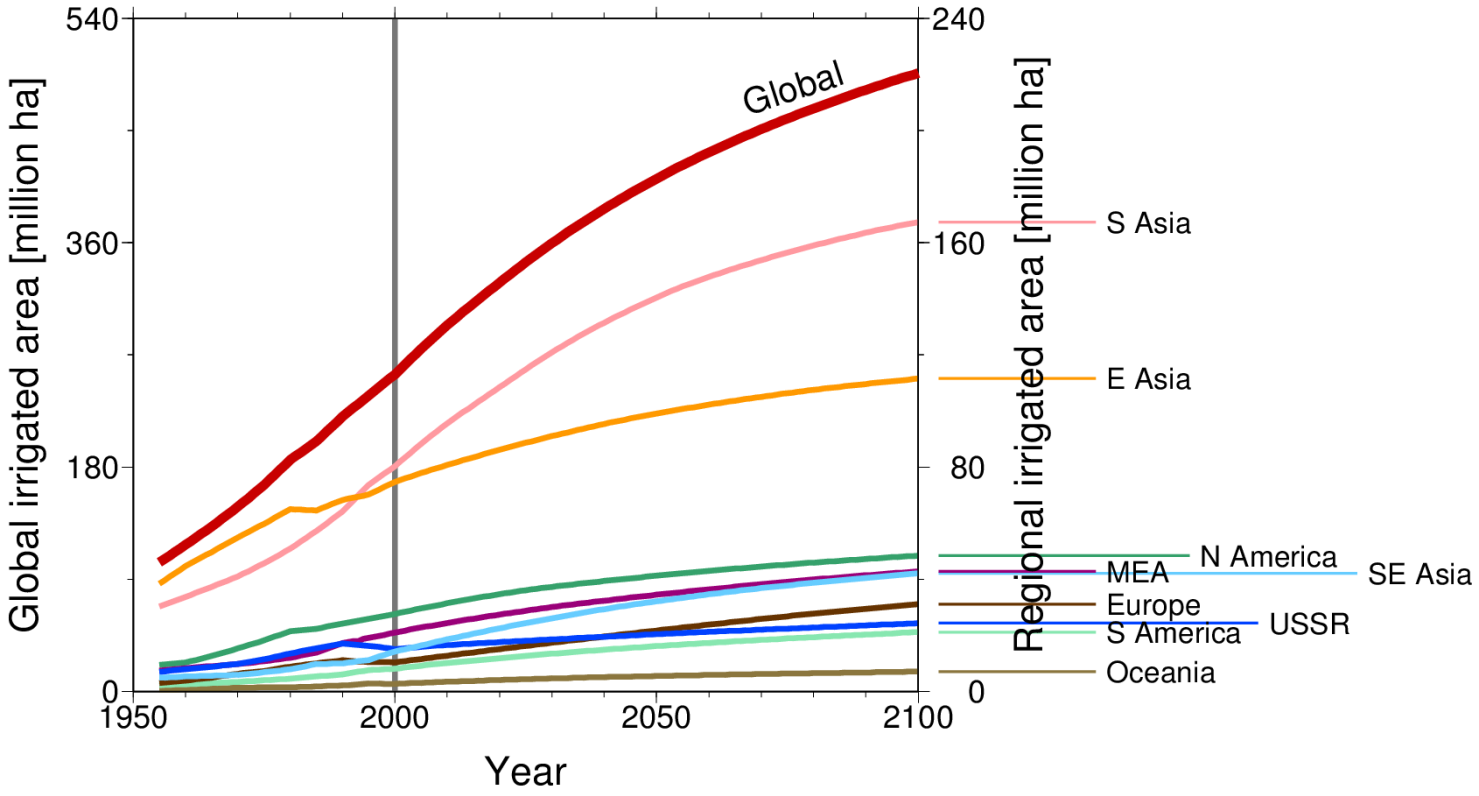




Adaptation effect due to irrigated area expanding



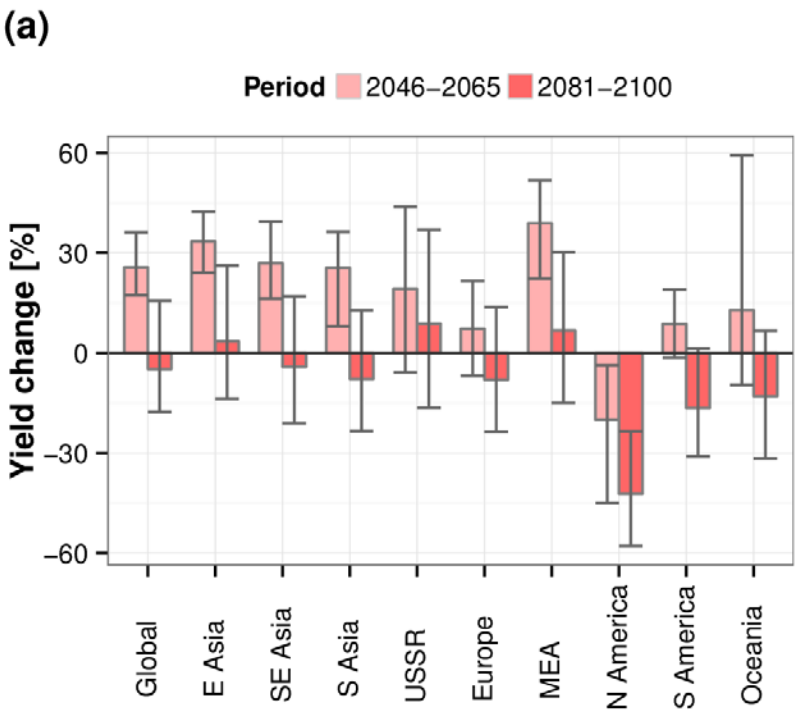
Irrigation area expansion scenario

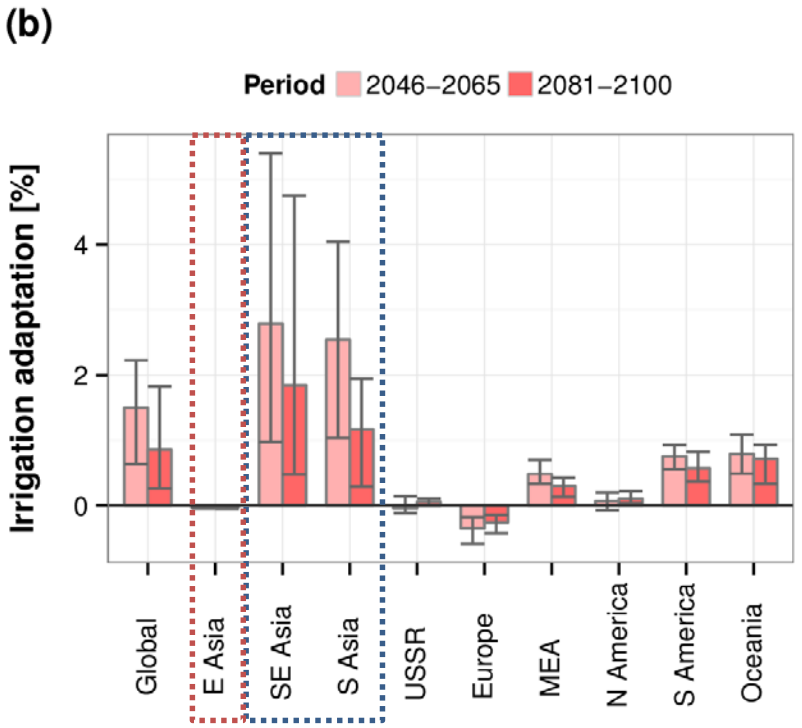


- The historical data was derived from HID product [Siebert *et al*. [2015] *HESS*].
- The future irrigated area was extrapolated from historical irrigation pattern.
- However, the future expansion of irrigated area was stayed when the sum of the irrigated and rainfed areas was greater than the current harvested area (MIRCA2000 [Portmann *et al*. [2010] *GBC*).

Simulated yield and irrigation adaptation effect（Rice）

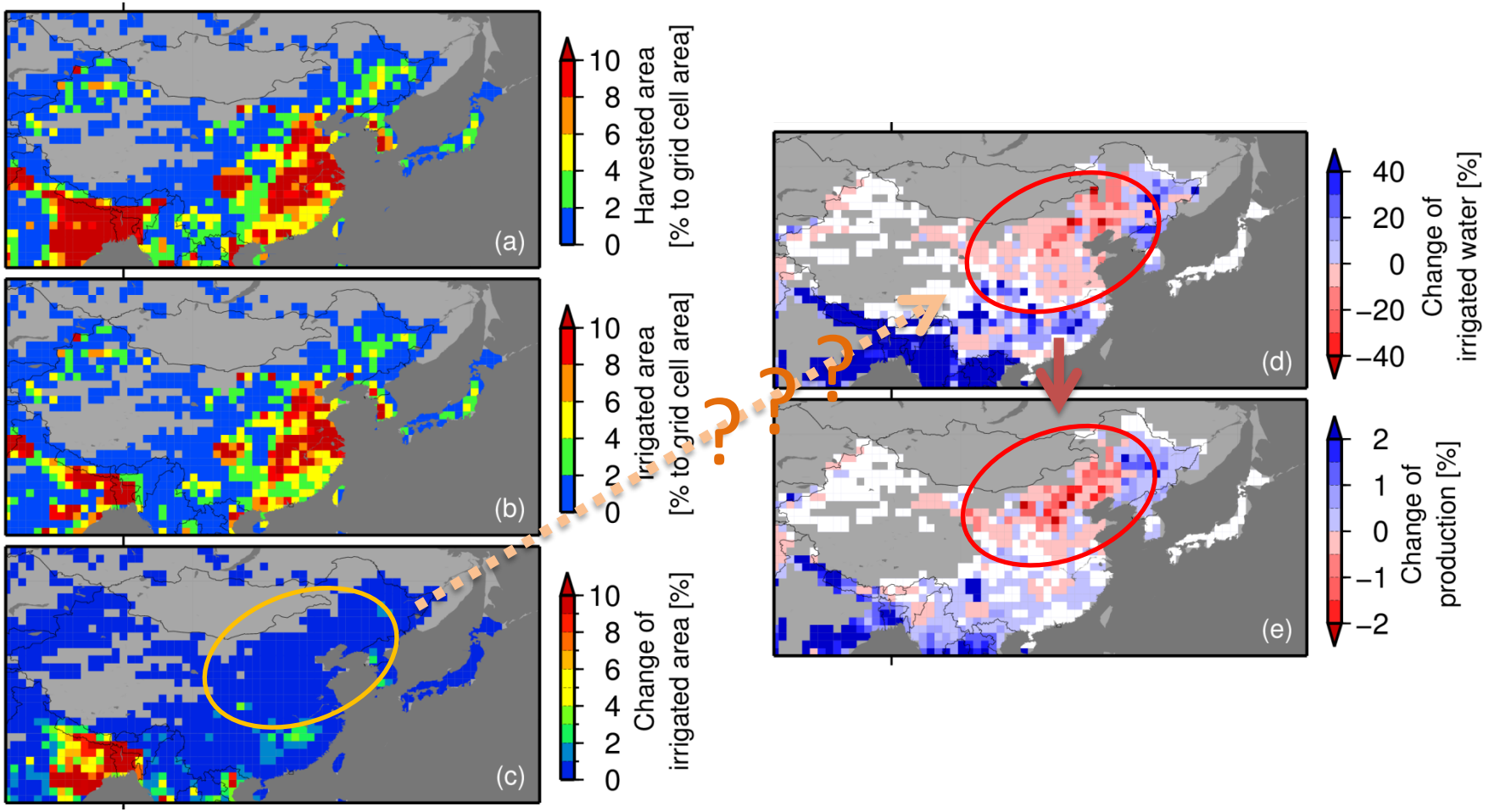
- **Yield change**：At the end of this century, the yield was projected to decrease on the most regions.
- **Irrigation adaptation effect**： Although the yield decrease was effectively improved by the irrigation adaptation in Southeast and South Asia, the expanded irrigated area slightly worsened the yield in East Asia.





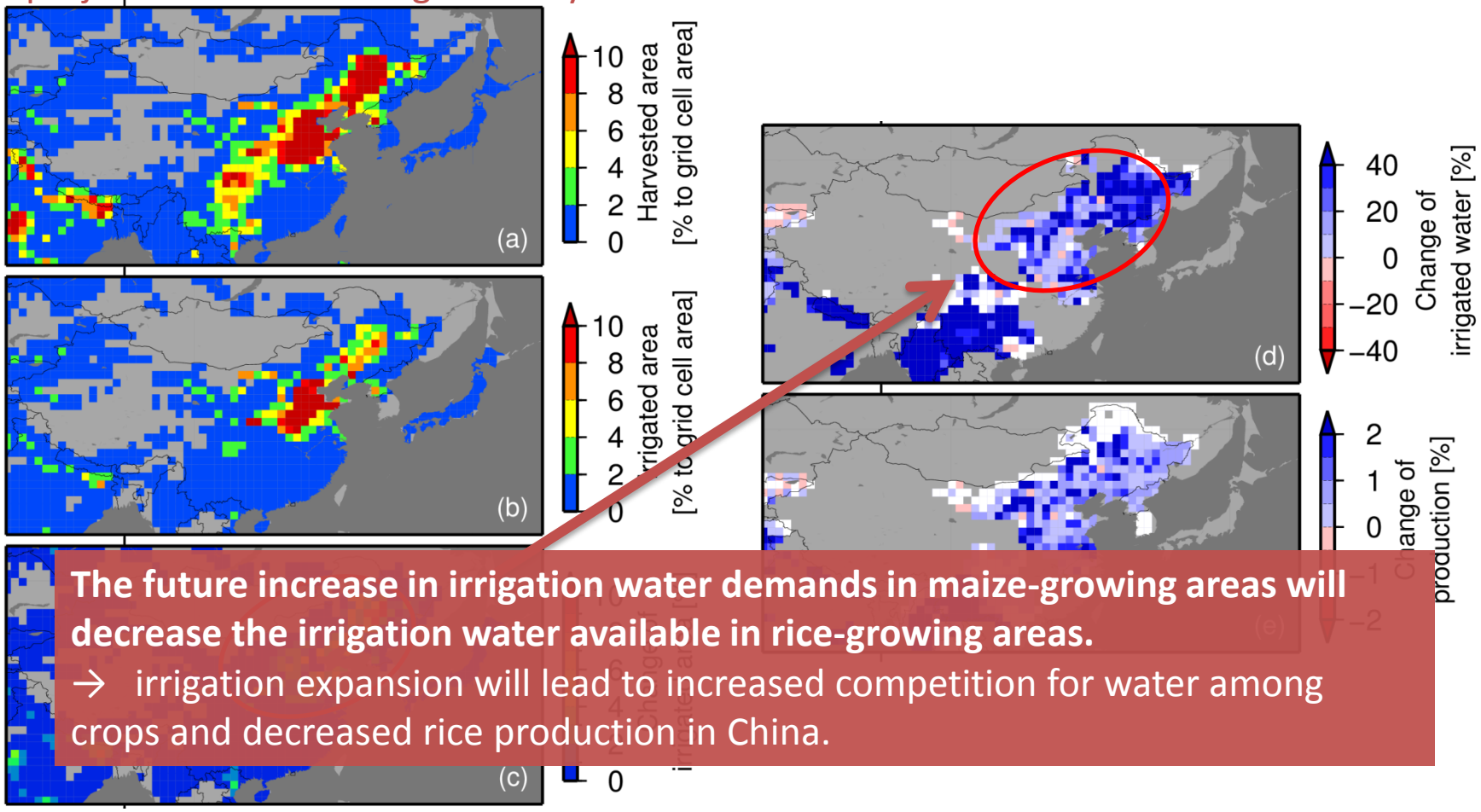
Change in irrigated water and crop production with the expanding irrigated area（Rice）

- Irrigated water was projected to decrease at the north part of China, although the irrigated area expands.
- It brought **decrease in rice production**.



Change in irrigated water and crop production with the expanding irrigated area（Maize）

- At the north part of China, the irrigated area of maize was estimated notable expansion.
- With the notable expanding irrigated area, the applied water to the maize field was projected to increase significantly.



The future increase in irrigation water demands in maize-growing areas will decrease the irrigation water available in rice-growing areas.

→ irrigation expansion will lead to increased competition for water among crops and decreased rice production in China.

Conclusion

- Our assessment reveals that expanding irrigation can be a useful adaptation measure in some areas where a single or a few major crops are grown under irrigated conditions (e.g., Europe),

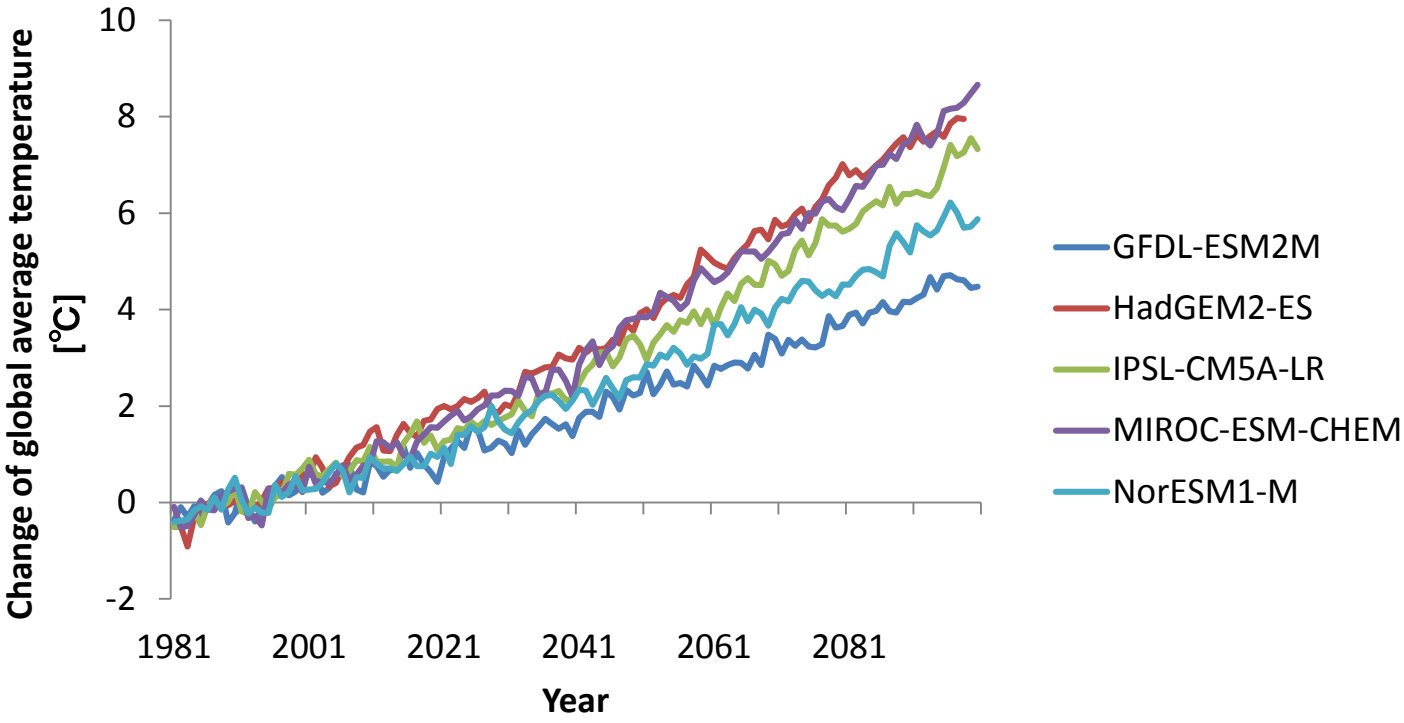
- but that irrigation expansion produces only limited crop production increases in areas where irrigation is already extensively used for multiple crops (e.g., East Asia) due to competitive water use among crops.

- These findings emphasize the importance of considering inter-crop water-use competition and the associated changes in the water availability when planning irrigation expansion to adapt to climate change.

- Our analysis demonstrates a complex water-food nexus using irrigation expansion and crop production under a changing climate as an example.

Thank you for your attention

Climate change scenario

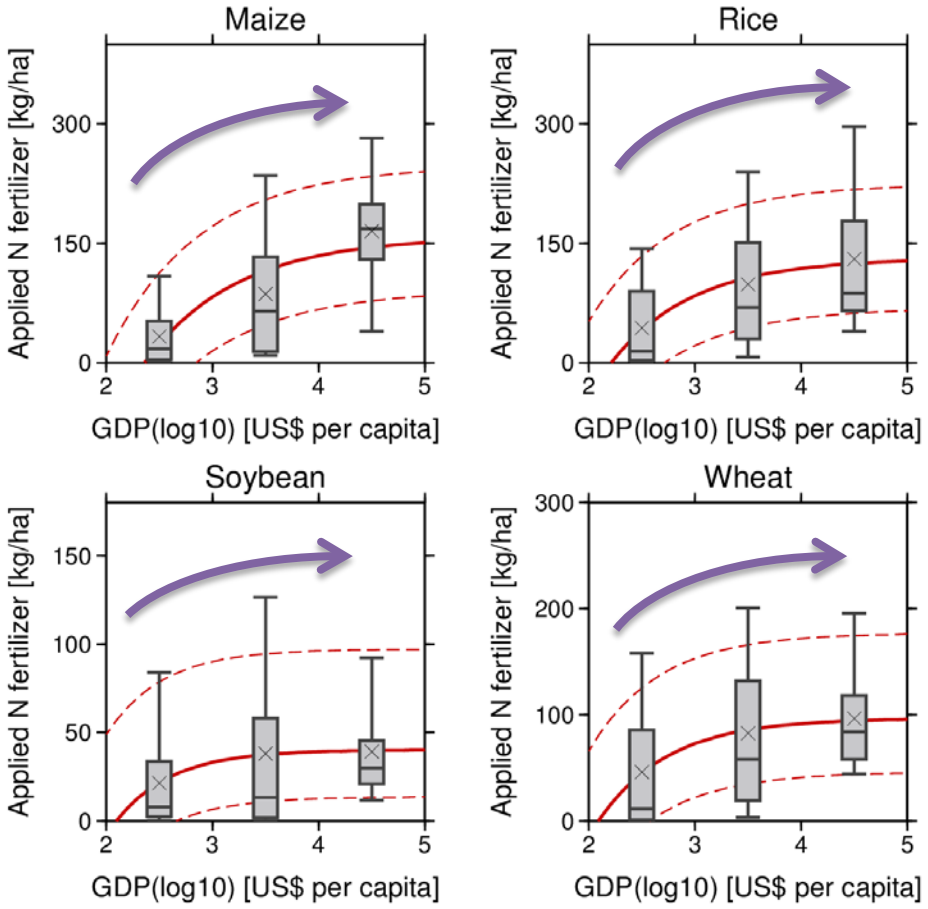


This study used the bias-corrected five GCMs outputs under the RCP 8.5 scenario.

- GFDL-ESM2M
- HadGEM2-ES
- IPSL-CM5A-LR
- MIROC-ESM-CHEM
- NorESM1-M

Fertilizer scenario

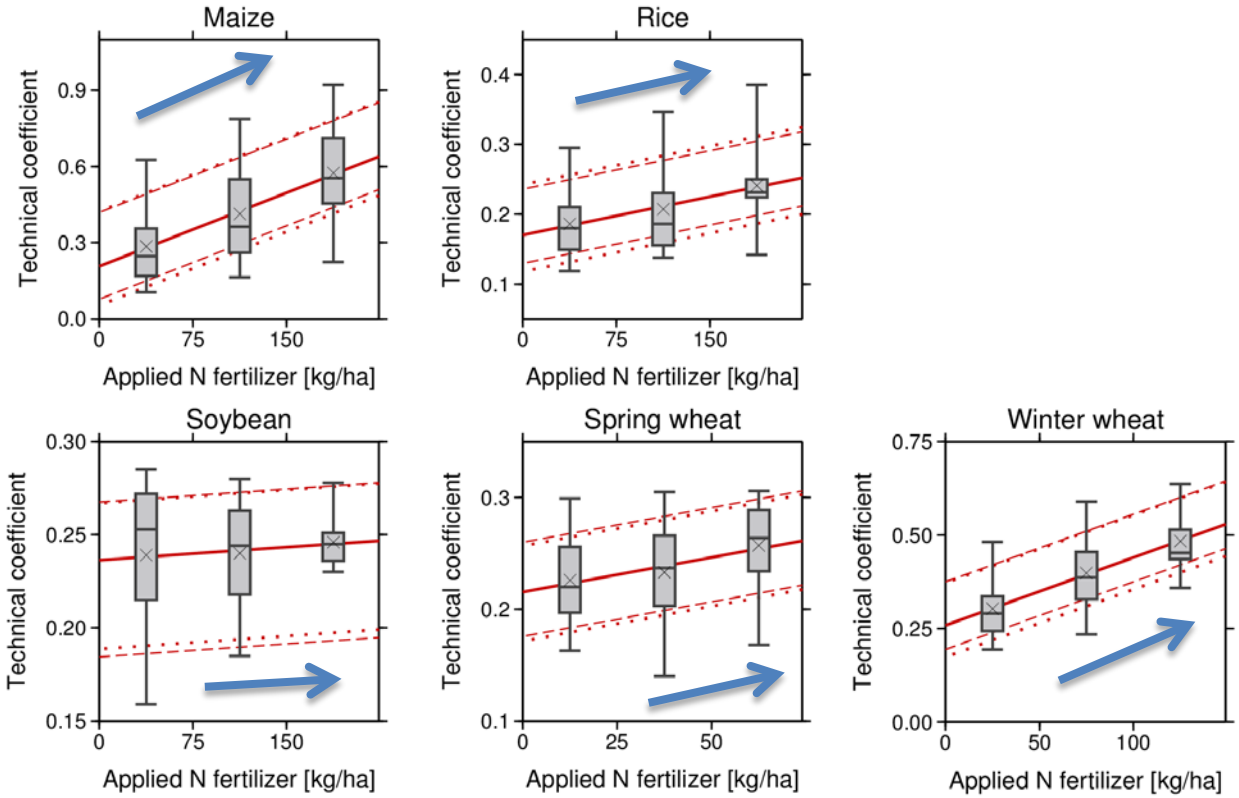
- The annual applied N fertilizer was assumed to depend on economic growth.
- The global relationship was derived from the country mean per capita GDP and the grid-based crop-specific N fertilizer circa 2000.



GDP per capita:
World bank, IMF, UN
N fertilizer:
Mueller et al. [2012] *Nat.*

Fertilizer scenario

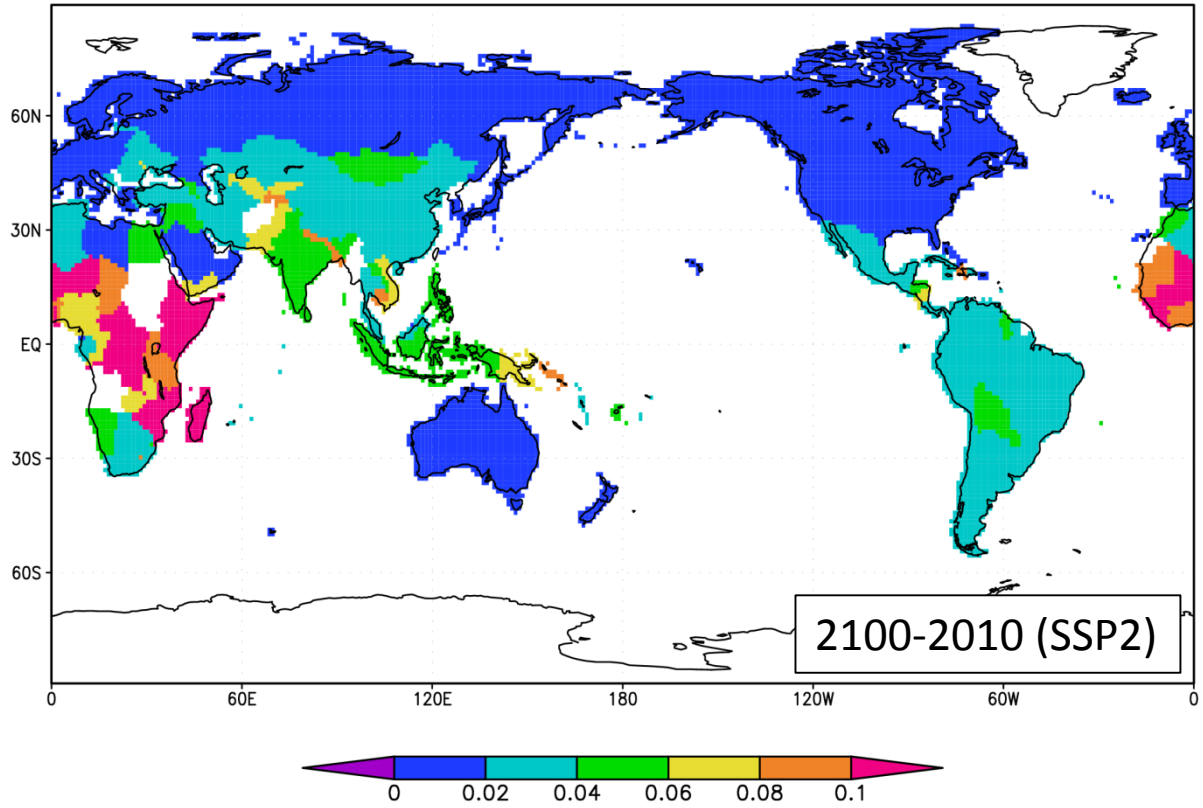
- The effect of increase in the fertilizer on crop yield was parameterized as technical coefficient. In this study, we did not operate the soil carbon dynamics component.
- The parameter was previously assimilated from historical yield data with PRYSBI-2 not using the fertilizer data.



N fertilizer:
Mueller et al. [2012] *Nat.*
Technical coefficient:
Model parameter

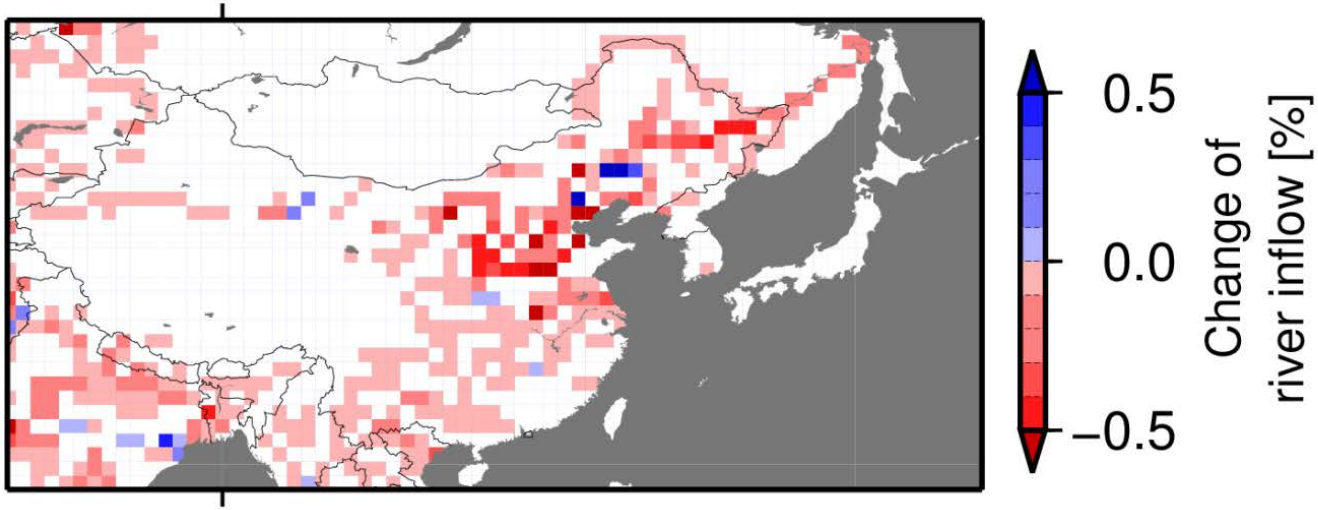
Fertilizer scenario

- Based on these relationships, the technical coefficient in the future was calculated using the future country mean per capita GDP data under SSP2 scenario [IIASA 2016], via estimating the applied N fertilizer.



Change of river inflow with the expanding irrigated area

- With the expanding irrigated area, the available water for irrigation on the adjacent lower grid cell projected to decrease.
- The substantial decrease was estimated at the north part of China.



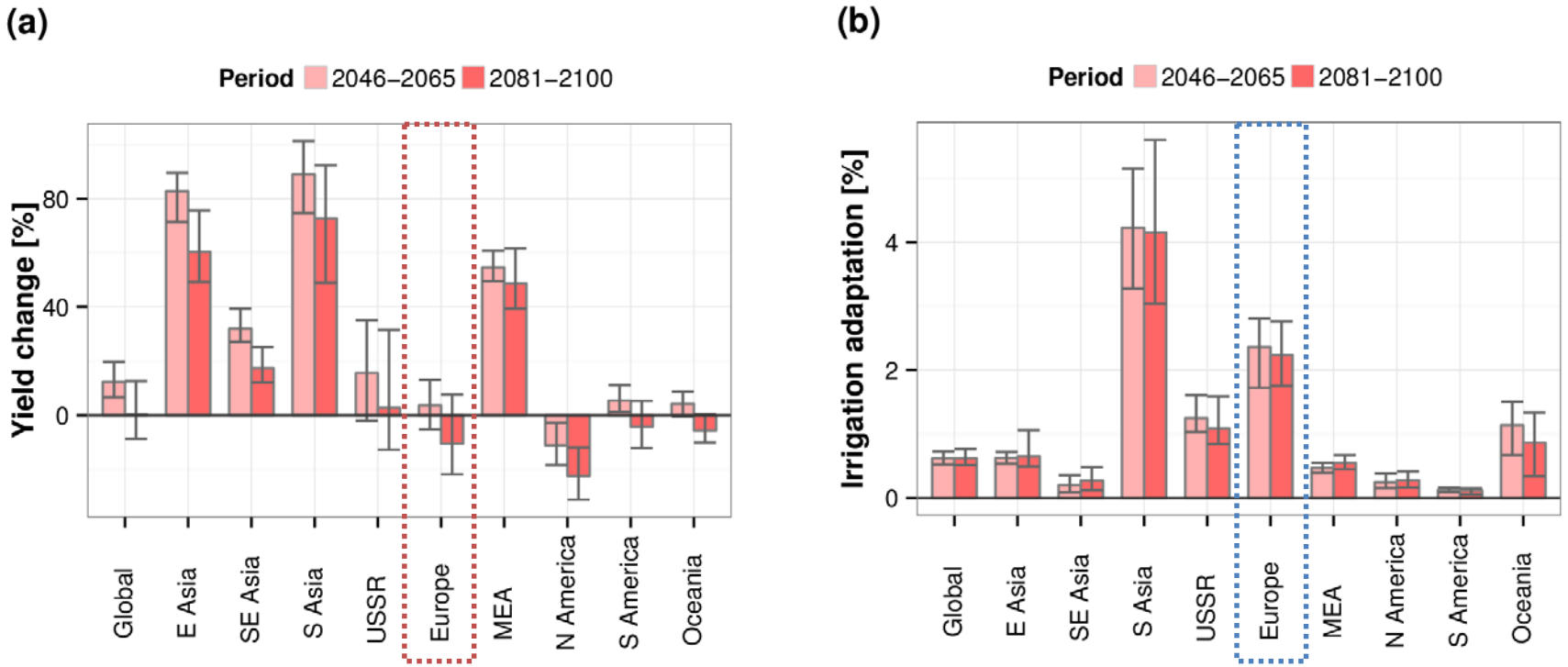
With the expanding irrigated area, slightly worsened the yield in East Asia results from

- the increase of irrigation water uptake on maize field with the significant expanding irrigated area at the north part of China,
- the increase of irrigation water uptake on the upstream area in each river watershed.

Simulated yield and irrigation adaptation effect（Maize）

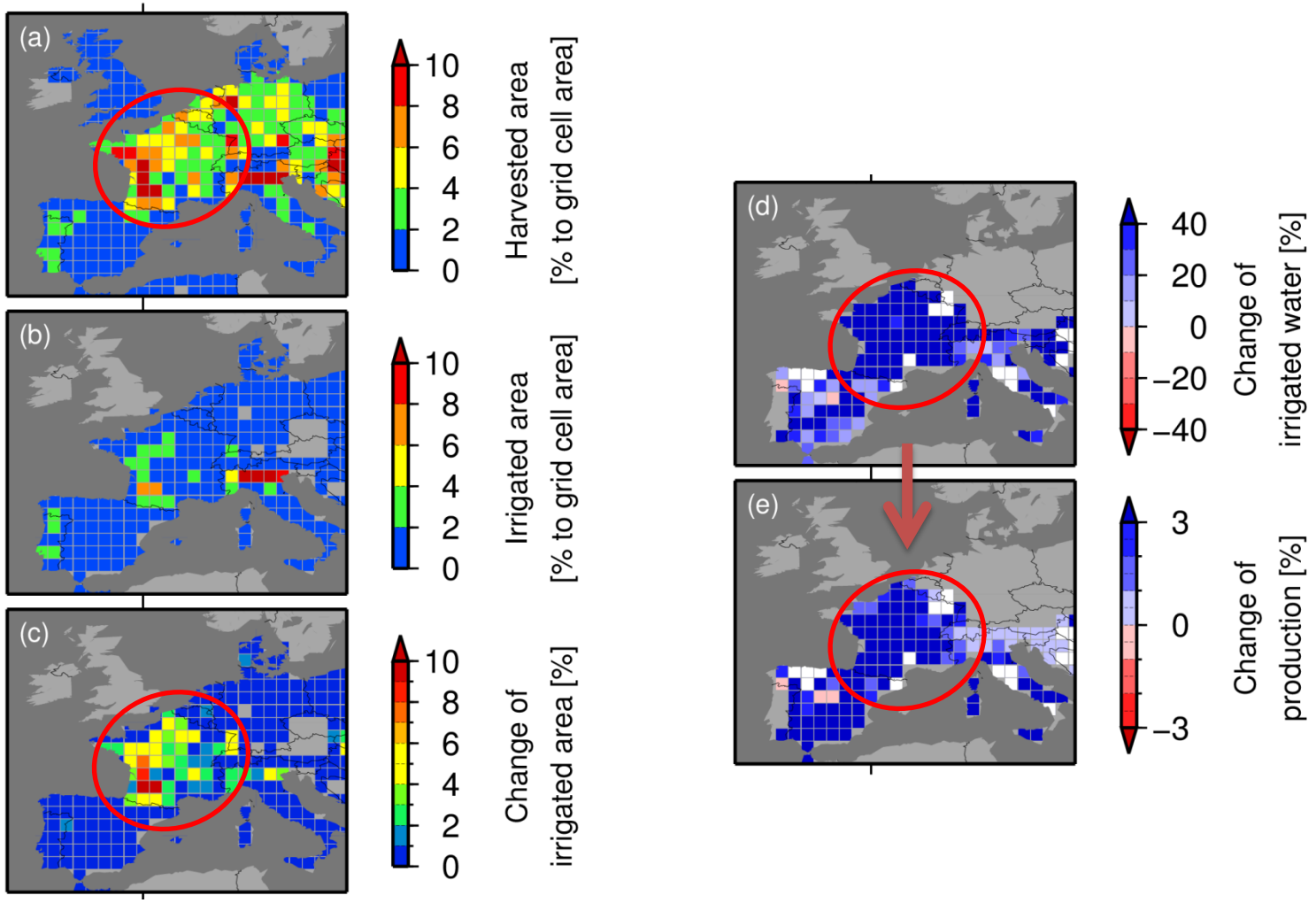
Of course, the irrigation adaptation provides benefits to crop production.

- **Yield change**：At the end of this century, although the yield was projected to increase in Asia, the yield decrease in Europe.
- **Irrigation adaptation effect**：The yield decrease was effectively mitigated by the irrigation adaptation in Europe.



Change in irrigated water and crop production with the expanding irrigated area（Maize）

- Irrigated water was projected to increase around France with the expanding irrigated area, brought increase in maize production.



Future distribution of irrigated area in major crops

- Irrigated areas of the other crops than maize are little.
- Water use for irrigation on maize field hardly compete with those on the other crops.