The response of crop yield to temperature increase in China

Chuang Zhao, Shilong Piao, Yao Huang, Mengtian Huang, Philippe Ciais, Xuhui Wang

2015.09.22

Food security in China

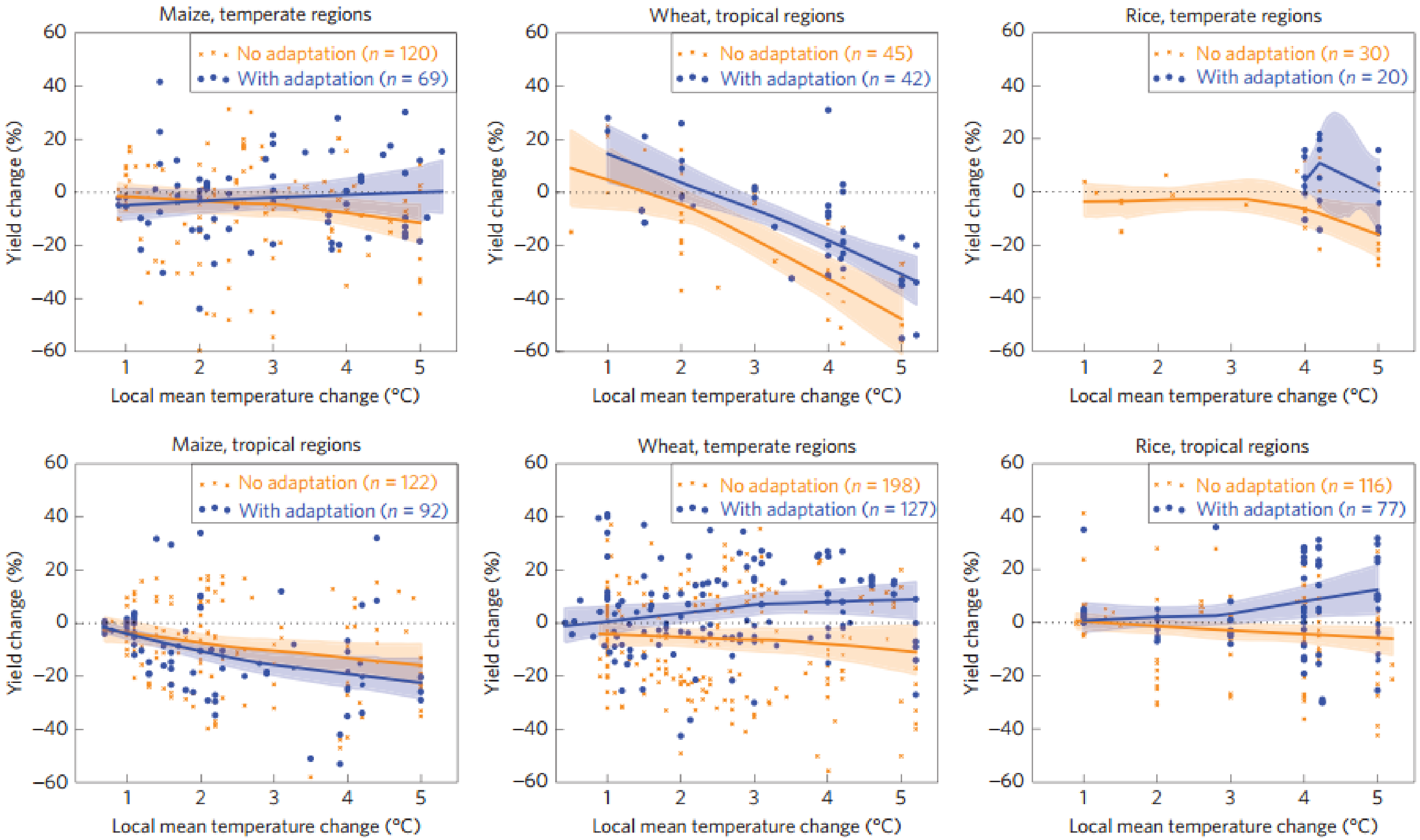
The facts

- 1.3 billion population
- 7% of world cropland but need to feed the 22% of world population

The risks

- Population growth
- Increased daily food consumption
- Climate change

Climate change impact



(IPCC AR5; Challinor et al., 2014)

Approaches

- Process-based crop models
- Statistical models
- Field warming experiments

Process-based crop models

Wheat

Input data:

cultivar, climate forcing, management and soil conditions.

Temperature sensitivity of crop yield($S_{Y,T}$):

A step-wise or progressive temperature increase

Process-based crop models

Disadvantages

- A large number of uncertain parameters.
- Differences in $S_{Y,T}$ between models are difficult to trace back to specific equations and parameters.

Statistical models

- The regression of observed crop yield against climate variables, including temperature.

$$\Delta \text{Yield}_{i,t} = \beta_{i,0} + \beta_{i,1} \Delta \text{Tmean}_{i,t} + \beta_{i,2} \Delta \text{P}_{i,t} + \beta_{i,3} \Delta \text{SR}_{\text{D}i,t} + \varepsilon_{i,t}$$

Advantages

- Their limited reliance on field calibration data
- their transparent assessment of model uncertainties.

Statistical models

Disadvantages

- Do not capture details of plant physiology or crop management
- Extrapolated outside the envelope of current-climate to predict yield
- Co-linearity between predictor variables (e.g., temperature, VPD and radiation).

Field warming experiments

- Provide direct warming treatments in field plots.
- climate conditions are artificially modified, offer the unique observations to estimate $S_{Y,T}$.

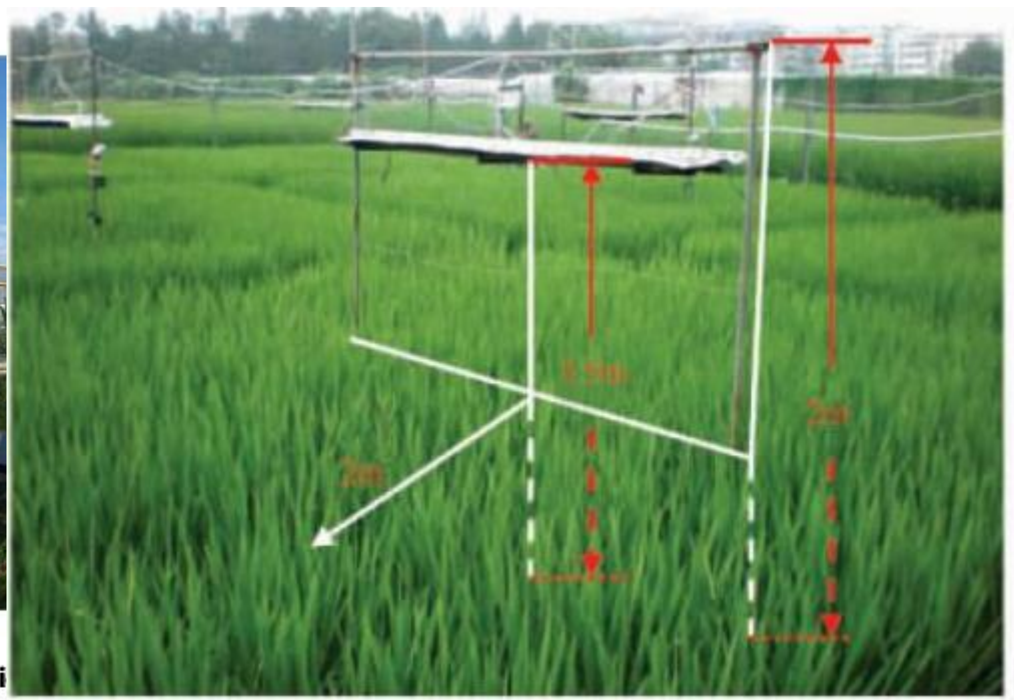


Figure 1. Vi
Liaoning province, China.
doi:10.1371/journal.pone.0098318.g001

arming and control (no artificial warming) under a frost ... 08 at Hebei province, China. Intensive frost in ambient control plots showed in upper-left side of the picture and no frost in the waming plots showed in center-right.

Field warming experiments

Some disadvantages

- The measurement error.
- Rather short time periods.
- Represent only a small range of genotypes or management types (IPCC, 2014).

Aims

- Synthesize from current literature on the sensitivity of crop yield to temperature changes in China based on the three approaches.

- Explore relationships between $S_{Y,T}$ and local background climate conditions.

Methods

- Collect all the peer-reviewed studies on the response of crop yield to temperature change.
- Three distinct approaches
- a common measure of temperature sensitivity of crop yield ($S_{Y,T}$, yield % change per ° C).

Methods

Global Gridded Crop Models (GGCMs)

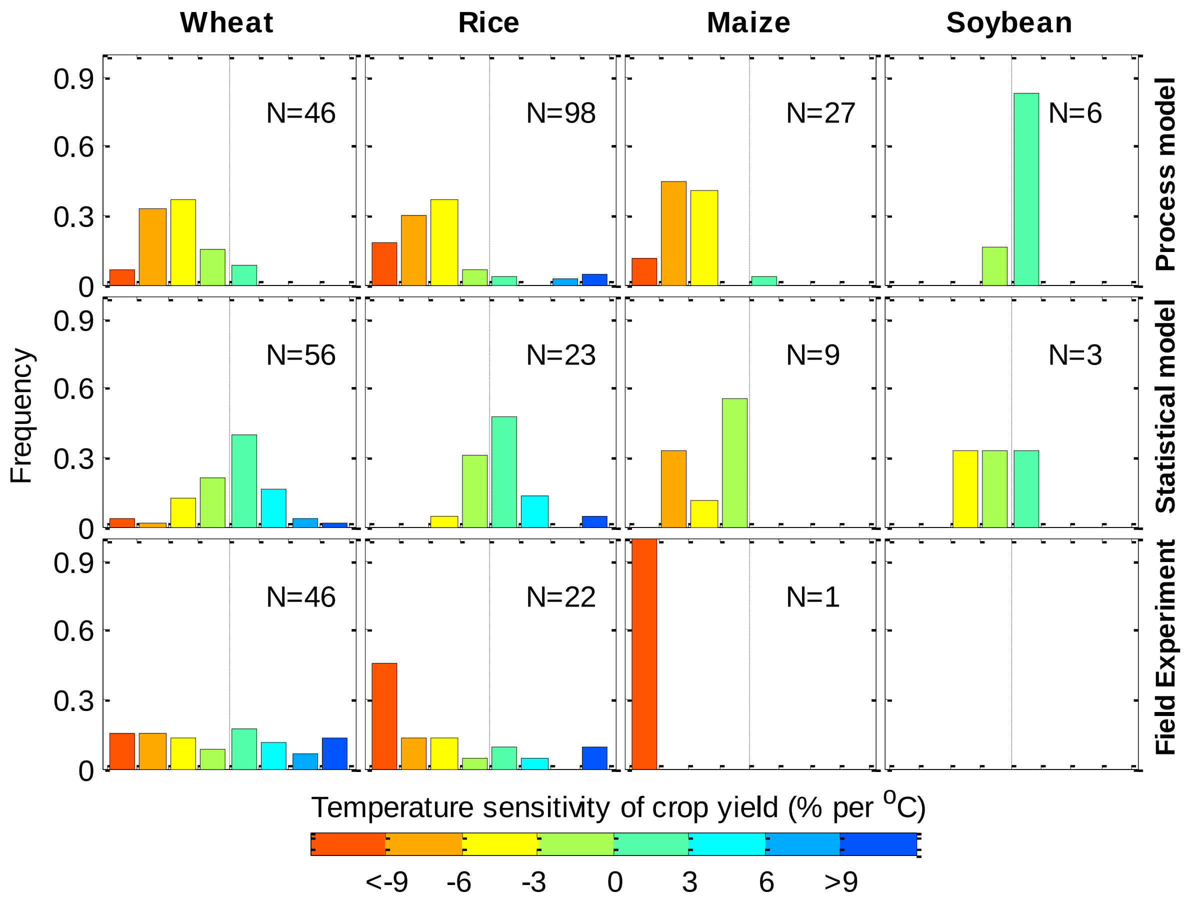
- EPIC, GEPIC, LPJ-GUESS, LPJml, pDSSAT and pEGASUS

Five Global Climate Models (GCMs)

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

$$Y_t = \beta_0 + \boldsymbol{S_{Y,T}} T_t + S_{Y,P} P_t + S_{Y,R} R_t + \varepsilon_t \quad (1971\text{-}2005)$$

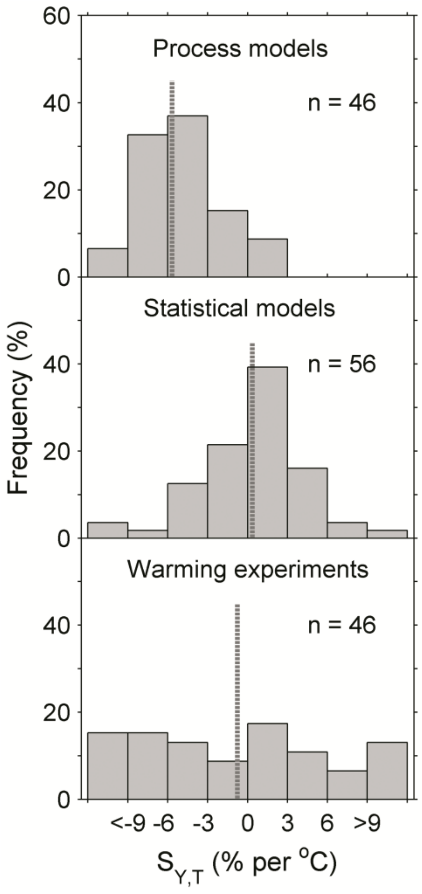
Results



Wheat
Rice
Maize
Soybean
Frequency
0.9
0.6
0.3
0
N=46
N=98
N=27
N=6
Process model
N=56
N=23
N=9
N=3
Statistical model
N=46
N=22
N=1
Field Experiment
Temperature sensitivity of crop yield (% per °C)
<-9
-6
-3
0
3
6
>9

Results

wheat

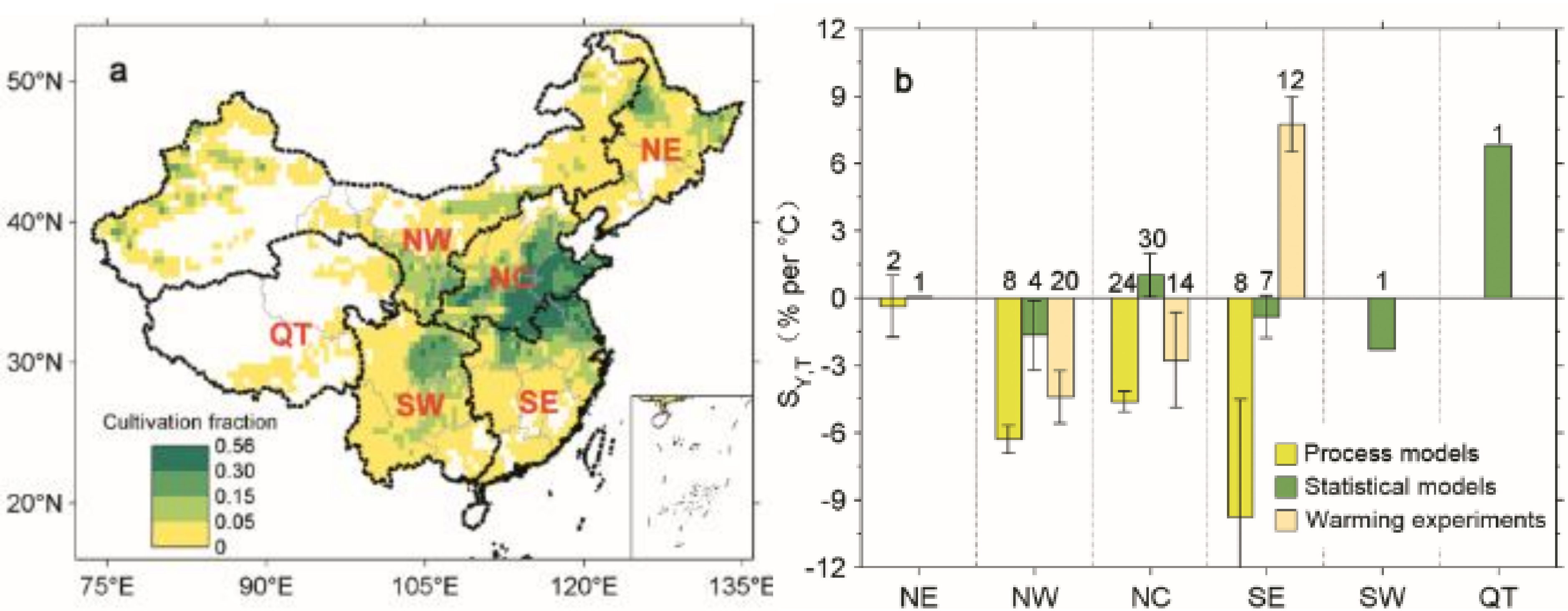


–5.7±6.5% per ℃

0.4±4.4% per ℃

–0.7±7.8% per ℃ (large ranges)

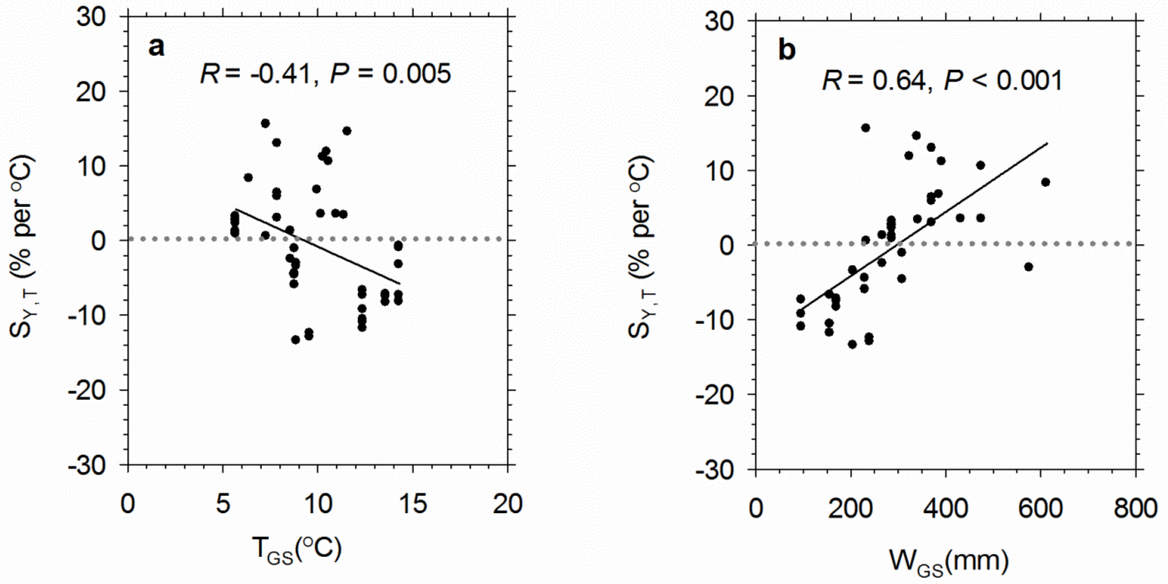
Regional differences



Relationship with background climates

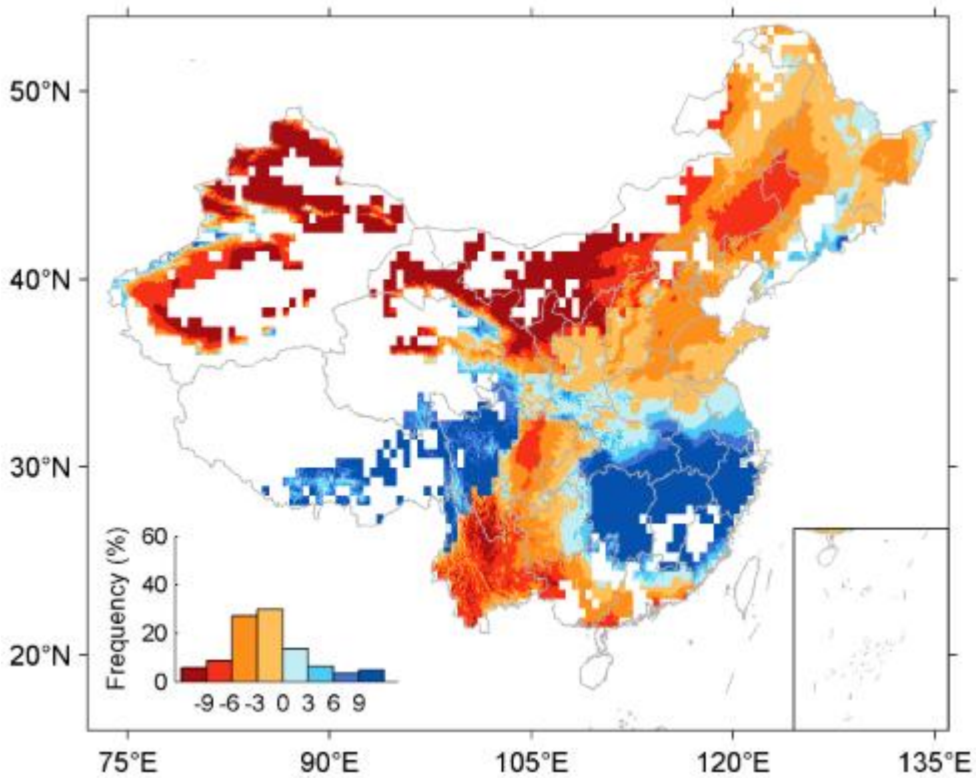
T_{GS}
growing season temperature

W_{GS} (water supply)
precipitation+irrigation



$$S_{Y,T} = -0.582\ T_{GS} + 0.038\ W_{GS} - 5.913\ (R2=0.43,\ P<0.001)$$

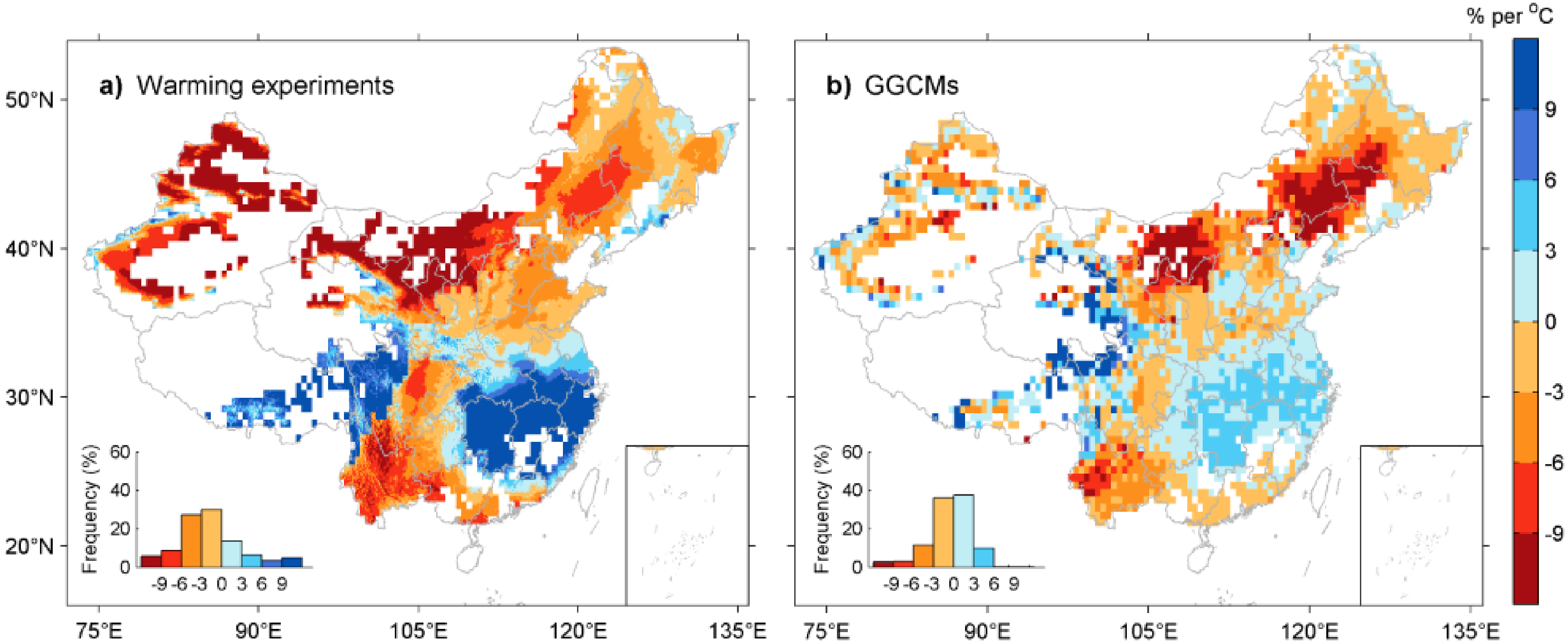
Gridded map of $S_{Y,T}$



Agree well with the average from local field warming experiments in NW, NC, SE.

In 71% of wheat growing area, $S_{Y,T}$ are negative!

GGCMs performance



Broadly consistent!

Summary

- Our study is the first comprehensive assessment of the temperature sensitivity of wheat yield in China based on three distinct approaches.
- $S_{Y,T}$ show considerable regional differences for field warming experiments, which might be explained by the local background climate condition.
- Multiple model-ensemble can reproduce the experimental regional patterns.

Thanks for your listening!