

Effects of agricultural intensification on regional climate: Looking at climate change from the ground up

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Key Points:

- Observations and numerical simulations both suggest that agricultural intensification has cooled

Twentieth Century Regional Climate Change During the Summer in the Central United States Attributed to Agricultural Intensification

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Science

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Productive corn fields are responsible for unique weather changes in the central United States. ISTOCK/COMSEASTOCK

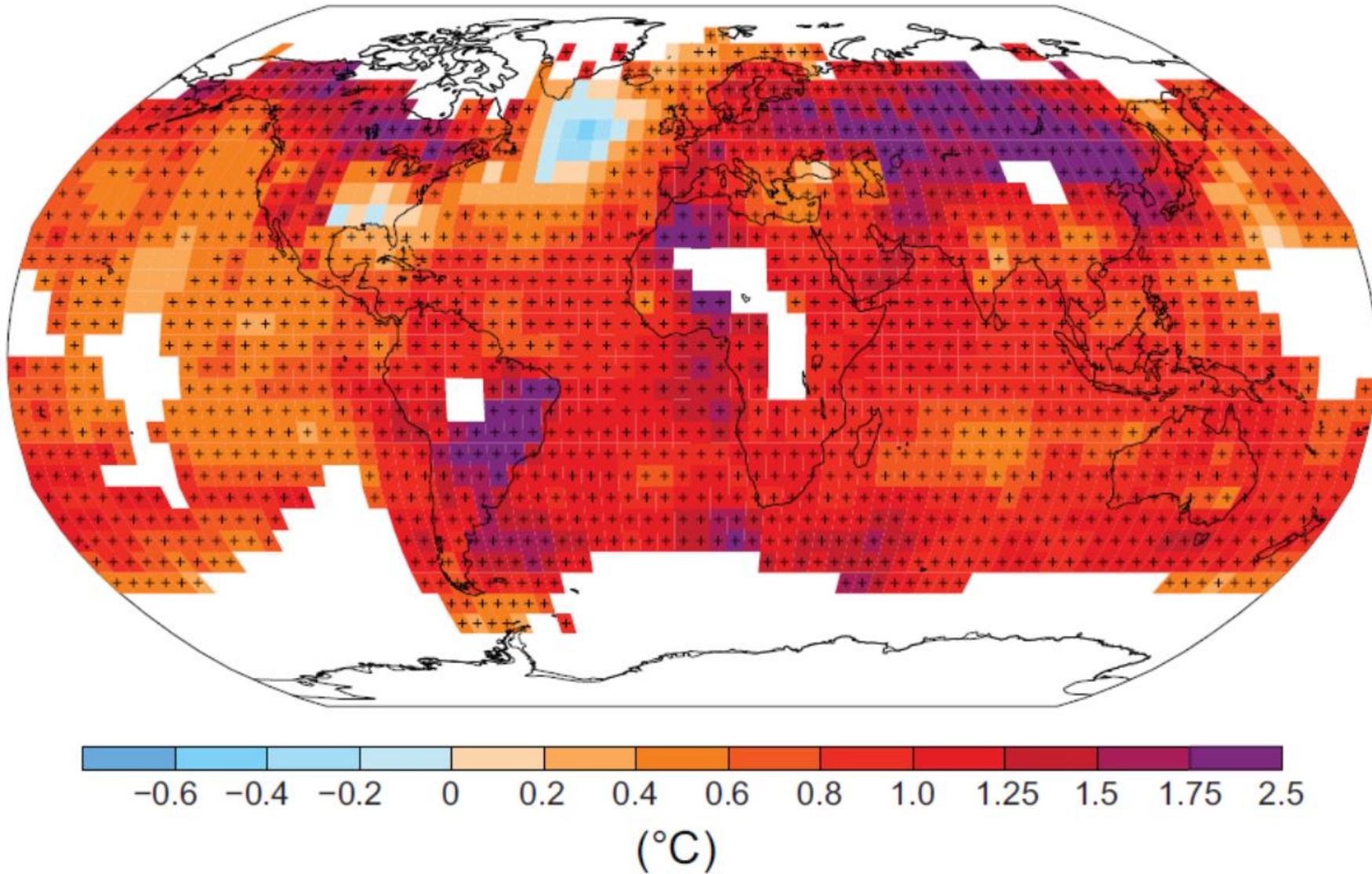
The United States's Corn Belt is making its own weather

Outline

- Global picture
- Research questions
- Agricultural intensification and regional climate
 - Background
 - Observational trends
 - Numerical modeling methodology
 - Modeling results
 - Proposed mechanisms
 - Conclusions and implications
- Take-home messages

Global picture

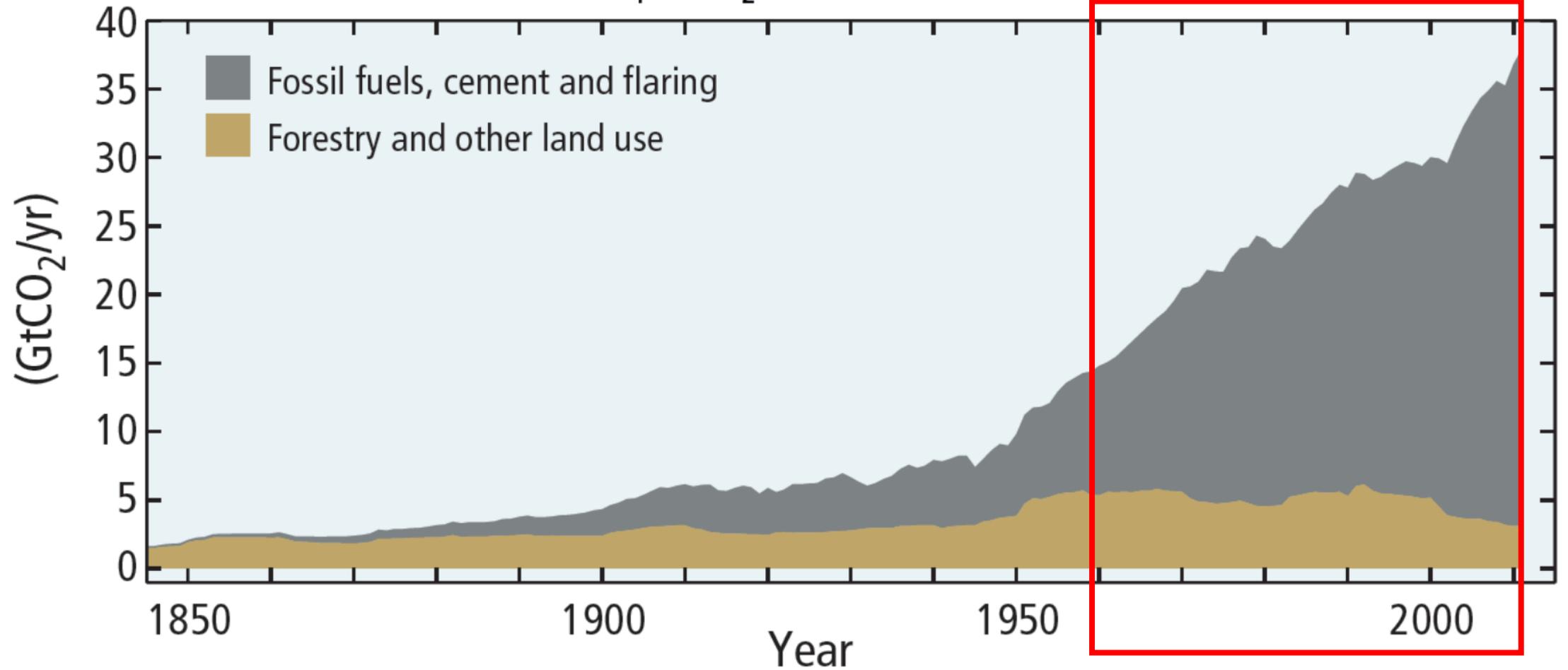
Observed change in surface temperature 1901–2012



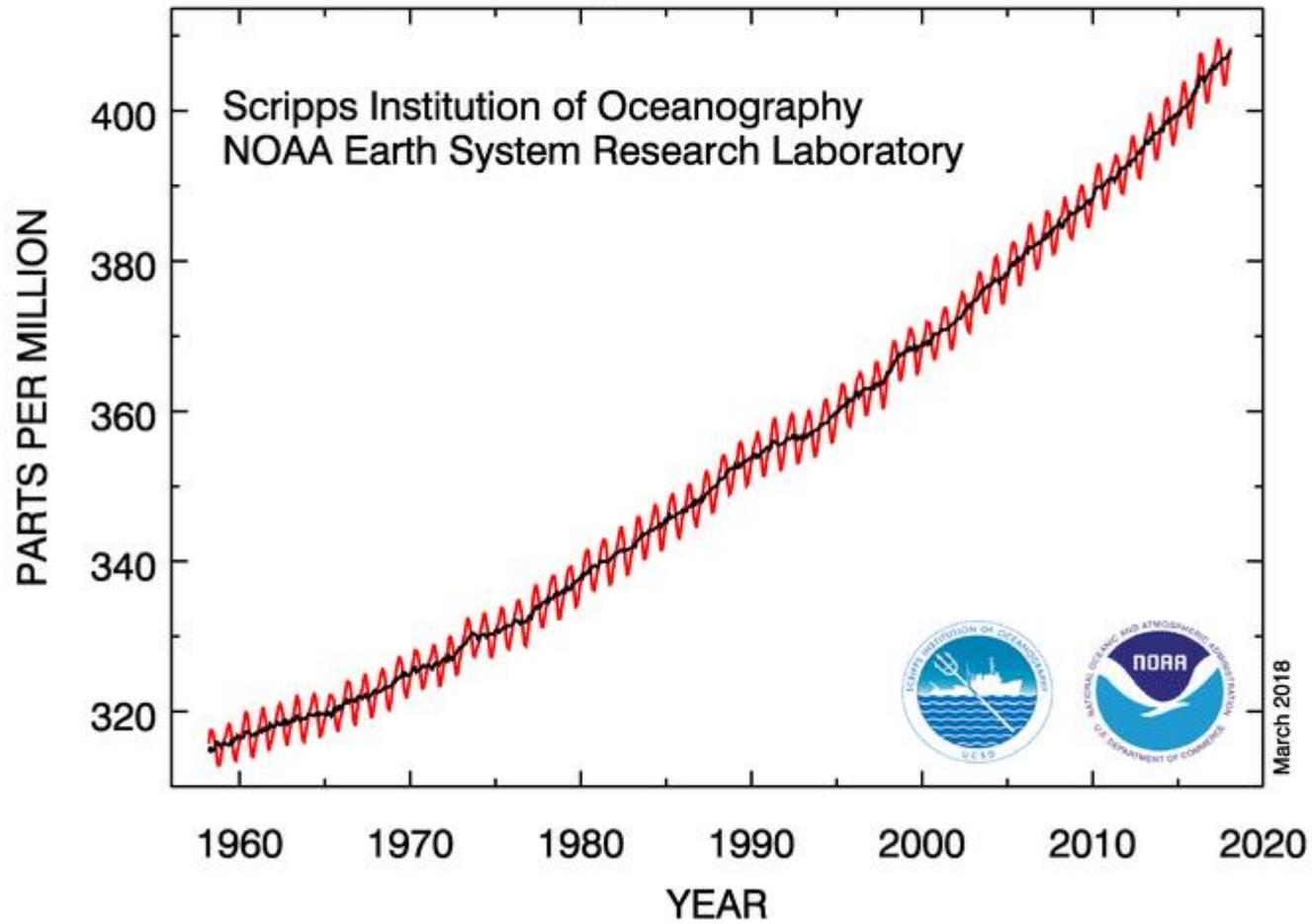
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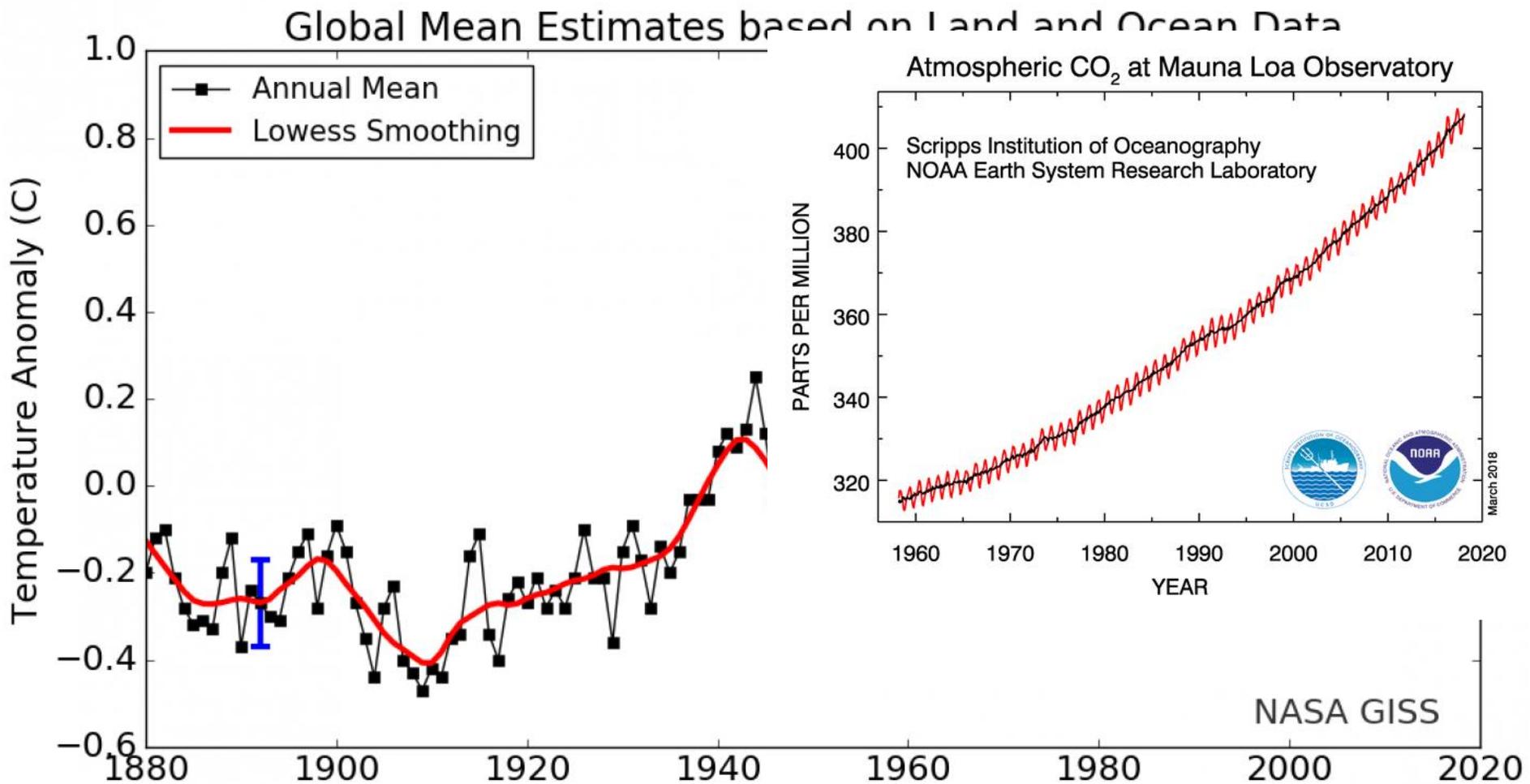
Global anthropogenic CO₂ emissions

Quantitative information of CH₄ and N₂O emission time series from 1850 to 1970 is limited



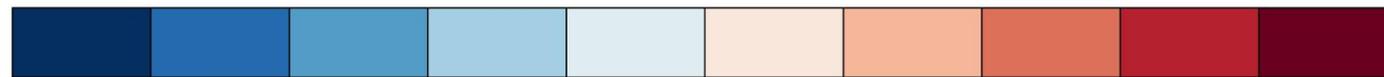
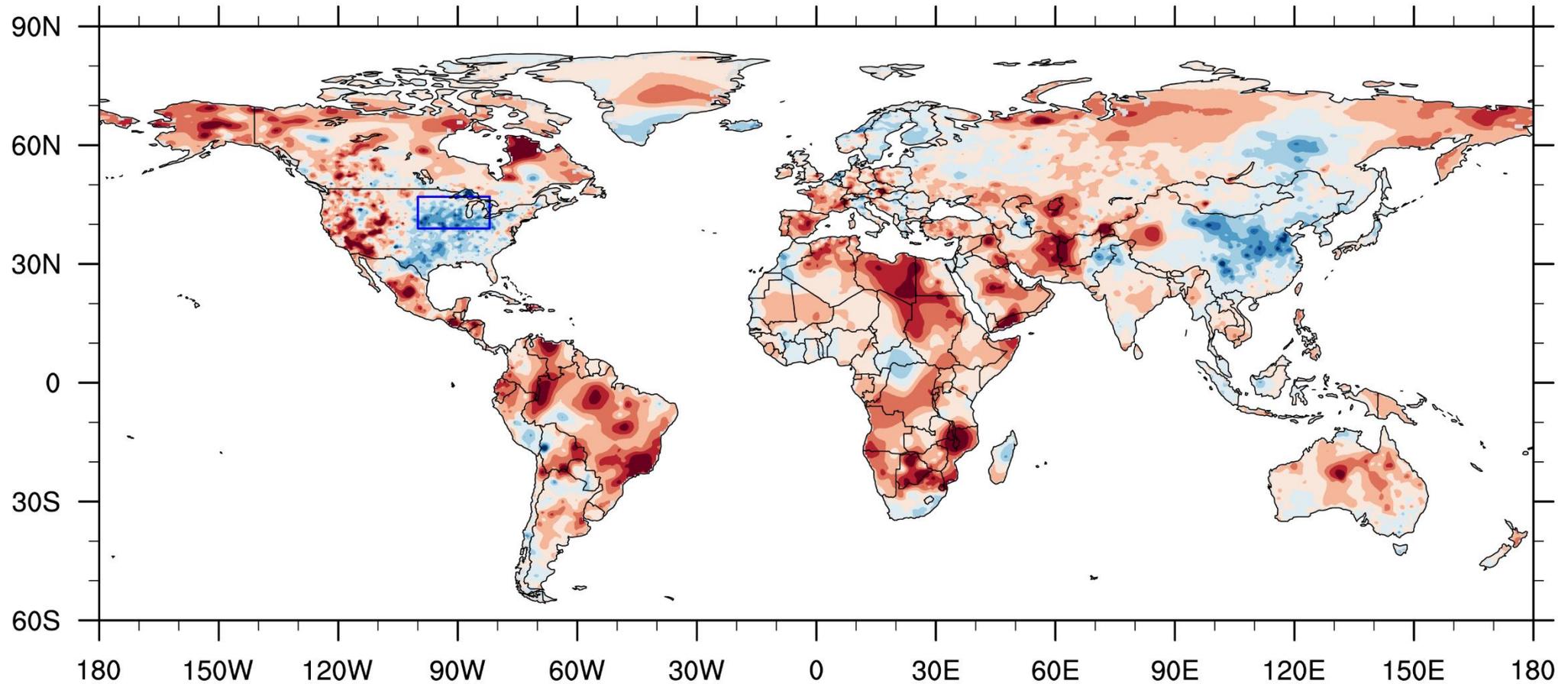
Atmospheric CO₂ at Mauna Loa Observatory





July-August – 1970-2009 minus 1910-1949

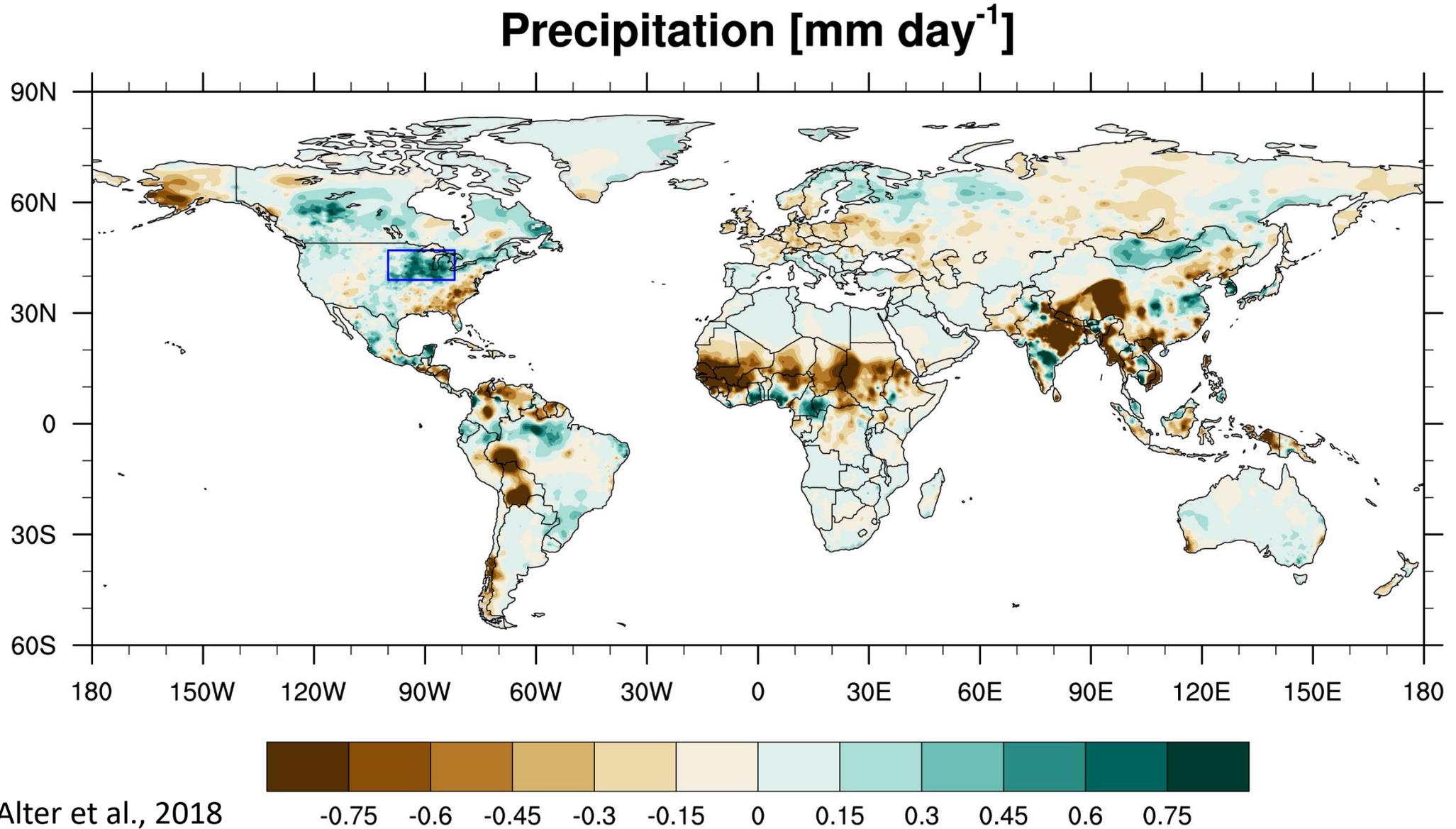
Temperature [°C]



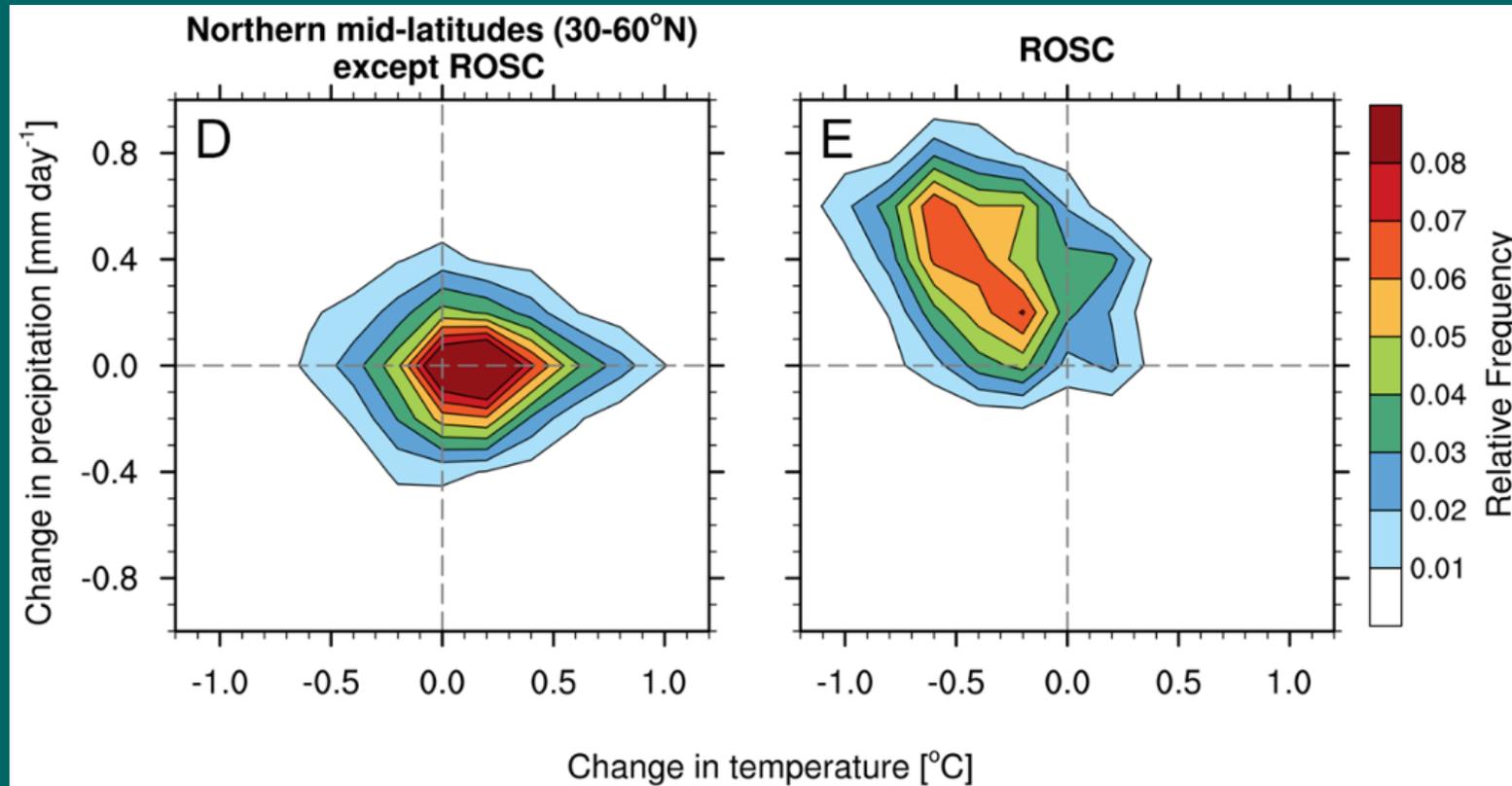
Alter et al., 2018

-1 -0.75 -0.5 -0.25 0 0.25 0.5 0.75 1

July-August – 1970-2009 minus 1910-1949



Central US vs. Northern mid-latitudes

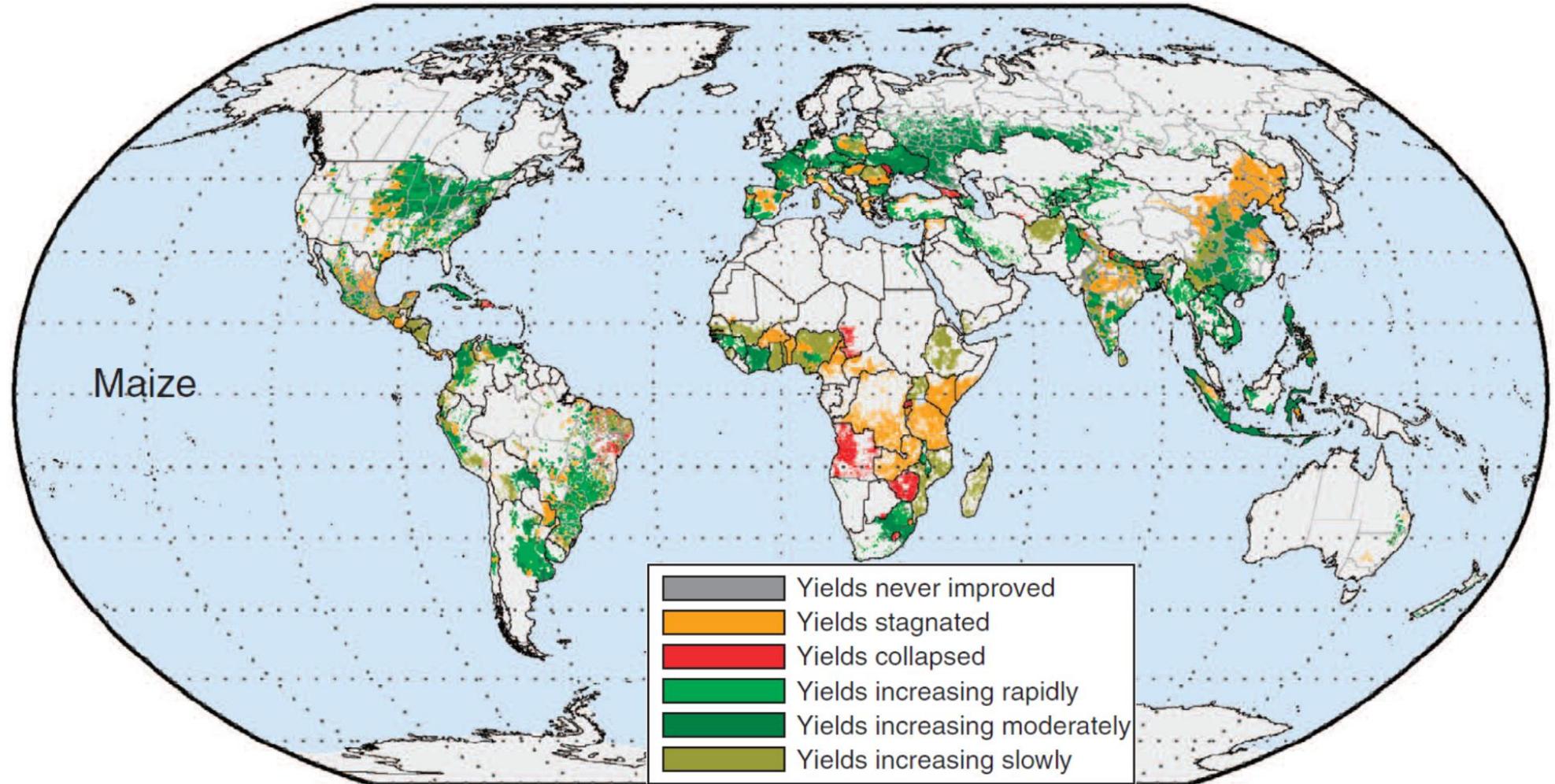


Cropland + Pastureland

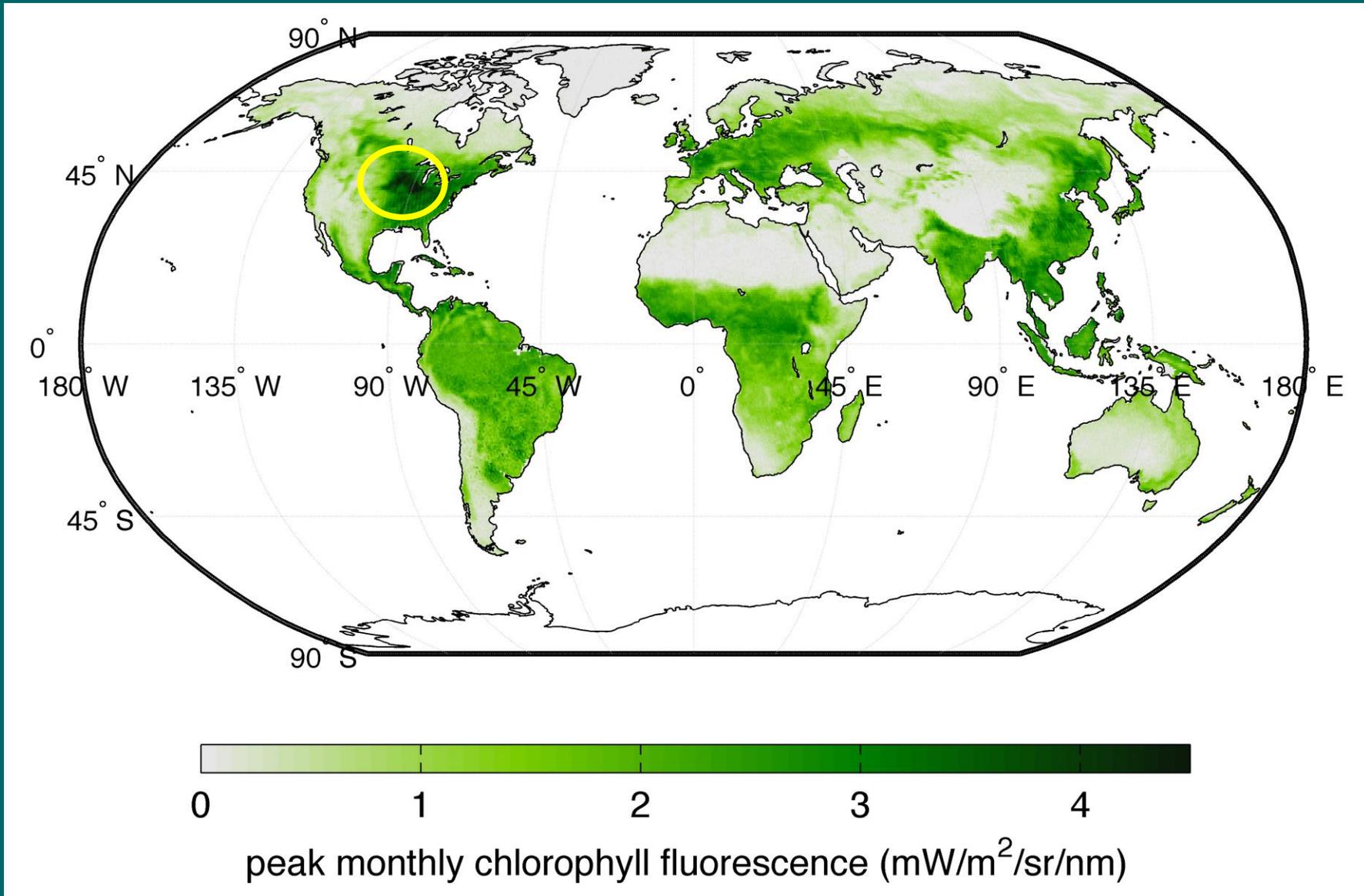


Crop Yield

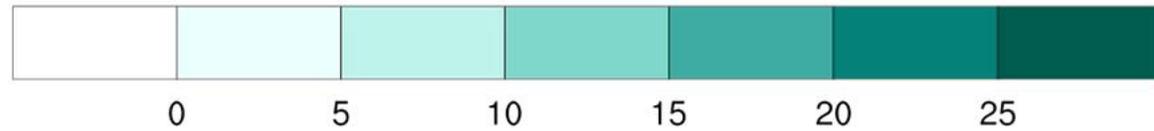
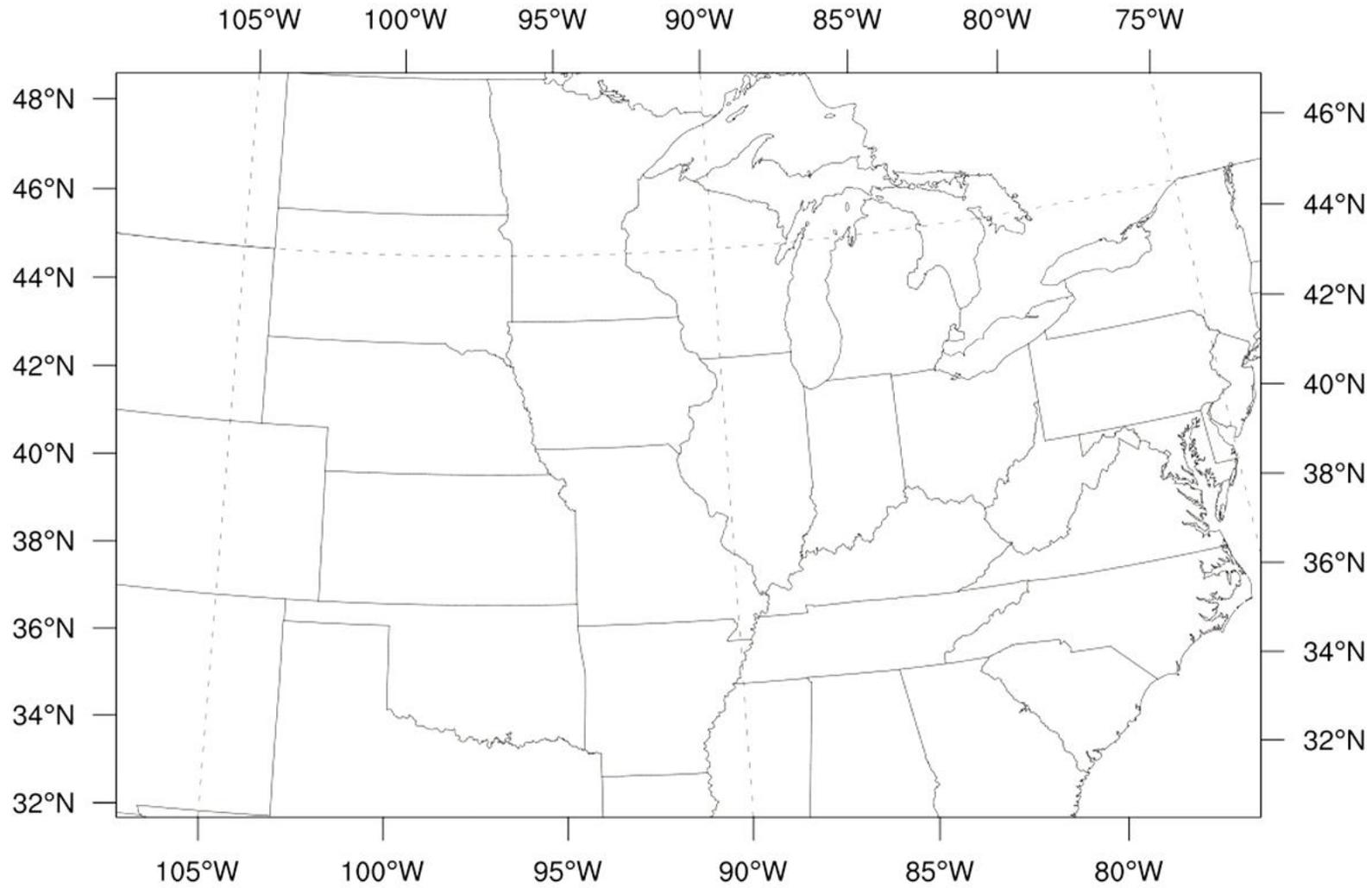
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Agricultural Intensity



Corn production [10^6 bushels], 1910



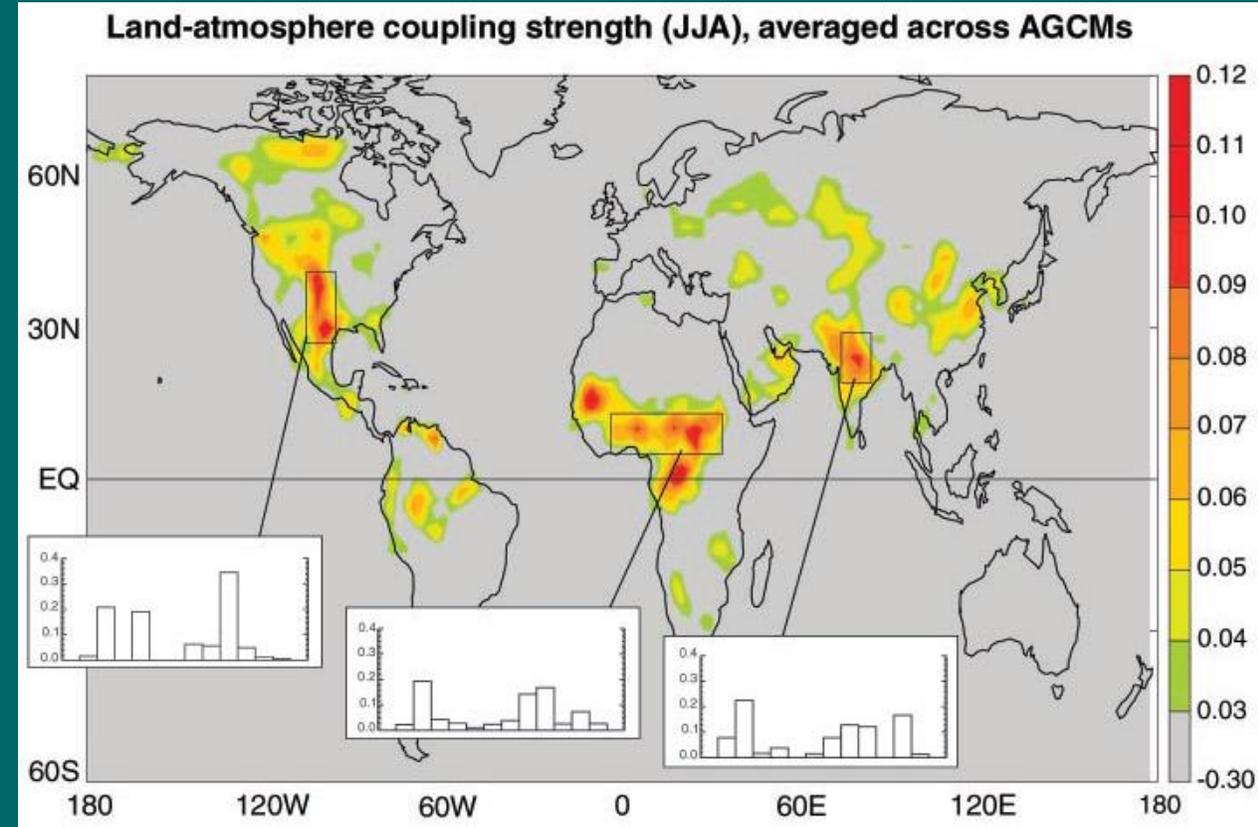
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J.M. Winter, and E.A.B. Eltahir
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Research questions

- **What are the impacts of agricultural intensification on regional climate in the central US?**
 - How do the **temporal and spatial aspects** of agricultural intensification compare to the historical rainfall and temperature records?
 - Which forcing has been more influential on observed regional climate change: **agricultural intensification or greenhouse gas (GHG) emissions**?
 - What are the **potential mechanisms** that lead from agricultural intensification to rainfall and temperature change?

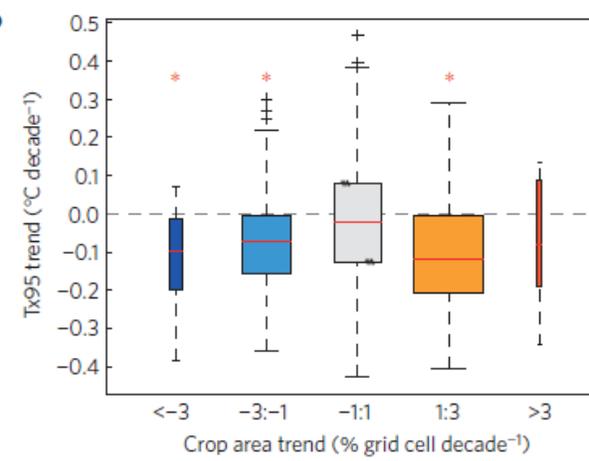
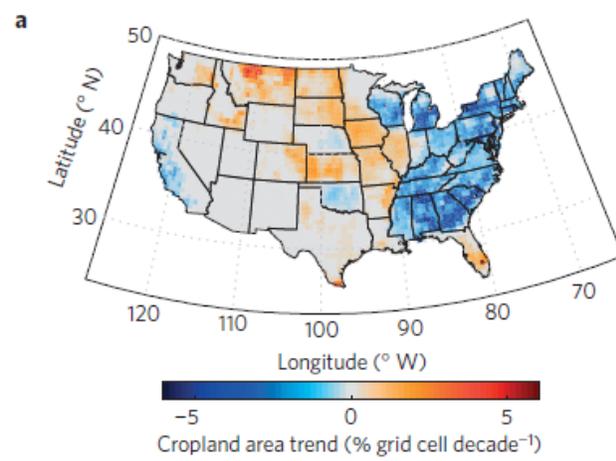
Connection to the atmosphere

- Established links between:
 - Vegetation,
 - Soil moisture,
 - Evapotranspiration (ET),
 - Temperature, and
 - Precipitation
- Especially during summer
 - e.g., Koster et al. 2004, Betts 2004, Findell and Eltahir 2003 a,b

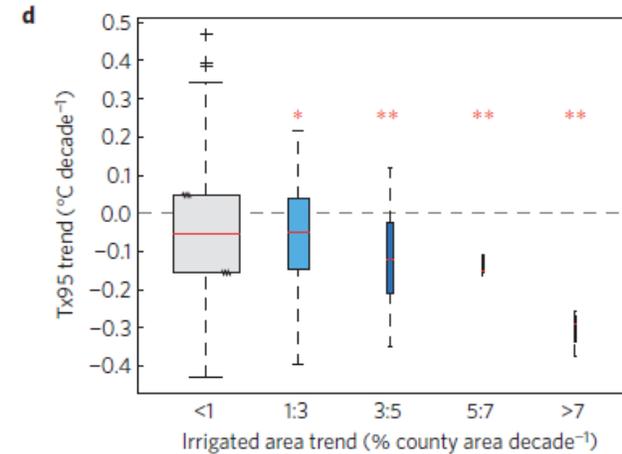
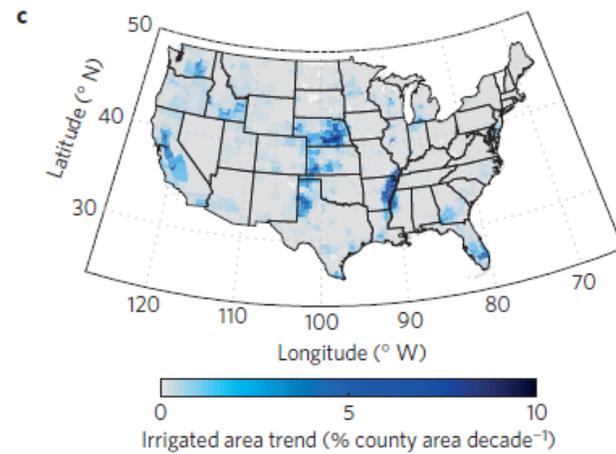


Koster et al., 2004

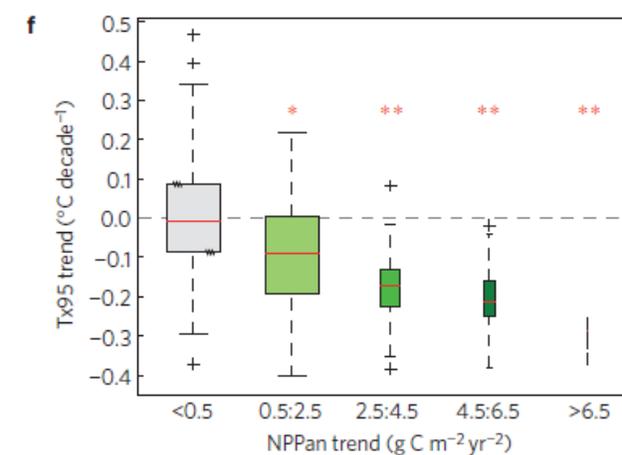
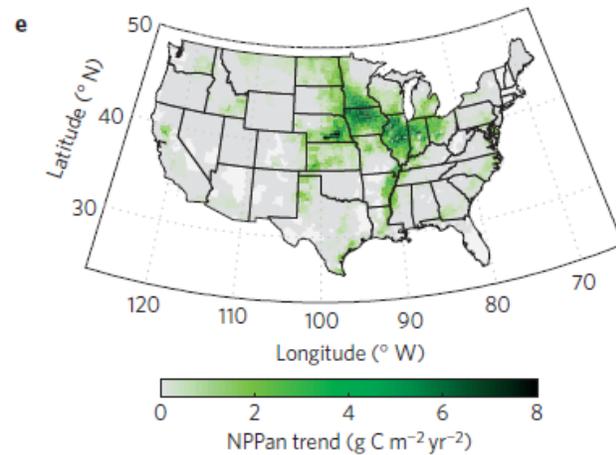
Cropland area



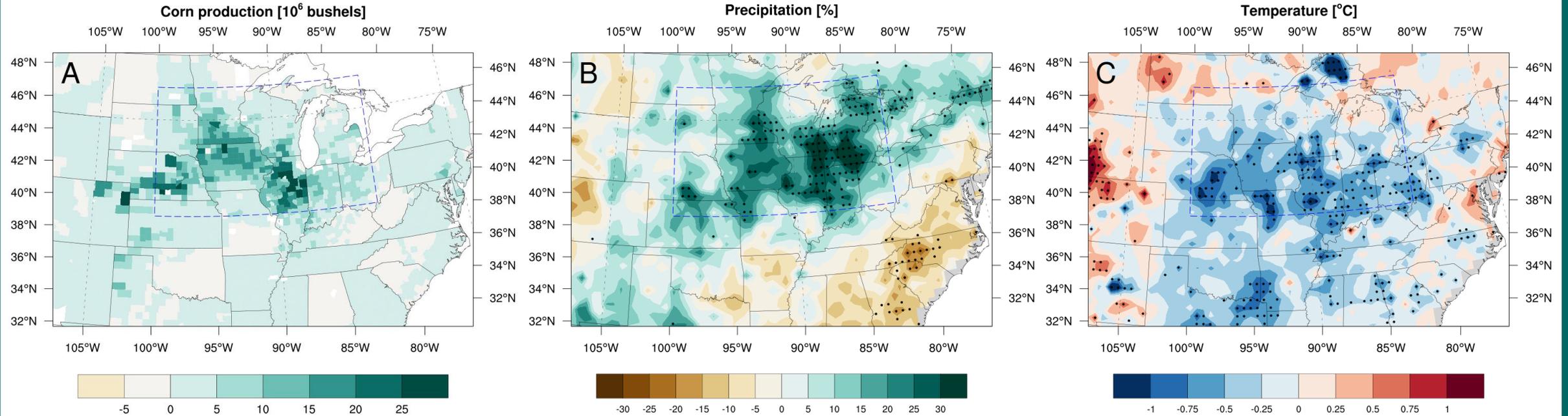
Irrigated area



Net primary productivity

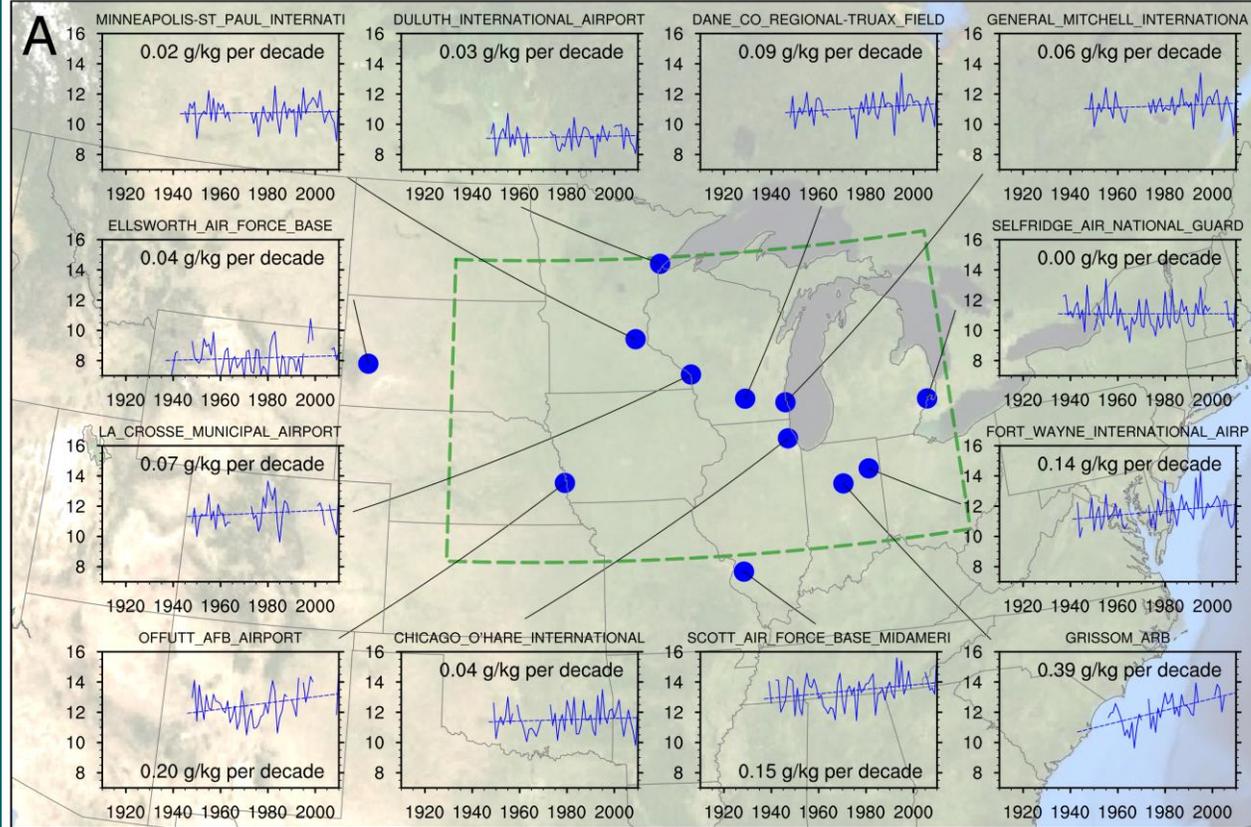


Observational trends – July-August – 1970-2009 minus 1910-1949

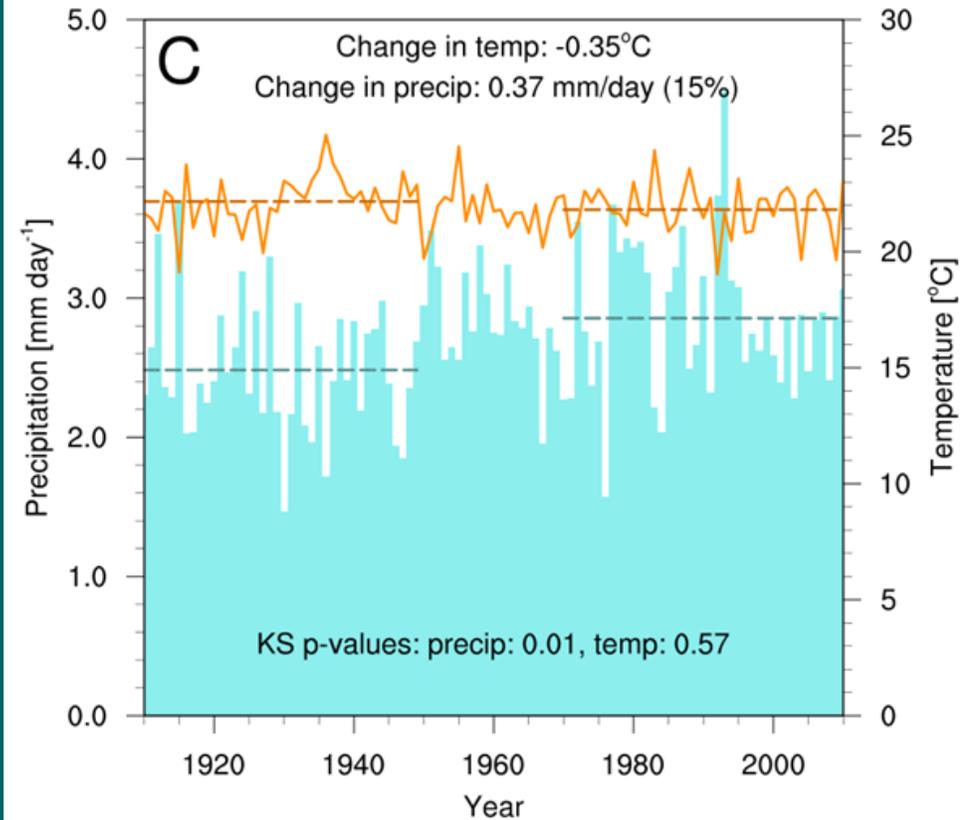


Temporal changes

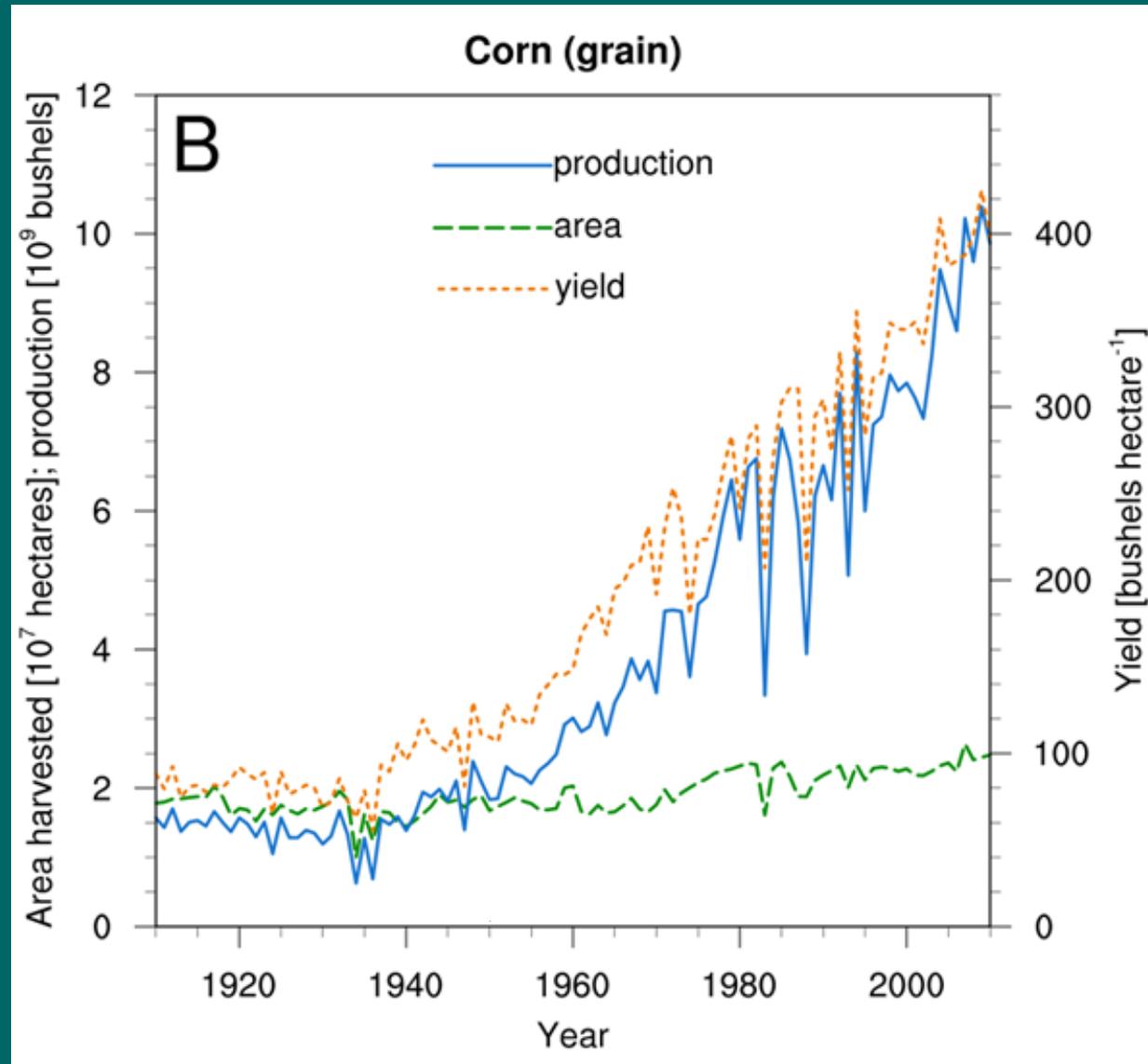
Specific humidity



Temperature and precipitation

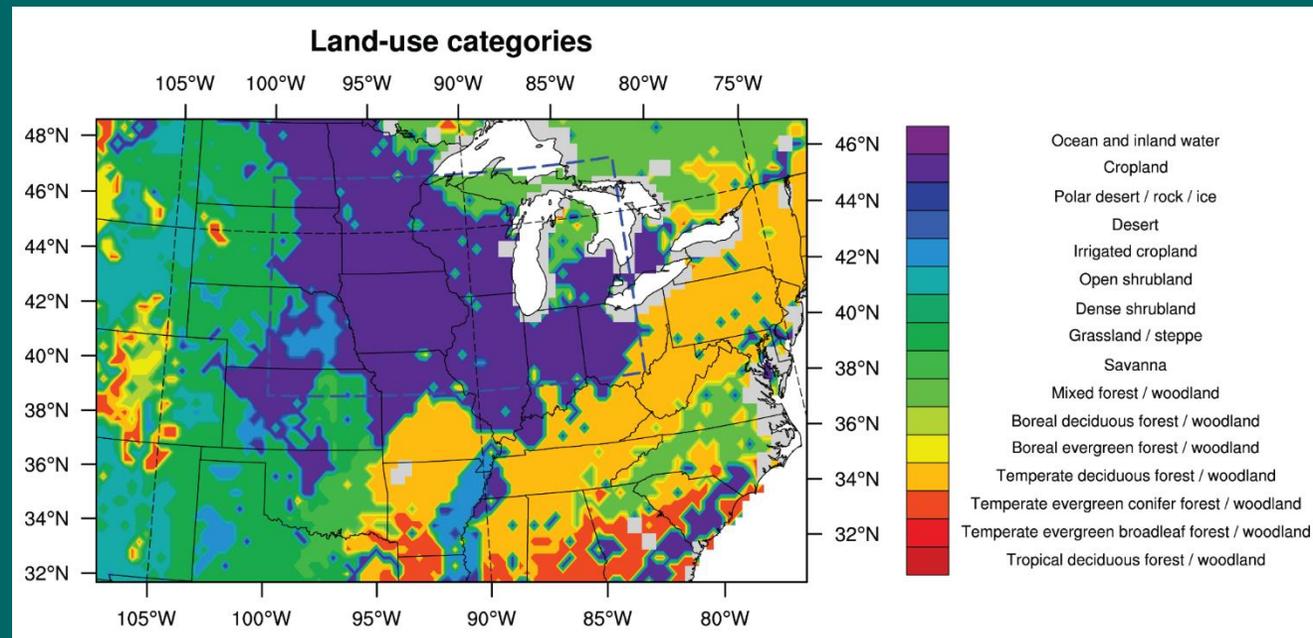


Increases in crop productivity



Numerical modeling methodology

- Simulations using the MIT regional climate model – MRCM
- Five 30-year simulations from 1982 to 2011 (150 total years)
 - 30-km horizontal grid increments
- Irrigated grid cells wetted to relative field capacity after hitting 75% of RFC (July to September)
- Photosynthesis increased by factor of six in experimental simulations

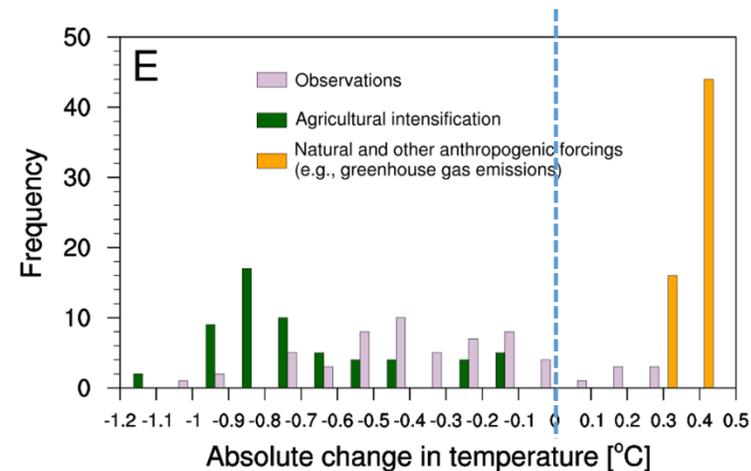
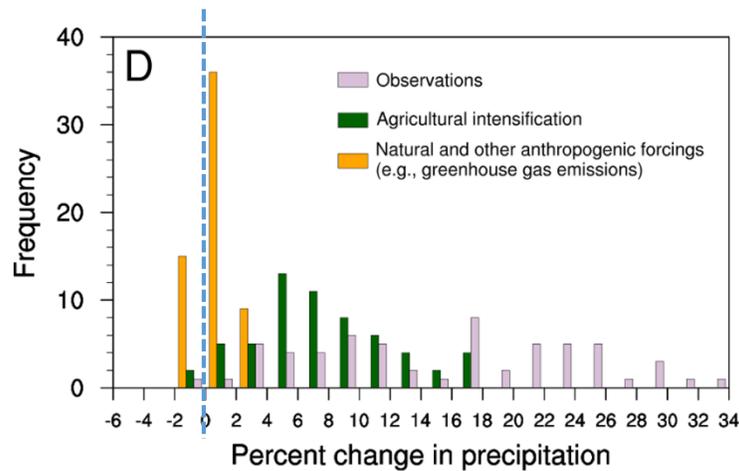
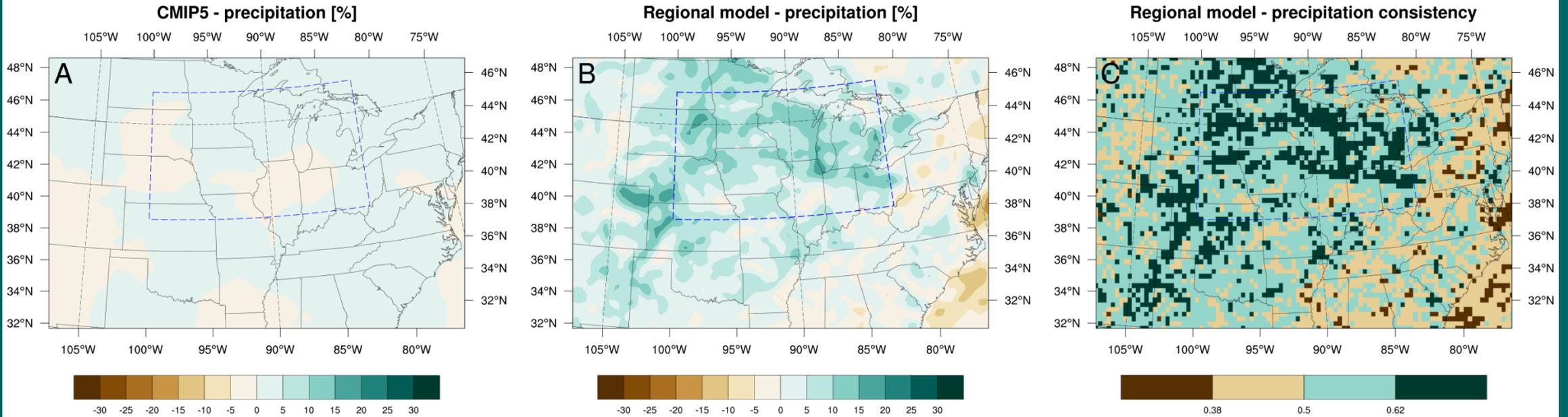


Modeling results

GHG and other forcings

Agricultural intensification

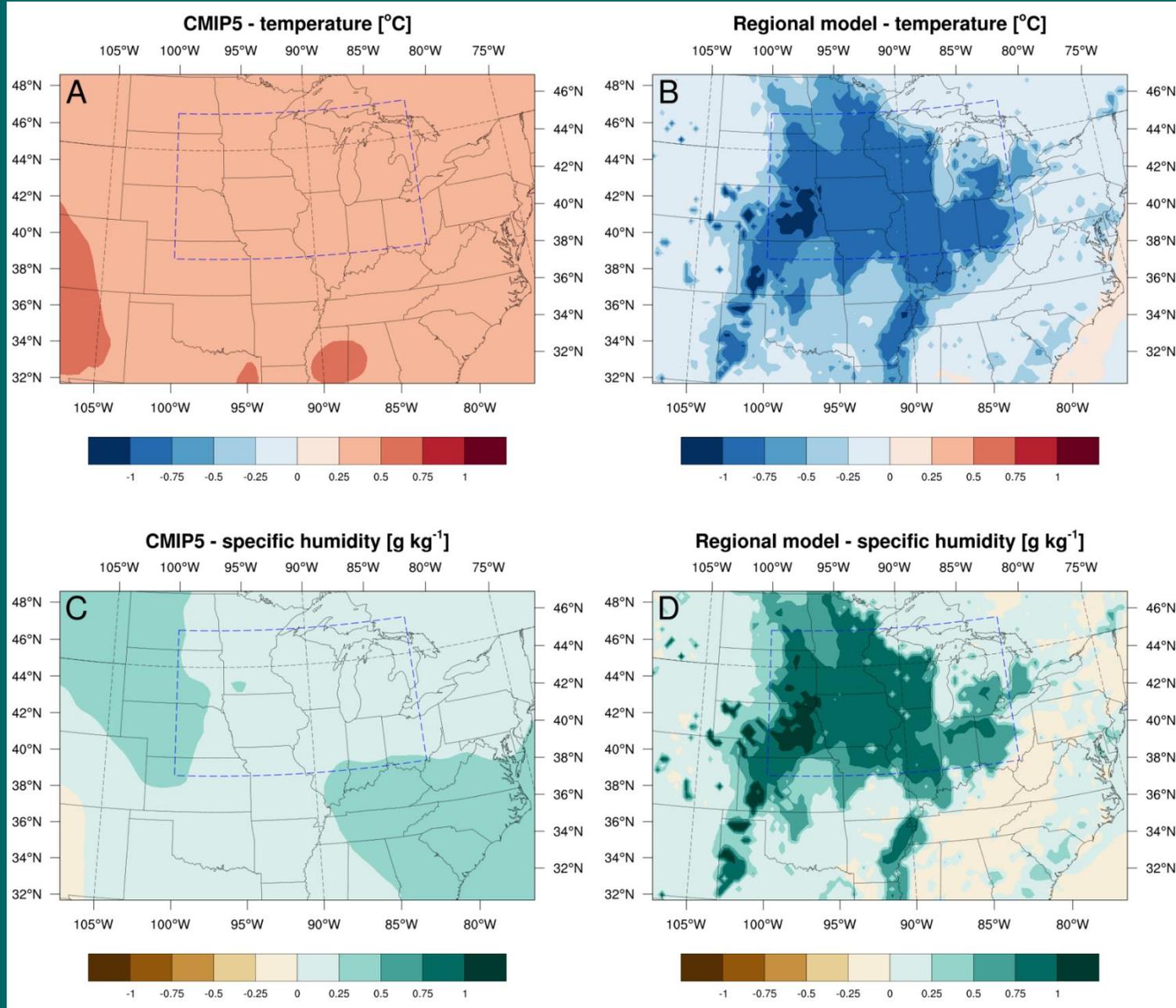
Consistency of changes



GHG and other forcings

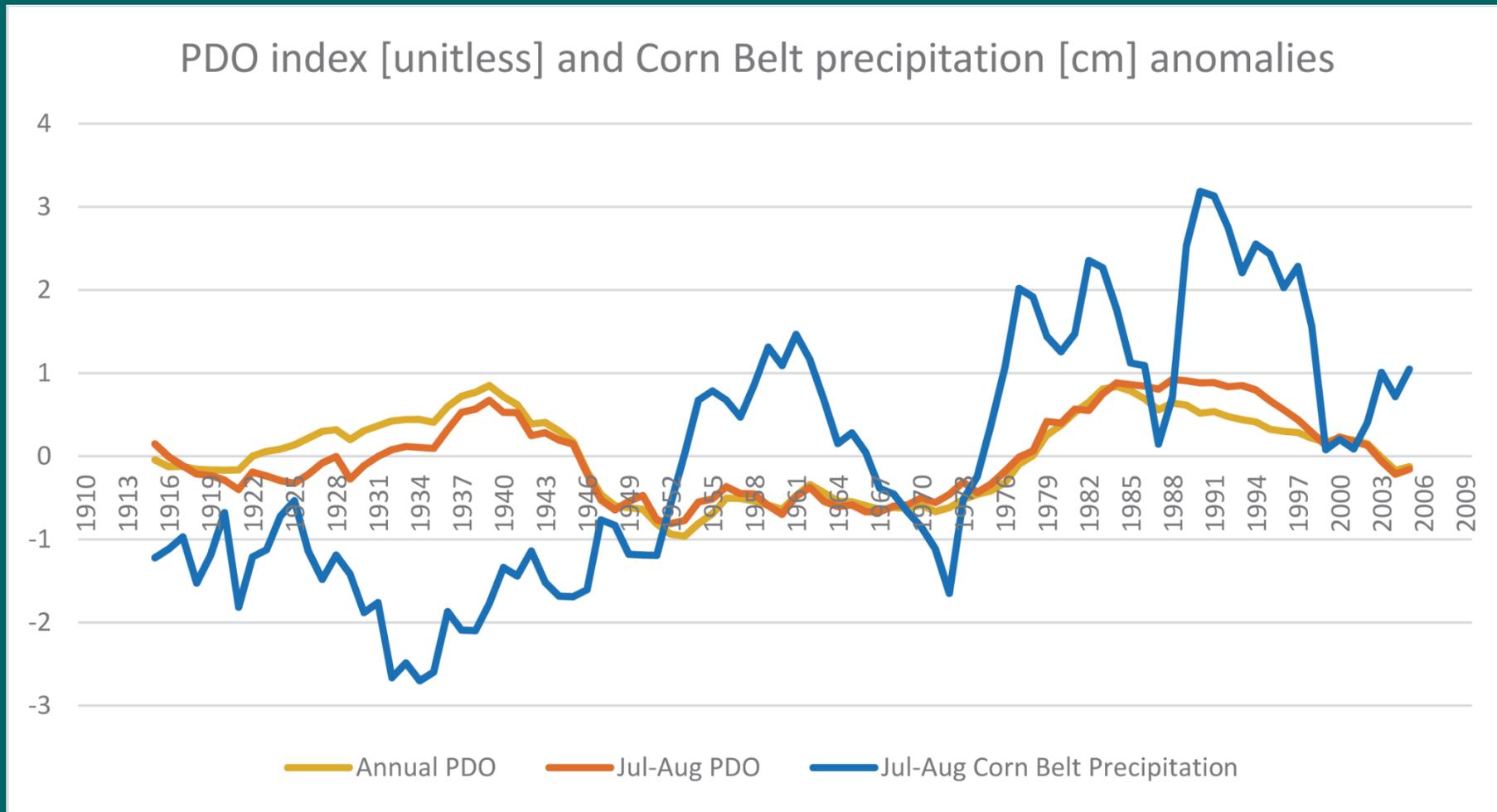
Agricultural intensification

Temperature



Specific humidity

Sea surface temperature



Proposed Mechanisms

- Increase in photosynthesis -> increase in stomatal conductance -> increase in transpiration
 - Increase in humidity and latent heat flux
 - Decrease in temperature and sensible heat flux

- **Mechanism 1**

- **Increase in moist static energy (MSE)**

$$\begin{matrix} (+) & (-) & (+) \end{matrix}$$

$$\text{MSE} = C_p T + gz + L_v r, \quad (1)$$

where

C_p specific heat of air at constant pressure ($\text{kJ kg}^{-1} \text{K}^{-1}$),

T air temperature (K),

g gravitational acceleration (m s^{-2}),

z height above some reference level (m),

L_v latent heat of vaporization for water (kJ kg^{-1}), and

r water vapor mixing ratio (kg kg^{-1}).

- **Mechanism 2**

- **Moisture recycling**

- Moisture transpired from crops falls out as precipitation in remote areas

Summary of changes

	Sign of observed change	Sign of predicted change	
		Agricultural intensification	Greenhouse gas (GHG) emissions
Rainfall	Positive ^{1,2}	Positive ³	Neutral ³
Surface temperature	Negative ^{1,2,3}	Negative ^{3,4}	Positive ^{3,4}
Surface humidity	Positive ²	Positive ⁴	Positive ⁴

Conclusions and Implications

- **Both simulations and observations indicate cooler temperatures and enhanced rainfall during the summer in the central US due to agricultural intensification**
 - **Agricultural intensification > GHG emissions for summer climate change in central US**
 - However, cooling due to agricultural intensification may have masked GHG-induced warming
 - Similar climatic effects in other world regions?
 - May have enabled further agricultural intensification by filling soil moisture deficits
- Encourages the **inclusion of crop productivity in next-generation climate models and predictions**
- Adds **complexity** to existing framework of **hydrological, agricultural, and economic sustainability**

Take-home messages

- **Agricultural intensification**

- ...has **cooled temperatures** and **enhanced rainfall** in the central US
- ...has been a **stronger forcing of observed summer climate change** in the central US **than increasing GHG emissions**
- ...and its climatic effects deserve **inclusion in future climate models and attribution studies**
- ...warrants future **consideration in plans to adapt to and mitigate climate change around the world**

A vibrant green cornfield under a bright blue sky with scattered white clouds. The corn plants are in the foreground, and the sky is filled with fluffy white clouds. The overall scene is bright and sunny.

Thank you!

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