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# The Joint Effects of Climate and LULCC on Terrestrial Hydrology over the Conterminous United State in the 21st century

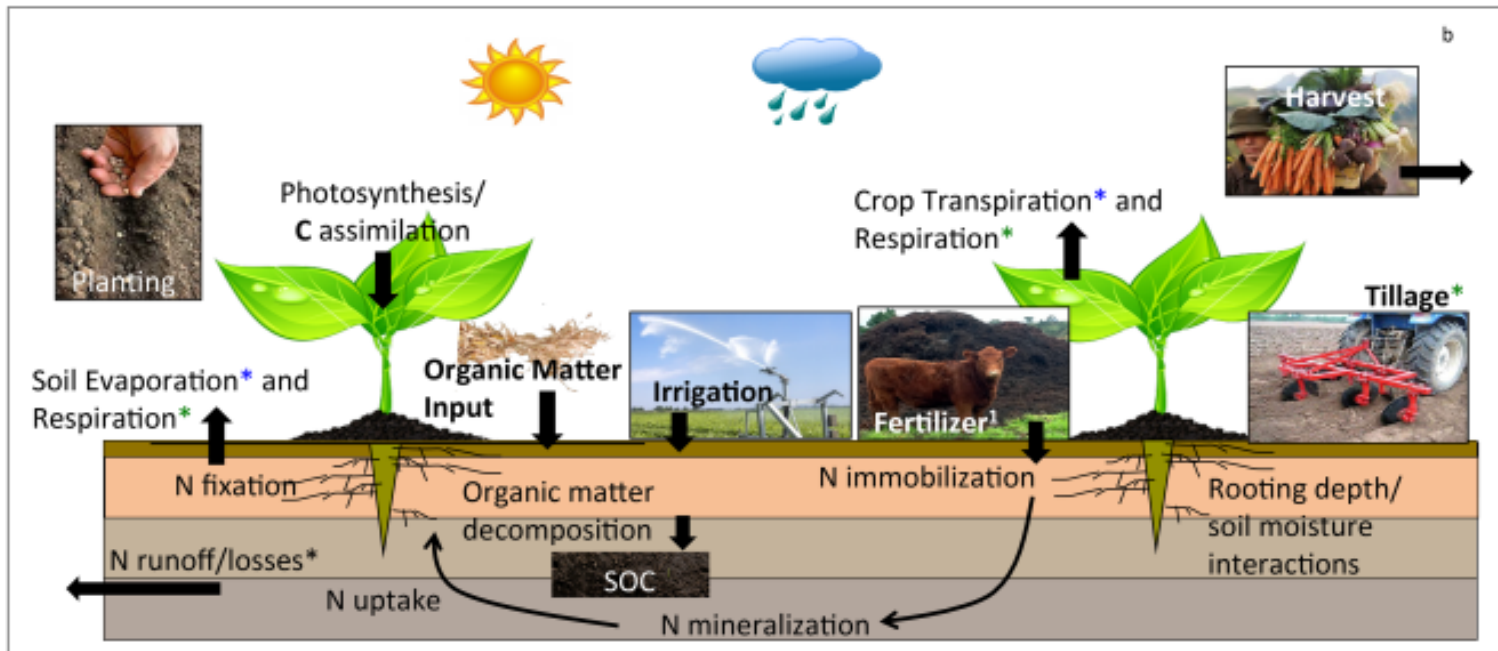
MAOYI HUANG, XUESONG ZHANG, YANNICK LE PAGE, IAN KRAUCUNAS

Pacific Northwest National Laboratory

2018 CESM LMWG/SDWG meetings, Mesa Lab, NCAR

# Importance of Representing Agriculture in ESMs

- ▶ Nearly 40% of Earth's land surface is devoted to agriculture, managed for various cropping, livestock grazing, or mixed farming systems;
- ▶ Key Agricultural management to capture:
  - **Irrigation**
  - **Agricultural management:** planting, harvest, fertilization, phenology/physiology (crop type specific)
  - **Linkage to biogeochemical cycling**

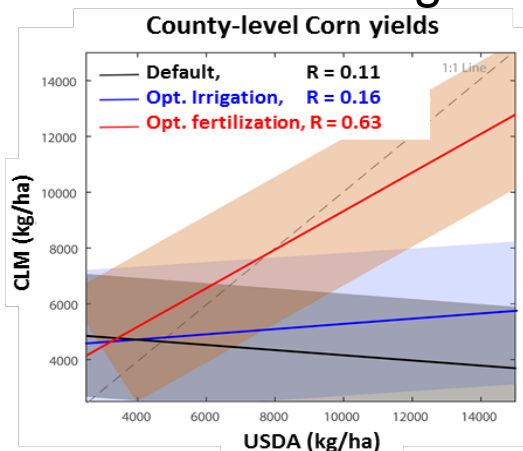


# Improving the Performance of ELM/CLM in Representing Regional Agro-ecosystems and Hydrology

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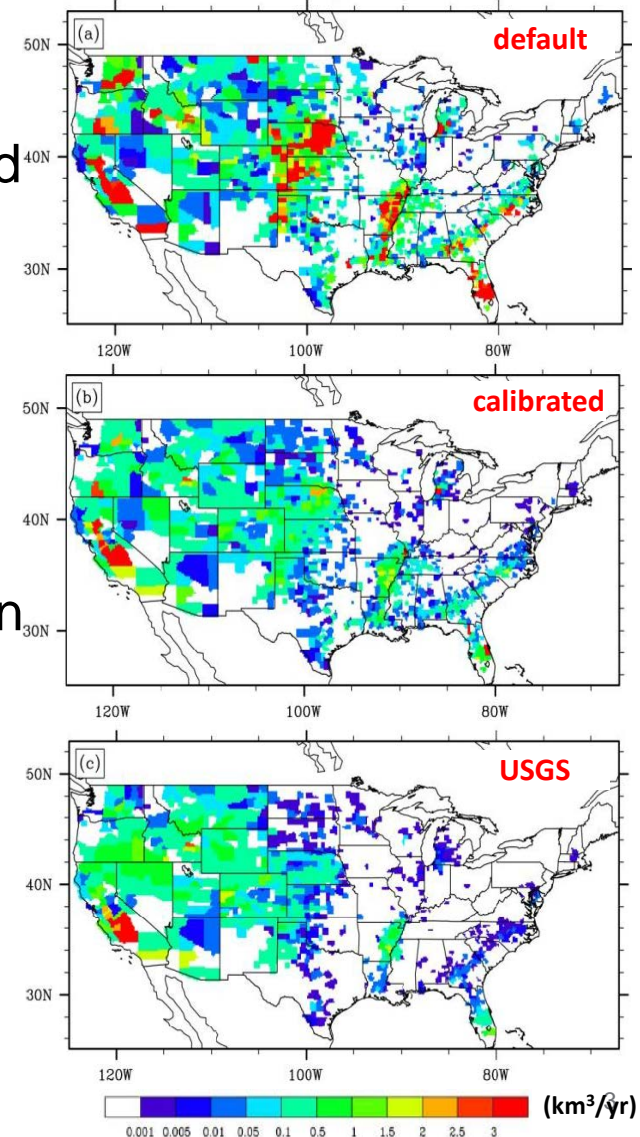
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- ▶ Incorporated groundwater pumping, and fertilization schemes into the Community Land Model (CLM);
- ▶ Calibrated CLM simulated irrigation amount and crop yields against county-level agricultural census;
- ▶ Demonstrated that irrigation, groundwater pumping, and crop management greatly alter regional water and carbon dynamics, and can influence local and regional climate;
- ▶ These tools and results are ready for integration with IAMs in a regional context.



Leng G., et al.  
JHM, 2014;  
JAMES 2016;

## County-level irrigation





# Inform ESM simulations with Demeter products

*Projected % change in land cover by 2090 compared to the 2005 condition*

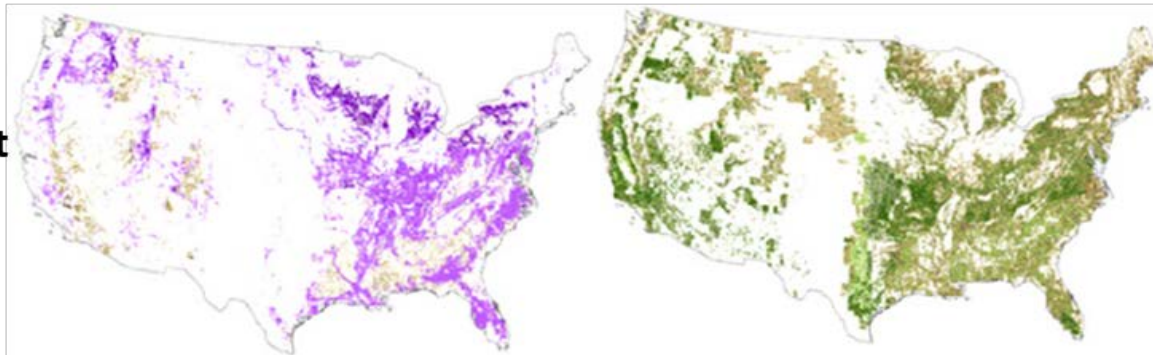
**RCP8.5**  
" Business as usual "

**RCP4.5**  
Mitigation

**Crops**



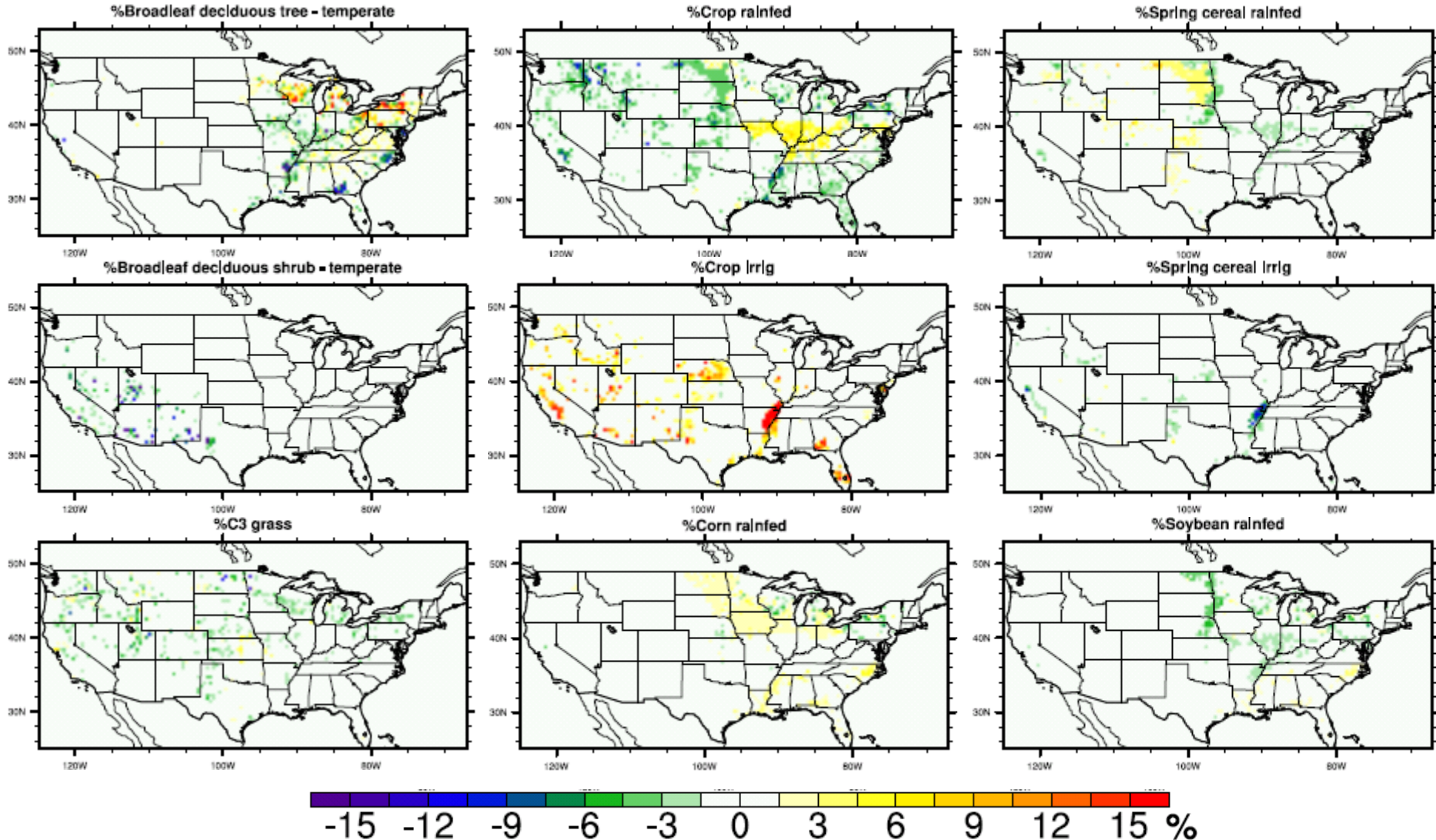
**Forest**



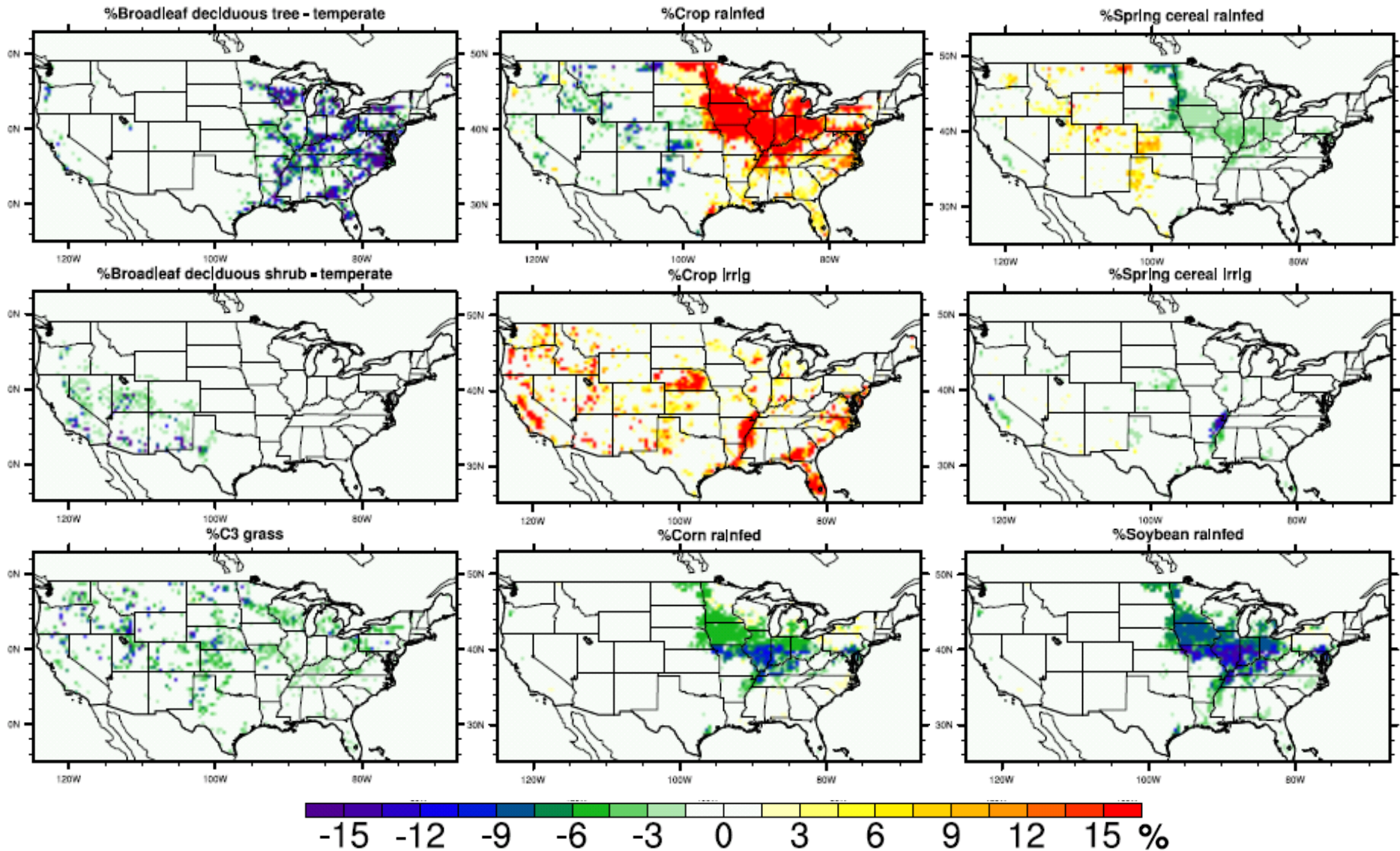
West et al., 2014



# GCAM PRIMA RCP8.5 LULCC scenario: dominant PFT changes



# GCAM PRIMA RCP4.5 LULCC scenario: dominant PFT changes





# Current GCAM→Demeter→CLM numerical experiments

- ▶ **Domain:** CONUS at 0.125×0.125 degree;
- ▶ **Land model:** CLM4.5 with the crop modules on  
(explicitly simulates corn/soybean/spring cereal);
- ▶ **Land cover:** Demeter downscaled land cover maps from GCAM at 5-year interval
- ▶ **Climate data:** RESM driven by CCSM4 for RCP4.5 and RCP8.5, bias-corrected by NLDAS  
(supported by PRIMA/RIAM)

## Experimental Design

CLIM	CO2	LCC	FERT	IRR	Pump
HIST	Constant	HIST	Default	Yes	No
RCP4.5	transient	RCP4.5	Optimized	No	Yes
RCP8.5		RCP8.5			

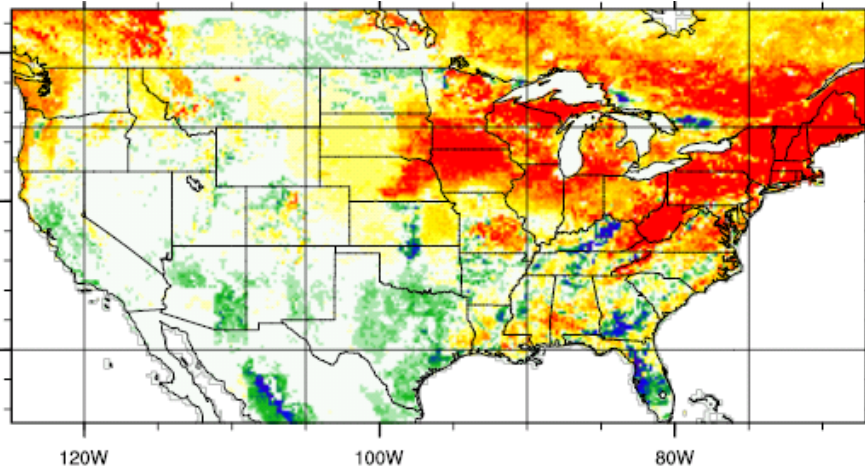
Huang, et al., in prep



# Change in summer net ecosystem exchange, RCP8.5, 2065-2094 vs. hist

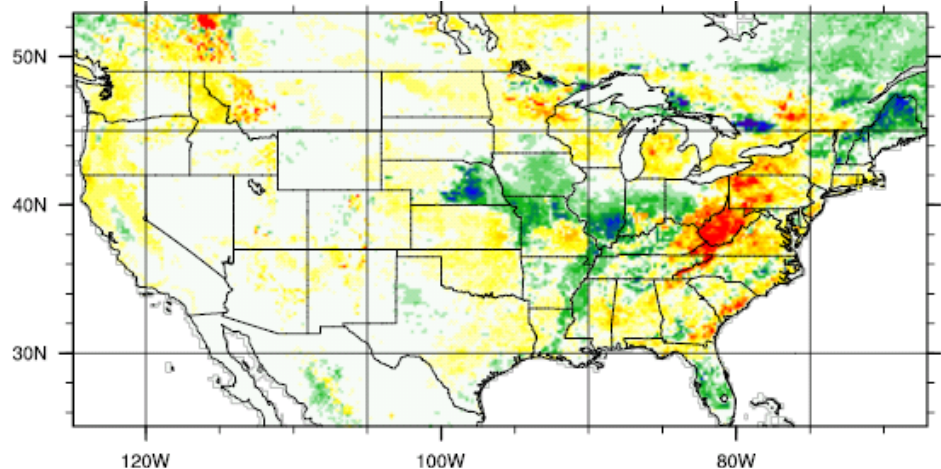
**Overall**

gC m<sup>-2</sup>d<sup>-1</sup>



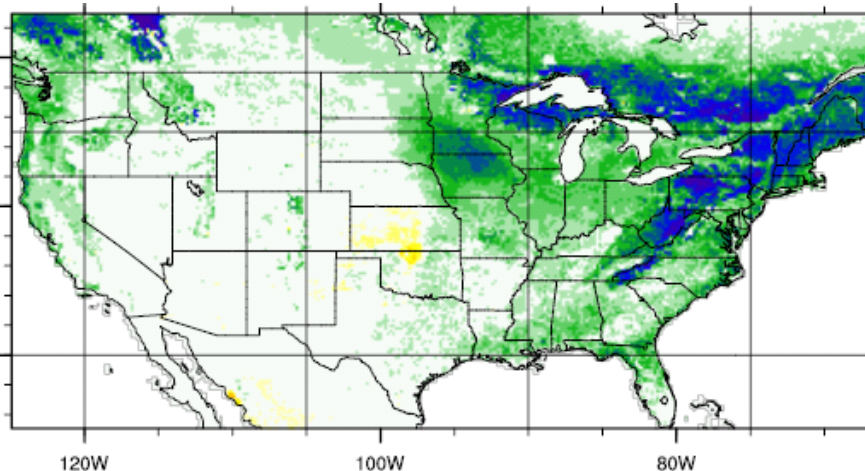
**Climate**

gC m<sup>-2</sup>d<sup>-1</sup>



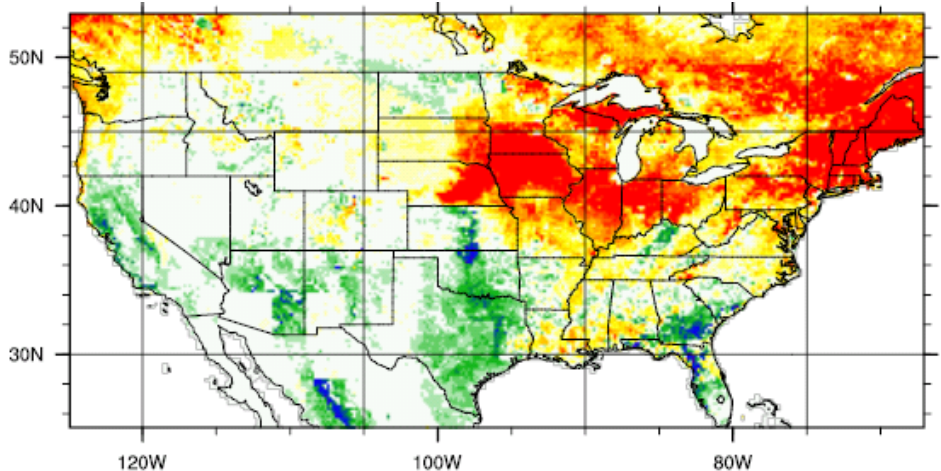
**CO2 fertilization**

gC m<sup>-2</sup>d<sup>-1</sup>

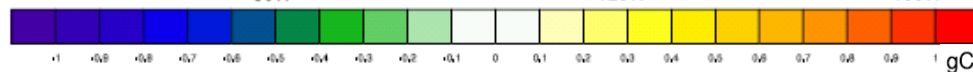


**LULCC**

gC m<sup>-2</sup>d<sup>-1</sup>



**Uptake**



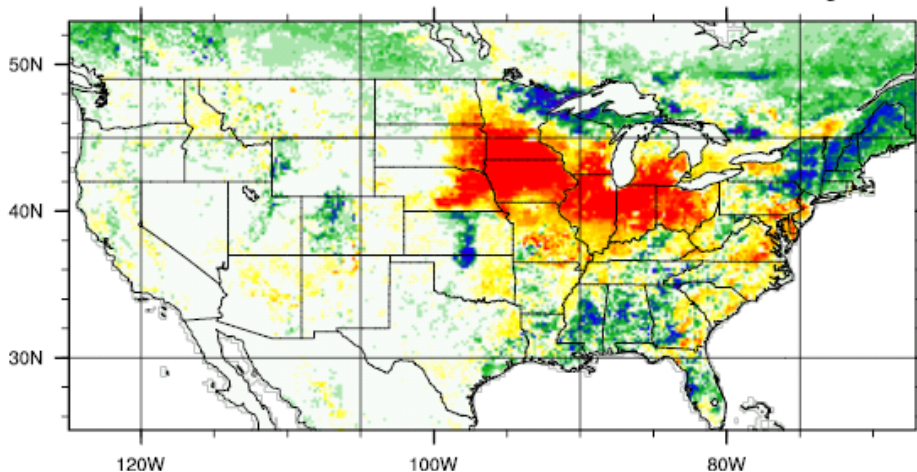
**Emission**



# Change in summer net ecosystem exchange, RCP4.5, 2065-2094 vs. hist

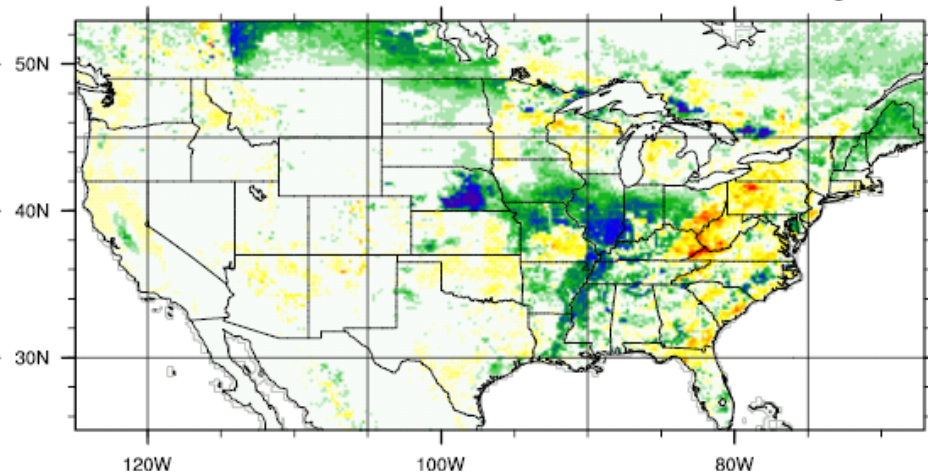
## Overall

$\text{gC m}^{-2}\text{d}^{-1}$



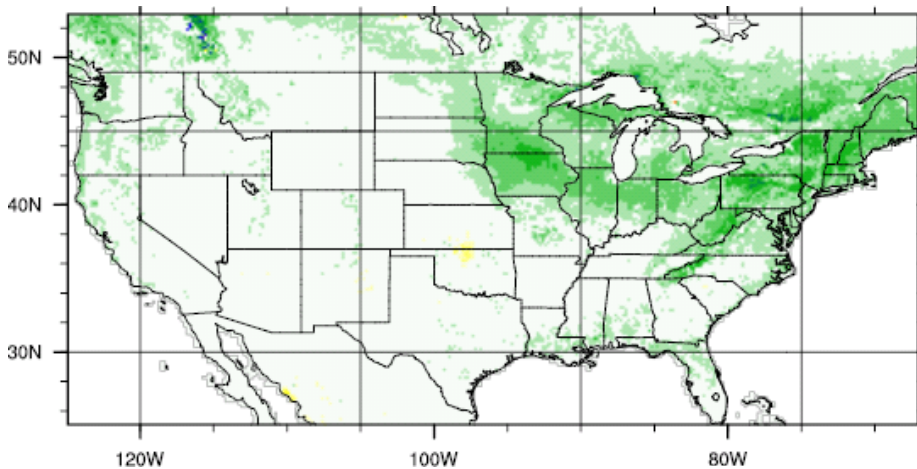
## Climate

$\text{gC m}^{-2}\text{d}^{-1}$



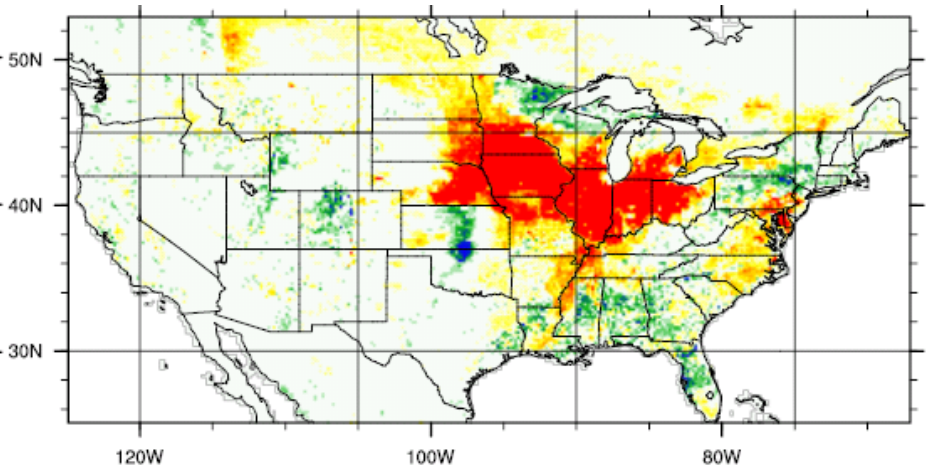
## CO2 fertilization

$\text{gC m}^{-2}\text{d}^{-1}$

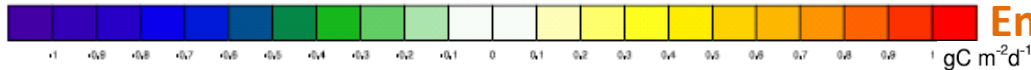


## LULCC

$\text{gC m}^{-2}\text{d}^{-1}$



**Uptake**

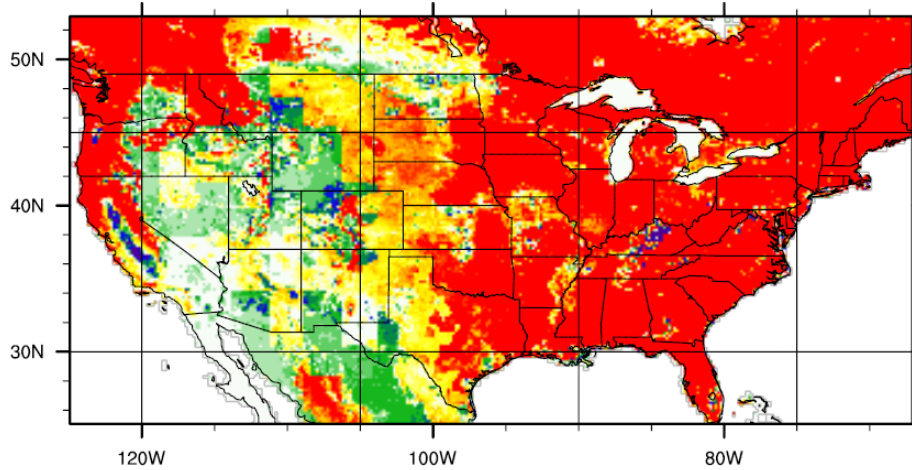


**Emission**

# Change in summer GPP, RCP8.5 2065-2094 vs. hist

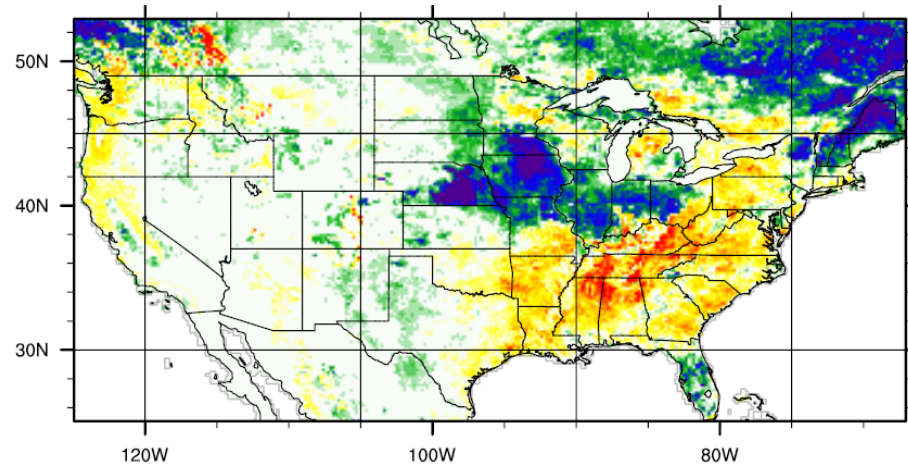
## Overall

$\text{gC m}^{-2}\text{d}^{-1}$



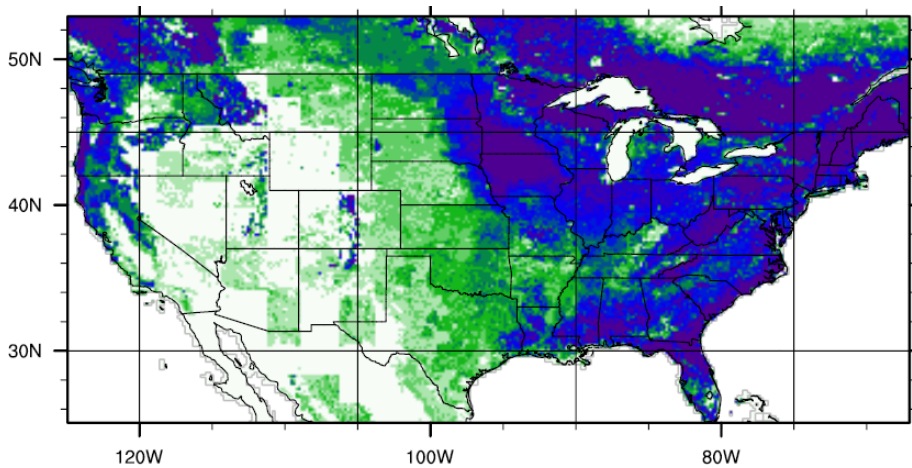
## Climate

$\text{gC m}^{-2}\text{d}^{-1}$



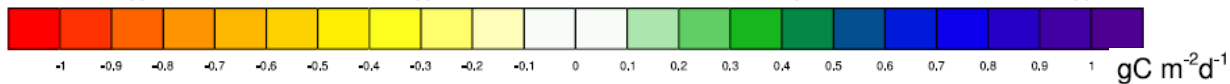
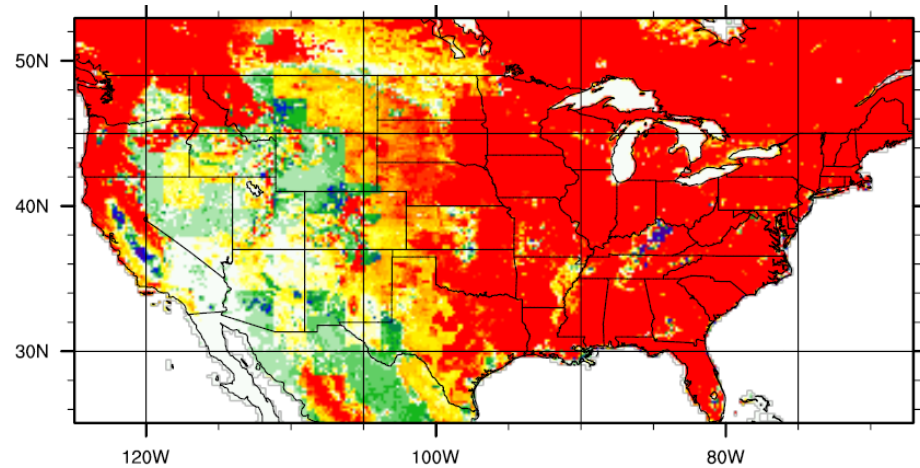
## CO2 fertilization

$\text{gC m}^{-2}\text{d}^{-1}$



## LULCC

$\text{gC m}^{-2}\text{d}^{-1}$





# Change in summer GPP, RCP4.5 2065-2094 vs. hist

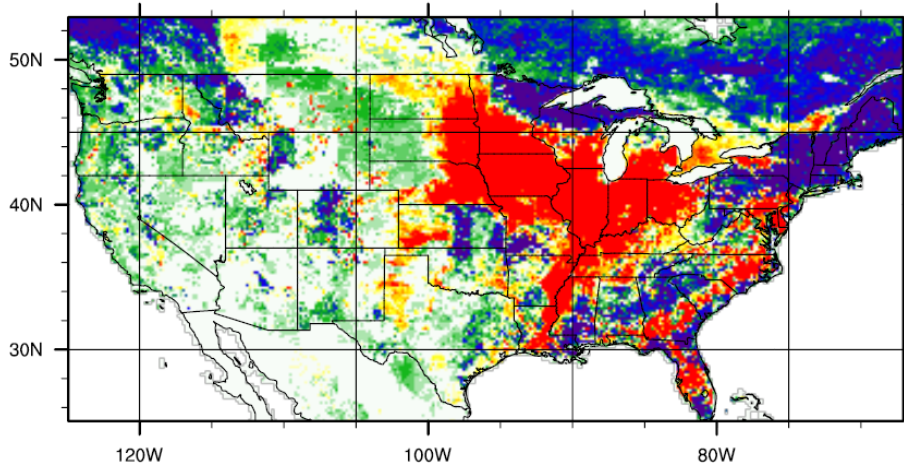


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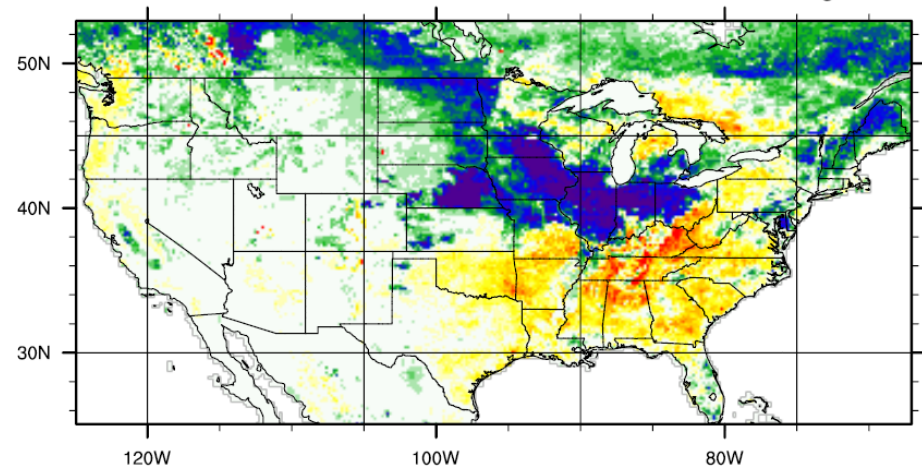
## Overall

$\text{gC m}^{-2}\text{d}^{-1}$



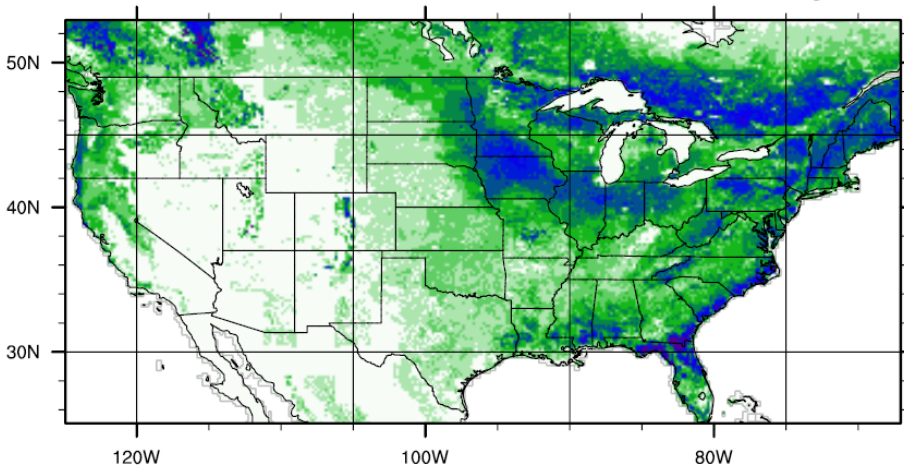
## Climate

$\text{gC m}^{-2}\text{d}^{-1}$



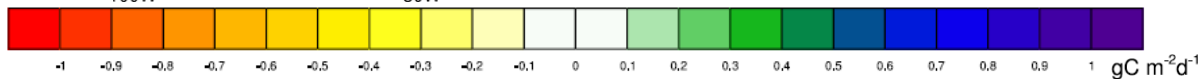
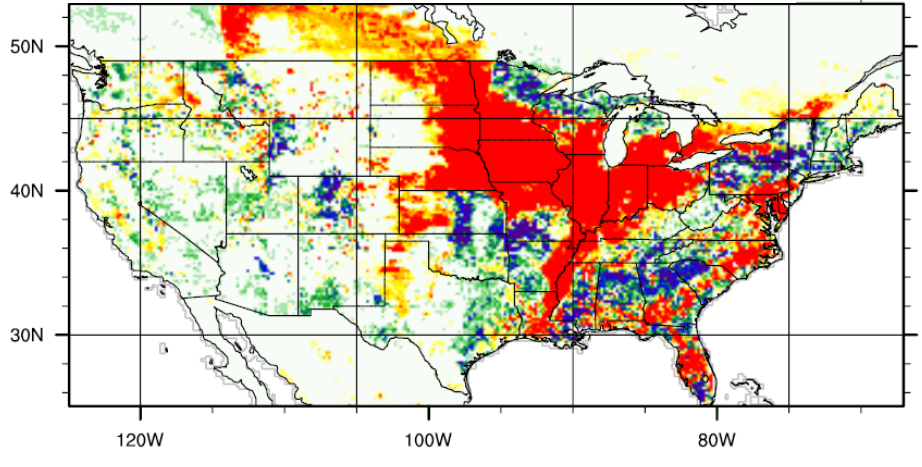
## CO2 fertilization

$\text{gC m}^{-2}\text{d}^{-1}$



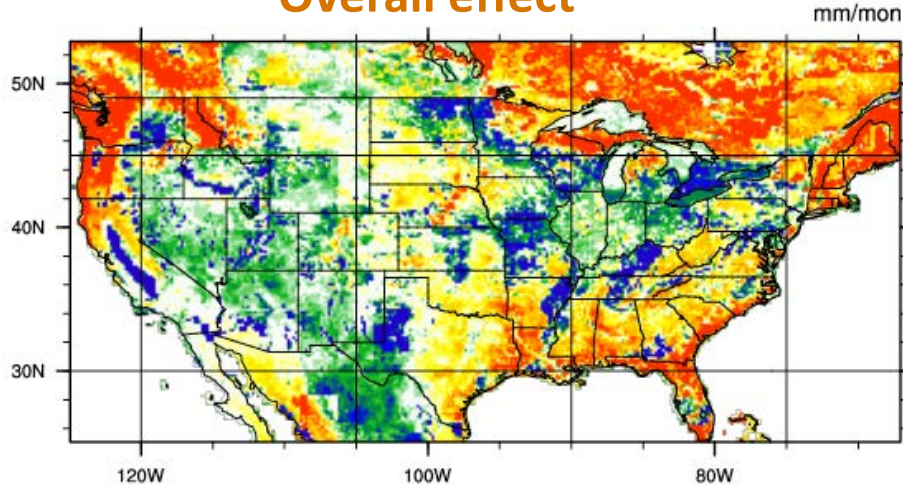
## LULCC

$\text{gC m}^{-2}\text{d}^{-1}$

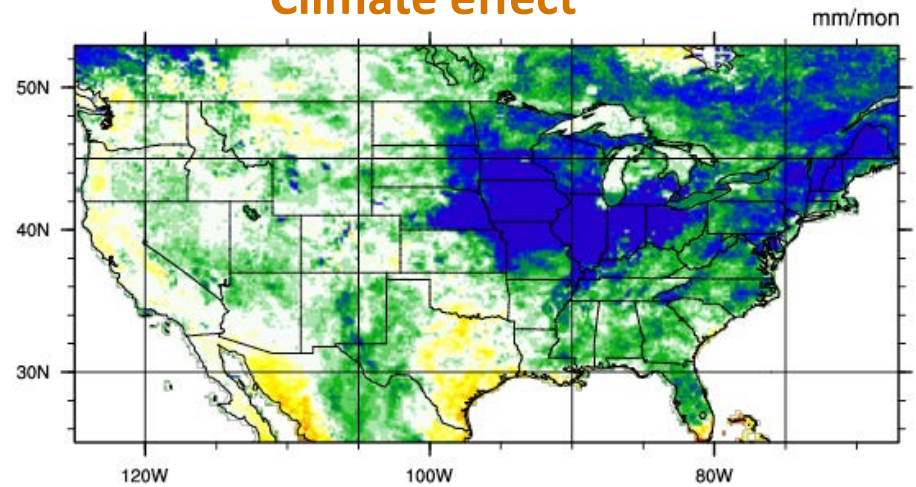


# Change in summer ET, RCP8.5 2065-2094 vs. hist

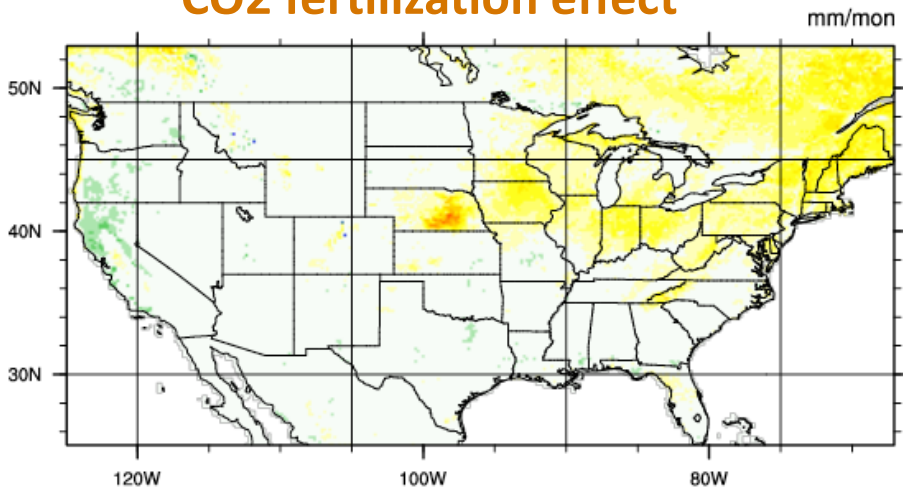
### Overall effect



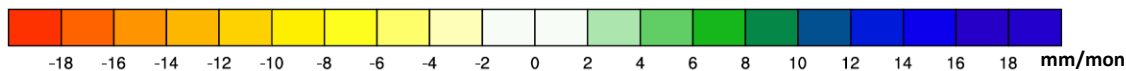
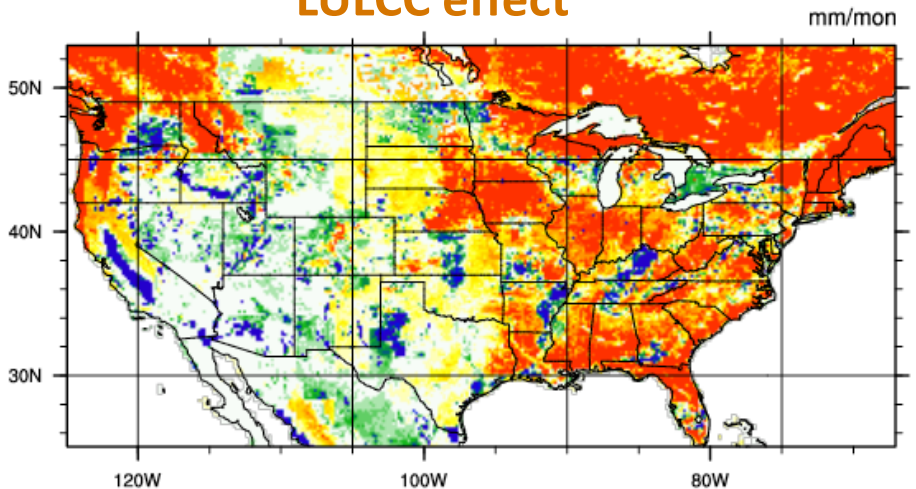
### Climate effect



### CO2 fertilization effect



### LULCC effect

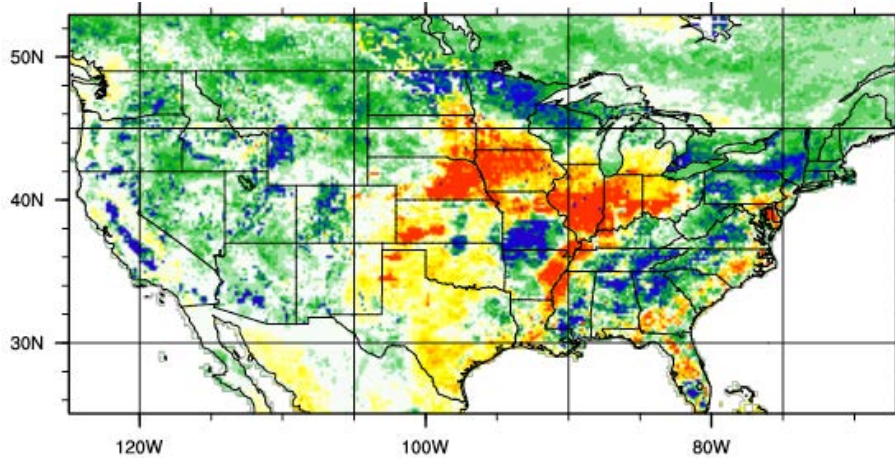




# Change in summer ET, RCP4.5 2065-2094 vs. hist

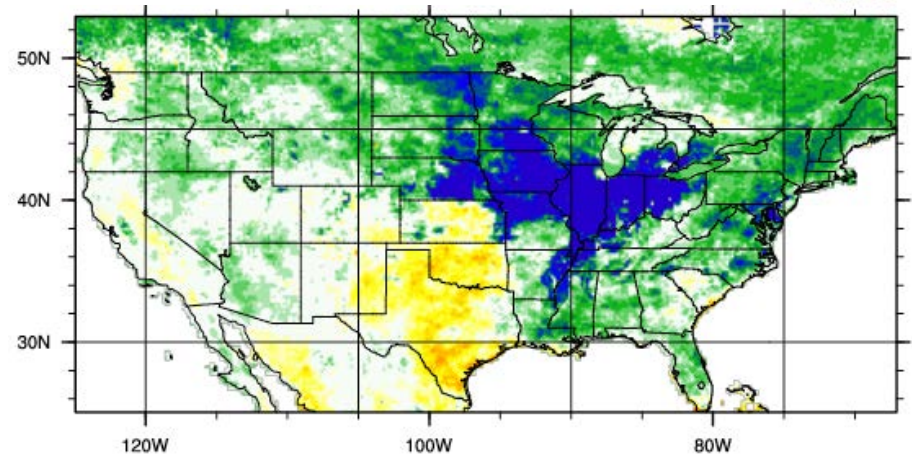
## Overall effect

mm/mon



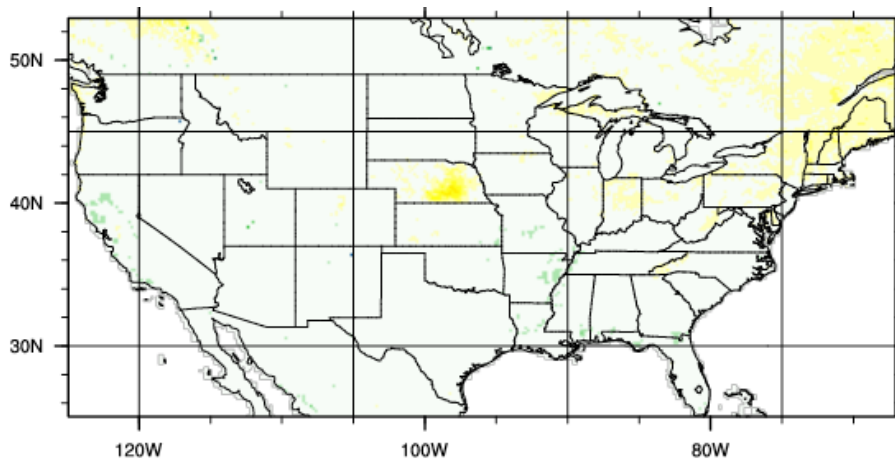
## Climate effect

mm/mon



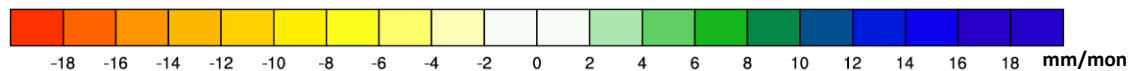
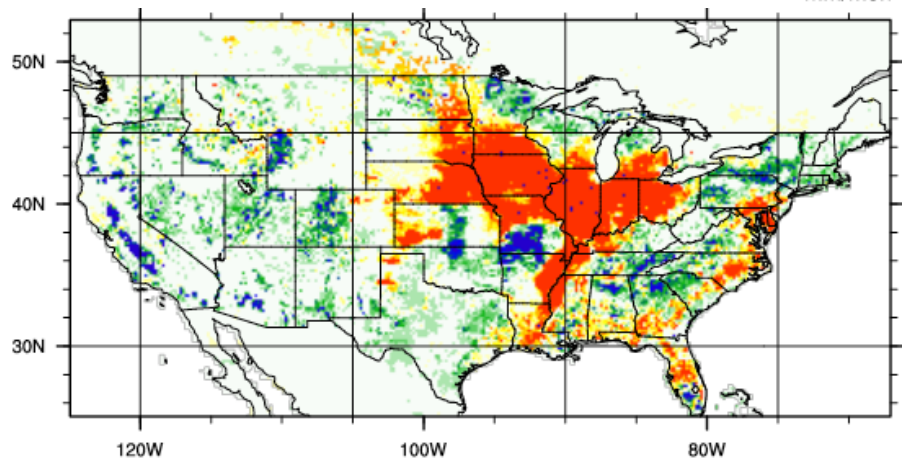
## CO2 fertilization effect

mm/mon



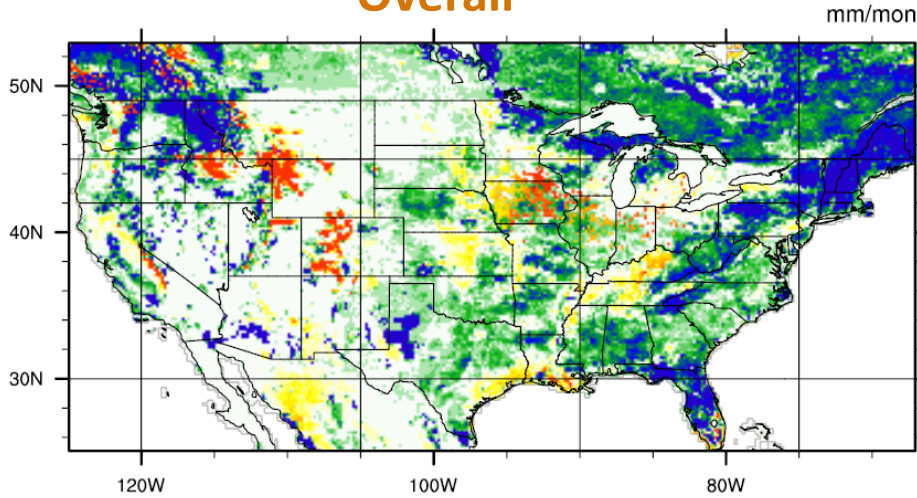
## LULCC effect

mm/mon

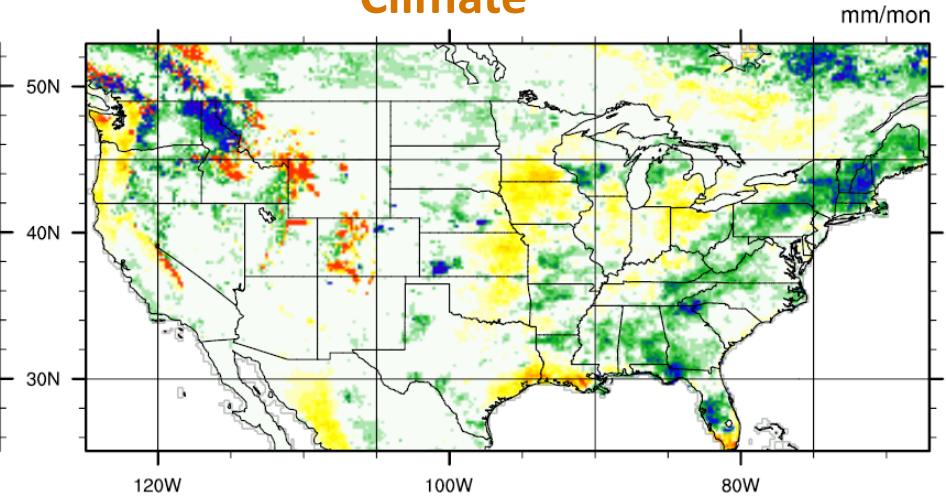


# Change in summer runoff, RCP8.5 2065-2094 vs. hist

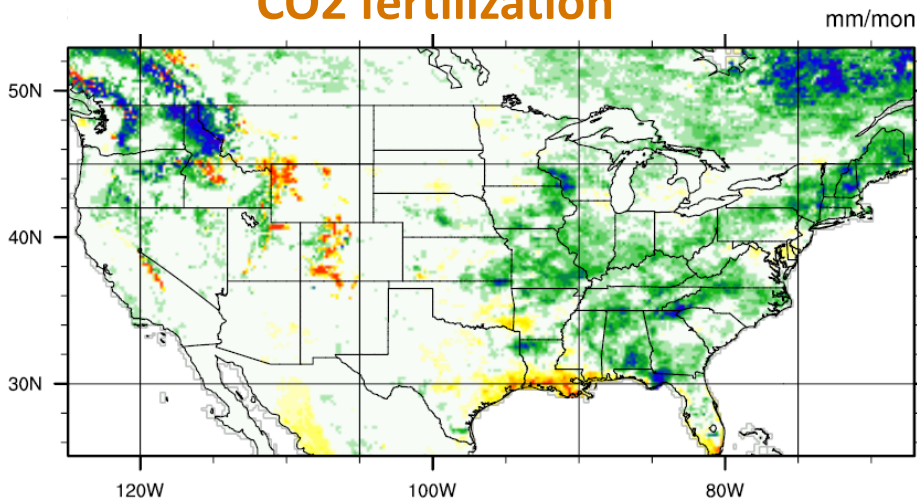
## Overall



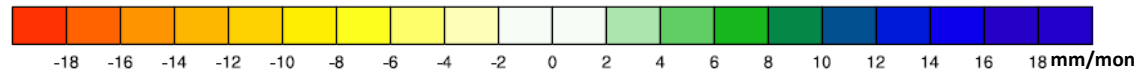
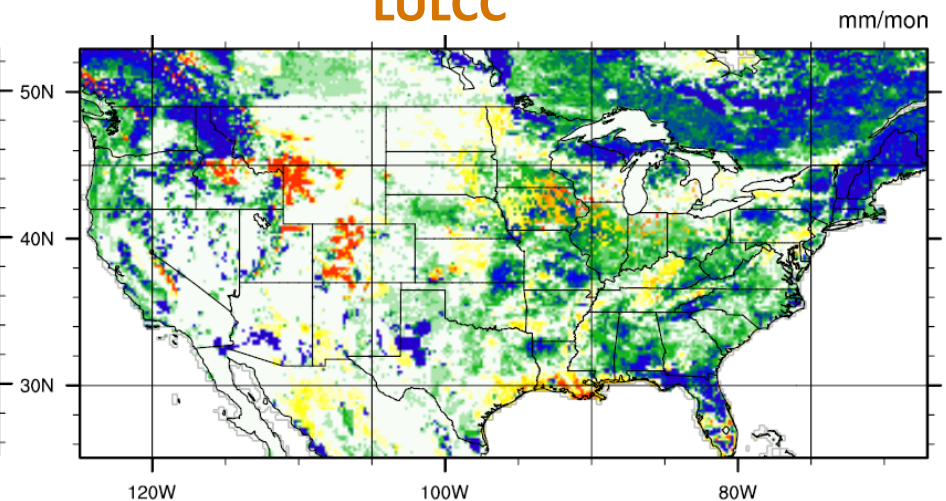
## Climate



## CO2 fertilization



## LULCC





# Change in summer runoff, RCP4.5

## 2065-2094 vs. hist

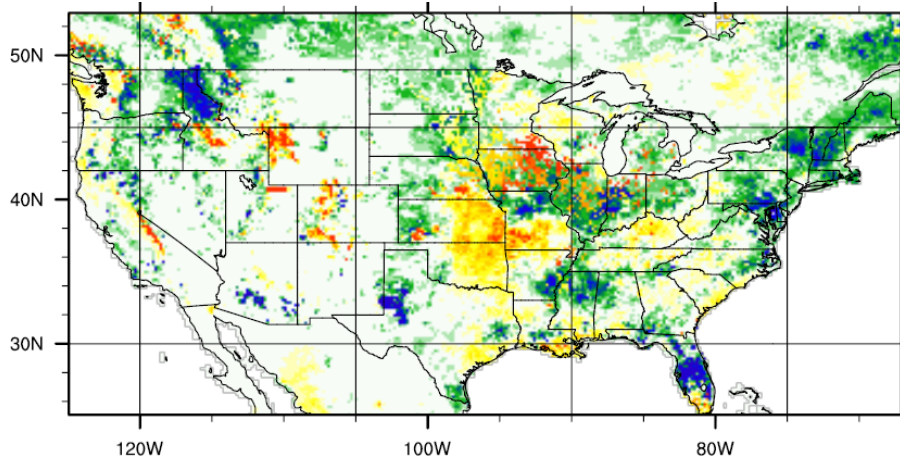


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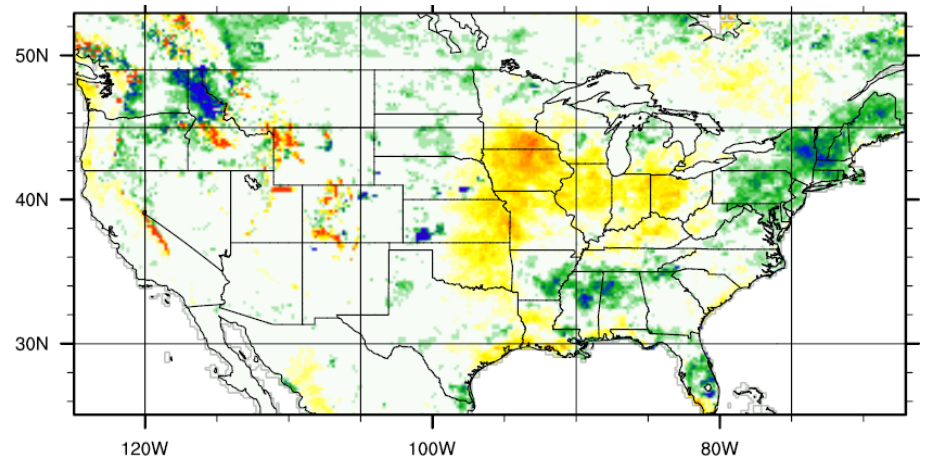
### Overall

mm/mon



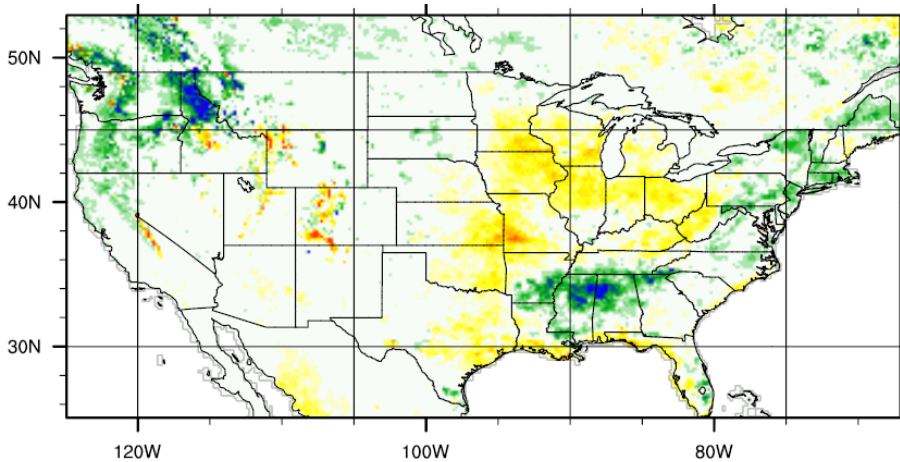
### Climate

mm/mon



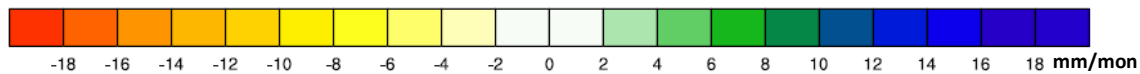
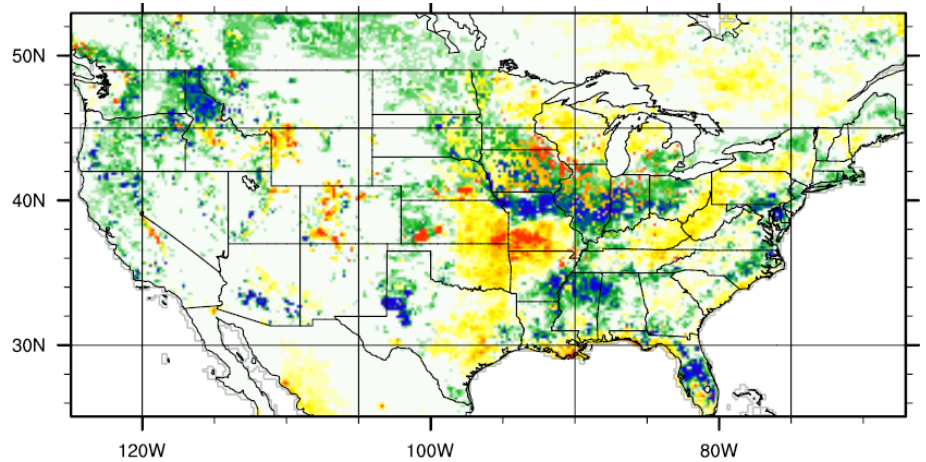
### CO2 concentration

mm/mon



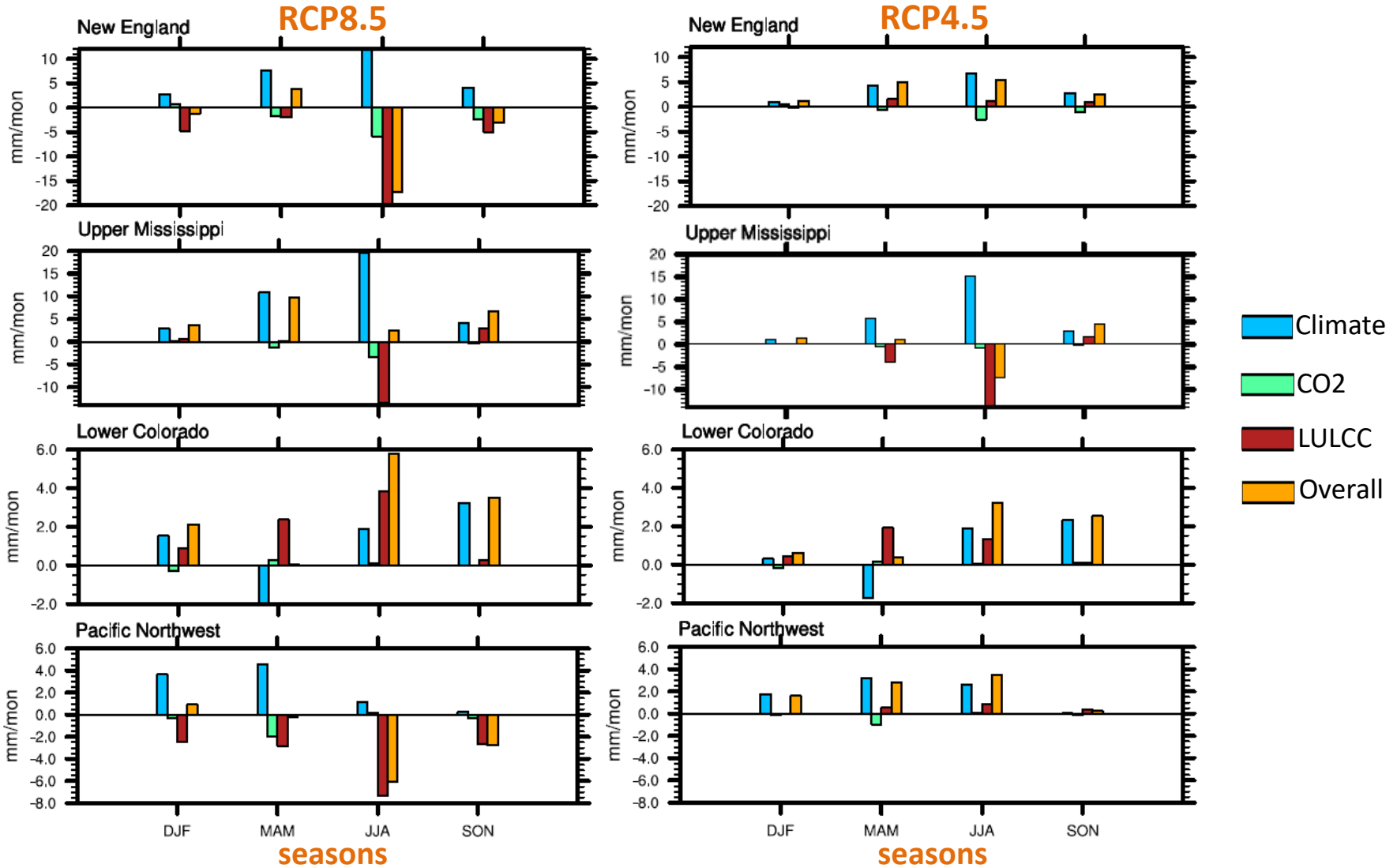
### LULCC

mm/mon





# ET changes at the water resource region level

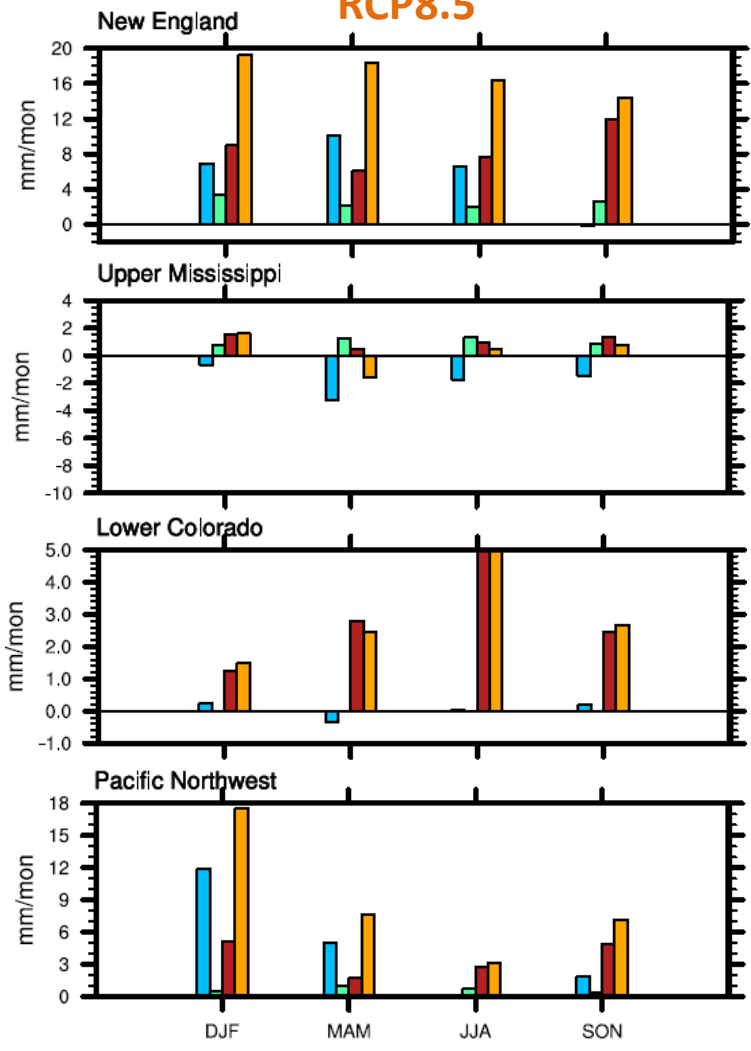




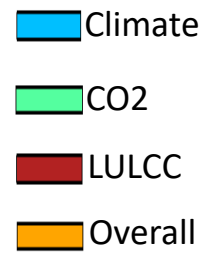
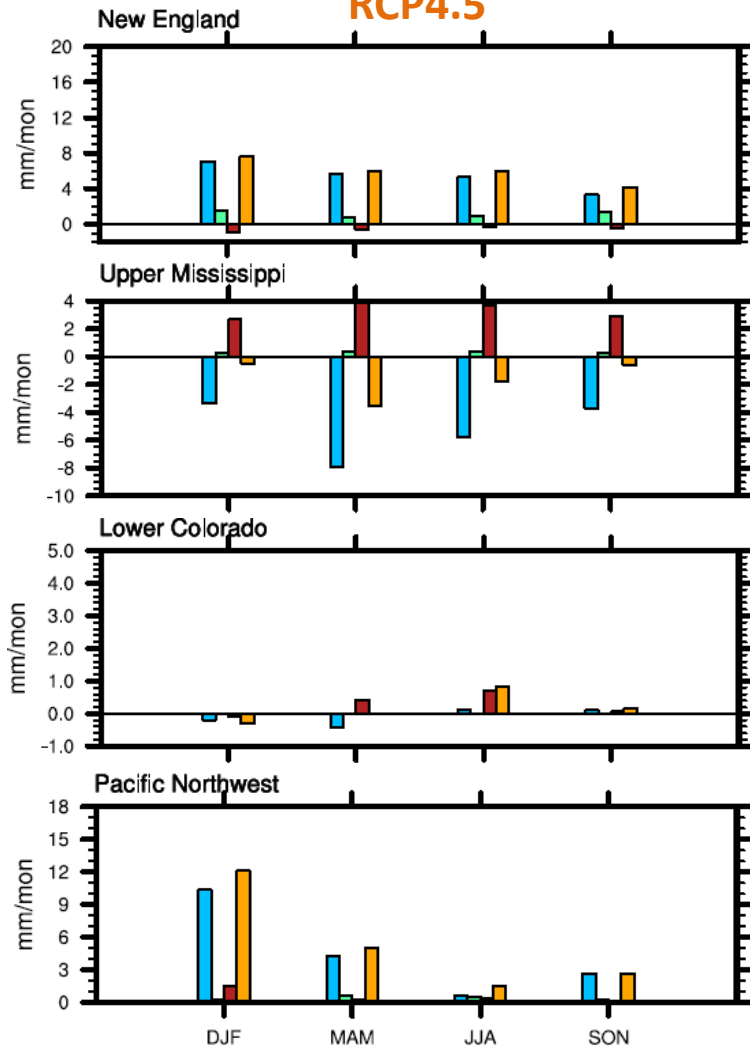


# Runoff changes at the water resource region level

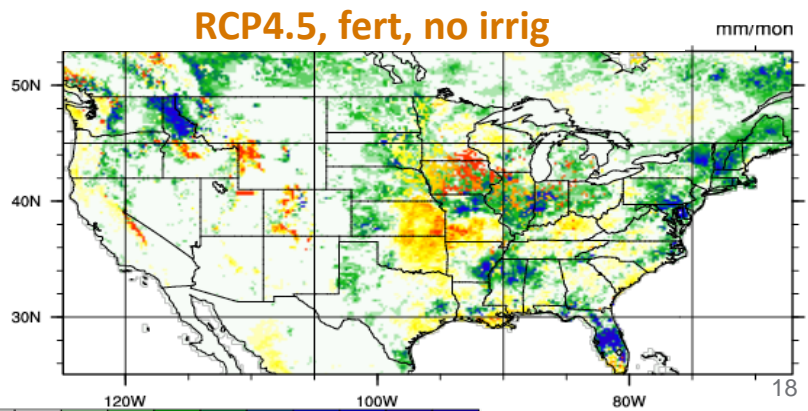
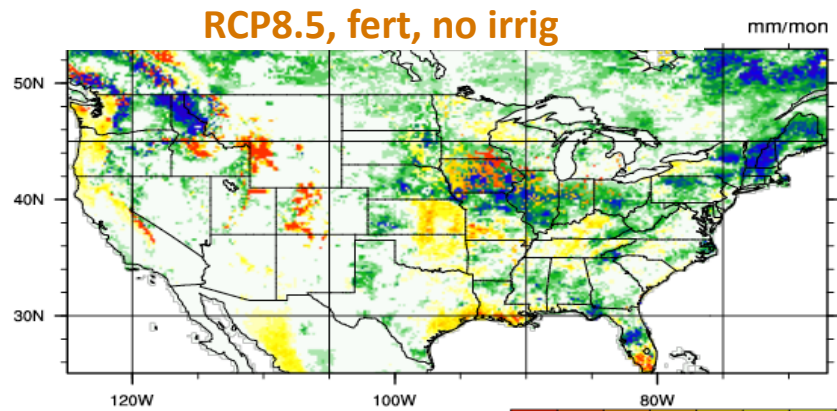
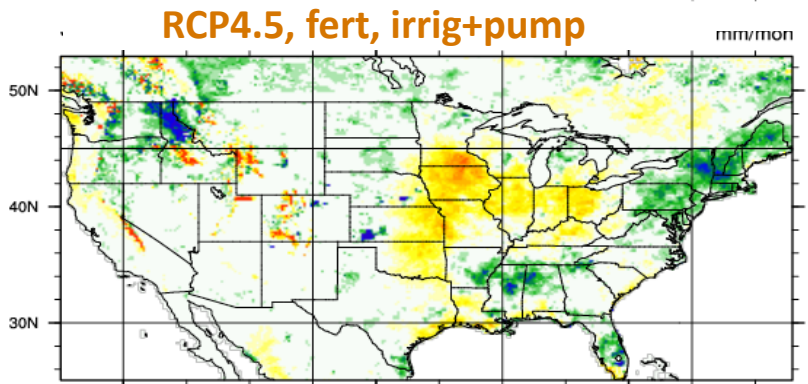
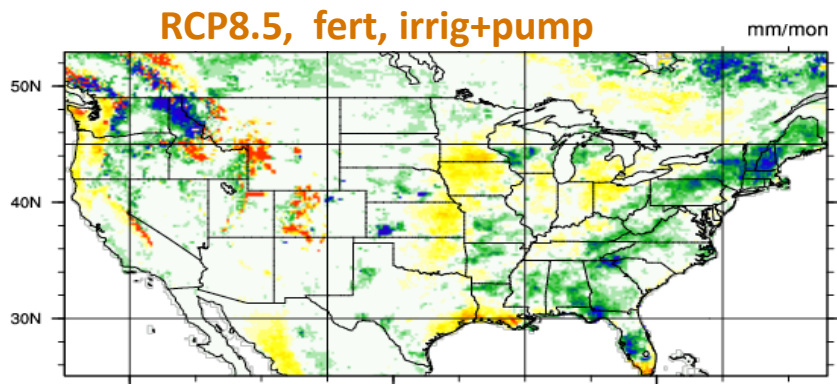
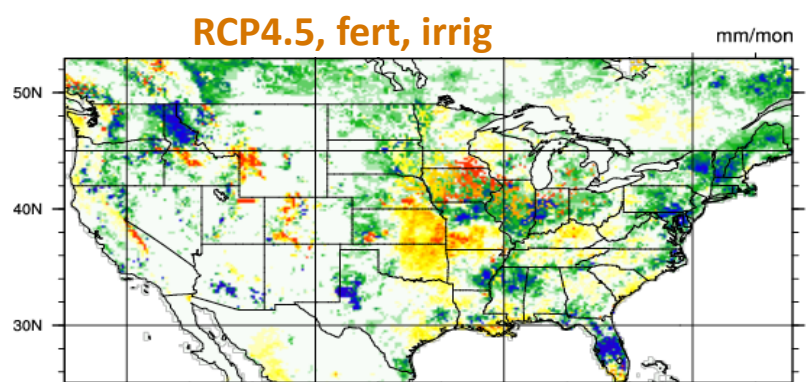
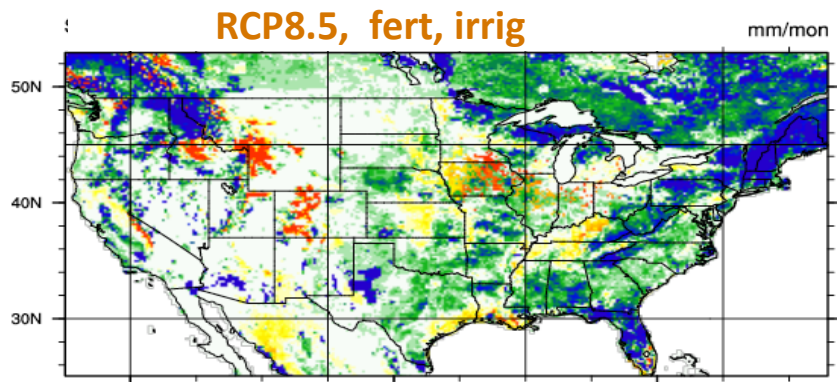
## RCP8.5



## RCP4.5



# Importance of representing management: effects on $\Delta$ runoff



## Conclusion and discussions

- ▶ ESM simulations allow us to assess the effects of climate and LULCC changes in a holistic way;
- ▶ Significant changes in terrestrial hydrology induced by climate and LULCC are projected by end of this century;
- ▶ The LULCC effect might amplify or cancel out the climate effect, depending on the water resources region or season of interest; Mitigation efforts could lead to unexpected consequences if the interactions among Earth system processes are not fully captured;
- ▶ Model assumptions in GCAM, Demeter, and CLM all contribute to uncertainties in our results. Future research will focus on understanding and quantifying such uncertainties.



# Acknowledgement

USDOE Office of Science: Integrated Assessment Research Program

Thank you!