

Advancing Integrated
Hydrological-Crop-Irrigation
Systems Modeling using CLM5

CESM LM/BGC WG Meeting 2026

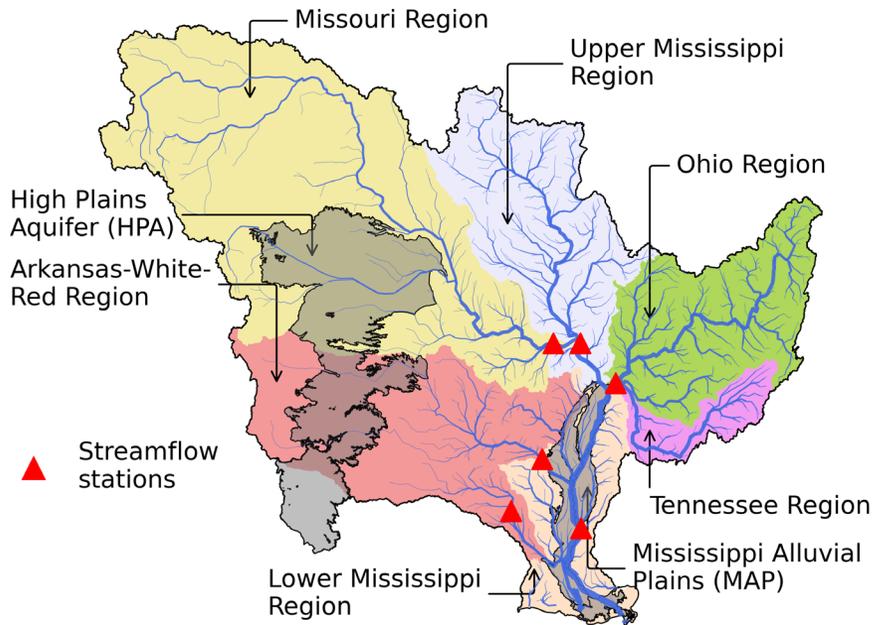
AMAN SHRESTHA, YADU POKHREL ET AL.

MICHIGAN STATE UNIVERSITY

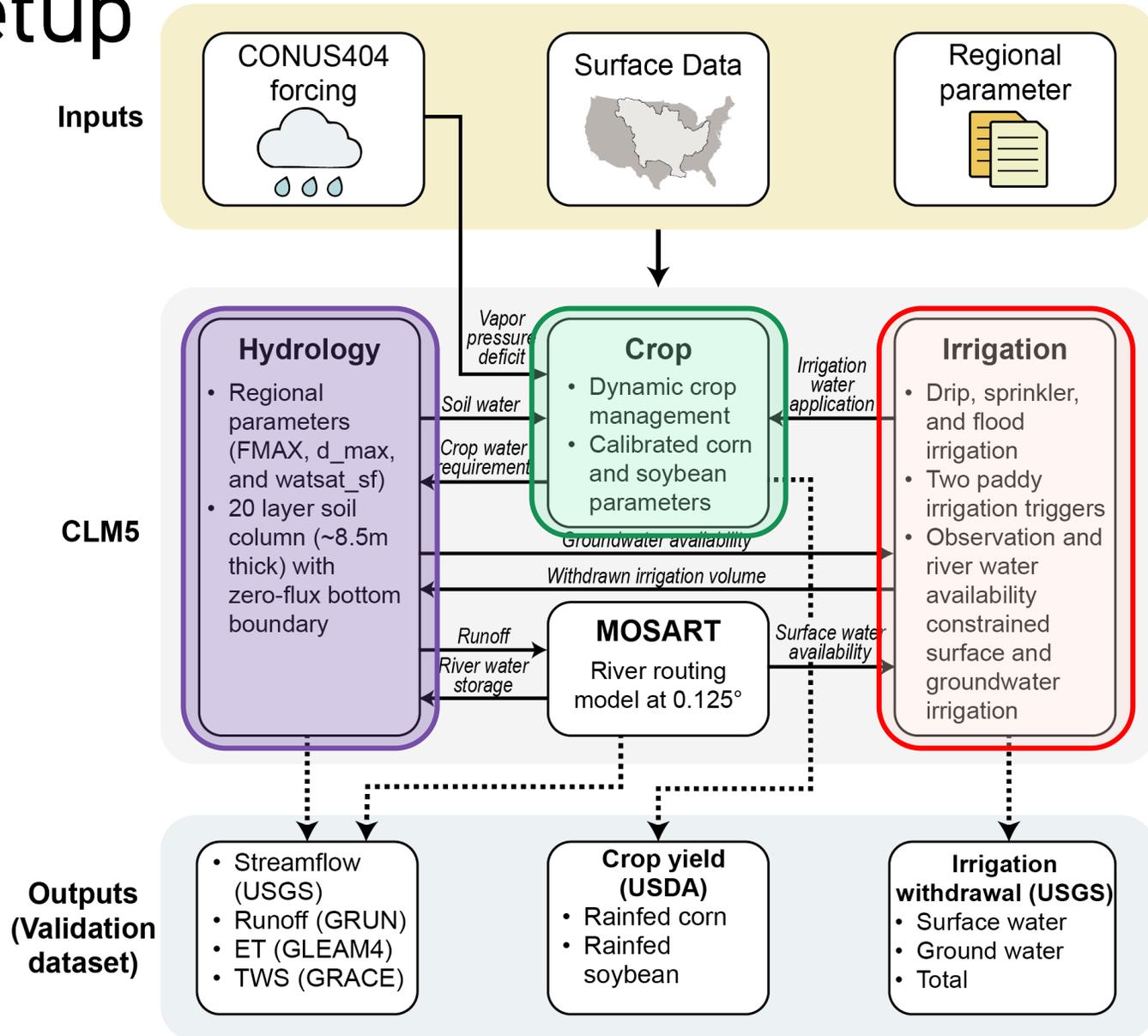
My Work

- PhD student at Michigan State University (Dr. Yadu Pokhrel – advisor)
- NSF project '**To Irrigate or Not**' – using **CLM5** to model the feasibility of agricultural and irrigation adaptation strategies in the Mississippi River Basin
- ~5km BGC mode CLM5 simulations with transient land use and regionally tuned parameters
- Integrating hydrology, crop, and irrigation modeling to
 - Advance the performance of CLM5 to model trends and variabilities of the past 40 years (1980–2020)
 - And assess the need of irrigation expansion to sustain crop production under future climate (-2100)

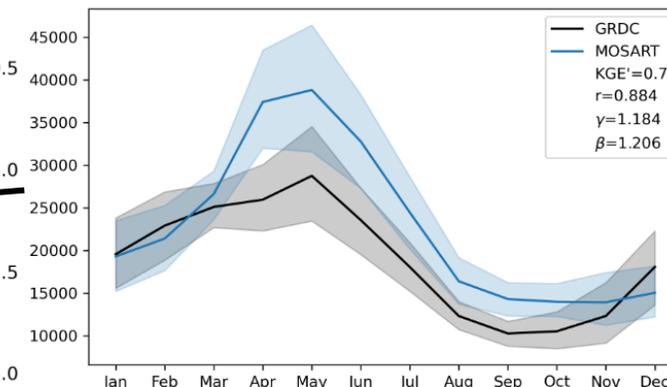
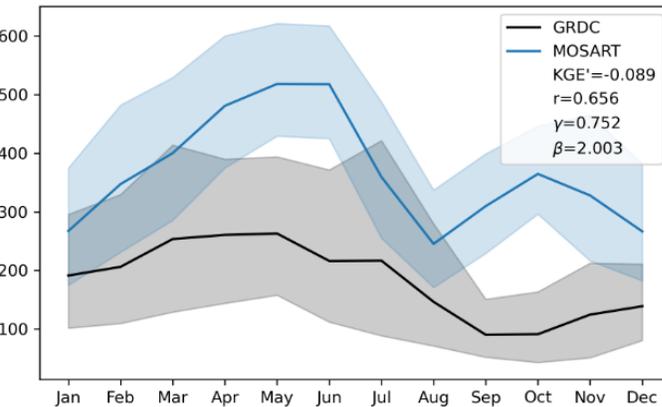
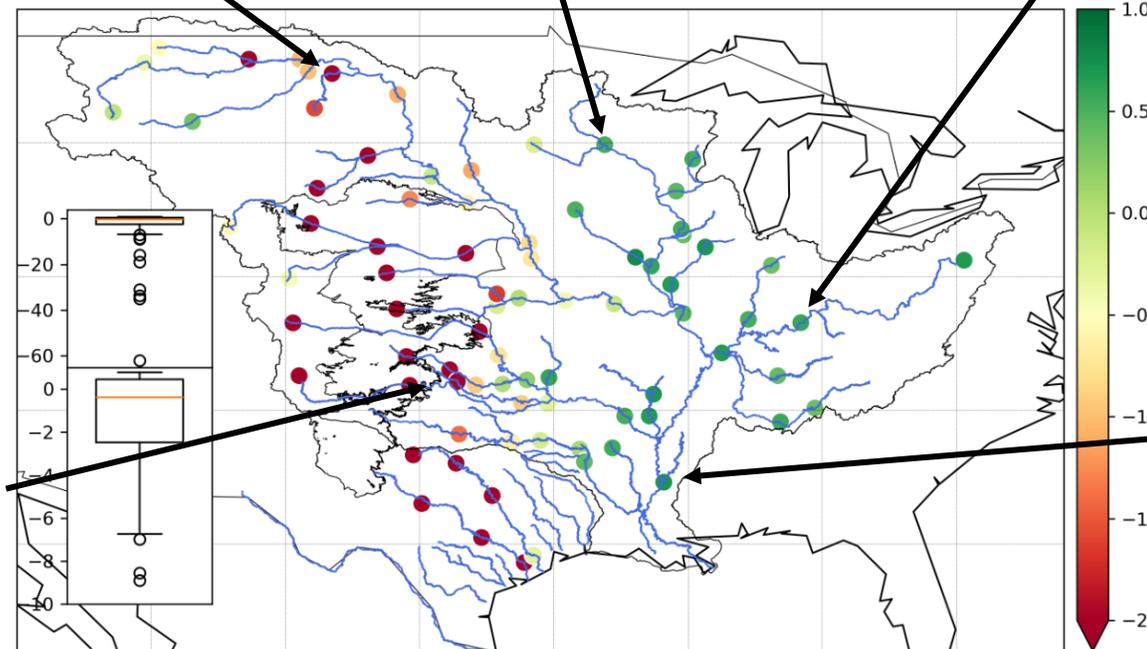
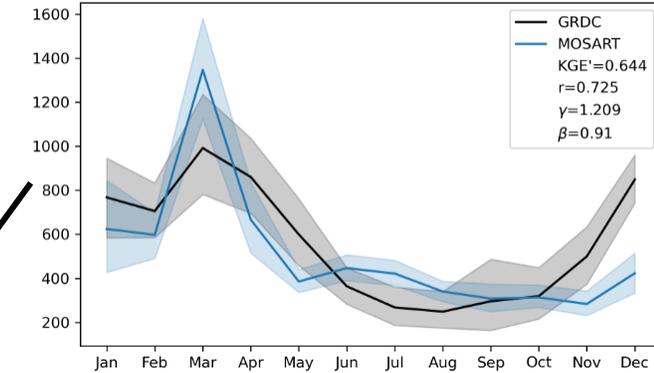
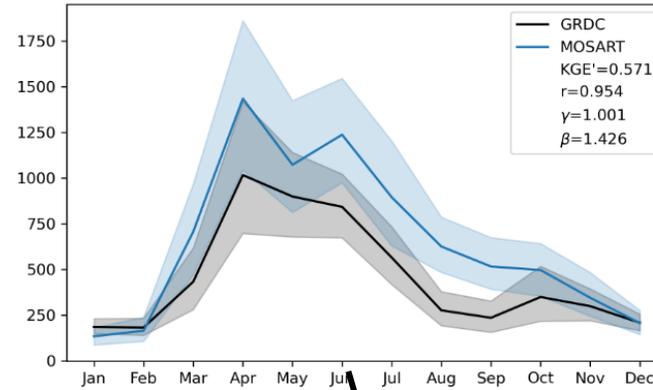
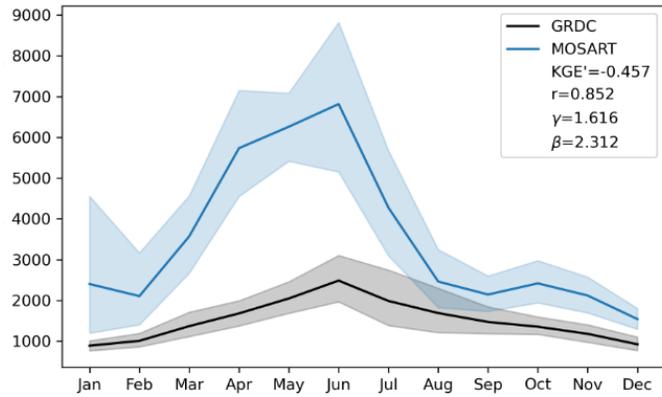
Model domain & setup



Shrestha et al.
(WRR, in review)

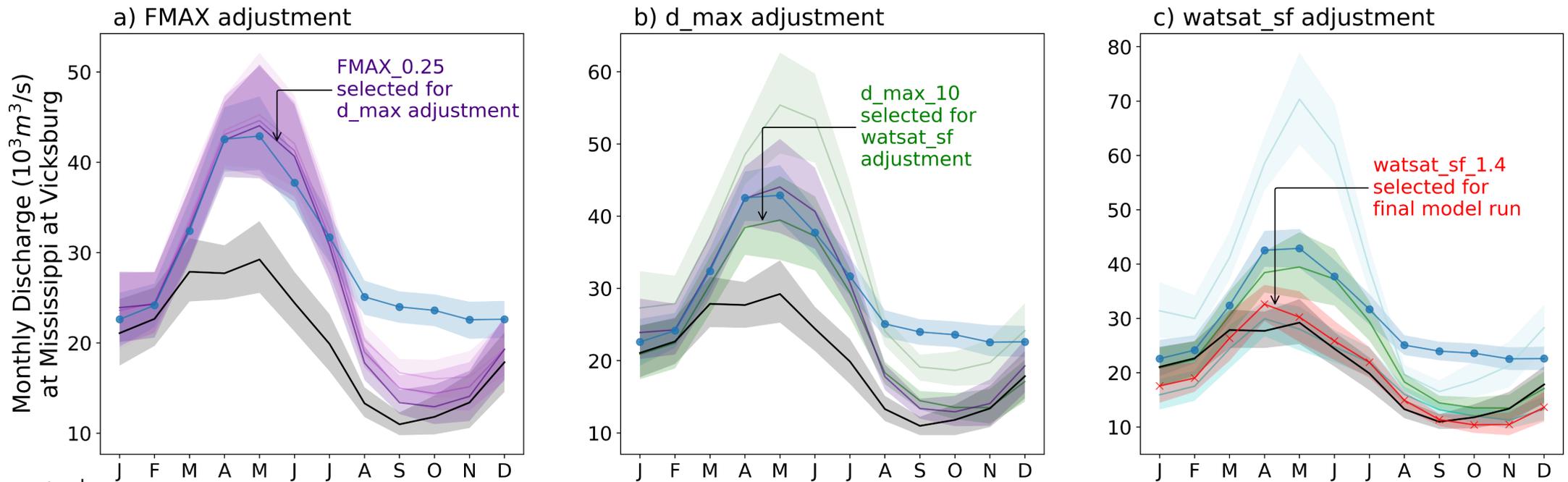


Hydrology – default parameter results

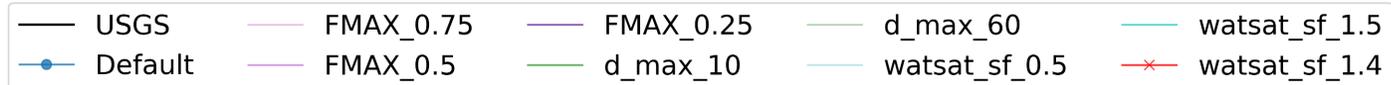


Hydrology – parameter adjustment

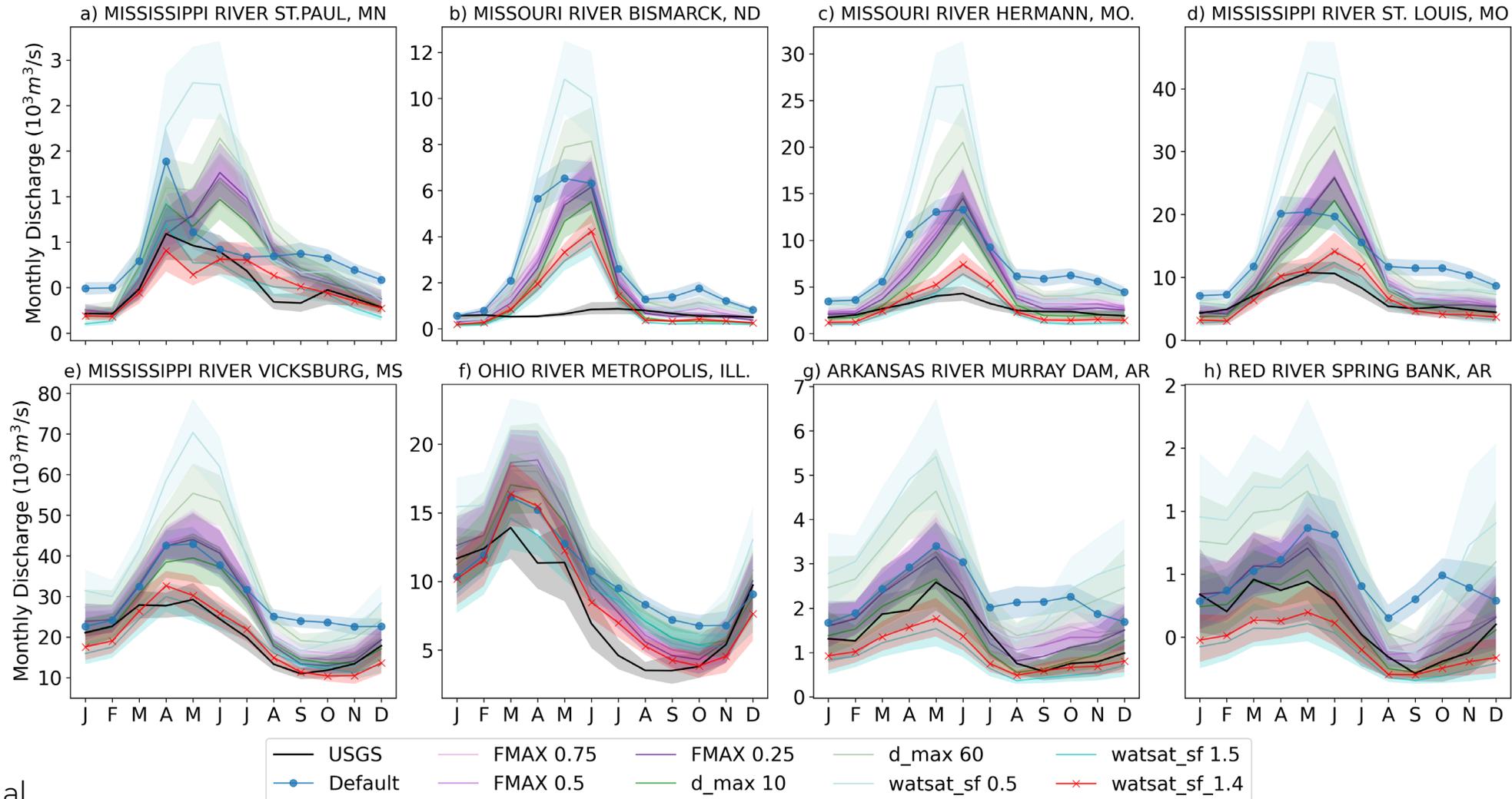
- Based on parameter sensitivity studies (Yan et al. 2023, Elkouk et al. 2025), three most sensitive parameters for streamflow were adjusted based on prior ranges.
 - FMAX – maximum saturated area fraction
 - d_max – dry surface layer thickness
 - watsat_sf – scalar factor for volumetric water content



Shrestha et al.
(WRR, in review)

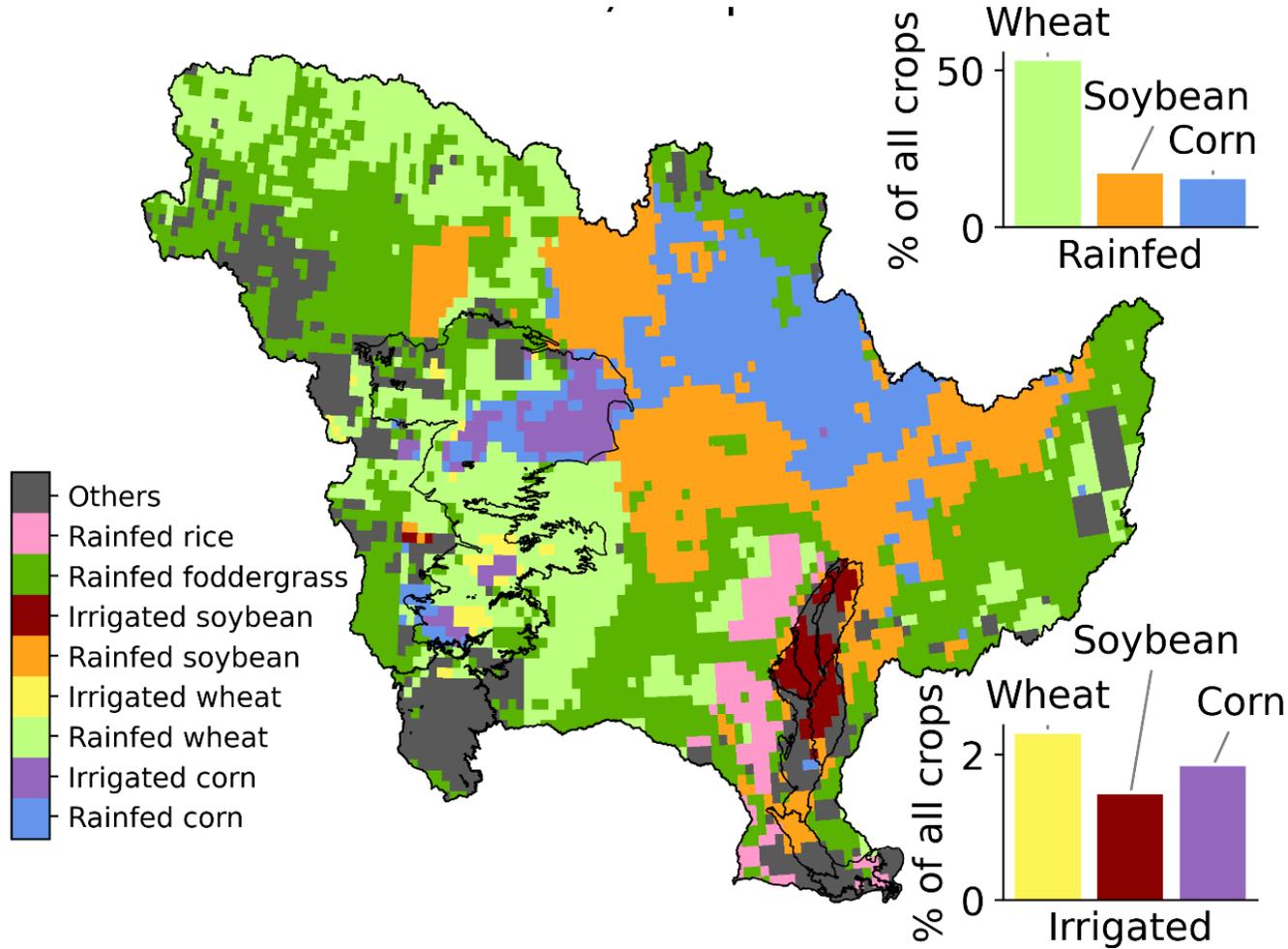


Hydrology – parameter adjustment all



Shrestha et al.
(WRR, in review)

Crop Modeling in the Mississippi



Crop Modeling in the Mississippi

- Crop parameters for corn and soybean were calibrated Cheng et al. (2020)
 - plant hydraulics, photosynthetic capacity, and planting temperature related parameters
 - Calibrated for county-level annual yield in the US Midwest

Parameter	Description	Unit	Corn		Soybean	
			Def	Cal	Def	Cal
baset	Base temperature	°C	8	10	10	10
i_vcad	Intercept of the relationship between leaf N per unit area and $V_{cmax25top}$	$\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$	3.21	9.21	4.71	4.71
s_vcad	Slope of the relationship between leaf N per unit area and $V_{cmax25top}$	$\frac{\mu\text{mol CO}_2 \text{ s}^{-1}}{\text{gN}^{-1}}$	20.48	60.48	59.23	65.23
laimx	Maximum leaf area index	-	5	5	6	5
planting_temp	Average 10-day temperature needed for planting	K	283.15	294.15	286.15	293.15
psi50	Water potential at 50% loss of conductance	mm H ₂ O	-340000	-52307.69	-340000	-680000

Crop Productivity in the Midwest -1

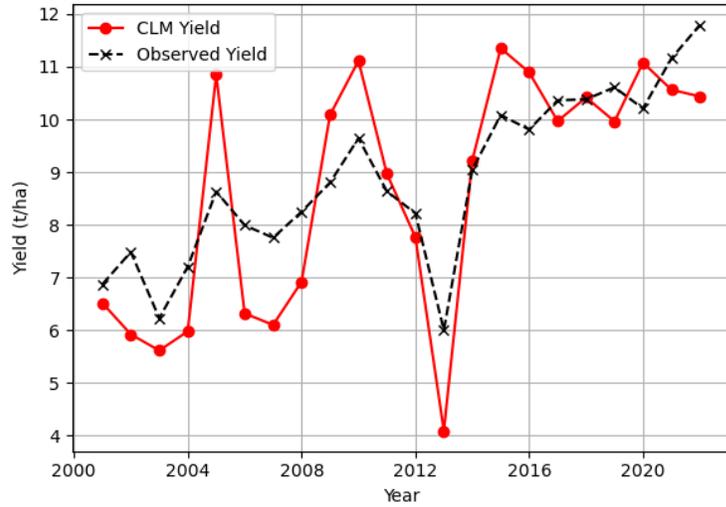
- Calibrated rainfed corn and rainfed soybean yields match better with reported yields from USDA, compared against default CLM5 crop model.

Metric	Unit	Rainfed Corn			Rainfed Soybean		
		USDA	Default	Calibrated	USDA	Default	Calibrated
Multi-year average	bu/acre	771.35	646.5	797.38	244.07	163.47	234.95
Trend	bu/acre/yr	12.47	0.91	7.5	2.71	1.83	2.79
RMSE	bu/acre	-	263.04	282.02	-	125.19	112.39
PBIAS	%	-	-14.31	3.39	-	-32.62	-1.91
r	-	-	0.52	0.58	-	0.41	0.37

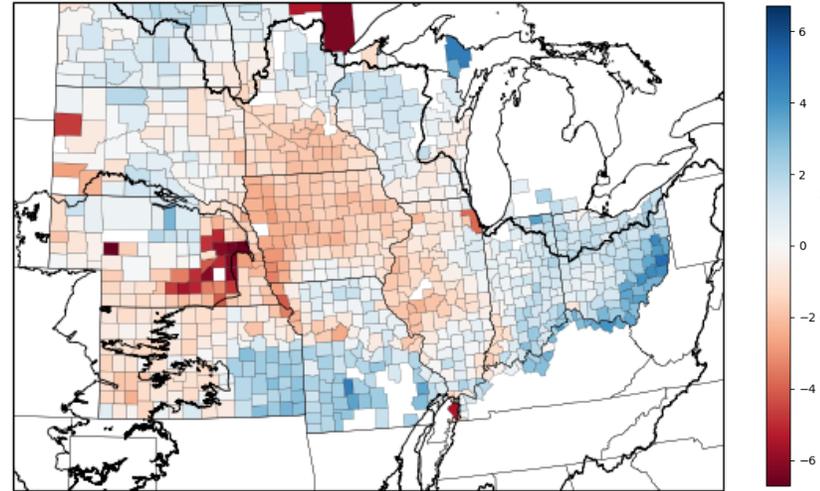
Shrestha et al.
(WRR, in review)

Crop Productivity in the Midwest -2

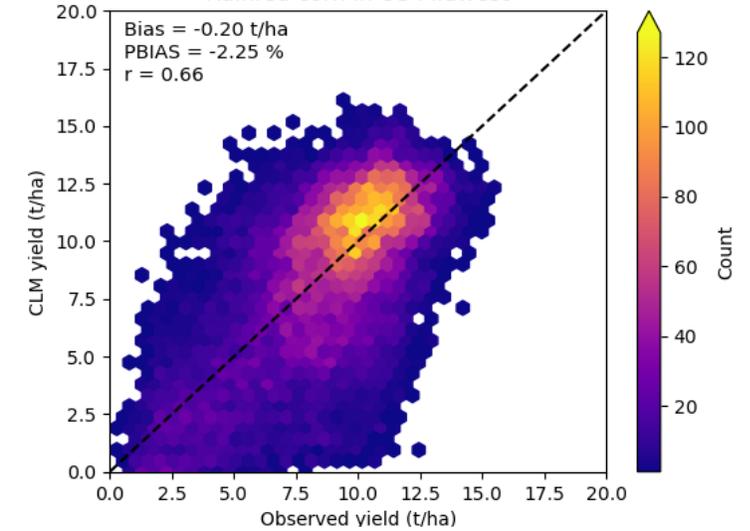
Rainfed corn in Midwest



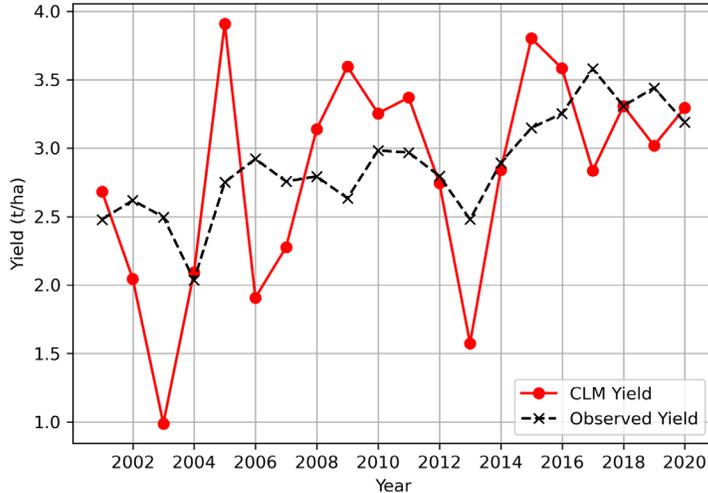
Yield bias in rainfed corn (t/ha)



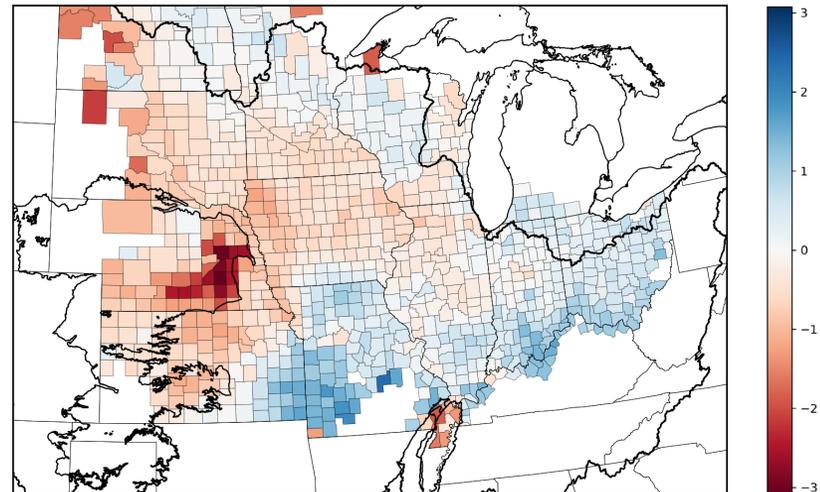
Rainfed corn in US Midwest



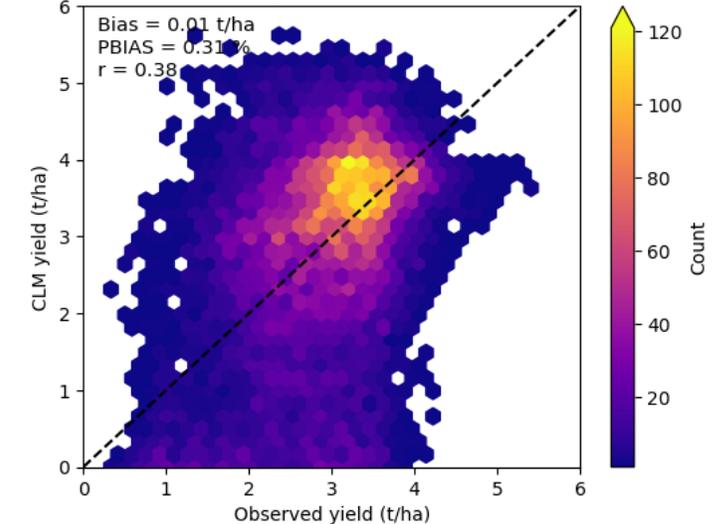
Rainfed soybean in Midwest



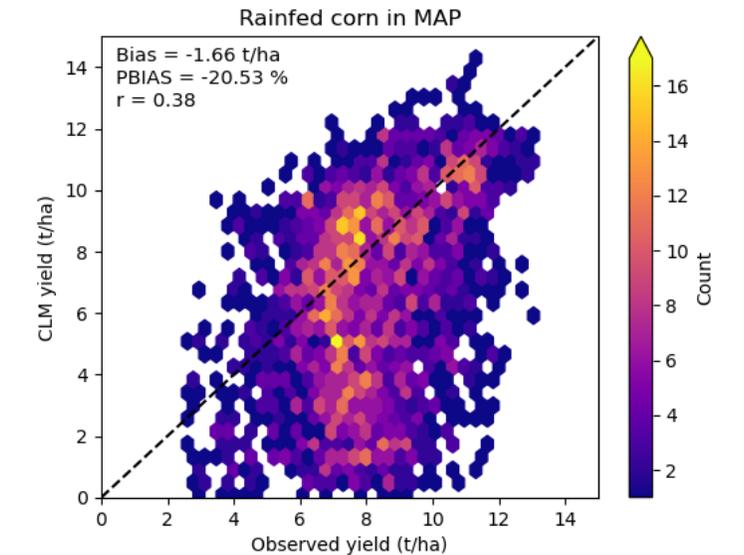
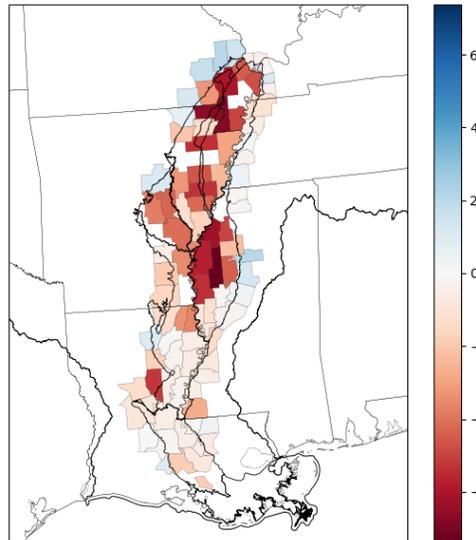
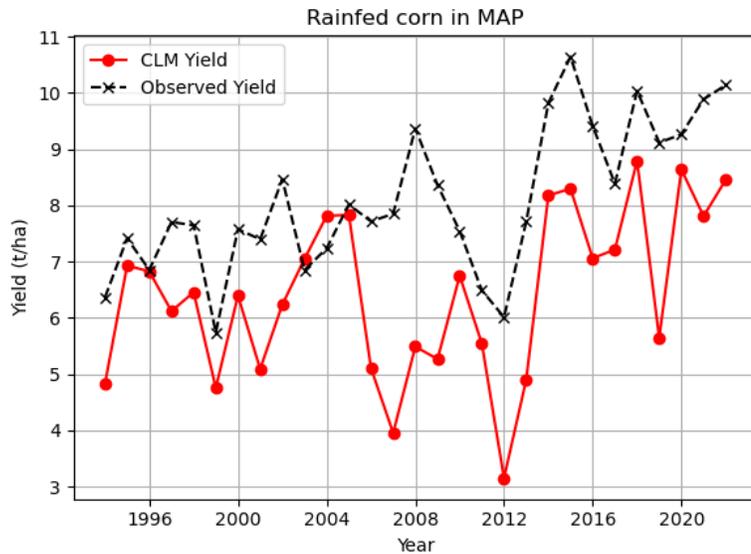
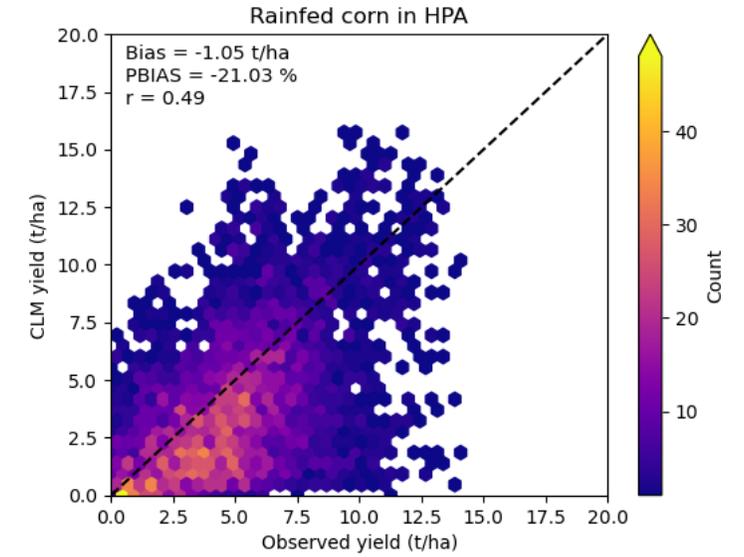
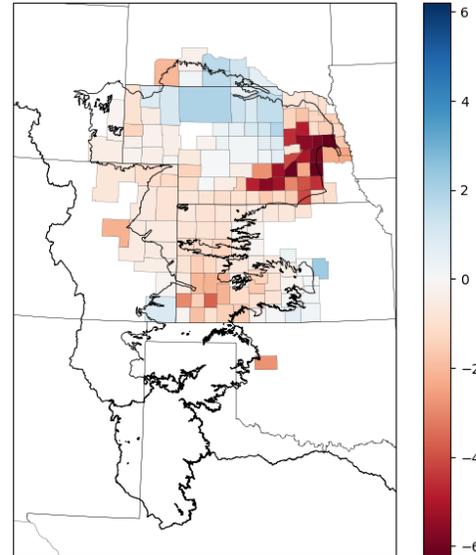
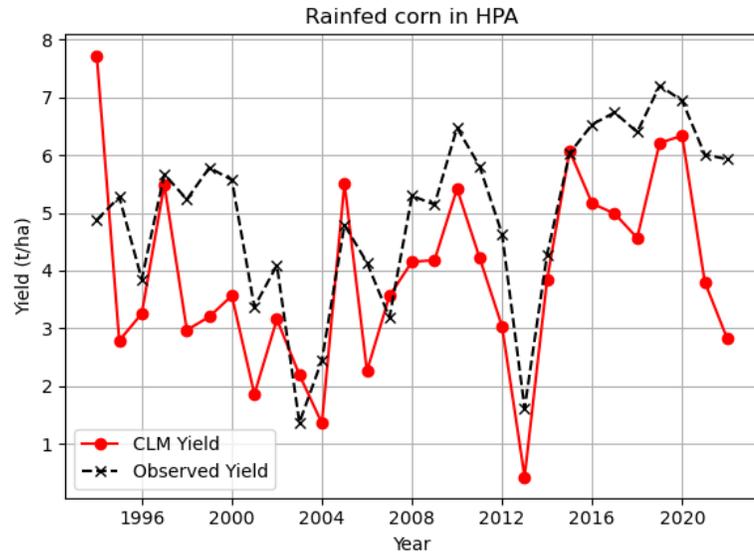
Yield bias in rainfed soybean (t/ha)



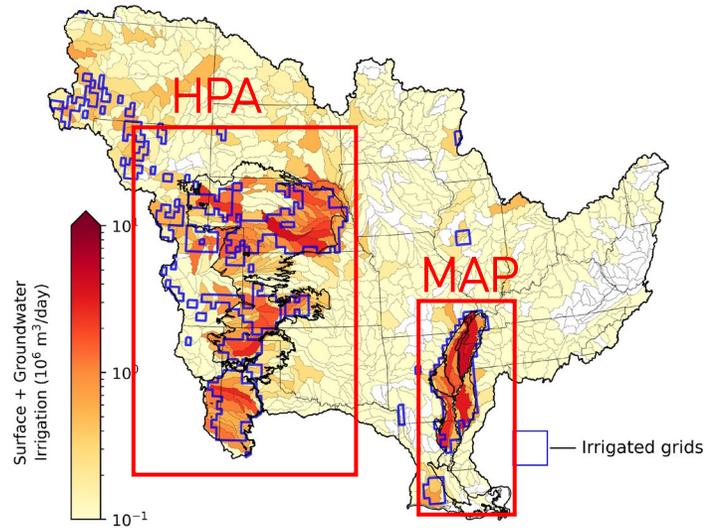
Rainfed soybean in US Midwest



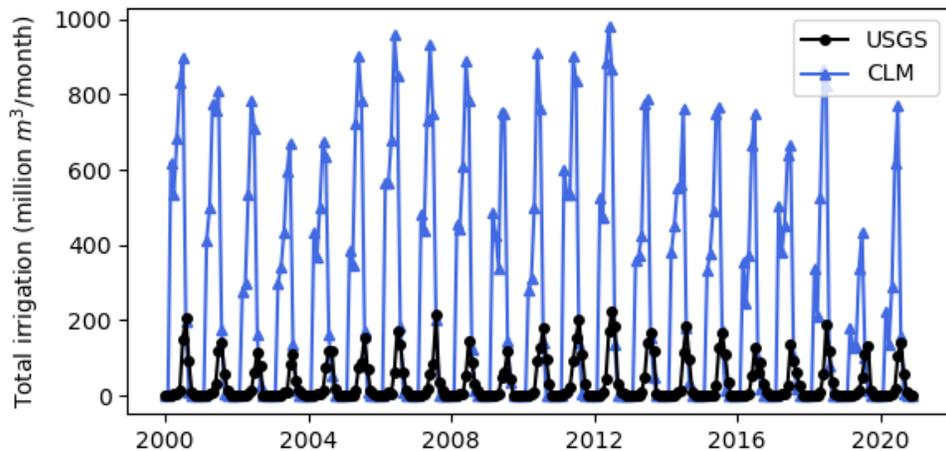
Crop Productivity outside the Midwest



Irrigation in the Mississippi



- Total irrigation withdrawal is severely overestimated.



- Paddy consumes substantially more water.
- Irrigated paddy less frequently (triggered when soil moisture is below a threshold).

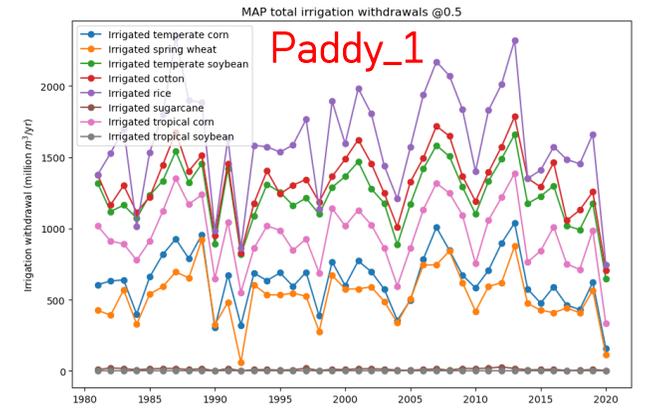
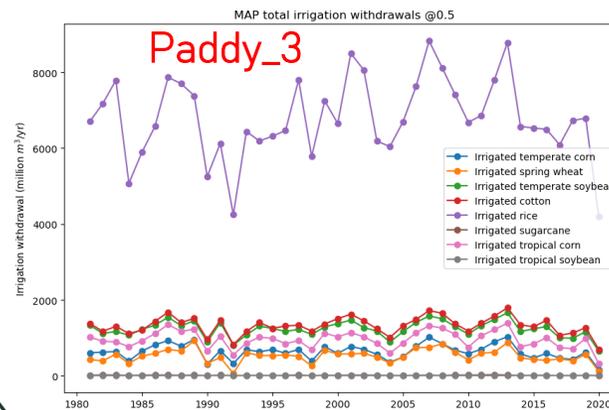
Table 1
Information on Irrigation Methods (All Parameters Are Described in Sections 2.2 and 2.3)

Method	Activation	Water amount	Place where water is applied	New water ponding module
Default	$W_{current} < W_{thresh}$	$W_{target} - W_{current}$	Under canopy	No
Sprinkler	$W_{current} < W_{thresh}$	$W_{target} - W_{current}$	Over canopy	No
Flood	$W_{current} < W_{thresh}$	$W_{satu} - W_{current}$	Under canopy	No
Paddy_1	$W_{current} < W_{thresh}$	$W_{satu} - W_{current}$	Under canopy	Yes
Paddy_2	$D_{sfc} < D_{th}$	$D_{max} - D_{sfc}$	Under canopy	Yes
Paddy_3	$W_{current} < W_{satu}$	$W_{satu} - W_{current}$	Under canopy	Yes

Paddy_3 is the final scheme used for irrigated rice.

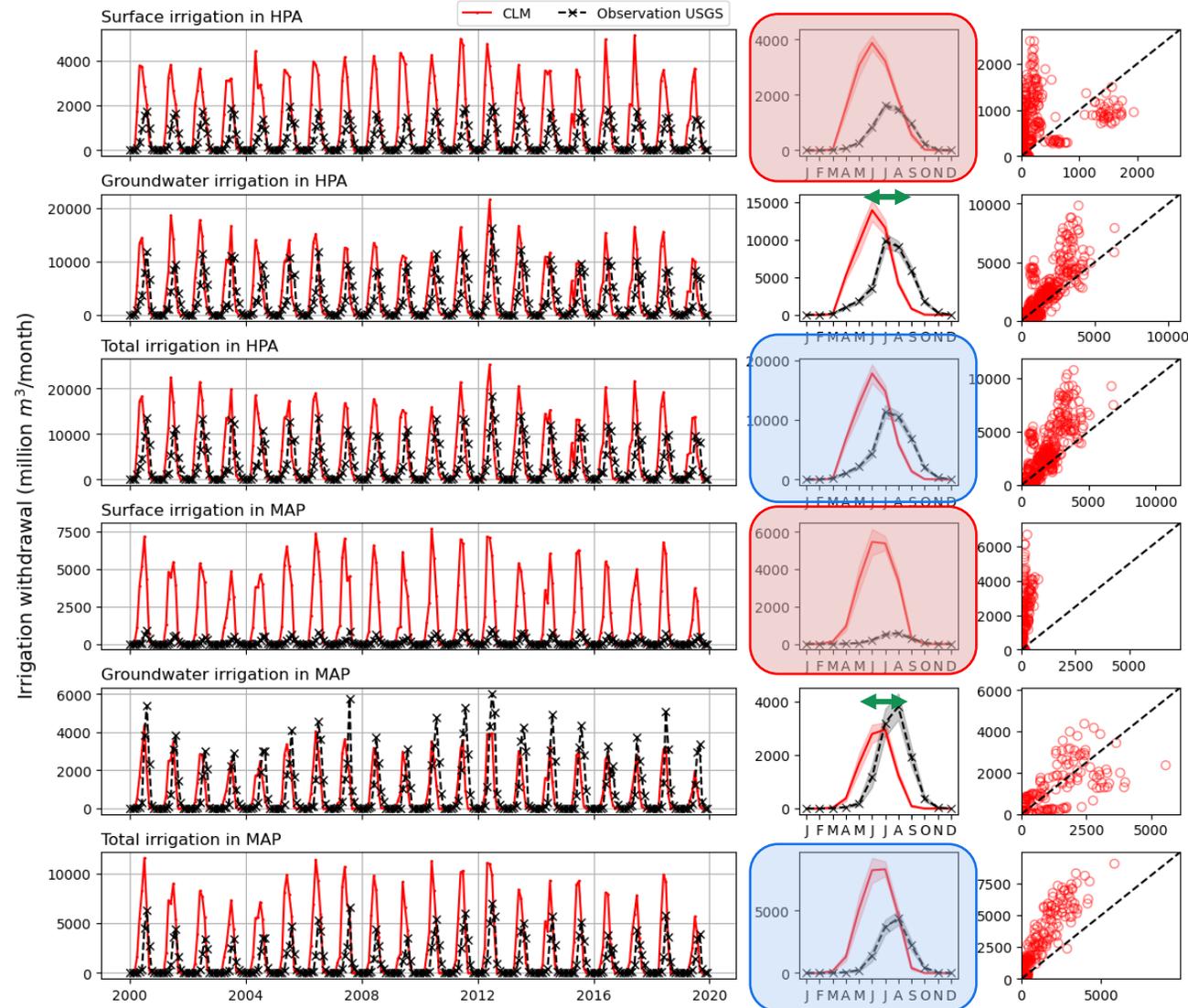
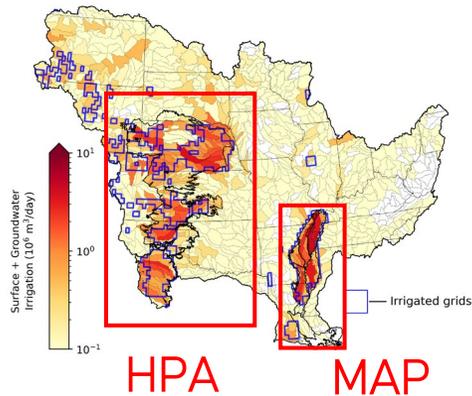
Yao et al. (2022)

- Substantial reduction for irrigated paddy



Irrigation in the Mississippi-2

- Still few issues remain.



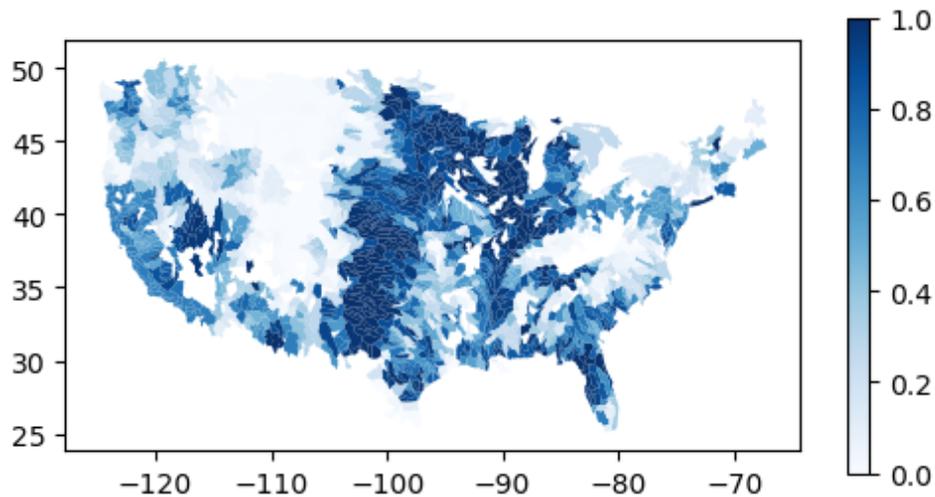
1. High surface water irrigation

2. Total irrigation withdrawals still overestimated

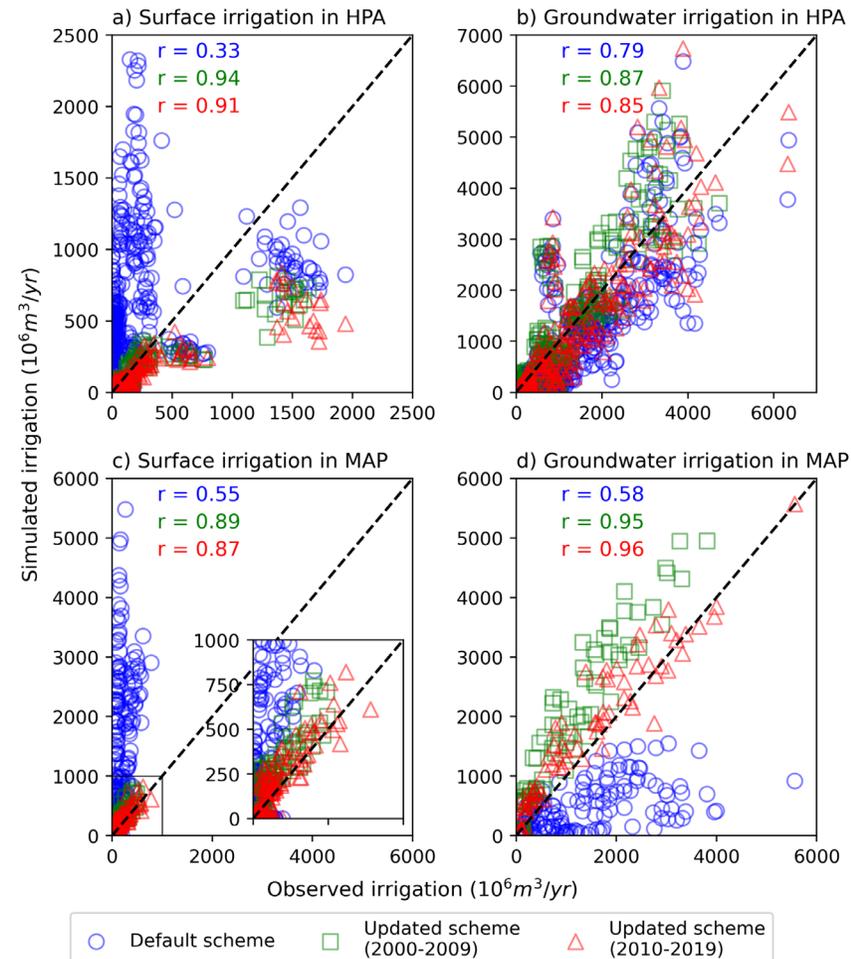
3. Irrigation timing is 2-3 months earlier.

Irrigation in the Mississippi-3

- Created a new irrigation partitioning module (modified IrrigationMod.F90)
 - Uses USGS irrigation dataset (2000-2009) to set the ratio of groundwater irrigation to total irrigation withdrawals in each grid cell
 - Default (2000-2019)
 - Baseline (2000-2009)
 - Validation (2010-2019)



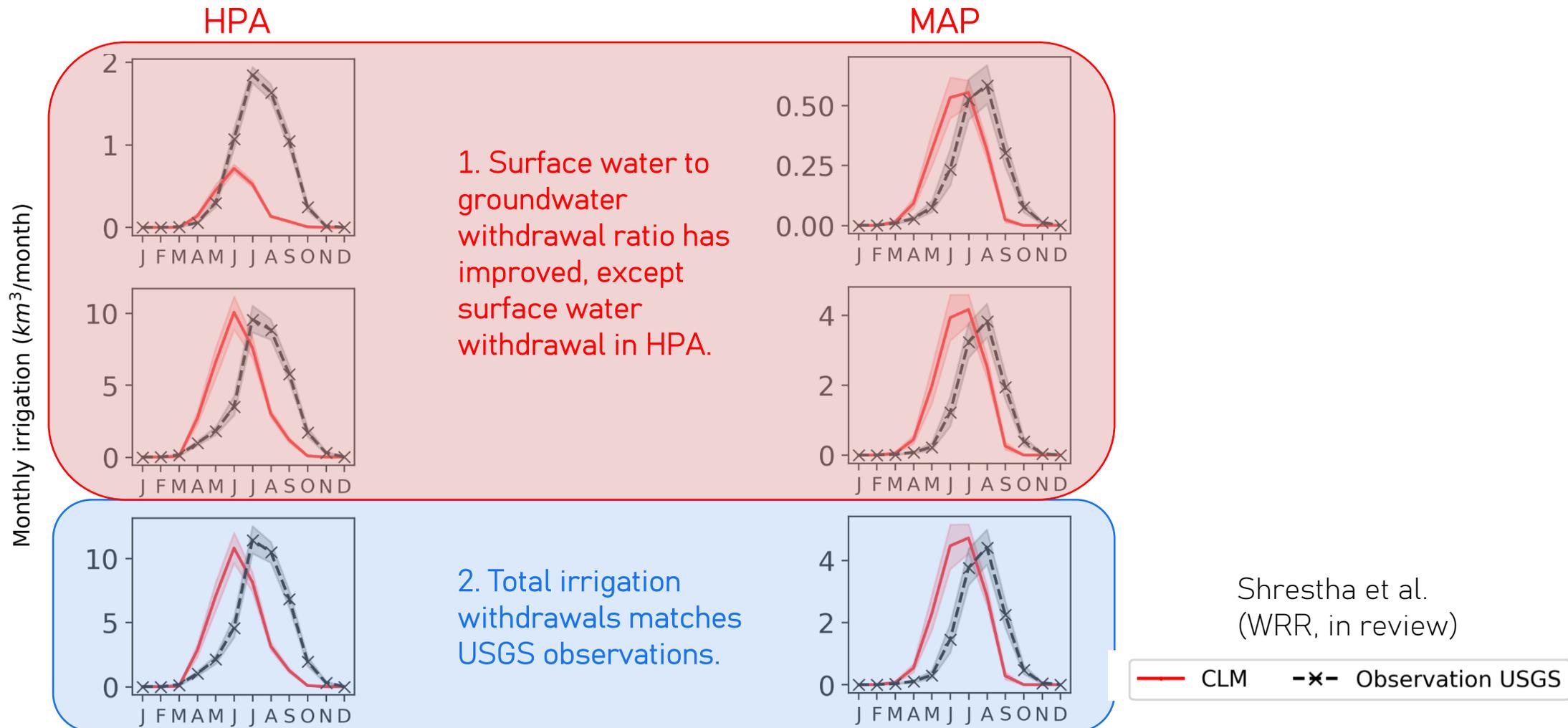
Groundwater to total irrigation ratio



Shrestha et al.
(WRR, in review)

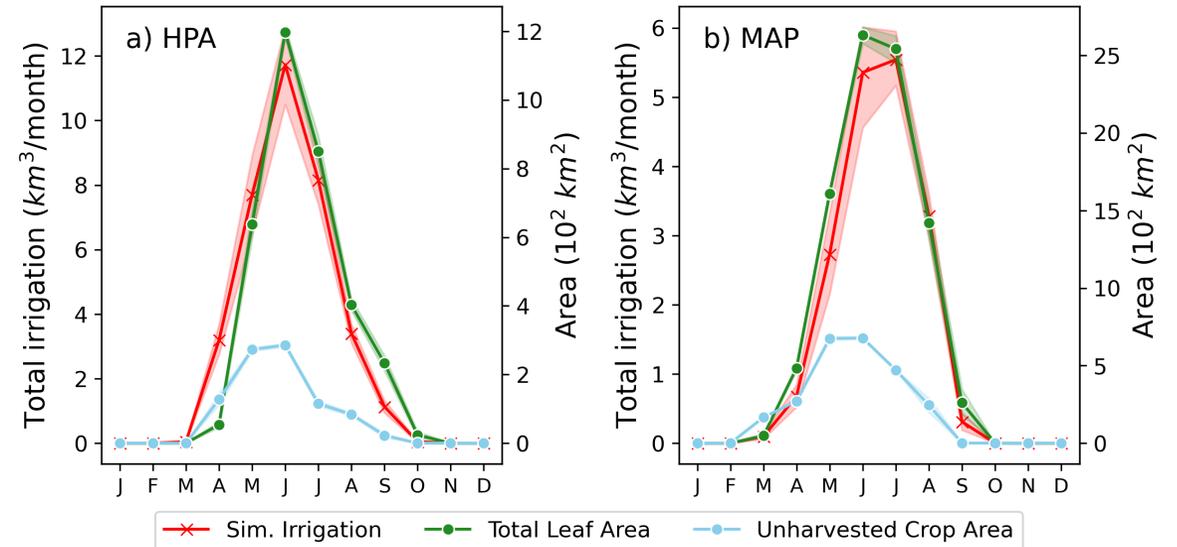
Irrigation in the Mississippi-4

2. Irrigation threshold set to 0.5 (irrig_threshold_fraction in the namelist file)

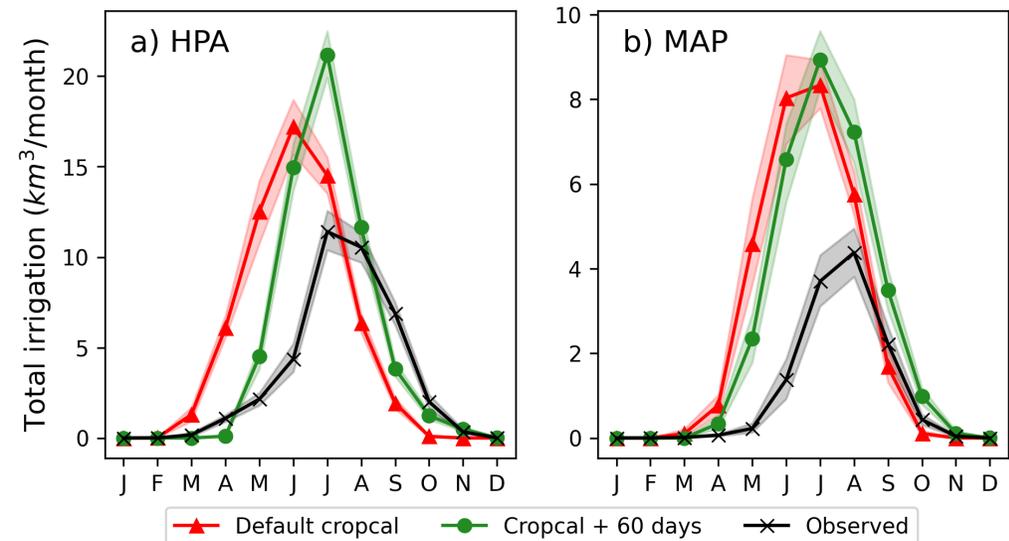


Irrigation in the Mississippi-5

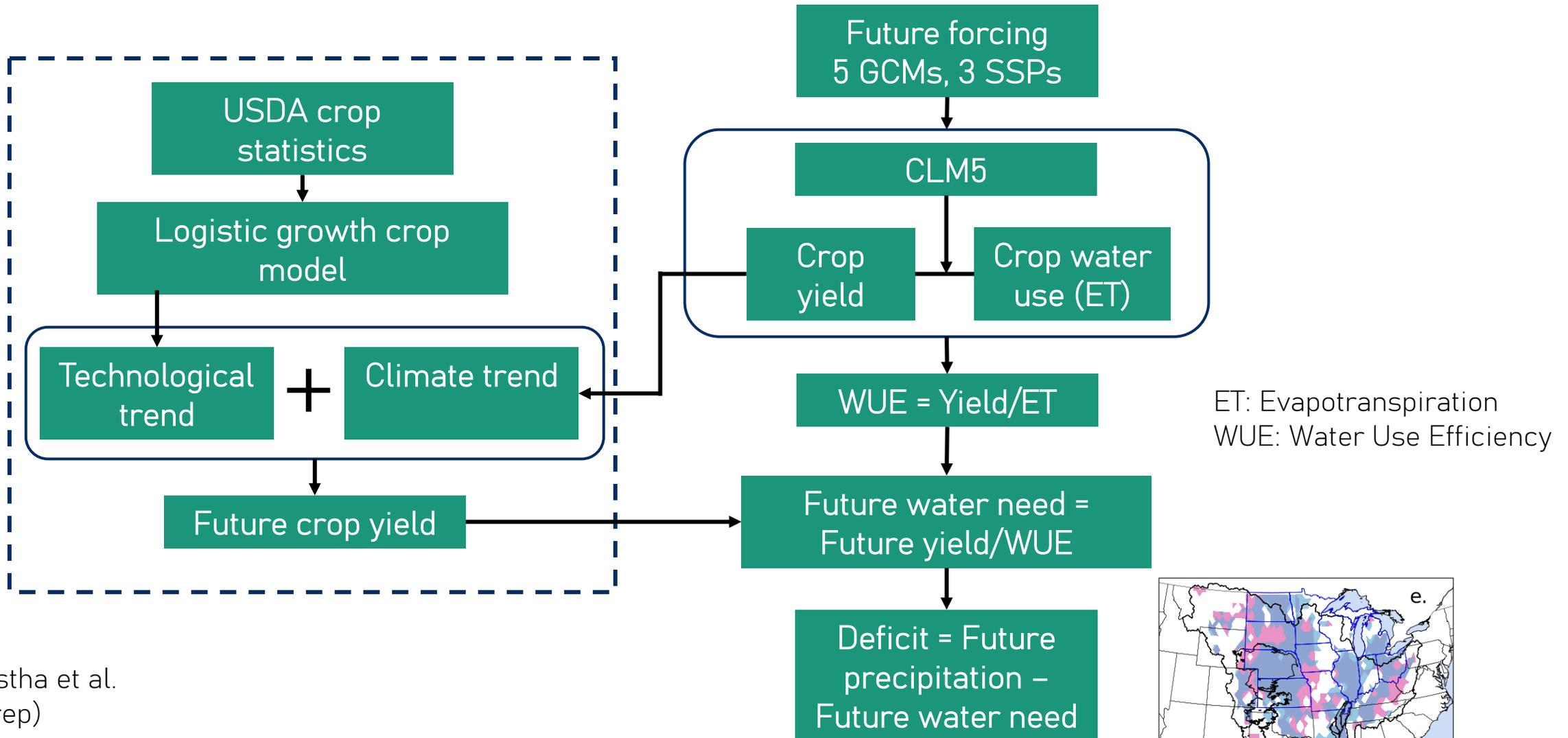
3. Crop planting date in CLM5 is the primary driver of irrigation timing.
 - Irrigation peak matches with peak total leaf area in the model.
 - Shifting crop planting windows shifts irrigation timing.
- However, farmers' decisions are difficult to accurately simulate.



Shrestha et al.
(WRR, in review)

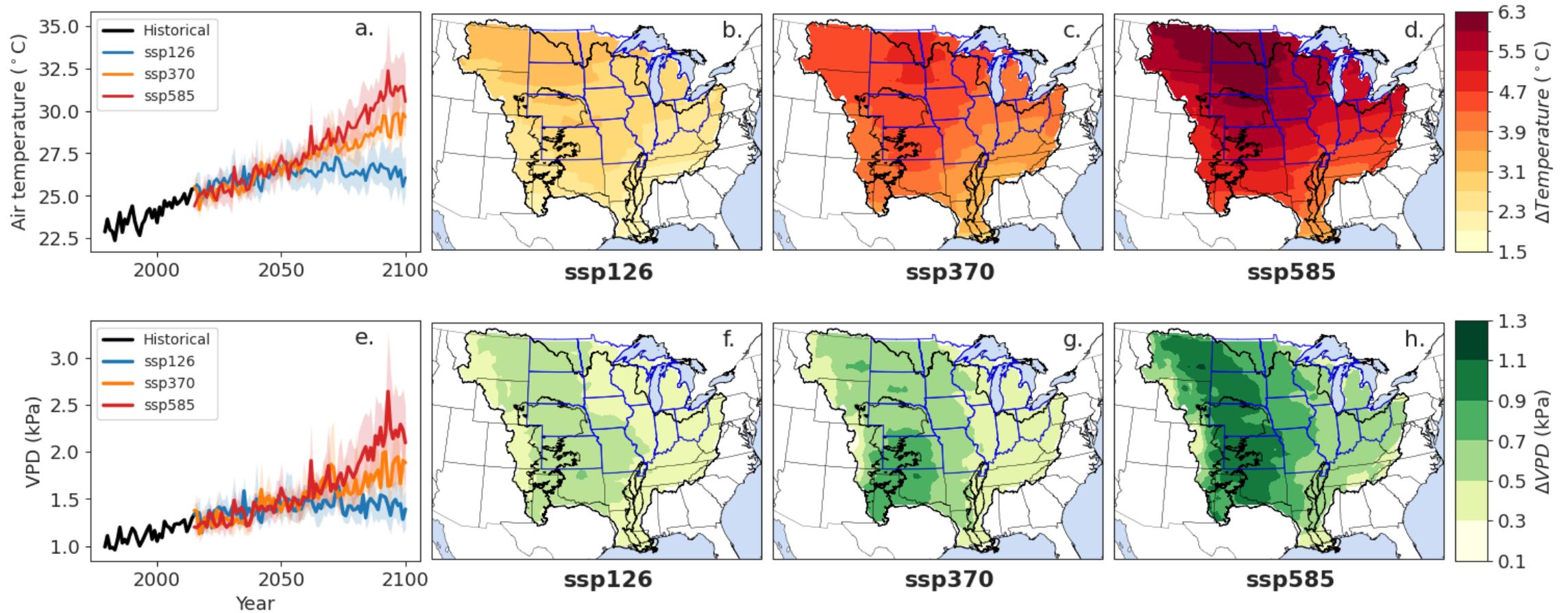


Assessing future water availability in rainfed crops



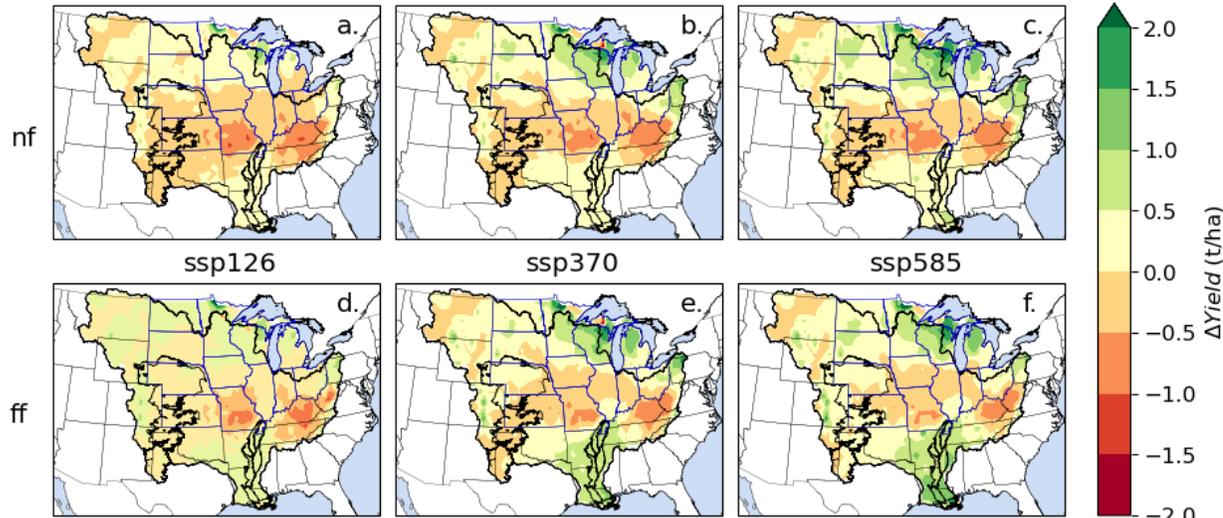
Shrestha et al.
(in prep)

Future climate in the Midwest

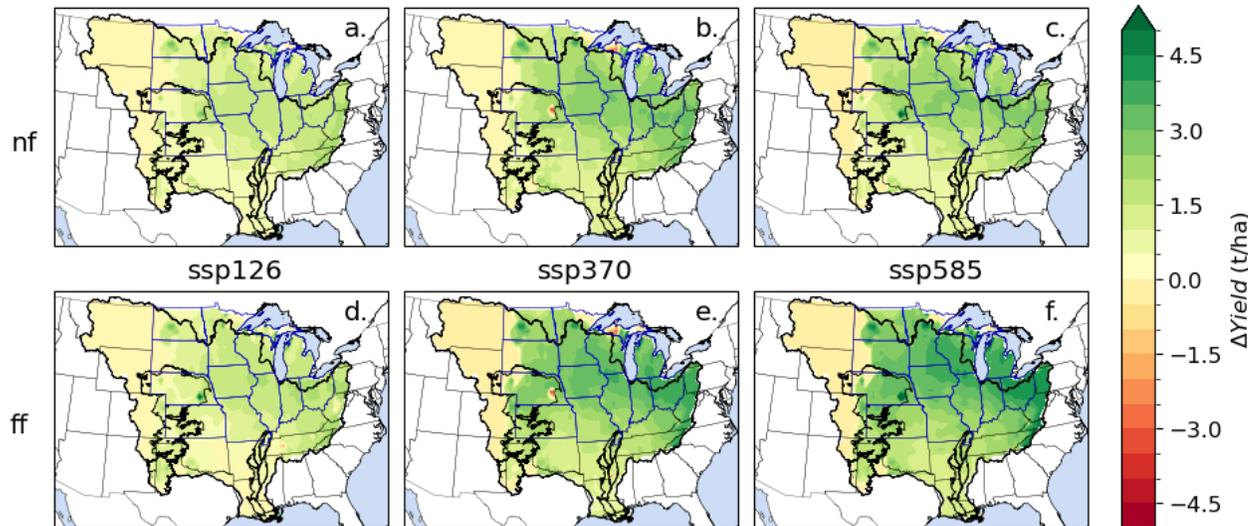


Changes in crop yield and WUE

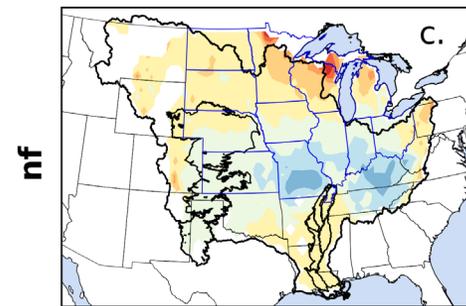
Rainfed corn



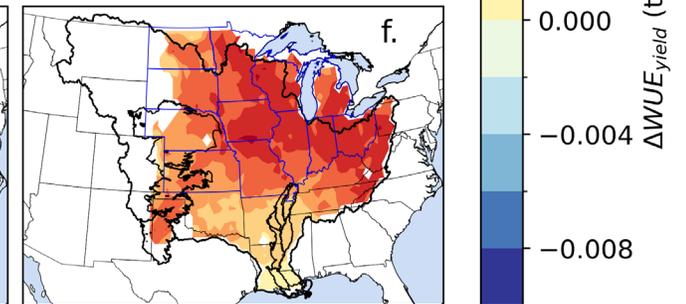
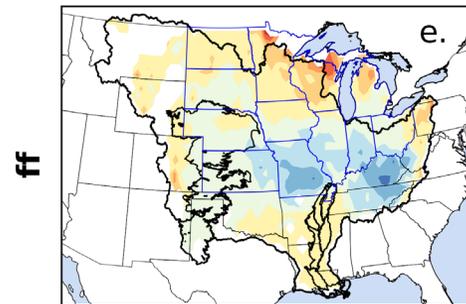
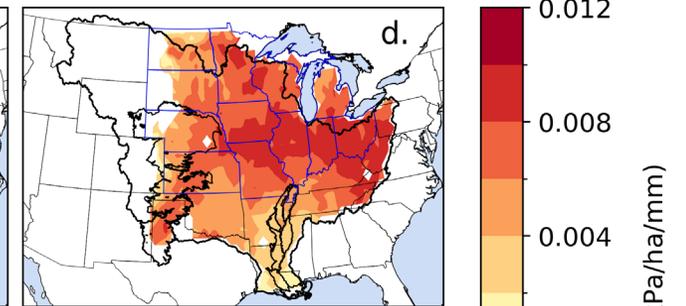
Rainfed soybean



Rainfed Corn

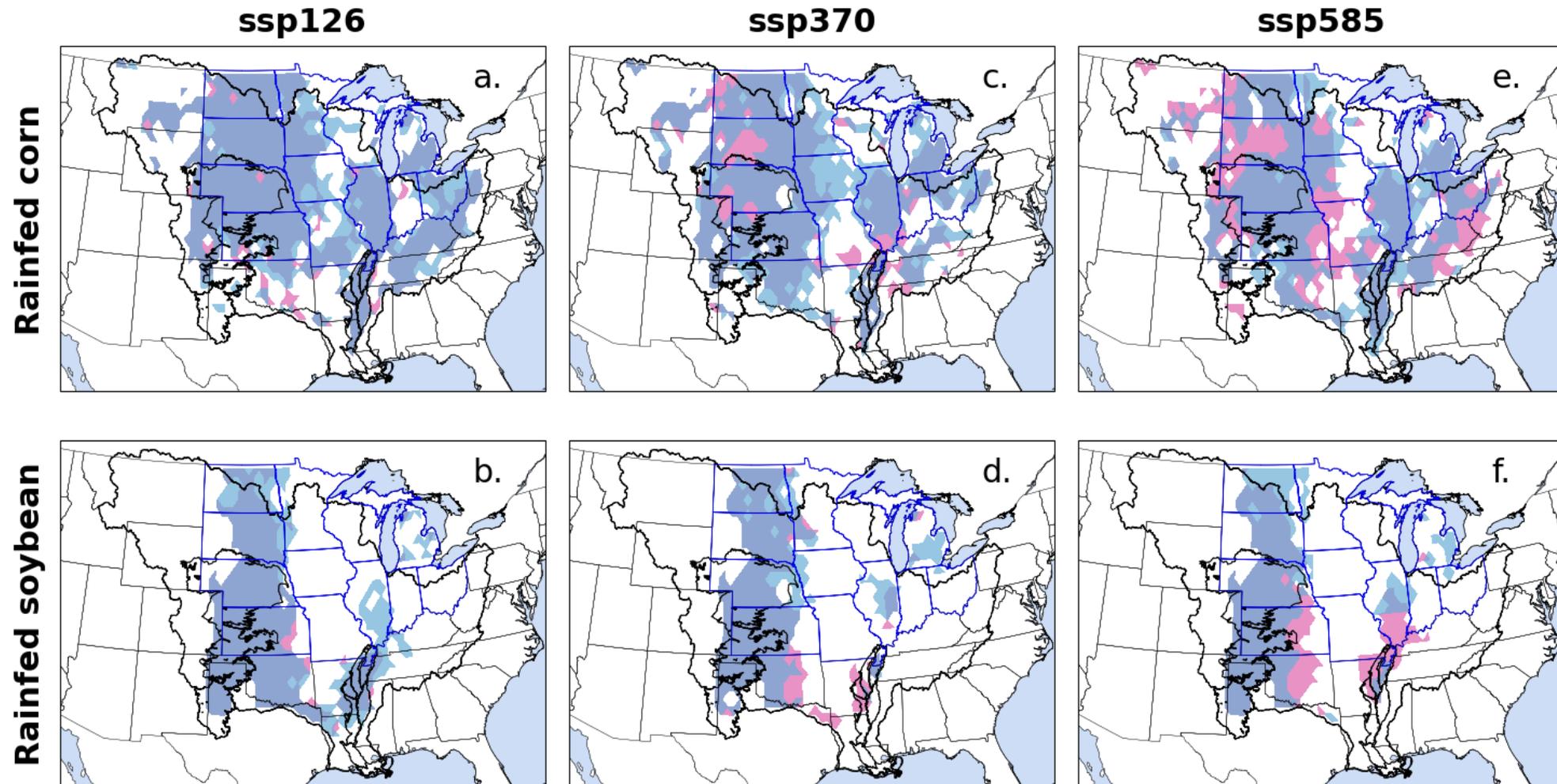


Rainfed Soybean



Shrestha et al.
(in prep)

Areas of frequent water deficits



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(in prep)

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THANK YOU!



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