



# Assessing the Sustainability of Groundwater Irrigation Using Earth System Models

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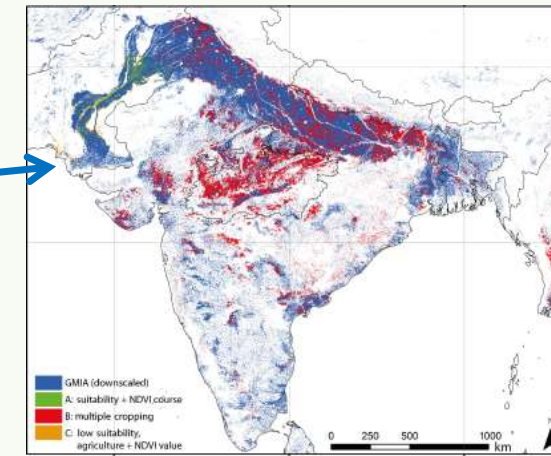
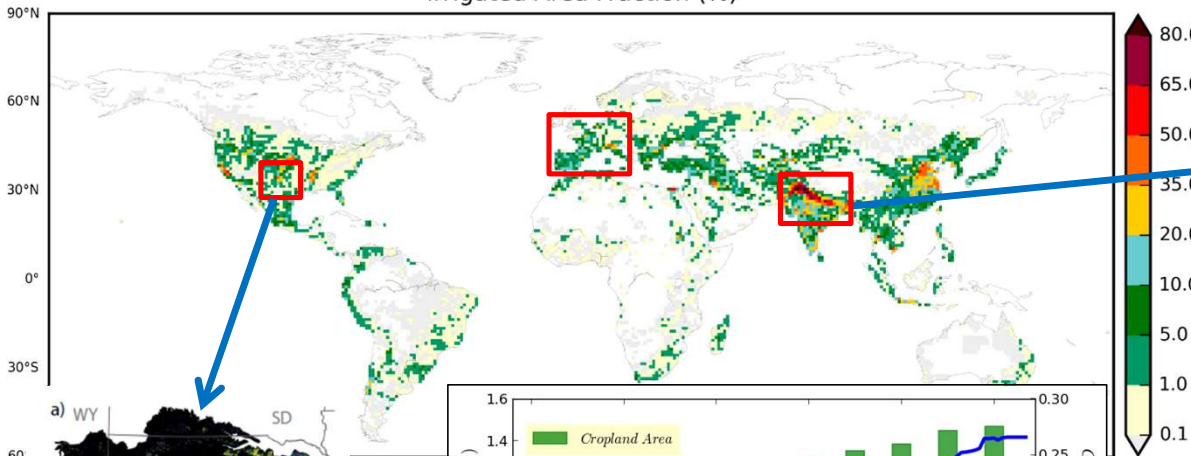
*Department of Civil & Environmental Engineering  
Michigan State University*

*International Conference – Groundwater, Key to the Sustainable Development Goals  
May 20, 2022 (Paris)*

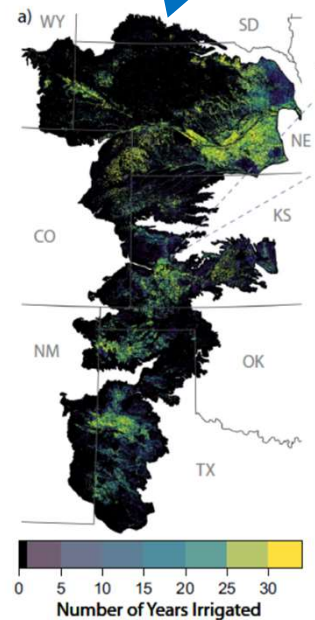
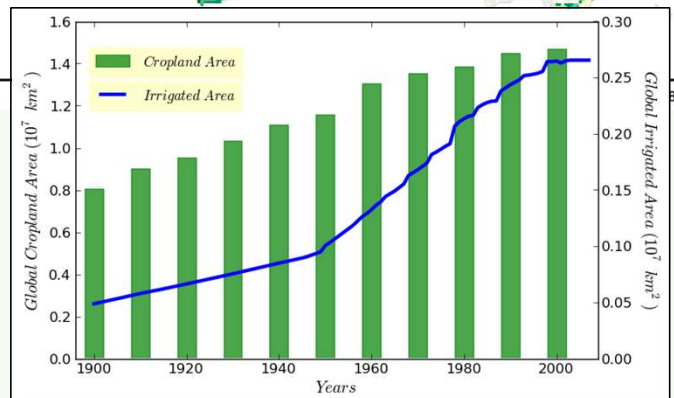
# Irrigation and Groundwater Extraction



Irrigated Area Fraction (%)

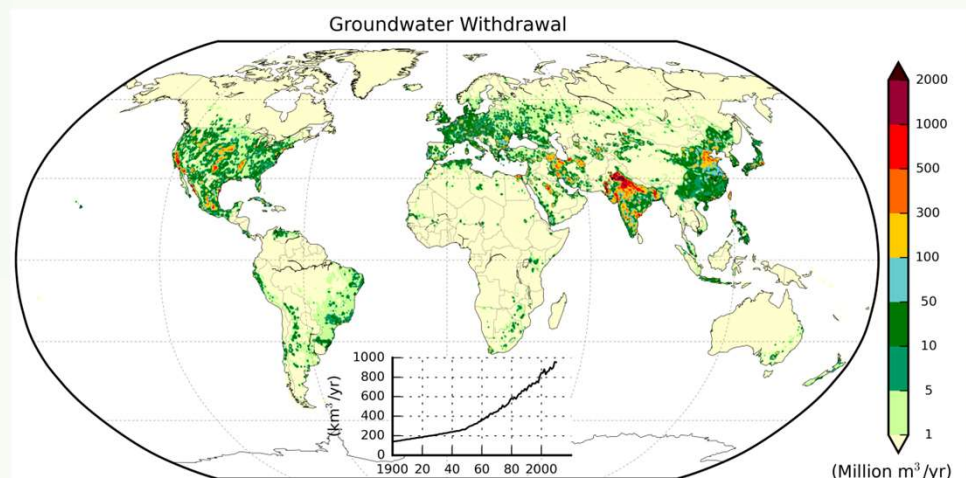


Meier et al. (2018)



High Plains Aquifer

Deines et al. (2019)



Pokhrel et al. (2016)

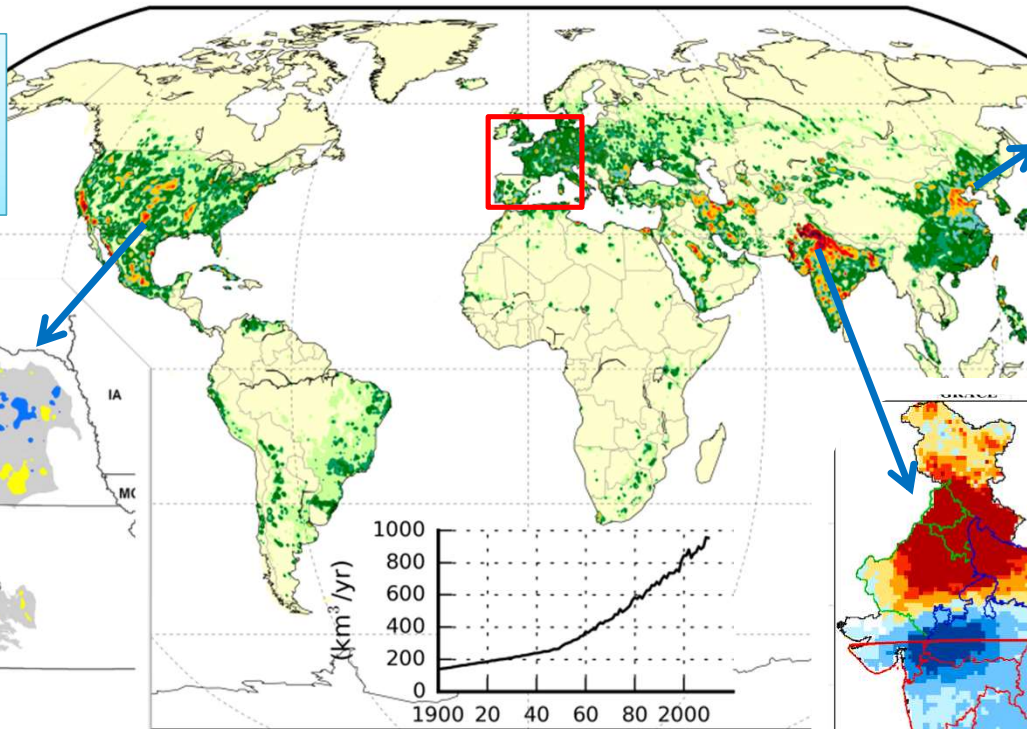
# Groundwater Overuse – Aquifer Depletion



95% of groundwater used for irrigation;  
**fundamentally unsustainable!**

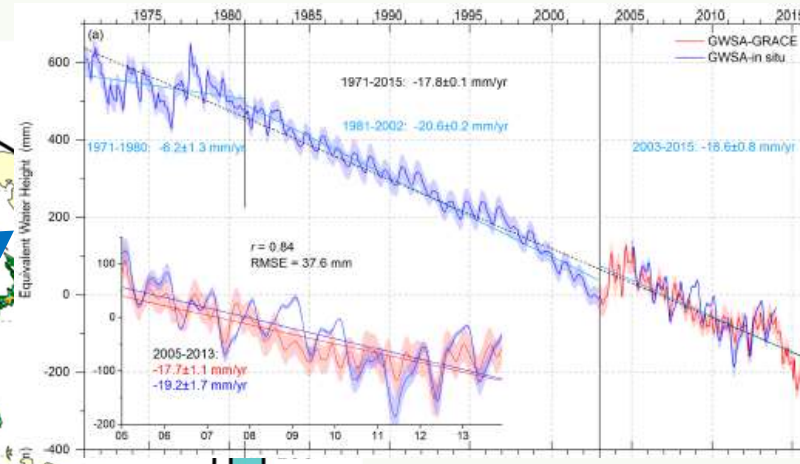
High Plains Aquifer

## Groundwater Withdrawal

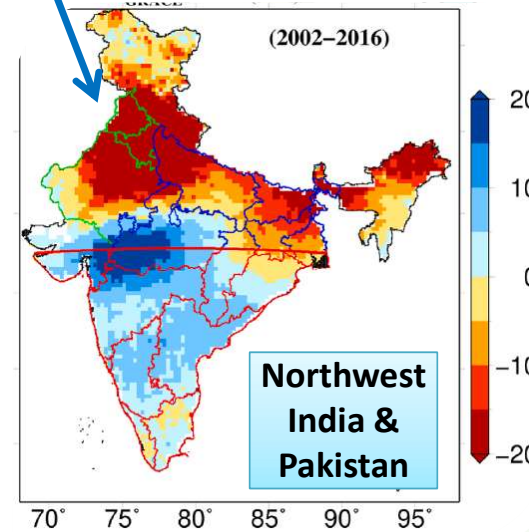


McGuire et al. (2014)

## North China Plain



Gong et al. (2018)

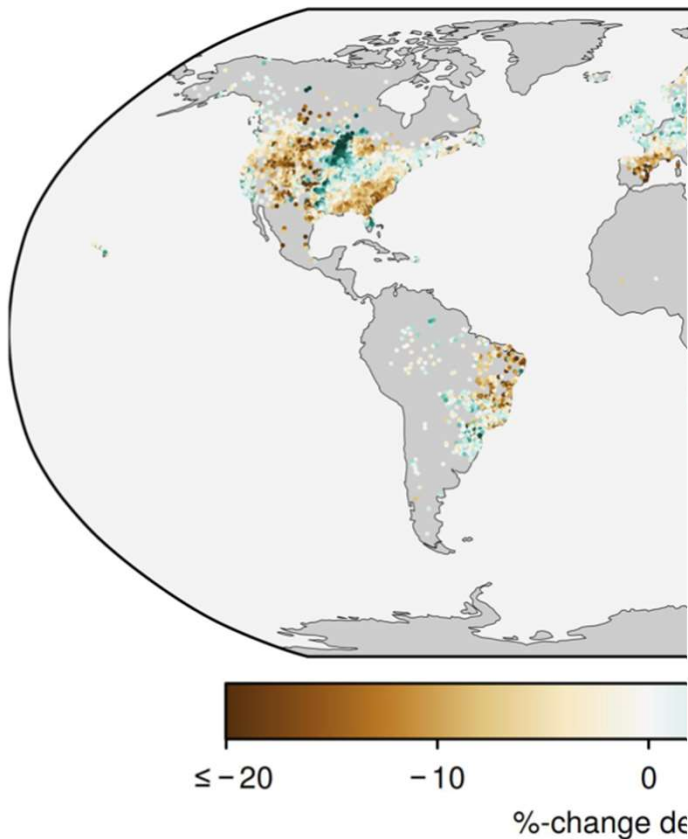


Dangar et al. (2021)

# Climate Change and Water Availability

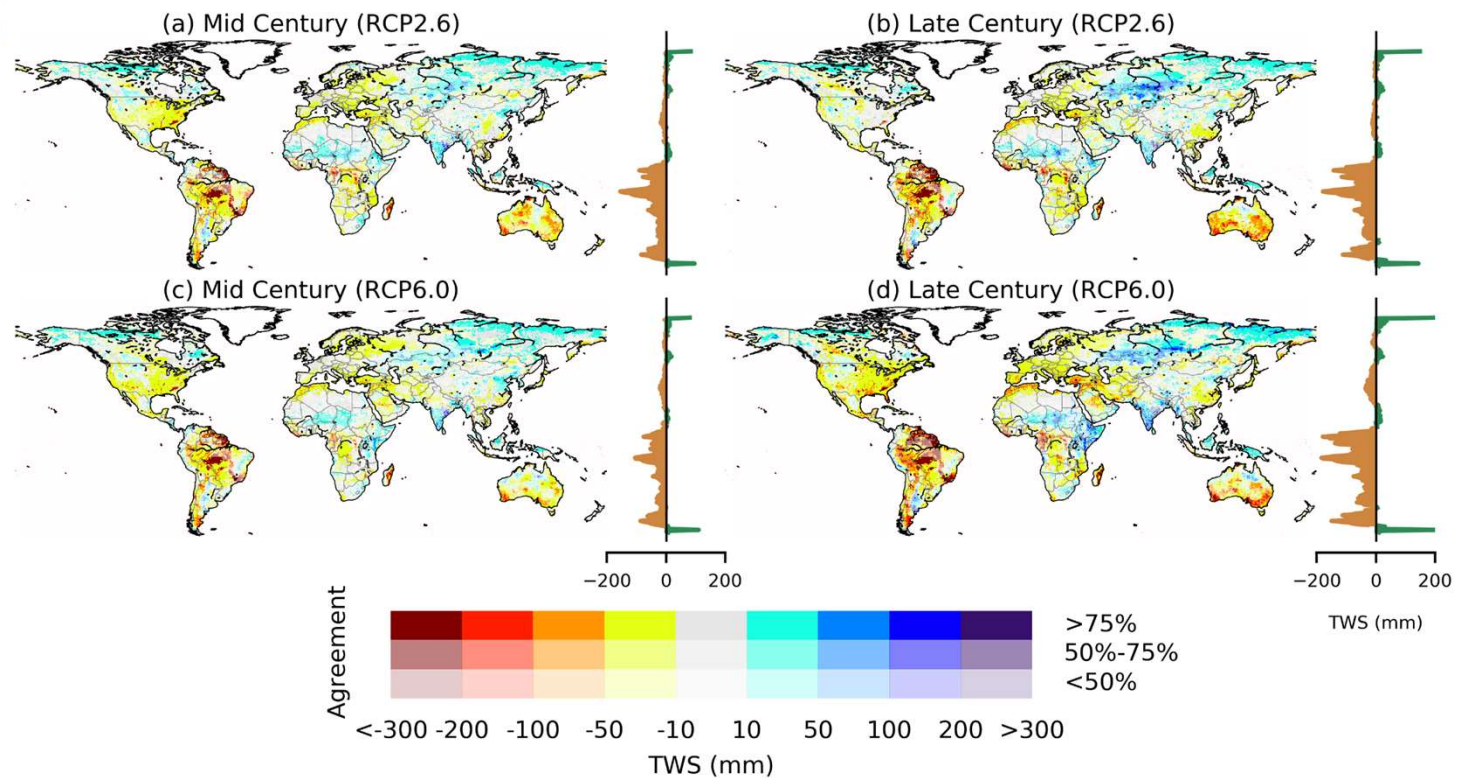


## Observed change in river flow



IPCC AR6, WGII (Ch. 4)

## Future land water availability



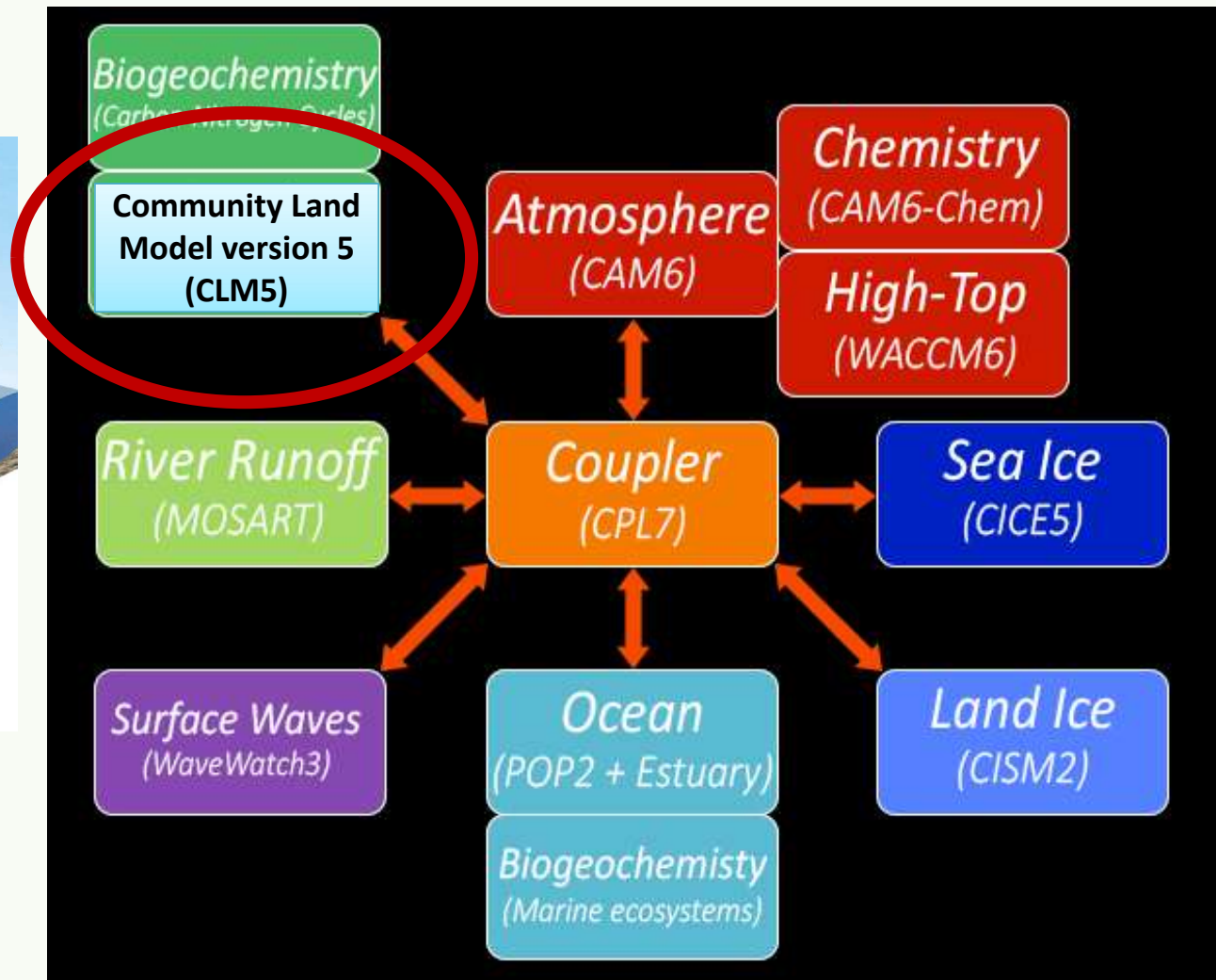
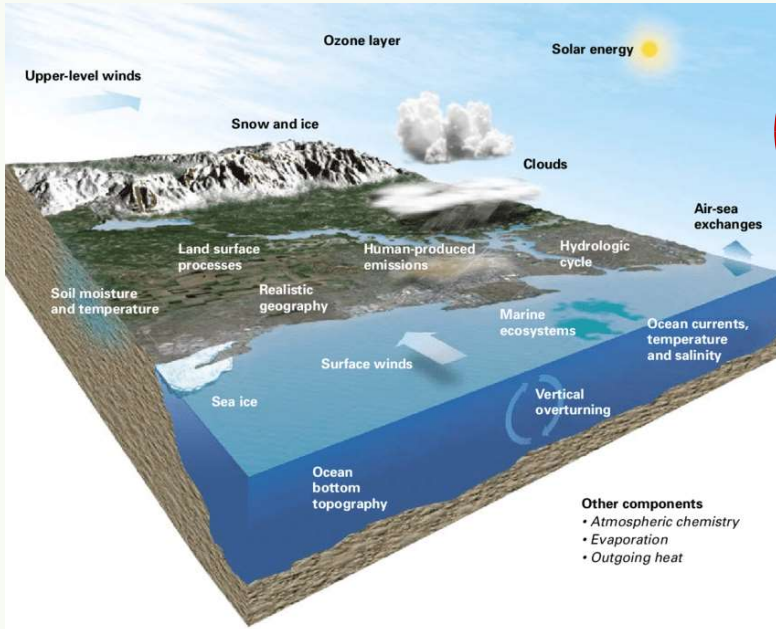
Pokhrel et al. (2021, Nature Climate Change)

# Irrigation & Groundwater in ESMs: Research Gaps

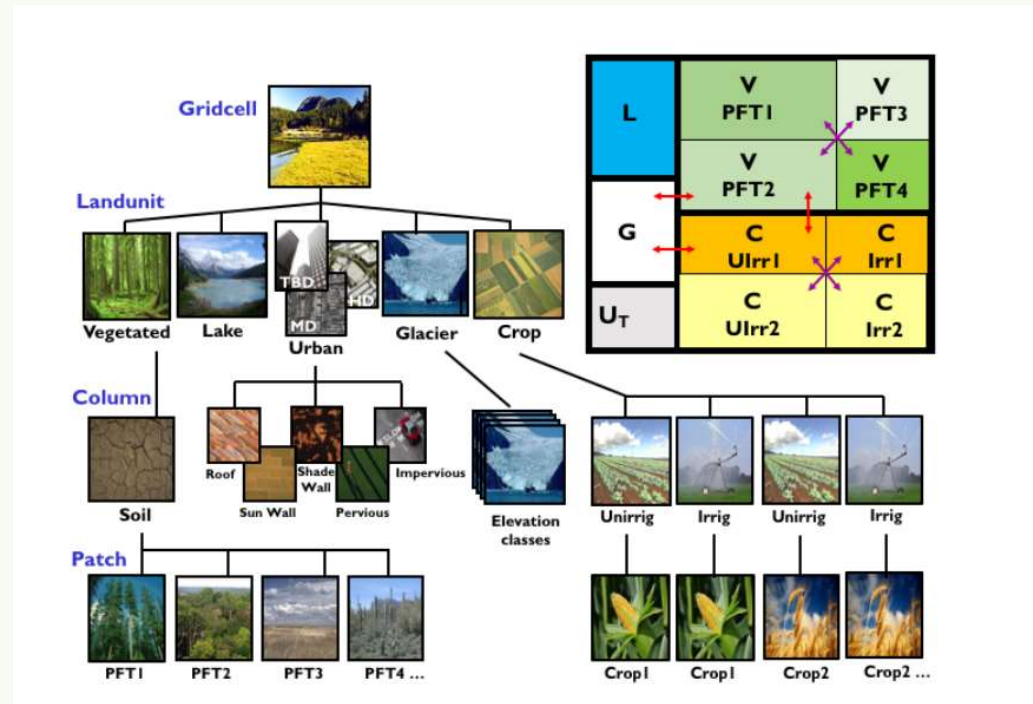
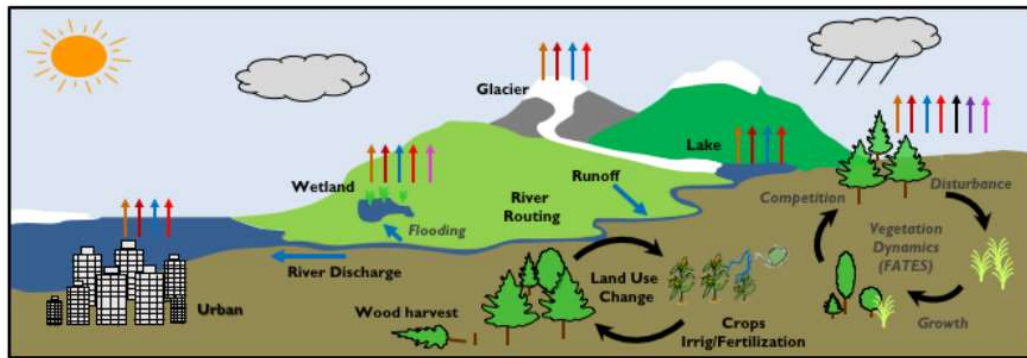
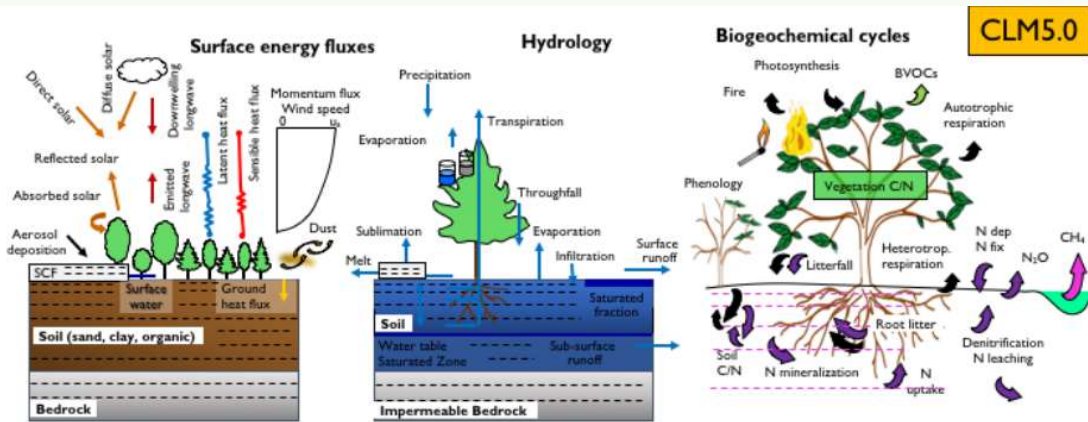


- Groundwater use for irrigation is **unsustainable** in many regions & its overexploitation is affecting **water, food, and climate systems**
- Climate change and increased water demands will likely compound these effects
- **Research Gaps and Needs:**
  - How increased irrigation (currently ~70% of total water use) will affect groundwater and climate remains poorly understood
  - **Irrigation & groundwater** is poorly represented Earth System Models (ESMs) used for future projections (e.g., IPCC)

# The Community Earth System Model (CESM) @ NCAR, USA

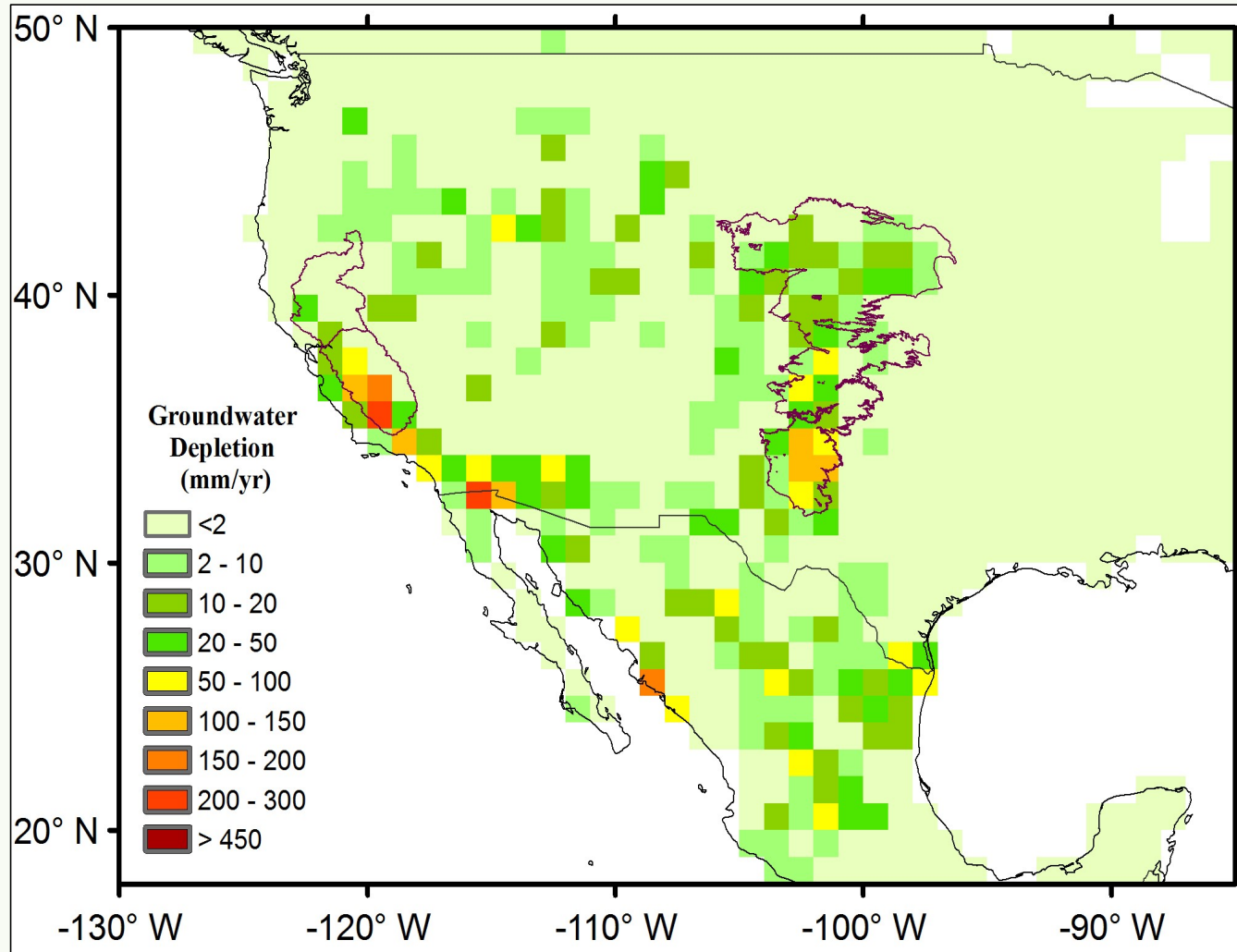


# The Community Land Model (CLM5)



**Simple irrigation mechanism & and lack of groundwater representation!**

# Groundwater in ESMs – Technical Challenges (>100 km grids)

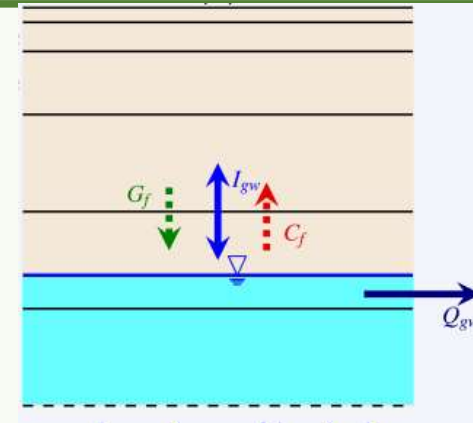


*Pokhrel et al. (2015)*

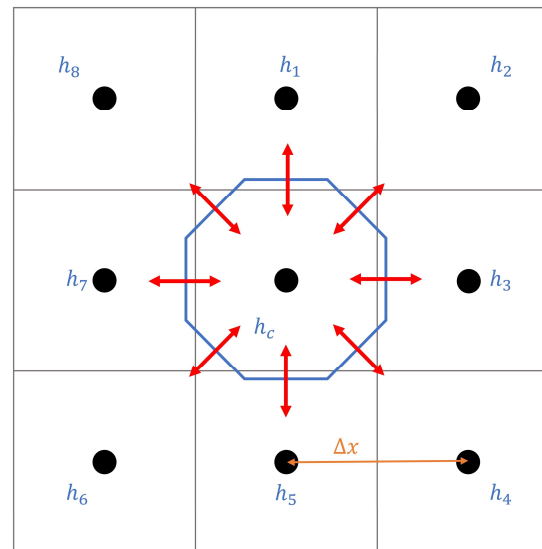


# Groundwater in CLM5 – Coupling with Irrigation

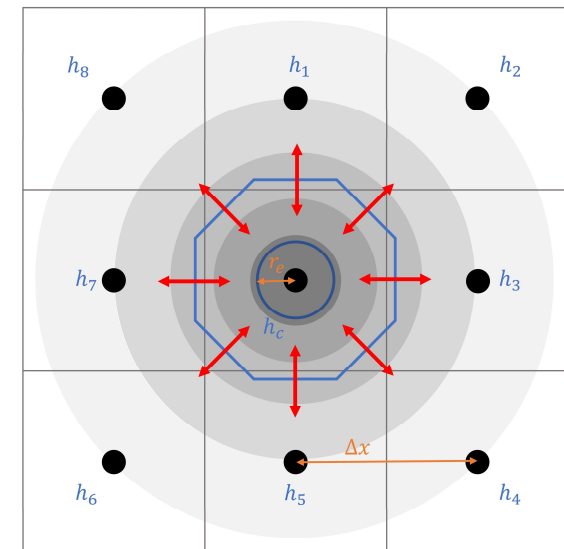
- Water table dynamics
- Later groundwater flow
- Conjunctive water use
  
- Global model – regional scale
- 5km grid size
- Coupled irrigation & groundwater



(a) Without Pumping

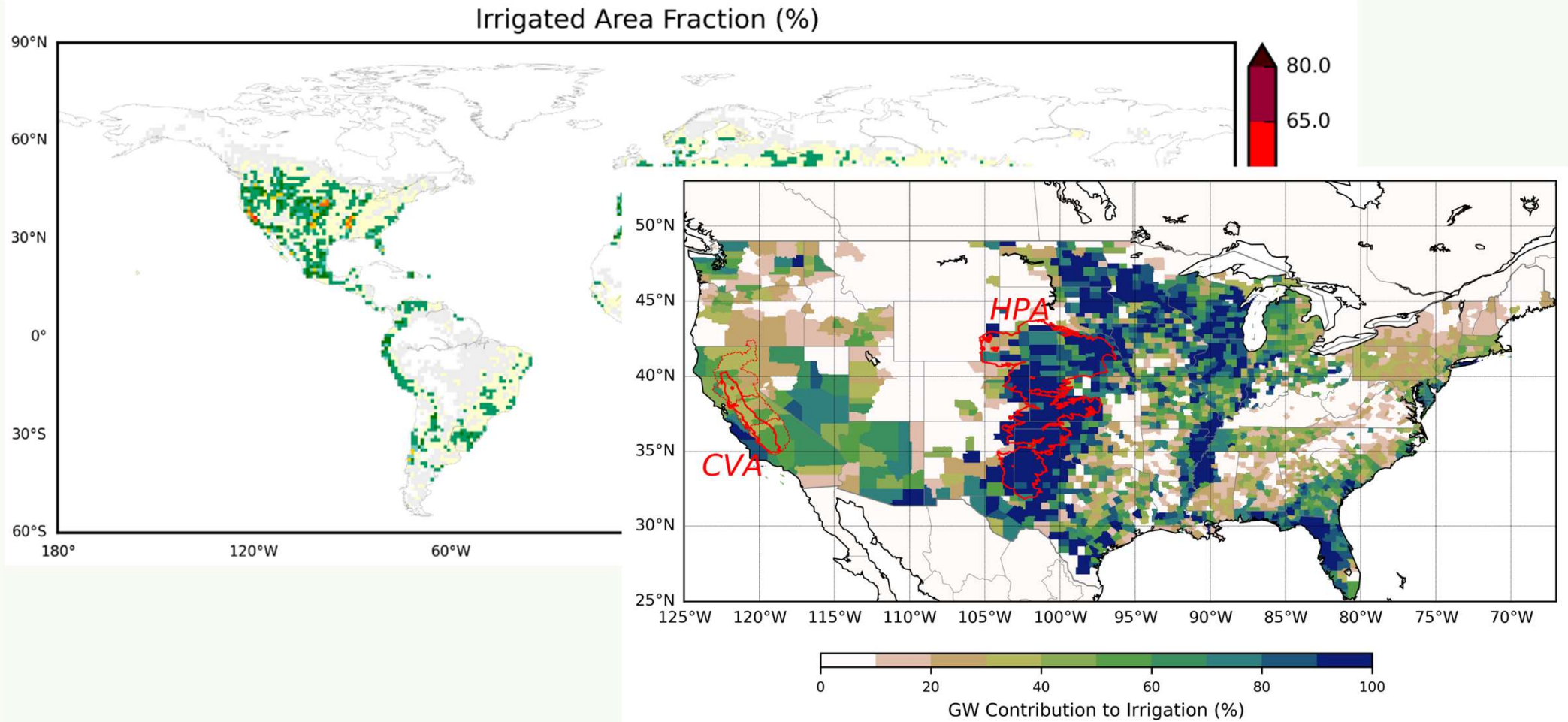


(b) With Pumping



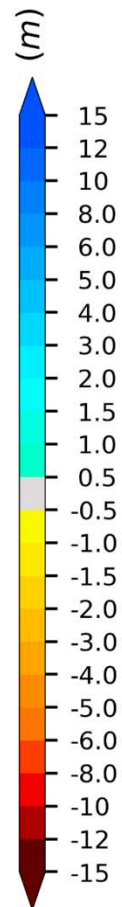
*Felfelani, Pokhrel et al. (2021, WRR)*

# Irrigation and Groundwater Pumping: US High Plains

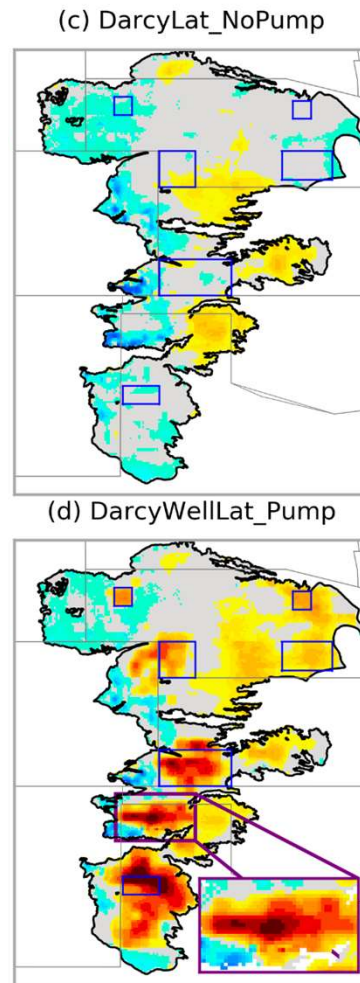


*Felfelani, Pokhrel et al. (2021, WRR)*

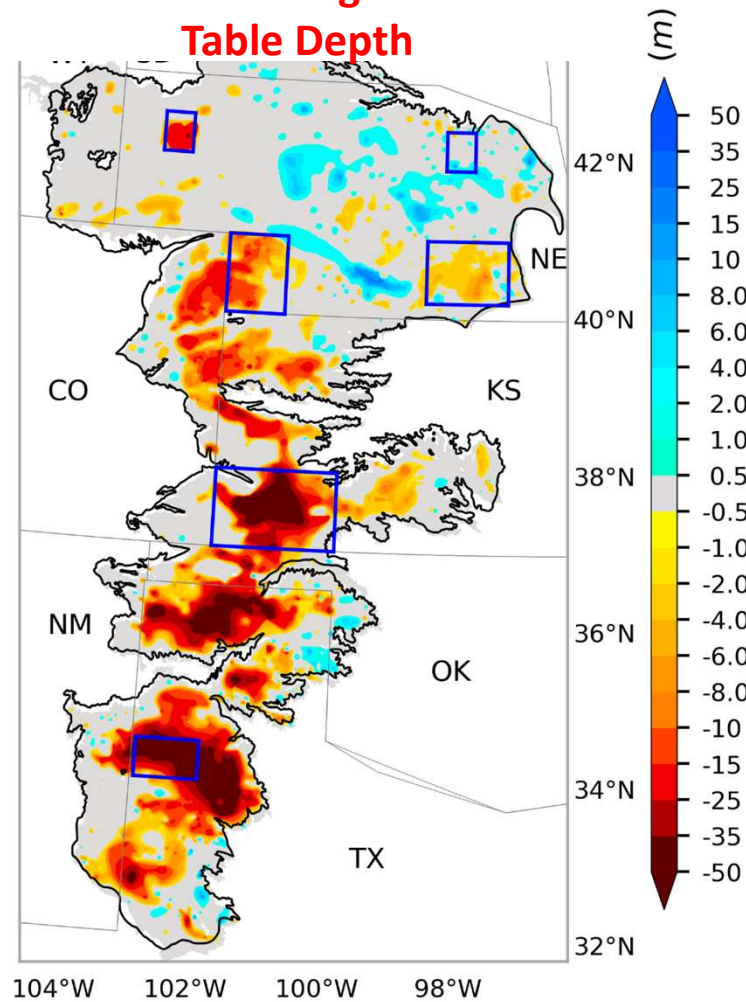
# Irrigation and Groundwater Depletion – High Plains Aquifer



Simulated  
change in  
water table  
depth

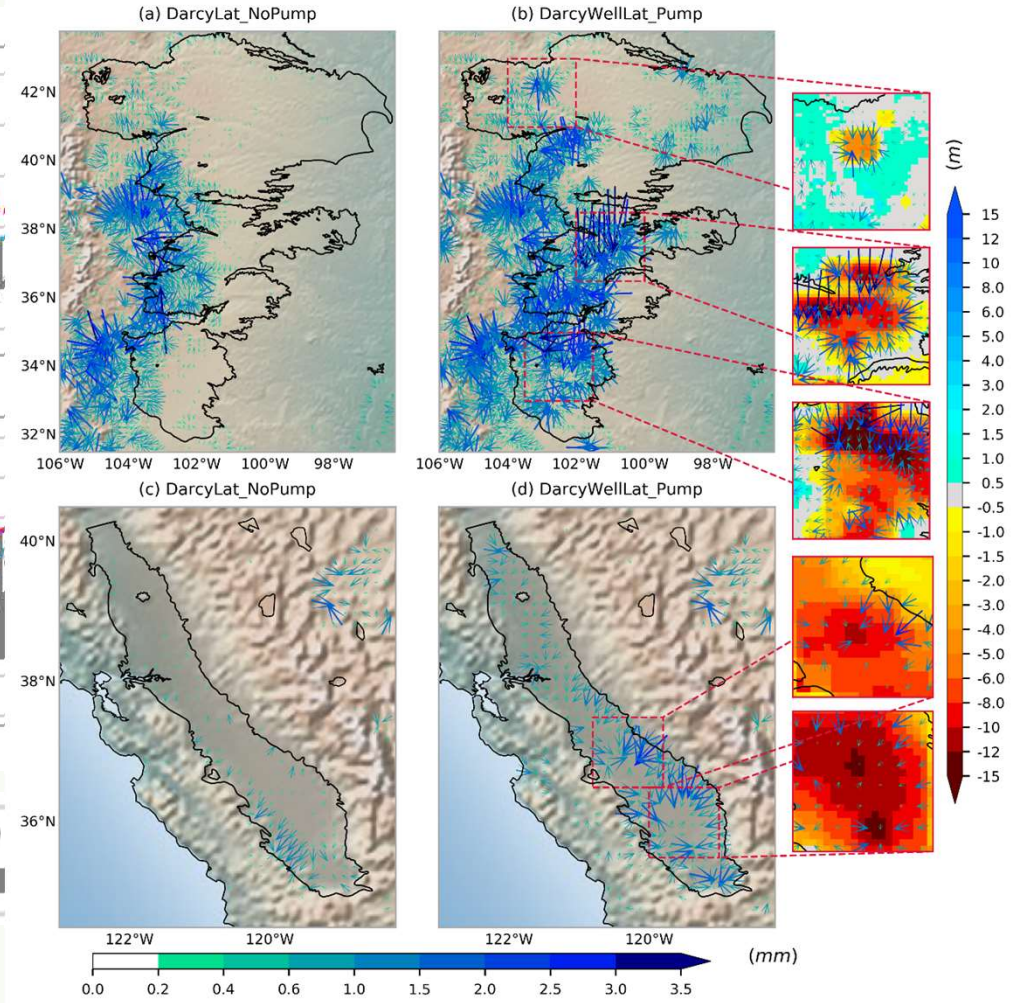
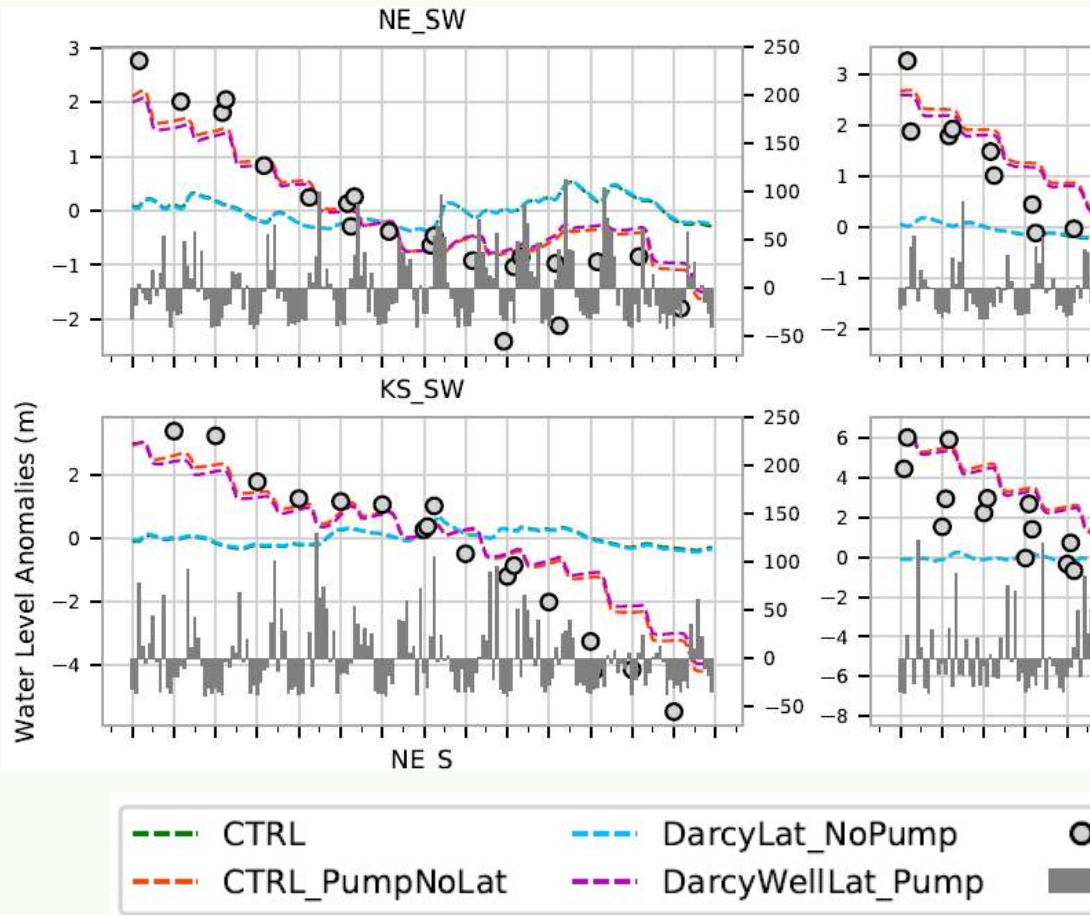


## Measured Change in Water Table Depth



*Felfelani et al., 2020 (WRR)*

# Irrigation and Groundwater Depletion – High Plains Aquifer



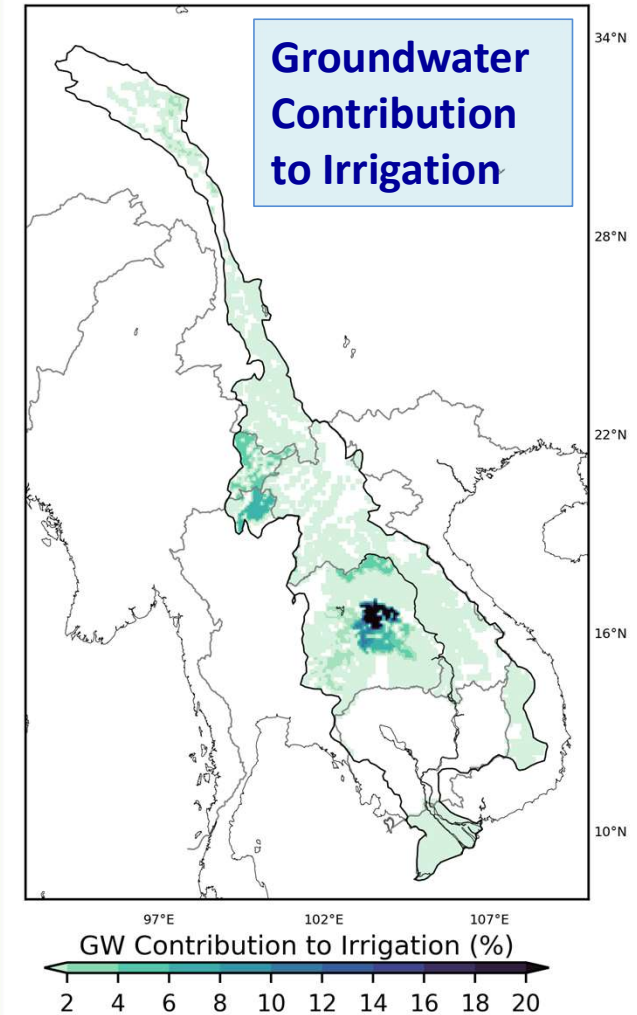
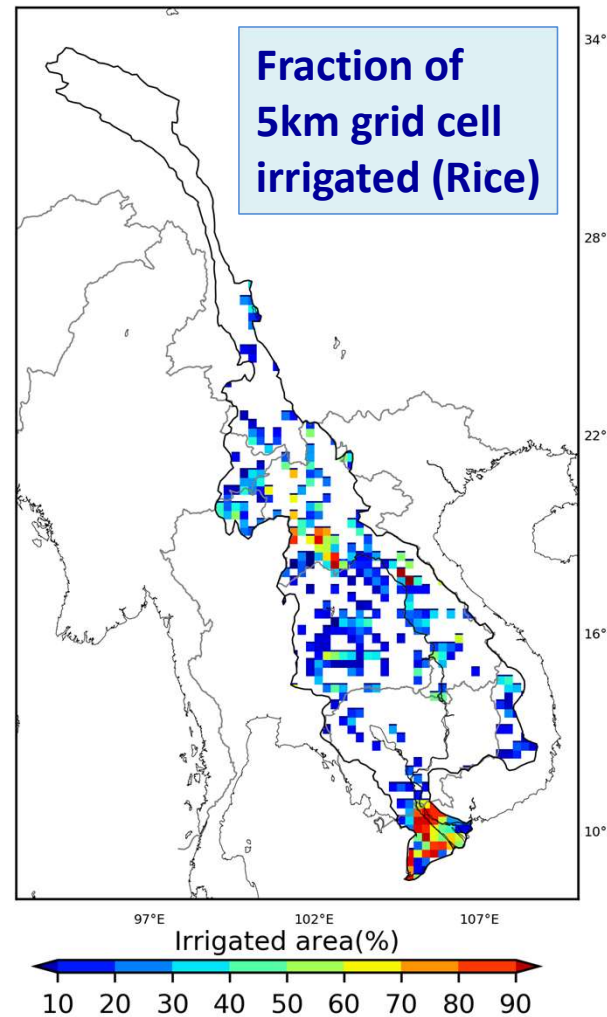
Felfelani, Pokhrel et al. (2021, WRR)

water.egr.msu.edu

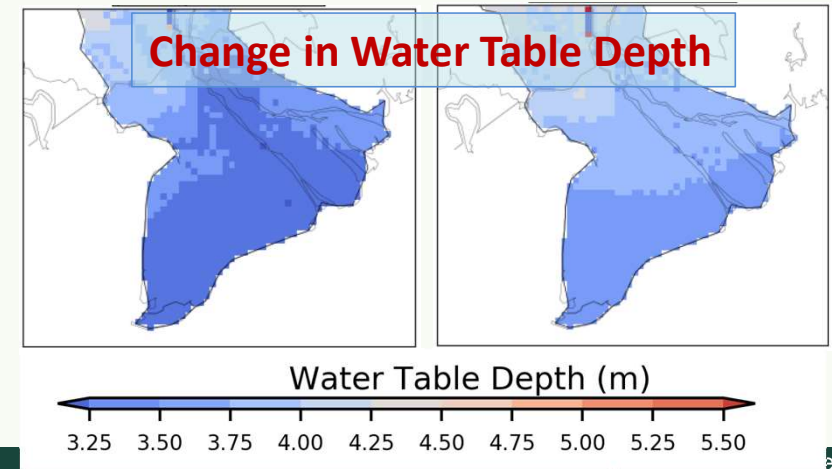
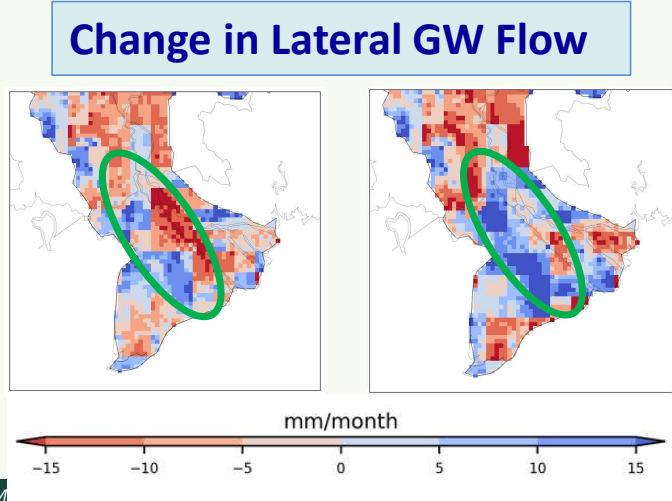
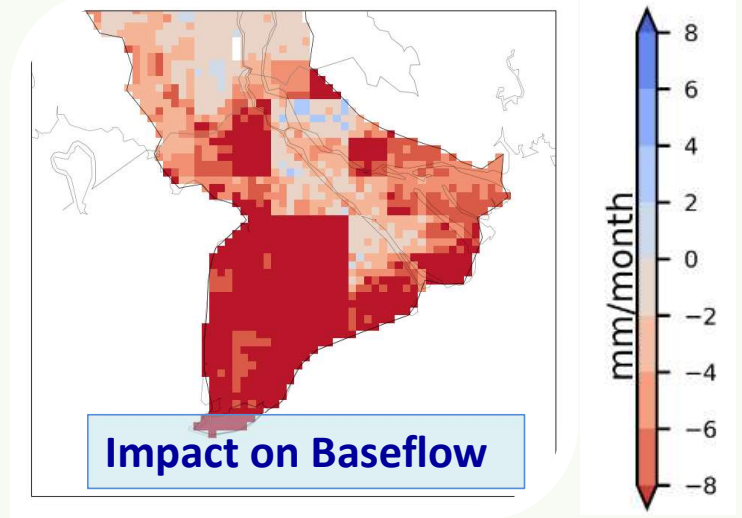
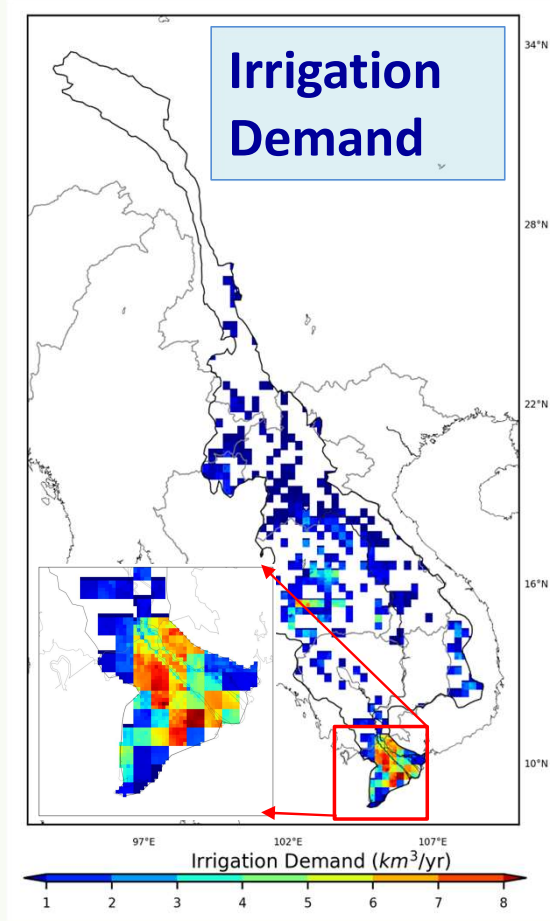
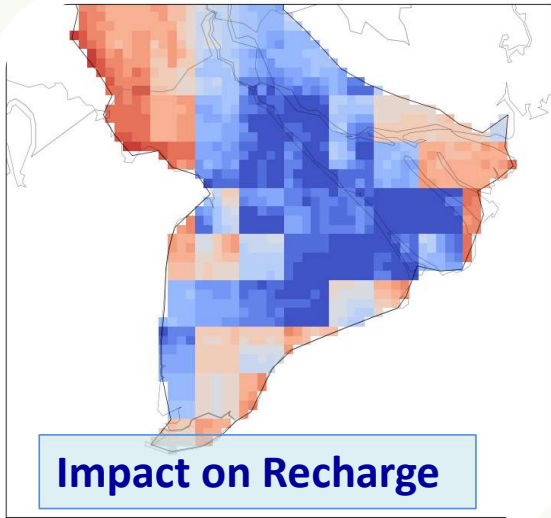
# Model Application – Mekong River Basin (Limited Data)



- ✓ Transboundary basin shared by six countries
- ✓ ~800,000 km<sup>2</sup> in area
- ✓ Expanding irrigation and groundwater use
- ✓ **Extremely limited information regarding groundwater availability and use**



# CLM5 Simulations – Irrigation Pumping and Groundwater (GW)



- Better representing groundwater (and irrigation) in ESMs is crucial to address **future groundwater sustainability** issues
- Many **opportunities & challenges** exist -- especially in data-limited regions
- Need for harnessing new **satellite data** and **improved ground monitoring**
- Need for concerted efforts to engage **social scientists, economists, and broader stakeholders!**



- Funded by the National Science Foundation
  - **CAREER** Award
  - **BLUEGEM** – Belmont Forum Project

**Thank you!**





# Global Irrigated Areas



- Change in irrigated areas (million hectares)

