



# Water Scarcity in the Serbian Danube: *Agricultural land use change and irrigation*

Jamshid Jalali and Sean Woznicki  
Annis Water Resources Institute  
Grand Valley State University

Co-Investigators: Tao Liu (MTU) and Molly Sears (MSU)  
Collaborators: Oskar Marko (BioSense Institute) and Nishan Bhattarai (OU)

*Joint SCERIN-MedRIN Workshop, 18 July 2024*



# Team members

---

## Co-Investigators

Tao Liu, MTU

Molly Sears, MSU

## Students

Jamshid Jalali, GVSU

Judy Long, MTU

Noormah Rizwan, MSU

Miljana Marković, BioSense

Mirjana Radulović, BioSense

Branislav Živaljević, BioSense

## Collaborators

Oskar Marko, BioSense

Gordan Mimic, BioSense

Nishan Bhattarai, OU



Grant #80NSSC22K0467



# Europe's Rivers, Starved by Drought, Reveal Shipwrecks, Relics and Bombs

August 23, 2022

The Danube River is running so low on water that the wreckage of German warships, sunk in 1944, has resurfaced, posing a danger to local ship traffic.

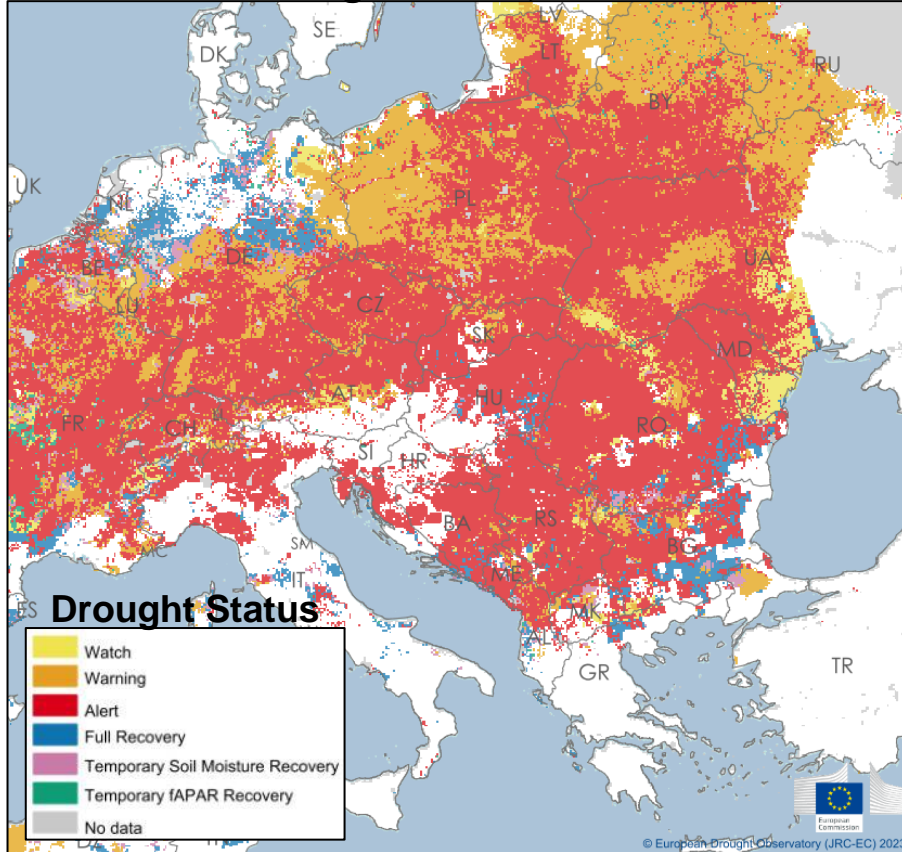
The Danube's dry riverbed (Banoštor, Serbia)

Wreckage of a World War II German warship in the Danube (Prahovo, Serbia)

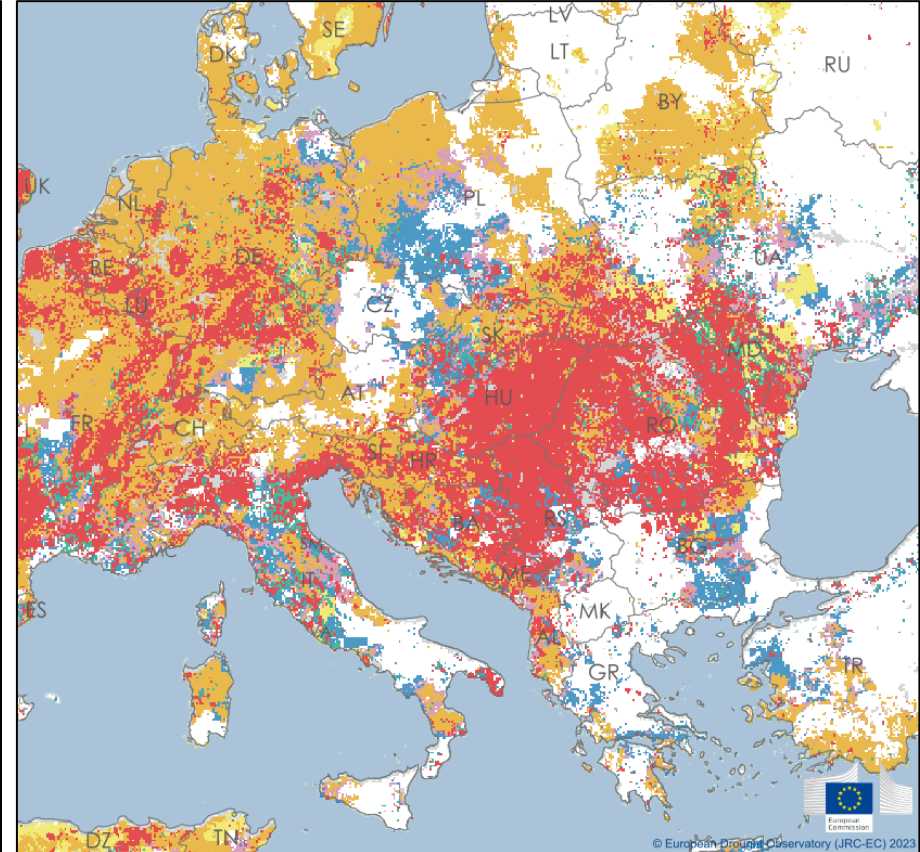


# Recurring droughts in the Danube River Basin

August 10-20, 2015



August 10-20, 2022

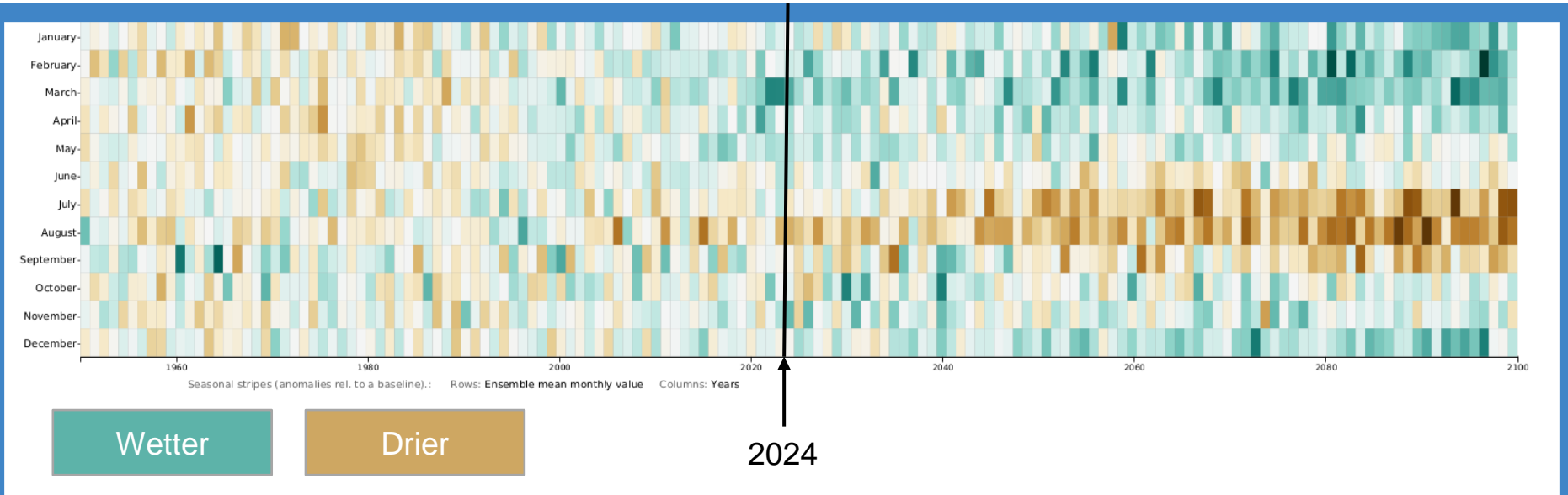


# A warmer and drier Danube (in the growing season)

Summer precipitation declines of ~15% (2041-2060) compared to 1981-2010 baseline

Equivalent to a loss of ~20-30 mm of rain

Increase in consecutive dry days

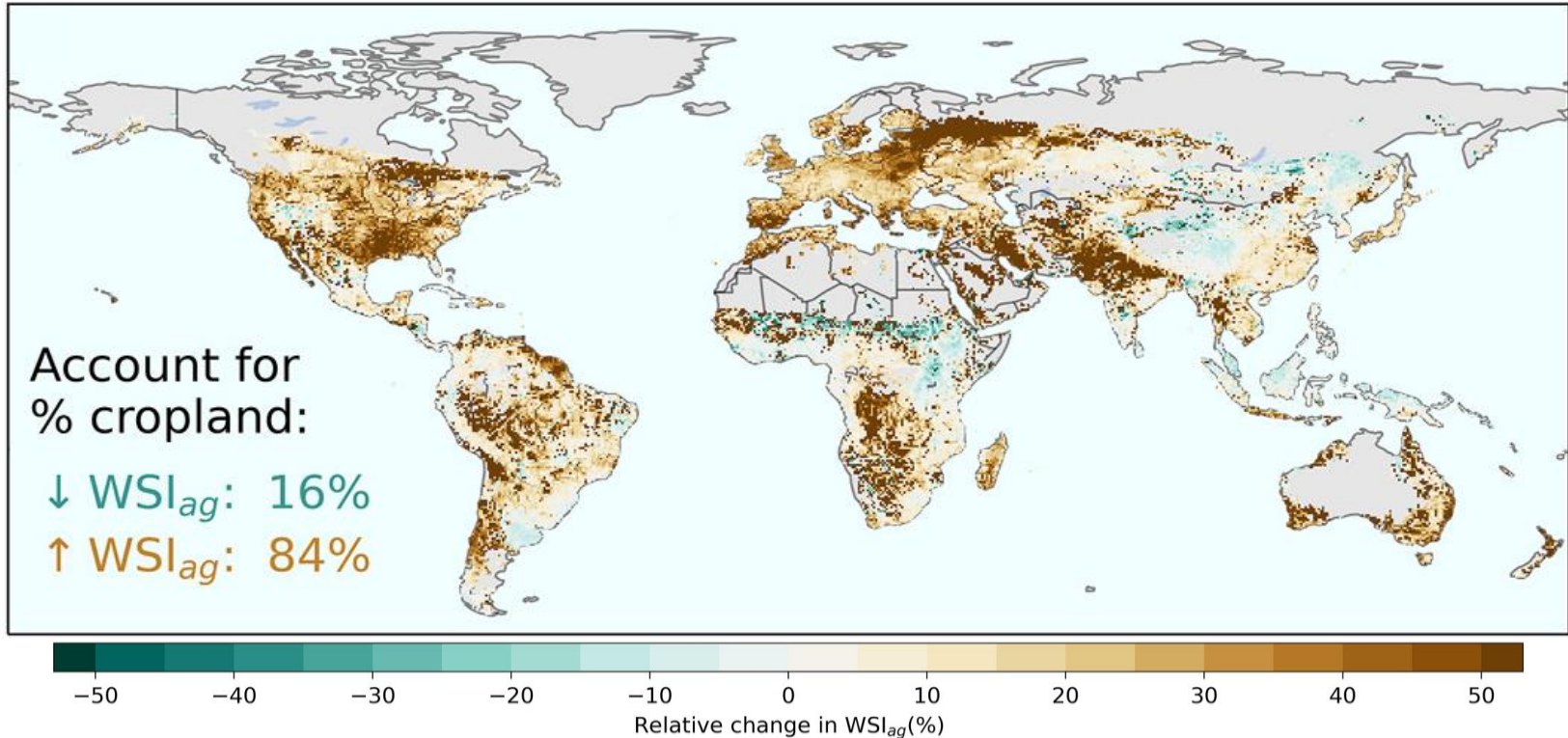


Total precipitation (PR) - Change (%)  
SSP2-4.5 (rel. to 1981-2010)  
CMIP6 - May to August (32 models)-Danube

# Global water scarcity in major agricultural regions

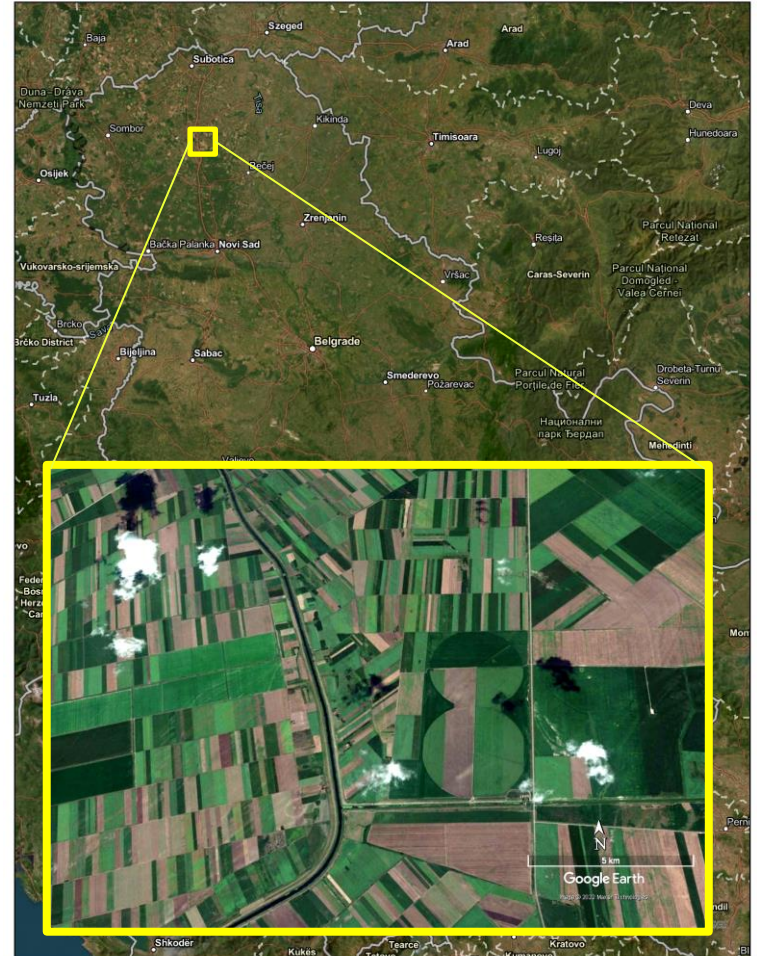
*Intensifying water scarcity will affect 80% of global cropland by 2050*

*Evapotranspiration demand outpaces green water (soil moisture) and blue water (surface and groundwater)*



# Agricultural sector in Serbia

- 6% of GDP, employs 15% of population
- 3.5 million ha of land in production, mostly in north and central regions
  - 70-120k ha are irrigated
- 560,000 farms (most < 10 ha)
- Crops planted in complex rotations (3-4 in sequence)
  - maize, wheat, soybean, sunflower, sugar beet, rapeseed



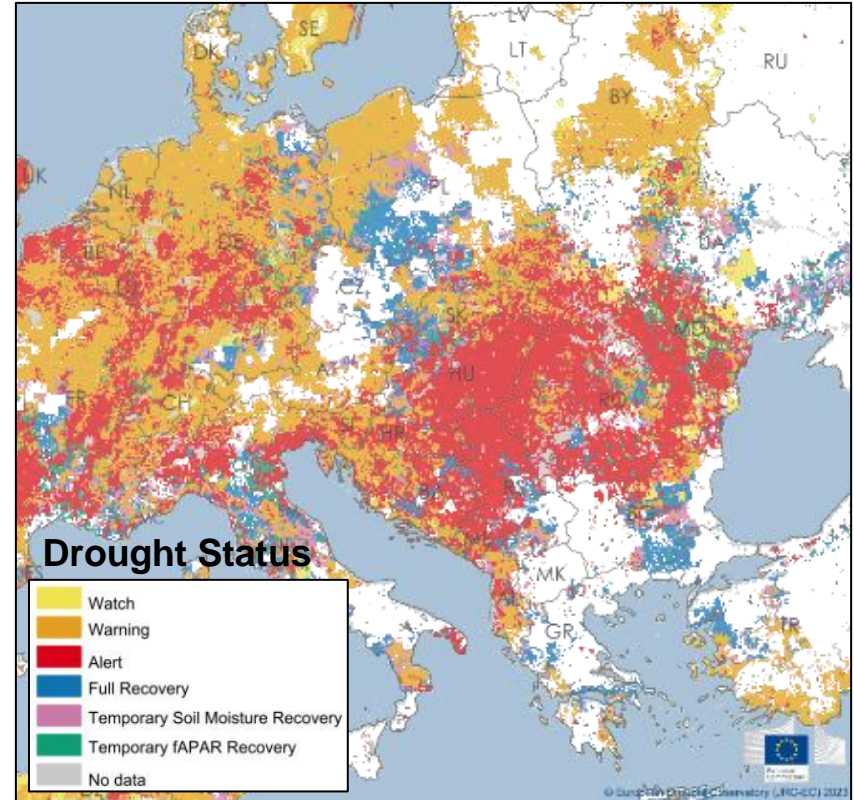
# Serbian agriculture and impact of droughts

2022 Production<sup>1</sup> = €1bn decline<sup>2</sup>

- Maize ↓ 25%
- Soybean ↓ 26%
- Sugar beet ↓ 21%
- Wheat ↑ 10% (wet spring)
- Sunflower ↑ 6% (drought tolerant; increased planting)

*70-120k ha actively irrigated  
(3% of total land in production)*

August 10-20, 2022



# Land and water management choices in a warmer and drier world

## The producer

- What to plant? (Markets, yield, weather)
- When should I plant?
- Should I adopt irrigation?

## The landscape

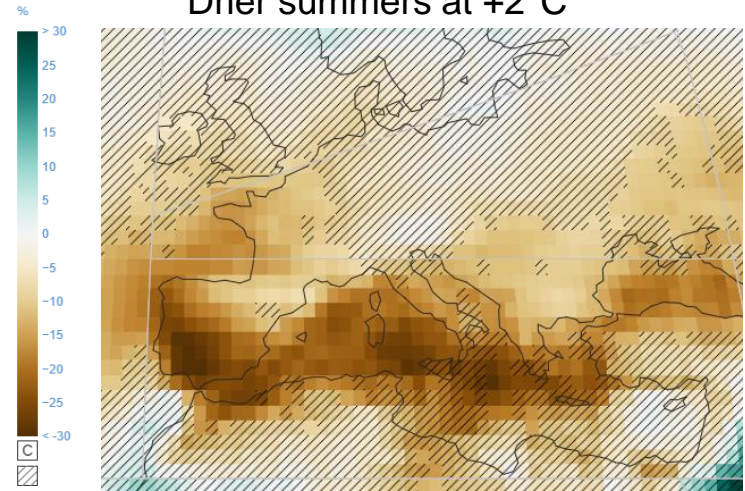
- How do these choices change the landscape?
- How do these choices affect water availability?
- Will this change in a warmer world?



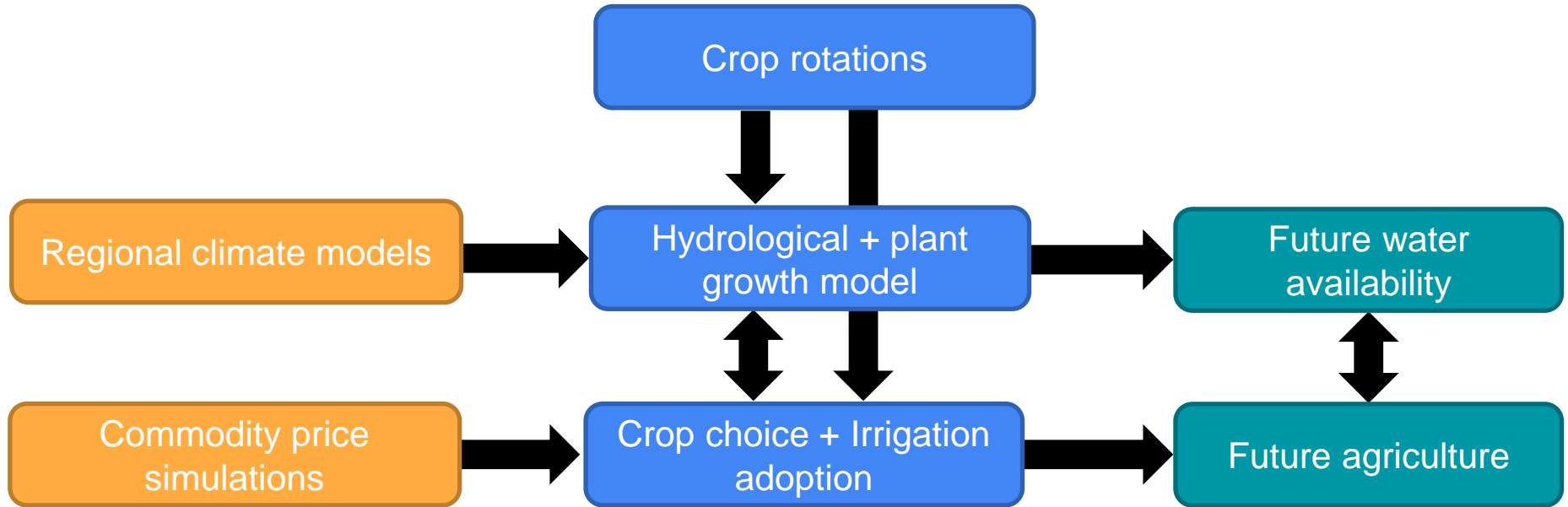
# Research Questions

1. How do crop rotations change over time?
  - Existing annual Sentinel-2 derived crop maps (2016-2023)
  - Landsat collection classification for pre-2016
2. How is water availability and use changing?
  - 1991-2020 → 2041-2070 (RCP4.5 and 8.5)
  - Blue water (surface and groundwater)
  - Green water (soil moisture)
3. What influences farmer decisions?
  - Market prices
  - Weather
  - Irrigation adoption?
4. How will climate change and water availability influence crop rotation and irrigation adoption?

Drier summers at +2°C



# How does a warmer and drier Serbia affect water availability ↔ cropping systems ↔ irrigation adoption?



# Q1: How do crop rotations change over time?

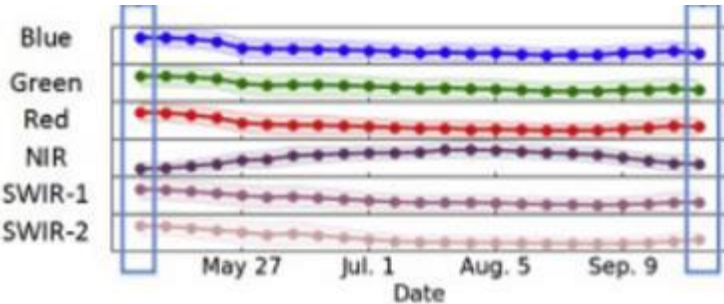
*Objective: Create annual crop maps from 1992-present*

Key crops

- Maize
- Wheat\barley
- Soybean
- Sugar beet
- Sunflower
- Oilseed
- Other crop

Landsat Collection 2

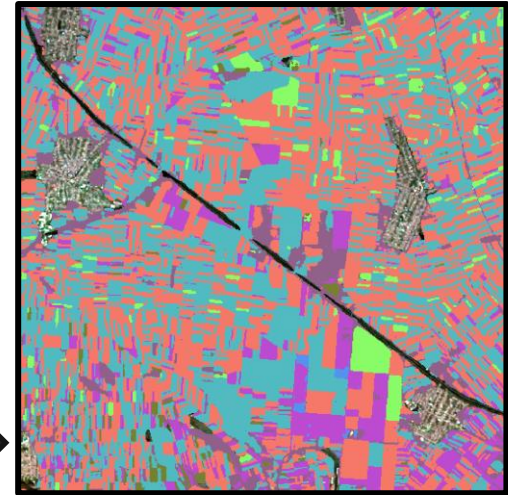
Field data and crop maps, 2016-2023  
(BioSense Institute)



Phenology

Conv-LSTM with  
semantic segmentation +  
temporal transfer learning

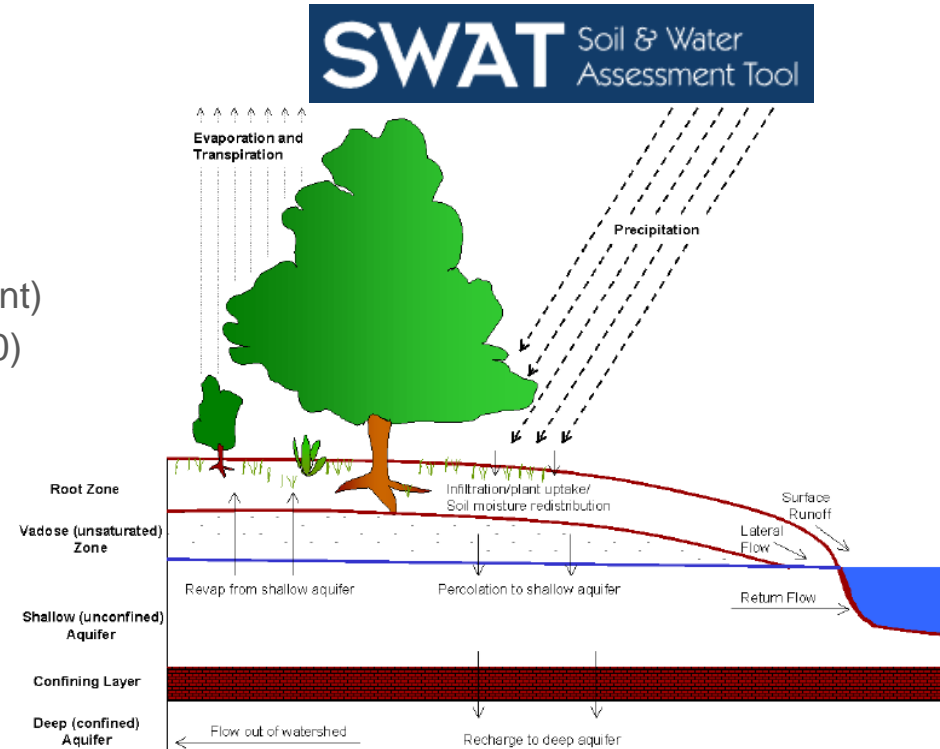
Crop rotation maps  
(annual, 6 key crops)



# Q2: How is water availability and water use changing?

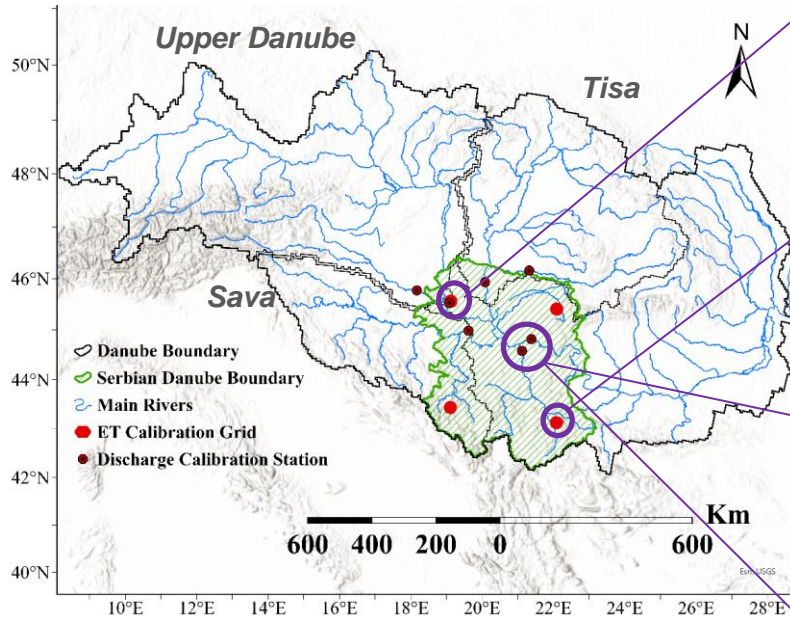
**Objective:** Quantify and map the water balance from 1991-2070

- Process-based hydrological model (SWAT+)
  - Water, N, and P cycles
  - Plant growth – yield estimates
- Daily weather time series
  - *Observed:* EU Copernicus E-OBS (1981-present)
  - *Future:* EURO-CORDEX ensemble (1981-2100)
- Agricultural practices parameterized
  - Crop rotations (from Q1 crop maps)
  - Irrigation (amount, frequency, source)
- Calibration and uncertainty analysis
  1. Global Runoff Data Centre discharge
  2. Annual country-level crop yield (RS Statistics)
  3. Remotely-sensed ET (8-day Penman-Monteith-Leuning V2, Google Earth Engine)

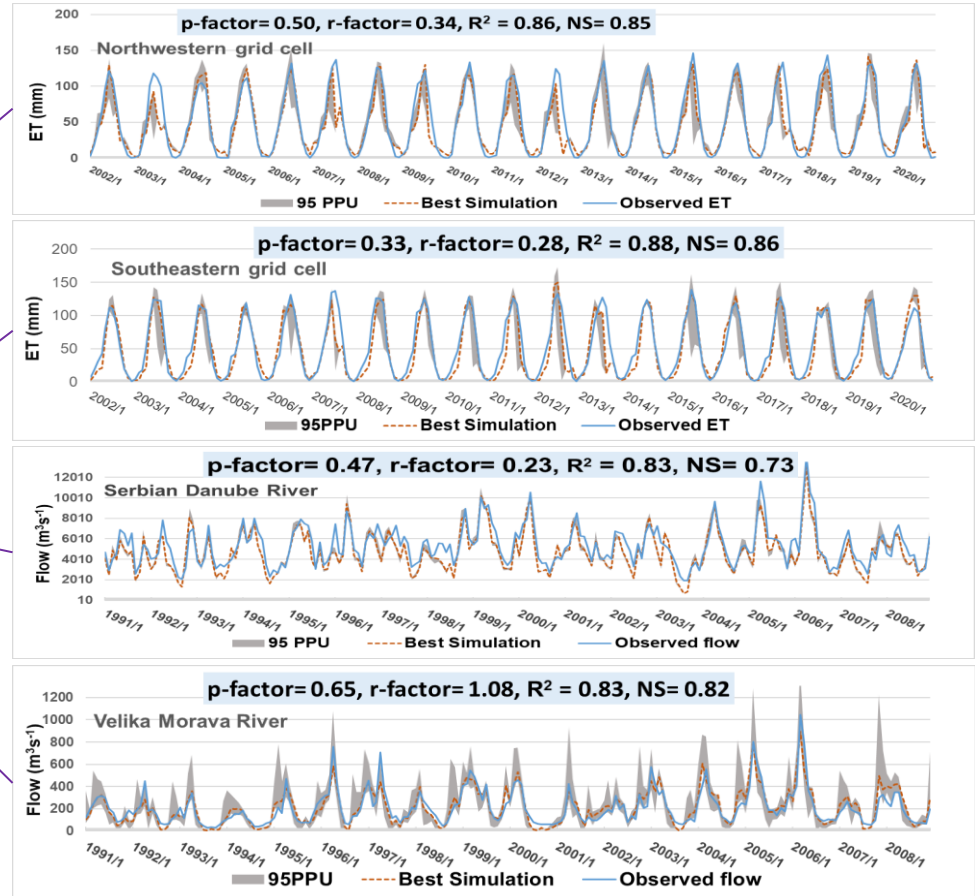


# Model configuration and calibration/uncertainty analysis

Statistical comparisons to river discharge and remotely-sensed ET and



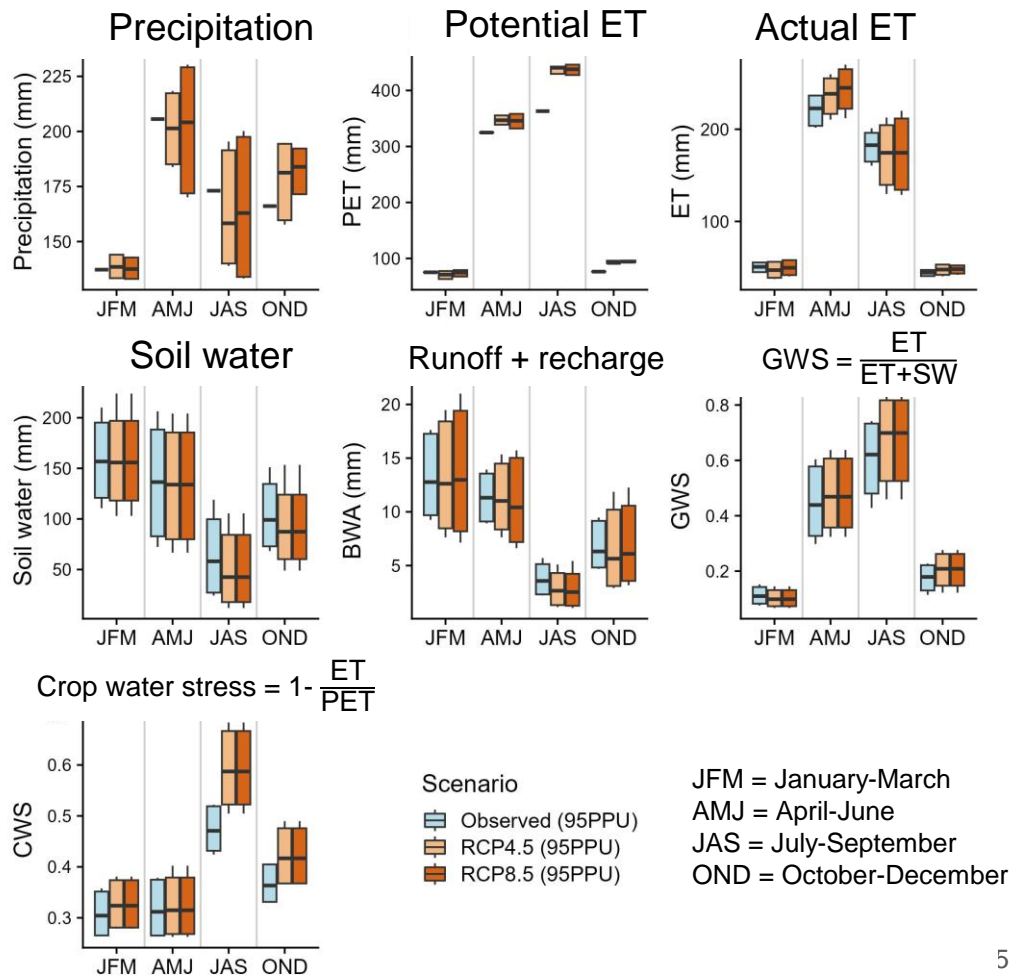
A multi-basin, multi-scale modeling approach using multiple lines of evidence for validation



# Water balance changes

1991-2020 vs 2041-2070

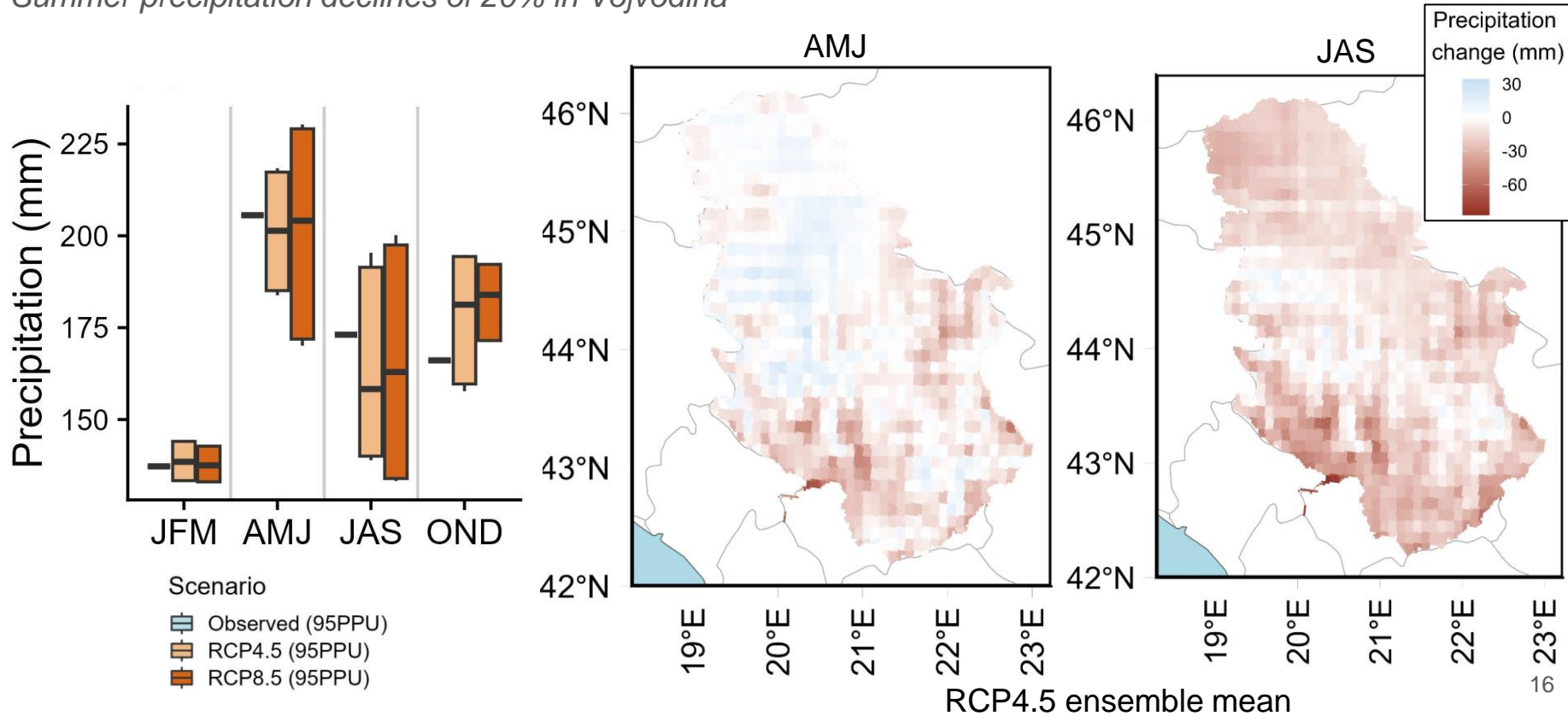
- Precipitation signal is mixed in spring, with drier summers
- Potential ET increases are greatest in summer
- Actual ET increase in spring, decrease in summer
- Soil water constant in spring, declines in summer
- Green water scarcity (GWS) and crop water stress (CWS) increase in the summer



# Precipitation declines in late growing season

*Spring has mixed future projections, but slightly wetter in northern Serbia (Vojvodina)*

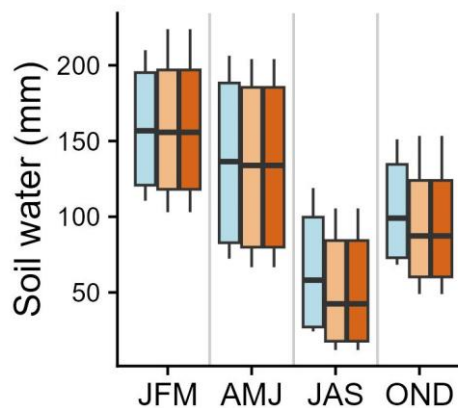
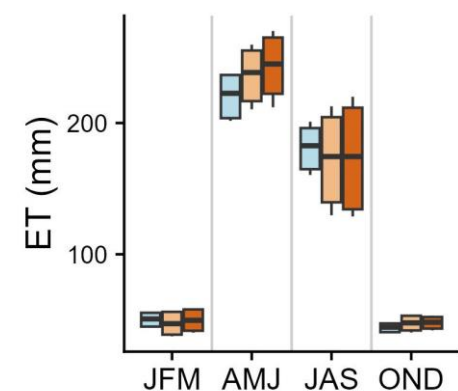
*Summer precipitation declines of 20% in Vojvodina*



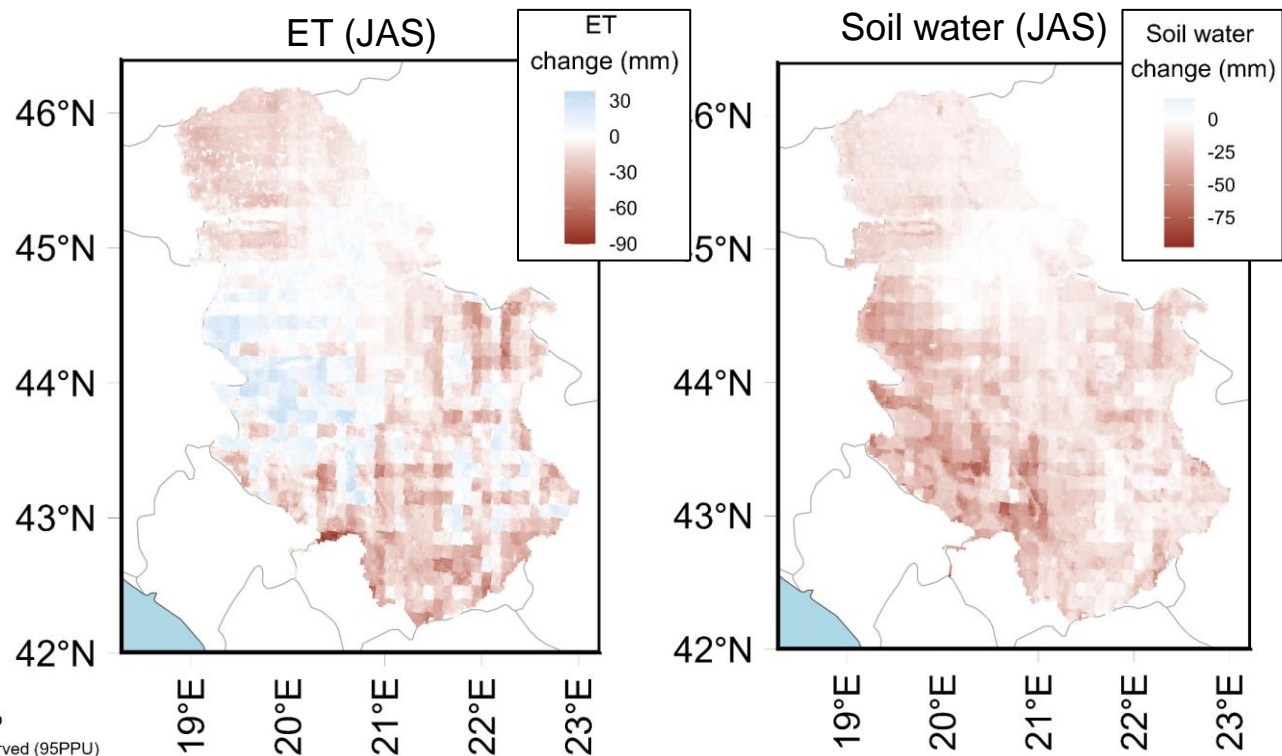
# ET and soil water decline in 2041-2070

*Precipitation declines reduce summer soil water, thus reducing ET*

*Spring ET increases (maps not shown) – soil water is available to meet evaporative demand*



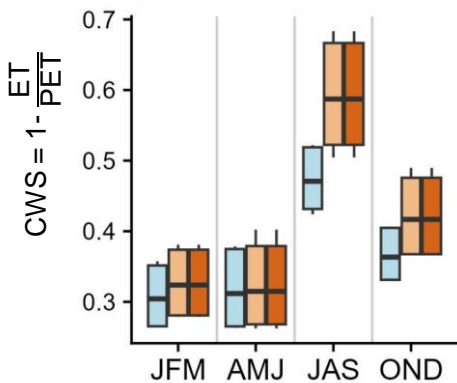
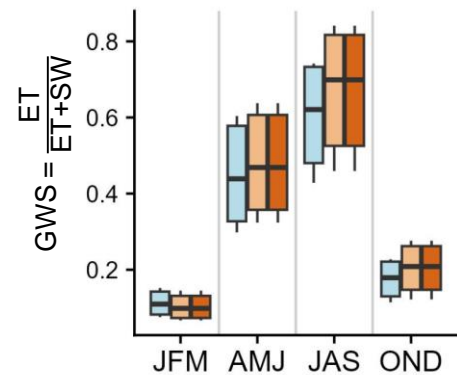
Scenario  
Observed (95PPU)  
RCP4.5 (95PPU)  
RCP8.5 (95PPU)



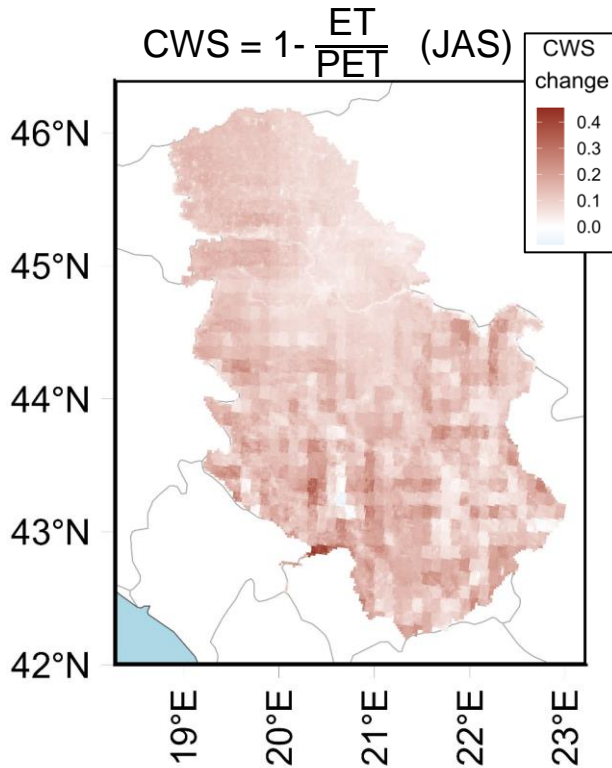
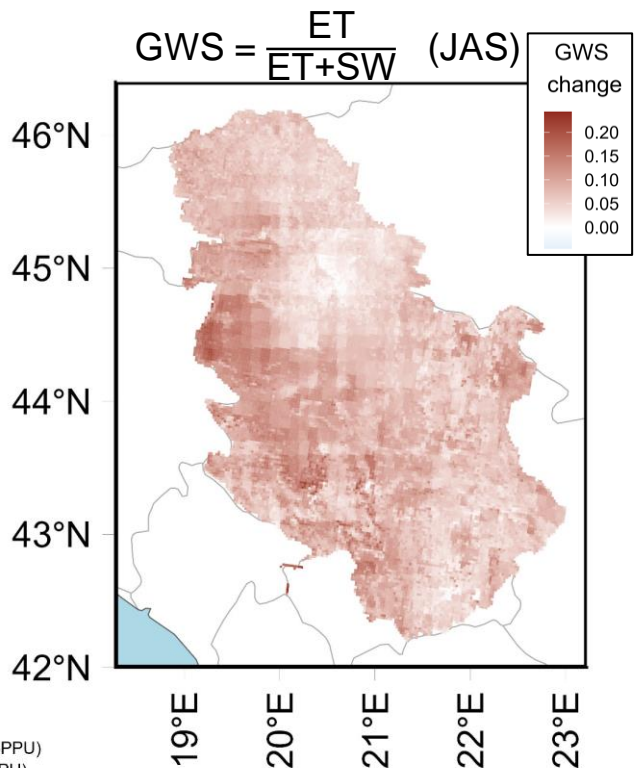
# Green water scarcity and crop water stress increase

Soil moisture declines result in less water for ET

Evaporative demand increases (PET)



Scenario  
Observed (95PPU)  
RCP4.5 (95PPU)  
RCP8.5 (95PPU)

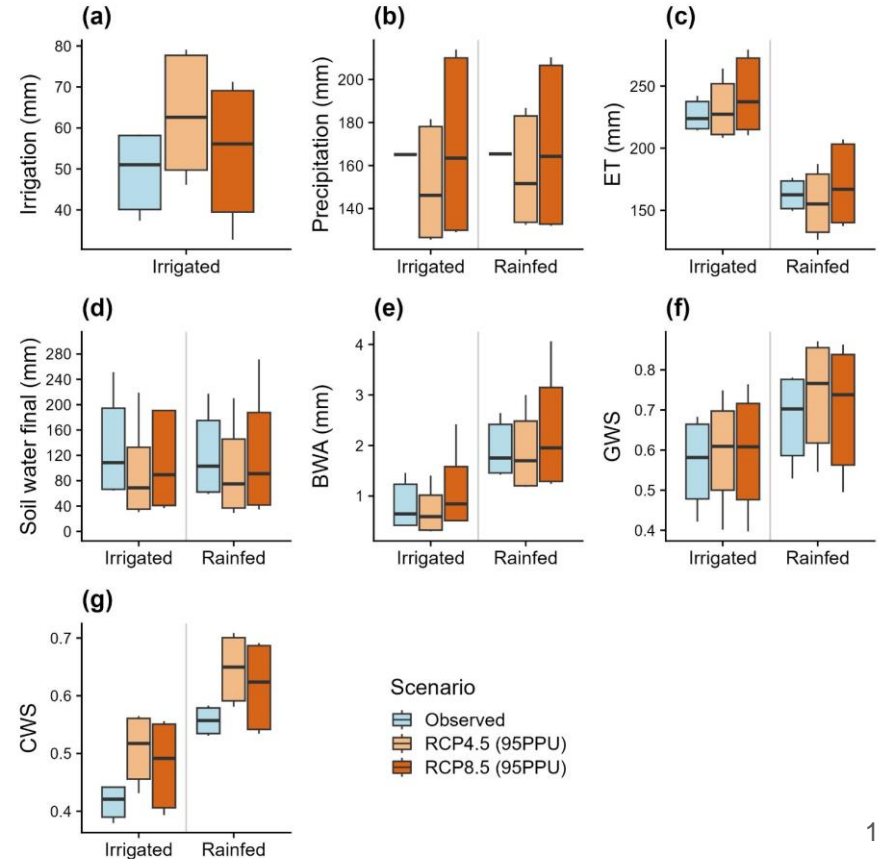


RCP4.5 ensemble mean

# Irrigation as a climate adaptation measure

*Irrigated vs. rainfed agriculture (maize, soybean, sugar beet)*

- Assuming no change in irrigated area (3%) in 2041-2070
- Irrigation water used (a) increases in the future, thus increasing crop ET (c)
- Green water scarcity (f) and crop water stress (g) are both lower on irrigated lands
- However, irrigation only partially offsets climate-driven increases in CWS (f) and GWS (g)



# Next steps and significance

- Create forecasts future water availability and changes to farmer behaviors (adaptation) – integration with economic models
  - Crop system transitions
  - Irrigation expansion
- Inform policy and decision-making related to public irrigation infrastructure and water use



Irrigated soybeans, 9 July 2024  
Water source: connected to Danube-Tisa-  
Danube Canal

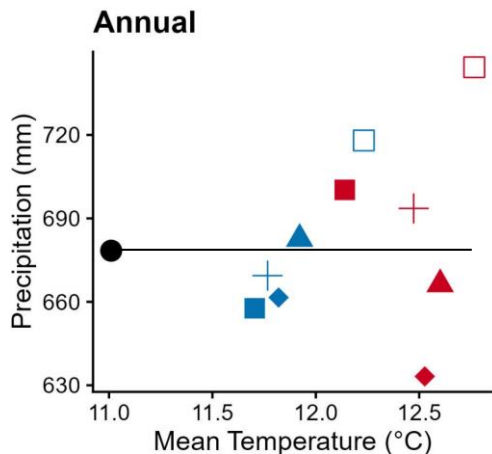
# Thank You!

woznicse@gvsu.edu



# EURO-CORDEX Projections

*Precipitation and temperature in 2041-2070 compared to 1991-2020*

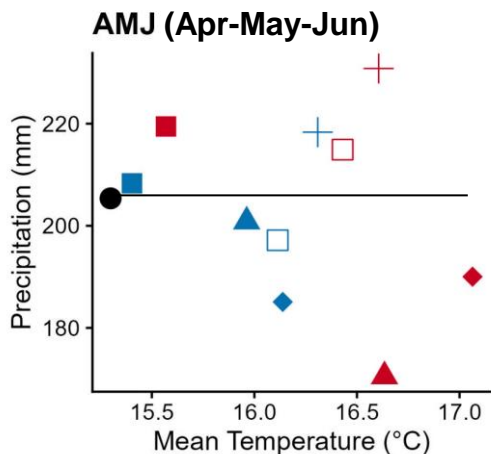


3/5 models drier

Max: +40 mm

Mean: no change

Min: - 20 mm

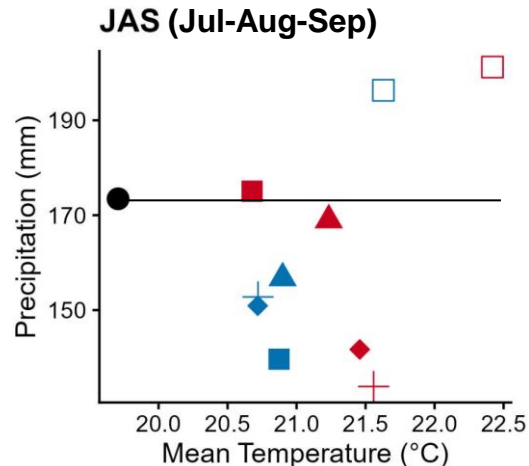


3/5 models drier

Max: +15 mm

Mean: -3 mm

Min: -20 mm



4/5 models drier

Max: +25 mm

Mean: -15 mm

Min: -30 mm

- Observed
- Model
  - CCLM-CNRM-CM5
  - ▲ CCLM-EC-EARTH
  - ◆ CCLM-MPI-ESM-LR
  - + RACMO-EC-EARTH
  - WRF-IPSL-CM5A
- Scenario
  - RCP 4.5
  - RCP 8.5