Development of a smart-and-connected irrigation system for rural communities in Nebraska

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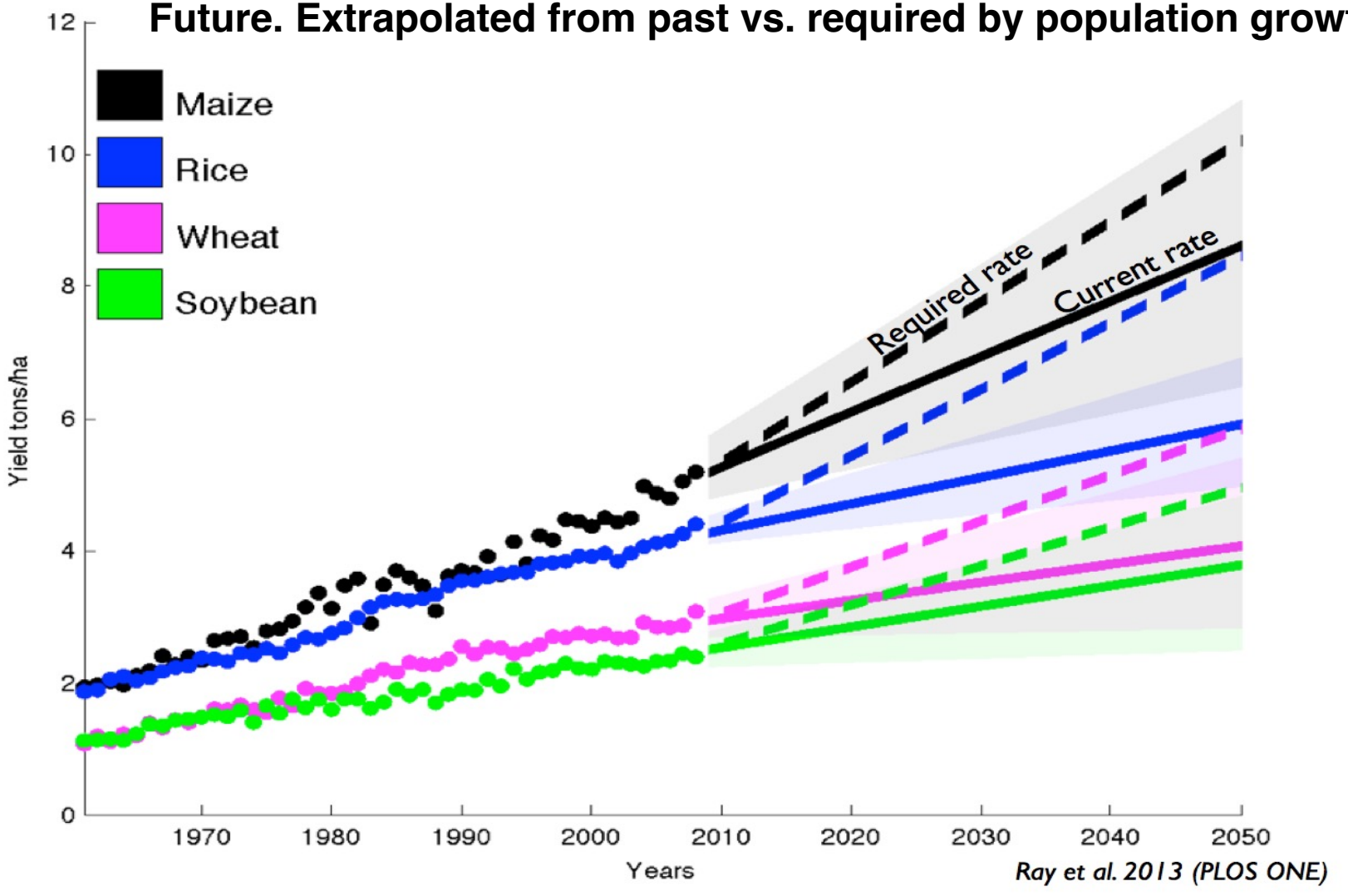
UNIVERSITY OF Nebraska Lincoln

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

THE UNIVERSITY OF UTAH

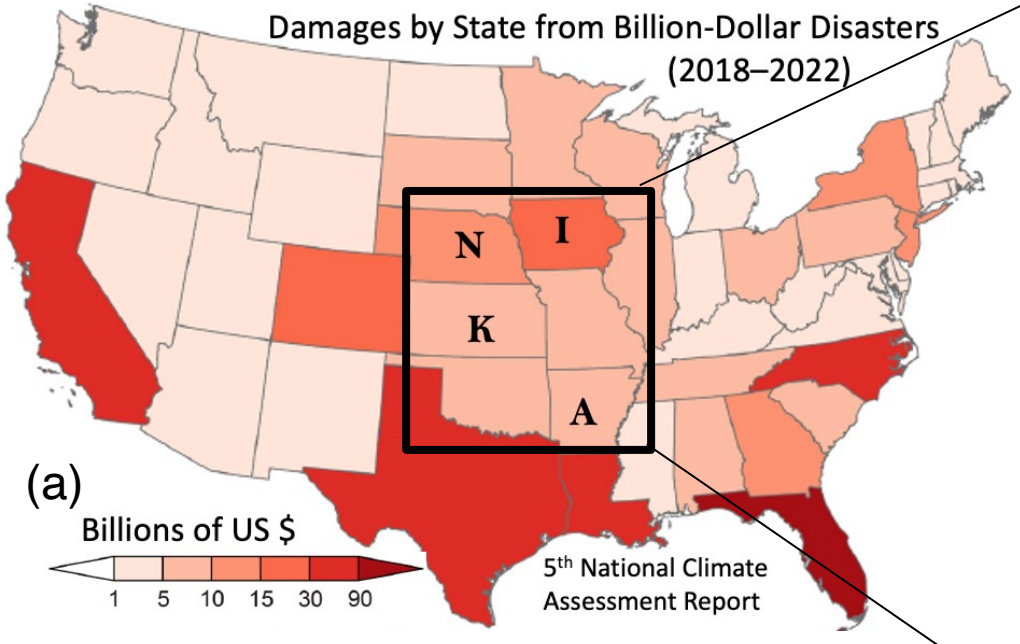
Yield/ha, Past & Future

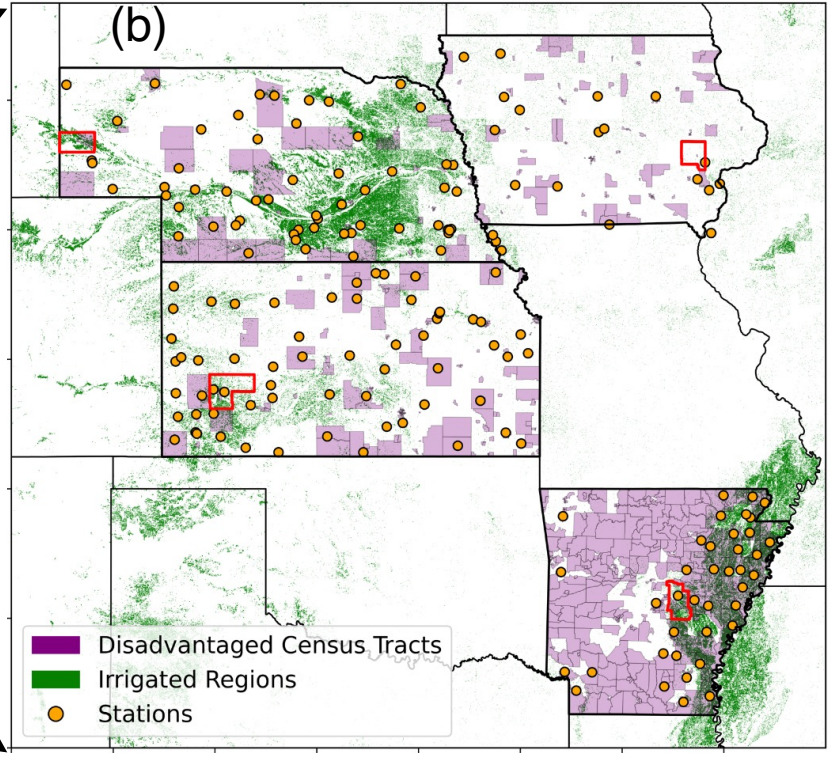
Future. Extrapolated from past vs. required by population growth



Ray et al. 2013 (PLOS ONE)

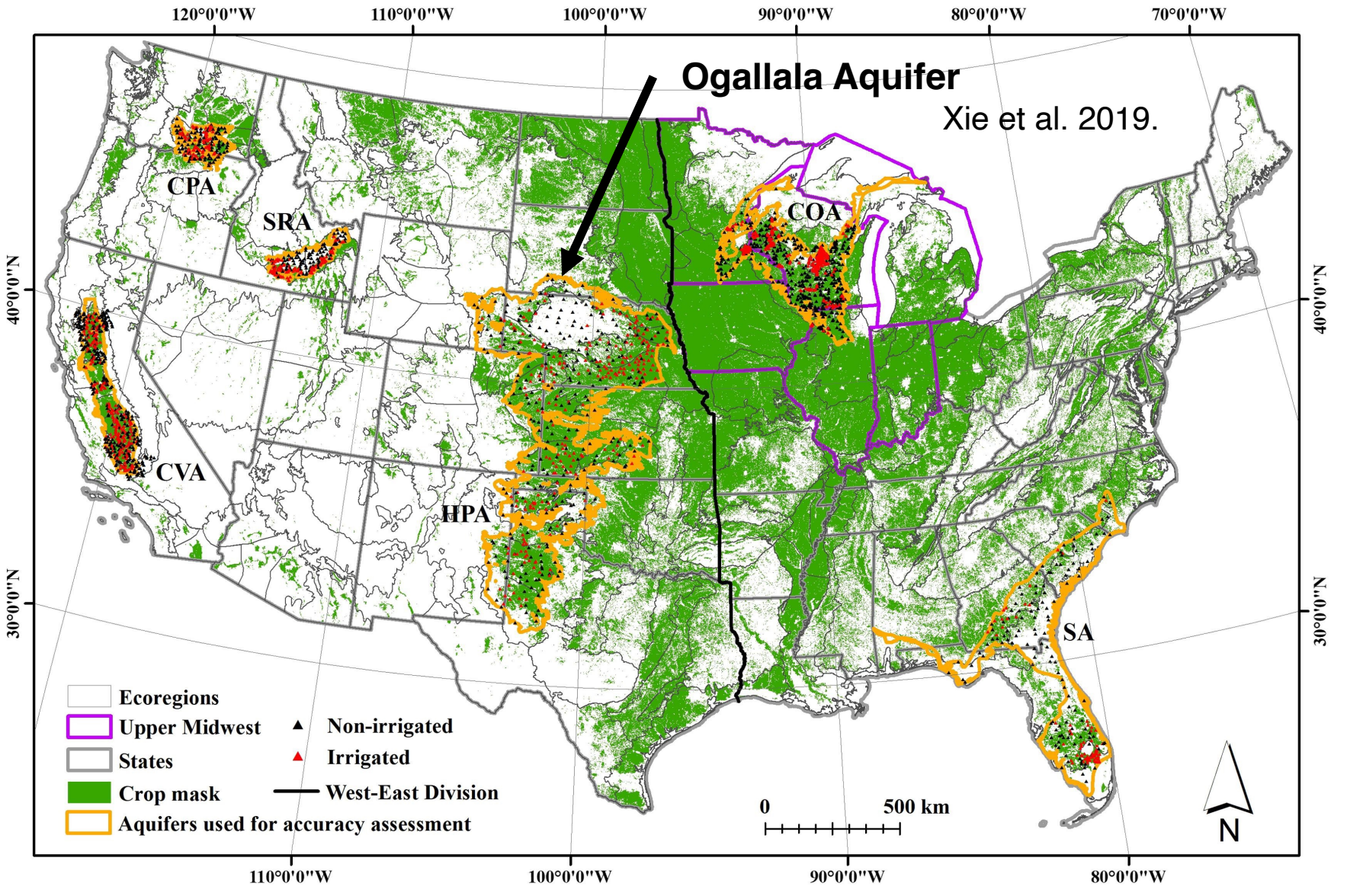
Lack of soil and weather intelligence in real time





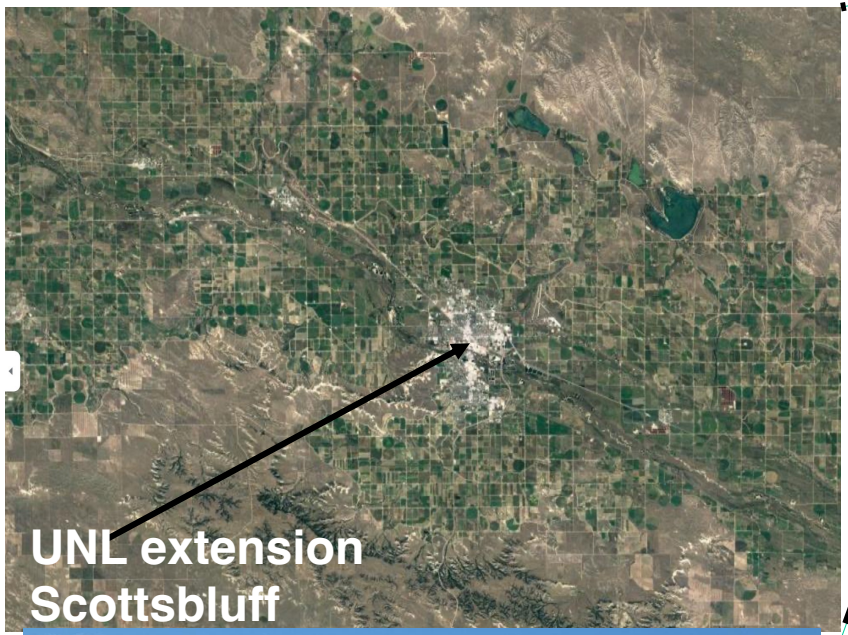
In 2020, the KANI states had ~172 real-time weather stations, less than ~50% of 375 counties. Soil stations are far less.

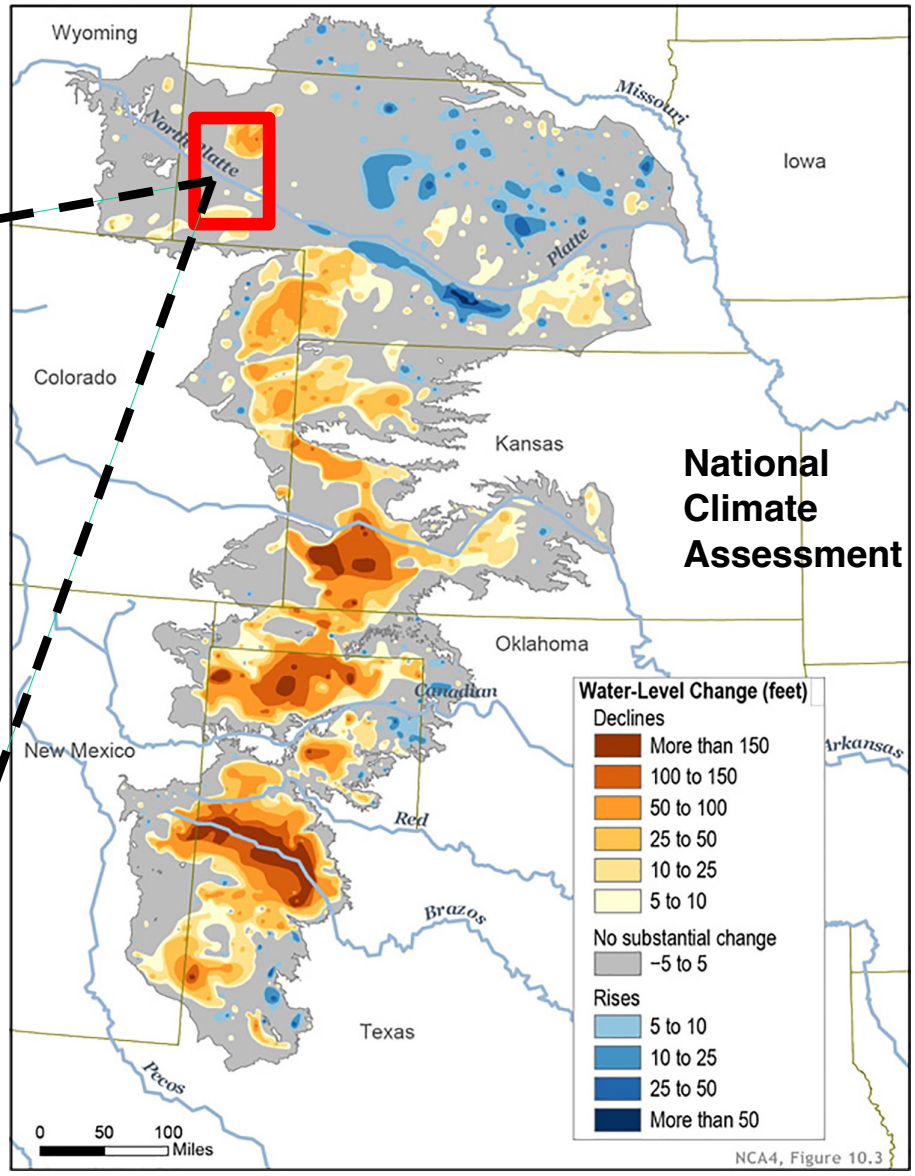
This scarcity of weather and soil observation sites is in stark contrast with the large economic loss from weather and climate disasters and the large areas of socioeconomically disadvantaged communities,


Ogallala Aquifer
Xie et al. 2019.
CPA
SRA
COA
CVA
HPA
SA
120°0'0"W
110°0'0"W
100°0'0"W
90°0'0"W
80°0'0"W
70°0'0"W
40°0'0"N
30°0'0"N
Ecoregions
Upper Midwest
States
Crop mask
Aquifers used for accuracy assessment
Non-irrigated
Irrigated
West-East Division
0
500 km
N

Western Nebraska

~ 50 km x 30 km

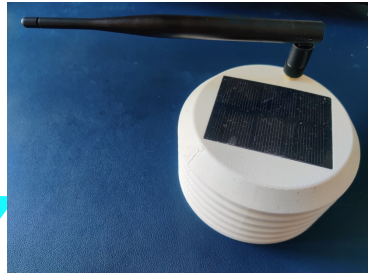


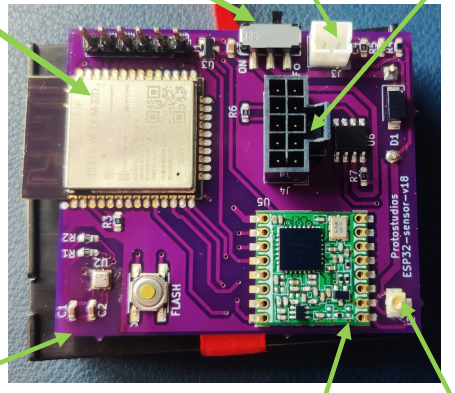


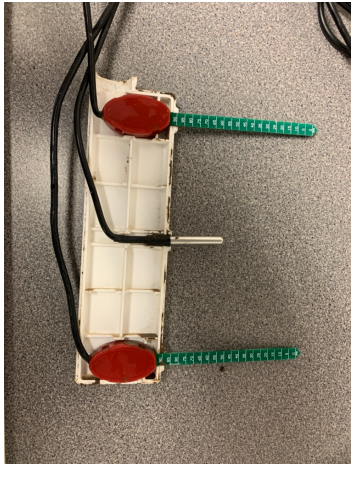
I-Canopy System

- Temperature, RH, pressure at 2 m
- Soil moisture at 5 cm and 20 cm
- Soil temperature at 10 cm

For details, please see poster #: A15P-08.







Microcontroller: ESP32 (WiFi integrated)
Weather: BME280 (deployed) / BME680 (in testing)

Weather forecast & evaluation with sensor data in near real time

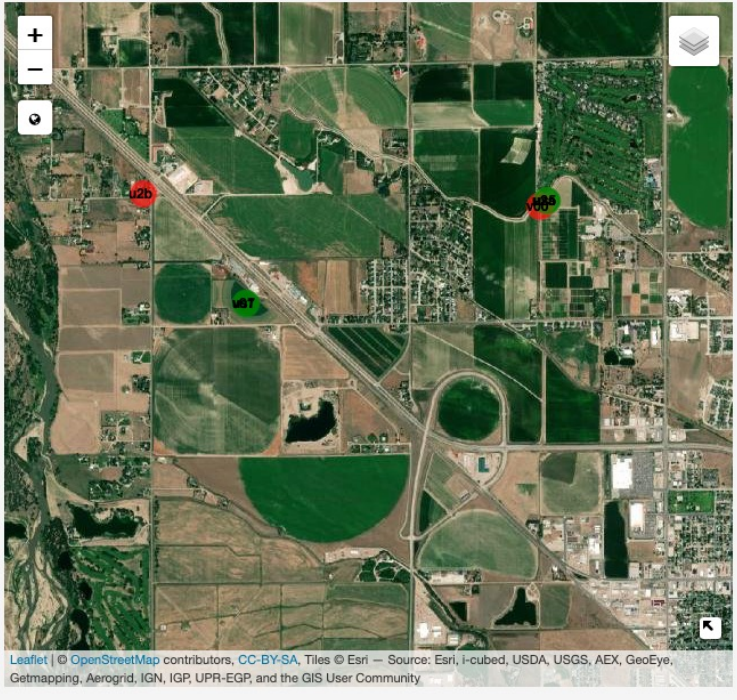
https://esmc.uiowa.edu

Home | Weather Predictions | Data Access | Citizen Data | LANCE | Satellite Data | Tutorials | I-DARE | About Us

UIOWA ESMC

Click on the circles to explore the sensors observations

Note: red suggests the need to change the battery, but COVID-19 pandemic made it difficult. We are in the processing to recover it.

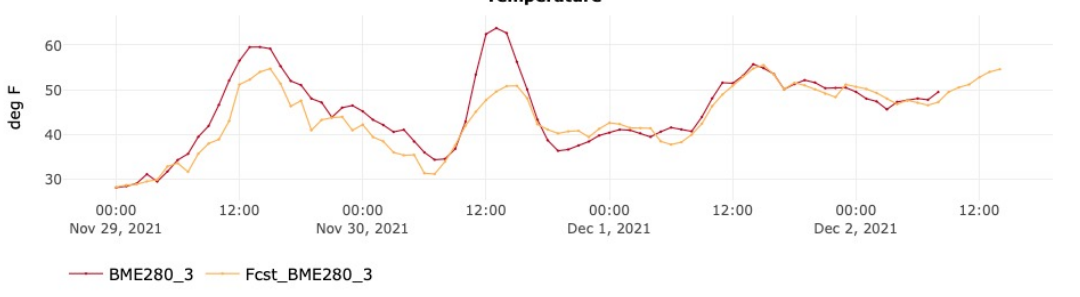


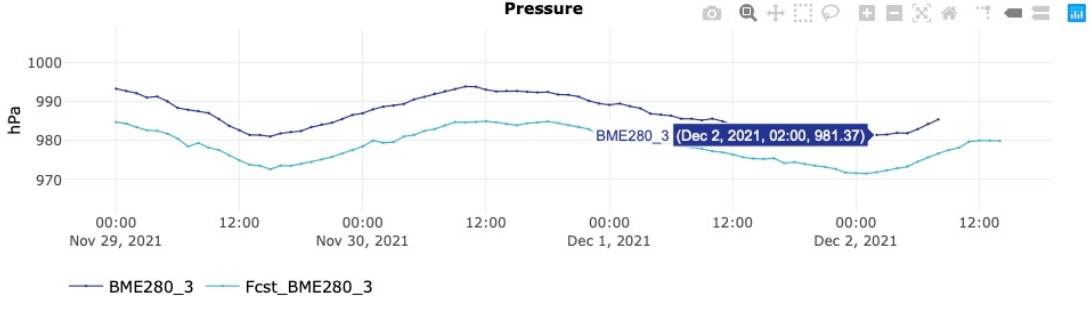
Citizen environmental monitoring & forecast data

Time zone: America/Chicago

Plots | Data

Refresh

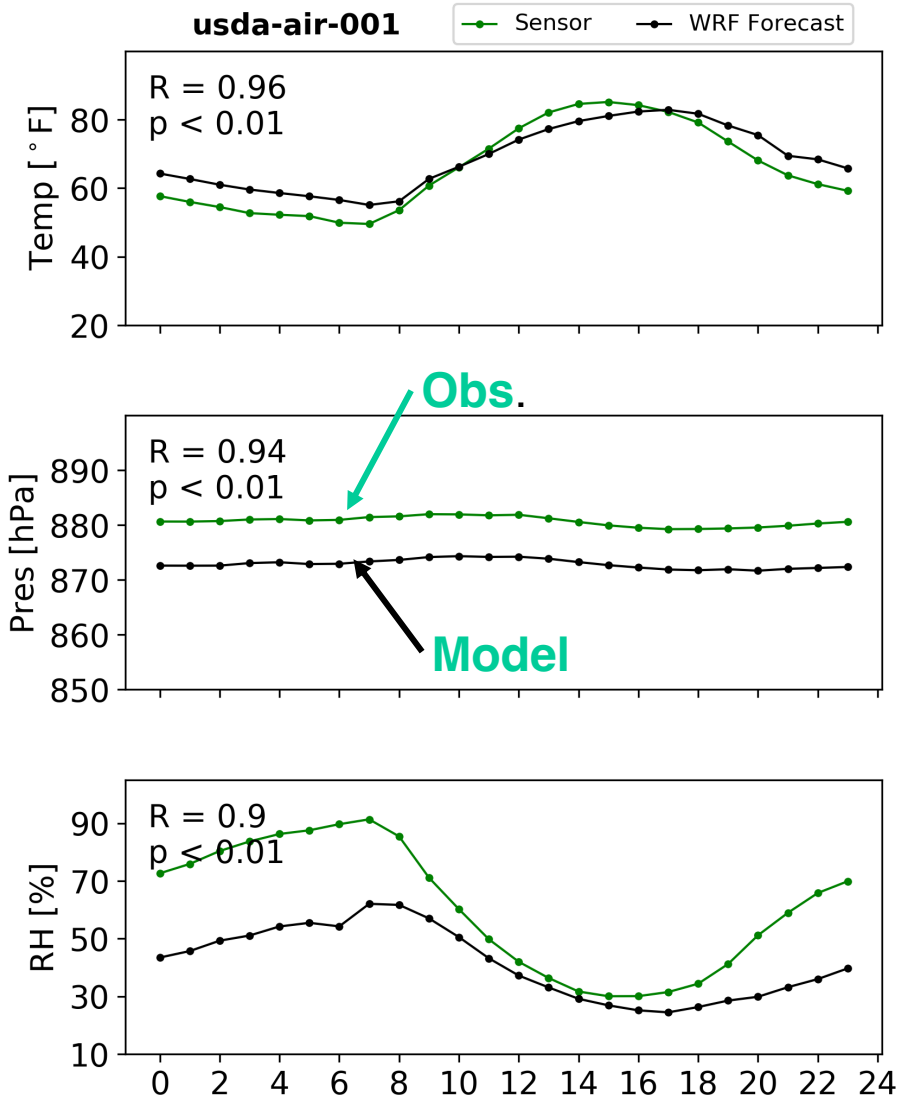




Forecast Evaluation

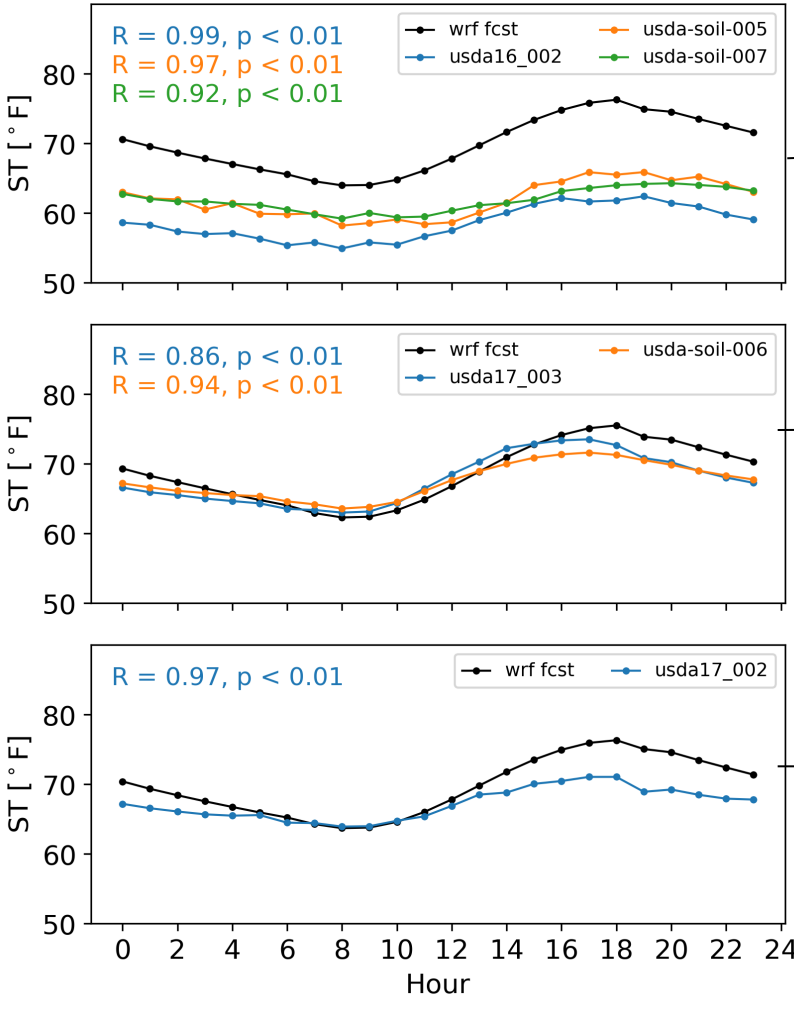
Air temperature, RH, and Pressure

- Model overestimates T_{min}, underestimates T_{max}, has significant low bias in RH.
- Results suggest the impacts of the irrigation on the surface energy budget and weather parameters that are not considered in WRF prediction.



Forecast Evaluation

Soil temperature, 10 cm below surface



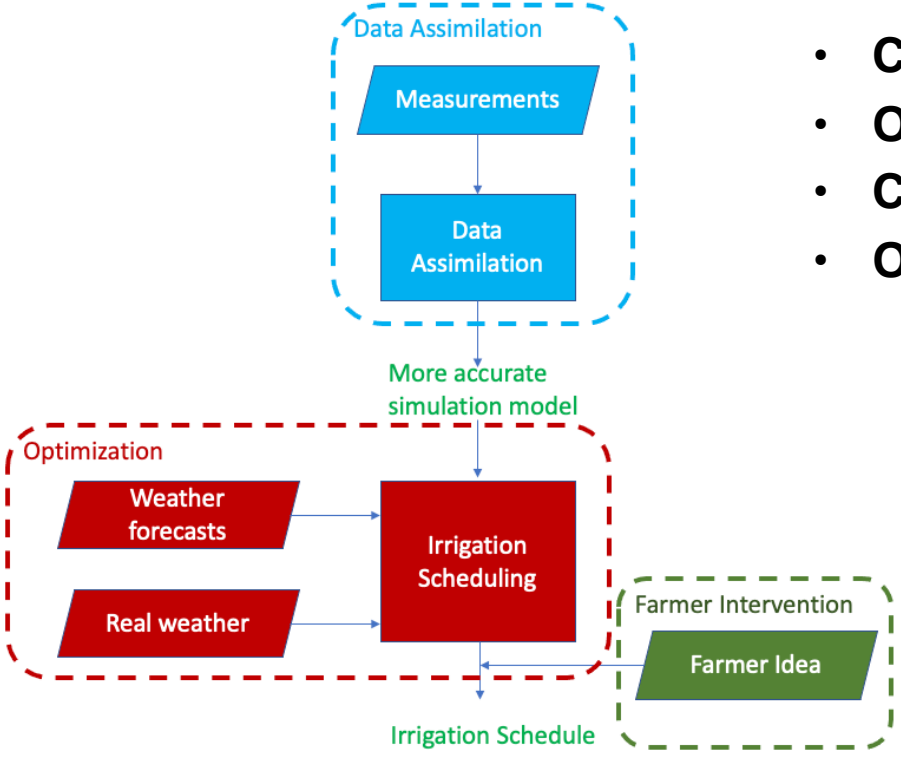
Irrigated

Rainfed

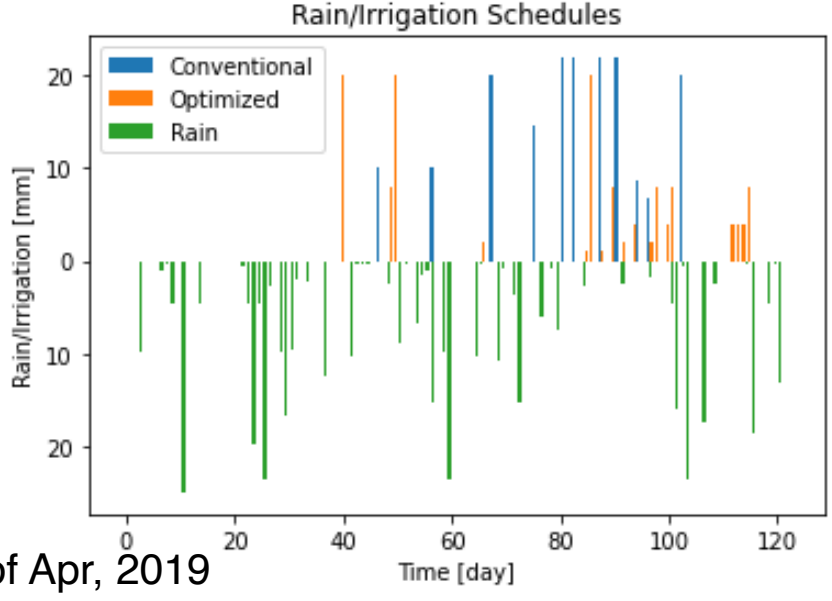
Irrigated

Irrigated fields clearly have lower soil temperature that are not captured by the model!

Irrigation Scheduling Optimization: Preliminary Results



- **Conventional: 178 mm**
- **Optimized: 106 mm**
- **Conventional Dry Matter: 13842 kg/ha**
- **Optimized Dry Matter: 15211 kg/ha**



Observation data helps to improve irrigation schedule optimization and lead to better outcomes!

26th of Apr, 2019

Summary & Next Steps

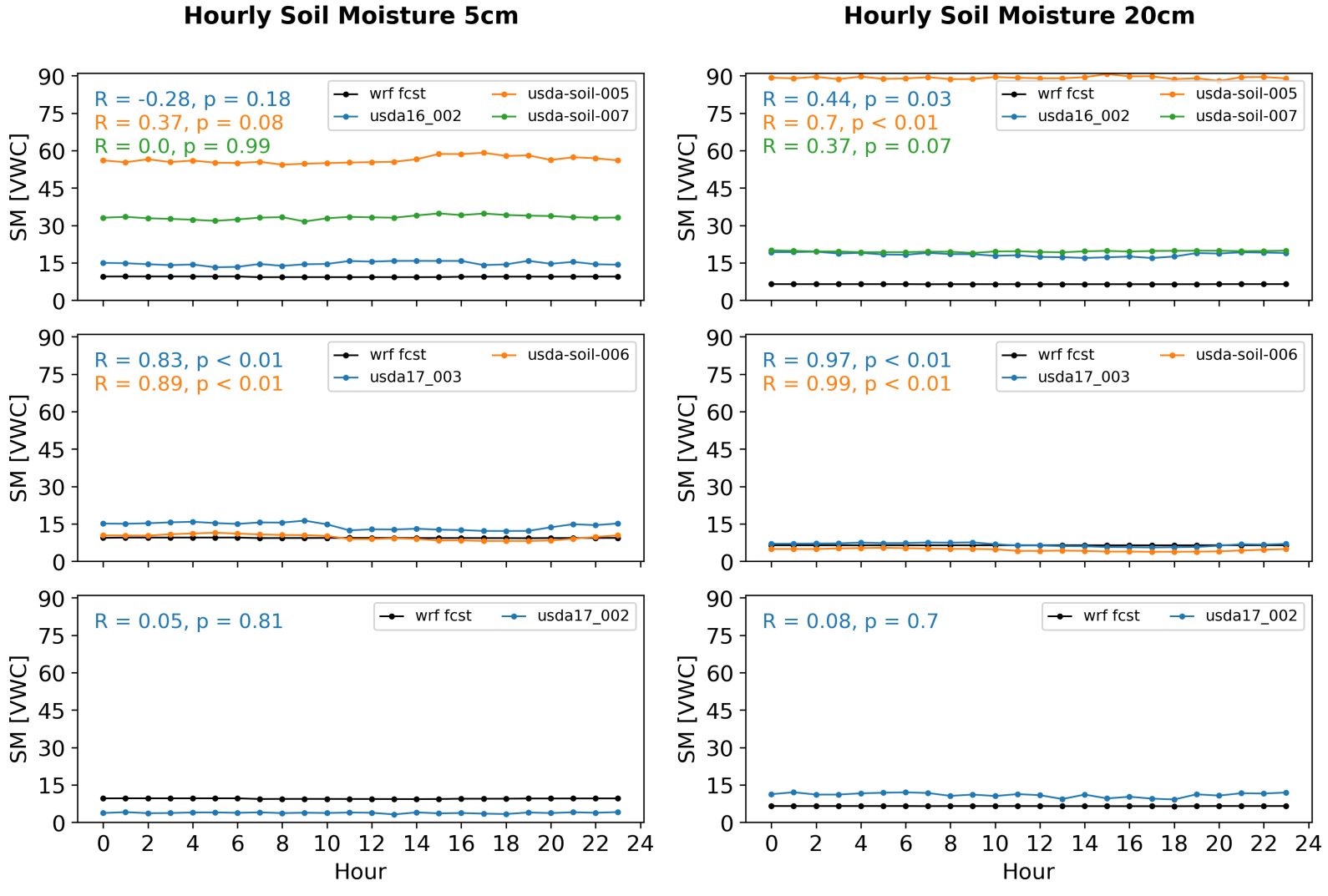
- **Developed a I-Canopy sensor that can measure soil and air properties 24/7 in real time in the crop fields. We did it by considering:**
  - low cost solution for data transmission (LoRa)
  - Resiliency for weather changes (hot summer, cold winter, water proof; good and low-cost rechargeable batteries)
  - Power efficiency management (solar panel; reconnecting scheduling; avoid overcharging in summer and saving energy in winter)
  - Irrigated water from the side (impossible to measure air temperature during irrigation)
  - Calibrating soil moisture
- **The I-canopy data is now being integrated with the weather forecast model, crop model, and irrigation scheduling optimization. This smart-and-connected system was tested in 2022 and 2023 growing season.**
- **I-Canopy data can be used together with satellite data to provide improved mapping of weather and soil intelligence.**

Thank you !

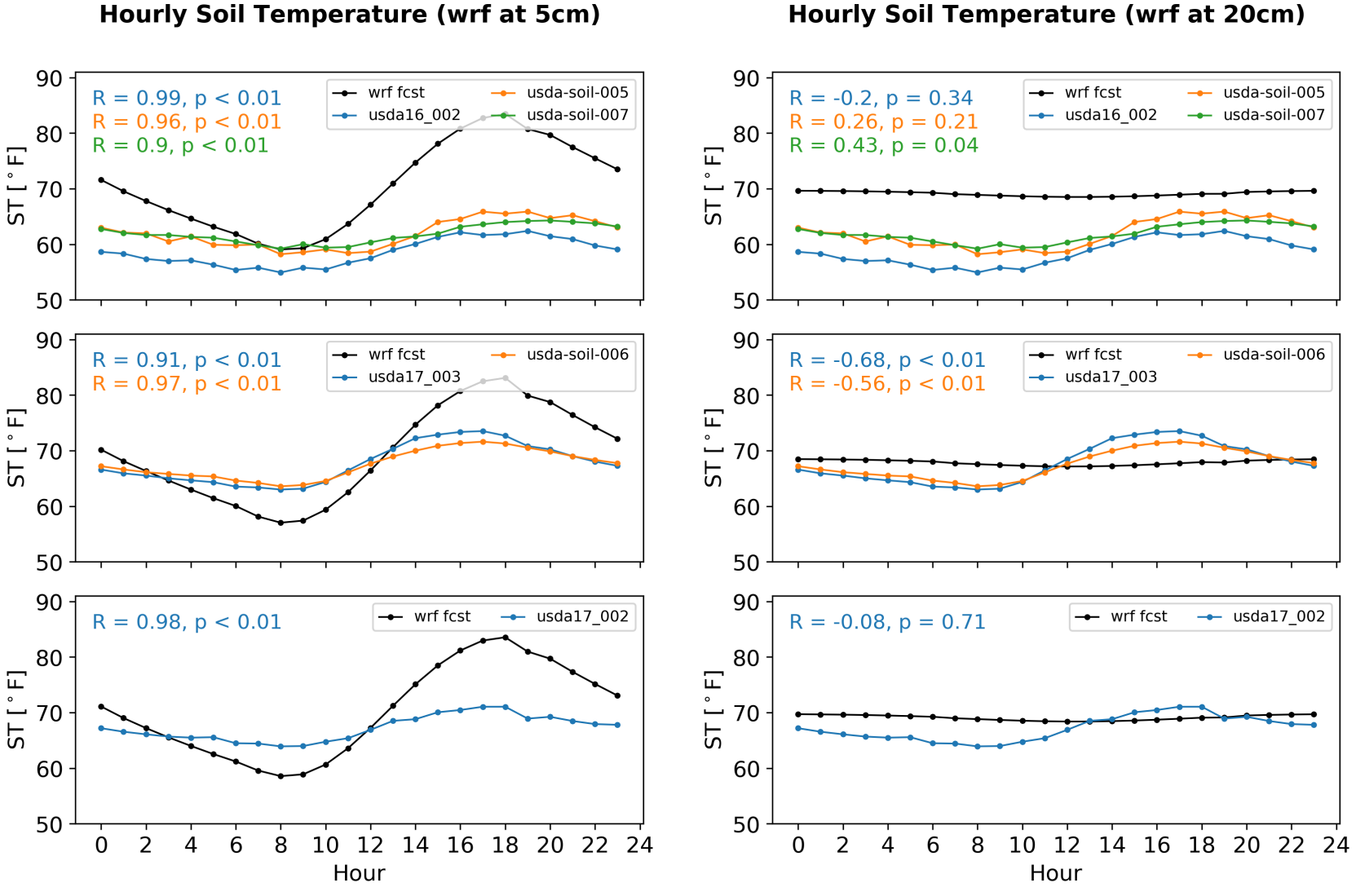
United States Department of Agriculture
National Institute of Food and Agriculture

Award #: 2019-67021-29227

Details on sensor design: poster #: A15P-08

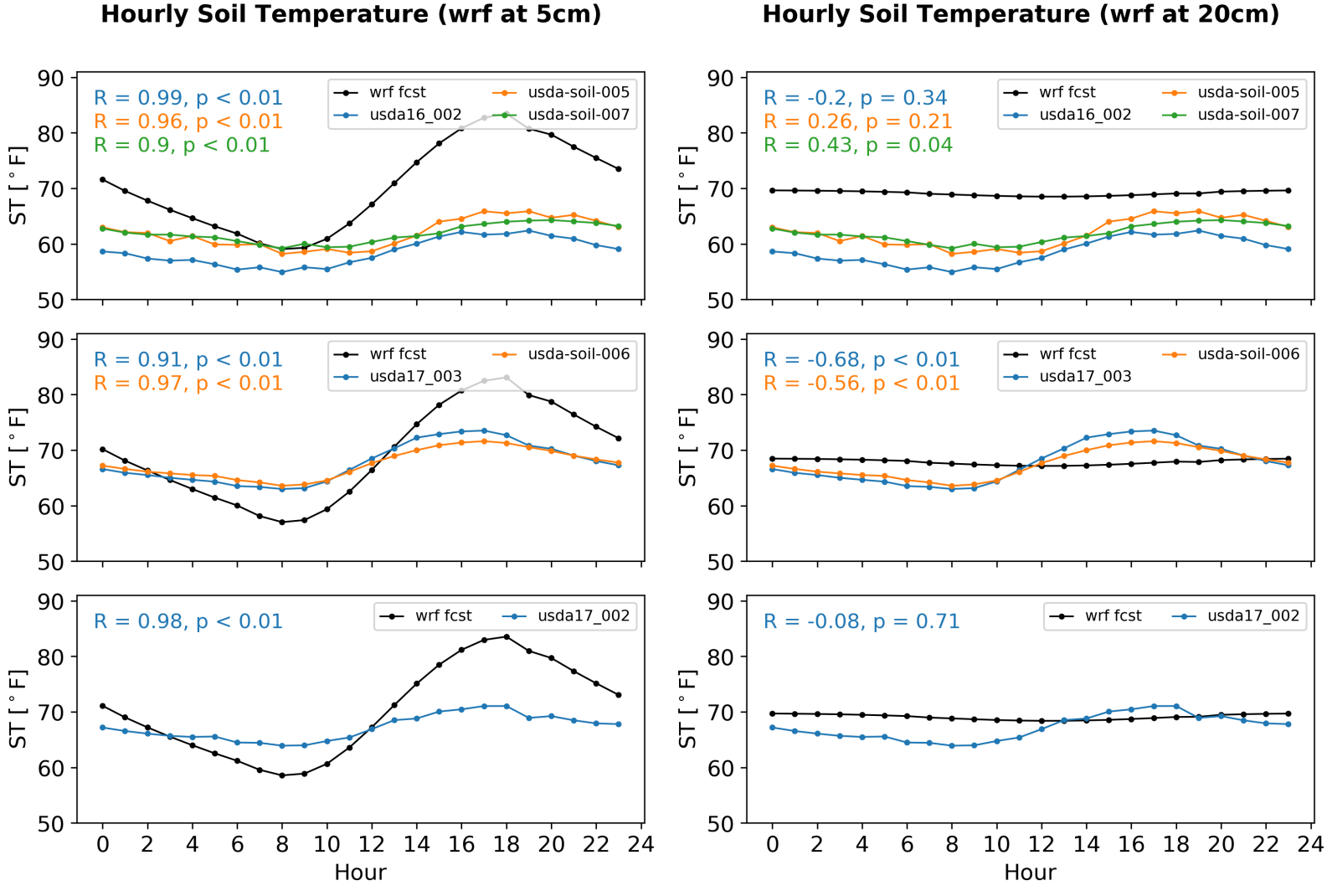

Hourly Soil Moisture 5cm
Hourly Soil Moisture 20cm
SM [VWC]
Hour
R = -0.28, p = 0.18
R = 0.37, p = 0.08
R = 0.0, p = 0.99
R = 0.44, p = 0.03
R = 0.7, p < 0.01
R = 0.37, p = 0.07
R = 0.83, p < 0.01
R = 0.89, p < 0.01
R = 0.97, p < 0.01
R = 0.99, p < 0.01
R = 0.05, p = 0.81
R = 0.08, p = 0.7
wrf fcst
usda16_002
usda-soil-005
usda-soil-007
usda17_003
usda-soil-006
usda17_002


IMMATIC


Hourly Soil Temperature (wrf at 5cm)
Hourly Soil Temperature (wrf at 20cm)
R = 0.99, p < 0.01
R = 0.96, p < 0.01
R = 0.9, p < 0.01
wrf fcst
usda16_002
usda-soil-005
usda-soil-007
R = -0.2, p = 0.34
R = 0.26, p = 0.21
R = 0.43, p = 0.04
R = 0.91, p < 0.01
R = 0.97, p < 0.01
usda17_003
usda-soil-006
R = -0.68, p < 0.01
R = -0.56, p < 0.01
R = 0.98, p < 0.01
usda17_002
R = -0.08, p = 0.71
ST [° F]
Hour

Cope with challenges in the irrigated crop field

- Air temperature needs to be measured in an open air environment.
- But, Stevenson Screen doesn't work in irrigated environment where water can penetrate the screen from the side and the below and damage the sensor.
- **Solution**: (a) put air sensor in the closed case to transmit the soil data only.
  (b) Put canopy sensor in the nearby field that is not irrigated.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wrf fcst
usda16_002
usda-soil-005
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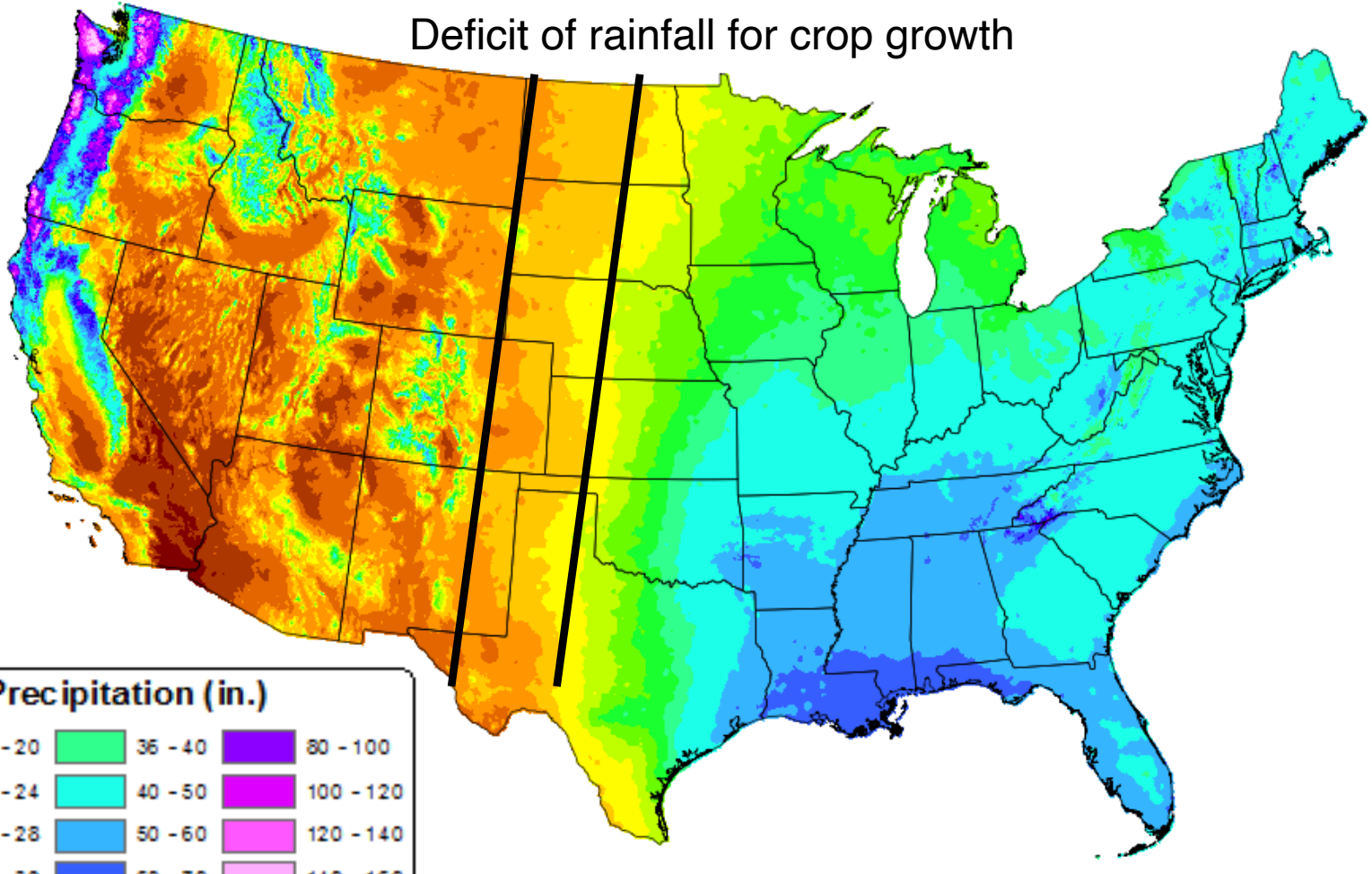
usda17_003
usda-soil-006
R = -0.68, p < 0.01
R = -0.56, p < 0.01
R = 0.98, p < 0.01
usda17_002
R = -0.08, p = 0.71
ST [° F]
Hour

30-yr Normal Precipitation: Annual

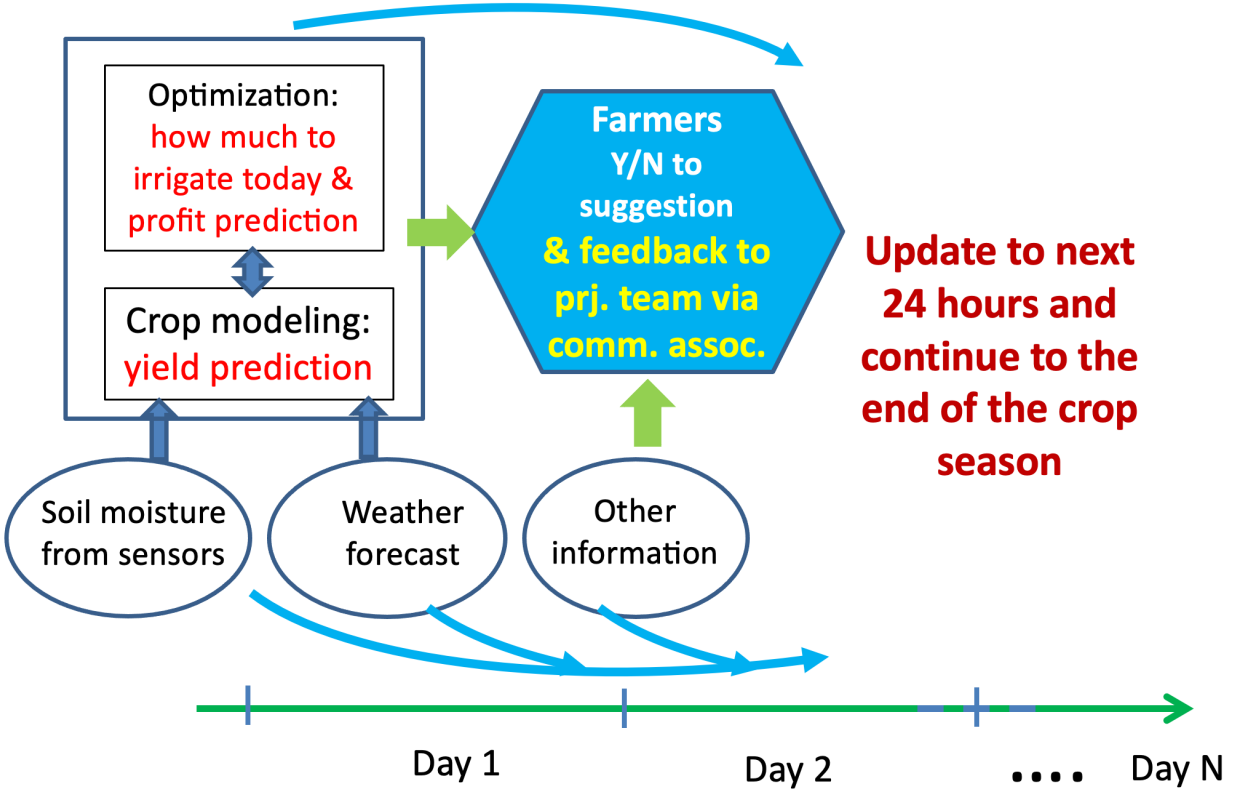
Period: 1981-2010

Deficit of rainfall for crop growth



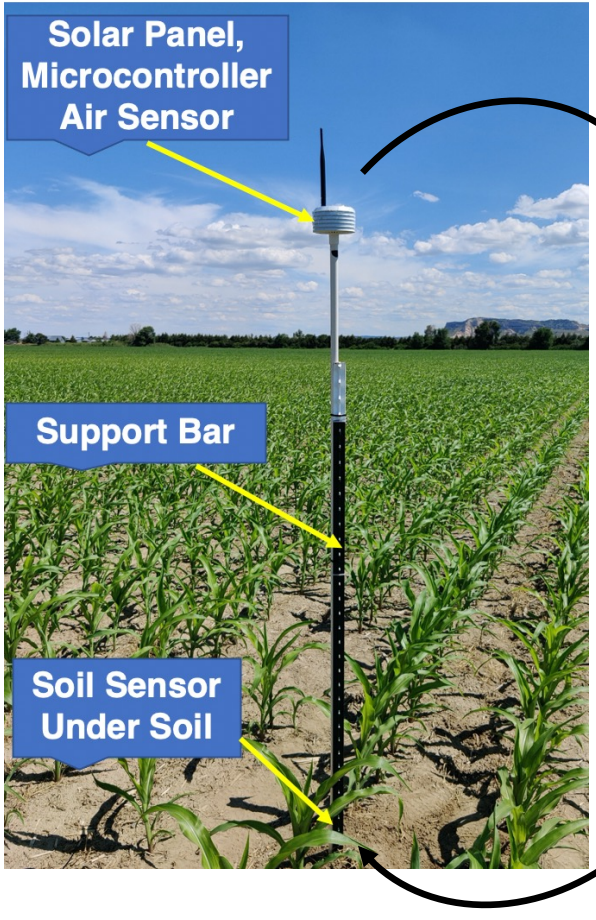
The smart-and-connected irrigation system

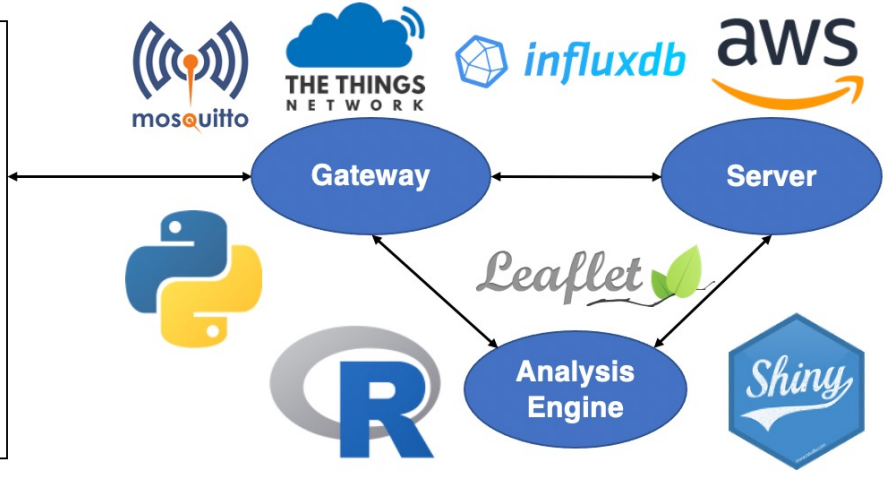
- Low-cost IoT-based sensors to measure soil moisture & temperature, air pressure, RH, and temperature
- Weather prediction model (WRF-Chem) run at 3 km resolution in real time
- Crop modeling for yield prediction and possible water deficit
- Optimization of irrigation schedule and delivery to stakeholders.



Key: community engagement; close collaboration between project team and local communities

Software and firmware

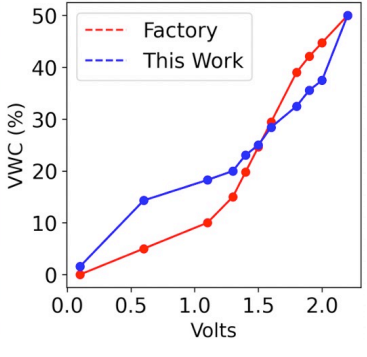




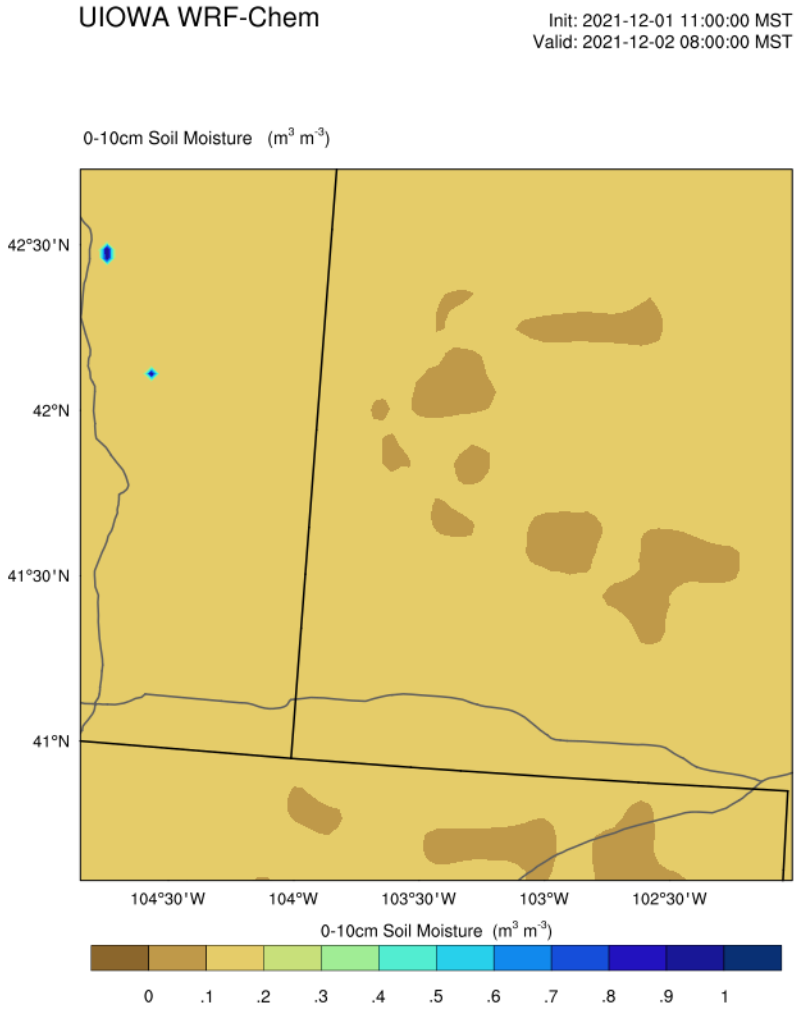
Soil temperature

Soil moisture

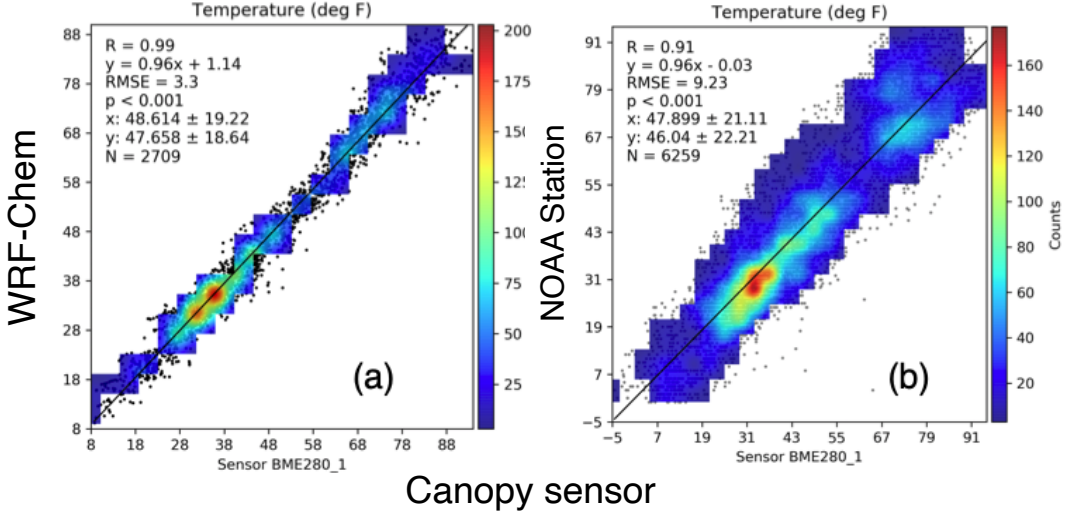
SM calibration curve



Soil moisture forecast at 3 km resolution

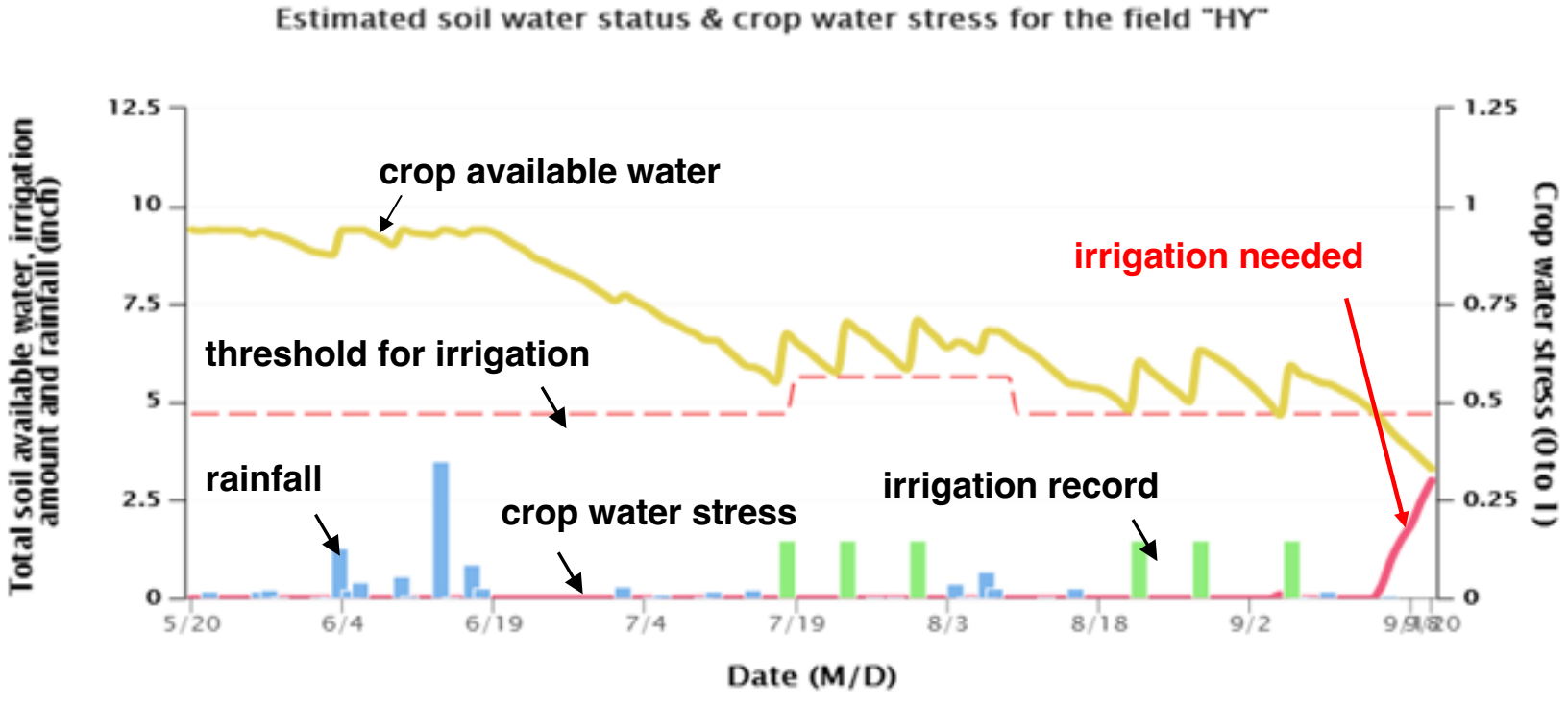


Temperature Intercomparison



Canopy sensor

Crop Modeling



The real-time canopy measurements and weather forecast model outputs are now used to drive the crop model prediction of crop growth and when and how much water needs to be irrigated.