# Leveraging In-Situ Soil Moisture Information to Improve the Assessment of Drought Conditions

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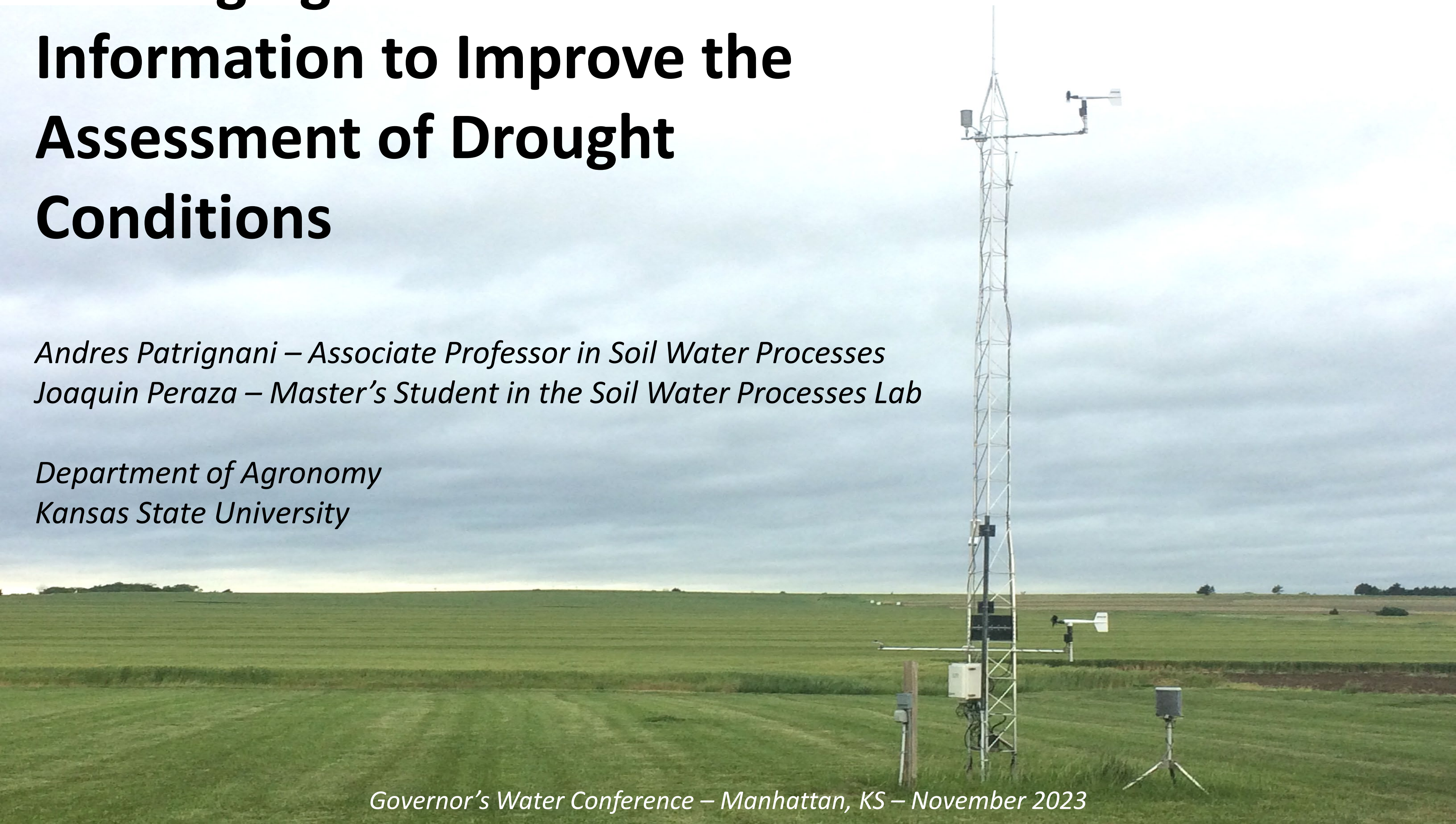
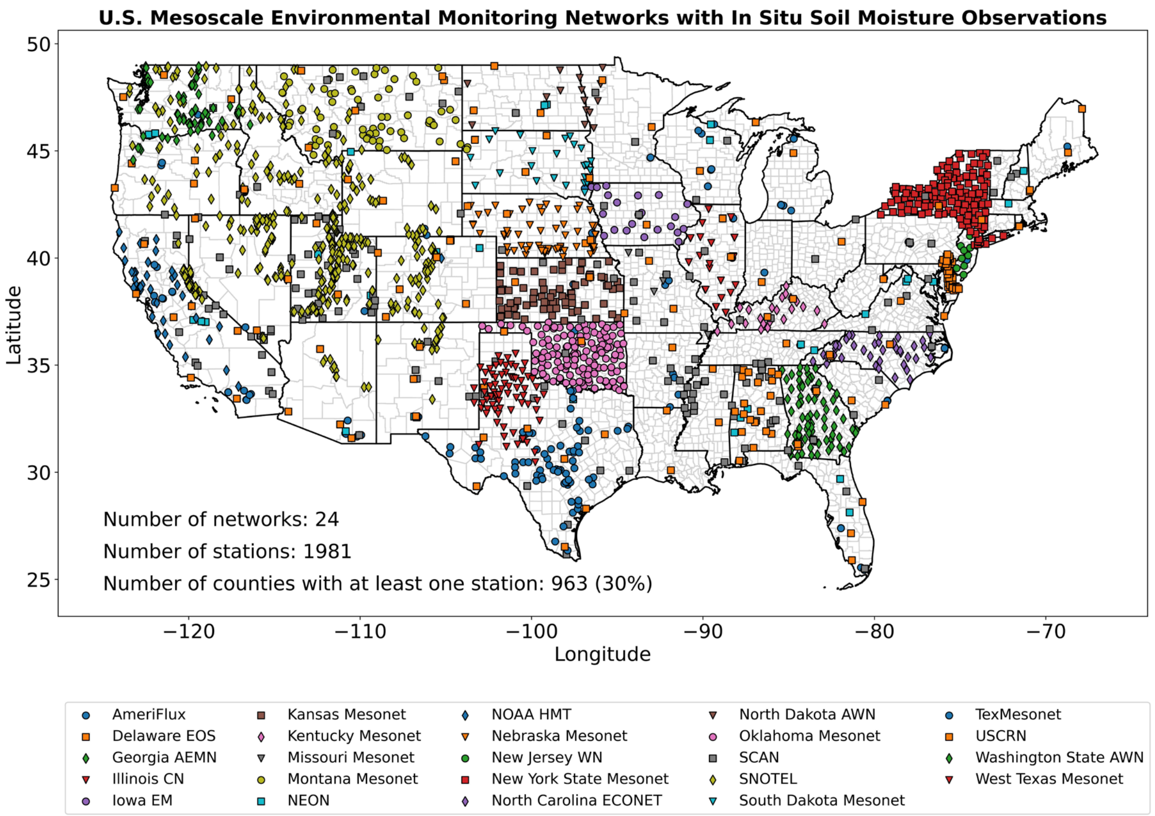


*Governor's Water Conference – Manhattan, KS – November 2023*

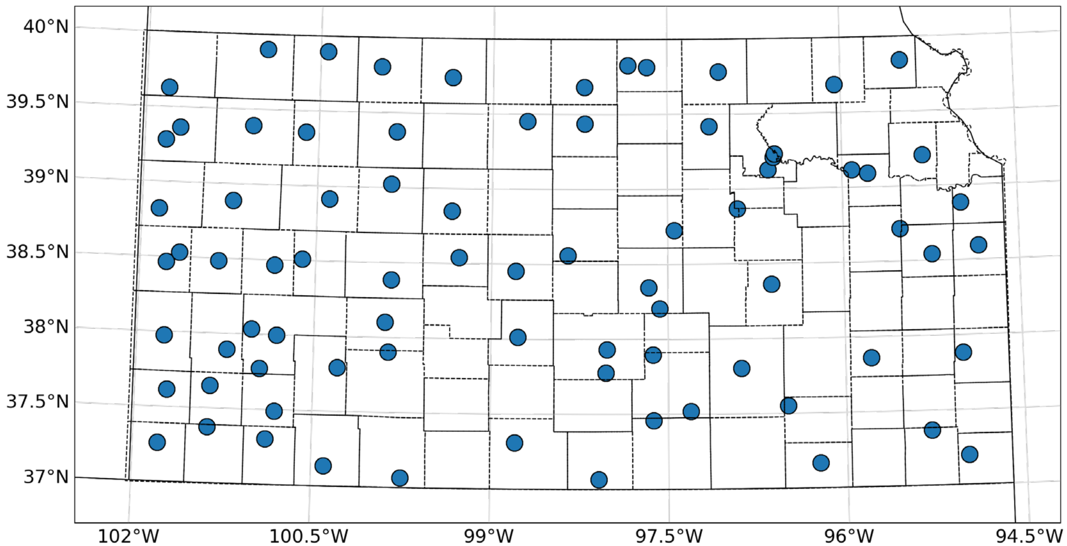
# Mesoscale Monitoring Networks Across the US




- Weather forecasting
- Assessing drought conditions
- Land-atmosphere feedback
- Land carbon uptake
- Flash-flooding predictions
- Wildfire preparedness

Distribution of the mesoscale monitoring network in the US that monitors soil moisture.

# The Kansas Mesonet: Spatial Distribution




Distribution of the Kansas Mesonet stations with soil moisture sensors.

Patrignani, A., Knapp, M., Redmond, C., & Santos, E. (2020). Technical overview of the Kansas Mesonet. Journal of Atmospheric and Oceanic Technology, 37(12), 2167-2183. https://doi.org/10.1175/JTECH-D-19-0214.1

- Established 1984 by Kansas University Research and Extension.
- The network has a total of 84 stations
- 54 stations equipped with point-level soil moisture sensors.

# The Kansas Mesonet: Station Layout

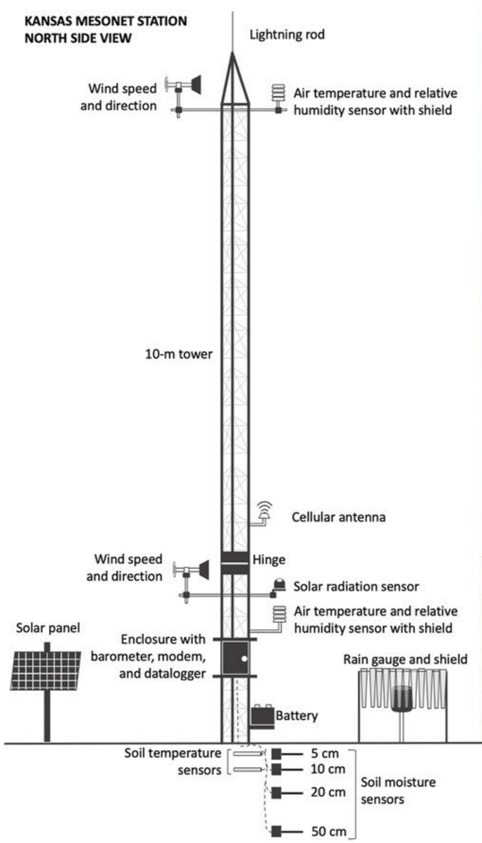



Diagram of a typical Kansas Mesonet monitoring station

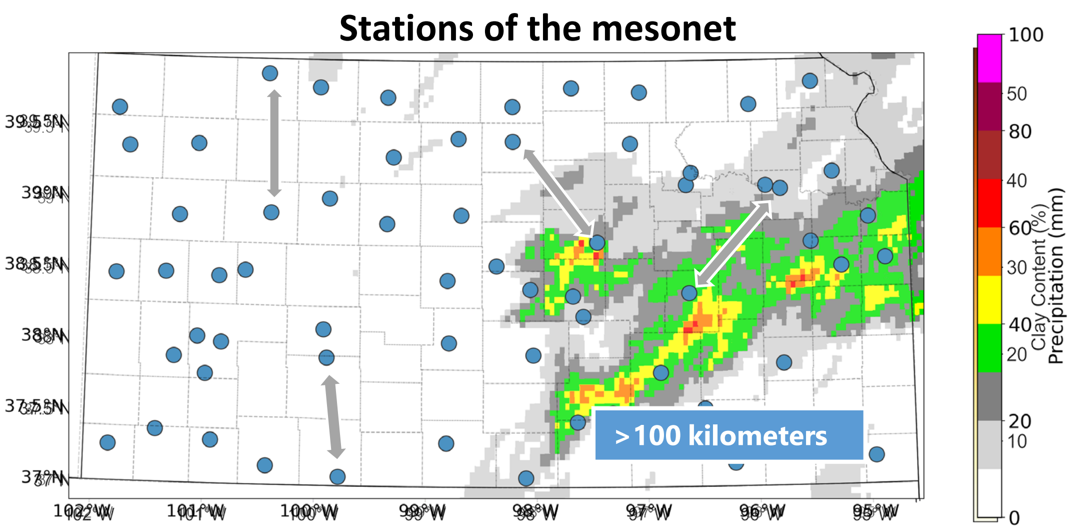
**<u>Variables</u>**

- Precipitation
- Air pressure, temperature, and humidity
- Wind speed and direction
- Soil temperature
- <u>Soil moisture</u>

- Soil moisture sensor: CS655 Soil water reflectometer (Campbell Scientific, Inc.) at 5, 10, 20 , and 50 cm depth
- Custom calibration equation with accuracy RMSE <0.04 $cm^3\ cm^{-3}$
- Small sensing volume (<1000 $cm^3$)

Patrignani, A., Ochsner, T. E., Feng, L., Dyer, D., & Rossini, P. R. (2022). Calibration and validation of soil water reflectometers. Vadose Zone Journal, 21(3), e20190.

# The Upscaling Challenge

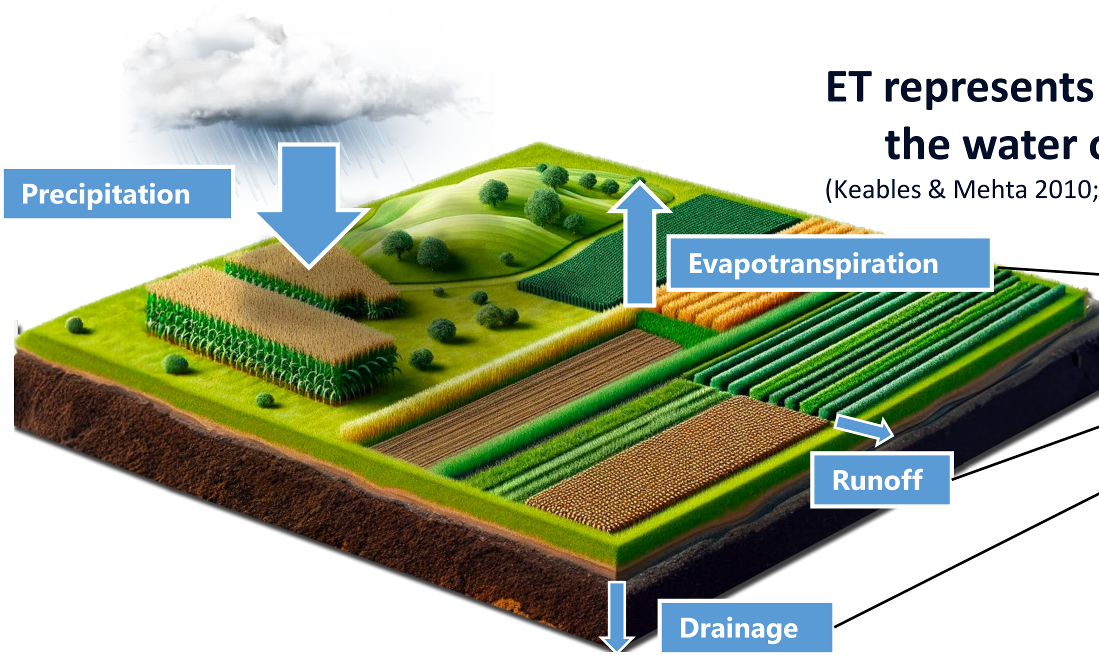



Average clay content for the top 50 cm at 250 m spatial resolution obtained from SoilGrids250m and radar precipitation estimates.

Q: How do we **upscale point-level soil moisture** observations from sparse monitoring networks?

A: **Integrate** spatial **model** estimates and ***in situ*** observations through data assimilation.

# A Simple Model of the Soil Water Balance




**ET represents 80-90% of the water outputs**

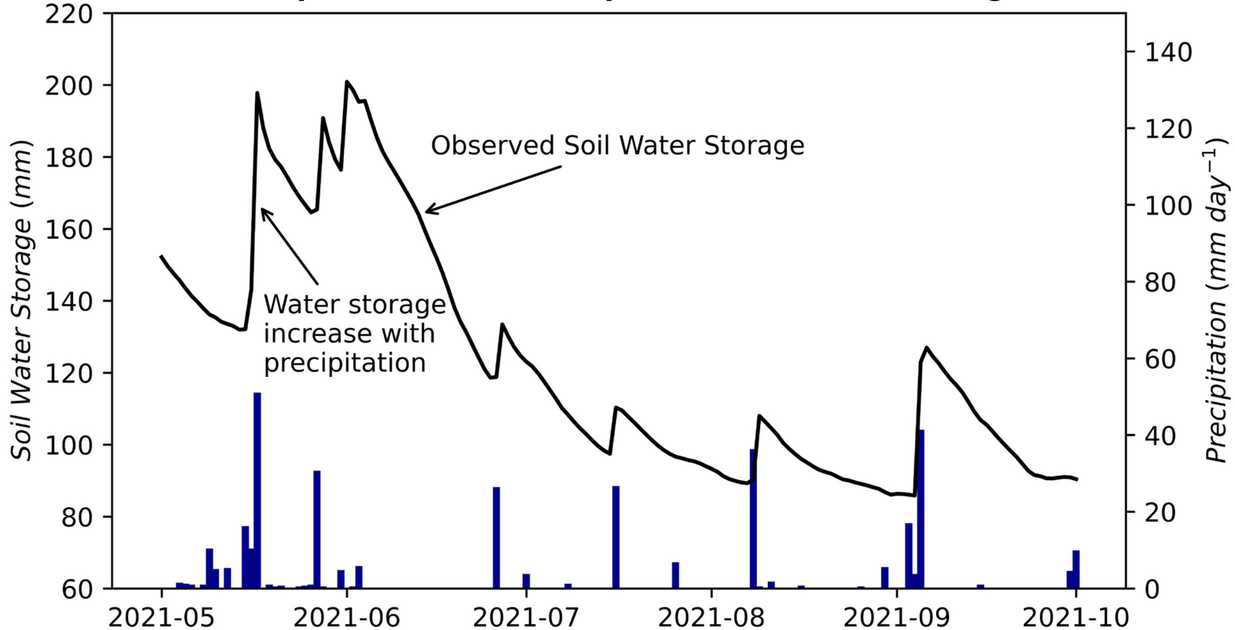
(Keables & Mehta 2010; Reitz et al., 2017)

$\lambda$ **Lumped loss coefficient**

**(Estimated based on vapor pressure deficit or reference ET)**

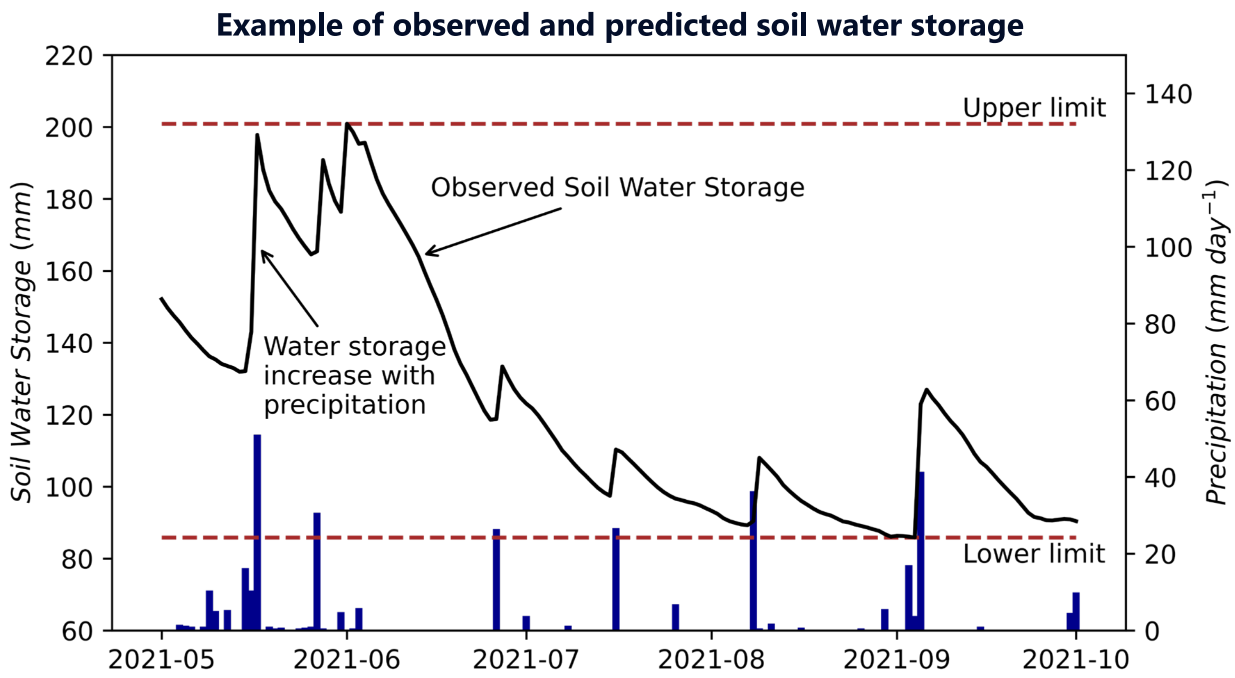
# A Simple Model of the Soil Water Balance

**Example of observed and predicted soil water storage**




Soil water storage for the top 50 cm obtained from the Gypsum station of the Kansas Mesonet.

# A Simple Model of the Soil Water Balance

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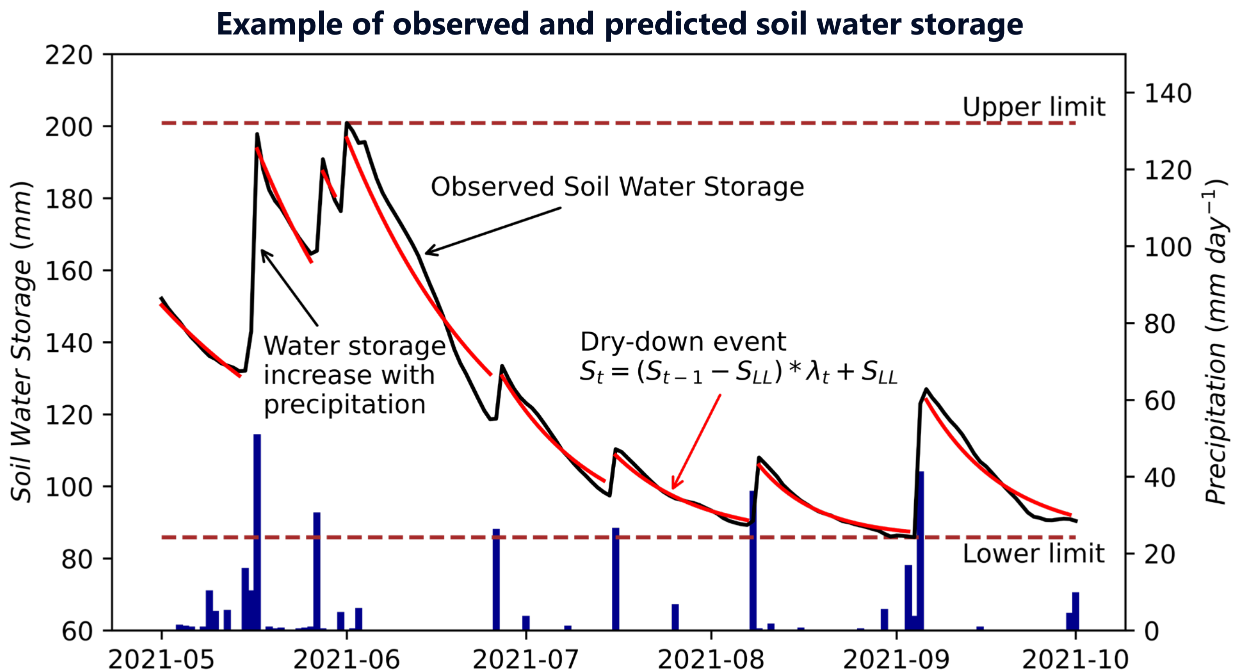
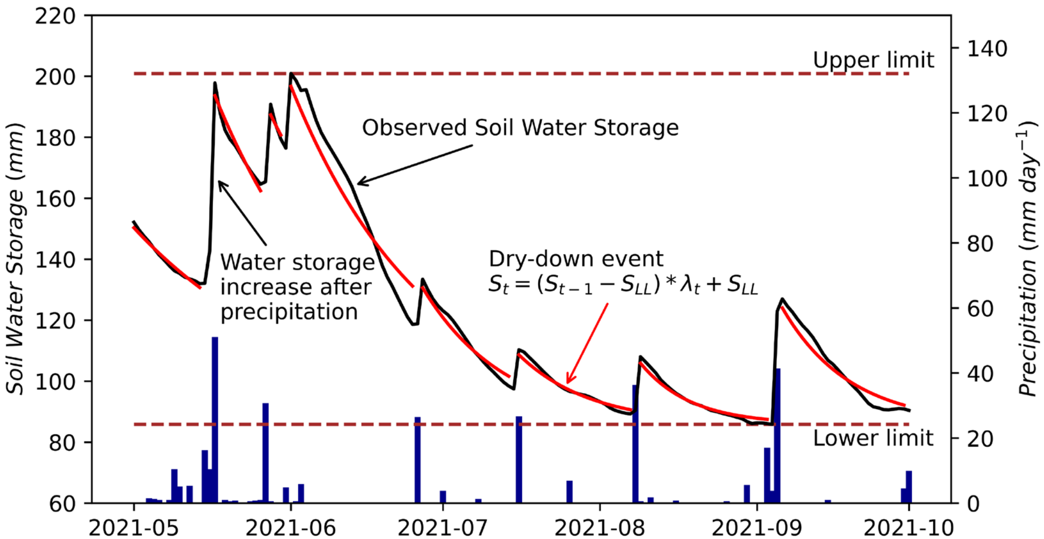



Soil water storage for the top 50 cm obtained from the Gypsum station of the Kansas Mesonet.

$$S_t = \begin{cases} (S_{t-1} - S_{LL})\,\lambda_t + S_{LL} + P_t & S_t \leq S_{UL} \\ S_{UL} & S_t > S_{UL} \end{cases}$$

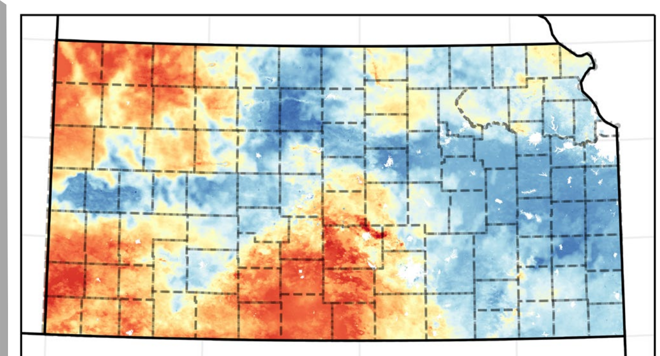
# High-spatial Resolution Soil Moisture Representation Using a Model

## Soil water storage model



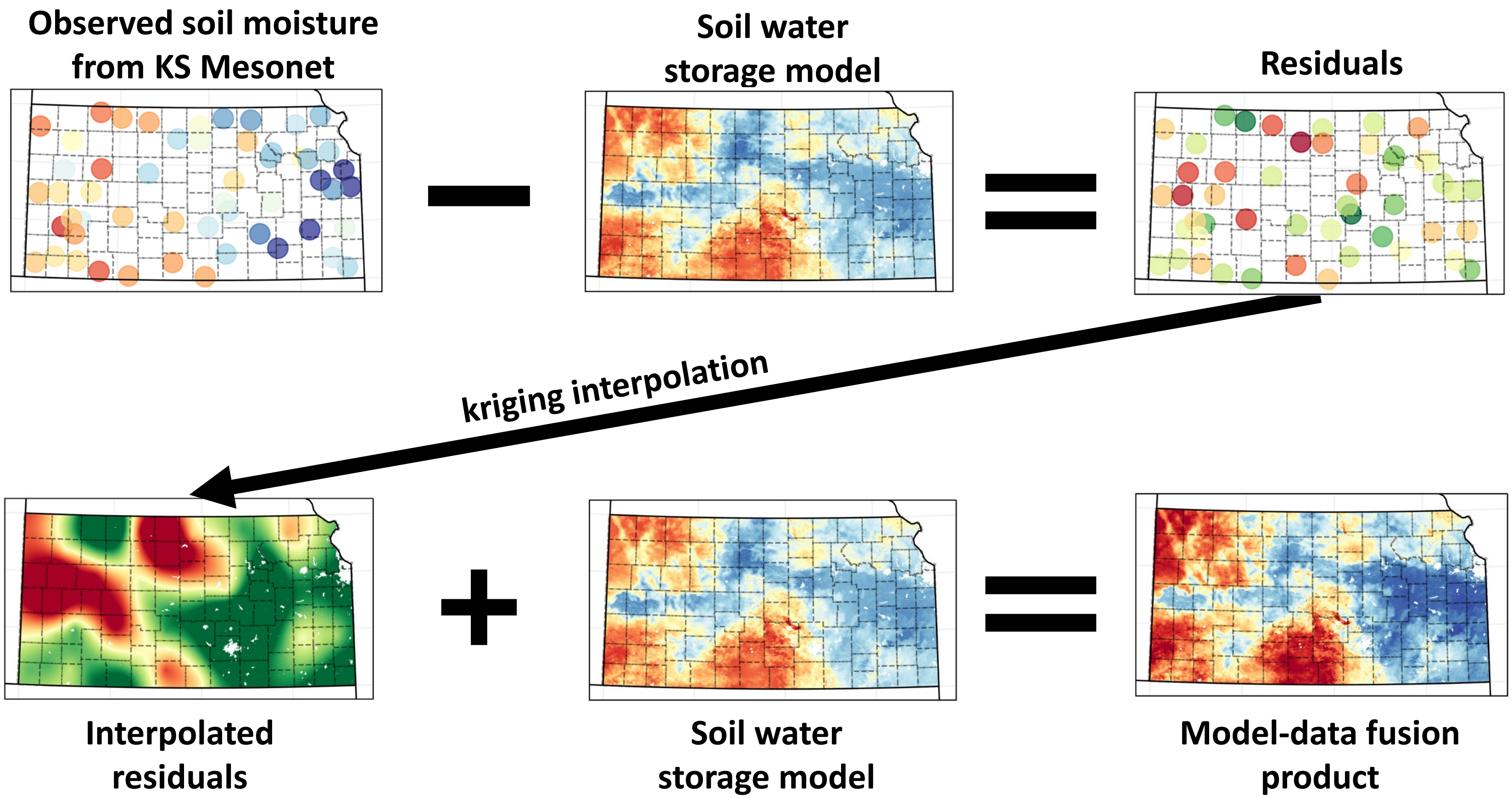

Example of the simple model representing conditions for the Gypsum station of the Kansas Mesonet.

## Apply the model to every 250-meter pixel



## Continuous spatial representation of soil moisture

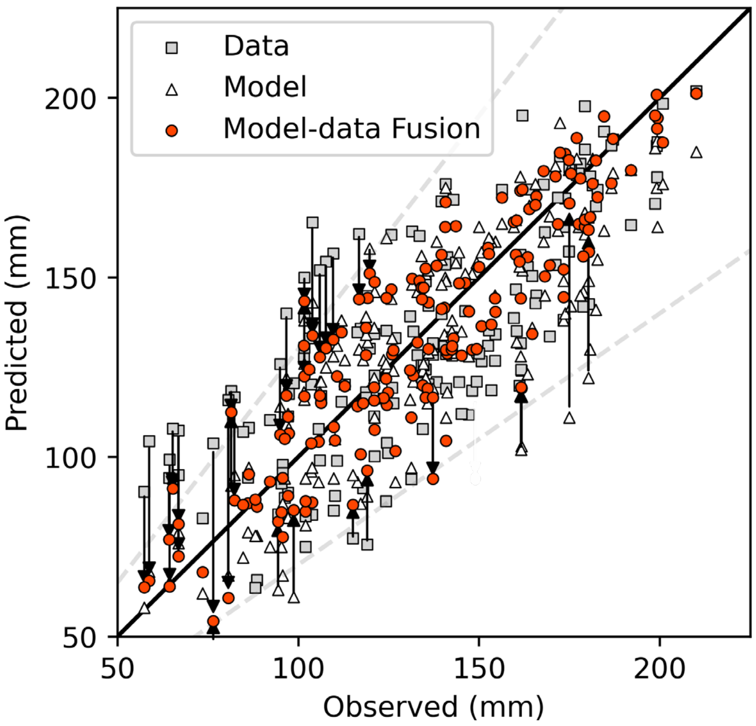
# Model-Data Fusion Workflow



# Accuracy of the Model-data Fusion Approach

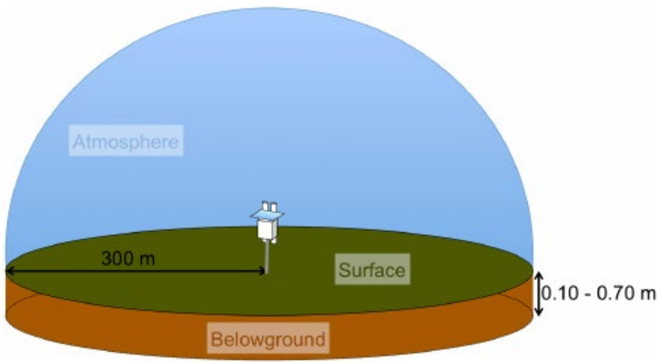
- The model-data assimilation reduced the error of **89%** of the points falling outside the $\pm$ 30% error bars

- Occasionally the model-data assimilation generated less accurate estimations of soil moisture




Sample of cross-validation results. In several cases, the model-data fusion was effective to reduce the uncertainty of model and interpolated in-situ observations.

# Validation Using Non-invasive Soil Moisture Sensing




Approximate COSMOS footprint (**top**) and KSU roving detector (**bottom**)

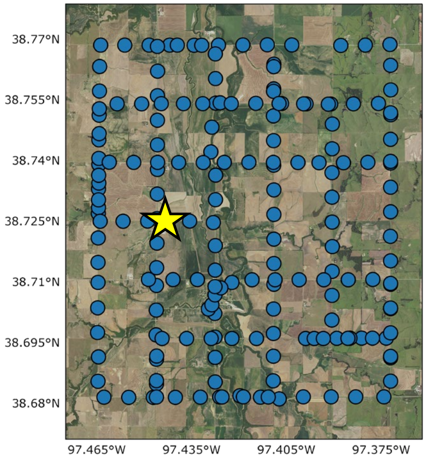
- **CO**smic-ray neutrons **S**oil **M**oisture **O**bserving **S**ystem (COSMOS).
- Monitors background fast-moving neutrons generated at the top of the atmosphere by the impingement of galactic cosmic-ray protons.
- Emerging technology with large sensing footprint (250-300 m in radius).
- Stationary probes and roving probes ideal for field-scale and landscape-scale observations.

# Validation Using CRNP Rover Surveys

**CRNP Rover**

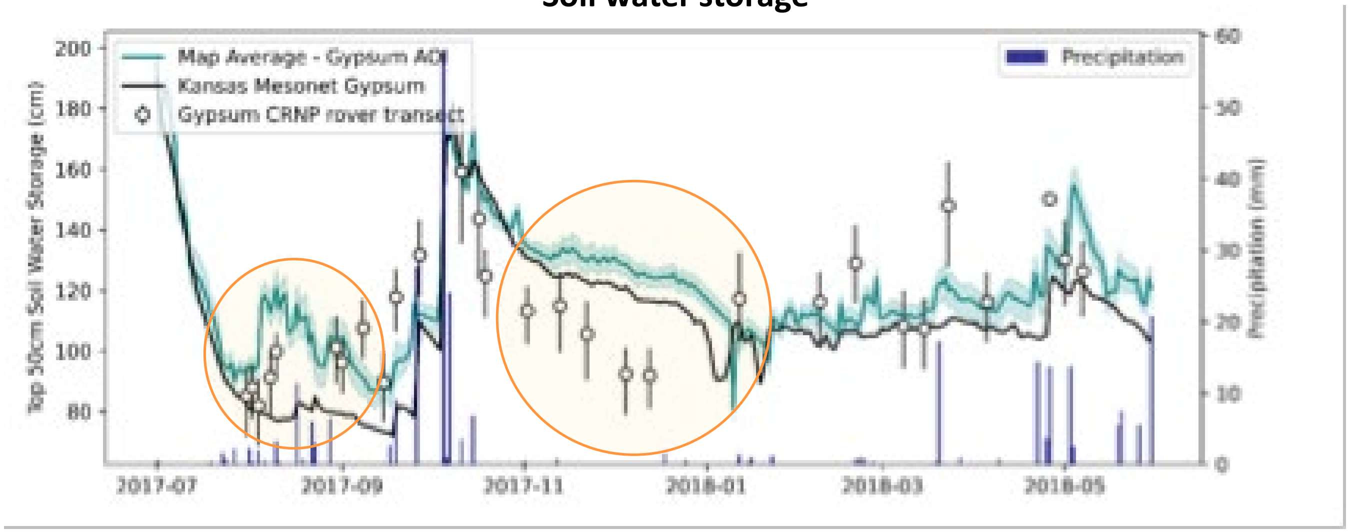
Rover instrument.

**Rover transect**




Rover transect in Gypsum, KS. Start represents the Gypsum station of the Kansas Mesonet.

**Soil water storage**




Time series of daily soil water storage in the top 50 cm obtained from the Gypsum station of the Kansas Mesonet, estimated from rover surveys, and with the data-assimilation method. Shaded area of the soil moisture time series from the data-assimilation method represents one standard deviation

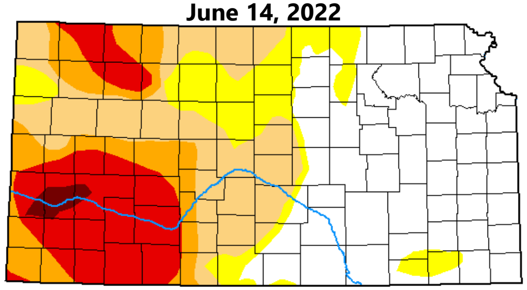
**The median absolute error** between the model-data assimilation and the rover surveys was **16.1 mm**

# Example Maps During the Summer 2022

- Period of 7 days with high atmospheric demand, no rainfall and rapid changes in rootzone soil moisture

- **Daily maps of soil water storage** could be used to identify and **assess flash droughts** at the state level

June 14, 2022



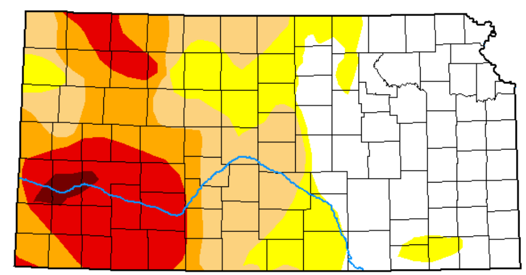
*Drought Conditions (Percent Area)*

| | None | D0-D4 | D1-D4 | D2-D4 | D3-D4 | D4 |
|---|---|---|---|---|---|---|
| Current | 41.37 | 58.63 | 46.39 | 26.73 | 16.25 | 1.03 |
| Last Week *06-07-2022* | 40.04 | 59.96 | 48.48 | 27.39 | 19.34 | 1.13 |
| 3 Months Ago *03-15-2022* | 1.48 | 98.52 | 75.43 | 55.85 | 9.68 | 1.66 |
| Start of Calendar Year *01-04-2022* | 25.19 | 74.81 | 52.34 | 14.06 | 2.45 | 0.00 |
| Start of Water Year *09-28-2021* | 51.22 | 48.78 | 15.04 | 4.14 | 0.00 | 0.00 |
| One Year Ago *06-15-2021* | 96.34 | 3.66 | 0.00 | 0.00 | 0.00 | 0.00 |

Intensity:
- None
- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

*The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. For more information on the Drought Monitor, go to https://droughtmonitor.unl.edu/About.aspx*

June 21, 2022



Sequence of maps illustrating the change in drought conditions reported by the U.S. Drought Monitor.

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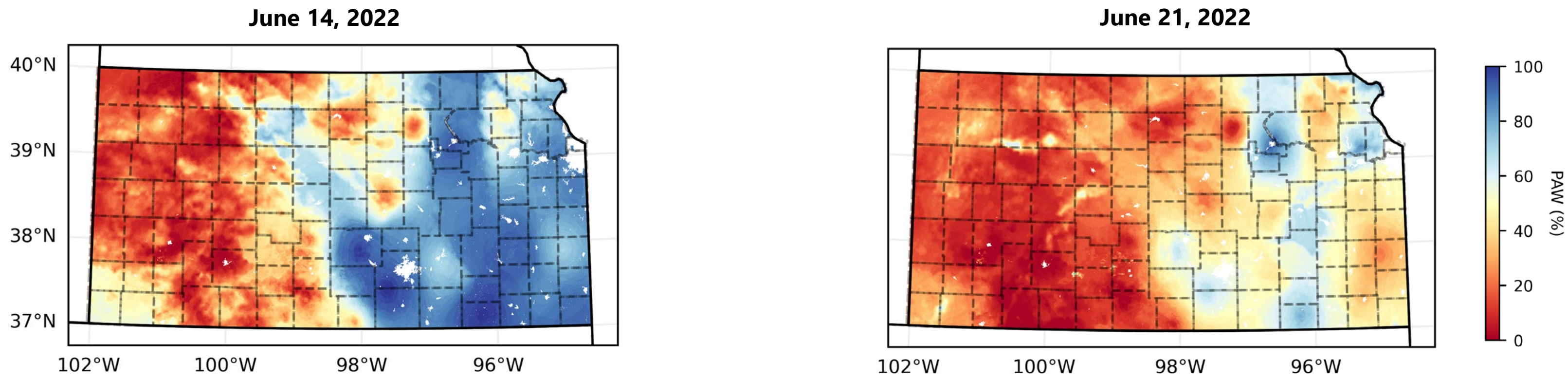
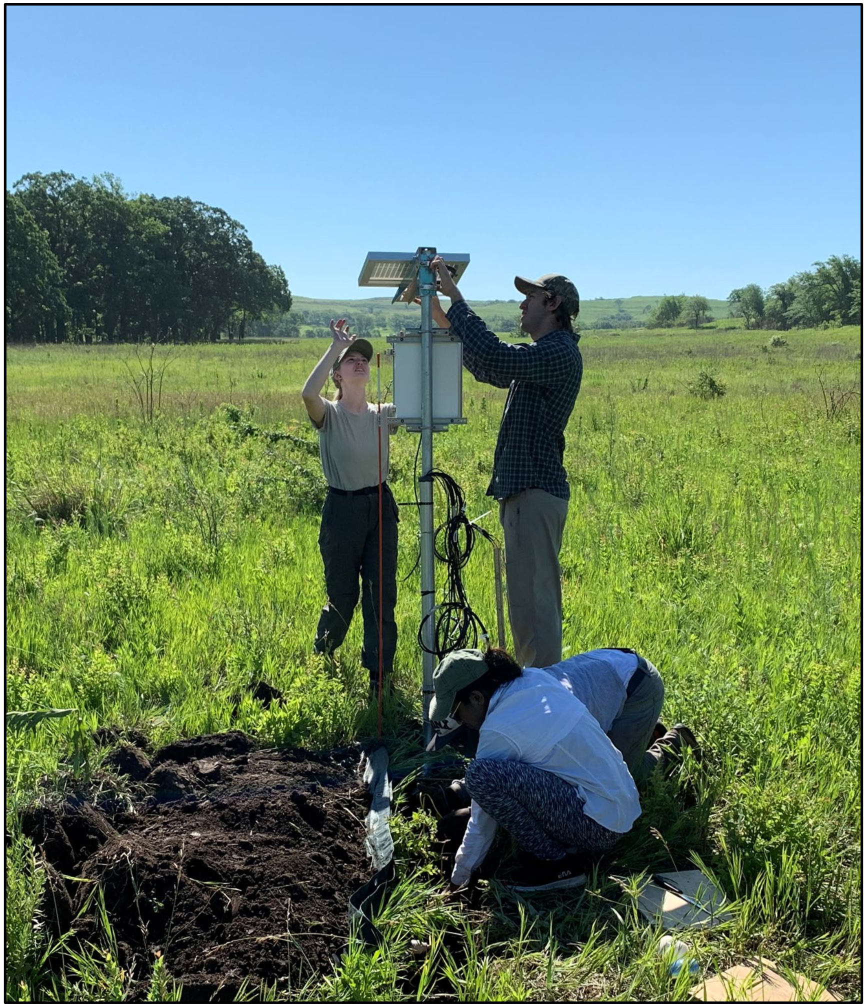



Sequence of maps illustrating the change in plant available water (PAW) across the state of Kansas in June 2022. The rapid decrease of soil moisture during short periods highlights the importance of developing high spatial and temporal resolution operational products to develop flash drought warning systems.



# Questions?

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- **Multistate Soil Moisture Testbeds**
- **Kings Creek Soil Moisture Network**
- **Stover Web App for classifying crop residue**