Challenges and Opportunities of Creating a High-resolution Soil Moisture Map for Kansas

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Nationwide in situ soil moisture monitoring stations (Ochsner et al., 2013).
Kansas In-situ Monitoring Stations
In situ Monitoring Stations

• Readily available ground-truth observations.

• Campbell Scientific 655 soil water reflectometer.

• Sensors deployed at 5, 10, 20, and 50 cm depth.

• Laboratory custom calibration equation.
In situ Monitoring Stations

Factory default
(Topp et al. 1980)

Custom calibration
\[ \theta_{\text{corrected}} = A + B \sqrt{\epsilon'} + C T \epsilon' \]

\( N = 136 \)

Default (left) and custom (right) calibration equations for the CS655 soil water reflectometer.
Fraction of available water capacity in the root-zone (top 50 cm of the soil profile) for the Kansas Mesonet station located near Gypsum, KS.

Threshold for moisture stress in plants (Allen et al. (1998))

88 consecutive days of severe drought
Remote Sensing Soil Moisture

- Measures top 5 cm of the soil profile.
- Latency of 2-3 days.
- Coarse grid of 36 x 36 km (<200 pixels to cover the state of Kansas).
- Daily products at 9x9 km when assimilated with land surface models.
- Ideal for large scale (i.e. nation, global) monitoring.

NASA Soil Moisture Active-Passive (SMAP) mission.
Volumetric Water Content

Mesonet near Gypsum, KS

SMAP
Volumetric Water Content

Mesonet near Gypsum, KS

SMAP

Mesonet

SMAP
Modeling Soil Moisture Dynamics

Soil moisture diagnostic equation:

\[
\theta = \theta_{re} + (\phi_e - \theta_{re})(1 - e^{-c_4B})
\]

\(\theta\) = Volumetric water content [m\(^3\) m\(^{-3}\)]
\(\theta_{re}\) = Residual water content [m\(^3\) m\(^{-3}\)]
\(\phi_e\) = Effective porosity [m\(^3\) m\(^{-3}\)]
\(C_4\) = Parameter that depends on the soil physical properties
\(B\) = Exponential filter applied to a precipitation timeseries

RMSE = 2.83 m$^3$ m$^{-3}$
Map of percent clay content in the top 5 cm at 800 m resolution for the state of Kansas. Darker colors represent higher clay content. Source: USDA-NRCS Soil Survey Geodatabase.
First Statewide Soil Moisture Map (0-5 cm)

Map of fraction of plant available water capacity in the top 5 cm at 800 m resolution for the state of Kansas. Source: soilwater.ksu.edu
Proximal sensing using Cosmic-ray Neutrons

- **COsmic-ray neutrons Soil Moisture Observing System (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.

Approximate COSMOS footprint (top) and KSU roving detector (bottom)
Maps of volumetric water content of a 9x9 km SMAP grid cell measured with a roving cosmic-ray neutron probe near Gypsum, KS before (left) and after (right) a series of rainfall events totaling 97 mm. Black markers represent rover measurements (N=220).
Challenges

• **Lack of guidelines** and standards for soil moisture monitoring across large-scale networks.

• Large-scale networks only monitor soil moisture under grassland vegetation. How do we **upscale** point-level observation to represent different land covers?

• **Downscaling** remote sensing coarse grids for field or watershed studies that often require finer resolution and knowledge of root-zone soil moisture.

• **Emerging technologies** still require simpler **calibration** and **validation** methods.

• **Spatial characterization** soil physical properties.