Long Short-Term Memory model to predict root zone soil water content from neutron count measured by CRNS

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Background

- Average root zone soil water content (e.g., 0 - 30 cm) is essential for management decisions such as irrigation, fertilization, and soil tillage
- Cosmic-Ray Neutron Sensing (CRNS) provides field – scale soil moisture measurement
- CRNS sensitivity varies with both depth and distance from the sensor, complicating accurate root zone soil moisture estimates

Problem statement

Forward calculation
- Using Hydrus1D – COSMIC
- Average soil moisture to neutron count rate

Backward calculation
- Neutron count rate to average soil moisture
- Non unique relationship (**Figure 1.**)

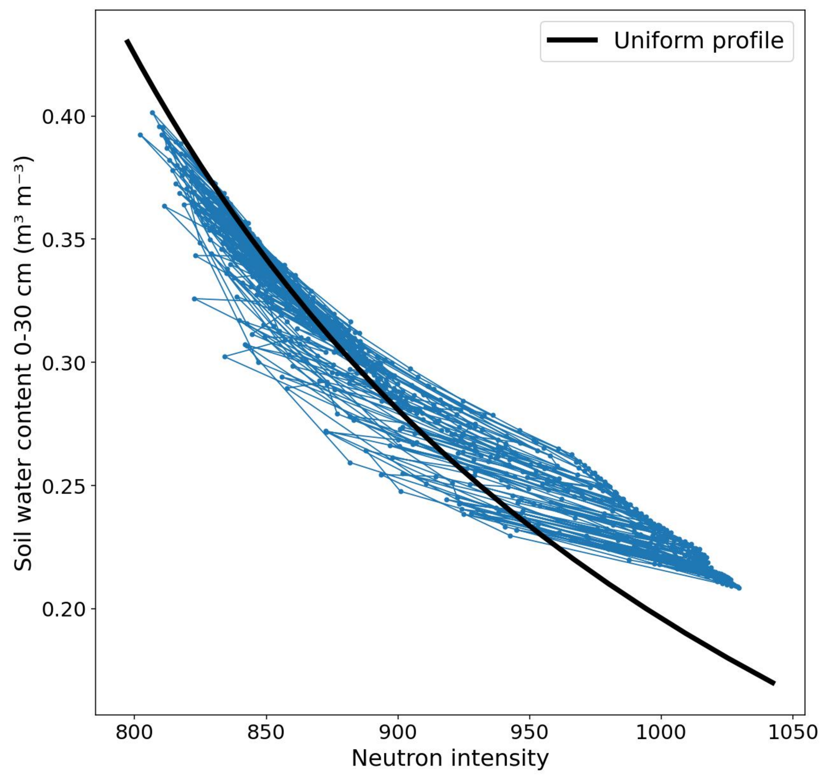

Figure 1. Neutron count vs average soil water content in 0-30 cm layer derived from Hydrus1D – COSMIC. The blue line shows the relationship in a non-homogeneous soil profile and black line shows the relationship in a homogeneous soil profile

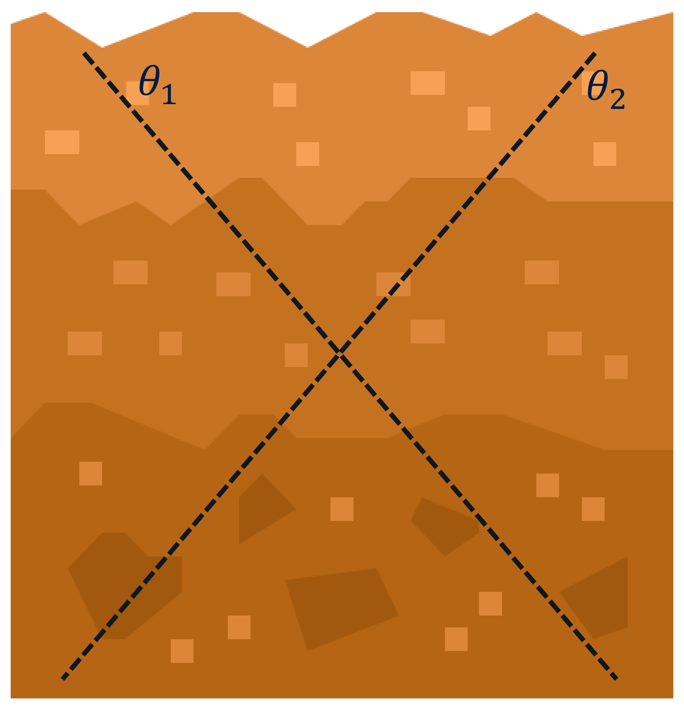

Figure 2. Illustration of two hypothetical soil moisture profiles, θ_1 (wetting) and θ_2 (drying) with the same average water content.

The topsoil layer, which CRNS is most sensitive to, responds first to drying (evapotranspiration) and wetting (infiltration). Leading to **underestimation during drying** and **overestimation during wetting.**

As a result, θ_1 will have a higher neutron count rate and θ_2 will have a lower neutron count rate, while they have the same average root zone soil moisture content,

Objective

Using a Long Short-Term Memory (LSTM) model to predict average root zone soil water content from neutron count rate.

Methods

1. Hydrus1D – COSMIC

Hydrus1D (Šimůnek et al., 2008) simulates the daily soil water content profile and average 0-30 cm soil water content. **COSMIC (Shuttleworth et al., 2013)** translates the soil water profile from Hydrus1D into neutron count rate.

The integrated **Hydrus1D-COSMIC** model **(Brunetti et al., 2019)** was used in this research to generate training data for the LSTM model.

Input Data
- Daily precipitation*
- Daily reference evapotranspiration*
- Bulk density**
- Lattice water

*KMI data, **Field sampling

→

Hydrus1D - COSMIC
- 20 years (2005 – 2025) simulation
- Silt loam soil*
- Bare soil

*Hydrus soil catalog

→

Output
- Average 0-30 cm soil water content
- Neutron count rate

2. Long Short – Term Memory (LSTM) model

The LSTM model (Hochreiter & Schmidhuber, 1997) was trained using the result from Hydrus1D-COSMIC simulation to predict average 0-30 cm soil water content.

Input Data
- Daily precipitation*
- Daily reference evapotranspiration*
- Neutron count rate

*KMI data

→

LSTM model
- Training:validation:testing (70:20:10)
- 20 years (2005-2025) data
- Evaluated with R^2 and $RMSE$

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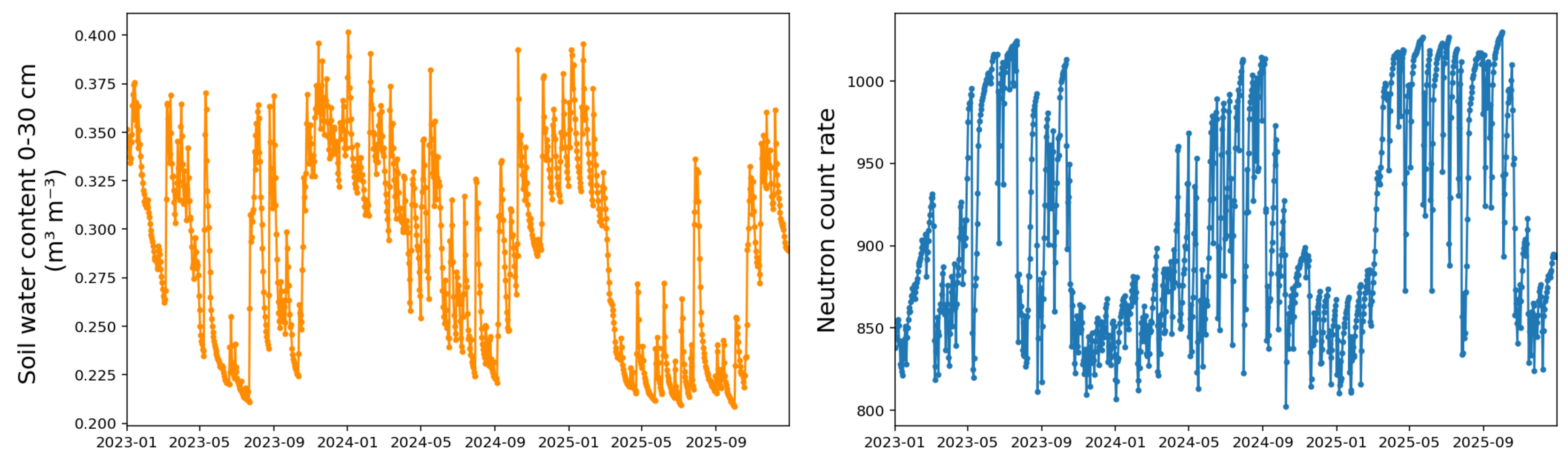
Output

Average 0-30 cm soil water content

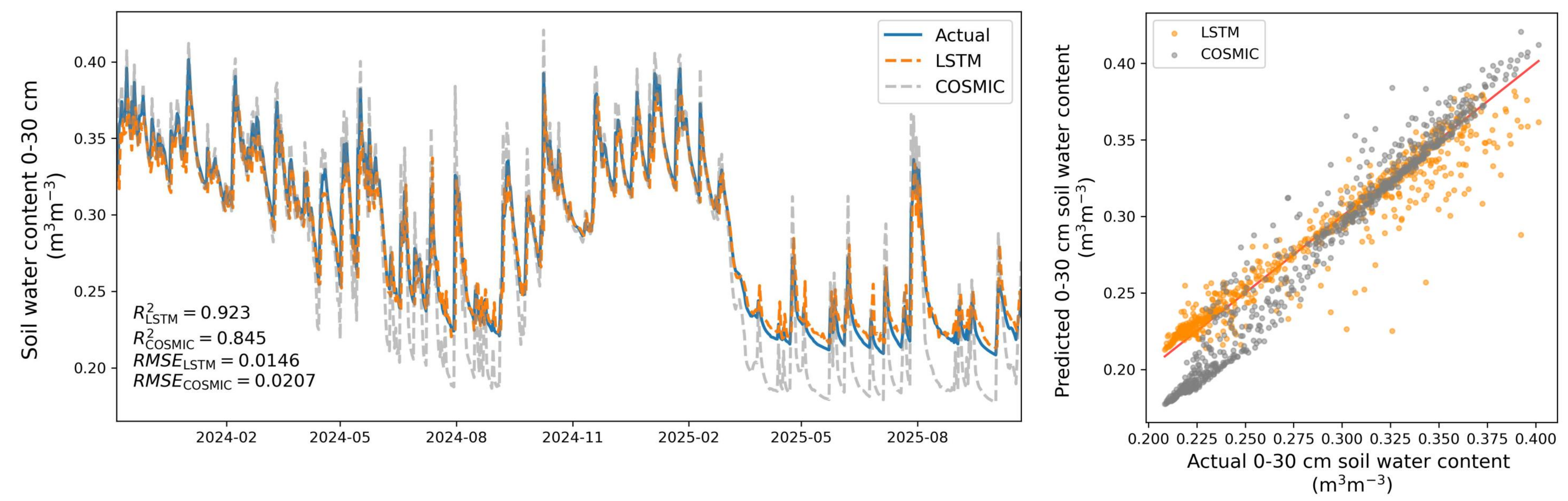
Results

Hydrus1D – COSMIC results



LSTM

Testing dataset (10%)



Both models perform well in capturing soil moisture dynamics during the wet season, particularly during drying events. However, COSMIC tends to overestimate peak values, while LSTM underestimates peak values.

During the dry season, LSTM performs better, as COSMIC exhibits larger biases and underestimates soil water content under drying conditions. Notably, the dry season coincides with the cropping period, when accurate soil moisture estimates are critical for management decisions such as irrigation scheduling.

Further work:

- Investigate how variations in soil hydraulic properties influence model performance
- Incorporate site-specific CRNS calibration
- Generate scenarios for different soil types
- Create vegetated simulations
- Evaluate the model performance with field measurement and soil sampling

Key references

Brunetti, G., Šimůnek, J., Bogena, H., Baatz, R., Huisman, J. A., Dahlke, H., & Vereecken, H. (2019). On the Information Content of Cosmic-Ray Neutron Data in the Inverse Estimation of Soil Hydraulic Properties. Vadose Zone Journal, 18(1), 180123. https://doi.org/10.2136/vzj2018.06.0123

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Shuttleworth, J., Rosolem, R., Zreda, M., & Franz, T. (2013). The COsmic-ray Soil Moisture Interaction Code (COSMIC) for use in data assimilation. Hydrology and Earth System Sciences, 17(8), 3205–3217. https://doi.org/10.5194/hess-17-3205-2013

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