Converting Cosmic Ray Neutron Sensing count rates into average topsoil moisture contents when vertical soil moisture gradients occur in the topsoil

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1. Introduction

The Cosmic Ray Neutron Sensor (CRNS) technique yields a depth-weighted average soil water content (swc), with the weights rapidly decreasing with depth. This is an issue if the soil water content varies with depth and we use CRNS for estimating the average swc of the topsoil (e.g., 0-30cm) for practical applications (e.g., irrigation scheduling)

Soil drying (soil evaporation) and wetting (infiltration) start from the soil surface, i.e., at the depth that is most influential. So CRNS may underestimate the average 0-30cm swc when the soil is drying, and overestimate it during or after infiltration events. This adds uncertainty to the CRNS-measured topsoil swc.

2. Questions:

- Up to which depth can the **average** soil water content of the topsoil be measured with CRNS with acceptable uncertainty?
- Can we correct for the errors arising from depth-weighing of CRNS?

3. Methods

- **Hydrus-1D** (Šimůnek et al., 2008) was used to simulate the soil water dynamics for a period of 1039 days for a silt loam soil and a sandy soil under weather conditions from Brussels (daily weather data). The simulations were done twice: for grassland (no soil evaporation) and bare soil.
- **COSMIC** (Shuttleworth et al., 2013) was used to translate Hydrus-simulated daily soil water profiles (1-cm vertical discretization) into relative CRNS count rates N/N_0 (with N_0 the count rate for a dry soil with the same COSMIC soil properties). The integrated Hydrus1D-COSMIC code developed by Brunetti et al. (2019) was used for this.
- From the simulated daily soil water content (swc) profiles we also calculated the daily average swc for topsoil layers 0-5cm, 0-10cm, 0-20cm and 0-30cm. For comparison with these 'true' average swc values, we calculated the topsoil swc from the simulated N/N_0 value with COSMIC as one would do if a measured CRNS relative count rate N/N_0 is used to predict the topsoil swc.
- We did not consider complications arising from corrections to be made for water in crop biomass or air humidity, incoming neutron intensity etc., as the focus is on errors coming from vertical swc gradients.

References:

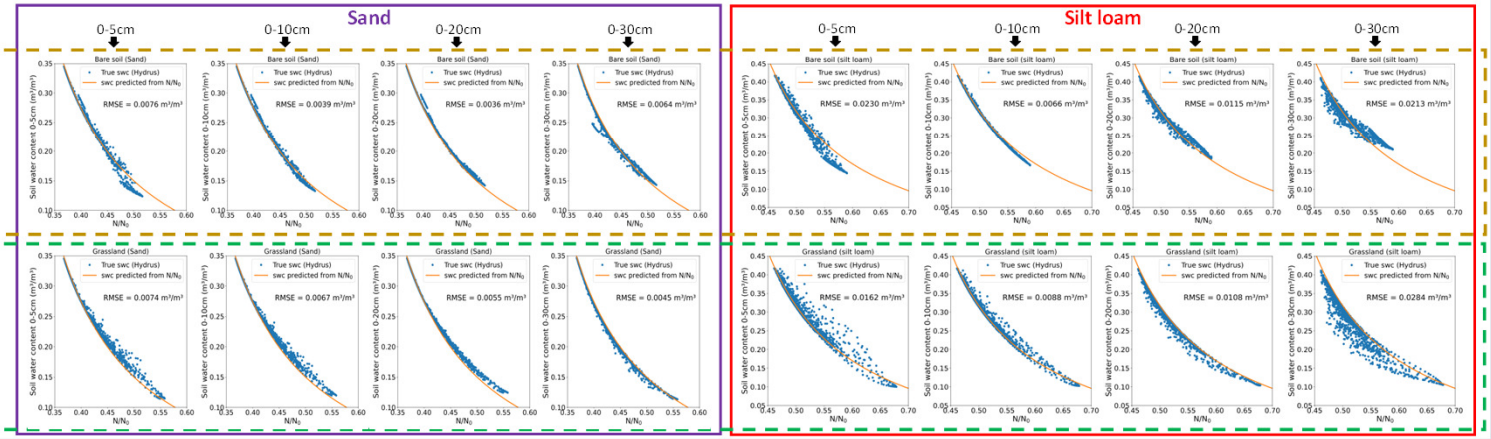
Brunetti, G., Šimůnek, J., Bogena, H., Baatz, R., Huisman, J.A., Dahlke, H., Vereecken, H., 2019. On the Information Content of Cosmic-Ray Neutron Data in the Inverse Estimation of Soil Hydraulic Properties. Vadose Zone J., 18(1): 180123. DOI:https://doi.org/10.2136/vzj2018.06.0123

Shuttleworth, J., Rosolem, R., Zreda, M., Franz, T., 2013. The COsmic-ray Soil Moisture Interaction Code (COSMIC) for use in data assimilation. Hydrol. Earth Syst. Sci., 17(8): 3205-3217. DOI:10.5194/hess-17-3205-2013

Šimůnek, J., Sejna, M., Saito, H., Sakai, M., van Genuchten, M.T., 2008. The HYDRUS-1D Software Package for Simulating the Movement of Water, Heat, and Multiple Solutes in Variably Saturated Media, Version 4.0, HYDRUS Software Series 3, Department of Environmental Sciences, University of California Riverside, Riverside, California, USA, 315 pp.

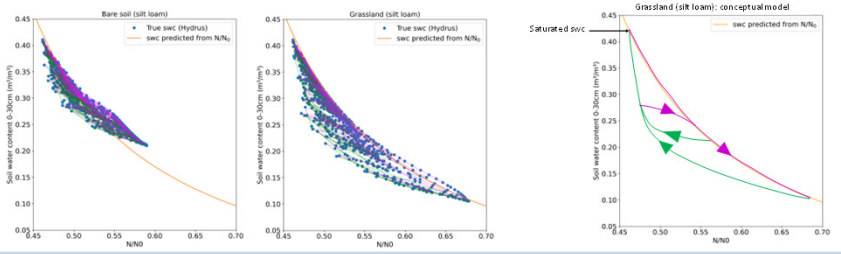
4. Results

- The graphs below compare the true daily average soil water content (0-5cm, 0-10cm, 0-20cm, 0-30cm) calculated from the Hydrus-simulated soil water contents (as blue dots) and compare them with topsoil water contents calculated with COSMIC from N/N_0 (orange line).
- For the **sandy soil**, differences are small with RMSE values ranging between 0.0036 and 0.0076 m^3/m^3. For the sandy soil, errors are small and the N/N_0 value can even provide a topsoil swc that differs little from the true average swc for the 0-30cm topsoil.
- Vertical swc gradients in the **silt loam** soil however create large errors, with RMSE values ranging between 0.0066 and 0.028 m^3/m^3. The CRNS N/N_0 value is best to predict the 0-10cm or 0-20cm average swc, and errors are increasing when it is used to predict 0-5cm or 0-30cm average swc.



5. Further analysis of results

- For the results for the case with the largest variation (predicting the average swc of the 0-30cm topsoil for the silt loam soil), we connected subsequent data points in the time series with a magenta line when N/N_0 is increasing, and with a green line when it is decreasing.
- This shows **clockwise hysteresis loops**: since both drying (soil evaporation from bare soil) and wetting (rain infiltration) start from the top, i.e., at the most influential depth, N/N_0 always reacts stronger than the average swc. Crop water uptake tends to remove swc gradients and hence brings the curves back to the orange line (magenta lines in the middle figure below). This is illustrated in the conceptual figure on the right.



6. Conclusions

- In the sandy soil, vertical swc gradients were small and the CRNS N/N_0 value provided a good estimate of the average smc of the topsoil (0-5cm, 0-10cm, 0-20cm, 0-30cm) with errors less than 0.01 m^3/m^3 arising from vertical swc gradients.
- In the silt loam soil vertical swc gradients are more important. The N/N_0 still predicts average swc with acceptable errors (RMSE of 0.08-0.10 m^3/m^3, but with swc errors up to 0.04 m^3/m^3), but errors become too large when predicting errors for the 0-5cm or 0-30cm topsoil.
- Soil drying and wetting starts from the top, thus causing clockwise hysteresis loops.
- One could try to improve estimates by deriving a hysteresis model to be estimated with doing model simulations and measurements of soil hydraulic properties, but this is complicated by the large spatial footprint of CRNS and the fact that the hysteretic behaviour differs between bare and cropped soil.

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Abstract