Forest plot soil moisture estimation using the cosmic-ray neutron (CRN) method and gamma-ray spectrometry (GRS)

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INTRODUCTION

- In forests, the water input to the ground is highly variable resulting in an uneven soil water content.
- Methods for estimating soil moisture at forest plot scale are necessary to understand the forest water budget.
- Gamma-ray spectrometry (GRS) can be used to estimate soil moisture using the procedure presented by Baldoncini et al. (2018).
- Soil moisture can be estimated for several depths using GRS measurements. The equipment is light and easy to handle, and only local data is required for the soil moisture estimation procedure.
- In this study, we compare GRS and cosmic-ray neutron (CRN) soil moisture estimates for a forest field site.

STUDY SITE AND INSTRUMENTATION

Study site:

- Gludsted forest plantation, Denmark (Figure 1)
- Coniferous forest planted in 1976 and 1984

Figure 1. Study site.

CRN

- CR2000/B system with bare and moderated detectors with and without a cadmium shield to obtain purer signals of thermal (T) and epithermal neutrons (E), and T/E ratios
- Footprint area: Around 200 m in diameter (Figure 2)
- Measurement depth: Around 20 cm.
- The signal is affected by all hydrogen in the footprint area (soil moisture, biomass, litter layer)
- Soil moisture is estimated from epithermal neutrons using the physically based site-specific conversion function (Andreasen et al, 2020)

GRS

- The gSMS-100 system records the nuclide concentration of 137-Cs, 40-K and 232-Th
- Detection height: 2 m and 28.2 m above the ground surface
- The GRS signal varies according to soil moisture changes. At canopy level, the signal is also affected by the vegetation and the water in and on the trees
- Footprint area: Increases with height above the ground (Figure 2)
- Measurement depth: Shallow depths are represented by the 137-Cs measurements. For 40-K and 232-Th, 95% of the GRS flux comes from the top 21 cm and 27 cm of the soil layer, respectively (Baldoncini et al., 2018)
- Volumetric soil moisture is estimated for each of the three nuclides using the calibration function of Baldoncini et al. (2018):

$$\theta = BD\left(\frac{S_0}{S}(0.903 + \frac{\theta_0}{BD}) - 0.903\right)$$

- BD is dry bulk density (1.60 g/cm^3)
- θ is soil moisture at time t and θ_0 is soil moisture at calibration
- S is GRS concentration at time t and S_0 is GRS concentration at calibration
- θ_0 and S_0 are determined using a least square minimum approach of soil moisture time-series estimated using GRS concentrations and CRN intensity
- For this first attempt, the "Baldoncini-constant" 0.903 is used

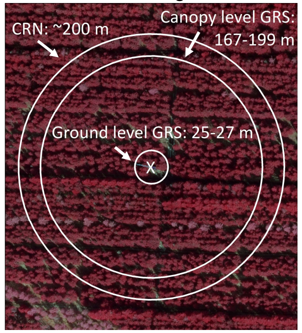
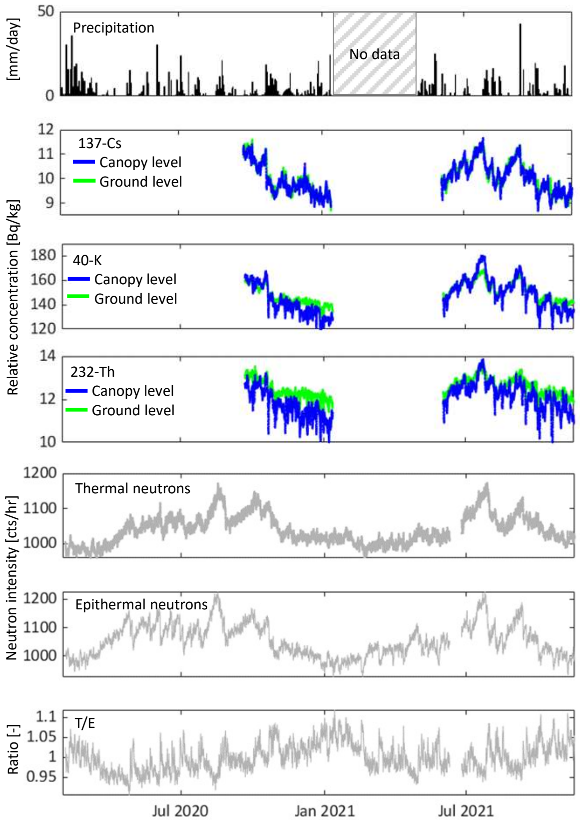


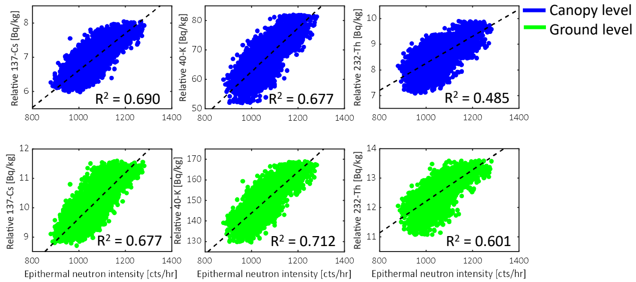
Figure 2. Footprint area of the CRN system, and the GRS detectors at ground- and canopy level. The values are the diameter of the footprint.

RESULTS: GRS AND CRN

- To compare the concentrations at the two height levels, relative values are considered.
- Clear responses in the GRS signal to precipitation.

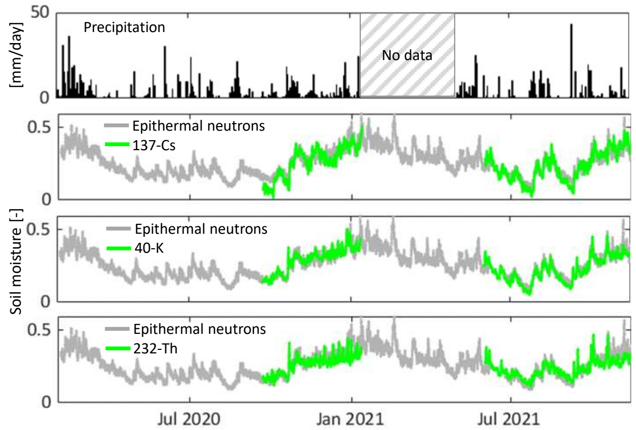


- A clear linear relationship of epithermal neutrons (used for CRN soil moisture estimation) and GRS concentrations, especially at ground level.



RESULTS: SOIL MOISTURE ESTIMATION

- The calibration function is determined for ground level GRS measurements. Therefore, only the ground level GRS signal is used for soil moisture estimation.
- GRS and CRN soil moisture are similar, especially for 40-K.

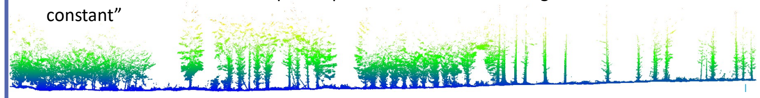


CONCLUSIONS

- We found a clear relationship of epithermal neutrons and GRS concentrations, especially at ground level.
- We estimate realistic soil moisture from GRS measurements comparable to estimates obtained from CRN measurements.
- We used a calibration function determined for agriculture land and expect even better GRS soil moisture estimates when the effect of forest cover is included in the calibration procedure.

NEXT STEP

- Height correction of GRS measurements. This will allow:
  1. A direct comparison of ground level and canopy level GRS measurements
  2. Soil moisture estimations using canopy level GRS measurements (with a footprint area like CRN soil moisture)
- Determine site- and nuclide-specific parameters instead of using the "Baldocini-constant"



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