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Cosmic Sense

Dynamic groundwater recharge rates at field scale: how to successfully use soil moisture from cosmic-ray neutron sensing

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Cosmic Ray Neutron Sensing (CRNS)

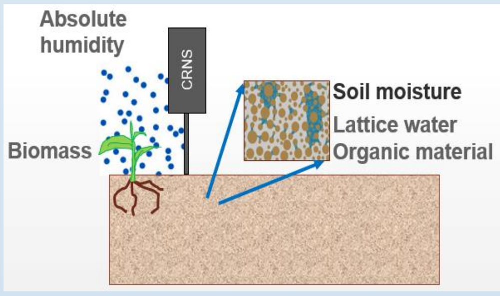
- Neutron probe to measure soil moisture (natural radiation, passive)
- Non-invasively, installed above ground
- Inverse relationship between neutrons and soil moisture

Integral field water content:

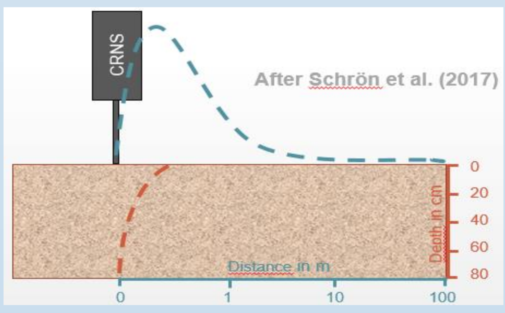
- **Depth of several tens of centimeters**
- **Horizontal coverage > 150 m radius**

How to get the soil water dynamics right

- **Corrections of neutron signal**
  (pressure, incoming radiation, water vapor, (biomass)
- **All hydrogen detected**
  (biomass, water vapor, water equivalent in soil organic carbon and crystal lattice)
- **Calibration**
  (invasive soil sampling, horizontal an vertical weighting, additional hydrogen pools)
- **Variable support volume**
  (distance to sensor, depth, dependence on soil moisture)



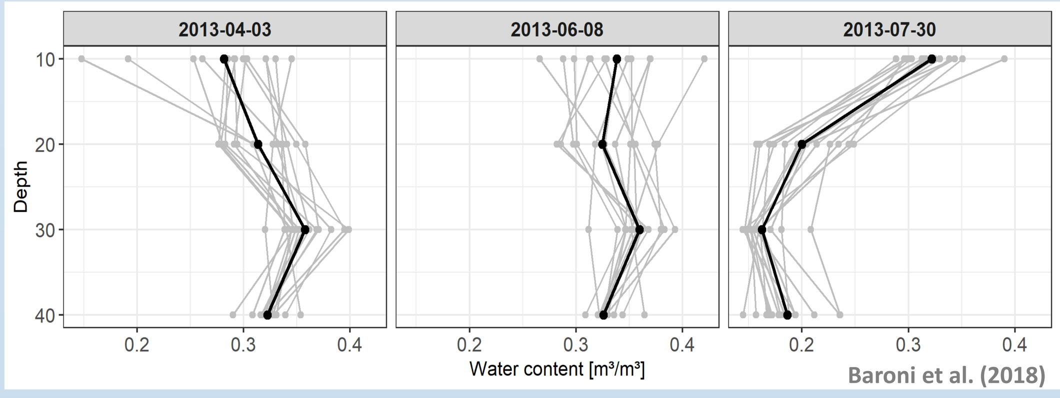
Hydrogen pools affecting the CRNS measurement



The approximate sensitivity of the sensor

Profile shape correction of CRNS-derived soil moisture

- Previous own work: uncertainty associated to soil moisture profile
- Cosmic ray soil moisture representing "total weighted water content"
- Hampering easy use for models and complicating interpretation
- Correction of CRNS based soil moisture profile shape and the weighting of the profile



Profiles of a sensor network for days with the same CRNS soil moisture (0.35 $m^3\ m^{-3}$). Very different profile shapes and average soil moistures (0.32, 0.34, 0.22 $m^3\ m^{-3}$, respectively) lead to the same CRNS soil moisture. This complicates he use of CRNS as a standalone method

Motivation

Groundwater recharge

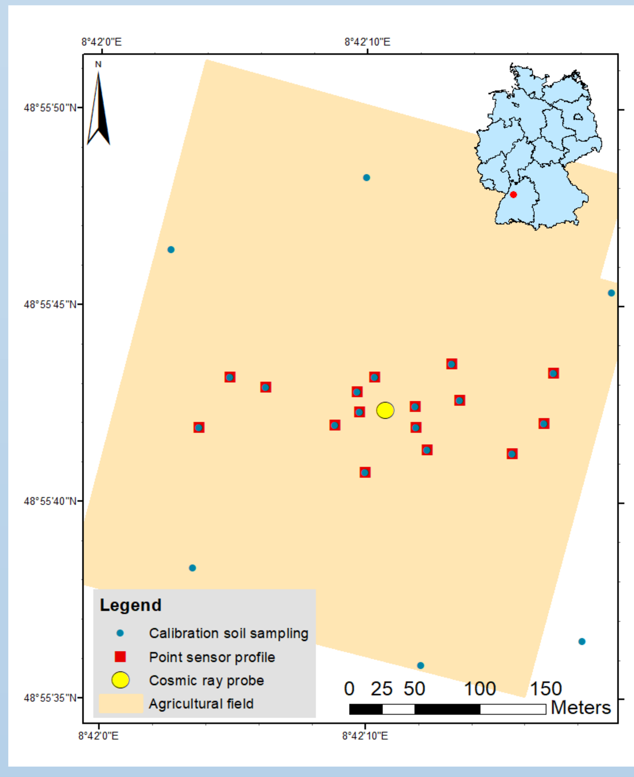
- Groundwater recharge estimation is fundamental for the sustainable use of groundwater resources in terms of quantity and quality
- Uncertainty of groundwater recharge is a major limitation for accuracy of groundwater models

Use of CRNS

- Field scale average of soil water content
- Promising to estimate effective soil hydraulic parameters and estimate recharge at relevant scales
- *How to deal with the sensitivity of the sensor to estimate water fluxes using CRNS soil moisture?*

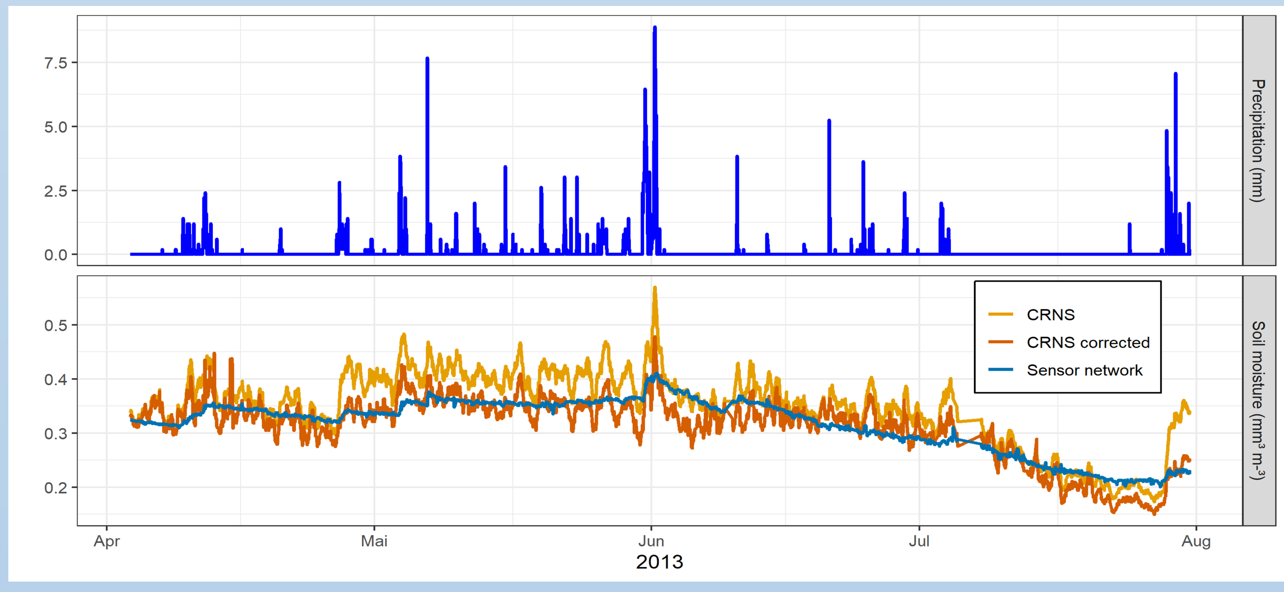
Field site example

- Katharinentaler Hof, winter wheat stand, April to August 2013
- Sensor network: volumetric soil moisture every 10 cm down to 90 cm



CRNS on an agricultural field site, cropped with winter wheat. The CRNS is installed in the center. Locations of the sensor network are randomly chosen to validate an Eddy Covariance station

Cosmic Ray Neutron Sensing provides a unique approach to estimate soil moisture dynamics at field scale with high temporal resolution



Precipitation (upper panel) and soil moisture (bottom panel) for the field site. Average soil moisture from the sensor network and CRNS soil moisture as well as CRNS with applied profile shape correction is shown. Corrected CRNS soil moisture shows better comparability to the sensor network; a higher variability remains due to sensitivity to upper soil layers and statistical variability

CRNS and intermediate scale groundwater recharge

Goals of the study

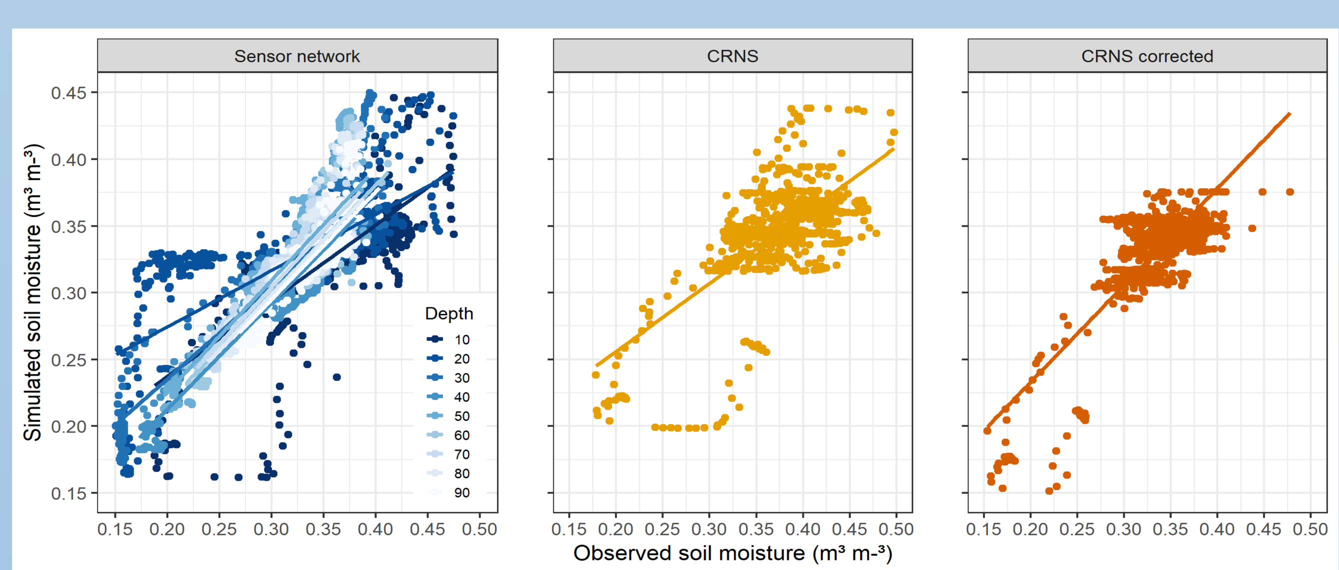
- Estimate groundwater recharge rates using an unsaturated soil hydrological model
- The sensitivity of CRNS can be addressed by using the Cosmic-Operator within soil hydrologic models (Brunetti et al. 2018)
- Use also CRNS soil moisture data directly
  - **Apply CNRS soil moisture and corrected CRNS soil moisture for calibration of soil hydraulic properties and compare to data from point scale sensor network**
  - Compare to results from Cosmic-Operator, when calibrating soil hydraulic properties on neutron counts (no results shown)

Methodology

- Estimation of potential groundwater recharge using inverse numerical modelling for 1D soil profiles (Hydrus: finite element model of water flow in variably saturated porous media, based on Richards Equation)
- Model input: measured precipitation, evapotranspiration calculated after Hargreaves with measured atmospheric data
- First estimate of soil parameters and model setup after Parker et al. (2016)

Preliminary Results using Hydrus

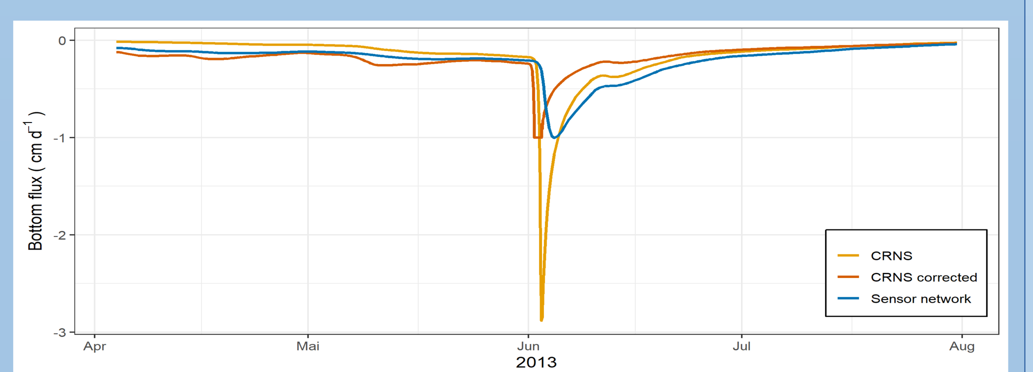
- Correction of CRNS soil moisture also improves model results in Hydrus



Automatic calibration yields optimized soil hydraulic properties and specific estimates of groundwater recharge with a high temporal resolution

Inverse Modelling	Cumulative bottom flux (cm)	R^2, simulated vs. observed soil moisture
Sensor network	24.1	0.757
CRNS	18.1	0.766
CRNS corrected	20.5	0.9

CRNS measurements are simulated for a depth of 25 cm. Issues are the integrative value of CNRS to compare to soil moisture of a specific depth from the model. This needs to be solved in external optimization



The bottom flux in 150 cm depth is the potential groundwater recharge. Substantia recharge occurs for the field site example only for one large precipitation event in June.

Establishing a massive CRNS observatory of soil water dynamics and groundwater recharge and future work

Approach

- Comparison to other methods of groundwater recharge estimation
- Develop a stand-alone method for estimating recharge at field scale based on CRNS (opportunities and limitations)
- Apply method for single probes and a dense network (joined field campaigns Cosmic Sense)
- Contribution to closing the water balance for joint field campaign area

Sketch of a massive CRNS observatory
(For details see Fersch et al. 2020)

Study site

- Up to 20 CRNS sensors form a network
- Soil moisture profiles (dielectric measurements)
- Groundwater wells
- Weather data
- Gravimetric sampling
- Geophysical information

Sources

Cosmic Sense, DFG Research Group FOR-2694
https://www.uni-potsdam.de/de/cosmicsense.html

Literature

Baroni, G., Scheiffele, L. M., Schrön, M., Ingwersen, J. and Oswald, S. E.: Uncertainty, sensitivity and improvements in soil moisture estimation with cosmic-ray neutron sensing, J. Hydrol., 564, 873–887, doi:10.1016/j.jhydrol.2018.07.053, **2018**.

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

Fersch, B., Francke, T., Heistermann, M., Schrön, M., Döpper, V., Jakobi, J., Baroni, G., Blume, T., Bogena, H., Budach, C., Gränzig, T., Förster, M., Güntner, A., Hendricks-Franssen, H.-J., Kasner, M., Köhli, M., Kleinschmit, B., Kunstmann, H., Patil, A., Rasche, D., Scheiffele, L., Schmidt, U., Szulc-Seyfried, S., Weimar, J., Zacharias, S., Zreda, M., Heber, B., Kiese, R., Mares, V., Mollenhauer, H., Völksch, I. and Oswald, S.: A dense network of cosmic-ray neutron sensors for soil moisture observation in a pre-alpine headwater catchment in Germany, Earth System Science Data Discussions, 1–35, doi:https://doi.org/10.5194/essd-2020-48, **2020**.

Parker, P., Ingwersen, J., Högy, P., Priesack, E. and Aurbacher, J.: Simulating regional climate-adaptive field cropping with fuzzy logic management rules and genetic advance, J. Agric. Sci., 154(2), 207–222, doi:10.1017/S0021859615000490, **2016**.

There is a manuscript on the systematic testing of the profile shape correction factor in preparation (Scheiffele et al.).