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Cosmic Sense

Local Groundwater Recharge Rates Determined with Soil Moisture from Cosmic-ray Neutron Sensing

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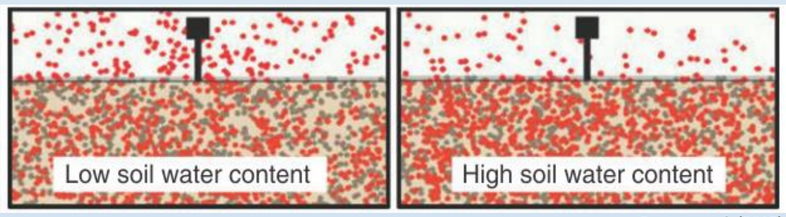
Cosmic Ray Neutron Sensing (CRNS) - how neutrons produced from cosmic radiation tell us about soil water dynamics on Earth's surface

- 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**



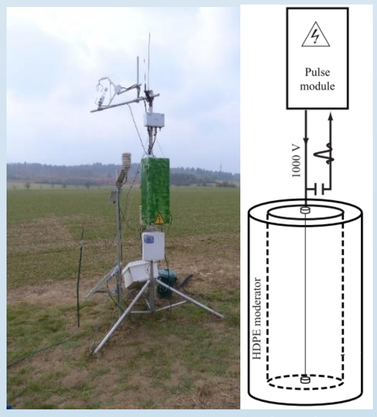
Bogena et al. (2015)

Footprint

- Neutrons travel fast
- Low particle density in air – large radius
- High particle density in soil – neutrons are scattered back from different depth

Physical Principle

- Cosmic radiation entering atmosphere
- Interactions with atmospheric particles create neutron cascade with decreasing energies through interactions
- Most effective in moderation for neutrons is Hydrogen
- Neutron abundance above ground is determined by moderation within soil
- Detection of epithermal neutrons



Baroni et al. (2018) Zreda et al. (2012)

How to get the soil water dynamics right

Corrections of neutron signal

- Pressure
- Incoming radiation
- Water vapor
- (Biomass)

Variable support volume

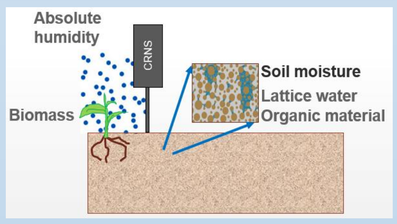
- Distance to sensor
- Depth
- Dependent on Soil Moisture

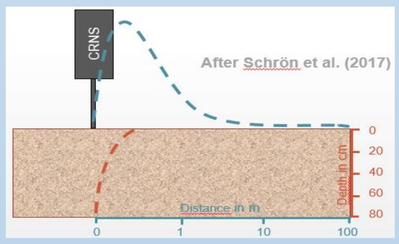
All hydrogen detected

- Biomass, water vapor
- Water equivalent in soil organic carbon and lattice water

Calibration

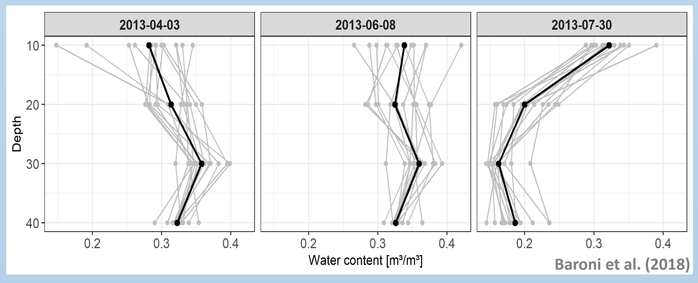
- Gravimetric water content (invasive soil sampling)
- Horizontal and vertical weighting
- Accounting for additional hydrogen pools





Novel 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 soil moisture based on shape of soil moisture profile and weighting function



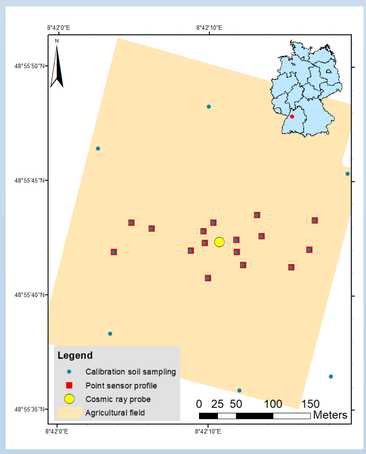
Baroni et al. (2018)

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

Field site example

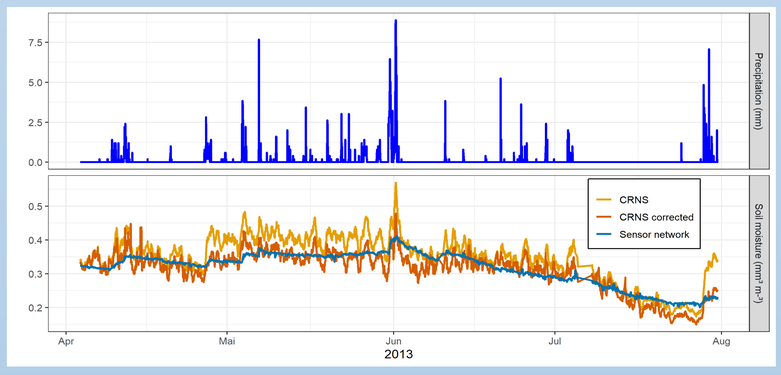
- Katharinentaler Hof, winter wheat stand, April to August 2013
- Sensor network: volumetric soil moisture every 10 cm down to 90 cm
- CRNS assumed to be representative for 0 to 50 cm depth

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



CRNS on an agricultural field site

Corrected CRNS soil moisture captures better response to precipitation and drying; a higher variability remains due to sensitivity to upper soil layers and statistical variability



CRNS and intermediate scale groundwater recharge

Motivation

- Groundwater recharge estimation is fundamental for the sustainable use of groundwater resources
- Uncertainty of groundwater recharge is a major limitation for accuracy of groundwater models
- This is important in a quantitative point of view but also for qualitative issues
- In agricultural landscapes groundwater quality might be threatened by diffuse recharge loads

Preliminary Results

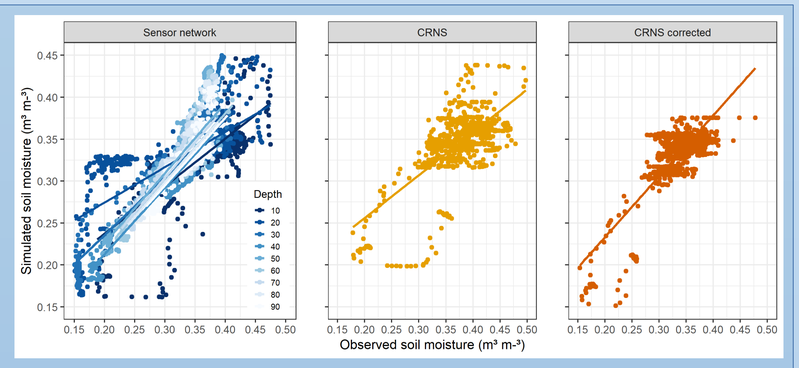
- Correction of CRNS soil moisture also improves model results in Hydrus

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

Methodology

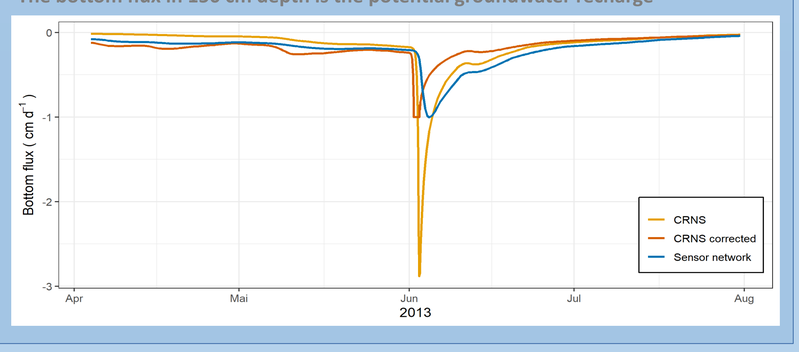
- Estimation of potential groundwater recharge using inverse numerical modelling for 1D soil profiles (Hydrus: finite element model of water flow in variably saturated porous media, based on Richards Equation)
- Model input: measured precipitation, evapotranspiration calculated after Penman-Monteith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

Inverse Modelling	Cumulative bottom flux	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

The bottom flux in 150 cm depth is the potential groundwater recharge



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

Approach

- Comparison to other methods of groundwater recharge
- Develop a stand-alone method for estimating groundwater 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

Distribution of 12 CRNS sensors at an agricultural site

Current study site

- 12 CRNS sensors form a network
- Soil moisture profiles (dielectric measurements)
- Tensiometers
- 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

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