Cosmic-Ray Neutron Sensing

precision soil moisture measurements at the hectare scale

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Accurate soil moisture (SM) measurements are key in hydrological observations and subsequent applications as it can greatly improve our understanding of soil processes. Recently, Cosmic-Ray Neutron Sensing (CRNS) has been recognized as a promising tool in SM monitoring due to its large footprint of several hectares and half a meter in depth. The key characteristic feature of the method is the exceptionally high moderation strength of hydrogen, which makes it nearly independent of the soil chemistry. CRNS has a great potential for hydrological research, irrigation planing and monitoring applications due to the non-invasive nature of the method and the low-maintenance, independently operating sensors. CRNS-assisted programs are also increasingly rolled out in the context of agriculture, e.g. irrigation management and soil moisture mapping, and have been integrated LoRa or NB-IoT networks for fast data transmission. In the recent years the understanding of neutron transport by Monte Carlo simulations led to major advancements in precision. Investigating the above-ground neutron flux by broadly based URANOS simulation campaign revealed a more detailed understanding of different contributions to this signal. Meanwhile, a manifold of measurement campaigns have targeted CRNS as a bridging technology between remote sensing products and in-situ sensors. The improvements in signal interpretation specifically could be successfully applied to the determination of the snow water equivalent in Alpine regions. The remarkable performance of the CRNS method provides researchers with a new tool to obtain representative soil moisture information either in stationary (timeseries) or mobile (snapshots) use cases.

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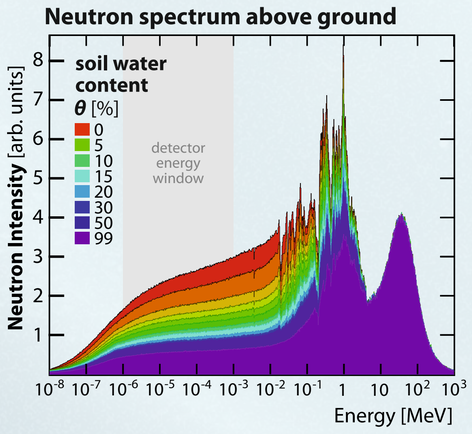
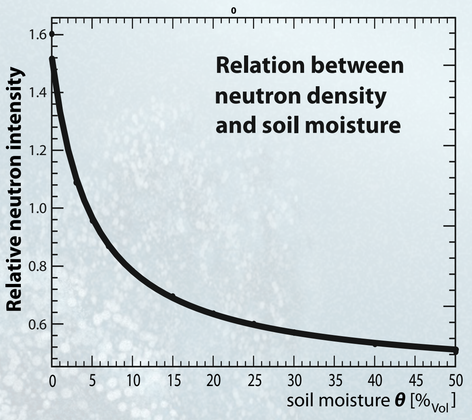
Cosmic-Ray Neutrons are a permanent source of radiation in the environment. The sensitivity of 10 eV - 100 keV neutrons to hydrogen is extraordinarily high. Thus, the intensity of ground albedo neutrons strongly relates to its water content. Transport in air leads to the density being represenative for several hectares.

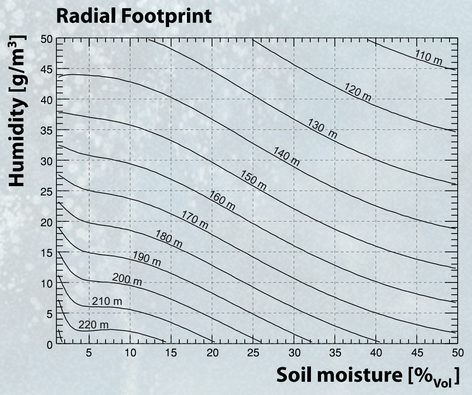
Measurement Principle

Neutron spectrum above ground

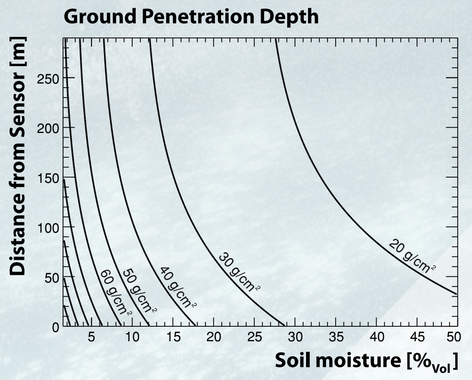




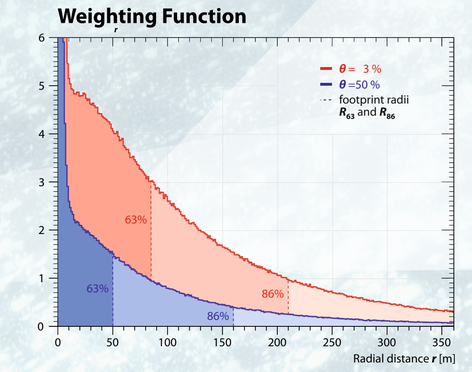
Radial Footprint



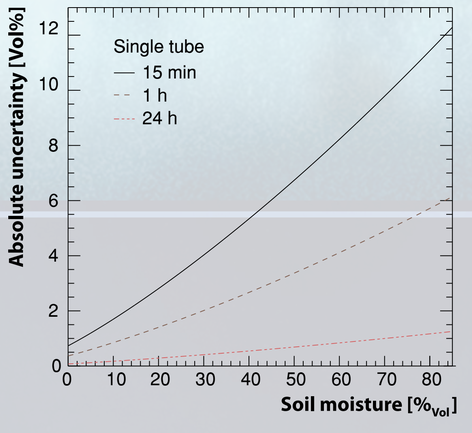
Ground Penetration Depth



Weighting Function



Measurement time



Applications

- **Snow height** measurements
- **Crop water** content / **yield** prediction
- **Forest** and **ground water** storage
- **Validation** of satellite products

- **Hydrological and Climate Models:** Soil Water Storage is a key variable for prediction of weather, floods and drought
- **Irrigation management in agriculture:** Knowlegde of soil moisture can save water

New and unrivaled technology for soil moisture monitoring

	Spatial resolution	Penetration depth	Temporal resolution
conventional point sensors	few cm	5-30 cm	snapshot/ continous
satellite remote sensing	4-24 km	0-5 cm	daily
airborne remote sensing	10-50 m	2-8 cm	irregular
Cosmic-Ray neutron sensor	100-200 m	10-80 cm	continous/ snapshot (mobile)

most representative data

Sensitivity to Water

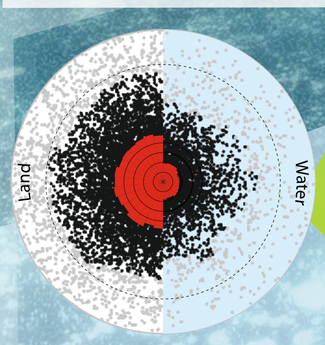
High-energy neutrons are comparatively insensitive to water. At lower energies, particularly in the **blue** domain, hydrogen can effectively moderate neutrons. **Thermal** neutrons are slow and sensitive also to other chemical compontents.

Detection

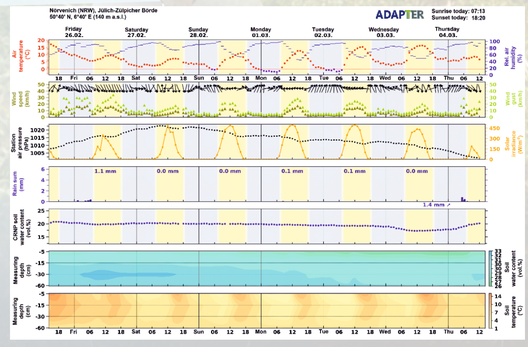
A moderated He detector counts **low-energy** neutrons.

Mixing in Air

Neutrons are able to travel hundreds of meters from origin (contact with the soil) to detection.

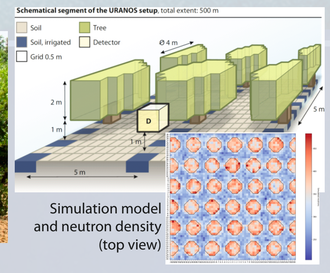


Sensors with IoT Interfaces



Complex use cases

Plantation in Spain (Valenica)

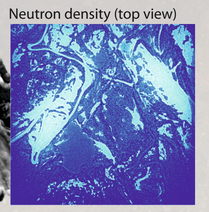


Simulation model and neutron density (top view)

Glacier in the Alps (Tyrol)

Simulation model

Neutron density (top view)



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