Finding Water with Cosmic-Ray Neutrons

On the global problem of water availability, the lack of representative measurements, and how Astrophysics can help!

Martin Schrön
UFZ Leipzig, MET + CHS

Steffen Zacharias
UFZ Leipzig, MET

Luis Samaniego
UFZ Leipzig, CHS

Sascha Oswald
Uni Potsdam

martin.schroen@ufz.de

Motivation

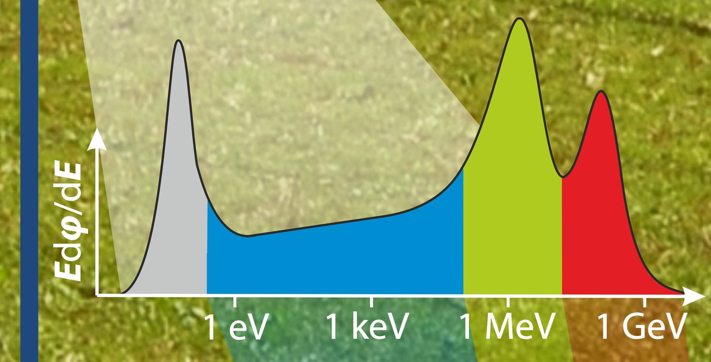
Soil moisture is a key variable to optimise irrigation management, estimate flood risk, or predict regional climate. Hydrological models rely on validation and calibration data to perform well. However, soil moisture data exists either at the point scale, or up to only a few cm depth. The omnipresent cosmic neutrons deliver both, high penetration depths and footprints of 30 ha, in which their number is reduced depending on the amount of hydrogen present. Is this new technology able to support soil moisture prediction?

Hypotheses

Due to the large averaging volume, the soil moisture signal from cosmic-ray neutrons can not resolve structures below 100m. However, it is the perfect scale to match the prediction of the mesoscale hydrological model mHM.

Method

We use a neutron physics code develloped together with Uni Heidelberg to track the origin of detected neutrons. In the Schäfertal catchment (1.6km²) a car containing the mobile neutron detector surveys the fields. A stationary sensor provides data converted to soil moisture with $SM=0.0808/(N/1400-0.372)-0.115$, which is compared with output from the conceptional hydrological model mHM.



Detection

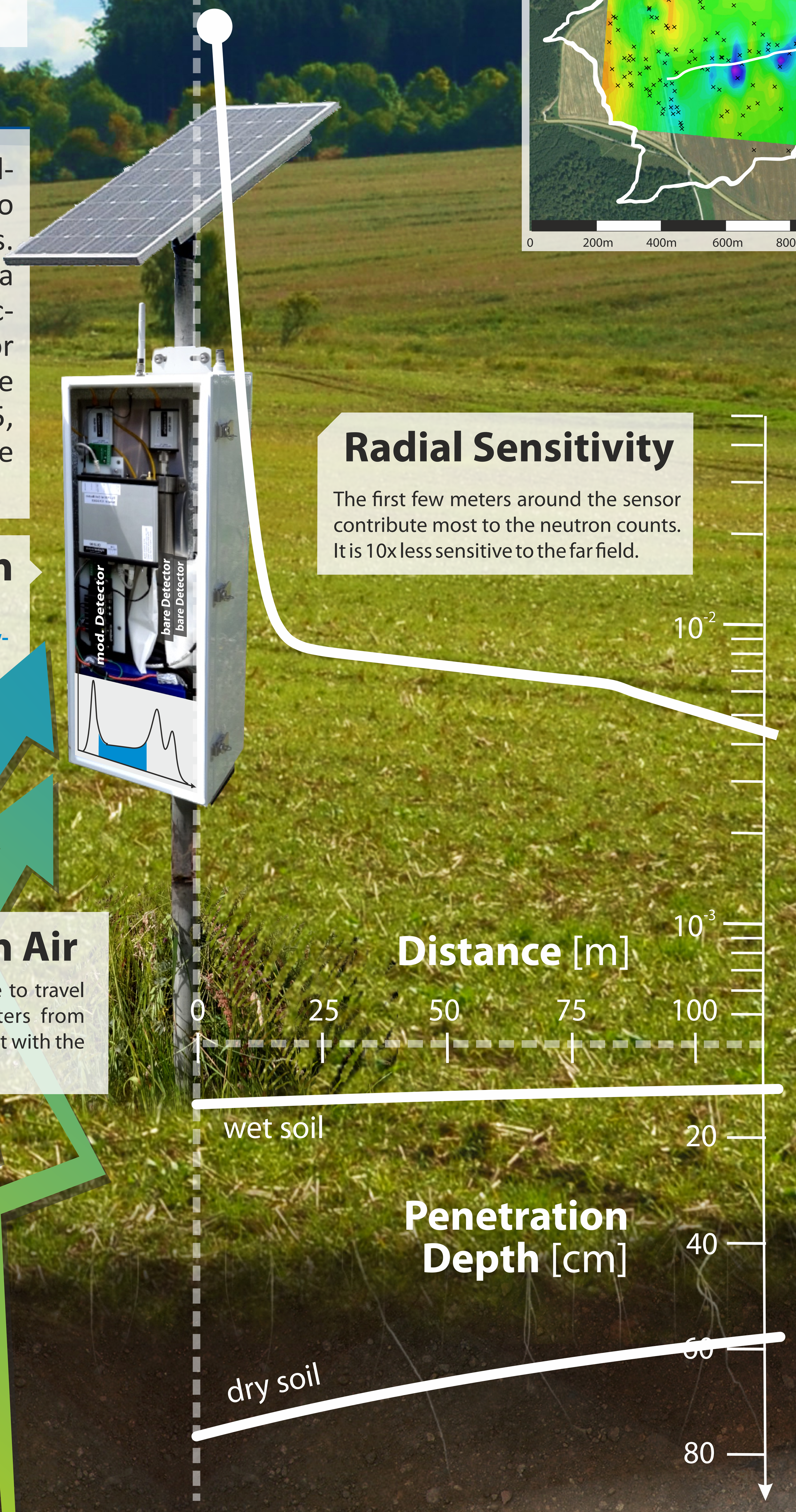
A moderated ^{3}He detector counts **low-energy** neutrons.

Mixing in Air

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

Radial Sensitivity

The first few meters around the sensor contribute most to the neutron counts. It is 10x less sensitive to the far field.



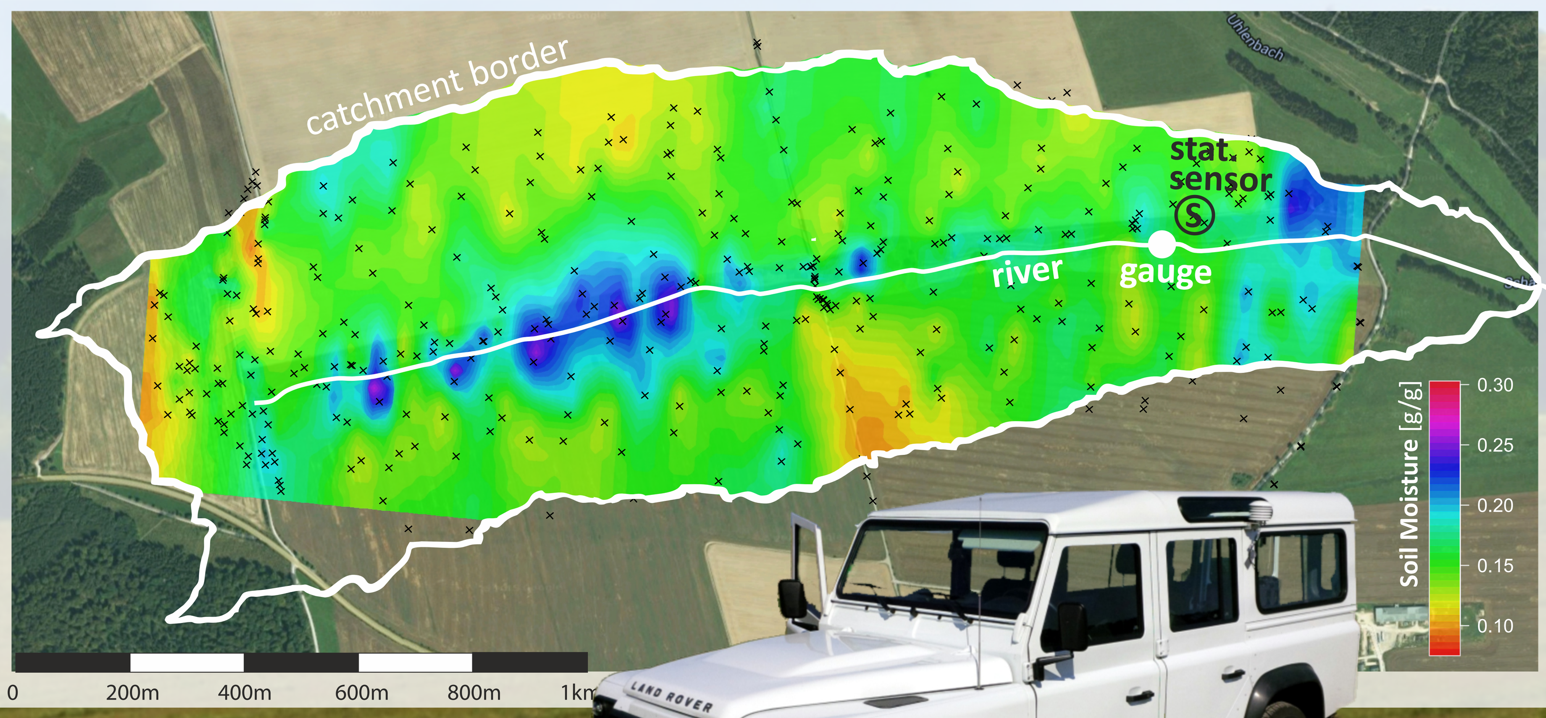
Sensitivity to Water

High-energy neutrons are comparatively insensitive to water. At lower energies, particularly in the **blue** domain, hydrogen can effectively slow down neutrons so much, that they stay in the soil or enter the **thermal** energy peak.

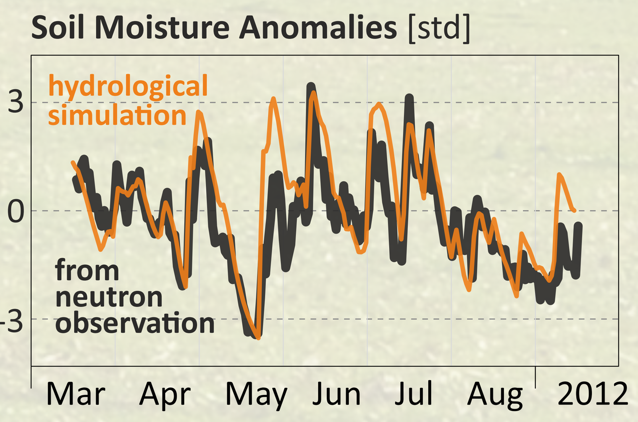
Results

Neutron physics simulations show that the low-energy bands (**blue**, **green**) of incoming radiation also contribute to the detector signal, in contradiction to the hitherto accepted assumption that only **high-energy** neutrons contribute. This reduces the footprint area by half, and discovers high sensitivity of the signal to the first few meters around the sensor.

Rover surveys in the Schäfertal reveal highly resolved soil moisture patterns. The wet areas around the river are real and an effect of shallow ground water. However, while nearby vegetation generates apparent wetness, and roads appear to be dry.



Soil water content in a 100m cell simulated by the hydrological model catches the dynamics of observed soil moisture measured with the neutron detector.



Conclusions

Cosmic-Ray Neutrons are a reliable tool to track spatial patterns of environmental water at the catchment-scale. The revised footprint analysis can explain why nearby vegetation, roads, or water ponds are clearly visible in the measurement. The conceptual hydrological model is able to use the data to validate soil moisture dynamics at the 100m scale.

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