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Measurements of Cosmic-Ray Neutrons for Hydrology at the Catchment Scale: Soil Moisture and Snow

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The capabilities of present technologies for measuring soil water content are not yet really able to fill the crucial gap of measurements at an intermediate scale. Soil moisture measurements at the point-scale have advanced with a wide range of in-situ sensors based on several soil properties. Measurements at the basin scale had a significant improvement with the increase of remote sensing technologies. At the continental scale, GRACE, SMOS, SMAP and others provide an excellent opportunity to estimate soil water content at the largest macro-scale.
New measurement methods are under development to fill the gap of soil moisture measurements at the intermediate scale. One of them is the so called cosmic ray method, recently introduced for soil moisture measurements by Zreda and co-workers. Secondary neutron fluxes, product of the interaction of primary cosmic-rays at the land surface, are strongly moderated by the presence of water in or above soil (soil moisture, snow and biomass water). Neutron counts at the ground/air interface result from an intermediate spatial scale, and can be used to quantify stored water while distinguishing different water holding compartments at the land surface.
The cosmic-ray method for hydrological measurements at the small catchment scale (30-Ha) was tested in an agricultural field (Bornim, Brandenburg, Germany) under three different situations. In a first scenario soil was cropped with corn (Zea Mays), and the cosmic-ray method was validated for the estimation of areal mean values of soil moisture. The new measurement method was compared with a classical soil moisture network (Theta Probes) and five soil sampling campaigns. Temporal development of corn biomass was also monitored. In a second period when soil was bare, cosmic-ray neutrons monitored in the field were only moderated by temporal variations of soil moisture. In a third period during winter, measurements of cosmic-ray neutrons in different energy levels are used to monitor water storage at the land-surface including snowfall events and snow cover.
Our observations suggest that the new approach using cosmic-ray neutrons can compensate the lack of data for hydrological processes at the intermediate scale between point measurements and large scale measurements; however, with only a temporal resolution not a spatial one. Areal mean values of soil moisture based on cosmic-ray neutrons and its observed temporal variability were compared quantitatively with classical soil moisture measurement techniques. The cosmic-ray method for soil moisture estimations responded well to fast and intensive precipitation events in the area, including snowfall, and snow water equivalent was correlated to measurements of cosmic-ray neutrons. Finally, our future work involves estimations of water mass in different compartments (soil moisture, snow and biomass water) for calibration and accurate prediction of hydrological models at the small catchment scale.