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Evaluation of uncertainty in field soil moisture estimations by cosmic-ray neutron sensing

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Cosmic-ray neutron sensing (CRNS) has developed into a valuable, indirect and non-invasive method to estimate soil moisture at the field scale. It provides continuous temporal data (hours to days), relatively large depth (10-70 cm), and intermediate spatial scale measurements (hundreds of meters), thereby overcoming some of the limitations in point measurements (e.g., TDR/FDR) and of remote sensing products. All these characteristics make CRNS a favorable approach for soil moisture estimation, especially for applications in cropped fields and agricultural water management. Various studies compare CRNS measurements to soil sensor networks and show a good agreement. However, CRNS is sensitive to more characteristics of the land-surface, e.g. additional hydrogen pools, soil bulk density, and biomass. Prior to calibration the standard atmospheric corrections are accounting for the effects of air pressure, humidity and variations in incoming neutrons. In addition, the standard calibration approach was further extended to account for hydrogen in lattice water and soil organic material. Some corrections were also proposed to account for water in biomass. Moreover, the sensitivity of the probe was found to decrease with distance and a weighting procedure for the calibration datasets was introduced to account for the sensors' radial sensitivity. On the one hand, all the mentioned corrections showed to improve the accuracy in estimated soil moisture values. On the other hand, they require substantial additional efforts in monitoring activities and they could inherently contribute to the overall uncertainty of the CRNS product. In this study we aim (i) to quantify the uncertainty in the field soil moisture estimated by CRNS and (ii) to understand the role of the different sources of uncertainty. To this end, two experimental sites in Germany were equipped with a CRNS probe and compared to values of a soil moisture network. The agricultural fields were cropped with winter wheat (Pforzheim, 2013) and maize (Braunschweig, 2014) and differ in soil type and management. The results confirm a general good agreement between soil moisture estimated by CRNS and the soil moisture network. However, several sources of uncertainty were identified i.e. overestimation of dry conditions, strong effects of the additional hydrogen pools and an influence of the vertical soil moisture profile. Based on that, a global sensitivity analysis based on Monte Carlo sampling can be performed and evaluated in terms of soil moisture and footprint characteristics. The results allow quantifying the role of the different factors and identifying further improvements in the method.