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Error estimation for soil moisture measurements with cosmic-ray neutron sensing and implications for rover surveys

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The cosmic ray neutron (CRN) probe is a non-invasive device to measure soil moisture at the field scale. This instrument relies on the inverse correlation between aboveground epithermal neutron intensity (1eV – 100 keV) and environmental water content. The measurement uncertainty of the neutron detector follows Poisson statistics and thus decreases with decreasing neutron intensity, which corresponds to increasing soil moisture. In order to reduce measurement uncertainty (e.g. < 0.03 m^3/m^3), the neutron count rate is often aggregated over large time windows (e.g. 12h or 24h). To enable shorter aggregation intervals, the measurement uncertainty can be reduced either by using more efficient detectors or by using arrays of detectors, as in the case of CRN rover applications. Depending on soil moisture and driving speed, aggregation of neutron counts may also be necessary to obtain sufficiently accurate soil moisture estimates in rover applications. To date, signal aggregation has not been investigated sufficiently with respect to the optimisation of temporal (stationary probes) and spatial (roving applications) resolution. In this work, we present an easy-to-use method for uncertainty quantification of soil moisture observations from CRN sensors based on Gaussian error propagation theory. We have estimated the uncertainty using a third order Taylor expansion and compared the result with a more computationally intensive Monte Carlo approach and found excellent agreement. Furthermore, we used our method to quantify the dependence of soil moisture uncertainty on CRN rover survey design and on selected aggregation time. We anticipate that the new approach helps to quantify cosmic ray neutron measurement uncertainty. In particular, it is anticipated that the strategic planning and evaluation of CRN rover surveys based on uncertainty requirements can be improved considerably.