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Potential use of Cosmic Ray Neutron Sensor in estimating state variables in hydrological models

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Knowing state variables-fluxes and storages of water and energy- that are propagated in time by the model physics is crucial in hydrological modeling. Soil moisture and snow water equivalent are the most important state variables of water storage. Measurement of soil moisture is possible via several methods including: Laboratory tests and time domain reflectometers (having high accuracies but smaller measurement footprints), ground penetrating radar and remote sensing methods (having large measurement footprints but lower accuracies and resolutions). Typical methods for measuring SWE include point measurements (snow tubes) and large-scale measurements (remote sensing).
In this study we want to present the potential use of the cosmic-ray neutron sensor (CRNS) to monitor soil moisture and SWE. The CRNS measures above-ground moderated neutron intensity within a radius of approximately 300 m. It was installed at elevation of 1459 m in the south part of Turkey and an ML3 ThetaProbe (CS 616) soil moisture sensor was established at 5cm depth to get continuous soil moisture values. There is a path eddy covariance system with energy balance sensors installed at 100 m north to the cosmic ray probe and daily snow depth has been measured at this location for the water year 2017.
Neutron count measurements were corrected for the changes in atmospheric pressure, atmospheric water vapor and intensity of incoming neutron flux. The calibration of the volumetric soil moisture was performed, from the laboratory analysis, the bulk density in the foot print of CRNS varies between 1.56(g/cm3) -1.25 (g/cm3), and the dominant soil texture is silty clay loam and silt loam. The water content reflectometer was calibrated for soil-specific conditions and soil moisture estimates were also corrected with respect to soil temperature. An average of 35% difference is observed between the daily volumetric soil moisture obtained from CRNS and CS616. Both sensors show consistent changes in soil moisture due to the storm events. Although CS 616 measurements are 30% larger than the CRP measurements, both sensors showed 4.5% increase in volumetric soil moisture due to the storm of 15.5 mm. Satellite soil moisture products obtained from the Soil Moisture and Ocean Salinity (SMOS) and the METOP-A/B Advanced Scatterometer (ASCAT) were compared with the measurements of the CRNS. The snow depth values were converted to SWE values by using the snow density values. The SWE values were negatively correlated with the CRNS-measured moderated neutron intensity, giving Pearson correlation coefficients of $\sim$0.92 (2016/2017). A linear regression performed on the calculated SWE values from measured snow depths and moderated neutron intensity counts for 2016/2017 yielded an R2 of 0.84. The results indicate high potential of CRNS to close the gap between point-scale measurements, hydrological models, and remote sensing of the cryosphere.