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Continuous monitoring of a mountain snowpack in the Austrian Alps by above-ground neutron sensing

Paul Schattan (1,2), Gabriele Baroni (3,4), Sascha E. Oswald (4), Johannes Schöber (5), Christine Fey (1,5), Till Francke (4), Matthias Huttenlau (1), and Stefan Achleitner (6)

(1) alpS Centre for Climate Change Adaptation, Innsbruck, Austria (schattan@alps-gmbh.com), (2) Institute of Geography, University of Innsbruck, Innsbruck, Austria, (3) UFZ – Helmholtz Centre for Environmental Research, Leipzig, Germany, (4) Institute of Earth and Environmental Science, University of Potsdam, Potsdam, Germany, (5) TIWAG Tiroler Wasserkraft AG, Innsbruck, Austria, (6) Unit of Hydraulic Engineering, University of Innsbruck, Innsbruck, Austria

In alpine catchments the knowledge of the spatially and temporally heterogeneous dynamics of snow accumulation and depletion is crucial for modelling and managing water resources. While snow covered area can be retrieved operationally from remote sensing data, continuous measurements of other snow state variables like snow depth (SD) or snow water equivalent (SWE) remain challenging. Existing methods of retrieving both variables in alpine terrain face severe issues like a lack of spatial representativeness, labour-intensity or discontinuity in time. Recently, promising new measurement techniques combining a larger support with low maintenance cost like above-ground gamma-ray scintillators, GPS interferometric reflectometry or above-ground cosmic-ray neutron sensors (CRNS) have been suggested. While CRNS has proven its potential for monitoring soil moisture in a wide range of environments and applications, the empirical knowledge of using CRNS for snowpack monitoring is still very limited and restricted to shallow snowpacks with rather uniform evolution.

The characteristics of an above-ground cosmic-ray neutron sensor (CRNS) were therefore evaluated for monitoring a mountain snowpack in the Austrian Alps (Kaunertal, Tyrol) during three winter seasons. The measurement campaign included a number of measurements during the period from 03/2014 to 06/2016: (i) neutron count measurements by CRNS, (ii) continuous point-scale SD and SWE measurements from an automatic weather station and (iii) 17 Terrestrial Laser Scanning (TLS) with simultaneous SD and SWE surveys. The highest accumulation in terms of SWE was found in 04/2014 with 600 mm.

Neutron counts were compared to all available snow data. While previous studies suggested a signal saturation at around 100 mm of SWE, no complete signal saturation was found. A strong non-linear relation was found for both SD and SWE with best fits for spatially distributed TLS based snow data. Initially slightly different shapes were found for accumulation and melting season conditions but this could be resolved by accounting for the limited measurement depth. This depth limit is in the range of 200 mm of SWE for dense snowpacks with high liquid water contents and associated snow density values around 450 kg m-3 and above. Furthermore, the results prove that for medium to high snowpack the inter-annual transferability of the results is very high regardless of pre-snowfall soil moisture conditions.

These results underline the high potential of CRNS for closing the gap between point-scale measurements, hydrological models and remote sensing in snow hydrology and alpine terrain.