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Cosmic-ray neutron production and propagation inside snow packs characterized by multi-particle Monte Carlo simulations

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Cosmic-ray neutron sensors buried below a snow pack provide a passive and autonomous monitoring technique of snow water equivalent (SWE). The effective neutron flux is attenuated inside the snow volume resulting in an inverse relationship between neutron intensity and the water equivalent of the snow column above the sensor. Neutrons are moderated and absorbed within the snow. Simultaneously, highly energetic cosmic rays produce further neutrons via spallation and evaporation processes. A comprehensive assessment of the neutron flux therefore requires multi-particle simulations which involve all relevant incoming particle species and transient particles from cosmic-ray showers which play a crucial role in neutron production.

In our study, we used the Monte Carlo toolkit MCNP6 and validated its high-energy evaporation and spallation models against a measured data set of a neutron intensity profile in water. Based on that we fitted analytical functions to a large variety of simulation setups that describe the neutron intensity as a function of SWE and the moisture content of the soil below the sensor. Moreover, single-particle tracking revealed that the radial footprint of the method does not exceed few meters for detectors below thick snow layers. In the case of shallow snow, however, the diffusive long-range neutron flux in the atmosphere may penetrate through the snow pack to the buried sensor and thereby increases the influence of distant objects. Since the diffusive flux is further sensitive to the atmospheric water content, we developed an air humidity correction tailored to snow-buried neutron detectors.

In general, the study aims at a holistic understanding of neutron production and transport processes in snow and the adjacent soil and air volumes in order to improve SWE monitoring by buried cosmic-ray neutron sensors and compares the simulation results to field data.