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Application of cosmic ray snow gauges to monitor the snow water equivalent on alpine glaciers

Rebecca Gugerli[1,2,3], Darin Desilets[4], and Nadine Salzmann[1,5,6]
[1]Department of Geosciences, University of Fribourg, Fribourg, Switzerland
[2]now at Environmental Remote Sensing Laboratory, Swiss Federal Institute of Technology Lausanne (EPFL), Lausanne, Switzerland (rebecca.gugerli@epfl.ch)
[3]now at Radar, Satellite and Nowcasting division, MeteoSwiss, Locarno-Monti, Switzerland
[4]Hydroinnova LLC, Albuquerque, New Mexico, USA
[5]now at WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland
[6]now at Climate Change, Extremes, and Natural Hazards in Alpine Regions Research Center CERC, Davos, Switzerland

Temporally continuous measurements of the snow water equivalent (SWE) are a key variable in many hydrological, meteorological and glaciological studies and are of particular importance in high mountain regions. Obtaining temporally continuous, accurate and reliable SWE observations in these harsh environments, however, remains a challenge. Recently, promising results have been achieved by using a neutronic cosmic ray snow gauge (n-CRSG). The n-CRSG device is deployed below the seasonal snowpack and counts fast neutrons from the secondary cascades of cosmic rays, which are efficiently moderated and absorbed by the hydrogen atoms contained in the snowpack. Based on the exponential relationship between neutrons and hydrogen atoms, we can infer SWE from the neutron count rate. We have installed and evaluated a n-CRSG on the Swiss Glacier de la Plaine Morte. Our validation with 22 manual measurements over five winter seasons (2016/17-2020/21) showed an average underestimation of -2% ±10% (one standard deviation).
In the present study, we explore the use of muons instead of neutrons to infer SWE. To this end, we deployed two muonic cosmic ray snow gauges (μ-CRSG), one below and one above the seasonal snowpack, for the winter season 2020/21 on the same glacier site in Switzerland. The difference in count rates between the top and bottom device can be related to the SWE of the snowpack. We derive a first-cut conversion function based on manual SWE observations by means of snow pits and snow cores. To evaluate the measurements by the μ-CRSG, we also compare them to SWE estimates by the n-CRSG. Over the winter season 2020/21, almost up to 2000 mm w.e. were observed. Overall, the μ-CRSG agrees well with the n-CRSG on the evolution of the snowpack at a high temporal resolution and thus demonstrates its great potential. Also, the inferred SWE measurements lie within the uncertainty of manual observations. Furthermore, the μ-CRSG has several advantages over the n-CRSG; It is cheaper, lighter and promises a higher measurement precision due to the improved counting statistics of the muon count rates. We conclude that the μ-CRSG has even greater potential than the n-CRSG to monitor SWE in remote high mountain environments.