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Cosmic-ray attenuation by seasonal snow cover revealed by neutron-detector monitoring: implications for cosmic-ray exposure studies in mountainous areas

Romain Delunel (1,4), Didier Bourlès (2), Peter van der Beek (1), and Emmanuel Paquet (3)

(1) ISTerre, Université Joseph Fourier, Grenoble, France (rdelunel@gmail.com), (4) University of Newcastle, School of Geography, Politics and Sociology, Newcastle Upon Tyne, UK, (2) CEREGE, Aix en Provence, France, (3) EDF-DTG, Grenoble, France

Attenuation of secondary cosmic-ray particles due to snow cover and its consequences for the production rates of Terrestrial Cosmogenic Nuclides (TCN) is a major source of uncertainty for cosmic-ray exposure dating in high-altitude and/or high-latitude regions. The snow-cover dependence of production rates for in-situ produced cosmogenic nuclides, and therefore of calculated cosmic-ray exposure ages and/or denudation rates, is usually modeled from scenarios inferring the thickness, duration and density of snow cover obtained from modern snow records, when these exist. We present cosmic-ray flux data monitored in a natural setting, which allow direct quantification of the effect of snow cover on cosmic-ray flux attenuation. Assuming that cosmic-ray flux measured during the summer season represents the theoretical radiation dose received by rock surfaces without snow cover, the cosmic-ray flux attenuation induced by snow cover can be estimated from the ratio between the yearly-averaged daily cosmic-ray flux and the summer-averaged flux. Moreover, comparing cosmic-ray flux data with water-equivalent snow thickness obtained through snow-pack core sampling reveal that cosmic-ray attenuation calculated using a simple depth-dependant exponential decrease of cosmic-ray flux is erroneous. Our results show that secondary neutrons are much more strongly attenuated in snow than previously documented, leading to systematic underestimations of cosmic-ray attenuation by snow cover. Considering an apparent neutron attenuation length of 150 g.cm^{-2}, a $\sim$40% underestimation of the real cosmic-ray attenuation is reached for a snow pack of $\sim$30 cm water-equivalent thickness. Therefore, our results highlight that cosmic-ray shielding due to snow cover has to be correctly and carefully treated in mountain areas prone to seasonal snow cover, as studies inferred from cosmogenic nuclide measurements in such areas may contain large and systematic errors.