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Cosmic-ray flux attenuation by seasonal snow cover revealed by neutron detector monitoring: Potential implications for cosmic-ray exposure dating

Romain Delunel (1,2,3), Didier Bourlès (4), Peter van der Beek (1), Ingo Leya (3), and Emmanuel Paquet (5)

(1) Institut des Sciences de la Terre, Université Joseph Fourier – Grenoble I, CNRS, BP 53, 38041 Grenoble, France (romain.delunel@geo.unibe.ch), (2) Institute of Geological Sciences, University of Bern, Switzerland , (3) Space Research and Planetary Sciences, University of Bern, Switzerland, (4) Aix Marseille Université, CNRS, Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement (CEREGE), UM 34, BP80, 13545 Aix en Provence, France, (5) EDF-DTG, 21 avenue de l'Europe, BP 41, 38040 Grenoble Cedex 9, France

Attenuation of secondary cosmic-ray particles due to snow cover and its effects on production rates of cosmogenic nuclides constitutes a major source of uncertainty for cosmic-ray exposure dating in regions characterized by frequent seasonal snow burial. 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 the snow cover obtained from modern snow records, where these exist.

We present direct cosmic-ray flux monitoring data in a natural setting that can be used to quantify the effect of snow cover on cosmic-ray flux attenuation. Data have been measured since July 2001 at seven stations located throughout the Ecrins-Pelvoux massif (French Western Alps) and its surroundings, at elevations ranging from 200 to 2500 m a.s.l. The daily averaged cosmic-ray flux shows strong temporal variations that pace with seasons and correlate with altitude. Showing that the cosmic-ray flux measured from July to October represents the theoretical radiation dose received by rock surfaces without snow cover, the mean cosmic-ray flux attenuation induced by snow cover can be calculated as the ratio between the mean annual cosmic-ray flux and the summer-averaged flux. From the difference in cosmic-ray flux observed in summer at different altitudes in the massif, which results from attenuation in the atmosphere, we infer an apparent neutron attenuation length of 148 g cm-2 at a latitude of $\sim$45°N and at altitudes ranging from $\sim$200 to 2500 m a.s.l. Moreover, using snow water equivalent measurements that overlap in time the neutron monitoring for five stations, we show that neutrons are much more strongly attenuated in snow than predicted by the atmospheric attenuation length.

Although the cosmic-ray monitors are mostly sensitive to fast (0.1-10 MeV) neutrons, independent data suggest that this behavior could be extrapolated to high-energy (>10 MeV) spallogenic neutrons. The observed strong attenuation probably results from the boundary effects at the atmosphere/snow interface induced by the high efficiency of water as a neutron moderator.

We propose an empirical model that allows calculating snow-shielding correction factors as a function of snow water equivalent. Our results highlight that cosmic-ray shielding due to seasonal snow cover has to be carefully treated in landscape evolution studies inferred from cosmogenic nuclide measurements in mid-latitude mountain areas, as these may contain large and systematic errors.