Influence of environmental parameters on secondary neutrons from cosmic rays at high altitudes in Alpine region

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Part of this programme: VAO-II, Teilprojekt TPII/02: Einfluss von Umweltparametern und solaren Eruptionen auf die kosmische Strahlung im alpinen Raum
EURADOS Working Group 11 - High energy radiation fields

Keywords: cosmic rays; neutron spectrometry; high-energy neutrons; Bonner sphere spectrometer; neutron monitor

1. Project description

Measurements of the secondary cosmic ray (CR) neutron spectra at ground level have shown that the neutron flux varies with the amount of snow in the environment being higher during the snowless period and lower during the period with huge snow cover (Rühm et al., 2012). Neutrons below energies of several MeV are most affected, while neutrons above about 20 MeV are least affected. This effect could be explained by the interaction of secondary neutrons with the surface of the Earth, and has its origin in ground albedo neutrons (from thermal energies to several MeV). The number of these neutrons depends on the amount of snow and water in the environment.

Figure 1. View of the Jungfraujoch during two different environmental conditions; with snow cover in June 2016 (left) and without snow cover in August/September 2018 (right) (Source: https://panocam.skiline.cc/jungfraujoch#).

To investigate this effect in detail, in June 2016 (Mares et al., 2017a, 2017b) and September 2018 measurement campaigns were carried out at the High Altitude Research Station Jungfraujoch, Switzerland, in cooperation with the University of Bern. The energy distributions of secondary CR neutrons were measured at two different locations: under the cupola of the astronomical observatory in the Sphinx building (3,571 m a.s.l.) and below the roof of the Research Station (RS) (3,466 m a.s.l.). The different environmental conditions (see Fig. 1) at the chosen measurement positions allow quantification of environmental conditions which affect the neutron spectral distribution in the whole neutron energy range from a few meV up to GeV.

A Neutron Monitor (NM) is a ground-based detector to measure CR variability at the surface of the Earth. NMs are very sensitive to high-energy neutrons (E > ~10 MeV) (Clem et al., 2000), but cannot provide information on the spectral fluence rate distribution of secondary neutrons. At Jungfraujoch, there are two NMs operated by the University of Bern (Flückiger et al., 2009). The 18-IGY NM is installed in the detector housing at the terrace of the Sphinx observatory, and the 3-NM64 is situated in the housing on the roof of the building of the RS. Close to each of these two locations the measurement positions during the two campaigns were located. Figure 2 shows long-term and short-term relative count rates from secondary CRs as detected by both NMs at Jungfraujoch during the last three years. The dates of both measurement campaigns are marked by vertical lines.

2. Methods

To provide experimental data on the spectral fluence rate distribution in the whole neutron energy range from a few MeV up to GeV, an Extended Range Bonner Sphere Spectrometer (ERBSS) was used (Mares et al., 1998a). Our ERBSS system includes Ø 3.3 cm spherical ^{3}He proportional counters (type SP9, Centronic Ltd.) within 15 polyethylene (PE) spheres with different diameters from 2.5 to 15 inch acting as moderators. Furthermore, two additional 9 inch spheres are used that include lead shells of different thickness to increase the response for high-energy neutrons (E > 20 MeV)

(Mares et al., 1998b). One ^{3}He proportional counter without any PE sphere is used to measure thermal neutrons. ^{3}He-filled proportional counters are most suitable for the detection of thermal neutrons because of their high neutron capture cross-section ($\sigma_{n,th}$ = 5.330 b) for the (n,p) nuclear reaction. Neutron energy spectra can be derived by unfolding the ERBSS count rates using the corresponding fluence response functions (Mares et al., 1991).

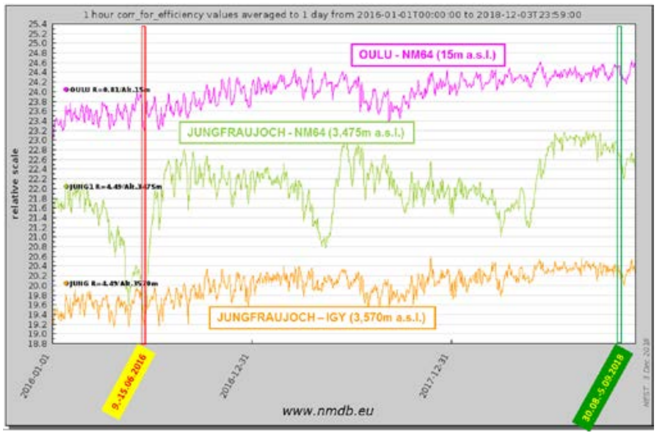

Figure 2. Relative count rate as detected by Neutron Monitors at Oulu, Finland and Jungfraujoch, Switzerland the last three years from 1st January 2016 until 1st October 2018 (Source: Neutron Monitor Data Base, www.nmdb.eu). The dates of both measurement campaigns are marked by red and green vertical lines.

Because the absorption properties of the atmosphere with respect to CRs depend on the atmospheric mass and its density as function of the altitude over the location of the observer, the atmospheric pressure is often used to consider the atmospheric effect on the secondary CR at the Earth's surface. Thus, the count rates measured by the ERBSS must be corrected for any changes in air pressure. Air pressure data were provided by the University of Bern and downloaded from the Neutron Monitor Data Base (NMDB) (htttp://www.nmdb.eu). Count rates measured in the Sphinx astronomical cupola were corrected to a reference pressure of 660 mbar, while those measured in the RS (roof) were corrected to a reference pressure of 669 mbar.

3. Results

Figure 3 shows the mean count rates measured in September 2018 in the Sphinx astronomical cupola and those measured below the roof of the RS using ERBSS system. The count rates measured at Sphinx are about a factor of 2 higher than those below the RS roof and the shapes of the so-called measuring vectors are also completely different. At Sphinx the largest count rate was measured with 6" PE sphere, while below RS roof the largest count rate was measured with 4" PE sphere. It is known that bare detector and Bonner spheres with smaller diameters are more sensitive to thermal and low-energy neutrons (Mares et al., 1991). The count rate of bare detector under the RS roof is about a factor of 3 greater than that measured at Sphinx. This was expected and can be explained by the different topology and environmental conditions of both two measurement positions. The high data points at 9 inch represent the count rates from the 9 inch spheres with lead shells.

Figure 4 shows the unfolded spectral fluence rate distributions using the mean count rates obtained at Sphinx in June 2016 (snowy winter condition) and September 2018 (summer condition with much less snow cover, see Fig. 1) corrected to a reference pressure of 660 mbar and to solar activity observed in September 2018. It is of interest to note that both neutron spectra do not differ much in their intensity and shape. This observation could be explained by the similar snow conditions at the steep rocky summit during the winter and summer time. A low fluence intensity of the Maxwell-Boltzmann (thermal) peak demonstrates an environment with a little amount of moderating materials.

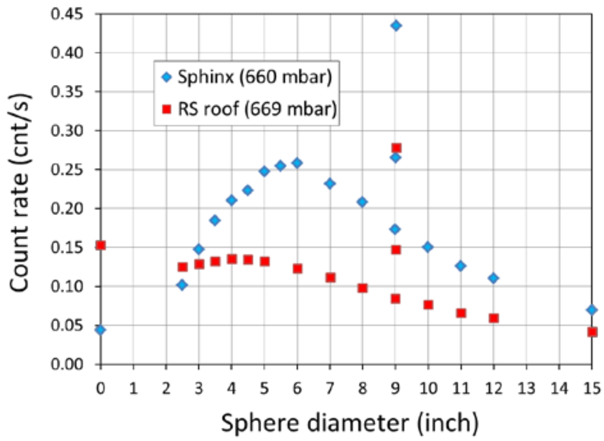

Figure 3. Mean count rates measured by ERBSS in September 2018 in the Sphinx astronomical cupola and below the roof of the RS at Jungfraujoch.

In contrast, Figure 5 shows the unfolded spectral fluence rate distribution measured at the Jungfraujoch RS (below the roof) in June 2016 and September 2018 corrected to a reference pressure of 669 mbar and solar activity in September 2018. In this case a large thermal peak is well documented. This is due to the fact that neutrons were moderated passing through the thick roof of the RS building. The evaporation peak is about a factor of 3 lower than that measured at Sphinx. This finding might be explained by the shielding of evaporation neutrons, which are isotropic, by the steep mountain slope where RS is situated, and partly also by the fact that these neutrons are efficiently moderated in the construction materials of the roof.

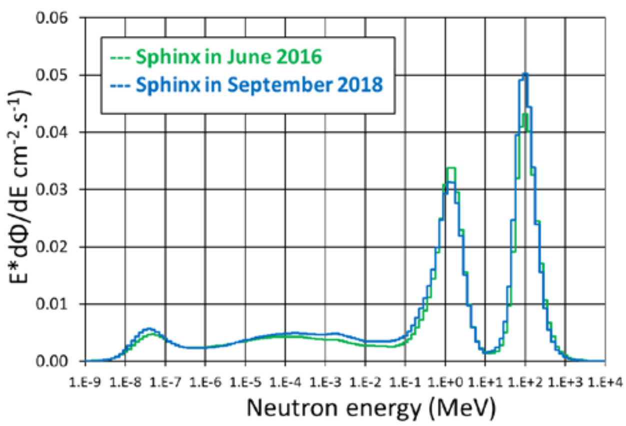

Figure 4. Spectral neutron fluence rate distribution measured in June 2016 and September 2018 in Sphinx astronomical cupola at Jungfraujoch (corrected to a reference pressure of 660 mbar and solar activity in September 2018).

Both the Sphinx and the RS roof neutron spectra were folded with fluence-to-dose conversion coefficients from (ICRP 1997, Pelliccioni 2000) to estimate the corresponding neutron ambient dose equivalent, *H**(10). The resulting *H**(10) dose rates measured in Sphinx astronomical cupola and RS roof in September 1918 were 182 nSv/h and 111 nSv/h respectively. These values are very close to those measured in June 2016, i.e. 176 nSv/h in Sphinx cupola and 103 nSv/h below a roof in RS.

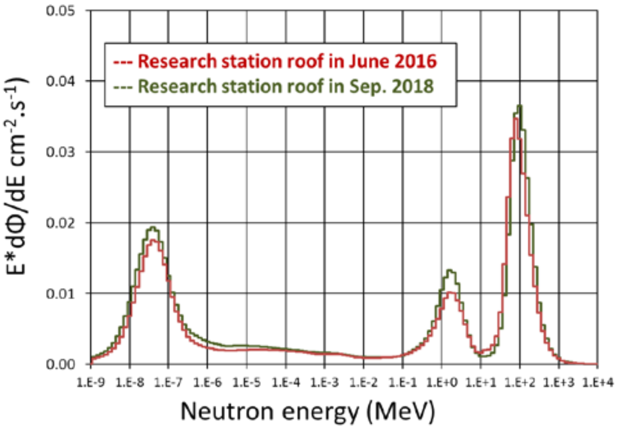

Figure 5. Spectral neutron fluence rate distribution measured in June 2016 and September 2018 below the roof of the research station at Jungfraujoch (corrected to a reference pressure of 669 mbar and solar activity in September 2018).

4. Conclusions

In the present study, an ERBSS was used to measure the spectral fluence rate distribution of neutrons from secondary CRs at Jungfraujoch during different environmental conditions in summer and winter. It was found that the neutron spectra (corrected for air pressure and solar activity) measured in June 2016 and September 2018 are very close to each other for both measurement positions.

As a next step, the measured results should be investigated in more detail with Monte Carlo particle transport simulation in the Earth's atmosphere taking into account all environmental parameters in Alpine region.

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Internet data bases

http://www.nmdb.eu

Collaborating partners / networks

University of Bern
International Foundation HFSJG - High Altitude Research Stations Jungfraujoch and Gornergrat
VAO - Virtuelles Alpenobservatorium
EURADOS WG11

Scientific publications and public outreach 2018

Theses

Brall, Thomas, Influence of environmental parameters and Solar eruptions on the cosmic radiation in Alpine region, PhD Thesis, 2015-2019, in preparation.

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