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REFERENCE STATIONS METHOD USAGE FOR EXCLUDING SNOW EFFECT BY 2018-2019 DATA

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Abstract. In this article the influence of the surrounding snow cover on the neutron monitors count rate of the World Wide Web was estimated using the method of reference stations. The applied technique also makes it possible to estimate the thickness of the snow cover at the observation point, which was done for more than two dozen stations. A comparison of the results of data correction for snow is carried out for case of automatic correction, based on the developed algorithm, and for manual one, with an error estimate.

Introduction

For some stations, snow become a big problem, because due to high humidity it effectively accumulates above and around the detector. At most of these stations, it is not possible to mechanically remove the snow. Therefore, the monitoring data for the neutron component, which are significantly distorted by a variable snow layer, are not suitable for studying many types of variations and require appropriate correction. The registration accuracy of the 18nm64 neutron monitor is 0.15% for the hourly-averaged interval. And already one centimeter of thick snow 0.5 cm of water equivalent above the detector leads to a distortion of the observed variations by 0.5%.

The nature of the snow effect is twofold. The snow cover above the detector is an additional absorber, and this leads to a decrease of count rate. In addition, the neutron monitor registers a certain fraction of neutrons that are generated in the substance surrounding the detector, in particular in the ground. The snow cover shields this neutron source, which also leads to count rate decreasing. The effect of snow has been considered in many works, for example [*Korotkov et al.*, 2011, 2013], which also review earlier works.

Data and method

We have learned how to exclude barometric effect, which has a similar nature, with using data of precision atmospheric pressure; so it is possible to make corrections by measuring the thickness of the snow cover. Indeed, if, in the absence of snow, the counting rate of the detector is N_i^{cor} (for each moment *i*), then the counting rate of the detector due to absorption with some effective range L (assuming that L does not depends on energy) in the snow depth x_i is equal to $N_i = N_i^{cor} \cdot \exp(-x_i/L)$. Thus, the restored count rate

$$N_i^{cor} = N_i/\varepsilon\text{, where } \varepsilon = \exp(-x_i/L), \tag{1}$$

where ε can formally be considered as a change of the detector efficiency, i.e. as a change in some properties of a detector or observation conditions. If we knew the thickness of the snow cover, then the data could be easily corrected for the effect of snow [*Blomster et al.*, 1969]. But precise data on the thickness of the snow cannot be obtained due to the inaccessibility of the stations. Therefore, we need to look for other approximate methods. One of them is based on comparing the variations recorded at the station under consideration with the variations at the station without snow (reference). Based on (1), the intensity variations ν_i^{cor} at detector *i* relative to the base value N_B, corrected for the snow effect and expressed in terms of the measured variations ν_i for each time *i* can be written as

$$\nu_i^{cor} = \frac{N_i^{cor}}{N_B} - 1 = \frac{N_i/\varepsilon}{N_B} - 1 = (\nu_i + 1)/\varepsilon_i - 1. \tag{2}$$

It can be seen from (2) that in order to determine the snow-corrected variations ν_i^{cor} from the measured variations ν_i, it is necessary to evaluate the efficiency ε_i. For this purpose, we will use the data of the reference detector *S*, which records approximately the same variations ν^S as the detector exposed to the influence of snow ν^{cor}, i.e.

$\nu^S \simeq \nu^{cor}$. The selection criterion for a reference detector is discussed below. If this condition is applied to some averaged time interval, then we can write that

$$\frac{\overline{S}}{S_B}-1=\frac{\overline{N}/\varepsilon}{N_B}-1 \text{ or } \varepsilon=\frac{\overline{N}/N_B}{\overline{S}/S_B}=\frac{\overline{\nu}+1}{\overline{\nu}^S+1}. \quad (3)$$

When determining the average values, the averaging interval is also important. We applied a filter of moving average [*Vasiliev et al.*, 2007]. If one-way filters are applied, then this technique can be applied in real time.

In ideal case, the detectors are identical and located at the same point. The selection of a closely located reference station is not always possible, since, as we will see, almost all mid- and high-latitude stations are affected by snow. In other cases, it is necessary to take into account their differences, using the reception coefficients of these detectors [*Kobelev et al.*, 2011, 2013]. Variations for each detector in the zero harmonic approximation can be written as $\nu^S = a_{10}C_{00}^S$ and $\nu = a_{10}C_{00}$, so $\nu^S/C_{00}^S = \nu/C_{00}$, and instead of (3) we got

$$\varepsilon=\frac{\overline{\nu}+1}{C_{00}/C_{00}^S\cdot\overline{\nu}^S+1}. \quad (4)$$

The final corrections from the effect of snow variations in the detector should be carried out using expression (2), which involves the efficiency ε obtained from equation (4).The receiving coefficients of the zero harmonic for some detectors, which must be freed from the snow effect and for the reference stations involved (lower part), are given in Table 1.

ESOI	**Magadan**	**Moscow**	**Jungfraujoch**	**AlmaAta**	**LomnitskyStit**	**Nain**	**Peawanuck**
0.4324	1.0044	0.9331	0.8924	0.6442	0.9113	1.1195	1.1194
Rome	**Mexico**	**Thailand**	**Jungfraujoch1**	**Athens**	**Potchefstrom**	**Tsumeb**	**Kiel**
0.5440	0.4518	0.2815	0.8924	0.4360	0.5383	0.4406	0.9505

Table 1. *The receiving coefficients of the zero harmonic for some detectors.*

Several options for a reference station were considered. The Rome reference station option is choosed as the best (guaranteed there is no snow, long observation range, stable operation, good statistics of the 17nm64 detector).

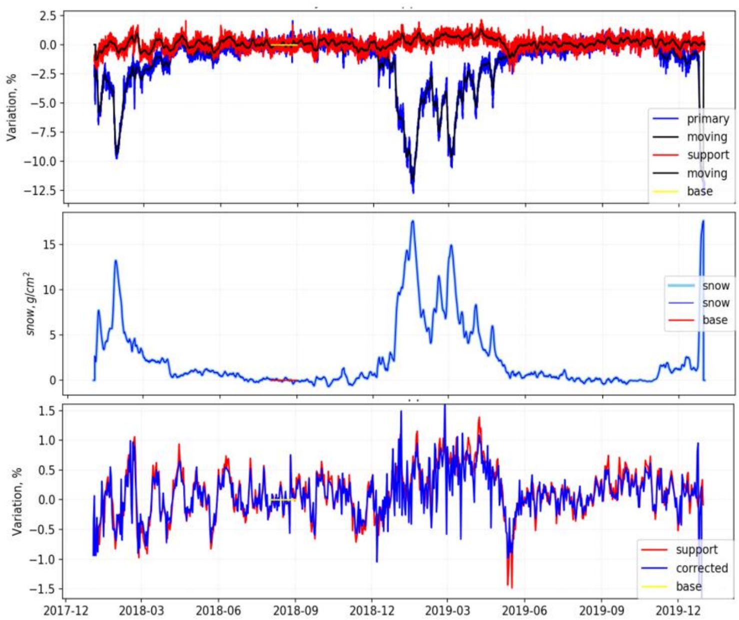

Figure 1. *Distorted by snow effect and corrected data from ESOI station for 2018-2019. Base station Rome.*

Discussion and Conclusion

The effective thickness of the snow cover at the ESOI station reaches 15 cm w.e. (Fig. 2). Effective snow depth is formed from the snow on the surface of the Faraday cage and the snow surrounding the station. It can be assumed that the notches in the middle panel in Fig. 1 are associated with the periodic growth and melting of snow on the surface of the Faraday cage, and also that 1/3 of the effect is due to the snow surrounding the station. Figure 3 compares data adjusted by the method under discussion and data adjusted manually by two independent operators. The spread averaged over a year is no more than 0.1%.

Figure 2. *Accumulation of snow on the surfaces of the Faraday cage, which surrounds the ESOI station for lightning protection.*

From mid-latitude stations (Moscow, Novosibirsk, Magadan, Irkutsk, Peawanuck, Nain), one can consider the Moscow station. Despite the fact that the detector at the station is located in a building with a hipped roof, the effective snow thickness reaches 2 cm w.e., and the contribution from each of the 4 sections of the neutron monitor is the same. This indicates that the collection of neutrons occurs from a sufficiently large area and the unevenness of its coverage is imperceptible. The meteorological data can be found on the [Ventusky, 2020].

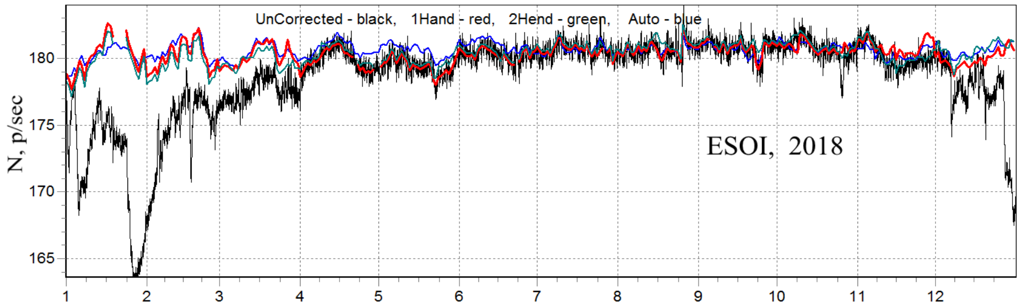

Figure 3. *Comparing manually and automatically corrected data.*

High-latitude cosmic ray stations can be divided into two groups. The stations of the first group are close to mid-latitude detectors in terms of the snow effect. The effective thickness of the accumulated snow for such stations is 2 - 3 cm w.e. and they are located in the polar latitudes, where the humidity of the air of the Gulf Stream is felt. Due to special conditions, this group also adjoins the Antarctic stations: Mirny, Terra Adeli, Mawson, YanBogo, Concordia, Sanae.

High-latitude stations of the second group are located in an area with sufficiently low humidity, where dry snow accumulates less on the roof and near the stations. These stations include Norilsk, Apatity (Fig. 4), Tiksi, Cape Schmidta, Inuvik, where the snow effect is insignificant and close to the method error, i.e. 0.5 cm w.e. during the winter period. For mountain stations the effective thickness of the snow cover in winter reaches 10 cm of water equivalent (cm w.e.), which leads to significant errors of observed variations of cosmic rays, up to ~ 10%.

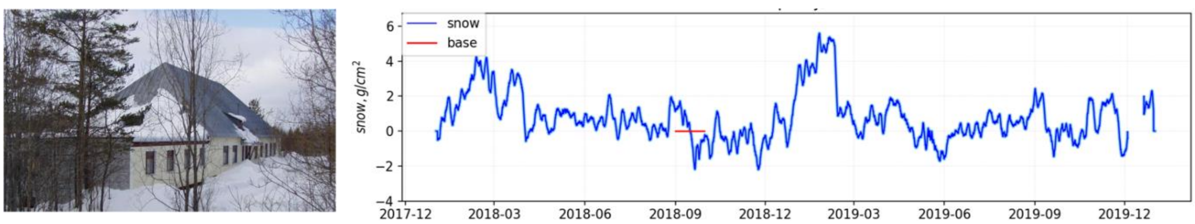

Figure 4. *Station Apatity and effective snow thickness. Reference station is Rome.*

Conclusions

The influence of snow cover near the detectors on their count rate was studied. Snow affects the data of all mountain, mid-latitude and most high-latitude detectors, which can be divided into groups. For mountain stations, the effective thickness of the snow cover in winter reaches 10 cm of water equivalent (cm w.e.), which leads to significant errors of observed variations of cosmic rays, up to ~ 10%. For mid-latitude and high-latitude stations, despite the use of hipped roofs, the effective thickness of the snow cover reaches about 2 cm w.e., which leads to errors of the observed variations in cosmic rays by up to 3%.However, some of the high-latitude stations are located in area with sufficiently low humidity, and dry snow accumulates less on the roof and near the stations. These stations include Norilsk, Tiksi, Cape Schmidt, Inuvik, Fort Smith.

The method of reference stations used in this work makes it possible to recover actual data almost automatically, by excluding the effect of snow influence. The error in this case depends on the thickness change rate of the snow cover (the characteristic time is a day). If the changes are slow (several days), then the errors introduced during data recovery can be neglected. If the changes are fast (several hours), then the errors that arise should be investigated especially, since they can increase the errors of the original data several times. But rapid changes are rare – only in moments of heavy snowfall, intense snow melting, or mechanical snow removal. The technique described in this work makes it possible not only to exclude the effect of snow, but also to estimate the effective thickness of the snow cover with an accuracy of 0.5 cm w.e.

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