Snow effect and practical questions of how to take it into account

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***Abstract*. In this work a method of exclusion of the snow cover effect from the neutron component data is described. It is particularly important for some polar and mountain cosmic ray stations. The results of manual data correction are compared with the results of automatic correction based on the developed algorithm. The described method has been approved for a number of CR stations with snow effect, for example Magadan, ESOI, MCRL and Jungfraujoch.**

***Keywords*: snow effect, neutrons component**

I. Introduction

For some stations, especially for mountain middle latitude and low latitude ones, snow is the big problem as it accumulates owing to the high humidity. Because of inaccessibility of such stations it is difficult to remove snow mechanically.

The nature of snow effect is dual. The snow cover over detector is an additional absorber and it decreases counting rate of the detector. However the big mass of snow not over detector but around it dissipates the neutron flux and creates an additional stream of neutrons to the detector, and it increases the counting rate. Both effects compete with each other but the effect of absorption dominates more often. On the one hand, the observable data are strongly distorted by a variable snow layer and so they are not suitable for studying of many types of variations. On the other hand, we have learnt a correction for the enough big barometric effect that has the same nature involving the data of the precision atmospheric pressure. Thus, measuring a snow cover thickness, it is easy to make proper corrections in the observable data. Really, if N_i^{cor} is the count rate of the detector without snow, then the count rate of the detector owing to absorption with some root-mean-square run L (we assume L does not depend on the energy) in the snow thickness x_i is equal $N_i = N_i^{cor}\exp(-x_i/L)$. From here the restored count rate is

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

The agreed notations are illustrated by Fig.1a in which the count rate change of the N_i detector as a result of snow effect is schematically shown. Formally it can be considered as the change of the detector efficiency ε, i.e. to be considered as the change of any properties of the detector or the change of observation conditions. If we got a thickness of a snow cover then it is easy to correct data on the snow effect [1, 4]. But the precise information about snow cover thickness cannot be obtained, as snow accumulates round the detector in the most variable ways. Therefore it is necessary to search for other approximate approachs of the snow effect account. One of them is to compare variations registered on the observed station with variations at the basic station without snow problems. Certainly it is not the perfect decision as the detector surrounded with snow, has a bit different coupling functions, but it is a good enough approach.

However it is the approximate estimator as the character of the neutrons absorption in the snow cover thickness depends on, so-called, boundary effect (air-snow-ground) and it is necessary to consider a two-component curve of absorption with low and fast fading neutron flux [7].

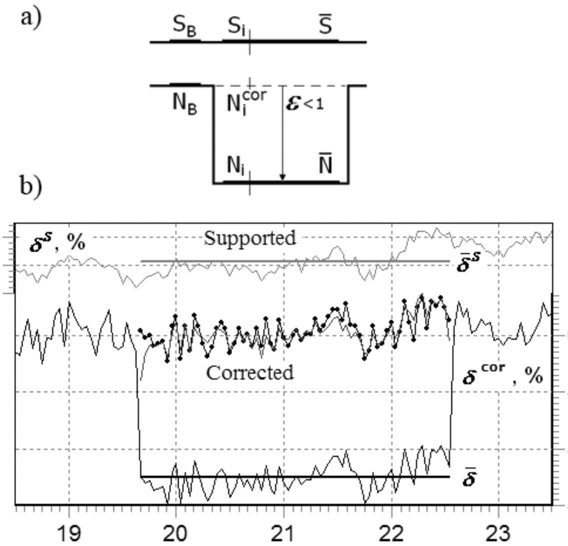

Fig. 1: a) Count rates of the based station S and the station with snow N
b) Count rate variations of the based station S (Moscow) and MCRL for the March 2009

II. The method of the snow effect exclusion

Let's consider the almost ideal case - instant snow falling which has been mechanically removed after a while. Such case was simulated by us and is shown in Fig. 1b.

Basing on (1) variations relative to the base period δ^{cor} corrected for the snow effect and expressed by way of the measured variations δ_i can be entered as

$$\delta_i^{cor} = \frac{N_i^{cor}}{N_B} - 1 = \frac{N_i/\varepsilon}{N_B} - 1 = (\delta_i + 1)/\varepsilon - 1 \quad (2)$$

Count rate during the base period is N_B. I.e. for the definition of the variations corrected for the snow effect by the measured variations it is necessary to estimate the efficiency ε. For that we use the data from the detector registering nearly the same variations δ^S as the detector with snow δ^{cor}, i.e. $\delta^S \cong \delta^{cor}$. The criterion of the basic detector choice will be discussed below. If this condition apply to some average time interval it is possible to write

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

Thus, having calculated for some interval average variations from the correct detector $\overline{\delta}$ and the basic detector $\overline{\delta}^S$, we according to (3) can define the average efficiency ε for this interval and therefore the variations corrected for the snow effect according to the expression (2).

In Fig. 1b the data corrected by means of the described method is shown. Just the same way the manual data correction is ccarried out: the interval is picked out visually, efficiency is calculated according to (3) and the data are corrected as it follows from (2). Event presented in Fig. 1a is the ideal event in all cases. First, very fast table-like transient, secondly, the thickness of snow during the whole period did not vary. Really the snow thickness varies in due course. That is why the method described above is necessary to be generalised taking into account a real situation. First of all for the calculation of the efficiency it is necessary to develop the criterion of averaging $\overline{\delta}$ and $\overline{\delta}^S$.

III. Data averaging and filtration

At a definition of the efficiency in considered above example in Fig. 1 the approximation in the form of linear function which is a special case of the high-cut filter was used. Thereby the low-frequency component of the signal has been extracted and in our simple case it was defined simply as an average value on the selected interval. *Approximation by polynomial* has been done for a polynomial $y_n = \sum_{i=0}^{m} a_i n^i$ of enough high degree m, where n - a number of hour in a month. The result is shown in Fig.2. In a case of the polynomial regression a very good step response at the beginning of December 2008 is visible.

A moving average prime filter in spite of its simplicity is optimal for the majority of tasks. The moving average filter equation is put down as $y_n = \sum_{i=-m}^{m} c_i x_{n+1}$ with the constant weight factor $c_i = 1/(2m+1)$ or even easier in the recursive form after the first step of calculations $y_n = y_{n-1} - x_{n-1-m} + x_{n+m}$.

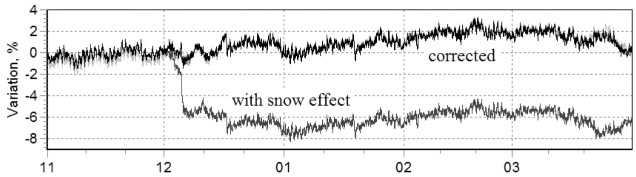

Fig. 2: Distorted by the snow effect and corrected data of Magadan station during November 2008 - April 2009. Black curve for Gaussian smoothing, grey curve - polynominal smoothing. The based station - Moscow.

Transfer function of the moving average filter $(2m+1)$ order [2] $H(w) = \frac{\sin((2m+1)\omega/2}{(2m+1)\sin(\omega/2)}$, where ω - non-dimensional frequency equal to the relation of the frequency of a signal ω_0 to a sampling frequency ω_S and possessing the values in the interval from 0 to 0,5 according to the sampling theorem. The Gaussian high-cut filter is a moving average filter in which the Gaussian function is applied as a weight function. It is realized as

$$y_n = \sum_{i=-m}^{m} c_i x_{n+i} \quad (4)$$

The weight factors are preset as $c_i = \exp(-i^2/\sigma^2)/C$, and the normalizing factor - $C = \sum_{i=-m}^{m} \exp(-i^2/\sigma^2)$. The value of the distribution dispersion σ^2 defines the required width of the distribution.

By default two-sided filter on 11 points from the central point or the filter of 23 degree was applied, i.e. about twenty-four hours for our hourly data. If the Gaussian filter was applied then the half-width $\sigma = 8$ has been chosen, $\pm 3\sigma$ corresponds to two days though the weight of the extreme points is insignificant, and the effective width is also about one day. Here it was necessary to make a compromise choice between spasmodic change of a signal and its slow enough changing with the representative period in some days. Besides, in our problem when a question of mathematical calculations efficiency is not main, we did not find out any advantages of the Gaussian filter over the moving average filter.

IV. The criterion of the basic detector choice

The ideal case is the presence at the station of two detectors one of which practically is not covered with snow. Such examples are detectors MCRL and 24nm64 at the Moscow station, or detectors at the Jungfraujoch station (3nm64 is covered with snow and 18IGY practically is not covered). The basic station for ESOI detector may be only a closely-spaced station, for example, Rome, Athens. And for Magadan station it may be, for example, Yakutsk station. However we can use such remote basic stations with care. The only right way is to define the variations expected

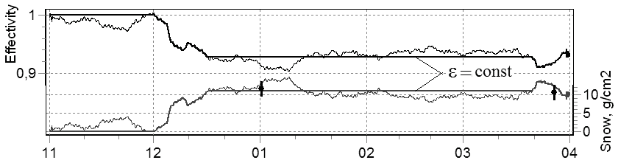

Fig. 3: The efficiency (top curve) and the snow cover thickness (bottom) for the Magadan station during November 2008 - April 2009.

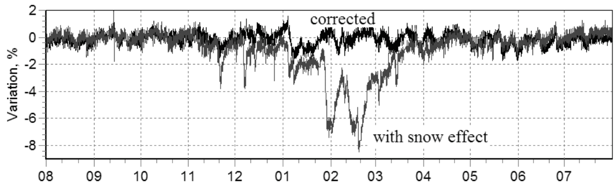

Fig. 4: Distorted by the snow effect and corrected data of ESOI station during August 2007 - July 2008. The based station is Rome.

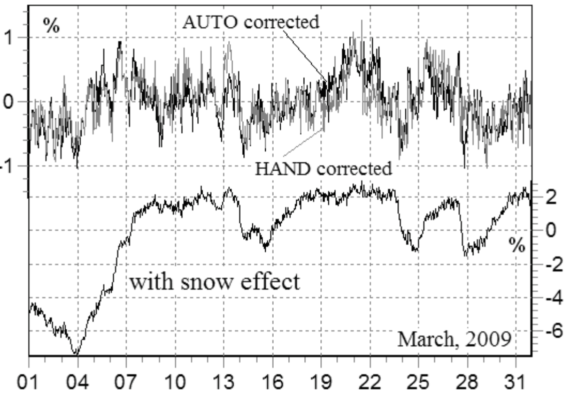

Fig. 5: On the top - the automatic (black curve) and the manual (grey curve) corrections for March 2009 for the ESOI station. On the bottom - the uncorrected data with snow effect

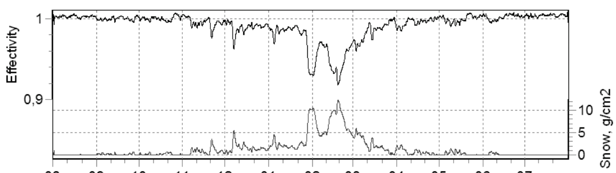

Fig. 6: Efficiency (top curve) and the snow cover thickness (bottom curve) for the ESOI station during August 2007 - July 2008.

in the given point by the results of variation model, for example, by a method of global survey and to use this result as the basic data. It is very laborious way, but if use the results of Internet project described in the work (Asipenka at al., 2008a, 2008b) http://cr20.izmiran.rssi.ru/AnisotropyCR/Index.php then expected variations can be calculated taking into account a zero harmonic and a first harmonic in the given point at any time. Such procedure guarantees this problem the correct solution with sufficient accuracy.

V. Results and discussion

The method of automatic data correction has been checked up for the event resulted in Fig.1a and the comparison with the result of manual data correction has been done. In addition we have examined the step response. The result of manual data correction (dotted curve) and the automatic correction result (continuous curve) are plotted on the right panel Fig.1a. We see the good agreement though at the moment of jump it was necessary to apply sufficiently narrow Gaussian filter (6 hours) to reduce the distortions.

For the Magadan station the results of automatic data correction for snow effect are shown in Fig.2. At the station the heavy snow was falling from the beginning of the December up to 5 December, and further there was being light snow up to 16 December. The maximum snow weight was 11-12 g/cm2. After 16 December to 20 March 2009 snow was not falling. There was moderate snow from 21 till 30 March 2009. The dimensioned snow weight at the end of this period was 10-11 g/cm2. The detector efficiency during this period is shown in Fig.3. If efficiency has been calculated then following to (1) we can estimate the effective snow cover thickness as $x = L\ln(N_i^{cor}/N_i$. It is correctly if snow is equidistributed over the whole surface within the directional pattern of the detector. The snow cover thickness is shown on the bottom of Fig.3 where it is compared with the direct measuring of snow cover thickness.

At the Magadan station it was snowing during the first half of December. The efficiency decreased to the minimum value and was remaining constant up to the end of March, to the next snowfall. Comparing the constant value of efficiency for this period and the behaviour of efficiency, when it was defined even at a constant snow cover thickness, it is possible to judge on the possible errors of the applied method on their mismatch. The error can be caused by the slow reduction of the snow thickness because of snow weathering (the negative trend in the snow thickness is visible), and because of the basic station drift. Therefore the described method is expedient for applying only to the periods of a heavy snowfall, and during other periods it is better to consider constant efficiency values.

At the ESOI station the observations have begun in 1998. Because of the damp mountain climate, during the winter period there are constantly big problems with the snow effect. The typical behaviour of variations is shown in Fig. 4. At the correction introduction the Rome station was used as the basic station. In fig. 5 the comparison of the automatic and the manual methods for March 2009 for the ESOI station is shown. Very good agreement is visible.

In Fig. 6 the efficiency and the dynamics of the snow cover thickness during the winter 2007-2008 are shown.

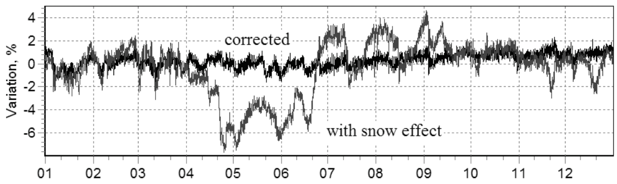

Fig. 7: Distorted by the snow effect and corrected data of the Jungfraujoch station (3nm64) during January - December 2008. The based stations are Jungfraujoch-18IGY (black curve) and Rome (grey curve).

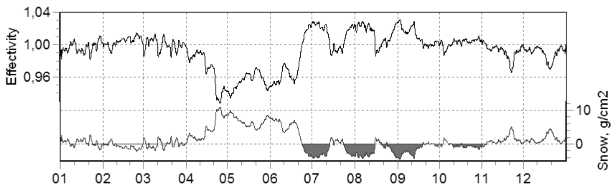

Fig. 8: Efficiency (top curve) and the snow cover thickness (bottom curve) for the Jungfraujoch station (3nm64) during January 2008 - December 2008.

It is visible that ESOI station data are very distorted by the snow effect.

While applying of smoothing filters the completeness of the corrected station data and the basic station data is important, otherwise in discontinuities there will be strong distortions which are necessary for removing later. Distortions defined by the width of the filter will be observed not only after the discontinuity but also before it, i.e. the data will be really damaged for this interval. To avoid this procedure, we replaced gap in data with average values, and at the final stage we deleted these periods, replacing them again with the gap.

There are two detectors at the Jungfraujoch station - 18IGY and 3nm64. The last detector is exposed to the snow effect. The typical variation behavior is shown in Fig.7. At the introduction of the corrections as the basic station the detector 18IGY was used and for the check up the station Rome with the same statistics was used.

From Fig.7 it is visible that the counting rate of the detector is decreased owing to absorption within the snow thickness over the detector in April-June, and there is the increase of counting rate owing to the lateral snow accumulation in June-September. It is a typical picture which is observed in other years, for example, 2002-2008. In Fig.8 the efficiency and the dynamics of the snow cover in the whole 2008 year is resulted. It is visible that the station data are strongly distorted by the snow effect for four-five months in a year. From Fig. 8 it is also visible that absorption within the snow thickness over the detector dominates in April-June, and the lateral snow accumulation dominates in June-September (in Fig.8 it is the negative values of the snow cover thickness).

VI. Conclusions

For some stations - Magadan, ESOI and Jungfraujoch - the method of exclusion of the snow cover effect from the data was tested. The method is based on the comparison of the variations of tested and based stations. The variations mismatch at these stations is characterized by the snow cover thickness effect at one of them, and another one is the based station. For the numeric evaluations and the exclusion of the snow cover effect from the data the averaging was made to find the characteristic trends related to the snow thickness dynamics. For this purpose the high-cut filters has been applied. While selecting the filter degree the compromise choice between spasmodic signal change and its sufficient slow change with a several days period had to be done. By default the effective width of the filter is about 24 hours.

The snow effect can be eliminated from the data with the accuracy of about 0.3-0.4%. The ideal case is when the detectors are identical and are in the close points. It guarantees the equal external variations. The choice of the nearby based station is possible but it is necessary to check up how close the variations of these stations are.

The described method allows not only to exclude the snow effect but also to make an estimation of the effective snow cover thickness.

The method can be applied in real time also if use one-sided filters. The main difficulty will be the determination of the period when such corrections are necessary to be implemented.

Acknowledgements

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