An Application of Cosmic-Ray Neutron Measurements to the Determination of the Snow Water Equivalent

PAQUET[1] E., LAVAL[1] M., BASALAEV L.M., BELOV[2] A., EROSHENKO[2] E., KARTYSHOV[2] V. STRUMINSKY[2] A., YANKE[2] V.
[1] *EDF DTG – Water Resources and Civil Works Monitoring Department 21 av. de l'Europe BP 41, 38040 Grenoble Cedex 9 – France.*
[2] *IZMIRAN, Pushkov N.V. Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation (RAS), IZMIRAN, 142190, Troitsk, Moscow region, Russia.*
yanke@izmiran.ru

Abstract: In this work a question of application of the neutron component absorption effect to the practical task on the snow cover thickness estimation is considered. It is discussed the influence of the primary CR variations, changes of atmospheric pressure and humidity concentration in the lay surface on the accuracy of the results obtained. Continue observations of a snow covering during several seasons have demonstrated an efficiency of this method even for a snow thickness of some meters. The accuracy of snow cover evaluation doesn't exceed several percentages by daily mean data.

1. Introduction

The exact information about the thickness of snow cover and, finally, about the store of fresh water in the mountains is useful and important by many reasons. It is important for the study of total store of fresh water, for the control of water stores on hydro technical constructions, and for a continue forecasting of the spring flood. Non destroyed methods of the snow cover definition are based on absorption of some kind of radiation. In principle three types of high level radiation: gamma-radiation (up to several dm of water equivalent), neutrons (some meters of water equivalent) and muons (up to several tens m of w. e.).

The estimation of snow cover thickness may be simply made by a method of absorption of artificial radiation (for example, neutron or gamma radiation), which exceeds natural background in many times. However, by ecological reasons, such a problem has to be solved using only natural radiation background. Herewith, except of significantly worse statistics, a set of additional technique and methodical difficulties arose, for example, necessity to carry out precise measurements of the pressure, to correct current monitoring data for the primary CR variations. In principle, all these difficulties may be avoided if to use in each point not one but two detectors: above and under the snow sheet, and then, to work with a ratio of their counting rates. But even in this approach the problem is not solved completely since these two detectors have different coupling functions: $W_{Rc}(R,h_0)$ (above) and $W_{Rc}(R,h_0+X)$ (under snow cover of X thickness).

In this work we leaned on the data from the French net of hydro meteorological stations [1] which by some reasons had only one common neutron detector under the snow. In this case we should corrected data for atmospheric pressure and for the primary CR variations- the last procedure is in all respects complicated and laborious. It is clear that to exclude completely primary CR variations from observable data is complicated enough. Roughly it may be done by the data from one station if to select high frequency variations with a period of less that one day and low frequency waves which content 27-day, solar diurnal variations and quasi periodical variations like Forbush effects. From high frequency variations it is possible to select the first harmonic of the expansion as daily variation. For more correct excluding of the primary variations it is necessary to incorporate data from world wide neutron monitor network and to derive cosmic ray density and three components of cosmic ray anisotropy beyond the magnetosphere. Detailed description of a correction for the primary variations may be found in [2] or in publication by the address http://cr20.izmiran.ru/AnisotropyCR/index.php.

2. Method of the snow thickness definition

On the early steps in 70-s such measurements were based on the use of artificial and nature sources of gamma radiation [3-4]. However, the use of neutron radiation turned out to be the most perspective [5]. It is caused by the following: 1) neutron component has absorption mean free path approximately in order larger than that for gamma radiation. Thus, with neutrons we can work on the

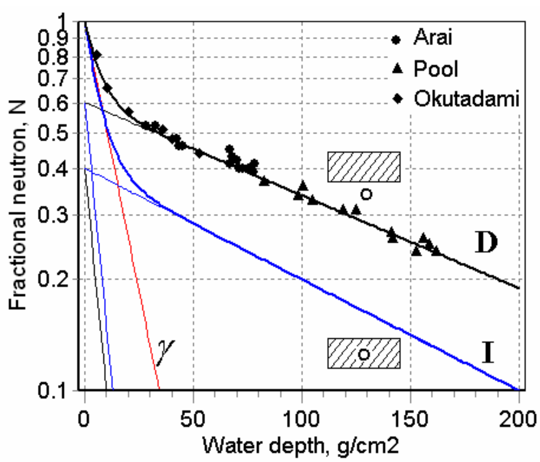

Figure 1: Curves of absorption of neutrons and gamma radiation: D for a detector located under snow and I located inside of snow. Experimental points show an absorption in snow at sea level (Arai и Pool) and in the mountain (Okutadami). Red curve shows an absorption of gamma. Data are adopted from [6].

thickness of several meters of w.e.; 2) since the neutrons may be considered as incident parallel beam then the problem of dissipation is absent; 3) High stability and long time service of the neutron BF^3 or He^3 counters and correspondingly less hard conditions for exploitation.

In [6] a question of utilizing the absorption effect of neutron component was considered as application to the estimation of the snow cover thickness. An experimental absorption curves were investigated in the cases when detector was placed under snow layer and inside of snow, as it is shown in Figure 1. There is also a curve of absorption for gamma radiation from the source ^{60}Co is presented (red line). The neutron absorption in water was studied also by means BF_3 detector in polyethylene moderator of 25.4 mm thickness. As it was found, so-called boundary effect (air-snow-ground) influences the character of neutron absorption in the snow. Curve D is presented for the case when detector is placed under absorber, and in this case detector is between layers of snow and soil. Fast intensity decrease at the small depths is related to the boundary effect of air-ground for the neutrons of moderate energies. This character did not change if surround detector by Ca layer, but it is changing if the neutrons of higher energy are recorded. Curve I is obtained when detector submerge in water, to avoid an influence of laying surface. When the wet soil appears in case D, then, if the curves are normalized to zero level the absorption curve is going between D and I.

Both curves D and I are the combined result of observations on different altitudes within the interval sea level-mountains. Since the neutrons of intermediate energies are in the balance in the low atmosphere then the energetic spectra are similar by the shape and inverse proportional to the neutron energy. It is reasonable to suppose that absorption curves normalized to the zero level are close to each other by the shape on different altitudes.

We performed data approximation as it was done in [6], as a sum of two exponents with different indices β: fast and slow decreasing neutron fluxes just for the curves D and I:

$$N_D = 0.3975 \cdot \exp(-0.139 \cdot X) + 0.6025 \cdot \exp(-0.00579 \cdot X)$$

$$N_I = 0.40 \cdot \exp(-0.139 \cdot X) + 0.60 \cdot \exp(-0.00693 \cdot X)$$

In Fig.1 the low and fast затухающий fluxes are also plotted. One can see that coefficient of the neutron absorption at the depths >30sm is less in order than that for gamma radiation (6.73 $\%/г/см^2$). It means that for monitoring of snow thickness more than 1m it is necessary to use absorption of neutron component.

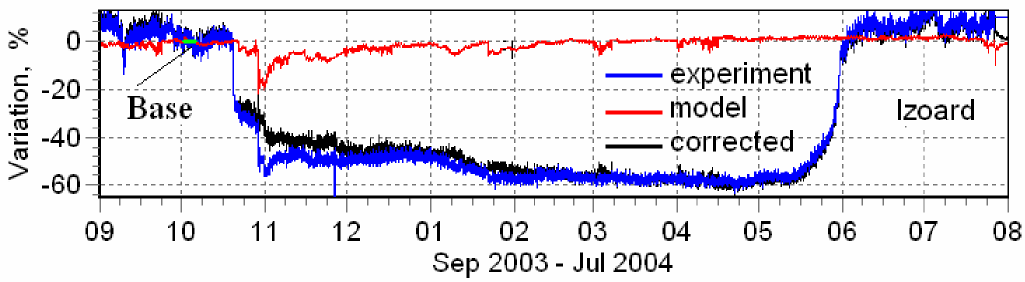

Figure 2: Experimental and expected variations on hydrometeorological station Izoard.

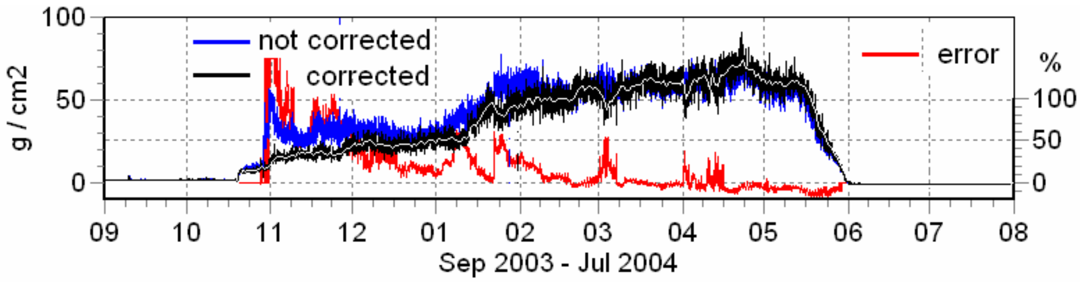

Figure 3: Time variations of the snow thickness on hydrometeorological station Izoard.

3. The sources of errors in the estimation of snow thickness

The requested accuracy of the snow thickness definition is about some percentages. How to provide it? There are some possible sources of errors: 1) statistical accuracy of the counting rate of detectors; 2) error because of mistakes in correction for atmospheric pressure; 3) error caused by not right correction for variations of non atmospheric origin; 4) difficult accounting of the effect from lay surface. Let us consider each of them.

1) Statistical accuracy of detector hourly counting rate is equal 4% for sea level and ~2% for mountain station.

2) The error for atmospheric pressure correction is rather small and is defined mainly by the precise of pressure measurements which should be not worse than 0.1-0.3 mb. This error may reach some tents of percentage.

3) Primary variations may change catastrophically the result of snow thickness estimation. For example, Forbush decrease in October 2003 reached about 25%, recovering lasted about one month. Forbush decreases of the less amplitude (6-8%) may occur several times per year. On the background of snow thickness of 500 mm w.e. a decrease of NM counting rate on 18% may be interpreted as additional absorber of 270 mm w.e. thickness that leads to the error of 54%. A mistake in correction for variations of non atmospheric origin may give several percentages. This follows from the accuracy of the obtaining of CR parameters by GSM method from NM Network data.

4) Effect of humidity of the lay surface may reach of 10%. This question takes an additional study. Neutron monitor counting rate is formed by a directional diagram of detector. Neutrons from "side" directions are mainly generated in the lay surface. And humidity store in this surface leads to the flux weakness by the same way as the snow layer above a detector.

4. Estimation of snow thickness by the neutron scan by the data from hydrometeorological station Izoard

Each of 38 mentioned in Paquet and Laval (Paquet E., Laval M., 2006) hydrometeorological stations has a neutron monitor. Detector consists of one helium counter 65NH45, surrounded by "side" polystyrene of 12 cm thickness and upper and low polystyrene of 7 cm. Counter size is Ø25×450mm, inside pressure of He^3 4 bar = 3000mmHg, 65 $count\cdot s^{-1}/n\cdot cm^{-2}\cdot s^{-1}$ sensitivity. In Figure 2 the measured counting rate (blue curve), corrected for primary CR variations counting rate (black one), and expected primary variations (red curve) are presented for the station Izoard (France, 44.82°N, 6.73°E, 2280 m, Po=774 mb, mean counting rate 50 imp./min).

Under correction for primary CR variations the role of primary variations is overestimated a little. It is related to at least two reasons. Firstly, the expected variations are obtained for a standard supermonitor NM64, but not for without lead NM of the net of meteorological stations. For such a design of NM the corresponding calculations or latitudinal measurements are necessary. Secondary, coupling functions have to be used not for the level H0, but for the H0+X, where X is unknown thickness of snow (in g/cm^2) above the NM since these functions depend on the amount of substation above a detector. After such a correction counting rate may be used for definition of snow thickness.

Count rate variations relatively to basic period 2003-10-02 / 2003-10-04 (in Figure 2 it is marked by horizontal segment) was recalculated into the snow thickness using the absorption curve D (from Figure 1). Time changes of the snow parameters in the units of water equivalent (w.e.) are presented in Figure 3 for station Izoard. There are snow thickness derived from uncorrected and corrected for primary CR variation data (blue and black curves correspondingly). The red curve indicates a possible error if not to correct data for the primary variations. In this case an error may get several tens percentages during several weeks.

5. Conclusions

If to plan an elaboration of system for remote and automated evaluation of the snow thickness then the best one will be a system of two detectors: above and below the snow cover. Such a system will allow the obtaining more correct results since in this case the necessity to introduce different kind of correction falls away. Of course, such a system should be constructed on the basis of neutron detectors since this allow the evaluation of snow thickness within necessary range.

However, if proceed from already operating system consisted of one detector, in this case a developed method allows us to obtain result fitted practical request by accuracy. Data of measurements in such a design take the introducing of complicated corrections with incorporation of large volume of data. The last circumstance makes lower the system stability. An accuracy which possible to be obtained in this approach is not worse than 5%./

The experimental data from French network of hydrometeorological stations showed sufficient stability despite of very hard conditions for operating system in autonomic regime in the high mountains.

Acknowledgements

These works is partly supported by RFBR grants 07-02-00915, 06-02-39028 and Program BR of the Presidium RAS "Neutrino Physics". We thank also all groups and collaborations provided continue monitoring of CR data, - please, look http://cr0.izmiran.rssi.ru/ThankYou/main.htm.

References

[1] Paquet E., Laval M., "*Experience feedback and future prospects for the use of EDF's Cosmic-Ray Snow Gauges*", 2006.

[2] Asipenka A.S., Belov A.V., Eroshenko E.F., Klepach E.G., Yanke, V.G., "*Interactive database on the cosmic ray anisotropy*". Proc. 30th ICRC, Mexico, SH.3.4, Id 1006, 2007.

[3] Kogan R.M., Niliforov M.V., Fridman Sh.D., Chirkov V.P., Yakovlev A.F. "*Determination of water equivalent of snow cover by the method of aerial gamma survey*", Sov. Hydrol. Sel. Pap., No 2, 183-187, 1965.

[4] Peak E.L., Bissell V.C., Jones E.B., Burge D.L. "*Evaluation of snow water equivalent by air borne measurement of passive terrestrial gamma radiation*", Water Resour. Res., 7, 1151-1159, 1971.

[5] Kodama M., Kawasaki S., Wada M. (1975) – "*A cosmic ray snow gauge*", Int. J. Appl. Radiat. Isot., 26, 774-775, 1975.

[6] Kodama M., Nakai K., Kawasaki S., Wada M., "*An application of cosmic-ray neutron measurements to the determination of the snow water equivalent*", Journal of Hydrology vol. 41, n 1-2, p. 85-92, 1979.