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Temperature effect of muon component and practical questions of its account

M. Berkova, Belov A., Eroshenko E., Smirnov D., Yanke V.

***Abstract*—Wide use of muon detectors at researching of cosmic rays variations is restrained by presence of the big temperature effect inherent to muon component of secondary space radiation. To except such effect the data of aerologic sounding near to point of the detector location are necessary. More often such data are absent in general and it is impossible to restore them in retrospective, or the soundings aren't carried out regularly. We offer another way of the temperature effect calculation, based on the global atmospheric models. Such models are created by means of the generalized meteorological data and allow receiving a temperature behavior in atmosphere in any point and at any moment. Using the altitudinal atmosphere temperature profile for standard isobaric levels from one of the models we have corrected the hourly data for 17 directions of Nagoya telescope, 3 directions of Yakutsk telescope, ionization chambers in Yakutsk and Beijing over the whole period of observations. Comparison of results received according to direct sounding of altitudinal distribution of temperature and the modeling data, allows us to assert that the offered approach can be applied successfully to correction of muon detectors data on temperature effect.**

1. INTRODUCTION

WHILE researching of cosmic ray (CR) variations first of all it is necessary to be released from variations of atmospheric origin. If barometric effect is defined by only one parameter, namely pressure at observation level, the temperature effect is defined by conditions in the whole atmosphere from the level of generation actable component of secondary space radiation to the level of their registration. Pressure at observation level is being measured continuously by precision pressure gauges with sufficient accuracy whereas aerologic sounding of temperature profile which is necessary for definition of atmosphere temperature cut is taken four times a day at the best. The difficulty of continuous number reception of hourly data about meteorological parameters near to location of muon telescope, rather the absence of such data, did not give a chance to use the richest experimental material in full obtained during several tens years. A method of crossed telescopes for a case of CR north-south anisotropy allowed the elegant solution of the problem of meteorological effects for muon component, but in a whole, there is no final offer for accounting of a temperature effect till now.

The relative role of CR meteorological effects is defined by the type of variations and in some cases the accounting of meteorological effects is especially important. It's clear that it is the most difficult to investigate those variations of extra-atmospheric origin (annual, 27-day, solar diurnal) which period coincides or it is close to the period of a corresponding variation and strongly masks by variations of atmospheric origin. Really, the daily wave amplitude of temperature effect can reach several percent for muon component. Temperature corrections become even more significant at research of 27-day or annual variations which correlate often with meteorological factors changes. The temperature effect brings the greatest contribution in annual variation which exceeds five percent for the muon component that is comparable with amplitudes of long-period variations for particles of these energy. The use of the crossed telescope method does almost insignificant temperature variation at research of CR anisotropy.

On the other hand, for the neutron component the temperature effect doesn't play some appreciable role as an annual wave amplitude is almost two order less than for muon component, and makes up just some hundredth percent. But at research of north-south anisotropy a situation is opposite as the data of neutron monitors located in opposite hemispheres is used. The big differences in temperature in northern and southern subpolar areas lead to considerable temperature variations in the neutron component which are comparable with north-south anisotropy and sometimes exceed it.

Particular problem of temperature effect in this case is that its planetary distribution can be very similar to distribution of north-south asymmetry, thus, for such class of problems the temperature effect is also necessary to be considered for neutron monitors [1].

2. TEMPERATURE SOUNDING DATA

For reception of the information on altitudinal distribution of temperature, besides direct atmosphere sounding close to the point of observation by muon telescope, another approach is possible also. As the global data radio-scan, optical, acoustic and radar-tracking sounding give only 15 % of information about altitudinal behavior of

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M. Berkova is with the Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation by Pushkov, Russian Academy of Sciences (IZMIRAN), 142190 Troitsk, MR, RF (e-mail: qvark8@yandex.ru)

A. Belov is with the IZMIRAN, 142190 Troitsk, MR, RF (e-mail: abelov@izmiran.rssi.ru)

E. Eroshenko is with the IZMIRAN, 142190 Troitsk, MR, RF (e-mail: erosh@izmiran.ru)

D Smirnov with the IZMIRAN, 142190 Troitsk, MR, RF (e-mail: smirnovdm@yandex.ru)

V. Yanke is with IZMIRAN, 142190 Troitsk, MR, RF (e-mail: yanke@izmiran.ru)

atmosphere temperature, leaving almost uncovering large oceanic, subpolar and mountain areas, and one can capture? these areas only by the satellite's measuring. In meteorology models which allow receiving altitudinal behavior of temperature in the atmosphere in any point and at any moment are built on the basis of the generalized data [2]. The one model's results are available in electronic publishing [3]. Such model allows to get 3D temperature field and its temporal variations beginning from 1950 on 18 isobaric levels: see level, 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10 mb. Such model data are available not only for retrospective analysis but they are supported in real time now that allows to except the temperature effect also in real time. We'll use just the same data in the future. The data accuracy is about a few degrees and it is depending on isobaric level. In Fig. 1 there is a comparison of temperature distribution in atmosphere according to the model and experimental data for Moscow meteorological station [4]. The comparison specifies that a divergence of experimental and modeling values is only some degrees. In paper [1] the temperature effect of CR neutron component was investigated according to the same model and the analysis has shown that accuracy of the modeling altitudinal temperature distribution in atmosphere is sufficient even for research of temperature effect of CR neutron component which is 10 times weaker. We have got the data of altitudinal sounding for time intervals at our points of interest using the data [2]. The model generates the data with 4 hour resolution which have been transformed to the hourly data as a result of interpolation by cubic spline functions [5].

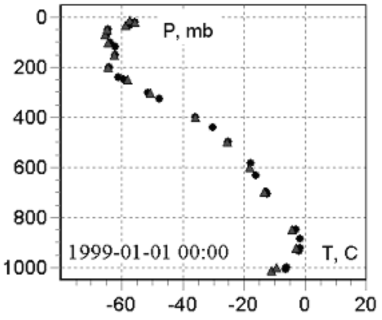

Fig. 1. Comparison of temperature distribution in atmosphere according to the model (triangles) and experimental data (circles).

3. DATA OF CONTINUE CR MONITORING

For various reasons continue monitoring of the muon component was carried out by means of several tools only. First of all, it is the most successful in Nagoya - at the point of construction multidirectional scintillation telescope [6] working since 1970. It has 17 independent directions: a vertical, 4 inclined on 30º, 49º and 64º and 4 azimuthally directions. Telescope data are accessible by the address [7], and real time data– by address [8]. Two other muon telescope [9] operating more than three decades are ground-level and underground on 7 mwe level devices in Yakutsk which have 3 independent directions: a vertical, the north and the south. In Yakutsk the observations by means of precision ionization chamber ASK-1 have also being conducted during more than 5 decades [10, 11]. Just the same chamber is working in Beijing [12]. All these detectors' data have been received with an hour average interval, corrected for atmospheric pressure, but not corrected for temperature effect.

4. TEMPERATURE EFFECT OF MUON COMPONENT

On the basis of the integrated method the variations caused by temperature effect δ_{tem} , for each direction of the detector can be considered as in

$$\delta_{tem} = \int_0^{h_0} \alpha(h)\cdot\delta T(h)\cdot dh,$$

where $\alpha(h)$ density of temperature coefficient and $\delta T(h)$ - temperature variation.

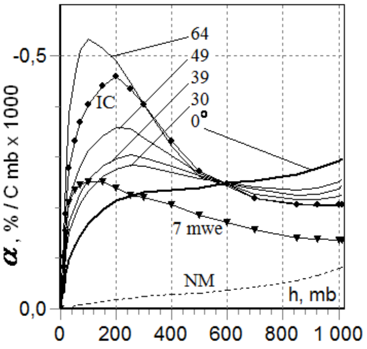

Fig. 2. Density of temperature coefficient for different detectors.

The temperature variation is defined as deviation of current temperature course in atmosphere $T(h)$ from a temperature course during the base period $T_B(h)$: $\delta T(h) = T_B(h) - T(h)$. Temperature coefficients densities $\alpha(h)$ of various detectors were received by calculation way and they are resulted in Fig. 2 [13]. There are the coefficients for all the directions of Nagoya telescope (0º, 30º, 39º, 49º, 64º), temperature coefficients densities of the Yakutsk complex telescopes (0º, sea level and 7 mwe) and ionization chamber IC plotted. For comparison the temperature coefficient density of the neutron monitor is also depicted.

5. RESULTS AND DISCUSSION

By the methods stated above we have corrected the hourly data from the beginning of observations for the following detectors:

- Nagoya multidirectional muon telescope, 17 directions of registration;
- Yakutsk ground-level muon telescope, 3 directions V, N, S;
- Yakutsk underground muon telescope, 7 mwe, 3 directions V, N, S;
- Yakutsk ionization chamber;
- Beijing ionization chamber.

Hourly data corrected for temperature effect is accessible in the Internet [14]

On the top panel in Fig. 3 the counting rates uncorrected and corrected for temperature effect for vertical direction of Nagoya muon telescope are presented.

While correcting we used the calculated densities of temperature coefficients resulted in Fig.2. Some residual annual wave can be caused either by the true annual variation or discrepancy of the used densities of temperature coefficients. It is obvious that for the further refinement of the result it is necessary to define densities of temperature coefficient experimentally and today this problem is quite solved.

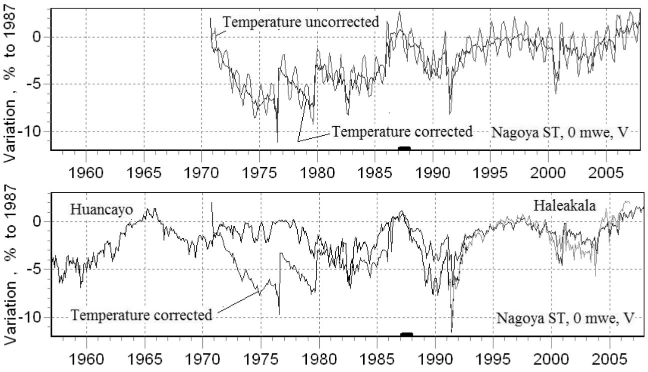

Fig. 3. Nagoya muon telescope, vertical. Top panel – count rate uncorrected and corrected for temperature effect. Comparison with Huancayo and Haleakala neutron monitor.

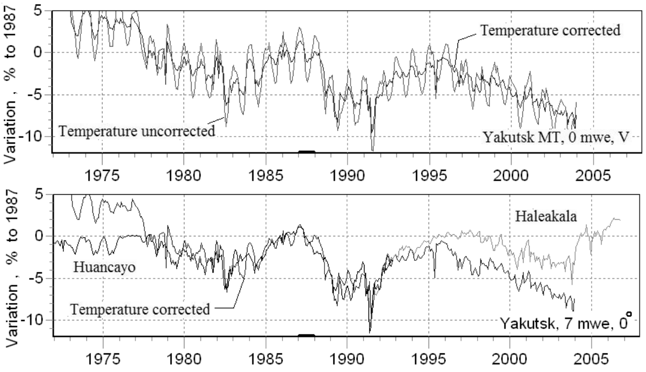

Fig. 4. Yakutsk muon telescope, 0 mwe, vertical. Top panel – speed of account not corrected and corrected on temperature effect. Comparison with Huancayo and Haleakala neutron monitor.

On the bottom panel in Fig. 3 corrected muon telescope data are compared with the data of equatorial neutron monitors from Huancayo and Haleakala stations. Though cut off rigidities are close enough (13.3 GV for Haleakala monitor and 11.5 GV for vertical muon telescope) median rigidity of neutron monitors 30.6 GV is less than those for muon telescope 53.5 GV that leads to different modulation depth in maxima of solar activity. In a whole it is possible to notice that, since the middle of 80th, the muon telescope has been worked stably enough, and variations are similar even in details. Besides, it is possible to deduce that vertical profiles of temperature distribution in atmosphere used by us and densities of temperature coefficients allow to except temperature effect from the observation data with high accuracy. Introduction of corrections for efficiency can eliminate drift at initial debugging stage.

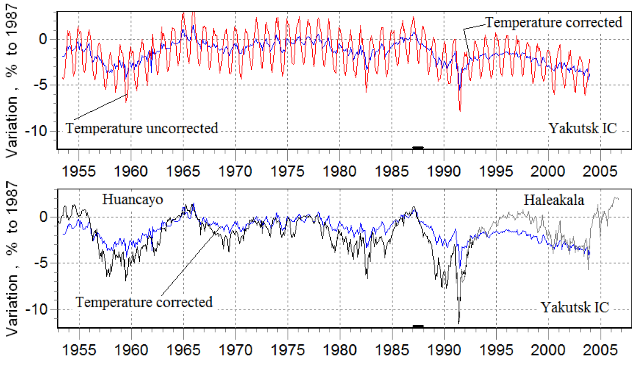

Fig. 6. Yakutsk ionization chamber. Top panel – count rates uncorrected and corrected for temperature effect. Comparison with Huancayo and Haleakala neutron monitor.

For vertical directions of ground-level and underground 7 mwe muon telescopes the primary and corrected data are plotted in Fig. 4 and Fig. 5 which are also compared with the data of equatorial neutron monitors. And in this case the median rigidity of muon component (42.0 GV and 69.4 GV for ground-level and underground telescopes accordingly) is higher than in case of neutron monitors. In case of Yakutsk complex telescopes it is possible to assert that the methods used by us give quite satisfactory results. The drift of count rate of the vertical telescope at sea level after 1995, probably, has the same reasons as the current drift of Yakutsk ionization chamber which is considered lower.

Current of Yakutsk ionization chamber uncorrected and corrected on temperature effect is presented on the top panel in Fig 6. At bringing in corrections we originally used the calculated densities of temperature coefficients resulted on fig. 2, i.e. the same as for inclined 60° telescope on a sea level. Bringing in temperature corrections thus removes a seasonal variation. For elimination of this fact it is necessary to decrease the density of temperature coefficient on 30±2 % approximately, i.e. this coefficient is very critical. The necessity of density correction of temperature coefficient was marked in earlier papers [15] and it was supposed that for Yakutsk ionization chamber it is connected with considerable thickness of the screen over the ionization chamber (about 1 mwe)

On the bottom panel in Fig. 6 corrected data from Yakutsk ionization chamber are compared with the data from equatorial neutron monitors of Huancayo and Haleakala stations. Median rigidity of Haleakala neutron monitor (30.6 GV) is closer to median rigidity of ionization chamber (66.1 GV). As a whole it is possible to notice that the ionization chamber works stably enough. Current drift after 1995, is probably connected with the data drift of the pressure gauge, and has the same reasons, as the drift of count rate of the sea level vertical telescope.

The data of Beijing ionization chamber is plotted in Fig.7. Though Beijing ionization chamber is under the screen in 0.1mwe thickness only, the density of temperature coefficient was used the same as for Yakutsk ionization chambers. Comparing on the middle panel with the data of neutron monitors from Huancayo and Haleakala stations one can note the stable work of Beijing ionization chamber, except of the 70th when these data indicate some drift. On the bottom panel Fig. 7 there are simultaneously variations of two ionization chambers: from Yakutsk and Beijing.

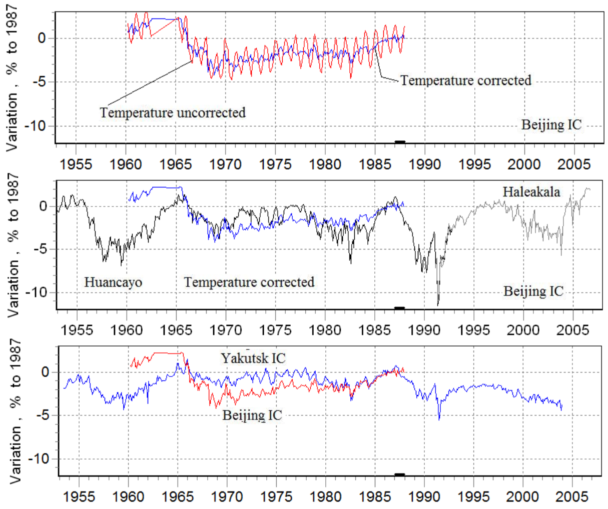

Fig. 7. Beijing ionization chamber. Top panel – count rate uncorrected and corrected for temperature effect. Middle panel - comparison with Huancayo and Haleakala neutron monitors. Bottom panel – comparison Yakutsk and Beijing IC.

Now it is necessary to estimate the accuracy (precise) of the corrections for temperature effect. For this purpose we should release the detector data from primary variations and analyze the remained signal which in ideal should represent flat noise. Proper correction of the detector data on primary variations is a difficult problem, and it can be solved with various degree of approach. We can avoid such difficult procedure if process signal by the corresponding filter. In Fig. 8 there is a residual signal after subtraction of mid-annual values.

Two variants are resulted - when calculated densities of temperature coefficients are reduced on 30 % and on 20 %. It is visible that the annual wave is removed during one periods and arises during another periods. It testifies that density coefficient depends on the level of solar activity though this dependence is weak.

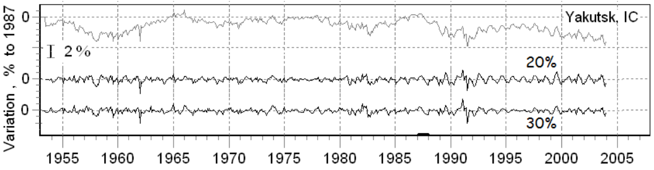

Fig. 8. Residual signal after processing the data of Yakutsk IC by filter. Two variants is resulted: calculated densities of temperature coefficients are reduced on 20% and 30%.

6. CONCLUSION

1) Vertical profiles of temperature distribution in atmosphere finding according to the atmosphere model, allow to except sufficiently the temperature effect from the hourly data of muon telescope and ionization chamber.

2) Comparison of the muon component data, corrected for temperature effect, with the data from other detectors has proved as a whole the correctness of the used densities of temperature coefficients for all directions though experimental definition of densities of temperature coefficients would be very useful in further.

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