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# The temperature effect of the muon component observed on A.I. Kuzmin cosmic ray spectrograph in Yakutsk

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Abstract. An estimation and accounting of a temperature effect in data of the complex of muon detectors of the Yakutsk cosmic ray spectrograph after A.I. Kuzmin are carried out. The results of determination of altitudinal distribution of the temperature from the database of world network of muon telescopes (MDDB), which are obtained using a model of the atmosphere developed in the National Centers for Environmental Prediction NCEP, are used. It is shown, that the vertical profiles of temperature distribution in the atmosphere that are presented in MDDB and the estimated temperature coefficients are allow qualitatively exclude the temperature effect from the data of registration of the muon component of secondary cosmic rays. The results of observation of the Yakutsk spectrograph and accounting of the temperature effect are presented in the Internet through the link http://www.ysn.ru/ipm.

### 1. The data of the Yakutsk spectrograph of CR and altitude distribution of the temperature

The Yakutsk cosmic ray (CR) spectrograph (61°59′N, 129°41′E) operates in ShICRA SB RAS and is designed to register the CR particles in the huge energy range from 2 to 300 GeV. The spectrograph consists of a neutron monitor 24-NM-64, ionization chamber ASK-1 and complex of 4 underground muon telescopes based on gasdischarge counters GMC-14. The data of detectors of the spectrograph are available through the link http://www.ysn.ru/ipm/index.html or the database of muon detectors [http://crsa.izmiran.ru/phpmyadmin, http://cr0.izmiran.ru/gmdnet].The ionization chamber (IC) operated since 1953 to 2003. The counter telescopes at levels 0, 7, 20 meters of water equivalent (m w.e.) operated continuously since 1971 to 2003 and, after a pause, since 2009 till nowadays. The telescope at 60 m w.e., which worked since 1993 to 1999, was relocated at the level 40 m w.e. Since 2016 multidirectional scintillation detectors with efficient area of 8  $m^2$  had been being placed at all levels.

An analysis of the temperature effect requires engaging of data of altitudinal distribution of temperature in the atmosphere. In the work, the results of a model of the atmosphere, that was developed in the USA's National Centers for Environmental Prediction NCEP

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http: //www.nco.ncep.noaa.gov/pmb/products/gfs, was used. The model based on all available data of global altitudinal probing (ground based, high-altitude, satellite) for their interpolation. The model allows to get both retrospective and prognostic data of the threedimensional temperature field. The output of the model is the data on temperature at 17 standard isobaric levels in range 10-1000 mb for 4 times a day (0, 6, 12, 18 UT). In order to get the data with a hourly time resolution the interpolation using cubic splines are done. A detailed description of the method is presented in [1, 2]. By the data of altitudinal distribution of the temperature there are calculated an effective temperature  $T_{eff}$ , taking into account a contribution of different levels, an average-mass temperature  $T_m$  and an altitude of effective 100 mb level of muon generation H100 which are necessary for estimation of the temperature effect of the muon component.

#### 2. Methods of determining the temperature effect

There are several methods for analysis the temperature effect of the muon component [3]. A universal integral method was developed in the beginning of 1950's [4, 5, 6]. Introduction of a function  $W_T^{\mu}(h,\theta)$ , which is temperature coefficient density, allows to determine the temperature variations as:

$$\frac{dN}{N}\Big|_{T} = \delta_{T} = \int_{0}^{h_{0}} W_{t}^{\mu}(h,\theta) \delta T(h) dh,$$

where  $\delta T(h)$  is a change of the temperature profile in the atmosphere relative to the base temperature profile. Simultaneously, the method of effective temperature was developed [7], which could be considered as another representation of the integral method:

$$\left. \frac{dN_{\mu}}{N_{\mu}} \right|_{Temp} = \int_{0}^{h_{0}} W_{t}^{\mu} \delta T(h) dh = \alpha_{T} \delta T_{eff}.$$

The method is used for underground detectors.

The average-mass temperature method [8], which is based on definition of average-mass temperature in the atmosphere, is a particular case of the integral method. Since the density of the temperature coefficient for above ground detectors does not significantly vary with the depth of the atmosphere h, then an average value  $\overline{\alpha}_T$  can be taken out from the integral sign, i.e.:

$$\left.\frac{dN_{\mu}}{N_{\mu}}\right|_{Temp} = \overline{\alpha_T} \int_0^{h_0} \delta T(h) dh = \overline{\alpha_T} \delta T_m,$$

where  $T_m$  is the average-mass temperature, which is calculated by the data of the probing or from the experiment.

#### **3.** Estimation of the temperature coefficients and their time dependence

The estimation of the temperature coefficients for every level of the muon telescope complex for 2009-2016 and the ionization chamber for 1953-2003 has been done. Except the level 60 m w.e., the calculations are well provided with statistics. In figure 1 (left panel) time dependencies of the temperature coefficients of the ionization chamber and the muon telescopes are presented. In values of the temperature coefficient for the ionization chamber clearly seen an 11-year wave and constant growth during 5 cycles of solar activity.

For every considered telescope (right panel) there is also shown a dependence of average values of the temperature coefficient on a zenith angle of registration. As expected, for the above ground telescope, the negative temperature effect rises with the increase of zenith angle.



**Figure 1.** A time dependence of the temperature coefficients of ionization chamber and vertical directions of the muon telescopes (left panel) and their zenith-angular dependence during 2014 (right panel).

#### 4. The results of data correction

As an example, in figure 2 there are shown uncorrected (Ip) and corrected (Ipt) on the temperature effect variations of CR intensity obtained by the data of vertical direction of the ground surface level muon telescope (MT0-ver) in 2010. Preliminarly, the data on Ip and Ipt are gotten rid of an influence of the atmospheric pressure. As seen from the figure, application of the temperature coefficients, that are obtained by the mentioned above methods, allows qualitatively take into account a seasonal change in the observed intensity of the muon component.



Figure 2. The uncorrected *Ip* and corrected *Ipt* on the temperature effect data of the vertical direction the muon telescope at 0 m w.e. (MT0-ver) in 2010.

In order to carry further estimations of the correctness of the accounting of temperature effect, the data of muon telescope MT0-ver are compared to the data of neutron monitor 24-NM-64. In figure 3 there are shown the data of the monitor 24-NM-64, corrected for pressure, and the data of the telescope MT0-ver, corrected for both pressure and temperature, in 2017. With the

known relation between the amplitudes of CR variations, that are observed by the devices, and almost complete absence of the temperature effect in neutron component, the both data show good agreeement. It is necessary to note that the application of the data of the world network of muon telescopes that are corrected on the temperature effect will increase the potential of the ground-based measurements [9, 10] for monitoring of the space weather.



Figure 3. The corrected on pressure data of the neutron monitor (24-NM-64) and corrected on both pressure and temperature effect data of the muon telescope (MT0-ver) in 2017.

#### 5. Results

1. Using the methods of average mass and effective temperatures, there are calculated the temperature coefficients for every level and direction of registration of the muon telescopes and ionization chamber of the Yakutsk spectrograph of CR. Results of the temperature effect corrections are presented in the Internet through the link http: //www.ysn.ru/ipm - T.

2. The negative temperature effect decreases with increasing of the depth of telescope placement. For the surface level telescope, the rise of the zenith angle of registration is accompanied by growth of the negative temperature effect.

3. The vertical profiles of the distribution of atmospheric temperature and densities of temperature coefficients are allows qualitatively exclude the temperature effect from the data of observation of the Yakutsk CR spectrograph.

4. The value of the temperature coefficient of the ionization chamber reveals stable 11-year wave for 5 solar activity cycles.

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