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ATMOSPHERIC EFFECTS OF THE COSMIC-RAY MU-MESON COMPONENT

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Abstract. Variations in the intensity of cosmic rays observed in the depth of the atmosphere include the atmospheric component of the variations. Cosmic-ray muon telescopes, along with the barometric effect, have a significant temperature effect due to the instability of detected particles. To take into account atmospheric effects in muon telescope data, meteorological coefficients of muon intensity are found. The meteorological coefficients of the intensity of muons recorded in the depth of the atmosphere are estimated from experimental data, using various methods of factor analysis. The results obtained from experimental data are compared with the results of theoretical calculations.

Keywords: cosmic rays, muons, temperature, atmosphere.

INTRODUCTION

Cosmic-ray (CR) intensity variations observed in the atmosphere with muon telescopes are a superposition of effects of different origin [Dorman, 1975]. The interplanetary component of CR intensity variations is conditioned by processes occurring on the Sun and in the interplanetary medium [Dvornikov et al., 2005], the magnetospheric component is caused by disturbances in the magnetosphere [Kichigin et al., 2017], and atmospheric variations associated with variations in atmospheric parameters (pressure, temperature, humidity, mass redistribution) [Dorman, 1972]. Atmospheric CR intensity variations are composed of barometric, temperature, and humidity effects. The contribution of each of these effects to the atmospheric component of CR variations for different secondary components varies. The decisive effect for the nucleon component is the barometric effect. The meson component consisting of unstable particles generally features a pronounced temperature effect in the presence of a small barometric effect. For the common ionizing component of secondary CR, all these effects contribute to atmospheric variations. When using observations made with muon telescopes [Yanchukovsky et al., 2016], it is necessary to correctly account for the contribution of atmospheric effects to data. To do this, we should assess the impact of atmospheric parameters on the muon intensity in the atmosphere. The integral method proposed by Dorman [1957] allows us to account for the temperature effect of the intensity of muons from the entire atmosphere. The method assumes the presence of regular data on the temperature section of the atmosphere and the knowledge of density distribution of temperature coefficients for muons in the atmosphere. Its calculation has been made for Novosibirsk muon telescope-hodoscope and Yakutsk underground complex of muon telescopes [Kuzmenko, Yanchukovsky, 2017]. In practice, however, the results of theoretical calculations should be carefully applied to the correction of observations because all the calculations are usually made with various approximations [Dorman, Yanke, 1971; Berkova et al., 2008; Dmitrieva et al., 2009; Kuzmenko, Yanchukovsky, 2017]. Experimental estimate of the density distribution of temperature coefficients is also difficult because temperature variations of different atmospheric layers are correlated. Therefore, to experimentally estimate the temperature coefficients of muon intensity from results of continuous observations, we have used different methods of data analysis.

METHODS

To analyze continuous observations, we adopt methods of factor analysis [Enyukov, 1989]: correlation/regression analysis [Draper, Smith, 2007; Ferster, Rents, 1981] and method of principal components (PC) [Aivazyan et al., 1989; Aivazyan, 2001].

Muon intensity variations y caused by variations in the temperature of n atmospheric layers are represented as a linear regression equation where the intensity effect is expressed in terms of $x_1, x_2, x_3, ..., x_n$:

$$y=a_0+a_1x_1+a_2x_2+\ldots+a_nx_n+\varepsilon$$

or

$$Y = A_0 + \sum_{j=1}^{n} A_j X_j + \varepsilon. \quad (1)$$

Here, $Y = \{y_1, ..., y_i, ..., y_m\}$ is muon intensity variations $\frac{I_{\text{м}i} - \bar{I}_{\text{м}}}{\bar{I}_{\text{м}}} 100 = \delta\bar{I}_{\text{м}i}$, the independent variables (factors) $X_j=\{x_{j1}, ..., x_{jm}\}$ are variations in the temperature of the j layer, $T_{ji} - \bar{T}_j = \Delta T_{ji}$, A_j is the regression coefficient having the meaning of the temperature coefficient of j-layer muon intensity; ε is the vector of random components, which distinguishes statistical data from data obtained by approximation. The parameters $A_j \left(j = \overline{0, n} \right)$ are determined using the least square method, which for linear regression equations reduces to solving a system of normal equations [Korn, Korn, 1984].

There is another type of multiple regression equations, which we will also use – the equation of regression on a standardized scale [Gorlach, 2006]. Represent equation (1) in such a way:

$$y_i = \alpha_1 x_{1i} + \alpha_2 x_{2i} + \alpha_3 x_{3i} + ... + \alpha_n x_{ni}, \qquad (2)$$

where $y_i = \frac{y_i - \bar{Y}}{\sigma_Y}$; $x_{ji} = \frac{x_{ji} - \bar{X}_j}{\sigma_{X_j}}$. $\left(i = \overline{1, m}\right)$

$\left(j = \overline{1, n}\right)$ are standardized variables; standardized regression coefficients α_j are found by solving the system of equations:

$$\begin{cases} r_{YX_1} = \alpha_1 + \alpha_2 r_{X_1X_2} + \alpha_3 r_{X_1X_3} + ... + \alpha_n r_{X_1X_n} \\ r_{YX_2} = \alpha_1 r_{X_2X_1} + \alpha_2 + \alpha_3 r_{X_2X_3} + ... + \alpha_n r_{X_2X_n} \\ r_{YX_3} = \alpha_1 r_{X_3X_1} + \alpha_2 r_{X_3X_2} + \alpha_3 + ... + \alpha_n r_{X_3X_n} \\ ... \\ r_{YX_n} = \alpha_1 r_{X_nX_1} + \alpha_2 r_{X_nX_2} + \alpha_3 r_{X_nX_3} + ... + \alpha_n. \end{cases} \qquad (3)$$

Here r_{YXj}, r_{XjXk} are coefficients of pair linear correlation between variables. System of equations (3) was solved by the direct Gauss, Cramer, and Gauss—Jordan methods [Ilyin, Poznyak, 2004; Volkov, 1987]. The transition from the resulting standardized coefficients α_j to desired multifactor regression coefficients A_j is made by the relation

$$A_j = \alpha j \frac{\sigma_Y}{\sigma_{X_j}}. \qquad (4)$$

The method of principal components [Aivazyan et al., 1989; Aivazyan, 2001], as well as methods of projections to latent structures PLS1 and PLS2 [Esbensen, 2005; Pomerantsev, 2014] have been used by us before [Kuzmenko, Yanchukovsky, 2015] to estimate the density of muon temperature coefficients from experimental data. The iterative algorithm for calculating factors in PC space for PLS1 and PLS2 has been described in detail in [Kuzmenko, Yanchukovsky, 2015]. The comparison of the results obtained by the PC, PLS1, and PLS2 methods shows that PLS2 yields the best result.

The Unscrambler X [http://www.camo.com/rt/Products/Unscrambler/unscrambler.html] enables us to adopt the PLS2 method to calculations using four algorithms:

NIPALS is a nonlinear iterative least square algorithm, which helps with the processing in the absence of some values in the data and is suitable for calculating only the first few factors from a dataset [Esbensen, 2005];

ORTHOGONAL SCORES PLS is the classical PLS algorithm involving NIPALS, which does not ensure the processing without some values in data [Martens, Naes, 1991];

WIDE-KERNEL PLS is an algorithm that does not work without some values in data and is best suited for the data with several samples and a large number of variables [Rannar et al., 1994];

KERNEL PLS is an algorithm that is best suited for a large number of samples (thousands of samples with several variables) [Lindgren et al., 1993; de Jong, Ter Braak, 1994; Dayal, McGregor, 1997].

We have employed the first two algorithms before [Kuzmenko, Yanchukovsky, 2015]. The third algorithm is not to be suited for this problem because it deals with a dataset with a small number of variables and large number of samples (the number of samples means the number of values in datasets for each variable). We therefore apply the fourth PLS KERNEL algorithm to the calculations.

DATA

The programs [Kuzmenko, Yanchukovsky, 2015] are designed to read and provide the desired format of the following data:

- upper-air sounding data (Bugrinskaya Roshcha, Novosibirsk): temperature, wind speed and direction at different isobaric levels: 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 50 mb [https://ruc.noaa.gov/raobs];
- ground-based CR-intensity measurement data: neutron component, the total ionizing component and muon component at different zenith (0°, 30°, 40°, 50°, 60°, 67°, 71°) and azimuth (southeast, northwest, southwest , northeast) angles, as well as atmospheric pressure and surface layer temperature (CR station Novosibirsk [http://cosm-rays.ipgg.sbras.ru]). The analysis is based on daily average observational data for 2004–2011. This data sampling is determined by the periodicity of upper-air sounding (12 hr).

METEOROLOGICAL COEFFICIENTS OF MUON INTENSITY

Intensity variations of muons detected at the level h_0 of the atmosphere at a point with the geomagnetic cutoff threshold R_c can be represented as follows:

$$\frac{\Delta J_{\text{м}}}{J_{\text{м}}}(h_0) = \left\{ \exp\left[-\int_{h_0}^{h} \beta_{\text{м}}(h)\,dh \right] - 1 \right\} + \int_0^h w_{\text{м}}(T_0, h_0, h)\,\Delta T(h)\,dh + \int_{R_c}^{\infty} \frac{\Delta D}{D}(R)\,W(R, h_0)\,dR, \qquad (5)$$

where $\beta_m(h)$ is the barometric coefficient of muon intensity; $w_m(T_0, h_0, h)$ is the function of density of temperature coefficients, which reflects the contribution of atmospheric layers to the creation of the integral temperature effect of intensity; $\Delta T(h)$ are time variations of atmospheric temperature as a function of height; $(\Delta D/D)(R)$ and $W(R, h_0)$ are the spectrum of variations in the primary flux and the coupling coefficients for the CR muon component respectively. Here R is the primary particle rigidity, h is the atmospheric pressure, h_0 and T_0 are pressure and temperature of the atmosphere at the level of muon observation.

Muon intensity variations (5) can be represented as a linear regression equation in which the barometric and temperature effects, as well as the effect of the primary CR variation, are expressed in terms of the factors x_1, x_2, x_3, x_4:

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + \varepsilon. \qquad (6)$$

The resulting factor y refers to muon intensity variations $\frac{J_{\text{м}i} - \bar{J}_{\text{м}}}{\bar{J}_{\text{м}}} 100 = \delta J_{\text{м}i}$; x_1, to atmospheric pressure variations $h_i - h_0 = \Delta h_i$; x_2, to variations in the temperature of a layer with variable mass $\left(T_{ni} - \bar{T}_n\right)\left(P_i - 950\right) = \Delta t_i \left(P_i - 950\right)$; x_3 refers to variations in mass average atmospheric temperature $T_{\text{см}i} - \bar{T}_{\text{см}} = \Delta T_{\text{см}i}$; x_4, to variations of neutron component intensity $\frac{N_i - \bar{N}}{\bar{N}} 100 = \delta n_i$ caused by changes in the spectrum of primary CR flux.

Equation (6) can be represented in a standardized scale similarly to Equation (2).

Find standardized regression coefficients by solving system of equations (3). Then proceed to the desired multifactor regression coefficients, using ratio (4). The coefficients thus obtained are shown in Table 1.

The results allow us to identify directly the temperature component of muon intensity variations in initial observations without employing, as was done previously in [Kuzmenko, Yanchukovsky, 2015], the spectrographic analysis of observed variations [Dvornikov et al., 1972; Yanchukovsky et al., 2011].

DENSITY OF TEMPERATURE COEFFICIENTS OF MUON INTENSITY

Correlation/regression analysis. The atmosphere is arbitrarily divided into 11 layers according to upper-air data, which are presented for 11 isobars: 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, and and 50 mb. Therefore, in expression (2) n=11. Solving system of equations (3), find the standardized regression coefficients. Using (4), convert them into the multifactor regression coefficients having the meaning of temperature coefficients. In passing to the density of temperature coefficients of muon intensity, as before, we account for the weighting factor depending on the relative weight of the atmospheric layer $\Delta h_i \Big/ \sum_{i=1}^{n} \Delta h_i$, where Δh_i={75, 50, 50, 50, 50, 75, 100, 150, 175, 125, 50} mb.

The results obtained from the correlation/regression analysis for muons recorded at zenith angles from 0° to 60° are summarized in Table 2.

The PLS2 method with the use of the PLS KERNEL algorithm. Temperature coefficients of muon intensity in the atmosphere for different zenith angles found by the PLS2 method (PLS KERNEL algorithm) are listed in Table 3.

In passing to the density of temperature coefficients of muon intensity, as previously we consider the relative mass Δh of the atmospheric layer.

The densities of muon intensity temperature coefficients obtained by PLS2 are shown in Table 4.

The choice of the number of principal components from 1 to 3 slightly affects the result. When including more than three principal components, we lose information in the initial data and have non-physical dynamics of resulting curves.

RESULTS AND DISCUSSION

For comparison, the results are shown in Figures 1 and 2. Figure 1 displays density distributions of temperature coefficients of vertically recorded (at a zenith angle of 0°) muon intensity without a shield (Figure 1, *a*) and with a 0.56 GeV shield (Figure 1, *b*).

Table 1

Coefficients of multifactor regression

A_j	Zenith angle θ, deg.							
	O.I.	0	30	40	50	60	67	71
A_1, %/mb	–0.185 ±0.025	–0.158 ±0.027	–0.158 ±0.029	–0.158 ±0.032	–0.173 ±0.034	–0.186 ±0.056	–0.245 ±0.061	–0.3 ±0.064
A_2, % /°C, 10-2	–0.0283 ±0.0056	–0.065 ±0.0046	–0.0652 ±0.0042	–0.0643 ±0.038	–0.066 ±0.0048	–0.065 ±0.0058	–0.068 ±0.0072	–0.07 ±0.009
A_3 , %/°C	–0.227 ±0.023	–0.228 ±0.025	–0.228 ±0.024	–0.242 ±0.028	–0.256 ±0.031	–0.262 ±0.035	–0.308 ±0.042	–0.31 ±0.052
A_4	0.381 ±0.0302	0.383 ±0.0306	0.356 ±0.0275	0.329 ±0.0268	0.288 ±0.0246	0.260 ±0.034	0.260 ±0.046	0.260 ±0.052

Here, A_1 is the barometric coefficient, A_2 is the temperature coefficient of the layer of variable mass (surface layer), A_3 is the temperature coefficient of the mass average temperature of the atmosphere, and A_4 is the regression coefficient with neutron monitor data on the intensity of muons recorded without a lead shield (O.I.) and with a lead shield at zenith angles of 0, 30, 40, 50, 60, 67, and 71°.

Table 2

Density of temperature coefficients of muon intensity in the atmosphere $w(h)$, obtained from the correlation/regression analysis

Depth of the atmosphere h, mb	Zenith angle θ, deg.					
	O.I.	0	30	40	50	60
50	–0.152 ±0.0605	–0.245 ±0.0975	–0.250 ±0.0985	–0.190 ±0.0703	–0.190 ±0.0804	–0.348 ±0.0909
100	–0.385 ±0.0723	–0.501 ±0.0939	–0.538 ±0.0935	–0.348 ±0.0731	–0.649 ±0.0957	–0.484 ±0.0913
150	–0.344 ±0.0417	–0.659 ±0.0798	–0.626 ±0.1217	–0.626 ±0.0703	–0.728 ±0.0806	–0.637 ±0.0879
200	–0.399 ±0.0589	–0.537 ±0.0794	–0.538 ±0.1184	–0.503 ±0.0982	–0.856 ±0.0987	–0.565 ±0.0949
250	–0.184 ±0.0738	–0.193 ±0.0798	–0.153 ±0.0696	–0.330 ±0.0830	–0.237 ±0.0906	–0.252 ±0.0266
300	–0.164 ±0.0712	–0.194 ±0.0844	–0.238 ±0.0853	–0.235 ±0.0906	–0.272 ±0.0948	–0.325 ±0.1056
400	–0.235 ±0.0820	–0.235 ±0.0820	–0.258 ±0.0920	–0.310 ±0.0932	–0.284 ±0.0953	–0.310 ±0.1092
500	–0.195 ±0.0681	–0.283 ±0.0988	–0.298 ±0.117	–0.318 ±0.127	–0.325 ±0.0975	–0.395 ±0.136
700	–0.275 ±0.0825	–0.371 ±0.111	–0.325 ±0.0990	–0.355 ±0.136	–0.385 ±0.0979	–0.260 ±0.1054
850	–0.225 ±0.0602	–0.315 ±0.0948	–0.363 ±0.113	–0.283 ±0.0909	–0.450 ±0.0938	–0.340 ±0.1077
925	–0.279 ±0.0599	–0.381 ±0.0818	–0.506 ±0.150	–0.351 ±0.123	–0.630 ±0.145	–0.500 ±0.147

Table 3

Temperature coefficients of muon intensity determined using the PLS2 method (KERNEL algorithm)

Depth of the atmosphere h, mb	Zenith angle θ, deg.							
	0	30	40	50	60	67	71	O.I.
50	–0.0470 ±0.0034	–0.0471 ±0.0072	–0.0475 ±0.0036	–0.0567 ±0.0061	–0.0503 ±0.0053	–0.0570 ±0.0072	–0.0388 ±0.0161	–0.0384 ±0.0034
100	–0.0392 ±0.0023	–0.0392 ±0.0054	–0.0395 ±0.0043	–0.0472 ±0.0048	–0.0419 ±0.0044	–0.0475 ±0.0046	–0.0323 ±0.0125	–0.0320 ±0.0023
150	–0.0324 ±0.0017	–0.0324 ±0.0042	–0.0327 ±0.0037	–0.0391 ±0.0030	–0.0346 ±0.0031	–0.0392 ±0.0041	–0.0267 ±0.0110	–0,0264 ±0.0017
200	–0.0299 ±0.0020	–0.0300 ±0.0044	–0.0302 ±0.0037	–0.0361 ±0.0039	–0.0320 ±0.0031	–0.0363 ±0.0036	–0.0247 ±0.0098	–0.0244 ±0.0020
250	–0.0276 ±0.0018	–0.0276 ±0.0042	–0.0278 ±0.0035	–0.0333 ±0.0035	–0.0295 ±0.0031	–0.0334 ±0.0041	–0.0227 ±0.0090	–0.0225 ±0.0018
300	–0.0214 ±0.0023	–0.0214 ±0.0041	–0.0216 ±0.0042	–0.0258 ±0.0030	–0.0228 ±0.0036	–0.0259 ±0.0046	–0.0176 ±0.0074	–0,0174 ±0.0023
400	–0.0160 ±0.0028	–0.0160 ±0.0045	–0.0162 ±0.0042	–0.0193 ±0.0030	–0.0171 ±0.0040	–0.0194 ±0.0051	–0.0132 ±0.0067	–0.0131 ±0.0029
500	–0.0144 ±0.0034	–0.0144 ±0.0057	–0.0145 ±0.0058	–0.0174 ±0.0052	–0.0154 ±0.0053	–0.0175 ±0.0072	–0.0119 ±0.0067	–0.0118 ±0.0034
700	–0.0160 ±0.0032	–0.0160 ±0.0049	–0.0161 ±0.0048	–0.0193 ±0.0039	–0.0171 ±0.0036	–0.0194 ±0.0056	–0.0132 ±0.0067	–0.0130 ±0.0032
850	–0.0155 ±0.0032	–0.0156 ±0.0049	–0.0157 ±0.0050	–0.0187 ±0.0039	–0.0166 ±0.0044	–0.01883 ±0.00513	–0.0128 ±0.0067	–0.0127 ±0.0032

Table 4

Density of temperature coefficients obtained by the PLS2 method (KERNEL algorithm)

Depth of the atmosphere *h*, mb	Zenith angle θ, deg.							
	0	30	40	50	60	67	71	O.I.
50	–0.580 ±0.041	–0.581 ±0.089	–0.585 ±0.044	–0.700 ±0.075	–0.620 ±0.066	–0.703 ±0.088	–0.479 ±0.198	–0.474 ±0.041
100	–0.725 ±0.043	–0.726 ±0.099	–0.731 ±0.080	–0.874 ±0.088	–0.775 ±0.082	–0.879 ±0.085	–0.598 ±0.232	–0.592 ±0.043
150	–0.599 ±0.031	–0.600 ±0.077	–0.604 ±0.068	–0.723 ±0.056	–0.640 ±0.057	–0.726 ±0.076	–0.494 ±0.203	–0.489 ±0.031
200	–0.554 ±0.037	–0.555 ±0.081	–0.559 ±0.068	–0.668 ±0.072	–0.592 ±0.057	–0.671 ±0.066	–0.457 ±0.181	–0.452 ±0.037
250	–0.510 ±0.034	–0.511 ±0.078	–0.515 ±0.065	–0.616 ±0.064	–0.546 ±0.057	–0.619 ±0.076	–0.421 ±0.167	–0.417 ±0.034
300	–0.263 ±0.029	–0.264 ±0.050	–0.266 ±0.051	–0.318 ±0.037	–0.282 ±0.044	–0.319 ±0.057	–0.217 ±0.092	–0.215 ±0.029
400	–0.148 ±0.026	–0.148 ±0.041	–0.150 ±0.039	–0.179 ±0.028	–0.159 ±0.037	–0.180 ±0.047	–0.122 ±0.062	–0.121 ±0.026
500	–0.089 ±0.021	–0.089 ±0.035	–0.090 ±0.036	–0.107 ±0.032	–0.095 ±0.033	–0.108 ±0.047	–0.073 ±0.041	–0.073 ±0.021
700	–0.084 ±0.017	–0.085 ±0.026	–0.085 ±0.025	–0.102 ±0.021	–0.090 ±0.019	–0.102 ±0.030	–0.070 ±0.035	–0.069 ±0.017
850	–0.115 ±0.024	–0.115 ±0.036	–0.116 ±0.037	–0.139 ±0.029	–0.123 ±0.033	–0.139 ±0.038	–0.095 ±0.049	–0.094 ±0.024
925	–0.313 ±0.067	–0.314 ±0.093	–0.316 ±0.111	–0.378 ±0.087	–0.335 ±0.099	–0.380 ±0.133	–0.258 ±0.138	–0.256 ±0.067

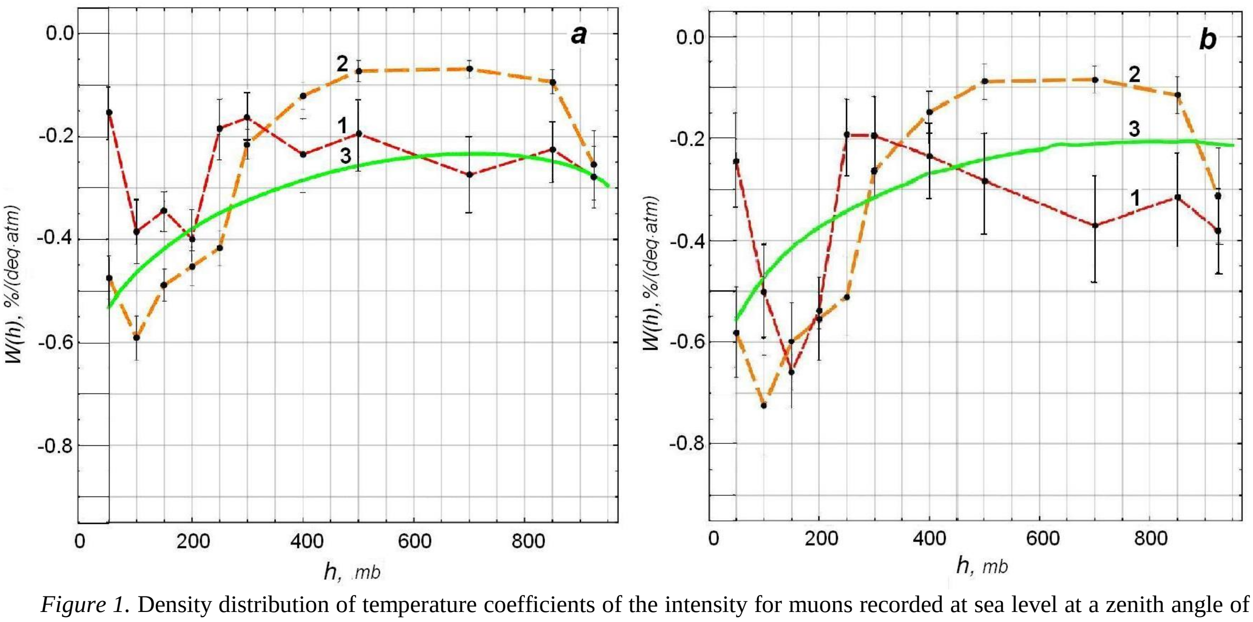

Figure 1. Density distribution of temperature coefficients of the intensity for muons recorded at sea level at a zenith angle of 0° without a shield (*a*) and with a shield (Δε=0.56 GeV) (*b*)

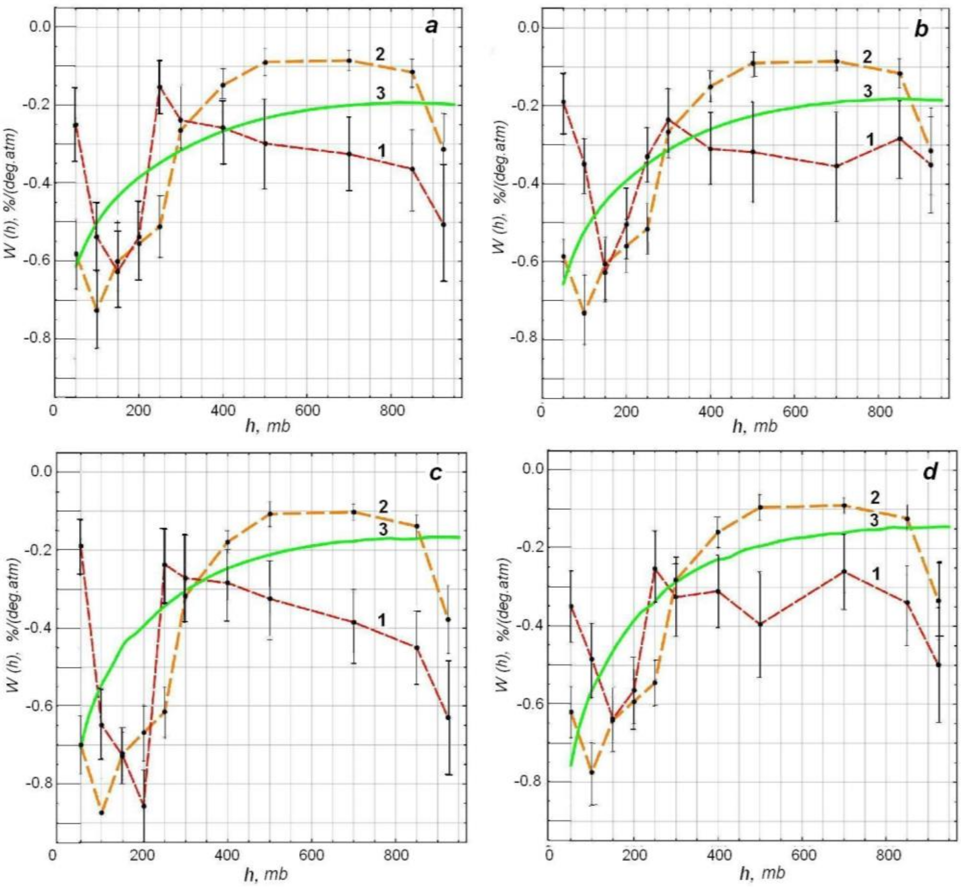

Figure 2. Density distribution of temperature coefficients of the intensity for muons recorded at sea level at zenith angles of 30° (*a*), 40° (*b*), 50° (*c*), and 60° (*d*)

Figure 2 shows density distributions of temperature coefficients for muons recorded at different zenith angles: 30° (*a*), 40° (*b*), 50° (*c*), and 60° (*d*).

These distributions have been obtained by different methods: from experimental data using the correlation/regression analysis (curve 1), by the PC PLS2 method (curve 2), from theoretical calculations (curve 3). To depths of <400 mb, the results of the two methods within the limits of error coincide, and begin to differ at depths of >400 mb. This can be explained by the fact that the PLS2 method in selecting the optimal number of principal components accounts for the statistical significance of variables in the total effect. This method (KERNEL algorithm) allows us to find the temperature coefficients of muon intensity from experimental data with greater accuracy than the correlation/regression analysis. The theoretically calculated distributions have better agreement with those found by PLS2 (KERNEL algorithm) for the following values of initial parameters: L_p=70 g/cm^2, l_π=110 g/cm^2, γ=2.75. Where L_p is the absorption range of protons, l_π is the absorption range of pions, γ is the component of the power spectrum of the primary cosmic-ray flux.

CONCLUSION

It is usually difficult to experimentally estimate density distributions of temperature coefficients because temperature variations in different atmospheric layers are correlated. We have shown that for the experimental estimate of the temperature coefficients of muon intensity from results of continuous observations, the method of principal components PLS2 (KERNEL algorithm) is more efficient and accurate than the multifactor regression analysis methods.

We used experimental data from the Unique Research Facility Russian National Network of Cosmic-Ray Stations.

REFERENCES

Aivazyan S.A. *Prikladnaya Statistika i Osnovy Ekonometriki* [Applied Statistics and Foundations of Econometrics]. Moscow, Yuniti Publ., 2001, 503 p. (In Russian).

Aivazyan S.A., Bukhshtaber V.M., Enyukov I.S., Meshalkin L.D. *Prikladnaya Statistika. Klassifikatsiya i Snizhenie Razmernosti* [Applied Statistics. Classification and Dimension Lowering]. Moscow, Finansy i Statistika Publ., 1989. 607 p. (In Russian).

Berkova M.D., Belov A.V., Eroshenko E.A., Yanke V.G. Temperature effect of the muon component of cosmic ray and practical possibilities of its accounting. *Proc. 21st ECRS*. Kosice, Slovakia, 9–12 September 2008, 2008, pp. 123–126.

Dayal B.S., McGregor J.F. Improved PLS Algorithms. *J. Chemometrics*, 1997, vol. 11, pp. 73–65.

de Jong S., Ter Braak C. Comments on the PLS kernel algorithm. *J. Chemometrics*, 1994, vol. 8, pp. 169–174.

Dmitrieva A.N., Kokoulin R.P., Petruhin A.A., Timashov D.A. Temperature coefficients for muons under different zenith angles. *Izvestiya RAN. Ser. Fizicheskaya*

[Bull. of the Russian Academy of Sciences: Physics]. 2009, vol. 73, no. 3, pp. 371–374. (In Russian).

Dorman L.I. *Variatsii kosmicheskikh luchei* [Cosmic Ray Variations]. Moscow, Gostekhizdat Publ., 1957. 285 p. (In Russian).

Dorman L.I. *Meteorologicheskie effekty kosmicheskikh luchei* [Meteorological Effects of Cosmic Rays]. Moscow, Nauka Publ., 1972. 211 p. (In Russian).

Dorman L.I. *Experimentalnye i teoreticheskie osnovy astrofiziki kosmicheskikh luchei* [Experimental and Theoretical Foundations of Astrophysics of Cosmic Rays]. Moscow, Nauka Publ., 1975. 462 p. (In Russian).

Dorman L.I., Yanke V.G. On theory of meteorological effects of cosmic rays. *Izvestiya AN SSSR. Ser. Fizicheskaya* [Bull. of the Russian Academy of Sciences: Physics]. 1971, vol. 35, no. 12, pp. 2556–2570. (In Russian).

Draper N.R., Smith H. Applied Regression Analysis. 3rd Edition by John Wiley & Sons Inc. 1998, 736 p.

Dvornikov V.M., Dorman L.I., Luzov A.A., Sergeev A.V., Yanchukovsky A.L. Analysis of cosmic ray variations of magnetospheric and interplanetary origin from the spectrograph data. *Izvestiya AN SSSR. Ser. Fizicheskaya* [Bull. of the Russian Academy of Sciences: Physics]. 1972, vol. 36, no. 11, pp. 2427–2434. (In Russian).

Dvornikov V.M., Sdobnov V.E., Kravtsova M.V. Cosmic ray modulation by regular electromagnetic fields in the heliosphere during solar proton events. Izvestiya RAN. Ser. Fizicheskaya [Bull. of the Russian Academy of Sciences. Physics]. 2005, vol. 69, no. 6, pp. 821–824.

Enyukov I.S. *Faktornyi, diskriminantnyi i klasternyi analiz* [Factorial, Discriminant, and Cluster Analysis]. Moscow, Finansy i Statistika Publ., 1989. 215 p. (In Russian).

Esbensen K. *Analiz mnogomernykh dannykh. Izbrannye glavy* [Analysis of Multidimensional Data. Selected Chapters / Trans. From English. S.V. Kucheryavsky/Ed. O.E. Rodionova] Chernogolovka, IPCP RAN Publ., 2005. 160 p. (In Russian).

Ferster E., Rents B. *Metody korrelyatsionnogo i regressionnogo analiza* [Methods of Correlation and Regression Analysis]. Moscow, Finansy i Statistika Publ., 1981. 302 p. (In Russian).

Gorlach B.A. *Matematika* [Mathematics]. Moscow, Nauka Publ., 2006. 911 p. (In Russian).

Ilyin V.A, Poznyak E.G. *Lineynaya algebra: Uchebnik dlya vuzov* [Linear Algebra: A Textbook for High Schools. 6th ed.]. Moscow, Fizmatlit Publ., 2004. 280 p. (In Russian).

Kichigin G.N., Kravtsova M.V., Sdobnov V.E. Parameters of current systems in the magnetosphere as derived from observations of cosmic rays during the June 2015 magnetic storm. *Solar-Terr. Phys*. 2017, vol. 3, no. 3, pp. 13–17. DOI: 10.12737/stp-33201702.

Korn G., Korn T. *Spravochnik po matematike dlya nauchnykh rabotnikov i inzhenerov* [A Handbook on Mathematics for Scientists and Engineers]. Moscow, Nauka Publ., 1984. 831 p. (In Russian).

Kuzmenko V.S., Yanchukovsky V.L. Determination of density of temperature coefficients the Earth's atmosphere muons. *Solar-Terr. Phys.* 2015, vol. 1, iss. 2, pp. 91–96. (In Russian). DOI: 10.12737/10403.

Kuzmenko V.S., Yanchukovsky V.L. Distribution of temperature coefficient density for muons in the atmosphere. *Solar-Terr. Phys*. 2017, vol. 3, iss. 4, pp. 93–102.

Lindgren F., Geladi P., Wold S. The kernel algorithm for PLS. *J. Chemometrics*. 1993, vol. 7, pp. 45–59.

Martens H., Naes T. *Multivariate Calibration*. Chichester, UK: John Wiley and Sons, 1991.

Pomerantsev A.L. *Khemometrika v Excel: Uchebnoe posobie* [Chemometrics in Excel: Tutorial]. Tomsk, TPU Publ., 2014. 435 p. (In Russian).

Rannar S., Lindgren F., Geladi P., Wold S. A PLS kernel algorithm for data sets with many variables and fewer objects. Pt. 1: Theory and Algorithm. *J. Chemometrics*. 1994, vol. 8, pp. 111–125.

Volkov E.A. *Chislennye metody* [Numerical Methods]. Moscow, Fizmatlit Publ., 2003. 367 p. (In Russian).

Yanchukovsky V.L., Kuzmenko V.S., Antsyz E.N. Results of cosmic ray monitoring with a multichannel complex. *Geomagnetism and Aeronomy*. 2011, vol. 51, no. 7, pp. 893–896.

Yanchukovsky V.L., Grigoryev V.G., Krymsky G.F., Kuz'menko V.S., Molchanov A.D. Receiving vectors of muon telescope of cosmic ray station Novosibirsk. *Solar-Terr. Phys*. 2016, vol. 2, iss. 1, pp. 103–119. DOI: 10.12737/19883.

URL: http://cosm-rays.ipgg.sbras.ru (accessed November 23, 2017).

URL: https://ruc.noaa.gov/raobs (accessed February 17, 2017).

URL: http://www.camo.com/rt/Products/Unscrambler/unscrambler.html (accessed February 17, 2017).

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