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Atmospheric Variations in Muon Intensity for Different Zenith Angles

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Abstract—The barometric and temperature coefficients of muon intensity for a layer of variable mass and the temperature coefficients for mass-weighted mean atmospheric temperature are found by regressions analysis from the results of continuous measurements of muon intensity at different zenith angles and atmospheric parameters. The temperature coefficients of muon intensity are determined for different atmospheric layers. Using the characteristics obtained, the changes in temperature are found for different atmospheric layers from the data on variations in muon intensity. The results obtained are compared with the observed temperature changes.

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INTRODUCTION

The calculated values of the temperature coefficient density $W_T(h)$ were reported in [1, 2] for the ground-based muon telescopes equipped with shields, having the detection threshold $\Delta\varepsilon \le 0.4$ GeV, and for the complex of underground muon telescopes with $\Delta\varepsilon \ge 1.6$ GeV. The muon telescope in Novosibirsk is equipped with a shield characterized by $\Delta\varepsilon = 0.54$ GeV (for a vertical muon flux), for which the meteorological coefficients of muon intensity are unknown.

METEOROLOGICAL COEFFICIENTS OF MUON INTENSITY AT DIFFERENT ZENITH ANGLES

Experimental estimation of atmospheric effects of muon intensity at different zenith angles against the background of possible primary variations was performed on the basis of the results of synchronous measurements of the cosmic-ray intensity, using a neutron monitor and the complex of meson telescopes with a large effective collection area [3]. The average (referred to as reference below) temperatures in the middle of each atmospheric layer on standard isobaric surfaces (900, 800, 700, 600, 500, 400, 300, 200, 100, and 50 mbar) were determined from the height distribution of the atmospheric temperature above Novosibirsk, obtained from the aerological data during the period from January 2004 to June 2005.

The regression equations for the variations in intensity of the total ionizing component and the muon component, recorded at different zenith angles, can be written as

$$\delta I_{\mathrm{tot},\mu}(\theta) = \alpha_0(\theta)(h_0 - 950)T_0 + \alpha_T(\theta)\Delta T_{\mathrm{mwm}} + \beta(\theta)\Delta h_0 + \gamma(\theta)\delta I_n. \quad (1)$$

Here, $\alpha_0(\theta)$, $\alpha_T(\theta)$, $\beta(\theta)$, and $\gamma(\theta)$ are the regression coefficients; T_0 and h_0 are, respectively, the atmospheric temperature and pressure at the cosmic-ray observation level; ΔT_{mwm} and Δh_0 are the changes in the mass-weighted mean atmospheric temperature and pressure, respectively; $\delta I_{\mathrm{tot},\mu}(\theta) = \Delta I_{\mathrm{tot},\mu}/I_{\mathrm{tot},\mu}(\theta)$ are variations in the intensity of the total and muon components; and $\delta I_n = \Delta I_n/I_n$ are variations in the intensity of the neutron component of cosmic rays, corrected to the barometric effect. Variations in the mass-weighted mean temperature are $\Delta T_{\mathrm{mwm}} = \frac{1}{k}\sum_{i=1}^{k}\Delta t_i$, where Δt_i are variations in the temperature in the ith atmospheric layer. The solutions to the regression equations (1) yield the noted coefficients (see the table).

TEMPERATURE-COEFFICIENT DENSITIES AND MUON INTENSITIES FOR DIFFERENT ZENITH ANGLES

Using the coefficients from the table, we introduced corrections into the initial data of measurements of the intensities of the total and muon cosmic-ray components for variations in the atmospheric pressure, the temperature of the near-ground layer, and the modulation of the primary cosmic-ray flux according to the neutron monitor data. Thus, variations in the muon

Meteorological coefficients of muon intensity at different zenith angles

Channel	TI	0°	30°	40°	50°	60°	67°	71°
$\alpha_0(\theta)$, 10^{-2} %/°C	−0.035 ± 0.002	−0.033 ± 0.004	−0.024 ± 0.003	−0.023 ± 0.003	−0.017 ± 0.004	−0.024 ± 0.005	−0.038 ± 0.009	−0.194 ± 0.05
$\alpha_T(\theta)$, %/°C	−0.247 ± 0.007	−0.371 ± 0.009	−0.380 ± 0.009	−0.383 ± 0.008	−0.381 ± 0.011	−0.388 ± 0.015	−0.39 ± 0.026	−0.401 ± 0.066
$\beta(\theta)$, %/mwm	−0.219 ± 0.005	−0.218 ± 0.006	−0.181 ± 0.005	−0.173 ± 0.005	−0.201 ± 0.007	−0.227 ± 0.009	−0.39 ± 0.015	−0.39 ± 0.038
$\gamma(\theta)$	0.389 ± 0.017	0.475 ± 0.023	0.279 ± 0.023	0.227 ± 0.022	0.153 ± 0.024	0.1 ± 0.04	0.01	0.001
r_{cor}	0.993	0.991	0.994	0.981	0.938	0.932	0.816	0.711

Note: TI is the total ionizing component and r_{cor} are the pair correlation coefficients for the left- and right-hand sides of expression (1) in the time interval where the reduced regression coefficients were determined.

intensity at different zenith angles were isolated, which are due only to variations in the atmospheric temperature:

$$\delta I_T(h_0, \theta) = \sum_{i=1}^{N} W_T(h, \theta)\Delta h_i \Delta T_i, \qquad (2)$$

where $W_T(h_i, \theta)$ is the temperature-coefficient density according to the definition of [1], Δh_i is the thickness of the ith atmospheric layer, and ΔT_i are temperature variations in the ith layer. Expression (2) is based on the integral method taking into account the temperature effect of muon intensity [1]. It was shown in [4] that

$$\delta I(h_0, \theta) = \sum_{i=1}^{N} k_i(\theta)\Delta T_i \approx \alpha_T(\theta)\Delta T_{mwm}, \qquad (3)$$

where $k_i(\theta) = W_T(h, \theta)\Delta h_i$ and ΔT_{mwm} are variations in the mass-weighted mean atmospheric temperature. Here, $\Delta h_i = 0.1$ atm for all layers. Solution of regression equations (3), taking into account that $\sum_{i=1}^{N} k_i(\theta) \approx \alpha_T(\theta)$, gave a distribution of the temperature-coefficient density (Fig. 1a). Using the found meteorological intensity coefficients $\alpha_0(\theta)$, $\beta(\theta)$, $\gamma(\theta)$, and $k_i(\theta)$, the data on the temperature of the near-ground layer, pressure, temperature variations ΔT_i in the ith atmospheric

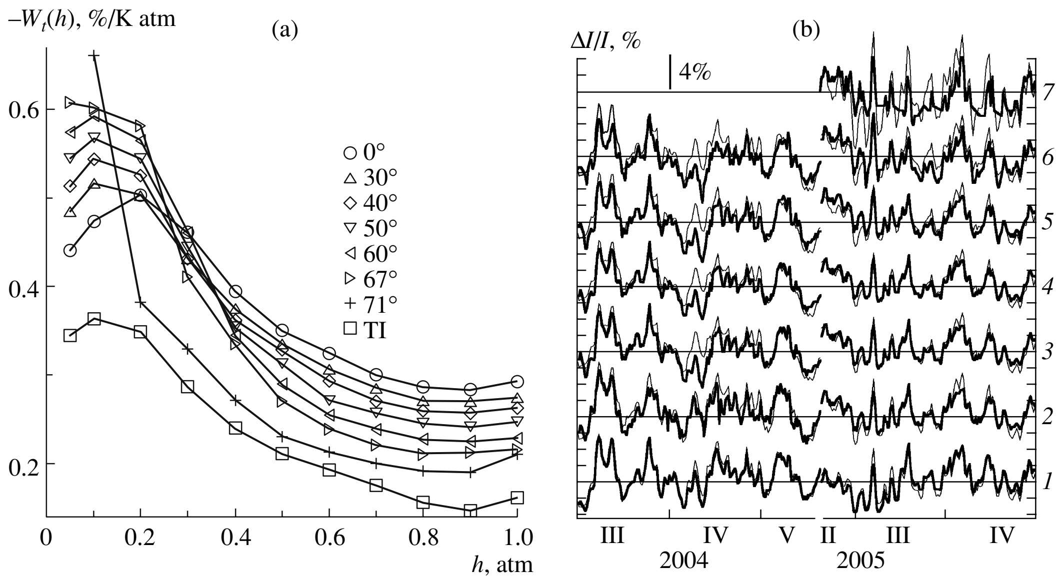

Fig. 1. Atmospheric effects of muon intensity at different zenith angles: (a) the temperature-coefficient density of muon intensity and (b) the expected (thin line) and observed (bold line) variations in the intensity of (*1*) the total ionizing component and (*2–7*) the muon component at zenith angles (*2*) 0°, (*3*) 30°, (*4*) 40°, (*5*) 50°, (*6*) 60°, and (*7*) 67°.

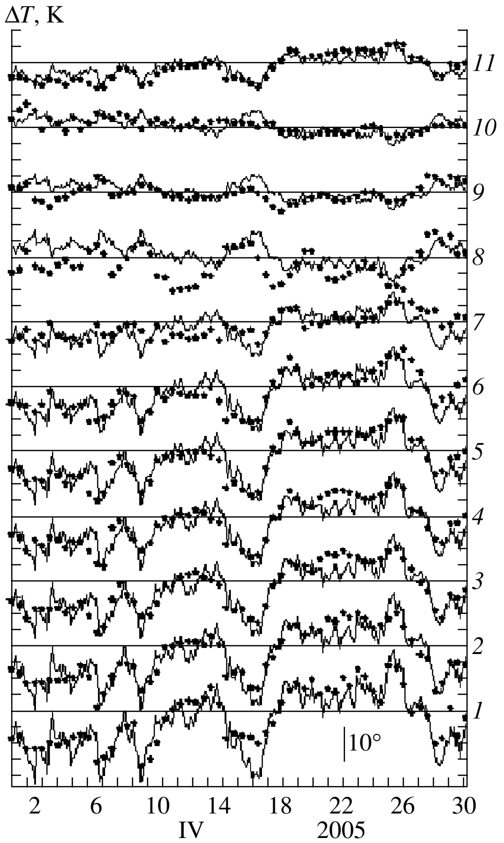

Fig. 2. Temperature variations for different atmosphere layers with pressures of (*1*) 900, (*2*) 800, (*3*) 700, (*4*) 600, (*5*) 500, (*6*) 400, (*7*) 300, (*8*) 200, (*9*) 100, and (*10*) 50 mbar and (*11*) the mass-weighted mean temperature.

layers, and the neutron monitor data, we calculated the expected variations in muon intensity at different angles by the integral method. The results of the calculations are compared with the observed variations in muon intensity in Fig. 1b.

The temperature variations in different atmospheric layers, derived from the data on the variations in the cosmic-ray intensity by solving the system of equations (2), are shown in Fig. 2 by solid lines, and the results of direct temperature measurements are given by dotted lines. The temperature variations ΔT_i can also be found as

$$\Delta T_i = \frac{1}{n}\sum_{k=1}^{n} \delta I_{T,k}(\theta)/R_k(\theta), \qquad (4)$$

where $\delta I_{T,k}(\theta)$ is the temperature component of the variation in muon intensity at different zenith angles, $R_k(\theta)$ are the regression coefficients for pairs of values $\delta I_{T,k}(\theta)$ and ΔT_i for the *i*th atmospheric layer, and *n* is the number of muon detection channels at zenith angles θ. The results obtained using (4) are in complete agreement with the data in Fig. 2.

CONCLUSIONS

The experimentally obtained meteorological coefficients of muon intensity in the atmosphere at different zenith angles make it possible, on the one hand, to take into account the variations of atmospheric origin and, on the other hand, allow diagnostics of the temperature atmospheric conditions according to the data on variations in the cosmic-ray intensity.

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REFERENCES

1. Dorman, L.I., *Meteorologicheskie effekty kosmicheskikh luchei* (Meteorological Effects of Cosmic Rays), Moscow: Nauka, 1972, p. 211.
2. Kuz'min, A.I., *Variatsii kosmicheskikh luchei vysokikh energii* (Variations in High-Energy Cosmic Rays), Moscow: Nauka, 1964, p. 159.
3. Yanchukovskii, V.L., Detection of Directed Cosmic-Ray Intensity, *Preprint of IGiG SO AN SSSR*, Novosibirsk, 1986, no. 20, p. 24.
4. Krest'yannikov, Yu.Ya., *Issled. Geomagn. Aeron. Fiz. Solntsa*, 1975, no. 37, p. 119.