The barometric effect in the intensity of near-horizontal cosmic ray muons according to the data of the coordinate-tracking detector DECOR

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Abstract. Experimental data on cosmic ray muons obtained with the coordinate-tracking detector DECOR in 2012 – 2017 are analyzed. The rate of the events exhibits variations significantly exceeding the statistical errors. It is shown that these variations are related to changes in the meteorological conditions (atmospheric pressure and air temperature). Barometric coefficient for near-horizontal muons has been estimated.

1. Introduction
In the frequency of the events formed as a result of interactions of cosmic rays in the atmosphere and recorded at the surface of the Earth, variations are observed that are related to the state of the atmosphere (atmospheric pressure, altitude distribution of air temperature and, respectively, air density, moisture content, etc.) [1].

An increase in the atmospheric pressure leads to an increase in the mass of the matter above the observation point and to a decrease in the intensity of muons due to the absorption of the less energetic particles in the atmosphere. This phenomenon is called the barometric effect and is approximately described by the introduction of the so-called barometric coefficient. For muons, the barometric effect decreases rapidly with increasing energy. In present work, the barometric effect for near-horizontal muons is studied. In contrast to the near-vertical muons, the particles in the investigated range of angles pass through the atmosphere a hugely larger path (geometrically ~ 400 km, and by the mass of matter ~ 20 kg/cm²) [2]. Earlier, variations in the intensity of near-horizontal muons were not studied.

2. Experimental data
Experimental data on cosmic ray muons obtained with the coordinate-tracking detector DECOR [3] in 2012 – 2017 are analyzed. DECOR is designed for studying multi-particle events and single muons at large zenith angles. The detector is deployed around the Cherenkov water calorimeter NEVOD. DECOR consists of 8 supermodules (SMs) with total area of ~ 70 m². Every SM includes 8 vertical streamer tube chamber planes. The events reconstructed from the data of SMs located in the opposite short galleries are analyzed. If the track segments registered in two SMs agree within a cone of 5°, it is supposed that both SMs were crossed by the same particle (a muon with energy of at least 7 GeV). Such events correspond to zenith angles from 85° to the horizon. The average zenith angle is 87.5°; the calculated average muon energy is about 100 GeV.
After preliminary analysis, 916 data sets (runs) with duration from 10 to 40 hours of «live time» were selected. The total live time amounted to 28508 hours. About 3% of available data were excluded from the consideration because of some fault conditions disclosed in them or runs were lasting less than 10 hours. The rate of the events exhibits variations significantly exceeding the statistical errors. It is naturally to assume that these variations are related to changes in the meteorological conditions (atmospheric pressure and air temperature).

The frequency of events selected during one of the periods of the measurements is represented by the points in the figure 1 (each point corresponds to a separate set); the line represents the atmospheric pressure values averaged over the set time. A negative correlation of the frequency of events with pressure is clearly noticeable: the extremely high values of atmospheric pressure correspond to the minimum values of the event frequency; on the other hand, an increased rate of events is observed, as a rule, during periods of a sharp drop in the atmospheric pressure.

**Figure 1.** Changes in the frequency of events and pressure over the period October 2014 - April 2015.

Values of atmospheric pressure were obtained with the help of a sensor, located near the installation (in the NEVOD building). The sensor measures the pressure every 22 seconds; from these data, the average pressure per set was calculated. In the sensor data, time intervals corresponding to each data set were found, and pressure averaging over these intervals was performed. Thus, for each data set, the mean atmospheric pressure for the NEVOD sensor was determined. The average pressure for all sets of three series of observations was also calculated (see table 1).

### 3. Barometric coefficient

A barometric coefficient is used to quantify the barometric effect. Empirically, it can be determined by a linear correlation between the data on the intensity of events with near-horizontal muons and atmospheric pressure data. The correlation between the frequency of selected events and atmospheric pressure for all series of observations is shown in the figure 2.

**Figure 2.** Correlation of event frequency and pressure for three series of observations. The line is the linear approximation (1).
Linear approximation of the obtained dependence by the method of least squares (the line in the figure) allows to obtain an estimate of the barometric coefficient for a given class of events. The line in the figure is the result of applying linear regression taking into account the statistical weights of the individual sets. The slope of the regression line for this relationship corresponds to the barometric coefficient.

The frequency of the selected events is approximated by a function in the form:

$$F_i = F_0(1 + \beta_p \Delta P); \quad \Delta P = P - <P>,$$

(1)

where $P$ is the current pressure value for a given set, $<P>$ is the pressure averaged over the whole series of measurements, and $\beta_p$ is the barometric coefficient.

The mean values of the atmospheric pressure over the experimental period and the barometric coefficient estimates for individual series, as well as for the entire observation period, are presented in the table 1.

**Table 1.** Summary results of estimating the barometric coefficient for the intensity of the near-horizontal muons of cosmic rays from the data of the present experiment.

| Series | I   | II  | III  | I - III |
|--------|-----|-----|------|---------|
| $<P>$ (mm Hg) | 746.3 | 747.0 | 746.1 | 746.6 |
| $\beta_p$ (‰/mm Hg) | -0.169±0.013 | -0.201±0.008 | -0.178±0.012 | -0.192±0.005 |

As can be seen from the table, the barometric coefficient estimates for different series are in satisfactory agreement with each other. It should be noted that the obtained estimates include not only the actual changes in the intensity of the near-horizontal muons, but also the apparatus component related with possible changes in the recording and event selection efficiency with changes in the atmospheric pressure. According to our estimates, the apparatus contribution to the barometric coefficient is about - (0.024±0.002) ‰/mm Hg. Thus, the final value of the barometric coefficient for near-horizontal cosmic ray muons with energy more than 7 GeV can be evaluated as - (0.168±0.005stat±0.002syst) ‰/mm Hg.

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**References**

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