Seasonal variations in the intensity of muon bundles detected at the ground level

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Abstract. Experimental data accumulated in a 3-year long series of measurements of cosmic ray muon bundles with the coordinate-tracking detector DECOR are analyzed. It has been found that the measured rate of the events exhibits clear seasonal variations, repeated every year of observations: in winter, the event rate is significantly higher than in summer; the difference between the average intensity of muon bundles recorded in winter and in summer exceeds 10%. Taking into account that the mean energy of muons registered in the bundles is of the order of several tera eV, the observed difference cannot be explained in frame of a well-known mechanism of the formation of the temperature effect due to decays of low energy particles in the atmosphere. An alternative explanation related with changes of the shape of the lateral distribution function of EAS muons in the atmosphere with a variable temperature profile is discussed.

Introduction

The rate of the events generated as a result of interactions of cosmic rays in the atmosphere is mainly determined by the processes taking place on the Earth’s surface, such as variations caused by atmospheric conditions (atmospheric pressure, altitude, distribution of temperature and, respectively, air density, water content, etc.). It is important to note that the values of meteorological effects as well as the physical processes responsible for their formation are different for different cosmic ray components (muon, hadron, electron-photon) and events of different classes. The correct understanding of the influence of atmospheric effects on the intensity of registered events is important for accurate comparison of the data of experiments conducted in different conditions and for introduction of necessary corrections.

In the present poster, seasonal variations and meteorological effects (barometric and temperature ones) in the intensity of muon bundles selected at the ground level are considered.

Seasonal variations

Experimental data accumulated in a 3-year long series of measurements (from May 2012 to April 2015) of cosmic ray muon bundles with the coordinate-tracking detector DECOR are analyzed. Total observation time amounted 17,760 h; about 4.4 million muon bundle candidate events were selected.

As it follows from the figure, clear seasonal variations repeated every year of observations are present in the event rate. The red curve in the figure represents the results of the fitting of experimental points with a harmonic function in the form:

\[ F(t) = C + \frac{A}{2 \pi} \sin (2 \pi t/365), \]

where \( t \) is the time moment (days from the beginning of 2012) corresponding to the middle of the i-th data set \((i)\), \( T_0 \) is the period equal to the mean calendar year \((365.244 \text{ days})\), and \( t_0 \) is the time moment in the year corresponding to the maximum of the first annual harmonic.

The parameters were estimated with weight least squares technique: \( C = 247.5 \pm 0.12 \text{ events/ h} \); \( A = 12.94 \pm 0.10 \text{ events/ h} \); \( t_0 = 21.43 \pm 0.8 \text{ days (errors are statistical)} \).

The amplitude of the first annual harmonic of the event rate has been estimated as \((5.2 \pm 0.1) \% \) with the maximal intensity in the middle of January, and the minimal one in July. Thus, the difference in the event rate in summer and winter months exceeds 10%.

Barometric and temperature effects

The slope of the regression line for the dependence on the atmospheric pressure (left figure) corresponds to the middle of the range of barometric points (325 mm Hg) we would obtain a quantitative estimate of the expected temperature coefficient due to the considered geometrical mechanism: \( \beta = (0.325 \pm 0.006) / \% \text{ mm Hg} \). At the same time, a large spread of the experimental points relative to the regression line is seen (the value of the corresponding correlation coefficient \( R \) equals 0.45), which indicates a strong influence of other factors that affect the muon bundle intensity (first of all, the changing temperature profile of the atmosphere).

Much more close correlations are observed in the comparison of the muon bundle detection rate with the mass average air temperature (right figure, correlation coefficient \( R = 0.90 \)), which evidences that the temperature effect is the main factor that influences the intensity of the events. The estimate of the temperature coefficient on the basis of linear regression of the data presented in the right figure is \( \beta = (0.708 \pm 0.008) / \% \text{ K} \) (the error is statistical). Such value of the temperature coefficient cannot be explained in the frame of a usual mechanism related with a decay of low energy muons.

Geometrical mechanism of the formation of the temperature effect for muon bundles [2]

Illustration of the increase of the radial spread of muons (left) and of changes of the lateral distribution function of EAS muons (right) at the heating of the atmosphere [2].

References

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BAROMETRIC AND TEMPERATURE EFFECTS

Correlations of the muon bundle detection rate with the mass average air temperature.

Detection of muon bundles at the surface corresponds to the selection of events (EAS muon component) according to value of the local muon density at the observation point [3]. The geometrical spread of muon bundles on the surface is mainly determined by the transverse momenta parent hadrons at production and the geometrical altitude of their generation. In its turn, for any fixed depth \( X \) (cm), in the atmosphere the altitude is proportional to the absolute atmosphere temperature.

Thus, the changes in the air temperature lead to the changes of the typical spread of muons at the level of observations and to a modification of the lateral distribution function of EAS muons (see the figure as an illustration).

If we take as an estimate of the effective temperature of the air the mean value of the mass average temperature over the observation period (247 K), we would obtain a quantitative estimate of the expected temperature coefficient due to the considered geometrical mechanism: \( \beta = (0.325 \pm 0.006) / \% \text{ mm Hg} \), which is in a quite good agreement with the value obtained experimentally.

The estimate of the temperature coefficient on the basis of linear regression of the data presented in the right figure is \( \beta = (0.708 \pm 0.008) / \% \text{ K} \) (the error is statistical). Such value of the temperature coefficient cannot be explained in the frame of a usual mechanism related with a decay of low energy muons.