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

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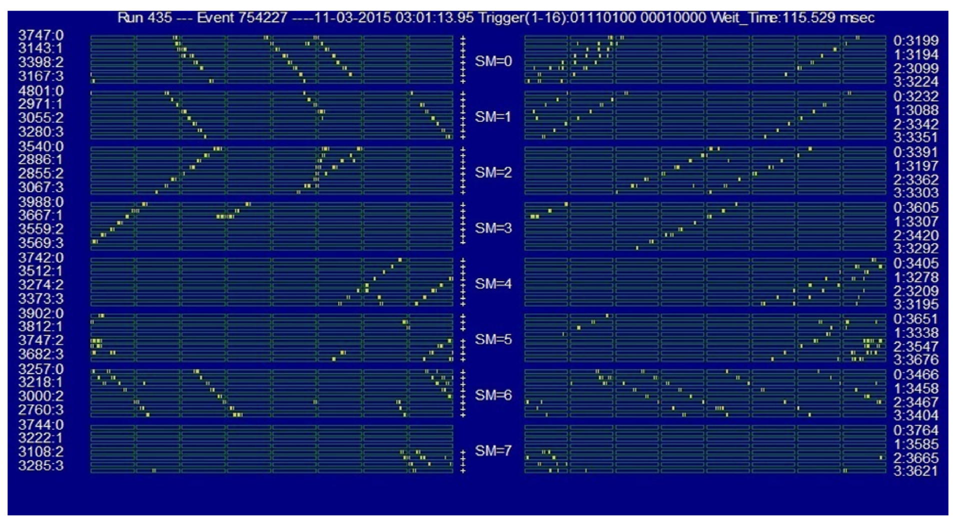
Abstract. Experimental data accumulated in a 3-year long series of measurements of cosmic ray muon bundles with the coordinate-tracking detector DECOR are analyzed. It has been found that the measured rate of the events exhibits clear seasonal variations, repeated every year of observations: in winter, 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 tens GeV, 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 and detected on the Earth's surface subject to 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, hadronic, 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 detected at the ground level are considered.

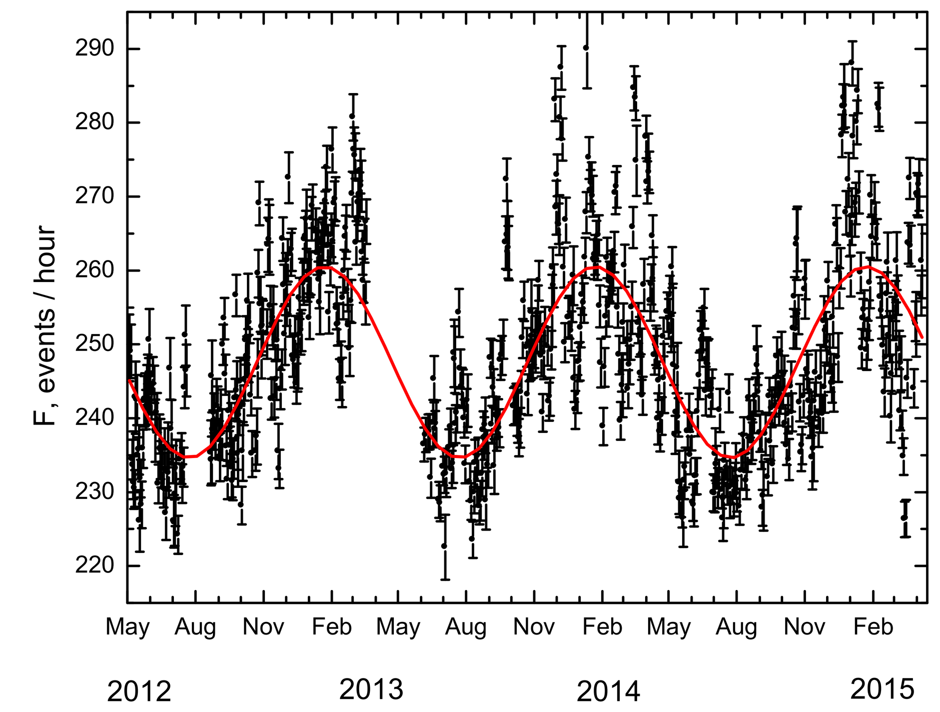
The *muon bundle* is an event with a simultaneous passage of several genetically related muons through the setup. The main source of the muon bundles are decays of pions and kaons produced in a nuclear cascade initiated by a high-energy primary cosmic ray particle. The mean energy of muons detected in the bundles is approximately by the order of magnitude higher than that of single muons. The selection of muon bundles in DECOR [1] is based on the assumption that the tracks of muons generated in the atmosphere at large distances from the setup are nearly parallel to each other. At a trigger level, the events with at least three of eight simultaneously (within the 250 ns time gate) actuated supermodules (SMs) of the coordinate detector are selected and registered. The trigger rate for such events is about 0.25 per second. At the off-line data processing, the geometry reconstruction of tracks in each SM is performed, and candidate events with at least three quasi-parallel tracks (coinciding in direction within 5° cone) detected in three different SMs of DECOR are selected.



X-projection Y-projection

An example of muon bundle detection: coordinate detector response

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.

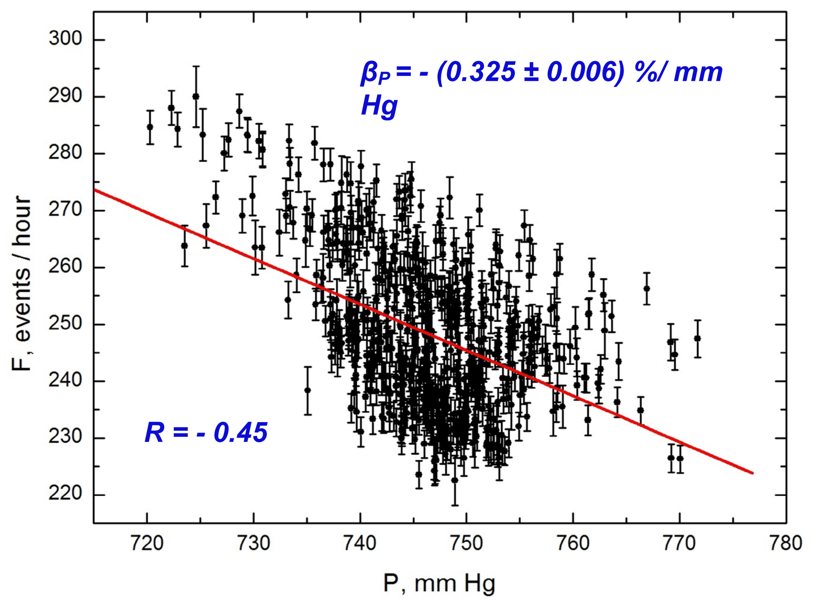
As it follows from the figure, clear seasonal variations repeated every year of observations are present in the event rate. The red curve in the figure represents the results of the fitting of experimental points with a harmonic function in the form:

$F(t) = C + A\cos(2\pi(t_i - t_m)/t_0)$, where t_i is the time moment (days from the beginning of 2012) corresponding to the middle of the i-th data set (run), t_0 is the period equal to the mean calendar year (365.24 days); t_m is the time moment in the year corresponding to the maximum of the first annual harmonic.

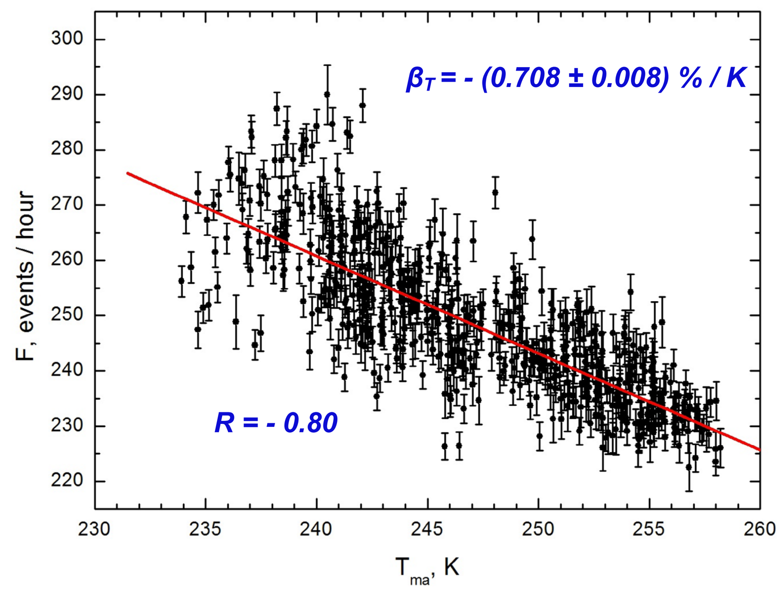
The parameters were estimated with weight last squares technique: C = 247.58±0.12 events/h; A = 12.94±0.17 events/h; t_m = 21.4±0.8 day (errors are statistical).

The amplitude of the first annual harmonic of the event rate has been estimated as (5.2 ± 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



Correlations of the rate of the muon bundle detection with the atmospheric pressure.



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

The slope of the regression line for the dependence on the atmospheric pressure (left figure) corresponds to the value of the barometric coefficient β_P = - *(0.325 ± 0.006) % /* 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 to – 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* = – 0.80), 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 β_T = - *(0.708 ± 0.008)* % / 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]

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 of parent hadrons at production and the geometrical altitude of their generation. In its turn, for any fixed depth *X* (g cm^{-2}) 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 will readily obtain a quantitative estimate of the expected temperature coefficient due to the considered geometrical mechanism: β_T = - *(0.77 ± 0.02)% / K* , which is in a quite good agreement with the value obtained experimentally.

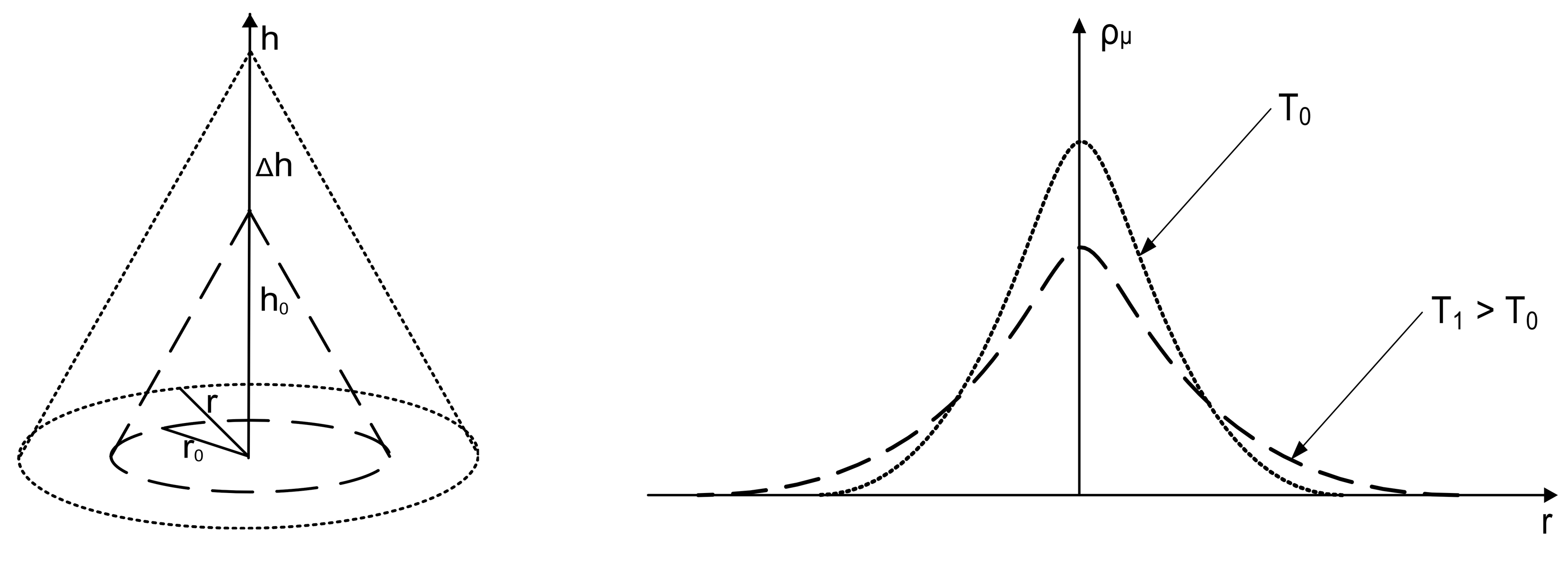


Illustration of the increase of the radial spread of muons (left) and of changes of the lateral distribution function of EAS muons (right) at the heating of the atmosphere [2].

References

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[3] A.G. Bogdanov *et al.*, *Phys. Atom. Nucl.*, 73, 1852 (2010).

Acknowledgments

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