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Analysis of muon flux response for thunderstorm events in Moscow region

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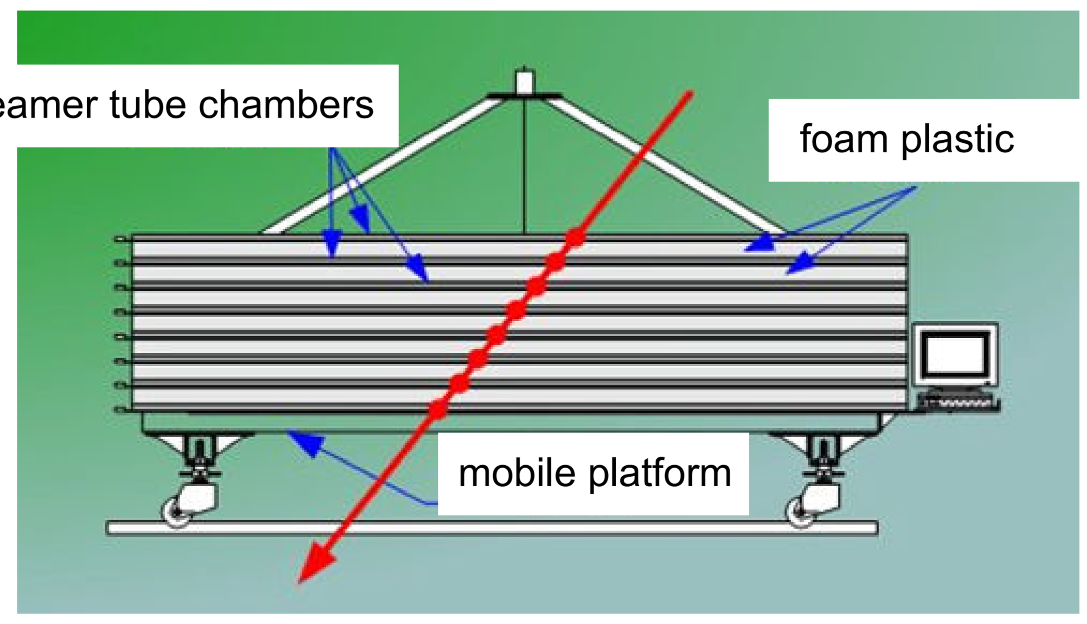
Monitoring of dangerous weather phenomena such as thunderstorms and severe squalls remains the actual problem of the day. Many of local weather disturbances cannot still be detected in advance, despite of the existence of a network of meteorological stations and weather satellites. At present, a new approach to monitoring of such processes by means of detectors sensitive to the muon component of cosmic rays is being developed [1].

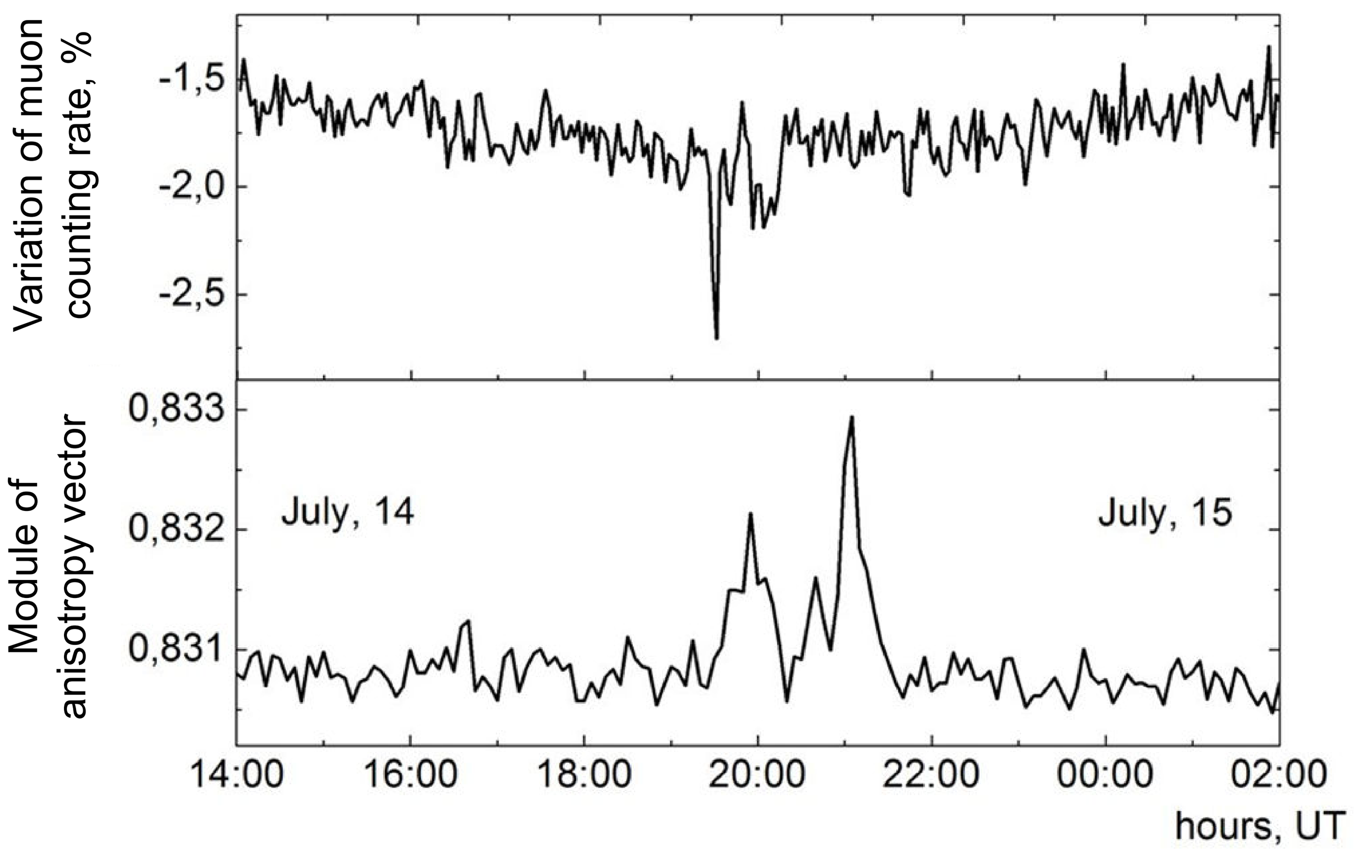
URAGAN

In this work, data of muon hodoscope are used to analyze variations of muon flux at the surface of the Earth. Muon hodoscope is a new type detector capable detecting muons simultaneously from different directions of celestial hemisphere. Muon hodoscope URAGAN [2] was constructed at the Scientific and Educational Center NEVOD (MEPhI) in 2005. It is a wide-aperture coordinate detector consisting of four separate supermodules with total area 46 m^2 and registers about 5500 muons/s.



To compare the data with the real weather, various atmospheric parameters in the vicinity of the muon hodoscope were recorded. To obtain the most complete picture of the thunderstorm activity, several sources of atmospheric data have been used, each of them served to indirectly verify the others. Twenty thunderstorm events were revealed during the period May-September 2009 in Moscow region.

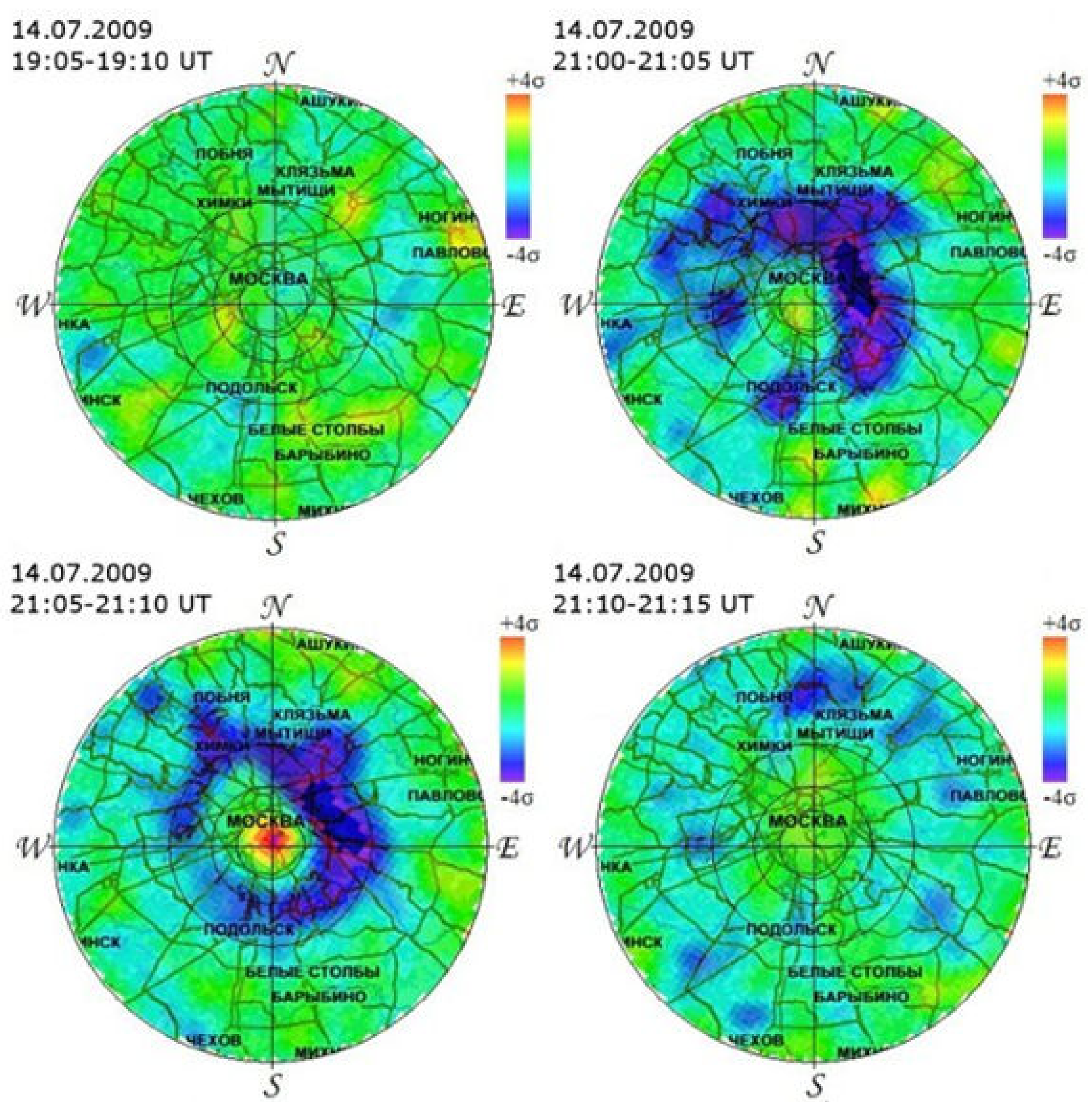
Counting rate and local anisotropy vector



Analysis of the integral counting rate of the muon hodoscope URAGAN shows that during the thunderstorm event a minimum (Fig. 1, top) is observed. As an angular variation characteristics of the muon flux, the local anisotropy vector is used, which indicates the average direction of muon arrival. Local anisotropy vector is calculated as the sum of unit vectors, each representing the direction of the individual track, normalized to the total number of muons [3]. The length of the vector depends on the shape of the angular distribution of the muon flux. The average direction of anisotropy vector is very close to the vertical but during atmospheric (and extra-atmospheric) disturbances rather strong deviations from the mean value, such as during a thunderstorm event on 14-15 July 2009 (Fig. 1, bottom), are observed.

Muon matrices

The main format of muon hodoscope data is a two-dimensional muon intensity matrix. On-line track reconstruction gives values of both zenith and azimuth angles, or projection zenith angles θ_X, θ_Y of muon track (in local coordinate system), on the basis of which the track is put in a corresponding cell of the matrix. To study muon flux variations, for every cell of this matrix the average number of muons (estimated during preceding 24 hours and corrected for atmospheric pressure) is subtracted, and results are divided by standard deviations (Fig. 2). To smooth Poisson fluctuations, the data were averaged over 5-minute intervals and a special Fourier filter was applied. Scales at the figures denote values of muon intensity changes in standard deviation units. Tints represent excess or deficit of muons coming from a certain direction. Thin lines identify North-South and West-East directions. The circles correspond to zenith angles 30°, 45° and 60°. Statistics of each image exceeds one million tracks.



In Fig. 2, the matrices for the thunderstorm event on July 14-15, 2009 are presented. During the quiet atmosphere, perturbation in muon "snap-shot" is practically not seen (upper-left matrix). On the other matrices disturbances are clearly visible, which correspond to the maximum of the event (21:00-21:10). This is consistent with a peak in the anisotropy vector plot and the minimum in the counting rate.

Conclusion

Analysis of the muon hodoscope data obtained during summer 2009 showed that approximately in 80% of thunderstorm events clear responses in muon hodoscope data were observed. Effects were detected both in the total counting rate and in angular dynamics of the muon flux. Thus, the flux of cosmic-ray muons is sensitive to local atmospheric disturbances. This result indicates promising perspectives of cosmic ray application as a tool for monitoring of atmospheric phenomena.

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[1] I.I. Yashin et al., Proc. 20th ECRS, Lisbon, Portugal (electronic form), 2006.
[2] N.S. Barbashina et al., Instr. Experim. Tech., 51, No.2, 180, 2008.
[3] D.A. Timashkov et al., Proc. 21st ECRS, Koshice, Slovakia, 338, 2008.