22-nd ECRS, Turku, Finland, 2010

Technique of temperature effect correction for ground-based muon hodoscopes

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Introduction

Studies of cosmic ray variations at ground level are being carried out more than a half of century. The longest series of cosmic ray variation data have been obtained by means of neutron monitors. The use of muon detectors provides valuable additional opportunities in comparison with neutron monitors: sensitivity to higher energies of primary particles, possibility to measure arrival directions of muons and, as a consequence, to study directional cosmic ray variations by means of a single setup. However analysis of muon intensity variations requires more complicated calculations of the atmospheric corrections taking into account both barometric and temperature effects: $N^{corr} = N^{obs} - \Delta N_T - \Delta N_P$. N^{corr} is muon counting rate, which contains variations of non-atmospheric type only, N^{obs} is the experimental muon counting rate, ΔN_T and ΔN_P are atmospheric corrections for changes of atmospheric temperature and pressure. Calculation of the correction on barometric effect is fairly simple: $\Delta N_P(E_{min},X,\theta)/N_0(E_{min},X,\theta) = \beta(E_{min},X,\theta)\cdot(P-P_0)/100$ %, where P and P_0 are current and average over a continuous period values of pressure at observation level X, β is barometric coefficient, $N_0(E_{min},X,\theta)$ – muon counting rate for "standard" atmosphere at observation level X for zenith angle θ and threshold energy E_{min}. For calculation of temperature effect correction, it is necessary to know differential temperature coefficients (DTC), which make it possible to correct counting rate taking into account changes of the temperature at all altitudes of the atmosphere. If atmospheric temperature is changed by $\Delta T(h)$ (h is the atmospheric depth in atm) the standard muon flux $N_0(E_{min},X,\theta)$ will be changed by $\Delta N_T(E_{min},X,\theta)$ and the relative change of the muon flux can be writen in a following way (L.I.Dorman, 1972):

$$\frac{\Delta N_T(E_{min},X,\theta)}{N_0(E_{min},X,\theta)\cdot 100\,\%} = \int_0^X W_T(E_{min},X,h,\theta)\Delta T(h)dh \qquad (1)$$

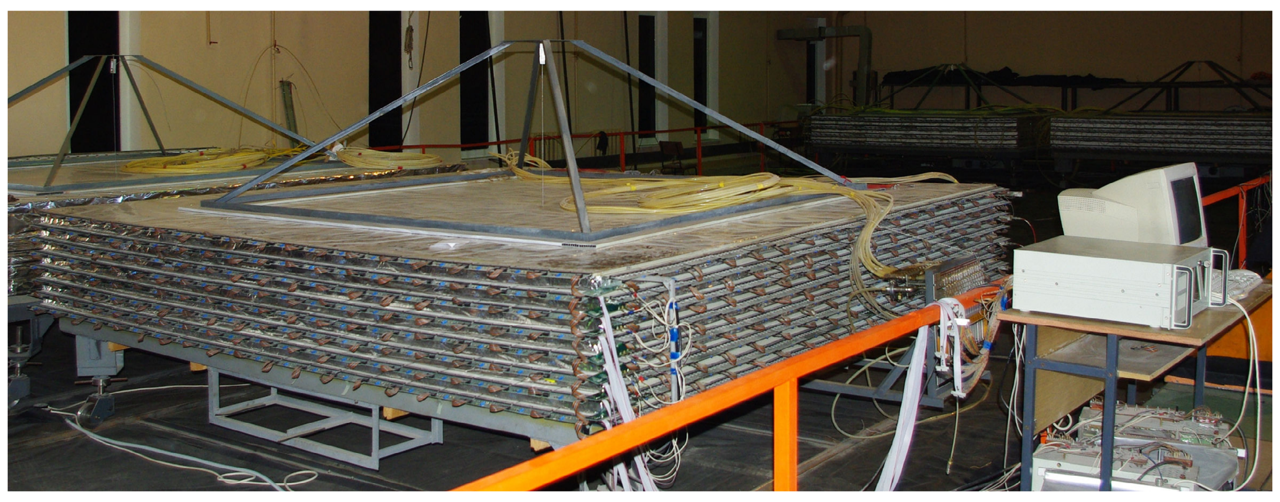
Here the function $W_T(E_{мин},X,h,\theta)$ is DTC. DTC can be found on the basis of the formulas describing muon production and propagation in the atmosphere (L.V.Volkova, 1969).

Method of DTC calculation for muon flux at different zenith angles, altitudes above sea level and threshold energies and results of DTC calculations are presented in the paper of A.N.Dmitrieva et al. (2009). In calculations, a six-layer stationary model of atmosphere is used, contributions of both pions and kaons are taken into account. Also for muons, relation between energy loss and muon energy is taken into account. Comparison of results of our DTC calculations with results of earlier works exhibited only qualitative agreement with the preceding results, whereas quantitative differences amounted to tens percent.

In this work, influence of atmospheric temperature and pressure on ground level muon flux is considered. Results of differential temperature coefficients (DTC) calculations for muon hodoscope URAGAN at different zenith angles are presented. Method of experimental data correction and some practical questions of the use of DTC for muon hodoscope data analysis are discussed.

Muon hodoscope URAGAN

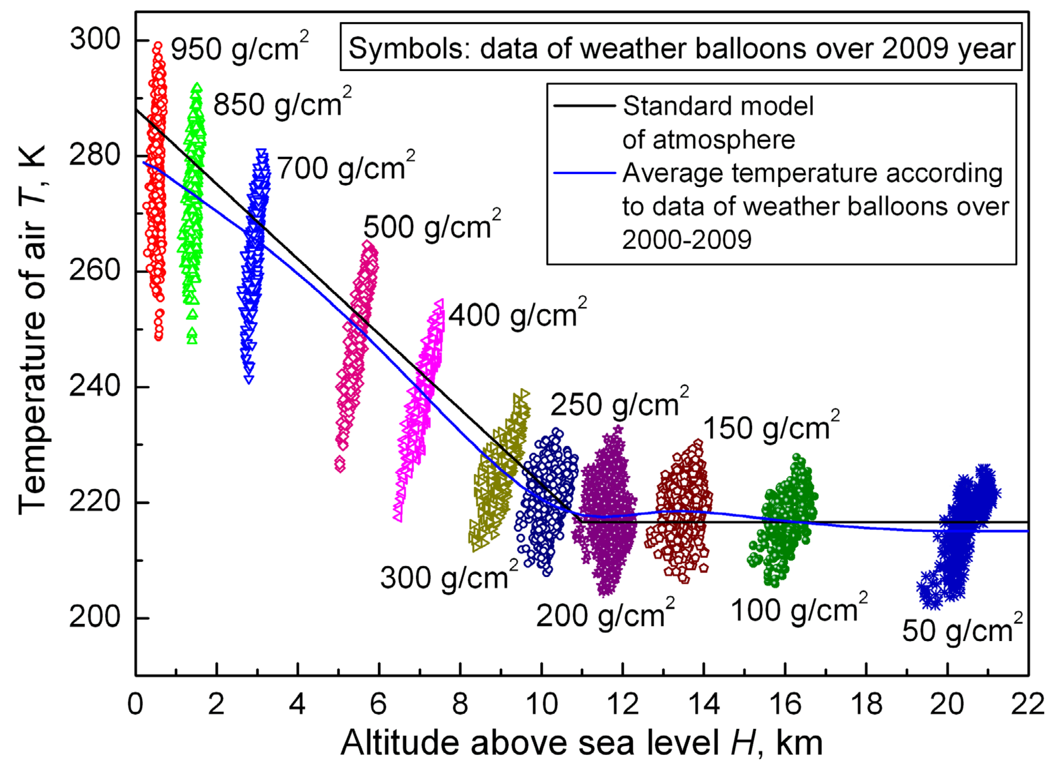
URAGAN, a wide-aperture precise muon hodoscope, is used to study atmospheric and heliospheric processes responsible for variations in the muon flux at the Earth surface.



The hodoscope consists of separate horizontal assemblies–supermodules–with the area of 11.5 m^2 each. Each supermodule consists of eight layers of streamer tube chambers equipped with a two-coordinate system of external readout strips. In every layer, there are 320 X-channels and 288 Y-channels with pitches of 1.0 and 1.2 cm, respectively. The layers are interleaved with 5 cm thick foam-plastic sheets. A limited streamer mode is maintained in the chambers by means of the three-component gas mixture (argon+CO_2+n-pentane) and proper selection of the operating voltage. The supermodule detects muons with high spatial and angular accuracies (1 cm and 1°, respectively) over a wide range of zenith angles 0°-80°). Threshold energy of SM URAGAN depends on zenith angle and takes values from 200 to 600 MeV. Average counting rate of one SM equals to ~ 1500 events per second. The total acceptance of SM is 27.7 m^2·sr. Barometric coefficient for one URAGAN supermodule is 0.18 %/mbar.

Temperature profile of atmosphere

For calculations of temperature effect correction, the dependence of air temperature on altitude above sea level has to be known. It can be taken from weather balloon data of the Central Aerological Observatory (Russia, Moscow region, Dolgoprudny, station number 27612). Measurements of air temperature for several pressure levels during 2009 are shown in bottom figure by symbols.



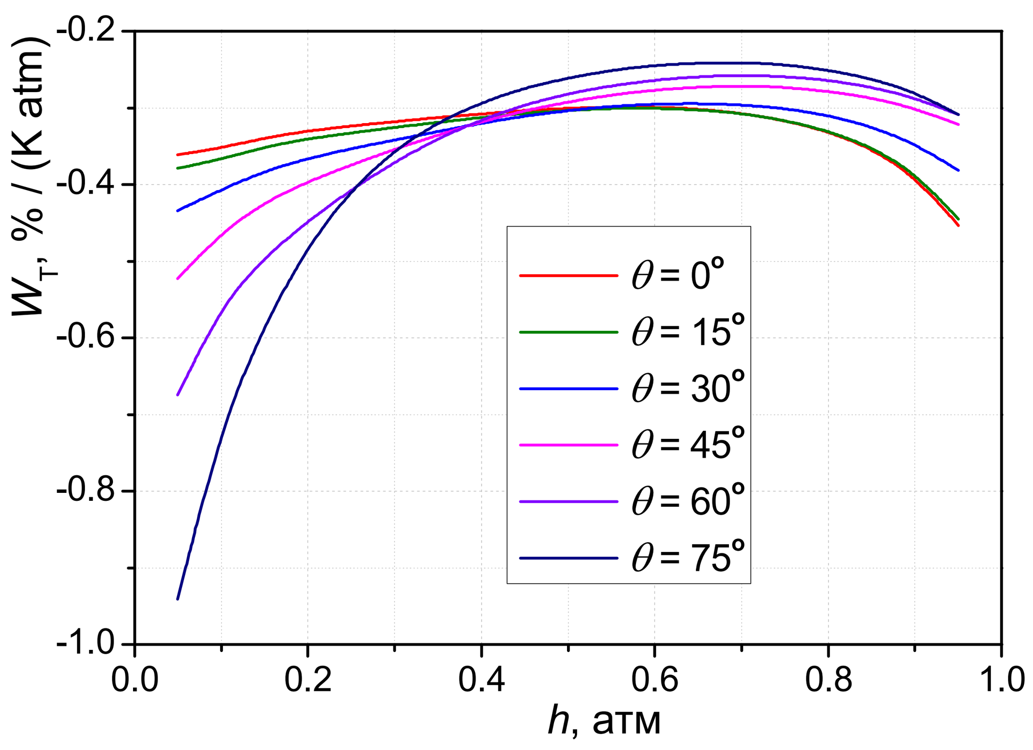
One can see from the figure that the difference between summer and winter days may reach about 40 K. In the same figure, the average profile of atmosphere $\langle T\rangle(h)$ calculated from weather balloon data over the period from 2000 to 2009 is shown by the blue line, and profile atmosphere which was used as "standard" for DTC calculations $T_{CA}(h)$ is shown by the black line.

Average temperature $\langle T\rangle(h)$ for Moscow region is lower than "standard" $T_{CA}(h)$ by several centigrades in a significant part of atmospheric altitudes. This fact is necessary to take into account for accurate calculations of temperature correction (see below).

DTC calculation for SM of URAGAN

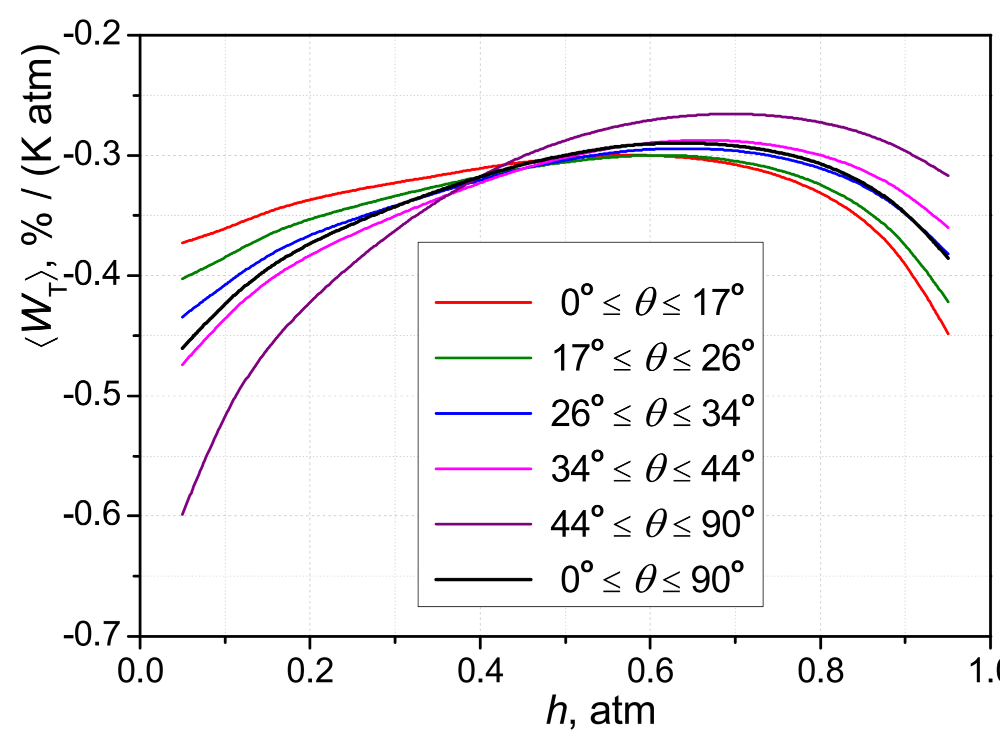
Results W_T calculations taking into account the setup altitude above sea level and dependence of threshold energy on zenith angle (see the table) for six values of θ are presented in the bottom figure.

θ	0°	15°	30°	45°	60°	75°
E_{min}, MeV	199	201	209	324	489	571



For different scientific tasks, for example for Forbush decrease (FD) analysis, it is necessary to consider muon counting rate in several intervals of zenith angle. For muon hodoscope URAGAN five intervals of zenith angle with a similar statistical accuracy are used: 0°-17°, 17°-26°, 26°-34°, 34°-44° и 44°-80°. In this case we have to average DTC taking into account muon counting rate versus θ:

$$\langle W_T\rangle(h,\theta_1\le\theta\le\theta_2) = \int_{\theta_1}^{\theta_2} W_T(E_{min},X,h,\theta)N_0(E_{min},X,\theta)d\theta \Big/ \int_{\theta_1}^{\theta_2} N_0(E_{min},X,\theta)d\theta$$



The choice of N_0 value

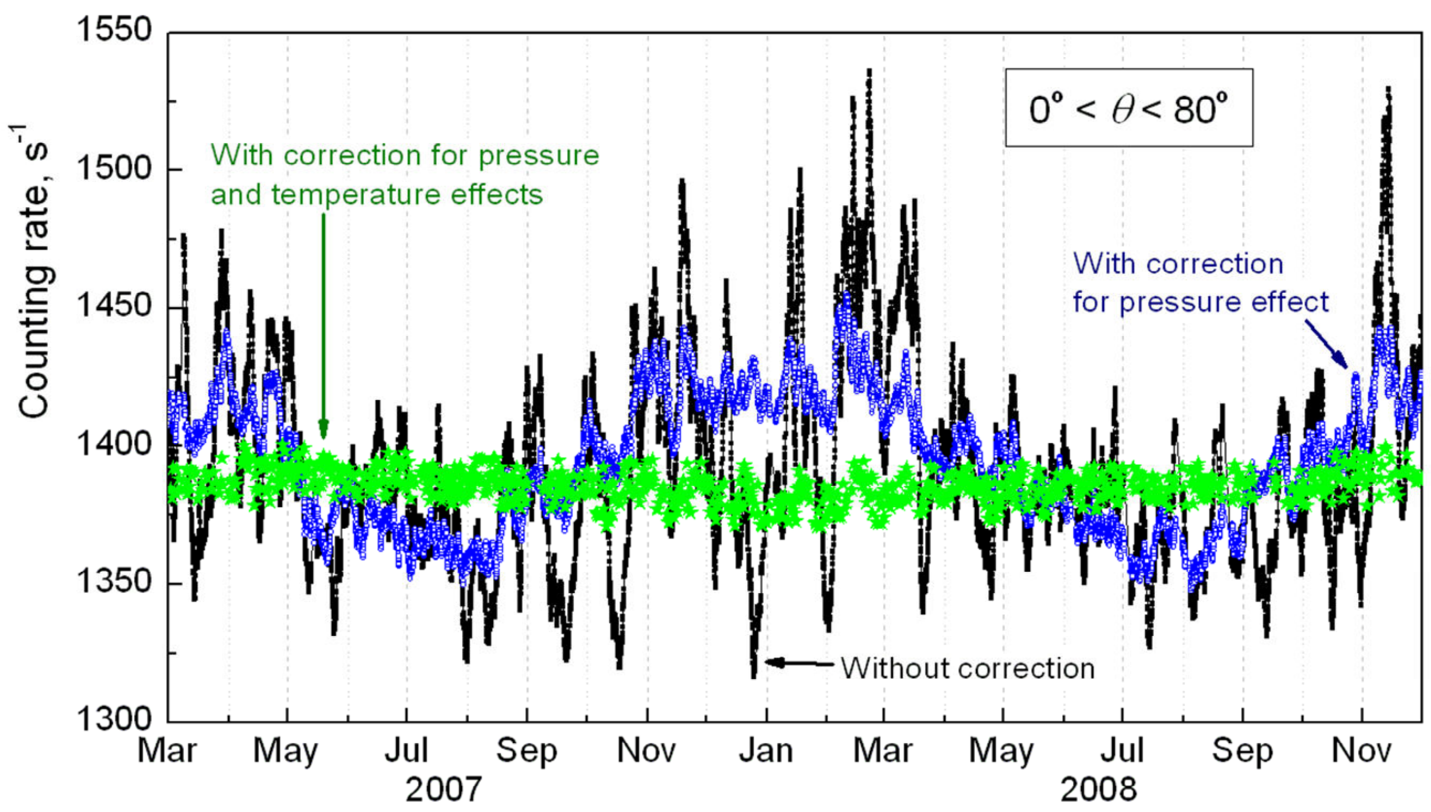
For correction of a certain setup data using formulae (1) it is more reasonable to use counting rate of this setup for standard atmosphere. At the same time, the average over a long period of time value of counting rate $<N^{эксп}>$ is often used as normalization constant N_0 ($N_0 \approx <N^{эксп}>$). But method of DTC calculation implies using of "standard" profile of atmosphere and corresponding counting rate at registration level. For Moscow region, the average profile of atmosphere $\langle T\rangle(h)$ lies lower than "standard" $T_{CA}(h)$ one and estimation N_0 on experimental data will be overrated. It is necessary to take into account this effect, and to re-calculated average value of counting rate to "standard" one N_0: $<N^{obs}> \approx N_0\cdot(1+\Delta)$, $N_0 \approx <N^{obs}>/(1+\Delta)$, where:

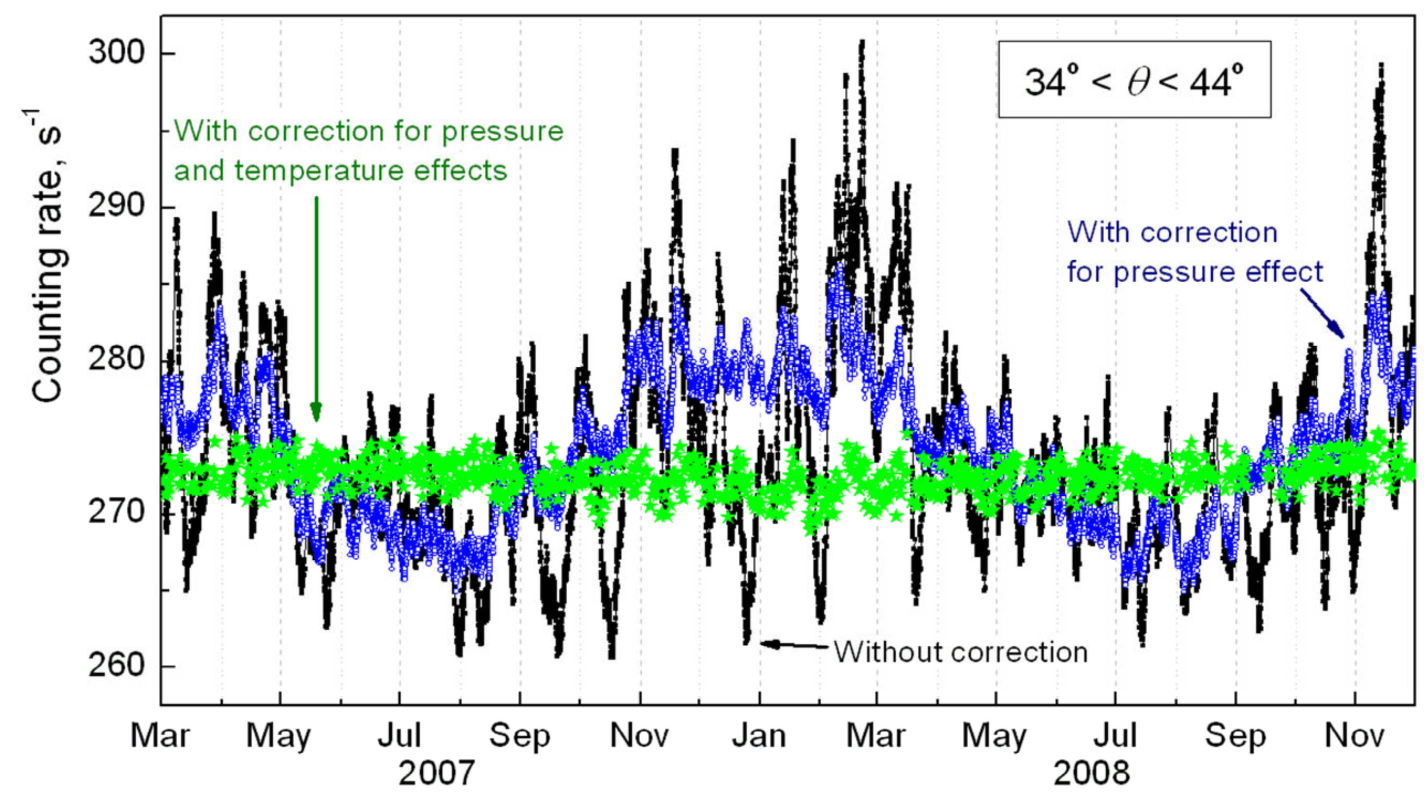
$$\Delta = \left[\sum_i W_T(E_{min},X,h_i,\theta)(\langle T\rangle(h_i) - T_{SA}(h_i))\Delta h\right] / 100\,\%$$

For muon counting rate of SM URAGAN $<N^{obs}> \approx 1398\pm24$ s^{-1}, correction $\Delta \approx 0.011$ and $N_0 \approx 1383\pm20$ s^{-1}. So, with known DTC and standard value of muon counting rate one can make correction of data for temperature effect.

Examples of temperature effect correction in SM URAGAN data

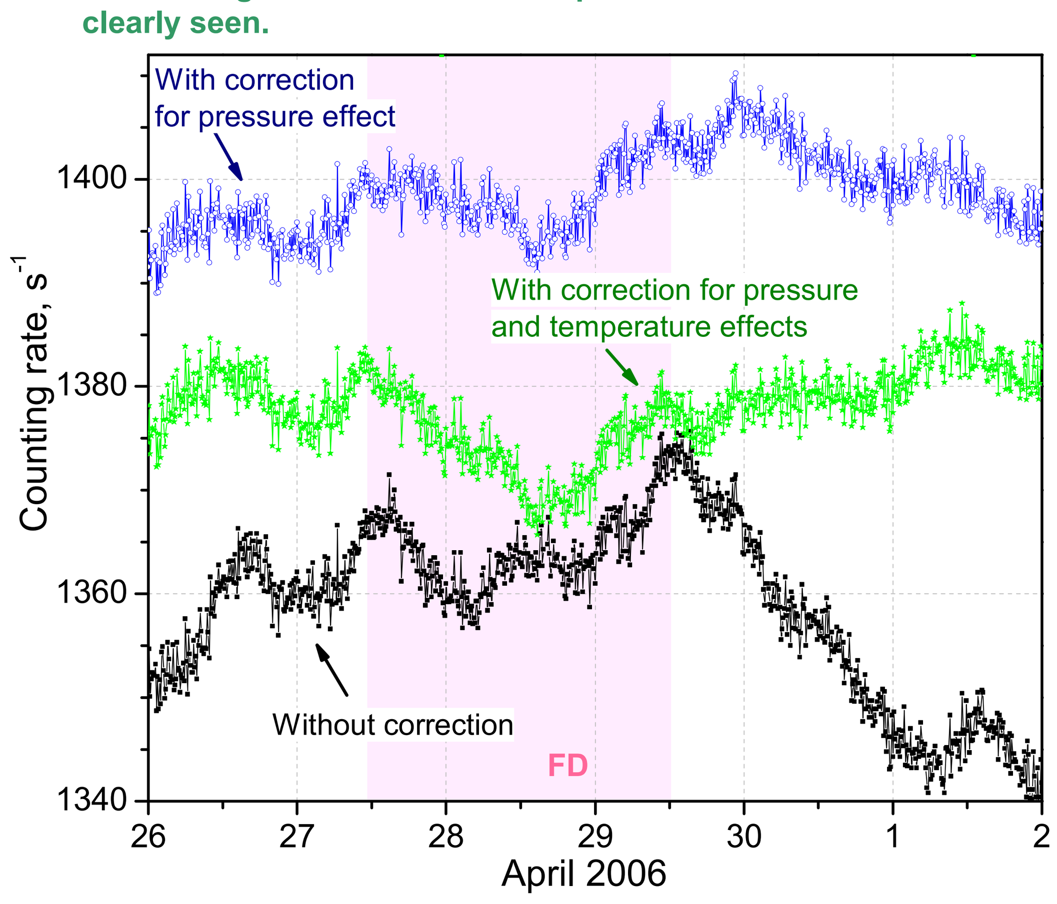
Integral intensity of reconstructed events and intensity for a limited zenith angle interval 34° ≤ θ ≤ 44° in one supermodule of the URAGAN hodoscope over the period March 2007–December 2008 without and with corrections for atmospheric effects are presented in bottom figures. This was a period of quite heliospheric weather and therefore there was no sharp changes in corrected muon counting rate.



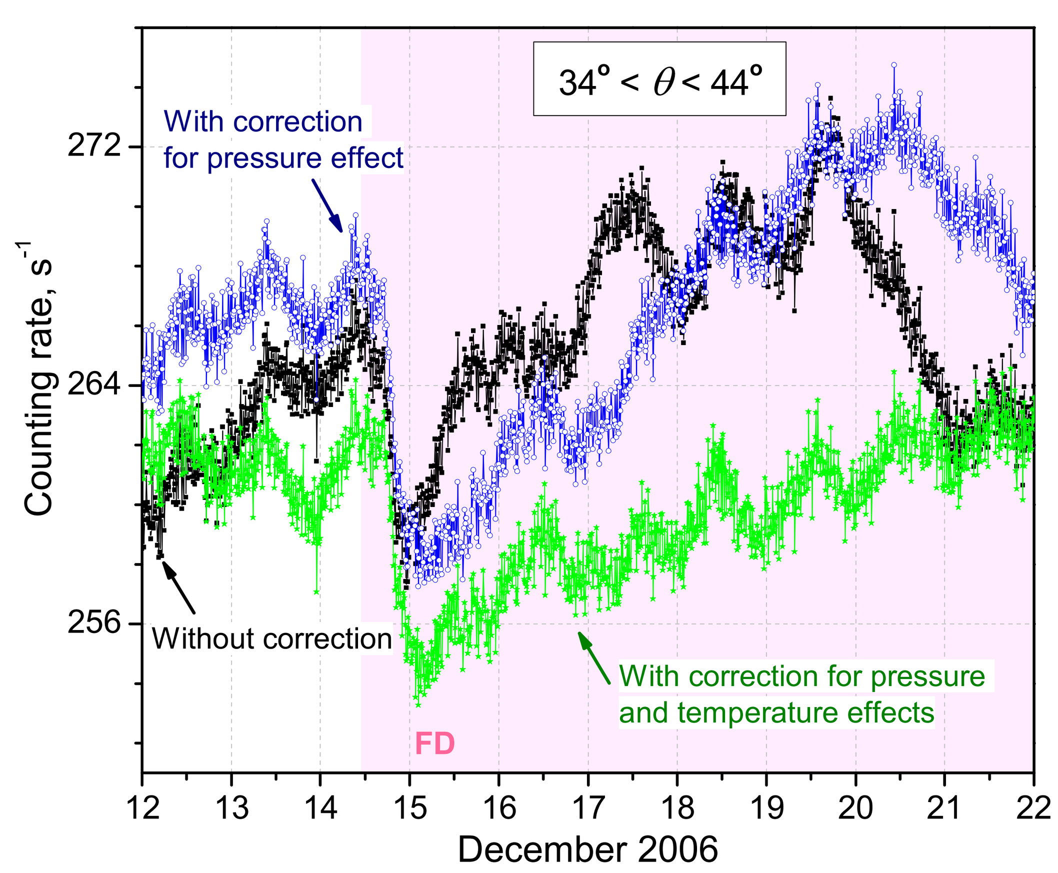


Forbush decreases in counting rate of SM URAGAN

Integral counting rate of one SM URAGAN during Forbush decrease (FD) of 27 April 2006 is shown in the bottom figure. In data without correction FD is not visible, but it becomes noticeable after correction for barometric effect. After introducing correction for temperature effect FD becomes clearly seen.



Counting rate of one SM URAGAN during Forbush decrease of 24 December 2006 is shown in the right figure. After correction for temperature effect, the estimate of Forbush decrease amplitude is changed from 3.55±0.11 % to 3.07±0.15 %.



Conclusion

- ✓ Differential temperature coefficients calculated for muon hodoscope URAGAN are presented.
- ✓ Method of experimental data correction for temperature effect and choice of the standard value N_0 for defined setup are described.
- ✓ Use of calculated DTC for temperature effect correction allows more reliably identify effects of non atmospheric origin in muon flux.

The research has been performed in Scientific and Educational Centre NEVOD with the support of Ministry of Education and Science (contract № 02.518.11.7166), Russian Foundation for Basic Research (grant 08-02-01204), the Federal Target Program "Scientific and educational cadres for innovative Russia" and leading scientific school grant НШ-5712.2010.2.