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Temperature effect correction for URAGAN based on CAO, GDAS, NOAA data

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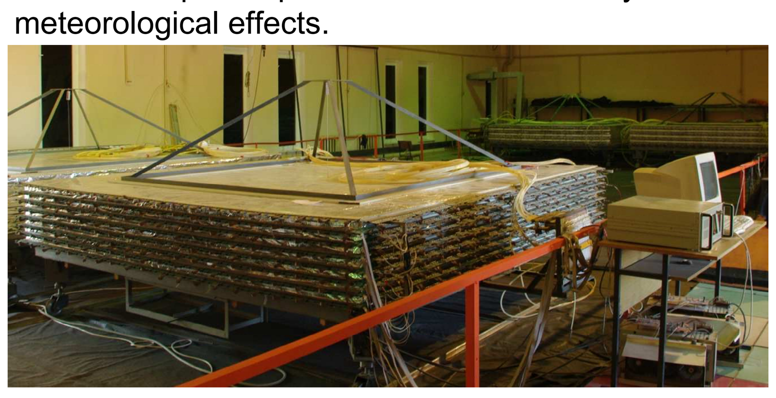
ECRS 2014 KIEL

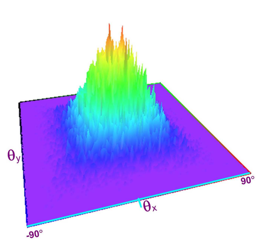
GEO S2-391

Muon hodoscope URAGAN

URAGAN (Moscow, Russia, 55.7° N, 37.7° E, 173 m a.s.l.) is a wide-aperture precision muon hodoscope which 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. Three supermodules of hodoscope (SM) are now under operation in the exposure mode. The supermodule detects muons with high spatial and angular accuracies (1 cm and 1°, respectively) over a wide range of zenith angles (0–80°). For the analysis of muon flux variations caused by extra-atmospheric processes it is necessary to introduce corrections for meteorological effects.



One-minute matrix contains ~ 70-80 thousand events



The basic atmospheric effects

Barometric effect is the anticorrelation of cosmic ray intensity with the pressure at the observation level.

Temperature effect is caused by changes of the temperature at all altitudes of the atmosphere.

Corrections for barometric and temperature effects:

$$M^{corr}\left(\theta,\varphi,t,\Delta t\right)=M\left(\theta,\varphi,t,\Delta t\right)+\Delta M_P(\theta,t,\Delta t)+\Delta M_T(\theta,t,\Delta t)$$

where θ and φ are zenith and azimuth angles for matrix cell centers; $M(\theta,\varphi)$ is the number of reconstructed events in a cell (θ,φ) of the matrix M; ΔM_T and ΔM_P are corrections for temperature and pressure effects.

$$\Delta M_P(\theta,t,\Delta t)=B(\theta)\cdot(P(t,\Delta t)-P_0)$$

P is the current pressure at registration level, P_0 = 993 mbar is the averaged over a long period pressure at the registration level, $B(\theta)$ are barometric coefficients.

$$\Delta M_T(\theta)=M_0(\theta)\cdot\sum_i W_T(h_i,\theta)\Delta T(h_i)\Delta h_i\ /100\%$$

$W_T(h,\theta)$ are differential in altitude temperature coefficients (DTC), $\Delta T(h)=T_{SMA}(h)-T(h)$ is the change of the temperature, h is the atmospheric depth, Δh = 0.05 atm, $T(h)$ is the current temperature profile of the atmosphere, $T_{SMA}(h)$ is the temperature profile for standard model of the atmosphere.

Information about temperature profile of the atmosphere

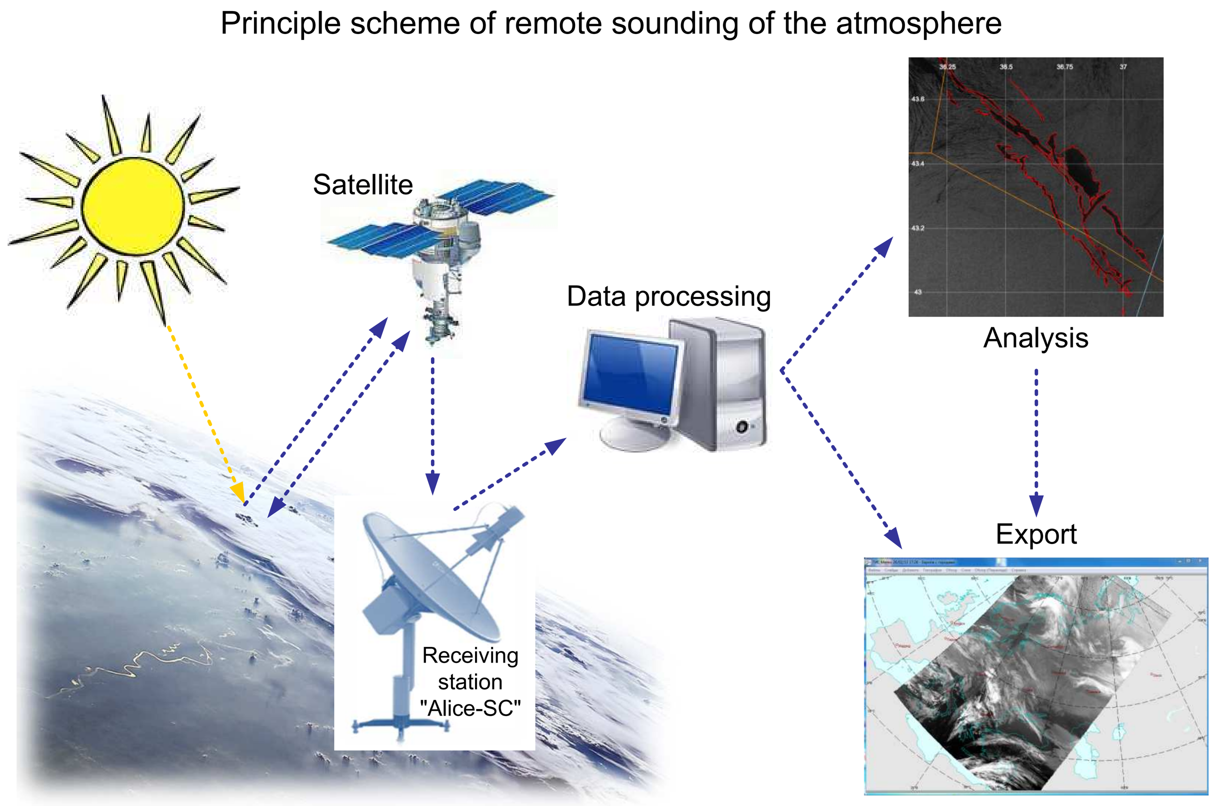
Information from meteorological balloon flights: Central Aerological Observatory (Russia, Dolgoprudny). Temperature profile is measured by meteorological balloons only two times a day: 00:00 and 12:00 UT. Unfortunately, sometimes launches of meteorological balloons do not carried out, or balloons do not raise high enough.

Weather forecasting models of the atmosphere: numerical forecasting model of atmosphere GDAS (The Global Data Assimilation System). GDAS output data are available the 4 times a day (at 00, 06, 12, and 18 UTC) for the whole globe (1 degree latitude-longitude grid) and for 23 constant pressure level (from 1000 to 20 mbar). Archive data (from 2005 year) are in open access.

Information from meteorological satellites: NOAA-18 and NOAA-19 are weather forecasting satellites run by National Oceanic and Atmospheric Administration (NOAA). They fly over the Moscow region on average 4 times a day with intervals from 10 minutes to 16 hours. Satellite data about atmosphere can be obtained with the help of the receiving station "Alice-SC", which was installed in the territory of MEPhI (on the roof of the experimental building of the Scientific and Educational Centre NEVOD) in November 2013.

Information from meteorological satellites

Principle scheme of remote sounding of the atmosphere



Available data of NOAA18 and NOAA19:

- Pressure levels at which the retrieved values are calculated (in hPa);
- Date and time of measurement;
- Latitude and longitude of current measurement point;
- Temperature retrieval profile (in K);
- Temperature guess profile (in K);
- Water vapor retrieval (in g/kg);
- Dew point temperature retrieval (in K);
- Total-column ozone;
- Cloud fraction;
- Cloud top pressure (in hPa);
- Cloud top temperature (in K);
- Clear/cloud index;
- Effective cloud amount;
- Total precipitable water (in mm);
- Additional data used for retrieval.

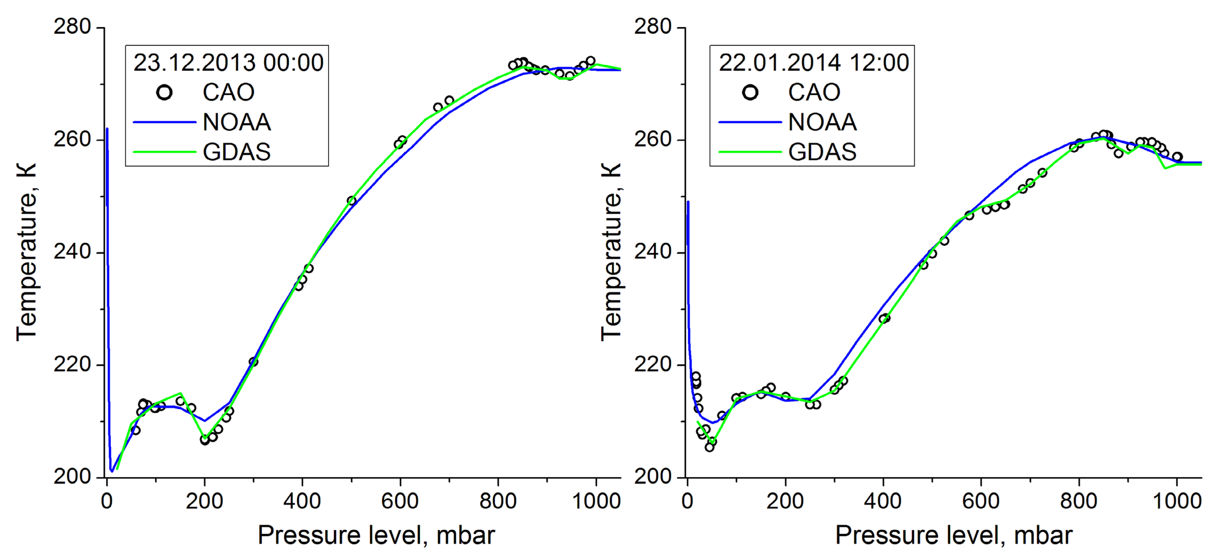
Receiving station "Alice-SC" on the roof of the experimental building

Map with marked points in which the measurements of atmosphere parameters were made by the NOAA-18 and NOAA-19 (points nearest by the distance to MEPhI are shown)

The comparison of GDAS and NOAA data with CAO data

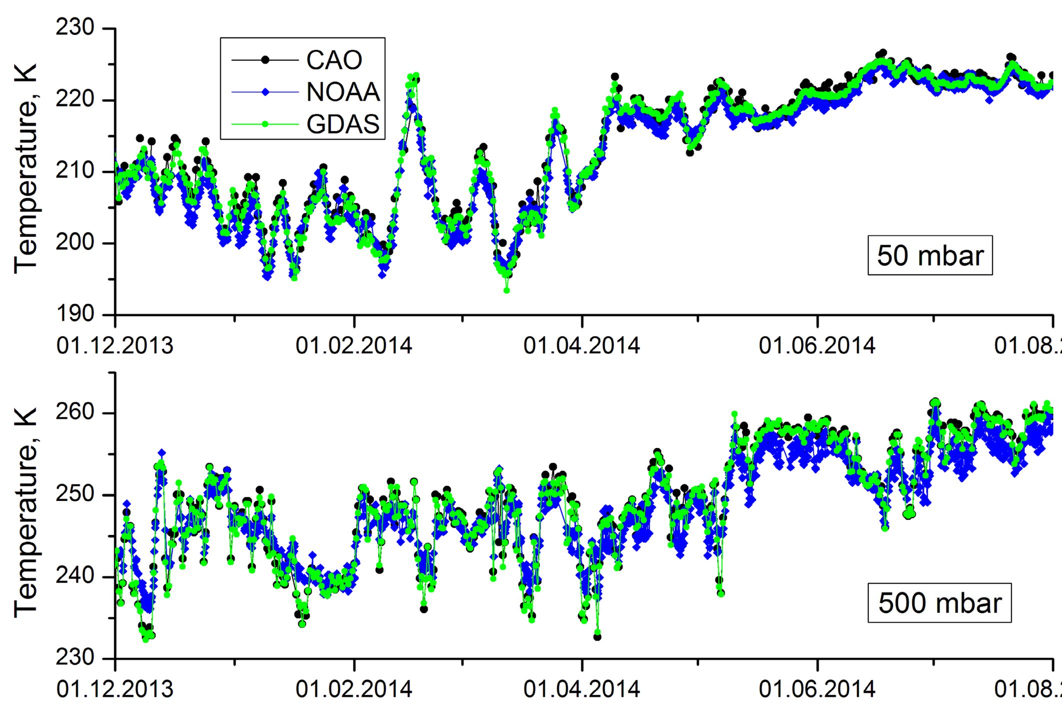
Vertical profiles of atmosphere temperature obtained from meteorological satellites NOAA and from forecasting model GDAS were compared with direct measurements by meteorological balloons. In the next figure results of two measurements are shown as an example: 23.12.2013 00:00 UTC (left) and 22.01.2014 12:00 UTC (right). Comparison shows very good agreement.

The dependence of air temperature on the pressure level



Dependence of atmosphere air temperature on time

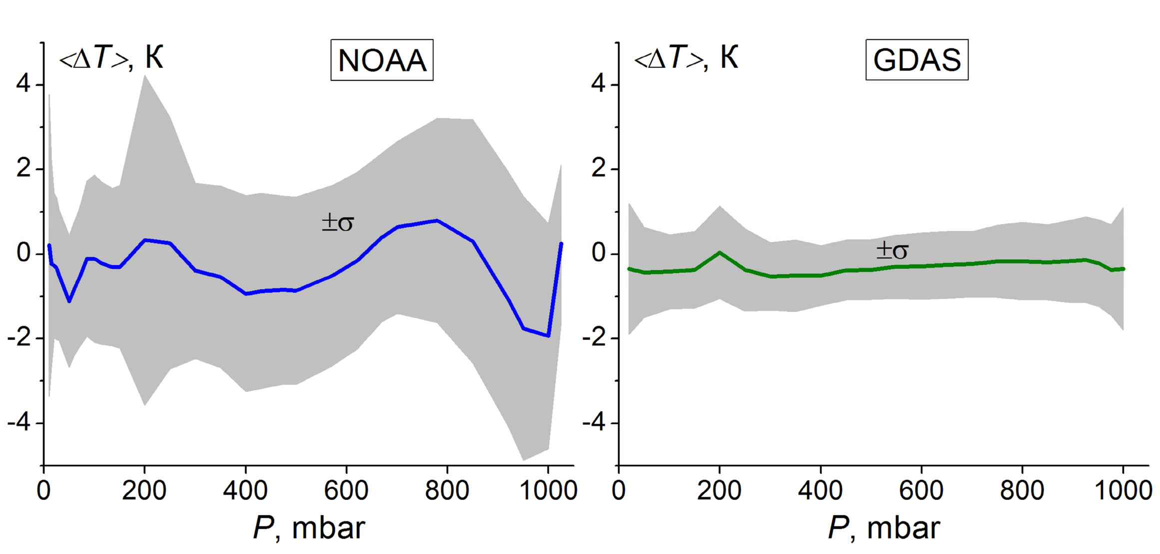
An example of dependence of atmosphere air temperature on time for two pressure levels (50 and 500 mbar) from alternative sources and from CAO data is shown in the figure below. Comparison also shows very good agreement.



Mean value of temperature difference <ΔT> between alternative sources and CAO data

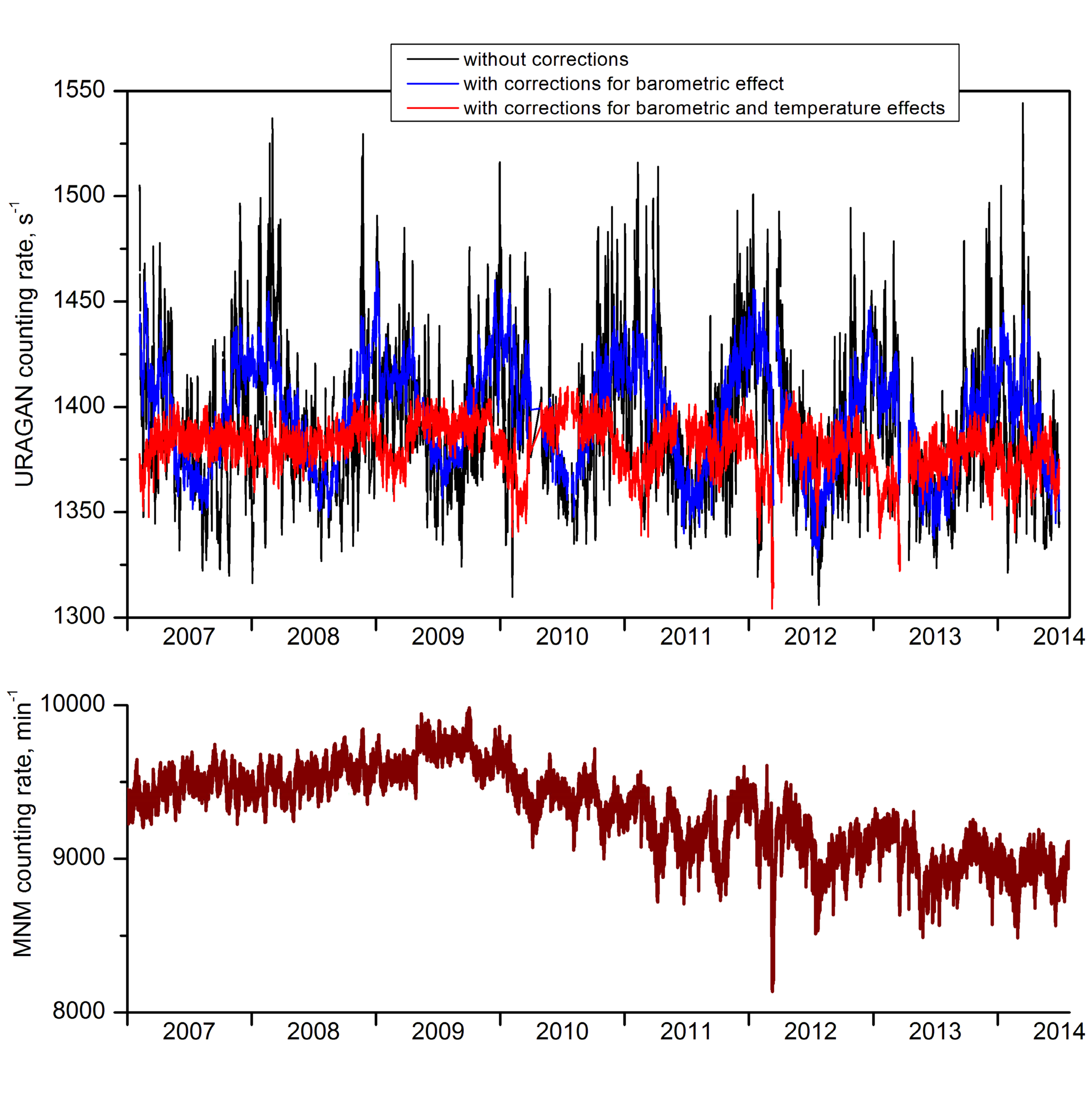
The dependence of mean value of the temperature difference between data of alternative source and CAO ($\Delta T(h,t) = T_{AS}(h,t) - T_{CAO}(h,t)$) on pressure level is shown in the left figure for NOAA and in tne right figure for GDAS. For most pressure levels $\langle\Delta T\rangle$ does not exceeding 1 K. So, the temperature profiles of these alternative sources can be used for correction of the muon hodoscope data for the temperature effect.

November 2013 - July 2014 2007–2013 years



Counting rate of the URAGAN hodoscope: 2007-2014

In the top figure, 1 h average counting rate of the URAGAN hodoscope without and with corrections for meteorological effects is shown. Barometric coefficients for URAGAN slightly depend on zenith angle and are about ~ 0.18%/mbar. After correction for barometric effect annual variations because of temperature effect (~ 8 %) become well visible. After correction for temperature effect, variations caused by extra-atmospheric processes appear. For comparison, in the bottom figure the counting rate of Moscow neutron monitor (MNM) is shown.



The vector of local anisotropy

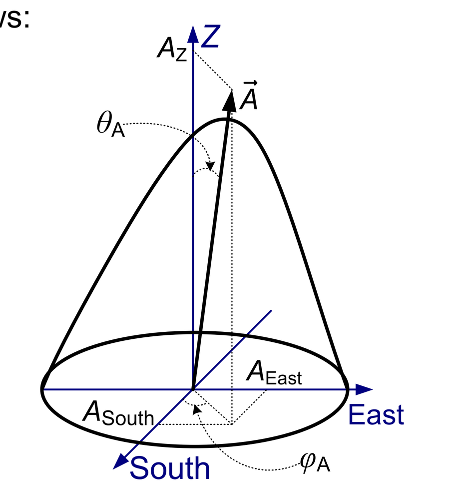
URAGAN allows to obtain the vectors of the particle arrival directions and we can use the vector sum. The summary vector normalized to the total number of muons (the vector of local anisotropy) will characterize the angular distribution of the detected particles. The projections of the vector of local anisotropy (A_{South}, A_{East}, and A_Z) by original matrix M data can be generally defined as follows:

$$A_{South}=\frac{1}{N}\sum_\theta\sum_\varphi M(\theta,\varphi)\cos\varphi\sin\theta\ ,$$

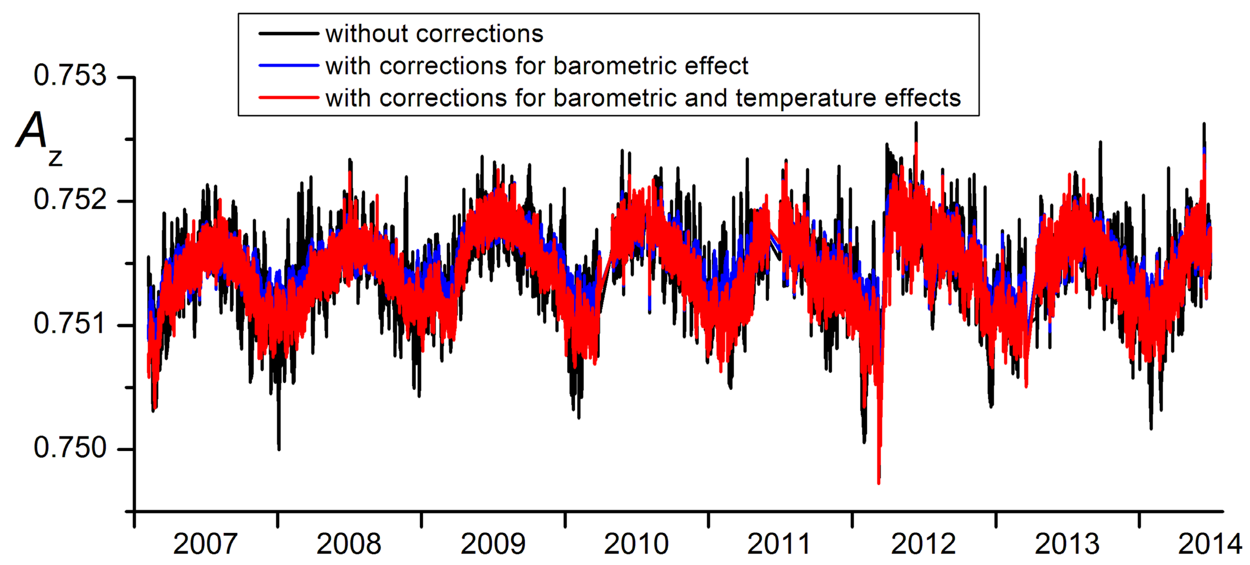
$$A_{East}=\frac{1}{N}\sum_\theta\sum_\varphi M(\theta,\varphi)\sin\varphi\sin\theta\ ,$$

$$A_Z=\frac{1}{N}\sum_\theta\sum_\varphi M(\theta,\varphi)\cos\theta\ ,$$

$$N=\sum_\theta\sum_\varphi M(\theta,\varphi)\ ,\quad A=\sqrt{A_{South}^2+A_{East}^2+A_Z^2}\ .$$

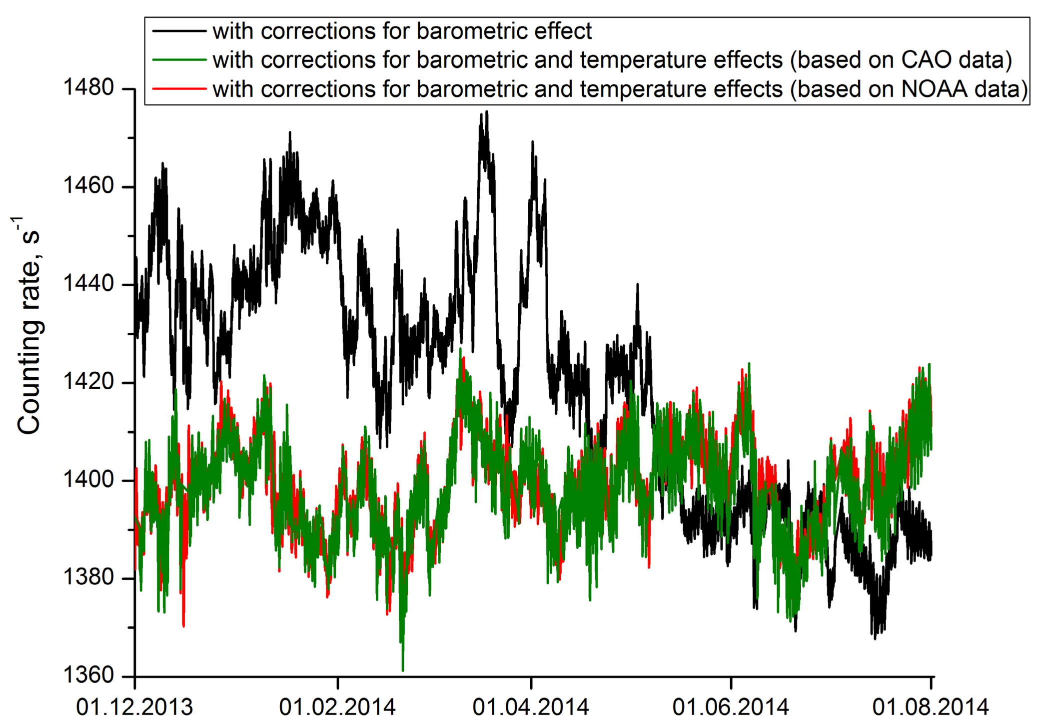


N is the total number of events in a given range of angles; A_{South} is the projection on the north–south axis, A_{East} is the projection on the west–east axis; and A_Z is the vertical projection. Horizontal projections A_{South} and A_{East} are calculated using the original matrices M without corrections for barometric and temperature effects. These corrections are annihilated when the values from the opposite azimuthal angles are added, while the use of corrections in the total value (N) has almost no effect on the result. The A_Z value was calculated using the values of the $M(\theta,\varphi)$ matrix with corrections for barometric and temperature effects. As you can see, annual variations after correction do not disappear.



URAGAN counting rate with temperature effect correction based on CAO and NOAA data

Comparison of correction for temperature effect with the help of satellite data with correction based on data from direct measurements shows good agreement. Satellite data can be used for the fast preliminary correction.



Conclusion

- Data of discussed alternative sources of the atmosphere temperature profile are sufficiently reliable for the correction of the muon hodoscope counting rate for the temperature effect.
- Additional information from GDAS can be used for temperature effect correction for previous years (since 2005).
- Satellite data can be used for the preliminary correction in the mode close to the on-line (with a delay of only a few hours).

The research has been performed in Scientific and Educational Centre NEVOD with the support of the Ministry of Education and Science of the Russian Federation (RFMEI59114X0002) and the grant of the Leading Scientific School NSh-4930.2014.2.