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Seasonal variations of the muon flux seen by muon telescope MuSTAnG

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Abstract. A research of the temperature effect of the muon cosmic ray (CR) component on the MuSTAnG super telescope data (Greifswald, Germany) for the whole period of its work (from 2007) was carried out. The primary hourly telescope's data were corrected for the temperature effect, using vertical temperature atmospheric profile at the standard isobaric levels obtained from the GFS model. To estimate the model accuracy and applicability the air sounding data for some years were used.

1. Introduction

A research of the temperature effect of the muon CR component on the MuSTAnG (**Mu**on **S**pace Weather **T**elescope for **An**isotropies) super telescope data (**G**reifswald, Germany) [1] for the whole period of its work (from 2007) was carried out. The MuSTAnG super telescope is a part of the global muon detectors network. This article continues a series of papers [2-4] on try-out the method of exclusion the temperature effect from the data of muon detectors of different geometry all over the world with the temperature data of the GFS model. Global meteorological models almost solved the problem of the lack of atmosphere temperature sounding data near the detector's location. The model's data allows solve the problem of the temperature effect of the CR muon component both retrospective and in real time.

2. Method of accounting the temperature effect of the muon component

To account for the temperature effect of the muon CR component the universal integral method [5] suitable for all types of the detectors was developed:

$$\left.\frac{\delta N}{N}\right|_T = \int_0^{h_0} W_T^{\mu}(h)\cdot\delta T(h)\cdot dh \qquad (1)$$

where $\delta N/N$ - variations due to the temperature effect, $\delta T(h)$ - temperature variations of the atmosphere, determined as a divergence of the running temperature profile and the temperature profile in the base period *B*: $\delta T(h) = T(h) - T_B(h)$. Densities of the temperature coefficients $W_T^{\mu}(h)$ have a dimension $\%/^{\circ}K\cdot atm$, and they are calculated for different depths and angles. The integral method

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(1) makes it possible to calculate the temperature effect with high accuracy, determining mostly by a precision of the temperature coefficient densities $W_T^{\mu}(h)$.

The formula (1) can be written as:

$$\left.\frac{\delta N_{\mu}}{N_{\mu}}\right|_{Temp} = \int_0^{h_0} W_T^{\mu}(h)\delta T(h)dh = \int_0^{h_0} W_T^{\mu}(h)dh \cdot \frac{\int_0^{h_0} W_T^{\mu}(h)\delta T(h)dh}{\int_0^{h_0} W_T^{\mu}(h)dh} = \alpha_T \cdot \delta T_{eff} \tag{2}$$

Here the temperature coefficient α_T (%/degree) and the effective temperature:

$$\alpha_T = \int_0^{h_0} W_T^{\mu}(h)dh \tag{3}$$

$$T_{eff} = 1/\alpha_T \cdot \int_0^{h_0} W_T^{\mu}(h)T(h)dh \tag{4}$$

Thus defining the effective temperature T_{eff} (4) we can experimentally determine the temperature coefficient α_T from the correlation (2). To calculate the temperature coefficient α_T for the MuSTAnG muon telescope we used the data for unperturbed 2009 in solar minimum. And then the obtained α_T was used for the muon component temperature effect calculation to the entire data series.

3. Super telescope MUSTANG

In recent years, several new super telescopes were built. One of which is the MuSTAnG - multidirectional muon detector of the University of Greifswald [6]. The super telescope (100 m above sea level, pressure 1013 mb) has two rows of 16 (4x4x2) plastic scintillation counters with a total area of 4 m^2 separated by 5 cm of lead. MuSTAnG runs stably from the end of 2007.

4. Temperature data

In this work the data of the Global Forecast System (GFS) temperature model representing by the National Centers for Environmental Prediction — NCEP (USA) has been made use of [7]. The model output data are temperature at the 17 isobaric levels: observation level, 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10 hPa for four times 00, 06, 12 and 18 hours every day. The data are interpolated on the grid of 1°×1° resolution. To obtain hourly data the interpolation by the cubic spline function [8] was carried out. Real time mode is provided by a forecast for a current day. Also, to estimate the applied model accuracy and applicability the air sounding data for some years were used. As sounding is carried out twice a day, so to get hourly data interpolation of the measured data was carried out.

5. Results

Correction of the MuSTAnG data for the temperature effect was carried out relatively to the base period of 2009, which is close to the mean-average temperatures for the entire period under consideration.

5.1. Verification of the model temperature data accuracy.

To estimate the accuracy of the GFS model's output data for Greifswald, an additional comparison of the temperature distribution in the atmosphere from the GFS model with the experimentally measured values for summer-winter and for spring-autumn periods of 2009 was carried out. Four random days for each season were selected and the vertical temperature profiles from measurements (points) and from GFS model (lines) for these days were built (figure 1). As it is seen from figure 1 the accuracy of the model does not exceed a few degrees for all isobaric levels.

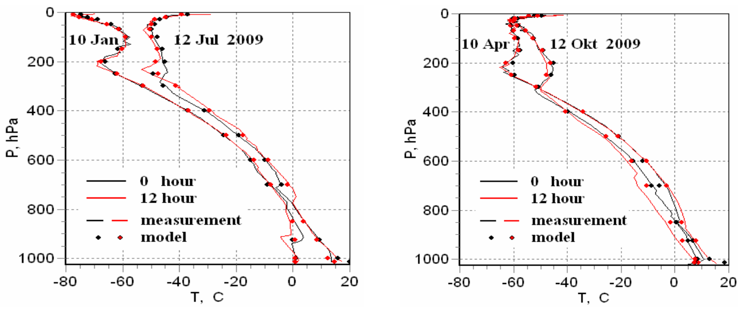

Figure 1. Comparison of GFS temperature profile with sounding measurements for Greifswald, summer-winter (left) and spring-autumn (right) 2009.

5.2. Calculation of the temperature effect of the muon component.

To determine the temperature coefficient as described above, first in accordance with (4) on the base of the model temperature data for 2009 the effective temperature T_{eff} is calculated. The densities of the temperature coefficients used for MuSTAnG, were given in [9]. Then, from the correlation (2) the experimental temperature coefficient α_E %/C is determined as the regression coefficient. The values of T_{eff}. and α_E are calculated separately for the vertical (0 º) and for each of the three angles of the particles arrival (30 º, 39 º and 49 º). All the data obtained are listed in table 1. For the control theoretical temperature coefficients α_T are calculated by the formula (3), and then the corresponding experimental and theoretical temperature coefficients are compared. From the obtained relations α_T / α_E (see table 1) we can conclude that the densities of the temperature coefficients W_T calculated before and well-suited for other ground-based telescopes (e.g., Nagoya), are somewhat different for MuSTAnG. Rather this is due to the peculiarities of the MuSTAnG (high latitude, special ceilings, geometry). After the corresponding adjustment of the temperature coefficients densities W_T, the theoretical temperature coefficients α_T were recalculated again. These corrected values are given in table 1. After adjusting theoretical and experimental temperature coefficients are minimally different.

Table 1. Results for MuSTAnG

angle	direction	N_c, Hz	ρ ±0.003	T_{eff}, C	α_E±0.004, %/C	α_T / α_E Before Correction	α_T, %/C
0º	**GFv0**	68.4	-0.965	-25.55	-0.4386	0.6749	-0.4390
30º	**GFn1**	28.9	-0.963	-25.88	-0.4072	0.7307	-0.4140
	GFs1	28.9	-0.965	-25.88	-0.4140	0.7187	-0.4140
	GFe1	28.4	-0.968	-25.88	-0.4196	0.7091	-0.4140
	GFw1	28.8	-0.965	-25.88	-0.4174	0.7129	-0.4140
39º	**GFne2**	13.3	-0.963	-26.15	-0.3868	0.7735	-0.3980
	GFnw2	13.1	-0.963	-26.15	-0.3982	0.7514	-0.3980
	GFse2	13.0	-0.969	-26.15	-0.4116	0.7269	-0.3980
	GFsw2	12.8	-0.966	-26.15	-0.4141	0.7225	-0.3980
49º	**GFn3**	9.9	-0.958	-26.81	-0.3882	0.7815	-0.3880
	GFs3	10.0	-0.969	-26.81	-0.3883	0.7813	-0.3880
	GFe3	9.9	-0.967	-26.81	-0.3857	0.7865	-0.3880
	GFw3	9.8	-0.963	-26.81	-0.4056	0.7479	-0.3880

There are effective temperature (T_{eff}), experimental (α_E) and calculated (α_T) temperature coefficients, the correlation coefficient (ρ) and the average muon rates N_c for MuSTAnG telescope in the table 1.

Calculating thus the temperature coefficients for different directions, we can determine the temperature effect by the formula (2). These calculations were made for the entire data series from 2007. The results for the vertical are shown in figure 2. Here, the upper curves show the corrected for temperature effect as described above MuSTAnG data, which are compared with neutron monitor data of Rome. Taking into account that the effective rigidity of the vertical telescope MuSTAnG higher than that of the Rome neutron monitor, it can be noted quite synchronous variations behavior of these two detectors since 2009. In the first phase of the telescope MuSTAnG running an instrumental drift is observed. At the bottom of Figure 2 variations of the vertical Nagoya telescope are compared with variations according to the Thailand neutron monitor for the same period. Very good agreement demonstrates close values of the effective rigidities of the two detectors. One might add that the Nagoya telescope is one of the most stable operating telescopes today.

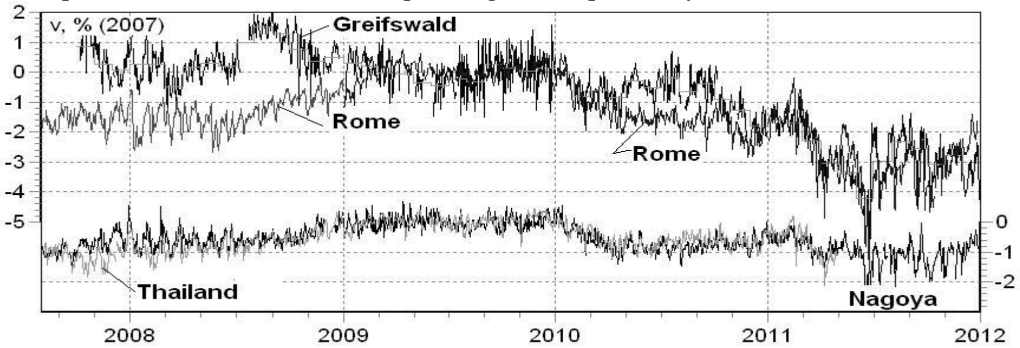

Figure 2. Top: corrected for the temperature effect MuSTAnG telescope's (black curve) and Rome neutron monitor (grey curve) variations. Bottom: variations of the vertical Nagoya telescope (black curve) and Thailand neutron monitor (grey curve)

6. Conclusions

The analysis have shown the stability of the MuSTAnG telescope since it started, maybe with the exception of the initial debugging period. Corrected for temperature variations of MuSTAnG (vertical) are in good agreement with the neutron monitor variations of Rome. Even better agreement is observed for the vertical direction of the Nagoya telescope and the neutron monitor of Thailand. For MuSTAnG the densities of the temperature coefficients were experimentally adjusted and the temperature coefficient was determined.

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