Temperature effect of muon component and practical questions of its account in real time

M. Berkova[1,2], A. Belov[1], E. Eroshenko[1], V. Yanke[1]

[1] *Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation RAS (IZMIRAN), Moscow, Russia; yanke@izmiran.ru*

[2] *Institute of Applied Mechanics RAS (IAM RAS), Moscow, Russia*

Abstract

The method of real time practical account of temperature effect of cosmic ray muon component registering by the muon telescopes of different geometry has been developed. Wide use of muon detectors in the process of study of cosmic rays variations is restrained by presence of the big temperature effect inherent to the muon component of secondary cosmic rays. To exclude such effect the data of aerologic sounding close to the detector location are necessary. More often such data are absent in general and it is impossible to restore them in retrospective, or the soundings aren't carried out regularly. The problem can be solved by using the results of meteorological models. On the base of generalized meteorological data models which makes it possible to obtain the temperature profile of the atmosphere in any place and at any time are developed. It provides a way to allow for the temperature effect in real time. In the paper 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 (http://www.nco.ncep.noaa.gov/pmb/products/gfs/). GFS model makes it possible to obtain both retrospective and prognostic data. By using this meteorological model namely vertical temperature profiles for the standard isobaric levels for the hourly data of muon telescopes the method of accounting the temperature effect in real time has been developed. The method developed has been used for processing of the data accessible in real time. It is the data of Nagoya telescope (17 directions), Yakutsk telescope on the sea level (3 directions), Yakutsk telescope on the 7 mwe level (3 directions), YangBaJing telescope in Tibet (9 directions), and Moscow telescope (17 directions). Comparison between the data of the temperature profile obtained via direct sounding and the data obtained via GFS model let us assert that proposed approach decides the problem well. The discrepancy between the forecast results for current time and the results of GFS model is several degrees that is quite sufficient for the required accuracy.

Free from the temperature effect data for all the telescopes are available to address: ftp://cr0.izmiran.rssi.ru/COSRAY!/FTP_TEL/ .

1 Introduction

Wide use of muon detectors in the process of study of cosmic rays variations is restrained by presence of the big temperature effect inherent to muon component of secondary cosmic rays. To exclude such effect the data of aerologic sounding close to the detector location are necessary. Aerologic sounding should be carried out regularly and with proper time resolution. The absence of sounding data results in partial data correcting of the muon telescopes world network (Nagoya, Hobart, Sao Martinho и Kuwait) [1]. Therefore it is more efficiently to use the data of the global atmosphere models instead of the experimental vertical temperature profile. Such models are developed on the base of generalized meteorological data and make it possible to obtain the temperature profile of the atmosphere in any place and at any time [2].

Such approach is realized in a number of papers [3-6, 16]. So, in the paper [3] the temperature effect of the cosmic rays neutron component was studied with the assistance of such meteorological models data. In the paper [4] the retrospective hourly data for 17 directions of Nagoya telescope, for 3 directions of Yakutsk telescope, forYakutsk and Beijing ionization chambers for the whole observation period were corrected by the integral method having used vertical temperature profiles of such meteorological model on the standard isobaric levels. The temperature effect of the muon detectors of the South Pole neutrino observatory was studied in the paper [5]. Using approximate approach for the effective level of generation and mass-average temperature the temperature effect for the underground detectors (+0.901 %/C) and for the ground-level ones (-0.360%/C) were received. In the paper [6] temperature effect of MINOS observatory muon detectors registering muons with the energy >700 GeV was studied. The temperature coefficient was obtained as +0.874 ± 0.009 %/C.

At the present time such atmospheric models are already working in real time and one of the goals of this work is the development of mathematical tools and software for query of the models data and exclusion the temperature effect in real time. Another goal is comparison of temperature effect exclusion methods: integral method and alternative approximate ones.

1 Temperature effect of the muon component

Temperature effect of the muon component is resulted by decay and interaction of pions and muons with atmospheric nuclei. With heating and of course expansion of the atmosphere the muon flux is both decreased (negative temperature effect) and increased due to additional pion decay (positive temperature effect). At the energies typical for the ground-level detectors the negative temperature effect is prevailed. And at the energies typical for the underground detectors the positive temperature effect is prevailed as the decay probability of high energy muons is small. To account the temperature effect the integral method with the desired precision was developed. It requires involving hourly data of the vertical atmosphere temperature profile, but it is often unsolvable problem. However there are alternative empiric methods.

The method of effective level of generation was developed before the rest, but it is in use to the present day. This method is based on the assumption that muons are generally generated at the isobaric level usually taking for 100 mb, and its height is changing with change of the atmosphere temperature. The muon component change due to [7, 8] is correlated with the change of the generation level height δH and with the air temperature of this layer δT, i.e.

$$\delta I_T = \alpha_H \delta H + \alpha_T \delta T, \quad (1)$$

where α_H (%/km) is so-called decay factor – negative effect, and α_T (%/C^0) – positive temperature coefficient. As a rule the height of 100 mb level is measured twice a day. If one knows the height relation *T(h),* then the height *H* is determined by the barometric formula as

$$P = P_0 \exp(-\frac{\mu g}{R}\int_0^H \frac{dh}{T(h)}). \quad (2)$$

Here, P_0 – pressure at the observation level, P - pressure at the height H, μ – gas molecular weight and R - universal gas constant. Nevertheless this method requires atmospheric sounding. So it is logical to apply the clear and developed integral method which makes it possible to exclude the temperature variations entirely.

The integral method has been developing by many authors, but it is presented in detail in the papers [9, 10]. Variations due to the atmospheric temperature effect are determined by the integral method as

$$\delta I_T = \int_0^{h_0} \alpha(h) \cdot \delta T(h) \cdot dh, \quad (3)$$

where δI_T - variation due to cosmic rays temperature effect, $\delta T(h)$ - temperature variations determining as current temperature deviation from the base period temperature B: $\delta T(h) = T_B(h) - T(h)$. Temperature coefficients densities $\alpha(h)$ of different detectors were calculated and in this work $\alpha(h)$ were the same as in our previous work [4].

The method of mass-average temperature is based on the atmosphere mass-average temperature determination. As the temperature coefficient density $\alpha(h)$ for the ground-level detectors are not grossly change with the atmospheric depth h, the average $\overline{\alpha}(h)$ can be carried out behind the integral sign, i. e.

$$\delta I_T = \overline{\alpha} \int_0^{h_0} \delta T(h) \cdot dh = \overline{\alpha} \sum_{n=1}^{Lskin} \cdot \frac{\Delta h_n}{h_0} \cdot \overline{T_n} = \overline{\alpha} \cdot \delta T_m , \qquad (4)$$

where T_m - mass-average temperature. Here the temperature within each layer is assumed to possess some average value T_n^*, L_{skin} - surface layer number. It was noted in the work [11] and was used in a number of next works [5,6,12]. For calculating of the mass-average temperature the atmospheric sounding data are required. However the mass-average temperature can be obtained by experiment (without aerological data) by solving a set of spectrographic equations of variations of several neutron and muon detectors [11].

2 Temperature data

In meteorology on the base of generalized data models enabling to obtain the temperature profile of the atmosphere both retrospective and prognostic are built. In this work the temperature model data of the Global Forecast System (GFS) representing by the National Centers for Environmental Prediction — NCEP (USA) has been made use of [13]. GFS model makes it possible to obtain both retrospective and prognostic data of 3D temperature field. GFS model includes the full parametrization set of the physical processes [14]. Real-time processing is providing by the current day forecast.

The accuracy of such data is about several degrees depending on isobaric level. In Fig. 1 there is a comparison of atmosphere temperature distribution obtained from the model and from the direct measurement at the Moscow meteostation (Meteo-27612). Analysis shows that remainder distribution of the experimental data and the model data is approximately governed by the Gaussian distribution with good enough value of σ=0.26 C°. The most error should be expected for the observation level as the temperature is more changeable in the lower layer. So, for the remainder of the hourly experimental and model data in the surface layer for Moscow σ=2.8 C°. Fig. 2 shows the possible errors for different levels.

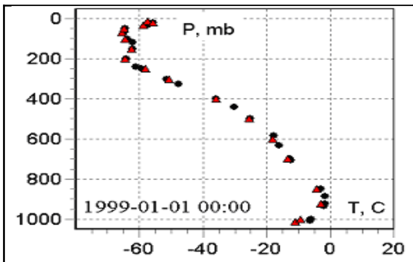


Fig. 1. Vertical temperature distribution in atmosphere for Moscow: model (red triangles) and measured (black circles).

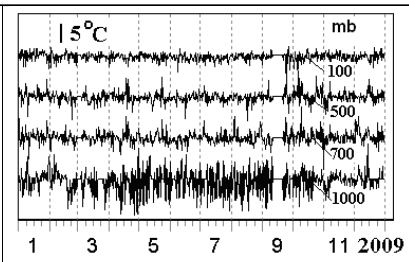


Fig. 2. Difference between experimental and model temperature data for Moscow station.

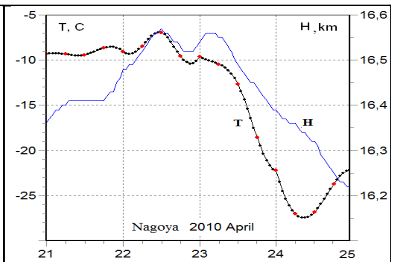


Fig. 3. Daily temperature (500 hPa isobaric level) at the height of the generation level 100 hPa (red points – nodal points of cubic spline function)

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°x1° resolution. To obtain hourly data the interpolation by the cubic spline function [15] on five nodal points is carried out. In Fig. 3 there is an example of interpolation for daily temperature at the 500 hPa isobaric level and 100 hPa height of the generation level. To correct detectors real-time data for the temperature the vertical temperature profile received as a forecast for a current day was used.

At present data of the muon telescopes world network are corrected for the temperature effect by the method of effective level of generation [1]. For this purpose the sounding data of the effective height of the 100 hPa generation level are received twice a day from the nearest airports, and then they are interpolated to get hourly data. Due to absence of sounding data only 25% of the telescope data were corrected by such method. Besides, not full correlation model (1) allowing for only the first summand was used, and it increases errors especially for the winter time.

We have developed a real-time method of temperature effect accounting for the hourly data of muon telescopes with the help of temperature data of the Global Forecast System (GFS) model. The developed method was applied for processing of accessible in real-time data of the next telescopes: Nagoya (17 directions), Yakutsk on the sea level (3 directions), Yakutsk on the 7 mwe level (3 directions), YangBaJing on Tibet (9 directions) and Moscow (15 directions). Comparison of the results obtained with the sounding temperature data and with the GFS model temperature data allows to assert that the approach proposed solves the problem well. A discrepancy between results of the current moment forecast and results of the GFS model is not more then several degrees on the sea level that is quite enough for the required accuracy. Results for the vertical temperature profile and temperature corrections are accessible at the address ftp://cr0.izmiran.rssi.ru/COSRAY!/FTP_METEO/ , and all telescopes data without temperature effect are at the address ftp://cr0.izmiran.rssi.ru/COSRAY!/FTP_TEL/. A query about temperature distribution is carried out at the beginning of every day, realizing the forecast for current day. Temperature corrections in integral approximation and in mass-average temperature approximation are calculated also as a forecast taking account of the telescopes geometry. All data are arranged for hourly and daily average interval.

Table 1. Muon telescopes of the world network.

name	**k**
Nagoya	17
Hobart	13
Sao Martinho	17
Kuwait	13
Yakutsk, sea level	3
Yakutsk, 7 mwe level	3
YangBaJing, Tibet	9
Novosibirsk	5
Moscow	15
Yerevan 2000	9
Greifswald	9
Mawson	5

3 Data of continuous cosmic ray monitoring

There were four muon detectors accessible in real-time: scintillation supertelescopes Nagoya (17 directions) and YangBaJing (9 directions), counter telescopes Yakutsk on the sea level (3 directions) and Yakutsk on the 7 mwe level (3 directions), counter telescope Moscow (15 directions). Besides, there were data of the counter telescope Novosibirsk (5 directions).

4 Results

The result of excluding the temperature variations by the method described above for all telescopes accessible in real-time is presented in Fig. 4. Hourly variations were under

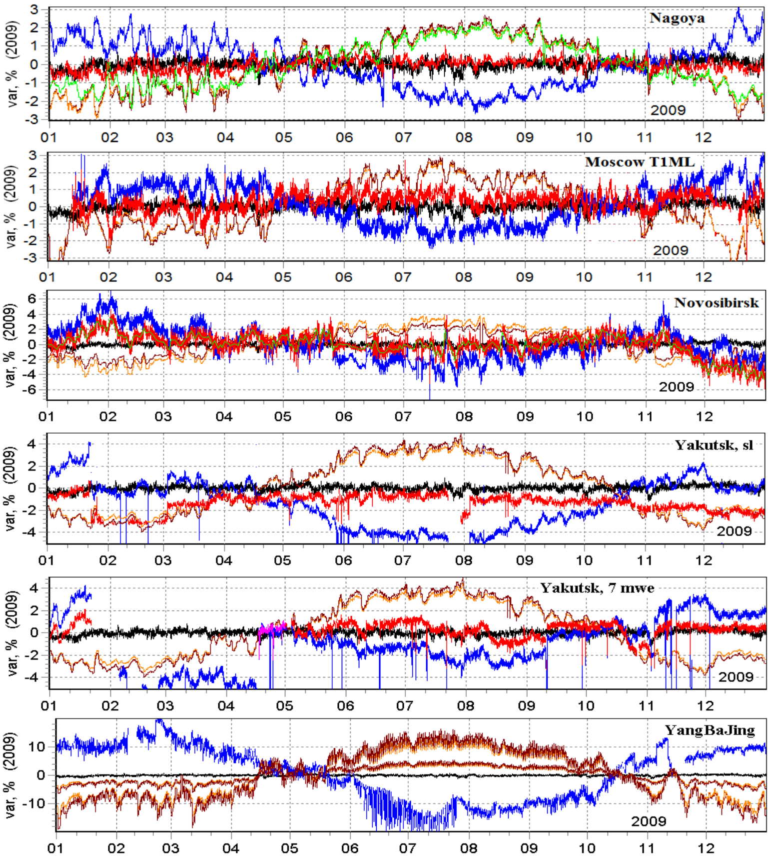
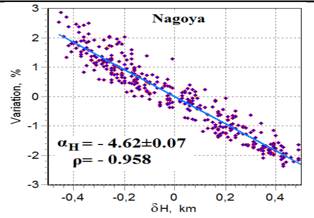
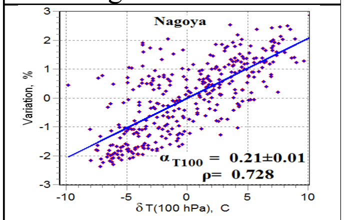


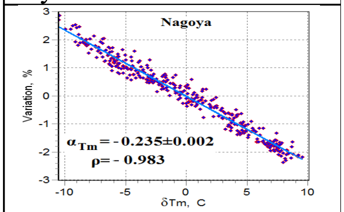
Fig. 4.



a) with 100 hPa level height



b) with temperature T_{100} of the lower 100 hPa layer



c) with atmosphere mass-average temperature T_m

Fig. 5. Correlation curve of the muon telescope variations (Nagoya, vertical)

consideration relative to the 2009 base year. For every figure there are original uncorrected data for the vertical direction (blue curve), correction for the temperature effect by the integral method (brown curve) and correction for the temperature effect by the mass-average temperature method (orange curve). Data corrected by the integral method are red and they are compared with variations of the equatorial neutron monitor Thailand (R_c=17 GeV). These results allow to conclude:

1) For all stations correction for the temperature effect calculated by the mass-average temperature method is very good approximation, and it virtually coincides with integral method correction. For Nagoya telescope there is correction calculated by the method of effective generation level (green curve). The most discrepancy is in winter.

2) Corrected Nagoya telescope data (vertical) are in good agreement with variations of the neutron monitor Thailand (black curve).

3) The rest of the telescopes concerned are in not so good agreement. First of all, this is due to their worse statistics and unstable work. Maybe some more precise of the temperature coefficient densities allowing for details of the detector's geometry is necessary.

4) There are very big season variations of the Tibet muon telescope. They are 4-5 times more then variations of other detectors concerned. Maybe there is an additional local instrumental temperature effect.

Let's check accounting accuracy of temperature effect by the alternative methods. In Fig. 5 there are a correlation curve of the vertical muon telescope variations with 100 hPa isobaric layer height and a correlation curve of the vertical telescope variations with the temperature within 100 hPa layer. It's clear that 100 hPa isobaric layer is a matter of convention. As the final result it is determined by the telescope effective energy. Fig. 4 shows that the method of effective generation level for the Nagoya telescope doesn't exclude temperature variations completely. Perhaps the model should be complicated by including a term allowing for temperature change within the 100 hPa isobaric layer according to (1).

The mass-average temperature method for the sea-level detectors at least gives far better results in spite of the fact that all atmosphere layers are allowed for with equal weights (4). The experimental temperature coefficient for the vertical telescope in Fig. 5c coincides within the errors with the calculated coefficient and it is characterized by strong correlation.

5 Conclusions

1) The vertical atmosphere temperature profiles obtained from the atmosphere model enable to exclude the temperature effect from the hourly observable data of the muon telescopes in real-time with the required accuracy.
2) Corrections for the temperature effect for all the muon telescopes data digitally available in real-time were get by the method described above. The original and corrected data are available at address ftp://cr0.izmiran.rssi.ru/CosRay!/FTP_TEL/.
3) The hourly vertical atmosphere temperature profile for all the points concerned are at address ftp://cr0.izmiran.rssi.ru/CosRay!/FTP_METEO/. Here corrections for the temperature effect for all telescopes of the world network with taking account of the telescopes geometry are arranged in real-time. All the corrections are relative to the base 2009 year.
4) Besides, the Internet-project with the detailed description of the world network of the muon detectors and their main characteristics is at the address http://cr0.izmiran.ru/GlobalMuonDetectorNetwork.

Acknowledgements

This work is partly supported by Program No 6 BR of the Presidium RAS "Neutrino Physics and Astrophysics" and Acknowledgements to http://cr0.izmiran.ru/ThankYou/main.htm

Literature

[1] *Okazaki Y., Fushishita A., Narumi T. at al.* Drift effects and the cosmic ray density gradient in a solar rotation period: First observation with the Global Muon Detector Network (GMDN). // The Astrophysical Journal. July, 2008. № 681. P. 693–707.
[2] NOAA, http://spidrd.ngdc.noaa.gov/class или http://phoenix.wdcb.ru/class или http://ideas.ngdc.noaa.gov/ideas.
[3] *Belov A.V., Dorman L.I., Gushchina R.T., Yanke V.G.* Temporal and latitude dependence of the temperature effect for neutron component of cosmic rays. // Proc. 24-th ICRC., Rome, Vol. 4, pp. 1141-1144, 1995;
[4] *Berkova M., Belov A., Eroshenko E., Yanke V.* Temperature effect of the muon component of cosmic ray and practical possibilities its accounting. // Proceedings of the 21st ECRS. 123 - 126. 2008.
[5] *Tilav S. at al. for the IceCube Collaboration*. Atmospheric Variations as observed by IceCube. // Proceedings of the 31st ICRC, ŁODZ, 2009.
[6] *Adamson P. at al. for the MINOS Collaboration*. Observation of muon intensity variations by season with the MINOS far detector. // Phys.Rev. 2010. D81:012001.
[7] *Blackett P.H.* On the instability of the barytron and the temperature effect of cosmic rays. // Phys. Rev. 1938. V.54. P. 973-974.

[8] *Duperier A.,* A New Cosmic-Ray Recorder and the Air Absorption and Decay of Particles. // Terrest. Magn. Atmospheric Electricity. 1944. № 49. P. 1-7; *Duperier A.,* The Meson Intensity at the Surface of the Earth and the Temperature at the Production Level. // Proc. Phys. 1949. Soc. 62**.** P. 684-696.

[9] *Dorman L.I.* Meteorological effects of cosmic rays. M., Nauka, p.211, 1972.

[10] *Maeda K. and M. Wada.* Atmospheric temperature effect upon the cosmic ray intensity at sea level. // J. Sci. Res. Inst., Tokyo. 1954. 48. P. 71-79; *K. Maeda:* Journal Atm. Ter. Phys. 1960. № 19. P. 184.

[11] *Dvornikov V.M., Krestyannikov Yu.Ya., Sergeev A.V.* Determination of the mass-average temperature on the cosmic ray intensity data. Geomagnetism and aeronomy. 1976, V. 16, № 5, pp. 923-925.

[12] *Yanchukovsky V., Filimonov G., Hisamov G.* Atmospheric Variations in Muon Intensity for Different Zenith Angles. // ISSN 1062-8738, Bulletin of the Russian Academy of Sciences: Physics. 2007. 71. №. 7. P. 1038–1040.

[13] NCEP, http://www.nco.ncep.noaa.gov/pmb/products/gfs/; weather server, http://esse.wdcb.ru; real-time temperature atmosphere profile, http://phoenix.wdcb.ru

[14] NOAA, http://wwwt.emc.ncep.noaa.gov/

[15] *G.E.Forsythe, M.A.Malkolm, C.B.Moler.* Computer methods for mathematical computations. M., Mir, 1980.

[16] *Shakiryanova I.P. at al.* Analysis of season variations of cosmic rays muon flux in LVD detector during 2001-2008. Proceedings of the 31th RCRC, Moscow, 2010