

Pressure and temperature effect corrections of atmospheric muon data in the Belgrade cosmic-ray station

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Abstract. We present results of continuous monitoring of the cosmic-ray muon intensity at the ground and shallow underground level at the Belgrade cosmic-ray station. The cosmic-ray muon measurements have been performed since 2002, by means of plastic scintillation detectors. The scintillator counts are corrected for atmospheric pressure for the whole period of measurements and, as well, for vertical temperature profile for the period of the last six years. The results are compared with other correction methods available. One-hour time series of the cosmic-ray muon intensity at the ground level are checked for correlation with European neutron monitors, with emphasis on occasional extreme solar events, e.g. Forbush decreases.

1. Introduction

The Belgrade cosmic-ray station, situated in the Low-level Laboratory for Nuclear Physics at Institute of Physics, Belgrade, have been continuously measuring the cosmic-ray intensity since 2002. The station is at near-sea level at the altitude of 78 m a.s.l.; its geomagnetic latitude is $39^{\circ} 32' N$ and geomagnetic vertical cut-off rigidity is 5.3 GV. It consists of two parts: the ground level lab (GLL) and the underground lab (UL); the UL is located at a depth of 12 metres below the surface, i.e. 25 metre water equivalent. At this depth practically only the muonic component is present. The cosmic-ray muon measurements are performed by means of plastic scintillation detectors, a pair of which is, along with instrumentation modules for data acquisition, placed in both the GLL and the UL. The set-up is quiet flexible, as the scintillators could be arranged in different ways, which allows conducting different experiments. The analyses of the measurements yielded some results on variations of the cosmic-ray muon intensity and on precise values of the integral muon flux at the ground level and at the depth of 25 m.w.e. [1,2,3,4].

2. Experimental set-up

The experimental set-up in both the GLL and the UL consists of a large plastic scintillation detector (rectangular shape, 100cm x 100cm x 5cm) and a data acquisition system (DAQ). The scintillator is polystyrene based UPS-89, with four 2-inch photomultiplier tubes attached to its corners, so that each PM tube looks at the rectangle diagonal. Preamplifier signals from two PM tubes looking at the same diagonal are summed in one output signal, thus two output signals are led to the DAQ from each scintillator.

The summed signals from the PM tubes on the same diagonal of the detectors are stored and digitized by the DAQ, which is based on 4-channel flash analog-to-digital converters (FADC), made by CAEN (type N1728B), with 100 MHz sampling frequency. The FADCs are capable of operating in



the event-list mode, when every analyzed event is fully recorded by the time of its occurrence and its amplitude. This enables the correlation of events, both prompt and arbitrarily delayed, at all four inputs with the time resolution of 10 ns. Single and coincident data can be organized into time series within any desired integration period. The FADCs can also be synchronized with each other for the additional coinciding of the events in the GLL and the UL.

For both the GLL and the UL detector, two input channels on the corresponding FADC are reserved for events recorded by each of detector's diagonals. The cosmic-ray events recorded by a single diagonal are drown in the background. Coinciding of the prompt events from two diagonals within a narrow time window gives the resulting experimental spectrum of the plastic scintillator, which is the energy deposit (ΔE) spectrum of the cosmic-ray particles (figure 1). Interpretation of the experimental spectra and their features as well as their calibration have been done using Geant4 based Monte Carlo simulation [4,5]. The spectra peak at ~ 11 MeV and have the instrumental thresholds at ~ 4 MeV. Comparing the spectra of the GLL detector and the UL detector one can notice the obvious difference in their shape, especially in the low-energy part below ~ 6 MeV. This difference points to the contribution of the cosmic-ray electrons and gammas (electromagnetic component) to the ΔE spectra at the ground level, which is absent in case of the underground detector.

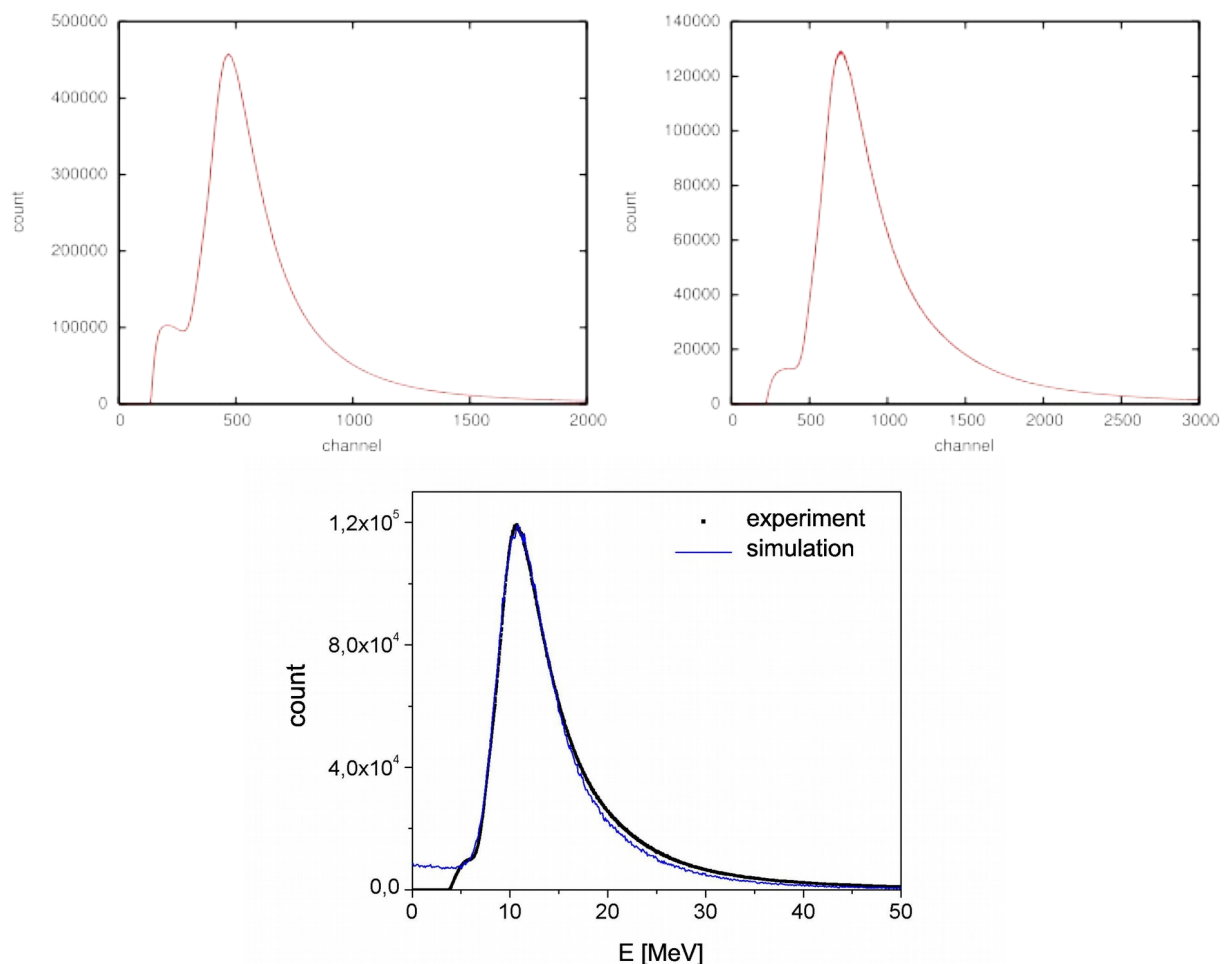


Figure 1. The cosmic-ray ΔE spectra of the GLL detector (top left) and the UL detector (top right). Experimental and simulated ΔE spectra of the UL detector (bottom).

3. Results and discussion

The cosmic-ray intensity data are automatically processed, using a web-based “robot” developed for this purpose, and published online at www.cosmic.ipb.ac.rs/muon_station. The online available data are raw scintillator counts in time series with resolution of 5 min or 1 h. Time series of the raw data are corrected for pressure and temperature effect; pressure corrections have been done for the whole data taking period and temperature effect corrections have been done for the the time period of the last six years.

3.1. Efficiency corrections

The first data corrections are related to detector assembly efficiency. As mentioned, the instrumental thresholds cut the spectra at ~ 3 MeV. However, the thresholds may vary, thus changing the initial spectrum and resulting in fluctuations of the integral spectrum count. Related to this, the necessary correction has been done by means of constant fraction discriminator (CFD) function (figure 2); with use of the CFD cut the spectrum fluctuations decreased significantly. The CFD is based on cut on chosen height as a percentage of peak height where the spectrum is cut. The simulation tells us that, for the underground detector, $\sim 6\%$ of muon events is also cut (figure 1).

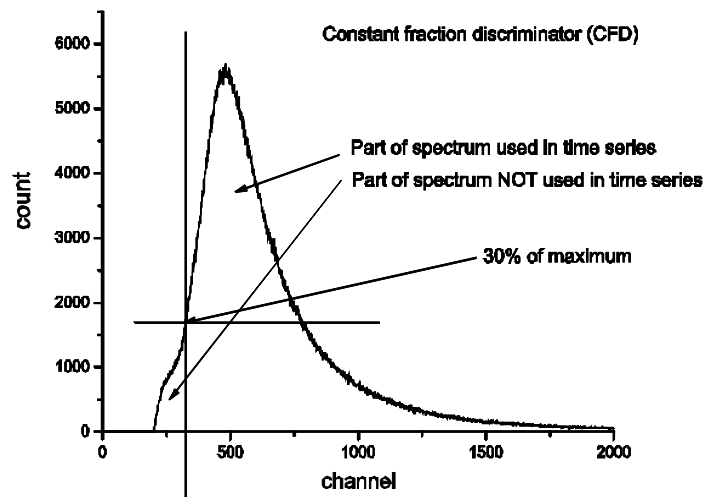


Figure 2. Constant fraction discriminator (CFD) applied in efficiency corrections. The obtained truncated spectrum is used for calculating time series.

The next step in the efficiency corrections is a correction of 5-min count values that are clearly lower than a mean 5-min count in surrounding time intervals. This undershoot comes at the beginning/end of runs, where events are not collected for all 5 min of measurement. The last and smallest correction is a correction of fluctuations of spectrum due to fluctuation in amplification which influence the cut on diagonals and efficiency of coincidence of two diagonals. We found that the CFD cut is proportional to efficiency of coincidence.

3.2. Corrections for atmospheric pressure and for temperature

Significant part of variation of cosmic ray muon component intensity can be attributed to meteorological effects. Here, two main contributors are barometric and temperature effect [6].

Barometric effect is caused by variation of the atmospheric mass above the detector. These pressure corrections are done by finding the linear regression coefficient, using only International Quiet Days, i.e. time series data from periods with more or less constant intensity of galactic cosmic rays, for creation of the distribution of scintillator counts vs. atmospheric pressure. Atmospheric pressure data are available due to on-site continuous measurement.

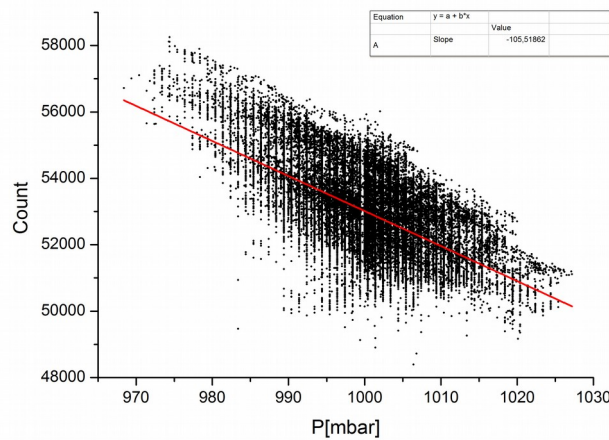


Figure 3. Dependence of 5-min counts on atmospheric pressure.

The temperature effect is related to the variation of the atmospheric temperature profile. The effect is two-fold, as it affects pion decay (positive contribution) as well as muon ionization losses and possible decay (negative contribution). To correct for these effects, integral correction method was applied [6,7]. The variation of the muon intensity due to temperature variations is calculated by using the formula:

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

where δI_T is the variation of the muon intensity due to the temperature effect, $\delta T(h)$ is the variation of the atmospheric temperature, which is calculated in reference to the mean temperature value for a given time period (denoted by index M): $\delta T(h) = T_M(h) - T(h)$, where h is atmospheric depth. Temperature coefficient densities $\alpha(h)$ are calculated according to [6].

Available meteorological models make it possible to have hourly atmospheric temperature profiles for 17 standard isobaric levels at the geographic position of the Belgrade muon station, necessary for application of formula shown above. The procedure used here is as described in [7]. Temperature profiles have been obtained from ftp://cr0.izmiran.rssi.ru/COSRAY/FTP_METEO/blgd_Th/, courtesy of IZMIRAN laboratory.

3.3. Time series of the cosmic-ray intensity

In Figure 4 the count rate time series is shown for all corrections. First, the corrected count rate for efficiency corrected data is shown. Also, the atmospheric pressure and combined atmospheric pressure and temperature corrections time series of count rates are shown.

One-hour time series of the cosmic-ray muon intensity at the ground level are checked for correlation with European neutron monitors (NM), with emphasis on occasional extreme solar events, e.g. Forbush decreases.

In Figure 5 the comparison of time series of pressure corrected and pressure and temperature corrected count rates for the Belgrade muon station and Jungfraujoch, Rome, Baksan and Oulu neutron monitors is presented for Forbush candidate in March 2012. The count rates of neutron monitors are shifted to be close to each-other for visibility. The count rate for the Belgrade station is shown in percentages with additional shift down for visibility. The count rate drop for the neutron monitors is clearly more pronounced than for Belgrade muon monitor.

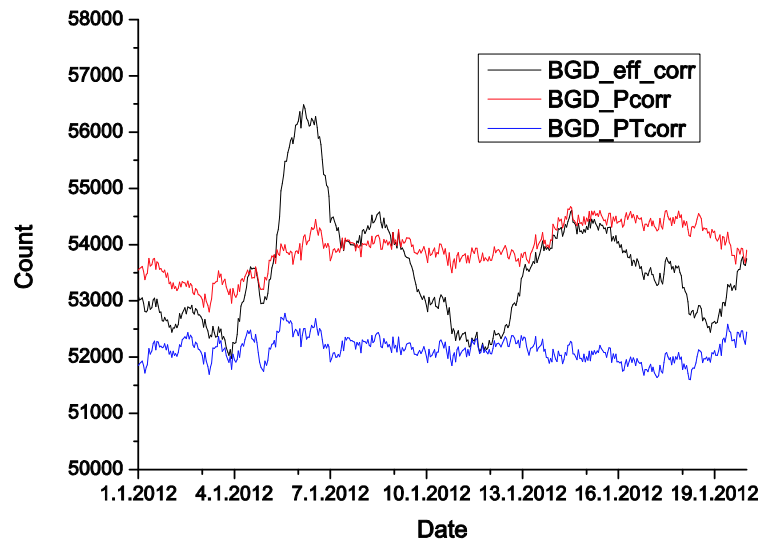


Figure 4. Time series of efficiency corrected, pressure corrected and pressure and temperature corrected counts.

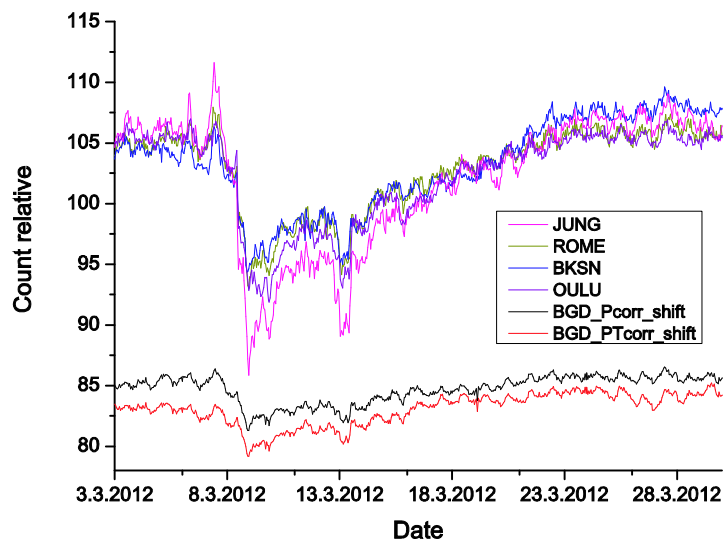


Figure 5. Comparison of time series of pressure corrected and pressure and temperature corrected count rates for the Belgrade muon monitor station and neutron monitors. Count rates are shifted for comparison.

In Figure 6 the comparison of time series of pressure corrected count rates for the Belgrade muon station Jungfraujoch, Rome, Baksan and Oulu neutron monitors is presented. The count rates of neutron monitors are shifted to be close to each-other for visibility. The count rate for Belgrade station is scaled in the way that the drop in count rate is similar to most of the stations (except Jungfraujoch, which is at high altitude). The visual comparison shows the good correlation of the count rates of Belgrade muon monitor and neutron monitors, previously noticed using correlative analyses of count rates. The pressure corrected count rates from Belgrade muon monitor is only dataset used for visual comparison, since neutron monitor data are also only pressure corrected. This was also observed previously using correlative analyses of count rates.

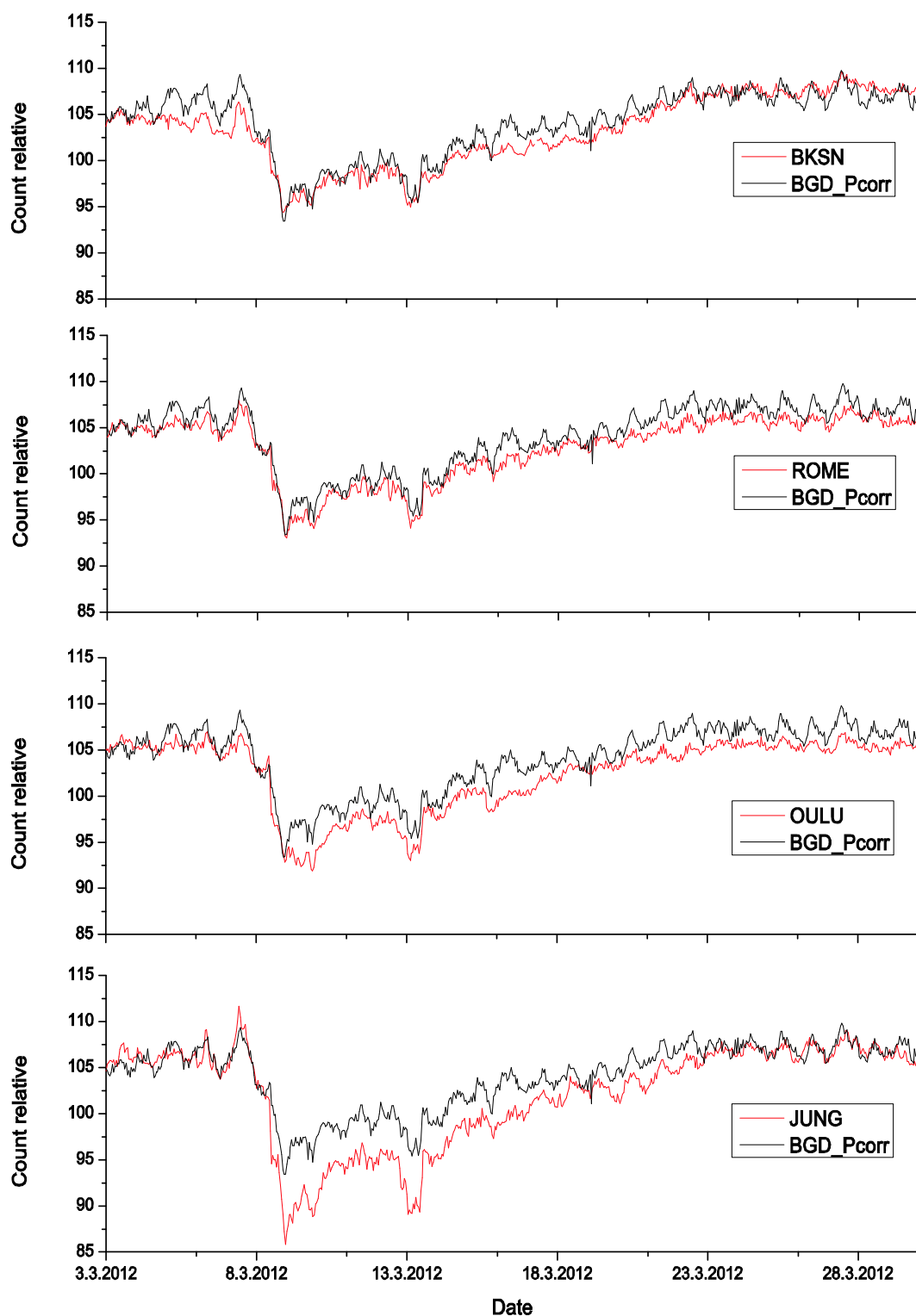


Figure 6. Comparison of time series of pressure corrected count rates for the Belgrade muon monitor station and neutron monitors. Count rates are shifted and scaled for comparison.

4. Conclusions

The results of continuous monitoring of the cosmic-ray muon intensity at the ground and shallow underground level at the Belgrade cosmic-ray station are presented. The scintillator counts are corrected for atmospheric pressure for the whole period of measurements and, as well, for vertical temperature profile for the period of the last six years. The results are compared with other correction methods available and showed excellent agreement. One-hour time series of the cosmic-ray muon intensity at the ground level are checked for correlation with European neutron monitors, with emphasis on occasional extreme solar events, e.g. Forbush decreases. As a result of correlative analysis, the Forbush candidate in March 2012 is the best choice to be used for visual comparison presented in this work. The comparison showed high correlation of the Belgrade muon monitor with neutron monitors, especially geographically closer neutron monitors such as Rome NM. In some specific time periods, like during the Forbush candidate in March 2012, we showed that our muon measurement system has sensitivity comparable to European neutron monitors in this period, but still not as efficient as NM with better geographical position (at high altitude), e.g. Jungfraujoch in the Swiss Alps.

5. Acknowledgements

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6. References

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