Seasonal variations of diurnal variations of CR muon flux

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***Abstract*. Cosmic-ray muon flux is continuously measured in descending phase of solar cycle 23 at ground level and at the depth of 25 m.w.e. in Belgrade (20°23′E and 44°51′N). Diurnal and semidiurnal variations are present in both data sets. The mean amplitude of diurnal variation for the investigated period is $1.96(7)\times10^{-3}$ for ground level data and $9(1)\times10^{-4}$ for underground data. Both diurnal and semidiurnal variations of the ground data exhibit significant seasonal variations, with amplitude maxima near solstices, while such variations are absent from the underground data within statistical uncertainty.**

***Keywords*: CR muons, diurnal variations**

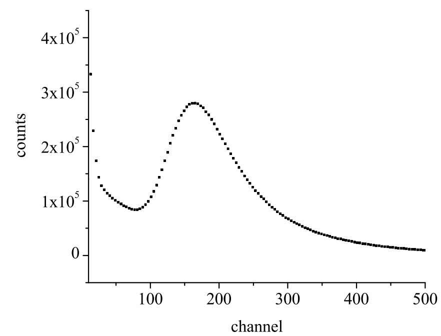

Fig. 1: Muon energy loss spectrum in the detector.

I. INTRODUCTION

In the Cosmic-ray Laboratory in Belgrade ($45°51'$N, vertical geomagnetic rigidity cut-off 5.3 GV) starting with the year 2002 we operate the two identical plastic scintillation detectors, one in the ground level laboratory (78 m above sea level) and the other in the 25 m.w.e. underground laboratory. Experimental setup is described in details in Ref. [1]. The detectors are of 0.125 m^2 each and have the vertically oriented thickness of 5 cm. An average vertical cosmic-ray muon thus loses about 10 MeV in the detector, while the energy loss spectrum reaches even beyond 200 MeV. This muon signature is thus well separated from the signatures of all environmental radiations in the energy loss spectra, taken at five minute intervals. Muon events are identified as those above the cut, placed at the valley separating low and high energy portion of the spectrum. Additionally, GEANT4 based Monte Carlo simulation helps in estimating muon-background signal mixing. Typical energy loss spectrum, integrated over one month period is shown in Fig. 1.

Careful inspection of the spectra reveals occasional instabilities, and on these grounds the whole day is discarded if such an instability is estimated to influence the daily series significantly. Days with incomplete data are also excluded from the analysis. Our analysis covers three years of data taking, from the year 2002 to 2004, belonging to descending phase of the solar cycle 23. After thorough cleanup of the data we were left with about four hundred clean complete daily series, for each of the detectors, distributed rather uniformly throughout the three years (the data corresponding to the recognized transient events were also removed).

II. RESULTS AND DISCUSSION

To investigate diurnal variation of CR muon intensity, the measurement data are organized into hourly bins in local solar time. Due to the smallness of the effect and the poor statistics in our small-size detectors, it is necessary to use the longer time span. The data from the three years of measurement are shown in Fig. 2. Counts are given in the form of relative deviation from the hourly mean. The sum of diurnal and semidiurnal wave is fitted through the data. For ground level data the mean amplitude of diurnal variation for the investigated period is $1.96(7)\times10^{-3}$ and phase $11.1(1)$hr LST. Amplitude of semidiurnal wave is $7.4(7)\times10^{-4}$ and the phase is $3.3(2)$hr LST. For underground data, amplitude of diurnal wave is $9(1)\times10^{-4}$ and $6(1)\times10^{-4}$ for semidiurnal wave.

For comparison, we mention result of Braun et al. obtained between October 1993 and May 2005 with muons with energy higher than 0.7GeV. After atmospheric correction, they found diurnal wave with 0.15% amplitude and 14.4hr phase, and semidiurnal wave with 0.05% amplitude, and 0.2hr phase.

Temporal evolution of both harmonics exhibits interesting behavior. Mean monthly values of amplitudes and phases for the period 2002-2004 is presented in Fig. II.

The near oscillatory character of the four quantities, with some departures, is evident. Probably the most interesting behavior exhibits the amplitude of the 24 hour harmonic. This is separately plotted in Fig. 4. It is remarkable that this turned out to have very nearly the six months period and the phase such that the maxima coincide with solstices and minima coincide with equinoxes. Similar analysis for the underground

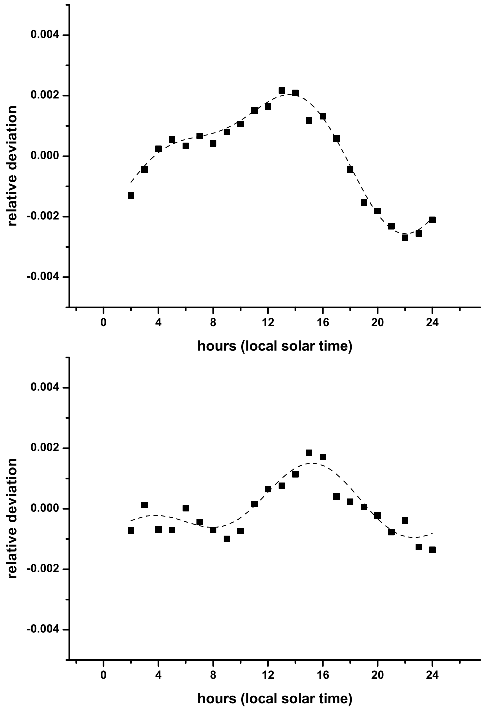

Fig. 2: Diurnal and semidiurnal variation of both ground (upper panel) and underground(lower panel) detector data.

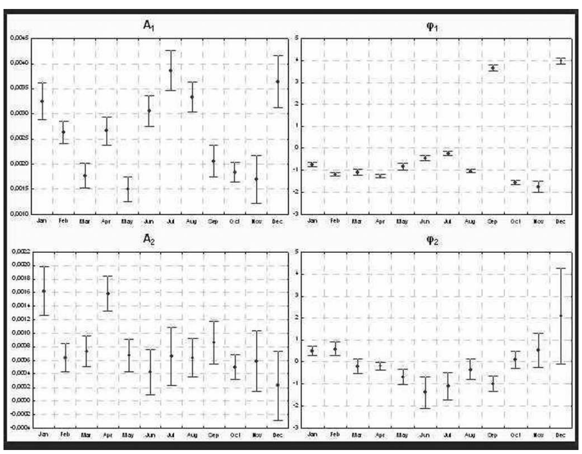

Fig. 3: Amplitudes (A) and phases (φ) of the 24 and 12 hour harmonics for each month of the year.

detector, within its four times lower statistics, did not reveal any significant seasonal variation of this kind.

Although dominant contribution to diurnal signal comes from solar modulation, atmospheric effects might play a role in the seasonal variations. The average annual temperature contribution to diurnal wave is estimated to lay in the range 0.05%-0.15%, and expected to vary with season [3]. Such variations are indeed observed by Elliot and Dolbear [4]. They found diurnal wave amplitude to be greatest in summer, in agreement with our findings.

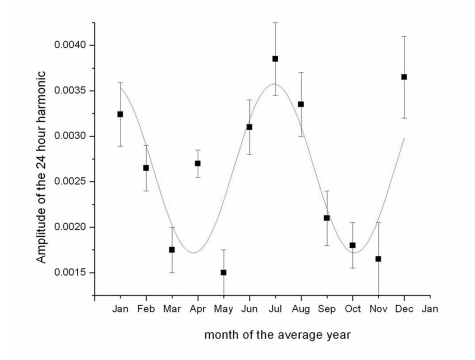

Fig. 4: The nearly 6 months period harmonic through the amplitudes of the 24 hour periodicity throughout the year. It peaks at solstices and dips at equinoxes.

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