Seasonal Variations of Diurnal Variation of Cosmic-ray Muon Intensity in Belgrade

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***Abstract*—The cosmic-ray muon energy loss spectra in plastic scintillation detectors are measured at five minute intervals in both the ground level (78 m a.s.l.) and underground (25 mwe) laboratories in Belgrade (~45°N, ~20°E), throughout the years 2002 to 2004, in the descending phase of solar cycle 23. Average diurnal variations of the intensities of these spectra for each average month of this three year period are obtained. These twelve different diurnal variation series for a ground level detector are all found to be well fitted by the sum of the 24 and 12 hour period harmonic functions of different amplitudes and phases. For the ground level detector the twelve amplitudes of the 24 hour harmonic exhibit well defined periodic behavior, with maxima at solstices and minima at equinoxes, while no significant seasonal variation of diurnal variation is, within the correspondingly lower statistics, observed for the underground 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 around the clock the two identical plastic scintillation detectors, one in the ground level laboratory (78 m a.s.l.) and the other in the 25 m.w.e. underground laboratory [1], [2]. 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, what eliminates the need for coincidence work. However, we take the complete energy loss spectra of both the detectors at five minute intervals (Fig.1) what offers some advantage over the simple counting experiments, since in this way we have full control over our measurements. 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. Our measurements from the years 2002 to 2004, in the descending phase of the solar cycle 23 are analyzed in this work. After thorough clean-up 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 non-periodic events were also removed).

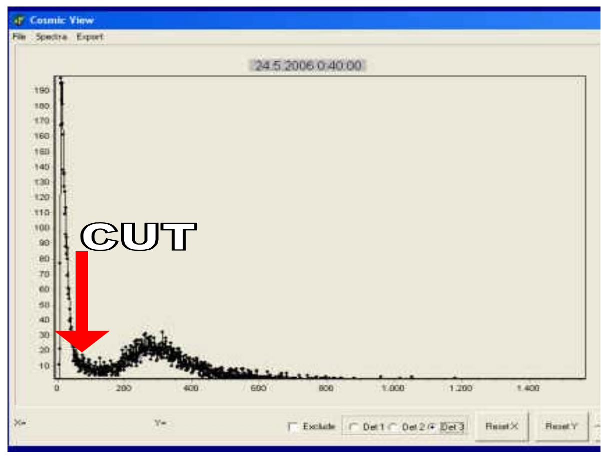

Fig.1. The 5 minute spectrum of the ground level detector with the indicated cut over which the spectra are integrated to yield the 5 minute counts which form the time series that is analyzed here.

To illustrate the overall quality of the data set obtained in this way in Fig.2 we present the histogram of all the 5 minute counts, obtained by integrating the spectra of the ground level detector starting with the channel marked "cut" in Fig.1.

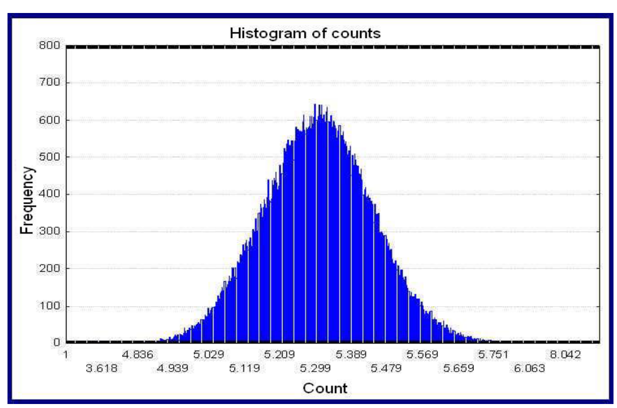

Fig.2. The histogram of the integral 5 minute counts of the ground detector for about 400 days in the years 2002 to 2004. It is a nice Gaussian, though wider than it would have been if the count was stationary. This demonstrates that the integral of the distribution is a good measure of the total average muon flux.

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II. Analysis and Results

The thus obtained time series for the two detectors are now subjected to further analysis. First the average daily series for a given month are produced. For the ground level detector this is done in the following way. The data from all the accepted clean days from a given month from any of the three years involved were added together, thus producing the average daily variation for a given average month, with about thirty to forty-fold statistics as compared to any single daily series. Twelve average daily series containing 288 five minute integral counts were thus obtained, one for each of the given average month for the years 2002 to 2004. Each of these twelve series were now reduced to 24 hourly counts, by adding together the 12 five minute counts for each hour of the given average day. This resulted in further twelve-fold increase in statistics for each of the 24 points that now represent the average daily series for each average month. Each of these counts is now converted into relative count, by subtracting the average count for this average day and by dividing by this value. To illustrate the result of this procedure in Fig.3 the final series for the average day in average February for the years involved is presented.

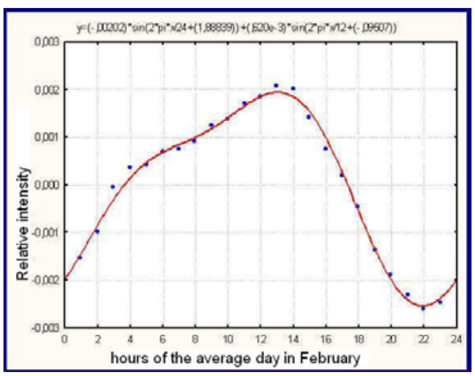

Fig.3. Diurnal variation of the CR muon intensity for an average day in February for the years 2002 to 2004, for the detector situated on the ground level.. The sum of 24 and 12 hour harmonic functions is fitted through the data.

For illustrative purposes in Fig.4 the same is presented for all twelve months. The difference in the diurnal variation throughout the year is obvious. In both figures the result of the fitting of the 24 and 12 hour harmonic functions through the data is also shown. It is seen, as the quality-of-the-fit criteria demonstrate, that these functions satisfy the data well, and that it does not seem necessary to invoke higher harmonics in the fit. It is perhaps of interest to stress that the 24 and 12 hour periodicities were, among many others, found by the periodogram analysis of the whole series. The amplitudes and phases of these two harmonics for each month are further presented in Fig.5. The question of the seasonal variation of the diurnal variation is now reduced to the time variation of these four quantities. The near oscillatory character of the four quantities, with some departures, is evident. Though the errors on the phases are much smaller, probably the most interesting behavior exhibits the amplitude of the 24 hour harmonic.

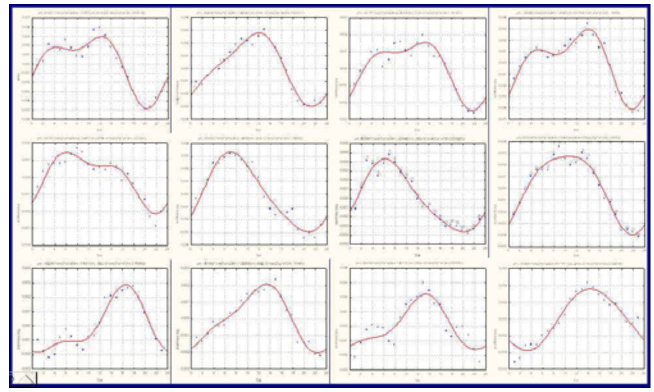

Fig.4. Average diurnal variation throughout the average year for the ground level detector. 24 and 12 hour harmonics are fitted through all the data.

This is separately plotted in Fig.6, together with a single harmonic function fitted through the points, with both amplitude and phase being the free fitting parameters. 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.

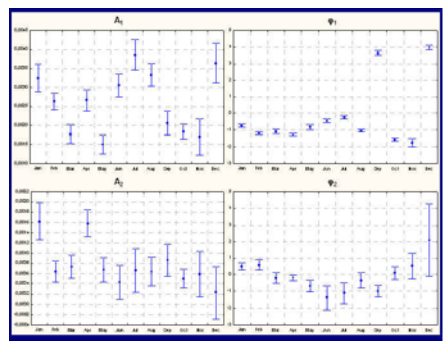

Fig.5. Amplitudes (A) and phases (φ) of the 24 and 12 hour harmonics for each month of the year.

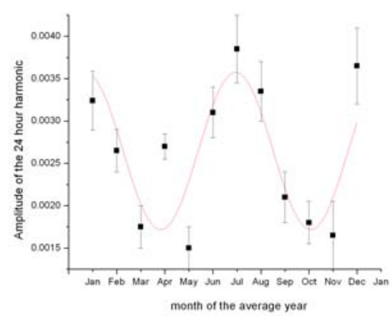

Fig.6. The nearly 6 months period harmonic through the amplitudes of the 24 hour periodicity throughout the year. It peaks at solstices and dips at equinoxes.

Similar analysis for the underground detector, within its four times lower statistics, did not reveal any significant seasonal variation of this kind. This is illustrated by our Fig.7 where the semiannual average diurnal variation is represented for both the detectors. It is seen that the significant difference between the two variations for the ground level detector is absent for the underground one.

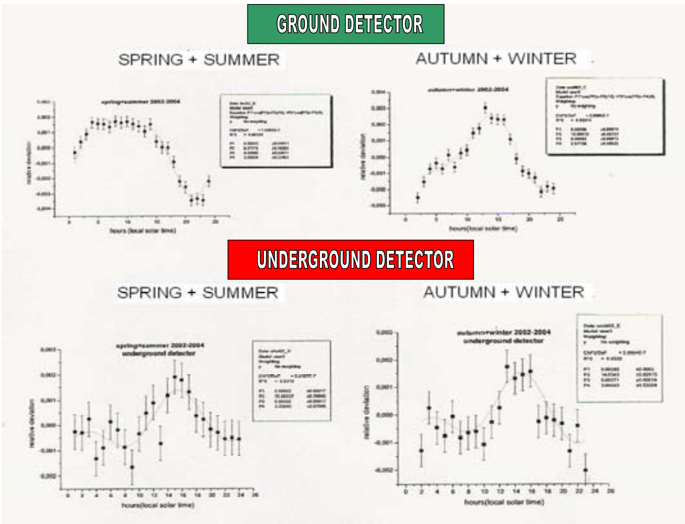

Fig. 7. Semiannual average diurnal variations of CR muon intensity for the ground level and underground detectors. It is seen that within the poor statistics of the underground detector the difference between the seasons is not significant.

ACKNOWLEDGMENT

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REFERENCES

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