

Investigation of Daily Variations of Cosmic Ray Fluxes in the Beginning of 24th Solar Activity Cycle

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Abstract. We have performed a study of daily variations of secondary Cosmic Rays (CR) using data on charged and neutral CR fluxes measured by particle detectors of Aragats Space Environmental Center (ASEC) and Space Environmental Analysis and Viewing Network (SEVAN), which continuously register different species of secondary CR with different threshold energies and incident angles. Data at the beginning of 24-th solar activity cycle are used to avoid biases due to solar transient events and to establish benchmark for the monitoring of solar activity in new started solar cycle. After eliminating changes associated with atmospheric pressure variations, solar diurnal variations are clearly seen in muon and neutron fluxes. Diurnal variations of neutron flux are higher for the high latitudes comparing with middle latitudes and for low energy muons comparing with higher energy muons. Time of maximum for high latitude neutron monitors is comparable with those for middle latitude monitors. Amplitude of variation is 0.24% and phase is about 14:00 and 14:30 local time, for Aragats and Nor Amberd neutron monitors respectively.

Keywords: Variations of cosmic rays, Secondary cosmic rays, Instrumentation and techniques

I. INTRODUCTION

After discovery of Cosmic Rays (CR) and after starting particle flux monitoring at different locations worldwide there were discovered different types of periodic variations of CR intensity. Some of them were connected with galactic rotation [1]; others with co-rotation of the CRs with Interplanetary Magnetic Field (IMF), attached to the sun [2]. The first effect becomes apparent as periodicity in sidereal time; the second as periodicity in local (solar) time, i.e. as diurnal variations.

CR flux can be decomposed into radial and tangential components. Solar wind convective outflow in radial direction compensates galactic CR flux. CR flux in tangential direction generates variations with maximum believed to happen at 18:00 local time [3]. However, as the Earth's magnetic field bends the flux in tangential direction we expect that the maximum of intensity occurs few hours earlier.

This paper presents the calculations of daily variations of secondary particle fluxes measured by particle detectors of Aragats Space Environmental Center

(ASEC), by particle detectors of the worldwide network SEVAN [4] and NMDB, - a European project to develop data base of minute count rates of several Eurasian neutron monitors.

The diurnal variations are the result of complex phenomena involving IMF, magnetosphere and in addition dependent on the latitude, longitude and altitude of detector location on the Earth. The diurnal CR variations comprise an important tool for understanding basic physics of the heliosphere and Earth's magnetosphere. Low energy galactic CRs (GCR, with energies below few tens of GeV) are moving mostly along lines of IMF and their intensity should peak at time of best connections of solar magnetic field (brought to 1 AU by solar wind) with magnetosphere (flux transfer events).

Diurnal variations can be characterized by the maximal value (amplitude) and phase (time of the maximal amplitude). Different species of the secondary CR undergo different diurnal variations. It is overall understanding that more the most probable primary energy of the monitored CR specie (neutron, electron, muon, etc) less should be the amplitude of diurnal variation.

The goal of the presented paper is to calculate phase and amplitude for some of the ASEC, SEVAN and NMDB monitors at the minimum of solar activity cycle. These data will be used for physical analysis of ASEC particle detectors' data as 24th solar activity cycle proceed.

II. DATA AND METHODOLOGY

For the daily variation studies, we use time series of ASEC and SEVAN monitors from May 2008 until January 2009. Data from the SEVAN Aragats (located at 3200m) is available from October 2008. We took data of SEVAN Yerevan from January and February 2009. Data from SEVAN Bulgaria and SEVAN Croatia - from December 2008. Data on muons $> 5\text{GeV}$ of AMMM were taken from December, 2006. Raw data were corrected by median filtering algorithm [5] to eliminate spikes and abrupt changes of mean, i.e. changes caused by errors of the data acquisition electronics. In case of neutron data we performed the following operations. Filtered and pressure corrected [6] daily data were fitted by the harmonic approximation function for each day of selected period. In this way, we get distributions

of amplitudes and phases of daily variation. Following approximation was used [7]:

$$f(t_i) = A + B \cos(\omega t_i + \psi) \quad (1)$$

Here A is the daily average value of cosmic ray intensity, B is the amplitude of daily variation, ω is the angular frequency and ψ is the phase of daily variations. Phase is directly connected to local (solar) time. The quality of fit d , difference between experimental data and the fit is calculated according to [7]:

$$d^2 = \sum_{i=1}^n d_i^2 = \sum_{i=1}^n [Y_i - f(t_i)]^2 \quad (2)$$

Amplitudes and phases obtained by means of equation 1 and fit quality calculated by the equation 2 for ASEC and some other neutron monitors are presented in the Table I in the section III. In case of SEVAN monitors we decided to present the monthly-averaged curves of daily variations, which were found to be more illustrative. Daily data were summed and presented in percents.

III. DAILY VARIATIONS DETECTED BY ASEC AND NMDB NEUTRON MONITORS

Recently new electronics was installed on the all ASEC particle detectors [8] and barometric coefficients were recalculated [6]. After appropriate filtering [5] the one-minute daily data were summed for all 18 channels of ASEC neutron monitors. Then 1 minute time series were summed into hourly time series. Daily 1 hour time series from May 2008 were pressure corrected and fitted by equation 1. Days with abnormal values (for example negative amplitudes) were eliminated. Two days were eliminated from NANM and five days from ArNM data.

In the Fig. 1 we present daily data typical for Nor Amberd Neutron Monitor (NANM). Data are pressure corrected and presented in percents, as 100% the average value of daily count rate is taken. As we can see the amplitude of variation is 0.24% and phase is 3.3 in radians, which corresponds to 11:22 in UT or 15:22 in local time.

The Neutron Monitor Data Base (NMDB) project (funded by European FP7 programme) contains time series of 12 neutron monitors located on high, middle and low latitudes. We compare daily waves of several monitors to investigate the latitude effects of diurnal variations. In the Fig. 2 Moscow, Alma-Ata and Nor Amberd neutron monitors daily data from 11 May, 2008 are compared. Variations of Moscow monitor are much bigger than two others. Times of maximum are almost the same.

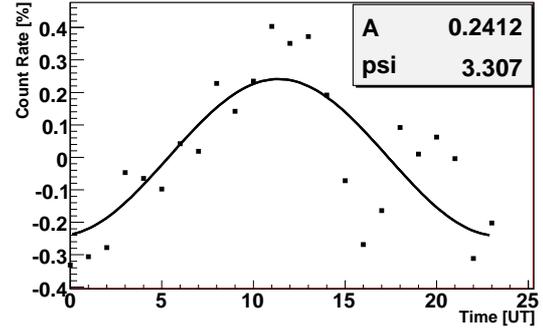


Fig. 1. Daily variations according to NANM pressure corrected, hourly data fitted by cosine function

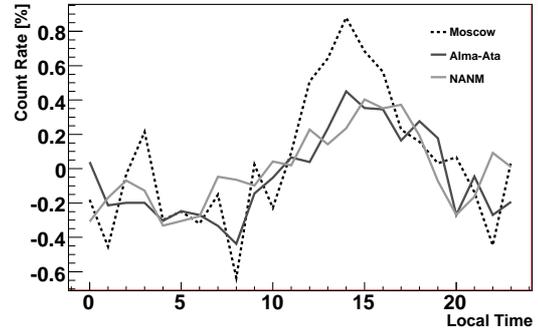


Fig. 2. Comparison of Moscow, Alma-Ata and Nor Amberd neutron monitors daily data

After fitting the 11 May, 2008 data of Moscow, Alma-Ata and Nor Amberd monitors the values of amplitudes 0.47%, 0.20% and 0.24% were obtained respectively. Phases in local time for these monitors are 14:53, 15:25 and 15:21 accordingly.

In Table I we present the parameters of the pressure corrected diurnal variations for 5 neutron monitors of NMDB project (data were taken from site <http://nmdb.eu/>). Most probable energies of primary particles were obtained from computer simulation using CORSIKA code [9]. We expect that primary particle (mostly protons) bending is weaker for high latitudes, consequently phases of diurnal variation were expected to be larger, i.e. local time of maximum is later for lower cutoff rigidity stations. At the same time amplitudes of variations should be bigger at high latitude stations, because of sensitiveness to lower energy primary CR. This statement is correct for 3 of 4 NMDB monitors. However, the amplitude of the Oulu monitor, being higher than calculated for Aragats monitors, is less comparing with IZMIRAN monitor. This discrepancy can give a hint to find some instrumental effects to check the quality of data. The quality of the interpolation is rather high for all monitors, i.e. diurnal variations are close to the sinusoidal and discrepancy between fitting curve and experimental data is small.

TABLE I
DAILY VARIATIONS OF NEUTRON DATA FROM NMDB

	Median amplitude [%]	Median phase [Local time]	Median quality of the fit	Most probable primary energies [GeV]
NANM	0.24	14:34	0.67	7.1
ARNM	0.24	14:07	0.62	7.1
Alma-Ata NM	0.24	14:38	0.61	6.7
Moscow NM	0.38	14:49	0.91	2.46
Oulu NM	0.29	15:13	1.03	0.81

IV. DAILY VARIATIONS OF MUON DATA

We investigated daily variations of charged secondary particle fluxes corresponding to the primary GCR with different energies. Most probable energies of primary particles generating secondary charged particles reaching the Earth's surface are higher, than energies of primaries corresponding to neutrons. For instance, most probable primary proton energies corresponding to muons with energies > 5 GeV is ≈ 40 GeV. However, for muons besides pressure corrections the temperature corrections are essential; see for example [10]. Unfortunately, due to the absence of appropriate temperature data we do not correct for changing gradient of temperature in atmosphere above detector.

In the Fig. 3 one can see the daily changes of Aragats Multichannel Muon Monitor data (AMMM). AMMM measures muons with energies higher than 5 GeV. The pattern of daily variations of 5 GeV muons is more complicated, than for neutrons. Existence of 2 minimums and maximum in between needs additional analysis for relevant interpretation. Apparently, AMMM data can not be fitted by equation 1, more complicated function is required, for taking into account both solar and sidereal [1] periodicities. To describe daily variations of muons with energies > 5 GeV, data were fitted by sum cosines with 24 and 12 hour periods.

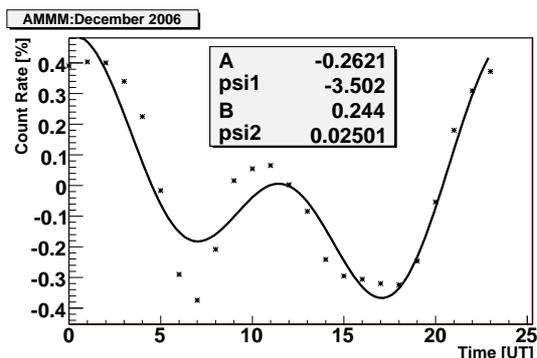


Fig. 3. Daily variations of AMMM data fitted by sum of cosines

SEVAN monitor consists of three layers of plastic scintillating detectors and 5 cm thick lead filters up and below middle detector (see Fig. 4). Upper and lower scintillators have a thickness of 5cm, middle scintillator is 25 cm thick and sensitive to neutrons. Lead filters absorb low energy muons and lower detector is sensitive

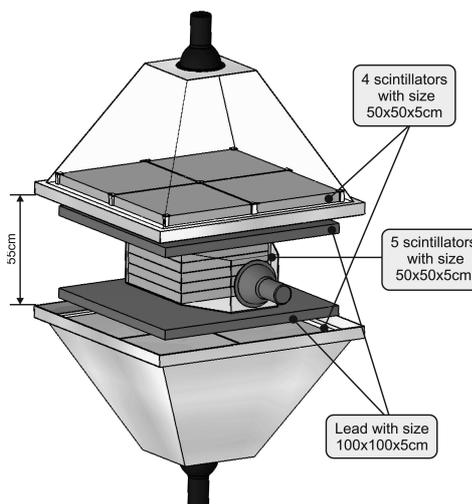


Fig. 4. Basic detecting unit of SEVAN network

to muons with energies > 250MeV. SEVAN hybrid particle detectors allow us register fluxes of neutral particles, fluxes of high (> 250MeV) and low (> 7MeV) energy charged particles. Using different coincidences of the three layered detector its possible to distinguish above mentioned components [4].

SEVAN monitors are already installed at Aragats (3200 m), Nor Amberd (2000 m), Yerevan (1000 m), Mt. Moussala (Bulgaria) and Zagreb (Croatia). The Fig. 5 shows daily variations of upper, lower and middle detectors of SEVAN monitors located at Nor Amberd. Aragats, Moussala and Zagreb. On the pictures geographical coordinates and altitudes of the monitors are also presented.

In Fig. 5 we can see that detectors located at close geographic co-ordinates demonstrate similar patterns of the daily variations. By comparing Aragats and Balkanian monitors we can deduce that both latitude and longitude of site location influence diurnal wave pattern. However very large amplitude of Moussala monitors middle scintillator point on possible defects in light proofing of middle detector. It is worth to mention that Balkanian SEVAN monitors are working in a test mode yet.

V. CONCLUSIONS

ASEC neutron monitors can register diurnal variations in large diapason of primary rigidities. It opens possibilities to investigate the changes of

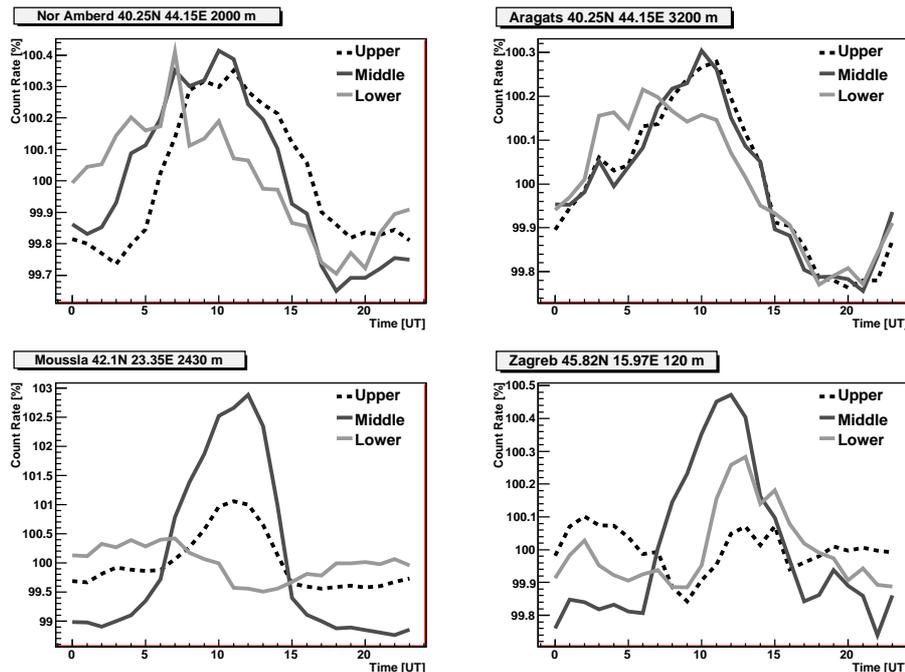


Fig. 5. Daily variations of high, low energy charged fluxes and neutral fluxes according to SEVAN detectors located in Nor Amberd, Aragats, Moussala and Zagreb. Month-averaged daily count rates, Nor Amberd data – May 2008, Aragats – October 2008, Moussala and Zagreb December 2008 – January 2009.

parameters of daily wave during starting 24th solar activity cycle.

Magnitude of daily variations of neutrons is comparable to the magnitude of variations of charged secondary CR. Diurnal variations of neutron flux are higher at high latitudes comparing with middle latitudes and for the low energy muons comparing with the high energy muons. Time of maximum for high latitude neutron monitors is comparable with those for middle latitude monitors. Amplitude of variation is 0.24% and phase is about 14:00 and 14:30 local time, for Aragats and Nor Amberd neutron monitors respectively.

Amplitudes of muon data are bigger or comparable with neutron data, except AMMM data (energy of primary protons higher than ~ 40 GeV), which have more complicated shape of variations and lower amplitude. First data available from SEVAN network demonstrate that charged component variations are comparable with neutron variation and that diurnal variations are sensitive to longitude of site location.

VI. ACKNOWLEDGMENT

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