On mid-term periodicities in cosmic rays: utilizing the NMDB archive

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***Abstract*. The contribution of quasi-periodic variations of cosmic rays (QPs) for T >27 days at the primary energies to which the neutron monitors (NM) are sensitive, has a rather complicated character. They were reported in several papers (e.g. [1]-[3] among others) from individual stations and for various time intervals covered. The data archive of several neutron monitor stations developed within the NMDB project (www.nmdb.eu) involves now long time series of measurements at NMs situated at different geomagnetic cut-off rigidity positions and at different altitudes. It is updated continually. Using the daily averages of cosmic ray intensity at three selected stations within NMDB a) the temporal evolution of the selected quasi-periodicities, especially those of ∼1.7 yr, ∼150 days and ∼26-32 days respectively until 2008 were reviewed, b) the similarities of the spectra were checked and c) the occurrence of QPs with those observed in solar, interplanetary and geomagnetic activities [5], [6] as well as in energetic particles below the atmospheric threshold were discussed [7].**

***Keywords*: Cosmic rays, neutron monitors, periodicities**

I. Introduction

Cosmic ray variability over long time interval is well known and a summary of the experimental and theoretical knowledge can be found in the book [8]. The modulation leading to variability of cosmic ray flux and the quasi-periodicities related to that effect are still studied and described by the analysis of the neutron monitor data (recently in [9]). Description of the variability of cosmic rays is important for the discussions about its influence on the atmosphere. Modulation is important for cosmic ray particles with energies <50 GeV and its ionization is predominant in atmospheric layers already above a few kilometers (review on related subjects can be found in [10]). A current hypothesis is that the variable ionization may affect the degree of cloudiness and the discussion on that is continuing [11]. Cosmic ray flux at energies to which the neutron monitors are sensitive is modulated by complex of physical mechanisms in the heliosphere driven mainly from the solar phenomena. Thus comparison of the temporal profiles of quasi-periodic characteristics representing the solar activity with those of cosmic rays is important. Today exist the records of neutron monitors at various places with different duration of operation. Here we present some characteristics of cosmic ray variability, mainly of quasi-periodic character, using just data of the three neutron monitor which are only a sample of more extensive archive created at present within the NMDB project.

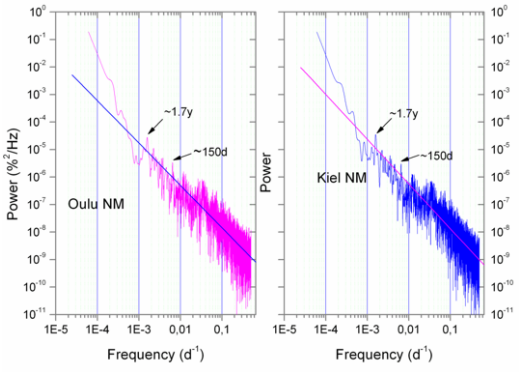

Fig. 1: Power spectra of Oulu and Kiel neutron monitors.

II. Integral power spectrum and selected quasi-periodicities

Daily means from three neutron monitors, namely Kiel (from day 182 of 1957 until the end of year 2008); Oulu (from day 92 of year 1964 until end of year 2008) and Lomnicky stit (day 1 of 1982 until day 182 of 2007) are used. For the power spectra we used FFT technique with Welch window method. The data gaps are either extrapolated from neighbour days (if the gap is smaller than 4 days) or the technique is used for spectra of unevenly spaced data which does not affect the spectra for the slightly longer gaps. Results are in Fig. 1. The slope of power spectrum density is larger above about T=20 months which is consistent with [12] based on data before 1990 at Climax and Calgary neutron monitors. The two relatively well pronounced quasi-periodicities, namely those at ∼1.7 year and∼150 days are seen on both spectra. The spectral composition of time series of cosmic rays has rather complicated character.

The slope is not correctly representing the contribution of several quasi-periodicities in the signal related to

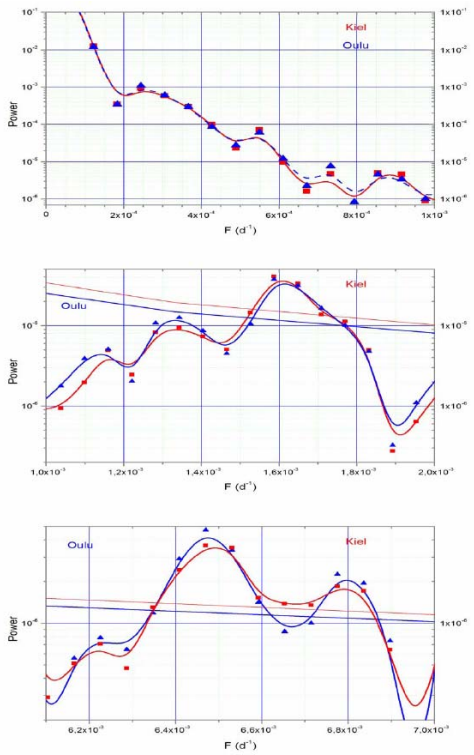

Fig. 2: Power spectral density (PSD) of neutron monitor time series at two positions (points). B-spline technique is used for the curves

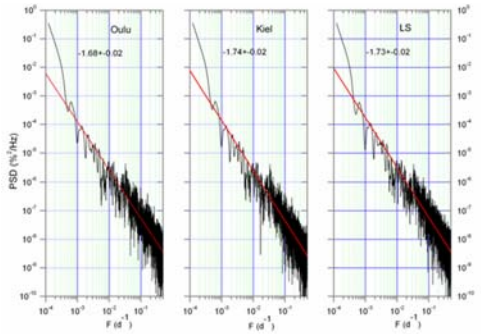

Fig. 3: Data normalized to 100 % for 1988.0794. The slopes of PSD are indicated

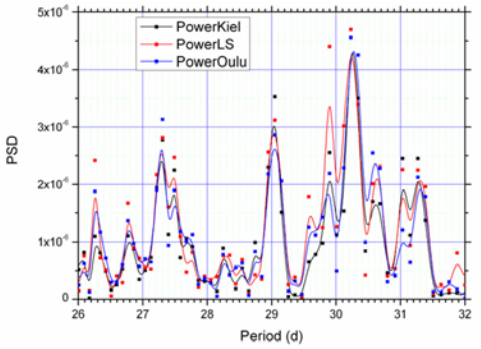

Fig. 4: Periodogram (PSD(T)) around the solar rotation period at three neutron monitors from the same interval as of Fig. 3.

quasi-periodic character of the solar wind, IMF, as well as irregular CME affecting the modulation.

The comparison of the spectral shape of CR at three different frequency intervals at the two neutron monitors presented Fig. 2. There is relatively clear consistence in the shape and in the values of PSD at all three selections of the frequency interval. In the upper panel, in addition to ∼11 year variation, the indication of ∼5 yr and ∼3 yr quasi-periodic signal is probably seen. The middle panel illustrates rather clear quasi-periodicity ∼1.7 yr reported from other data and earlier periods. The lowest panel, showing again similarity in spectral shape, demonstrates probably the double peak structure of quasi-periodicity, namely ∼154 day and 148 days. The power spectra of the three stations (including also a high altitude one) for which the data are simultaneously available, is illustrated in Fig. 3. Comparison of the PSD near ∼27 days from the three neutron monitors is presented in Fig. 4. Although the values of PSD at the three NMs are not identical, the similarity of the shape and positions of the three maxima (∼30.2, ∼29.05 and ∼27.4 d) at all NMs are probably not accidental. Paper [13] shows the complicated structure of differential rotation of solar disc deduced from chromospheric line emissions. The authors indicates that beside the basic period around 27 days there are signals at 32-35 days corresponding to the rotation rate at very high latitudes. Since cosmic ray modulation is affected also by high latitude structure of IMF, the detailed studies of the fine structure of quasi-periodicities in the region mentioned above should be of importance.

III. Long term evolution of the spectra

For non-stationary time series, as the cosmic ray at neutron monitor energy is, the checking of the contribution of various quasi-periodic signals to the power spectrum density discussed in part 2 as the integral over long time, can be done by wavelet methods frequently used in recent years in many studies of solar-terrestrial relations (WDS - wavelet spectrum density). Out of the three NMs for this type of analysis we used Kiel with most extensive data coverage. Figure 5 shows the wavelet spectra for the time interval covered in NMDB base. Although there are not many clear significant periodicities apparent (critical limits in Fig. 5, upper), especially at higher frequencies, the wavelet spectra density provides an insight on variability of the contribution of different quasi-periodic signals to the total counting rate profiles. Such insight is seen by plotting the WSD in frequency-time profile in Fig. 6.

IV. Discussion and summary

Using relatively long data sets of the selected neutron monitors from NMDB data archive, the earlier indications of quasi-periodicities in cosmic rays (e.g. in [1]-[5]) based mainly on earlier data sets and other neutron monitor positions, were confirmed at three positions with

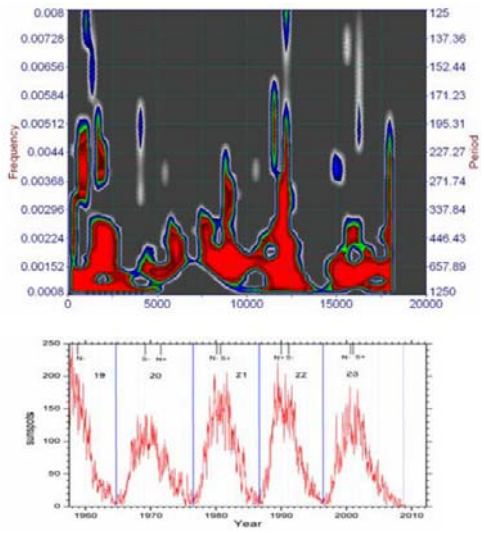

Fig. 5: Upper panel: Kiel NM (days from 182 of 1957) wavelet critical limit gradients: grey-scale from 10 to 50 %, 8-level cyan-scale from 50-90 %, 8 level green-scale 90-95 %, 8 level yellow-scale 95-99 %, and 8-level red-scale 99-99.9 %. Morlet mother function with adj 16 (def. in [14]) used. Lower panel: smoothed sunspot numbers from [15]

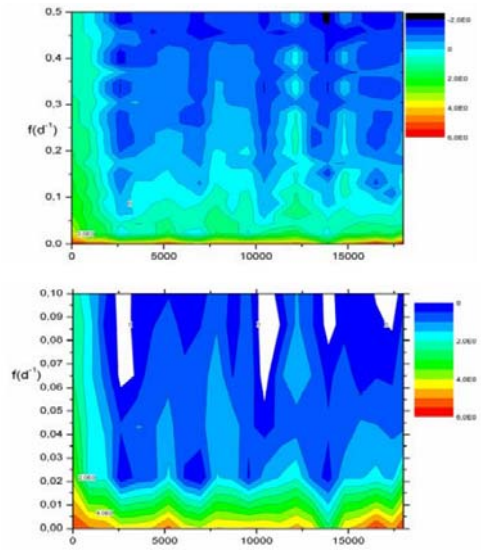

Fig. 6: Lines of constant logarithm of WDS function for Kiel, x axis scale is the same as in Fig. 5

different cut-off rigidity and altitude. The ∼1.3 year periodicity (not shown here, indication at the right corner of middle panel Fig.2) discussed e.g. in solar wind [6] is also observed. Out of the periodicities reported recently at lower energies (below the atmospheric threshold) in [7] that one at ∼1.7-2.2 yr could probably be attributed at higher energies to double peak structure in middle panel Fig.2. The assessment of ∼3.8 yr is also apparent from the upper panel of that figure. Distinction of ∼11 year from ∼9.8yr reported from IMP data is difficult to state according to present technique. The quasi-periodicity about ∼154 d in solar flares was reported in [18]. This is seen also in cosmic ray spectra (lowest panel Fig.2). The spectral slope of PSD at the three stations is mutually consistent and it agrees with that reported earlier at higher frequencies (e.g. in [16]) and with the observed slope of IMF B reported in [17] which is close to Kolmogorov type of spectra. The complicated character of the PSD and its similarity on three NM stations near ∼27 days is needed to be studied in more details in comparison with solar physicists. Continuation of the detailed study of the spectral properties of cosmic ray time series at various energies require the compilation and checking the quality of the existing cosmic ray data available in various laboratories and comparison with characteristics of IMF, solar wind and geomagnetic activity. Using additional data from NMDB for this purpose is in progress.

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