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Abstract: The contribution of quasi-periodic variations of cosmic rays for T > 27 days at the primary energies to which the neutron monitors are sensitive, has a rather complicated char¬acter. They were reported in several papers (e.g. Valdes-Galicia et al., 1996; Mavromichalaki et al., 2003; Kudela et al., 2002 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 neutron monitors situated at different geomagnetic cut-off rigidity positions and at different altitudes. It is updated continuously. Using the daily averages of cosmic ray intensity at three selected stations within NMDB a) the tem¬poral evolution of the selected quasi-periodicities, especially those of ~1.7 yr, ~150 days and ~26 - 32 days respectively, until 2008 are reviewed, b) the similarities of the spectra are checked and c) the occurrence of quasi-periodicities with those observed in solar, interplanetary and geomagnetic activities (Moussas et al., 2005; Richardson and Cane, 2005) as well as in energetic particles below the atmospheric threshold are discussed (Laurenza et al., 2009).

On mid-term periodicities in cosmic rays

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Abstract. The contribution of quasi-periodic variations of cosmic rays for T > 27 days at the primary energies to which the neutron monitors are sensitive, has a rather complicated character. They were reported in several papers (e.g. Valdes-Galicia et al., 1996; Mavromichalaki et al., 2003; Kudela et al., 2002 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 neutron monitors situated at different geomagnetic cut-off rigidity positions and at different altitudes. It is updated continuously. 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 are reviewed, b) the similarities of the spectra are checked and c) the occurrence of quasi-periodicities with those observed in solar, interplanetary and geomagnetic activities (Moussas et al., 2005; Richardson and Cane, 2005) as well as in energetic particles below the atmospheric threshold are discussed (Laurenza et al., 2009).

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I. INTRODUCTION.

Cosmic ray variability over long time interval is relatively well known for the era of direct measurements and a summary of the experimental and theoretical knowledge can be found e.g. in the book (Dorman, 2004). 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 by Zaarouk and Bennacceur, 2009). 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 paper by De Jager, 2005. Current hypothesis is that the variable ionization may affect the degree of cloudiness and the discussion on that is continuing (Sloan and Wolfendale, 2008). 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 surface. 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 data of the three neutron monitor which are only a sample of more extensive archive created at present within the NMDB project.

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 Lomnický štít (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 Figure 1. The slope of power spectrum density is larger above about T=20 months which is consistent with (Kudela et al., 1991) 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 at ~ 150 days are seen in both spectra.

The spectral composition of time series of cosmic rays (CR) has rather complicated character. The slope fitted is affected by the contribution of several quasi-periodicities in the signal related to quasi-periodic character of the solar wind, interplanetary magnetic field (IMF), as well as irregular appearance of coronal mass ejections affecting the modulation.

The comparison of the spectral shape of CR in three different frequency intervals at the two neutron monitors is presented in Figure 2. Kiel and Oulu covers longer time interval of measurement than Lomnický štít. There is relatively clear consistence in the shape and in the values of power spectrum density (PSD) at all three selections in the frequency interval covered. In the upper panel, in addition to ~ 11 year variation, the indication of ~ 5yr and ~ 3yr 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) during the long time period for which the data are simultaneously available, is illustrated in Fig. 3. The spectral indices of PSD versus frequency are similar. The long interval of measurements covers epochs with both solar magnetic field polarity. Paper (Sabbah and Duldig, 2007) shows different slopes at higher energies for positive and negative polarity. The value of the spectral index here is between the values for A>0 and A<0 in the cited paper.

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 neutron monitors are not identical, the similarity of the shape and positions of the three maxima (~ 30.2, ~ 29.05 and ~ 27.4 d) at all monitors are probably not accidental. Paper (Hasler et al., 2002) shows the complicated structure of differential rotation of solar disc deduced from the chromospheric line emissions. The authors indicate 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 for future.

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 (WSD -wavelet spectrum density). Out of the three neutron monitors for this type of analysis we used Kiel with the 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 panel) 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 Figure 6.

IV. DISCUSSION AND SUMMARY

Using relatively long time data sets of the selected neutron monitors from NMDB data archive, the earlier indications of quasi-periodicities in cosmic rays based mainly on earlier data sets, shorter time intervals and other neutron monitor positions, were confirmed at three positions with different cut-off rigidity and altitude. The ~ 1.3 year periodicity (not shown here, indication at the right corner of middle panel of Figure 2) discussed e.g. in solar wind (Richardson and Cane, 2005) is also observed. Out of the quasi-periodicities reported recently at lower energies (below the atmospheric threshold) in paper by (Laurenza et al., 2009) that one at ~ 1.7-2.2 yr could probably be attributed at higher energies to double peak structure in middle panel of Figure 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 the present technique. The quasi-periodicity about ~ 154 d in solar flares was reported in (Kile and Cliver, 1991). This is seen also in the cosmic ray spectra (lowest panel Figure 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 Bershadskii, 2002) and with the observed slope of the IMF B reported by (Burlaga and Ness, 1991) 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 data analyzed by 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 of neutron monitors and muon telescopes for this purpose is in progress.

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Figure captions.

Fig. 1. Power spectra of Oulu and Kiel neutron monitors constructed from daily means of pressure corrected data.

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

Fig. 3. Power spectra of cosmic ray time series measured at three neutron monitors for identical time interval. Data are normalized to 100 % for 1988.0794. The slopes of PSD are indicated with n according to fit PSD(f) = const. f^{-n}.

Fig. 4. Periodogram (PSD as a function of periodicity) around the solar rotation period at three neutron monitors from the same interval as of Figure 3.

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 (definition in Torrence and Compo, 1998) is used. Lower panel: smoothed sunspot numbers from (http://www.ngdc.noaa.gov/stp/SOLAR/).

Fig. 6. Lines of constant logarithm of WSD function for Kiel neutron monitor, x axis scale is the same as in Figure 5.

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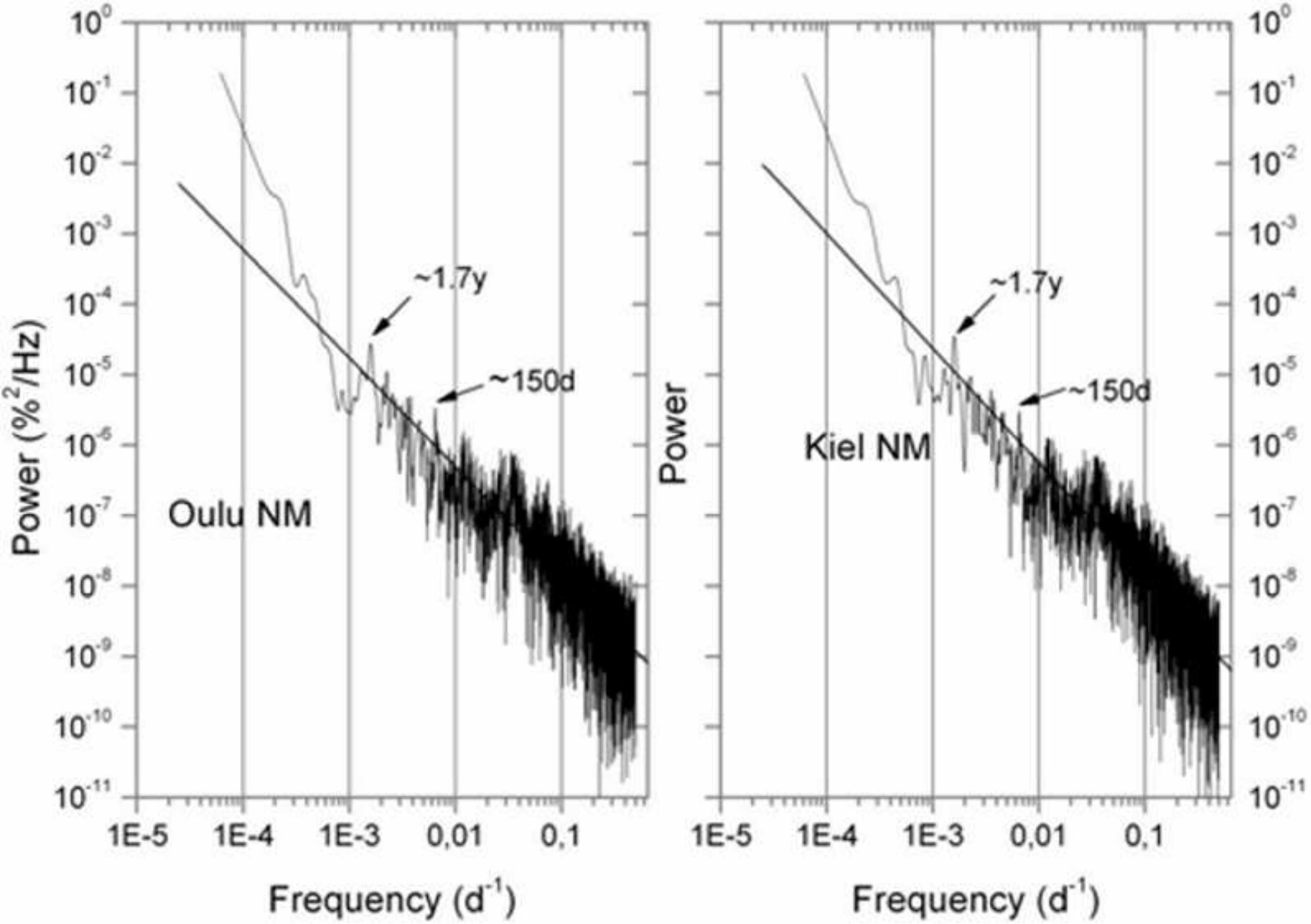

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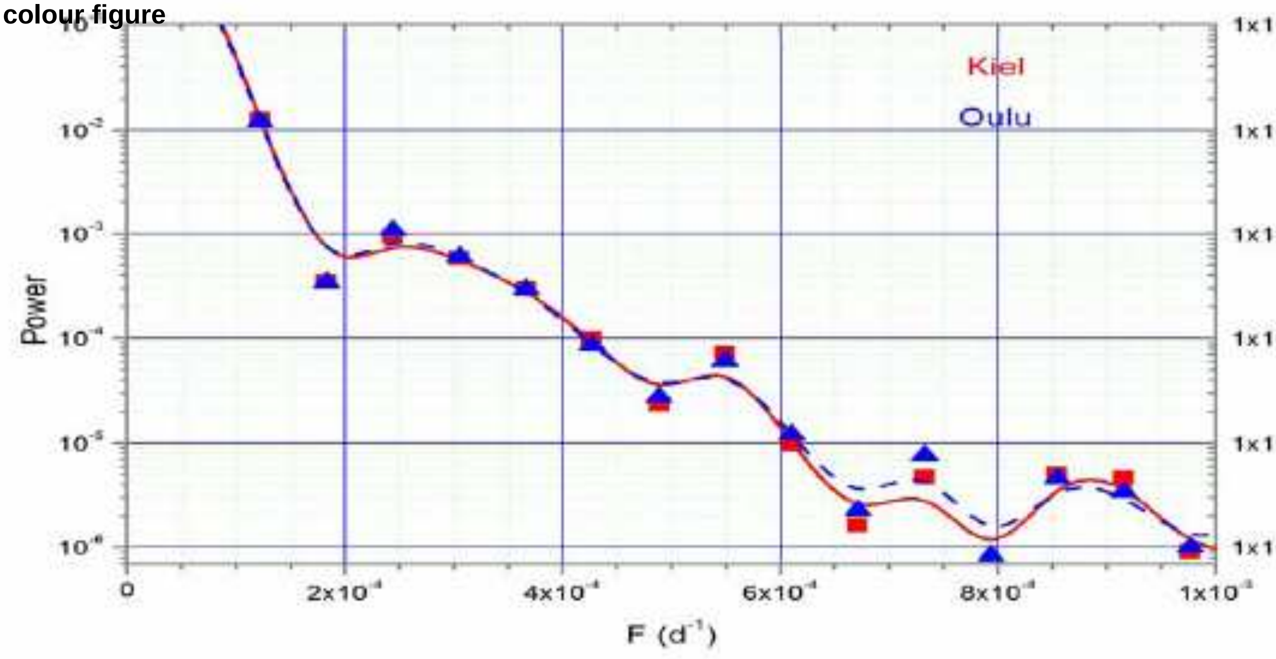

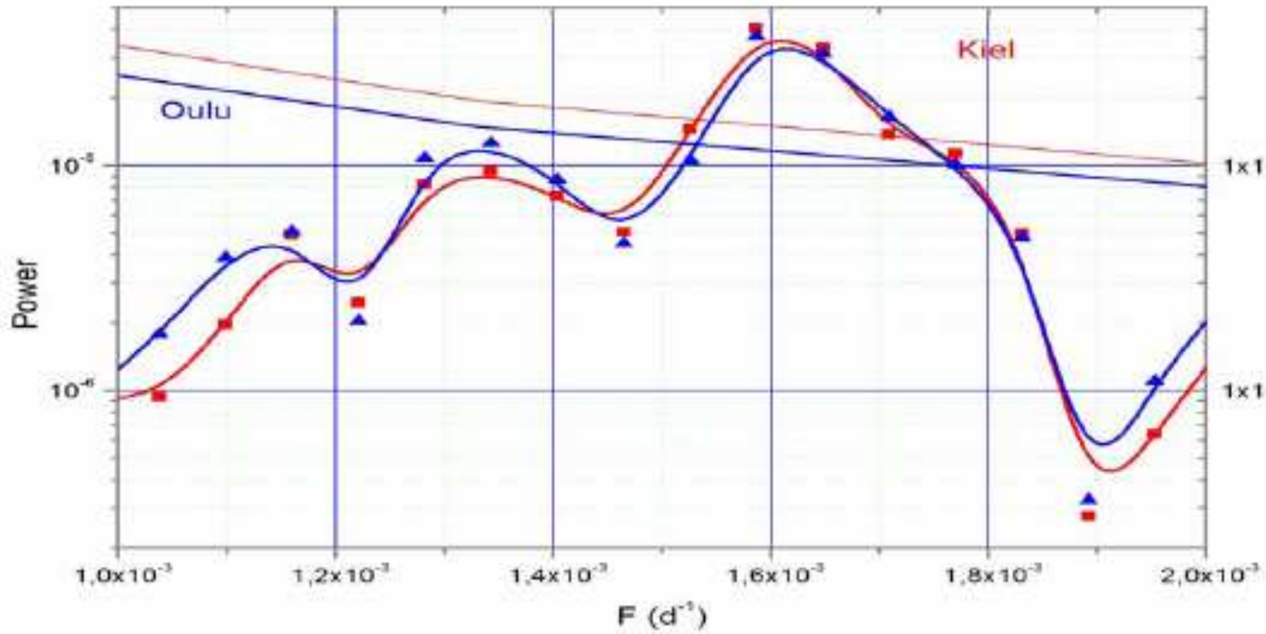

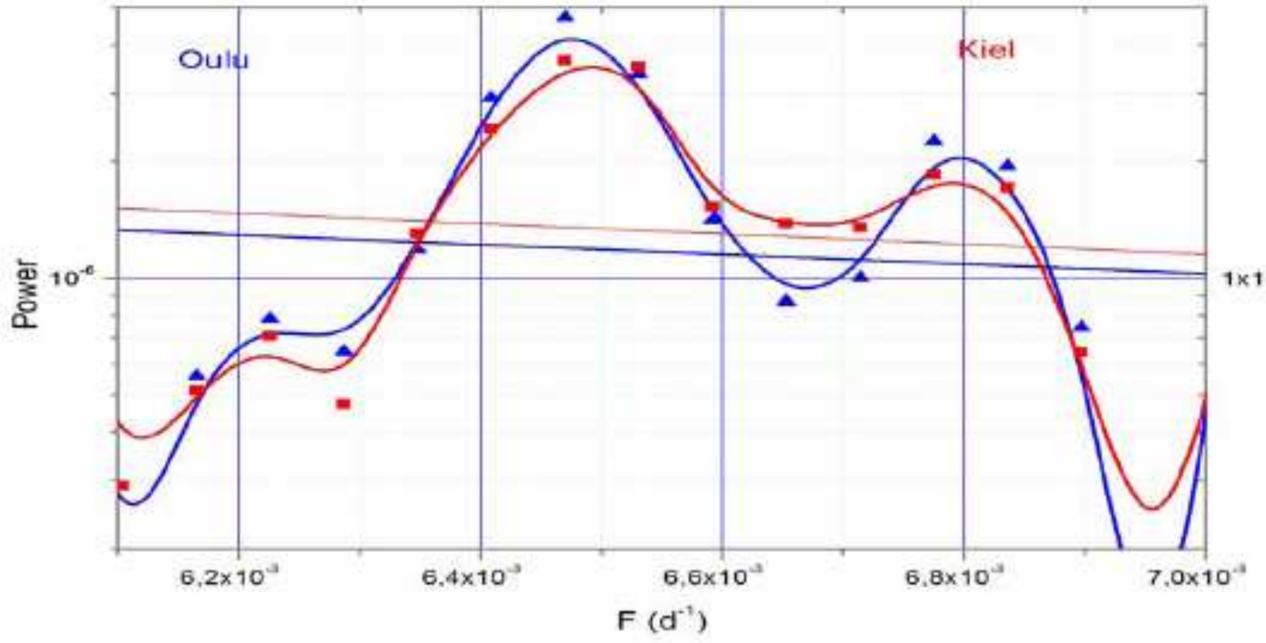

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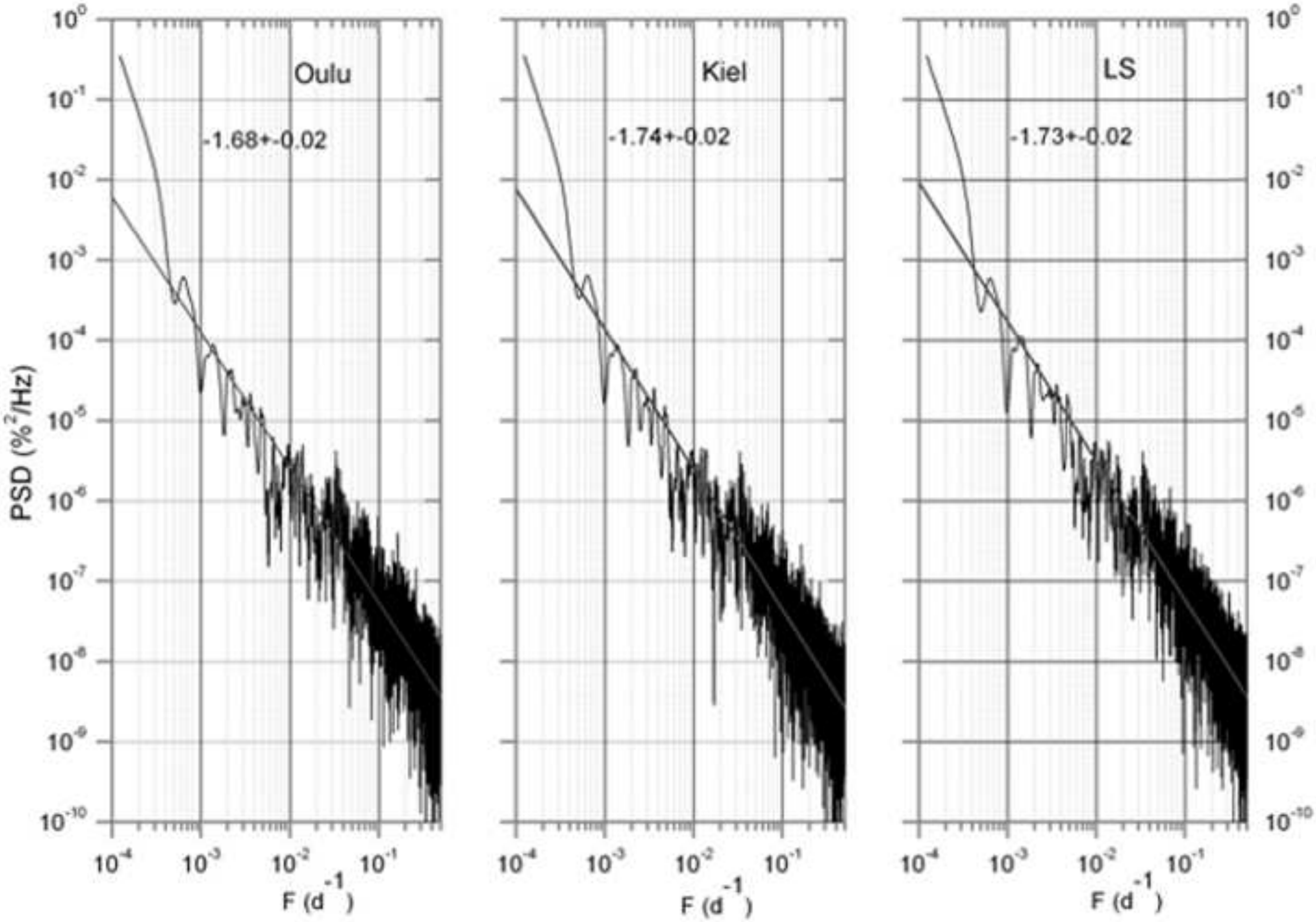

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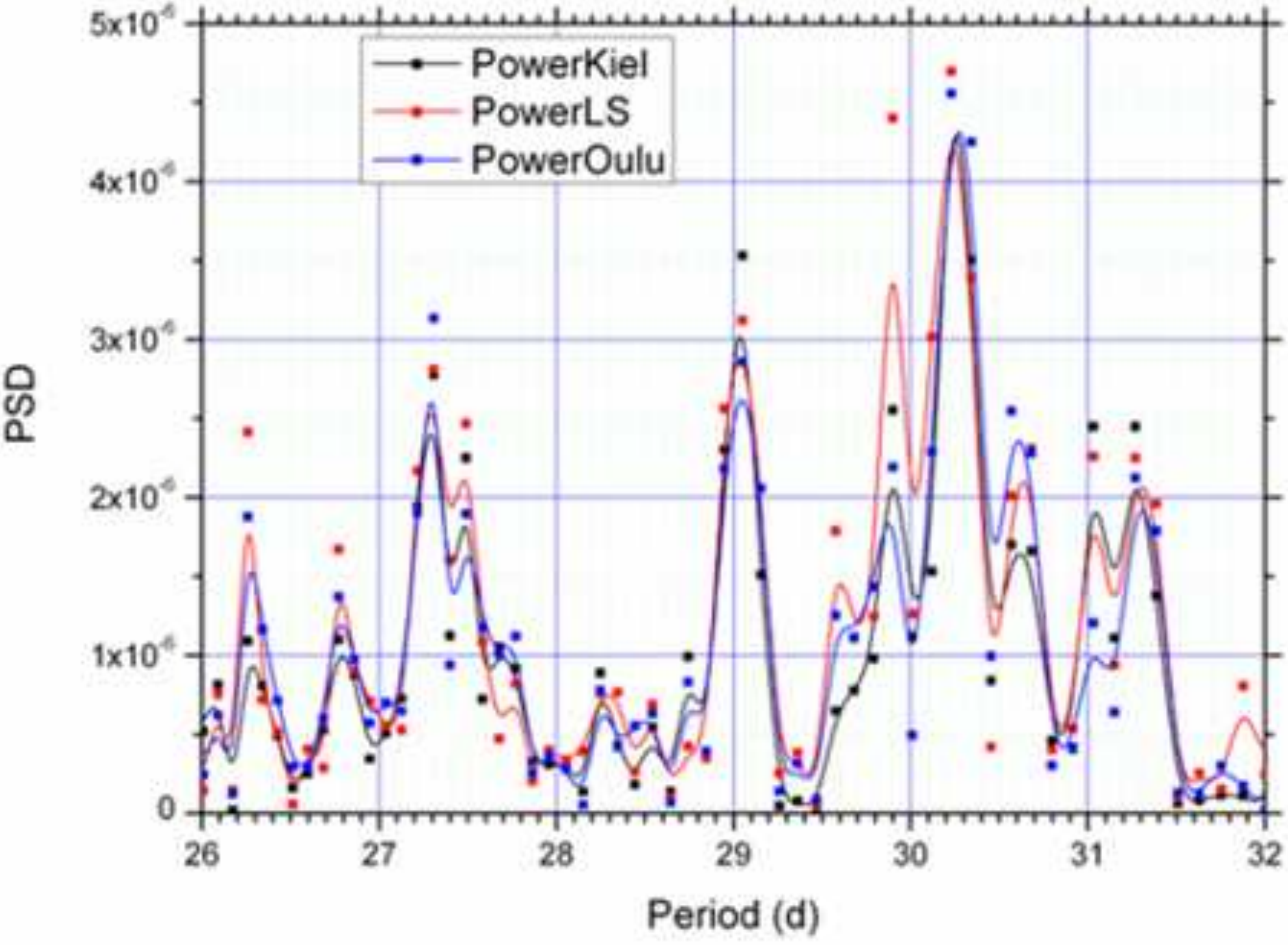

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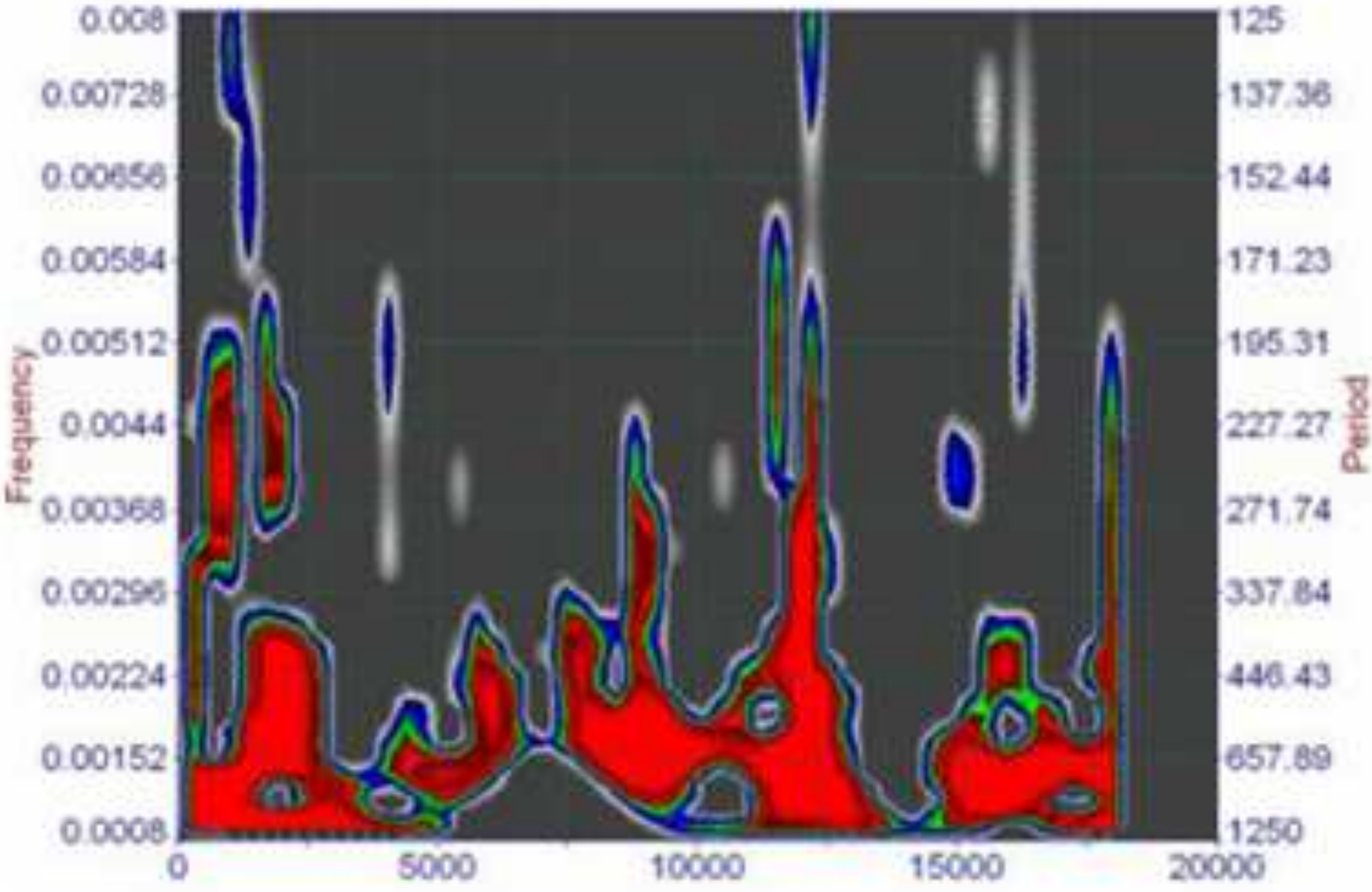

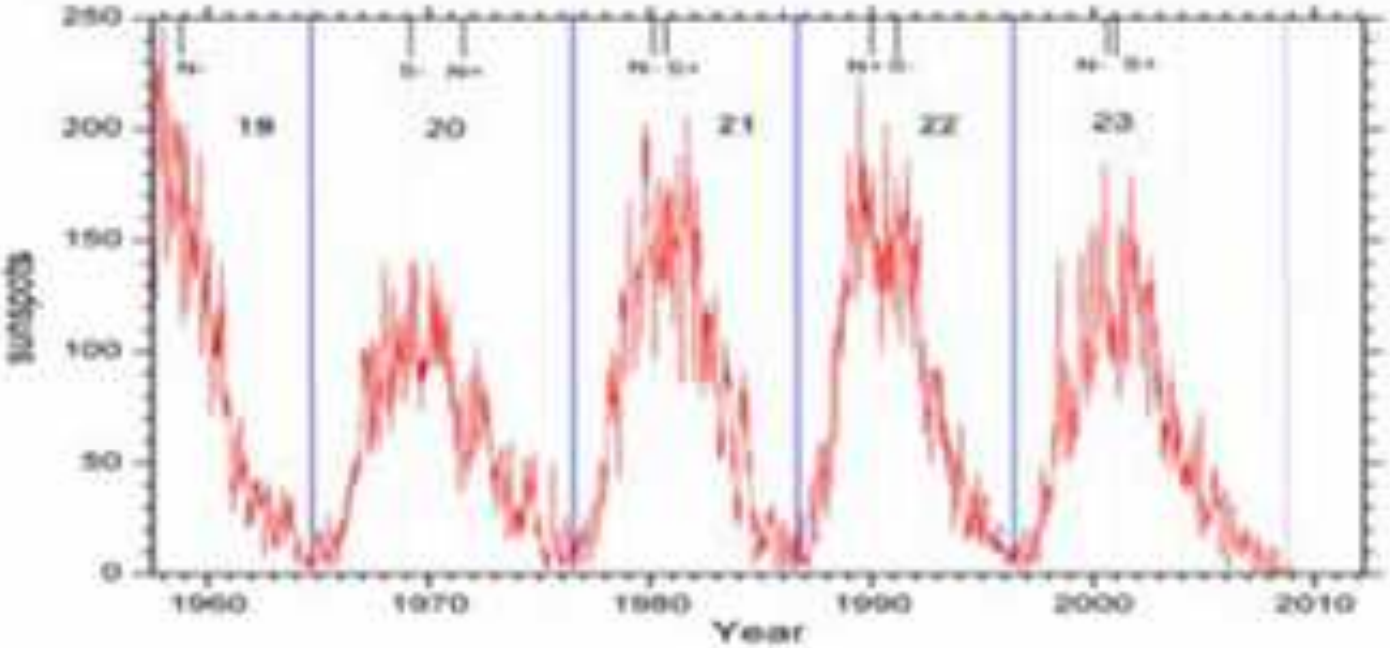

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