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Power Spectra of Solar, Interplanetary Magnetic Field Parameters and Geomagnetic Indices

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Abstract: Data of daily interplanetary plasma (field magnitude |B|, solar wind speed V and ion density n) and solar parameters (sunspot number Rz, geomagnetic indices aa and kp during the period 1970-2007 have been used to examine their dependence on solar minimum (m) and maximum (M) period. The ~27-day variation and its two harmonics in both interplanetary plasma and solar parameters during minimum solar activity, during which, the ion density values for the case for negative polarity epoch $A_1< 0$ has higher values than of positive polarity epoch $A_2> 0$. While, during maximum solar activity epoch ($M_{2)}$ has higher n-values than $M_1$and M_3 for all parameters.

Key words: Spectral analysis · Minimum solar activity · Maximum solar activity

INTRODUCTION

Most interplanetary plasma parameters are highly variable on time scales ranging from minutes to the solar activity cycle and vary with heliographic latitude and longitude Gazis [1]. The state of interplanetary plasma permanently changes in conformity with cyclicity in the solar activity. Besides the 11-year variations in the velocity and scintillation index, there is also an increasing linear trend of these variables, which is presumably due to a secular 80-90 years cycle of solar activity. The observed difference between the 11-year variations and trends in the solar wind velocity and interplanetary scintillation index suggest that the 11-year and secular cycles have different origins Gazis, Barnes, Mihalov, *et al*., [2]. It has been found that these trends occur in different periods in each link of the Sun-Earth system: the solar activity indices, in the characteristics of the interplanetary medium and practically in all characteristics of geographical, demographical and other Earth`s processes. From the entire set of facts, we can conclude that most of the analyzed earth' processes are dominated not by anthropogenic factors, but by the effect of the secular cyclic processes of the solar activity El-Borie, Duldig and Humble [3].

The solar magnetic field is frozen in the solar plasma and carried outward by the solar wind. When the Sun rotates, the field at equatorial latitudes forms a spiral structure. In addition, a neutral sheet results from this structure, maintaining a separation between northern and southern regimes. This averaged warped hemispheric current sheet (HCS) separates regions with opposite polarities of the magnetic field. The structure of the (HCS) changes substantially during 11-year sunspot cycle Hoeksema, Wilcox and Scherrer [4]; Hoeksema, Wilcox and Scherrer [5]; Hoeksema [6]; El-Borie [7, 8]; Vlasov [9] with a relatively flat sheet at the solar minima years, but neutral sheet waves extend up to 70^0 heliolatitude at solar maxima epochs. Furthermore, the solar field polarity reverses at each solar maximum giving rise to a 22-year periodicity in the heliomagnetic field. North the current sheet, the IMF is directed away from the Sun above the current sheet and south of the current sheet the IMF is directed toward the Sun during epochs of positive- polarity. When the solar dipole moment is directed northward the radial component of the IMF is directed outward (away). In this case, the Earth is located above the current sheet and inward (toward) when the Earth is located below the current sheet.

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The aim of this work is to study the interplanetary and solar parameter for positive A.>0 and negative A<0 solar polarity epochs interplanetary as well as their variations during maximum and minimum solar activities.

Data and Analysis: Daily averages of interplanetary and solar indices for positive polarity A>0 and negative polarity A<0 years, during solar maximum and minimum activity years were used in this study. Epochs of positive A>0 are 7/1971-10/1980 and 2/1992-11/2000, while epochs of negative A<0 are 2/1981-2/1991 and 5/2002-12/2007. A series of power spectral density (PSD) have been performed. Fast Fourier Transformations (FFT) have been used to yield the power spectral density (PSD). The results were smoothed using the Hanning window function. This is necessary since most of the disturbed features will completely disappear, while the significant peaks are clearly defined. Nevertheless, the particular window chosen dose not shifts the positions of the spectral peaks. Next, each spectrum is independently normalized to the largest peak in the complete spectrum. This restriction was chosen in order to avoid spurious strengths often associated with peaks near the start and end of the data set. This normalization dose not introduce any errors into our identification of the peaks because it changes only the relative amplitude and not the position of the peak spectrum.

RESULT AND DISCUSSION

Solar Polarity Dependence: A series of PSD have been performed for daily average of interplanetary and solar indices during periods of different IMF polarities, $A_1>0$ (1971-1980), $A_1<0$ (1981-1991), $A_2>0$ (1992-2000) and $A_2<0$ (2000-2007). The interplanetary and solar indices datasets were then separated into different epochs of positive polarity A>0 years and A<0 years. The power spectrum for each epoch are separated into two windows ($1x10^{-2} – 5x10^{-2}$ c d^{-1}) and ($5x10^{-2} – 15x10^{-2}$ c d^{-1}).

The first and second positive solar period $A_1>0$ and $A_2>0$ (not shown) have displayed periodicities at 82, 73, 62, 52.5-51.2, 43.6, 37, 33.3-30, 29.3, 27.3-26.8, 25.5, 24.5-24, 19-18, 16.3, 14.6, 13.5-13.2, 12.4, 11, 9, 9.4-days for $A_1>0$ and 87, 69.4, 54, 45, 40.6, 31.3, 28.8, 27, 25.8-20.7, 19.2-19, 16, 15, 14.2, 13.7-13.2, 11.7-11, 10.8, 9.8-9, 8.6, 7.8- days foe $A_2>0$. The first negative solar period $A_1<0$ (not shown) has reflected periodicities 67-63, 46, 38.6-34.2, 31.3-30, 28.3, 27, 26, ~22.6, 18, 15.7-15.4, 13.8-13.6, 12.8-12.6, 9.4, 8-days. While the second negative polarity period $A_2<0$ (Fig. 1) representing the PSD has reflected periodicities

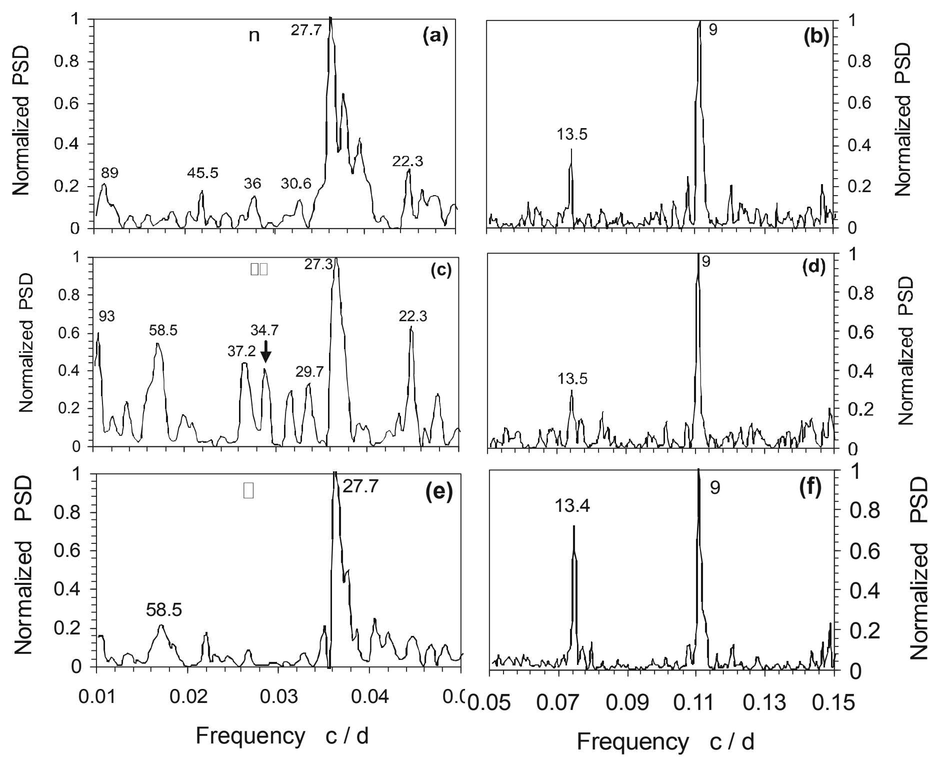

Fig. 1: PSD of: (a) n, (b) |B|, and (c) V during $A_2< 0$ (2002-2007). The frequency range is (0.01-0.15c/d ~6.7-100 d)

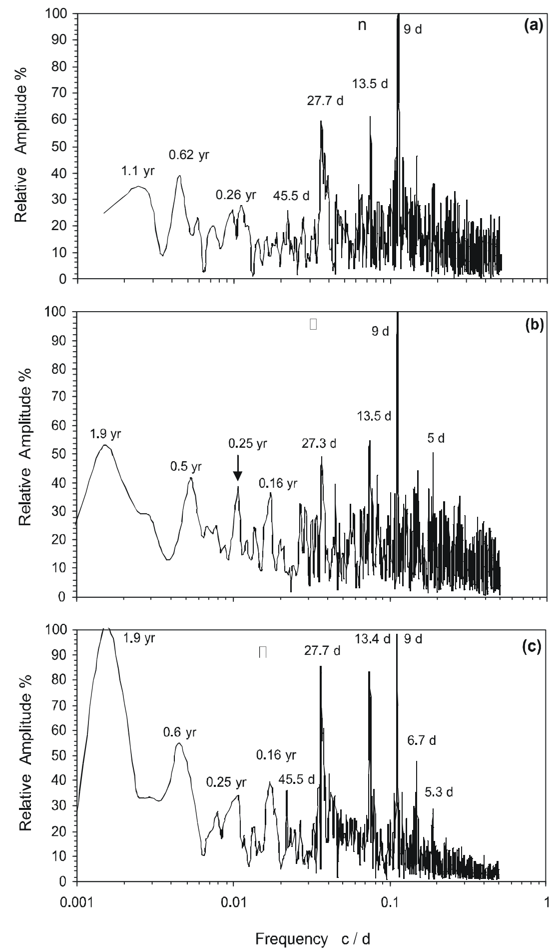

Fig. 2: PSD of: (a) n, (b) |B|, and (c) V during $A_2<0$ (2002-2007). The frequency range is (0.01-0.15 c d-1= 6.7-100 d).

at: 93, 89, 58.5, 45.5, 36- 37.2, 30.6, 29.7, 27.3-27.7, 22.3, 13.5 and 9-days. The powers of both ion density and solar wind speed (SWS) show low amplitudes through a periods range 30-d to 100-d (from 0.4 μHz to 0.11 μHz).

Fig. 2 displays the PSD (for the whole considered period) of ion density (n) (panel a), field magnitude |B| (panel b) and (SWS) (panel c) during $A_2<0$. Positive solar polarity period $A_1>0$ (not shown) has significant peaks at: 2.24, 1.6-1.4, 1.12- 1, 0.7- 0.8, 0.4-0.56, 0.22-0.35 yr and 24- 29.3, 29, 13.2 and 9-days. A periodicity of ~ 1-yr in the three parameters which caused by the earth's rotation. There is also some indication for the presence of a 1.6-yr periodicity in the field magnitude and the SWS. The spectrum of ion density and SWS indicate significant peaks at the solar rotation period (~27-d) and its two harmonics (13.5 and 9-d) while the spectra of field magnitude indicate weaker peaks. The second positive polarity $A_2>0$ (not shown and from which peaks) at: 2.24, 1.9, 1.4, 0.86-0.93 and 0.43-0.5-yr and 27-28.8, 13.7-14 and 9-day had been found. The 1.9-yr periodicity (the biennial variation) had been found in the field magnitude and SWS before in the neutron monitor data El-Borie [10]] and in the low- energy cosmic ray intensity in space Kolomeets, Mukanov and Shvartsman [11]. The nature of the highly correlated solar and geomagnetic oscillations is not yet understood. This result may indicate the possibility of the relation between the 2-yr variations in the cosmic- ray intensity and the 2-yr variation in the solar activity, a fact confirming the change of the variation with the asymptotic longitude Charakhchyan [12]. In this case the dependence of the polarity of the interplanetary medium with respect to the geomagnetic field can also play an important role. The obvious question is whether the periodicity of about 1.3- yr found in SWS is related to a fundamental oscillation related to structural changes on the sun. On the other hand, there exist two studies concerning solar-wind over long time's periods which show similar periods. The first study carried out Charakhchyan, Oklopkov and Oklopkova [13], for values of C_i, a measure of the disturbance of earth's magnetic field as determined from a ground- based magnetometer network, obtained between 1884 and 1964, from which it was found a 1.4-year variation in C_i, but at a marginal confidence level. The second study Shapiro [14], a power spectral analysis had been carried out for a data set of visual observations of aurora in Sweden between 1721 and 1943. This analysis found a peak at 1.4-years between a 90 and 95% confidence level. The importance of this 1.4-year peak varies with a roughly 65-year period, the phase of which would imply that this peak is of lesser importance in the current epoch, with a projected minimum in 1980. This variation may be consistent with the observations of solar wind described above in which the ~1.3-year oscillation is obvious only after 1987. The same periodicity had been also found in the total solar irradiance between the years 1980 and 1988 Silverman and Shapiro [15] which increasing the significance of this observation.

The 1.3-to 1.4-year oscillation corresponds to no obvious variation in the orientation of earth with respect to the solar wind, so by implication this period must correspond to a time scale for solar processes. Solar wind velocity structure is closely related to the magnetic topology of coronal holes and, in particular, to the divergence rate of magnetic flux tubes in the solar corona Pap, Tobiska and Bouwer [16]. Thus, there is a possibility that this period is related to the formation rate and life time

Table 1: Values of power-law index n of solar and interplanetary indices for solar magnetic polarities, as well as minimum and maximum periods

a	n	|B|	*V*	*aa*	Kp	Rz
A_1 >0(71 - 80)	0.8±0.016	0.53±0.01	0.96±0.019	0.83±0.016	0.92±0.018	0.95±0.019
A_1 < 0(81-91)	0.44±0.009	0.5±0.01	0.85±0.017	0.64±0.013	0.75±0.015	0.94±0.018
A_2 > 0(92-00)	0.67±0.013	0.86±0.017	1±0.02	0.9±0.018	0.97±0.019	0.73±0.014
A_2 < 0(02-07)	0.89±0.018	0.8±0.016	1±0.02	0.53±0.01	0.88±0.017	0.8±0.016
m_1 (75- 76);A > 0	0.78±0.015	0.6±0.012	1.5±0.03	1.15±0.023	1.5±0.03	0.94±0.019
m_2 (85- 86);A < 0	1±0.02	0.32±0.006	1±0.02	0.28±0.006	1±0.02	0.38±0.008
m_3 (94- 95);A > 0	0.3±0.006	0.93±0.019	0.56±0.011	1..26±0.025	1.25±0.025	0.38±0.008
M_1 (79- 80)	0.32±0.006	0.26±0.005	0.6±0.012	0.5±0.01	0.78±0.016	1.33±0.027
M_2 (89- 90)	0.1±0.002	1±0.02	0.24±0.005	0.62±0.012	1±0.02	0.97±0.019
M_3 (00- 01)	0.67±0.013	1.26±0.025	0.66±0.013	0.58±0.012	0.88±0.018	0.9±0.018

of such open magnetic structures, which in turn are determined by flux generation processes inside the sun and the subsequent transport of the erupted active- region flux over the solar surface Wang and Sheeley [17]. One should suggest that the observed periodicity of 0.8-yr in SWS spectrum is a harmonic of the 1.3-yr oscillation. A similar period of 0.63 ± 0.04-yr in the north- south component of the IMF had found Wang and Sheeley [18]. The connection between the observations of SWS and the B_z of the IMF shed some lights on the nature of these oscillations. A broad peak near 250- 280-days (0.68- 0.77-year) in the cosmic- ray power spectrum during the epoch 1964- 1995 had found Szabo, Lepping and King [19]. The spectrum analysis was carried out over a wide range of rigidities. These periodicities were attributed to changes in the coronal holes and solar active regions near coronal hole boundaries El-Borie [20].

A single power-law index approximation is appropriate for the whole frequency interval. A better approximation is a narrow interval of the frequencies. The power spectral density P (f) α f^{-n}, where n is the power law index and it was essentially used in describing the irregularity of the parameters n, |B| and V during positive and negative solar polarity epochs, respectively. In order to have a better look at the structure of the spectral density, we have designed the feedback digital filter method to eliminate the intense or/and persistent components. So, the resultant power spectra (after passing the digital filter) have been fitted with a straight line expressed by a single power law.

Table 1 represents the values of n, |B|, V, aa, Kp and Rz for positive and negative polarity epochs. The comparison between positive A>0 and negative A<0 solar polarity epochs for all parameters shows that for positive polarity epoch A_1>0 has a higher power index than that for negative polarity A_1<0. On the other hand, A_2>0 has a higher power index for |B|, aa and Kp.

Maximum and Minimum Solar Activity: The time of the minimum can obtained by using a smoothed average over 12 months of sunspot activity, so identifying the date of the solar minimum which can only happen usually 6 months after the minimum takes place.

Solar Minimum: Solar activity minima have periods as follows: m_1 (1975-1976), m_2 (1985-1986) and m_3(1994-1995). The normalized PSD Figures (hidden) for Solar parameters (aa, kp and Rz) for the solar minima m_1, m_2, m_3 and solar polarity A_1>0, A_1<0 and A_2>0 displayed that there are no significant peaks in aa and Kp during m_1 and m_3 (positive polarity) between 100-30-day. The most common periodicity for all cases is ~27-d variation and its two harmonics. The PSD of daily averages of solar parameters at different minimum solar activity periods m_1, m_2 and m_3 for polarity A_1>0, A_1<0 and A_2>0, (not shown) show that the most significant peaks are at: 341, 205 (~ 0.5- yr), 171, 102- 128, 73- 79, 60- 68 and 51- 54- days. El-Borie and Al-Thoyaib [21] discovered that the 154- day and related periodicities of 51, 78, 104 and 129-days of solar activity are sub- harmonics of a fundamental period of 25.8 days. In their study the cause of 154-day periodicity remains unknown, suggesting that it may be related to enhance flare activity in certain longitude bands. Mursula and Zieger [22] also reported that 51- day and 150- 157-day periods are more pronounced in solar data which are related to a strong magnetic field. El- Borie [23] reported that the 170-day periodicity of cosmic rays in is related to a strong magnetic field, it was interpreted in the base of six solar rotations and may be connected to the instability of the solar core. This means that six solar rotations is the duration for energy build- up time to produce strong magnetic field. Accordingly, we can conclude that a 150- 170-day period is related to a strong magnetic field.

Some evidence for the presence of intermediate- term periodicities around 323- days and 18 months which had been identified by several authors. Concerning the periodicity at 323-days, Bai [24] who studied the monthly mean Zürich relative sunspot number from 1749 to 1979 and found a peak in his Fourier spectrum at 36.3 nHz (˜319-days). However, Joshi [25] pointed out that the prominence of this peak due to the running- mean smoothing and normalization of the time series is partly an artifact. Wolf [26] had found this peak in the power spectrum of the solar diameter measurements from 1975 to 1984. Hudson [27] had found it to be significant in the power spectrum of the sunspot blocking function the 10.7 cm radio flux, the Ca I IK plage index and Zürich sunspot number, during cycle 21. Delache, Laclare and Sadsoud [28] claim the existence of a periodicity between 240- 330-days in the 10.7 cm radio flux (1947- 1989). Oliver, Carbonell and Ballester [29] studied the intermediate-term periodicities in solar activity had studied the results obtained indicate that the existence of a periodicity at 323-days was only confirmed for solar cycle 21, while its presence throughout the historical record of solar activity is very doubtful. A peak at 351 days can be found with very high significance in the periodograms of whole sunspot area and Zürich sunspot number for the period 1878- 1982 (cycles 12- 21) and, when individual cycles are considered, it was found, near that period in sunspot area and Zürich sunspot number of cycles 14, 16, 17 and 18. The only confirmation for its presence comes from the sunspot blocking function Lean and Brueckner [30], which is proportional to sun spot areas. Our results confirm the existence of a periodicity around 340-days in aa during m_1 and has a higher amplitude than that found in aa during m_3. Also, the same variation found in Kp indices during m_1 solar activity periods. The ~27-d variation and its two harmonics are common for all solar parameters and all three cases.

Table (1) shows the values of the power index for interplanetary and solar indices during minimum solar activity epochs m_1, m_2 and m_3 and solar polarity $A<0$, $A_2>0$ and $A_1>0$, respectively. We found that the power law index (n) for Rz has the highest value for all solar minima cases and solar polarities.

Solar Maximum: Figs. (3-5) represent the PSD of aa (panel a), Kp (panel b) and R_z (panel c) during maximum solar activity years [M_1(1979-80), M_2(1989-90) and M_3(2000-01)] in the frequency range (0.001-1 c/d). The plots confirmed the peak 341-day in sunspot numbers during M_1 and M_2 epochs which has been observed in aa

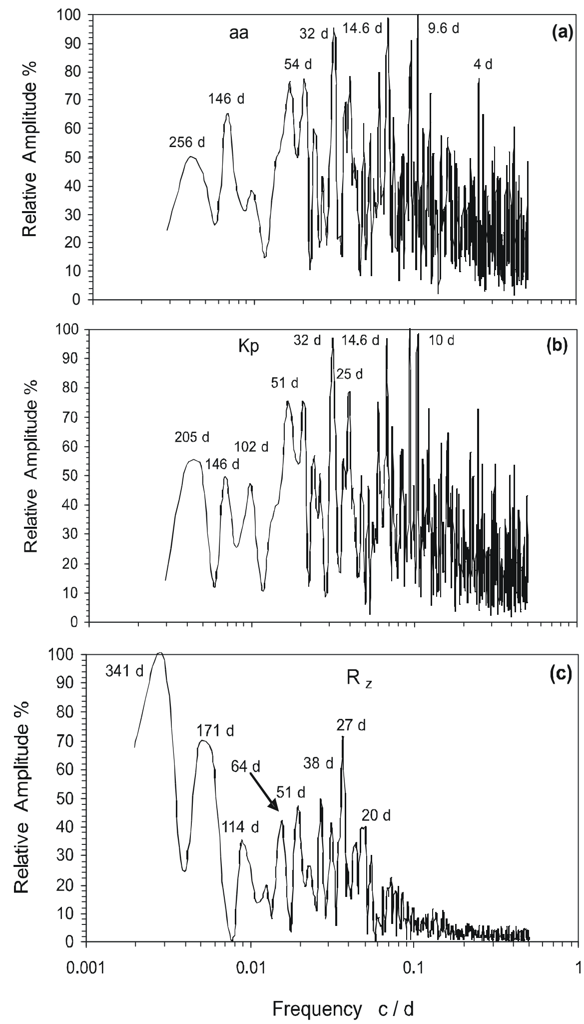

Fig. 3: PSD of: (a) *aa*, (b) *Kp*, and (c) Rz during maximum solar activity M_1 (1979-1980).

index during solar activity minimum (m_1 and m_3) and Kp index during m_1 only. The 171-d fluctuation is a common periodicity in Rz during M_1 and also,in aa and Kp indicies during M_2 and M_3. This 171-d fluctuation has been observed during solar minima m_1 and m_3 in aa and Kp indices, while it has been found during solar minims m_2 in Rz. Results also, indicated a flat spectrum for frequencies = 0.12d-1 only in Rz, while high peaks are found in aa and Kp indices during maximum periods.

Table (1) shows the values of the power law index n for interplanetary and solar indices during maximum solar activity epochs M_1, M_2 and M_3 respectively. We note that the power law index n during M_2 (89-90) has a higher value than M_1(79-80) and M_3(00-1) for all parameters. The n values of sunspot number during M_1, M_2 and M_3 have a maximum value.

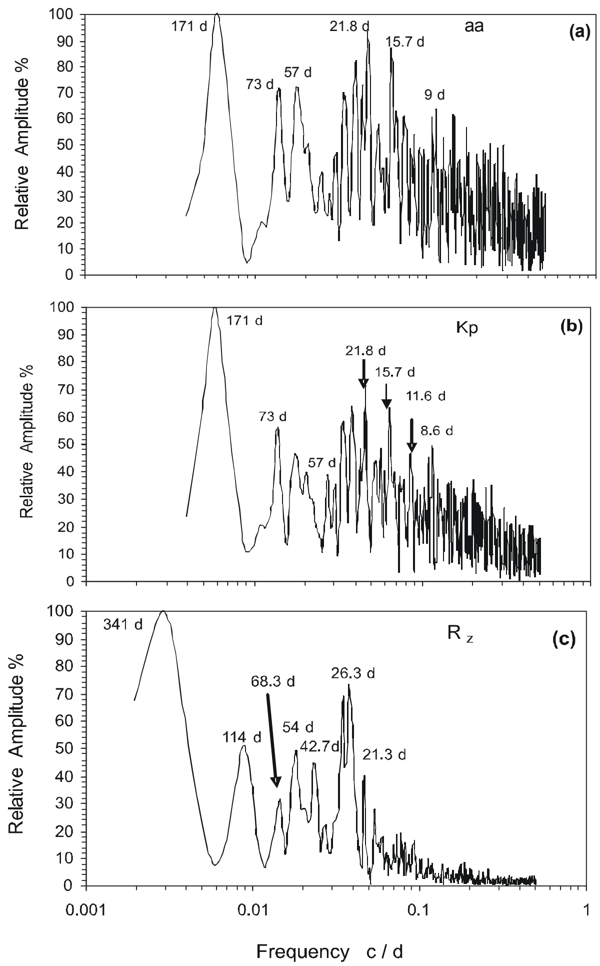

Fig. 4: PSD of: (a) *aa*, (b) *Kp*, and (c) Rz during maximum solar activity M_2 (1989-1990).

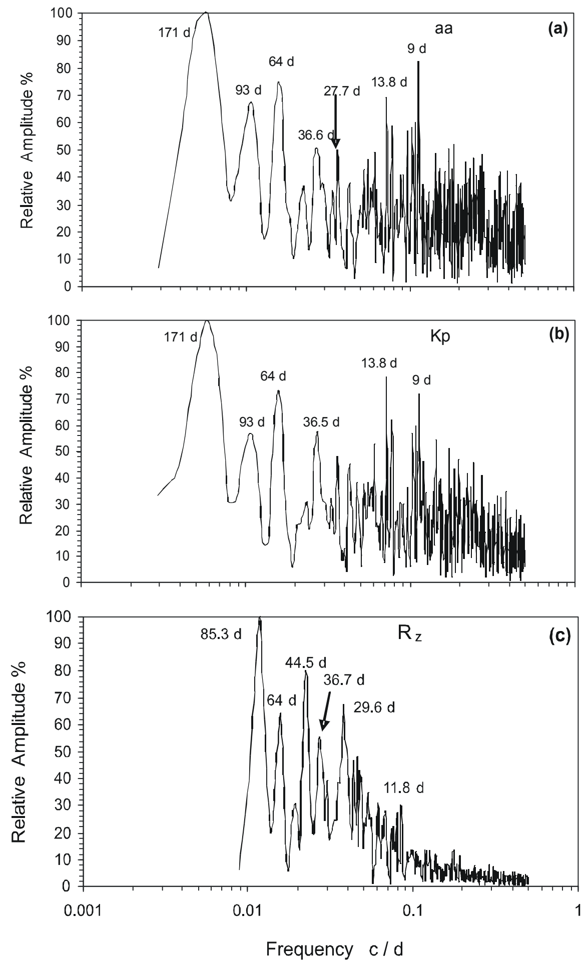

Fig. 5: PSD of: (a) *aa*, (b) *Kp*, and (c) Rz during maximum solar activity M_3 (2000-2001).

CONCLUSION

The spectral analyses of daily average of interplanetary and solar parameters have been studied to present a comprehensive description of the behavior of spectral density distribution in a wide range of frequency from (1×10^{-2}-15×10^{-2} c d^{-1}) during positive and negative polarity periods. The PSD of both ion density and SWS for A>0 and A<0 displayed low amplitudes during the period range of 30 to 100 days. The comparison of PSDs for A>0 and A<0 epochs has reflected the dependence of polarity of the interplanetary medium to geomagnetic field. The~1.3 variation found in SWS is related to a fundamental oscillation for structure changes on the Sun. For the A<0 epochs specifically for A_1<0 epoch periodicity of around one year caused by Earth rotation and its harmonic at 0.5 yr is more pronounced in the ion density and SWS than that in the field magnitude |B|. The (~27-d) and its harmonics are found only in the ion density and SWS. For A_2<0 epoch 1.9- yr variation in SWS (V) is more pronounced than in |B| while, this variation vanished in (n). The comparison between A>0 and A<0 solar polarity epochs for all parameters declares that the A_1<0 has a higher power index value-n than that for the A_2>0. The PSD for solar minima activity m_1 and m_3 (A>0) reflected no significant peaks in aa and Kp indices from 100-30-day. The observed variation 150-170-day period is related to a strong magnetic field as obtained before by several authors. The 171-d fluctuation is found in aa and Kp spectra during minima solar activity m_1 and m_3 while, in Rz spectrum is found only during m_2. The same fluctuation is observed in Rz, aa and Kp spectra during M_1 and in aa and Kp spectra during M_3. A periodicity around 340-days is found in aa spectrum during m_1 has a higher amplitude than that found in aa during m_3 while, it is found in Kp spectrum during m_1.

During solar maxima M_1 and M_2 the same periodicity is found in Rz. The~27-d variation and its two harmonics are common for all solar parameters during minima solar activity and for A>0, A<0 epochs. Finally, Rz has the highest n-value of the power index during minima solar activity. While, the power law index value-n during maximum solar activity M_2 has a higher value than M_1 and M_3. The n-values of sunspot number Rz during maxima solar activity have a maximum value than others.

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