Periodicities in solar activity and their signature in the terrestrial environment

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Abstract. Solar output and activity exhibit periodic variations in a wide range of time scales. Investigation of the patterns of these periodicities and their evolution, at various regions in the Sun, interplanetary medium and Earth, can reveal different aspects of solar terrestrial relation. Identification of the patterns of these periodicities may also provide a tool for space weather prediction. Some of these periods in the solar terrestrial parameters are present intermittently and some vary with time. These periodicities are separated into short-term, mid-term and long-term types depending on the length of their periods. Short term periodicities and their evolution are attributed to the solar rotation, evolution of active regions and the outflow of solar wind. Rapid time evolution of dominant active regions on the solar surface in successive Carrington rotations may cause the wider spectral lines. The spectral widths of short periods are narrow in IMF components and wider in solar wind parameters and sunspots. The short period oscillations are more pronounced during the sunspot maximum in sunspot numbers. In solar wind parameters, they are stronger during the declining phase of solar cycle, since the solar active regions and the magnetic fields are better organized and long lived during this period. The mid-term periods, 154 d and the 1.3 y periods observed in various solar and interplanetary parameters show how the variations differential rotation and the evolution of solar dynamo linked with solar surface, interplanetary and terrestrial parameters. The investigation of semiannual and annual variations in solar terrestrial parameters reveals the geoeffectiveness of solar wind structures in causing geomagnetic activity and the relative roles of solar dipole cycle, Rosenberg-Coleman effect and Russell-McPherron effect. Though the most prominent long term periodicity is the sunspot cycle, the 16 y global cycle has its signature on the solar wind, IMF and geomagnetic activity. The geomagnetic activity and ionosperic parameters are found to respond to the periodicities exhibited by solar activity and solar wind plasma.

Index Terms. Solar activity, solar periodicities, solar wind, IMF, geomagnetic activity, ionospheric temperature.

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1. Introduction

The solar terrestrial environment is continuously changing due the high variability in the energy input from the Sun. Most of these solar variations have their signature in the interplanetary medium and in the terrestrial environment. The periodic variations in the solar-terrestrial environment have been studied extensively ever since the discovery of the solar rotation and the 11-year periodicity in the sunspot numbers. The appearance and evolution of the active regions observed on the Sun depends on the physical condition, location of the region and the general level of solar activity. The lifetime of such regions depend on their size and ranges from a few seconds to decades.

The observed periodicities in solar environment are grouped into short-term, mid-term and long-term types. Short-term periods are associated with the rotation of active longitudes or magnetic field structures (Mursula and Zieger, 1996; Ivanov and Obridko, 2002; Nayar et al., 2001, 2002). The characteristics of the active regions are carried out to the interplanetary medium and to the terrestrial environment due to solar rotation and the outflow of solar wind. The uncertainties in the rotation period depend on the lifetime, latitudinal and longitudinal extensions of the active region. The mid-term periods, mainly 154 d, 180 d, 1y and 1.3 y are associated with solar dynamo, emergence of magnetic flux and the excursion of Earth in heliolatitude. The long term periods, in general, are related to the evolution of large scale solar magnetic field and observed as sunspot cycle, dipole cycle, global solar cycle or Hale cycle.

The prolonged solar cycle of solar magnetic field is made up of the dipole cycle and the following out-of-phase sunspot cycle (Legrand and Simon, 1991). Since the observation of sunspot numbers and the geomagnetic activity are available over a long duration, the periodicities in them and their evolution have been studied extensively (Fraser-Smith, 1972; Gonzalez et al., 1993; Nayar et al., 2002). Though the periodicity happens to be the same for different parameters, the physical process or region associated with them need not be the same (Donnelly and Puga, 1990; Kane, 2002). Most of the periodicities evolve on a longer time scale or occur intermittently. The large scale organization of the interplanetary magnetic field and dominant polarity regions are decided by the solar magnetic multipoles. The presence of higher order solar magnetic multipoles causes asymmetry between north and south magnetic hemispheres. This results in the north-south offset of the heliospheric current sheet and the organization of solar wind (Girish and Nayar, 1988). In this work, the sources and characteristics of periodicities present in the solar surface and their signature in the interplanetary medium and terrestrial parameters are studied. The solar terrestrial parameters are analyzed using the Lomb-Scargle method and the wavelet technique; the natures of periodicities present in them are discussed.

2. Short term periodicities

The most prominent short term periodic variation in the solar terrestrial parameters is the one associated with the solar rotation (sidereal 25.38 d). The Carrington rotation period (27.275 d) specifies the solar rotation observed on Earth. The uncertainty obtained in the 27 d period suggests the presence of other mechanisms active on the solar surface, in addition to rotation. The solar active regions may emerge or disappear rapidly causing longitudinal shift in their position on the solar surface (Kane, 2003). If the active region structure is long lived, the 27 d periodicity will be sharper in the spectrum of the parameter considered. If multiple active regions are present, and if the two regions are diametrically opposite, the related parameters exhibit a period less than 27 d. The tilting of the dipole axis and warping of the heliospheric current sheet (HCS) can also introduce multiple dominant polarity regions around the solar equator. The distribution of magnetic structures and active regions on the solar surface, and the outflow of solar wind associated with these regions introduce a variety of short period variations, with periods less than 27 d, in the interplanetary medium.

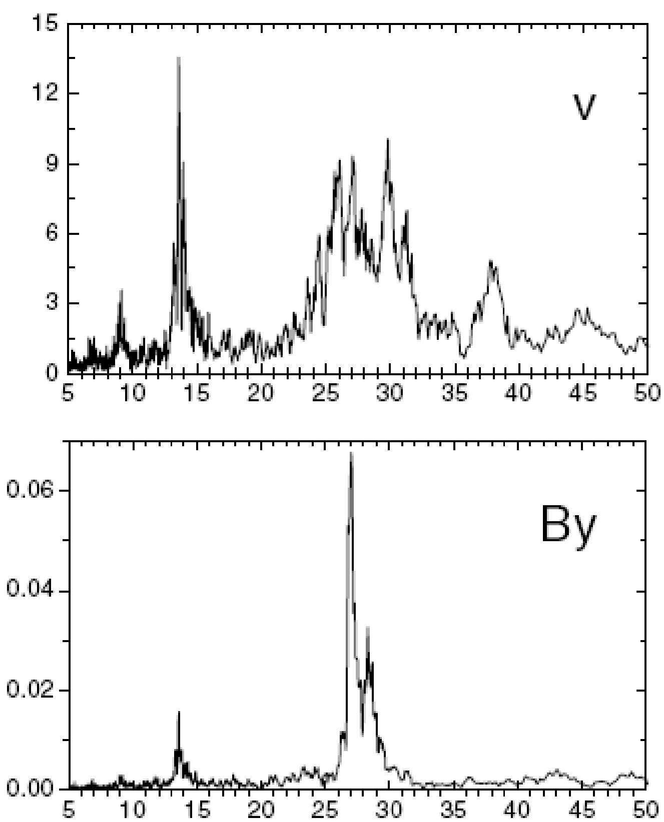

Fig. 1. Fourier spectrum of solar wind velocity (top) and IMF By component (bottom). The x-axis indicates the period in days and Y-axis power in arbitrary units.

The Fourier spectra of solar wind velocity and IMF By component are depicted in Fig. 1. The spectral peak of solar wind velocity around 27 d is wide and distributed over a range 22-32 d. In the case of the spectrum of IMF By component, the spectral peak around 27 d is very sharp. The comparison of these two spectra indicate that the solar wind sources associated with the 27 d peak undergo rapid evolution or have multiple sources, and the associated By are long lived. Thus the formation of new active regions at widely separated longitudes can result in uncertainty in the rotational periods.

The rotation rate decreases with latitude and increases when passing from solar maximum to minimum (Baranyi and Ludmany, 2003). The 27 d and 13.5 d periods are the prominent oscillations in the short period range. The 13.5 d period is associated with both active longitudes and tilted dipole structure. The 27 d and 13.5 d periods are observed in most of the solar terrestrial parameters. Both these periods are observed in solar wind, IMF, solar emissions, plages, sunspot area, sunspot number, emergence of solar magnetic flux, geomagnetic activity, ionospheric parameters etc. (Mursula and Zieger, 2000; Nayar et al., 2001; 2002; 2004). Donelly and Puga (1990) made an extensive study of the 13.5 d periodicity at several wavelengths of solar radiation and found that the power of the 13.5 d period is dependent on the wavelength or the source at the solar surface. Bai (2003) studied longitudinal distributions of flares during solar cycles 19 to 23 and identified active longitudes (hotspots), causing flare periods ranging from 25 to 29 d. The 27 d solar rotation period is more pronounced in the declining phase of a solar cycle.

Fig. 2 depicts the wavelet spectrum generated by using sunspot number and solar wind velocity data during 1964-2003. The amplitude of the short periods in sunspot number exhibits larger power around solar maximum and lower power around minimum period.

The evolution of the wavelet power of solar wind velocity is found to be different from that of sunspot number. Solar wind sources are decided by the local solar magnetic field geometry, coronal holes and CME. The solar wind during solar maximum is generally dominated by the slow solar wind which is emitted from the many streamer belts that may coexist all over the solar surface during solar maximum. After the solar maximum, the polar coronal holes reappear corresponding to the reversal in the direction of the global magnetic field after the solar maximum. During the declining phase of the solar cycle, the polar coronal holes often tend toward the solar mid-latitudes, leading to a strongly tilted streamer belt and HCS. Such a period is called the excursion phase and leads to a strong variation of solar wind properties either once or twice during one solar rotation. During the declining phase and minimum, the streamer belt is systematically displaced from the equator, which means that the heliosphere is north-south asymmetric at these times. It had been known for many decades that the declining phase of sunspot cycle was dominated by recurrent streams which were not prominent during the ascending phase or at maxima. In addition, the size of the hourly average southward component of the IMF had characteristic variation that more or less

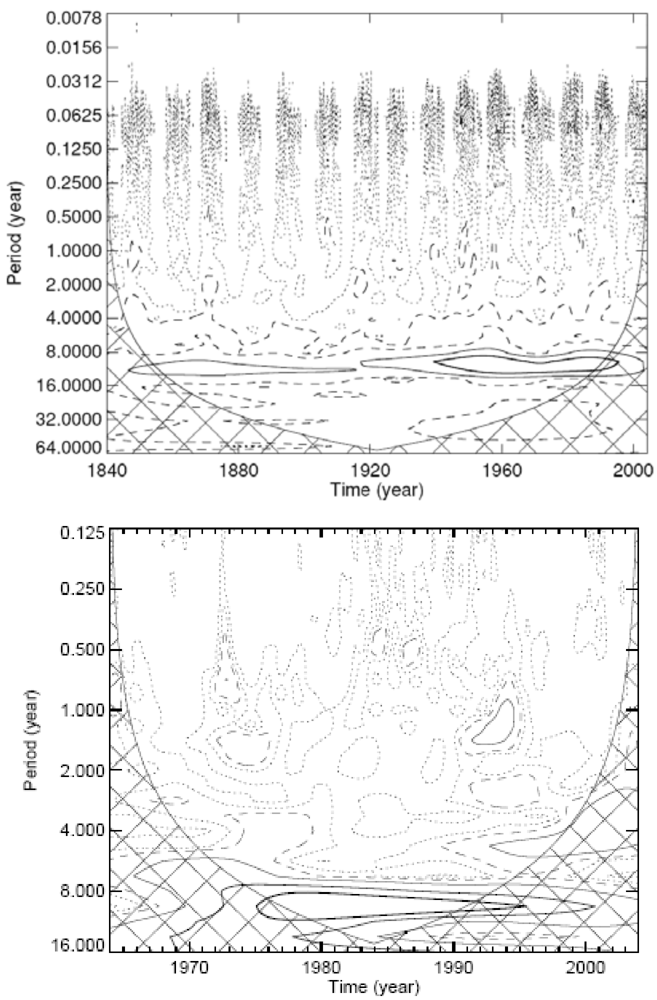

Fig. 2. Wavelet spectrum of sunspot number (top) during 1840 to 2003 and solar wind velocity (bottom) data during 1965-2003.

followed the sunspot number (Keating et al., 2001). Fisher and Sime (1984) considered the relation between the rotation rate and the phase of solar cycle and found that the rotation rate is related to the level of solar activity. One possible interpretation of the multiple peak nature in the short-term periods is differential rotation. Significant power in the 27-30 d range indicates that the sources of high-speed solar wind streams should be seen at all solar longitudes if observations are made over an interval of several years. As a rule, rotational modes with a period of 27.8 - 30.0 d dominate the phase of rising activity, whereas the mode with a period of 27 d dominates the phase of decreasing activity. The amplitude of quasi-periodicities in various solar parameters may change from maximum to minimum in a characteristic way associated with the development of active regions on the solar surface during different solar cycles. In addition, the presence of coronal holes near the solar equatorial region introduces high-speed, low-density regions in the solar wind. Polar coronal holes are regions of high-speed solar wind. The location and size of coronal holes vary dramatically over the solar cycle, expanding toward the heliomagnetic equator in the declining phase and contracting to polar regions in the ascending phase. Thus, during the declining phase, the width of the equatorial low speed belt decreases, developing larger heliomagnetic latitudinal gradients in solar wind speed. During solar maximum years, the coronal holes retreat back to the poles, and therefore no stable regions of high-speed solar wind exist around the heliomagnetic equator which is closer to the ecliptic. During solar maximum, the solar wind speed gradients around HCS are smaller than that in the late declining phase (Newkirk and Fisk, 1985). Changes can also occur in the relative amplitude and positions of solar wind streams. Thus, for understanding the evolution of active regions on the solar surface, it is important to examine the stability of periods and how the variation of amplitudes of such periodicities change with different phases of the solar cycle. The wavelet method provides an important tool to study such time evolutions. Periodicities like 13.5 d and 27 d are common to all parameters and some exhibit time evolutions with the phase of the solar cycle. The spectral power of 13.5 d period in solar wind velocity is large and confined to a narrow band of periods. This periodicity has maximum strength during the second half of the declining phase of the solar cycles 20, 21 and 22.

3. Midterm periodicities

Most prominent medium scale periodicities are the 154 d Rieger period, 180 d semiannual period, annual period and the 1.3 y period. While the 154 d period is found to be related to the newly emerging magnetic flux on the solar surface (Oliver et al., 1998), the 1.3 y period is related to the variation in the rotation rate at the bottom of the solar convection zone (Howe et al., 2000). The annual period is associated with the excursion of Earth in the heliolatitude known as the Rosenberg-Coleman effect (Rosenberg and Coleman, 1969). The 154 d periodicity was discovered (Rieger et al., 1984) in the occurrence rate of g-ray flares observed by the gamma-ray spectrometer onboard the Solar Maximum Mission satellite. Subsequently, this period was found in various solar flare activities and sunspot areas or groups around the solar maximum and have been extensively monitored using different wavelengths. The 154 day period has also been detected in many indicators of solar activity, such as solar wind velocity, IMF and geomagnetic activity. The exact period is found to vary between 140 d and 170 d. There is a slow drift in the position of this period over the centuries (Silverman, 1990). Richardson and Cane (2005) studied this periodicity in solar and interplanetary activity levels during solar cycle 23 and found that, this period present only intermittently, and also varied in period. The 154 d periodicity appears to be associated preferentially with regions on the solar disk of compact magnetic field structures associated with sunspots rather than in the more dispersed weaker magnetic field and thus it may be confined to complex active regions containing large spots called 'super active regions'. The Voyager 1 has detected this periodicity in cosmic ray fluxes in the outer reaches of the heliosphere.

Fig. 3 depicts the Lomb-Scargle spectrum of solar wind velocity data during 1964-2003. The horizontal line indicates the 90% confidence level. The 9 d, 13.5 d, and 27 d periods are significant in the short period range. The 13.5 day period has larger power than the 27 d period. The 154 d, 180 d, 1 y and 1.3 y periods are the prominent periods in the mid-term level. In the long period range, the peaks occur at 9.6 y and 16 y. In the solar wind velocity spectrum, the power in the long period range is much larger than that associated with short period and mid term periods.

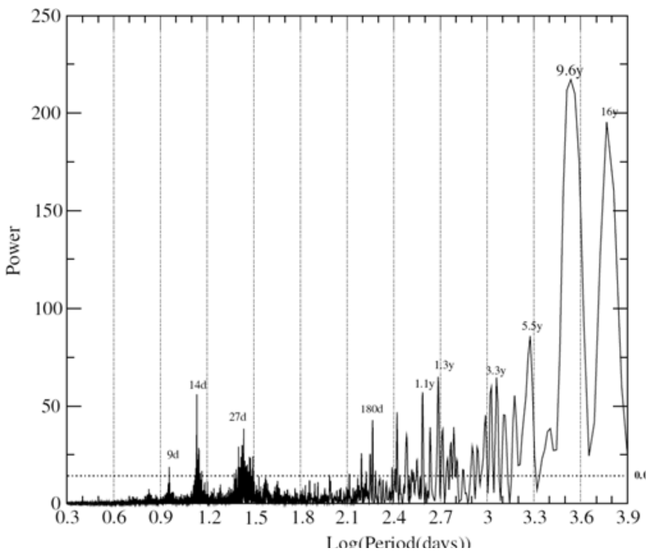

Fig. 3. Spectrum of solar wind velocity (1964-2003). The periods corresponding to spectral peaks are indicated.

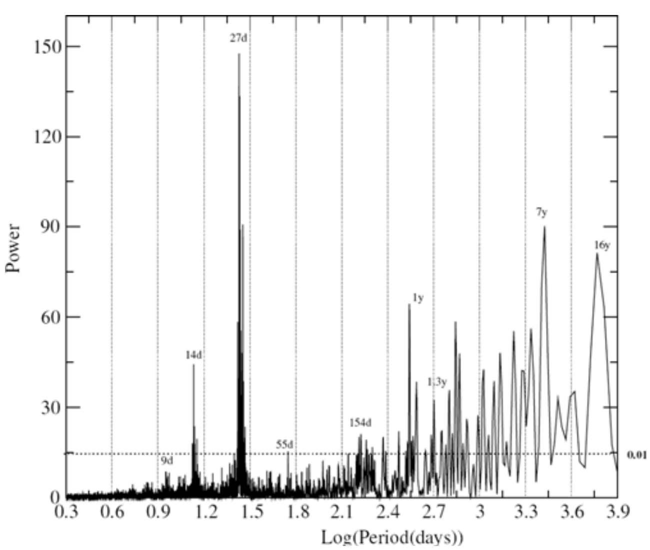

Fig. 4. Spectrum of IMF By (1964-2003). The periods corresponding to spectral peaks are indicated.

Fig. 4 presents the Lomb-Scargle spectrum of IMF By component using the data during 1964-2003. The horizontal line indicates the 90% confidence level. For IMF By, the 27 day period has largest power in the spectrum. This result indicates that large scale solar magnetic field, which decides the IMF, display more rigid rotation than other active centers including sunspots. The 154 d, 180 d, 1 y and 1.3 y periods in IMF By are the prominent periods in the mid-term level. The semiannual peak is not prominent in the By spectrum compared to that in solar wind velocity. In the long period range the 16 y period is the prominent peak. The investigation showed that the solar cycle period is absent for both the ecliptic components of IMF Bx and By. Whereas in the north-south IMF component Bz, the solar cycle period is the most prominent variation and it is possible to predict the Bz component as in the case of sunspot number (Keating et al., 2001). Fig. 5. depicts the wavelet spectrum of IMF By component. For generating wavelet spectrum in Fig.5, the short period variations are removed by taking 27 day average of the By data. The evolution of 154 d and 1.3 y periods are marked with horizontal lines in Fig. 5. It is noticed that the amplitude of both the periods evolve with time. The 154 d periodicity has been time coincident with a periodic emergence of magnetic flux (Oliver et al., 1998) which appears around the solar maximum period and may be associated with equatorially trapped Rossby-type waves at the solar interior.

Richardson et al. (1994) observed a strong periodicity about 1.3 y in solar wind speed by using IMP-8 and Voyager 2 observations. A similar period is also seen in the Bz components of IMF (Szabo et al., 1995), solar wind velocity and geomagnetic activity (Mursula and Zieger, 2000; Nayar et al., 2002). Howe et al. (2000) found a 1.3-y periodicity in the variation of the solar rotation rate at the bottom of the convection layer, suggesting that the 1.3 y periodicity is a fundamental property related to the solar dynamo. A slightly longer periodicity of about 1.7 y was observed in cosmic rays during cycle 21 by Valdes-Galicia et al. (1996). This period has been identified in solar wind speed, north-south component of IMF and geomagnetic activity (Gazis et al., 1995; Szabo et al., 1995; Paularena et al., 1995; Nayar et al., 2002). A strong 1.3 y variation in solar wind speed occurs concurrently at different heliocentric distances around the ecliptic. The power in both 154 d and 1.3 y periods is found to follow the total number of sunspots and both vary approximately in phase. Krivova and Solanki (2002) made a detailed analysis of the sunspot number data using wavelet analysis and found significant power at all multiplets of 1.3 y up to 10.4 y, which is nearly equal to the period of the solar cycle.

The ecliptic IMF components Bx and By exhibit a strong annual oscillation. Due to the 7.2^0 tilt of the solar rotation axis with respect to the normal of ecliptic, the Earth reaches the highest northern and southern heliographic latitude on September 6 and March 5, respectively. Since the solar wind velocity increases with heliographic latitude, the solar wind velocity exhibit maximum around September 6 and March 5.

Bolton (1990) reported one year variations in solar wind velocity and ion density. The annual variation in the Bx and By components are due to this dominant polarity regions observed by the Earth due to its excursion to higher heliolatitudes. The 155 d periodicity is stronger in cycle 21 for sunspot number than in other cycles. The chromospheric activity was significantly higher during solar cycle 21 as compared to the preceding cycle (Ozguc and Atac, 1989). This variation is manifested in the 154 d periodicity of Ap index and solar wind velocity also.

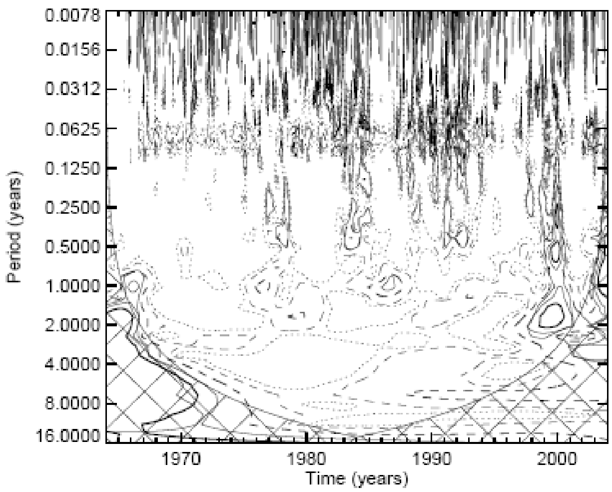

Fig. 5. Wavelet spectrum of IMF By component. The horizontal lines correspond to periods 154 days and 1.3 years.

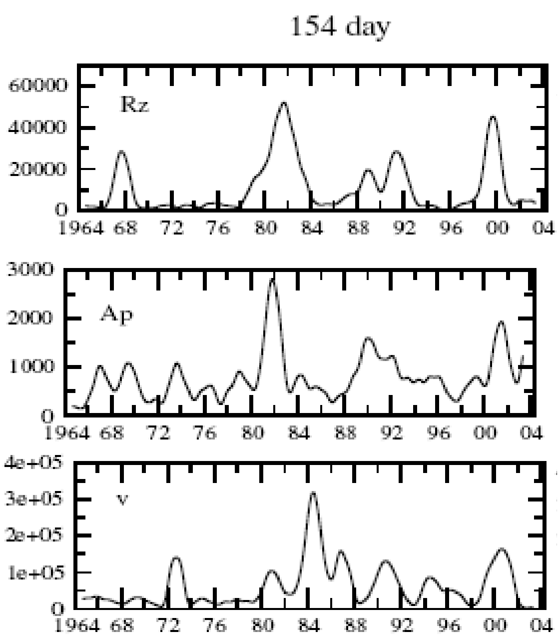

Fig. 6. Evolution of the wavelet power of 154 d period in sunspot number (top), solar wind velocity (middle) and Ap index (bottom) during 1964 to 2003.

For sunspot number, the wavelet power of periods less than one year show a cyclic evolution with the phase of the solar cycle. According to Bai and Sturrock (1987), the 154 d periodicity is a global phenomenon and therefore the underlying cause of this periodicity must be a mechanism involving the whole Sun. Bai and Cliver (1990) studied proton flare data during 1958-1986 and concluded that the 154 d periodicity was dominant during 1958-1971 and 1978-1983. The sunspot number, solar wind velocity and Ap index depicted in Fig.6 exhibit dominant 154 d period during 1978-1983 in agreement with the observation of Bai and Cliver (1990). The solar wind velocity exhibits a prominent 154 day period around 1973 and 1985. Similarly, the 1.3 year period in the solar wind velocity reaches maximum around 1973 and 1992 as in the case of Ap index. To test whether solar rotation rate variations have significant impact on the solar dynamo, Krivova and Solanki (2002) analyzed sunspot area and sunspot numbers as representative of emerging solar surface magnetic field. The fluctuation in the dynamo process will manifest itself most clearly in relatively freshly emerged flux. They found that the 154 d period varied approximately in phase with 1.3 y period and the power in both approximately follow the total number of sunspots.

4. Long scale periodicities

The most important index of long period solar activity has been the sunspot numbers. The sunspot number is used to represent the level of solar activity since it correlate extremely well with various physical measures of solar activity. Each solar cycle is unique in intensity, duration, and distribution of activity. At the beginning of the sunspot cycle, the solar magnetic field is predominantly dipolar which is almost aligned with its rotation axis. The dipole strength vanishes around the solar maximum and reverses its polarity about one year after the maximum. In the declining phase of the solar cycle, the dipole field is restored with polarity in the opposite direction. The dipole strength has a cyclic variation known as dipole cycle. The dipole cycle is more important in deciding the evolution of large scale solar magnetic field. If we take into account the reversal of the magnetic polarity of the Sun, the magnetic cycle repeats every 22 y and is known as the Hale cycle. The period of the sunspot cycle is not constant, but varies both in cycle length (9.5-12.5 y) and maximum amplitude Ochadlick et al. (1993). The uncertainty in the period of sunspot number is noticed from the spectral width of the solar cycle period in Fig. 7. The sunspot cycle period is seen in the data of solar wind velocity, IMF, geomagnetic activity and many other terrestrial parameters (Fig. 8). The solar wind has a variety of sources like coronal holes, CME etc. which occur at different phase difference with sunspot cycle. Similarly the ecliptic IMF components are decided by the solar dipole variations. This results in both the shift of period and variation in amplitude of the solar cycle period in solar wind and IMF. However, The IMF Bz component exhibits strong solar cycle period and hence the mean magnitude of Bz can be predicted (Keating et al., 2001).

The prolonged global activity cycle (Markov and Silverman, 1989) with period 16 to 18 y is associate with coronal hole topology and manifested in the distribution of open magnetic field structures. The global solar cycle with period around 16 y is prominent in the ecliptic IMF components (Fig. 4), solar wind (Fig. 3) and geomagnetic activity (Fig. 8). Juckett (1998) observed a dominant 16–17 yr periodicity in the net exposure times of the Earth to Toward and Away field directions of the interplanetary magnetic field. The 16 y solar cycle is a fundamental oscillation of the coronal hole topology, which is transferred to Earth via variations in the HCS. The wavelet decomposition analysis also exhibits the presence of a 33 year variation in all the solar terrestrial parameters with a minimum amplitude centered around 1997. This period is intermittent and has an unstable behavior in solar and solar-terrestrial phenomena (Ochadlick et al., 1993). Maravilla et al. (2001) observed this period in both coronal hole area and sunspot numbers. The origin of this fluctuation remains unknown. It could be due to interaction of the lower frequency cyclic phenomena.

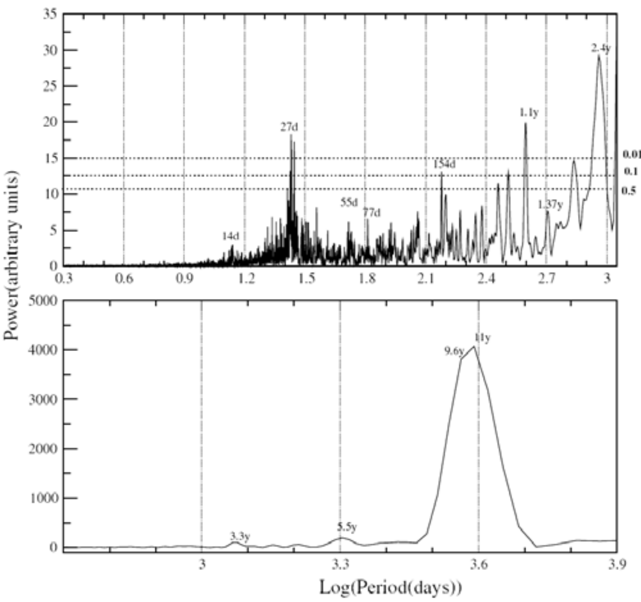

Fig. 7. The Lomb-Scargle spectrum of sunspot numbers data during 1964 to 2003.

5. Periodicities in geomagnetic activity

Since the solar radiation, solar wind velocity and IMF are commonly used as input to model geomagnetic activity, it is natural to observe the periodicities observed in solar activity and solar wind in geomagnetic activity also. In geomagnetic activity, the most prominent period is the one associated with sunspot cycle. Most of the geo-effective solar parameters contribute to this period. From Fig. 8, it is noticed that the geomagnetic activity depicts a variety of periodicity from short-scale to mid-term and long-scale periodicities. The solar rotation period has uncertainty with period over a wider range of 27 d. The 9 d and 14 d periods are very sharp and have greater significance. These two periods are associated with dominant magnetic polarity sectors which have longer lifetime compared to other active regions. Periodicities like180 d, 1.3 y, 5.5 y, 10.4 y and the 16 y periods are significant in the spectrum. The Ap index exhibit a prominent semi annual variation. The amplitude of the semi annual variation is most prominent during the declining phase of solar activity. The semiannual period is one of the earliest recognized patterns in geomagnetic activity. The highest heliospheric latitude position of Earth is on 7 March, when it is on southern heliosphere, and on 9 September, when it is at the northern heliosphere. Since at these two latitudes, the solar wind velocity tends to be higher, Earth faces higher velocity solar wind and higher geomagnetic activity. As the heliolatitude of Earth increases, there is a statistical tendency to be in polarity (dominant polarity) of the corresponding hemisphere (Rosenberg and Coleman, 1969). Since the dominant polarity of the hemisphere is decided by the By component of IMF, Earth experiences two opposite annual variations according to positive and negative By. The semiannual variation has been attributed to geo-effectiveness of the solar wind/IMF and explained in terms of the transformation of magnetic field orientation from GSE to GSM system (Russell and McPherron, 1973).

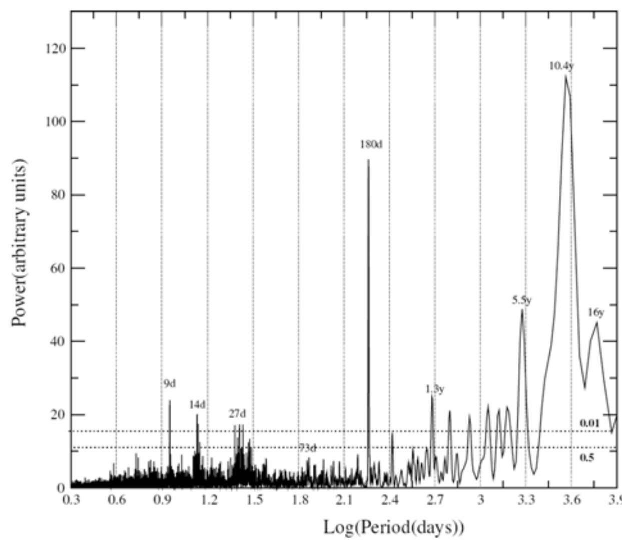

Fig. 8. Lomb-Scargle power spectrum of geomagnetic activity index Ap.

The 1.3 year period in Ap show that the changes occurring at the bottom of the solar convection zone leave signatures on the terrestrial environment. The 1.3 y period peaks around 1973 and 1992 during the solar cycles 20 and 22 (Fig. 6). In geomagnetic activity, since the semiannual period is very dominant, it is difficult to separate out the 154 day period. The annual period is also strong in geomagnetic activity. The annual variation has maximum amplitude around the sunspot minimum and its phase reverses after the solar maximum. (Zieger and Mursula, 1998). The 11 year variation in Ap is most prominent during the solar cycle 22. Long period variations in geomagnetic activity are in general related to the large scale structure of the heliospheric magnetic field and the organization of solar wind plasma. The relative orientation of the Sun-Earth system also controls the periodic variations. The large scale structure of the heliospheric magnetic field depends on the solar dipole magnitude, orientation and their cyclic variation called dipole cycle. The periodicity of the high-speed streams is controlled by the dipole cycle, which has a phase lag with the sunspot cycle. Geomagnetic activity is dominated by high-speed streams, and the CME related structures contribute only a small percentage. Legrand and Simon (1991) showed that the integral solar of period ~ 16 y is made up of a dipole cycle of length 11 y and part of the following out-of-phase cycle. The source of enhanced solar wind velocity and geomagnetic activity occurring during the declining phase of solar cycle is the intensity and inclination of the solar dipole axis which decides the following sunspot cycle.

6. Periodicities in ionospheric parameters

The diurnal, seasonal and solar cycle variations in the electron/ion density of the ionosphere are explained on the basis of changes in the input of solar UV and X-ray flux. However, problems like day-to-day variability, equinoctial maximum, sudden changes in layer height and density etc. cannot be explained using variation in radiation flux. Variations in the solar wind pressure and interplanetary magnetic field (IMF) can cause significant disturbances in the middle- and low-latitude ionosphere. In one event, when the solar wind pressure suddenly dropped and IMF changed its direction, the F-region electron density showed a sudden decrease of 25-30 % (Huang et al., 2002). Oscillations in all midlatitude ionospheric F-region electron density, ion velocity, electron temperature, and ion temperature were detected associated with IMF/solar wind pressure oscillations. The correlation between the solar wind and the ionosphere is related to the penetration of the interplanetary electric field into the ionosphere. The oscillations in the Bz component of IMF cause the oscillation of interplanetary electric field in the dawn-dusk direction, and the penetration electric field in the ionosphere is in the east-west direction. During daytime the eastward electric field will move the ionospheric plasma to higher altitudes, and a westward electric field will move the plasma to lower altitudes.

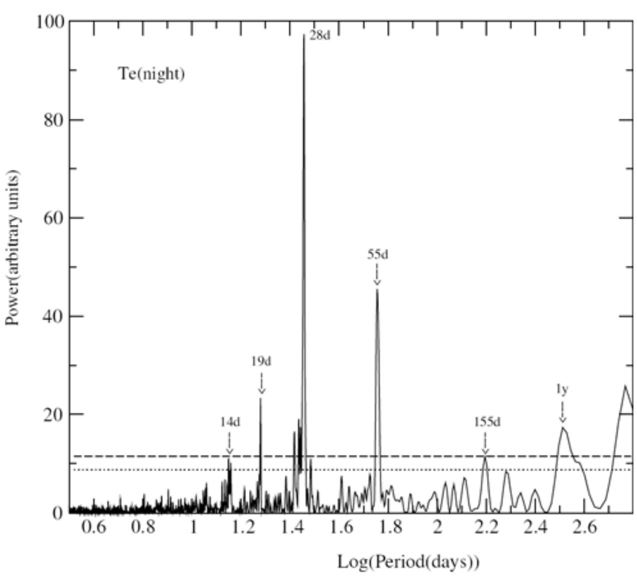

Fig. 9. Lomb-Scargle spectrum of electron temperature.

Nayar et al. (2004), using the observations of SROSS-C2 RPA data during 1995 to 2000, studied the electron and ion temperatures at low latitude ionosphere using the Lomb-Scargle (Fig. 9) and wavelet techniques (Fig. 10). The analysis showed the presence of 13.5 d, 18 d, 27 d, 55 d, 155 d, 180 d and 1 y periods in electron and ion temperatures. The 27 d peak in the electron temperature data is very prominent and narrow unlike that observed in sunspot number and solar wind velocity. The 13.5 day period is also significant in the low latitude electron temperature. The 55 day period can be the second harmonic of the 27 d period. The 154 d and 1 y periods are also prominent in the electron temperature. While the Fourier spectrum gives information about the power existing during the entire period of data, the wavelet spectrum (Fig. 10) provides information about the evolution of each period. Most of these periodicities observed in ionospheric parameters are closely related to the changes associated with the Sun and are found to evolve with the phase of the solar cycle (Nayar et al., 2004). Spectral peaks obtained within the range of 10 to 20 days maybe associated with processes of a terrestrial origin, solar origin, or a combination of both. The presence of these periods in electron and ion temperatures of low latitude ionosphere can give an indication of the sources of temperature variation at the upper ionosphere, which responds to solar variations. The ionospheric variations are influenced by changes in solar radiations, variations in solar wind plasma parameters and other variations due to vertical transport of planetary wave energy generated at the lower atmosphere. The electron and ion temperatures at the upper

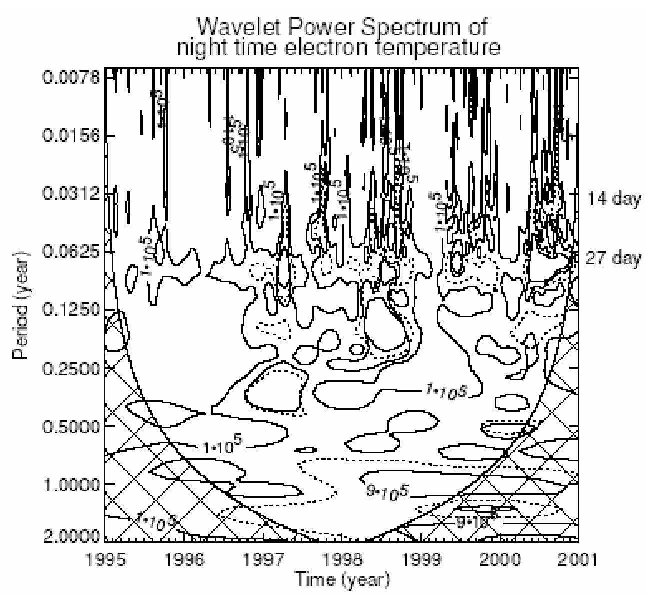

Fig. 10. Wavelet spectrum of electron temperature.

ionosphere are also affected by the electric field variations and the related characteristics of the Fourier and wavelet spectrum help us to infer the prominent processes associated with the heating of the upper ionosphere. Most of the periods present in T_e and T_i are associated both with the solar wind and solar radiation, and are associated with active centers at the solar surface. Though some of the periods have their

Fourier power below the significant level, the wavelet spectrum (Fig. 10) indicates their prominence during certain epochs. The study of the similarities of the time evolution of the wavelet power of A_p and F10.7 indices with T_e and T_i, and the cross wavelet spectrum indicate that the plasma temperature at the upper ionosphere is controlled by solar wind around the solar minimum and by both the solar radiation and solar wind around solar maximum.

7. Conclusion

The differential rotation of the Sun is the main cause of the solar dynamo located at the base of the convection zone and generation of solar magnetic field. Most of the periodic variations observed on the Sun are related to the dynamo region and its evolution. These periodic variations, though having their sources at entirely different solar active regions, are expected to have links between them. In this work, the characteristics of periodicities existing in the solar activity and interplanetary medium and their signature in the terrestrial environment are investigated. The amplitude of the periodicity depends on the parameter considered and each of them evolves differently.

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