Periodic Variations of Interplanetary Magnetic Field in Different Phases of Solar Cycle 23

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Abstract- *solar terrestrial environment is continuously changing due to the high variability in the energy output from the Sun. As the result of this, periodic and aperiodic variations are observed. The present work analyse the periodicities of interplanetary magnetic field compu\onent in solar wind during ascending and descending phase phases of solar cycle 23 using ULYSSES and ACE spacecraft data. The prominent periodicities observed during this period are 14 day, 27 day, 154 day, 180 day.*

Keywords- solar wind parameters - Solar cycle, periodicity, magnetic field component

I. INTRODUCTION

Due to the high variability in the energy input from the Sun, the solar terrestrial environment is continuously changing. Around the heliospheric equator, the tilting of the dipole axis and warping of the heliospheric current sheet (HCS) introduce multiple dominant polarity regions. In the interplanetary medium, these complex magnetic structures and active regions on the solar surface and the outflow of solar wind from these regions introduce a variety of short period variations. These fluctuations in the interplanetary medium with periods of about 14 days or less are associated with the presence of dominant polarity sectors or active regions on the solar surface and those around 27 days are associated with the solar rotation. The magnetic field of the Sun is well organized, and the dipole approximation for the magnetic field is well justified, during the solar cycle minimum period.

The polar coronal holes often tend toward the solar mid-latitudes, during the declining phase of the solar cycle, which leads to a strongly tilted streamer belt and heliospheric current sheet. 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 of about 27 days (Mursula and Zieger, 1996). The streamer belt is systematically displaced from the equator, during the declining phase and minimum which means that the heliosphere is north-south asymmetric at these times which is also been shown by Mursula et al., (2002).

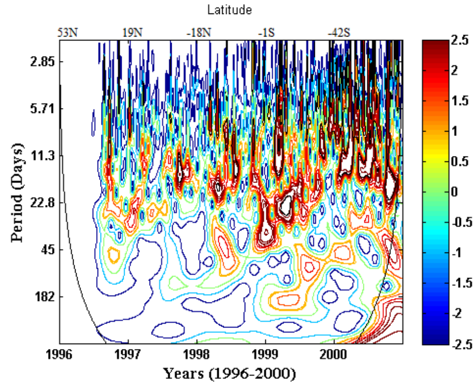
Modifying the properties of the solar wind and the interplanetary magnetic field, this periodicity also affects the near and distant heliosphere, as well as other parameters dependent on them. The period of present study (1996 - 2008) includes four solar cycles representing various phases of solar activity. In a characteristic way associated with the development of active regions on the solar surface during different solar cycles, the amplitude of quasi periodicities in various solar parameters may change from maximum to minimum. The presences of coronal holes near the solar equatorial region introduce high speed low density regions in the solar wind additionally. Polar coronal holes are regions of high-speed solar wind. Expanding toward the heliomagnetic equator in the declining phase and contracting to polar regions in the ascending phase, the location and size of coronal holes vary dramatically over the solar cycle. During the declining phase as a result, the width of the equatorial low speed belt decreases developing larger heliomagnetic latitudinal gradients in solar wind speed. The coronal holes retreat back to the poles, during the solar maximum years and therefore no stable regions of high speed solar wind exist around the heliomagnetic equator which is closer to the ecliptic. The solar wind speed gradients around the heliospheric current sheet are smaller than that in the late declining phase (Newkirk and Fisk, 1985) during the solar maximum. These types of variations in solar wind speed and speed gradients are taking place during the 11 year period. 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. Wavelet method provides an important tool to study such time evolutions. During cycles 21, 22 and 23 there are many wide structures of the evolution of 27 day periodicity which lasts for more than a year. During the minimum of different cycles, the periodicities are weak. The 27 day periodicity is present in the ascending phase of cycle 23. In this paper the evolution of short period quasi-periods are investigated using wavelet technique.

II. DATA AND METHOD OF ANALYSIS

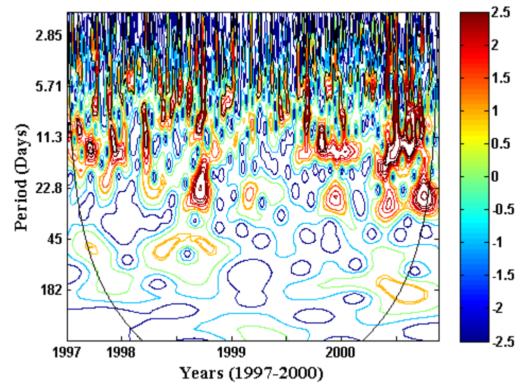
The data from Vector Helium Magnetometer (VHM) (Balogh et. al., 1992) Ulysses experiments and the Magnetic Field Experiment (MAG) (Smith et al., 1998), are utilized for carrying out this work. The IMF data contains the B_R, B_T and B_N components of IMF and the absolute value of IMF. Daily average values are computed from the hourly values of solar wind and interplanetary plasma parameters. During ascending (1996 - 2000) and descending phase (2001 – 2008) phase of solar cycle 23, the solar and interplanetary data are obtained from the official website of ULYSSES space Science Data Centre and ACE in electronic form. In this work, the Morlet wavelet analysis was used. It is possible to construct a picture showing the amplitude of any characteristics versus scale and how this amplitude varies with time (Torrence and compo, 1998), by varying the wavelet scale and translating in time.

III. WAVELET SPECTRUM OF INTERPLANETARY MAGNETIC FIELD (IMF)

During solar cycle 23 (1996 – 2008), the wavelet spectrum are generated by using solar interplanetary magnetic field data. The 11 years daily average solar interplanetary magnetic field (B) data were split up into two sections of ascending phase (1996-2000) and descending phase (2001-2008). The figure 1a and 1b shows the wavelet spectrum of interplanetary magnetic field observed by Ulysses and ACE spacecrafts during the ascending phase. The figure 1a gives idea about the overall solar magnetism that controls the interplanetary magnetic field. The periodicity study provides the magnetic activity around the Sun, since Ulysses moves in a latitudinal path around the Sun. The periodicities in the solar magnetic field are mainly contributed by the prevailing sector structures and the solar transients mainly evolved in the relaxation of solar magnetic field. Gonzalez and Gonzalez (1987) discussed various periods and their connection to sector structure.From the figure 1b the periods like 12.5 days and 26 days shows strong periodicities. During the solar maximum of cycle 23, (2000), 14 days and 27 days of periods are prominent in both figures. Due to the reduced size of the hole or the features would have been lost in travelling larger radial distance along with other dynamic events and as a result IMF is very weak and smooth over 1990 and 1996.

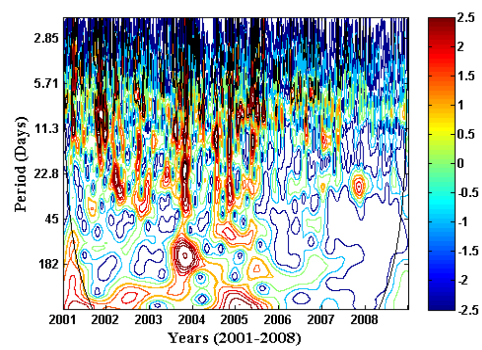


1a

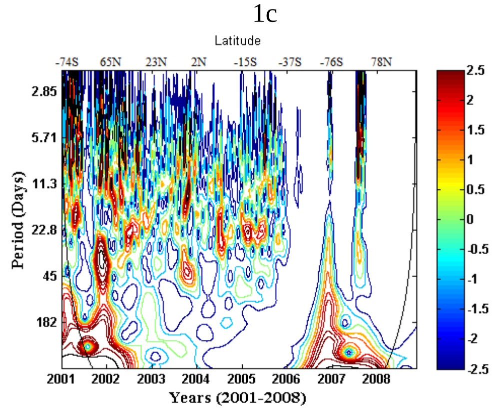


1b

Figure 1a and 1b : Wavelet spectrum of IMF B during during the ascending phase observed by Ulysses and ACE.



1c



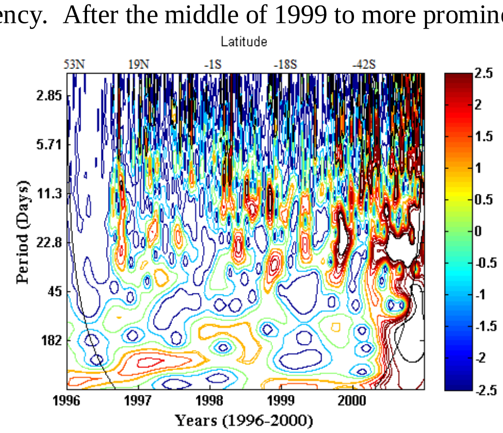
1d

Figure 1c and 1d: Wavelet spectrum of IMF B during descending phase observed by Ulysses and ACE.

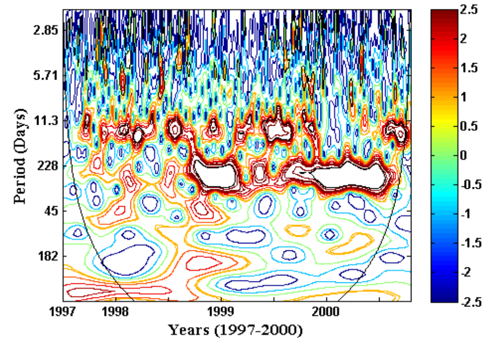
The figure 1c and 1d are shows the wavelet spectrum of interplanetary magnetic field for descending phase of solar cycle 23 observed by Ulysses and ACE spacecrafts. The 12.5 days associated with the solar rotation and 26 day with the variation of solar magnetic field, both the periods are found to be stronger in the declining phase of the solar cycle in eccliptic and polar regions. At near 2004 which appears to be the second maximum of solar cycle 23 also the solar rotation is found to be predominantly active and stable one. The periods like 7, 15, 21, and 26 days dominate in the polar regions, these different periods reflect the spatial distribution of solar activity in the polar regions when the Sun is approaching the peak of the maximum phase.

IV. WAVELET SPECTRUM OF RADIAL COMPONENT OF IMF (B_R)

The wavelet spectrum of IMF B_R during ascending phase of solar cycle 23 is shown in figure 2a and 2b. In the short period range, the periods evolve sporadically with the ascending and maximum phase of sunspot cycle. The B_R component also exhibits a clear solar cycle evolution of wavelet power of the different periods. The spectral band near 27 days is very clear in polar regions and periods like 27 days and 14 days are clear in eccliptic region and is found to evolve with time and this period is more prominent during cycle 23. Some periods in the range 45 - 100 days are evident during 2000 in the maximum period of solar cycle 23. From the figure, in the minimum phase and ascending phase (1996 to middle of 1999) of this solar cycle there is no prominent frequency. After the middle of 1999 to more prominent.



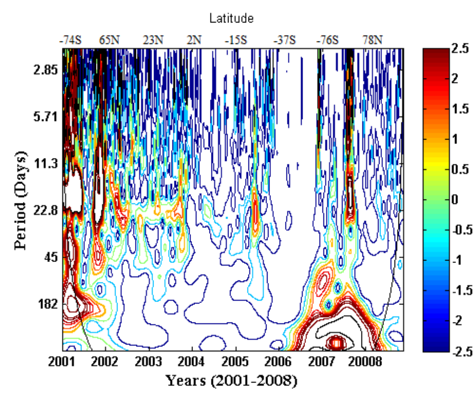
2a



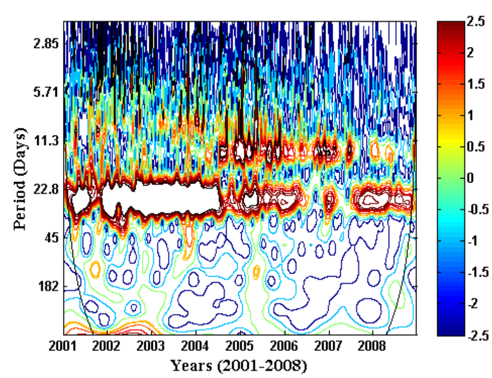
2b

Figure 2a and 2b: Wavelet spectrum of IMF B_R during ascending phase observed by Ulysses and ACE.

The wavelet spectrum of IMF B_R during descending phase of solar cycle 23 is shown in figure 2c and 2d The wavelet spectrum of B_R component is very peculiar as the 14 day and 27 periods appear as a spectral band in the period range 22-32 days which is evolving with time. Unlike the spectra of other parameters analysed here, there are no other prominent period present in the short period range. The 27 day periodicity is more prominent in eccliptic region. The evolutions of periodicities follow the phase of the solar cycle with their wavelet amplitude maximizing near solar maximum.



2c

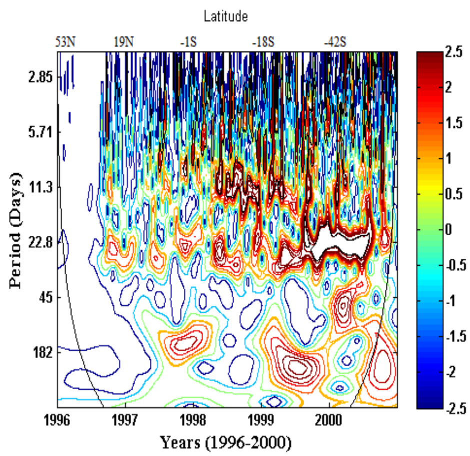


2d

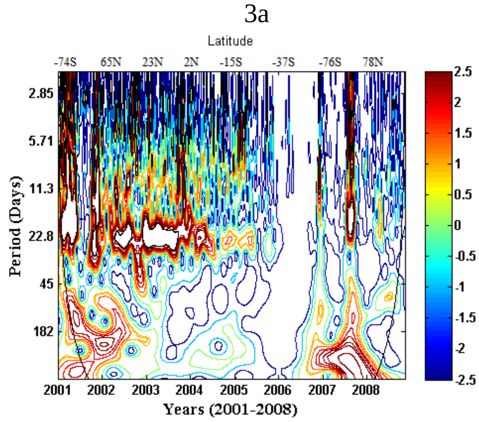
Figure 2c and 2d: Wavelet spectrum of IMF B_R during descending phase observed by Ulysses and ACE.

The solar rotation period is found to be stable for most of the time which last for more than one solar rotation. It has also been shown (Mursula et al., 2002) that 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. In figure 2d the 27 day is very active. During minimum phase, ACE recorded the most striking periods near 12.5 days. The Another important observation here is that the 12.5 days period has been dominant during the minimum phase and shows weak prevalence near 6 day period, which is mainly attributed to the equatorial coronal streamers and corotating interaction regions.

Wavelet spectrum of tangentiual component of IMF (B_T)



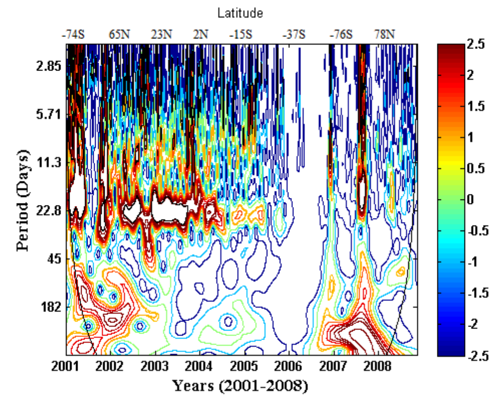
3a



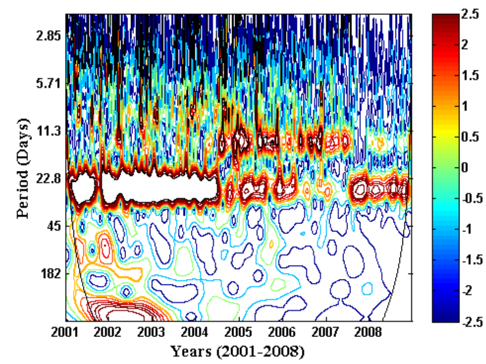
3b

Figure 3a and 3b: Wavelet spectrum of IMF B_T during ascending phase observed by Ulysses and ACE.

The wavelet spectrum of IMF B_T during ascending phase of solar cycle 23 is shown in figure 3a and 3b. The B_T component exhibits a stronger wavelet power in the short period range compared to that of B_R component. The midterm quasi periodicities are also found to evolve with solar cycle. However the high amplitude oscillations in the 180 days to 1.3 year range during 1998-2000 is noted. The 27 day period is very stronger than that of 14 day in ecliptic region. The periodicities in 1999 and 2000 is very prominent in 27 day period. Here the 14 day and 27 day periodicities are prominent following the phase of solar cycle. The wavelet amplitude corresponding to 27 day periodicity are more stronger than the 14 day period for major part of the cycle.



3c



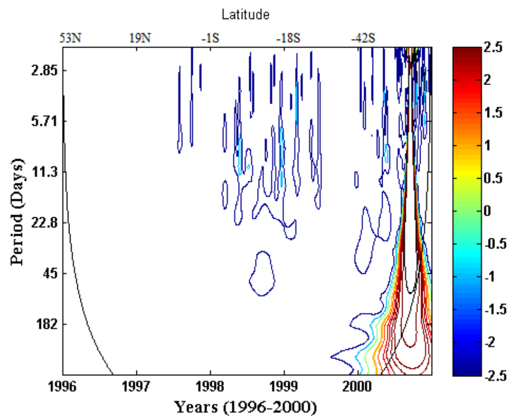
3d

Figure 3c and 3d: Wavelet spectrum of IMF B_T during descending phase observed by Ulysses and ACE.

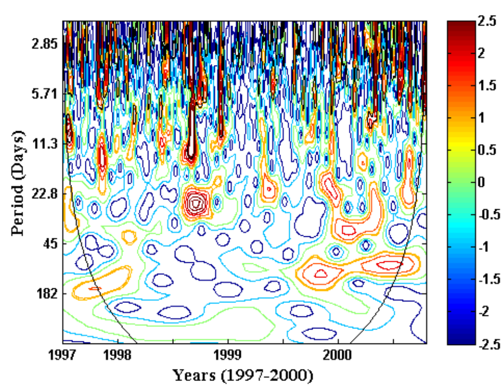
Figure 3c and 3d are the wavelet spectrum (IMF B_T) for the descending phase during 2001 – 2008 of Ulysses and ACE spacecrafts respectively. The high wavelet power corresponding to all periods in cycle 23 is notable here as in the case of other IMF components. This periodicity is found to be strong in the late declining phase of the solar cycle in the case of heliospheric variables and around sunspot maximum in the case of solar variables (Mursula and Ziegler, 1996, 1998). The presence of 14 day period was also reported in the solar magnetic field by Das and Nag (1999).The solar magnetic field and the heliosheet are strongly perturbed and no sizable 13.5 day periodicity appears in the heliospheric variables during solar maximum years (Newkirk and Fisk, 1985).

There was considerable controversy about possible solar cycle variations in the magnitude of the IMF but the spectral density of IMF fluctuations appeared to have a solar cycle dependence (Feynman, 1983). In addition, the size of the hourly average southward component of the IMF had characteristic variation that more or less followed the sunspot number Siscoe et al. (1978). 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. A wide range of periodicities have been found, the near 26 day recurrent period and 13.5 day dominate in the region. In ACE, the 26 day is very dominant in other regions. In the year 2001 - 2004 the periodicities are more prominent near 26 days.

Wavelet spectrum of normal component of IMF (B_N)



4a

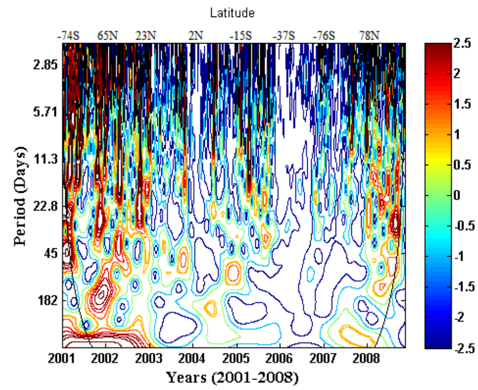


4b

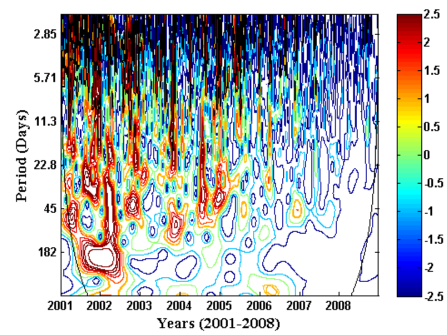
Figure 4a and 4b: Wavelet spectrum of IMF B_N during ascending phase observed by Ulysses and ACE.

The wavelet spectrum of IMF B_N in ascending phase during 1996- 2000 is depicted in figure 4a in 4b. Ulysses observed, unlike the B_R and B_T components the time evolutions of the wavelet spectrum of BN component do not exhibit any systematic pattern. In the ascending phase there is no prominent spectrum. Near the solar maximum (2000) 182 day dominate in this region.

Figure 4b shows the wavelet spectrum of IMF B_N of ACE spacecraft during 1997 – 2000. Figure 4c and 4d are depicts the wavelet spectrum of IMF B_N component during the period of 2001 to 2008, in the descending phase of solar cycle 23. The spectrum of B_N is different from the spectra of other parameters like B_R and B_T in many respects. Unlike the spectra of other parameters studied here, the spectrum is very diffused. The periodicities near 14 and 27 days are showing comparable strength in the declining phase of most of the solar cycles.



4c



4d

Figure 4c and 4d: Wavelet spectrum of IMF B_N during descending phase observed by Ulysses and ACE.

During the declining phase of cycle 23, period ranges are found to be active and their strength is comparable to that of 27 day periodicity. Some higher periodicities are present during 2004 - 2005 which corresponds to the descending phase of cycle 23 in the ecliptic plane. The periodicities in the range 120- 200 days are found to be prominent showing some temporal evolution.

V. CONCLUSIONS

The Morlet wavelet spectral methods are used to identify the significant periods in the spectrum of interplanetary magnetic field and RTN components observed during 1996-2008, during the solar cycle 23. In general, the prominent oscillations in the time series of solar wind magnetic field component observed are 14 day, 27 day and tracecs of much or less periodicities close to these periodicities. These periods have different amplitudes in different phases of solar cycles. The 27 day period is the most prominent short period oscillation observed in almost all component of interplanetary magnetic field component. The 14 day and 27 day period in magnetic field is very sharp due to slow evolution of magnetic field structures. The IMF B_R and B_T components show larger amplitude around 14 day and 27 day period which evolve with time. 14 day and 27 day periods in B_R and B_T have larger amplitude during the declining phase of this solar cycle.

VI. ACKNOWLEDGMENT

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