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Prominent short-, mid-, and long-term periodicities in solar and geomagnetic activity: Wavelet analysis

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ABSTRACT

Study of periodicities in solar and geomagnetic parameters has been useful in relating solar variability to variations in other phenomena in order to search for the solar cause of, and effects in, the variability observed in near earth space environment. Implementing wavelet analysis on daily, monthly and yearly time resolution data of sunspot number and geomagnetic aa-index, we observed periodicities of 27.8-, 157-, 370-days, and 2.2-, 5.5-, 11-, 22.7-, 38.6-years in the sunspot spot number and 13.8-, 26.6-, 185-days, and 5.3-, 11-, 30-, 46-years in the geomagnetic aa-index. We discuss these periodicities, relation between solar and geomagnetic periodicities and their implications for near-earth space environmental effects.

1. Introduction

The variability in the solar output is responsible for the changes in the solar environment and these variations affect the Earth's environment as well as the environment around other planets. This variability disturbs the geomagnetic activity and produces geomagnetic storms of various amplitudes.

Long range of periodic and non-periodic variations in the solar activity data have been reported in previous studies. On the basis of all the observed variations, they are grouped into three broad categories, short-, mid- and long-term periods. Variations of different periods in solar, interplanetary plasma, geomagnetic activity and cosmic ray intensity data have been reported in the past (e.g. Svalgaard and Wilcox, 1975; Bolton, 1990; Alicia et al., 1993; Richardson et al., 1994; Mursula and Zieger, 1996, 2000; Nayar et al., 2001, 2002; Kudela et al., 1993, 2010; Valdes-Galicia et al., 1996; Mavromichalaki et al., 2003a, 2003b; Alania et al., 2008; Sabbah and Kudela, 2009, 2011; Laurenza and Storini, 2009; Chowdhury et al., 2010; Ahluwalia, 2012; Katsavrias et al., 2012; Perez-Peraza et al., 2012; Singh et al., 2012).

The geomagnetic activity depends strongly on the solar wind velocity and interplanetary magnetic field at the Earth's orbit (e.g., see Badruddin, 1998; Badruddin and Singh, 2009; Singh and Badruddin, 2012 and references there in). The 1–2 years of periodicities have been reported in solar wind velocity, geomagnetic activity and cosmic ray intensity (Bolton, 1990). Solar wind and geomagnetic activity index Ap were found to exhibit around 1.3-years during even cycles and around 1.5–1.7 years during odd cycles (Valdes-Galicia et al., 1996; Mursula and Zieger, 2000). The 154-day periodicity in solar flare activity, 10.7 cm radio flux, sunspot number and global magnetic field were reported by many authors (e.g. Rieger et al., 1984; Bai and Sturrock, 1993 and others).

Although a long range of periodicities have been reported in various solar, cosmic and geomagnetic parameters starting from short- to long-term, but the exact cause of many of the periodicities are still unknown. However, few well known periodicities like 26–29 days from minimum to maximum epochs relate to helio-latitudinal distribution of active region. Few periodicities are sub harmonics of a fundamental period reported in many papers (e.g. Bai and Sturrock, 1991; Krivova and Solanki, 2002; Sabbah and Kudela, 2011). There are quasi-biennial variations in solar activity like ~1.3–2 years (Hathaway, 2010) and associated with double peaks of the solar cycle. Besides these, regular and quasi-biennial variations, there are many ephemeral periodicities in the solar, geomagnetic activity and cosmic ray data (e.g. Polygiannakis et al., 2002; Rouillard and Lockwood, 2004; Mavromichalaki et al., 2003a; Alania et al., 2008; Laurenza and Storini, 2009; Sabbah and Kudela, 2011; Singh et al., 2012). However, the study of periodicities of different periods using data of different time resolutions is still required.

2. Data and analysis technique

In this work, we have utilized the three different time resolution data of solar activity parameter sunspot number (SSN) and

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geomagnetic parameter (aa-index) averaged over three time resolutions, daily, monthly and yearly. About 160-years (1849–2009) daily SSN data, 260-years (1749–2009) of monthly SSN data and 310-years (1700–2009) of yearly SSN data, in addition to about 140-years (1868–2009) of daily, monthly and yearly aa-index data have been utilized in this work. These data were subjected to wavelet analysis.

Utilizing the wavelet software developed by C. Torrence and G. Compo (http://paos.colorodo.edu/research/wavelets/), sunspot numbers and geomagnetic aa-index data with three time resolutions have been analyzed using Morlet wavelet, and both the global spectra and scalogram were obtained to study the presence and evolution of various periodicities. The results have been obtained using a single selected mother function and selected scaling parameters. In the wavelet power spectrum (WPS), the contours provide information about the levels of spectral power corresponding to each variation at different time periods. The yellow and green areas correspond to lower power regions and red color areas correspond to the regions of larger power. The colored regions, however in all the figures indicate the region of the spectrum below the 95% confidence level and thick (black line) contours are the regions of the spectrum at the 95% confidence level. In global power spectrum (right panel) of the each wavelet figure the variation of power is shown with period, the thick dashed line in the panel is the line at 95% confidence level. The Cone of Influence (COI) is also shown in all the wavelet power spectra that describe the region influenced by the zero padding or shows edge effect.

3. Results and discussion

Fig. 1 shows the wavelet power spectrum and corresponding global wavelet spectrum (GWS) of yearly sunspot number. In the wavelet power spectrum of the figure, three long-term variations can be seen. The well-known Schwabe (∼11 year) variation is dominating and significant variation seen in both the spectra (WPS and GWS). This variation was first demonstrated by Schwabe (1843). The whole time length of the 11-year variation in the wavelet power spectrum is divided in to two significant contours. The first significant contour is observed around the years 1725 to 1790, while the other starts around 1830 and lasts till 2010. In between these two contours, feeble signature of Schwabe period is observed. This period may be of interest from the point of view of solar physicists. Since there are more temporal variations (WPS of Fig. 1) in this periodicity, therefore power distribution around the variation is broad at the base. Periodicities ∼5-year and ∼52-years are the other observed long-term variations in the yearly SSN data. These variations are observed in the GWS spectrum of the figure with low-peak power values. The ∼5-year variation shows random behavior in the GWS, but ∼52-year variation is more prominent during 1700–1850. Le and Wang (2003) found that ∼53-year variation is dominant during 1750–1850 and has much higher power than that of 11-year variation. Signature of a period ∼36-year (38.6-year) seen in WPS of the figure is worth mentioning. This is one of the controversial variations the Bruckner cycle (Bruckner, 1890) mainly observed in the climate data (e.g. Henry, 1927; Raspopov et al., 2004). Since the power of this variation is not high enough, it appears only in the WPS, during 1950–2000.

Fig. 2 shows the WPS and GWS of monthly average SSN. In the spectrum three well known, and one controversial variation, are observed with different power values. 11-year variation is the dominating and highly significant variation, which is found throughout the time length of the SSN. From the wavelet power spectrum it is also clear that there is about 1–2 years of temporal variation in the upper and lower boundaries of the 11-year variation contour, but the lower (high periodicity) side boundary is smoother than upper one. The power density of this variation is more pronounced during 1940–1990 followed by during 1840–1880, and then around 1770. The study of wavelet power spectrum of this figure is important in view of the clear signature of the controversial Bruckner cycle (∼36-year) and can be easily seen during 1940–2010. However, this cycle is apparently less pronounced with week signatures in the spectrum obtained using yearly average SSN data. This periodicity was observed in climate data.

Fig. 4 shows the WPS and corresponding GWS of yearly averages geomagnetic aa-index data. The well-known 11-year periodicity variation is dominant variation in both the spectra. Although seen throughout the spectrum, this variation is more pronounced around 1920 and during 1980–2000. In the GWS, there are two signatures of smaller amplitudes, one corresponds to ∼22-year and other ∼32-years. The former is more pronounced in the early phase, while the later during the end phase of the spectrum. The distribution of the powers of these two variations in the WPS is not good, as both the power peaks corresponding to these variations lie below the 95% confidence level, but their signatures are reeled in the power spectrum.

The digital values of power give six periodic variations in the wavelet analysis of monthly aa-data. These variations are of 6-month, 5.2-year, 11.0-year, 23.5-year, 31.4-year and 45-year period. The 11-year variation is the most dominating variation of the data and more pronounced during 1868–1960 and from 1980

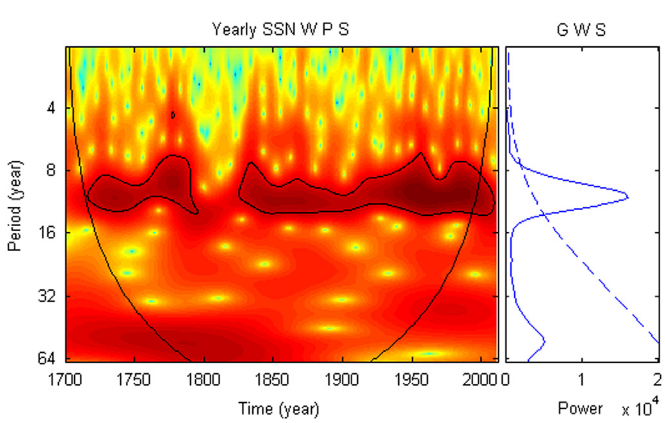

Fig. 1. Wavelet power (a) and global wavelet (b) spectrum for yearly sunspot number (SSN) during 1700–2009. The cone of influence is also shown in WPS. The dashed line in GWS represents the 95% significant level. (a) SSN WPS and (b) GWS. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

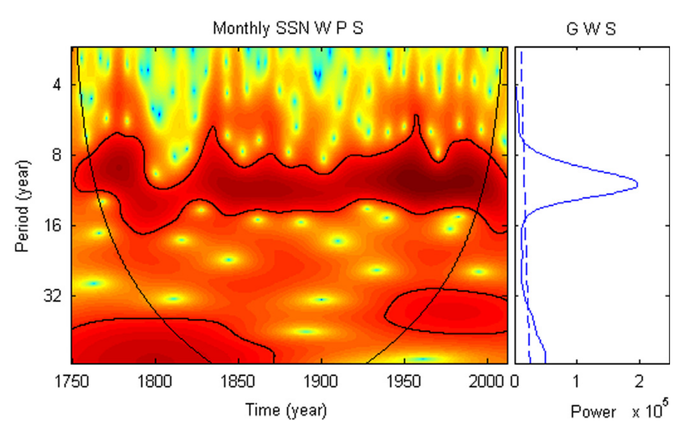

Fig. 2. Same as Fig. 1, but for monthly sunspot number (SSN) during 1749–2009. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)