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Asymmetry in the Rosenberg-Coleman effect around solar minimum revealed by wavelet analysis of the interplanetary magnetic field polarity data (1927–2002)

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[1] Interplanetary magnetic field (IMF) polarity data for the years 1927–2002 were studied by wavelet analysis technique, which permits the identification of non-steady features in the IMF polarity data. It was found that the annual variation in the IMF polarity (the Rosenberg-Coleman effect) is present only during the rise phase of solar cycles. This result is confirmed by the observed B_x (radial) solar wind measurements since 1964. This asymmetry could be caused by a more stable and flat heliospheric current sheet being present only in the rise phase of solar cycles, with co-rotating high speed streams disturbing it during the descending phases. This finding bears on the generally accepted explanation of the 22-year geomagnetic activity cycle. *INDEX TERMS:* 2134 Interplanetary Physics: Interplanetary magnetic fields; 2162 Interplanetary Physics: Solar cycle variations (7536); 2784 Magnetospheric Physics: Solar wind/magnetosphere interactions. **Citation:** Echer, E., and L. Svalgaard (2004), Asymmetry in the Rosenberg-Coleman effect around solar minimum revealed by wavelet analysis of the interplanetary magnetic field polarity data (1927–2002), *Geophys. Res. Lett.*, *31*, L12808, doi:10.1029/2004GL020228.

1. Introduction

[2] *Svalgaard* [1968] and *Mansurov* [1969] discovered a relation between the interplanetary magnetic field (IMF) polarity and the diurnal variation of the vertical component of the geomagnetic field of the polar cap (Thule, 86.8° inv. latitude and Vostok, −84.9° inv. latitude). This effect is also observed in the lower latitude stations, but in the horizontal component (e.g., Godhavn, 77.5° inv. latitude). It was found that, by this effect, one is able to infer the IMF polarity from ground-based geomagnetic field observations. This result is of extreme importance in long-term Sun-Earth studies, since in situ solar wind observations started only in the 1960s. *Svalgaard* [1972] using Godhavn and Thule observations, inferred the IMF polarity since 1926, which, combined with in situ solar wind observations, produces a near 80 years continuous IMF polarity record.

[3] The IMF polarity was found to have a 27 days variation, associated with the Sun's rotation [*Wilcox and Gonzalez*, 1971] besides its second – 13–14 days- and higher order harmonics [*Gonzalez and Gonzalez*, 1987]. Several other studies have been dedicated to the long-term variation of interplanetary sector structure [*Wilcox*, 1972; *Svalgaard and Wilcox*, 1975].

[4] *Rosenberg and Coleman* [1969], analyzing the 1965–1968 spacecraft data found that there is an annual modulation in the relative IMF amount toward and away from the Sun (the Rosenberg-Coleman effect (RC)): from December 7 to June 7 the Earth is at southern heliographic latitudes and the dominant polarity corresponds to the Sun's southern hemisphere; from June 7–December 7, the Earth is at northern heliographic latitudes and the dominant IMF polarity corresponds to the northern solar hemisphere. However, *Wilcox and Colburn* [1972], using spacecraft data during 1969–1972 solar maximum, did not confirm the RC effect. Later, *Wilcox and Scherrer* [1972], using the *Svalgaard* [1972] inferred IMF polarities, showed that the RC effect was real and that it changed sign a year after solar maximum, approximately when the solar polar fields changed polarity. This effect is only observed when the Sun's polar fields are strong (around sunspot minimum) and disappears as the polar fields disappear, during solar maximum. The RC-effect has been used, together with the Russell-McPherron – RM mechanism [*Russell and McPherron*, 1973], to account for the 22-year cycle in geomagnetic activity [*Russell*, 1974].

[5] The main criticism against the sector polarity inferred by *Svalgaard* [1972] was that it is strongly geomagnetically biased and that the maximum attainable accuracy in infer IMF polarity is estimated in 88% [*Russell and Rosenberg*, 1974].

[6] In the present paper, a wavelet analysis of the entire IMF polarity data set– 1927–2002 is performed. Non-steady characteristics in the IMF spectrum are shown. It was found that the RC effect is not symmetric around solar minimum, as it was thought, but instead it occurs preferentially in the rising phase. This result could imply that a more stable, plane heliospheric current sheet is present only in this solar cycle phase. Further, this result could also have important implications in understanding the 22-year magnetic activity cycle origin.

2. Data and Methodology

[7] The IMF polarity data set used in this work was constructed based in all data available – ground-based and in situ spacecrafts measurements. It is a weighted mean of the ground based *Svalgaard* [1972] polarity data, from the Vostok derived polarity data by *Mansurov* [1969], from the ground-based re-inferred polarity by *Vennerstroem et al.* [2001] (kindly given by Eigil-Friis-Christensen, personal communication, 2003) and from IMF polarity determined from spacecraft data after 1964.

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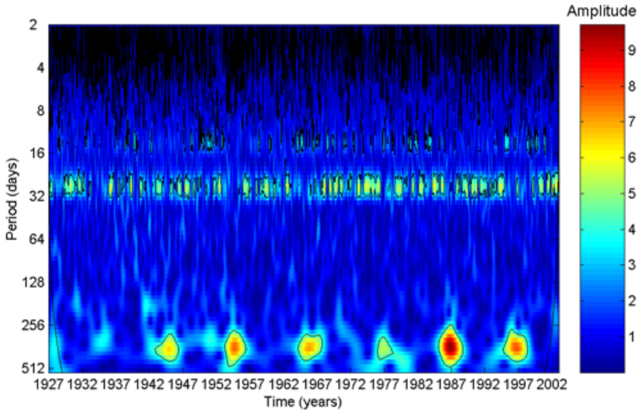

Figure 1. Morlet wavelet map of the interplanetary magnetic field polarity 1927–2002 showing periodicities from 2 to 512 days. Y-axis is the scale (period) in days, X-axis is the time, in years. The color code indicates the amplitude (power$^{1/2}$) of each periodicity at a given time.

[8] Data used in the present analysis were selected from January 1, 1927 to December, 31, 2002, in order to include only entire years.

[9] In addition, sunspot number (R_z) data were taken from National Geophysical Data Center (www.ngdc.noaa.gov) and interplanetary magnetic field radial (B_x) component were obtained from the OMNIweb data base (www.nssdc.nasa.gov).

[10] The wavelet transform is a very powerful tool to analyze non-stationary signals. It permits the identification of main periodicities in a time series and the evolution with time of each frequency. [*Torrence and Compo*, 1998; *Percival and Walden*, 2000]. The wavelet transform of a discrete data series is defined as the convolution between the data series with a scaled and translated version of the wavelet function chosen.

[11] In this work, the complex Morlet wavelet analysis was used because it is the most adequate to detect variations in the periodicities of geophysical signals in a continuous way along time scales. The Morlet Wavelet is a plane wave modulated by a Gaussian function. By varying the wavelet scale and translating it in time, 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; *Percival and Walden*, 2000].

3. Results and Discussion

[12] Figure 1 shows the Morlet wavelet spectrum map of the IMF polarity series, for periods varying between 2–512 days. The Y-axis is the scale (period) in days, X-axis is the time, in years. The color code indicates the amplitude (power$^{1/2}$) of each periodicity at a given time. Periodicities significant at 95% confidence level are delimited by contour lines. Also important is the cone of influence region (delimited by a paraboloidal curve): the region external to this curve is where edge effects, when padding a time series, became important. Thus only the region inside the cone of influence curve should be analysed [*Torrence and Compo*, 1998].

[13] In Figure 1, all periodicities are within the cone of influence curve (its lines are seen in the lower left and right Figure 1 edges), thus it is safe to analyse the entire spectrum. The main difference in these maps to classic spectrum is that it is possible to see that periodicities are intermittent, i.e., the amplitude varies with time, alternatively high and low. Three spectral regions are prominent in this map: the 27 days, the 13–14 days and the annual period. All these signals are seen to have non-steady features, with their power varying with time and spreading in frequency.

[14] The annual variation is seen in the 256–512 days band. The RC effect is clear in every minimum, being weaker around the 1932–1934 (not significant at 95% confidence level, but with higher power than the background) and 1976–1977 minima. An unexpected finding is that the RC effect is present only during the ascending part of each cycle. It was thought that this effect was equally strong around solar minimum, both in descending and ascending phases, because the HCS is more flat and stable around solar minimum than around solar maximum [*Smith*, 2001] but the wavelet results clearly show that RC effect is absent in the descending phase.

[15] Regarding the 27 and 13–14 days periodicities, it can be seen that, when the RC effect is strong, the 27 days period is weak. It is also possible to see that the 27 days signal is present most of the time, being weaker or absent in some, but not in all, solar minimum periods (absent around 1930s, 1950s, 1960s and 1990s minimum). Second harmonic (13–14 days) periods are more intermittent and weaker. They tend to be stronger when first harmonic signal (27 days) is weak.

[16] It is possible, from the wavelet map, to extract a time series of the power as a function of time, for a given periodicity. In order to study the evolution of the 1 year signal as contrasted with the sunspot number, the wavelet amplitude of IMF polarity in the middle of 256–512 days band (dotted lines) was taken and it is plotted with R_z (solid lines) in Figure 2. Vertical dashed lines mark the solar cycle minimum years.

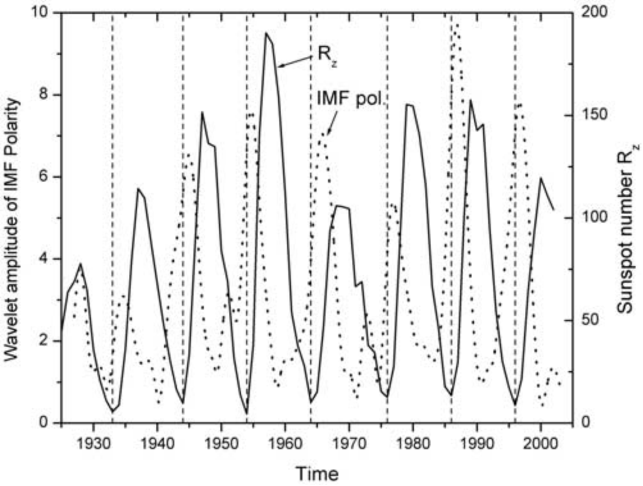

Figure 2. Yearly averages of sunspot number R_z (continuous lines) and the amplitude of IMF polarity taken from Morlet plot (Figure 1) in the band 256–512 days (dotted lines). Vertical dashed lines mark the solar cycle minimum years.

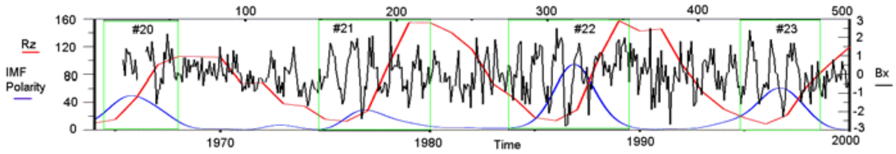

Figure 3. Yearly averages of sunspot number R_z (red line), the amplitude of IMF polarity taken from Morlet plot (Figure 1) in the band 256–512 days (blue line) and IMF B_x component (black line) for the 1964–2000 period. Green boxes indicate the periods when the RC effect is stronger.

[17] It can be easily seen that higher amplitude/power of the IMF polarity signal is observed after solar minimum, in the rise phase of solar cycle. The signal is weak around solar maximum, as expected, but it is also weak in the descending phase. Thus the wavelet power in the 1 year signal is highly concentrated in only a fraction of the solar cycle period.

[18] It might also be of interest to report the result of a direct measurement of this effect. In order to do this, 27-day averages of the IMF B_x component were computed from OMNIweb database. Figure 3 shows the variation of these B_x averages ((black lines) conjoint with sunspot number (red lines) and IMF polarity wavelet amplitude (blue line) for the period 1964–2000. Cycles were defined from maximum to maximum, i.e., 1958–1969, 1970–1979, 1980–1989 and 1990–2000 and for the intervals 1970–1979 and 1990–2000 the B_x values are plotted with the opposite sign because the Sun's magnetic field switches polarity at or just after sunspot maximum. Green boxes show when the RC effect is stronger (drawn by visual fit to IMF data). It is seen then that the RC effect is also seen in B_x, i.e., high fluctuations in B_x are seen mainly when IMF polarity wavelet power is high.

[19] The cause of this asymmetric behavior in the RC effect is presently unknown. It is well known that the heliosphere is magnetically quieter during solar minimum than during solar maximum, when it is strongly disturbed by interplanetary transients and when the HCS is highly warped and inclined to the ecliptic plane. However, around solar minimum, the heliosphere is not quite symmetrical, being disturbed in the declining solar cycle phase by co-rotating interaction regions (CIRs). These regions are a result of the compression of the low speed solar wind streams by coronal hole high speed streams. Thus, the fact that RC effect is asymmetrical around solar minimum might be due to the HCS be more flat and calm only in the rise phase (when the annual variation signal is seen) and being more disturbed during the declining phase by CIRs. But this hypothesis needs to be confirmed with further observational and theoretical work.

[20] An interesting question that follows from the finding of the asymmetry in RC effect is that the 22 year variation in geomagnetic activity is attributed mainly to the RM effect working in conjunction with the RC polarity effect. But if the RC effect only operates for a few years during each cycle, this explanation is not enough to account the variability in geomagnetic activity. Actually, *Cliver et al.* [1996] postulated that an intrinsic solar variation (other than the polarity reversal) could be the dominant cause of the 22 year geomagnetic activity cycle. The solar variation is revealed in the systematic low-high alternation of even-odd sunspot maximum. In this scenario, the excess of coronal mass ejections during the rise and maximum of odd cycles conjoined with the Hale sunspot number pattern and the dynamo model of sunspots, with stronger poloidal magnetic field during the decay of even cycles, could account to the geomagnetic activity behavior. The results presented in this work support the *Cliver et al.* [1996] conclusions, that the 22 year magnetic activity cycle can not be attributed mainly to RC-RM effects, but other cause is operating. The main candidate to be this cause seems to be an internal solar variation.

4. Conclusions

[21] An asymmetry in the annual variation (RC effect) of IMF polarity around solar minimum was revealed in this work through wavelet analysis of IMF polarity 1927–2002 data. It was found that RC effect occurs preferentially during the rise phase of solar cycles. A possible explanation for this preference is that the heliospheric current sheet is more stable and flat during this phase, and it is more disturbed by high-speed co-rotating streams in the descending phase. As a consequence of this RC effect localized occurrence within a solar cycle, the 22-year variation in geomagnetic activity can not be mainly accounted by this effect combined with the Russell-McPherron mechanism. It seems that the most likely cause of the 22 year cycle in geomagnetic activity is due to an internal solar variation (other than the polarity reversal around solar maximum), but further studies are needed to assess this hypothesis.

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