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Coincident 1.3-year periodicities in the *ap* geomagnetic index and the solar wind

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Abstract. Recent observations show an approximately 1.3-year period in the speed of the solar wind detected by the IMP 8 and Voyager 2 spacecraft. A similar period is also seen in the north-south (GSE) component of the magnetic field observed by IMP 8. Since both parameters are commonly used as input to models of geomagnetic activity, the *ap* index (a measure of geomagnetic disturbance) is examined to look for this periodicity. The Lomb-Scargle periodogram method is used on the *ap*, plasma, and magnetic field data during the 1973-1994 time range. A dynamic FFT periodogram method is also used to analyze the *ap* data during this time, as well as to look for periods present between 1932 and 1972. A clear 1.3-year periodicity is present in the post-1986 data when the same period is observed in the plasma and field data. The $V^2 B_{zsm}$ and $V^2 B_s$ proxies for geomagnetic activity also show this periodicity. However, the southward (GSM) component of the magnetic field does not have a 1.3-year period, and neither do solar wind or *ap* data from 1973-1985. This demonstrates that the *ap* geomagnetic index can act as a proxy for solar wind periodicities at this time scale. Historic *ap* data are examined, and show that a similar periodicity in *ap* exists around 1942. Since auroral data show a 1.4-year periodicity, all these similar periods may result from a common underlying solar mechanism.

Introduction

Plasma observations from both the IMP 8 and Voyager 2 spacecraft contain an approximately 1.3-year periodicity in the radial component of the solar wind speed after 1986 [*Richardson et al.*, 1994, hereinafter referred to as RPBL]. During the same time range, this approximate periodicity (actually, a period of 1.25 ± 0.12 years) is also apparent in the north-south (GSE) component of the magnetic field in the OMNI dataset, which is derived largely from the magnetometer aboard IMP 8 [*Szabo et al.*, 1995, hereinafter referred to as SLK]. Observations from the Pioneer Venus Orbiter and the Pioneer 10 and 11 spacecraft also show speed enhancements with an approximately 1.3-year period at that time [*Gazis et al.*, 1995].

We hypothesized that the *ap* data would show a similar periodicity because both the plasma speed and the magnetic field affect geomagnetic activity [see, for example, *Courtillot and Le Mouël*, 1976; *Crooker et al.*, 1977; and *Akasofu*, 1980; 1981]. The *ap* index is a quasi-linearized version of the Kp index, which is used to represent the level of geomagnetic disturbance reported by observatories located at middle latitudes [*Mayaud*, 1980]. Although *ap* may not be the best index to examine for geomagnetic detection of solar wind behavior [*Holzer and Slavin*, 1982, for example], it has the virtue of a long baseline for comparison, especially when changes between various solar cycles are being examined. Additionally, because its three-hour resolution is closer to the one-hour resolution of the spacecraft data used, it should be a better index for the purposes of this study than the *Ap* index (a daily average of eight *ap* indices) used by other authors. The *ap* index values for the time period from 1932 to early 1995 were obtained from the National Geophysical Data Center via the World Wide Web (WWW).

Although many papers have discussed periodicities in the *Ap* index (see, for example, *Clúa de Gonzalez et al.* [1993] and references therein), a 1.3-year period has not been reported previously. A 1.4-year periodicity was detected in the *Ap* index (for example, *Fraser-Smith* [1972] and *Delouis and Mayaud* [1975]) and the C_i index [*Shapiro*, 1967, and while both the 1.3- and 1.4-year periodicities may in fact be variations on some fundamental period, the periodicity we report is closer to the approximately 1.3-year periodicity apparent in the post-1986 solar wind observations. In fact, although a weak 1.3-year period in the Zurich sunspot number is noted on Figure 8 of *Gonzalez and Gonzalez* [1987], *Fraser-Smith* [1972] felt that his 1.4-year period in *Ap* was not related to solar activity since he did not observe such a period in the sunspot data. However, the 1.4-year period in auroral frequency described by *Silverman and Shapiro* [1983] is probably a solar effect, as is the RPBL

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period, and we believe that the *ap* periodicity we report here is a solar effect, as well.

The solar wind data used for comparison are hourly averages obtained from instruments on two spacecraft. The IMP 8 spacecraft has provided solar wind data from Earth orbit from its launch in 1973 to the present. Voyager 2 was launched in 1977 and also provides solar wind data, though at increasing heliospheric distances and, since 1989, at increasing heliolatitudes (Voyager 2 is currently over 46 AU from the Sun, at -14° latitude). Both spacecraft carry plasma and magnetic field instruments, which provide information about the plasma velocity, temperature, and density, and the magnetic field strength and direction. The plasma data sets for both instruments reside at MIT, while the IMP 8 magnetic field components (GSM) were obtained from the OMNI data set via WWW.

Method

The IMP 8 plasma and magnetic field data were examined for periodicities using the Lomb-Scargle periodogram method [*Press et al.*, 1992, and references therein]. This method is ideally suited for determining periodicities in unevenly-sampled data, such as those obtained from IMP 8, where gaps in solar wind coverage result from the spacecraft's traversal of the magnetosheath and magnetosphere. The technique does not introduce spurious periodicities at the frequencies of the data gaps, making it unnecessary to interpolate or to hold the data to a fixed value across gaps.

We applied the Lomb-Scargle method to the *ap* index as well as to hourly averages of the IMP 8 plasma speed (V), the GSM magnetic field components B_{zsm} and B_s, and two commonly-used products, $V^2 B_{zsm}$ and $V^2 B_s$. In order to retain long period information, the data were not detrended before being analyzed. To focus on the time range where the 1.3-year period is most evident, the data were analyzed in two separate pieces: 1973-1985 and 1986-1995. It is important to note that the Lomb-Scargle method first removes the average of the entire data set (i.e., it removes the zero-frequency component of the periodogram). The entire data set for each specified time range was used to calculate a periodogram, without windowing to smaller ranges. This process can result in spectral leakage to sidelobes [*Scargle*, 1982] though that is not a problem due to the large strength of the periodicity analyzed here.

One serious drawback of the Lomb-Scargle method is the difficulty of assigning statistical measures of confidence to the resulting period peaks. The suggested method in *Press et al.* [1992] overstates the confidence levels of peaks when large data sets are used (the IMP 8 plasma data set, for example, contains over 69,000 points) [see also *Koen*, 1990]. The other method suggested by *Press et al.* [1992] to determine confidence levels requires that the data be Gaussian in distribution, which is not the case for solar wind parameters [see, for example, *Burlaga and King*, 1979, *Feynman and Ruzmaikin*, 1994]. Therefore, in order to examine the relative importance of peaks, the periodogram for each parameter was normalized to the strength of the largest peak in that parameter which had a period longer than 30 days and shorter than 1600 days. This restriction was chosen in order to avoid the solar rotation period peak and the spurious strengths often associated with peaks near the length of the data set. In this case, 1600 days limits normalization to peaks occurring in the first half of the shortest data set being studied (the 1986-1994 period).

The *ap* index periodicities were also analyzed using a more standard implementation of the FFT, with a moving time window as discussed in SLK. No interpolation of the data was required since the *ap* data are evenly sampled. The data were split into two pieces covering the years 1932-1973 and 1973-1995 to emphasize the time range which overlaps the spacecraft data. Each time segment was detrended using a high-order polynomial (15-degree for the earlier segment, 12-degree for the later one). The detrended data were smoothed using a 49-day moving boxcar average. A 5-year-long FFT window was then moved across the data in 40-day steps, and the resulting spectra were calculated. The strengths of these peaks were also normalized, in this case to the strength of the largest 0.5-year peak in each piece of the data set. The particular advantage of this dynamic periodogram method is that the period's strength can be examined as a function of time. However, the detrending of the data, particularly necessary when dealing with short windows (especially five-year windows, which are short relative to the solar cycle period), limits both the resolution and length range of the periods which are obtained.

Observations

The approximately 1.3-year period is very evident in the *ap* indices observed between 1986 and 1994 (Figure 1), although it is located at a slightly shorter period than the speed (V) peak. The north-south component of the magnetic field (B_{zsm}) and the south component of the field (B_s) are also shown on the top panel of Figure 1. Clearly there is no peak in B_s at a comparable period, although B_{zsm} displays a periodicity similar to that reported in SLK for B_{zse}. The bottom panel of

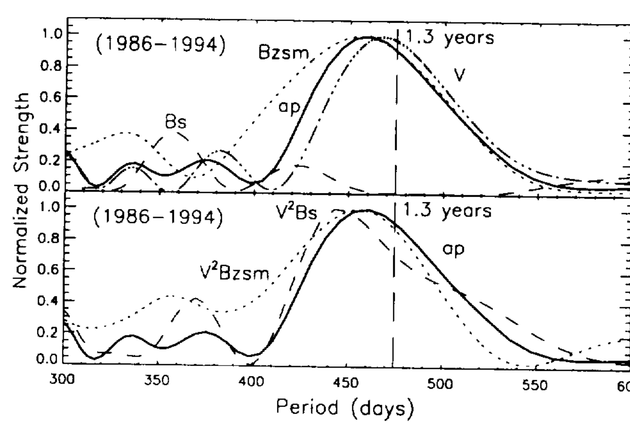

Figure 1. Comparison of periods for 1986-1994. Top: ap, V, B_s, and B_{zsm}. Bottom: ap, $V^2 B_s$, and $V^2 B_{zsm}$.

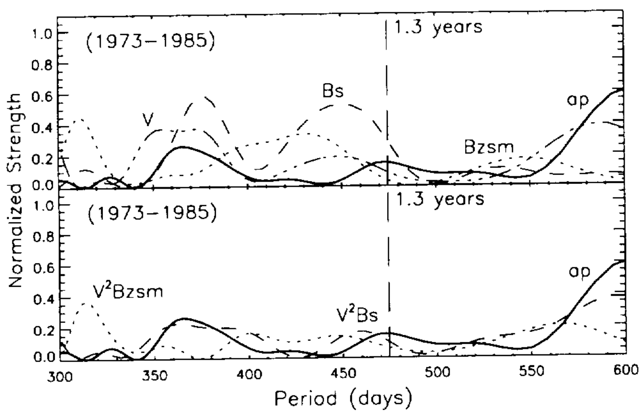

Figure 2. Comparison of periods for 1973-1985. Top: ap, V, B_s, and B_{zsm}. Bottom: ap, V^2B_s, and V^2B_{zsm}.

Figure 1 shows the V^2B_{zsm} and V^2B_s periodograms with the *ap* periodogram for comparison. Both products show peaks closely aligned with the *ap* peak, as would be expected given their usually-good correlation with geomagnetic activity [e.g., *Baker et al.*, 1983, *Crooker and Gringauz*, 1993].

Figure 2 shows the same sets of periodograms for the 1973-1985 data. Here, there is a minor peak in *ap* at the 1.3-year period (top panel), and minor peaks in V, B_s (top panel) and their product (bottom panel), all at a slightly shorter period. Because the strengths of th ap peak and the V^2B_s peak are so small, we do not consider these peaks to be significant examples of the 1.3-year periodicity being studied here.

We note that a one-year period is clearly evident in all the parameters with the exception of B_{zsm} and its product. An *Ap* peak with this period has been reported and discussed before [for example, *Fraser-Smith,* 1972; *Silverman and Shapiro,* 1983; *Lean and Brueckner,* 1989], as have one-year periodicities in the plasma velocity and density [*Bolton,* 1990; *Gazis et al.,* 1995]. Because an approximately one-year period is weakly evident in the two subsets of the data, we consider this to be a significant period, rather than an alias or sidelobe of some other period. This period, like the 1.3-year period, is also apparent in Voyager 2 plasma data. Future work will examine the one-year period in more detail.

To look for the existence of the 1.3-year period in earlier *ap* data, and particularly to examine its behavior with time, we used the SLK method on the entire *ap* data set and on the subset covering the IMP 8 data range. Figure 3 shows the resulting spectra, where the grey-scale shading denotes the power in a given period bin. The only peaks shown are those whose power exceeded the noise level of the spectrum by at least a factor of four. The resolution of the bins rapidly decreases as the period increases because the number of such periods in the 5-year calculation window decreases. A more detailed discussion may be found in SLK. The top panel of Figure 3 shows the evolution of periods in the 1- to 5-year range from 1973 to 1994. The vertical axis shows the time at the beginning of each FFT subwindow analyzed; because the window is five years long, the top

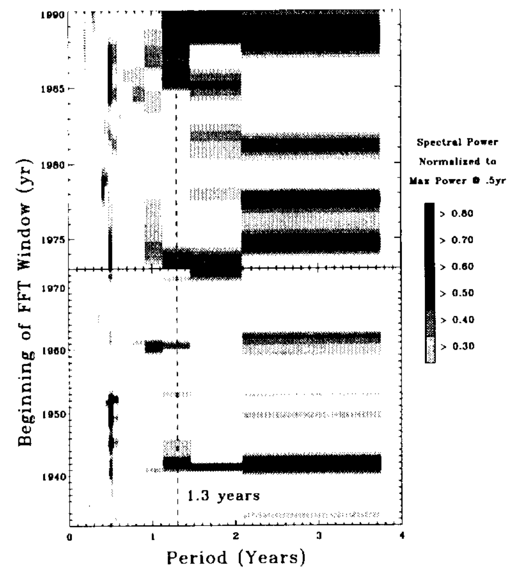

Figure 3. Time-dependence of ap periodicities. Top: 1973-1994. Bottom: 1932-1972. Note the change in vertical scale between the top and bottom panels. The vertical axis shows the time at the beginning of each of the analysis periods; the top panel thus covers four years of data past the last time shown (see text).

panel ends at 1990 (1990+4=1994). The 1.3-year period is only significant for windows beginning after 1985, although it is weakly present in 1973. The *ap* periodicity spectra for years before 1973 is shown in the bottom panel of Figure 3. Note that the time (vertical) scales change between panels. The 1.3-year peak, although occasionally weakly present, particularly around 1942, is never as dominant as in the 1986-1994 time range. This figure also shows evidence of peaks at longer periods (> 2.1 years). However, due to the five-year window length, such peaks are not analyzed well, and will not be discussed in this paper.

Because there is no obvious solar source for a 1.3-year periodicity, and as the eighth harmonic of a 10.2-

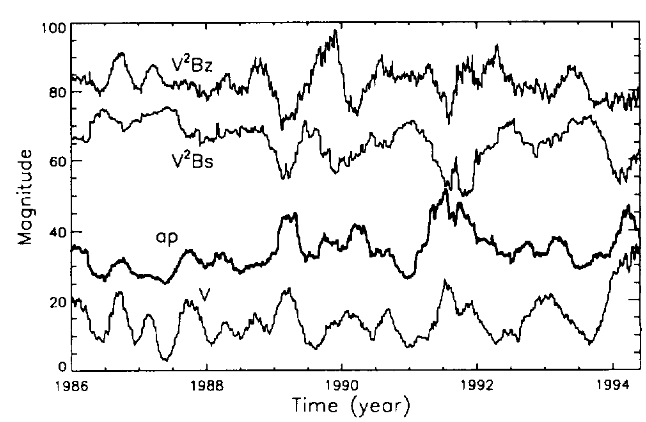

Figure 4. Smoothed ap and IMP 8 V, V^2B_s, and V^2B_z. Values were multiplied by factors to approximately duplicate dynamic range and vertically shifted to provide comparison without overlap.

to 11-year solar cycle fundamental is a 1.27- to 1.37-year periodicity, we wished to examine whether the 1.3-year period was an artifact of the periodogram method. Figure 4 shows four smoothed parameters: IMP 8 speed, *ap* and IMP 8 $V^2 B_{zsm}$ and $V^2 B_s$ for years after 1986. To facilitate comparison, the parameters were smoothed using a moving boxcar average (800 points for each parameter except $V^2 B_s$, where 400 points were used as the entire data set is approximately half the size for the same time span). The amplitude of the resulting V, ap, $V^2 B_{zsm}$ and $V^2 B_s$ values were then adjusted to obtain similar dynamic ranges, and shifted vertically to reduce overlap in the figure. This figure demonstrates that the period can easily be observed visually when present.

Conclusions

The 1.3-year periodicity which was observed in the solar wind plasma radial velocity beginning in 1986 [RPBL; *Gazis et al.*, 1995] and in the north-south (GSE) component of the magnetic field observed at Earth [SLK] is also present in the *ap* geomagnetic index and in the $V^2 B_{zsm}$ and $V^2 B_s$ proxies for geomagnetic behavior for the years 1986-1994. Although weakly present in ap data around 1942, this period does not occur strongly in earlier time ranges. Perhaps whatever solar mechanism causes this periodicity in the solar wind parameters, and thus in the geomagnetic activity measured by *ap*, varies between solar cycles. Such a variation may imply that the 1.3-year period seen here is a slight divergence from a more usual 1.4-year period, as might be expected from the examination of very long-term auroral data [*Silverman and Shapiro*, 1983]. It remains to be seen whether this strong 1.3-year periodicity will persist, and if so, for how long.

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