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Mid Term Cosmic Ray Quasi Periodicities And Solar Magnetic Activity Manifestations

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A wavelet analysis of cosmic ray intensity and solar magnetic fluxes estimated in the period 1971-1998 is reported. We searched mainly for significant mid-term periodicities (1-2yr). The periodicity of 1.7yr is the dominant for all the series analysed. The quasi-annual peak is not significantly different to that at 1.3yr. All the high frequency variations are in phase with the 11yr solar cycle.

1. Introduction

Galactic cosmic ray (GCR) quasi-periodicities of either 1.3yr or 1.7yr alternating during even and odd solar cycles and that are the most important peaks of the Power Spectral Density (PSD) of a forty years GCR series, once the 11yr variation is filtered out were found by [1]. These were confirmed later on by many authors [2]. Nowadays the existence of these mid-term variations in GCR is nowadays beyond any doubt.

Mid-term variations were also found in other solar and interplanetary phenomena [3]. The behavior of these mid-term quasi-periodicities is consistent with that of GCR. The *aa* geomagnetic index series result is important as it extends the behavior found to a larger time span; the 1.3yr and 1.7yr quasi-periodicities in the *aa* index disappear when the Sun is extremely quiet. This suggests that these mid-term periodicities must be closely linked to the varying strength of the solar dynamo. Moreover there seems to be a precursor signal announcing a weakened solar dynamo as the absolute minimum in the power of mid-term periodicities was found slightly before the interval of the very weak sunspot cycles [3]. A similar decrease of power at mid-term periodicities may occur before any long-term decrease of solar activity. Unfortunately this can not be confirmed via GCR variations as we do not have continuous records extending beyond the 1950's.

Research in solar wind speed and heliospheric magnetic field (HMF) intensity with spacecraft in the inner and outer heliosphere reveal some latitudinal structure [4]. It was found that 1.7yr and 1.3 yr quasi-periodicities coexist during solar cycle 22, a result consistent with that of [1]. These suggest possible fundamental differences in the two halves of the solar magnetic cycle.

To understand how the relationship between mid term quasi-periodicities in heliospheric parameters and the magnetic solar dynamics could be established we must search a phenomenon that connects the solar interior with its atmosphere. The solar magnetic flux arises as a consequence of buoyant forces pushing up from the boundary region between the solar radiative and convective zones (the tacholine). Generated deep in the Sun, the solar magnetic flux emerges at the surface. Thus it could establish the aimed connection.

Here we report an analysis of the magnetic fluxes estimated in the period 1971-1998 [5] and the cosmic ray intensity as represented by the Oulu neutron monitor. We use the total and open fluxes. The open flux can be measured separately for low ($\lambda < 45°$) and high ($\lambda > 45°$) latitudes.

2. Data and Method

We work with the extrapolation of the observed photospheric magnetic field into the corona given by [6]. They obtained the total magnetic flux (closed and open flux regions) and the open flux. The open flux in turn was divided in high latitude flux (> 45°), and low latitude flux (< 45°).

To find the time evolution of the main frequencies of the time series we apply the wavelet method using the Morlet wavelet [6].

In the wavelet PSD Figures, the interval of 95% confidence is marked by solid curved lines. The global wavelet spectrum is also shown, the uncertainties of every peak position are obtained from the peak full width at half maximum. The dashed curve in each of the global power spectrum density Figures indicates the red noise level at the 95% confidence. We separated the time series in high (< 4 yrs) and low (> 4 yrs) frequencies and worked mainly with the series corresponding to the high frequency range.

3. Results and Discussion

Figure 1 presents the time series of, total, open high and low latitude magnetic fluxes with their low and high frequency components separated. Figure 2 shows the same series for cosmic rays. As we are interested in the mid-term fluctuations, 1-2yr, in what follows we refer only to the high frequency series.

The high frequency total flux series appears in Figure 3a. The global PSD shows two peaks (Figure 3c), the 1.7yr fluctuation, is the dominant periodicity, it appears in the descending phase of cycle 20 and all along the solar cycle 21 (see Figure 3b). The annual peak is present in the descending phases of cycles 20-21; due to the uncertainties involved, the range of this variation contains a possible 1.3yr periodicity. The closed flux PSD shows similar features (not shown).

The open flux time series global wavelet PSD (not shown) presents two peaks. The 1.7yr is dominant; it appears in the descending phase of cycle 20, almost all cycle 21 and around the maximum and descending phases of cycle 22. The 1yr variation is present intermittently in the descending phase of cycle 20, near the maximum of cycle 21, the maximum and descending phase of cycle 22.

The low latitude open flux time series is shown in Figure 4a. The global wavelet spectrum presents two peaks (Figure 4c). The 1.7yr fluctuation is the dominant periodicity and appears in cycles 20 and 21 during the descending phases and along a good part of cycle 22 (Figure 4b). The high latitude open flux time series is shown in Figure 5a. The global wavelet spectrum presents three peaks (Figure 5c). The 1.7yr fluctuation is the dominant periodicity and appears in the descending phases of cycles 21 and 22. The variation centered at 1yr is present in the descending phases of cycles 20 and cycle 21 (Figure 5b).

The cosmic ray time series is shown in Figure 6a. Two peaks, at 1.7yr and at 1.3yr appear above the 95% confidence level (Figure 6c). The 1.7yr variation is dominant, it appears mainly in the descending phases of cycles 21 and 22 (Figure 6b) .

Mid-term periodicities in solar wind speed and heliospheric magnetic field (HMF) intensity with spacecraft near earth and in the outer heliosphere were found [4]. According to these authors, in the interplanetary medium the 1.3yr variation can be assigned to low latitudes and the 1.7yr to mid latitudes. The HMF comes from solar open field regions; our open fluxes have both, 1 and 1.7yr frequencies at low and high latitudes, both fluxes have a strongly dominant 1.7yr fluctuation, the 1yr peak is more important at high than at low latitudes. Cadavid et al.[7] (2005) used independent component analysis to study temporal and spatial variations of the axisymmetric solar magnetic field over 25 years. They found that polar and high latitude fields present 1-1.5yr variations while low and mid-latitude phenomena show 1, 1.3 and 1.7yr fluctuations; we found at high latitudes 1-1.7yr variations and at low latitudes only the 1.7 yr fluctuation. All these apparently different or even contradictory results are only an indication that the solar magnetic variations transport to the heliosphere does not follow a simple pattern.

To propagate from the base of the convective zone to the solar surface, any variation must be transmitted through three layers of convective cells of different sizes. It is difficult to imagine that buoyant forces keep frequency along the whole journey. If in fact the 1-1.3yr variation comes from the tacholine [4, 8], it could also be plausible that the convective zone behaves as a resonant cavity, that has 1-1.3yr as a natural period. The 1.7yr variation has not been clearly observed in the solar interior. In any case the propagation of this variation could also be trough a resonant process with a 1.7yr periodicity. Alternatively, mid term periodicities could be generated just below the photosphere, these variations could be a shifting of a quasi-biennial variation, observed in the helicity of solar magnetic fields generated in the subsurface region due to either radial or latitudinal shears of the angular velocity in this region [9].

It could be tempting to think that the quasi-biennial periodicities represent a more basic cycle than that of 11yr. The low frequency component of all the signals analysed here has a strong 11yr signal. In all the series analysed here, except the open high latitude flux, these high frequency variations are modulated by the 11yr cycle (dashed curves in Figures 2-4) as they tend to appear most significantly in the years of maximum solar activity, strongly suggesting that they are regulated by the emergence of the bipolar active regions. The high latitude open flux behaves somewhat different from the rest it has , this could be due to the predominance of the polar coronal hole dynamics during the minimum and the flux transport from the low latitude bipolar regions during the maximum, as the open field regions form mainly through the emergence and dispersal of active region (closed) fields[5]. These findings rule out the possibility of a high frequency basic periodicity. Mid-term solar rhythm signatures are found from the solar interior to the outer regions of the heliosphere, however, the magnetic machine of the Sun has a predominant 11yr and 22yr cyclicities.

3. Conclusions

1. the mid-term periodicity of 1.7yr is present and dominant in all the series analyzed; it has a strong tendency to appear during the descending phases of solar activity,
2. the mid-term fluctuation of 1yr is very significantly present in total and closed, it is less important in open fluxes, but for the low latitude open flux it is absent and is more important for the high latitude flux. Due to the uncertainties involved in the quasi-annual peak, this variation is not significantly different to that with a 1.3yr periodicity that is clearly present in cosmic rays,
3. the high frequency fluctuations of all the series, except the high latitude open flux, are in phase with the 11yr solar cycle. The high latitude flux tends to be present all the time showing the contributions to this flux of the bipolar active regions and the polar coronal holes. These findings rule out the possibility of a more basic periodicity, different from the 11yr (22yr) cycle.

References

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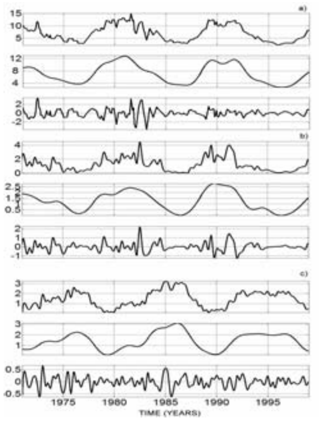

Figure 1. Time series of total (a), open high (b) and open low (c) latitude solar magnetic flux.

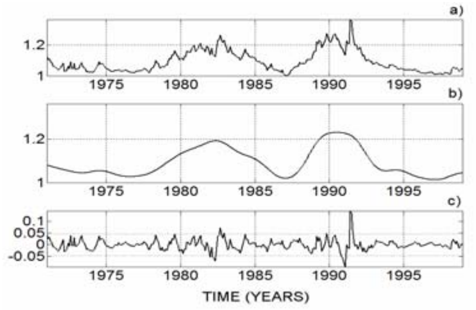

Figure 2. Time series of cosmic rays (a), low frequency (b) and high frequency (c).

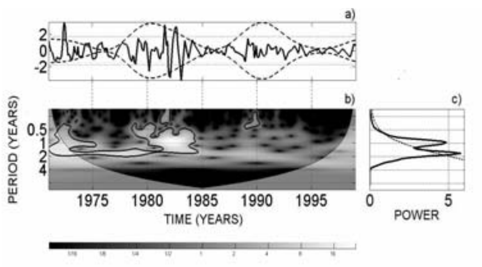

Figure 3. a)High frequency series of total magnetic flux, b)Wavelet PSD, c)Global PSD

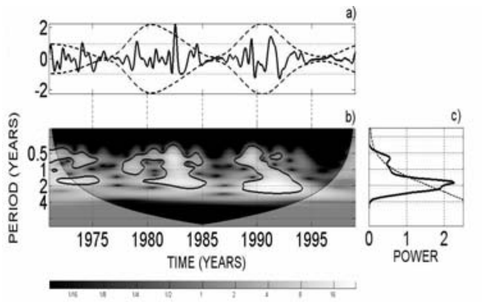

Figure 4. a)High frequency series of low latitude open magnetic flux, b)Wavelet PSD, c)Global PSD

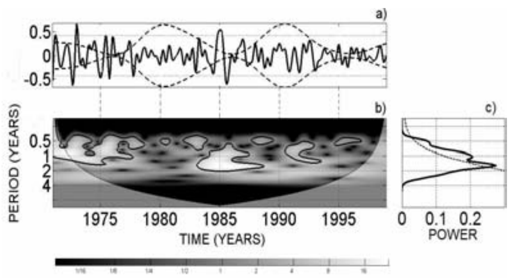

Figure 5. a) High frequency series of high latitude open solar magnetic flux, b) Wavelet PSD, c) Global PSD

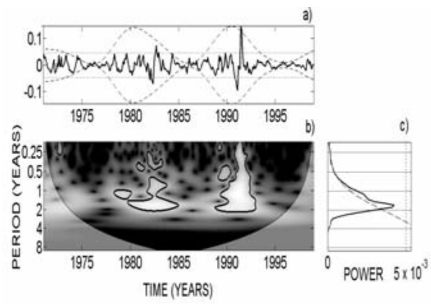

Figure 6. a) High frequency series of cosmic ray intensity at Oulu NM, b) Wavelet PSD, c) Global PSD.