Long Term Cosmic Ray Variations in Association With Solar Magnetic Flux

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Abstract

We investigate the fluctuations on the solar magnetic flux over the period 1971-1999 by means of the MEM in the frequency range 5×10^{-9} to 10^{-7} Hz. We use monthly data for the total, open and closed magnetic solar fluxes. We found fluctuations between 1.3 to 1.7y in the solar magnetic flux that are directly related with variations in cosmic rays and solar wind parameters.

1. Introduction

A current debate exists as to what is the relative importance of IMF strength as compared to CMEs or other solar wind structures in cosmic ray modulation (e.g. Caballero and Mc Donald, 2003). Statistical studies of cosmic ray variations on the earth provide clues to advance our understanding of the modulation caused by the Sun. A cosmic ray fluctuation of around 1.7y that alternates with a 1.3y periodicity between even and odd cycles was reported by Valdes-Galicia et al (1996) and confirmed later on (e.g. Kudela et al., 2002). These fluctuations are also present in solar phenomena solar wind and geomagnetic phenomena (Mursula et al., 2003). If these periodicities are rooted in the solar interior they may be of fundamental importance to construct the solar magnetic cycle.

As it is an underlying driving force for many manifestations of solar activity, and it is also related to the solar interior dynamics, magnetic flux emergence evolution is a key to relate the deep Sun with solar activity and interplanetary phenomena.

In order to assess the relations of solar magnetic flux emergence with cosmic ray fluctuations and other interplanetary phenomena and search for the relevance of the 1.7-1.3y fluctuations, we performed a spectral analysis of the solar magnetic flux estimated from photospheric measurements and the IMF radial component.

2. Data and Method

As measurements of the total solar flux (open plus closed) we used the values derived by Wang et al (2000) obtained from the integration of the solar

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field at the source-surface during the years 1971-1999. The field at the source-surface is estimated from photospheric Carrington synoptic maps, according to the potential field approximation. The flux is then divided by the total area of the Sun to convert to the equivalent field strength.

Wang et al (2000) calculated the solar open flux from their approximation. The correlation of their values with IMF radial component measurements at 1AU is very good, except for the years around solar minimum due to the difficulty of measuring solar polar fields. We have used the measurements of the radial IMF scaled up to the solar source-surface as representatives of the magnetic solar open flux. The closed flux is the difference of the total minus the open flux.

In Figure 1 we present the flux data used in this work, a plot of the (inverted) normalized cosmic ray intensity in Oulu is also shown.

The MEM was selected to compute the power spectral density (PSD) of the time series of solar magnetic fluxes. The MEM is known to have a very good frequency resolution. The PSD is defined as the discrete fourier transform of the autocorrelation sequence extrapolated according to Burg(1975) in order to maximize the entropy of the time series. The noise level was estimated by randomly mixing the original data fifty times and obtaining the average PSD of these fifty series. The dashed lines in Figure 2 represent the 3 σ (99%) level of confidence.

3. Results

To have a better picture of the relative importance of the peaks in the spectra with periodicities shorter than the well known 11y wave, we removed it of the series using a high-pass filter. The calculated spectra are shown in Figure 2. There we present calculations for the whole period and also for cycles 21 and 22 separately. As the closed flux PSD reproduces almost identically that of the total flux we only plot closed and open flux spectra. The 3 σ level of fluctuations is shown.

In the PSD calculations for the whole period (upper panels), the quasi-quinquenial and quasi triennial fluctuations in both series are identifiable. The most relevant feature of our results is the 1.7y fluctuation as the highest peak in closed flux and only second in the open flux. In the open flux the peak appears at 1.6y. This fluctuation exists in cosmic rays and many other solar interplanetary and geomagnetic phenomena. The 1.3y peak is manifest in the closed flux just above the established level of significance and shifted to about 1.35y. In the open flux is present above the 3 σ line. The annual periodicity exists in both spectra. There are other significant fluctuations at around 10, 9 and 7 months.

The spectra for separate solar cycles 21 and 22 show some striking features: the 1.7y fluctuation is present only in solar cycle 21 in both series, again shifted to 1.6y in the open flux. In solar cycle 22, a peak appears almost exactly at 1.3y

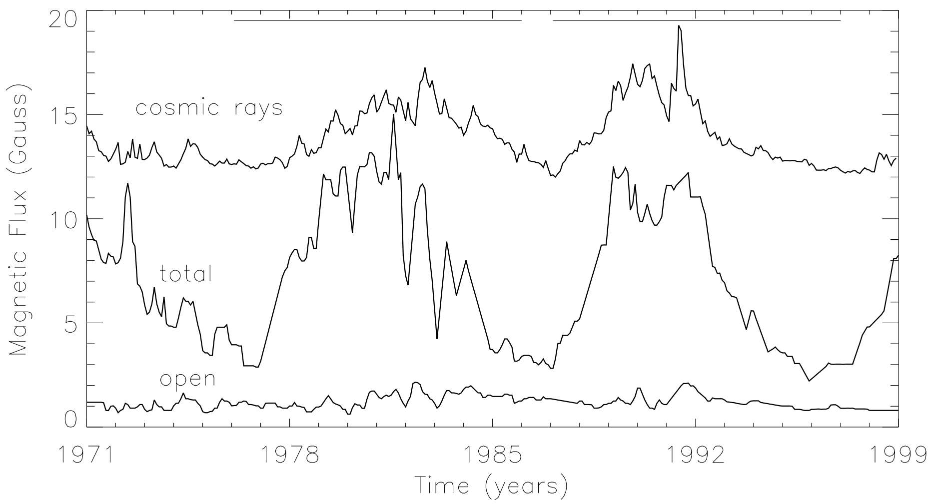

Fig. 1. Total and open flux for the whole period used in this work.

in the open flux, the closed flux shows a spectral fluctuation around 1.4y. Again an alternance of the 1.7y and 1.3y fluctuations between odd and even cycles is found, this time in a phenomenon connected to the solar interior such as magnetic flux emergence.

4. Discussion and Conclusions

The open solar magnetic flux extending to the interplanetary medium originates in active bipolar magnetic regions and is carried up to high latitudes by meridional flow (Wang et al 2000b). There are evidences that the rate at which this magnetic flux transport arrives to the polar regions and produces fluctuations of the solar poloidal magnetic field is between 1.5 to 2.5y (Benevolenskaya, 1995). A prominent 1.7y spectral peak in both open and closed solar magnetic flux for the whole period analysed here are commensurable with the meridional flux transport rate, and reinforce the picture of the bipolar magnetic regions feeding the open regions. This transport is clearly influencing the whole heliosphere dynamics as cosmic ray intensity and interplanetary and geomagnetic phenomena present important fluctuations at the appropriate periodicity. The alternate importance of the 1.7y and 1.3y fluctuations in odd and even cycles found here is also coincident with the findings for these fluctuations in cosmic rays and other related parameters. A phenomenon that is deeply rooted in the Sun and partially controls the solar activity as well as some of the heliosphere dynamics is now before our eyes. This line of thought is reinforced by the recent observation of a 1.3y periodicity in the variation of the solar rotation speed at the bottom of

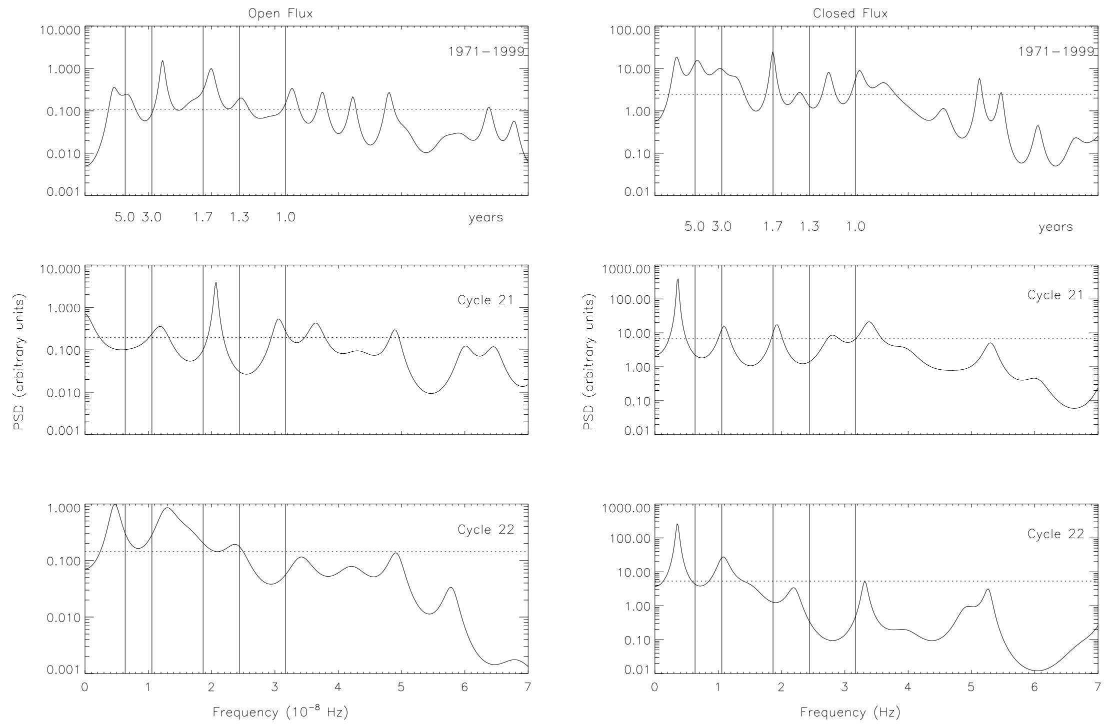

Fig. 2. PSD for the open (left) and closed (right) magnetic solar flux. Upper panels show the spectra for the period 1971-1999. Mid panels correspond to data on cycle 21. Lower panels are the same but for cycle 22.

the solar convection zone (Howe et al, 2000). Additionally Mursula et al (2003) working with the geomagnetic aa index over a period of 160 years found a behaviour of fluctuations consistent with this picture, and therefore a long trend term behaviour of the solar magnetc machine.

In the context of the mentioned debate on the relative importance of IMF strength as opposed to transient structures in cosmic ray modulation, our results show that both are playing a role.

5. References

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