

# Simultaneous Occurrence of Mid-term Periodicities in Solar Wind Speed, Geomagnetic Activity and Cosmic Rays

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## Abstract

Several authors have reported periodicities between 1 and 2 years in various heliospheric parameters and cosmic rays. We have recently shown (Mursula and Zieger, 1999) that a 1.3-1.4-year quasi-periodicity exists in solar wind speed and geomagnetic activity during the last three even solar cycles (SC 18, 20, 22) and that, during odd cycles, somewhat longer periodicities were detected with the period varying from 1.5 years in SC 19 to 1.7 years in SC 21. Valdez-Galicia *et al.* (1996) showed that a 1.7-year periodicity exists even in cosmic rays in SC 21. Here we study these mid-term periodicities in cosmic rays and compare them with those detected in solar wind and geomagnetic activity. We find that all these heliospheric parameters depict the same mid-term periodicities at the above mentioned times. *E.g.*, the 1.3-1.4-year periodicity exists in cosmic rays at least during the last two even cycles, and the slightly longer periodicities of 1.5-1.7 years are found during the last two odd cycles. The cross spectrum between cosmic rays and the solar wind speed shows that they are in anticorrelation. Moreover, the same periodicities are found in the tilt angle of the heliospheric current sheet in anti-phase with cosmic rays.

## 1 Introduction

A few years ago, Richardson *et al.* (1994) noted on a new strong periodicity in solar wind (SW) speed with a period of about 1.3 years. The SW speeds showed variations of about 100 km/s which dominated the SW speed time series from 1987 onwards. They also compared the SW speeds at 1 AU and in the outer heliosphere using Voyager 2 data to show that very similar fluctuations are observed at both heliocentric distances. Gazis *et al.* (1995) extended this analysis using data from additional spacecraft, and verified that the 1.3-year periodicity was dominating the low-latitude heliosphere after 1987 from inner heliosphere (Venus orbit at 0.72 AU) to outer heliosphere (almost 60 AU). Later, Gazis (1996) showed that the SW speed enhancements responsible for the 1.3-year variation do not arise from the merging of structures during SW evolution, and suggested that these enhancements are of solar origin.

Long before the observation of Richardson *et al.* (1994), several authors had detected related spectral peaks in geomagnetic activity (*e.g.* Fraser-Smith, 1972; Delouis and Mayaud, 1975) and auroral activity (Silverman and Shapiro, 1983) at varying level of significance at different times. Paularena *et al.* (1995) showed that the 1.3-year periodicity occurs concurrently in SW speed and geomagnetic activity after 1987. We have recently shown (Mursula and Zieger, 1999) that the 1.3-1.4-year quasi-periodicity exists in solar wind speed and geomagnetic activity during the last three even solar cycles (SC 18, 20, 22). We found somewhat longer periodicities during odd cycles, with the period varying from 1.5 years in SC 19 to 1.7 years in SC 21. We noted that the pattern of

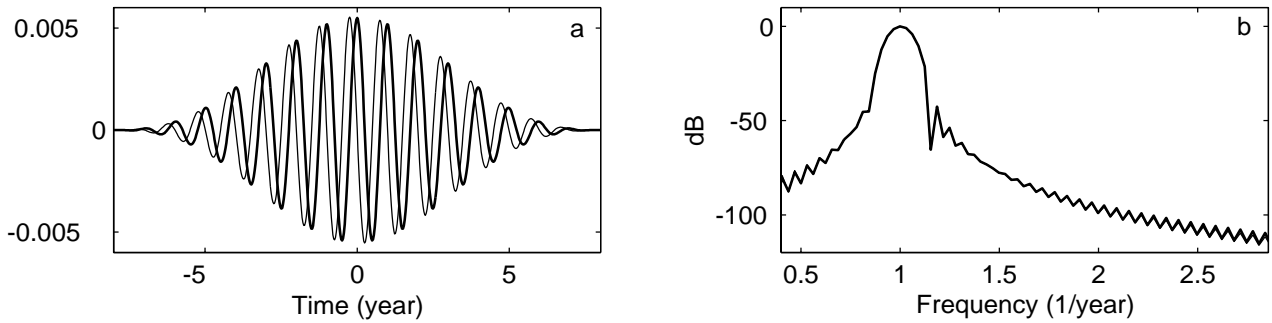


Fig. 1. In-phase (thick line) and out-of-phase (thin line) bandpass filters for a central period of one year in (a) time domain and (b) frequency domain.

alternating periodicities seems to be systematic and, therefore, implies a new fundamental difference between even and odd solar cycles.

Valdez-Galicia *et al.* (1996) showed that a 1.7-year periodicity exists even in cosmic rays in SC 21. This periodicity is the same as that existing in SW speed and geomagnetic activity at the same time (Mursula and Zieger, 1999). In this paper we study the mid-term periodicities in cosmic rays, and their connection with the similar periodicities in other heliospheric parameters.

## 2 Data and Method

We use here the neutron monitor (NM) data from Oulu station (cutoff rigidity  $\leq 1$  GeV), and the SW speed data included in the NSSDC OMNI data set. We averaged the daily NM data to 10-day averages, and made a linear interpolation over the remaining few data gaps. A bandpass convolution filter (boxcar tapered with Hanning window) was repeatedly applied to the data to extract their long-term variation. Fig. 1 depicts the filter for a central period of one year in the time domain (impulse response functions of the in-phase and out-of-phase filters) and frequency domain (transfer function). The filter has a pass band width of  $\pm 5\%$  of the central period. As seen in Fig. 1, the filter attenuates periods outside 10% of the central period by about 15 dB. The half-width length of the 1-year filter (effective time resolution) is about 6-7 years. Varying the central period of

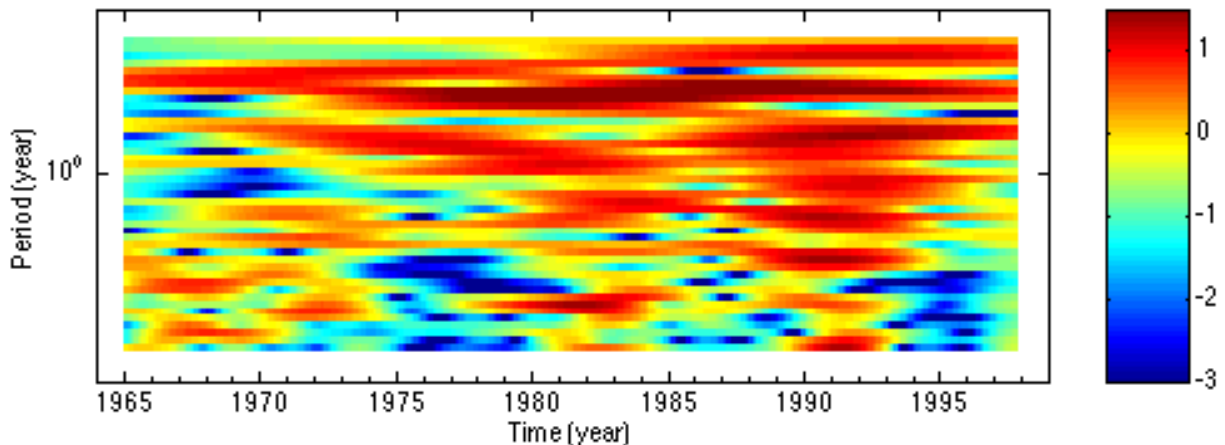


Fig. 2. Dynamic spectrum of Oulu NM data constructed from the amplitudes of filtered data. Logarithmic scale (b&w in proceedings, colored on cd-rom) at right is given in powers of two.

the filter in steps of 5%, we covered the period range from 0.3-2.5 years. The amplitudes were calculated from the in-phase (real part of the complex wave vector) and out-of-phase (imaginary part) signals for each data point. Moreover, the amplitudes were normalised by the mean amplitude in the 0.3-2.5-year period range to allow intercomparison between the two parameters. These relative amplitudes were then plotted as an intensity diagram with time and period, producing a kind of dynamic spectrum.

### 3 Results and discussion

Fig. 2 shows the dynamic spectrum for Oulu cosmic ray NM registrations for 1963-1997. Concentrating first on periods between 1 and 2 years, the strongest periodicity with a period of about 1.6-1.7 years occurs from late 1970's to late 1980's. This is the variation discovered in cosmic rays earlier by Valdés-Galicia *et al.* (1996). A 1.3-1.4-year periodicity is found during the next solar cycle 22 from late 1980's to mid-1990's. This periodicity is concurrent with the periodicity observed by Richardson *et al.* (1994). The same periodicity exists at a considerably weaker level even in early to mid-1970's. We have verified the significance of these periodicities using the Stellingwerf (1978) method in the respective 5-year intervals (times of maximum amplitude): 1970-74 (period 1.4 years), 1980-84 (1.7 years) and 1988-92 (1.4 years).

We have also analysed the registrations of the low-latitude Huancayo NM station (cutoff rigidity about 13 GeV) with the same method. We found a very similar pattern of periodicities at Huancayo and Oulu, giving further evidence for the above results. Moreover, since the Huancayo data exist since earlier years, they also cover the maximum of the previous odd cycle 19. These results (not shown here) verify the 1.5-year periodicity at around 1960, in agreement with earlier observations using geomagnetic activity (Mursula and Zieger, 1999).

At periods below one year, cosmic rays have a strong enhancement at about  $T=0.7$  years at around 1990, and a weaker one in early 1970's. This periodicity has also been found in several solar parameters (see *e.g.* Pap *et al.*, 1990). In early 1980's there is a strong enhancement at about 0.4 years which is also observed in sunspots and solar flares (see *e.g.* Oliver *et al.*, 1998).

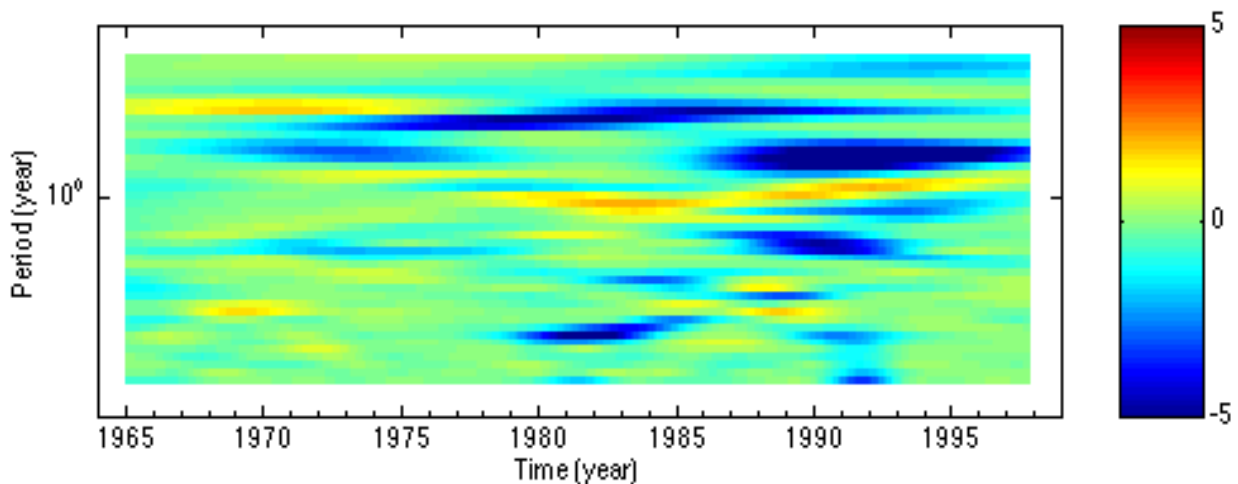


Fig. 3. Dynamic cross coherence spectrum between cosmic rays (Oulu NM data) and SW speed constructed from the amplitudes of filtered data. Linear scale (b&w in proceedings, colored on cd-rom) is given at right.

All the above periodicities are the same as observed earlier (Mursula and Zieger, 1999) for SW speed and geomagnetic activity during the same time intervals. We have studied the correlation between cosmic rays and SW speed with respect to the periodicities discussed above. Fig. 3 shows the dynamic cross coherence spectrum for the two variables. There is a significant anticorrelation between the two variables for all the main variations mentioned above. This can arise from two effects. First, the outward convection of cosmic ray particles may be enhanced due to an enhanced SW speed, leading to cosmic ray depletion on Earth. Second, the two variables may be indirectly connected through the tilt of the heliospheric current sheet (HCS). We have calculated the dynamic spectrum of the tilt (not shown here due to space limitations). According to these calculations the tilt depicts the same variations discussed above. Since the long-term occurrence of cosmic rays is known to be inversely related with the tilt, a similar relation for mid-term variations is expected.

#### 4 Conclusions

We have shown that the mid-term variations of cosmic rays closely follows the periodicity pattern observed earlier for solar wind speed and geomagnetic activity. The main quasi-periodicities are the 1.3-1.4-year variation during even cycles 20 and 22, and slightly longer periodicities of 1.5-1.7 years in SC 19 and 21. These variations are due to solar processes which affect the whole low-latitude heliosphere. McIntosh *et al.* (1992) have observed the 1.6-1.7-year periodicity in coronal hole area during SC 21. Accordingly, it is probable that these periodicities arise from the changes in coronal holes and the active solar regions related to the coronal hole boundaries. The results also verify the pattern of alternating periods for even and odd cycles which seems to be systematic during the last 5 solar cycles at least (Mursula and Zieger, 1999). This suggests that the coronal holes develop systematically differently during even and odd solar cycles.

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