Modulation Signatures on Cosmic-ray Periodicities Before a Forbush Decrease

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***Abstract*. The Wavelet technique on 5-min Rome neutron-monitor data (SVIRCO Observatory & TPL) were used to evaluate differences in cosmic ray periodicities by using two subsets of data, one before a Forbush decrease onset and the other one including it; each subset contains several time series of 7-day data, shifted by one hour. The September 2005 Forbush decrease is investigated and a clear modulation in the about 8-h periodicity is emerging from the pre-Forbush subsets.**

***Keywords*: Wavelet technique, cosmic ray periodicities, Space Weather**

I. Introduction

Planetary environments and heliospheric dynamics strongly depend on Sun's activity through the different solar outputs (i.e. electromagnetic and corpuscular radiations) reaching the interplanetary medium. Nowadays, Space Weather and Space Climatology become important branches of Space Physics, as Meteorology and Climate for the terrestrial weather. Indeed, a large amount of work has been performed to develop right tools for Space Weather, particularly for what concerns the applied research (e.g. Vainio et al., 2009 [1]). In this context, Cosmic Rays (CRs) have certainly a significant role, since they probe the interplanetary space condition. For instance, some interplanetary storm precursors were identified in CR data (e.g. [2], [3], [4], among others).
Particular attention is paid to the pre-Forbush Decrease (pre-FD) period and to the search for possible signatures in CR records of the incoming transient interplanetary perturbation at the Earth location, by using the Wavelet Technique (WT). The September 2005 FD was selected as a case study (see [5] for details). Figure 1 illustrates CR data for the whole month [upper panel: GOES 11 - 10 MeV proton chanel[1]; lower panel Rome (SVIRCO) and Oulu hourly neutron monitor intensities]. From the Figure it is possible to single out that the big discontinuity (main decrease) in the neutron monitor intensities occurs at 24 UT of September 10, 2005. In the following that time is considered as a *key time* for the analysis.

[1]http://www.ngdc.noaa.gov/stp/GOES/goes.html

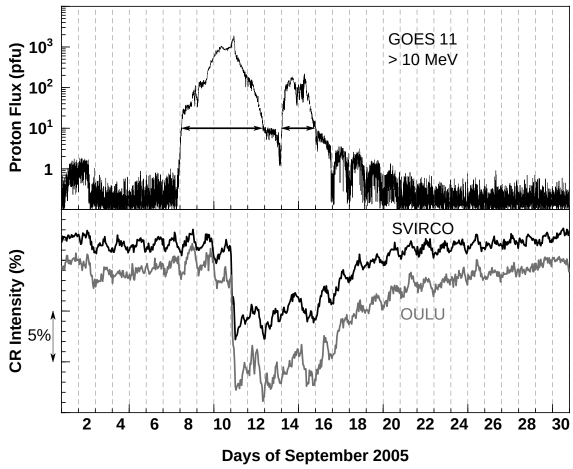

Fig. 1: CR data for September 2005. **Upper panel** : Proton flux as measured by GOES 11, 10 MeV chanel; horizontal arrows delimitate SEP events as defined by NOAA. **Lower panel** : CR intensities as recorded by SVIRCO and Oulu neutron monitors.

II. Data used and analysis

The study is based on the Rome (SVIRCO Observatory & TPL; geographic coordinates: 41.86°N, 12.47°E, height: $\sim$ s.l., and threshold rigidity: $\sim$ 6.3 GV) neutron monitor data. Aiming to investigate a pre-FD period, the data have been taken in the form of 5-min averages [6] and 25 datasets [DS_k (k = 1, ..., 25)], of 7 days each, were built up to span the FD *key time* with 1-h resolution time-step (12 datasets just before the FD *key time* [k = 13] and 13 including it) for the FD of September 2005. More precisely, DS_1 starts at 12 UT of 3 September and finishes at 12 UT of 10 September, whereas DS_{25} starts at 12 UT of 4 September and concludes at 12 UT of 11 September (i.e. 12 hours after the FD *key time*).
We searched for periodicities in the above data sets by using the wavelet transform (WT) technique [7].

WT technique allows to investigate non-stationary processes containing multi-scale features. It is able to determine both the dominant variability modes and how those modes vary in time, by decomposing a time series into the time-frequency space.
The Morlet mother function is used to compute the wavelet power spectrum (WPS) and the global wavelet power spectrum (GWPS) by setting the nondimensional frequency ω_0 = 6 and the frequency resolution δ_j =

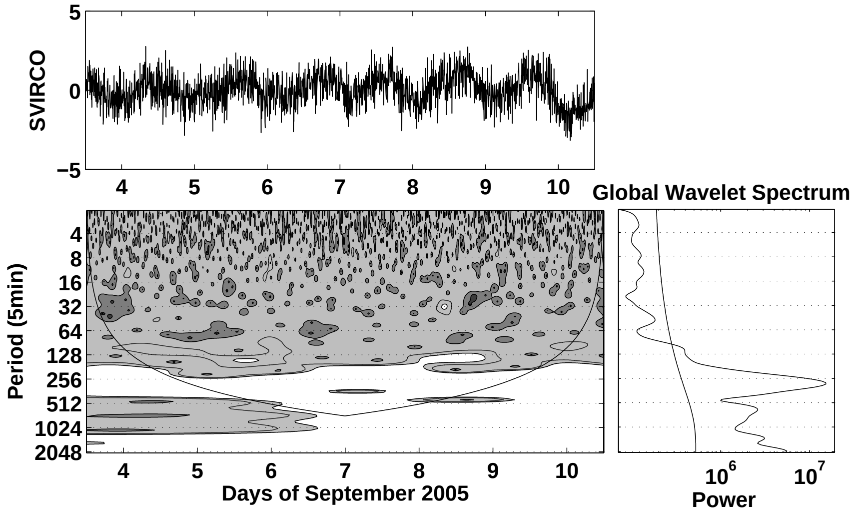

Fig. 2: Wavelet response to the DS_1 (from 3 September, 2005: 12 UT to 10 September, 2005: 12 UT. WPS versus time and period (lower left panel) and GWPS versus period (lower right panel) for the 5-min Rome cosmic-ray intensity (upper panel).

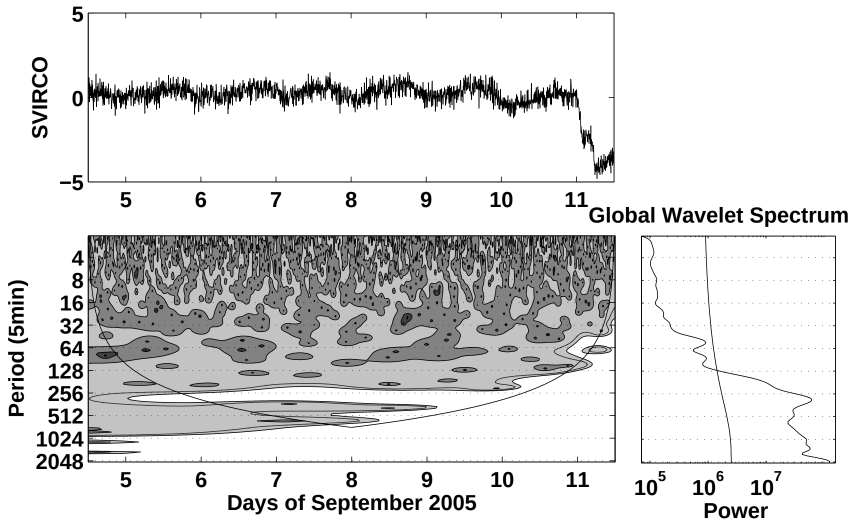

Fig. 3: Wavelet response to the DS_{25} (from 4 September, 2005: 12 UT to 11 September, 2005: 12 UT. WPS versus time and period (lower left panel) and GWPS versus period (lower right panel) for the 5-min Rome cosmic-ray intensity (upper panel).

0.0625. We chose the period scales as powers of 2. Hence, being the set of scales used in the analysis of nonlinear type, the uncertainty associated with each scale is asymmetric (see [8] for details). Moreover, the significance of the peaks in the power spectra was evaluated against a white noise background at the 95 % statistical confidence level. Also the cone of influence (COI) has been evaluated to identify portions of the WPS where edge effects become important.
Figures 2 and 3 exemplify the obtained results for DS_1 and DS_{25}, respectively. To notice in the GWPS of Figure 3 the enhancement of the white noise background, induced by the presence of the FD main phase (September 11).
Comparing Figure 2 and Figure 3 it is possible to single out a relevant change in the obtained results. In the next Section all the GWPSs will be compared to search for useful signatures to our aim.

III. Global Wavelet Power Spectra

The obtained results from all the GWPSs of the DS_k (k = 1,..., 25) were divided into two subsets: GN1 [from DS_1 to DS_{13}: assumed as pre-FD intervals] and GN2 [from DS_{14} to DS_{25}]. Figure 4 illustrates such findings, showing in the upper panel those for GN1 and in the lower one those for GN2. GN1 trends put in evidence that the spectra are practically the same with

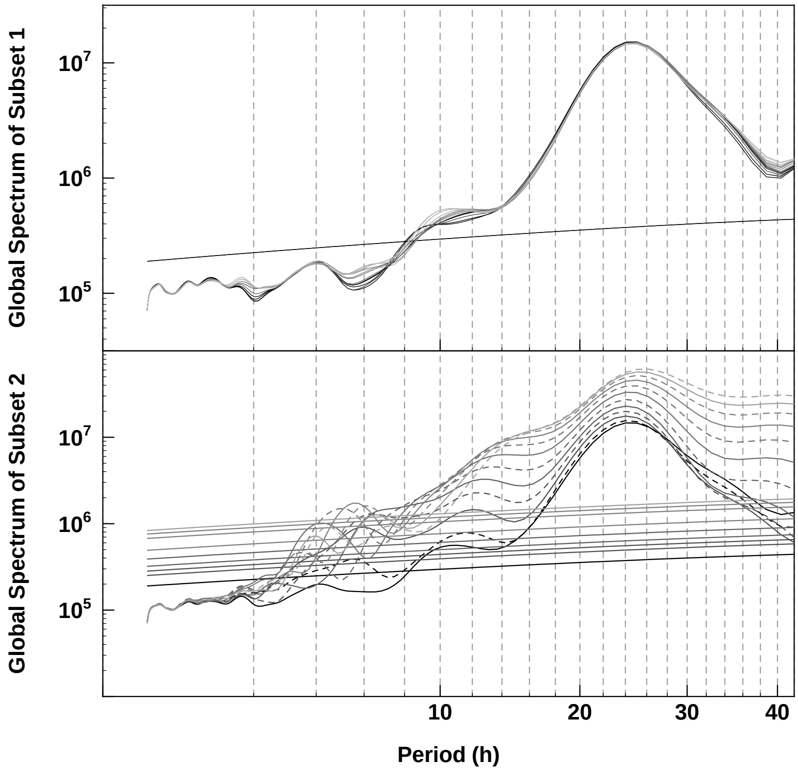

Fig. 4: All the GWPSs of subset GN1 [from DS_1 to DS_{13}- upper panel] and subset GN2 [from DS_{14} (bottom curve) to DS_{25} (upper curve)- lower panel], together with their white noise backgrounds (see the text for details).

a 24-h periodicity well identified (as expected from diurnal variations registered by the CR measurement sites with mainly equatorial view directions). From GN2 it is possible to derive the FD main phase effect (discontinuities in the data series): GWPSs and related noise levels change their shapes from DS_{14} to DS_{25}. However, these results for the 24-h periodicity seem to be not useful to identify a pre-FD signature for a transient interplanetary perturbation approaching the Earth.

Nevertheless, looking at the WPS of Figure 2 and Figure 3 it is possible to notice local significant regions for the 8-h periodicity, that will be investigated in the following Section.

IV. THE 8 HOUR PERIODICITY

Figure 5 shows in the upper panel the power to noise trends for the 8-h periodicity derived from GN1. Only three significant peaks are detected with the power/noise ratio greater than 1 [September 4, September 6 and September 10, 2005]. While for September 6 all the trends are overlayed, the two peaks at the borders show a time-shift of the maximum value of the peak (to the right the first, to the left the second [this last translation is indicated by an arrow]). The peak of September 4 change the position of its maximum in a fairly regular way and according with the derived COI it is practically unreliable and it is due to edge effects. On the contrary, the second one needs a further investigation because the change of the position for the maximum is less regular (fast for the initial DSs and practically null for the others; see below).

The lower panel of Figure 5 shows results from GN2. Once again there are significant peaks at the left border (September 4, 2005) with a regular shift of their maxima (as in the upper panel). The September 6, 2005 peaks are significant for DS_{14} and DS_{15} without any shift; no shift is also found (indicated by the arrow) for the peaks of September 10, 2005, which are always below the background. Are the features observed in the upper panel of Figure 5 a mere consequence of the edge effect or are there also useful signatures for Space Weather?

In order to better understand the ”edge effect” we performed the analysis for a new subset of data ($DS*_k$, k = 1, ..., 25) constructed to check the variability of the September 6 peak as already performed for September 10 peak (25 datasets with $DS*_1$, starting on 31 August at 12 UT and ending on 6 September at 12 UT, ..., $DS*_{25}$ from 1 September at 12 UT to 7 September at 12 UT; i.e. from 12 to 36 hours after the peak).

Figure 6 illustrates the obtained shifts of the maximum position for the 6 September peak (triangles) compared with the ones for the 11 September, 2005 (circles). While for September 6 the shift is significant for the first nine datasets but restricted to $\Delta h \leq 1.1$ h, for September 11 (pre-FD main phase) the shifts concern six datasets with Δh up to 3.4 h.

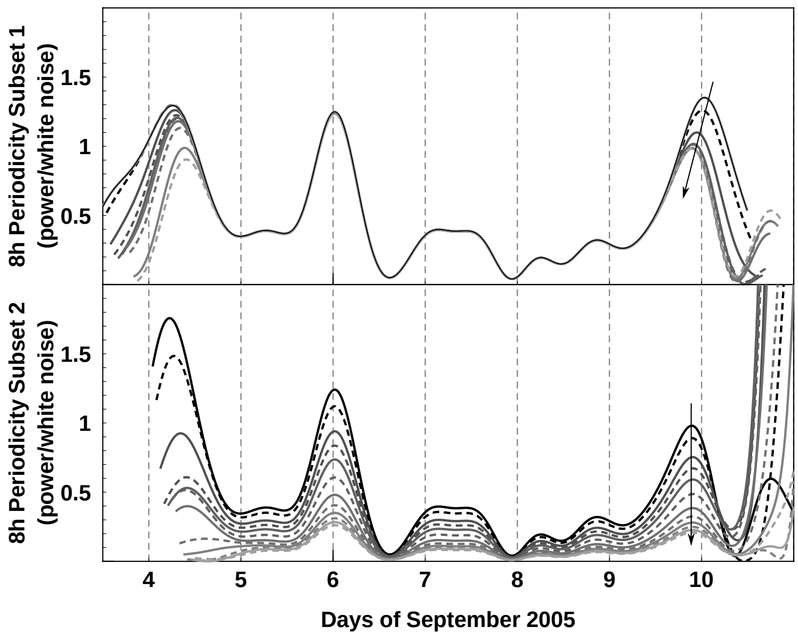

Fig. 5: Power to noise ratio of the 8-h wave of cosmic rays versus time for subset GN1 (upper panel; from top to bottom: DS_1 to DS_{13}) and subset GN2 (lower panel; from top to bottom: DS_{14} to DS_{25}. Arrows indicate peak occurrences during the day before the onset of the FD main phase.

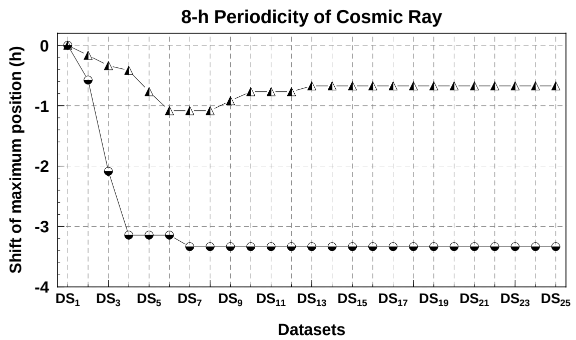

Fig. 6: Shift of the maximum peak position vs. Dataset for 6 September, 2005: 00 UT (triangles) and 11 September, 2005: 00 UT (circles); zero shift refers to the time of the maximum in the power/noise trend derived from DS^*_1 (September 6) and DS_1 (September 11).

From the above analysis it is possible to infer that edge effect concerns only peak shifts of low entity, while large shifts can contain precursor features for interplanetary storms.

V. Conclusion

Preliminary investigations performed to test the use of the WT on CR data series for Space Weather issues have been reported. The analyzed case study suggests that CR datasets, containing seven days of data with 5-min time resolution, can give a signal for interplanetary storms approaching the Earth up to 9 hours before the onset of the FD-main phase. If this is true, the basis for an engineeristic forecasting model has been found.

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