Anysotropy of the Solar Variables Measured by SOHO Satellite

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Abstract

We studied the anisotropy in turbulent time-series of the solar wind velocity and proton density measured by SOHO satellite, during the two conditions of Solar acitivities, moderate (years 1996 and 1997) and high activities (years 1999 to 2004). An approach based in the correlation coefficient between of the great and small scales and Morlet Wavelet Transform are used. The results, explained in terms of memory effect, shown that the high activities of the Sun promote an increase of memory in both variables. Furthermore, an explanation in terms of Coherent Structure in the turbulent flows are presented.

Introduction

In focus of the eventually departure of isotropy in the small scales, we studied the possible interactions between great and small scales in the magnetohydrodynamic (MHD) flows. It is interesting to remember that the local isotropy hipothesis to need of the absence of any interactions between great and small scales in the velocity field (Katul et al., 1995). If these interactions exists, so the anisotropy of movement of the eddies in the great scales to excite directly in movement of the eddies of the small scales.

In this work, we used the time-series of the solar wind velocity and proton density, measured by SOHO satellite at sample rate of 1 point by hour, in two conditions of solar activities. The moderate conditions (MC) given by 1996 and 1997 years and, high conditions (HC) given by 1999 to 2004.

Method

To study these interactions, we used the Katul's methodology (Katul et al., 1995), based in the fact of the any position of *x*, the scale of velocity of the movement eddies in the small scales (length r), into the inertial subrange, is characterized by difference of velocity $\Delta w = w(x + \Delta r) - w(x)$. Thus, a measure of interaction between great and small scales of the flows is given by correlation coefficient $\rho_{(w,\Delta w)}$, defined by:

$$\rho_{(w,\Delta w)} = \frac{\left\langle \left(w(x) - \langle w(x) \rangle\right)\left(\Delta w(x,r) - \langle \Delta w(x,r) \rangle\right) \right\rangle}{\sigma_w \sigma_{\Delta w}}$$

were σ_x is the standard deviation of the variable x of the flow, and given by

$$\sigma_x = \left\langle \left(x - \langle x \rangle\right)^2 \right\rangle^{1/2}$$

were <.> denote the mean value of the enclosed quantity.

The departure of the isotropy can be explain through of presence of the called Coherent Structures (CS) in the turbulent flows (Robinson, 1991). For this, we also used the Wavelet Transform to identify the presence of the Coherent Structures. We performed the Morlet Wavelet Transform applied in the time-series of solar wind and proton density measured in same time. It is interesting to do a brief theoretical introduction about Wavelet Transform. The wavelet word indicate a set of functions with form of little waves created by dilations, $\Psi(t) = \Psi(2t)$, and translations, $\Psi(t) = \Psi(t+1)$, from of simple generator function, $\Psi(t)$, called mother-wavelet. Mathematicaly, the wavelet function in scale a and position b is given by:

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{2}} \psi\left(\frac{t-b}{a}\right)$$

where a and b are real and a > 0. The Wavelet transform is defined by:

$$W_\Psi f(a,b) = \frac{1}{\sqrt{a}} \int f(t) \Psi\left(\frac{t-b}{a}\right) dt$$

where the temporal function f(t) is the any time-series.

In wavelet, exist two types of wavelet functions, the continuous and discrete wavelets where, to more informations consult the work of Bolzan (2004).

We perfomed the variance in each periods given by Wavelet Transform. This procedure have the objective of the identify the more energetic periods be long the years (Torrence and Compo, 1998). For this, we summed the energy associated in each period or scale a, according the following equation:

$$M(a) = \int |W(a,t)|^2 \, dt$$

The procedure exposed above is commumly called of the Global Wavelet Spectra, that is similar to Power Spectrum Density given by Fast Fourier Transform (FFT).

Results

The absence of interaction between the movement of eddies of great and small scales to need that the quantity $\rho_{(w,\Delta w)}$ to be zero. Figure 1 show the correlation coefficient performed to solar wind velocity for two conditions of the solar activities. We note that the high correlation between the great and small scales in the 10 days for HC and, 8 days for MC. Furthermore, we note the secondary scale to HC in 100-120 days.

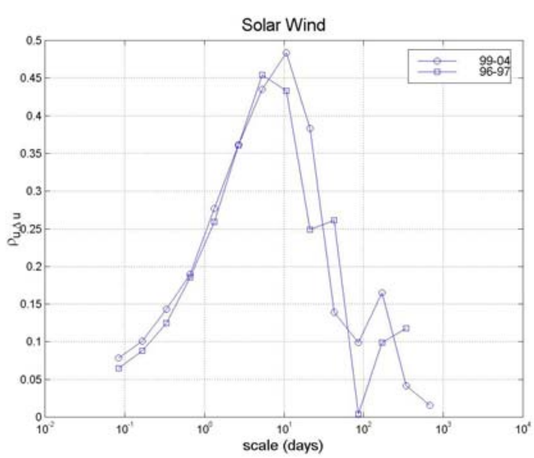

Figure 1: Correlation coefficient calculated to solar wind velocity for two conditions solar activities.

For proton density time-series, we note the presence of the scales of 5 days, for HC, and 10 days for MC, show in Figure 2.

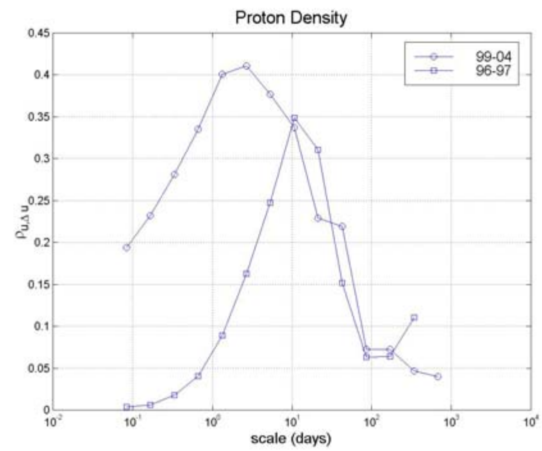

Figure 2: Correlation coefficient to proton density for two conditions to solar activities.

With the objective to investigate the possible source of anisotropy, mainly to HC, we performed the Morlet Wavelet Transform applied to both variables. The Figures 3a) and 3d) shows the six years time-series of solar wind and proton density, respectively. Figures 3b) and 3e) shows the wavelet periodogram to solar wind and proton density, respectively. Finally, Figures 3c) and 3f) shows the Global Wavelet Spectrum (GWS) to solar wind and proton density.

To solar wind, we observer structures of order at 10, 30, 51 and 120 days, as shown in Figure 3b) and 3c). However, the period more energetic was the 30 days, where this period has been found also in correlation coefficient. Thus, we think that the possible high correlation in this scales can be associated with solar disturbances that occurr in more times in HC of solar wind. To proton density, we found the following periods to proton density, 10, 27 and 130 days, as shown in Figures 3e) and 3f).

Analyzing the results above to the solar wind correlations, the following physical pictures emerge. Comparing the both solar cycle, MC and HC, we note that the both cycles has, approximately, the high correlation in the same periods, 8 to 10 days, where the difference exists in the order of magnitude of the correlation. This behavior can be due the great numbers of solar disturbances that occur in HC, promoting the increase of energy in these periods. This energy to need be transferred to small scales through of the eddies movement, the cascade phenomenology by Kolmogorov (1941). Thus, the transfer increase the correlation between the great and small scales, build up the memory effect in the system.

Now, to proton density, it is necessary to note that this variable is a passive scalar, in contrast to solar wind that is a vetorial quantity, beyond to be a derivate one from solar wind. According Warhaft (2000), the passive scalar to play to special role in the turbulent hydrodynamics flows and thus, we have to special attention also in the turbulent magnetohydrodynamic flows. These aspects to help us to understand better the distinct behavior that occurred between the both variables. Figure 2, the MC cycle the memory effect decrease to faster if compared to HC cycle. The few number of solar disturbances in MC did not promote the spatial gradient of the proton density and thus, the correlations between scales diminish more faster.

Conclusions

In this work, we used the solar wind and proton density time series during the two conditions of Solar acitivities, moderate (years 1996 and 1997) and high activities (years 1999 to 2004). We applied the Katul's methodology based in the correlation coefficient between of the great and small scales. Preliminars results shown that the predominant value of this parameter to solar wind increase of 8 days in MC to 10 days in HC. For proton density, the inverse behavior occurred, i.e., we found the predominant value in 5 days in HC, changing to 10 days in MC. However, both behavior shown two characteristics, first, presence of anisotropy, i.e., influence between great and small scales and, second, show that the influence of solar activities as anisotropy source. The use of the Morlet Wavelet Transform shown that the an important source of anisotropy is due to intermittent phenomena caused by solar disturbances. In resume, the influence of movements of great scales on the small scales provoke the anisotropy through of the intermittent phenomena. This influence has been stronger in periods of high solar activity.

Acknowledgments

All the data used in this work were obtained from MTOF/PM Data by Carrington Rotation from the website: http://umtof.umd.edu/pm/crn/.

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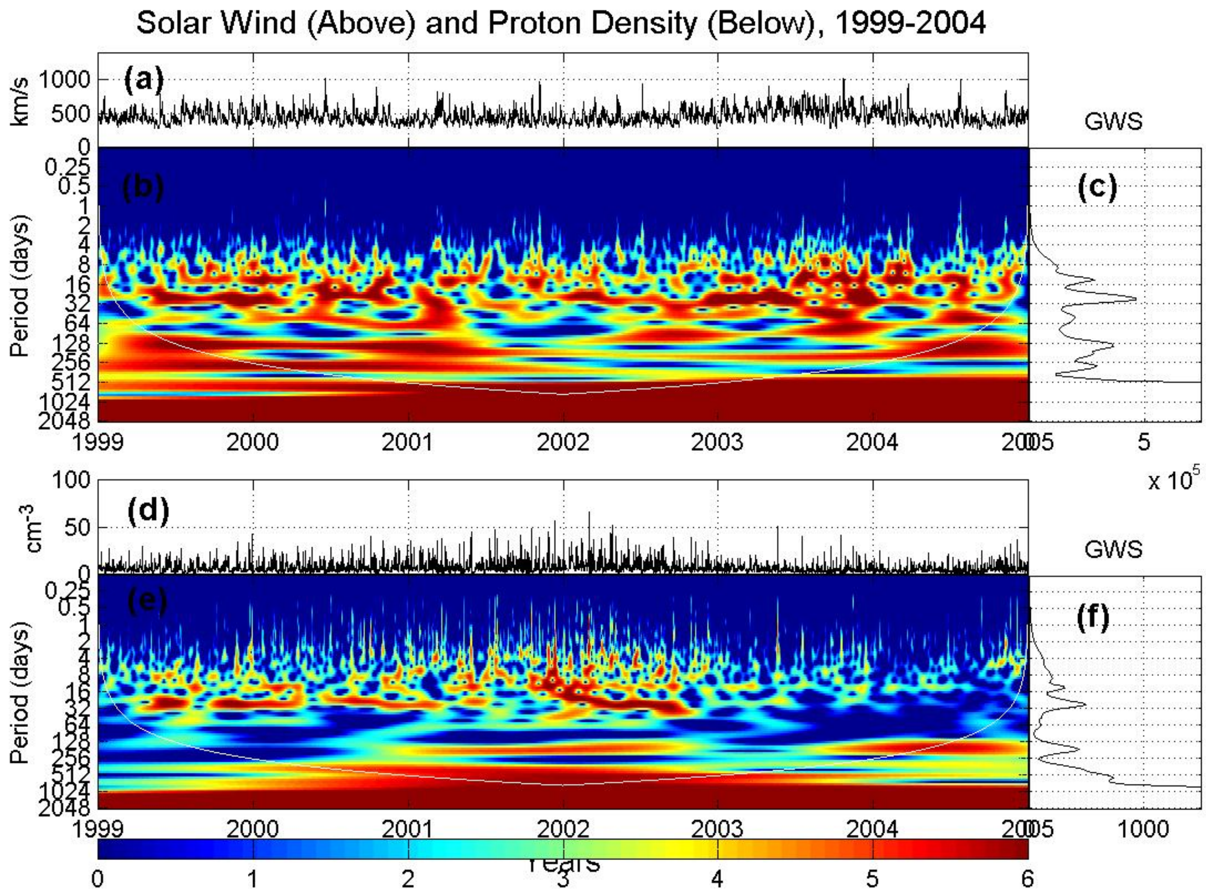
Solar Wind (Above) and Proton Density (Below), 1999-2004
(a)
km/s
(b)
Period (days)
GWS
(c)
x 10^5
(d)
cm^-3
(e)
GWS
(f)
Years