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# REFLECTION OF THE DYNAMICS OF SOLAR PLASMA FLOWS IN THE WAVELET SKELETON PATTERNS FOR NEAR SPACE PARAMETERS

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**Abstract.** Research to the establishment of the spectral features skeleton disturbances for parameters of Solar plasma flows in the form of magnetic clouds (MC), areas of interaction flows (CIR), shock waves (Shocks) and high-speed streams from coronal holes (HSS), recorded at the Earth's orbit patrol spacecraft is devoted. The proposed approach to the diagnosis of near-adjacent space will allow for early identification of geoeffective structures in Solar wind for predict the evolution of the magnetospheric disturbance. As used herein, the wavelet skeleton processing, which results in a signal in time and frequency sweep, is easy to use on-line monitoring of plasma flows.

## 1. Introduction

A number of studies have repeatedly noted that the spectral composition of the low-frequency disturbances associated with Solar plasma flows due to their type [*Wawrzaszek and Macek*, 2010]. Most low-frequency disturbances caused by turbulent areas with a flows. In [*Tessein et al.*, 2011] drew attention to the possibility of generating wide zones of turbulent areas of interaction of fast and slow Solar fluxes (CIR - Corotating Interaction Regions). The most geoeffective plasma streams such as magnetic clouds (MC - Magnetic Cloud) also often contain turbulent transition region at the front of cloud [*Steed et al.*, 2011]. It should be noted that most of the research focused on the study of the nature of turbulence flows. It does not draw conclusions about the type of flow and also the algorithms classify flows according to their spectral characteristics. Thus, it seems urgent task differentiate types of flows from the characteristic spectral features. The proposed study to clarify the type of Solar wind plasma flow from the characteristic spectral features of variations of velocity, density, temperature, magnetic field, should demonstrate an appropriate reflection of the internal structure of the plasma formation in the vibrational spectrum of the recorded variations.

The ideas developed in the framework of classification tasks differentiate types of plasma flows are based on the current physical understanding of the evolution of oscillatory processes in isolated Solar wind structures. According to the hypothesis of this study, each type geoeffective flow not just a specific set of parameters (velocity, density, pressure, temperature, value of the magnetic field) is characterized, but the fundamental characteristic of relationships between them. These linkages appear to be in sync with their associated wave packets. The developed approach allows the study to quantify the level of pairwise synchronization harmonic distribution parameters for recorded plasma formation and the results of a multi-parameter estimates to conclude that it belongs to a particular type. The advantage of this method of classification is independent of the algorithm on the intensity and duration of the event.

## 2. The data used and processing techniques

Monitoring of geoeffective structures in near-Earth space for currently geliogeophysics is an important issue. It is based on the problem of classification and identification geoeffective types of structures in the flow of the Solar wind. In turn, classification for type of streams is difficult of universal selection algorithm releasing characteristics as transient (e.g., shock wave) or long (e.g., magnetic clouds) processes. In the present study proposed an algorithm based on concise information on the magnetic and dynamic parameters of the flow and presentation of them in the form of wavelet skeleton spectral patterns.

For test the algorithm and setting of numerical experiments selected by 6 cases of different types of near-Earth space geoeffective structures recorded in the period from 2000 to 2007 according NASA catalogs (*http://cdaw.gsfc.nasa.gov*) and NOAA catalogs (http://ngdc.noaa.gov). Total selected 24 events, including: MC (28.07.2000, 29.12.2000, 12.04.2001, 28.05.2001, 09.08.2001, 17.04.2002), CIR (27.07.2003, 05.04.2005, 07.05.2007, 20.09 .2007, 27.09.2007, 25.10.2007), Shocks (19.12.2002, 27.02.2003, 14.07.2003, 17.07.2003, 12.04.2004, 22.07.2004), HSS (01.03.2000, 26.07.2003, 20.11 .2004, 04.07.2006, 29.07.2007, 17.12.2007). On the web site CDAW (*http://cdaweb.gsfc.nasa.gov*) for each one-minute data for Solar wind parameters (PSW): N (density), V (velocity), T (temperature) and data on the magnitude of the interplanetary magnetic field (IMF) |B|, Bx, By, Bz in the Solar ecliptic coordinate system were obtained, registered in patrol spacecraft.

It is well known that the technique of wavelet transform is used in applications that require data compression with minimal losses. The advantage of this approach, in contrast to the Fourier transform that operates infinite harmonic functions provided primarily defined as a finite basis functions being selected for a specific numerical experiment. In addition, wavelet analysis allows to obtain the spectrum at a specific frequency range, which makes it possible to limit the search features of the original signal. Additional specification information by computing the wavelet skeleton spectra may be provided, reflecting the internal dynamics of the processes of various types and scales.

In the present study as a basic wavelet in numerical experiments is selected Daubechies function of the fourth order. In discrete data equal to 1 minute scale wavelet transform coefficients addressed in two frequency bands, a high frequency with a maximum period of 300 seconds and a maximum in the low period 1500 sec. The resulting pattern of the wavelet transformation is further processed to present the results of the calculation in the form of wavelet skeleton spectrum. The resulting matrix skeleton range of each parameter of each event is a matrix with elements 0 and 1, where 1 corresponds to the local maximum (point on skeleton image) at a particular frequency at a particular time. Then, by plotting each point of skeleton exactly corresponds to one pixel in the image. This feature to further an objective comparison of the spectra of pairs of skeletons will be used.

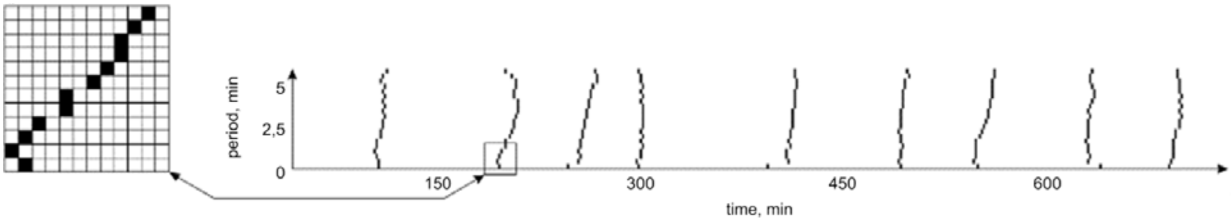


**Fig. 1** Example of a graph for wavelet skeleton spectrum for IMF Bz parameter calculated in the high scale with a maximum period of 300 seconds. Enlarged area shows how plotting the skeleton in which each point of skeleton exactly corresponds to one pixel of image

## 3. The algorithm of objective calculation of the synchronization flow parameters

An important advantage of wavelet skeleton technique in tasks that require numerical assessment of the consistency of the spectra obtained is shown. To successfully assess the consistency of the spectral pattern should contain only the key features. This can be achieved by calculating the corresponding skeletons and comparing them. The conclusion that the consistency of any two sets of skeletons obtained for the same time interval is performed by calculating the normalized standard deviation of the registration of the local maxima for spectrum presented in the form of a matrix with elements 0 and 1. The normalized standard deviation using the formula is calculated:

$$E = 1 - \frac{1}{n}\sum_{i=1}^{P}\left(A_i - B_i\right)^2 ,$$

where n - total number of points that make all the skeletons of the first and second set, A and B - the matrix analyzed skeletons patterns, P - the total number of pixels (the number of elements of A or B) create the image for skeleton spectrum. Subtract the sum of the squares of the unit allows you to operate with an intuitive scale: closer to 1 - a high similarity, closer to 0 - highest difference a pair of skeleton spectra. Fig. 2 shows an example of calculation for the parameter pairs [Bz-V] and [N-V] shock registered 22.07.2004.

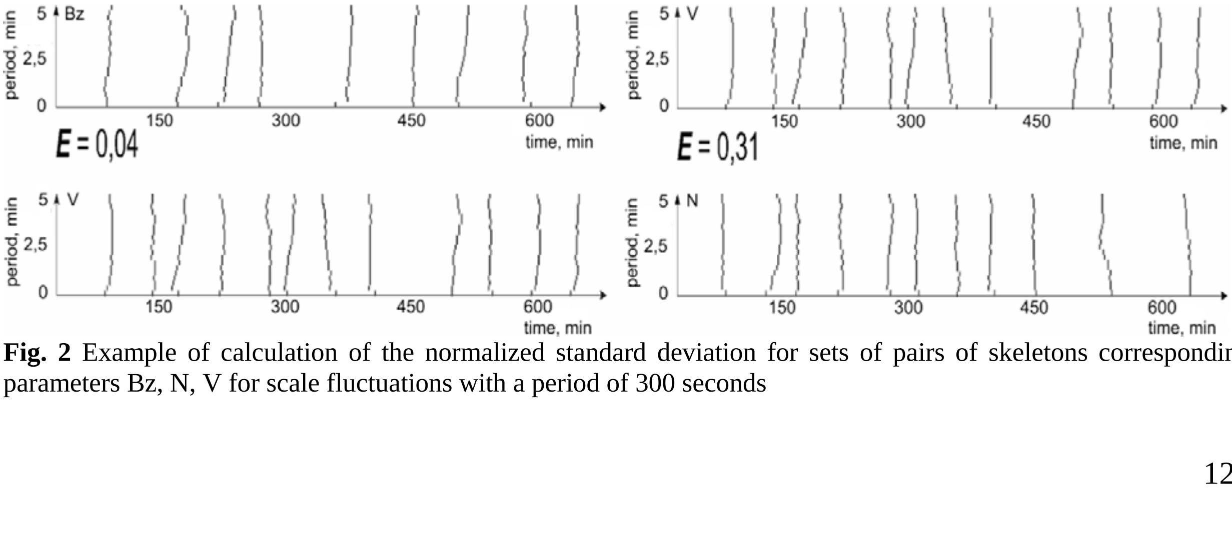


**Fig. 2** Example of calculation of the normalized standard deviation for sets of pairs of skeletons corresponding parameters Bz, N, V for scale fluctuations with a period of 300 seconds

In the future work of the classification algorithm for each flow value of E for the two scale fluctuations (up to 300 s and 1500 s) is calculated and for each pair of parameters: B-Bx; B-By; B-Bz; BN; BV; BT; Bx-By; Bx-Bz; Bx-N; Bx-V; Bx-T; By-Bz; By-N; By-V; By-T; Bz-N; Bz-V; Bz-T; N-V; N-T; V-T. Thus, each event next parametric row containing 21 (the number of combinations of pairs of parameters) × 2 (number of investigated scales) = 42 values is described.

## 4. Classification algorithm and the results of its application

The first stage of the classification algorithm identified all possible combinations of pairs of parameters (B, Bx, By, Bz, N, V, T - 21 combination) in each type of flow (CIR, Shock, MC, HSS). Next, we calculated the total standard deviation of E over all the experiments separately for the high-frequency (with periods up to 300 sec) and low frequencies (with periods up to 1500 sec). As a result, for each type of flow two different parametric vector for analyzed scale fluctuations $E_{300}$ and $E_{1500}$ were obtained. Each vector contains 21 values.

At the second stage of the classification algorithm all the possible combinations of pairs of flows types (Shock-CIR; Shock-HSS; Shock-MC; CIR-HSS; CIR-MC; HSS-MC - 6 combinations) was identified. Next, we calculated the difference between the modules of the corresponding vectors $E_{300}$ and $E_{1500}$ and performed normalization of the resulting series of data. Visualization of the normalized difference vectors modules $E_{300}$ and $E_{1500}$ in Figure 3a and 3b is shown, respectively. In other words, there are sets of pairs of spectral images of PSW and the IMF, which are different (closer to 100%) or similar (closer to 0%) flow types. We have proposed a statistically significant 75% threshold above which ensures appropriate differentiation of plasma formations within certain parameters.

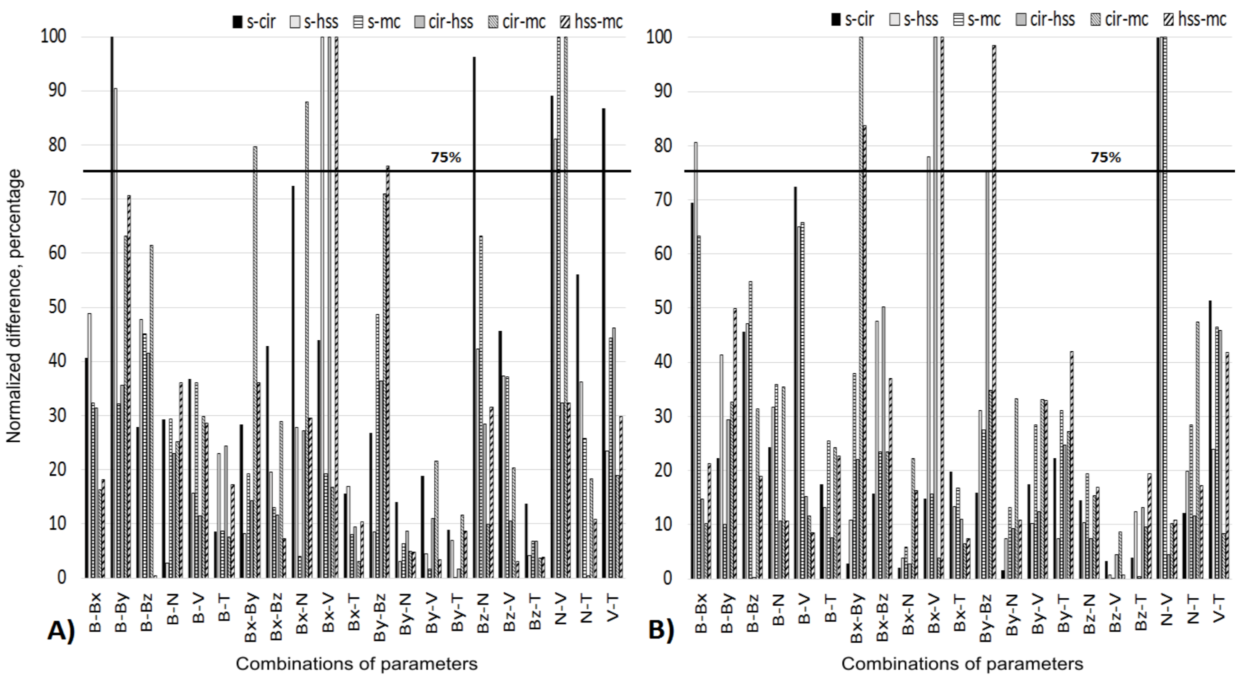


**Fig. 3** The normalized difference between the modulus of $E_{300}$ (a) and $E_{1500}$ (b). The horizontal line corresponds to 75%

The results in Table 1 as combined are shown.

| | **Shock** | **CIR** | **HSS** | **MC** |
|---|---|---|---|---|
| **Shock** | | N-V; | B-Bx; Bx-V; N-V; | N-V; |
| **CIR** | B-By; Bz-N; N-V; V-T; | | Bx-V; | Bx-By; |
| **HSS** | B-By; Bx-V; N-V; | Bx-V; | | Bx-By; Bx-V; By-Bz; |
| **MC** | N-V; | Bx-By; Bx-N; N-V; | Bx-V; By-Bz; | |

**Table 1.** The intersections of rows and columns show the sets of pairs of spectral images of PSW and IMF, which are different types of flows (by 75% or more) - on a white background for high-frequency part with periods up to 300 seconds, on a gray background – for the low periods up to 1500 seconds.

## Conclusion

According to the modern physical notions about the existence of oscillatory processes in isolated Solar wind structures classification approach to the problem of differentiating types of geoeffective plasma flows was proposed. It is shown that each type of flow is characterized not only a characteristic set of parameters such as velocity, density, pressure, temperature, strength of the magnetic field, as well as the fundamental relationships between these parameters. Such connections in the synchronization parameters associated with the flow of the wave packets are shown. Numerical assessment of the level of pairwise synchronization parameters recorded plasma formation suggests to a particular type it belongs. As a result of the referring of classification algorithm found the following patterns:

1. The identification of flow-type Shock possible to synchronize N-V.
2. The identification of flow-type CIR possible to synchronize oscillations parameter pairs Bx-N, Bz-N.
3. The identification of flow-type HSS possible to synchronize oscillations parameter pair Bx-V.
4. The identification of flow-type MC possible to synchronize oscillations parameter pairs Bx-By, By-Bz.
5. Low-frequency (periods up to 1500 sec) part of spectral disturbances of the PSW and IMF analyzed flows demonstrate their individual character, which actually reflects the duration of the event. High-frequency (periods up to 300 sec) part of disturbances PSW and IMF analyzed flow separates them only on dynamic characteristics of the Solar wind.
6. In general, the flow type MC characterized by long-term changes. Streams such as CIR can be identified by relatively rapid changes in all parameters in all of the analyzed scale of disturbances. Flows type Shocks cause abrupt changes in all parameters, especially when a low-frequency part of the spectrum analysis. Streams such as HSS can be identified by slow changes in the parameters of velocity, density, temperature, and rapid changes in components of the magnetic field.

The results are expected to be tested by events that are not included in this study.

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