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POST-PROCESSING OF WAVELET TRANSFORMS FOR MAGNETOGRAMS RECEIVED ALONG THE NORTHERN PART OF THE GEOMAGNETIC MERIDIAN AS A NEW TOOL FOR CLASSIFICATION AND PREDICTION OF MAGNETOSPHERIC STORMS

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Abstract. Research to analyzing the results of the post-processing of the wavelet components for horizontal component of the geomagnetic field perturbation in range Pc4-5 recorded along the meridian chain of stations during different strength of geomagnetic storms is devoted. Concludes that the intensity of the expected or rising geomagnetic storm. Analysis of spatial and temporal spectrum distribution of geomagnetic variations to the existing network of geomagnetic stations allows us to study the dynamics of displacement of polar cap and auroral oval boundary during magnetospheric disturbances. The proposed method for classification and forecast geomagnetic storms can be used.

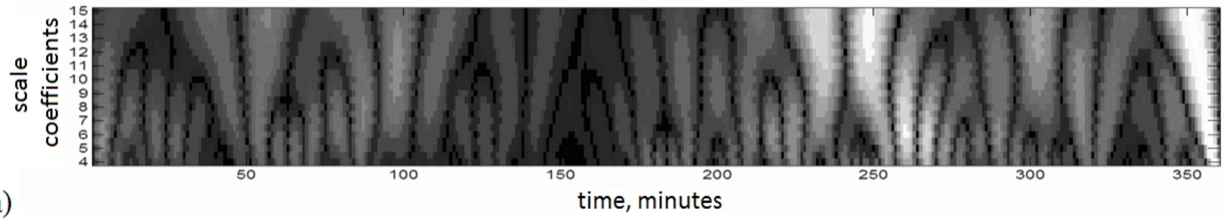
Introduction

Spectral processing of satellite and ground observations for study Solar-Terrestrial relationships with the accumulation of information about the state of the interplanetary medium and geomagnetic field has been advanced. Spectral and wavelet analysis of satellite and Earth-surface data at different stages of magnetospheric storms have allowed groups of the Institute of Earth Physics and Space Research Institute a number of features of Solar-Terrestrial relations [*Pilipenko et al., 1999; Kozyreva et al, 2006*] to establish. However, there is difficulty interpreting the results obtained using these techniques. Of particular difficulty the analysis of the wavelet patterns is represented. It is connected by that the technics of wavelet transformation as a result of calculation gives a superfluous information picture of a spectrum. The essence of our proposed post-processing is focused to reporting the results as graphs or local maxima of wavelet skeletons, allowing you the key features of the spectra dynamics present.

The data used and processing techniques

In study minutes data for geomagnetic field components from a network of stations IMAGE (http://www.geo.fmi.fi/image) is used. Intervals of station data with intervals of dayside (for a network of stations), magnetospheric storms with shape of a classic «bay» and with varying intensity on the indication of the Dst-index (http://spidr.ngdc.noaa.gov/spidr/) recorded between 2000 to 2003 were collected. A total of 12 intervals with 72 hours duration were found. In this intervals weak and moderate storms (Dst> -100 nT), severe storms (Dst> -200 nT) and extreme storms (Dst <-200 nT) were collected. All intervals contain the key stages in the expansion of magnetospheric storms – sudden commencement, main phase and the beginning of the recovery phase. For the analysis of geomagnetic disturbances 7 stations (Hornsund, Bear Island, Kevo, Masi, Sodankylä, Oulujärvi, Uppsala) located at approximately the same geomagnetic meridian (106-109) were selected.

Data processing by the wavelet transform and the post-processing results of the wavelet patterns are performed. The basic wavelet in numerical simulations Doubechies fourth-order function has been chosen. Scaling coefficients of the wavelet transform in the range of 4 to 15, which corresponds to the range studied oscillation periods of 120 seconds (Pc4) to 450 seconds (Pc5) are used. Example of wavelet processing technique for fragment of the magnetogram corresponding to the geomagnetic storm main phase recorded at the station Kevo 18.04.2001 in Fig. 1a are shown. Here, the bright areas correspond to high correlation of the signal with the base wavelet, dark areas correspond to low correlation. It is known that in a calculation technique of wavelet transforms is superfluous spectral information. The redundancy of this representation can be intensely reduced when only the maxima of the spectrum on the graph are shown. This forms the «wavelet skeleton» or «skeletons» are called, which consists of a set of curved lines that track the position of local maxima in the spectrum. Thus, in place of high values for coefficients in the wavelet pattern «skeleton» points are located. This technique for presentation results like «skeleton» of the wavelet pattern lets you focus on the key features of the dynamics of the spectra. On Fig. 1b an example of the spectrum shown in Fig. 1a in the «wavelet skeleton» form so-called local maxima graph is shows.

a) 

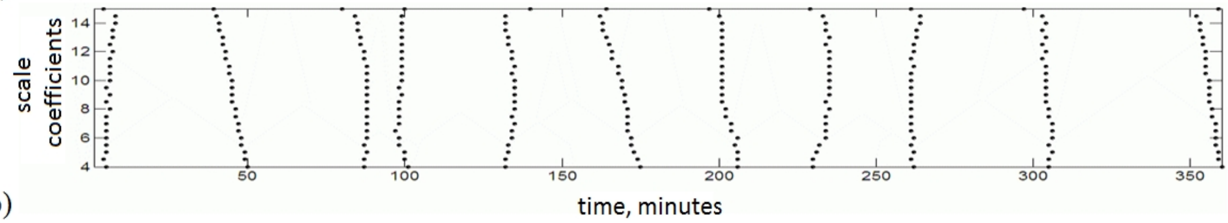
b) 

Fig. 1. a – geomagnetic storm main phase recorded at the station Kevo 18.04.2001, b – «wavelet skeleton» form or so-called local maxima graph for Fig. 1a

The results of the post-processing for wavelet transforms have the following interpretation. Skeleton of the first type «|» is very rapid process of change fluctuations state are shows. At the high-latitude stations under auroral oval this type of skeleton moving boundary between the polar cap and the auroral oval are registered. At sub-auroral stations such skeleton the boundary between auroral oval and sub-auroral region are corresponds. Skeleton of the second type «/» is process of fluctuations energy dissipation with transition from high-frequency pulsations to low-frequency range are corresponds. It may indicate a decrease in the level of energy introduced into the oscillating system from an external source. Skeleton of the third type «\» is process of pumping the fluctuations energy to the transition from a range of low-frequency pulsations to the range of high frequency are corresponds. It may indicate an increase in the level of energy introduced into the oscillating system from an external source. Nonexistence the skeleton in the given time interval a steady state fluctuations are not released in amplitude and frequency in the investigated range of the scale coefficients (frequency range) can be interpreted.

Features of geomagnetic storms based on wavelet analysis of skeletons

Postprocessing of wavelet transforms to the analysis of magnetograms from stations IMAGE network with the aim of identifying different strength of the magnetospheric disturbances are applied. According to the results of parallel analysis of the dynamics of skeletons magnetograms classification of geomagnetic disturbances in the period range Pc4-5 registered at the stations along the northern part of the geomagnetic meridian is made. At the same time characteristic features of geomagnetic disturbances arising from the growth of different strength magnetospheric storms is revealed. It is noticed that the main features of skeletons corresponding to the geomagnetic disturbances of varying intensity in the main phase of storms has manifested.

For the first group of space-time properties of disturbances, corresponding to weak and moderate storms (Dst > -100 nT) during the three hours before and during the initial phase, disturbances at low-latitude subauroral stations of network are characterized. On the main phases of storms observed extension of registration region with other skeletons (the other frequency dynamics) to the south from high-latitude stations. Characterized by a clear separation groups of skeletons in the north (the zone of the polar cap and auroral oval) and southern (sub-auroral zone). This phenomena simultaneously with an increase the diffuse auroral region is registered with respect PGI RAS model (http://webapps.pgia.ru/apm).

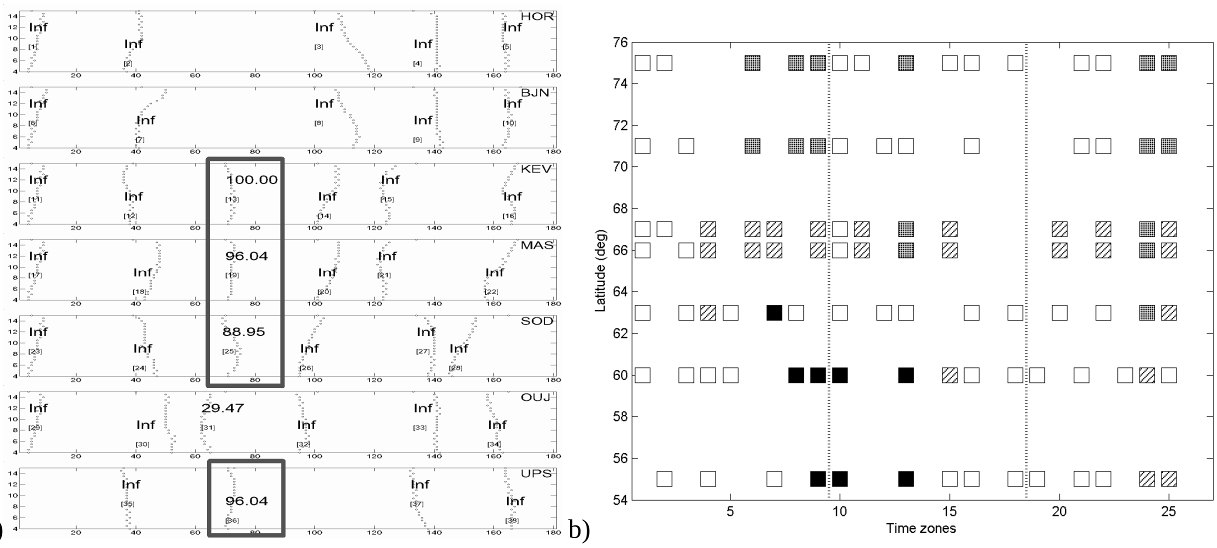
For the second group of space-time properties of disturbances, corresponding to strong storms (Dst> -200 nT), different dynamics at subauroral latitudes before the initial phases are characterized. For the initial and main phases disturbances with the same dynamics are amplified simultaneously with auroral oval expansion with respect PGI RAS model. At the same time visibly display at least three groups of skeletons (the polar cap, oval, sub-auroral zone). Disturbances at high-latitude stations do not have a stable dynamic of frequency pattern in the geomagnetic storm evolution process.

For the third group of space-time properties of disturbances corresponding to extreme storms (Dst <-200 nT), increased amplitudes of disturbances at the high-latitude stations even before the initial phases is characterized. The initial phase characterized by the appearance of disturbances with the same dynamics in subauroral regions. At this time the deformation of the polar cap and its shift to the night side in progress [*Galperin and Feldsiein, 1996*]. On the main phases of storms on the low-latitude stations of network observed the appearance of disturbances with different frequency dynamics (skeletons) followed by an extension of the auroral oval and/or diffuse auroral region.

Control of dynamics for high latitude active zones

The results of the post-processing of the wavelet components of the horizontal component for geomagnetic field to determine the boundaries of high-active zones can be used. Indeed, analysis of concurrent plots of local maxima (skeletons) for the different stations identical fragments of the spectrum at different times at different latitudes is detects. To obtain a quantitative evaluation of the identity of skeletons an algorithm that allows to mark some skeletons and calculate the standard deviation between them we have developed. In the first phase of the algorithm the coordinates of points on the horizontal axis (time) $X=\left[x_1\ x_2\ \dots x_n\right]$ and the vertical axis (frequency) $Y=\left[y_1\ y_2\ \dots y_n\right]$ forming a skeleton in his frame are determined. For each pair of skeletons the standard deviation $Dx=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i^{s1}-x_i^{s2}\right)^2}$ where n – number of points (in our experiments n = 23) forming the skeleton, s1, s2 – indexes belonging to the skeleton in a selected pair has calculated. The resulting deviation to the total maximum value is normalized and as a percentage is calculated: $Dxn_i=\left(1-\frac{Dx_i}{\max\left(Dx\right)}\right)\cdot 100\%$

Note that the spacing between neighboring skeleton (excluding skeletons on the edge, whose appearance by edge effect is caused) the characteristic time scale in the investigated frequency range is indicates. For the wavelet scale factor from 4 to 15 (2-8 MHz) it averages about 30 minutes this space is equal. I.e. with such an interval in the frequency range all oscillating system is changing. In this regard, the skeletons on investigated latitudes for calculate *Dxn* inside the half-hour time window is formed. Consistent skeleton for which the value of *Dxn* exceeded 70% we considered only. By calculating all possible combinations values for *Dxn* identical groups of skeletons at different latitudes can be found. Fig. 2a examples of skeletons are consistent within the group is shows.



a) b)

Fig. 2. Examples of skeletons within the group for which the value Dxn exceeded 70% (a) are consistent. Skeletons, which were not included in the group with «Inf» are marked; the abscissa present time in minutes, the ordinate present wavelet coefficients, station code in the upper right corner is present.

The dynamics of the conditional distribution map of disturbances during extreme storms 24/11/2001 (b) are presented. Vertical dashed lines phase of the storm (quiet state, the initial phase and main phase) is separate. The color coding consistent skeleton for the polar cap (gray), the auroral oval (shading) and sub-auroral zone (black) is indicates.

Combining the obtained estimates for the corresponding pattern of time intervals the map of the distribution of identical pieces of the spectrum, with an indication of its latitude magnetograms registration stations can be obtained. At the next stage of the selected group of skeletons on the basis of belonging to different active high-latitude regions – the polar cap, the auroral oval and sub-auroral zone can be further combined. Fig. 2b the evolution of map of the distribution of disturbances during extreme storm 11/24/2001 are shows.

The obtained borders on the distribution map of disturbances with the calculated boundaries of the auroral oval, according to the model of PGI RAS, allowing with indices Dst and AL restore an instantaneous image of the high-field with the active zones of precipitation can be compared. For all studied 12 intervals of geomagnetic storms the correlation research for positions obtained and calculated boundaries is carry out. It turned out that satisfactory results (correlation coefficient greater than 0.7) for the southern border of the auroral oval (see Table 1) are observed only. A more precise definition of the northern (polar) auroral oval boundaries is difficult due to the fact that it is also the boundary of the active region of the polar cap. This area projection of open magnetic field lines from the magnetospheric tail rarefied plasma is present.

Table 1. The results of correlation research of calculating boundaries in accordance with PGI RAS auroral oval and map the distribution maps of disturbances (skeletons). The upper value corresponds of the correlation to the northern borders; the lower value corresponds to the correlation of the southern border.

Weak storms		Strong storms		Extreme storms	
Date	North	Date	North	Date	North
	South		South		South
01.11.2000	0,06	23.05.2000	0,11	15.07.2000	0,12
	0,68		0,66		0,81
18.06.2001	-0,04	18.04.2001	-0,01	24.11.2001	-0,04
	0,7		0,72		0,74
19.05.2002	0,13	03.09.2002	0,02	07.09.2002	0,02
	0,7		0,8		0,77
04.11.2003	-0,21	18.06.2003	0,11	20.11.2003	-0,04
	0,75		0,65		0,79

Conclusion

Postprocessing technique of space-time wavelet analysis of magnetic disturbances range Pc4-5 along the meridian chain stations accompanying geomagnetic storms for classification and prediction of expected or rising storms are used. Characteristic features of the computed dynamic spectra based on the study of storms of varying intensity are set and as a tool for classification of geomagnetic storms is used. Time interval analysis of the spectra of the meridional network of observatories to 3 days expanded, which makes it possible to obtain information about the intensity of geomagnetic activity on the dynamic spectrum of the magnetograms per day before the main phase of the storm and within two days after the storm beginning. With this approach, the division investigated perturbation at least three groups of intensity it was discovered.

Numerical analysis of the skeletons to identify the boundaries of active high-latitude regions also helped. The results of post-processing of wavelet transforms considered magnetograms quantitatively with a map of active high-latitude zones according to the model of PGI RAS is compared. Show that the dynamics of the polar cap boundary and the auroral oval during magnetospheric disturbances by the characteristic features of disturbances in the distribution of skeletons in the expansion of different strength of geomagnetic storms can be detected.

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