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MATHEMATICAL ANALYSIS OF THE PI2 GEOMAGNETIC PULSATIONS IN "POLAR" AND "HIGH-LATITUDE" SUBSTORMS

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Abstract: *In our terminology, the "polar substorms" are isolated substorms, observed at geomagnetic latitudes higher 70° and not accompanied or preceded by substorms at auroral latitudes; the "high-latitude substorms" are the substorms which start at auroral and then drift to the polar latitudes. Here we apply the methods of the discrete mathematical analysis (DMA), namely the calculation of the general dispersion of the two-dimensional covariance matrix of the wave, to study the global latitudinal structure of the Pi2 (f=8-25 mHz) geomagnetic pulsations, which were observed during several polar and high-latitude substorms. For this analysis, we used the observations of 10-s sampled IMAGE meridian magnetometer profile data and 1-s sampled data from some mid-latitude and equatorial INTERMAGNET stations. We found that generally the Pi2 pulsations bursts associated with both types of substorms occurred simultaneously from polar to equatorial latitudes. However, the wave polarization was different at different latitudes. The strongest Pi2 pulsations were recorded at the electrojet location latitudes. The Pi2 behaviour during two considered types of substorms is presented and discussed.*

Introduction

Despite the fact that Pi2 geomagnetic pulsations (f=8-20 mHz) have been widely studied for more than half a century and several hundred works are devoted to them, the mechanism of their generation and their role in the physics of magnetosphere substorms have not been finally established so far. There are some monographs and reviews in which the morphological characteristics of Pi2 pulsations at different latitudes and possible mechanisms of their generation are discussed (e.g., [1], [2],[3],[4],[5],[6],[7],[8]). The mechanisms of Pi2 propagation in the magnetosphere from the generation area to the Earth's surface have also not been established. Consequently, the analysis of Pi2 features remains an important task for studying the physical mechanism of the generation of this type of pulsation and its source localization.

One of the most important properties of Pi2 pulsations is their clear link with onset of the explosive phase (breakup) of the magnetospheric substorm [9]. The magnetic substorms are observed not only at auroral latitudes but at polar latitudes as well. All substorm disturbances observed in polar latitudes we divided into two types: "high-latitude substorms" [10], which expand from auroral (<70°) to polar (>70°) geomagnetic latitudes and "polar substorms" [11], which are observed at geomagnetic latitudes higher than 70° in the absence of disturbances below 70°.

The aim of this paper is to study the Pi2 latitude distribution and wave polarization during these types of substorms. For the analysis, we used the observations of 10-s sampled IMAGE meridian magnetometer profile data and 1-s sampled data from some mid-latitude and equatorial INTERMAGNET stations.

Method of the analysis

The Pi2 pulsations here have been analyzed by applying the fuzzy logic methods of the Discrete Mathematical Analysis –DMA developed in some papers (e.g., [12], [13], [14]).

The first step of the observation data processing included the filtration within the 8–20 mHz range using a band-pass Butterworth filter with a zero-phase shift [15], the amplitude-response curve of which is maximally smooth in the frequency bandwidth. The chosen DMA rectification for this analysis was so called the generalized variance, calculated as the Kolmogorov mean [16] of eigenvectors of the covariance component data [17]. The covariance matrix calculation in the window is the known procedure for polarization analysis.

Results

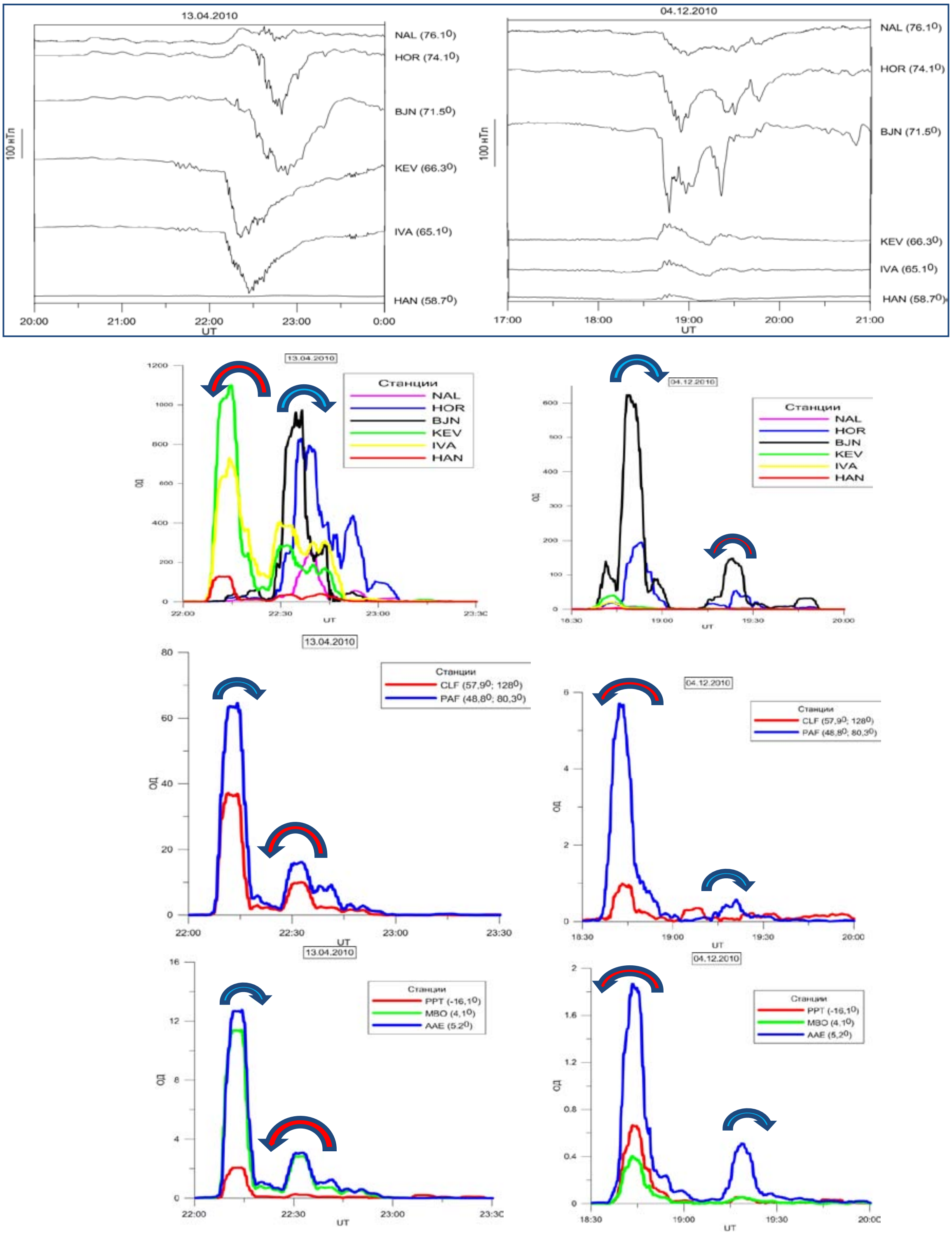

Fig. 1**.** Magnetograms from some IMAGE stations and plots of the generalized variance of Pi2 pulsations (relative units) at high, middle, and equatorial latitudes during the “high-latitude” (left) and “polar” (right) substorms; the arrows indicate the rotation direction of the wave polarization.

First at all it was found that each Pi2 bursts in both types of substorms was observed in the global scale of the latitude: the Pi2 bursts were coherent at high, middle and equatorial stations located along the same geomagnetic meridian. It was sharp amplitude decreasing with latitude declining. The Pi2 amplitude at the equator was much stronger at night side than at day side.

The principal axis of the polarization ellipse and the direction of the polarization vector rotation were determined (shown by the arrows in Fig. 1). It can be seen that the auroral burst of Pi2 pulsations in the region of their amplitude maximum was characterized by the left-hand polarization, while the polar Pi2 burst was chartered by the right-hand polarization. We note that the right-hand polarization burst of Pi2 pulsations at polar latitudes was also observed during the "polar substorm" (right side of the Fig. 1). The change of the Pi2 polarization with the substorm shift from auroral to polar latitude is seen in the left part of Fig. 1.

We found that the Pi2 polarization change near the geomagnetic latitude ~70° is the regular fact. One can see it clearly in Fig.2, illustrated that for two more examples.

Another change of the sign of the wave polarization was observed near the plasmapause and then it remains the same to the equator (Fig. 1).

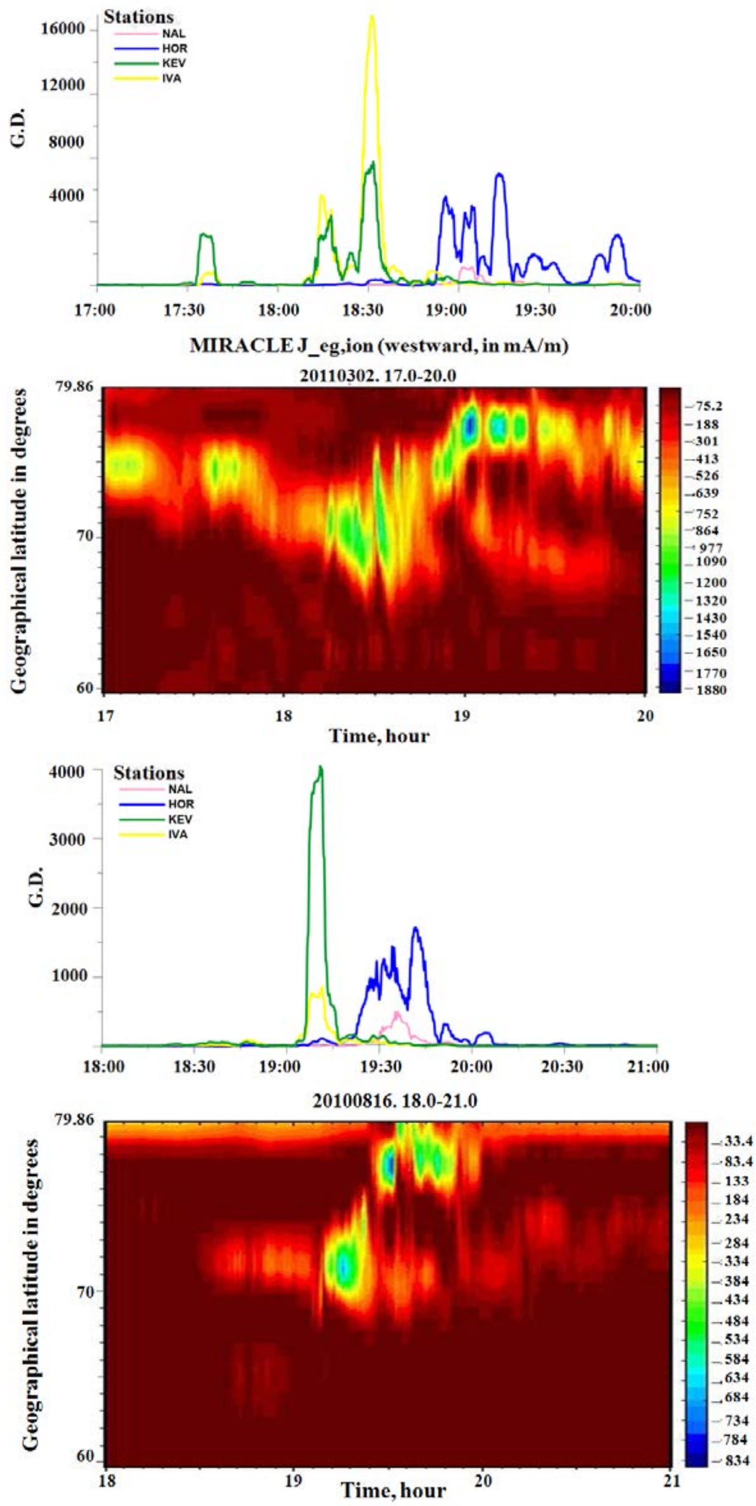

Fig. 2. Two more examples of Pi2 pulsations in the "high-latitude" substorms

It was found that the solar wind and IMF parameters are different in the case of the ”polar” and “high-latitude” substorms. Typically, the “polar” substorms occur under the low solar wind velocity < 500 km/s in the late recovery phase of a magnetic storm. Contrary to that, the “high-latitude” substorms are observed during high speed solar wind streams (HSS) in the early recovery phase of a magnetic storm under the high solar wind velocity > 500 km/s ([18]). The typical solar wind and IMF parameters for the “high-latitude” substorms are shown in Fig. 3.

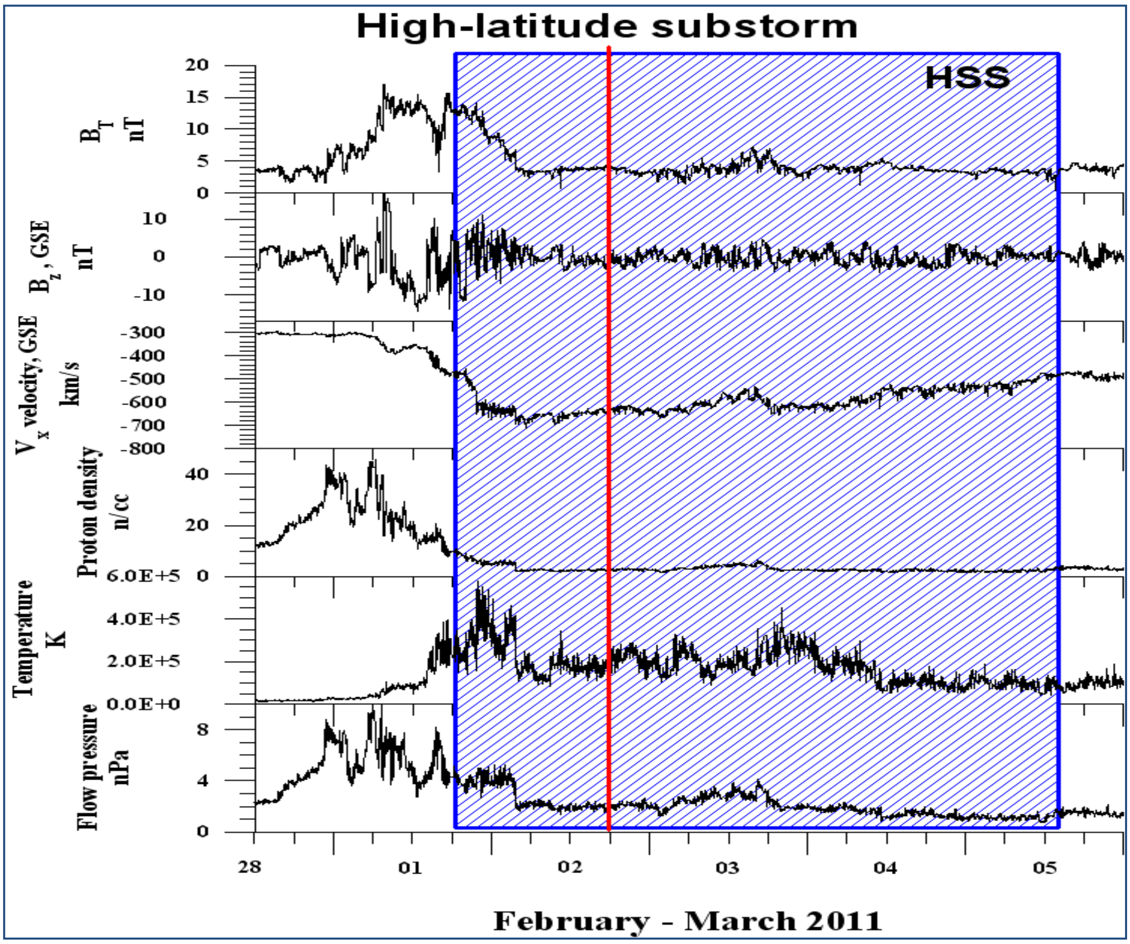

Fig. 3. Solar wind and IMF parameters typical for “high-latitude” magnetic substorm

One of the presumable sources of the Pi2 pulsations could be fast plasma flows in the magnetotail (BBFs) that are directed to the Earth. A statistical link of these flows with generation of Pi2 pulsations is shown in a number of works (e.g., [19]). A possible scheme of the generation of the BBF-induced Pi2 pulsations is shown by [6]. A BBF “impact” on the closed magnetosphere generates a fast mode of wave (compression wave) propagating along the Earth`s radius to the equator, as it was recorded on satellites and at the ground-based low-latitude stations. These Pi2 pulsations are referred by [6] to “*directly driven Pi*2”. Moreover, the appearance of the fluctuating field aligned electric currents is most likely connected to the auroral and polar bursts of Pi2 pulsations discussed in this work.

Conclusions

- It was shown that the bursts of Pi2 pulsations in a frequency band of 8–20 mHz accompanied substorm both types (”polar” and “high-latitude”) occur simultaneously at a global latitude scale: from polar to equatorial latitudes. The spatial dynamics of the maximum amplitude location of the Pi2 pulsations corresponds to the spatial dynamics of the westward electrojet center location.

- We revealed a very important fact, namely, the regular change of the polarization rotation direction of the substorm associated Pi2. It was left-handed at the auroral latitudes (< 70°) while right-handed at the polar ones (> 70°). During both types of substorms, the sigh of the polarization vector rotation changed near plasmapause and then remains the same to the equator. Thus, the direction of the Pi2 polarization vector rotation, observed at low and even equatorial latitudes could be used as an indicator where are these Pi2 pulsations were generated low or higher of 70° geomagnetic latitude.

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