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AVERAGE ULF INTENSITY LEVEL DURING STRONG GEOMAGNETIC STORMS

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Abstract. A new wave ULF-index has been applied for analyzing daytime wave activity in ultra low frequency range (ULF, namely, 2-6 mHz) during 19 strong magnetic storm (-150 nT $< Dst_{min} < -100$ nT). It is found that at autoral latitudes the most intensive morning-noon geomagnetic pulsations are observed in the main phase of the magnetic storms. It is shown the magnetic storm sudden commencement, characterizing by the solar wind density enhancement and the solar wind speed jump, is accompanied by the sharp increasing ULF- index. In the storm recovery phase the ULF-index level increased, an appearance of some separate time intervals with the negative values Bz- component of IMF during this phase leads to the short-time ULF- index increasing.

1. Introduction

The turbulent character of solar wind drivers and the existence of natural MHD waveguides and resonators in the ULF frequency range (~1-10 mHz) ensures a quasi-periodic magnetosphere response. Therefore, much of the turbulent nature of solar wind-magnetosphere-ionosphere interactions can be monitored with ground-based ULF observations.

Various geomagnetic indices (Kp, Ap, Dst, SYM-H, AE, AU, AL, PC, etc.) characterize the level of the electrodynamics of the near-Earth environment. However, there is no index characterizing the wave activity.

We developed the new index of the dayside wave activity as a rough proxy of the level and character of low-frequency turbulence, which we called **"ULF-index"** [Kozyreva et al., 2007]**.** The most promising frequency range for the index definition is the Pc5 band (~ 2-7 mHz) with the most intense fluctuations is of key importance.

The first attempts to create the activity index of Pc5 geomagnetic pulsations were made at the end of the past century. Thus, Glassmeier [1995] proposed to use the ratio of the pulsation energy in a relatively narrow band to the energy in a wide band. A similar parameter, defined as a ratio of the pulsation power in the band 2–10 mHz to such a power at 0.2–10 mHz, was used by Posch et al. [2003] in order to study Pc5 pulsations during magnetic storms. However, Posch et al. [2003] analyzed data from stations located only in one longitudinal sector, which could not completely reflect wave activity on the global scale.

O'Brien et al. [2001] used the magnetic observations at 11 stations of the INTERMAGNET network, located at $L = 3.5$–7.0, in order to study the wave activity. They calculated the Fourier spectrum of the total field vector for each station (all three components were taken into account) in a 2-hour sliding window in the 150–600 s range of periods. Then, the station where the oscillation power was maximal was selected, but the station local time was not taken into account in this case. As a result, nighttime oscillations in this range, which belong to the class of irregular Pi3 pulsations, participated in the estimation of wave activity. In addition, it is insufficiently correct to use the total field vector since the *Z* field component is very sensitive to local geoelectric inhomogeneities.

Since an analysis of ground based observations at one selected observatory or at any one meridian does not give information about the level of wave activity on the global scale, a new index was developed in order to estimate global wave activity in the daytime (0300–1800 MLT) sector of the magnetosphere [Kozyreva et al., 2007]. Romanova et al. [2007] used the *ULF* index to study acceleration of energetic electrons in the Earth's magnetosphere.

The aim of the present work is to estimate the level of daytime wave geomagnetic activity during different phases of strong magnetic storms using the *ULF* index.

2. Brief description of ULF-index

The wave index as a proxy of global ULF activity is reconstructed from the 1-minute data from the arrays of magnetic stations in Northern hemisphere:

- INTERMAGNET
- Greenland Array
- MACCS
- 210 Magnetic Meridian Chain
- Russian Arctic magnetic stations
- DMI WDC selected observatories

Figure 1 presents the map of location of the observatories used to calculate the *ULF* index. The stations are automatically selected for each hour of day, depending on the specified range of geomagnetic latitudes, in order to calculate the hourly values of the *ULF* index. The Fourier spectra are first calculated for these stations in a 1-hour window for two horizontal components of the geomagnetic field. Only the stations with the highest signal level are finally used to calculate the global *ULF* index (the logarithm of the maximal oscillation amplitude during the selected hour). The technique for calculating the *ULF* index is considered in more detail in [Kozyreva et al., 2007].

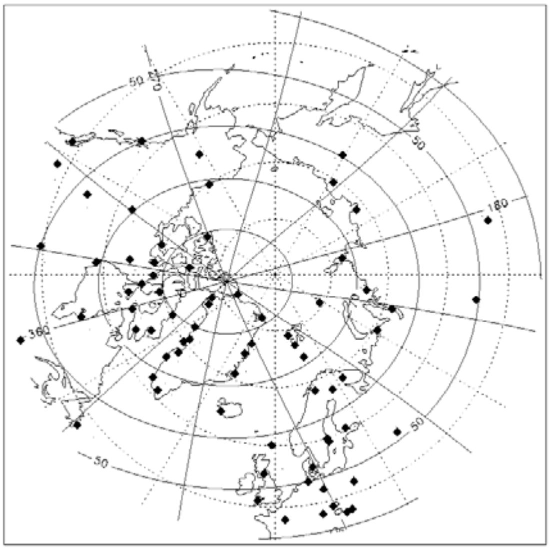

Figure 1. Location of the Northern hemisphere observatories used for ULF-index calculation.

The *ULF* index for the near Earth space is considered in a similar way. The data of the GOES geostationary satellites are used in this case. The data of the WIND, ACE, IMP-8, or 1-min OMNI data (ftp://nssdcftp.gsfc.nasa.gov/spacecraft_data/omni/high_res_omni/monthly_1min/) are used to calculate the *ULF* index in order to estimate IMF wave activity.

The database of the *ULF* index hourly values is freely available via anonymous FTP Internet site (ftp://space.augsburg.edu/MACCS/ULF_index/). The data for each month of a year are presented as tables and figures. The *ULF* index values on the Earth's surface and in the near Earth and interplanetary space are completed with the data on the solar wind velocity (*V*) and density (*N*), IMF *Bz* component, and *Dst* index. By the present, the *ULF* index has been calculated for the period 1991–2005, but this database is still widened and becomes more exact.

3. Analysis of daytime wave activity

To analyze geomagnetic pulsations of the Pc5 type at frequencies of 2–6 mHz, we calculated the *ULF* wave index for the morning–daytime sector (0300–1500 MLT) of auroral latitudes ($\Phi = 60°–70°$). First, the background level of wave turbulence (i.e., the level of daytime *ULF* activity during the magnetically quiet period) was determined. The days with $|Dst| < 20$ nT and $Kp < 2$ were selected for 1995–2001 (605 days, including 207 days in winter, 253 days in summer, and 145 days during the periods of vernal and autumnal equinoxes). The average value of the *ULF* index under quiet conditions was 0.29 ± 18. In this case the *ULF* index value in summer (0.32) was larger than in winter (0.26) and in the equinox (0.27). This is apparently the result of the ionospheric effect on the level of wave turbulence on the Earth's surface (see [Kozyreva et al., 2006]).

To study the level of morning–daytime ULF activity during different phases of a magnetic storm, we selected 19 strong storms with the *Dst* index varying from –150 to –100 nT at a maximum of the storm main phase and with a duration of not more than a day from the storm commencement to the main phase maximum. We did not consider the so-called "double storms" [Kamide et al., 1998; Tsurutani et al., 1999], when the storm main phase is composed of two minimums following each other at an interval of several hours. We continued studying using the superposed epoch method. The universal time of the minimal *Dst* index value during the magnetic storm main phase was taken as a reference point. The time interval of 48 hours (i.e., a day before and after the *Dst* minimum) was analyzed for each storm. The results of this analysis are shown in Fig. 2, where the plots of the *ULF* index (interplanetary, magnetospheric, and ground-based) and the *Dst* index hourly values (the bottom panel) are presented for all studied storms, thick lines show the averaged hourly value and rms deviation (±σ).

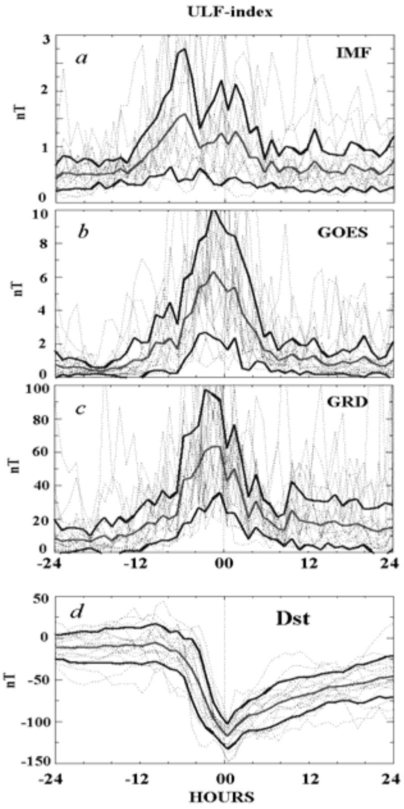

Figure 2. Averaged variations of the *ULF* (interplanetary, magnetospheric, and ground-based) and *Dst* indices during 19 magnetic storms.

We now consider the features of the ground-based *ULF* index (Fig.2c). It is clear that the intensity of the daytime geomagnetic pulsations in the Pc5 range increases and considerably exceeds the background values at the beginning of a magnetic storm. It was indicated [Kozyreva et al., 2004; Kozyreva and Kleimenova, 2007] that, during the storm initial phase, most intense geomagnetic pulsation in the range 1–6 mHz are observed in the polar cap daytime sector, they could be result of a direct penetration of hydromagnetic waves from the interplanetary space. Part of such oscillations probably penetrates to auroral latitudes.

The performed studies indicated that daytime wave activity is maximal during the storm main phase rather than during the recovery phase as it was considered previously. The deviation (±σ) of the ground-based *ULF* index values is also minimal during the storm main phase. The amplitude of the daytime oscillations rapidly decreases at the early stage of the magnetic storm recovery phase. At the late stage of this phase, average activity of ULF waves remains almost unchanged for a long time.

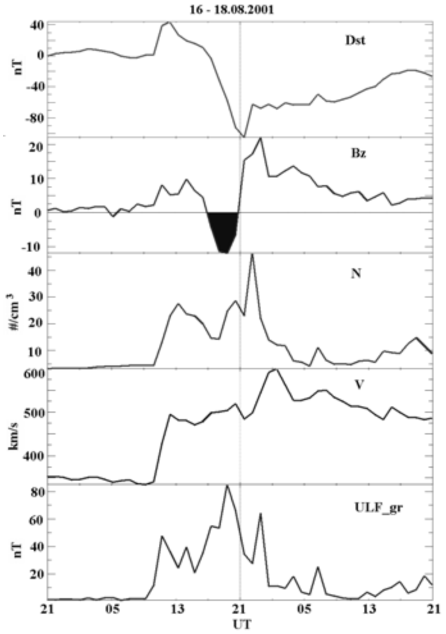

Figure 3. Example of variations of the *Dst* index, IMF *Bz* component, solar wind density (*N*) and velocity (*V*), and the ground-based *ULF* index during magnetic storm on August 16-18, 2001.

The variations in the *ULF* index during magnetic storm of 16-18 August, 2001 is presented in detail in Fig. 3, where the variations in the *Dst* index, IMF *Bz* component, solar wind density (*N*) and velocity (*V*), and ground-based *ULF* index are shown. Sudden commencement of magnetic storms was characterized by a considerable jump of the solar wind density and velocity and was accompanied by an abrupt increase in the *ULF* index (the pulsation amplitude increased by more than an order of magnitude in this case). It has long been known that geomagnetic pulsations are generated during storm sudden commencement (SC) [e.g., Gogatishvili, 1976]. The southward turning of the IMF *Bz* component and the development of the magnetic storm main phase were accompanied by a gradual increase in the *ULF* index The value of the *ULF* index started decreasing when the IMF *Bz* component turned northward and the storm recovery phase developed.

Comparing the variations in the level of ground-based (Fig. 2c) and inner magnetosphere (Fig. 2b) activity, we can state that daytime wave turbulence in the magnetosphere increases faster and more intensely than on the Earth's surface at the beginning of strong magnetic storms. Consequently, geomagnetic pulsations on the Earth's surface represent only part of magnetospheric wave activity. Among other sources, these pulsations are also caused by hydromagnetic waves in the solar wind (Fig. 2a), which can penetrate immediately into the magnetosphere [e.g., Kepko et al., 2002]. A comparison of Figs. 2a and 2b indicates that the level of wave turbulence in the solar wind during the storm main phase is even slightly lower than during the initial phase, whereas this level sharply increases in the magnetosphere. This makes it possible to assume that wave activity in the Earth's magnetosphere mostly results from the action of intramagnetospheric mechanisms.

It is known that the main phase of a magnetospheric storm is accompanied by the development of magnetospheric substorms and irregular geomagnetic pulsations. One would think that wave activity during the storm main phase should also be higher in the nighttime sector than in the daytime one. However, our studies indicated that the pattern is opposite (Fig. 2). To understand this situation, we constructed the maps of the global distribution of the geomagnetic pulsation intensity in the frequency band, corresponding to the oscillation spectral maximum, in coordinates corrected geomagnetic latitude (CGM) and magnetic local time (MLT) for the time intervals near the maximum of the magnetic storm main phase of August 17–18, 2001 (Fig. 4). The magnetograms of the stations located in the Earth's morning (CMO, CHD, TIX) and nighttime (SOD) sectors are shown in Fig.5.

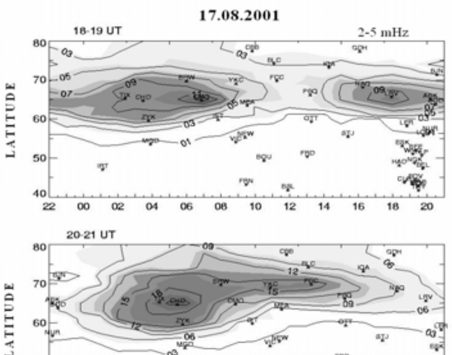

Figure 4. The maps of the spatial distribution of global ULF activity during the main phase of the magnetic storm on August 17, 2001.

The maps indicate that activity of Pc5 pulsations in the morning sector is higher than in the evening and nighttime sectors. Intense Pc5 pulsations as a rule develop during the substorm recovery phase.

Thus, the substorm, caused by a sudden change in the solar wind density, began at about 1845 UT (Fig. 3). The substorm onset in the evening sector was accompanied by a short term burst of irregular pulsations of the Pi3 type, which is shown at 1600–2000 MLT on the upper map (Fig. 4). In this case Pc5 pulsations, which were most intense near CMO (0800 MLT) and were used to calculate the *ULF* index, were simultaneously observed in the morning sector (0200–0800 MLT). The second map, constructed for 2000–2100 UT (Fig. 4), corresponds to the substorm development phase, which was observed at that time near local midnight (SOD) and was not accompanied by night-time geomagnetic pulsations. Intense oscillations, which were used to calculate the *ULF* index, were simultaneously registered in the morning sector during the late recovery phase of the previous substorm. The situation was approximately the same during all studied storms. This allows us to conclude that morning geomagnetic pulsations during the substorm recovery phase mainly contribute to daytime wave activity in the progress of the magnetic storm main phase.

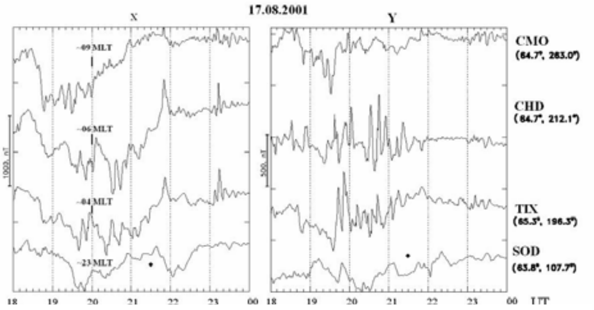

Figure 5. Magnetograms from stations in the morning (CMO, CHD, TIX) and nighttime (SOD) in main phase of the magnetic storm on August 17, 2001

4. Conclusion

We analyzed the level of daytime wave geomagnetic turbulence at frequencies of Pc5 pulsations (2–6 mHz) during 19 strong magnetic storms ($Dst_{\min}$ varied from –150 to –100 nT), using the new *ULF* index of wave activity [Kozyreva et al., 2007]. We found out that the intensity of daytime geomagnetic pulsations at auroral latitudes is maximal during the magnetic storm main phase rather than during the recovery phase as it was considered previously. We indicated that geomagnetic pulsations during the substorm recovery phase mainly contribute to daytime wave activity in the course of the magnetic storm main phase. At the beginning of a magnetic storm, daytime wave turbulence in the magnetosphere increases faster than on the Earth's surface. This indicates that only part of the wave energy can reach this surface. The value of the *ULF* index decreases when the IMF *Bz* component turns northward and the storm recovery phase develops.

Note that these results were obtained when we analyzed strong magnetic storms related to interplanetary magnetic clouds that approached the Earth. During the main phase of such storms, substorms usually develop not only in the nighttime sector but also in the evening and morning sectors. In the case of weak and moderate storms, caused by high speed streams from coronal holes [e.g., Zhang et al., 2006]), regularities can be different since main substorm activity is as a rule registered only in the nighttime sector.

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