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ULF-INDEX VARIATIONS DURING STRONG MAGNETIC STORMS

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Abstract
Using the new wave ULF- index we have carried out the statistic study of the wave geomagnetic activity level in the morning, afternoon and night sectors during the strong magnetic storms (Dst_{min} from -100 to -150 nT). It was found, that in the initial phase of the magnetic storm the greatest intensity of the geomagnetic pulsations in the frequency range 2-7 mHz was observed in the polar latitudes in the morning sector and in the auroral latitudes in the night. During the main phase of the magnetic storm the greatest wave activity was observed in the morning sector of auroral zone, not in the night: the intensity of pulsations in the night sector was two times lower than in the morning. The basic contribution to the morning wave activity gave the geomagnetic pulsations of the magnetospheric substorms associated with the storm main phase. During the recovery phase of the magnetic storm the ULF wave activity in the auroral zone decreased and the level of the morning and night pulsations became compared. The night ULF activity could be noted also in the subauroral latitudes.

1. Introduction
Geomagnetic pulsations at frequencies of ~2–7 mHz are the most typical oscillations in the geomagnetic field and are represented by quasi-sinusoidal Pc5 pulsations in the morning–daytime sector of the magnetosphere and impulsive bursts of Pi3 pulsations in the evening–nighttime sector [Saito, 1969].

Geomagnetic pulsations were mostly studied based on an analysis of individual events. In order to study statistical regularities it was necessary to develop a quantitative index, characterizing the intensity of these variations. Kozyreva et al. [2007] developed a new ULF index in order to estimate planetary wave activity in the range of Pc5 pulsations (f = 2–7 mHz) in the dayside (0300–1800 MLT) magnetosphere.

Kozyreva and Kleimenova [2008] used this ULF index to study the variations in the level of daytime wave geomagnetic activity of Pc5 pulsations at auroral latitudes during strong magnetic storms. It was found out that activity of daytime geomagnetic pulsations at auroral latitudes was maximal during the magnetic storm main phase rather than the recovery phase, as was considered previously. However, the ULF index has not yet been used to analyze wave activity in other local time sectors.

The aim of this work is to continue analyzing the variations in the amplitudes of ground-level geomagnetic pulsations at frequencies of 2–7 mHz during strong magnetic storms (Dst_{min} varies from -100 to -150 nT), depending on magnetic local time. The ULF index was previously used to study wave activity only at auroral latitudes. At the same time, it was established [e.g. Kozyreva et al., 2004] that ULF activity during the magnetic storm initial phase is mainly observed in the dayside polar cap. Therefore, it was reasonable to calculate the ULF index during magnetic storms for polar latitudes too. Since the maximum of pulsation appearance on the Earth's surface shifts toward lower latitudes with increasing magnetic activity, we calculated here the ground-level ULF index not only for auroral and polar latitudes but also for subauroral ones.

2. ULF-index
The ULF index of ground-level wave activity is calculated based on 1-min data of observations at the global networks of magnetometers in the Northern Hemisphere (INTERMAGNET, MACCS, 210 MM, GIMA, CARISMA, IMAGE, Greenland and Russian Arctic coast), including more than 50 stations.

In this work the ULF index was calculated for three ranges of geomagnetic latitudes. We will consider that polar, auroral, and subauroral latitudes are the regions of corrected geomagnetic latitudes (Φ') of 70°–90°, 60°–70°, and 50°–60°, respectively.

The program automatically selects stations, depending on a specified range of geomagnetic latitudes, in order to calculate the ULF index. The Fourier spectra for two horizontal components of the geomagnetic field (X, Y) in the 1-h window are calculated for the data from selected stations according to the Filon method. The total spectral power of a horizontal component is determined, as a sum of the spectral powers of the X and Y components. The hourly values of the total power obtained for each station are normalized to the frequency band and the number of components, and the square root is taken. In essence, obtained values are oscillation amplitudes in terms of nanoteslas. The stations that fall in the selected MLT sector at a given UT are selected from the set of stations. Then, the stations with the highest signal level at the selected time are determined, and the signal average value is calculated. The method for calculating the ULF index is considered in detail in [Kozyreva et al., 2007].

The calculated hourly values of the ULF index characterize the maximal amplitude of geomagnetic pulsations in the specified morning (03–12 MLT), afternoon (12–18 MLT), and night-time (21–03 MLT) longitudinal sectors for three selected latitudinal zones.

3. Variations of ULF activity

We studied strong and moderate magnetic storms that occurred from 1995 to 2002 in order to estimate the level of ULF wave activity during different magnetic storm phases. For an analysis we selected 19 strong (with the $Dst_{\min}$ index from –100 to –150 nT at the main phase maximum) isolated storms that continued for not more than two days. We also analyzed the variations in the ULF index during 37 moderate storms ($Dst_{\min}$ from -50 to -100 nT) for comparison. Using the above method, we calculated the Ground-level ULF index for each of 56 storms analyzed.

We have applied the epoch superposition method to analyze wave activity during strong and moderate magnetic storms. The universal time (UT) of the minimal *Dst* value during the main phase of each storm, which corresponds to the maximum of the magnetic storm main phase was accepted as a reference point. We studied one day before and one day after the *Dst* minimum.

Figure 1 shows the average values of the solar wind dynamic pressure and *Dst* index for the considered 19 strong magnetic storms. Thin vertical lines in Fig. 1 (as well Fig. 2) mark the boundaries of the storm initial, main, and recovery phases. The storm main phase (i.e., the interval from the beginning of an abrupt decrease in the *Dst* index to the time when this index became minimal) on average continued for ~7 h during the selected storms.

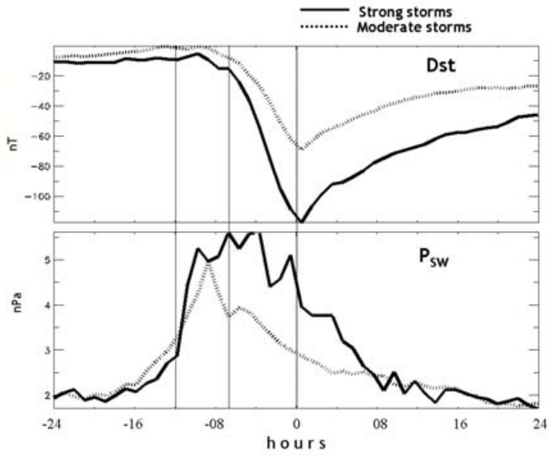

Fig. 1. Results of a statistical analysis of strong and moderate magnetic storms, performed using the epoch superposition method: the *Dst* index and solar wind dynamic pressure.

Figure 2 presents the variations in the average values of the ULF index in different latitudinal zones during selected strong magnetic storms As can be seen the ULF index increased at polar and auroral latitudes during the storm initial phase, which is accompanied by an abrupt increase in the solar wind dynamic pressure. In this case the ULF index was maximal in the morning sector at polar latitudes and in the nighttime and morning sectors at auroral latitudes.

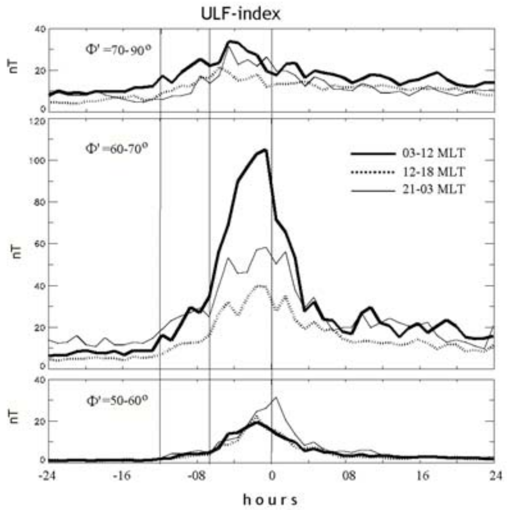

Fig. 2. Results of a statistical analysis of strong magnetic storms, performed using the epoch superposition method: ULF index for the polar, auroral, and subauroral zones.

In the magnetic storm main phase when the solar wind dynamic pressure is increased (as shown in Figure 1), wave activity was maximal in the morning sector of the auroral zone (Fig. 2). The pulsation intensity in the nighttime sector was twice as low as in the morning sector. Near the *Dst* minimum, nighttime ULF activity also increased in the subauroral zone, which results from the well known shift of substorm activity to lower latitudes [e.g. Tverskaya et al., 1989]. The averaged time variations in the ULF index in the afternoon and nighttime sectors of the auroral zone demonstrate that the peaks of these variations are in good agreement with each other, which indicates that wave activity simultaneously develops in the extensive longitudinal sector of the magnetosphere. In this case the level of nighttime activity is much higher than that of afternoon activity.

In the magnetic storm recovery phase, the values of the ULF index in the auroral zone sharply decrease, especially in going from the early to late stages of this phase. In the early stage of recovery phase, when the *Dst* index positive gradients are steeper and the solar wind dynamic pressure is still rather high, evening and nighttime wave activities continue, which is confirmed by the ULF index peaks. However, wave activity is maximal in the morning sector of the auroral zone at that time, when typical morning time Pc5 pulsations are observed during the magnetic storm recovery phase [Troitskaya et al., 1965]. Isolated bursts of the solar wind dynamic pressure are often observed during this phase, which manifests itself in a simultaneous increase in the ULF index in the morning sector.

We compare the variations in the ULF index in the auroral zone during strong magnetic storms with $Dst_{\min}$ varying from –100 to –150 nT and moderate storms with $Dst_{\min}$ varying from –50 to –100 nT. Figure 3 demonstrates the result of such comparison for the auroral zone. As can be seen, that wave activity is maximal in the morning sector during the main phases of both strong and moderate storms. Wave activity in the morning sector is higher than in the nighttime sector by factors of 2 and 1.5 during strong and moderate storms, respectively. Thus, the general regularities in the geomagnetic pulsation variations during strong and moderate storms are similar and differ in only the level of amplitudes.

The performed studies indicated that, during all phases of magnetic storms, activity of geomagnetic pulsations at frequencies of 2–7 mHz is maximal in the morning sector. This is most evident during the magnetic storm main phase (Fig. 2). It is well known that the storm main phase is accompanied by the series of magnetospheric substorms in the auroral zone shifting toward lower latitudes in the course of storm development. The substorm breakup and recovery phases are characterized by the generation of bursts of Pi3 and morning Pc5 pulsations, respectively.

Our analysis indicated that intense ULF pulsations are generated in the morning and premidnight (evening) sectors during the main phase of strong and moderate magnetic storms, and the oscillation amplitude in the morning sector is much larger than in the evening sector.

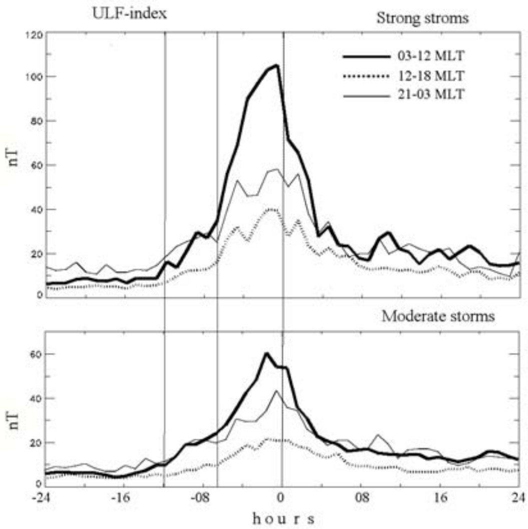

Fig. 3. Results of a statistical analysis of the ULF index for the auroral zone for strong (the upper plot) and moderate (the lower plot) magnetic storms.

4. Case study: magnetic storm of May 15, 1997

We now consider how the general regularities in the ULF index variations manifest themselves in specific storms. As an example, we selected a strong magnetic storm of May 14–16, 1997, which has been the subject of wide speculation in the literature [e.g. Pilipenko et al., 2001].

Figure 4 shows the variations in the solar wind velocity (*V*) and density (*N*), IMF *Bz* component, and *Dst* index as well as the calculated values of the ULF index in different MLT intervals for three latitudinal

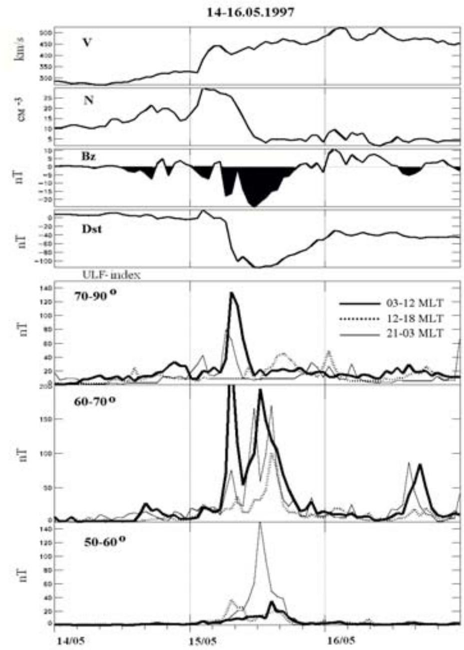

Fig. 4. The variations in the solar wind velocity (*V*) and density (*N*), IMF *Bz* component (negative values are colored black), *Dst* index, and ULF index during the magnetic storm of May 14–16, 1997.

zones. From Fig. 4 it is seen that wave activity in the morning sector of the polar and auroral zones abruptly increased at the beginning of the storm main phase (~07 UT on May 15, 1997), and ULF activity in the morning sector was much higher than in the nighttime sector (twice in the polar zone and a factor of more than 3 in the auroral zone). This was typical for the analyzed magnetic storms (Fig. 2). The second burst of wave activity, which was most intense in the morning and nighttime sectors of the auroral zone and in the nighttime sector of the subauroral zone, was registered at a storm development maximum (~11–16 UT). The peak of morning pulsations was observed slightly later than the nighttime peak.

We constructed the maps of the pulsation amplitude global distribution on the Earth's surface in the geomagnetic latitude–MLT coordinates. Figure 5 presents the maps for the 07–09 and 14–16 UT intervals, when the maximal values of the ULF index were obtained. It is clear that pulsations were most intense in the morning sector at latitudes of 65°– 72°, which corresponded to the morning maximum of the ULF index in the auroral and polar zones (Fig. 2). At that time, wave activity in the nighttime sector was much lower, especially in the first interval. Thus, the time variations in the amplitudes of geomagnetic pulsations at frequencies of 2–7 mHz during the

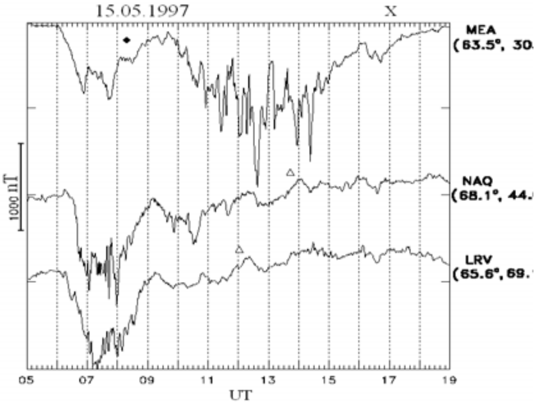

Fig. 6. The magnetograms from several observatories, located at auroral latitudes during the magnetic storm on 15 May 1997.

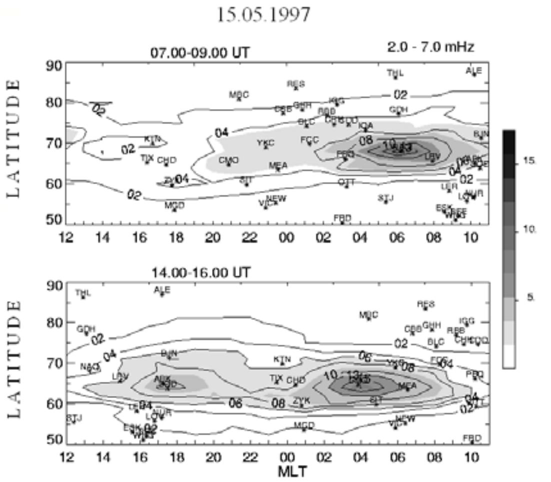

Fig. 5. The global distribution of the geomagnetic pulsation intensity on the Earth's surface for 07– 09 and 14–16 UT.

magnetic storm of May 15, 1997, are similar to the variations in the averaged values of the ULF index during storm magnetic storms.

Figure 6 presents the magnetograms from several observatories, located at auroral latitudes. It is evident that substorm activity is mainly registered in the midnight and morning sectors during the storm main phase. Morning ULF pulsations are registered near the substorm maximum and during its recovery phase. The relation between morning Pc5 pulsations and the development of a preceding substorm was reported in the early works. Raspopov et al. [1972] established that the Pc5 amplitude almost linearly depends on the amplitude of a preceding substorm. The generation of morning Pc5 pulsations is related to the development of substorm and the processes in the auroral electrojet.

Thus, we can assume that the amplitudes of morning ULF pulsations are much larger than those of evening pulsations during the main phase of a strong magnetic storm because substorm activity shifts into the morning sector. In this case Pc5 pulsations during the recovery phase of magnetospheric substorms mainly contribute to morning wave activity.

5. Summary

Based on the new ULF wave index, we performed statistical studies of the geomagnetic wave activity level in the morning, afternoon, and night-time sectors during strong magnetic storms with $Dst_{\min}$ varying from –100 to –150 nT.

We found out that geomagnetic pulsations at frequencies of 2–7 mHz during the magnetic storm initial phase are most intense in the morning sector at polar latitudes and in the night-time and morning sectors at auroral latitudes.

In the magnetic storm main phase, wave activity is observed in the morning sector of the auroral zone. The pulsation intensity in the night-time sector is twice as low as in the morning sector. We indicated that substorm activity shifts into the post-midnight sector during the magnetic storm main phase, and geomagnetic pulsations during the magnetosphere substorm recovery phase mainly contribute to morning ULF activity.

In the storm recovery phase, wave activity is maximal in the morning and nighttime sectors of the auroral zone, and nighttime activity is also observed in the subauroral zone.

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