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DAYSIDE STORM-TIME ULF PULSATION IN THE SOLAR ACTIVITY MINIMUM

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Abstract. The dayside ULF-pulsation activity has been analyzed during the selected succession of 10 recurrent magnetic storms (CIR-storms), repeated with the periodicity of about 27 days in 2006. This time corresponds to the solar activity minimum. The ULF-index, characterized the wave activity in the frequency range 2-7 mHz, was calculated according to the ground-based 1-min observations at the pre-noon (03-12 MLT) and afternoon (12-18 MLT) sectors for auroral (60-70º) and polar (70-90º) latitudes. It was found that in all phases of the magnetic storms under consideration, the maximum of the enhanced ULF-activity was observed at the polar latitudes (>70°). In the studied CIR-storms, the value of the solar wind velocity was very large (more 600 km/c) provided the Kelvin-Helmholz instability enhancement and correspondingly the ULF wave generation. The comparison of the ULF-activity during the CIR-storms (typical for the solar activity minimum) and CME-storms (typical for the solar activity maximum) showed that the ULF-activity associated with the CIR-storms was observed at the higher latitudes then in the CME-storms.

1. Introduction

It is known [e.g. Tsurutani et al, 2006] that in the years of the solar activity minimum, the dominant solar phenomena affecting geomagnetic activity are high-speed streams (HSS) from the coronal holes. When HSS overtakes slow-speed stream, the interaction of the flows with different velocities forms a region of compression plasma, so called the "corotating interaction region" (CIR). In the maximum of the solar activity the most geoeffective structures of solar wind, which cause the magnetic storms, are the coronal mass ejection (CME) [e.g., Yermolaev and Yermolaev, 2002; Borovsky and Denton, 2006]. For the brevity, the magnetic storms, caused by CIR, we will call CIR-storms, and the storms, caused by CME - CME-storms.

There are a large number of works, dedicated to a study of the differences between CME- and CIR-storms. For instance, [Borovsky and Denton, 2006] gave 21 differences between CME- and CIR-storms. They noted that in CIR-storms there are observed the more prolonged ULF pulsations related with the more prolonged time intervals with high solar wind velocity. Some authors [e.g., Singer et al, 1977, Rostoker et al, 1998; Engebretson et al, 1998; Mathie and Mann, 2000, 2001; O' Brien et al, 2001] also showed that both the amplitude and the probability of the ULF waves in the range of the Pc5 pulsation (f~2-7 mHz) grows with an increase of solar wind velocity.

In our previous works [Kozyreva and Kleimenova, 2004, 2008, 2009] we showed that the initial phase of CME-storms is characterized by the excitation of the Pc5-6 pulsations (T~5-20 min) with the greatest amplitude in the morning sector of the polar cap. During the main phase of CME-storms wave Pc5-6 activity is shifted into the region of the closed magnetosphere.

The aim of this work is to study the global spatial distribution of dayside Pc5 geomagnetic pulsations during the different phases of the CIR-storms, developing in the minimum of the 23rd solar cycle.

2. Data and results

For the analysis we selected 10 sequential recurrent storms (CIR-storms) in 2006 (year of the minimum of the 23rd solar cycle).

The list of the analyzed storms is given in the Table, where for each storm we show the minimum values of Dst, the solar wind density prior to the storm beginning (N_0) and its maximum (N_{max}) in the compression region, the minimum value of the solar

Table. Characteristics of the analyzed storms

№	Date	Dst_{min} nT	N_0 $см^{-3}$	N_{max} $см^{-3}$	V_{min} km/s	V_{max} km/s
1	18-22.02.2006	-40	5	27	350	680
2	18-22.03.2006	-40	4	20	350	720
3	12-16.04.2006	-100	4	16	360	670
4	10-14.05.2006	-20	2	15	370	650
5	06-10.06.2006	-40	5	42	350	650
6	04-07.07.2006	-30	6	50	340	620
7	31.07-03.08.2006	-20	5	20	380	630
8	26-30.08.2006	-40	3	50	330	650
9	23-27.09.2006	-60	7	65	350	650
10	20-23.10.2006	-25	5	27	300	650
11	14-16.12.2006	-145	2	10	540	900

wind speed in the compression region (V_{min}) and the maximum (V_{max}) of the velocity of HSS. The storm № 11 is CME- storm (14-16.12.2006), for this storm we give V_{min} as the value of the solar wind speed prior to the storm.

It is evident from the table that in all considered CIR-storms, in spite of the great significances of density (15-65 cm^{-3}) and velocity (620-720 km/s) of the solar wind, the Dst-index was small.

For the analysis of the ground-based Pc5 activity we used the ULF-index [Kozyreva et al, 2007], characterized the intensity of the pulsations in the range of 2-7 mHz, and calculated from 1-min data of the global magnetometer network of the northern hemisphere.

As an example we consider the Pc5 pulsation during the CIR-storm on May 9-14, 2006 (Fig.1). One can

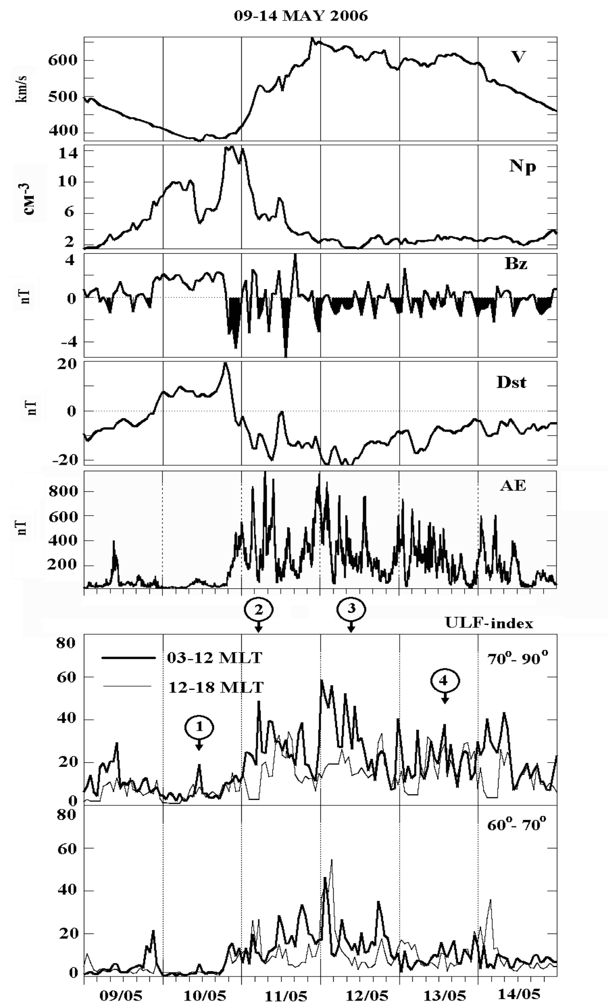

Fig. 1. The variations in the velocity (V) and the density (N) of solar wind, Bz component of IMF, Dst- and AE- indices, and also ULF- of index for the auroral and polar zones in the forenoon and post-noon sectors the magnetic storm on May 09-14, 2006 (CIR-storm).

see that during the initial phase of this storm (interval 1) the most intensive Pc5 pulsations were observed in the pre-noon sector of polar latitudes. During the main phase of storm (interval 2) the ULF- index grew both in the polar and in the auroral latitudes, the sharp increase of the wave activity coincided with the AE-index enhancement.

During the recovery phase of storm (interval 3 and 4) the solar wind velocity remained high (about 600 km/s), and the AE-index attained 400-500 nT. The most intensive ULF were observed in the pre-noon sector of the polar latitudes.

The similar Pc5 pulsations distribution was found in all considered CIR-storms: the storm initial phase is characterized by the Pc5 enhancement in the pre-noon sector of the polar latitudes; the storm main phase - the Pc5 enhancement in the pre-noon and afternoon on the polar latitudes, the pulsations amplitude grows with the AE-index; in the storm recovery phase the most intensive Pc5 pulsation are observed also in the pre-noon sector of the polar latitudes. Thus, during all phases of CIR-storm the most intensive Pc5 pulsations are observed on the latitudes higher than 70º and predominantly in the pre-noon time.

As it was reported in the papers [Kozyreva and Kleimenova, 2008, 2009], the spatial distribution of Pc5 pulsation during CME-storms demonstrates the different signature. The initial phase of CME- storm is characterized by the intensive ULF waves in the morning sector of the polar and auroral latitudes. In the storm main phase, the strongest Pc5 pulsations are observed in the morning sector of the auroral zone during the development of substorms. In the storm early recovery phase the wave activity still remained in the morning sector of the auroral zone, but in the late recovery phase it shifts to the higher latitudes.

The similar spatial characteristics of the Pc5 pulsations were observed during the strong CME-storm on December 14-16, 2006 (Fig. 2), caused by series of powerful solar flares. Conditions in the solar wind and in Bz IMF during this storm are shown in the upper panels of Fig. 2. Velocity of solar wind was very strong and reached ~900 km/s, the maximum of the solar wind density was small (~10 cm^{-3}) in comparison with the previous CIR-storms (see Table). In contrast to the discussed CIR-storms, the solar wind velocity was large even in the storm initial phase (on December 14).

The bottom panels of Fig. 2 demonstrate the spatial-temporal dynamics of the ULF activity during this CME magnetic storm. One can see that in the initial phase (interval 1) the most intensive waves were recorded in the pre-noon and afternoon sectors at the polar latitudes. In the storm main phase the maximum of the ULF-index were, at least, 4-5 times it is higher than in the considered CIR-storm on May 09-14, 2006 (Fig. 1) and was observed in the pre-noon sector mostly at the auroral latitudes (interval 2).

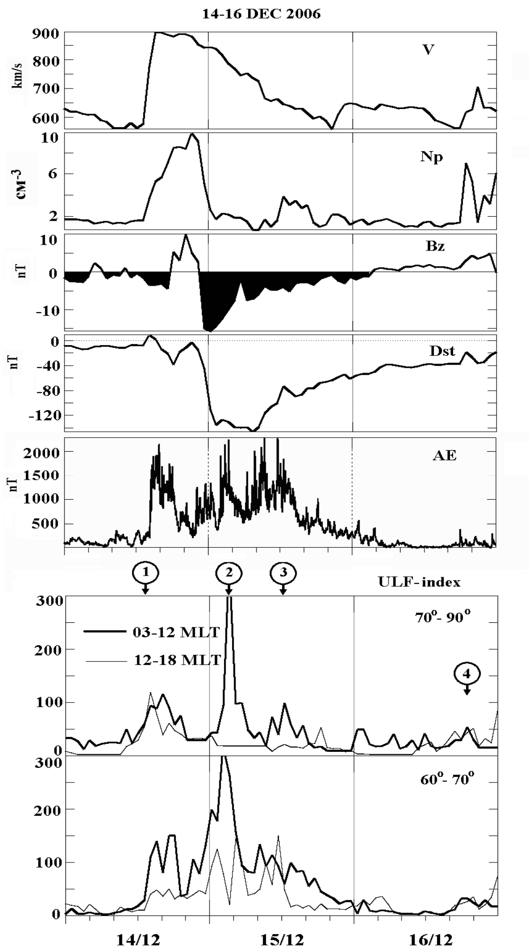

Fig. 2. The variations in the velocity (V) and the density (N) of solar wind, Bz component of IMF, Dst- and AE- indices, and also ULF- of index for the auroral and polar zones in the forenoon and post-noon sectors the magnetic storm on December 14-16, 2006 (CME-storm).

In the early recovery phase of this storm (interval 3) the Pc5 pulsations had the typical spatial distribution for CME-storms [Kozyreva and Kleimenova, 2008, 2009]. In the late recovery phase (interval 4) the Pc5 pulsations activity was shifted to the polar latitudes and was observed both in the pre-noon and afternoon sectors.

3. Discussion

We carried out the detail comparison of the spatial-temporal distribution of the Pc5 pulsations during CIR- and CME-storms, considered in Fig. 1 and Fig. 2. The maps of the pulsation amplitude global distribution on the Earth's surface in the geomagnetic latitude–MLT coordinates were constructed. Figure 3 presents these maps for the different phases of two magnetic storms: the CIR-storm on May 09-14, 2006 (left panel) and the CME-storm on December 14-16, 2006 (right panel).

It is seen that in the initial phase (interval 1) of the CIR-storm as well the CME-storm, the most intensive daytime wave activity was observed at the polar latitudes, but during the CIR-storm – at the latitudes of ~74-78º, while during the CME-storm - on the lower latitudes (~ 72-76º). This difference is probably a result of the different dimension of the Earth magnetosphere during the discussed storms, caused by different values of the solar wind velocity (~370 km/s in the CIR-storm and ~900 km/s in the CME-storm). The estimated the dayside magnetopause location was at L~8 in the initial phase of the CIR-storm and at L~7 in the initial phase of the CME-storm.

In the main phase (interval 2), the region of the most intense Pc5 pulsations was different in the CIR- and CME-storms. It was located at the latitudes higher than 70º during the CIR-storm and lower than 70º during the CME-storm. The CIR associated ULF waves were observed in the large longitudinal sector (~06-17 MLT), however, the CME associated ULF waves – only in the local morning.

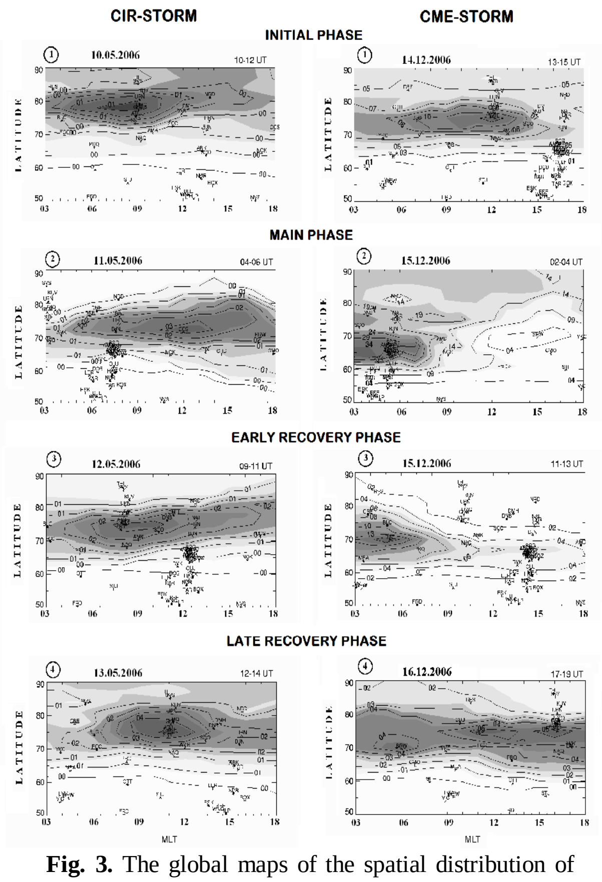

Fig. 3. The global maps of the spatial distribution of ULF activity during the initial, main and recovery phases of the CIR- (May 09-14, 2006) and CME- (December 14-16, 2006) magnetic storms.

The CME-storm recovery phase could be divided into an early and late stage, but in the CIR-storms sometimes it is not clear evident, as in the considered CIR-storm on May 09-14, 2006. In the early recovery phase of CME-storm (on December 15) Pc5 pulsations had the same spatial distribution (Fig. 3, interval 3) as during the main phase of this storm (Fig. 3, interval 2), but at a little higher latitudes with the center at ~70º. We suppose that the interval 3 on May 12, 2006 could be applied to the early recovery phase of the CIR-storm. In this time the Pc5 spatial distribution was very similar to the storm main phase one.

In the late recovery phase (Fig. 3, interval 4) the Pc5 pulsations were recorded at the polar latitudes both in the CIR- and CME-storms.

Thus, a basic difference in the Pc5 geomagnetic pulsations during CIR- and CME-storms is the different wave intensity and the different latitudinal location of the maximum of the ULF waves activity: in the CIR-storms the Pc5 amplitude is several times lower, and they are observed on the higher latitudes than the CME-storms.

4. Conclusion

The analysis of daytime ULF activity during 10 recurrent storms (CIR- storms) in the minimum of the 23rd solar cycle (2006) showed that high velocity of the solar wind (more than 600 km/s) it contributes to enhancement of the generation ULF waves in the Earth magnetosphere, apparently, due to the development of Kelvin-Helmholtz instability on the magnetopause. On the earth's surface the most intensive daytime Pc5 geomagnetic pulsations in all phases of CIR-storms were observed predominantly in the pre-noon sector on the latitudes higher than 70º, while in the CME-storms - on the latitudes lower than 70º.

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