"Physics of Auroral Phenomena", Proc. XXXVI Annual Seminar, Apatity, pp. 113 - 116, 2013

Polar Geophysical Institute

FLUCTUATIONS IN THE SOLAR WIND DENSITY AND IMF

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Abstract. We studied the level of the *ULF* fluctuations in the frequency range of (2-7) mHz in the solar wind (SW) density (*Np*) and IMF by applying the special *ULF-index*, based on 1-min OMNI data. The set of the 63 evens of the high speed solar wind streams (HSSs) observed during the solar activity minimum (2006-2009) have been collected and analyzed. The superposed epoch method was chosen as our research technique. It was shown that the strongest *ULF* fluctuations in the solar wind density (*ULF_Np*) and in the IMF B (*ULF_B)* were observed at the front edge of the HSSs in the solar plasma compression region which leads to development of a storm initial phase. The maximum of *ULF* fluctuations in the SW density (*ULF_Np*) was recorded under the relatively low values of the SW velocity during its increasing phase. The *ULF_Np* maximum was ahead (for ~4 hours) the maximum of the *ULF_B*. We found that both, the amplitude of the *ULF_Np* and *ULF_B*, increased with increasing the values of themselves *Np* and IMF *B* values.

1. Introduction

The interaction of solar wind (SW) and Interplanetary Magnetic Field (IMF) with the magnetosphere is one of the important problems of the geophysics. Now it is generally accepted that the main agents which transported disturbances from the Sun to the Earth's magnetosphere, are high-speed streams (HSSs) of the solar wind. During the minimum of the solar activity the HSSs are mainly originated from coronal holes, in which case the HSSs have the form of corotating regions of interaction (CIR) between slow and fast solar wind. The magnetic turbulence, especially in the *ULF* range (2-7 mHz), may play an significant role in the process of the energy transfer from the solar wind into the magnetosphere.

Many authors have studied wave activity in the SW [e.g., *Horbury and Balog*, 2001; *Walker*, 2002; *Kessel,* 2008; *Borovsky and Denton*, 2010]. However, only few of them paid attention to effects of these waves on the geomagnetic pulsation generation [e.g., *Walker*, 2002; *Kessel*, 2008; *Romanova and Pilipenko*, 2009].

The aim of the current work is to statistical study the properties of the *ULF* (2-7 mHz) fluctuations in the solar wind density (*ULF_N*) and IMF B (*ULF_B*) during the passage of HSSs in form of CIRs which play a dominant role in geomagnetic activity during the solar minimum.

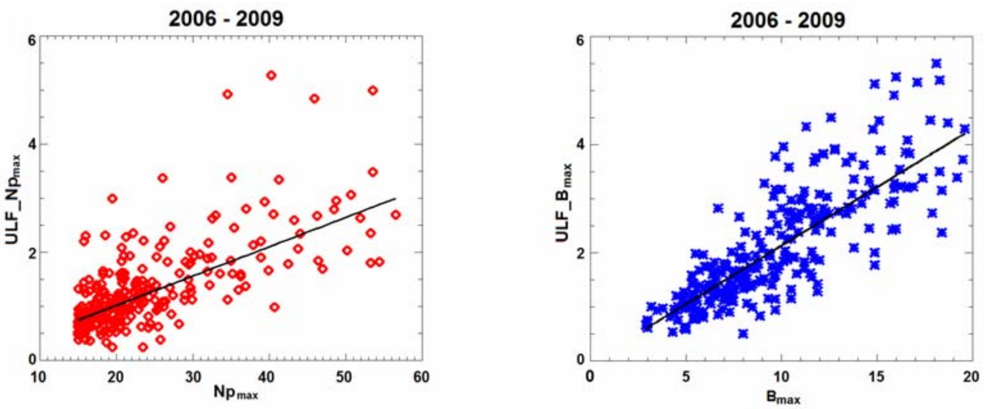

Fig. 1 The dependence of the ULF_N_{max} on the Np_{max} in cm^{-3}and ULF_B_{max} on the B_{max} in nT, where ULF_N_{max}, ULF_B_{max}, and Np_{max}, and B_{max} are the maximal values of the *ULF_N*, and *ULF_B*, and *Np* and *B*, correspondingly, observed in a given day.

2. Data analysis

The SW and IMF data collected during the solar activity minimum (2006-2009) have been analyzed. As research technique, we used the superposed epoch method, widely employed by many scientists. Earlier superposed epoch studies of CIRs can be found in the work of e.g., [*Richter and Luttrell,* 1986; *Denton and Borovsky*, 2008; *Borovsky and Denton*, 2010]. Moreover, to assess the level of the *ULF* (2-7 mHz) fluctuations in the solar wind density (*Np*) and total magnetic field IMF *B*, we applied the special *ULF-index,* development by [*Kozyreva et al*., 2007], based on 1-min OMNI data.

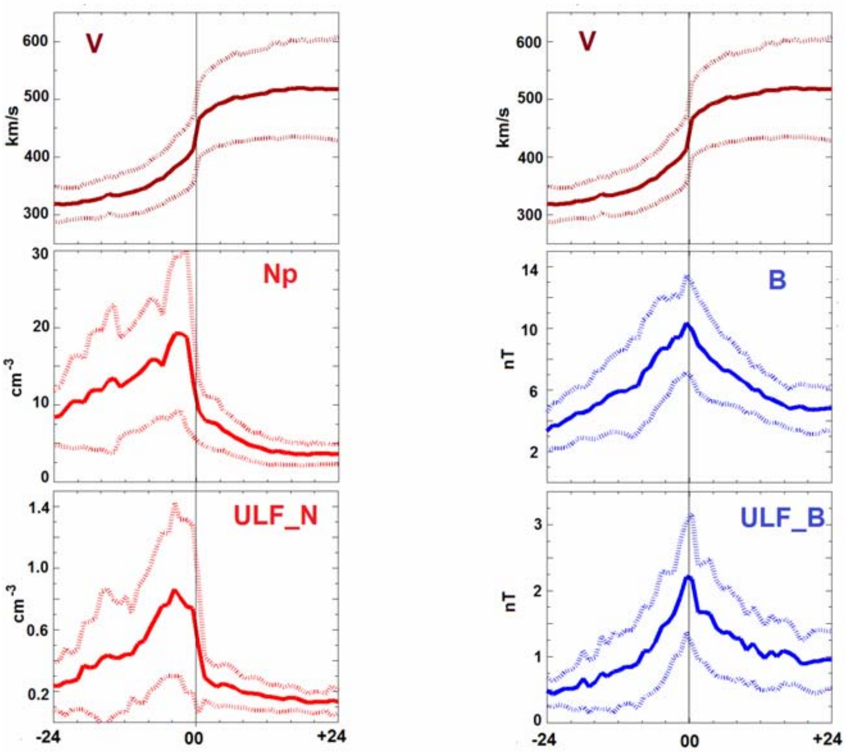

Fig. 2 The results of the statistical analysis of 63 HSSs: the mean values (solid line) and the standard deviation (dashed lines) of the SW velocity (*V*), SW density (*Np*), IMF (*B*), and *ULF* fluctuations in the SW density (*ULF_N*) and IMF B (*ULF_B*).

To study the dependence of the *ULF* fluctuations level on values of the total field IMF *B* and SW density (*Np*) we selected the events with $Np_{max} > 15$ cm^{-3}**.** The obtained results are shown in Fig. 1.

Fig. 1 demonstrates the clear enhancement of the amplitude of the maximal fluctuations in *Np* and IMF *B* (i.e. ULF_N_{max} and ULF_B_{max}) with increasing the values of the themselves Np_{max} and IMF B_{max}.

The statistical analysis of the level of *ULF* fluctuations (*ULF_N* and *ULF_B*) in the high-speed streams in form of CIR has been performed by applying the superposed epoch method. We selected set of the 63 events of the HSSs in which the maximal number plasma density (Np_{max}) in the region of compression was > 25 cm^{-3} and the solar wind speed (V_{max}) was > 450 km/s. Following to [*Borovsky and Denton*, 2010], the passage of the stream interface (the boundary between the slow and fast solar wind in the CIR structure), i.e., the UT time when the rate of speed stream increase (*dV/dt*) was maximal (maximum in the plasma vorticity in term of [*Borovsky and Denton*, 2010]), was taken as a “zero” of epoch.

The top panel of Fig. 2 shows the rise in the SW speed associated with the passage of the CIR. One can see in Fig. 2 that the averaged maximum of the fluctuations in the SW density (*ULF_N*) coincides with the maximum of the *Np*, and the maximum of the fluctuation in IMF B (*ULF_B*) coincides with the maximum of the IMF *B*. Note that the magnetic field strength IMF B peaking near the stream interface (zero epoch) as it was shown previously by *Richter and Luttrell* [1986] and *Borovsky and Denton* [2010].

The mean values of the SW speed (*V*), *ULF_N* and *ULF_B*, calculated by the superposed epoch method of 63 events, are plotted in Fig. 3. Clearly, the mean value of SW speed (top panel) in Fig. 3 demonstrates the trend of 63 various HSSs events: the solar wind is slow prior to the CIR passage, it quickly rises through the CIR, and is fast afterward.

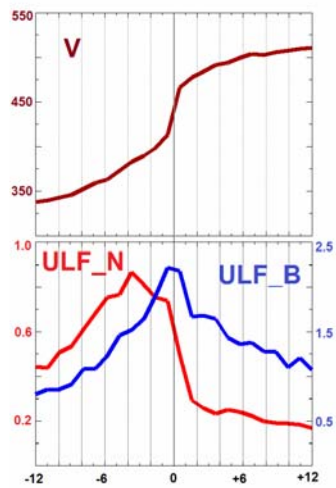

Fig. 3 The mean values of the SW speed (*V*), *ULF_N* and *ULF_B*.

It is also seen that the maximum of the *ULF_N* was observed under low values of the SW speed at the phase of its increasing. The *ULF_N* maximum was ahead the *ULF_B* maximum at ~ 4 hours.

Two examples (22-24 January 2006 and 10-12 July 2007) of the high-speed SW streams passage are shown in Fig. 4, there are shown (up to down) the time variations of SW velocity (*V*), SW density (*Np*), IMF total magnetic field (*B*) obtained from 1-min OMNI database and the calculated the *ULF-index* for the SW density (*ULF_N*) and IMF B (*ULF_B*).

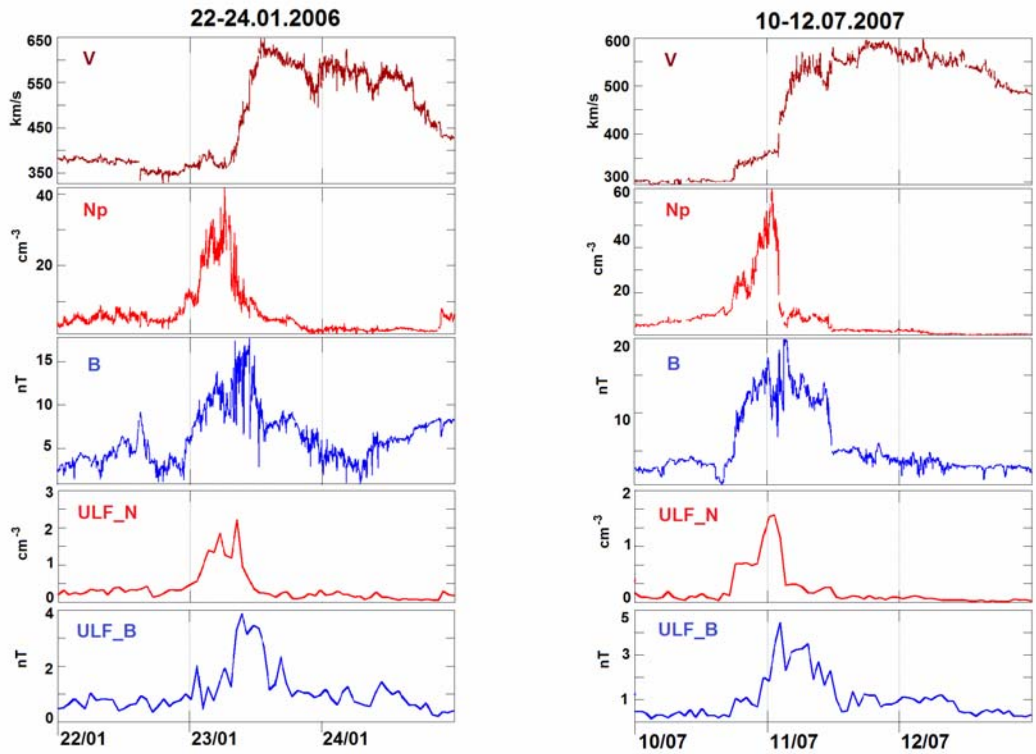

Fig. 4 Two example of the SW speed (*V*), SW density (*Np*) and the level of fluctuations of the SW density (*ULF_N)* and IMF B (*ULF_B)* during the passage of high-speed streams.

The examples in Fig. 4 demonstrate the general properties of the HSSs front edge structure, confirming those established by our statistical analysis: the amplitude maximum of the (2-7) mHz fluctuations in the SW density (*ULF_N)* and its temporal slop followed the time variations of SW density (*Np*) and the same for the *ULF_B* and IMF *B*. It is seen that density increases was gradual. It means the storm initial phase begins gradually without sudden impulse (SC). The SW density dramatically drops at the SW stream interface. The variations of the *ULF_B* and IMF *B* have bell-like slope with maximum around the SW stream interface.

3. Discussion

As it is known that CIRs are produced when the outward of the Sun flowing fast wind (HSS) overtakes the outward flowing slow wind, an oblique region of compression and velocity shear results. Beyond the CIR there is the slow solar wind. Along the center of the CIR is the stream interface, i.e. a boundary between slow and fast solar wind [e.g., *Forsyth and Marsch*, 1999; *Borovsky and Denton*, 2010]. CIR interaction with the Earth's magnetosphere produces only weak to moderate intensity magnetic storms.

Our analysis of the SW density and IMF B distribution associated with HSSs space structure showed (middle panel in Fig. 2) that 24 hours prior to the SW interface boundary (in the area of slow wind), the SW density and its fluctuations (*ULF_N)* were twice higher than 24 hours behind this boundary (in the area of fast wind). The *Np* maximum was observed a few hours before the stream interface. Some authors [e.g., *Richter and Luttrell*, 1986; *Borovsky and Denton*, 2010] also found that the SW plasma number density (*Np*) is peaking prior of to the stream interface on the slow SW side.

The middle panel in Fig. 2 also demonstrates that the IMF B maximum was located in the interface area. The same results was obtained by [*Richter and Luttrell*, 1986; *Borovsky and Denton*, 2010].

According to Fig. 2, the amplitude of the *ULF* fluctuations in the SW density (*ULF_N)* composed ~1/15 - 1/20 of the value of the SW number density and the amplitude of the *ULF* fluctuations in the IMF B (*ULF_B*) – about 1/5 of the value of the total IMF *B*.

The strong variations of SW and IMF parameters, associated with CIR structure passage, have to affect on the magnetosphere *ULF* wave generation, for example, on the excitation of field line resonances [e.g., *Walker*, 2002; *Kessel*, 2008]. To the present time, there are no detailed studies of the geomagnetic effects separately of *ULF_N* and *ULF_B* during the HSSs passage. But the general properties of ground-based *ULF* pulsations during 10 successive recurrent storms of 2006 (this interval is part of discussed here solar activity minimum) have been analyzed by *Kozyreva and Kleimenova* [2010]. It was found that in a CIR storm initial phase, correspondent to HSS passage, the (2-7) mHz geomagnetic pulsations were mainly observed at the geomagnetic latitudes higher than 70° the morning or prenoon local time. These waves could be associated with the *ULF_N* and/or *ULF_B* of HSSs, directly penetrating into open polar cap or guiding by magnetopause with nonlinear transformation in the magnetosphere turbulent boundary layers.

4. Conclusion

The statistical analysis of the level of the *ULF* fluctuations in the frequency range of (2-7) mHz in the solar wind density (*Np*) and total magnetic field IMF *B*, computed by using special *ULF*-index [*Kozyreva et al*., 2007], based on the 1-min OMNI data, has been performed for the set of 63 events of the high speed solar wind streams (HSSs) during the solar activity minimum (2006-2009).

We found that the strongest amplitudes of the *ULF* fluctuations in *Np* and IMF *B* were recorded in the front edge of the HSSs which had the form of the corotating interactive regions (CIR).

The amplitudes of the *ULF* fluctuations, both in *Np* and IMF, strongly increased with increasing the solar wind density and *B* IMF.

The amplitude maximum of the fluctuations in the SW density (*ULF_N*) observed under low SW speed prior to the stream interface and was ahead (~4 hours) the amplitude maximum of the fluctuations in the B IMF (*ULF_B*), which was observed around the stream interface.

Acknowledgements. This work was supported by RFBR grant 12-05-01030 and partly 13-05-00233.

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