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Similarities and differences between heliosphere-geosphere couplings associated with the short and long lived subauroral ionospheric storms: November 2004, F2 region, North East Asia

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We analysed ground and in situ data collected on 9-10 November 2004 during the first day of the long-lived ionospheric storm which consequences were observed in the ionosphere till 13 November and compared the results with those obtained from the short-lived 7-8 November ionospheric storm study. During the first day of each storm we observed a positive nocturnal phase associated with a movement of the plasma sheet inner edge towards the Earth and westward auroral electrojet amplification. In both cases morning-midday negative phases of the storms evolved over the north-west electrojet in the compressed magnetosphere. The short-lived negative phase of 7-8 November storm evolved with the south-west interplanetary magnetic field (IMF), solar wind velocity V_{SW} about 600 km/s and was associated with irregular geomagnetic pulsations. The long-lived negative phase of 9-13 November storm started with the north-west IMF, solar wind velocity about 800 km/s, and was associated with continuous Pc5 pulsations. We suppose that the high-latitude reconnection and Pc5 provided an additional energy input to the subauroral ionosphere and thereby contributed to formation of the long-lived neutral composition disturbance zone.

Key words: magnetosphere-ionosphere interactions, ionospheric disturbances

INTRODUCTION

Investigation of physical processes which transfer a solar wind energy through the magnetosphere to the ionosphere/thermosphere is one of the key topics of the solar-terrestrial physics. Although these processes have been studied for years, gaps remain in our knowledge of the details. A cause of considerable differences in a duration of a depletion of the morning subauroral F2-layer (negative ionospheric storm phase) is one of these gaps. It is generally agreed that morning negative phase is caused by the Joule heating, which leads to formation of the neutral gas composition disturbance zone with large ionization losses [7]. In [1] it was shown that significant energy can be deposited in the ionosphere but it produces no commensurate heating [1]. To elucidate other processes causing the negative ionospheric storm phase we compared heliospheric and magnetospheric disturbances accompanied by the short-lived and long-lived F2-layer depletions over North-East Asia during November 2004 magnetic super-storms.

ANALYSIS

For analysis we used ground-based data from the ionospheric and magnetic stations listed in Table 1 and in-situ data from ACE, WIND and LANL-97A (L7) satellites. Geomagnetic coordinates are calculated from geographic ones using http://sscweb.gsfc.nasa.gov/cgi-bin/sscweb/CoordCalculator.cgi. Notice, that the L7 northern footprint point (given in Table 1) and the ground stations coordinates were rather similar. Fig. 1 shows changes in *SYM-H* index (it describes the geomagnetic field disturbance in mid-latitudes with 1 minute resolution[1]) and the F2-layer critical frequency (*foF2*) over Zhigansk and Yakutsk from 7 to 14 November. Thick lines and dots show the *foF2* values; thin lines show those for 6 November quiet day. Significant positive and negative deviations of *foF2* from the quiet level are clearly seen in the plot for Yakutsk. In the plot for Zhigansk they

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[1] `http://wdc.kugi.kyoto-u.ac.jp/aeasy/asy.pdf`

are interrupted by total absorptions.

There were two ionospheric storms during this period. The first one began with a nocturnal positive phase (*foF2* is higher than the quiet one) on 7 November at 16:00 UT and at 21:00 UT over Zhigansk and Yakutsk respectively. The phase commencement is marked by arrow at the each station plot. A negative phase (*foF2* is more than two times lower than the quiet one, marked with shaded rectangle) was observed in Yakutsk from 22:30 UT on 7 to 03:00 UT on 8 November. F2-layer critical frequency over Yakutsk returned to the quiet level at 23:00 UT on 8 November and was undisturbed till 05:30 UT on 9 November. Thus, this storm was over [5]. The second storm over Yakutsk consisted of two negative and one positive phases. The former negative phase started at 07:00 UT on 9 November. Then positive (11:30-21:30 UT, marked with arrow) and latter negative (22:45-05:45 UT, 9–10 November, marked with shaded rectangle) phases were observed. Judging by several *foF2* values, the same sequence of phases was observed over Zhigansk. The distinguishing feature of the latter negative phase is its residual effect registered by the ionospheric stations in the morning-midday sector for at least 3 days.

Table 1: Coordinates of stations and satellite footprint.

N	Station	Code	Geomagnetic	
			lat.	long.
1	Kotel'nyy	(KTN)	65.21	195.55
2	LANL-97A	(L7)	63.90	210.88
3	Chokurdakh	(CHD)	62.04	206.71
4	Tixie	(TIK)	61.81	193.49
5	Zyryanka	(ZYK)	57.58	211.02
6	Zhigansk	(ZGN)	56.81	190.70
7	Yakutsk	(YAK)	52.39	196.25
8	Magadan	(MGD)	50.68	210.94

From comparative analysis of the ground-based magnetic and in-situ (L7) plasma data it follows that the nocturnal positive phases of both ionospheric storms evolved during intensive auroral precipitations, shifting towards the equator. The former negative phase of the second ionospheric storm was observed during a passage of the main ionospheric trough over the stations [6]. Recall that the primary goal of our paper is to clarify differences between processes that caused the short-lived and long-lived negative phases in the subauroral morning-midday ionosphere on 7-8 and 9-10 November, respectively. Throughout the paper they are referred as the phase 1 and the phase 2 correspondingly and are marked with shaded rectangles in the figures.

We note above that a negative ionospheric storm phase in the morning-midday is usually associated with the thermosphere heating. Judging by the duration of negative phases, such a stable zone was formed only during the second ionosphere storm. In simulations an efficiency of the heating is estimated from *F10.7* and geomagnetic (*Ap* or *Kp*) indices [1, 2]. Information on *Kp* values and average values of *AE* / *SYM-H* indices during the phase 1 and the phase 2 is given in Table 2. It is seen that the values of the indices corresponding to the phase 2 are smaller than those corresponding to the phase 1. Thus the difference in durations can not be explained in terms of averaged models. The similar conclusion was made by Burke et al. [1].

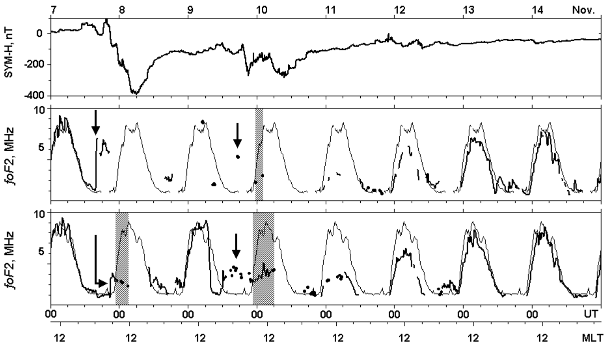

Fig. 1: Variations of the F2 layer critical frequency over Zhigansk and Yakutsk

Fig. 2 shows variations in the magnetospheric convection field (E_c) and the distance to the subsolar magnetopause (R_m, calculated by pressure balance equation [9]). Because of the absence of the WIND data of the IMF and the gap in the ACE data on solar wind density we calculated E_c using the ACE data and R_m was calculated using the WIND (GSE coordinates $X = 199\ R_E$, $Y = 57\ R_E$, $Z = -9\ R_E$) data. Changes in B_z components of the IMF and geomagnetic field at geosynchronous orbit (registered by GOES 10 satellite; northern footprint point at geomagnetic latitude 66.1°, longitude 294.5°) are shown in the middle panel by thin and thick lines correspondingly. During the phase 2 the convection field was weaker than that during the phase 1. In both cases the subsolar magnetosphere was contracted to geosynchronous orbit and GOES 10 and L7 entered the magnetosheath. In the GOES 10 data it was manifested by negative B_z values during the southward IMF; and by a sharp increase in a density of high energy ions (N_i, 0.13-45 keV/e) and a decrease of their temperature up to $T_i < 1$ keV in the L7 data. L7 was in the magnetosheath almost all the time of the phase 1. During the phase 2 it was near the magnetopause and entered the magnetosheath when the IMF was southward possibly due to erosion of the day-side magnetosphere.

In the 5-7 columns of Table 2 we presented the information about IMF orientation in the Y-Z plane (see also Fig. 3), mean solar wind velocity (V_{SW}) and density (N_{SW}). One can see that the phase 1 was developed during the southward IMF. On the contrary, the phase 2 began for the northward IMF. The IMF turned to the south in 3 hours. Both negative phases were observed for the westward IMF ($B_y < 0$) and almost the same N_{SW} but different V_{SW}. During the phase 1 and the phase 2 the solar wind velocity was about 650 km/s and about 800 km/s respectively.

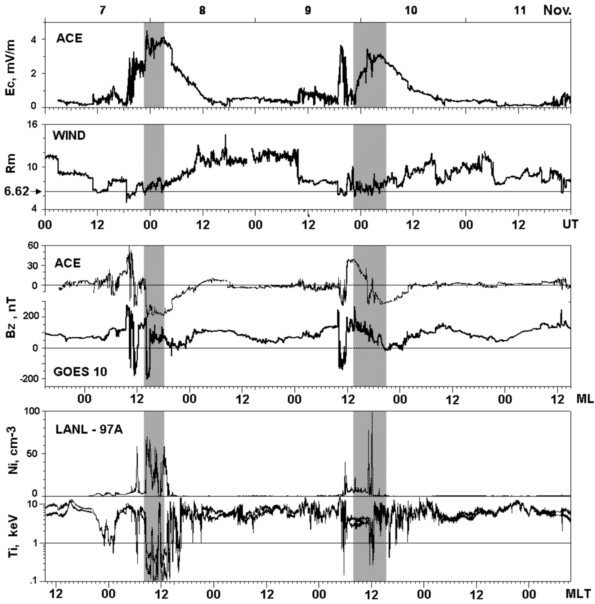

Fig. 2: Magnetosphere response to the heliosphere inhomogeneity impact

There are experimental and theoretical evidences that high-speed solar wind generates surface waves on the magnetopause which are energy source for magnetospheric Alfvén waves [8, 3]. We carried out spectral analysis of magnetic field variations observed under disturbed ionosphere. Amplitude spectra (A) of the variations observed 2 hours before each of the negative phases and during them are given in Fig. 3. The spectra were calculated from one hour sets of one minute sampling data from Tixie, Chogurdakh and Yakutsk stations. In the left and right panels one can see the spectra for the phase 1 and the phase 2 respectively. The phase 1 was preceded and accompanied by noisy (Pi) geomagnetic variations; the phase 2 by relatively narrowband Pc5 pulsations.

In order to evaluate the Joule heating effect within LT (local time) sector sampled by the ground observatories and L7 satellite we analysed geomagnetic disturbances observed under the depleted subauroral F2 region. In the middle panel of Fig. 4 variations of magnitude of horizontal magnetic field disturbances (DH) are shown (see also mean $\overline{DH}_{TIX}$ and $\overline{DH}_{YAK}$ values in Table 2). One can see that DH was much lower during the phase 2 than that during the phase 1. On the contrary, at Yakutsk geomagnetic activity was notably stronger in three hours before the phase 2 ($\overline{DH}_{YAK} = 740$ nT) than before the phase 1 ($\overline{DH}_{YAK} = 116$ nT). In the upper (lower) panel of Fig. 4 declination (D) of vector of horizontal magnetic field disturbance at Tixie (Yakutsk) is plotted by dots. The left and right ordinate axis represents values of declination and corresponding jet direction respectively. It is seen that both negative phases were observed at Yakutsk over the north-west electrojet, i. e. in the south-east convection region. Model calculation made in [4] reveals that in such a region electron density and altitude of the F2 layer decrease. Hence the expanded convection electric field could be one of the causes of F2 layer depletion in both cases.

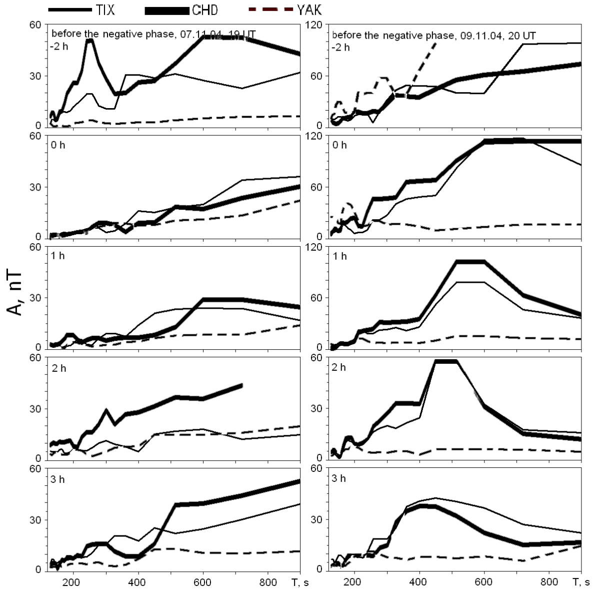

Fig. 3: Spectra of geomagnetic variations at Tixie, Chigurdakh and Yakutsk

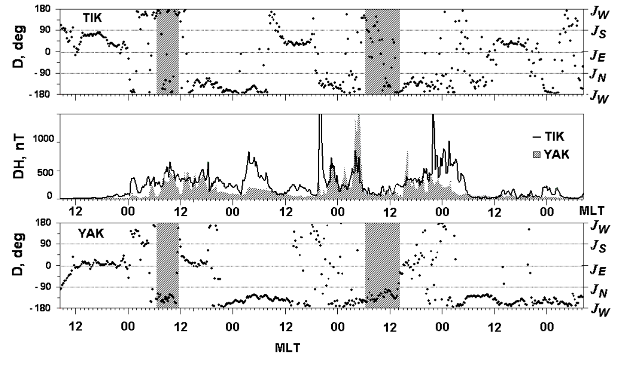

Fig. 4: Variations in magnitude (DH) and declination (D) of vectors of horizontal geomagnetic field disturbances at Tixie and Yakutsk

Table 2: Conditions of negative phases development.

Phase	Kp	$\overline{AE}$	$\overline{SYM-H}$	IMF		$\overline{N}_{SW}$,	$\overline{V}_{SW}$,	Pulsations	$\overline{DH}_{TIX}$,	$\overline{DH}_{YAK}$,
				B_z	B_y	cm^{-3}	km/s		nT	nT
Phase 1	8, 9_-	870	-180	< 0	< 0	17	660	Pi	310	305
Phase 2	4_+, 4.5	575	-160	$> 0 \rightarrow < 0$	< 0	14	794	Pc	98	359

DISCUSSION AND CONCLUSIONS

Data presented above demonstrate that the short-lived phase 1 and the long-lived phase 2 were observed at LT sector of the magnetosphere compressed to geostationary orbit. Both phases were registered over the north-west electrojet during the IMF $B_y < 0$ and almost equal solar wind density. Geomagnetic indices associated with the phase 2 were nearly equal to or lower than those associated with the phase 1.

We find out the following differences in the heliosphere-magnetosphere processes observed during and before the phases:

- The phase 1 developed during period of IMF $B_z < 0$ and $B_y < 0$, the second one began during period of IMF $B_z > 0$, $B_y < 0$ and only in 3 hours the IMF turned to the south. Hence the high-latitude reconnection in the morning northern hemisphere could contribute to subauroral ionosphere/thermosphere restructuring.
- During the phase 2 the solar wind speed was about 150 km/s higher than that during the phase 1.
- The phase 1 was preceded and accompanied by noisy geomagnetic pulsations and the phase 2 by relatively narrowband Pc5 pulsations.
- At Yakutsk auroral electrojet was notably stronger before the phase 2 than before the phase 1.

The listed differences show that: (1) intense Joule heating at night over Yakutsk could be the cause of the long-living changes in the composition of the neutral atmosphere showed itself as the long-living negative phase 2, (2) high-speed solar wind could generate Pc5 geomagnetic pulsations, (3) high-latitude reconnection and Pc5 pulsations could provide the subauroral ionosphere with extra energy and thus contribute to formation of the long-lived neutral composition disturbance zone.

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