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THE CHARACTER OF GEOMAGNETIC AND AURORAL RESPONSE TO SOLAR WIND DYNAMIC PRESSURE VARIATIONS AND THE DYNAMICS OF PARTICLES INJECTED INTO THE MAGNETOSPHERE

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1. Introduction

The sharp changes in the solar wind dynamic pressure (Pd) result in series of effects which were manifested in the magnetosphere, ionosphere and on the Earth. One of the bright manifestation of Pd variations is the sudden geomagnetic impulse (SI or SC if it is followed by a magnetic storm) generation.

Simultaneously and after the SC the energetic particle precipitation into the ionosphere, the auroral luminosity enhancement in the region of auroral oval happen. The electric fields are generated and ionospheric current intensity are increased. SC stimulates the geomagnetic pulsations (Psc) in the wide range of frequencies [Saito and Matsushita, 1967].

SC also results in the generation of VLF-emission in the wide frequency range (1-15 kHz). Other phenomena in ionospheric, riometric disturbances etc. appear.

The objective of this work is to summarize some results concerning the manifestation of Pd variations in geophysics phenomena obtained in general by the Institute of cosmophysical research and aeronomy team by data of complex geophysical and global geomagnetic observations with 1-20 s time resolution.

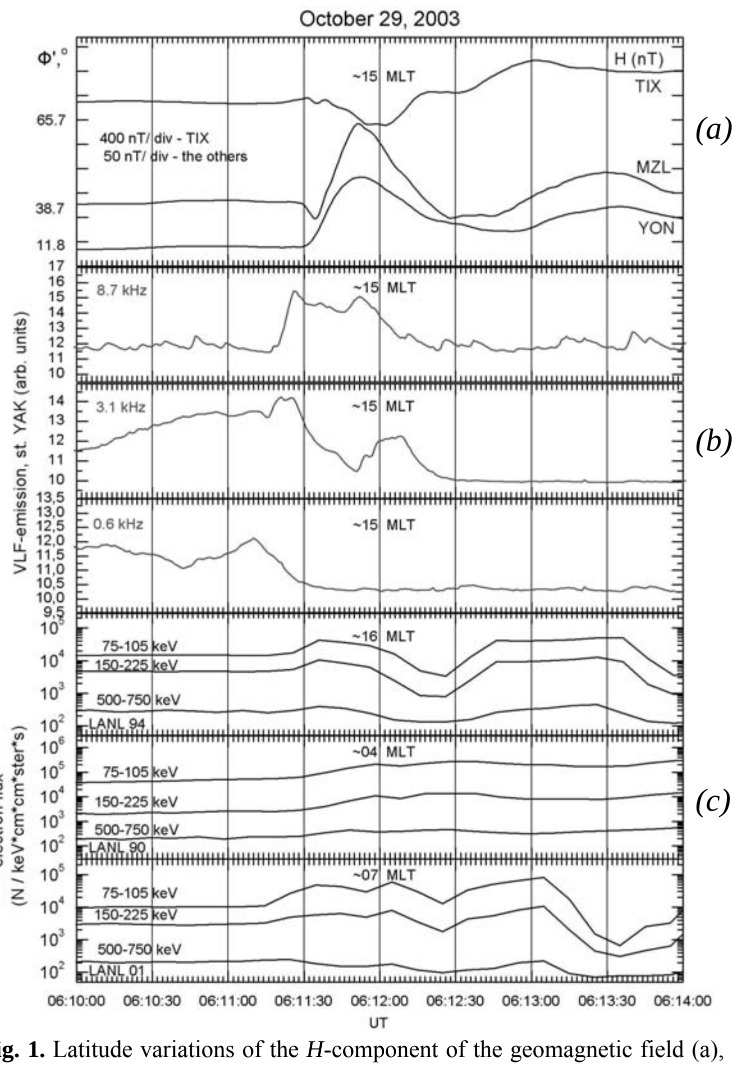

Fig. 1. Latitude variations of the *H*-component of the geomagnetic field (a), the data of detection of VLF emission in three frequency bands at the Yakutsk station (ϕ' = 56.4°) (b), and variations of fluxes of energetic particles in the three energy ranges according to the data of the *LANL* satellites (c) during the SC on October 29, 2003 from 06:10 to 06:14 UT.

2. Main results

2.1. The generation of SC, VLF-emission and variations of energetic particle fluxes in the magnetosphere

We present the results of studying the global geomagnetic response to the commencement of the magnetic storm on October 29, 2003 at 06:11:30 UT. Figure 1 presents the variations of the *H* -component at different latitudes along the Yakutsk meridian near 15 MLT and the intensity of bursts of VLF emission according to observations at the Yakutsk station. In the bottom panels in Fig. 1 the time variation of the fluxes of energetic electrons are shown for three energy channels as measured by the geosynchronous satellites *LANL* located at the ~16, 04, 07 MLT meridians. The

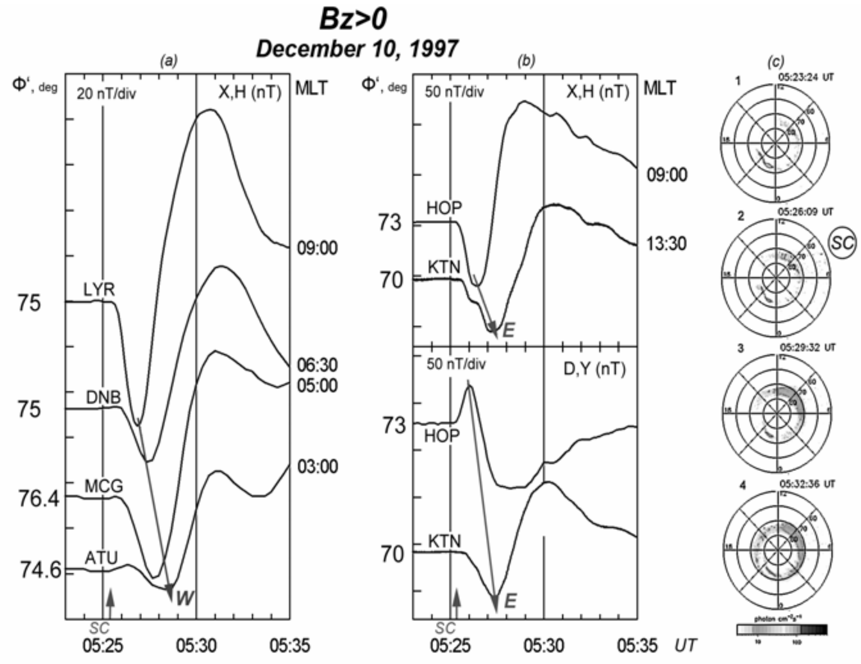

Fig. 2. (a) Latitude variations in the X component in the morning sector and (b) longitudinal variations in the H, X, and Y components of the geomagnetic field in the 0000–0900 MLT sector at latitudes of Φ'=74-76° during the SC event started at ~0525:30 UT on December 10, 1997. Auroral dynamics according to the POLAR data from ~0523 to ~0532 UT during the same event (c).

SC onset was preceded by a burst of VLF emission (~15 s earlier). A similar SC effect is usually detected in VLF emission when SW shock waves interact with the magnetosphere [Yachmenev et al., 1989]. The dispersionless injection of energetic electrons in the inner magnetosphere was detected practically simultaneously at different meridians coinciding with the burst of VLF emission (see Fig. 1b,c). The magnetic field variations at meridional and azimuthal station chains showed that during the 5 min after the SC the two-vortex current system of a DP2 type enhancement took place [Solovyev et al., 2004]. One can make an approximate estimate of *Va* in this event on the basis of the time of delay of a hydromagnetic pulse relative to the SC in the VLF emission (Fig. 1). The time of propagation of VLF waves from the equatorial plane of the magnetosphere (the source) to the ground surface is that of electromagnetic wave propagation and equal or less than 1 s, while the hydromagnetic pulse propagates with the velocity *Va*. Assuming that *Va* remains constant along the field line and taking into account the length of field lines in the dipole approximation corresponding to L = 4 and t ~ 15 s, we have from such an estimate *Va* ~ 880 km/s.

2.2. Precipitation of energetic particles on the ionospheric heights during SC

The sharp magnetosphere compression by the solar wind results in energetic particles precipitation in the ionosphere. The particle precipitation leads to a brightening of auroral arc and diffuse background and to the subsequent propagation of these forms poleward and equatorward, respectively. Another manifestation of SC is the global intensification of luminosity of the dayside part of auroral oval [Roldugin, 1974;Vorobjev, 1974; Solovyev et al., 2004; Boudouridis et al, 2003] with expansion of luminosity region from dayside to the nightside at the velocity of ~10 km/s [Zhou and Tsurutani, 1999] (see Fig. 2). According to Fig. 2 the SC azimuthward and possible poleward propagation coincides with the expansion of the auroral luminosity region along the auroral oval in the same direction and at approximately the same rate. Unfortunately the time resolution of POLAR data does not allow us to estimate the poleward propagation of the luminosity region in this event. The polar boundary luminocity (PBL) of the night side of the auroral oval poleward and eastward expansion is registered with the same velocity of about 1 km/s [Liou, 2002; Solovyev et al., 2003] (see Fig. 3). As seen from Fig. 3 during the periods of Pd growth the expansion of diffuse aurora region with a predominantly poleward and eastward motion of its poleward boundary in the midnight–morning sector is observed. According to Boudouridis et al. [2003] almost simultaneous growth of the luminosity intensity and poleward expansion of PBL in a wide sector of longitudes (~12 hours) are observed. In this case the precipitation of energetic particles can be the result of their interaction with MHD waves i.e. the time delay in the 12-h longitude sector shouldn't be more than 1–2 min. Boudouridis *et al.* [2003] noted that this time delay was equal to ~1 min for one of the events of such particle

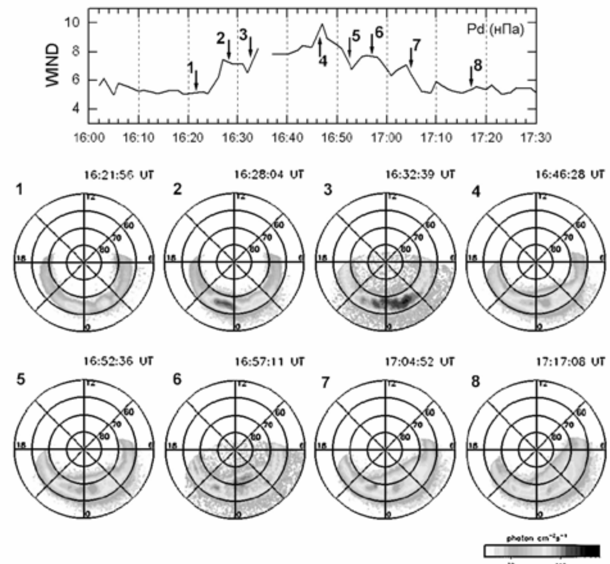

Fig. 3 Variations of solar wind dynamic pressure onboard Wind satellite, dynamics of auroral luminosity by POLAR data for the event of January 6, 1998.

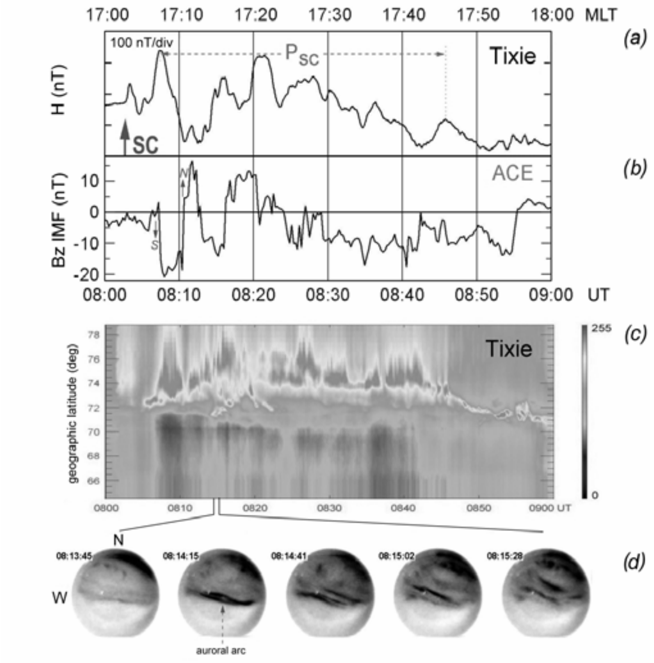

Fig. 4 Variations of the geomagnetic field H-component at Tixie station (φ'≈65.69°, Λ≈196.98°) (a), Bz component IMF variations onboard ACE satellite (b), spatial-temporal variations of auroral luminosity (c), TV frames of all-sky camera (d) during SC on November 7, 2004

precipitation. Assuming that *Va~1000 km/s* in the magnetosphere at the ionosphere level it will make about 30-40 km/s.

Thus, three types of the response of auroral particle precipitation to *Pd* variations with different azimuthal velocities of disturbance propagation: ~1 km/s, ~10 km/s, 30-40 km/s exist. These types of auroral response to *Pd* is possibly indicative of different processes or sources responsible for the precipitation of particles into ionospheric altitudes.

The existence of the second and third types of response is confirmed by the analysis of SI azimuthal propagation in the paper by [Solovyev et al., 2004]. They found two modes of ionospheric SI velocities: *V1* ~ 30–40 km/s and *V2* ~ 10 km/s equal to the velocity of aurora expansion along the auroral oval. *V1* velocities probably correspond to the processes of interaction of fast magnetosonic waves with magnetospheric particles. According to [Zhou and Tsurutani, 1999] *V2* velocity is equal to ~300 km/s in the magnetosphere, this velocity corresponds to the compression wave propagation along the magnetopause.

The velocities of plasma magnetospheric convection are ~1 km/s [Ponomarev, 1985], and precipitation can be caused by pitch-angle diffusion of particles. Thus, three types of the response of auroral particle precipitation to *Pd* variations probably reflect the processes of interaction of magnetosonic and/or Alfven waves, surface waves on the magnetopause, and electromagnetic waves with particles of the trapped magnetospheric plasma and their pitch-angle diffusion.

2.3. Geomagnetic pulsations excitation and their manifestation in the dynamics of auroral luminosity

It is known that after SC the excitation of geomagnetic pulsations with periods from 1 s to 5-10 min occurred. The duration of oscillations is in the range of some minutes to 1-2 hours. The variety of Psc exists: quasiperiodical oscillations similar to Pc3-5 pulsations (T=30-600 c), irregular oscillations rather long periodical in the range of Pc5 pulsations (5-10 minutes). Sometimes higher frequency pulsations with frequency of about 1 Hz in the range of Pc1 or IPDP are excited [Parkhomov et al., 1990].

In this section the peculiarities of pulsations observed after the two SC events on November 20, 2003 at 0805 UT and November 7, 2004 at 1827 UT. It is shown that during a superstorm the Psc excitation with periods of oscillations T=5-6 min (Fig.4a) by consecutive changes of the IMF Bz sign (Fig.4b) and quasiperiodical spatial modulation of auroral luminosity intensity (Fig.4c) is stimulated. The modulation of luminosity intensity represents an aurora shift recurring poleward by means of origin of new arc poleward in comparison with previous arc. An unusually high velocity of the arc origin of about 5 arc per 1.5 min is registered (Fig.4d). The Psc generation is probably caused by modulation of two-vortex current system DP2 type and the fast origin of new arcs is due to the high velocity of reconnection during superstorms in comparison with substorms. Thus, variations of electric field proportional to changes of the IMF Bz sign (Fig.4b) and quasiperiodical variations of ionospheric conductivity caused by fluxes of precipitation particles in the ionosphere influenced Psc excitation.

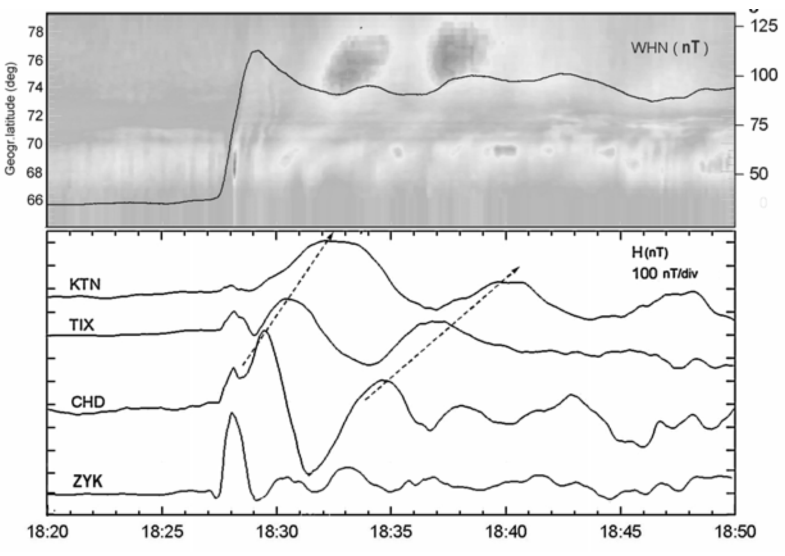

Fig. 5 Keogram of spatial-temporal variations of auroral luminosity by all-sky TV camera data at Tixie station (a), latitudinal variations of the geomagnetic field H-component (b) during SC on November 7, 2004.

A similar effect of Psc with T=5-6 min excitation accompanied by the spatial modulation of auroral luminosity intensity with the extension of aurora poleward took place at latitudes Φ'≥ 65° during November 7, 2004 SC event (Fig.5). Simultaneously at latitudes ~60° during 1.5 h the Psc with periods T=2-3 min are excited. These Psc during the origin of auroral arc are observed at the same latitude (i.e. ~60°). In the arc there were the wave-like oscillations.

2.4. Response of the geomagnetic (convection and substorm) disturbances to the SC generation

Just after the SC the geomagnetic disturbances very often take place. The classification of these disturbances, stimulated by Pd growth, remains debatable. According to the early statistical studies [Kokubun et al., 1977], the growth of Pd leads to the generation of typical substorms and convection disturbances. Similar results were obtained in [Zhou and Tsurutani, 2001]. A disturbance with enhancement of the westward electrojet in the near-midnight sector and with appearance of positive magnetic disturbances at low latitudes is considered as a typical substorm [Kokubun et al., 1977]. At the same time, according to [Sergeev and Tsyganenko, 1980; Lyons, 2001], the generation of the substorm current wedge and the formation of the auroral bulge and the westward traveling surge (WTS) with the luminosity region expanded poleward and westward are the main elements of a typical or classical substorm. Convection disturbances are caused by the generation of the two-vortex current system of the DP2 type [Sergeev et al., 1996].

According to the data presented in [Lyons, 2001; Liou et al., 2002; Boudouridis et al., 2003; Solovyev et al., 2003], the growth of Pd leads to disturbances which are not typical substorms. According to Lyons [2001] and Boudouridis et al. [2003], dynamic pressure disturbance (DPD) or polar boundary intensification (PBI), respectively, are observed during such periods. According to [Shue and Kamide, 1998; Liou et al., 2002], the growth of Pd leads to the enhancement of negative geomagnetic disturbances which are not always associated with the development of a typical substorm. We suppose (see Solovyev et al. [2003, 2006]) that the reconfiguration of the DP2 current system takes place during such periods.

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