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GEOMAGNETIC SUDDEN IMPULSE CHARACTERISTICS IN DEPENDENCE OF THE IMF ORIENTATION

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1. Introduction

Geomagnetic SIs, consisting of the preliminary (PI) and main (MI) impulses, appear during sharp changes in the solar wind dynamic pressure (Pd) under the conditions of both negative and positive values of the IMF Bz component. However, the SI studies at high and low latitudes were mainly carried out at $B\,z < 0$; their results are summarized in the form of a physical model in [Araki, 1994]. According to this model, the source of PI at high latitudes is the generation of the ionospheric two-vortices current system with the clockwise (counterclockwise) direction of currents in the afternoon–evening (prenoon–morning) sector and with the opposite direction during MI The SI properties in the Bz > 0 periods were studied on the basis of midlatitude and low-latitude [Russell and Ginskey, 1995] and high-latitude [Iyemory and Araki, 1982; Moiseyev *et al.*, 2002; Moretto *et al.*, 2000] observations. These investigations showed that there are some distinctions between the properties of SIs observed at midlatitudes and low latitudes at Bz < 0 and Bz > 0, and the properties of SIs at high latitudes obtained by different authors in the periods Bz > 0 are not always consistent. The influence of the IMF By on the formation and propagation of SI have not yet been studied.

This work investigates the specific features of distribution of the SI ionospheric current systems depending on the sign of the IMF Bz and By components in the |By/Bz| <= 1 and |By/Bz| > 1 periods. In total the 14 events were studied.

The examples of the IMF $B\,z$ and $B\,y$ components and the Pd variations in Figure 1, associated with the SI generation, for the events of May 25, 1997 ($Bz > 0$ and $By > 0$, Fig. 1a) and January 6, 1998 ($Bz < 0$ and $By < 0$, Fig. 1b) are shown. The magnetic field variations at Eusebio (EUS) equatorial station located in the daytime sector are given below.

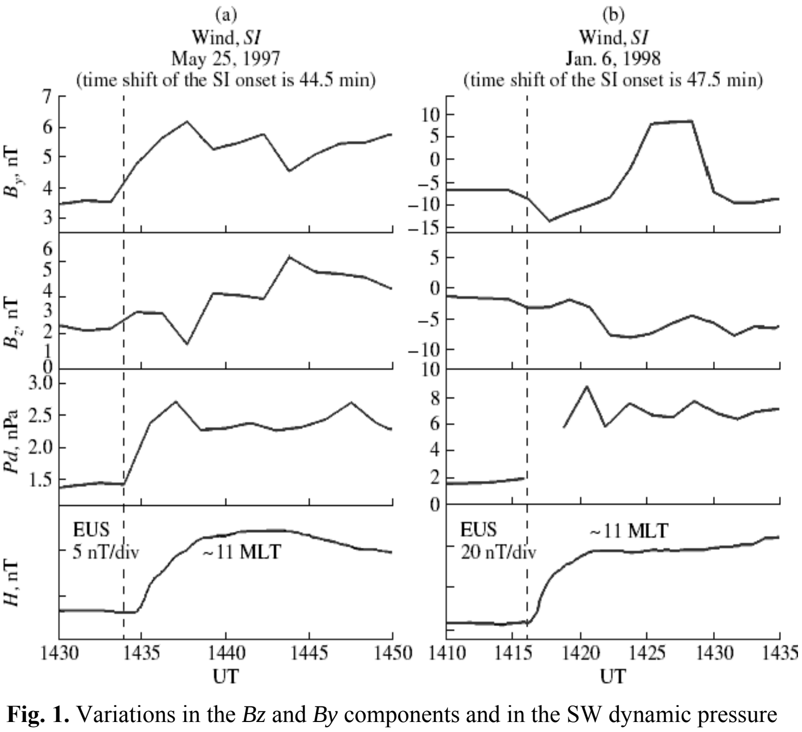

Fig. 1. Variations in the *Bz* and *By* components and in the SW dynamic pressure (*Pd*) in the (a) $Bz > 0$ and $By > 0$ and (b) $Bz < 0$ and $By < 0$ periods measured on board the Wind satellite, and the magnetic field variations measured at Eusebio (EUS) station (Φ'~0.10°) (below).

2. Results of analysis

2.1. Dependence of SI Properties on the Orientation of the IMF Bz Component

Latitude variations in the *H* and *X* components of the SI geomagnetic field in the afternoon–evening and prenoon – morning sectors for the IMF northward ($Bz > 0$, Fig. 2a) and southward ($Bz < 0$, Fig. 2b) orientations are shown in Fig. 2. This figure indicates that both at $Bz > 0$, $Bz < 0$ cases SI has two-impulse structure consisting from PI and MI impulses (showed in the fig. 2a). However at $Bz > 0$, the pattern is more dynamic: due to the poleward motion of PI and MI beginning from latitudes of Φ' ~ 65-67° to 75-78° (Fig. 2a). Poleward propagation velocity is about 1-3 km/s. In the events during $Bz < 0$ the poleward propagation is not observed or badly expressed.

Figure 3 illustrates the distributions of the current vectors depending on the invariant geomagnetic latitude and MLT ~2–5 min after the SI onset (which approximately corresponds to

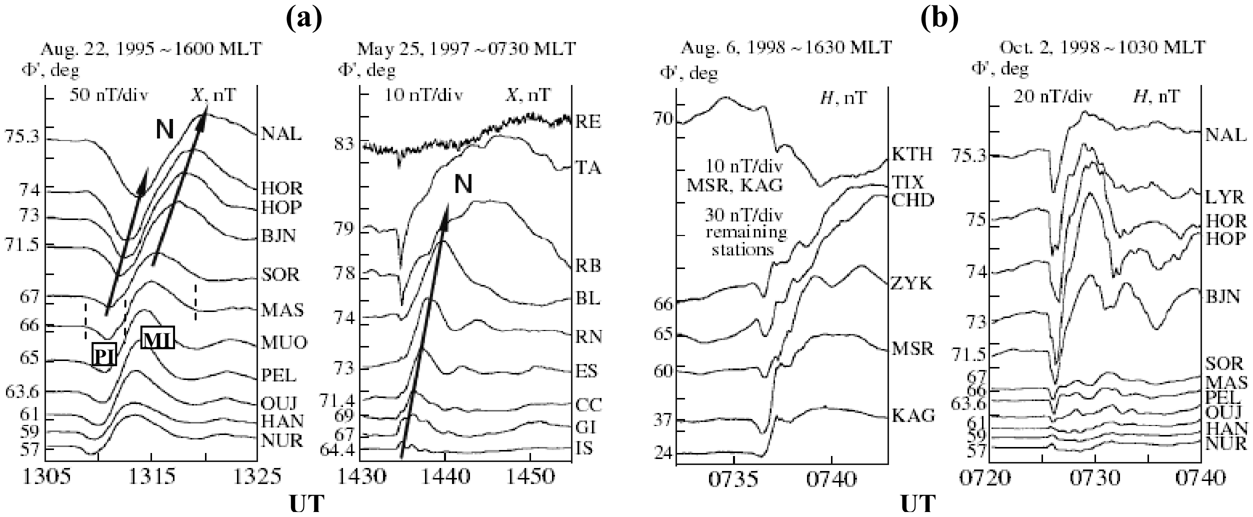

Fig. 2. Latitude variations in the *H* and *X* components of the geomagnetic field recorded during the SI events at (a) *Bz* > 0 and (b) *Bz* < 0 in the afternoon–evening and prenoon–morning sectors.

the MI generation time) at *Bz* > 0 (Fig. 3a) and at *Bz* < 0 (Fig. 3b). Figure 3 indicates that in general, both at *Bz* > 0, *Bz* < 0 cases, at latitudes of Φ'≥65°, the eastward currents mainly prevail in both time sectors of the dayside ionosphere, except for the afternoon sector, where the westward currents flow at latitudes of Φ' ~ 70–75°. The spreading of currents to lower latitudes and into the polar cap region is observed.

However, for some SI events (e.g., the event of May 15, 1997, Fig. 3b), the MI current systems at *Bz* < 0 differ from those observed at *Bz* > 0 (Fig. 3a). In this event the westward currents in morning hours are registered. Thus, two current system types are possibly generated at negative IMF *Bz*.

2.2. Influence of the IMF By Component on the Formation and Propagation of SI in the |By/Bz| ≤ 1 and |By/Bz| > 1 Periods

Figure 4 show the examples of the azimuthal SI propagation at latitudes of Φ' ~ 74–76° in the |*By*/*Bz*| ≤ 1 and |*By*/*Bz*| > 1 periods. Figure 4a indicates that, at small *Bz* and *By* and at |*By*/*Bz*| ≤ 1, SI propagates from the noon meridian (marked with a triangle in Fig. 4) toward the evening and morning sides, i.e., eastward (indicated with the E arrow) in the afternoon sector and westward (indicated with the W arrow) in the prenoon sector at latitudes of Φ' ~ 74–76°. The azimuthal SI propagation velocity was ~7–10 km/s. The SI events generated at *By* > 0 (+3…+6 nT) and at *By* < 0 (–7…–14 nT) at |*By*/*Bz*| >1 are presented in Figs. 4b and 4c, respectively. As follows from this figure, at |*By*/*Bz*| >1 at latitudes ~74–76°, the propagation direction with respect to the noon meridian does not change, as was observed during the event presented in Fig. 4a, and the propagation in the same direction in dependence on the IMF *By* sign is observed in the daytime sector from ~1500 to ~0800 MLT. At *By* > 0 (*By* < 0), SI propagates westward (eastward). The propagation velocity was ~10–22 km/s.

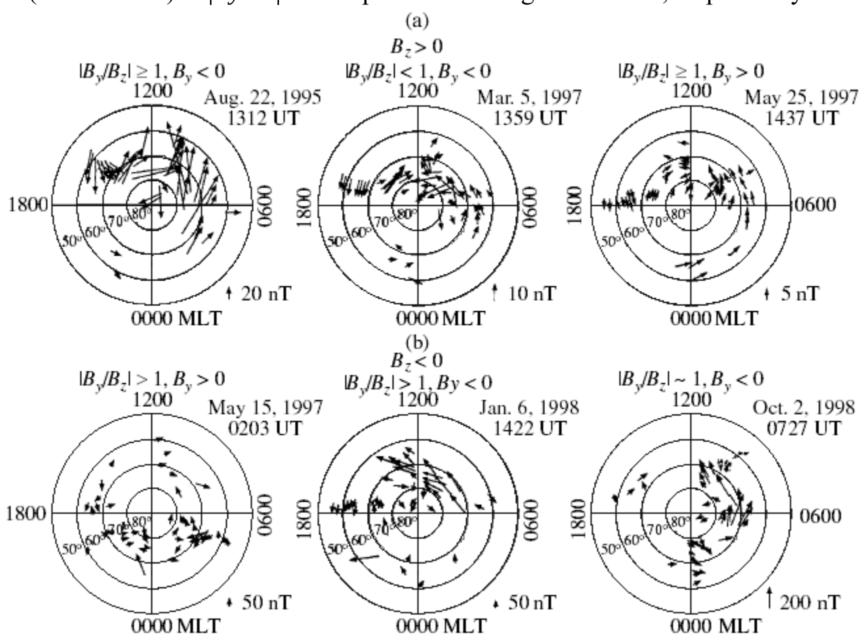

Fig. 3. Distributions of the vectors of the equivalent currents responsible for MI at latitudes of Φ'>=60° depending on the geomagnetic latitude and MLT in the (a) *Bz* > 0 and (b) *Bz* < 0 periods.

3. Discussion of results

3.1. Effects of SI Poleward and Azimuthal Propagation. The Influence of the IMF Bz and By Components

SI poleward propagation Poleward displacement can be easier explained as a consequence of the poleward motion of the region of particle precipitation in the ionosphere due to the generation of the eastward electric field. According to [Lyatsky and Sibeck, 1997], the field of polarization under the development of the balloon (or interchange) instability can be the source of such a field. On the other hand, the sharp magnetosphere compression by SW can result in the generation induction electric field of eastward direction at $Bz > 0$ [Maltsev, 1997] and westward direction at $Bz < 0$ [Maltsev, 1997]. Therefore at $Bz > 0$ the polarization [Lyatsky and Sibeck, 1997] and induction electric fields have the same direction that could have resulted in a more intense SI poleward propagation at $Bz > 0$ periods as compared with $Bz < 0$ periods. The effects of field line reconnection [Smith and Lockwood, 1996] can also cause the SI poleward propagation. However, reconnection is more efficient during $Bz < 0$.

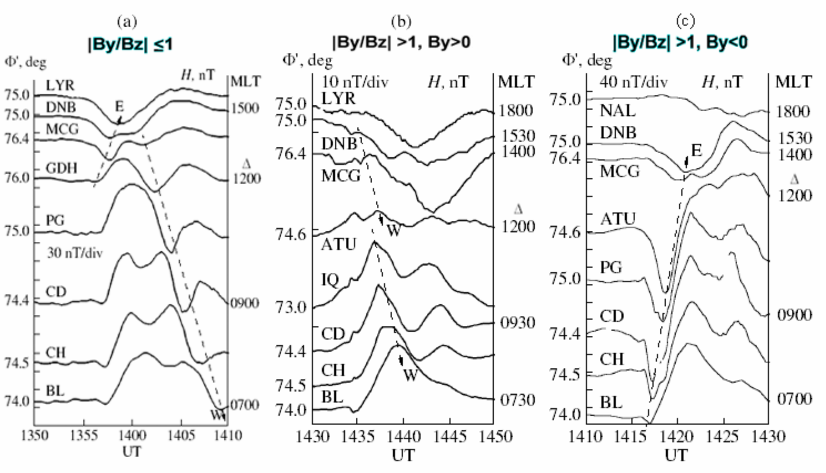

Fig. 4. Examples of the SI azimuthal propagation at latitudes Φ'=74–76° in $|By/Bz| \leq 1$ case in the event of March 5, 1997 (a) and in $|By/Bz|>1$ case in different MLT sectors during the periods of By>0 (+3…+6 nT) in the event of May 25, 1997 - b and By<0 (–7…–14 nT) in January 6, 1998 - c.

SI azimuthal propagation As follows from the experimental data two types of SI azimuthal propagation exist. The first westward and eastward from the noon meridian or from the nose part of the magnetosphere tailward during $|By/Bz| \leq 1$ periods (fig. 4a). The second at $|By/Bz| > 1$ SI propagates in one direction in 08-16 MLT sector eastward (westward) at $By < 0$ ($By > 0$). In the event that was observed on January 10, 1997 (not shown) during $|By/Bz| \sim 1$ periods of SI propagation from the noon meridian, both eastward and westward, at the velocity of ~10 km/s was accompanied by the expansion of the auroral luminosity region along the auroral oval in the same direction and at approximately the same rate [Solovyev et al., 2004]. This phenomenon indicates that, at the enhancement of field-aligned currents (FACs) and electric fields in the periods of magnetosphere compression, ionospheric conductivity variations will lead to the reorganization of ionospheric currents, as assumed in the paper [Solovyev et al., 2004], and to the displacement of their centers from the dayside to the nightside. In the Zhou and Tsurutani [1999] model, expansion of the auroral luminosity region along the auroral oval with velocity of ~10 km/s is explained by propagation of the magnetospheric compression from its nose part along the magnetopause into the tail with simultaneous precipitation of particles previously captured in the magnetosphere due to their interaction with the electromagnetic waves. The velocities of the SI azimuthal propagation (20–40 km/s) can be interpreted so that SI propagates in the form of an MHD wave at the velocity of ~600– 1200 km/s, e.g., in the inhomogeneous ionospheric waveguide [Makarov *et al.*, 2002]. The data presented also indicate that the IMF *By* component affects the SI azimuthal propagation at latitudes of ~75° in the daytime MLT sector (Fig. 4*b, c*), which can be explained based on the model of field line reconnection at the cusp latitudes [Smith and Lockwood, 1996].

3.2. SI Generation Sources and Current Systems

According to the numerical model described in [Rezhenov and Lyatsky, 1987], apart from the electric field enhancement across the polar cap, a sharp compression of the magnetosphere leads the equatorward displacement of the polar-cap boundary. As a result, the disturbed convection has the form of two narrow jets at high latitudes, with the flow reversal at lower latitudes, and is similar to the convection under a quasi-viscous interaction between SW and the magnetosphere [Lyatsky et al., 1985]. The appearance of such a convection is related to the enhancement of the FACs of regions 0 (R0) and 1 (R1) [Kustov et al., 2000]. The intensification of the R0 and R1 FACs will lead to the enhancement of the Hall currents between the layers of these FACs, as well as the currents closing the R0 and R1 FACs in the daytime magnetosphere, as was suggested in [Moiseyev *et al.*, 2002]. The enhancement of the R0 and R1 FACs can explain the observed current distributions in Fig. 3, both at $Bz > 0$ and $Bz < 0$. At the same time in the May 15, 1997 event (Fig. 3b), the SI current system similar to those proposed in the Araki [1994] model, i.e., including the enhancement of the eastward current in the evening sector and of the westward current in the morning hours at Φ'=65°–70°, i.e., the vertical currents produced by the R1 FACs, can be observed in the $Bz < 0$ periods. Another cause of such a current distribution can be a simultaneous enhancement of the FACs of region 2 (R2). The Halls currents between the R1 and R2 FACs will have the western (eastern) direction in the morning (evening) hours. In addition to the R0, R1, R2 FACs, the FACs caused by IMF By may intensified. These FACs will result in current system similar to the DPY enhancement [Friis-Christensen *et al.*, 1985; Troshichev *et al.*, 1997].

Conclusion

(1) We indicated that, in the |*By*/*Bz*| ≤1 periods, regardless of the sign of the IMF *Bz* and *By* components, the SI generation is mainly accompanied by the enhancement of the eastward (westward) current at latitudes of Φ'=70–75° in the prenoon–morning (afternoon– evening) sector with a possible spreading of the currents to lower latitudes and into the polar cap region. In the periods of MI generation at lower latitudes in the daytime ionosphere, the eastward currents appear in both sectors. In the |*By*/*Bz*|> 1 periods, during the SI generation in the daytime (1600–0900) MLT sector, the eastward (westward) currents are also increased at latitudes of Φ'=75° at *By* > 0 (*By* < 0).
(2) We experimentally corroborated that SI propagates poleward, which is most noticeable at *Bz* > 0, and along the azimuth from the noon meridian both eastward and westward at |*By*/*Bz*|≤1. In the periods of large IMF *By* values at *By* > 0 (*By* < 0), SI propagates westward (eastward) in the daytime (~1600–0900) MLT sector at latitudes of Φ'≈75°.
(3) It is assumed that the generation of a geomagnetic disturbance under a sharp compression of the magnetosphere by SW is mainly caused by the enhancement of the R0 and R1 FACs and, during some SI events, by the intensification of the R2 FACs and of the currents caused by IMF *By*. The disturbance caused by the magnetospheric compression propagates from the nose part of the magnetosphere to its tail in the form of a surface wave and is accompanied by the simultaneous precipitation of particles, previously captured in the magnetosphere, into the ionosphere. Spatiotemporal variations in the ionospheric conductivity lead to the reorganization of the ionospheric current systems responsible for SI. A sharp compression of the magnetosphere also leads to the generation of MHD waves propagating in the inhomogeneous magnetospheric waveguide.

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