"Physics of Auroral Phenomena", Proc. XXV Annual Seminar, Apatity, pp.51-54, 2002

Polar Geophysical Institute

RELATION BETWEEN THE FORMATION OF PRELIMINARY AND MAIN SI IMPULSES DURING A SHARP COMPRESSION OF THE MAGNETOSPHERE BY SOLAR WIND

A.V.Moiseyev, S.I.Solovyev (*Institute of Cosmophysical Research and Aeronomy, Yakutsk, Russia*)
K.Yumoto (*Department of Earth and Planetary Sciences, Kyushu University, Fukuoka, Japan*)

Abstract. Specific features and development of Pi and Pm impulses at latitudes from the equator to the polar cap are studied. It is shown that formation of Pi and Pm impulses at high latitudes (Φ′=70°) is related to simultaneous intensifications of the westward and eastward currents on the dayside of the magnetosphere with a consequent shift of the eastward current to the pole. It leads to an increase of duration of Pi impulse with the growth of latitude. Inversion of Pi and Pm signs relative to the noon meridian takes place only at Φ′≈36-60°. At these latitudes the duration of Pi impulse also increases with growth of latitude, but the increase velocity is one order of magnitude larger than at Φ′=65-83°.The current system of SI impulse and possible reasons of Pi and Pm formation at different latitudes are discussed.

Introduction

A sharp growth of the dynamical solar wind (sw) pressure (Pd) leads to the generation of a sudden geomagnetic impulse (SI) consisting of a preliminary (Pi) and main (Pm) impulses which are often of opposite signs [Nishida, 1978]. Durations of Pi and Pm – impulses are ~1-2 min and ~5-10 min, respectively. According to the Araki physical model [1994], the sources of Pi (Pm) at high latitudes are the intensification of a pair of field-aligned currents (FACs) at latitudes of ~75°, inflowing (outflowing) in the after-noon sector and outflowing (inflowing) in the pre-noon and the formation of two-vortical current systems. It is assumed that the formation of two-vortical current system, responsible for the Pi impulse, is due to incidence of the Alfvenic wave in the ionosphere at the beginning of compression, and the Pm impulse is a result of intensification of the magnetospheric convection and zone 1 FACs [Araki, 1994].

However, the analysis of global geomagnetic data shows [Solovyev et al., 2002] that geomagnetic field variations during quasi-periodic changes of Pd are of essentially different characteristics at latitudes higher and lower than ~75° , which are not consistent with the Araki model [1994]. It is also noted in the papers [Moretto et al., 2000, Lam and Rodger, 2001]. about some difficulties in explaining experimental data compared to this model.

Here we study peculiarities of the evolution of Pi and Pm at latitudes from the equator to the polar cap.

Analysis of experimental data

The characteristics of SI in the period of a sharp increase of Pd (Fig. 1, WIND) are studied by the global magnetic station chain data including ~80 high-latitude, ~20 low-latitude and equatorial stations as well as observations of the magnetic field in the magnetosphere (GOES-8, 9).

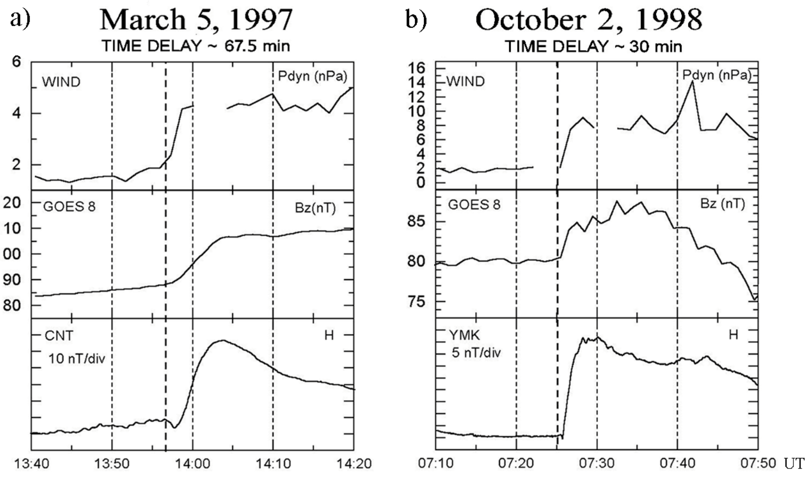

Fig. 1 Variations of the sw dynamical pressure from the WIND, Bz-component of magnetic field from the GOES 8 and geomagnetic field H-component at low-latitude stations Canete (CNT Φ′≈0.75°, pre-noon sector) on March 5, 1997 (a) and Yamakawa (YMK Φ′≈24.08°, post-noon sector of MLT) on October 2, 1998 (b).

Fig. 2a, b presents H-component variations from Φ′≈56-60° to 76-83° along 16-17 MLT meridian (Fig. 2a) and along 07-08 MLT meridian (Fig. 2b) during SI with an onset at 1356 UT on March 5, 1997 (Fig. 1a). Fig. 2c presents H-component longitudinal variations relative to the noon meridian at Φ′≈78-80°. From Fig. 2 it follows that, in the first place, the negative Pi is of the identical sign at Φ′≥73° in the evening and morning sectors, and it is possible that the inversion of Pi sign relative to the noon meridian takes place at lower latitudes (Φ′=71°). The duration of Pi increases with the increase of the latitude in both sectors. Secondly, in the both sectors at Φ′>60° the sign of the positive Pm is not changed. The negative and the positive ΔH variations are of the maximum intensity in the post-noon-evening and the pre-noon-morning sectors, respectively (Fig. 2a-c).

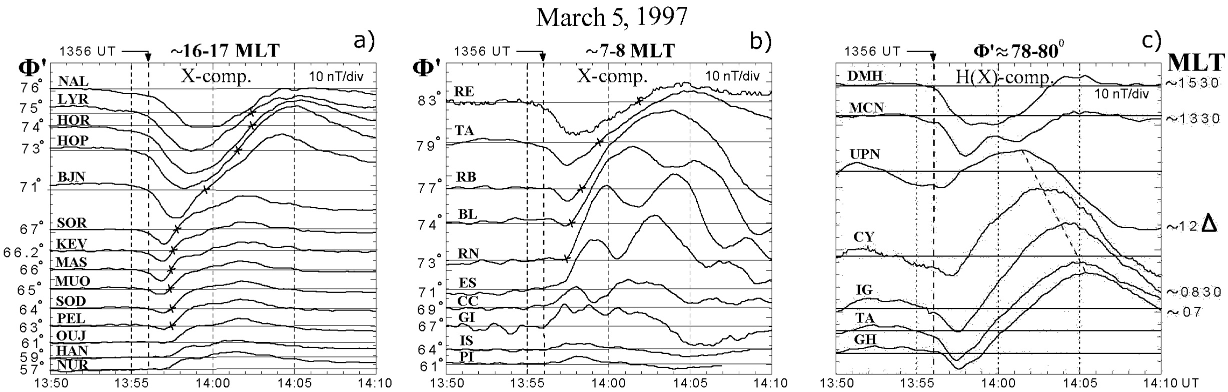

Fig. 2 Latitudinal variations at the ~16-17 MLT (a) and ~7-8 MLT (b) meridians, longitudinal variations of the magnetic field H-component at Φ′≈78-80º (c) on March 5, 1997 at 1350-1410 UT. Triangle is 12 MLT.

Fig. 3 illustrates the transition moment from Pi to Pm (crosses in Fig. 2 a, b), or Pi duration, depending on the latitude for the two meridians. One can see that the moment of this transition, or the time of Pm onset, is of the linear dependence on the latitude and is shifted to the pole with ~1,8 deg/min velocity at the both meridians. Simultaneously, the maximum Pi and Pm amplitudes are shifted to the pole (Fig. 2a, b).

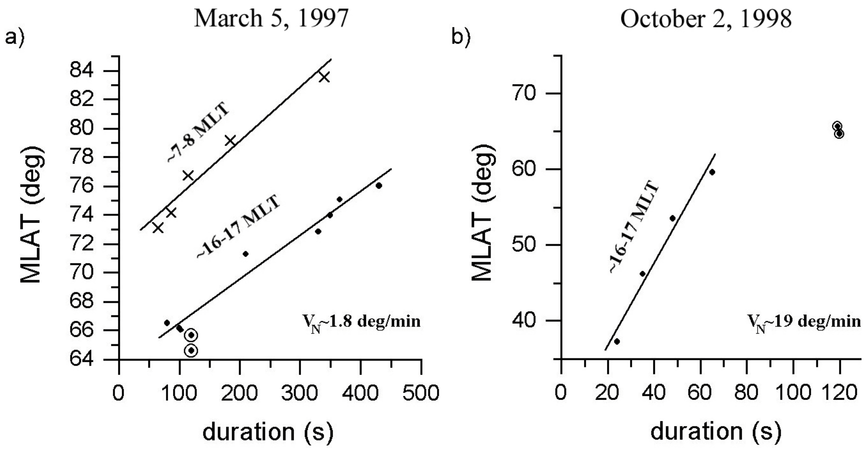

Fig. 3 Duration of Pi-impulse versus latitude at ~7-8 MLT and ~16-17 MLT for Si on March 5, 1997 with an onset at ~1356 UT (a) and ~16-17 MLT for Si on October 2, 1998 (b) with an onset at ~0726 UT.

Fig. 4 presents H-component variations at latitudes from the equator to the auroral zone (Φ′≈65-66°) in after-noon (a) and pre-noon (b) sectors for SI with an onset at ~0726 UT on October 2, 1998 (Fig. 1b). For this event, as for the event in Fig. 2, the signs of Pi and Pm impulses do not change at Φ′≈65° and higher latitudes (not shown) in pre- and after-noon, but the inversion of the Pi and Pm signs takes place in these sectors at Φ′≈40-60°. At latitudes from the equator to Φ′≈30° the Pi is poorly pronounced, and the sign of positive Pm is not changed at the stations located on each side of the noon meridian. The duration of Pi increases from ~30 s to ~2 min with increasing latitude from Φ′≈37° (MSR) to Φ′≈65-66° (TIX, CHD). As it becomes evident from Fig. 3b, the time of Pm onset depends linearly on the latitude up to Φ′≈60°. However, the shift to the pole occurs with the ~19 deg/min velocity, i.e. one order of magnitude larger, in comparison with higher latitudes (Φ′≥65°, Fig. 3a).

Discussion

The current system of SI impulse at high latitudes

The data in Fig 2 a, b and c show that during a sharp compression of the magnetosphere and SI generation the westward (negative ΔH) and eastward (positive ΔH) currents on the dayside of the magnetosphere are simultaneously enhanced. During the first minutes of compression the westward current is located at higher latitudes in comparison with the eastward one and is observed during 5-7 minutes, i.e. during the excitation period of Pi and Pm impulses. The largest intensity of westward (eastward) current is located in longitude in the post-noon (pre-noon) MLT sector. Unlike the Araki model [1994], in order to explain the observed current distribution it is necessary to assume that besides the enhancement of field-aligned currents (FACs) of the zone 1, the FACs at latitudes of a cusp-cleft (zone 0 or 3) are also enhanced as it is schematically shown in Fig. 5a. It will lead to a rise of Hall ionospheric currents of western (eastern) direction in the post-noon (pre-noon) sector (open arrows), and perhaps of ionospheric currents closing FACs zones 1 and 0 (solid dark and dashed arrows). The distribution of equivalent ionospheric currents for the October 2, 1998 event (Fig. 5b) shows that there is an effect of predominant spread of currents to the side of lower latitudes (similar to the March 5, 1997 event (not shown)).

Such a current distribution (Fig. 5a and b) is similar to the SI current system appearing when the boundaries of the polar cap change at the periods of Pd enhancement and correspond to the picture of disturbed convection in the form of two narrow streams at high latitudes and reverse flow at lower latitudes [Rezhenov and Lyatsky, 1987]. According to [Rezhenov and Lyatsky, 1987], such a structure is similar to the convection caused by the quasi-viscous interaction of the solar wind to the magnetosphere [Lyatsky et al., 1985].

Formation of Pi and Pm impulses

*Pi impulse. T*here are, at least two mechanisms of formation of Pi impulse. Mechanism 1: the formation of two-vortical current system as a result of the ingress of Alfven wave into ionosphere [Tamao, 1964, Araki, 1994]. Mechanism 2: the reconstruction effect of the ionospheric current system at the expense of sudden change of precipitating particle flow and ionospheric conductivity at high latitudes [Safargaleev and Maltsev, 1987 and references in it]. The data in Fig. 2-4 show that the formation of Pi at high and lower latitudes are, probably, different.

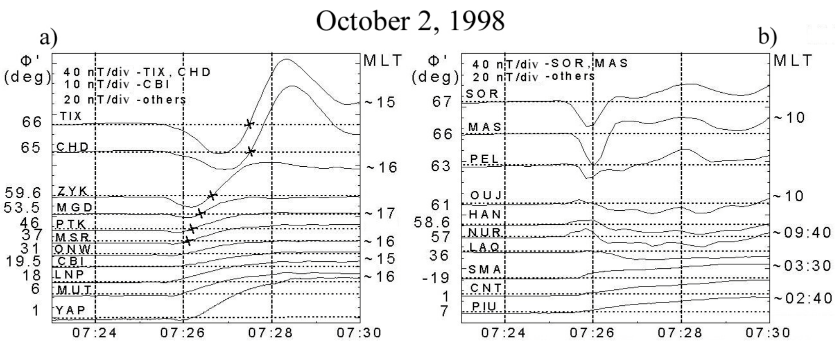

Fig. 4 Latitudinal variations of the magnetic field H-component from the equator to the auroral zone in the afternoon (a) and pre-noon (b) sectors for Si on October 2, 1998 with an onset at ~0726 UT.

At high latitudes the Pi sign reversal relative to the noon meridian (Fig. 2a and b) does not take place and the duration of Pi increases with the rise of latitude and becomes comparable with the duration of Pm at Φ′>73° (Fig. 2a and 3a). As it follows from Fig. 2a and b, a sequential shift of the eastward current to the pole and the gradual compensation of the westward current intensity can be a reason of the increase of Pi duration with the latitude. Thus, the reason for the formation of Pi at high latitudes is the reconstruction of the ionospheric current system, probably, in connection with the drift of precipitating particles region poleward (mechanism 2).

At lower latitudes Φ′=65-60° the reversal of the sign of Pi relatively the noon meridian (Fig. 4a and b) is observed. The duration of Pi increases with the growth of latitude (Fig. 3b) from 0.5 to 2 min with a substantially greater velocity than at the latitude Φ′=65° (Fig. 3a).The change of the sign of Pi agrees with the mechanism 1 in the model [Araki, 1994], but it takes place at lower latitudes. The reason of such reversal of the sign of Pi at lower latitudes can be the transformation of the fast magnetosonic wave, generated at the beginning of the magnetosphere compression, into the Alfven mode at a sharp gradient of magnetospheric plasma (for example, at the plasmapause). A similar note has been made in a recent paper [Lam and Rodger, 2001].

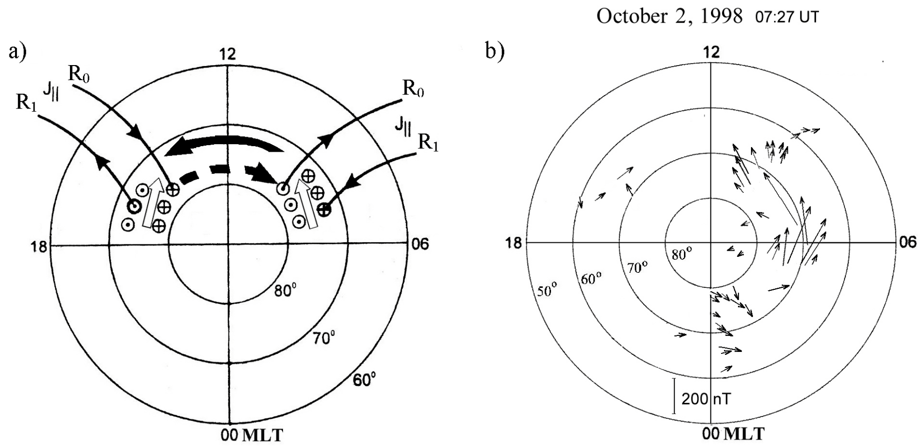

Fig. 5 A scheme of localization for field-aligned and high-latitude ionospheric currents responsible for the Si-impulse (a) and the distribution of equivalent ionospheric currents on October 2, 1998 at ~0727 UT (b).

Pm impulse. According to the Araki [1994] the source of Pm at high latitudes is ionospheric currents similar to the current system of DP 2 and at low latitudes are currents flowing at the magnetopause (DL are disturbances). In our event the current system of SI (Fig. 5 a, b) is different from DP 2 and so the sourse of Pm at high latitudes is the eastern ionospheric currents flowing in the whole dayside (a solid dark and right open arrows in Fig. 5a), but with the most of the intensity in the pre-noon sector.

At lower latitudes $\Phi'\approx$60-40° the reversal of the sign of Pm in pre-noon hours (Fig. 4b) is observed which can be caused by the effect of reversal of the direction of high-latitudinal eastward currents (Fig. 5b) mainly due to their closing at lower latitudes.

At latitudes from the equator up to $\Phi'\approx$30-40° (Fig. 4a and b) the sign of Pm remains to be positive in both sectors where it follows that the source of Pm is currents at the magnetopause [Araki, 1994].

Possible effects in azimuth propagation of SI

The duration of Pi at (Fig. 3b) increases rapidly with increase in latitude. The dependence, similar to that in Fig. 3b, has been obtained for the time of Pi maximum at $\Phi'\approx$55-65° [Takeuchi et al., 2000] for the negative SI, where this dependence is interpreted as a result of the mutual influence of more high-latitude DPi currents and low-latitude currents responsible for DL-disturbances. Another explanation of the dependence in Fig. 3b (and also partially in Fig. 3a, besides the poleward shift of the eastward current) in our opinion, can be an effect of propagation of the Pm in azimuth in the inhomogeneous magnetospheric waveguide, if the azimuth velocity (Va), decreases with the increasing latitude, as it is shown in the paper [Makarov et al., 2002]. Some confirmation of such a dependence is an estimation by the presence of the phase signal delay at the stations located at close latitudes, but stretched in longitude: stations at $\Phi'\approx$78-80° (Fig. 2c, inclined line), TIX and CHD at $\Phi'\approx$65-66°, LNP and CBI at $\Phi'\approx$20° (Fig. 4a). These estimations of Va for indicated latitudes give the meanings ~7-8 km/s, ~50 km/s and ~430 km/s, respectively.

Conclusion

The formation of Pi and Pm at high latitudes (Φ'=70°) is related to the simultaneous intensification of westward and eastward currents at the dayside magnetosphere with the following poleward shift of the eastward current with the velocity $V_N\approx$1.8 deg/min. The current system of SI at these latitudes is similar to the distribution of equivalent ionospheric currents caused by the quasi-viscous interaction of the solar wind to the magnetosphere [Rezhenov and Lyatsky, 1987].

At lower latitudes the Pi and Pm formation can be influenced by the effect of propagation of the fast magnetosonic waves in azimuth in the inhomogeneous magnetospheric waveguide and its transformation to an Alfvenic mode at the sharp gradients of magnetospheric plasma as well as an inversion of the high-latitudinal ionospheric currents and intensification eastward currents at the magnetopause.

Acknowledgments The authors address their sincere gratitude for the magnetic observation data to the leaders of the following projects: MACCS, CANOPUS, IMAGE, Greenland magnetometer array. The data from the satellites were obtained through Internet from NASA GSFS. The work is supported by RFBR grant 01-05-64710.

References

Araki T. A physical model of the geomagnetic sudden commencement // Solar wind Sources of magnetospheric ultra-low-frequency waves Geophys. Monograph 81, 1994.

Lam, M.M., and A.S. Rodger, A case study test of Araki's physical model of geomagnetic sudden commencement // *J. Geophys. Res., 106*, 13135-13144, 2001.

Lyatsky V.B., Maltsev Yu.P., Rezhenov B.V. Ionospheric convection is due to the solar wind quasi-viscous interaction with the magnetosphere // Geomagnetism and Aeronomy, V.25, № 4, P. 566-570, 1985. (in russian)

Makarov G.A., Solovyev S.I., Engebretson M., Yumoto K. Azimuthal propagation of the geomagnetic sudden impulse at high latitudes during a sharp decrease of the solar wind density // Geomagnetism and Aeronomy, V.42, № 1, P. 42-50, 2002. (in russian)

Moretto T., Ridley A.J., Engebretson M.J., Rasmussen O. High-latitude ionospheric response to a sudden impulse event during northward IMF conditions // J. Geophys. Res. V. 105. № A2. P. 2521-2531. 2000.

Nishida A. Geomagnetic diagnosis of the magnetosphere. Moscow: Mir, 1980. 302p. (in russian)

Rezhenov B.V., Lyatsky V.B. The current system of sudden impulse SI // Geomagnetism and Aeronomy, V.27, № 2, P. 242-246, 1987. (in russian)

Safargaleev V.V., Maltsev Yu.P. The generation of the preliminary impulse and the long-periodic pulsations during the SI // Geomagnetism and Aeronomy, V.27, № 2, P. 247-252, 1987. (in russian)

Solovyev S.I., Moiseyev A.V., Baishev D.G., Makarov G.A., Yumoto K., Engebretson M. The characteristics of global geomagnetic response to quasi-periodic variations of solar wind dynamic pressure // Geomagnetism and Aeronomy, 2002. (in press)

Takeuchi T., Araki T., Luehr H., Rasmussen O., Watermann J., Milling D.K., Mann I.R., Yumoto K., Shiokawa K., Nagai T. Geomagnetic negative sudden impulse due to a magnetic cloud observed on May 13, 1995 // *J. Geophys. Res.,* V. 105. № A8, p. 18,835-18,846, 2000.

Tamao T. Hydromagnetic interpretation of geomagnetic ssc* // Rep. Ionos. Space Res. Japan V.18, P.16-31, 1964.