Proceedings of the Research Institute of Atmospherics,
Nagoya University, Vol. 36, No. 2 (1989)

A GEOMAGNETIC SUDDEN COMMENCEMENT AND SUDDEN IMPULSES ON FEBRUARY 6–9, 1986

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Abstract

Using data obtained by the satellites IMP–J, ISEE–2, GOES–5 and –6, and ground-based magnetometers, we studied characteristics of a geomagnetic sudden commencement (SC) and two sudden impulses (SI's) observed in the magnetosphere on Feb. 6– 9, 1986. The SC on Feb. 6 was observed at Kakioka in the night side earlier than by GOES–5 near 8h LT at the synchronous orbit. This fact is explained by taking into account the angle at which the interplanetary shock front collided with the magnetosphere.

1. SC and SI's on February 6–9

Figures 1 to 4 show solar wind plasma and interplanetary magnetic field (IMF), and geomagnetic fields in the magnetosphere and on the ground from Feb. 6 to 9, respectively. The top panel of each figure indicates solar wind bulk velocity, proton number density and dynamic pressure measured by IMP–J. The second panel indicates three components, B_x, B_y and B_z, in the solar ecliptic coordinate system, and total intensity B_T of the IMF observed by IMP–J. The third panel indicates H_P component of geomagnetic field observed by the geostationary satellite GOES– 5. Here the H_P denotes the component parallel to the earth's rotation axis. The bottom panel shows H (horizontal) component obtained by a ground-based magnetometer at Kakioka (26.5° N; 207.6° E in the geomagnetic coordinates). It can be conjectured from the positive jumps in the solar wind bulk velocity, proton number density, dynamic pressure and total intensity of IMF as shown in Figure 1 that an interplanetary shock passed through near 13h20m UT. A geomagnetic sudden commencement (SC) was produced by a magnetospheric compression caused on the occasion of the passage of the shock. The SC can be seen in the geomagnetic field data observed by GOES–5 and at Kakioka of Figure 1. A very intense geomagnetic storm lasted for about ten days after this SC. The upper and second panels in Figure 2 on Feb. 7 show the positive jumps in each physical quantity near 15h30m UT. This shock produced a sudden impulse (SI) in the magnetosphere during the main phase of the geomagnetic storm, as shown in the magnetic field data observed by GOES–5 and at Kakioka. The H component, observed by GOES–5 , changed largely into a negative value one hour after this SI. The local time (LT) was about 10h30m. This phenomenon indicates a magnetopause crossing at the synchronous orbit which was caused by the magnetospheric compression produced owing to the strong increase of dynamic pressure. Then, in the H component at Kakioka, an SI–like phenomenon was not conspicuous. This was probably due to the gradual increase of dynamic pressure. As shown in GOES–5 magnetic field data of the third panel of Figure 3 on Feb. 8, magnetopause crossings at the synchronous orbit occurred near 14h40m (about 9h40m LT) and 20h10m UT (about 14h10m LT). As shown in the H component at Kakioka, SI–like phenomena were caused corresponding to these crossings during the recovery phase of the storm. Another very intense geomagnetic storm occurred after the second SI–like phenomenon. It is very regrettable that the information of solar wind by IMP–J is lacking. The H component at Kakioka indicates a very large SI near 17h40m UT during the recovery phase of the second geomagnetic storm, as shown in the bottom panel of Figure 4 on Feb. 9. Then, GOES–5 observed large variations as shown in the H_P component. These were probably produced by magnetopause crossings at the synchronous orbit near 12h LT. To our regret, both solar wind plasma and IMF data were lacking during the interval. Nevertheless, the dynamic pressure seemed to increase and the total intensity of IMF seemed to decrease at that time. This decrease is sure from ISEE–2 magnetic field data, although the data are not indicated in this paper. Therefore, what caused this SI in the magnetosphere was probably not a fast but a slow shock or a discontinuity in interplanetary space.

2. Propagation of the SC on February 6

Figure 5(a) and 5(b) show three components, H_P, H_E and H_N, of 3.06–sec geomagnetic field data observed by the geostationary satellites GOES–5 and –6, respectively, during the interval 1300 to 1330 UT on Feb. 6. Here, the H_E component is radially earthward and H_N is azimuthally eastward in the geographic equatorial plane. GOES–5 and –6 observed the SC at 1312:45 UT and 1313:40 UT, respectively, as shown in these figures. The UT corresponds to about 8h20m LT for GOES–5 and about 6h LT for GOES–6. Figure 5(c) shows three components, H, D (declination), Z (vertical component), of 1–sec geomagnetic field data at Kakioka during the same interval. The SC was observed at 1312:00 UT. Then the magnetic local time (MLT) at Kakioka was about 22h20m. Furthermore, Figure 6 shows three components, H, D and Z, by an induction magnetometer, and three components, H, D and Z, by a flux gate magnetometer of 1–sec geomagnetic field data observed at Syowa Station (66.1°S; 70.8°E in the geomagnetic coordinates) and 2–sec geomagnetic field data at Isafördur (67.8°S; 69.6°E in the geomagnetic coordinates). These stations are geomagnetic conjugate on the ground. Both stations observed the SC at 1311:45 UT, which was about 1315 MLT. In general, an SC phenomenon caused by the collision with the front magnetopause of an interplanetary shock is considered to propagate toward the earth from dayside in the magnetosphere. Therefore, it is curious that the SC was observed by GOES–5 in the dayside later than at Kakioka in the night side. In order to explicate this problem, we examined the angle at which the shock front collided with the magnetosphere, that is to say, the shock normal.

The upper panel of Figure 7(a) shows 1–2 minute solar wind plasma data measured by IMP–J during the interval 1300 to 1330 UT on Feb. 6. With regard to the values of bulk velocity V and proton number density N (1) in front of and (2) behind the shock front, we obtain V_1 = 343 km/s, V_2 = 428 km/s, N_1 = 5.5 cm^{-3} and N_2 = 42 cm^{-3}, respectively, from this figure. The shock velocity becomes Vs = 456 km/s by computing from these values. On the other hand, the shock was observed at 13h20.3m UT by IMP–J as shown from 15.36–sec magnetic field data in the solar magnetospheric coordinate system (SM system) of the lower panel of Figure 7(a). Then, the location of the IMP–J in the SM system was (–1.0, –31.2, –7.3) R_E. The shock was observed at 1319 UT by ISEE–2 as shown in 1–minute magnetic field data of Figure 7(b). Then, the location of the ISEE–2 in the SM system was (–4.4, –18.7, –2.8) R_E. The location and time of three observational points are necessary to compute the shock normal $\mathbf{n}$ by the use of the relation $\mathbf{n}\cdot\Delta\mathbf{r} = Vs\Delta t$. Here $\Delta\mathbf{r}$ and Δt denote the distance and delay time between two observational points, respectively. Next, we select a point on the front magnetopause. Supposing that the shock front collided with the point of (8, 6.5, 0) R_E on the magnetopause at 1311 UT, we obtain $\mathbf{n}$ = (0.66, 0.62, –0.43). Figure 8 illustrates the tilt of the shock front on the occasion of the collision with the magnetopause and the fronts of the SC compressional wave in the magnetosphere. The speed of the compressional wave in the outer magnetosphere will become faster than that of the interplanetary shock wave. The compressional wave has a slower speed in the plasmasphere because the particle density is higher. As soon as the wave arrives at the dayside ionosphere, the SC phenomenon is considered to propagate immediately to the nightside ionosphere. The direct propagation speed of the SC between GOES–5 and –6 became 447 km/s by calculating from the delay time. Thus, the fact that the SC was observed at Kakioka in the night side earlier than by GOES–5 near 8h LT at the synchronous orbit is explained by taking into account the angle at which the interplanetary shock front collided with the magnetosphere.

3. Discussion

The very intense geomagnetic storm observed in early February 1986 had been preceded by a series of six solar flares during the period Feb. 3 to 7 (Howard et al., 1987). The X–ray maximum time for these flares was (1) 2047 UT on Feb. 3, (2) 0741 UT on Feb. 4, (3) 1029 UT on Feb. 4, (4) 1255 UT on Feb. 5, (5) 0625 UT on Feb. 6 and (6) 1034 UT on Feb. 7 [Solar Geophysical Data (Comprehensive Reports), August 1986]. The flare (2) on Feb. 4 was the largest of all six flares, the second large flare was (5) on Feb. 6 and the third large one was (6) on Feb. 7. Howard *et al.* (1987) developed a numerical simulation for the shocks assumed to have been generated by the six flares and the subsequent propagation in interplanetary space. They demonstrated, presumably from computing the shock transit time to the earth on the assumption of shock velocity and piston driving time, that the SC on Feb. 6 and the SI on Feb. 9 were caused by the shock arrival at 1 AU from the flare (2) on Feb. 4 and the flare (6) on Feb. 7, respectively. Furthermore, they reported that no SC for the shock arrival from the flare (5) on Feb. 6 is reasonably explained by the intense geomagnetic activity already in progress as a result of the disturbance from the flare (2). However, we suggest from the fact of the decrease of the total intensity of IMF that the SI on Feb. 9 was caused not by a fast shock but a slow shock or a discontinuity. Furthermore, we suggest from the consideration of the results of the shock transit time to the earth computed by them, that the SI on Feb. 7 was caused by the shock arrival from the flare (5) on Feb. 6.

It is important to know the aspect of propagation of a magnetospheric compressional wave excited by the sudden increase of solar wind dynamic pressure, but it is difficult because of the complicated configuration of particles and magnetic fields in the magnetosphere. When an interplanetary shock or discontinuity collides with the magnetosphere, the dawn-to-dusk magnetopause current is enhanced and the magnetic field in the magnetosphere begins to increase. This increase propagates toward the earth as a compressional hydromagnetic wave. Along the wavefront a dusk-to-dawn polarization current flows to shield the increase of the magnetic field. A dusk-to-dawn electric field along the wavefront is transmitted as a transverse hydromagnetic wave along the lines of force to the polar ionosphere and produces twin vortex type ionospheric currents. Thus, a preliminary impulse of an SC in high latitudes on the ground is indicated as the superposition of both disturbances. Such a point of view has been developed by Tamao (1964), Araki (1977) and Nagano *et al.* (1985). As a matter of course, an SC is observed earlier in high latitudes than in middle or low latitudes, as known from the delay time between Syowa Station or Isafjördur in high latitudes and Kakioka in middle latitudes. Wilken *et al.* (1982) studied the propagation in the magnetosphere for the SC on July 29, 1977. They presented an illustration of the propagation of the wave fronts in the magnetosphere and the solar wind similar to Figure 8. The fact that the SC on Feb. 6 was observed at Kakioka in the night side earlier than by GOES–5 near 8h LT at the synchronous orbit cannot be explained from their illustration. The tilt of an interplanetary shock or discontinuity on the occasion of the collision with the magnetosphere and the three-dimensional situation for propagation of a compressional wave in the magnetosphere should be taken into account in order to explain an SC phenomenon.

Acknowledgement

The author wishes to thank T. Watanabe and A. Iwata for utilization of the data stored by the Research Institute of Atmospherics, Nagoya University. The author gratefully acknowledges S.H. Bridge for IMP–J solar wind data, R.P. Lepping for IMP–J magnetic field data, C. Russell for ISEE–2 magnetic field data and the National Space Science Data Center through the World Data Center–A for Rockets and Satellites. The author is also indebted to the National Environmental Satellite, Data and Information Service, NOAA for GOES–5 and –6 magnetic field data, the National Institute of Polar Research for Syowa Station and Isafjördur magnetic field data, and the Kakioka Magnetic Observatory, Japan Meteorological Agency for Kakioka magnetic field data.

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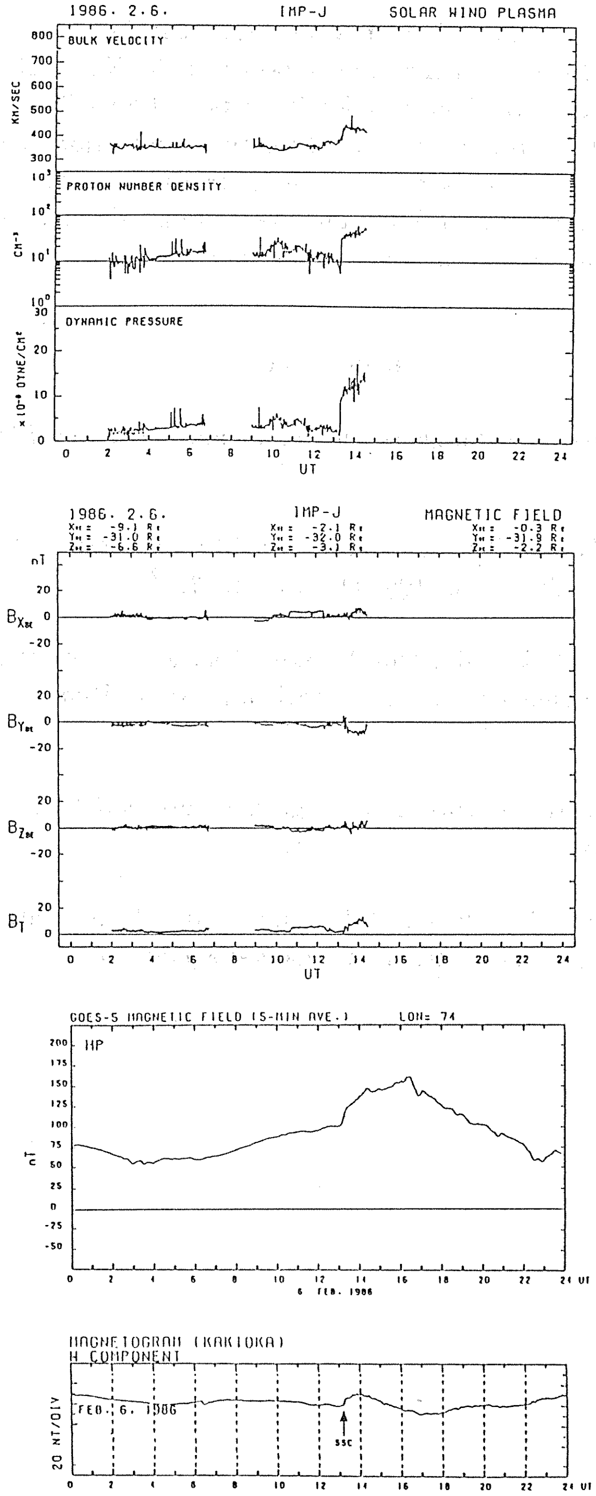


Fig. 1. Solar wind bulk velocity, proton number density and dynamic pressure measured by IMP–J, three components B_x, B_y and B_z and total intensity B_T of the IMF observed by IMP–J, H_P component of geomagnetic field observed by GOES–5; and H component of geomagnetic field observed at Kakioka on Feb. 6, 1986.

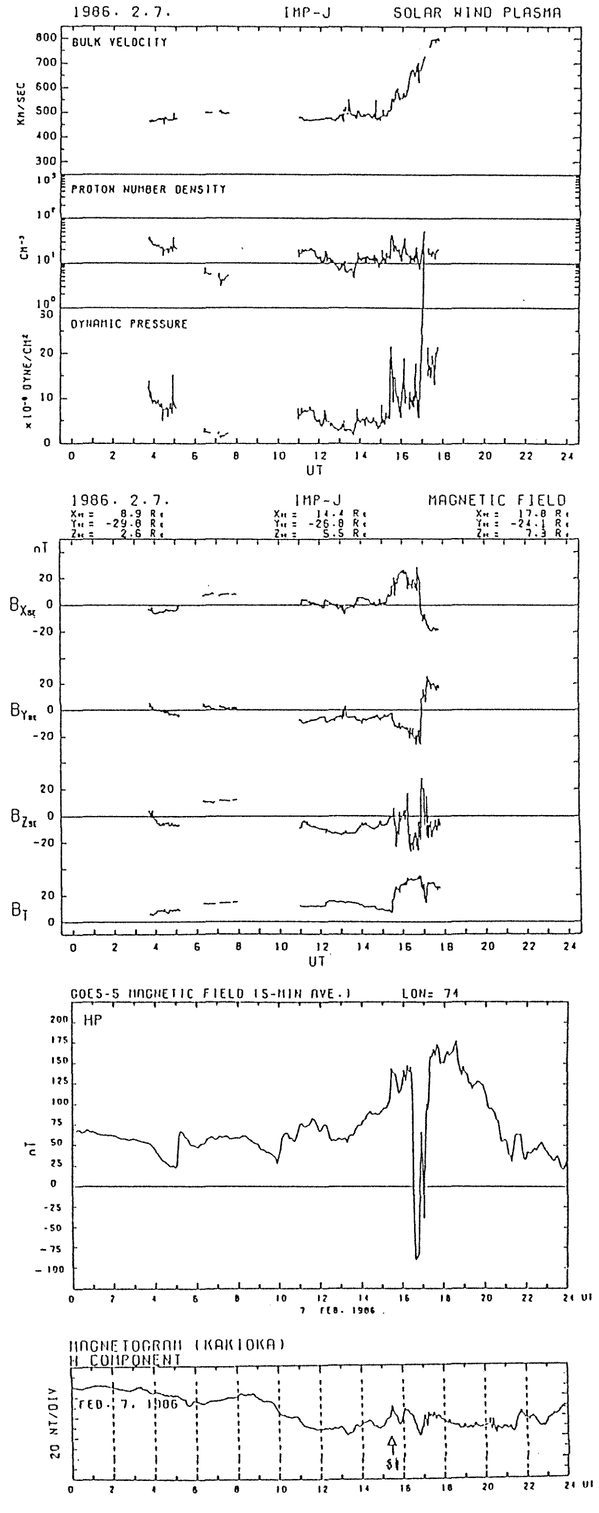
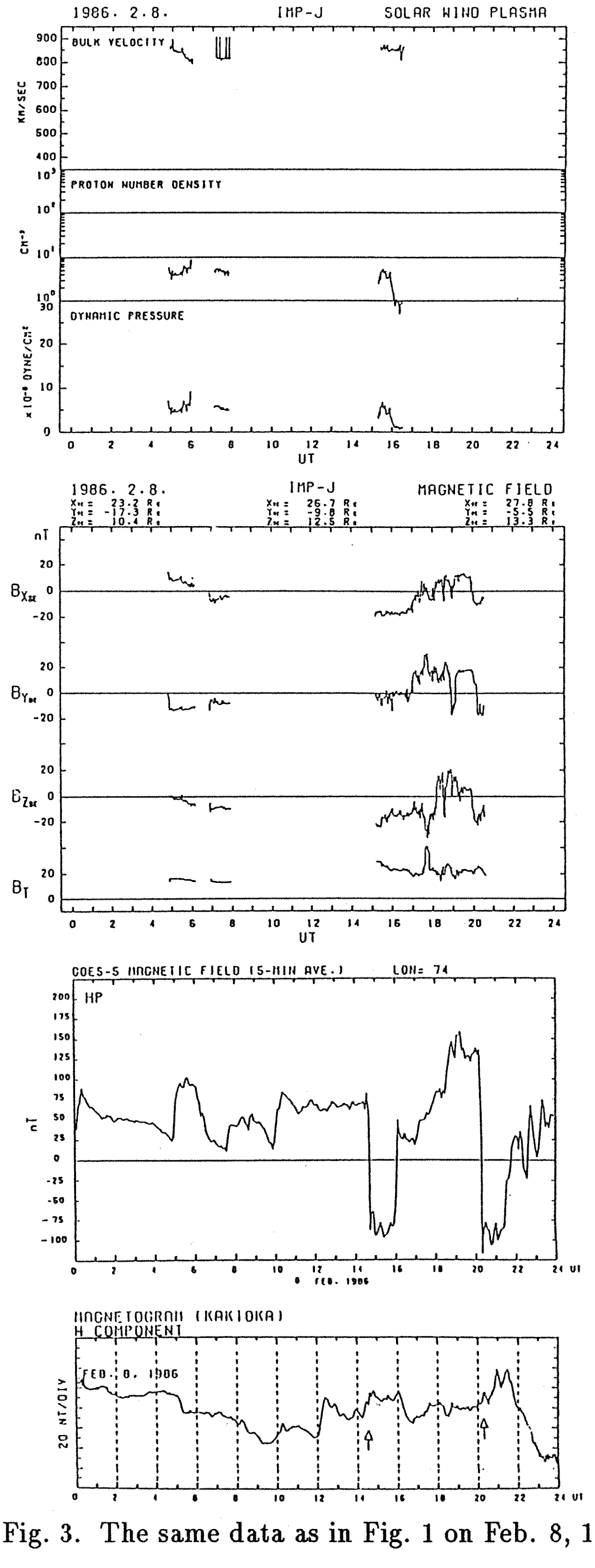


Fig. 2. The same data as in Fig. 1 on Feb. 7, 1986.



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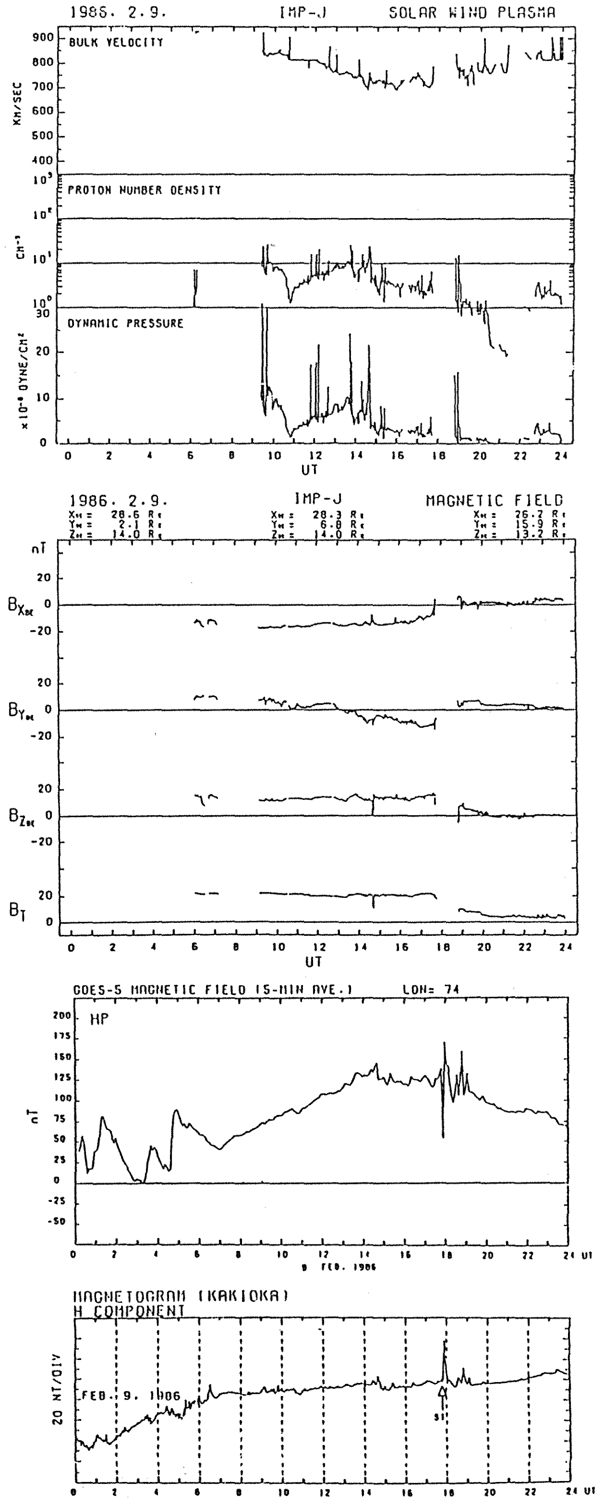


Fig. 4. The same data as in Fig. 1 on Feb. 9, 1986.

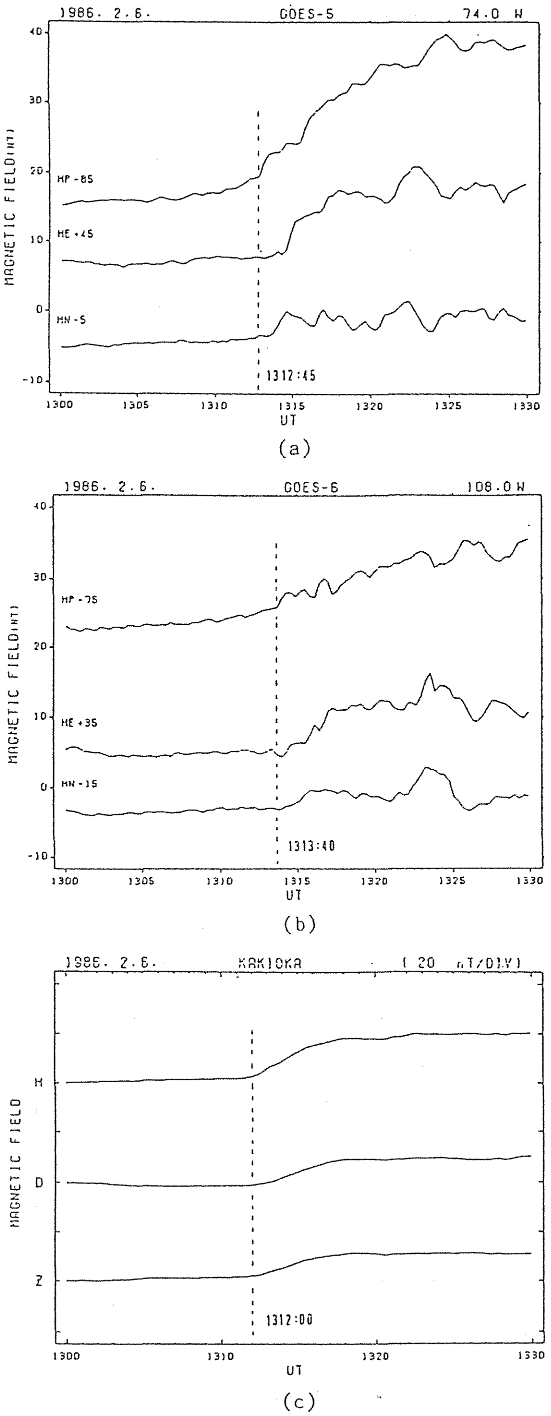
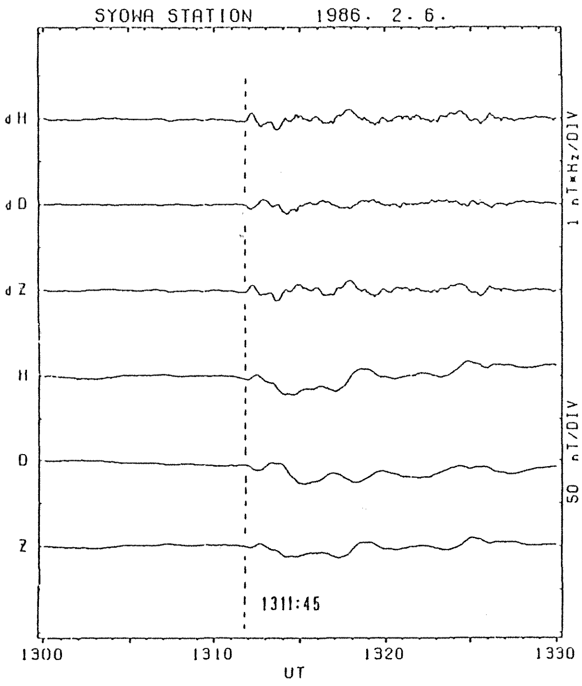
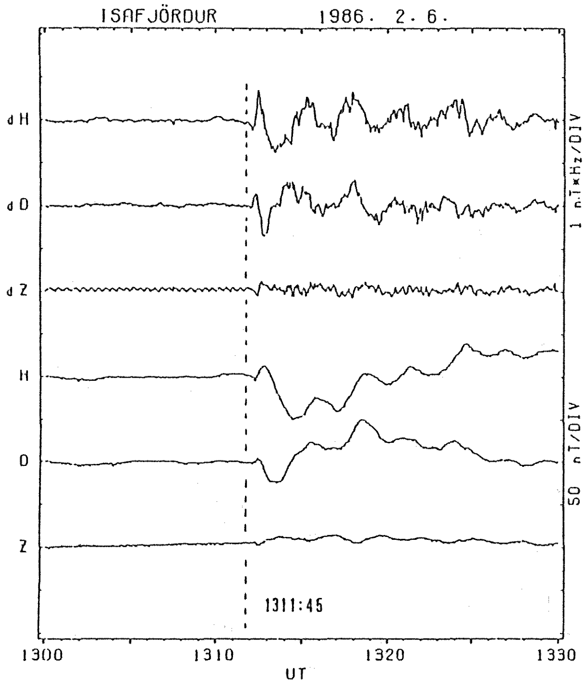


Fig. 5. Three components H_P, H_E and H_N of geomagnetic field observed by (a) GOES–5 and (b) GOES–6, and (C) three components H, D and Z of geomagnetic field observed at Kakioka during the interval 1300 to 1330 UT on Feb. 6, 1986.

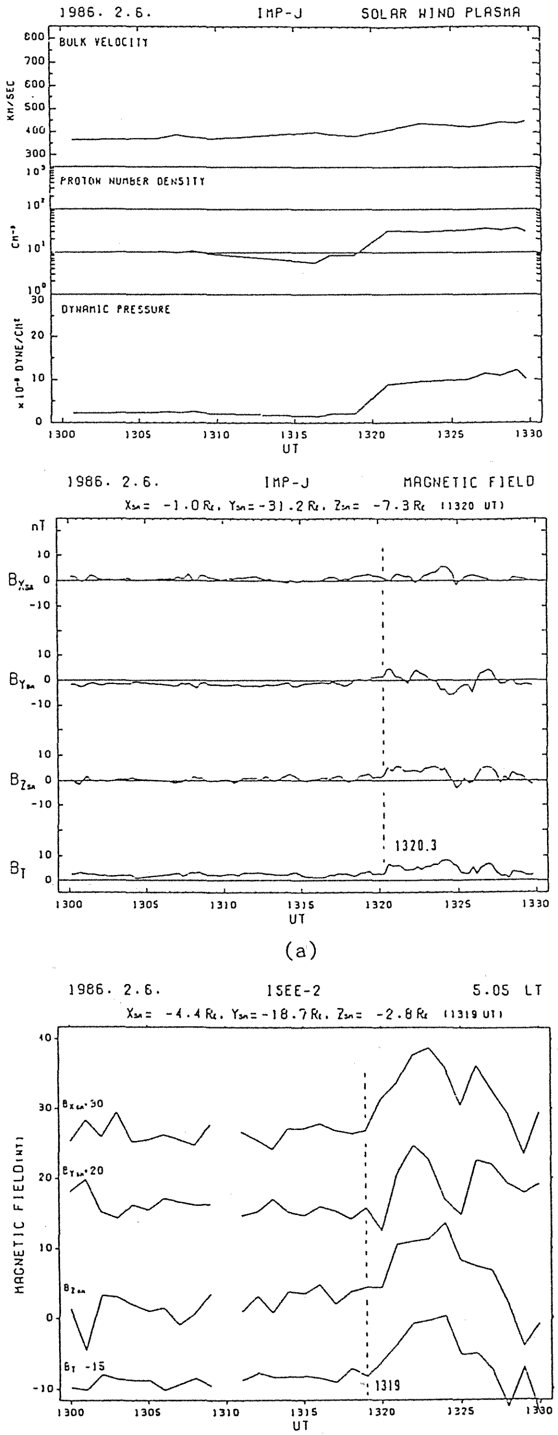


(a)



(b)

Fig. 6. Three components H, D and Z by an induction magnetometer and three components H, D and Z by a flux gate magnetometer of geomagnetic field observed at (a) Syowa Station and (b) Isafjördur during the interval 1300 to 1330 UT on Feb. 6, 1986.



(a)

(b)

Fig. 7. (a) Solar wind bulk velocity, proton number density, dynamic pressure, and three components B_x, B_y and B_z of the IMF in the SM system observed by IMP–J, and (b) the same components of the IMF observed by ISEE–2 during the interval 1300 to 1330 on Feb. 6, 1986.

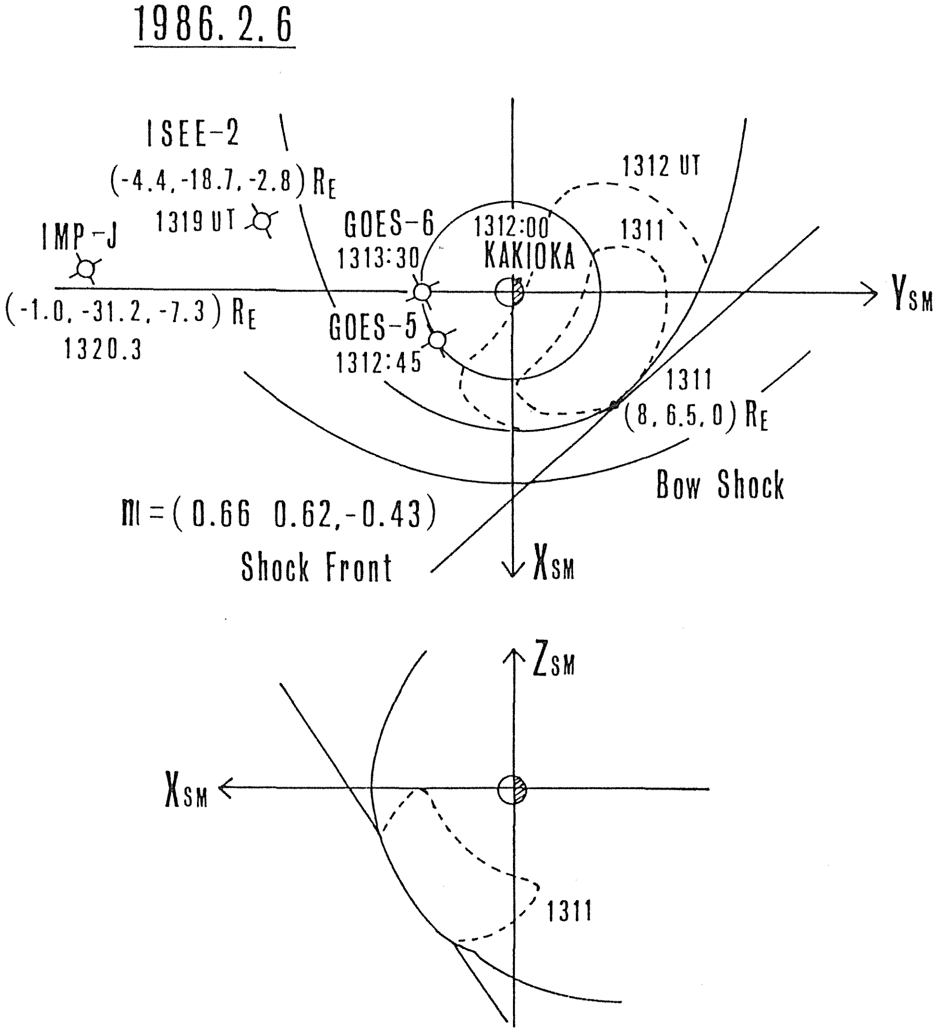


Fig. 8. Illustration of the location of the satellites and the observational time of the shock or the SC, the shock front (solid line) on the occasion of the collision with the magnetopause and the expected fronts (broken lines) of the compressional wave in the magnetosphere of the SC on Feb. 6, 1986 in the SM system.