SIMULTANEOUS OBSERVATION OF GEOMAGNETIC SUDDEN COMMENCEMENT ABOVE AND BELOW THE IONOSPHERE

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Abstract: A geomagnetic sudden commencement (SC) was observed by the low altitude geomagnetic satellite, MAGSAT, when it was flying very closely above a ground station (Magadan in east Siberia, geomagnetic latitude=51.1°) in a duskside (16–17 h LT) meridian. The *H*-component at the satellite showed a positive pulse of 52 nT and the *D*-component a negative pulse of 43 nT in the beginning part of the SC. The duration of the pulse was 2–3 min. The SC observed by normal-run magnetographs at Magadan and other ground stations near the satellite orbit was preceded by a typical preliminary impulse (PI) of which sense is opposite to that of the pulse observed by MAGSAT. By the use of high time resolution data from the IMS magnetometer network Alaska chain, the pulse detected by MAGSAT was identified with the PI observed at the ground stations. It was concluded that the main source current for the PI flowed between the satellite and the ground, that is, in the ionosphere, but effects of other source currents including field aligned currents should be taken into account.

1. Introduction

When an interplanetary shock or discontinuity collides with the magnetosphere, the dawn-to-dusk magnetopause current suddenly increases in the equatorial plane so that the resultant Ampere force may prevent the magnetospheric compression due to an increase of the dynamic pressure of the solar wind. The current produces an increase of the magnetic field in the magnetosphere and the magnetospheric plasma reacts to shield it by producing a dusk-to-dawn polarization current. The resultant Ampere force compresses the plasma earthward. This reaction propagates toward the earth as the compressional hydromagnetic wave. When the wavefront reaches the dayside ionosphere, a westward conduction current begins to flow there and, almost simultaneously, the earth current is induced in the same direction. The increase of the geomagnetic *H*-component of geomagnetic sudden commencement (abbreviated to SC here) observed at low latitude ground stations is produced mainly by these currents. This part of the disturbance field of SC is denoted by DL_{mi} (ARAKI, 1977; mi and *DL* mean a main impulse of SC and a disturbance dominant in low latitudes, respectively).

If the hydromagnetic wave propagated purely two dimensionally in the equatorial plane, the main impulse (MI) of SC might be completely determined by the current system described above. The inhomogeneity of the magnetospheric plasma and magnetic field, however, produces the conversion of the hydromagnetic wave from the compressional mode to the transverse one (TAMAO, 1964a) which transmits the dusk-to-dawn electric field to the polar ionosphere along magnetic lines of force. This electric field generates a twin vortices type ionospheric current which, in turn, produces the preliminary impulse (PI) of SC on the ground (TAMAO, 1964b; ARAKI, 1977).

After the tailward passage of the compressional wave front, the magnetospheric convection will be enhanced by the enhanced solar wind behind the interplanetary shock. Consequently, the dawn-to-dusk electric field impressed to the polar ionosphere increases and magnetic disturbances due to the ionospheric current of the DP-2 (twin vortices) type is superposed on the DL_{mi} field. IYEMORI and ARAKI (1982) suggested that an equivalent current system of the single vortex type instead of the twin vortices type appears when the interplanetary magnetic field is northward.

If the polar originating disturbance fields for PI and MI are denoted by DP_{pi} and DP_{mi}, respectively, the whole SC field, Dsc, can be expressed as (ARAKI, 1977)

$$Dsc = DP_{\mathrm{pi}} + DL_{\mathrm{mi}} + DP_{\mathrm{mi}}\ .$$

In order to detect the ionospheric currents which play an important role in each of three parts of the SC-field above, observations of the magnetic field have to be made simultaneously above and below the ionosphere. This is not easy, however, because the magnetic change caused by the SC-related ionospheric current is very small compared with the ambient magnetic field and decays rapidly with an increasing altitude. Moreover, it can be hardly expected that a satellite is flying just above a ground station during a short period (several minutes) when an SC occurs.

MAGSAT taking data for about 7 months from November 1979 to May 1980, was the first satellite which could measure the vector magnetic field associated with SC in low altitudes (260–560 km). The accuracy (6 nT for vector components) and time resolution (about 60 ms) were highest of all measurements made so far. ARAKI *et al.* (1982) showed that a negative impulse of the D-component observed by MAGSAT on its low latitude dawnside orbit during the beginning part of an SC was consistent with the existence of a global ionospheric current for PI. However, there was no magnetic observatory below MAGSAT at that time and the conclusion was obtained on the circumstancial evidence.

On March 19, 1980, a very rare event was realized in which an SC occurred when MAGSAT was flying very closely above a ground magnetic observatory. In this paper, results of a detailed analysis are presented for this event.

2. Data Analysis

An SC occurred on March 19, 1980, when MAGSAT was along a duskside (16–17 h LT) northbound path above near Magadan (the geomagnetic latitude=51.1°), east Siberia. Figure 1 shows magnetic data observed by MAGSAT and 5 ground stations near the MAGSAT orbit. The main field of the earth was subtracted from the satellite data by the use of the geomagnetic field model, MGST 6/80 (LANGEL *et al.*, 1980). The D-component observed by MAGSAT first decreased to the west by 43 nT in about 2 min and recovered to the original level. Shortly later, the H-component increased by 52 nT in about one min. The Z-component did not vary significantly.

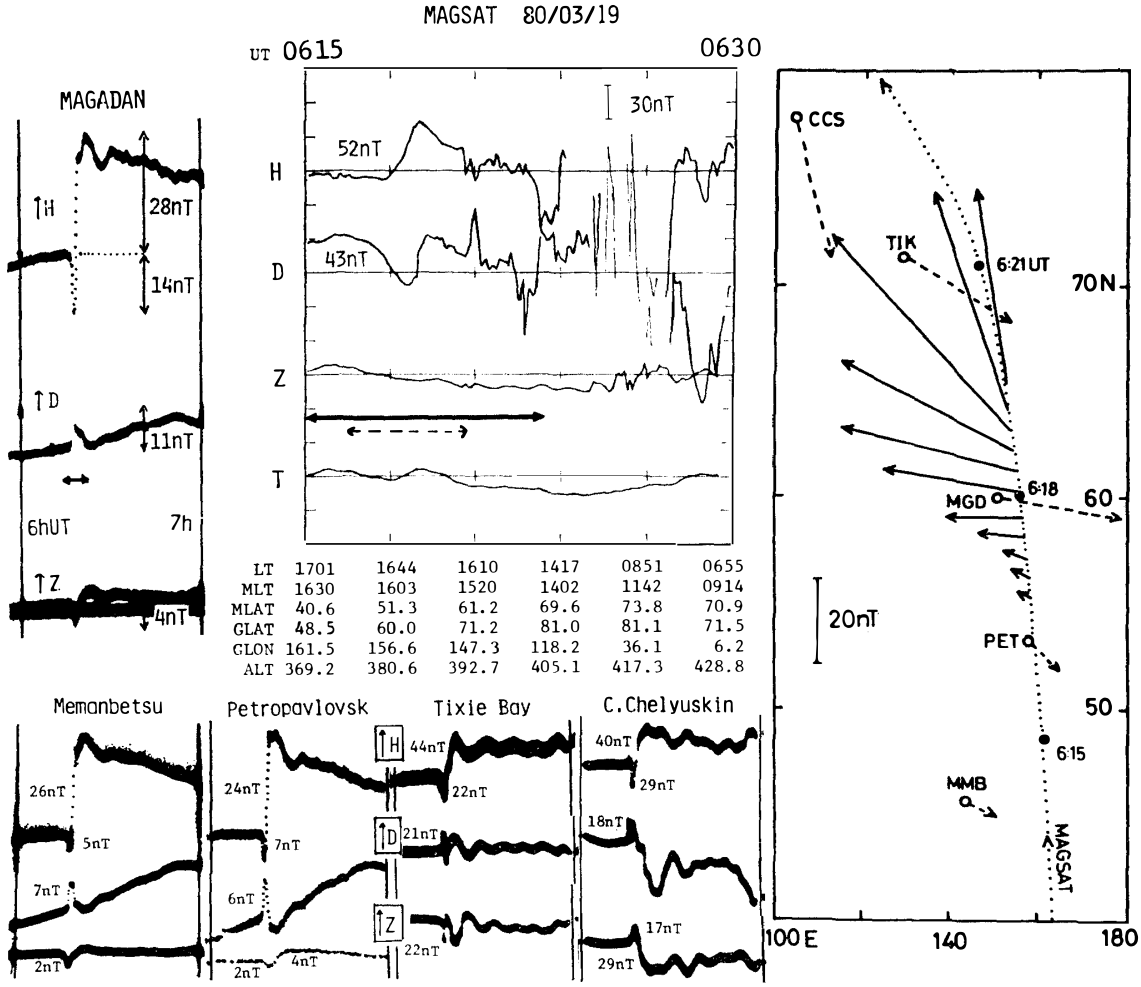

Fig. 1. Sudden commencement observed simultaneously by MAGSAT and ground stations near the MAGSAT orbit on March 19, 1980. The amplitude of each pulse is given in the magnetograms. Solid arrows in the right panel show successive horizontal vector deviations of the first pulse observed by MAGSAT for an interval indicated by a horizontal dashed bar in the center panel. Dashed arrows in the right panel are the horizontal vector deviations of PI (preliminary impulse) observed by the ground stations. The MAGSAT orbit is shown by a dotted line. The horizontal solid bar in the center and the left panel shows the same time interval.

After 0621 UT irregular disturbances masked variations associated with the SC. The variation of the horizontal vector of the pulse along the MAGSAT orbit is presented by solid arrows in the right panel. Magnetograms from ground stations near the satellite orbit show a clear preliminary impulse which is negative in the *H*-component and positive (eastward) in the *D*-component. The PI in the *H*-component is followed by a positive main impulse but the main impulse in the *D*-component is not clear except at C. Chelyuskin. A pulsation associated with the SC (Psc) occurred at Tixie.

The SC with a similar shape was also observed at College, Alaska where the local time (around 20 h) is about 4 hours later than that at Magadan. As shown in Fig. 2a, the SC at College was preceded by a small but clear preliminary impulse in both *H*- and *D*-components and their sense was the same as that of the PI in east Siberia.

In the morning side high latitude, on the other hand, an impulse which is positive in the *H*-component and negative in the *D*-component appeared (Fig. 2b) corresponding to the impulse of opposite sense in the afternoon side. This distribution of the sense of the pulse is consistent with the equivalent current system of PI (NAGATA and ABE, 1955; ARAKI *et al.*, 1985).

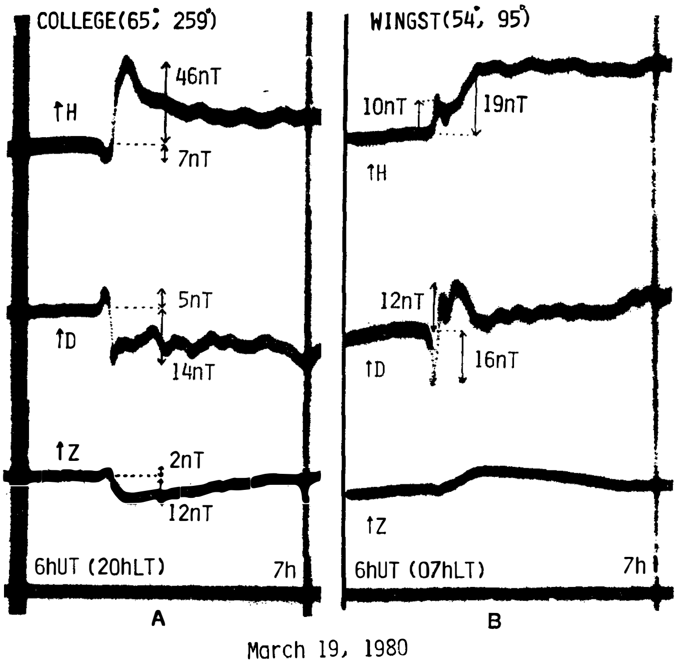

Fig. 2. SC of March 19, 1980, observed in the morning (Wingst) and afternoon (College) high latitude. Numbers in the parentheses indicate geomagnetic coordinates of the two stations.

The time of the peak of the PI and MI measured on the ground is given in Table 1 together with that of the pulse observed MAGSAT. From this table, we can see that the peak time at MAGSAT is nearer to the peak time of PI on the ground than that of MI. If we take into account errors in the time measurement from normal-run magnetograms, it seems that the peak time of the pulse at MAGSAT coincides well with that of PI on the ground.

In order to know more precise occurrence time of the PI observed on the ground, higher time resolution data from the IMS magnetometer network chains were checked. Figure 3 shows 15 min record of the *H*- and *D*-components from 6 stations of the Mid-latitude chain and 5 stations of the Alaska meridional chain. Although College is one of the stations of the Alaska chain (the geomagnetic latitude of College is between Fort Yukon and Talkeetna), the data for the SC under consideration were not available. The roughness of each curve comes from the coarse resolution (1 nT) of the digital magnetometers used in the IMS network observation. At the stations of the Mid-latitude chain, the SC shows a similar pattern in which the *H*-component rises smoothly and the *D*-component varies only slightly. This shows the predominance of the *DL*-field in low latitudes. In the Alaska chain, the pattern varies from station to station but a small pulse with the duration of 2–3 min is commonly seen in the beginning

Table 1. Time (UT) of the peak of the impulse observed by MAGSAT and ground stations on March 19, 1980.

	H		D
	PI	MI	PI
C. Chelyuskin	0617.2	0621.6	0616.5
Tixie Bay	0617.3	0621.4	0617.5
Magadan	0618.0	0621.9	0617.9
Petropavlovsk	0618.3	0622.2	0618.6
Y. Sakhalinsk	0618.8	0622.9	0618.3
Memanbetsu	0618.0	0622.4	0618.8
College	0618.0	0621.6	0618.0
Wingst	0618.0	0625.8	0617.6
Average	0618.0	0622.0	0617.9
MAGSAT	0619.0		0618.7

part of the SC as indicated by vertical arrows. The sense of the pulse is negative in the *H* and positive in the *D*-component.

The sense of the pulses in both *H*- and *D*-components coincides with that of PI observed by the normal-run magnetographs at College and the stations near the MAGSAT orbit. The peak time of the pulse (between 0618 and 0619 UT in Fig. 3) also agrees with that of PI at College and east Siberian stations within the time accuracy of the normal-run magnetogram. We can reasonably identify, therefore, the pulses observed at the Alaska chain stations as the PI observed by the normal-run magnetographs.

Since the time of the peak of the pulse detected by MAGSAT (0619.0 UT for *H* and 0618.7 UT for *D*) coincides well with that in the Alaska chain data, it is concluded that MAGSAT detected the PI. The horizontal vector deviations of the ground PI the pre-SC level are shown by dashed arrows in the right panel of Fig. 1. Comparing the vector deviation at MAGSAT and the ground, we can see the deviation has an approximately opposite direction above and below the ionosphere. The nearly opposite direction of the horizontal vector at MAGSAT and the ground suggests that the electric current responsible for the PI flowed between the two observing points, that is, in the ionosphere. In this case it should be considered that irregular variations at higher latitudes masked a variation at MAGSAT altitude corresponding to the main impulse on the ground.

The amplitude of the horizontal vector of the PI at MAGSAT takes the maximum value around (63°N, 154°E) of geographic coordinates. Among the ground stations near the MAGSAT orbit, Magadan (geographic coordinates; 60°N and 151°E) was nearest to MAGSAT at that time. If we assume that the peak time of the PI at MAGSAT and Magadan coincides with each other, the ratio of the amplitude of the PI at MAGSAT to that on the ground was 3.7 for the *H*-component and 3.9 for the *D*-component, that is, MAGSAT observed a much larger pulse.

In Fig. 4, the horizontal polarization of the SC along the Alaska chain is given for the first 4 min (0617–0621 UT). At 3 stations in the lower latitude of the chain

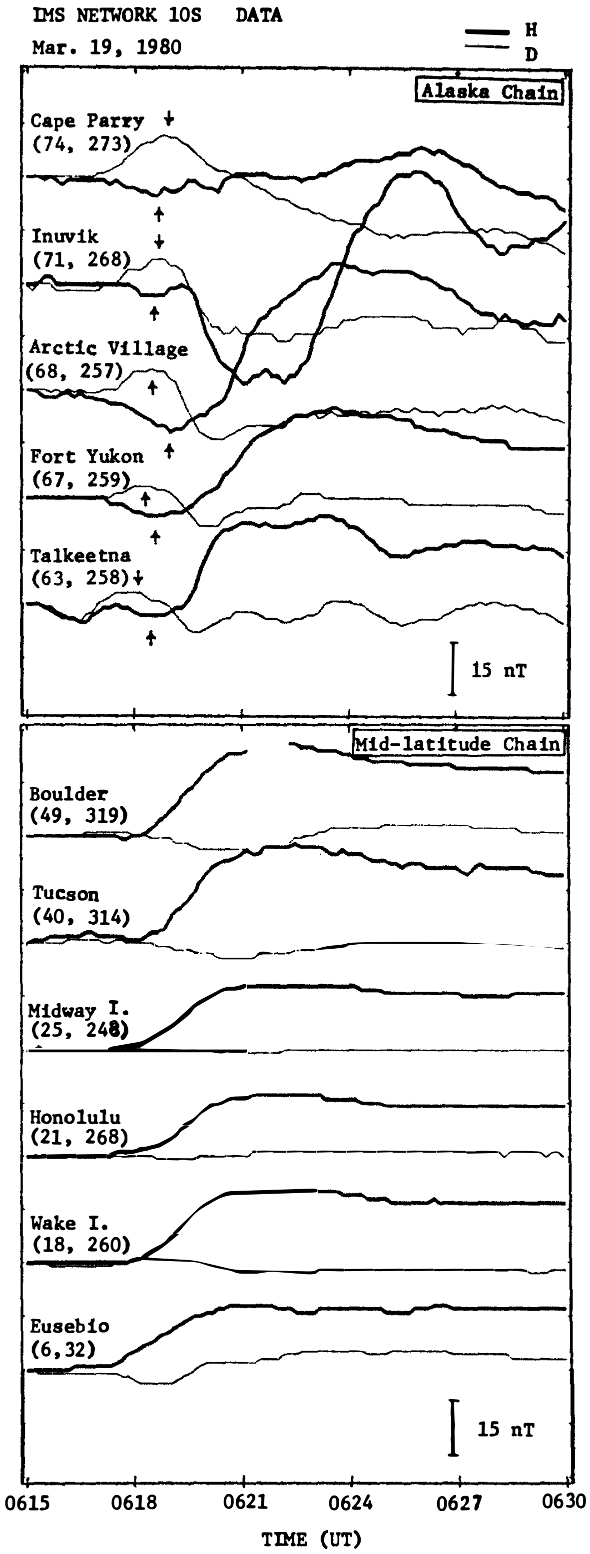

Fig. 3. SC of March 19, 1980, observed at the IMS magnetometer network stations. Numbers in the parentheses indicate geomagnetic coordinates of each station.

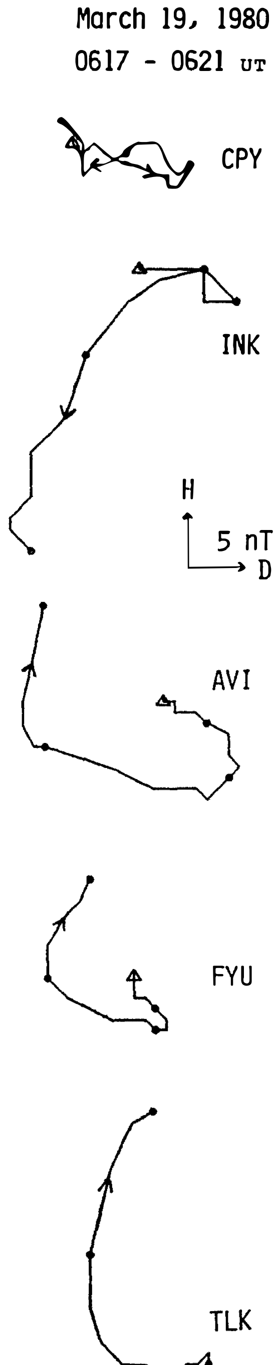

Fig. 4. Horizontal polarization for the first 4 min (0617–0621 UT) of the SC observed at the Alaska chain stations on March 19, 1980.

(Arctic Village, Fort Yukon and Talkeetna), the horizontal vector rotates clockwise. This sense of the rotation is the same as that for the pulse observed by MAGSAT (right panel of Fig. 1), although the latter includes both temporal and spatial variations.

3. Discussion

The nearly opposite direction of the horizontal vector of the PI simultaneously observed at MAGSAT and on the ground suggests that the main source current flowed in the ionosphere. If the ionospheric current (flowing in the E-region) was the only source, however, the magnitude of the horizontal vector should be smaller at MAGSAT than on the ground, because the height of the current layer which has a finite horizontal scale is smaller than the distance between the satellite and the current layer, and the current induced in the earth enhances the field on the ground. Since the actual field magnitude observed by MAGSAT is much larger than on the ground, we must explore a mechanism for the enhancement of the field at MAGSAT.

First, we should consider that the DL_{mi}-field contributes to the increase of the H-component and so the amplitude of the negative pulse of the H-component on the ground is reduced while the positive pulse at the satellite is enhanced. The second modification may come from the field-aligned current and the ionospheric current produced by it. According to the theorem of FUKUSHIMA (1969), the ground magnetic field produced by a vertical field-aligned current (FAC) is approximately cancelled out by the magnetic field due to the ionospheric Pedersen current produced by it, if the ionospheric conductivity is uniform. Thus the ground magnetic field is determined only by the Hall current in the ionosphere. Above the ionosphere, however, the direction of the FAC-field is the same as the Pedersen field, and both fields are added to the Hall field perpendicular to them. If the field added is much larger than the Hall field, the resultant field is nearly perpendicular to the Hall field and a 90° rotation should be observed between the directions of the magnetic field measured above and below the ionosphere.

The source field-aligned current for PI flows into the ionosphere in the duskside and goes out from it in the duskside. In this actual case, the orthogonality between the Pedersen field and the FAC-field is broken because of the inhomogeneity of the ionospheric conductivity and the inclination of the field-alignend current. Thus the cancellation of the Pedersen field and the FAC-field on the ground and the augmentation of the fields above the ionosphere are both modified. Effects of those deviations from the assumptions used in FUKUSHIMA's theorem have not been clarified in the present stage. A simulation study using a realistic model of the field-aligned current and the ionospheric conductivity is needed.

Although the discussion above is limited to the static aspect of the pulse under consideration, wave properties should also be considered. Since the wavelength of the transverse hydromagnetic wave which transmits the magnetospheric dusk-to-dawn electric field to the polar ionosphere is much larger than the distance between MAGSAT and the ionosphere, a current associated with the wave flows also at the MAGSAT altitude when the ionospheric current is flowing. Multiple reflection between the ionosphere and the earth's surface will play an important role for determination of the wave field. INOUE (1973) calculated altitude dependence of the amplitude and polarization of a hydromagnetic wave for Pc 5 vertically incident to the polar ionosphere. His results show that if the wave is localized bidirectionally in the horizontal plane, the magnetic field is much reduced on the ground.

The clockwise rotation of the horizontal vector of the PI observed by MAGSAT and the Alaska chain stations is consistent with the local time dependence (clockwise in the afternoon and anticlockwise in the morning) of SC deduced from a statistical study (WILSON and SUGIURA, 1961). At the two higher latitude stations of the Alaska chain, Inuvik and Cape Parry, the polarization is almost linear (or slightly anticlockwise at Inuvik). Since the polarization of SC reverses the sense at a certain latitude around the auroral zone (ARAKI and ALLEN, 1982) as in the case of geomagnetic pulsation (SAMSON *et al.*, 1971), the polarization of SC under consideration might be anticlockwise at latitudes higher than that of Cape Parry. If this is the case, MAGSAT observed the SC at the lower latitude side of the demarcation line of the polarization reversal.

MAGSAT did not detect a significant Z-component variation corresponding to the PI, while it appeared clearly at the ground stations (Fig. 1). This suggests a dominant influence of the induced earth current to the Z-component and a broad distribution of the ionospheric current.

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