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DETECTION OF AN IONOSPHERIC CURRENT FOR THE PRELIMINARY IMPULSE OF THE GEOMAGNETIC SUDDEN COMMENCEMENT

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Abstract. MAGSAT observed a geomagnetic sudden commencement at an altitude of 550 km on its dawnside orbit above the South Atlantic Ocean. The H-component of the magnetic field increased monotonically by 46 nT in about 4 minutes, while the D-component decreased westward by 10 nT in the first 1-2 minutes and then increased gradually. There was no significant deviation in the Z-component. The comparison with ground-based magnetograms showed that the negative impulse of the D-component provided the first experimental evidence of the global ionospheric current system for the preliminary impulse of the geomagnetic sudden commencement.

Introduction

Although the geomagnetic sudden commencement (SC) is generally considered as a simple compression of the magnetosphere, characteristics of an SC may be greatly modified by ionospheric currents generated during an SC. In the very beginning part of an SC, a preliminary impulse (PI) is frequently superposed on a smooth increase of the main impulse. The PI appears as a negative impulse in the H-component in the dayside equatorial and afternoon regions at high latitudes [Matsushita, 1962] and is called a preliminary reverse impulse (PRI) there. The complex distribution of amplitudes and waveforms of a PI can be explained only by taking into account a global ionospheric current system [Tamao, 1964; Nishida et al., 1966; Araki, 1977].

In order to verify the existence of actual ionospheric currents which has been assumed in data analyses of ground-based magnetograms, it is necessary to accumulate data for simultaneous observations on the ground and above the ionosphere. Since the magnetic field due to ionospheric currents attenuates rapidly with increasing height, it can not be detected in the distant magnetosphere. Some spacecraft have observed an SC in the outer magnetosphere [e.g. Patel et al., 1974], but it has been difficult to get measurements near the ionosphere, because the magnetic change of an SC relative to the background magnetic field is too small. This difficulty has been removed with the launching of MAGSAT which provided the first lower altitude global survey of vector components of the geomagnetic field. Here we show the first evidence of detection of an ionospheric current for the preliminary impulse of an SC.

Observations

During the first two months (November and December, 1979) after the launching of MAGSAT, there were 6 events which were classified as an SC in 'Solar Geophysical Data' (Lincoln, Ed.) by more than two observatories. From Table 1, we can see that MAGSAT detected magnetic changes associated with the 3 largest SC's in these two months. However, the magnetic changes for two SC's which occurred November 11 and 18 were so small that our analysis was made only for the remaining one event.

At dawn on November 30, 1979, MAGSAT observed an SC on its southbound orbit above the South Atlantic Ocean. By checking magnetograms from high latitudes, it was known that the SC occurred just after some of high latitude stations near the midnight meridian had observed the beginning of the expansion phase of a substorm. Magnetograms from the IMS midlatitude chain of stations indicated that the amplitude of the SC in the H-component ranged from 28 nT at San Juan (29.5° geomag. lat.) to 58 nT at Tucson (40.5° geomag. lat.).

Figure 1 shows the H- and D-components measured by MAGSAT along 8 successive southbound orbits near the dawn meridian (0500-0600 LT). The satellite altitude is between 500 km and 555 km. The internal magnetic field is subtracted by the use of the geomagnetic field model MGST(80/6). Along the first 4 orbits, the magnetic field is relatively steady except in the high latitude region where the contribution of field aligned currents is large. The SC occurred when MAGSAT was near -24° dip-latitude on the 5th orbit. After the SC, both the H- and D-components deviate greatly from the pre-SC level as shown by the shaded portions in the figure. Large deviations along the 6th orbit are the storm-time variations. Figure 2 shows a time-plot of the three components (H, D and Z) and the total force of the magnetic field for 12 minutes including the SC event. Discontinuous jumps due to inaccuracy of the satellite attitude data are corrected by dotted lines. After the SC, the H-component increased monotonically by 46 nT with a rise time of about 4 minutes and then decreased to the level higher than the pre-SC level. The D-component showed a westward decrease of about 10 nT in the first 1-2 minutes and then increased gradually. The duration of the first negative impulse is about 3 minutes. The high latitude portion of the D-plot is affected by variations of field aligned currents. There is no significant deviation in the Z-component for at least 7 minutes after the onset of the SC.

Figure 3 shows normal-run magnetograms from three stations near the satellite orbit which was between Hermanus, South Africa, and Trelew, Argentina. San Juan, Puerto Rico, was selected because of its geomagnetically conjugate location to Trelew. The H-component variations at all three stations are similar in shape showing sharp smooth increases, although the amplitude is much

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TABLE 1. List of SC's in November and December 1979 (none in December).

Date	UT	ΔH at Honolulu	MAGSAT Location (Geomag. Lat.)	MAGSAT Magnetic Change
Nov. 7	1347	14.0 nT	Dusk (-65°)	no
9	1203	4.4 nT	Dawn (31°)	no
11	0225	18.2 nT	Dusk (3°)	yes (small)
18	0209	17.0 nT	Dawn (22°)	yes (small)
29	1647	12.6 nT	Dusk (16°)	no
30	0738	33.8 nT	Dawn (-17°)	yes

larger at Trelew (ΔH = 51 nT) and Hermanus (ΔH = 45 nT) than at San Juan (ΔH = 28 nT). The SC in the D-component consists of a preliminary impulse (PI) and a following main impulse. The sense of the PI at Trelew is westward and opposite to that at the other two stations. By enlarging the magnetograms, the amplitude and duration of the PI in the D-component, PI(D), were measured. The results are given in Table 2.

The similarity in the waveforms of the PI(D) with almost equal duration observed simultaneously by MAGSAT and the ground stations indicates that it has a common source current system. A fairly large difference in the amplitude of the PI(D) suggests that the source should not be a distant current. The opposite sense of the PI(D) at Trelew and San Juan shows that the direction of the north-south component of the source current is opposite in the northern and the southern hemisphere (equatorward in the meridian through the two stations).

Discussion

The disturbance field of an SC, D_{sc}, can be expressed as follows [Araki, 1977],

$$D_{sc} = DP_{pi} + DL_{mi} + DP_{mi}$$

where DP and DL, respectively, mean a disturbance of the polar origin and a disturbance dominant in low latitudes. The preliminary impulse and main impulse are abbreviated to pi and mi.

Associated with a sudden compression of the magnetosphere, a dawn-to-dusk current begins to flow on the front of the magnetopause. This current partly closes on the magnetopause, but part of it flows as a polarization current from dusk to dawn in the magnetosphere and the resulting earthward Ampere force forms a compressional wavefront propagating toward the earth. The magnetic field increases in the current loop made by the wavefront and the magnetopause. When the wavefront reaches the ionosphere, the polarization current is converted to a conduction current. Almost simultaneously a current is induced in the earth in the same direction (dusk-to-dawn), and the magnetic field begins to increase on the ground. The complete current system flowing on the magnetopause and in the magnetosphere, the ionosphere and the earth causes the increase of the magnetic field on the ground. This is the DL_{mi}-field.

The dusk-to-dawn electric field along the compressional wavefront propagating in the dayside magnetosphere is transmitted also along lines of force to the polar ionosphere [Tamao, 1964]. The ionospheric current driven by this polar electric field produces the DP_{pi}-field for which the averaged current system is shown in Figure 4. This current system is a modified version of an origi-

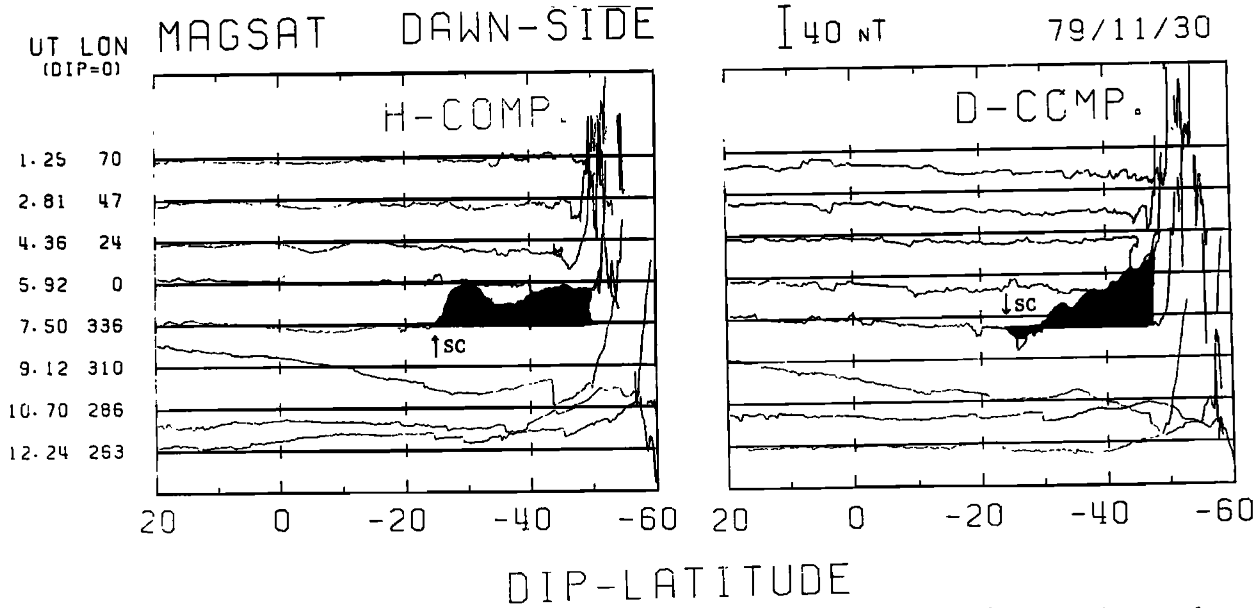

Fig. 1. H- and D-components versus dip-latitude observed by MAGSAT along 8 successive southbound orbits through dawnside (05^h-06^h). The universal time and geographic longitude at the dip equator are given in the left two columns.

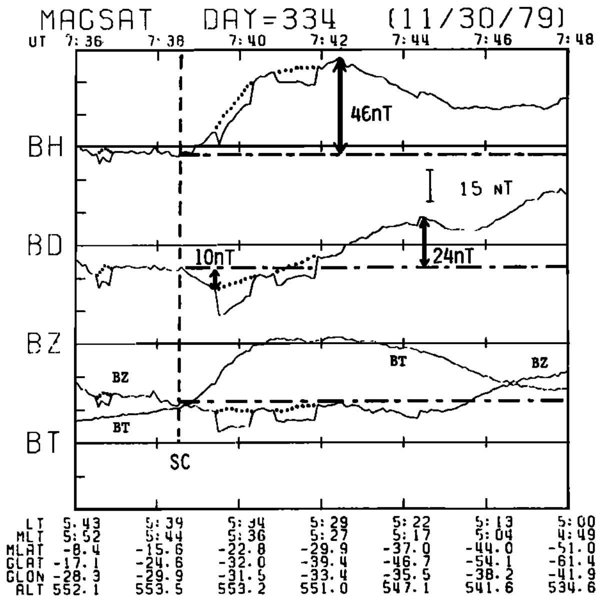

Fig. 2. The time variation of the three components and the total force observed by MAGSAT during the SC. The local time, magnetic local time, magnetic latitude, geographic latitude and longitude, and altitude are given at the bottom.

nal current system proposed by Nagata and Abe [1955]. The following two new statistical analyses are taken into account;

(1) The equatorial preliminary reverse impulse (PRI) in the H-component has the maximum occurrence rate around noon [Araki, 1977].

(2) Corresponding to a PRI at the dayside equator, a small positive impulse is superposed on a smooth increase in the H-component of an SC at a nightside equatorial station. This type of SC occurs most frequently around 03^h LT [Araki, to be published].

The DP_{mi} is caused by the enhanced magnetospheric convection field after the compression by the interplanetary shock. The direction of the electric field transmitted to the polar ionosphere is dawn-to-dusk. The resulting ionospheric current distribution is similar to that for DP_{pi} but the direction of the current flow is reversed.

The D_{st}- and the DS-field of an SC proposed by Obayashi et al. [1957] are the first approximations to the DL_{mi}- and the DP_{mi}-field, respectively.

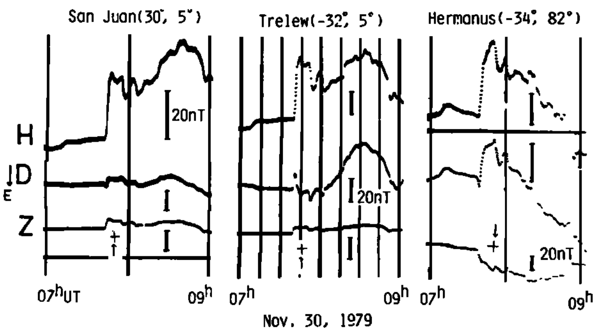

Fig. 3. Normal-run magnetograms from 3 stations near the satellite orbit. The geomagnetic coordinates are given in the parentheses.

TABLE 2. The amplitude and duration of PI(D)

	ΔD (nT)	ΔT (min.)
San Juan	3	2.6
Trelew	-12	3.3
Hermanus	5	3.2
MAGSAT	-10	3.0

The DL_{mi} is essentially a disturbance of the H-component, and monotonically increases from the onset of an SC at any latitude and local time. The DP-field contributes to both H- and D-components and is highly dependent upon the latitude and local time. The beginning part of an SC is determined by the combination of DP_{pi} and DL_{mi}. The DL_{mi} and DP_{mi} determine the last part of the SC.

In the beginning part of an SC, both DL_{mi}- and DP_{pi}-fields contribute to the H-component variation, and it is difficult to separate the two fields. The contribution to a D-component variation, however, mainly comes from the DP_{pi}-field. The ionospheric current distribution for the DP_{pi}, therefore, can be deduced from the global distribution of PI(D). In Figure 4, the direction of the N-S (north-south) component of a current which produced the PI(D)'s at Trelew, Hermanus, Port aux Francais (PAF) and MAGSAT are projected to the northern hemisphere on the assumptions that the current flows in the ionosphere under the satellite and the N-S component of the current reverses its direction in the northern hemisphere (note that the direction of the N-S component of the DP_{pi}-current should be opposite in the northern and the southern hemi-

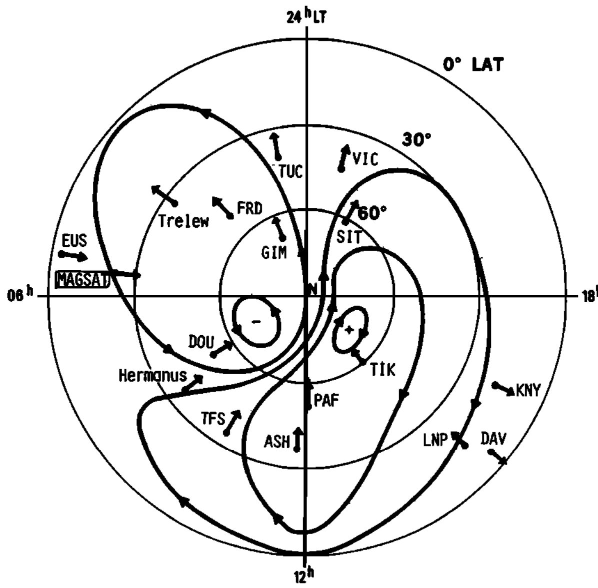

Fig. 4. Ionospheric current system for the averaged DP_{pi}-field in the northern hemisphere in geomagnetic latitude-local time coordinates. Arrows indicate the direction of the N-S component of an assumed ionospheric current for the PI(D) observed by MAGSAT and ground stations. Positions of MAGSAT, Trelew, Hermanus and Port aux Francais (PAF) are projected from the southern hemisphere.

sphere). In Figure 4 are also shown directions of the N-S component of the PI-current measured from PI(D)'s at several stations in the northern hemisphere. The distribution of the arrows for the ground stations except LUN (Lunping) shows a fairly good agreement with the DP_{pi}-current system which was derived as an averaged pattern by a statistical analysis for many PI events, although a better agreement might be obtained by a small anti-clockwise rotation of the averaged current system. The current direction deduced from the PI(D) observed by MAGSAT on the assumption that the current flowed under the satellite is also consistent with both the averaged current system and the global distribution of the current directions for this particular PI event.

One ambiguous point might be that the change of the D-component had a different sign at Trelew and Hermanus, and MAGSAT was located between the two. This ambiguity may be avoided by a fact that a clear westward impulse in the D-component was detected at Eusevio, Brazil (EUV in Figure 4, 5.6° geomag. lat.) which is located near the meridian of MAGSAT. Since this means that the N-S component of the PI current system is northward near the MAGSAT meridian in the northern hemisphere, it should be southward in the southern hemisphere as long as the reversal of its direction in both hemispheres can be assumed. This southward current should flow under MAGSAT in order to explain the westward change in D detected by the satellite.

We may, therefore, reasonably conclude that the PI(D) observed by MAGSAT in the beginning part of the SC was produced by the DP_{pi}-current which actually flowed in the ionosphere.

What happened during the SC near MAGSAT in the southern hemisphere may be described as follows:

(1) The DL_{mi}-field increased continuously during the first 4 minutes after the onset of the SC, and then decreased to a level higher than the pre-SC level. This field contributed mainly to the H-component variation.

(2) In the beginning part of the SC (first 1-2 minutes), an ionospheric current for DP_{pi}-field developed. The N-S component of the current was directed southward under the satellite in the southern hemisphere so that a westward change in the D-component was observed at the satellite altitude. The east-west component of this current was probably small, and had little effect on the H-component.

(3) After 1-2 minutes from the onset of the SC, the DP_{pi}-field began to decay, and then the DP_{mi}-field developed. The ionospheric current for this field had a northward component, and made a positive (eastward) change in D (up to 24 nT) at the satellite.

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