CHARACTERISTICS OF POLARIZATION OF GEOMAGNETIC SUDDEN COMMENCEMENTS OBSERVED AT SYOWA STATION

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Abstract: In order to clarify local time dependence of polarization of geomagnetic sudden commencements (SC's) at Syowa Station, digital magnetic data obtained during the interval from April 1981 to January 1983 was statistically analyzed. The polarization in the horizontal plane is clockwise in the morning side and counterclockwise in the afternoon side from a view looking down onto the earth's surface. This is consistent with the statistical results from ground-based magnetic data (C. R. WILSON and M. SUGIURA: J. Geophys. Res., **66**, 4097, 1961; T. NAGATA *et al.*: JARE. Sci. Rep., Ser. A, **3**, 64p., 1966) and from geostationary satellite magnetic data (H. NAGANO and T. ARAKI: J. Geophys. Res., **89**, 11018, 1984). The relationship between the SC polarization sense in the horizontal plane and the pattern of SC wave form was examined. It is found that there is a fairly good correlation between them.

1. Introduction

A geomagnetic sudden commencement (SC) is believed to be associated with the magnetospheric compression induced by interplanetary shocks and discontinuities. SC signatures in the magnetosphere and on the ground have been investigated by a number of researchers (see the reviews of MATSUSHITA, 1967; NAGATA and FUKUSHIMA, 1971; AKASOFU and CHAPMAN, 1972; NISHIDA, 1978). From the analysis of forty SC events in the rapid-run magnetograms obtained during the IGY, WILSON and SUGIURA (1961) showed statistically that the SC polarization in the horizontal plane at high and higher-middle latitudes is counterclockwise in the morning side (2200–1000 LT) and clockwise in the afternoon side (1000–2200 LT) from a view looking down onto the earth's surface in the northern hemisphere, and *vice versa* in the southern hemisphere. They interpreted that SC perturbations produced by the impact of an interplanetary shock or discontinuity are propagated to the earth primarily by longitudinal hydromagnetic waves in low latitudes and by transverse hydromagnetic waves in high latitudes. MATSUSHITA (1962) critisized the results of WILSON and SUGIURA (1961) by reporting that only about one-fifth of the total forty-five SC events examined by him was in agreement with their polarization rules. Afterwards the dispute between them continued for a while (WILSON and SUGIURA, 1963; MATSUSHITA, 1963).

NAGATA *et al.* (1966) examined polarization characteristics of sixty-six SC's by using the simultaneous records obtained at Syowa Station and Reykjavik near the conjugate point in order to settle the discrepancy. Their analysis was consistent with the result by WILSON and SUGIURA (1961), and then they supported the hydromagnetic wave theory for SC phenomena. Hydromagnetic descriptions of SC have been developed by TAMAO (1964, 1975), NISHIDA (1964, 1978) and ARAKI (1977). ARAKI and ALLEN (1982) studied latitudinal variations of the polarization of eighteen SC events obtained by the North American IMS magnetometers and showed the existence of a latitudinal polarization reversal between 64° and 72°N in geomagnetic latitude.

PATEL and CAHILL (1974) studied the polarization of nineteen sudden impulse (SI) and SC events, using Explorer 26 magnetic data observed in the magnetospheric region of L=3–6 and 1100–1500 LT with a geomagnetic latitude range from $-6°$ to 27°. They reported that the polarization patterns in the afternoon magnetosphere are in general agreement with the statistical results from ground-based magnetic data by WILSON and SUGIURA (1961). NAGANO and ARAKI (1984) studied statistically the local time dependence of polarization of 123 SC's obtained by geostationary satellites GOES 2 and 3, and showed that the polarization viewed along the field direction is counterclockwise in the morning side and clockwise in the afternoon side, which is consistent with the results of WILSON and SUGIURA (1961). KUWASHIMA *et al.* (1985) and KUWASHIMA and FUKUNISHI (1985) studied characteristic directions of the initial movement of Psc magnetic pulsations observed by geostationary satellites, and reported the result similar to that by NAGANO and ARAKI (1984). In the present paper, we statistically examine the local time dependence of polarization of 71 SC's and a relationship between the polarization and the pattern of the wave form by analyzing digital magnetic data obtained at Syowa Station.

2. Data Analysis

Using 1-s digital magnetic data obtained at Syowa Station during the interval from April 1981 to January 1983, characteristics of SC polarization are statistically studied. Syowa Station in Antarctica is located at 66.1° S and 70.6° E in the magnetic coordinates. The magnetic local time (MLT) at Syowa Station corresponds to the universal time (UT) plus 13 min. We examined the events reported as an SC in 'Solar Geophysical Data' (H. E. COFFEY, ed.). The number of SC's was 71 in the period examined. Figure 1 shows an example of an SC event observed in the morning. The SC occurred at 0434 UT (0447 MLT) on August 10, 1981. The upper panel shows magnetograms of three components H (northward), D (eastward) and Z (upward). After the SC onset the H, D and Z components indicate positive, negative and positive variations, respectively. The patterns of SC's observed at higher latitudes are in general classified into four types: ordinary SC, inverted SC, SC* and inverted SC* (FERRARO *et al.*, 1951). The pattern in the upper panel of Fig. 1 shows a typical inverted SC*. Pulsations having a period of about 3 min appear in association with the SC. The lower panel of Fig. 1 indicates the rotation of the SC vector in the H-D, D-Z and Z-H planes viewed from the Z, H and D directions, respectively, during 8 min after the SC onset. The polarization is elliptical with clockwise rotation in the

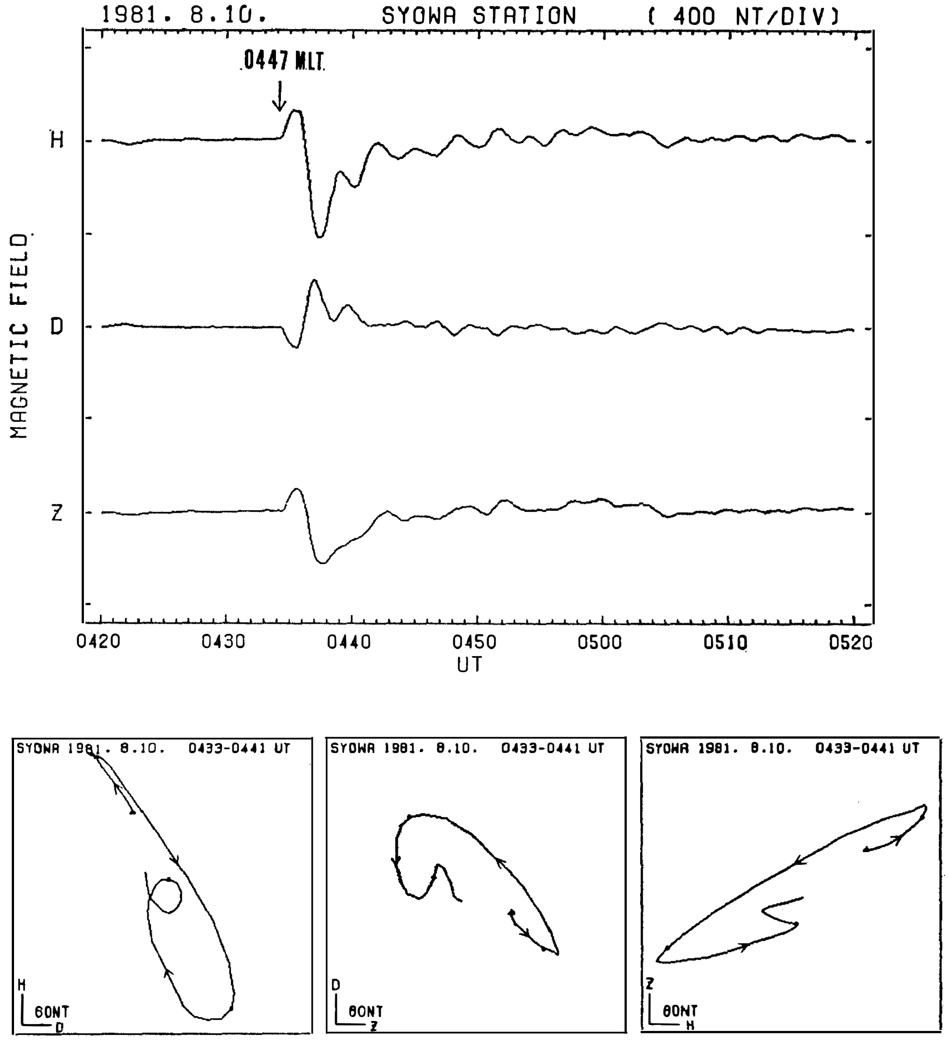

Fig. 1. Magnetograms of three components H, D and Z for an SC at 0434 UT (0447 MLT) on August 10, 1981 (upper panel), and rotation of the SC vector in the H-D, D-Z and Z-H planes viewed from the Z, H and D directions, respectively, during the interval 0433 to 0441 UT (lower panel).

H-D plane and with counterclockwise rotation in the *D-Z* and *Z-H* planes.

Figure 2 shows an example of an SC observed in the afternoon. The SC occurred at 1702 UT (1715 MLT) on April 16, 1982. The variations in the *H*, *D* and *Z* components after the SC onset are negative, positive and negative, respectively, as shown in the upper panel. This pattern indicates a typical SC* and the sense of the three components is reversed as compared with the previous event. The polarization has a counterclockwise rotation in all the three planes as shown in the lower panel. The sense of the rotation in the *D-Z* and *Z-H* planes is the same as that for the previous event in Fig. 1, but the sense in the *H-D* plane is reversed. Another example of an afternoon SC event is shown in Fig. 3. The SC occurred at 1745 UT (1758 MLT) on January 29, 1982. In this case the *H*, *D* and *Z* components after the SC onset indicate positive, negative and positive variations, respectively, which correspond to the inverted SC*. The polarization is counterclockwise in the *H-D* and *Z-H* planes

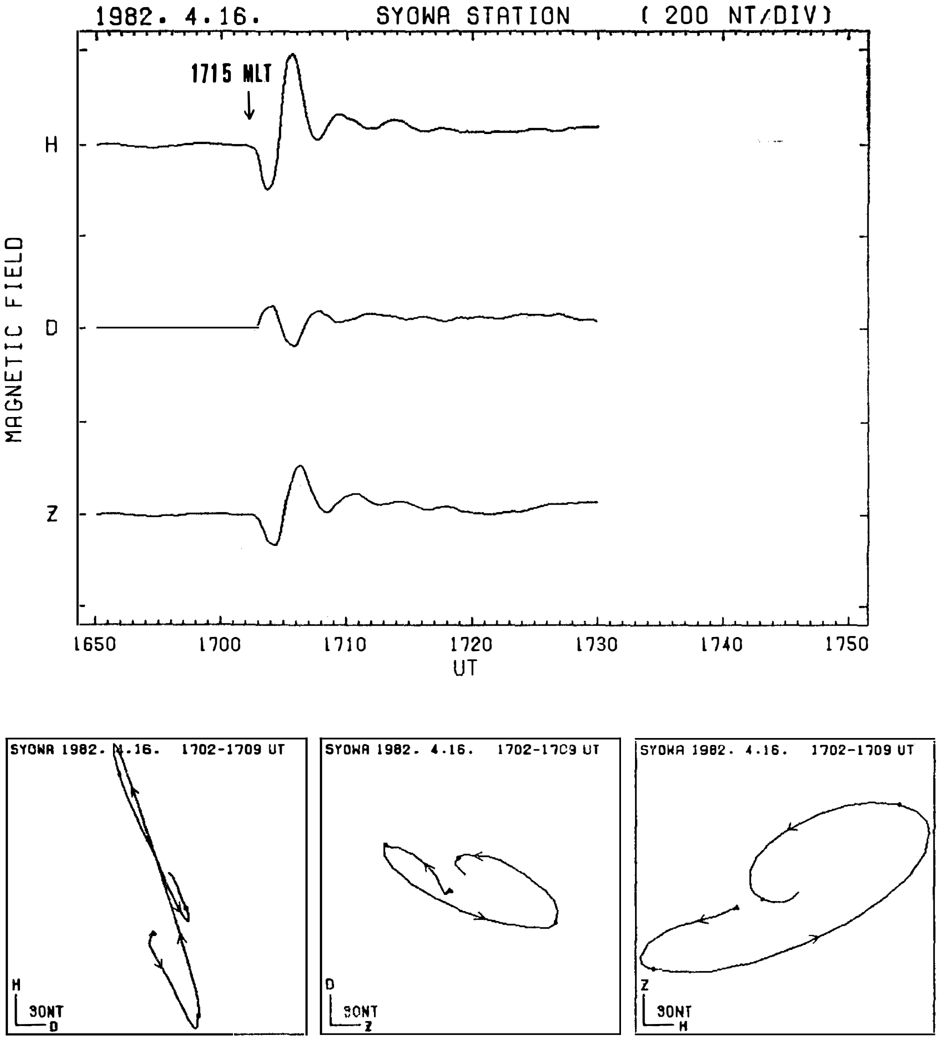

Fig. 2. Magnetograms of three components H, D and Z for an SC at 1702 UT (1715 MLT) on April 16, 1982 (upper panel), and rotation of the SC vector in the H-D, D-Z and Z-H planes during the interval 1702 to 1709 UT (lower panel).

and clockwise in the *D-Z* plane as shown in the lower panel of Fig. 3. The pattern of the SC is reversed as compared with the previous afternoon event of Fig. 2, but the rotation of SC vector in the *H-D* plane is the same sense for both events.

Figure 4 shows the local time dependence of polarization sense in the *H-D* plane for total 71 SC's. The local time distribution of the occurrence of the SC's examined is indicated in the upper panel. The number of SC's during the each interval of 3 hours is between 7 to 13. As shown in the lower panel of Fig. 4, polarization sense is classified into five types according to the degree of rotation of SC vector as follows: clockwise (clear), clockwise, linear or complex, counterclockwise and counterlockwise (clear). In the morning side (0000–1200 MLT) the occurrence rate of clockwise polarization was about 62% (about 41% was clear clockwise) and the rate of counterclockwise polarization was 8%. In the afternoon side (1200–2400 MLT) about 53% was counterclockwise (about 25% was clear counterclockwise) and about 22% was clockwise. Therefore, the statistical result indicates that the SC polarization in the

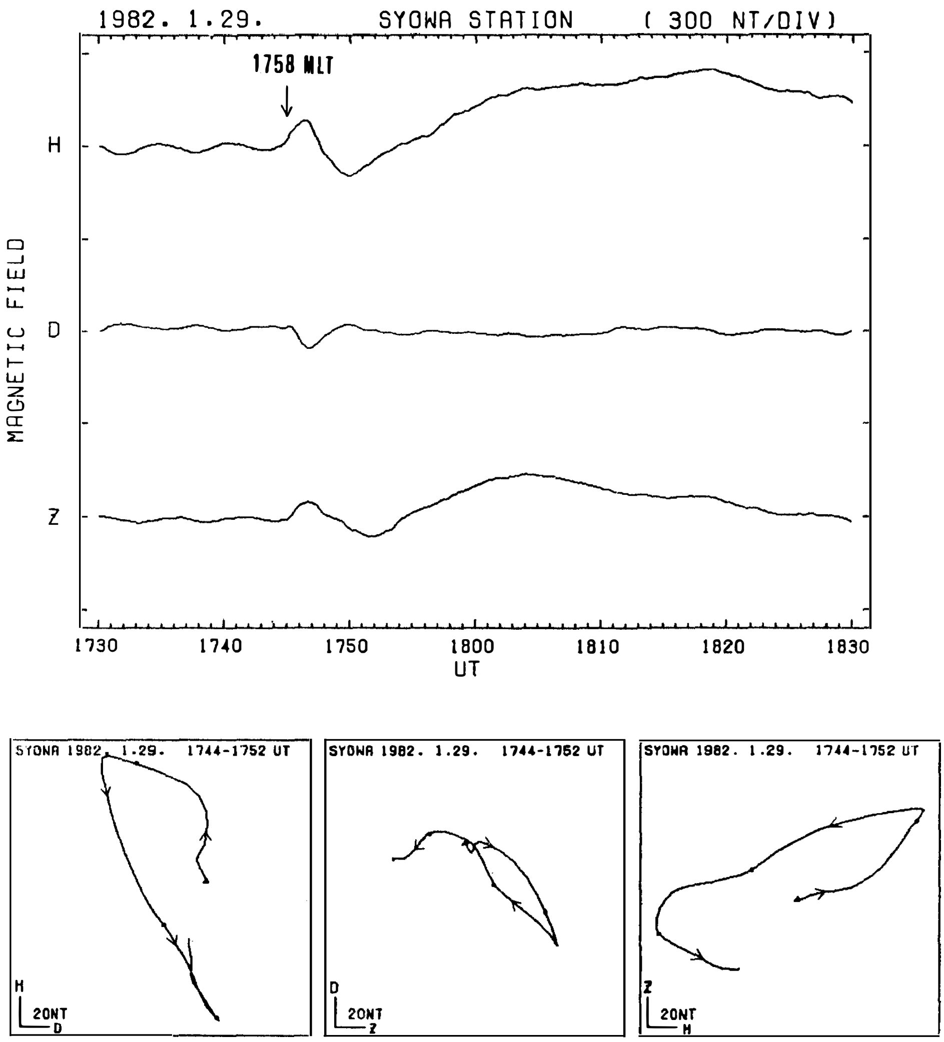

Fig. 3. Magnetograms of three components H, D and Z for an SC at 1745 UT (1758 MLT) on January 29, 1982 (upper panel), and rotation of the SC vector in the H-D, D-Z and Z-H planes during the interval 1744 to 1752 UT (lower panel).

H-D plane at Syowa Station is clockwise in the morning side and counterclockwise in the afternoon side. This is consistent with the statistical result obtained by WILSON and SUGIURA (1961). The rate obeying their polarization rules was about 52%. We can see from this figure that the demarcation lines, across which the rotational sense is reversed, are probably located between 1200 and 1500 MLT, and near 2400 MLT. Figures 5a and 5b show the local time dependence of polarization in the *D-Z* and *Z-H* planes, respectively. On the whole, counterclockwise polarization is dominant in both figures. In the *D-Z* plane the rate of counterclockwise polarization was about 72% (about 38% was clear counterclockwise) and the rate of clockwise polarization was 6%. In the *Z-H* plane about 83% was counterclockwise (about 51% was clear counterclockwise) and about 6% was clockwise. A relationship between the polarization sense in the *H-D* plane and the pattern of SC wave form was examined, and the local time dependence of the occurrence rate is summarized in Fig. 6. In this figure the pattern is divided into three parts: SC*, inverted SC* and

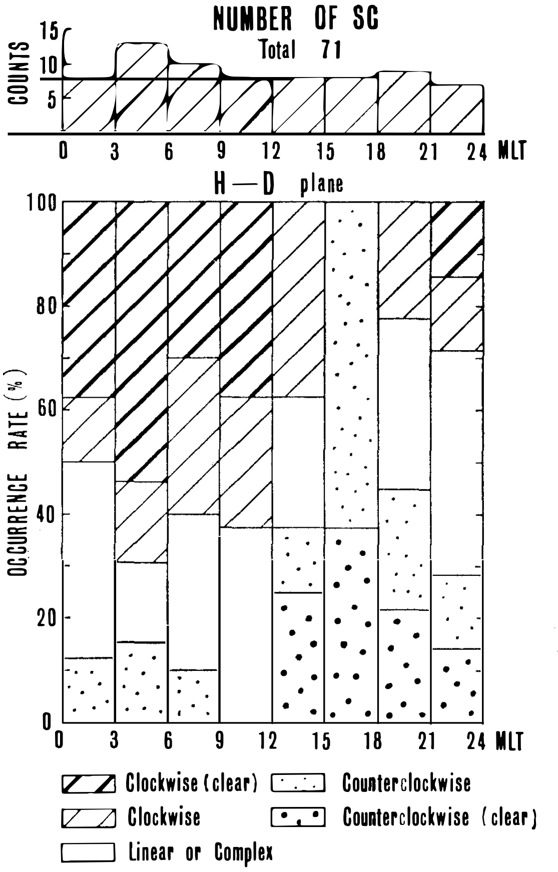

Fig. 4. Local time distribution of total 71 SC's observed at Syowa Station (upper panel) and occurrence rate for each type of SC polarization in the H-D plane (lower panel).

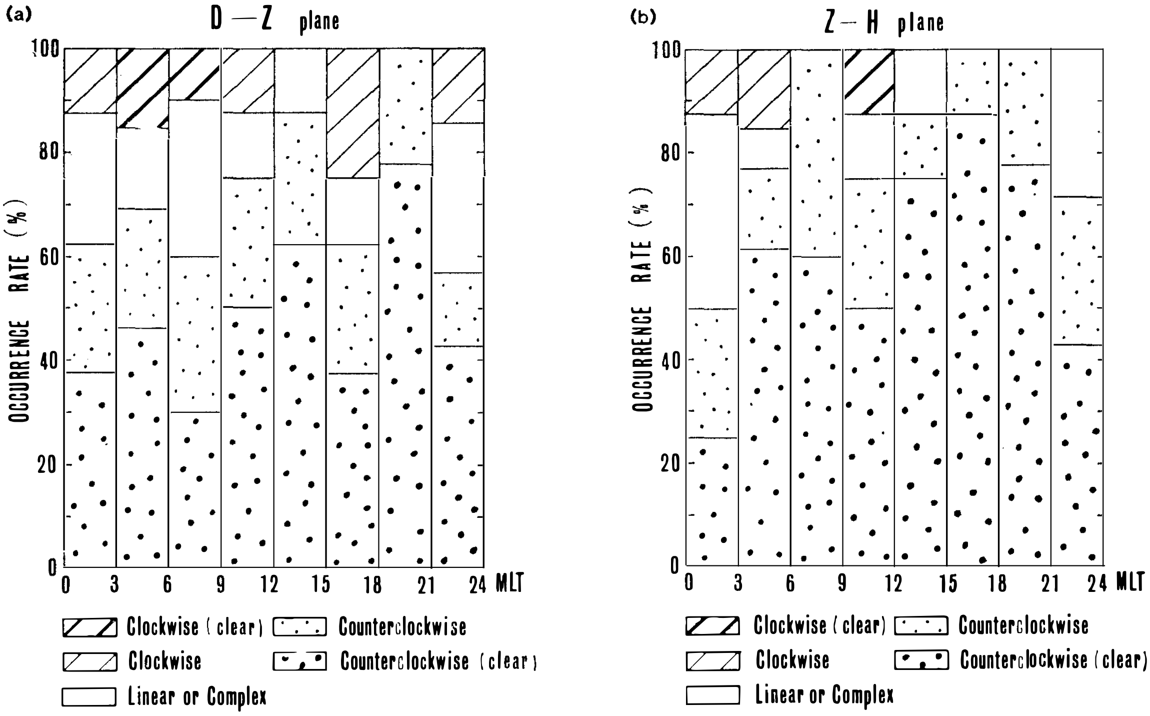

Fig. 5. (a) Occurrence rate for each type of SC polarization in the D-Z plane and (b) occurrence rate in the Z-H plane.

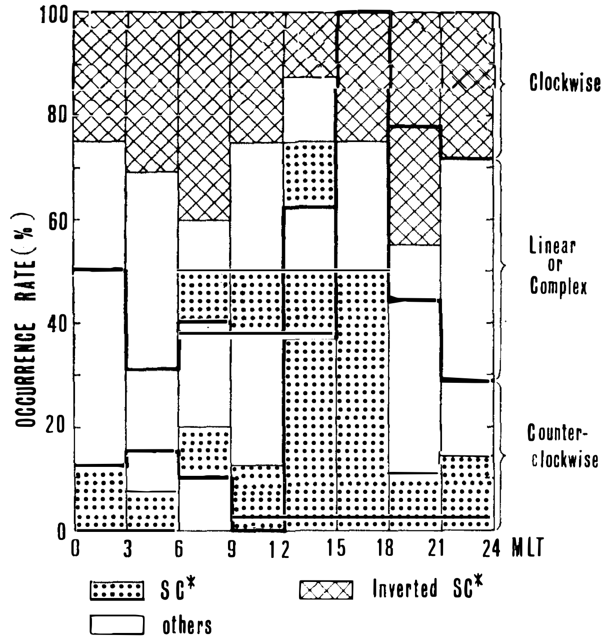

Fig. 6. Occurrence rate for each type of SC wave form in the three regions of polarization sense divided into clockwise, counterclockwise and linear or complex by two thick lines.

others. As a whole the occurrence rate of SC* is about 10% for the clockwise polarization and about 52% for the counterclockwise polarization. The rate of inverted SC* is about 55% and 10% for the clockwise and counterclockwise polarization, respectively. For the linear or complex polarization the rate of others is about 74%. Therefore, this figure denotes that clockwise polarization is mainly related with inverted SC* and counterclockwise polarization is mainly related with SC*.

We could obtain only one SC event data with respect to a study of geomagnetic conjugacy between Syowa Station and the conjugate station. The SC event was observed at 2115:40 UT on November 12, 1977. The conjugate station is Husafell in Iceland, which is located at 66.5°N and 70.3°E in the magnetic coordinates. The MLT at Husafell corresponds to UT plus 11 min. The magnetic data used is digital data, which was converted from analogue data obtained by the induction magnetometer at each station, with a sampling period of 4.8 s. Figure 7a shows magnetograms of three components $\dot{H}$ (northward), $\dot{D}$ (eastward) and $\dot{Z}$ (upward) for the SC observed at Syowa Station, and hodograms of the SC vector in the three planes. After the SC onset the initial impulses in the $\dot{H}$ and $\dot{D}$ components are positive and negative, respectively. Although the angle of the rotation in the $\dot{H}$-$\dot{D}$ plane will generally differ from that in the H-D plane, the polarization sense is the same between them. The polarization is counterclockwise in all the planes. This is consistent with the statistical result of the SC's occurring in the afternoon side as shown in Fig. 4. Figure 7b shows magnetograms of two components $\dot{H}$ (northward) and $\dot{D}$ (eastward) for the SC observed at Husafell, and hodogram of the SC vector in the $\dot{H}$-$\dot{D}$ plane viewed along the magnetic field. The initial variations of both components indicate positive after the SC onset. The polarization sense was clockwise in the $\dot{H}$-$\dot{D}$ plane.

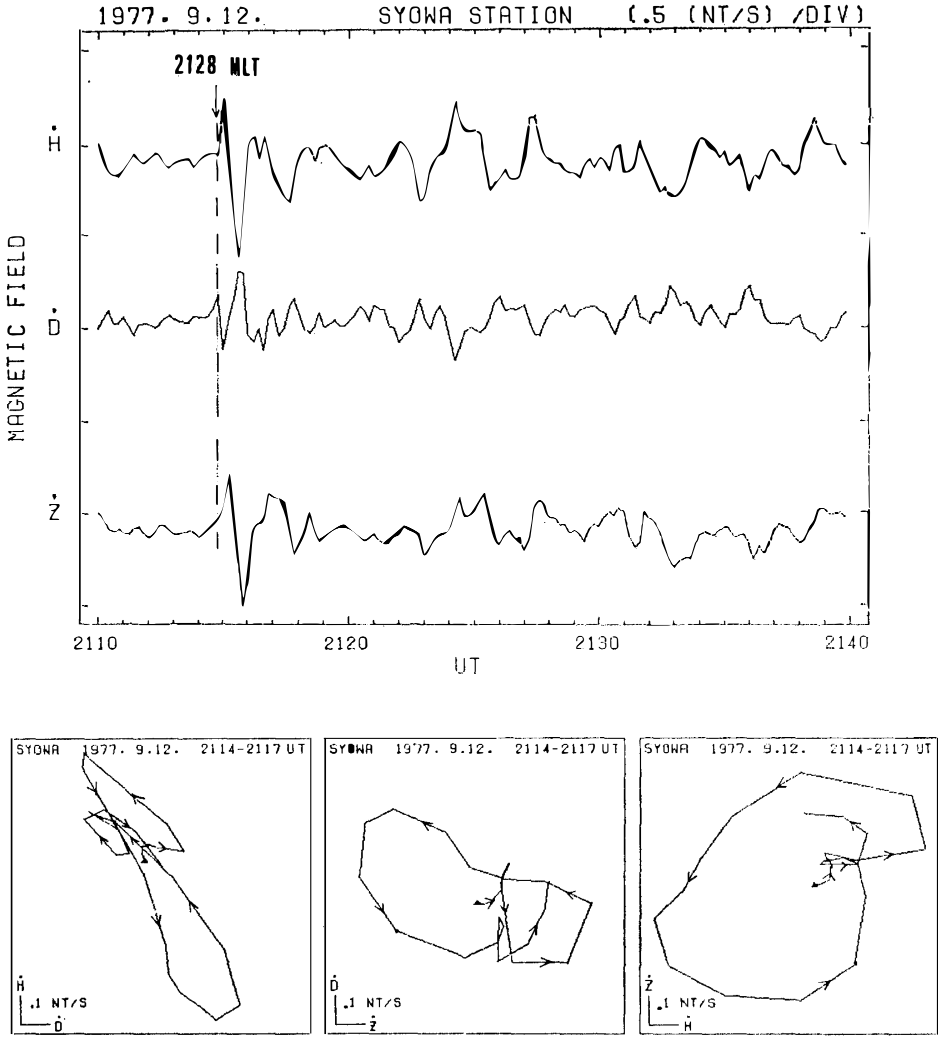

Fig. 7a.

Fig. 7. (a) Magnetograms of three components $\dot{H}$, $\dot{D}$ and $\dot{Z}$ for an SC at 2114:40 UT (2128 MLT) on September 12, 1977, observed by an induction magnetometer at Syowa Station (upper panel) and rotation of the SC vector in the $\dot{H}$-$\dot{D}$, $\dot{D}$-$\dot{Z}$ and $\dot{Z}$-$\dot{H}$ planes viewed from the $\dot{Z}$, $\dot{H}$ and $\dot{D}$ directions, respectively, during the interval 2114 to 2117 UT (lower panel), and (b) magnetograms of two components $\dot{H}$ and $\dot{D}$ for the same SC observed at the conjugate station Husafell (upper panel) and rotation of the SC vector in the $\dot{H}$-$\dot{D}$ plane viewed from the -$\dot{Z}$ direction during the same interval (lower panel).

3. Discussions

The statistical analysis of SC polarization in the *H-D* plane at Syowa Station indicates that the rotational sense is clockwise in the morning side and counterclockwise in the afternoon side, when viewed down onto the earth's surface. WILSON and SUGIURA (1961) showed statistically that the polarization of the horizontal SC vector in higher latitudes on the ground is counterclockwise in the morning side and clockwise in the afternoon side in the northern hemisphere, and *vice versa* in the southern hemisphere, from a view looking down onto the earth's surface. WILSON and SUGIURA

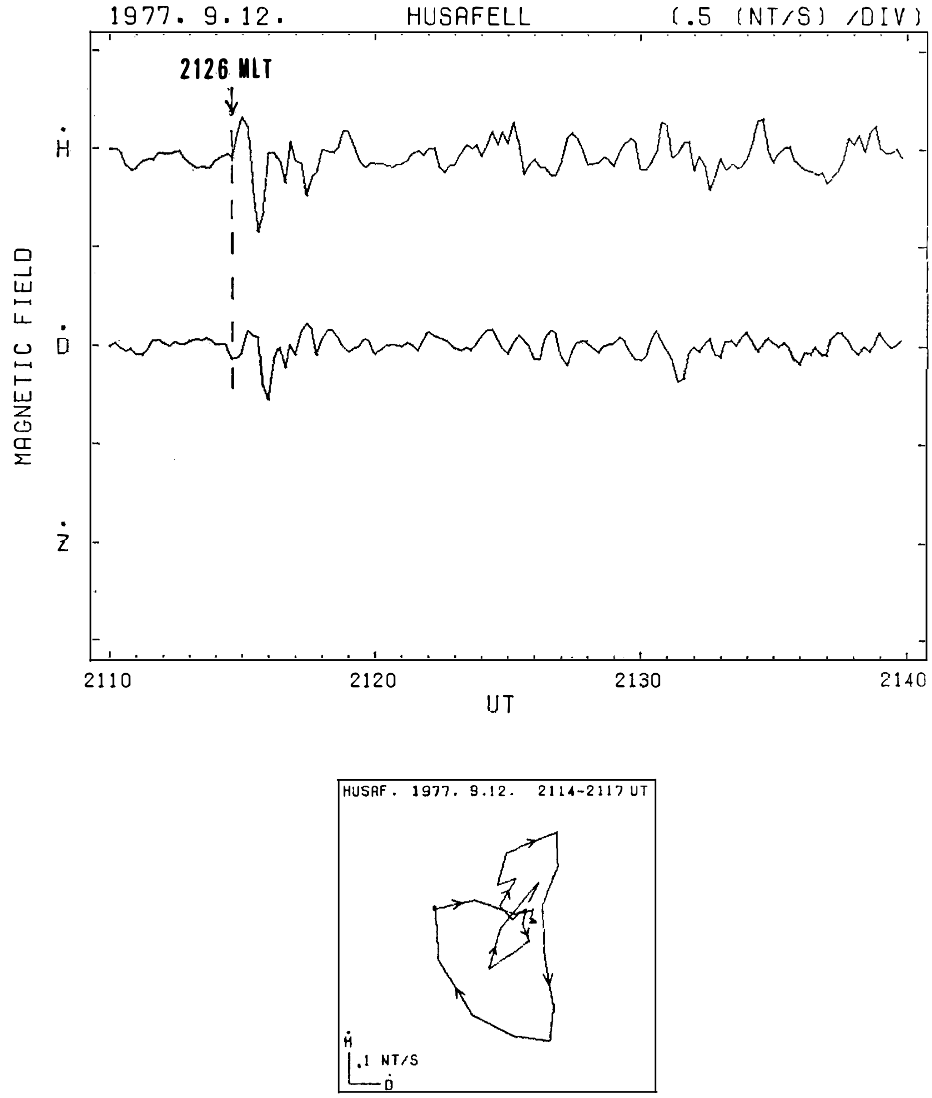

Fig. 7b.

(1963) reported that the rate obeying their polarization rules was about 58% of all the SC's observed at Byrd Station (70.6°S in geomagnetic latitude). According to NAGATA *et al.* (1966) the rate was about 67% of the total SC's observed at Syowa Station. Although our analysis indicates that the rate obeying the rules was smaller than those by WILSON and SUGIURA (1963) and NAGATA *et al.* (1966), it comes to the conclusion that it is consistent with the results by them. SC polarization viewed along the field direction at the GOES geostationary satellite is counterclockwise in the morning side and clockwise in the afternoon side (NAGANO and ARAKI, 1984; NAGANO *et al.*, 1985). Our statistical analysis of SC polarization at Syowa Station is also consistent with the result at the geostationary orbit. From the statistical analysis of the simultaneous data at Syowa Station and the conjugate station Reykjavik (66.6° N; 71.2° E in the geomagnetic coordinates), NAGATA *et al.* (1966) reported that the polarization characteristics at the conjugate pair are identical from a view looking along the direction of the geomagnetic field lines; namely, counterclockwise rotation

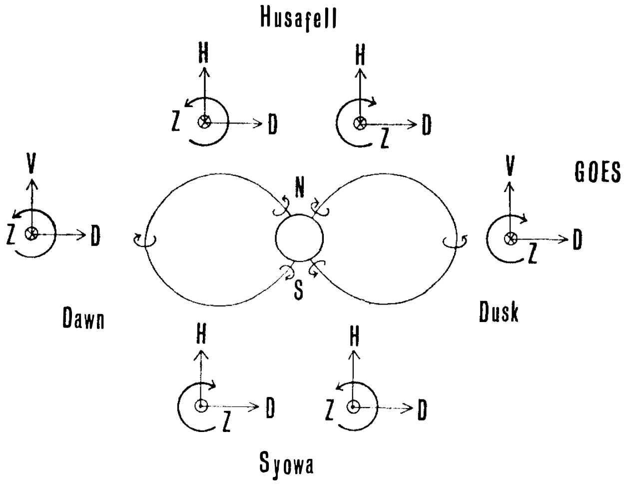

Fig. 8. Schematic picture describing the rotational sense of horizontal SC vectors at Syowa Station and Husafell on the ground and at the GOES geostationary satellite in the dawn and dusk sides. The polarization for Syowa Station is in the plane viewed from the Z axis and the polarization for Husafell and GOES is in the plane viewed from the -Z axis.

in the morning side and clockwise rotation in the afternoon side. Horizontal SC polarization sense at the Syowa Station–Husafell conjugate pair is consistent with the result by NAGATA *et al.* (1966). Figure 8 shows a schematic picture describing the rotational sense of horizontal SC vectors at Syowa Station and Husafell on the ground and at the GOES geostationary satellite in the dawn and dusk sides. When the dynamic pressure of the solar wind is enhanced suddenly, magnetic lines of force in both sides of the magnetosphere are believed to be swept back tailward. Then, the disturbance vector in the plane perpendicular to the magnetic field near the equator shows counterclockwise rotation in the morning side and clockwise rotation in the afternoon side, when viewed along the magnetic field (NAGANO and ARAKI, 1984). Such a rotation of magnetic field lines in space can be observed as the SC polarization obeying WILSON and SUGIURA's law at Syowa Station and Husafell on the ground. This may correspond to an odd mode of standing field-line oscillation, because the variations in the $\dot{H}$ and $\dot{D}$ components are in phase and out of phase, respectively, between the conjugate stations as shown in Figs. 7a and 7b (see SUGIURA and WILSON, 1964).

ARAKI and ALLEN (1982) found, using the North American IMS magnetometer data, that 14 SC's out of 18 examined by them showed a clear latitudinal polarization reversal between 64° and 72°N in geomagnetic latitude. Among these 14 SC's both of 2 events occurring in the morning side changed the polarization sense from counterclockwise to clockwise with increasing latitude and 5 events out of 11 occurring in the afternoon side changed it from clockwise to counterclockwise with increasing latitude. Examining the polarization sense at Cape Perry (70.58°N in geomagnetic latitude) located at a latitude similar to Syowa Station in the northern hemisphere, the rate obeying WILSON and SUGIURA's rules was found to be about 67% in the morning side and about 62% in the afternoon side for all the events. Therefore, the statistical result may obey the polarization rules at a relatively high rate although individual events will indicate a latitudinal reversal of SC polarization. A more precise examination of a latitudinal reversal is desired for many more events. The rotational sense of SC vectors in the *D-Z* and *Z-H* planes is predominantly clockwise. This sense seems to be different from that of Pc 5 pulsations (SAMSON, 1972; LAM and ROSTOKER, 1978) and Pi 3 pulsations (SUZUKI *et al.*, 1981). Further study using latitudinal chain data is needed to examine whether a latitudinal polarization reversal in the *D-Z* and *Z-H* planes appears or not.

SANO (1962, 1964) reported that SC* appears mainly in the afternoon side and inverted SC* appears mainly in the morning side and that this relation becomes reversed in the polar cap. Our statistical result of the SC wave form at Syowa Station indicates a tendency similar to that by SANO (1964). Examining the relationship between the polarization sense in the horizontal plane and the pattern of the SC wave form, clockwise polarization was found to be related mainly with inverted SC*, while counterclockwise polarizalion was related mainly with SC*. Therefore, it is believed that there is a fairly good correlation between the SC polarization sense and the wave form.

4. Summary

Some characteristics of SC polarization obtained at Syowa Station were statistically examined. Our results are summarized as follows:

(1) The polarization in the horizontal plane is clockwise in the morning side and counterclockwise in the afternoon side from a view looking down onto the earth's surface. This is consistent with the statistical results from ground-based magnetic data (WILSON and SUGIURA, 1961; NAGATA *et al.*, 1966) and from geostationary satellite magnetic data (NAGANO and ARAKI, 1984).

(2) The polarization in the *D-Z* and *Z-H* planes is predominantly clockwise when viewed from the *H* and *D* directions, respectively.

(3) There is a fairly good correlation between SC polarization sense and the wave form.

Only one SC event obtained simultaneously at Syowa Station and the conjugate station Husafell indicates that the variations in the $\dot{H}$ and $\dot{D}$ components are in phase and out of phase, respectively. This corresponds to an odd mode of standing field-line oscillation.

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