MAGNETIC AND AURORAL SUBSTORMS ASSOCIATED WITH STORM SUDDEN COMMENCEMENTS AND SUDDEN IMPULSES

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***Abstract*:** In order to study the diurnal occurrences of the ssc triggered magnetic substorm at the high latitude station, Syowa, 134 ssc's were selected in the period from 1966 to 1979. The statistical results show that the substorms are easily excited by ssc's in the late evening and midnight hours. Especially, from 00 h to 03 h geomagnetic local time, 80% of the ssc's examined are associated with excitations of substorms. By using the all-sky photographs taken every 10 s and the space-time auroral diagrams for the electron (OI 5577Å) and proton (H_β, 4861Å) auroras, the behavior of auroras associated with ssc's at Syowa Station are investigated. The ssc auroral substorms in the midnight sector show similar characteristics to those of the substorms excited by the physical processes inherent in the magnetosphere not associated with ssc's. In the evening sector, both electron and proton auroras suddenly brighten when an ssc takes place, and show expansion towards the equator. From the auroral aspect during the phase preceding the ssc triggered substorm, it is found that the auroras with luminosity of a few kR in λ 4278Å are covering the region in which the ssc auroral substorm starts.

1. Introduction

It has been pointed out that magnetic substorms at high latitudes are often associated with storm sudden commencements (ssc's) or sudden impulses (si's) caused by sudden magnetospheric compression (HEPPNER, 1955; KAWASAKI *et al.*, 1971; KOKUBUN *et al.*, 1977). It has been also reported that the triggering probability of the substorm is dependent on the conditions prior to the substorm (SCHIELDGE and SISCOE, 1970; BURCH, 1972; KOKUBUN, 1972). Based on the magnetic and auroral data obtained at the typical high latitude station, Syowa, Antarctica, an attempt is made to examine the diurnal probability of ssc triggered substorms and the behavior of auroras which may indicate the phase preceding the substorms.

2. Magnetic Substorms Associated with Ssc's

Five typical examples of the magnetic substorms associated with ssc's observed at Syowa Station (Geomag. lat. −70.0°, long. 79.4°), Antarctica, are shown in Fig. 1. As clearly seen in the H-component magnetograms for Syowa in Fig. 1, the ssc's are followed by magnetic substorms. When a substorms had already started preceding the occurrence of an ssc, it was much enhanced just after the onset of the ssc, as is illustrated in the third example of Fig. 1 (July 28, 1977).

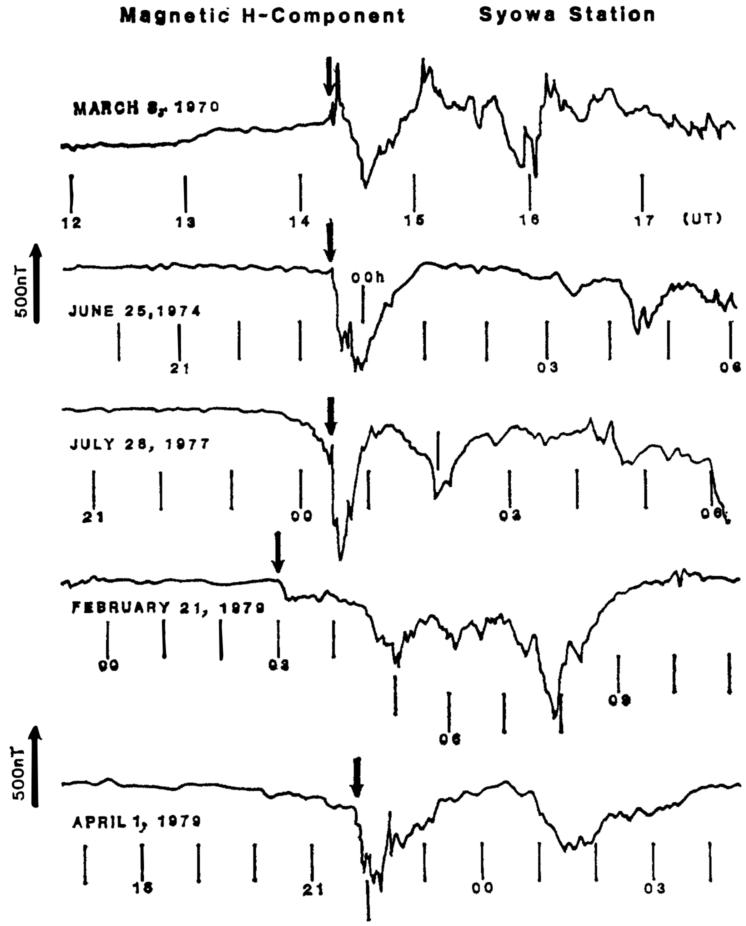

Fig. 1. Magnetic substorms typical of those associated with ssc's observed at Syowa Station for the 14 years, 1966–1979.

It has been noted that ssc's are not always followed by substorms at high latitude stations, but that the occurrences of the substorms associated with ssc's are dependent upon the geomagnetic local time (GLT). The excitations of the substorms by ssc's are investigated at Syowa using 134 selected ssc's which were observed in the period from 1966 to 1979. These ssc's were accompanied by magnetic storms with decreases greater than 100 nT in horizontal intensity (H) at the middle latitude station, Kakioka (Geomag. lat. +26.0°, long. 206.0°). It is seen in Fig. 2 that at Syowa in the midnight and late evening hours, most of ssc's are followed by the excitation of substorms. Especially, from 00 to 03 GLT, out of 19 ssc events examined here, 80% are associated with excitations or enhancements of substorms.

To examine the possibility that the ssc substorm is also dependent upon the ssc magnitude, we have plotted in Fig. 3 the ssc magnitude at Kakioka versus the geomagnetic local time at Syowa. Open circles indicate triggered substorms, while black triangles show the non-triggered ones. The present analysis shows that in the evening hours (12–18 GLT), large magnitude ssc's (more than about 30 nT at Kakioka) excite magnetic substorm, while small ones are not followed by substorms. As for the night hours (18–03 GLT), almost all ssc's produce substorms even when the ssc magnitude is smaller than 10 nT in the range of H intensity at Kakioka. The results shown in

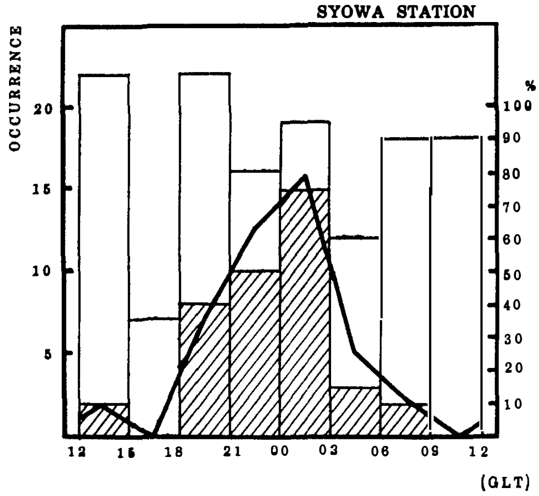

Fig. 2. Diurnal variation of occurrences of substorms associated with ssc's. The unhatched histogram shows the total number of the selected ssc's observed in the period from 1966 to 1979, while the hatched histogram shows the number of ssc's with the excitations or enhancements of substorms at the high latitude station, Syowa. GLT means geomagnetic local time at Syowa Station.

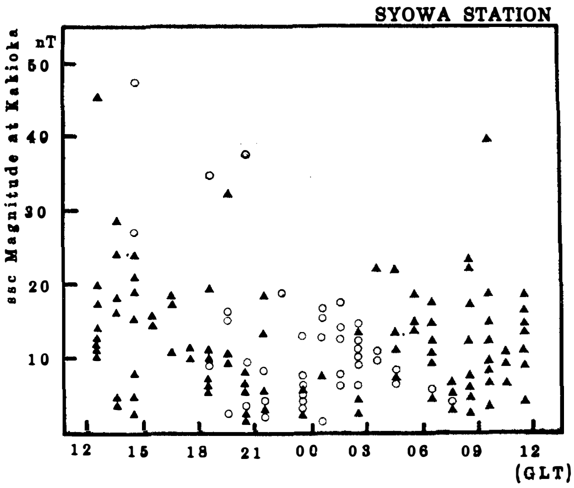

Fig. 3. Dependence of the ssc-triggered magnetic substorms at Syowa on the ssc magnitude at Kakioka and the geomagnetic local time at Syowa. Open circles indicate the triggered substorms, while black triangles show the non-triggered ones.

Figs. 2 and 3 show that statistically the triggering probability of magnetic substorms by the ssc's strongly depends upon the geomagnetic local hour and that substorms are easily excited by ssc's in the late evening and midnight sector at a typical auroral (AE) station*, such as Syowa Station.

3. Auroral Substorms Associated with Ssc's

It has been pointed out that the first indication of the auroral substorm is a sudden brightening of the quiet arcs lying in the midnight sector of the auroral oval. Within a few minutes after the onset of the auroral substorm, the arcs suddenly become active and show rapid motions; this phenomenon is the socalled auroral breakup. After this activity, the aurora in the form of a diffused surface or rays still remains over the whole sky. This stage is often referred to as the post-breakup phase of the auroral substorm (AKASOFU, 1968; HIRASAWA and NAGATA, 1972).

An example of the ssc substorm at Syowa is shown in Fig. 4a together with the simultaneous H-component magnetogram for the middle latitude station, San Juan (Geomag. lat. 29.7°, long. 4.7°). As seen in the magnetogram for San Juan, an ssc occurred around 2304 UT** on July 13, 1978 and a magnetic substorm with the

* Leirvogur Station in Iceland is one of twelve AE stations in the northern polar region. Syowa Station in Antarctica is located very close to the geomagnetic conjugate point of Leirvogur Station.

** Universal time (UT) and geomagnetic local time (GLT) are nearly the same at Syowa Station. Therefore, universal time is adopted in this paper.

maximum amplitude of about 700 nT was observed at Syowa associated with the ssc. In Fig. 4b, all-sky camera photographs at Syowa are illustrated every 10 s in the period from 2303 to 2322 UT on July 13, 1978. In these all-sky photographs, an arc is lying quiet and motionless above the northern horizon of Syowa before the onset of the ssc (2304: 20). About 2 min after the onset of the ssc (around 2306), a new auroral arc with a discrete structure begins to appear on the southern side of the preceding arc, shows sudden brightening (2306: 30) and moves westwards very rapidly with folding shapes (2307–2312). Within 10 min after the ssc (from 2314 to 2320), the active auroras spread and blanket the whole sky of the observing station. This example illustrates the typical auroral breakup caused by the triggering of an ssc.

In Figs. 5a and 5b, another example of an ssc auroral substorm is shown. The *H*-component magnetogram at San Juan in Fig. 5a indicated that an ssc with a magnitude of about 20 nT occurred around 2318 UT on May 12, 1978. Preceding the ssc, a substorm started around 2100 at Syowa, reaching the maximum stage of the substorm with an amplitude of about 400 nT around 2200 and then showed a gradual recovery. The ssc occurs at the end of the recovery phase of the preceding substorm and the substorm is enhanced again associated with the ssc. The progress of the above substorm is also seen in the all-sky photographs at Syowa illustrated in Fig. 5b. Before the ssc, the sky over Syowa was filled with comparatively weak aurora in the form of a diffuse surface and rays, which are usually observed in the post breakup or recovery phase of an auroral substorm. Immediately after the onset of the ssc, the luminosity of the aurora suddenly intensified covering the whole sky. The magnetic *H*-component trace for San Juan in Fig. 5a shows that the ssc starts around 2318, gradually increases and reaches the maximum magnitude around 2326. After the maximum of the ssc, the auroras with discrete structures begin to appear and show general poleward movements as seen in the all-sky photographs in Fig. 5b for the period from 2327 to 2332. This example shows that in the recovery phase of a preceding substorm the substorm can be excited again by an ssc.

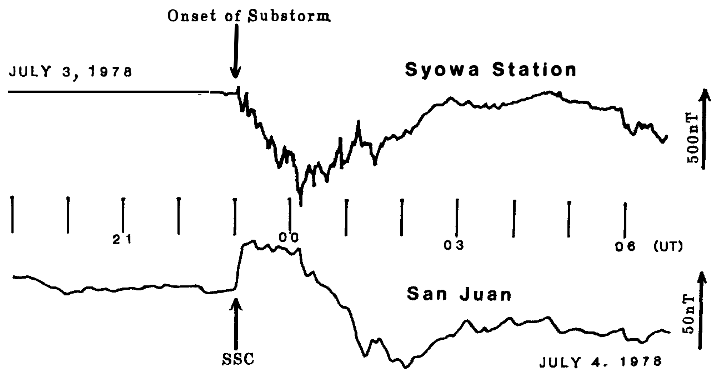

Fig. 4a. Ssc triggered substorm observed at Syowa on July 3 1978 and the simultaneous H-component magnetogram at the middle latitude station, San Juan.

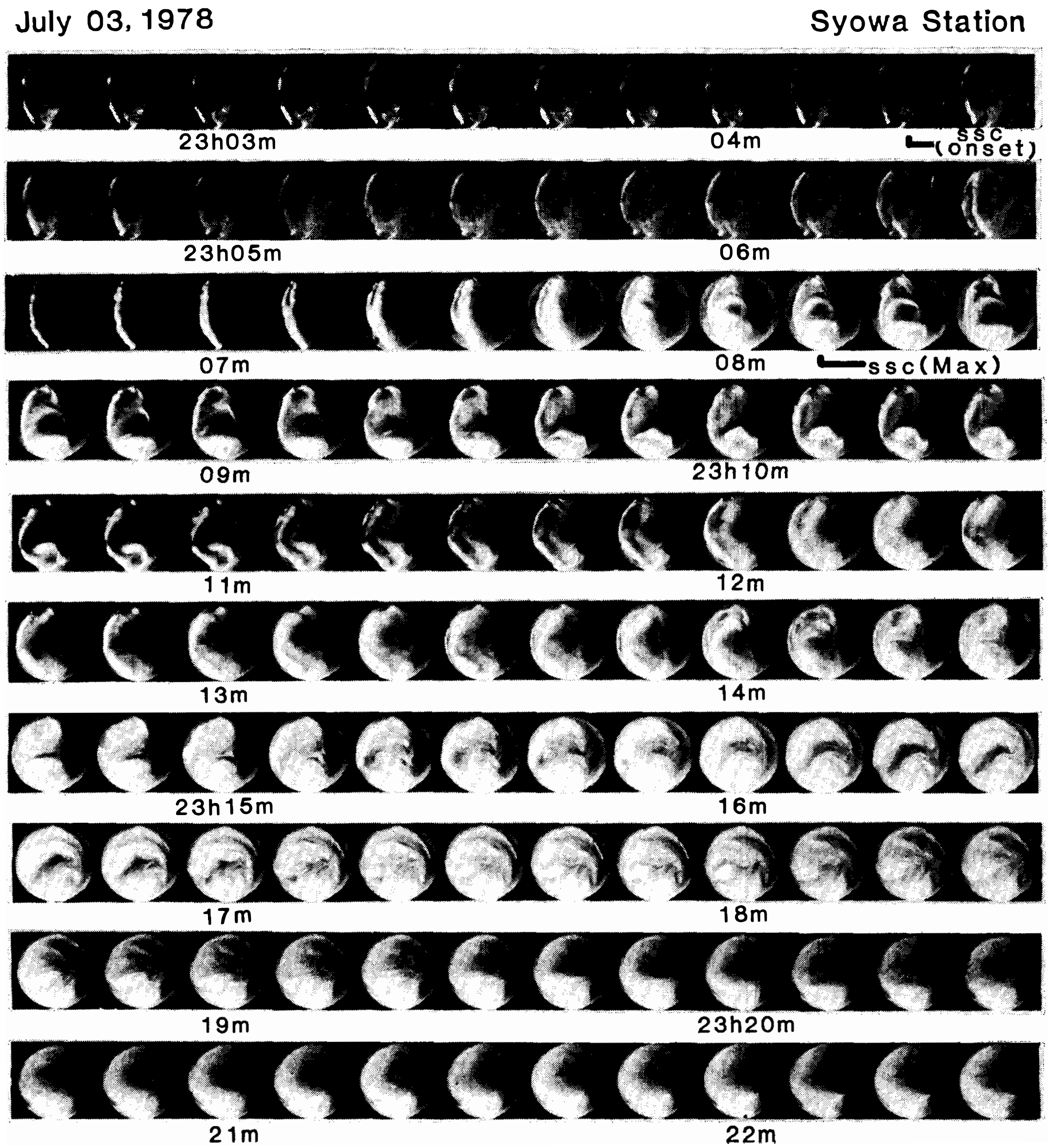

Fig. 4b. Example of auroral substorm associated with an ssc. All-sky photographs are taken every 10 s at Syowa. Geomagnetic north (equatorward) is towards the left and the south (poleward) is towards the right.

4. Expansion of Active Auroras towards the Equator in the Evening Hours Associated with Ssc's

To examine the auroral behavior in the evening hours at the time of ssc's, two typical examples of the meridian-time diagrams of auroral luminosity (auroral diagram) for electron aurora (OI 5577Å) and proton aurora (H_β, 4861Å) observed at Syowa are shown in Figs. 6 and 7 together with the simultaneous *H*-component magnetograms for Syowa and San Juan. In Fig. 6a, an ssc with a magnitude of 25 nT was observed

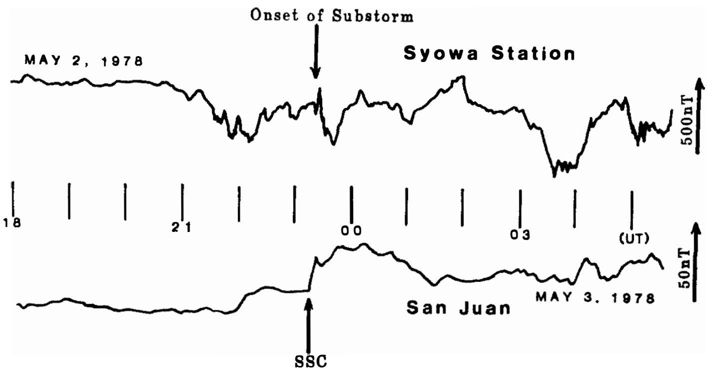

Fig. 5a. Ssc triggered substorm observed at Syowa on May 2, 1978 and the simultaneous H-component magnetogram at the middle latitude station, San Juan.

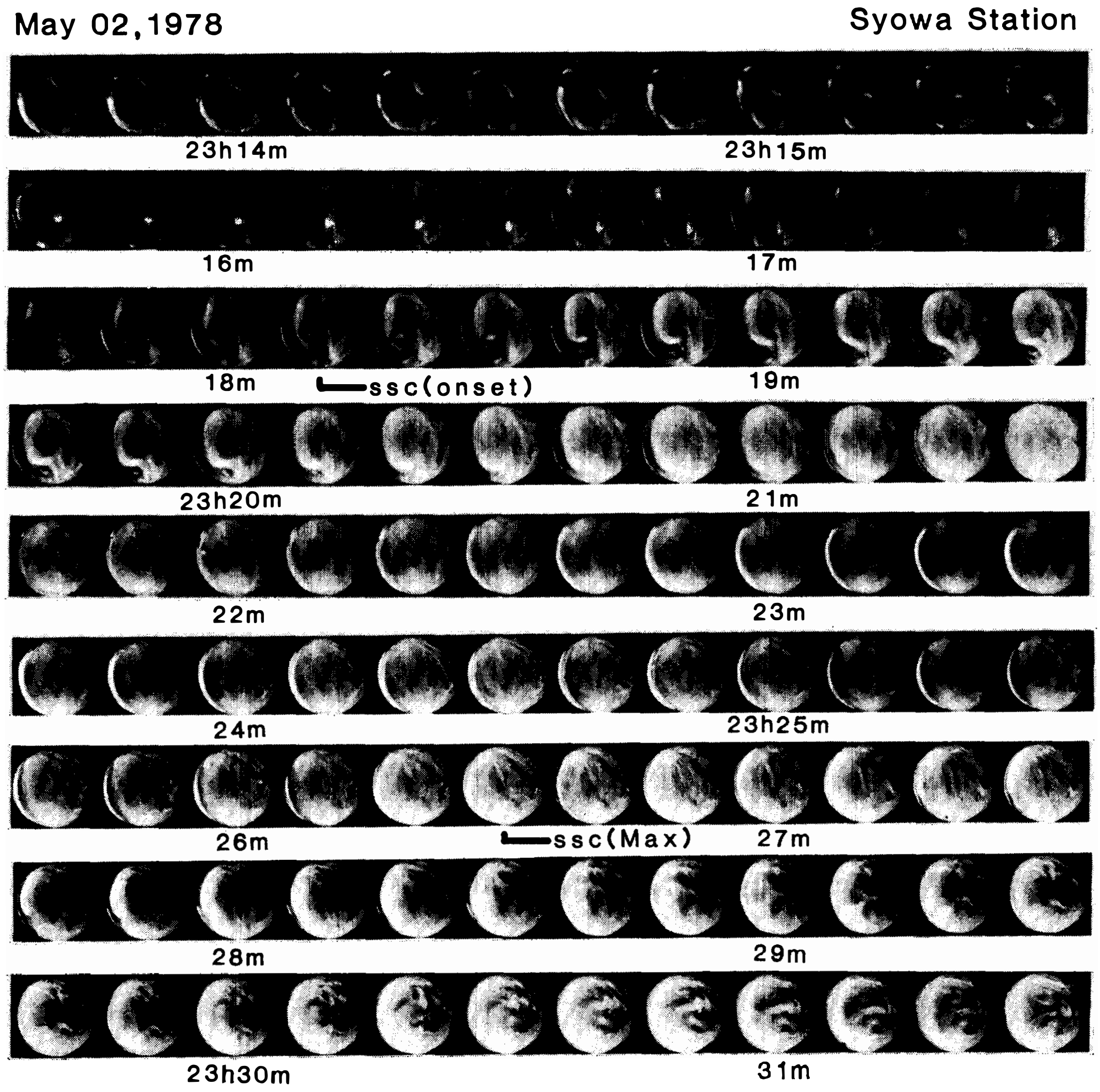

Fig. 5b. Example of auroral substorm associated with an ssc. All-sky photographs are taken every 10 s at Syowa. Geomagnetic north (equatorward) is towards the left and the south (poleward) is towards the right.

at 2116 UT on June 10, 1978 at San Juan. Associated with the ssc the Syowa magnetogram shows a negative decrease with an amplitude of about 100 nT and successive oscillations of pc 5 pulsations. In the auroral diagrams of Fig. 6b, corresponding well with the occurrence of the ssc, the enhancement and the expansion towards the north (equator wards) of the auroral activities are observed in the diagrams for both

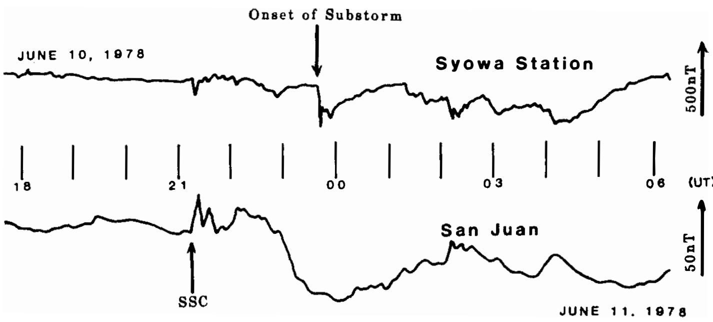

Fig. 6a. H-component magnetograms at Syowa and San Juan stations on June 10–11, 1978.

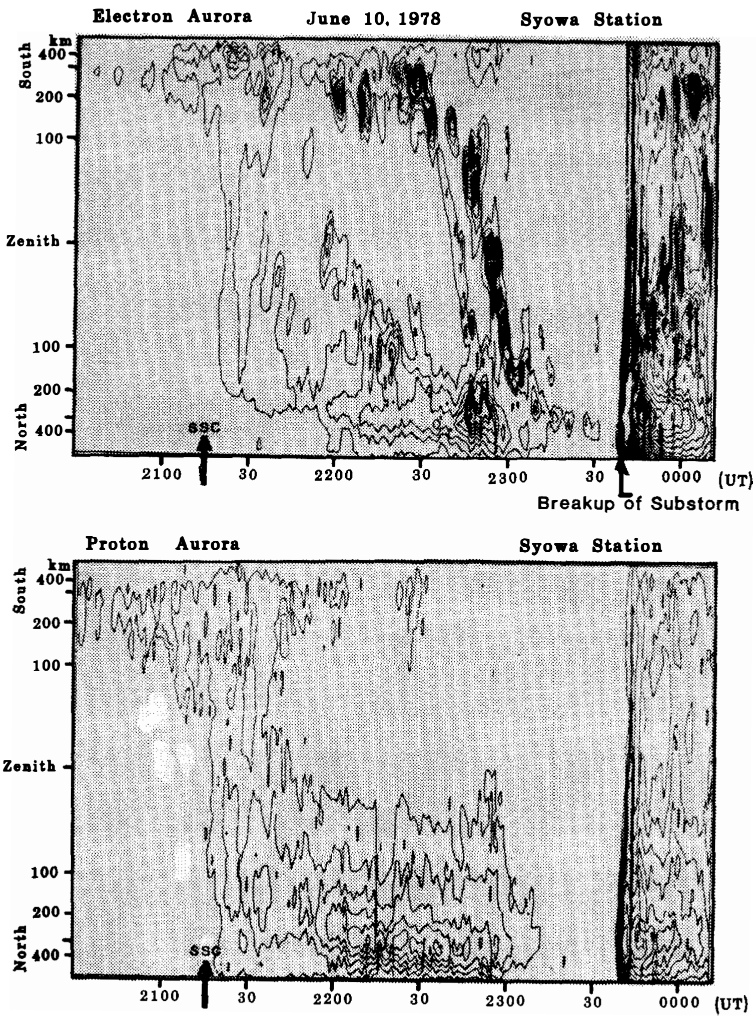

Fig. 6b. Meridian-time diagram of OI 5577Å electron auroras (top) and H_β 4861Å proton auroras (bottom) observed at Syowa on June 10–11, 1978.

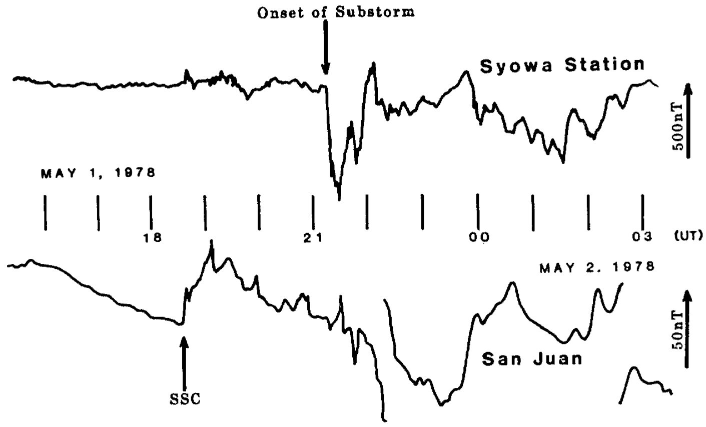

Fig. 7a. H-component magnetograms at Syowa and San Juan stations on May 1–2, 1978.

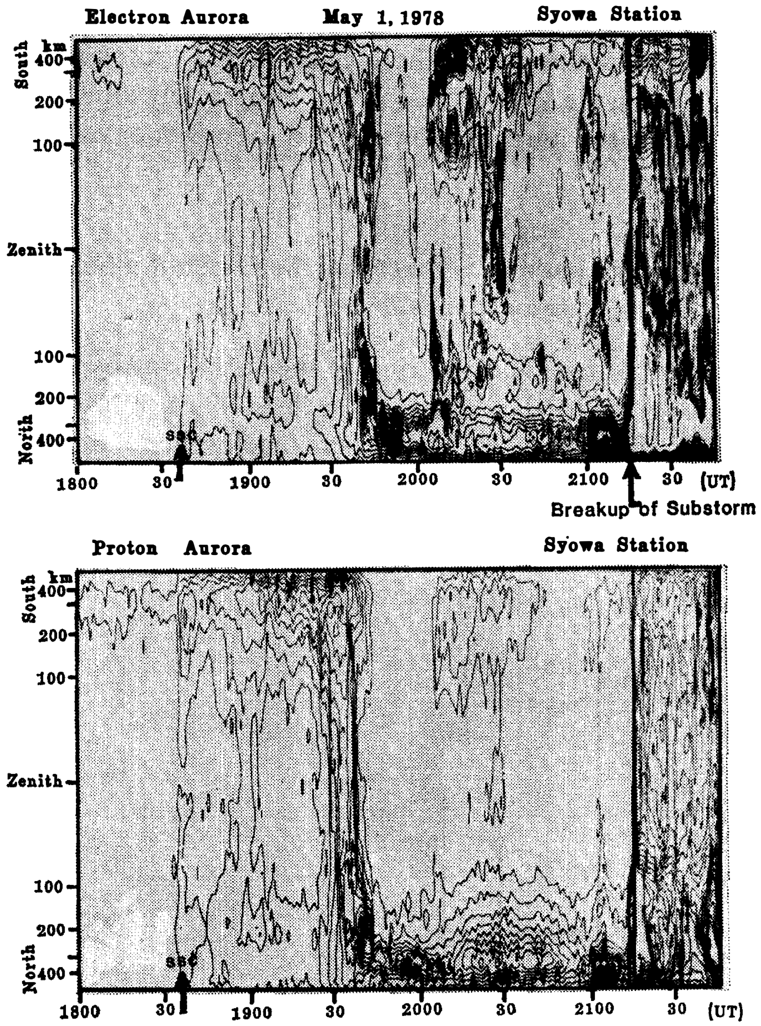

Fig. 7b. Meridian-time diagram of OI 5577Å electron auroras (top) and H_β 4861Å proton auroras (bottom) observed at Syowa on May 1–2, 1978.

electron and proton auroras. In the auroral diagram for proton auroras shown in the bottom panel of Fig. 6b, before the ssc the proton auroras with comparatively faint luminosity are located in the southern (poleward) sky of Syowa. Immediately after the ssc, the proton auroras begin to be active and shift vey rapidly toward the north (equator) with a speed of about 300 m/s. About 30 min after the ssc (around 2150), an active area of proton aurora still exists on the equatorward side of Syowa (about 400 km equatorward from the zenith of Syowa).

The time-sequence of the auroral displays illustrated in Fig. 7b is a similar example to that shown in Fig. 6b. In this example, the sudden activation of the electron and proton auroras follow the ssc which occurred at 1834 UT on May 1, 1978 (see Fig. 7a). After the ssc, both active electron and proton auroras which are located above the poleward horizon of Syowa (about 300–400 km from Syowa) begin to expand towards the north (equator), although their movements are not appreciable up to 1920. In the period from 1920 to 1945, these auroras show very rapid equatorwards movements with increasing luminosity to the northern part of the sky about 400 km from Syowa.

From the above two examples of the auroral displays following ssc's in the evening hours, it is seen that the luminosities of both electron and proton auroras are suddenly activated by ssc's. After the ssc's, occasionally immediately after them, the activated areas of electron and proton auroras show rapid movements or expansion towards the equator.

5. Auroral Appearance Preceding the Onset of a Substorm Associated with Ssc's and Si's

It has been reported that the triggering of the substorms by ssc's or si's depends upon the conditions prior to the substorm, such as the southward direction of the IMF (BURCH, 1972; KOKUBUN, 1972) and magnetospheric tail-like configuration (SCHILDGE and SISCOE, 1970). It has been also noted by HIRASAWA and NAGATA (1972) that auroral agitations with an intensity of about several kR (at λ4278Å) in luminosity are observable preceding the onset of auroral substorm. In other words,

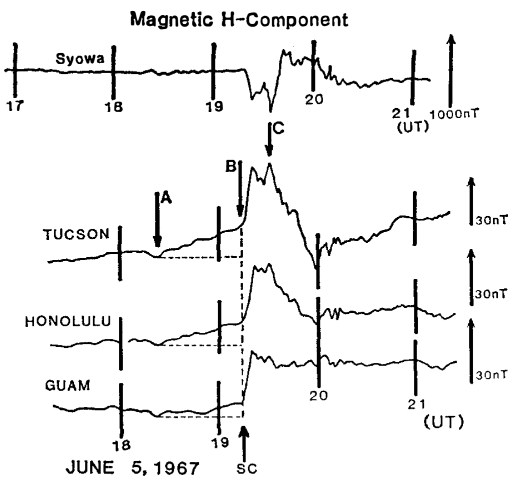

Fig. 8a. H-component magnetograms at high-latitude station, Syowa and at low latitude stations, Tucson, Honolulu and Guam.

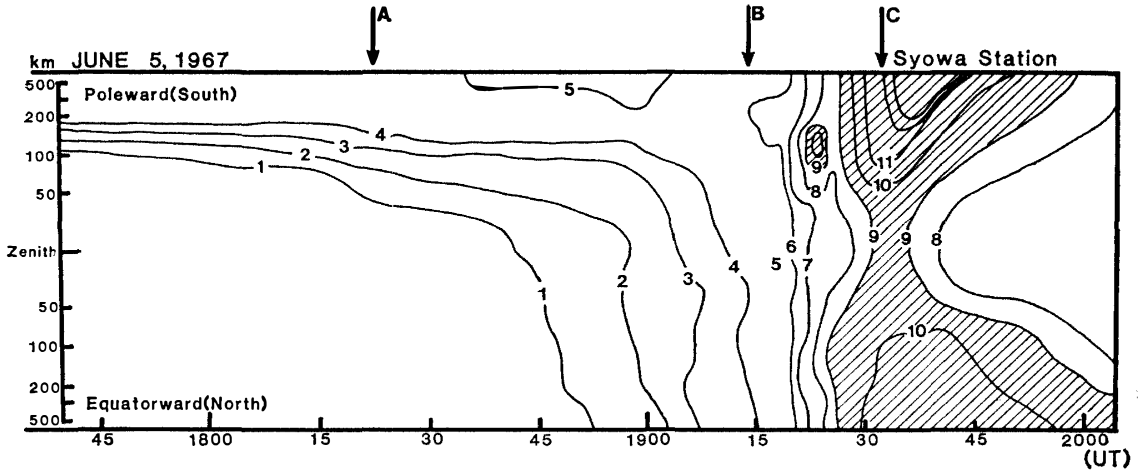

Fig. 8b. Meridian-time diagram of λ4278Å auroras observed at Syowa on June 5, 1967. Contour, "1" corresponds to about 1 kR.

it is extremely rare for the auroral substorm to occur without any auroral appearance before it. In this section, the characteristics of aurora, prior to the substorm associated with ssc's and si's is examined.

An ssc substorm observed at Syowa is shown in Fig. 8a together with three simultaneous magnetograms of widely separated middle and low latitude stations (Tucson, Honolulu and Guam). In the magnetograms from the three stations, an ssc occurred at 1915 UT on June 5, 1967 (indicated by arrow B). Associated with the ssc, a magnetic substorm with the amplitude of about 500 nT was observed at Syowa as illustrated at the top of Fig. 8a. It is also noted in Fig. 8a that the *H*-component variations at the three middle and low latitude stations show simultaneous gradual increases from 1820 (indicated by arrow A) to the onset of the ssc (arrow B). A magnetic variation of this type could be interpreted to be caused by compression of the magnetosphere (NISHIDA and CAHILL, 1964; HIRASAWA *et al.*, 1966). In Fig. 8b, the λ4278Å electron auroral diagram at Syowa is illustrated for the period from 1745 to 2900 UT on June 5, 1967. It is noted in the auroral diagram that the expansion of the auroral region toward the equator (indicated by arrows from A to B) is simultaneous with the positive gradual increase of magnetic *H*-component with amplitudes of about 2–10 nT at the three low and middle latitude stations. This auroral display indicates the expansion of the auroral oval associated with the compression of the magnetosphere. It is also found in Figs. 8a and 8b that the magnetic and auroral substorms suddenly start when the ssc take place at about 1915 (arrow B).

The magnetic *H*-component records at San Juan, Honolulu and Guam in Fig. 9a show the successive occurrences of si's (indicated by the arrows A, B, C and D) between 1500 and 1830 UT on May 28, 1967. In the auroral diagram in Fig. 9b, the faint auroras with the luminosity of a few k*R* at λ4278Å appear on the poleward side of Syowa at about 1500. The auroras suddenly begin to spread towards the equator 1830, cover the zenith of Syowa and reach to the equatorward (north) horizon at about 1900. This shows the expansion of the auroral oval towards the equator. After 1900, the oval covers the sky from the north to the south of the station. As clearly

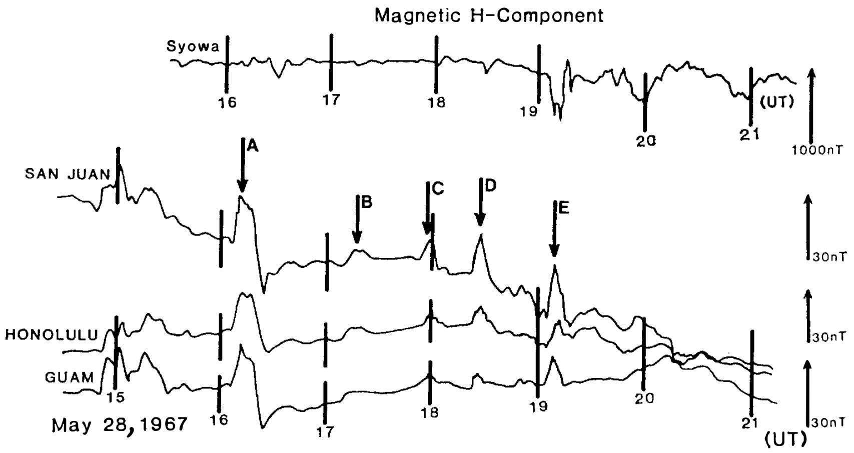

Fig. 9a. H-component magnetograms at high-latitude station, Syowa and at low latitude stations, San Juan, Honolulu and Guam.

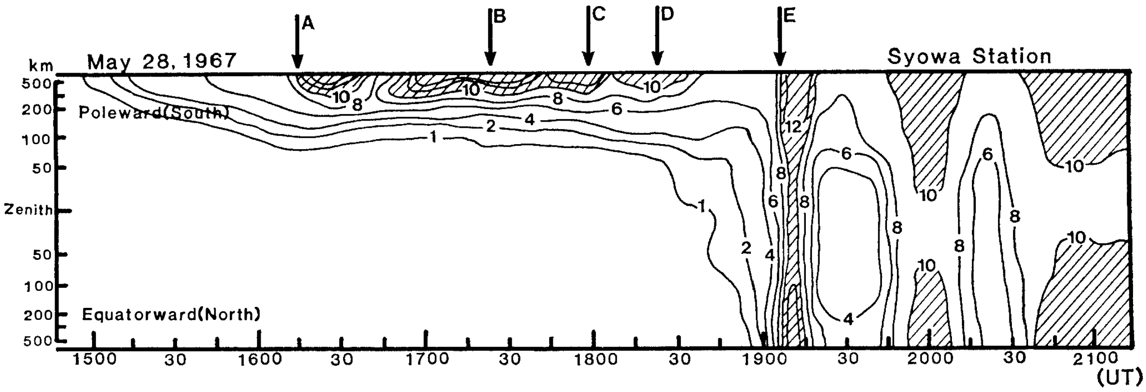

Fig. 9b. Meridian-time diagram of λ4278Å auroras observed at Syowa on May 28, 1967. Contour, "1" corresponds to about 1 kR.

seen in the auroral diagram of Fig. 9b and corresponding well to the si's, the enhancement of auroral activity, probably the occurrences of the auroral substorms were successively observed on the poleward side of Syowa Station (indicated by A, B, C and D arrows in Fig. 9b). At around 1905, when the aurora cover the sky at Syowa from the northern to southern horizon, a magnetic and auroral substorm occurs at Syowa associated with an si with an amplitude of about 10 nT at the low latitude stations (indicated by arrow E).

As described above, it should be noted that the auroral agitations with intensity of about 2–3 k*R* (in λ4278Å) exist preceding the onset of the auroral substorms associated with ssc's and si's. It is considered, therefore, that substorms are excited or enhanced by ssc's or si's when the observing station is covered with aurora preceding the substorms.

6. Summary

Based on the data obtained at the high latitude station, Syowa, we have statistically investigated the triggering of magnetic substorms by sudden magnetospheric compressions associated with ssc's and si's. For the 14 years 1966–1979, 134 ssc's were selected to examine the diurnal dependence of the occurrence of the ssc substroms. The statistical results show that most of ssc's are followed by substorms when Syowa Station is situated in the midnight and late evening hours. Especially, from 00 h to 03 h in GLT (midnight hours), 80% of the ssc's examined are associated with excitations or enhancements of substorms. In the midnight hours, the substorm are easily excited by ssc's even when the magnitude of the ssc is relatively small (for example, smaller than 10 nT at the low and middle latitude stations).

The auroral substorms triggered by ssc's in the midnight sector are investigated by using all-sky photographs taken every 10 s. The result shows that the behavior of the ssc auroral substorm is similar to that of the substorm excited by the physical processes other than ssc's inherent in the magnetosphere. In the evening hours, the auroral displays associated with ssc's are much different from those near midnight. When an ssc takes place, both electron and proton auroras suddenly brighten, but do not show the displays of the auroral substorm in the night hours. That is to say, it is very rare for a substorm to start in the evening hours. After the ssc, the active areas of electron and proton auroras show rapid movements or expansion towards the equator.

The auroral aspect during the phase preceding substorms is examined based on the auroral diagrams before and after a typical ssc and during the successive occurrences of si's. From the viewpoint of the auroral behavior, it is reasonably deduced that substorms can be excited or enhanced by ssc's and si's in the region over which the preceding auroral agitations are observed.

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