Energetic Particle Observations at Synchronous Orbit —Multiple-Satellite Study for Flux Variation by GOES-2, GOES-3 and GMS and Nightside Flux Depression for Continuous Geomagnetic Activity by GMS—

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静止衛星軌道における高エネルギー粒子の観測

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要旨： 本論文では，磁気圏嵐時の静止衛星軌道における高エネルギー粒子のフラックス変動について報告する．3つの静止衛星の同時観測により，夕方側で粒子の減少がみえる時に，真夜中から朝側にかけては，粒子の増加がみられることを明確に示した．また，地磁気じょう乱が引き続いて起きている時には，比較的大きなしかも孤立して起きた磁気圏嵐の時とやや異なる粒子フラックスの変動がみられることを2日間の例を使い示した．

***Abstract*:** This article reports the results of studying the behavior of the energetic particle flux obtained at synchronous orbit during substorms. The multi-satellite study has clearly showed that the evening particle flux decrease contrasts with the behavior in the midnight-morning side, where the energetic particle flux increases at the substorm expansion onset. Two-days' examples indicate that the flux behavior during the periods of the continued geomagnetic activities seems to be somewhat different from that for the relatively large and isolated events.

1. Introduction

It has been found that the energetic particle flux at synchronous orbit (6.6 R_E) exhibits large variations during magnetospheric substorms. In the nightside prior to the substorm expansion phase onset, which is defined by a low-latitude positive bay onset, the energetic particle flux decreases, while subsequently it increases just after that onset (BOGOTT and MOZER, 1973; WALKER *et al.*, 1976; ERICKSON *et al.*, 1979).

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On the other hand, it is reported that the energetic particle flux decreases during substorms in the evening side (LEZNIAK and WINCKLER, 1970; ERICKSON and WINCKLER, 1973; LIN and PARKS, 1974). LEZNIAK and WINCKLER (1970) interpreted that this flux decrease is caused by the magnetospheric inflation due to the enhancement of the plasma energy density. However, the relationship between the behavior in the evening side and that occurring farther eastward in local time has not been clearly established.

We have studied the variations of the energetic particle flux observed by three geostationary satellites; GOES-2, GOES-3 and GMS, to study the local time-dependent characteristics of the variations during the substorms. In this study we only have analyzed the relatively large and isolated events. We have examined further the behavior of the energetic particle flux obtained by GMS during the period when the substorms occur successively.

2. Data

In the following we have used the data of the energetic proton and electron fluxes obtained by three geostationary satellites. GOES-2, GOES-3 and GMS are situated at 75°W, 135°W and 140°E, respectively. The energy range of the adopted proton channel is 0.8–4 MeV for GOES-2 and GOES-3 and 1.2–4 MeV for GMS. The energy range of the adopted electron channel is >2 MeV for the three satellites. Each satellite is spin stabilized at 100 rpm and the spin axis is perpendicular to the plane of the orbit. The energetic particle sensors look radially outwards. The basic accumulation time is 1.44 sec for GOES-2 and GOES-3 and 0.992 sec for GMS. The data sampling is repeated every 6.13 sec for GOES-2 and GOES-3 and 16.4 sec for GMS

3. Observations

3.1. Multi-satellite study on July 6–8, 1978

The data of the energetic particle flux obtained by three satellites are presented in Fig. 1 and the H or X component traces of the auroral zone magnetograms are in Figs. 2a, 2b and 2c. Each vertical line indicates the time of the major onset of the substorm expansion phase, which is signified by an onset of the low-latitude positive bay, except two cases; the 0100 substorm on July 7 and the 0024 substorm on July 8. As the flux units and the time-resolutions of the data are different for the three satellites, we only note the gross behavior of the particle flux for each substorm. Two principal findings can be summarized as follows:

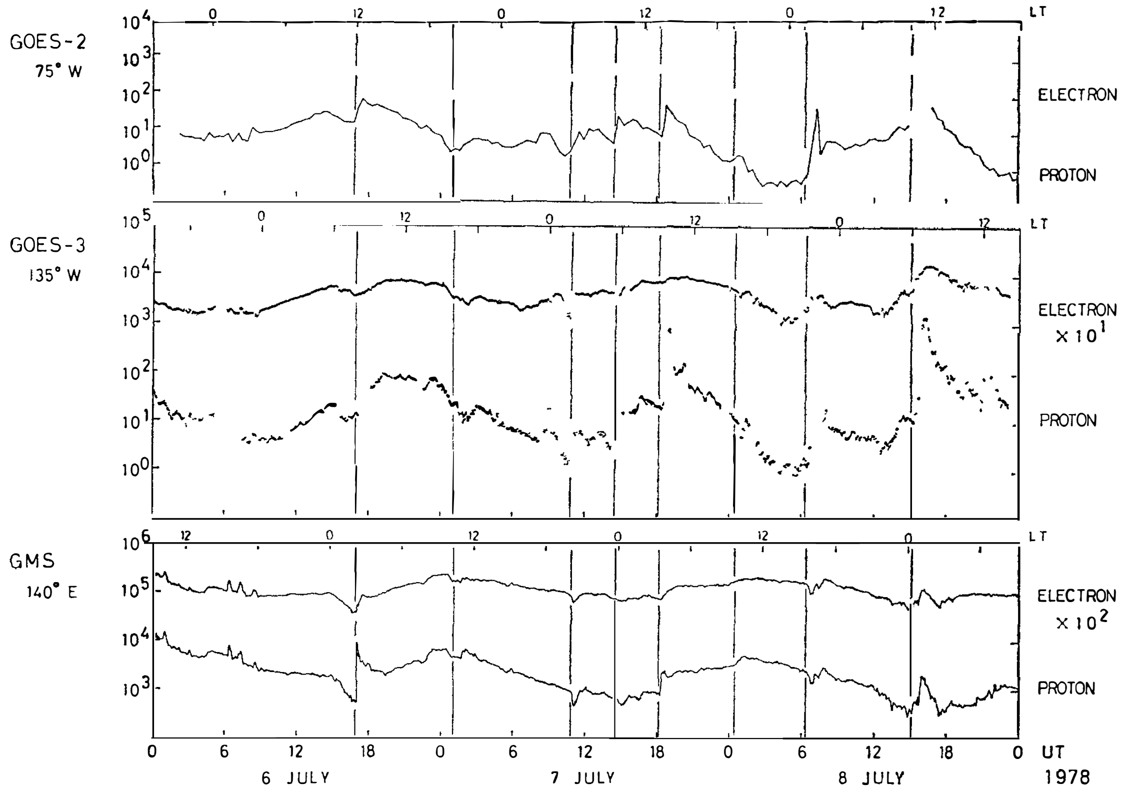

Fig. 1. Energetic electron flux (>2 MeV) and energetic proton flux (0.8–4 MeV for GOES-2 and GOES-3 and 1.2–4 MeV for GMS) observed by three geostationary satellites on July 6–8, 1978. The flux unit is particles sec^{-1} for GOES-2, particles·cm^{-2} sec^{-1} sr^{-1} MeV^{-1} for GOES-3 and particles·cm^{-2} sec^{-1} sr^{-1} for GMS, respectively. The two-min averaged values are used for GMS. Each vertical line indicates the major onset of the substorm expansion phase, which is defined from the ground magnetograms

3.1.1. 1651 substorm on July 6 (0211 LT for GMS, 0751 LT for GOES-3 and 1151 LT for GOES-2)

The ground geomagnetic activities in the auroral zone began around 1500 UT as shown in Fig. 2a. The negative bay in the auroral zone occurred in the dawn sector and the positive bay in the auroral zone occurred in the dusk sector. No concentration of the westward current existed in the midnight auroral zone and no clear mid-latitude positive bay and no Pi 2 were recorded in the examined mid-latitude magnetograms (Fig. 3). The traces of the *H* and *D* components in the polar cap stations (Thule and Godhavn) are presented in Fig. 4. The examinations of the geomagnetic variations show that the equivalent current flow over Thule flowed anti-sunward before 15 UT and it flowed to the pre-noon direction after 15 UT. This might be due, though

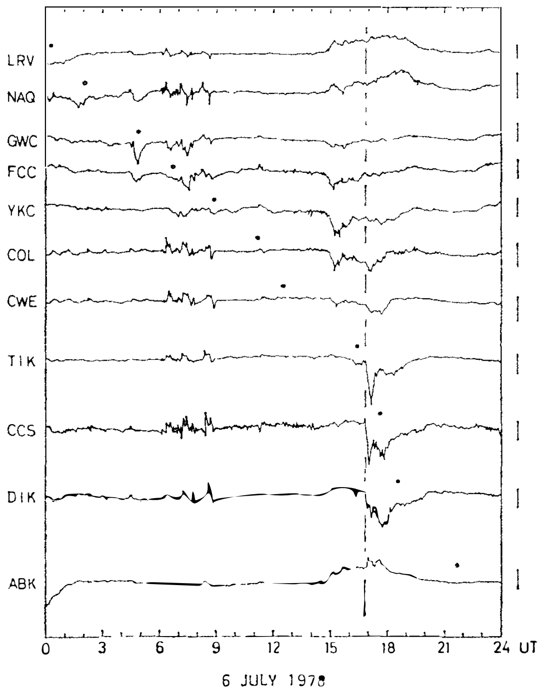

Fig 2a

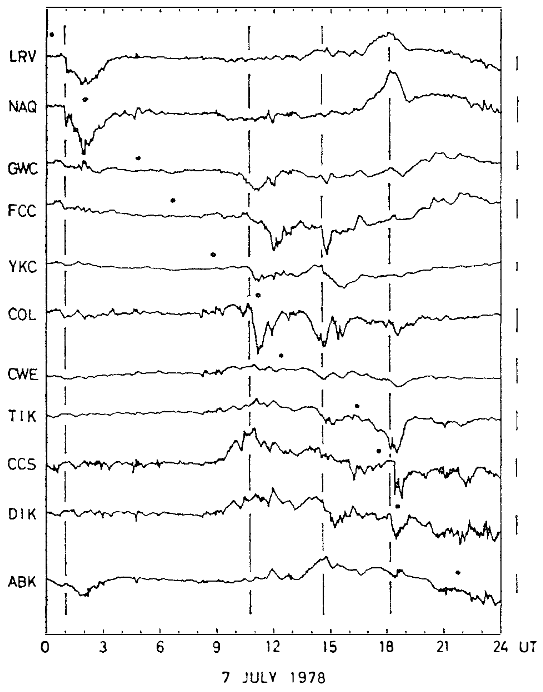

Fig. 2b

Fig 2a–c The H(X) component traces of the ground magnetograms at the auroral zone stations The X component traces are used for GWC, FCC and YKC. Vertical line indicates the major onset of the substorm expansion phase Each dot indicates the local midnight for each station Each vertical bar represents 200 nT The stations are Leirvogur (LRV), Narssarssuaq (NAQ), Great Whale River (GWC), Fort Churchill (FCC), Yellowknife (YKC), College (COL), Cape Wellen (CWE), Tixie Bay (TIK), Cape Chelyuskin (CCS), Dixon (DIK) and Abisko (ABK)

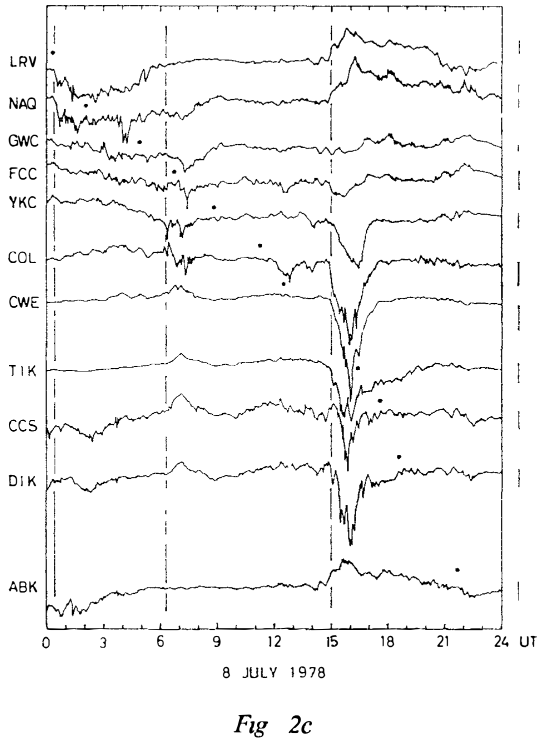

Fig 2c

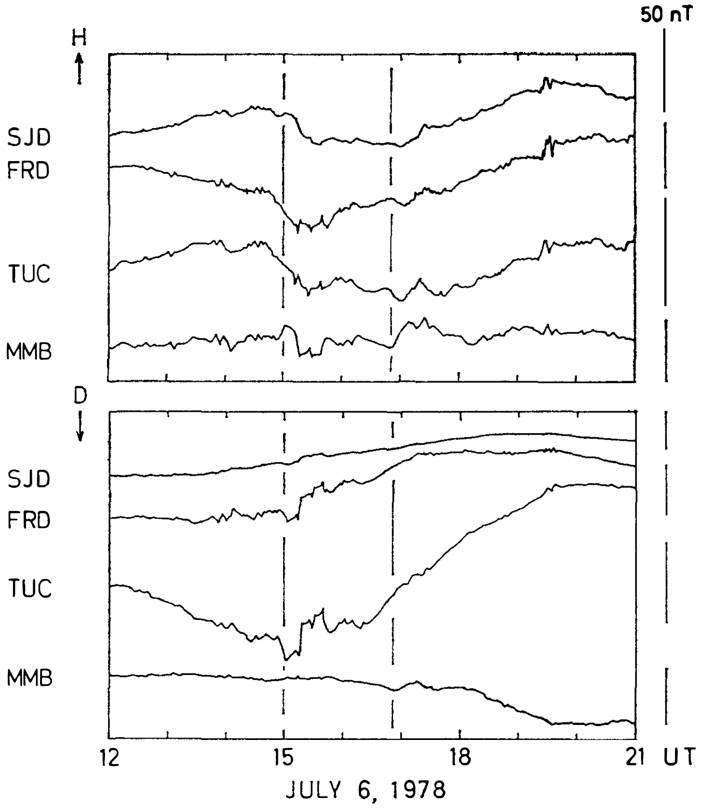

Fig 3. The traces of the H and D components of the magnetograms on July 6, 1978 at four mid-latitude stations; San Juan (SJD, geomag. lat. 29.0°, local midnight is near 4 UT), Fredericksburg (FRD, 49.6°, near 5 UT), Tucson (TUC, 40.4°, near 7 UT) and Memambetsu (MMB, 34.0°, near 15 UT). A clear positive bay was seen around 1651 at MMB, while no clear positive bay was seen around 1500

unconfirmed, to the northward-to-southward turning of IMF B_z around 15 UT (MAEZAWA, 1976). The above characteristics indicate that the geomagnetic activities, which began around 15 UT, may be due to the enhancement of the magnetospheric convection (*e.g.* NISHIDA, 1978). A well-defined onset was not seen until 1651.

The fluxes of the protons and the electrons began to decrease around 1500, which seems to correspond with the enhancement of the magnetospheric convection, at each satellite's position. At the 1651 onset of the substorm expansion phase an increase of the particle flux was seen at each satellite's position. The electron flux seemed to recover gradually to the pre-substorm level. On the other hand, the marked enhancement could be found in the proton flux, especially at GMS and GOES-3. The time for the increase of the proton flux at GMS was about 15 minutes earlier than that at GOES-3. It is noteworthy that the flux variation could be found near noon meridian, as indicated in the data obtained by GOES-2.

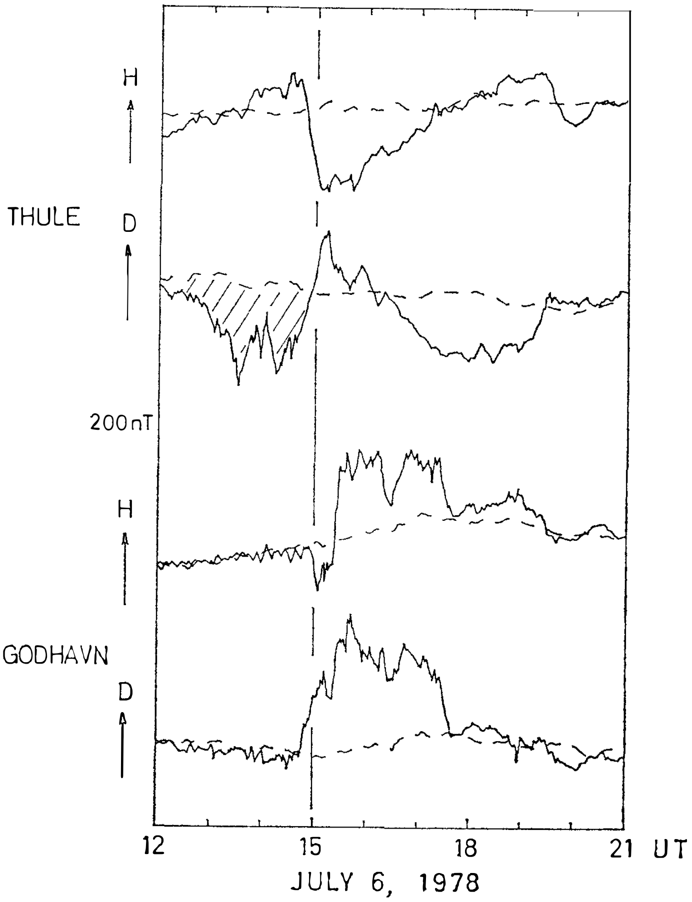

Fig 4. The traces of the H and D components of the magnetograms on July 6, 1978 at two polar cap stations, Thule (87 7°) and Godhavn (77.7°). The broken lines indicate the traces of the quiet day's variation (July 31, 1978) The local noon is near 14 UT for the two stations The negative ΔD variation before 15 UT indicates that the equivalent current flowed anti-sunward over Thule

The similar behavior of the energetic particle flux could be seen for the 1809 substorm on July 7 and the 1500 substorm on July 8, when the three satellites were located in the dawn side.

3.1.2. 1045 substorm on July 7 (2005 LT for GMS, 0145 LT for GOES-3 and 0545 LT for GOES-2)

In this case GMS was situated in the evening side and GOES-3 and GOES-2 were in the postmidnight-morning side The positive ΔH variations in the afternoon auroral zone began around 0900 and the negative ΔH variations in the morning side auroral zone began around 1000. The major onset of the substorm was not seen in the magnetograms of the Fort Churchill chain, the East-West chain and the Alaska chain until 1045 Before the 1045 onset the flux decrease was seen in the midnight-morning side, but no variation was seen at GMS. At the onset the particle flux recovered to the pre-substorm level in the midnight-morning side and the particle flux decreased in the evening side. The particle flux in the evening side returned to the predecrease level around 1130, which seemed to be before the end of the substorm. This event shows that the behavior of the energetic particle flux in the evening side contrasts with that in the midnight-morning side.

The similar behavior of the energetic particle flux could be seen for the 0100 substorm on July 7 and the 0024 substorm on July 8.

The magnetic activities were quite active even after the 1809 substorm on July 7 and the positive ΔH variations with magnitude of about 200 nT were seen at Great Whale River and Fort Churchill. A clear substorm onset was seen at 0024 on July 8. The broad auroral zone negative bay was seen in the midnight-morning side and the positive ΔH variations with magnitude of 100–200 nT were seen at Yellowknife and College in the early hours on July 8. After the 0024 substorm on July 8 the energetic particle flux decreased in the evening-midnight side. Two clear onsets were recorded at 0618 and 0713 in the northern part of the Alaska chain and the recovery of the particle flux from the depression level was associated with these substorms. The enhancement of the proton flux was recorded at GOES-2 and probably at GOES-3 and the decrease was observed simultaneously for both protons and electrons at GMS.

3.2. March 5, 1978 $Kp=0_{+}0_{0}1_{0}2_{+}2_{+}3_{-}2_{0}1_{+}$

The data of the energetic particle flux and the traces of the H or X component of the magnetograms are presented in Fig. 5. We find no substorm activity during the period between 12 UT on March 4 and 06 UT on March 5. The substorms were recorded around 0657 (Fort Churchill), 0830 (Yellowknife), 1034 (College), 1145 (College), 1404 (Cape Wellen and Tixie Bay) and 1630 (Tixie Bay) in the auroral zone magnetograms. For the first substorm (0657) no variation was seen in the particle flux. The flux decrease steepened around 0915 in both the proton flux and the electron flux, which might be associated with the 0830 substorm. The particle flux became below the noise level around 1145. The sequences of the steepening of the flux decrease and the small recovery were recorded around 1030 and 1115. The start times of these sequences seemed to correspond to the Pi 2 activities (1036 and 1115) at Memambetsu (this station is situated near the GMS meridian). In the case of the 1145 large substorm, the energetic particle flux was below the noise level. For the 1404 substorm, the sharp increase with a short duration was recorded in both the proton flux and the electron flux. The low-latitude positive bay was not clear in the midnight sector for this substorm. A clear positive bay was recorded around 1635 at Memambetsu and the particle flux recovered in association with this substorm. After this

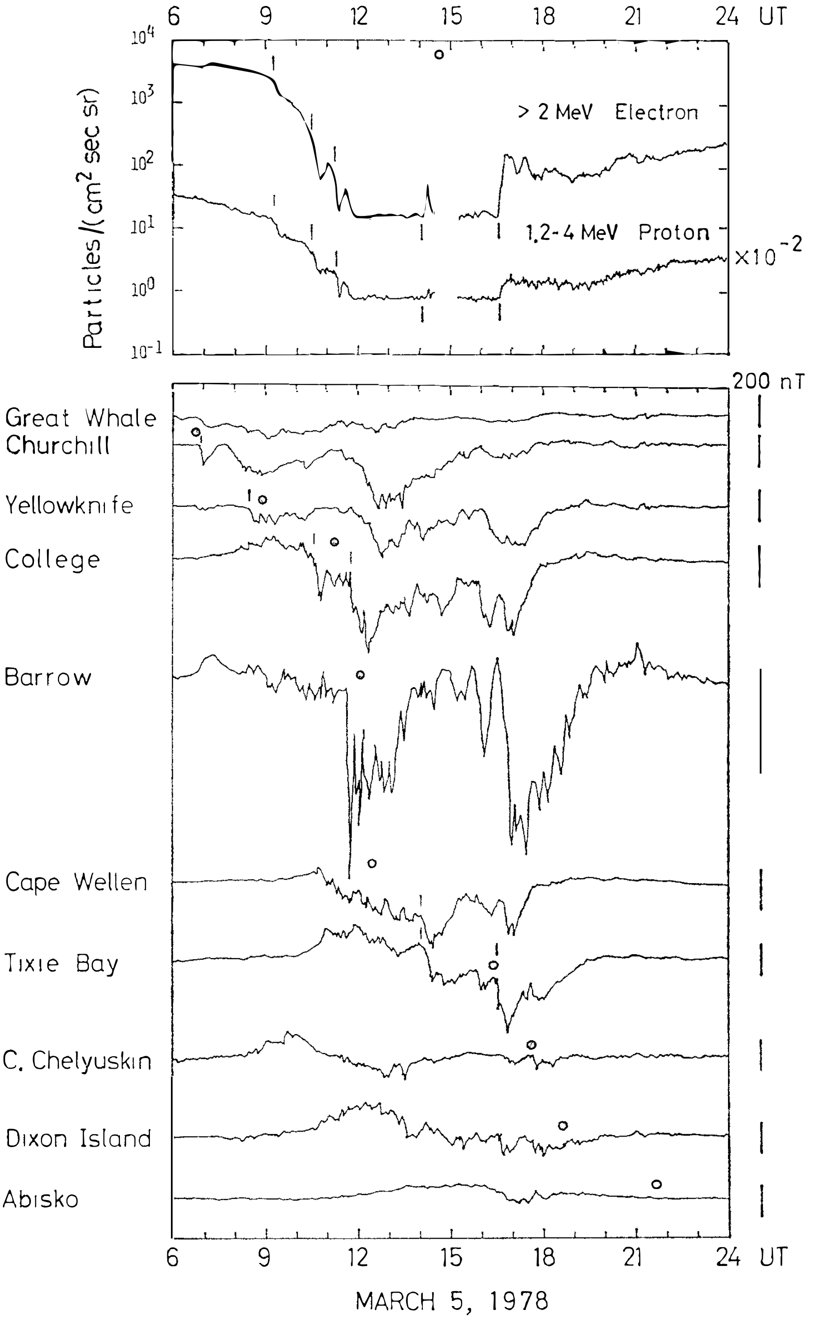

Fig 5. The upper panel shows the energetic particle flux obtained by GMS The lower panel shows the H or X component traces of the magnetograms at auroral zone stations Each dot indicates the local midnight

substorm the substorm activity was not seen until 08 UT on March 6, 1978. It is noted that the flux did not recover to the pre-substorm level even when the last substorm activity disappeared.

3.3. February 21, 1978 $Kp=2_{-}2_{+}1_{0}2_{+}2_{+}4_{+}3_{0}3_{0}$

The data of the energetic particle flux and the traces of the H or X component of the magnetograms are presented in Fig. 6. We find no substorm activity from 07 UT

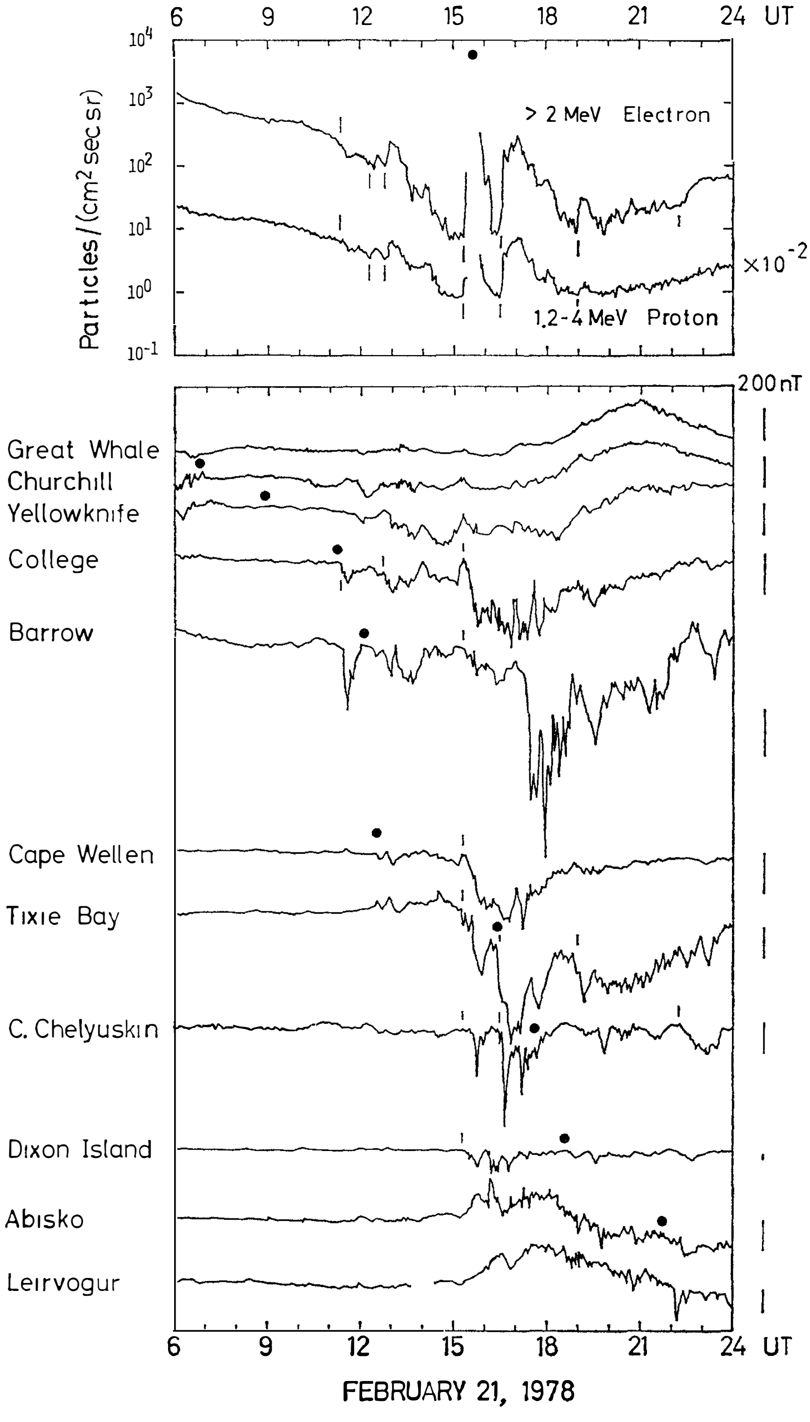

Fig 6. The upper panel shows the energetic particle flux obtained by GMS. The lower panel shows the H or X component traces of the magnetograms at auroral zone stations. Each dot indicates the local midnight.

to 11 UT on this day. The Pi 2 activities were recorded around 1124, 1217 and 1245 at Memambetsu and the developments of the westward electrojets were recorded around 1123 and 1243 at College. The flux decrease steepened around 1125 in both the proton flux and the electron flux, and the flux showed the small recoveries in association with other two substorms The particle flux gradually decreased after these substorms and it became below the noise level around 1450 During the period when the flux decreased no Pi 2 was recorded at Memambetsu New substorm sequences started after 1515 Though the weak Pi 2 activities were recorded around 1515, 1536 and 1545, the intense Pi 2 activity was recorded around 1526. The auroral zone negative bay was seen in the large region from College to Dixon in association with the Pi 2 activities. The sharp recovery of the particle flux started before 1522. The intense Pi 2 activities occurred at Memambetsu at 1609 and 1615, successively. The auroral zone negative bay was seen at Tixie Bay, Cape Chelyuskin and Dixon The sharp recovery of the particle flux started before 1632, but the flux was decreasing rapidly at the times of the two intense Pi 2 activities Though the next substorm started around 1900 at Tixie Bay and the small recovery was seen in the particle flux, the flux decreased after 1700 and it continued to be in the lower level During the period when the particle flux was in the low level the broad negative bay was recorded at Tixie Bay and the broad positive bay was recorded at Great Whale River, Fort Churchill and Yellowknife The increase of the electron flux around 2215 seemed to be associated with the substorm at Cape Chelyuskin (a mid-latitude positive bay was recorded at Tashkent).

4. Summary and Discussion

From the multi-satellite study, it has been shown that the gross behavior of the energetic particle flux in the evening side contrasts with that in the midnight-morning side for the major onset of the substorm expansion phase The particle flux increases at the onset in the midnight-morning side and the flux depression is seen prior to that onset, while the flux decreases after the onset in the evening side This result is consistent with the 'fault-line' concept, which was suggested by Lezniak and Winckler (1970), based upon the statistical analysis. The flux decrease prior to the major onset seems to be associated with the convection-type geomagnetic activity, as described earlier by Kokubun (1978) In order to completely understand the physical processes, many data are required and we should take the positions of the satellites in the geomagnetic coordinate into consideration An important point whether or not every substorm has a 'fault-line' in the evening side should be also examined. In connection with this point we have indicated that the flux behavior, during the period when the substorm occurred successively, seems to be different from that for the relatively large and isolated substorm. When the continued geomagnetic activities are seen in the auroral zone, the particle flux shows a depression in the night side and the small increase of the particle flux with a short duration is seen at each substorm onset. As the variation of the proton flux is quite similar to that of the electron flux at any local time (in the cases on March 5 and February 21), the increase of the particle flux could not be caused by the particle injection. The change of the configuration of the magnetosphere may be important in these processes.

The above results are derived from only a few examples of the data obtained mainly by GMS, but the behavior of the energetic particle flux is quite complex in most cases. We are currently studying in more detail the characteristics of the energetic particle phenomena.

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