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Some Characters of Substorm-Associated Geomagnetic Phenomena in the Southern Polar Region (1)

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Abstract

Continuous observations of geomagnetic phenomena have been carried out during September and December, 1973 at Syowa Station and the inland station (Mizuho Camp and Yamato Mountain Base Camp) in Antarctica simultaneously. During substorm time, geomagnetic variations of the inland station show quite different characters with that from Syowa Station, although their distances are only a few hundred kilometers or so. Some preliminary results of characters of those phenomena are presented.

1. Introduction

The magnetospheric substorm which is a dramatic phenomenon in the whole magnetosphere has various manifestations that are polar magnetic substorm, electron aurora substorm, proton aurora substorm, magnetic pulsation substorm, ionospheric substorm, X-ray substorm and VLF emission substorm (Akasofu, 1968). Those phenomena are observed both in space by satellites or rockets and on the ground stations. The space vehicle observation has an advantage of direct measurements of magnetic and electric fields, wave emissions and particles in the magnetosphere. But it is difficult to distinguish between time-dependent and position-dependent components from the space data. The ground observation has an advantage of monitoring geomagnetic phenomena at a fixed point for a long time.

An example of some manifestations of the magnetospheric substorm which are observed at the auroral station in Antarctica, Syowa Station, is shown in Fig. 1. The figure contains auroral substorm, magnetic pulsation substorm and VLF emission substorm. It is recognized that they are closely related phenomena. They are suddenly activated at the same time of substorm onset, 2209 MLT on September 15 for example except VLF substorm which is rather suddenly diminished from the pre-raised level coinciding with the onset.

One of the most essential characters of substorm is a drastic movement of the active region. For example, coinciding with substorm onset a rapid poleward motion of aurora is observed (Akasofu, 1968). Yanagihara (1963) has compared substorm-associated Pi pulsations at Churchill, Great Whale and Byrd, the last of which is located near the conjugate position of the former two. Based on the analysis, he suggests that the active center of Pi pulsations may move westward. Geomagnetic phenomena must be studied by data of many ground stations spaced in systematic

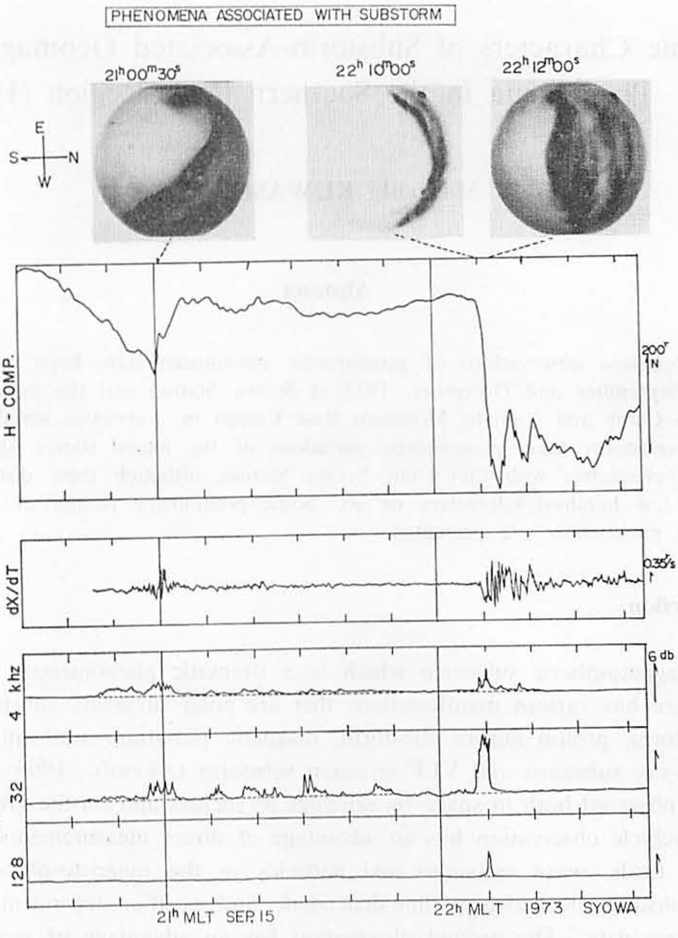

Fig. 1. Records of all sky camera photographs, horizontal component of magnetic variation, X component of magnetic pulsation and intensity of VLF hiss emissions, observed at Syowa Station on September 15, 1973. In this example, the substorm breakups occur at about 2058 MLT and 2210 MLT.

arrays to solve various aspect of substorm such as those mentioned above.

Recently, observations at stations which chain latitudinally have been made in the auroral zone (Samson, et al. 1971) and near the plasmapause (Fukunishi, et al. 1974; Fukunishi, 1975). The former has been used to study Pc5 pulsations and the latter to study Pc3, 4 pulsations, Pi2 pulsations as well as Pc5 pulsations. The trial of simultaneous observations at several stations has been also carried out around Syowa Station, in Antarctica. Magnetic field and magnetic pulsation measurements have been made from August 28 to September 29, 1973 at Mizuho Camp and from December 1 to 10, 1973 at Yamato Mountain in the Antarctic inland area with a portable flux-gate magnetometer and an induction magnetometer respectively.

Similar observations have been made simultaneously at Syowa Station. Mizuho Camp is located along the almost same geomagnetic meridian of Syowa Station and about 2 degrees poleward in geomagnetic latitude. L values of two stations are 8.0 and 6.5 respectively. In magnetically disturbed conditions, substorm-time for example, geomagnetic phenomena at two stations occasionally show quite different aspects. Investigation of substorm-associated phenomena are in progress by the author by comparing the data of Mizuho and those of Syowa. In this paper, concerning with Mizuho and Syowa, some preliminary results are reported.

Geomagnetic coordinates of the stations used in the analysis are listed in Table 1. The locations of those stations are also shown in Fig. 2.

Table 1 Geomagnetic Locations

Station	Geomagnetic Lat.	Geomagnetic Long.
Mawson	−73.1°	102.9°
Mizuho	−71.8	76.9
Yamato Mt.	−70.6	68.4
Syowa	−69.6	76.2
Sanae	−63.6	44.2
Hermanus	−33.3	80.5

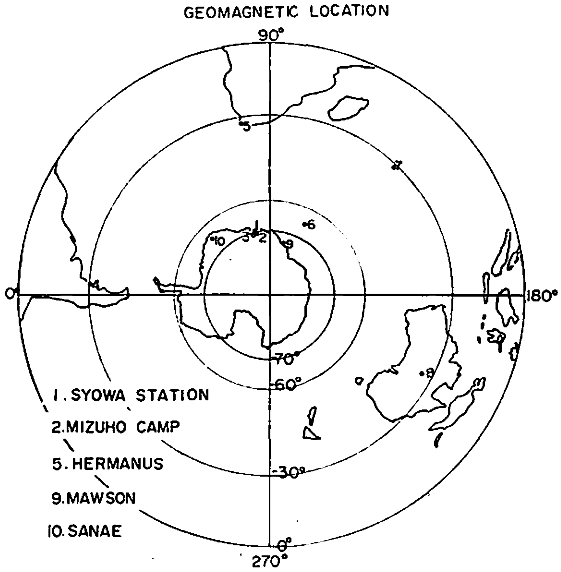

Fig. 2. Geomagnetic location of the stations which are used in this paper.

2. Magnetic substorms and auroral substorms

In magnetically quiet condition, the shapes of trace of magnetic variations observed simultaneously at Mizuho and Syowa are similar. On the other hand in magnetically disturbed condition, during substorm for example, magnetic variations at two stations show different characters each other. Fig. 3 shows three typical examples of magnetic substorm simultaneously observed at Syowa and Mizuho. Concerning Z-component, there are distinct differences between Syowa and Mizuho not only in shapes of trace but also in directions of variation. In Fig. 3 at about 2209 MLT on September 15, 1973, Z-component of each station show a sudden upward change. At Syowa the variation is converted to downward change at 2211 MLT (2 minutes after the onset), when upward change is still in progress at Mizuho.

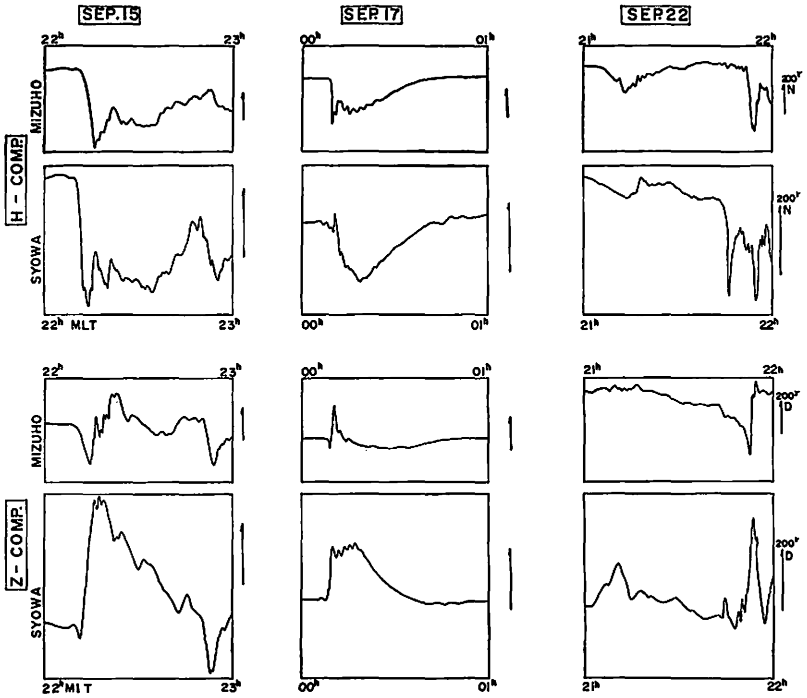

Fig. 3. H and Z component magnetic variations simultaneously observed at Mizuho and Syowa on September 15 (left), September 17 (middle) and September 22 (right).

Upward change at Mizuho is converted to downward one at 2214 MLT (3 minutes after that at Syowa). Z-component at Syowa shows conspicuous downward change from 2211 MLT to 2216 MLT and the maximum deviation from the pre-storm level reaches to 359 gammas. On the other hand there is no distinct downward change at the same time at Mizuho. The maximum deviation of the upward change from the pre-storm level at Mizuho is 244 gammas, which is much larger than that at Syowa (46 gammas).

Another example of different directions of Z-component changes start at about 2214 MLT and 2151 MLT respectively. Their maximum ranges of variation are 66 gammas and 309 gammas. On the other hand, at Mizuho there are also two Z-component changes corresponding to those at Syowa, but their directions are upward. The maximum deviations of upward change at Mizuho are 79 gammas and 232 gammas respectively. In these events, the directions of Z-component variation are opposed each other for Syowa and Mizuho.

Concerning H-component, roughly speaking, shapes of trace of its variation at two stations are similar. But the maximum ranges of H-component decrease are not necessarily the same value for Syowa and Mizuho. For example in the September 15 event in Fig. 3, the maximum deviations of H-component at the two stations are nearly the same; −490 gammas at Syowa and −525 gammas at Mizuho. But in the September 17 event, the maximum deviation at Syowa is about ⅔ of that at Mizuho, −209 gammas and −308 gammas respectively. In the September 22 event, at Syowa two sharp decreases of H-component start at 2144 MLT and 2151 MLT respectively, but at Mizuho only one corresponding change at the latter time is found.

From the above discussion, it becomes clear that at the substorm time magnetic variations at Syowa and Mizuho which are located with a distance of only two hundred and fifty kilometers show different characters in their shapes of trace, directions and ranges of variation. The most possible source which causes above differences between two stations may be a sharply concentrated westward auroral electrojet (abbreviated to AE hereafter) assumed to flow in the ionospheric E layer associated with the auroral substorm. If AE is the source of magnetic disturbances observed on the ground, the situation shown in Fig. 4 should be suggested. Concerning H-component, the nearer AE approaches towards an observing station, the larger the decrease of field intensity of station becomes. Concerning Z-component following three cases are thought.

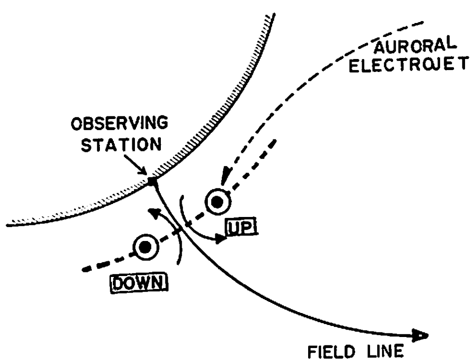

Fig. 4. Schematic illustration for the relation between the location of AE and the sense of magnetic variation observed on the ground.

1) AE is located in the equatorside of an observing station. In this case, an upward Z-component change should be observed.

2) AE is located near the zenith of a station. In this case, any Z-component change should not be observed.

3) AE is located in the polarside of a station. In this case, a downward Z-component change should be observed.

It should be noted that both magnitudes of H- and Z-component variations will depend not only on a location of AE but also on a rise and fall of AE activity. It should be also noted that if earth induction effects were as large as those by AE, such a systematic variations as supposed from Fig. 4 would not be expressed.

AE is thought to be westward currents in the ionospheric E layer and be connected with plasmasheet through three dimensional field aligned current. Auroral breakup is thought to be also brought about by the precipitation of the energetic particles from the plasmasheet along the field line into the E layer. Thus AE and aurora have common source and are thought to be the same phenomena essentially. Recently by rocket experiments in the southern polar region by Japanese Antarctic Research Expedition team, the following facts are observed (Miyazaki, et al. 1974, Nagata, et al. 1974). When auroral activity increases near Syowa, the electron density and the intensity of electric field in a height of 100 kilometers (E layer) are largely increased. So it is naturally assumed that when the activity of AE increases in the ionosphere, auroral substorm usually occurs there and vice versa. So, we may be able to monitor the dynamic behavior of AE by constructing space-time diagrams of aurora. Standing on the point of view, the idea of Fig. 4 is examined.

Fig 5 shows a space-time diagram of typical electron aurora (5577Å) observed at Syowa as well as simultaneously observed magnetic H- and Z-components at Syowa and Mizuho. The space-time diagram is constructed from the records of the meridian scanning photometers.

In the space-time diagram of aurora, there are two auroral breakup events, one starts at about 2143 MLT on September 22 and another starts at about 2152 MLT. In the first event, two auroras at different latitudes suddenly brighten simultaneously at about 2143 MLT. Then the poleside one moves poleward rapidly with a speed of 4 kilometers/sec and arrives at the position which is distant from Syowa about 50 kilometers poleward at about 2145 MLT, via the zenith of Syowa. The equatorside one doesn't show any distinct motion. During that event, a sudden decrease of H-component is observed at Syowa with the maximum deviation of 370 gammas. At Mizuho there is a little variation in H-component. In the second events, simultaneous decrease of H-component at two stations are found and those variations are coincident with the auroral poleward movement and brightening which start at about 2152 MLT. The maximum ranges of H-component decreases are −309 gammas at Syowa and −475 gammas at Mizuho respectively.

Concerning Z-component in the first event, there is no distinct change at both two stations. There are only small changes, 66 gammas downward at Syowa and 79 gammas upward at Mizuho at 2145 MLT, when aurora is located at 50 kilometers distance from Syowa to the poleward (200 kilometers equatorward from Mizuho). In the second event, poleward motion of aurora starts at about 2152 MLT and aurora passes over Mizuho at about 2153.5 MLT. Coinciding with the passage over Mizuho, a sudden reversal of the direction of Z-component variation, from upward to downward, is observed at Mizuho. During that event, aurora is always located in the poleside of Syowa, and the direction of variation of Z-component is always downward at Syowa.

In this section, the comparison between the movement of aurora (AE) and the magnetic variation has been treated. It is evident that the assumption shown in Fig. 4 is consistent with the observed phenomena, at least in the first order approximation. It is also evident that at the onset of the substorm, AE flows westward with so narrow width that its motion is able to be monitored by using differences

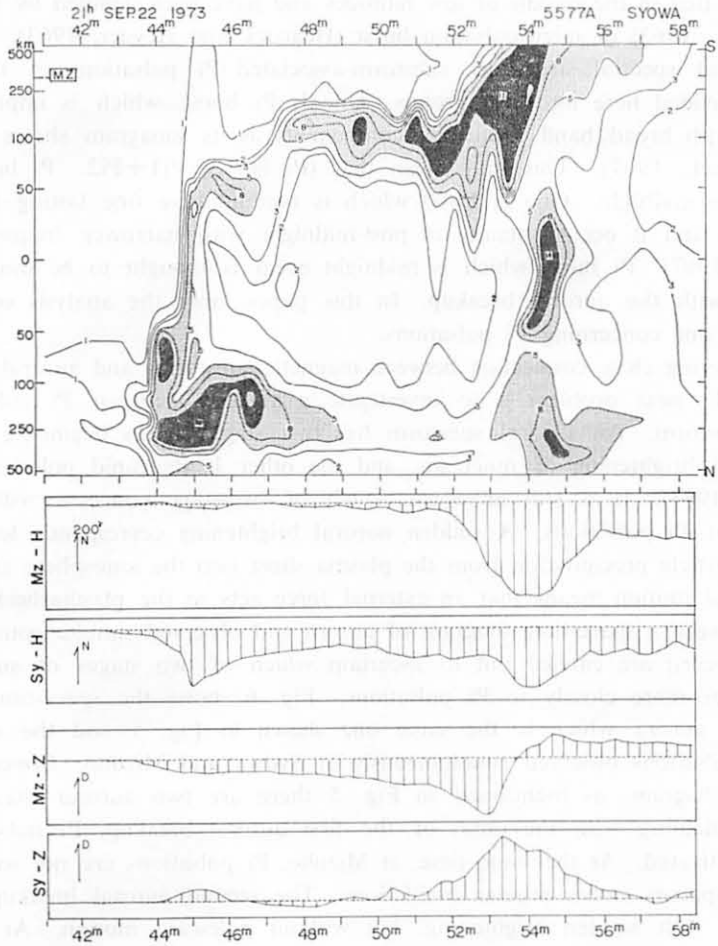

Fig. 5. Space-time diagram of electron aurora (5577A) and simultaneously observed magnetic variations at Mizuho and Syowa. Numerals of the isointensity contours of electron aurora are given in units of 500 rayleighs.

of magnetic variations between at Syowa and at Mizuho. The distance between two stations is only 250 kilometers.

3. Relations between Pi pulsations and auroral and magnetic substorms

Pi pulsations are thought to begin coinciding with the beginning of a bay. According to period, they are divided into two groups, Pi1 (1-40 sec) and Pi2 (40-150 sec). Pi2 is traced back to damped-type magnetic oscillations in the middle or low latitudes (Pt) and Pi1 is to short period component of Pt (Saito, 1960) or spt (Yanagihara, 1959). But Pi pulsations in the auroral zone have more noisy waveforms than that in the middle or low latitudes and have been denoted by noise burst (Yanagihara, 1963) or micropulsation burst (Heacock and Hessler, 1963). According to dynamical spectral structures, substorm-associated Pi pulsations in the auroral zone are divided here into two groups. One is Pi burst, which is impulsive phenomenon with broad band frequency components as its sonagram shows a vertical line (Heacock, 1967). This may mean that (Pi burst)=Pi1+Pi2. Pi burst occurs mainly near midnight. One is Pi(C) which is nonimpulsive one lasting for one to three hours and it occurs mainly in post-midnight with narrower frequency range (Heacock, 1967). Pi burst which is midnight event is thought to be more directly associated with the auroral breakup. In this paper, only the analysis of Pi burst are carried out concerning Pi pulsations.

Considering close connection between magnetic substorms and auroral substorms through AE, next problem is to investigate a relation between Pi pulsation and auroral substorm. An auroral substorm has two stages at its beginning part, one is a sudden brightening of quiet arc and the other is its rapid poleward motion (Akasofu, 1968). It is still unknown which of two-stage concerns with start or activation of Pi pulsations. A sudden auroral brightening corresponds to a drastic energetic particle precipitation from the plasma sheet into the ionosphere and a poleward auroral motion means that an external force acts in the plasmasheet. A comparison between a space-time diagram of aurora and observed simultaneous magnetic pulsation record are carried out to ascertain which of two stages of auroral substorm relates more closely to Pi pulsations. Fig. 6 shows the space-time diagram of electron aurora which is the same one shown in Fig. 5 and the records of magnetic pulsations observed simultaneously at Syowa and Mizuho. Concerning the space-time diagram, as mentioned in Fig. 5 there are two auroral breakups. At Syowa, coinciding with the onset of the first auroral breakup, Pi pulsations are suddenly activated. At the same time, at Mizuho, Pi pulsations are not so activated, but there appears rather regular oscillations. The second auroral breakup starts at 2148 MLT with sudden brightening, but without poleward motion. At the same time there is no distinct activation of Pi pulsations at Mizuho as well as Syowa. At Mizuho, an activation of Pi pulsations begins at about 2152 MLT, when poleward auroral motion begins. From the relation shown in Fig. 6 it is suggested that Pi pulsations are more largely activated at the stage of poleward auroral motion than at the stage of sudden auroral brightening.

Fig. 7 shows sonagrams of substorm-associated Pi pulsations observed simultaneously at Syowa and Mizuho as well as magnetic H-component variations. In the figure, Pi burst events are found at 2210 MLT on September 15, 0035, 0050, 0110 MLT on September 16, 0008 MLT on September 17 and 2144, 2152 MLT on September 22, respectively. Three events among the whole of seven are accompanied with sudden decrease of H-component at two stations, and four events are accompanied with H-component decrease observed only at Syowa. Considering a sudden decrease of H-component corresponds to the onset of a magnetic substorm, it is evident that a Pi burst event is coincident with the onset of a magnetic substorm. On the other hand the middle and low latitude Pi2 (Pt) is also known to

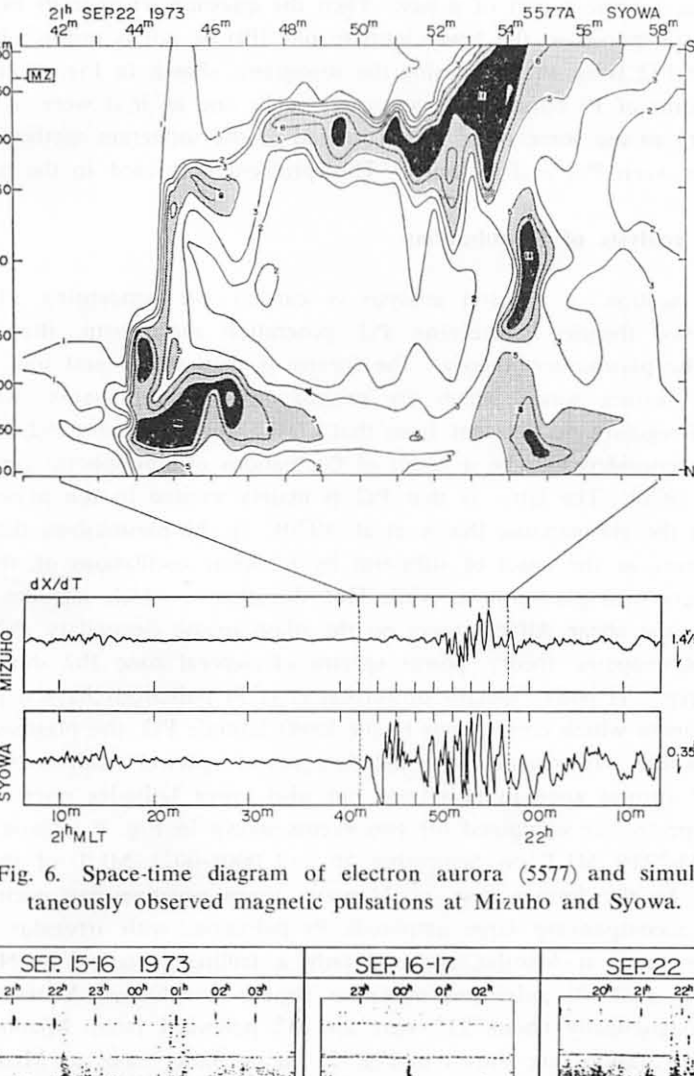

Fig. 6. Space-time diagram of electron aurora (5577) and simultaneously observed magnetic pulsations at Mizuho and Syowa.

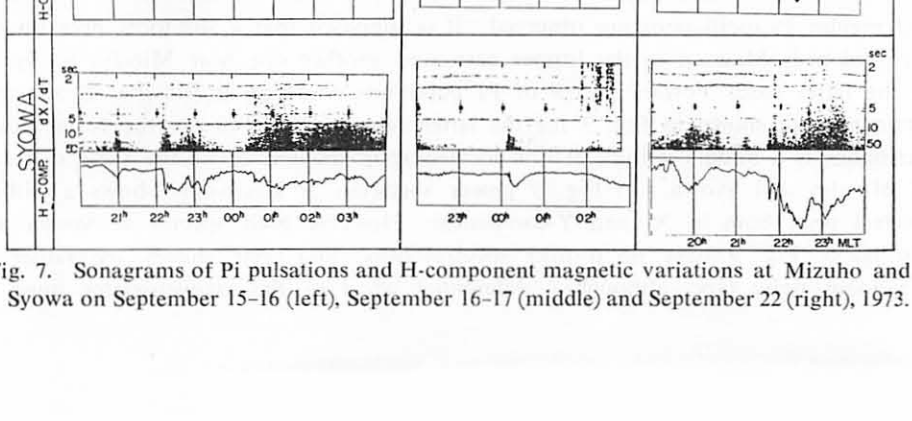

Fig. 7. Sonagrams of Pi pulsations and H-component magnetic variations at Mizuho and Syowa on September 15-16 (left), September 16-17 (middle) and September 22 (right), 1973.

appear at the beginning part of a bay. Then the question whether Pi burst contains Pi2 which corresponds to the lower latitude one (Pt) or not is arisen. It is difficult to distinguish Pi2 from Pi burst using the sonagrams shown in Fig. 7, in which the dynamic spectra of Pi burst shows vertical straight line as if it were a white noise. It is necessary to use some other means instead of the sonagram method to find the distinction between Pi2 and Pi burst. This problem is treated in the next section.

4. Spectral analysis of Pi pulsations

In this section, a spectral analysis is carried out concerning Pi pulsations. There are two theories concerning Pi2 generation mechanism, the plasmapause theory and the plasmasheet theory. The former is that middle and low latitude Pi2 are transient surface waves which are excited on the plasmapause, while auroral zone Pi2 is irregular and different from that of the lower latitudes Pi2. The auroral zone Pi2 are considered to be a result of fluctuations of ionospheric current (Fukushi, et al. 1970). The latter is that Pi2 is mainly excited in the plasmasheet and secondary on the plasmapause (Saito, et al. 1970). In the plasmasheet theory auroral zone Pi2 occurs at the onset of substorm by torsional oscillations of the field line which connects with plasmasheet, while HM disturbance which intrudes toward the earth induces the shear Alfve'n wave on the plasmapause (secondary Pi2). According to the plasmapause theory, power spectra of auroral zone Pi2 should be of a white noise type. If power spectra of auroral zone Pi pulsations have a predominant period component which corresponds to the lower latitude Pi2, the plasmasheet theory will be favorable. To examine the theories, power spectral analysis is carried out for not only auroral zone Pi pulsations but also lower latitudes ones.

Power spectra are computed for two events shown in Fig. 8. Those time intervals are 2203-2216 MLT on September 16 and 0008-0021 MLT of the next day respectively. In the former case, at Mawson, sharp negative bay occurs at about 2203 MLT accompanying large amplitude Pi pulsations with irregular waveforms. At the same time, at Mizuho, there is only a trifling variation in H-component accompanying small Pi pulsations of rather regular waveforms. Mawson station is located geomagnetically about 23° east and 4° poleward from Mizuho. The locations of two stations are shown in Fig. 2. In the latter case, at Mizuho, sudden decrease of H-component starts at 0008 MLT accompanying Pi pulsation with large amplitudes. Simultaneously at Mawson, there is a little variation in H-component and regular Pi oscillations are observed. It is supposed that a substorm breakup has occurred near Mawson in the former case, and another one near Mizuho or Syowa in the latter case. Power spectra of Pi pulsations observed at Mizuho, Syowa and Hermanus are shown in Fig. 9 for the latter case and Fig. 10 for the former case. Hermanus is a middle latitude station located approximately along the same meridian of Mizuho and Syowa. In Fig. 9 power spectrum at Hermanus shows a distinct spectral peak both in X- and Y-component. However both spectra at Syowa and Mizuho of Fig. 9 have no distinct spectral peak, and their shapes are rather of a random noise type, although a differential effect of the magnetometer must be

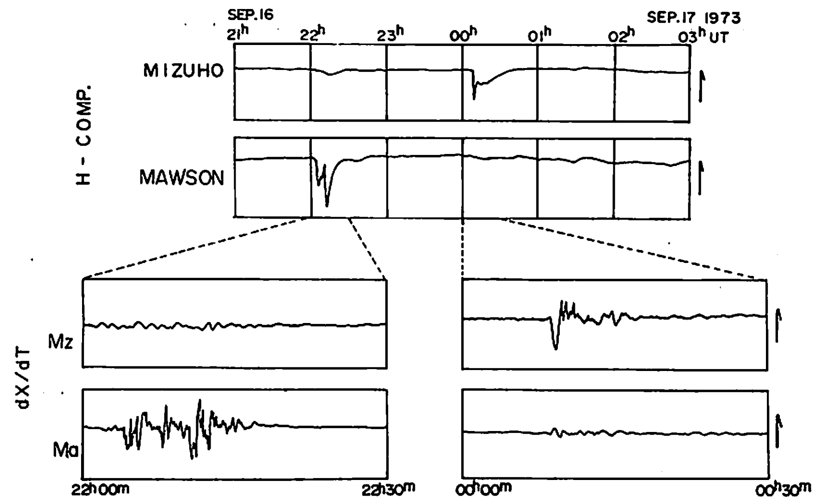

Fig. 8. H-component magnetic variations and simultaneously observed Pi pulsations at Mizuho and Mawson.

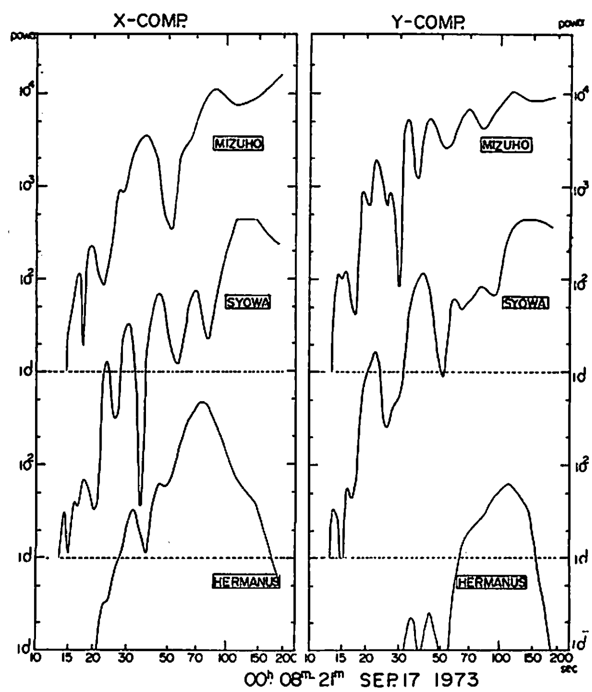

Fig. 9. Power spectra of Pi pulsations observed during 0008-0021 MLT on September 17 at Mizuho (top), Syowa (middle) and Hermanus (bottom). At about 0008 MLT a substorm breakup has occurred near Mizuho and Syowa.

considered. It is ambiguous whether a spectral peak which corresponds to that at Hermanus exists in their spectrum or not. In Fig. 10 a common predominant spectral peak is found about 80 sec both in X- and Y-component at three stations. This fact is more favorable to the plasmasheet theory. The reason why we cannot find a predominant spectral peak in power spectra at Syowa or Mizuho in Fig. 9 may be that regular Pi2 component is masked by Pi burst which are intense near the region where substorm breakup occurs.

From the results given in Figs. 9 and 10, the following situation is supposed. Pi pulsations observed near midnight in the auroral zone are (regular Pi2)+(Pi burst). The latter is local phenomena and it is intense only near the region where the substorm breakup occurs. The former one is not local, and corresponds to the lower latitude Pi2 (Pt).

Waveforms of Pi pulsations at Mizuho and Syowa are shown in enlarged scale in Fig. 11 for the event whose substorm breakup has occurred near their zenith. The substorm breakup occurs at 0008 MLT at the region between Syowa and Mizuho. Coinciding with the substorm onset, large amplitude oscillations starts at each station. During a few minutes from the onset, the waveforms have not any similarity

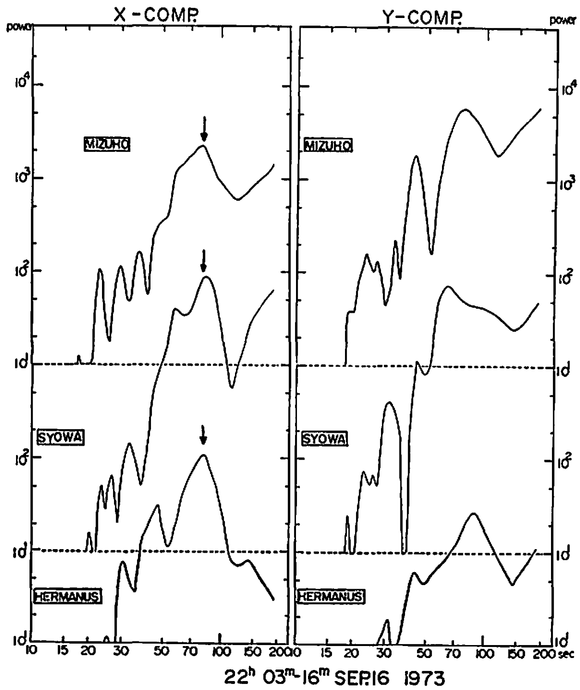

Fig. 10. Power spectra of Pi pulsations observed during 2203-2216 MLT on September 16 at Mizuho (top), Syowa (middle) and Hermanus (bottom). At about 2203 MLT a substorm breakup has occurred near Mawson, which is about 2000 kilometers to the east of Syowa of Mizuho.

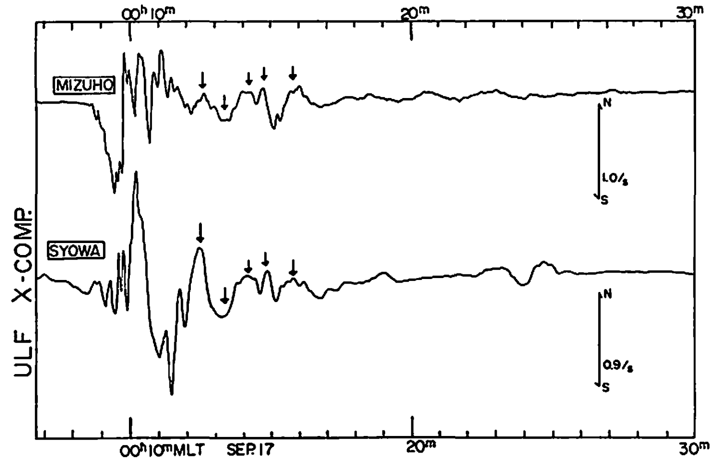

Fig. 11. Waveforms of Pi pulsations simultaneously observed at Mizuho and Syowa. A substorm breakup has occurred at about 0008 MLT between the two stations.

in the two stations. About 0012 MLT (4 minutes after the onset), sinusoidal waveforms appear at two stations with peak to peak correspondences. It seems that the first part is consisted of (Pi burst which has irregular waveforms with larger amplitude)+(regular Pi2) and the latter one is regular Pi2 only.

5. Discussion

Substorm-associated phenomena and their interrelations have been investigated and preliminary results of the analysis have been reported in section 2-4.

1) It is evident from a comparison between magnetic substorms and auroral substorms that the magnetic disturbances observed in the auroral zone are induced by AE which flows in the ionospheric E layer associated with an auroral substorm. Coinciding with the substorm onset AE is intensified and rapidly moves polewards following poleward auroral motion. AE is so enough concentrated that its motion can be monitored from differences of magnetograms between Syowa and Mizuho, which are apart only 250 kilometers from each other. Recently discrete auroras which have line structure are observed by DAPP satellite (Akasofu, 1974). There is a possibility that AE flows associated with those discrete auroras. But the magnetic variations discussed in the above sections are confined to only spike like impulsive sharp negative bay. That is observed mainly near midnight. In post-midnight broad negative bay with long duration (lasts one to three hours) is frequently observed. A broad negative bay appears in more wide area than that of a sharp negative bay. Concerning a broad negative bay, there is not so distinct difference between Syowa and Mizuho as that in a sharp negative bay. A broad negative bay may correspond to diffused aurora observed in post-midnight. Therefore it should be noted that the good correlation between aurora (AE) and magnetic variation shown in section 2 is

only obtained for the phenomena near midnight (a discrete aurora and a sharp negative bay). Concerning the phenomena in post-midnight (a diffused aurora and a broad negative bay) no analysis has been given in this paper, because the distance between Syowa and Mizuho is too short to examine an occurrence area of a broad negative bay.

2) Pi pulsations seem to be intensified associated with the auroral poleward motion. Considering Pi pulsations in the auroral zone contain several sub-types, it is still uncertain which of the types is intensified. After classification of Pi pulsations is examined, that investigation should be continued.

3) It is found in the discussion in section 4 that Pi pulsation observed near midnight in the auroral zone have a predominant spectral peak, which is corresponds to the one in the lower latitude Pi2. That result is more favorable to the plasmasheet theory than to the plasmapause theory in the Pi2 generation mechanism. Pi pulsation near midnight is seemed to be consisted of the following two parts, (Pi2 which is regular)+(Pi burst which is irregular). Regular Pi2 corresponds to the middle- and low-latitude Pi2 and essentially HM wave derived by the torsional oscillations of field line in the auroral zone. Pi bursts are local phenomena and are intensified only near the region, where substorm breakup occurs. In the case that substorm breakup occurs near an observing station, power spectrum of Pi pulsations shows a random noise type in appearance. That may be owing to the effect that Pi2 component is masked by the intensified Pi burst.

In this paper Pi pulsations are investigated confined to the midnight phenomena. There are also Pi pulsations in pre-midnight (IPDP), in post-midnight (Pi(c)) and even in the dayside (Pid). The synthetical spectral analysis of Pi pulsations is desired to understand HM phenomena in the magnetosphere.

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e) The Director of Antarctic Division, Australia for the data at Mawson.

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南半球極光帯における，サブストーム時の地磁気現象の特性（1）

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概　　要

1973年9月に南極の昭和基地と内陸みずほ前進基地で同年12月に昭和基地と内陸大和山脈 E. F. G 郡中間点で，地磁気 H, D, Z 3成分および磁気脈動 X, Y 2成分の連続同時観測が行なわれた。昭和基地と内陸基地とは数 100 km しか離れていないにもかかわらず，地磁気活動が高くなると両観測点で地磁気現象の出現に大きな違いがみられた。

これらの事象に関する2～3の結果を報告し，考察を加える。