EFFECTS OF MAGNETOSPHERIC COMPRESSION AND EXPANSION ON SPECTRAL STRUCTURE OF ULF EMISSIONS

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Abstract: Changes in the spectrum of ULF emissions associated with ssc's and si's are investigated on the basis of the frequency-time displays (*f-t* diagrams) obtained at Syowa and Mizuho Stations, Antarctica and it is concluded that the spectral structures of ULF emissions with frequency above 0.1 Hz are strongly affected by the magnetospheric compression and expansion which are accompanied by ssc's and positive and negative si's.

1. Introduction

ULF emissions with the frequency above 0.1 Hz, which are most frequently observed in the polar region, are called pc1 and pi1 geomagnetic pulsations according to the definition adopted by IAGA in 1963. The spectral studies, using frequency/ time analyses (*f-t* diagram), have revealed various kinds of distinct types of spectral forms in this frequency range. KOKUBUN (1970) and NAGATA *et al.* (1980) showed that ULF emissions can be classified into six types, *i.e.* periodic hydromagnetic (HM) emission, HM chorus, HM emission burst, IPDP (sweeper), unstructured Pc1-2 band and irregular HM emission.

It has been suggested that most of ULF emissions with frequency above 0.1 Hz are caused by proton cyclotron resonance in the outermost part of the magnetosphere (JACOBS and WATANABE, 1964; CORNWALL, 1965; OBAYASHI, 1965). The proton cyclotron waves (ULF emissions) grow due to their gyroresonant interaction with the proton stream in the magnetosphere (CORNWALL, 1965; KENNEL and PETSCHEK, 1966). The anisotropy of the pitch angle distribution in the proton stream greatly increases the growth of the proton cyclotron instability (KENNEL and PETSCHEK, 1966). These theories imply that the excitation and growth of ULF waves are dependent upon the compression and expansion of the magnetosphere. Since it has been shown that the storm sudden commencement (ssc) and sudden impulse (si) in the ground magnetic field are caused by changes in the volume of the magnetosphere (NISHIDA and CAHILL, 1964; HIRASAWA *et al.*, 1966), the spectral structures of ULF emissions are expected, then, to change at the times of ssc's and si's. In this paper, the changes in the *f-t* dynamic spectrum of ULF emissions are compared in detail with ssc's and si's ground-base magnetic variations.

2. Excitation of ULF Emission by Ssc's

TROITSKAYA *et al.* (1968) and TEPLEY and WENTWORTH (1962) first reported that short period geomagnetic pulsations with frequency of about 1.0 Hz (ULF emissions) are frequently observed after ssc's at middle latitudes. It was also shown by HEACOCK and HESSLER (1965) and KOKUBUN and OGUTI (1968) that ULF emission bands were suddenly intensified in association with ssc's at high latitude station.

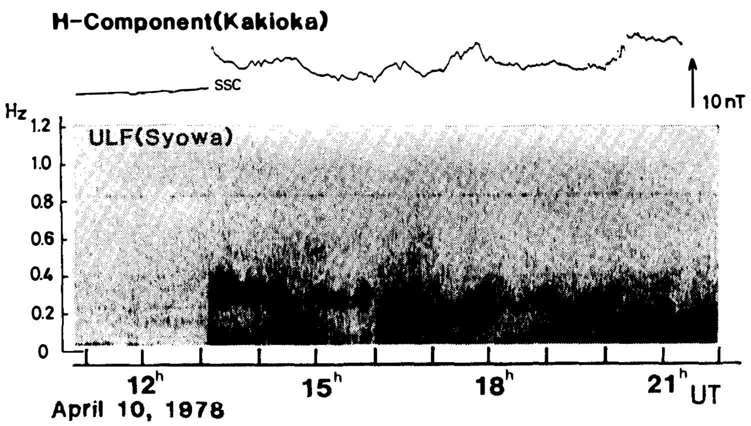

Fig. 1. Magnetic H-component variation recorded at low-latitude station, Kakioka (top) and frequency-time display (f-t diagram) of ULF emission (HM chorus) at Syowa Station (bottom).

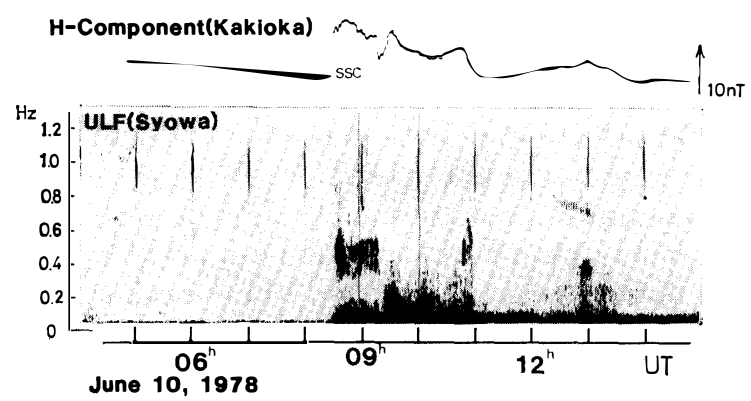

Fig. 2. Magnetic H-component variation recorded at low-latitude station, Kakioka (top) and f-t diagram of ULF emission (HM periodic emission) at Syowa Station (bottom).

Three typical *f-t* diagrams (sonagram) of ULF emissions observed at Syowa Station, Antarctica (geomag. lat. $-70.0°$, long. $79.4°$) are shown in Figs. 1–3 together with the simultaneous magnetic *H*-component records at a low-latitude station, Kakioka (geomag. lat. +26.0°, long. 206.0°). As clearly identified in the H-component magnetogram in the top of Fig. 1, an ssc event occurred at 1306 UT on April 10, 1978. The ssc was followed by ULF emissions with two frequency bands of about 0.35 Hz and below 0.1 Hz. In the event observed on June 10, 1978, illustrated in Fig. 2, ULF emission of HM periodic emission type with frequency of 0.4 Hz was enhanced just after the onset time (0828 UT) of an ssc. In this example, it is also noted in H-component variation at Kakioka that a negative sudden impulse (si) took place around 0917 UT and the enhanced ULF emission suddenly disappeared corresponding well to the negative si.

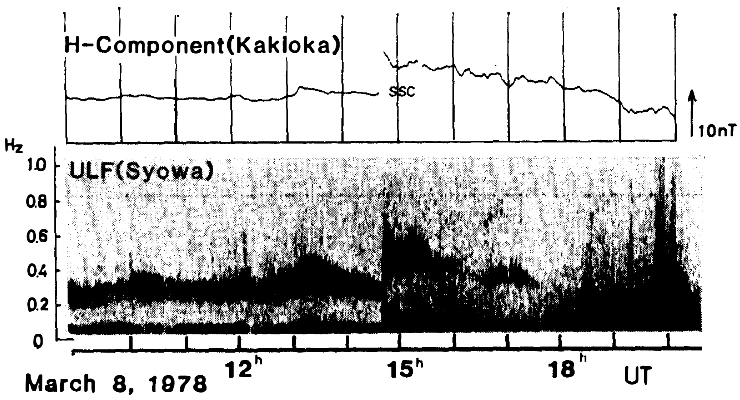

Fig. 3. Magnetic H-component variation recorded at low-latitude station, Kakioka (top) and f-t diagram of ULF emission (HM chorus) at Syowa Station (bottom).

The ULF emission of HM chorus type is an irregularly spaced sequence of rising elements or an unstructured continuous noise band near 0.3 Hz in frequency. A typical spectrum of HM chorus obtained at Syowa Station is shown in Fig. 3. This is a long-duration event lasting more than ten hours. In this sequence of HM chorus, an ssc event occurred at 1439 UT on March 8, 1978, as clearly identified in the magnetic H-component record at Kakioka. Associated with the ssc, the HM chorus emission band characteristics changed markedly; nearby the centered frequency of HM chorus band suddenly stepped up from 0.25 Hz to 0.5 Hz, and its intensity was strongly enhanced. In the magnetic H-component record at Kakioka, positive variation with a range of about 3–5 nT took place successively around 1000, 1210 and 1315 UT. The magnetic variation of this type could be interpreted to have been caused by compression of the magnetosphere (cf. Sections 3 and 4). Corresponding to these magnetic positive variations, the activity of the HM chorus band was intensified and its frequency increased. From the data illustrated above and in the appendix of this report, it is concluded that most of ULF emissions are affected considerably by ssc and si events.

Kokubun and Oguti (1968) showed that ssc's were not always followed by ULF

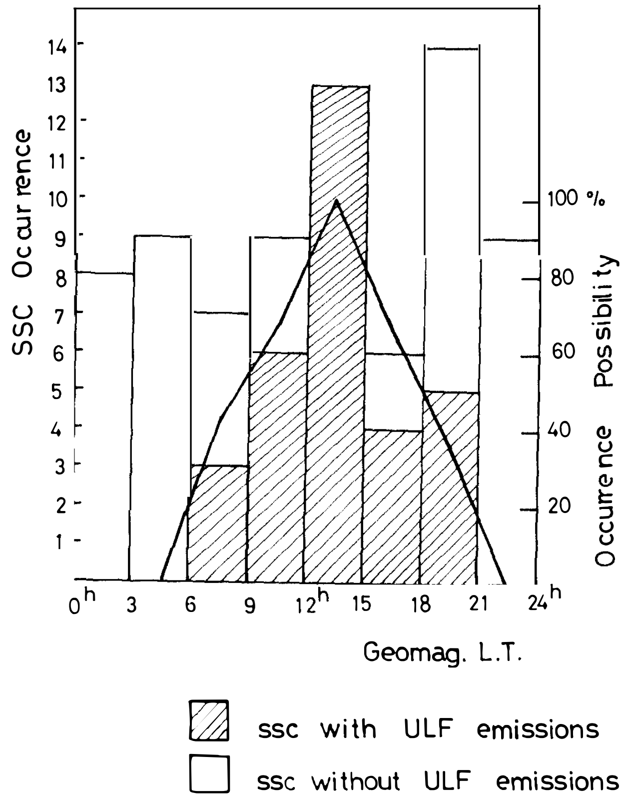

Fig. 4. Diurnal variation of occurrence of ULF emissions associated with ssc's. The unhatched histogram shows the total number of ssc's observed in the period from 1977 to 1979, while the hatched histogram shows the number of ssc's with the enhancements of ULF emissions.

emissions, but the occurrences of the ULF emissions associated with ssc's are dependent upon the geomagnetic local hour when ssc's take place. It is noted that, in the daytime and evening side between 11h and 20h GLT, eight cases out of eleven ssc's (about 70%) are accompanied by ULF emissions. In the present study, the enhancement of ULF emission associated with ssc is investigated using 75 ssc events which were observed in the period from 1977 to 1979. The similar tendency to that by KOKUBUN and OGUTI is clearly seen in Fig. 4. When Syowa Station is situated in the daytime and evening side, most of ssc's are accompanied by the enhancement of ULF emissions. Especially, from 12h to 15h in geomagnetic local hours, the sudden compression of the magnetosphere associated with ssc always excites or enhances ULF emissions.

3. Excitation and Enhancement of ULF Emission during the Initial Phase of a Magnetic Storm

There is considerable variability from storm to storm in the character and intensity of the initial phase of a magnetic storm. The general pattern may persist for some minutes to several hours. In general, the increase of magnetic horizontal intensity at middle and low latitudes during the initial phase of a storm is considered to be ascribed to a compression of the magnetosphere caused by the intensified solar stream.

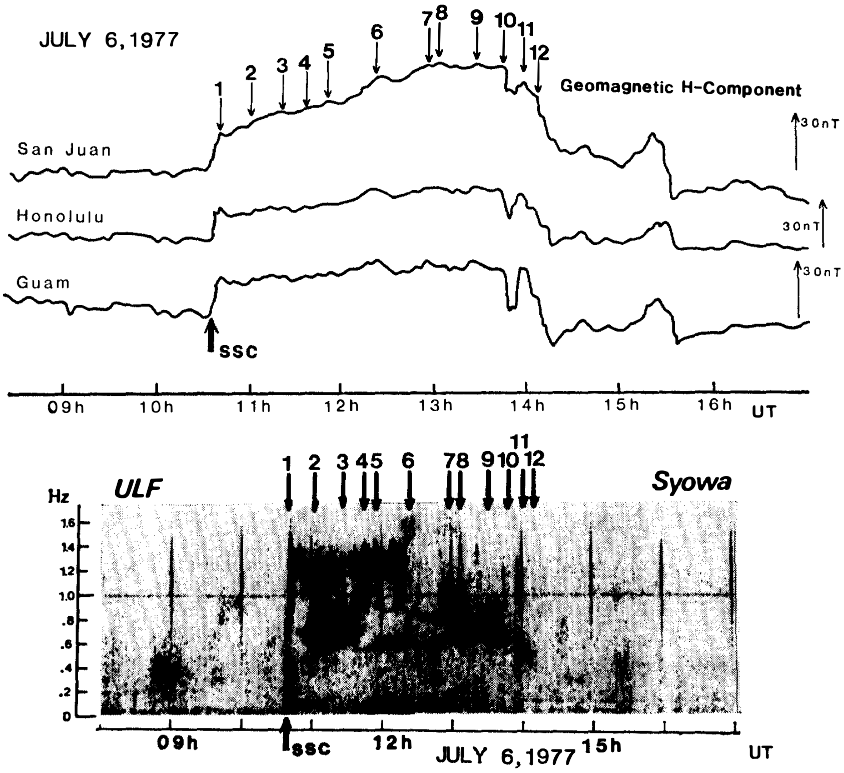

Fig. 5. Magnetic H-component variations recorded at low-latitude stations, San Juan (geomag. lat. 29.7°, long. 4.7°), Honolulu (29.6°, 328.6°) and Guam (4.2°, 214.3°) (top) and f-t diagram of ULF emissions (HM periodic emission and HM emission burst) at Syowa Station during the initial phase of a magnetic storm (bottom).

The typical *f-t* diagram of ULF emissions during the initial phase of a storm is shown in Fig. 5 together with the simultaneous magnetograms of widely separated middle and low latitude stations, where horizontal component records only are reproduced, since the magnetic variations during the initial phase of a storm appear most clearly in this component at these latitudes. As seen in magnetograms from three stations, an ssc occurred at 1038 UT on July 6, 1977 and the initial phase of the storm lasted up to about 1410 UT. In the *f-t* diagram, ULF emissions were intensified during the initial phase between 1038 and 1410 UT. From a comparison between the ULF emissions in the *f-t* diagram and the magnetic *H*-component variations at San Juan, Honolulu and Guam, it is noted that the enhancements of ULF

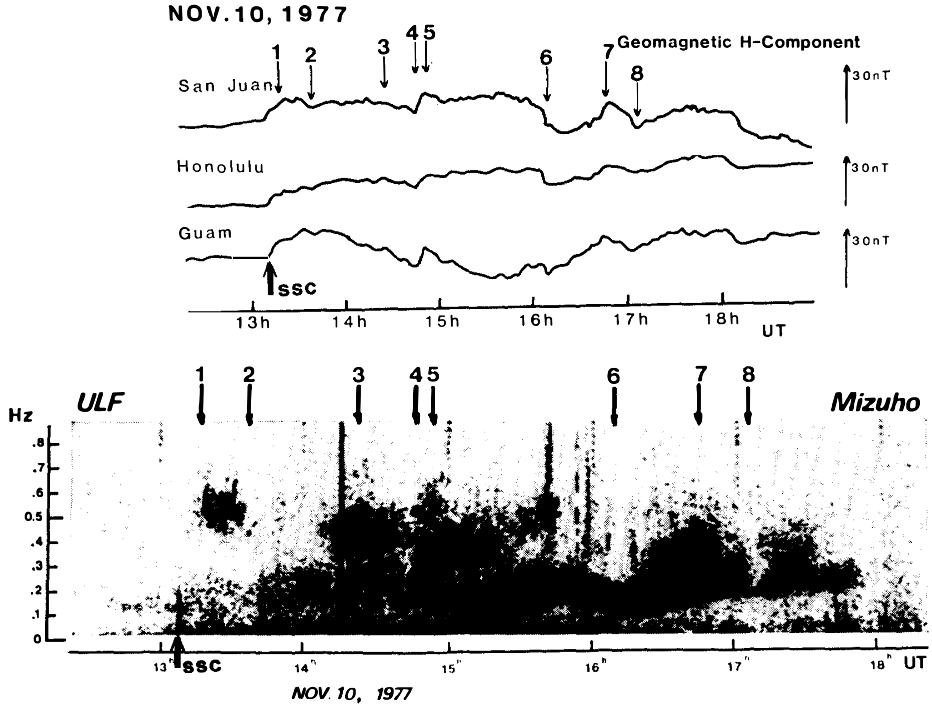

Fig. 6. Magnetic H-component variations recorded at low-latitude stations, San Juan (geomag. lat. 29.7°, long. 4.7°), Honolulu (29.6°, 328.6°) and Guam (4.2°, 214.3°) (top) and f-t diagram of ULF emissions (HM chorus) at Mizuho Station (geomag. lat. −72.3°, long. 80.6°) during the initial phase of a magnetic storm (bottom).

emissions correspond well to the positive variations of magnetic H-component with amplitude of about 2–20 nT (indicated by No. 2–No. 11 arrows). It is also found in Fig. 5 that ULF emissions suddenly disappeared when negative si's took place, for example, at about 1340 UT (No. 10 arrows) and 1410 UT (No. 12 arrow).

A typical spectrum of ULF emission shown in Fig. 6 is a long-duration event lasting in the course of the initial phase of a storm. An ssc event occurred at 1313 UT on November 10, 1977, as clearly identified in the magnetic H-component records obtained at low-latitude stations. Associated with the ssc, the burst-like emission with frequency of below 0.2 Hz was enhanced. In the magnetograms shown at the top of Fig. 6, positive si's (Nos. 1, 3, 5 and 7 arrows) and negative si's (Nos. 2, 4, 6 and 8 arrows) variations with a range of about 2–10 nT were observed successively. Corresponding to these magnetic positive variations, the ULF emissions were enhanced and their frequency increased. To the contrary, the intensity of ULF emissions diminished and their frequency decreased associated with the negative si's.

4. Excitation of ULF Emissions by Succesive Si Type Magnetic Variations

In the f-t diagram in Fig. 7, ULF emissions with burst-like spectral structure

(HM emission burst) were observed continually between 0900 and 1715 UT on May 4, 1977, being superposed on ULF emissions of HM chorus type with a stable frequency of about 0.5 Hz. It is noted that all the magnetic variations at San Juan, Honolulu and Guam in the top of Fig. 7 show a gradual increase in the *H*-component from 0900 to 1715 UT when a large-amplitude negative si occurred (indicated by No. 18 arrow in Fig. 7). The simultaneous positive increases in the magnetic *H*-component at these three low-latitude stations are originated in the gradual compression of the earth's magnetosphere (HIRASAWA *et al.*, 1966). According to the magnetospheric compression, ULF emissions are growingactive. From a comparison between the ULF emissions in the *f-t* diagram and the magnetic *H*-component variations at three stations, it is found that the enhancements of HM emission bursts correspond well to the positive variations of magnetic *H*-component with amplitude of about 2–20 nT (Nos. 1～9 and 11～17 arrows) which are considered to be the si

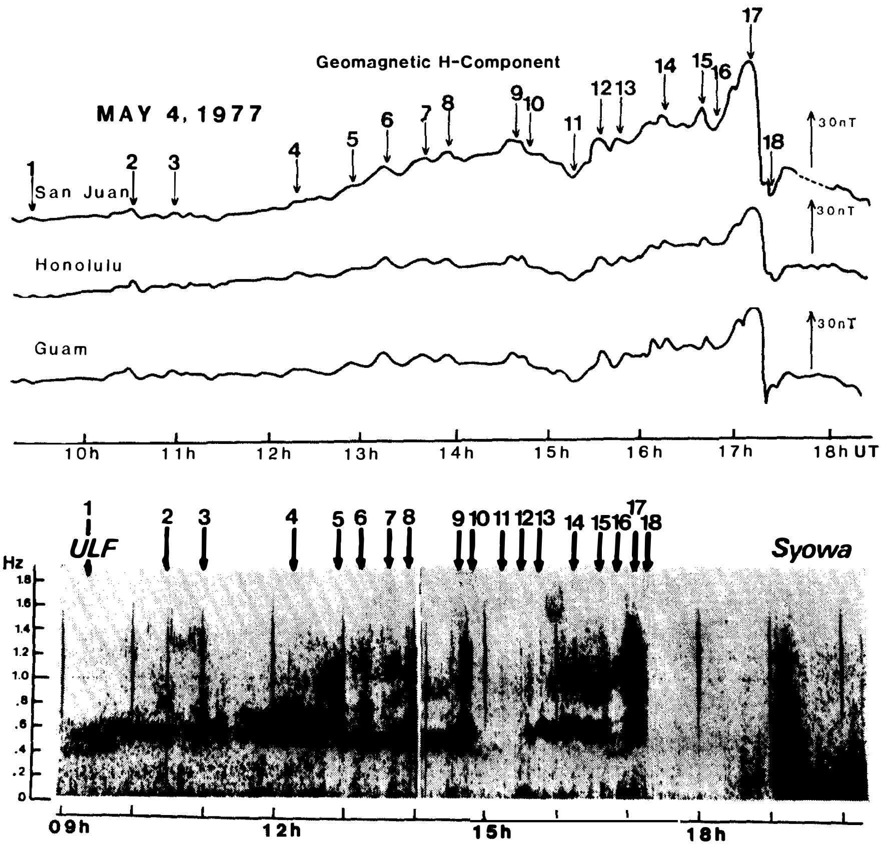

Fig. 7. Magnetic H-component variatinons recorded at low-latitude stations, San Juan (geomag. lat. 29.7°, long. 4.7°), Honolulu (29.6°, 328.6°) and Guam (4.2°, 214.3°) (top) and f-t diagram of ULF emissions (HM chorus and HM emission burst) at Syowa Station during successive si type magnetic variations.

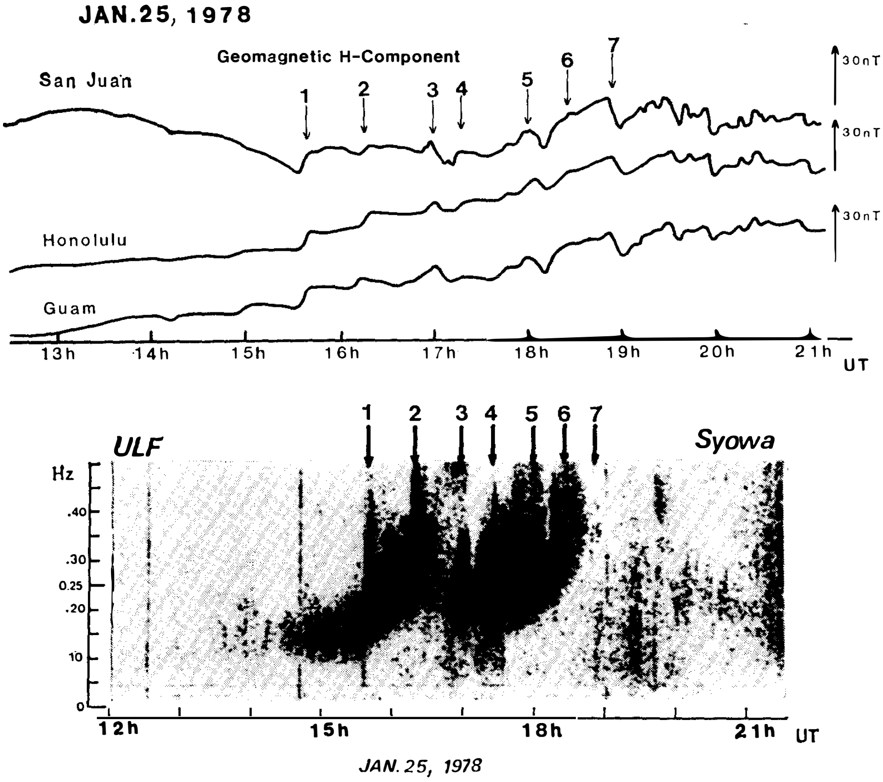

Fig. 8. Magnetic H-component variations recorded at low-latitude stations, San Juan (geomag. lat. 29.7°, long. 4.7°), Honolulu (29.6°, 328.6°) and Guam (4.2°, 214.3°) (top) and f-t diagram of ULF emissions (IPDP emission) at Syowa Station during successive si type magnetic variations.

type ones. It is also observed in Fig. 7 that ULF emissions suddenly disappeared when negative si's took place, for example, at about 1440 UT (indicated by No. 10 arrow) and 1710 UT (No. 18 arrow).

Two successive occurrences of ULF emissions of IPDP type (TROITSKAYA, 1961) are shown in the *f-t* diagram of Fig. 8. The mid-frequency of IPDP increases with time and the spectrum of the emissions contains unstructured diffuse burst-like noise and irregularly spaced rising elements. In Fig. 8, the magnetic *H*-component records at low-latitude stations and simultaneous *f-t* diagram of IPDP emissions show that the spectral structures of IPDP emissions are strongly modified by si type magnetic variations which are caused by the compression and expansion of the magnetosphere. The *f-t* diagram in Fig. 9 illustrates the successive occurrences of ULF emissions with burst-like spectral structures (pi-burst) between 0430 and 0845 UT on July 6, 1978. The enhancement of each pi-burst with a duration of about 5–30 minutes has a good relation with the positive variation of magnetic *H*-component (si-type) with amplitude of about 5–20 nT observed at low-latitude stations, San Juan and Guam.

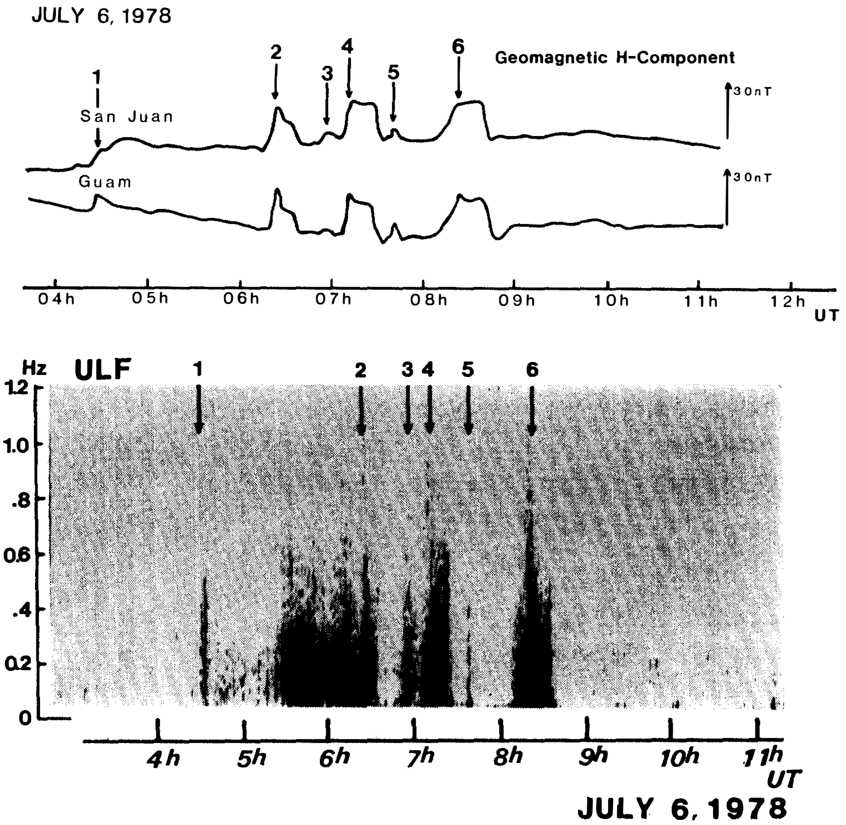

Fig. 9. Magnetic H-component variations recorded at low-latitude stations, San Juan (geomag. lat. 29.7°, long. 4.7°) and Guam (4.2°, 214.3°) (top) and f-t diagram of ULF emissions (pi-burst) at Syowa Station during successive si type magnetic variations.

5. Summary and Conclusions

From the studies of the ssc and si effects on the ULF emissions on the basis of the data illustrated above, it is concluded that most of ULF emissions with frequency above 0.1 Hz are considerably affected by the compression and the expansion of the earth's magnetosphere. The characteristics of high-latitude ULF emissions associated with ssc's and positive and negative si's are summarized as follows.

(1) Ssc and positive si events cause the sudden enhancements of various types of ULF emissions, for example, hydromagnetic (HM) chorus, HM periodic emission, HM emission burst, IPDP and pi-burst. When ULF emissions are observed preceding to the ssc's and si's the mid-frequency and bandwidth of ULF emission suddenly step up at the onset times of ssc's and positive si's to be about 1.5~10 times greater than those of preceding emissions (*cf.* Fig. 3 and Appendix).

(2) The ULF emissions associated with ssc's are frequently observed in the daytime and the evening side from 06h to 18h in the geomagnetic local time (MLT).

In the afternoon hours of 12–15 MLT, almost all ssc's are accompanied by the enhancements of ULF emissions (*cf.* Fig. 4).

(3) The increase and decrease in the intensity as well as in the frequency of high-latitude ULF emission correspond well to the positive and negative geomagnetic variations in the horizontal component at low latitude stations. Occasionally, the sudden decreases or fadeouts in ULF emission intensity are observed when the negative si's take place.

The above facts may indicate that most of ULF emissions are caused by the proton cyclotron instability originated from the anisotropic pitch angle distribution, as discussed by KENNEL and PETSCHEK (1966). KOKUBUN (1970) also illustrated that the magnetospheric compression at the time of ssc and si tends to result in an enhancement of anisotropy in the pitch angle distribution of energetic protons due to the betatron acceleration. Then, the enhanced anisotropy may increase the wave energy through the cyclotron instability process.

References

CORNWALL, J. M. (1965): Cyclotron instabilities and electromagnetic emission in the ultra low frequency and very low frequency ranges. J. Geophys. Res., **70**, 61–69.

HIRASAWA, T., NISHIDA, A. and NAGATA, T. (1966): Changes in pc5 periods accompanying sudden impulses resulting from the magnetosphere deformations. Rep. Ionos. Space Res. Jpn, **20**, 51–56.

HEACOCK, R. R. and HESSLER, V. P. (1965): Pearl-type micropulsations associated with magnetic storm sudden commencements. J. Geophys. Res., **70**, 1103–1111.

JACOBS, J. A. and WATANABE, T. (1967): Theoretical notes on whistlers and periodic emissions in the hydromagnetic regime. Planet. Space Sci., **15**, 799.

KENNEL, L. F. and PETSCHEK, H. E. (1966): Limit of stably trapped particle flux. J. Geophys. Res., **71**, 1–28.

KOKUBUN, S. (1970): Fine structure of ULF emissions in the frequency range of 0.1–2 Hz. Rep. Ionos. Space Res. Jpn, **24**, 24–44.

KOKUBUN, S. and OGUTI, T. (1968): Hydromagnetic emissions associated with storm sudden commencements. Rep. Ionos. Space Res. Jpn, **22**, 45–59.

NAGATA, T., HIRASAWA, T., FUKUNISHI, H., AYUKAWA, M., SATO, N., FUJII, R. and KAWAMURA, M. (1980): Classification of pc1 and pi1 waves observed in high latitudes. Mem. Natl Inst. Polar Res., Spec. Issue, **16**, 56–71.

NISHIDA, A. and CAHILL, L. J., JR. (1964): Sudden impulses in the magnetosphere observed by Explorer 12. J. Geophys. Res., **69**, 2243–2255.

OBAYASHI, T. (1965): Hydromagnetic whistlers. J. Geophys. Res., **70**, 1069–1078.

TEPLEY, L. R. and WENTWORTH, R. C. (1962): Hydromagnetic emissions, X-ray bursts, and electron bunches, Part I: Experimental results. J. Geophys. Res., **67**, 3317–3333.

TROITSKAYA, V. A., MATVEEVA, E. T., ILIANOV, K. G. and GUL'ELMI, A. V. (1968): Change in the frequency of Pc1 micropulsations during a sudden deformation of the magnetosphere. Geomagn. Aeronom., **8**, 784–786.

TROITSKAYA, V. A. (1961): Pulsations of the earth's electromagnetic field and their connection with phenomena in the high atmosphere. J. Geophys. Res., **66**, 5–18.

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Appendix

Examples of frequency-time displdy (*f-t* diagram) of ULF emissions associated with storm sudden commencements (ssc) observed during the three years 1977–1979 at high-latitude Stations, Syowa and Mizuho, Antarctica, and simultaneous variations in the magnetic horizontal component recorded at low-latitude station, Kakioka.

The geographic and geomagnetic coordinates, L values of Syowa, Mizuho and Kakioka Stations are given below.

Station name	Geographic		Geomagnetic		L
	Latitude	Longitude	Latitude	Longitude	
Syowa Station	69.0°S	39.6°E	−70.0°	79.4°	6.02
Mizuho Station	70.7°S	44.3°E	−72.3°	80.6°	7.04
Kakioka	36.2°N	140.2°E	+26.0°	+206.0°	

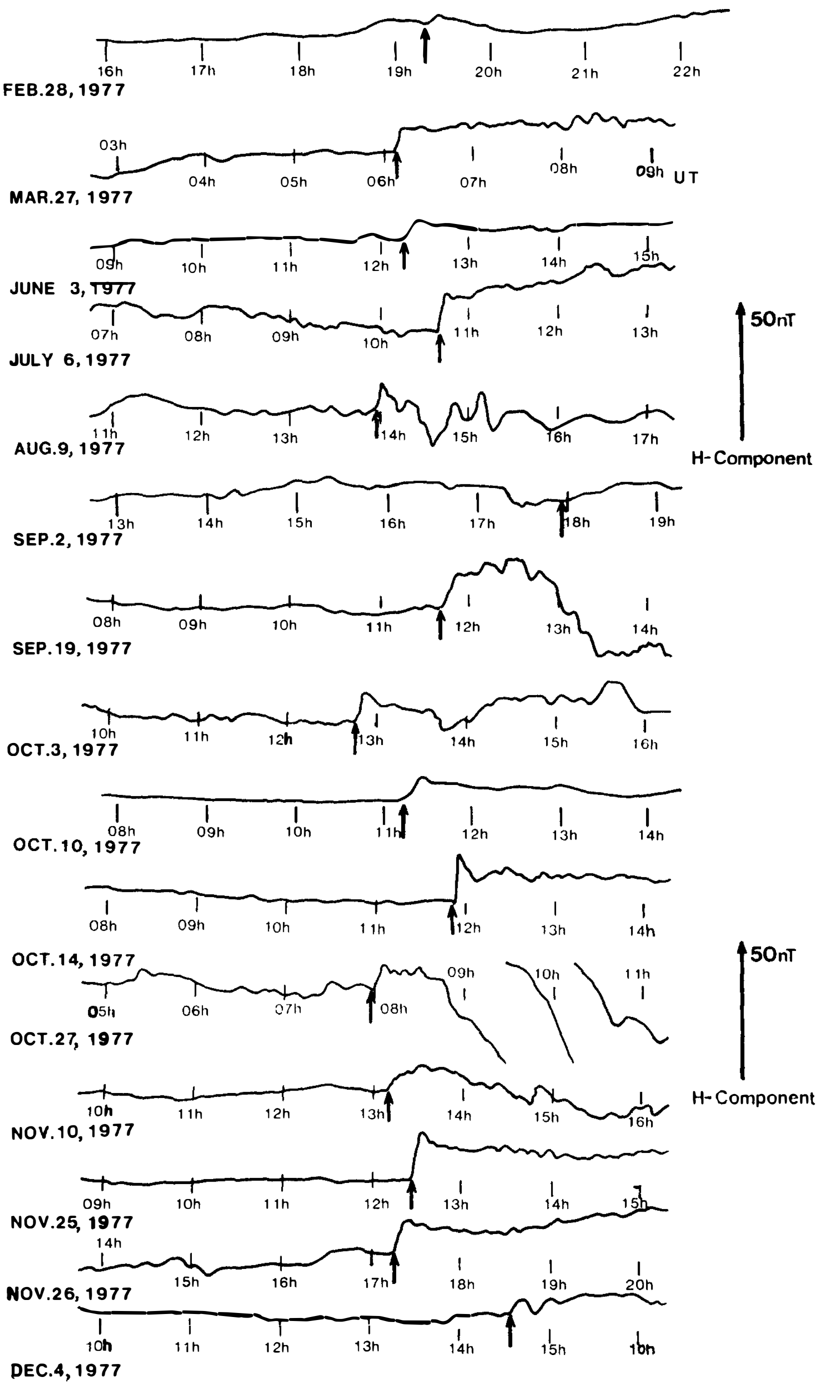


Fig. A-1. *Storm sudden commencements (ssc's) records at Kakioka in 1977. Onset times of ssc's are indicated by arrows in each horizontal component trace.*

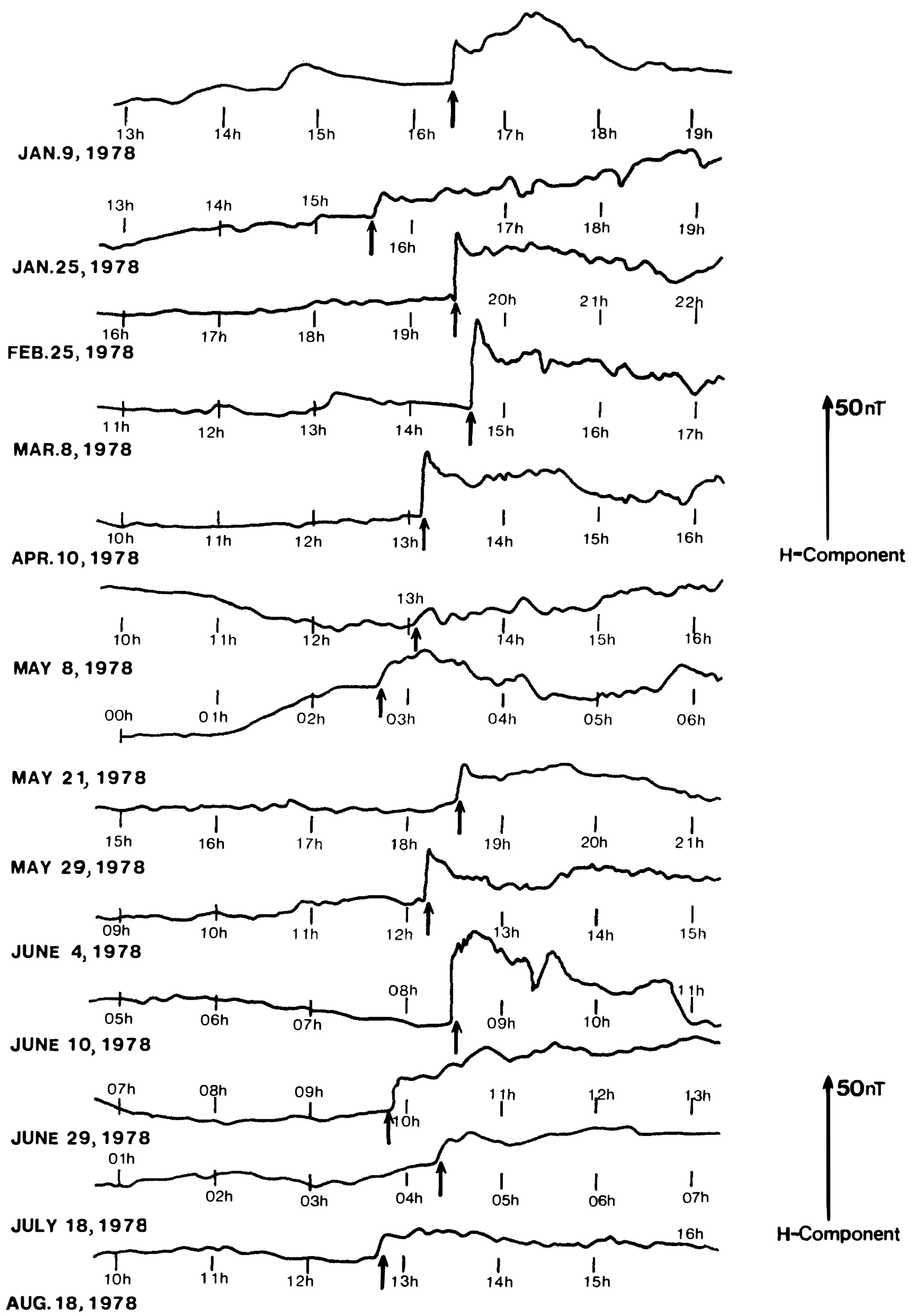


Fig. A-2. Storm sudden commencements (ssc's) records at Kakioka in 1978. Onset times of ssc's are indicated by arrows in each horizontal component trace.

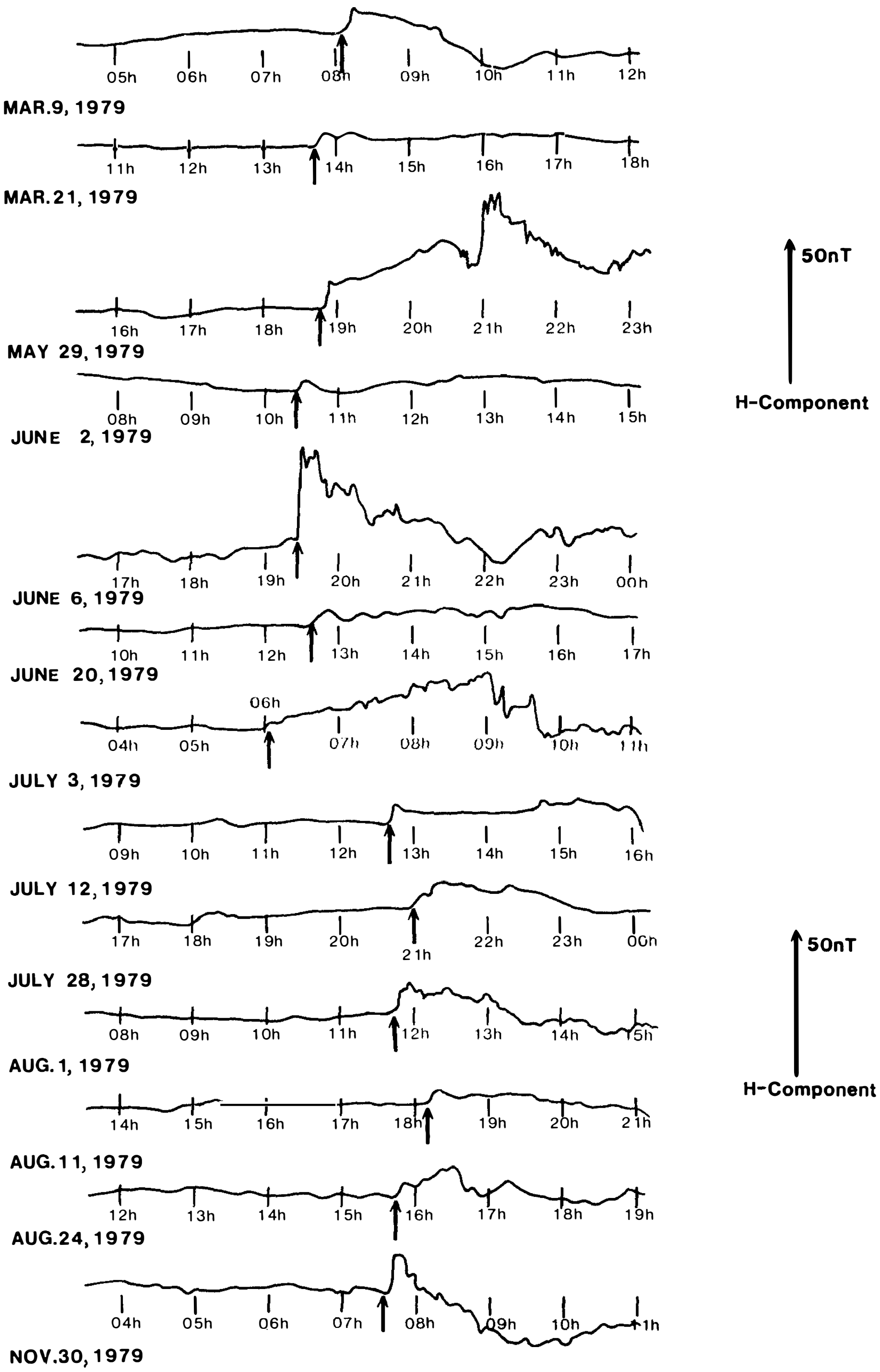


Fig. A-3. Storm sudden commencements (ssc's) records at Kakioka in 1979. Onset times of ssc's are indicated by arrows in each horizontal component trace.

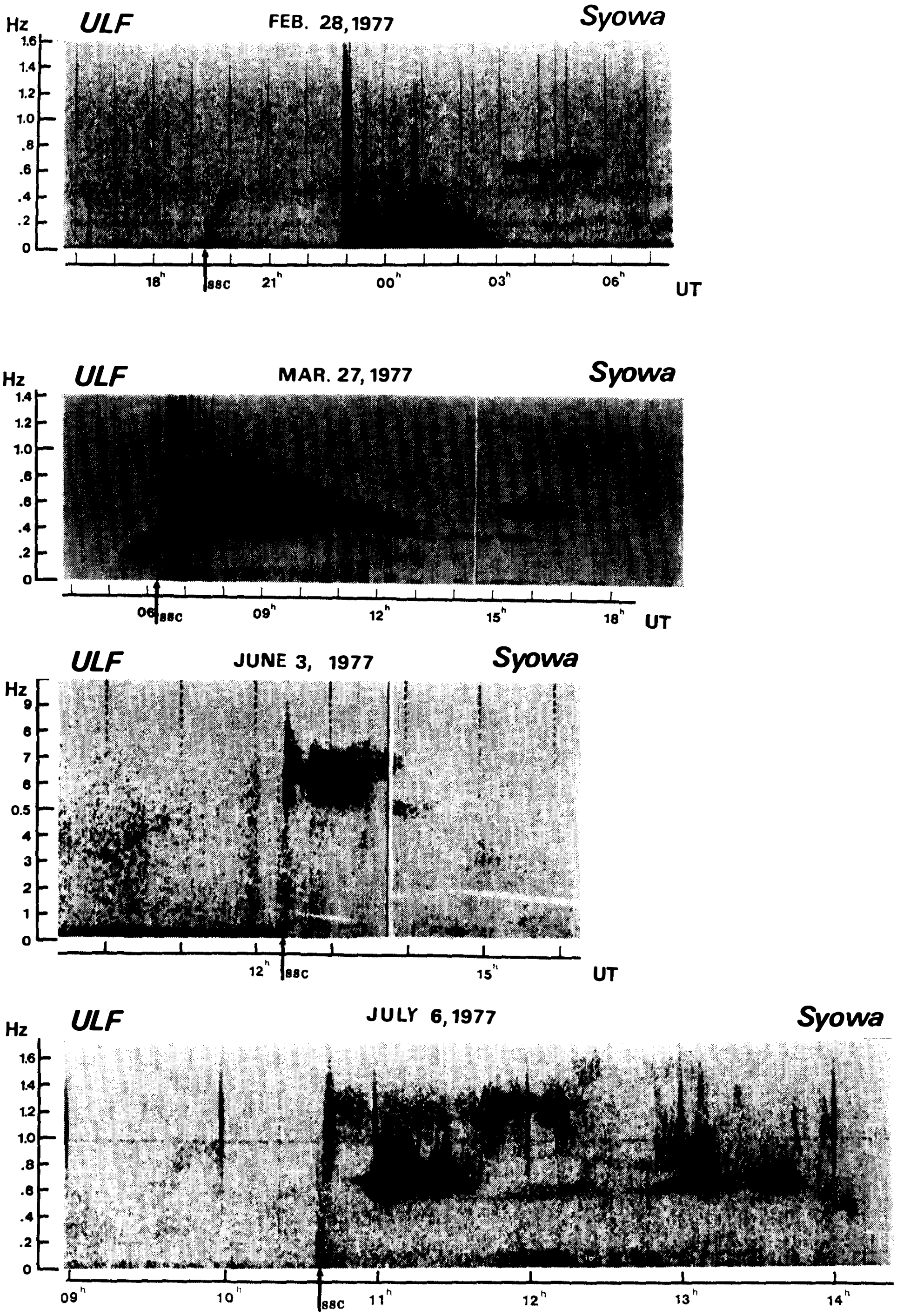


Fig. A-4. Examples of frequency-times display (f-t diagram) of ULF emissions associated with storm sudden commencements (ssc's). Onset times of ssc's are indicated by arrows in each diagram.

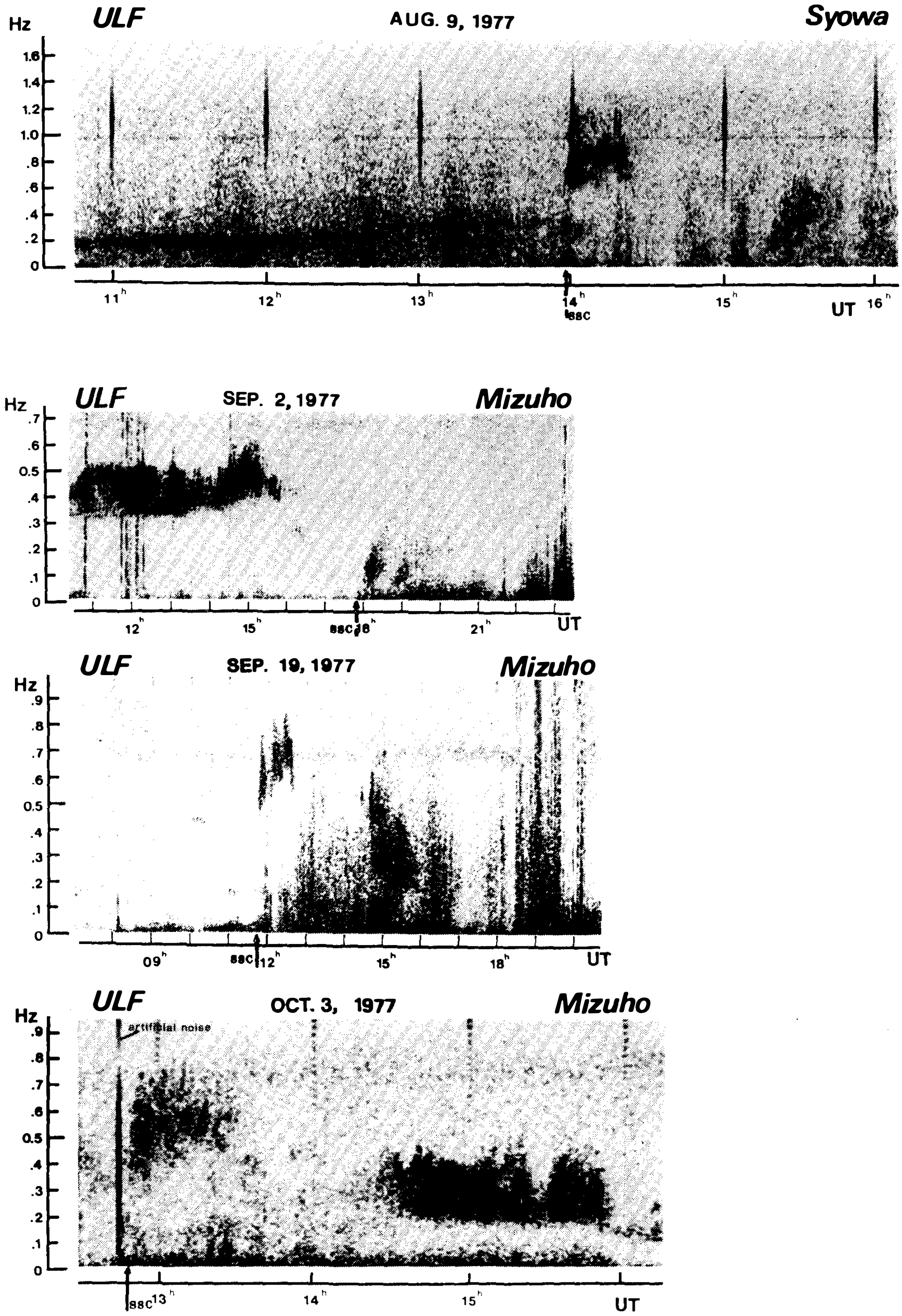


Fig. A-5. The same as that for Fig. A-4.

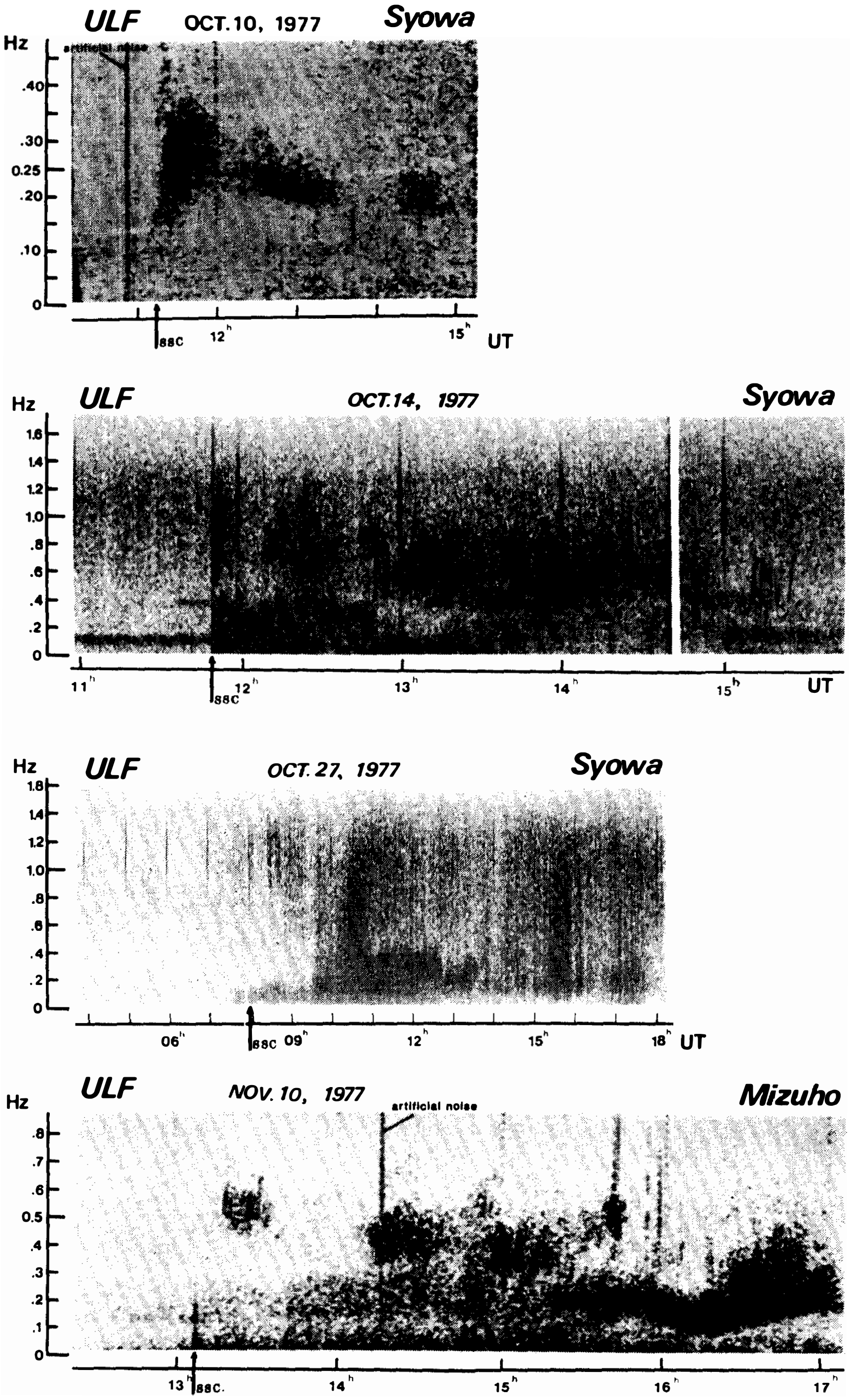
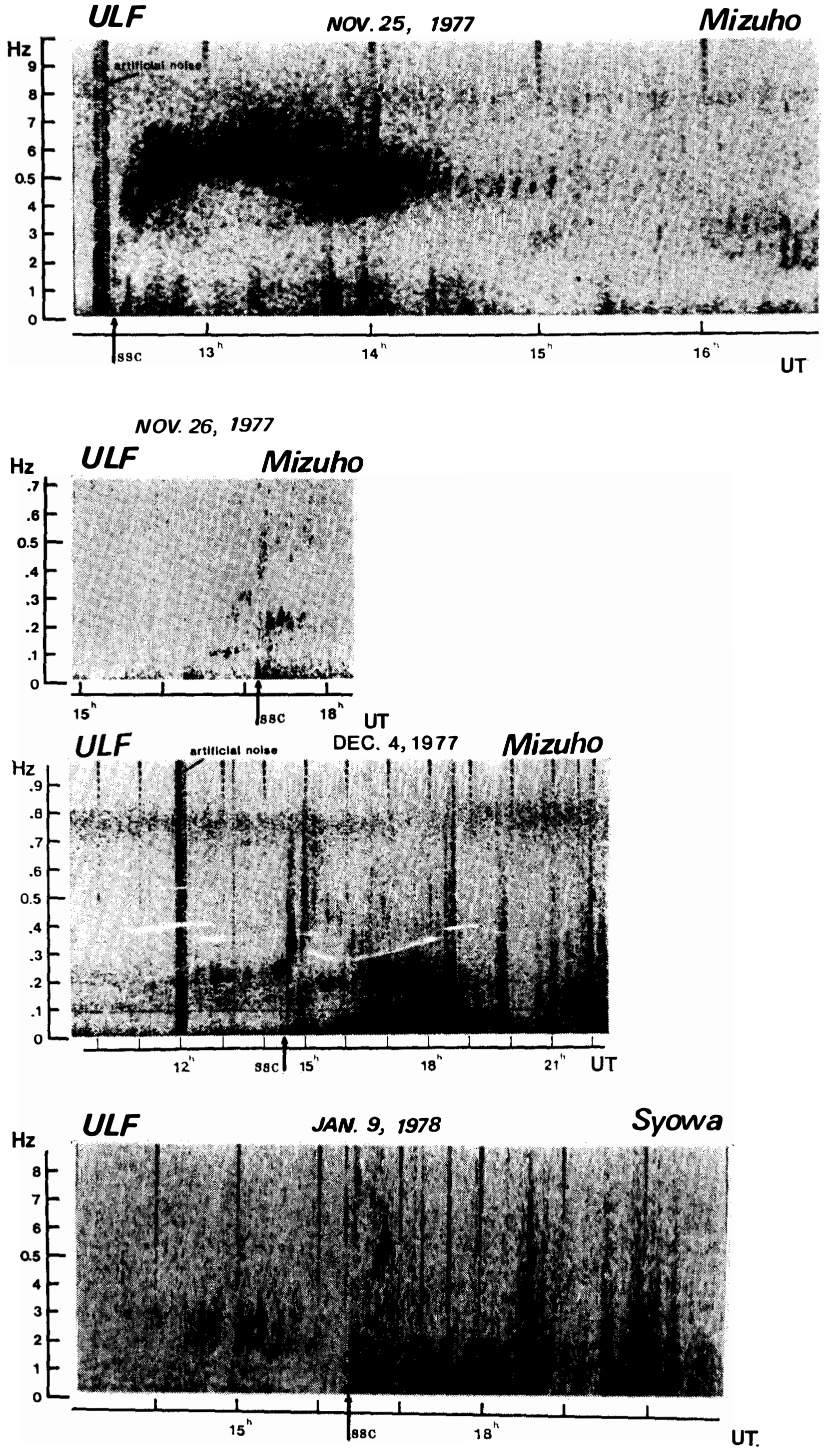


Fig. A-6. The same as that for Fig. A-4.



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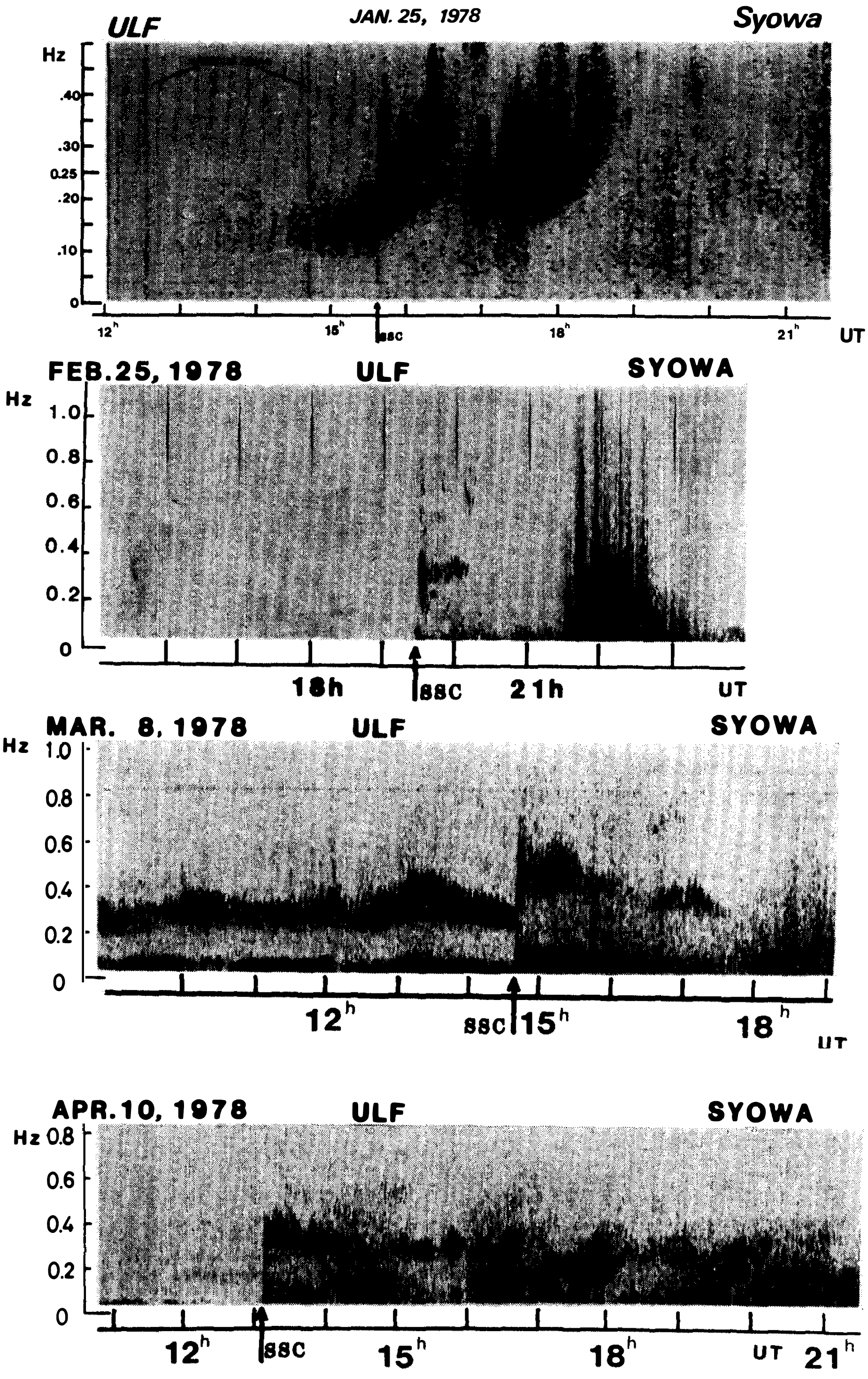

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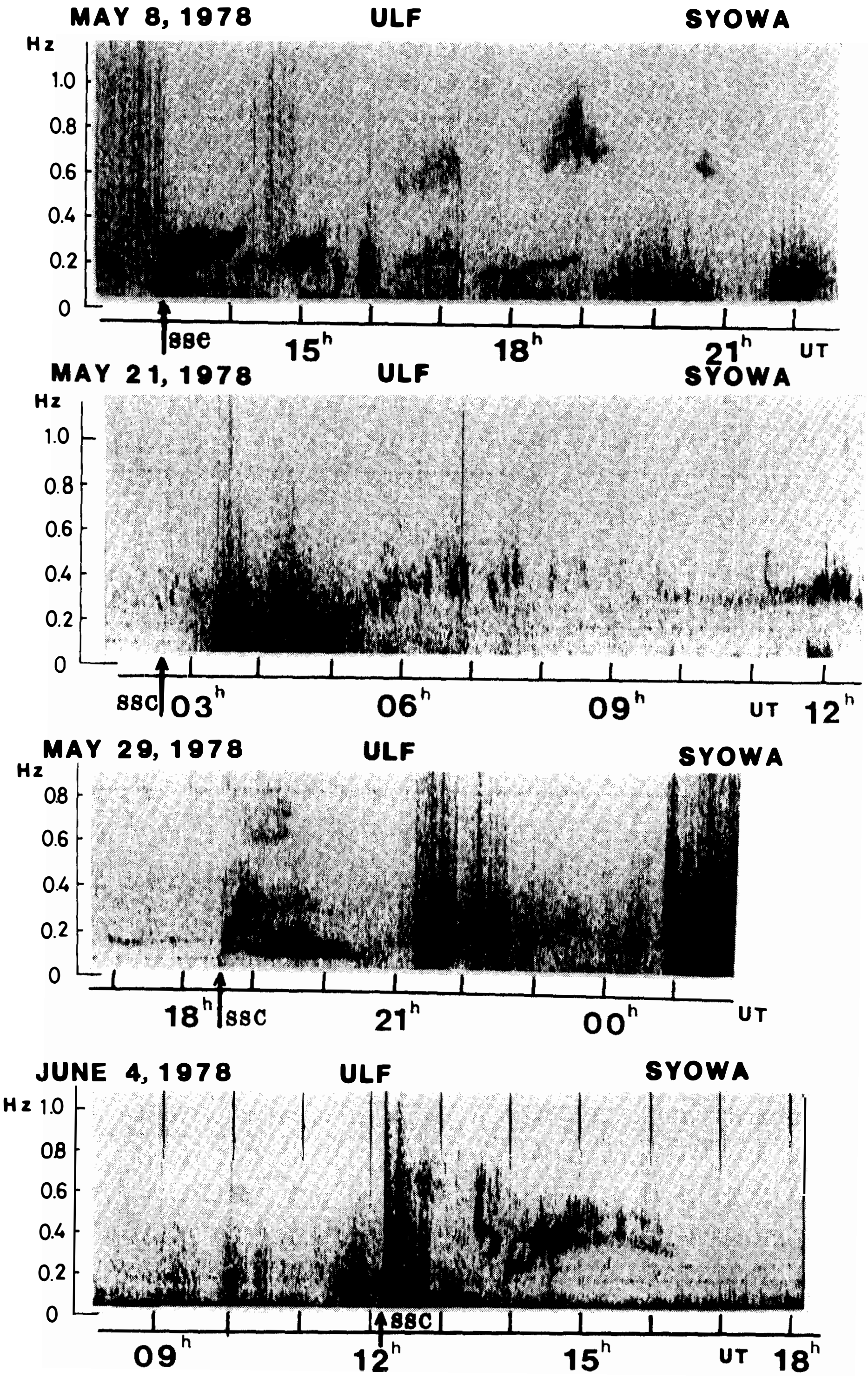

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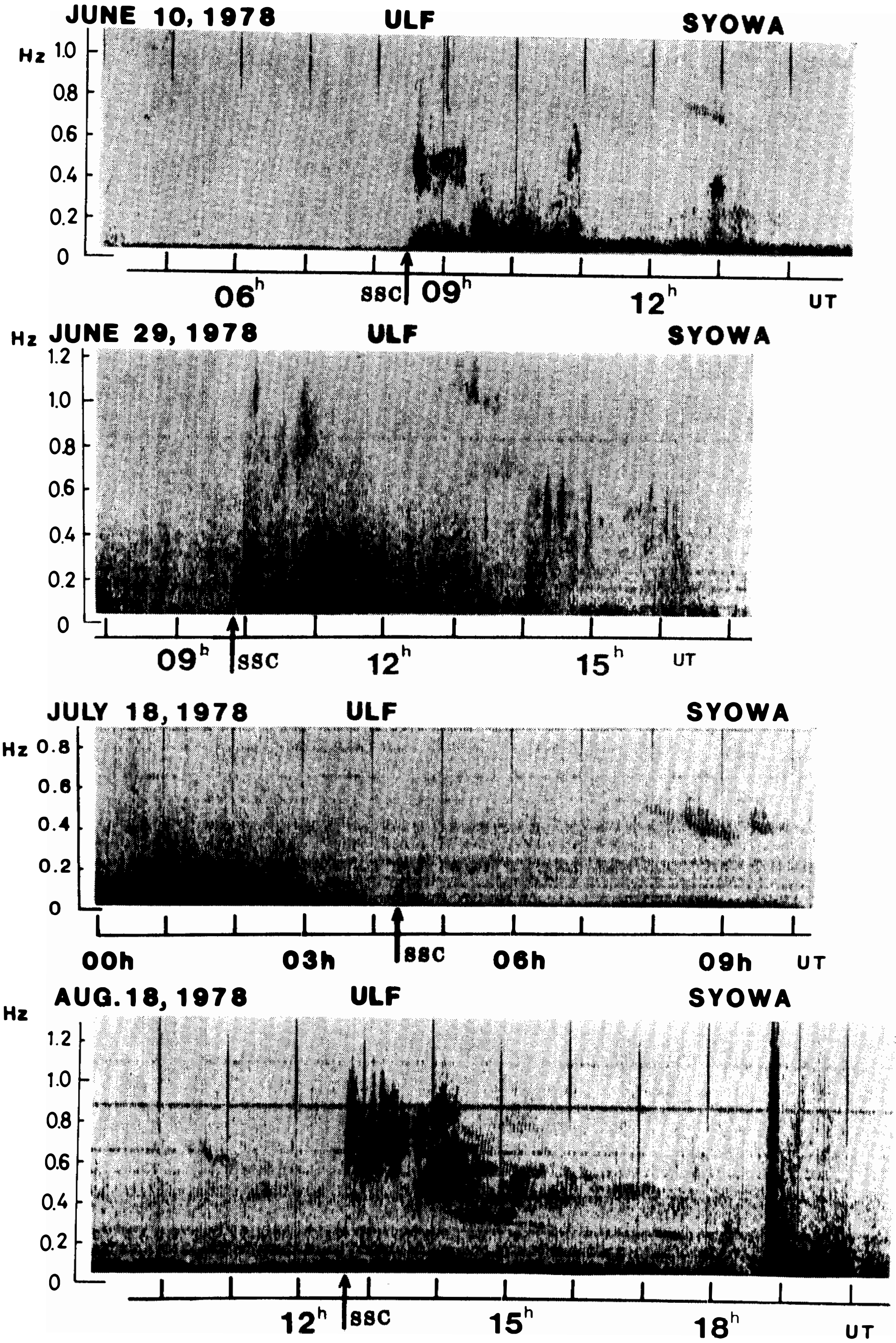

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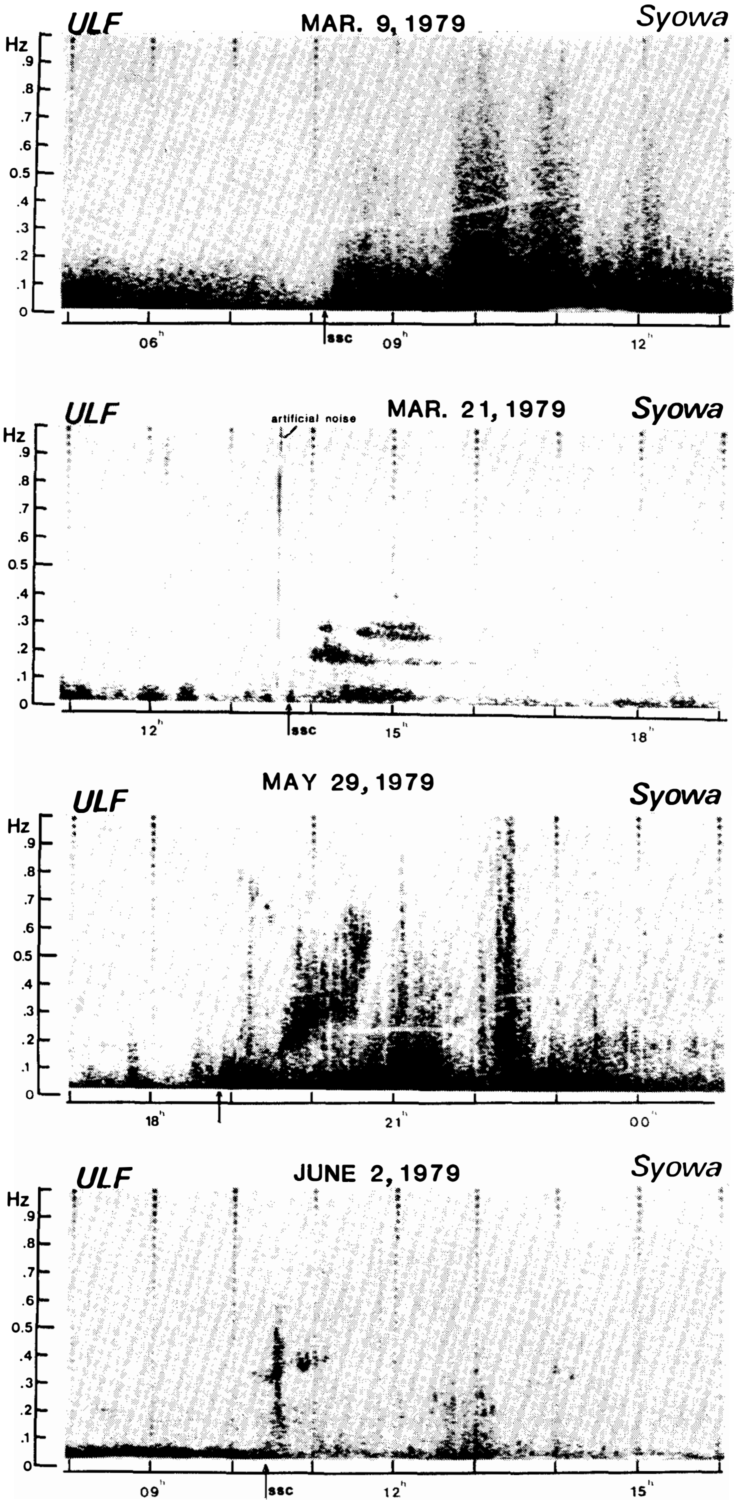
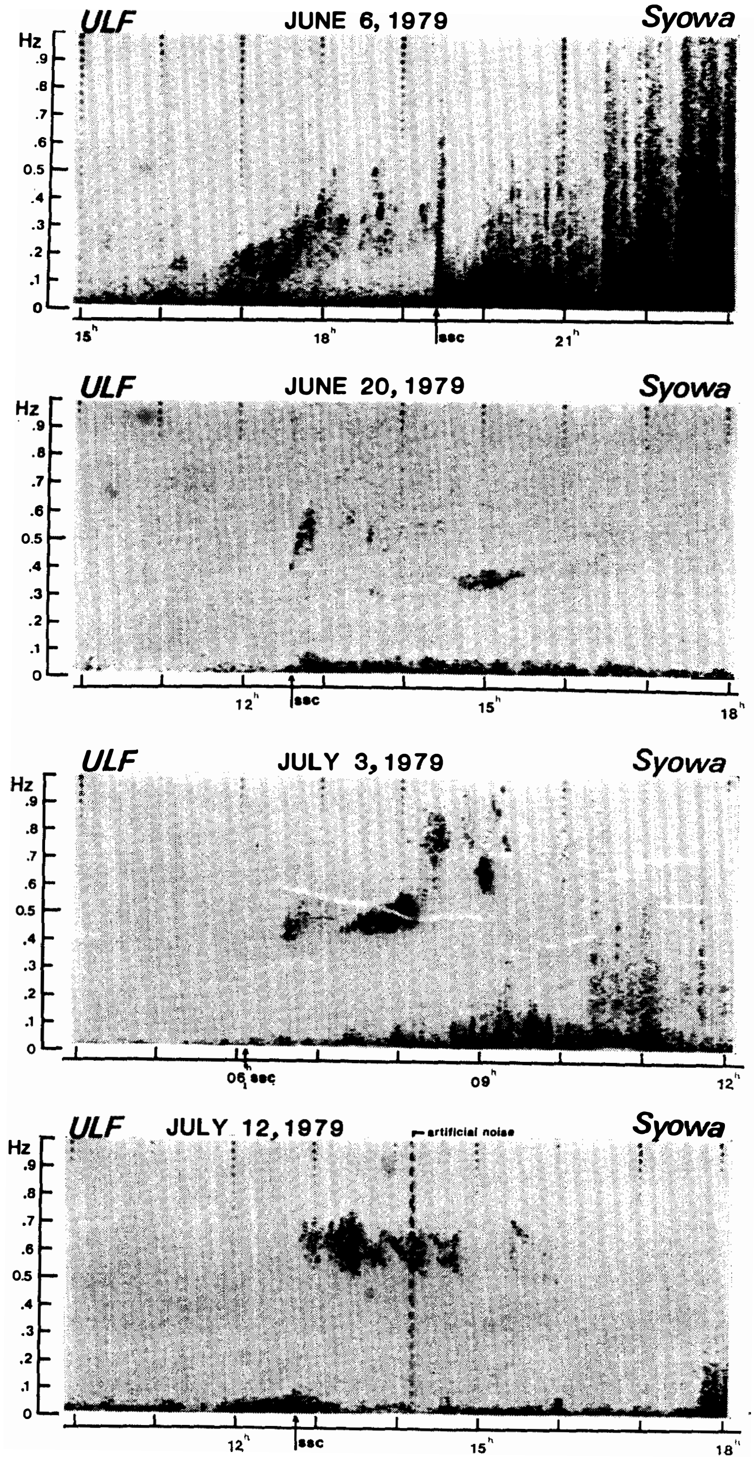


Fig. A-11. The same as that for Fig. A-4.



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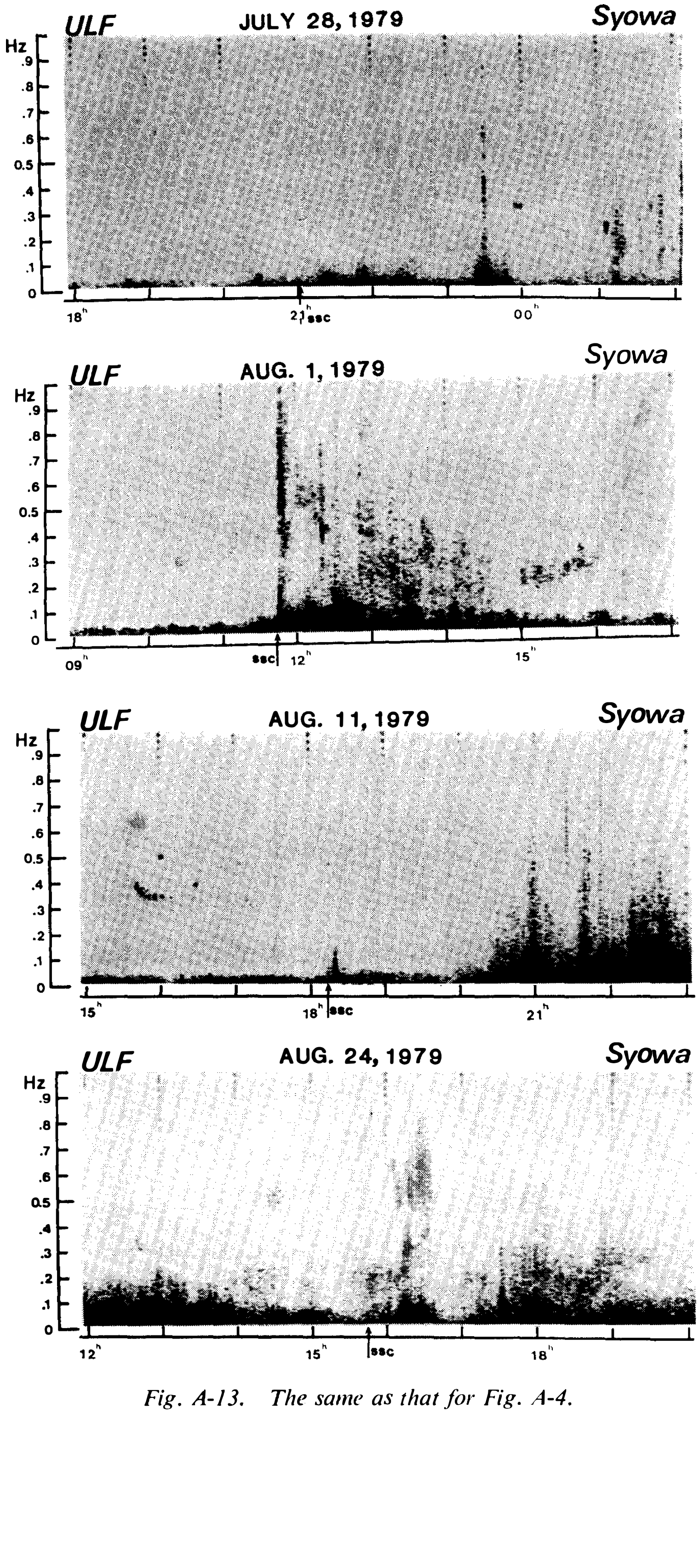

Fig. A-13. The same as that for Fig. A-4.

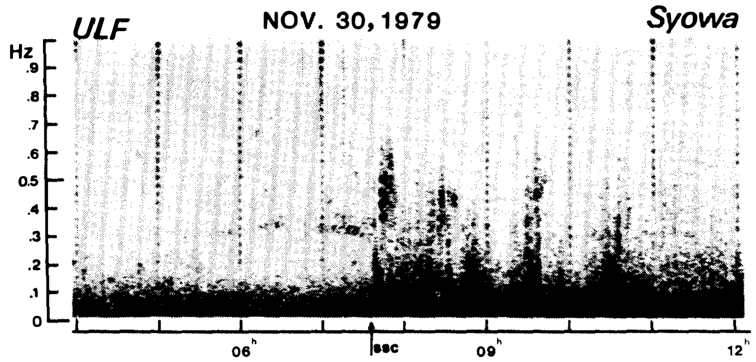

Fig. A-14. The same as that for Fig. A-4.