ULF-VLF WAVES OBSERVED AT THE SYOWA STATION-ICELAND CONJUGATE PAIR

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***Abstract*:** Conjugate observations of magnetic pulsations and ELF-VLF emissions were carried out at Syowa and Mizuho Stations in Antarctica and Husafell in Iceland during the northern summer seasons in 1977 and 1978. Husafell is located about 50 km from the conjugate point of Syowa Station. Conjugacies of Pc 1, Pi 1 and Pc 3–5 magnetic pulsations are briefly summarized. It is also shown that the activity of polar chorus and quasi-periodic emissions observed in the daytime is well correlated at the conjugate points, while the conjugacy of discrete emissions and auroral hiss emissions observed in the nighttime is quite low.

1. Introduction

Coordinated observations of magnetic pulsations and ELF-VLF emissions were carried out at Syowa and Mizuho Stations, Antarctica and Husafell in Iceland during the two periods from July 29 to September 18, 1977 and from August 20 to September 27, 1978. The geographic and geomagnetic coordinates, L values and the locations of the magnetic conjugate points of these stations are given in Table 1.

Table 1. Locations of Husafell, Syowa and Mizuho Stations in geographic and geomagnetic coordinates, L values and conjugate points of these stations.

Station name	Geographic		Geomagnetic		L	Conjugate geographic	
	Latitude	Longitude	Latitude	Longitude		Latitude	Longitude
Husafell	64.7°N	20.9°W	70.2°	74.2°	6.14	68.9°S	40.1°E
Syowa Station	69.0°S	39.6°E	−70.0°	79.4°	6.02	64.3°N	21.2°W
Mizuho Station	70.7°S	44.3°E	−72.3°	80.6°	7.04	65.9°N	22.7°W

The locations of the magnetic conjugate points were calculated from the 1975 international geomagnetic reference field (IGRF) model. As shown in Fig. 1, Husafell is located about 50 km north of the conjugate point of Syowa Station. The conjugate experiment in 1977 was carried out under the joint research program

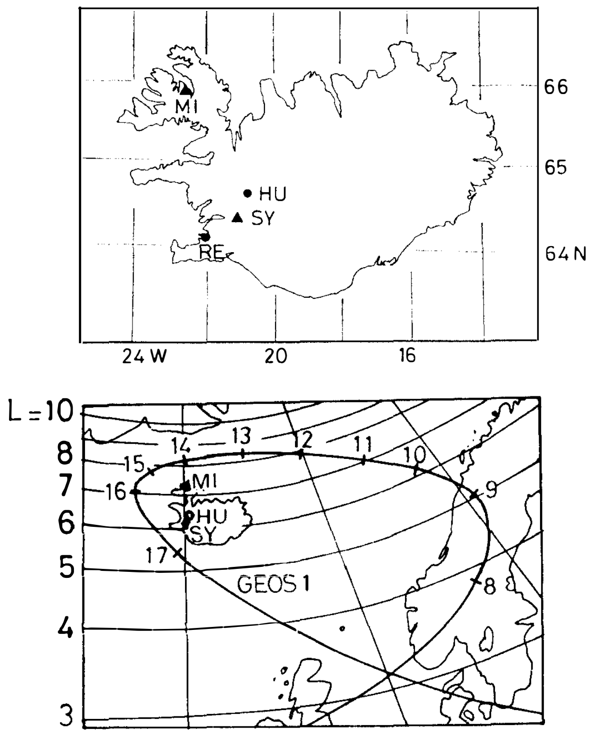

Fig. 1. Locations of Husafell and Reykjavik and the conjugate points of Syowa and Mizuho Stations and the magnetic foot points of GEOS-1.

between National Institute of Polar Research, Japan and the GEOS S-300 experimenters (GENDRIN *et al.*, 1978). The foot points of the magnetic field lines through GEOS-1 were located near the area covered by the present station network during the observation period in 1977, as shown in Fig. 1. The magnetic local time is almost equal to universal time, while the geographic local time is equal to UT -1 hour at Husafell and UT $+3$ hours at Syowa and Mizuho Stations.

In the present paper, conjugate characteristics of ULF and ELF-VLF waves near $L=6$ are briefly summarized by use of the data observed during the northern summer season in 1977.

2. ULF Waves Observed at the Syowa Station-Husafell Conjugate Pair

2.1. *Conjugacy of Pc 1 magnetic pulsations*

Magnetic pulsations in the Pc 1 frequency range (0.2–5 Hz) include several different types; HM whistler, HM periodic emissions, HM chorus, and IPDP event (KOKUBUN, 1970). It is well known that discrete risers in HM whistler and HM periodic emission appear alternately in the conjugate regions. However, it is found from the Syowa Station-Husafell conjugate data that activities of HM whistler and HM periodic emissions are different at the conjugate points. For example, HM periodic emissions were often observed only at Syowa Station in the winter hemisphere (Fig. 2). It is also found that when Pc 1 pulsations consist of a few

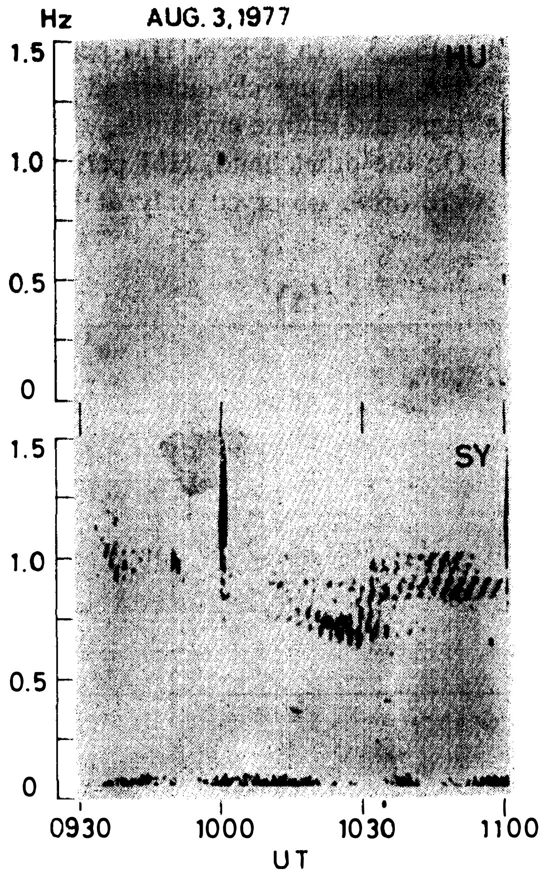

Fig. 2. Example of HM periodic emissions only observed at Syowa Station.

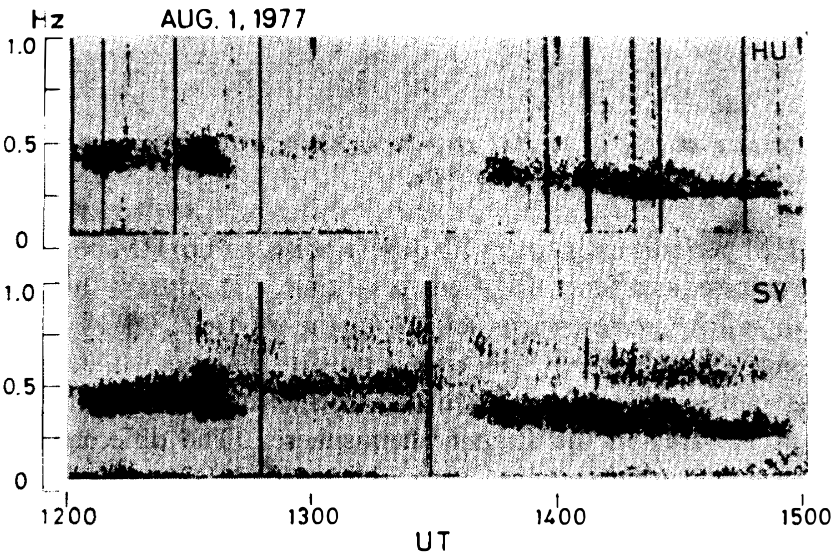

Fig. 3. Example of HM periodic emissions which consist of two spectral bands.

spectral bands, different bands have different degrees of conjugacy. Such an example is given in Fig. 3. In general, HM periodic emissions in the frequency range lower than 0.5 Hz, which are characterized by a spectral structure of a combination of discrete risers and diffuse emissions, were observed simultaneously at the conjugate points. On the other hand, HM periodic emissions in the frequency range above 0.5 Hz were often observed only at Syowa Station. Fig. 4 gives the occurrence

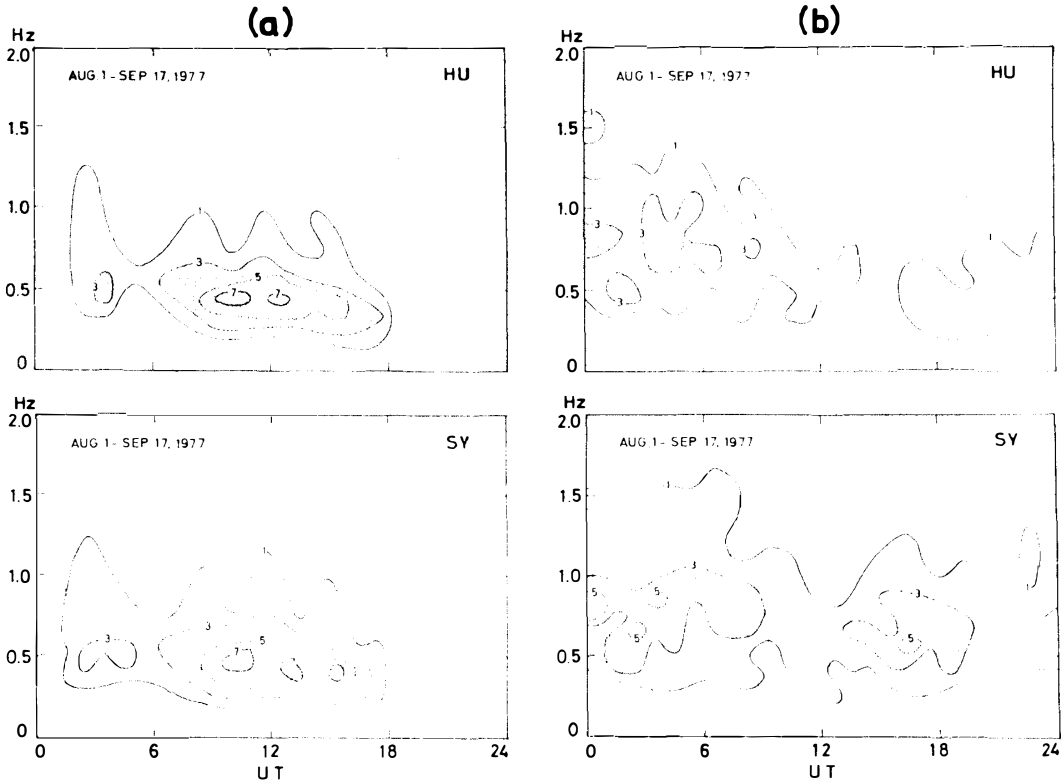

Fig. 4. Occurrence number of a) HM periodic emissions with diffuse noise, and b) HM periodic emissions without diffuse noise.

number of a) HM periodic emissions with diffuse noise, and b) HM periodic emissions without diffuse noise, as a function of universal time. It appears that HM periodic emissions with diffuse noise appear mostly in the daytime, 06–18 MLT, with the same occurrence probability at the two conjugate points, while HM emissions without diffuse noise appear more frequently at Syowa Station in the winter hemisphere than at Husafell in the summer hemisphere. The difference in the local time dependence at conjugate points may indicate that HM periodic emissions in the lower frequency range are generated near the Syowa Station-Husafell conjugate path, while HM periodic emissions in the higher frequency range are generated at lower latitudes than Syowa Station and Husafell and propagate toward higher latitudes through the ionospheric waveguide. This is because the intensity of Pc 1 is greatly attenuated during the propagation through the ionospheric waveguide in the daytime of the summer hemisphere.

Pc 1 pulsations were frequently observed on the GEOS satellite (GENDRIN *et al.*, 1978). However, HM whistler and periodic emissions were rare phenomena on GEOS. As is seen in Fig. 5, Pc 1 event observed on GEOS-1 usually showed a burst-like structure. This suggests that GEOS-1 was located in the ion cyclotron instability region near the equatorial plane of the outer magnetosphere.

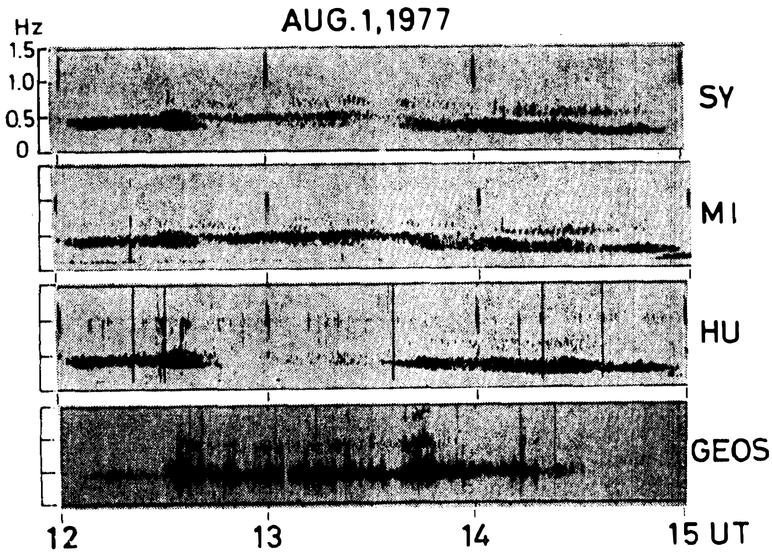

Fig. 5. Example of Pc 1 event simultaneously observed on the ground and on the GEOS-1 satellite.

2.2. *Conjugacy of Pi 1 magnetic pulsations*

It is known that Pi bursts with enhancements in the frequency range of 0.2–1 Hz occur at high latitudes near the magnetic local midnight (HEACOCK, 1967). From the comparison of the Syowa Station-Husafell conjugate data, it is found that enhancements near 0.3 Hz are much higher at Husafell than at Syowa Station in the pre-midnight hours, while the opposite occurs in the post-midnight hours. The *f-t* spectra of the pre-midnight Pi 1 event in Fig. 6 show that enhancements near 0.3 Hz occurred only at Husafell in the summer hemisphere, whereas the *f-t* spectra of the post-midnight Pi 1 event in Fig. 7 show that enhancements near 0.3 Hz occurred only at Syowa Station in the winter hemisphere. Also it is often found that the frequencies of enhanced Pi 1 bands are different between the conjugate points (Fig. 8). These results indicate that the regions of Pi 1 pulsations are sharply localized and the enhancements near 0.3 Hz are greatly affected by the ionospheric conditions. It is also suggested that the real conjugate point of

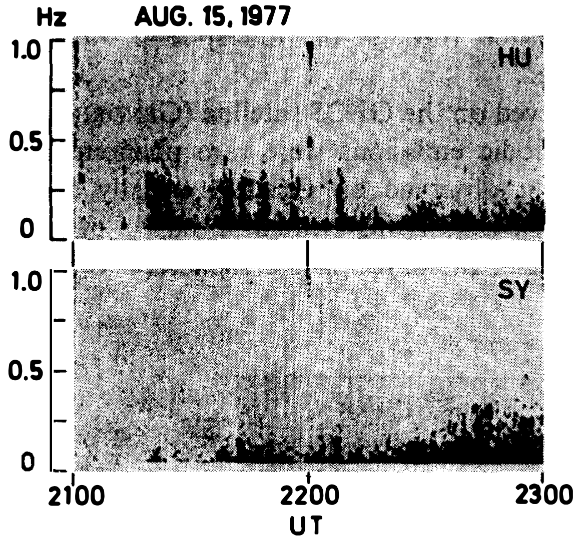

Fig. 6. Example of Pi 1 event observed in the pre-midnight hours.

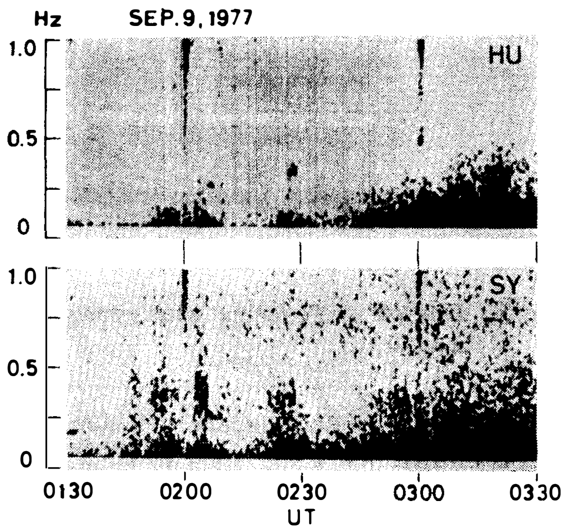

Fig. 7. Example of Pi 1 event observed in the post-midnight hours.

Syowa Station moves as a function of magnetic local time, although the IGRF model calculation indicates that Husafell is located close to the conjugate point of Syowa Station.

2.3. *Conjugacy of Pc 3–4 magnetic pulsations*

In the Pc 3–5 frequency range (1.6–100 mHz), two spectral bands were observed in the daytime at the Syowa Station-Husafell conjugate pair. One spectral band occurs in the 20–40 mHz range, while the other band occurs in the 4–8 mHz range, often independently of that in the 20–40 mHz band. It is found that the *f-t* spectral patterns of these pulsation bands are quite similar at the two conjugate points

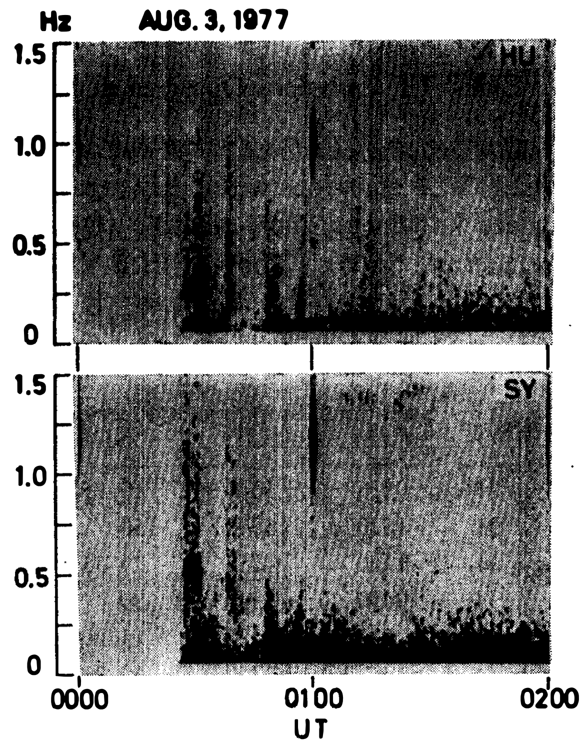

Fig. 8. Example of Pi 1 event with different frequencies at the Syowa Station-Husafell conjugate pair.

(Fig. 9). FUKUNISHI (1979) and IWABUCHI *et al.* (1980) showed that both bands have the wave phase characteristic of odd-mode standing oscillations along the local magnetic field lines. They also showed that the orientation angles of the two polarization ellipses in the H-D plane switch across the magnetic local noon. These results suggest that the 20–40 mHz band and the 4–8 mHz band pulsations are due to standing oscillations along resonant field lines excited by external driving forces such as the Kelvin-Helmholtz instability at the magnetopause and/or the MHD

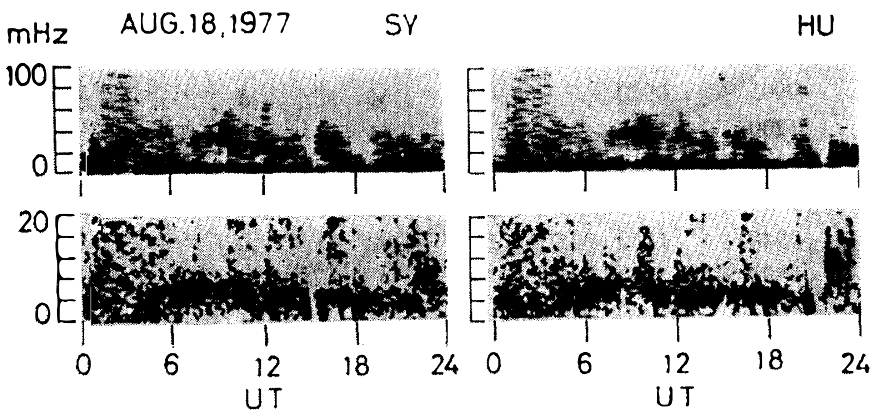

Fig. 9. Example of two spectral bands observed in the Pc 3–5 frequency range.

waves generated near the bow shock.

3. ELF-VLF Emissions Observed at the Syowa Station-Husafell Conjugate Pair

3.1. *Conjugacy of ELF-VLF QP emissions*

ELF-VLF emissions with fairly regular periods longer than the two-hop whistler delay are known as quasi-periodic (QP) ELF-VLF emissions (HELLIWELL, 1965; CARSON *et al.*, 1965). The QP ELF-VLF emissions have been classified into two

Table 2. Conjugacy of quasi-periodic emissions.

Date	Start time (UT)	Stop time (UT)	QP period (s)	GP activity at Husafell	GP activity at Syowa	Type of QP emissions	Conjugacy of QP activity
July 31	0855	1046	10–15	M	M	2	Yes
31	1820	1840	150	A	A	1	Yes
Aug. 1	1150	1255	25–35	M	M	1	Yes
4	0450	1540	80	A	M	1	Yes
4	1155	1220	15–20	M	M	1	Yes
4	1300	1350	50–70	W	W	(?)	?
4	1605	1735	25–35	W	W	(?)	?
5	1000	1430	20–60	A	A	1	Yes
6	0920	0925	30	A	A	1	Yes
6	1340	1520	25–35	A	A	1	Yes
8	0920	1000	12–18	W	N	?	Yes
8	1105	1300	25–40	A	A	1	Yes
9	0900	0930	10–15	W	W	2	Yes
9	0950	1030	15–20	W	W	2	Yes
10	1330	1340	35–45	W	W	2	Yes
16	0850	1140	15–25	W	W	1 and 2	Yes
18	0840	1510	20–40	A	A	1	Yes
19	0750	0920	25–35	A	A	1	Yes
19	1220	1510	30–40	A	A	1	Yes
20	0905	0920	35–40	M	M	1	Yes
20	1200	1520	50–70	M	M	1	Yes
23	1040	1120	30–40	W	W	2	Yes
26	0710	0750	10–15	M	M	1 and 2	Yes
31	0940	1520	15–25	W	W	2	Yes
Sep. 3	0800	1120	15–20	A	A	1	Yes
3	1605	1740	50–70	M	M	2(?)	Yes
14	0940	1530	20–40	M	M	1	Yes
17	1910	2020	25–30	N	N	2	Yes

A: Active, M: Modelate, W: Weak, N: Nothing.

types (Type 1 and Type 2) dependent upon whether the QPs are closely associated with magnetic pulsations or not (SATO *et al.*, 1974). In the period from July 31 to September 17, 1977, 28 QP events were observed at the Syowa Station-Husafell conjugate pair. As summarized in Table 2, it is found that most of QPs (including Type 1 and Type 2 QPs) have a good conjugacy. This result is inconsistent with

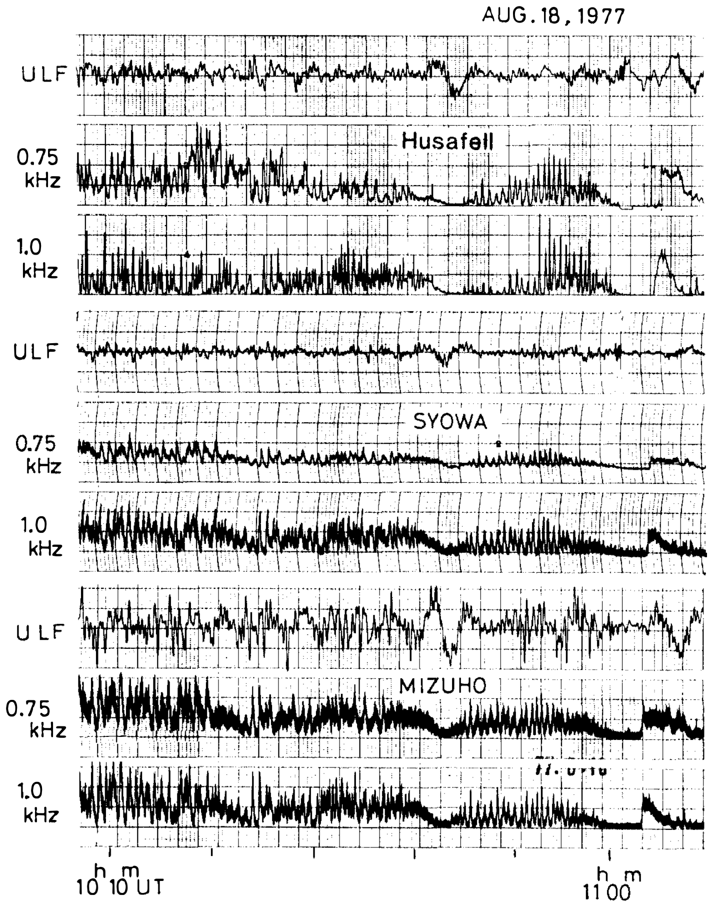

Fig. 10a. Example of Type 1 QP emissions observed simultaneously at Husafell, Syowa and Mizuho Stations.

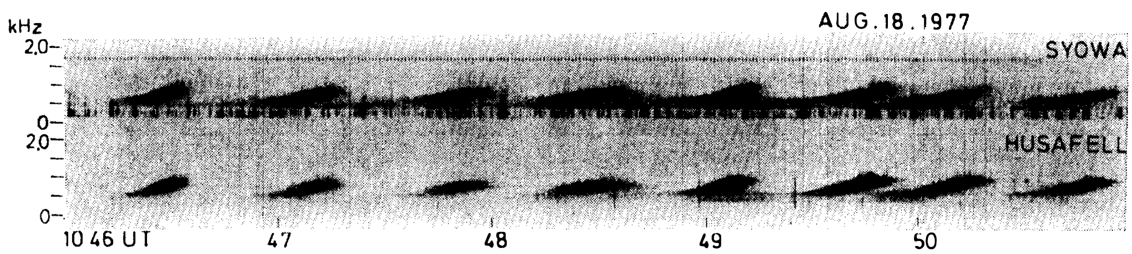

Fig. 10b. Frequency-time spectra of QPs in the time interval of 1046–1051 UT in Fig. 10a.

the result of KITAMURA *et al.* (1969). They could not find a conjugacy for Type 1 QPs at the Great Whale-Byrd conjugate pair. This discrepancy suggests that the Syowa Station-Husafell pair is much better conjugate network than the Great Whale-Byrd pair.

A typical example of Type 1 QP emissions is given in Fig. 10a. It is evident that QP emissions and magnetic pulsations occurred simultaneously at Husafell, Syowa and Mizuho Stations. These QP emissions were observed on GEOS-1 as well as on the ground (CORNILLEAU-WEHRLIN *et al.*, 1978). Frequency-time spectra of this QP event are shown in Fig. 10b. It appears that risers in QP emissions

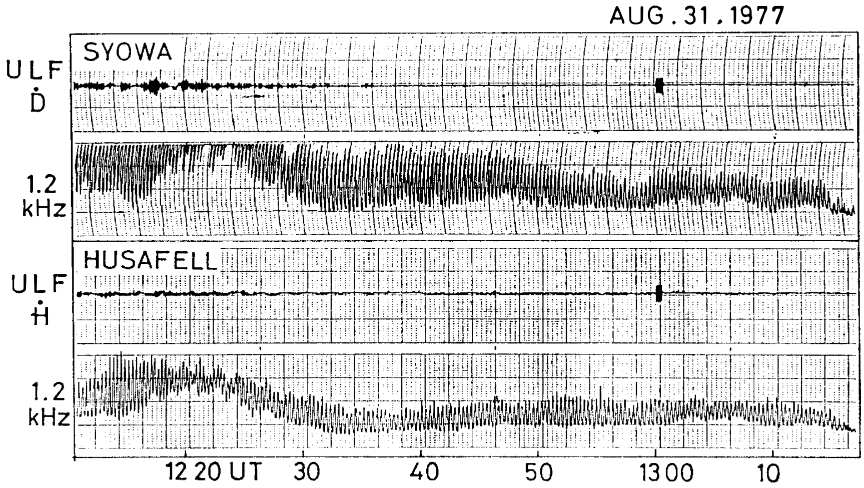

Fig. 11a. Example of Type 2 QP emissions observed at the Syowa Station-Husafell conjugate pair.

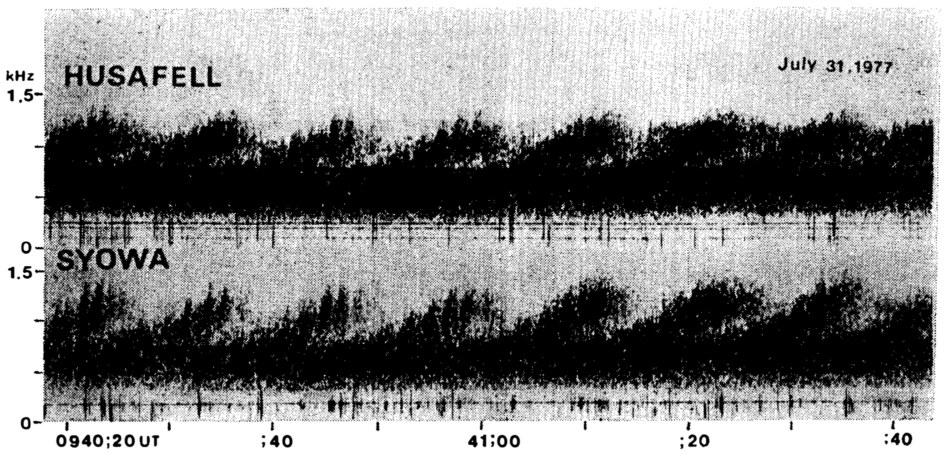

Fig. 11b. Example of frequency-time spectra of Type 2 QP emissions observed at the conjugate points.

appear simultaneously at the two conjugate points. This fact suggests that QP emissions are generated near the equatorial plane in the outer magnetosphere by the modulation of ULF waves (*cf.* SATO and KOKUBUN, 1980; SATO and FUKUNISHI, 1980).

An example of Type 2 QP emissions is shown in Figs. 11a and b. It is found that rising-tone type QP emissions occur simultaneously at the conjugate points just as in the example of Type 1 QPs given in Fig. 10b, although the activity of magnetic pulsations is quite low during the QP emission event (*cf.* SATO and KOKUBUN, 1980b).

3.2. Conjugacy of discrete emissions and auroral hiss emissions

Transient emissions usually with a duration of a few seconds or less are called discrete emissions. These discrete emissions are mostly observed in the early morning during disturbed magnetic activity. For the Syowa Station-Husafell conjugate pair, discrete emissions showed poor conjugacy and the emission intensity was much higher at Husafell than at Syowa Station. A typical example of the *f-t* spectrum of discrete emissions is shown in Fig. 12. It is found that a group of discrete risers occurred only at Husafell in the summer hemisphere.

In contrast with the conjugate relationship of bursts of discrete emissions, the intensity of auroral hiss emissions was much higher at Syowa Station (winter hemisphere) than at Husafell (summer hemisphere). Fig. 13 shows the amplitude records of magnetic pulsations and the emission intensities in the frequency bands of 0.75, 1, and 2 kHz at Husafell, Syowa and Mizuho Stations. Intense auroral hiss emissions occurred at Syowa and Mizuho Stations, closely associated with the activity of magnetic disturbances, while hiss emissions were not observed at Husafell.

The poor conjugacy of discrete emissions and auroral hiss emissions can not be explained only by the absorption effect in the ionosphere since the two types of emissions showed the opposite conjugate relationships. An alternative idea to interprete the observed poor conjugacy is illustrated in Fig. 14. Discrete emissions are assumed to be generated by the electron cyclotron resonance between electron

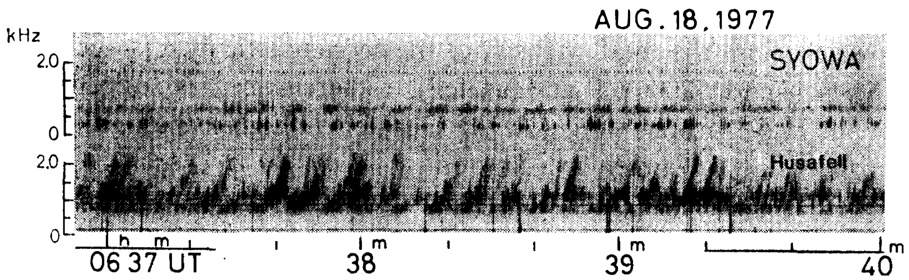

Fig. 12. Example of frequency-time spectra of discrete emissions called auroral chorus observed at the conjugate-pair stations in the morning hours.

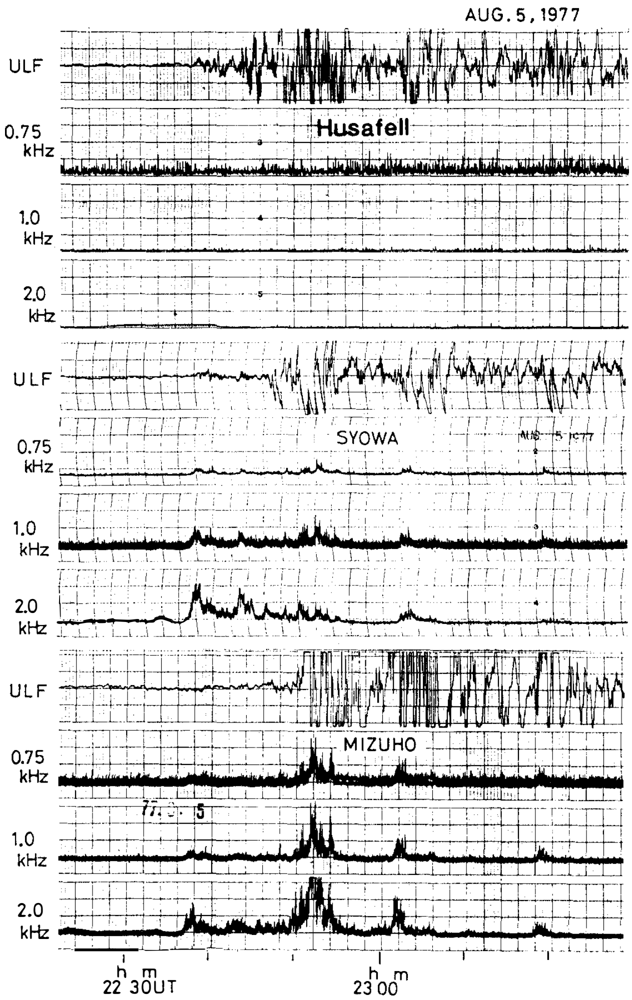

Fig. 13. Example of auroral hiss observed at Husafell, Syowa and Mizuho Stations.

beams and whistler mode waves (*cf.* KIMURA, 1967). In this model the wave is emitted in the opposite direction to the electron beam. Furthermore, it is likely that the intensity of the electron beam toward Syowa Station is higher than that of the electron beam toward Husafell since the mirror height is higher at Husafell than at Syowa Station (the total intensity of the geomagnetic field is about 45000 nT at Syowa Station and 52000 nT at Husafell). Therefore, it is suggested that the intensity of the wave propagating toward Husafell is higher than the intensity of the wave propagating toward Syowa Station.

On the other hand, the poor conjugacy of auroral hiss may be explained by both the differences in the cold plasma density at the conjugate points and the differences in the mirror height. Recently, MAGGS (1976) has shown that the amplification of the whistler-mode wave by the convective instability caused by the beam of precipitating auroral electrons can account for the observed power flux of VLF

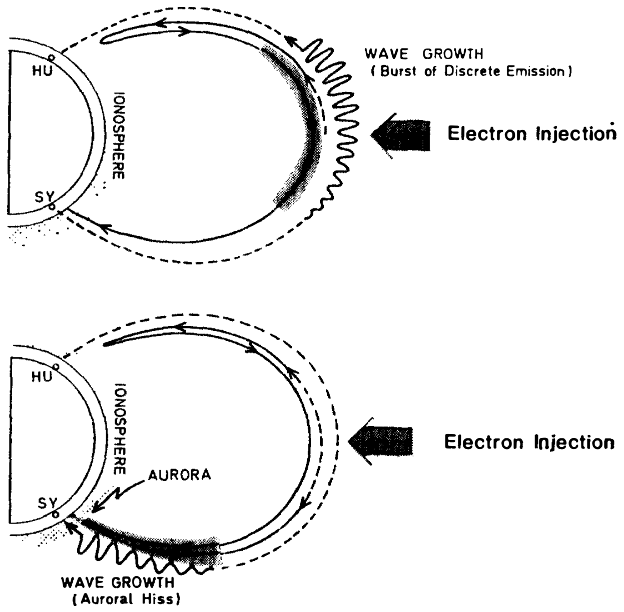

Fig. 14. Schematic illustration for explaining the opposite conjugacies between discrete emissions and auroral hiss emissions.

hiss. The growth rate of auroral hiss generated by the convective instability can be written as follows (Maggs, 1978; Yamamoto, 1979; Makita, 1978).

$$\gamma \propto \frac{n_b}{n_0},$$

where γ, n_b and n_0 denote growth rate, density of the electron beam and the ambient plasma density, respectively. In the northern summer, the ambient plasma density in the northern hemisphere is much higher than that in the southern hemisphere. Furthermore, the beam density of precipitating electrons is higher at Syowa Station than that at Husafell, as mentioned above. Therefore, it is suggested that the auroral hiss grows mostly in the southern hemisphere in the observation period July–September. This result can well explain the seasonal variation of auroral hiss without considering absorption in the lower ionosphere in the summer hemisphere.

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