AURORAL VLF EMISSIONS IN ANTARCTICA

S. KOKUBUN, T. OGUTI, K. HAYASHI and T. NAGATA*

Geophysics Research Laboratory, University of Tokyo, Bunkyo-ku, Tokyo 113, Japan

Abstract: Recent topics of VLF observations at Syowa Station, Antarctica, are summarized. In the frequency-time spectra of quasi-periodic VLF emissions, regular modulation is often found accompanying Pc 4 and Pc 5 pulsations, while complex patterns of modulation are observed usually in association with Pc 2 or Pc 3 pulsations, whose period is shorter than 30~40 seconds.

A certain kind of ELF noise band with a center frequency of about 300 Hz is sometimes observed during auroral hiss events. The noise band is nearly monochromatic and the duration is about ten seconds. The spectral characteristics of the noise are very similar to those of a ELF noise associated with low-energy auroral electron precipitation, found by the Injun 5 observation.

During the recovery phase of substorm, chorus emission of a special type is observed in the early morning. The spectral structure of this chorus is considerably different from that of the daytime chorus. The emission consists of groups of risers of about 0.2 seconds in duration, and the time interval of these groups is of the order of 10 seconds. A typical event comprises short sequences of riser groups overlapping in time in the frequency range of 0.5~2 kHz. Relationship between this chorus and pulsating auroras is discussed on the basis of the coordinated VLF and auroral TV experiments.

Introduction

Recent investigations of very low-frequency wave phenomena based on the Antarctic observations have been mainly focussed on the dynamic behaviors of whistler ducts during magnetospheric substorms (CARPENTER, 1973; BULLOUGH and SAGREDO, 1973) and coherent wave phenomena, such as artificially stimulated emissions, near the plasmapause (HELLIWELL, 1973). In connection with VLF emissions studies have been made on conjugacy of polar chorus and auroral hiss (HUDSON, 1971) quasi-periodic emissions and related phenomena (KOKUBUN, 1971; HO, 1972; SATO and FUKUNISHI, 1973), and VLF emission substorms (HAYASHI and KOKUBUN, 1971; KOKUBUN *et al.*, 1972).

The purpose of this paper is not to review these works, but to summarize recent observations at Syowa Station (geomagnetic coordinate, −69.6°, 77.1°). Relation between quasi-periodic emissions and geomagnetic pulsations is discussed first. Among VLF-ELF phenomena associated with substorms characteristics of a type of ELF noise band in the late evening and chorus emissions in the early

* At present: National Institute of Polar Research.

morning are briefly summarized. The ELF noise band is a phenomenon, found recently by observations at Syowa, which appears during auroral hiss event.

In order to examine complicated-temporal characteristics of VLF emissions, continuous recording of VLF signals with frequency below 4 kHz has been carried out at Syowa Station since 1969, using a magnetic tape recorder with an automatic reverse device. Emission signal strengths of 5 selected bands below 4 kHz have also been registered in a strip chart together with geomagnetic pulsation signals.

Since 1971 the use of a super-sensitive TV camera with a secondary electron multiplication technique has been introduced for the observation of dynamic morphology of auroras in real time. Coordinated VLF experiments with this TV observation have been made also. In addition to the simultaneous recording of VLF and auroral TV signals on the same magnetic tape, the central part of TV field view has been simultaneously monitored since 1972 by a photometer with a filter of N_2^+ 4278Å and a view angle of 5 degrees.

The coordinated observation revealed that VLF hiss appeared concurrently with increase in brightness of sheet type auroras and associated rapid motions of microstructures along auroral sheets. The TV display with the aural monitor of VLF signals was presented at the Commission XI meeting of IAGA, in Kyoto, in order to demonstrate the close association of auroral hiss and morning chorus with auroral displays.

Relationship between Quasi-Periodic Emissions and Geomagnetic Pulsations

KITAMURA *et al.* (1969) have examined the association between quasi-periodic emissions (QP) and geomagnetic pulsations (GP) based on the observations made at Eights and Byrd. The result has revealed that the QP emission is a daytime phenomenon and that there are some characteristic differences between QP associated with GP and QP without concurrent GP. As for QP emissions associated with geomagnetic pulsations, hydromagnetic modulation of the basic emission source in the magnetosphere is considered to be a possible cause (CORONITI and KENNEL, 1970; KOKUBUN, 1971; SATO and FUKUNISHI, 1973). In this section this problem is briefly discussed.

Fig. 1 shows examples of QPs associated with GP (type I), and not associated with GP (type II). As already noted (KITAMURA *et al.*, 1969; SATO and FUKUNISHI, 1973), features are different between these two types. In Table 1 the emission properties of the two types are summarized.

The GP-associated QP mostly occurs around noon as in the case of polar chorus (KOKUBUN *et al.*, 1969; HUDSON, 1971), whereas type II emission tends to appear in the afternoon-evening hours. The periodicity of type II is generally more regular than that of type I, as clearly seen in Fig. 1. The periods of both types range mostly from 15 seconds to 60 seconds, and tend to become longer with the local time.

Emissions of type I are observed in moderate magnetic activity of $Kp \sim 3$ and those of type II in rather quiet activity of $Kp \sim 1$. QP emissions observed at Eights ($L \simeq 4$) appear mostly in the late afternoon and in quiet magnetic conditions (Ho,

Table 1. Characteristics of quasi-periodic emission.

	GP-associated QP (type I)	QP without corresponding GP (type II)
Occurrence (MLT)	$6\sim15^h$	$9\sim20^h$
Magnetic activity	Moderate	Quiet
Period	The mean period tends to increase gradually with the local time and the average period of type I is longer than that of type II.	
Periodicity	Not so regular	Regular
Emission frequency	$0.3\sim1.5$ kHz	Slightly higher than that of type I
Emission spectra	Polar chorus type. The emission frequency is almost constant or the upper boundary changes synchronously with the signal strength. An increase of emission freqency during one quasi-period is observed when the QP period is shorter than $30\sim40$ seconds.	Diffuse or discrete emissions (periodic) or a combination of both with a frequency increase during one quasi-period.

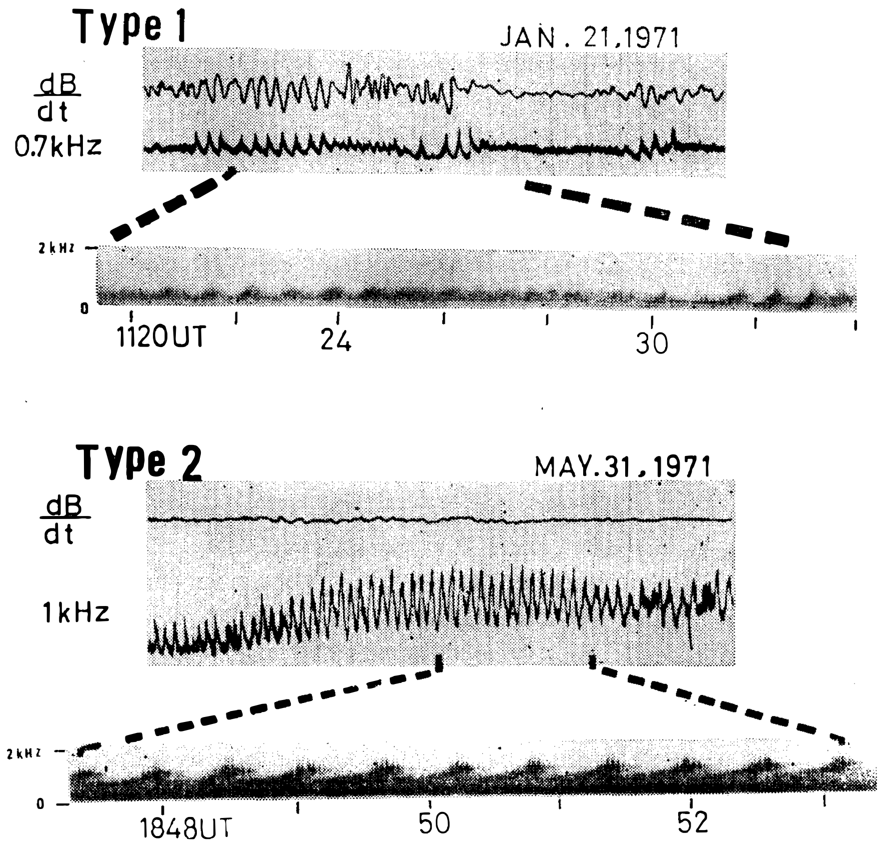

Fig. 1. Frequency-time spectra of QP emissions and records of geomagnetic pulsations. The upper panel shows an example of QP emission associated with pulsations and the lower one an example of QP emission without concurrent pulsation.

1972). Emission spectra at Eights are very similar to those of the type II QP emissions. In the example of QP's without concurrent GP, reported by KITAMURA *et al.* (1969), it is also noted that these emissions were observed mostly at Eights. These facts suggest that the QP emission without a close correlation to geomagnetic pulsations is a phenomenon occurring near the plasmapause.

As evident from Fig. 1 the period of type I emission is not so regular as that of type II emission. Corresponding geomagnetic pulsations also are not so regular. Geomagnetic pulsation events generally consist of series of trains with several wave cycles, so that a clear one-to-one correspondence cannot always be seen between peaks of pulsation wave forms and emission intensity through the whole course of an event. However, this may not indicate an apparent relationship between the phenomena, because simultaneous onsets or cessations are often observed.

Fig. 2 illustrates the examples of frequency-time spectra of QP's and pulsation wave forms in a fine time resolution. In comparison of the upper two spectra with the lower ones, it is noted that spectral structures are significantly affected by the modulation period. When the period is 20 seconds or so, the emission spectra are characterized by a positive drift of midfrequency and a gradual increase of intensity in each component, and a sudden shift of frequency and an intensity decrease in the stage of transition to the next component. On the other hand, a midfrequency drift and a sudden transition from one QP component to another are not observed when the period is longer than 30~40 seconds. Rather, the mean frequency is almost constant or the upper boundary of the emission

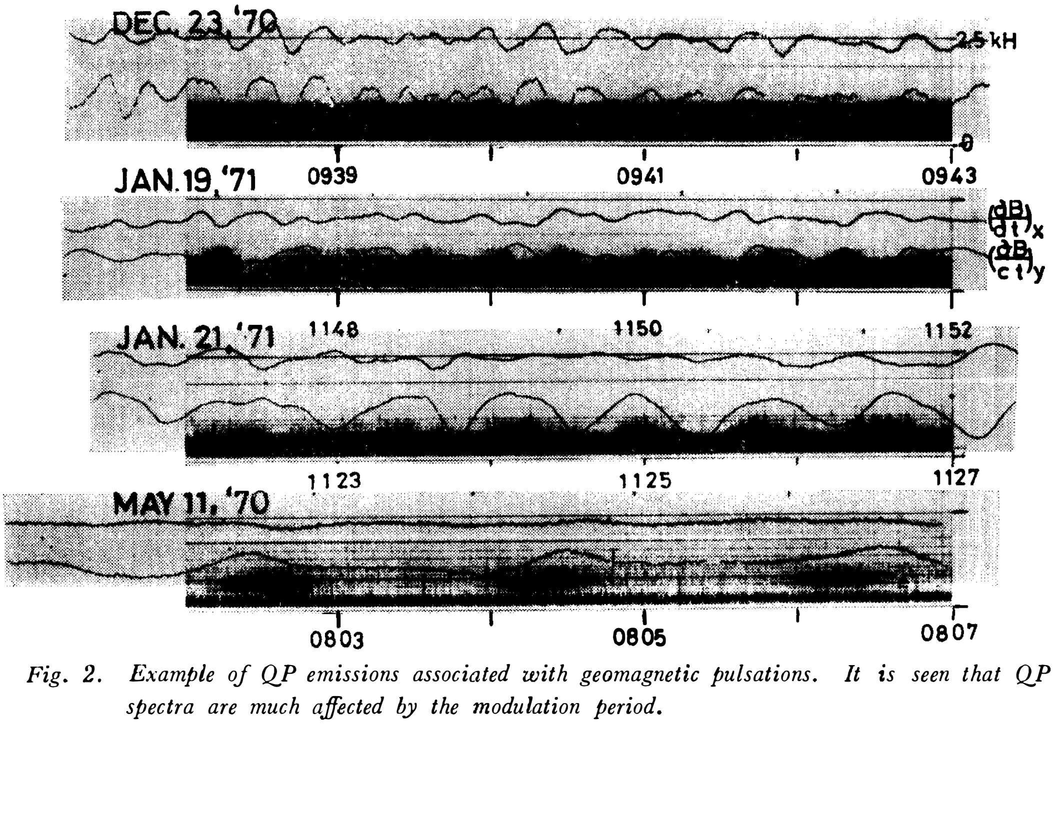

Fig. 2. Example of QP emissions associated with geomagnetic pulsations. It is seen that QP spectra are much affected by the modulation period.

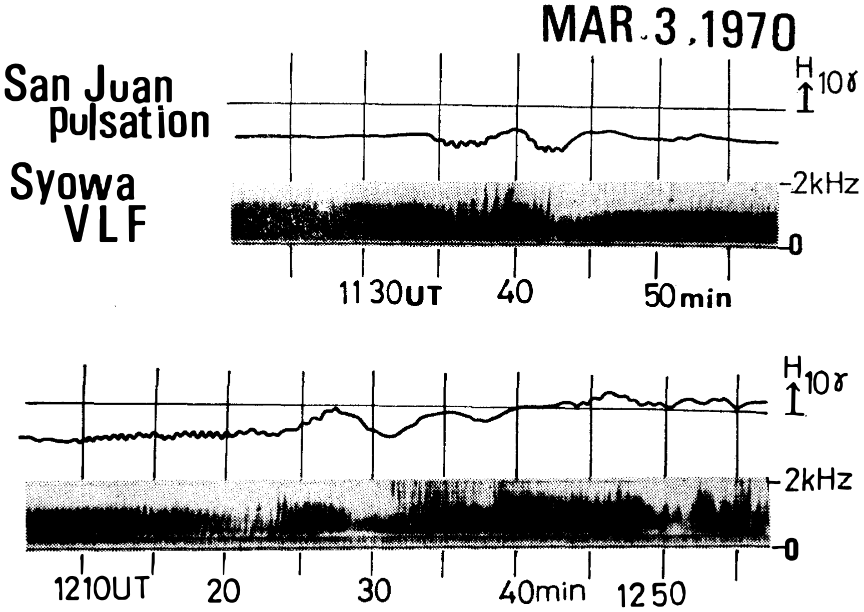

Fig. 3. Changes of emission spectrum of type I associated with world-wide variations of geomagnetic field.

band may change synchronously with the signal strength, suggesting that the emission source is adiabatically modulated by geomagnetic pulsations.

Fig. 3 also indicates an example of a series of events showing the above-mentioned two characteristics. Geomagnetic variations, which correspond to the GP-associated QP emission events at Syowa, are sometimes found at low latitude station, such as San Juan (geomagnetic coordinate, 29.8°, 04.0°) separate from Syowa longitudinally by 75°. In Fig. 3 a good correlation between QP emissions and geomagnetic variations at San Juan can be seen for short period variations in 11^h34^m-43^m, 12^h10^m-27^m and 12^h43^m-50^m. It is also observed that the emission intensity almost synchronously changed in association with a slowly varying magnetic variation of several minutes. Spectral features for shorter and longer period variations are essentially similar to those of the cases in Fig. 2. The examination of magnetic records at low latitudes revealed that the occurrence of such a slowly varying magnetic variation was of a global scale. When the horizontal component of geomagnetic field increases, the intensity of emission increases. A negative variation causes an intensity decrease or a fadeout of emission, as already noted by HAYASHI *et al.* (1968) and KOKUBUN (1971). The characteristics are likely to indicate that a large scale compressional mode of hydromagnetic wave causes modulation of VLF wave source.

In connection with the type II emission, effect of global geomagnetic variation was also found. Fig. 4 is the spectrum of QP emission without concurrent pulsation at the time of a sudden impulse. As seen in the lower panel, a positive sudden impulse at 0852 gave rise to increase in emission intensity and period. The period change in this case is 14 seconds from 25 seconds to 11 seconds. A small negative variation at 0915 caused a decrease in intensity, and periodic components disappeared till about 0920. It is also noted that a rate of mean frequency rise in a quasi-period increased when associated with positive si. The rate decreased when associated with negative sudden impulses.

As for the periodicity of QP emissions without concurrent micropulsations, we do not have any plausible explanation at present. Even if the period is determined by hydromagnetic wave which is not observed on the ground, we cannot explain such a large change in QP period associated with a small magnetic variation in terms of the field line resonance mechanism of geomagnetic pulsation. On the other hand, Ho (1972) has recently shown that the period of QP emission at Eights is closely related to the emission and background hiss intensities. When the emission intensity increases and the associated hiss remains unchanged, the QP period tends to decrease. The event shown in Fig. 4 seems to be such a case, because there is no observable hiss background. When the emission intensity increases with no

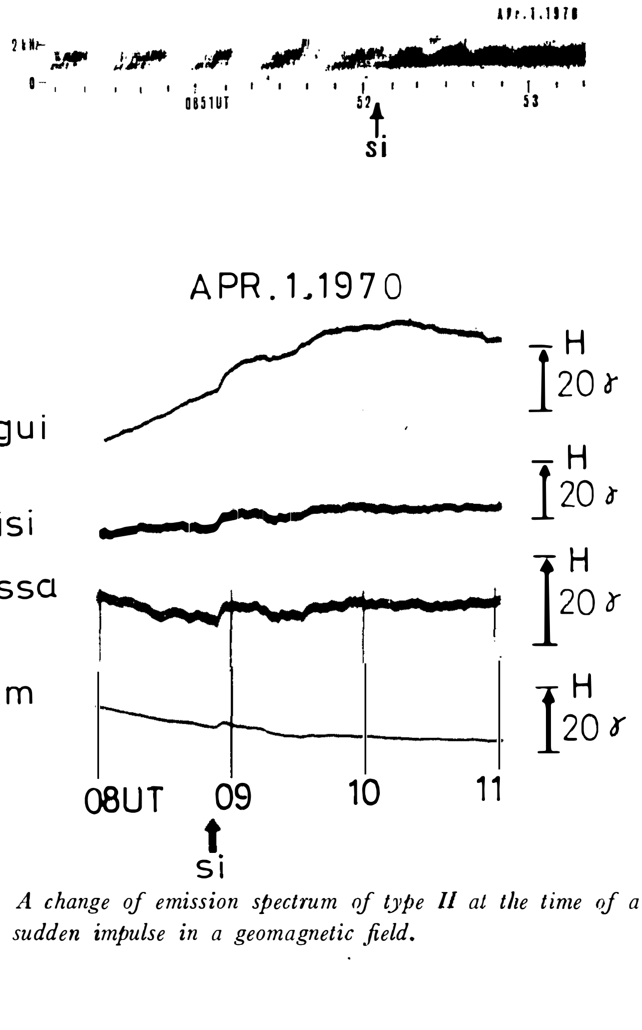

Fig. 4. A change of emission spectrum of type II at the time of a sudden impulse in a geomagnetic field.

increase in hiss intensity, the QP period decreases. In the case of the GP-associated QP, no systematic relationship is found between the emission intensity and period. These facts may indicate that the period of the type II QP emission is determined by a different mechanism from that for the type I.

ELF Noise Bands during Auroral Hiss Event

This section discusses a new type of emission in ELF range, recently found by observation at Syowa. Fig. 5 shows the spectrum of this emission, together with similar ELF noise bands observed by satellites.

By the observation in 1969, about ten cases of particular ELF emissions were found to occur during auroral hiss events in the late evening. The emission properties are summarized as follows; the center frequency is in the range of 200~300 Hz, the emission band is almost monochromatic with a band width of ~100 Hz, and the duration is mostly 10 seconds or so.

These characteristics are very similar to those of the ELF noise band associated with auroral electron precipitation observed with Injun 5 (GURNETT and FRANK, 1972). Since this ELF noise band is a whistler mode phenomenon, the emission observed on the ground seems to be the same phenomenon.

In Fig. 5 a spectrum of a lion's roar emission reported by SMITH *et al.* (1969)

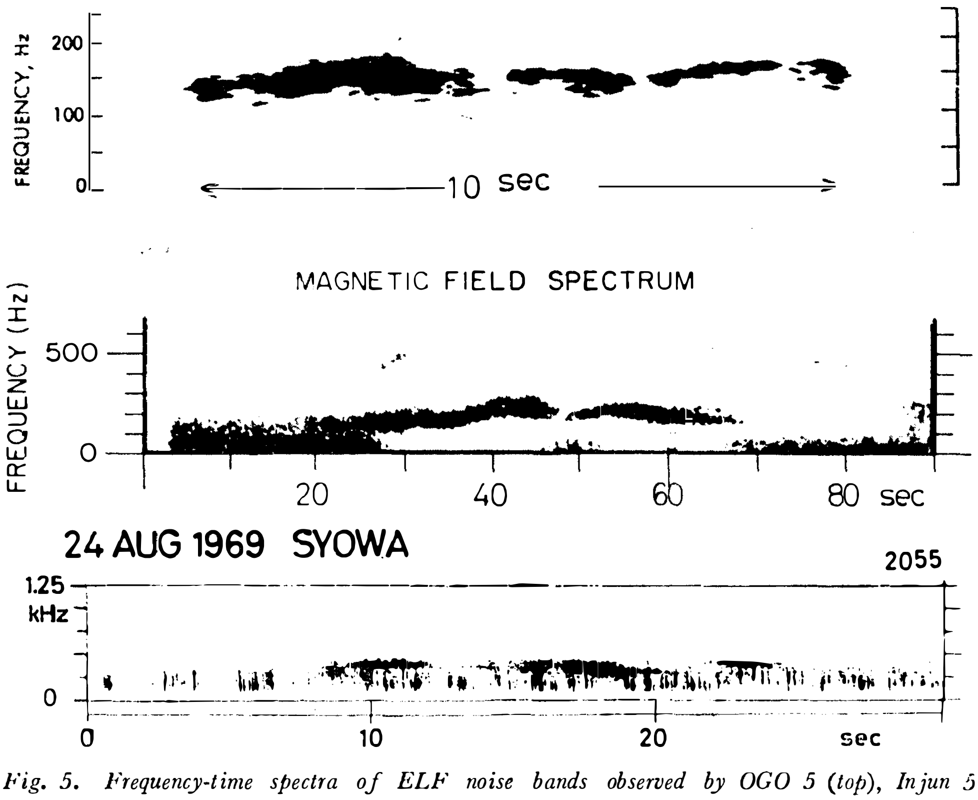

Fig. 5. Frequency-time spectra of ELF noise bands observed by OGO 5 (top), Injun 5 (middle) and on the ground (bottom).

is also shown. They have shown that somewhat discrete tone-like burst sporadically occur in the magnetosheath, at a certain frequency, typically between 50 and 200 Hz. As seen in Fig. 5, emission properties of these noise bands observed in different regions are very similar. However, frequencies of emissions at the low-altitude satellite level and on the ground are slightly higher (100∼300 Hz) than that of the lion's roar emission.

GURNETT and FRANK have suggested that the ELF noise band observed with Injun 5 was caused by lion's roar emissions that were propagating down to the satellite level along the open magnetic field line in the cusp region. Also, there seems to be a possibility of some instability process in the ionospheric region associated with auroral electron precipitation, since the noise band is observed during the auroral hiss event in the late evening on the ground.

Chorus Emissions and Auroral Displays during Post-Breakup Phase of Substorm

It has been reported by MOROZUMI (1965) and HAYASHI and KOKUBUN (1971) that a special type of chorus emission appears in the early-morning auroral zone during the recovery phase of substorm. HAYASHI and KOKUBUN (1971) have pointed out that the temporal feature of this chorus emission is very similar to that of pulsating auroras, and suggested that the source mechanism of emission is closely related to the electron precipitation which causes pulsating auroras. In connection with the electron precipitation a one-to-one correspondence has been found between short bursts of X-ray at a baloon altitude and discrete VLF emissions in the early morning at Siple ($L \simeq 4$) during a substorm, indicating a direct link between wave phenomena and electron precipitation (ROSENBERG *et al.*, 1971). In this section the observations of chorus emissions and pulsating auroras at Syowa Station are briefly summarized.

Fig. 6 shows typical examples of emission spectra observed in the morning and the daytime. It is known well that in the daytime emission at high latitudes the polar chorus is composed of a series of risers and the hiss band in the frequency range below 1.5 kHz. The discrete elements often appear in a quasi-steady hiss or at the upper edge of a hiss band. On the other hand, the spectral structure of the early morning chorus is characterized by rising elements of a very short duration, 0.1∼0.5 seconds. The frequency range of individual risers is generally narrower than that of daytime chorus emissions. These risers intermittently appear in groups of several seconds duration, and the time interval between the groups is of the order of 10 seconds, though this interval is not so regular. The early morning chorus events seem to consist of short sequences of riser groups, overlapping in time in the frequency range of 0.5∼2 kHz, as seen in Fig. 7. These sequential characteristics of morning chorus are very similar to those of auroras summarized by CRESSWELL and DAVIS (1966). However, a one-to-one correspondence has not yet been obtained between VLF risers and pulsation auroral forms.

In order to examine the association between chorus emissions and pulsating auroras further, the coordinate VLF and auroral experiments have been made since 1971. Here a preliminary result of this observation is given.

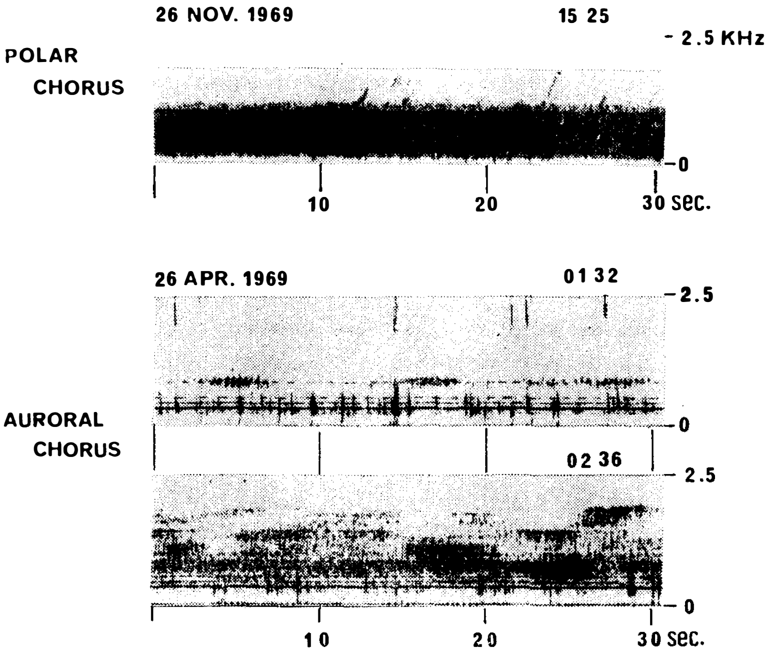

Fig. 6. Frequency-time spectra of daytime and early morning chorus emissions.

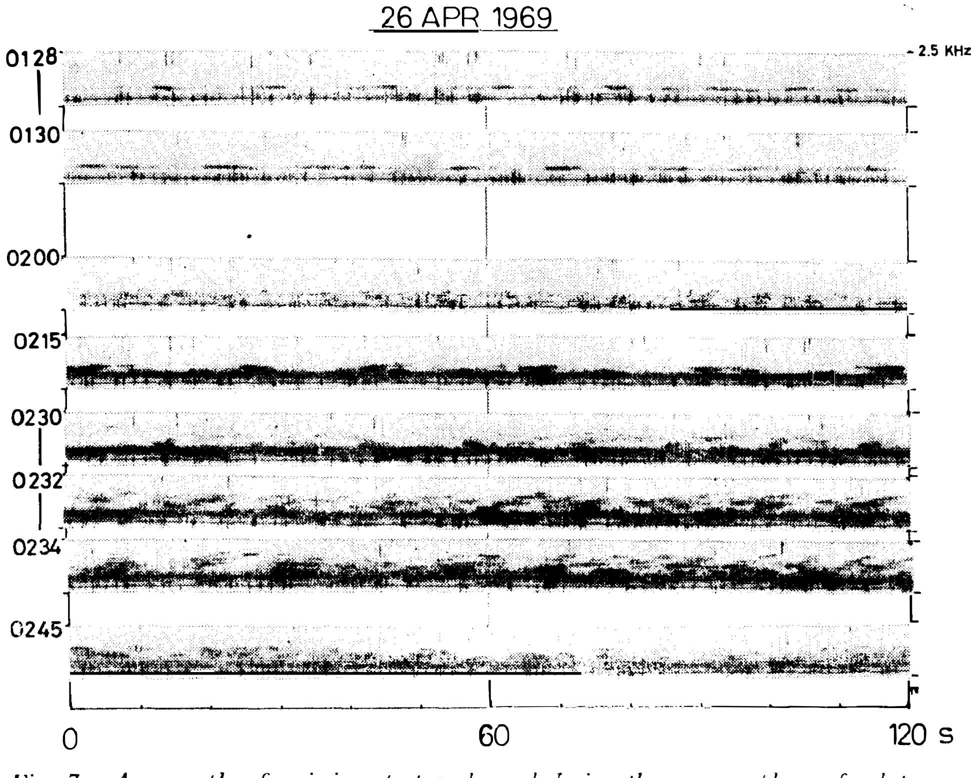

Fig. 7. An example of emission spectra observed during the recovery phase of substorm.

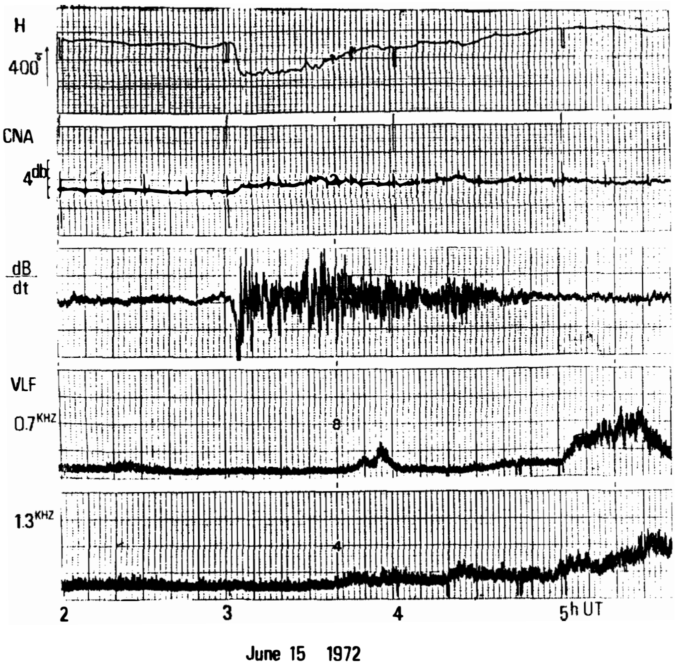

Fig. 8. Correlation record of a substorm event observed at Syowa on June 15, 1972.

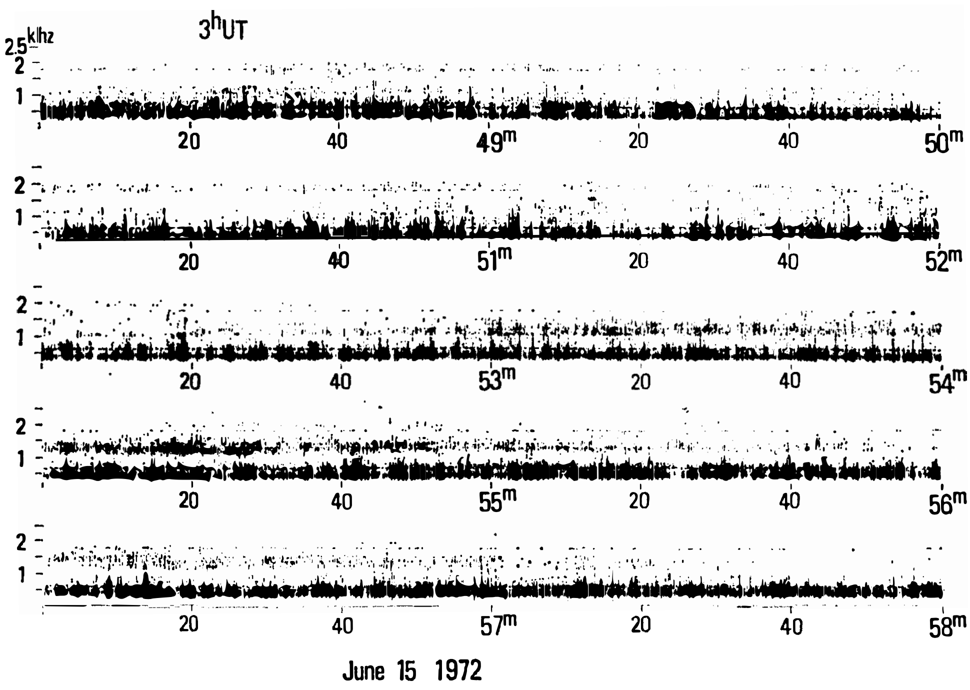

Fig. 9. Emission spectra around the maximum phase of VLF event on June 15, 1972.

Fig. 8 is the correlation record of June 15, 1972. As seen in Fig. 8 chorus emissions occurred during the recovery phase of substorm when the irregular pulsating activity and cosmic noise absorptions increased. We could observe with TV camera that active subvisual pulsating patches appeared on the equatorial side of Syowa during this recovery phase. Frequency-time spectra around the maximum stage of VLF event are shown in Fig. 9. The average power spectrum of 4278Å auroral light fluctuations in the direction of 35° north was also computed for 6 minutes from 0351 to 0357 (Fig. 10). Emissions are composed of fine-discrete risers with a sharp slope and of 0.1~0.2 second duration, as seen in Fig. 9. In the auroral light spectrum the main peak is seen at about 0.1 Hz like the spectra already reported in pulsation aurora studies. It is also noted that there are significant spectral components around 2 Hz. By inspecting the strip chart records it was confirmed that a small variation of frequency, about 2 Hz, was superposed on large fluctuations of several seconds period. This similarity between repetition periods of VLF discrete emissions and auroral-light pulsation periods suggests a close relationship between these phenomena, though one-to-one corresponces have

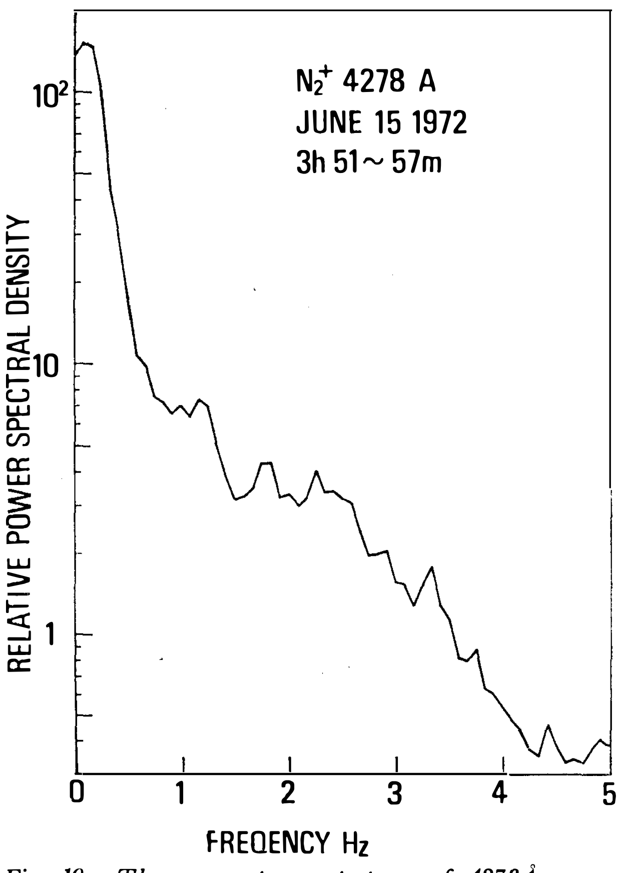

Fig. 10. The average power spectrum of 4278Å auroral light pulsations from 0351 to 0357, June 15, 1972.

not yet been obtained. Since pulsating auroras show complicated features in time and space, further detailed studies will be necessary to elucidate the relation between VLF wave phenomena and electron precipitation.

Conclusion

Recent topics of VLF observations at Syowa Station, Antarctica are summarized. Possible interactions between the VLF emission generation and hydromagnetic waves in the magnetosphere are discussed in the first section. The result for QP emissions associated with geomagnetic pulsations is consistent with a theoretical inference for modulation of the whistler turbulence by compressional hydromagnetic wave (CORONITI and KENNEL, 1970). This interpretation may be supported by the earlier observation of VLF emission modulation at times of sudden commencements and sudden impulses (HAYASHI *et al.*, 1968). Thus it is concluded that the study of interrelations between QP emissions and geomagnetic pulsations is important for understanding not only the VLF emission generation but also the cause of geomagnetic pulsations.

As to chorus emissions during the recovery phase of substorm, the similarity of temporal features between chorus emissions and pulsating auroras is pointed out. It is highly probable, however, that evidence of a direct link between chorus bursts and auroral electron precipitation whould be obtained through detailed examination of simultaneous VLF and auroral-TV data.

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