STATISTICAL CHARACTERISTICS OF 750-Hz BAND ELF EMISSIONS OBSERVED AT SYOWA STATION

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Abstract: The digital recording system of ELF-VLF emissions was installed at Syowa Station, Antarctica (L=6.1) in 1981. With the digital data recorded from June 1981 to January 1983, statistical characteristics of emission occurrences at a 750-Hz band were examined. The noticeable occurrence distributions depending on diurnal variation, seasonal variation, and Kp indices are found. We discussed some reasons of the seasonal variation effects.

1. Introduction

Natural radio waves with the frequency of 0.1–100 kHz are frequently observed in the polar region on the ground. These emissions are classified into polar chorus, auroral chorus, discrete emission, quasi-periodic (QP) emission and auroral hiss (HELLIWELL, 1965). The statistical characteristics observed on the ground were examined by many researchers in the recent twenty years. For example, polar chorus emissions are observed in the daytime and also in the local summer with the frequency band of a few hundred Hz to a few kHz (POPE, 1963; UNGSTRUP and JACKEROTT, 1963; EGELAND *et al.*, 1965). In the post-midnight and the early morning hours, auroral chorus type emissions are observed associated with pulsating aurora (HAYASHI and KOKUBUN, 1971). QP emissions with the period of 10–100 s have maximum occurrence around the noon (SATO *et al.*, 1974; SATO and KOKUBUN, 1980). It is well known that auroral hiss is associated with the appearance of auroral arcs (OGUTI, 1975; MAKITA, 1979). Pronounced diurnal and seasonal variations of auroral hiss are found, that is, emission is predominantly observed between 18 and 03 at magnetic local time and during the equinox and the local winter season (WATTS *et al.*, 1963; HARANG and LARSEN, 1965; MAKITA, 1979). However, these statistical results were based on analogue technique, *i.e.*, analyses from chart paper, frequency-time (*f-t*) spectra and audio-speaker monitor. So these results are mostly qualitative.

Although the continuous recording system of ELF-VLF emissions was installed at Syowa Station in Antarctica (66.1°S, 70.8°E, L=6.1 in invariant geomagnetic coordinate) in 1966, the state of artificial noise, mostly 50-Hz harmonics from the power line, grew worse year by year in proportion to expansion of the station area and activity. In 1981, a new remote station was set up at 5 km apart from the center of Syowa Station. By the new system the man-made noise level in ELF-VLF signals became negligibly low throughout the year. The ELF-VLF receiving system at the remote station comprises triangle-shaped three-turn loop antenna (10 m in height, 20 m in length at the base), pre-amplifier and main amplifier. The ELF-VLF signals are continuously transmitted to the mother station by UHF telemetry system. Then wave intensity at 0.35, 0.75, 1.2, 2, 4, 8, 30, 60 and 95 kHz is measured by 9-channel filter units. The sensitivity of this system is 10^{-17}–10^{-12} W/m^2·Hz, and the frequency range is 100 Hz–100 kHz. Wide-band signals up to 15 kHz are recorded on audio tape recorders. The wide-band signals are also supplied to FFT spectral analyzer, and dynamic spectra in the frequency ranges of 0–2 kHz and 0–10 kHz are recorded on digital magnetic tapes. Output signals from the 9-channel filter units are recorded on digital magnetic tapes with sampling frequency of 0.5 Hz. Details of the new system are summarized by SATO *et al.* (1984).

These digital data recorded at Syowa Station are most useful for analyzing the statistical characteristics of ELF-VLF emissions quantitatively.

In this paper, we report the preliminary results for the statistical characteristics of 750-Hz band ELF emission occurrences, the diurnal variation, seasonal variation and *Kp* dependency, using FACOM/HITAC M-180 computer system. The data period in this analysis is from June 1981 to January 1983.

2. Analysis Method

Sampling frequency and dynamic range of the A/D converter recorded at Syowa Station in 1981 and 1982 are 0.5 Hz and 12 bits, respectively. The most difficult and

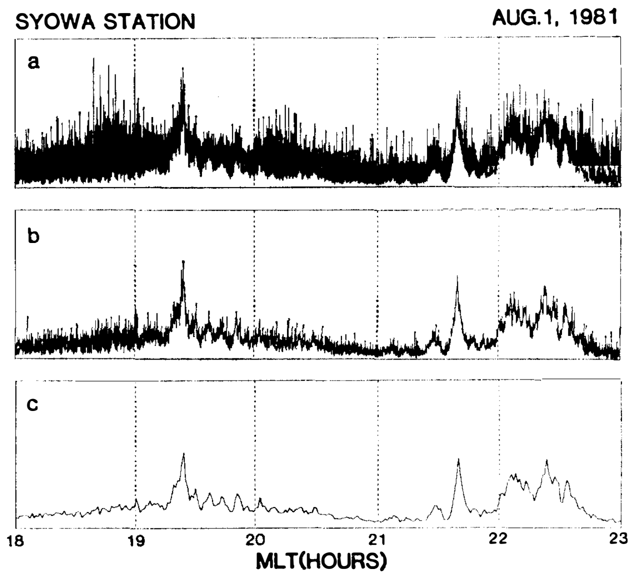

Fig. 1. Digital plots of 2-kHz band intensity record during the time interval of 18–23 UT on August 1, 1981. Upper, middle and lower panels demonstrate the original plots at the sampling frequency of 0.5 Hz, the minimum reading plots of every 6 s, and the averaged plots of every one min, respectively. During the period, auroral hiss emissions are observed overlapping intense atmospheric impulses.

important problem is how to reject the atmospheric impulses from the natural emissions recorded on the digital data. Since an atmospheric impulse level is very high, a minimum reading detector or low pass filter units cannot reject the impulses completely. In this analysis we try the minimum reading every 6 s from the original digital data. Figure 1 shows the digital plots of the 2-kHz band intensity recorded during the interval of 18–23 UT on August 1, 1981. The upper, middle and lower panels show the original plots, the minimum reading plots every 6 s and the averaged plots every 1 min, respectively. The original data show that intense atmospheric impulses are overlapped with auroral hiss emissions. Minimum reading data shown in the middle and the bottom panels of Fig. 1 indicate that intense impulses are clearly rejected and auroral hiss emissions of long duration more than 6 s became evident. This minimum reading technique is most useful for the events of long duration, such as polar chorus, auroral hiss and long-term QP emissions. However, events of short duration such as discrete emissions, periodic emissions and auroral chorus are almost rejected from the analysis data by this method. Any other technique cannot take the place of the minimum reading method at present, so that we used this technique in the present work. In the following statistical work we use the one-minute averaged data as a unit datum calculated from the minimum reading at every 6 s.

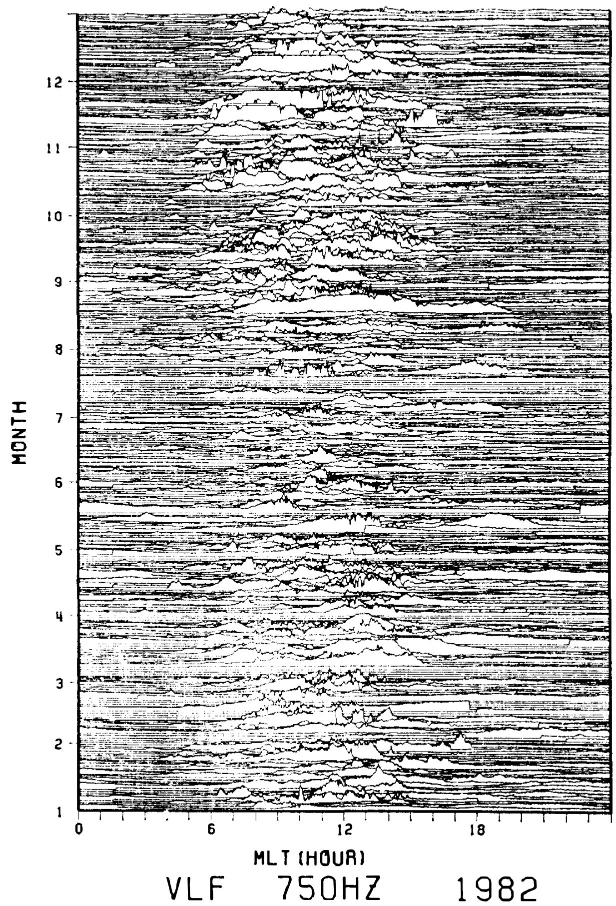

Fig. 2. 750 Hz band emission intensities displayed every day from January 1 to December 31, 1982.

3. Observation

Some statistical characteristics of VLF emissions at the 750-Hz band are demonstrated in this section. The frequency band of 750 Hz represents a typical type of polar chorus emission at Syowa Station (HAYASHI *et al.*, 1968).

Figure 2 demonstrates diurnal variation of the 750-Hz emission intensity displayed every day from January 1, 1982 to December 31, 1982. The geomagnetic local time (MLT) is almost equal to the universal time (within 15 min) at Syowa Station. It is evident that most of the 750-Hz band emissions are observed in the daytime of 07–14 MLT. Furthermore, seasonal variation of the emission intensity is also recognized. Emission intensity becomes minimum during the austral winter season from June to July. Details of these characteristics are examined in the following.

Statistical characteristics of diurnal variation of the 750-Hz emissions are displayed in Fig. 3. In this statistical analysis, we used 20 months data from June 1, 1981 to January 31, 1983 and the emission intensities larger than 1.5×10^{-6} V/m$\cdot\sqrt{\text{Hz}}$. It is evident that most emissions are observed in the daytime from 07 to 14 MLT. Occurrence peaks are noticeable around 11 MLT.

We examined the seasonal variation of the 750-Hz emission occurrences. Figure 4 shows the 750-Hz occurrence probabilities *vs.* data from June 1981 to January 1983

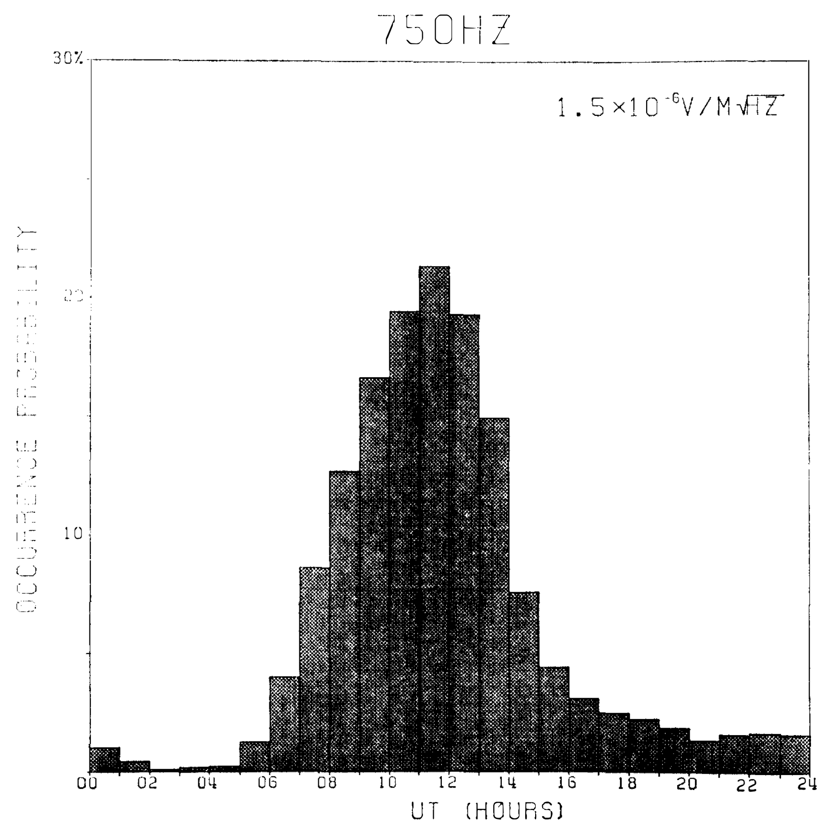

Fig. 3. Diurnal variation of 750-Hz emissions with the intensity level larger than 1.5×10^{-6} V/m$\cdot\sqrt{Hz}$ by using the 20 months data from June 1, 1981 to January 31, 1983.

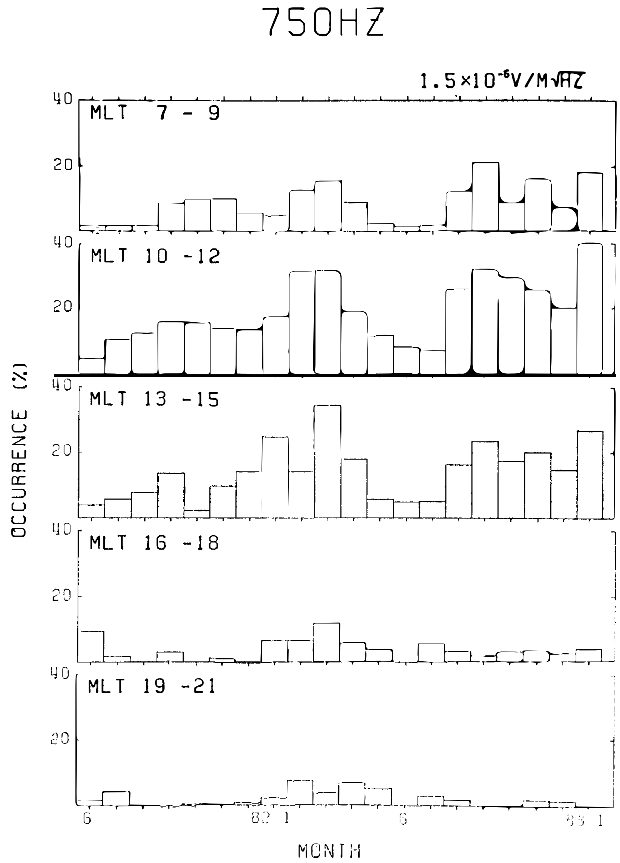

Fig. 4. Seasonal variation of 750-Hz emission occurrences at the intensity level larger than 1.5×10^{-6} V/m·$\sqrt{Hz}$.

every 3 hours from 07 to 21 MLT. Each occurrence probability is displayed for every month. From the display of occurrences in the early morning (07–09 MLT), in the late morning (10–12 MLT) and in the afternoon (13–15 MLT), it is evident that the emission probability becomes maximum during the equinox and becomes minimum during the austral winter between May and July. Furthermore, it is interesting that the occurrences show sub-minimum during the austral summer from November to December. On the other hand, as for the seasonal variation of the occurrences in the late afternoon (16–18 MLT) it is noticeable that the maximum occurrence peak is found only in the austral fall season between February and May.

Figure 5 shows the relation between the diurnal variation of 750 Hz emission occurrences and the geomagnetic activities at the emission intensity greater than 1.0×10^{-6} V/m·$\sqrt{\text{Hz}}$. *Kp* indices are used as the indicator of geomagnetic activities. Total number of periods of *Kp* indices for $0\leq Kp<1$, $1\leq Kp<2$, $2\leq Kp<3$, $3\leq Kp<4$, $4\leq Kp$ in this statistics is 353, 928, 1317, 1147 and 1141, respectively. It is clearly shown that the daytime 750-Hz emissions are observed mostly during moderately disturbed periods of $2\leq Kp<3$, $3\leq Kp<4$ and $1\leq Kp<2$. In the periods of quiet days and of more disturbed days, the occurrences are depressed. It is worth noting that occurrences in the late afternoon of 16–19 MLT show maximum under the quiet geomagnetic conditions of $0\leq Kp<1$ and $1\leq Kp<2$.

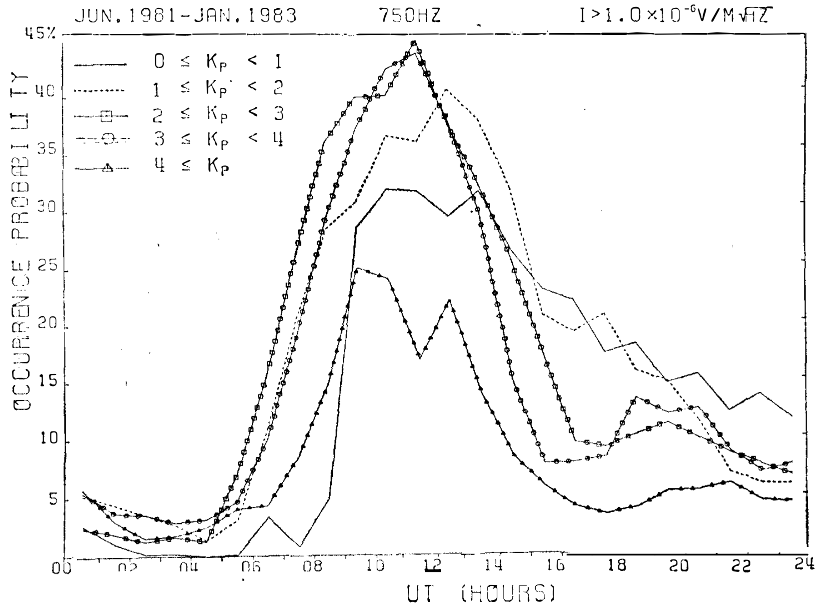

Fig. 5. Relation between diurnal variation of 750-Hz emission occurrences and geomagnetic activities at the intensity level greater than 1.0×10^{-6} $V/m \cdot \sqrt{Hz}$.

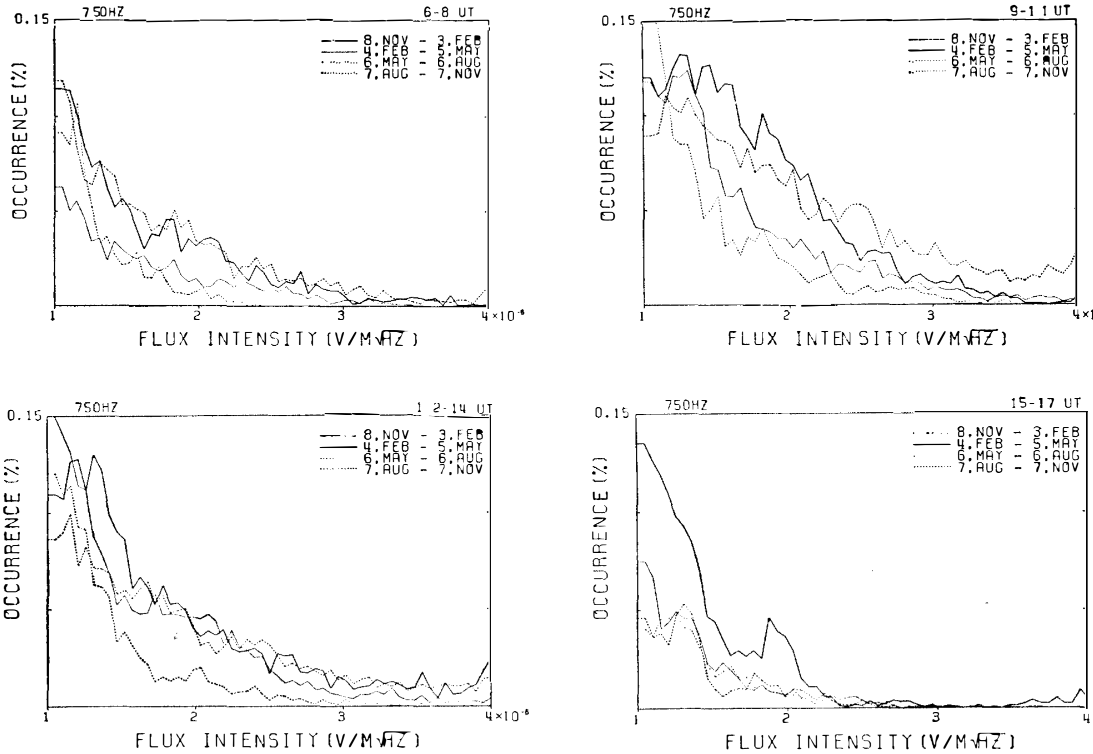

Fig. 6. Occurrence distributions of 750-Hz band emissions observed in each season vs. emission intensity during different local time intervals of 06–08, 09–11, 12–14 and 15–17 MLT, respectively.

We also examined the distribution of emission intensity against seasonal variation and geomagnetic activities. Figure 6 shows occurrence distribution *vs.* emission intensity at 06–08, 09–11, 12–14 and 15–17 MLT observed in each season. It is easily found that occurrences of emissions are minimum at all intensity levels and local times during the austral winter season from May to August. In the early morning (06–08 MLT) the emission intensity is almost the same for autumn and spring. In the late morning (09–11 MLT) occurrences become maximum during autumn (February–May) when the emission intensity is less than 2.2×10^{-6} V/m·$\sqrt{\text{Hz}}$, but it becomes maximum during spring (August–November) when the emission intensity is larger than it. Such an intensity distribution changes during the afternoon hours (12–14 MLT). No meaningful differences are found between spring, summer and autumn when emission intensity is larger than 1.6×10^{-6} V/m·$\sqrt{\text{Hz}}$. However, emissions during the winter are still depressed. In the late afternoon (15–17 MLT) it is noticeable that occurrences during the spring season of August–November become depressed and show pronounced maximum during the autumn season of February–May. Figure 7 shows the occurrence distribution between emission intensity and geomagnetic activities at different intervals of 06–09, 09–12, 12–15 and 15–18 MLT, respectively. As shown in Fig. 5 the emissions occur mostly during a moderately disturbed period

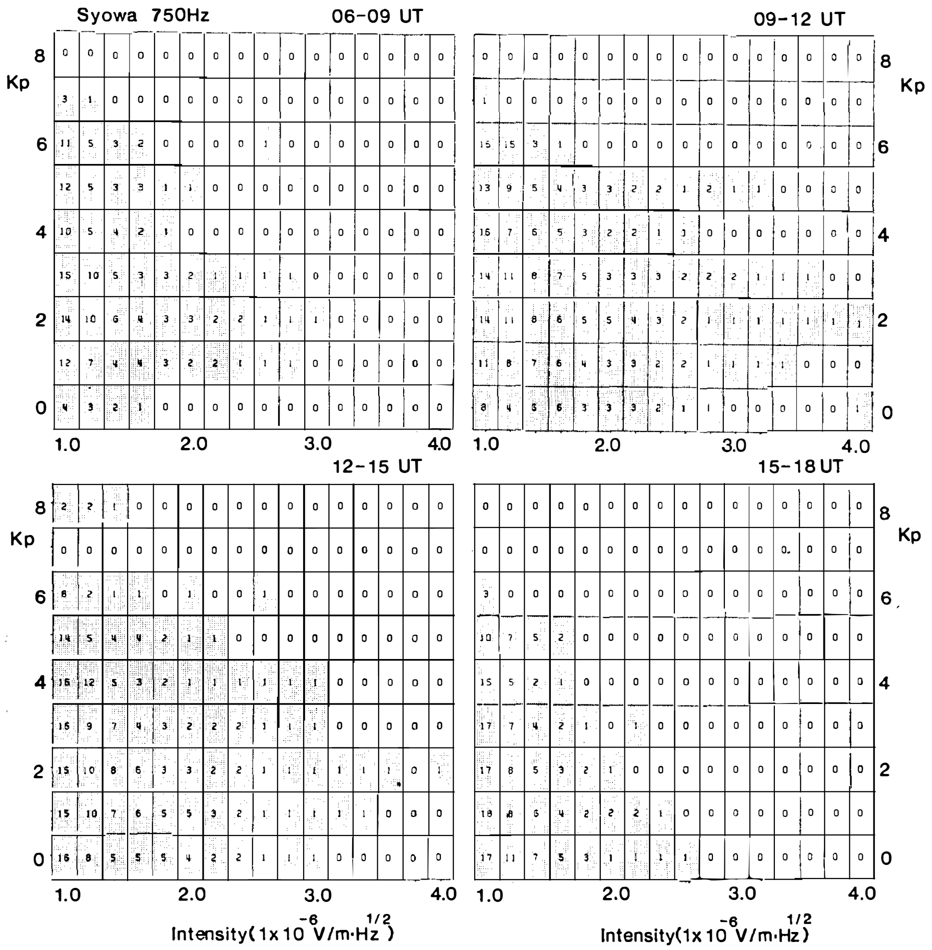

Fig. 7. Occurrence distributions between 750-Hz emission intensity and geomagnetic activities during intensity and geomagnetic activities during different local time intervals of 06–09, 09–12, 12–15 and 15–18 MLT, respectively. The numbers plotted in this figure demonstrate the occurrence probabilities normalized by each Kp index.

of $Kp=2$–4, with a maximum at $Kp=2$–3. Such a tendency is also found in Fig. 7 at 06–09, 09–12 and 12–15 MLT. However, noticeable relations between the emission intensity and the Kp indices are found during the period of 15–18 MLT, when emission occurrences increase in association with the decrease of Kp indices. That is, emissions are more often observed in the late afternoon hours of 15–18 MLT when emission activities become quiet as demonstrated in Fig. 5.

4. Discussion

Statistical characteristics of emission occurrences may be important for studying general conditions of generation and propagation mechanisms of VLF emissions. The diurnal variation of polar chorus has been examined by many workers (UNGSTRUP and JACKEROTT, 1963; KOKUBUN *et al.*, 1969; TSURUTANI and SMITH, 1977). They showed that most emissions occurred in the daytime and had maximum occurrences during the pre-noon period, same as the result reported in this paper. The intensification of polar chorus in the daytime can be explained by the enhancement of wave-particle interactions. The ambient plasma density in the outer magnetosphere increases in the daytime, on account of the heating of the sunlit ionosphere (BANKS and HOLZER, 1968; BRICE and LUCAS, 1971). The effective index of refraction is increased, and the wave phase velocity, which in first order is inversely proportional to the square root of the plasma number density, is decreased. The cyclotron resonance equation shows that cyclotron resonant energy of the electrons will be lower owing to the lower wave phase velocity when all other parameters remain constant. Because of the typical e-folding spectrum of electrons in the outer magnetosphere, more particles are available for resonance when resonant energy becomes low, and hence greater wave-particle interaction and more rapid wave growth take place. The sub-peak of emission occurrence during the late afternoon with the quiet geomagnetic activity may be reasonably interpreted as follows: The location of plasmapause extends more than $L=6$ in the late afternoon ($\sim$15–18 MLT) and under quiet geomagnetic conditions ($Kp \leq 2$) (CHAPPELL *et al.*, 1970). So the geomagnetic field line extending from Syowa Station ($L=6.1$) is located inside the plasmapause during this period. Normally, high-energy electron flux decreases in the late afternoon sector in comparison with the morning and the noon sectors, but when the region crosses the plasmapause where plasma density is higher, the polar chorus emissions are enhanced again.

Polar chorus emission shows strong seasonal variations as reported in this manuscript and also by other researchers (UNGSTRUP and JACKEROTT, 1963; KOKUBUN *et al.*, 1969). That is, emission occurrences become minimum during the winter season and become maximum during the equinox. Why emission occurrences show such a strong seasonal variation is still unknown at present. But there are some possibilities as follows: 1) Seasonal variation of ambient plasma density, 2) Seasonal variation of enhancement of wave duct, 3) Seasonal variation of geomagnetic activity, 4) Seasonal variation of wave absorption in the ionosphere.

Ambient plasma density becomes minimum during the winter season because ambient plasma density in the magnetosphere is caused by the heating of the sunlit ionosphere. So the minimum occurrences of emission activities in winter are reasonably explained by the decrease of ambient plasma density in the wave generation region. However, we must take the effect of opposite hemisphere into account. The plasma produced by the sunshine in the summer hemisphere may propagate to the other hemisphere along the geomagnetic field line as a polar wind (BANKS and HOLZER, 1968). So the asymmetry of ambient plasma density between the northern and the southern hemispheres may be cancelled quickly. The asymmetry of wave duct enhancement is more reasonable to account for the seasonal variation of emission intensity than that of ambient plasma density between the two hemispheres, because the density irregularity along the geomagnetic field line which acts as a wave duct may be more easily producted in the sunlit hemisphere.

Table 1. Seasonal variation of the distribution of Kp index from August 1981 to October 1982.

Season	*Kp* Index				
	$0\text{–}1_-$	$1_0\text{–}2_-$	$2_0\text{–}3_-$	$3_0\text{–}4_-$	$4_0 \leq$
Spring 1981 August–October	6.1	20.1	30.3	25.0	18.5
Summer 1981–1982 November–January	15.2	25.0	29.2	18.3	12.2
Autumn 1982 February–April	5.4	13.1	23.6	24.0	33.8
Winter 1982 May–July	5.3	18.2	24.7	21.3	30.4
Spring 1982 August–October	2.7	13.2	24.6	29.8	29.8

The emission occurrences are also related with geomagnetic activities as shown in Figs. 5 and 7. If there is a seasonal variation of *Kp* index, the emission occurrences may also be controlled by it. Table 1 shows seasonal variation of the distribution of *Kp* index during the period analyzed in this paper from August 1981 to October 1982. It is noticeable that geomagnetic activities are relatively high during the equinox and become minimum during the austral summer season. Such a seasonal variation of geomagnetic activities shows the same tendency as that of the polar chorus occurrences except in the winter season.

Wave absorption effect in the ionosphere is difficult to identify from the data observed on the ground. In order to define the effect quantitatively, we must compare the emission intensity observed simultaneously on board satellite and on the ground in the two hemispheres. But it is very difficult to find one-to-one correspondence of the phenomena observed on board satellite and on the ground as reported by SATO *et al.* (1981). However, KELLY *et al.* (1975) using satellite data reported statistically that there were strong seasonal variations of emission intensity between the winter hemisphere and the summer hemisphere. That is, the intensity in the summer hemisphere is three times stronger than that in the winter hemisphere. These statistical results observed on board satellite are relatively the same as that observed on the ground. So it is suggested that seasonal variation of wave absorption effects may be relatively weak in comparison with the seasonal asymmetry of occurrences or propagation effects.

We cannot find out the direct cause of seasonal variation of polar chorus occurrences at present. We hope to extend these works by using long-term data analysis, geomagnetic conjugate-pair data and simultaneous observation on board satellite and on the ground.

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References

BANKS, P. M. and HOLZER, T. E. (1968): The polar wind. J. Geophys. Res., **73**, 6846–6854.

BRICE, N. and LUCAS, C. (1971): Influence of magnetospheric convection and polar wind on loss of electrons from the outer radiation belt. J. Geophys. Res., **76**, 900–908.

CHAPPELL, C. R., HARRIS, K. K. and SHARP, G. W. (1970): A study of the influence of magnetic activity on the location of the plasmapause as measured by OGO 5. J. Geophys. Res., **75**, 50–56.

EGELAND, A., GUSTAFSSON, G., OLSEN, S., ARONS, J. and BARRON, W. (1965): Auroral emissions centered at 700 cycles per second. J. Geophys. Res., **70**, 1079–1082.

HARANG, L. and LARSEN, R. (1965): Radio wave emission in the VLF-band observed near the auroral zone-I. Occurrence of emissions during disturbances. J. Atmos. Terr. Phys., **27**, 481–497.

HAYASHI, K. and KOKUBUN, S. (1971): VLF emissions during post breakup phase of polar substorm. Rep. Ionos. Space Res. Jpn., **25**, 369–382.

HAYASHI, K., KOKUBUN, S. and OGUTI, T. (1968): Polar chorus emissions and worldwide geomagnetic variations. Rep. Ionos. Space Res. Jpn., **22**, 149–160.

HELLIWELL, R. A. (1965): Whistlers and Related Ionospheric Phenomena. Stanford, Stanford Univ. Press, 349 p.

KELLEY, M. C., TSURUTANI, B. T. and MOZER, F. S. (1975): Properties of ELF electromagnetic waves in and above the earth's ionosphere deduced from plasma wave experiments on the OV1-17 and Ogo 6 satellites. J. Geophys. Res., **80**, 4603–4611.

KOKUBUN, S., HAYASHI, K. and OGUTI, T. (1969): VLF emission study at Syowa Station, Antarctica; Polar chorus emission and worldwide geomagnetic variation. JARE Sci. Rep., Ser. A, **6**, 34 p.

MAKITA, K. (1979): VLF-LF hiss emissions associated with aurora. Mem. Natl Inst. Polar Res., Ser. A, **16**, 126 p.

OGUTI, T. (1975): Hiss emitting auroral activity. J. Atmos. Terr. Phys., **37**, 761–768.

POPE, J. H. (1963): A high-latitude investigation of natural-very-low-frequency electromagnetic radiation known as chorus. J. Geophys. Res., **68**, 83–99.

SATO, N. and KOKUBUN, S. (1980): Interaction between ELF-VLF emissions and magnetic pulsations; Quasi-periodic ELF-VLF emissions and their geomagnetic conjugacy. J. Geophys. Res., **85**, 101–113.

SATO, N., HAYASHI, K., KOKUBUN, S., OGUTI, T. and FUKUNISHI, H. (1974): Relationships between quasi-periodic VLF emission and geomagnetic pulsation. J. Atmos. Terr. Phys., **36**, 1515–1526.

SATO, N., FUKUNISHI, H., OZAKI, T. and YOSHINO, T. (1981): Simultaneous ground-satellite observations of quasi-periodic (QP) ELF-VLF emissions near $L=6$. J. Geophys. Res., **86**, 9953–9960.

SATO, N., FUJII, R., FUKUNISHI, H. and NAKAJIMA, D. (1984): Upper atmosphere physics data, Syowa Station, 1981. JARE Data Rep., **93** (Upper Atmos. Phys. 1), 206 p.

TSURUTANI, B. T. and SMITH, E. J. (1977): Two types of magnetospheric ELF chorus and their substorm dependences. J. Geophys. Res., **82**, 5112–5128.

UNGSTRUP, E. and JACKEROTT, I. M. (1963): Observations of chorus below 1500 cycles per second at Godhavn, Greenland, from July 1957 to December 1961. J. Geophys. Res., **68**, 2141–2146.

WATTS, J. M., KOCH, J. A. and GALLET, R. M. (1963): Observations and results from the "hiss recorder", an instrument to continuously observe the VLF emissions. J. Res. Natl. Bur. Stand., Sect. D, **67D**, 569–579.

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