Unstructured Pcl–2 Pulsations Observed at Geomagnetically Conjugate Stations in the Auroral Zones

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1. Introduction

The propagation of magnetic pulsations depends on the structure of the magnetosphere and the ionosphere. Measurements of conjugacy and non-conjugacy of magnetic pulsations at geomagnetically conjugate points give us useful information on the generation and propagation mechanisms of ULF waves, and provide us an important opportunity to separate the magnetospheric and ionospheric effects. A classification of Pcl magnetic pulsations in the frequency-local time domain has been reported by FUKUNISHI et al. (1981). According to the classification we have examined the conjugacy of Pcl magnetic pulsations, using simultaneous observation data at the conjugate pair of stations Syowa and Husafell. The type of unstructured Pcl–2 magnetic pulsations showed obvious non-conjugacy for seasonal and diurnal variations, and other types of pulsations showed conjugacy. We shall limit our investigation to unstructured Pcl–2 pulsations in this paper. From the classification of FUKUNISHI et al. (1981), the frequency-time spectra of unstructured Pcl–2 magnetic pulsations are characterized by a diffuse band mainly in the frequency range of 0.1–0.4 Hz. The emissions usually appear in the daytime with long durations of several hours. Unstructured Pcl–2 pulsations have their maximum occurrence in the summer and often occur simultaneously in the auroral zone and in the polar cap regions (HEACOCK et al., 1970; HEACOCK, 1974; BOLSHAKOVA et al., 1980; TROITSKAYA et al., 1980). However, why the pulsations show a strong seasonal and diurnal variation is still unknown. In this paper, we report on the characteristics of the seasonal and diurnal dependence of unstructured Pcl–2 magnetic pulsations, using frequency-time spectra obtained simultaneously at Syowa (−69.0°, 39.6°; −66.2°, 71.4°, L~6.2) in geographic and corrected geomagnetic coordinates) and Mizuho (−70.7°, 44.3°; −68.1°, 71.7°, L~7.2) in Antarctica, and at Husafell (64.7°, −21.0°; 65.9°, 69.4°, L~6.0) and Isafjördur (66.1°, −23.1°; 67.7°, 68.9°, L~6.9) in Iceland. The conjugate points of Syowa and Mizuho Stations in Antarctica are located in the vicinity of Husafell and Isafjördur in Iceland, respectively. The geomagnetic local time (MLT) is almost equal to Universal Time (within 20 minutes) at the four stations (ONO, 1987). Magnetic pulsations were detected by search coil magnetometers. The output signals were fed to a long-term FM data recorder, and the frequency-time spectra of Pcl–2 pulsations were obtained reproducing the analogue signals with an FFT spectrum analyzer. Details of the specifications and facilities of the conjugate observations have been reported by SATO et al. (1984).
2. Observations

Figure 1 shows the frequency-time (f-t) spectra of the \( H \) component of magnetic pulsations in the 0–0.8 Hz frequency range observed simultaneously at Husafell and Syowa on November 5, 1985. From the \( f\)-\( t \) spectra at Syowa it is found that higher frequency band pulsations in the \( \sim0.3–0.8 \) Hz frequency range and lower frequency band pulsations in the \( \sim0.1–0.2 \) Hz range are observed in the time interval of \( \sim12:10–13:30 \) UT and \( \sim08:00–15:00 \) UT. In reference to the categories of FUKUNISHI et al. (1981), the lower frequency band pulsations and the higher frequency band pulsations were classified into unstructured Pc1–2 band pulsations and hydromagnetic (HM) chorus pulsations, respectively. Figure 2 shows the \( f\)-\( t \) spectra expanded in time and frequency from Fig. 1 during the time interval of 09–15 UT and frequency range of 0–0.3 Hz observed at Syowa. The \( f\)-\( t \) spectra of this type pulsation are characterized by such a diffuse band. For the geomagnetic conjugacy of pulsations from Fig. 1, it is clear that hydromagnetic (HM) chorus-type emissions are observed simultaneously at both stations. On the other hand, unstructured Pc1–2 band pulsations in the frequency range of \( \sim0.1–0.2 \) Hz are observed only at Syowa in the interval of \( \sim08–15 \) UT. It is notable that the example in Fig. 1 was obtained in the season of early summer at Syowa and early winter at Husafell.

We shall now demonstrate the seasonal and latitudinal dependence of unstructured Pc1–2 pulsations using the data obtained at the conjugate pair of stations located on the
same geomagnetic meridian. Figure 3 shows frequency-time spectra for the $H$ component of magnetic pulsations observed at Isafjördur and Husafell in Iceland, and at Syowa and Mizuho in Antarctica in the interval of 07–18 UT on January 29, 1985. It is clear that unstructured Pc1–2 pulsations in the frequency range around 0.2 Hz are observed only at the stations in Antarctica in the interval of ~09:30–14:00 UT. It is also notable that the intensity of the unstructured Pc1–2 pulsations is relatively higher at Mizuho than at Syowa. In other words, the intensity of unstructured Pc1–2 pulsations is relatively higher in the local summer hemisphere (Antarctica) than in the winter hemisphere (Iceland) and at the higher latitude station. It is worth noting that IPDP (interval of pulsations with diminishing period) pulsations are observed simultaneously at all the stations in the frequency range of ~0.05–0.2 Hz during ~16:40–17:40 UT. Figure 4 shows the same as Fig. 3 for the event of 09–22 UT on August 1, 1985. It is interesting that unstructured Pc1–2 pulsations in the frequency range around 0.3 Hz are observed only at the stations in Iceland during ~11–15 UT. The pulsations are not detectable at the stations in Antarctica, though the data quality at Mizuho is admittedly rather poor. It is worth noting that the intensity of unstructured Pc1–2 pulsations is relatively higher at Isafjördur than at Husafell. Therefore, the characteristics of seasonal and latitudinal dependence of the August 1 event are the same as those of the event in Fig. 3. Another example of unstructured Pc1–2 pulsations is demonstrated in Fig. 5. This figure shows the same as Figs. 3 and 4 for the event of 08–21 UT on May 17, 1985 observed at Husafell and Syowa. Unstructured Pc1–2 pulsations in the frequency range of ~0.2–0.3 Hz are observed during ~10–15 UT at Husafell and during ~10–12 UT at Syowa. Therefore, unstructured Pc1–2 pulsations show conjugacy during ~10–12 UT and non-conjugacy during ~12–15 UT.

The statical characteristics of the seasonal and diurnal variations of unstructured Pc1–2 pulsations have also been studied. The examination of frequency-time spectra was made using one year of data beginning January 1, 1984 obtained simultaneously at Syowa and Husafell. The occurrence number, duration and center frequency of pulsations were counted from the frequency-time spectra. Figure 6 shows the seasonal variation of occurrence number (left panel) and occurrence probability (right panel) of unstructured Pc1–2 pulsations. The upper, middle and bottom panel of Fig. 6 demonstrate non-conjugate events where emissions are received only at Husafell, conjugate
events where emissions are received simultaneously at the conjugate stations and non-conjugate events where emissions are received only at Syowa, respectively. It is obvious that the occurrence of non-conjugate cases is concentrated in the local summer hemisphere, and that the conjugate cases occur mostly in the equinox season. The diurnal variation of occurrence of non-conjugate cases is shown in Fig. 7. Emissions which are observed only at Syowa are at a maximum around 10 UT. On the other hand, the emissions observed only at Husafell have a maximum around 14 UT, accompanied by a
Fig. 4. The same as Fig. 3 for the August 1, 1985 event.
reduction in morning occurrences in comparison to Syowa. Therefore, the magnetic local
time when the occurrence of the pulsations reaches maximum differs from one station to
the other, the difference being about 4 hours.

3. Discussion

A knowledge of the seasonal and diurnal dependence of unstructured Pc1–2
pulsation occurrences and their geomagnetic conjugacy is important for the study of the
generation and propagation of these pulsations. The strong seasonal dependence of the
occurrence of pulsations described above suggests that sunlight in the topside ionosphere,
by causing an increase in electron density, affects the propagation of waves from the
magnetosphere to the ground through the ionosphere. That is, the emission intensity of
unstructured Pc1–2 pulsations is drastically depressed when the waves propagate through
the dark ionosphere where the electron density is low (winter and dark hemisphere).

The difference in magnetic local time when the occurrence of emission reaches a
maximum (about 4 hours earlier at Syowa than at Husafell as shown in Fig. 7) may also
be explained by the effects of sunlight in the ionosphere, as follows. The geographic local
time (LT) at Syowa is approximately MLT (~UT) plus 3 hours and that at Husafell is
approximately MLT (~UT) minus 1 hour (ONO, 1987). Therefore, the occurrence
maximum at ~10 UT at Syowa and at ~14 UT at Husafell corresponds to geographic
noon (~13 LT). Thus the difference in diurnal variation of pulsation occurrence at the
conjugate stations can be ascribed to the difference in geographic local time (solar zenith
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Fig. 6. Seasonal dependence of the occurrence numbers (left panel) and the probability of occurrence (right panel) of unstructured Pcl–2 band emissions for non-conjugate events where emissions were received only at Husafell (upper panel), conjugate events (middle) and non-conjugate events where emissions were received only at Syowa (bottom).

angle). It is suggested that sunlight effects in the topside ionosphere may control unstructured Pcl–2 pulsation intensities observed on the ground, even if MLT and season are the same at the conjugate pair of stations. Similar seasonal and diurnal dependence of ELF/VLF emission and Pc3–5 pulsation intensity at the conjugate stations have been reported by SUZUKI and SATO (1987), SATO et al. (1987) and SAITO et al. (1989).

Why unstructured Pcl–2 pulsations show such a strong seasonal and diurnal variation is still unknown, but some possibilities are discussed here. The plasma produced by sunlight in the summer hemisphere may propagate to the other hemisphere along the geomagnetic field lines as a polar wind (BANKS and HOLZER, 1968). Thus the asymmetry of ambient plasma density between the northern and southern hemispheres near the equatorial plane in the magnetosphere may be cancelled quickly. Therefore, the seasonal variation of emission occurrences is not caused by the asymmetry of ambient plasma density near the equatorial plane in the outer magnetosphere where the pulsation
Fig. 7. Diurnal dependence of the occurrence of unstructured Pcl–2 band emission observed at Husafell and Syowa for non-conjugate events.

may be generated. Satellite data show that Pcl–2 pulsations did not exhibit north-south asymmetry and were observed in both hemispheres near the equatorial plane at $L \sim 7$–14 during the period of October–February (Kaye and Kivelson, 1979). According to a previous study (Heacock, 1974), the occurrence of pulsations observed on the ground is also related to geomagnetic activity. They demonstrated that a positive correlation to $AE$ is seen through moderate values of $AE$. However, geomagnetic activity did not show apparent seasonal dependence in 1984–1985. Therefore, the effect of geomagnetic activity can be distinguished from the seasonal variation of Pcl–2 pulsations. Hence, it is difficult to accept that the seasonal variation is caused by an asymmetry in the generating region. Wave absorption effects in the ionosphere are difficult to identify from the data observed at ground level. If we examine the absorption effects quantitatively, we must compare the emission intensity observed simultaneously onboard a low-altitude satellite and on the ground.

Yamagishi (1989) recently examined the seasonal variation of ELF emission intensity using a full-wave ray tracing technique, and concluded that ELF emission intensity below the altitude of 3000 km in the summer hemisphere is higher than in winter by 4–6 dB, because waves tend to propagate along the field line in the summer hemisphere where the electron density gradient increases along a line of force. The statistical characteristics of the seasonal and diurnal variation of unstructured Pcl–2 pulsations is very similar to that of 750 Hz emission intensity obtained at conjugate stations as reported by Suzuki and Sato (1987). On the analogy of the similarity between both phenomena, the effects of asymmetry of wave propagation from the magnetosphere to the ionosphere provide a more reasonable explanation for the seasonal and diurnal variation of emission occurrences because a density gradient along a geomagnetic field line may be produced in the sunlit hemisphere. In the future we will confirm the effect by using the ray tracing technique and reasonable density gradient along a field line.

Bolshakova et al. (1980) and Troitskaya et al. (1980) reported that the generating region of unstructured Pcl–2 pulsations is directly connected with the day-
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side cusp. They suggested that the seasonal and diurnal variation of the Pc1–2 pulsations at a given station is related to the distance of this station from the cusp. The latitudinal dependence of the relative intensity and diurnal variation of the unstructured Pc1–2 pulsations demonstrated in our Figs. 3, 4 and 6 supports the idea that the generation region is located at a higher latitude near the day-side cusp region. However, it seems very unlikely that the relative distance between station and cusp is the main reason for the seasonal and diurnal variations of Pc1–2 pulsations emerging from our simultaneous observations at geomagnetic conjugate stations. This is because Pc1–2 pulsation activity is closely related to local season and local time at conjugate stations, but it does not depend on the relative distance between a station and cusp.

We have examined and discussed the seasonal and diurnal dependence of unstructured Pc1–2 pulsation occurrences observed at geomagnetically conjugate stations in the auroral zones. Our conclusion is that unstructured Pc1–2 pulsations observed on the ground are seen as strongly controlled by sunlight effects. Sunlight may cause the asymmetry of wave propagation from the magnetosphere to the ionosphere in both hemispheres. On the basis of this conclusion, we suggest that Pc1–2 pulsations observed in the polar cusp and cleft region on the ground may exhibit even stronger sunlight effects because most of these regions are located at a higher geographic latitude and have longer periods of daylight and darkness than the auroral zones. The Universal Time dependence in this region is also important because the difference of location between the geographic pole and geomagnetic pole causes an asymmetry of interaction between the solar wind and the magnetosphere.

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