CNA PULSATIONS AND RELATED PHENOMENA NEAR $L \sim 6$

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Abstract: Quasi-periodic variation of cosmic radio noise absorption (called CNA pulsation), measured by a fast-response 30 MHz riometer at Syowa Station in Antarctica ($L \sim 6$), was examined. CNA pulsations with the period of 10–500 s are observed mostly during morning hours. Most of the CNA pulsations are associated with magnetic pulsations and quasi-periodic (QP) VLF emissions. The examination of the relationships among CNA pulsations, magnetic pulsations and QP emissions, using the cross correlation analysis method, shows that some CNA pulsations with the period of 10–500 s are well related to magnetic pulsations and QP emissions. In these cases CNA pulsations are more correlated with the *D* component of magnetic pulsations than with the *H* component. It is also shown that the phase of the CNA pulsations lags behind QP emissions by 60–120 degrees is independent of the pulsation period.

1. Introduction

Cosmic radio noise absorption (CNA) measured by a riometer is generally regarded as an effect of enhanced ionization in the ionospheric *D* region produced by particle precipitation. CNA has unique importance to the study of the particle precipitation in the daytime because a visible aurora, an indication of particle precipitation, is not useful in the daytime. Therefore, CNA is an essential information in order to study the wave-particle interaction phenomena observed in the daytime. Cosmic radio noise data sometimes show quasi-periodic variations, called hereafter "CNA pulsation", associated with magnetic pulsations (REID, 1976; OLSON *et al.*, 1980; ROSENBERG *et al.*, 1979), and pulsating aurora (REID and PHILLIPS, 1971; HOLT and OMHOLT, 1962; BERKEY, 1974).

SATO and KOKUBUN (1980) reported preliminary results of the relation between quasi-periodic (QP) VLF emissions and CNA pulsations. They demonstrated qualitatively that QP emissions are sometimes associated with CNA pulsation, and stated that the conclusion is due to the electron precipitations and VLF wave arrivals caused by wave-particle interaction at the magnetospheric equatorial place. However, they did not analyze the phase relation between these phenomena because the response of the riometer in their study was as large as 30 s, and accordingly the conclusion included some ambiguities.

We examine in this paper the correlation as well as phase relationships among

QP VLF emissions, magnetic pulsations and CNA pulsations by using high time resolution (4 Hz) riometer data installed in 1981 at Syowa Station in Antarctica (−66.1°, 70.8°, L=6.1, in invariant geomagnetic coordinate). Details of the system at Syowa Station in 1981 are descrived by SATO *et al.* (1984). It will be shown that these correlation analyses confirm the validity of the model proposed by SATO and KOKUBUN (1980) for explaining the relationship between QP emission of VLF waves and CNA pulsations to apply to the short period ($T\sim 30$ s) CNA pulsations also associated with QP emissions. Some new evidences will also be shown in the phase relation between CNA pulsations and QP emissions.

2. Observation

2.1. General characteristics of CNA pulsation event

In order to show what kind of CNA pulsation is studied in this paper, an example of CNA pulsation and related phenomena observed at Syowa Station are demonstrated in Fig. 1 for convenience of the readers. From the top to the bottom the figure shows the intensity of VLF wave of 750 Hz band, CNA at 30 MHz, the H and the D components of magnetic variation for the time interval of 0900–1100 UT on July 25, 1981. On

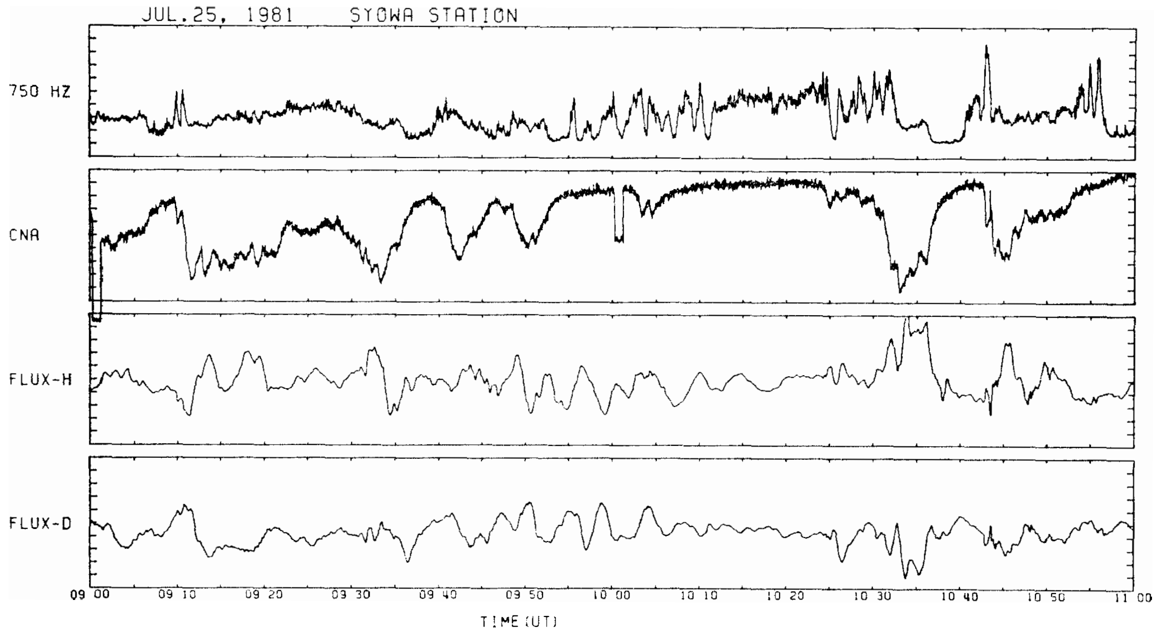

Fig. 1. Intensity of 750 Hz emissions, cosmic noise absorption (CNA) at 30 MHz, the H and the D components of magnetic variation in the time interval of 0900–1100 UT on July 25, 1981. In the CNA data display, downward direction corresponds to increase of the absorption intensity.

the CNA plot in this figure (and also in the following figures), the increase of absorption is downward. In this figure, long period CNA pulsation with the period of 5–10 min is found to be superimposed with short period pulsations with the period of 20–100 s for the interval of 0905–0955 UT and 1025–1100 UT. Some parts of the CNA pulsations appear to be related with QP emissions and magnetic pulsations.

We first examine the diurnal variation of CNA pulsation phenomenon at Syowa Station. The data period is about a year from April 1981 to January 1982. The CNA pulsation events are picked up on chart records. Figure 2 shows the occurrence probability of CNA pulsation with the period of 10–500 s *versus* magnetic local time. An occurrence peak of CNA pulsation phenomena is noticeable during morning hours in this figure. Small peaks are also found in the evening and early morning.

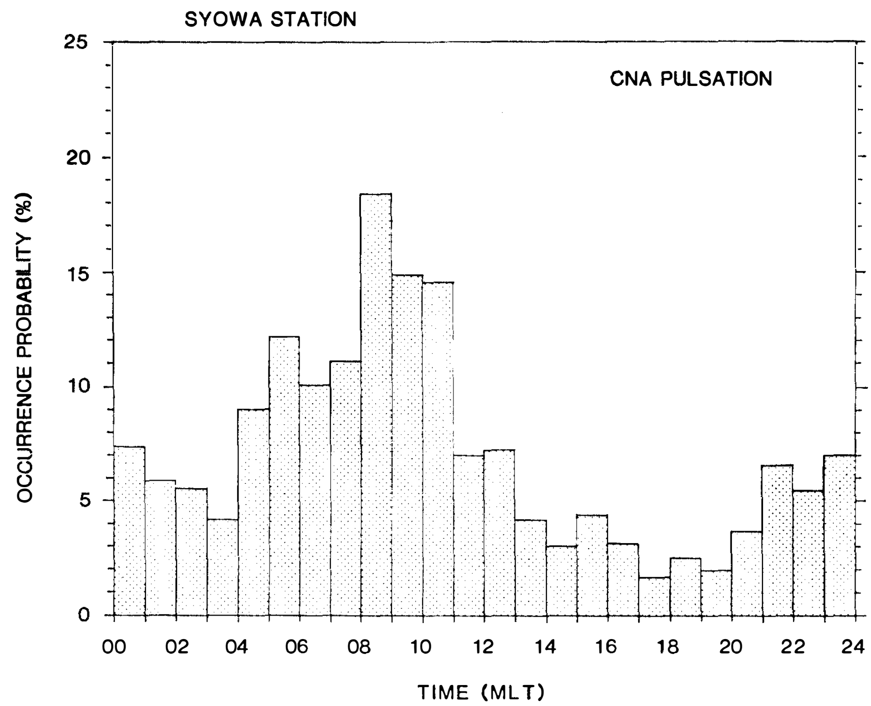

Fig. 2. Diurnal variations of CNA pulsation with the modulation period of 10–500 s by using the data from April 1981 to January 1982.

2.2. Correlation between CNA pulsation and related phenomena

(1) April 20, 1981 event

Figure 3 shows another example of VLF emission intensity at 750 Hz and CNA data at 30 MHz for the time interval of 0900–0940 UT on April 20, 1981. It is evident that quasi-periodic intensity variations with the period of 80 s occur on VLF wave intensity at 750 Hz and CNA, especially for the interval of 0915–0921 UT. Figure 4 shows relative powers (upper panel), coherency (middle panel) and relative phase (bottom panel) between intensity variations of VLF emission at 750 Hz and CNA for the time interval of 0902–0932 UT on April 20, 1981. Evidently, both quasi-periodic intensity variations of VLF wave of 750 Hz and CNA have a peak power at a common frequency around 12.5 mHz, and the coherency between them amounts to 0.9. The figure also shows that the phase of the enhancement of CNA lags 70–80 degrees behind the enhancement of VLF emission.

(2) September 20, 1982 event

Another good example was obtained on September 20, 1982. Figure 5 shows the intensity of VLF wave of 750 Hz, 1.2 kHz, CNA and the H component of magnetic

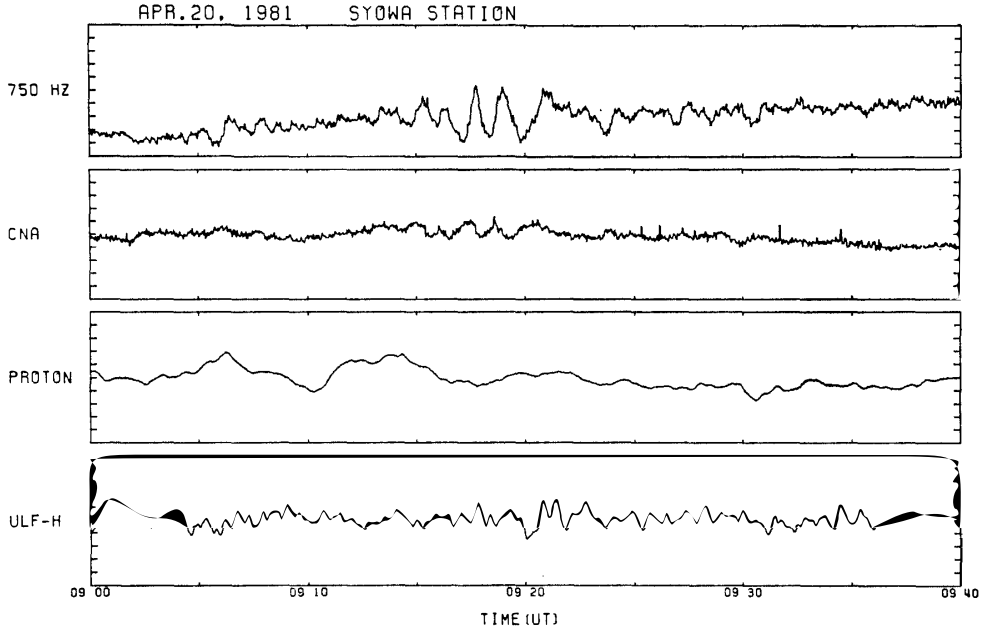

Fig. 3. Computer plots of VLF emission intensity at 750 Hz and CNA data at 30 MHz in the time interval of 0900–0940 UT on April 20, 1981.

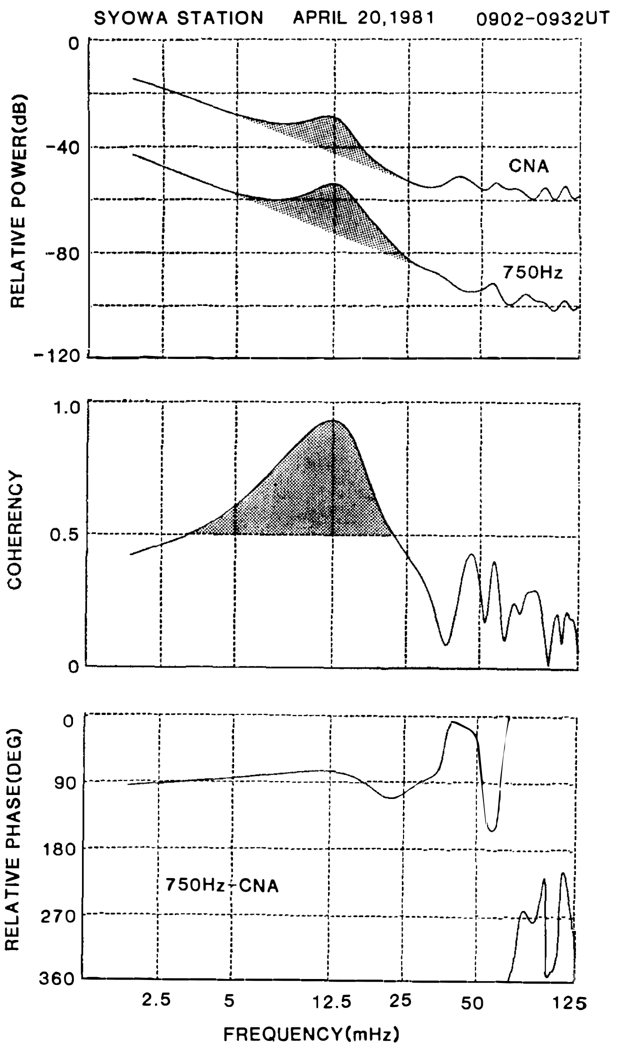

Fig. 4. Relative powers (upper panel), coherency (middle panel) and relative phase (bottom panel) between intensity variations of VLF emissions at 750 Hz and CNA in the time interval of 0902–0932 UT on April 20, 1981.

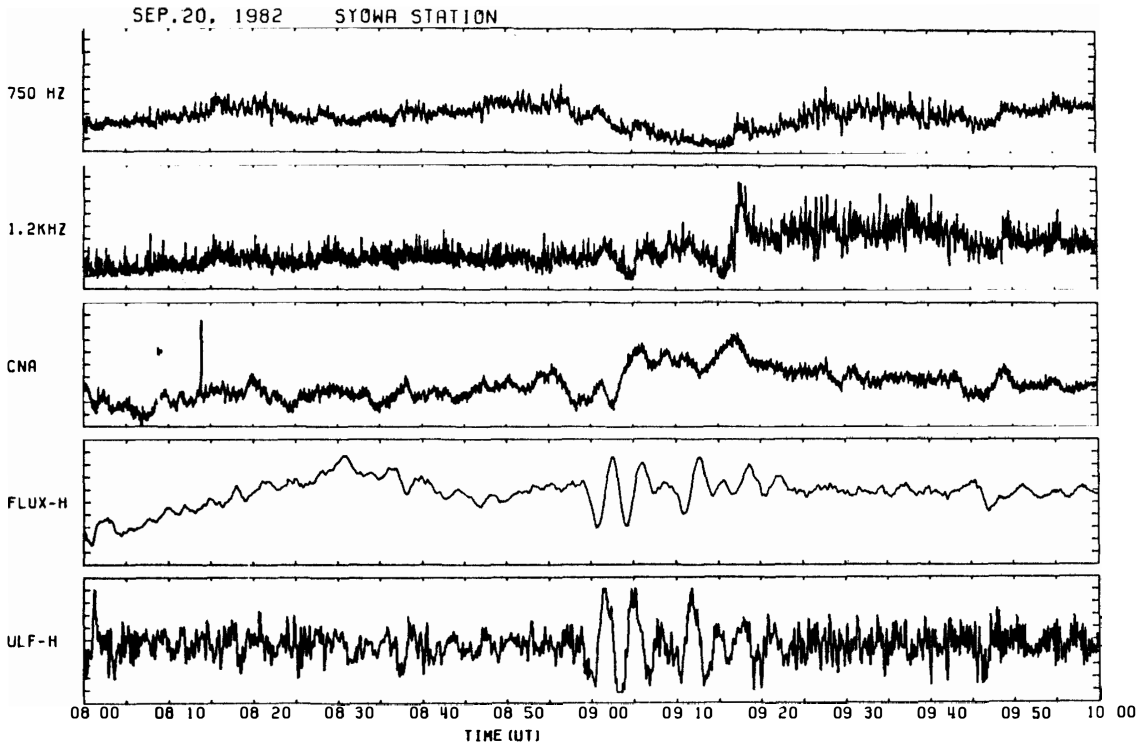

Fig. 5. Digital plots of the intensity of 750 Hz, 1.2 kHz, CNA and the H component of magnetic variations observed by fluxgate magnetometer during the time interval of 0800–1000 UT on September 20, 1982.

variations observed by a fluxgate magnetometer during the time interval of 0800–1000 UT on September 20, 1982. In this figure, it is found that quasi-periodic intensity variations of VLF wave and magnetic variations with the period of Pc 3 range (15–45 s) and Pc 5 range (150–600 s) occur simultaneously throughout the whole period. Figure 6 shows relative power spectra of the *H* and the *D* components of magnetic pulsations, CNA, VLF emissions at 750 Hz and 1.2 kHz for the time interval of 0945–1015 UT on September 20, 1982. In this figure, several spectral peaks are found in each spectrum, some being at a common frequency and some others not. The sharp peak for the *D* component of magnetic pulsations at 100 mHz is an artificial noise and must be disregarded. The coherencies among these variations during the same time interval as Fig. 6 are shown in Fig. 7. It is worth noting that CNA pulsations and QP emissions are well correlated with the *D* component of magnetic pulsations than with the *H* component of magnetic pulsation. Furthermore, CNA pulsations also show good coherency with QP emissions of VLF waves at 750 Hz and 1.2 kHz bands. It is interesting that the frequency with some coherency peaks as indicated by shaded areas in Fig. 7 is not necessarily common to all of these combinations. Relative phases on the September 20 event for the time interval of 0800–1400 UT are shown in the bottom panel of Fig. 8. In this figure relative phases are plotted for the frequency only when the value of coherencies is larger than 0.5. The most striking result in this figure is that the phases of the CNA pulsations lag 60–120 degrees behind QP emissions are independent of the pulsation period.

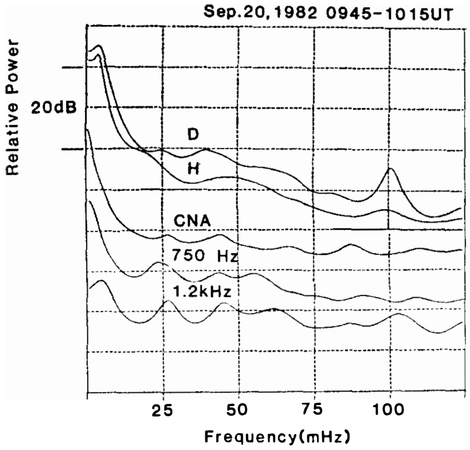

Fig. 6. Relative power spectra of the H and the D components of magnetic pulsations, CNA, VLF emissions at 750 Hz and 1.2 kHz in the time interval of 0945–1015 UT on September 20, 1982.

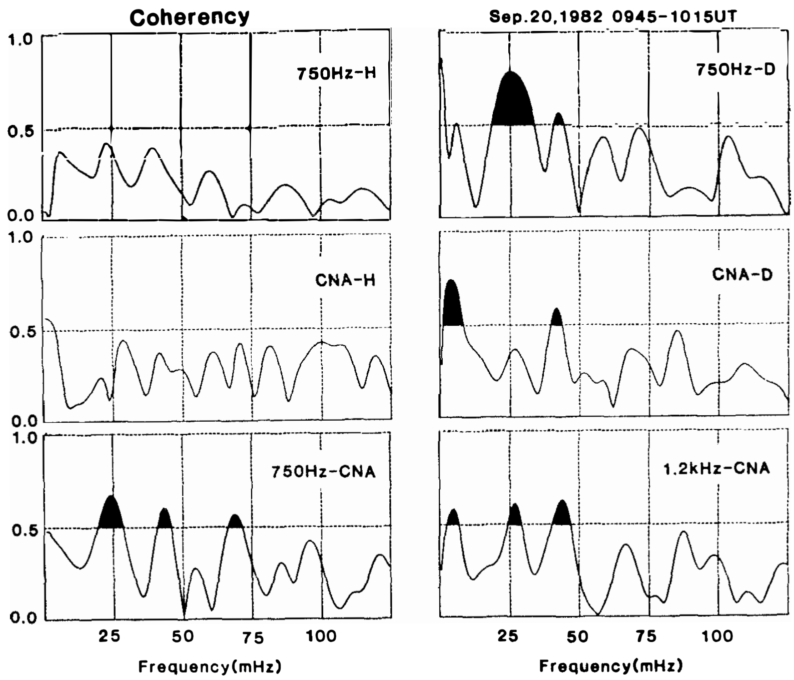

Fig. 7. Coherency among the H and the D components of magnetic pulsations, CNA, VLF emissions at 750 Hz and 1.2 kHz in the time interval of 0945–1015 UT on September 20, 1982.

3. Summary and Discussion

The characteristics of quasi-periodic cosmic noise absorption (CNA pulsation) and relationships among CNA pulsation, QP emission and magnetic pulsation in this study are summarized as follows:

(1) CNA pulsations with the period of 10–500 s occur mostly during morning hours.

(2) Most of the CNA pulsations are often associated with magnetic pulsations and QP emissions.

(3) The coherency between the *D* component of magnetic pulsations and the CNA

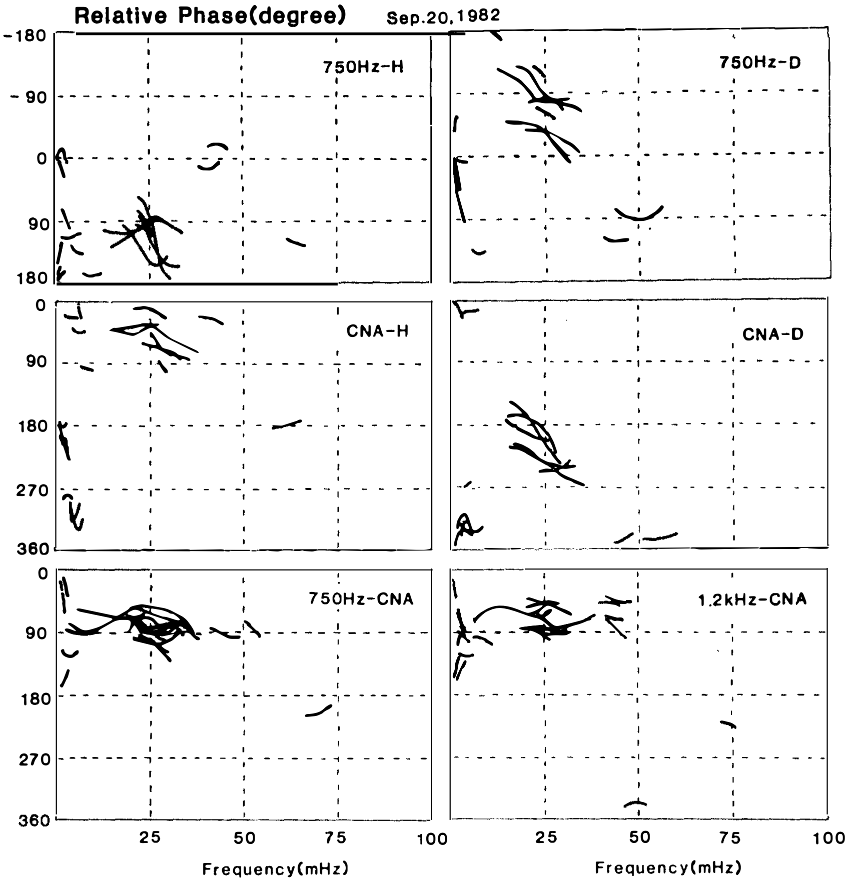

Fig. 8. Relative phases on the September 20 event in the time interval of 0800–1400 UT. In this figure relative phases are plotted for the frequency only when the value of coherencies is larger than 0.5.

pulsations or intensity variations of QP emissions is much higher than that between the *H* component of magnetic pulsations and the CNA pulsations or QP emissions.

(4) The phase of the CNA pulsation lags behind QP emission by 60–120 degrees is independent of the pulsation period.

These characteristics between magnetic pulsations and QP emissions of VLF waves are the same as those reported by SATO and KOKUBUN (1980). In relation to their results of long period pulsations, they predicted that short period QP emissions with the period of 10–30 s could also be associated with CNA pulsations. The results (3) appear to confirm the validity of their prediction. In addition to the above results, the phase relation between CNA pulsations and QP emissions, summarized in (4), is a new finding of this study. The time difference between the arrival of 20 keV electrons and that of whistler mode waves is estimated to be less than 1 s, when the electrons, going backward to the waves at the magnetospheric equatorial plane and reflected at the opposite conjugate point, come back again to precipitate while whistler mode waves directly propagate down to the station (YAMAGISHI *et al.*, 1984). Therefore, if the relaxation time of the ionization, representing CNA, is as small as 1 s, the phase difference between CNA pulsation and intensity modulation of QP emissions may not be detectable. On the other hand, if the relaxation time is large, for example as large as 10 s, the relative phase of CNA pulsation to the intensity modulation of QP emission should be in a range of 90° to 180° for the Pc 3 frequency range (15–40 s), appreciably depending on the period of pulsations. YAMAGISHI *et al.* (1984) reported that the intensity variation of X-rays observed on board balloons and that of QP emissions observed on the ground are almost in phase independent of the period of pulsation. Therefore, the interpretation of the phase difference between CNA pulsations and QP emissions needs other factors. One might imagine that the phase delay of CNA may be due to the depressions of VLF emission intensity on the ground caused by the enhancement of the ionospheric absorption. However, the ionospheric absorption is found not to be important for the QP emissions because QP emission at the satellite level has one-to-one correspondence with the intensity modulation of QP emission on the ground without a phase lag as reported by SATO *et al.* (1981). The other factor which must be considered is that precipitation region may move in association with the movement of occurrence region of QP emissions. But we have no data to examine this. At present, we do not intend to interpret the phase difference between QP emission and CNA pulsation.

The relative phase between QP emission at 750 Hz band and magnetic pulsation shown in the top panel of Fig. 8 demonstrates that the phase appears to be widely scattered between QP emissions and the H component of magnetic pulsations. However, a systematic relation can be found on the relative phase of QP emissions and the D component of magnetic pulsations when the uncertainty of the phase measurement by $2\pi n$ is taken into account. These results are the same as that reported by SATO and KOKUBUN (1980). The phase relation between CNA pulsation and the D component of magnetic pulsation shown in the middle panel of Fig. 8 demonstrates that the phase lag depends on frequency, indicating the same characteristics as the relative phase between QP emission and the D component of magnetic pulsations. The results suggest that the difference in propagation speed between high energy particles and Alfvén waves is the cause of the phase difference as predicted by SATO and KOKUBUN (1980).

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