CNA PULSATIONS ASSOCIATED WITH Pc 3–5 MAGNETIC PULSATIONS

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Abstract: The correlation between Pc 3–5 magnetic pulsations and fluctuations of cosmic noise absorption (*i.e.*, CNA pulsation) observed at Syowa Station in Antarctica is examined. It is confirmed that the coherency of the D component of Pc 3–4 magnetic pulsations to CNA pulsations is much higher than that of the H component of Pc 3–4 magnetic pulsations. On the other hand, the H component of Pc 5 magnetic pulsations tends to be more correlated with CNA pulsations rather than the D component of Pc 5 magnetic pulsations. The relative amplitude of magnetic pulsations against that of CNA pulsations depends on pulsation frequency. These characteristics suggest some differences in generation and modulation mechanisms of CNA pulsations for PC 3–5 magnetic pulsations. The polarization of Pc 3–5 magnetic pulsations associated with CNA pulsations is predominantly counterclockwise independent of pulsation period during the morning hours.

1. Introduction

The relationships among magnetic pulsations and particle precipitation associated with pulsating aurora, modulation of auroral X-ray pulsations, and CNA pulsations have been reported by many authors (OGUTI and WATANABE, 1976; BARCUS and ROSENBERG, 1965; ROSENBERG *et al.*, 1979). SATO and KOKUBUN (1980) studied the characteristics of quasi-periodic (QP) VLF emissions with periods of 10–50 s and their relationships to magnetic pulsations. It was concluded that QP VLF emissions are modulated by compressional hydromagnetic waves in the frequency range of Pc 3 magnetic pulsations near the equatorial plane in the outer magnetosphere. OLSON *et al.* (1980) investigated the correlation between riometer and magnetometer variations in the Pc 4–5 frequency range of magnetic pulsations at multiple stations. It was pointed out that the azimuthal phase variations of riometer signals were consistent with those of the magnetometer signals. Namely, apparent azimuthal phase propagation of Pc 4–5 magnetic pulsations changed from westward in the morning side to eastward in the evening side. It was also concluded that the electron precipitation associated with CNA pulsations was controlled by the activity of Pc 4–5 magnetic pulsations in the magnetosphere.

SATO *et al.* (1985) studied the correlation as well as the phase relationships among Pc 3–5 magnetic pulsations, CNA pulsations, and QP VLF emissions by using high time resolution (4 Hz) riometer signals observed at Syowa Station in Antarctica. It was confirmed that the CNA pulsations with the period of 10–500 s occurred mostly during the morning hours and some CNA pulsations are well related to magnetic pulsations and QP emissions. The phase of CNA pulsations lags behind QP emissions by 60–120 degrees independent of pulsation period.

On the other hand, KUWASHIMA (1974) noticed that Pc 5 magnetic pulsations were modulated by the ionospheric currents induced by the periodically precipitating particles using the cross correlation analysis method. On the basis of sensitive riometers and magnetometers in the conjugate areas near $L=4.0$, LANZEROTTI and ROSENBERG (1983) also investigated the relation between impulsive particle precipitation and concurrent magnetic field variations in order to clarify the modulation of ionospheric currents and the phase relation between the southern and northern hemispheres. It was concluded that the north-south ionospheric currents were predominantly modified by the impulsive particle precipitation.

Therefore, it is not yet sufficiently understood that the magnetic pulsations are modulated by the ionospheric currents induced by the precipitating particles, or that the particle precipitations are modulated by the magnetic pulsations in the magnetosphere, at least in the case of Pc 5 magnetic pulsations. In order to clarify the above problem we will analyze the coherency and phase relation between Pc 3–5 magnetic pulsations and CNA pulsations, and the ellipticity of Pc 3–5 magnetic pulsations associated with CNA pulsations observed at Syowa Station in Antarctica.

2. Coherency and Phase Relation between Pc 3–5 Magnetic Pulsations and CNA Pulsations

Data used here are obtained at Syowa Station (66.1°, 70.8° in invariant geomagnetic coordinates, $L=6.1$) in Antarctica during 1981. Details of the system at Syowa Station are described by SATO *et al.* (1984). The selected events of CNA pulsations associated with Pc 3–5 magnetic pulsations are listed in Table 1. Spectral analysis in the present study was carried out by using the conversational spectral analysis program (CSAP) system developed by IWABUCHI *et al.* (1978). The power spectrum,

Table 1. Selected events of CNA pulsations associated with Pc 3–5 magnetic pulsations.

	Events	UT
1.	April 20, 1981	0910–0926
2.	May 19	0609–0624
3.	July 26	0804–0834
		0905–0935
4.	July 28	0533–0603
5.	October 3	0601–0616
		0745–0800
6.	October 4	0602–0632
		0730–0800
		1015–1045
7.	October 20	0619–0633
8.	December 13	1003–1037

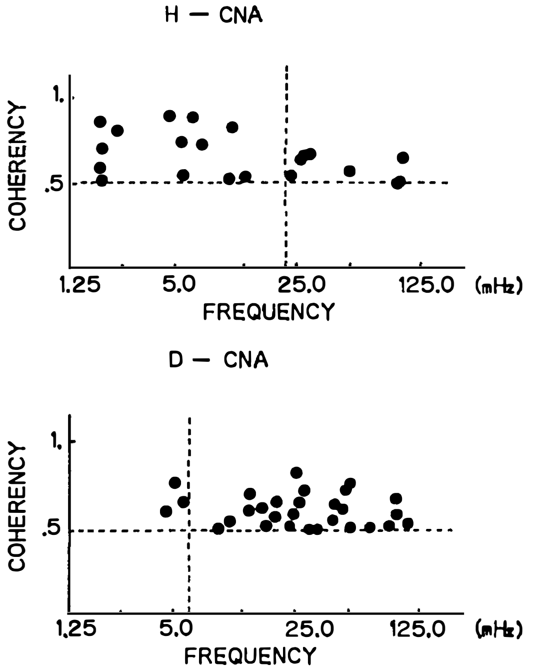

Fig. 1. Coherency of the H component of Pc 3–5 magnetic pulsations to CNA pulsations (top panel). Coherency of the D component of Pc 3–5 magnetic pulsations to CNA pulsations (bottom panel). The examples of coherency larger than 0.5 are plotted in the figure. The vertical dashed lines represent the frequency boundaries of Pc 3, Pc 4 and Pc 5 magnetic pulsations.

relative phase, cross spectrum, and coherency were calculated for both Pc 3–5 magnetic pulsations and CNA pulsations. The polarization and ellipticity were also calculated for Pc 3–5 magnetic pulsations associated with CNA pulsations. Figure 1 shows the plots of coherency *vs.* pulsation frequency between the *H* component of magnetic pulsations and CNA pulsations (top panel), and between the *D* component of magnetic pulsations and CNA pulsations (bottom panel). The examples of coherency larger than 0.5 are plotted in the figure. It is noteworthy that CNA pulsations in the Pc 5 frequency range tend to be more correlated with the *H* component of magnetic pulsations rather than with the *D* component of magnetic pulsations. On the other hand, CNA pulsations in the Pc 3 frequency range are more correlated with

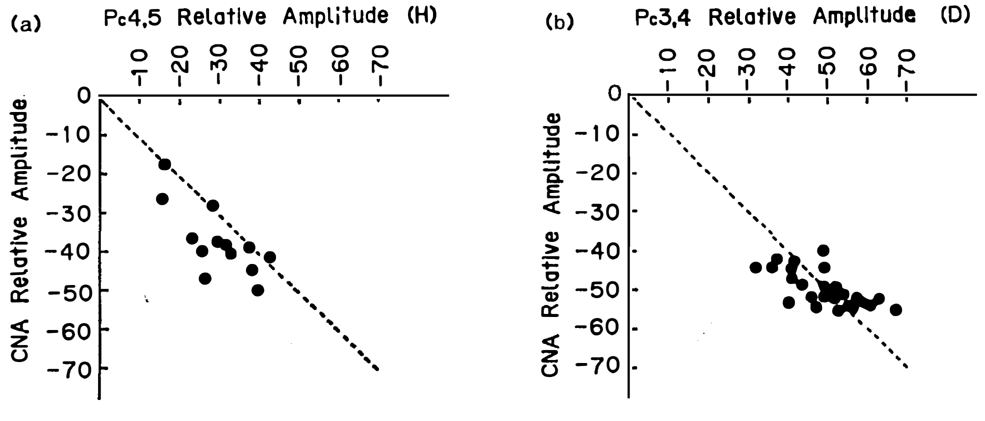

Fig. 2. (a) The relative amplitude of CNA pulsations vs. the relative amplitude of the H component of Pc 5 magnetic pulsations.

(b) The relative amplitude of CNA pulsations vs. the relative amplitude of the D component of Pc 3–4 magnetic pulsations.

the *D* component of magnetic pulsations than the *H* component of magnetic pulsations.

Figure 2a shows the plots of relative amplitude (standardized by max. = 1.0 E +08) of CNA pulsations *vs.* that of the *H* component of Pc 5 magnetic pulsations. A high correlation can be recognized between these amplitudes. In some cases the relative amplitude of CNA pulsations tends to be smaller than the relative amplitude of Pc 5 magnetic pulsations. Figure 2b shows the plots of relative amplitude of CNA pulsations *vs.* the relative amplitude of the *D* component of Pc 3 magnetic pulsations. In this case the relative amplitude of CNA pulsations is not proportional to the relative amplitude of Pc 3 magnetic pulsations. It is found that the correlation between the relative amplitude of magnetic pulsations and that of CNA pulsations depends on pulsation frequency. These characteristics suggest some differences in generation and modulation mechanisms of the CNA pulsations for Pc 3 and Pc 5 magnetic pulsations.

The velocity of precipitating electrons which cause the CNA pulsations is different from the group velocity of hydromagnetic waves. A difference in arrival time should exist between the precipitating electrons and the magnetic pulsations on the ground if the interaction occurs near the equatorial plane in the magnetosphere. The difference in propagation velocity between the two phenomena should affect the phase relation on the ground. SATO and KOKUBUN (1980) inferred the modulation region of QP emissions by analyzing the phase differences between the QP emissions and the magnetic pulsations. The same method can be applied to the CNA pulsations. The relative phase differences integrated over all events are illustrated in Fig. 3 in

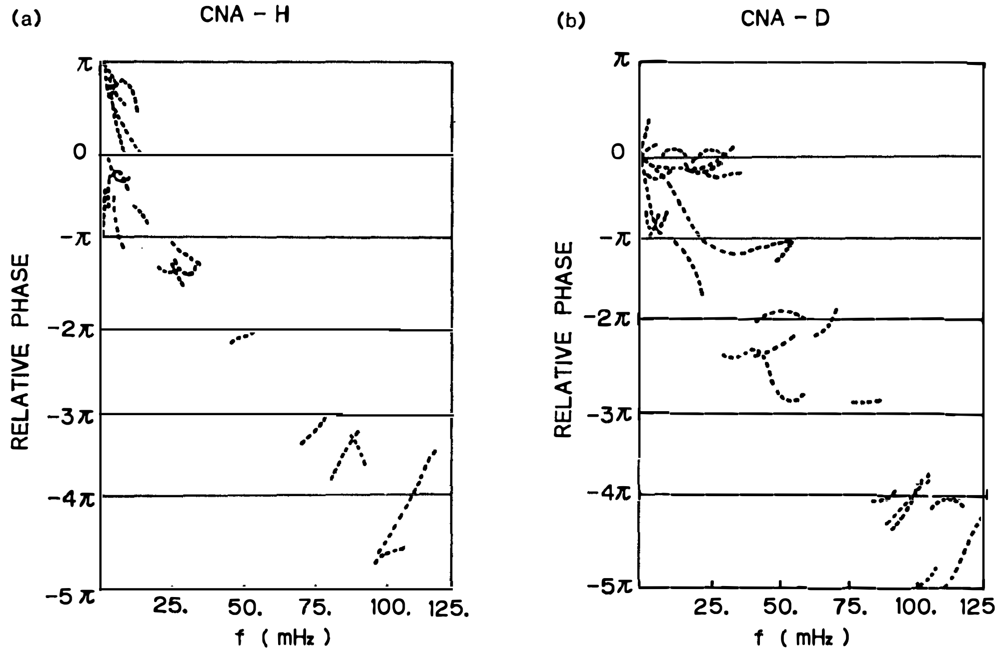

Fig. 3. (a) The relative phase difference between the CNA pulsations and the H component of Pc 3–5 magnetic pulsations when the coherency is larger than 0.5.
(b) Same as Fig. 3a but for D component.

order to show the averaged phase relation. Figure 3a shows the relative phase difference between the CNA pulsations and the H component of Pc 3–5 magnetic pulsations when the coherency is larger than 0.5. Figure 3b shows the relative phase difference between the CNA pulsations and the D component of Pc 3–5 magnetic pulsations when the coherency is larger than 0.5. It is noteworthy that a linear relationship *vs.* pulsation frequency is actually seen in the phase difference between the CNA pulsations and the magnetic pulsations. The difference in arrival time between the precipitating electrons and the magnetic pulsations from the equatorial plane to the ground (SATO and KOKUBUN, 1980) is given by

$$\Delta T = -(1/2\pi)\mathrm{d}\theta/\mathrm{d}f,$$

where $\mathrm{d}\theta/\mathrm{d}f$ is the rate of increase of phase difference. Thus, from Figs. 3a and 3b, we have $\Delta T=20$ (s) for $\mathrm{d}\theta/\mathrm{d}f \sim -5\pi/0.125$. The value of ΔT is approximately equal to the results by SATO and KOKUBUN (1980), suggesting that the particle modulation of CNA pulsations by hydromagnetic waves occurs near the equatorial plane in the magnetosphere.

3. Polarization and Ellipticity

The polarization parameters of Pc 3–5 magnetic pulsations associated with CNA

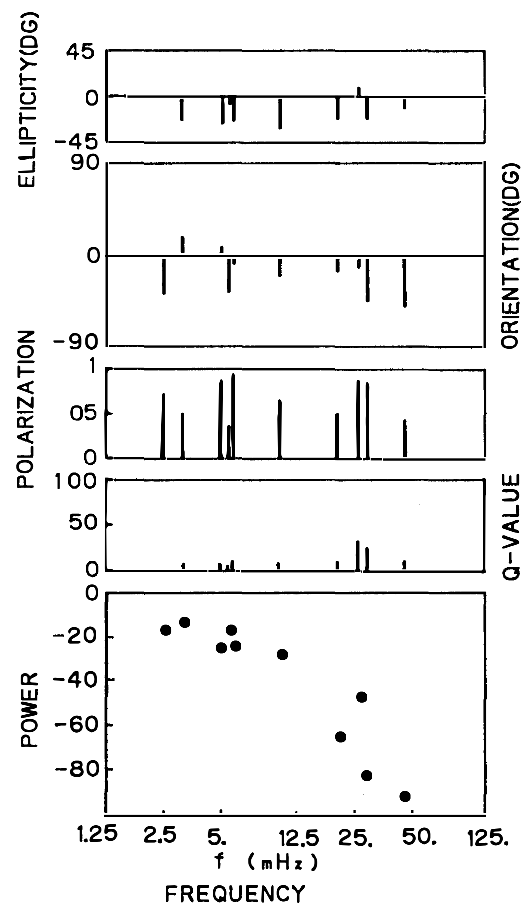

Fig. 4. The polarization parameters of Pc 3–5 magnetic pulsations associated with CNA pulsations. The relative power and Q-values for Pc 3–5 magnetic pulsations are also illustrated.

pulsations are estimated by using the CSAP system with a graphic display terminal. The four polarization parameters associated with a quasi-monochromatic signal are defined by the degree of polarization, orientation angle, ellipticity, and sense of polarization. These quantities are represented in Fig. 4 with the relative power and the Q values of Pc 3–5 magnetic pulsations. The data are selected only when the coherency between the Pc 3–5 magnetic pulsations and the CNA pulsations is larger than 0.5. As seen in the figure, it is evident that the orientation angle is mostly in the northwest direction, and the ellipticity is predominantly negative indicating the left-handed sense of polarization. Since the CNA pulsations occur predominantly during the morning hours as listed in Table 1, the result of polarization analysis is consistent with the observation of Pc 5 magnetic pulsations (SAMSON, 1972).

4. Summary and Discussion

The characteristics of relationships between Pc 3–5 magnetic pulsations and CNA pulsations are summarized as follows:

(a) The coherency of the D component of Pc 3 magnetic pulsations to CNA pulsations is much higher than that of the H component of Pc 3 magnetic pulsations. On the other hand, the H component of Pc 5 magnetic pulsations tends to be more correlated with CNA pulsations rather than the D component of Pc 5 magnetic pulsations.

(b) The correlation between the relative amplitude of magnetic pulsations and that of CNA pulsations depends on pulsation frequency.

(c) The relative phase difference between Pc 3–5 magnetic pulsations and CNA pulsations shows a linear relationship; the phase difference becomes larger as the pulsation period becomes shorter.

(d) The polarization of Pc 3–5 magnetic pulsations associated with CNA pulsations is predominantly counterclockwise independent of pulsation period during the morning hours.

In order to interpret the coherency between Pc 3–5 magnetic pulsations and CNA pulsations, two different kinds of generation and propagation mechanisms for magnetic pulsations in the magnetosphere have to be considered. One source is compressional Pc 3–4 upstream waves, which are excited by reflected ion beam in the earth's foreshock, transmitted through the bow shock, the magnetosheath, and the magnetopause, and propagating across the ambient magnetic field in the inner magnetosphere (YUMOTO, 1985). Since the polarization axis of Alfvén-mode waves rotates at a right angle in propagating through the ionosphere to the ground (HUGHES and SOUTHWOOD, 1976), the D (east-west) component of Pc 3 magnetic pulsations observed on the ground is believed to be associated with the radial component of Alfvén-mode waves in the magnetosphere. If the compressional Pc 3 source waves couple into a poloidal Alfvén wave and interact with electron particles in the magnetosphere, the high coherency is expected between the D component of Pc 3 magnetic pulsations and CNA pulsations on the ground. The other source mechanism for Pc 5 magnetic pulsations observed in the outer magnetosphere is a Kelvin-Helmholtz type instability in the magnetospheric boundary layer (ATKINSON and WATANABE, 1966; YUMOTO, 1984). The sur-

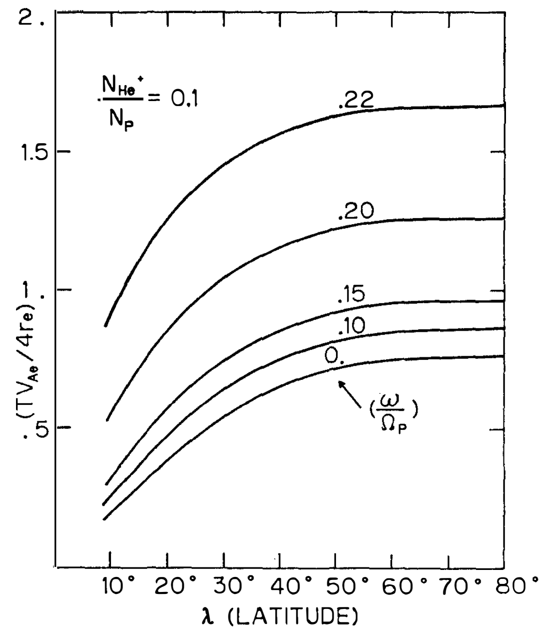

Fig. 5. The normalized group bounce period for the low frequency branch of ion cyclotron waves between a pair of conjugate points in a dipole magnetic field model as a functinon of geomagnetic latitude.

face waves excited at the boundary layer are believed to couple resonantly into a toroidal standing field-line oscillation in the morning side (KOKUBUN, 1980). The resonant toroidal oscillation in the magnetosphere is associated with the H (north-south) component of Pc 5 magnetic pulsations observed on the ground. If the electron particles are modulated by the toroidal Alfvén oscillation in the magnetosphere, the high coherency between the H component of Pc 5 magnetic pulsations and CNA pulsations can be expected on the ground.

In order to interpret the relative phase difference between Pc 3–5 magnetic pulsations and CNA pulsations, the normalized group bounce period T is estimated as shown in Fig. 5 for the low frequency branch of ion cyclotron waves between a pair of conjugate points. Assuming the plasma distribution of the gyrofrequency model and a dipolar magnetic field in the magnetosphere, the group bounce period of hydromagnetic waves can be obtained as follows (HIGUCHI, 1981, 1985).

$$T(\lambda_o,0)=\left(\frac{4r_e}{V_{ae}}\right)\int_0^{\lambda_o}\mathrm{d}\,\lambda\,\cos^4\lambda\,(4-3\cos^2\lambda)^{1/4}\,(1+4\underline{N})^{1/2},$$

where λ is the magnetic latitude, and r_e is the equatorial distance of the magnetic line of force from the center of the earth, V_{ae} is the Alfvén velocity at the equatorial plane and $\underline{N}$ stands for the ratio of Helium ion number density to proton number density. Near Syowa Station in Antarctica $(TV_{ae}/4r_e)=0.75$ for $\lambda=70°$. The propagation time of the hydromagnetic waves from the equatorial plane to the ground can be estimated as follows:

$$T/4=0.75\,(r_e/V_{ae})=28.7\ \text{(s)}.$$

Since the real geomagnetic field is not a simple dipolar field, the estimated propagation time should be reduced at a high latitude. The estimated propagation time is in agreement with the observational value of ΔT as shown in Fig. 3. Thus, it is theoretically concluded that the particle modulations of CNA pulsations are induced by hydromagnetic waves near the equatorial plane in the magnetosphere.

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