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Pc 3 MAGNETIC PULSATIONS OBSERVED AT VERY LOW LATITUDES ($|\Phi|<20°$)

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Abstract: Magnetic pulsation data obtained simultaneously at northern and southern stations, *i.e.*, Chung-Li ($\Phi=13.8°$, $\Lambda=189.5°$), Taiwan, and Cepu ($-18.3°$, $182.5°$), Indonesia, have been analyzed to clarify characteristics of Pc 3 pulsations at very low latitudes. Near local noon, although Pc 3 amplitudes at Cepu were slightly larger than those at Chung-Li, wave packets with $\sim$3–5 min duration appeared concurrently at the very low latitudes ($|\Phi|<20°$). It is found that the senses of Pc 3 polarizations at $|\Phi|\sim10°$–$20°$ were statistically opposite to those at conjugate stations of $|\Phi|\sim35°$. Pc 3 polarization ellipses at the very low latitudes changed the major axis orientation predominantly from NW-SE (NE-SW) in the morning to NE-SW/NW-SE (NW-SE) in the afternoon in the northern (southern) hemisphere, which is consistent with the characteristics at conjugate stations of $|\Phi|\sim35°$.

1. Introduction

On the basis of observational relationships of the solar wind parameters with pulsation parameters, it has been established that the magnetosonic upstream wave in the Pc 3–4 frequency range ($\sim$15–100 mHz) in the earth's foreshock is transmitted into the magnetosphere without significant changes in spectra (GREENSTADT *et al.*, 1983; YUMOTO, 1985), and could be a main source of low-latitude Pc 3 pulsations at $L\sim1.5$–3.0 (see review of YUMOTO, 1986a; RUSSELL *et al.*, 1983; YUMOTO *et al.*, 1984, 1985a; WOLFE *et al.*, 1985). These transmitted compressional waves can propagate across the ambient magnetic field into the inner plasmasphere, and then can couple with various hydromagnetic oscillations, *e.g.*, trapped oscillations of fast magnetosonic waves in the Alfvén trough ($L\sim1.7$–L_{pp}), fundamental (at $L=1.7$–2.6) and higher-harmonic (at $L\gtrsim2.6$) standing oscillations of local field lines (see YUMOTO and SAITO, 1983; YUMOTO *et al.*, 1985b).

However, Pc 3 pulsations at very low latitudes ($|\Phi|<22°$) are not yet sufficiently clarified either observationally or theoretically. SAITO (1983) noted an evening maximum of Pc 3 activity in the subtropical region of approximately 5°–20° in geomagnetic latitudes. The evening maximum of subtropical Pc 3 at $|\Phi|<22°$ cannot be explained by the local-noon (or morning) maximum of Pc 3 pulsations at $|\Phi|\sim30°$–

50°. KUWASHIMA *et al.* (1979) also pointed out that the diurnal variation of subtropical Pc 3 polarizations at Chichijima ($\Phi=17.1°$, $\Lambda=208.9°$) is different from that of low-latitude Pc 3's observed simultaneously at Memambetsu (34.0°, 208.4°).

The purpose of the present paper is to clarify characteristics of Pc 3 magnetic pulsations detected simultaneously at very low-latitude northern and southern stations ($|\Phi|\sim 10°$–$20°$). Wave characteristics of the Pc 3 pulsations observed at very low latitudes will be discussed through comparison with those at low-latitude conjugate stations (at $|\Phi|\sim 35°$) (see YUMOTO *et al.*, 1985b).

2. Pc 3 Activity at Very Low Latitudes ($|\Phi|<20°$)

Simultaneous magnetic observations were carried out at Chung-Li (CNL), Taiwan, and Cepu (CEP), Indonesia, in the interval from May 28 to June 13, 1983, in order to investigate the total solar eclipse effect on wave characteristics of low-latitude Pc 3 pulsations. The geographic and geomagnetic (dipolar) coordinates, and L-values of the CNL and CEP stations are ($\lambda=121.17°$, $\phi=25.00°$, $\Lambda=189.5°$, $\Phi=13.8°$, $L=1.06$) and (111.59°, −7.13°, 182.46°, −18.32°, 1.11), respectively. It is noteworthy that the maximum height of the magnetic lines of force at $|\Phi|<22°$ is about 1000 km above the ground, therefore, the field lines from CNL and CEP are almost in the ionosphere. Magnetic pulsation signals at CNL and CEP were detected by means of rulfmeters (ring-core-type fluxgate magnetometer). Methods of data recording were described in detail by SAITO *et al.* (1984) and YUMOTO *et al.* (1985b). The time resolution and noise levels in amplitude of reproduced magnetic data from analog cassette tapes are (0.5 s, 0.07 nT) at CEP and (0.5 s, 0.12 nT) at CNL.

Figure 1 shows temporal evolution of Pc 3 amplitudes at the very low latitude northern and southern stations obtained through a narrow band filter centered near the dominant frequency of individual events. Typical examples of amplitude-time records of subtropical Pc 3 pulsations are shown separately for those observed before sunrise, in the local morning, near noon, and in the evening sector. Before sunrise, Pc 3 activities at CEP ($\Phi=-18.3°$) from 0320 to 0350 LT were lower than those observed simultaneously at CNL (13.8°) from 0420 to 0450 LT. In the morning of 0630–0800 LT, Pc 3 activities at the CEP and CNL stations were comparable, despite the separation of these two stations with $\Delta\Lambda\sim 7°$ in geomagnetic longitude and $\Delta\Phi\sim 5°$ in geomagnetic latitude. However, wave packets of Pc 3's tend to appear slightly non-concurrently between the H- and D-components and the separated stations. This feature may be due to either local time and latitudinal dependences of wave characteristics or propagations of Pc 3 pulsations at very low latitudes. When CNL ($\Phi=13.8°$) and CEP (−18.3°) stations were located near local noon, wave packets of Pc 3's with ~3–5 min duration are found to appear concurrently at the separated stations, although Pc 3 amplitudes at CEP are slightly larger than those at CNL, *i.e.*, $\delta B(\text{CEP})/\delta B(\text{CNL})\sim 0.78\ \text{nT}/0.6\ \text{nT}\sim 1.3$. In the afternoon, Pc 3 activities tend to be lower in the D component than in the H component, which is in agreement with the characteristic of Pc 3's observed at low-latitude conjugate stations of $|\Phi|\sim 35°$ (see Figs. 4c and 4d of YUMOTO *et al.*, 1985b).

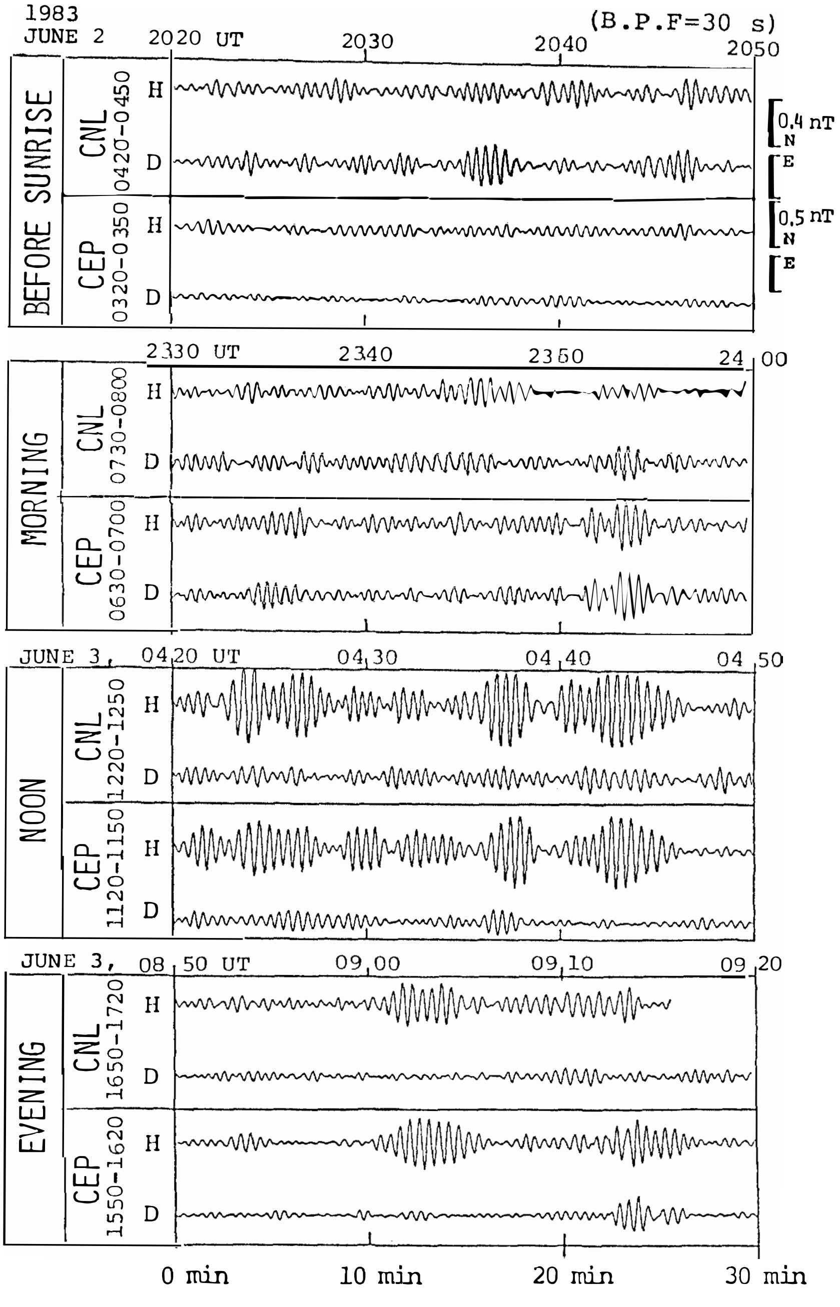

Fig. 1. Typical examples of simultaneous amplitude-time records of Pc 3 pulsations at very low-latitude northern (CNL) and southern (CEP) stations before sunrise, in the morning, near noon, and in the local evening hours.

3. Pc 3 Polarizations at CNL and CEP

In order to clarify polarization characteristics of Pc 3's at $|\Phi|\sim 10°–20°$, we analyzed magnetic pulsation data from Chung-Li and Cepu stations during the interval from 1 to 13 June 1983. The diurnal variation of senses of Pc 3 polarizations in the H-D plane at CNL ($\Phi=13.8°$) and CEP ($-18.3°$) is summarized in the top and bottom panels of Fig. 2, respectively. The time interval of 20-min segment for Pc 3 events

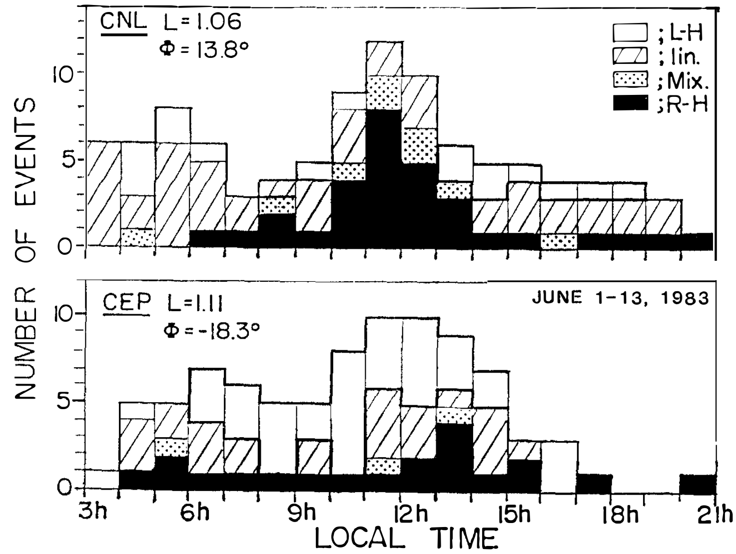

Fig. 2. Diurnal variations of Pc 3 polarizations in the H-D plane observed simultaneously at very low-latitude northern (CNL) and southern (CEP) stations. Open, shaded, dotted, and solid areas indicate left-handed, linear, mixed, and right-handed polarizations from a view looking down onto the earth in each hemisphere, respectively.

was selected, since Pc 3 magnetic pulsations tend to have a wave packet structure with a typical spacing of ~5 min (*cf.* YUMOTO *et al.*, 1985b). The Pc 3 pulsations at very low latitudes appeared predominantly in the morning (~0600 LT) and near local noon (~1200 LT) during the selected interval. Open, shaded, dotted, and solid areas indicate, respectively, left-handed, linear, mixed, and right-handed polarizations from a view looking down onto the earth in each hemisphere. Even within the limitations of the campaign interval of only two weeks, the Pc 3 polarizations at the low-latitude northern (southern) station are found to tend to change from right-handed (left-handed) in the morning hours to left/right-handed (right/left-handed) in the afternoon hours. The polarization reversal (or change) near local noon is consistent with that of Pc 3 pulsations observed at $|\Phi| \sim 35°$. The polarization senses at the very low latitudes ($|\Phi| \sim 10°$–$20°$) are, however, found to be opposite to those of Pc 3's at the conjugate stations of $|\Phi| \sim 35°$, where left-handed (right-handed) Pc 3's appear predominantly in the morning and right-handed (left-handed) ones occur predominantly in the afternoon sector at Moshiri (Birdsville) in the northern (southern) hemisphere (see Fig. 6 of YUMOTO *et al.*, 1985b).

Figure 3 shows the local time dependence of orientations of major axes of Pc 3 polarization ellipses in the H-D plane at the very low latitudes, Chung-Li (top panel) and Cepu (bottom panel). The orientation angle of the major axis from the H axis can be approximately expressed by $\tan^{-1}(\delta D/\delta H)$. The angles in the NE-SW and the NW-SE quadrants are taken to be positive and negative, respectively. It is found that the Pc 3 polarization ellipse changes the major axis orientation at Chung-Li (Cepu) in the northern (sourthern) hemisphere predominantly from NW-SE (NE-SW) in the morning to NE-SW/NW-SE (NW-SE) in the afternoon sector. It is also noteworthy that the diurnal variation of Pc 3 orientation angles at the very low latitudes (CNL, CEP; $|\Phi| \sim 10°$–$20°$) is in agreement with those at the low-latitude conjugate stations

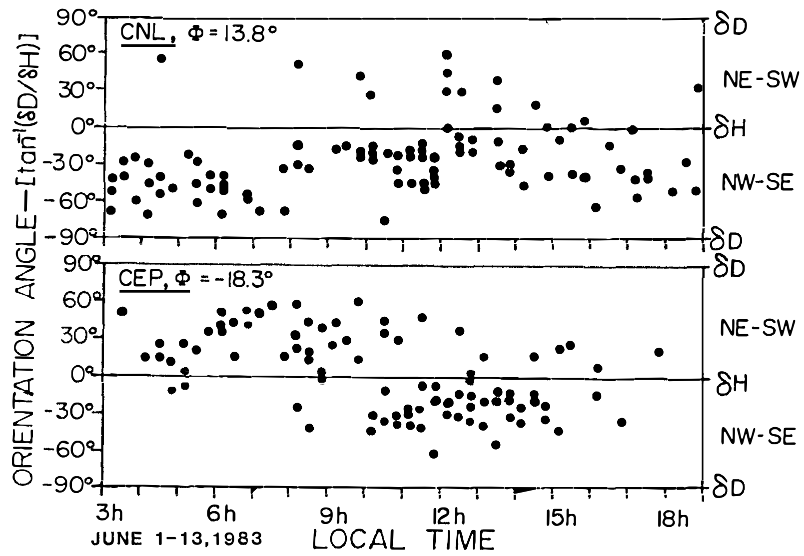

Fig. 3. Diurnal variations of major axis orientations of very low-latitude Pc 3 polarization ellipses in the H-D plane detected at CNL and CEP from 1 to 13 June, 1983. The orientation angle of the major axis measured from the H axis toward the NE-SW (NW-SE) quadrant is taken to be positive (negative).

(MSR, BVL; $|\Phi| \sim 35°$), except for the sunrise effect (see Fig. 5 of YUMOTO *et al.*, (1985b)). Because of the limitations for magnetic data obtained during the campaign, we could not clarify sunrise and sunset effects on Pc 3 polarizations at the very low latitudes in this paper. Further coordinated observations are required at the very low-latitude conjugate stations.

4. Summary and Discussion

We analyzed Pc 3 pulsations data from very low-latitude stations, Chung-Li and Cepu, which are separated with $\Delta\Lambda \sim 7°$ in geomagnetic longitude and $\Delta\Phi \sim 5°$ in geomagnetic latitude, during the interval from 1 to 13 June 1983. The observational facts can be summarized as follows:

(1) Near local noon, Pc 3 amplitudes at CEP ($\Phi = -18.3°$, $\Lambda = 182.5°$, $L = 1.11$) are slightly larger than those at CNL (13.8°, 189.5°, 1.06). The Pc 3 wavepackets with ~3–5 min duration appeared concurrently at these two stations (Fig. 1).

(2) The polarization reversal across local noon could be sometimes detected at both the stations. However, the statistical senses of Pc 3 polarizations at $|\Phi| \sim 10°$–$20°$ were opposite to those of Pc 3's at the conjugate stations of $|\Phi| \sim 35°$ (see Fig. 2 in the present study and Fig. 6 of YUMOTO *et al.* (1985b)).

(3) The diurnal variations of Pc 3 orientation angles at the very low latitudes (CNL, CEP) were consistent with those at the low-latitude conjugate stations ($|\Phi| \sim 35°$), except for the sunrise effect. The polarization ellipse in the northern (southern) hemisphere changed the major axis orientation predominantly from NW-SE (NE-SW) in the morning to NE-SW/NW-SE (NW-SE) in the afternoon sector (see Fig. 3 in the present study and Fig. 5 of YUMOTO *et al.* (1985b)).

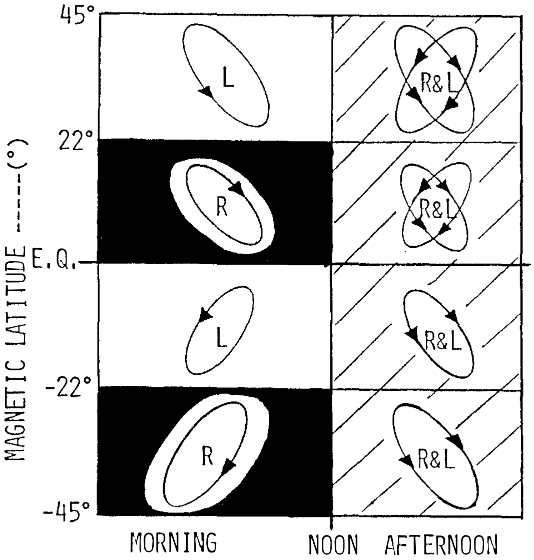

Fig. 4. Local time and latitudinal dependences of Pc 3 polarizations at lower latitudes ($|\Phi| \lesssim 45°$) in the sunlit hemisphere, which are based on the observations of YUMOTO *et al. (1985b) and in this paper.*

From the observations, we can state that the Pc 3 polarizations at very low latitudes ($|\Phi| \sim 10°$–$20°$) statistically change from right-handed (left-handed) with the major axis in the NW-SE (NE-SW) quadrant to left/right-handed (right/left-handed) with the axis in no specific (NW-SE) quadrant near the local noon in the northern (southern) hemisphere (see Fig. 4). LANZEROTTI *et al.* (1981), FRASER and ANSARI (1985), and YUMOTO *et al.* (1985b) also pointed out the diurnal variations of Pc 3 polarizations at $|\Phi| \sim 30°$–$50°$, *i.e.*, the polarization reversal from left-handed to right-handed and the orientation change of major axis from a NW-SE direction to a mixed NE-SW/NW-SE direction near local noon as schematically shown in Fig. 4. The latitudinal reversal of the Pc 3 polarization senses indicates a possibility that at least, two different-type magnetic oscillations are induced at low latitudes of $|\Phi| \lesssim 35°$. In order to interpret the Pc 3 polarization characteristics at lower latitudes ($|\Phi| \lesssim 45°$), YUMOTO (1986b) and YUMOTO *et al.* (1987) proposed a probable, new qualitative model in which two (or more) superimposed ionospheric eddy currents, oscillating with slightly different frequencies in the Pc 3 range and in apparent azimuthal wave number, move azimuthally at low latitudes ($|\Phi| \lesssim 45°$). Near low latitudes of $|\Phi| \sim 45°$ ionospheric rotational Hall currents would be induced by field-aligned currents associated with localized shear Alfvén waves which are excited by compressional Pc 3 source waves near $|\Phi| \sim 45°$. Near the equatorial region ionospheric Pedersen eddy currents may be caused by inductive electric fields of compressional Pc 3 source waves which would arrive from the outer magnetosphere to the equatorial ionosphere (YUMOTO *et al.*, 1987). The polarization and orientation changes of Pc 3's across local noon at $|\Phi| \sim 10°$–$50°$ may be associated with a switch in sign of the azimuthal wave propagation direction of Pc 3 source waves in the magnetosphere. By using the AFGL-network and the south-east Australia pulsation data, SAKA and KIM (1985) and ANSARI and FRASER (1985) recently examined azimuthal wave numbers of Pc 3 pulsations observed at $|\Phi| \sim 55°$ and 41°–52° in magnetic latitude, respectively. They found that the longitudinal phase propagation changes statistically from westward in the morning to eastward in the afternoon sector. Thus, Pc 3 source waves in the inner magnetosphere are believed to propagate statistically in the opposite longitudinal directions.

SAITO (1983) summarized diurnal variations of Pc 2–3 occurrences at very low-latitude stations in the different periods. The evening maximum of Pc 3 activities was noted to be a peculiar feature only in the subtropical region of approximately 5°–20° in magnetic latitude, supporting a possibility of existence of internal Pc 3 source wave at very low latitudes. On the other hand, the diurnal variation of f_oF_2 indicates mostly the feature of total electron content (TEC) in the ionosphere near equatorial latitudes, and shows the "noon bite-out" in ionization (*cf.* ANDERSON, 1973; RAJARAM, 1977). This "noon bite-out" feature is very similar to the occurrence pattern of the very low-latitude Pc 2–3's. The bite-out effect is markedly dependent on longitude (ANDERSON, 1973) and also on the solar cycle epoch (RAO, 1963). During solar maximum years the morning peak gains in importance, while during solar minimum years the afternoon peak gains prominence, and thus two peaks can be observed. Although Pc 3 activities at *mid-latitude* show an anticorrelation to increase in *F*-region electron concentrations (VERÖ and MENK, 1986), CHAO (private communication, 1985) suggested that the afternoon peak of Pc 3 occurrence at very low latitude (Chung-Li; $\Phi=13.8°$) during the declining phase of solar cycle is consistent with that of the TEC obtained by satellite differential Doppler measurements. The TEC is generally considered to be proportional to ionization. If the TEC is inversely proportional to ion-neutral particle collisions, the good correlation between the afternoon peaks of Pc 3 occurrence and the TEC at Chung-Li suggests a filtering action of transversely propagating compressional Pc 3 waves through the ionosphere at very low latitudes (*cf.* PRINCE and BOSTICK, 1964). The anticorrelation between mid-latitude Pc 3 activity and F2-layer electron concentration and the correlation between subtropical Pc 3 activity and increase of the TEC in the F2-layer support the following possible model: Pc 3 pulsations observed at mid and very low latitudes are associated mainly with an ionospheric Hall eddy current induced by a standing field-line oscillation at $L\sim2.0$ and with an ionospheric Pedersen eddy current induced by compressional waves at $L\lesssim1.1$, respectively (see YUMOTO *et al.*, 1987). However, the ionospheric parameters at very low latitudes depend on magnetic activity, diurnal, latitudinal, seasonal, and solar cycle dependences (*cf.* RAJARAM, 1977).

Further theoretical studies and simultaneous multiple conjugate observations of Pc 3 pulsations and ionospheric variations (*e.g.*, SUTCLIFFE and POOLE, 1984) at very low latitudes ($|\Phi|<22°$) are needed to examine whether or not an external Pc 3 source waves exist in the subtropical region, to clarify what kind of magnetic oscillations show the latitudinal changes of Pc 3 polarization senses at $|\Phi|\lesssim35°$, and then to understand completely the propagation and generation mechanism of low-latitude Pc 3 magnetic pulsations.

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