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Wave characteristics of daytime and nighttime Pi 2 pulsations at the equatorial and low latitudes

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Abstract. Peculiarities of daytime and nighttime Pi 2 pulsations at the dip equator are examined by using multipoint measurements from the 210° magnetic meridian (MM) magnetometer network. We found that during daytime the amplitude of Pi 2 pulsations at the dip equator is enhanced, and the phase lags ~ 34° behind those at low-latitude (magnetic latitude Φ = 19.5–46.2°) stations. On the other hand, during nighttime the amplitude of Pi 2 pulsations at the dip equator is depressed, and the phase lags ~ 18° behind those at the lower latitudes. Because the zonal ionospheric conductivity at the dip equator is much higher than that at the off-dip equator region, Pi 2 signals are expected to be distorted more effectively at the dip equator. The observations imply that the daytime and nighttime Pi 2 pulsations in the equatorial and low-latitude regions can be explained by invoking an instantaneous penetration of electric field variations from the nightside polar ionosphere to the dayside equatorial ionosphere, and a direct incidence of compressional oscillations from the nightside inner magnetosphere, respectively.

Introduction

Pi 2 magnetic pulsations at mid and low latitudes have received much attention. *Stuart and Barsczus* [1980] compared Pi 2 pulsations observed at low-latitude stations in the daytime with those in the local midnight sector. *Lester et al.* [1983, 1989] reported that the orientation pattern of the major axis of Pi 2 polarization was ordered by the substorm current wedge at low (40° N) and mid (55° N) latitudes. *Yeoman and Orr* [1989] examined the characteristics of midlatitude Pi 2 pulsations near the plasmapause on the U.K. meridian. Magnetic field data from the 210° magnetic meridian (MM) magnetometer network were recently used to investigate latitudinal characteristics of low-latitude Pi 2 pulsations [*Yumoto et al.*, 1994; *Osaki et al.*, 1996]. However, their discussion was limited to the nighttime Pi 2's and did not include those at the dip equator.

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Pi 2 pulsations observed at the dip equator have been reported in only a few papers. *Sastry et al.* [1983] pointed out the amplitude enhancement of Pi 2 at the dip equator in the daytime. *Kitamura et al.* [1988] showed that the phase difference of Pi 2 pulsations observed at longitudinally separated (~ 90°) equatorial stations is much less than 1/10 of the pulsation period. However, the characteristics of equatorial Pi 2 pulsations are not yet well understood.

In the work reported here, we analyzed magnetic field data obtained at the dip equator station and the 210° MM magnetometer network to examine day/night differences in the characteristics of Pi 2 pulsations, with particular emphasis on latitudinal structure around the dip equator.

Daytime Pi 2 Pulsations

The magnetometer data used here were obtained from a dip equator station at Pohnpei (POH), a near-equatorial station at Eusebio (EUS), and ten latitudinally distributed stations along the 210° MM. POH and the 210° MM stations are located on similar meridians. EUS is longitudinally separated (163.3°) from POH. Data from these stations are used to confirm the global occurrence of Pi 2 pulsations. The coordinates of the stations are summarized in Table 1. The instruments at POH and EUS are different from those at the 210° MM stations; details of the systems were presented by *Tachihara et al.* [1996] and *Yumoto and the 210° MM Magnetic Observation Group* [1996], respectively. The sampling times of magnetometers at the 210° MM stations and at the equatorial stations are 1 s and 3 s, respectively, but the time accuracy of these systems was kept within 0.1 s. The amplitude resolution of data is 0.015 nT at POH, EUS, GUA, CBI, KAG, ONW, and MSR, 0.037 nT at PTK, MGD, and ZYK, and 0.074 nT at CHD and KTN.

The first event occurred at 0139 UT on January 29, 1995. Figure 1 shows bandpass-filtered (40–150 s) data for the H-component magnetic variations observed at the latitudinally distributed (Φ = 0–70°) stations in the daytime (around 1119 LT) and at EUS in the nighttime (2305 LT). A similar Pi 2 wave form could be seen at the globally separated, nightside station EUS. Similar Pi 2 oscillations also appeared in the dayside region from the 46.2° latitude station (PTK) to the dip equator station (POH), but Pi 2 oscillations could not be identified at the higher-latitude dayside stations at KTN, CHD, ZYK, and MGD. We confirmed statistically that during daytime the concurrent appearance of similar Pi 2 oscillations at the higher latitudes is less than 20% of those at the lower latitudes. Daytime Pi 2's are found to be predominant in the lower-latitude region (Φ < 46.2°).

The Pi 2 H-component amplitude was 1.5 nT at MSR, and it decreased gradually with decreasing magnetic latitude until CBI. This trend changed to an increase at GUA, and the maximum amplitude was 2.8 nT at POH. Phase differences among the stations were very small, with the exception of the dip equator POH.

We reconfirmed statistically that the D/H ratio of Pi 2 amplitudes observed at low-latitude stations (Φ < 40°) is

Table 1. Coordinates of stations

Station Name	Abbreviation	Geographic Latitude	Geographic Longitude	Geomagnetic Latitude	Geomagnetic Longitude	L	Dip Latitude[a]
Kotel'nny isl.	KTN	75.9	137.7	70.0	201.2	8.9	—
Chokurdakh	CHD	70.6	147.9	64.7	212.3	5.5	—
Zyryanka	ZYK	65.8	150.8	59.6	216.9	3.9	—
Magadan	MGD	60.0	150.9	53.5	218.9	2.8	—
St. Paratunka	PTK	52.9	158.3	46.2	226.1	2.1	—
Moshiri	MSR	44.4	142.3	37.3	213.5	1.6	—
Onagawa	ONW	38.4	141.5	31.2	212.7	1.4	—
Kagoshima	KAG	31.5	130.7	24.4	202.4	1.2	—
Chichijima	CBI	27.2	142.3	19.5	213.2	1.1	-
Guam	GUA	13.6	144.9	5.6	215.6	1.0	5.6
Pohnpei	POH	7.0	158.3	0.1	229.2	1.0	0.4
Eusebio	EUS	−3.9	−38.4	0.1	34.7	1.0	−4.3

[a] Dip latitude is defined as the geocentric angle that corresponds to the distance from the dip equator. It is shown only for POH, GUA, and EUS.

small in both the daytime and the nighttime, as shown in Figs. 7 and 8 of *Osaki et al.* [1996]. Therefore, only the H-component magnetic data are analyzed in the present paper.

In order to clarify the latitudinal variations of amplitude and phase difference of daytime Pi 2's, we statistically analyzed 46 Pi 2 events observed in the local daytime from 0900 to 1800 during the period from January 22, 1995, to February 25, 1995. We selected Pi 2 events that show similar wave forms at both the dayside and nightside equator, POH and EUS, with amplitudes $\geq$ 0.5 nT. By using the correlated data adaptive noise canceling method, *Sutcliffe and Yumoto* [1991] statistically confirmed that 80% of nighttime Pi 2's were accompanied by daytime Pi 2's at low latitudes. In the future we will examine how many of the nighttime Pi 2 events can be identified in the dayside equatorial region by using the same method.

The latitudinal profile of daytime Pi 2 amplitudes is shown in Figure 2a. The plot shows the ratio of Pi 2 amplitudes observed at six stations to that at GUA. Pi 2 amplitudes are found to be small and almost the same in the low-latitude region from PTK to CBI, with an amplitude ratio of 0.51–0.67. On the other hand, an enhanced amplitude ratio of 2.0 can be seen at the dip equator station POH. The dayside equatorial Pi 2 amplitudes are found to reach 3–4 times those at $\Phi = 19.5$–$46.2°$. Because of the absence of stations between CBI and GUA, we do not know the magnetic latitude at which daytime Pi 2 amplitudes begin to increase in the equatorial region.

Figure 2b shows the latitudinal variation of Pi 2 phase differences between GUA and the other six stations. The phase differences were obtained by using cross-correlation analysis. A positive (negative) sign indicates that the signal leads (lags) that at GUA. Small phase differences are seen in the low-latitude ($\Phi = 5.6$–$46.2°$) region from PTK to GUA, while a large phase lag of 34° can be recognized at the dip equator station POH. The peculiar phase lag of daytime Pi 2's is found to appear within a few degrees of magnetic latitude near the dip equator.

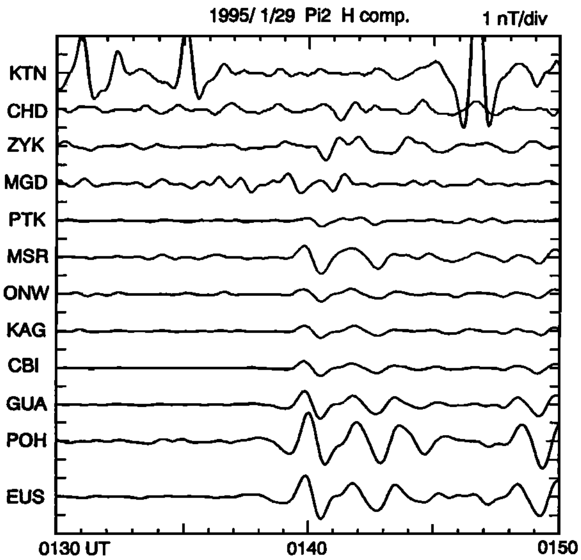

Figure 1. H-component magnetograms of daytime Pi 2 observed along the 210° MM stations, except for EUS in nightside, during the period from 0130 to 0150 UT on January 29, 1995. The magnetograms have been bandpass filtered in the period from 40 to 150 s.

Nighttime Pi 2 Pulsations

The second Pi 2 event occurred at 1338 UT on February 17, 1995. Figure 3 shows bandpass-filtered (40–150 s) data for the H-component magnetic variations observed in the nighttime (around 2318 LT) and in the daytime (1104 LT) near the equator EUS. Similar nighttime Pi 2 oscillations occurred clearly at all the stations, although the phase reversal appeared between ZYK (L = 3.9) and MGD (2.8). Daytime Pi 2 pulsations also appeared concurrently at EUS. Large-amplitude Pi 2 pulsations occurred at high latitudes, as shown by KTN (43.8 nT), CHD (29.2 nT), and ZYK (10.4 nT). Nighttime Pi 2 amplitudes at MGD were 4.2 nT, and at the lower latitude stations the amplitudes were less than 4.3 nT. This result is consistent with that of *Yumoto et al.* [1994]. They suggested that Pi 2 H-component pulsations at high and low latitudes must be associated with different modes, namely, ionospheric current and global compressional oscillations, respectively. Our aim in this paper is to clarify the characteristics of Pi 2 pulsations in the equatorial and low-latitude regions, so we will restrict our discussion to the area within 0–53.5° magnetic latitude.

In this region, the maximum Pi 2 amplitudes were observed at MGD (4.2 nT) and MSR (4.3 nT), and the amplitudes gradually decreased with decreasing magnetic latitude, i.e., 3.2 nT at ONW, 2.6 nT at KAG, and 2.0 nT at CBI. The nighttime Pi 2 amplitude slightly increased to 2.8 nT at GUA, and then a small decrease to 2.2 nT could be

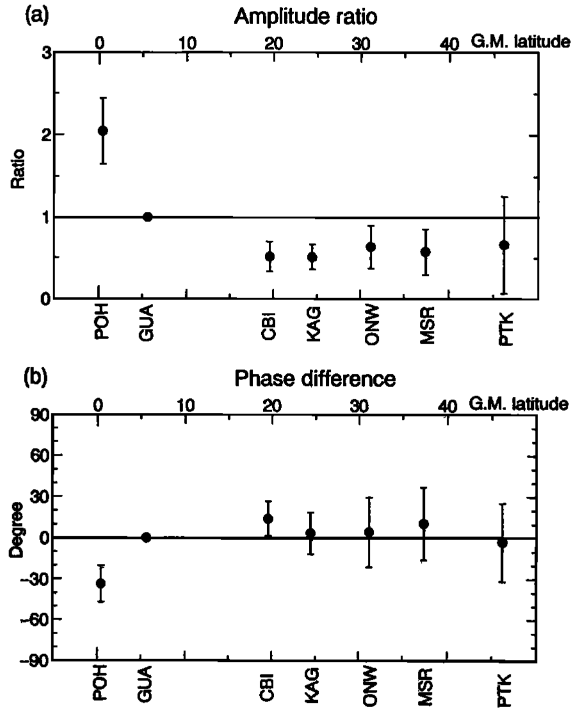

Figure 2. Latitudinal variations in amplitude ratio (a), and phase difference (b), of daytime Pi 2 pulsations observed at the 210° MM stations with respect to GUA. Standard deviations are indicated (bars).

seen at the dip equator POH. The phase differences among the stations were very small, with the exception of the dip equator POH.

Nighttime Pi 2 pulsations during 2200–0300 LT were selected because a change in latitudinal variation was found to appear around 2200 LT. Pi 2 pulsations observed during 1800–2200 LT show intermediate characteristics of amplitude ratio and phase relationship with regard to those at the daytime and nighttime Pi 2's. *Takahashi et al.* [1992] discussed the concurrent occurrence of Pi 2 pulsations in the low-latitude ground station and in the inner magnetosphere (L = 2–5). The great majority of compressional Pi 2's were observed mainly within about ±3 hours of midnight

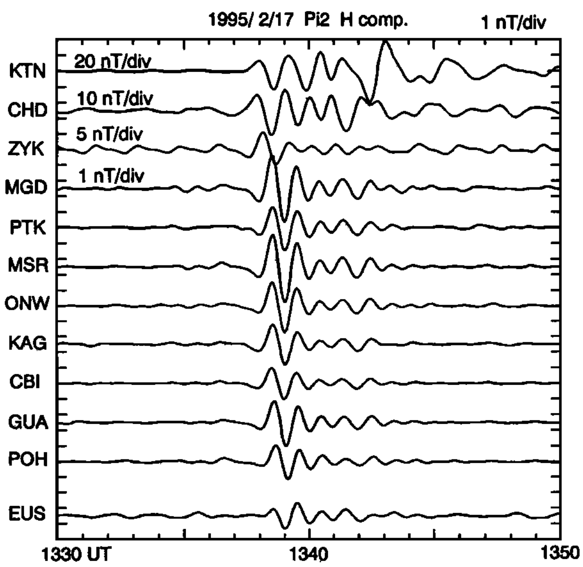

Figure 3. Same as in Figure 1, but showing for nighttime Pi 2 pulsations during the period from 1330 to 1350 UT on February 17, 1995.

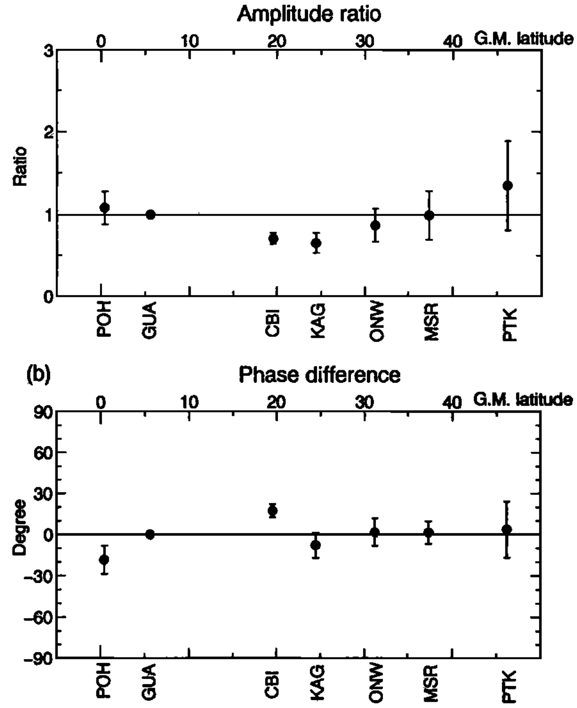

Figure 4. Same as in Figure 2, but showing for nighttime Pi 2 pulsations.

in the inner magnetosphere. Therefore, it is reasonable to limit the time interval to 2200–0300 LT for studies of the characteristics of nighttime Pi 2's.

We have analyzed 36 nighttime Pi 2 events. Figure 4a shows the latitudinal variation of the nighttime Pi 2 amplitude ratio with respect to GUA. With decreasing magnetic latitude, the amplitudes of Pi 2 H-components decrease gradually until CBI. The amplitude at GUA is enhanced a little, but depressed at POH. The averaged amplitude ratio of POH to GUA is 0.78. Figure 4b shows the phase difference of nighttime Pi 2's along the 210° magnetic meridian. The latitudinal phase variation from PTK to GUA is similar to that of the daytime Pi 2's as shown in Figure 2b. However, the averaged phase lag, 18°, of nighttime Pi 2's at the dip equator POH to GUA is smaller than that in the daytime, i.e., it is about half the daytime value.

Both daytime and nighttime Pi 2 events show a similar phase difference (~ 15°) between GUA and CBI. This phase difference may be caused by the conductivity anomaly effect of Guam and Chichijima Islands [see *Seto et al.*, 1996]. This characteristic will be re-examined in detail and presented in a future paper.

Discussion

In the work reported here, we have analyzed the 210° MM magnetic field data from the dip to 70.0° latitude to clarify the day/night difference in latitudinal variations of Pi 2 amplitude ratios and phase relationships. In the daytime, peculiarities of Pi 2's are found near the dip equator (Φ = 0–5.6°), in spite of the amplitude and phase being almost the same in the low-latitude region (Φ = 19.5–46.2°). The phase of daytime Pi 2 pulsations at the dip equator lags behind those at the low latitudes, and the amplitude of equatorial Pi 2 pulsations is enhanced. In the nighttime, the behavior of the amplitude ratio is bit a complex. At low latitudes (Φ = 19.5–53.5°), nighttime Pi 2 amplitudes gradually decrease with decreasing magnetic latitude. A small enhancement of amplitude can be seen at GUA (Φ = 5.6°), but a small depression of amplitude and a small value of phase lag are also found at the dip equator.

Our results are important to the discussion of the global generation and propagation mechanisms of daytime and nighttime Pi 2 pulsations, because our observations covered a broad worldwide region, from the dip equator to 70° magnetic latitude.

Peculiarities at the dip equator should be associated with the equatorial enhancement of zonal ionospheric conductivity. It occurs strongly in the daytime. In the nighttime, the ionospheric conductivity is relatively reduced; however, the equatorial enhancement of zonal ionospheric conductivity is still recognizable in the sunspot minimum phase [*Takeda and Araki*, 1985]. In the work described in this paper, we used data for January–February 1995, which period is in the sunspot minimum phase. Therefore, during this period incident electromagnetic signals must be distorted more effectively at the dip equator, not only in the daytime but also in the nighttime.

Kikuchi and Araki [1979a] demonstrated that in the equatorial E-region, there is a screening effect on the compressional hydromagnetic wave transmitted from the magnetosphere to the equatorial ionosphere. Then, magnetic variations observed on the ground decrease at the dip equator. The small depression of Pi 2 amplitude observed at the nightside equator (see Figure 4) could be explained by invoking this screening effect. This observation implies that compressional Pi 2 oscillations from the nightside magnetosphere are directly incident on the nightside equatorial ionosphere.

On the other hand, daytime Pi 2 pulsations show amplitude enhancement at the dip equator (see Figure 2). In order to explain the amplitude enhancement of the preliminary reverse impulse at the dayside equator, *Kikuchi and Araki* [1979b] also proposed an instantaneous transmission of polar ionospheric electric field variations into the equatorial ionosphere. Geomagnetic variations due to ionospheric currents driven by the transmitted electric field should decrease exponentially with decreasing magnetic latitude but increase abruptly at the dip equator, where the ionospheric conductivity becomes much higher. The dayside equatorial and low-latitude Pi 2 pulsations might be explained using the same transmission mechanism of the ionospheric electric field variations from the nightside polar ionosphere to the dayside equator.

Yumoto et al. [1989] presented a possible scenario for the excitation of low-latitude Pi 2's. They assumed that magnetohydrodynamic (MHD) waves are launched at the time of field dipolarization in the near-Earth tail. The compressional portion of the MHD disturbance propagates across the equatorial magnetic field, and then couples into a cavity-like oscillation in the nightside inner magnetosphere. On the other hand, a disturbance can propagate along the field line in the Alfvén mode to the high-latitude ionosphere. At that time, it is possible for a Pi 2-associated electric field in the magnetosphere to be impressed on the polar ionosphere and transmitted instantaneously to the dayside low-latitude and equatorial ionosphere; it would then be expected to amplify the equatorial current in the conductivity-enhanced region. Then, Pi 2 magnetic pulsations can be observed in the dayside equatorial region.

However, further theoretical studies are needed to explain the propagation/transmission mechanism of daytime Pi 2 pulsations.

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