A comparison of THEMIS Pi2 observations near the dawn and dusk sectors in the inner magnetosphere

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Received 11 August 2010; revised 1 October 2010; accepted 7 October 2010; published 10 December 2010.

[1] Pi2 pulsations observed in the inner magnetosphere have been explained as radially trapped fast mode waves in the plasmasphere (i.e., plasmaspheric resonance). This model suggests that these waves can be globally detected at all local times in the inner magnetosphere when azimuthal propagation is allowed. There are no reports of Pi2-associated fast mode waves on the dayside in the inner magnetosphere, however. In this case study we focus on a Pi2 pulsation that was observed by the low-latitude Bohyun station (L = 1.35) in the postmidnight sector (MLT = 3.1) at 1853 UT on 27 February 2008. During the Pi2 event, Time History of Events and Macroscale Interactions during Substorms (THEMIS)-E was near the dawnside inner magnetosphere (MLT = 5.1 and L = 2.6), and THEMIS-D was near the duskside inner magnetosphere (MLT = 17.8 and L = 3.1), which are transition regions between nightside and dayside. On the dawnside, THEMIS-E observed poloidal oscillations characterized by the azimuthal component of the electric field (δE_y) and the radial (δB_x) and compressional (δB_z) components of the magnetic field. These components had high coherence (>0.8) with a low-latitude Pi2 pulsation at Bohyun. We confirmed that the poloidal oscillations are radially standing fast mode waves excited by plasmaspheric resonance. On the duskside, however, no poloidal oscillations in the Pi2 frequency band were detected at THEMIS-D, indicating that the plasmaspheric resonance may not establish itself globally. We suggest that there is strong longitudinal attenuation of fast mode waves near the duskside, which may be due to complicated duskside plasmapause structures. In addition, a well-defined, trapped fast mode oscillation would be expected as a two-dimensional mode structure near the meridian plane of a source region.

Citation: Kim, K.-H., H.-J. Kwon, D.-H. Lee, H. Jin, K. Takahashi, V. Angelopoulos, J. W. Bonnell, K. H. Glassmeier, Y.-D. Park, and P. Sutcliffe (2010), A comparison of THEMIS Pi2 observations near the dawn and dusk sectors in the inner magnetosphere, *J. Geophys. Res.*, *115*, A12226, doi:10.1029/2010JA016010.

1. Introduction

[2] Nightside geomagnetic pulsations in the frequency band of ~6–25 mHz (period = 40–150 s) have been routinely observed in space and on the ground. Known as Pi2 pulsations, they are usually excited during onset or intensification of magnetospheric substorms [e.g., *Saito*, 1969]. Although these ground pulsations have been widely observed from high to low latitudes, their spectral content and local time occurrence appear to be latitudinally dependent. This suggests that Pi2 pulsations have different source and response mechanisms for different latitudes [*Olson*, 1999].

[3] High-latitude Pi2 pulsations, which are mainly observed in the region of substorm-enhanced ionospheric electrojet [*Olson and Rostoker*, 1975], have a peak occurrence near 2000–2400 local time [e.g., *Akasofu*, 1968]. These pulsations have been interpreted as transient Alfvén waves [*Baumjohann and Glassmeier*, 1984; *Bauer et al.*, 1995]. The wave period is determined by the Alfvén travel time between the auroral ionosphere and the neutral sheet. The transient Alfvén waves, associated with field-aligned currents diverted from the cross-tail current, produce additional east-west perturbations at mid latitudes.

[4] Ground-based observations at low latitudes and mid-latitudes (L < 4) show that Pi2 pulsations have a common frequency over a wide range of latitude and longitude

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0148-0227/10/2010JA016010

without significant time delay. Thus, cavity mode resonance of the plasmasphere has been proposed as a mechanism for middle-/low-latitude Pi2 pulsations [*Sutcliffe and Yumoto*, 1989; *Yeoman and Orr*, 1989]. In a ground-satellite statistical study, *Takahashi et al.* [1995] found that Pi2-associated magnetic field oscillations observed by CCE in the inner magnetosphere ($L \sim 2$–4) are dominated by compressional and radial components, (i.e., poloidal components) and have high coherence with Pi2 pulsations at the low-latitude Kakioka station when CCE was on the nightside and at $L < 4$. Their spatial phase structure is consistent with that expected from a radial standing wave of a cavity mode excited in a box magnetosphere. The observed radial standing waves have been interpreted as plasmaspheric cavity resonance [*Takahashi et al.*, 2001, 2003], in which the wave energy is confined inside the plasmapause, or plasmaspheric virtual resonance [*Kim* et al., 2005; *Teramoto et al.*, 2008], in which part of wave energy inside the plasmasphere tunnels through the plasmapause. Numerical and analytical studies support plasmaspheric cavity resonance [*Fujita and Glassmeier*, 1995; *Fujita et al.*, 2000; *Lee*, 1996; *Lee and Kim*, 1999] and plasmaspheric virtual resonance [*Lee*, 1998; *Lee and Lysak*, 1999; *Fujita et al.*, 2002].

[5] Because low-latitude Pi2 pulsations occur simultaneously in both the nightside and dayside hemispheres without a significant time delay and have nearly identical waveform and spectral shape [*Sutcliffe and Yumoto*, 1989, 1991], they are global phenomena at all local times. Thus, daytime low-latitude ground Pi2 pulsations have been explained as global cavity mode oscillation. However, ground-satellite coherence analysis of Pi2 pulsations showed that spacecraft magnetic field data in the compressional and radial components on the dayside at $2 < L < 4$ have low (<0.2) coherence with low-latitude ground Pi2 pulsations near midnight [*Takahashi et al.*, 1995]. Using CHAMP low-Earth-orbit data, *Sutcliffe and Lühr* [2010] reported no convincing evidence of daytime Pi2 occurrence at CHAMP altitude near ~400 km. *Han et al.* [2004] suggested that daytime Pi2 pulsation is produced by currents flowing in the ionosphere rather than global cavity mode resonance. According to *Nosé et al.* [2003] a Pi2 pulsation observed at the ETS-VI satellite located at $L = 6$ on the morningside has the same waveform and period as low-latitude Pi2 on the nightside, an observation explained by the plasmaspheric cavity mode. Thus, it is still unclear how a Pi2 pulsation excited at the nightside propagates through the magnetosphere to dayside to set up a global compressional oscillation.

[6] In this paper we report a low-latitude Pi2 pulsation event that occurred at 1853 UT on 27 February 2008. During this event electric and magnetic field data from Time History of Events and Macroscale Interactions during Substorms (THEMIS)-E on the dawnside and THEMIS-D on the duskside in the inner magnetosphere ($L \sim 2$–3) were obtained. To the authors' knowledge, this is the first report of simultaneous spacecraft dawn and dusk observations of Pi2s in the inner magnetosphere. Since dawn and dusk are transition regions between nightside and dayside, we can examine how the plasmaspheric resonance mode propagates toward the dayside. We observed well-defined, radially standing poloidal waves at THEMIS-E on the dawnside with high coherence with a low-latitude Pi2 pulsation observed at postmidnight. On the duskside, however, there were no poloidal oscillations in the Pi2 frequency band. We will discuss what causes this significant difference between dawn and dusk field variations.

2. Data Sets

[7] This study uses the electric [*Bonnell et al.*, 2008] and magnetic fields [*Auster et al.*, 2008] measured in the inner magnetosphere ($L < 4$) by the THEMIS-D (THD) and THEMIS-E (THE) spacecraft [*Sibeck and Angelopoulos*, 2008] and magnetic fields measured on the ground at Bohyun (BOH), Korea, and Hermanus (HER), South Africa. The THEMIS electric field data used in this study are spin-fit (~3 s) vector samples constructed from 2-D spin plane components using the condition $\mathbf{E} \cdot \mathbf{B} = 0$. The spin fit (~3 s) electric and magnetic field data were exactly resampled at 3 s intervals after interpolation.

[8] To separate the field perturbations into transverse and compressional components, the THEMIS electric and magnetic field data were rotated into mean-field-aligned coordinates in which $\hat{\mathbf{e}}_z$ is along the averaged magnetic field defined by taking the 5 min boxcar running averages of the 3 s data; the azimuthal direction $\hat{\mathbf{e}}_y$ (eastward) is parallel to $\hat{\mathbf{e}}_z \times \mathbf{r}$, where $\mathbf{r}$ is the spacecraft position vector with respect to the center of the Earth; and the radially outward component is given by $\hat{\mathbf{e}}_x = \hat{\mathbf{e}}_y \times \hat{\mathbf{e}}_z$. The transverse components δB_x and δB_y are high-pass-filtered perturbations by definition, and the parallel component δB_z defined by B_z (3 s averages) minus B_z (5 min averages) is the high-pass-filtered compressional component. Likewise, the perturbed electric field is defined as $E_{x,y}$ (3 s averages) minus $E_{x,y}$ (5 min averages). The parallel electric field δE_z is assumed to be zero.

[9] Magnetometer data from the BOH and HER stations are used to identify low-latitude Pi2 pulsations. BOH is located at a magnetic latitude of 29.8° ($L = 1.35$), a geographic latitude of 36.2°, and a geographic longitude of 128.9°. HER is located at a magnetic latitude of −42.42° ($L = 1.83$), a geographic latitude of −34.4°, and a geographic longitude of 19.2°. BOH provides fluxgate magnetometer data. The geomagnetic field measurements at HER were made with an induction magnetometer with 1 s sampling. The induction magnetometer data were converted to nT units by correcting for the frequency-dependent amplitude and phase response of the system. The response determination was carried out by placing the induction sensor in a large solenoid and generating known magnetic fields over a range of frequencies with a calibrated signal generator. The response correction was carried out by Fourier transforming the phase-shifted output voltage signal of the induction sensor, multiplying by the complex response function, and then inverse Fourier transforming to obtain the signal in nT with zero phase shift. The BOH and HER magnetometer data are provided at 1 s resolution, and we have taken 3 s running averages to make the data comparable to the THEMIS field data. BOH and HER are separated by about 8 h local time.

3. Observations

[10] Figure 1a shows the provisional auroral electrojet *AL* index from 1800 to 2000 UT on 27 February 2008. Since

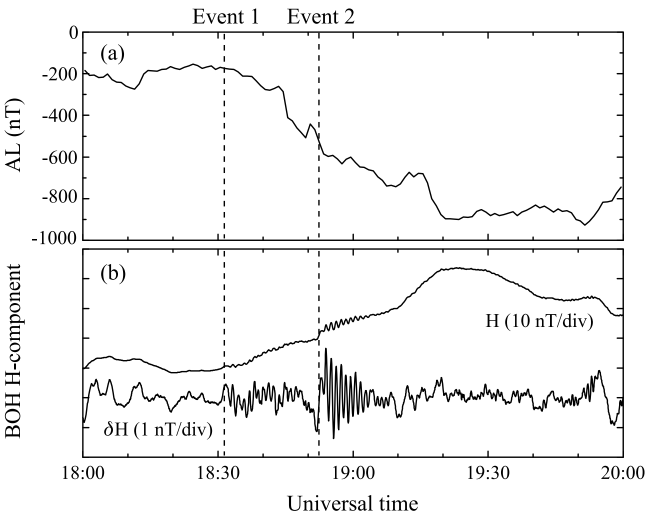

Figure 1. (a) The auroral electrojet *AL* index and (b) Bohyun *H* and *δH* from 1800 to 2000 UT on 27 February 2008. *δH* is 3 s samples with the 300 s running averages removed. The vertical dashed lines indicate Pi2 onsets at 1831 UT (event 1) and at 1853 UT (event 2) on 27 February 2008.

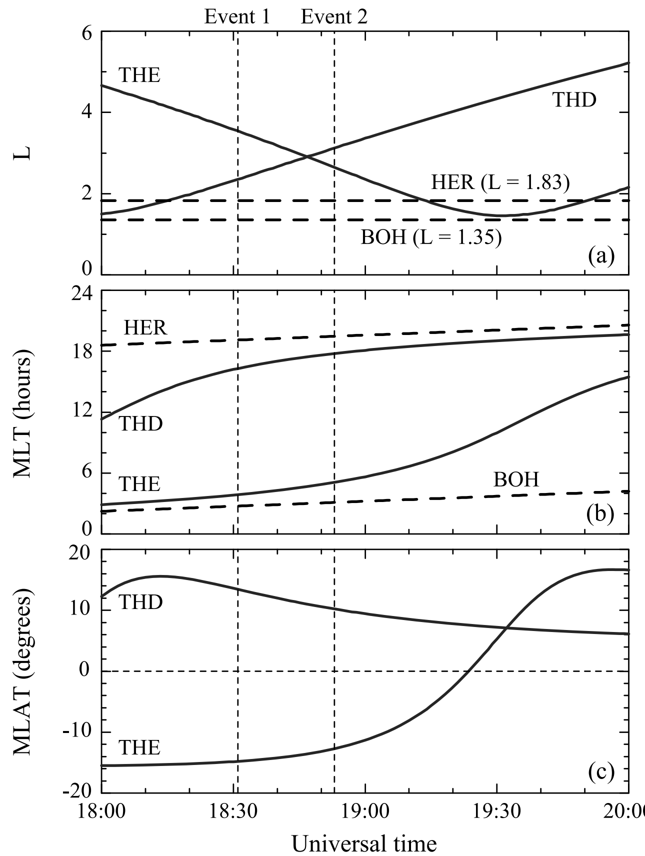

Figure 2. The (a) dipole shell parameter *L*, (b) magnetic local time (MLT), and (c) magnetic latitude (MLAT) of THEMIS-D (THD), THEMIS-E (THE), Bohyun (BOH), and Hermanus (HER) for the same interval as in Figure 1.

the 3 h *Kp* value corresponding to this time interval was 4+, the magnetosphere was not in a quiet condition. The BOH station *H* component magnetic field data and its perturbations (*δH*) using a 5 min high-pass filter are plotted in Figure 1b. At 1831 UT the *AL* index started to decrease. At BOH, a positive bay associated with a magnetic substorm signature in the low-latitude magnetic field and an *AL* decrease began almost simultaneously.

[11] The vertical dashed lines at 1831 UT (event 1) and 1853 UT (event 2) represent Pi2 onsets identified from a visual inspection of the BOH *δH* data time series plot. Pi2 onset at 1831 UT is accompanied by *AL* decrease. *AL* recovered from −500 nT to −441 nT around 1850 UT, then suddenly decreased again. Around that time, a large (up to 2.7 nT peak to peak), clear Pi2 pulsation was observed. Thus, the Pi2s in our study are substorm-associated phenomena (i.e., substorm expansions/intensifications).

[12] Figure 2 shows the location of THD, THE, BOH, and HER during the interval shown in Figure 1 as a function of universal time, using the magnetic shell parameter *L*, magnetic local time MLT, and magnetic latitude MLAT. The two vertical dashed lines indicate the onset times of events 1 and 2. During the 2 h interval, THD was north of the magnetic equator with a magnetic latitude between 6° and 16°, and it moved outward from *L* = 1.5 (perigee) near noon to *L* = 5.2 on the duskside. From 1800 to 1930 UT, THE moved inward from *L* = 4.7 to *L* = 1.5, mostly below the magnetic equator, and moved from 2.5 to 9.9 in MLT. BOH and HER were postmidnight and premidnight, respectively, during the 1.5 h interval.

[13] Figure 3 shows an *L* versus MLT plot of the location of the THEMIS spacecraft and low-latitude BOH and HER stations at the onset times of event 1 (open circles) and event 2 (solid circles). Events 1 and 2 were observed when THE and BOH were near dawnside with a small local time separation (<2 h); THD was dayside for event 1 and duskside for event 2. HER was located ~2–3 h later than THD in local time. These simultaneous multipoint observations near dawn and dusk allow us to discuss how and where substorm-associated fast mode waves get established as a regular oscillation in the inner magnetosphere (*L* < 4).

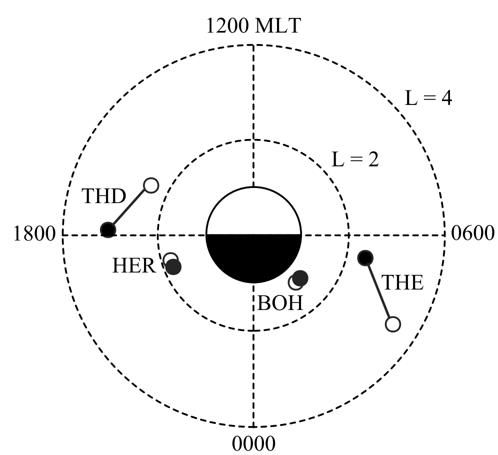

Figure 3. Magnetic local time (MLT) and dipole *L* plots of the locations of THEMIS spacecraft and ground stations at Pi2 onset times 1831 UT (the open circles) and 1853 UT (the solid circles) on 27 February 2008.

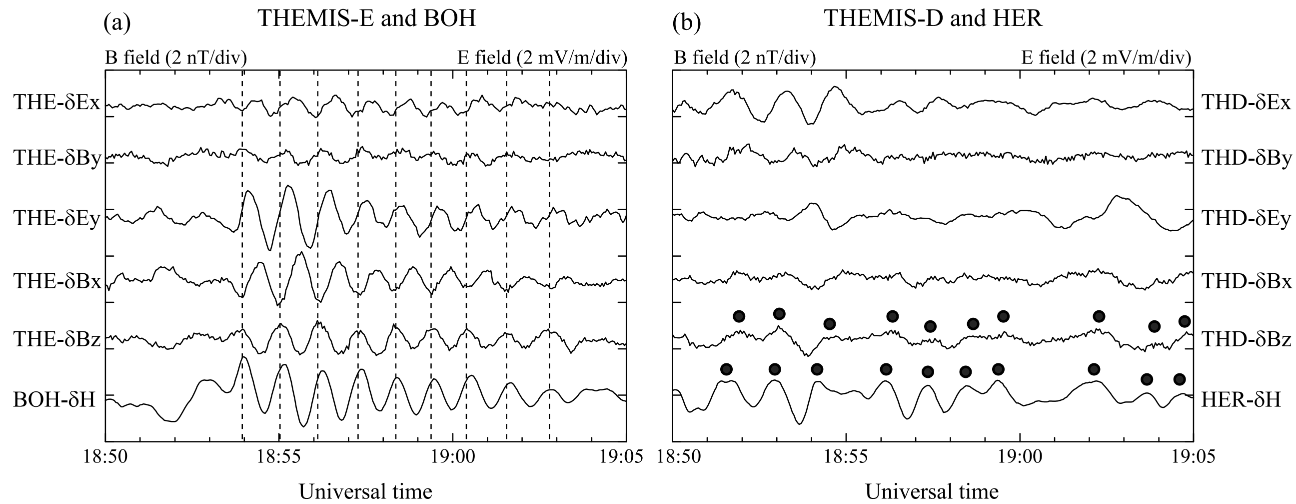

Figure 4. (a) THEMIS-E (THE) and Bohyun (BOH) and (b) THEMIS-D (THD) and Hermanus (HER) data for event 2. The THEMIS field toroidal (δE_x and δB_y) and poloidal (δE_y, δB_x, and δB_z) components are 3 s samples with 300 s running averages removed. The BOH and HER magnetic field H components are 3 s samples with 300 s running averages removed.

[14] Figure 4a shows time series plots of δE_x, δB_y, δE_y, δB_x, and δB_z at THE and δH at BOH near dawnside for event 2. To compare the field variations with those observed near duskside, THD and HER data are plotted in Figure 4b in the same format as in Figure 4a. Toroidal waves are characterized by field perturbations in the azimuthal magnetic field (δB_y) and the radial electric field (δE_x). Poloidal waves are characterized by the azimuthal electric field component (δE_y) and the radial (δB_x) and compressional (δB_z) magnetic field components. The BOH and HER data in Figure 4 were filtered by removing 300 s running averages from the H component. The vertical dashed lines in Figure 4a are drawn through the peaks of δB_z for visual inspection of the phase delay.

[15] Pulsations in all field components at THE oscillated with nearly identical periods. The waveforms are quite sinusoidal. The dominant components are δE_y, δB_x, and δB_z. That is, THE observed strongly poloidal oscillations at $L \sim 2.6$ and on the dawnside (MLT = 5.1). The poloidal components, δB_x, and δB_z, oscillate exactly in antiphase with comparable amplitudes. The δB_z (δB_x) peaks lead (lag) those of δE_y by a quarter of the wave period. These phase relationships among the poloidal components (δE_y, δB_x, and δB_z) suggest that the poloidal wave was radially standing [*Kim and Takahashi*, 1999; *Takahashi et al.*, 2001, 2003].

[16] The toroidal components, δE_y and δB_y, at THE are directly related to the poloidal components of the pulsation at the same wave period. Following the vertical dashed lines in Figure 4a, we find that the periods of the poloidal wave and the toroidal wave are nearly identical. δE_x and δB_y oscillated almost in quadrature. Thus, the δE_x and δB_y oscillations can be explained by toroidal mode standing Alfvén waves excited by field line resonance [*Chen and Hasegawa*, 1974; *Southwood*, 1974]. This implies that energy is transferred from the poloidal mode to the toroidal mode.

[17] The poloidal oscillations at THE are nearly identical to the oscillation in H at BOH, indicating that the pulsations observed in space and on the ground are excited by a common source mechanism. δB_x oscillates nearly out of phase with H, whereas δB_z oscillates nearly in phase with H. These phase signatures are consistent with those of Pi2 pulsations observed by CCE at $L < 3$ [*Takahashi et al.*, 1992, 1995].

[18] THD on the duskside (L = 3.1 and MLT = 17.8) did not observe well-defined poloidal oscillations in the Pi2 oscillation period. Although there are field perturbations in the poloidal components at THD, their waveform is not truly sinusoidal, and the field perturbations differ significantly from the oscillations at THE. Perturbations started at around 1851 UT in the toroidal component at THD. They lasted 3 cycles and have a phase delay of a quarter of the wave period between the δE_x and δB_y, implying toroidal mode standing Alfvén waves.

[19] The oscillations at BOH and HER have similar amplitudes, but the wave packet structures at both ground stations differ significantly. An interesting feature to note is that perturbations in the poloidal components (δB_x and δB_z) at THD match those in the HER data, as plotted with solid dots above the time series of δB_z and δH, although the oscillations are not quite regular at THD. This indicates that the poloidal perturbation at THD is directly related to the low-latitude ground perturbation at HER.

[20] To confirm the radially standing poloidal wave mentioned above, we use spectral analysis for the poloidal components at THE and the H component at BOH for the interval from 1853 UT to 1903 UT (see Figure 4a). The result, shown in Figure 5, includes (from top to bottom) the power spectral density, coherence, and cross phase. The spectral parameters were computed from the high-pass-filtered data using Fourier transform with five-point smoothing in the frequency domain. The coherence in Figure 5b and the cross phase in Figure 5c represent combinations of δE_y-δB_z, δB_x-δB_z, and δH-δB_z. The cross phase is calculated only for frequencies at which the coherence is greater than 0.8.

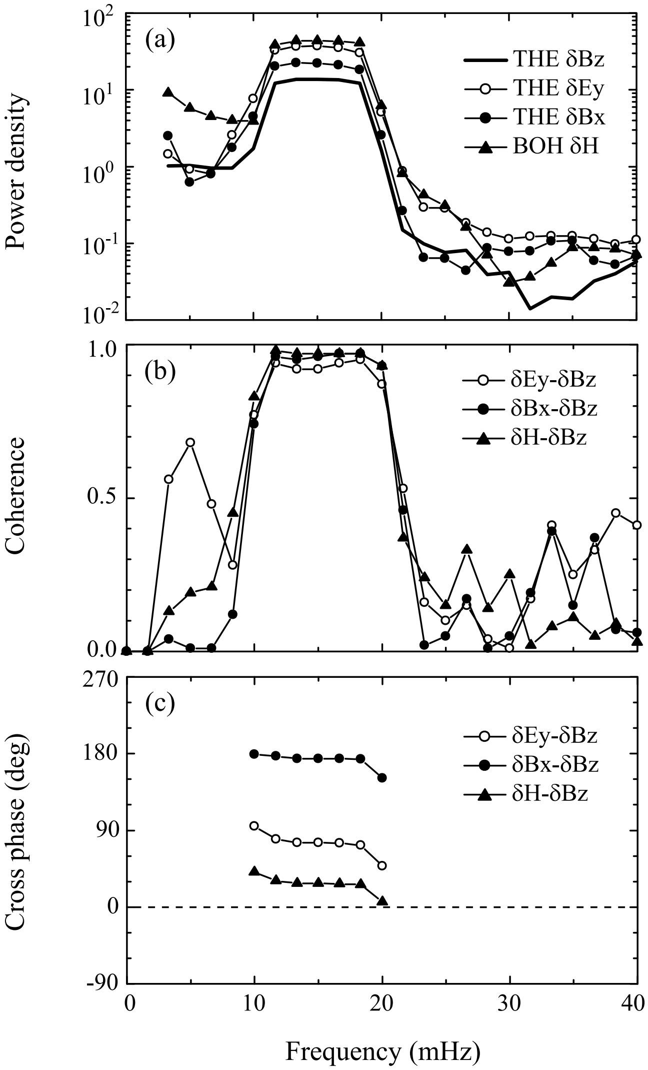

Figure 5. Spectral properties of THEMIS-E poloidal (δE_y, δB_x, and δB_z) components and Bohyun H component for event 2. (a) Power spectra for the poloidal components at THEMIS-E and H component at Bohyun. (b) Coherence. (c) Cross phase.

[21] As expected, the time series plots of the poloidal components at THE and the H component at BOH in Figure 4a, have almost identical spectral shapes. The pulsation power is strong in the frequency band from ~12 mHz to ~18 mHz centered at ~15 mHz. The nearly perfect coherence between THE δB_z and BOH δH in this band indicates that the oscillations in space are directly related to those on the ground. The phases of δB_x and δE_y relative to δB_z are close to 180° and 90°, respectively. The phase difference between δH and δB_z is small (~30°). These phase signatures can be expected when a radially standing poloidal wave is observed by a spacecraft inward of the δB_z nodal point of the fundamental mode and below the magnetic equator (MLAT < 0) [*Takahashi et al.*, 1992, 1995; *Kim and Takahashi*, 1999; *Takahashi et al.*, 2001, 2003]. Considering THE's location (L = 2.6 and MLAT = −12.7°), we conclude that the Pi2-associated poloidal oscillations at THE are radially standing waves.

[22] It should be noted that the ground-space phase delay is not exactly 0° but ~30°. Since the positive value of the cross phase indicates that the phase at THE leads the phase at BOH, the pulsations were propagating westward in the azimuthal direction (see Figures 3 and 4a). As a possible representative value of azimuthal wave number (m), we adopt m = 1. A statistical study by *Li et al.* [1998] reported small m values at low-latitude ground stations (L < 2). This m value of 1 is equivalent to a 15° (=1 × 360°/24) phase delay per hour of local time. With the 2 h separation between THE and BOH, the phase delay amounts 30°, which is consistent with the observed value. This indicates that the plasmaspheric resonance waves observed near the dawnside are propagating westward.

[23] Figure 6 shows a spectral analysis of the toroidal components (δE_x and δB_y) for event 2. The spectral shapes of δE_x and δB_y are almost identical, and in the enhanced frequency band (12–18 mHz) of these components the coherence between them was very high (>0.8). The cross

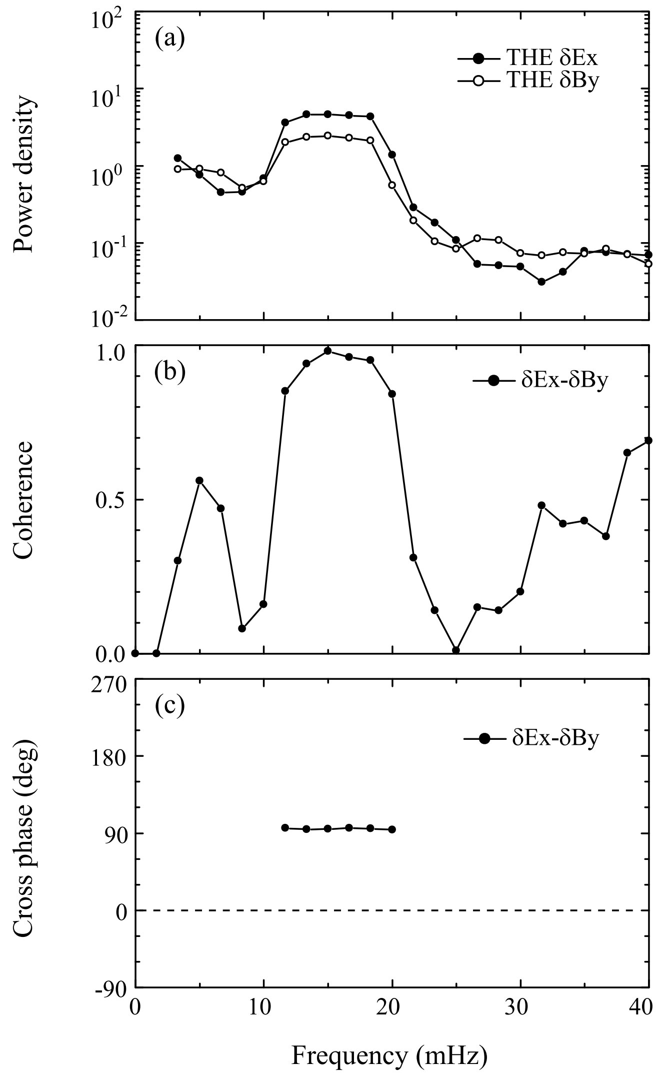

Figure 6. Spectral properties of THEMIS-E toroidal (δE_x and δB_y) components for event 2. (a) Power spectra for δE_x and δB_y. (b) Coherence. (c) Cross phase.

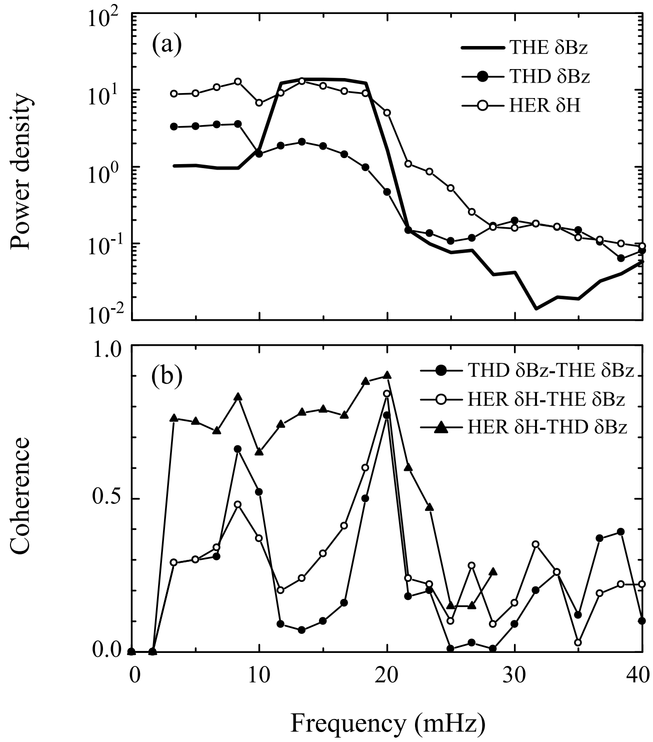

Figure 7. (a) Power spectra for δB_Z at THEMIS-E, δB_Z at THEMIS-D, and δH at Hermanus. (b) Coherence.

phase is 90°, indicating that the oscillations in the toroidal components are standing Alfveń waves guided along the background magnetic field. As expected from the waveform plots in Figure 4a, the spectral shapes of the toroidal components are nearly identical to those of the poloidal components. It is not surprising that the poloidal components at THE oscillate at the same frequency as the toroidal components if a standing Alfveń wave is established as a result of field line resonance [*Chen and Hasegawa*, 1974; *Southwood*, 1974].

[24] The power spectral density of the compressional component (δB_z) at THD and the H component at HER on the duskside are plotted with the power spectral density δB_z at THE on the dawnside in Figure 7a. In order to examine the longitudinal variations, coherences between THD δB_z and THE δB_z and between HER δH and THE δB_z, i.e., between parameters at the dawn and dusk sectors, are plotted in Figure 7b with the coherence between HER δH and THD δB_z. Note that HER δH-THD δB_z coherence is plotted only up to 28 mHz. The spectral shapes of HER δH and THD δB_z are almost identical in the frequency band of ~3–20 mHz. The coherence is high (>0.7) in that frequency band. Although there are perturbations in δB_z at THD and in δH at HER (see Figure 4b), these components have a spectral shape different from that of δB_z at THE. Also, in the frequency band (~12–18 mHz) where enhanced compressional power was seen at THE, the dawn-dusk coherence is low (<0.3). This indicates that the poloidal waves observed by THE on dawn are not directly related to those observed at HER and THD.

[25] The field components from THE, THD, BOH, and HER for event 1 are plotted in Figure 8 with the same format as in Figure 4. During the time interval in Figure 8, THE was located near L = 3.5, MLT = 3.9, and MLAT = −14.8° and BOH was located around MLT = 2.8, about 1.0 h west of THE. At BOH δH oscillates sinusoidally with a period of ~67 s (frequency = 15 mHz). At THE the poloidal components, δE_y and δB_x, are dominant, and they exhibit oscillations with a period identical to that of δH at BOH. Visual inspection of δE_y at THE and δH at BOH indicates that both components oscillate nearly in quadrature. δB_x oscillates ~180° out of phase with δH. These phases are consistent with the radially standing poloidal oscillation of the fundamental mode. There is no perturbation in δB_z, as in event 2. This may be due to the fact that THE was near the node in the fundamental mode δB_z perturbation.

[26] During event 1, THD was near L = 2.4, MLAT = 13.46°, and on the afternoonside (MLT = 16.3). Pi2 oscillations starting around 1832 UT were observed at HER,

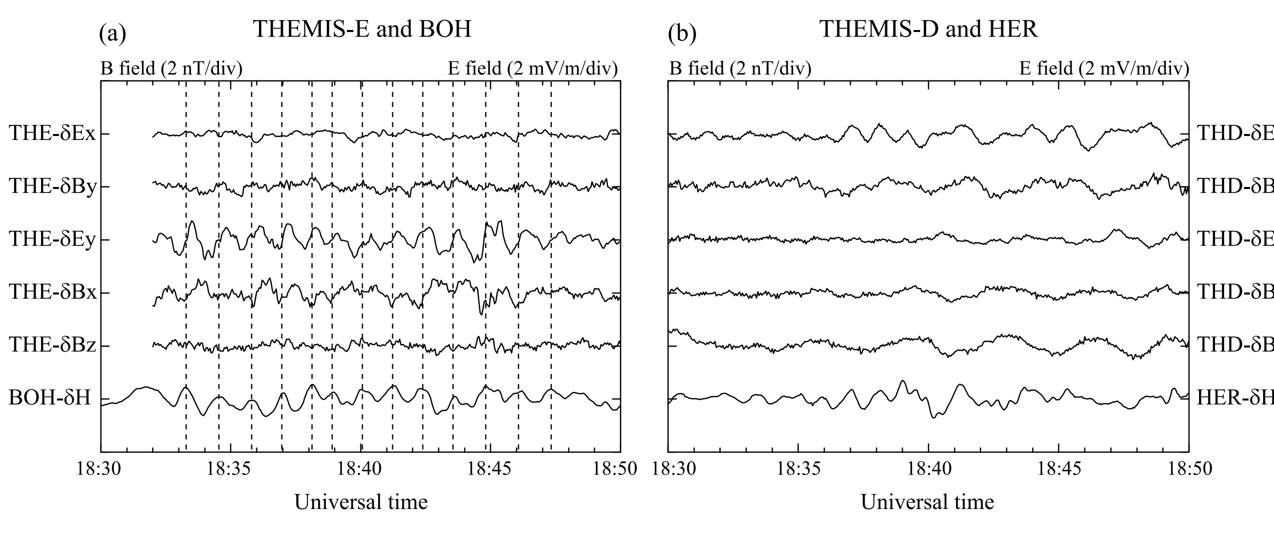

Figure 8. (a) THEMIS-E (THE) and Bohyun (BOH) and (b) THEMIS-D (THD) and Hermanus (HER) data for event 1. The format is the same as in Figure 4.

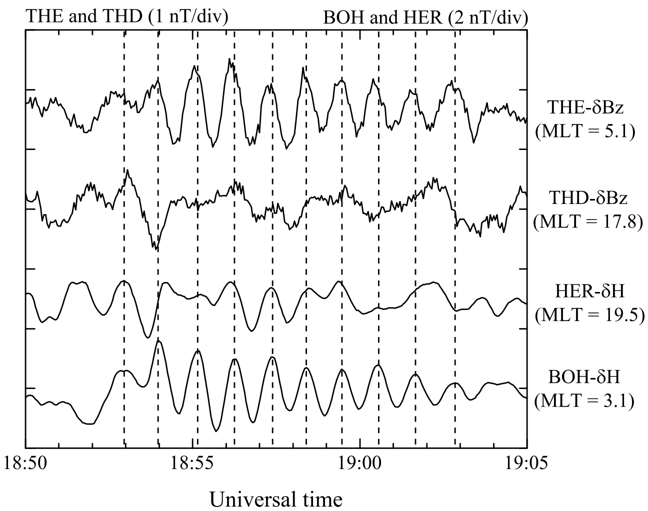

Figure 9. Comparison of magnetic field perturbations observed near dawn and dusk.

which is located at MLT = 19.1. Their waveform and period are not the same as those at BOH. The poloidal components at THD do not oscillate with the same period as δH at HER. This indicates that the Pi2 pulsation observed at night does not exist simultaneously in the afternoonside. These observations are consistent with the previous statistical result by *Takahashi et al.* [1995], who found no evidence of Pi2 pulsations propagating to the dayside in a compressional mode. There are considerable δE_x oscillations at THD, starting from 1836 UT. The δE_x oscillations can be classified as toroidal mode waves, which are excited by dayside source, on local geomagnetic field lines.

4. Discussion and Conclusions

[27] We examined electric and magnetic field variations observed at THE and THD during two low-latitude Pi2 events. The first event (event 1) was observed at THE (MLT = 3.9 and L = 3.5) and BOH (MLT = 2.8 and L = 1.35) in the postmidnight. THD on the dayside (MLT = 16.3 and L = 2.4) did not observe any Pi2 pulsations, however. Our observation is consistent with a previous statistical result by *Takahashi et al.* [1995], who concluded that there is no evidence of propagation of compressional Pi2 pulsations excited on the nightside to the dayside.

[28] During the second Pi2 event (event 2), THE, which was located on the dawnside in the inner magnetosphere (MLT = 5.1 and L = 2.6), observed electric and magnetic field oscillations in the poloidal components (δE_y, δB_x, and δB_z) with an enhanced spectral power content at ~12–18 mHz. These components exhibited a δB_x-δB_z cross phase of ~180° and δE_y-δB_z cross phase of ~90°. The poloidal oscillations at THE had high coherence (more than 0.8) with the Pi2 pulsation in the H component at the low-latitude BOH station near dawn (MLT = 3.1). The ground (δH)-satellite (δB_z) phase lag was close to zero. These phase relationships among the poloidal components at THE and between ground and satellite are consistent with those expected from a radially standing wave excited by plasmaspheric resonance if a satellite is inward of the δB_z nodal point and below the magnetic equator [*Takahashi et al.*, 1992, 1995, 2001, 2003; *Kim and Takahashi*, 1999]. As shown in Figure 2, THE was in the southern hemisphere and at L = 2.6 for event 2. Thus, the poloidal oscillations observed at THE are radially standing, fast mode waves associated with plasmaspheric resonance, and a node of δB_z was located somewhere beyond L = 2.6.

[29] Unlike THE, THD on the duskside in the inner magnetosphere (MLT = 17.8 and L = 3.1) did not observe Pi2-associated poloidal oscillations. The field perturbations at THD are significantly different from those at THE, implying that a plasmaspheric resonance mode is not globally observed at all longitudes. In order to examine the longitudinal variations of the second Pi2 event, we compare the magnetic field perturbations in δB_z at THE and THD, and δH at BOH and HER in Figure 9. The local time difference between the two low-latitude stations, BOH and HER, is about 8 h. The BOH and HER data show similar Pi2 oscillations from 1853 to 1900 UT. If those oscillations are excited by a common source, the Pi2 source region is located near postmidnight rather than premidnight because the Pi2 amplitude at BOH is larger than that at HER. After 1900 UT, BOH δH exhibited three cycles of a periodic oscillation with a period of ~67 s, but HER did not show such a periodic oscillation. That is, the wave packet structure at the two stations is different.

[30] As shown in Figure 9, there are irregular perturbations in δB_z at THD with a period longer than our Pi2 event. The perturbations were present prior to the onset of event 1 (1831 UT) (data not shown here). Thus, they may be excited by another, perhaps dayside source. Although the δB_z perturbations at THD are not quite regular, weak peaks at THD match those in the HER data (see also Figure 4b). Thus, we suggest that the Pi2 pulsations excited by plasmaspheric resonance near the postmidnight sector are spatially decaying along the local time toward the dusk and that the attenuated Pi2 oscillations on the duskside are masked by irregular perturbations excited by another source. This implies that a well-defined plasmaspheric resonance would be excited as limited extent, nearly two-dimensional mode in the meridian plane near a source region.

[31] Longitudinal attenuation of Pi2-associated poloidal oscillations may be larger on the duskside than on the dawnside because of plasmaspheric drainage plume, which is connected to the dayside magnetopause, on the duskside [e.g., *Goldstein et al.*, 2005]. There is loss of wave energy from plume region. As a consequence, the plasmaspheric resonance may not fully establish on the duskside and afternoonside. With this argument we can explain a previous observation by *Takahashi et al.* [2003] (see Figure 3 in their study) explaining why high-coherence events did not occur near dusk. This indicates that the possibility of detecting Pi2-associated poloidal oscillations may be higher in the morningside than in the afternoonside. Although ground-based observations do not provide the polarization state of the waves in the magnetosphere, the occurrence rate of low-latitude Pi2 pulsations, which have been considered as radially trapped fast mode waves in the plasmasphere, is higher in the prenoon sector than in the postnoon sector

[*Nosé et al.*, 1998]. Thus, previous low-latitude Pi2 result supports our suggestion.

[32] In conclusion we have examined the electric and magnetic field variations observed by THE on the dawnside and THD on the duskside in the inner magnetosphere ($L \sim 3$) during two low-latitude Pi2 pulsations detected on the ground at BOH ($L = 1.35$) in the postmidnight sector. The electric and magnetic field oscillations in the poloidal components at THE are directly related to the low-latitude Pi2. We confirmed that the poloidal oscillations at THE are a radially standing mode associated with plasmaspheric resonance. However, the poloidal components at THD showed little evidence of Pi2 signal on the duskside. We suggest that plasmaspheric resonance energy escapes azimuthally and that its longitudinal attenuation is larger on the duskside than on the dawnside. That is, the plasmaspheric resonance may not be established along all local times in the inner magnetosphere but may be excited as a two-dimensional mode confined near the meridian plane of the source region. Then, we would expect the longitudinal dependence of the frequency of Pi2 pulsations in the longitudinally nonuniform plasmasphere; the Pi2s on the postmidnight have higher frequency than those on the premidnight and dusk. Such different frequencies of Pi2s have been reported from ground based Pi2 observations [*Han et al.*, 2003, 2008]. Until now, however, there is no space observation to confirm that the dominant frequency of the plasmaspheric resonance varies with longitude. In near future we will examine longitudinal variation of Pi2 frequency using the data observed at longitudinally separated THEMIS spacecraft in the inner magnetosphere.

[33] **Acknowledgments.** The geomagnetic indices (*Kp* and *AL*) were provided by World Data Center C2 (WDC-C2) for Geomagnetism, Kyoto University. The Bohyun magnetic field data were provided by the Solar and Space Weather Research Group in Korea Astronomy and Space Science Institute. This work was supported by the WCU program through NRF funded by MEST of Korea (R31-10016). Work of K.-H. Kim was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2010-0007393). This work was supported by NASA contract NAS5-02099 and DLR contract 50 OC 0302.

[34] Robert Lysak thanks the reviewers for their assistance in evaluating this paper.

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