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RELATION BETWEEN Pi 2 MAGNETIC PULSATIONS AT L=1.3–2.1 AND DIPOLARIZATIONS AT AMPTE/CCE

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Abstract: In order to investigate relations between low-latitude Pi 1–2 pulsations on the ground and substorm-associated variations in space, we analyzed magnetic data from the conjugate area of L=1.3–2.1 and $\lambda \sim 140°$E, and from AMPTE/CCE in the midnight sector during August 9 to September 4, 1986. From the correlation analysis, most of low-latitude Pi pulsations are found to occur within +1 to −2 min of the onsets of substorm-associated dipolarizations at geocentric distances of 8–9 R_E in the magnetotail. The dipolarizations appear to be localized in the magnetotail, because the orbiting spacecraft often cannot detect a dipolarization corresponding to an obvious Pi 2 on the grouud.

1. Introduction

Pi 2 magnetic pulsations (period=40–150 s) associated with the expansion phase onset of magnetospheric substorms have been a subject of topical research during the last two decades. Early studies of the pulsations which used data from a small number of ground based stations clarified the timing between the Pi 2 onsets and substorm expansion phase onsets (HOLMBERG, 1953; KATO *et al.*, 1953; SAITO *et al.*, 1976; SAKURAI and SAITO, 1976). KATO (1965) first found an interesting correlation between substorm-associated magnetic variations (sampled at 5.46 min by IMP-1 in the magnetotail) and Pi 2 pulsations observed at a low-latitude station Onagawa. Subsequent studies established the statistical properties of Pi 2 waves, including amplitude behavior, dynamic spectrum and polarization hodogram (see reviews by SAITO, 1969; JACOBS, 1970; ORR, 1973; LANZEROTTI and FUKUNISHI, 1974; SOUTHWOOD and STUART, 1980; MCPHERRON, 1980). Recent studies with data from multiple stations on the ground and in space revealed spatial dependence of the Pi 2 pulsations (see reviews by HUGHES, 1983; SAMSON and ROSTOKER, 1983; BAUMJOHANN and GLASSMEIER, 1984; VERÖ, 1986; YUMOTO, 1986).

In the present paper we study the relation between Pi 2 pulsations observed on the ground at low latitudes and magnetic field variations observed by AMPTE/CCE in the near-earth tail at the expansion phase onset of magnetospheric substorms. We will confirm that most of low-latitude Pi 2 pulsation are excited within +1 to −2 min of a sudden increase in the northward component of the magnetic field at CCE at geocentric distance of 7–9 R_E.

2. Experiments and Data

Data presented in this paper were obtained during the period from July 20 to September 16, 1986, when a network of stations was operated in Japan-Australia conjugate area (YUMOTO *et al.*, 1988). The stations were located at Asahikawa (ASH; geographic latitude $\phi=43.97°$, geographic longitude $\lambda=142.20°$, $L=1.55$). Onagawa (ONW; 38.43°, 141.48°, 1.30), Birdsville (BSV; −25.83°, 139.3°, 1.55), Dalby (DAL; −27.18°, 151.20°, 1.56), St. Kilda (SKD; −34.70°, 138.50°, 2.11). BSV and ASH are magnetically conjugate, and ONW and SKD are approximately on the same meridian of the conjugate pair. The DAL site is situated near the same latitude and ~12° east of the conjugate station, BSV. The magnetic field measurements at ASH, BSV, DAL, and SKD were made with ring-core fluxgate magnetometers specially designed for measuring ULF waves (rulfmeter). The measurement at ONW was done with an induction magnetometer. Amplitude and time resolutions of reproduced analog data from the rulfmeter system are 0.07 nT and 0.5 s, respectively.

During the magnetometer campaign, the apogee of the AMPTE/CCE spacecraft was fortunately located on the nightside (see TAKAHASHI *et al.*, 1987; YUMOTO *et al.*, 1989). Magnetic field data from the satellite is used in this study as an indicator of substorm activity. CCE was launched in August 1984 into an elliptical geocentric orbit with an apogee of 8.8 R_E, an inclination of 4.8°, an orbital period of 15.7 hours. During the low-latitude campaign CCE had its apogee in the 2330–0230 magnetic local time sector, an ideal location for monitoring the magnetic field variations associated with substorms. Magnetic field at the spacecraft was measured with a fluxgate magnetometer (POTEMRA *et al.*, 1985), with an original sampling rate of 8.06 vectors per second. We use 6.2 s median values of the data throughout this study, and the vector data will be presented in the dipole VDH coordinate system. In the system, $\hat{e}_H$ is antiparallel to the earth's dipole axis, $\hat{e}_D$ is parallel to $\hat{e}_H \times \hat{r}$, and $\hat{e}_V = \hat{e}_D \times \hat{e}_H$ completes a triad.

3. Low-Latitude Pi 2's and Dipolarizations at AMPTE/CCE

Figure 1 shows an example of magnetic field data obtained concurrently on the ground at ONW and in space at AMPTE/CCE around the time of a substorm onset. At CCE, the magnetic field had a small northward component B_H ~7 nT until 1223 UT, when it suddenly jumped to ~20 nT. (The H-component magnetic variation (B_H) at CCE is not shown in the figure, but nearly equal to the total magnetic field (B_T) as presented in Fig. 2, whenever the spacecraft was located near the magnetic equator with B_D and $B_V \lesssim 10$ nT.) The field change is accompanied by irregular disturbances in all field components. Magnetic field variations of this type have been known to occur at the expansion phase of substorms in the near-earth tail (MCPHERRON *et al.*, 1973). When the same phenomenon is observed at the equator, the B_H change is accompanied by a field orientation change from tail-like to dipole-like. We defined dipolarization onset at the beginning time of step-like

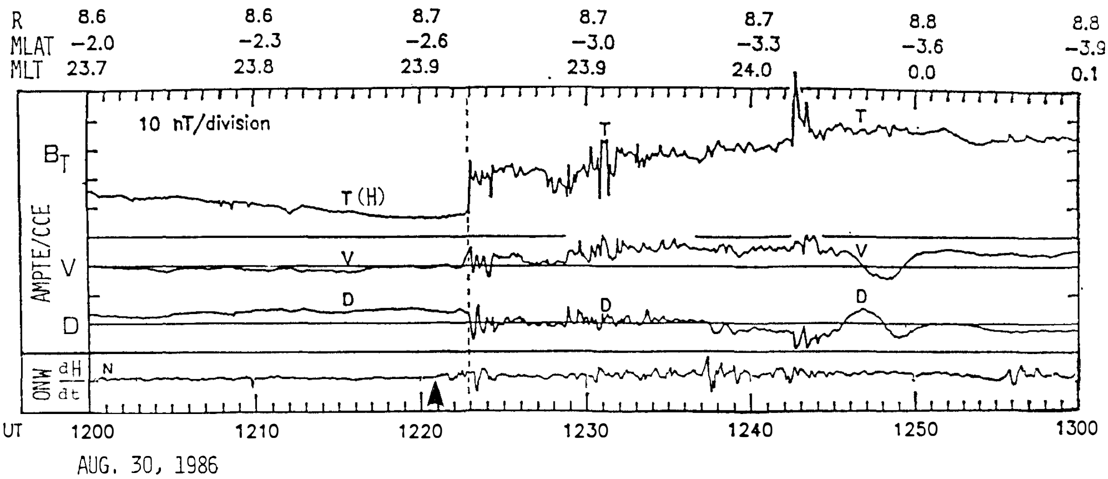

Fig. 1. An example of amplitude-time records of substorm-associated magnetic variation at AMPTE/CCE and induction magnetogram at low-latitude ground station (ONW) on August 30, 1986. B_T (or T), H, V, and D are the total field, component antiparallel to the dipole axis, radial (outward) and azimuthal (east) components, respectively. The vertical broken line and arrow indicate onsets of dipolarizations at CCE and Pi 2's at ONW, respectively.

variation in the H-component magnetic field. Therefore, it is convenient to use the term "dipolarization" to describe such a field variation in general. Dipolarization can be understood as the result of a sudden disappearance of the cross tail sheet current from the near-earth portion of the tail.

Near the 1223 UT dipolarization at CCE, the ONW magnetogram showed an onset of an irregular pulsation. Although the onset time of Pi 2 pulsation is sometimes difficult to be determined with an accuracy better than 1 min, we empirically defined Pi 2 onset at the beginning time of magnetic increase ($dH/dt>0$). The defined start time of the pulsation was 1221 UT, that is, 2 min before the dipolarization onset at CCE.

In order to investigate statistically ground/satellite correlation we surveyed data in the following manner. First, the CCE magnetic field data plotted in the dipole VDH coordinates with 68 s time resolution were scanned for events showing a step-like increase in the B_H component. Only events occurring in the universal time of 1100–1900 were selected because during this interval we can expect the detection of Pi 2 signals at the low-latitude conjugate stations. Second, the induction magnetograms at ONW ($L=1.3$) and rulfgrams at SKD ($L=2.1$) were scanned for Pi 2 pulsations occurring near the time of the dipolarization observed at CCE. Sixteen events were found from the CCE data and all events had clearly associated Pi 2 signals on the ground. The high probability of Pi 2 occurrence very near the magnetic field dipolarization at CCE confirms the well known relation between expansion phase onset and Pi 2 excitation.

Figures 2–5 are other examples of magnetic fields observed simultaneously at AMPTE/CCE in space and at ONW on the ground on August 9, 24, 28 and September 4, 1986, respectively.

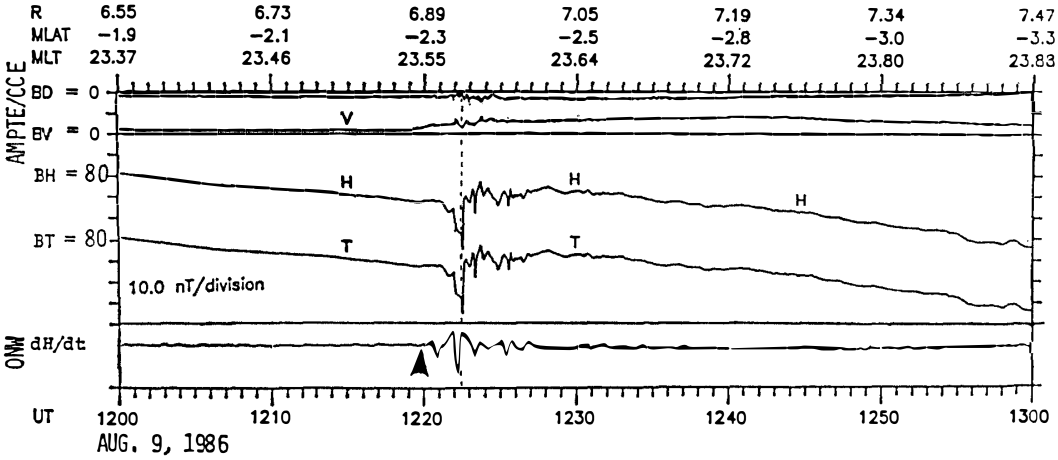

Fig. 2. The same as Fig. 1, except August 9, 1986.

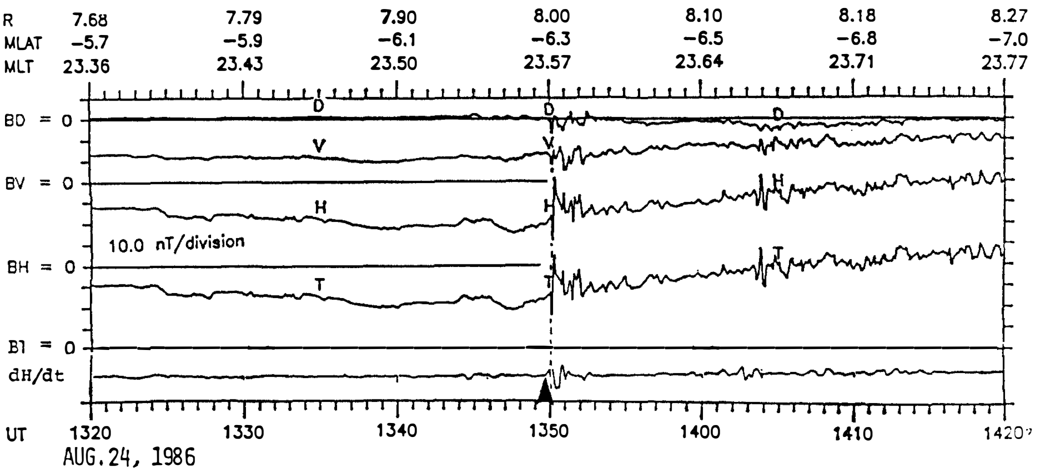

Fig. 3. The same as Fig. 1, except August 24, 1986.

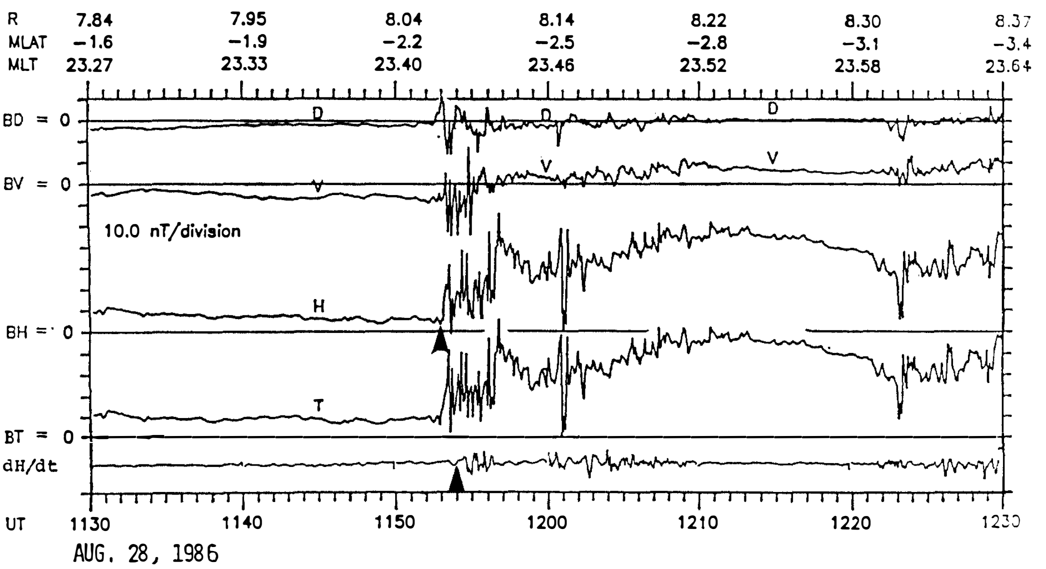

Fig. 4. The same as Fig. 1, except August 28, 1986.

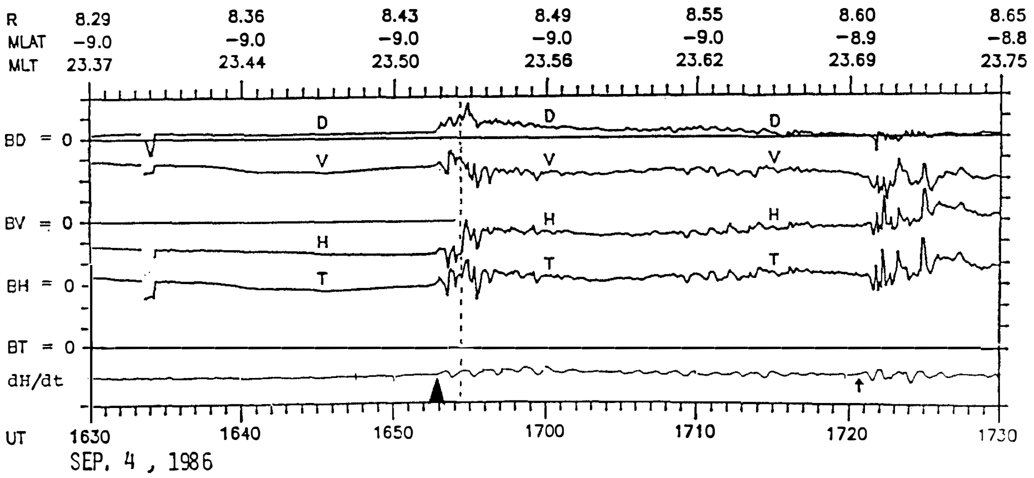

Fig. 5. The same as Fig. 1, except September 4, 1986.

Table 1. "Dipolarization" onset at the AMPTE/CCE location and Pi 2 onset at low-latitude stations (SKD and ONW; L=1.3–2.1) during substorm expansions in the period of 1130–1830 UT from August 9 to September 4, 1986.

Date 1986	Dipolarization (AMPTE/CCE)				Pi 2 (Ground)	Time lag	K_p
	Onset time (UT)	MLT (h)	R	ΔZ	Onset time (UT)	T_G-T_S (min)	
Aug. 9	1222	23.6	6.9 R_E	−0.1 R_E	1220	−2	2_-
	1452	0.7	8.5	−0.5	1445	−7	2_-
Aug. 15	1139	0.3	8.5	−0.5	1137	−2	2_-
Aug. 22	1231	22.3	5.7	−0.5	1224	−7	3
Aug. 24	1350	23.6	8.0	−0.7	1350	0	2_+
	1611	0.5	8.8	−0.9	1610	−1	4
	1801	1.1	8.6	−1.1	1801	0	5_-
Aug. 28	1153	23.4	8.1	−0.1	1154	1	2
	1556	0.8	8.6	−1.0	1554	−2	3_+
Aug. 29	1640	22.2	5.8	−0.7	1636	−4	4_-
	1759	23.0	7.2	−0.7	1757	−2	4_-
Aug. 30	1223	23.9	8.7	−0.2	1221	−2	3_+
	1501	0.8	8.6	−0.8	1500	−1	3_-
Aug. 31	1834	23.6	8.3	−0.7	1834	0	3
Sep. 2	1531	22.6	6.9	−1.0	1529	−2	2
Sep. 4	1654	23.5	8.4	−1.0	1653	−1	2_-

The spacecraft location (MLT, geocentric distance (R), separation (ΔZ) from the neutral sheet), the onset times of Pi 2 on the ground and dipolarization at AMPTE/CCE, and the K_p index for the selected 16 events are listed in Table 1. The onset times of Pi 2 pulsations on the ground and dipolarization at AMPTE/CCE don't have an accuracy better than 1 min. The satellite separation (ΔZ) from the tail current sheet was estimated using an empirical formula derived by FAIRFIELD *et al.* (1987). The concentration of the events at radial distances greater than 8 R_E reflects the fact that the spacecraft spends a long time in the region of high altitude. The time lag (T_G−T_S) stands for a difference from the onset of "dipolarization"

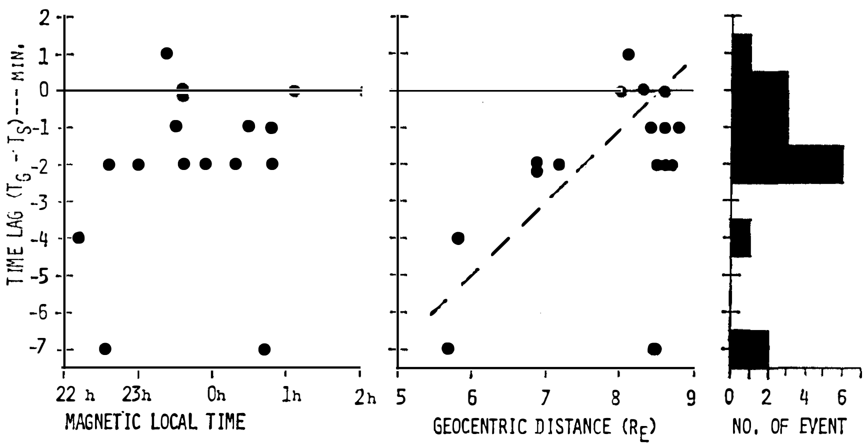

Fig. 6. Scatter plots of the time lag from "dipolarization" onset (T_S) at AMPTE/CCE to Pi 2 onset (T_G) at low-latitude ground stations ($L=1.3$–2.1) against the satellite position (magnetic local time, geocentric distance) when substorms occurred during 1130–1830 UT from August 9 to September 4, 1986. (see Table 1).

at AMPTE/CCE to that of Pi 2 pulsations at the ground station. Figure 6 summarizes the relation between the time lag (T_G–T_S) and the AMPTE/CCE location. Although the statistics are poor, a weak positive correlation can be seen in the scatter plots of the time lag against the geocentric radial location of AMPTE/CCE. The time lag from the ground to space at geocentric distance (R) of 8–9 R_E is less than 2 min except for one event, while the time lag from space at $R \lesssim 8$ R_E to the ground becomes shorter with decreasing the geocentric distance. This observation suggests a possibility of earthward propagation of the "dipolarization process" in the near-earth magnetotail ($R=5$–8 R_E), namely, the onset time of dipolarization in the inner magnetosphere is slightly delayed relative to that at $R \sim 8$–9 R_E. This is in agreement with the result obtained by the multi-satellite observation (MOORE *et al.*, 1981; NAGAI *et al.*, 1987).

In the above analysis, the CCE data were first examined for substorm onset signature. When the event survey is made in the reversed order we have different results; a clear dipolarization may not be found at CCE for a Pi 2 signal detected on the ground. Figure 7 shows one such example. In this case Pi 2 pulsations occurred in succession at 1435, 1443, and 1500 UT. The 1435 UT Pi 2 accompanied a small pulse-like variation in B_D and B_V at CCE, but no step-like increase in B_H can be seen. The 1443 UT Pi 2 is not associated with any clear field variation at CCE. Only the 1500 UT Pi 2 is associated with a clear step-like increase in B_H at CCE. The lack of tail field variation for the first two Pi 2 pulsations implies that a dipolarization occurred in a limited small region and it terminated before reaching CCE. During these events AMPTE/CCE is believed to be located near an outer boundary of the plasma sheet in the southern hemisphere. If the reconnection region were far from the spacecraft, *e.g.*, the spacecraft were outside the substorm current wedge, the substorm-associated change could not be detected in the near-earth magnetotail. From the AMPTE/CCE trajectory during the 25-min interval from 1435 UT, the separation distance from the reconnection (or disruption) region

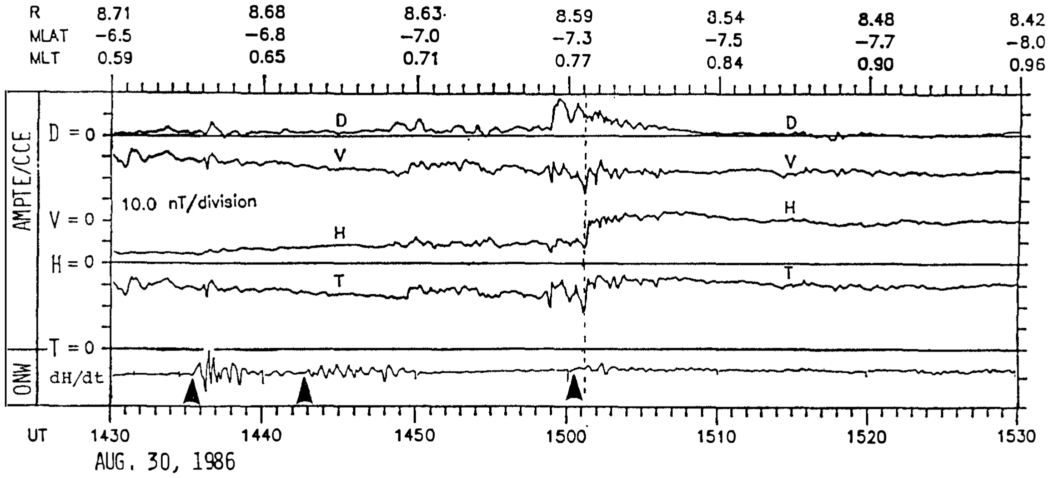

Fig. 7. The same as Fig. 1, except August 30, 1986.

to the spacecraft is likely to be within ~0.11 R_E in the radial distance, ~0.34 R_E in the longitudinal direction and/or 0.6° in the magnetic latitude at R~8.7 R_E in the magnetotail.

4. Summary and Conclusion

From the correlation analysis of magnetic field data from the conjugate-pair stations around L=1.3–2.1 and the AMPTE/CCE spacecraft for the period of 1130–1830 UT from August 9 to September 4, 1986, we found the following relations between low-latitude Pi 2 pulsations and substorm-associated phenomena at AMPTE/CCE:

1. Low-latitude Pi 2 pulsations at L=1.3–2.1 tend to occur within +1 to −2 min of onsets of "dipolarization process" at AMPTE/CCE at geocentric distance of 7–9 R_E during substorm expansion phase (Figs. 1–5).

2. The time lag, (T_S–T_G), from the onset of low-latitude Pi 2 pulsations to the onset of dipolarization at CCE in the near-earth tail ($\lesssim$8 R_E) tends to become shorter with the increase in the spacecraft geocentric distance. This implies that dipolarization propagates toward the earth at a finite speed (Fig. 6).

3. Often the dipolarization change cannot be detected at CCE even when an obvious Pi 2 is observed on the ground (see Fig. 7), indicating the localization of the dipolarization process in the near-earth magnetotail.

If we ignore a data point at (8.5 R_E, −7 min) in Fig. 6, we can draw a regression line which indicates that the lag increases as the satellite moves earthward. Again assuming an immediate excitation of a Pi 2 for any dipolarization onset in the near-earth tail, it is possible to interpret this observation as the result of an earthward propagation of the region of dipolarization in a manner similar to the propagating substorm injection front as has been proposed by MOORE *et al.* (1981). If we assume such a radial propagation, the observed time lag of ~6 min over a radial distance of 3 R_E corresponds to a velocity of ~50 km/s, which is not inconsistent with the observation of MOORE *et al.* (1981).

We shall not make a further discussion on the propagation of the region of dipolarization, since the number of events shown here is obviously too small for making any definitive determination of the propagation direction and velocity. We are in the process of enlarging the Pi 2/dipolarization data base to study the propagation in greater detail, and the result will be presented elsewhere in the near future.

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