A Long-Period Pi 2 Associated with a Mini-Substorm Observed by the Japanese Satellite JIKIKEN (EXOS-B)

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Being associated with a typical mini-substorm, a very-long-period Pi 2 event was observed simultaneously at both Onagawa, Japan, and the satellite, JIKIKEN, at 14–15 hUT on December 11, 1978. The fundamental period of the Pi 2 attained to 220 sec and the range of the substorm at Onagawa on the 23 h local time meridian was only 2 nT. The plasmopause was observed by JIKIKEN on the 21h local time meridian to be at $L > 6.3$.

This Pi 2 event in the extreme case is well explained by such an odd-mode model that a temporal odd-mode torsional oscillation of the dipole-like field lines anchored in the auroral ovals is observed as Pi 2. The analysis reveals that the ignition region for this mini-substorm must be $|X| > 16R_E$ in the magnetotail and that the tail-like configuration of the field line must be changed to the dipole-like one within several min. This event provides valuable information on one of the smallest cases of the magnetospheric substorm.

1. Introduction

It is quite important for the study of magnetospheric substorm to find the simplest and the most fundamental substorm and to investigate the occurrence mechanism of it. The simplest one was denoted by SAITO *et al.* (1976) as *mini-substorm* based on various kinds of ground-based magnetograms. The purpose of the present study is to analyze the first mini-substorm that has ever been observed by satellites and to interpret its mechanism in relation to the plasmashet model on Pi 2 type magnetic pulsation. As for the magnetometer and orbital elements of JIKIKEN, the reader may refer to AOYAMA *et al.* (1979).

2. Observation

Figure 1A shows the mini-substorm event observed on December 11, 1978 while the satellite “JIKIKEN” was in the night-side magnetosphere. Geomagnetic

Fig. 1. Mini-substorm event on Dec. 11, 1978.

Fig. 2. Trajectory during the mini-substorm.

activity had been extremely low for about 10 days before the event as shown in K_p in Fig. 1C. The stimulated plasma wave (SPW) experiment at JIKIKEN revealed that the plasmopause was situated at $L > 6.3$ before the event, while $L = 5.6$ after the event (OYA, 1979). Both of Figs. 1B and 1C confirm that the event is a typical mini-substorm and support our assertion that mini-substorm occurs during an extremely calm magnetic condition.

The trajectory of JIKIKEN is shown in Fig. 2, where the equatorial position of the field line anchoring in Onagawa is also exhibited. The position of JIKIKEN is also projected on the equatorial plane in Fig. 2B along the dipole field line. It is noteworthy that both of JIKIKEN and Onagawa were situated in the midnight sector where substorms are well registered.

3. Analysis

The magnetic field variations observed at both JIKIKEN and Onagawa during the mini-substorm event are analyzed into hissograms as shown in Fig. 3. (As for hissagram, see SAITO, 1976). It is revealed from Fig. 3 that the event observed at Onagawa contains two spectral components at ~ 220 and ~ 140 sec, respectively. The ~ 140 sec component of the mini-substorm is also recognized clearly in the

Fig. 3. Hissagram of the mini-substorm.

dynamic spectrogram obtained from the JIKIKEN magnetometer. (It should be noted that a fluctuating altitude of the satellite due to the 102-m (tip-to-tip) antennas generates a fluctuating magnetic noise near around 210 sec as shown in Fig. 3A.)

4 Interpretation

All substorm is surely associated with Pi-type magnetic pulsation (SAITO, 1969). There is an inverse relation between the Pi 2 period and the substorm magnitude; substorm with the smaller magnitude is associated with Pi 2 with the longer period (SAITO *et al.*, 1968; SAITO *et al.*, 1976). According to the odd-mode model of Pi 2, it has generally two spectral component; one correspond to the temporal odd-mode oscillation of the field line anchoring in the midnight auroral oval (SAITO, 1979; KUWASHIMA *et al.*, 1979), and the other to the field line near the plasmapause (FUKUNISHI, 1975). The ~ 220 sec component of the mini-substorm is considered to be the former, while the ~ 140 sec component belongs to the latter. It should be noted here that JIKIKEN was situated near the plasmapause while it observed the ~ 140 sec component of magnetic fluctuations.

5. Calculation

The odd-mode model is schematically illustrated in Fig. 4A. Here we commit ourselves to the reconnection model for the triggering of the substorms where Alfvén waves generated at the X-type neutral line in the magnetotail (0) are considered to

Fig. 4. Odd-mode model of Pi 2.

propagate along the field lines A and A' , being reflected back by the polar ionosphere, and make a temporal standing oscillation along the field line BB' . If radial distance, magnetic field intensity (B_p), and plasma density (N_p) of the apex (R_p) of a magnetic field line anchoring in geomagnetic latitude (Φ) are assumed to be $\Phi = 70^\circ$, $R_p = 9.2$, $B_p = 41$, $N_p = 3$ for the field line BB' for the mini-substorm event as listed at the middle of Fig. 4, the period of the odd-mode oscillation is calculated to be 220 sec as shown in Fig. 4B. On the other hand we can assume from the SPW experiment at JIKIKEN that $\Phi = 65^\circ$, $R_p = 5.6$, $B_p = 180$, and $N_p = 55$ for the field line just inside the plasmopause, where a temporally standing oscillation is secondarily excited due to the plasma instability at the X-type neutral line. The oscillation near the plasmopause is then calculated to be 140 sec as shown in Fig. 4B. The calculated values of 220 and 140 sec correspond quite well with the observed values and justify the odd-mode model (namely, the plasma-sheet model (SAITO *et al.*, 1970) of Pi 2.).

6. Discussion and conclusion

A mini-substorm event was observed simultaneously at the satellite, JIKIKEN, and at the ground-based station, Onagawa, at 14h UT on 11th of December, 1978. A comparative dynamic spectral analysis of these data provides the following conclusions on the wave phenomenon during the mini-substorm.

1) The ~ 220 -sec component which was observed at Onagawa is the fundamental odd mode of the Alfvén wave that was propagated from the plasma instability source at the X-type neutral line in the magnetotail which resulted the substorm event.

2) The ~ 140 -sec component which was observed commonly at JIKIKEN and at Onagawa is the Alfvén wave excited secondarily on the plasmopause by the plasma instability in the magnetotail.

3) The present analysis substantiates the plasma-sheet theory (SAITO *et al.*, 1970) that the main component of Pi 2 is related to the field line corresponding not to the plasma pause, but to the plasma sheet.

4) The present Pi 2 event has so clear and long period that can be well detected on ordinary magnetograms. For example, this event is clearly identified as Pi 2 wave with as large amplitude as 4 nT on the ordinary magnetogram from Kiruna even though it was situated near the noon meridian during the event. It means that Pi 2 associating with mini-substorm is quite useful to study the world-wide characteristics of Pi 2 waves.

Besides the Pi 2 waves, the present analysis of the Dec. 11, 1978 mini-substorm event derived the following important informations on the magnetosphere physics. (The reader may refer to SAITO *et al.* (1979) for the further explanation on the derivation.)

- 1) The position of the X -type neutral line (0 in Fig. 4A) must be $X \sim -20R_E$ for the smallest substorm, while $X \sim -5R_E$ for the largest substorm.
- 2) Time duration of the contraction from the tail-like magnetic field configuration to the dipole-like one (see Fig. 4A) must be ~ 4 min for the smallest substorm while ~ 0.5 min for the largest substorm.
- 3) Although the plasmasphere was considered to need about one month to expand up to $\sim 6R_E$, the present analysis reveals that it needs only about one week. This conclusion agrees well with the SPW experiment.

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