A SEQUENTIAL STUDY ON THREE LONG-PERIOD Pi2 EVENTS ASSOCIATED WITH MINI-SUBSTORMS

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Abstract: The smallest of the observed substorms, called mini-substorms, are found to accompany long-period (ranging from 150 to 300 s) Pi2 pulsations. Worldwide and sequential features of Pi2 waves can be studied in detail by examining Pi2 events associated with mini-substorms. Three such events that occurred on December 11, 1978, March 18, 1974 and November 17, 1971 are studied in this paper. It is found that an enhancement of Pi2 amplitude at the dayside equator takes place sequentially. World wide polarization distribution of Pi2 waves is also found to be consistent with the statistical distribution. The odd-mode model of Pi2 is substantiated.

1. Introduction

In order to understand the complex mechanism of the substorm that is the most basic disturbance in the magnetosphere-ionosphere system, we have studied mini-substorms that were found to be the most simplified substorm (SAITO, 1977, 1978, 1979; SAITO *et al.*, 1979, 1980; SAKURAI and SAITO, 1976). Since the mini-substorms accompany clear Pi2 events with extremely long periods ranging from 150 to 300 s, such Pi2 waves can be recorded on ordinary magnetometers which are operated at more stations than induction magnetometers in the world. Hence, sequential studies of the worldwide Pi2 waves can be made only for the Pi2 events associated with the mini-substorms.

The purpose of this paper is to examine sequentially three Pi2 events associated with three mini-substorms; the December 11, 1978 event (Section 2), March 18, 1974 event (Section 3), and November 17, 1971 event (Section 4). Conclusions will be given in the last section.

2. December 11, 1978 Event

While the Japanese satellite JIKIKEN was orbiting in the pre-midnight sector (AOYAMA *et al.*, 1979), a long-period Pi2 pulsation took place at 1355 UT on December 11, 1978 as shown in Fig. 1 which is reproduced from SAITO *et al.* (1979).

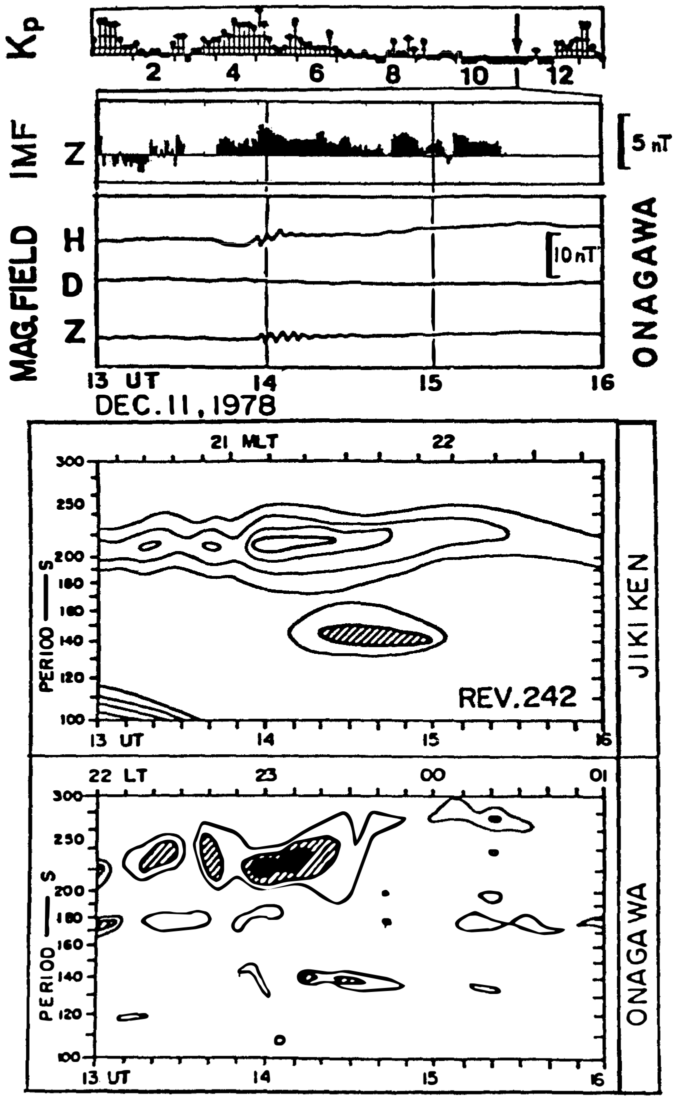

Fig. 1. Mini-substorm event observed by JIKIKEN on December 11, 1978. Upper panel shows the magnetic index Kp and the IMF. Bottom panel shows hissagrams of the mini-substorm recorded by JIKIKEN and at the Onagawa Magnetic Observatory.

Geomagnetic activity was extremely low for five days preceding the event and the plasmasphere was expanded up to $L \sim 6.3$ (OYA, 1979). It is noted that this substorm occurred when the B_z component of the interplanetary magnetic field (IMF)

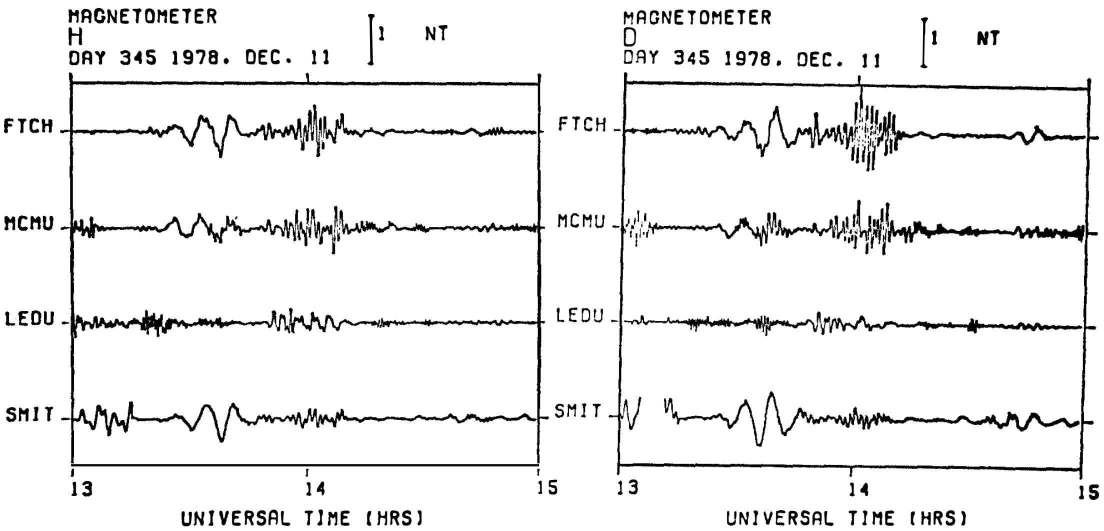

Fig. 2. Magnetograms which are obtained at Alberta chain stations filtered with a data-adaptive polarization filter (courtesy of J. C. SAMSON). Pi2 which has two dominant periods occurs at 1355 UT, December 11, 1978.

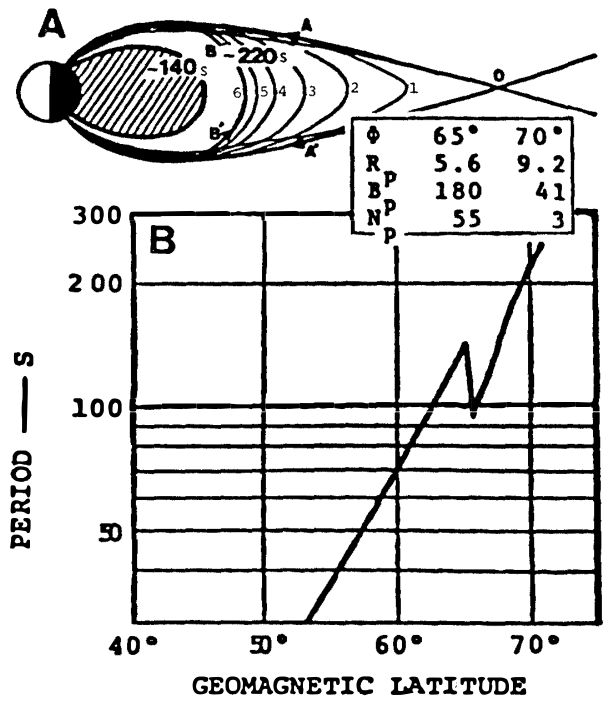

Fig. 3. Odd-mode model of Pi2.
(A): The model is schematically illustrated. The tail-like field line (A, A′) becomes the dipole-like one (B, B′) during substorm onset.
(B): Fundamental period of the torsional oscillation of individual distorted field line.

was directed northward and it did not accompany any distinct bay component in low-latitudes. It was associated with an outstanding long-period Pi2 pulsation (SAITO, 1977; SAITO and SAKURAI, 1970; SAITO *et al.*, 1978).

As shown in the lower panels of Fig. 1 (SAITO, 1976), the Pi2 observed at a low-latitude station, Onagawa, has two dominant peaks, one near ~220 s and the other at ~140 s, while that observed by JIKIKEN near the plasmapause was ~140 s. Fig. 2 shows a magnetogram which has been filtered with a data-adaptive polarization filter developed by SAMSON and OLSON (1980). There is a clear Pi2 which has two dominant periods (~220 and ~80 s) in the data from the University of Alberta array near ~1355 UT (~0600 LGT).

The ~220 and ~140 s components of the Pi2 event are explained in Fig. 3. The fundamental period of the torsional oscillation of individual distorted field lines is calculated for various plasma density and substorm magnitude, and tabulated in tables of SAITO (1977, 1979). The ~220 s component is regarded as a fundamental torsional oscillation of the field line anchoring in the polar ionosphere at ~70° geomagnetic latitude, while the ~140 s component as an oscillation of the field line at the plasmapause that was anchoring at ~65° geomagnetic latitude (SAITO and YUMOTO, 1980).

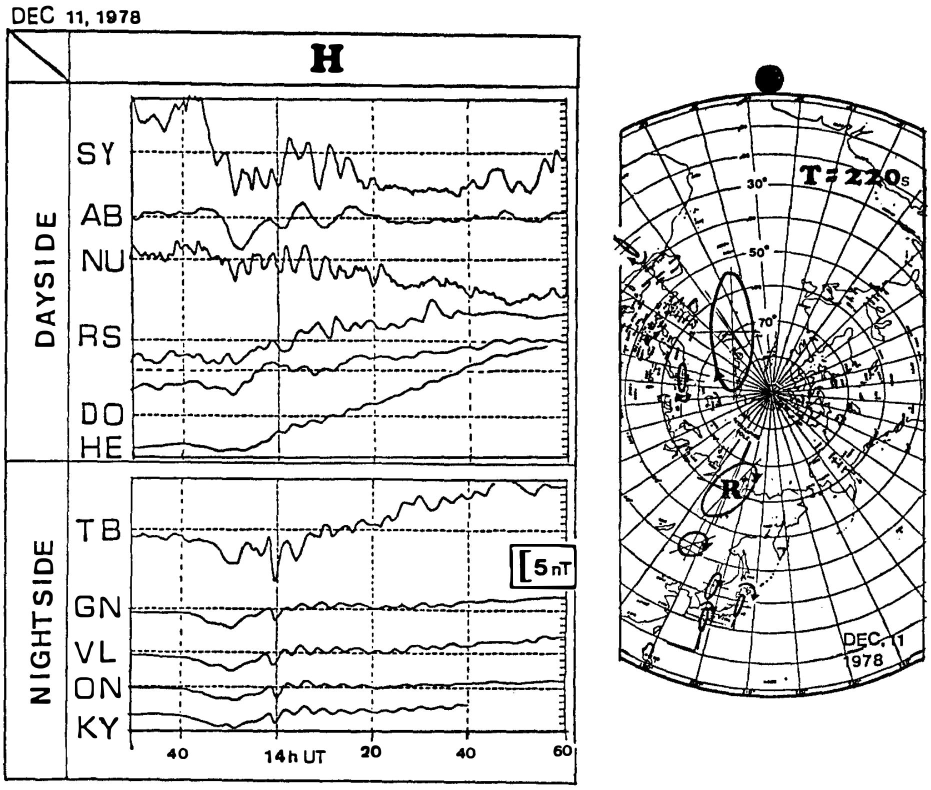

Fig. 4. Pi2 waveform recorded simultaneously at worldwide stations. Hodograms of Pi2 magnetic variations are illustrated in the right-side panel.

Although the tail-like configuration of magnetic field lines has been proposed to be collapsed and to form the dipole-like configuration in conjunction with a substorm onset, there is no definite study on how fast the collapse occurs. A detailed analysis by SAITO *et al.* (1979) of this particular mini-substorm event clarified that the tail-like configuration contracts the dipole-like one whose apex is at about $X = -9.2\ R_E$ within 230 s. One of the merits to study mini-substorms is that Pi2 pulsation can be analyzed by records of ordinary magnetometers which are much more widely distributed in the world than induction magnetometers, since Pi2 associated with mini-substorms has a sufficiently long period and is little transformed by steep bay disturbances. The Pi2 waves registered on ordinary magnetograms obtained at both dayside and nightside of the earth are reproduced by the program by IWABUCHI *et al.* (1978, 1979) and are shown in Fig. 4. The nightside Pi2 waves show a maximum in amplitude near the auroral oval and the gradual decay towards lower latitudes. On the other hand, the dayside magnetograms show that fairly large Pi2 waves were simultaneously observed. The present analysis indicates that an effect of the torsional oscillation of the field lines anchoring near the midnight auroral ovals is observed as Pi2 magnetic variations which has been regarded to be a night-time phenomenon even at day-side low-latitude stations. Although the worldwide propagation mechanism of the Pi2 wave is subject to a future clarification, this provides the first clear evidence that a Pi2 waveform is simultaneously detected widely in both dayside and nightside of the earth. Such a clear and simultaneous detection of Pi2 can be made only with Pi2 events associated with mini-substorms.

3. March 18, 1974 Event

GUPTA and NIBLETT (1979) reported a *spacequake* phenomenon which is a damped-type pulsation in the Pc5 period range that occurred on a magnetically quiet day of March 18, 1974. Although mechanism of this phenomenon was not proposed, this is quite likely to be a mini-substorm event because of the following evidences;

(1) It occurred during a period of quiet magnetic activity as shown in the bottom panel of Fig. 5.

(2) It occurred after a half day of the northward IMF.

(3) The AE index shows a small disturbance during the spacequake.

(4) An auroral photograph taken from DMSP satellite near the onset of this spacequake event, an auroral breakup signature is seen at high latitudes ($\Phi \sim 71°$).

Consequently, this Pc5-like phenomenon is inferred to be an extremely long-period Pi2 associated with a mini-substorm event, indicating that resonators for both Pc5 and Pi2 are similar field lines anchoring near the auroral oval, although the excitation mechanism of Pc5 is different from that Pi2.

This pulsative event had the primary amplitude maximum near 71°, which was very close to the auroral breakup position identified by the DMSP auroral photo-

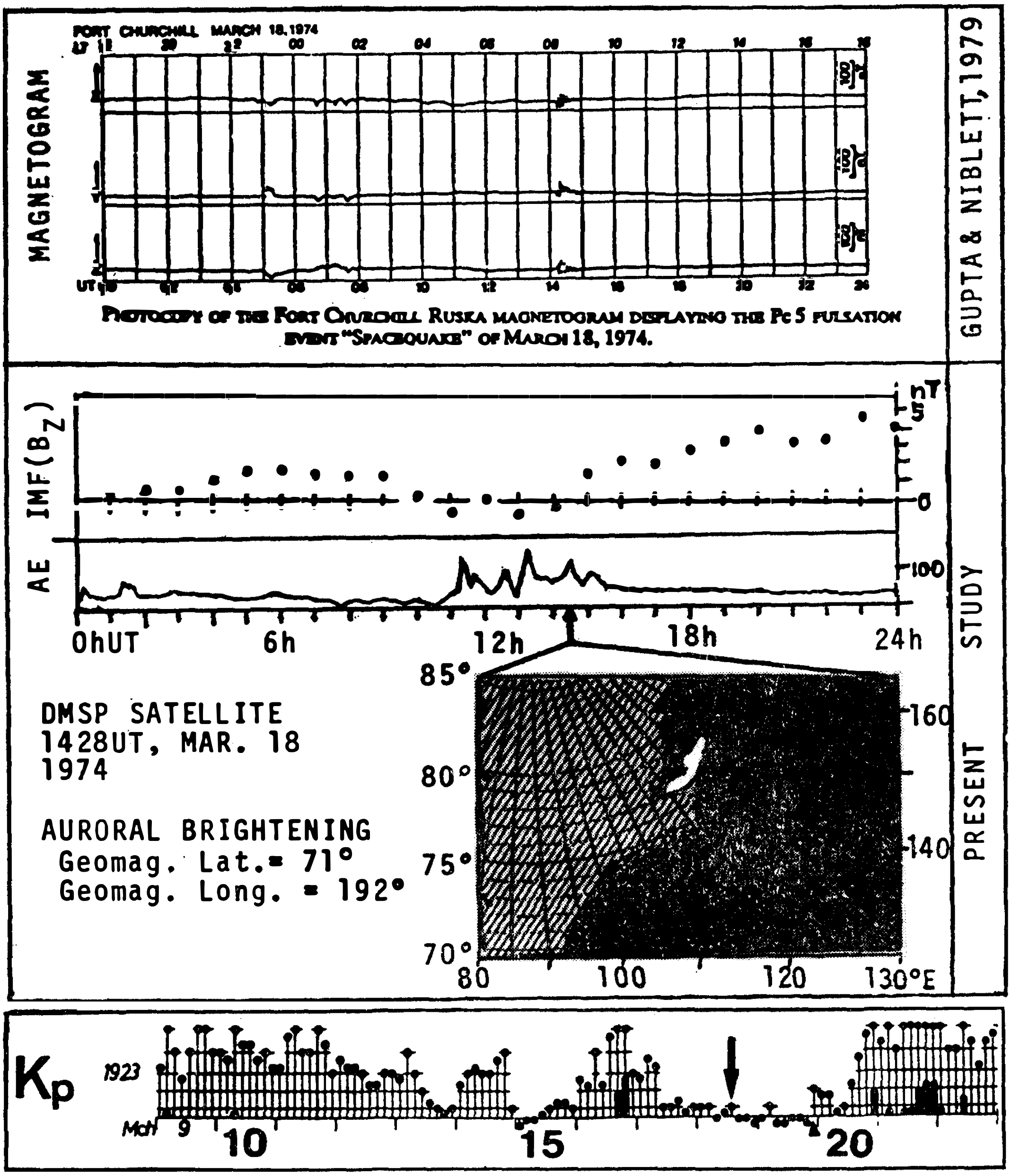

Fig. 5. Mini-substorm event observed on March 18, 1974. Upper panel shows "Spacequake" event suggested by GUPTA *and* NIBLETT *(1979). Middle panel shows the magnetic activity index and auroral photograph obtained by DMSP satellite. Bottom panel shows the magnetic index Kp.*

graph, and had another maximum near the dayside equator (see Fig. 4 of GUPTA and NIBLETT, 1979). It is important to study the propagation mechanism of Pi2 waves when the dayside equatorial enhancement can be decisively detected, that should throw light on the worldwide magnetosphere-ionosphere coupling system.

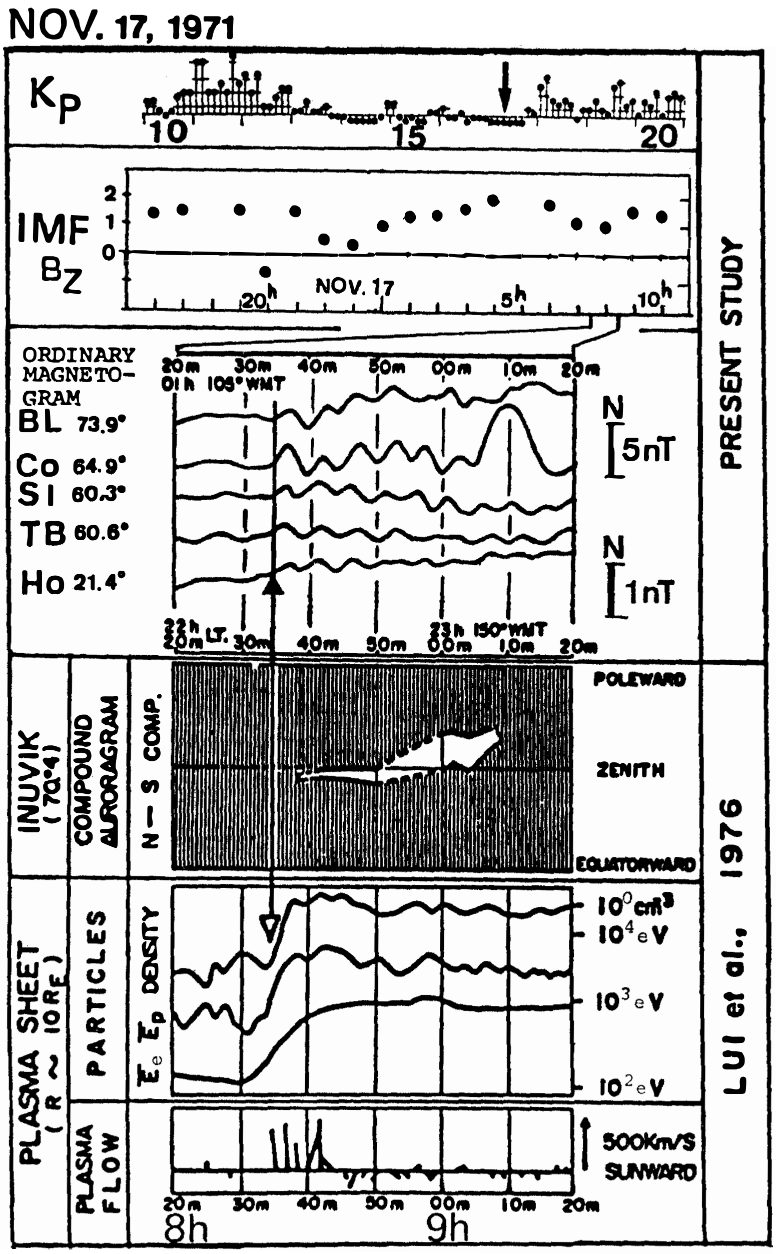

Fig. 6. Mini-substorm event observed on November 17, 1971. Upper to lower, magnetic index Kp, B_z component of IMF, ordinary magnetogram in midnight sector, auroragram at Inuvik, and plasma variation in the plasmasheet.

4. November 17, 1971 Event

SAITO (1977) found a typical long-period Pi2 wave occurred on November 17, 1971, at the same time as the onset of an auroral substorm along the contracted oval

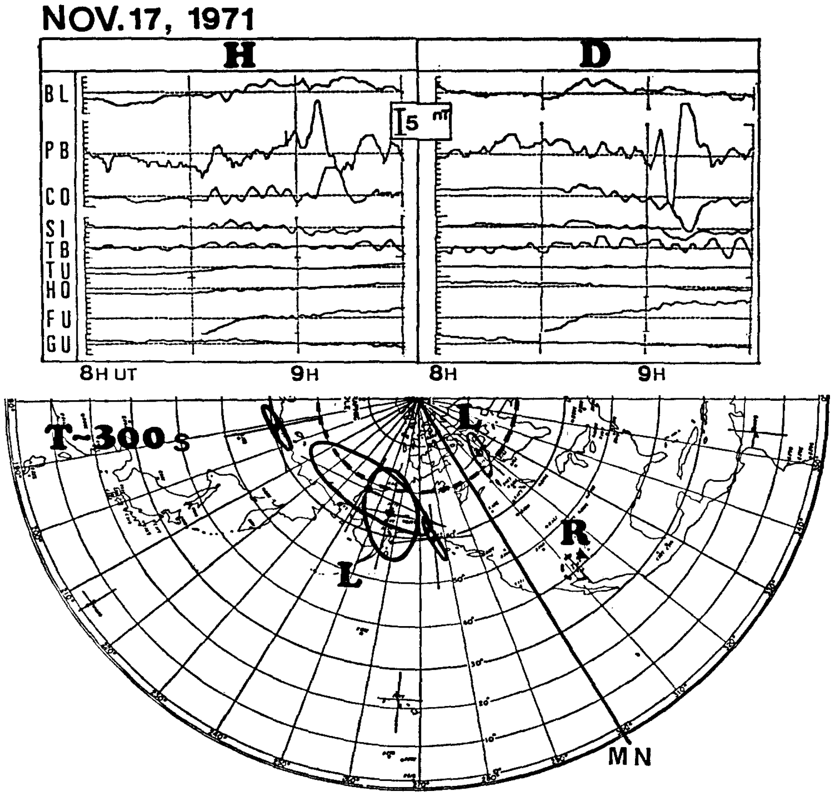

Fig. 7. Worldwide distribution of the Pi2 polarizations observed on November 17, 1971. Solid and broken lines indicate the demarcation lines.

that was identified by LUI *et al.* (1976). The event was associated with low *Kp*, the northward IMF, the typical auroral breakup at Inuvik at $\Phi=70.4°$, and an earthward plasma flow in the tail plasma sheet as shown in Fig. 6. Since the long-period Pi2 wave can be detected on ordinary magnetograms from high (Baker Lake) to low (Honolulu) latitudes, Pi2 hodographs can be drawn at each station as shown in Fig. 7. It is indicated that the waves with the 300-s period of the main spectral component have the polarization distribution with the two demarcation lines; the midnight meridian and the $\Phi \sim 70°$ circle which corresponds to the auroral breakup latitude. This sequential distribution is quite similar to the statistical distribution of the Pi2 polarization. Such a sequential study on the worldwide distribution of the Pi2 polarization is possible only by examining the long-period, Pi2 associated with mini-substorms as is analyzed in the present study, since we need not be bothered by the short-period Pi2 waves which can hardly be detected on normal-run magnetograms.

5. Conclusions

A sequential study has been made for the three Pi2 events associated with mini-substorms. The conclusions derived are as follows;

(1) The effect of the torsional oscillation of the field lines anchoring near the midnight auroral ovals is found to be observed worldwidely and sequentially, at day-side low-latitude stations.

(2) The dayside equatorial enhancement of Pi2 amplitude is also found to occur successively.

(3) Worldwide and sequential polarization distribution of Pi2 wave is found to be coincident with the statistical distribution.

These conclusions substantiate the model that Pi2 is a transient odd-mode torsional oscillation of night-side auroral field-lines (SAITO and YUMOTO, 1980) that is excited associated with auroral particle precipitation into the night-side ovals (AKASOFU, 1977). The worldwide propagation mechanisms of the Pi2 waves is subject to a future clarification.

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References

AKASOFU, S.-I. (1977): Physics of Magnetospheric Substorms. Dordrecht, D. Reidel, 599 p. (Astrophys. Space Sci. Lib., **47**).

AOYAMA, I., TOYAMA, F., TAKAHASHI, T., TONEGAWA, T., SAKURAI, T., SAITO, T. and YUMOTO, K. (1979): The field-aligned currents observed by "JIKIKEN". Japanese IMS Symp. Tokyo, Inst. Space Aeronaut. Sci., Univ. Tokyo, 126–132.

GUPTA, J. C. and NIBLETT, E. R. (1979): On the quiet-time Pc5 pulsation events (Spacequakes). Planet. Space Sci., **27**, 131–143.

IWABUCHI, M., FUJII, R. and UTSUMI, T. (1978): Conversational system of spectrum analysis by the use of graphic display. Nankyoku Shiryô (Antarct. Rec.), **62**, 29–70.

IWABUCHI, M., SATO, N. and FUKUNISHI, H. (1979): Application of conversational spectral analysis program (CSAP) system for magnetic pulsations observed at Mizuho and Syowa Stations. Nankyoku Shiryô (Antarct. Rec.), **64**, 111–126.

LUI, A. T., AKASOFU, S.-I., HONES, E. W., JR., BAME, S. J. and MCILWAIN, C. E. (1976): Observation of the plasma sheet during a contracted oval substorm in a prolonged quiet period. J. Geophys. Res., **81**, 1415–1419.

OYA, H. (1979): Summary on plasma wave emissions observed by Jikiken—Preliminary report for the initial phase of the observation results. Magnetospheric Study 1979. Tokyo, Japanese IMS Committee, 200–213.

SAITO, T. (1976): The HISSA (high-speed spectrum analysis) method to analyze various time-varying phenomena in space physics. Rep. Ionos. Space Res. Jpn, **30**, 3/4, 69–80.

SAITO, T. (1977): Study of mini-substorm as a suitable research theme during IMS. Japanese IMS Symp. Tokyo, Inst. Space Aeronaut. Sci., Univ. Tokyo, 203–212.

SAITO, T. (1978): Long-period irregular magnetic pulsation, Pi3. Space Sci. Rev., **21**, 427–467.

SAITO, T. (1979): Pi2-type pulsations associated with magnetospheric substorms. Magnetospheric Study 1979. Japanese IMS Committee, 104–114.

SAITO, T. and SAKURAI, T. (1970): Mechanism of geomagnetic Pi2 pulsations in magnetically quiet condition. Sci. Rep. Tohoku Univ., Ser. 5 (Geophys.), **20**, 49.

SAITO, T., SAKURAI, T., TAMURA, T. and YUMOTO, K. (1978): Magnetospheric disturbances and ULF —Hissagram and prediction of mini-substorm. Japanese IMS Symp. Tokyo, Inst. Space Aeronaut. Sci., Univ. Tokyo, 82–93.

SAITO, T., YUMOTO, K., AOYAMA, I., TOYAMA, F. and TAKAHASHI, T. (1979): Typical mini-substorm and long-period Pi2 event observed by the Jikiken satellite on December 11, 1978. Bull. Inst. Space Aeronaut. Sci., Univ. Tokyo, Spec. Vol. (Space Sci.), **15**, 3(B), 739–750.

SAITO, T. and YUMOTO, K. (1980): Examination of the odd mode model of Pi2 based on an analysis of ULF signals received at the Syowa Station. Nankyoku Shiryô (Antarct. Rec.), **68**, 276–281.

SAKURAI, T. and SAITO, T. (1976): Magnetic pulsation Pi2 and substorm onset. Planet. Space Sci., **24**, 573–575.

SAMSON, J. C. and OLSON, J. V. (1980): Data-adaptive polarization filters for multichannel geophysical data. to be published in Geophysics.

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