EFFECTS OF THE SUNRISE ON POLARIZATION CHARACTERISTICS OF LOW-LATITUDE Pc3-4 BAND MICROPULSATIONS

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Abstract: The sunrise effect for Pc3 and Pc4 bands was confirmed from the long-term continuous data obtained at Aso (22°N, 198° in geomagnetic coordinate) by an induction magnetometer. The D component of the pulsations increases with the sunrise. This D component increment causes the major axis rotation of the H-D plane ellipse, but hardly influences the ellipticity. This means that the D component increment is due to the ionospheric conductivity enhancement in association with the sunrise.

1. Introduction

The precise measurements of the geomagnetic micropulsations were initiated at Aso (22°N, 198° in geomagnetic coordinate) by setting up a SQUID magnetometer which was constructed in our laboratory (ISHIZU and KITAMURA, 1978). The early investigation of the data thus obtained led to a suggestion that the D component of the pulsations in the period range from 10 to 150 s (Pc3 and Pc4) increases with the sunrise (SAKA *et al.*, 1980). However, the amount of the data by the SQUID was much limited, because of the difficulty in long-term observations due mainly to the lack of the system for the continuous replenishment of the liquid helium, and so the final conclusion was left over until more data become available. Besides this sunrise effect, the pulsatons observed at Aso reveal a noticeable characteristic that the vertical component of the pulsations is much smaller in amplitude than the other components (see Fig. 1). This fact appears to imply that the total field at Aso represents the source field, namely, the horizontal component of the total field is simply twice in amplitude of that of the source field with no phase difference (PRICE, 1967). Because of this, the investigation of the data from Aso is thought to be convenient for understanding the behaviors of the low-latitude pulsations.

An induction magnetometer has thus been set up at Aso in November 1979, and the necessary amount of the data are becoming now available. The purpose of this paper is to confirm the sunrise effect from the long-term continuous data obtained by using the induction magnetometer and to investigate the effect of the sunrise on the polarization characteristics of the pulsations.

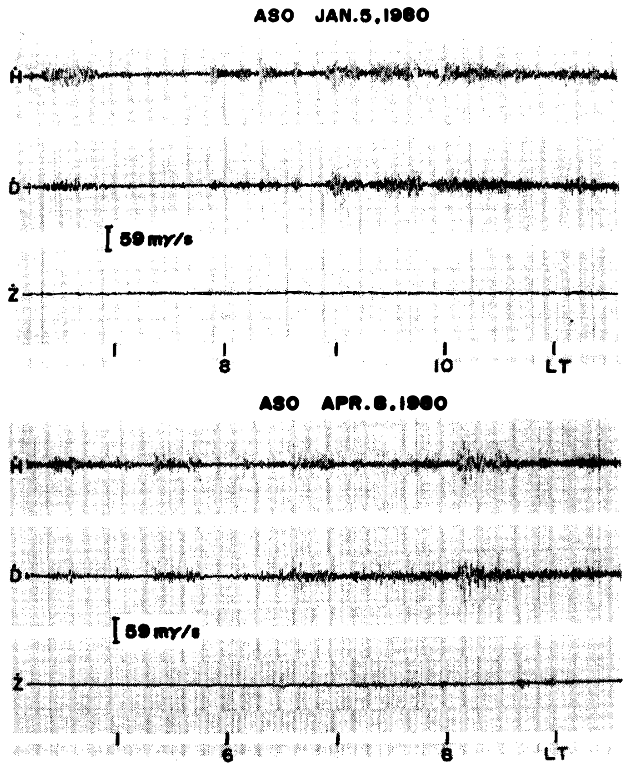

Fig. 1. *Typical examples of micropulsations. The data have been filtered in the 20–200 s period band. In the example of April 8, 1980, the spikes seen on the Z component are noises. Note that the Z (vertical) component are smaller in amplitude than the other components.*

2. Sunrise Effect

A simple method to confirm the sunrise effect is to identify the onset time of the D component increment of the pulsations by visual inspection of data and compare it with the ionospheric sounding data. Fig. 2 shows typical examples of band-pass filtered data (Pc3 band) at Aso. It is found in Fig. 2 that the amplitude of the D components increases at ~0830 LT (December 9, 1979), ~0820 LT (January 5, 1980), ~0615 LT (May 13, 1980) and ~0545 LT (June 9, 1980), respectively. For Pc4 band pulsations, typical examples are given in Fig. 3. It is also found in Fig. 3 that the amplitude of the D components increases at ~0825 LT (December 10, 1979), ~0900 LT (January 5, 1980), ~0600 LT (May 12, 1980) and ~0500 LT (June 8, 1980), respectively. It should be noted that the onset time of the D component increment in spring and summer is clearly ahead of that in winter.

Then we investigated the seasonal variation of the onset time of the D component increment in both the Pc3 and Pc4 band data obtained from November 1979 to July 1980 in comparison with the f_oE (ordinary wave critical frequency for the ionospheric

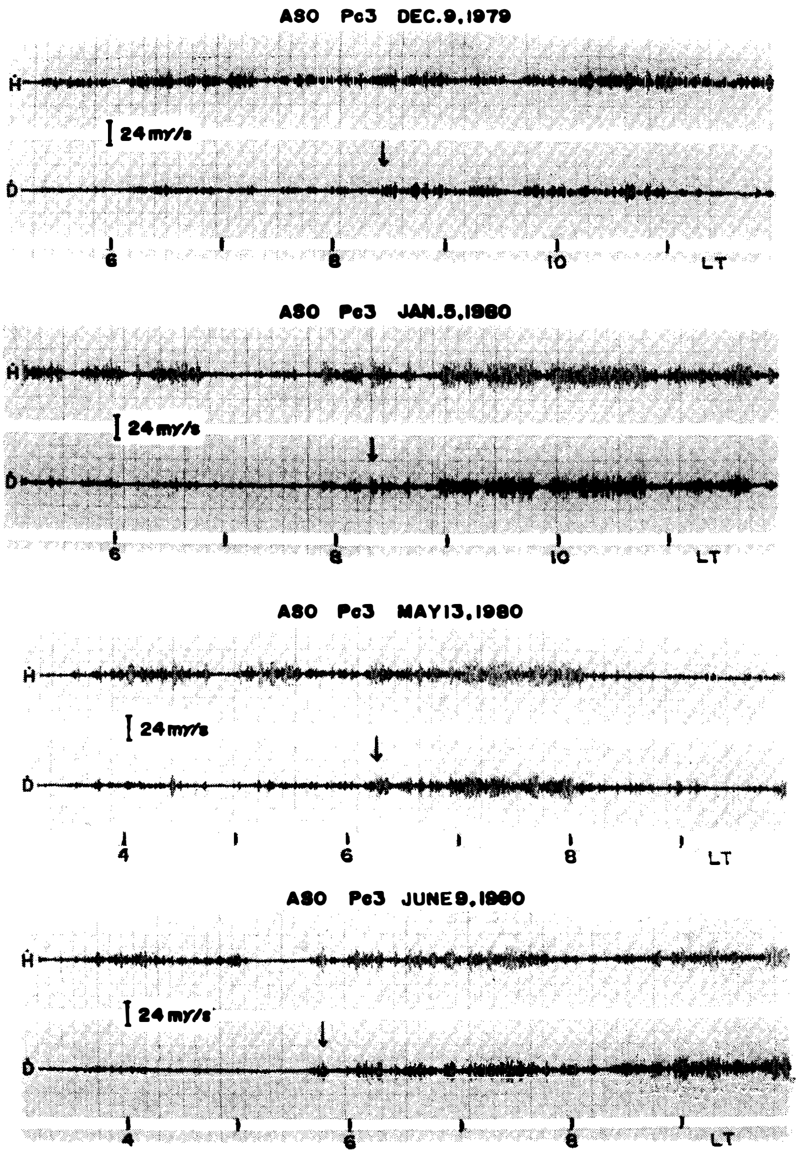

Fig. 2. Typical examples of Pc3 band data. The D components increase around the times designated by arrows.

E layer) data at Yamagawa (20.4°N, 198.3° in geomagnetic coordinate) (Fig. 4). The onset time of the D component increment is not always identifiable by visual inspection of data, and involves an error even if identifiable. Hence, it is indicated with an interval of one hour (vertical bar) in Fig. 4. The broken line in this figure indicates the time when the hourly value of f_0E starts daily to be tabulated at Yamagawa station, and it appears to tell an approximate time of the sunrise. With respect to the f_0E data from June to July, the data obtained in 1979 were used. From this figure it is found that the seasonal variation of the onset time of the D component increment

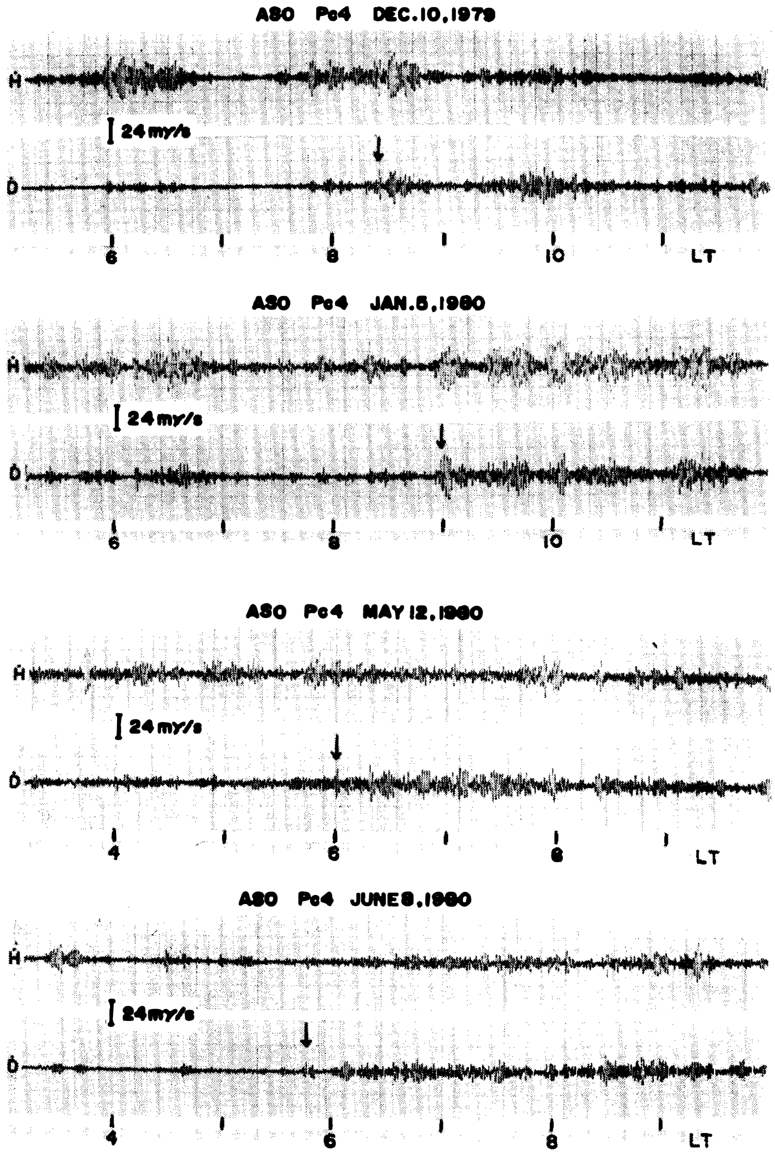

Fig. 3. Typical examples of Pc4 band data. The D components increase around the times designated by arrows.

is consistent with that of the sunrise. Therefore, it might be said that the D component increment in the morning is due to the ionospheric conductivity enhancement in association with the sunrise rather than the change of the source field in the magnetosphere.

3. Polarization Characteristics

In this section we will investigate the effect of the sunrise on the polarization

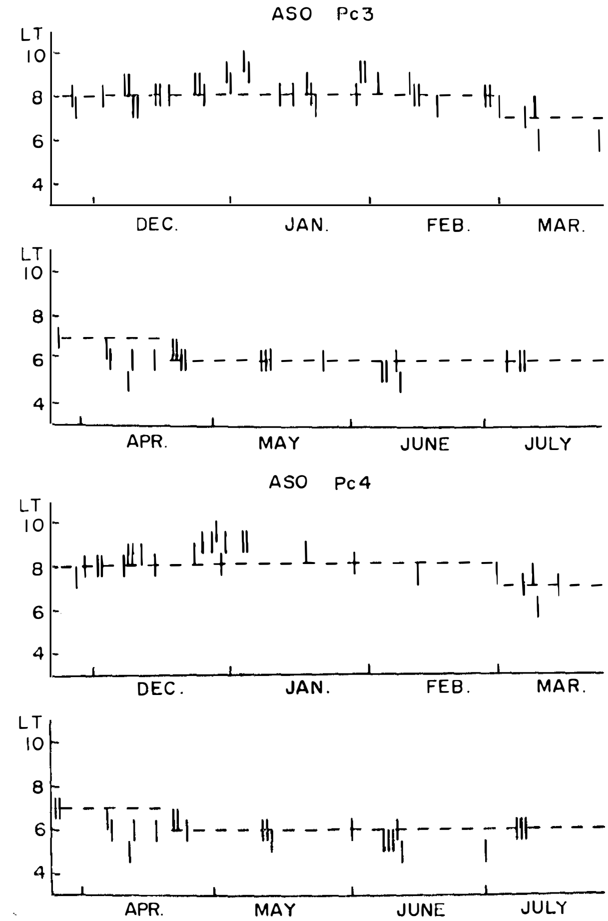

Fig. 4. Seasonal variation of the onset time of the D component increment for Pc3 (upper) and Pc4 (lower) bands. Since the identification of the onset time of the D component increment by visual inspection inevitably involves an error, the onset time is indicated with an interval of the hour (vertical bar). The broken line indicates the approximate time of the sunrise.

characteristics of the pulsations. Fig. 5 illustrates the computed results of Pc3 band during January 4–6 and June 9, 1980, and similarily Fig. 6 illustrates those of Pc4 band during January 4–6 and June 8, 1980. The orientation angle (θ) is defined as an angle between the major axis of the polarization ellipse in the H-D plane and the H axis, a positive (negative) angle corresponding to a northeast (northwest) direction. The ellipticity (ε) is defined as the ratio of the minor to the major axis of the H-D plane ellipse, a positive (negative) ellipticity corresponding to a counterclockwise (clockwise) sense when we look down the H-D plane. In Figs. 5 and 6 it is seen that the major axis of the H-D plane ellipse oriented almost in the north direction at night starts to rotate towards the west direction ($-\theta$) around 0800 LT in winter and 0600

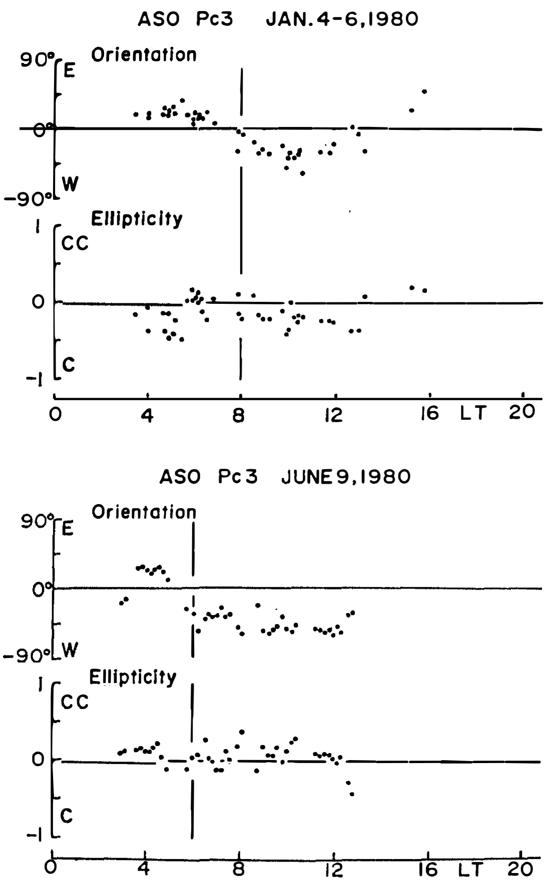

Fig. 5. *Orientation angle and ellipticity of the H-D plane ellipse for Pc3 band events during January 4–6 and June 9, 1980. The vertical line indicates the approximate time of the sunrise.*

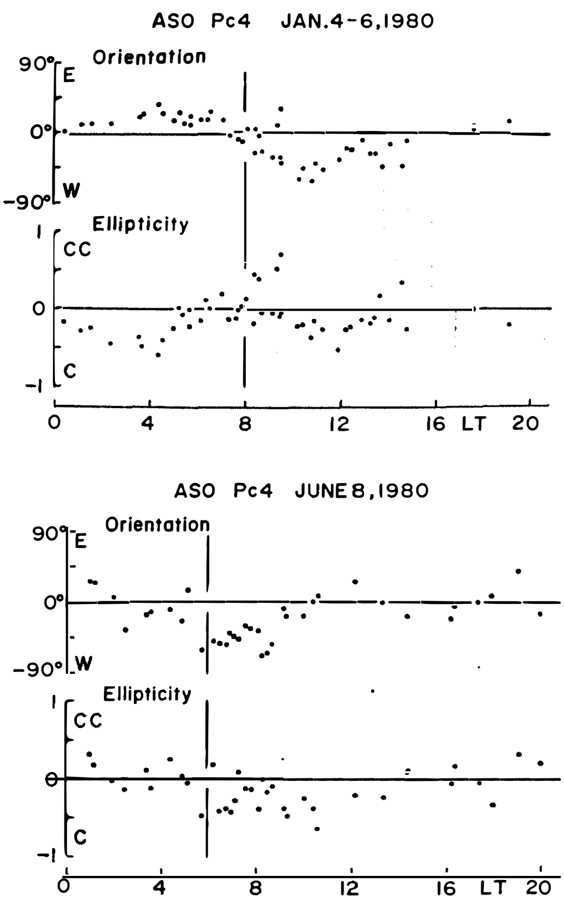

Fig. 6. *Orientation angle and ellipticity of the H-D plane ellipse for Pc4 band events during January 4–6 and June 8, 1980. The vertical line indicates the approximate time of the sunrise.*

LT in summer, namely, around sunrise. It is also seen that the ellipticity exhibits a less clear change before and after sunrise.

To confirm this statistically, the events from 00 LT to 12 LT were classified into two groups, before and after sunrise, and the distributions of the polarization parameters (θ and ε) for both groups were investigated (Figs. 7 and 8). The mean values of these parameters are listed in Table 1. From these histograms it is understood that the orientation angle exhibits a clear change before and after sunrise, while the ellipticity shows no clear change except that its distribution spreads slightly after sunrise. The *D* component increment associated with the sunrise thus causes the major axis rotation of the *H-D* plane ellipse, but hardly influences the ellipticity.

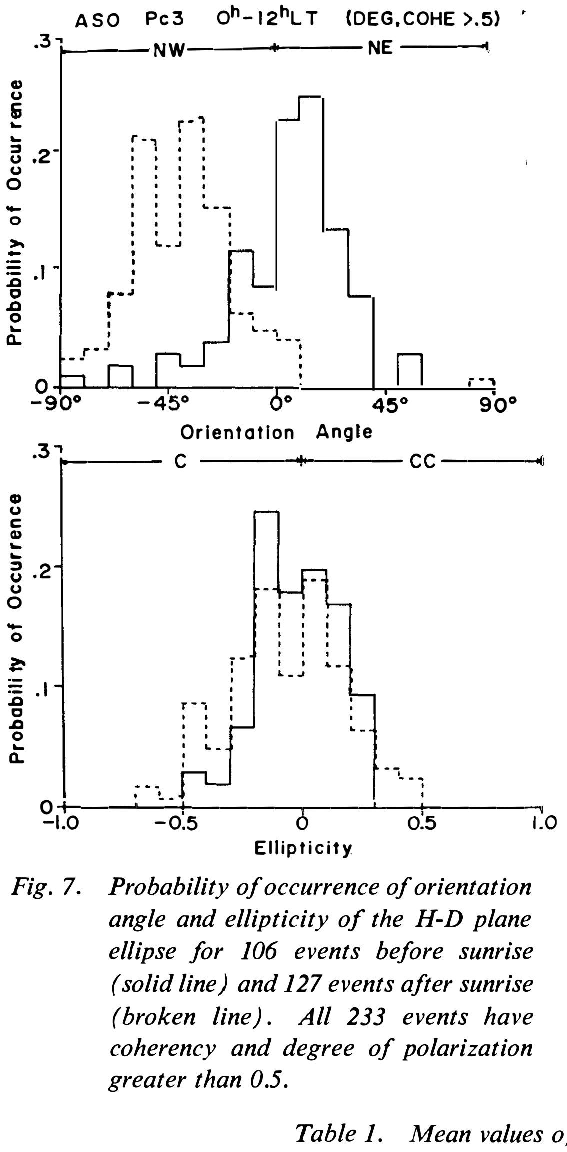

Fig. 7. Probability of occurrence of orientation angle and ellipticity of the H-D plane ellipse for 106 events before sunrise (solid line) and 127 events after sunrise (broken line). All 233 events have coherency and degree of polarization greater than 0.5.

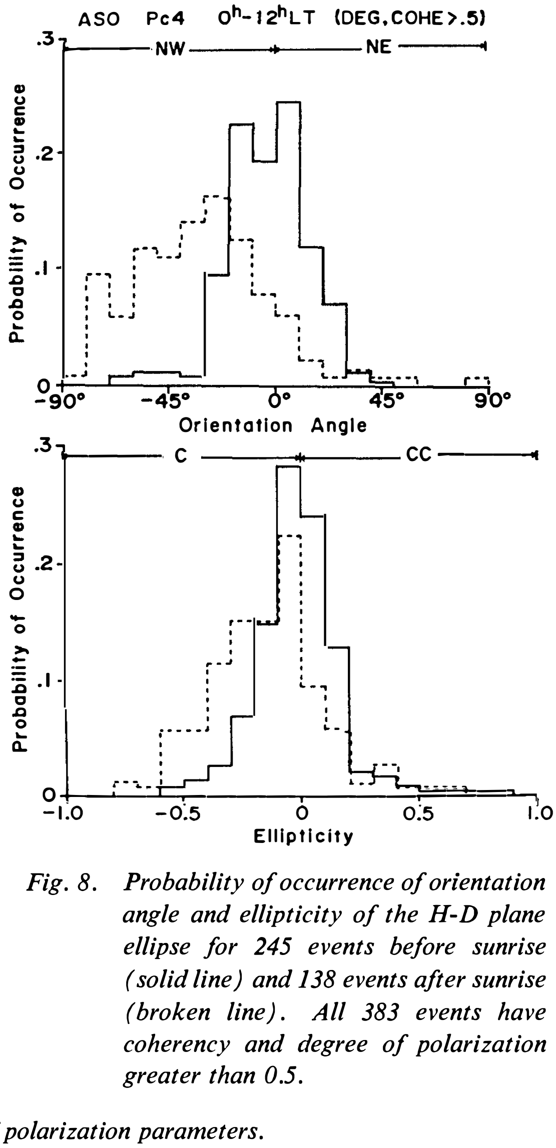

Fig. 8. Probability of occurrence of orientation angle and ellipticity of the H-D plane ellipse for 245 events before sunrise (solid line) and 138 events after sunrise (broken line). All 383 events have coherency and degree of polarization greater than 0.5.

Table 1. Mean values of polarization parameters.

Parameters	Before sunrise	After sunrise	Bands
θ	4.8°	−38.5°	Pc3
	−3.4°	−31.1°	Pc4
ε	−0.14	−0.20	Pc3
	−0.14	−0.23	Pc4

4. Discussion

The characteristics of the low-latitude geomagnetic micropulsations (Pc3 and Pc4) observed at Aso are summarized as follows.

1) The amplitude of the vertical component of the pulsations is much smaller than those of the other components.

2) The *H-D* plane ellipse is oriented almost in the north direction before sunrise. After sunrise the *D* component increases and the major axis of the *H-D* plane ellipse is tilted largely towards the west direction.

3) The ellipticity of the *H-D* plane ellipse exhibits no clear change before and after sunrise, and it remains relatively small throughout the periods of observations.

The first result implies that the total field at Aso represents the source field. This implication would be correct, unless the observations at Aso undergo effects of conductivity anomalies such as a coastline effect. The coastline effect propagates to a distance of the order of skin depth δ, which is defined as $\delta=(\rho T/\pi\mu)^{1/2}$ in MKSA units (RANKIN and REDDY, 1972). Skin depth δ is estimated to be $\sim$35 km for representative crustal value $\rho=100\ \Omega\cdot\text{m}$ and $T=50$ s. Since Aso is located $\sim$40 km away from the coastline, the observations are thought to be hardly affected by the coastline effect. Therefore, as far as there exists no higher conductor with a smaller scale under the ground at Aso, the above implication would be correct. However, if there exists a higher conductor with a smaller scale, another possibility may appear. In this case the vertical component of the total field may vanish on the ground, while the horizontal component of the total field may not necessarily become twice in amplitude of that of the source field with no phase difference (HUGHES, 1974). This problem can not be resolved by the present single-point observation. The multipoint observation covering wider areas including Aso will be necessary for defining the source field unambiguously from the ground observation.

The *D* component increment associated with the sunrise causes the major axis rotation of the *H-D* plane ellipse, but hardly influences the ellipticity. This can be explained qualitatively by the transmission model that the HM waves transmitted through the lower magnetosphere and the ionosphere will be observed as geomagnetic pulsations on the ground. Since the ionospheric Hall conductivity is relatively low before sunrise ($\sigma_H\sim10^{-6}$ S/m for the *E* layer), the coupling in the ionosphere between the toroidal and the poloidal modes by the Hall current is so weak that the source magnetic field incident from the magnetosphere, which is assumed to be a poloidal mode (*H* component), would be received on the ground without a significant modification by the ionosphere. After sunrise, however, the ionospheric Hall conductivity is appreciably high ($\sigma_H\sim10^{-4}$ S/m for the *E* layer). Then, the coupling in the ionosphere by the Hall current is so strong that the toroidal field (*D* component) comparable to the source poloidal field would be newly emitted from the ionosphere and received on the ground. The addition of the toroidal field causes the major axis rotation of the *H-D* plane ellipse, but hardly influences the ellipticity, because the ionosphere behaves as an anisotropic metallic medium for the long-period pulsations (Pc3 and Pc4) and the imaginary parts of the ionospheric conductivities (PEDERSEN and HALL) can be neglected (WATANABE, 1962; PRINCE and BOSTICK, 1964).

SAKA *et al.* (1980) explained in part this sunrise effect by presenting a simple model of direct transmission of HM waves through the lower magnetosphere. This simple model, however, failed to explain the large rotation of the major axis of the *H-D* plane ellipse. More theoretical works should be necessary for explaining quantitatively the sunrise effect.

Acknowledgments

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