Geomagnetic Pulsations at the Conjugate Stations during the March 9, 1997, Total Solar Eclipse

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Geomagnetic Pulsations at the Conjugate Stations during the March 9, 1997, Total Solar Eclipse

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Abstract

Pi 2 and Pc 4 geomagnetic pulsations were observed at Mohe (MOH, L=2.22), China, during the period of the total solar eclipse of March 9, 1997. Polarization analysis was performed on the pulsations with dominant frequencies in the 12.5-25 mHz range. We compared the pulsations observed at Mohe with those at Katanning (KAT, L=2.13), Australia, which is located near a magnetic conjugate point of Mohe. During the solar eclipse, the orientation of the polarization major axis changed at MOH, however, a similar variation was also observed at KAT. The results indicate that the solar eclipse effect is small for the magnetic pulsations in the 12.5-25 mHz frequency range.

1. Introduction

The effect of the solar eclipse on the geomagnetic pulsations has been studied since the beginning of the twentieth century. Y. KATO (1965) reported that the orientation of the polarization major axis of Pc 3 pulsations shifted during the solar eclipse, and they explained the result by a special ionospheric current system expected from the decrease of the electrical conductivity in the ionosphere during the solar eclipse. LANZEROTTI *et al* (1970) reported that there were no significant changes in the orientation of the major axis of the geomagnetic pulsations during the solar eclipse, which was consistent with the small E layer ionization changes measured at the same time. KATO and OKUDA (1956) also presented the decrease of pulsation amplitude during the solar eclipse. However, most of the results were obtained by the observation at one station near the solar eclipse region. Therefore, it has not been clear that these phenomena occurred locally under a condition of the solar eclipse.

We participated in the observations of the total solar eclipse at Mohe (MOH, L=2.22), China, on March 9, 1997. The solar eclipse effect on the magnetic field was surveyed by using a fluxgate magnetometer during the period of solar eclipse. Furthermore, data from the Circum-pan Pacific Magnetometer Network (CPMN) are used to investigate the spatial structure of the solar eclipse effect. The CPMN project is being conducted by Kyushu University since 1996 as a newly integrated network, which consists of the 210° MM Magnetometer Network (YUMOTO *et al.*, 1996) and the Equatorial Magnetometer Network (TACHIHARA *et al.*, 1996). Katanning (KAT, L=2.13), Australia, is particularly focused, because it is located near a magnetic conjugate point of Mohe. The data from another pair

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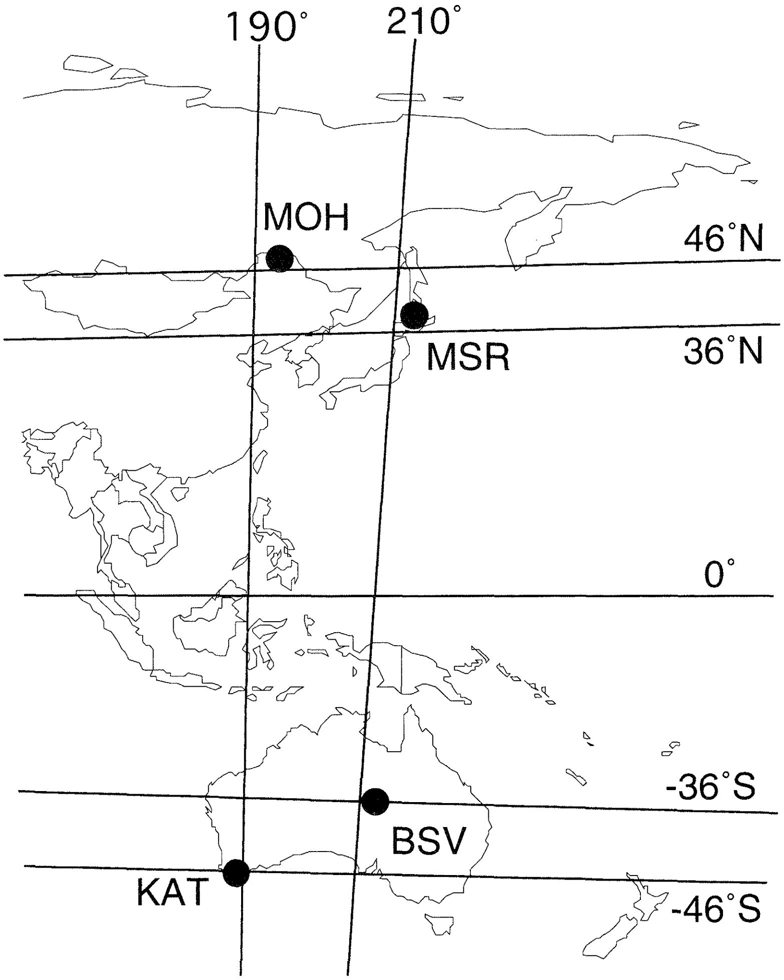

Fig 1. Station locations of Mohe (MOH), where the total solar eclipse occurred on March 9, 1997, and the Circum-pan Pacific Magnetometer Network array. The horizontal and vertical lines show the geomagnetic latitude and longitude, respectively. KAT is located near the magnetic conjugate point of MOH. MSR and BSV are another pair of magnetic conjugate stations.

of conjugate stations at lower latitude, Moshiri (MSR, $L=1.61$), Japan, and Birdsville (BSV, $L=1.56$), Australia, are analyzed to compare with results from a pair of MOH and KAT. The sampling times of magnetometers are 1 s at all the stations. The magnetometer digitization step is 0.037 nT at MOH and KAT, and 0.015 nT at MSR, BSV. The locations and coordinates of these stations are presented in Fig. 1 and Table 1.

Fig. 2 shows the daily variations of the H (top) and D (bottom) components of the magnetic field observed at these four stations on March 9, 1997. We define LT at MOH as UT + 8 hr. Vertical lines indicate the time interval of the solar eclipse observed at MOH. The magnetic activity of the day is relatively quiet ($Kp=-1\sim+2$). It should be noticed that large artificial noise can be seen at MSR. Fig. 3 shows the amplitude time records of

Table 1. Coordinates of stations.

Station Name	Abbreviation	Geographic Latitude	Geographic Longitude	Geomagnetic Latitude	Geomagnetic Longitude	L
Mohe	MOH	53.29	122.23	47.45	194.73	2.22
Moshiri	MSR	44.37	142.27	37.32	213.47	1.61
Birdsville	BSV	−25.54	139.21	−36.09	213.18	1.56
Katanning	KAT	−33.68	117.62	−46.37	188.44	2.13
Eusebio	EUS	− 3.85	−38.42	0.09	34.74	1.00

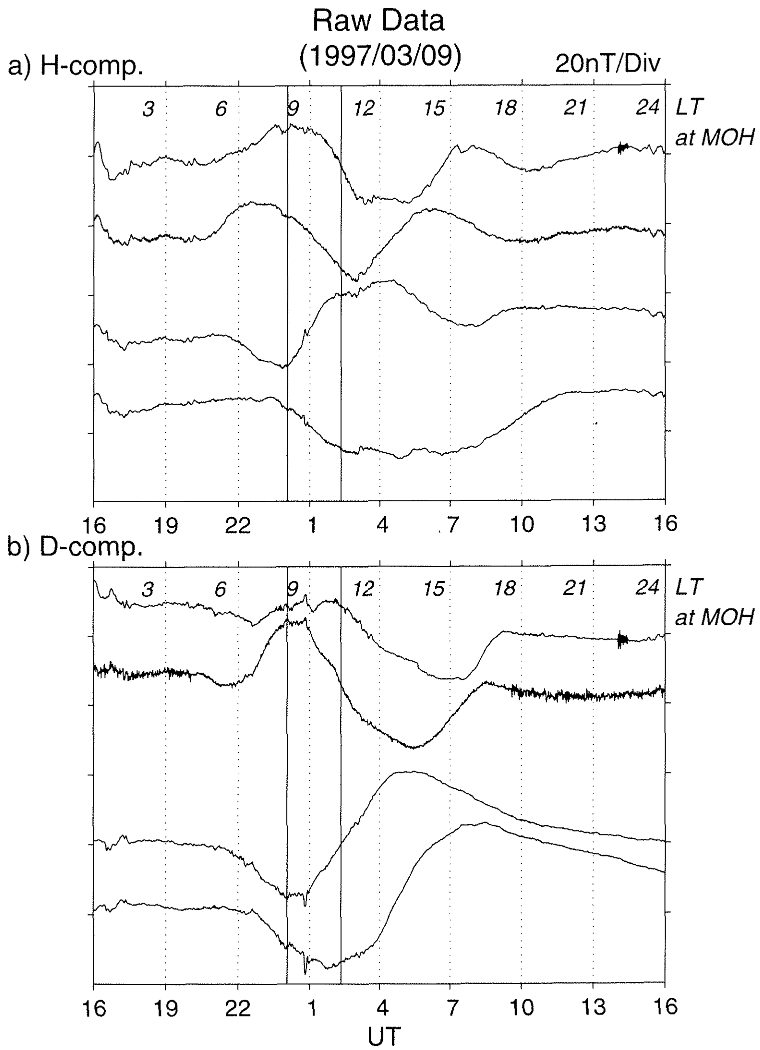

Fig 2. *H* (a) and *D* (b) component variations of magnetic field observed at MOH, MSR, BSV, and KAT. Vertical lines indicate a time interval of the solar eclipse observed at MOH.

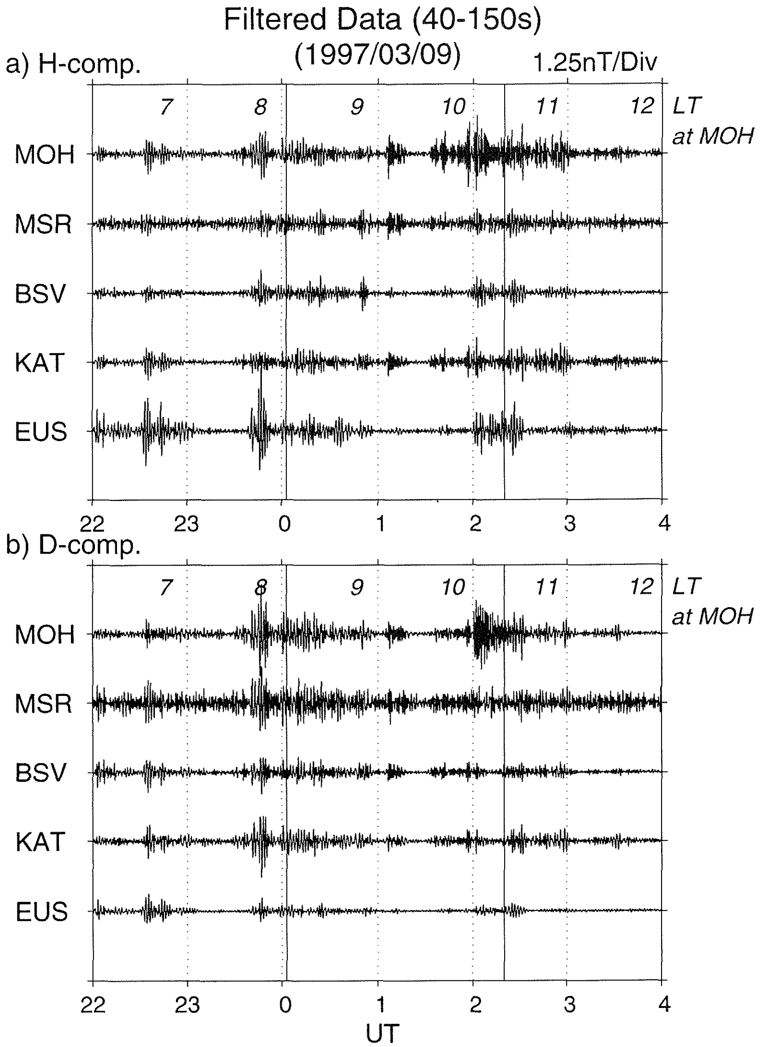

Fig 3. Band pass filtered (40 to 150 s) plots of the H (a) and D (b) components during the period from 0600 to 1200 LT. LT is defined as UT+8 hr at MOH. Eusebio (EUS), which is located on the dip equator around the midnight, is added to find Pi 2 pulsations related to the substorm onset. Vertical lines show a time interval of the solar eclipse observed at MOH.

band-pass filtered data (40-150s). In order to confirm that these pulsations were related to the substorm, we use data from Eusebio (EUS, $L=1.00$), Brazil, which is located on the dip equator around the local midnight (2130-2400 LT) during the period of the solar eclipse. By a visual scan of the filtered data, three Pi 2 events related to a substorm onset at 0630, 0735, and 1000 LT and three Pc 4 pulsations at 0905-0920, 0930-1000, and 1030-1130 LT were found. The event observed at 0800-0900 LT is Pi 2 and/or Pc 4 pulsation that may be related to the substorm. All the events are listed in the Table 2, together with their observation time, and dominant frequencies. In the next section, we investigate the behavior of these Pi 2 and Pc

Table 2. Geomagnetic pulsation events observed around the period of the total solar eclipse.

Event Number	Start Time	Pulsation Type	Dominant Frequencies
1	0630LT	$Pi2$	10,22mHz
2	0735LT	$Pi2$	9,22mHz
3	0800LT	$Pi2 or Pc4$	9,22mHz
4	0905LT	$Pc4$	17mHz
5	0930LT	$Pc4$	14mHz
6	1000LT	$Pi2$	?
7	1030LT	$Pc4$	12,20mHz

4 pulsations at the magnetic conjugate stations.

2. Polarization characteristics of Pi 2 and Pc 4 pulsations

We first calculated a power spectral density of the horizontal components by using the fast Fourier transform (FFT) method in order to determine the dominant frequencies of each event. Prior to the FFT analysis, the data were band-pass filtered in the 10-600 s period range and they were reduced to 3-second sampling (Nyquist frequency=167 mHz). A time window

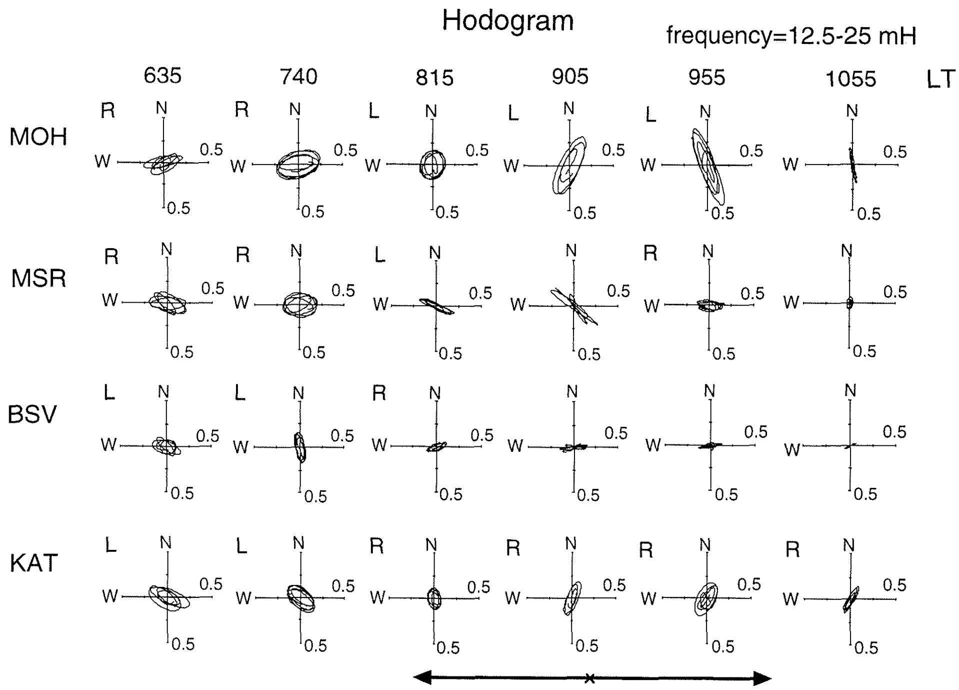

Fig 4. Hodograms in the H-D plane of the pulsations observed at four stations on March 9. R and L indicate right-handed and left-handed sense of polarization, respectively. Arrow at the bottom means the interval of the solar eclipse.

of 256 points (12.8 min) was shifted by 10 min, and the power spectral density was averaged over the duration of Pi 2 or Pc 4 pulsations. From the power spectral density, two main spectral peaks were found in many of the events; one is in the 12.5-25 mHz (T=40-80 s) frequency range and the other is in the 6.6-12.5 mHz (T=80-150 s) range. The dominant frequencies of each event are listed in Table 2. In particular, we focus on the 12.5-25 mHz frequency range, because the events cover the time interval around the totality of the solar eclipse.

Hodograms in the *H-D* plane at four stations are drawn in Fig. 4. Arrow at the bottom indicates the time interval of the solar eclipse from the first contact at 0803 LT to the last contact at 1019 LT. The middle eclipse (co-centers of the sun and moon) at 0910 LT is shown as cross (x). The notations, R and L, means right-hand and left-hand sense of polarization, respectively. The first thing to be noticed is that most of the events exhibit a mirror relation at the magnetic conjugate stations, MOH and KAT. Before the solar eclipse, the major axes of polarization are in the NE-SW quadrant at MOH and in the NW-SE quadrant at KAT. Their senses of polarization are right-handed in the northern hemisphere and left-handed in the southern hemisphere. The sense of polarization reverses in both hemispheres across 0800 LT (from R to L in the northern hemisphere and from L to R in the southern hemisphere). When the Pc 4 event started at 0930 LT, MOH showed a change of the orientation of the

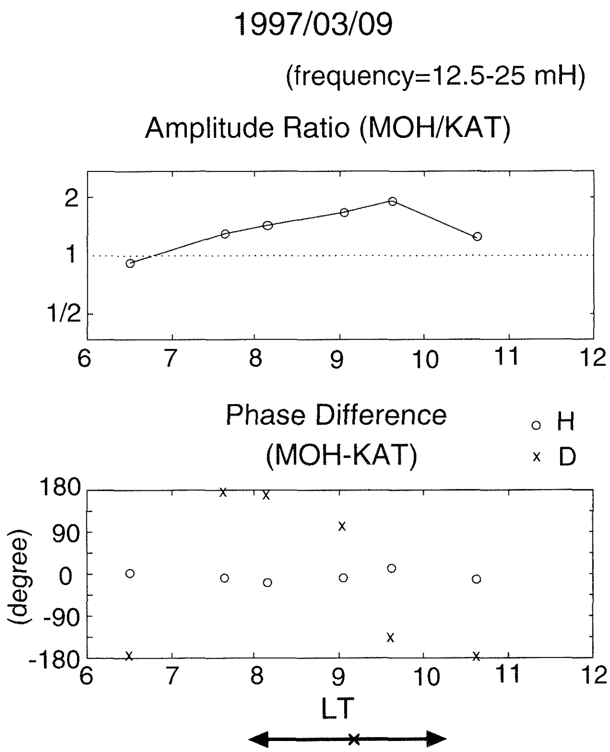

Fig 5. Top panel shows a time variation of the amplitude ratio (MOH /KAT) of the pulsations observed on March 9. Phase difference between MOH and KAT is presented in the bottom panel. A positive (negative) sign means that the signal at MOH leads (lags) that at KAT.

major axis from NE-SW to NW-SE, however, the mirror relation was kept between MOH and KAT. The mirror relation was broken only for the Pc 4 event at 0905 LT just before the totality of the solar eclipse. The hodograms of another pair of conjugate stations, MSR and BSV, also show the mirror relation even for the Pc 4 event at 0905 LT, however, MSR contains a large noise as seen in Fig. 3.

Top panel of Fig. 5 shows the amplitude ratio of Pi 2 and Pc 4 pulsations between MOH and KAT. The amplitude ratio was calculated as $\sqrt{P_{H+D}(\mathrm{MOH})/P_{H+D}(\mathrm{KAT})}$, where P_{H+D} denotes the sum of power spectral density of both the H and D components. The time interval of the solar eclipse is shown as the arrow again. With regard to Pi 2 pulsations observed at 0630 LT near sunrise, the amplitude ratio is nearly 1. After the sunrise, the amplitude ratio gradually increases until 0940 LT, when the amplitude ratio is maximum (1.92). After the solar eclipse finished, the amplitude ratio decreased to 1.25 at 1030 LT. Phase difference of the H and D components between MOH and KAT is presented in the bottom panel of Fig. 5. A positive (negative) sign means that the signal at MOH leads (lags) that at KAT. All events show an in-phase relation in the H component and an out-of-phase relation in the D component, except for the Pc 4 pulsation observed at 0905 LT just before the totality of the solar eclipse. The 90° phase difference in the D component at 0905 LT corresponds to the destruction of the mirror relation between MOH and KAT.

We also analyzed the events that have dominant frequencies in the 6.6-12.5 mHz (T=

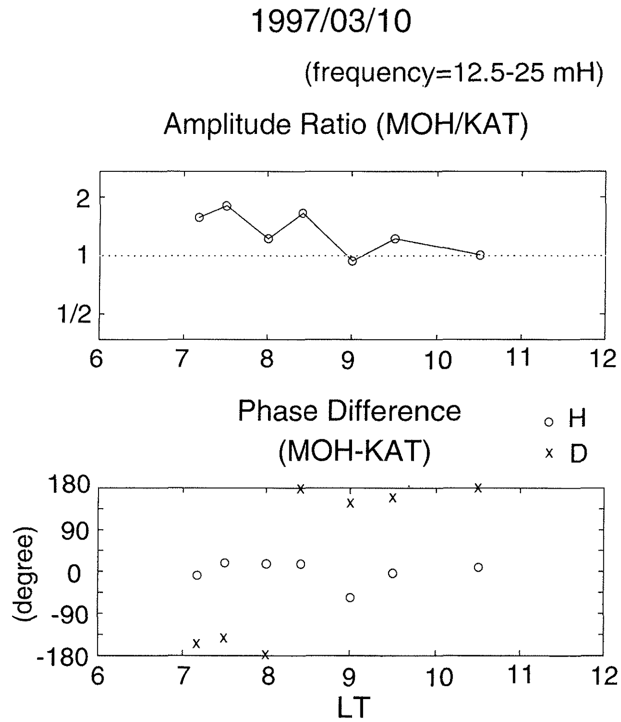

Fig 6. Time variation of the amplitude ratio (top) and phase difference (bottom) between MOH and KAT, with respect to Pc3 pulsations observed on March 10.

80-150 s) range. The results are not displayed here, because there is no events in this frequency range during the period of the solar eclipse. Furthermore, we analyzed the data obtained on March 10 to identify if the results were caused by the solar eclipse effect or not. Fig. 6 shows the amplitude ratio and phase difference between MOH and KAT, with respect to Pc 3 pulsations observed on March 10. The amplitude ratio shown in the top panel is equal to or larger than 1 in the interval from 0700 to 1030 LT, which is similar to Fig. 5. For the phase difference in the bottom panel, in-phase relation of the H component and out of phase relation of the D component indicate the mirror relation between MOH and KAT.

3. Summary and Discussion

The major results can be summarized as follows :

1, The dayside Pi 2 and Pc 4 pulsations were observed prior to and during the period of the solar eclipse on March 9, 1997.

2, All the events showed a mirror relation between the magnetic conjugate stations, MOH and KAT, except for one event. The mirror relation was broken only for the Pc 4 event at 0905 LT just before the totality of the solar eclipse.

3, The amplitude of the pulsations at MOH was larger than that at KAT during the solar eclipse. A similar tendency was also seen on March 10.

Under the condition of the solar eclipse, the electrical conductivity of the ionosphere is expected to change because of the decrease of the ionization in the E layer. RAMASASTRY and SCHMIDT (1970), and KLOBUCHAR and MALIK (1970) reported that the decrease in total ionosphere electron content during the eclipse was approximately a factor of 3. The change of the electrical conductivity affects an ionospheric current system of the geomagnetic pulsations (Y. KATO, 1963). Therefore, the orientation of the major axis of polarization can change during the period of the solar eclipse. The major axis and sense of polarization apparently varied at MOH during the solar eclipse (Fig. 4). However, the variation was also recognized at the magnetic conjugate station, KAT. YUMOTO *et al*. (1988) reported that the low-latitude Pc 3 pulsations show the mirror relation between the magnetic conjugate stations, and their major axis orientations change abruptly across the local noon. Therefore, the change of the major axis orientation during the period of the solar eclipse can be interpreted as the local time variation that occurred independently of the solar eclipse. The destruction of the mirror relation occurred only for one case of Pc 4 event detected just before the totality of the solar eclipse. It is not clear whether it was caused by ionospheric conductivity effect.

The result 3 may be related to the decrease of the conductivity of the ionosphere during the period of solar eclipse. The decrease of the conductivity weakens the shielding effect of the ionosphere, so the large energy of pulsations coming from the magnetosphere can penetrate through the ionosphere. However, it must be noted that the events consist of two kinds of pulsations. Pc 4 pulsations are generally believed to be standing Alfvén mode waves excited by the field line resonance, so the pulsations should have larger amplitudes at MOH during the period of the solar eclipse due to the weaker shielding effect of the ionosphere. This idea is consistent with the result 3. On the other hand, there are some explanations for the dayside Pi 2 pulsations at low latitudes, including an instantaneous horizontal transmission of electromagnetic signals from the nightside ionosphere (S. FUJITA, personal communication, 1998). At present, it is not clear how the decrease of the electrical conductivity of the ionosphere at the solar eclipse point affects on the amplitude of Pi 2 pulsations.

However, a similar amplitude ratio was seen on March 10, 1997. Thus, we conclude that the effect of the solar eclipse on the amplitude of pulsations is quite small. Recently, computations of northern/southern asymmetry of Pc 3-5 pulsations were performed by YOSHIKAWA (1997). He shows that the amplitude of the pulsations with the period of 50 s is larger in the northern hemisphere than in the southern hemisphere in the vernal equinox. This result is caused by the fact that the intensity of the ambient magnetic field is smaller in the northern hemisphere than in the southern hemisphere. We speculate that the larger amplitude at MOH attributes to the northern/southern asymmetry of pulsations. A statistical analysis of the data obtained at $L\sim2$ is needed to confirm the northern/southern asymmetry.

Acknowledgments

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