Techniques to Investigate the ionospheric effect ON ULF WAVES

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ABSTRACT

New techniques are introduced to investigate the ionospheric effect on Pc 3-5 pulsations. One technique is to calculate the power ratio of the pulsations observed at high-latitude geomagnetic conjugate stations. The other is to extract the daily variation in amplitude of the pulsations from the geomagnetic data observed at three coordinated sites. Using these techniques, we found that Pc 3-5 amplitudes on the ground are relatively small as a consequence of the highly-conducting ionosphere (in the summer hemisphere and around local noon). These techniques are also found to be useful in order to understand aspects of magnetosphere-ionosphere coupling processes.

1. INTRODUCTION

Pc 3-5 magnetic pulsations are ultra-low-frequency (ULF) hydro-magnetic waves generated in the dayside magnetosphere, where the amplitudes detected on the ground are modified by ionospheric conditions resulting from various physical processes. For example, ionospheric conductivities change the amplitude and phase structure of standing waves along the magnetic field line [1][2]. The relation between magnetic perturbations above the ionosphere and those on the ground can be expressed as a function of ionospheric conductivity [e.g., 3]. However, the effect of ionospheric conditions on Pc 3-5 pulsations characteristics have not yet been clarified observationally. The estimation of ionospheric effects on magnetic pulsation characteristics is important in order to improve our understanding of magnetosphere-ionosphere coupling processes.

Conjugate observations provide an advantage in estimating any ionospheric effects, since conjugate observations make it possible to examine the oscillations simultaneously at both ends of a magnetic field line. In this paper, we will discuss two analysis methods and use their results to investigate Pc 3-5 amplitudes of geomagnetic variations observed on the ground. Three stations were selected from the Circum-pan Pacific Magnetometer Network (CPMN) [4]: Kotzebue (KOT) in Alaska (the geographic latitude, longitude, the geomagnetic latitude, longitude, and L-value are 66.88˚, -162.60˚, 64.50˚, 249.82˚, and 5.40, respectively), Macquarie Island (MCQ) in Australia (-54.50˚, 158.95˚, -64.49˚, 248.07˚, 5.40), and Chokurdakh (CHD) in Russia (70.62˚, 147.89˚, 64.67˚, 212.12˚, 5.46). KOT and MCQ are geomagnetic conjugate stations with local time (LT) and magnetic local time (MLT) differences of 2.5 and 0.4 hours respectively whereas KOT and CHD are located at approximately same geomagnetic latitude with LT and MLT differences of 2.3 and 2.5 hour respectively.

One technique is to calculate of power ratio of Pc 3-5 pulsations observed simultaneously at the conjugate stations. The other technique is to extract the daily variation component of Pc 4 amplitude using the difference in LT between the three stations. These techniques allow us to extract the ionospheric effect on Pc 3-5 amplitudes from geomagnetic data observed at the three coordinated magnetometer sites.

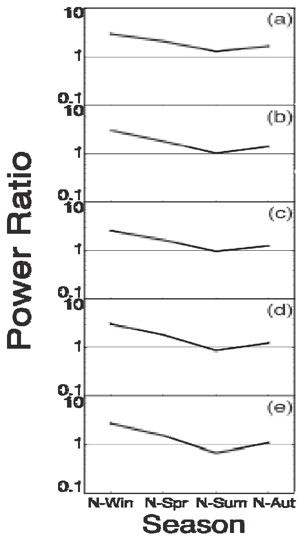

Fig. 1. The seasonal dependence of the power ratio between KOT and MCQ in the frequency bands of 1-6 mHz (a), 6-10 mHz (b), 10-20 mHz (c), 35-45 mHz (d), and 50-60 mHz (e). They are calculated from data observed during the interval 2330-0030 UT. Horizontal axes indicate season. Vertical axes represent the power ratio, where positive values correspond to higher power in the northern hemisphere.

2. NORTH-SOUTH HEMISPHERE ASYMMETRY OF PC 3-5 POWER

In this section, we examine characteristics of the north-south hemisphere asymmetry of Pc 3-5 pulsations in the five frequency bands (1-6, 6-10, 10-20, 35-45, and 50-60 mHz). The data used here are the H-component (projection of the background magnetic field onto the horizontal plane) of geomagnetic data observed at KOT and MCQ during the period from 20 November 1993 to 29 September 1994. Coherence and power ratio of the ULF waves were calculated from fast-Fourier-transform (FFT) analysis in order to identify Pc 3-5 pulsations simultaneously generated at the conjugate stations. The window widths of FFT are 1024 s and 512 s for the 1-6 mHz and for the other frequency bands, respectively. Power spectral density and coherence of a event are calculated by averaging over five time windows. The overall sizes of the time window are 1824 s for the 1-6 mHz and 912 s for the other frequency bands. We selected events with a coherence greater than 0.7 between KOT and MCQ. The power ratios were averaged for the five frequency bands.

The seasonal variations of the power ratio for the five frequency bands are plotted from the top to bottom panel of Figure 1. The vertical and the horizontal axes show the power ratio and season, respectively. Shown are average values of the power ratio observed during the interval 2300-0030 UT (around local noon). They were calculated from at least 176 events. From the results shown in the Figure 1, two aspects of the power ratio are evident. The first is a distinct "seasonal variation" of the power ratio. For all the frequency bands, the power ratio shows a maximum in the northern winter and a minimum in the northern summer. This tendency is noticeable in the higher frequency bands. We interpret this to mean that Pc 3-5 power observed in the summer hemisphere becomes relatively smaller than that simultaneously observed in the winter hemisphere. The second effect is the "positive offset" of the power ratio. The seasonal variation of the power ratio shows a north-south hemisphere asymmetry. In the frequency band of 1-6 mHz, the power ratio remains positive for all seasons. For the higher frequency bands, absolute values of the power ratio for the northern summer are smaller than those for the northern winter. Such behavior leads to the conclusion that the power ratio has a positive offset, which is larger in the lower frequency bands.

The "seasonal variation" may imply that incident magnetohydrodynamic (MHD) waves from the magnetosphere are shielded by the highly-conducting summer ionosphere. The "positive offset" may reflect a difference in the background at the conjugate stations (e.g., background magnetic field intensity, geographic latitude, and electric conductivities of the Earth's interior).

3. SEPARATION OF LOCAL TIME EFFECT

The results presented in the previous section imply that Pc 3-5 pulsations observed in the summer hemisphere are attenuated when passing through the highly-conducting ionosphere. If the shielding effect exists, it may also cause the daily variation of Pc 3-5 amplitude to have a minimum around local noon. In this section, we examine the daily variation of ULF amplitude in the Pc 4 frequency band. We utilise a new technique to separate several factors that control ULF amplitudes observed on the ground. A significant advantage of the technique is that both LT and MLT dependencies are estimated separately. The H-component of the geomagnetic field observed at KOT, MCQ, and CHD during the interval 13-14 March 1994 were used.

3.1. Scheme of the analysis

We assumed that the Pc 4 amplitude on the ground (A) can be expressed by

$$A = BF(MLT)\,f(LT)\,\sigma \,, \qquad (1)$$

where, B, F(MLT), f(LT), and σ are; the amplitude of source wave, the MLT dependence of wave amplitude in the magnetosphere, a function of ionospheric conductivity at the LT of a station, and an amplification factor for each station, respectively. During equinox the north-south hemisphere asymmetry of ionospheric conductivity is very small, so Pc 4 pulsation observed at the three stations would share a common f(LT) value.

First, we used the geomagnetic data observed at the geomagnetic conjugate stations. Because the difference of MLT between the conjugate stations can be negligible, amplitude ratio is given by

$$\frac{A_{KOT}}{A_{MCQ}} \approx \frac{f(LT_{KOT})\sigma_{KOT}}{f(LT_{MCQ})\sigma_{MCQ}} \,, \qquad (2)$$

and f(LT) and σ can be calculated statistically. Whereas, the difference in MLT is finite between non-conjugate pairs. Thus, the amplitude ratio normalized by f(LT) is given by

$$\frac{A_{KOT} / f(LT_{KOT})}{A_{CHD} / f(LT_{CHD})} = \frac{F(MLT_{KOT})\sigma_{KOT}}{F(MLT_{CHD})\sigma_{CHD}} \,, \qquad (3)$$

where, F(MLT) can be calculated statistically.

3.2. Analysis

In order to separate several factors of Pc 4 amplitude, we calculated power spectral density of the H-component geomagnetic data observed at KOT, MCQ, and CHD by using FFT. The window width and time resolution of the FFT is 512 s and 200 s, respectively. The data observed during the interval from 1200 UT on 13 to 1200 UT on 14 March 1994 were selected, because in this interval, dominant Pc 4 pulsations were continuously observed in the dayside. A total of 228 events were selected according to the following criteria: 1) Average power in the Pc 4 frequency band (6.66-22.2 mHz) at each stations keeps more than 1.0 nT^2/Hz; and 2) In order to exclude Pi 2 events, events observed in the time zone for any of the stations located in 1900-0300 LT (0554-1754 UT) were not selected. We then calculated f(LT), F(MLT), and σ using the statistical method proposed by [5] and equations 2 and 3.

Figure 2 shows LT dependence of f(LT) of Pc 4 H-component amplitude. The horizontal axis indicates local time at the station. The f(LT) versus LT U-shape curve shows that Pc 4 amplitude around local noon is approximately 35% attenuated in comparison with that in the morning and evening. This appears to reveal that incident MHD waves from the magnetosphere are shielded by the highly-conducting ionosphere around noon. This characteristic for Pc 4 amplitude is consistent with the results given in section 2.

Figure 3 shows the MLT dependence of F(MLT) for H-component Pc 4 amplitude. The horizontal axis shows magnetic local time of the station. F(MLT) has a large maximum around 0730 MLT. This means that Pc 4 amplitude around

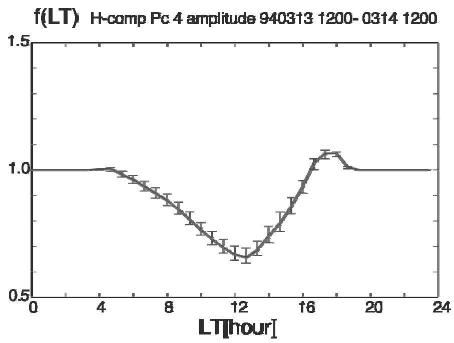

Fig. 2. The f(LT) dependence for H-component Pc 4 pulsation power versus LT. Error bars represent ranges of the standard deviations.

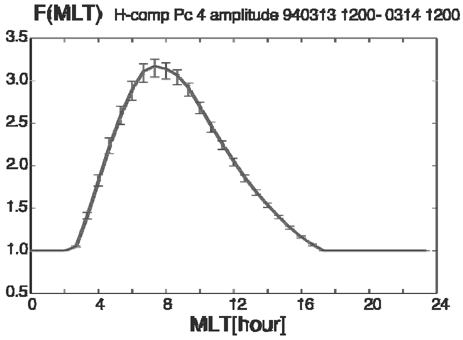

Fig. 3. The F(MLT) dependence for H-component Pc 4 pulsation power versus MLT. Error bars show ranges of the standard deviations.

0730 MLT become 3.2 times larger than that in the morning and evening. This appears to reflect the spatial distribution of the amplitudes of source waves in the magnetosphere.

We set σ = 1 at CHD and then determined the amplification factors for Pc 4 amplitude at KOT and MCQ to be 1.88 and 1.11, respectively (Not shown).

It is noteworthy that f(LT) as shown in the Figure 2 and F(MLT) as shown in the Figure 3 have very different daily variations. This implies that they indicate different physical processes.

4. SUMMARY AND CONCLUSION

In this paper, new techniques were proposed to extract the ionospheric effect on Pc 3-5 amplitudes. First, we calculated H-component power ratio of Pc 3-5 pulsations simultaneously observed at the geomagnetic conjugate stations, KOT and MCQ. The result shows that Pc 3-5 power observed in the summer hemisphere becomes relatively smaller than that simultaneously observed in the winter hemisphere. Second, we extracted several factors controlling Pc 4 amplitudes from the H-component of geomagnetic data observed at three coordinated sites including the conjugate stations. We found that the LT dependence of Pc 4 amplitude has a minimum around local noon. The reported attenuation of Pc 3-5 pulsations through the highly-conducting ionosphere is consistent with earlier studies [e.g., 6]. Verö and Menk found the amplitude of Pc 3, 4 pulsations at mid-latitude stations were attenuated by up to 30 % on days when the peak value of foF2 exceeded approximately 11 Mhz. The attenuation of Pc 3-5 pulsations in the highly-conducting ionosphere would be explained by inductive shielding effects associated with the divergent Hall current in the ionosphere [e.g. 7]. In this paper, f(LT) and F(MLT) were calculated for only one day to show that the technique is working. We have to confirm by further analysis, whether the daily variation patterns of f(LT) and F(MLT) shown in Figures 2 and 3 are typical or not. Analysis of Pc 3-5 pulsations from conjugate observations will have much potential for understanding aspects of magnetosphere-ionosphere coupling processes.

5. REFERENCES

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