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DIURNAL PHASE AND AMPLITUDE VARIATIONS OF 12.1 kHz OMEGA SIGNAL ALONG THE AURORAL ZONE

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Abstract: The diurnal and seasonal variations in the phase and amplitude of Omega radio navigation signal at 12.1 kHz band (from Aldra in Norway) received at Tjörnes in Iceland are analyzed in order to know the propagation mode of the VLF wave signal in high latitudes for a better understanding of the behavior of the lower ionosphere. It is found that the diurnal variation of the VLF phase and amplitude is closely correlated with solar zenith angle. A rapid change of VLF phase shift and VLF amplitude occurs at the times of sunrise and sunset during magnetically quiet period.

1. Introduction

It is well known that the characteristics of VLF wave propagation are closely related to the conditions of the ionosphere (*e.g.*, EGELAND and NAUSTVIK, 1967; SNYDER and BICKEL, 1967; MENDES and KRISHNAN, 1972). Various qualitative studies of the VLF Omega signal propagation in high latitudes have been so far carried out with respect to VLF phase and intensity change (ARAKI *et al.*, 1986, 1987; PAPPERT and HITNEY, 1988). However, we do not know yet well about the actual wave propagation characteristics in high latitudes during magnetically disturbed period. In order to study the influence of high-latitude ionospheric disturbances on the VLF propagation more quantitatively, it is necessary to know the diurnal variations of the VLF phase and signal intensity on quiet days throughout a year.

An observation of the VLF signal at 12.1 kHz from Aldra Omega Station in Norway (66.42°N, 12.15°E in geographic coordinate) has been carried out at Tjörnes in Iceland (66.20°N, 17.12°W in geographic coordinate) from 1984 (SATO *et al.*, 1984). Aldra Station is located about 1300 km distant from Tjörnes at approximately the same geographic latitude along the auroral oval, as shown in Fig. 1. Therefore, the observation at Tjörnes is advantageous for studying the wave propagation along the same geographic latitude circle. This advantage will enable us to separate the effects of sunlight and an auroral activity caused on the wave propagation through a comparison of the data on quiet days and disturbed days.

In this preliminary report, we will concentrate our attention mainly to the quiet day period, and will analyze the diurnal and seasonal variations of the VLF phase and

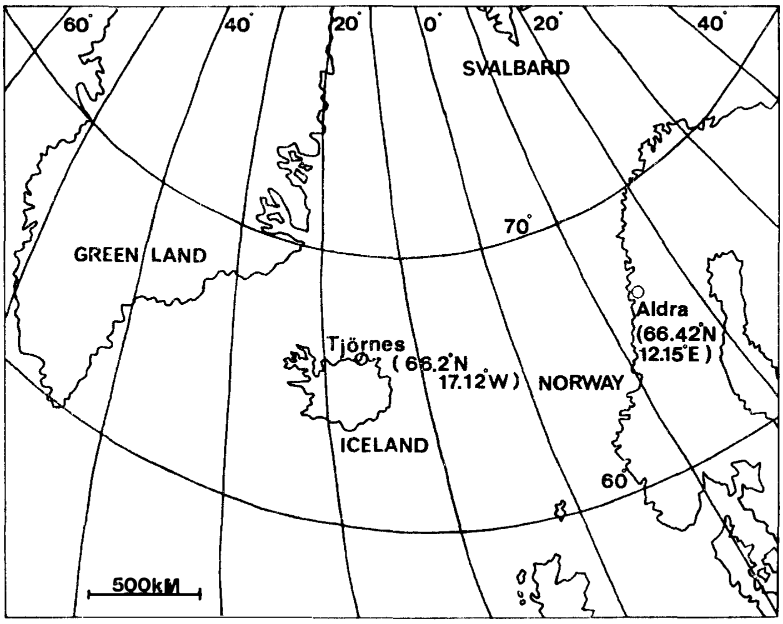

Fig. 1. Location of Tjörnes in Iceland and Aldra Omega Station in Norway.

intensity in order to study the effect of sunlight on the wave propagation.

2. Instrumentation

The VLF receiving techniques are now more or less standardized; we will therefore give only a brief description here. The VLF signals are received through an electric shield loop antenna with an effective antenna area of $\sim 100\ m^2$. The phase of the received signal is compared with a local reference signal from a crystal oscillator (frequency standard). The crystal oscillator has a stability of 5×10^{-8}. The sensitivity of the receiver is 0.01 μV (corresponding to 0.3 microvolt/meter at 20 kHz). The signal-to-noise ratio is kept as low as -50 dB. The phase and amplitude of the VLF signal are registered by a digital recorder with a sampling rate of 2 second together with geomagnetic variations, CNA, VLF natural radio waves *etc.* (SATO *et al.*, 1984; UCHIDA *et al.*, 1988). The recording range of VLF signal in the digital recorder is 100 μs full-scale for the wave phase and 40 dB full-scale for the wave amplitude.

3. Observation

3.1. Observation period and analysis

This paper shows some analytic results of the data observed for a year in 1985. Since the stability of the frequency standard is about 5×10^{-8}, the phase records always drift as shown in Fig. 2. This drift is always to the same direction, and is very gradual in comparison with SPA (Sudden Phase Anomaly) and other phase shift events. Hence, we may assume that the frequency standard drift is always constant, and we correct the data, after estimating the drifting slope of the observed curve.

Figure 3 shows an example of the final corrected data. We can easily detect the

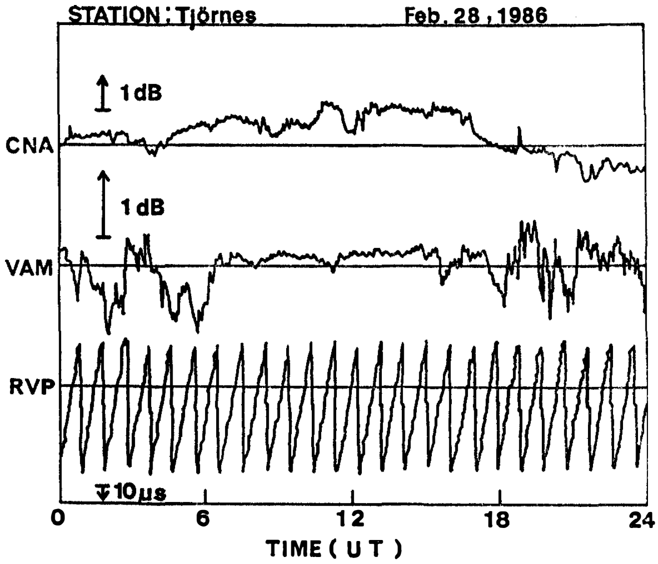

Fig. 2. Diurnal variations in the riometer and VLF signals at Tjörnes in Iceland. CNA: cosmic noise absorption. VAM: Amplitude of VLF omega signals. RVP: Raw data plot of raw VLF phase change.

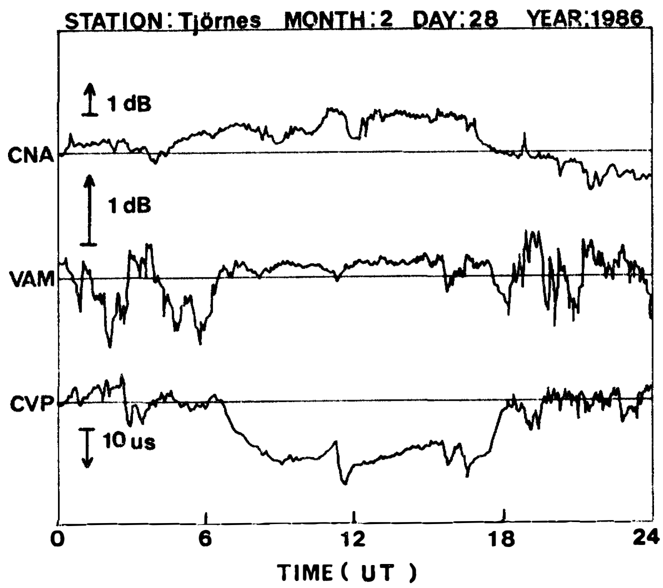

Fig. 3. Diurnal variation in the riometer and VLF signals at Tjörnes in Iceland. CVP: Corrected data plot of VLF phase change.

relative phase shift in this figure.

3.2. *Diurnal and seasonal variations in the phase and amplitude of 12.1 kHz Omega signal*

In the summer solstice, the whole path of wave propagation is almost illuminated all the day by the sun for the path from Aldra Station, Norway to Tjörnes in Iceland. On the other hand, the whole path has almost no sunshine all day long in the winter solstice. It is interesting to examine the sunlight effect on VLF propagation comparing the data at different seasons.

Figure 4a shows the diurnal variation in the phase and amplitude of the 12.1 kHz Omega signal observed at Tjörnes during the equinox season on March 23, 1985. The sunrise and sunset time (solar zenith angle becomes 90°) at Tjörnes are also indicated in this figure. It is found that the VLF phase shows a gradual delay from ~0500 UT (T1) to ~0610 UT (T2). The phase remains almost constant between ~0700 UT and ~1700 UT, then it increases from ~1730 UT (T3) to ~1910 UT (T4). The sunrise and sunset times on March 23, 1985 are ~0600 UT and 1830 UT, respectively. As for the diurnal variation of the VLF amplitude, we can find that the amplitude changes in association with the sunrise and sunset, and the amplitude increases during the daytime. It is worth noting from the figure that the VLF phase and amplitude are disturbed during the nighttime while they are relatively quiet during the daytime. Therefore it is suggested from this event that the onset time of the phase shift and amplitude variations are correlated with the sunrise and sunset times.

Figure 4b shows the same display as Fig. 4a except for the data observed at Tjörnes on April 25, 1985. It is found that the onset time of the phase shift is coincident with the sunrise and sunset times which are shifted with season in comparison to Fig. 4a. That is, the onset time is about 4 hours different between the March 23 and April 25 events. It is noteworthy that the phase shift phenomena are recognizable more clearly than the amplitude change phenomena during the sunrise and sunset period. It is also

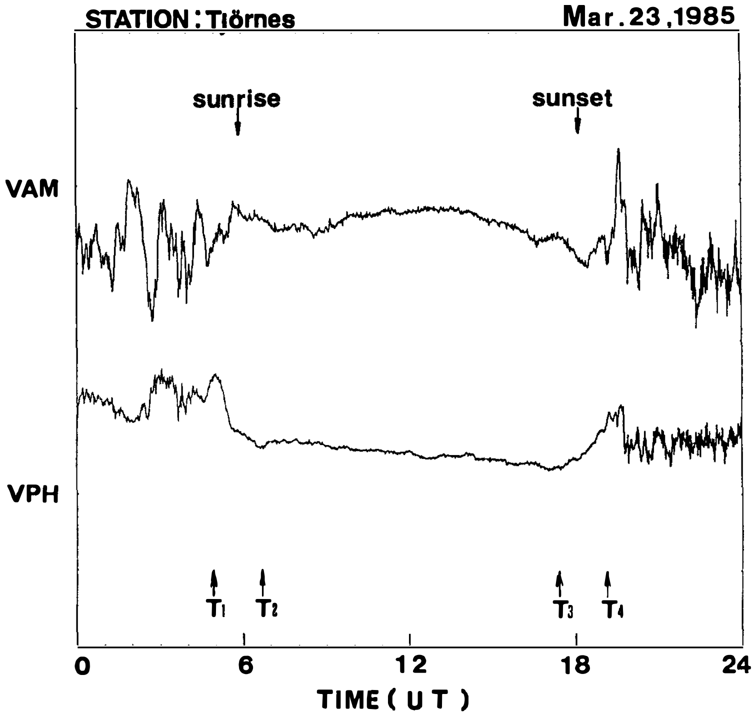

Fig. 4a. Diurnal variation in the phase and amplitude of the 12.1 kHz band Omega signal observed at Tjörnes on March 23, 1985. The times of sunrise and sunset at Tjörnes are also indicated in this figure.

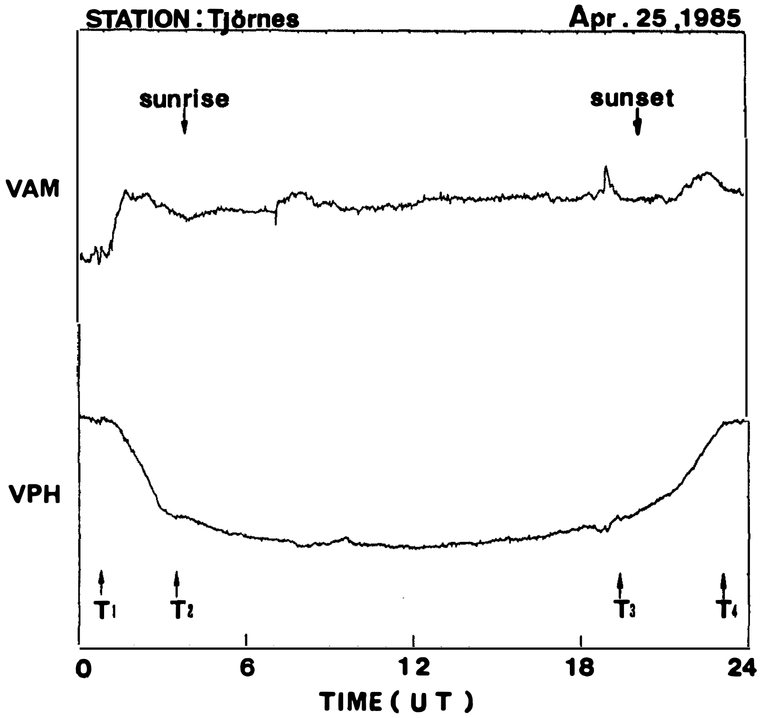

Fig. 4b. The same as Fig. 4a but for April 25, 1985.

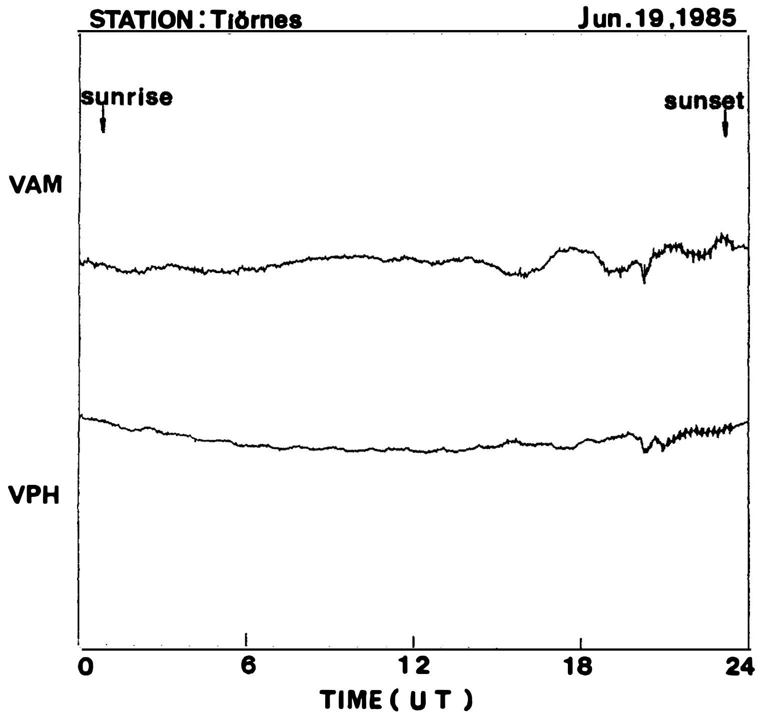

Fig. 4c. The same as Fig. 4a but for June 19, 1985.

found that the phase shift at sunrise is more rapid with time than that at sunset.

Figure 4c shows an example observed in the summer solstice on June 19, 1985.

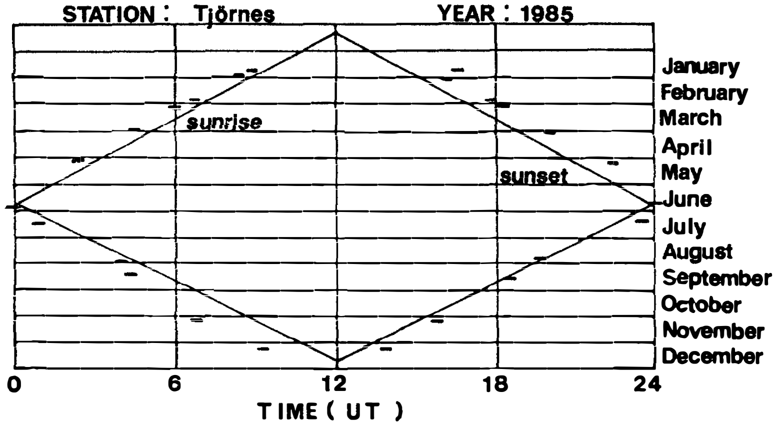

Fig. 5. Seasonal variation of times of phase shift phenomena associated with sunrise and sunset. The times of sunrise and sunset (90° solar zenith angle at Tjörnes) are approximately by straight lines.

It is found that the slope of the phase and amplitude curve is almost flat all day long. It is suggested therefore that the phase and amplitude do not show any noticeable diurnal variation in the summer solstice when the wave path from Aldra to Iceland is illuminated all the day by the sun.

In order to find the seasonal variation for the relationship among the times of the phase shift, amplitude change, sunrise and sunset, we picked up the whole remarkable events observed through the year at Tjörnes in 1985. At high latitudes, the solar illumination time increases from winter to summer. The seasonal variation of the sunrise and sunset times (90° solar zenith angle) at Tjörnes are given approximately by straight lines in Fig. 5. The times of the VLF phase shift associated with sunrise and sunset are also plotted in Fig. 5. It is found that the seasonal variation of the times of the phase shift are closely related with the times of sunrise and sunset. It is worth noting that the times of the phase shift precede and lag behind respectively the sunrise and sunset times by a few hours, especially in the northern winter season.

4. Summary

From the high latitude VLF Omega data described in Section 3, the main findings for the diurnal and seasonal variations of the VLF phase and amplitude may be summarized as follows;

1) The VLF phase shows a gradual delay during sunrise and a gradual increase during sunset. The phase shift at sunrise is more rapid with time than that at sunset.

2) The VLF amplitude increases during daytime.

3) The VLF phase and amplitude are disturbed during the nighttime, but they are relatively quiet during the daytime.

4) The phase shift phenomena are observed more clearly than the amplitude change during both the sunrise and sunset periods.

5) The seasonal variations of the phase shift time are closely correlated with the times of sunrise and sunset.

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