

Observation and Analysis of Solar Flares that Cause Large-area Short-wave Communication Interruption

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Research Article

Keywords: Solar flares , SID , VLF , Shortwave communication interrupted , Forecast of Shortwave Communication Environment

Posted Date: June 1st, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-425202/v1>

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Observation and analysis of solar flares that cause large-area short-wave communication interruption

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Received: date / Accepted: date

Abstract When a solar flare erupts, the sun emits a flood of X-rays and high-energy particles that reach Earth at the speed of light, causing a sudden ionospheric disturbance event (SID event). The D layer of the ionosphere absorbs high-frequency radio signals. With the increase of flare intensity, the D layer's absorption capacity becomes stronger, which leads to the decline of shortwave communication quality and even the interruption of shortwave communication. In this paper, solar flares, which caused large area short-wave communication interruption in recent years, are observed and analyzed by very low frequency (VLF) method, and the influence of solar flares on short-wave communication is summarized. Finally, several methods to deal with the short-wave communication interruption caused by solar flares are proposed.

Keywords Solar flares · SID · VLF · Shortwave communication interrupted · Forecast of Shortwave Communication Environment

1 Introduction

Short wave, also known as high frequency radio wave (HF), its wavelength is generally between 10 to 100 meters, and its frequency is between 3 MHz to 30 MHz, Shortwave communication has the advantage of long propagation distance, which can circle the earth. It is often used in different distance point-to-point communication, international communication, daily radio listening, flood control and disaster relief, marine rescue, low-speed data and image, etc. However, the quality of short wave communication is closely related to many

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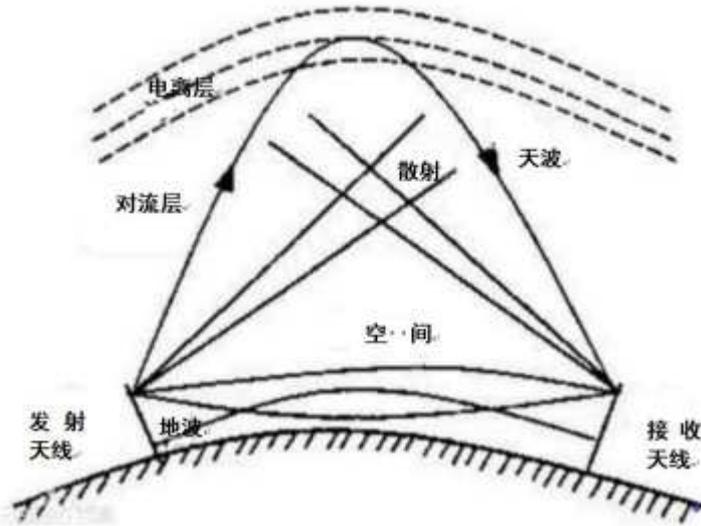


Fig. 1 Schematic diagram of shortwave communication

factors, including the equivalent height of the ionosphere, the electron density of the ionosphere, and the influence of day and night, season, climate, etc. In particular, the eruption of solar flares is more likely to cause a large area of short wave communication interruption. VLF signal mainly propagates in the waveguide formed between the ground and the lower ionosphere, and shortwave radio signal mainly propagates in a long distance through the reflection of the ground and the ionosphere, and its propagation path is shown in Figure 1. When a flare suddenly erupts, the sun radiates a lot of X-rays and high-energy particles. When X-rays arrive near the earth at the speed of light, the ionization degree of D layer in the low ionosphere increases, the electron concentration increases, and the equivalent reflection height of the low ionosphere decreases, resulting in the phase advance of VLF signal propagation. When the flare level reaches m or above, the D layer of the ionosphere absorbs the short wave signal strongly, and the short wave communication may be interrupted. Therefore, by monitoring the VLF phase change, we can alarm the short wave communication interruption events by observing the advance of VLF signal phase, and understand the exact reason of short wave interruption in time, which is very beneficial and necessary for taking necessary measures in advance to ensure the smooth shortwave communication line as far as possible.

2 Analysis of the response of very low frequency (VLF) propagation characteristics to solar flares

Very low frequency (VLF) signals propagate very stably in the ground low ionospheric waveguide. When solar flares erupt, intense X-rays arrive near the earth, resulting in the increase of ionospheric ionization, the increase of electron concentration, the decrease of equivalent reflection height of low ionosphere, and the sudden advance of VLF signal phase. The phase of VLF signal is very sensitive to Sid events, so VLF method can be used as a very effective means to monitor solar activity. At the same time, the variation characteristics of low ionosphere can be studied by inversion.

When solar flares erupt, the phase advance of VLF signal $\Delta\varphi$ is affected by many factors, including the equivalent reflection height of the low ionosphere h_0 the frequency of the signal radiated by the VLF transmitting antenna f the direction of propagation path, the long distance of the path, and the ground conductivity. VLF radio waves propagate in the spherical shell space between the earth's surface and the lower ionosphere for a long distance. Generally, the "waveguide mode" theory is used to analyze the propagation. With the increase of distance, the higher-order mode decays rapidly, while the lower order mode decays slowly. In the place far away from the VLF transmitter, the existence of the higher-order mode can be ignored, and only the first-order mode can be calculated.

According to the waveguide mode theory, the first-order mode phase velocity v_p of VLF signal can be calculated

$$v_p \approx v_c \left(1 - 0.36 \frac{h_0}{a} + \frac{v_c^2}{32f^2h_0^2} \right) \quad (1)$$

Where, v_c is the speed of light propagation in free space, a is the average radius of the earth, taking $a = 6371km$. The phase offset of VLF $\Delta\varphi$ can be expressed as:

$$\Delta\varphi = d \left(\frac{1}{v'_p - \frac{1}{v_p}} \right) \quad (2)$$

Where, d is the great circle distance of the earth between the transmitting station and the receiving point, v_p is the phase velocity of the first-order mode of VLF signal without solar flare, and v'_p is the phase velocity of the first-order mode of VLF signal with solar flare.

The relationship between the offset of equivalent reflection height Δh_0 the offset of phase (radian) $\Delta\varphi$ is:

$$\Delta h_0 = \frac{h_0\lambda}{2\pi d [0.36 \frac{h_0}{a} + (\frac{\lambda}{4h_0})]} \Delta\varphi \quad (3)$$

Where, λ is the wavelength of VLF signal. When a solar flare erupts, the peak X-ray flux F_0 is

$$F_0 = 1.86e^{0.343 \times |\Delta h_0|} \times 10^{-3} \quad (4)$$

Finally, the level of solar flare can be judged according to the size of F_0 . When the flare level reaches M level, the D layer of ionosphere absorbs the short wave signal strongly, which may cause the interruption of short wave communication. Therefore, by monitoring the VLF phase change, we can give an alarm to the short wave communication interruption events, understand the exact reason of the short wave interruption in time, and take corresponding measures.

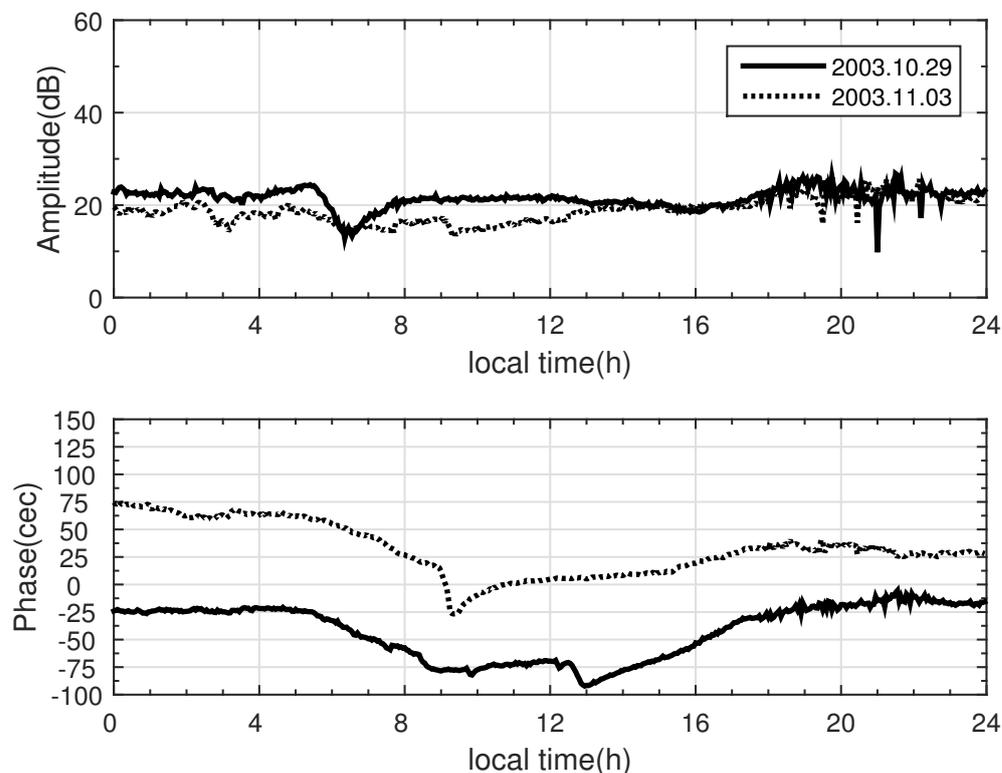
3 Observation and analysis of solar flares causing interruption of large area shortwave communication

By analyzing in the second section, VLF method can be used to observe solar flares.

From the end of October to the beginning of November 2003, during the western countries' Halloween, the sun erupted the strongest flare ever observed by goes satellite. We chose October 29, 2003 and after November 3, 2003 to observe the solar flare in Haikou, Hainan Province, China. In Haikou, we received three signals from the Russian alpha VLF navigation system. The amplitude and phase curves of the VLF signal with the radio station frequency of 11.9kHz are plotted as shown in Fig. 2 to Fig. 4 (the solid line is the amplitude and phase curve on October 29, 2003, and the dotted line is the amplitude and phase curve on November 3, 2003). It can be seen from the figure that at 13:06BT on October 29, 2003, the solar flare eruption reached its peak, and the maximum phase lead of 11.9kHz VLF signals from west sub station, main station, East sub station to Haikou are 25cec, 27cec and 52cec respectively; according to the earth's long distance, the distances from west sub station, main station and East sub station to Haikou receiving point of alpha system can be calculated to be about 25cec, 27cec and 52cec respectively. It is 7022.5km, 4546.7km and 3875.7km. Through calculation, we get that the solar flare level is M3.8, the results observed by the US goes satellite are M3.5, which is basically consistent with our observation results; At 09:30 (BT) on November 3, the solar flare eruption reached its peak. The maximum phase advance of 11.9kHz VLF signals from west sub station, main station and East sub station to Haikou are 53cec, 48cec and 72cec respectively. Through calculation, we get that the solar flare level is X2.4, and the result observed by goes satellite is X2.7, which is consistent with our calculation results within the allowable error range. It is in accordance with this law; The specific data of solar flares in these two days are shown in Table 1. Similarly, we observed the solar flare activity on November 5, 2003, but when the solar flare erupted at X28 on November 5, 2003, it was at 03:50 am in China, so we failed to receive the corresponding VLF signal phase change. The flare has a wide range of influence. The short wave communication at home and abroad has been greatly affected. The global communication has been interfered, the maritime emergency call system has been paralyzed, the communication of the Everest expedition has been interrupted, and the accuracy of the global positioning system has been

Table 1 Solar flare distance data on October 29 and November 3, 2003

Date	Start time	Peak time	End time	Calculation level	Goes observation level
2003.10.29	12:37	13:06	14:02	M3.8	M3.5
2003.11.03	09:09	09:30	09:45	X2.4	X2.7

**Fig. 2** Alpha West Substation-Haikou 11.9kHz Amplitude and Phase Curve

reduced. Among them, the situation of short wave communication in northern China was seriously damaged, and the short wave signal of radio observation points in Beijing and Manzhouli was once interrupted, in foreign countries, a power system in the south of Malmö city in Sweden was damaged, and the power demand of more than 50000 people was affected, which had a great impact on people's lives. Therefore, the second solar flare is during the western countries' Halloween and is known as the "Halloween solar storm".

In recent years, there are many reports about the interruption of short wave communication caused by solar flares: for example, on January 20, 2005, the X7.9 flare broke out, a large area of short wave communication channel was

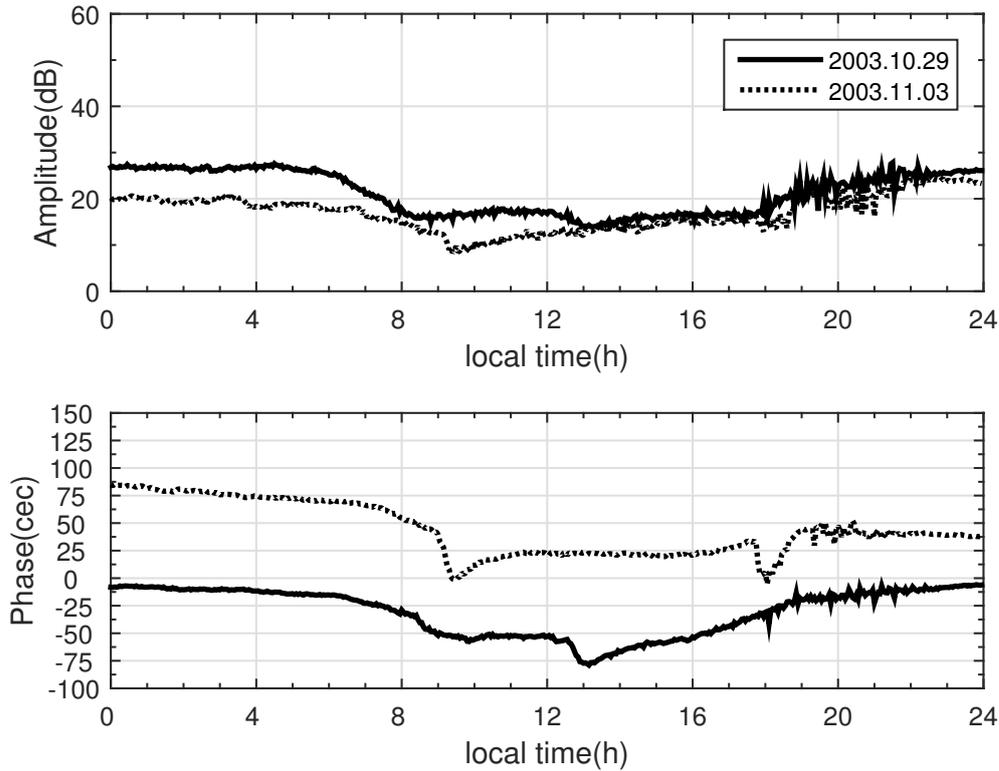


Fig. 3 Alpha main station-Haikou 11.9kHz amplitude and phase curve

damaged, and the short wave communication was seriously affected, among which the signal in Beijing area was interrupted for more than one hour, around 10:40(BT) on December 13, 2006, the solar flare level reached X3.0, most areas in China The short wave communication was interrupted and lasted for a long time[9]. The short wave detection signal of radio wave observation stations in Guangzhou, Haikou, Chongqing, Xinxiang and other areas was interrupted in the whole band from about 10:20(BT), and the signal began to recover until 11:15(BT).

Based on the analysis of the solar activity in the event of short wave communication interruption, we can draw a conclusion: if the solar flare burst level is low (below M level) or the duration of the event is very short, the change of low ionospheric electron concentration is not obvious, the change of low ionospheric height is not obvious, and the VLF signal advance is not obvious, it may only cause the instability of short time short wave communication signal; but Under the influence of some special space weather, the intensity and duration of the flare is large, the phase of VLF signal is seriously advanced,

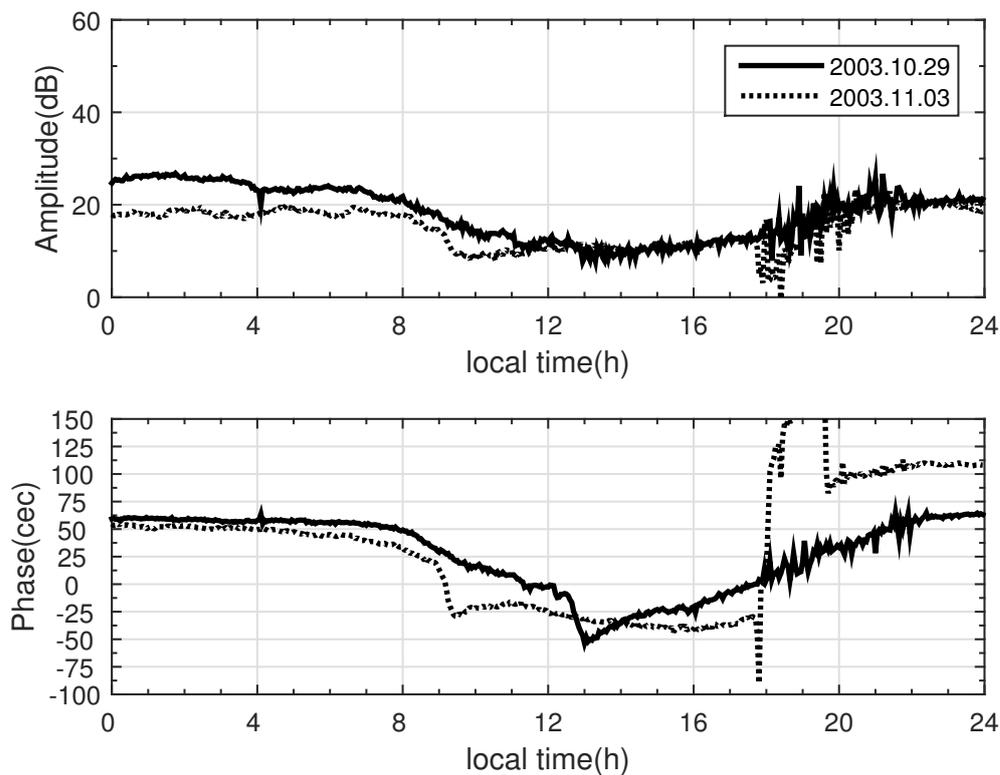


Fig. 4 Alpha East Substation-Haikou 11.9kHz Amplitude and Phase Curve

and the ionospheric disturbance can last for dozens of minutes or even several hours. This situation may cause a long-time interruption of short wave communication or even a large area power outage.

4 CONCLUSION

The eruption of solar flares will not only affect the earth's ionosphere, but also affect the earth's climate and magnetic field. The magnetic storms caused by solar flares will also have a serious impact on the reception of short wave communication signals. In the period of frequent solar activity, the received signal is often weak or even interrupted. We can use VLF observation methods to monitor the electron concentration in the D-Layer ionosphere or to predict the critical frequency in the F-layer, and take corresponding preventive measures before solar flare, so as to ensure the stability of short wave communication.

Acknowledgements This research received support from the National Natural Science Foundation of China(61801172).The author is very grateful to Li Jianlong and Wang Xi-angkang for their experimental work! Thanks also to the world map provided by the National Bureau of Surveying and Mapping of China, as well as every author in the references!

Conflict of interest

I declare that I have no conflict of interest with other authors

Declarations

This research has received support from the National Natural Science Foundation of China(61801172), which was chaired by Mr. Liu Weina. The data in this paper has been confirmed to ensure the availability of the data.

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Figures

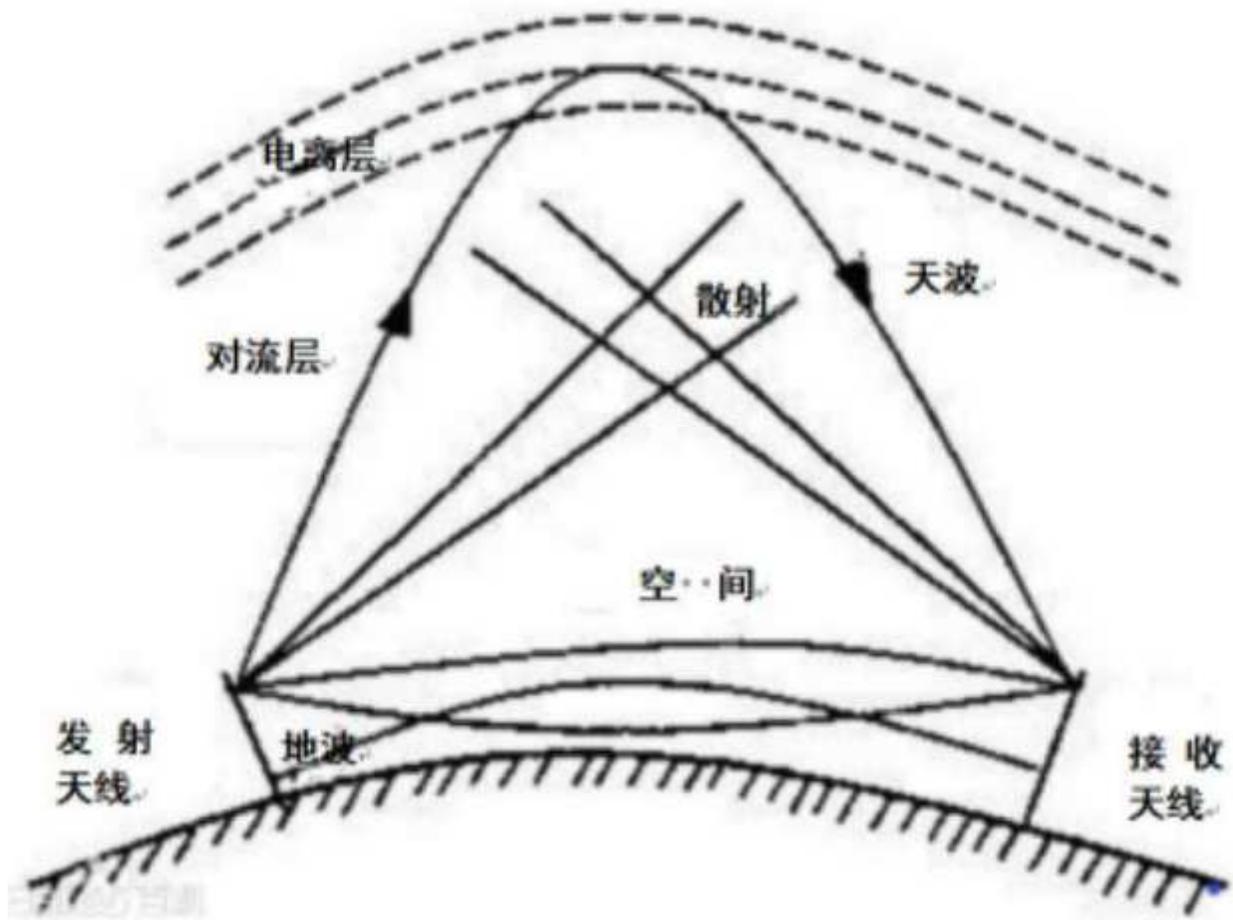


Figure 1

Schematic diagram of shortwave communication

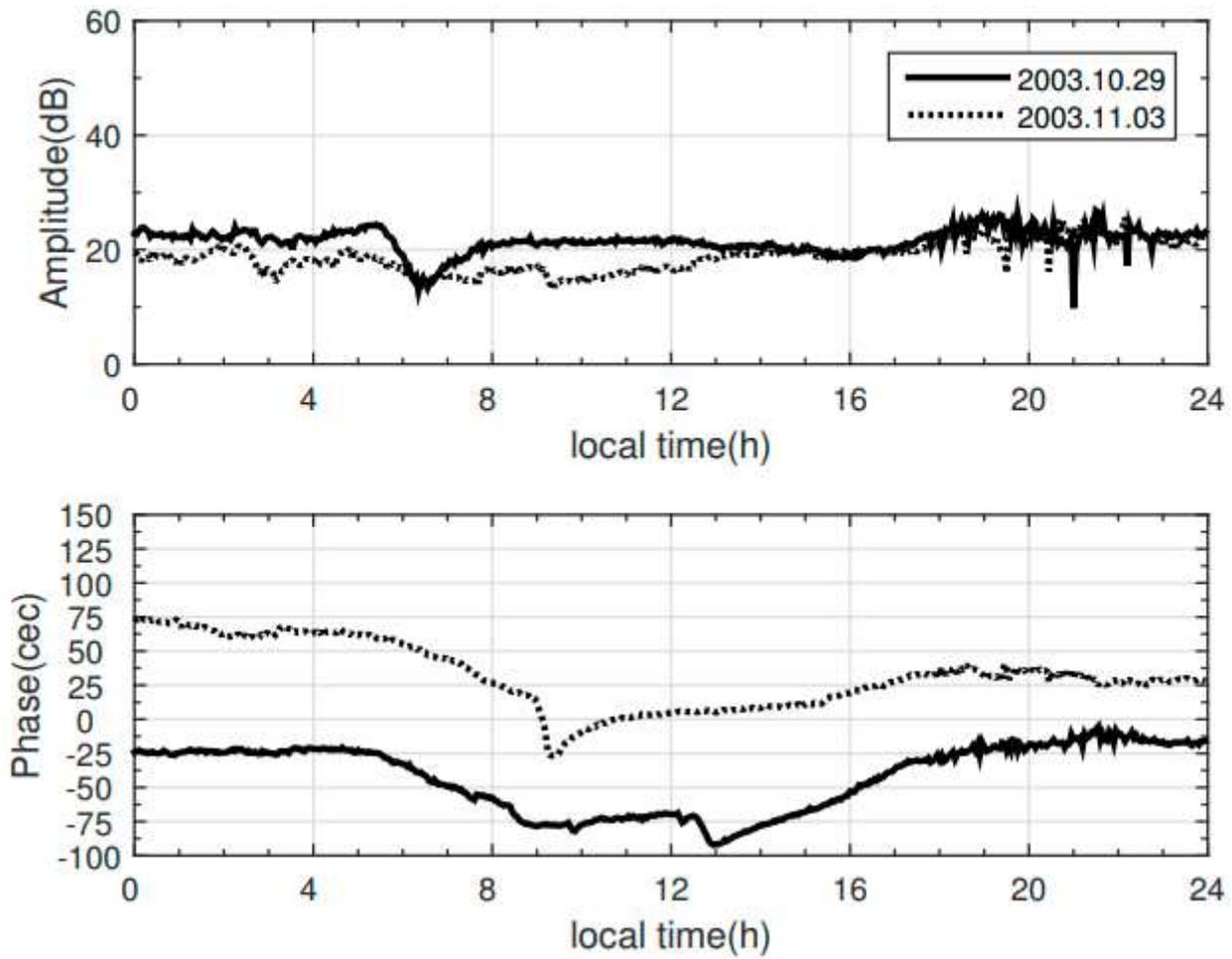


Figure 2

Alpha West Substation-Haikou 11.9kHz Amplitude and Phase Curve

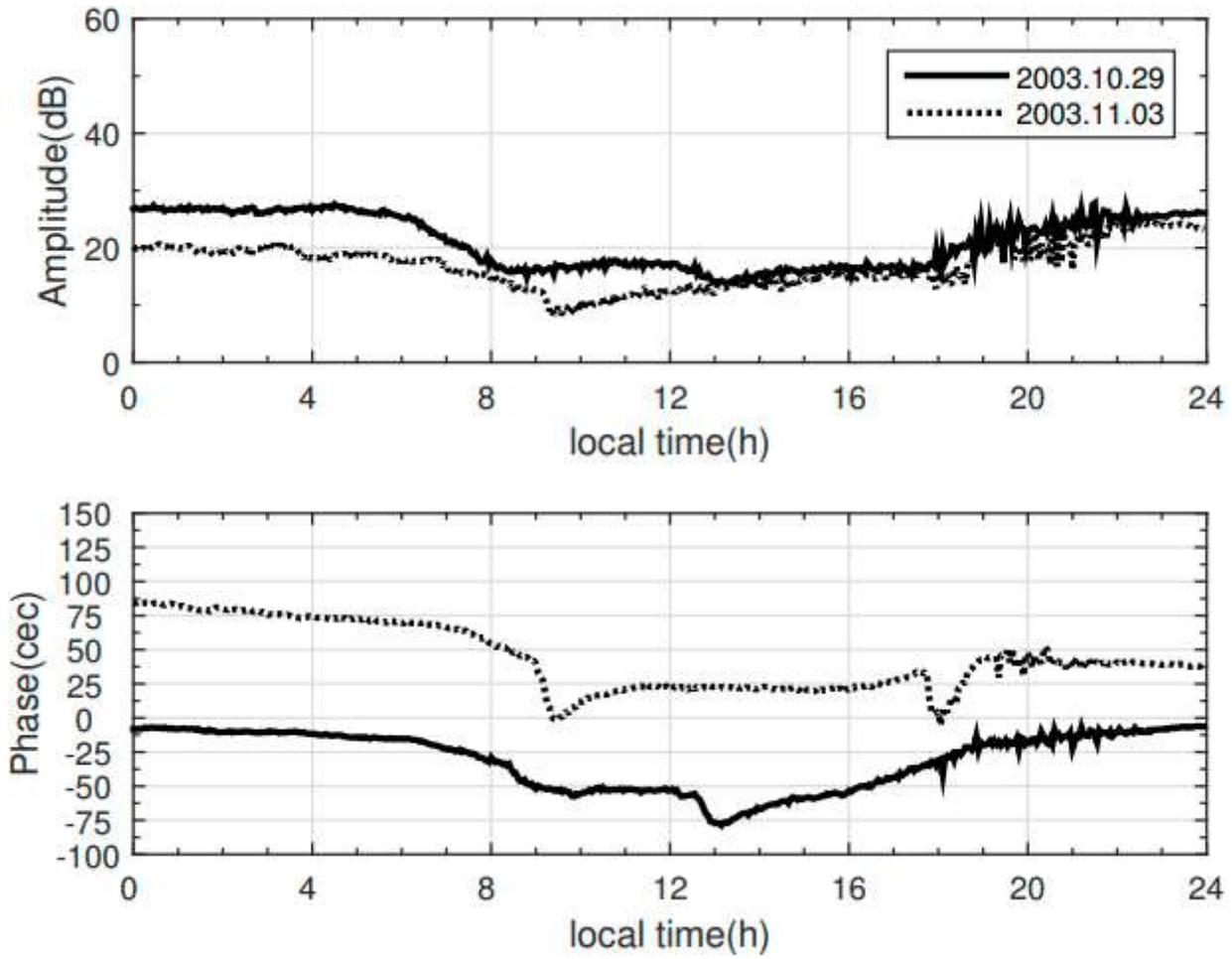


Figure 3

Alpha main station-Haikou 11.9kHz amplitude and phase curve

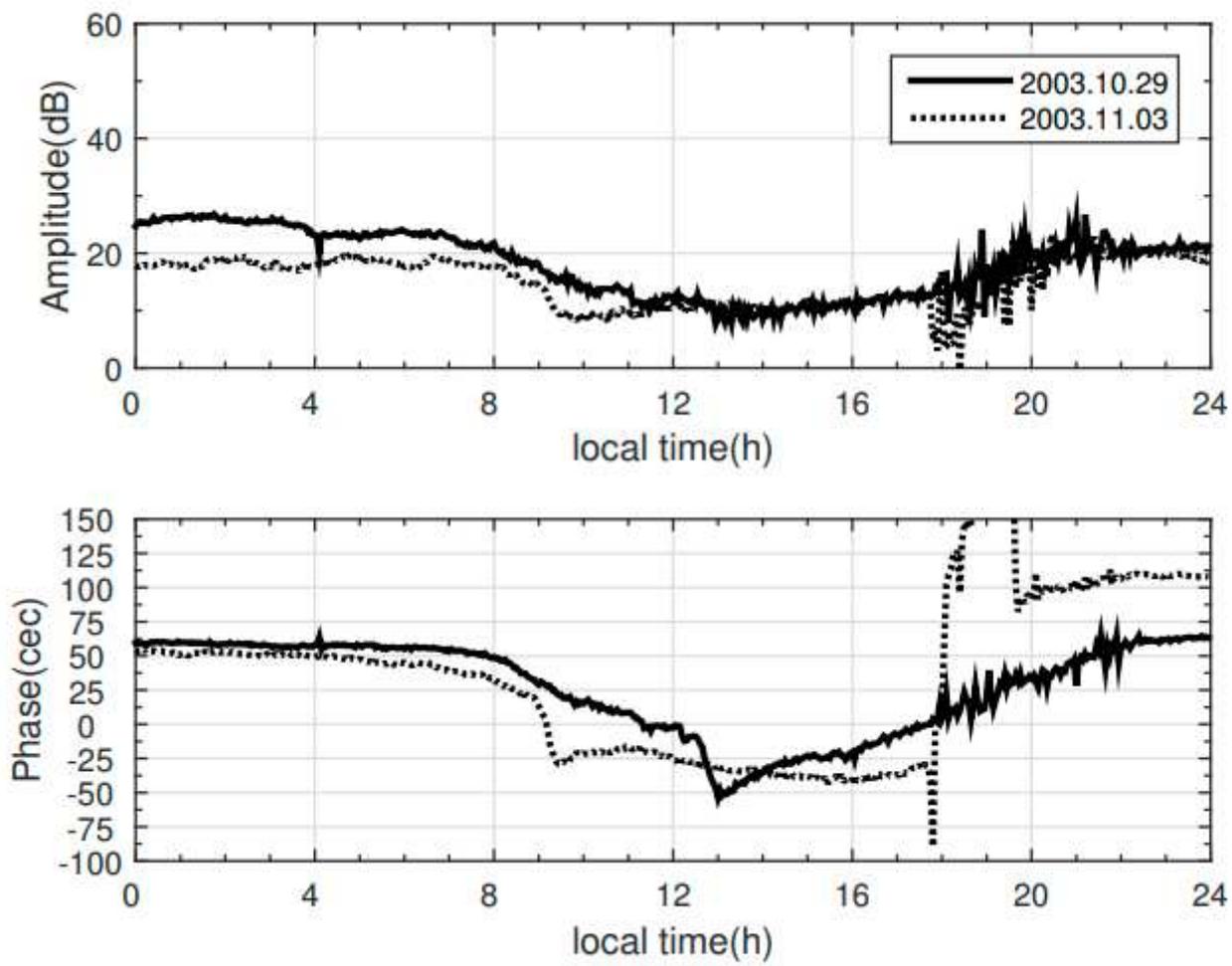


Figure 4

Alpha East Substation-Haikou 11.9kHz Amplitude and Phase Curve