Coseismic Ionospheric Disturbances at Multiple Altitudes Associated with the Foreshock of Tohoku Earthquake Observed by HF Doppler Sounding

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1 Introduction

Many studies have reported that ionospheric disturbances occur after big earthquakes. One of the causes of these coseismic ionospheric disturbances (CIDs) is the infrasound wave excited by Rayleigh wave propagated on the ground from the epicenter. The infrasound wave propagates upward and produces CIDs. In this study, using HF Doppler sounding system (HFD), CIDs at the different altitudes associated with the foreshock of Tohoku Earthquake were examined.

2 Observation

The HF Doppler sounding system observes the vertical motion of the ionosphere from the Doppler shift frequency of the reflected wave. In this study, HFD sounding system maintained by the University of Electro-Communications (UEC) is used. Sugadaira observatory (38.81°N, 141.68°E in geographical coordinates) receives four radio waves (5.006, 6.055, 8.006, and 9.595 MHz). Radio waves at frequencies of 5.006 and 8.006 MHz are transmitted from Chofu Campus of UEC (35.65°N, 139.55°E) and waves at 6.055 MHz and 9.595 MHz are transmitted from Nagara Transmitter of Nikkei Radio Broadcasting Cooperation (35.46°N, 140.21°E). The temporal resolution of the HFD sounding data is 5.12 s. For seismometer data, we used Broadband Seismograph Network (F-net) installed by National Research Institute for Earth Science and Disaster Prevention (NIED). The seismic observatories are equipped with a broadband sensor STS-2 with a flat response to ground speeds over a broad frequency range (0.1–120 s). The data sampling at Onishi Station was performed once every second. The location of this seismometer nearly coincides with the midpoint between Sugadaira and Chofu, and the distance from another midpoint between Sugadaira and Nagara is about 32 km.

3 Results

The foreshock of Tohoku earthquake occurred at 02:45 UT on March 9, 2011, two days before the main shock. Its magnitude was Mw7.3. The location of the epicenter was (38.33°N, 143.28°E) and the depth of the focus is 8 km. From HFD and seismometer data (the left panel of Figure 1), it is found that the ionospheric disturbances are attributable to the ground disturbances. In the waveform at the higher altitudes, the longer disturbances remain. From the right panel of Figure 1, in the ground disturbance, the spectral intensity of the ground disturbance reaches its maximum at about 80 mHz. There are small peaks around 30 and 70–80 mHz at the lowest altitude (5 MHz). The disturbances at the lower frequencies remain in the higher altitude, with a peak at approximately 20–30 mHz at the highest altitude (9 MHz). The vertical profiles of the amplitude ratios of ionospheric disturbances compared to the ground disturbance is shown in Figure 2. The height variations of the disturbances for lower frequencies (10.0–25.6 mHz and 25.6–45.5 mHz) have the same tendencies as the theoretical values. The disturbances of 25.6–45.5 mHz also decay with altitude but this decay is weaker than those for 45.5–76.9 mHz. The disturbances of 10.0–25.6 mHz are constant in altitude. Especially the ionospheric disturbances for lower frequency components are smaller than the theoretical results. The reflection of the acoustic wave in the lower atmosphere (about 50 km) might cause the differences of the amplitude ratio [1]. The lower-frequency components are easily affected by external disturbances or noise in the atmosphere. The ratio of the pressure disturbance to the ground vertical speed is highly perturbed at lower frequency owing to the background noise [2].

4 Summary

Coseismic ionospheric disturbances were examined using an HF Doppler sounding system and a seismometer. The disturbances were excited by an acoustic wave resulting from a Rayleigh wave propagating from the focus.
The vertical speed of the acoustic wave is determined by the equation shown in the previous studies [3, 4], which considered the attenuation due to viscosity, thermal conductivity, and relaxation loss. The characteristic features of the acoustic wave are explained qualitatively by those of the acoustic wave. On the other hand, the amplitudes of lower-frequency disturbances are smaller than the theoretical values at all altitude, while the higher-frequency components fit them in higher altitudes.

![Figure 1.](image1.png)  
Figure 1. Ionospheric disturbances observed at Sugadaira observatory using HFD (left top panel) and the ground disturbance observed by the seismometer at Onishi (left bottom panel). The HFD data are shown as Doppler shift frequency [Hz] and the seismometer data are shown as vertical speeds [mm/s]. The time of the HFD data is delayed 8 min to the seismometer data. Right panel shows Spectral intensities of the HFD shift frequencies and ground disturbances as shown in the left panel.

![Figure 2.](image2.png)  
Figure 2. Altitude profiles of the amplitude ratios of the acoustic waves. The background curves are theoretical amplitude ratios according to Chum et al. [3]

References


