Observation of The 2011 Tohoku Tsunami by Using HF Radar in Ise Bay

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***Abstract* - A tsunami generated by "The 2011 off the Pacific coast of Tohoku Earthquake" was observed by two high frequency ocean surface radars (HF radars) and four tide gauges installed on Ise Bay. The tsunami wave arrived initially at 16:50 was observed by tide gauge which is installed on the mouth of the Bay. This wave propagation was also observed by HF radars installed on the inner part of the Bay. Therefore, these observations were considered to be correlated. The result of spectral analysis, the tsunami wave had energy with period bands of 120-140, 60-90 and 30-40 min. In comparison to the previous study suggest that these 60-90 and 30-40 min periods oscillations were attributed to the tsunami source fault.**

***Index Terms* — HF radar, remote sensing, tsunami, Ise Bay.**

1. Introduction

Japan is an island country surrounded by the sea on all sides and located on the border zone of the four tectonic plates. Because earthquakes occur frequently in Japan, tsunamis also occur frequently and inflict widespread damage. Five years ago, the Pacific side of the Tohoku region, east-northern part of Japan, was severely damaged by the tsunami caused by "The 2011 off the Pacific coast of Tohoku Earthquake" and it was responsible for almost 20,000 deaths. The tsunami waves were observed by high frequency ocean surface radars (HF radars) not only in Japan but also across the Pacific Ocean near the Californian and the Chilean coast [1], [2], [3].

The tsunami waves were also observed by HF radars and tide gauges installed on the coast of Ise Bay which is located in the southern part of the central Honshu Island with a by length of 70 km and a mean water depth of 20 m. The radars are located Nabeta (NABE) of Aichi prefecture and Tsumatsuzaka (MATU) of Mie prefecture shown in Fig. 1.

The purpose of the study is to investigate how the tsunami was observed with the HF radars, and to describe the behaver of the tsunami arrival in Ise Bay. The data at NABE and MATU were provided by Chubu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan.

2. Observation Method in HF Radar

The HF radar observes the sea surface current by measuring Bragg scatter from ocean wave which wavelength is a half of the radar transmitted wavelength. The HF radars both NABE and MATU (shown in Fig. 1) are operated with 24.5 MHz. Thus, the radar system obtained current velocities of 6-m long wavelength. The sweep bandwidth is 100 kHz, hence a spatial resolution is calculated for 1.5 km interval.

3. HF Radar and Tide Gauge data

In the environmental monitoring mode of HF radar in Ise Bay, the data is ordinary observed with 1-hour interval. In order to analysis a short time phenomenon such as a tsunami, we use 5-min interval data. However, it caused many missing data points because of decreasing the signal to noise ratio owing to short data acquisition time.

To resolve this problem we used spatial average for radial velocities ranging from 8 to 10 km from the radar site with 6-km width perpendicular to the beam direction. In this study, we discus about the direction of 190° (NABE) and 112° (MATU) from the north, as shown in Fig. 1. This method is referred to in Lipa et al. [2].

We also examined the sea surface heights in order to understand the tsunami effect in Ise Bay and to compare with the radar observations. Fig. 2 shows the velocity components (upper two rows) and the sea surface heights (lower four rows). The sampling intervals are 5-min for NABE and MATU; 1-min for Nagoya, Onizaki and Toba and 10-min for Yokkaichi. To extract the wave component generated by tsunami wave from background motion, we used a band-pass

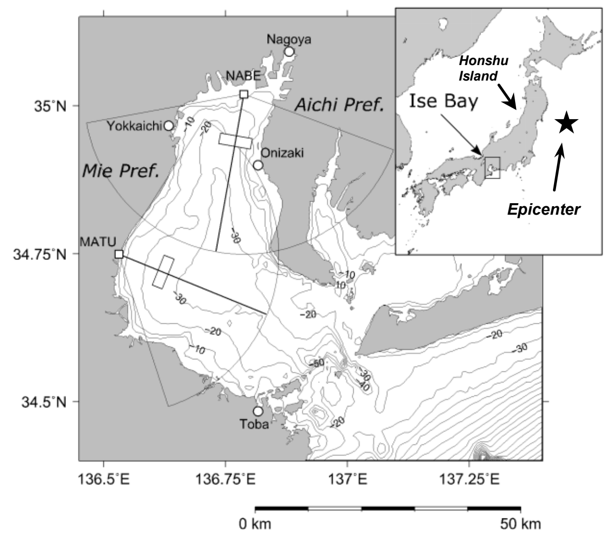

Fig. 1. HF radar sites (squares) and tide gauges (circles) in Ise Bay. The radial velocities which included rectangle regions are analyzed in this study.

(2-360 min) filter on all the data except NABE, MATU and Yokkaichi which was used a high-pass (~360 min) filter.

From Fig. 2, the first wave crest arrived initially at 16:50 at Toba in the mouth of Ise Bay. We can confirm its propagation to the inner part of the bay by the progression of time of the first wave crest at each tide gage. Similarly we can confirm the velocity components excited by the tsunami wave at 17:10 at MATU and 17:30 at NABE. The oscillation after the first wave packet remained 12 hours. These result of the velocity components are considered to be correlated with fluctuation of sea surface heights.

4. Spectral Analysis

Fourier transform is applied to the velocity oscillations and the sea surface height oscillations. The spectra of velocity oscillations have maximum peak in the 60-90 min period band both NABE and MATU. There are secondary spectrum peaks in the 120-140 and 30-40 min period bands at NABE, and at the approximately 40 min period at MATU shown in Fig. 3 (a). The spectra of sea surface height oscillations have peaks with period bands of 120-140, 60-90, and 30-40 min in Fig. 3 (b).

The largest spectral peak of velocity and sea surface height oscillations appeared in the 60-90 min period band at all station expect for Onizaki. The maximum spectral peak for Onizaki is at the 30-40 min period band.

The oscillation period bands of 50-80 and 30-40 min were also appeared in the tsunami waves observed by using HF radars and tide gages in Kii Channel, Japan [1]. These are close to the period observed by HF radars and tide gauges in Ise Bay. Therefore, the oscillations of 60-90 and 30-40 min period bands appeared in Ise Bay are not a local oscillation but possibly attributed to the size of the tsunami source fault.

5. Summary

In this research, we explained about the tsunami signal and its spectra in Ise Bay. From the results of the time series of velocities and sea surface heights, we confirmed its propagation to the inner part of the bay. According to the result of the spectral analysis, the velocity and the sea surface oscillations with period bands of 60-90 and 30-40 min were amplified. In comparison to the previous study, we concluded that these periods were possibly related to the source fault. In this way, the HF radars were capable of observing detailed tsunami propagation and its behavior. These results suggest that the HF radar is useful in estimating tsunami inundation and damaged area. For this reason, the HF radar has an advantage for tsunami disaster mitigation.

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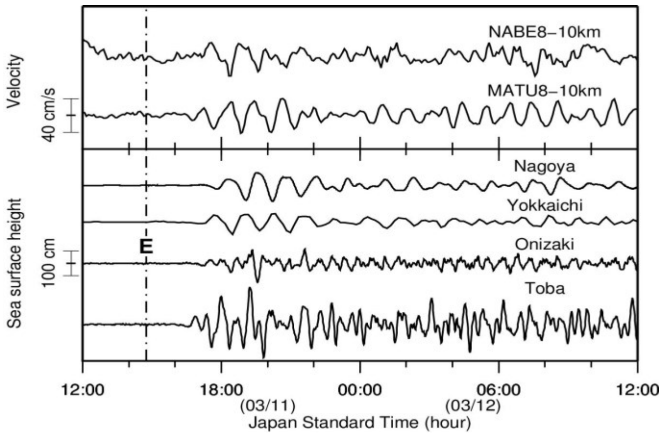

Fig. 2. Time series of velocity components of 8-10 km at NABE and MATU in the upper two rows and sea surface heights at Nagoya, Yokkaichi, Onizaki, Toba in the lower four rows. The dashed vertical line labeled "E" denotes the time of the earthquake occurrence.

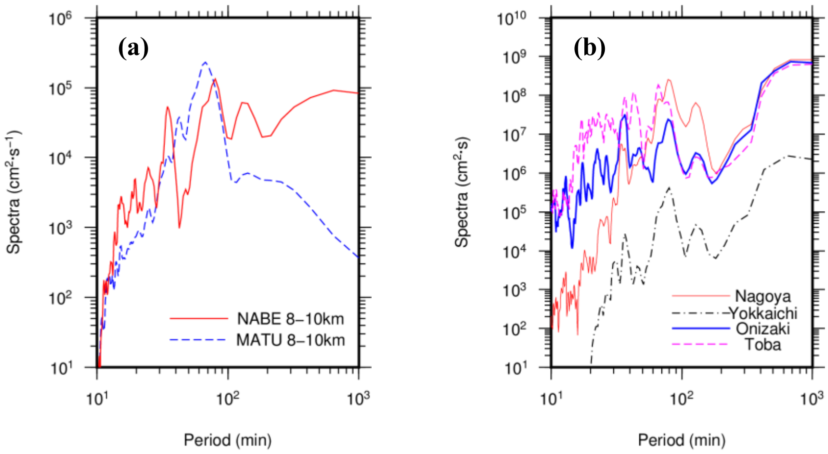

Fig. 3. The tsunami spectra of (a) velocities and (b) sea surface heights.