Oceangraphic Radar Tsunami Measurement System

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1. Introduction

The Great East Japan Earthquake and Tsunami has renewed awareness of and interest in the importance of disaster prevention measures at sea.

It is also essential to understand various marine phenomena. However, most conventional marine observations have consisted mainly of direct point measurements of values such as wave height and current velocity, using equipment deployed over wide areas and requiring on-going maintenance and management for measurements, at great effort and cost.

In contrast, installation and maintenance of oceanographic radar on land is easy, and it can make continuous observations of broad areas over long periods of time, so coastal marine instruments are attracting attention. Oceanographic radar uses frequencies in the HF to low-VHF bands, and its utility was recognized at the 2012 World Radiocommunication Conference (WRC-12), when nine frequency bands, of width 25 to 500 kHz and in the range from 3 to 50 MHz, were allocated internationally for oceanographic radar.

2. Tsunami Observation using Oceanographic Radar

Oceanographic radar is able to measure changes in surface current velocities continuously, so its potential for detecting tsunamis was noted from the time it was first developed. Prompted in particular by the large amount of damage from the tsunami after the Sumatra-Andaman Earthquake in 2004, there has been much research on observing and detecting tsunamis using oceanographic radar.

Upon this background, the Great East Japan Earthquake and Tsunami occurred in March, 2011. This was the first tsunami observed using oceanographic radar, and coastal areas were observed not only in Japan but also across the Pacific Ocean in areas like California and Chile [1, 2, 3].

Changes in radial components of surface current velocities at 12 km offshore from 24.5 MHz radar installed in the Minato area of Wakayama City, together with records of sea surface height nearby, are shown in Figure 1. Fluctuations in surface current velocities detected 12 km offshore as the tsunami passed can be seen preceding the tide-gauge measurements in Kainan port.

It is also possible to compute tsunami height distributions from surface current velocities measured using oceanographic radar by a long wave approximation. Figure 2 shows the current velocity field measured by two 42 MHz radars installed on the Kameda Peninsula (one in Usujiri and one in Kinaoshi) of Hakodate City in Hokkaido, together with the tsunami height distributions estimated from them. The ability to obtain sea height distributions when a tsunami arrives in this way is extremely useful for disaster prevention.

3. Attempts to make Early Tsunami Monitoring Possible

If it is possible to use oceanographic radar to detect the arrival of a tsunami as far as possible from the coast, it will have great potential to reduce damage from the tsunami. To do this tsunami arrival must be recognized from changes in current velocities in real time.

However, current velocity measured by oceanographic radar include components due to tides and wind-driven surface currents, in addition to current velocity changes due to tsunamis. Such fluctuations due to other than tsunamis must be eliminated from current velocity values. Also, averaging is ordinarily done over periods of 15 minutes to one hour, to reduce the effects of noise

Figure 1: Tsunami observed in the Kii Channel[1]

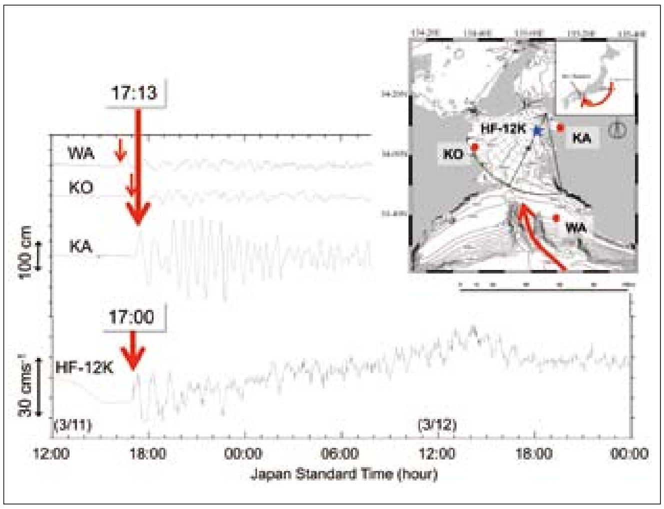


Figure 2: The tsunami height superimposed on the total current velocity field measured using two oceanographic radars[2]

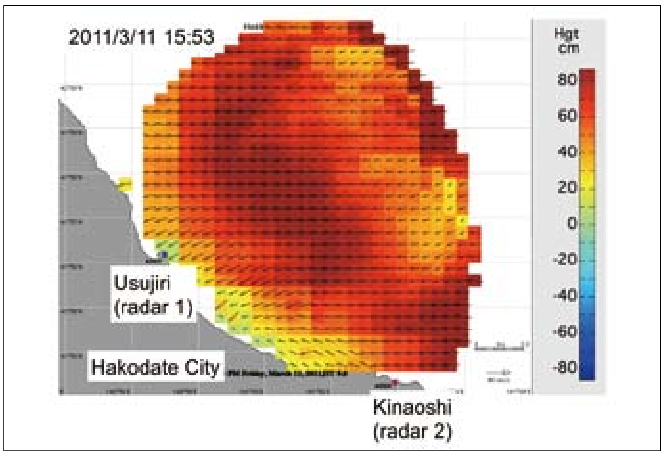
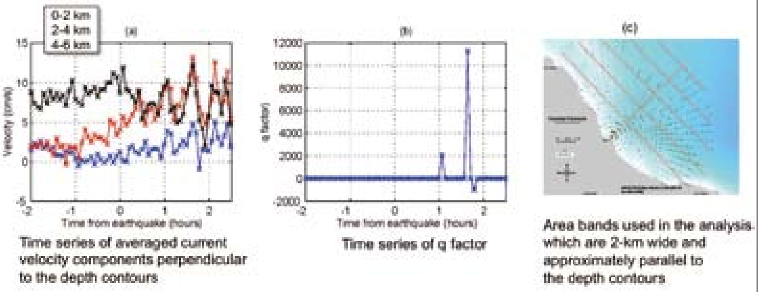


Figure 3: Time series of averaged current velocity components and q factor, and bands used in the analysis[4]



Time series of averaged current velocity components perpendicular to the depth contours

Time series of q factor

Area bands used in the analysis, which are 2-km wide and approximately parallel to the depth contours

when computing current velocities using oceanographic radar, but tsunamis travel quickly and their period is short, so there is no time to perform such averaging. Because of this, current velocities are read from a Doppler spectrum with large noise effects. (Velocities in Figures 1 and 2 have tidal components removed and filtering applied.)

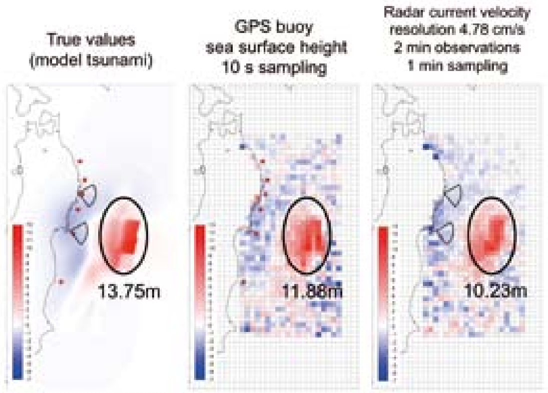
For these problems, a tsunami detection method with a simple computation using properties of tsunamis has been proposed[4]. With this method, radial current velocities obtained by short-term Doppler spectra (4-minute time resolution) in area bands 2-km wide and approximately parallel to depth contours, are resolved in the direction perpendicular to the depth contour and pointing onshore. These 4-minute velocity components are averaged over each band. An index indicating the arrival of a tsunami, called the q-factor, is computed by multiplying three values: the deviation in this time sequence from the average of the preceding hour, the difference with the velocity from two adjacent time intervals, and whether the velocities have increased or decreased with time in three adjacent bands, expressed as a value of 100 or 1.

Figure 3 shows time series of averaged current velocity components and the q-factors computed from them, for three 2-km bands ranging from 0 to 6 km, from the radar located in Kinaoshi, Hakodate City in Hokkaido. It is difficult to accurately determine when the tsunami arrived from the velocity time series, but the arrival time can be seen clearly in the q factor, by the sudden change in the value at the time. Computing the q factor itself is extremely simple, but it captures the characteristics of tsunami arrival well, so it is able to detect arrival early without needing to extract tsunami characteristics or perform complex filtering.

4. Application for Estimating Tsunami Origin

In the Great East Japan Earthquake, damage spanned broad areas including administrative facilities in populated areas, so the inability to know quickly, which areas were most severely hit, magnified the effects. On the other hand, if initial sea surface height of the tsunami can be obtained, it will be possible to numerically predict the areas of severe damage quickly. The accuracy of such numerical computations depends heavily on the accuracy of initial tsunami height distributions. Currently, we are attempting to compute the origin of the tsunami by back propagating sea-level data from GPS buoy point measurements, but if we can estimate how a tsunami spreads out from its origin using high resolution surface current velocity distributions from oceanographic radar, we can expect to increase the accuracy of estimating severely damaged areas significantly.

Figure 4: Sea surface height field of model tsunami source, from sea surface heights measured by GPS buoys and from radial current velocities measured by oceanographic radar[5]



RMSE	0.99m	1.07m
RMSE ratio*	7.2%	7.8%

*RMSE/max. height of true values

Using the 2011 Great East Japan Earthquake as a model, we verified the accuracy of using radial current velocities observed by oceanographic radar to estimate initial tsunami height as shown in Figure 4[5]. This result shows that computing initial tsunami height from the radial current velocities from two oceanographic radar stations, had approximately the same accuracy as values computed from data from six GPS buoys located over a wide area.

5. Conclusion

We have discussed how oceanographic radar measurement data has great potential for tsunami disaster prevention and mitigation, including detecting tsunamis, issuing early warnings, back-propagating to the origin of the tsunami, and predicting areas of serious damage. It is imperative to research these methods to further increase their accuracy. It is also desirable to improve the capabilities of oceanographic radar itself, studying spectral estimation methods for obtaining accurate Doppler spectra quickly, and increasing the SN ratio of receivers. It will also be important to establish hardware and operational methods that allow frequency sharing when operating multiple radar installations simultaneously.

Advancing oceanographic radar in these ways will contribute to preserving the marine environment as well as to tsunami disaster prevention, and we hope that building an oceanographic radar network that covers the nation-wide coast-line will demonstrate this capability.

References

1 H. Hinata, S. Fujii, K. Furukawa, T. Kataoka, M. Miyata, T. Kobayashi, M. Mizutani, T. Kokai and N. Kanatsu: "Propagating tsunami wave and subsequent resonant response signals detected by HF radar in the Kii Channel, Japan", Estuarine, Coastal and Shelf Science, Vol.95, pp. 268-273, 2011.

2 B. Lipa, D. Barrick, S. Saitoh, Y. Ishikawa, T. Awaji, J. Largier and N. Garfield: "Japan tsunami current flows observed by HF radars on two continents", Remote Sensing, Vol.3, pp. 1663-1679, 2011.

3 HELZEL: "WERA in Chile Observed Tsunami Signatures", WERA Newsletter, August 2011.

4 B. Lipa, J. Isaacson, B. Nyden and D. Barrick: "Tsunami Arrival Detection with High Frequency (HF) Radar", Remote Sensing, Vol.4, pp.1448-1461, 2012.

5 R. Fuji, H. Hinata, S. Fujii and T. Takahashi: "Influences of Time Integration on the Accuracy of Inversion based on Ocean Radar", Journal of Japan Society of Civil Engineers, Ser. B2, Coastal engineering, Vol. 69, pp. 436-440, 2013.