Submitted 27 April 2011, Accepted by IEEE for Presentation at Oceans '11 MTS/IEEE Kona Conference

Japan Tsunami Detected by HF Radars on Two Continents

Donald Barrick & Belinda Lipa
CODAR Ocean Sensors, Ltd.
Mountain View, CA 94043

An article 32 years ago [1] elucidated the mechanism whereby coastal HF radars could observe a tsunami; a subsequent analysis refined this concept and demonstrated a pattern recognition algorithm that could detect a tsunami by a single radar among the background currents present [2]. All of this work led to hopes that this new sensor might define modes of radar operation that could prove useful for tsunami observations. Because a tsunami is a rare event, this prior work was based on theory and simulations. As the number of worldwide HF radars grew and began operating as networks in real time, the question remained: could an HF radar actually observe this important event?

The powerful subsea earthquake off Japan on March 11, 2011 generated a significant tsunami. This provided the opportunity to search for and analyze data from HF radars operating at that time. We present evidence demonstrating that the CODAR SeaSonde radars have indeed detected that tsunami, and in fact, the first such tsunami observation reported with any HF radar. We examine preliminary data from radars on two continents: Japan and the U.S. West Coast. These data sets were measured at three different frequencies: 5, 13.5, and 42 MHz. Different analysis methods were employed for each case, highlighting the utility of the tsunami surface signal sensed by the radars, regardless of methodology details.

The surface currents seen by HF radars originate from Bragg scatter by ocean waves half the radar wavelength (with periods between 1.5 and 4.5 seconds). A tsunami is a shallow-water ocean wave with periods between 25 and 50 minutes. It is usually visualized as a series of height crests/troughs with open-ocean wavelengths of 400 - 800 km, corresponding to their above long temporal periods. These waves are accompanied by "orbital" back/forth flows or currents at their troughs/crests, the same as for any water wave. These orbital velocities at the tsunami crests and troughs impart additional velocities to the short Bragg waves that the radar sees. In deeper water, these tsunami-induced currents fall below a detectable threshold for HF radars, but as the depth of the continental shelf decreases to 200 m or less, the radar-detectable velocity increases, in fact more rapidly than does the tsunami height with decreasing depth. This is the mechanism whereby the tsunami becomes observable to HF radars.

Our first example of the detected tsunami comes from the West Coast of the U.S. off central California. There are several 13 MHz SeaSondes looking into the Pacific surrounding Golden Gate, a part of the U.S. coast with minimal continental shelf. Here we examined the Bragg-echo spectral peak, looking at its centroid shift over time in 256-s steps. A plot of this Doppler shift, converted to radial velocity with respect to the radar at Commonweal is shown in Fig. 1, for the three SeaSonde antenna signals (two colocated crossed loops and monopole). This represents the echo from a 3-km range circle 9-km offshore where water depth varied between 20 - 50 m. We study the period from 14:00 to 20:30 UT on March 11. The figure shows the onset of the current variations beginning about 16:00 that represent the tsunami. Tides and other longer-term trends have been removed, so that the tsunami-induced current is evident. Swings as much as 25 cm/s are visible.

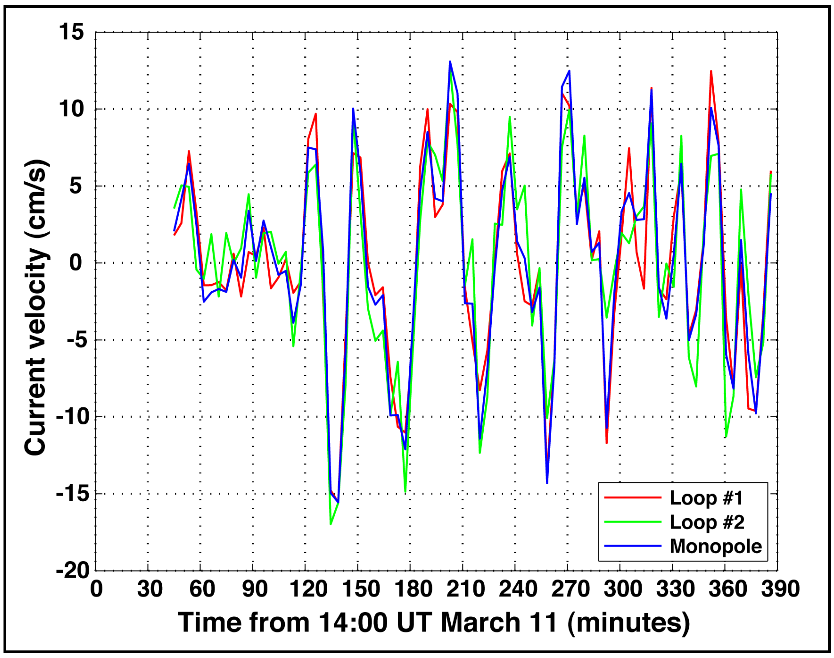

Figure 1.
Radial current velocity measured from SeaSonde at Commonweal, 25 km Northwest of Golden Gate, California

Submitted 27 April 2011, Accepted by IEEE for Presentation at Oceans '11 MTS/IEEE Kona Conference

We also show in Fig. 2 the water height measured at Ft. Point under the Golden Gate bridge in San Francisco, which is 25 km from the radar. The latter confirms the onset of the tsunami at about 16:00; both show period variations between 15 and 40 seconds that were confirmed in other records of this event. In the case of the water level, the tidal fluctuation and longer-term trends have also been removed, as they were in the radar record. Also, one should not expect quantitative agreement among features, because height and current are not in phase with each other, but are in quadrature as determined by boundary conditions at the coast. Other sites on the U.S. West coast also observed the tsunami: both at 13 and 5 MHz.

We have also captured similar time-history records of the tsunami from 42-MHz SeaSondes in Japan on the Hokkaido coast, looking Northeast. In this case, the radial-velocity current patterns were calculated and analyzed, a process different than that used in our California study above. Water depth in the measurement region was also 40 - 50 m. Velocity swings were as much as 15 cm/s. Temporal period here is better defined, close to 40 minutes. One expects that the periodicity to be more obscured in California in both water level and surface velocity, because of the constructive and destructive interference of different tsunami propagation ray paths across the intervening 8200 km ocean basin. More results from the Japanese observations will be presented, including animations.

This is the first step: actual observations of a tsunami for the first time with HF radar and independent confirmation. Now we begin refining the relevant dependencies and improving the real-time tsunami detection/observation software.

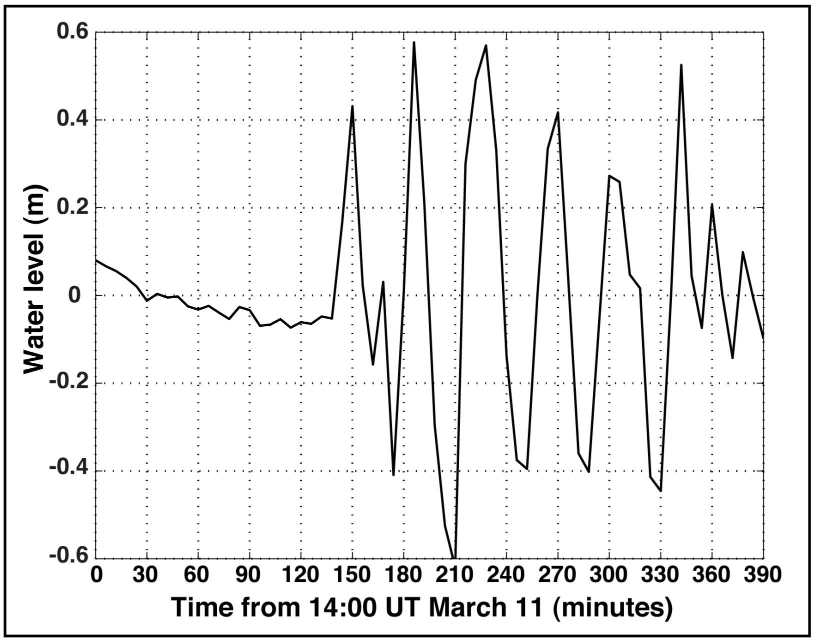

Figure 2.
Water level observed at Ft Point in San Francisco under Golden Gate Bridge.

References

1. D. E. Barrick, "A coastal radar system for tsunami warning," *Remote Sensing of Environ.*, vol. 8, 1979.
2. B.J. Lipa, D. E. Barrick, J. Bourg, and B. L. Nyden, "HF Radar Detection of Tsunamis," *Journal of Oceanography,* vol. 62, 2006.

CODAR OCEAN SENSORS

CODAR Ocean Sensors
1914 Plymouth Street,
Mountain View, CA 94043 USA

+1 (408)773-8240
info@codar.com
www.codar.com