CODAR OCEAN SENSORS

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TSUNAMI DETECTIONS WITH CODAR SEASONDE® HIGH FREQUENCY (HF) RADAR

An investigation on using our early HF CODAR radars to detect or measure the strength of tsunami surface signatures was conducted and published in the late 1970s [Barrick, D. E. (1979), A coastal radar system for tsunami warning, "Remote Sensing of Environment" , vol. 8, pp. 353-358]. (available for download as a PDF at the publications section of our website http://www.codaros.com/bib_79-70.htm) At that time, the result seemed of marginal utility because the radars could see only 30-40 km at best, providing little tsunami warning time. Nowadays our SeaSonde® HF radars (successors of the CODAR model) can see out farther, potentially increasing the time between tsunami detection and it's arrival at the shore.

First, a little on how tsunami waves propagate into an area and how the HF radar sees them. Then, a bit on how data from the radar network in parallel “current-mapping and tsunami modes" might be processed and transferred when needed.

HOW TSUNAMI WAVES PROPAGATE

Typically it is an earthquake, volcanic eruption or underwater rockslide that generates a tsunami, which is a series of waves that have time periods between consecutive crest passages typically between 20 and 30 minutes. In any ocean wave, the time period (once generated) never changes; the spatial period, height of the wave, and velocity of propagation all change depending on the water column depth, but the time period is invariant.

To use an example, suppose the tsunami wave propagating across an ocean basin has a height of 20 cm (crest height) in water depth of 4000 m with a period of 20 minutes. In water this depth, it will have a propagation speed near 700 km/hr (independent of its time period), but a spatial period of 300 km. There are very few technologies that could possibly detect this potentially damaging wave in deep water, in real time; with its small crest height, it will simply raise any floating buoy or ship by 20 cm over a 20 minute period as the crest passes by, an undetectable motion. Bottom pressure sensors (like those on the NOAA-engineered DART buoys in the Pacific Ocean) can feel the weight of this water rise as it passes overhead.

As this wave moves into shallower water (e.g., 180 m depth at a distance of 100 km from shore, typical of parts of United States bathymetry), its crest height will increase to 50 cm, and its speed will slow to about 140 km/hr. At even shallower depths closer to shore, crest height increases further, while propagation speed decreases as does the spatial period.

HOW AN HF RADAR "SEES" A TSUNAMI WAVE

The most sensitive measurement the HF radar makes is velocity, from the Doppler shift of the echo. However, what the HF radar sees is NOT the very fast propagation speed of the tsunami wave (e.g., 140 km/hr at 180 m depth), but the "current speed" of the orbital velocity at the crests and troughs. The HF signal is scattering from Bragg waves that are 6 to 30 meters long, depending on the radar transmitted frequency. These, in turn are shifted by any underlying currents. Near the crest and trough of ANY wave (including a tsunami wave), the water undergoes an orbital motion: forward at the crest and backward at the trough. For the case considered here, this velocity is +10 cm/s, which is enough to be detected by the HF radar from the background noise. With a spatial period of 45 km at 100 km distance, this pattern will be apparent in the data, because closer to shore at the next trough 22 km away, the current will reverse, and be -10 cm/s.

As the tsunami moves into shallower water 90 m deep, at say, 50 km from shore, this orbital velocity will increase to +/-17 cm/s, while the spatial period decreases (between crest and trough) to perhaps 16 km. So, you begin to see even stronger currents with shorter spatial periods as the tsunami wave gets closer, into shallower water-- an increasingly robust signal.

The variation of the tsunami wave with distance from shore is known because the depth is known. What isn't known is the strength of the tsunami wave. This strength is obtained from the orbital velocity measured by the HF radar at crests and troughs: the higher the orbital velocity, the more energy in the tsunami wave, and the higher the crest heights will be when the tsunami steepens and crashes on shore in very shallow water. Also, by looking at the strength of the currents as two crests pass the same point, one could make a prediction of how many tsunami waves will be devastating, till it dies out. In other words, is it still increasing, or has begun to decrease?

HOW COULD SOFTWARE PICK OUT A TSUNAMI FROM A BACKGROUND OF SIMILAR PERIOD OR WAVELENGTH SIGNALS?

There really are no other significant waves on the ocean of 10-30 minute periods other than tsunamis. That is a much longer period than the very longest swells, which might have 15-20 second periods. And it is much shorter than the shortest tidal periods of 6 hours (tides are just another type of wave, like tsunamis and swells.) To put this into perspective, there are typically 20 tsunami-genic earthquakes that occur anywhere on earth per year, with 4-6 of these having sufficient magnitude to cause varying amounts of destruction and loss of life.

HOW MUCH TIME IS THERE BETWEEN TSUNAMI DETECTION AND ARRIVAL AT THE SHORE?

There are several factors affecting the time between tsunami detection by the radar and it's arrival at the shore. The bathymetry is a very important factor; a wider, shallower shelf will make it possible to detect the signature wave farther offshore than in an area where the bathymetry is very deep right up to the coast. A second important factor is the amplitude of the tsunami wave that gets generated by the earthquake or rockslide. This varies widely also. CODAR staff have written simple routines that will estimate the wave detection-versus-onshore arrival time for any place on the globe.

HOW WOULD "TSUNAMI MODE" DATA PROCESSING WORK?

Only very rarely would there be a tsunami-like wave in an HF radar's field of view. In the meantime, one could be performing parallel processing of data for standard surface current mapping and monitoring of general wave parameters (such as significant wave height), with background parallel processing for the tsunami mode taking place in real time on the field computers at the radar receive stations. The tsunami monitoring is like the normal SeaSonde current and wave processing, but update rates occur at a much shorter interval (2-4 minutes) so as to catch the rapidly evolving nature of the tsunami field. Because, tsunamis are present so rarely, one wouldn't necessarily need or want to transfer all of the tsunami data back at near real-time intervals, if there are limited communication baud rates available at radar field station. However, one could have the data sent back regularly at near real-time, or could program the system for rapid transmissions only when an earthquake and/or tsunami has been detected (by another sensor). Typically any earthquake that can generate a significant tsunami is detected seconds after it occurs (and the "tsunami watch" begins). At that point, the central station (typically located at client's headquarters) linked to the remote SeaSonde radar computers could be triggered to begin requesting the higher-rate tsunami-mode data from the remote stations. Then at the central station(s), you begin to do the calculations to look for the telltale orbital pattern and estimate the strength of the tsunami as it approaches that stretch of coast. With SeaSondes, it is usually the central station at the users office that initiates and requests data transfers from the remote stations, but this could also work in reverse.

Such special software for an operational "tsunami mode" configuration must still be created. CODAR Ocean Sensors is interested in spearheading or assisting this effort if #1. It would be used in the field (after plenty of bench testing), #2. The SeaSonde owner does comparison work with other tsunami detection/monitoring equipment (or at least share such data and allow us to do comparisons), and, most important, #3. This work is viewed as a research effort. Results from a research effort such as this often produce something a bit different that what was initially sought, but in many occasions that turns out to be even more useful than the original target.

THE REALITY -- WHAT OTHER TECHNOLOGY IS OUT THERE, AND OF WHAT BENEFIT COULD USE OF HF RADARS REALLY BE FOR TSUNAMI OBSERVATION AND RESEARCH?

There are clever numerical computer model programs that can predict earthquake-generated tsunami impacts, along with when, where and how strong these impacts will be. The longer the wave (and tsunamis are very long waves), the simpler and more robust the model program becomes. Such programs includes ocean scale bathymetry. Since earthquakes at or near the sea can only occur at fault lines (most of which are known), one wouldn't even need to wait for an earthquake to happen to run such a program. Every possible epicenter point (e.g. 50 km spacing) along these fault lines could have the model run for it, with different levels of intensity and duration --all prior to any actual seismic activity. (Today's processing horsepower and data-base storage are more than adequate for this job.) The coastal locations at risk for impact can be predicted, along with time from epicenter to impact at coast. At that point it is a question of whether the international community has created protocol for rapid data dissemination of seismic data and tsunami model predictions between foreign governments; if so, then local authorities would receive warnings and have capability to spread instructions to civilians in the at-risk locations. Such models, modes of cooperation, and local emergency warnings are in effect at very few regions on the globe, and might take years/decades to develop.

While models taking into account fault lines, and bathymetry are obviously critical for tsunami prediction and planning, models are not perfect, and will benefit from real-time improvement. Localized and quantitative data from instruments such as HF radars and bottom-mounted pressure sensors (also not considered fully operational for this application) will fine tune the cruder model forecasts. Any better refinements will aid in preparations, e.g., by focusing on which areas are going to need helicopter and rescue vessels. Having real data gathered by a country's own HF radar could also be another source of early detection directly available to local authorities, in case the string of required international communications fails or hits a fatal choke point. Global models may not necessarily work perfectly for a particular area whose bathymetry or physical parameters have not accurately been quantified in the model database. (This is especially true in the developing nations who do not conduct regular bathymetric/hydrological surveys.) And, those instances when a quake epicenter is close to shore may not allow enough time for the international communication chain to occur, leaving a direct, local detection with HF radar or a pressure sensor as the only hope for advance detection/warning and information refinement.

Finally, the present tsunami prediction models and early warning schemes have been designed for those generated by earthquakes, so if the source of the tsunami wave train is an underwater rockslide, then the present scheme of an earthquake detection activating the tsunami warning will not occur.
A more detailed analysis of tsunami detection using SeaSonde HF radars is presently underway, including simulations. Results of this study should be available within the coming weeks, and will be posted on our website (www.codaros.com).

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