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Observing the 2011 Honshu Tsunami at the Coast of Chile by HF radar

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The magnitude 9 earthquake near the coast of Japan at 11 March 2011 05:46 UTC triggered a major tsunami, which hit the Japanese coast about 30 minutes later and caused severe damage including the destruction of the nuclear powerplant in Fukushima, where the wave height exceeded 9.3 m. The tsunami propagated across the Pacific ocean and arrived at the coast of Chile near Concepción about 23:00 hours later. The tsunami's amplitude in this area still reached up to 1.8 m height measured by a tide gauge at Lebu located about 110 km south of Concepción.

In the deep ocean, a tsunami wave is hard to detect. Bottom-mounted pressure sensors, which form a network of *Deep-ocean Assessment and Reporting of Tsunamis* (DART) buoys are commonly used. Recent developments within the *German Indonesian Tsunami Early Warning System* (GITEWS) include buoys with GPS sensors to measure the tsunami at the surface. Remote sensing of tsunamis can be achieved by satellite altimetry, however a dense network of satellites and a real-time downlink of the data is required for an early warning application. HF radars can measure the ocean currents generated by the tsunami, which reach high levels up to 1 m/s once the tsunami enters from the deep ocean (4,000 m depth) into more shallow waters (200...500 m depth). An HF radar system uses electromagnetic waves in the decameter range (10...50 m), which due to groundwave propagation are linked to the ocean surface and propagate beyond the horizon. Depending on the radar frequency, ranges up to 200 km can be achieved for measuring surface currents by means of Bragg-resonant backscatter from the ocean waves.

The University of Concepción had just finished the installation of an 8-channel WERA HF radar system at Rumena (37°11'S, 73°37'W) about 60 km south of Concepción, and was able to start the measurements right in time to capture the tsunami wave. The system at Rumena was operated in the 23 MHz frequency range and reached up to 45 km off the coast. The shelf in front of Rumena is very narrow. Shallow water, i.e. less than 200 m depth, extends to about 20 km. At 24 km, the depth is already 1,100 m and at 47 km it goes down to 2,100 m. As expected from theory, clear tsunami-induced current signatures could be observed up to distances of 20 km, with a strong increase in current variation within the closest 7 km. However, the WERA HF radar was also able to measure the bands of oscillating currents at distances up to 40 km at 1,000 m depth. The structure of the observed ocean currents caused by the tsunami significantly correlates with the sea level measured by the tide gauge at Lebu, 50 km south of Rumena.

The tsunami's speed at 4,000 m water depth is about 700 km/h and it slows down to 150 km/h only within the closest 10 km. This narrow shelf allows the tsunami to be detected at a range of 10 km about 4 min before it arrives at the coast. Simulations had shown early warning times of 45 min, if the shelf is 100 km wide and the measurements at Rumena are confirming the theory behind the simulation.