DART BUOYS PROVIDE REAL-TIME REPORTING OF TSUNAMIS

Summarized by L. Kong (ITIC) from International Tsunami Symposium 2001 Proceedings
E N. Bernard, F. I. Gonzalez, C. Meinig, and H. B. Milburn, Early Detection and Real-Time Reporting of Deep-Ocean Tsunamis, NTHMP Review Session, Paper R-6
M. C. Eble, S. E. Stalin, and E. F. Burger, Acquiistion and Quality Assurance of DART data, Session 5, Paper 5-9

The Deep-ocean Assessment and Reporting of Tsunamis (DART) Project is an ongoing effort of the U.S. National Tsunami Hazard Mitigation Program (NTHMP) to develop and implement a capability for the early detection and real-time reporting of tsunamis in the open ocean. Project goals are the reduction in loss of life and property in U.S. coastal communities, and the elimination of false alarms. A network of real-time reporting DART buoys sited in regions where great earthquakes can potentially generate destructive tsunamis was conceived to provide timely warnings to at-risk communities. (Figure 1). The siting of buoys ensured the detection of tsunami within these regions within 30 minutes of the generating earthquake, followed by the immediate relay of the tsunami data to the warning centers and the states.

Bottom Presssure Recorders (BPR's) developed at the National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory (PMEL), and used for over a decade to measure and record tsunami amplitudes of less than 1 cm in the open ocean, are the foundation of the DART system. DART development required the sustained efforts over the past five years of over 25 scientists, engineers, technicians, and software developers. The NTHMP provided about US $3.6 million of the US $6.2 million, including ship time, required for development and implementation.

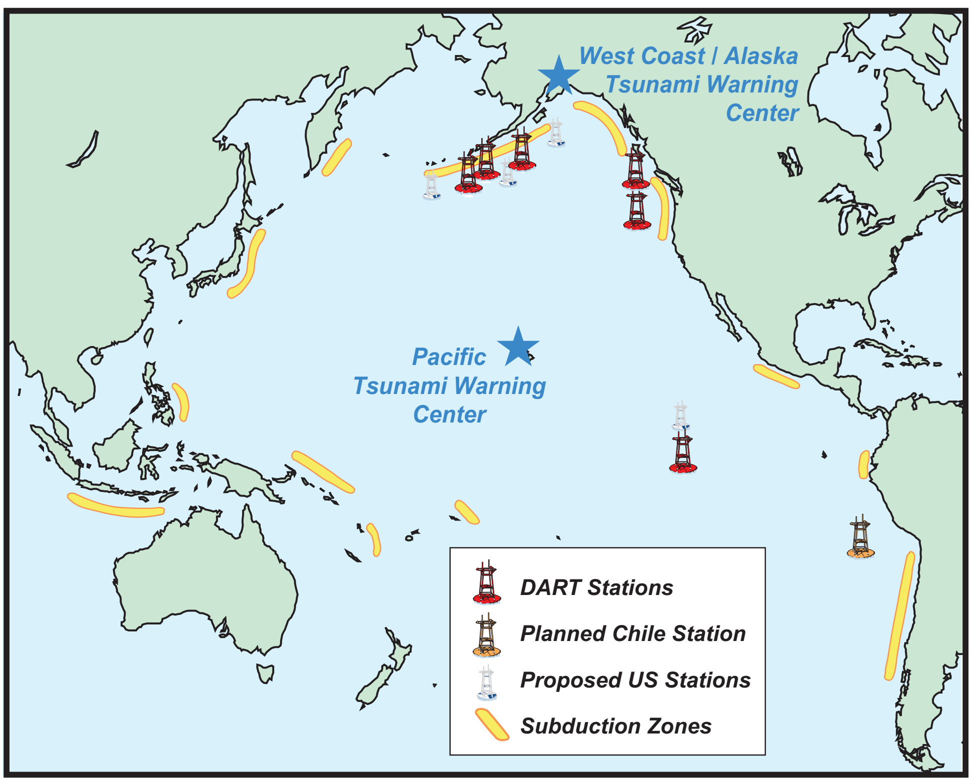

Figure 1. Locations of the DART real-time reporting buoys, including the planned cooperative US/ Chile buoy off Iquique, Chile. The locations of subduction zones where large earthquakes have produced significant Pacific-wide tsunamis are shown in yellow.

Although there has been no detected tsunami generated since the array has been installed, end-to-end tests of each DART system have been conducted in-situ, with pre-programmed, artificial signals used to trigger the initiation of the tsunami reporting mode. Additionally, DART stations have been triggered into tsunami reporting mode on several occasions when seismic surface waves from local earthquakes have imparted vertical acceleration to the BPR that induced an apparent change in pressure.

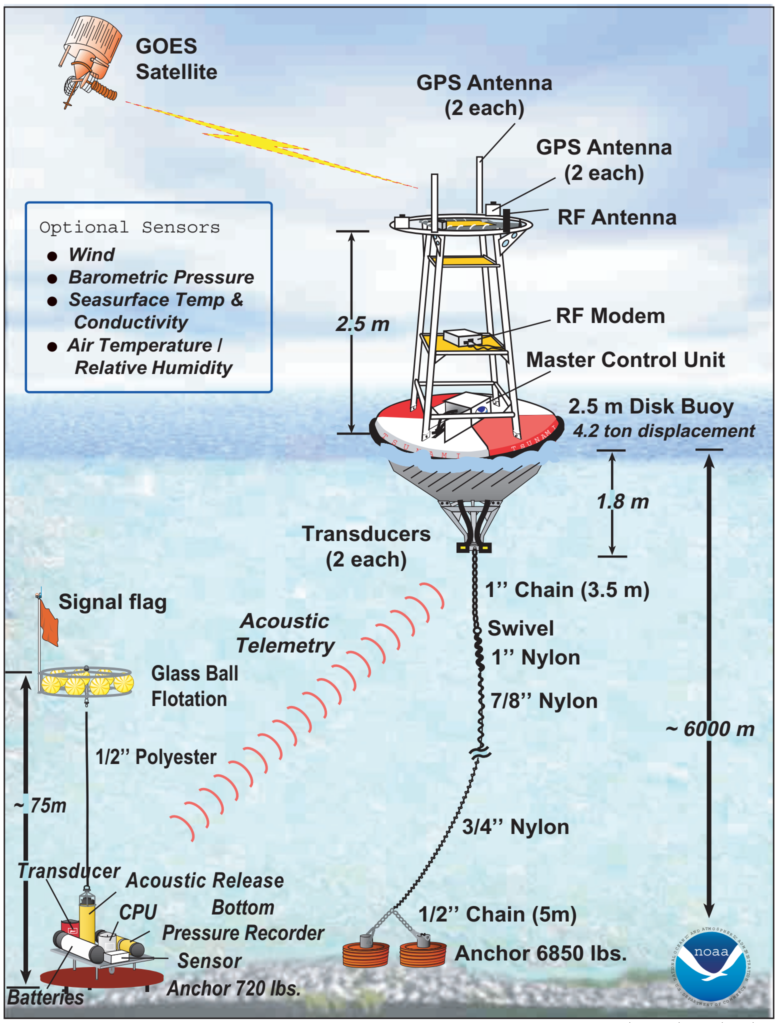

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Figure 2. Schematic of the DART mooring system showing the coupling between the bottom pressure recorder package and the surface buoy anchored nearby.

DART Data Acquisition and Dissemination

A DART mooring system consists of an anchored seafloor package and a moored surface buoy for real-time communications. Each seafloor system couples acoustic modem technology with bottom pressure recorders capable of detecting and measuring tsunamis with amplitude as small as 1 cm in 6000 m of water. The BPR uses a pressure transducer to make 15-s averaged measurements of the pressure exerted on it by the overlying water column.

An acoustic link is used to transmit the BPR data from the seafloor system to its accompanying DART surface buoy. The commercially-available modem pairs are technologically similar to the familiar telephone-based computer modem.

The GOES Data Collection System (DCS) is used to transmit data in near real time. The GOES DCS is a communications system that uses a transponder carried on the GOES spacecraft to relay UHF transmissions from data collection platforms by S-band to properly equipped ground receiving stations. Once data are relayed to the ground stations, the signals are demodulated and immediately disseminated to NOAA's Tsunami Warning Centers in Alaska and Hawaii, and to PMEL for quality control.

A DART system operates in two modes. Tide mode provides 15-minute data every hour to verify that the system is operating properly. The detection algorithm running in the BPR generates predicted water height values and compares all new data samples with the recently predicted values (Mofjeld, http://www.pmel.noaa.gov/tsunami/tda_documentation.html). If two 15-s water level values exceed that predicted by a preset cutoff threshold, typically 1-3 cm, the system will go into Tsunami mode. In Tsunami mode, high frequency data are transmitted at short intervals on the random channel for a minimum of three hours. During the first hour, the BPR sends 1-min data, comprised of the average of four 15-s values, for the preceding two hours (120 values). This redundant transmission scheme ensures the receipt of all data during an event. If the ocean is still perturbed after the nominal 3 hours of the Tsunami mode, the hourly self-timed transmission of 120 1-min averaged values will continue. The system returns to normal tide-reporting mode only after 3 hours of undisturbed water heights.

The DART Data Quality Control web page (http://tsunami.pmel.noaa.gov/dartqc/WaveWatcher) is accessible to all interested parties, including State officials and the Tsunami Warning Centers. Tsunami Warning Centers, however, rely on separate, dedicated data streams to acquire their operational data.

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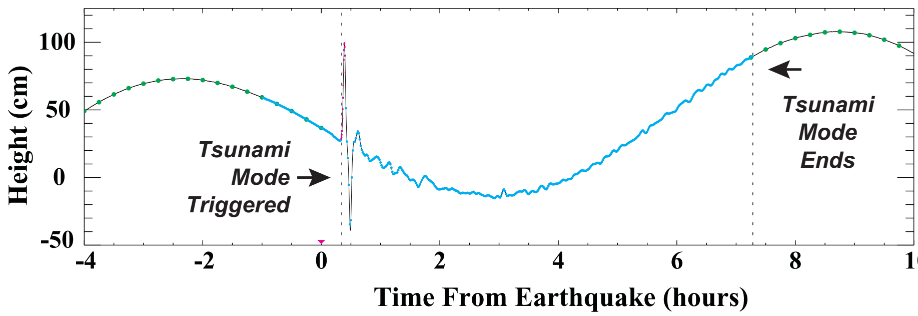

Figure 3. An artificially generated tsunami signal superimposed on a synthetic time series illustrates the sampling scheme and the transitions between tide and event modes.

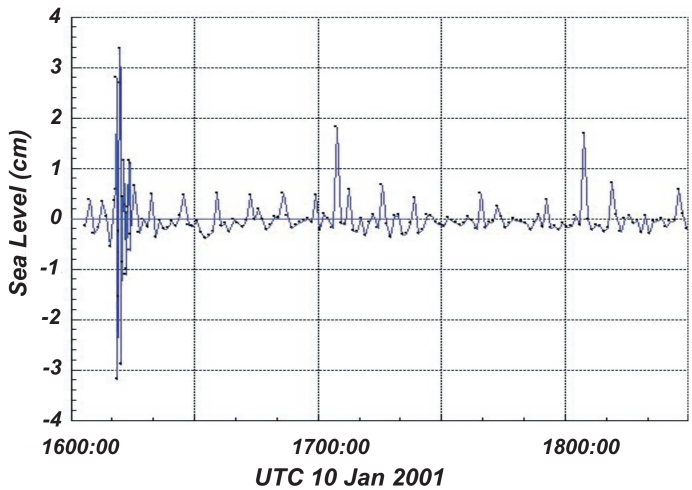

Figure 4. DART data for the January 2001 Alaska earthquake (tides removed).

Earthquake Triggers DART Buoy

The 10 January 2001 M6.9 Alaskan earthquake was an excellent example of the value of DART data to quickly confirm potentially destructive tsunamis and reduce false alarms. The earthquake occurred at 07:03 local time about 70 miles southwest of Kodiak, Alaska, and an information bulletin was issued at 07:08 by the warning center. At 07:11, a DART system at 51 deg N and 157 deg W picked up the earthquake waves that induced an apparent sea level change of approximately six cm and triggered the buoy to start transmitting 1-minute data. By 07:13 these data were plotted on the web site, and showed no tsunami present. Charles McCreery, Geophysicist-in-Charge of the National Weather Service's Pacific Tsunami Warning Center, said, "While the earthquake was too small to automatically trigger a tsunami warning, the Pacific TsunamiWarning Center closely monitored the Kodiak buoy data to quickly confirm that potentially destructive tsunami waves were not propagating towards Hawaii or the rest of the Pacific."

The Future

The NTHMP is seeking to expand the array from six DART buoys to ten buoys in order to achieve better coverage for tsunamis generated in Alaska, which pose the greatest threat to the five western U.S. states, add coverage of South America, which has generated destructive tsunamis in the past, and continue good coverage of the Cascadia Subduction Zone.

The siting strategy has required the evaluation of trade-offs between two important, but somewhat conflicting, operational requirements:

1. Early detection to maximize the time available for assessment and warning
2. Full coverage of tsunamigenic zones, with sufficient spatial resolution to estimate the directional distribution of the tsunami energy.

Figure 5 graphically illustrates these tradeoffs. A minimum of three DART measurements are required to estimate the width of the main beam of tsunami energy. Since the beam widens with increasing distance from the source, DART station spacing increases and fewer stations are required. However, the time available for assessment and warning decreases because the tsunami takes longer to reach the stations. In

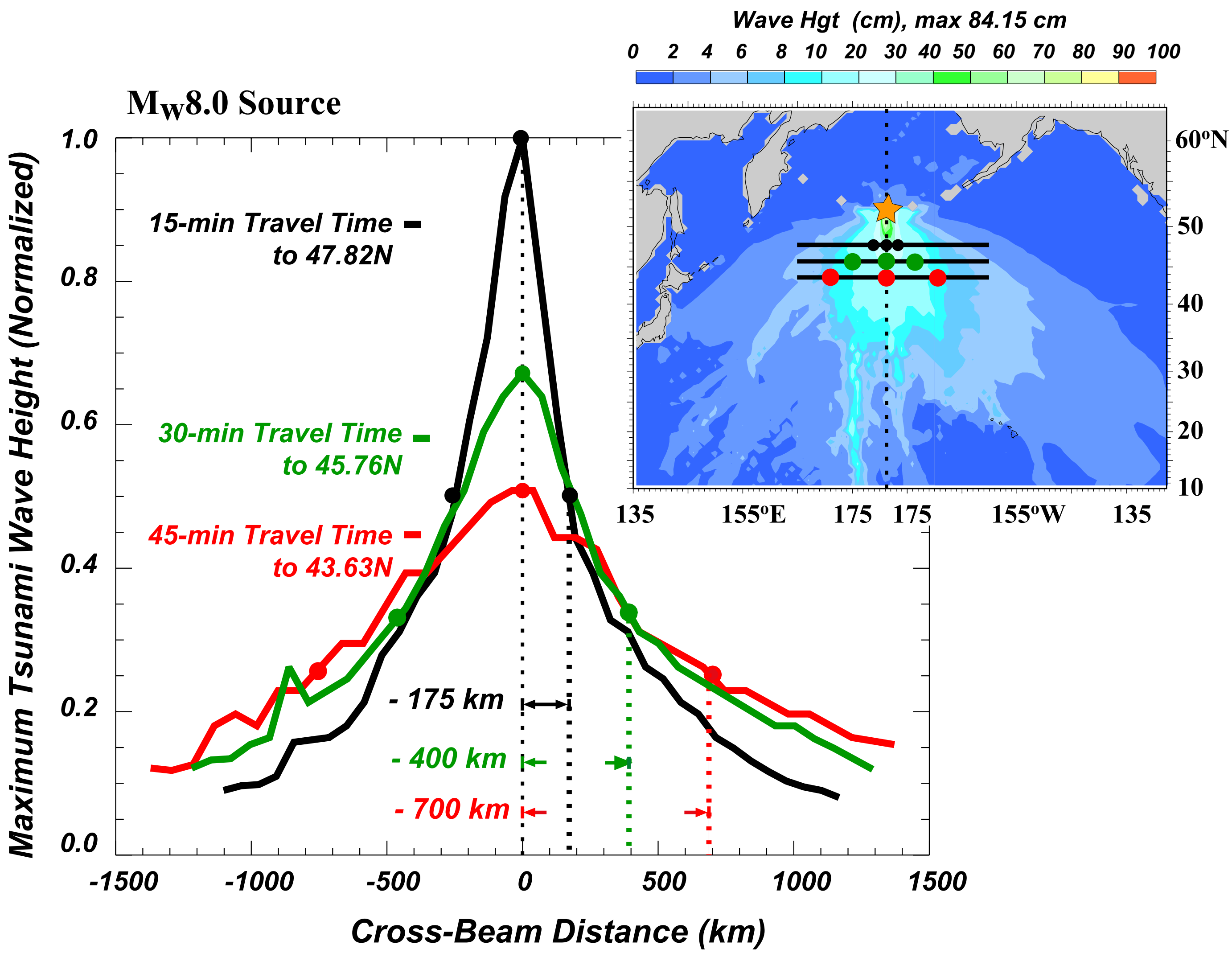

Figure 5. Trade-off between early detection and source coverage. Map shows maximum wave height model results for a magnitude 8.0 earthquake (yellow star) in Alaska, with horizontal lines indicating location of computed maximum wave height profiles, shown to left. Dots indicate hypothetical DART measurements at the "half-amplitude" points, and the dashed vertical lines suggest minimum DART station spacing required to estimate the height and width of the profile for detection 15, 30, and 45 minutes after the earthquake.

addition to these operational considerations, siting decisions are naturally constrained by the total number of stations that can reasonably be established, given practical logistical problems and budgetary realities. Currently, the cost to purchase a DART buoy is about US $250,000 and the cost to maintain a DART buoy is about US $125,000/year exclusive of ship time. About 20 days of Class I ship time are required each year to maintain the current 6-station array.

Under a joint Memorandum of Agreement between the U.S. National Weather Service Pacific Region and the Servicio Hidrografico y Oceanografico de la Armada de Chile (SHOA) to improve the Chilean sea-level monitoring system, PMEL will be installing a DART buoy at 20 deg S, 85 deg W offshore of Iquique, Chile. The DART system to be deployed will be identical to those currently deployed in the northern Pacific, and will utilize the standard DART communications systems for data transmission. When in place, the system will provide real-time confirmations of offshore tsunamis for Chile. Points of contact for this project are Dr. Eddie Bernard, Director, PMEL, and Dr. Rodrigo Nunez, Head, Dept. of Oceanography, SHOA.