Acquisition and quality assurance of DART data

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Abstract. The Deep-ocean Assessment and Reporting of Tsunamis Project is an ongoing effort of the U.S. National Tsunami Hazard Mitigation Program 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. The real-time data path begins at the bottom pressure recorder anchored at any one of five sites currently occupied in the network of real-time reporting buoys around the Pacific Ocean Basin and terminates with the end user. Data quality is monitored along the transmission path with the routine evaluation of system power measurements and message quality indicators embedded in each transmission.

1. Introduction

Bottom pressure recorders (BPR's) developed at the Pacific Marine Environmental Laboratory (PMEL) in Seattle, Washington have been used for over a decade to measure and record tsunami amplitudes of less than 1 cm in the open ocean. This technology is the foundation of the Deep-ocean Assessment and Reporting of Tsunamis (DART) system developed as part of the U.S. National Tsunami Hazard Mitigation Program (NTHMP). A network of real-time reporting DART buoys was conceived to provide timely warnings to at-risk communities. To ensure the early detection of tsunamis and to acquire data critical to real-time forecasts, six sites were chosen in regions where great earthquakes would potentially generate destructive tsunamis. There are currently five DART real-time reporting buoys deployed, the sixth in the original NTHMP network plan (NTHMP Steering Group, 1996) is scheduled for deployment this August 2001. Half of the six buoys are sited in the North Pacific Ocean south of the Alaska Aleutian Island chain. Two DART systems are sited off of the United States Pacific Northwest Coast. The sixth buoy in the network will occupy a site in the Equatorial Pacific, providing coverage of the seismically active subduction zone along the South American Coast. This extended region was recently impacted by an 8.1 magnitude earthquake followed by a destructive tsunami off the coast of Camana, Peru.

Locations of the DART real-time reporting buoys in the network are given in Table 1. Future plans include increasing the network from six to ten buoys. Three additional DART systems would be sited in the North Pacific Ocean and one would be added in the Equatorial Pacific. A map of the DART network is shown in Fig. 1. The red and white colored buoys identify the five currently deployed DART stations and the Equatorial station that will be occupied by the end of the 2001 field season. Blue and white buoys show the locations of proposed DART stations.

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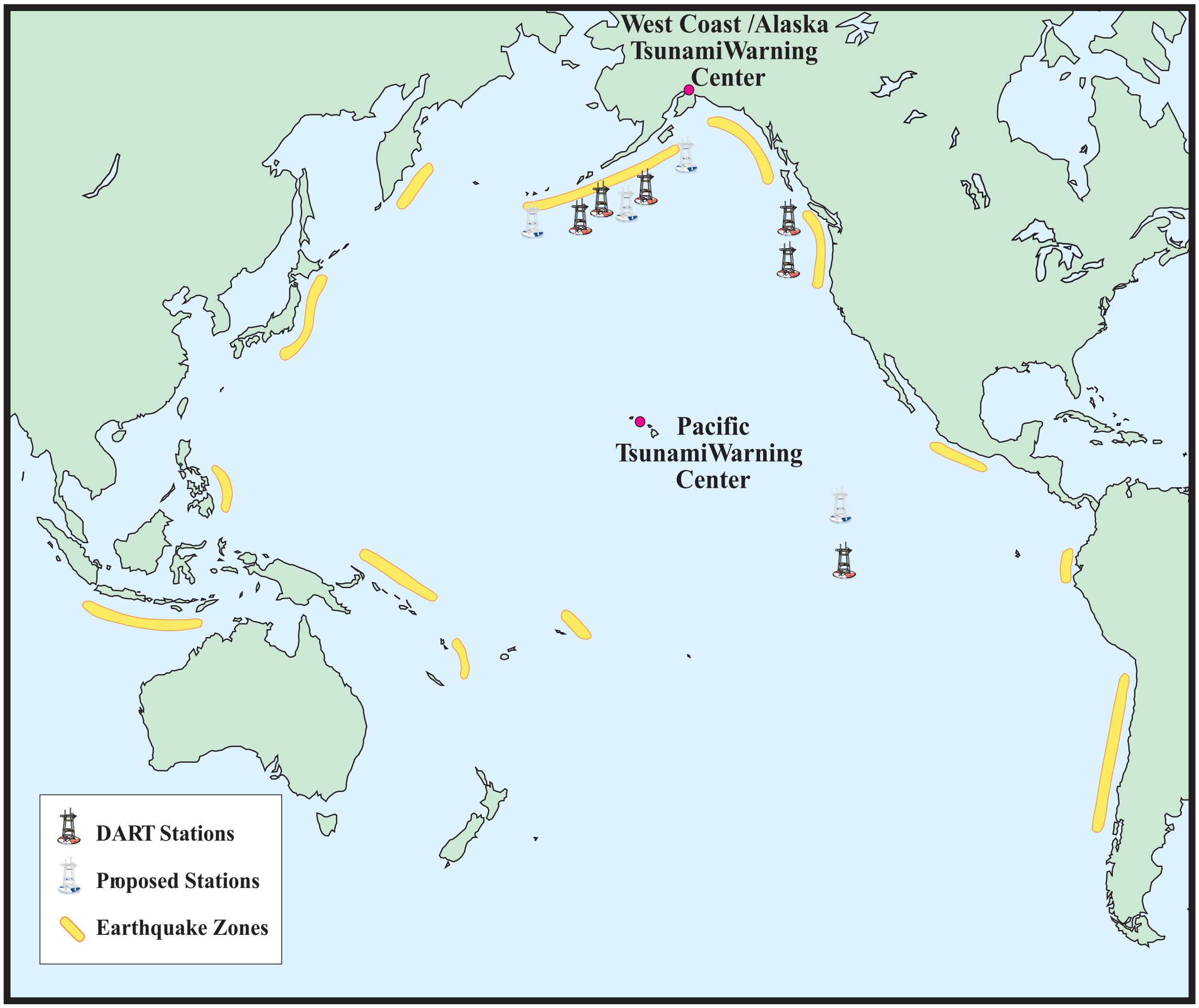

Figure 1: Locations of the DART real-time reporting buoys.

2. Mooring System

The DART mooring system is illustrated in Fig. 2. Each system consists of a seafloor BPR and a moored surface buoy with related electronics for real-time communications. The BPR uses a pressure transducer manufactured by Paroscientific, Inc. to make 15-s averaged measurements of the pressure exerted on it by the overlying water column (Eble *et al.*, 1991). These transducers use a very thin quartz crystal beam, electrically induced to vibrate at its lowest resonant mode. In DART applications, the transducer is sensitive to changes in wave height of less than a millimeter. An acoustic link is used to transmit data from the BPR on the seafloor to the surface buoy. The data are then relayed via a NOAA Geostationary Operational Environmental Satellite (GOES) satellite link to ground stations, which demodulate the signals for immediate dissemination to NOAA's Tsunami Warning Centers

Table 1: DART system positions.

DART site	Depth (m)	Latitude	Longitude
D128	2740	45° 51.65′N	128° 46.34′W
D130	3460	42° 54.18′N	130° 54.63′W
D157	4480	52° 5.19′N	156° 36.69′W
D165	4850	50° 31.84′N	164° 56.47′W
D171	5500	46° 38.52′N	170° 48.00′W
D125	—	∼5°S	∼125°W

in Alaska and Hawaii (see Fig. 1) and the Pacific Marine Environmental Laboratory (PMEL).

Under normal tide reporting conditions, in which no tsunami or earthquake induced perturbation has been detected, the BPR sends a four-sample data message to the surface buoy on an hourly schedule. The hourly messages are comprised of four 15-min values, each of which is calculated from single 15-s averages. Individual 15-s averaged data values are stored internally by the BPR for post-recovery downloading and processing. The BPR can make up to three tries to get acknowledgment from the surface buoy that the hourly data message was received. Data are then reformatted and sent via the GOES self-timed channel, then ultimately displayed at http://tsunami.pmel.noaa.gov/dartqc/WaveWatcher to show open ocean tides that dominate the data record at each DART site.

The hourly messages give a regular indication of the health and condition of the entire system. If data are not received from the bottom, the surface buoy uses the Global Positioning Satellite (GPS) buoy position for the self-timed message. The reported position is checked to ensure that the buoy has not parted from its anchor. An 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 cutoff threshold of ∼3 cm, the system will go into event mode. In event mode high frequency data at short intervals is transmitted on the random channel (132) for a minimum of 3 hours. Every event mode GOES transmission includes time T = 0, which corresponds with the second out-of-bound value that was detected, as well as an ID that identifies data type and time as minutes after T = 0. During the first hour, the BPR sends 1-min data, comprised of the average of four 15-s values, for the preceding 2 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 event 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. Figure 3 shows an artificially generated tsunami signal superimposed on a synthetic time series to illustrate the sampling scheme and the transitions between tide and event modes. A perturbation that exceeds the threshold at hour 3 causes the BPR to remain in event mode.

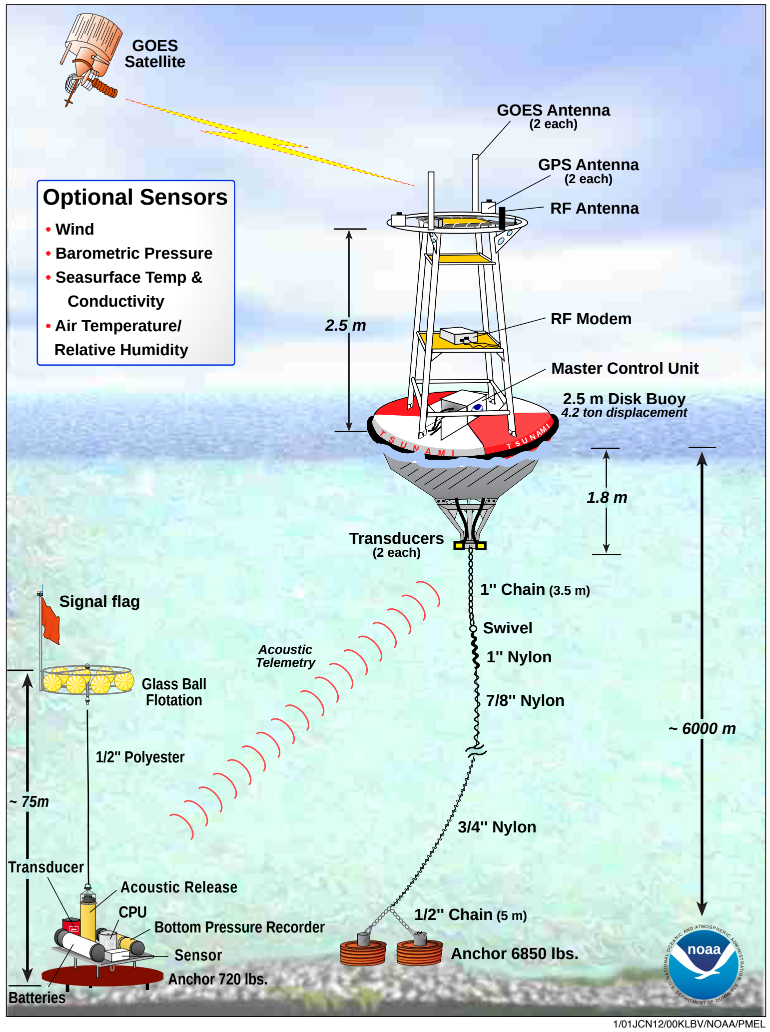

Figure 2: Schematic of the DART mooring system showing the coupling between the bottom pressure recorder package and the surface buoy anchored nearby.

All DART data use a simple data compression scheme. The first data value is the full water column height in millimeters of seawater. The following values are signed, 16-bit numbers representing departures from the full values in millimeters of seawater.

3. Data Acquisition and Dissemination

The data path from a DART buoy to the end user can be described in terms of five distinct stages. A flowchart of the stages is presented in Fig. 4.

1. Bottom pressure recorder data to surface buoy
2. Surface buoy to receiver
3. Receiver to data file

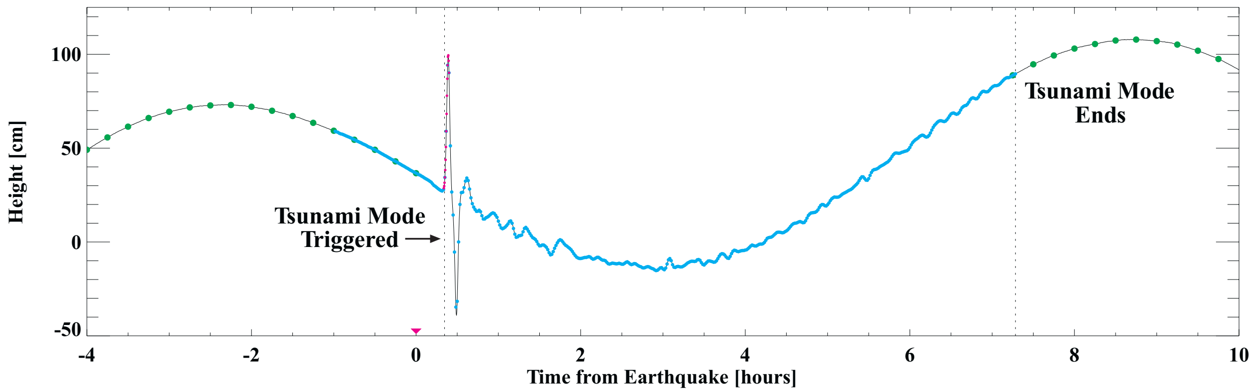

Figure 3: An artificially generated tsunami signal superimposed on a synthetic time series to illustrate the sampling scheme and the transitions between tide and event modes.

4. Processing and archival

5. Data web access

3.1 Bottom pressure recorder data to surface buoy

Commercially available modem pairs that are technologically similar to the familiar telephone-based computer modem are used to transmit data acoustically from the BPR to the DART surface buoy. The modems use a 300-baud MFSK telemetry with frequencies in the 9–14 kHz range, and acoustic source levels of >190 db are 1 upa, making an effective transmission range of 5 km possible. The BPR will make up to three attempts to send data to the surface buoy after which it will abandon the transmission of the current message. If a transmission is abandoned the time series will contain a temporal data gap.

DART messages exchanged between the surface and sub-surface unit are fixed format. Each message block contains a message integrity element, a fixed four-character header, a cyclic redundancy check (CRC) of the block, a character count of the block, a message type identifier, and height observations.

3.2 DART surface buoy to receiver

DART systems make use of the GOES Data Collection System (DCS) 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 (DCP's) by S-band to properly equipped ground receiving stations (NOAA Technical Memorandum NESDIS-40).

Under normal operating conditions, the system reports data in "tide" mode, transmitting hourly, or self-timed messages. When the BPR is triggered by an event, the system reports data in "event" mode, transmitting random messages. The message schedules for these transmissions have been

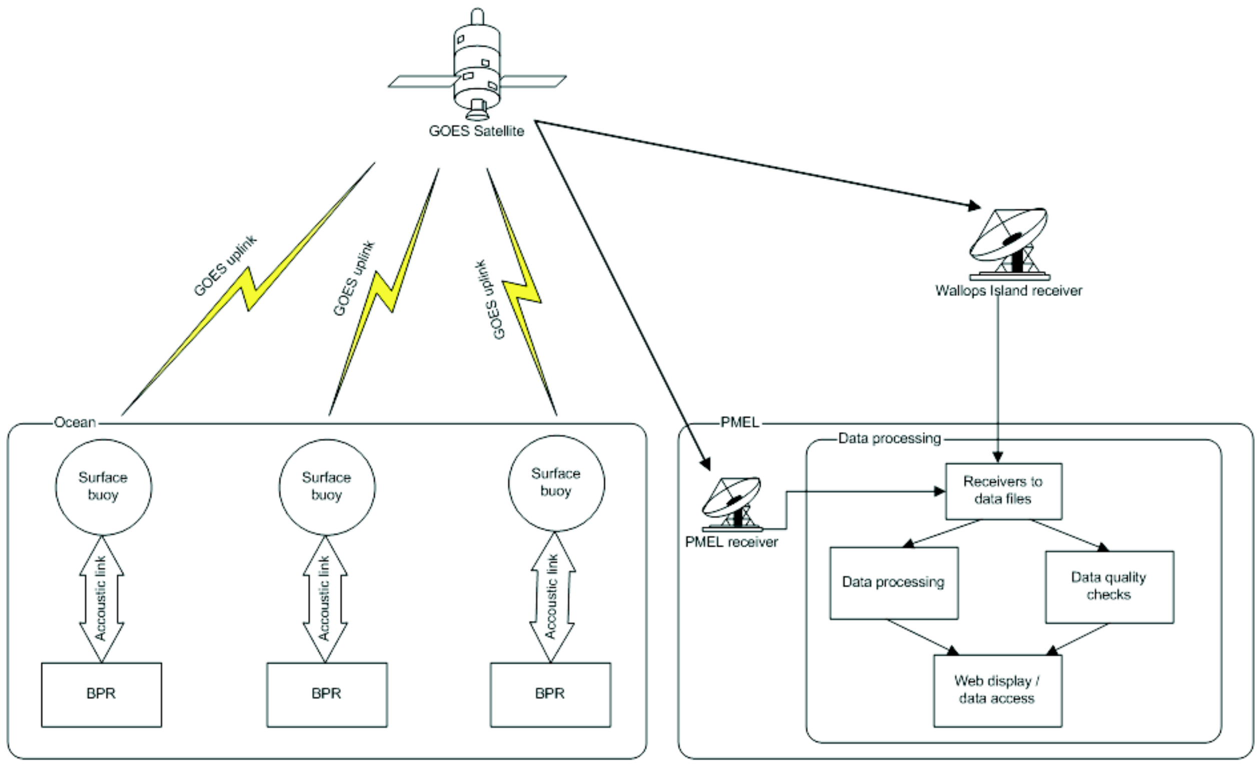

Figure 4: Flowchart of the PMEL DART data path beginning at the point of observation and ending with the web site data display at http://tsunami.pmel.noaa.gov/dartqc/WaveWatcher. The data path is depicted in general terms. Each step is comprised of many sub-elements.

previously discussed. All data are transmitted and received on preset channels determined when the transmitter is registered with NESDIS.

3.3 Receiver to data file

PMEL accesses the data messages transmitted by each DART system from two separate receivers, the PMEL Direct Read Ground Station (DRGS) and the DCS Automated Processing System (DAPS) on Wallops Island, Virginia.

3.3.1 PMEL DRGS

The PMEL DRGS system is the primary DART message receiving station for PMEL. The system consists of a satellite antenna and a receiver. The receiver is connected to a PC running Linux, on which incoming messages are saved.

Incoming data on preset channels are filtered for DART platform messages. A header that contains the transmitter ID, reception time, and message quality is attached to each DART message. Messages are then archived in files separated by day.

3.3.2 Wallops DAPS

Data from the GOES receiving station on Wallops Island is retrieved via telnet sessions from the DAPS system. Since this station is dedicated to receiving and processing DCS data, it serves as a backup DART receiving station. Messages that are lost or received incomplete by the PMEL DRGS are retrieved from the Wallops Island DAPS. This is done with a telnet connection to DAPS every 30 min.

3.4 DART messages processing and archiving

The DRGS computer is checked for new DART messages every 60 s. Messages are retrieved and written into files delineated by site and transmitter ID. A JAVA program running on a Sun Systems Ultra 60 workstation separates or parses these messages and writes the individual data elements into both flat files and a SQL database.

Individual DART message parameters (height, message quality, meteorological data) are presently parsed from the flat files on demand. Currently used parsing scripts are written in PERL.

In addition to data archival, the scripts generate data plots of the most recently received data, and alert selected users by e-mail if any event mode messages are received. Event mode messages trigger scripts to generate detail plots of the DART data during the time the BPR is reporting in event mode.

3.5 DART Web Access

The DART web page (http://tsunami.pmel.noaa.gov/dartqc/WaveWatcher) serves as a portal to the DART data archived at PMEL.

The site makes extensive use of JAVA servlets to access the most recently generated data plots for display on the DART page. If any of the DART buoys are in event mode, this is indicated on the page. Additional pages are also dynamically created to disseminate event information.

Data is available to end users from the DART Quality Control web page (http://tsunami.pmel.noaa.gov/dart/qc/tsun_data.shtml). Parsed data and raw unparsed data messages can be retrieved for any of the DART transmitters presently deployed.

4. Quality Assurance

DART data is reported from two separate transmitters on the surface buoy at each site. This system redundancy has resulted in improved data return rates (Meinig *et al.*, 2001). DART data messages received at PMEL from the transmitters at each DART site are compared with one-another for any discrepancies. These data messages are then compared with those downloaded from the Wallops Island receiver via a telnet session. Wallops data messages are inserted into the data stream when a corresponding data message is not received at the PMEL receiver site.

Daily position fixes in conjunction with measurements of system parameters (battery voltages, etc.) and message quality indicators embedded in each message transmission provide information necessary to evaluate the overall health of each DART system. Tidal analysis of DART time series is being pursued to verify the quality of the DART time series data.

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5. References

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