From Research to Commercial Operations: The Next Generation Easy-to-Deploy (ETD) Tsunami Assessment Buoy

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Abstract-**This paper addresses the transition from research to commercial operations of a next generation tsunami assessment system. Over the last five years, NOAA's Pacific Marine Environmental Laboratory (PMEL) has developed the next-generation Easy-to-Deploy (ETD) Deep-ocean Assessment and Recording of Tsunamis (DART®) buoy system. Through a technology transfer and license agreement, Science Applications International Corporation (SAIC) produced the first commercial ETD DART® system based on the PMEL design. The SAIC ETD DART® was deployed northeast of Australia in the Coral Sea on August 27, 2010 and has reported several small tsunami events and the Honshu tsunami since that time. By design, the ETD DART® offers significant cost advantages over standard tsunami assessment systems. Current tsunami buoy systems require a large, specialized ship and multiple trained technicians to install. The ETD DART® is designed to be deployed by small and fast response vessels such as commercial fishing boats, requires fewer trained personnel and only minutes of deployment time. The ETD consists of a modular self-deploying surface buoy, a single housing bottom pressure recorder (BPR), and a mooring/anchoring system. The SAIC ETD DART has been declared fully operational and is now an important new technology available to support the global tsunami detection network.**

I. INTRODUCTION

Since the 2004 Boxing Day tsunami, the focus of the Science Applications International Corporation (SAIC) Tsunami Buoy (STB) program has been to produce a commercially available, fully operational, tsunami assessment system built to a set of NOAA published standards [1] and subject to stringent customer testing requirements. Until late 2007, the only operational buoy-based real-time tsunami detection system produced was the Deep-ocean Assessment and Recording of Tsunamis (DART®[1]) system developed by the Pacific Marine Environmental Laboratory (PMEL), NOAA's research and development Lab for tsunami observations and modeling research. In 2007 the STB team successfully completed a one year at-sea test, and the data was independently evaluated by NOAA [2] as meeting or exceeding operational performance criteria established for the Deep-ocean Assessment and Recording of Tsunamis (DART® II) system. SAIC is currently the only commercial company licensed by PMEL to produce DART® based commercial tsunami buoy systems.

Over the last five years, PMEL has continued to invest in the development of a new generation of tsunami assessment technology called the Easy-to-Deploy (ETD) DART® buoy [http://www.pmel.noaa.gov/pico/]. The ETD DART® is a redesigned DART® that incorporates a number of technical improvements to increase endurance, decrease production costs, and greatly decrease deployment costs. PMEL has made over 15 test deployments over the last several years, including deployments in the challenging conditions of the Gulf of Alaska and Tasman Sea. PMEL ETD DART® systems have been deployed for extended durations in the Tasman Sea and Fiji Basin in a joint test with the Australian Bureau of Meteorology (AUS-BOM). AUS-BOM has been a key partner in this development effort, providing deployment opportunities, data sharing and operational feedback from these prototype ETD DART® systems.

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During a 2-year endurance test in 2007, PMEL performed a side-by-side test with an operational DART® II buoy system off the coast of Hawaii. The ETD DART® was put through the same operational tests and held to the same performance criteria that the STB was subjected to during its independent test. The ETD DART® was found to meet or exceed DART® operational performance criteria under all conditions, including measuring a small tsunami [3]. In 2010, SAIC produced the first three commercial ETD DART® systems through a license agreement with PMEL. The first system was deployed in the Coral Sea by AUS-BOM on August 27, 2010, and was declared operational by AUS-BOM several days later. The Coral Sea ETD DART® has performed exceptionally since then, including surviving a direct strike by super-cyclone Yasi and detecting the Honshu tsunami wave on March 11, 2011. The second and third SAIC ETD DART® systems are expected to be deployed in the Tasman Sea and Indian Ocean in 2011.

II. EASY-TO-DEPLOY (ETD) SYSTEM

The ETD DART® System is a gravity-launched integrated buoy, mooring, and anchoring system designed to be quickly and easily deployed from a wide range of small, fast vessels with minimal gear deck gear required. The anchoring system includes a new single pressure vessel bottom pressure recorder (BPR). Once at the deployment site, the ETD DART® requires only a few minutes of deployment time and a minimum of personnel. The ETD DART® can be safely deployed in higher sea states up to a maximum of sea state 5. For ocean locations with light surface and subsurface currents < 80 cm/sec (~1.5 kn) and depths less than 5,500 m (18,040 ft), the ETD DART® offers a flexible and cost-effective solution for tsunami warning and ocean observations. Fig. 1 provides a depiction of the ETD DART® and the major components of the system.

As a result of engineering improvements, incorporation of improved technology, and experience gained with the DART® system, the overall size and weight of the ETD DART® has been reduced while maintaining DART® performance and communication standards. This reduction in size and weight along with the integrated buoy, mooring, and anchor configuration allows for a very simple and rapid deployment. The ability to deploy off small, fast ships can provide substantial savings in deployment costs when compared to the traditional method of using a large, slow-moving ship, equipped with an A-Frame and a large, well-trained crew. In the right oceanographic conditions, the ETD DART® provides countries an alternative option to large ships that is very cost efficient, flexible and timely.

Fig. 2 shows the ETD DART® on the production line with its protective cowling removed and sitting next to three STB buoy systems. This figure illustrates the size difference between an ETD DART® and the surface portion of the standard STB DART® system, and also provides an intuitive understanding of the differences in the complexity of deployment between the systems.

A. Components of the ETD DART® System

Surface Buoy: The surface buoy subsystem integrates a fiberglass-over-foam hull with an electronics well, meteorological (wind speed and direction, barometric pressure, and sea surface temperature) sensors, load cell, and acoustic communications modems. The electronics well includes the Global Positioning System (GPS), Iridium satellite communications systems, on-board processing, batteries, and other electronics. The surface buoy has redundant processing, communications, and power to improve system reliability over long durations. The low profile hull is difficult for fisherman or pirates to notice at sea. Critical electronics, modems and antennas are internal housed, adding additional protection against vandalism.

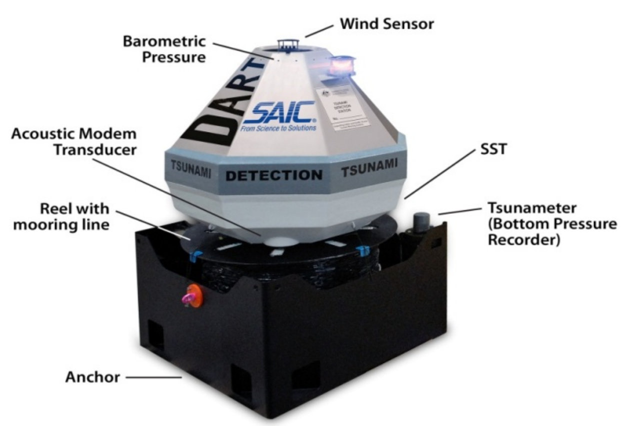

Fig. 1. ETD DART® buoy components.

Fig. 2. Size comparison of ETD DART® system to STB.

Bottom Pressure Recorder (BPR): The ETD DART® BPR subsystem is housed in a single 6000m rated aluminum vessel (Fig. 3). Acoustic communications between the BPR and the surface buoy is accomplished with directional mid-frequency (16-21 kHz) acoustic modems and transducers. The new ETD BPR design eliminates four housings and all wet-mate interconnect cables found on standard DART® systems that are expensive to build and test.

Mooring and Anchor Subsystem: The patented ETD DART® mooring line is manufactured from a number of composite materials and is produced in one continuous length. Optional fish-bite resistant material can be incorporated in the top portion of the mooring line for improved survivability. The continuous mooring line is contained on a reel integrated into the system's anchor and run thru a series of sheaves When the ETD is deployed over the side, the anchor and reel detach from the buoy and drop to the bottom with the mooring line paid out continuously as the anchor sinks. The ETD DART® mooring is designed as a slack-line mooring and precise depth information is not required, as is the case for the standard DART® system.

Cost-containment is achieved by sharing many common core components between the ETD DART®, STB, and DART®. Changes in packaging of these components and inclusion of a novel anchor/spooling mechanism have resulted in the advent of the ETD system. We have leveraged the success of the standard DART® system and made no changes to the data logger CPU, acoustic modem PCB, BPR electronics, Paroscientific pressure sensor, Iridium satellite communications modem and transmission protocol, system modes, or tsunami detection scheme. Minor changes have been made to the acoustic modem transducer and preamplifier, system software, and GPS.

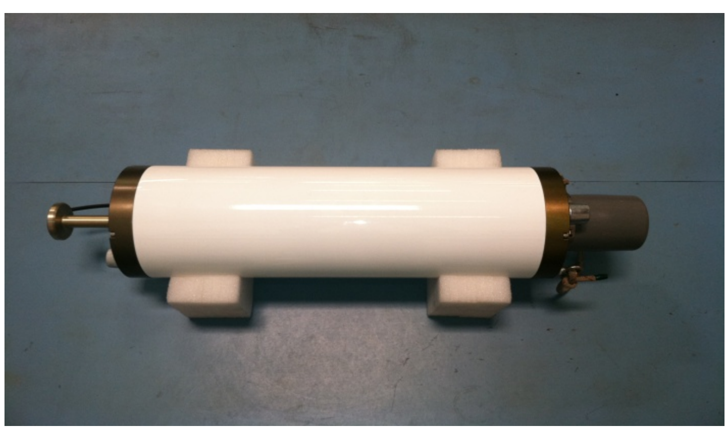

Fig. 3. Bottom Pressure Recorder (BPR) subsystem.

B. Summary of improvements to the standard DART® design by the next-generation ETD DART®

1) Deployments made less hazardous in higher sea state conditions
    a) Smaller system size and integrated shipping/deployment pallet
    b) Faster and less complicated deployment tasks
2) Eliminated need for large deployment ship and skilled crew
    a) Ship charter-hire costs significantly reduced
    b) Labor costs significantly reduced
3) Increased reliability of the BPR by eliminating wet-mate cables and connectors
4) Reduced BPR material costs by eliminating four pressure vessels (both titanium and aluminum)
5) Reduced labor costs of overall production
6) Enhanced vandalism protection
7) Potentially reduced lifecycle costs
8) Economized operations resulting from ETD design, as compared with traditional requirements (and constraints) for deployment of fixed moorings in the open ocean.

III. ETD DART® DEPLOYMENT

Built and shipped as a single modularized system, the ETD DART® can be deployed off relatively small platforms by a small crew with minimal training and on-board equipment. The pre-packaged and palletized ETD system is simply unloaded from the shipping container and placed on-deck. Once on location, the ETD is unsecured from its shipping frame and then tipped ~1 m off the deck causing the ETD to slide into the water and self-deploy. The anchor and mooring reel separate from the buoy on water entry and then the anchor sinks at ~100 m /min.

The ETD system has a maximum deployment depth of 5500 m and is not designed to be deployed in strong current regimes. Design survivability can be estimated from mooring modeling software if measured surface and subsurface current data are not available. Therefore it is recognized that the ETD is a good substitute for the STB at locations where oceanographic conditions do not exceed the design limitations.

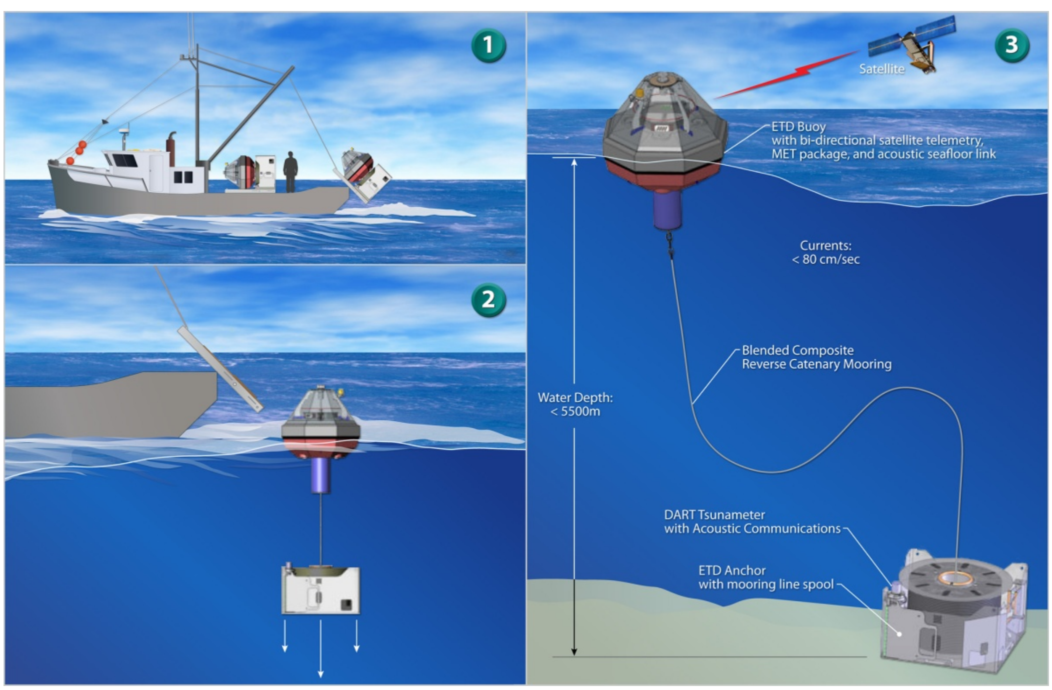

Fig.4. ETD deployment.

IV. From Research to Commercial Operations

With the development of the STB in 2006–2007, SAIC has supplied tsunami assessment systems to Australia, Thailand, India, China, and Russia, and is recognized as a global provider of reliable tsunami buoy systems. As a result, in late 2008 PMEL agreed to work with SAIC to accelerate the development of the ETD from a research and development project into a fully operational commercial system. Under the SAIC DART® patent license and a studies agreement, PMEL worked with the STB team in San Diego, California, to develop a multiphase transition program that took over one year to complete.

Phase one of this program included developing the funding requirements, intellectual property protection, technical assistance, and initial training. Initial training included several visits to PMEL, where SAIC technicians familiarized themselves with the ETD DART® system. Once training was complete, drawings were refined and converted into a production-grade bill of material. As the bill of material came together, the process of finding and qualifying local suppliers of high quality components began. A number of the suppliers had worked with the STB program previously and understood the quality required to become a preferred supplier. The goal was to develop multiple local suppliers for the bulk of most of the components to encourage competition and ease logistical issues normally associated with geographically disbursed supply chains. Within several months the required suppliers were identified and their ability to provide high quality components was verified.

Phase two of the transition began in the late fall of 2009 when SAIC engineers and technicians began production of the first prototype commercial ETD DART® systems. With PMEL engineers providing periodic oversight and making quality control recommendations, production on the first system began. Production proceeded slowly over the next several months as the systems came together, fabrication and integration processes were developed and tested, and a production manual documented the process and lessons learned.

Before the first system was shipped from its San Diego production facility, the ETD DART® went through nearly four weeks of final acceptance testing and burn-in. Standard STB and DART® operational tests were applied including exercising the complete series of back-channel commands which, direct the buoy to go into various modes, transmit high-resolution data for a particular time frame, or transmit buoy health and status information. Fig. 7 shows the completed system, just prior to being loaded in its shipping container. The anemometer is removed from the top of the cowling for safety during shipment, and is easily reattached prior to deployment. Not only does the ETD DART® configuration make it easy to load and ship, but four complete systems can be packed in one standard 20 ft marine container.

Fig. 7. SAIC ETD DART® System Number 1 strapped on shipping frame.

V. Operations in the Coral Sea

On June 2, 2010, the first SAIC ETD DART® system was shipped via maritime freight to the Bureau of Meteorology in Melbourne, Australia. With the concurrence of the Australian Bureau of Meteorology (AUS-BOM) the SAIC ETD DART® was designated to replace a STB system that had been damaged by a category five tropical cyclone in the Coral Sea. The ETD DART® deployment team mobilized in Townsville, Australia, on August 21, 2010, making preparations to get underway. AUS-BOM chartered the PMG PRIDE, a relatively small ocean-going workboat having a length overall of 34 m (Fig. 8) to serve as the deployment platform. While making preparations for sea, the ETD DART® was loaded and the electronics fully energized. For the next four days data transmissions were monitored from the BPR through the surface buoy, to the satellite, down to the ground station, and ultimately to AUS-BOM in Melbourne. The ETD DART® performed perfectly and was certified ready for deployment.

Fig. 8. PMG PRIDE

On August 24, 2010, a team made up of representatives from AUS-BOM, NOAA, and SAIC departed Townsville late in the day. During the next three days as the PMG PRIDE transited to its deployment point, winds increased to above 30 kn and seas built from 3–5 m. In the early hours of August 27, the ship arrived on station and quickly prepared for deployment during a short break in the weather when the seas dropped to less than 3 m. After verifying the specific deployment location, reviewing safety precautions, and making a few last minute checks to the buoy, permission for the drop was given and the ship steamed to the drop point. Upon reaching the designated drop point, the ship's A-Frame system lifted the end of the shipping frame off the deck approximately 1 m when gravity took over, sliding the integrated buoy-mooring-anchor system down the frame and into the sea (Fig. 9). It took less than 10 sec from the time the lift began to the buoy entering the water and separating from the anchor. The anchor settled on the bottom ~45 min later. Throughout the descent, the BPR provided depth reports every 2 min. Over the next several days, the Australian Tsunami Warning Center closely monitored the performance of the ETD DART®. On September 1, 2010, the ETD DART® designated as station 55023 was declared fully operational. It operates as one of the six principle deep ocean tsunami sensors for AUS-BOM and real-time data is publicly available (http://www.ndbc.noaa.gov/).

Fig. 9. ETD DART® deployed in the Coral Sea on August 27, 2010.

Since deployment, the Coral Sea ETD DART® has performed exceptionally well, alerting on several earthquakes in the region and detecting several small tsunamis. On February 2, 2011, the system demonstrated its reliability and resistance to extremely severe weather after surviving a direct strike by a category five cyclone named Yasi. Super-cyclone Yasi generated winds of ~130 kn and seas estimated at ~15 m (~49 ft). The eye of the cyclone passed over the ETD DART® as shown in the barometer data shown in Fig. 10. The barometer recorded a drop in atmospheric pressure from 1004 to 941 mbar in a span of 3 h. As a result of the strength of the cyclone, there were some lengthy dropouts in data just after the cyclone passed. These have been artificially filled with dashed lines in the plot. Although the system was not expected to withstand such harsh conditions, the ETD DART® survived and continued to operate as designed, while missing just a few hours of data while Yasi was passing over the system. Except for the anemometer being carried away by the wind, the ETD DART® remains fully operational and performing it's very important mission off the northeast coast of Australia.

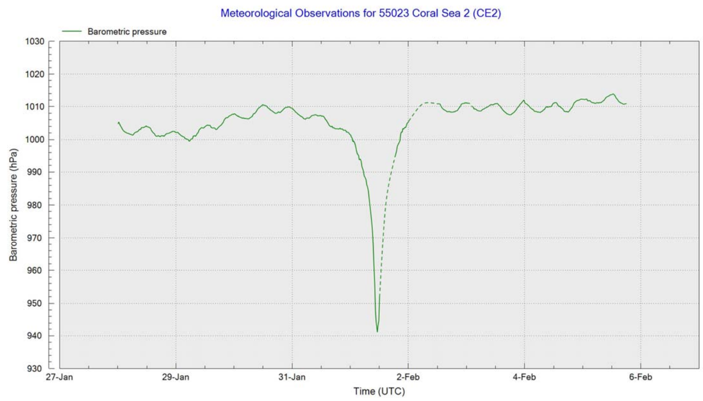

Fig. 10. Atmospheric pressure drop recorded by ETD DART® during passage of Super-cyclone Yasi.

On March 11, 2011, a 9.0 Mw earthquake struck an area approximately 130 km east of Sendai, Japan. As one of the most powerful ever recorded in Japan, the earthquake generated global-scale tsunami waves that were detected around the world by 30 DART® systems. As a result, the entire Pacific Basin was put into tsunami warnings or watches. The tsunami was so powerful it not only caused massive damage in Japan but also resulted in wide-scale damage across Oceania, and the Pacific coasts of North and South America. Surprisingly, in spite of the distance from the generation point, interaction with ocean floor bathymetric features, and partial shielding provided by the Solomon Islands and New Guinea, a number of significant tsunami waves were detected by the Coral Sea ETD DART® system nearly 9.5 h after the earthquake. At approximately 1508 UTC, ETD DART® station 55023 detected the first wave with an amplitude slightly less than 30 mm and a 35 min period, seen in Fig. 11. Over the next 24 hours a number of tsunami waves of various amplitudes moved past the station and were observed by the ETD DART®. Using this data, AUS-BOM was able to monitor the tsunami and have the confidence in providing 'No Threat' warnings to the coastal populations in northeast Australia.

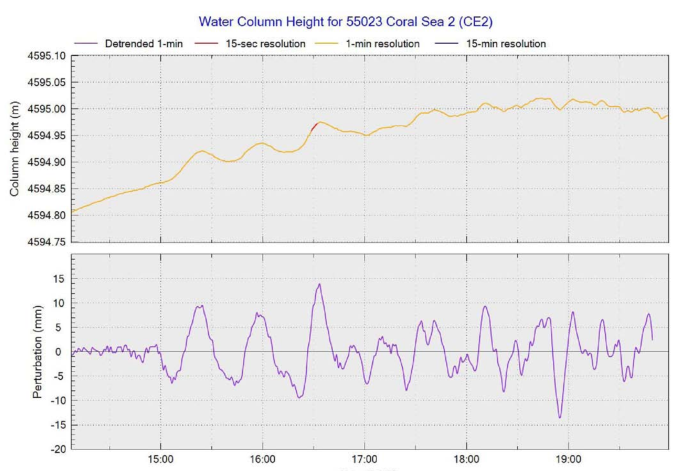

Fig. 11. Honshu Tsunami wave detected by the ETD DART® in the Coral Sea.

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REFERENCES

[1] C. Meinig, S. Stalin, A. Nakamura, H. Milburn. (2005, June). Real-Time Deep-Ocean Tsunami Measuring, Monitoring, and Reporting System: The NOAA DART II Description and Disclosure, Available: http://nctr.pmel.noaa.gov/Dart/dart_ref.html

[2] "Capability Assessment of the SAIC Tsunami Buoy," August 2007 Technote, NOAA National Data Buoy Center, OPS52 Branch, unpublished.

[3] "Capability Assessment of the DART-ETD Tsunami Buoy," November 2007 Technote, NOAA Pacific Marine Environmental Laboratory, unpublished.