Spatial requirements for DART and GPS for real-time warning

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Through an international effort focusing on the recording and transmitting of information about passing tsunami, the fleet of Deep-Ocean Assessment and Reporting of Tsunami (DART) gauges deployed globally has steadily increased in number. Information that these gauges record about the passing tsunami threat is analyzed and disseminated as tsunami warnings to affected communities in real time. With careful placement, newly deployed DART gauges can increase the temporal window for tsunami early warning at localities near the tsunami nucleation site. Potentially acting in concert, arrays of high-rate continuous GPS near coasts can aid in determining the degree of hazard stemming from offshore events. For early warning systems it may be beneficial to extend the evacuation times through the utilization and placement of coastal DART gauges and GPS arrays that could work in concert for rapid joint assessments of an earthquake's tsunami potential [e.g. Williamson et al., 2017]. Key questions to answer include (1) where DART and GPS instrumentation exist and already sufficiently facilitate near-field early warning; and (2) which regions are underrepresented and could potentially benefit from the addition of new sensors.

By modeling the location and tsunami propagation of potential tsunamigenic megathrust earthquakes on a global scale, we calculate contours relating to maximum gauge placement per amount of warning time. The goal is to spatially map the maximum distance/spacing that DART gauges must be located for the nearby community to benefit from an early warning. This represents the most aggressive early warning scenarios possible as it focuses on the nearest communities that would typically have the shortest window to receive and heed an evacuation warning.

In order to model the maximum possible warning time, we calculate the impact of shallow, tsunamigenic characteristic source events for most major subduction zones throughout the Pacific and Indian basins. The potential tsunami is modeled at a regional scale using the Method of Splitting-Tsunami (MOST) algorithm [Titov & Gonzales, 1997] using ETOPO 1 arc minute bathymetry to track the wave from its nucleation site as it propagates to the coast. The MOST model solves the non-linear shallow water wave equations and is currently used at the NOAA Center for Tsunami Research for not only tsunami generation and propagation, but also as a tool in coastal inundation studies and for real time tsunami forecasting and assessment through the Short-Term Inundation Forecasting (SIFT) program [*Gica et al, 2008*]. The timing of the first arrival of tsunami waves to the coast (white star in Figure 1) is considered when determining hazard warning contours. Each contour outlines the location inside of which a pressure sensor should be placed in order to detect the tsunami wave prior to the earliest coastal inundation.

Characteristic events created for analysis consider a shallow dipping, uniformly slipping planar unit source with a rupture area of 5,000 km^2 and a center of slip at a depth of 15 kilometers. However, refined sources that incorporate locally determined fault geometries through Slab 1.0 [Hayes et al., 2012] and locations of past major earthquakes can be considered, enriching our understanding of region specific hazards.

Referencing the Japan demonstrative example shown in Figure 1, a theoretical tsunamigenic earthquake occurring northeast of Sendai would first inundate the southern point of the island of Hokkaido (star). Gauges inside of the purple and blue contours would allow for a maximum of 15 and 5 minutes of warning, respectively.

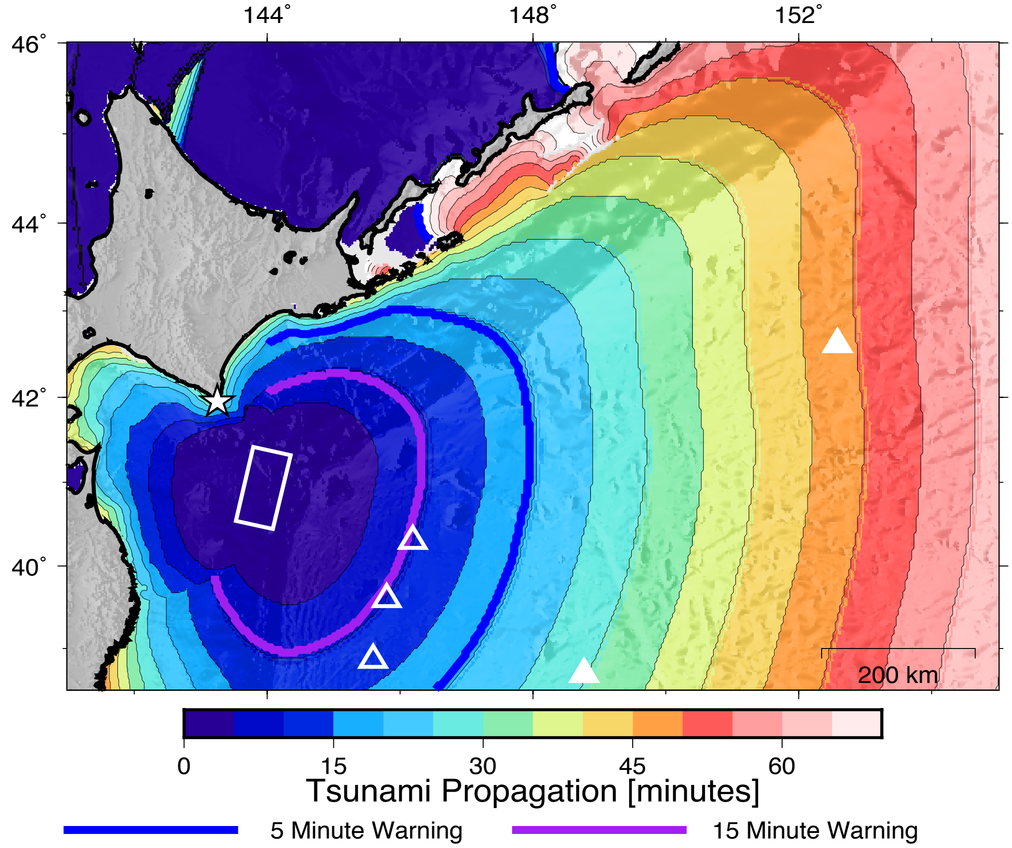

Figure 1. Demonstrative of the methodology for assessing the maximum possible warning times available for near-source regions using DART gauges. The source area is a near-trench shallow dipping planar unit source with uniform slip. Colored contours indicate the tsunami travel time as it propagates away from the nucleation region. The white star indicates the first point of coastal contact of the predicted tsunami. This allows for the calculation of warning contours that act as spatial thresholds for the maximum distance from the source that a gauge must be to allow for a certain amount of warning. Blue and purple contours indicate 5- and 15-minute warning times for inundation at the starred location. Current DART gauges (DART 21418 and DART 21401) are shown as shaded white triangles. Open white triangles indicate DART gauges that were discontinued in September, 2016.

We've used this methodology for an initial assessment across the major megathrust environments globally (Figure 2). In this case, we additionally include the on-land threshold for complementary GPS stations to sufficiently characterize fault displacement and be used for geodetic early warning. As shown for many regions including Cascadia, DART gauges are deployed seaward of the zone necessary for near-field early warning. This is in part to preserve DART gauges from potential damage due to earthquakes or other submarine hazards. However, newer DART 4G models, such as those deployed off the coast of Chile during the fall of 2016 are designed to sit closer to the trench, providing a new resource to near field communities immediately following tsunamis. New DART gauges can additionally supplement pre-existing bottom pressure arrays, such as ones already in place off the coast of Cascadia and Japan.

Future focus will be placed on detailing expected behavior in specific seismically active regions, including the Sunda megathrust, the Peru-Chile trench, and the Cascadia subduction zone. Additional emphasis will be placed on near-field warning following synthetic events at known seismic gaps with the goal of identifying regions where the addition of new instrumentation would be beneficial to nearby communities.

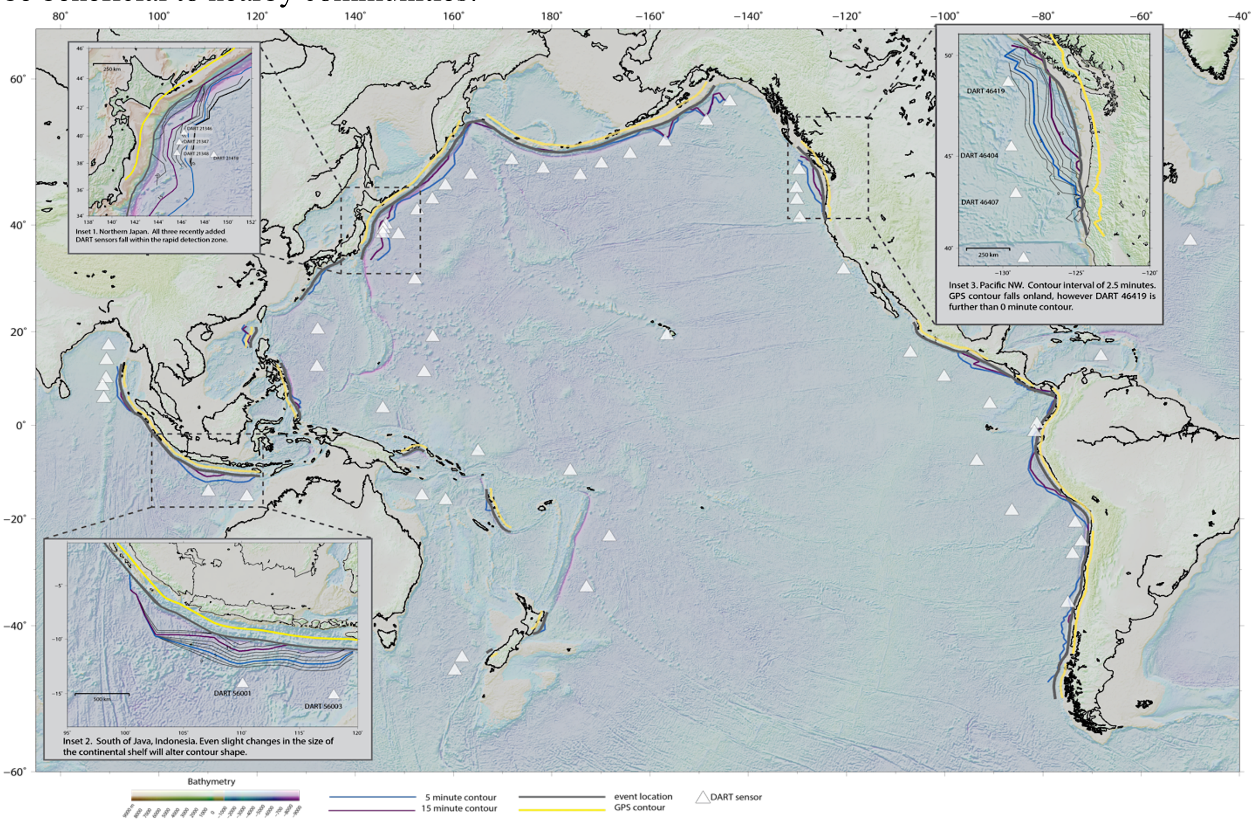

Figure 2. Global perspective on the use of GPS and DART gauges for early warning purposes. Considering DART gauges (white triangles), the location of synthetic unit sources (gray line), and warning contours indicating 15 and 5 minutes of warning (purple and blue contours respectively), early warning capabilities may be possible if DART gauges are located inland from measured contours. The yellow contour indicates 100 km from the trench. Land seaward of this yellow line allow for the best assessment of a tsunamigenic hazard from GPS. Insets 1, 2, and 3 show analysis of Japan, Indonesia, and Cascadia, respectively. For almost all cases, the DART gauge placement is not optimal for early warnings to be issues for near field regions. New DART 4G gauges will allow for the possibility of early warning where deployed.

References:

Gica, Edison, et al. *Development of the Forecast Propagation Database for NOAA's Short-Term Inundation Forecast for Tsunamis(SIFT)*. 2008.

Hayes, Gavin, D.J. Ward, and R.L. Johnson. Slab 1.0: A three-dimensional model of global subduction zone geometries. *Journal of Geophysical Research*, 117. 2012.

Titov, Vasily V., and F. I. Gonzalez. *Implementation and testing of the method of splitting tsunami (MOST) model*. US Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, Pacific Marine Environmental Laboratory, 1997.

Williamson, A. L., A. V. Newman, P. R. Cummins, Reconstruction of coseismic slip from the 2015 Illapel earthquake using combined geodetic and tsunami waveform data *J. Geophys. Res. Solid Earth, 122*, JGRB51991, doi: 10.1002/2016JB013883, 2017.