NH43D-0969. Design Considerations for an Offshore Instrument Network for Tsunami Early Warning in the Cascadia Subduction Zone

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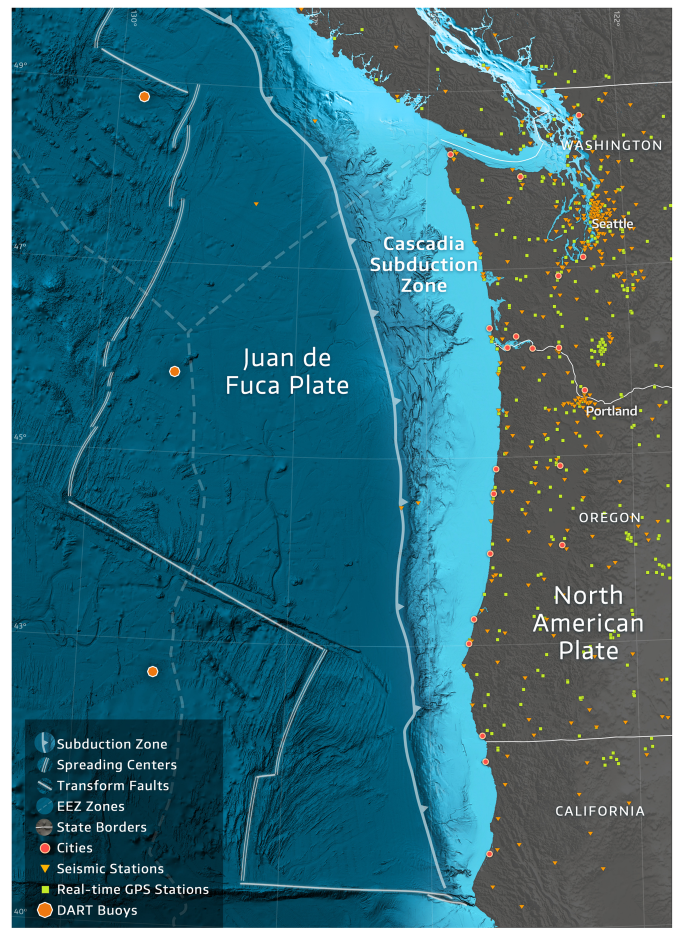
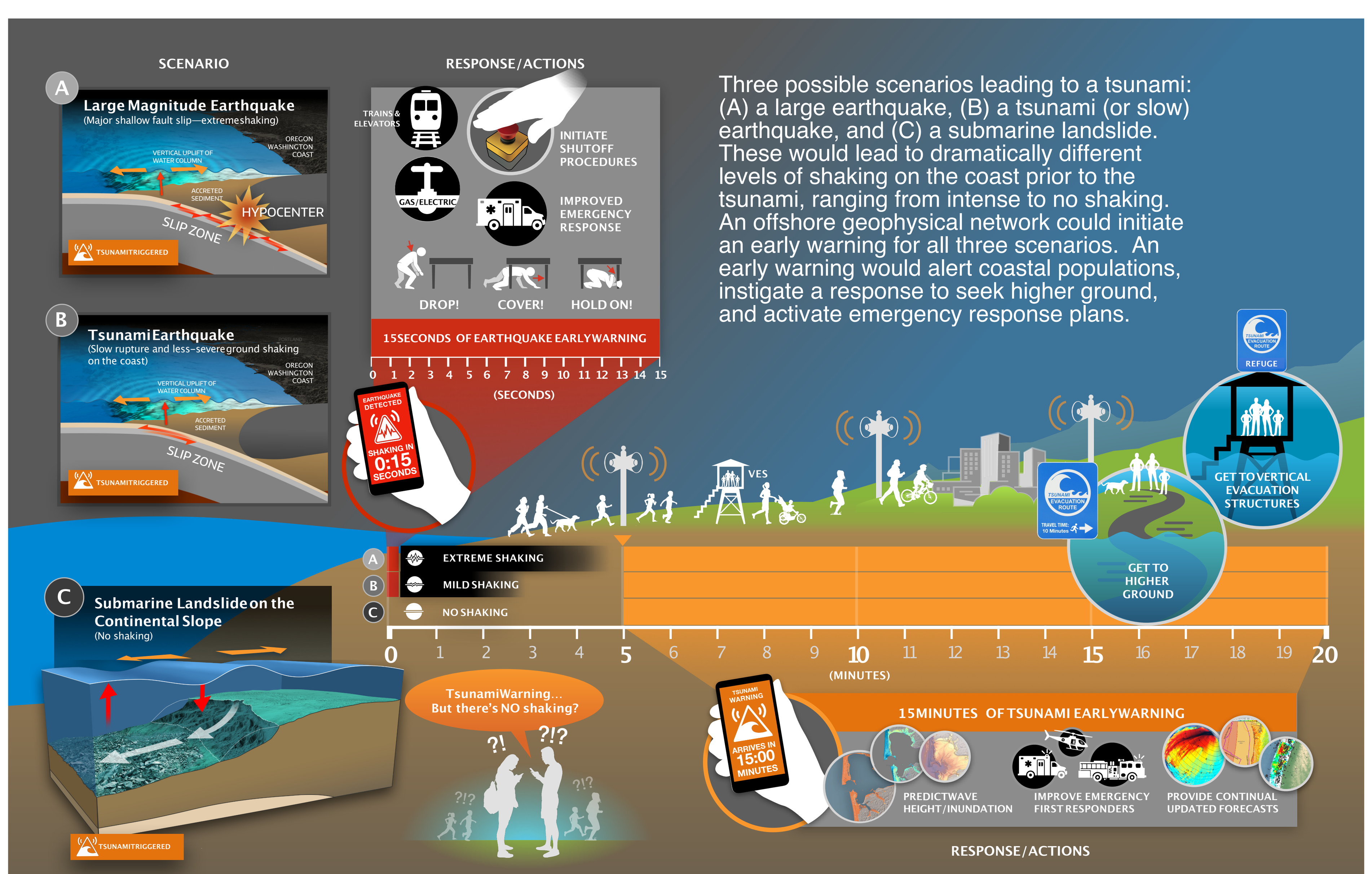
With support from the Gordon and Betty Moore Foundation, we have completed a feasibility study for an offshore instrument network in the Cascadia subduction zone to improve earthquake and tsunami early warning. For tsunami early warning:

- The global DART buoy network provides effective warning for far-field tsunamis.
- Near-field tsunami warning is more challenging: lead time is short and near-source observations are rarely available. It presently relies on rapid point source seismic inversions that do not estimate wave height.
- Efforts are underway to incorporate GNSS data into rapid source inversions that would support an initial near-field tsunami prediction.
- Offshore observations would contribute further to near-field tsunami warnings:
  - direct observations of seafloor and sea surface displacements during earthquake rupture,
  - ongoing measurements for continued forecast refinement,
  - better detection of tsunamis triggered by submarine landslides or "tsunami" earthquakes.
- Pressure observations in the source zone will be challenging to interpret; they are dominated by seafloor accelerations and hydroacoustic waves rather than changes in hydrostatic pressure.
- It may be necessary to complement these with other observations, such as inertial measurements of seafloor displacement, GNSS buoys and high-frequency coastal radar.



Map of the Pacific Northwest. The source zone for Cascadia megathrust earthquakes and tsunamis is below the continental shelf and slope. Three DART tsunami buoys are located about ~200 miles offshore and would not detect the tsunami from a Cascadia earthquake until after the first waves had reached the coast.

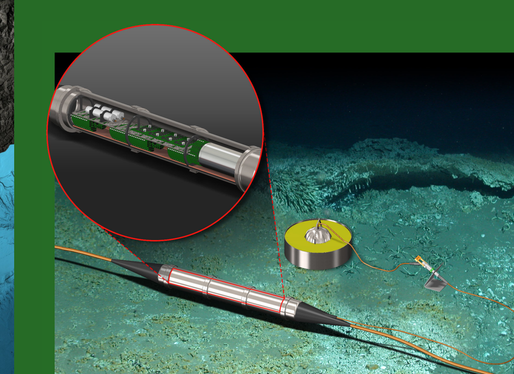
- It may be important to place pressure sensors just seaward of the source zone to measure the developing tsunami in a region with an undisturbed seafloor.
- A cabled early warning system could either use sensors that are hardwired in-line or a connectorized system with sensors attached to a flexible secondary infrastructure extending from nodes on the primary cable.
- The design might also incorporate buoys to provide redundancy and early observations of the tsunami propagating offshore.
- An offshore early warning system has the potential to save many lives if incorporated as part of a holistic approach to improving earthquake and tsunami preparedness.



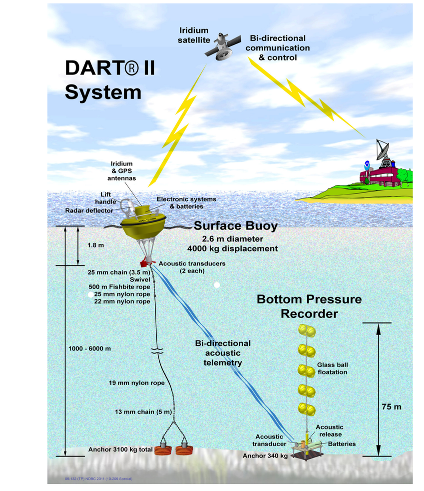
Three possible scenarios leading to a tsunami: (A) a large earthquake, (B) a tsunami (or slow) earthquake, and (C) a submarine landslide. These would lead to dramatically different levels of shaking on the coast prior to the tsunami, ranging from intense to no shaking. An offshore geophysical network could initiate an early warning for all three scenarios. An early warning would alert coastal populations, instigate a response to seek higher ground, and activate emergency response plans.

Offshore monitoring in Cascadia can contribute substantially to the timeliness, reliability, and accuracy of earthquake and tsunami early warnings and has the potential to save many lives.

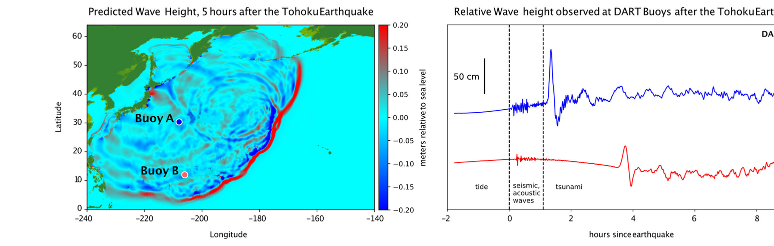
Designs for early warning: (A) in-line instrumentation and (B) nodal arrays



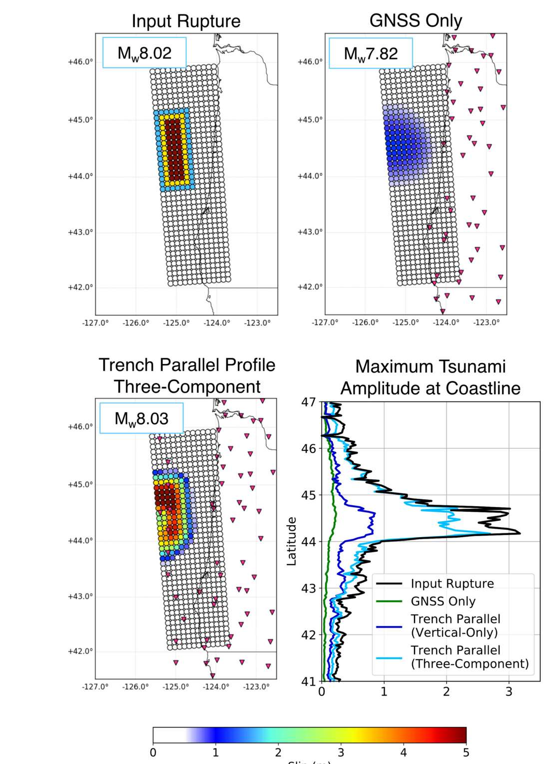
Take a picture to visit the Early Warning Offshore Cascadia (EWOC) website and download the white paper for this study.



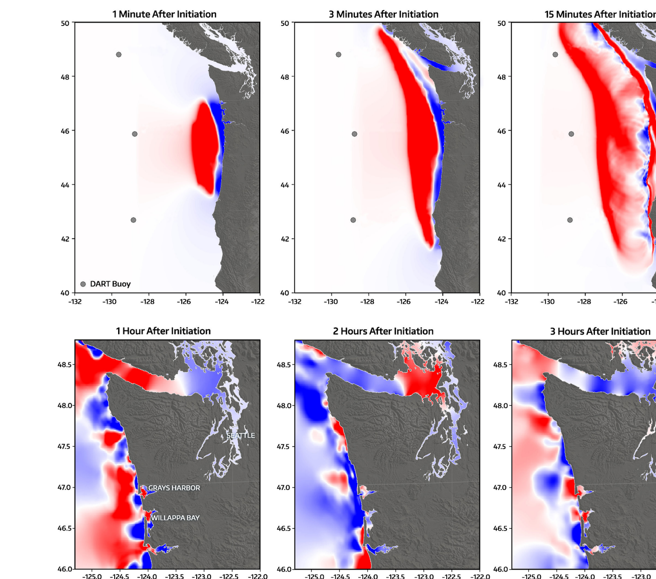
DART II tsunami detection system.



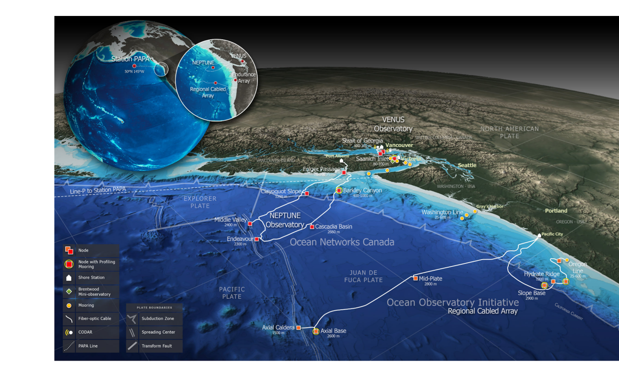
(left) A tsunami simulation of the 2011 Tohoku Japan tsunami, 5 hours after the earthquake. (right) Pressure series recorded by two DART instruments. Seismic and hydroacoustic waves arrive at the instruments within the first hour after the earthquake, while the tsunami takes roughly 1.5 and 3.5 hours.



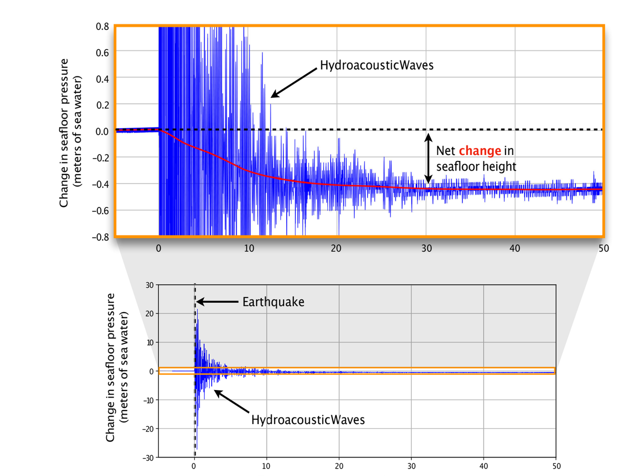
Simulated M8 rupture (top left) and the predicted tsunami wave height at the coastline (bottom right) obtained from onshore GNSS data only and from the inclusion of a trench parallel line of seafloor deformation sensors (Adapted from Saunders and Haase, 2018).



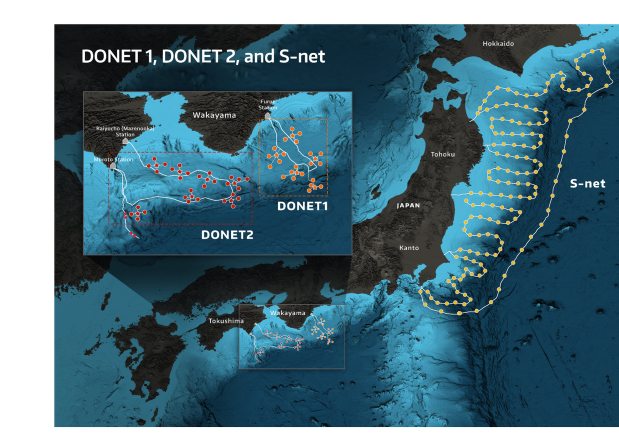
Tsunami predicted by a numerical model for a hypothetical magnitude ~9 earthquake in Cascadia. The initial seafloor deformation is –2.7 to +8.6 m. The red-blue color indicates elevation of the tsunami waves above or below sea level, respectively. The colors saturate at ±1-m elevations, although the tsunami generated is more than 10 m when striking parts of the coast. The top three frames also show the three DART buoys in the region.



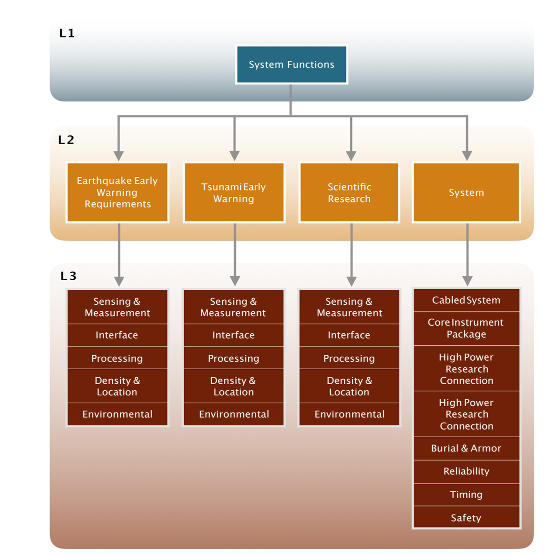
NSF OOI Cabled Array and ONC NEPTUNE multidisciplinary cabled observatories.



Tsunami recorded by a bottom pressure recorder deployed off the coast of Hokkaido Japan, within the source region of the 2003 magnitude 8.1 Tokachi, Japan earthquake.



DONET1, DONET2 and S-net monitoring systems offshore Japan.



Level 1, 2 and 3 requirements for a Cascadia earthquake and tsunami early warning offshore instrument network.

	HARDWIRED CABLE	CONNECTORIZED CABLE	BUOY ARRAY	MOBILE WIRELESS
EEW Capability	High	High	Low	Low
TEW Capability	High	High	High	Medium
Maturity*	High	High	High	Low
Installation Cost	Med–High	High	Low	Med–Low
O&M Cost	Low	Medium	High	High
Reliability	High	Med–High	Low	Low
Maintainability	Low	High	High	Low
Flexibility	Low	High	Low	Medium
Data Latency to Shore	<1 second	<1 second	10s of Seconds	10s of seconds

Relative merits of the different offshore platforms for an earthquake and tsunami early warning system.

YEAR	MAGNITUDE (M_W)	LOCATION	TSUNAMI Deaths	TSUNAMI Max Run Up	EARTHQUAKE DEATHS	INJURIES*	DAMAGES (Uninflated)
2011	9.1	Tohoku	16,959	128	1,475	6,152	$220 billion
2010	8.8	Chile	156	95	402	12,000	$30 billion
2004	9.1	Sumatra	226,898	166	1,001	–	$10 billion
1964	9.2	Alaska	124	170	15	–	$0.4 billion
1960	9.5	Chile	2,226**	82	2,226**	3,000	$1 billion

Earthquakes of magnitude ≥ 8.8 and their societal impacts since 1960.

Ocosta Elementary School, Westport, WA.

Poster design from Mike Morrison - @mikemorrison and https://osf.io/ef53g/