TsuInfo Alert

prepared by the Washington State Department of Natural Resources on behalf of the

National Tsunami Hazard Mitigation Program

a state/federal partnership funded through the National Oceanic and Atmospheric Administration (NOAA)

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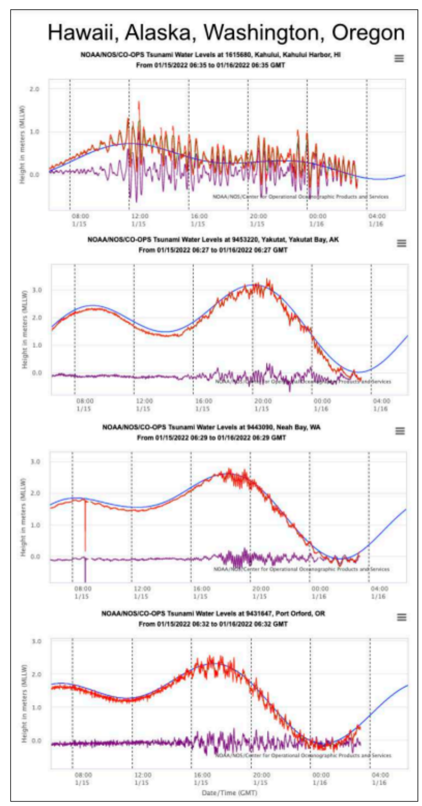
15 January 2022, Hunga-Tonga Hunga-Ha'apai Volcanic Eruption and Tsunami

By International Tsunami Information Center

IN THIS ISSUE:

The Hunga-Tonga Hunga-Ha‘apai (HTHH) volcano, located 60 kilometres northwest of Tongatapu, Tonga began erupting at 407 UTC on 15 January 2022 based on Himawari-8 satellite images, with a massive explosive eruption at 0414 UTC from seismic data. The eruption triggered a tsunami that caused damage locally, regionally, and across the Pacific. The local tsunami killed three people and caused major destruction to many low-lying coastal communities on Tongatapu, ‘Eua and the Ha‘apai Group of Tonga; runups up to 15 m and 500 m inundation were reported for Mango Island by the Tonga Geological Services (TGS).



Elsewhere waves up to 2 m in amplitude were reported by the Pacific Tsunami Warning Centre (PTWC). To save lives, countries issued warning and advisory alerts, and in some places evacuated coastal populations. Many countries experienced waves greater than 0.3 meter in amplitude, which typically triggers marine advisories recommending to citizens to stay out of the water as strong currents and/or unusual waves may occur. Damaging waves struck harbours and coasts in New Zealand, Rarotonga, Hawaii and the US west Coast, and as far away as Peru (additionally, two deaths occurred), Chile in the eastern Pacific, and Japan in the northwestern Pacific. Altogether, the PTWC issued 12 bulletins over a 20-hour time span and reported 117 tsunami wave measurements from 26 countries.

The gigantic eruption obliterated the volcanic cone-caldera complex that had grown connecting the two islands, generating an atmospheric disturbance that extended into the stratosphere and that was observed by international satellites. The multiple explosions were heard loudly not only on the Tonga islands, but also in Fiji and American Samoa. The resulting shockwaves were measured on barometers as they traversed the globe. The coupling of the air wave with the ocean surface generated small waves (meteotsunamis) observed in the Pacific and also on coastal gauges in the Caribbean and across the Atlantic in the Azores and Madeira, and as far as Cabo Verde as well as in the Indian Ocean in Mauritius.

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15 January 2022, Hunga-Tonga Hunga-Ha'apai Volcanic Eruption and Tsunami

By International Tsunami Information Center

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Previous eruptions were in March 2009 and November-December 2014, but none of them generated tsunamis. The volcanic activity resumed in December 2021. On 13 January, a smaller eruption occurred for which the Tonga NTWC issued a tsunami advisory lasting about one day – the advisory was cancelled at 1102 local time. Unfortunately, while the potential for continued volcanic activity was expected, a massive explosion was not expected.

This is the first time that the PTWS has had to respond to a destructive volcanic event of these characteristics as the PTWS has primarily focused on earthquake-generated tsunamis that cause nearly 90% of the world's tsunamis. To move forward, the PTWS is immediately convening Post-Event Briefs to share information and experience, and provide interim guidance should another volcanic eruption occur.

Link to the ITIC volcanic eruption and tsunami summary as well as additional information including post event briefings, media releases, global sea level data, etc. can be found here: http://itic.ioc-unesco.org/index.php.

Link to the poster Hunga-Tonga Hunga Ha'apai Eruption and Tsunami: Importance of Real-time Sea Level Data for Tsunami Warning Decision-making (poster) can be accessed here:
http://itic.ioc-unesco.org/images/stories/list_of_tsunamis/2022/15Jan2022_Hunga-Tonga/HTHH_SLTsunamiWarning_IntlOceanData_LauraKong_feb22_4_A4.pdf

The Hunga Volcano: Past Eruptions and Geological History

By International Tsunami Information Center, itic.tsunami@noaa.gov

M 5.8 Volcanic Eruption (USGS preliminary estimate 02-01-2021)
68 km NNW of Nuku'alofa, Tonga, 20.546°S 175.390°W
2022-01-15 04:14:45 UTC (per USGS, from seismic surface waves)

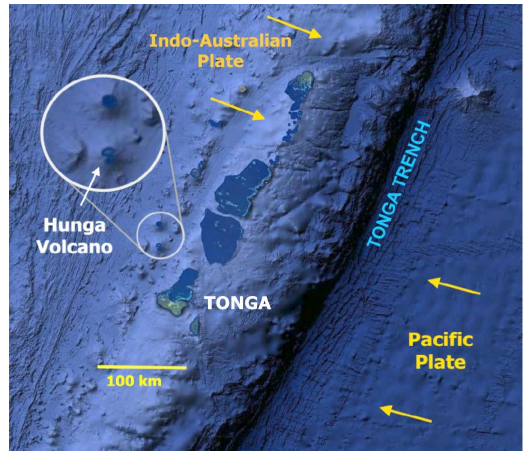

Figure 1: Regional map of the Tonga Volcanic Arc

The volcanic islands of Tonga form a submarine ridge at the eastern edge of the Indo-Australian Plate where it is overriding the Pacific Plate (**Figure 1**), forming the Tonga Trench, the second deepest ocean trench in the world (10,800 meters). The island arc extends about 500 km, with seamounts and volcanoes rising up from a depth of over 2000 meters. Standing 1800 meters high and 20 kilometers wide, the submarine Hunga volcano is in the southern portion of the arc, about 65 km north of the inhabited island of Tongatapu where the Tongan capitol is located. The topography and paleomagnetic data of the volcanoes in the Tonga arc indicate their formation has been relatively recent, and small to moderate sized eruptions occur every few years; individual volcanoes erupt with periods of 20-50 years (Bryan et al. 1972).

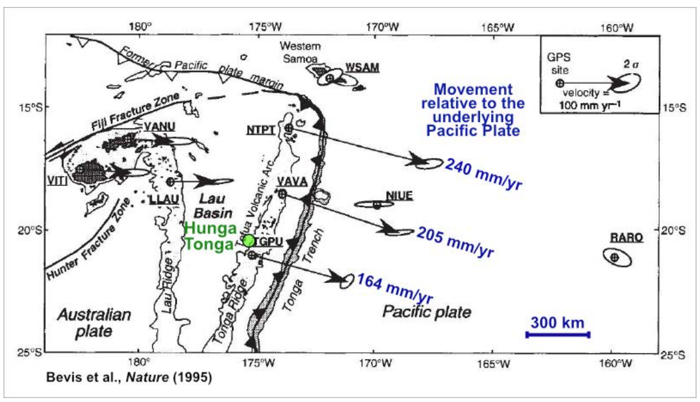

Figure 2: Relative plate motion along the Tonga Trench

The island arc also lies at the eastern boundary of the rapidly spreading Lau Basin, and through the combination of convergence of the larger plates and divergence of the basin, the relative plate motion has been measured at 164 mm/yr on the southern end to 240 mm/yr at the north, the fastest subduction rate ever measured (**Figure 2**; Pelletier & Louat, 1989; Bevis et al., 2005; Smith and Price, 2006). The rapid subduction, as well as possible strain from the Pacific Plate bending around the Australian, gives rise to extreme seismic activity (**Figure 3**).

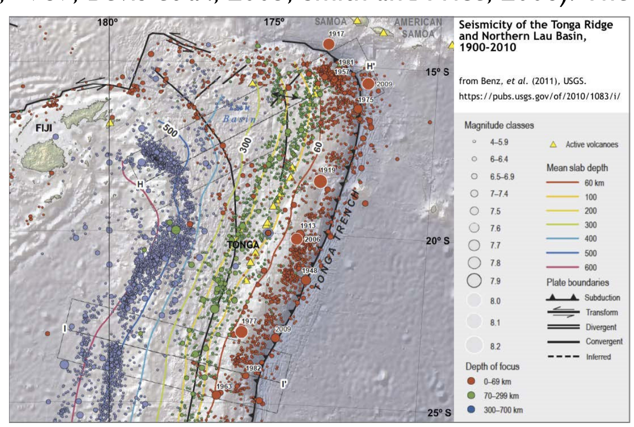

Figure 3: Seismicity along the Tonga Trench. The Hunga volcano is located at 20.4°S, just north of the Tongan capitol.

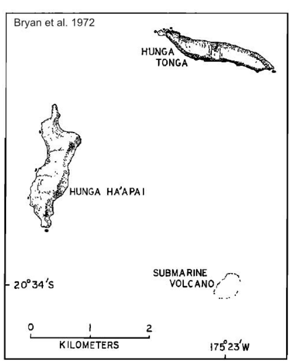

Figure 4: The islands around the Hunga volcano, as observed by Bryan et al. c. 1970.

The site of the January 2022 eruption was near the uninhabited islands Hunga Tonga (to the north) and Hunga Ha'apai (on the west). The two islands are described by Bryan et al. (1972) as "elongated and tangent to a circle centered on a rocky shoal about 3 km to the south of Hunga Tonga, which was the site of volcanic eruptions in 1912 and 1937" (**Figure 4**). Samples collected on Hunga Tonga revealed "alternating layers of andesitic lava flows and beds of scoria [porous lava rock], lapilli ["little stones" of erupted lava], and ash, which dip gently away from the center of the circle."

(Continues on page 4)

The Hunga Volcano: Past Eruptions and Geological History

By International Tsunami Information Center, itic.tsunami@noaa.gov

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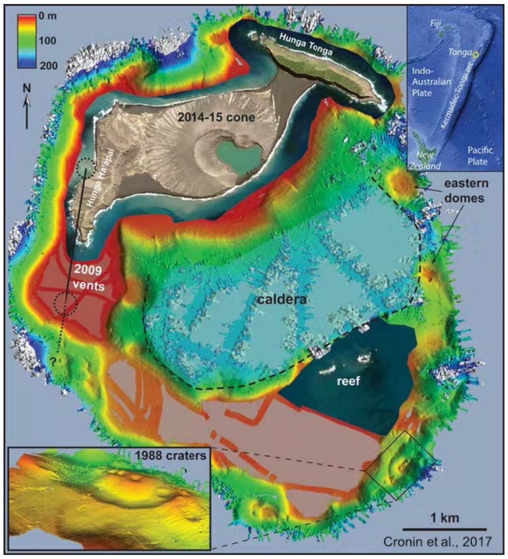

Figure 5: Hunga Tonga and Hunga Ha'apai islands, joined by a new volcanic cone, as observed by Cronin et al. after the 2014- 2015 eruptions. Sonar surveys revealed a large central caldera and features of previous eruptions.

They hypothesized that the islands were the visible northern and western remnants of the ridge around a large submarine caldera atop an active volcano.

Further eruptions of the Hunga volcano were recorded in 1988 (3 days) and 2009 (1 week). On 19 December 2014 another eruptive event occurred that lasted for 5 weeks. Plumes of steam 17 kilometers high formed from the violent reaction of seawater with hot magma. The 2014-2015 eruptions created a cone that initially formed a third island; soon it merged with Hunga Ha'apai and eventually joined with Hunga Tonga to form a single island.

Shane Cronin and a team of researchers from the University of Aukland (NZ) and the Tonga Ministry of Lands and Natural Resources surveyed the new formation later in 2015 (**Figure 5**). The team also uncovered previous deposits from superheated pyroclastic flows, evidence of huge explosive eruptions over millennial time spans. One contained carbon dated to around 1100 CE, closely corresponding to an event in 1108 CE that resulted in global temperature cooling by 1°C (Cronin et al., 2017; Sigl et al., 2015). High-resolution multibeam sonar surveys also revealed a 4 × 2 kilometer, 150 meter deep depression in the location of the submarine caldera (Bryan et al., 1972). A feature of this size would form by the explosive collapse of a previous volcanic structure in the course of an earlier eruption.

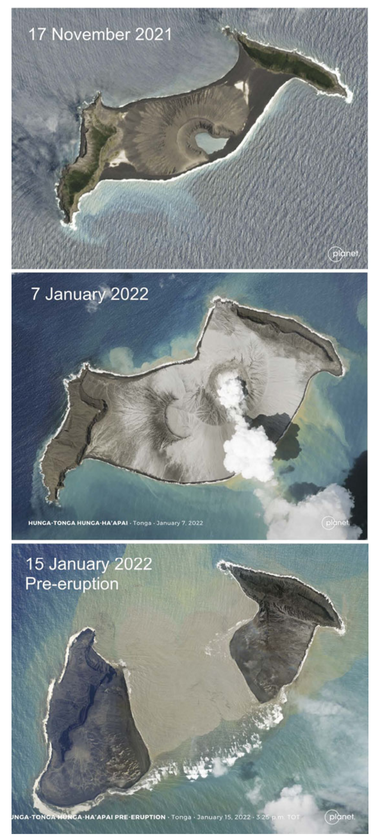

Figure 6: Hunga Tonga-Hunga Ha'apai in the months before the 2022 eruption. [Planet Labs SkySat imagery]

By November 2021, despite some shoreline erosion and settling, Hunga Tonga – Hunga Ha'apai appeared much the same as in late 2015 (**Figure 6, top**). Then on December 20th and January 13th two moderate eruptions occurred. The first increased the land area of the combined island (**center**), while the second added area to the western island but submerged the entire middle formed by the 2015 cone, splitting the formation in two once again (**bottom**).

Cronin notes that smaller eruptions typically occur around the edge of the central caldera, but large ones erupt from the caldera itself and introduce fresh, gas charged magma with even more violent power. The massive explosion at 0415 GMT on January 15th appeared to confirm that. The explosive reaction of magma and seawater 150-200 meters below the surface can create plumes like those seen in 2015, but the eruption in 2022 sent a plume over twice as high, 39 kilometers into the atmosphere, with a diameter of 260 kilometers — from an explosion that lasted only about 10 minutes (**Figure 7**).

(Continues on page 5)

The Hunga Volcano: Past Eruptions and Geological History

By International Tsunami Information Center, itic.tsunami@noaa.gov

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The tsunami that followed the Hunga eruption was different in several respects from the tsunamis following large earthquakes, which are much more common. First, unlike an earthquake that displaces ocean water from the seafloor up, along a fault line that can be hundreds of kilometers long, a volcanic explosion is more like a point source. Current tsunami forecasting models are based on the characteristics of 100 kilometer long segments of subduction zone faults in areas known to generate tsunamis. Volcanic eruptions do not fit this type of model, so estimates of travel time and wave height must be calculated differently, from observations of the tsunami waves themselves at the nearest tide stations or buoys.

Figure 7: The plume from 14 January 2022, the day before the gigantic 15 January 2022 eruption. [Taaniela Kula, Tonga Geological Services]

In addition, more than one mechanism can produce a tsunami in a large volcanic eruption, and all differ substantially from subduction zone earthquakes:

1. The submarine explosion itself may displace water, but instead of pushing up from the deep seafloor (at 1000-5000 meters depth), the explosion would originate near the top of a submerged volcano (a few hundred meters below the sea surface) and radiate out to the side(s) as well;

2. Caldera collapse, similar to an underwater landslide;

3. Pyroclastic flow into the ocean, also similar to an underwater landslide;

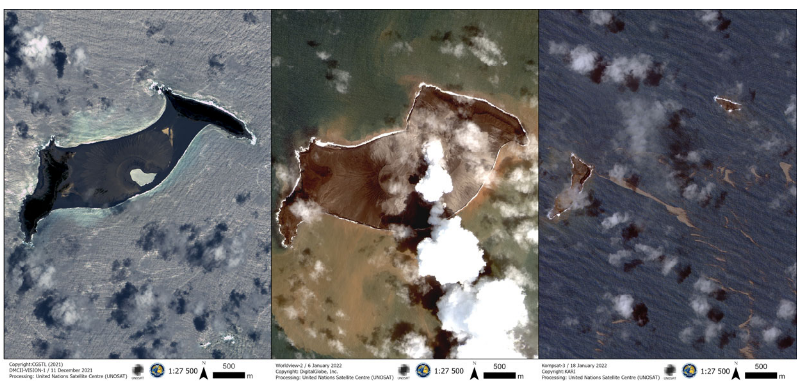

Figure 8: Satellite images of the volcano before (11 December 2021 and 6 January 2022) and after the 15 January 2022 eruption. [UNOSAT Emergency Mapping Service]

4. Acoustic pressure waves that generate coupled air-sea waves. These displace water from the top down, travel much faster than water waves, and are not bounded by land barriers.

Just weeks after the Hunga eruption, it is not known yet which of the first three mechanisms were responsible for the main tsunami (i.e., the tsunami generated directly in the ocean near the source). But strong atmospheric pressure waves were observed circling the globe several times, and tsunami-like waves reached remote regions such as the Caribbean too fast and at too great a height to have traveled through water the entire distance from Tonga, so the fourth mechanism must certainly have played a role.

Post-eruption satellite images show what appear to be smaller remnants of the two rim islands, with scattered shoals of debris (**Figure 8**). Findings from the survey in 2015 suggest that massive eruptions like that in January 2022 occur only every 1000 years or so, but the period of activity each event covers varies. Material uncovered from previous events appears to have been deposited over the course of multiple explosions, so the eruptive forecast for the coming months and years is uncertain.

(Continues on page 6)

The Hunga Volcano: Past Eruptions and Geological History

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Smithsonian Global Volcanism Program, Hunga Tonga-Hunga Ha'apai https://volcano.si.edu/volcano.cfm?vn=243040

USGS Seminar on the Hunga Tonga-Hunga Ha'apai Volcanic Eruption of 15 January 2022

Seminar held on Friday January 21, 2022

Presenters:

- Introduction—*Walter Mooney*
- Global Context of Tsunamis with a Volcanic Source—*Jessica Reid*
- Geophysical Studies of the Volcanic Back-arc—*Dave Scholl*
- Observations: The 15 Eruption and Tsunami—*Emile Okal*

USGS Seminar on the Hunga Tonga-Hunga Ha'apai Volcanic Eruption of 15 January 2022

Link to Presentation: https://www.youtube.com/watch?v=HesfxdTo198&t=4s

Social Media Successes and Lessons Learned During the January 15th Tonga Tsunami

By Elyssa Tappero, Washington Emergency Management Division (WA EMD)

When the Hunga-Tonga-Hunga-Ha'apai volcano eruption unleashed a tsunami which traveled across the entire Pacific Basin, many people in Washington State turned to social media for more information.

There they found a wealth of information about the ongoing US west coast tsunami advisory provided by a host of dedicated scientists, emergency managers, and public information officers at the federal, state, and local levels. Coordination between these various agencies allowed vetted, timely messaging to be shared in a variety of formats to reach as many people in the state as possible. It's easy to see how these efforts paid off when you look at metrics from January 15th.

Here is a sampling of social media highlights from Washington Emergency Management Division and partners:

- A WA EMD NextDoor post targeted to coastal areas reached *60,000 people*
- WA EMD Facebook posts reached a total of *885,000 people*
- The @WaShakeOut Twitter reached a total of *139,000 people*
- The @WaEMD Twitter reached a total of *797,000 people*
- NWS Seattle Facebook posts reached a total of *538,000 people*
- The @NWSSeattle Twitter reached a total of just under *3 million people*

What can't be captured in simple metrics is the value of those social media interactions. Monitoring social media during the event allowed the WA EMD tsunami team to answer questions directly, correct misinformation, and respond in real-time to trends or concerns by pivoting messaging as needed. That personal touch helped build trust with the public and provided some impromptu tsunami 101 education for those who weren't as familiar with the hazard. It was also a valuable opportunity to direct people to online resources like the WA EMD alerts page, where the public can sign up for different kinds of emergency alerts.

Like all real-world events, the Tonga tsunami advisory also provided many lessons learned, especially when it comes to utilizing social media during a disaster:

1. *Use simple, eye-catching graphics*—During the tsunami advisory, Facebook and Twitter posts accompanied by a graphic received more views and interactions than those without. In fact, people often paid more attention to the information in the graphic than in the body of the post, meaning you can't assume your audience will take the time to read the additional text in the body of your post. Any graphics shared should contain your most important messaging in the plainest language possible. Be sure to include an alt text description so people using screen readers can access the information as well. Check out this Social Media Image Sizes cheat sheet to ensure your graphics are sized properly.

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Social Media Successes and Lessons Learned During the January 15th Tonga Tsunami

By Elyssa Tappero, Washington Emergency Management Division (WA EMD)

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2. *Have canned messaging prepared and shared*—In a widespread event such as a tsunami where multiple jurisdictions are pushing out messaging at the same time, it's imperative that messaging be standardized to reduce confusion. Providing canned messaging in the form of pre-prepared graphics, videos/gifs, and text already formatted to fit certain social media sites saves valuable time and reduces the chances of confusing the public with conflicting information. Providing this canned messaging beforehand to your partners and stakeholders ensures a united front is maintained across agencies – and saves them time so they can focus on responding!

3. *Use trending hashtags*—It's important to use trending hashtags to ensure your social media posts are seen by as wide an audience as possible. Otherwise, your official messaging may get lost in the flood of online chatter. Pay attention to what hashtags your partners and the media are using; some of the popular hashtags used in Washington on 1/15 included #WaWx, #TsunamiAdvisory, #Tsunami, #WACoast, and #Tonga. Remember to capitalize the first letter of each word in your hashtag so screen readers properly pronounce them.

4. *Prepare for the long haul*—Messaging for events that unfold over hours or days can be especially challenging as it requires frequent monitoring and posting of new content on social media platforms. This can be quite draining so it's good to break the work into shifts when possible. For example, instead of having two people covering social media messaging at the same time for the length of the event, have those same people trade off every hour or more to ensure they get time to rest. Seems simple, but sometimes these things don't occur to us when we're in the middle of a response!

What was your messaging experience for the Tonga event? Do you have metrics from that day, or personal observations of what went well or what didn't? Our team would love to know! Email me at Elyssa.Tappero@mil.wa.gov.

Hunga-Tonga Hunga-Ha'apai Volcanic Eruption and Tsunami

January 15, 2022, Tsunami Advisory in California from Tonga Volcanic Eruption

By Rick Wilson, Senior Engineering Geologist, Manager of Tsunami Unit at California Geological Survey

During the January 15, 2022 Pacific-wide tsunami generated by the volcanic eruption near the island of Tonga, the California coast was placed into an "Advisory" tsunami alert status at 456 AM (Pacific) by the National Tsunami Warning Center (NTWC). The NTWC forecasted that the tsunami would first arrive between 700-730 AM (Pacific) in California, wave amplitudes would likely range from 1-3 feet in height, and beaches and harbors could be impacted.

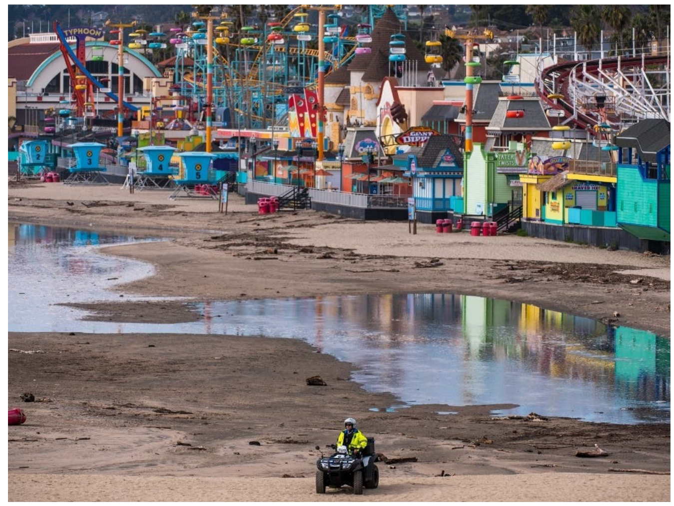

Figure 1. Tsunami flooding at high tide near Santa Cruz Beach and Boardwalk (photo credit: AP Photo/Nic Coury).

The State of California Tsunami Program (CTP), comprised of the California Geological Survey (CGS) and the California Governor's Office of Emergency Services (Cal OES), recognized that the tsunami would arrive coincident with daily high-tide conditions, increasing the potential for localized flooding. Cal OES and CGS sent this information to the members of our Tsunami Event Distribution List of 200+ county, city, and harbor officials along the coast, followed by a conference call at 530AM. The CTP also had direct communication with officials at key tsunami "hot spots" along the coast, including Santa Cruz and Crescent City harbors. Many cities evacuated beaches and harbors evacuated people from docks and those living aboard their boats, prior to the arrival of the first tsunami surge.

Figure 2. Photo of CGS engineering geologist Nick Graehl showing dock damage in Santa Cruz Harbor (selfie by Nick Graehl).

Leading up to and during most of the tsunami activity, the NTWC held hourly phone calls with State and National Weather Service officials to share information, and the CTP also held hourly calls with constituents at the county, city, and harbor level to transfer that information and answer questions. Strong to moderate currents were observed in dozens of harbors statewide. Localized flooding occurred along many beaches and within a number of harbors due to the largest tsunami waves, which reached 4-5 feet in some locations, arriving at high-tide conditions. Emergency response officials and news media outlets reported that some people who ignored the evacuations, such as surfers and beach visitors, had to be rescued because of the large surges and strong currents. For the rest of the day, the Advisory was cancelled for select locations along the coast once tsunami amplitudes stayed below one foot on tide gauges for three hours, which is part of the NTWC protocol; San Luis Obispo County along the central coast was the last area to have the Advisory cancelled, about 19-1/2 hours after the Advisory went into effect.

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January 15, 2022, Tsunami Advisory in California from Tonga Volcanic Eruption

By Rick Wilson, Senior Engineering Geologist, Manager of Tsunami Unit at California Geological Survey

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In coordination with tsunami scientists from the U.S. Geological Survey, the University of Southern California, and Cal Poly Humboldt, CGS deployed a number of field teams over a three week period to collect tsunami response, effects, and damage information from harbor and other local officials. A questionnaire was made available to officials and the public (https://arcg.is/1Duvmy0). Many harbors and other local officials utilized tsunami decision support tools (a.k.a. tsunami "playbooks) developed by the CTP for Advisory level events to understand dangerous areas within harbors and along beaches. Initial estimates from field teams, the survey, and the media are that there was approximately $10 million in damage to nearly a dozen locations from minor flooding and strong currents, including:

- Santa Cruz Harbor – $6.5 million from minor to moderate flooding (Figure 1) and dock damage from strong currents (Figure 2).
- Ventura Harbor - $1-2 million in damage to 20 docks and a harbor patrol boat which sunk due to strong currents.
- Tens to hundreds of thousands of dollars in damage to boats, docks, and vehicles in areas like Mill Valley, Moss Landing, Monterey, Port San Luis, Oceano Dunes, Santa Barbara, and Shelter Island in San Diego Bay.

CGS has created a website for this event at tsunami.ca.gov/tonga which will be updated on a regular basis, including the CGS event summary report to be completed in April 2022.

The Tsunami Could Kill Thousands. Can They Build an Escape?

A major quake in the Pacific Northwest, expected sooner or later, will most likely create waves big enough to wipe out entire towns. Evacuation towers may be the only hope, if they ever get built.

By Mike Baker, New York Times

OCEAN SHORES, Wash. — The 350 children at Ocean Shores Elementary School have practiced their earthquake survival plans, dropping under desks to ride out the convulsions, then racing upstairs to the second floor to await the coming tsunami.

Unless something changes, their preparations will most likely be futile.

The Cascadia fault off the Pacific Northwest coast is poised for a massive, 9.0-magnitude earthquake at some point, scientists say, a rupture that would propel a wall of water across much of the Northwest coast within minutes. Low-lying coastal neighborhoods in Washington, Oregon and Northern California would be under 10 feet or more of water, with the elementary school in Ocean Shores, Wash., facing an inundation that could be 23 feet deep.

The second-floor refuge students rush to in their drills stands 13 feet off the ground — in a structure that was not built to withstand a raging tsunami in the first place.

"The fact of the matter is that if a tsunami occurs tomorrow, we are going to lose all of our children," said Andrew

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The Tsunami Could Kill Thousands. Can They Build an Escape?

By Mike Baker, New York Times

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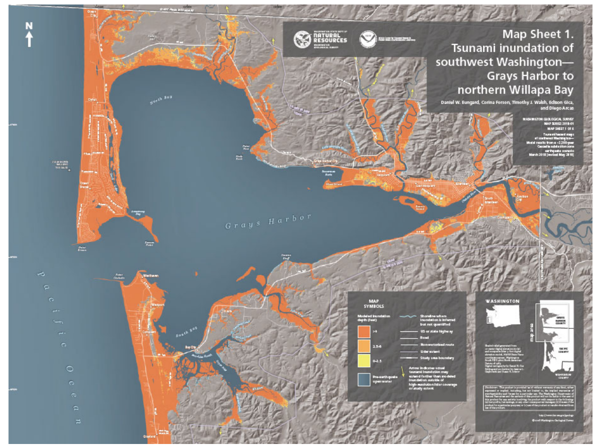
Kelly, the superintendent of the North Beach School District, which includes Ocean Shores. Mr. Kelly is one of a growing number of local officials who are calling for a network of elevated buildings and platforms along the Northwest coast that could provide an escape for thousands of people who might otherwise be doomed in the event of a tsunami.



On Tuesday, voters in Ocean Shores and neighboring communities will decide whether to approve a bond measure that would, in part, build new vertical additions at two schools, offering students and nearby residents a place to flee from a surging ocean.

Scientists have been warning for years that another catastrophic quake could erupt at any time in the Cascadia subduction zone, a 600-mile-long "megathrust" fault that stretches from Vancouver Island, British Columbia, to Cape Mendocino, Calif.

A quake from the fault, located roughly 70 miles offshore, could cause land along the shore to immediately drop by several feet. The sudden movement under the sea would send massive waves toward shore. And while recent tsunamis caused by earthquakes and volcanoes in the Pacific Rim have resulted in small surges on the West Coast of the United States hours later, a Cascadia wave would arrive at shorelines within 15 minutes.

Along many stretches of the Northwest coast, there are no bluffs or high buildings to climb — nowhere to go.

The lack of evacuation options means that the death toll could be almost unfathomable, far surpassing any other natural disaster in U.S. history. In Washington State, according to a 9.0 scenario the state uses for its estimates, about 70,000 people would likely be within the lowlands that could be engulfed by a large tsunami, and 32,000 of them would have no nearby high ground to escape to within 15 minutes.

Depending on the season and the time of day, Oregon estimates that 5,000 to 20,000 could die along the coast in a similar event, largely because of a lack of escape options; the state has planned for an even deadlier quake, based on the geological record, that could create a tsunami 100 feet high in some places. Additional deaths are expected in Northern California, notably in Crescent City, where a tsunami that came all the way from Alaska killed 11 people in 1964.

The question, scientists say, is not if but when. The chance of a 9.0 megaquake on the Cascadia fault in the next 50 years, according to the research, is about one in nine (although the chance of the precise kind of quake envisioned in the planning models used by each state would be less); the odds of a smaller but still powerful earthquake — of a magnitude greater than 7.0 — are one in three. Pressure is continuing to build along the hundreds of miles where the Juan de Fuca plate is pushing under the North American plate.

"Every day, on average, they are being pushed together at about the rate fingernails grow," said Corina Allen, the chief hazards geologist in Washington State. "Every year that the earthquake doesn't happen, there's a higher chance that it will the next year."

(Continues on page 12)

The Tsunami Could Kill Thousands. Can They Build an Escape?

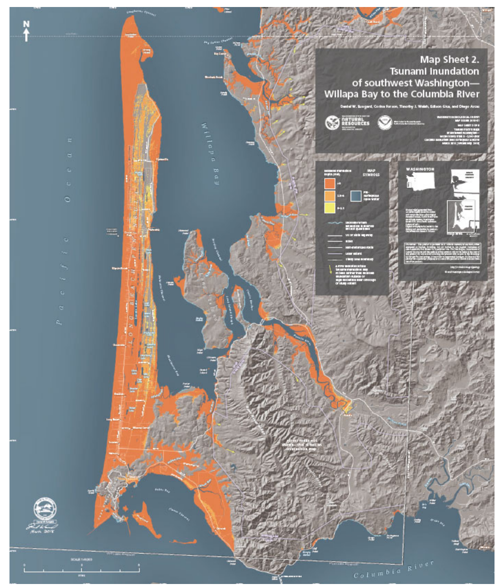
By Mike Baker, New York Times

(Continued from page 11)

Officials over the years have posted signs for evacuation routes and plotted ways to move people to higher ground. But many communities remain painfully vulnerable.

In the Long Beach area of Washington, for example, several communities — home to thousands — lie along a flat, narrow peninsula that stretches more than 20 miles. Officials in recent years had considered building an artificial hill to help with tsunami evacuation but abandoned the idea when modeling showed it needed to be much higher than was feasible.

Perhaps nowhere is more vulnerable than Ocean Shores, an idyllic community of 6,700 residents, with thousands more who visit in the summer to escape urban life and enjoy the miles of pristine beach next to thundering waves. The town has little elevation, and the tsunami that could accompany a 9.0 rupture would wash over all of it.



People could try driving out, but officials expect roads to be buckled and sunken, or covered in power lines, trees and debris. The expected subduction would cause the entire area to abruptly sink up to seven feet; the shaking could cause liquefaction of sandy soils before the tsunami reached shore.

People could try running to high ground outside of town, but Ocean Shores sits on a six-mile-long peninsula. Those who live toward the southern end would be about eight miles away from high ground. Depending on their location, residents might have only 10 minutes after the shaking stopped before the wave started washing over them.

"In 10 minutes, there's not that much time to go very far," Ms. Allen said.

The best option may be to get on a rooftop or to climb a tree. But many of the region's buildings were not constructed to withstand such a quake, let alone a tsunami, which would be hurtling cars and logs and other debris at objects in its path.

Dozens of other waterfront communities are also at risk, researchers said, including Seaside, Gearhart and Tillamook, in Oregon; Crescent City and the Samoa Peninsula, near Eureka, in California; and areas up and down the Washington coast.

To improve the chances of survival, officials in Washington State have proposed a network of 58 vertical evacuation structures along the outer coast and advised considering dozens of others. They could provide 22,000 people with an option for escape, although thousands of others would remain out of range.

Each structure could cost about $3 million.

Vertical evacuation structures have been embraced in Japan for years, in the form of platforms, towers and artificial berms. They became a refuge for many in the 2011 earthquake and tsunami, although that event still killed more than 19,000 people.

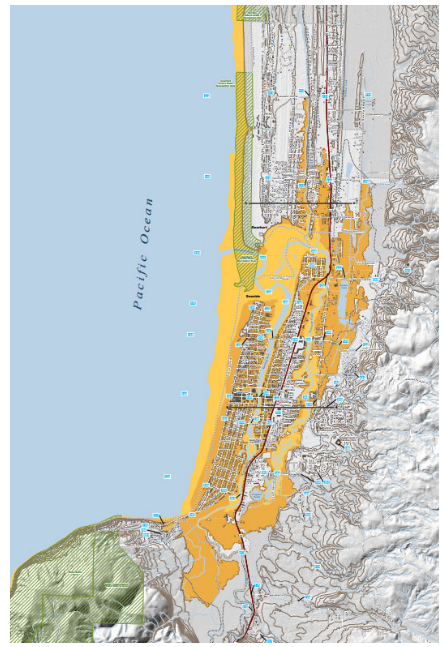
(Continues on page 13)

The Tsunami Could Kill Thousands. Can They Build an Escape?

By Mike Baker, New York Times

(Continued from page 12)

In the Pacific Northwest, only two vertical evacuation structures have been built so far. One is an Oregon State University building in Newport, Ore. The other is a portion of Ocosta Elementary School in Washington. Other cities have considered but not yet built evacuation towers, including Seaside, Ore., which relocated its middle school and high school to hills east of town.



In Tokeland, Wash., Charlene Nelson, the chairwoman of the Shoalwater Bay Tribe, said the tribe has been working for about 18 years on escape strategies. Their first recourse was a building up in the hills designed as an evacuation center, with supplies.

They ran practice events to get people to high ground, but one of the many families living on the narrow strip of land jutting into Willapa Bay found it took them 56 minutes by foot to get up to the center. The wave would most likely arrive in 20 minutes.

The tribe recently broke ground on a tower, largely funded by the Federal Emergency Management Agency, with pilings buried 51 feet in the ground and two elevated platforms that could hold hundreds of people.

Even when the structure is completed, Ms. Nelson said, people will need to practice their escape plans and know the routes to possible safety. They need a bag ready to go with key supplies — but not so many that it will slow them down when running for their lives. There won't be time for hesitation or for figuring out which direction to head.

"You need to be prepared, and you need to know what to do, and you need to do it," she said.

Aside from whatever damage a tsunami might bring, the earthquake itself would bring widespread devastation, with crumbling buildings, failing bridges, energy disruptions and mass casualties across a 140,000-square-mile area, including Seattle and Portland.

The urgency has been building over the past few years, which in coastal towns have felt like a ticking clock.

The last large quake on the Cascadia fault occurred on Jan. 26, 1700, scientists say. Chris Goldfinger, a researcher at Oregon State University, said geologic evidence from the past 10,000 years indicates that massive quakes with a magnitude of around 9.0 happen on the fault on an average of every 430 years. When including smaller but still powerful quakes on portions of the fault, the timeline in some areas shrinks to every 250 years.

It has been 322 years.

Bringing the expected casualty numbers down is difficult when the response planning has largely been left up to each community, Mr. Goldfinger said. A comprehensive federal solution with accompanying funding is needed, he said, and there is little time for delay given the amount of work needed to prepare.

"It's going to dwarf the scale of any disaster we have ever had," Mr. Goldfinger said. "We know it's coming."

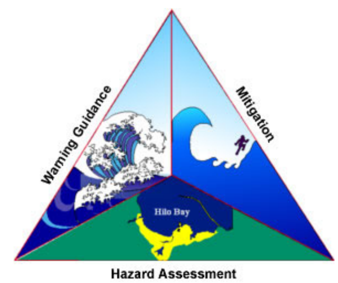
Link to original NYT article: https://www.nytimes.com/2022/02/07/us/tsunami-northwest-evacuation-towers.html

Mapping and Modeling Sub-Committee of the NTHMP Meets Virtually this Winter

By Alex Dolcimascolo, Jon Allan and Summer Ohlendorf

The ongoing COVID-19 pandemic has led to the cancellation of the in-person NTHMP Winter Meeting previously scheduled to be held in Portland, Oregon. Nevertheless, the Mapping and Modeling Sub-Committee (MMS) overcame the adversity caused by the rise of Omicron variant and held an abridged, yet efficient virtual winter meeting. At this meeting, members of the MMS presented progress updates on a variety of topics in the annual work plan including:

- The USGS-led Powell Center workshops & a tsunami source database
    - Alaska-Aleutian subduction zone (AASZ)
    - Landslide modeling & probabilistic tsunami hazard assessment (PTHA)
- National Centers for Environmental Information (NCEI) DEM development
- Maritime guidance and current modeling criteria
- Tsunami debris modeling



The Powell Center working group on tsunami sources communicated a goal to increase coordination on common tsunamigenic sources that transcend the state and territory boundaries. They have previously held three meetings focused on 1) determining their process, 2) the tsunami sources for the AASZ, and 3) landslide and seismic PTHA. MMS guest Hong Kie Thio (AECOM) presented on the development of an Alaska-Aleutian recurrence model for earthquake and tsunami hazards. This presentation outlined a few main objectives, which include developing a framework for PTHA source characterization for the AASZ, in addition to a probabilistic tsunami source characterization, and an assessable source database (with collaboration from California). MMS member Stephan Grilli also presented and outlined the methodology for a Monte Carlo approach for estimating the tsunami hazard from submarine mass failures along the U.S. Coasts. Their main objective is to probabilistically assess the landslide tsunami hazard for the U.S. Future scheduled Powell Center meetings will focus on Cascadia (May 2022) and other Pacific sources (August 2022).

NCEI recently completed the following NOAA-funded DEM updates: 1) Juan de Fuca Strait, Washington, 2) Brookings, Coos Bay to the California border, and 3) Tyonek, Kenai, Ninilchik, Anchor Point (Cook Inlet), Alaska; DEM updates for San Francisco Bay is still pending. Other non-NOAA funded DEM updates completed by NCEI included: Hawaii, Northeast U.S. Coast, and the Texas Gulf Coast, with Guam in the final review process. DEMs for Puerto Rico and CNMI are scheduled to be completed in the following grant cycle. NCEI is planning to host and maintain an online dashboard of all DEMs in the future.

Additionally, the maritime guidance website led by California has been reviewed by the NTHMP and can be viewed here: https://arcg.is/0DeHrG. Future work includes creating a specific guidance document to summarize procedures for documenting modeled current speeds in ports and harbors.

(Continues on page 15)

Mapping and Modeling Sub-Committee of the NTHMP Meets Virtually this Winter

By Alex Dolcimascolo, Jon Allan and Summer Ohlendorf

(Continued from page 14)

The MMS also discussed efforts to integrate and evaluate tsunami debris modeling capabilities within existing tsunami models. To address this topic, a joint University of Southern California/Oregon State University two-day tsunami debris modeling benchmarking workshop is being planned for mid-August 2022 in Newport, Oregon; tentative dates are currently set for the week of August 15th. The goal of this workshop is to evaluate the ability of existing tsunami models to simulate a variety of case studies, including simulating movement of a single debris piece, multiple debris pieces, a debris field, and results from field studies. A sediment transport benchmarking workshop is also tentatively scheduled for 2022 to evaluate the ability of tsunami models to address beach/dune erosion in response to tsunamis and their implication for tsunami inundation modeling. This latter workshop will largely focus on evaluating existing scientific knowledge of tsunami induced erosion, leading up to a second benchmarking workshop.

The MMS hopes to reconvene in-person for the annual NTHMP summer meeting, slated to be held in Palm Springs, California (dates TBD). In this meeting, we will hear possible lightning talks from our federal and state partners and continue to present updates on the annual work plan. MMS members will also have the opportunity to hear presentations on post-tsunami data collection plans by the USGS/ITIC & California, in addition to Washington's state-lead efforts to set up a multi-hazard clearinghouse.

NTHMP Mitigation and Education Subcommittee Virtual Winter Meeting – February 2022

By Todd Becker, Christa von Hillebrandt-Andrade, Tamra Biasco

The National Tsunami Hazard Mitigation Program (NTHMP) Mitigation and Education Subcommittee (MES) Winter Meeting was held virtually on February 2, 2022. Over 40 people gathered virtually for this MES Winter Meeting. Participants from NTHMP partner agencies and supporting organizations signed in from locations spanning seven time zones and thousands of miles across the globe. MES Co-chairs Todd Becker, Christa von Hillebrandt-Andrade, Tamra Biasco and NTHMP Administrator Ian Sears facilitated the meeting.

Following introductions, the meeting began with a review of the NTMHP MES Terms of Reference (TOR), 2019. The TOR describes the MES Purpose, Membership, Leadership, Communications, and Activities which provide the framework for stakeholder engagement. The MES is guided by the NTHMP Strategic Plan (2018-2023).

The MES reviewed the 2021 Work Plan Activities and noted the completed tasks. Work Plan Activities from 2021 with opportunities for continuing efforts in the 2022 Work Plan and beyond include TsunamiZone.org, exercise planning, and TsunamiReady®. The MES will identify additional activities for inclusion in the 2022 Work Plan and will finalize the Work Plan at the Summer Meeting which hopefully will be an in-person event.

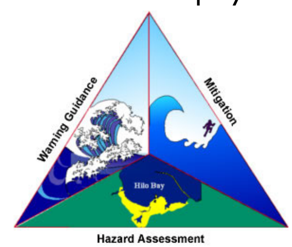
(Continues on page 16)

NTHMP Mitigation and Education Subcommittee Virtual Winter Meeting – February 2022

By Todd Becker, Christa von Hillebrandt-Andrade, Tamra Biasco

(Continued from page 15)

MES partners shared lightning presentations of activities being considered by States and Territories for inclusion in their fiscal year 2022 grant proposals. A common thread throughout many of the planned activities is a focus on equity and inclusion and the continued efforts to reach and support coastal communities with messaging, information, and resources to reduce the risk of populations exposed to tsunami hazard.



An MES election was held to elect a new First and Second Vice Chair. After many years of dedication and contributions to the MES by Christa von Hillebrandt-Andrade and Tamra Biasco, they were stepping down from their chair positions. Following nominations and a unanimous vote with no dissentions, the MES elected Nicolás Arcos from NOAA NCEI as the new Federal Representative for the First Vice Chair and Regina Browne from VITEMA USVI as the new State/Territory Representative for Second Vice Chair. The MES will recommend the Co-chairs elect for approval by the NTHMP Coordinating Committee at their next meeting.

Report and Recommendations Concerning Tsunami Science and Technology Issues for the United States transmitted to NOAA Administrator

By Rocky Lopes and Rick Wilson, Co-Chairs, Tsunami Science & Technology Advisory Panel

The NOAA Tsunami Science & Technology Advisory Panel (TSTAP), which was first discussed in TsuInfo back in October 2020 (https://www.dnr.wa.gov/publications/ger_tsuinfo_2020_v22_no5.pdf), has completed its first full report. It was submitted to the NOAA Administrator on January 3, 2022.

The TSTAP advises the NOAA Science Advisory Board (SAB) which, in turn, serves as the official Federal Advisory Committee to provide advice to the NOAA Administrator and to Congress.

The TSTAP Report has recommendations for NOAA about tsunami research, detection, forecasting, warning, mitigation, resilience, and preparation as called for in the authorizing legislation. This task was daunting because the last time a comprehensive report about these issues was done was in the 2011 National Academy of Science's *Tsunami Warning and Preparedness: An Assessment of the U.S. Tsunami Program and the Nation's Preparedness Efforts* ("the NAS Report") many of us have referenced for the past 11 years.

The TSTAP began by reviewing the 42 recommendations in the NAS Report and assessing what had been accomplished, what had stalled, and what had not been done. We investigated gaps in tsunami detection, warning, mapping, and modeling capabilities and research actions that were not included in the NAS report. We invited briefings by 10 top scientists and NOAA leaders to inform us about gaps, trends, new technologies, and pressing issues affecting U.S. tsunami capabilities today.

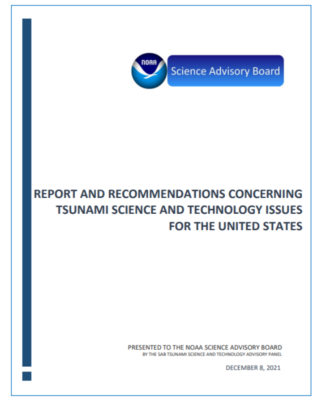
In 15 months and during 20 meetings, the TSTAP developed eight overarching recommendations, each of which had 2 to 5 specific sub-recommendations.

(Continues on page 17)

Report and Recommendations Concerning Tsunami Science and Technology Issues for the United States transmitted to NOAA Administrator

By Rocky Lopes and Rick Wilson, Co-Chairs, Tsunami Science & Technology Advisory Panel

(Continued from page 16)


Science Advisory Board

REPORT AND RECOMMENDATIONS CONCERNING TSUNAMI SCIENCE AND TECHNOLOGY ISSUES FOR THE UNITED STATES

PRESENTED TO THE NOAA SCIENCE ADVISORY BOARD

DECEMBER 8, 2021

The recommendations in this report include:

1. Improve unification and capabilities of the Tsunami Forecast System
2. Improve tsunami detection and observation systems
3. Provide more extensive, consistent, and accurate tsunami messages and products
4. Develop enhancements to Tsunami Warning Center forecasts and alert systems
5. Improve consistency in tsunami preparedness and mitigation products for communities
6. Produce guidance for improving long-term community resilience to tsunami hazards
7. Improve tsunami hydrodynamic modeling
8. Develop tsunami research priorities and leverage research opportunities

What does this mean? How will it be used?

The TSTAP Report is a comprehensive and thorough review of high priority issues facing the current NOAA Tsunami Program. It poses recommendations for NOAA and its partners, including the U.S. Geological Survey, Federal Emergency Management Agency, and the National Tsunami Hazard Mitigation Program to consider and address. We laid out the issues, backed up with citations from science, grounded observations from recent events, and input from many professionals and academic researchers.

We presented the report to the NOAA SAB in December 2021. It is telling that the Transmittal Letter of this Report sent from the SAB to the NOAA Administrator on January 3, 2022, said:

… if the recommendations provided are not addressed, hundreds of thousands of people on the west coast could be at risk of confusion and even potential injury and death. This risk is extended to other parts of the U.S. from other local tsunami sources, such as in Alaska, American Samoa, and Puerto Rico. It should also be stressed that the Nation's ability to save more lives from local tsunamis generated by nearby subduction zone earthquakes will be due to implementation of recommendations related to improving and funding state and local preparedness, mitigation, communication, and education efforts. Recommendation #3 further highlights the significant need to improve integration of TWC warning functions with USGS, state, and local warning needs and functions. This collaboration is critical for effective warnings.

The NOAA Administrator has one year from the date of receipt of this Report to provide a written response; technically, that is early January 2023. Co-Chair Rick Wilson and I received an email from NOAA Administrator Dr. Rick Spinrad one day after receiving the TSTAP Report that said, "Please pass my thanks on to the TSTAP for their diligence and careful attention to this important topic. We will give this report the attention and follow up that it so well deserves."

We are hopeful that this Report will be used by NOAA to make constructive improvements to the U.S. Tsunami Warning System to enhance and improve tsunami capabilities for our country and look forward to NOAA's official response.

The TSTAP's Report and Recommendations Concerning Tsunami Science and Technology Issues for the United States can be found on the web here: https://sab.noaa.gov/wp-content/uploads/2022/01/TSTAP-Report_Oct2021_Final_withCoverandLetter.pdf

What's Next?

While the TSTAP Report was a major step in updating the most urgent priority recommendations about the NOAA Tsunami Program, it scratched the surface. There remain more issues that we did not have time to investigate more thoroughly and have begun to do that during 2022 and beyond.

Please direct questions about the TSTAP or this Report to the Co-Chairs, Rocky Lopes and Rick Wilson.

How the PRSN Tsunami Program Positively Impacts Students, Even During Tough Times

By Vanesa Muñiz Llorens, Roy Ruiz-Vélez, Elizabeth Vanacore, Victor Huérfano, Puerto Rico Seismic Network

The Puerto Rico component of the National Tsunami Hazard and Mitigation Program (PR NTHMP) was started in 2006 with the purpose of assessing the tsunami hazards, preparedness, mitigation, and education for the public and official emergency agencies of Puerto Rico. With funding from the National Oceanic and Atmospheric Administration (NOAA), the Puerto Rico Tsunami Program has been able to provide meaningful opportunities for undergraduate and graduate students.

Because the Puerto Rico Seismic Network (PRSN) is part of the Department of Geology at the University of Puerto Rico – Mayagüez, it has created opportunities for students in a variety of fields ranging from scientific research to education and outreach. This has proven to be beneficial for many students that want to gain experience in their field, and has also provided some economic assistance as well. Students can serve as volunteers for events such as the ShakeOut and CARIBE WAVE or even apply for part-time positions in the fields of geology, geophysics, seismology, software engineering, or marine sciences. In this way students can acquire skills and experience that can positively impact their future careers.

Volunteers for the 2018 Caribe Wave exercise.

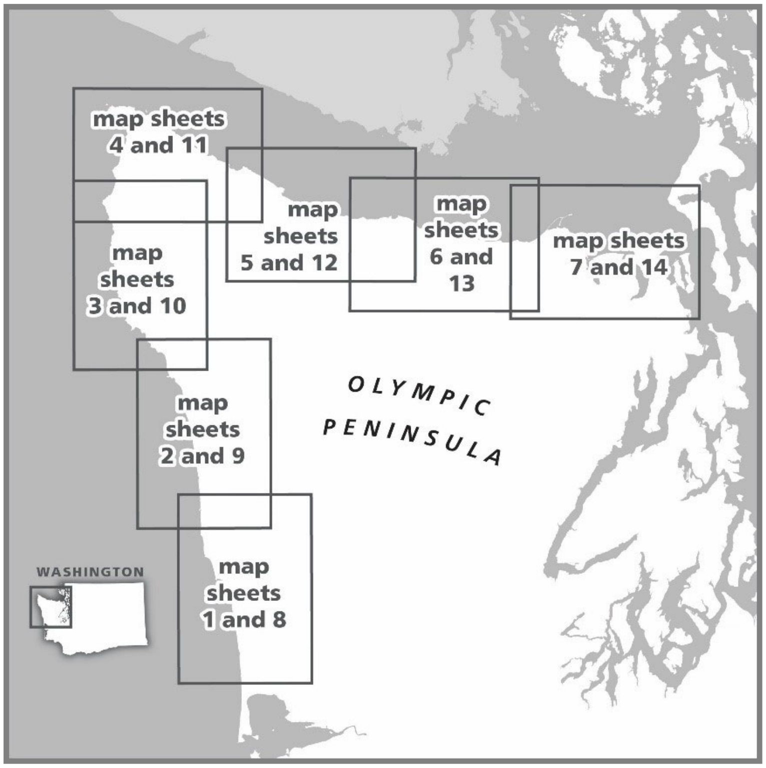
The TsunamiReady component has served as a significant step to academic and professional success for many university students, even during tough time such as the COVID-19 pandemic. As a consequence of the pandemic, PRSN successfully navigated a switch from in-person to remote work, indirectly benefiting students that are only able to work because of the remote option. In addition to receiving a job, students also have access to academic and professional advice from a dedicated team of supervisors/ mentors.

The PRSN has created opportunities for students to develop knowledge and capabilities in their field. Some of the task's students have been working on within the tsunami program include: tsunami modeling, locating earthquake sources, GIS data analysis, tsunami evacuation map updates, EMWIN systems deployment and maintenance, Puerto Rico Tsunami Education website updates, and the development of educational material and talks. All students work under the close supervision of PRSN's Tsunami Program research associate and professors.

Currently, the PRSN Tsunami Program works with 2 undergraduate students and 2 graduate students. These projects include the web development of the Puerto Rico Tsunami Education web portal, pedestrian analysis of evacuation times, tsunami sources and HAZUS modeling. Some of them even had the opportunity to present research and projects, in collaboration with the PRSN, and participate in important scientific conference's such as the American Geophysical Union (AGU) Fall Meeting or the Geological Society of America Annual Conference. For instance, the Puerto Rico Tsunami Education Portal was presented at the 2021 AGU Fall meeting in a presentation by Muñiz Llorens et al. Participation in these meetings provide valuable networking opportunities that are more difficult due to the geographic isolation of Puerto Rico. The participation in meetings also provide professional development for the students with exposure to current scientific findings/methods and practice of professional communication skills. Providing students with practical experience in the geosciences and mentoring students to set them up for future success is and will always be one of the central tenants of the PR Tsunami Program.

New Tsunami Hazard Maps of the Olympic Peninsula from a Large Cascadia Scenario

By Alex Dolcimascolo, Washington Geological Survey



The Washington Geological Survey has released a new publication showing tsunami model results from a large magnitude 9.0 Cascadia subduction zone megathrust earthquake scenario for the Olympic Peninsula in northwest Washington. This publication includes 14 supplemental map sheets showing maximum tsunami inundation, estimated first wave arrival times, and current speeds for locations covering Pacific Beach, Grays Harbor County to Neah Bay, Clallam County to Discovery Bay, Jefferson County.

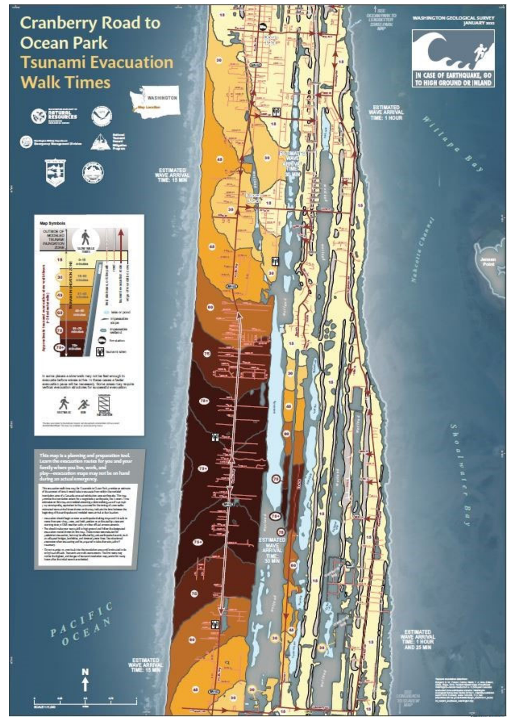
These are the first published tsunami hazard maps for many areas within this region using a Cascadia subduction zone scenario. The first tsunami wave hits the outer coast near La Push approximately 10 minutes after the earthquake starts. The wave then impacts all of the Pacific Coast and enters the Strait of Juan de Fuca at Neah Bay within 20 minutes, and reaches Port Angeles ~1 hour after the earthquake starts. The tsunami arrives as a trough, with sea level gradually receding at all locations. However, the initial trough may not be noticeable along the Pacific coast if it occurs concurrently with local flooding from assumed coseismic subsidence. Modeling results show inundation depths of ~60 feet or more along the shoreline of the Pacific coast, and 20 feet or more along the Strait of Juan de Fuca. Estimated currents from the tsunami waves locally exceed 9 knots (considered to be highly destructive) off Washington's Pacific coastline and within some areas in the Strait of Juan de Fuca, presenting a major hazard to boaters, the maritime industry, and port facilities. Tsunami wave activity would likely continue over 8 hours and remain hazardous to maritime operations for more than 24 hours.

The results presented in this publication are for a very large earthquake and tsunami, producing inundation that the next event is unlikely to exceed. We did this to encourage hazard planning for a maximum considered scenario and increase community resilience on the Olympic Peninsula. All tsunami hazard zones should be evacuated immediately after the earthquake when safe to do so and any felt earthquake shaking is an immediate warning. We recommend using this modeling as a tool to assist with emergency preparations and evacuation planning prior to a Cascadia subduction zone event or to determine locations where a tsunami vertical evacuation refuge would be appropriate.

This publication is available on our tsunami hazard maps webpage and downloadable using the following hyperlink: https://fortress.wa.gov/dnr/geologydata/tsunami_hazard_maps/ger_ms2022-01_tsunami_hazard_olympic_peninsula.zip

Tsunami Evacuation Walk Time Maps Published in Washington State

By Washington Geological Survey



The Washington Geological Survey has published "Tsunami Evacuation Walk Time" maps for the entire Long Beach Peninsula north of Cranberry Road, North Cove and the west side of Shoalwater Bay Reservation, and a re-release of the Anacortes area map on January 26th, 2022. The maps show the amount of time it would take to evacuate from within the modeled inundation zone of a magnitude 9.0 Cascadia-sourced subduction zone earthquake. The maps show the extent of the tsunami inundation zone and the paths of tsunami evacuation routes. Colors indicate how many minutes it would take to get to safety from any given location within the inundation zone.

These maps were developed using the U.S. Geological Survey's Pedestrian Evacuation Analyst Tool (https://www.usgs.gov/software/pedestrian-evacuation-analyst-tool) for ArcGIS. Emergency managers, planners, and local elected officials were heavily involved in the project providing valuable local knowledge and decision making to best serve the communities represented. The walk time maps are available for download using the following links:

Cranberry Road to Ocean Park:

- https://fortress.wa.gov/dnr/geologydata/tsunami_walkmaps/ger_tsunami_walkmap_cranberry_road_to_ocean_park.zip

Ocean Park to Leadbetter State Park:

- https://fortress.wa.gov/dnr/geologydata/tsunami_walkmaps/ger_tsunami_walkmap_ocean_park_to_leadbetter_state_park.zip

Leadbetter State Park:

- https://fortress.wa.gov/dnr/geologydata/tsunami_walkmaps/ger_tsunami_walkmap_leadbetter_point.zip

North Cove and part of the Shoalwater Bay Reservation:

- https://fortress.wa.gov/dnr/geologydata/tsunami_walkmaps/ger_tsunami_walkmap_north_cove_shoalwater_bay.zip

Anacortes area:

- https://fortress.wa.gov/dnr/geologydata/tsunami_walkmaps/ger_tsunami_walkmap_anacortes.zip

The maps are also available through an interactive map on our website:

https://www.dnr.wa.gov/programs-and-services/geology/geologic-hazards/tsunamis#tsunami-evacuation-maps

The interactive map also provides access to tsunami evacuation brochures for areas that do not have walk time maps yet.

TSUNAMI RESEARCH & EVENTS

RESEARCH

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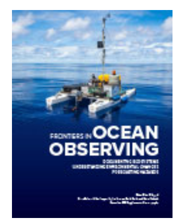
frontiers in Earth Science



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Yahav, Amir; Salamon, Amos, 2022, Tsunami Alert Efficiency: Encyclopedia of Engineering, v. 2, no. 1, p. 383-399, https://doi.org/10.3390/encyclopedia2010023.

E encyclopedia

UPCOMING NTHMP & RELATED EVENTS

- March 10, 2022—CARIBE WAVE 21 Tsunami Exercise https://www.weather.gov/ctwp/caribewave22
- March 21-25,2022—California's Tsunami Preparedness Week https://www.tsunamizone.org/california/
- April 19-23, 2022—SSA Annual Meeting (Virtual) https://www.seismosoc.org/annual-meeting/
- July 18-22, 2022—NTHMP Summer Meeting (Palm Springs, CA) https://nws.weather.gov/nthmp/index.html

Caribe Wave

SSA Seismological Society of America