NOAA TSUNAMI SCIENCE AND TECHNOLOGY ADVISORY PANEL POST-TSUNAMI REVIEW REPORT

PRESENTED TO THE NOAA SCIENCE ADVISORY BOARD

BY THE SAB TSUNAMI SCIENCE AND TECHNOLOGY ADVISORY PANEL

APRIL 27, 2022

NOAA Tsunami Science and Technology Advisory Panel (TSTAP) Post-Tsunami Review Report to the Science Advisory Board (SAB)

Review of the National Tsunami Warning System Activities During the Tsunami Generated by the January 15, 2022, Hunga Tonga-Hunga Ha'apai Volcanic Eruption

Tsunami Source: Hunga Tonga-Hunga Ha'apai is an uninhabited volcanic island located in the southwest Pacific Ocean between New Zealand and Fiji, to the northwest of Tonga. The volcano began an eruption sequence in December of 2021 and culminated in a violent eruption on January 15, 2022, that created an ash plume 600 kilometers (375 miles) in diameter. This explosive eruption produced a tsunami that affected the entire Pacific Ocean, and atmospheric pressure waves that circled Earth several times causing minor tsunamis visible on tide gauges (marigrams) in the Gulf of Mexico, the Caribbean, and even the Mediterranean Sea.

Tsunami Forecast, Response, and Impacts: Both the Pacific and National Tsunami Warning Centers (PTWC and NTWC, or TWCs) monitored the tsunami with forecast systems not designed to evaluate non-seismic source events. Both the TWCs have stated during public post-event briefings that the complexity of the event and inadequacies in the forecast system led to uncertainties and delays in the tsunami forecasts for U.S. territories in the South Pacific and the more distant coasts of the States of Hawaii, Alaska, and the West Coast of the U.S. Mainland. Despite the forecast uncertainty and the millions of U.S. coastal residents and visitors exposed to tsunami hazards around the Pacific Ocean, the forecasts of "Advisory" level surges (0.3m to 1.0m) for U.S. Territories and States were relatively accurate and no loss of life was reported in these areas. Initial estimates of damage from tsunami currents and flooding along U.S. coasts were about $10,000,000, primarily to harbors and waterfront structures (California Geological Survey, in press).

TSTAP Assessment: The January 15, 2022, tsunami provides the TSTAP with an opportunity to evaluate the recommendations for NOAA and the Tsunami Warning System provided to the SAB in our report dated December 8, 2021. This evaluation is based on real-time observations by TSTAP members who were working with the TWCs as part of their official tsunami response duties, and others who were observing the active tsunami response as private individuals. TSTAP members, in their role as State tsunami operational representatives, also took part in post-tsunami briefings with the TWCs and other officials involved in tsunami forecast and response, and then reported back to TSTAP members. Based on the TSTAP assessment, many of the forecast and messaging issues observed during the January 15, 2022, event, were previously identified in the December 2021 TSTAP recommendations report.

Conclusions: The following table summarizes a number of these issues and references related recommendations from the TSTAP report. While the comments are not ranked, the first four comments listed are of higher priority. We have determined that at least 15 of the 22 recommendations made in the December 2021 report are fully or partially substantiated by the outcomes from the January 15, 2022, event. Because this event was unique, complicated, and beyond the present capabilities of NOAA to fully analyze and forecast, it is not the intent of the TSTAP to lay blame on NOAA, its National Weather Service, the TWCs, or their personnel. The goal of this assessment is to demonstrate the urgency for NOAA to address the recommendations in the original report to help protect U.S. coastal residents, visitors, and property during future tsunamis.

Comment/Issue from TSTAP Evaluation of January 15, 2022, Tsunami Event	Supported Recommendations from December 2021 TSTAP Report
<u>**Source and Forecast Uncertainties:**</u> Because this was a volcanic source event, the TWCs did not have a system in place to provide accurate forecast information. For example, to utilize the existing forecast models, the NTWC had to replicate a M8.6 earthquake in the region to develop forecasts for the Pacific. In addition, the number of useful deep-ocean buoys were limited so the TWCs could not compensate and correct initial source information using the buoy readings. There were also a limited number of tide gauges in the region to observe the propagating tsunami in the early hours of the event. **Expanding TWC capabilities to include volcanic and other non-seismic sources will be essential to accurately forecast these sources in the future.**	**1.2 – Upgrade enterprise-wide technology** **1.3 – Work with USGS to improve non-seismic source analysis, like volcanoes** **2.2 – Expand detection capabilities, like tide gauges** **2.4 – Consider use of airborne and satellite observing platforms** **5.1 – Standardized sources including volcanic and landslide sources** **8.1 – Leveraging research to assess volcanic and landslide sources**
<u>**Delayed Messaging and Forecast:**</u> Although the eruption and tsunami started at 20:15PM PST the previous evening (January 14), the NTWC did not put the West Coast into an Advisory until 04:57 AM PST, nearly nine hours later. With first tsunami surges forecasted to arrive at around 07:00 AM PST, coastal areas only had two hours for implementing response activities; these activities typically take three to four hours to complete. **Decision-support information about the potential Advisory and/or threat could have been sent earlier, possibly within the first several hours after the eruption cautioning emergency managers and giving them more time to implement response activities and inform local officials who authorize actions such as closing beaches and harbors.**	**3.2 – Early messaging and providing information in a timely manner**
<u>**Messaging Issues:**</u> Some messages from the NTWC were confusing and/or different. They used a M1.0 for the volcanic eruption. Later in the event, the NTWC would have had to change the earthquake magnitude to a M6.5 to activate their system to report observed tsunami amplitudes in messaging and online; this effort was abandoned based on feedback from State-level emergency managers. Both issues seem to be because of limitations in the NTWC software and/or system. **Upgrading the notification and messaging system could address these messaging issues.**	**1.2 – Upgrade enterprise-wide technology** **3.2 – Tsunami Bulletins – simplifying the bulletins**
<u>**Confusion Over the Term "Advisory"**</u>: The tsunami alert terminology is sometimes confusing. Some people, including the media, misunderstood what actions should be taken during a Tsunami Advisory and some media outlets miscommunicated it as a "tsunami warning." NOAA is considering replacing the term "Tsunami Advisory" but this has been a difficult and controversial discussion. One suggested alternative is to call a Tsunami Advisory a "Marine and Beach Warning," as is used in New Zealand. In many areas, this event demonstrated that "harbor and beach" areas were at the greatest risk of and impacted by flooding and damage. However, there are concerns if Tsunami Advisories were replaced by the phrase "Marine and Beach Warnings" that it will lessen the impact of the term "Warning" during larger events. TSTAP should consider a new recommendation for NOAA to examine the tsunami alert terminology (not just Tsunami Advisory) for more Impact-based Decision Support Services (IDSS) terminology. **At the very least, NOAA should evaluate messaging and impacts of this event in greater detail prior to any changes to tsunami alert terminology, especially changes to the Tsunami Advisory alert status.**	**3.2 – Improve tsunami message composition to explain potential impacts**

<u>**Incorporating Tidal Conditions:**</u> Minor flooding in Hawaii and along the West Coast caught locals off guard because during a Tsunami Advisory, inundation is uncommon. Post-tsunami analyses indicated that this flooding was caused by high tides which coincided with the largest tsunami amplitudes. States like California have a system in place to incorporate tides and other factors influencing flooding into decision support products during an event. However, the tsunami forecast amplitudes are needed for this flood evaluation and the TWCs were not able to provide this information. Post-tsunami analysis indicated this decision support tool would have captured this flooding given the appropriate data. **This event highlights the importance of providing forecast amplitude data during future events and finding a way to incorporate the tides and other potential flood factors globally in real time.**	**1.1 – Producing consistent products (forecast amplitudes) by both TWCs** **2.1 – Improve observation networks, increasing tide gauges** **4.2 – Update forecast areas, breakpoints, and forecast points** **7.1 – Improvements to hydrodynamic modeling, including tides**
<u>**Complicated Waterways**</u>: The NTWC was not able to provide wave arrival times or forecast information for inland waters, such as the Puget Sound, WA or near Juneau, AK. In addition, the interior and outer coast of San Francisco Bay, which have different tsunami hazard levels, could not have separate alert levels because an alert breakpoint does not exist between these areas. This inability to provide hazard and alert information for these complicated waterways (where millions of people live and major ports operate) is essential for understanding the full hazard and clearly communicating it. **The TWCs have indicated that improvements to alerting these complicated waterways cannot be made until the enterprise-wide upgrades have been performed on the tsunami warning system.**	**1.2 – Upgrade enterprise-wide technology** **4.1 – Expand granularity in tsunami alert regions where complicated waterways exist (e.g., Puget Sound, San Francisco Bay, etc.)** **4.2 – Update forecast areas, breakpoints, and forecast points**
<u>**Inconsistent Forecasts in Puget Sound:**</u> Washington shares several waterways with Canada. The advisory was canceled for British Columbia (BC) before it was canceled for Washington for the same waterway (the Strait of Juan De Fuca). This difference in alert level and messaging is confusing for people who live on either side of the Strait. It was determined in past discussions among the NTWC, Washington, and BC that they wanted to have uniform alerting for these areas that share a waterway. **This again supports the need for increased granularity in forecast and alert capabilities.**	**4.1 – Expand granularity in tsunami alert regions where complicated waterways exist (e.g., Puget Sound, San Francisco Bay, etc.)** **4.2 – Update forecast areas, breakpoints, and forecast points**
<u>**Delays in Downgrading/Canceling Alert:**</u> For portions of the West Coast, the tsunami Advisory alert lasted from 04:57AM PST on January 15 until 12:30AM PST on January 16, some 19-1/2 hours. The protocol for canceling an Advisory is to wait for tide gauge readings to show that the tsunami amplitudes are less than the lower Advisory threshold (0.3m) for at least three hours. First, it would be helpful to inform states when they are within the three hour advisory cancellation window. Also, because of the way tsunami waves amplify or resonate near tide gauges in some harbors, these readings can show an inaccurate reading of tsunami activity and incorrectly extend the Advisory alert status. There may be a better way to evaluate how to end an Advisory. For example, a simple pass filter (or some other form of rapid assessment) of the gauge data to evaluate rates of change might help. Installing additional tide gauges might have also helped with this decision-making or provided the ability to pick tide gauge information that is not influenced by immediate surroundings. It is likely the Advisory would have been canceled many hours earlier for this tsunami event which reduces the stress on the TWC staff, State and Local emergency officials, and the population and business owners that were evacuated. **Improving communication about changes to alert levels and increasing the number of tide gauges and evaluating the accuracy of existing tide gauges will improve the accuracy of monitoring tsunamis, downgrading alerts, and improve overall local response.**	**2.1 – Increase tide gauges and other observation systems** **2.2 – Expand detection capabilities** **3.2 – Early messaging and providing information in a timely manner**

<u>**Collaboration Between TWCs:**</u> TSTAP members were briefed that the PTWC and NTWC were in communication with each other during the event and that forecasts along the West Coast were improved by conversations about impacts which were occurring in Hawaii. **This event demonstrated the benefits of the two TWCs working more closely together in the future.**	**1.2 – TWC unification and software** **1.4 – Improved collaboration between TWCs**
<u>**Performance of NOAA Tsunami Website:**</u> While tsunami.gov performed well, there were occasional times when it failed, perhaps due to overloading from the number of online visitors. Errors observed:" Earthquake layer failed to load / Alerts/Threats layer failed to load." Several times throughout the day of January 15, 2022, when refreshing the site, a spinning circle was observed with a blank screen behind it. Refresh again, and it worked. **Correcting observed errors and improving the capacity of online visitors during a tsunami is vital to notifying the public.**	**3.2 – Improve performance of tsunami.gov**
<u>**Wireless Emergency Alert Status:**</u> Tsunami Advisory "lit up" the entire coast of North America, from Alaska through Canada, all the way to the Mexico border. If this were a full Tsunami Warning level event on which a Wireless Emergency Alert (WEA) is activated, since device-based geofencing (DBGF) was turned off Nov. 2019 due to excess number of vertices and polygons over the WEA 3.0 limit, the WEA would alert via the current "WEA 2.0" method, which alerts by FIPS codes aligned with county borders. The TSTAP recognizes that NOAA does not control the Wireless Emergency Alert System which is governed by the Federal Communications Commission (FCC) and implemented by FEMA. However, FEMA has stated that either one of two things must happen for DBGF to work: 1) the FCC could issue an updated "Report and Order" to allow for a greater number of polygons and vertices to be alerted beyond the 10 polygon/100 vertices maximum under "WEA 3.0" (DBGF precision); or 2) states could agree to reduce the number of breakpoints for coastlines between the borders of Canada and Mexico to be within the 10 polygon /100 vertices total limit, which goes against the recommendation to increase them. **Getting DBGF to work for the tsunami warning system and improving WEA for notifying vulnerable coastal populations without over-notifying safe inland areas.**	**1.2 – Upgrade enterprise-wide technology** **3.1 – Testing WEA and other platforms** **4.1 – Increase capabilities of WEA**
<u>**Incorporate Forecasts on Current Velocities**</u>: This event was primarily a hazard within and around ports and harbors where strong, unpredictable currents can occur. Information about current velocity would be helpful for understanding the potential impact a tsunami may have. It would be great if the NTWC could provide estimated current speed information in their bulletins. An alternative being used by some states is to match the forecasted amplitudes for the event with a previously modeled scenario; this method was used in California during this event. This identifies the level and location of hazardous conditions within harbors. **Additional information on hazardous currents would be beneficial to provide as a decision-support tool for port and harbor response.**	**3.3 – Make available foundational forecast data**
<u>**Messaging about Volcanic "Pressure Wave"**</u>: Because this was an unusual, non-earthquake sourced event there were many things that didn't go as usual. One interesting feature that was not included in the forecasted wave arrival times was the earlier arrival of a minor tsunami wave caused by an atmospheric pressure wave from the volcanic eruption. For the West Coast, this minor tsunami (below 0.3m) arrived three-to-four hours before the primary tsunami activity started. Early in the event, the NTWC informed participants on their information call about this early arriving wave activity and confirmed that it would be minor and non-threatening. Although it was non-threatening, it was difficult to communicate this rare occurrence to the local decision-makers. Additional research about this phenomenon is needed to understand potential impacts better in the future. **The TWCs should research and explore ways to provide more detailed information about the event and potential tsunami activity hours before the tsunami arrives.**	**3.2 – Early messaging and providing information in a timely manner** **8.1 – Leveraging research to assess volcanic and landslide sources**