Tsunami Science and Technology Advisory Panel

Working Group Report and Recommendations to the NOAA Science Advisory Board concerning Tsunami Science and Technology Issues for the United States

(August, 2021)

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Executive Summary

The purpose of this report is to provide advice to the National Oceanic and Atmospheric Administration's (NOAA) Administrator on matters regarding tsunami science, technology, and regional preparedness. This is the first report developed by the Tsunami Science Technical Advisory Panel (TSTAP) to be delivered to the NOAA Science Advisory Board (SAB). This report provides eight major recommendations (and multiple sub-recommendations) relating to improving tsunami research, detection, forecasting, warning, mitigation, resiliency, and preparation, all of which are the TSTAP's charges under the *Tsunami Warning, Education, and Research Act of 2017*.

The TSTAP began by reviewing the National Academy of Science's (NAS) 2011 report, *Tsunami Warning and Preparedness: An Assessment of the U.S. Tsunami Program*[1]. Following this review the TSAP invited scientists and other professionals to provide briefings on various technical issues to receive the most up to date information regarding the state of the science and to learn about strengths and gaps in the NOAA/NWS Tsunami Program. These briefings informed the TSTAP's recommendations and were the foundation of the observations and findings to support these critical recommendations to improve NOAA's ability to prepare for and mitigate impacts from future tsunamis.

The table below summarizes the recommendations provided in this report and identifies the key partners NOAA may collaborate with to accomplish these tasks. The TSTAP has organized the recommendations based on the categories similar to what the legislation calls for: evaluation of tsunami research, detection, forecasting, warning, mitigation, resiliency, and preparedness. The recommendations have been prioritized in a different order based on the Panel's judgment of their importance to improving the tsunami warning system as well as protecting the public.

Focus Area	Recommendation	Sub Recommendations: It is recommended that the NOAA Administrator…	Potential Partners with NOAA
PROGRAMMATIC	1. Improve unification and capabilities of the Tsunami Forecast System.	A. Align and consolidate TWCs and overhaul the forecast system to unify detecting earthquake parameters and produce the same products (e.g., forecast wave heights).	USGS
		B. Undertake a comprehensive, enterprise-wide technology upgrade for the warning system/program.	
		C. Strengthen the collaborative relationship and expand MOU with the USGS for identifying earthquake parameters and source mechanism.	USGS
		D. Ensure sufficient backup capabilities for tsunami forecasting and alerting.	

DETECTION	2. Improve tsunami detection and observation systems.	A. Increase development and improve dissemination of observation networks like tide gauges, web-cameras, and real-time observer programs.	NTHMP
		B. Expand detection capabilities to all seismic and non-seismic sources.	USGS
		C. Work with NSF and international partners to share and expand the use of GNSS to determine fault rupture extent and movement.	NASA NSF
		D. Further consider the use of airborne and satellite observing platforms.	NASA
FORECAST & WARNING	3. Provide more extensive, consistent, and accurate tsunami messages and products.	A. Improve the integration of TWC warning functions with USGS, state, and local warning needs and functions.	NTHMP USGS
		B. Improve tsunami message composition and dissemination methods including updating the tsunami.gov website, creating a single domestic bulletin, and early messaging before a tsunami forecast is developed.	NTHMP
		C. Make available foundational forecast data from propagation models and inundation model results to constituents.	NTHMP
FORECAST & WARNING	4. Develop enhancements to tsunami warning center forecasts and alert systems.	A. Expand granularity in tsunami alert regions where complicated waterways exist (e.g., Puget Sound, San Francisco Bay, etc.).	
		B. Update special procedure areas, threat database thresholds, breakpoints, and forecast point locations.	
PREPAREDNESS & MITIGATION	5. Improve consistency in tsunami preparedness and mitigation products for communities.	A. Develop a standardized framework for characterizing, selecting, and using consistent tsunami sources between states.	NTHMP
		B. Improve guidelines for evacuation maps that ensures consistency between states/communities and develop a national online repository.	NTHMP
		C. Prioritize probabilistic tsunami hazard mapping at a national scale, especially for updating ASCE/Building Code “Tsunami Design Zone” maps.	ASCE, NTHMP USGS

RESILIENCE	6. Produce guidance for improving long-term community resilience to tsunami hazards.	A. Develop guidance and products for tsunami mitigation/recovery consistent with and leveraging climate change adaptation strategies.	FEMA NTHMP
		B. Conduct evacuation modeling, feasibility studies, and risk analyses for vertical evacuation structures.	FEMA NTHMP
RESEARCH	7. Improve tsunami hydrodynamic modeling.	A. Improve tsunami modeling capabilities in the following conditions/areas: variable landscapes (i.e., surface roughness), heavy vegetation, built environment, and dynamic river systems.	NTHMP
		B. Conduct a greater number of high-resolution bathymetric surveys.	
		C. Develop a data portal for detailed information for advancing research and model development.	
RESEARCH	8. Develop tsunami research priorities and leverage research opportunities	A. Coordinate with Federal, state and territory agencies that have funded research that includes tsunami to leverage and prioritize research opportunities and provide consistent and useful products.	FEMA NASA NSF State/territory partners USGS

It is not a matter of if, but when the next tsunami will strike the U.S. coastline. The TSTAP sees an urgent need for action to ensure our nation is doing more to mitigate this risk and also doing everything possible to prepare and equip the end-to-end tsunami program with the tools and staff necessary to detect, forecast, and alert the public in a clear and timely fashion.

The most significant recommendations from the TSTAP involve improvements to the NOAA Tsunami Warning System and its two tsunami warning centers. Although TSTAP believes that NOAA is fulfilling their mission adequately with the resources and staff available, our recommendations for improvements are based on perceived gaps and inconsistencies throughout the tsunami forecast and warning process. The TSTAP feels that these recommendations are the most critical and timely to be acted on with deliberate attention and speed. In doing so, the nation's coastlines, residents, and coastal visitors will be more safe from the potential of a destructive tsunami when the next one strikes our shores.

The TSTAP asks that the NOAA Administrator review this report and develop a plan and schedule for addressing the TSTAP's recommendations and other program priorities. If NOAA indicates a particular recommendation cannot be addressed due to a lack of resources, an estimate of the resources needed should be provided to the TSTAP with an explanation. Additionally, because this is the first report of many the TSTAP is charged with authoring, it is critical to continue to have a collaborative working relationship with NOAA. To that end, the TSTAP kindly requests semiannual progress reports on how recommendations are being addressed by NOAA and who is working on them. The TSTAP will continue to meet and provide reports to the SAB every four years, or sooner if the need arises.

Foundation of Tsunami Science and Technology Advisory Panel (TSTAP)

The TSTAP was established in Public Law 115-25, §3206a. Full citation is in Appendix I.

Introduction

Charge to the TSTAP: The TSTAP was established under the *Tsunami Warning, Education, and Research Act of 2017* ("the Act") appended to *The Weather Research and Forecast Innovation Act of 2017*. *The TSTAP will provide advice to the NOAA Administrator on matters regarding tsunami science, technology and regional preparedness. In order to accomplish this, the TSTAP will: (1) review at least once every four years (beginning 2021) the activities of the Administration and other Federal activities as appropriate, relating to tsunami research, detection, forecasting, warning, mitigation, resiliency and preparation, (2) submit findings from the review through the SAB to the NOAA Administrator at least once every four years (beginning 2021) along with recommendations for legislative or administrative action to improve Federal tsunami research, detection, forecasting, warning, mitigation, resiliency and preparation, and (3) address such other matters as the NOAA Administrator and/or Science Advisory Board members may request.*

Over the past decade, the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) and its numerous governmental and academic partners have made significant advancements in applied tsunami science and technology. These advancements include enhancements to the tsunami warning system, improvements in tsunami source characterization and modeling, and improvements to tsunami preparedness and mitigation planning. Many of these are highlighted in the "Accomplishments" section.

Despite these many advancements, there are areas for improvement. The TSTAP has completed its first-year assessment of NOAA/NWS' tsunami program and provides recommendations for future work in this document. These recommendations span a broad spectrum of topical tsunami strategies and planning efforts considered in *the Act*, including tsunami research, detection, forecasting, warning, mitigation, resiliency, and preparation. Implementing these recommendations will strengthen the overall national tsunami warning system and help protect lives and property in the U.S. during future tsunami events.

Urgent Need for Action

The most significant recommendations from the TSTAP involve improvements to the NOAA NWS tsunami warning system and its two tsunami warning centers. These recommendations are based on perceived gaps and inconsistencies throughout the tsunami forecast and warning process. Currently, the Tsunami Warning Centers (TWCs) are fulfilling their mission adequately with the resources and staff available. However, in order to improve Impact Based Decision Support Services (IDSS) to U.S. states and territories, significant investments and actions recommended in this report are needed to continue to improve the U.S. Tsunami Program and public safety when tsunamis strike U.S. coastlines. Our system and resources have not been tested in a large event and, based on briefings to this panel and recent earthquake events, there is a clear need for improved technology, resources, and funding to ensure our capabilities are up to the job of preparing for alerting the impacted populations in a timely manner.

This is an opportune time to act on significant technological upgrades to tsunami detection and warning capabilities and for improving consistency, coordination, and products from the two TWCs. For detection and warning, several opportunities exist which have been researched and demonstrated, such as obtaining data from Global Navigation Satellite Systems (GNSS) and placing detection equipment on undersea cables. However, transition from research to operational implementation has been slow, delayed, or lacking. As technological improvements are being made, it is also an opportunity for the two TWCs to better coordinate and align their methods, forecasting, and messaging.This will help reduce sometimes conflicting tsunami alert messaging and improve response products.

Population at risk

Population density along U.S. Coastlines continues to increase. This has a major impact on public tsunami exposure and risk. While precise data for at-risk populations are not available, it is estimated that hundreds of thousands of residents and employees as well as millions of visitors exist in or visit tsunami prone areas along the coastal regions of the U.S. each year (Dr. Nate Wood, USGS; personal communications). While it is recommended that more precise numbers be generated using the 2020 U.S. census data, these estimates of population exposure demonstrate a need for ongoing protection from tsunami hazards at the federal, state, and local levels. The existing and likely increasing coastal population also elevates the actions and activities recommended in this document to an “urgent” level.

Approach to Review and Recommendations

Interviews and References

The TSTAP first convened virtually on August 20, 2020. During regular meetings, it was agreed to hold virtual meetings twice each month through March 2021 and then monthly after that.

The TSTAP began its work by thoroughly reviewing the National Academy of Science’s (NAS) 2011 report, *Tsunami Warning and Preparedness: An Assessment of the U.S. Tsunami Program*[1] (Hereinafter referred to as the “NAS Report”).

The development of the NAS Report was assigned to the National Academy of Sciences (NAS) in Public Law 109-479, Title VIII, *Tsunami Warning and Education Act of 2006.* It described in great detail viewpoints of a body of professionals convened by the NAS Ocean Studies Board. The authors of the report reviewed the status of the U.S. Tsunami Program as it was operating in 2009/2010.

The NAS Report provided 42 recommendations for improvements or adjustments to the U.S. Tsunami Program and other entities such as the National Tsunami Hazard Mitigation Program (NTHMP).

In October 2013, NOAA issued comments[2] on the NAS Report. In the NOAA comments, some of the recommendations were noted as complete; some were being worked on; some were considered out of scope or not germane.

The TSTAP reviewed the NAS Report recommendations as well as NOAA’s comments and considered actions taken by NOAA and its partners to address those issues up to and through 2020 since the time the recommendations were made in 2011. Many of the NAS Report recommendations were addressed (See “Accomplishments,” page 10); however, there are some gaps in fulfillment of some of the recommendations. This informed the TSTAP on some content for the report.

In need of more current information about the status of issues affecting tsunami science and technology, the TSTAP invited scientists and other professionals to provide briefings on various technical issues.

TSTAP leadership developed questions for the briefers to address matters identified from the TSTAP review and update of the NAS Report's Recommendations.

The following professionals briefed the TSTAP between September 2020 and March 2021:

- Mr. Michael Angove, Tsunami Program Lead, NOAA/National Weather Service
- Dr. Diego Arcas, Director, NOAA Center for Tsunami Research
- Dr. Lori Dengler, Professor Emeritus, Humboldt State University
- Dr. Paul Earle, Director of Operations, National Earthquake Information Center, U.S. Geological Survey
- Dr. James Gridley, Director, National Tsunami Warning Center
- Mr. Michael Hornick, Natural Hazards Program Specialist, FEMA Region IX
- Mr. John McCandless, Community Planner, FEMA Region X
- Dr. Charles (Chip) McCreery, Director, Pacific Tsunami Warning Center
- Dr. Summer Ohlendorf, Science Operations Officer, National Tsunami Warning Center
- Dr. Jeff Payne, Director, NOAA Office for Coastal Management

Organizing Recommendations

The TSTAP documented its findings and observations based on its reviews of recommendations from the NAS Report and the professional briefings from scientists and professionals. From there, draft recommendations were reached through a collaborative process as described above. Half of the TSTAP meeting times were dedicated to discussion of the recommendations-in-development, and the background, findings, and observations that support the recommendations in this report.

Informed by the scientific briefings and with input from Federal agency liaisons, the TSTAP collaborative process determined the ultimate organization of this report and its recommendations. The TSTAP:

- Listed findings and observations along with recommendations related to gaps or concerns about the current state of affairs of the NOAA Tsunami Program.
- Reviewed and consolidated as many as 100 individual and specific recommendations to align and organize them along the lines of the nine focus areas identified in the driving legislation.
- The resulting list of 24 recommendations were further reviewed during a TSTAP meeting to discuss prioritization. Consensus on priorities was not achieved by discussion, so the TSTAP members ranked the recommendations on three criteria: a) opportunity -- is it the right time for NOAA to be working on this issue considering available resources, time, and human capital? b) is it a priority of national scope and consequence, or geographically/regionally limited? c) how does the recommendation directly address public and life safety?
- The TSTAP considered using the Analytical Hierarchy Process (AHP) to rank recommendations, but AHP was exceptionally complicated and such an academic approach was not necessary to achieve the prioritization goal.
- Instead, a simple mathematical approach was applied where members were asked to rank by forced choice (1,2,3, with no ties). Results were averaged and standard deviations among ranking averages were computed. There was consistency among individual member rankings, though not all were the same.
- The results from the ranking exercise were used as a guide to develop the sequence of the recommendations by priority, but also included consideration of "what needs to be done first? What comes next?" or "you can't do this unless you do that first," and so on.

Though tedious, this process is replicable by any group of SMEs. The results were clear, consistent, and confirmed a consensus without objection of any individual TSTAP members.

Accomplishments of the NOAA Tsunami Program and its Partners

The TSTAP found that progress on several NOAA Tsunami Program activities had been made in addressing the recommendations from the NAS Report in addition to other issues identified after tsunami events over the past decade. Work, both internal and external to NOAA, has improved the U.S. tsunami warning system and tsunami preparedness and mitigation at the state and local levels. Before describing these accomplishments, we highlight the important partners NOAA collaborates with to accomplish its goals.

Expanding Partnerships and Collaboration to Accelerate Progress

Who are the partners? How do they interact with NOAA?

1. U.S. Geological Survey (USGS)

   The USGS is a science bureau within the United States Department of the Interior. The chief activity of the USGS on which NOAA relies is the science about the natural hazards that threaten lives and livelihoods, particularly earthquakes. The USGS National Earthquake Information Center (NEIC) based in Golden, Colorado, is an important partner to NOAA/NWS Tsunami Warning Centers to evaluate and provide information about earthquakes that may be tsunamigenic. Further, USGS research has led to significantly improved application of knowledge so that tsunami source characterization, modeling, forecasting, and warning can be more accurate and time-saving for public safety. Additionally, USGS scientists collaborate with state partners for improved tsunami risk assessments, safety analysis, mapping, and outreach/education.

2. Federal Emergency Management Agency (FEMA)

   FEMA has been a partner with the NTHMP since its inception. FEMA provides advice, technical support, and funding to improve state and local capacity-building, earthquake and tsunami mitigation planning and actions. FEMA has helped support planning and construction of vertical evacuation structures along the U.S. West Coast as well as preparedness and mitigation products for ports and harbors. FEMA's software, *Hazus-Tsunami*, is used to estimate losses from earthquakes and tsunamis and is an important tool for understanding economic losses as well as estimating injuries and fatalities. The TSTAP also desires to have more engagement by FEMA on actions related to coastal land use as FEMA becomes more active with climate change and response to the threat of sea level rise and increased coastal erosion and sedimentation.

3. National Tsunami Hazard Mitigation Program (NTHMP)

   In 1995, recognizing the tsunami threat to the United States, the U.S. Congress directed NOAA to form and lead a federal/state working group to develop a plan for reducing tsunami risk to U.S. coastal communities. This group formed what has become a model for federal/state partnerships—the NTHMP. Today's NTHMP includes representatives from NOAA, FEMA, USGS, and 28 U.S. states and territories (states). This strong and active partnership connects states with the Federal agencies responsible for the U.S. Tsunami Warning System and brings together the expertise and experiences of all the partners. This enables all levels of government to work together toward the common goals of protecting lives and reducing economic losses from tsunamis at the community level.

4. American Society of Civil Engineers (ASCE)

   The ASCE provides initial building standards and commentary to the International Building Code as well as building codes developed by U.S. states and local governments. In 2016, the ASCE Tsunami Loads and Effects Subcommittee developed building standards for critical and essential facilities in the U.S., including standards for designing and constructing tsunami vertical evacuation structures. The ASCE continues to work on improving mitigation strategies to reduce impacts from hydrodynamic forces, debris impact, and foundation scour. Although not a direct partner with the NOAA Tsunami Program, some coastal states within the NTHMP see value in utilizing the expertise of the ASCE and encourage more collaboration between the NOAA Tsunami Program and the NTHMP in future building code revisions and updates to probabilistic tsunami hazard analysis.

Accomplishments of the NOAA Tsunami Program and Partners

NOAA,its Line Offices, and its partners have implemented many planning efforts and created products over the past decade related to the seven topical categories outlined in the Act: research, detection, forecasting, warning, mitigation, resiliency, and preparation. During the TSTAP Review of the NAS Report as well as during scientist/professional briefings, the following accomplishments for the NOAA Tsunami Program and its partners were noted:

- Consistent 24/7/365 x 2 staffing of both NOAA/NWS Tsunami Warning Centers in Hawaii and Alaska
- Improvement of tsunami detection –
    - Increased and localized seismic monitoring, both contracted exclusively by NOAA (Hawaii, Alaska, Puerto Rico, U.S. Virgin Islands) and extensively supplemented by the U.S. Geological Survey.
    - Expansion, ongoing maintenance, and significant technological improvements of Deep Ocean and Assessment of Tsunami (DART®) stations and network.
    - Development and deployment of tsunami-capable water level stations by NOAA National Ocean Service Center for Operational Oceanographic Products & Services (CO-OPS). A few additional water level stations have been independently deployed by both Tsunami Warning Centers for greater accuracy of water levels on certain coastlines of Hawaii and the Aleutian Islands of Alaska.
- Significant improvements to tsunami forecasting and accuracy to tsunami modeling, including evaluation benchmarking by the NTHMP.
- Support for robust capacity-building, hazard assessment, preparedness, mitigation, recovery, warning coordination, and public outreach & education among U.S. states and territories through the NTHMP and ongoing grant funding provided by the NWS as appropriated by Congress.
- Development of guidelines for production of evacuation maps to foster consistency in format and quality across the United States were developed in 2012 by the NTHMP and were updated in 2017.
- NOAA's National Centers for Environmental Information (NCEI), in collaboration with the USGS, developed and published the National Tsunami Hazard Assessment titled: *U.S. States and Territories National Tsunami Hazard Assessment: Historical Record and Sources for Waves*. This assessment was updated in 2015.
- Development and launch of a single website, tsunami.gov, that represents information from both U.S. Tsunami Warning Centers in near real-time. (More work on this website is also recommended – see related recommendation on Page 12.)
- FEMA developed *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis,* a comprehensive guidebook for state and local personnel to consider how to strengthen structures on the coast that can serve for purposes of access to nearby vertical evacuation when a tsunami strikes. FEMA updated these Guidelines in 2019 and offers workshops and training for state and local partners regularly.

- FEMA developed and deployed *Hazus-Tsunami* which is a software tool that supports tsunami loss estimation for potential losses from tsunami hazards. This software enables users to anticipate the consequences of future tsunamis and to develop plans and strategies for reducing risk.
- The creation of ASCE 7-16 Standards and Commentary provides the foundation and framework for the first significant tsunami building code to protect essential and critical structures in western U.S. states. ASCE 7-22 will provide updates to these Standards as well as Tsunami Design Zone maps in several states using improved mapping techniques developed by those states.

Recommendations for Implementation

The NOAA Administrator or delegate is requested to:

1. Develop a plan and schedule for addressing the TSTAP's recommendations and other program priorities. If NOAA indicates a particular recommendation can not be addressed due to a lack of resources, an estimate of the resources needed should be provided to the TSTAP with an explanation.
2. Provide periodic updates on how recommendations are being addressed and who is working on them. It is recommended that NOAA provide a semi-annual progress report on how the recommendations are being addressed.

Recommendations

I. Improve unification and capabilities of the Tsunami Forecast System.

A. It is recommended that the NOAA Administrator align and consolidate TWCs and overhaul the forecast system to unify detecting earthquake parameters and produce the same products (e.g., forecast wave heights).

Disparity in earthquake solutions and forecast messages: When an earthquake happens, particularly in the Pacific Basin, each TWC performs an independent analysis of the earthquake event. Although there are procedures in place to ensure multiple potentially contradictory sets of parameters are not published, these independent analyses can lead to different interpretations of the tsunami source and potential impacts. Often the TWC published parameters will be in conflict with the official USGS parameters, creating additional confusion.

Each TWC Director has stated in briefings to the TSTAP that the TWCs are so busy during the initial seismic analysis phase that they do not coordinate with each other. Sometimes one TWC copies the analysis from the other center into its products, and sometimes they do not.

It would be prudent to use a single analysis of the precipitating event to eliminate inconsistency and confusion, and to prevent public safety officials potentially making decisions based on "least-case" scenarios of their own choice. Social science studies of behavior in response to risk indicate that a majority of decision-makers will choose the least worrisome of data presented to them[3]. Further, social science studies indicate that most decision-makers and the public do not want to believe (or deny) danger or harm [4]. People tend to pick the least harmful scenario if given a choice.

Consistent Tsunami Products: There is an inconsistency between the National Tsunami Warning Center (NTWC), Palmer, Alaska, and the Pacific Tsunami Warning Center (PTWC), Honolulu, Hawaii, in the tsunami forecast information provided to their designated service areas (DSAs) (formerly "areas of responsibility" [AORs]). For example, during a tsunami event, the NTWC provides forecast tsunami wave height information (amplitudes) for about 100 locations along the West Coast and Alaska, however the PTWC does not provide any forecast wave heights to their DSA[5]. States and communities have found that this forecast wave height information is very valuable for their response efforts, it provides knowledge of what level of tsunami hazard to anticipate. One example of this is that California uses these forecast wave heights along with the NWS forecasted storm and tidal information to estimate the “total water” flood elevation for their coastal communities and harbors. With this, they can recommend potential adjustments in real-time response activities and products to communities during distant-source tsunami events[6]. Expanding the number of forecast locations and providing consistent forecast products by the TWCs would be beneficial to decision support for communities. With two TWCs, product consistency and accuracy should be of great importance.

B. It is recommended that the NOAA Administrator undertake a comprehensive, enterprise-wide technology upgrade for the warning system/program.

Technology Upgrade: The existing warning software is outdated and not purpose built, consisting of a series of patches and fixes developed over decades as complicated alert and warning issues have been discovered. In addition, there are features that states and territories need, such as additional coastal alert segments, and refinements to special procedures areas, that the current system is unable to provide. Moreover, TWC earthquake analysis systems are outdated and difficult to maintain and manage.

USGS and NOAA missions do not fully overlap but both agencies are interested in improving the timing and accuracy of automatic results and reducing the time to determine earthquake mechanism (e.g., Centroid Moment Tensor [CMT]).

There could be stronger collaboration in these areas between NOAA and USGS which may also allow NOAA to re-evaluate the need to maintain an independent seismic analysis capability. The current analysis systems in both TWCs are based on technologies that the USGS replaced ten years ago; continuing use of these systems will endanger the TWC mission as support and maintenance of outdated software concepts and architectures becomes more and more challenging. Similarly, expansions needed by new technologies (such as GNSS) are difficult to implement.

TWC Unification and Software: The existing software and systems are outdated and in order to bring the system up to date, a large overhaul is needed. Improved unification and capabilities of the Tsunami Forecast System are required. Since 2015, the NWS has invested significant funding for I.T. modernization and harmonization of the TWC detection and alerting systems. While hardware upgrades were made at both TWCs, comprehensive software systems needed to unify TWC operations have yet to be designed, deployed, tested, and brought to full operation.

C. It is recommended that the NOAA Administrator strengthen the collaborative relationship and expand MOU with the USGS for identifying earthquake parameters and source mechanisms.

Strengthening NOAA/USGS Collaboration: Initial tsunami warning messages are typically based on the location, depth, and magnitude of the source earthquake. These are parameters produced by both the two TWCs and the USGS during an earthquake. There is significant overlap between the USGS and NOAA earthquake monitoring missions, but fundamental differences exist. NOAA's focus is on speed for Tsunami warning with set time requirements to release information whereas the USGS's focus is on accuracy for shaking impact assessment (ShakeMap ground shaking estimates and PAGER fatality and economic loss estimates). The USGS currently has release-time goals that are focused almost entirely on solution quality and accuracy. The different missions have led to optimizing different aspects of software, operations and focused development and research that improves robustness and source characterization of earthquakes. The missions are different but both NOAA and the USGS benefit from faster and more accurate solutions.

The TSTAP recommends a full review of NOAA and USGS capabilities and requirements to determine how the USGS and NOAA can benefit from tighter collaboration given their overlapping missions. This collaboration can cover different responsibilities on several levels, such as more simply assigning responsibility to the USGS for generation of basic earthquake parameters to the creation of a joint operations center. Both of these options could require considerable investment and planning. A more easily attainable goal that can be started before a full review would be more efficient sharing of current products such as earthquake moment tensor information. Additionally, generation of rapid models of earthquake faulting (finite fault models), based on either seismic waveform analysis or GNSS offset

measurements could be attainable in the short term. Coordination of software development is another area to be explored as well as tighter integration with the operation of seismic stations. The USGS currently coordinates station operation with NOAA through the Hawaiian and Alaska Volcano Observatories but also operates the Albuquerque Seismological Laboratory, a premier center that installs, operates, and maintains seismic stations worldwide.

The GAO Report (25 March 2021) titled *Earthquakes: Progress Made to Implement Early Warning System, but Actions Needed to Improve Program Management*[7] says on Page 61, "NWS officials said they have discussed partnering with USGS, such that the National Earthquake Information Center would provide preliminary results regarding the source and magnitude of an earthquake to the Tsunami Warning Centers within five minutes, or perform the analysis for them. However, NWS officials stated they were unsuccessful in engaging USGS officials because USGS is not required to provide its preliminary analyses to the NWS." The GAO report suggested that the NWS-USGS MOU be revised to address this issue specifically. This would be a good opportunity for other potential areas of coordination and collaboration to be explored and added to this MOU.

Non-seismic source tsunamis: Some tsunamis are created by non-seismic hazards such as landslides, volcanic activity, and even offshore storm activity (meteotsunamis). NOAA, the USGS, and state geological surveys have expertise in identifying areas where these hazards exist but there has been no standardized system developed for real-time monitoring of the activity, tsunami potential, and tsunami risk from these sources. In the short term, states have the capability to set up regional collaborative working groups to which they may invite Federal partners. For example, the State of Alaska has developed an interagency science team, which includes NOAA and the USGS, to monitor activity of the Barry Arm Landslide and its potential for generating a tsunami which could impact nearby coastal communities. The TSTAP endorses further collaboration between state and Federal partners on such activities. Over the long term to address this issue, NOAA and the USGS should explore improving integration of the non-seismic sources into the tsunami forecast databases within the NOAA Tsunami Warning System. This will improve the consistency and accuracy of tsunami warnings related to these sources.

D. It is recommended that the NOAA Administrator ensure sufficient backup capabilities for tsunami forecasting and alerting.

The two TWCs (NTWC and PTWC) have independent technology and standard operating procedures. Each TWC is meant to support each other, especially if one TWC is unable to function and the other must step in as a backup. However, due to the different geographic regions they serve and the myriad of fixes to the forecasting system since each center's inception, there are certain parameters that are not unified between the TWCs.

Act citation: *§3203. Tsunami forecasting and warning program, (d) Tsunami warning centers, (1) In general--The Administrator shall support or maintain centers to support the tsunami warning system required by subsection (c). The Centers shall include—(A) the National Tsunami Warning Center, located in Alaska, which is primarily responsible for Alaska and the continental United States; (B) the Pacific Tsunami Warning Center, located in Hawaii, which is primarily responsible for Hawaii, the Caribbean, and other areas of the Pacific not covered by the National Center; (3)* ***Fail-safe warning capability****--The tsunami warning centers supported or maintained under paragraph (1) shall maintain a fail-safe warning capability and perform back-up duties for each other.*

The TWCs do not perform regular exercises to test backup capabilities for typical earthquake events or for complicated and unique events that require use of special procedures that are the primary domain of the NTWC. An example of this is an earthquake on the Seattle fault which would

invoke an NTWC special procedure for alerting. Further, the NTWC's special procedures are not tested regularly through exercises with state partners.

Backup capabilities of the PTWC to implement the NTWC's special procedures have not been practiced. Regular exercises to ensure sufficient backup capability and synchronization of the NTWC's special procedures (as well as core alerting capabilities) would be helpful to ensure complete and thorough backup capabilities.

It is imperative that the TWCs improve collaboration to demonstrate they can provide backup functions for each other. In addition, with limited staff and resources available at both TWCs, NOAA should perform a study to determine if continuing to have two Warning Centers is the best alternative for seamless and consistent alerting.

II. Improve Tsunami Detection and Observation Systems

A. It is recommended that the NOAA Administrator increase development and improve dissemination of observation networks like tide gauges, web-cameras, and real-time observer programs.

NOAA utilizes a network of DART® sensors and coastal tide gauges to monitor and record tsunami activity. This network is used for detection, determining when tsunami alerts should be reduced or cancelled, and post-tsunami model validation. Because DART® sensors can be costly to deploy, maintain, and keep fully functional, increasing the number of tsunami monitoring and observation points using other technologies (tide gauges, web-cameras, field observers, etc.) will help fill in gaps in the network and enhance the entire tsunami warning system. NOAA has information on various methods that can be applied to expand this network using low-cost alternatives. One such alternative is installation of "tsunami water level gauges" by NOAA's National Weather Service which have a lower cost to develop and are easier to maintain than the more complex tide gauge instruments installed by NOAA's National Ocean Service. These networks are typically established through Federal and state resources and can be maintained by state and local agencies.

B. It is recommended that the NOAA Administrator expand detection capabilities to all seismic and non-seismic sources.

Both TWCs have identified an imperative for faster and more accurate alerting which can be enhanced with more tsunami-capable tide gauges with a high speed and high frequency transmission of data to be able to detect non-earthquake tsunami sources (landslides, glacial collapse, etc.). Increased density of tide gauges can provide and validate forecast information to at-risk population centers. Increased tide gauge density can also be used to monitor storm surge, coastal flooding, and sea level rise.

Existing observational capabilities at the TWCs include seismic data, DART® buoys, tsunami-capable tide gauges, and a few local water-level gauges. Additional capabilities suggested include a range of solutions including low-cost tsunami gauges, installing pressure sensors on deep-ocean industry fiber-optic cables, using GNSS-based ground data to infer deformation more precisely related to earthquakes that cause tsunamis, and taking advantage of spaced-based tsunami detection means. If these data streams were included in operational decision-making space, then tsunami forecasts and alerts would dramatically improve in both timeliness and accuracy as well as increase capability for alerting for non-seismic tsunami sources.

The National Science Foundation (NSF) has deployed fiber optic cables used for ocean observing; however, those cable systems are not operational for tsunami detection purposes.

C. It is recommended that the NOAA Administrator work with NSF and international partners to share and expand the use of GNSS to determine fault rupture extent and movement.

The core system (Earlybird) at NTWC to evaluate detection data is very old and written in proprietary code. Updating this system is necessary for incorporating new data such as Global Navigation Satellite System (GNSS) to improve forecasts.

GNSS data capture, interpretation, and application is a critical need for rapid understanding of earthquake magnitude for large earthquakes (M 7.0 or higher). By maintaining and building out this system and integrating it into the Tsunami Warning Center workflow it could help to characterize earthquake magnitude and assist with alerting the appropriate coastlines as seismic solutions are being solved and updated. This is crucial for providing critical alert messages and not underestimating magnitude as was the case for the 2011 magnitude 9 Great East Japan event. The networking and computational requirements are significant and would need to be included in TWC upgrades in the future.

The GNSS network (in the U.S.) was originally deployed strictly for research and is currently operated almost entirely with NSF funds. NSF has indicated it will partially divest from this support in the near future. For example, they will continue to maintain the network but not pay for the added cost of serving data in real-time and with low latency. Worldwide networks from international partners which can provide important data are slowly opening access. Facilitating ingestion of these new data streams into TWC operations is important.

D. It is recommended that the NOAA Administrator further consider the use of airborne and satellite observing platforms.

Ship time to operate and maintain DART® buoys is an ongoing concern and is very expensive ($12M annual). Remote sensing approaches are newer technology enhancements for tsunami detection and may be both more efficient and significantly less expensive to operate and maintain. In addition to exploring expanding land-based technologies such as tide gauges, NOAA should investigate the use of airborne and satellite observing platforms to supplement land- and ocean-based approaches.

III. Provide More Extensive, Consistent, and Accurate Tsunami Messages and Products

A. It is recommended that the NOAA Administrator improve the integration of TWC warning functions with USGS, state, and local warning needs and functions.

There is a need to collaborate with states and USGS regarding tsunami warning functions particularly in coordination with the USGS operated ShakeAlert Earthquake Early Warning (EEW) system used in CA, OR, & WA. This is also an area that could benefit from discussion among federal partners (primarily NOAA and USGS) regarding coordination between themselves and states with respect to the relationship between EEW and tsunami warning. Both USGS EEW and NWS Tsunami Warning will generate a Wireless Emergency Alert (WEA). These will likely be at different times (EEW first; tsunami warning 4/5 minutes later) and may alert different geographic zones. We find that having two WEAs for the same event can be confusing for public safety professionals and the public unless the differences are thoroughly explained and understood. Additionally, there has not been a test of EEW and tsunami warning WEA messaging for the same earthquake event; it is unknown how these two critical alerts will be delivered and if the system at FEMA that broadcasts WEAs (IPAWS) will be able to handle it.

B. It is recommended that the NOAA Administrator improve tsunami message composition and dissemination methods including updating the tsunami.gov website, creating a single domestic bulletin, and early messaging before a tsunami forecast is developed.

Tsunami.gov: The website Tsunami.gov is the authoritative source for the most up-to-date information on tsunami alerts and bulletins. Unfortunately, this website has a history of crashing when a large number of people tried to visit it at the same time to find tsunami hazard information. In response to site overload and significant delays in providing data, the NWS has implemented improvements designed to increase uptime during heavy use periods. A large tsunami event has not occurred since these improvements have been implemented, so the situation is yet untested. Furthermore, many emergency managers and members of the public believe the website is outdated and very difficult to navigate and use. This was pointed out during a presentation to the TSTAP by Dr. Lori Dengler.

Tsunami Bulletins: For a single earthquake event there are tsunami bulletins that are posted on tsunami.gov from each of the TWCs for their designated service areas. This can cause confusion for the public when they visit the site and are not sure which bulletin to view. Additionally, the format of the bulletins is very technical and not well suited for someone who is not familiar with reading them. Simplifying the bulletins and producing a single one for each earthquake event could help to reduce confusion.

Early Messaging/Communication: The TWCs work to provide the most accurate tsunami forecasts in a timely manner. However, it still typically takes between 1-1/2 to 3 hours for the first tsunami forecast to be released to regional and distant designated service areas[9]. For example, during the recent magnitude 8.2 earthquake in Alaska on July 28, 2021, west coast states were considered “under evaluation” for the first six official NTWC issued bulletins and three hours’ time after the earthquake which left less than an hour for state/local emergency officials to implement response plans if this would have been an actionable event. While it is understandable that the TWCs want to provide highly accurate forecasts, the first several hours after a potential tsunamigenic earthquake prior to the final forecast being made are critical for state and local emergency managers because they must communicate with high-level officials and event responders the likely course of action if a tsunami arrives, which could be 3-4 hours for the West Coast from an Alaska event. Therefore, communicating early estimates of expected local impacts, even with 75% confidence, would be of great benefit to state and local communities within the first hour after the start of the event. This early estimate message could be provided in Information Statements to all members of the public or separately through a direct message to State Emergency Duty Officers for them to distribute to coastal community decision makers. The message could include language that the estimated impacts are "subject to change with additional information being gathered." An alternative would be to provide states with a tsunami forecast with at least three hours of lead time before tsunami arrival, a practice the PTWC has in their protocols for the State of Hawaii. The recent Alaska events where the “threat is being evaluated” leaves decision makers lost and unable to make important life safety decisions in the timeframe necessary to issue a successful evacuation if needed.

C. It is recommended that the NOAA Administrator make available foundational forecast data from propagation models and inundation model results to constituents.

NOAA should prioritize the availability of greater foundational data from currently run tsunami propagation models. For example, after an event occurs, a map showing the potential timing of tsunami waves appears on TWC websites. This is just a graphic and there is no underlying data which partners could use to better describe the tsunami hazard, much like NOAA disseminates raw forecast model output.

IV. Develop Enhancements to Tsunami Warning Center Forecasts and Alert systems

A. It is recommended that the NOAA Administrator expand granularity in tsunami alert regions where complicated waterways and large bays exist (e.g., Puget Sound, San Francisco Bay, etc.)

TWC tsunami alerting should be based on tsunami arrival times and forecasted impacts. For complicated waterways and large bays in the states of Washington, California, and Alaska, there is a limit to the number of alert areas or breakpoints the system can handle. The existing tsunami alerting system does not have the capability to provide custom tsunami alerts for complicated waterways, such as the Puget Sound in Washington State. Ideally, tsunami forecasts could have multiple alert levels. For example, different alert levels for Washington State could include: a Tsunami Warning for Washington's Pacific coast, a Tsunami Advisory for the Strait of Juan de Fuca, and a Tsunami Watch for Puget Sound. The existing software cannot handle breaking up a geographic area to alert the impacted population of the forecasted threat adequately. The ability to have this granularity of alerting would help emergency managers make decisions to evacuate (or not) large cities and population centers such as Seattle, Tacoma, San Francisco, San Diego, and many Alaskan communities. Increased granularity will also avoid issuing blanket warnings over areas with an unequal tsunami threat. Additionally, there needs to be coordination with WEA regarding the number of alerting polygons under FEMA IPAWS limitations ("WEA 2.0" restrictions to no more than 10 polygons and no more than 100 vertices in total).[10] **[check again]**

B. It is recommended that the NOAA Administrator update special procedure areas, threat database thresholds, breakpoints, and forecast point locations.

The NTWC special procedure areas and protocols are limited and do not provide adequate alerting and wave arrival time information for complicated waterways. Special procedures are in place for areas that have a tsunami threat from known crustal faults. These areas have limited geographic extent and limited magnitude range. This has significant implications for what tsunami alert message, if any, would be generated. For example: The Seattle fault runs east-west through downtown Seattle and there is geologic evidence for past ruptures that tsunamis have been generated. There is a special procedure in the NTWC's system that would trigger an alert if an earthquake happens within a pre-designated area (a rectangle surrounding Seattle), as long as the earthquake is within a pre-specified magnitude range (7.1-7.5). If an earthquake with a magnitude of 7.6 happened in that box then the system would assume that it was a subduction zone earthquake and not a crustal fault and would therefore trigger an alert for Washington's outer coast and not the Puget Sound. This is just one example of how the special procedures are limited and could have dire consequences. Additionally, the states of California and Alaska have such special procedures in place and state officials may not know the intricacies or implications of them.

As science advances and new faults are discovered or refined there should be a system in place for TWCs to work with states and the USGS to review and update such databases regularly.

V. Improve Consistency in Tsunami Preparedness and Mitigation Products for Communities

A. It is recommended that the NOAA Administrator develop a standardized framework for characterizing, selecting, and using consistent tsunami sources between states.

States are individually responsible for selecting the tsunami sources they model for hazard awareness, land use planning, and evacuation for constituents. Although there is national guidance for how to perform modeling and make maps, there is no guidance for selecting source parameters, and this leads to a lack of consistency between individual states when they use the same source (for example a magnitude 9 Cascadia earthquake). Important source parameters requiring more consistency include recurrence potential, rupture area and slip amount for faults, and reasonable volumes for landslides. It can be confusing for residents, visitors, and decision makers when maps depict different sources; for example, the hazard map for evacuation could be using the worst case event, whereas the building code or land-use planning maps are using an event with a higher probability but much less severe impacts. NOAA could work with the NTHMP as it develops guidance for states on consistent tsunami source parameters.

B. It is recommended that the NOAA Administrator improve guidelines for evacuation maps that ensures consistency between states/communities and develop a national online repository.

Currently, tsunami evacuation maps are available on individual state websites, and are vastly different in appearance and symbology. To improve public usability and access to evacuation maps, NOAA could develop an on-line repository for all tsunami evacuation maps and host a consistent on-line mapping application for all tsunami evacuation zones across the United States. Additionally, NOAA through collaboration with NTHMP, could develop guidelines on best-practices for evacuation maps using social science guidance for evacuation map usability.

C. It is recommended that the NOAA Administrator prioritize probabilistic tsunami hazard mapping at a national scale, especially for updating ASCE/Building Code “Tsunami Design Zone” maps.

For the first time ever, the International Building Code (2018) is incorporating tsunami loads for new critical and high occupancy facilities in West Coast states. The language in this new building code also provides requirements for construction of new vertical evacuation structures. The American Society of Civil Engineers’ (ASCE) Tsunami Loads and Effects chapter (7-16) provides a Tsunami Design Zone (TDZ) based on probabilistic tsunami hazard analysis (PTHA). PTHA can also provide the foundation for other regulatory inundation zones for new critical infrastructure and high occupancy buildings. The ASCE developed the PTHA and initial TDZ for ASCE 7-16 because a nationwide probabilistic tsunami hazard map (as there is for seismic hazards) does not exist. States are then expected to develop more accurate PTHA/TDZ maps to supplement or replace the ASCE maps. There is a need for consistency among states and territories regarding these maps and their implementation. The National Seismic Hazard Map (USGS) is updated every four years and is the authoritative resource for seismic design and building codes. Tsunami loads and vertical evacuation would benefit from a national and/or state-collaborative mapping effort as well. In addition, comprehensive guidance through a federal or state-collaborative effort should also be developed to create guidance for consistent use of PTHA products for evacuation, land-use, and other structure and infrastructure planning.

VI. Produce Guidance for Improving Long-Term Community Resilience to Tsunami Hazards

A. It is recommended that the NOAA Administrator develop guidance and products for tsunami mitigation/recovery consistent with and leveraging climate change adaptation strategies.

Many coastal states and communities are working to address coastal hazards related to climate change. These hazards include long-term sea-level rise, increased storm activity, and increased wave activity and erosion potential. Many of the mitigation strategies developed to address climate change may also reduce impacts from tsunami hazards, and vice versa. As NOAA and other federal and state agencies develop guidance and funding opportunities to help states and communities adapt to climate change hazards, it is recommended that tsunami hazards be included in evaluations to create a multi-hazard planning and mitigation approach. In addition, NOAA could encourage that tsunami mitigation is included as acceptable within the scope of funding opportunities for climate change.

B. It is recommended that the NOAA Administrator conduct evacuation modeling, feasibility studies, and risk analyses for vertical evacuation structures.

Many communities in the U.S. are located in areas subject to such severe tsunami inundation that there is no way for people to evacuate in time. There is the potential for many thousands of lives to be lost because of this in the next large earthquake and tsunami. NTHMP partners are working on mapping at-risk communities for horizontal evacuation options (pedestrian, vehicle, and maritime evacuation). However, even in instances when there is a clear indication that no horizontal evacuation is possible (i.e. large swaths of southwestern WA) there may be no building codes or regulatory requirements stating that vertical evacuation structures must be constructed. Additionally, there is insufficient funding for such structures at the scale needed given the size of the exposed population.

VII. Improve Tsunami Hydrodynamic Modeling

A. It is recommended that the NOAA Administrator improve tsunami modeling capabilities in the following conditions/areas: variable landscapes (i.e. surface roughness), heavy vegetation, built environment, and dynamic river systems.

There are a number of features numerical tsunami models do not incorporate which can significantly increase tsunami flooding and damage. Tsunami modeling used to generate inundation and evacuation maps generally use bare earth topography which does not account for the built or natural environment (buildings, roads, trees etc.). Additionally, numerical models do not take into account debris (generated from the tsunami or sediment moved by the strong waves), both of which significantly increase tsunami damage. Including these components in future modeling will lead to more realistic inundation maps that can better guide evacuation plans and real time inundation forecasts. Improving these methodologies will also help to inform planners where there will be accumulation of debris and sediment following an event and where emergency supplies should be staged.

In addition to impacts from the built environment and debris and sediment movement, tsunamis can flood up rivers many miles inland but the most widely-used tsunami models do not have the ability to model the physics needed for a reliable simulation of tsunami flooding up rivers. Incorporating river stages as well as tidal impacts into tsunami modeling will lead to more realistic hazard mapping.

B. It is recommended that the NOAA Administrator conduct a greater number of high resolution bathymetric surveys.

Bathymetry and topography data are critical for tsunami modeling and understanding the hazard. High resolution bathymetry is needed for many offshore and inland waters. In a briefing to the TSTAP, Dr. Payne of the NOAA Office for Coastal Management, discussed the need for overlapping high-resolution bathymetric and topographic data for coastal flood and tsunami modeling. This aligns with Congress passing the Digital Coast Act[8] which codified collecting and making such data available. Areas without high-resolution geodetics, lidar, bathymetry, and satellite imagery should be prioritized for additional mapping.

C. It is recommended that the NOAA Administrator develop a data portal for detailed information for advancing research and model development.

Different agencies and data centers archive the datasets used in tsunami research, but there is not a central repository to access this information with the essential metadata included. In addition to field observations, laboratory and model simulation studies also could be archived at such a center.

VIII. Develop Tsunami Research Priorities and Leverage Research Opportunities

A. It is recommended that the NOAA Administrator coordinate with Federal, state, and territory agencies that fund research that includes tsunami to leverage and prioritize research opportunities and provide consistent and useful products.

There is very little coordination between the multiple Federal funding sources (NOAA, NEHRP, NSF, FEMA, USGS, etc.) available for tsunami research and products. In some cases, this lack of coordination results in numerous tsunami research and planning efforts with redundant outcomes and products. Without coordination, developing products through different funding streams can lead to findings and products that are inconsistent and/or in conflict with each other. This not only leads to potential wasted research funding but also could be confusing for the data users or public if duplicate products exist. Coordination between these funding sources/agencies would result in leveraging limited funding amounts and provide more consistency in efforts and products.

Since the NOAA Administrator serves as a Co-Chair on the The Interagency Council on Advancing Meteorological Services (ICAMS) under the White House Office of Science and Technology Policy (OSTP), perhaps this recommendation can be referred to ICAMS for attention.

Recommendations for other organizations

While the TSTAP is charged with preparing recommendations for the NOAA SAB and the NOAA Administrator, there are some recommendations that overlap or may be better placed with other partners. See the table in the Executive Summary for these recommendations for partner consideration.

Next Steps

As noted in the TSTAP charge, this report is being provided in 2021 to the NOAA Science Advisory Board (SAB) through the Environmental Information Services Work Group (EISWG). Per the *Tsunami Warning, Research, and Education Act of 2017* (as appended to *The Weather Act*), the NOAA

Administrator shall submit a copy of this report to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives. If inquiries from Congressional committees or staff about this report are directed to the TSTAP, the TSTAP will be prepared to address them. If inquiries about issues in this report are directed to NOAA or other Federal agency, the TSTAP wishes to be informed as to the nature of the inquiry and be provided a copy of the agency's response when the response is provided to Congress.

In the years in which a report is not submitted to Congress by the NOAA Administrator, the TSTAP will:

- continue to examine progress on this report's recommendations;
- develop or refine additional recommendations related to the TSTAP's charge;
- monitor the dynamic environment that may impact tsunami science and technology;
- review and document information and experience from any tsunami event that may occur; and,
- provide a report on its activities to the SAB as requested or needed on a periodic basis.

Summary

It is not a matter of if, but when the next tsunami will strike the U.S. coastline. The TSTAP sees an urgent need for action to ensure our nation is doing more to mitigate this risk and also doing everything possible to prepare and equip our tsunami program with the tools and staff necessary to detect, forecast, and alert the public in a clear and timely fashion. To that end the TSTAP has developed eight primary recommendations with 22 sub-recommendations, recommendations for other agencies, as well as two overarching implementation recommendations for reporting and updating the TSTAP on this report's implementation progress.

The TSTAP feels that these recommendations are the most critical and timely to be acted on with deliberate attention and speed. In doing so, the nation's coastlines, residents, and coastal visitors will be more safe from the potential of a destructive tsunami when the next one strikes our shores.

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[10] P.L. 116-223: *Digital Coast Act*. Signed into Law December 18, 2020. https://www.congress.gov/116/plaws/publ223/PLAW-116publ223.pdf

List of Members

The NOAA Administrator appointed the following people to serve on the TSTAP in August, 2020:

Co-Chairs:

- Dr. Rocky Lopes, Certified Emergency Manager, formerly supporting the NOAA/NWS Tsunami Program. Retired.
- Mr. Rick Wilson, Senior Engineering Geologist, California Geological Survey

Members:

- Ms. Corina Allen, Chief Hazards Geologist for the Washington State Geological Survey
- Dr. Carrie Garrison-Laney, Tsunami Hazards Specialist and NOAA Center for Tsunami Research/Pacific Marine Environmental Lab Liaison, Washington Sea Grant
- Dr. Diego Melgar, Assistant Professor of Geophysics, University of Oregon
- Dr. Aurelio Mercado, Retired Professor of Oceanography, University of Puerto Rico
- Dr. Mark Merrifield, Professor, Integrative Oceanography Division, Marine Sciences, Scripps Institute of Oceanography, University of California at San Diego

NOAA/NWS Representative:

- Mr. Michael Angove, NWS Tsunami Program Lead

USGS Representative:

- Dr. Paul Earle, Director of Operations, USGS National Earthquake Information Center

Environmental Information Services Working Group Liaisons:

- Dr. Tom Altshuler, Vice President And Group General Manager, Teledyne Marine Systems
- Mr. Jonathan Porter, Vice President of Innovation and Development, AccuWeather, Inc.

APPENDIX 1: Legislative Foundation of Tsunami Science and Technology Advisory Panel

PUBLIC LAW 115-25, April 18, 2017

The Weather Research and Forecasting Innovation Act

Amendment full addition of Title V -- *Tsunami Warning, Education, and Research Act of 2017*

§3202. Purposes

The purposes of this chapter are—

(1) to improve tsunami detection, forecasting, warnings, research, notification, outreach, and mitigation to protect life and property in the United States;

(2) to enhance and modernize the existing United States Tsunami Warning System to increase the accuracy of forecasts and warnings, to ensure full coverage of tsunami threats to the United States with a network of detection assets, and to reduce false alarms;

(3) to improve and develop standards and guidelines for mapping, modeling, and assessment efforts to improve tsunami detection, forecasting, warnings, notification, mitigation, resiliency, response, outreach, and recovery;

(4) to improve research efforts related to improving tsunami detection, forecasting, warnings, notification, mitigation, resiliency, response, outreach, and recovery;

(5) to improve, increase, and develop uniform standards and guidelines for education and outreach activities and ensure that those receiving tsunami warnings and the at-risk public know what to do when a tsunami is approaching, including the warning signs of locally generated tsunami;

(6) to provide technical and other assistance to speed international efforts to establish regional tsunami warning systems in vulnerable areas worldwide;

(7) to foster resilient communities in the face of tsunami and other similar coastal hazards; and

(8) to improve Federal, State, and international coordination for detection, warnings, and outreach for tsunami and other coastal impacts.

Establishment of the Tsunami Science and Technology Advisory Panel – SAB Working Group

The following section of the authorizing legislation establishes the charge of this Panel –

§3206a. Tsunami Science and Technology Advisory Panel (herein after “TSTAP”)

(a) Designation

The Administrator shall designate an existing working group within the Science Advisory Board of the Administration to serve as the Tsunami Science and Technology Advisory Panel to provide advice to the Administrator on matters regarding tsunami science, technology, and regional preparedness.

(b) Membership

(1) Composition

The Panel shall be composed of no fewer than 7 members selected by the Administrator from among individuals from academia or State agencies who have academic or practical expertise in physical sciences, social sciences, information technology, coastal resilience, emergency management, or such other disciplines as the Administrator considers appropriate.

(2) Federal employment

No member of the Panel may be a Federal employee.

(c) Responsibilities

Not less frequently than once every 4 years, the Panel shall—

(1) review the activities of the Administration, and other Federal activities as appropriate, relating to tsunami research, detection, forecasting, warning, mitigation, resiliency, and preparation; and

(2) submit to the Administrator and such others as the Administrator considers appropriate—

(A) the findings of the working group with respect to the most recent review conducted underparagraph (1); and

(B) such recommendations for legislative or administrative action as the working group considers appropriate to improve Federal tsunami research, detection, forecasting, warning, mitigation, resiliency, and preparation.

(d) Reports to Congress

Not less frequently than once every 4 years, the Administrator shall submit to the Committee on Commerce, Science, and Transportation of the Senate, and the Committee on Science, Space, and Technology of the House of Representatives a report on the findings and recommendations received by the Administrator under subsection (c)(2).