2023 NATIONAL REPORT
Submitted by United States

BASIC INFORMATION

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4. **U.S. Domestic Tsunami Standard Operating Procedures for Local (< 1 hour travel time), Regional (1-3 hour travel time), and Distant Tsunamis (> 3 hour travel time)**

The standard operating procedures for tsunamis in the United States are largely the same for local, regional, and distant tsunamis. Where there are differences, they are noted here.

What organization identifies and characterizes tsunamigenic events?

The National Oceanic and Atmospheric Administration's (NOAA) Pacific Tsunami Warning Center (PTWC) in Hawaii provides domestic tsunami alert services for Hawaii, American Samoa, Guam and the Commonwealth of the Northern Mariana Islands, and Puerto Rico and the U.S. and British Virgin Islands. The NOAA U.S. National Tsunami Warning Center (US NTWC) in Alaska provides domestic tsunami alert services for the continental United States, Alaska, and Canada. Each center serves as the other center's backup.

Both NOAA centers independently characterize potential tsunamigenic events that occur in the Caribbean and Atlantic. To avoid conflicting information, each center is assigned tsunami source regions for which they are authoritative in tsunami warning center products. In this way, the preliminary earthquake parameters that appear in PTWC and US NTWC products are always the same.

What is the threshold or criteria for declaring a potential tsunami emergency?

PTWC issues initial messages based solely on an earthquake's preliminary location, depth, and magnitude determined from a rapid seismic analysis as well as the distance of the earthquake from Puerto Rico and the Virgin Islands in terms of tsunami travel time or kilometers.

<u>Puerto Rico and the Virgin Islands</u>
For earthquakes located further than three hours tsunami travel time from Puerto Rico and the Virgin Islands, PTWC uses the seismic criteria in Table 1 to determine initial products.

Table 1. Criteria for PTWC initial tsunami products for Puerto Rico/Virgin Islands for distant earthquakes

Earthquake					Alert Level
Sea	**Land**	**Depth**	**Magnitude**	**ETA**	
Yes	Yes	< 62 miles (100 km)	6.5 - 7.8	> 3 hr	Information statement No threat
Yes	Yes	≥ 62 miles (100 km)	≥ 6.5	> 3 hr	Information statement No threat
Yes	Near Sea	< 62 miles (100 km)	≥ 7.9	> 6 hr	Information statement Potential threat
Yes	Near Sea	< 62 miles (100 km)	≥ 7.9	3–6 hr	Watch

Source: Users' Guide Tsunami Warning Products for Puerto Rico, U.S. Virgin Islands, and British Virgin Islands Version 1.1 March 15, 2017

For earthquakes located within three hours tsunami travel time of Puerto Rico and the Virgin Islands, PTWC uses the earthquake's proximity to Puerto Rico and the Virgin Islands and the preliminary seismic parameters in Table 2 to determine initial products.

Table 2. Criteria for PTWC initial tsunami products for Puerto Rico and the Virgin Islands for nearby earthquakes

Earthquake			Alert Level
Source Location	**Depth**	**Magnitude**	
Within 186 miles (300 km) of Puerto Rico/Virgin Islands	< 62 miles (100 km)	4.5-6.4	Information Statement
	≥ 62 miles (100 km)	≥ 4.5	
	< 62 miles (100 km)	≥ 7.1	Warning
	< 62 miles (100 km)	6.5–7.0	Advisory
Between 186 miles (300 km) and 621 miles (1000 km) of Puerto Rico/Virgin Islands	< 62 miles (100 km)	≥ 7.6	Warning
	< 62 miles (100 km)	7.1–7.5	Advisory
> 621 miles (1000 km) of Puerto Rico/Virgin Islands	< 62 miles (100 km)	≥ 7.9	Warning
	< 62 miles (100 km)	7.6-7.8	Advisory

Notes:

- *If the earthquake has a preliminary depth less than 62 miles (100 km) with preliminary magnitude of 6.5 or greater but does meet location criteria above for an advisory or warning, then only an information statement will be issued indicating no tsunami threat.*
- *If the preliminary earthquake depth is greater than or equal to 62 miles (100 km) and the preliminary earthquake magnitude is greater than or equal to 6.5, then only an information statement will be issued indicating no tsunami threat from a deep earthquake.*

Source: Users' Guide Tsunami Warning Products for Puerto Rico, U.S. Virgin Islands, and British Virgin Islands Version 1.1 March 15, 2017

Once PTWC generates a forecast for an event, alert levels may be revised in supplemental messages to reflect forecast wave heights as shown in Table 3 or based on observed wave heights.

Table 3. Criteria for PTWC supplemental text products for Puerto Rico/Virgin Islands

Maximum Expected Rise of Sea Level above the Tide	Alert Level
0–1 feet (0–0.3 m)	None
1–3.3 feet (0.3–1 m)	Advisory
> 3.3 feet (> 1 m)	Warning

Source: Users' Guide Tsunami Warning Products for Puerto Rico, U.S. Virgin Islands, and British Virgin Islands Version 1.1 March 15, 2017

PTWC may increase alert levels if new information justifies such an increase. They will not lower alert levels before impact unless an updated evaluation has a very high level of confidence and there is a clear benefit to lowering the alert. They may lower alert levels after impact as conditions warrant until cancellation.

What organization acts on the information provided by the agency responsible for characterizing the potential tsunami threat?

Puerto Rico and the Virgin Islands

- Puerto Rico Emergency Management and Disaster Administration Bureau (also a CARIBE-EWS Tsunami Warning Focal Point)
- U.S. National Weather Service San Juan, Puerto Rico, Weather Forecast Office (also a CARIBE-EWS Tsunami Warning Focal Point, Alternate)
- Puerto Rico Seismic Network, University of Puerto Rico at Mayaguez (also a CARIBE-EWS Tsunami Warning Focal Point, Alternate)
- Virgin Islands Territorial Emergency Management Agency (also a CARIBE-EWS Tsunami Warning Focal Point)
- British Virgin Islands Department of Disaster Management (also a CARIBE-EWS Tsunami Warning Focal Point)
- British Royal Police Force (also a CARIBE-EWS Tsunami Warning Focal Point, Alternate)

How is the tsunami information (warning, public safety action, etc.) disseminated within your country? Who is it disseminated to?

In general, tsunami information is disseminated from PTWC to the officially designated responsible government agencies in each jurisdiction through a variety of channels as depicted in Figure 1.

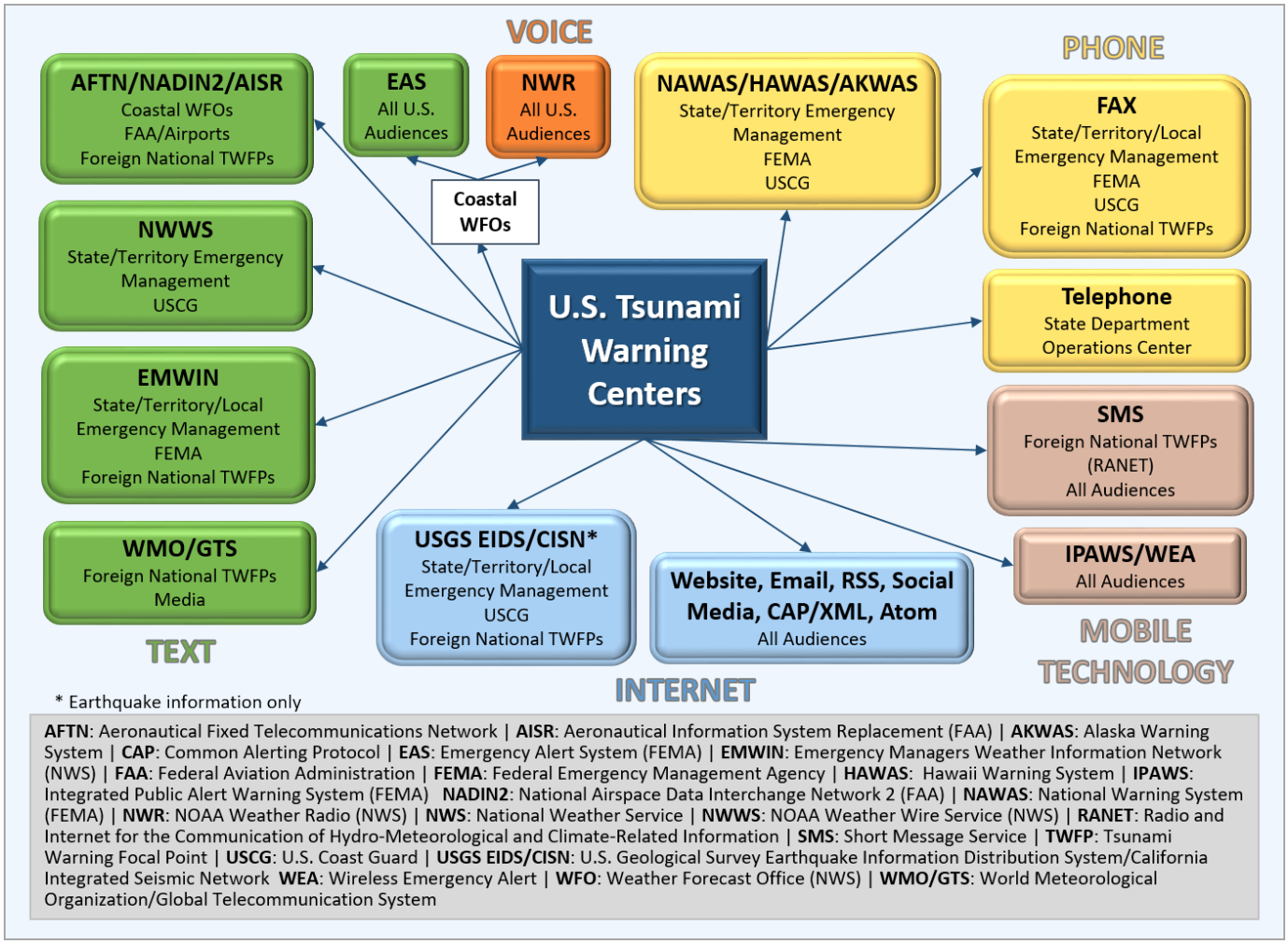
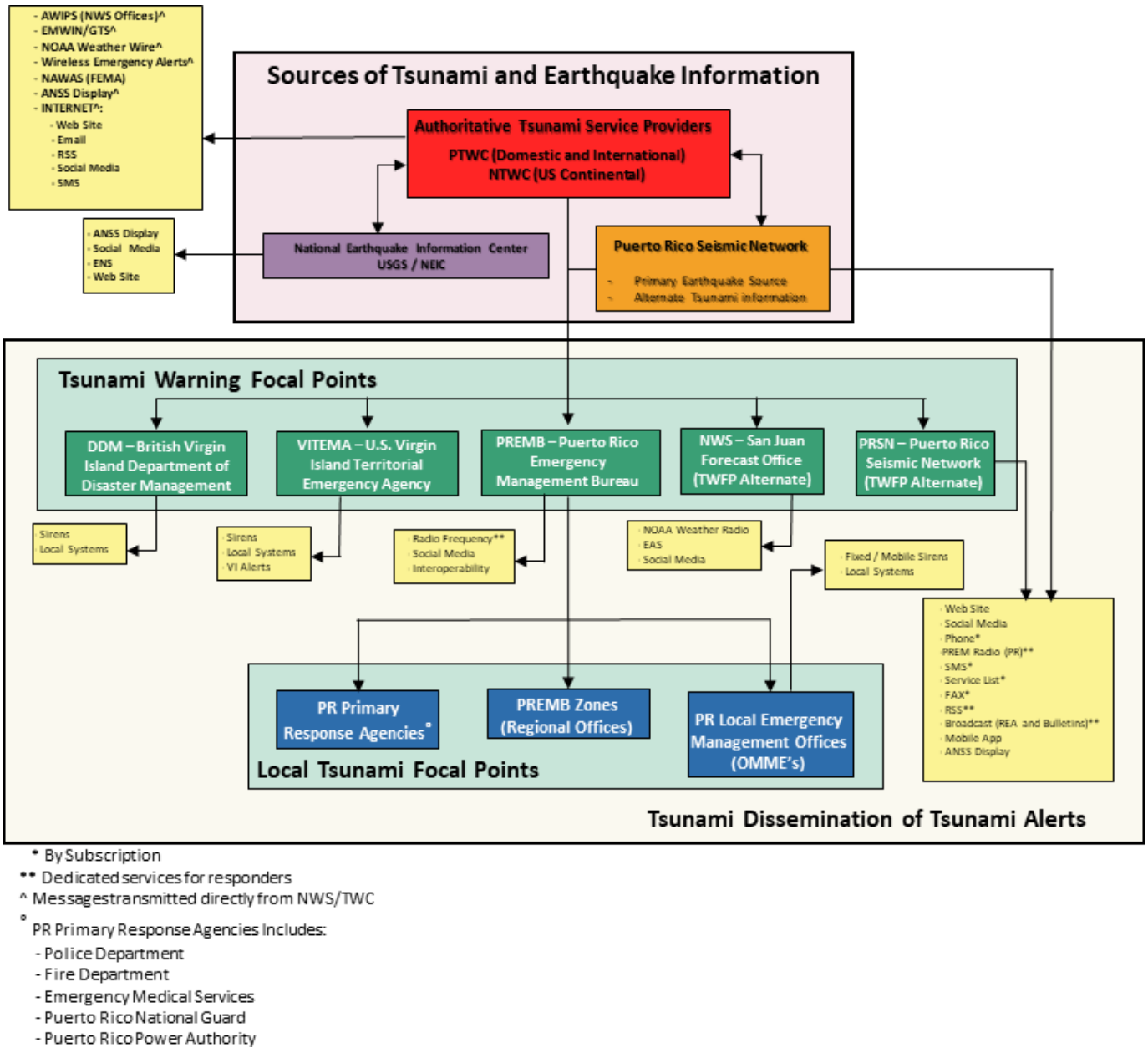


Figure 1. NOAA tsunami warning center dissemination methods.

<u>Puerto Rico and the Virgin Islands</u>

- As Tsunami Warning Focal Points, the Puerto Rico Emergency Management and Disaster Administration Bureau and the U.S. Virgin Islands Territorial Emergency Management Agency alert the public (through interoperability systems, sirens, and other means); police, fire, rescue, and other response agencies; and media outlets. Recently, the WEA/IPAWS was tested in Puerto Rico.
- The US Virgin Islands utilizes Alert VI - mass message notification / Everbridge which reaches 21% of the population (2020 US Census). VITEMA uses WEA/IPAWS which requires FCC approval during training and drills.
- The U.S. National Weather Service San Juan Weather Forecast Office activates the Emergency Alert System (EAS) for Puerto Rico and the U.S. Virgin Islands to interrupt commercial radio and television with a message and broadcasts tsunami information over NOAA Weather Radio.
- The Puerto Rico Seismic Network (PRSN) provides guidance to the emergency management agencies in Puerto Rico and the Virgin Islands, the media, and the San Juan Weather Forecast Office as well as the Dominican Republic National Meteorological Office (ONAMET). The PRSN further disseminates official tsunami messages through RSS, email, the web, social media, and more.
- Upon receipt, the media may also interpret and re-disseminate tsunami information.
- Upon receipt, NOAA's Caribbean Office of the International Tsunami Warning Center may also interpret and re-disseminate tsunami information.



* By Subscription
** Dedicated services for responders
^ Messages transmitted directly from NWS/TWC
° PR Primary Response Agencies Includes:
- Police Department
- Fire Department
- Emergency Medical Services
- Puerto Rico National Guard
- Puerto Rico Power Authority

Figure 2. Tsunami communication protocol for Puerto Rico and the Virgin Islands (Rev 2023).

Communication Testing

As shown in Figure 2, PTWC confirms communication links with each of the key recipient agencies in Puerto Rico and the Virgin Islands following the issuance of each product – typically about once a month. Agencies also receive the monthly CARIBE-EWS communication tests and the test associated with each year's CARIBE WAVE Exercise. PRSN also tests communication lines monthly and annually as part of the CARIBE WAVE and ShakeOut earthquake exercises.

How is the emergency situation terminated?

Puerto Rico and the Virgin Islands

PTWC issues a cancellation after an evaluation of water-level data confirms that a destructive tsunami will not impact an area under an alert (warning, advisory, or watch) or that a tsunami has diminished to a level where additional damage is not expected. This does not mean it is safe to return to evacuated areas. Local authorities determine when it is safe (issued all clear) to return based on local information about continuing wave conditions and related hazards such as fires or downed power lines.

For distant tsunamis, what actions were taken in response to warnings issued by PTWC and/or US NTWC during the intersessional period?

There were no warnings for U.S. Caribbean, Gulf of Mexico, or Atlantic coasts issued by PTWC or US NTWC during the intersessional period.

5. **Seismic Monitoring Network**

The United States supports an extensive network of seismic sensors in the Pacific, Atlantic, Caribbean, and Gulf of Mexico. A number of other entities also support earthquake monitoring activities in the Caribbean and adjacent regions.

- The U.S. Geological Survey (USGS) National Earthquake Information Center and Albuquerque Seismological Laboratory coordinate field and monitoring operations to ensure reliable mission-critical data to the tsunami warning centers. One hundred and fifty of these stations are part of the Global Seismographic Network (GSN) and are jointly operated by the USGS, University of California San Diego (IDA) and the EarthScope Consortium. An additional 97 stations are part of the Advanced National Seismic System (ANSS). Seismic station details are provided at the GSN and ANSS URLs listed in Section 9.
- The PRSN, with the support from the Puerto Rico Strong Motion Program (PRSMP), and in partnership with the ANSS, monitors the seismic activity in Puerto Rico and the U.S. and British Virgins Islands. The stations operated by the PR network include more than 100 ground motion stations (75 in Puerto Rico and the Virgin Islands and 12 in nearby countries, including Anguila and Aruba as well as the Dominican Republic); the broadband stations are equipped with velocity and acceleration sensors. Some stations are equipped with GNSS displacement sensors.
- In response to the damage caused by 2017 hurricanes, USGS ASL worked with PRSN to upgrade a total of 25 seismic stations. Each site was upgraded with new sensors (posthole broadband seismometer and accelerometer), digitizers, and solar power backups. Twelve (12) of these sites have VSAT connections to PRSN and NEIC maintain monitoring capability if island wide power and internet go down again. The backbone network of strong motion stations were updated as well, and the communications improved mostly with cell phone circuits and telemetry.
- In response to the 2020 southwestern Puerto Rico earthquake the PRSN in partnership with the USGS installed 11 temporary real time seismic stations (GS.PR01-GS.PR06) in southwestern Puerto Rico to monitor the sequence. The data is openly available as part of the GS network via EarthScope data services (DS).
- The Puerto Rico Science Trust, with the support from the Clinton Foundation and the University of Puerto Rico at Mayaguez (Seismic Network) are installing over 100 type-C accelerometers, this effort is to study the feasibility of developing an earthquake early warning in Puerto Rico.

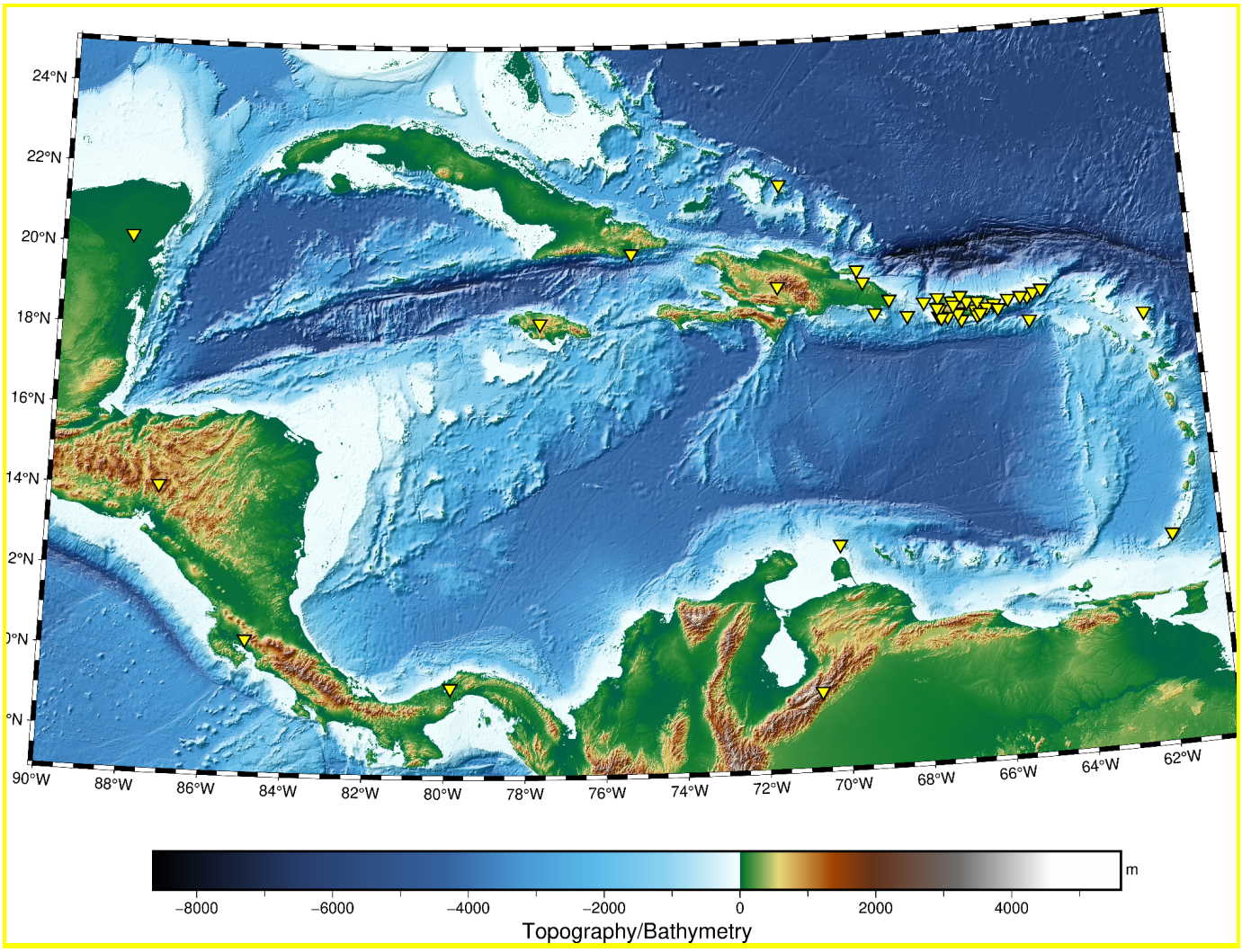


Figure 3.Distribution of seismic instruments supported or operated by PRSN (PR) and the USGS (II, IU, CU) in the CARIBE-EWS system. A table of these instruments is available as Appendix A (below).

6. National Sea Level Network

The United States supports an extensive sea level network in the Pacific, Atlantic, Caribbean, and Gulf of Mexico. In the Caribbean, this includes coastal water-level stations and Deep-ocean Assessment and Reporting of Tsunami (DART) systems as described below and cataloged in Table 5.

U.S. Caribbean Coastal Water-Level Stations

Coastal water-level stations in the United States are operated by a variety of entities. Many of these stations are part of the international Global Sea-Level Observing System (GLOSS), which is coordinated by UNESCO/IOC. The data from these stations are made available to the NOAA tsunami warning centers and can be viewed on the UNESCO/IOC Sea Level Data Facility and through programs like Tide Tool, which is run in many CARIBE EWS tsunami warning centers.

- NOAA's Center for Operational Oceanographic Products and Services operates 11 stations in the Caribbean (Puerto Rico, U.S. Virgin Islands, Bermuda) as part of its National Water Level Observation Network (NWLON). These multi-purpose stations have, at a minimum, a primary and backup sensor and data collection platform. High-frequency 1-minute water-level data are collected and transmitted every six minutes over GOES-East, telephone, IP modem, or Iridium

to the tsunami warning centers. The NWLON also includes stations along the U.S. East and Gulf Coasts.
    - Tide gauge data from the NOAA-operated stations are quality controlled (for research), processed, and archived at NOAA's National Centers for Environmental Information (NCEI). Data is available for download from an interactive timeline at https://www.ngdc.noaa.gov/hazard/tide/.
- The University of Hawaii Sea Level Center (UHSLC) operates 10 stations in the region and assists with installation and maintenance of additional stations when necessary. The UHSLC stations have a primary and backup sensor and sample once per minute. Data is sent over GOES-East with a five-minute transmission interval at most locations with no longer than ten-minute intervals. Data transmission at all stations will be migrated to Iridium over coming years with data flow to GTS maintained.
- With support from NOAA, the government of Puerto Rico and the University of Puerto Rico, the PRSN operates ten stations in Puerto Rico and the Dominican Republic. These stations are NWLON-compliant and transmit data every six minutes over GOES-HRIT, and some of them each minute via internet through an earthworm module using the seedlink protocol. Two new stations were installed in 2021, in the Central Aguirre power facility and Aguadilla (Muelle de Azucar); plans exist for the installation of three other stations. With NOAA funds, the PRSN also supports the operations of one station in Haiti, and one in the British Virgin Islands.
- The Smithsonian Institution has installed, operates, and maintains two tsunami-capable water-level stations in Belize and Panama that transmit data every five minutes. The station in Belize has been non-operational since October 2019.
- UNAVCO installed two stations (Port Royal, Jamaica, in 2014 and Puerto Morelos, Mexico, in 2015) as part of the National Science Foundation-funded Continuously Operating Caribbean GPS Observational Network (COCONet) project. These stations transmit data every five minutes over the GOES system. Jamaica has not been operational since March, 2020.

U.S. Caribbean Deep-ocean Assessment and Reporting of Tsunami (DART) Systems

NOAA's National Data Buoy Center (NDBC) operates 32 second-generation DART systems in the Pacific Ocean and 7 in the Atlantic Ocean (including 1 in the Gulf of Mexico and 3 in the Caribbean and adjacent seas region). The DART system technology uses a bottom pressure recorder (BPR) that samples the pressure at 15-second intervals and communicates with a surface buoy. In standard mode, DART systems communicate every six hours with a 15-minute subsampling of the full 15-second sampling intervals.

DART systems can be triggered by the tsunami detection algorithm in the BPR or manually by a tsunami warning center. NDBC's Mission Control Center continuously monitors the DART systems and validates triggers with the tsunami warning centers. In triggered mode, a DART system provides a few minutes of the 15-second full-resolution data and then approximately six hours of one-minute averages, which are sent every few minutes. After six hours of triggered mode, unless re-triggered, the system will return to standard mode.

NDBC receives DART data via Iridium and reformats it into messages for distribution on the Global Telecommunication System (GTS) and NOAAPORT. Data from the seven Atlantic DART systems goes out under the GTS bulletin header SZNT01 KWNB. NDBC also posts the data to its website. The high-resolution 15-second data is sent to NCEI for processing, quality control, and long-term archive. Data is available from an interactive timeline at https://www.ngdc.noaa.gov/hazard/dart/.

Vandalism to DART systems and other sensors in the region has impacted their operations over the past decade. NOAA is working with international partners under the IOC and World Meteorological Organization to educate members of the fishing community and others to combat the incidence of vandalism, both intentional and unintentional. Regional marine fisheries organizations are also collaborating to address the issue. More information about reporting vandalism to these and other ocean and coastal observing systems can be found at https://www.gc.noaa.gov/gcil_buoys.html. All

members are encouraged to share the importance of these sensing systems for accurately forecasting tsunamis and vandalism can make vulnerable communities even more at risk.

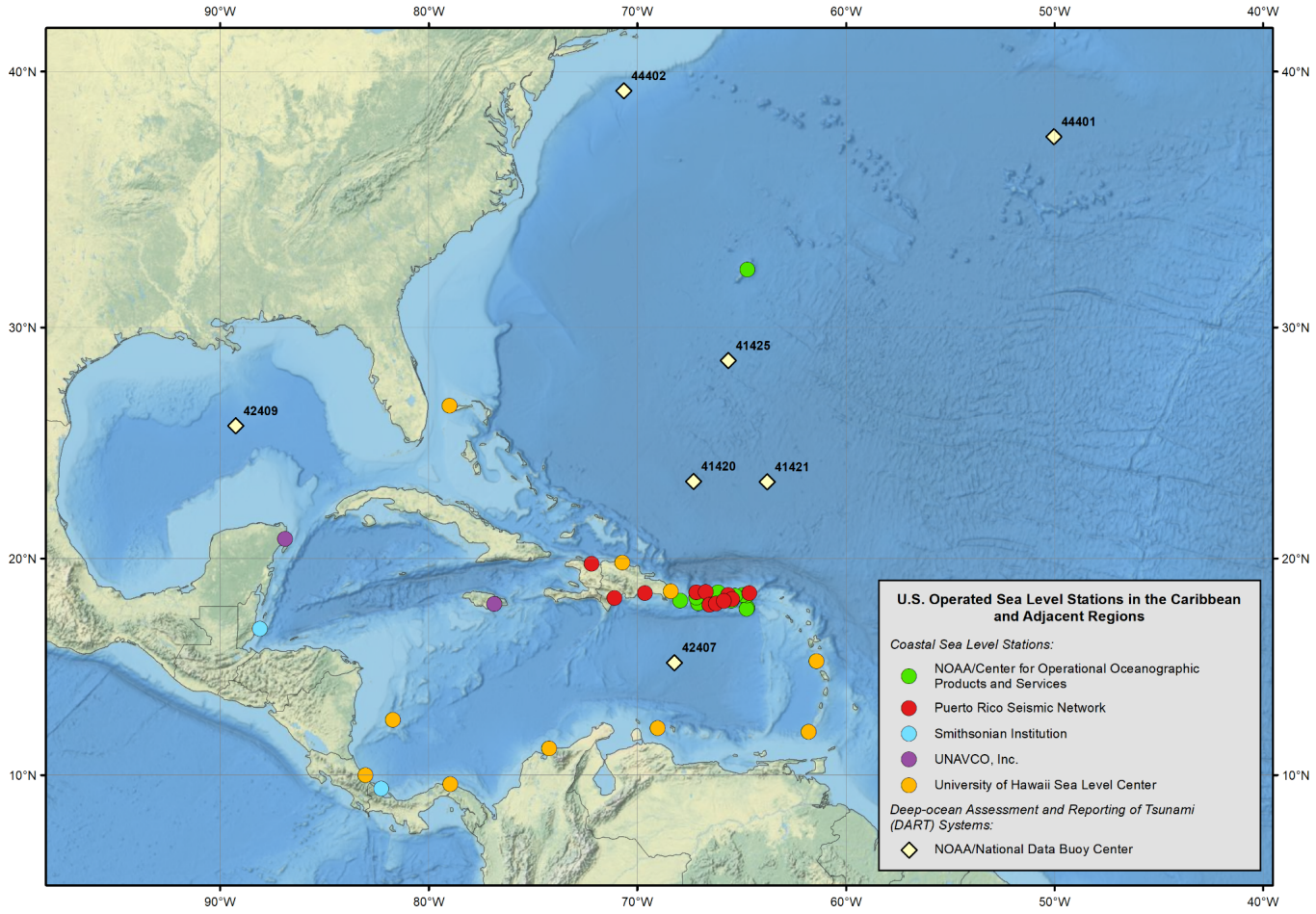


Figure 4: U.S.-operated sea level stations in Caribbean and adjacent regions.

Table 4: U.S.-operated sea level stations in Caribbean and adjacent regions.

Location	Latitude	Longitude	Status*	Operator
Coastal Water-Level Stations**				
Christiansted Harbor, St. Croix, U.S. Virgin Islands	17.75 N	64.70 W	Fully Operational	NOAA/Center for Operational Oceanographic Products and Services[1]
Lime Tree Bay. St. Croix, U.S. Virgin Islands	17.70 N	64.75 W	Fully Operational	
Lameshur Bay, St. John, U.S. Virgin Islands	18.32 N	64.72 W	Fully Operational	
Charlotte Amalie, St. Thomas, U.S. Virgin Islands	18.34 N	64.92 W	Fully Operational	
Culebra, Puerto Rico	18.30 N	65.30 W	Fully Operational	

Esperanza, Vieques Island, Puerto Rico	18.09 N	65.47 W	Fully Operational	
Magueyes Island, Puerto Rico	17.97 N	67.06 W	Fully Operational	
Mayagüez, Puerto Rico	18.22 N	67.16 W	Fully Operational	
Mona Island, Puerto Rico	18.09 N	67.94 W	Operation with Gaps*	
San Juan, La Puntilla, San Juan Bay, Puerto Rico	18.46 N	66.12 W	Fully Operational	
Bermuda, Biological Station	32.37 N	64.70 W	Fully Operational	
San Andres, Colombia	12.58 N	81.70 W	Fully Operational	University of Hawaii Sea Level Center
Santa Marta, Colombia	11.24 N	74.22 W	Down for relocation	
Limon, Costa Rica	9.99 N	83.02 W	Fully Operational	
Bullen Bay, Curacao	12.19 N	69.02 W	Operational	
Roseau, Dominica	15.31 N	61.39 W	Operational	
Puerto Plata, Dominican Republic	19.80 N	70.70 W	Fully Operational	
Punta Cana, Dominican Republic	18.51 N	68.38 W	Fully Operational	
Prickly Bay, Grenada	12.01 N	61.77 W	Operational	
El Porvenir, Panama	9.56 N	78.95 W	Operational	
Settlement Point, Bahamas	26.69 N	78.98 W	Fully Operational	
Aguadilla, Puerto Rico	18.46 N	67.16 W	Operational	Puerto Rico Seismic Network *operated with the support of ONAMET (Oficina Nacional de Meteorologia de la RD) and Globalmatrix eng. **PRSN and DDM
Arecibo, Puerto Rico	18.48 N	66.70 W	Operational	
Caja de Muertos, Puerto Rico	17.89 N	66.53 W	Damaged	
Salinas, Puerto Rico	17.949 N	66.226 W	Operational	
Guayanilla, Puerto Rico	18.01 N	-66.77 W	Operational	
Fajardo, Puerto Rico	18.338 N	65.631 W	Operational	
Isabel Segunda, Vieques Island, Puerto Rico	18.15 N	65.44 W	Operational	
Yabucoa Harbor, Puerto Rico	18.06 N	65.84 W	Operational	
Tortola, British Virgin Islands**	18.42 N	64.61 W	Unknown	

Barahona, Dominican Republic*	18.21 N	71.09 W	Operational	
Puerto Caucedo, Dominican Republic*	18.42 N	69.63 W	BWL Operational	
Cap-Haitien, Haiti	19.76 N	72.19 W	Radar Operational, Pressure Sensor and Bubbler Not Operational	Puerto Rico Seismic Network with UH Sea Level Center
Bocas del Toro, Panama	9.35 N	82.26 W	Fully Operational	Smithsonian Institution
Carrie Bow Cay off Belize	16.80 N	88.08 W	Pressure Sensor Operational, Radar not Operational	
Puerto Morelos, Mexico	20.87 N	86.87 W	Radar Operational, Pressure Sensor Not Operational	Earthscope (PUMO2 to be transferred to UNAM)
Port Royal, Jamaica	17.93 N	76.85 W	Station Not Operational, Pressure Sensor Not Operational	
Deep-ocean Assessment and Reporting of Tsunami Systems				
South Puerto Rico—230 nautical miles southwest of San Juan, Puerto Rico (42407)	15.25 N	68.22 W	Requires maintenance	NOAA/National Data Buoy Center
North Santo Domingo—328 nautical miles north northeast of Santo Domingo, Dominican Republic (41420)	23.43 N	67.31 W	Requires maintenance	
North St. Thomas—300 nautical miles north of St Thomas, Virgin Islands (41421)	23.41 N	63.78 W	Fully Operational	
Southwest Bermuda—200 nautical miles south southwest of Hamilton, Bermuda (41425)	28.63 N	65.65 W	Fully Operational	
Southeast Block Canyon—130 nautical miles southeast of Fire Island, New York (44402)	39.30 N	70.66 W	Maintenance/Repair	
Sable Island Bank, Canada (44403)	41.91 N	61.64 W	Requires Maintenance	

Gulf of Mexico–247 nautical miles south of New Orleans, Louisiana (42409)	25.85 N	89.25 W	Fully Operational	

** Status as of April 12, 2023*
*** To see other NOAA/Center for Operational Oceanographic Products and Services coastal water-level stations in the Atlantic Ocean, visit https://tidesandcurrents.noaa.gov/tsunami/.*

7. National GNSS Networks

The United States is actively pursuing techniques that will enable real-time, dynamic characterization and modeling of earthquake-generated tsunami sources. One of the most promising emerging datasets to accomplish this is the displacement vectors measured by the GNSS (Global Navigation Satellite System). While the United States does not currently have the capability to perform this type of characterization in an operational setting, we continue to support the deployment and maintenance of the underpinning networks. Continuously operating real-time GNSS stations in the United States and the Caribbean region are operated by a number of entities, including EarthScope Consortium that operates the GAGE Facility and Network of the Americas for NSF, NOAA, and the PRSN.

Table 5.. U.S.-operated GNSS Networks in the Caribbean and adjacent regions.

GNSS Network Name	Region	Number of GNSS stations	Number of Stations Providing 1-Hz Data Streams in Real Time to Enhance Caribbean Tsunami Early Warning	Operator
Network of the Americas (NOTA)	U.S./Alaska/ Caribbean/Mexico	1147	60	GAGE Facility/ EarthScope Consortium
PRSN	Puerto Rico/Virgin Islands	16	16	Puerto Rico Seismic Network
CORS	Worldwide	42 stations: 3 in Caribbean region	0	National Geodetic Survey (NOAA)

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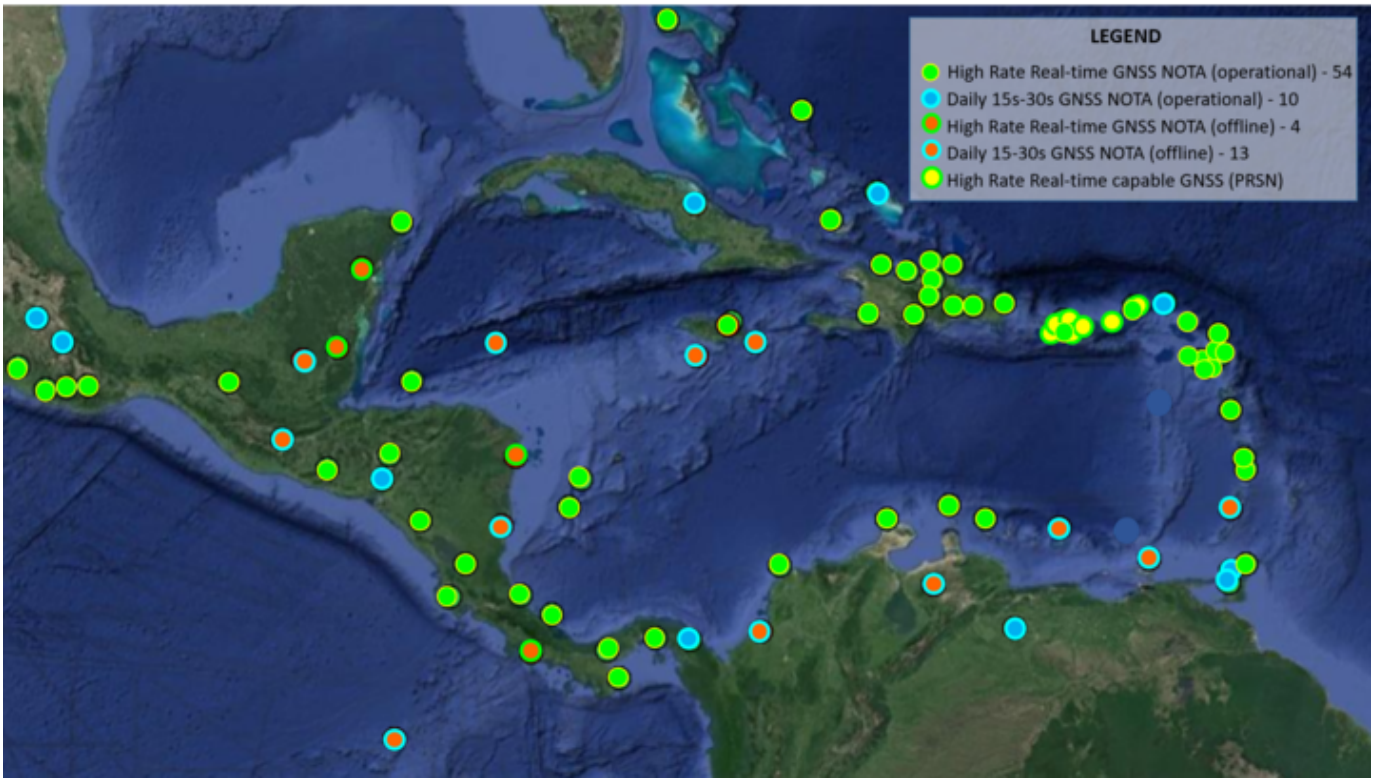

Figure 5. Caribbean regional GNSS assets, including NOTA and PRSN (total number of stations shown is 81). COVID-related travel disruptions introduced major challenges to maintenance activities in international geophysical networks. Since these restrictions were lifted, recent maintenance and upgrades have dramatically improved network uptime across the Caribbean Basin Region to 79% (64 of 81 stations operational as of 4/13/23). Fifty-eight (58) stations are now streaming real time 1Hz data, for potential use in rapid earthquake and volcano response and tsunami early warning system integrations.

EarthScope Contribution: The Network of the Americas

UNAVCO and IRIS merged to form the EarthScope Consortium, Inc. on January 1, 2023. The NSF-funded SAGE Facility, formerly operated by IRIS, and the NSF-funded GAGE Facility, formerly operated by UNAVCO, are now operated by the EarthScope Consortium. The EarthScope Consortium, Inc., a non-profit university-governed consortium funded by the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the United States Geological Survey (USGS), manages three large GNSS networks in the western hemisphere. These three networks, known collectively as the Network of the Americas (NOTA), consist of the earthscope Plate Boundary Observatory (PBO), the Continuously Operating Caribbean GPS Observational Network (COCONet), and the Trans-boundary Land and Atmospheric Long-term Observational and Collaborative Network (TLALOCNet) in Mexico.

NSF has awarded UNAVCO a 5-year Cooperative Agreement (Geodesy Advancing Geosciences - GAGE) Facility, which started Oct. 1, 2018 and was originally scheduled to continue through Sep. 30, 2023. The NSF has recently announced its intention to extend the GAGE Facility through September 30, 2025 and the EarthScope Consortium is in the process of preparing a renewal plan to be submitted to NSF on April 14, 2023. Most of the RT-GNSS resources that national, regional, or state EEW and TWS will use once fully operational, are cGNSS assets that were funded primarily by the NSF through the previous earthscope MREFC and GAGE Facility CAs. UNAVCO has also received funding through USGS as part of the ShakeAlert program (during 2017-2021) to upgrade and modernize a subset of Network of the Americas cGNSS stations in Northern California, Oregon, and Washington. These stations continue to be operated by the EarthScope Consortium with NSF funding as part of NOTA.

The construction phase of NOTA is finished, with stations producing high-quality, low-latency GNSS data and data products from 1,147 continuously operating GNSS stations, over 900 of which provide both 1-Hz raw GNSS code and phase data and ambiguity-resolved precise point positions in real time, which are required for tsunami warning. Sixty one (60) of these real-time stations are located in the Caribbean Basin, of which 57 are currently operational.

UNAVCO, and now the EarthScope Consortium, has tested real-time algorithms to determine Peak Ground Displacement (PGD) from RT-GNSS position estimates (Hodgkinson et al., 2020). For events greater than ~M7, the system worked well and has been able to estimate the “final” magnitude with high accuracy and in a timely way (<300 s) for several events in Alaska, Mexico, and the Caribbean (Hodgkinson et al., 2020).

Puerto Rico Seismic Network Contribution

The PRSN also operates a GNSS network of 16 real-time/high-rate stations (originally) funded by NSF. Ten of them are equipped with alloy receivers. NOAA’s National Geodetic Survey (NGS) also has non-real-time GPS stations in Puerto Rico, the Virgin Islands, Bermuda, and Barbados. All the permanent GPS stations are equipped with Trimble receivers and antennae. All PRSN stations receive 1-Hz position corrections through Trimble's RTX service, and data are shared through the EarthScope server or PRSN earthworm/seedlink system.

At the PRSN, continuous data are simultaneously logged to three sessions with different sampling rates depending on their designated usage. Data is transferred from field sites to the data-collection server on a daily basis and is made available for download through UNAVCO's Data Archive. Real-time data is available through a dedicated NTRIP caster. An Earthworm module actively receives RTX (corrected) positions from PRSN remote sites and serves those streams via export or seedlink.

8. Information on Tsunami Occurrences/Tsunami Exercises

Tsunami Occurrences. Since the last report in 2021, there were no significant tsunamis impacting the U.S. in the Caribbean or Atlantic region.

Exercises

The US helped coordinate and participated in the annual CARIBE WAVE Exercises which are further discussed in the narrative.

9. National Tsunami-related Websites

General Resources

- U.S. Tsunami Warning System: https://www.tsunami.gov
- International Tsunami Information Center (ITIC): http://www.tsunamiwave.org; http://itic.ioc-unesco.org
- National Centers for Environmental Information (NCEI) Tsunami Data and Information: https://www.ngdc.noaa.gov/hazard/tsu.shtml
- NOAA Center for Tsunami Research/Pacific Marine Environmental Laboratory (PMEL): https://nctr.pmel.noaa.gov/index.html
- U.S. Agency for International Development (USAID): https://www.usaid.gov/ https://www.usaid.gov/what-we-do
- Office of U.S. Foreign Disaster Assistance (OFDA):

https://www.usaid.gov/who-we-are/organization/bureaus/bureau-democracy-conflict-and-humanitarian-assistance/office-us

Warning Center User's Guides

- Communication Plan for the Interim Tsunami Advisory Information Service to the Caribbean Sea and Adjacent Regions 23 July 2006 Version. https://www.weather.gov/media/ctwp/PDF/CommunicationsPlanICG-CARIBE_EWS-II-11.pdf
- User's Guide for the Pacific Tsunami Warning Center Enhanced Products for the Tsunami and other Coastal Hazards Warning System for the Caribbean and Adjacent Regions (CARIBE EWS, 2017). https://www.weather.gov/media/ctwp/PDF/Users%20guide%202017.pdf
- Users' Guide Tsunami Warning Products for Puerto Rico, U.S Virgin Islands, and British Virgin Islands (2017) - In process of being updated https://tsunami.gov/operations/PRVIUserGuide.pdf

Seismic Information

- U.S. Geological Survey (USGS) Earthquakes Hazard Program: https://earthquake.usgs.gov/earthquakes/
- Puerto Rico Seismic Network (PRSN): http://redsismica.uprm.edu
- Earthscope CARIBE EWS Virtual Seismic Network: http://ds.iris.edu/gmap/#network=_CARIBE EWS&planet=earth
- Earthscope Data Management Center (DMC) https://ds.iris.edu/ds/nodes/dmc/
- International Tsunami Information Center Caribbean Office - Caribbean Tsunami Warning Program (Seismic Stations Reports and Maps): http://caribewave.info

Sea Level Tools/Information

- Center for Operational Oceanographic Products & Services Tsunami website https://tidesandcurrents.noaa.gov/tsunami/
- International Tsunami Information Center (Tide Tool) http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=1573:tsunami-warning-operations-sea-level-monitoring-tide-tool-and-ioc-sea-level-monitoring-facility&catid=2141&Itemid=2565
- International Tsunami Information Center Caribbean Office (Sea Level Stations Reports and Maps): http://caribewave.info
- National Data Buoy Center (NDBC) DART Program: https://www.ndbc.noaa.gov/dart/dart.shtml
- Puerto Rico Seismic Network Station Monitoring System: http://www.prsn.uprm.edu/English/EstacionesV3/gauges.php
- University of Hawaii Sea Level Center (UHSLC): https://uhslc.soest.hawaii.edu/network/
- National Centers for Environmental Information (NCEI) Long-term Archive of NOAA Water-level Data: https://www.ngdc.noaa.gov/hazard/tide/ https://www.ngdc.noaa.gov/hazard/dart/

10. Summary Plans for Future Tsunami Warning and Mitigation System Improvements

Tsunami detection and measurement. The United States continues to work toward a near-real-time, direct tsunami detection and measurement capability. If realized, we expect this will yield significant

improvement in tsunami forecast accuracy. We expect this capability will consist of analyzing and integrating a number of discrete real-time data inputs, including traditional seismic waveforms and w-phase CMT calculations, but also place increasing emphasis on direct deep ocean and coastal sea-level readings, and added emphasis on determining coseismic deformation through GNSS offset data.

DART 4G: NOAA's 4th generation of DART is currently being deployed. It provides a more robust communications and mooring capability, and through the use of seismic band-pass filters, allows the bottom pressure recorder to be placed much closer to the seismic source than was possible with previous generations. This presents the opportunity to make direct tsunami detections within 10s of minutes as opposed to hours, provided the instruments are properly relocated and densified. NOAA is exploring a revised DART deployment grid to take advantage of the 4G capability to include the CARIBE EWS region.

GNSS Update: To facilitate incorporation of GNSS into TWC operations, NOAA's National Center for Tsunami Research is building a test-bed at the Pacific Marine Environmental Laboratory (PMEL) in Seattle WA. They will be incorporating algorithm development done at various academic institutions into a prototype operational analysis system. As of Q3 of fiscal year 2022 the testbed has been detecting and characterizing small events, and the initial operational system is scheduled to be installed at NOAA's Tsunami Warning Centers by June 2023. Funding to the EarthScope Consortium for the operation of GAGE Facility, including the Network of the Americas, will end at close of Fiscal Year 2025. The future funding of NOTA by NSF is uncertain after September 30, 2025, although the EarthScope Consortium expects that NSF will be releasing a solicitation sometime in Summer 2023 for an integrated seismological and geodetic facility after the close-out of the current SAGE and GAGE Facility Cooperative Agreements. While the scope that would be included in the NSF solicitation is unknown at this time, EarthScope Consortium senior management believe that NOTA will continue to be supported at some level after the close-out of the GAGE Facility. The UPRM and the PRSN are also working to study the use of the Ionospheric Total Electron Content (TEC).

SMART Cables: Science Monitoring And Reliable Telecommunications (SMART) Cables are sensor-enabled subsea fiber optic cables that will be equipped with seismic, pressure, and temperature sensors. The goal of SMART Cables is to provide enhanced capabilities for Tsunami Early Warning (TEW), Earthquake Early Warning (EEW), climate monitoring, and telecommunications resiliency. These sensors are emplaced in and near cable repeaters, which are spaced 60-120 km apart and amplify cable signals. SMART Cable technological developments are ongoing, including hardware development by Subsea Data Systems, a U.S. startup supported by several foundations, including National Science Foundation, Schmidt Marine Technology Partners, and the Gordon and Betty Moore Foundation. A significant recent development is that several SMART Cable initiatives have made substantial progress toward implementation. The most significant (and currently funded at €154M) system is the Portuguese CAM system, which is a 3,700 km, 50-repeater ring system. Several other SMART Cable projects are in various stages of development. In the CARIBE EWS region, SMART Cables could provide a cost-effective solution to substantially improve earthquake and tsunami warning for the region.

U.S. Tsunami Warning Center (TWC) Alignment. The U.S. National Weather Service is undertaking a comprehensive re-design of the US Tsunami Warning System in order to both improve capabilities and ensure 100% failover capability between TWCs. This includes designing and building a comprehensive and common analytic system that will ensure both TWCs are working from the same scientific and procedural baseline when a tsunami event occurs, and ensuring common hardware and software infrastructure between PTWC and US NTWC to improve and align data ingestion and analysis, tsunami forecast model guidance, and message creation and dissemination, in a way that advances a seamlessly coordinated backup between the two tsunami warning centers. The first major milestone is the transition of legacy TWC messaging generation software to NWS supported architecture by early CY25.

Hazard Simplification. The US National Weather Service has started a process to consider the transition of the domestic "Tsunami Advisory" alert category to "Tsunami Warning for Beach and Harbors". This process is expected to take 4-5 years. While this does not affect the CARIBE EWS products, the US is aware that many countries have followed and adopted US domestic messages.

Seismic Monitoring.

- The PRSN is working with the Dominican Republic to maintain the four seismic stations operated there and two tsunami-capable tide gauges. Plans are to install a new Tide Gauge station in the province of Samana. Also, a new tsunami-capable tide gauge will be installed in the British Virgin Island of Anegada. In Puerto Rico, the PRSN is planning the installation of four new broadband seismic stations.
- The PRSN released two new software modules to feed a central Earthworm system with real-time data streams from tide gauge satlink data servers and RTX GPS corrected data messages.
- The PRSN is coordinating the replacement of the seismic station in Aruba.
- The PRSN is planning to add two new tsunami camera devices and the reinstallation of the tide gauge in the Caja de Muertos Island.
- The ITIC-CAR in coordination with the PTWC, PRSN, Earthscope, network operators and CARIBE EWS Working Group 1, will continue to prepare and share monthly maps on seismic data availability at PTWC and biannual reports on status of CARIBE EWS stations through the intersessional period. During this time ITIC-CAR looks forward to reviewing the reports, their effectiveness and way forward as it will not be able to support this task as of 2024.

Sea level monitoring. The ITIC-CAR in coordination with the PTWC, PRSN and the IOC Sea Level Monitoring Facility, network operators and CARIBE EWS Working Group 1 will continue to prepare and share monthly maps on sea level data availability at PTWC and biannual reports on CARIBE EWS sea level stations through the intersessional period. During this time ITIC-CAR looks forward to reviewing the reports with the WG 1 and the way forward as it will not be able to support this task as of 2024.

Map Viewers

- NCEI continues to update the Caribbean and Adjacent Regions Tsunami Sources and Models (CATSAM) map viewer.
- The PRSN the Tsunami Map Tool, and develops a manual and user guides.

Seismic Hazard Map for Puerto Rico and the U.S. Virgin Islands

- USGS, and local scientists, are working on update for 2025

Digital Elevation Models (DEM).

- NCEI released an updated global relief model, ETOPO 2022, as described in Section 12.
- NCEI in 2022 updated 32 high-resolution tiled DEMs for Puerto Rico and the U.S Virgin Islands, as described in Section 12.

US TsunamiReady® Program

- Through NTHMP, NOAA will continue to support renewals of 49 communities recognized by the US National Weather Service in Puerto Rico and the US Virgin Islands, including the strengthening of local and territorial capabilities.

UNESCO IOC Tsunami Ready Programme

- ITIC-CAR with USAID/BHA funding will continue to support Tsunami Ready projects in Saint Vincent and The Grenadines, Barbados, Saint Lucia and Dominica
- NWS has requested additional funding from USAID/BHA for ITIC-CAR to support Tsunami Ready renewals in Anguilla and Honduras and new designations in Antigua and Barbuda during 2023–2025.
- The Tsunami Ready page hosted by the International Tsunami Information Center (ITIC) (TsunamiReady.org) will be continuously updated. This page includes documentation on Tsunami Ready, as well as a map and the documentation of Tsunami Ready communities.

- ITIC-CAR will hold a Tsunami Ready workshop in San Jose, Costa Rica on Apr 24, 2023 for stakeholders from USAID supported projects and interested parties from other countries

CARIBE WAVE Exercise. The ITIC-CAR and PTWC will continue to coordinate and support this annual tsunami exercise, including the development of simulated products, handbook and reports, the conduct of webinars, survey, website (caribewave.org) and registration system (tsunamizone.gov)

- ITIC-CAR with the CTIC is organizing a multiannual tsunami exercise training workshop and CARIBE WAVE Task Team meeting in Barbados in June 2023

World Tsunami Awareness Day (WTAD)

- ITIC will continue to support World Tsunami Awareness Day by hosting a page on its website, providing still and moving visuals and documentation, and subject matter expertise.
- Using all available social media platforms, the PRSN and the PR Bureau for Emergency Management (BEM) will participate and promote the participation in the WTAD.

UN Decade of Ocean Science

- NOAA will continue to support and be actively engaged in the UN Decade of Ocean Science for Sustainable Development through Programmes, Projects, and Contributions which have been proposed, or are under the IOC's Ocean Decade Tsunami Programme (ODTP)
- NOAA will continue to advocate for the development and implementation of SMART Cables, and other emerging technologies that support direct detection and measurement in support of tsunami early warning
- NOAA will continue to advocate and support (as funding permits) the implementation and maintenance of UNESCO/IOC Tsunami Ready Recognition Programme, including the Chairing of UNESCO/IOC Tsunami Ready Coalition by Dr. Laura Kong, Director of ITIC.
- ITIC-CAR will continue to engage in the coordination of the UN Decade of Ocean Science for Sustainable Development in the Western Atlantic (WTA), including participation in the WTA Working Group for Safe Ocean and the endorsed Decade Project, Integrating Coastal Hazards Early Warning Systems (iCHEWS).

Outreach, Education, and Communications

- ITIC and ITIC-CAR will continue to distribute educational and decision support resources. A Google Form has been created for Member States to request materials. (https://docs.google.com/forms/d/1Ohu8sKBT9JbMVOS5FAGnSfZt1ABkweepUw6KtH3oGDs/edit)
- ITIC-CAR will continue to support the IOC Caribbean Tsunami Information Center (CTIC) mission activities, including collaborating for tsunami training in warning, response, and evacuation planning and warning decision support tools, Tsunami Ready, and outreach and awareness building.
- ITIC, as an IOC Ocean Teacher Global Academy Specialized Training Center (OTGA STC), will develop online and hybrid training courses, to be available to all CARIBE-EWS Member States, and globally. The courses are being done in coordination with the IOC Tsunami information Centers (CTIC, IOTIC, NEAMTIC), Member State practitioner experts, and the Indonesia OTGA STC, Courses planned are:
    - Tsunami Awareness (6-hr online), in final stages
    - Tsunami Ready (6-hr online) - (led by Indonesia), in final stages
    - Tsunami Early Warning Systems (40-hr online/blended) to be started
    - Tsunami Warning Center and Emergency Response Standard Operating Procedures (40-hr online/blended) - planned
    - Tsunami Maps, Plans, and Procedures, including inundation mapping (TEMPP) (160-hr online/blended) - planned
    - Tsunami Hazard and Risk Assessment (40-hr course) - (led by Indonesia)
    - Tsunami Warning Center Staff Basic Competencies (120-hr online/blended) - planning 2023

- At TOWS XVI it was recommended that the IOC Tsunami Secretariat to facilitate the finalization of the OTGA basic tsunami training materials as soon as possible. For June 2023 ITIC will be hosting a meeting of the IOC Tsunami Secretariat, IOTIC and other Subject Matter Experts to finalize the Tsunami Ready module.

    - NOAA will continue to support the GEONET CAST Americas as an additional method to receive Tsunami products from the Pacific Tsunami Warning Center
    - NOAA thru ITIC-CAR will support the integration of social science research thru identification of resources and tools.

NATIONAL PROGRAMMES AND ACTIVITIES INFORMATION

11. Executive Summary

Overview
During the last intersessional period, there has been a continued focus on fully restoring U.S. tsunami detection, forecast, warning, and community alerting capacity in the Caribbean region degraded by tropical cyclone damage in 2017, and again in 2022. Most capabilities have been restored as of April 2023. Tsunami forecast and warning operations continued as normal with no alert-level events.

Improved tsunami detection and source characterization. These efforts include:

a. Continued testing of the 4th Generation of DART with advanced seismic noise filtering to allow for near-field placement.
b. Continued testing and development of advanced **geodetic analysis** in tsunami source estimation using GNSS station static offsets. We expect to field and initial capability to use this technique in operations within 2 years.
c. The PRSN completed a regional study toward the implementation of a rapid tool to compute the focal mechanism via the W-phase method, and will also support research regarding the Tsunami detection using the ionospheric total electron content (TEC) methodology.

Improved tsunami forecast capability.

a. NCEI developed 32 high-resolution tiled DEMs in 2022 for all of Puerto Rico and the U.S Virgin Islands via funding under the COASTAL Act.
b. Images from the November 18, 1867 Virgin Islands earthquake and tsunami were added to the Natural Hazards Image Database and archived at NCEI. These include images of the U.S. Navy vessel *USS Monongahela* after it washed ashore during the event. This event is the oldest event recorded in the Natural Hazards Image Database.

US TsunamiReady Program.

a. There are currently 46 TsunamiReady communities, and 14 TsunamiReady supporters, in Puerto Rico and 3 in USVI.The renewal cycle is 4 years. https://www.weather.gov/TsunamiReady/communities
b. NOAA, through the National Tsunami Hazard Mitigation Program (NTHMP), provides funding to the Puerto Rico Seismic Network (UPRM), the Puerto Rico Emergency Management Bureau and VITEMA for the TsunamiReady renewal activities. FEMA, through hurricane recovery and mitigation funding, has also supported activities associated with the TsunamiReady guidelines.

Other Preparedness and Mitigation activities.

a. PRSN, ITIC-CAR, PREMB and VITEMA have resumed in person outreach activities in which tsunami guidance was provided.
b. ITIC-CAR supported development of IOC Manual and Guide 86 *Multi-annual community tsunami exercise programme: guidelines for the tsunami and other coastal hazards warning system for the Caribbean and Adjacent Regions* was published in 2021 (English) and 2022 (French). It provided a review for the Spanish version, which is pending publication.

c. NCEI and ITIC updated its Global Historical Tsunami, Significant Earthquake, and Significant Volcanic Eruption posters to 2022.
d. NCEI and ITIC are updating the Historical Tsunami Effects: Caribbean, Central America, Mexico and Adjacent Regions (1530–2020) Poster with event through March 2023. Additional regional maps are available for regions near the Tonga Trench, New Guinea and Bismarck Trenches, and New Hebrides Trenches
e. PMEL, ITIC, and PTWC continued the development of new features in the TsuCAT software and made it available to some of the training participants. New features for V4.3 (released Feb 2023) include the addition of automated, customized exercise injects.
f. ITIC is developing online and blended training as an IOC Ocean Teacher Global Academy. Specialized Training Center for Tsunamis with courses available in 2023.
g. ITIC has created informational training videos on the PTWC Products for the Caribbean and Pacific (English, French, Spanish), PTWC Product Staging for the Caribbean and Pacific (English), and a narrative video on PTWC TWC Operations for a Pacific earthquake. Videos are available for viewing and download from the ITIC Vimeo site https://vimeo.com/showcase/8956022, Password: training
h. ITIC set up in 2023 a YouTube Channel for sharing of videos https://youtu.be/a6_ZiRItqOM

Emergency Managers Weather Information Network (**EMWIN**). EMWIN continues to be affected by NOAA's transition of GOES-East. Users should understand how they may be affected by the transition and take steps to ensure they have the proper equipment and software to receive tsunami (and other) messages over EMWIN. Full details provided in the Narrative section.

Exercises

a. CARIBE WAVE
   i. Puerto Rico and the US Virgin Islands participated in the CARIBE WAVE 23 exercise in March 2023. The scenario chosen was Mount Pelee Volcano, Martinique.
   ii. Puerto Rico and the US Virgin Islands participated in the CARIBE WAVE 22 exercise on March 10. The scenario chosen was Western Muertos Trough.
   iii. ITIC CAR published an article on 10 years of CARIBE WAVE exercises: Stephanie Soto, Christa von Hillebrandt-Andrade, Elizabeth A. Vanacore, Silvia Chacón-Barrantes, Alison Brome; CARIBE WAVE: A Decade of Exercises for Validating Tsunami Preparedness in the Caribbean and Adjacent Regions. Bulletin of the Seismological Society of America 2022; 113 (1): 236–251. doi: https://doi.org/10.1785/0120220095
   iv. ITIC-CAR created a 2-minute informational video in English, French, Spanish to support the annual CARIBEWAVE exercises. It can be viewed and downloaded from the ITIC Vimeo page https://vimeo.com/showcase/9334456
b. Routine Communications Tests
   i. PTWC confirms communications over all circuits and with key partner agencies following each message issuance.
   ii. Puerto Rico and the U.S. Virgin Islands participated in international CARIBE EWS tsunami communication tests with PTWC.

12. **Narrative**

Detailed description of innovations or modifications to National tsunami warnings procedures or operations since last National Report, tsunami research projects, tsunami mitigation activities and best practices (especially in preparedness and emergency management), tsunami exercises, as well as public education programmes or other measures taken to heighten awareness of the tsunami hazard and risk.

Focus Areas

The US Is focused on facilitating implementation of the IOC Tsunami Ocean Decade Framework developed by the UN Ocean Decade Tsunami Programme (ODTP) Scientific Committee. This will focus on two primary areas: (1) exploration and development of instrumentation and techniques to more rapidly detect and measure tsunamis independent of generating source; and, (2) ensuring capacities lifted across the region to enable the ODTP goal of *100% communities at risk are prepared for and resilient to tsunamis* through programs like the UNESCO IOC Tsunami Ready Recognition Programme. More specifically we will strive to accomplish this by:

1. Detection and Measurement
    a. Advocate full sharing of available data at time and space resolutions necessary for tsunami detection and measurement
    b. Determine spatial and temporal resolutions necessary to detect and measure tsunamis from all sources
    c. Identify candidate new capabilities to be tested and possibly deployed within the region
    d. Consider new research initiatives to add detection and measurement capabilities not current developed (eg Ionospheric TEC)
    e. Identify instrumentation and or communications investments can make in order to contribute to the CARIBE EWS Rapid Tsunami Detection and Measurement initiative
2. Risk Assessment, Warning Communications and Preparedness and Response
    a. Advance the understanding of tsunami risk and hazard assessments from all sources of tsunamis.
    b. Ensure that all people at risk from a tsunami are alerted and reinforce the warning messages.
    c. Maintain and augment the number of communities in the US and globally that are recognized by the US National Weather Service or UNESCO as Tsunami Ready.
3. Support multi hazard early warning alignment by linking hazard-specific systems together.
4. Apply an inclusive approach by providing a balanced platform for gender and generational participation.

Warning Center Operations

There were no significant changes to PTWC's procedures or operations, although the magnitude threshold for issuing Information Statements to Puerto Rico and the Virgin Islands was raised from 4.0 to 4.5 in response to the earthquake swarm that began with the January 7, 2020 earthquake referenced above. A summary of products issued is contained in Section 8.

Observation Systems

DART station 44401, originally located 620 nautical miles south of St John's Newfoundland, Canada, was relocated to station 44403 near Sable Island Bank. NDBC plans to repair DART 42409, which is 247 nautical miles south of New Orleans, LA; station 41421, which is located 300 nautical miles north of Saint Thomas, Virgin Islands; and station 44402, 130 nautical miles southeast of Fire Island, NY, as part of their regular maintenance and repair schedule this spring.

EMWIN Update

The NWS EMWIN satellite broadcast and FTP file server services fully transitioned to the US NWS Enterprise Architecture at College Park MD and Boulder CO in December 2020. This transition enabled the EMWIN broadcast stream to be transmitted via the GOES-East (GOES-16, 75.2°West) and GOES-West (GOES-17, 137.2°West) satellites through the NESDIS HRIT/EMWIN broadcast service

(1694.1 MHz) using Virtual Channels 20, 21 and 22. The EMWIN FTP file service transitioned as well, and is available via an anonymous FTP server at:

https://tgftp.nws.noaa.gov/SL.us008001/CU.EMWIN/DF.xt/DC.gsatR/OPS/

With the introduction of the GOES-16/17 HRIT/EMWIN modified broadcast format, EMWIN users had to replace their legacy EMWIN receivers with HRIT receivers if they desired to continue receiving products over a satellite broadcast. Unfortunately, the major EMWIN legacy satellite receiver manufacturers did not pursue the manufacture of affordable HRIT/EMWIN receiving systems due in part to the reported likelihood of interference from new G5 cell phone service upstarts in the recently auctioned adjacent radio frequency spectrum. Existing EMWIN users were left with a limited number of alternatives: (1) investing in a high-end commercial HRIT/EMWN receiver costing upwards of 10x the price of the previous receiver, (2) constructing a hobbyist EMWIN receiving systems from parts and software and support the systems locally, or (3) looking elsewhere for dissemination services to meet the local information requirements. Consequently, a large segment of the EMWIN user community transitioned to alternate systems and services to receive timely alerts and warnings including, among others, the NWS NOAA Weather Wire Service (NWWS) and its associated internet dissemination service, and the NESDIS GEONetcast-Americas satellite broadcast service.

The NWS continues to investigate alternatives for the legacy EMWIN ByteBlaster Internet dissemination service which could not transition into the US NWS Enterprise Architecture at College Park Md and Boulder CO due to an inability to meet IT operational compliance requirements.

Interested parties are encouraged to visit the EMWIN web page for periodic updates: https://www.weather.gov/emwin/

Any questions regarding the NWS EMWIN services may be directed to: nws.emwin.support@noaa.gov

Tsunami Research Projects

GNSS

- NOAA continued to work with NASA and NSF GAGE Facility operated by the Earthscope Consortium, Inc. to explore employing GNSS-derived offsets as a component of its tsunami forecast and warning capability. Over the past year, data streams have become more reliable and are now sufficient to calculate earthquake magnitude (from Peak Ground Displacement) earlier than by traditional seismic waveform analysis alone in certain regions. NOAA's tsunami warning centers will soon have a means of fully analyzing and incorporating GNSS offset data as this project transitions to operations.
- The NOAA Center for Tsunami Research continues to conduct research and develop software to incorporate the GNSS technology into the SIFT Tsunami Forecast System. The first operational GNSS-characterized forecast feature is scheduled for deployment during Q3 2023. The January 28th, 2020 Lucea earthquake with epicenter located in the Oriente Fault Zone between Cuba and Jamaica was investigated as data from 4 GNSS stations located in Jamaica and the Cayman Islands recorded the earthquake. Although this particular event had a non-tsunamigenic rupture mechanism, its study showed the need for additional real-time GNSS stations in the area for rapid seismic assessment.
- The UPRM and the PRSN are working in an effort to study the use of the Ionospheric Total Electron Content (TEC)

Other

- NCEI released an updated global relief model, ETOPO 2022.The new model adds enhanced resolution that incorporates recent advances in data sources and processing techniques. ETOPO 2022 uses a combination of numerous airborne lidar, satellite-derived topography, and shipborne bathymetry datasets from U.S. and global sources. Its predecessor, ETOPO1, has been an important modeling tool for the tsunami community since its introduction more than a decade ago. ETOPO1 had a grid resolution of about 2 km. The new ETOPO 2022 resolution will be an enhanced 15 arc-second resolution, about 0.5 km, which is four times higher than ETOPO1.
  https://www.ncei.noaa.gov/products/etopo-global-relief-model

- NCEI updated 32 high-resolution tiled DEMs for Puerto Rico and the U.S Virgin Islands via funding under the Bipartisan Budget Act of 2018: NOAA Supplemental Funding for Hurricanes Harvey, Irma, and Maria, and also generated 88 additional offshore tiled DEMs in support of the COASTAL Act.
  https://chs.coast.noaa.gov/htdata/raster5/elevation/NCEI_ninth_Topobathy_PuertoRico_9525/
  https://chs.coast.noaa.gov/htdata/raster5/elevation/NCEI_third_Topobathy_PuertoRico_9524/
  https://chs.coast.noaa.gov/htdata/raster5/elevation/NCEI_ninth_Topobathy_USVI_9529/
  https://chs.coast.noaa.gov/htdata/raster5/elevation/NCEI_third_Topobathy_USVI_9528/
  And here for the development report:
  https://www.ngdc.noaa.gov/mgg/dat/dems/tiled_tr/prvi_tiled_prvd_vivd_2022.pdf
- NCEI has evaluated FABDEM (Forest And Buildings removed Copernicus 30m DEM) for the development of a baseline regional coastal DEM for the inundation modeling and evacuation mapping of tsunami and other coastal hazards.
- In addition to archiving and processing preliminary 1-minute water level data from CO-OPS tide gauge stations in the Caribbean, NCEI continues to archive preliminary and verified 6-minute, verified highs and lows, verified hourly, and verified monthly mean water levels for these same stations. Seven of these stations in the Caribbean were reported by the Tsunami Warning Centers of having detected the tsunami from the January 15, 2022 eruption of Hunga Tonga-Hunga Ha'apai Volcano in the southwest Pacific. The largest wave was detected at Arecibo, Puerto Rico (17 cm). These records have been quality-controlled and de-tided by NCEI and collected together with other DART and tide gauge observations on the event page at: https://www.ngdc.noaa.gov/hazard/dart/2022tonga.html
- Images from the November 18, 1867 Virgin Islands earthquake and tsunami were added to the Natural Hazards Image Database and archived at NCEI. These include images of the U.S. Navy vessel USS Monongahela after it washed ashore during the event. This event is the oldest event recorded in the Natural Hazards Image Database.
- The PRSN completed a regional study toward the implementation of a rapid tool to compute the focal mechanism via the W-phase method. Their results show the performance of the algorithms and the capability to improve the regional detection of larger tsunamigenic earthquakes. Also, two new software modules were developed to feed a central Earthworm system with real-time streams from tide gauge satlink data servers and RTX GNSS corrected data messages.

Tsunami Mitigation Activities and Best Practices

- Puerto Rico and the US Virgin Islands have been recognized as TsunamiReady® by the National Weather Service since 2016 and 2014, respectively. Within Puerto Rico there are 46 TsunamiReady communities, while for the USVI the total number is 3. In 2021, the renewal cycle was changed from 3 to 4 years.
- In addition to the TsunamiReady communities, there are fourteenTsunamiReady supporters in Puerto Rico. https://www.weather.gov/tsunamiready/communities

- NOAA thru NTHMP provides funding to the Puerto Rico Seismic Network (UPRM), the Puerto Rico Emergency Management Bureau and VITEMA for the TsunamiReady renewal activities.
- As a result of the hurricanes of 2017, a significant number of tsunami signs, EMWIN systems and sirens were destroyed in Puerto Rico and the U.S. Virgin Islands. The replacement effort has almost been completed.
- FEMA, through hurricane recovery and mitigation funding, has also supported activities associated with the TsunamiReady guidelines.
- Puerto Rico has held meetings and prepared a guidance document on vertical evacuation for tsunamis.
- PRSN, PREMB, VITEMA and ITIC-CAR have resumed in-person outreach activities in which tsunami guidance was provided.
- PRSN with NOAA/NTHMP funding is currently updating its Tsunami Media tool kit (Spanish) http://www.prsn.uprm.edu/mediakit/ PRSN with NOAA/NTHMP funding updated the tsunami maritime guidance (in Spanish). http://redsismica.uprm.edu/Spanish/tsunami/programatsunami/prc/documentos/Maritima/GuiadeTsunamis_Comunidad_Maritima_Final2019.pdf
- PRSN with NOAA/NTMP funding is updating the TsunamiMap tool for online access to tsunami inundation, community pedestrian models, evacuation and signage information http://prddst.uprm.edu/apps/prtmp/
- PRSN with NOAA/NTHMP funding is coordinating a protocol and a pilot effort to include the Amateur Radio associations into the tsunami alerting system.
- ITIC CAR supported thefinalization of UNESCO/IOC as Manual and Guide 86 “The Multi-Annual Community Tsunami Exercise Programme: Guidelines for the Tsunami and other Coastal Hazards Warning System for the Caribbean and Adjacent Regions. It was translated into French, the Spanish version is still pending. The document can be accessed at: http://itic.ioc-unesco.org/images/stories/tsunami_exercises/international_exercises/caribewave/caribewave23/Supporting_Documents/MG86_380540eng.pdf (English) and http://itic.ioc-unesco.org/images/stories/tsunami_exercises/international_exercises/caribewave/caribewave23/Supporting_Documents/MG86_380540fre.pdf (French)
- NCEI and ITIC updated its Global Historical Tsunami, Significant Earthquake, and Significant Volcanic Eruption posters to 2022. As well as being general public outreach materials, the posters are used as historical references for experts and as a way to communicate to the media during an event. The posters are distributed to warning and response personnel by the ITIC and are available digitally through both NCEI and the ITIC. Hard copies available on request.http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=1672&Itemid=2698
- PMEL, ITIC, and PTWC continued the development of new features in the TsuCAT software and made it available to some of the training participants. TsuCAT v4.3 supports tsunami hazard assessment and tsunami exercises using the PTWC Products; the newest feature adds the option to automatically produce customized exercise injects. http://itic.ioc-unesco.org/index.php?option=com_content&view=category&layout=blog&id=2239&Itemid=2763
- ITIC compiled US and international resources on Marine Preparedness, including for Ports and Harbors. http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=2071&Itemid=2926
- ITIC compiled US and international resources on Vertical Evacuation http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=2070&Itemid=2927
- ITIC is developing online and blended training as an IOC Ocean Teacher Global Academy Specialized Training Center for Tsunamis. Courses available in 2023-2024 will be Tsunami Awareness, Tsunami Ready, and Tsunami Early Warning Systems. http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=2138&Itemid=3207

Tsunami Exercises and Communication Tests

Caribe Wave 2021, 2022 and 2023

Puerto Rico and the US Virgin Islands participated in the CARIBE WAVE 21 exercise on March 19. The scenario chosen was Jamaica. Given the onset of COVID 19 pandemic it was limited to only a communications test between PTWC and the Tsunami Warning Focal Points.

Puerto Rico and the USVI participated in the CARIBE WAVE 2022 exercise on March 10. It was both a domestic and international exercise and consisted of two exercise scenarios (Muertos Trough and Muertos Trough)) for each country to choose from. Puerto Rico and the USVI chose Muertos Trough. The PTWC prepared simulated domestic messages for this scenario, in addition to the international messages. According to TsunamiZone.org, 410,292 people from Bermuda through Brazil were registered to participate;. From Puerto Rico, 117,696 people were registered, while for the USVI, the number was 12,351.

Puerto Rico and the USVI participated in the CARIBE WAVE 2023 exercise on March 23. It was both a domestic and international exercise and consisted of two exercise scenarios (Gulf of Honduras and Mount Pelee) for each country to choose from. Puerto Rico and the USVI chose Mount Pelee. The PTWC prepared simulated domestic messages for this scenario, in addition to the international messages. According to TsunamiZone.org, 421, 486 people from Bermuda through Brazil were registered to participate. From Puerto Rico, 129,844 people were registered, while for the USVI, the number was 17,904.

For both exercises, the PTWC issued one dummy message at the start of the exercise that was followed by the simulated products, which were sent according to the scenario each country had selected. In Puerto Rico and the U.S. Virgin Islands, activities included communication tests, activation of the Emergency Alert System, testing the use of radio operators to disseminate information, and drills. The exercise was coordinated at the regional level by the ICG CARIBE EWS CARIBE WAVE Task Team. The International Tsunami Information Center Caribbean Office served as exercise coordinator, with documentation, website, communication and webinars. Also, all reports and documentation for the exercise are now posted on the website of the International Tsunami Information Center. Locally the exercise was coordinated by the PRSN, the Puerto Rico Emergency Management Bureau, the San Juan Weather Forecast Office, and the Virgin Islands Territorial Emergency Management Agency. PRSN's contribution included providing support and guidance to local stakeholders to participate in the exercise. The University of Southern California supported the TsunamiZone.org registry web tool, which is funded through the National Tsunami Hazard Mitigation Program.

For CARIBE WAVE 24 the US recommends that one of the scenarios be the Puerto Rico Trench. Also the date of the exercise should avoid being on World Meteorologist Day.

The US suggests that the Task Team on Tsunamis from Volcanic Activity continue their work focusing on the sensing, communication and tsunami modeling challenges.

Communication Tests

- PTWC's communication tests with Puerto Rico and the Virgin Islands were suspended during the intersessional period due to problems with third-party distributors of tsunami alerts that inadvertently sent out a tsunami warning in response to a US NTWC communication test. This problem is being addressed by mandating a change to the VTEC codes used in the U.S. NTWC has resumed test messages, and PTWC is considering renewing monthly tests with Puerto Rico and the Virgin Islands stakeholders.
- Puerto Rico and the U.S. Virgin Islands participated in international tsunami communication tests with PTWC.
- Puerto Rico Seismic Network has implemented a local monthly test.

- Puerto Rico municipalities conduct a silent test of its sirens every first Wednesday of the month and audible test on the last Wednesday of every month.
- USVI holds weekly meetings to review the status of its siren systems and coordination of communication tests.

END

Appendix A: *Seismic stations operated by the PRSN and the USGS in the CARIBE_EWS*

Location	Latitude	Longitude	Net_Stat	Sensors	Status*
Anegada, British Virgin Islands	18.73 N	64.33 W	ABVI	Velocity + Acceleration + GPS	No Comms.
Tortola, British Virgin Islands	18.42 N	64.62 W	TBVI	Velocity + Acceleration	No Comms.
Virgin Gorda, British Virgin Islands	18.49 N	64.40 W	VGBI	Velocity + Acceleration + GNSS	No Comms.
Aguadilla, Puerto Rico	18.47 N	67.11 W	AGPR	Velocity + Acceleration + GNSS	Ok
Arecibo, Puerto Rico	18.35 N	66.75 W	AOPR	Velocity + Acceleration + GNSS	Ok
St. Croix, U.S. Virgin Islands	17.75 N	64.77 W	CDVI	Velocity + Acceleration + GPS (CORS)	Ok.
Cerillos Dam, Ponce, Puerto Rico	18.07 N	66.58 W	CELP	Velocity + Acceleration	Ok
Cabo Rojo, Puerto Rico	18.01 N	67.11 W	CRPR	Velocity + Acceleration + GNSS	Ok
Culebra, Puerto Rico	18.31 N	65.281 W	CUPR	Velocity + Acceleration + GNSS	Ok
Manati, Puerto Rico	18.48 N	66.53 W	EMPR	Velocity + Acceleration + GNSS	Ok
Guanica, Puerto Rico	17.98 N	66.88 W	GBPR	Velocity	Ok
Guaynabo, Puerto Rico	18.31 N	66.08 W	GCPR	Velocity + Acceleration	Ok
Humacao, Puerto Rico	18.14 N	65.86 W	HUMP	Velocity + Acceleration + GPS	Ok
Isla Caja de Muertos, Puerto Rico	17.89 N	66.53 W	ICMP	Velocity + Acceleration + GNSS	OK
Isla Desecheo, Puerto Rico	18.39 N	67.47 W	IDE	Velocity	Ok
Guayama, Puerto Rico	17.97 N	66.11 W	IGPR	Velocity + Acceleration + GNSS	Ok
Isla Mona, Puerto Rico	18.08 N	67.93 W	IMPR	Velocity + Acceleration + GNSS	OK.

Mayagüez, Puerto Rico	18.18 N	67.09 W	LSP	Velocity	Ok
Lajas, Puerto Rico	17.97 N	67.04 W	MLPR	Velocity + Acceleration + GNSS	Ok
Vieques, Puerto Rico	18.10 N	65.55 W	MTP	Velocity + Acceleration	Ok..
Obispado, Ponce, Puerto Rico	18.04 N	66.61 W	OBIP	Velocity + Acceleration	Ok
Patillas, Puerto Rico	18.02 N	66.02 W	PDPR	Velocity + Acceleration + GNSS	Ok
U Puerto Rico Mayagüez, Puerto Rico	18.22 N	67.14 W	PRSN	Velocity + Acceleration + GNSS	Ok
St. John, U.S. Virgin Islands	18.33 N	64.77 W	SJVI	Velocity + Acceleration	Ok.
St. Thomas, U.S. Virgin Islands	18.35 N	64.96 W	STVI	Velocity + Acceleration + GPS	Ok.
Utuado, Puerto Rico	18.25 N	66.72 W	UUPR	Velocity + Acceleration	Ok
Corozal, Puerto Rico	18.32 N	66.36 W	ECPR	Velocity + Acceleration + GNSS	Ok.
Ceiba, Puerto Rico	18.22 N	65.666 W	FAPR	Strong Motion Seismometer	Ok
Punta Cana, Dominican Republic	18.51 N	68.38 W	PCDR	Velocity + Acceleration	Ok
Miches, Dominican Republic	18.98 N	69.05 W	MIDR	Velocity + Acceleration	Ok
Samana, Dominican Republic	19.29 N	69.19 W	SMDR	Velocity + Acceleration	Ok
Isla Saona, Dominican Republic	18.19 N	68.78 W	SADR	Velocity + Acceleration	Ok
North Barbuda Island	17.67N	61.79 W	ANWB	Velocity	Ok
Gun Hill	13.14 N	59.56 W	BBGH	Velocity	Ok
Isla Barro Colorado	9.17 N	79.83W	BCIP	Velocity	Ok
Grand Turk	21.51 N	71.13W	GRTK	Velocity	Ok
Grenville	12.13N	61.65 W	GRGR	Velocity	Ok

Guantanamo Bay	19.23N	75.11 W	GTBY	Velocity	Ok
Mount Denham, Jamaica	18.23N	77.53W	MTDJ	Velocity	Ok
Presa de Sabenta, Dominican Republic	18.98N	71.29W	SDDR	Velocity	Ok
Tegucigalpa	14.06N	87.27W	TGUH	Velocity	Ok
Albuquerque	34.95N	106.46W	ANMO	Velocity	Ok
Ankara	39.87N	32.79E	ANTO	Velocity	Ok
Bermuda Institute of Ocean Sciences	32.37N	64.70W	BBSR	Velocity	Ok
Disney Wilderness Preserve	28.11N	81.43W	DWPF	Velocity	Ok
	29.96N	95.84W	HKT	Velocity	Ok
Kilima Mbogo	1.13S	37.25E	KMBO	Velocity	Ok
Kongsberg	59.65N	9.59E	KONO	Velocity	Ok
Las Campanas Astronomical Observatory	29.01S	70.70W	LCO	Velocity	Ok
Lusaka	15.28S	28.19E	LSZ	Velocity	Ok
Otavalo	0.24N	78.45W	OTAV	Velocity	Ok
San Pablo	39.54N	4.35W	PAB	Velocity	Ok
Puerto Ayora	0.67S	90.29W	PAYG	Velocity	Ok
Palmer Station	64.77S	64.05W	PMSA	Velocity	Ok
Pohakuloa	19.75N	155.53W	POHA	Velocity	Ok
Riachuelo	5.83S	35.90W	RCBR	Velocity	Ok
Samuel	8.95S	63.18W	SAML	Velocity	Ok

Santo Domingo	8.88N	70.63W	SDV	Velocity	Ok
Sondre Stromfjord	67.00N	50.62W	SFJD	Velocity	Ok
San Juan	18.11N	66.15W	SJG	Velocity	Ok
Sierra la Laguna Baja California Sur	23.69N	109.94W	SLBS	Velocity	Ok
Standing Stone	40.64N	77.89W	SSPA	Velocity	Ok
Tepich	20.23N	88.28W	TEIG	Velocity	Ok
	37.07S	12.32W	TRIS	Velocity	Ok
Tucson	32.31N	110.78W	TUC	Velocity	Ok
Waverly	36.13N	87.83W	WVT	Velocity	Ok