NATIONAL REPORT
Submitted by United States

BASIC INFORMATION

1. ICG/CARIBE EWS Tsunami National Contact (TNC)

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2. ICG/CARIBE EWS Tsunami Warning Focal Point (TWFP)

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   Name:
   Title: Acting Commissioner
   Responsible Organization: Puerto Rico Bureau for Emergency Management
   Postal Address: P.O. Box 194140, San Juan, Puerto Rico 00919-4140 USA
   E-mail Address: 
   Emergency Telephone Number:
   Office Telephone Number:
   Emergency Fax Number:
   Emergency Cellular Telephone Number:

   Tsunami Warning Focal Point (TWFP)—Puerto Rico (Alternates)
   Name:
   Title: Meteorologist in Charge
   Responsible Organization: National Oceanic and Atmospheric Administration/National Weather Service/San Juan Weather Forecast Office
   Postal Address: Nº 4000 Road 190, Carolina, Puerto Rico 00979 USA
   E-mail Address:
   Emergency Telephone Number:
   Emergency Fax Number:
   Emergency Cellular Telephone Number:

   Name:
   Title: Interim Director
Responsible Organization: Puerto Rico Seismic Network (PRSN)
Postal Address: 259 Boulevard Alfonso Valdés, Building D, University of Puerto Rico at Mayagüez, Mayagüez, Puerto Rico 00680 USA
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Emergency Fax Number: +1 787-265-1684
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Tsunami Warning Focal Point (TWFP)—Virgin Islands

Name:
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Postal Address: 2164 King Cross Street, Christiansted, Virgin Islands 00820 USA
E-mail Address:
Emergency Telephone Number:
Emergency Fax Number:
Emergency Cellular Telephone Number:

National Tsunami Warning Centre
Person in Charge:
Title: Director
Responsible Organization: National Oceanic and Atmospheric Administration/National Weather Service/Pacific Tsunami Warning Center (PTWC)
Postal Address: 1845 Wasp Boulevard, Building 176, Honolulu, Hawaii 96818 USA
E-mail Address:
Emergency Telephone Number:
Emergency Fax Number:
Emergency Cellular Telephone Number:

Backup
Person in Charge:
Title: Director
Responsible Organization: National Oceanic and Atmospheric Administration/National Weather Service/National Tsunami Warning Center (NTWC)
Postal Address: 910 S. Felton Street, Palmer, Alaska 99645 USA
E-mail Address:
Emergency Telephone Number:
Emergency Fax Number:

3. **Tsunami Advisor(s), if applicable**

Name: Christa G. von Hillebrandt-Andrade
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E-mail Address:
Emergency Telephone Number:
Emergency Fax Number:
Emergency Cellular Telephone Number:

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 is the Tsunami Service Provider for CARIBE EWS Member States, by agreement and in coordination with the Tsunami Program of the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific, and Cultural Organization (UNESCO/IOC) as well as with the Intergovernmental Coordination Group for the CARIBE EWS. Domestically, PTWC provides tsunami alert services for Puerto Rico and the U.S. and British Virgin Islands. The U.S. National Tsunami Warning Center (NTWC) in Alaska, which serves the continental United States, Alaska, and Canada is PTWC’s backup.

While PTWC is the primary tsunami warning center for Puerto Rico and the Virgin Islands and is the Tsunami Service Provider for CARIBE EWS, 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 NTWC products are always the same. These responsibilities in the Caribbean/Atlantic Region are as follows:

- NTWC is the authoritative source for the preliminary parameters of earthquakes north of 23.5 degrees north latitude and in the Gulf of Mexico.
- PTWC is the authoritative source for the preliminary parameters of earthquakes in all other areas of the Caribbean and Atlantic Region.

**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 and the distance of the earthquake from Puerto Rico and the Virgin Islands in terms of tsunami travel time or kilometers.

**Puerto Rico and the Virgin Islands**

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>
<thead>
<tr>
<th>Earthquake</th>
<th>Alert Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea</td>
<td>Land</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Yes</td>
<td>Near Sea</td>
</tr>
<tr>
<td>Yes</td>
<td>Near Sea</td>
</tr>
</tbody>
</table>


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 text products for Puerto Rico/Virgin Islands nearby Caribbean-region earthquakes**
Earthquake Alert Level

<table>
<thead>
<tr>
<th>Source Location</th>
<th>Depth</th>
<th>Magnitude</th>
<th>Alert Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within 186 miles (300 km) of Puerto Rico/Virgin Islands</td>
<td>&lt; 62 miles (100 km)</td>
<td>≥ 7.1</td>
<td>Warning</td>
</tr>
<tr>
<td></td>
<td>&lt; 62 miles (100 km)</td>
<td>6.5–7.0</td>
<td>Advisory</td>
</tr>
<tr>
<td>Between 186 miles (300 km) and 621 miles (1000 km) of Puerto Rico/Virgin Islands</td>
<td>&lt; 62 miles (100 km)</td>
<td>≥ 7.6</td>
<td>Warning</td>
</tr>
<tr>
<td></td>
<td>&lt; 62 miles (100 km)</td>
<td>7.1–7.5</td>
<td>Advisory</td>
</tr>
<tr>
<td>&gt; 621 miles (1000 km) of Puerto Rico/Virgin Islands</td>
<td>&lt; 62 miles (100 km)</td>
<td>≥ 7.9</td>
<td>Warning</td>
</tr>
<tr>
<td></td>
<td>&lt; 62 miles (100 km)</td>
<td>7.6–7.8</td>
<td>Advisory</td>
</tr>
</tbody>
</table>

Notes:
- If the earthquake has a preliminary depth less than 62 miles (100 km) with a preliminary magnitude of 6.5 or greater but does not meet any of the 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.


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.

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

<table>
<thead>
<tr>
<th>Maximum Expected Rise of Sea Level above the Tide</th>
<th>Alert Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–1 feet (0–0.3 m)</td>
<td>None</td>
</tr>
<tr>
<td>1–3.3 feet (0.3–1 m)</td>
<td>Advisory</td>
</tr>
<tr>
<td>&gt; 3.3 feet (&gt; 1 m)</td>
<td>Warning</td>
</tr>
</tbody>
</table>


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 State Emergency Management Agency (Tsunami Warning Focal Point)
- U.S. National Weather Service San Juan, Puerto Rico, Weather Forecast Office (Tsunami Warning Focal Point, Alternate)
- Puerto Rico Seismic Network (Tsunami Warning Focal Point, Alternate)
- Virgin Islands Territorial Emergency Management Agency (Tsunami Warning Focal Point)
- British Virgin Islands Department of Disaster Management (Tsunami Warning Focal Point)
- British Royal Police Force (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

Puerto Rico and the Virgin Islands

- As Tsunami Warning Focal Points, the Puerto Rico State Emergency Management Agency 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.
- 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 Tsunami Warning Program (CTWP) may also interpret and re-disseminate tsunami information.
Communication Testing
Communication methods for message dissemination from PTWC to the Tsunami Warning Focal Points are tested approximately monthly. PTWC also does one unannounced test annually and also as part of CARIBE WAVE annual tsunami exercise. PRSN also tests communication lines monthly and annually as part of the ShakeOut earthquake exercise.

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 USNTWC during the intersessional period?

There were no warnings for U.S. coasts issued by PTWC or USNTWC 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 San Diego (IDA), and the Incorporated Research Institute for Seismology (IRIS). 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 network (PRSMP), monitors the seismic activity in Puerto Rico and the U.S. and British Virgins Islands. The stations operated by the PR network includes 40 ground motion stations (28 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 GPS displacement sensors.

- In response to the damage caused by 2017 hurricanes, USGS ASL is working with PRSN on upgrading a total of 25 seismic stations. Each site will have new sensors (broadband seismometer and accelerometer), digitizers, and solar power backups. Twelve (12) of these sites will have VSAT connections to PRSN and NEIC so that if the island wide power and internet go down again, there will still be monitoring capability. To date, two stations were improved with the new equipment (Mayaguez/PRSN and Lajas/MLPR), the next to go is in Arecibo (AOPR).

Table 4. Seismic stations operated by the PRSN in Puerto Rico and the Virgin Islands

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Net_Stat</th>
<th>Sensors</th>
<th>Status*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anegada, British Virgin Islands</td>
<td>18.73 N</td>
<td>64.33 W</td>
<td>ABVI</td>
<td>Velocity + Acceleration + GPS</td>
<td>No Comms.</td>
</tr>
<tr>
<td>Tortola, British Virgin Islands</td>
<td>18.42 N</td>
<td>64.62 W</td>
<td>TBVI</td>
<td>Velocity</td>
<td>No Comms.</td>
</tr>
<tr>
<td>Virgin Gorda, British Virgin Islands</td>
<td>18.49 N</td>
<td>64.40 W</td>
<td>VGBI</td>
<td>Velocity + Acceleration + GPS</td>
<td>No Comms.</td>
</tr>
<tr>
<td>Aguadilla, Puerto Rico</td>
<td>18.47 N</td>
<td>67.11 W</td>
<td>AGPR</td>
<td>Velocity + Acceleration + GPS</td>
<td>Ok</td>
</tr>
<tr>
<td>Arecibo, Puerto Rico</td>
<td>18.35 N</td>
<td>66.75 W</td>
<td>AOPR</td>
<td>Velocity + Acceleration + GPS</td>
<td>Ok</td>
</tr>
<tr>
<td>Canobanas, Puerto Rico</td>
<td>18.27 N</td>
<td>65.86 W</td>
<td>CBYP</td>
<td>Velocity + Acceleration</td>
<td>Removed</td>
</tr>
<tr>
<td>St. Croix, U.S. Virgin Islands</td>
<td>17.75 N</td>
<td>64.77 W</td>
<td>CDVI</td>
<td>Velocity + Acceleration</td>
<td>No Comms.</td>
</tr>
<tr>
<td>Ponce, Puerto Rico</td>
<td>18.07 N</td>
<td>66.58 W</td>
<td>CELP</td>
<td>Velocity + GPS</td>
<td>Ok</td>
</tr>
<tr>
<td>Cabo Rojo, Puerto Rico</td>
<td>18.01 N</td>
<td>67.11 W</td>
<td>CRPR</td>
<td>Velocity + Acceleration</td>
<td>Ok</td>
</tr>
<tr>
<td>Culebra, Puerto Rico</td>
<td>18.31 N</td>
<td>65.281 W</td>
<td>CUPR</td>
<td>Velocity + Acceleration</td>
<td>No comms</td>
</tr>
<tr>
<td>Manati, Puerto Rico</td>
<td>18.48 N</td>
<td>66.53 W</td>
<td>EMPR</td>
<td>Velocity + Acceleration + GPS</td>
<td>Ok</td>
</tr>
<tr>
<td>Guanica, Puerto Rico</td>
<td>17.98 N</td>
<td>66.88 W</td>
<td>GBPR</td>
<td>Velocity</td>
<td>Ok</td>
</tr>
<tr>
<td>Location</td>
<td>Latitude</td>
<td>Longitude</td>
<td>Station Type</td>
<td>Data Quality</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>-----------</td>
<td>-----------</td>
<td>--------------</td>
<td>--------------</td>
<td></td>
</tr>
<tr>
<td>Guaynabo, Puerto Rico</td>
<td>18.31 N</td>
<td>66.08 W</td>
<td>GCPR</td>
<td>Velocity + Acceleration Ok</td>
<td></td>
</tr>
<tr>
<td>Humacao, Puerto Rico</td>
<td>18.14 N</td>
<td>65.86 W</td>
<td>HUMP</td>
<td>Velocity + Acceleration + GPS Ok</td>
<td></td>
</tr>
<tr>
<td>Isla Caja de Muertos, Puerto Rico</td>
<td>17.89 N</td>
<td>66.53 W</td>
<td>ICMP</td>
<td>Velocity + Acceleration + GPS No Comms.</td>
<td></td>
</tr>
<tr>
<td>Isla Desecheo, Puerto Rico</td>
<td>18.39 N</td>
<td>67.47 W</td>
<td>IDE</td>
<td>Velocity Ok</td>
<td></td>
</tr>
<tr>
<td>Guayama, Puerto Rico</td>
<td>17.97 N</td>
<td>66.11 W</td>
<td>IGPR</td>
<td>Velocity + Acceleration + GPS Ok</td>
<td></td>
</tr>
<tr>
<td>Isla Mona, Puerto Rico</td>
<td>18.08 N</td>
<td>67.93 W</td>
<td>IMPR</td>
<td>Velocity + Acceleration + GPS No Comms.</td>
<td></td>
</tr>
<tr>
<td>Mayaguez, Puerto Rico</td>
<td>18.18 N</td>
<td>67.09 W</td>
<td>LSP</td>
<td>Velocity Ok</td>
<td></td>
</tr>
<tr>
<td>Lajas, Puerto Rico</td>
<td>17.97 N</td>
<td>67.04 W</td>
<td>MLPR</td>
<td>Velocity + Acceleration Ok</td>
<td></td>
</tr>
<tr>
<td>Vieques, Puerto Rico</td>
<td>18.10 N</td>
<td>65.55 W</td>
<td>MTP</td>
<td>Velocity + Acceleration No Comms.</td>
<td></td>
</tr>
<tr>
<td>Obispado, Ponce, Puerto Rico</td>
<td>18.04 N</td>
<td>66.61 W</td>
<td>OBIP</td>
<td>Velocity Ok</td>
<td></td>
</tr>
<tr>
<td>Patillas, Puerto Rico</td>
<td>18.02 N</td>
<td>66.02 W</td>
<td>PDPR</td>
<td>Velocity + Acceleration + GPS Ok</td>
<td></td>
</tr>
<tr>
<td>Puerto Rico</td>
<td>18.22 N</td>
<td>67.14 W</td>
<td>PRSN</td>
<td>Velocity + Acceleration + GPS Ok</td>
<td></td>
</tr>
<tr>
<td>St. John, U.S. Virgin Islands</td>
<td>18.33 N</td>
<td>64.77 W</td>
<td>SJVI</td>
<td>Velocity + Acceleration No Comms.</td>
<td></td>
</tr>
<tr>
<td>St. Thomas, U.S. Virgin Islands</td>
<td>18.35 N</td>
<td>64.96 W</td>
<td>STVI</td>
<td>Velocity + Acceleration + GPS No Comms.</td>
<td></td>
</tr>
<tr>
<td>Utuado, Puerto Rico</td>
<td>18.25 N</td>
<td>66.72 W</td>
<td>UUPR</td>
<td>Velocity + Acceleration Ok</td>
<td></td>
</tr>
<tr>
<td>Corozal, Puerto Rico</td>
<td>18.32 N</td>
<td>66.36 W</td>
<td>ECPR</td>
<td>Velocity + Acceleration Ok</td>
<td></td>
</tr>
</tbody>
</table>

* Status as of April 12, 2018

**Figure 3.** Distribution of stations operated by the PRSN in Puerto Rico and the Virgin Islands. Black triangles represent the broadband or intermediate sensors, white triangles are the short periods, and gray triangles are the free-field accelerometers. Due to damage from Hurricane Maria, plans are in place to upgrade the backbone stations (green squares) to include VSAT terminals and reinforce the structure of each station. Red circles indicate where stations will be moved or newly installed.

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 catalogued 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/](https://www.ngdc.noaa.gov/hazard/tide/).
- The University of Hawaii Sea Level Center operates 10 stations in the region. These stations have a primary and backup sensor and are typically operated for a specific application. Most stations sample at 1 sample per minute. Data is sent over GOES-East with a five-minute transmission interval.
- With support from NOAA and the government of Puerto Rico, the PRSN operates six stations in Puerto Rico. These stations are NWLon-compliant and transmit data every six minutes over GOES-East. Of the six stations, three are operational and three are waiting for repairs, some include major civil construction to repair the piers. With NOAA funds, the PRSN also supports the operations of four other stations in the region (Dominican Republic, Haiti, and the British Virgin Islands), of these only Barahona (Dominican Republic) is operational, and the other stations are under maintenance/repair.
- The Smithsonian Institution has installed, operates, and maintains two tsunami-capable water-level stations in Belize and Panama that transmit data every five minutes.
- 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.

**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 Data Assembly 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](image)

Table 5: U.S.-operated sea level stations in Caribbean and adjacent regions

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Status*</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coastal Water-Level Stations**</td>
<td>Latitude</td>
<td>Longitude</td>
<td>Status</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------</td>
<td>-----------</td>
<td>-----------------</td>
<td></td>
</tr>
<tr>
<td>Christiansted Harbor, St. Croix, U.S. Virgin Islands</td>
<td>17.75 N</td>
<td>64.70 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Lime Tree Bay, St. Croix, U.S. Virgin Islands</td>
<td>17.70 N</td>
<td>64.75 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Lameshur Bay, St. John, U.S. Virgin Islands</td>
<td>18.32 N</td>
<td>64.72 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Charlotte Amalie, St. Thomas, U.S. Virgin Islands</td>
<td>18.34 N</td>
<td>64.92 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Culebra, Puerto Rico</td>
<td>18.30 N</td>
<td>65.30 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Esperanza, Vieques Island, Puerto Rico</td>
<td>18.09 N</td>
<td>65.47 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Magueyes Island, Puerto Rico</td>
<td>17.97 N</td>
<td>67.06 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Mayagüez, Puerto Rico</td>
<td>18.22 N</td>
<td>67.16 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Mona Island, Puerto Rico</td>
<td>18.09 N</td>
<td>67.94 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>San Juan, La Puntilla, San Juan Bay, Puerto Rico</td>
<td>18.46 N</td>
<td>66.12 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Bermuda, Ferry Reach Channel</td>
<td>32.37 N</td>
<td>64.70 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>San Andres, Colombia</td>
<td>12.58 N</td>
<td>81.70 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Santa Marta, Colombia</td>
<td>11.24 N</td>
<td>74.22 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Limón, Costa Rica</td>
<td>9.99 N</td>
<td>83.02 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Bullen Bay, Curacao</td>
<td>12.19 N</td>
<td>69.02 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Roseau, Dominica</td>
<td>15.31 N</td>
<td>61.39 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Puerto Plata, Dominican Republic</td>
<td>19.80 N</td>
<td>70.70 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Punta Cana, Dominican Republic</td>
<td>18.51 N</td>
<td>68.38 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Prickly Bay, Grenada</td>
<td>12.01 N</td>
<td>61.77 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>El Porvenir, Panama</td>
<td>9.56 N</td>
<td>78.95 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Settlement Point, Bahamas</td>
<td>26.69 N</td>
<td>78.98 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Aguadilla, Puerto Rico</td>
<td>18.46 N</td>
<td>67.16 W</td>
<td>Needs Replacement</td>
<td></td>
</tr>
<tr>
<td>Arecibo, Puerto Rico</td>
<td>18.48 N</td>
<td>66.70 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Caja de Muertos, Puerto Rico</td>
<td>17.89 N</td>
<td>66.53 W</td>
<td>Destroyed and will be relocated to Salinas</td>
<td></td>
</tr>
<tr>
<td>Fajardo, Puerto Rico</td>
<td>18.33 N</td>
<td>65.63 W</td>
<td>Under Maintenance/Repair Relocation in process</td>
<td></td>
</tr>
<tr>
<td>Isabel Segunda, Vieques Island, Puerto Rico</td>
<td>18.15 N</td>
<td>65.44 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Yabucoa Harbor, Puerto Rico</td>
<td>18.06 N</td>
<td>65.84 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Tortola, British Virgin Islands</td>
<td>18.42 N</td>
<td>64.61 W</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Barahona, Dominican Republic</td>
<td>18.21 N</td>
<td>71.09 W</td>
<td>Fully Operational</td>
<td></td>
</tr>
<tr>
<td>Puerto Caucedo, Dominican Republic</td>
<td>18.42 N</td>
<td>69.63 W</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Cap-Haitien, Haiti</td>
<td>19.76 N</td>
<td>72.19 W</td>
<td>Radar Operational, Pressure Sensor</td>
<td></td>
</tr>
</tbody>
</table>

---

1. NOAA/Center for Operational Oceanographic Products and Services

2. University of Hawaii Sea Level Center

3. Puerto Rico Seismic Network
<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Status Details</th>
<th>Responsible Party</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bocas del Toro, Panama</td>
<td>9.35 N</td>
<td>82.26 W</td>
<td>Fully Operational</td>
<td>Smithsonian Institution</td>
</tr>
<tr>
<td>Carrie Bow Cay off Belize</td>
<td>16.80 N</td>
<td>88.08 W</td>
<td>Pressure Sensor Operational, Radar not Operational</td>
<td>UNAVCO, Inc.</td>
</tr>
<tr>
<td>Puerto Morelos, Mexico</td>
<td>20.87 N</td>
<td>86.87 W</td>
<td>Radar Operational, Pressure Sensor Not Operational</td>
<td>NOA/National Data Buoy Center</td>
</tr>
<tr>
<td>Port Royal, Jamaica</td>
<td>17.93 N</td>
<td>76.85 W</td>
<td>Radar Operational, Pressure Sensor Not Operational</td>
<td>UNAVCO, Inc.</td>
</tr>
</tbody>
</table>

**Deep-ocean Assessment and Reporting of Tsunami Systems**

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Status Details</th>
<th>Responsible Party</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Puerto Rico—230 nautical miles southwest of San Juan, Puerto Rico (42407)</td>
<td>15.25 N</td>
<td>68.22 W</td>
<td>Under Maintenance/Repair</td>
<td>UNAVCO, Inc.</td>
</tr>
<tr>
<td>North Santo Domingo—328 nautical miles north northeast of Santo Domingo, Dominican Republic (41420)</td>
<td>23.43 N</td>
<td>67.31 W</td>
<td>Adrift, Plans to Reestablish</td>
<td>UNAVCO, Inc.</td>
</tr>
<tr>
<td>North St. Thomas—300 nautical miles north of St Thomas, Virgin Islands (41421)</td>
<td>23.41 N</td>
<td>63.78 W</td>
<td>Fully Operational</td>
<td>NOA/National Data Buoy Center</td>
</tr>
<tr>
<td>Southwest Bermuda—200 nautical miles south southwest of Hamilton, Bermuda (41425)</td>
<td>28.63 N</td>
<td>65.65 W</td>
<td>Fully Operational</td>
<td>NOA/National Data Buoy Center</td>
</tr>
<tr>
<td>Southeast Block Canyon—130 nautical miles southeast of Fire Island, New York (44402)</td>
<td>39.30 N</td>
<td>70.66 W</td>
<td>Fully Operational</td>
<td>NOA/National Data Buoy Center</td>
</tr>
<tr>
<td>Northeast Castle Rock Seamount—620 nautical miles south of St. John's Newfoundland, Canada (44401)</td>
<td>37.59 N</td>
<td>50.03 W</td>
<td>To Be Relocated near Sable Island Bank</td>
<td>NOA/National Data Buoy Center</td>
</tr>
<tr>
<td>Gulf of Mexico—247 nautical miles south of New Orleans, Louisiana (42409)</td>
<td>25.85 N</td>
<td>89.25 W</td>
<td>Fully Operational</td>
<td>NOA/National Data Buoy Center</td>
</tr>
</tbody>
</table>

* Status as of April 12, 2019
** 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 modelling 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 UNAVCO, NOAA, and the PRSN.
Table 6. U.S.-operated GNSS Networks in the Caribbean and adjacent regions.

<table>
<thead>
<tr>
<th>GNSS Network Name</th>
<th>Region</th>
<th>Number of GNSS stations</th>
<th>Number of Stations Providing 1-Hz Data Streams in Real Time to Enhance Caribbean Tsunami Early Warning</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network of the Americas (NOTA)</td>
<td>U.S./Alaska/Caribbean/Me xico</td>
<td>1255</td>
<td>67</td>
<td>UNAVCO, Inc.</td>
</tr>
<tr>
<td>PRSN</td>
<td>Puerto Rico/Virgin Islands</td>
<td>16</td>
<td>16</td>
<td>Puerto Rico Seismic Network</td>
</tr>
<tr>
<td>CORS</td>
<td>Worldwide</td>
<td>42 stations: 3 in Caribbean region</td>
<td>0</td>
<td>National Geodetic Survey (NOAA)</td>
</tr>
</tbody>
</table>

UNAVCO Contribution: The Network of the Americas

UNAVCO, a non-profit university-governed consortium funded by the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA), 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 new, 5-year cooperative agreement (Geodesy Advancing Geosciences - GAGE) Facility which started Oct. 1, 2018 and will continue through Sep. 30, 2023. Most of the RT-GNSS resources that national, regional, or state EEW and TEWS will use once fully operational, are cGNSS assets that were funded primarily by the NSF through the EarthScope and GAGE Facility CAs. UNAVCO has recently received funding through USGS as part of the ShakeAlert program to upgrade and modernize a subset of Network of the Americas cGNSS stations in Northern California, Oregon, and Washington.

UNAVCO has tested real-time algorithms to determine Peak Ground Displacement (PGD) from RT-GNSS position estimates. 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.

The construction phase of NOTA is finished, with stations producing high-quality, low-latency GNSS data and data products from 1,255 continuously operating GNSS stations, over 850 of which provide both 1-Hz raw data and ambiguity-resolved precise point positions in real time, which are necessary for tsunami early warning. Sixty-seven of these real-time stations are located in the Caribbean basin (Figure 5). In order to meet budgetary constraints for NOTA, UNAVCO is developing a plan to decommission up to 130 GNSS stations that are poorly performing, redundant, expensive to maintain, of limited scientific value, or stations that can be turned over to another organization for continued operations and maintenance.

Puerto Rico Seismic Network Contribution

The PRSN also operates a GPS (Global Positioning System) network of 16 real-time/high-rate stations funded by NSF, of those, nine R9 are being updated to receive GNSS (glonass and galileo) constellations, two new alloy receivers were acquired. 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. One PRSN station receives 1-Hz position corrections through Trimble’s RTX service, that station is now serving RT data into the central earthworm server.

At the PRSN, continuous data are simultaneously logged to three sessions with different sampling rate 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 either through the PRSN FTP server or UNAVCO's Data Archive. Real-time data is also available through a dedicated NTRIP caster. A new Earthworm module is active receiving the RTX (corrected) positions from PRSN site to the central seismic software for visualization of displacegrams from the 1-Hz positions.

8. Information on Tsunami Occurrences/Tsunami Exercises

Since the last report in 2018, there were no tsunamis impacting U.S. in the Caribbean region.

Products Issued
Since the last report, PTWC issued Tsunami Information Statements for Puerto Rico and the Virgin Islands for 32 events with magnitudes greater than or equal to 4.0. Several of these earthquakes were large enough to be felt by the public, and numerous associated inquiries were made to the San Juan Weather Forecast Office, the PRSN, and PTWC. None were associated with a tsunami occurrence. PTWC also issued 6 Tsunami Information Statements for Puerto Rico and the Virgin Islands for larger earthquakes in the Caribbean and Atlantic that triggered CARIBE-EWS products.

Exercises
Exercises are discussed in the narrative.

9. Websites (URLs) of National Tsunami-related Websites

General Resources
- U.S. Tsunami Warning System: [https://www.tsunami.gov](https://www.tsunami.gov)
- Caribbean Tsunami Warning Program (CTWP): [http://caribewave.info](http://caribewave.info)
- International Tsunami Information Center (ITIC): [http://www.tsunamiwave.org](http://www.tsunamiwave.org); [http://itic.ioc-unesco.org](http://itic.ioc-unesco.org)
- National Centers for Environmental Information (NCEI) Tsunami Data and Information: [https://www.ngdc.noaa.gov/hazard/tsu.shtml](https://www.ngdc.noaa.gov/hazard/tsu.shtml)
- NOAA Pacific Marine Environmental Laboratory (PMEL): [https://nctr.pmel.noaa.gov/index.html](https://nctr.pmel.noaa.gov/index.html)

Warning Center User’s Guides

Seismic Information
- Advanced National Seismic System (ANSS):
https://earthquake.usgs.gov/monitoring/anss/
● Caribbean Tsunami Warning Program (CTWP) (Data Availability Reports)
   http://caribewave.info
● Puerto Rico Seismic Network (PRSN):
   http://redsismica.uprm.edu
● IRIS CARIBE EWS Virtual Seismic Network:
   http://ds.iris.edu/gmap/#network=_CARIBE_EWS&planet=earth
● IRIS Data Management Center (DMC)
   https://ds.iris.edu/ds/nodes/dmc/
● USGS California Integrated Seismic Network (CISN) real-time Earthquake Monitoring Display,
   with PTWC and NTWC tsunami message links, Information

Sea Level Tools/Information
● Tide Tool:
● Caribbean Sea Level Stations Reports and Maps:
  http://caribewave.info
● NOAA Center for Operational Oceanographic Products and Services Tsunami-Capable Coastal Water-Level Stations:
  https://co-ops.nos.noaa.gov/tsunami/
● National Data Buoy Center (NDBC) DART Program:
  http://www.ndbc.noaa.gov/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 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 of Future Tsunami Warning and Mitigation System Improvements

● The United States continues to work toward a near-real-time, fully dynamic tsunami source characterization 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, deep ocean and coastal sea-level readings, and offset data provided by GNSS networks for analysis at the US tsunami warning centers.
  ○ 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. We expect an initial operational capability to be fielded at NOAA’s Tsunami Warning Centers by 2020. The funding for the operation of UNAVCO’s GNSS Network of the Americas will end at the end of fiscal year 2018. Funding for the continued operation and maintenance of these networks has been requested in the UNAVCO proposal to NSF to operate the geodetic component of the National Geophysical Observatory, which would begin October 1, 2018. To date, there has been no official notification about the status of this proposal. Consequently, there is some uncertainty with regard to future operational capability of the Network of the Americas.
The U.S. National Weather Service is working to develop a common hardware and software infrastructure for PTWC and NTWC to improve and align their seismic and sea level 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 U.S. National Weather Service will continue to improve both the content and graphic depictions on Tsunami.gov to better meet both domestic and international partners’ product and information needs.

DART station 44401, originally located 620 nautical miles south of St John's Newfoundland, Canada, is not currently operational. NDBC intends to relocate this station to 44403 near Sable Island Bank. NDBC plans to repair DART 42407, which is 230 nautical miles southwest of San Juan, Puerto Rico and to reestablish DART 41420, which is located 325 nautical miles north of Santo Domingo, Dominican Republic as part of their regular maintenance and repair schedule this spring.

NOAA and PRSN has restored the majority of the coastal water-level stations affected by the hurricanes of 2017.

Funding from the USGS will support repairing and reinforcing a backbone of seismic stations operated by the PRSN and USGS in the Caribbean with state-of-the-art hurricane-resistant engineering, including more robust telecommunications and data analysis systems.

To improve the seismic monitoring in the northeastern Caribbean, the PRSN will work with the Dominican Republic to install two additional seismic stations and one tsunami-capable tide gauge. Also, a new tsunami-capable tide gauge will be installed on the British Virgin Island of Anegada.

Following testing, the PRSN will release 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.

In 2018, NCEI made public the Caribbean and Adjacent Regions Tsunami Sources and Models (CATSAM) map viewer.

The USGS plans to begin the process to update the Seismic Hazard Map for Puerto Rico and the U.S. Virgin Islands in 2019.

In 2018, NCEI provided the digital elevation model (DEM) of the north shore of Puerto Rico as described in Section 12.

NCEI DEM development for Jamaica (a community on the western side of the island) and Belize (in one community) started in December, 2018 as part of a U.S. Agency for International Development/Office of U.S. Foreign Disaster Assistance (USAID/OFDA)-funded International Tsunami Ready pilot.

PMEL has conducted a Tsunami Hazard Assessment for the Saint Vincent and the Grenadines and has conducted one ComMIT (Community Model Interface for Tsunamis) on the island of Saint Vincent February 25-March 1, 2019, also as part of as part of a U.S. Agency for International Development/Office of U.S. Foreign Disaster Assistance (USAID/OFDA)-funded International Tsunami Ready pilot.

PMEL will conduct an additional ComMIT workshop in Belize, tentatively during the month of April 2019, with participants from Belize, Jamaica, and El Salvador. PMEL will follow up with the participants during the months after the workshop to ensure the completion of tsunami inundation maps for their respective communities.

The International Tsunami Information Center (ITIC) will be hosting its ITIC Training Programme in Hawaii (ITP-Hawaii) in September 2019. Representatives from CARIBE EWS Member States are invited and encouraged to attend. USAID/OFDA funding for the Tsunami Ready project will be used to support trainees from Caribbean.

Two new Tsunami Ready communities, St. Patrick (Grenada) and Fort Liberte (Haiti) were recognized by UNESCO IOC in 2018. Funding was provided by USAID/OFDA thru the CTWP.


USAID/OFDA expects to provide additional funding through the CTWP for additional UNESCO IOC Tsunami Ready pilots in the Caribbean during 2019–2020.
The CTWP and PTWC supported the CARIBE WAVE 2019 exercise and will support the CARIBE WAVE 2020 exercise.

**NATIONAL PROGRAMMES AND ACTIVITIES INFORMATION**

11. Executive Summary

During the last intersessional period, there has been a significant focus on restoring U.S. tsunami detection, forecast, warning, and community alerting capacity in the Caribbean region. Most base-level capabilities have been restored as of April 2019, but some sensing and communication systems remain compromised and will require years of dedicated recovery efforts. The Puerto Rico Seismic Network (PRSN), with the support of the U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA) has embarked on an effort to storm-harden components of the tsunami observation network throughout the Caribbean.

Tsunami forecast and warning operations continued as normal with no alert-level events. The 7.3 Mw earthquake near Venezuela on August 21, 2019 was too far away and too small to result in a Watch, Advisory or Warning to Puerto Rico and the Virgin Islands.

Other key US advancements and developments include:

**Improved tsunami source detection and characterization.** These efforts include:

- Deploying 4th Generation of DART with advanced seismic noise filtering to allow for near-field placement.

- Investigating advanced **geodetic analysis** in tsunami source estimation using GNSS station static offsets. We have strongly supported the effort to establish, maintain, and provide data from GNSS networks to promote this potential application.

- Testing of regional W-phase Centroid Moment Tensor (WCMT) technique to provide earthquake mechanisms and magnitudes 5-10 minutes sooner than the global WCMT currently in use. WCMTs are computed from the seismic waveforms and they drive PTWC international tsunami forecasts through the RIFT model.

- The US is also investigating other emerging tsunami detection capabilities including **ionospheric detection techniques** made possible by the GNSS satellite constellation. This capability is particularly useful when considering non-seismic source tsunamis.

- The US has begun **repositioning tsunameters** in critical regions of the Cascadia subduction zone and Aleutian trench in order to provide quicker and more precise tsunami detection density. NDBC additionally intends to relocate station 44401 which is not operational to 44403 near Sable Island Bank. NDBC plans to repair DART 42407, which is 230 nautical miles southwest of San Juan, Puerto Rico and to reestablish DART 41420, which is located 325 nautical miles north of Santo Domingo, Dominican Republic as part of their regular maintenance and repair schedule during spring 2019.

- The US has led the description of these and other efforts to improve tsunami source characterization in a white paper submission to OceanObs19.

**Improved tsunami forecast capability.** The US will be deploying Version 5 of the Short-term Inundation and Forecasting of Tsunami (SIFT) system in combination with new GPU accelerators at the TWCs. SIFT Version 5 features a CUDA-parallelized version of the tsunami simulation code, MOST that capitalizes on the new computational hardware recently installed at the TWCs. The result is a new SIFT version with enhanced computational capabilities that allows for rapid computation of inundation forecasts within 2-3 minutes, and
will provide SIFT operators with the additional capability of computing deep-water propagation forecasts for any arbitrary source, effectively reducing the dependency on precomputed unit sources. In addition, the new version will feature an improved auto-inversion tool for the estimation of DART-inverted sources as well as the possibility of generating event-summary pages in PDF format for locations for which inundation forecasts are available.

**US TsunamiReady Program.** As of March 2019, the U.S. has 197 coastal communities recognized as TsunamiReady located in 11 states, Puerto Rico, Guam, Commonwealth of the Northern Mariana Islands, and American Samoa.

**International Tsunami Ready.** The CTWP, with support from the U.S. Agency for International Development/Office of U.S. Foreign Disaster Assistance (USAID/OFDA), continues to support the piloting of UNESCO/IOC's International Tsunami Ready recognition program. Both St. Patrick, Grenada, and Fort Liberté, Haiti were recognized in 2018. USAID/OFDA has committed $500,000 to supporting additional UNESCO/IOC Tsunami Ready pilots in Belize, El Salvador, Jamaica, and St. Vincent and the Grenadines during 2018/2019. USAID/OFDA is committed to support additional Tsunami Ready pilots in the Caribbean during 2019-2020. The Caribbean Tsunami Warning Program (CTWP) participated in capacity-building workshops in Grenada and St. Vincent and The Grenadines during the most recent intersessional period.

**International Capacity Building Tools.** NOAA through ITIC and CTWP, in close cooperation with the IOC Tsunami Unit and USAID, has invested over $500KUSD in the past three years to develop a set of community tsunami preparedness tools to assist IOC member states. The tools developed by Tsunami Evacuation Maps, Plans, and Procedures Training Pilot (2015-2017) will be published as a IOC Manual and Guide as a Quick Guide and Supplement in 2019. These tools allow local communities to establish hazard maps, inundation zones and evacuation plans. The U.S. is also assisting IOC member states apply these tools in an effort to pilot an International version of its US TsunamiReady recognition program.

**Enhanced back-up capability.** The US is also working on two projects that should make backup operations between the two U.S. tsunami warning centers more seamless and harmonious. The need to improve this capability became apparent this past year when PTWC had to shut down for three days in anticipation of a strong hurricane forecast to impact Honolulu because it would be a safety risk for any PTWC staff remaining in the Center building.

**Tsunami.gov improvements.** The US Tsunami Program is leading an effort to improve U.S. Tsunami Warning Center’s website (https://tsunami.gov) to make it better organized and easier to navigate by users including the international customers in the PTWS and CARIBE-EWS served by PTWC. When the modifications have reached a suitable level, and after a notification to users through IOC channels, then the old PTWC website (https://ptwc.weather.gov) will be retired.

Caribe Wave '19. Thru CTWP and PTWC the United States supported Caribe Wave 2019 on March 14, 2019. As of March 11, almost 340,000 people were registered from Bermuda thru Brazil on TsunamiZone.org which is also supported by NOAA/NWS. The United States also ensured regular communications paths and tests were maintained and conducted.

**EMWIN** (Emergency Managers Weather Information Network) has been 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.

The **PRSN** significantly enhanced its seismic analysis capability. During the intersessional, the PRSN studied regional implementation of the W-phase seismic analysis technique. Applying this technique in operations will allow the PRSN to determine critical earthquake parameters related to tsunami potential more quickly and accurately. The main processing system will be upgraded to the ANSS base AQMS which will complement the current EarlyBird real time processing.
Digital elevation model (DEM) efforts also advanced during the intersessional period. Of particular note was a major undertaking to construct a series of 10 one-degree DEM tiles along the northern coast of Puerto Rico. This was delivered April 2018. The tiles allow individual components of the DEM to be updated as new data becomes available. Development also began on DEMs for Jamaica and Belize. NCEI has also developed regional DEM for the Antilles funded under NWS/COASTAL Act. Additional DEMs in this region are to be completed within 2019.

Global Historical Tsunami Database Improvements. The Global Historical Tsunami Database includes information on over 2,200 tsunami sources and over 26,000 runups. The tsunami database, maintained by NOAA NCEI and collocated World Data Service for Geophysics, continues to be regularly updated. Further, the tsunami database is undergoing a redesign of the user interface to ensure a more secure platform and enhanced user experience. However, Member States are strongly encouraged to provide edits, updates, and/or new data to be incorporated into the NCEI/WDS global tsunami database, thereby, ensuring completeness.

Tsunami-resistant Design Provisions and Vertical Evacuation. Through the American Society of Civil Engineers (ASCE) in 2016, the US created a new Chapter 6 - Tsunami Loads and Effects for the ASCE 7-16 Standard, applicable to Alaska, Washington, Oregon, California, and Hawaii. It was approved for reference in the International Building Code (IBC) in 2018. The ASCE 7 tsunami provisions apply to design for community planning and resilience before a tsunami event. Many people can be saved in multi-story buildings, and many structures can be designed to withstand tsunami effects. Maps and criteria in the ASCE 7 design standard are based on engineering risk analysis and reliability targets, rather than deterministic scenarios. US States are expected to adopt the IBC 2018 starting in 2020.


Marine Preparedness and Safety Products. Through the US National Tsunami Hazard Mitigation Program (NTHMP), States in cooperation with Federal and Local stakeholders, such as the US Coast Guard and Port Authorities, have begun to develop modeling-based safety products for the evacuation of marine vessels in ports and harbors. The NTHMP is finalizing a Guidebook on Marine Preparedness in 2019. California has developed playbooks for different scenarios and Hawaii has developed threshold tables for PTWC tsunami warning and advisory levels.

12. Narrative

National Tsunami Warnings Procedures or Operations

Hurricane Impacts
Puerto Rico and the U.S. Virgin Islands continue to recover from the impacts of Hurricanes Irma and Maria on its sensing and local dissemination capabilities.

Puerto Rico and the US Virgin Islands are still trying to identify funding to fully restore the siren systems.

Due to the impacts of the hurricanes in 2017, the PRSN, with support from the USGS and NOAA, established a program to storm-harden all components of the regional tsunami monitoring and warning infrastructure.

Warning Center Operations
There were no significant changes to PTWC’s procedures or operations. PTWC issued information statements for Puerto Rico and the Virgin Islands for 32 potentially felt events near Puerto Rico with
magnitudes greater than or equal to 4.0 and for the 6 larger events in the Caribbean and Atlantic that triggered CARIBE-EWS products.

Observation Systems
DART station 44401, originally located 620 nautical miles south of St John's Newfoundland, Canada, is not currently operational. NDBC intends to relocate this station to 44403 near Sable Island Bank. NDBC plans to repair DART 42407, which is 230 nautical miles southwest of San Juan, Puerto Rico and to reestablish DART 41420, which is located 325 nautical miles north of Santo Domingo, Dominican Republic as part of their regular maintenance and repair schedule this spring.

NOAA's GOES-East and GOES-West Transition Impacts on EMWIN
- The transition of the NESDIS GOES-East and GOES-West satellites from GOES-13 and GOES-15, to the next generation satellite (GOES-16 and GOES-17), has been completed. The NWS is now in the process of completing the implementation of the new Enterprise EMWIN ground services necessary to complete the transition of the EMWIN broadcast from the GOES-13 and 15 satellites to the GOES-16 and 17 satellites. The information below provides additional details and schedules for this transition.

The EMWIN Operational Satellite Broadcast and Associated Services.
- The operational EMWIN broadcast (1692.7 MHz) from the GOES-14 satellite at 105°W, and the GOES-15 satellite at 128°W, is scheduled to remain active through July 2019.
- The associate EMWIN ByteBlaster Internet distribution service and EMWIN FTP service provide the same products as the satellite broadcast over the public Internet. These services will be extended to the end of September 2019 to provide a safety net for users having difficulty transitioning to the new HRIT/EMWIN broadcast.
- Users of the GOES-14 broadcast are forewarned that due to operational issues and resource constraints, NESDIS has found it necessary on rare occasions in the past to transition the GOES-14 uplink from the Wallops Command and Data Acquisition Station (CDAS) to the Consolidated Backup Unit (CBU) in West Virginia. When this occurs the EMWIN uplink cannot be sustained and the broadcast stops. The broadcast does resume after the uplink is restored to the Wallops CDAS. The GOES-15 service is not impacted with the uplink transition to the CBU. For this reason, Users are encouraged to use the GOES-15 EMWIN broadcast if possible.

EMWIN on the HRIT/EMWIN Broadcast and the New EMWIN FTP Service.
- The GOES-16 satellite became the operational NESDIS GOES-East satellite at 75.2°W in December 2017. The GOES-17 satellite became the operational NESDIS GOES-West satellite at 137.2°W in February 2019. The EMWIN product stream is provided over both satellites over the HRIT/EMWIN broadcast (1694.1 MHz) Virtual Channel Identifiers (VCIDs) 20, 21, and. Users will need to replace the GOES-14/15 EMWIN receiving systems with new HRIT/EMWIN receiving station hardware and software to demodulate, store and display the product from the HRIT/EMWIN VCIDs.
- A listing of the HRIT/EMWIN virtual channels and their content follows:

<table>
<thead>
<tr>
<th>HRIT/EMWIN Virtual Channel ID</th>
<th>Group</th>
<th>Product Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Imagery</td>
<td>Admin Text Messages</td>
</tr>
<tr>
<td>1</td>
<td>Imagery</td>
<td>Mesoscale 1km (ch. 2, 7, 13)</td>
</tr>
<tr>
<td>2</td>
<td>Imagery</td>
<td>Band 2 - Red</td>
</tr>
<tr>
<td></td>
<td>Imagery</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-----------------</td>
<td>------------------</td>
</tr>
<tr>
<td>3</td>
<td>Imagery</td>
<td>GOES-13 IR</td>
</tr>
<tr>
<td>6</td>
<td>Imagery</td>
<td>GOES-15 IR</td>
</tr>
<tr>
<td>7</td>
<td>Imagery</td>
<td>Band 7 - Shortwave Window</td>
</tr>
<tr>
<td>8</td>
<td>Imagery</td>
<td>Band 8</td>
</tr>
<tr>
<td>9</td>
<td>Imagery</td>
<td>Band 9 - Mid-Level Trop</td>
</tr>
<tr>
<td>13</td>
<td>Imagery</td>
<td>band 13</td>
</tr>
<tr>
<td>14</td>
<td>Imagery</td>
<td>Band 14 - IR</td>
</tr>
<tr>
<td>15</td>
<td>Imagery</td>
<td>Band 15</td>
</tr>
<tr>
<td>20</td>
<td>EMWIN</td>
<td>Priority – Pri 1 &amp; 2 .TXT</td>
</tr>
<tr>
<td>21</td>
<td>EMWIN</td>
<td>Graphics</td>
</tr>
<tr>
<td>22</td>
<td>EMWIN</td>
<td>Other - Pri 3 &amp; 4 .TXT</td>
</tr>
<tr>
<td>23</td>
<td>Imagery</td>
<td>NWS Products</td>
</tr>
<tr>
<td>24</td>
<td>Imagery</td>
<td>NHC Graphics Products</td>
</tr>
<tr>
<td>25</td>
<td>Imagery</td>
<td>GOES-R JPG Products</td>
</tr>
<tr>
<td>26</td>
<td>Imagery</td>
<td>International Graphics Products</td>
</tr>
<tr>
<td>30</td>
<td>DCS</td>
<td>DCS Admin</td>
</tr>
</tbody>
</table>
While the HRIT/EMWIN broadcast is operational on both satellites, products received on the EMWIN channels (VCI#s 20, 21, and 22) are not approved for operational use at this time. Users should avoid using any product received over these channels until the NWS has announced the channels are approved for operational use. The release of the announcement is scheduled to take place by July 2019.

When the EMWIN VCIDs become operational, an associated EMWIN FTP Service will also become available over the public Internet for operational use. The FTP server will not require a user account to access the server and download files. Information on the FTP Service will be made available on the EMWIN web page.

Additional information will be published on the NWS EMWIN web page in the months preceding the operational deployment. Users are encouraged to visit the EMWIN web page periodically for updates: https://www.nws.noaa.gov/emwin/

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

Figure 6. GOES-West (135° W) and GOES-East (75° W) Satellite Coverage (Footprint)

Other
- 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 GPS corrected data messages. These modules are currently being tested.

Tsunami Research Projects

GNSS
- NOAA continued to work with NASA and UNAVCO 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 (Magnitude
from Peak Ground Displacement) earlier than by traditional seismic waveform analysis alone in certain regions. NOAA’s tsunami warning centers do not yet have a means of fully analyzing and incorporating GNSS offset data within operational production systems.

- UNAVCO added three TLALOCNet GNSS stations to its real-time distribution system, resulting in seventy stations now providing high-rate (1 Hz) data streams to users in real time for TLALOCNet and COCONet. The data are processed in real time at UNAVCO using precise point positioning (PPP) algorithms with real-time orbit and clock corrections, and position estimates are broadcast via an NTRIP caster along with the raw data streams. The data are freely available to registered users and demand has grown almost exponentially since 2010.

**Other**

- NCEI is currently developing a new high-resolution DEM of the north shore of Puerto Rico. The DEM will contain 10 one-degree tiles at 1/9 arc-second resolution with the majority of the coastal lidar data collected during the years 2006–2016. DEMs are tiled to enable targeted, rapid updates as new data become available. The DEM will be released in the spring of 2018 and made available from NCEI's thredds data catalog.
- Through the USGS Powell Center, a working group began a project in 2018 that will extend until 2019 to develop a static and GIS database of maximum tsunami generating sources for the U.S. Caribbean for probabilistic tsunami hazard assessments.. A workshop focused on tsunami sources on NE Caribbean will be held in May 2019.
- In addition to archiving and processing preliminary 1-minute water level data from CO-OPS tide gauge stations in the Caribbean, NCEI started archiving preliminary and verified 6-minute, verified highs and lows, verified hourly, and verified monthly mean water levels for these same stations.

**Tsunami Mitigation Activities and Best Practices**

- The National Weather Service renewed TsunamiReady recognition for municipios of Puerto Rico). As a result of the hurricanes, a significant number of tsunami signs were destroyed in Puerto Rico and the U.S. Virgin Islands. The replacement effort is still underway.
- With funding from USAID/OFDA, the CTWP complete UNESCO/IOC Tsunami Ready pilots in St. Patrick, Grenada, and Fort Liberté, Haiti.
- NOAA ITIC and CTWP, and IOC, with USAID support completed the Tsunami Evacuation Maps, Plans Procedures (TEMPP) Pilot Training Project 2017. The IOC Manual and Guide Preparing for Community Tsunami Evacuations: From Inundation to Evacuation Maps, Response Plans, and Exercises has been prepared. The Quick Guide in English and Spanish (hard copy) will be available in April 2019 and the Supplement in English (electronic) in June 2019. It consists of 4 modules: Hazard Assessment-Inundation Modelling, Evacuation Mapping, Response Planning, Exercising, and can be used by CARIBE EWS Member States to achieve the UNESCO IOC Tsunami Ready recognition.
- NCEI and ITIC updated its Global Historical Tsunami, Significant Earthquake, and Significant Volcanic Eruption posters through 2017. 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.
- CTWP conducted a Training Workshop on Pacific Tsunami Warning Center Enhanced Tsunami Products for Grenada in September 2018.
- NCEI and ITIC updated the Historical Tsunamis (1530-2018) Caribbean, Central America, Mexico and Adjacent Regions Poster. Hard copies are available on request.
- NOAA’s PMEL conducted a ComMIT Tsunami Inundation Modeling workshop in Kingstown, St. Vincent February 25th to March 1st, 2019 in support of NOAA’s Caribbean Tsunami Warning Program and TsunamiReady. The outcome of the workshop will be an evacuation map for the islands of St. Vincent and Union. Representatives from the SVG Physical Planning Department and National Emergency Management Organization participated in the process and coordinated community outreach activities and the creation of Standard Operating Procedures in accordance with the TsunamiReady program.
NOAA’s PMEL conducted a Tsunami Hazard Assessment study for St. Vincent and the Grenadines (SVG). Full inundation results of the study were presented to the local authorities during the ComMIT workshop celebrated February 25th to March 1st, 2019

NOAA’s PMEL will conduct an additional ComMIT Tsunami Inundation Modeling workshop in Jamaica during 2019 with participants from Belize and Jamaica. The workshop will cover essentials on development of tsunami inundation maps. PMEL will perform follow up with the participants as they develop inundation maps for their respective locations.

In August 2018, the ITIC and PTWC successfully conducted the ITP-Hawaii in Chile, hosted by the Chilean Navy (SHOA), using Chile as a working example of an end-to-end tsunami warning and mitigation system. This was the largest ITP-Hawaii ever (35 persons, 12 countries) and 1st time the ITP-Hawaii was ever conducted outside of Hawaii. Several representatives from CARIBE-EWS countries attended. In September 2019, the ITIC will conduct the ITP-Hawaii in Hawaii.

ITIC organized with the IOC, and CTWP and the PTWC supported and participated in the Regional Training Workshop on Pacific Tsunami Warning Center Enhanced Tsunami Products for ICG/CARIBE EWS in Cartagena, Colombia (October 30–November 1, 2017). Building from regional PTWC Enhanced Products SOP trainings in 2013-2014, 2015, and 2017, the ITIC, at the request of the IOC CTIC, and working with CTWP and PTWC, will organize and conduct regional and national SOP protocol trainings in 2019.

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, which will support tsunami hazard assessment and tsunami exercising with the PTWC Enhanced Products, will be introduced to the Caribbean at the ICG/CARIBE-EWS XIV.


Tsunami Exercises and Communication Tests

Caribe Wave 2019
The Caribe Wave 2018 exercise was conducted on March 14 and executed in support of the 48 countries and territories in the Caribbean and adjacent regions. It was both a domestic and international exercise and consisted of two exercise scenarios (Kick ‘em Jenny and Panama)) for each country to choose from. According to TsunamiZone.org, over 500,000 people from Bermuda through Brazil were registered to participate. 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, and drills. The exercise was coordinated at the regional level by the CTWP and executed locally by the PRSN, the Puerto Rico Emergency Management Agency, 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 and making use of the regional tools and the TsunamiZone.org registry web tool.

PTWC developed both experimental international and domestic messages for CARIBE WAVE 19 to advise on the threat of tsunamis generated by Kick ‘em Jenny volcanic activity. The outcomes of CARIBE WAVE 19 will be discussed during the ICG. NOAA capability for issuing products and forecasting tsunamis from non-seismic sources is under development and no official forecast for these events can be promised. Future action on these hazards require more sensing capability, communication protocols between volcano observatories and the PTWC and tsunami modeling capabilities.
US suggest 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 USNTWC communication test. This problem is being addressed by mandating a change to the VTEC codes used in U.S. TWC test messages, and PTWC monthly tests with Puerto Rico and the Virgin Islands will resume later in 2019.
- Puerto Rico and the U.S. Virgin Islands also participated in domestic and international tsunami communication tests with PTWC.