NATIONAL REPORT
(2023-25)
Submitted by the United States of America

BASIC INFORMATION

1. ICG/PTWS Acting Tsunami National Contact (TNC)

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2. ICG/PTWS

Tsunami Warning Focal Point (TWFP)

Pacific Tsunami Warning Center (PTWC)
Person in Charge: Dr. Charles McCreery
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National Tsunami Warning Centre (NTWC) (*if different from the above*)

Pacific Tsunami Warning Center (PTWC)
(covers U.S. island states and territories, backup for NTWC)
Person in Charge: Dr. Charles McCreery
Title: Director, Pacific Tsunami Warning Center (PTWC)
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National Tsunami Warning Center (NTWC)
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3. Tsunami Advisor(s), if applicable

International Tsunami Information Center (ITIC)
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4. Tsunami Standard Operating Procedures for a Local Tsunami (when a local tsunami hazard exists)

In the Pacific region, the United States has potential local tsunami hazards in along the coastlines of the states of Hawaii, Alaska, Washington, Oregon, California, and the territories of Guam, the Northern Mariana Islands, and American Samoa, due to their nearby seismic zones. The Pacific Tsunami Warning Center (PTWC) monitors earthquakes in Hawaii with a relatively dense seismic network and will issue a local tsunami warning within a few minutes of any shallow, near-shore or offshore earthquake with a moment magnitude of 6.9 or greater. Similarly, the U.S. National Tsunami Warning Center (NTWC) monitors earthquakes in Alaska, Washington, Oregon, and California with a relatively dense seismic network and will issue a local tsunami warning within a few minutes of any shallow, near-shore or offshore earthquake with a magnitude of 7.0 or greater. Further, each NWS Tsunami Warning Center (TWC) monitors a relatively dense nearby network of sea level stations in those respective areas and can confirm whether a tsunami exists and the size of the tsunami threat within a few additional minutes. Based on the sea level data and any other information, the warning can be continued, upgraded or canceled.

PTWC also monitors sensor data for large earthquakes near the Commonwealth of the Northern Mariana Islands (CNMI), the Freely Associated Compact States of the Republic of Palau, the Federated States of Micronesia (FSM), the Republic of the Marshall Islands (RMI) but only with much sparser seismic and sea level networks. Consequently, initial domestic tsunami warnings for Guam, CNMI, and American Samoa, or international tsunami threat information for Palau, FSM, and RMI, are only possible within about 10 minutes of the earthquake, with confirmation of the tsunami wave potentially taking up to an hour. The NWS Weather Forecast Office (WFO) in Guam also supports the Compact States to ensure the Compact countries have received the international alerts. After the 2009 South Pacific Tsunami, PTWC implemented a local tsunami warning procedure for American Samoa that allows the on-duty staff at their local NWS Weather Service Office (WSO) to quickly alert the island of the potential tsunami threat, in the event of an Mw 7.1 or higher local earthquake. It should be noted that these U.S. territories and associated states do not possess the capability to analyze seismic data locally and are dependent on the PTWC and/or natural tsunami warning signs to be the indicators of a local tsunami threat. In this way, these jurisdictions share similar challenges for local or nearby tsunami threats as those other Pacific Island countries face and require their citizens to react quickly to indications of possible local tsunamis. The International Tsunami Information Center (ITIC) supports PTWC areas of service responsibility with Impact-based Decision Support Services (IDSS), available during live events to provide the latest information about any public products that were issued, or information about the earthquake and any known facts about the tsunami wave. ITIC also performs and administers various training and outreach events, for tsunami preparedness. PTWC also serves as the Tsunami Service Provider for Members of the Intergovernmental Oceanographic Commission (IOC) Caribbean Intergovernmental Working Group (ICG-CARIBE) Early Warning System (EWS) and provides forecasts and guidance for that basin.

Warnings and other tsunami products issued by PTWC and NTWC are generated from their Advanced Weather Interactive Processing System (AWIPS) and disseminated by a variety of means including telephone, emails to known/valid addresses, and faxes to the responsible government agencies. Dedicated circuits such as Global Telecommunication System (GTS), Aeronautical Fixed Telecommunication Network (AFTN), and the Emergency Managers Weather Information Network (EMWIN) are used as well. Each responsible agency then carries out their procedures for alerting the public with sirens or by other means, and for alerting emergency responders such as the police, fire departments, and rescue units. TWC warnings are also sent simultaneously to WFOs in each region that can, for example, assist with the public dissemination and local interpretation by activating the Emergency Alert System (EAS) to interrupt commercial radio and television with a message, and by broadcasting warning information over the NOAA Weather Radio. The EAS feature, utilizing NOAA Weather Radio (NWR), also has a built-in alarming/wake up call feature. Tsunami Warnings, issued by the TWCs, activates Wireless Emergency Alerts (WEA) via cell phones for areas under the warning. Tsunami Warnings may also be received and subsequently interpreted and/or further disseminated by the media and other third parties. For the Freely Associated States, dissemination of Tsunami Watch and Warning messages to the hundreds of populated islands, primarily reliant on commercial and public radio stations and High Frequency (HF) availability of reliable communications, continues to be a major challenge. The U.S. has sought to address this issue with low bandwidth technology solutions such as the Iridium satellite based RANET Chatty Beetle, which functions like a 2-way pager (though much more rugged) in its own water proofed case, and has an alarm feature that can call a small island into alert at night/weekends. GEONETCast Americas is also a reliable mechanism to get environmental data and warnings by satellite to some countries in the Americas.

PTWC and NTWC will monitor a local tsunami using all available means, including data from sea level gauges, information from the media, and reports received by telephone from the public or through government agencies. Based on these data, the TWCs determine when the threat has passed and the warning can be cancelled. A cancellation, however, does not necessarily mean that it is safe to return to evacuated areas. This determination must be made by local authorities based upon local information about any continuing wave conditions and other hazards that may be present such as fires or downed power lines.

5. Tsunami Standard Operating Procedures for a Distant Tsunami (when a distant tsunami hazard exists)

The Hawaiian Islands are under the largest potential threat from distant tsunamis, due to their central location in the Pacific, as well as the large bathymetric extent which causes tsunami waves to shoal and grow in size. The Pacific Ocean also has the most tsunami activity than anywhere else in the world. Hawaii has historically been struck by destructive distant tsunamis a few times each century, and these have come from great earthquakes off the coast of South America, Alaska and the Aleutian Islands, Kamchatka, and Japan. However, the coasts of all U.S. states, territories, and other interests in the Pacific are all threatened to some extent by distant tsunamis.

Both PTWC and NTWC monitor the entire Pacific region for large earthquakes that may cause a destructive distant tsunami. NTWC has the primary responsibility for the analysis of such earthquakes that occur off the coasts of Alaska, British Columbia, Washington, Oregon, and California. PTWC has the primary responsibility for the analysis of such earthquakes that occur elsewhere in the Pacific. For all large earthquakes that occur away from U.S. coasts, PTWC and NTWC confer on their respective earthquake analyses and coordinate their parameters before issuing message products. For distant earthquakes with a moment magnitude of 6.5 or greater, a warning, advisory, watch, or information statement will be initially issued for some or all coasts following criteria based on the earthquake's location, depth and magnitude, the estimated time until first tsunami impact, and guidance from pre-modeled and historical earthquakes and tsunamis. Each TWC subsequently monitors data from relevant stations of the Pacific-wide network of coastal and deep-ocean sea level stations as the tsunami propagates outward from the source and passes each gauge. Based on the sea level data, additional seismic analyses, forecast model outputs, and any other information, the initial alert status will be continued, upgraded or canceled. The ITIC supports the PTWC Area of Service with Impact-based Decision Support Services (IDSS) by being on call and reaching out directly to States, Territories and Pacific countries when needed during an event, and with routine training and outreach outside of events.

Distant Tsunami Warnings issued by PTWC and NTWC are disseminated by a variety of means including telephone, dedicated text circuits, email, and fax to the responsible government agencies in each jurisdiction that may, depending upon the local laws and policy, be the state, county, or municipality. The responsible agencies then carry out their procedures for alerting the public with sirens or by other means, and for alerting emergency responders such as the police, fire departments, and rescue units. TWC warnings are also simultaneously sent to Weather Forecast Offices in each region. They will assist with the public dissemination and local interpretation by activating EAS to interrupt commercial radio and television with a message, and by broadcasting warning information over the NWR. All PTWC and NTWC products are publicly available and may also be received and subsequently interpreted and re-disseminated by the media and third-party providers.

6. U.S. National Sea Level Network

The U.S. supports an extensive sea level network in the Pacific for a variety of purposes, including tsunami detection and measurement. Gauges are operated by PTWC, US NTWC, NOAA's National Ocean Service (NOS), NOAA's National Data Buoy Center (NDBC), and the University of Hawaii Sea Level Center (UHSLC). Figure 1 shows the location of each gauge operated by these as well as other international organizations, and Table 1 provides some of the parametric data for the U.S. stations.

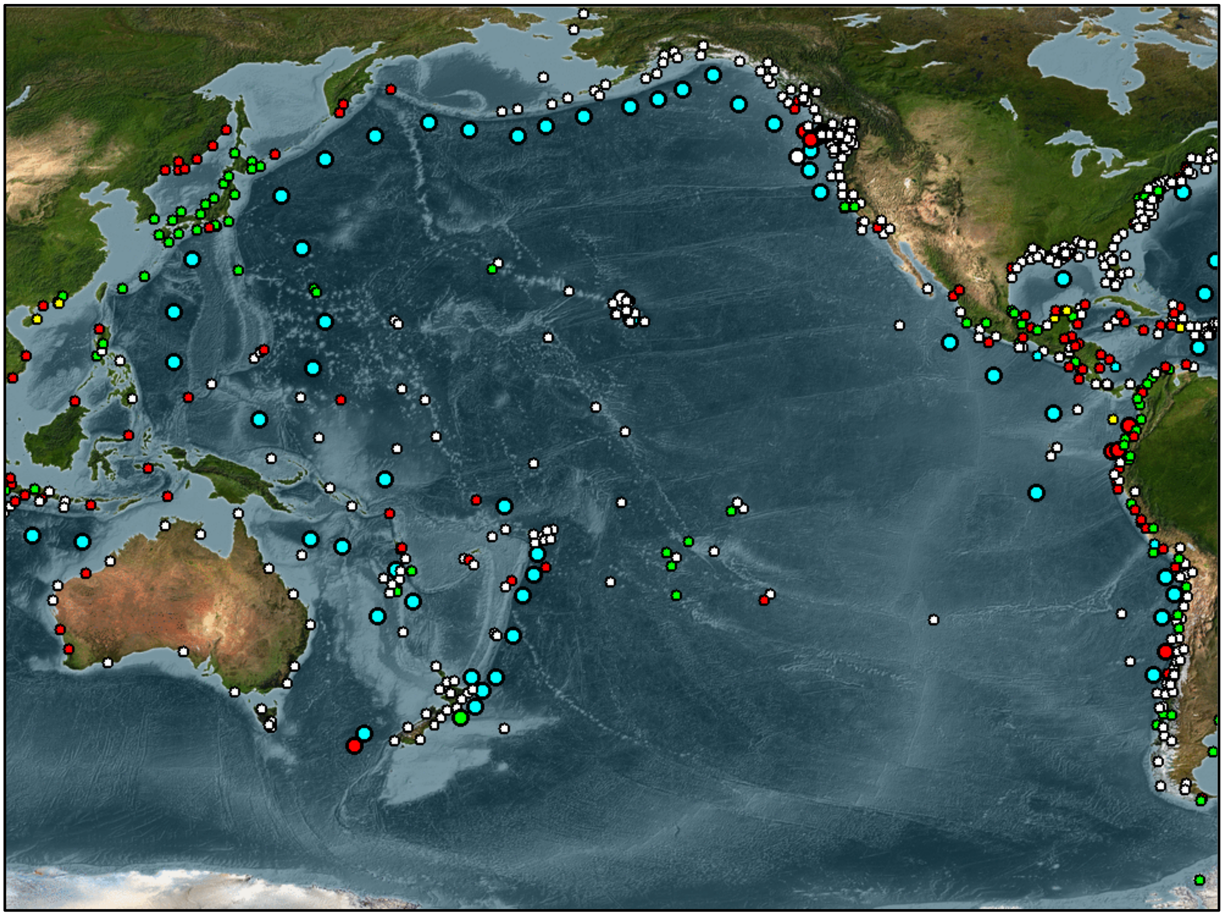

Figure 1: *Sea-level gauges in the Pacific Region monitored by the two U.S. tsunami warning Centers to detect and measure tsunami waves. Smaller circles are coastal gauges and larger circles are deep-ocean tsunameters. The fill color of each circle indicates the elapsed time since data from that gauge was received. In general, white or green indicate a working coastal gauge, and white, green or blue indicate a working deep-ocean tsunameter. Red-filled circles are gauges that are not currently operational. Date: August 18, 2023.*

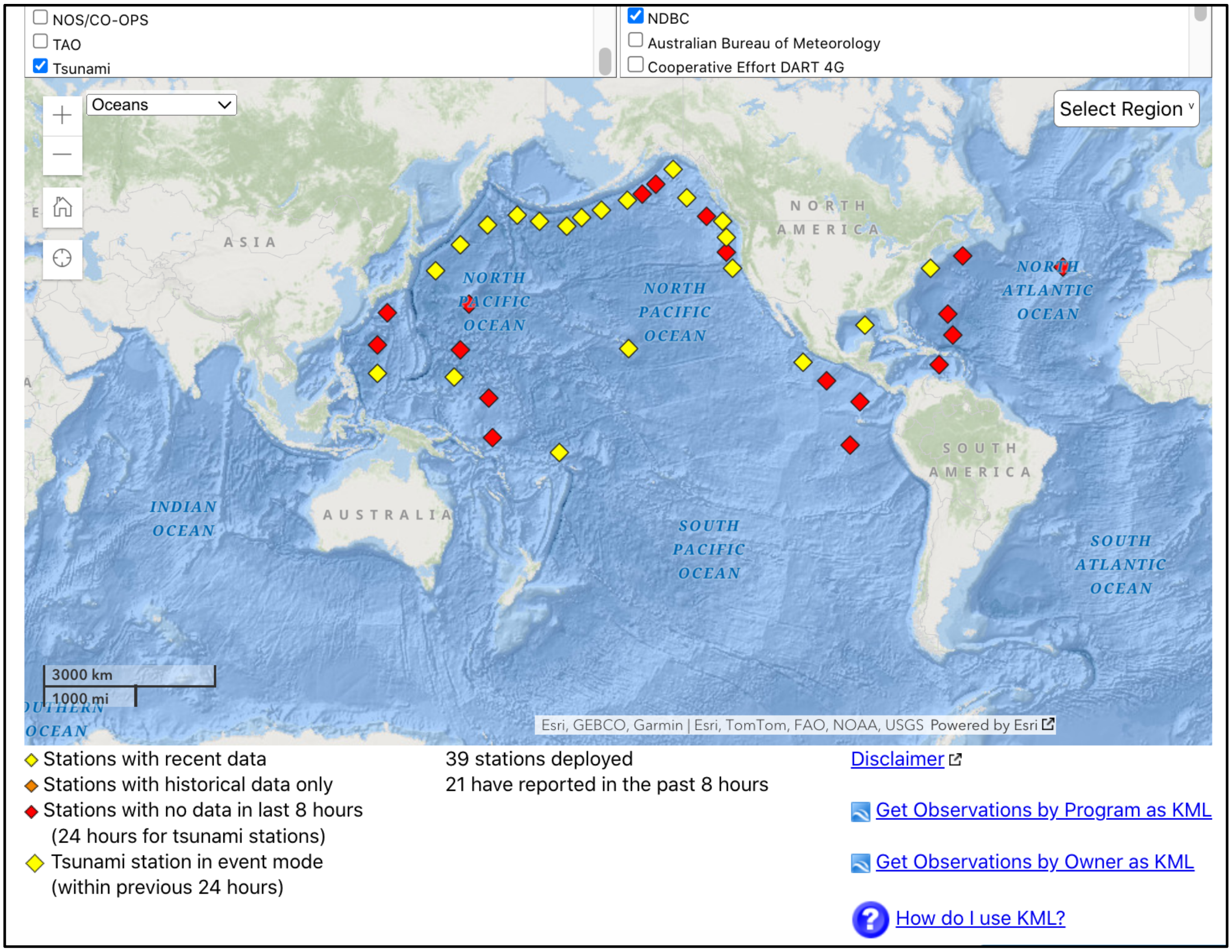

Figure 2: *Deep-ocean Assessment and Reporting of Tsunami (DART®) stations operated by the US National Data Buoy Center. Source: https://www.ndbc.noaa.gov/. Date: March 13, 2025*

A brief synopsis of the various gauges follows:

- ***National Ocean Service (NOS)***. The NOS Center for Operational Oceanographic Products and Services (CO-OPS) operates most of the U.S. coastal stations through the National Water Level Observation Network (NWLON) and the Physical Oceanographic Real-Time System (PORTS) program. These gauges each have a primary and backup sensor, sample the primary sensor at a rate of one sample per minute, and send their data every 6 minutes over one of the two U.S. meteorological satellites (GOES-E or GOES-W).
- ***University of Hawaii Sea Level Center (UHSLC)***. A number of coastal gauges in the Pacific are operated for IOC's Global Sea Level Network (GLOSS) by the UHSLC. Similar to the NOS gauges, UHSLC gauges have a primary and backup sensor. Most gauges provide 1-minute averages with data sent in most cases over either a GOES satellite or Japan meteorological satellite (Himawari) with a transmission interval of either 5 or 15 minutes. Communications are increasingly being transitioned via Iridium, however, with similar transmission intervals.
- ***National Data Buoy Center (NDBC)***. Thirty-three deep ocean sensors, known as Bottom Pressure Recorders (BPR), are now operated by the NWS/NDBC in the Pacific. The BPR and its associated surface buoy is known as a Deep-Ocean Assessment and

Reporting of Tsunamis (DART) system. In their non-triggered mode the "DART" gauges communicate via the IRIDIUM constellation once every 6 hours with a 15-minute sampling interval. All DARTs have a triggered mode (either self-triggered or externally triggered) to sample at a higher rate (either every 15 seconds or every minute) and to transmit every few minutes. Data from these gauges are critical for observing and constraining tsunami forecast models.

- ***Pacific Tsunami Warning Center (PTWC)***. PTWC operates a network of sea-level stations in Hawaii that transmit in real time over dedicated circuits. The UHSLC also maintains an array of sea-level stations in Hawaii which transmit data via the GTS. The PTWC also operates a few run-up detectors on land near shore in Hawaii that will provide an alert if they are flooded by a tsunami.
- ***U.S. National Tsunami Warning Center (NTWC).*** To provide adequate coverage, NTWC operates a network of real-time coastal stations in Alaska and California that send their data over dedicated circuits.

Table 1. Sea level gauges in the Pacific operated by the U.S.

Gauge Name	Lat(+N,-S)	Lon(+E,-W)	SR	XR	Comms	Org
DART_Acapulco_43413	10.8400	-100.0850	1	008	IRDM	NDBC
DART_Adak_46413	48.8610	-175.6010	1	008	IRDM	NDBC
DART_Anchorage_46410	57.5000	-144.0000	1	008	IRDM	NDBC
DART_Apia_51425	-9.5000	-176.2500	1	008	IRDM	NDBC
DART_Arica_32401	-19.5478	-74.8136	1	008	IRDM	NDBC
DART_Astoria_46404	45.8590	-128.7780	1	008	IRDM	NDBC
DART_Attu_21415	50.1730	171.8370	1	008	IRDM	NDBC
DART_Auckland_54401	-33.0050	-172.9850	1	008	IRDM	NDBC
DART_Chuginadak_46408	49.6261	-169.8714	1	008	IRDM	NDBC
DART_Coos_Bay_46407	42.6040	-128.9000	1	008	IRDM	NDBC
DART_Dutch_Hbr_46402	51.0690	-164.0110	1	008	IRDM	NDBC
DART_Guam_52405	12.8800	132.3340	1	008	IRDM	NDBC
DART_Hawaii_51407	19.6300	-156.5250	1	008	IRDM	NDBC
DART_Honiara_52406	-5.3320	165.0810	1	008	IRDM	NDBC
DART_Kamchatka_21416	48.0440	163.4880	1	008	IRDM	NDBC
DART_Kodiak_46409	55.3000	-148.5000	1	008	IRDM	NDBC
DART_Kuril_Is_21417	43.1920	157.1420	1	008	IRDM	NDBC

Gauge Name	Lat(+N,-S)	Lon(+E,-W)	SR	XR	Comms	Org
DART_Kwajalein_52402	11.5750	154.5880	1	008	IRDM	NDBC
DART_Lima_32412	-17.9750	-86.3920	1	008	IRDM	NDBC
DART_Manila_52404	20.9360	132.3090	1	008	IRDM	NDBC
DART_Manzanillo_43412	16.0340	-107.0010	1	008	IRDM	NDBC
DART_Marquesas_51406	-8.4890	-125.0060	1	008	IRDM	NDBC
DART_NW_PAC_21414	48.9420	178.2700	1	008	IRDM	NDBC
DART_Panama_32411	4.9230	-90.6850	1	008	IRDM	NDBC
DART_Saipan_52401	19.2860	155.7660	1	008	IRDM	NDBC
DART_San_Diego_46412	32.2460	-120.6980	1	008	IRDM	NDBC
DART_San_Francisco_46411	39.3400	-127.0070	1	008	IRDM	NDBC
DART_Seattle_46419	48.7620	-129.6170	1	008	IRDM	NDBC
DART_Sendai_21418	38.7060	148.6650	1	008	IRDM	NDBC
DART_Shumagin_46403	52.6500	-156.9400	1	008	IRDM	NDBC
DART_Tokyo_21413	30.5500	152.1186	1	008	IRDM	NDBC
DART_Tonga_51426	-22.9930	-168.0980	1	008	IRDM	NDBC
DART_Truk_52403	4.0320	145.5960	1	008	IRDM	NDBC
Midway	28.2149	-177.3608	1	006	GOES	NOS
Adak_AK	51.8617	-176.6343	1	006	GOES	NOS
Pago_Pago_AS	-14.2762	-170.6829	1	006	GOES	NOS
Nikolski_AK	52.9417	-168.8716	1	006	GOES	NOS
Dutch_Hbr,Unalaska	53.8800	-166.5370	1	006	GOES	NOS
Nome_AK	64.4942	-165.4389	1	006	GOES	NOS
Red_Dog_AK	67.0650	-164.0650	1	006	GOES	NOS
King_Cove_AK	55.0594	-162.3236	1	006	GOES	NOS
Sand_Point_AK	55.3318	-160.5043	1	006	GOES	NOS
Port_Allen,Kauai	21.9030	-159.5920	6	060	GOES	NOS

Gauge Name	Lat(+N,-S)	Lon(+E,-W)	SR	XR	Comms	Org
Nawiliwili,Kauai	21.9570	-159.3600	1	006	GOES	NOS
Honolulu,Oahu	21.3033	-157.8644	1	006	GOES	NOS
Mokuoloe,Oahu	21.4370	-157.7930	1	006	GOES	NOS
Kahului,Maui	20.8980	-156.4720	1	006	GOES	NOS
Kawaihae,Hawaii	20.0360	-155.8320	1	006	GOES	NOS
Hilo,Hawaii	19.7305	-155.0561	1	006	GOES	NOS
Alitak_US	56.8975	-154.2481	1	006	GOES	NOS
Kodiak_AK	57.7317	-152.5117	1	006	GOES	NOS
Seldovia_AK	59.4370	-151.7170	1	006	GOES	NOS
Nikiski_AK	60.6866	-151.3966	1	006	GOES	NOS
Anchorage_AK	61.2380	-149.8880	1	006	GOES	NOS
Seward_AK	60.1190	-149.4270	1	006	GOES	NOS
Prudhoe_Bay_AK	70.4017	-148.5298	1	006	GOES	NOS
Valdez_AK	61.1250	-146.3620	1	006	GOES	NOS
Cordova_AK	60.5580	-145.7530	1	006	GOES	NOS
Yakutat_AK	59.5480	-139.7350	1	006	GOES	NOS
Elfin_Cove_AK	58.1933	-136.3433	1	006	GOES	NOS
Sitka_AK	57.0514	-135.3433	1	006	GOES	NOS
Skagway_AK	59.4500	-135.3267	1	006	GOES	NOS
Port_Alexander_AK	56.2467	-134.6467	1	006	GOES	NOS
Juneau_AK	58.2983	-134.4117	1	006	GOES	NOS
Ketchikan_AK	55.3333	-131.6250	1	006	GOES	NOS
La_Push_WA	47.9133	-124.6367	1	006	GOES	NOS
Neah_Bay	48.3680	-124.6170	1	006	GOES	NOS
Port_Orford_OR	42.7370	-124.4970	1	006	GOES	NOS
Charleston_OR	43.3450	-124.3217	1	006	GOES	NOS

Gauge Name	**Lat(+N,-S)**	**Lon(+E,-W)**	**SR**	**XR**	**Comms**	**Org**
North_Spit,Humboldt	40.7670	-124.2170	1	060	GOES	NOS
Crescent_City_CA	41.7450	-124.1830	1	006	GOES	NOS
Westport,WA	46.9083	-124.1100	1	006	GOES	NOS
South_Beach_OR	44.6256	-124.0450	1	006	GOES	NOS
Willapa_Bay,Toke_Pt	46.7050	-123.9590	1	006	GOES	NOS
Garibaldi_OR	45.5550	-123.9117	1	006	GOES	NOS
Astoria_OR	46.2080	-123.7670	1	006	GOES	NOS
Arena_Cove_CA	38.9130	-123.7050	1	006	GOES	NOS
Port_Angeles_WA	48.1250	-123.4400	1	006	GOES	NOS
Friday_Harbor_WA	48.5467	-123.0100	1	006	GOES	NOS
Point_Reyes_CA	37.9970	-122.9750	1	006	GOES	NOS
Longview_WA	46.0917	-122.9567	1	006	GOES	NOS
Cherry_Point_WA	48.8630	-122.7580	1	006	GOES	NOS
Port_Townsend_WA	48.1010	-122.7580	1	006	GOES	NOS
Tacoma_WA	48.1010	-122.7580	1	006	GOES	NOS
Ft_Point,San_Fran	37.8070	-122.4650	1	006	GOES	NOS
Redwood_City_CA	37.9280	-122.4000	1	006	GOES	NOS
Elliot_Bay,Seattle	47.6020	-122.3350	1	006	GOES	NOS
Alameda_CA	37.7720	-122.2980	1	006	GOES	NOS
Port_Chicago_CA	38.0567	-122.0383	1	006	GOES	NOS
Monterey_Harbor_CA	36.6050	-121.8880	1	006	GOES	NOS
Port_San_Luis_CA	35.1680	-120.7530	1	006	GOES	NOS
Santa_Barbara_CA	34.4080	-119.6850	1	006	GOES	NOS
Santa_Monica_CA	34.0080	-118.5000	1	006	GOES	NOS
Los_Angeles_CA	33.7190	-118.2720	1	006	GOES	NOS
La_Jolla_CA	32.8670	-117.2575	1	006	GOES	NOS

Gauge Name	Lat(+N,-S)	Lon(+E,-W)	SR	XR	Comms	Org
San_Diego_CA	32.7130	-117.1730	1	006	GOES	NOS
Guam_US	13.4436	144.6566	1	006	GOES	NOS
Wake_US	19.2906	166.6177	1	006	GOES	NOS
Wake_US	19.2906	166.6177	1	006	GOES	NOS
Kwajalein_MH	8.7333	167.7333	1	006	GOES	NOS
Baltra,Galapags_EC	-0.4367	-90.2850	1	005	GOES	UHSLC
Christmas_KI	1.9840	-157.4730	1	015	GOES	UHSLC
Davao_PH	7.0833	125.6333	1	006	JMA	UHSLC
Johnston_US	16.7363	-169.5282	1	005	GOES	UHSLC
Kanton_KI	-2.8010	-171.7180	1	015	GOES	UHSLC
Kapingamarangi_FM	1.1000	154.7833	4	005	GOES	UHSLC
Malakal,Koror_PW	7.3282	134.4502	1	005	IRDM	UHSLC
Manilla_PH	14.5833	120.9667	1	006	JMA	UHSLC
Nuku_Hiva,Marquesas	-8.9213	-140.0953	1	005	GOES	UHSLC
Papeete,Tahiti	-17.5330	-149.5670	1	005	GOES	UHSLC
Penrhyn_CK	-8.9833	-158.0500	1	005	GOES	UHSLC
Rikitea_PF	-23.1333	-134.9500	1	005	GOES	UHSLC
Saipan_US	15.2266	145.7416	1	005	IRDM	UHSLC
SantaCruz,Galapagos	-0.7216	-90.3133	1	005	GOES	UHSLC
Tern,Fr. Frigate_US	23.8690	-166.2884	1	005	GOES	UHSLC
Yap_FM	9.5142	138.1246	1	005	IRDM	UHSLC
Acajutla_El Salvador	13.5737	-89.8381	1	005	GOES	UHSLC
La_Libertad_Galapagos	-2.2178	-80.9061	1	005	GOES	UHSLC
Quepos_Costa_Rica	9.4255	-84.1701	1	005	IRDM	UHSLC
Cocos_Is_Costa_Rica	5.5562	-87.0481	1	005	GOES	UHSLC
Callao_Peru	-12.0690	-77.1667	1	005	GOES	UHSLC
Matarani_Peru	-17.0010	-72.1088	1	005	GOES	UHSLC
Talara_Peru	-4.5751	-81.2832	1	005	GOES	UHSLC
Barbers_Pt_Hawaii	21.3259	-158.1100	1	005	GOES	UHSLC
Palmyra_USA	5.8883	-162.0892	1	005	GOES	UHSLC
Makai_Pier_Hawaii	21.3196	-157.6683	1	005	GOES	UHSLC
Hiva_Oa_PF	-9.8048	-139.0345	1	015	GOES	UHSLC
Legaspi_PH	13.1447	123.7566	1	006	JMA	UHSLC
Chuuk_FSM	7.4520	151.8979	1	005	IRDM	UHSLC
Aausi_AS	-14.2716	-170.5729	1	005	IRDM	UHSLC
Aunuu_AS	-14.2835	-170.5698	1	005	IRDM	UHSLC
Ofu_AS	-14.1634	-169.6810	1	005	IRDM	UHSLC
Tau_AS	-14.2405	-169.5106	1	005	IRDM	UHSLC
Acajutla_SV	13.5739	-89.8383	2	060	GOES	PTWC
Atico_PE	-16.2311	-73.6944	2	060	GOES	PTWC
Callao,La-Punta_PE	-12.0710	-77.1670	2	060	GOES	PTWC
Corinto_NI	12.4836	-87.1675	2	060	GOES	PTWC

Gauge Name	**Lat(+N,-S)**	**Lon(+E,-W)**	**SR**	**XR**	**Comms**	**Org**
La_Libertad_EC	-2.2177	-80.9064	2	060	GOES	PTWC
Legaspi_PH	13.1459	123.7577	1	012	GMS	PTWC
Lobos_de_Afuera_PE	-6.9350	-80.7200	2	060	GOES	PTWC
Niue	-19.0525	-169.9214	2	060	GOES	PTWC
Nuku_Hiva,Marquesas	-8.9213	-140.0953	2	060	GOES	PTWC
Severo_Kurilsk_RU	50.6780	156.1388	1	012	GMS	PTWC
Socorro_MX	18.7288	-110.9493	3	015	GOES	PTWC
Ust-Kamchatsk_RU	56.0000	163.0000	2	012	GMS	PTWC
Waitangi,Chatham_NZ	-43.9458	-176.5608	2	060	GOES	PTWC
Hanalei,Kauai	22.2156	-159.5008	1	000	REAl	PTWC
Nawiliwili,Kauai	21.9570	-159.3600	1	000	REAL	PTWC
Waianae,Oahu	21.4400	-158.1700	1	000	REAL	PTWC
Haleiwa,Oahu	21.6000	-158.1100	1	000	REAL	PTWC
Makapu`u,Oahu	21.3232	-157.6716	1	000	REAL	PTWC
Kalaupapa,Molokai	21.2100	-156.9800	1	000	REAL	PTWC
Lahaina,Maui	20.8750	-156.6920	1	000	REAL	PTWC
Kahului,Maui	20.8980	-156.4720	1	000	REAL	PTWC
Honokohau,Hawaii	19.6710	-156.0280	1	000	REAL	PTWC
Honokohau,Hawaii	19.6710	-156.0280	1	000	REAL	PTWC
Milolii	19.1883	-155.9104	1	000	REAL	PTWC
Mahukona,Hawaii	20.1860	-155.9060	1	000	REAL	PTWC
Honuapo,Hawaii	19.0870	-155.5530	1	000	REAL	PTWC
Lapahoehoe,Hawaii	19.9949	-155.2431	1	000	REAL	PTWC
Hilo, Hawaii	19.7307	-155.0558	1	000	REAL	PTWC
Amchitka, AK	51.3783	-179.3019	0	000	REAL	NTWC
Akutan, AK	54.1330	-165.7778	0	000	REAL	NTWC

Gauge Name	Lat(+N,-S)	Lon(+E,-W)	SR	XR	Comms	Org
Sand Point, AK	55.3367	-160.5017	0	000	REAL	NTWC
Old_Harbor, AK	57.2200	-153.3056	0	000	REAL	NTWC
Sitka, AK	57.0517	-135.3417	0	000	REAL	NTWC
Craig, AK	55.4770	-133.1410	0	000	REAL	NTWC
Shemya, AK	52.7308	174.1031	0	000	REAL	NTWC
Chignik, AK	56.306	-158.377	0	000	REAL	NTWC
Ventura, CA	34.2517	-119.2671	0	000	REAL	NTWC
Whittier, AK	60.771	-148.673	0	000	REAL	NTWC
Barry Arm Point Doran, AK	61.06824	-148.1614	0	000	REAL	NTWC
Barry Arm North Shore, AK	61.0375	-148.1149	0	000	REAL	NTWC
Esther Passage, AK	61.0083	-148.0680	0	000	REAL	NTWC

SR is the sample rate in minutes
XR is frequency of data transmissions in minutes. A zero is for real time data.
Comms is the communication method.

- REAL = Continuous real time data over a dedicated link
- DIAL = Dial-up over commercial telephone line
- GOES = Data packets sent via a GOES satellite every XR minutes
- GMS = Data packets sent via the GMS satellite every XR minutes
- IRDM = Data packets sent via Iridium satellites every XR minutes

Org is the U.S. organization that operates (or helps operate) the gauge.

- PTWC = NOAA/NWS Pacific Tsunami Warning Center
- NTWC = NOAA/NWS National Tsunami Warning Center
- NDBC = NOAA/NWS National Data Buoy Center
- NOS = NOAA National Ocean Service
- UHSLC = University of Hawaii Sea Level Center

7. GNSS-Augmented Observational Network

Real-time GNSS is an evolving technology whose on-going proliferation of stations and networks along the coasts in areas of earthquake and tsunami risk may be used to augment hazard monitoring. Thousands of real-time GNSS stations currently operate throughout the PTWS-ICG and other ICG regions and could be integrated into the existing system for strengthening the accuracy for seismic and tsunami characterization of significant events.

The U.S. has recently completed the first phase of a prototype monitoring and observing system for the characterization of large earthquake location, magnitude, and faulting spatial distribution incorporating real-time GNSS stations. This is to integrate with the existing systems (GFAST) operated by USGS and NOAA and a foundation for on-going expansion as part of the regional and global system. NASA and NOAA have formed an applied research and operational Tsunami GNSS Collaborative (TGC) with members from multiple institutions including University of Central Washington, University of Washington, Scripps Institute of Oceanography, NASA, UC

Berkeley, USGS, and the National and Pacific Tsunami Warning Centers.

The TGC have developed and implemented a proto-type architecture to collect, process, merge, and disseminate GNSS-based position data from a set of existing and representative real-time stations on the Pacific coast with quasi-operational reliability and backup using disparate processing algorithms. At the operational centers the data is ingested into an EarthWorm environment adapted to support GNSS data analysis. A preliminary set of event simulations and recorded events has been developed in order to evaluate the operational system. Current activities (Phase 1) include testing algorithms and modules with operations, identifying and promoting access to extend geographical data coverage, engaging additional warning centers, and evaluating the utility of GNSS-based augmentation of earthquake location and magnitude estimation in the operational environment.

In Phase 2 of the project, there will be an evaluation of 1300 Cascadia simulated earthquake events. Once this is completed the goal is to expand effort across PTWS and establish initial criteria for sufficiently real-time multi-use GNSS data stations and regional network configuration (type of station/data and site map). The team will select an appropriate set of PTWS stations as representative for a wider initial testing capability and engage partners and organizations to develop initial data sharing policies, agreements and standards to access and utilize for test and evaluation in a regional demonstration with selected GNSS data. Eventually they would like to develop a plan for a sustainable integration of these technologies into the existing network.

In particular, in terms of using ionosphere-based GNSS monitoring as early detection capabilities, NASA's Jet Propulsion Laboratory (JPL) is developing the GNSS-based Upper Atmospheric Real-time Disaster Information and Alert Network (GUARDIAN) system. See Section 13, "Tsunami Research Projects" below.

In addition to GNSS networks, the U.S. is also supporting the development and deployment of Science Monitoring And Reliable Telecommunications (SMART) Cables. These dual-purpose telecommunications-science cables include sensors that measure key ocean variables, including real time bottom pressure (for tsunami detection), temperature, and seismic motion. SMART Cables represent a complementary technology to existing tsunami detection systems, providing improved spatial and temporal coverage while leveraging telecommunication cable infrastructure. SMART Cable networks, once deployed throughout the Pacific, will significantly enhance the ability to detect, measure, and characterize tsunamis quickly, regardless of source mechanism. U.S. researchers are involved in the Tamtam cable project that is deploying a telecommunication cable between Vanuatu and New Caledonia that contains environmental sensors to make climate observations and improve tsunami early warning capabilities in these two countries. The US National Science Foundation is exploring route alternatives for the Antarctic SMART telecommunications cable project that would monitor the Antarctic Circumpolar Current (ACC) and directly observe Antarctic Deep Water formation as it spreads into all ocean basins

EarthScope Contributions to Enhancing GNSS Globally

The EarthScope Consortium, Inc., is a non-profit, university-governed consortium, which is funded by the National Science Foundation (NSF), USGS, and NASA. EarthScope facilitates geoscience research and education using seismic and geodetic instrumentation. One of the major projects that EarthScope supports is the NSF-funded Network of the Americas (NOTA), a network of geophysical instrumentation, which spans the western U.S. Pacific North American plate boundary. NOTA includes continuous GNSS, borehole strainmeter and seismometer, short-baseline electronic tilt, long-baseline laser strainmeter, and meteorological observations at over 1200 locations throughout the network. These observations, in particular high-rate (1 Hz) real-time (<2 ms) GNSS (RT-GNSS) observations, have the potential to contribute to the success of tsunami and earthquake early warning systems.

In the case of tsunami early warning, RT-GNSS networks can provide multiple inputs in an operational system starting with rapid assessment of earthquake sources and associated deformation, which leads to the initial model of ocean forcing and tsunami generation. In addition, terrestrial GNSS can provide direct measurements of the tsunami through the associated traveling ionospheric disturbance from several hundreds of km away as they approach the shoreline, which in turn can be used to refine tsunami inundation models. Any operational system like this has multiple communities that rely on a pan-Pacific real-time open data set. While progress has been made toward more open and free data access across national borders and toward more cooperation among government sanctioned early warning agencies, some impediments remain making a truly operational system a work in progress.

The Geodesy Advancing Geosciences (GAGE) Facility, managed by EarthScope, currently operates a network of over 1000, real-time, high-rate GNSS stations. The majority of these real-time stations are part of the EarthScope NOTA network, with over 600 stations included in the USGS earthquake early warning system called ShakeAlert. Sixty-seven sites are distributed throughout the Mexico and Caribbean region originally as part of the NSF-funded TLALOCNet and COCONet projects (Figure 3). In addition, there are nearly 300 NOTA stations in Alaska and Cascadia that may also be critical to tsunami warning. The entire network is processed in real-time at EarthScope 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 GNSS data streams. The data are freely available to registered users and demand has grown almost exponentially since 2010.

Real-time (RT)-GNSS data and position estimates use is multidisciplinary, including tectonic and volcanic deformation studies, meteorological applications and atmospheric science research. RT-GNSS also has the potential to provide early characterization of geophysical events and improved warning of hazards to emergency managers, utilities, infrastructure managers and first responders. Twenty-three RT-GNSS stations within NOTA now include 100 sps low-cost MEMS accelerometers as part of a prototype seismo-geodetic Earthquake Early Warning (EEW) and Tsunami Early Warning (TEW) system. The growing need for the development of EEW and TEW systems worldwide has brought into focus the importance of not only managing a robust data delivery system but also monitoring data quality in a near real-time fashion. Robust, low-latency, low-noise levels and completeness of the real-time data streams are critical for the success of any early warning system. To meet these needs, EarthScope monitors the latency and completeness of the incoming raw observations and is developing tools to rapidly assess the quality of the real-time processed data.

EarthScope has embarked on significant improvements to the original infrastructure and scope of NOTA. It is anticipated that NOTA and related networks will form a backbone for these efforts by providing high quality, low latency raw and processed GNSS data. This will require substantial upgrades to the entire system, however, starting with installation of state-of-the-art multi-constellation GNSS receivers and upgraded broad-band GNSS antennas at more stations across existing networks, improved power infrastructure at remote sites, hardened and redundant telemetry links, robust data collection (lossless), enhanced archiving and open distribution mechanisms, and ultimately more efficient data-processing strategies.

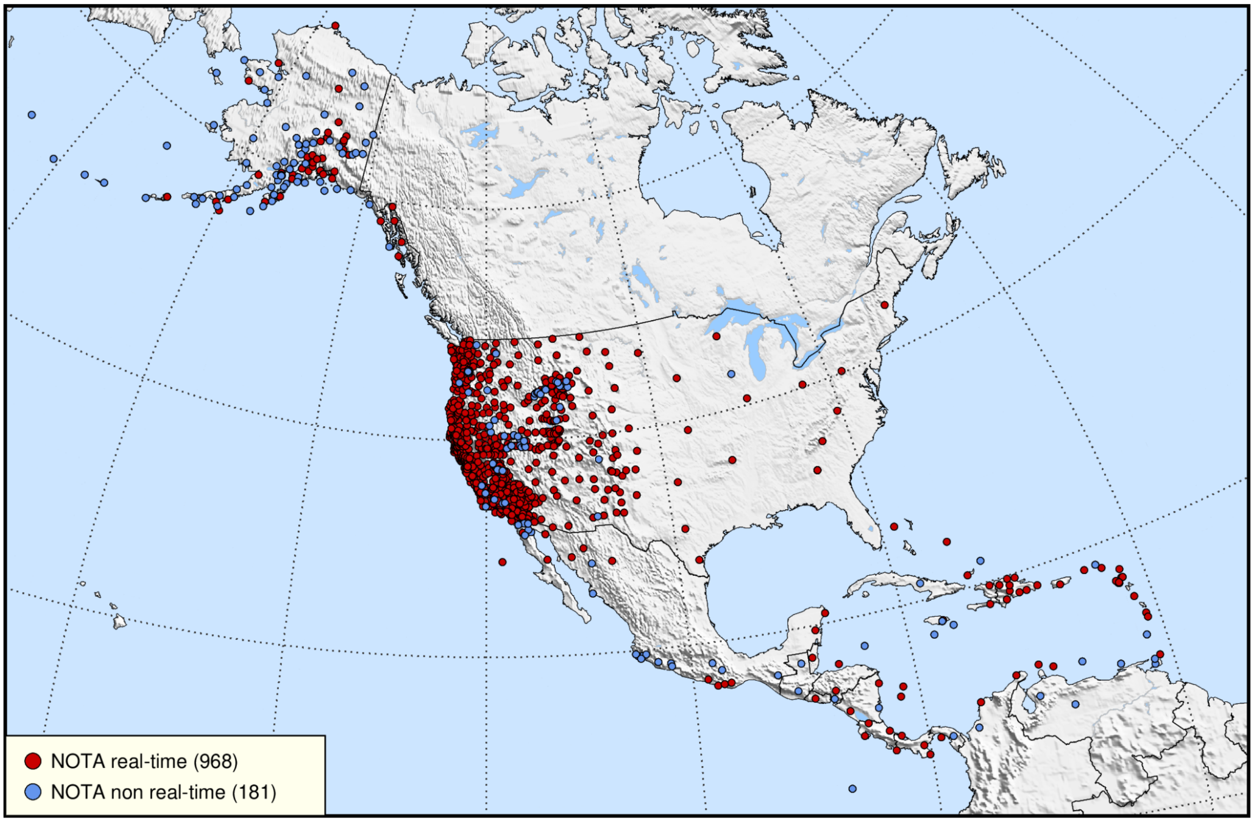

Figure 3: *Distribution of the Network of the Americas (NOTA) cGPS/GNSS stations on May 31, 2023. NOTA is a federation of the former networks: PBO (U.S.), TLALOCNet (Mexico) and COCONet (Caribbean). The 1,257 station network spans Shemya Island in the western Aleutians to Puerto Rico in the northeastern Caribbean and to northern South America. Subduction zones along western North and South America are major tsunamigenic earthquake source zones for the Pacific. Real-time NOTA stations are available to the PTWC for tsunami early warning.*

8. Tsunami Data Archives: National Centers for Environmental Information (NCEI) and the World Data Service (WDS) for Geophysics

NOAA's National Center for Environmental Information (NCEI) hosts the World Data Service (WDS) for Geophysics, in Boulder, Colorado, USA. In support of the NOAA/NWS Tsunami Program, the NOAA/WDS provides long-term archive, data management, and access to national and global tsunami data for research and mitigation of tsunami hazards, and collaborates with the NOAA Office of Atmospheric Research's (OAR) Pacific Marine Environmental Lab (PMEL) to provide bathymetry and topography data in support of tsunami inundation modeling. Archive responsibilities include the global historic tsunami event and run-up database, tsunami deposits database, ocean bottom pressure data (temperature and pressure from both the older bottom pressure recorder and newer DART platforms, high-resolution coastal tide gauge data, as well as other related hazards and bathymetric data and information. NCEI also produces value-added products for the tsunami research community, including high-resolution, quality-controlled and de-tided water level (DART and tide gauge) products.

NCEI/WDS Recent Accomplishments:

- NCEI DiDEM Team completed new and updated existing digital elevation models (DEMs) for: Columbia River, OR and WA; Puget Sound and Salish Sea, WA; Point Reyes, CA; Nome, Norton Sound, Northwestern Bering Sea, Alaska; and an updated the Central Pacific (vol.7) Coastal Relief Model The DEMs are available via the NCEI Thematic Real-time Environmental Distributed Data Services (THREDDS) data server, NCEI Coastal Relief Model or NOAA's Digital Coast.
- Additional updates to development processes and innovations included DEM validation using IceSat-2 elevation photons data and improvements to spatial metadata and DEM uncertainty grids. Current DEM development processes are documented in Amante, C.J.; Love, M.; Carignan, K.; Sutherland, M.G.; MacFerrin, M.; Lim, E. *Continuously Updated Digital Elevation Models (CUDEMs) to Support Coastal Inundation Modeling*. Remote Sens. 2023, 15, 1702. https://doi.org/10.3390/rs15061702. DEM and ancillary data product development code available at https://github.com/ciresdem/cudem.
- Beginning in 2020, NCEI publishes a semiannual update on their tsunami water level data products and services. Past updates can be found at: https://www.ncei.noaa.gov/products/natural-hazards/tsunamis-earthquakes-volcanoes/tsunamis/publications-reports.
- The global historical tsunami event and run-up database interface has been updated for improved discoverability and access. Paper marigrams (tide gauge data) collected between 1854 and 1994 are also available on the interface: https://www.ngdc.noaa.gov/hazel/
- NCEI and the International Tsunami Information Center (ITIC) updated the *Global Historical Tsunami, Significant Earthquake, and Significant Volcanic Eruption* posters to 2023.
- NCEI and ITIC updated the *Historical Tsunami Effects:Tonga Trench (1837-2023)* Poster. Additional regional maps are available for regions near New Guinea and Bismarck Trenches, and New Hebrides Trenches.
- NCEI and ITIC created and printed the Historical Tsunami Effects: 2004 Indian Ocean Tsunami Poster.
- NCEI’s Image database has added over 150 images from 6 tsunami events since 2023, with ITIC being a major contributor. https://www.ngdc.noaa.gov/hazardimages/#/

9. Information on Tsunami Occurrences

During the intersessional period going back to September of 2023, U.S. Pacific coasts experienced just a single tsunami that prompted an alerts. This was the December 5, 2024, magnitude 7.0 earthquake located off the coast of northern California. NTWC issued a Tsunami Warning within 5 minutes for the nearest coastal areas in response, but was able to cancel the warning about an hour later based upon the nearby sea level readings. The undersea earthquake occurred on a transform fault with mostly sideways motion that is not efficient at generating tsunami waves. All other Pacific region earthquakes prompted only Tsunami Information Statements (TIS) from PTWC and NTWC, some for large but distant earthquakes and others for smaller felt local earthquakes.

In its role as a Tsunami Service Provider for the Pacific Tsunami Warning and Mitigation System, PTWC also issued 44 Tsunami Information Statements in response to large but non-tsunamigenic Pacific region earthquakes, as well as Tsunami Threat Message sequences for 9 large Pacific-region earthquakes that either generated tsunami waves or had the potential to do so. These events will be detailed in PTWC’s Tsunami Service Provider (TSP) report to the ICG/PTWS.

10. Web sites (URLs) of national tsunami-related web sites

General Resources

- U.S. Tsunami Warning System: https://www.tsunami.gov
- International Tsunami Information Center (ITIC):
  U.S. ITIC: https://tsunami.gov/?page=itic
  U.S. ITIC Caribbean Office: https://www.weather.gov/itic-car/#
  International, IOC: https://tsunami.ioc.unesco.org/en/pacific/itic?hub=48-
- National Centers for Environmental Information (NCEI) Tsunami Data and Information: https://www.ncei.noaa.gov/products/natural-hazards/tsunamis-earthquakes-volcanoes/tsunamis
- NOAA Center for Tsunami Research/Pacific Marine Environmental Laboratory (PMEL): https://nctr.pmel.noaa.gov/index.html
- Smart Cables
  ITU Joint Task Force:
  https://www.itu.int/en/ITU-T/climatechange/task-force-sc/Pages/default.aspx
  JTF International Program Office: https://www.smartcables.org/

Warning Center User's Guides

- Users Guide for the Pacific Tsunami Warning Center Enhanced Products for the Pacific Tsunami Warning System. IOC Technical Series No 105, Revised edition. UNESCO/IOC 2014 (English; Spanish).
  https://unesdoc.unesco.org/ark:/48223/pf0000220368?posInSet=1&queryId=b03eec55-7994-448d-89fe-bc223d0b9cc5
- *Operational Users Guide for the Pacific Tsunami Warning and Mitigation System (PTWS).* IOC Technical Series No 87, Second Edition. UNESCO/IOC 2009 (English only).
  https://unesdoc.unesco.org/ark:/48223/pf0000180097?posInSet=1&queryId=cc25ea38-8db7-4b22-9d13-946d72e1f7f7
- User's Guide for the Tsunami Warning System in the U.S. National Tsunami Warning Center Area-of-Responsibility, 2017, https://tsunami.gov/operations/opsmanual.pdf

Seismic Information

- U.S. Geological Survey (USGS) Earthquakes Hazard Program:
  https://earthquake.usgs.gov/earthquakes/
- Earthscope Data Management Center (DMC): https://ds.iris.edu/ds/nodes/dmc/

Sea Level Tools/Information

- Center for Operational Oceanographic Products & Services Tsunami website:
  https://tidesandcurrents.noaa.gov/tsunami/
- International Tsunami Information Center (Tide Tool): https://legacy.itic.ioc-unesco.org/legacy.itic.ioc-unesco.org/indexe38e.html?option=com_content&view=article&id=1573&Itemid=2931
- National Data Buoy Center (NDBC) DART Program:
  https://www.ndbc.noaa.gov/dart/dart.shtml
- University of Hawaii Sea Level Center (UHSLC):
  https://uhslc.soest.hawaii.edu/network/
- National Centers for Environmental Information (NCEI) Long-term Archive of NOAA Tsunami Water Level Data:

https://www.ncei.noaa.gov/products/natural-hazards/tsunamis-earthquakes-volcanoes/tsunamis/tide-gauge-data
https://www.ncei.noaa.gov/products/natural-hazards/tsunamis-earthquakes-volcanoes/tsunamis/dart-ocean-bottom-pressure
https://www.ngdc.noaa.gov/hazel/view/hazards/tsunami/marigram-search

11. Summary plans for future tsunami warning and mitigation system improvements.

Tsunami detection and measurement. The U.S. continues to work in concert with its international partners 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 Centroid Moment Tensor (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 (4G) of the DART network is currently in deployment phase. 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 10’s 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 as part of the PTWS instrumentation planning efforts.

GNSS Update: To facilitate incorporation of GNSS into TWC operations, PMEL’s NOAA Center for Tsunami Research (NCTR) is building a testbed at their location in Seattle, WA. They will be incorporating algorithm development done at various academic institutions into a prototype operational analysis system. GFAST was installed at the TWCs in Q4 FY24 and the capability has been successfully transferred to operations as an experimental augmentation for rapid earthquake source characterization. Funding to the EarthScope Consortium for the operation of GAGE Facility, including the Network of the Americas, will end at the close of FY 2025. The future funding of NOTA by the National Science Foundation (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 U.S. is also working to study the use of the Ionospheric total electron content (TEC) anomalies in tsunami detection and measurement; in particular, NASA’s Jet Propulsion Laboratory (JPL) is developing the GNSS-based Upper Atmospheric Real-time Disaster Information and Alert Network (GUARDIAN) system (see Section 13, “Tsunami Research Projects” below).

Science Monitoring And Reliable Telecommunications (SMART) Cables offer a compelling solution by integrating environmental sensors directly into commercial telecommunications infrastructure, creating permanent observatories across previously inaccessible ocean regions. At intervals of ~100 kilometers along a cable's length, repeaters that amplify telecommunications signals are equipped with seismic, pressure, and temperature sensors.

These sensors continuously collect data that flows alongside internet traffic, requiring minimal additional power while providing unprecedented insights into our ocean's depths. Ocean temperature and bottom pressure are Essential Ocean Variables (EOVs) of the Global Ocean Observing System (GOOS). SMART Cables has been designated an Emerging Observing Network of GOOS (one of 16 total).

After years of planning and technological development, the SMART Cable vision is now becoming reality. Off the coast of Sicily, the InSEA SMART Wet Demonstration Project has successfully deployed a 21-kilometer system featuring accelerometers, seismometers, and pressure and temperature sensors. This installation is providing real-time data, proving that sensitive scientific instruments can operate reliably within telecommunications repeater housings.

Building on this success, more ambitious projects are underway. Portugal's Atlantic CAM SMART system will soon create a 4,000-kilometer ring connecting the mainland to the Azores and Madeira Islands, featuring approximately 20 sensor nodes and fiber for distributed acoustic sensing. In the South Pacific, the TamTam SMART Cable will link New Caledonia and Vanuatu across 450 kilometers, placing critical monitoring capabilities directly within one of the world's most tectonically active yet under-observed regions.

These initial deployments are just the beginning. Planning is advancing for systems in the Southern Ocean—one of Earth's most challenging environments for scientific observation. The NSF Antarctic Cable will stretch from New Zealand to McMurdo/Scott Station, crossing the Antarctic Circumpolar Current and terminating at McMurdo Station on the shore of the Ross Sea, a primary formation zone for Antarctic Bottom Water. Similarly, the Chile Antarctic Cable will traverse the Drake Passage from Puerto Williams to King George Island, monitoring the narrowest chokepoint of the world's most influential ocean current.

The scientific community's excitement about these installations stems from their transformative potential. For climate scientists, SMART Cables offer continuous, non-aliased observations of critical ocean circulation patterns. Antarctic Bottom Water will now be tracked year-round. The powerful Antarctic Circumpolar Current, whose transport estimates vary significantly due to measurement limitations, will be continuously monitored with unprecedented precision.

For communities vulnerable to tsunamis, these cables promise improved early warning capabilities. The TamTam system, for instance, will monitor the complex Vanuatu subduction zone—a region with significant tsunami generation potential threatening multiple Pacific nations. As highlighted in the UNESCO experts meeting report, the southern Vanuatu Trench area represents a critical knowledge gap with significant tsunami generation potential that threatens multiple Pacific nations simultaneously. Its sensors will help characterize maximum potential earthquakes, improve understanding of segmentation along the subduction zone, detect slow earthquakes that influence tsunami generation, and monitor non-seismic tsunami sources. And, the motivation behind the Atlantic CAM SMART system is the devastating 1755 earthquake and tsunami. SMART Cable networks, once deployed throughout the Pacific, will significantly enhance the ability to detect, measure, and characterize tsunamis quickly, regardless of source mechanism.

The momentum behind SMART Cables continues to build. With approximately €200 million already invested and ten additional systems in planning stages worldwide, this approach is increasingly recognized as a cost-effective solution for improving both scientific understanding and hazard resilience. As other nations adopt the technology, the United States continues its support through agencies including the National Science Foundation and National Oceanographic and Atmospheric Administration.

The global network of SMART Cables now emerging represents far more than an incremental improvement in ocean observation capabilities. It marks a paradigm shift—transforming static telecommunications infrastructure into dynamic observatories that continuously monitor our planet's vital signs. As climate change accelerates and coastal populations grow, these dual-purpose systems will provide the data foundation needed for both scientific advancement and societal resilience in the face of ocean-borne threats.

Earthquake Early Warning: Earthquake early warning systems are operational or in development in many countries around the world (e.g., Mexico, Japan, United States, Romania, China, Italy, Costa Rica, El Salvador, Nicaragua, India, Israel, Switzerland, South Korea, and Taiwan). These systems automatically detect and characterize earthquakes in seconds to provide warnings of pending ground shaking. Many of these systems, such as the USGS ShakeAlert system, required the expansion and hardening of seismic instrumentation, telemetry, and alerting systems. Tsunami monitoring may directly benefit from both the rapid earthquake detections and improved seismic networks(e.g., SMART cables with seismic sensors). Opportunities may also exist to leverage improved automatic detection algorithms and coordinate Earthquake Early Warning and Tsunami Alerts which result from seismic events.

U.S. Tsunami Warning Center (TWC) Alignment. The U.S. National Weather Service (NWS) is undertaking a comprehensive redesign of the U.S. Tsunami Warning System in order to both improve capabilities and ensure 100% failover capability between the two TWCs. This includes designing and building a comprehensive Common Analytic System (CAS) to ensure both TWCs are working from the same scientific and procedural baseline when a tsunami event occurs. The first major milestone is the transition of legacy TWC messaging generation software to NWS supported architecture in mid/late 2025. Having the same operational hardware ensures that the process of message creation and seamless backup capabilities will be possible, once the appropriate testing and evaluation activities is complete.

The second goal of the redesign is to ensure that NWS tsunami core partners, such as U.S. State and territorial emergency management agencies and international core partners (Pacific and Caribbean country national tsunami warning centers and emergency management agencies, tsunami warning focal points, and tsunami national contacts) receive IDSS designed to meet their needs to provide warnings and public safety. IDSS is defined broadly to encompass both routine (non-event) and episodic (event) services. Routine IDSS activities prepare in advance for the next tsunami, and can encompass training (informational, operational, hazard risk assessment, response, etc), exercises, education, and awareness. Episodic IDSS activities in real time during the actual event to ensure that the TWC products are received and understood, and so enable core partners to make more informed public-safety decisions.

Progress on new Tsunami.gov Public Webpage. The long-standing tsunami.gov website (https://www.tsunami.gov/) is undergoing a major redesign of the current functionality. The new prototype webpage remains under development with a goal of improved usability, enhanced functionality, and more dynamic methods to display, download, and ingest data from the site. Among the improvements is a dynamic GIS-based web display of recent notable and/or current seismic events. Metadata and issued products will be more readily available and displayed in a more aesthetically appealing manner to review event data in dashboard offering. Overall, the new prototype webpage is easier to navigate and contains more information about recent past events, activities relevant to U.S. and international partners and customers, and archived, historical cases.

Hazard Simplification for NWS Tsunami Headline Products. The U.S. National Weather Service (NWS) is evaluating the effectiveness and clarity of the current headline terms for tsunami messages (Watch, Advisory, and Warning). This is a supplemental effort to a larger study for these terms for other weather-based service program areas (i.e. Winter, Public, Fire, Marine, and Tropical) that was performed a few years prior. This project is utilizing Social, Behavioral, and Economic Sciences (SBES) to assess the effectiveness of current tsunami hazard messaging (i.e., headline terms, messaging body) via a survey of members of the public, core partners, and stakeholders, primarily across the Pacific. Eastern Research Group, Inc. (ERG) is leading this project to develop and deploy a survey instrument, testing the current terms, potential new terminology, and other options for improved messaging. Headlines and messages tested in this study must be compatible with established dissemination and communications methods. Domestic PTWS products will not be adjusted at this time, as the NWS is aware that many countries have followed and adopted U.S. NWS domestic alert messages. After the survey results are gathered, a final report will be provided to the NWS.

Seismic Monitoring. The U.S. supports an extensive Global Seismograph Network (GSN) in the Pacific, Indian Ocean, Atlantic, Caribbean, and Gulf of America. The U.S. Geological Survey (USGS) National Earthquake Information Center (NEIC) 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 and the EarthScope Consortium. In addition to the GSN stations, 97 U.S. backbone stations are part of the Advanced National Seismic System (ANSS). Over the last several years the primary sensors at many of the GSN stations have been upgraded to the latest generation of very broadband seismometers. The USGS has been working with Fiji and Tonga to install new seismic stations, the first is scheduled for October 2023. During that installation the USGS will visit nearby GSN stations to try and fix communication issues. To obtain real-time data from the USGS, email David Mason (dmason1@usgs.gov). To access realtime or archived data from Earthscope visit https://ds.iris.edu/ds/.

A number of other U.S. institutions also support earthquake monitoring activities in the Pacific and adjacent regions such as the Alaska Earthquake Center (AEC), Pacific Northwest Seismic Network (PNWSN), and the northern and southern California seismic networks.

Map Viewers

- The NCEI Natural Hazards Viewer is currently being re-designed using modern web technologies/frameworks. Users will see increased performance/responsiveness, better usability on mobile devices, and improved accessibility.
- NCEI updated the interactive Tsunami Events (1850 to Present) Time-Lapse Animation to include runup observations.

Digital Elevation Models (DEM)

- Through the U.S. National Tsunami Hazard Mitigation Program (NTHMP), NOAA supported NCEI in the release of:
    - Updated regional-scale Central Pacific (vol.7) Coastal Relief Model as described in Section 8, above.

- New and updated high-resolution tiled DEMs for Columbia River, OR and WA; Puget Sound and Salish Sea, WA; Point Reyes, CA; Nome, Norton Sound, Northwestern Bering Sea, Alaska as described in Section 8, above.

U.S. TsunamiReady® Program

- Through the NWS Tsunami Program, NOAA supported renewals of 31 communities in Hawaii, Guam, and American Samoa, including the strengthening of local and territorial capabilities.

UNESCO IOC Tsunami Ready Recognition Programme

- ITIC, as the PTWS Tsunami Information Center, has a mandate to facilitate the Tsunami Ready Recognition Programme in the PTWS. Current active requests to facilitate Tsunami Ready recognition are from Ecuador, Mexico, and Peru.
- ITIC and ITIC's sub-office in the Caribbean (ITIC-CAR) received US funding to support support Tsunami Ready projects in the Pacific (previouslyFiji, Federated States of Micronesia, Marshall Islands, Palau, and partially for Kiribati, Samoa, Solomon Islands, Vanuatu) and Caribbean (previously Barbados, Dominica, Saint Lucia, and partially for Anguilla, Antigua and Barbuda, Honduras).
- ITIC has prepared videos highlighting implementation of the Programme in several recognized communities in the Caribbean and Pacific.

World Tsunami Awareness Day (WTAD)

- ITIC support World Tsunami Awareness Day (November 5, 2024) hosted a website, providing static and moving visuals and documentation, subject matter expertise, and working in collaboration with the IOC Tsunami Resilience Section and the UN Office of Disaster Risk Reduction.

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 sustainment of the UNESCO/IOC Tsunami Ready Recognition Programme, including the Chairing of UNESCO/IOC Tsunami Ready Coalition by Dr. Laura Kong, Director of ITIC, and supporting the ITIC as the PTWS TIC to facilitate the implementation of the UNESCO-IOC Tsunami Ready Recognition Programme.

Outreach, Education, and Communications

- ITIC conducted in-person trainings in coordination and collaboration with the IOC for Tsunami Ready, Tsunami Warning Center and Emergency Response Standard Operating Procedures, and Tsunami Evacuation Planning.
- ITIC conducted its 2-week ITIC Training Programme on Tsunami Early Warning Systems, including the PTWC Enhanced Products and Tsunami Ready in Hawaii in August 2023 for 21 Pacific and 5 Caribbean countries, and in Chile in August 2024 for 18 Pacific and Caribbean countries hosted by the Chilean Hydrographic and Oceanographic Service (SHOA), who serves as the ITIC Associate Director.

- ITIC will continue to develop and distribute educational and decision support resources.
- ITIC and PMEL continue to develop and distribute the Tsunami Coastal Assessment Tool, TsuCAT, to assist countries in hazard assessment, response planning, and in conducting exercises (scenario development, PTWC message generation, exercise situational injects).
- ITIC will continue to collaborate with all Pacific countries to organize and provide training in tsunami warning, response, and evacuation planning and warning decision support tools, facilitate Tsunami Ready implementation, and support outreach and awareness-building activities.
- ITIC, as an IOC Ocean Teacher Global Academy Specialized Training Center (OTGA STC), will develop online and hybrid training courses, available to all PTWS Member States, and globally. The courses are developed in coordination with the IOC Tsunami Resilience Section. Courses that are currently available are
    - UNESCO-IOC Tsunami Awareness (6-hr online, self-paced), since July 2024
    - UNESCO-IOC Tsunami Ready (3-hr online, self-paced), since January 2025

  Course that are planned will support the PTWS Tsunami Warning Center Minimum Staff Competencies Training Course, which is envisioned to be comprised of the above courses, and additionally planned for 2025 are:
    - Science Core Knowledge in earthquakes and tsunamis (online, self-paced)
    - Tsunami Warning Center and Emergency Response Standard Operating Procedures (online and blended, based on ITIC in-person training courses)
    - Communicating Risks using the IOC Tsunami Service Provider Tsunami Products, including from the PTWC (online, self-paced)

  Future courses planned are other ITIC in-person training courses, such as
    - Tsunami Maps, Plans, and Procedures, including inundation mapping (TEMPP) (160-hr online/blended) - planned

  At TOWS-XVI (March 2023), the Group noted the PTWS's progress as a step toward with the goal of developing a global framework for all ICGs to use At the ICG/PTWS-XXX (September 2023), PTWS National Tsunami Warning Centre (NTWC) Competency Framework was approved by Member States, and the offer of , by the ITIC to pilot the Framework by developing a Training Course accepted. The ITIC is currently developing course modules in partnership with Member States with advanced tsunami warning centers, such as the Pacific Tsunami Warning Center.
- The U.S. welcomes the elimination of fax services for PTWS TSP bulletins at the end of March 2025.

NATIONAL PROGRAMMES AND ACTIVITIES INFORMATION

12. EXECUTIVE SUMMARY

Overview

During the last intersessional period, the U.S. has focused on improving tsunami detection, measurement and forecasting capabilities in the Pacific as well as supporting advanced mitigation and preparedness efforts.

Improved tsunami detection and source characterization. These efforts include:

- Continued testing of the **4th Generation of DART** with advanced seismic noise filtering to allow for near-field placement.
- Continued testing and development of advanced **geodetic analysis** in tsunami source

estimation using GNSS station static offsets. We expect initial capability to use this technique operationally within 2 years.
- Continuing to investigate tools to rapidly compute **EQ focal mechanism via the W-phase method**, and supporting research regarding tsunami detection using the ionospheric **total electron content** (TEC) methodology.
- Supporting the continued development of **SMART cables** to augment legacy tsunami detection and measurement networks.

Improved tsunami forecast capability.
- TWC Operational System upgrades to enable input of GNSS-based deformation results, and on-the-fly tsunami source computation.
- DEM expansion for coastal U.S. locations with high tsunami impact risk
- Alignment of tsunami detection, measurement and forecasting procedures between U.S. TWCs, and proactive efforts to provide IDSS to core partners, such as U.S. emergency management agencies, and Pacific and Caribbean national agencies responsible for tsunami warning, such as national tsunami warning centers and emergency management agencies.

U.S. TsunamiReady Program.
- There are currently 31 TsunamiReady communities in the Pacific: Hawaii (22), Guam (6), and American Samoa (3). The renewal cycle is 4 years. https://www.weather.gov/TsunamiReady/communities
- NOAA, through the National Tsunami Hazard Mitigation Program (NTHMP), provides funding to Guam, CNMI and American Samoa that support Tsunami Ready.

Other Preparedness and Mitigation activities.
- ITIC has resumed in-person outreach activities in which tsunami guidance is provided, including its 2-week ITIC Training Program in Tsunami Early Warning Systems held in Hawaii in 2023 and Chile in 2024
- NCEI and ITIC updated the *Global Historical Tsunami, Significant Earthquake, and Significant Volcanic Eruption* posters in 2023.
- NCEI and ITIC updated the *Global Historical Tsunami, Significant Earthquake,* and *Significant Volcanic Eruption,* and *American Samoa/Samoa/Tonga* regional posters to 2023. Additionally, the NCEI and ITIC developed Historical Tsunami Effects: 2004 Indian Ocean Tsunami poster.
- PMEL, ITIC, and PTWC continued the development of new features in the TsuCAT software and made it available to training participants. New features for V4.4(released August 2024) include the addition of automated, customized exercise injects.
- PMEL is developing tsunami hazard risk assessment products for several coastal locations around the Pacific as part of the DOS natural hazard assessment project.
- PMEL continued to maintain and update ComMIT modeling tools for tsunami inundation simulations. New version ComMIT 1.8.3 has been released and has been used for several IOC training and tsunami hazard assessment activities in the Pacific and Caribbean regions.
- ITIC developed online training as an IOC Ocean Teacher Global Academy Specialized Training Center for Tsunamis, with courses available in 2024 as UNESCO-IOC Tsunami Awareness and in 2025 UNESCO-IOC Tsunami Ready.
- ITIC created informational videos for Tsunami Ready recognitions in Fiji, and for ITP-Hawaii 2023 and ITP-TEWS Chile 2024. A global Tsunami Ready video by NWS Director, Ken Graham was created in 2023. Videos are available at the ITIC You Tube site

- ITIC has created informational training videos on the PTWC Products for the Pacific and Caribbean (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 (*Password: training).*

Exercises

- PACIFIC WAVE
  - Exercise Pacific Wave 2024 (PacWave). ITIC supported the Task Team to develop the format, create the Exercise Manual, host the web site, and post-exercise evaluation tool. ITIC was also active in the development and conduct of the Pacific Island Countries Regional Tsunami Exercise, and hosted the email list-serve that was part of the live communication sharing. The PTWC provided the exercise messages.
- PACIFEX24
  - Pacific Exercise 2024 (Pacifex24) was conduced on May 23, 2024. NTWC created and distributed the exercise materials (Exercise Manual, hosted the web site, and post-exercise evaluation process) to participants ahead of the event. NTWC also supported the format of the exercise, based on U.S. West Coast partner requirements and disseminated the test exercise messages, facilitated the online chat room (NWSChat 2.0 on Slack) coordination, exercise injects, mock event images. Participants in the live exercise included at least 9 NOAA National Weather Service (NWS) Weather Forecast Offices (San Diego, Oxnard, Monterey, Eureka, Medford, Portland, Seattle, Juneau, Anchorage) other NWS participants, at least 3 state/provincial Emergency Management agencies, and international partners from Environment and Climate Change Canada, Natural Resources Canada, and the Canadian Hydrographic Service. Multiple additional groups observed the exercise while participating less directly.
- Routine Communications Testing
  - PTWC and NTWC confirms the successful communication of informational and alerting messages with key domestic partner agencies following each informational or alerting message issuance and follows up when needed on any dissemination shortcomings reported.
  - PTWC, as a PTWS TSP, issues regularly-scheduled monthly communication tests to all PTWS TWFPs and NTWCs via their designated contact information and similarly follows up when needed for any dissemination shortcomings reported.
  - PTWC also contacts by telephone, when possible, the nearest affected Member State TWFPs or NTWCs to confirm the receipt of threat messages and otherwise advise regarding the situation.
  - NTWC conducts monthly communications test with key partners and stakeholders and routinely checks and adjusts communication addressing to groups and stakeholders.

13. NARRATIVE

Focus Areas

The U.S. 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:

- Detection and Measurement
    - Advocate full sharing of available data at time and space resolutions necessary for tsunami detection and measurement
    - Determine spatial and temporal resolutions necessary to detect and measure tsunamis from all sources
    - Identify candidate new capabilities to be tested and possibly deployed within the region
    - Consider new research initiatives to add detection and measurement capabilities currently developed as prototype at NASA JPL (e.g., ionospheric TEC)
    - Identify instrumentation and or communications investments can make in order to contribute to the PTWS Tsunami Detection and Measurement initiatives
    - Support the development and deployment of SMART Cables to create a more robust and redundant tsunami detection network that can detect tsunamis from all sources and provide more rapid detection and measurements

- Risk Assessment, Warning Communications and Preparedness and Response
    - Advance the understanding of tsunami risk and hazard assessments from all sources of tsunamis.
    - Ensure that all people at risk from a tsunami are alerted and reinforce the warning messages.
    - Maintain and augment the number of communities in the U.S. and globally that are recognized by the U.S. National Weather Service or UNESCO as Tsunami Ready.
- Support multi hazard early warning alignment by linking hazard-specific systems together.
- Apply an inclusive approach by providing a balanced platform for gender and generational participation as recommended by the United Nations (UN).

Tsunami Warning Center Operations

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 in 2024.

Tsunami Research Projects

<u>GNSS</u>

- 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 (NCTR) 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.
- NCTR is developing tsunami modeling capabilities for forecasting volcano tsunamis and meteotsunami impact, following the 2022 Hunga Tonga-Hunga Ha'apai tsunami event. Forecast modeling from both flank-collapse and atmospheric forcing are being considered.
- PMEL continued development, training and research toward improving tsunami inundation forecast capabilities for the U.S. and Pacific coastlines. Collaboration efforts with New Zealand and Chile established a common tsunami flooding forecast framework using tools developed by PMEL: ComMIT, Tweb and SIFT.
- NASA's Jet Propulsion Laboratory is developing the GNSS-based Upper Atmospheric Real-time Disaster Information and Alert Network (GUARDIAN) system, a near-time-time ionosphere-based disaster monitoring capability.
  It relies on monitoring measurements of the ionospheric total electron content (TEC) obtained through ground-based GNSS stations. This technique is particularly valuable because it allows the monitoring of disasters in a radius of about 1200 km around each station. The only delay in detection is the time it takes for sounds, (infrasound or gravity waves) to travel from the Earth's surface to the ionosphere – 8 to 40 minutes depending on the type of event or wave.
- The GUARDIAN system relies on three main components: the real-time collection of data and computation of observables, the automatic detection of disaster-related perturbations in those observables, and possible creation of relevant warnings. The architecture and the first component are described by Martire *et al.* (2023, 10.1007/s10291-022-01365-6). A publicly-accessible portal intended for subject matter experts displays near-real-time GNSS-based TEC measurements and first-order analytics. GUARDIAN is based on technologies originally developed using JPL's Global Differential GPS (GDGPS) system, also utilizes real-time GNSS stations as part of the International GNSS Service (IGS) - all ensuring open-access and high-quality observations. AI-based automated detections have been demonstrated (Luhrmann *et al.*, 2025, 10.1007/s10291-024-01808-2) and will be implemented in the pipeline shortly. The GUARDIAN system's primary objective is to provide augmentation to already existing tsunami early warning systems. However, the technique may also be also applicable to monitoring other types of events including volcanic eruptions, various space weather phenomena, earthquakes, and anthropogenic hazards.

Other

- NCEI is collaborating with the University of Colorado-Boulder Library to scan and catalog tide gauge records from microfilm rolls of tsunami events prior to 1994. Six of the 13 uncatalogued microfilm rolls have been scanned by NCEI to produce 3,548 TIFF images. Once catalogued and archived, these records will become searchable and discoverable online.
- Updates to NCEI's DEM development processes and innovations included DEM validation using IceSat-2 elevation photons data and improvements to spatial metadata and DEM uncertainty grids. (See Section 8, above).
- 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

- ITIC has resumed in-person outreach activities, including in-person trainings, in which tsunami guidance was provided. ITIC maintains an office in Mayaguez, PR (ITIC-CAR) to support the Caribbean and its CTIC.
- NCEI and ITIC updated the *Global Historical Tsunami, Significant Earthquake,* and *Significant Volcanic Eruption,* and *American Samoa/Samoa/Tonga* regional posters to 2023. Additionally, the NCEI and ITIC developed Historical Tsunami Effects: 2004 Indian Ocean Tsunami poster. 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. Global and Regional Historical Tsunami Maps.
- PMEL, PTWC, and ITIC continued the development of new features in the TsuCAT software and made it available to some of the training participants. TsuCAT v4.4supports tsunami hazard assessment and tsunami exercises using the PTWC Products; the newest feature adds the option to automatically produce customized exercise injects. TsuCAT (ITIC).
- ITIC compiled U.S. and international resources on Marine Preparedness, including for Ports and Harbors (ITIC Guide).
- ITIC compiled U.S. and international resources on Vertical Evacuation (ITIC Guide).
- ITIC has online training as an IOC Ocean Teacher Global Academy Specialized Training Center for Tsunamis. Courses available in 2025 are *Tsunami Awareness and Tsunami Ready,* Ocean Teacher Global Academy - Disaster Risk Reduction.