NATIONAL REPORT

Submitted by the United States of America

BASIC INFORMATION

1. ICG/PTWS Tsunami National Contact (TNC)

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National Weather Service
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National Weather Service
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Cellular Telephone Number:

2. ICG/PTWS

Tsunami Warning Focal Point (TWFP)

Pacific Tsunami Warning Center (PTWC)
Person in Charge:
Title: Director, Pacific Tsunami Warning Center (PTWC)
Responsible Organization: NOAA/NWS/Pacific Region/PTWC
Address: 1845 Wasp Boulevard, Building 176; Honolulu, Hawaii 96818 USA
E-mail Address:
Emergency Telephone Number:
Emergency Fax Number:
Emergency Cellular Telephone Number:

National Tsunami Warning Centre (NTWC) (*if different from the above*)

Pacific Tsunami Warning Center (PTWC)
(covers U.S. island states and territories, backup for USNTWC)
Person in Charge:
Title: Director, Pacific Tsunami Warning Center (PTWC)
Responsible Organization: National Oceanic and Atmospheric Administration
National Weather Service
Address: 1845 Wasp Boulevard, Building 176, Honolulu, Hawaii 96818 USA
E-mail Address:
Emergency Telephone Number:
Emergency Fax Number: +
Emergency Cellular Telephone Number: +

U.S. National Tsunami Warning Center (USNTWC)
(covers other U.S. coastal states, backup for PTWC)
Person in Charge:
Title: Director
Responsible Organization: National Oceanic and Atmospheric Administration
National Weather Service
Address: 910 S. Felton Street, Palmer, Alaska 99645 USA
E-mail Address:
Emergency Telephone Number:
Emergency Fax Number:

3. Tsunami Advisor(s), if applicable

International Tsunami Information Center (ITIC)
Person in Charge: Dr. Laura Kong
Title: Director
Responsible Organization: National Oceanic and Atmospheric Administration
National Weather Service
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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 Hawaii, Alaska, Washington, Oregon, California, Guam, the Northern Mariana Islands, and American Samoa, due to their nearby seismic zones. 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, USNTWC 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 Center 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 large earthquakes near Guam, the Commonwealth of the Northern Mariana Islands, the Freely Associated States of the Republic of Palau, the Federated States of Micronesia, the Republic of the Marshall Islands, and for the Territory of American Samoa, but only with much sparser seismic and sea level networks. Consequently, initial warnings are only possible within about 10 minutes of the earthquake and wave confirmation could take up to an hour. After the 2009 South Pacific Tsunami, the PTWC implemented a local tsunami warning procedure for American Samoa that quickly alerts the population 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. PTWC also serves as the Tsunami Service Provider for Members of the IOC Caribbean Intergovernmental Working Group (ICG-CARIBE EWS) and provides forecasts and guidance for that basin.

Warnings and other tsunami products issued by PTWC and USNTWC are disseminated by a variety of means including telephone, dedicated circuits such as GTS, AFTN, EMWIN, and AWIPS, email, and fax to the responsible government agencies in each jurisdiction that may be the state, county, or municipality depending upon the local laws and policy. 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 sent simultaneously to Weather Forecast Offices 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, also has a built-in alarming/wake up call feature. TWC warnings will also activate Wireless Emergency Alerts (WEAs) via cell phones to the coastal areas under those warnings. Warnings may also be received and subsequently interpreted and re-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 HF availability of reliable communications, continues to be a major challenge. The U.S. has sought to address this issue with low 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 USNTWC 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 canceled. A cancellation, however, does not mean 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)

Due to Hawaii's central location in the Pacific (where most of the world's tsunamis occur) as well as its large bathymetric extent which causes tsunami waves to shoal and grow in size, the islands of Hawaii are the U.S. coastal areas most threatened by distant tsunamis – those tsunamis that cause damage far from their source. Hawaii has historically been struck by destructive distant tsunamis a few times each century, and 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 USNTWC monitor the entire Pacific region for large earthquakes that may cause a destructive distant tsunami. USNTWC 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 USNTWC 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 Center 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.

Distant tsunami warnings issued by PTWC and USNTWC 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 the Emergency Alert System to interrupt commercial radio and television with a message, and by broadcasting warning information over the NOAA Weather Radio. All PTWC and USNTWC products are publically 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 United States supports an extensive sea level network in the Pacific for a variety of purposes, including tsunami detection and measurement. Gauges are operated by PTWC, USNTWC, NOAA's National Ocean Service (NOS), NOAA's National Data Buoy Center (NDBC), and the University of Hawaii Sea Level Center (UHSLC). Figure 2 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.

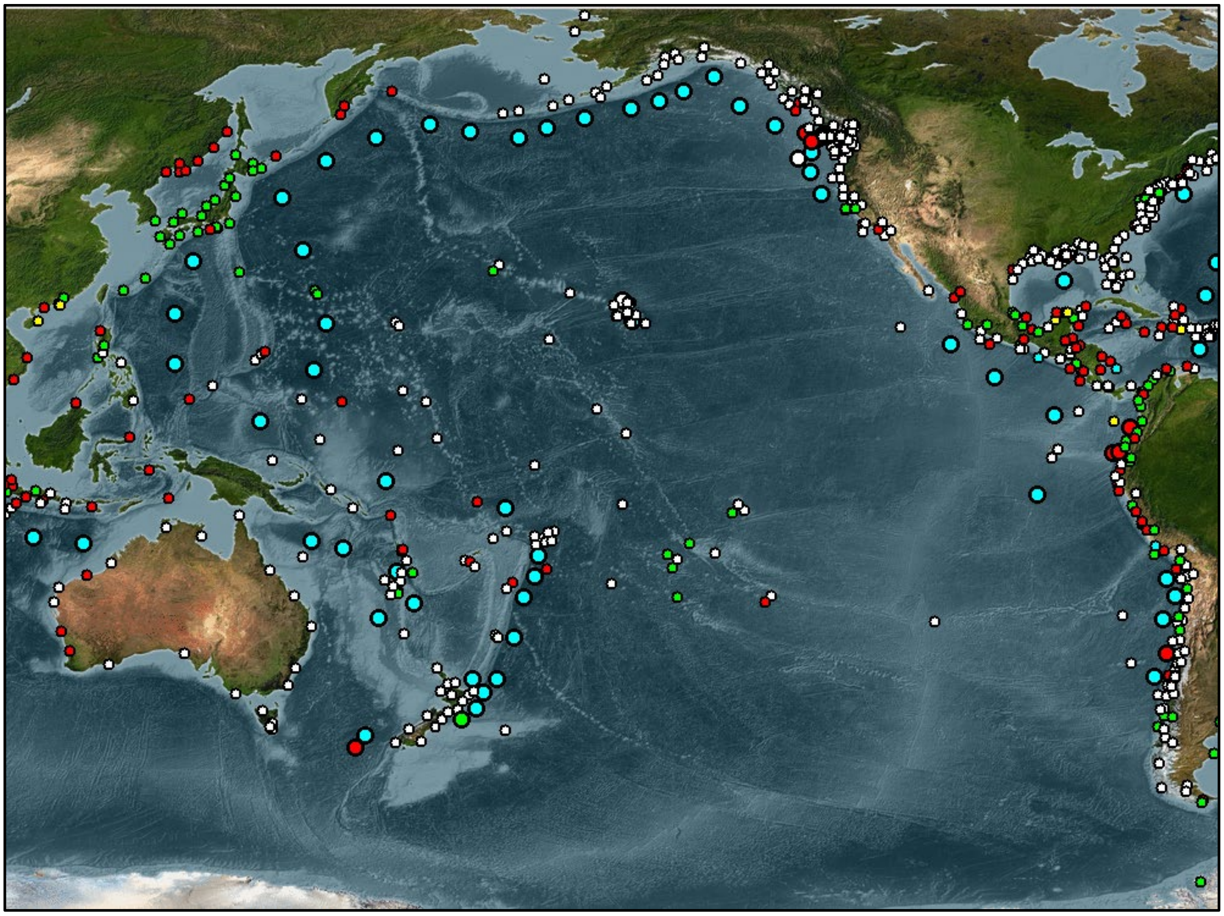

Figure 2: *Sea-level gauges in the Pacific Region monitored by the two U.S. tsunami warning Centers to detect and measure tsunami waves. Smaller circles are coastal gauges and larger circles are deep-ocean tsunameters. The fill color of each circle indicates the elapsed time since data from that gauge 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.*

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 (GMS) 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-two, nine deep ocean sensors, known as Bottom Pressure Recorders (BPR), are now operated by the National Weather Service/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 a commercial satellite 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 dense array of stations in Hawaii that transmit in real time over dedicated circuits or are accessed by a dial-up telephone line. They also operate 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 (USNTWC).*** To provide adequate coverage, USNTWC 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

Gauge Name	**Lat(+N,-S)**	**Lon(+E,-W)**	**SR**	**XR**	**Comms**	**Org**
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
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

Gauge Name	**Lat(+N,-S)**	**Lon(+E,-W)**	**SR**	**XR**	**Comms**	**Org**
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
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

Gauge Name	Lat(+N,-S)	Lon(+E,-W)	SR	XR	Comms	Org
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
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

Gauge Name	**Lat(+N,-S)**	**Lon(+E,-W)**	**SR**	**XR**	**Comms**	**Org**
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
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

Gauge Name	Lat(+N,-S)	Lon(+E,-W)	SR	XR	Comms	Org
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
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	DIAL	PTWC
Nawiliwili,Kauai	21.9570	-159.3600	1	000	DIAL	PTWC
Waianae,Oahu	21.4400	-158.1700	1	000	DIAL	PTWC
Haleiwa,Oahu	21.6000	-158.1100	1	000	DIAL	PTWC
Makapu`u,Oahu	21.3232	-157.6716	1	000	DIAL	PTWC
Kalaupapa,Molokai	21.2100	-156.9800	1	000	DIAL	PTWC
Lahaina,Maui	20.8750	-156.6920	1	000	DIAL	PTWC
Kahului,Maui	20.8980	-156.4720	1	000	DIAL	PTWC
Kapoho,Hawaii	19.5000	-154.8170	1	000	DIAL	PTWC
Honokohau,Hawaii	19.6710	-156.0280	1	000	DIAL	PTWC
Honokohau,Hawaii	19.6710	-156.0280	1	000	REAL	PTWC

Gauge Name	Lat(+N,-S)	Lon(+E,-W)	SR	XR	Comms	Org
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	1	000	REAL	USNTWC
Akutan_AK	54.1330	-165.7778	1	000	REAL	USNTWC
Sand_Point_AK	55.3367	-160.5017	1	000	REAL	USNTWC
Old_Harbor_AK	57.2200	-153.3056	1	000	REAL	USNTWC
Sitka_AK	57.0517	-135.3417	1	000	REAL	USNTWC
Craig_AK	55.4770	-133.1410	1	000	REAL	USNTWC
Shemya_AK	52.7308	174.1031	1	000	REAL	USNTWC

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
- USNTWC = 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.

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 1). 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.

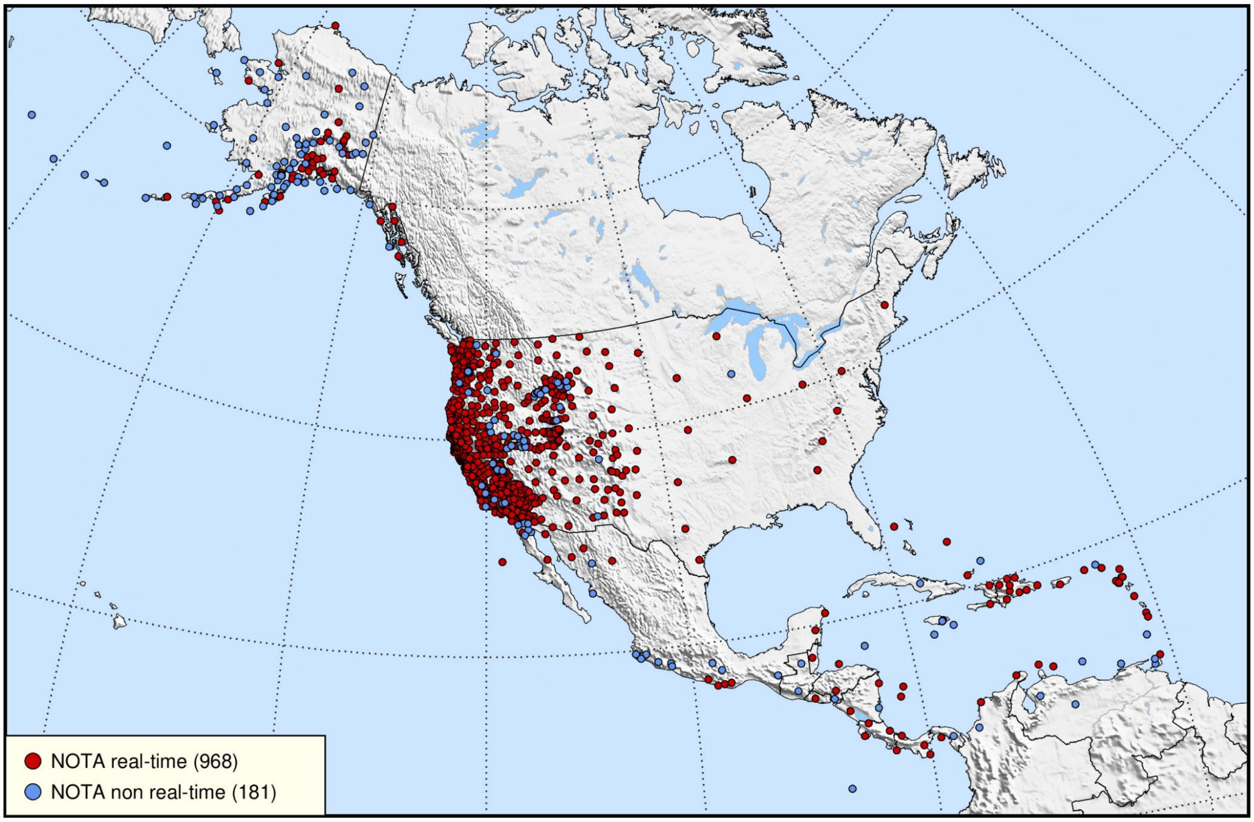

Figure 1: Distribution of the Network of the Americas (NOTA) cGPS/GNSS stations on May 31, 2023. NOTA is a federation of the former networks: PBO (U.S.), TLALOCNet (Mexico) and COCONet (Caribbean). The 1,257 station network spans Shemya Island in the western Aleutians to Puerto Rico in the northeastern 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 NOAA's 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 NOAA's 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 bottom data (temperature and pressure from both the older bottom pressure recorder and newer Deep-Ocean Assessment and Reporting of Tsunamis – DART platforms), coastal tide gauge data, as well as other related hazards and bathymetric data and information.

NCEI/WDS Recent Accomplishments:

- NCEI DEM Team completed new and updated existing digital elevation models (DEMs) for: Guam; American Samoa; Washington State Northern Coast; Strait of Juan de Fuca; Central Puget Sound; Oregon Coast; San Francisco Bay and Santa Cruz, California; Kenai, Ninilchik, Anchor Point, Tyonek, Prince of Wales Island, and Cook Inlet, Alaska. The DEMs are available via the NCEI Thredds data server or NOAA's Digital Coast and https://chs.coast.noaa.gov/htdata/raster2/elevation/NCEI_third_Topobathy_2014_8580/
- NCEI's DEM Team updated the global relief model ETOPO 2022. The new ETOPO 2022 resolution is an enhanced 15 arc-second resolution, about 0.5 km, which is four times higher than ETOPO1. Other notable improvements include improved global bathymetry, as well as improved global topography with reduced elevation bias from vegetation/ buildings. Access from NCEI at: https://www.ncei.noaa.gov/products/etopo-global-relief-model
- 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
- Since February 2020, NCEI has published a semiannual update on their tsunami data products and services. This includes an analysis of water level data observations of the tsunami caused by the January 15, 2022 eruption of Hunga Tonga – Hunga Ha'apai Volcano. https://www.ngdc.noaa.gov/hazard/dart/2022tonga.html
- 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 ITIC updated the *Global Historical Tsunami, Significant Earthquake, and Significant Volcanic Eruption* posters to 2022.
- NCEI and ITIC updated the *Historical Tsunami Effects:Tonga Trench (1837-2022)* Poster. Additional regional maps are available for regions near New Guinea and Bismarck Trenches, and New Hebrides Trenches.
- NCEI's Image database has added over 160 images from 13 tsunami events since 2021, with ITIC being a major contributor. https://www.ngdc.noaa.gov/hazardimages/#/

9. Information on Tsunami Occurrences

During the intersessional period going back to December of 2021, U.S. Pacific coasts experienced several tsunamis that prompted alerts from PTWC, USNTWC, or both. The most notable of these was the tsunami from the January 15, 2022, eruption of the Hunga Tonga - Hunga Ha`apai Volcano in Tonga. PTWC issued an Advisory and Warning for American Samoa and an Advisory for Hawaii, while USNTWC issued an Advisory for all of its Pacific service area stretching from the Aleutian Islands to California. Coastal gauge amplitudes were mostly in the Advisory range of 0.3 to 1 meter, but tsunami run-ups measured post-event exceeded 3 meters in some areas of the U.S. West Coast. There were no U.S. casualties from this event, but there was significant boat damage in some harbors. There were many lessons to be learned from this event including recognizing the need for better procedures and tools for evaluating tsunamis from non-seismic sources and more efficiently creating and disseminating products for non-seismic source tsunamis. The Advisories issued in Hawaii and along the U.S. West Coast did not reach the public through sirens or federally-coordinated wireless alerts. Consequently, some boat owners did not know about the tsunami hazard that came during the night. The more general problem of quickly identifying and forecasting hazardous tsunamis from non-seismic sources is being examined in the U.S. as well as the international tsunami community.

PTWC issued Tsunami Advisories for American Samoa for two other events, a magnitude 7.3 earthquake in Tonga on November 11, 2022, and a magnitude 6.9 earthquake south of Samoa on December 4, 2022. Neither event created hazardous tsunami waves in American Samoa.

USNTWC also issued an initial Warning (later downgraded to an Advisory) on 16 July 2023 for parts of the Alaskan coast following a magnitude 7.2 earthquake off the Alaska Peninsula. The maximum recorded tsunami amplitude was 0.15 m and no damage was reported along the Alaskan coast.

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

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). http://itic.ioc-unesco.org/images/stories/about_warnings/what_are_they/ts105-Rev2_eo_220368E.pdf
- *Operational Users Guide for the Pacific Tsunami Warning and Mitigation System (PTWS).* IOC Technical Series No 87, Second Edition. UNESCO/IOC 2009 (English only.)
  http://itic.ioc-unesco.org/images/stories/ptws/ptws_userguide2011_180097e.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) http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=1573:tsunami-warning-operations-sea-level-monitoring-tide-tool-and-ioc-sea-level-monitoring-facility&catid=2141&Itemid=2565
- 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.ngdc.noaa.gov/hazard/tide/
https://www.ngdc.noaa.gov/hazard/dart/
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 United States 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 CMT calculations, but also place increasing emphasis on direct deep ocean and coastal sea-level readings, and added emphasis on determining coseismic deformation through GNSS offset data.

DART 4G: NOAA's 4th generation of DART is currently being deployed. It provides a more robust communications and mooring capability, and through the use of seismic band-pass filters, allows the bottom pressure recorder to be placed much closer to the seismic source than was possible with previous generations. This presents the opportunity to make direct tsunami detections within 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, NOAA's National Center for Tsunami Research is building a test-bed at the Pacific Marine Environmental Laboratory (PMEL) in Seattle WA. They will be incorporating algorithm development done at various academic institutions into a prototype operational analysis system. As of Q3 of FY 2023 the testbed has been detecting and characterizing small events, and the initial operational system is scheduled to be installed at NOAA's Tsunami Warning Centers by November 2023. 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 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.)

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

As other countries are beginning to adopt SMART cables for ocean data collection, including tsunami detection and measurement, the U.S. will continue to support additional cable deployments through the U.S. National Science Foundation, National Oceanographic and Atmospheric Administration and other avenues, as SMART is seen as an important tool allowing for more targeted deployments of tsunameters in the highest risk areas, as well as accelerometers for the seismic parameters.

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 is undertaking a comprehensive re-design of the U.S. Tsunami Warning System in order to both improve capabilities and ensure 100% failover capability between TWCs. This includes designing and building a comprehensive and common analytic system that will ensure both TWCs are working from the same scientific and procedural baseline when a tsunami event occurs, and ensuring common hardware and software infrastructure between PTWC and USNTWC to improve and align data ingestion and analysis, tsunami forecast model guidance, and message creation and dissemination, in a way that advances a seamlessly coordinated backup between the two tsunami warning centers. The first major milestone is the transition of legacy TWC messaging generation software to NWS supported architecture by early CY 2025.

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

Seismic Monitoring. The United States supports an extensive Global Seismograph Network (GSN) in the Pacific, Indian Ocean, Atlantic, Caribbean, and Gulf of Mexico. 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 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

- NCEI developed the interactive Tsunami Events (1850 to Present) Time-Lapse Animation.

Digital Elevation Models (DEM).

- NCEI released an updated global relief model, ETOPO 2022, as described in Section 8, above.
- NCEI updated high-resolution tiled DEMs for Guam; American Samoa; Washington State Northern Coast; Strait of Juan de Fuca; Central Puget Sound; Oregon Coast; San Francisco Bay and Santa Cruz, California; Kenai, Ninilchik, Anchor Point, Tyonek, Prince of Wales Island, and Cook Inlet, Alaska, as described in Section 8, above.

U.S. TsunamiReady® Program

- Through the U.S. National Tsunami Hazard Mitigation Program, NOAA will continue to support 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 TIC, has a mandate to facilitate the Tsunami Ready Recognition Programme in the PTWS. Current active requests to facilitate Tsunami Ready recognition are from Ecuador and Mexico.
- The UNESCO IOC Tsunami Ready Recognition Programme web pages are hosted by the International Tsunami Information Center (ITIC) (TsunamiReady.org) and

regularly updated. This page includes documentation on Tsunami Ready, as well as a map and documentation of Tsunami Ready communities.

- ITIC and ITIC's sub-office in the Caribbean (ITIC-CAR) with USAID/BHA funding will continue to support Tsunami Ready projects in the Pacific (current support to Fiji, Federated States of Micronesia, Marshall Islands, Palau, new support starting in 2024 to Kiribati, Samoa, Solomon Islands, Vanuatu) and Caribbean (current support to Barbados, Dominica, Saint Lucia, new support starting in 2024 for Anguila, Antigua and Barbuda, Honduras).
- ITIC will be preparing videos highlighting implementation of the Programme in communities funded by USAID/BHA.

World Tsunami Awareness Day (WTAD)

- ITIC will continue to support World Tsunami Awareness Day by hosting a page on its website, providing still and moving visuals and documentation, 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 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 conducted in coordination with the IOC Tsunami Information Centers (CTIC, IOTIC, NEAMTIC), and Member States. Courses planned (2023-2025) are:
    - Tsunami Awareness (6-hr online), in final stages
    - Tsunami Ready (6-hr online) - (led by IOTIC), in final stages
    - Tsunami Early Warning Systems (40-hr online/blended) to be started

    - Tsunami Warning Center and Emergency Response Standard Operating Procedures (40-hr online/blended) - planned
    - Tsunami Maps, Plans, and Procedures, including inundation mapping (TEMPP) (160-hr online/blended) - planned
    - Tsunami Warning 'Center Staff Basic Competencies (120-hr online/blended) - proposed to pilot in 2024.
- At TOWS XVI it was recommended that:
    - The IOC Tsunami Secretariat facilitate the completion of the OTGA basic tsunami training materials as soon as possible. In June 2023, ITIC and the IOTIC met in order to finalize the Tsunami Ready module content.
    - The PTWS National Tsunami Warning Centre (NTWC) Competency Framework be finalized for endorsement by ICG/PTWS, and that the ITIC will pilot the Framework with the goal to develop a global framework for all ICGs to use. The ITIC is requesting support from USAID to develop and pilot the training component based on the Framework.
- The U.S. supports the WG2 recommendation to **eliminate the use of fax services for PTWS TSP bulletins** due to costs, redundancies and low usage rates. We support sunsetting this service in consultation with IOC/PTWS ICG.

<u>NATIONAL PROGRAMMES AND ACTIVITIES INFORMATION</u>

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.
- Released global relief model (ETOPO 2022)
- DEM expansion for coastal U.S. locations with high tsunami impact risk
- Alignment of tsunami detection, measurement and forecasting procedures between U.S. TWCs.

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.
- NCEI and ITIC updated the*Global Historical Tsunami, Significant Earthquake, and Significant Volcanic Eruption* posters in 2023.
- NCEI and ITIC are updating the American Samoa / Samoa / Tonga posters, *Historical Tsunami Effects: Caribbean, Central America, Mexico and Adjacent Regions (1530–2020)* Poster in 2023, and finalizing its *New Hebrides* poster in 2023. Additional regional maps are available for regions near the New Guinea and Bismarck Trenches
- PMEL, ITIC, and PTWC continued the development of new features in the TsuCAT software and made it available to training participants. New features for V4.3.2 (released August 2023) 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 is developing online and blended training as an IOC Ocean Teacher Global Academy Specialized Training Center for Tsunamis, with courses available in 2023.
- ITIC created informational video for Exercise Pacific Wave, and PSA for Exercise Caribbean Wave 2023 English, French, Spanish.
- 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).*
- *In 2023,* ITIC set up a YouTube Channel for sharing videos, including a Tsunami Ready video by NWS Director, Ken Graham.

Exercises

- PACIFIC WAVE
  - Exercise Pacific Wave 2022 (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.
- PACIFEX23
  - Pacific Exercise 2023 (Pacifex23). The USNTWC created and supported the format based on U.S. West Coast partner requirements, created the Exercise Manual, hosted the web site, and post-exercise evaluation process. USNTWC provided the exercise messages, online chat room coordination, event support,

exercise injects, images, and responses to questions in a Google Chat Room. 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 USNTWC 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.
  - USNTWC 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
- 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.

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

GNSS

- NOAA continued to work with NASA and NSF GAGE Facility operated by the Earthscope Consortium, Inc. to explore employing GNSS-derived offsets as a component of its tsunami forecast and warning capability. Over the past year, data streams have become more reliable and are now sufficient to calculate earthquake magnitude (from Peak Ground Displacement) earlier than by traditional seismic waveform analysis alone in certain regions. NOAA's tsunami warning centers will soon have a means of fully analyzing and incorporating GNSS offset data as this project transitions to operations.
- The NOAA Center for Tsunami Research (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, https://doi.org/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 utilizing real-time GNSS stations as part of the International GNSS Service (IGS) ensuring open-access and high-quality observations. Automated detections have been demonstrated (Luhrmann *et al.*, under review) 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.

<u>Other</u>

- NCEI released an updated global relief model, ETOPO 2022. The new model adds enhanced resolution that incorporates recent advances in data sources and processing techniques. ETOPO 2022 uses a combination of numerous airborne lidar, satellite-derived topography, and shipborne bathymetry datasets from U.S. and global sources. Its predecessor, ETOPO1, has been an important modeling tool for the tsunami community since its introduction more than a decade ago. ETOPO1 had a grid resolution of about 2 km. The new ETOPO 2022 resolution will be an enhanced 15 arc-second resolution, about 0.5 km, which is four times higher than ETOPO1.
ETOPO Global Relief Model | National Centers for Environmental Information (NCEI)
- 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 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. 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 Hazard Maps - International Tsunami Information Center
- PMEL, ITIC, and PTWC continued the development of new features in the TsuCAT software and made it available to some of the training participants. TsuCAT v4.3.2 supports tsunami hazard assessment and tsunami exercises using the PTWC Products; the newest feature adds the option to automatically produce customized exercise injects. TsuCAT - International Tsunami Information Center
- ITIC compiled U.S. and international resources on Marine Preparedness, including for Ports and Harbors. Marine Ports Guide - International Tsunami Information Center.
- ITIC compiled U.S. and international resources on Vertical Evacuation Vertical Evac Guide - International Tsunami Information Center.
- ITIC is developing online and blended training as an IOC Ocean Teacher Global Academy Specialized Training Center for Tsunamis. Courses available in 2023-2024 will be *Tsunami Awareness, Tsunami Ready, and Tsunami Early Warning Systems.* Ocean Teacher Global Academy - International Tsunami Information Center.