



Weather 101: Tsunamis

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Historical Tsunamis You May Recall...

Japan Earthquake + Tsunami of March 11, 2011 (Pacific Ocean) with wave height up to 130 feet (~40 m)



Destruction in Japan during the March 2011 tsunami.
Source: NOAA, Tsunami Strike: Japan video series



Devastation in Banda Aceh, Indonesia after the 2004 tsunami.
Source: NOAA Jetstream, Hokkaido University, Yuichi Nishimura

Boxing Day Earthquake + Tsunami of December 26, 2004 (Indian Ocean) with wave height up to 167 feet (~51 m)

Lituya Bay Earthquake, Landslide + Megatsunami of July 9, 1958 (Alaska, USA) with wave height up to 1720 feet (~524 m)



Lituya Bay in 1958 after the tsunami.
Source: NASA Earth Observatory



Tsunami Impacts

- Among the most infrequent, yet most devastating natural disasters on Earth
- Massive losses to life, water/power/communication infrastructure, agriculture
- Changes to shorelines, waterways, population distribution, socioeconomic status
- Extremely difficult, dangerous, and prolonged response and recovery efforts



Tsunami inundation on 9/29/2009 in American Samoa. Source: NOAA/NOS



Tsunami damage in Crescent City, CA from the 2011 tsunami, 10 hrs later
Source: NOAA Jetstream



Tsunamis: What They Are and Aren't

Tsunamis are...

- A **series** of **waves** with 10s to 100s of miles in between crests
- Caused by a **sudden** and **massive displacement** of ocean water
- Are **trackable** after they have started
- Somewhat predictable once they are detected
- Based on the Japanese characters for harbor (“tsu”) and wave (“name”)

津波

Tsunamis are not...

- **Tidal waves/bores** – caused by the gravitational pull of the Sun and Moon and the presence of a shallow waterway with a large tidal range
- **Rogue/Killer waves** – “Extreme storm waves” which are taller than twice the height of surrounding waves, often caused by constructive interference



So What Exactly is a Tidal Wave/Bore?

- Can look like a turbulent wall of water moving up a river or other tidal waterway
- Found where tidal ranges (water level between high and low tide) exceed 6 m (20 feet)
- Most common in shallow and narrow waterways which have a wide opening into the sea
- Most pronounced during spring tides – the higher high tides during Full or New Moon phase



A tidal bore in the Qiantang River, Hangzhou, China. Image courtesy of [Gwydion M. Williams](#), Flickr



A tidal bore at sunset in one of the rivers emptying into the Bay of Fundy between Canadian provinces of New Brunswick and Nova Scotia. Image courtesy of [Petra Yaremkowych](#), National Geographic Society

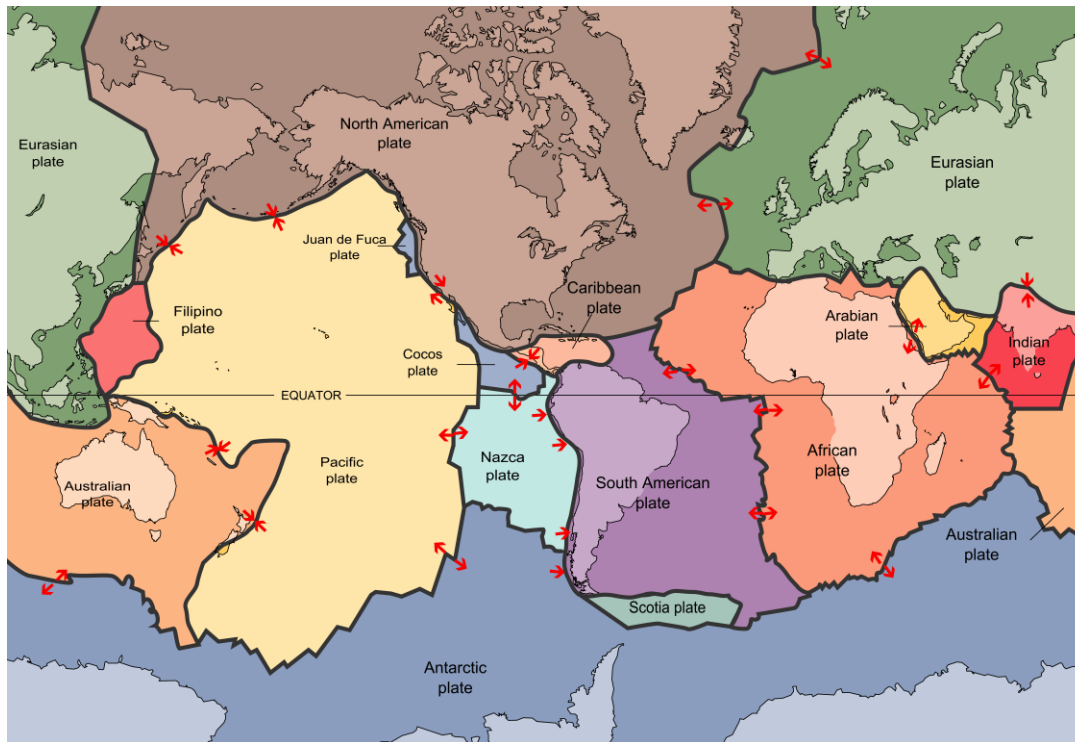


A tidal bore in the River Ribble, Lancashire, United Kingdom. Image courtesy of [Frangle Plazma Goat](#), Wikimedia Commons



Tsunami Causes: Earthquakes

RECALL: Earth's surface is composed of tectonic plates which are slowly but constantly moving

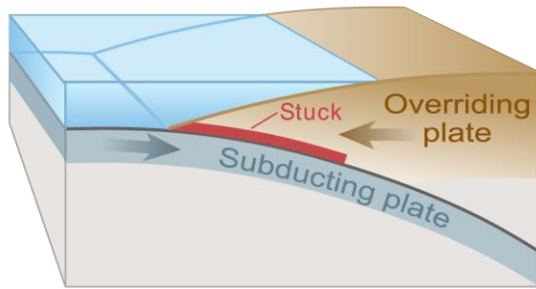


Map of tectonic plates and their directions of motion. Source: USGS

Tsunami Causes: Earthquakes

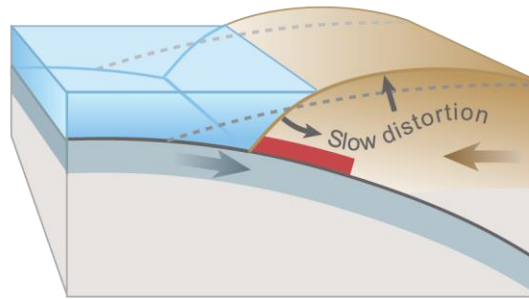
RECALL: Earthquakes occur when the overriding plate in a subduction zone snaps back.
DID YOU KNOW? Most earthquake-generating tsunamis are **M7.0 or greater** and **less than 100 km (62 mi)** below Earth's surface.

Tsunami starts during earthquake



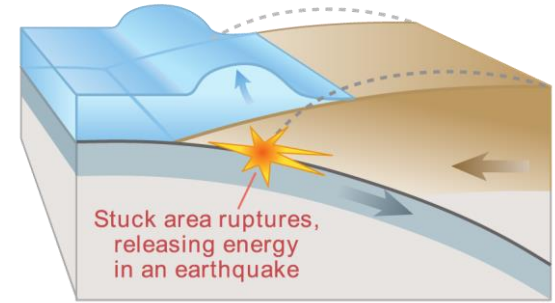
STEP 1

Subducting plate catches rocky edge of overriding plate.



STEP 2

Subducting plate pulls back edge of overriding plate, building up elastic potential energy, like pulling back a slingshot.



STEP 3

Overriding plate edge ruptures and rapidly springs back, causing an earthquake and displacement of water above it.



Graphics' source: NOAA Jetstream



Tsunami Causes: Landslides

RECALL: Landslides occur when rock, soil, and/or debris slide down a hill or mountainside above OR below water.

DID YOU KNOW? Even if an earthquake does not directly cause a tsunami by uplifting the ocean along a fault, a landslide resulting from an earthquake can still cause a tsunami, whether that landslide is above (subaerial) or below (submarine) water.



In November 1929, a magnitude 7.3 earthquake in the Atlantic Ocean triggered a submarine landslide that generated a tsunami. Waves up to 43 feet (13 meters) high were responsible for 28 deaths and \$14 million (2017 dollars) in damage along the coast of Newfoundland, Canada. Source: Natural Resources Canada; Harris M. Mosdell, from the collection of W.M. Chisholm

Tsunami Causes: Volcanoes

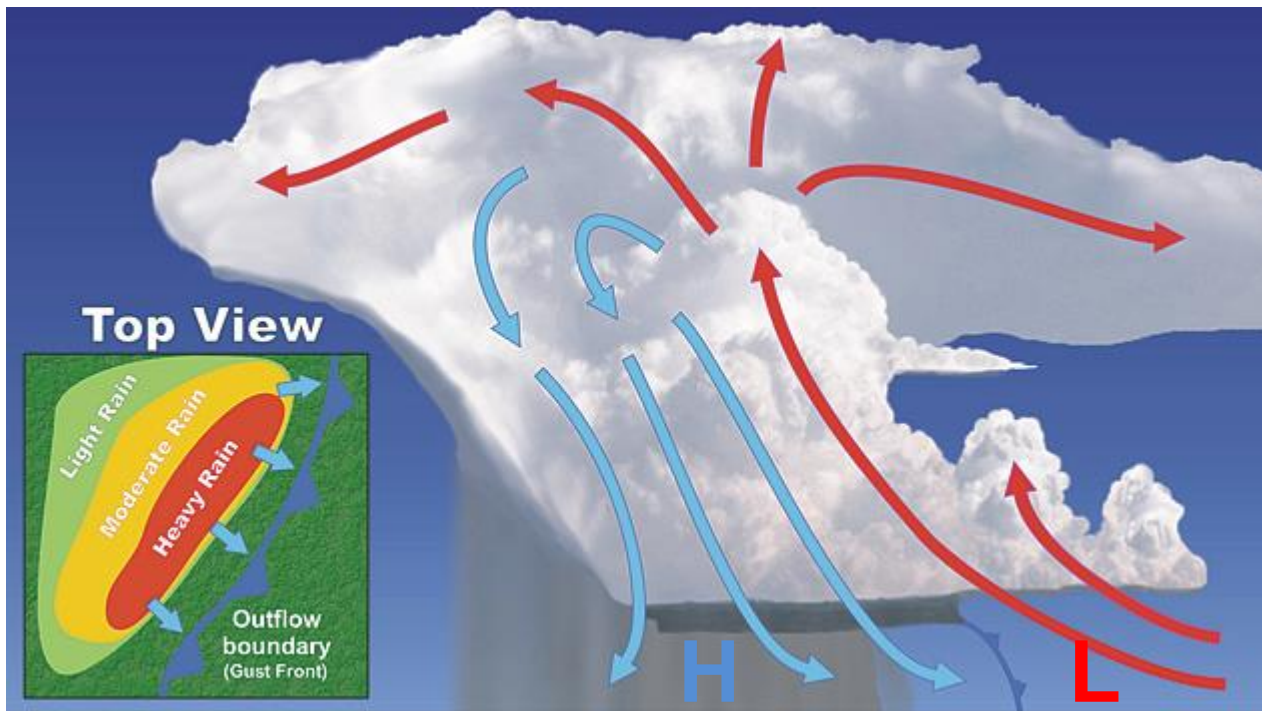
RECALL: Volcanic eruptions often produce a mass of lava, rock, and ash, called pyroclastic flow.
DID YOU KNOW? Landslides, pyroclastic flows, or a collapse of a volcano's walls can cause a landslide large enough to produce a local tsunami.
Submarine explosions near the surface and sideways eruptions out of volcanic vents can also cause local tsunamis.



The Augustine Volcano in Alaska (2006). In 1883, a debris flow from the collapse of the north face of the Augustine Volcano's peak caused a local tsunami. Damage to homes and fishing boats was reported. Source: U.S. Geological Survey, Game McGimsey

Tsunami Causes: Weather

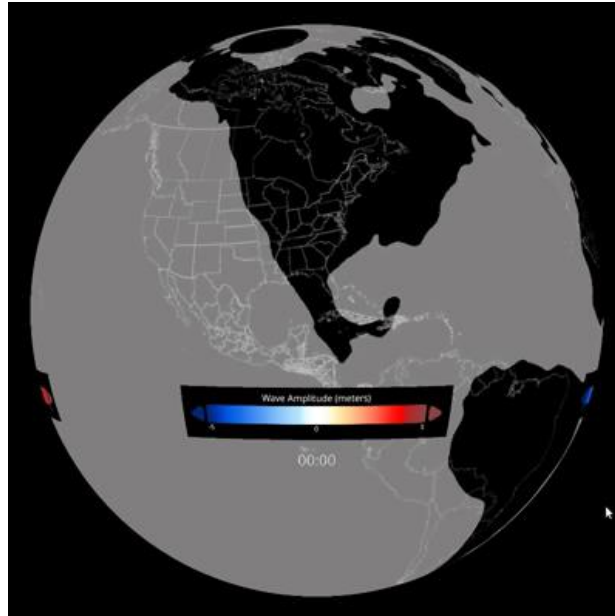
RECALL: Intense lines of thunderstorms produce large pressure changes over a short distance.
DID YOU KNOW? In some cases, this air pressure disturbance can cause a local tsunami in a similar fashion to an earthquake, but from above the water surface instead of below.



Tsunami Causes: Meteorites

RECALL: Any major displacement of water can result in a tsunami, including large meteorites
DID YOU KNOW? ~66 million years ago, a 6+ mile wide meteorite is widely accepted to have hit Earth and caused a megatsunami which wiped out most dinosaurs and about 75% of all plants and animals on Earth.

- The modeled wave reached up to 1.5 km (0.93 mi) high
- First wave may have reached up to 4.5 km (2.8 mi) high
- Black color fill depicts approximate shape and position of continents 66 million years ago



Source: NOAA Pacific Marine Environmental Lab and Geophysical Fluid Dynamics Lab



Tsunami Source Locations

Tsunami Sources 1610 B.C. to A.D. 2023
From Earthquakes, Volcanic Eruptions, Landslides, and Other Causes

Initiation Points

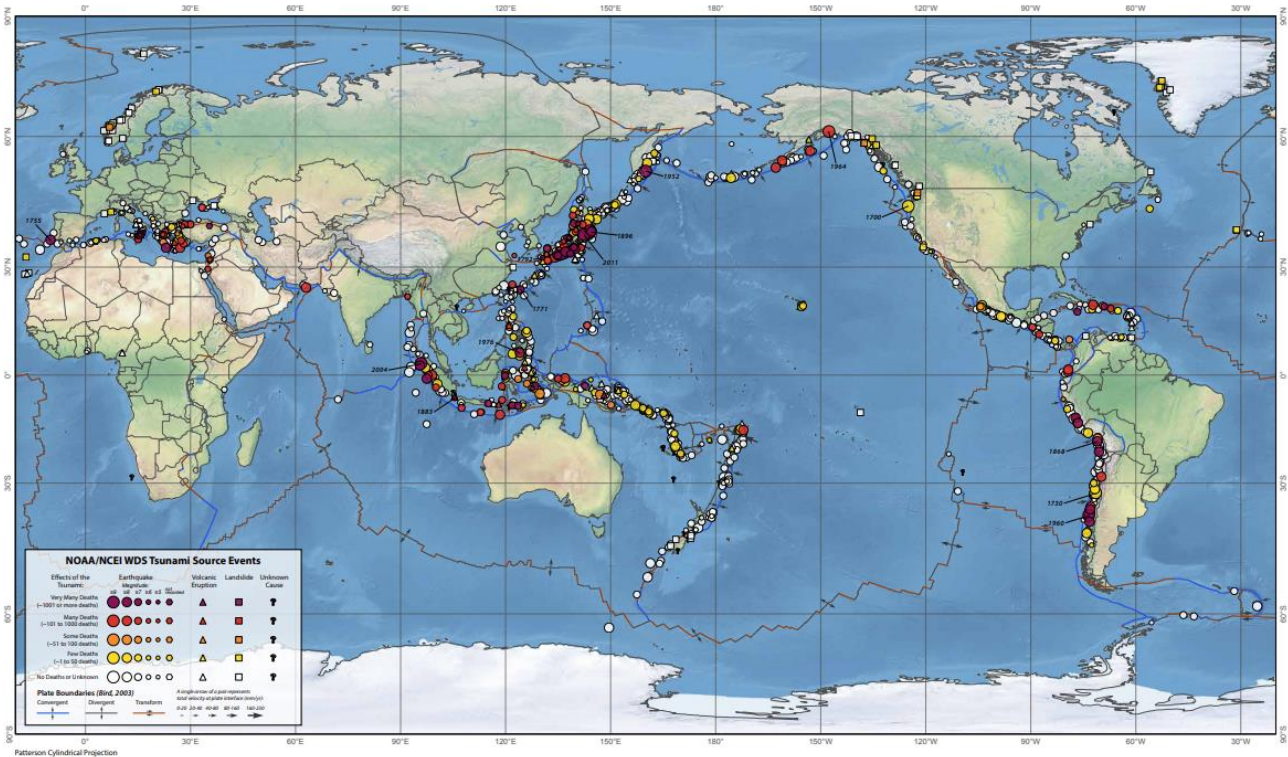
78% - Pacific Ocean

9% - Atlantic Ocean and
Caribbean Sea

6% - Mediterranean Sea

5% - Indian Ocean

1% - Other Seas



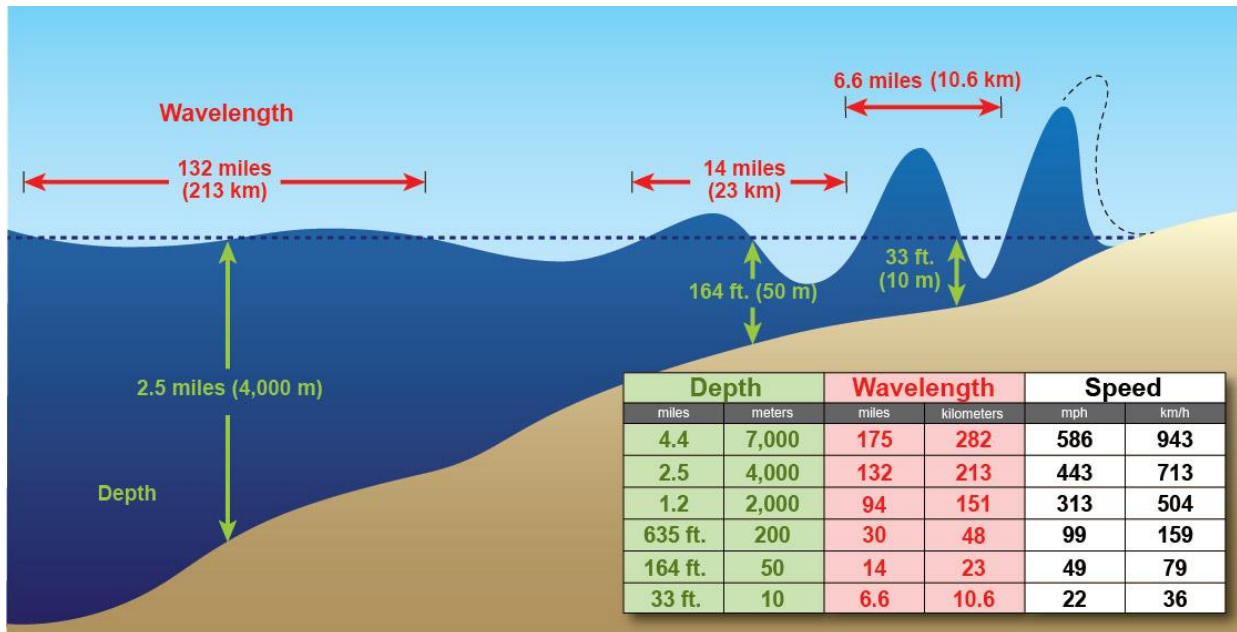
Patterson Cylindrical Projection
Symbol drawing order: more deaths on top of fewer deaths, volcanoes and landslides on top of earthquakes, lower magnitude earthquakes on top of higher magnitude.

Explore this data: <https://www.ncei.noaa.gov/maps/hazards/>



Tsunami Propagation: How They Move

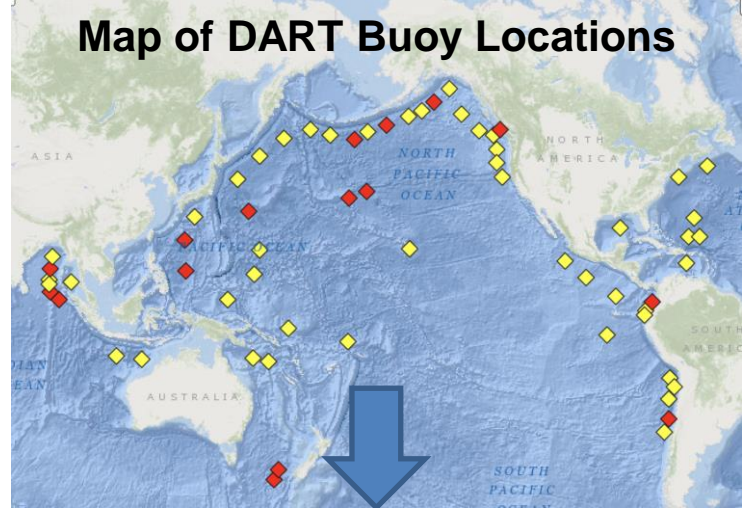
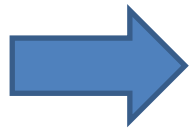
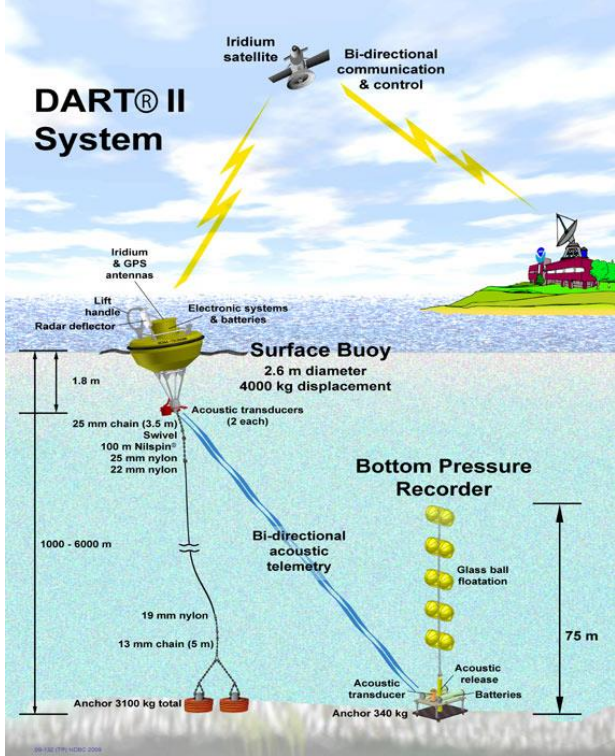
Fact: Tsunamis radiate outward in all directions from their source and travel faster in deep water



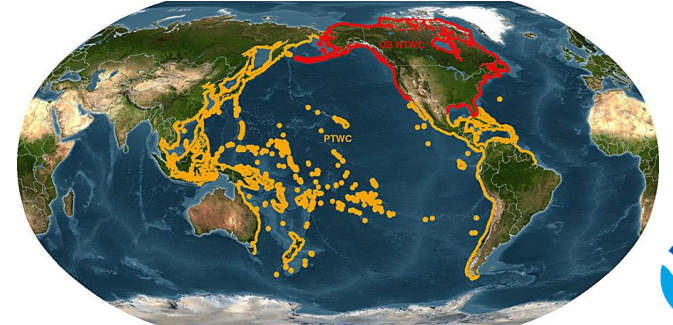
Graphic and chart showing how tsunami wave speed changes with ocean floor depth. Tsunamis travel faster in deep water and slow down in shallow water. Source: NOAA Jetstream



Tsunami Tracking: DART Buoys



Tsunami Warning Centers



DART = Deep-ocean Assessment and Reporting of Tsunamis



Tsunami Preparedness and Safety

- Understand tsunami warning signals – official tsunami warnings and natural signs
- Have multiple ways to receive earthquake and tsunami alerts
- Know your tsunami risk
- Know your evacuation routes and where to find higher ground
- If on a boat and in a harbor – exit the boat and find higher ground
- If on a boat and on open ocean – move to deeper water



NATURAL
Tsunami Warning Signs

- Feel a strong or long earthquake
- See a sudden rise or fall of the ocean
- Hear a Loud roar from the ocean

OFFICIAL
Tsunami Warnings
(broadcast through)

- Radio
- Outdoor Sirens
- Wireless Emergency Alerts and Text Messages
- TV
- Telephone Notifications

tsunami.gov

Warning	Dangerous coastal flooding & powerful currents possible	Move to high ground or inland
Advisory	Strong currents & waves dangerous to those in/very near water possible	Stay out of water, away from beaches & waterways
Watch	Distant tsunami possible	Stay tuned for information Be prepared to act
Information Statement	No threat or very distant event & threat not determined	Relax





Thank you!

Learn more: www.noaa.gov/jetstream/tsunamis

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