CASCADIA

News & information from the Oregon Department of Geology and Mineral Industries WINTER 2012

A similar earthquake and tsunami are in our future—

The 2011 Japan earthquake and tsunami: Lessons for the Oregon Coast

The March 11, 2011 Tōhoku, Japan earthquake was a magnitude 9.0 subduction zone earthquake 80 miles off the coast of Japan. The earthquake triggered a devastating tsunami that inundated the northeast coast of Japan within minutes. The quake and tsunami had massive societal impacts: according to the National Police Agency of Japan, 15,845 were confirmed killed and another 3,380 are still missing; thousands more were injured. Over 1.1 million buildings were damaged or destroyed, including 6,751 school buildings and more than 300 hospitals. The tsunami created 24 million tons of waste debris. The reinsurance company Munich Re† estimated economic losses at US$210 billion, excluding the subsequent nuclear accident.* ***Is Oregon prepared for an earthquake like the one in Japan? What happened? Can it happen here? What can we do to prepare?***

Follow the trail of the Tōhoku tsunami!

An aerial view of damage to Ōtsuchi, Iwate prefecture, Japan on March 15, 2011, after the magnitude 9.0 Tōhoku earthquake and subsequent tsunami devastated the area; 11.6% (1,378 people) of the exposed population were killed or are missing. In Iwate prefecture, 4,667 were killed and 1,363 remain missing. *(U.S. Navy photo by Mass Communication Specialist 3rd Class Alexander Tidd/Released)*

*National Policy Agency of Japan: http://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf
†Munich Re: http://www.munichre.com/en/media_relations/press_releases/2012/2012_01_04_press_release.aspx

Notes from your State Geologist

— Building a Culture of Preparedness

by Vicki S. McConnell, Oregon State Geologist

Almost a year after the March 11, 2011 Tōhoku earthquake and tsunami, Japan is still working through their recovery and we in Oregon are still considering our options for preparation for *our* subduction zone earthquake. Indeed, we are still responding to the effects of Tōhoku. The western coastal states and Hawai'i are tracking the tremendous amount of debris washed out to sea from the tsunami as the material drifts across the Pacific Ocean. We expect to begin seeing evidence of the debris off the Oregon coast later this year. So two years after the earthquake and tsunami we will still be responding to the effects of this disaster from across the Pacific. Imagine how long it will take us to respond and recover from a Cascadia Subduction Zone (CSZ) earthquake.

Magnitude 9 earthquakes like the Tōhoku, Japan earthquake are frequent in geologic time. An earthquake similar in force to the Tōhoku earthquake struck the Pacific Northwest in 1700 when the Cascadia Subduction Zone, not far offshore Oregon, ruptured in the form of an earthquake and created a tsunami that caused devastation on our coast and well-documented flooding and damage on the Pacific coast of Japan. The Pacific Northwest will experience another large earthquake—U.S. Geological Survey scientists estimate there is a 10% chance in the next 30 years.

We can significantly reduce the amount of recovery time in the event of a local earthquake and tsunami by doing our homework now. The more we understand what to expect and the more we prepare for the inevitable the more quickly we will spring back. We want to build a Culture of Preparedness here in Oregon that will lead us to individual and community resilience. DOGAMI staff as well as many scientists and emergency managers from Oregon have participated in investigation teams to observe and record the impacts of the earthquake and tsunami in Japan. The data and information these teams bring back will help us anticipate what to expect here as well as help Japan prepare for their long-term earthquake hazards.

We have compiled some of that information in this *Cascadia* to help you understand what happened, and why and what we all can and should do to prepare. You can start with the easy things: know when you are in a tsunami inundation zone if you are on the coast, make sure you download our tsunami evacuation brochures for the communities you will visit, and have your emergency kit ready in your home, school, workplace, and automobile. We at DOGAMI will continue to improve our understanding of how the Cascadia Subduction Zone works by creating state-of-the-art elevation maps, modeling tsunami inundation zones, and researching previous CSZ tsunamis. We will communicate that information to you. Together, we can make Oregon safer where we live, work, and play.

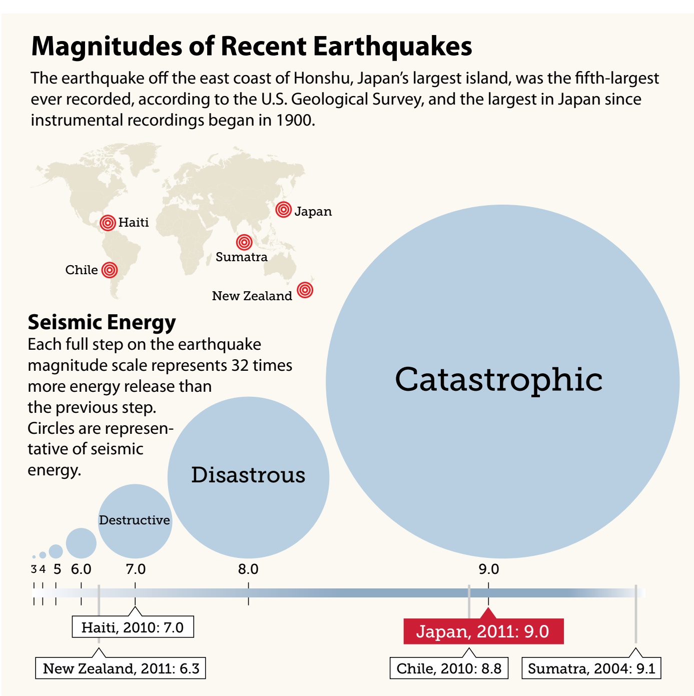

Diagram after Russ Toro, www.OurAmazingPlanet.com

Cascadia is published by the Oregon Department of Geology and Mineral Industries
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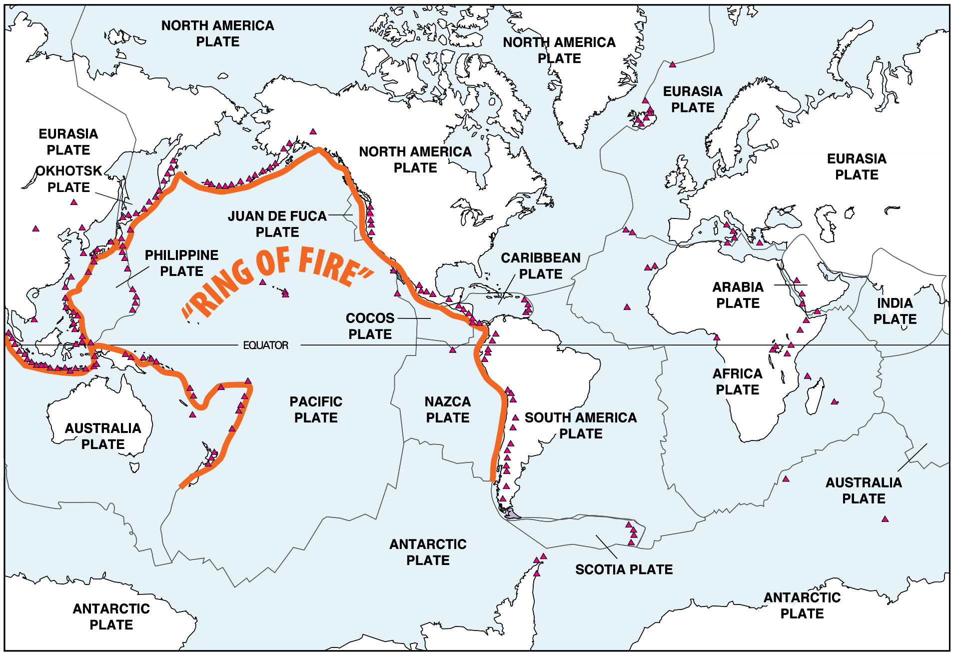
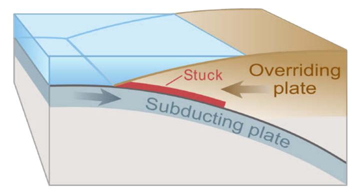
"Ring of Fire"



Modified from http://pubs.usgs.gov/gip/117/

A "Ring of Fire," a zone of active earthquakes and volcanoes, surrounds much of the Pacific Ocean. Volcanoes and earthquakes are caused by the movements of tectonic plates, huge plates of rock that make up the shell of the earth. One type of movement is called subduction — when thin, oceanic plates such as those that compose the rock beneath the Pacific Ocean sink beneath thicker, lighter plates that make up continental plates.



Subduction Zone. One of the many plates that make up Earth's outer shell descends, or "subducts," under an adjacent plate. This kind of boundary is called a subduction zone. When the plates move suddenly in an area where they usually stick, an earthquake happens.

Oregon's tectonic setting: a mirror image of Japan's

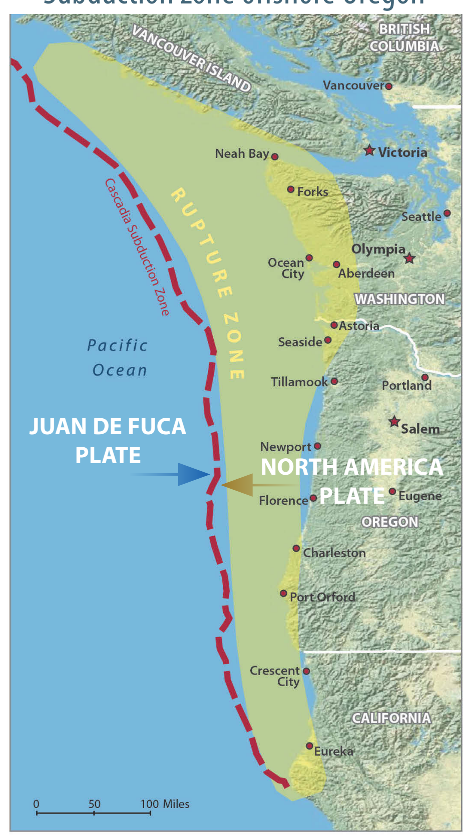
The Tōhoku earthquake is a good example of what Oregon faces in the future. Both Japan and Oregon sit on active subduction zones, giant faults where the ocean floor is slowly thrust beneath the land. Where frictional resistance on the fault is greater than the stress across the fault, the rocks are "locked" together. Stored energy is eventually released in an earthquake when frictional resistance is overcome. The rupture zone is the area along which the earthquake can occur; it is equivalent to the green zones shown in the diagrams (*right*).

The March 11, 2011 Tōhoku earthquake resulted from a very large movement on the Japanese subduction fault. An area almost 250 miles long and 150 miles wide slipped about 80 feet, producing an earthquake of magnitude 9. A vertical shift of 10 feet displaced a vast amount of water and caused a tsunami.

Offshore Oregon, a subduction fault similar to the Japanese subduction fault but plunging in the opposite direction is also building up stored energy. When enough energy is built up, earthquakes occur. A magnitude 9 earthquake would likely cause slip movement of about 40-60 feet over an area 600 miles long and 60 miles wide.

Subduction zone offshore Japan

Subduction zone offshore Oregon



(left) **Green zone is the exact footprint of the Tōhoku rupture zone.** *(right)* **Green zone indicates a region where earthquakes can occur in the Pacific Northwest.**

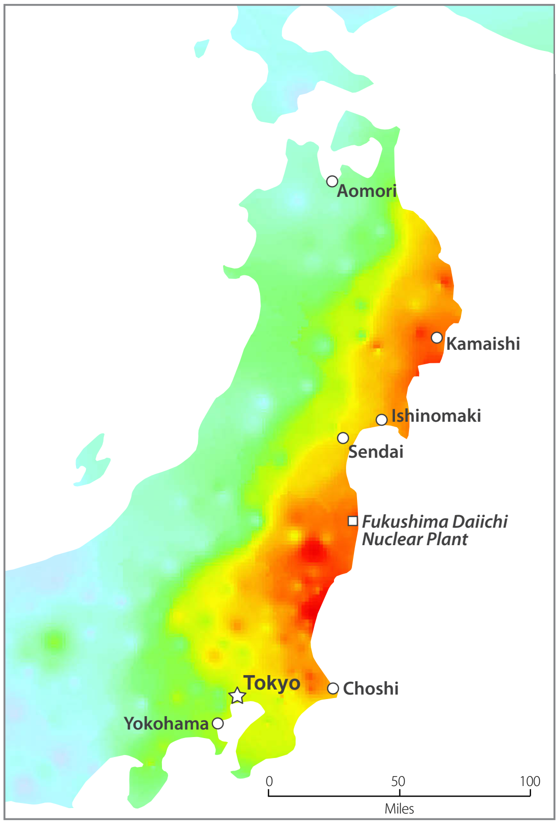
Earthquake shaking

During the Tōhoku earthquake the ground shook hard over much of northern Japan for 3 to 5 minutes and continued to shake for more than 30 minutes. The shaking was recorded on hundreds of seismic instruments across Japan. The shakemap for Japan (below, left) was made using those records and shows the strength of shaking and degree of damage expected.

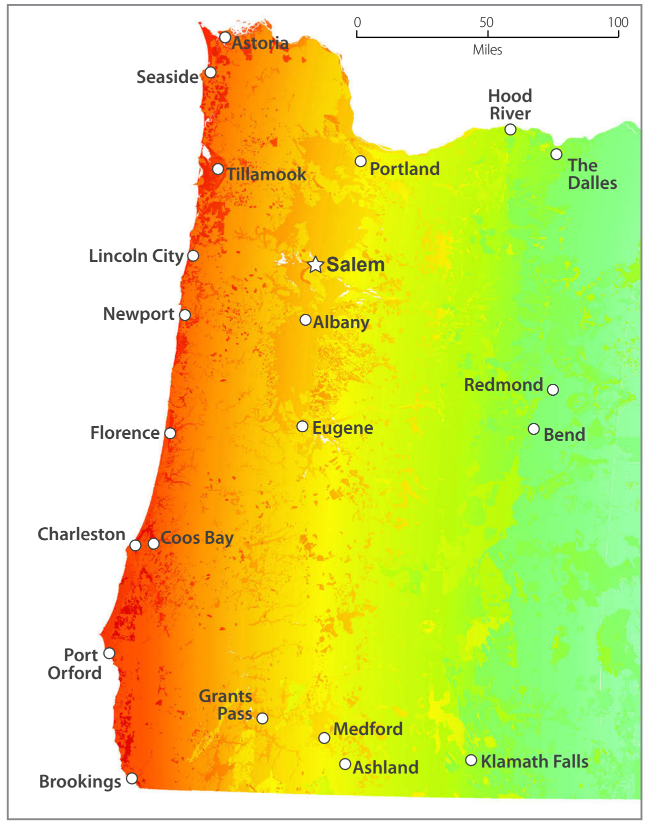
The shakemap for Oregon (below, right) is a computer simulation of the effects of a magnitude 9 earthquake on the Cascadia Subduction Zone — similar to the earthquake magnitude for the Tōhoku event. Areas far inland of the earthquake would experience damage, and 90 percent of the state's population of nearly 4 million would be directly affected.

ShakeMaps (http://earthquake.usgs.gov/earthquakes/shakemap) are designed as rapid response tools to portray the extent and variation of ground shaking throughout the affected region immediately following significant earthquakes. The maps shown here do not take into account liquefaction and ground failure, which can significantly increase damage.

ShakeMap for March 11, 2011 Tōhoku M9 earthquake



ShakeMap for SIMULATED M9 Cascadia earthquake



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
WHAT HAPPENS AT EACH INTENSITY? *Text descriptions from http://quake.abag.ca.gov/shaking/mmi/*	Not felt.	II. Felt by people sitting or on upper floors of buildings. III. Felt by almost all indoors. Hanging objects swing. Vibration like passing of light trucks. May not be recognized as an earthquake.	Vibration felt like passing of heavy trucks. Stopped cars rock. Hanging objects swing. Windows, dishes, doors rattle. Glasses clink. In the upper range of IV, wooden walls and frames creak.	Felt outdoors. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing. Pictures move. Pendulum clocks stop.	Felt by all. People walk unsteadily. Windows crack. Dishes, glassware, knickknacks, and books fall off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster, adobe buildings, and some poorly built masonry buildings cracked. Trees and bushes shake visibly.	Difficult to stand or walk. Noticed by drivers of cars. Furniture broken. Damage to poorly built masonry buildings. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, unbraced parapets and porches. Some cracks in better masonry buildings. Waves on ponds.	Steering of cars affected. Extensive damage to unreinforced masonry buildings, including partial collapse. Fall of some masonry walls. Twisting, falling of chimneys and monuments. Wood-frame houses moved on foundations if not bolted; loose partition walls thrown out. Tree branches broken.	General panic. Damage to masonry buildings ranges from collapse to serious damage unless modern design. Wood-frame structures rack, and, if not bolted, shifted off foundations. Underground pipes broken.	Poorly built structures destroyed with their foundations. Even some well-built wooden structures and bridges heavily damaged and needing replacement. Water thrown on banks of canals, rivers, lakes, etc. Pipelines may be completely out of service.

Tsunami essentials

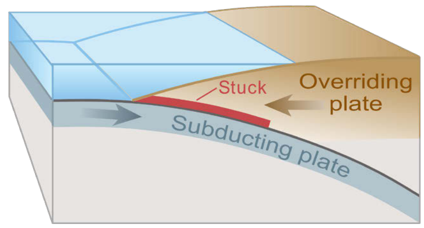
A tsunami is a series of ocean waves generated by disturbances of the sea floor during shallow, undersea earthquakes. Less commonly, landslides and volcanic eruptions can trigger a tsunami. In the deep water of the open ocean, tsunami waves can travel at speeds up to 500 miles per hour and are imperceptible to ships because the wave height is typically less than a few feet.

As a tsunami approaches the coast, it slows dramatically, but its height may multiply by a factor of 10 or more and have catastrophic consequences to people living at the coast. As a result, people on the beach, in low-lying areas of the coast, and near bay mouths or tidal flats face the greatest danger from tsunamis.

A tsunami can be triggered by earthquakes around the Pacific Ocean including undersea earthquakes with epicenters located only tens of miles offshore the Oregon coast (see Ring of Fire, page 3). Over the last century, wave heights of tsunamis in the Pacific Ocean have reached up to 45 feet above the shoreline near the earthquake source. In a few rare cases, local conditions amplified the height of a tsunami to over 100 feet.

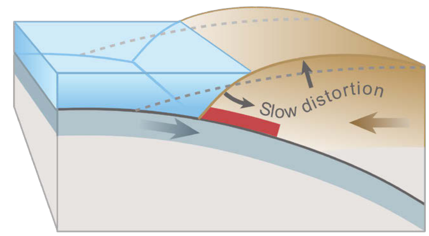
Tsunami Generation

1 Subduction Zone



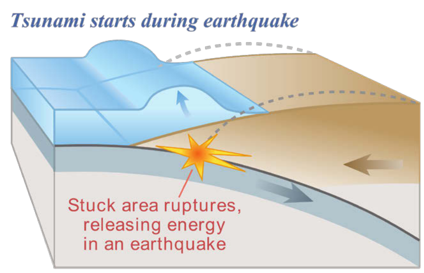
One of the many plates that make up Earth's outer shell descends, or "subducts," under an adjacent plate. This kind of boundary is called a subduction zone. When the plates move suddenly in an area where they usually stick, an earthquake happens.

2 Between Earthquakes



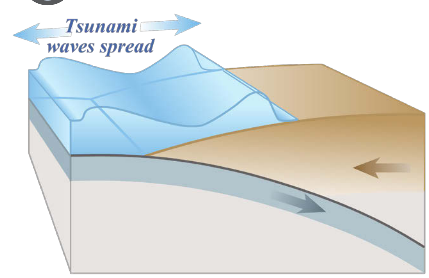
Stuck to the subducting plate, the overriding plate gets squeezed. Its leading edge is dragged down, while an area behind bulges upward. This movement goes on for decades or centuries, slowly building up stress.

3 During an Earthquake



An earthquake along a subduction zone happens when the leading edge of the overriding plate breaks free and springs seaward, raising the sea floor and water above it. This uplift starts a tsunami. Meanwhile, the bulge behind the leading lead collapses, flexing the plate downward and lowering the coastal area.

4 Minutes Later



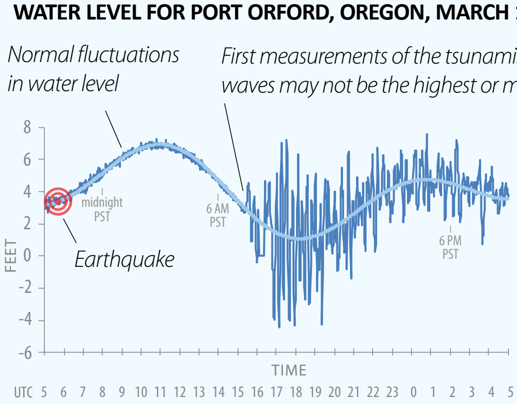
Part of the tsunami races toward nearby land, growing taller as it comes in to shore. Another part heads across the ocean toward distant shores.

Tsunami diagrams: http://pubs.usgs.gov/circ/c1187/

Measuring tsunamis

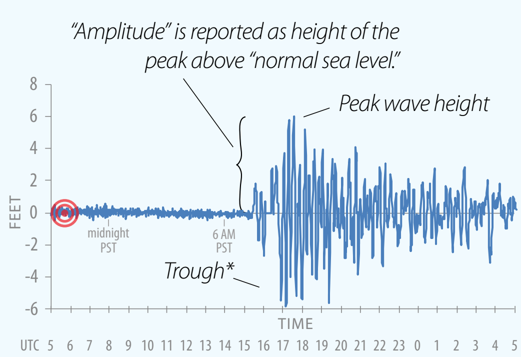
A tsunami is really a series of waves. A tide gauge measures the water level every minute, effectively measuring the height of each wave as it passes the gauge. After the predicted normal water level, including tides, is removed, the result shows the deviation from normal water levels due to a tsunami.

WATER LEVEL FOR PORT ORFORD, OREGON, MARCH 11, 2011



Measured at the NOAA Port Orford Tide Station (9431647).
Data source: http://tidesandcurrents.noaa.gov

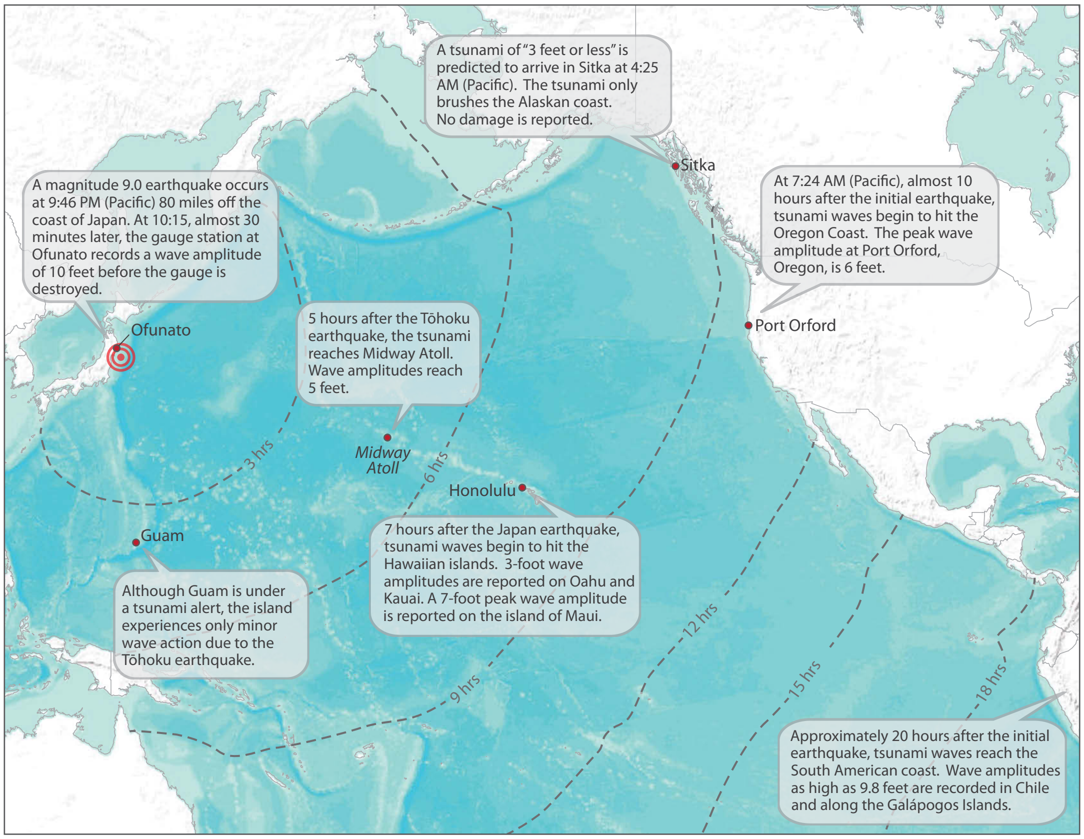
WATER LEVEL WITH TIDAL EFFECTS REMOVED



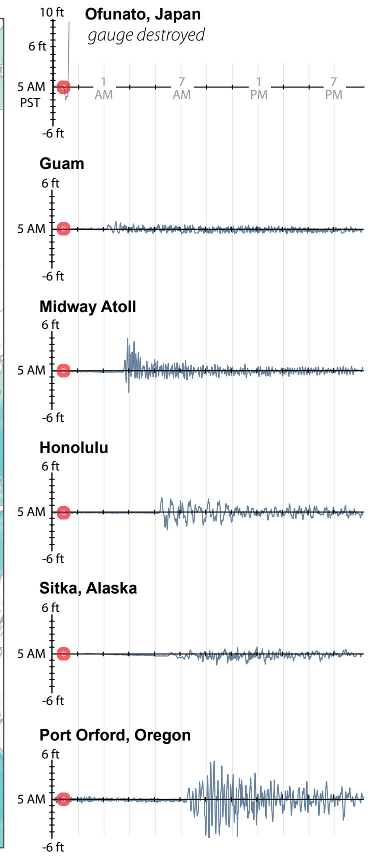
**Extreme trough waves can empty a harbor of its water. Quickly receding shorelines indicate wave troughs.*

Progression of the Tōhoku tsunami across the Pacific Ocean

As the tsunami moved at speeds up to 500 miles per hour, alerts were broadcast and measurements were made. The map below shows how the tsunami affected different locations. Features such as reefs, bays, and undersea formations can dissipate the energy of a tsunami, so a wide range in wave heights was recorded. Tide gauges measured both the initial tsunami surge and the variation in water level.



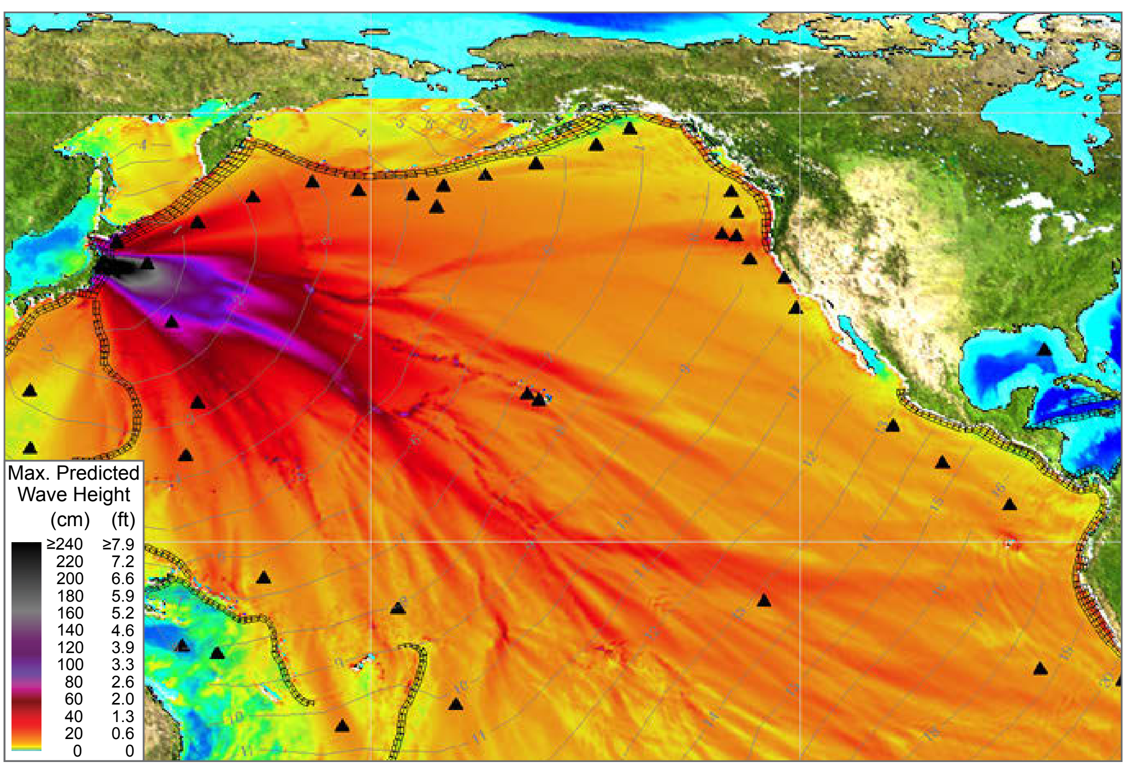
NOAA tide gauge water level measurements showing deviation from predicted tide levels



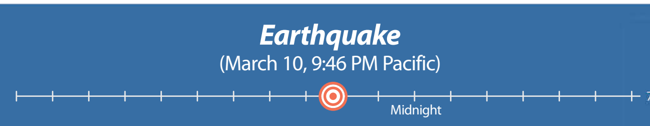
Tsunami wave height prediction

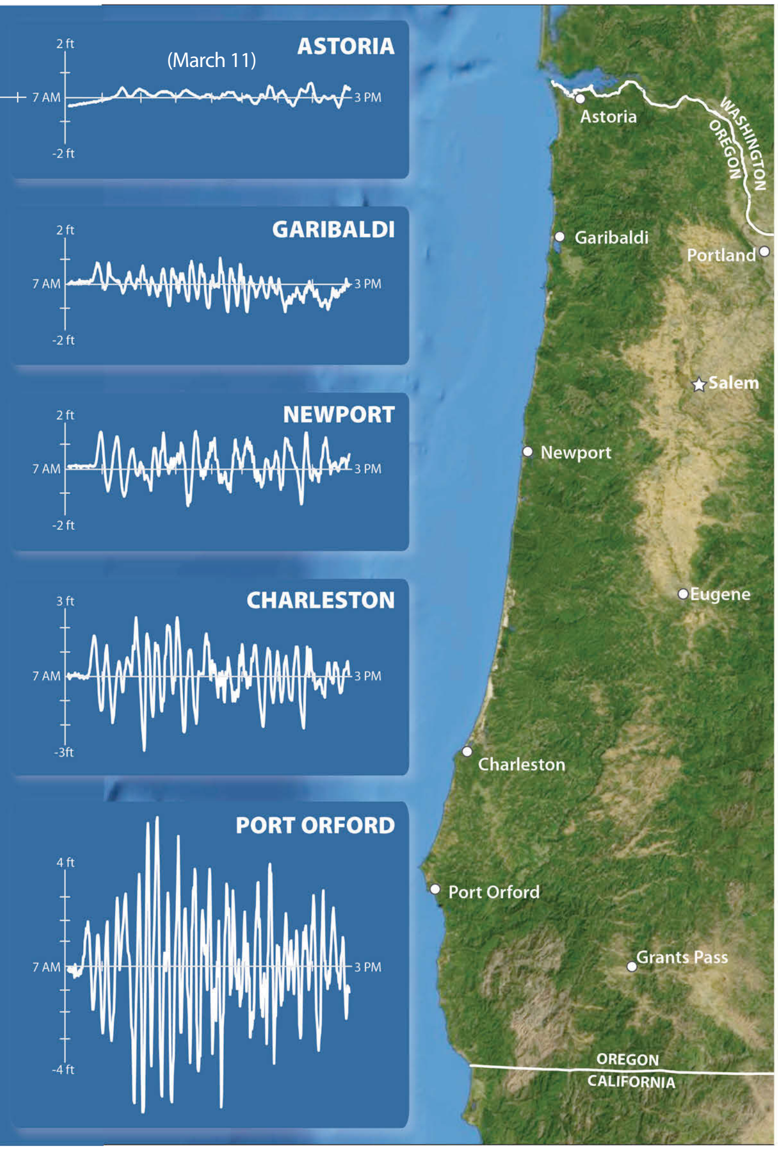
A NOAA model (right) shows the maximum tsunami wave height predicted for 24 hours of wave propagation after the March 11, 2011 Tōhoku earthquake. Contours show computed tsunami arrival time. Triangles are tide gauges.

Source: NOAA Center for Tsunami Research: http://nctr.pmel.noaa.gov/honshu20110311



Tōhoku tsunami measurements in Oregon





How did the Tōhoku tsunami affect Oregon coastal communities?

The tsunami swept the entire Oregon coast and was recorded at tide gauge stations.

The effect of the tsunami was dramatically different in different areas along the coast.

These "tsunamigrams" show changes in water level over an 8-hour period.

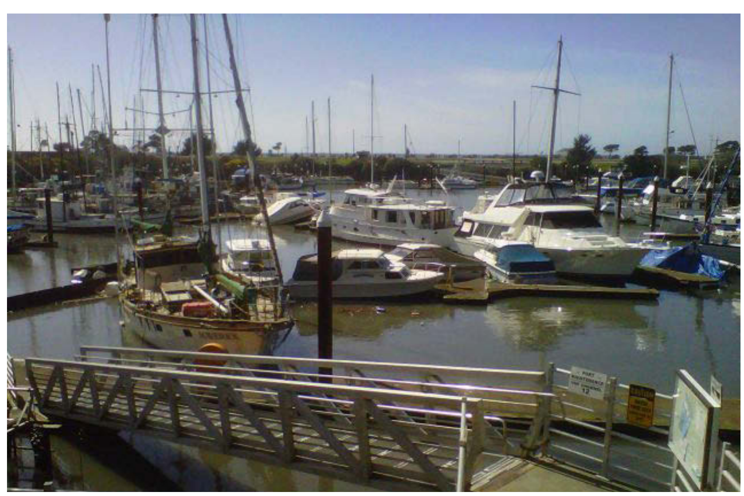
Port Orford stats:
First arrival: 7:24 AM
First peak: 7:34 AM
Peak wave amplitude: 5.97 ft at 9:32 AM
Lowest trough: –5.7 ft at 9:07 AM
Biggest change: 11.5 ft in 8 minutes
Significant waves: 29

Data source: http://tidesandcurrents.noaa.gov/

The NOAA West Coast/Alaska Tsunami Warning Center (http://wcatwc.arh.noaa.gov/previous.events/03-11-11_Honshu/) reported these peak wave amplitudes (height of the peak above "normal sea level") for Oregon and northern California:

Astoria, OR: 0.6 ft	Port Orford, OR: 6.0 ft
South Beach, OR: 1.1 ft	Crescent City, CA: 8.0 ft
Charleston, OR: 2.5 ft	Point Reyes, CA: 4.4 ft

Not-so-fun fact—
Water that is waist deep (3 ft) can knock down an adult male at 2.6 mph, knee deep (2 ft) at 4 mph, ankle deep (1 ft) at 6.7 mph. The Tōhoku tsunami travelled over the Sendai Plain at 15 mph and carried tons of debris – there is no way to outrun such a force.



Brookings, Oregon, March 11, 2011. *Photo courtesy of Oregon State Police*

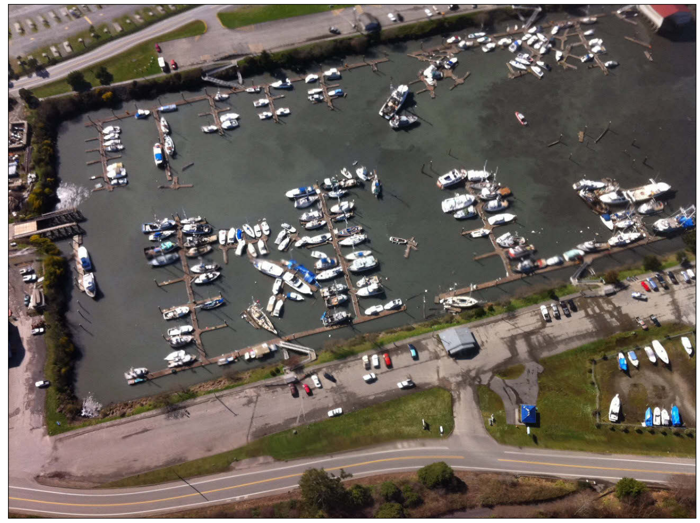
Tōhoku tsunami impacts in Oregon

By the time the tsunami reached Oregon, the waves were more like a tide surging in and out about every 10 to 15 minutes (see page 7). Many coastal areas reported minor damage.

Significant damage occurred at Brookings not because of abnormally high water — the tsunami probably never exceeded high tide mark — but due to strong currents. Mooring and docks were torn up, boats were damaged or sunk, oil slicks developed, and debris littered the coast and harbor.

There are no tide gauges at Brookings, but DOGAMI computer simulations of a similarly sized distant tsunami show maximum currents at the mouth of the Chetco River of 6 mph.

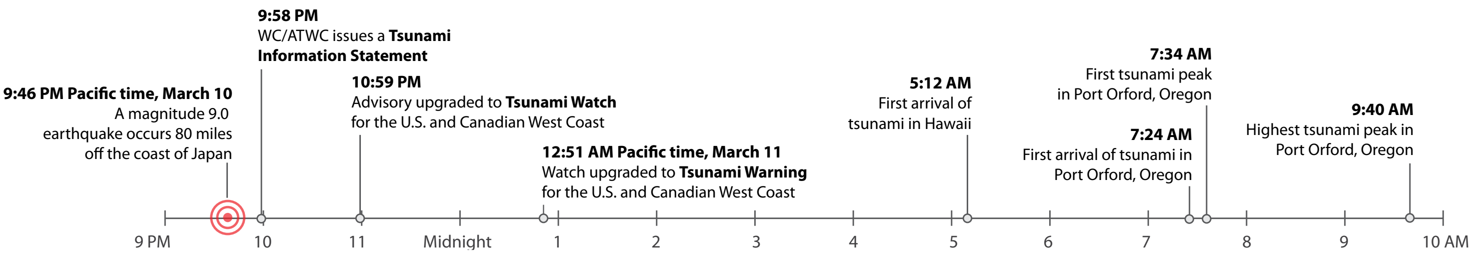
A DOGAMI simulation of a magnitude 9 Cascadia (local source, see page 10) earthquake and tsunami at Brookings shows that the water level would reach to 53 ft above the tide and the currents would reach 23 mph.



Damage at Port of Brookings-Harbor after tsunami waves hit March 11, 2011. *Photo: Jamie Francis/The Oregonian.*

How the tsunami warning system works

When the earthquake occurred, a network of international, national, state, and local agencies immediately began monitoring the event and issuing warnings according to the defined protocol.



Protocol:

West Coast and Alaska Tsunami Warning Center (Palmer, AK)

WC/ATWC monitors earthquakes and detects a tsunami...

1. NWS sends Tsunami EAS Message to:
- **State OERS**
- **Local Jurisdictions**
- **Broadcasters**
- **Public** (via NOAA Weather Radio: http://www.nws.noaa.gov/nwr/)

2. State OERS:
1. Relays NWS Tsunami Warning
2. Issues Supplemental Tsunami EAS to:
   - **County Warning Points**
   - **Broadcasters**
   - **Public**

3. County and Local Warning Points:
- Contact Local Emergency Officials
- Have Evacuation Authority
- Conduct Emergency Operations

4. Tsunami Warning Cancellation
Issued by WC/ATWC

5. All-Clear/Re-entry Notification
Issued by Local Emergency Officials
Decisions related to reoccupation of coastal zones must be made by local authorities.

Abbreviations:
WC/ATWC West Coast and Alaska Tsunami Warning Center
OERS Oregon Emergency Response System
NWS National Weather Service
EAS Emergency Alert System

Federal Communications Commission
EAS Emergency Alert System

Aftermath — Learning from the disaster in Japan

Two DOGAMI staff were part of post earthquake investigation teams that traveled to Japan to see the effects of the disaster first-hand. Yumei Wang, Geotechnical Engineer, was part of the Technical Council on Lifeline Earthquake Engineering (TCLEE) team that looked at lifeline damage. Rob Witter, Coastal Geologist, joined the 2011 International Tsunami Survey Team to document physical evidence of tsunami flow characteristics.

Earthquake ground shaking and tsunami flooding resulted in damage to lifeline infrastructure including bridges, highways, railways, ports, airports, oil and gas facilities, power plants, dams, and systems involving water, waste-water, electrical, and telecommunications, as well as buildings including schools, hospitals, and industrial plants. Severe damage occurred at several nuclear power plants resulting in uncontrolled radioactive releases. Numerous coastal communities and inland areas had extensive liquefaction and landslide damage. Emergency response efforts were delayed due to fuel shortages, telecommunication disruptions, and damage to transportation systems, hospitals, and fire and police stations. Large aftershocks caused additional damage.

As was known from previous subduction zone earthquakes and confirmed in Japan, concentrated damage occurs in three areas: 1) tsunami flood zones, 2) areas of weak soils that are prone to liquefy, amplify shaking, or have permanent ground movements (settlement, lateral spreading, and landslides), and 3) areas of weak infrastructure, such as unreinforced masonry (URM) and other nonductile buildings and nonbuilding structures.

After assessing the damage in Japan, DOGAMI urged the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) should further explore five areas to help manage Oregon's earthquake exposure and risks:

- **Mitigate, replace, or re-purpose important facilities at high risk** such as schools and emergency facilities including fire stations, police stations, and hospitals, especially those on weak soils prone to liquefaction, landslides, or amplification or in tsunami zones.
- **Mitigate critical facilities** such as energy, telecommunication, and hazardous materials facilities to prevent severe socioeconomic and environmental impacts following an earthquake.
- **Examine major lifelines** that may require special performance consideration because they are co-located and/or are interdependent with other lifelines in order to avoid multiple and/or cascading failures. Each Oregon community depends on many lifelines, such as water, waste water, electricity, and communication systems. Existing lifelines at high risk should be mitigated to meet performance standards judged acceptable.
- **Review Resiliency Plan** (Oregon Partnership for Disaster Resilience, http://csc.uoregon.edu/opdr/) options and work with appropriate parties to assemble an integrated view of current state and community capabilities and gaps in statewide resilience planning to make recommendations on policy direction to protect lives and keep commerce flowing.
- **Develop Sister state/prefecture and Sister city relationships** to augment learning and facilitate exchange to help Oregon prepare for Cascadia earthquakes.

Yumei Wang, DOGAMI Geotechnical Engineer, in Japan after the March 11, 2011 Tōhoku earthquake. Yumei is straddling vertically displaced ground that experienced liquefaction and lateral spreading. Fuel and liquefied natural gas (LNG) tanks in the background were shaken by the earthquake and inundated by the tsunami.

The challenges ahead

The Tōhoku earthquake, in a tectonic setting so similar to that of Oregon, is a benchmark for a Cascadia Subduction Zone earthquake. The Tōhoku earthquake and tsunami illustrated that even technologically advanced countries are vulnerable. Oregon must prepare for a Tōhoku-sized event or face similar consequences.

- Bridges and lifelines along the coast are extremely vulnerable
- Coastal erosion and subsidence will impact shoreline
- Huge volumes of debris will impact recovery efforts

Creating a culture of tsunami preparedness

How do we cultivate a culture of tsunami preparedness?

- Get prepared and be involved
- Know your evacuation route
- Make a disaster plan
- Prepare disaster kits
- During and earthquake, "Drop, cover, and hold on!"
- Evacuate if necessary
- Follow your plan

One-third of a mile (1,800 feet) inland from the Sendai beach the tsunami deposited 8.5 inches of sand. *Photo: Rob Witter.*

New modeling provides basis for next generation of tsunami inundation maps for Oregon

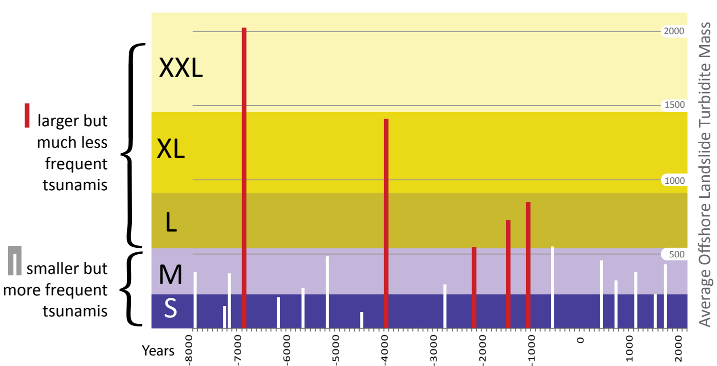
Scientific research looking 10,000 years into the geologic past indicates great earthquakes and tsunamis of force similar to the 2011 Tōhoku earthquake and tsunami have been generated by a rupture of the Cascadia Subduction Zone with alarming frequency (see time line below). DOGAMI uses this historical information along with state-of-the-art numerical simulations to model earthquake-generated tsunamis. The model results are used to created tsunami inundation maps for the Oregon coast.

After completing two pilot mapping studies in the Cannon Beach and Bandon areas, DOGAMI has embarked on completely remodeling and remapping tsunami inundation for the entire Oregon coast at scales of 1:8,000 to 1:12,000. The new maps will aid local emergency preparedness efforts and form the basis for tsunami evacuation maps used by the public (see page 11).

CASCADIA EARTHQUAKE TIME LINE

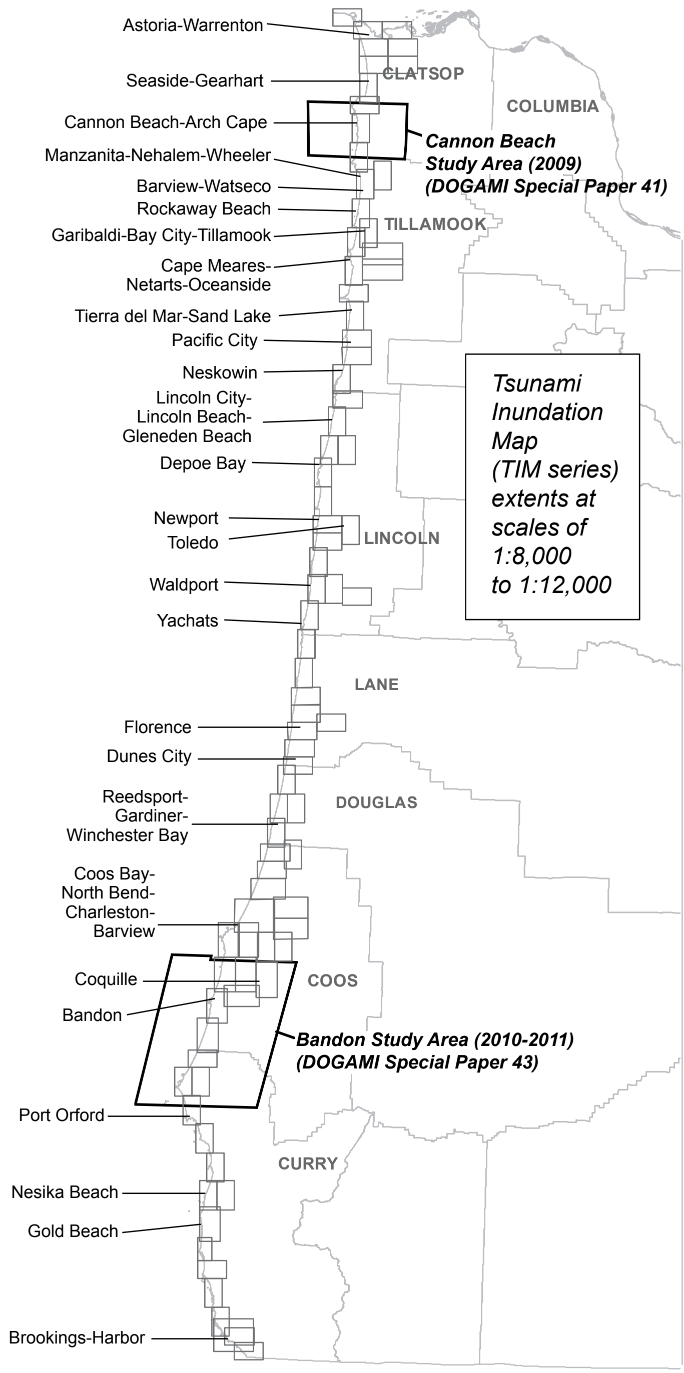
Occurrence and Relative Size of Cascadia Subduction Zone Megathrust Earthquakes

(Modified from Witter and others, 2011; DOGAMI Special Paper 43)



Research-indicated radiocarbon age of CSZ event (most recent in January 1700)

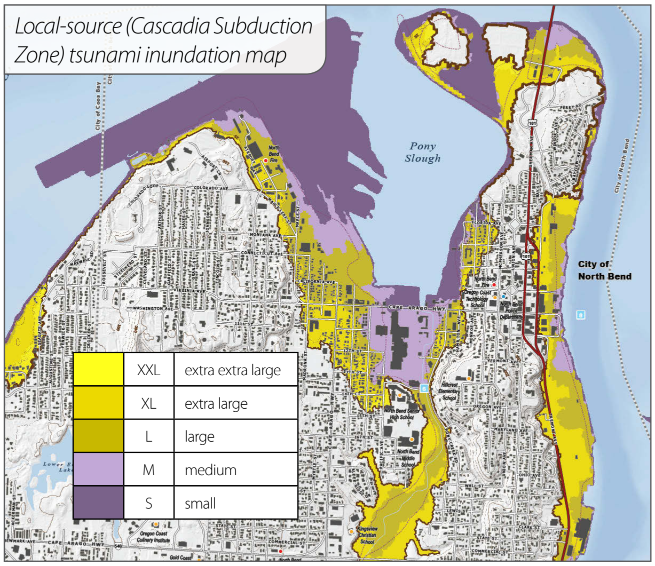
Average offshore landslide turbidite mass is used as a proxy for earthquake size.

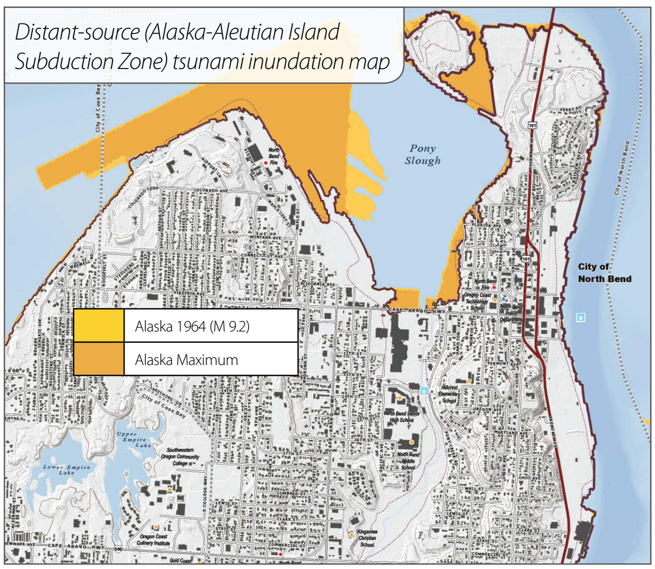


What is the difference between a Cascadia (local) tsunami and a distant tsunami?

An earthquake on the Cascadia Subduction Zone, a 600-mile-long earthquake fault zone that sits off the Pacific Northwest coast (see page 3), can create a **Cascadia (local) tsunami** that will reach the Oregon coast within 15 to 20 minutes. Massive earthquakes of magnitude 9 or greater that can last for several minutes have been generated on the fault zone (see time line, above). A destructive tsunami can follow moments later. The new generation of DOGAMI tsunami inundation maps (TIM series) show five Cascadia (local source) tsunami scenarios: small, medium large, extra-large, and extra-extra-large (see page 11).

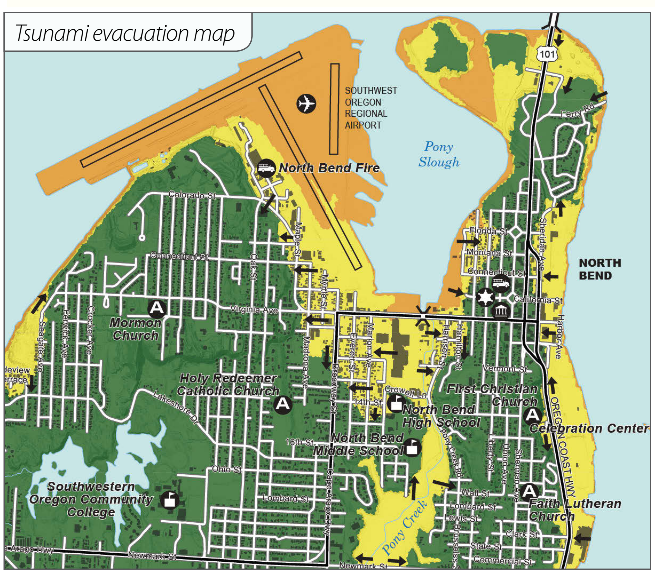
A **distant tsunami** produced by an earthquake far from Oregon (such as the 2011 Tōhoku earthquake or the 1964 Alaska earthquake) will take 4 or more hours to travel across the Pacific Ocean, usually allowing time for an official warning and evacuation, if necessary. A distant tsunami will be smaller in size and much less destructive, but it can still be very dangerous. DOGAMI TIM maps show two distant source scenarios: magnitude 9.2 1964 Alaska and magnitude 9.2 Alaska maximum.





maximum local source (yellow) maximum distant source (orange)

Combine the maximum tsunami scenario from each map ...



Understanding the relationship between tsunami **inundation** maps and tsunami **evacuation** maps

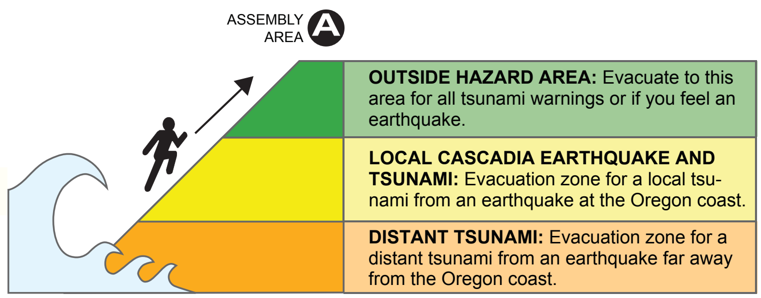
DOGAMI scientists and GIS analysts use the results of numerical simulations of local-source (Cascadia Subduction Zone) and distant-source tsunami scenarios to create tsunami inundation maps.

Cascadia Subduction Zone models can show a wide range of inundation in the same area. To make it easier to understand the simulations for different earthquake size classes, the classes are labeled like T-shirt sizes: small (S, releasing fault slip built up for 300 years), medium (M, 425–525 years), large (L, 650–800 years), extra-large (XL, 1,050–1,200 years), and extra-extra-large (XXL, 1,200 years). XL and XXL scenarios simulate tsunamis similar to the Tōhoku tsunami.

Similar models have been developed for two distant-source earthquakes: one model simulates the 1964 Alaska M9.2 earthquake and tsunami, while another simulates a hypothetical Alaska M9.2 event.

After the inundation maps have been created, the tsunami inundation zones derived from the Cascadia XXL tsunami scenario (yellow area, top figure, left) and the hypothetical maximum Alaska tsunami (orange area, middle figure, left) and are put together on one map to create a tsunami evacuation map (bottom, left). Green on the evacuation map shows typically higher elevation areas that lie outside the zones prone to tsunami hazard. The purpose of the evacuation map is to help people identify safe evacuation routes, as developed by local emergency authorities.

◀ *Portions of DOGAMI TIM-Coos-05 map plates, the first maps in the new Tsunami Inundation Map Series. Inundation scenarios are shown for local-source (Cascadia)* (top) *and distant-source* (middle) *tsunami scenarios. The maximum inundation scenario from each source is used to create the tsunami evacuation map* (bottom), *which also shows evacuation routes and assembly areas.*



▶ *In addition to the map, each tsunami evacuation brochure includes local emergency contacts and basic information on what to do before and during an earthquake and tsunami event.*

DOGAMI earthquake and tsunami outreach

DOGAMI is funded by the NOAA National Tsunami Hazards Mitigation Program (NTHMP) to mitigate tsunami risk in Oregon by accurately mapping the hazard zone, increasing awareness of where the zone is and what the warning signs will be for the approaching tsunami, and enhancing formal preparedness and evacuation planning with local authorities and stakeholders. As part of our Tsunami Outreach Oregon campaign, DOGAMI hires temporary employees to act as local tsunami champions to recruit volunteers, conduct door-to-door education campaigns, distribute maps and preparedness materials, and help communities conduct tsunami evacuation drills. This effort is aimed at building a sustainable, volunteer-based, tsunami mitigation effort in coastal communities. In this, DOGAMI collaborates with Oregon Emergency Management (OEM), local National Weather Service (NWS) offices, Tribes, Community Emergency Response Teams (CERT), K-12 schools, community colleges, and universities. The primary goal is to reduce loss of life and property damage from tsunamis.

Coos Bay region Tsunami Outreach Oregon community coordinators Mikel Chavez and Lindsey Bishop

DOGAMI has implemented the Tsunami Outreach Oregon campaign in half of the named communities at risk in recent years and is vigorously continuing the effort during 2011-12:

Tsunami Outreach Oregon Campaign	Outreach Communities:
2009-10	Manzanita, Nehalem, Wheeler, Rockaway Beach, Yachats, Waldport, Seal Rock, Bandon
2010-11	Astoria, Warrenton, Pacific City, Neskowin, Port Orford, Gold Beach
2011-12	Coos Bay, North Bend, Charleston, Garibaldi, Bay City, Tillamook, Cape Meares, Oceanside, Netarts

Examples of the kind and nature of activities the Tsunami Outreach Oregon campaign is involved in is captured by this abbreviated listing of events held during the first half of 2011:

February 2011
- Map Your Neighborhood volunteer training workshop – Port Orford, Gold Beach, Brookings
- Astoria High School student volunteer recruitment activity in collaboration with American Red Cross
- Tsunami awareness presentation for Warrenton High School seniors
- One-on-one discussions with various lodging managers – Pacific City/Neskowin

March 2011
- Emergency preparedness fairs in Portland metropolitan area
- Tsunami awareness talk to Warrenton Elementary and High School. OEM met with Hatfield Marine Science Center to begin discussions of tsunami evacuation procedures
- Middle and high school assembly – Port Orford and Gold Beach

April 2011
- NOAA weather radio workshops in Warrenton
- Cascadia earthquake and tsunami preparedness talk at the Bagdad Theater in Portland
- Earthquake and tsunami preparedness talk at Coos Bay Emergency Preparedness Fair
- Door-to-door/disaster exercise – Warrenton
- Table-top for evacuation drill – Gold Beach/Port Orford
- Tsunami awareness presentation for Port Orford and Brookings League of Women Voters and for Gold Beach Chamber of Commerce
- CERT (Community Emergency Response Team) training workshop – Pacific City area

May 2011
- Earthquake and tsunami vulnerability talk – Northwest Transportation Commission
- Tsunami evacuation drills – Pacific City/Neskowin, Port Orford, Gold Beach, Warrenton

June 2011
- Door-to-door outreach in tsunami evacuation areas – Pacific City/Neskowin
- Post-outreach surveys conducted – Gold Beach, Port Orford, Pacific City/Neskowin, Warrenton/Astoria

We are modernizing the way tsunami evacuation information and educational materials are disseminated to the public via an online interactive map interface (http://www.nanoos.org/nvs/nvs.php?section=NVS-Products-Tsunamis-Evacuation) and through a centralized Tsunami Information Clearinghouse (www.OregonTsunami.org).

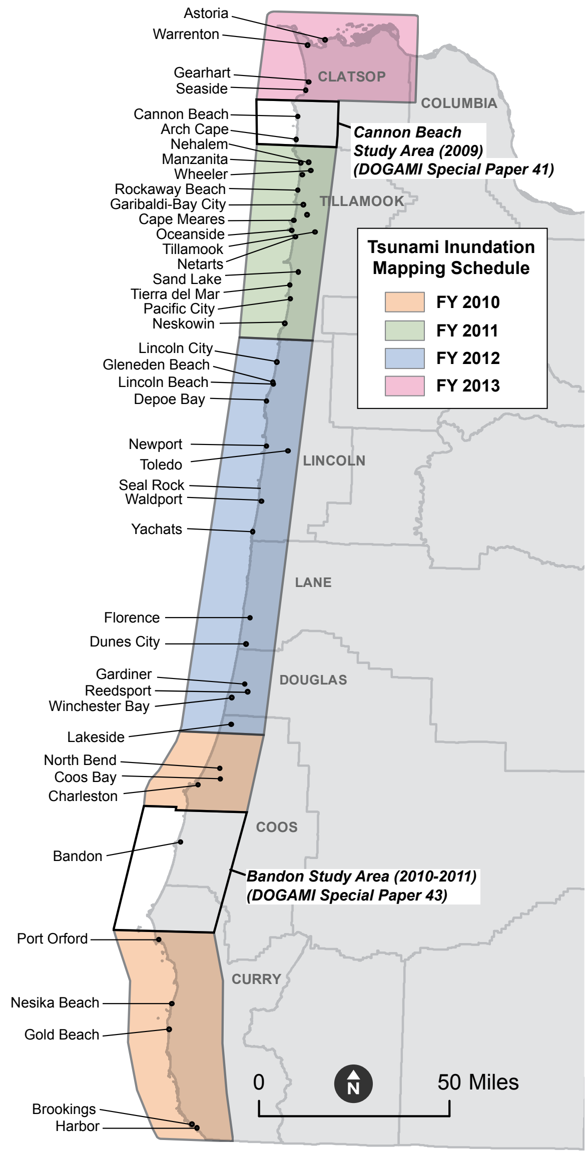
Related Outreach Efforts

Several related efforts present opportunities that contribute toward advancing the goal and completing the objectives of Oregon's tsunami hazard mitigation program, including:
- DOGAMI staff participated in August 2011 aerial flights with the Civil Air Patrol and the U.S. Coast Guard for the purposes of obtaining reconnaissance oblique photographs of the coast and simulating post-event response.
- OEM coordinated ShakeOut Oregon, a drop, cover, and hold earthquake drill held on October 20, 2011.
- DOGAMI and OEM continue to work with NWS to facilitate the procurement of tsunami warning signs, communications infrastructure, and other mitigation tools to help communities meet TsunamiReady™ guidelines.

Tsunami inundation modeling and mapping accomplishments and anticipated schedule

Community	1st-generation maps: Tsunami inundation map	1st-generation maps: Tsunami evacuation map	2nd-generation (TIM) maps: Tsunami inundation map	2nd-generation (TIM) maps: New tsunami evacuation map
☑ Cannon Beach	no	no	yes (SP-41)	yes
☑ Arch Cape	no	no	yes (SP-41)	yes
Bandon	no	no	yes (SP-43)	yes
Port Orford	no	no	May 2012	Jun 2012
Gold Beach	yes (IMS-13)	yes	May 2012	Jun 2012
Nesika Beach	yes (IMS-13)	yes	May 2012	Jun 2012
Brookings	no	no	May 2012	Jun 2012
Harbor	no	no	May 2012	Jun 2012
North Bend	yes (IMS-21)	yes	Jan 2012	Feb 2012
Coos Bay	yes (IMS-21)	yes	Jan 2012	Feb 2012
Charleston	yes (IMS-21)	yes	Jan 2012	Feb 2012
☑ Rockaway Beach	no	yes	Mar 2012	Apr 2012
Garibaldi	no	no	Feb 2012	Mar 2012
Bay City	no	no	Feb 2012	Mar 2012
Tillamook	no	no	Feb 2012	Mar 2012
Cape Meares	no	yes	Feb 2012	Mar 2012
Oceanside	no	yes	Feb 2012	Mar 2012
Netarts	no	yes	Feb 2012	Mar 2012
Sand Lake	no	yes	Jun 2012	Aug 2012
Tierra del Mar	no	yes	Jun 2012	Aug 2012
Pacific City	no	yes	Jun 2012	Aug 2012
Neskowin	no	yes	Mar 2012	Apr 2012
☑ Manzanita	no	yes	Mar 2012	Apr 2012
☑ Nehalem	no	yes	Mar 2012	Apr 2012
☑ Wheeler	no	yes	Mar 2012	Apr 2012
☑ Lincoln City	yes (GMS-99)	yes	Sept 2012	Oct 2012
Gleneden Beach	yes (GMS-99)	yes	Oct 2012	Nov 2012
Lincoln Beach	yes (GMS-99)	yes	Oct 2012	Nov 2012
Depoe Bay	no	yes	Nov 2012	Dec 2012
Newport	yes (IMS-2)	yes	Dec 2012	Jan 2013
Toledo	no	no	Dec 2012	Jan 2013
Seal Rock	no	no	Feb 2013	Mar 2013
Waldport	yes (IMS-23)	yes	Feb 2013	Mar 2013
Yachats	no	yes	May 2013	Jun 2013
☑ Florence	yes (IMS-25)	yes	May 2013	Jun 2013
Dunes City	no	yes	May 2013	Jun 2013
Gardiner	no	yes	Jun 2013	Aug 2013
Reedsport	no	yes	Jul 2013	Aug 2013
Winchester Bay	no	yes	Jul 2013	Aug 2013
Lakeside	no	no	Aug 2013	Sep 2013
Astoria	yes (IMS-11)	no	Nov 2013	Jan 2014
Warrenton	yes (IMS-12)	yes	Nov 2013	Jan 2014
Gearhart	yes (IMS-3)	yes	Jan 2014	Mar 2014
☑ Seaside	yes (IMS-3)	yes	Jan 2014	Mar 2014

☑ **TsunamiReady™ Community.** Several *counties* in Oregon including Tillamook, Douglas, Coos, and Clatsop also meet TsunamiReady™ requirements. SP: DOGAMI Special Paper; IMS: DOGAMI Interpretive Map; GMS: DOGAMI Geologic Map.



◀ Thirty-one of the 44 TsunamiReady™ target communities in Oregon currently have older-style tsunami evacuation maps; three communities have new, second-generation maps. ▲ Highlighted regions along the coast indicate four project areas for accelerated tsunami inundation mapping in Oregon. Black boxes define areas of detailed hazard assessments already conducted at Cannon Beach and Bandon.

TsunamiReady NATIONAL WEATHER SERVICE

http://www.tsunamiready.noaa.gov/

Additional resources

Earthquake & tsunami preparedness

Living on Shaky Ground: How to Survive Earthquakes and Tsunamis in Oregon
http://www.oregongeology.org/tsuclearinghouse/resources/pdfs/shakygroundmagazine_Oregon.pdf

American Red Cross
http://www.redcross.org/

Federal Emergency Management Agency (FEMA)
http://www.fema.gov/

NOAA West Coast and Alaska Tsunami Warning Center
http://wcatwc.arh.noaa.gov/

Are You Ready? An In-depth Guide to Citizen Preparedness by FEMA
http://www.fema.gov/areyouready/

Quake Safe Schools (Oregon Dept. of Ed.)
http://www.ode.state.or.us/go/quakesafeschools/

FEMA 395, Incremental Seismic Rehabilitation of School Buildings (K-12)
http://www.fema.gov/library/viewRecord.do?id=1980

Oregon Emergency Management (OEM) Seismic Rehabilitation Grant Program
http://www.oregon.gov/OMD/OEM/plans_train/SRGP.shtml

Oregon Building Codes Division
http://www.cbs.state.or.us/bcd/

Online tsunami training modules, COMET Meteorology Education Program
https://www.meted.ucar.edu/ —several tsunami modules for different audiences

Earthquake & tsunami organizations

National Tsunami Hazard Mitigation Program (NTHMP)
http://nthmp.tsunami.gov/

Oregon Seismic Safety Policy Advisory Commission (OSSPAC)
http://www.oregon.gov/OMD/OEM/osspac/osspac.shtml

Western States Seismic Policy Council (WSSPC)
http://www.wsspc.org/

Oregon Partnership for Disaster Resilience
http://opdr.uoregon.edu/

Cascadia Region Earthquake Workgroup (CREW)
http://www.crew.org/

DOGAMI earthquake & tsunami publications

Tsunami hazard zone and evacuation maps online
http://www.oregongeology.org/sub/earthquakes/Coastal/Tsumaps.HTM

Simulating tsunami inundation at Bandon, Coos County, Oregon, using hypothetical Cascadia and Alaska earthquake scenarios (Special Paper 43), by R.C. Witter and others, 2011. Includes report, plates, GIS and data files, and animations.

Tsunami hazard assessment of the northern Oregon coast: A multi-deterministic approach tested at Cannon Beach, Clatsop County, Oregon (Special Paper 41), by G. R. Priest and others, 2009, 87 p. plus app., GIS data files, time histories, and animations.

Oregon Public Utilities Commission–DOGAMI Leadership Forum and Seismic Critical Energy Infrastructures Workshop, April 2, 2008 (Open-File Report 08-10), by Y. Wang and J. R. Gonzalez, 2008, 13 p.

Statewide seismic needs assessment: Implementation of Oregon 2005 Senate Bill 2 relating to public safety, earthquakes, and seismic rehabilitation of public buildings (Open-File Report 07-02), by D. Lewis, 2007, 140 p. plus app.
http://www.oregongeology.org/sub/projects/rvs/default.htm

Enhanced rapid visual screening (E-RVS) for prioritization of seismic retrofits in Oregon, (Special Paper 39), by Y. Wang and K. A. Goettel, 2007, 27 p.

Cascadia Subduction Zone earthquakes: A magnitude 9.0 earthquake scenario (Open-File Report 05-05), by Cascadia Region Earthquake Workgroup, J. Roddey, and L. Clark, 2005, 21 p.
http://www.crew.org/sites/default/files/CREWCascadia-Final.pdf

Earthquake damage in Oregon: Preliminary estimates of future earthquake losses (Special Paper 29), by Y. Wang and J. L. Clark, 1999, 59 p.

Tsunami Evacuation Building Workshop, September 28-29, 2009, Cannon Beach, Seaside, and Portland, Oregon (Open-File Report 10-02), Y. Wang, complier, 2010, 35 p.

Prehistoric Cascadia tsunami inundation and runup at Cannon Beach, Clatsop County, Oregon (Open-File Report 08-12), by R. C. Witter, 2008, 36 p. and 3 app.

Tōhoku earthquake & tsunami resources

Tōhoku Japan Earthquake and Tsunami Clearinghouse, Earthquake Engineering Research Institute (EERI)
http://www.eqclearinghouse.org/2011-03-11-sendai/

NOAA Tōhoku resource page http://www.ngdc.noaa.gov/hazard/honshu_11mar2011.shtml

USGS Poster of the Great Tōhoku Earthquake
http://earthquake.usgs.gov/earthquakes/eqarchives/poster/2011/20110311.php

The March 2011 Tōhoku tsunami and its impacts along the U.S. West Coast, by J. C. Allan and others, Journal of Coastal Research, in press, 2012.

Earthquake science

Pacific Northwest Seismic Network (PNSN)
http://www.pnsn.org/

U.S. Geological Survey Oregon Earthquake Information
http://earthquake.usgs.gov/earthquakes/states/?region=Oregon

National Earthquake Hazards Reduction Program (NEHRP)
http://www.nehrp.gov/

Teaching About the Ocean System Using New Research Techniques: Data, Models and Visualization
http://serc.carleton.edu/NAGTWorkshops/ocean/visualizations/tsunami.html

Fact Sheet: TsunamiReady, TsunamiPrepared: Oregon Coast-Wide National Tsunami Hazard Mitigation Program, 2010, 2 p.
http://www.oregongeology.org/pubs/fs/TsunamiPreparedFactSheetAlt-12-28-09.pdf

Fact Sheet: Tsunami hazards in Oregon, 2008, 4 p.
http://www.oregongeology.org/pubs/fs/tsunami-factsheet_onscreen.pdf

OregonTsunami.org
http://www.OregonTsunami.org

NANOOS Visualization System
http://www.nanoos.org/nvs/nvs.php?section=NVS-Products-Tsunamis-Evacuation interactive viewer

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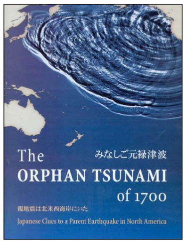
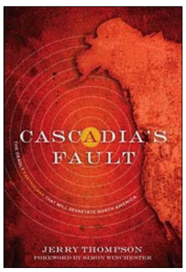


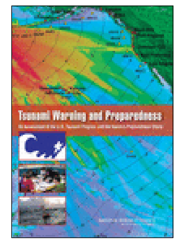
The Orphan Tsunami of 1700—Japanese Clues to a Parent Earthquake in North America, U.S. Geological Survey Professional Paper 1707, by Brian Atwater and others, 2005, 144 p., 325 illus, paperback, $24.95.

Tells the scientific detective story of the tsunami through clues from both sides of the Pacific. Also available as a PDF file: http://pubs.usgs.gov/pp/pp1707/pp1707.pdf



Cascadia's Fault: The Earthquake and Tsunami That Could Devastate North America, by Jerry Thompson, Counterpoint Press, Berkeley, Calif., 2011, 352 p., $26.

Written by a journalist who has been following this story for twenty-five years, Cascadia's Fault tells the tale of this potentially devastating earthquake and the killer waves it will spawn.



Tsunami Warning and Preparedness: An Assessment of the U.S. Tsunami Program and the Nation's Preparedness Efforts, by National Research Council, The National Academies Press, Washington D.C., 2011, 284 p., $64.00.

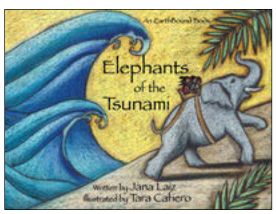
Also available online: http://www.nap.edu/catalog.php?record_id=12628#toc

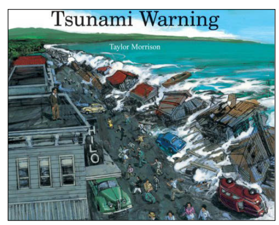
For kids

Elephants of the Tsunami, 2nd ed., by Jana Laiz; illustrated by Tara Cafiero, Earthbound Books, the Berkshires, Mass., 2007, 24 p., $10.

Reading level: ages 4 to 8.

Pictorial re-telling of an extraordinary true event that occurred in Thailand the morning of the devastating 2004 South Asian Tsunami.





Tsunami Warning, by Taylor Morrison, Houghton Mifflin, Eugene, Oregon, 2007, 48 p., $17.

Reading level: ages 9 to 12.

Recounts stories of survivors of the 1946 Hawaii tsunami and how sensor networks are now providing advance warning of tsunamis.

A complete list of DOGAMI publications can be found online at www.OregonGeology.org.
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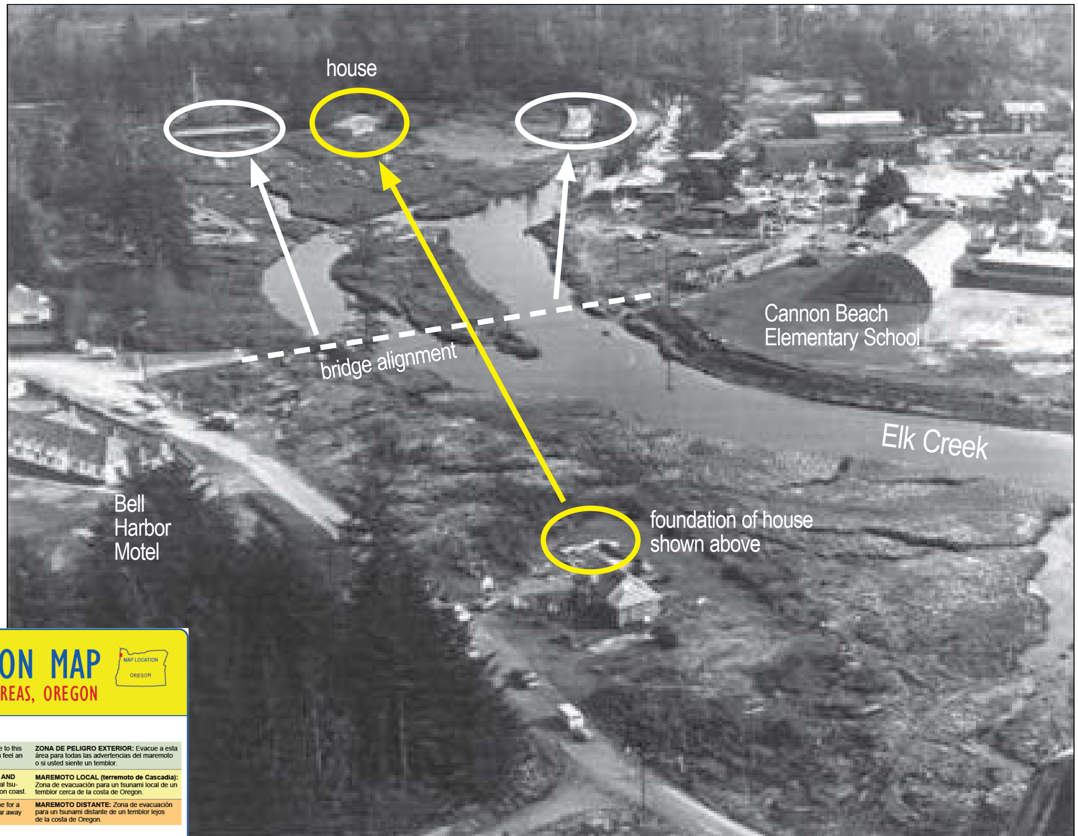
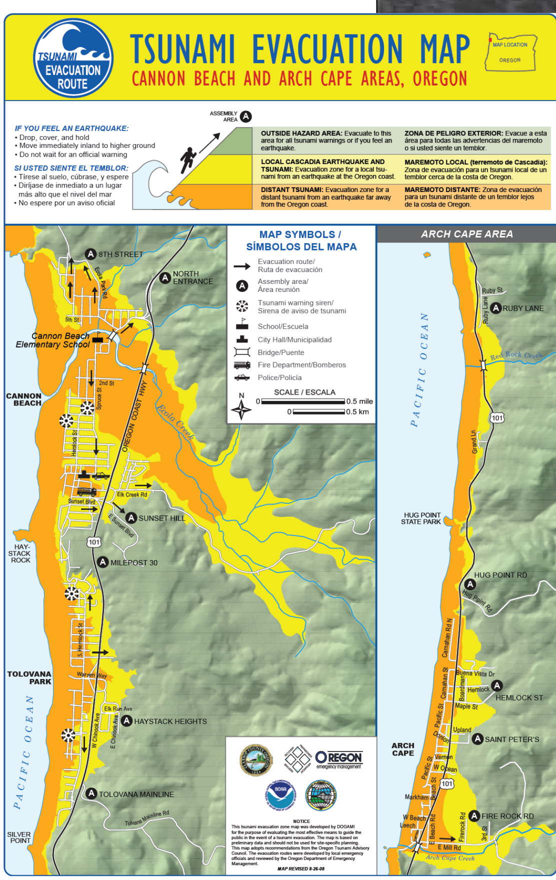
Places to see: Cannon Beach

Cannon Beach is a quiet coastal town known for its relaxing atmosphere. But on March 28, 1964, a tsunami struck, reaching Cannon Beach approximately 4 hours after the magnitude 9.2 Prince William Sound earthquake occurred in the Gulf of Alaska. The tsunami flooded parts of downtown Cannon Beach, floated a building from its foundation, and destroyed a bridge. This tsunami was a produced by a ***distant source, over 1,300 miles away***. What kind of damage would result from a tsunami generated by a magnitude 9 ***local source***?



▶Impact of the 1964 Alaska tsunami at Cannon Beach. This oblique aerial photograph of the lower Elk Creek valley (now Ecola Creek) flows through downtown Cannon Beach. Decking from the old Elk Creek bridge was torn from its abutments and transported 980 feet upstream (white ovals). A foundation in the lower part of the photo marks the original position of a house that was carried 1,300 feet upstream and deposited between the bridge sections (yellow ovals). From DOGAMI Special Paper 41, Figure 2; photograph courtesy of the Cannon Beach Historical Society.



▶Cannon Beach has installed signage on the beach depicting the new (2008) evacuation map prepared by DOGAMI.

◀Tsunami evacuation brochure PDFs are available at: http://www.OregontTsunami.org.

You can also see tsunami zones online by using the Northwest Association of Networked Ocean Observing Systems (NANOOS) Visualization System interactive map: http://www.nanoos.org/nvs/nvs.php?section=NVS-Products-Tsunamis-Evacuation

Photo: Yumei Wang, DOGAMI.

Learn more about Oregon's geology at www.OregonGeology.org.