Maritime Guidance for Distant Source Tsunami Events

Port of Brookings Harbor, Curry County, Oregon

Oregon Maritime Tsunami Response Guidance (MTRG) No. 2024-OR-01

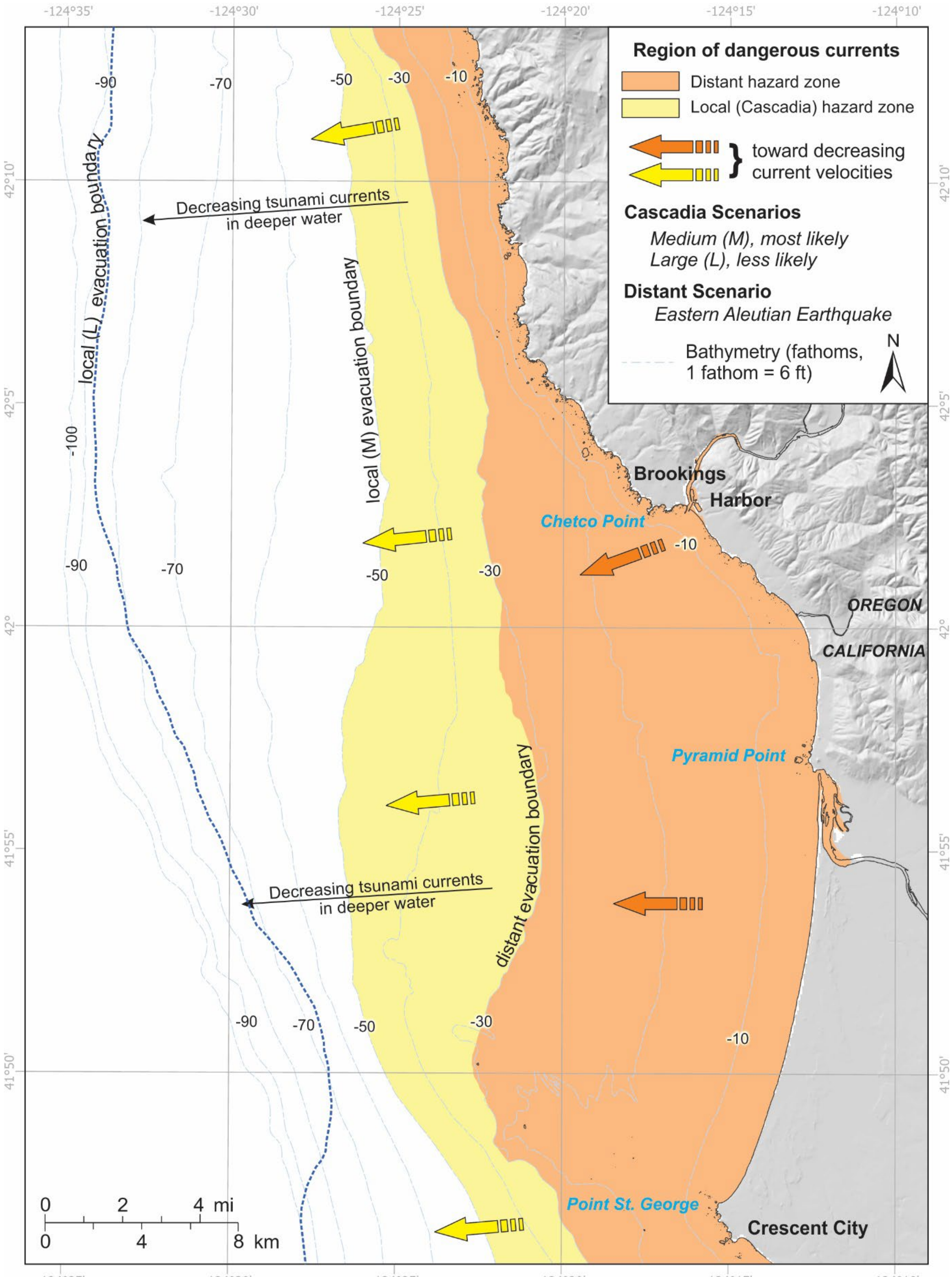
Maritime response guidance in this document is based primarily on anticipated effects of a **maximum-considered distant tsunami event** originating from the eastern part of the Alaska-Aleutian subduction zone (scenario *AKMax* of the Oregon Department of Geology and Mineral Industries). Smaller distant source tsunamis generated throughout the Pacific Rim will occur more frequently and are likely to cause much less damage than the *AKMax* scenario. Check with local authorities for more specific guidance that may be appropriate for smaller distant tsunami events. Although the focus of this document is on a distant source tsunami event, general guidance is also given for a much larger tsunami generated by a local earthquake on the Cascadia subduction zone.

Cover Photo: Chetco River mouth and marina. Photo Credit: ShoreZone, CC-BY-SA, June 2011.

A summary of key actionable responses is provided in the table below for both a distant eastern Alaska-Aleutian subduction zone earthquake-generated, and a local Cascadia subduction zone tsunami; Figure 1 shows the maritime evacuation map for the area offshore from Brookings:

Distant tsunamis: *You have a minimum of 4 hours after the earthquake to take action*. If you are on the water, first check with the U.S. Coast Guard before taking any action. If advised to evacuate to deep water and this option is practical for your vessel and your capabilities to remain offshore for an extended period (at least 24 hours), including having to potentially travel to an alternate safe harbor if Brookings-Harbor is too heavily damaged, **proceed to a staging area greater than 30 fathoms (180 ft)** *(**Figure 1**, located ~4.6 nautical mile west of the Chetco River mouth)*. **Dangerous currents (greater than 5 knots) are expected to occur at depths shallower than 15 fathoms (90 ft), especially within the river mouth, navigation channel and marina (orange hazard zone in Figure 1**). If conditions do not permit offshore evacuation, dock your boat and get out of the tsunami evacuation zone. Note that significant wave heights may be greatly amplified by strong opposing tsunami currents.
Local (CSZ) tsunamis: *You have as little as ~15 minutes to take action; plan in advance*. If your boat is docked, you do NOT have time to take your vessel offshore; doing so will likely damage your vessel and harm your crew. Instead, evacuate by foot to high ground immediately. If you are on the water seaward of the Chetco River at the time of a local earthquake, **proceed to a staging area greater than 50 fathoms (300 ft)** water depth (**Figure 1**), located ~7 nautical miles west of the Chetco River. *Safety improves significantly with additional westward travel. The preferred staging area is in depths greater than 70 fathoms (420 ft), located 12 nautical miles west of the Chetco River*). Sail directly toward the nearest deep water or in a general westward direction. **Dangerous currents (greater than 5 knots) are expected to occur at depths shallower than 50 fathoms (300 ft; yellow and orange hazard zones in Figure 1)**. Note that significant wave heights may be greatly amplified by strong opposing tsunami currents.

Figure 1. Offshore maritime staging areas for the Brookings area. Map identifies the minimum water depths to the distant (>30 fathoms) and local (>50 fathoms) offshore maritime tsunami staging areas. Note: bathymetric contours on the map are fathoms (1 fathom = 6 ft); shaded regions define areas subject to dangerous current velocities.



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INTRODUCTION

Tsunamis with the potential to impact the west coast of the United States can be triggered by large earthquakes (generally earthquakes greater than magnitude 8) anywhere around the Pacific Rim and will cause sudden water level and current changes for many hours after their first arrival. The location of the earthquake plays an important role in determining the tsunami propagation travel time to the coastal community.

This document provides response guidance in the event of a **distant tsunami** for maritime vessels operating in the Brookings-Harbor area, including commercial fishing vessels and small recreational craft. Review DOGAMI Open-File-Report O-24-03 (Allan and others, *2024*) for additional detailed maritime tsunami information on distant and local tsunamis affecting the entire Brookings-Harbor region.

DISTANT TSUNAMIS

These are caused by large subduction zone earthquakes far away from the Oregon coast and will arrive at the mouth of the Chetco River more than 4 hours after the earthquake. Tsunami waves will cause water level and current changes for many hours after the arrival of the first wave.

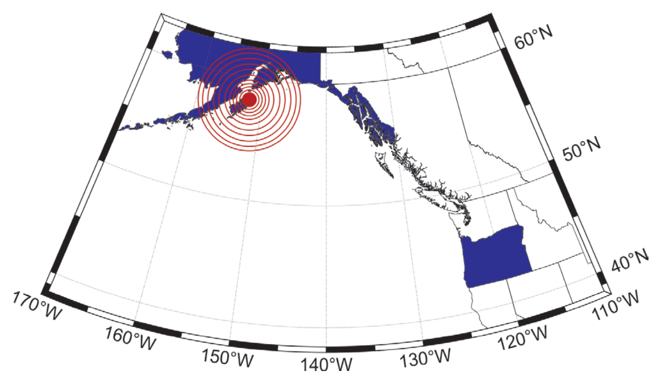


Figure 2. The greatest threat to the Oregon coast from a distant tsunami is an earthquake occurring in the eastern Aleutian Islands, Alaska. Tsunamis originating from this source would strike the coast in approximately 4 hours.

The closest distant earthquake source to Oregon is along the eastern Aleutian Islands, Alaska. Modeled wave arrival times for such an earthquake indicate that the tsunami would reach the Chetco River mouth in about 4 hours. Tsunami modeling revealed that the largest waves were observed at the entrance to the marina. However, large waves continued to impact the Brookings area within the first 30 hours following the earthquake. Furthermore, depending on the tidal stage the largest tsunami waves could affect the Port of Brookings Harbor, approximately 16 to 19 hours after the earthquake (Allan and others, 2024). Tsunami resonance producing 3 to 9 ft waves was found to continue to occur up to 72 hours after the earthquake; tsunami currents dropped below 3 knots at about hour 30. Accordingly, dangerous tsunami conditions are expected to impact the Port of Brookings Harbor and offshore area for at least 30 hours and will decrease significantly up to 72 hours after the event.

LOCAL TSUNAMIS

These are caused by locally generated earthquakes on the Cascadia Subduction Zone (CSZ) immediately offshore the Oregon coast. Local tsunamis will produce catastrophic tsunami waves that will reach the mouth of the Chetco River *approximately* 15 minutes after the start of the earthquake (the peak tsunami wave arrives approximately 5 minutes after water levels begin to rise) and will fully inundate and flood the Chetco River estuary in approximately 21 minutes.

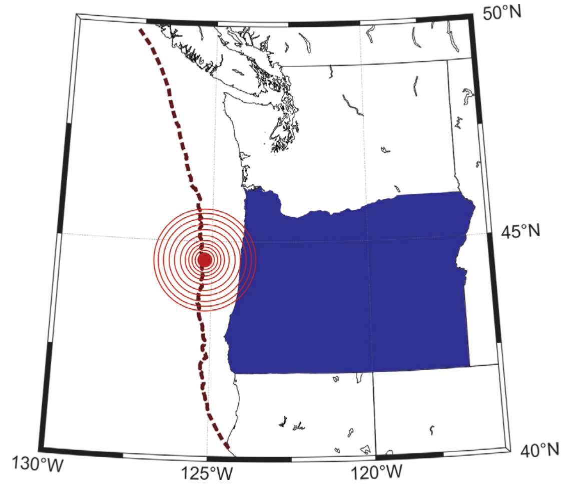


Figure 3. A local CSZ earthquake poses the greatest risk to the Oregon coast. A tsunami triggered here would strike the coast in 10 to 20 minutes.

Modeled initial wave arrival times (peak wave arrival times in parentheses) for a CSZ tsunami are 15 (20) minutes at the river mouth, and 17 (21) minutes in the marina. However, these times will likely vary by a few minutes depending on the characteristics of the earthquake rupture and tidal stage.

Tsunami Hazards

Tsunami wave impacts are greatest in and around ocean beaches, low-lying coastal areas, and bounded water bodies such as harbors and estuaries. These areas should always be avoided during tsunami events. Any tsunami event can threaten harbors, including facilities and vessels.

Tsunami hazards that can directly affect boats and boaters include:

- Sudden water-level fluctuations, which could result in:
    - docks overtopping piles as water levels rise; and
    - grounding of boats and docks as water levels drop.
- strong and unpredictable currents, especially where there are narrow openings/parts of harbor;
- tsunami bores and amplified waves resulting in swamping of boats and damage to docks;
- eddies/whirlpools causing boats to lose control;
- drag on deep draught ships causing damaging forces to moored vessels; and
- collision with other vessels, docks, and debris in the water.

Dangerous tsunami conditions can last tens of hours after the first wave arrival, causing problems for inexperienced and unprepared boaters who take their boats offshore.

Relationship between Tsunami Current Speed and Harbor Damage

Analysis of recent tsunami events indicates a relationship between current speed and harbor damage. The Damage Index from Lynett and others (2014) below has been used to evaluate potential harbor damage resulting from tsunami current velocities. The color code explained here (green, yellow, orange, and red) is used on maps showing tsunami current thresholds (**Figure 5**, p16 and Appendix A tsunami current maps).

Damage Index:	Damage Type:
5	*Complete destruction*
4	*Major dock/boat damage, large vessels off moorings*
3	*Moderate dock/boat damage, mid-sized vessels off moorings*
2	*1-2 docks/small boats damaged, large buoys moved*
1	*Small buoys moved*
0	*No damage*

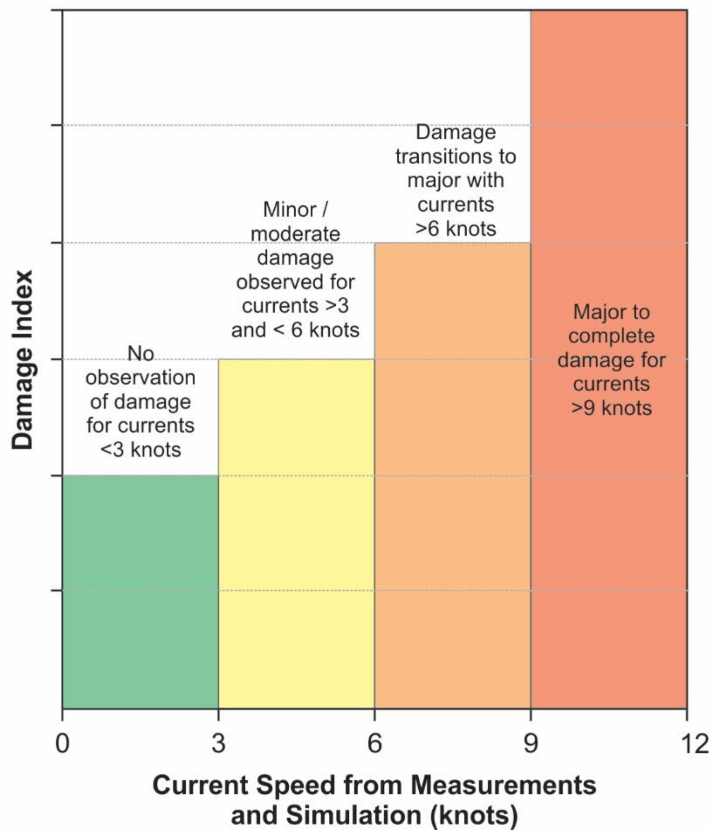


Figure 4. Graphic showing the relationship between strong tsunami currents and damage observed in a number of California harbors following real events. Modified from Lynett and others (2014) and NTHMP (2015).

BACKGROUND ON TSUNAMIS

Very large underwater earthquakes are the most common cause of tsunami waves, which can result in significant damage at very distant shores. Earthquake-caused tsunami waves occur when the seafloor abruptly deforms and vertically displaces (lifts) the overlying water column. The displaced water travels outward in a series of waves that grow in height as they encounter shallower water along coastlines. Tsunami wave impacts are greatest in and around ocean beaches, low-lying coastal areas, and bounded water bodies such as harbors and estuaries. Potential tsunami wave impact areas should always be avoided during tsunami events.

Any tsunami event can threaten harbors, facilities, and vessels. Unlike a local tsunami, which requires the public to evacuate immediately to high ground (or to deep water if out on the ocean), a distant tsunami does allow at least some time for local agencies and citizens to take steps to help reduce the expected impacts of tsunami surges. However, the time available for response is minimal and may not be sufficient for completing all needed mitigation actions. Therefore, the actions to be taken must be prioritized and based on life-safety preservation.

The source location of a distant tsunami greatly impacts the ability of local governments to respond and the public to mitigate expected impacts. A tsunami originating in *Chile (14–15 hours away)* or *Japan (9–10 hours away)* provides much more time for local mitigation activity than will a tsunami originating in the *Gulf of Alaska or the Aleutian Islands (3.5–5 hours away)*. Of these, the eastern Aleutian Islands represent the closest and most impactful distant earthquake source to the Oregon coast (~4 hours for the waves to arrive at the mouth of the Chetco River).

Response entities and the public should allow enough time to complete the necessary steps to prepare for a distant tsunami. For example, if you are on the water, first check with the U.S. Coast Guard before taking any action. If advised to evacuate to deep water and this option is practical for your vessel and you are capable of remaining offshore for an extended time period (at least 24 hours), including having to potentially travel to an alternate safe harbor if Brookings-Harbor is too heavily damaged, proceed to a staging area **greater than 30 fathoms (180 ft)** (*dashed orange line in* **Figure 1***, ~4-5 nautical miles west of the Chetco River mouth*). If conditions do not permit maritime evacuation, dock your boat and evacuate out of the distant (orange) hazard zone located on the Brookings and Harbor tsunami evacuation map; links to various community tsunami evacuation maps are provided on page **19** of this guidance document. Be aware that local mitigation activities such as taking vessels offshore or land-based evacuation to higher ground will be extensive and could involve large numbers of people, resulting in congestion and delays that could cost lives. It may not be possible to complete normally simple mitigation actions in the time frame available.

NOTABLE HISTORICAL TSUNAMIS

Table 1 provides basic information about historical tsunami events either observed (e.g., near Brookings) or measured at the Port Orford tide gauge on the south-central Oregon coast; some additional minor tsunamis are not included. According to NCEI (2023) there are effectively two types of observations:

1. Water heights as observed (estimated) by an eyewitness (i.e., the maximum elevation of the wave), and
2. Measurements from a tide gauge, with the measured tsunami water level expressed as a *wave amplitude*, which is half the height of the tsunami wave.

The largest, most damaging distant-source tsunamis to affect the Chetco River have come from large earthquakes in the Alaska-Aleutian Islands region (1964) and most recently from Japan (2011) (**Table 1**). The peak wave amplitude and damage information provided in **Table 1** may help guide port authorities in their decision-making when responding to future Advisory and Warning level tsunamis in the area. For example, the 1964 Alaska tsunami provides a threshold for comparison of predicted wave amplitudes, since damage was reported for Brookings-Harbor for an estimated tsunami water level of ~11 ft relative to MLLW on a high tide; the same event produced an extreme water level of ~13.3 ft, 0.3 mi upriver from the mouth of the Smith River.

Table 1. Historical tsunami events observed (Chetco, Winchuck, and Smith Rivers) or measured (Port Orford tide gauge) on the south-central Oregon coast since 1964 (NCEI, 2023). Bold rows highlight the effects of the 1964 Alaska and 2011 Japan events that resulted in damage to port facilities, versus other events that produced small to negligible tsunami waves.

Location	Event	Peak Amplitude Observed (ft)	NTWC Tsunami Alert Level Assigned	Tides During First 5 Hours	Damage Summary
Chetco River	**1964 M9.2 Alaska**	**5.6**	**Warning**	**High***	**damage reported**
Winchuck River	**1964 M9.2 Alaska**	**0.5**	**Warning**	**High***	**damage reported**
Smith River	**1964 M9.2 Alaska**	**6.7**	**Warning**	**High***	**damage reported**
Port Orford	2006 M8.3 Kuril	0.6	—	Low	no damage reported
Port Orford	2009 M8.0 Samoa	0.4	Advisory**	High	no damage reported
Port Orford	2010 M8.8 Chile	0.5	Advisory**	Low	no damage reported
Port Orford	**2011 M9.0 Japan**	**2.3**	**Warning****	**Low**	**Significant damage reported at Brookings-Harbor**
Port Orford	2012 M7.7 Canada	0.4	Information	High	no damage reported
Port Orford	2022 Hunga Tonga volcanic eruption	0.8	Advisory**	High	no damage reported

*Alaska 1964 arrival on PNW coast was at mean high water flood tide.

**Alert assigned by forecast outside of bay.

The 2011 Japan tsunami (**Table 1**) resulted in very significant damage in the Brookings-Harbor marina. The tsunami destroyed 70% of the commercial part of the harbor and about one third of the sports basin; the total damage was estimated at about $10 million. According to Chris Cantwell, Brookings Port Operations supervisor “it wasn’t the size of the waves that inflicted damage but the current and power.” Part of the damage can be attributed to fishing boats breaking free under the forces of the wave-induced currents and colliding with other vessels, sinking several boats. Damage would likely have been even more significant had this event occurred at or near high tide.

Lessons Learned in Northern California from the March 11, 2011, Japanese Tsunami

During the March 11, 2011, event, nearly two-thirds of the fishing boats in Crescent City Harbor headed to sea (Wilson and others, 2013). Many were prepared and practiced evacuation from the harbor prior to the event. Once the tsunami hit and operators realized they were unable to return to Crescent City Harbor, decisions had to be made as to where to go because of a huge storm approaching the coast. Some vessels had enough fuel to make it to Brookings Harbor, Oregon or to Humboldt Bay, California. Some smaller vessels did not have enough fuel and made the choice to re-enter Crescent City Harbor to anchor. Some Crescent City captains had never been to Humboldt Bay and some were running single handed as they did not have enough time to round up crewmen. As with captains who chose to go to Brookings, captains headed to Humboldt Bay kept in close contact with each other for safety and moral support. Even though the tsunami initially impacted the west coast on the morning of March 11, 2011, the largest surges in Crescent City did not arrive until later in the evening. In summary, the lessons learned include:

1. For most distant source tsunami events, it is unlikely that significant damage will occur in harbors. Therefore, leaving your vessel docked may be your best and safest option.
2. If vessels are to be taken offshore, it is recommended that harbors and vessels practice their offshore evacuation plan.
3. If evacuating to deep water, operators should ensure that their vessels are equipped to handle both the existing and forecast ocean conditions and have sufficient fuel and supplies to remain offshore for several days.
4. Recognize that the port of departure may have been damaged by the tsunami, such that vessel operators may not be able to return to the same port. For example, the Port of Brookings Harbor experienced significant damage to its boat basin, including damage to all of its docks.
5. The largest surges may not arrive until much later. Modeling by Allan and others (2024) indicates that an eastern Aleutian Islands distant tsunami would continue to produce the largest waves within the first 30 hours after the earthquake. However, tsunami resonance producing 3 to 9 ft waves was found to continue to occur up to 72 hours after the earthquake.

ACTIONABLE TSUNAMI ALERT LEVELS

The National Tsunami Warning Center (NTWC) issues four alert levels. The two non-actionable levels are Tsunami Information Statements where the NTWC notify the public that there was a potential tsunami triggering event, and a Tsunami Watch which indicates there may be an actionable event, but the NTWC is still gathering information. Tsunami Advisories and Warnings are the two <u>actionable</u> alert levels for maritime communities.

For both Advisory and Warning level events, it is important that clear and consistent directions are provided to the entire boating community and waterfront businesses. Sign up to receive official notifications from the NTWC in Palmer, Alaska (visit www.tsunami.gov or https://ntwc.ncep.noaa.gov/?page=productRetrieval; the same alerts are also provided via the NANOOS TsunamiEvac application, http://www.nanoos.org/mobile/tsunami_evac_app.php), which also includes tsunami evacuation maps useful for emergency response planning.

The NTWC issues two types of alert bulletins that require action by Oregon boaters:

⚠ Tsunami Advisories	⚠ Tsunami Warnings
Peak tsunami wave heights of 1 to 3 feet (above existing tidal conditions) are expected, indicating strong and dangerous currents can be produced in harbors near the open coast. • **SIGNIFICANT** tsunami currents or damage are possible **near to the river mouth, in the Chetco River navigation channel, and in the marina** or narrow constrictions.	Tsunami wave heights could exceed 3 feet (above existing tidal conditions) in harbors near the open coast, indicating very strong, dangerous currents and inundation of dry land is anticipated. • **SIGNIFICANT** tsunami currents or damage are possible **near to the river mouth, in the Chetco River navigation channel, and in the marina** or narrow constrictions. • Depending on the size of the tsunami and the tidal conditions, **docks may overtop the pilings.**

GENERAL GUIDANCE ON RESPONSE TO NTWC ADVISORIES AND WARNINGS

In and near Brookings-Harbor Marina

⚠ Tsunami Advisories

- **<u>During the distant event</u>** (before the tsunami arrives):
  - ➢ Evacuate from all structures and vessels in the water.
  - ➢ Public access to waterfront areas will be limited by local authorities.
  - ➢ All personnel working on or near the water should wear personal flotation devices.
  - ➢ Port authorities will shut off fuel to fuel docks, and all electrical and water services to all docks.
  - ➢ Secure and strengthen all mooring lines throughout the harbor, specifically areas near the entrance or narrow constrictions.

- If you are on the water:
  - Check with the U.S. Coast Guard before taking any action.
  - Monitor VHF FM Channel 16 and the marine WX channels for periodic updates of tsunami and general weather conditions; additional information will be available from NOAA Weather Radio.
  - If advised that offshore evacuation is an option and this is practical for your vessel and you are capable of staying offshore for an extended time period, **proceed to depths greater than 30 fathoms (180 ft)**.
  - **For the area offshore of Brookings-Harbor, the Chetco River navigation channel and marina, evacuate from the orange hazard zone (Figure 1) and head to depths greater than 30 fathoms, located ~4 to 5 nautical mile west of the mouth of the Chetco River**.

- **After the event**: Port authorities will not allow the public to re-enter structures and vessels in the water until the NTWC Advisory is cancelled and local authorities have deemed it safe to return.

Tsunami Warnings

- **During the distant event** (before the tsunami arrives)**:**
  - Public access to waterfront areas will be limited by local authorities.
  - Port authorities will shut off fuel to fuel docks, and all electrical and water services to all docks.
  - If you are on the water:
    - Check with the U.S. Coast Guard before taking any action.
    - Monitor VHF FM Channel 16 and the marine WX channels for periodic updates of tsunami and general weather conditions; additional information will be available from NOAA Weather Radio.
    - If advised that offshore evacuation is an option and this option looks practical for your vessel and you are capable of staying offshore for an extended time period, **proceed to depths greater than 30 fathoms (180 ft).**
    - **For the area offshore of Brookings-Harbor, the Chetco River navigation channel and marina, evacuate from the orange hazard zone (Figure 1) and head to depths greater than 30 fathoms, located ~4 to 5 nautical mile west of the mouth of the Chetco River**.
    - If conditions do not permit marine evacuation, dock your boat and get out of the distant tsunami evacuation zone (orange hazard zone on the **Brookings and Harbor TSUNAMI EVACUATION MAP**; links to various community tsunami evacuation maps are provided on page **19** of this guidance document).
    - Vessels considering leaving the harbor and heading to sea, please consider the following:
      - Know the anticipated tsunami arrival time.
      - Check tide, bar, and ocean conditions.
      - Check the weather forecast for the next couple of days.
      - Ensure you have enough fuel, food, and water to last a couple of days.

    - Have someone drive you to the marina so your vehicle is not in the DISTANT Tsunami Evacuation Zone (ORANGE zone on the **Brookings and Harbor TSUNAMI EVACUATION MAP**; links to various community tsunami evacuation maps are provided on page **19** of this guidance document).
    - PLEASE REMEMBER: There may be road congestion. There may also be vessel congestion in the harbor as ships, barges, and other vessels attempt to depart at the same time. All vessels should monitor VHF Channel 16 and use extreme caution. NEVER impede another vessel.
    - **<u>If you do not have time to accomplish your preparation activities, you should not make the attempt to take your vessel offshore</u>**.
  - Vessels that remain in port should check with local port authorities for guidance on what is practical or necessary with respect to vessel removal or mooring options, given the latest information on the distant tsunami event; then evacuate to an area outside of the distant tsunami evacuation zone (orange hazard zone on the **Brookings and Harbor TSUNAMI EVACUATION MAP**; links to various community tsunami evacuation maps are provided on page **19** of this guidance document).

- **<u>After the event</u>:**
  - The "CAUTIONARY RE-ENTRY" message DOES NOT MEAN THAT THE HARBOR IS OPEN. It is for land entry only.
  - Mariners at sea should stay at sea until after the U.S. Coast Guard has issued a message stating that the port is open for traffic.
  - Check with your docking facility to determine its ability to receive vessels. Adverse tsunami surge impacts may preclude safe use of the harbor. Vessels may be forced to anchor offshore or to travel great distances to seek safe harbor.
  - An extended stay at sea is a possibility if the harbor is impacted by debris or shoaling. Make sure your vessel is prepared to stay at sea. Where possible, mariners should congregate for mutual support while at sea, at anchor, or during transit elsewhere.
  - If in an onshore assembly or evacuation area, check with local authorities for guidance before returning to the inundation zone.

BROOKINGS-HARBOR PORT SPECIFIC GUIDANCE

Figure 5 presents a map of the (*top*) maximum water levels and (*bottom*) tsunami current velocities and expected port damage resulting from a maximum-considered distant tsunami initiating near the eastern Aleutian Islands, Alaska (Allan and others, 2024).

Tsunami modeling indicates that the highest tsunami water levels are observed along the open coast, especially near the Winchuck River, the Smith River, and offshore of Lake Earl in California. Dangerous conditions are also observed at the mouth of the Chetco River, immediately north of the jetties, and within the Brookings-Harbor marina.

Tsunami modeling indicates potentially dangerous currents at the Chetco River mouth, within the navigation channel, and the Port of Brookings Harbor marina. Extremely dangerous currents exceeding 9 knots (red color, **Figure 5** bottom) are expected to occur between the jetties at the mouth of the river, within the navigation channel, and in both boat basins (**Figure 5**, *bottom*). Of major concern will be the interaction of incoming tsunami waves with opposing currents generated during an ebb or ebb slack tide coupled with seaward directed tsunami drainage, which will likely contribute to the amplification of waves occurring near the mouth (see Appendix A).

For vessels moored in the Brookings-Harbor marina, currents of this magnitude could result in major/significant damage, including vessels breaking free of their mooring lines and colliding with other vessels and docks. Overtopping and inundation of much of the port facilities can be expected under this scenario. There is precedent for overtopping of the marina, which occurred as a result of the 1964 Alaska tsunami.

Upriver from the Marina entrance, model results indicate that the river channel would be affected by strong currents in the 3–9 knot range (yellow-orange color, **Figure 5**, *bottom*).

For vessels evacuating the Port of Brookings-Harbor marina, pass through the orange hazard zone (Figure 1) as quickly as possible and head to depths greater than 30 fathoms (180 ft), located ~4-5 nautical mile west of the mouth of the Chetco River.

Maritime evacuation will depend on how long it takes for a vessel to get underway, the speed at which a vessel can travel, and offshore marine conditions. For example, the distance from the marina to the offshore staging area is 4-5 nautical miles (**Figure 1**). For a vessel traveling at 6 knots, this equals ~43 to 53 minutes travel time. Offshore evacuation assumes that conditions at the estuary mouth are manageable for vessels trying to move out through the mouth into the Pacific Ocean.

In addition to powerful tsunami-induced currents, the navigation channel, ports, marinas, and docks may also be susceptible to the occurrence of whirlpools and gyres (**Figure 6**, *top*). Strong currents and vorticity will be especially significant at entrances to the Chetco River (dash ellipses in **Figure 6**, *top*). Rise of water above prevailing tide is expected to be +14 to +16 ft within the marina (**Figure 5**, *top*), decreasing to +8 ft at the Chetco River Highway 101 bridge; these values are relative to Mean Higher

High Water (MHHW), which is 7.3 ft above mean lower low water in this area. Floating dock pilings should therefore be constructed to handle this change in water level.

Dangerous tsunami currents are expected to persist for at least 30 hours after the initial wave arrival. Tsunamis may be characterized by multiple surges of water lasting at least several hours. Withdrawing tsunami waves (**Figure 6**, *bottom*, red/brown colors; white color indicates complete exposure of the sea bed) will rapidly drain the estuary and can ground vessels, making them vulnerable to being sunk by the next tsunami surge. This is likely to be an issue over large parts of the river channel and marina; grounding in the navigation channel is less likely to occur.

Wind waves can be significantly amplified due to the occurrence of opposing currents. Besides the occurrence of strong currents at the mouth of the Chetco River, strong currents may be felt out on the ocean. Model simulations in the vicinity of the river indicate that dangerous currents will be especially significant up to 4 nautical miles west of the mouth (**Figure 5**, *bottom*), with strong currents persisting for over 30 hours after the first wave arrives. Wind waves may also be amplified, especially on the tsunami outgoing (ebb) flow (Appendix A). For example, a 5-ft wave could be amplified 12–30% by a 3-knot opposing current generated by a tsunami, and by as much as 95% if currents approach 6 knots. If using existing single-point moorings or when anchoring, be aware that the dead-man or anchor could move, or the mooring lines or chains could break because of strong or changing currents. Initial evaluations and some field observations of anchor stability indicate that currents greater than 3 to 4 knots will move a dead-man or anchor.

Figure 5. Model results of the maximum tsunami water levels (top) and currents (bottom) generated by an eastern Aleutian Islands, Alaska earthquake and distant tsunami (AKMax). Time histories of water levels and currents are provided in Appendix A for Station-6, 7 (jetty entrance), 10 (Marina entrance), and 14 (west marina).

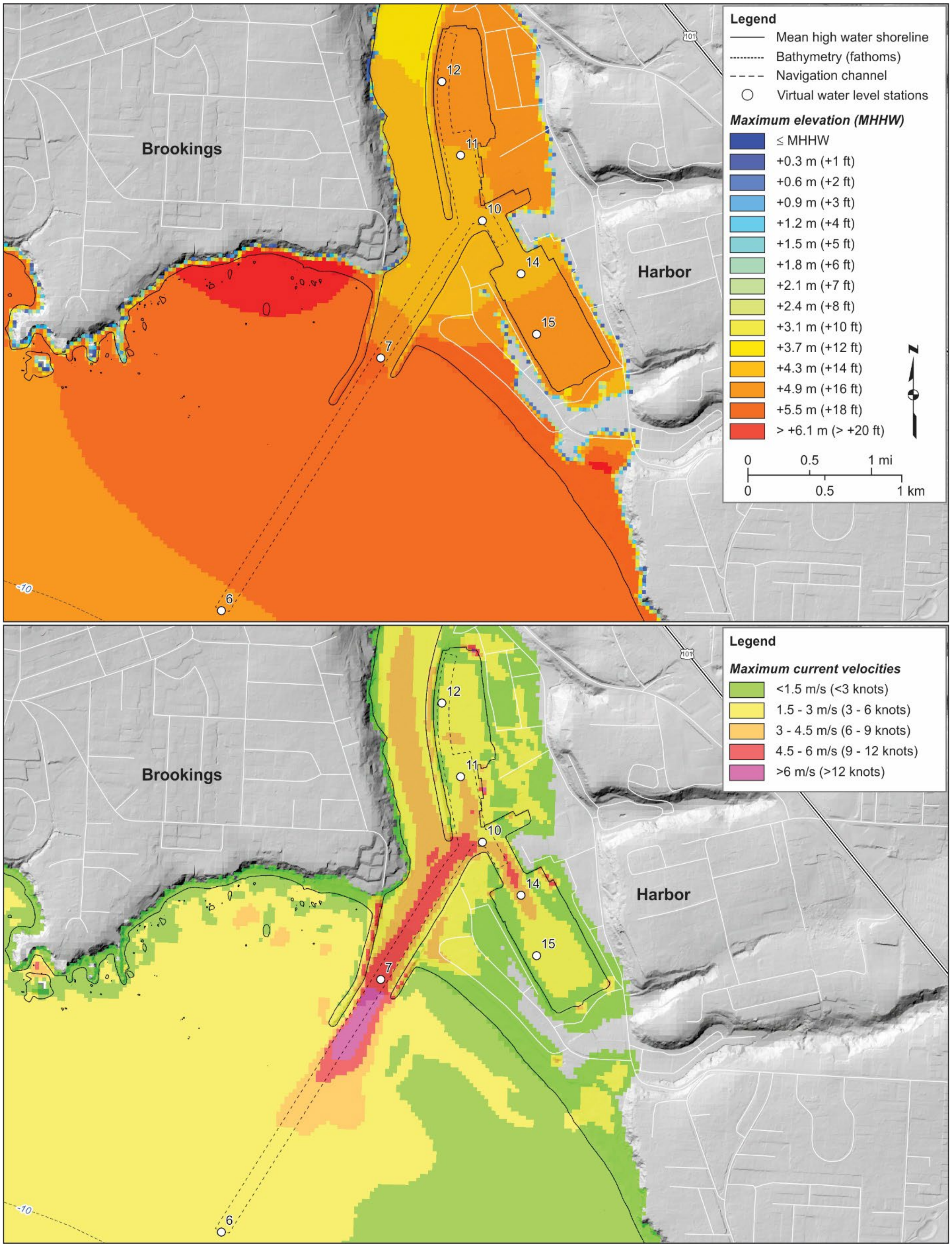
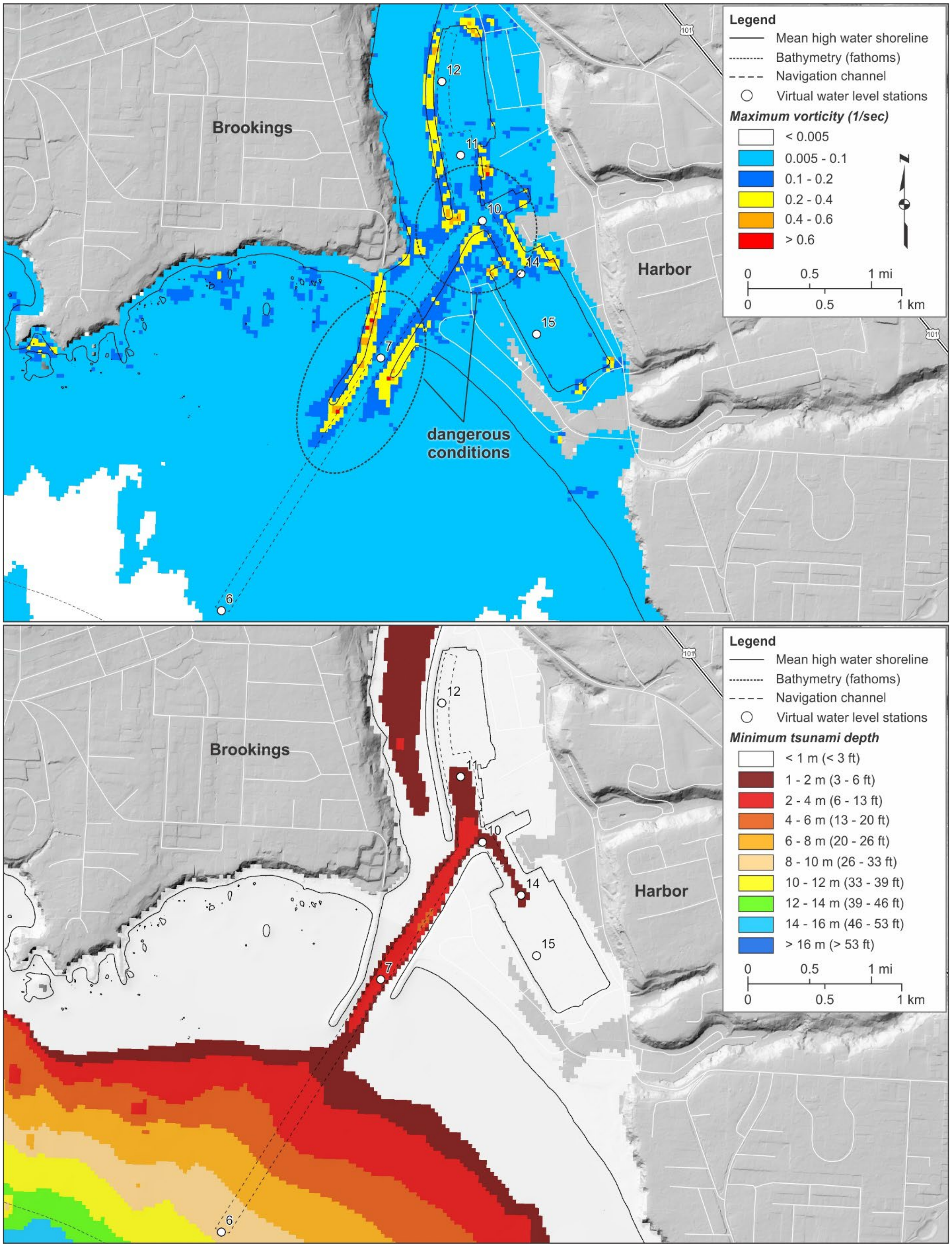


Figure 6. Ensemble model results of the maximum vorticity (top) and minimum water depths (bottom) generated by an eastern Aleutian Islands, Alaska earthquake and distant tsunami (AKMax). The top plot is a measure of the potential for rotation (gyres and whirlpools – hot colors indicate strong potential), while the bottom shows the expected minimum water depths from tsunamis.



ADDITIONAL GUIDANCE

Do Your Homework

Check the DOGAMI Tsunami Clearinghouse (https://www.oregon.gov/dogami/tsuclearinghouse/Pages/default.aspx) for detailed information on tsunami hazards in your area and tips on preparedness. Preparedness information is also available from Oregon Emergency Management (https://www.oregon.gov/OEM/hazardsprep/Pages/Tsunami.aspx). Download and review the statewide tsunami maritime guidance brochure (https://www.oregon.gov/dogami/tsuclearinghouse/Pages/maritime.aspx). For general information on tsunami maritime hazards consult https://www.tsunami.noaa.gov/ and the information below.

Know real-time and permanent mitigation measures appropriate for your area

This information can be used to identify real-time response mitigation measures, determine where infrastructure enhancements should be initiated, and provide a mechanism for pre-disaster hazard mitigation funding through additions to local hazard mitigation plans. Although these products, plans, and related mitigation efforts will not eliminate all casualties and damages from future tsunamis, they will provide a basis for reducing future impacts on life-safety, infrastructure, and recovery in Oregon maritime communities.

Real-Time Response Mitigation Measures	Permanent Mitigation measures
Move boats and ships out of harbors	Fortify and armor breakwaters
Reposition ships within harbor	Increase size and stability of dock piles
Move large, deep draft ships from harbor entrances	Strengthen cleats and single-point moorings
Remove small boats/assets from water	Improve floatation portions of docks
Shut down infrastructure before tsunami arrives	Increase flexibility of interconnected docks
Evacuate public/vehicles from water-front areas	Improve movement along dock/pile connections
Restrict boats from moving during tsunami	Increase height of piles to prevent overtopping
Prevent boats from entering harbor during event	Deepen/dredge channels near high hazard zones
Secure boat/ship moorings	Move docks/assets away from high hazard zones
Personal flotation devices/vests for harbor staff	Reduce exposure of petroleum/chemical facilities
Move hazardous materials away from water	Strengthen boat/ship moorings
Move buoyant assets away from water	Construct floodgates
Stage emergency equipment outside affected area	Prevent uplift of wharfs by stabilizing platform
Activate Mutual Aid System as necessary	Add debris deflection booms to protect docks
Activate Incident Command at evacuation sites	Make harbor control structures tsunami resistant
Alert key first responders at local level	Construct breakwaters farther away from harbor
Aid traffic evacuating harbor	Install tsunami warning signs
Personnel to assist rescue, survey, and salvage	Strengthen equipment/assets (patrol/tug/fireboats, cranes, etc.) to assist emergency response activities
Identify boat owners/liveaboards; establish phone tree, or other notification processes	

Land-based Tsunami Evacuation Maps

Consult your local community tsunami evacuation resources

For land-based tsunami evacuation guidance, use existing tsunami evacuation maps provided on the Oregon Tsunami website (https://www.oregon.gov/dogami/tsuclearinghouse/Pages/default.aspx) to determine an evacuation location safe from a distant (orange zone) or local (yellow zone) tsunami.

Brookings and Harbor tsunami evacuation zone maps can be found online at:

- PDF: https://pubs.oregon.gov/dogami/tsubrochures/BrookingsHarbor-EvacBrochure_onscreen.pdf
- Interactive web portal map: http://nvs.nanoos.org/TsunamiEvac

Smartphone app:

- http://www.nanoos.org/mobile/tsunami_evac_app.php

Warning: After a local earthquake and tsunami, cell phone towers may be damaged or overloaded. Know and practice your evacuation plan beforehand, so you don't have to rely on cell phone service.

Additional Resources:

Oregon Tsunami Clearinghouse:
https://www.oregon.gov/dogami/tsuclearinghouse/Pages/default.aspx

Oregon Emergency Management: https://www.oregon.gov/OEM/

Oregon Statewide Maritime Evacuation Guidance brochure:

https://pubs.oregon.gov/dogami/tsubrochures/TsunamiBrochureMaritime.pdf

Document adapted from the Humboldt Bay Tsunami Maritime Actions website: (http://humboldtharborsafety.org/sites/humboldtharborsafety.org/files/BMP%20Tsunami%20Maritime%20Actions%20Small%20Craft%20Final.pdf).

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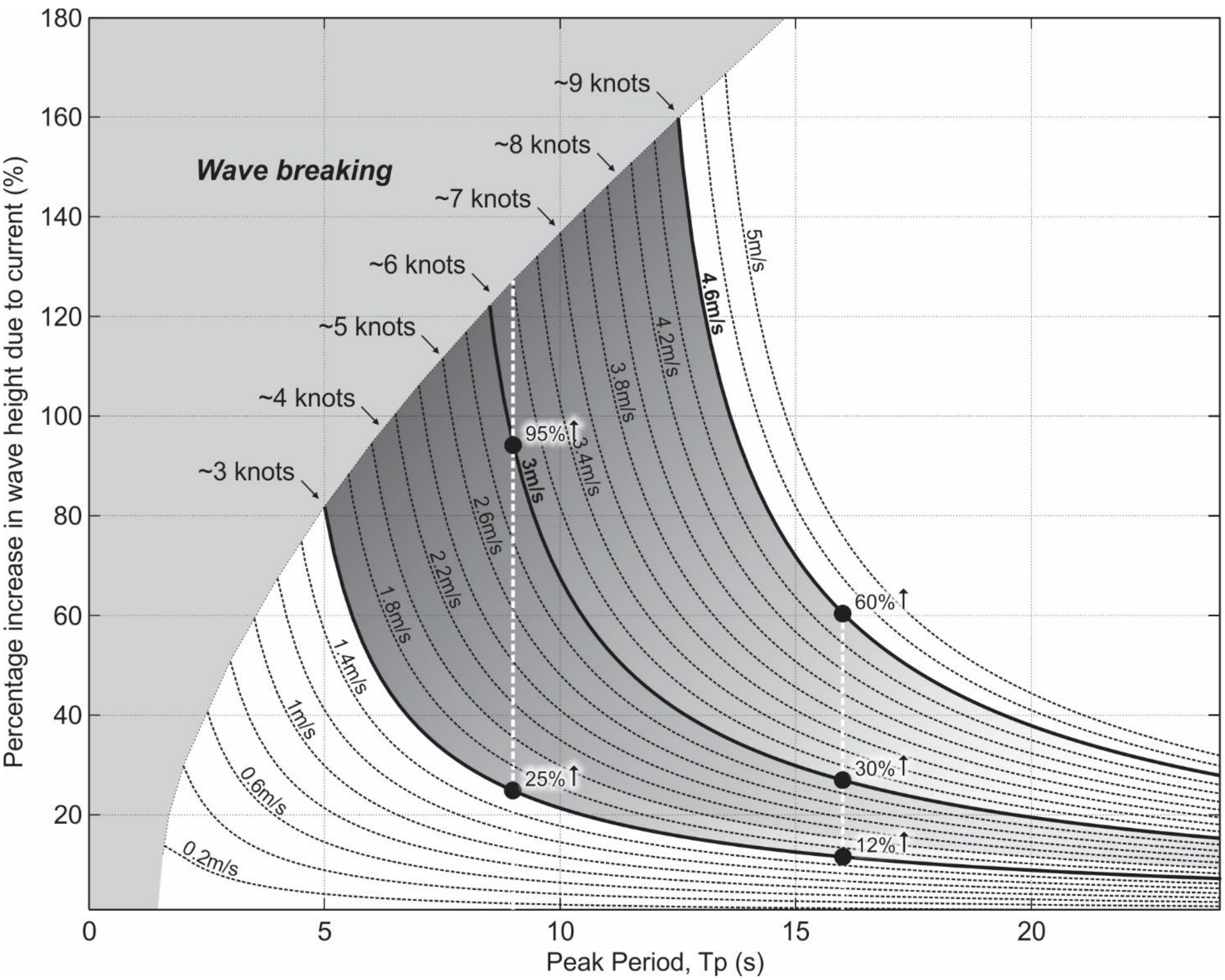
APPENDIX A — ADDITIONAL MAPS

Unless otherwise indicated, maps on the following pages are from Allan and others (*in prep*):

- Plot showing change in wave amplitudes based on opposing currents
- Tsunami wave arrival times for an eastern Aleutian Islands (***DISTANT***) earthquake and tsunami
- Time histories of water levels for the Chetco River mouth and Brookings-Harbor marina for an AKMax ***DISTANT*** tsunami
- Time histories of tsunami currents for the Chetco River mouth and Brookings-Harbor marina for an AKMax ***DISTANT*** tsunami

Wave amplification estimate. Plot shows change in wave amplitudes based on opposing currents (from Allan others, 2018):



How to use:

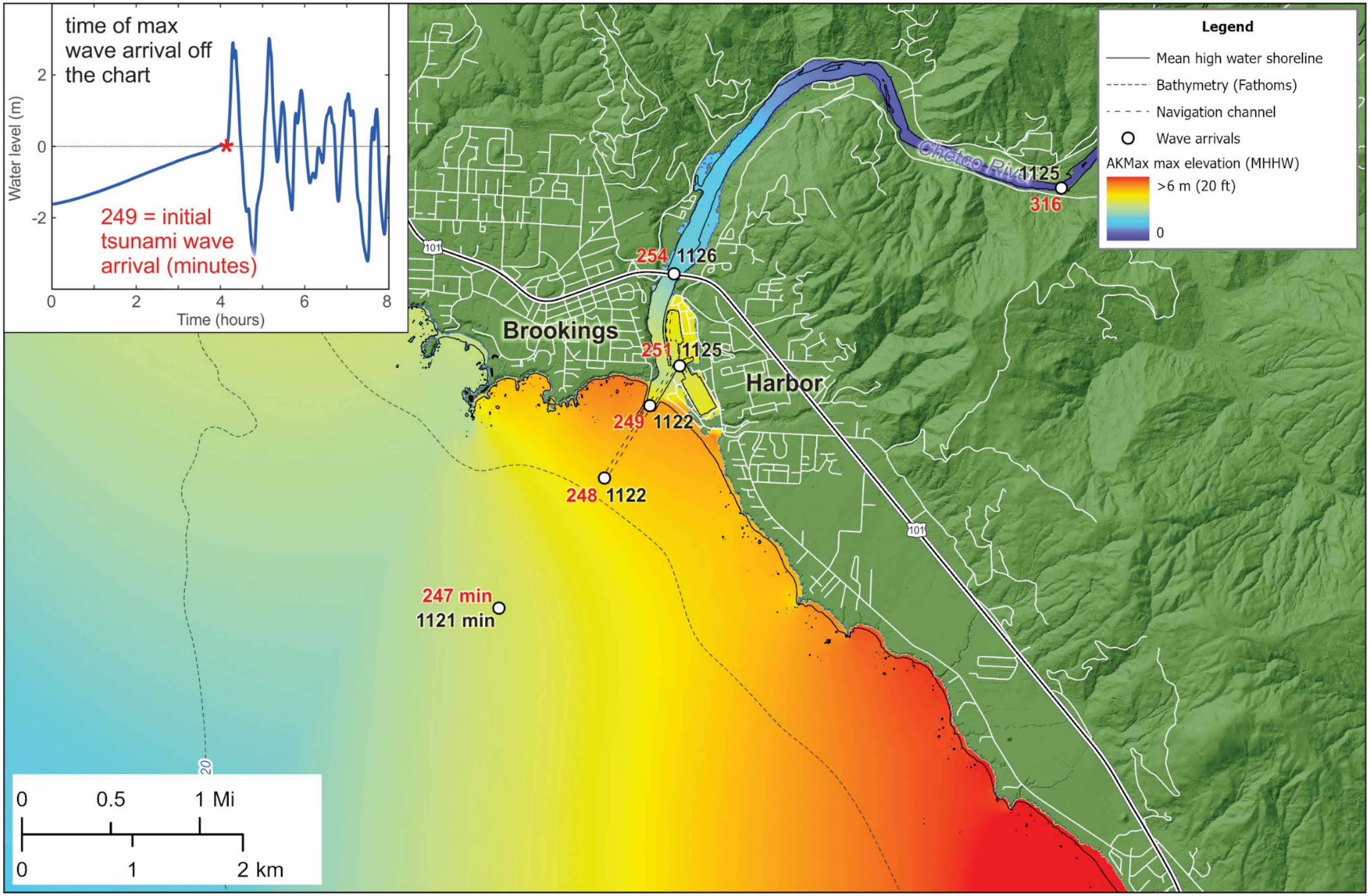
Step 1. Identify the prevailing peak wave period defined for the x-axis.

Step 2. Determine the outgoing (opposing) current velocity (knots).

Step 3. From steps 1 and 2, identify on the y-axis the calculated percentage increase in wave height.

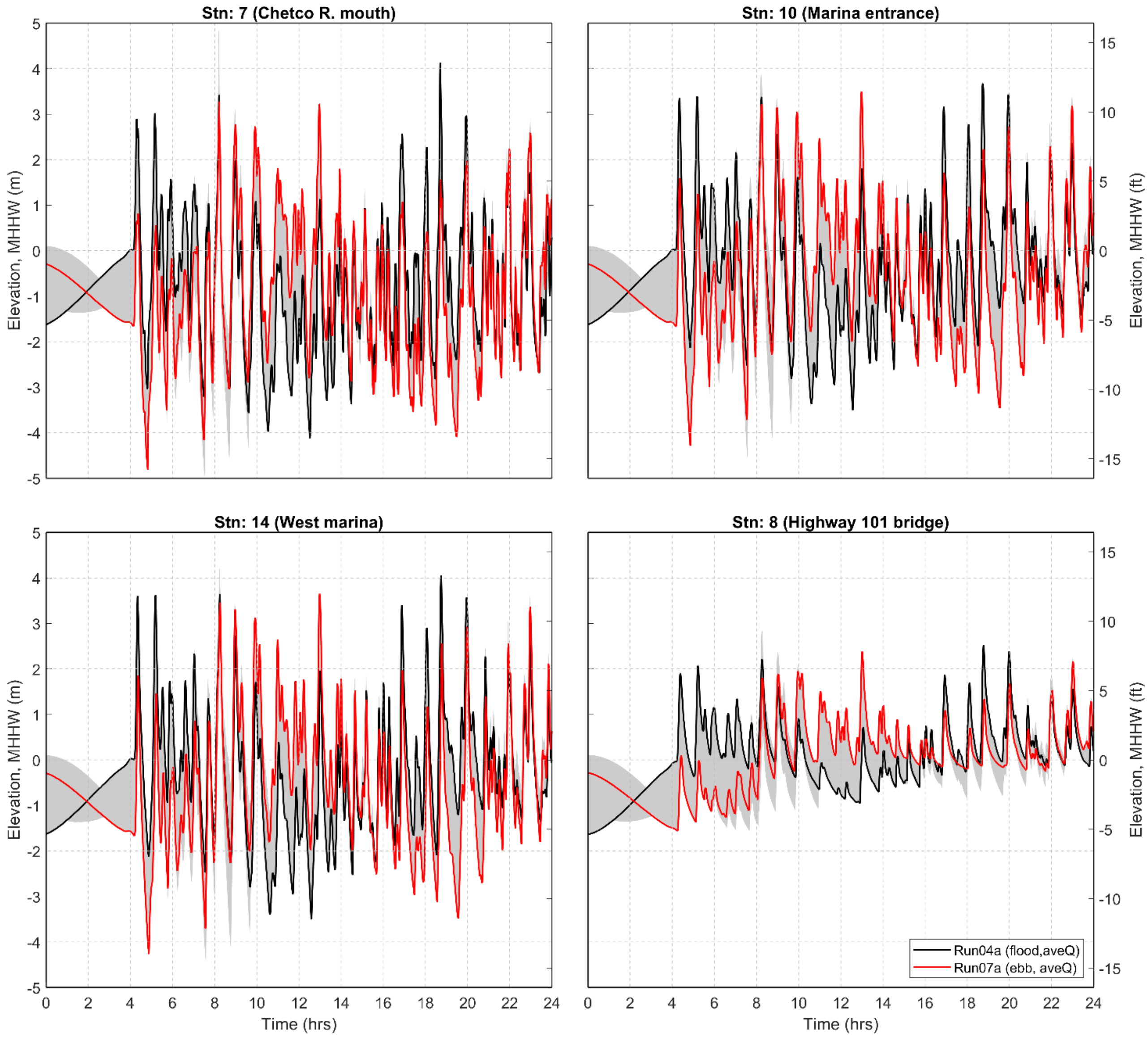
Example: A peak period of 16 sec will yield a 12% (60%) increase in the wave height with a 3 (9) knot opposing current.

Tsunami wave arrival times defined for AKMax (*DISTANT*) for discrete locations offshore from Brookings and along the Chetco River. Times reported are in minutes. Red numbers correspond to the initial wave arrival (the point at which the water level begins to depart from normal), while the bold, black number reflects the time at which the maximum wave occurs. Dangerous wave and current conditions are thus expected to persist for greater than 19 hours after a large Alaska subduction zone earthquake.



Maritime Guidance for Distant Source Tsunami Events

Time histories of tsunami waves and water levels for select sites resulting from a distant tsunami (AKmax) initiating near the eastern Aleutian Islands, Alaska. Simulations shown include both a flood and ebb tide condition. Gray shading defines the envelope of variability of tsunami water levels from a suite of simulations.



Time histories of tsunami current velocities for select sites resulting from a distant tsunami (AKmax) initiating near the eastern Aleutian Islands, Alaska. Simulations shown include both a flood and ebb tide condition. Gray shading defines the envelope of variability of tsunami current velocities from all simulations.