Port of Astoria, Clatsop County, Oregon and Lower Columbia River Estuary

Oregon Maritime Tsunami Response Guidance (MTRG) No. 2018-OR-01

Maritime response guidance in this document is based primarily on anticipated effects of a **maximum-considered distant tsunami event** (scenario *AKMax* of the Oregon Department of Geology and Mineral Industries), although general guidance is also given for a much larger tsunami from an earthquake on the Cascadia subduction zone (see www.oregontsunami.org for more information on these tsunami scenarios). Smaller distant source tsunamis will occur more commonly 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.

Oregon Department Geology and Mineral Industries

Oregon Office of Emergency Management

Virginia Institute of Marine Sciences

National Oceanic and Atmospheric Administration

Members of the Oregon Marine Advisory Council

Funded by the National Tsunami Hazard Mitigation Program (NTHMP) and conforms to NTHMP guidance. Document also 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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INTRODUCTION

Tsunamis can be triggered by earthquakes 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.

DISTANT TSUNAMIS are caused by great earthquakes far away from the Oregon coast and will arrive at the mouth of the Columbia River (MCR) *approximately* 3 hours 38 minutes or more after the earthquake and will cause water level and current changes for many hours after first arrival.

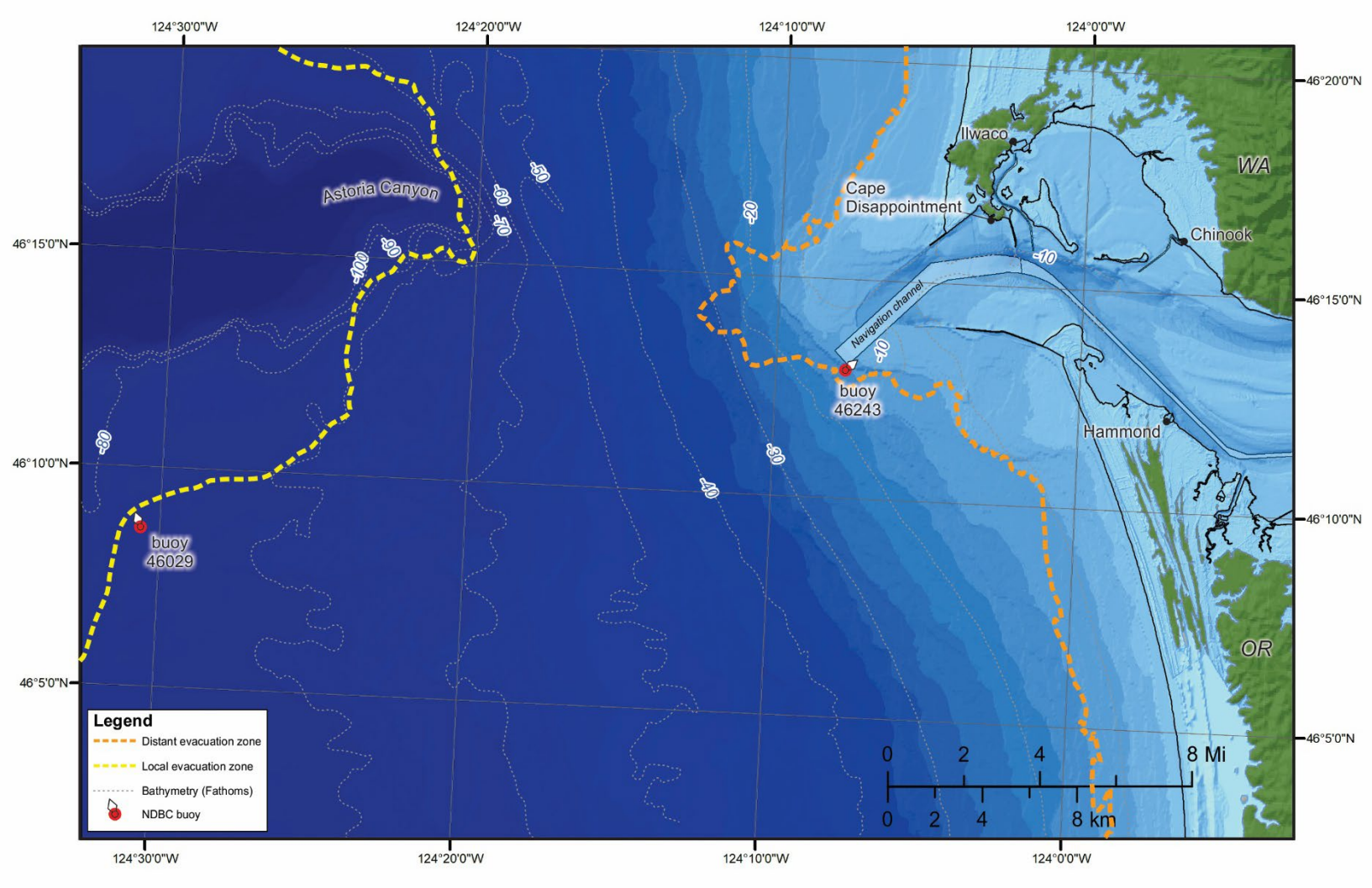
A locally generated earthquake on the Cascadia subduction zone (CSZ) offshore the Oregon coast will produce catastrophic tsunami waves that will reach the MCR in ~ 7 minutes after the start of the earthquake and will flood the lower Columbia River estuary in 25 to 60 minutes. Modeled wave arrival times for a **LOCAL TSUNAMI** are 35 minutes at Hammond, 43 minutes at Warrenton, 42 minutes at Astoria, 50 minutes at Tongue Point, and ~109 minutes at Wauna.

This document provides response guidance in the event of a **DISTANT TSUNAMI**, **FOR SMALL CRAFT** (vessels under 300 gross tons) such as recreational and commercial fishing vessels. Review DOGAMI Special Paper 51 (Allan and others, 2018a) for detailed maritime tsunami guidance on distant and local tsunamis affecting the entire Columbia River estuary. A brief summary of the key actionable responses is provided below for both types of events.

DISTANT Tsunamis: *You have a minimum of 3 hours 38 minutes after the distant 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, proceed to a staging area **greater than 25 fathoms (150 ft)** (*orange line in* **Figure 1**, *located ~5 nautical miles southwest of the Cape Disappointment lighthouse [near the Clatsop Spit buoy 46243]*). Dangerous currents (> 5 knots) are expected to occur at depths shallower than 15 fathoms, and especially within the MCR. If conditions do not permit offshore evacuation, dock your boat and get out of the tsunami evacuation zone.

LOCAL Tsunamis: *You have as little as ~7 minutes to take action; plan in advance*. If your boat is docked, you do NOT have time to take your vessel offshore; instead, evacuate by foot to high ground immediately. If you are on the water seaward of the MCR at the time of a local earthquake, head toward **Astoria Canyon** to **greater than 80 fathoms (480 ft)** water depth (*yellow line in* **Figure 1**, *located ~12 nautical miles west of the Cape Disappointment lighthouse or 9.1 nautical miles west northwest of buoy 46243*). Sail directly toward the nearest deep water or in a general westward direction. Dangerous currents (> 5 knots) are expected to occur at depths shallower than 50 fathoms. Note that significant wave heights may be greatly amplified by strong opposing tsunami currents.

Figure 1. Offshore maritime staging area for the Columbia River area. Map identifies the locations of the DISTANT (orange) and LOCAL (yellow) tsunami evacuations zones offshore the coast. These zones define the region where tsunami currents fall below 4 knots. Note: bathymetric contours shown on the map are fathoms (1 fathom = 6 ft).



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, facilities, and vessels.

Tsunami hazards that can directly affect boats/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 vessels tied to docks.
- Collision with other vessels, docks, and debris in the water.
- Dangerous tsunami conditions can last tens of hours after 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 damage indicates a relationship between current speed and harbor damage. The Damage Index (from Lynett and others, 2013) to the right has been used to determine the following relationship (see color codes here for green, yellow, orange, and red areas and on the maps showing tsunami current thresholds (Figure 2 and Appendix A tsunami current maps):

CURRENTS = DAMAGE
0-3 knots = No Damage
3-6 knots = Minor/Moderate Damage
6-9 knots = Moderate/Major Damage
>9 knots = Major/Complete Damage

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

BACKGROUND ON TSUNAMIS

Very large underwater earthquakes are the most likely cause of tsunami waves, which can cause 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 intensity 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—all needed mitigation actions probably cannot be accomplished. 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)* will allow much more 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 distant earthquake source to the Oregon coast (~3 hours, 38 minutes for the waves to arrive at the MCR).

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, proceed to a staging area **greater than 25 fathoms (150 ft)** (*orange line in* **Figure 1***, located ~5 nautical miles southwest of the Cape Disappointment lighthouse (near the Clatsop Spit buoy 46243)*). If conditions do not permit maritime evacuation, dock your boat and evacuate out of the ORANGE zone located on the **Columbia River tsunami evacuation** map; links to various community tsunami evacuation maps are provided on page **16** of this guidance document. Be aware that local mitigation activities will be extensive and could involve large numbers of people, resulting in congestion and delayed actions—it may not be possible to complete normally simple mitigation actions in the time frame available.

NOTABLE HISTORICAL TSUNAMIS IN ASTORIA

Table 1 provides basic information about historical tsunami events either observed (e.g., Cape Disappointment) or measured (Tongue Point tide gauge) on the northern Oregon coast; some additional minor tsunamis are not included. Here we distinguish between two types of observations:

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

The largest, most damaging distant-source tsunamis to affect the lower Columbia River estuary 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 with their decision making when responding to future Advisory and Warning level tsunamis in the area. For example, the 1964 Alaska tsunami provides a threshold, since damage was reported for select sites in the Columbia River for a tsunami wave amplitude (wave height) of 1.7 m (5.6 ft), occurring on a higher tide.

Table 1. Historical tsunami events observed (e.g. Cape Disappointment and Ilwaco) or measured (Tongue Point) on the northern Oregon coast since 1964 (NGDC, 2017). Bold rows highlight the effects of the 1964 event that resulted in some damage, versus other events that produced small to negligible tsunami waves.

Location	Event	Peak Amplitude Observed		NTWC Tsunami Alert Level Assigned	Tides During First 5 Hours	Damage Summary
		(m)	(ft)			
Cape Disappointment	**1964 M9.2 Alaska**	**1.74**	**5.7**	**Warning**	**High***	**damage reported**
Ilwaco	**1964 M9.2 Alaska**	**1.4**	**4.6**	**Warning**	**High***	**damage reported**
Tongue Point	2006 M8.3 Kuril	0.04	0.1	—	Low	no damage reported
Tongue Point	2009 M8.0 Samoa	0.03	0.1	Advisory**	High	no damage reported
Tongue Point	2010 M8.8 Chile	0.05	0.2	Advisory**	Low	no damage reported
Tongue Point	2011 M9.0 Japan	0.19	0.6	Warning**	Low	no damage reported
Tongue Point	2012 M7.7 Canada	0.03	0.1	Information	High	no damage reported

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

**Alert assigned by forecast OUTSIDE of bay.

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

During the March 11, 2011 event, Crescent City boats headed to sea. 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 in 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 crewman. As with captains who chose to go to Brookings, captains heading to Humboldt Bay kept in close contact with each other for safety and for 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 reflect:

1. If evacuating to deep water, ensure that your vessel is equipped to handle the ocean conditions and has sufficient fuel and supplies to remain offshore for several days;
2. Recognize that the port you left may have been damaged by the tsunami, such that you may not be able to return to the same port; and
3. The largest surges may not arrive until much later.

ACTIONABLE TSUNAMI ALERT LEVELS

Tsunami Advisories and Warnings are the two actionable 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 to waterfront businesses. Sign up to receive notifications from the National Tsunami Warning Center in Palmer, Alaska (http://wcatwc.arh.noaa.gov/?page=productRetrieval), which issues two types of bulletins that require action by Oregon boaters:

Tsunami Advisories	Tsunami Warnings
Peak tsunami wave heights of 1 to 3 feet are expected, indicating strong and dangerous currents can be produced in harbors near the open coast. • **SIGNIFICANT** tsunami currents or damage are possible **in the Columbia River** near harbor entrances or narrow constrictions.	Tsunami wave heights could exceed 3 feet 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 **in the Columbia River**. • Depending on the tidal conditions, **docks may overtop the pilings at various Columbia River ports.**

GENERAL GUIDANCE ON RESPONSE TO NOAA ADVISORIES AND WARNINGS

In and near Columbia River estuary

Tsunami Advisories

- **During the *DISTANT* event** (before the tsunami arrives):
  - Evacuate from all structures and vessels in the water.
  - Access of public along 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 harbor, specifically areas near the entrance or narrow constrictions.
  - If you are on the water,
    - Check with the U.S. Coast Guard (USCG) 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 25 fathoms (150 ft)**.
  - **For the Columbia River go to greater than 5 nautical miles southwest of the Cape Disappointment lighthouse (near the Clatsop Spit buoy 46243) (see Figure 1)**.

- **After the event**: Port authorities will not allow public to re-enter structures and vessels in the water until the Advisory is cancelled.

Tsunami Warnings

- **During the *DISTANT* event:**
  - Access of public along 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 (USCG) 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 25 fathoms (150 ft)**.

(continued on next page)

- **For the Columbia River go to greater than 5 nautical miles southwest of the Cape Disappointment lighthouse (near the Clatsop Spit buoy 46243) (see Figure 1)**.

If conditions do not permit marine evacuation, dock your boat and get out of the ***DISTANT Tsunami Evacuation Zone*** (ORANGE zone on the **Columbia River tsunami evacuation** map; links to various community tsunami evacuation maps are provided on page **16** of this guidance document).

- VESSELS considering leaving the harbor and heading to sea, please consider the following:
  - Make sure your family is safe first.
  - 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 **Columbia River tsunami evacuation** map; links to various community tsunami evacuation maps are provided on page **16** 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.
  - If you do not have time to accomplish your goal, you should not make the attempt.
- **VESSELS that stay 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 go outside the DISTANT Tsunami Evacuation Zone (ORANGE zone on the **Columbia River tsunami evacuation** map; links to various community tsunami evacuation maps are provided on page **16** of this guidance document).

- **After the event**:
  - The "CAUTIONARY RE-ENTRY" DOES NOT MEAN THAT THE HARBOR IS OPEN. The “CAUTIONARY RE-ENTRY” message is for land entry only.
  - Mariners at sea should stay at sea until after the United States 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.

Figure 2 presents a map of the maximum water levels (*top*) and tsunami current velocities (*bottom*) and expected port damage resulting from a maximum-considered ***DISTANT*** tsunami occurring on the eastern Aleutian Islands (Allan and others, 2018a). More detailed maps specific to the Astoria/Tongue Point area are included at the end of this report on page 17. The modeling reveals that the highest tsunami water levels are observed along the open coast, especially offshore the Clatsop Plains. Dangerous conditions are also observed at the MCR, within Baker Bay (e.g. Ilwaco and Chinook) and Young's Bay, and by Tongue Point.

More telling are the modeled tsunami currents, which indicate potentially dangerous currents occurring within the MCR (**Figure 2**, *bottom*). Strong currents exceeding 9 knots (hot colors) are prevalent in the MCR navigation channel, north of Clatsop Spit, and in the narrows between Cape Disappointment and Sand Island, Sand Island, and East Sand Island, and near Chinook (**Figure 2**, *bottom*). Of major concern will be the interaction of incoming tsunami waves with opposing currents generated during an ebb tide coupled with seaward directed tsunami drainage, which will likely contribute to the amplification of waves occurring near the mouth (see Appendix A).

Within the estuary, the model results indicate that large parts of the estuary would be affected by currents in the 3–6 knot range (**Figure 2**, *bottom*). Currents of this magnitude are likely to cause moderate damage to facilities located in ports and harbors. For ships and boats moored in the navigation channel (e.g. between Astoria and Rice Island) and in harbors, currents of this magnitude will likely necessitate ship operators adding additional drag anchors to the larger vessels. Evacuation upriver toward Fitzpatrick Island may be feasible depending on how long it takes the vessel to get underway (a conservative estimate is about 1 hour for large ships), the availability of river pilots, and the speed at which the ship can travel. For example, the distance to where tsunami currents fall below 4 knots upriver from Tongue Point is 8.6 nautical miles (**Table 2**). For a vessel travelling at 6 knots, this equals ~1 hour 26 minutes travel time. Offshore evacuation is not recommended for vessels moored near Tongue Point. This is because the distance to the 25-fathom line offshore the MCR is 22 nautical miles, and a vessel travelling at 6 knots would take ~3 hours 14 minutes to reach areas of expected low currents, providing little buffer between leaving the MCR and the arrival of the tsunami. The latter also assumes that conditions at the MCR are manageable for vessels trying to move out through the MCR into the Pacific Ocean.

Figure 2. Maximum water levels (top) and tsunami current velocities (bottom) and expected port damage resulting from the AKMax DISTANT tsunami impacting the lower Columbia River estuary. Dangerous eddies and whirlpools can be expected in narrow channel constrictions such as adjacent to the jetties, the port breakwater, and next to the port dock facilities. Time histories of water levels and currents are provided in Appendix A for stations 3 (MCR), 19 (Astoria), 23 (Tongue Point), and 32 (Fitzpatrick Island).

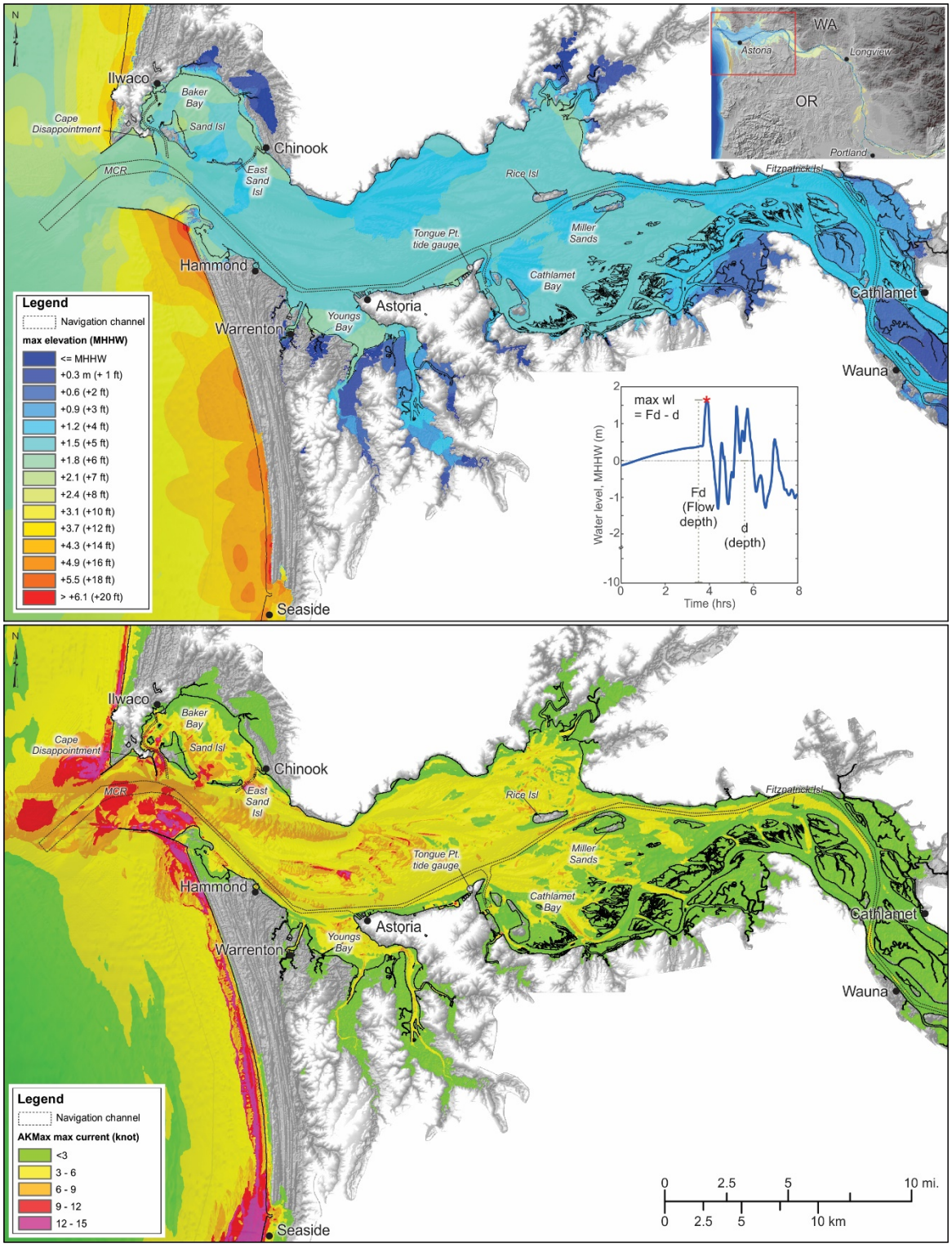


Table 2. Maritime evacuation times to nearest offshore[a] (where currents fall below 4 knots) and upriver[b] staging destinations. Evacuations times assume an average Vessel speed of 6 knots. (NM = Nautical Miles)

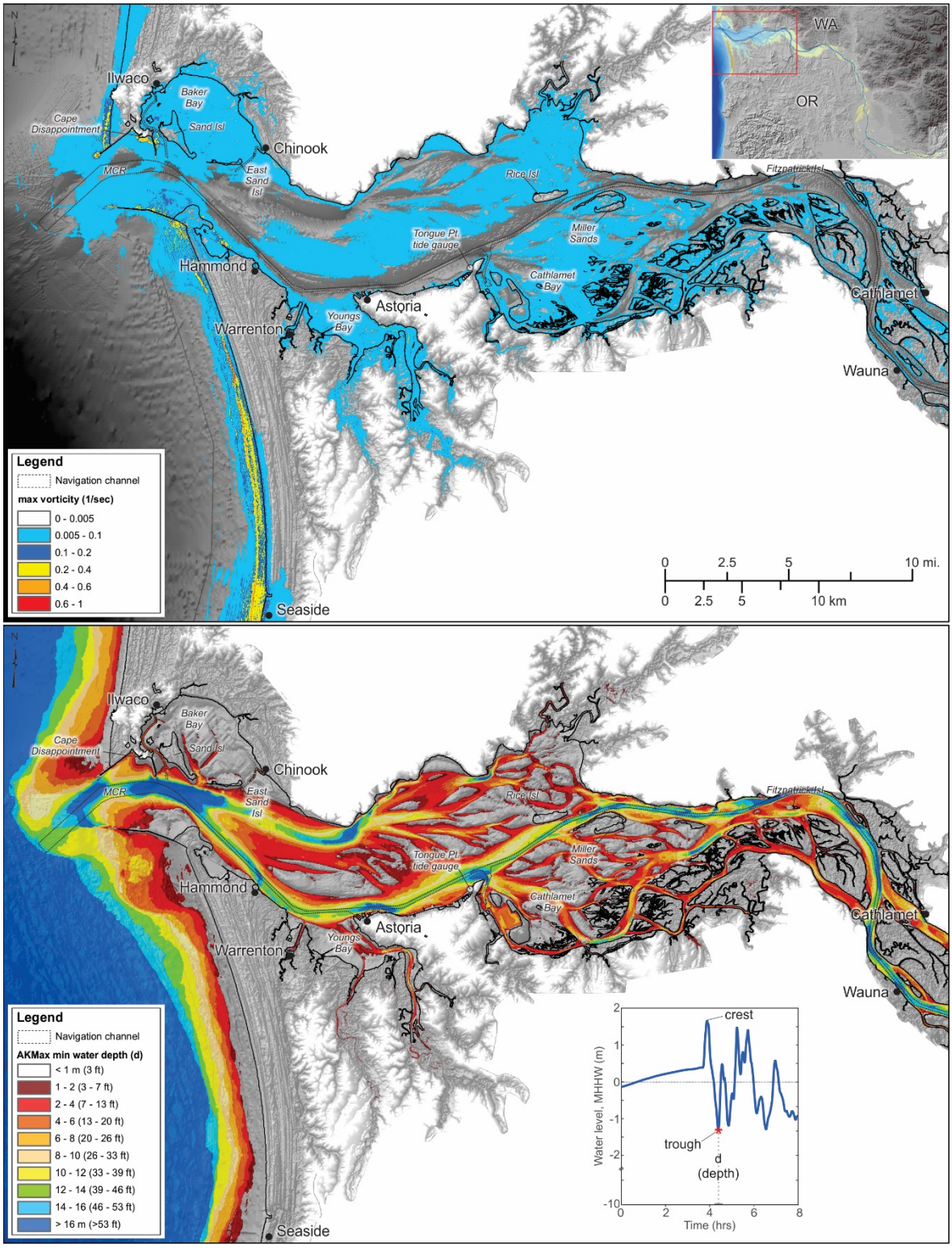
Location	Distance to Offshore[a] Staging (NM)	Time to Safety	Distance to Upriver[b] Staging (NM)	Time to Safety
Ilwaco, WA	9.2	1 hour 31 min	25.4	4 hours 14 min
Chinook, WA	9.7	1 hour 37 min	22.0	3 hours 41 min
Hammond, OR	10.8	1 hour 48 min	17.8	2 hours 58 min
Warrenton, OR	13.5	2 hours 15 min	16.7	2 hours 47 min
Astoria, OR	14.0	2 hours 22 min	13.5	2 hours 15 min
Tongue Point, OR	22.4	3 hours 14 min	8.6	1 hour 26 min

Strong current velocities are expected within the ports, at the entrance to the various marinas, and around the docks. These areas will also be susceptible to the occurrence of vorticity (rotation), leading to the development of whirlpools and gyres (**Figure 3**, *top*). Strong currents and vorticity will be especially significant at the Tongue Point marina (see Tongue Point maps in appendix). Rise of water above prevailing tide is expected to be +5 to 6 ft above the tide around the docks at Astoria and within the Tongue Point marina (**Figure 2**, *top*). Floating dock pilings should therefore be constructed to handle this change in water level plus an appropriate tide such as Mean Higher High Water (MHHW). MHHW is 8.6 ft above geodetic mean sea level (NAVD88) in this area.

Be aware that tsunamis may be characterized by multiple surges of water lasting at least several hours. Analyses of the AKMax distant scenario indicate that dangerous tsunami currents persist for at least 4 hours after the initial wave arrival. Withdrawing tsunami waves (**Figure 3**, *bottom*, red/brown colors) 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 estuary (**Figure 3**, *bottom*), while grounding in the navigation channel is unlikely to occur.

In addition to the occurrence of strong currents at the mouth of the Columbia River, Oregon boaters need to be aware of the potential occurrence of strong currents out on the ocean. For example, model simulations indicate that strong currents (including potential for whirlpool development) will be especially significant up to 5.5 nautical miles west of the MCR (**Figure 2**, *bottom*), with strong currents persisting for several hours after the first wave arrives. This is especially important to maritime safety because wind waves can be significantly amplified due to the occurrence of opposing currents (see Appendix A). The greatest potential for wave amplification will occur on the tsunami outgoing (ebb) flow. 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% as 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 3-4 knots will move a dead-man or anchor.

Figure 3. Maximum vorticity (top) and minimum water depths (bottom) generated by a the AKMax DISTANT tsunami impacting the lower Columbia River estuary. Top plot is a measure of the potential for rotation (gyres and whirlpools), while the bottom shows the expected minimum water depths from tsunamis.



ADDITIONAL GUIDANCE

Do Your Homework

Check the DOGAMI Tsunami Clearinghouse (http://www.oregontsunami.org) 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.oregongeology.org/pubs/tsubrochures/TsunamiBrochureMaritime.pdf). 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
Moving boats and ships out of harbors	Fortify and armor breakwaters
Repositioning 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	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	Equipment/assets (patrol/tug/fireboats, cranes, etc.) to assist response activities
Identify boat owners/live-aboards; establish phone tree, or other notification process	

Consult your community tsunami evacuation map

Use the tsunami evacuation maps to determine where it is safe from a ***DISTANT*** (orange zone) or ***LOCAL*** (yellow zone) tsunami:

Columbia River tsunami evacuation maps

Detailed tsunami evacuation zones can be found online at:

- PDFs = https://www.oregongeology.org/tsuclearinghouse/pubs-evacbro.htm
- Interactive web portal map: http://nvs.nanoos.org/TsunamiEvac

Regional maps covering Clatsop Spit, Warrenton, and Astoria in Oregon may be found here:

https://www.oregongeology.org/pubs/tsubrochures/WarrentonEvacBrochure-5-29-13_onscreen.pdf

https://www.oregongeology.org/pubs/tsubrochures/AstoriaEvacBrochure-6-6-13_onscreen.pdf

Maps for Ilwaco and Chinook on the Washington coast may be found here:

http://www.dnr.wa.gov/Publications/ger_tsunami_evac_longbeach.pdf

http://www.dnr.wa.gov/Publications/ger_tsunami_evac_chinook.pdf

Smartphone app:

iPhone: https://itunes.apple.com/us/app/tsunamievac-nw/id478984841?mt=8
Warning: After an earthquake and tsunami, cell phone towers might be damaged. Know and practice your evacuation plan beforehand.

Additional Resources:

Oregon Tsunami Clearinghouse: http://www.oregontsunami.org

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

Oregon Statewide Maritime Evacuation Guidance brochure:

https://www.oregongeology.org/pubs/tsubrochures/TsunamiBrochureMaritime.pdf

REFERENCES CITED

Allan, J.C., Zhang, J., O'Brien, F., and Gabel, L., 2018a, Columbia River tsunami modeling: Toward improved maritime planning response: Oregon Department of Geology and Mineral Industries Special Paper 51, 77 p. https://www.oregongeology.org/pubs/sp/p-SP-51.htm

Allan, J.C., Priest, G.R., Zhang, Y. J., and Gabel, L. L., 2018b, Maritime tsunami evacuation guidelines for the Pacific Northwest coast of Oregon: Natural Hazards, v. 94, no. 1, p. 21–52. https://doi.org/10.1007/s11069-018-3372-2

Lynett, P., Borrero, J., Son, S., Wilson, R., and Miller, K., 2013, Assessment of the tsunami-induced current hazards: Geophysical Research Letters, v. 41, no. 6, 2048-2055.

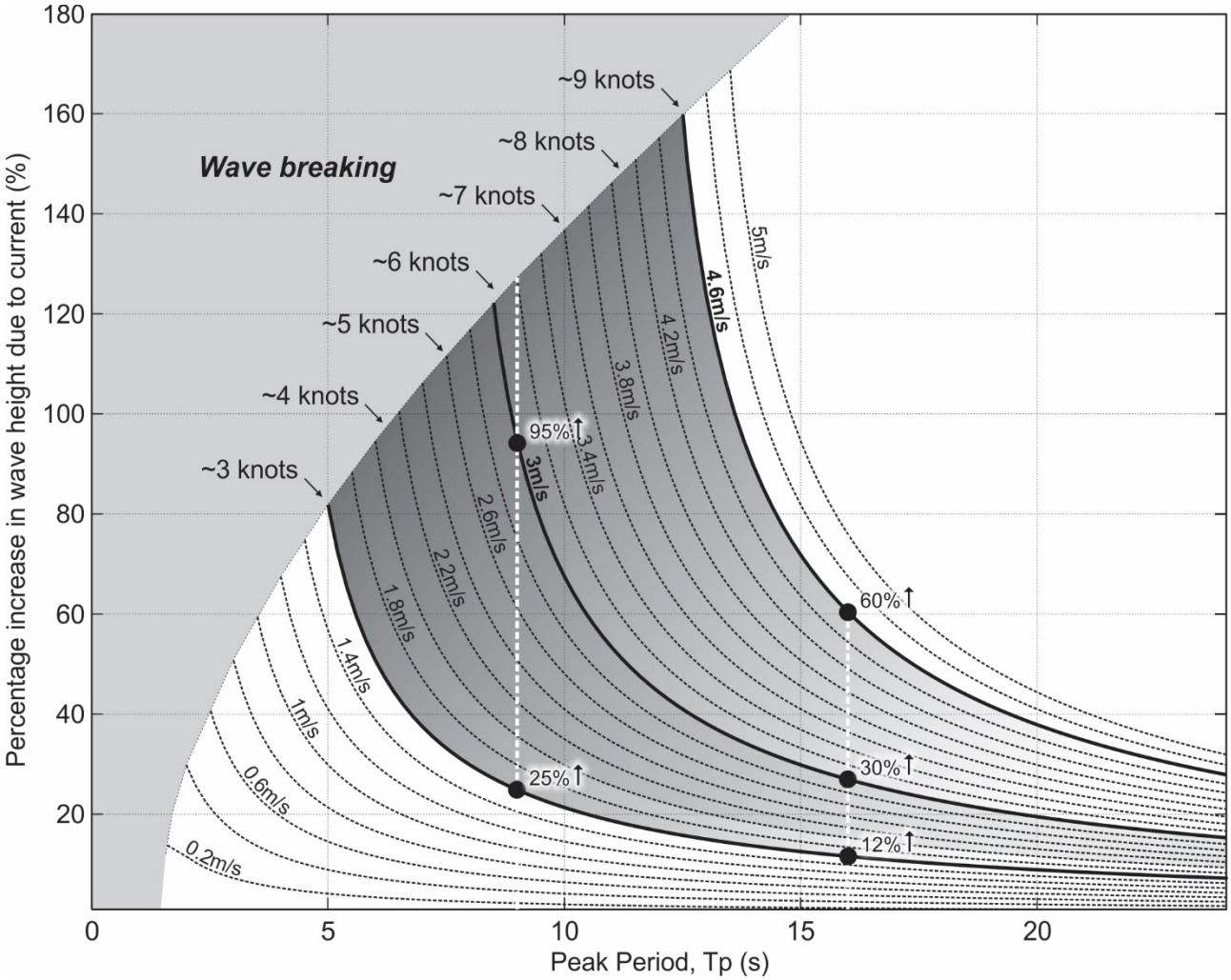
National Geophysical Data Center/World Data Service, 2017, NCEI/WDS Global Historical Tsunami Database. NOAA National Centers for Environmental Information. https://doi.org/10.7289/v5pn93h7 [accessed June 2017]

APPENDIX A — ADDITIONAL MAPS

Unless otherwise indicated, maps on the following pages are from Allan and others (2018a):

- Plot showing change in wave amplitudes based on opposing currents
- Tsunami wave arrival times for an Eastern Aleutian Island (***DISTANT***) earthquake and tsunami
- Maximum water levels and currents at the Port of Astoria
- Vorticity and minimum water depths at the Port of Astoria
- Maximum water levels and currents around Tongue Point
- Vorticity and minimum water depths around Tongue Point
- Time histories of water levels for the MCR, Astoria, Tongue Point, and Fitzpatrick Island sites for an AKMax ***DISTANT*** tsunami
- Time histories of tsunami currents for the MCR, Astoria, Tongue Point, and Fitzpatrick Island sites for an AKMax ***DISTANT*** tsunami

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



How to use:

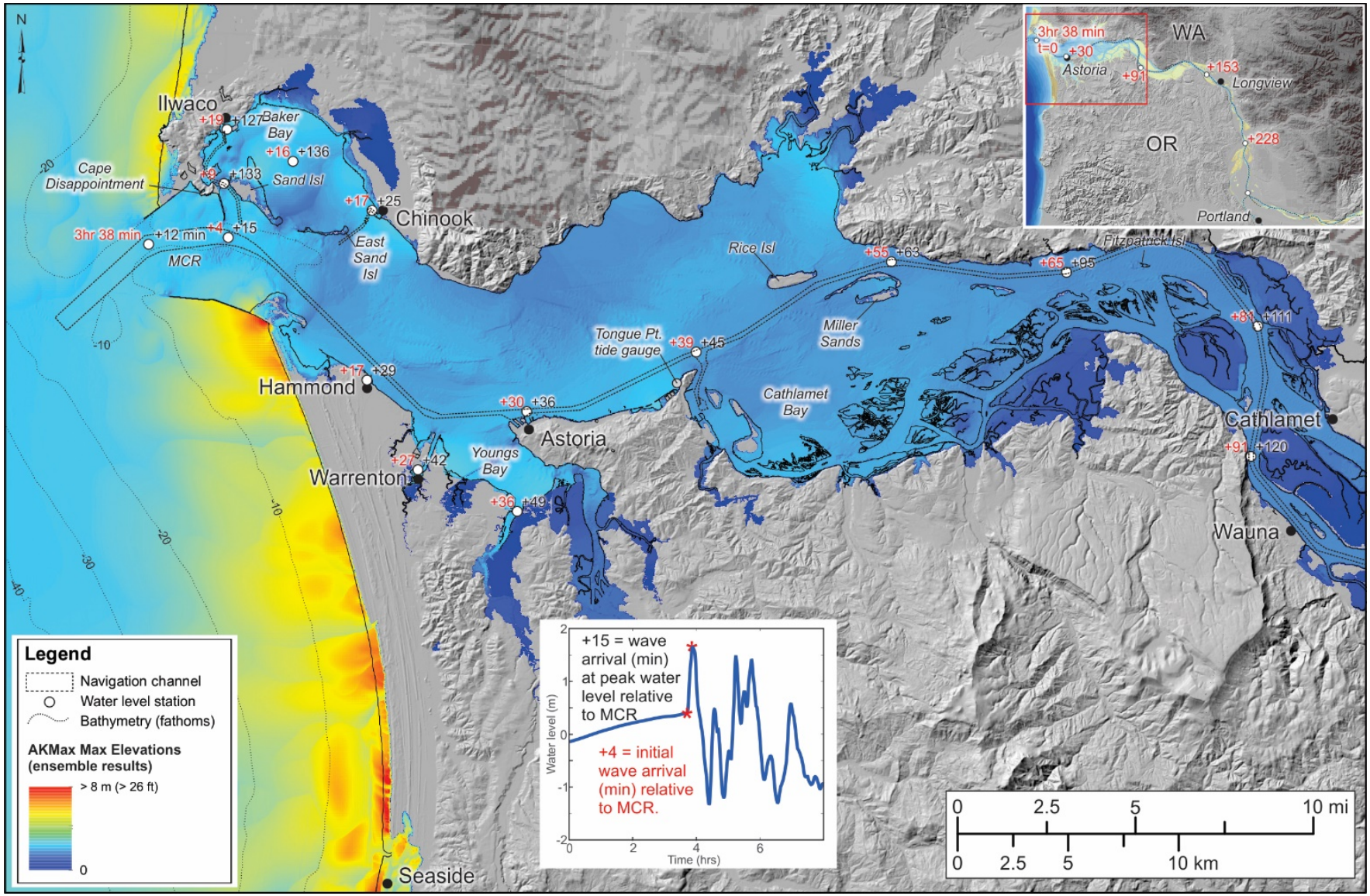
Step 1. Identify the prevailing peak wave period defined for the x-axis.

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.

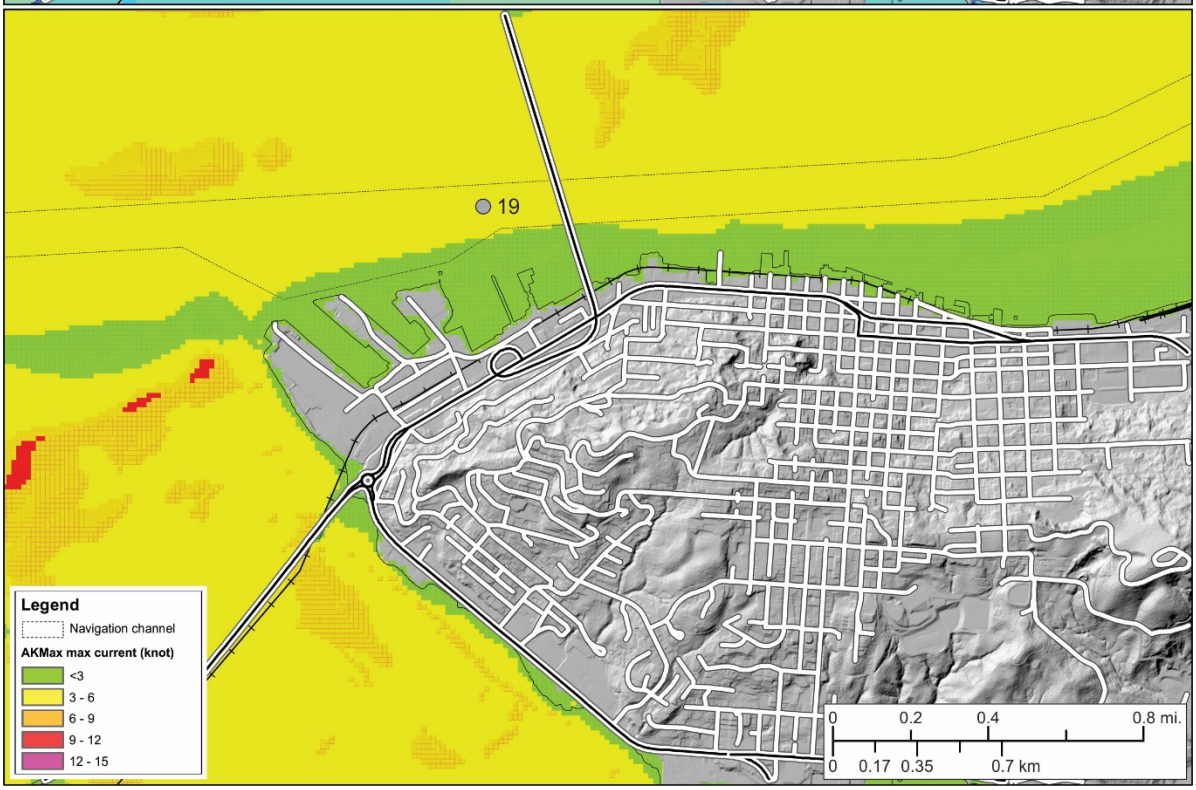
Example: A peak period of 16 sec will yield a 12% (60%) increase in the wave height with a 3 (9) knot opposing current.

Tsunami arrival times defined for AKMax (*DISTANT*) for discrete locations along the Columbia River. Times reported are in minutes and are relative to the initial (3 hr 38 min) wave arrival at the MCR. Red numbers correspond to the initial wave arrival (the point at which the water level begins to depart from normal), while the black number reflects the time at which the maximum wave arrives.

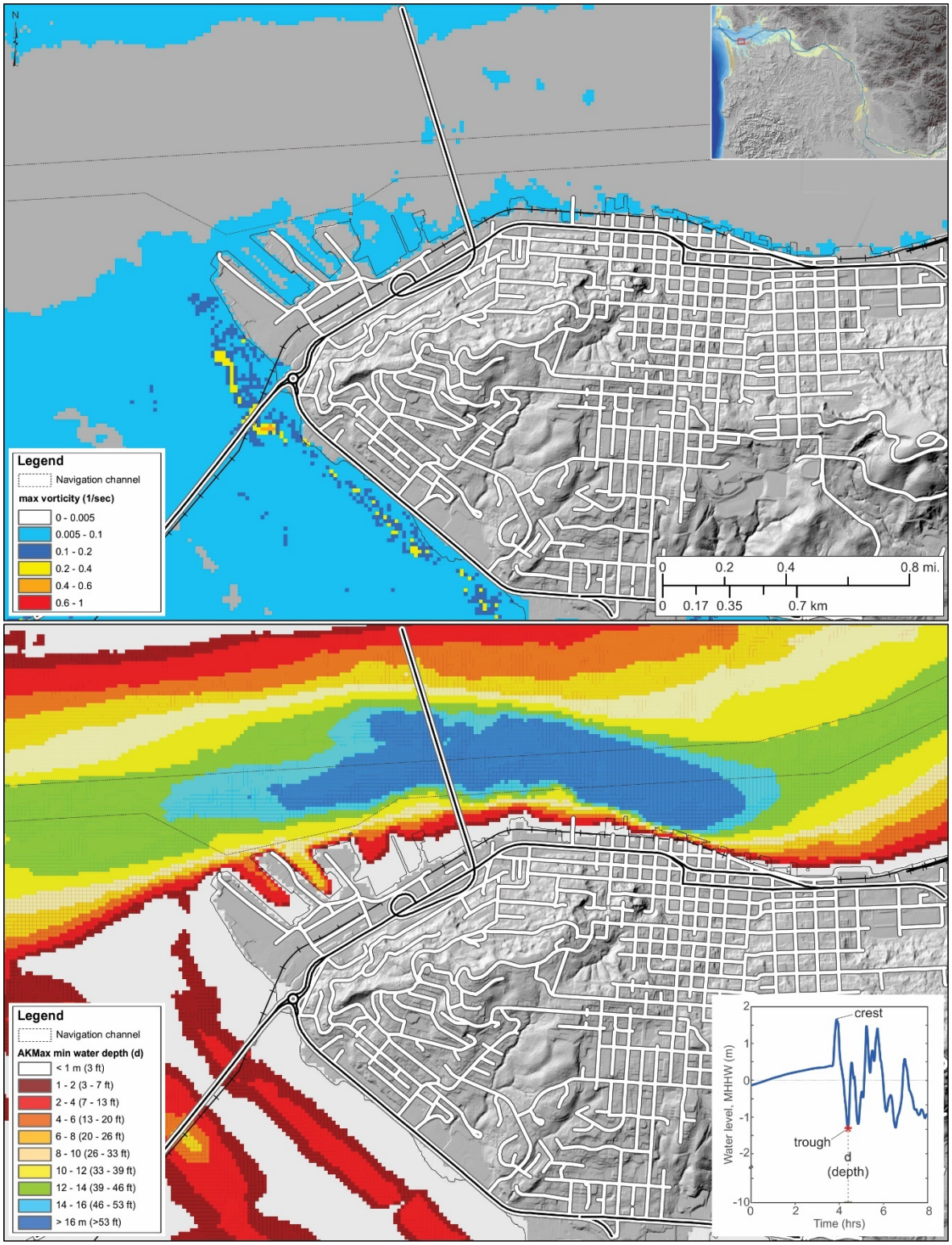


Maritime Guidance for Distant Source Tsunami Events

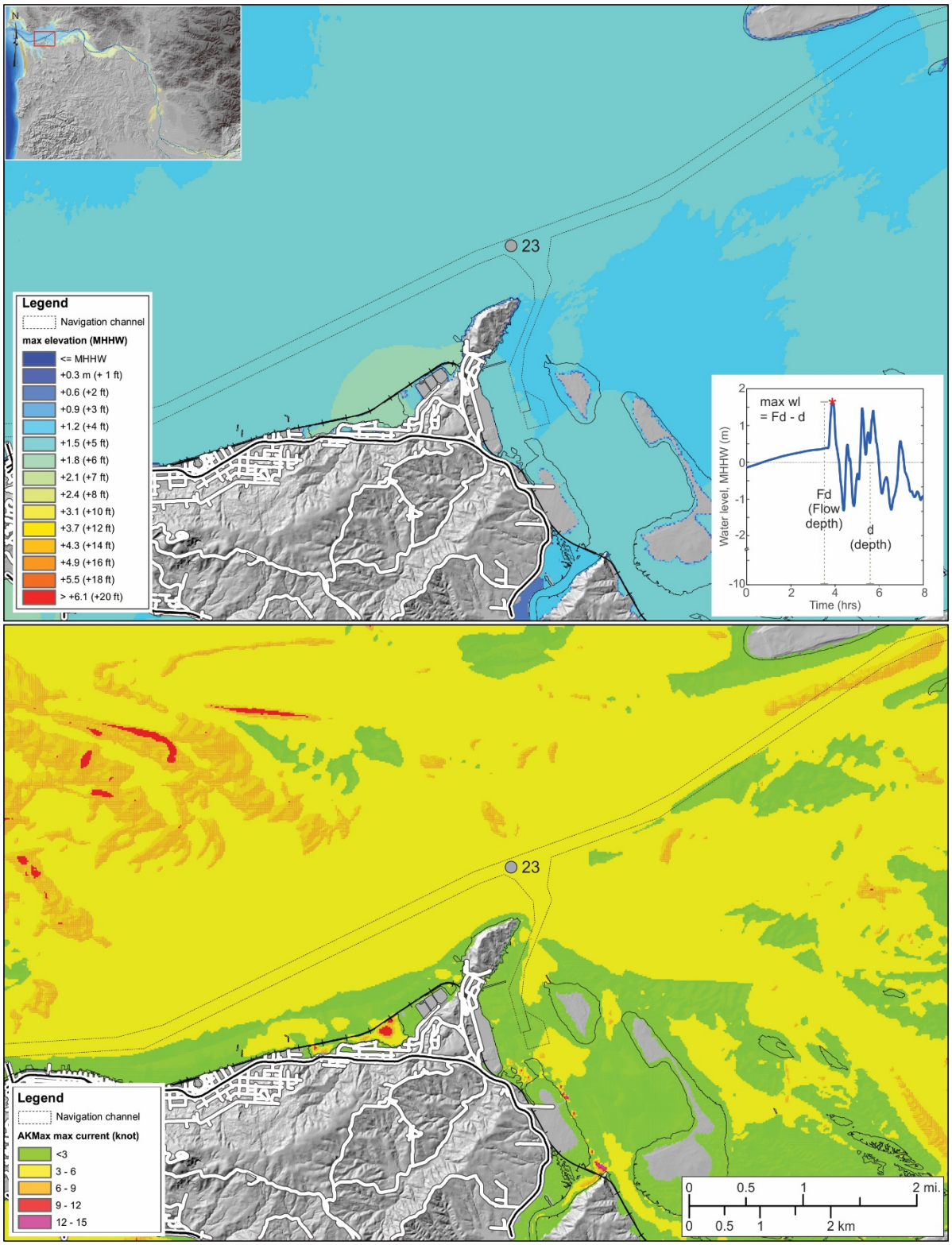
Port of Astoria: Maximum water levels (*top*) and tsunami current velocities (*bottom*) and expected port damage resulting from a maximum-considered *DISTANT* tsunami occurring on the Eastern Aleutian Islands (AKMax).



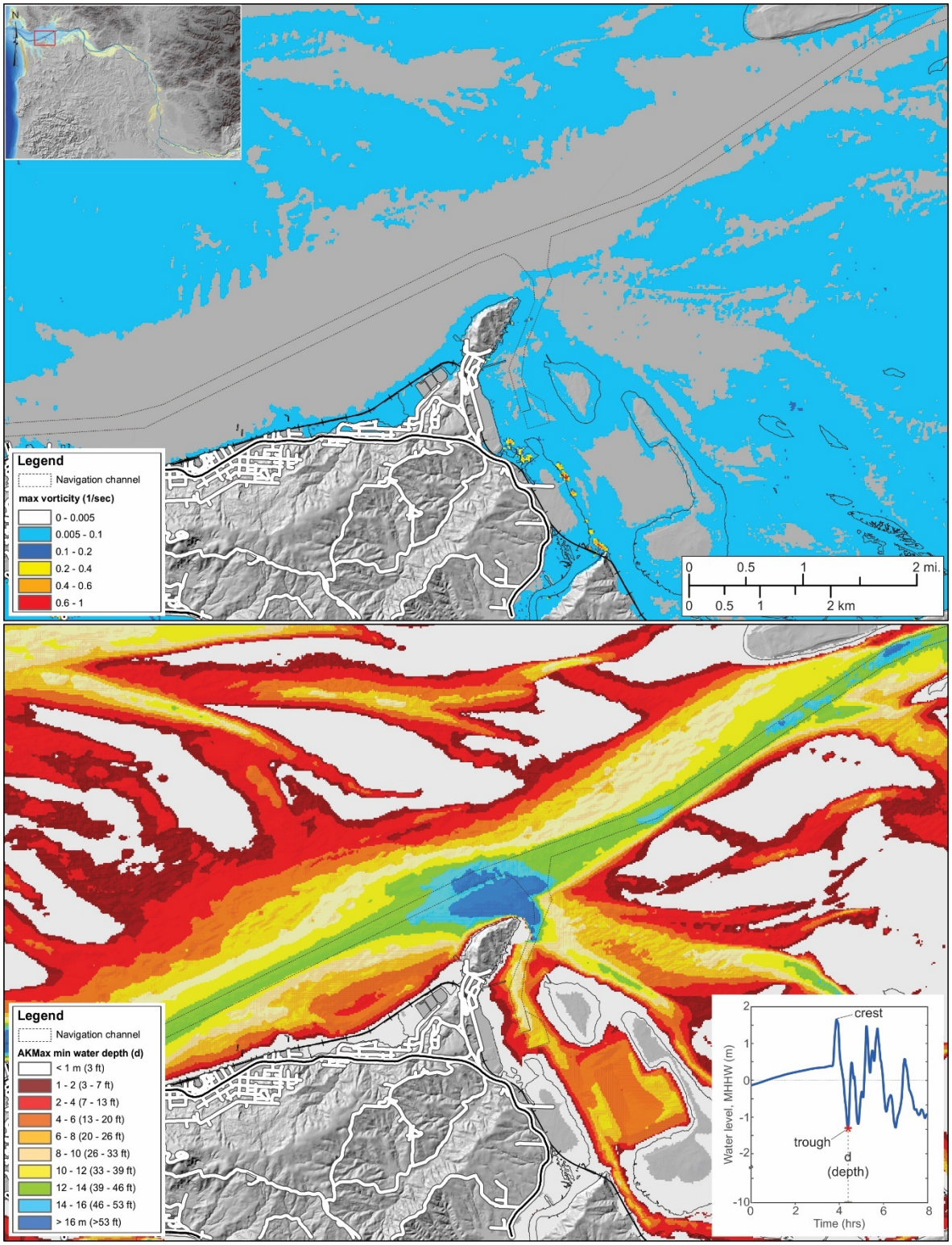
<u>Port of Astoria</u>: Map of the <u>maximum vorticity</u> (*top*) and <u>minimum water depths</u> (*bottom*) generated by a maximum considered *DISTANT* earthquake and tsunami occurring on the Eastern Aleutian Islands (AKMax). Top plot is a measure of the potential for rotation (gyres and whirlpools), while the bottom shows the expected minimum water depths from the tsunamis.



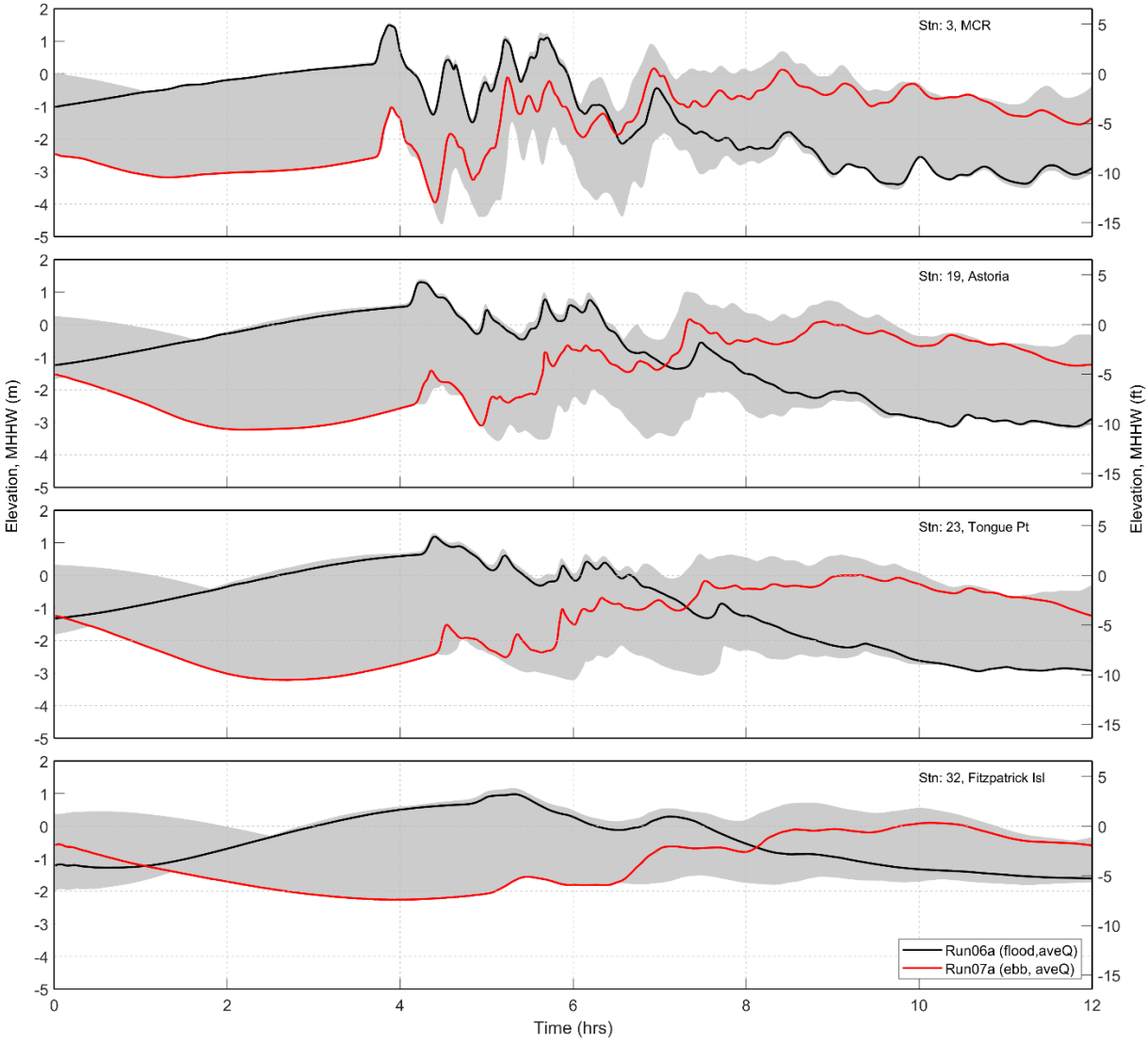
<u>Tongue Point</u>: <u>Maximum water levels</u> (*top*) and <u>tsunami current velocities</u> (*bottom*) and expected port damage resulting from a maximum-considered *DISTANT* tsunami occurring on the Eastern Aleutian Islands (AKMax).



<u>Tongue Point</u>: Map of the <u>maximum vorticity</u> (*top*) and <u>minimum water depths</u> (*bottom*) generated by a maximum considered *DISTANT* earthquake and tsunami occurring on the Eastern Aleutian Islands (AKMax). Top plot is a measure of the potential for rotation (gyres and whirlpools), while the bottom shows the expected minimum water depths from the tsunamis.



Time histories of tsunami water levels for select sites (top to bottom: MCR, Astoria, Tongue Point, and Fitzpatrick Island) resulting from a maximum-considered *DISTANT* tsunami (AKMax) occurring on the Eastern Aleutian Islands. Simulations shown include both a flood and ebb tide condition. Gray shading defines the envelope of variability of tsunami water levels from all simulations.



Time histories of tsunami current velocities for select sites (top to bottom: MCR, Astoria, Tongue Point, and Fitzpatrick Island) resulting from a maximum-considered *DISTANT* tsunami (AKMax) occurring on the Eastern Aleutian Islands. Simulations shown include both a flood and ebb tide condition. Gray shading defines the envelope of variability of tsunami current velocities from all simulations.