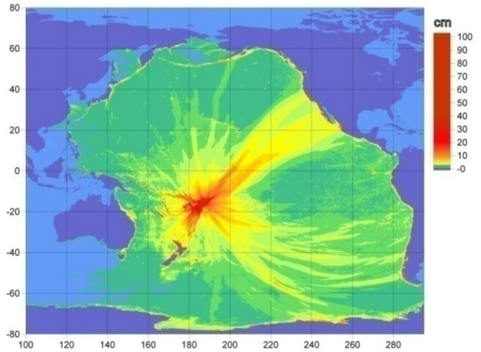
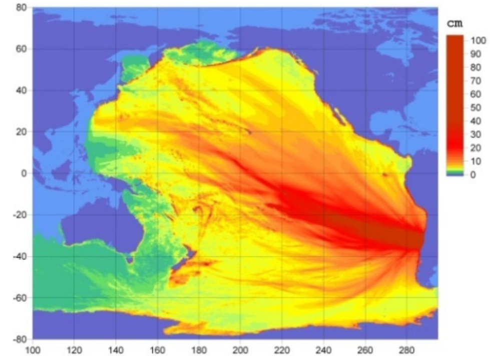
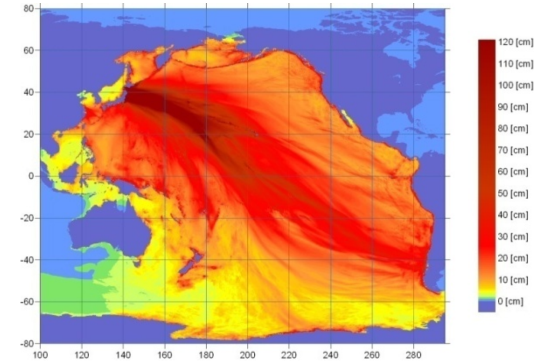
Tsunami Maritime Preparedness Efforts in California



2009 Samoa



2010 Chile



2011 Japan

Rick Wilson, California Geological Survey

Kevin Miller, California Office of Emergency Services

Pat Lynett, University of Southern California

Partners =

Multi-State Collaborations: Oregon, others through

THE NATIONAL TSUNAMI HAZARD MITIGATION PROGRAM (U.S.)

Maritime lessons learned

- **Need maritime response plan and guidance for different scenarios**
- **Need educational materials for boaters**
- **Determine if, when, and where should boats leave harbor**
- **Plan for long term evacuation at sea for maritime community**
- **Guidance/Plan for mitigation and recovery**

CA Tsunami Maritime Safety Plan

1. Create in-harbor hazard maps by modeling major harbors’ tsunami hazards [damaging currents]

2. Create offshore safety zone maps for use by harbors that recommend repositioning ships or sending vessels to sea

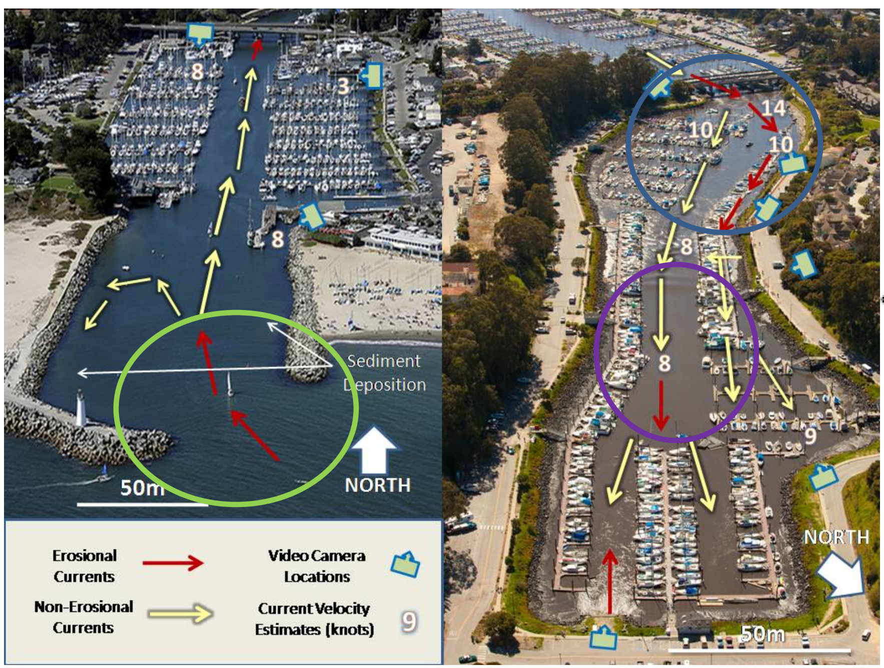
3. Provide statewide guidance for evacuation planning and harbor protection [based on above results]

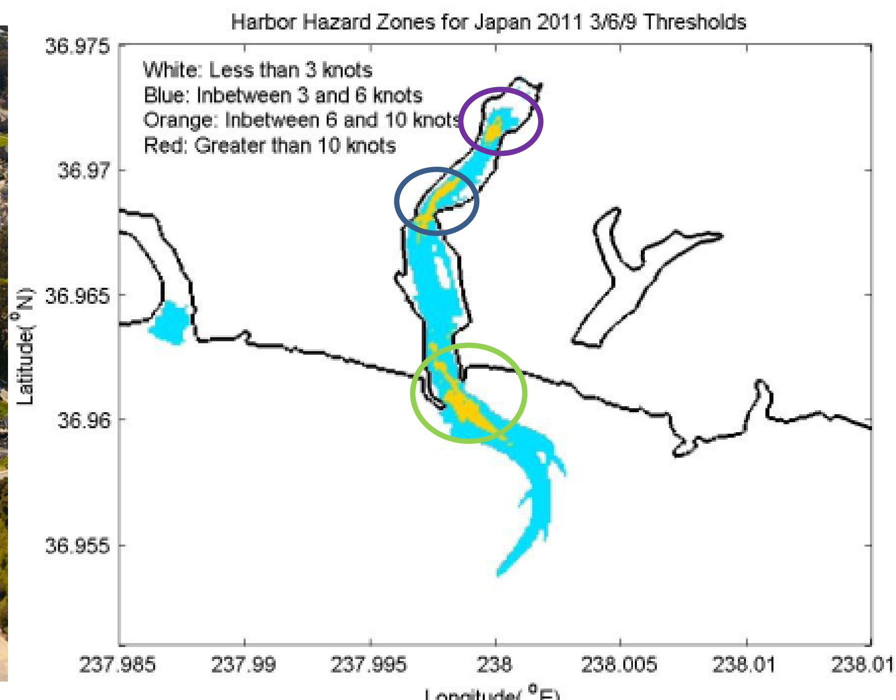
Maritime Safety Products

Analysis of 2010 and 2011 tsunamis in pilot study harbors

Crescent City, Santa Cruz, Ventura, Ports of LA/Long Beach, and San Diego Bay

Video and other analyses of currents, sediment scour/deposition, areas of damage, safe areas



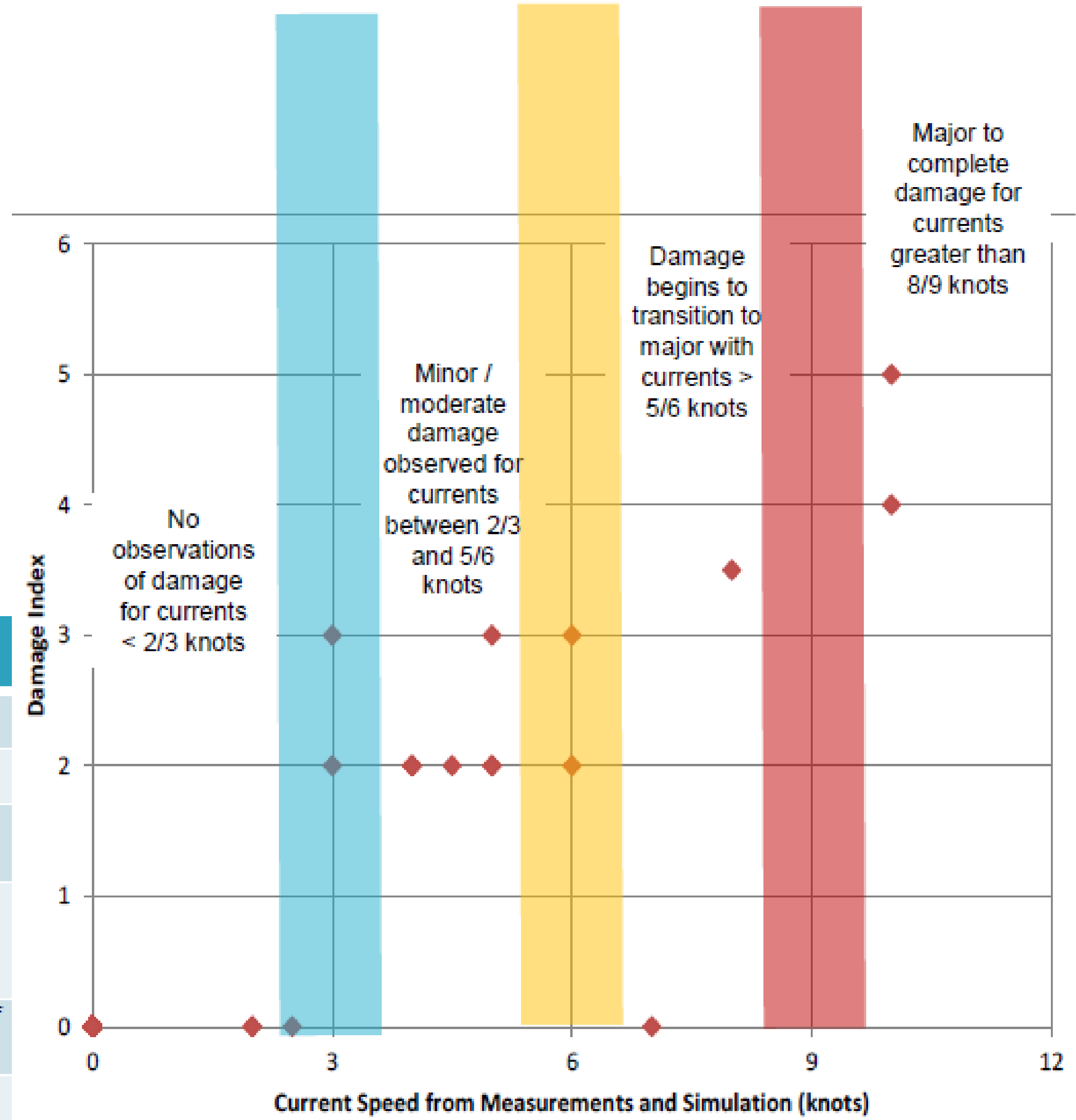


March 11, 2011 tsunami in Santa Cruz

Tsunami Current Hazard Maps
Map Generation

- **Can we filter this information, create areas where certain levels of damage might be expected?**
- **Need to develop current–damage relationships**
  - **Based on previous observations of damage, and numerical hindcast & direct speed measurements at the damage location**

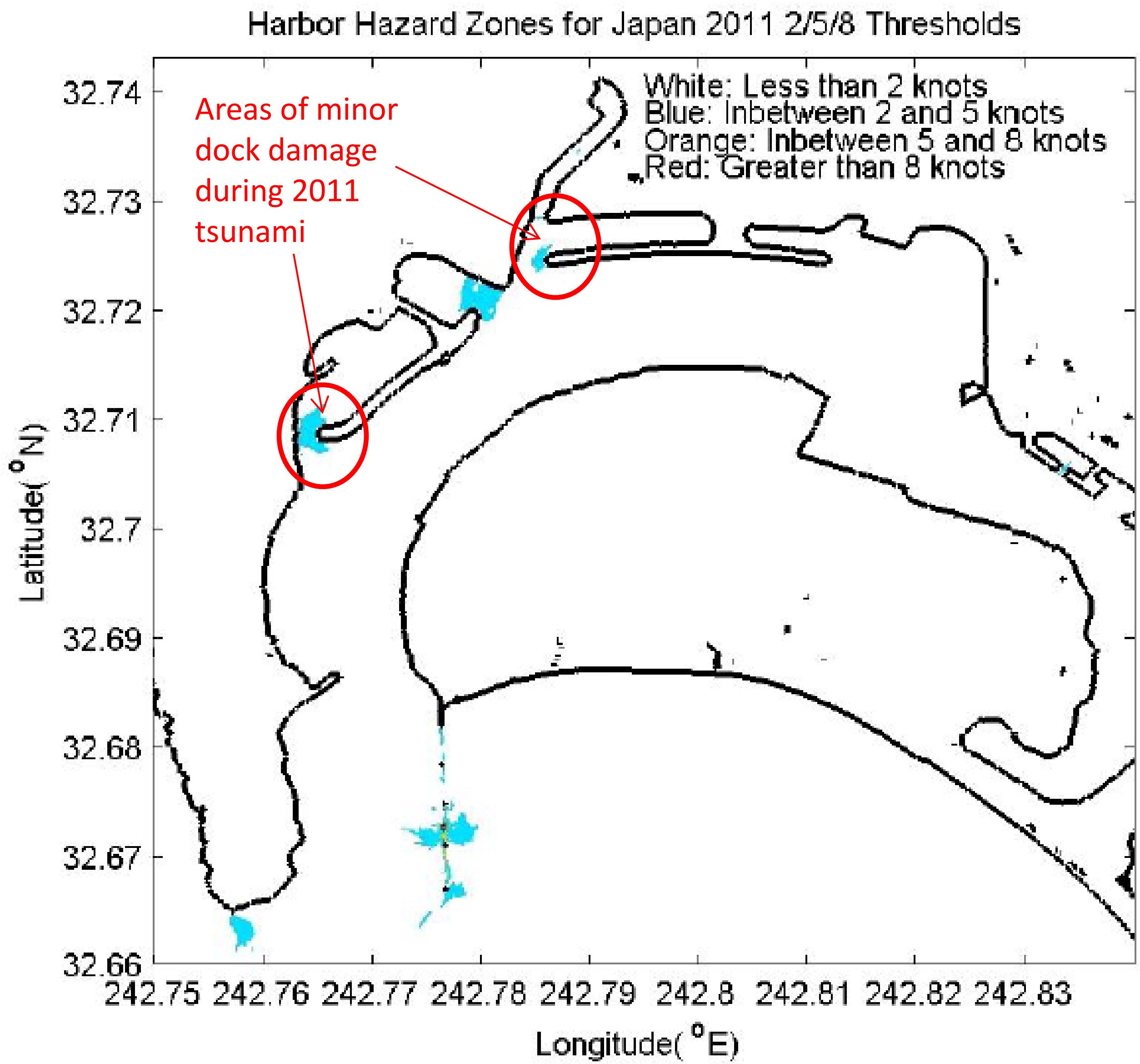
Damage Index:	Damage Type:
0	no damage
1	small buoys moved
2	1-2 docks/small boats damaged, large buoys moved
3	Moderate dock/boat damage, mid-sized vessels off moorings
4	Major dock/boat damage, large vessels off moorings
5	Complete destruction



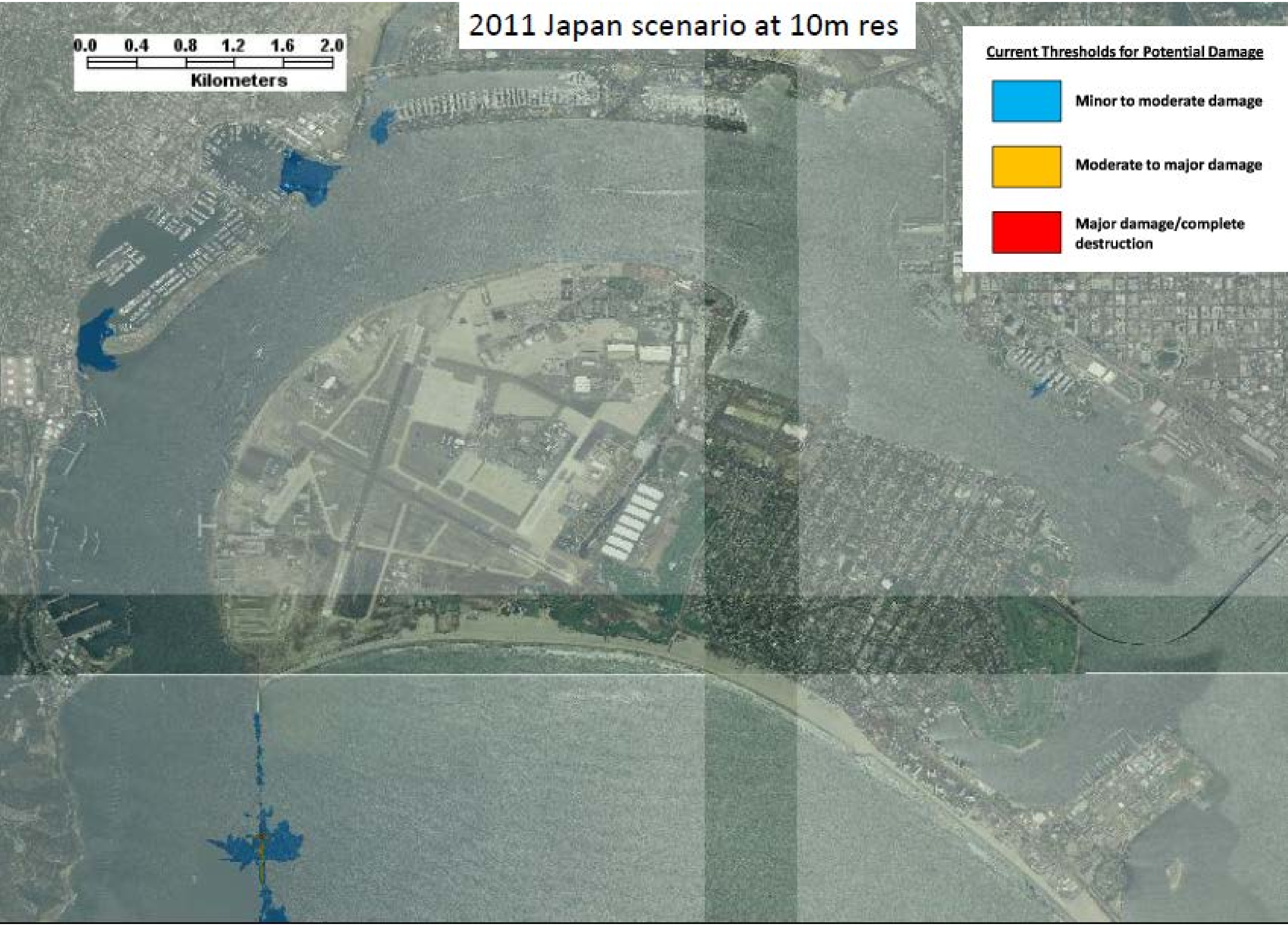
Tsunami Current Hazard Maps
Map Generation

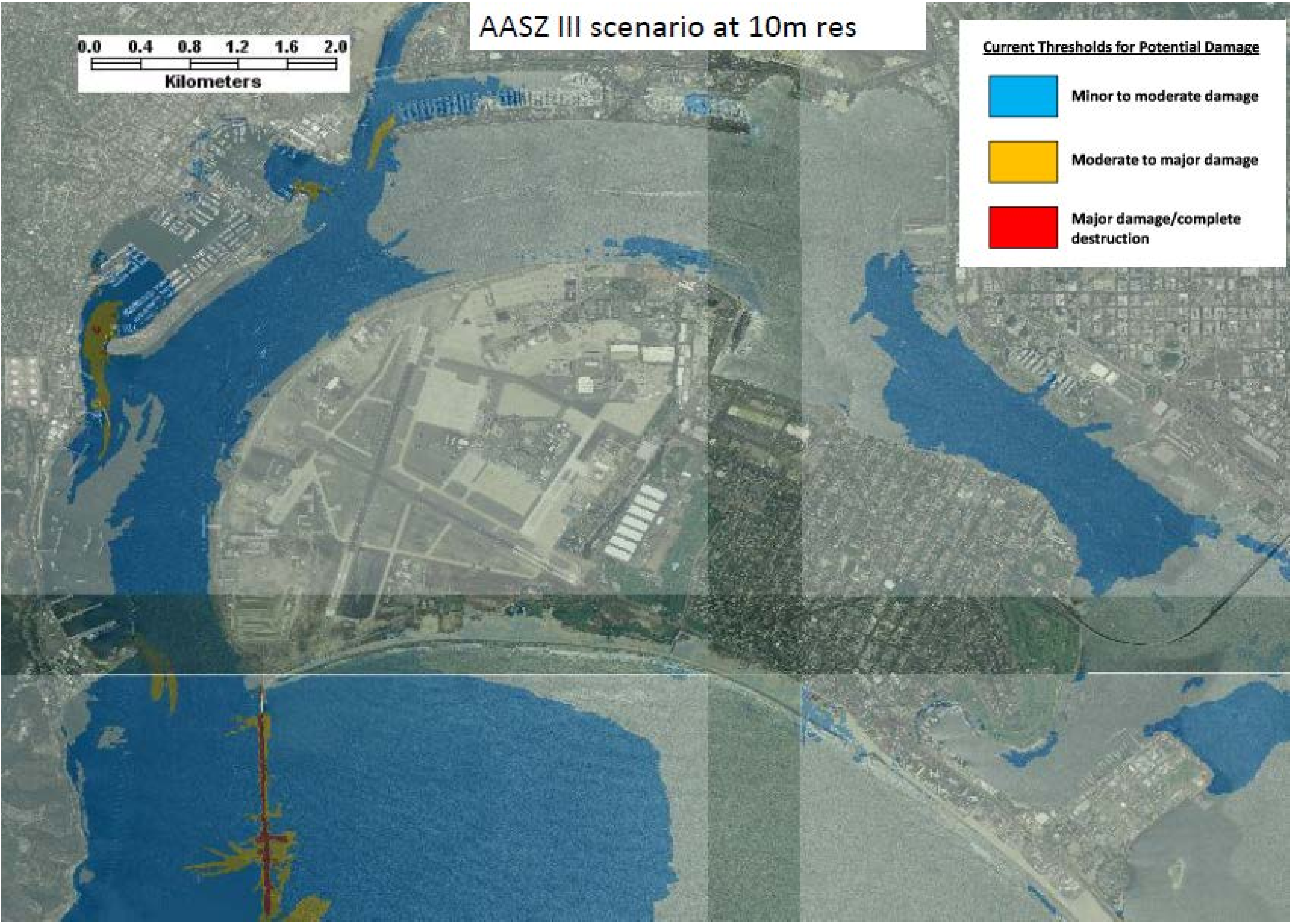
- **current– damage relationships**
  - **Based on previous observations of damage, and numerical hindcast & direct speed measurements at the damage**

Damage Type:
no damage
small buoys moved
1-2 docks/small boats damaged, large buoys moved
Moderate dock/boat damage, mid-sized vessels off moorings
Major dock/boat damage, large vessels off moorings
Complete destruction



2011 Japan scenario at 10m res

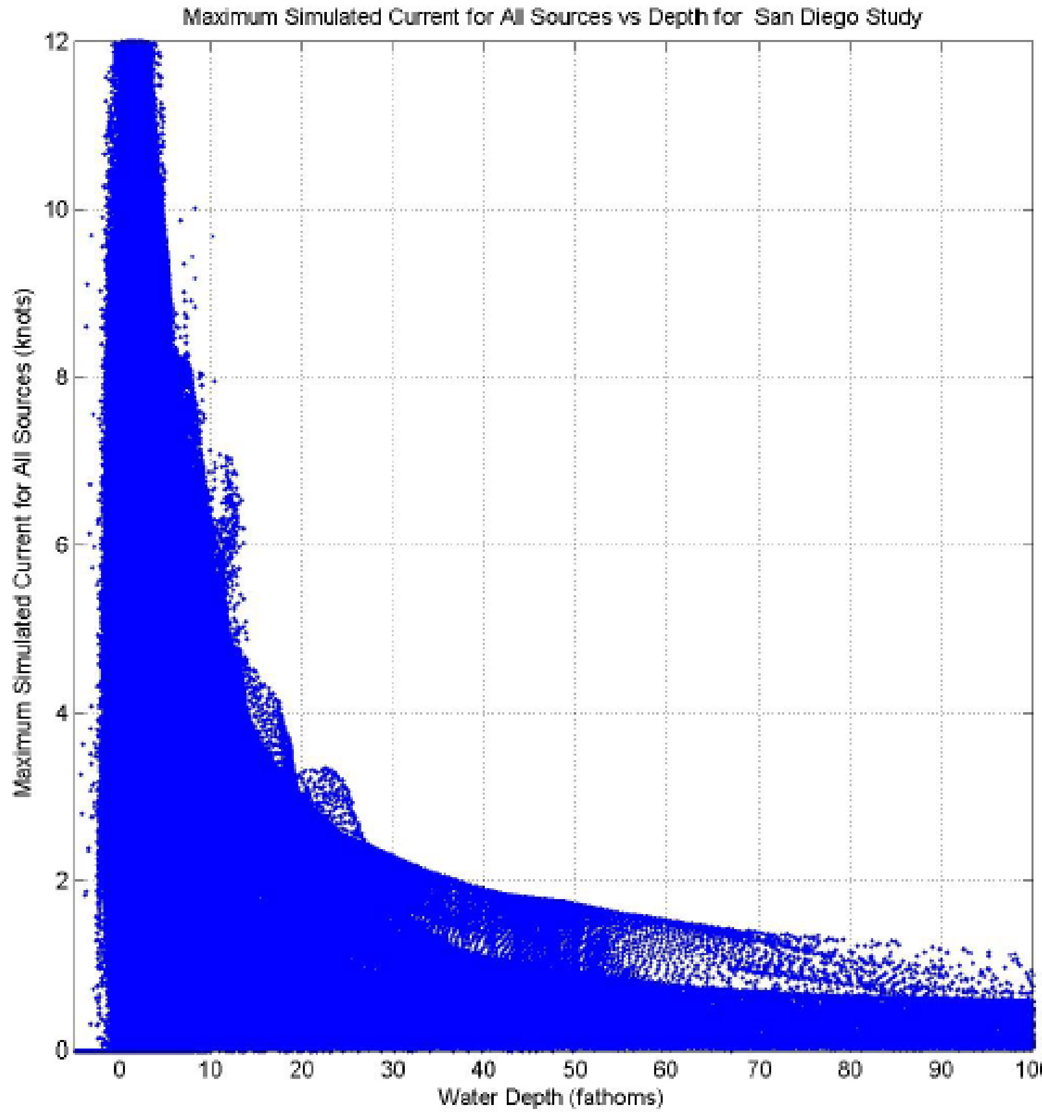




AASZ III scenario at 10m res
0.0 0.4 0.8 1.2 1.6 2.0
Kilometers
Current Thresholds for Potential Damage
Minor to moderate damage
Moderate to major damage
Major damage/complete destruction

Offshore Safety Zones

- Example application – San Diego
- Run simulations for a range for different sources
- Create a maximum current map for each source
- Plot the (max current, depth) pairs for each source, as a scatter plot
- Determine current variability at all depths
- Set an acceptable current & depth threshold



1 fathom = 1.8 meters = 6 feet

Offshore Safety Zones

- Example application – Crescent City
- Run simulations for a range for different sources
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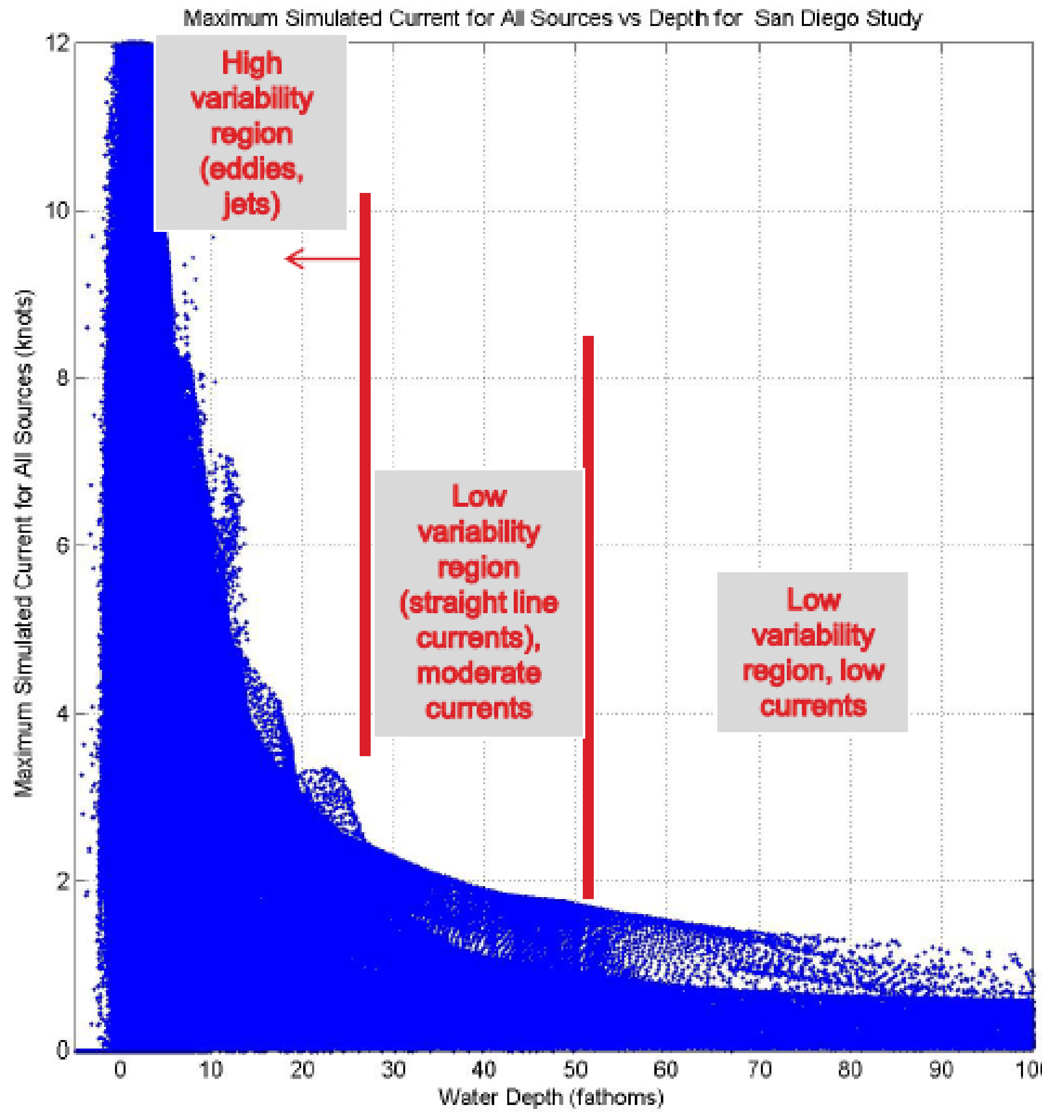


1 fathom = 1.8 meters = 6 feet

Best to display on 11X17 paper

DRAFT - Tsunami Response Plan Playbook
North San Diego Bay Maritime Community

Purpose and Use of this Real-time Tsunami Response Plan Playbook

PURPOSE: This product will help the harbor prepare, plan, and respond to strong currents and damage from future tsunamis. It has been developed with assistance from the harbor by the California Tsunami Program and funding from FEMA. It is essential that harbor staff become familiar with the playbook before use. The information within the playbook can also help the harbor develop tsunami mitigation strategies (other guidance is available for this).

USE: This playbook is designed to help the harbor with tsunami response activities by providing enhanced info about the tsunami based on specific inputs for the harbor.

First, it requires that the **harbor fill out information about their harbor** (see "Background information" on Page 2, and Playbook information on Pages 4-7); this should be done when the Playbook is first received. The California Tsunami Program will work with the harbor to get this information.

When a tsunami is occurring, follow the steps outlined on Page 2. The harbor master or emergency response manager should **fill out information about the source earthquake and tsunami on Page 2**; this information can be obtained from multiple sources, including the tsunami alert message from the National Tsunami Warning Center, the city or county emergency manager, and/or the National Weather Service, Regional Weather Forecast Office. Keep in mind that this information can change during the first hour or two after the earthquake occurs.

Finally, **compare the tsunami forecast amplitude (wave height) to the maximum tsunami amplitude on the scenario table on Page 3.** Choose the scenario (Page 4-7) which best matches the forecast information. Follow the instructions on the page for that scenario. Each scenario Playbook may be accompanied by a digital file indicating the response and evacuation plans; this can be shared during an emergency with emergency responders in the field.

Background Information on Harbor

Table of Contents – Tsunami Response Plan Playbooks

Explanation of FASTER Analytical Tool: To determine the full impact of the tsunami, other variables such as tidal and storm conditions must be considered. An analytical method has been created which incorporates important variables that will impact the ultimate tsunami flood level. The FASTER calculation, which will be provided by the local jurisdiction to the harbor during a tsunami event, is used on Page 3 to determine if piles will be overtopped and inundation of dry land will occur. The simplified components of the calculation are as follows:

Forecast Amplitude + Storm conditions + Tidal conditions + Error in forecast + Run-up per location = FASTER Tsunami Flood Level

Background information (previously filled out by harbor):

Harbor/Jurisdiction/Geographic Location:________________________

Height of shortest pilings above Mean Sea Level: __________________

Elevation of lowest land above Mean Sea Level: ___________________

Areas of harbor previously damaged or showing potential for damage:____

Areas known to be safe in previous events and based on modeling:

____

Distance offshore and time to reach 30 fathom (180 feet) depth (see Pg. 11):____

Background information on harbor:

1) Height of piles and land where inundation might occur. Useful for determining if the tsunami will overtop piles and if land inundation will occur.

2) Summary of areas of past tsunami damage and areas that will be safe during all tsunamis.

3) Offshore distance and time for ships to reach 30 fathoms. This has been determined a safe depth for vessels during all distant tsunamis.

Quick Reference Page for Determining Real-Time Tsunami Response Activities

NOTE: It is important to review all sections of this Playbook prior to using it during a tsunami emergency. When a Tsunami Alert is issued, fill out the Quick Reference page below and follow steps on the right side of the page to determine response activities for the harbor:

USER SUPPLIED INFO

Step 1: Obtain information about earthquake and tsunami from National Tsunami Warning Center in Alaska, regional NOAA-Weather Forecast Office, and/or county emergency manager. (e.g. www.tsunami.gov)

Event/Incident Name ______________________

Earthquake location ______________________

Earthquake magnitude ______________________

Tsunami Alert level ______________________

Forecasted tsunami amplitude/wave height (*will be compared to Peak Amplitude in Step 2*) ____________

Forecasted tsunami arrival time ______________

Highest projected tidal height (above Mean Sea Level) for first 5 hrs after arrival ______________

Ambient ocean/storm conditions for first 5 hrs after arrival ______________

Calculate/obtain FASTER tsunami run-up value in first 5 hours (see Page 2 for FASTER approach)__________

Calculate/obtain FASTER tsunami run-up value at highest tide (see Page 2 for FASTER approach)__________

STEP 1: Collect general tsunami information, used with table in Step 2 to determine appropriate actions to follow:

1) Earthquake location and magnitude.
2) Tsunami Alert level.
3) Forecast amplitude and arrival time provided by Warning Center.
4) Tidal and storm conditions provided by local Weather Forecast Office.
5) "FASTER" calculation, provided by WFO or county.

HISTORICAL/MODELED INFO (FOR COMPARISON)

Step 2: Compare and match forecasted tsunami amplitude/wave height in Step 1 to "Peak Amplitude" in the table. Refer to associated Playbook page to determine actions for securing vessels and repositioning ships away from areas of expected damage to safe areas within the harbor or offshore (Pg. 11) (modeled data in parentheses).

More Details in Maritime Playbook	Past events and modeled scenarios	Alert level	Earthquake magnitude	Source location	Peak Amp. (m)	Tidal condition (first 5hrs)	Peak Vel. (knots)	Damage summary	Damage Index (USC)
	2009	Advisory	8.0	Samoa	-	High	-	No damage	0
Page 6	2010	Advisory	8.8	Chile	0.3	[illegible]	[illegible]	North Isl.-moderate boat/dock damage	3
Page 7	Modeled Scenario #1	(Advisory)	(9.0)	(Cascadia)	(0.5)	High	(4)		
Page 8	2011	Advisory	9.0	Japan	0.8	Low	5	South Isl.-moderate boat/dock damage	3
Page 9	Modeled Scenario #2	(Warning)	(9.2)	(Aleutians)	(1.4)	High	(+9)		

STEP 2: Chose scenario/event from Step 1 that best matches tsunami information on the table:

1) Compare forecast amplitude/wave height from real event in Step 1 to peak amplitude column from historical events/ scenarios on table (highlighted in red box at left).
2) Find matching scenario in "playbook."
3) Go to appropriate playbook page and follow instructions for response.
4) Each Playbook scenario may have digital maps or information available for sharing with people in the field or other offices.

USER SUPPLIED INFO

Step 3: Infrastructure considerations:

Will the tsunami overtop harbor pilings? (compare FASTER run-up value to lowest pile height)

____

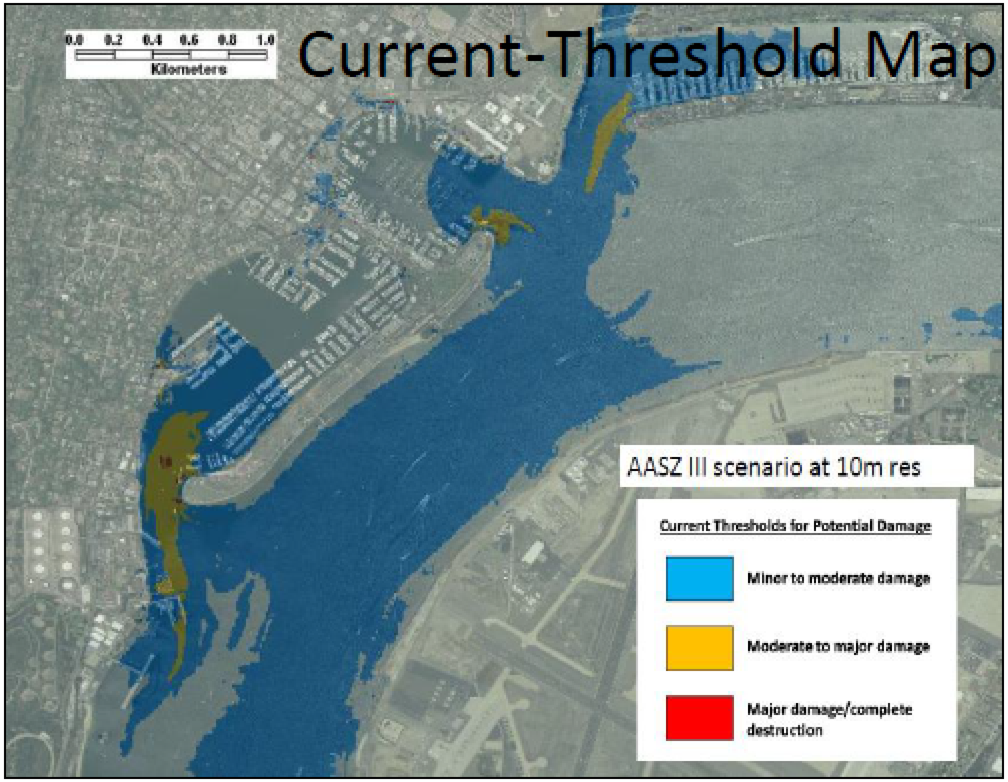
Will the tsunami inundate dry land? (compare FASTER run-up value to lowest land elevation)

____

STEP 3: Estimate of potential inundation of land and overtopping of piles:

Helps estimate the potential and amount of inundation, and if piles will be overtopped. Land evacuation should be coordinated with city or county emergency manager.

M9.2 Eastern Aleutian/Alaska Scenario



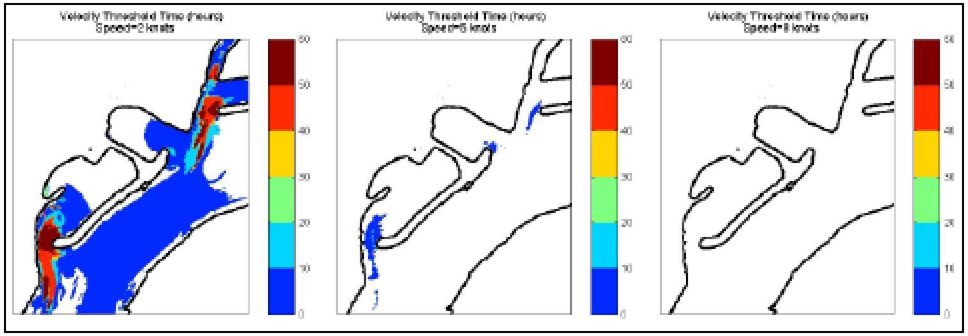
Background Information:
Alert level = Warning
Peak Amplitude = 1.4 meters (tide gauge)
Peak Velocity = +9 knots
Projected duration of strong currents (see location maps below):
2 knots = 60 hrs; 5 knots = 20 hrs; 8 knots > 10 hrs

Specific Instructions:

- Follow general guidance for Warning-level tsunamis (pg 2)
- Strong currents and potential scour are expected in areas identified in blue –yellow-red on the map to the right. Consider relocating vessels located within 100 meters (300 feet) of these areas.
- Specific areas where vessels should be relocated from and docks secured:
  - Western half of south Shelter Island,
  - Eastern half of north Shelter Island,
  - Western two-thirds of west Harbor Island....
  - (completed with maritime community input)

Safe areas for repositioning vessels within San Diego Bay: Areas in the southern portion of San Diego Bay..... (completed with maritime community input)

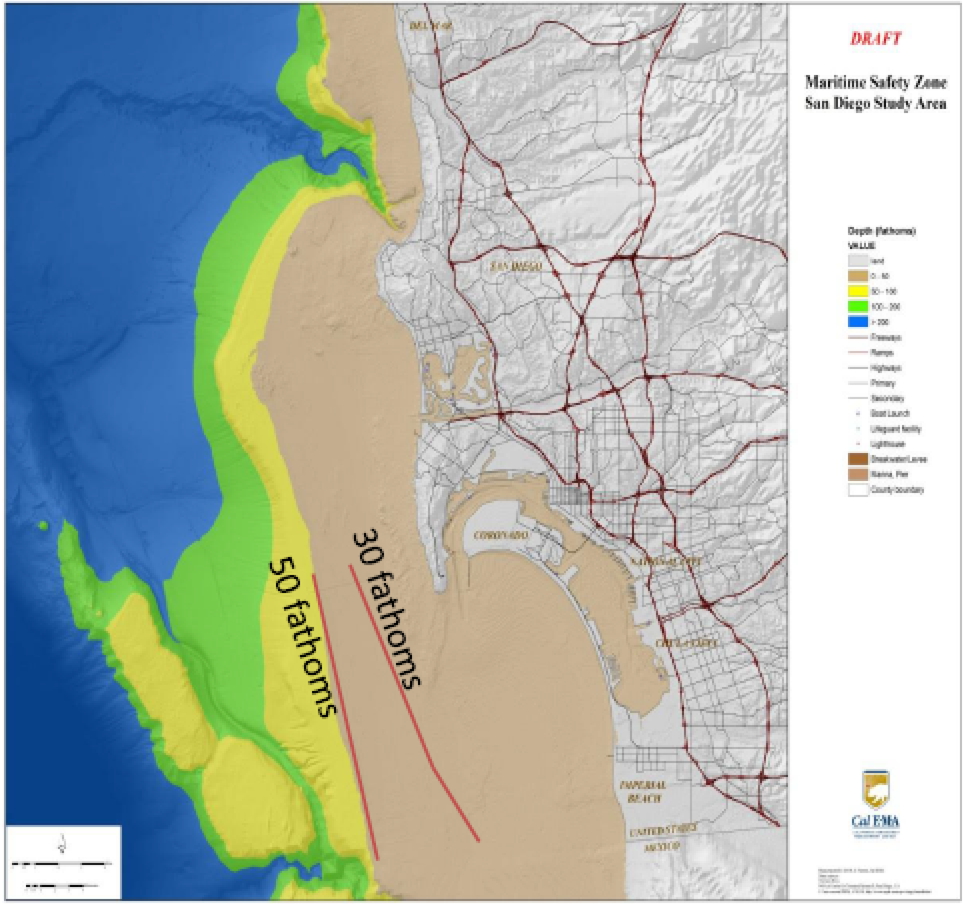
Map of areas of potential sedimentation, debris accumulation, and extreme shallow conditions (keel damage)



Plan for Safe Offshore Evacuation of Boats

<u>NOTE: The safety of the boating public should outweigh the benefit of saving boats and harbor property during a tsunami.</u>

- For most harbors in California, it is safer to keep boats docked during a tsunami because most tsunamis are relatively small.
- On the rare occasion when a large, damaging tsunami and associated strong currents are expected and there are no safe areas within the harbor, the boat owner may consider taking their boat offshore.
- There are a number of factors that should be considered prior to recommending boats evacuate offshore prior to the arrival of the tsunamis, including:
  - (1) the SIZE of the tsunami;
  - (2) is there sufficient TIME to get to the <u>30 fathom depth</u>, which has been evaluated as safe depth for boats during distant source tsunamis (map at right);
  - (3) the PREPAREDNESS of the boat and its captain to stay at sea over 24 hours;
  - (4) the WEATHER at sea could be as dangerous as the tsunami itself; and,
  - (5) if significant damage occurs within the harbor, boaters should have enough fuel and supplies to travel to a non-damaged harbor.



Note for trailer boat owners: Expect congested boat ramps and remember that you have to get your boat to the trailer, out of the water, and out of the tsunami zone before the tsunami arrives.

Information on this page could be replaced with harbor specific evacuation plan/map.

Maritime Mitigation – Recovery/Business Continuity/Resiliency

Crescent City – Feb/2013 – Reconstruction in Small Boat Basin includes new 30-inch piles

Santa Cruz – March 2013 – Reconstruction includes new and improved docks/floats

FEMA

Tsunami Hazard Mitigation Activities in California Maritime Communities

Tsunami hazard mitigation activities are the focus of the California Tsunami Program, comprised of the California Geological Survey (CGS) and the California Emergency Management Agency (CalEMA), its modeling, engineering, and academic partners at the University of Southern California (USC) and Humboldt State University (HSU), and its Cooperative Technical Partners at FEMA. Nowhere is the need more apparent for initiating tsunami hazard mitigation measures than within the state's 70+ coastal maritime communities. Relatively small to moderate teletsunami events in 2006, 2010, and 2011 caused over $100M in total damage within at least two dozen of these maritime communities. According to the USGS-led Science Application for Risk Reduction Project (SAFRR; in progress), larger tsunami events have the potential of causing tens of billions of dollars in damages and a large number of casualties in California.

With the assistance of the California Tsunami Program and state/federal funding, these maritime communities have begun implementing a number of life-safety and damage-reduction mitigation measures for tsunami hazards. These measures include non-structural mitigation efforts that include real-time (pre-tsunami) ship movement and infrastructure strengthening. and permanent mitigation measures that include wave-jetty fortification, pile reinforcement, and dock improvements. A number of other mitigation measures that may be implemented in the future include improved harbor emergency response and planning activities, repositioned/improved docks and infrastructure, increased harbor dredging, entrance channel widening, and removal of exposed petroleum/chemical facilities.

The following information offers a few examples of tsunami hazard mitigation activities. both structural and non-structural, that have been implemented in California:

Crescent City Harbor – The 2006 and 2011 teletsunamis caused $50M in damages in Crescent City Harbor. In 2011. destruction of most docks and deposition of 150,000 cubic meters of sediment in the small boat basin caused nine months to a year of delays in initiating recovery of the commercial fishing industry in Crescent City, which is vital to the community's survival. The harbor has proactively initiated several mitigation measures to reduce the direct impact of future tsunamis. Before the 2011 tsunami, harbor officials and the commercial fishing community worked with the Redwood Coast Tsunami Work Group to initiate a plan to evacuate the fishing fleet from the harbor once a tsunami warning was issued. During the 2011 tsunami, 90 percent of the sea-worthy fleet was able to evacuate the harbor, greatly reducing the potential for more

Angeles and Long Beach are a vital international
ompleted on a daily basis. Although there was
in the Ports, other historical tsunamis in 1960
acilities. The California Tsunami Program has
isk Reduction (SAFRR) Project to evaluate the
Ports. Potential at-risk facilities and large ship
ts are in the process of improving their tsunami
ed assets, such as large cargo ships and
mi hazards within the Ports may also lead to
ks for large ships away from narrow harbor

sunami Program, FEMA, and its partners are
fornia maritime communities mitigate damages
nclude: 1) detailed maps identifying in-harbor
plitude surges, large tidal fluctuations, etc.), 2)
gather during a tsunami, and 3) preparedness,
ime communities be more resilient to tsunami
maritime communities to determine where
provide a mechanism for pre-disaster hazard
zard Mitigation Plans (see the list of potential
. plans, and related mitigation efforts will not
is, they will provide a basis for greatly reducing
recovery in California maritime communities.

Mitigation Measures for Reducing Impacts of Tsunami Hazards in Maritime Communities

Real-time response mitigation measures

- Moving boats and ships out of harbors
- Repositioning ships within harbor
- Remove small boats/assets from water
- Shut down infrastructure before tsunami arrives
- Evacuate public/vehicles from water-front areas
- Restrict boats from moving during tsunami
- Prevent boats from entering harbor during event
- Secure boat/ship moorings
- Harbor staff donning personal flotation devices/vests
- Remove hazardous materials away from water
- Remove buoyant assets away from water
- Stage emergency equipment outside affected area
- Activate Mutual Aid System as necessary
- Activate of Incident Command at evacuation sites
- Alert key first responders at local level
- Restrict traffic entering port; aid traffic evacuating
- Provide personnel to assist rescue, survey and salvage
- Identify boat owners/live-aboards; establish phone tree, 'reverse-911,' or other notification process

Permanent mitigation measures

- Fortify and armor breakwaters
- Increase size and stability of dock piles
- Improve floatation portions of docks
- Increase flexibility of interconnected docks
- Improve movement along dock/pile connections
- Increase height of piles to prevent overtopping
- Deepen/Dredge channels near high hazard zones
- Move docks/assets away from high hazard zones
- Widen size of harbor entrance to prevent jetting
- Reduce exposure of petroleum/chemical facilities
- Strengthen boat/ship moorings
- Construct flood gates
- Prevent uplift of wharfs by stabilizing platform
- Debris deflection booms to protect docks
- Harbor control structures should be tsunami resistant
- Construct breakwaters further away from harbor
- Install Tsunami Warning Signs
- Purchase equipment/assets (patrol boats, tug boats, fire boats, cranes, etc.) to assist in response activities

Maritime Tsunami Hazards Guidance: Should the 100-fathom rule be revised?

Oregon Investigation

George R. Priest

Oregon Dept. of Geology and Mineral Industries

Maximum-Considered Distant and Local Tsunami Sources for Maritime Evacuation Guidance (M_w 9.1-9.2)

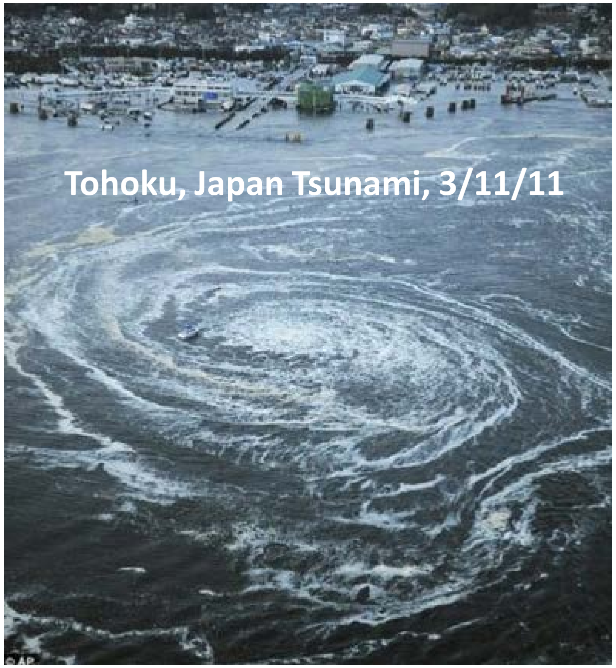
Source	Peak Slip	Peak Uplift
Cascadia XXL1 (Witter et al., 2011)	135 ft (41 m)	33 ft (10.2 m)
Maximum Alaska - AKmax (Source 3, Gonzalez et al., 2008)	98 ft (30 m)	43 ft (13 m)

Shear Flow/Vorticity

Vorticity >0.1 = very strong shear

EXPLANATION OF VORTICITY UNITS:
Vorticity =|dv/dx-du/dy| where
dv = change of north velocity,
du = change of east velocity
dx= change of distance east
dy = change of distance north

Example: 0.01 units of 1/sec = velocity changing 1m/sec over 100-m distance



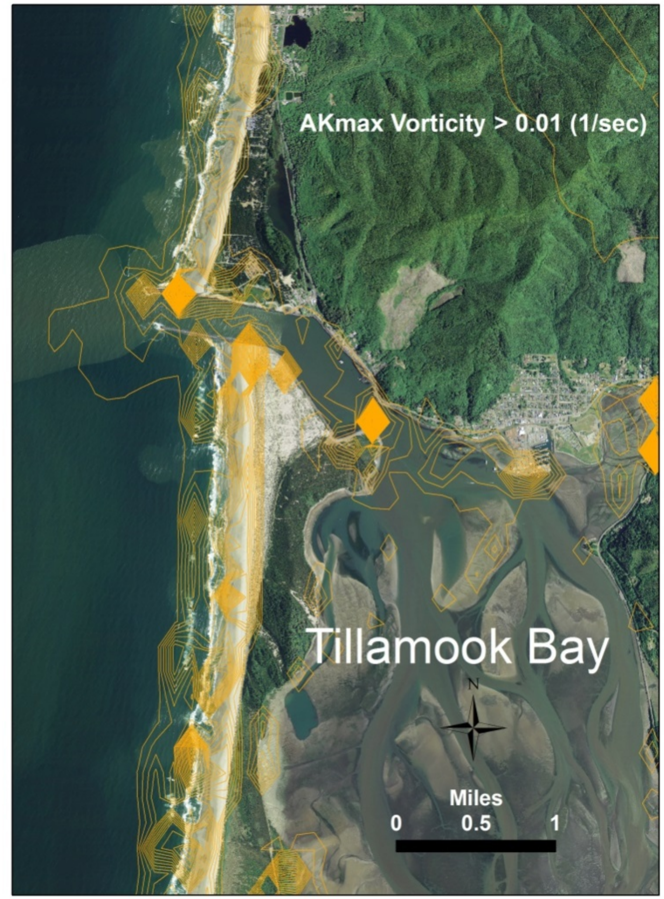
Source of picture: http://news.nationalgeographic.com/news/2011/03/pictures/110311-tsunami-earthquake-japan-hawaii-science-world-waves/#/japan-tsunami-earthquake-hits-northeast-whirlpool_33139_600x450.jpg

Thresholds

Vorticity, Minimum Flow Depth, Velocity

- Velocity threshold **>3 knots** = damaging in open ocean?
  - Without wind waves
  - With wind waves
- Minimum flow depth threshold = **~50 ft**
  - Max. displacement of aircraft carrier ~40 ft
  - Are there larger vessel displacements?
- Threshold vorticity
  - **>0.1** for very strong shear
  - Could be as low as **>0.01** for any shear

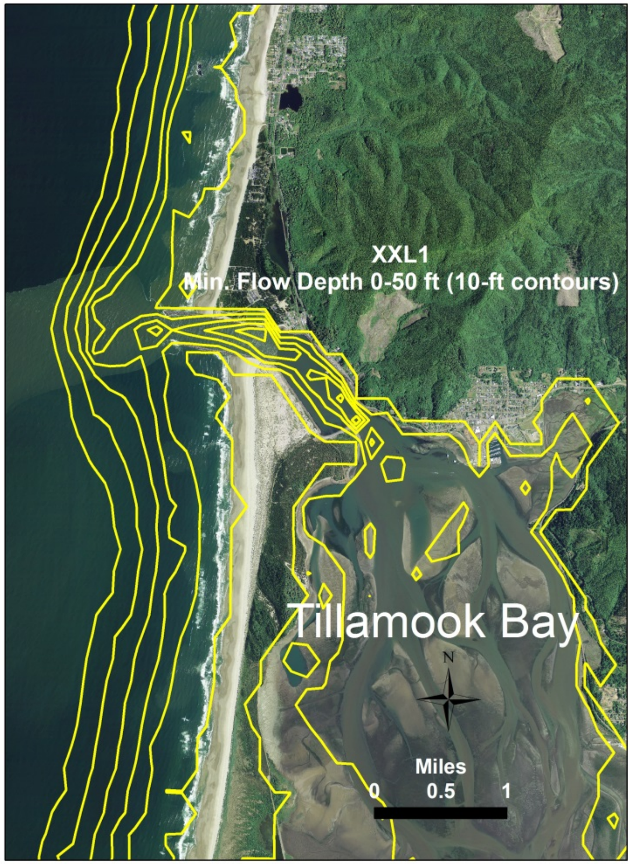
Alaska and Cascadia
Maximum Vorticities at Tillamook Bay

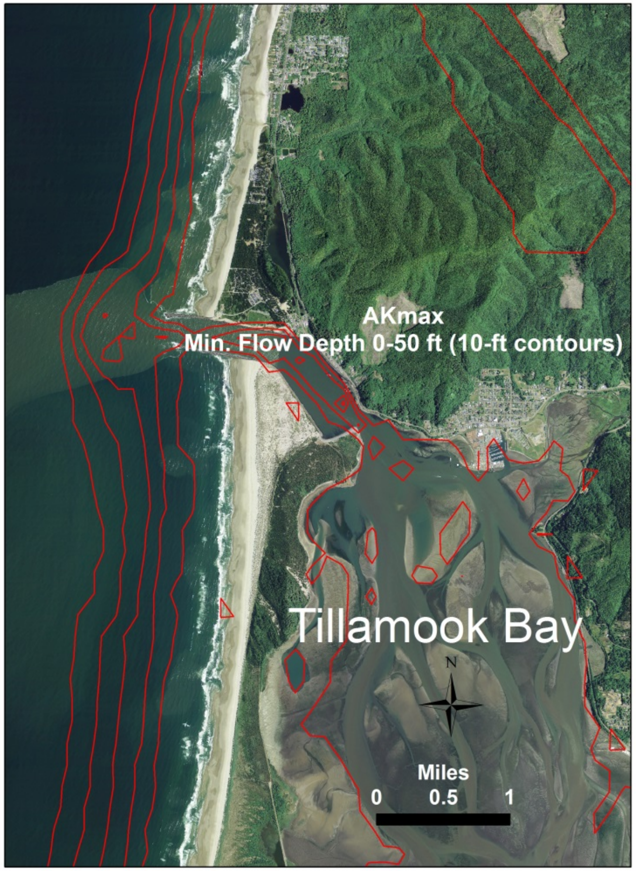


Alaska and Cascadia

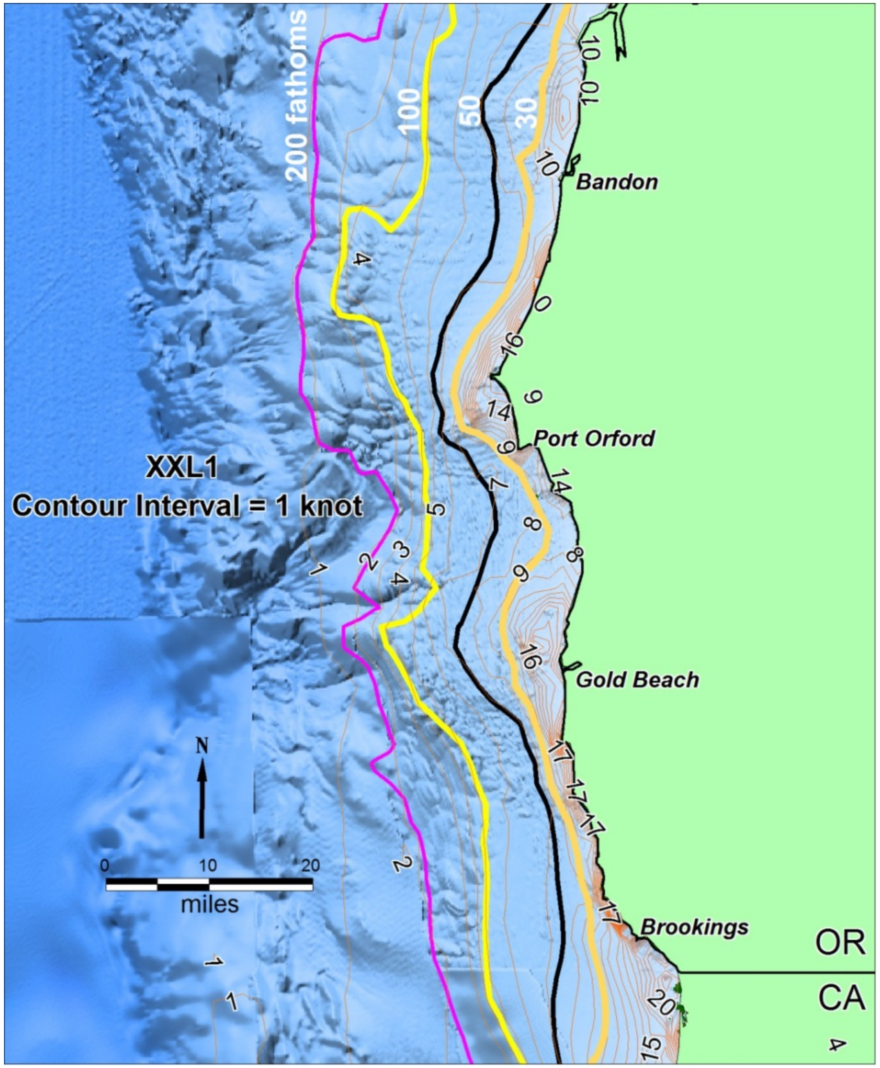
Minimum Flow Depths <50 feet at Tillamook Bay

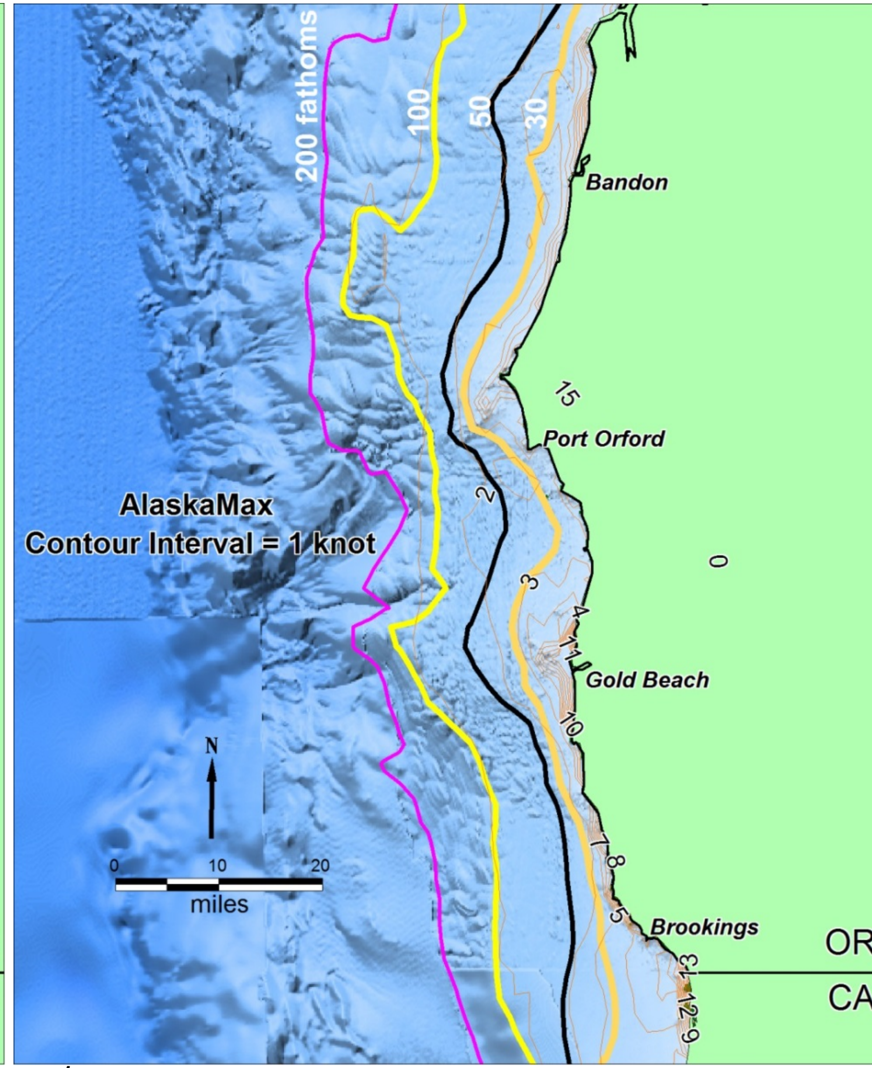
(~40-50 ft = maximum ship displacement)



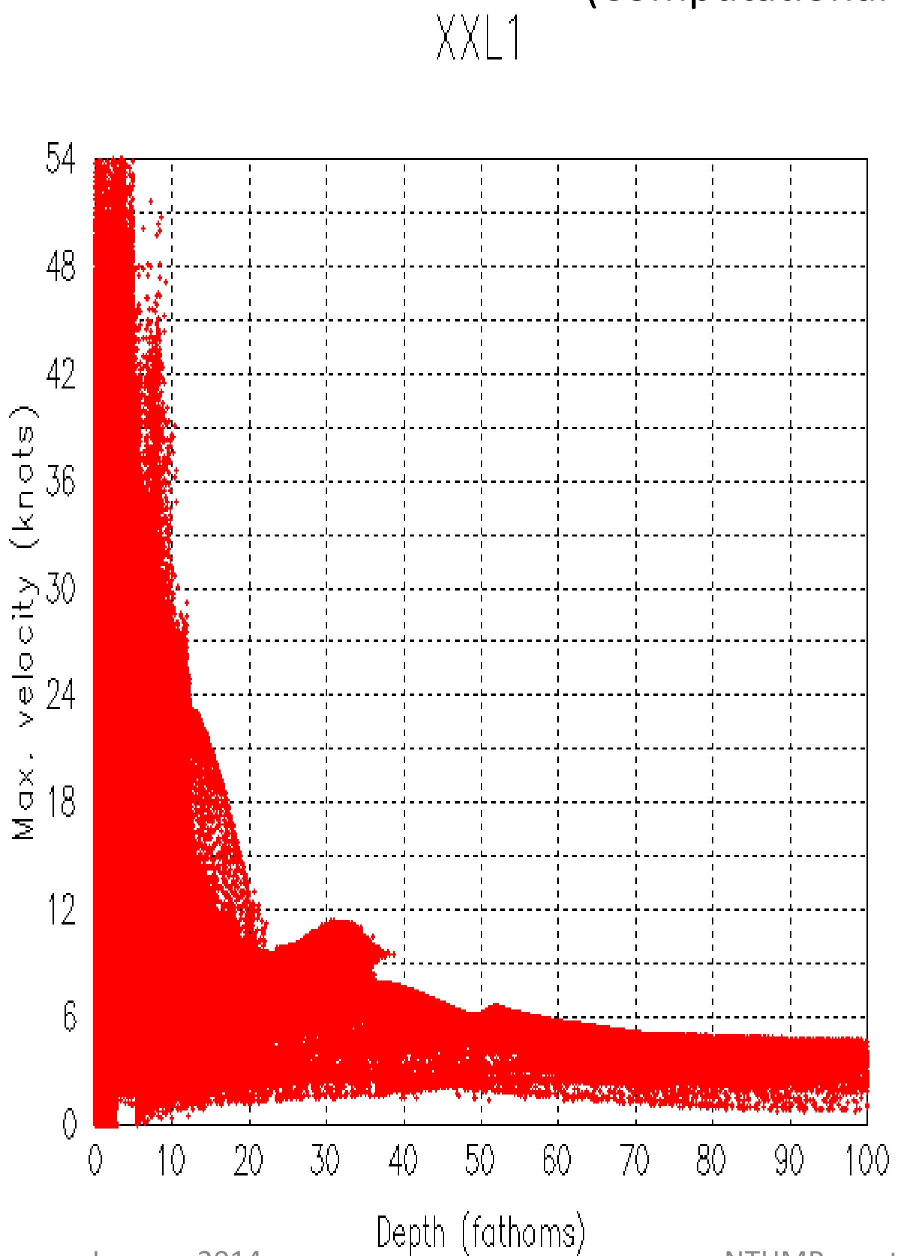


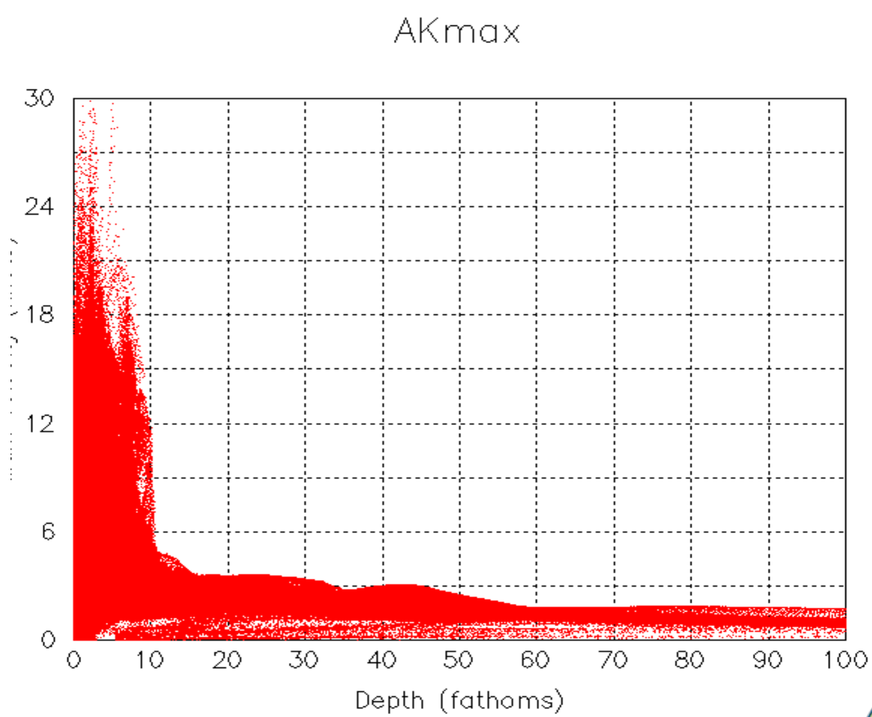
Alaska (Akmax) and Cascadia (XXL1) Maximum Velocities - Southern Oregon Coast





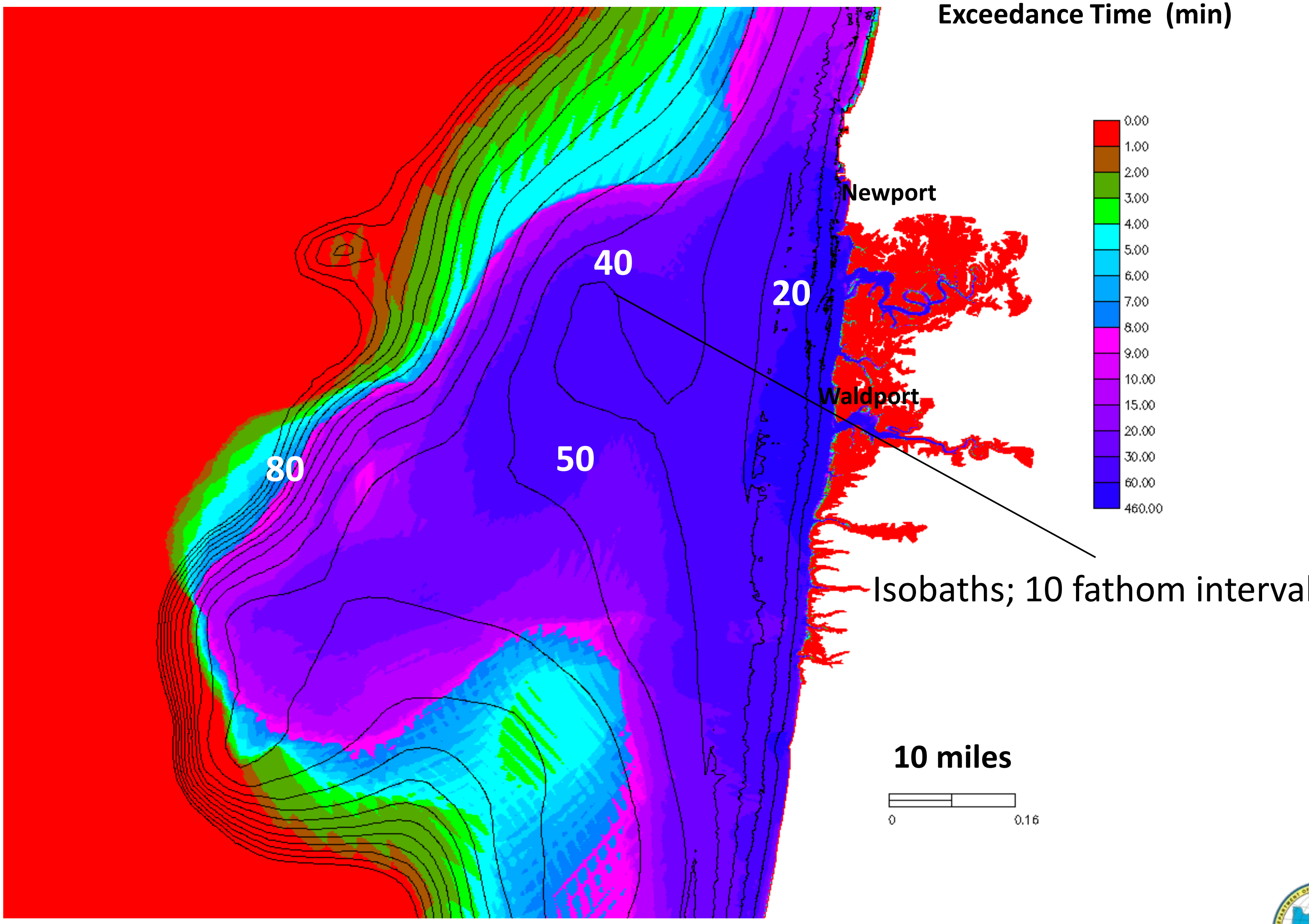
Velocity versus Depth - Central Oregon Coast
(Computational Points for Grid B)





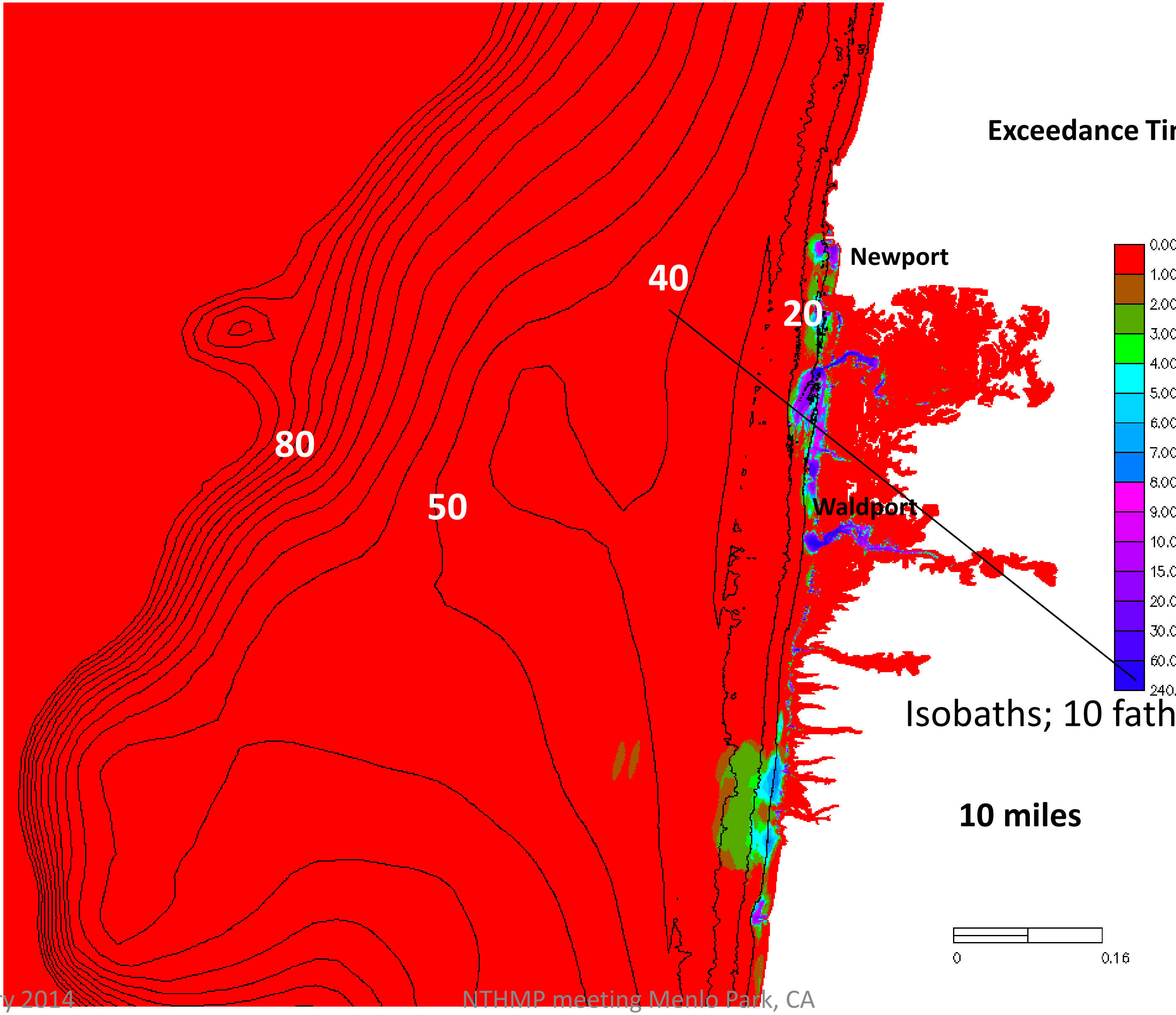
XXL1

Central Oregon Coast Map of 3-Knot Exceedance Times (over 8-hr simulation)



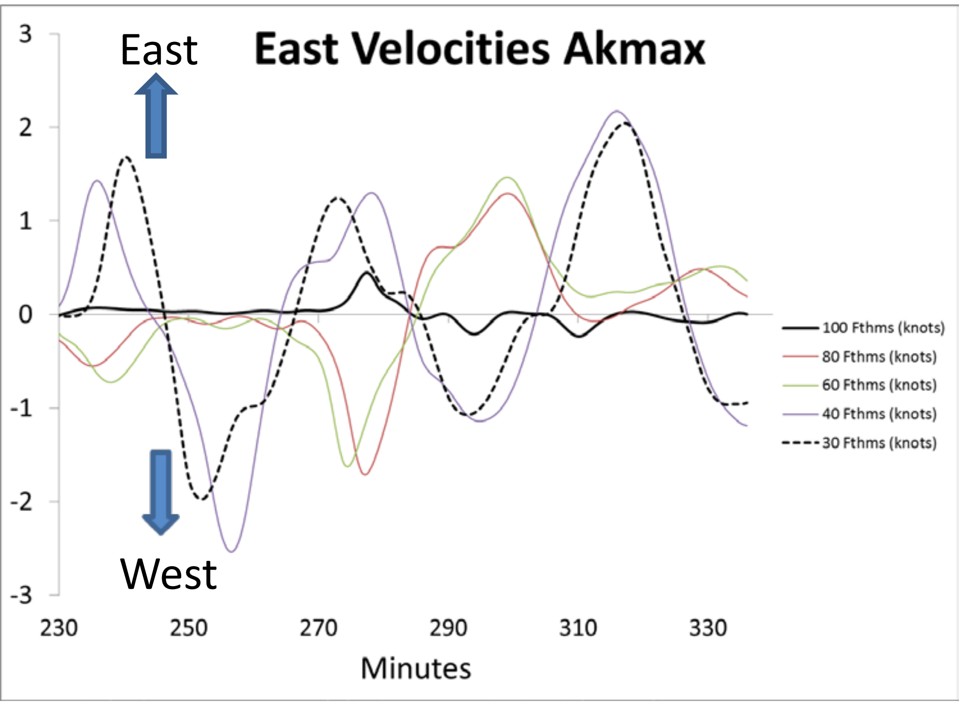
AKmax

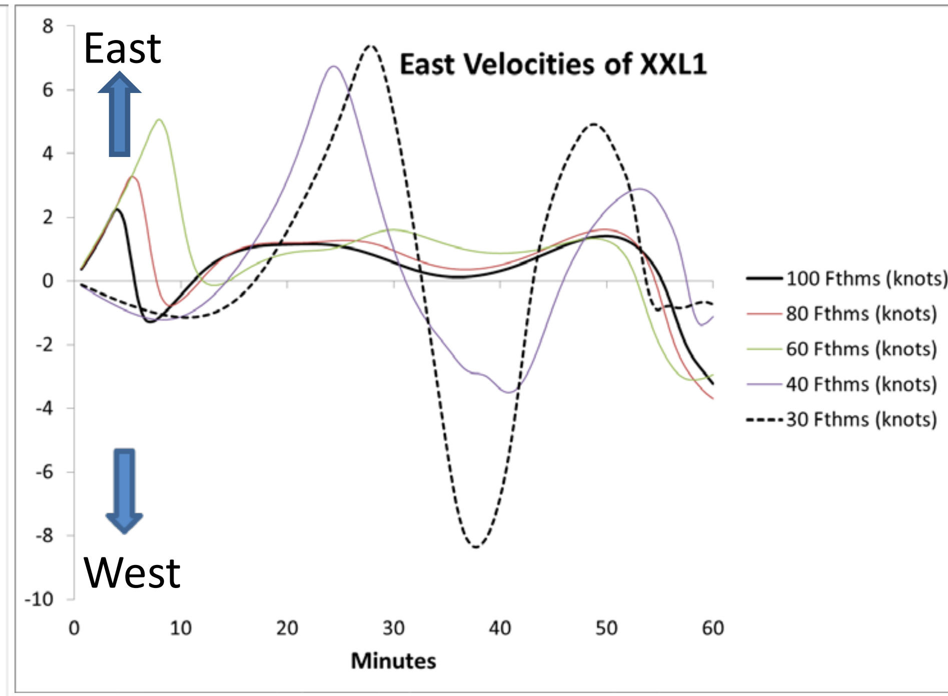
Central Oregon Coast Map of 3-Knot Exceedance Times (over 8-hr simulation)



Speed of East Velocity Changes

30, 40, 60, 80, 100 fathoms



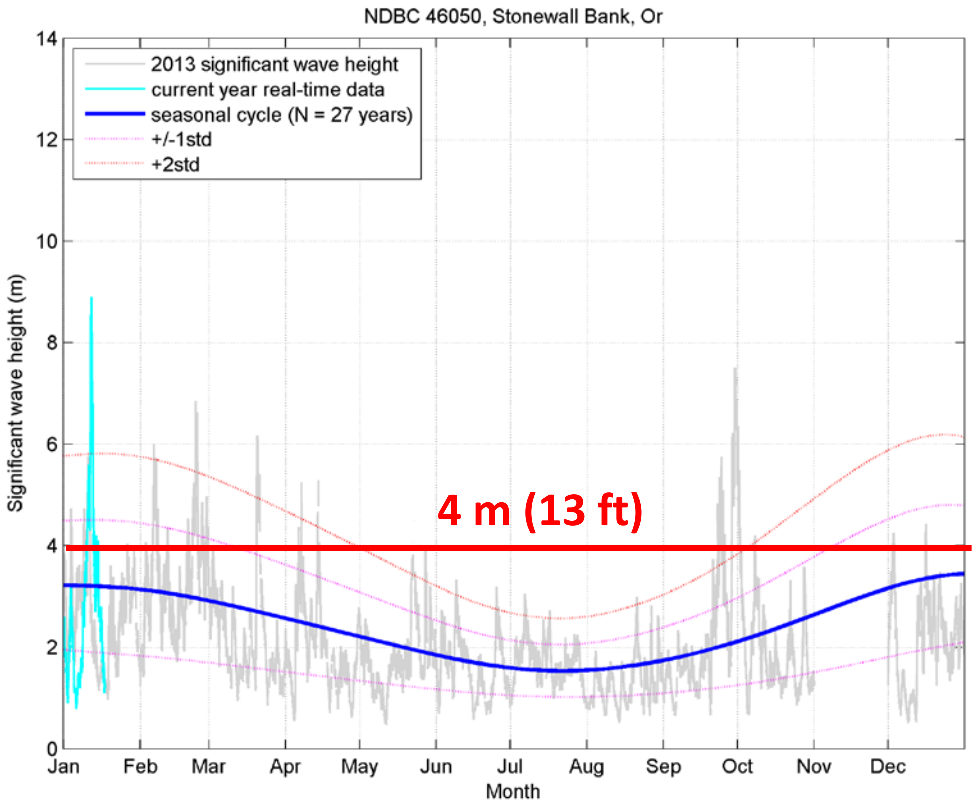


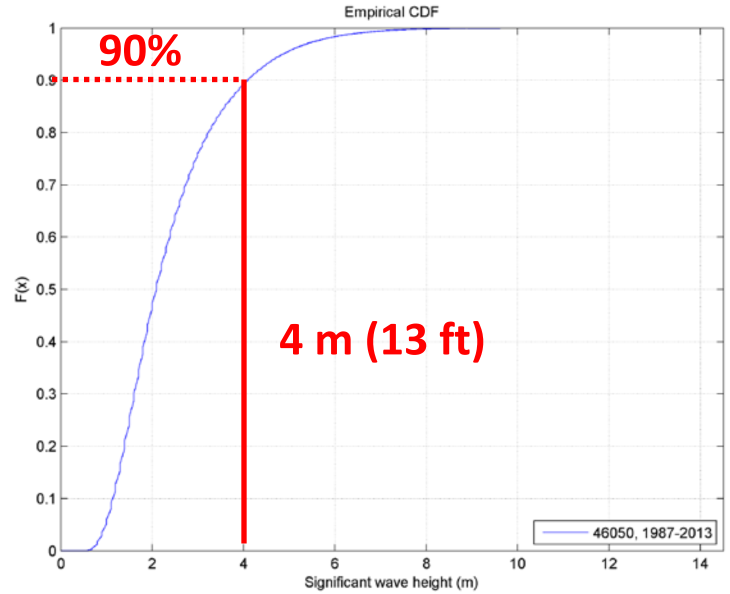
Amplification of wind waves by tsunami currents?

- Currents opposed to wind waves can significantly amplify wave height.
- How much amplification occurs for “typical” PNW wind waves for reasonable tsunami currents?

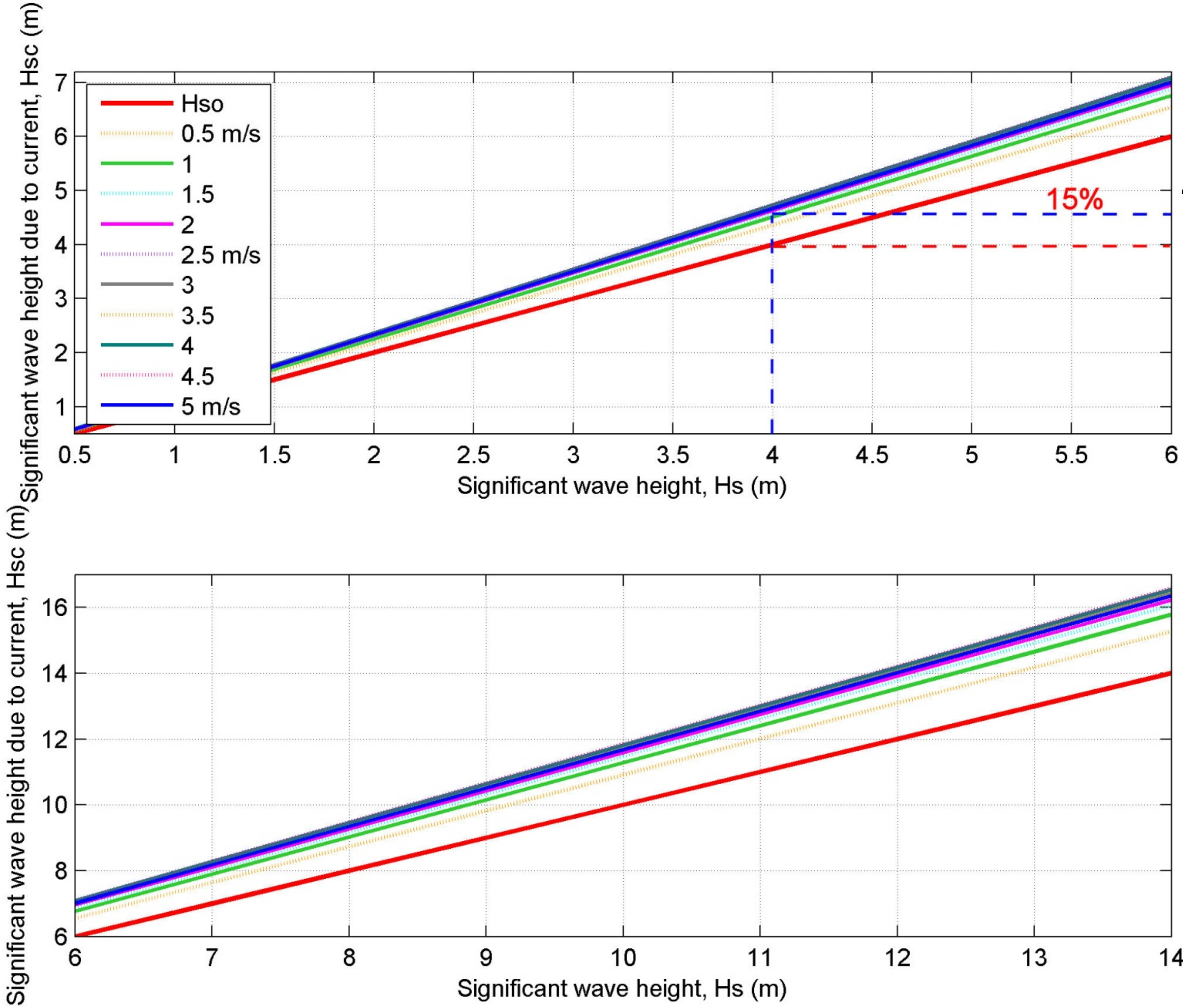
27 Years of Wave Data – Central Oregon (Stonewall Bank)

for significant wave height = highest 1/3 of waves





Wind Wave Amplification by Currents Offshore Central Oregon



~2-10 knots

~13 ft Hs

DISCUSSION

- **if** >3 knots = threat, then velocity data justifies **2-zone evacuation:**
  - Local tsunami zone = >**100 fathoms**
  - Distant tsunami zone = >**30 fathoms**
- **If** only vorticity and minimum flow depth = threat, then
  1-zone evacuation = **>30 fathoms**.
- How dangerous are the current reversals over 15-20 minutes?
- Are 2-zones too complicated?
- If we choose 1 zone = 100 fathoms
  - Up to 40 miles from the coast
  - Excessive for distant tsunamis where ~2 miles is adequate.
- If we choose 1 zone = 30 fathoms,
  - Adequate for distant tsunamis, but
  - Can vessels survive 7-10-knot peaks and >3 knots for ~1hr for XXL1 tsunamis?
- Wind wave amplification by tsunami currents:

~15%, so only a factor for extreme storm waves (<<90% of all events)

SUMMARY OF POSSIBLE 2-ZONE MITIGATION GUIDANCE

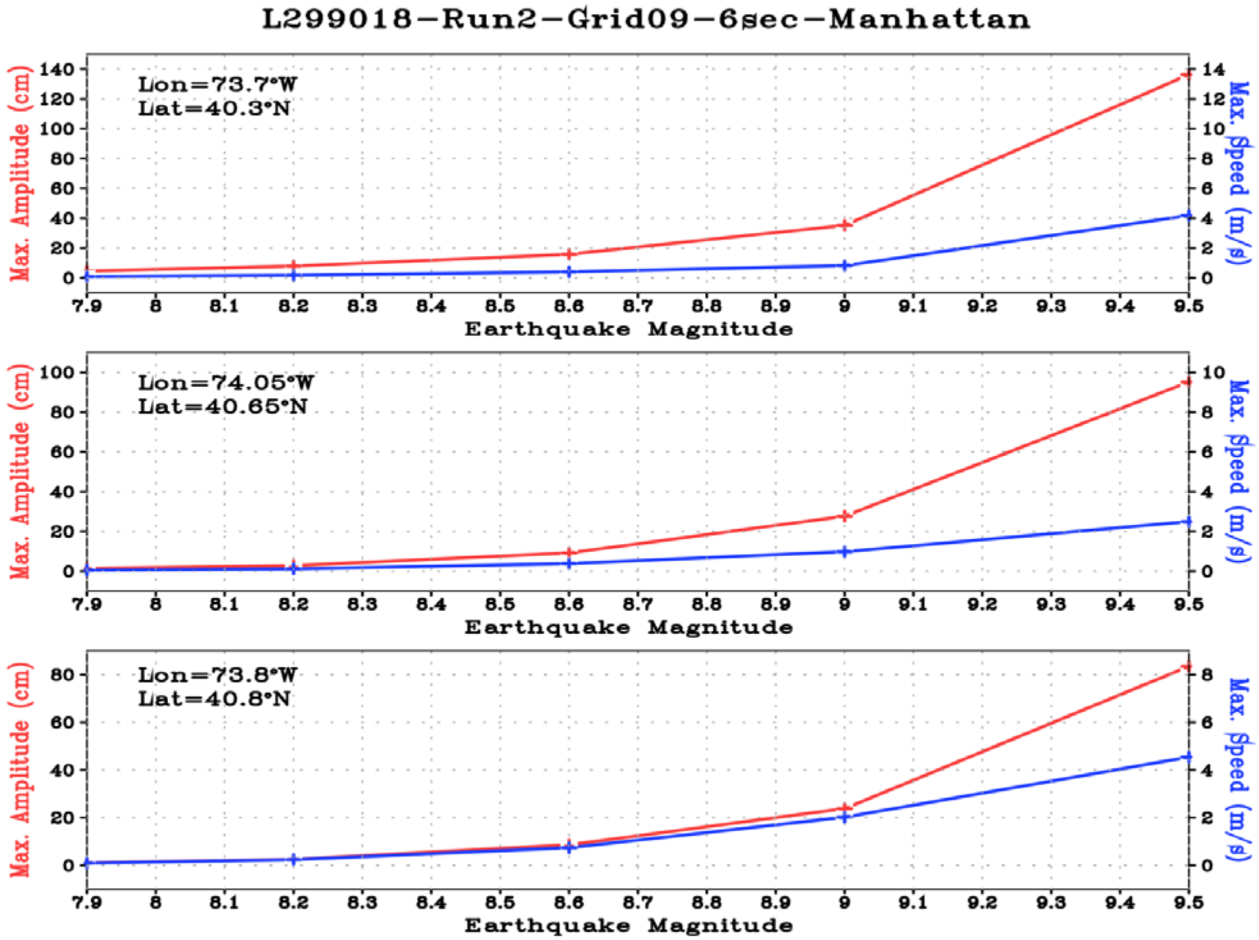
Distant Tsunamis

- Warning: NOAA
- Tsunami arrival: ≥ 4 hrs
- Tied to dock: Check w. port for guidance.
- Offshore: go to **>30 fathoms**
- Land: Go to evacuation site until local officials say it is safe to return.

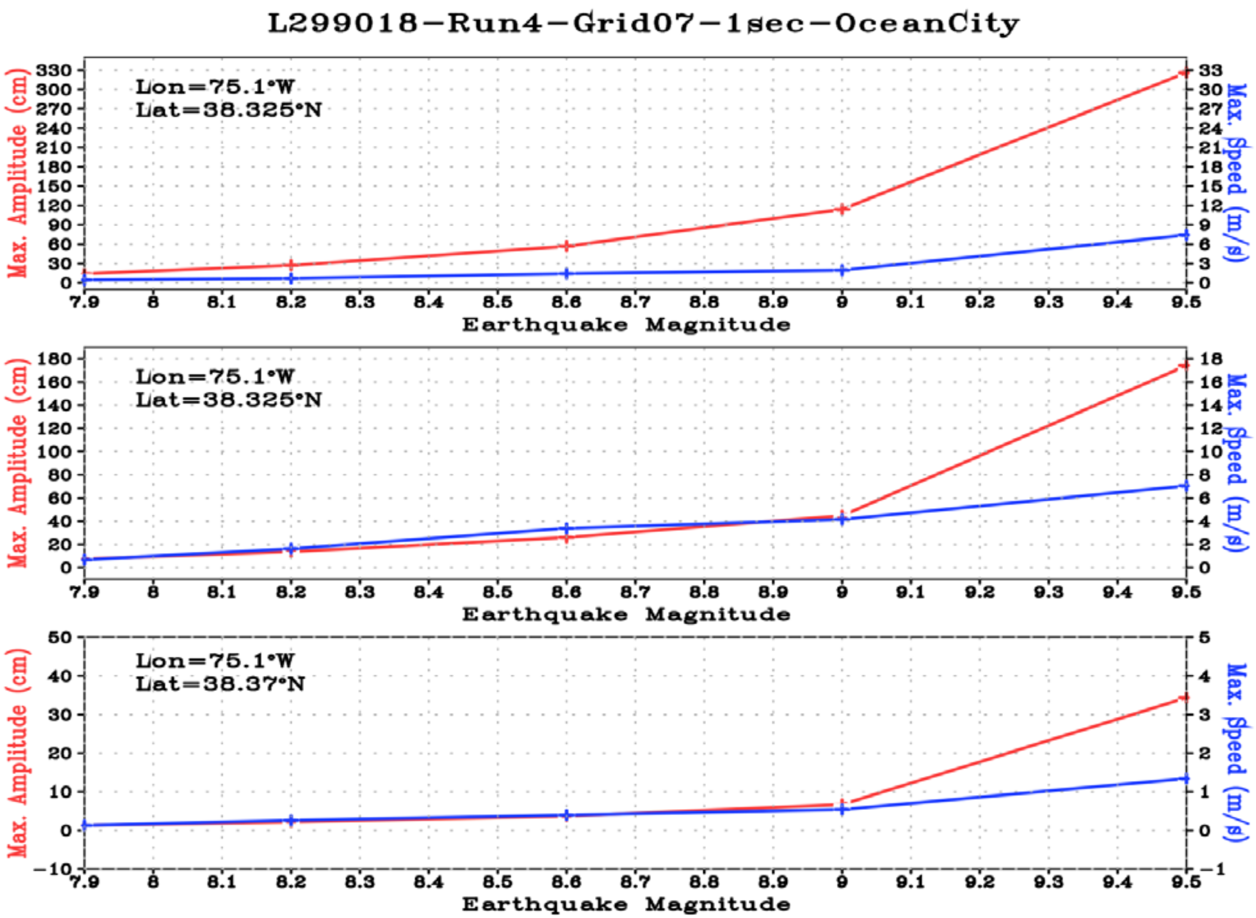
Local Tsunamis

- Warning:
  - Ground shaking
  - Ocean roar
  - Water receding or surging
- Tsunami arrival = 15-20 min.
- Tied to dock: Go to evacuation site until local officials say it is safe to return.
- Offshore: go to **>100 fathoms**
- Land: Go to evacuation site until local officials say it is safe to return.

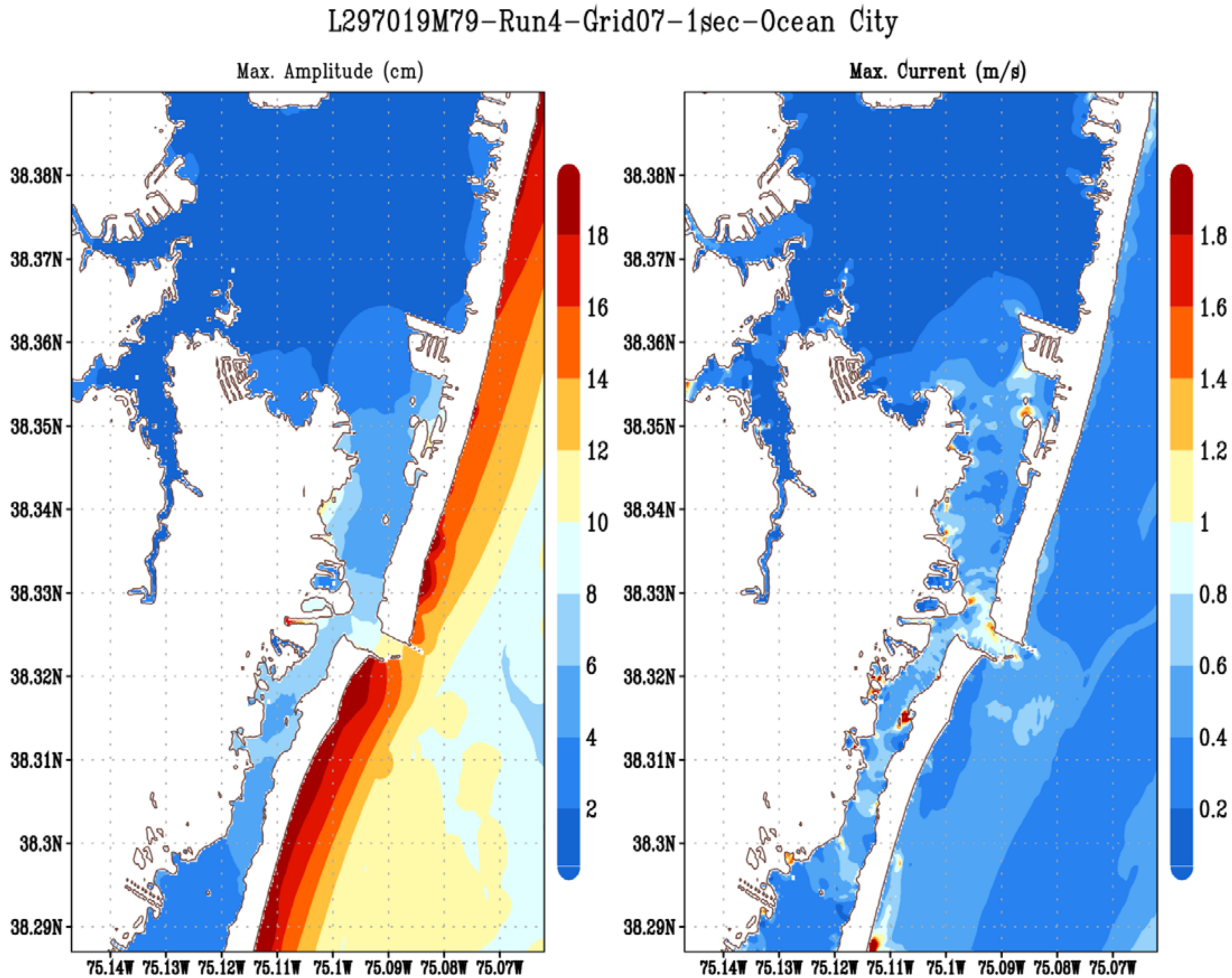
Scaling relationship between current and amplitude



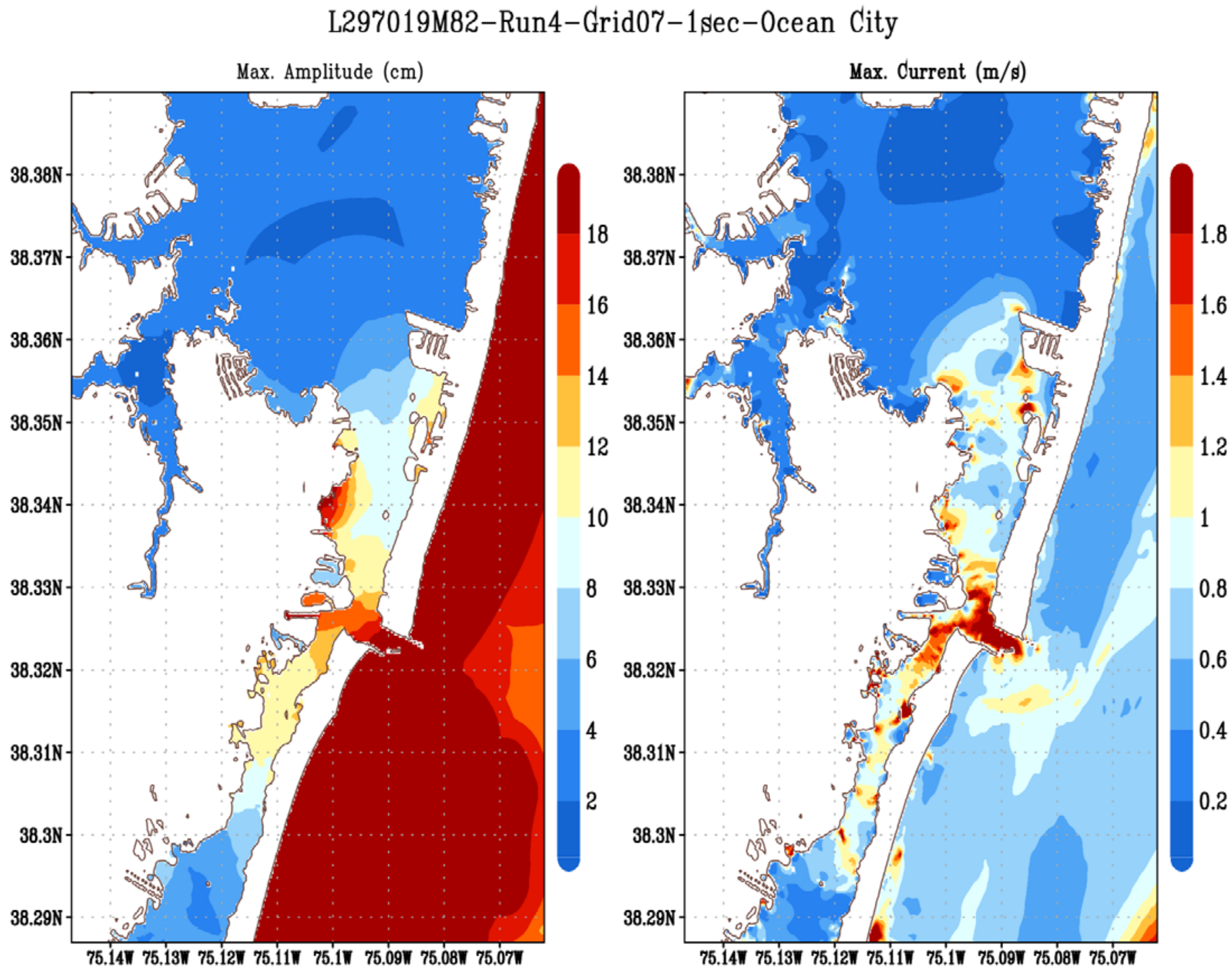
Scaling relationship between current and amplitude



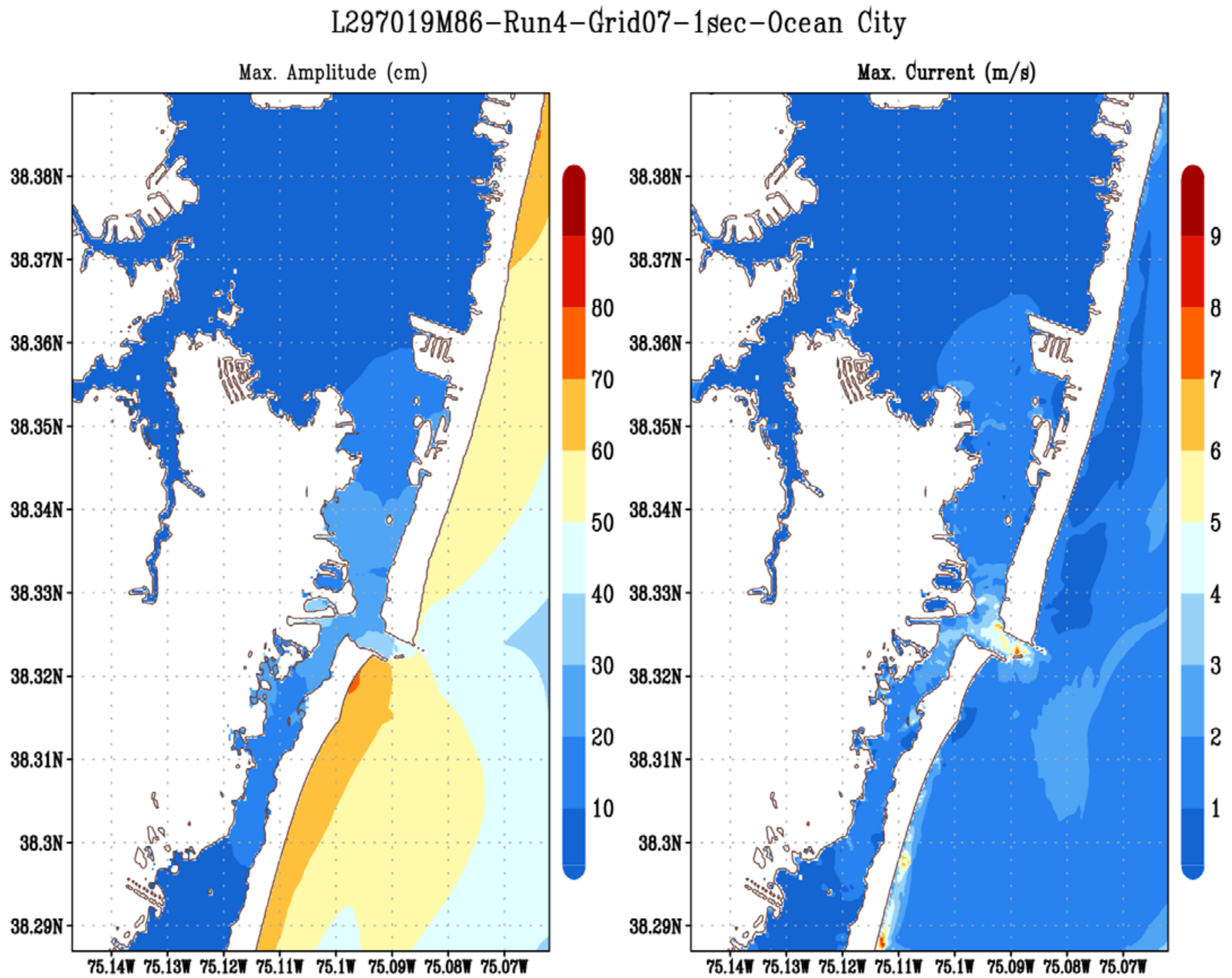
Max current map on right for Ocean City, MD
Source M=7.9 Puerto Rico



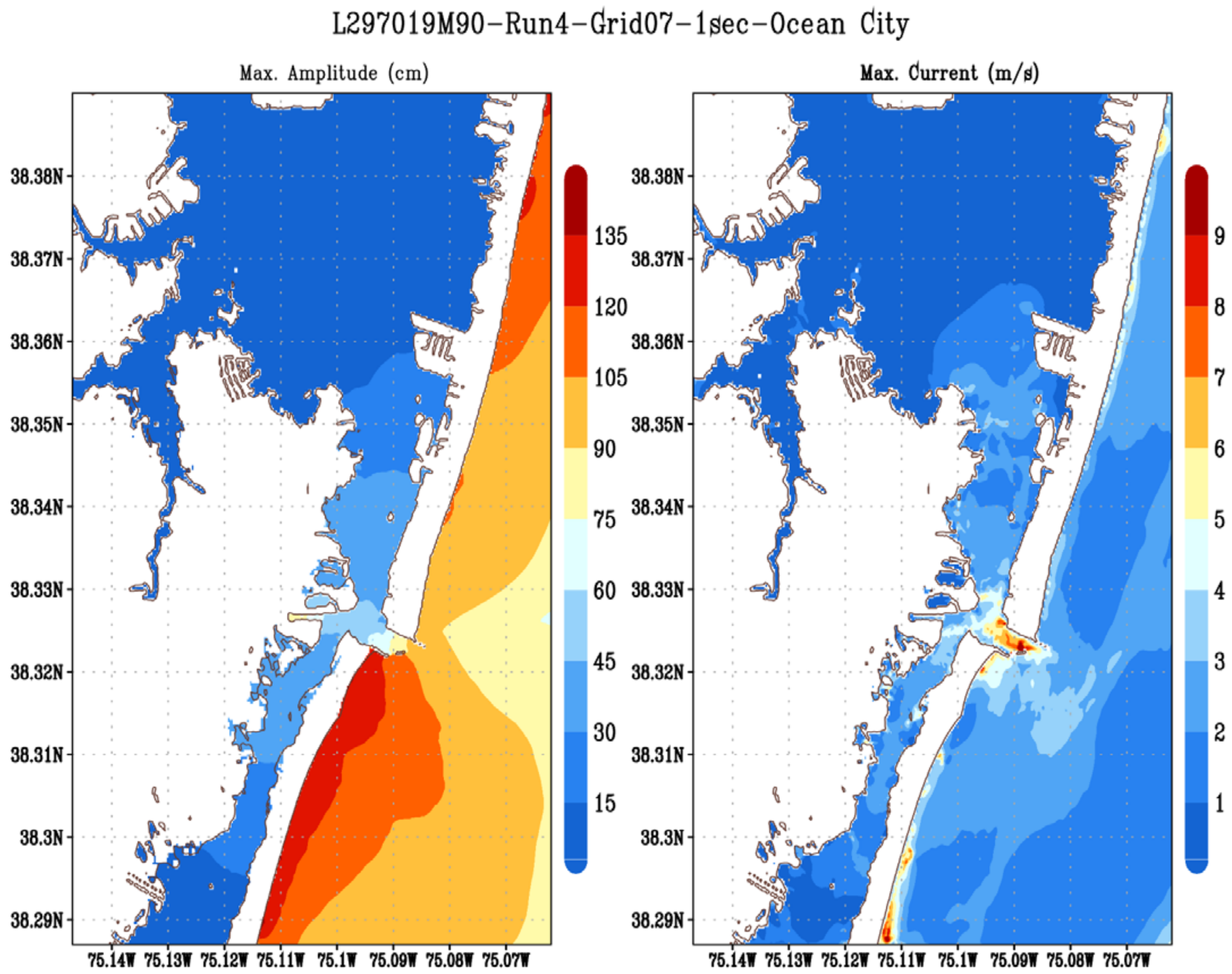
Max current map on right for Ocean City, MD
Source M=8.2 Puerto Rico



Max current map on right for Ocean City, MD
Source M=8.6 Puerto Rico



Max current map on right for Ocean City, MD
Source M=9.0 Puerto Rico



Max current map on right for Ocean City, MD
Source M=9.5 Puerto Rico