From Post-Tsunami Survey to Policy: Building Resilience in Ports and Harbors

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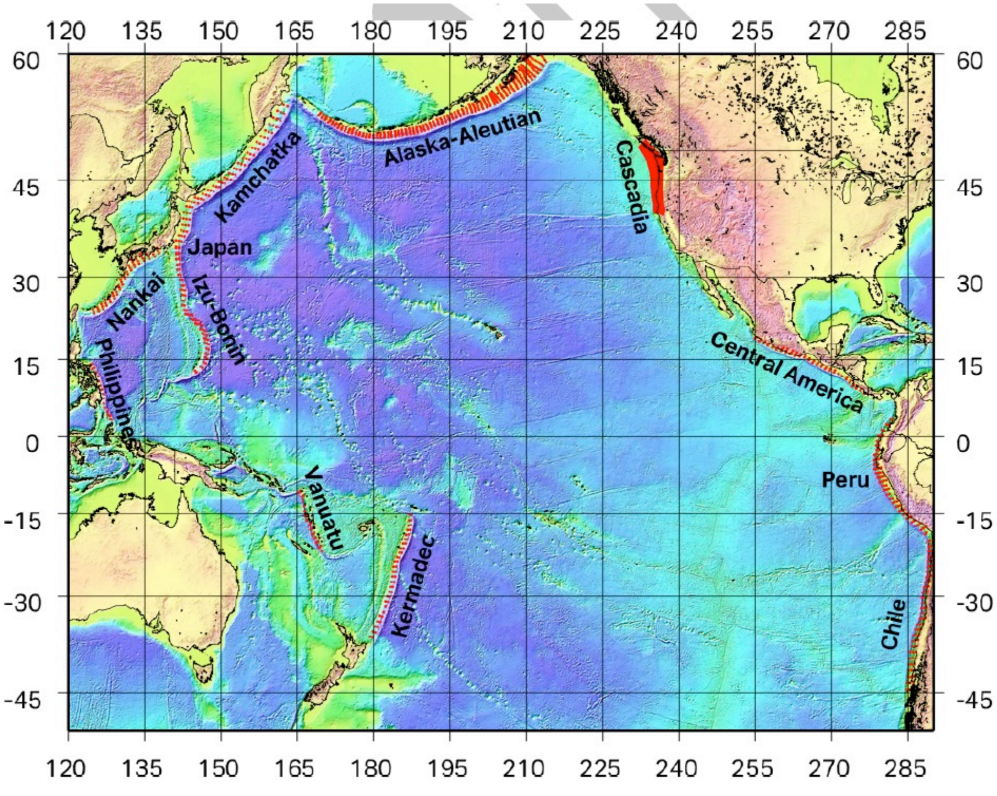
Outline

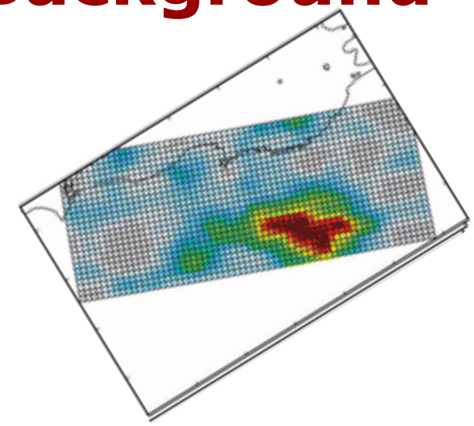
Review tsunami observations and the laboratory, numerical, and engineering studies they inspired, with a focus on ports & harbors

- Quick tsunami background
- Tsunami height vs Tsunami current
- Observations of tsunamis in ports & harbors in the past decade
- Experimental and numerical efforts working towards the goals of:
  - Developing tsunami hazard maps for response and emergency management
  - Engineering analysis for mitigation

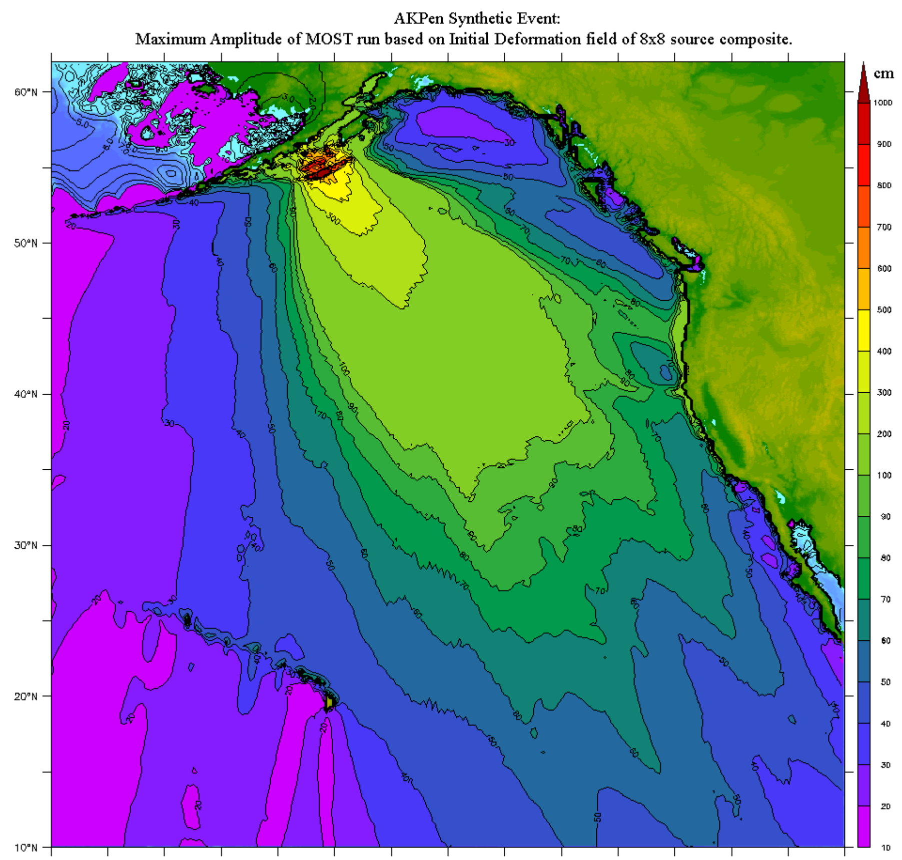
Tsunamis – A Quick Background

1. Choose Source Region



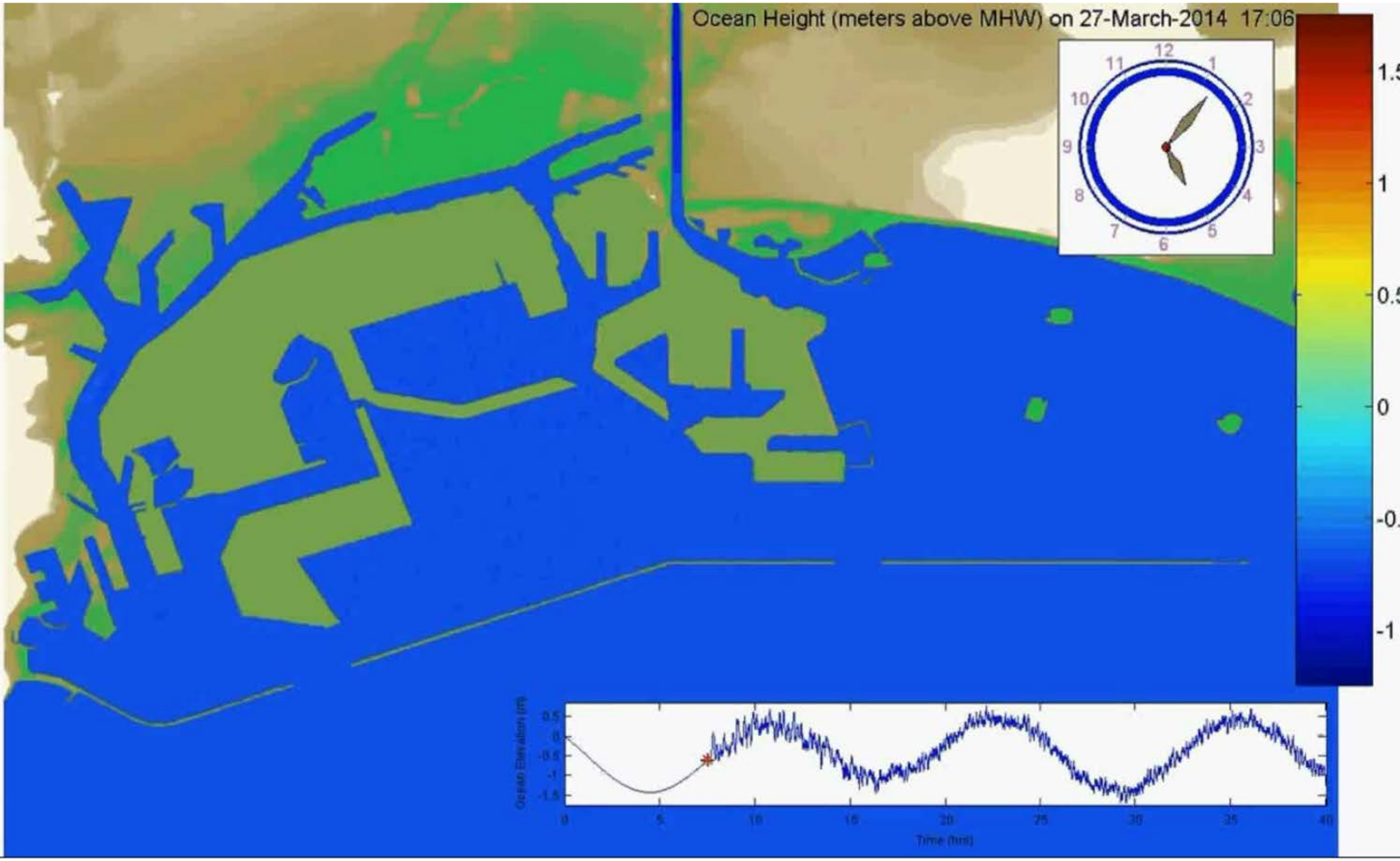


2. Determine Tsunami Initial Condition based on a Slip Distribution

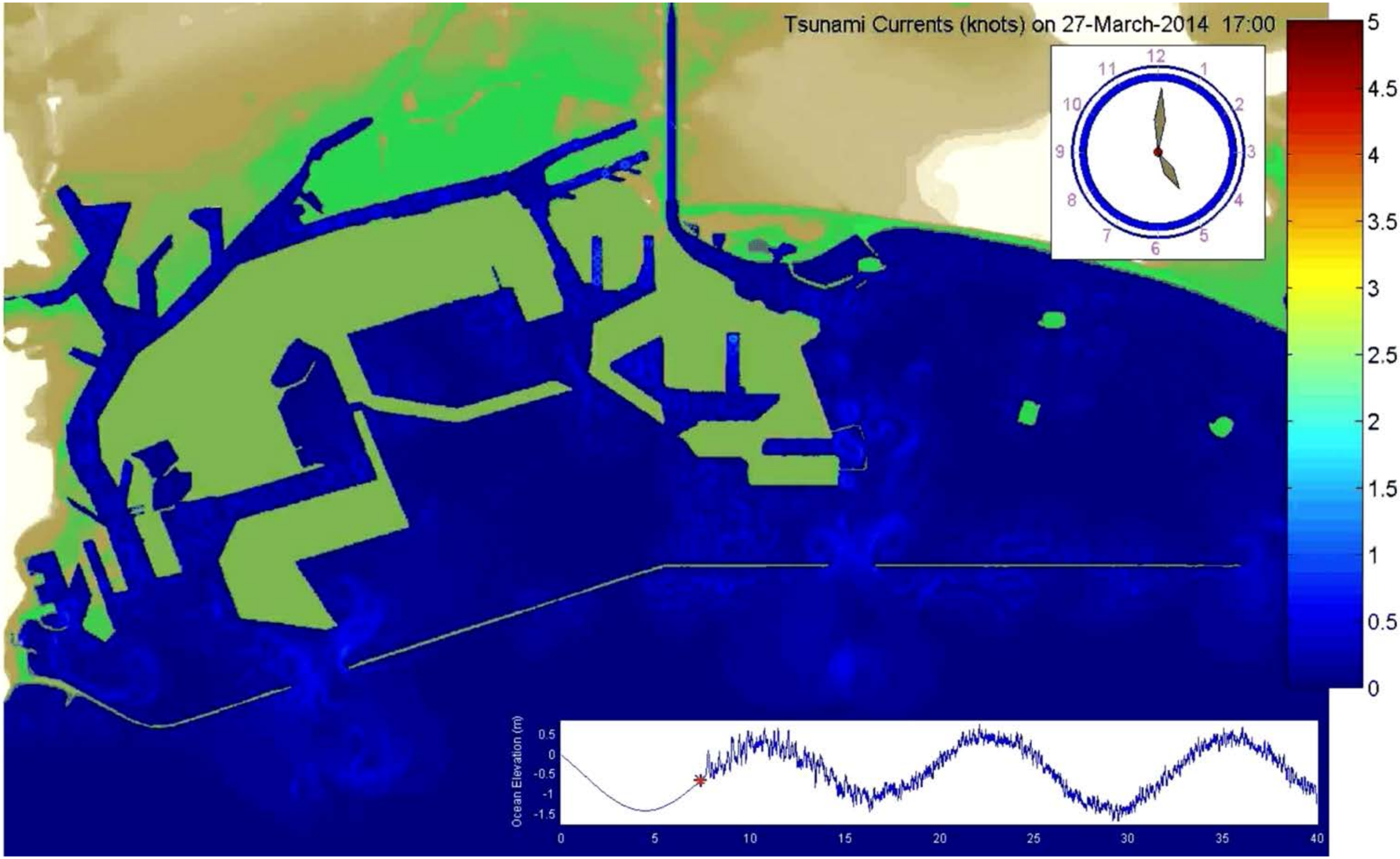


3. Propagate Tsunami across Basin using wave equations (shallow water)

Why focus on currents?



Animation shows the ocean surface height (above / below MHW) at POLALB



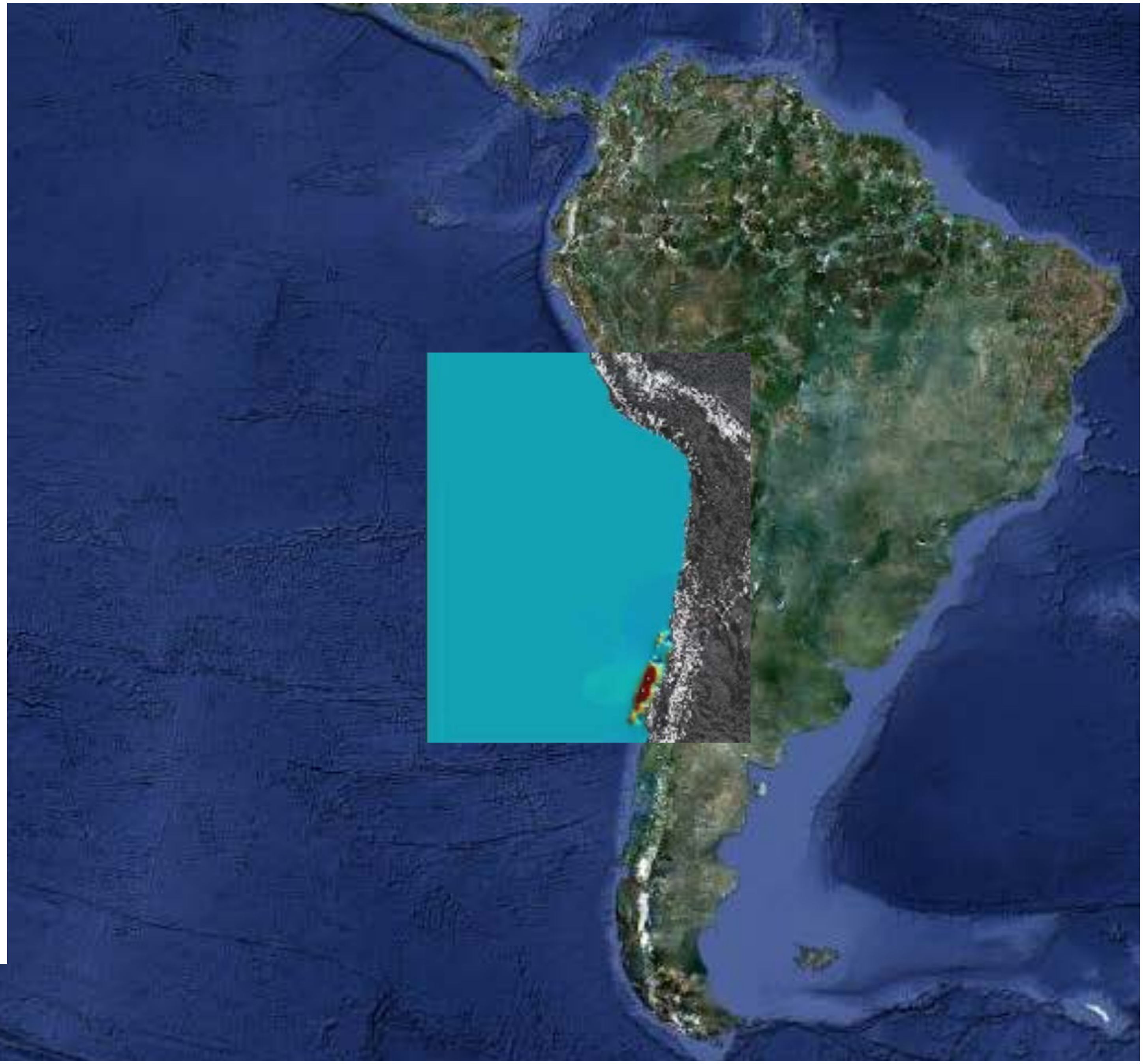
Animation shows the ocean currents (knots) at POLALB

Gates and channel opens show strong focusing of currents, and the creation of large eddies & whirlpools

Events & Observations: The 2010's

2010 Chile

- *8.8 Mag EQ*
- *Tsunami Warnings issued in 53 countries*
- *30 m runup along cliffside in Chile*
- *Widespread 5-10 m runup in Chile near epicenter*
- *4,200 boats were damaged or destroyed by the earthquake and tsunami in the Valparaiso-Concepción-Temuco area*
- *1+m in many locations, including Hawaii, Japan, south Pacific islands*



Seismic and Tsunami – Induced Liquefaction

Events & Observations: The 2010's

- Debris Impact

Shipping containers were originally stacked on the wharf area and displaced up to 300 meters in the direction of the flow.

Events & Observations: The 2010's

Damaged Containers – Chile

Photos: I.N. Robertson and G. Chock

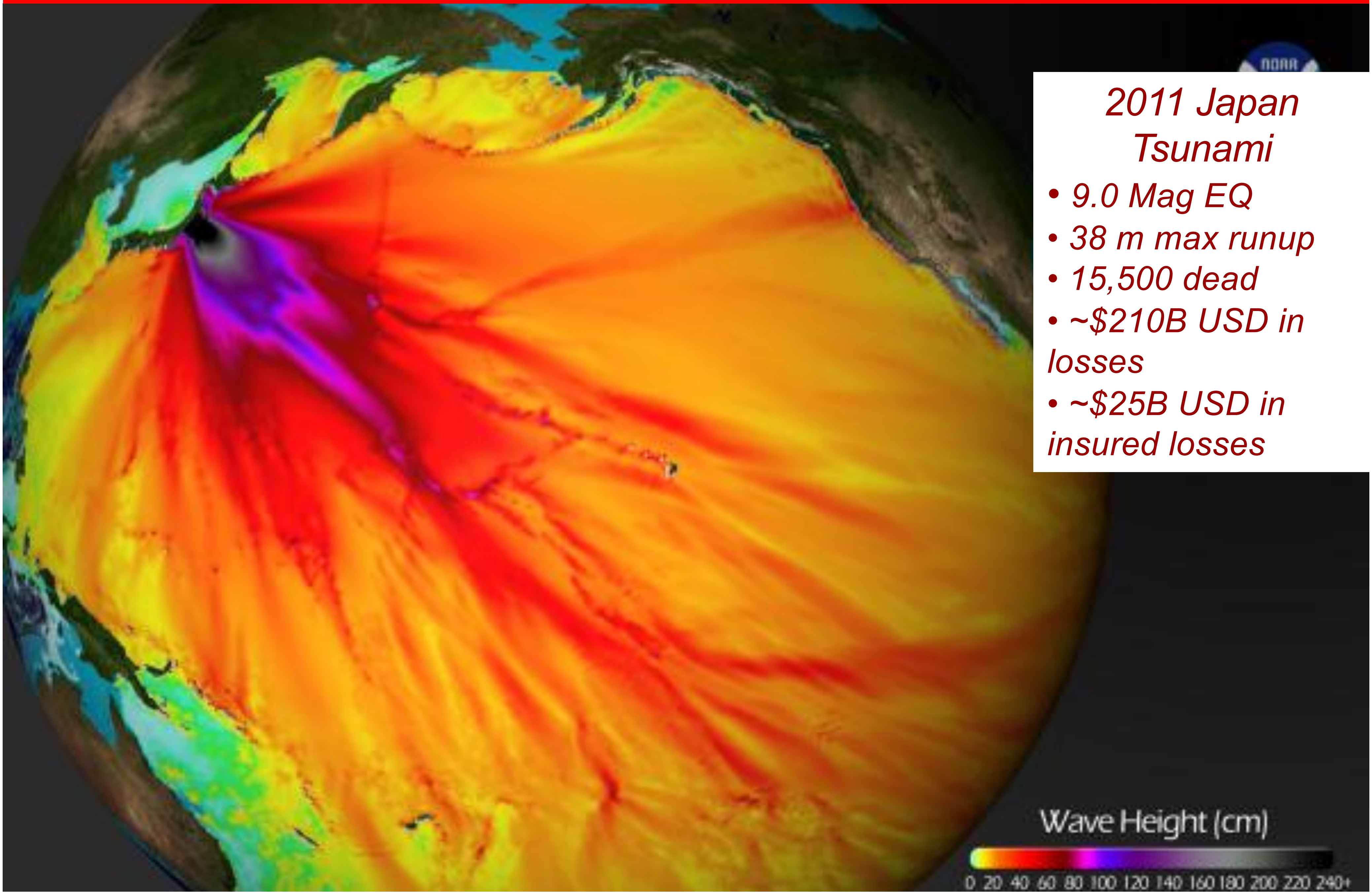
Events & Observations: The 2010's

- Lashed ships move as single unit

Events & Observations: The 2010's

- Bollard pulled from dock, Talcahuano

Events & Observations: The 2010's



2011 Japan Tsunami

- *9.0 Mag EQ*
- *38 m max runup*
- *15,500 dead*
- *~$210B USD in losses*
- *~$25B USD in insured losses*

Events & Observations: The 2010's

2011 Japan Tsunami

- *350 ports suffered some damage*
- *18,000+ fishing boats out of operation*

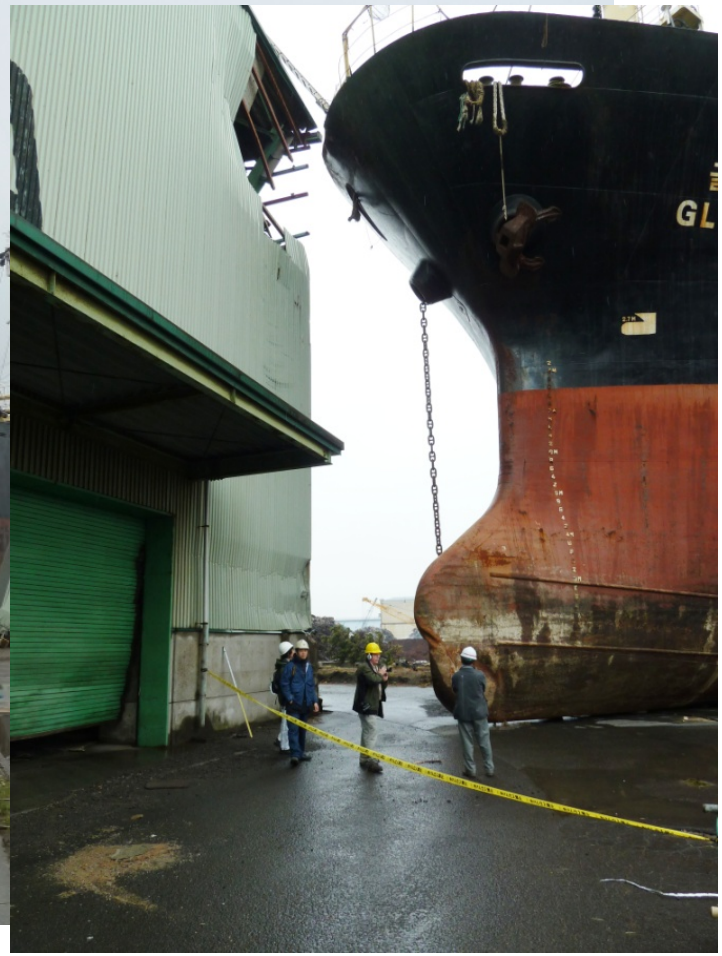
Events & Observations: The 2010's


Image © 2019 Maxar Technologies
Google Earth


Image © 2019 Maxar Technologies
Google Earth

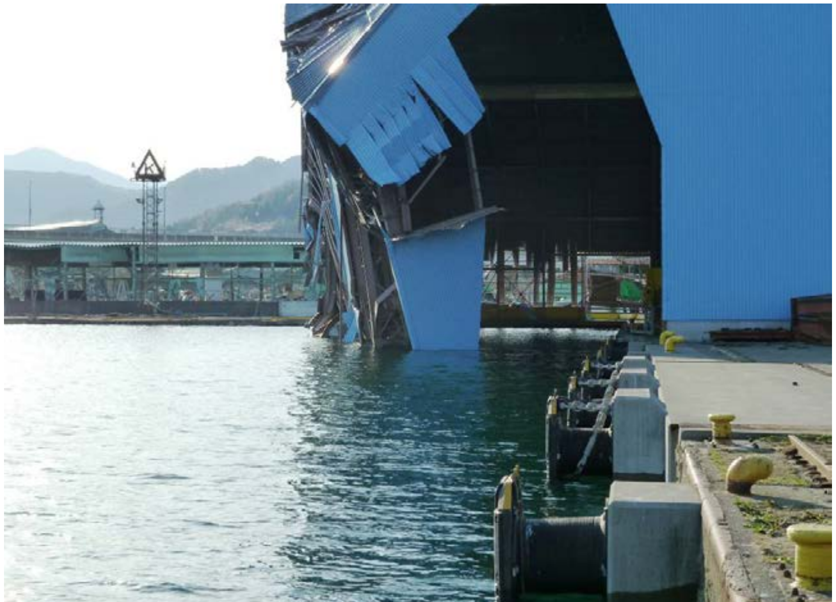
Events & Observations: The 2010's

Ship Impact – Sendai Port



Events & Observations: The 2010's

Kamaishi - Ship Impact damage

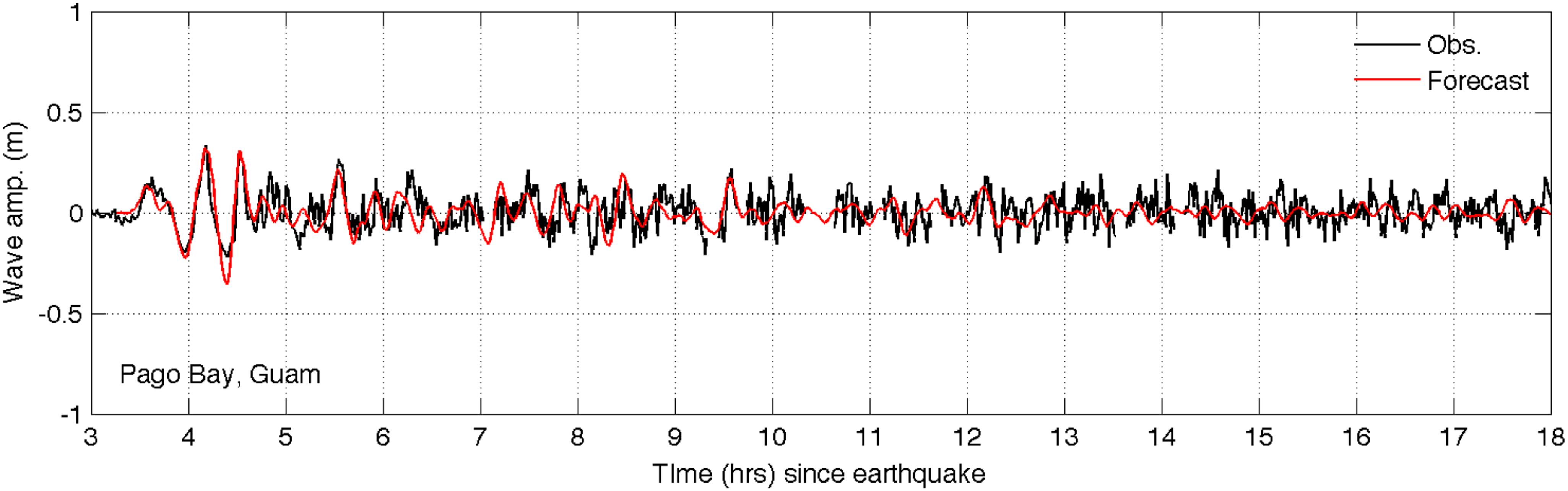


Damage to pier and warehouse due to multiple impacts from single loose ship

Events & Observations: The 2010's

2011 Japan Tsunami
In Guam, two nuclear submarines (USS Houston and USS City of Corpus Christi) broke free of moorings

Events & Observations: The 2010's



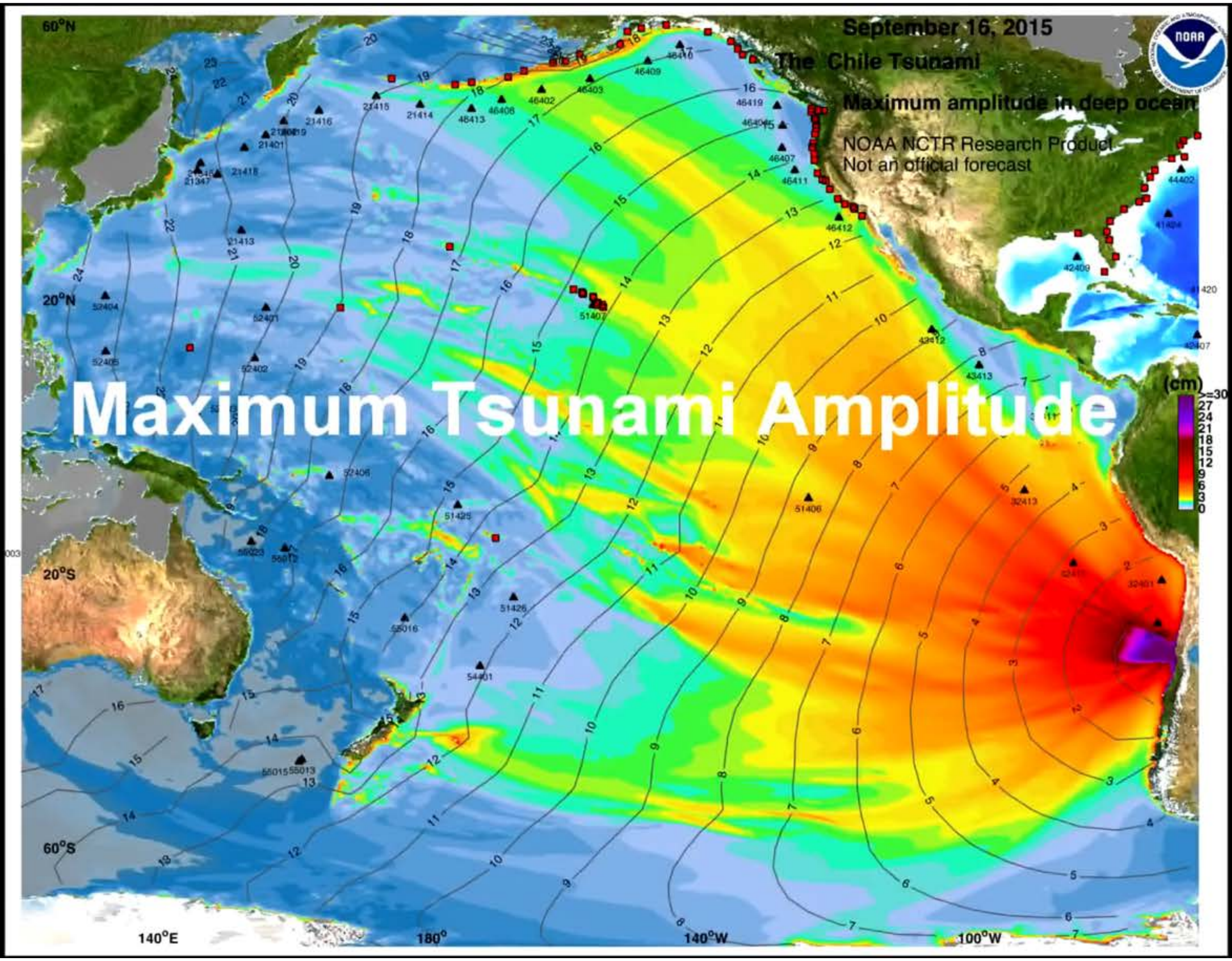
Honshu (northeastern Taiheiyou) tsunami, 11 March 2011

NOAA Center for Tsunami Research

2011 Japan Tsunami In Guam, two nuclear submarines (USS Houston and USS City of Corpus Christi) broke free of moorings

Events & Observations: The 2010's

Rapid deployment to capture field-scale tsunami-induced currents in a harbor
Chile 2015 tsunami field measurements in Ventura, CA

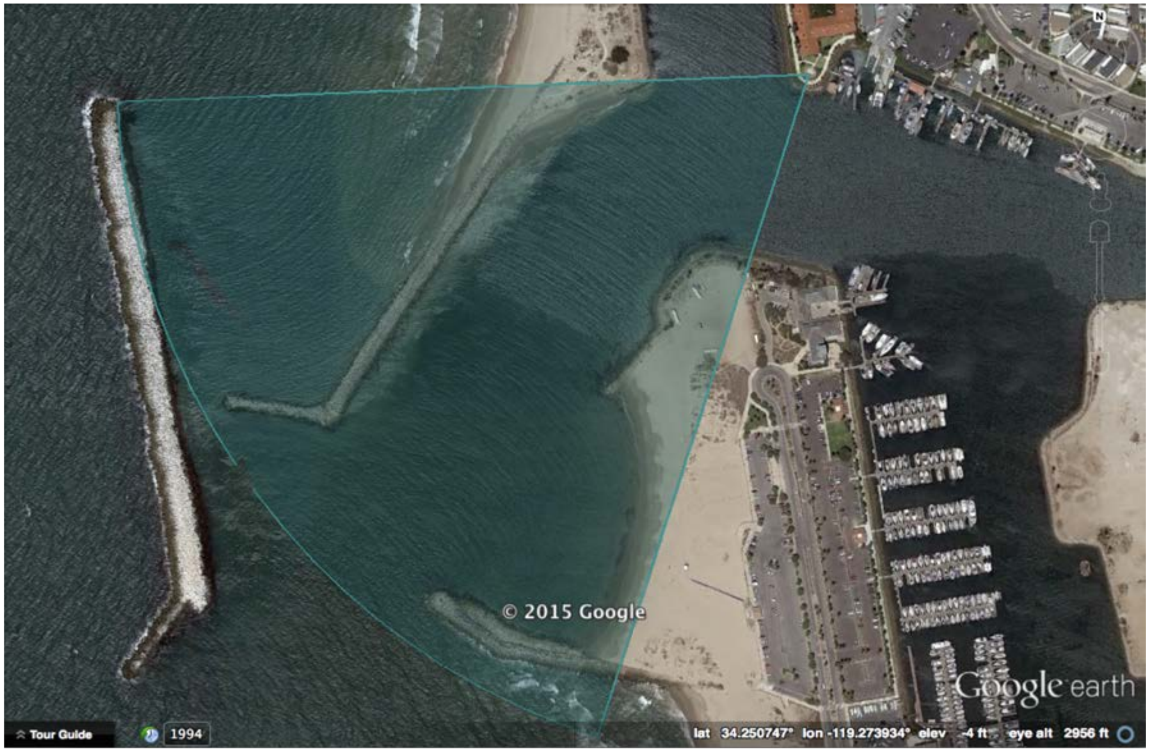


Events & Observations: The 2010's

Rapid deployment to capture field-scale tsunami-induced currents in a harbor
Chile 2015 tsunami field measurements in Ventura, CA

Instrumentation

- Deployed three GPS receivers on floating devices prior to the arrival of the tsunami.
- One GPS receiver logging every 2sec and the other two every 2min.
- We setup cameras observing the entrance channel of the harbor.
- The cameras were used to trace floating particles and extract surface velocities.

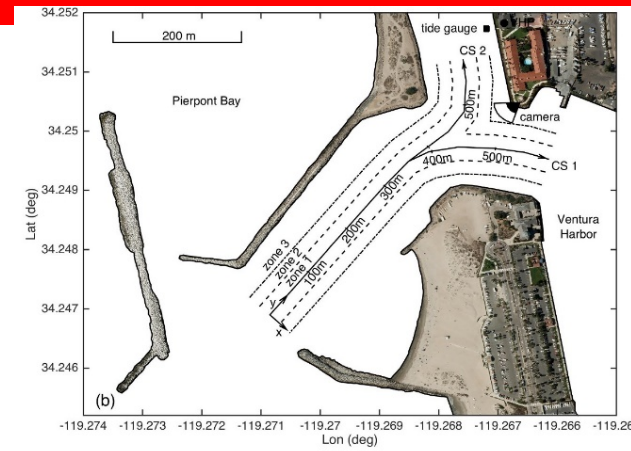


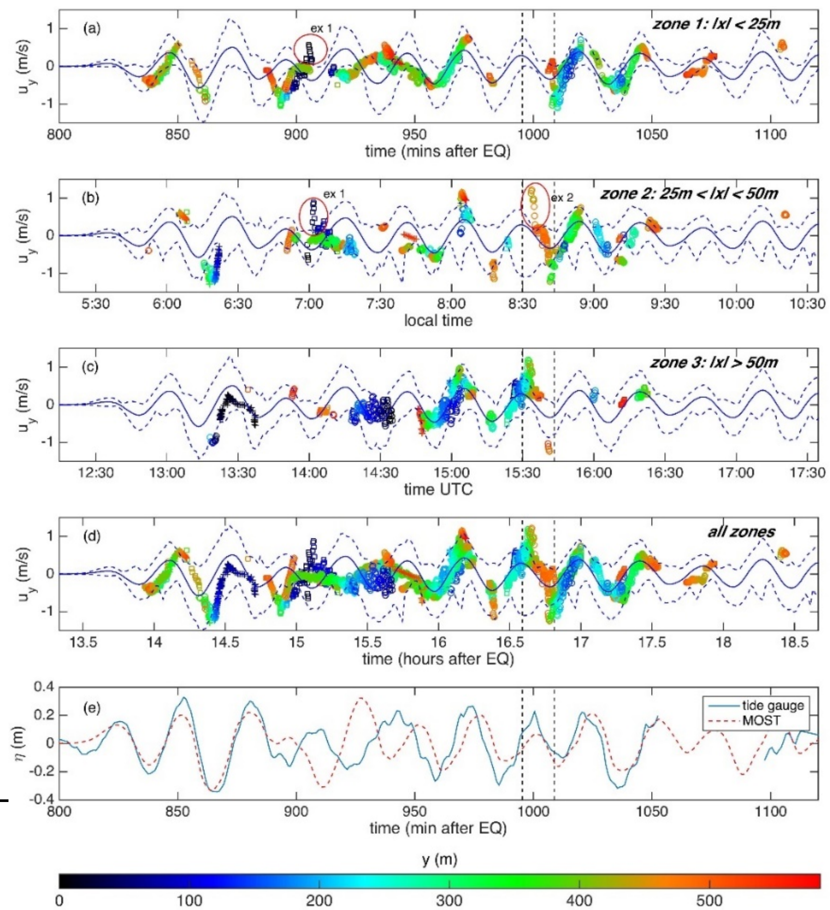
Events & Observations: The 2010's

Timelapse of the tsunami event, time shown PST

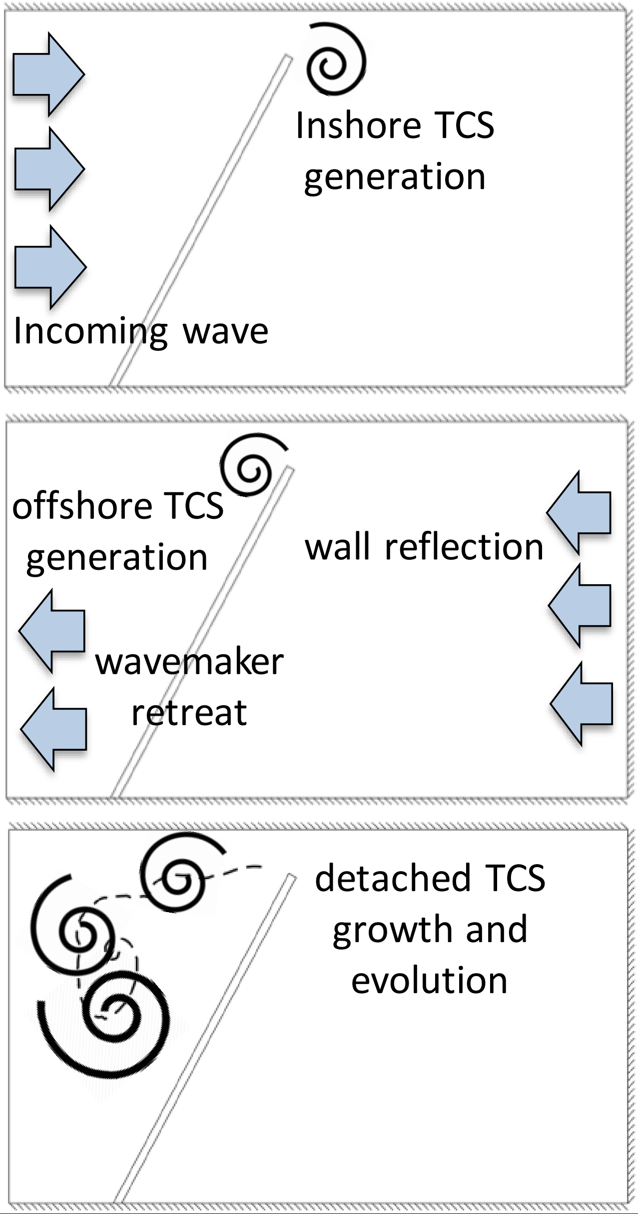
Through surveying many control points of known location, we are able to geo-rectify the video

Events & Observations: The 2010's



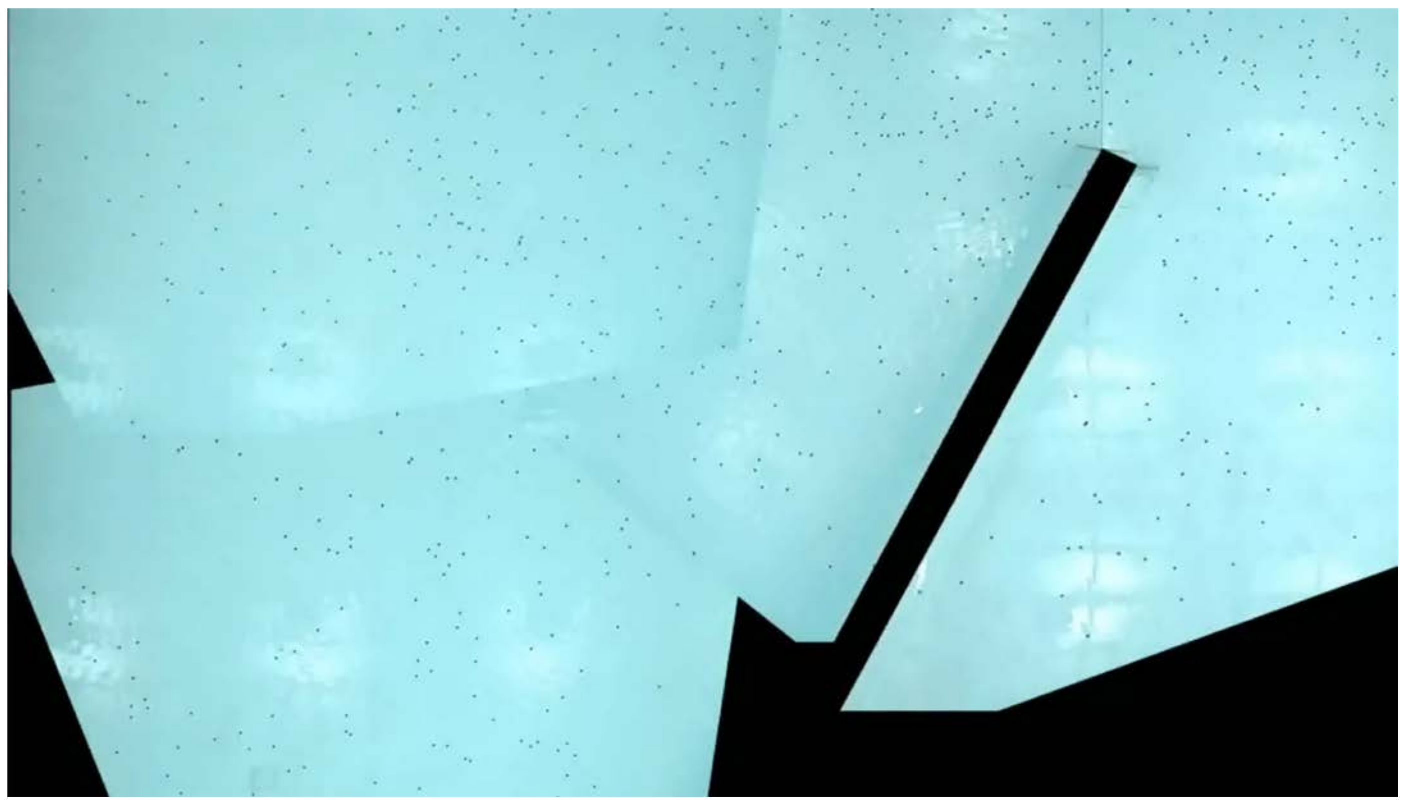


Field-Motivated Laboratory Work

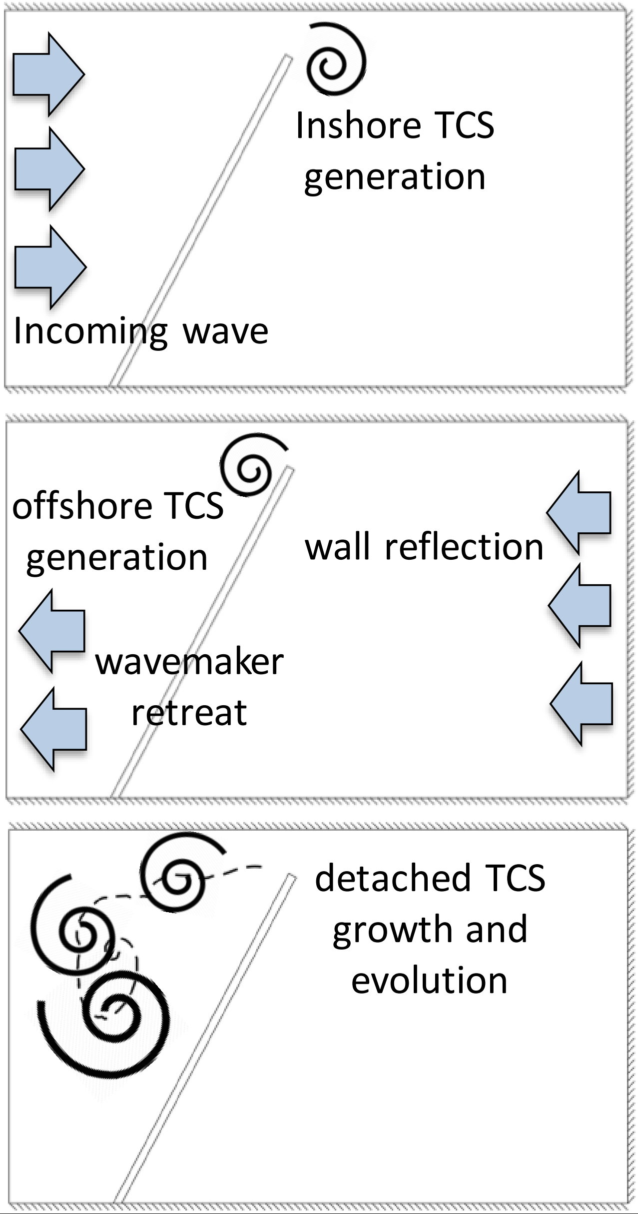


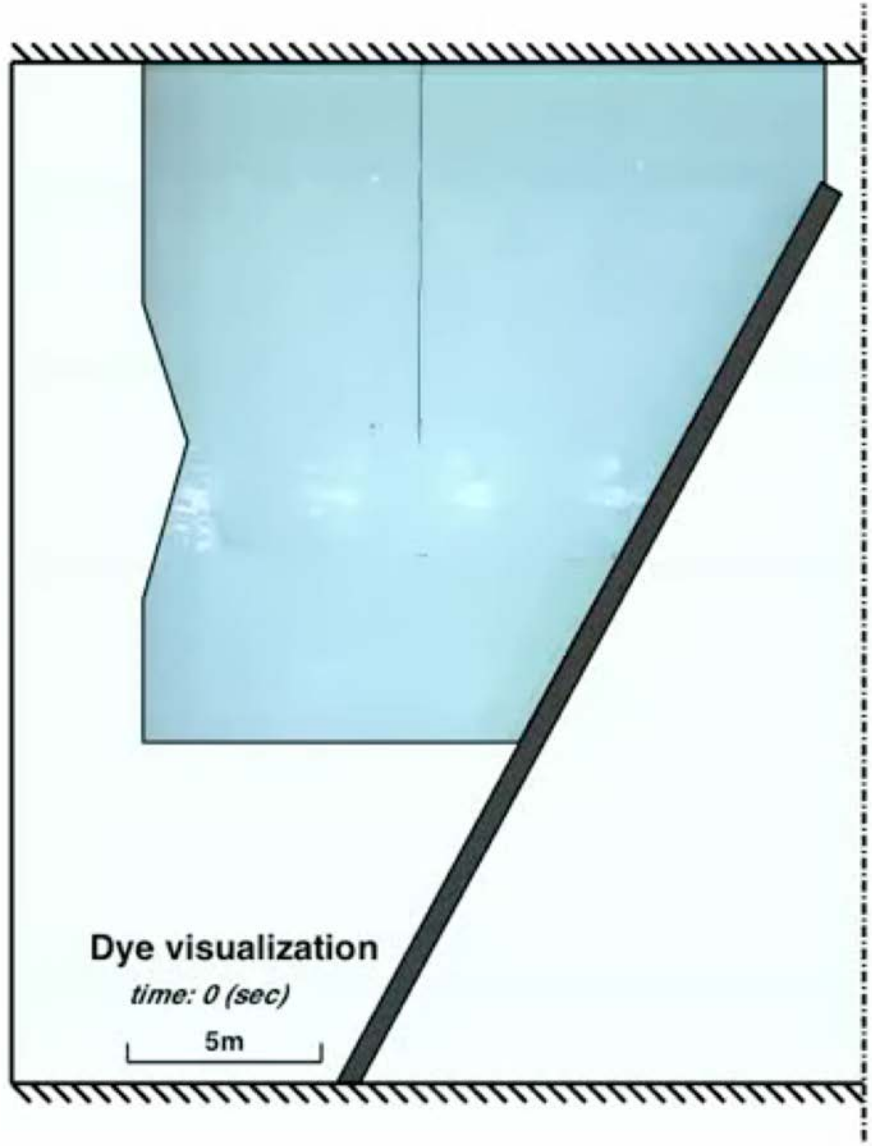
Large-scale experimental work to recreate the rotational currents always observed in harbors during tsunami events

Performed in the Tsunami Wave Basin (Directional Wave Basin) at OSU

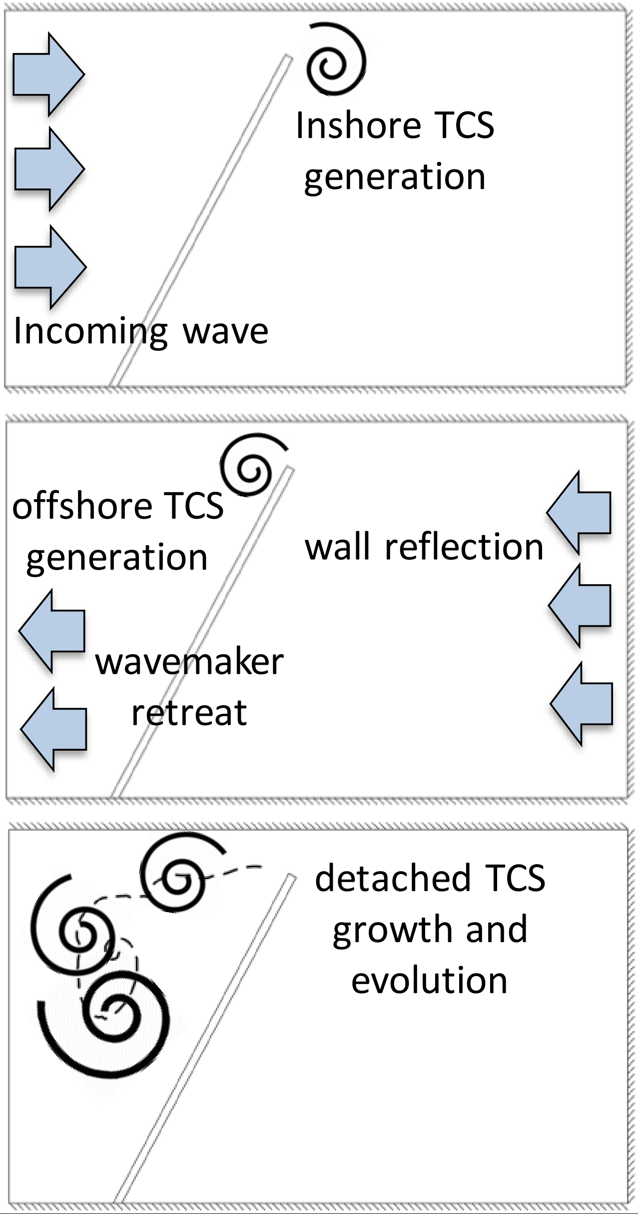


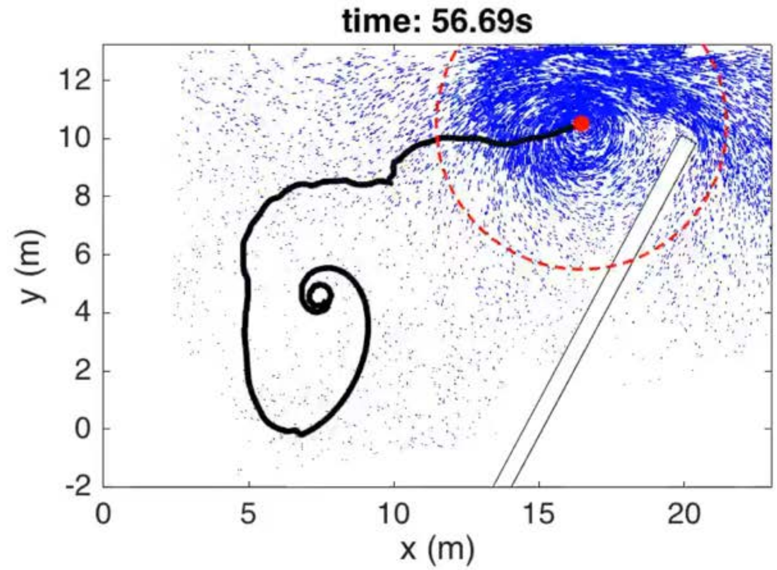
Field-Motivated Laboratory Work

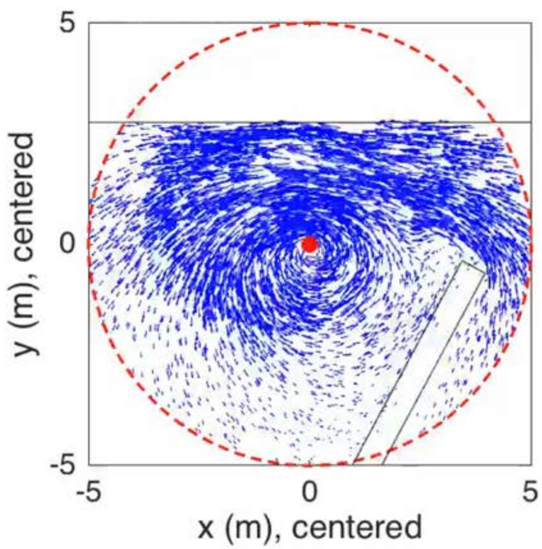


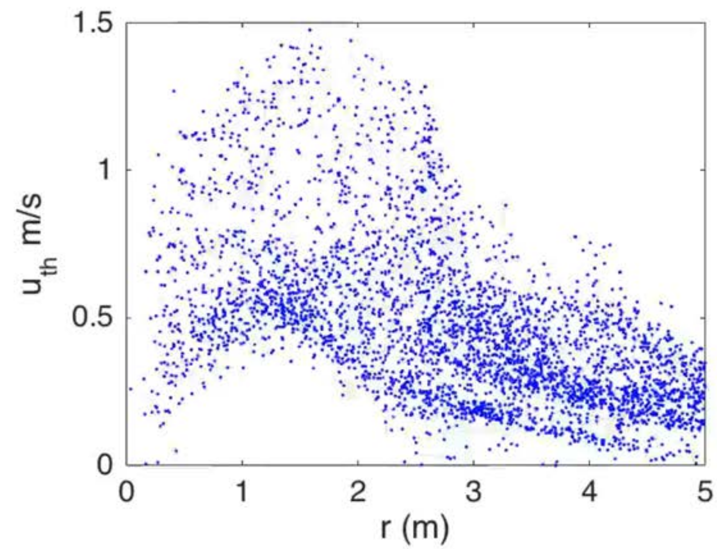


Field-Motivated Laboratory Work







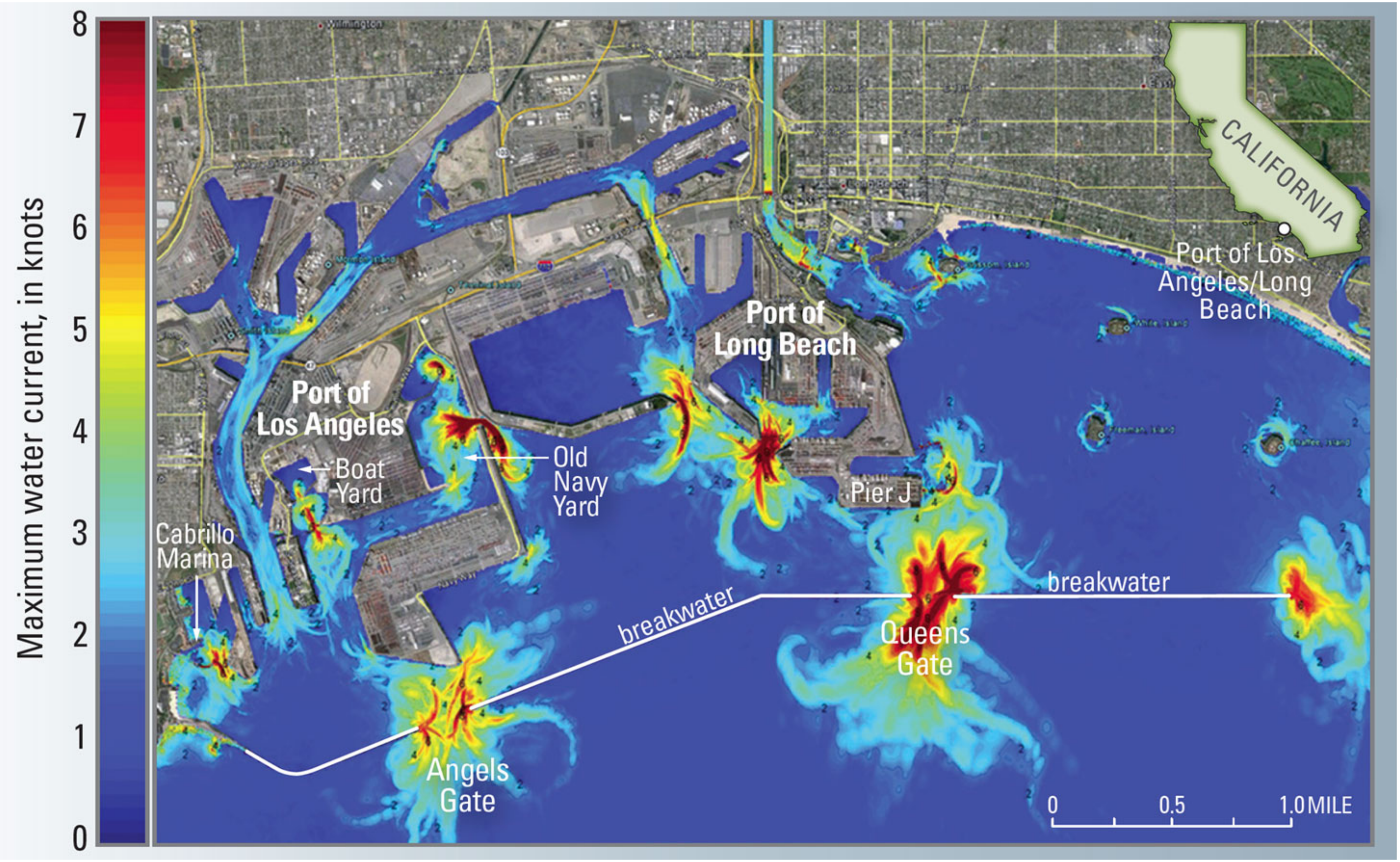


Use this data to calibrate / validate numerical prediction models…

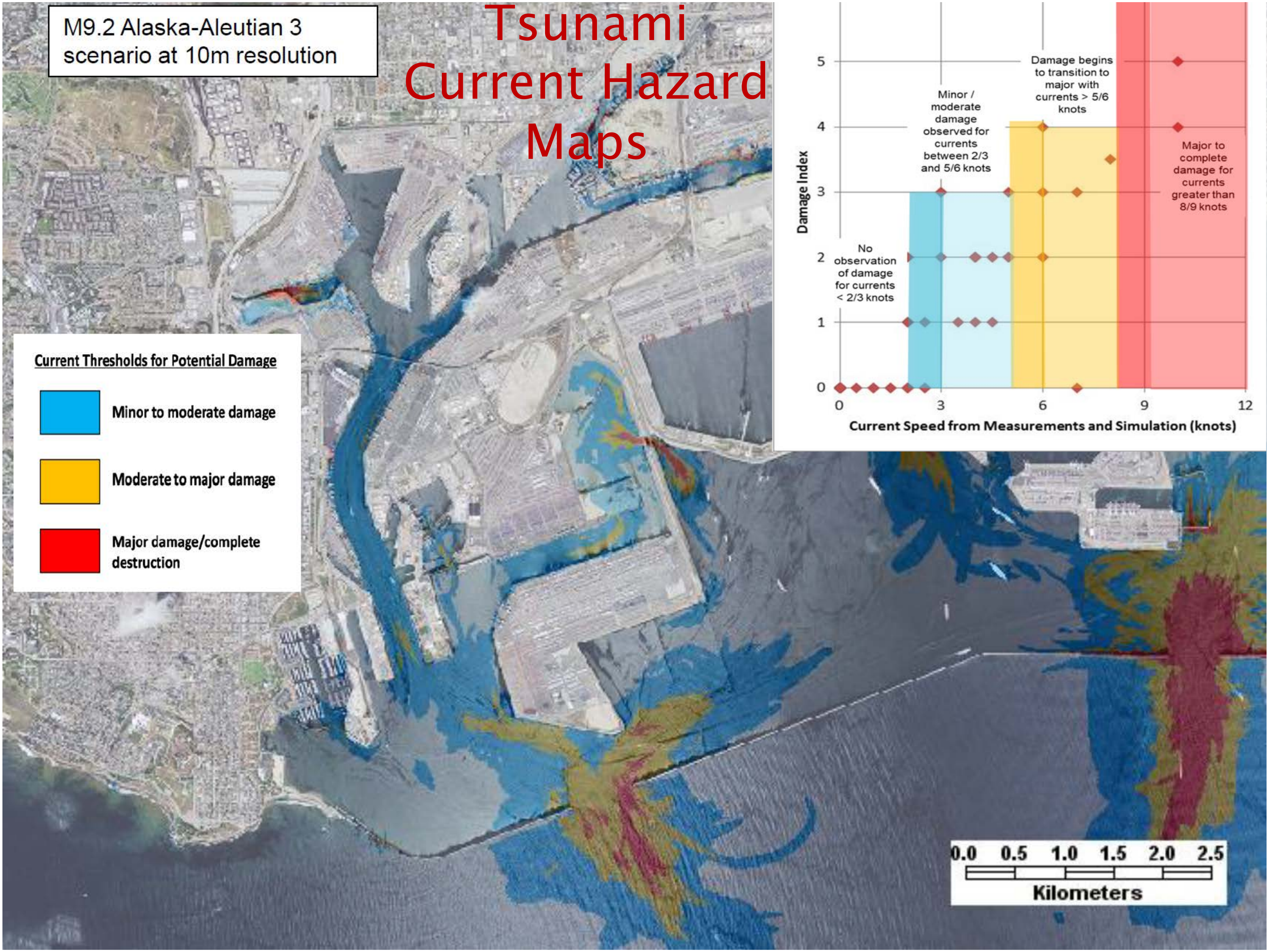
Field & Lab Motivated Modeling

Confidence in using models for engineering analyses in ports

Harbor Damage Assessments



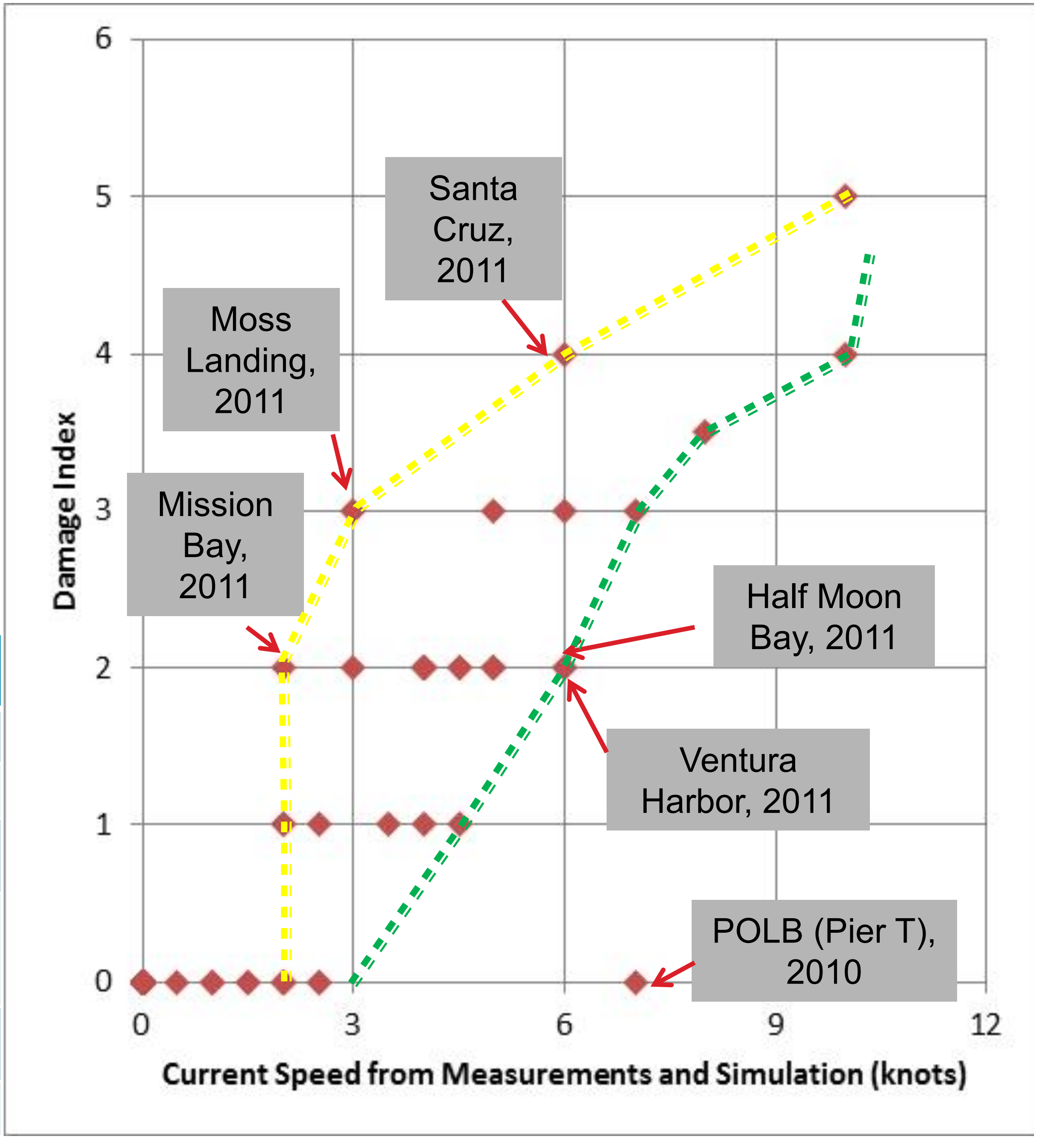
These modeling results describe the hazard level, but what about the *vulnerability*?


M9.2 Alaska-Aleutian 3 scenario at 10m resolution
Tsunami Current Hazard Maps
Current Thresholds for Potential Damage
Minor to moderate damage
Moderate to major damage
Major damage/complete destruction
Damage Index
Current Speed from Measurements and Simulation (knots)
No observation of damage for currents < 2/3 knots
Minor / moderate damage observed for currents between 2/3 and 5/6 knots
Damage begins to transition to major with currents > 5/6 knots
Major to complete damage for currents greater than 8/9 knots
0.0 0.5 1.0 1.5 2.0 2.5
Kilometers

Tsunami Current Hazard Maps
Map Generation

- **Can we filter this information, create areas where certain levels of damage might be expected?**
- **<u>Need to develop current–damage relationships</u>**
  - **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



Connecting Science with Engineering

(hazard) **(vulnerability)**

- Use a Demand – Capacity approach
- Demand is found through form and friction drag equations for vessels and floating docks. These equations are a function of
  - Fluid speed
  - Fluid direction
  - Fluid density
  - Geometry and properties of the floating object
- Capacity is determined by the properties of the structural components
  - Material
  - Connection
  - Age / deterioration
- Include uncertainties via Monte-Carlo simulation

$$F_{yc} = \frac{1}{2}\rho_w V_c^2 L_{wl} T C_{yc} \sin\theta$$

$$F_{xc} = F_{x\,FORM} + F_{x\,FRICTION}$$

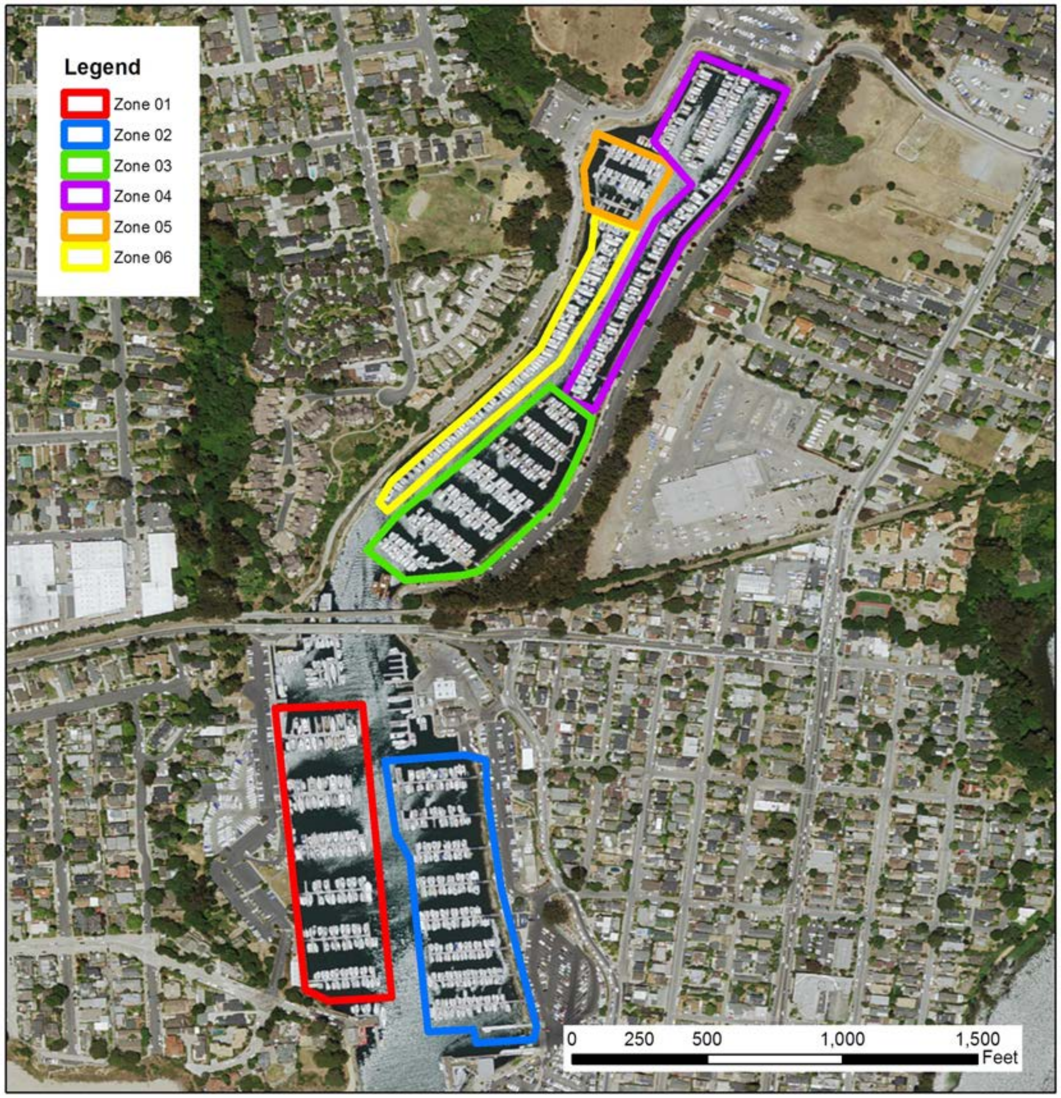
$$F_{x\,FORM} = \frac{1}{2}\rho_w V_c^2 B T C_{xcb} \cos\theta$$

$$F_{x\,FRICTION} = \frac{1}{2}\rho_w V_c^2 B S C_{xca} \cos\theta$$

USC University of Southern California

Keen, Adam S., et al. "Monte Carlo–Based Approach to Estimating Fragility Curves of Floating Docks for Small Craft Marinas." *Journal of Waterway, Port, Coastal, and Ocean Engineering* (2017): 04017004.

Harbor Tsunami Damage Assessments



Cleat Damage Estimate

Tsunami Event	Zone					
	1	2	3	4	5	6
2010 Magnitude 8.8 Chile Event (Historical)	Low	Low	Low	Low	Low	Moderate
Magnitude 9.0 Cascadia Scenario	Moderate	Moderate	Low	Moderate	Low	High
2011 Magnitude 9.0 Japan Event (Historical)	Low	Low	Moderate	Moderate	Low	Moderate
Magnitude 9.4 Chile North Scenario	Low	Moderate	Moderate	Moderate	Low	Moderate
Magnitude 9.2 Eastern Aleutian-Alaska Scenario	Moderate	Moderate	Moderate	Moderate	Moderate	High

Pile Guide Damage Estimate

Tsunami Event	Zone					
	1	2	3	4	5	6
2010 Magnitude 8.8 Chile Event (Historical)	Low	Low	Low	Low	Low	Moderate
Magnitude 9.0 Cascadia Scenario	Moderate	Moderate	Moderate	Moderate	Low	High
2011 Magnitude 9.0 Japan Event (Historical)	Moderate	Low	High	Moderate	Low	Moderate
Magnitude 9.4 Chile North Scenario	Moderate	Moderate	High	Moderate	Moderate	Moderate
Magnitude 9.2 Eastern Aleutian-Alaska Scenario	High	Moderate	Moderate	Moderate	Moderate	High

USC University of Southern California

Keen, Adam S., et al. "Monte Carlo–Based Approach to Estimating Fragility Curves of Floating Docks for Small Craft Marinas." *Journal of Waterway, Port, Coastal, and Ocean Engineering* (2017): 04017004.

The results of these field-lab-modeling efforts are applied to develop various response and mitigation recommendations for ports and harbors throughout the state

"Playbooks" for guidance on tsunami effects in harbors

California Maritime Tsunami Response Playbook And Mitigation Guidance

Port of Los Angeles – Los Angeles County

Maritime Tsunami Response Playbook (MTRP) No. 2014-LA-01

DURING AN EMERGENCY, USE THE "QUICK REFERENCE" SHEET ON THE BACK PAGE (PAGE 22).

(For the expanded Playbook format, use directions on page 7)

California Maritime Tsunami Response Playbook No. 2014-LA-01

California Geological Survey
California Governor's Office of Emergency Services
University of Southern California
Humboldt State University
National Oceanic and Atmospheric Administration

Funded by the Federal Emergency Management Agency and the National Tsunami Hazard Mitigation Program

Step 1: Obtain basic information about the earthquake and tsunami from National Tsunami Warning Center in Alaska, regional National Weather Service office, and/or county emergency manager. **NOTE: Tsunami Alert Level may change in first couple hours after the earthquake; WATCH may be upgraded to ADVISORY or WARNING.**

Earthquake location ______________________

Earthquake magnitude ______________________

Tsunami Alert level (circle one) WATCH ADVISORY WARNING

Closest forecasted tsunami amplitude/wave height ____________

Forecasted tsunami arrival time ______________________

Step 2: Tsunami evacuation and response will depend on the amount of time before the tsunami arrival. Four (4) hours is considered the threshold time needed for evacuation. As a quick reference, we offer the following guidance:

1) **If less than four hours before tsunami arrival, we recommend the following:**
   - ADVISORY – evacuate beaches, harbor docks, and piers
   - WARNING – evacuate entire maximum on-land evacuation zone, or follow guidance provided by local emergency manager

2) **If greater than four hours before tsunami arrival**, and your harbor has fully developed its tsunami response Playbook plans, the harbor can utilize the FORECAST AMPLITUDE from Step 1 on the table on the right to identify the appropriate response plan to use.

Reference Pages for Details in Maritime Playbook	Scenario Playbook Plan Letter	Peak Amplitude/ wave height (in meters)
	(No action)	0.2
Page 8-9	A	0.5
Page 10-11	B	0.6
Page 12-13	C	0.8
Page 14-15	D	1.0
Page 16-17	E	1.2

ACTIONABLE TSUNAMI ALERT LEVELS

Tsunami **Advisories** and **Warnings** are the two actionable Alert levels for maritime communities.

Actions taken will depend on the Alert level and the forecasted tsunami wave height or amplitude for a particular harbor. For both Advisory and Warning level events, it is important that clear and consistent directions are provided to the entire boating community and waterfront or pier businesses.

If there is not sufficient time to use the Playbooks, consider the following general actions for your maritime communities for either Advisory or Warning level events:

GENERAL "WARNING" LEVEL RECOMMENDATIONS

All activities below should be completed no later than 30 minutes before forecasted tsunami arrival.

- Advise facility maintenance to 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.
- Evacuate the public and harbor personnel from all structures and vessels in the water, as well as all land-ward areas identified in the mapped tsunami evacuation area (last page).
- Do not allow public to re-enter tsunami evacuation area until an official "all clear" message is provided by local emergency managers.
- Follow instructions for an Advisory if Warning is downgraded to Advisory level.

GENERAL "ADVISORY" LEVEL RECOMMENDATIONS

All activities below should be completed no later than 30 minutes before forecasted tsunami arrival.

- Advise facility maintenance to 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.
- Evacuate the public from all structures and vessels in the water.
- Coordinate with local law enforcement to limit access of public along waterfront areas.
- While the tsunami is active, all personnel working on or near the water should wear personal flotation devices.
- Do not allow public to re-enter structures and vessels in the water until and official "all clear" message is provided by local emergency managers.

The results of these field-lab-modeling efforts are applied to develop various response and mitigation recommendations for ports and harbors throughout the state

"Harbor Improvement Reports" for mitigation and planning recommendations

Harbor Improvement Report

Maritime Tsunami and Coastal Hazard Mitigation Guidance

For Harbor Engineers and Emergency Managers

Berkeley Marina – Alameda County

Harbor Improvement Report (HIR) No. 20XX-SD-01

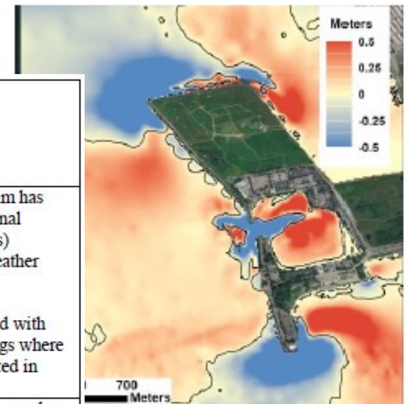
Completed February/20XX

By California Geological Survey
University of Southern California
California State Lands Commission
California Governor's Office of Emergency Services

Funded through a Cooperative Technical Partnership with the Federal Emergency Management Agency

Table 2 Cleat Damage Estimate (By Tsunami Event/Zone) for Berkeley Marina

Zone	Model Results				
	Alaska	Cascadia	Chile 2010	Chile North	Japan 2011
Zone 01	Moderate	Low	Low	Low	Low
Zone 02	Moderate	Low	Low	Moderate	Moderate
Zone 03	Moderate	Moderate	Moderate	Moderate	Moderate
Zone 04	Moderate	Low	Low	Low	Low
Zone 05	Moderate	Low	Low	Low	Low
Zone 06	Moderate	Low	Low	Low	Low
Zone 07	Low	Low	Low	Low	Low
Zone 08	Moderate	Low	Low	Low	Low



Description of Mitigation Activity	Prioritization (High, Medium, Low) and Timeframe	Hazards Addressed	Responsible Agency	(B/C) Benefits-Costs (TF) Technical Feasibility
Develop and share educational materials with boating community (recreational and commercial) that identify the hazards and provide sensible response actions for extreme events like tsunamis.	High Short term - Ongoing	All coastal hazards		B/C: Sustained mitigation outreach program has minimal cost, especially with the educational resources (brochures, guidance, Playbooks) provided by the State and the National Weather Service (NWS). TF: This low cost activity can be combined with recurring outreach opportunities at meetings where hazard specific information can be presented in small increments.
Develop a harbor response plan, using tsunami response Playbooks or other format, which outlines specific response activities for extreme events of different sizes like tsunamis. Close coordination with community emergency managers will be required.	High Short term	All coastal hazards		B/C: Developing or updating harbor response plans has a minimal cost, especially with the resources, like the Playbooks, provided by the State and the NWS. TF: This relatively low cost activity can be completed with the help of the local community emergency manager as well as the State and NWS.
Maintain and/or replace old cleats and mooring lines in Zones 1 and 5.	Medium Short term	Tsunamis		B/C: Cleat and mooring line failures are common during moderate to large tsunamis, but the cost of replacing these features is relatively minor. TF: Replacing cleats and mooring lines is a simple process.
Maintain and/or replace old dock pile guides in Zone 1.	Medium Short term	Tsunamis; Extreme tides		B/C: Dock pile guides are a common point of failure during tsunamis where strong surges and moderate water-level fluctuations occur. The cost of replacing pile guides is minor to moderate. TF: Replacing all or part of the pile guides is a simple process.