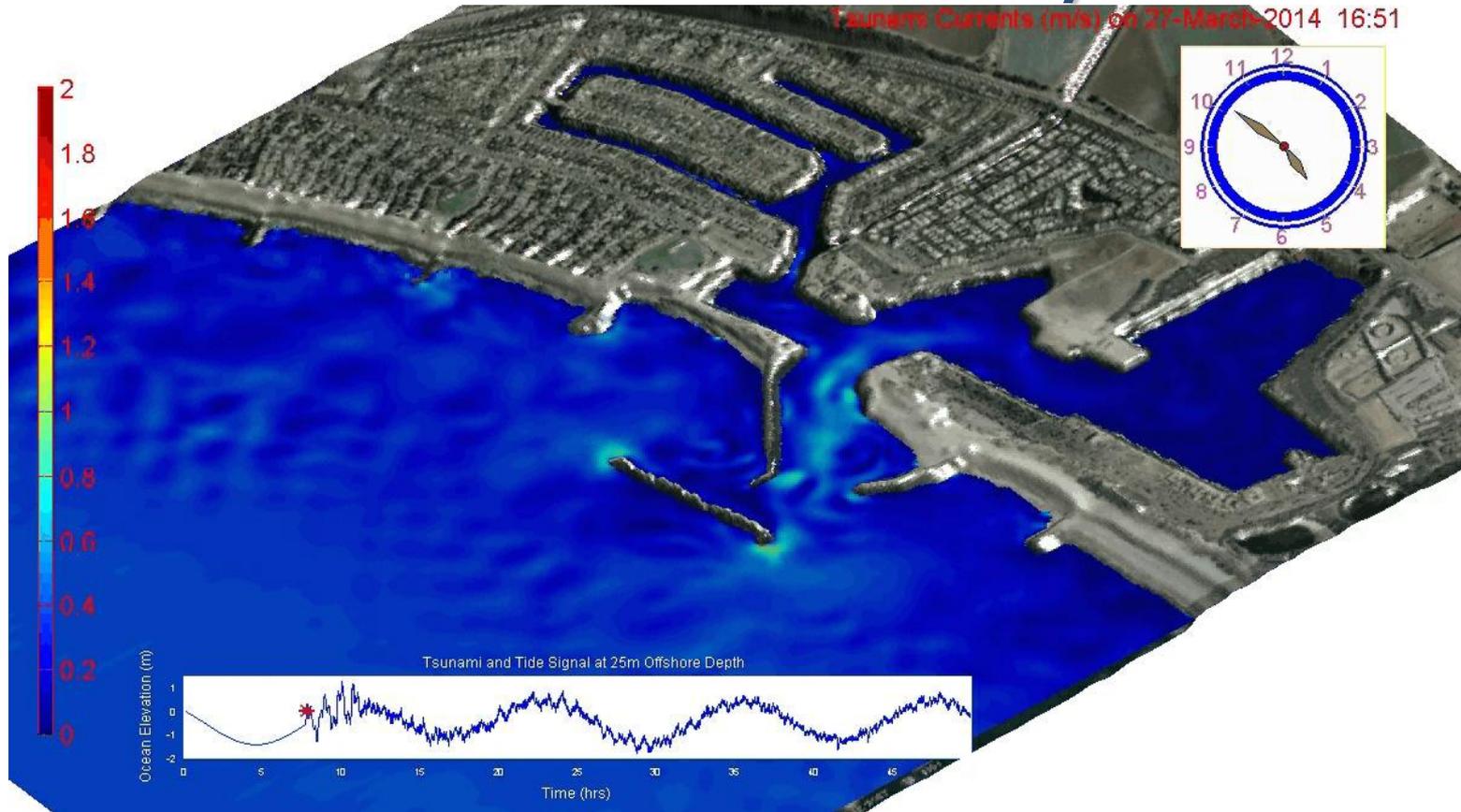


# Maritime Hazard Analysis



Patrick Lynett, University of Southern California

Rick Wilson, California Geological Survey

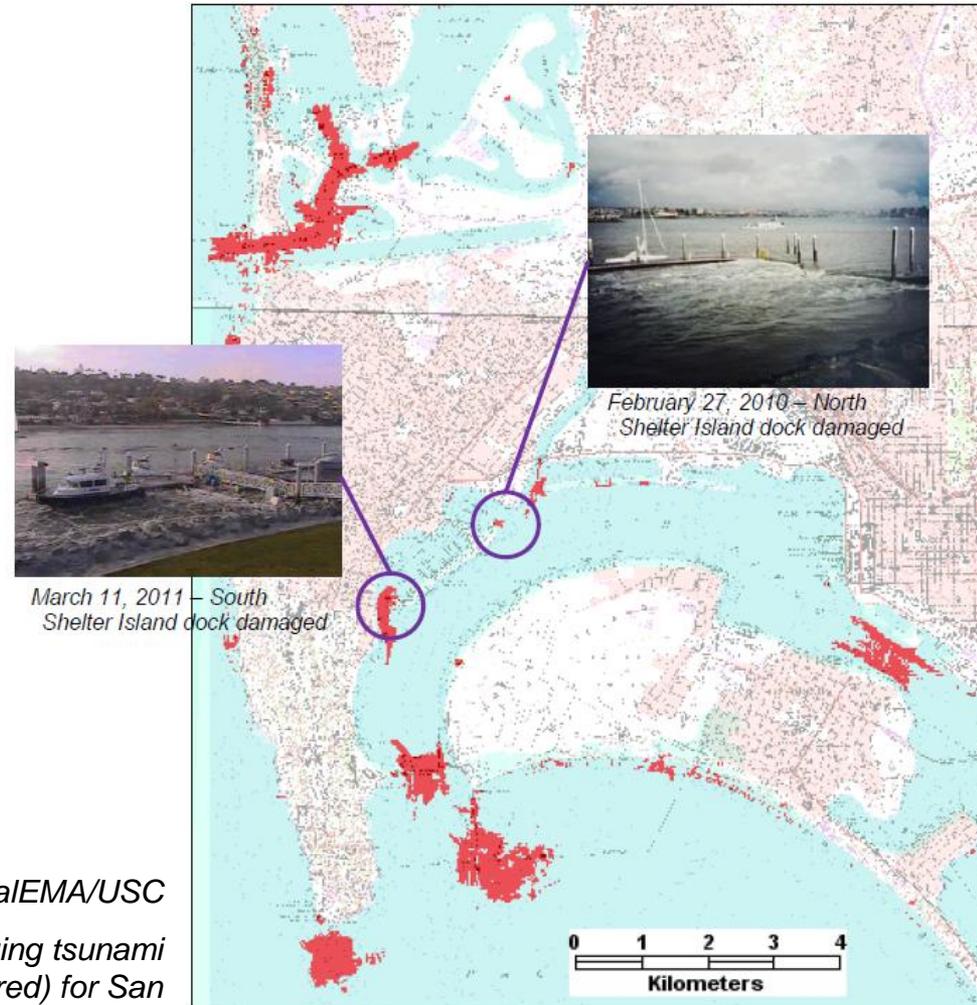
Kevin Miller, California Emergency Management Agency

Partners =



# Tsunami Current Hazard Maps

- Harbor/marina infrastructure and maritime evacuation planning
- Emergency response planning for harbor patrol
- Guidance for harbor masters
- Fall 2011 – first CA draft maps for San Diego Bay

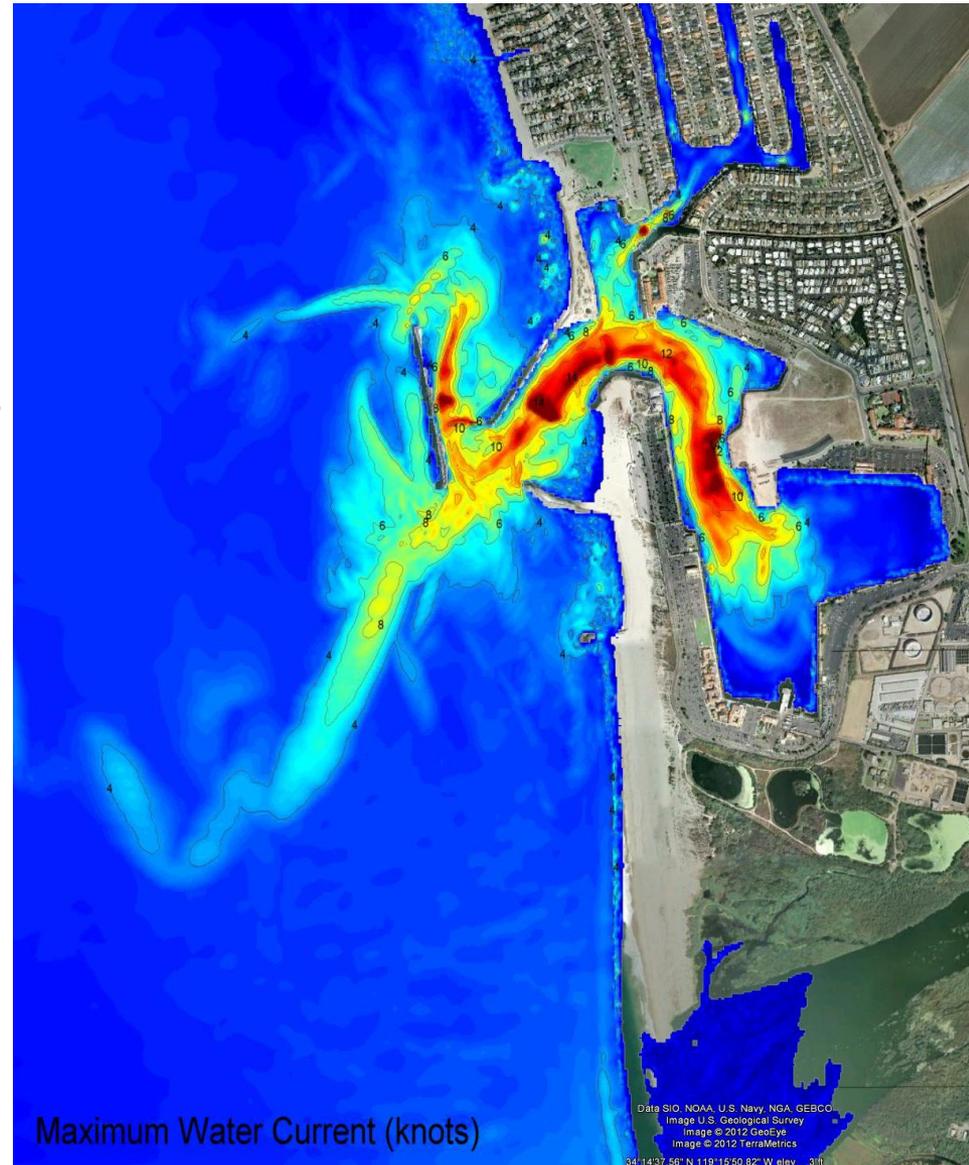


2011 – CGS/CalEMA/USC

Potentially damaging tsunami currents (+4 knots; in red) for San Diego area from M9.2 earthquake on eastern Aleutian Islands subduction zone

# Tsunami Current Hazard Maps Map Generation

- Example – examine Ventura Harbor, CA
- Create Maximum Current map comprehensive of all sources simulated
- Decide on bins of current-damage relationships
  - For example (not for real map use):
    - 12+ knots = widespread major damage to harbor structures, vessels of all sizes pulled from mooring lines
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  - Using currents only does not include effects of vertical water rise/fall
    - Combine in some way with inundation maps
  - Momentum flux not a good indicator of floating structure damage
- Visual identification of “zones”



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**Table 1: Recorded and observed measurements and damage estimates in California from the February 27, 2010 and March 11, 2011 tsunamis. Current speed estimates may be overvalued because of inexperience of observers. Blank cells indicate that data was not collected for those locations; they do not represent zero values. Red boxes associated with photos to the left.**

Harbors, Ports, Bays, and Docks Surveyed (from north to south)	Feb. 27, 2010 First Arrival Times		Maximum Tsunami Amplitudes				Estimated Maximum Current Speeds (knots)		Reported Damage or Other Effects from Tsunami (NDR = no damage reported)	
	Forecasted (PDT)	Observed Tide Gauges (PDT)	Feb. 27, 2010 Forecasted (meters)	Feb. 27, 2010 Observed Tide Gauges (meters)	Feb. 27, 2010 Estimated By Others (meters)	March 11, 2011 Observed or Estimated (meters)	Feb. 27, 2010	March 11, 2011	Feb. 27, 2010	March 11, 2011
Crescent City	1340	1346	0.61	0.64		2.47		20-25	NDR	Near complete destruction of small boat harbor (\$20M)
Eureka	1336	1333	0.2	0.23		0.97			NDR	NDR
Noyo River						0.8-1.0		15-20	NDR	Major damage to docks/boats (\$4M)
Arena Cove	1248	1304	0.49	0.39		1.74			NDR	NDR
Point Reyes	1259	1259	0.46			1.35			NDR	NDR
Martinez						0.06			NDR	NDR
Oakland						0.51		4-6	NDR	Minor damage at nearby Berkeley Marina
Alameda	1344	1345	0.18	0.12		0.51		4-6	NDR	NDR
San Francisco	1320	1326	0.22	0.32		0.62		7	NDR	NDR
Half Moon Bay			0.96		0.6	0.7	7-10	7-15	NDR	NDR
Santa Cruz			0.51		0.9	1.6-1.9	8-10	20-25	Minor damage to boats and harbor infrastructure	Multiple docks destroyed, 20 boats sunk (\$28M)
Moss Landing					0.3	2		15-25	NDR	200 piles damaged (\$1.8M)
Monterey	1231	1243	0.45	0.36	0.3	0.7	2	6-7	NDR	NDR
Morro Bay			0.82		0.5	1.6	4-6	15-20	NDR	Damage to several docks and boats (\$500k)
Port San Luis			0.84		0.8	2.02		5	NDR	NDR
Pismo Beach			1.43		0.9-1.2	0.7-1.0			NDR	NDR
Santa Barbara	1230	1231	0.75	0.91		1.02	8-10	10-20	Minor damage to dredging equipment	Damage to barges and boats (\$70k)
Ventura					0.6-0.9	1.3	12-15	10-15	Over 20 docks damaged, buoys moved	Damage to dock and number of boats (\$150k)
Oxnard					1.0	0.9-1.2	2-3	8-10	Dock damage from large boat wake	Minor damage to docks
Port Hueneume					0.5-0.7	1.2-1.4			NDR	NDR
Santa Monica	1225	1225	1.18	0.64		0.85			NDR	NDR
Marina Del Rey					0.1	0.9-1.0		6-8	Minor damage to dock	Minor damage to docks; dingies sunk
Two Harbors/Catalina					0.6-0.9			12-15	Minor damage to several docks	Damage to several docks and 10 boats
Los Angeles	1215	1215	0.77	0.42		0.49	4-6		Minor damage to docks and marine infrastructure	Minor damage to docks and boats
Long Beach							10-12		NDR	Minor damage to docks and boats
Sunset					0.3-0.6				NDR	NDR
Huntington						0.72	5-8	8-10	NDR	Boat pulled off mooring
Newport					0.5	0.3	8-10	5	NDR	NDR
Dana Point					0.5-0.7	0.6	10-12	10-15	Bait barge severed	Pylon damaged when hit by boat
Oceanside					0.6	0.5	5-10	4-6	Minor dock damage; several buoys carried to sea; boat trailer swamped	NDR
La Jolla	1202	1202	0.84	0.60		0.39			NDR	NDR
Mission Bay							8-10	6-8	Small sailboat swamped trying to leave harbor; buoys moved	Dock destroyed, 13 boats damaged (\$136k)
North Shelter Island, San Diego Bay					0.9-1.2	0.3	12-15	7-8	Moderate damage to docks, concrete piers, and boats	NDR to north Shelter Island; however, a boat sunk and there was damage to dock in south Shelter Island
Cabrillo Island, San Diego Bay					0.3-0.5				NDR	NDR
Marine Corps RD, San Diego Bay					0.6				NDR	NDR
Navy Pier, San Diego Bay	1204	1208	0.27	0.40	0.6	0.63			NDR	NDR
Marriot Marina, San Diego Bay					0.3-0.6	0.6			Wake buoy moved	NDR
National City, San Diego Bay									NDR	NDR

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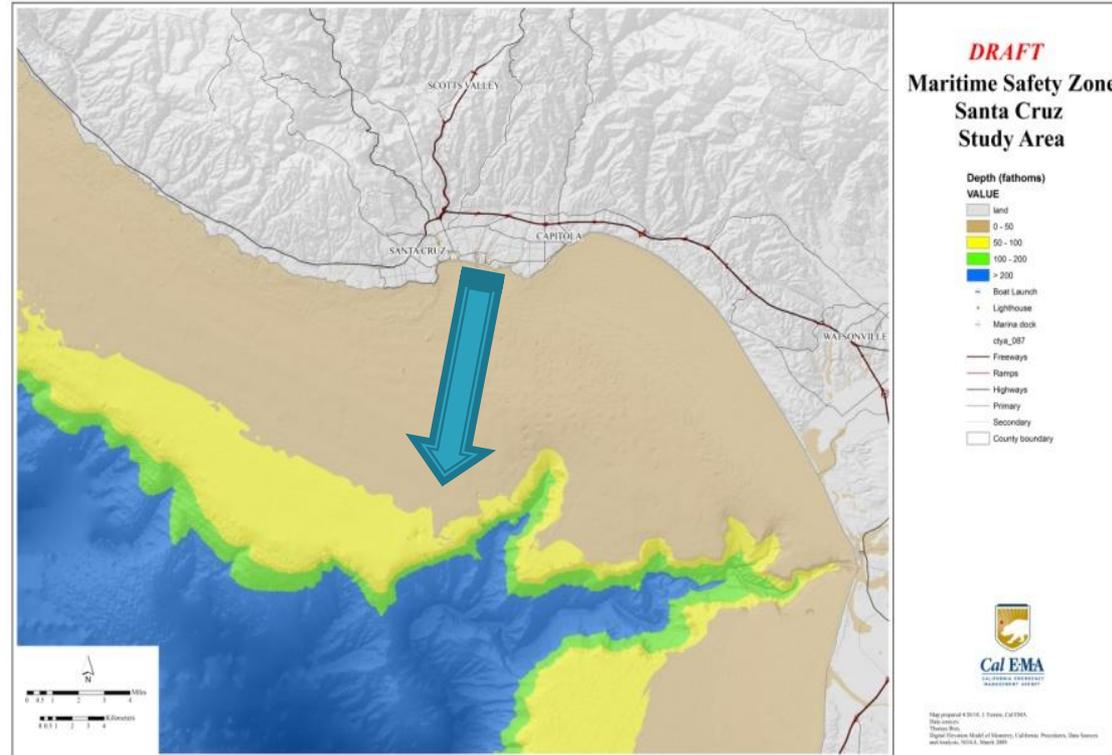
# Tsunami Current Hazard Maps Map Generation

- Example – examine Ventura Harbor, CA
- Create Time-Threshold Map
  - Time-threshold = time interval between arrival of initial wave to a later time after which current does not exceed a given value (threshold)
- For example:
  - 8 knot threshold map
- Allow for an estimation of how long until location is “safe”
- Useful for showing maximum possible duration of damaging tsunami effects
- A more difficult piece of information to convey



# Offshore Safety Zones

- “Rule of thumb” for safety is 100 fathoms
- This is likely to be highly conservative in general
- Offshore safe zone should be controlled by expected offshore currents
  - What is a “safe” offshore tsunami current?
- Zones will be harbor/boat specific and included in navigational charts
- Statewide Guidance for Advisory and Warning events



# Crescent City Pilot Area

## ▪ March 11, 2011:

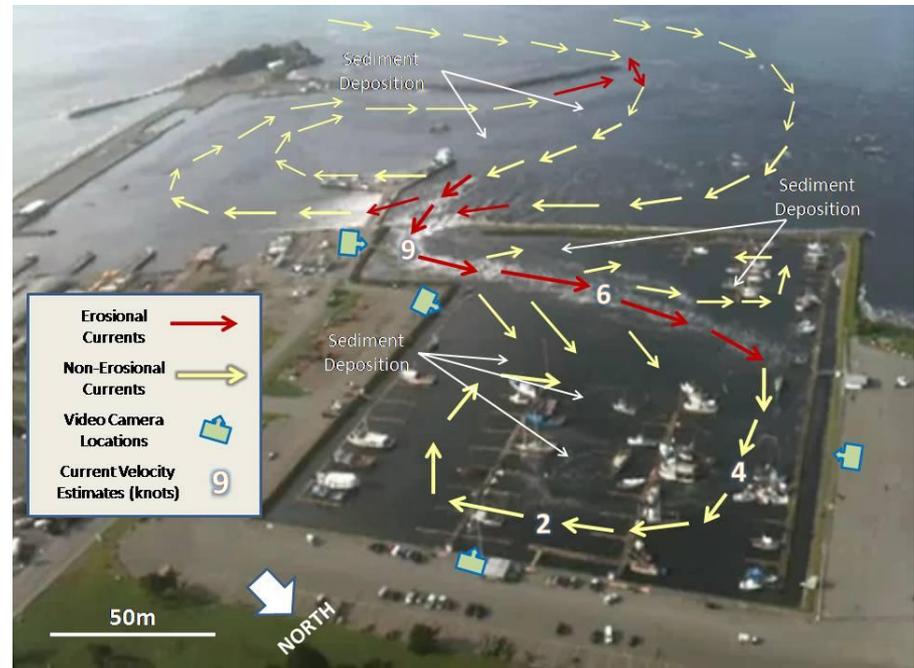
- Warning, then Advisory
- Largest tidal fluctuations
- \$20M in damages
- 9 month delays in recovery



*March 11, 2011  
Crescent City  
from Coast  
Guard  
helicopter*

## ▪ Work update

- Collected and reviewing 30+ videos from 2010 and 2011 events
- Evaluation of currents from videos complete
- Analysis of sediment scour/deposition complete
- Interviews with harbor master
- Preliminary modeling complete



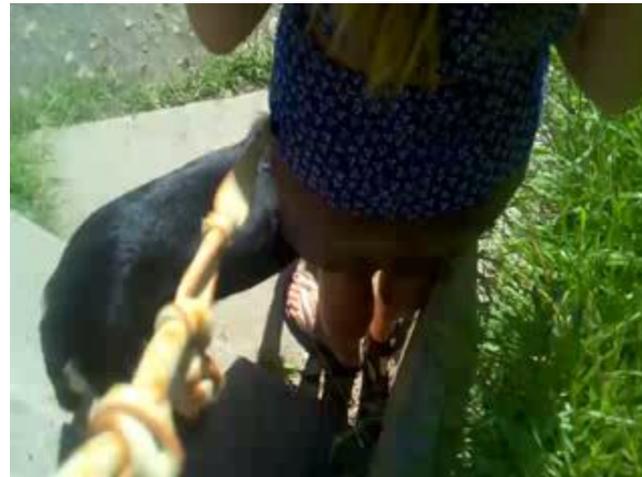
# Santa Cruz Pilot Area

## March 11, 2011:

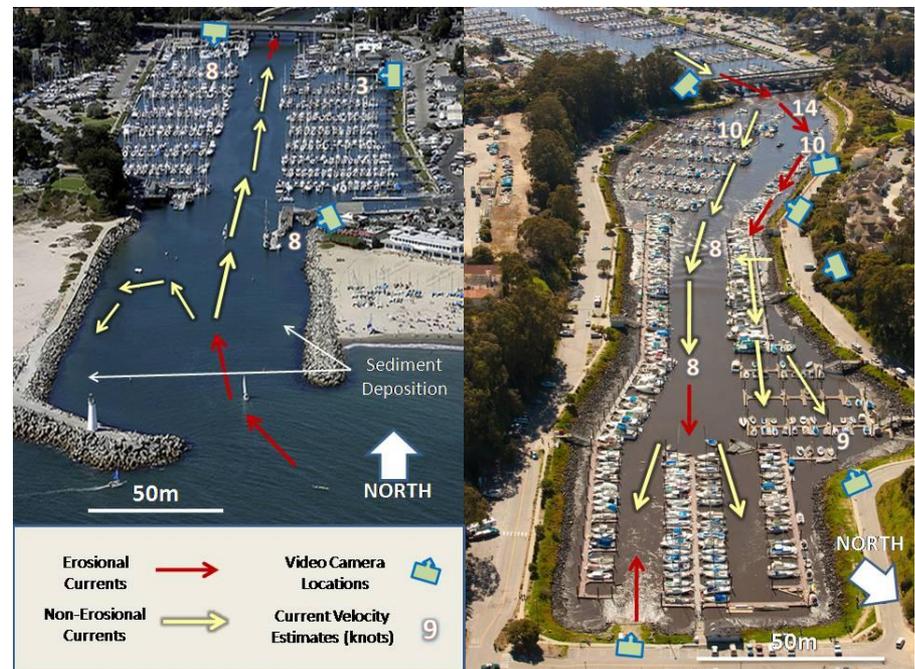
- Warning, then Advisory
- Strong surges and large bores
- \$28M in damages
- 9 month delays in dredging

## Work update

- Collected and reviewing 90+ videos from 2010 and 2011 events
- Evaluation of sediment scour/deposition complete
- Preliminary review of currents from 2010 and 2011 events complete
- Interview with harbor master
- Contracts on modeling moving forward



**March 11, 2011  
severe bores  
causing  
damage to  
docks and  
boats in upper  
Santa Cruz  
Harbor**



# Ventura Pilot Area

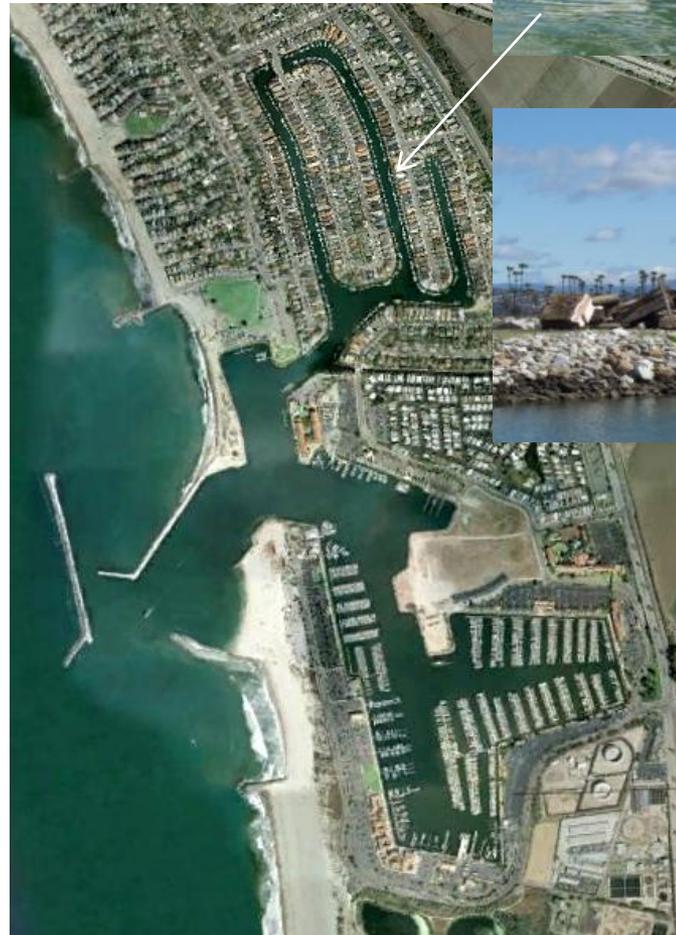
## Recent tsunamis:

- Advisory during 2010 and 2011
- Strong surges but in different areas in 2010 and 2011
- \$500k in 2010 damages
- Multiple issues with recreational boaters

## Work update

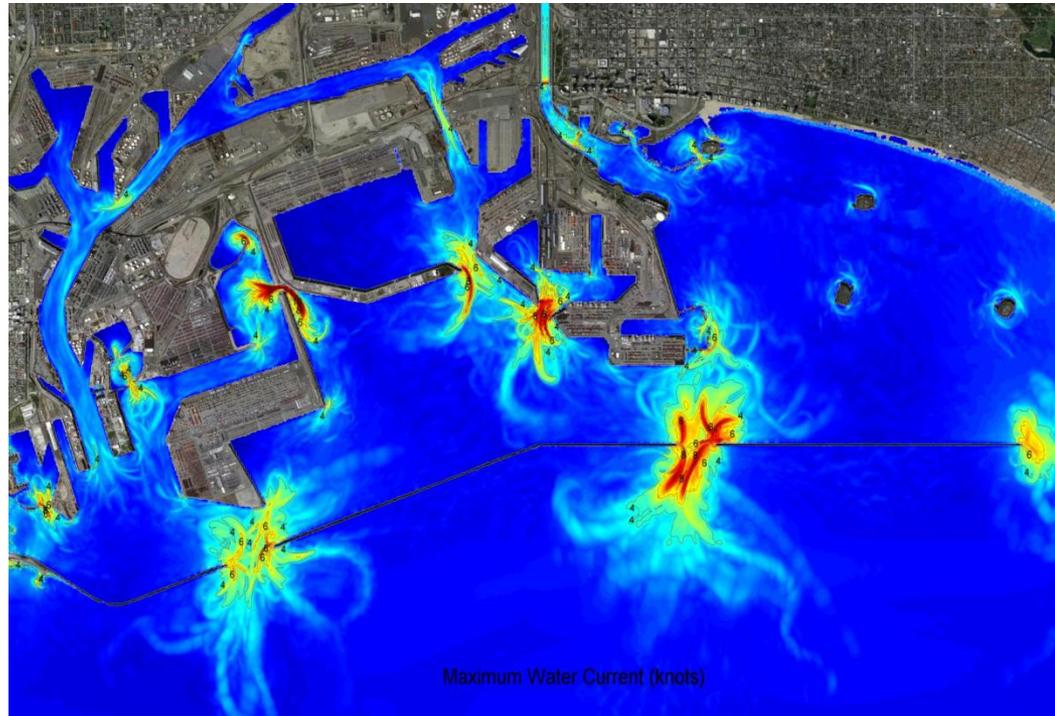
- CGS at harbor during 2011 event
- Collected and reviewing 20+ videos from 2010 and 2011 events
- Evaluation of currents has begun
- Contracts on modeling moving forward

*Ventura Harbor  
damage to the docks  
in The Keys during  
Feb. 27, 2010 event*



# Port of LA/LB Pilot Area

- **Recent tsunamis:**
  - Advisory during 2010 and 2011
  - Moderate surges in 2010 and 2011
  - Minimal damage
  - Multiple issues with large vessel traffic in both Ports
- **Work update**
  - Collected and reviewing 30+ videos from 2010 and 2011 events
  - Evaluation of currents has begun
  - Preliminary modeling underway
  - Collaborating and leveraging work with USGS SAFRR Project
  - Formal briefing with Ports complete



2012– USGS/CGS/CalEMA/USC

# Shelter Island (SD Bay) Pilot Area

## ▪ Recent tsunamis:

- Advisory during 2010 and 2011
- Strong surges in 2010 and 2011
- Damage to docks and boats in different areas of Island

## ▪ Work update

- Collected and reviewing 30+ videos from 2010 and 2011 events
- Evaluation of currents has begun
- Preliminary modeling finished (earlier map)
- Working with Seismic Safety Commission, Navy, and Port
- Formal briefing with Navy/Ports complete



*February 27, 2010 – North Shelter Island dock damaged*



*March 11, 2011 – South Shelter Island boat sunk*

# Policy/Guidance/Outreach

- Several types of boating communities (different size ships and levels of experience):
  - Recreational
  - Commercial/Fishing
  - Large transport/cruise ships/military
- Policy group forming
  - Planning issues
  - Recovery issues
- Guidance for harbor masters and boaters needed
  - Advisory and Warning events
- Brochures for boaters (right)

**TSUNAMIS!**  
What  
**BOATERS**  
should know



The March 11, 2011 tsunami in Santa Cruz Harbor



Crescent City Harbor after the March 11, 2011 tsunami

Prepared by:   

Funded by:   

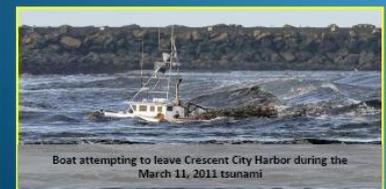
## How should boat owners **PREPARE** for tsunamis?

*Prior to arrival of the March 11, 2011 tsunami along the California coast, many boat owners took their boats offshore without adequate supplies or knowledge of how long they would need to stay offshore. As a result, boaters tried to re-enter harbors too early, while dangerous tsunami conditions still existed. They put themselves and harbor personnel at risk of injury and death.*

Before you plan to leave safe harbor, consider the following:

- Talk to the harbor master or related officials to learn about your harbor's tsunami safety protocols.
- Sign up to receive tsunami alerts from NOAA and emergency calls from your harbor master or community emergency services office.
- Know weather conditions out on the ocean.
- Know how long it takes your boat to get to deep water. The 100-fathom line is the NOAA recommendation.
- Have adequate supplies (water, shelter, food) and fuel to remain at sea for 24 hrs or more.
- Have a family plan for tsunamis in place so you know your family will be safe.

If you do not have these essential preparedness items covered, **DO NOT** attempt to take your boat offshore. Secure your boat to the dock and leave the dock area before the tsunami arrives.

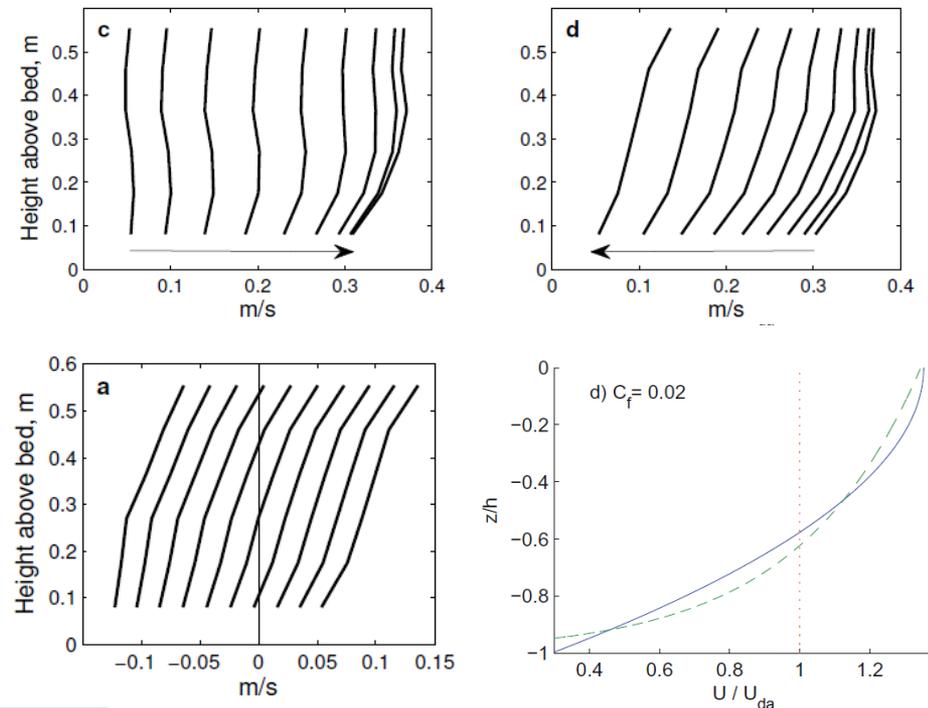
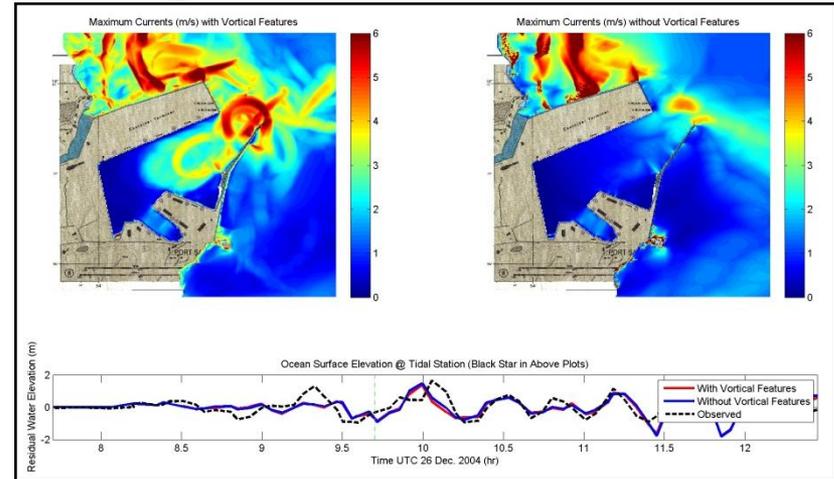


# Tsunami Current Hazard Maps

## Difficulties in Modeling Currents

From Lynett et al. "Observations and Modeling of Tsunami-Induced Currents in Ports and Harbors," *Earth and Planetary Science Letters*, 2012.

- **Strongest currents can be due to confined jets and large eddies**
  - Models need to be able to capture these features
  - Current-based benchmarking?
- **Should NOT expect currents under a tsunami to have a uniform vertical profile**
  - Bottom shear (friction) will lead to a sheared (log-law) profile, with shear rate related to bottom stress (roughness)
  - Surface currents can be much larger (50+%) than depth-averaged currents. Effect is greatest at time of max currents
  - Model predictions should include this correction in some way
- **Tides?**
- **Long duration simulations?**



Images from J.R. Lacy, D.M.. Rubin and D. Buscombe. Currents, drag, and sediment transport induced by a tsunami. In review, *Journal of Geophysical Research-Oceans*.