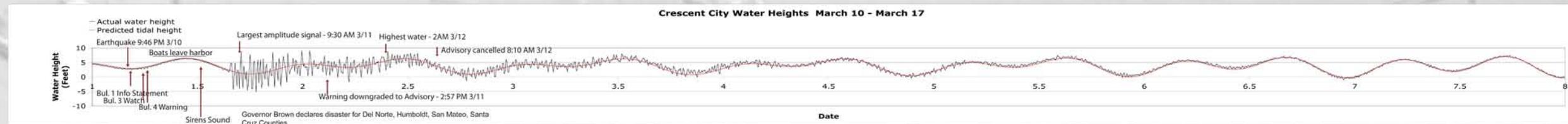


# The Effect of the 2011 Tohoku Tsunami on the California Coastline

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## ABSTRACT

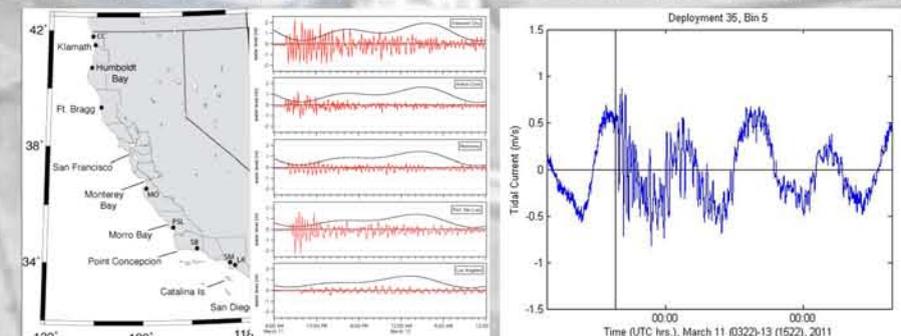
At 12:51 AM PDT, a little over three hours after the Tohoku earthquake origin time, the West Coast Alaska Tsunami Warning Center placed the California coast north of Point Conception in a Tsunami Warning, and the coast south of the Point in a Tsunami Advisory. The Warning/Advisory forecast tsunami amplitudes 0.3 to 2.5 meters, with the highest surge forecasted for Crescent City. Hourly conference calls were held with the county operational areas and counties within the Warning-level area began evacuation procedures. The tsunami arrived at Arena Cove in northern California at 7:29 AM PDT on March 11, and moved southward along the coast over the next hour and a half. Peak amplitudes at tide gauge locations in the state ranged from 0.15 meters to a high of 2.36 meters at Crescent City. At most locations, the strongest surges were recorded within the first five hours. Because the largest surges arrived at low-tide, only minor inundation outside of harbor and river environments occurred. Several tide gauge instruments, like those at Crescent City and Santa Barbara, recorded large surges nearly 15 hours after the initial onset when the tide was high. These late surges created hazardous conditions and resulted in additional localized damage. Very strong currents (up to 25 knots) and large tidal fluctuations (over 4.5 meters peak-to-trough in Crescent City) caused significant damage to harbors throughout the State but primarily in northern and central California. Damage estimates are over fifty million dollars, the largest since 1964, with the greatest damage occurring in Crescent City and Santa Cruz harbors. The State deployed a pre-tsunami field team and collected data during and after the event through an information clearinghouse. Detailed evaluation of the maritime response activities, harbor damage, and measured/observed tsunami current velocity data will help the California tsunami program develop improved tsunami hazard maps and guidance for maritime communities.



Selected frames from the Crescent City Harbor Security camera. The view is to the north across their entrance to the small boat basin where all of the damage occurred. The height of the exposed breakwater in the first frame is three meters (red bar). In these frames, the highest water is shown in the 9:35 AM photo, when the actual water height was 8.5 feet above MLLW. Note the displaced dock in the last frame. The maximum current velocity at this location was 8.2 knots.

Location	Maximum Forecast Amplitude (m)	Maximum Measured Amplitude (m)	Maximum Observed Amplitude (m)	Forecast First Arrival Times PST	Observed First Arrival Times PST	Approx. Time of Maximum Amplitude PST	Current (knots)*	Damage	Unofficial damage estimate (UNK=unknown)	Description	
Smith River	1.5-2.0						15-20	N		Strong surges and boats flowing up river	
Crescent City Harbor	2.5	2.47	2.73-0.0	723	730	750	8.2	Y	\$36,000,000	Destruction of harbor; 16 boats sunk	
Klamath River mouth	2.36		2.0-2.3					N		One fatality, body found April 2 near Astoria, OR	
North Spit/Port of Humboldt Bay	1.33	0.97		722	734	900	1.5	N		One boat knocked from moorings	
Novo River Harbor			0.8-1.0				15-25	Y	\$4,000,000	50 small docks damaged and sunk; boats damaged	
Dolphin Isle Marina, Noyo River			0.8-0.8				15-20	Y	UNK	Numerous docks and boats damaged/sunk	
Albion			0.6-0.6				5-10	N		Boats traveled up river	
Waldo Point Marina (Seasaltto)	0.37		1.2-1.5				15-18	Y	UNK	Broken PVC sewer line	
Berkeley Marina			0.6				8-9	Y	\$125,000	Damage to docks; no boat damage	
Marina Bay Yacht Harbor (Richmond)	0.35			845	1015	1100	3-6	Y		Four buoys displaced	
Emery Cove Yacht Harbor (Emeryville)			0.4-0.6				4-6	N		Boat observed entering bay near Emeryville	
San Francisco Marina	0.73	0.62		808	832	1006	7	Y		Two piles broken; boats heeled over	
Pillar Point Harbor	0.92		0.7				7-15	Y	UNK	Minor damage; abalone raft broke lose; floats moved from docks	
Santa Cruz Harbor	1.01		1.6-1.9				20-25	Y	\$23,000,000	Multiple docks destroyed; 20 ships sunk, 100 damaged	
Rio Del Mar/Aptos (Santa Cruz Co.)	1.62			744	840	1100	15-25	Y	\$1,020,000	Boats traveled up Aptos Creek in video; 209 timber piles damaged; 65 characterized as severe. Three piles and three finger docks broken; damage to ships	
Moss Landing Harbor											
Morro Bay Harbor	1.18	1.6		800	830	1130	15-20	Y	\$500,000	NOTE: no damage but evacuated over 100 recreational vehicles	
Oceans Dunes SRA	0.73		0.7-1.0				830	1430	N	Damage to crane and bait barges; damage to several boats	
Santa Barbara Harbor	0.48	1.02		829	1000/2400	10-20	Y	\$70,000		Damage to dock and a number of boats; injury during boat docking	
Ventura Harbor	0.88		1.3				900	1153/1121	Y	\$150,000	UNK
Channel Islands Harbor	0.9-1.2			830	1000		8-10	Y		Damage to docks by boats	
Marina Del Rey	0.9-1.0			830	1000		6-8	Y	UNK	Three small dingies sunk; minor dock damage	
Balboa Creek	0.4-0.6						8-10	N		Video of one boat traveled at least 1.7 mi upstream	
King Harbor (Redondo Beach)	0.65		0.6-0.7				10-15	Y	\$15,000	One dock destroyed and five boats damaged	
Port of Los Angeles	0.39	0.49		832	840			Y	UNK	Minor damage to docks/boats	
Port of Long Beach								Y	UNK	Minor damage to docks/boats	
Long Beach Marina-Shoreline			0.6-0.7				1000	8-10	Y	UNK	Minor damage to docks/boats
Two Harbors (Catalina)							1330	12-15	Y	UNK	Several docks and 10 boats damaged
Huntington Harbor	0.73						900	8-10	Y	UNK	Boat pulled off mooring. Possible scour to Hwy 1
Dana Point Harbor			0.6				830	10-15	Y	UNK	Pylon damaged when boat hit
Mission Bay - Quivira Basin/Lifeguard HQ							900	1430	Y	\$800	Lifeguard dock damaged
Mission Bay - Quivira Basin/Seafarth Marina							1530	6-8	Y	\$136,000	Bait dock destroyed; 13 boats damaged; 26 piles damaged
Ocean Beach			1						N		Family knocked into water during Advisory, were rescued
Shelter Island-South Harbor Police Dock			0.8				1615	12-25	Y	\$110,000	Pontoon patrol boat sunk; damage to docks and other boats
Harbor Island West Marina			0.3				1640	10-15	Y	UNK	Damage to docks

Observed tsunami effects in California: Research teams visited 180 locations, including all ports and harbors, along the California coast between March 12 and March 19. Sites where damage or specific impacts were observed are summarized in this table. The damage estimates are preliminary. Note: the majority of the current velocity estimates are based on eyewitness observations and are subject to error. At two sites, the velocities are measured. In Humboldt Bay, an acoustic doppler current profiler has been installed specifically to measure tsunami currents. The current estimates at Crescent City are based on an analysis of the time-stamped video camera at the mouth of the small boat basin.



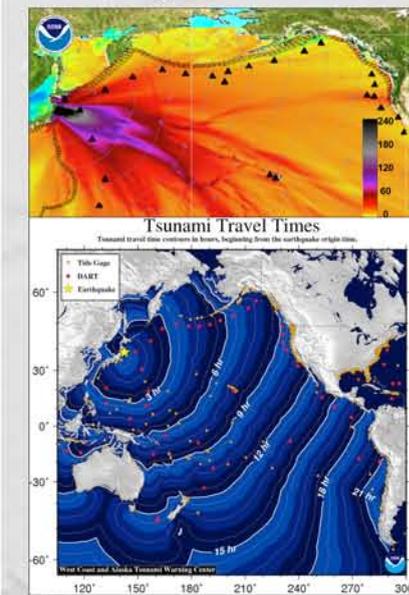
Left: Water level recordings along the California coast. Red signals are the detided tsunami for the first day of the event. Black shows the predicted tide. Damage was minimized in California because the largest amplitude surges coincided with low tide. Right: Current velocities recorded inside Humboldt Bay on a Nortek Aquadopp Acoustic Doppler 2D current profiler. Vertical line is the onset of the tsunami. All of the damage on the California coast was caused by strong currents. Harbors with a small or elongate narrow opening, or within river valleys were particularly vulnerable. Damage was concentrated near the entrance or where there are restrictions inside, or within the entrance along the direction of flow. The most vulnerable docks were those with a large number of boats tied to them, or with boats with large keels, perpendicular to the normal flow direction.



Santa Cruz Harbor. All of the damage was caused by a series of surges in the channel. An estimated \$26.4 million in damages were reported in Santa Cruz, the largest losses in the state. Since the tsunami, businesses estimate continuing losses in revenue of \$59,000 at day. Linda Azevedo photographs.

## LESSONS LEARNED

1. All harbors need a tsunami maritime plan for different scenarios
2. Improved communication between counties and maritime communities and between emergency officials and clients of ports and harbors.
3. Need to develop educational materials for maritime communities.
4. Improve methods of keeping bystanders near waterfront from danger.
5. Need to address communication issues with Warning Centers - Media found out before authorities.
6. Long duration of the event - Reduce fatigue in emergency managers so they can still be function during full events.
7. Consider tidal conditions (low vs. high tide) in evacuation.
8. Provide temporary signage for coastal access points.
9. Language barriers - need to reach non-English speaking populations.
10. Plan for long term evacuation at sea for maritime community
11. Do not return to harbor during tsunami activity.
12. Improve communication with media before and during event.
13. Reduce information overload on county emergency managers.



NOAA modeling of the March 11 tsunami. Modeled maximum water heights. Scale on lower right is in centimeters. Note the zone of amplification on the Northern California and Southern Oregon coast.

Modeled arrival time of the first tsunami surges from the Tohoku tsunami. Times ranged from about 9.5 hours at the north end of the state to 11.3 hours at San Diego.