U21E-2184

Role of State Tsunami Geoscientists during Emergency Response Activities: Example from the State of California (USA) during the September 29, 2009, Samoa Tsunami Event

by *Rick I. Wilson[1], Lori A. Dengler[2], James D. Goltz[3], Mark R. Legg[4], Kevin M. Miller[3], John G. Parrish[1], and Paul M. Whitmore[5]

1 California Geological Survey (*correspondence: rick.wilson@conservation.ca.gov)
2 Humboldt State University
3 California Emergency Management Agency
4 Legg Geophysical
5 West Coast/Alaska Tsunami Warning Center, NOAA-NWS

ABSTRACT: California tsunami geoscientists work closely with federal, state and local government emergency managers to help prepare coastal communities for potential impacts from a tsunami before, during, and after an event. For teletsunamis, as scientific information (forecast model wave heights, first-wave arrival times, etc.) from NOAA's West Coast and Alaska's Tsunami Warning Center is made available, state-level emergency managers must help convey this information in a concise and comprehendible manner to local officials who ultimately determine the appropriate response activities for their jurisdictions. During the Samoa Tsunami Advisory for California on September 29, 2009, geoscientists from the California Geological Survey and Humboldt State University assisted the California Emergency Management Agency in this information transfer by providing technical assistance during teleconference meetings with NOAA and other state and local emergency managers prior to the arrival of the tsunami. State geoscientists gathered additional background information on anticipated tidal conditions and wave heights for areas not covered by NOAA's forecast models. The participation of the state geoscientists in the emergency response process resulted in clarifying which regions were potentially at-risk, as well as those having a low risk from the tsunami. Future tsunami response activities for state geoscientists include: 1) working closely with NOAA to simplify their tsunami alert messaging and expand their forecast modeling coverage, 2) creation of "playbooks" containing information from existing tsunami scenarios for local emergency managers to reference during an event, and 3) development of a state-level information "clearinghouse" and pre-tsunami field response team to assist local officials as well as observe and report tsunami effects.

Background: For more than a decade, both governmental and private geoscientists have worked closely with federal, state and local emergency managers to help identify and mitigate tsunami hazards within California. As one of the original states participating in the National Tsunami Hazard Mitigation Program (NTHMP), both a state emergency manager and a state geoscientist share the responsibility for California on the program's Coordinating Committee. Today, the California Emergency Management Agency (CalEMA) and the California Geological Survey (CGS) fill these roles, working together to implement the state tsunami hazard mitigation and preparedness plan. Part of this plan is for CGS to continue to provide scientific expertise before, during, and after a tsunami.

The National Oceanic and Atmospheric Administration (NOAA) works closely with CalEMA and regional emergency managers during a Tsunami Alert, providing forecast information for five locations in the state. However, California's 840-mile coastline has 20 counties and over 80 cities that are vulnerable to tsunamis and may ask for additional technical assistance from the state. CalEMA consults with a number of state geoscience experts, including: the State Geologist and members of the Tsunami Hazard Program at CGS, Dr. Lori Dengler from Humboldt State University, and other tsunami experts from the Tsunami Research Center at the University of Southern California and private industry. During the September 29, 2009 Tsunami Alert response, state geoscientists were utilized to provide information and support to decision makers at the federal, state, and local agency levels. This presentation summarizes the actions taken by geoscientists during this event, and evaluates the needs and discusses the plans of the state geoscientists during future NOAA Tsunami Alerts.

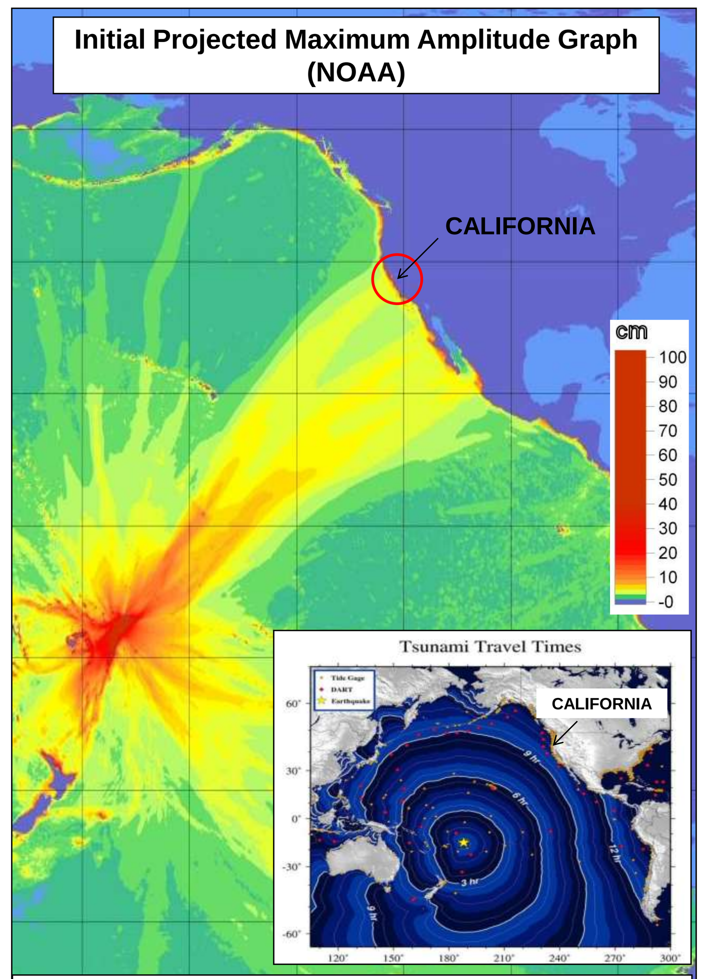


Figure 1
(from http://wcatwc.arh.noaa.gov/previous.events/09-29-09-Samoa/09-29-09.htm)

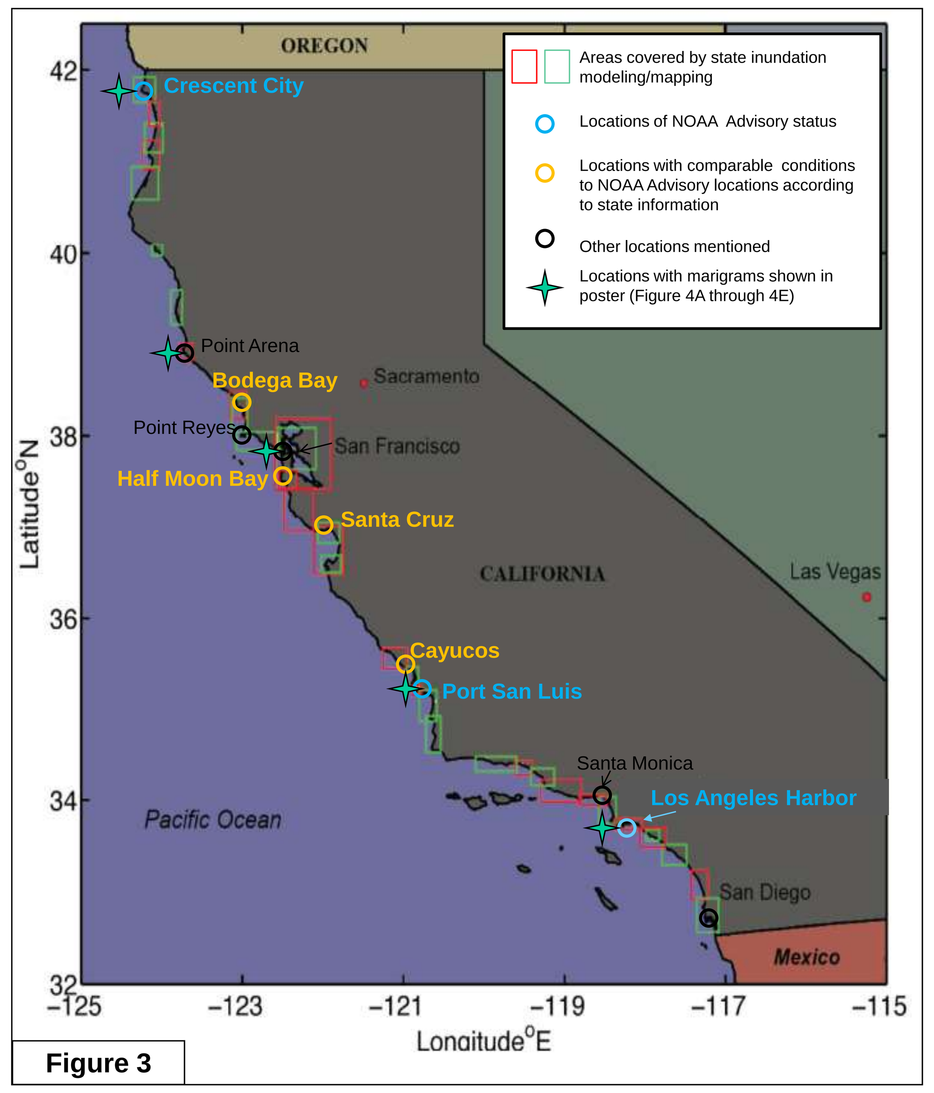


Figure 3

NOAA's West Coast/Alaska Tsunami Warning Center (WC/ATWC) Tsunami Alert Criteria

California is located within the WC/ATWC Area-of-Responsibility, and has four regional National Weather Service offices with Warning Coordinating Meteorologists to assist with Tsunami Alerts. To help clarify the tsunami alert messaging, new criteria were recently developed for alerting this region about a potential tsunami or tsunami hazards (summarized from Whitmore and others, 2008):

Tsunami Information Statement - issued to inform and update emergency managers and the public that an earthquake has occurred, or that a tsunami warning, watch or advisory has been issued elsewhere in the ocean.

Tsunami Watch - issued to alert emergency managers and the public of an event which may later impact the watch area; may be upgraded to a warning or advisory - or canceled - based on updated information/analysis.

Tsunami Advisory - issued due to the threat of a potential tsunami which may produce strong currents or waves dangerous to those in or near the water (typically tsunami forecast amplitudes 30 cm to 1 m).

Tsunami Warning - issued when a potential tsunami with significant widespread inundation is imminent or expected (typically tsunami forecast amplitudes over 1 m).

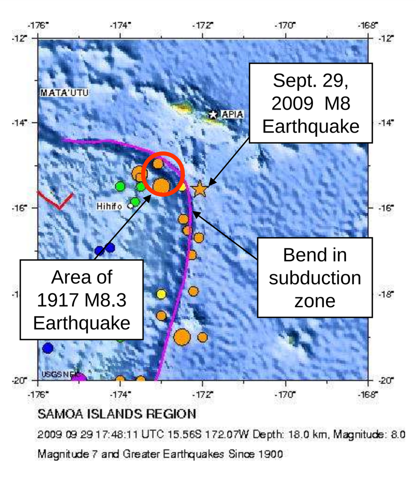


Figure 2
(from http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/us2009mdbi.php)

EVENT RESPONSE TIMELINE

September 29, 2009 - Tsunami Alert Messages for California from the NOAA WC/ATWC

10:48 PDT – Earthquake occurs in Samoa Islands region

10:57 PDT – WC/ATWC issues "observatory message" to federal and state tsunami observatories

#1 - 11:02 PDT - M 7.9 Information

#2 - 11:59 PDT - M 8.3 Information

#3 - 15:02 PDT - M 8.0 Advisory
- Provided tsunami arrival times to the minute for many locations along California coast (Figure 1).
- Shared initial forecast model flow-depth results for 5 locations in California (Figure 3):
  - **Crescent City = 65 cm ("Advisory" conditions)**
  - San Francisco = 20 cm
  - **Port San Luis = 60 cm ("Advisory" conditions)**
  - **Los Angeles = 30 cm ("Advisory" conditions)**
  - San Diego = 15 cm

#4 - 16:14 PDT - M 8.0 Advisory

#5 - 17:21 PDT - M 8.0 Advisory
- The peak tsunami amplitudes have passed in Hawaii. Observations in Hawaii support forecasts of 10 cm to 60 cm along the California Coast.

#6 - 19:24 PDT - M 8.0 Advisory

#7 - 21:28 PDT - M 8.0 Advisory

#8 - 23:30 PDT - M 8.0 Advisory
- The tsunami is reaching its maximum amplitude at many locations along the west coast. Expectations are for the amplitude to decrease over the next few hours.

#9 - 9/30 1:28 PDT - Cancellation

September 29, 2009 – Supplemental information provided by CGS and Dr. Lori Dengler (Humboldt State University) to State Emergency Managers (EMs), NOAA WC/ATWC and regional Warning Coordination Meteorologists (WCMs), and Local EMs.

14:39 PDT - CGS to State EMs: Searched NOAA/National Geophysical Data Center Tsunami Event Database for **similar past tsunami events** from source region and discovered M 8.3 event on June 26, 1917, that caused small tsunami in California (Figure 3). Tsunami amplitudes at tide gauges from San Francisco and San Diego were 10 cm and 4 cm, respectively. Lander and others (1999) reported no damage in California from this event.

15:50 PDT - Dengler to NOAA WCMs, State, and Local EMs: During state-wide teleconference for emergency managers, **provided explanation of NOAA Tsunami Advisory and answered questions** about tsunami hazards local communities might expect from potential strong tsunami currents and prolonged tsunami activity that might extend for a period of time.

17:17 PDT - CGS to State EMs and NOAA WC/ATWC and WCMs: Provided information about **potential additional communities** at risk based on existing numerical models and work related to the statewide mapping project (Figure 2; Wilson and others, 2008; Barberopoulou and others, 2009). Four locations with conditions comparable to Crescent City and Port San Luis (crescent-shaped, south-facing coves) were noted:
- **Bodega Bay** (modeled data from southwest Pacific Ocean show amplified tsunami runups)
- **Half Moon Bay** (modeled data show amplified tsunami runups)
- **Santa Cruz** (modeled data show amplified tsunami runups)
- **Cayucos** (modeled data show amplified tsunami runups)

Other discussion points included:
- CGS indicated tidal projections showed area north of San Francisco Bay would be at **high tide** at the time of first wave arrival.
- CGS recommended that local communities be made aware that **actual arrival times in California could vary by 10-to-15 minutes**.
- NOAA and CGS discussed that **potential errors in the forecast modeling could arise** from uncertainties/differences in the earthquake source dynamics and location. Crustal complexities exhibited by the tight bend in the source region subduction zone complicate directionality projections (Figure 2). Because the source was a normal fault instead of a thrust fault, reported forecast model results developed for thrust faults might be in error.

Tsunami Response Evaluation for California

The following table summarizes initially projected versus recorded tsunami amplitudes and arrival times in California from the Samoa tsunami (from WC/ATWC website; one-minute marigrams for some locations Figure 4A through 4E):

	Tsunami Amplitudes (zero to peak in cm)			First Arrival Times		
Locations	Projected	Recorded	% Difference (less)	Projected Time	Recorded Time	Difference (min. later)
Crescent City	65	33	51%	21:20	21:44	24
Arena Cove		44		20:58	21:15	17
Point Reyes		39		21:02	21:50	48
San Francisco	20	10	50%	21:31	21:48	17
Port San Luis	60	28	47%	21:07	21:30	23
Santa Monica		15		21:20	21:39	19
Los Angeles Harbor	30	13	43%	21:15	*	
San Diego	15	*		*	*	
* Not measurable		Average Difference =	48%		Average Difference =	25 minutes

Recorded tsunami amplitudes were approximately one half (48%) of the initially projected amplitudes which coincides with the potential error in forecast modeling described by Whitmore (2003). Also, the first arrival times were 17 to 48 minutes later at points recorded along the coast. A post-event evaluation by NOAA determined this difference in wave amplitude and travel time is likely due to several factors: 1) differences in the forecast model fault motion (thrust) and the actual fault motion (normal), 2) complexities in the source region producing uncertainty in the directionality of the tsunami, and 3) observed first arrivals being masked by tide gauge noise at some locations in California. A better understanding of the uncertainties in the forecasted amplitudes and arrival times is needed so that it can be explained to non-geoscientists.

CGS is in the process of gathering information about tsunami amplitudes in the four locations (Bodega Bay, Half Moon Bay, Santa Cruz, and Cayucos) where the tsunami vulnerability was thought comparable to Crescent City and Port San Luis. None of these locations have permanent tide gauges but one location, thus far, had an eye-witness account of the tsunami. Andy Ritchie of the USGS observed that in Santa Cruz harbor, tsunami wave amplitudes appeared to be about 0.7m above normal conditions (Andy Ritchie, personal communication). Thus far, this estimate is the largest amplitude observed in California from the September 29th tsunami and helps validate the adding of this location to an advisory-like status for this event.

According to post-event surveys of state and local emergency managers, information from state geoscientists helped emergency managers decide what actions to take during the event. Information provided by CGS … areas of potential increased tsunami amplitudes and vulnerability, high-tide conditions north of San Francisco Bay, and uncertainties in tsunami arrival times…was received by coastal emergency managers through tsunami alert messaging and teleconferences, and incorporated into their decision making process. The participation of Dr. Lori Dengler during the initial statewide teleconference helped emergency managers better understand the NOAA alert messaging, forecast information, and the expected tsunami hazard.

****New Statewide Tsunami Inundation Maps for Emergency Response Planning****

To see the NEW California tsunami inundation maps discussed in this presentation, visit:

http://www.conservation.ca.gov/cgs/geologic_hazards/Tsunami

Figure 4A – Marigram for Crescent City

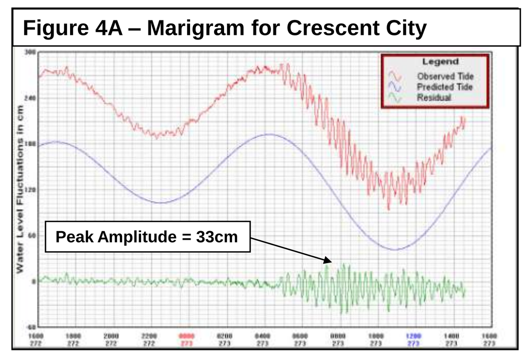


Figure 4B – Marigram for Arena Cove

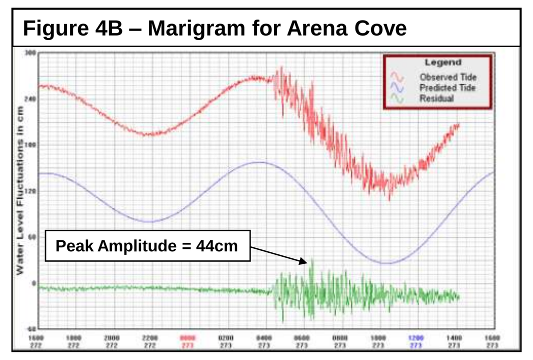


Figure 4C – Marigram for San Francisco

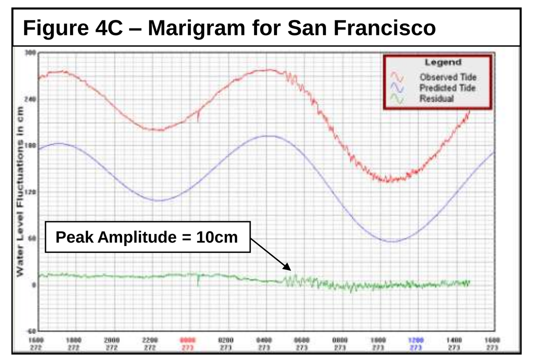


Figure 4D – Marigram for Port San Luis

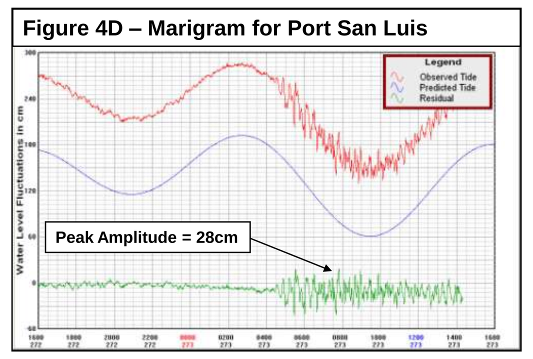
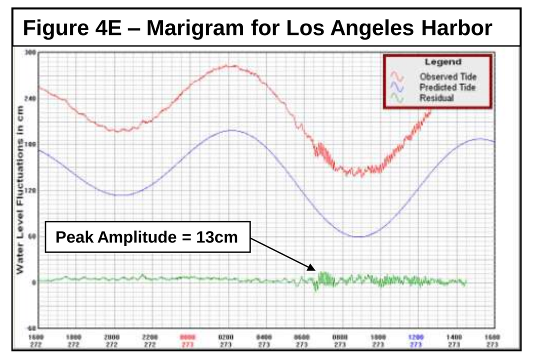


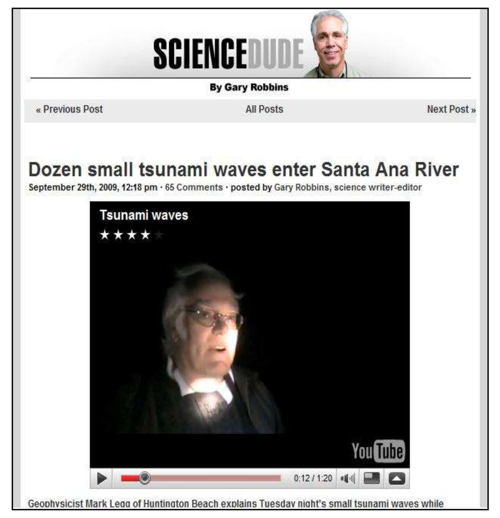
Figure 4E – Marigram for Los Angeles Harbor



Pre-Tsunami Field Response in California to September 29, 2009 Event by Geoscientists

Organized field teams of geoscientists collect perishable tsunami data in the field after an event has occurred. However, there has not a been a organized effort to establish field response teams prior to a teletsunami's arrival to collect data and provide immediate feedback to other geoscientists, emergency managers and the public.

Like Andy Ritchie in Santa Cruz, Dr. Mark Legg, a geophysicist from southern California, demonstrated how this type of field work could be useful. Legg observed the tsunami near the mouth of the Santa Ana River in southern California and noted several dozen small waves, up to six-inches in height, riding up and over the outward flow of the river. Legg noted that the drawdown was so rapid that it caused the outgoing tidal flow to accelerate and sand along the river bed to rapidly erode.



In addition to Legg making scientific observations, he arranged to meet a local reporter and was video taped discussing what he observed at the time of the tsunami's arrival. The video was placed on YouTube and has since been copied to many other websites and discussion boards. Legg's analysis demonstrated to the public that not all tsunamis are large events, and that even studying small tsunamis can provide useful information.

Observations made by field geoscientists during an event could also be very valuable to emergency managers if organized through a state-wide clearinghouse. Field geoscientists could relay information to the local emergency manager, and to a regional field manager to be shared with the clearinghouse leader. Similar to the tsunami observer programs in Hawaii, real-time scientific information could help determine where state response resources could be best utilized.

Conclusions and Future Work

As illustrated by California's experience during the Samoa teletsunami event, state geoscientists can provide emergency managers with useful information and assistance during a tsunami alert. They can convey the uncertainties in the NOAA tsunami amplitude forecast and travel time data so that state and local emergency managers can make the best decisions on actions taken in their jurisdictions. In addition, because forecast modeling is only done for only five of the over 80 communities along the California coast, state geoscientists can use existing tsunami inundation data to determine the hazard level for other communities. Field geoscientists can also provide real-time feedback to state and local emergency managers and the public in general.

Although CGS is integrated into the statewide tsunami emergency response network, the role of CGS and other geoscientists during tsunami response activities should be expanded. CGS will work more closely with NOAA and state and local emergency managers to **formalize a coordinated tsunami response plan** to help provide the most valuable and timely information to those in decision making roles for their communities. This response plan will include:
- Participation by primary and backup geoscience contacts in all pertinent meetings and teleconferences with NOAA and state and local emergency managers.
- Review of historic records for comparison to the active event.
- Evaluating the predicted, statewide tidal conditions that will exist at the time of the tsunami's activity.
- Provide supplemental information of the expected tsunami hazard (flow depths, strong currents, etc.) for areas not covered by NOAA's forecast models.

Potential additional future tsunami response planning activities for state geoscientists include:
- Through the NTHMP, the California tsunami program will continue to work closely with NOAA to **simplify their tsunami alert messaging and expand their forecast modeling coverage**. California geoscientists will provide feedback on NOAA's Messages that will help clarify the uncertainties in the tsunami forecast data. In addition, California is supporting the expansion of NOAA's development of digital elevation models used for production of tsunami forecast models within the state.
- CGS plans to **create tsunami response "playbooks"** containing information from the recent statewide inundation mapping project, for local emergency managers to reference during an event. Information in these playbooks will help identify the relative hazard level for their coastal communities and include estimates on tsunami flow depths, current speeds, and travel times.
- CGS is **developing a pre- and post-tsunami field response team and state-level information "clearinghouse" made up of geoscientists** to assist state and local officials. In addition to noting the effects of incoming tsunamis, members of these field response teams will meet annually and be available before, during, and after a tsunami to provide assistance to local emergency managers and the public.

Acknowledgements and References

The authors would like to thank NOAA/NTHMP for supporting tsunami hazard mitigation and response activities in California. Thank you to the county emergency managers who are part of the California Tsunami Program Steering Committee for their participation in the post-event survey.

Barberopoulou, A., Borrero, J.C., Uslu, B., Kalligeris, N., Goltz, J.D., Wilson, R.I., and Synolakis, C.E., 2009, Unprecedented coverage of the Californian coast promises improved tsunami response: EOS Trans. American Geophysical Union.

Lander, J., Lockridge, P.A., and Kozuch, J., 1993, Tsunamis affecting the west coast of the United States 1806-1992: NGDC Key to Geophysical Research Documentation No. 29, USDOC/NOAA/NESDIS/NGDC, Boulder, CO, USA, 242 pp.

Whitmore, P. M., 2003, Tsunami amplitude prediction during events: a test based on previous tsunamis: Science of Tsunami Hazards, 21, p. 135-143.

Whitmore, P.M., Benz, H., Bolton, M., Crawford , G., Dengler, L., Fryer, G., Goltz, J., Hanson, R., Kryzanowski, K., Malone, S., Oppenheimer, D., Petty, E., Rogers, G., and Wilson, J., 2008, NOAA/West Coast and Alaska Tsunami Warning Center Pacific Ocean Response Criteria, Science of Tsunami Hazards, 27, 1-21.

Wilson, R.I., Barberopoulou, A., Miller, K.M., Goltz, J.D., and Synolakis, C.E., 2008, New maximum tsunami inundation maps for use by local emergency planners in the State of California, USA: EOS Trans. American Geophysical Union 89(53), Fall Meeting Supplement, Abstract OS43D-1343.