

EERI Preliminary Notes on Tsunami Damage and  
Response:

**Tsunami Generated by  $M_w$ 8.1 Chiapas,  
Mexico, Earthquake on September 7, 2017**



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# 1 PURPOSE

The Earthquake Engineering Research Institute (EERI) supports gathering and sharing information about the effects and damage caused by tsunamis as well as the lessons learned about tsunami notification, evacuation and response activities. This report summarizes the observations and response outcomes of the tsunami that was generated by the  $M_w$ 8.1 Chiapas, Mexico, earthquake on September 7, 2017 (Figure 1). Although EERI-related field teams were not deployed specifically for the tsunami, this report provides information compiled by the authors from various references, colleagues, and their own personal experiences during and after the event. The information presented should be considered preliminary; for updates, the authors recommend readers visit the scientific and emergency management websites discussed herein.

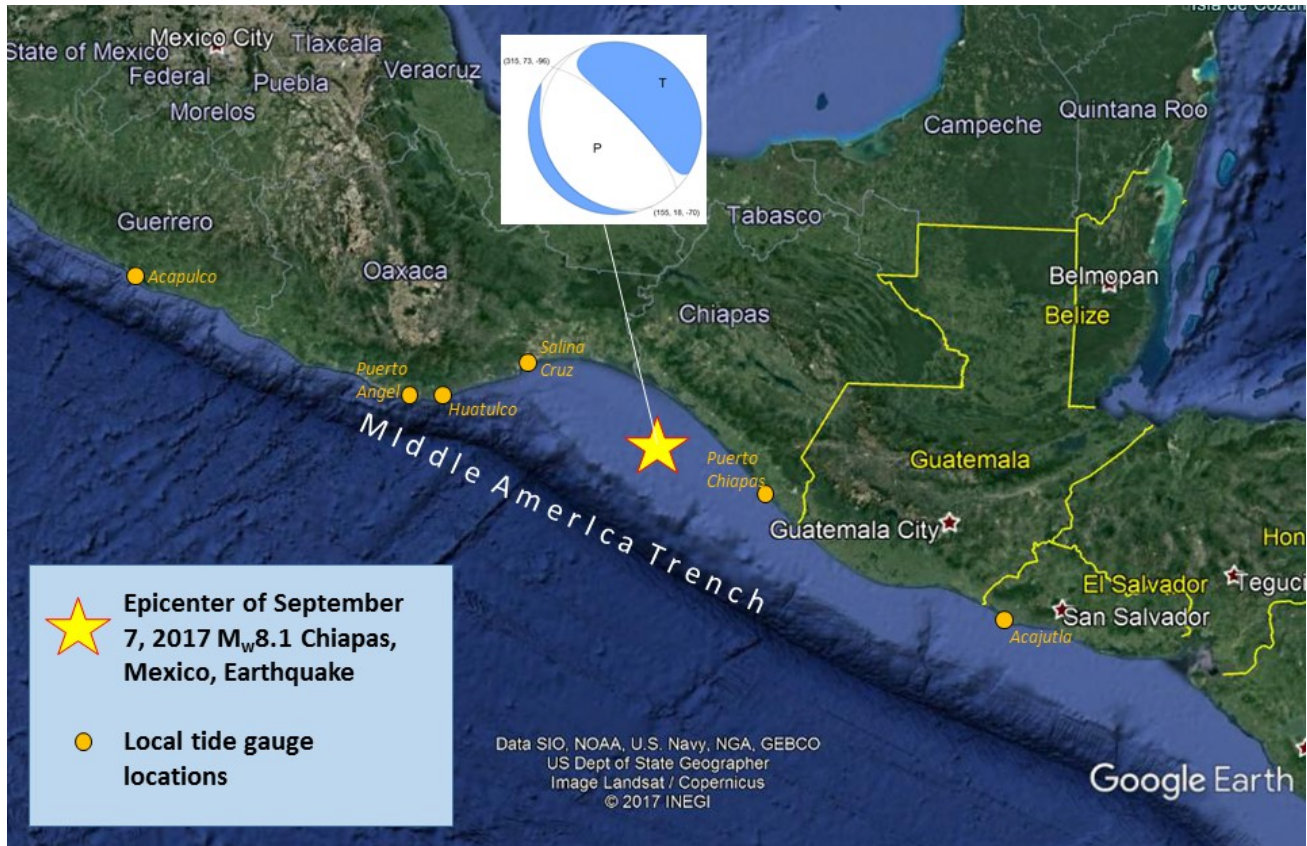


Figure 1 Map showing the epicentral area of the  $M$ 8.1 Chiapas, Mexico Earthquake. The moment tensor diagram for the event from the USGS earthquake page and several of the tide gauge locations are also provided.

The authors who compiled this information include:

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The authors' objectives for this paper include:

1. Summarizing the physical tsunami effects from the event.
2. Documenting tsunami notification and response activities both in Mexico and elsewhere.
3. Discussing potential lessons learned and future improvements for tsunami-related scientific research, engineering, notification and response (NOTE: discussion about lessons learned represent the opinions of the authors).

## 2 EARTHQUAKE RUPTURE PATTERN AND TSUNAMI EFFECTS

### 2.1 Event Description

The Mw 8.1 earthquake occurred at 04:49 UTC on September 8, 2017 (23:49 local Chiapas, Mexico, time on Thursday, September 7, 2017). The earthquake hypocenter was located offshore of the states of Chiapas and Oaxaca, approximately 87 km south of Pijijiapan, Mexico, at a depth of 69.7 km (Figure 1) (USGS). The earthquake occurred near the tectonic junction where the North American Plate and Caribbean Plate override the Cocos Plate towards the west along the Middle American trench subduction zone (Ramirez-Herrera et al, 2016). Based on information from the USGS earthquake and Temblor websites for this event (see links in reference section), the earthquake was an intraplate normal-fault event below the subduction zone surface within the subducting Cocos Plate, and not along the actual subduction zone. Based on the moment tensor and aftershock pattern, the rupture was along a normal fault dipping to the northeast which indicates that the primary tsunami energy would likely propagate to the northeast and southwest perpendicular to the fault (Figure 2).

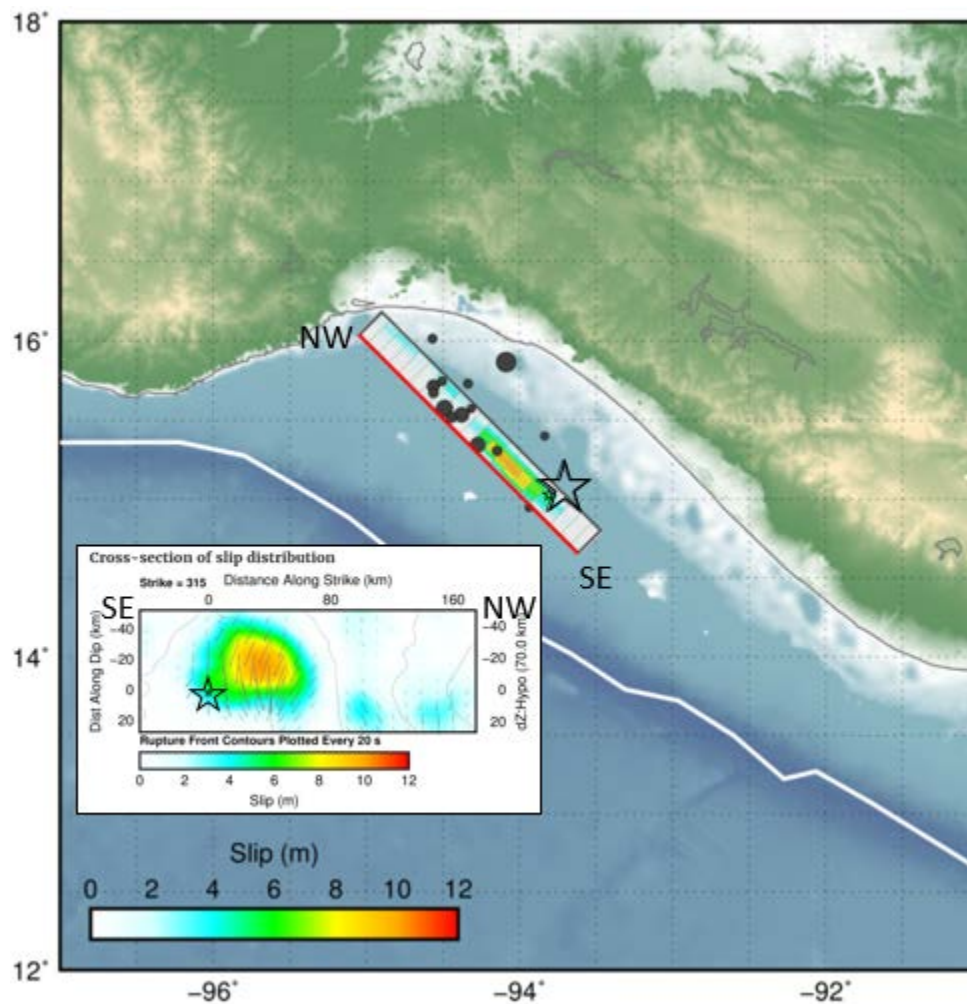


Figure 2 Surface projection and cross section of slip distribution from the September 7, 2017 Chiapas, Mexico, Earthquake. The hypocenter of the event is designated by the star. Modified from USGS event website.

Figure 3, modified from Ramirez-Herrera et al (2016), shows that the September 7<sup>th</sup> earthquake occurred within the subducting Cocos plate beneath the “Tehuantepec seismic gap.” According to statements attributed to Gavin Hayes (USGS) on the Temblor.net earthquake website, although some of the aftershocks were compressional and along the megathrust, the main rupture did not occur along the subduction zone and it is unknown if the earthquake relieved stress within the seismic gap.

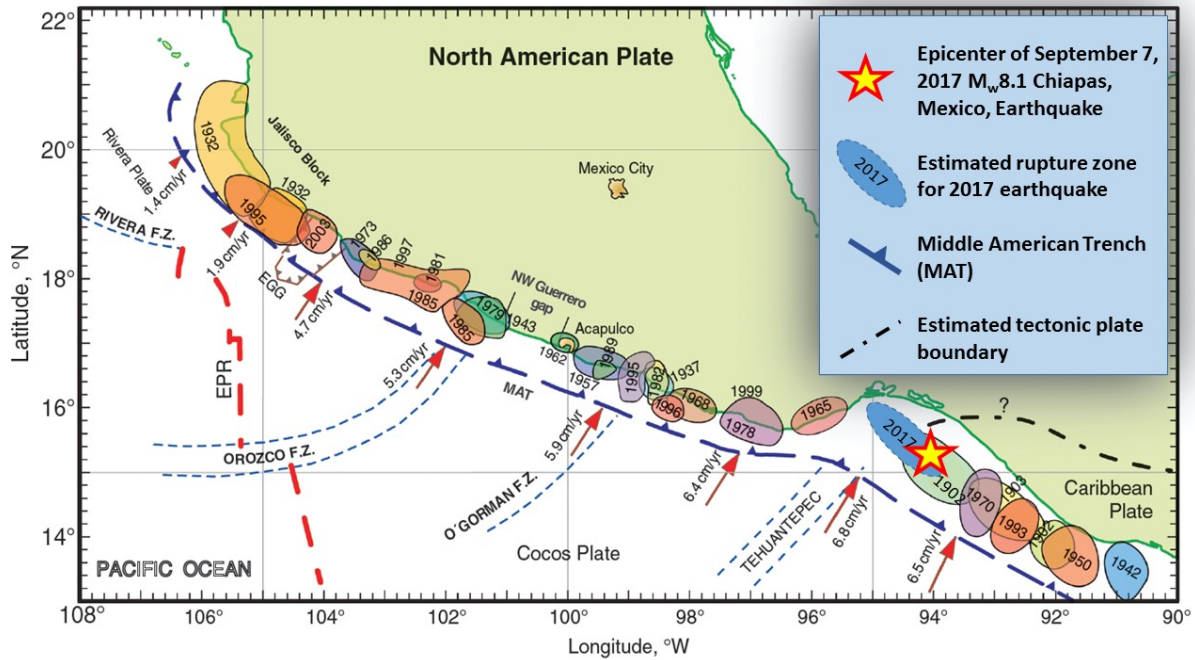


Figure 3 Tectonic and seismic setting of the Pacific Coast of Mexico. Abbreviations: MAT = Middle American Trench, F.Z. = Fracture zones, EPR = East Pacific Rise, EGG = El Gordo Graben. Symbols: Shaded circles indicate rupture areas and numbers the years of most important subduction seismic events of last century. Small dashed lines indicate fracture zones; thick dash with arrowheads show subduction zone. Thick dash shows location of EPR. Plate convergence rates are shown in cm/yr. Arrows indicate direction of convergence. Figure and caption modified from Ramirez-Herrera et al (2016).

A small- to moderate-size tsunami was generated by the September 7<sup>th</sup> earthquake, and detected along the Pacific coast in the region of the earthquake. According to initial water-level measurements by Stuart Weinstein of the Pacific Tsunami Warning Center (PTWC) (via the International Tsunami Bulletin Board), the tsunami was recorded on several tide gauges in southern Mexico and El Salvador (see Figure 1 for locations and Table 1 for information). Based on this information, the largest tsunami amplitudes occurred during the first five hours of the observed arrival times at each tide gauge except for the El Salvador location, where the peak occurred 14 hours after first arrival. Videos posted on Youtube indicate that there was minor flooding along the waterfront of the harbor at Puerto Chiapas. In the far field, the maximum tsunami amplitudes from this event were all less than 0.35m, which was the measured amplitude in Owenga, Chatham Islands, in New Zealand (PTWC).

Table 1 Initial tsunami information from tide gauges in the region of the earthquake, from north to south (summarized from Stuart Weinstein, PTWC). See Figure 1 for the location of the tide gauges.

Tide Gauge Measurement Location	Observed Arrival Time (UTC)	Peak Amplitude (above sea level in meters)	Time of Peak Amplitude (UTC)
Acapulco, Mexico	05:25	0.93	06:09
Puerto Angel, Mexico	04:57	0.30	05:17
Huatulco, Mexico	05:01	0.44	09:50
Salina Cruz, Mexico	05:15	1.22	06:22
Puerto Chiapas, Mexico	06:07	1.68	09:55
Acajutla, El Salvador	06:15	0.53	18:08

## 2.2 Geotechnical Setting and Effects

Field teams that deployed to the region just after the event have not completed analyses of the tsunami water heights and impacts along the coast. Field work has been complicated by the need for geotechnical teams to respond to the more recent and more damaging September 19, 2017, M7.1 earthquake in central Mexico. This will likely cause delays in completing tsunami field work and reporting. This report includes some initial findings from field teams and on-line

newspaper articles and videos, and documents minor to moderate flooding and damage isolated to harbors and waterfront areas. However, some of this information may change as the complete field reports become available.

A field team from the National Autonomous University of Mexico (UNAM field team), co-led by co-author Maria-Teresa Ramirez-Herrera, compiled observations about the effects of the earthquake and tsunami. Earthquake damage to buildings and houses was relatively minor in the Chiapas coastal towns compared to those in Oaxaca. In Punta Arista, fishermen described the sea retreating 60-70 meters exposing their fishing nets. After they evacuated approximately 100 meters to the nearest hill, the seawater reportedly reached chest level. Additional observations from the UNAM field team specific to tsunami notifications and response are provided in a later section.

Still images from a Youtube video shows Marina Chiapas, a small-boat facility at Puerto Chiapas, with some structural damage; however, there was apparently no damage to boats (Figure 4; <https://www.youtube.com/watch?v=bBBVt1wLM9g>). According to the *MexicoBoating.com* website, Marina Chiapas was constructed in 2011 so the docks and facilities are relatively new. The Youtube videographer indicated that tsunami flooding was a couple meters high, inundating the area around the harbor and lifting the floating docks over the top of the piles. The docks were dislodged from the piles and damaged when the surges receded and continued to oscillate. Infrastructure on and around the docks was also damaged, including a vessel travel lift when the tsunami flooded its engine. The marina is located at the end of a narrow channel near the back of the main port, and localized amplification of the tsunami likely occurred there.



Figure 4 Video screen captures of dock damage in Marina Chiapas the day after the September 7, 2017, earthquake. According to the videographer, the amplitude of the tsunami in this area was several meters causing the floating docks to overtop the piles, and damage to the docks themselves (video link: <https://www.youtube.com/watch?v=bBBVt1wLM9g>).

There were no reports of tsunami damage to large ports within the epicentral region. The state oil company Pemex indicated that their 330,000 barrel per day refinery in Salina Cruz did not sustain structural damage from the earthquake or tsunami.

### 3 EMERGENCY NOTIFICATION AND RESPONSE

#### 3.1 Local Tsunami Warning System, Emergency Notifications, and Response Activities

In 2012, the Mexican government launched its tsunami warning system (CAT – Centro de Alerta de Tsunami) involving multiple agencies and academic institutions (Agence France-Presse, 2012). These agencies work with the PTWC and use their alert messages to determine the threat level and notify the communities along the Mexico coast. The PTWC provides information statements to the international community about the general forecast wave-height range and forecast arrival times and identifies a relative threat level. National authorities have the responsibility to issue evacuation orders based on PTWC information and other data. Table 2 summarizes the international tsunami information statements from the PTWC after the earthquake; the domestic U.S. messages will be summarized later in this report.

*Table 2 Summary of international tsunami information messages from the PTWC for Mexico and other non-U.S. areas within PTWC's responsibility.*

International Tsunami Threat Messages from PTWC	Time Message Sent by PTWC (Local Chiapas, Mexico, time)	Information about Earthquake (Local Chiapas, Mexico, time)	Forecast message about Tsunami
Message #1	11:54PM	Event time 11:49PM M8.0 Depth=33km	<ul style="list-style-type: none"> <li>• "Hazardous tsunami waves" are possible within next three hours in: Mexico, Guatemala, El Salvador, Costa Rica, Nicaragua, Panama, Honduras, and Ecuador.</li> <li>• Estimated arrival times for these areas provided.</li> </ul>
Message #2	12:24AM	Event time 11:49PM M8.2 Depth=33km	<p>"Tsunami forecast is updated in this message."</p> <ul style="list-style-type: none"> <li>• "Tsunami waves reaching more than 3 meters" for Mexico.</li> <li>• "Tsunami waves are forecast to be less than 0.3 meters" for other areas including Hawaiian Islands.</li> </ul>
Message #3	12:42AM	Event time 11:49PM M8.2 Depth=33km	<p>"Tsunami forecast is unchanged in this message," however there were changes:</p> <ul style="list-style-type: none"> <li>• "Tsunami waves reaching more than 3 meters" for Mexico.</li> <li>• "Tsunami waves reaching 0.3 to 1 meter" for countries near epicentral area, and islands to the southwest including American Samoa.</li> <li>• "Tsunami waves are forecast to be less than 0.3 meters" for numerous other countries around the Pacific, and U.S. areas like Hawaiian Islands, Guam, and Northern Marianas.</li> </ul>
Message #4	12:53AM	Event time 11:49PM M8.2 Depth=33km	<p>"Tsunami forecast is unchanged in this message," which is the case as it did not change from Message #3.</p> <ul style="list-style-type: none"> <li>• "Tsunami Waves have been observed." Peak wave height information from three local tide gauges were provided.</li> </ul>
Messages #5 through Message #16	01:53AM through 12:50PM	Event time 11:49PM M8.2 Depth=33km	<p>"Tsunami forecast is unchanged in this message," which is the case.</p> <ul style="list-style-type: none"> <li>• Peak wave height information was updated throughout these messages.</li> </ul>
Message #17	01:26PM	Event time 11:49PM M8.2 Depth=33km	<p>"PTWC Final Tsunami Threat Message"</p> <ul style="list-style-type: none"> <li>• "The tsunami threat has now largely passed."</li> </ul>

According to multiple sources, thousands of people in the coastal areas were evacuated as a precaution. Many people self-evacuated after feeling the ground shake during the earthquake or saw the ocean recede, and others were officially notified to evacuate.

The following are some of the initial reports from the UNAM field team:

- The Mexican tsunami early warning (CAT – Centro de Alerta de Tsunami) issued tsunami bulletins, however the warning for the September 7 tsunami did not reach people in the small towns along the Chiapas and Oaxaca coast, with one exception. At Boca de Cielo, where a Navy station is based, people were notified and asked to evacuate. Because the community is located on a sandbar across an estuary, a boat was required to cross to the mainland to safety. While on the mainland, people were self-organized and evacuated but those with no car were left behind.
- Some locals, who felt the earthquake on the Chiapas coast, described it as a strong earthquake in Punta Arista but did not immediately evacuate, some even stayed at the beach. Only when they saw the ocean retreating, they evacuated inland on foot and by car.
- At El Madresal, a small coastal town in Chiapas, people did not evacuate after they felt the earthquake. Instead some people walked to the beach to observe the ocean.
- At San Mateo del Mar, Oaxaca, an indigenous Ikoot community, local people felt the earthquake and knew that there was a possibility of a tsunami after a strong earthquake. On September 8 at 1222 AM local time, San Mateo del Mar locals were sharing on Facebook information of the first tsunami warning issued by a local app (SkyAlert). Later, at 1244 AM, the Ikoot community were warning local people on Facebook using information from NOAA and confirmed later again by SkyAlert. The Ikoot community were self-organized calling people to move to higher ground and some of them drove to Huazantlán del Río, not returning until the following day. According to the Facebook page, damage in San Mateo del Mar occurred during the earthquake and not the tsunami.
- Based on reports, although the CAT issued a tsunami warning alert, this alert did not reach most people along the Chiapas coast due to the multi-tiered notification system, which follows a chain of notifications: 1) the CAT to the Federal government; 2) then to the Federal civil protection office; 3) then to the state-level civil protection office; 4) then to the local municipality civil protection office; and 5) then the notifications are shared with the people.

### **3.2 Emergency Notifications and Response for Distant U.S. Coastal Areas**

The U.S. Pacific and National Tsunami Warning Centers (PTWC and NTWC) provided tsunami notification information to the domestic U.S. (Table 3) and other international regions (Table 2) around the Pacific Ocean after the earthquake. For example, the NTWC provided a “Tsunami Information Bulletin” about the tsunami threat to the west coast of the U.S.

Over the past year, the two tsunami warning centers began sharing the same website for providing detailed warning information for their areas of responsibilities. During this event, because some areas under the international jurisdiction were under a “threat” from a tsunami, the warning center website used a purple banner with the words “Tsunami Threat” to indicate that a threat existed at the time. For domestic U.S. regions, this banner had only been used in the past to identify if there was a “Warning,” “Advisory,” “Watch” alert level or “No Threat” statement. Although this banner was meant for the international community, emergency managers in some U.S. locations that were told that they had no threat in their individual information statements were confused by this banner.

United States coastal state/territory emergency managers and duty officers under the PTWC/NTWC areas of responsibility approved jurisdictionally actionable and authoritative Emergency Response Plans (EOPs) incorporating official national-level protocols based upon the NOAA-provided alert levels of WARNING, ADVISORY, WATCH or INFORMATION STATEMENT. Response training for duty officers, first responders, the public and others has followed on and adhered to protocols conforming to NOAA Alert Protocols laid out within newly developed, tsunami-specific EOPs. Additionally, these response and evacuation plans built upon these alerting protocol are not cursory or easily changed.

Most require Board of Supervisor acceptance/approval, and EOP Tsunami Annexes for a large county can run to several hundred pages. Nowhere in any existing U.S. State or Territory is emergency response plan or duty officer protocol instruction pertaining to a purple banner, which states TSUNAMI THREAT. Finally, [www.tsunami.gov](http://www.tsunami.gov) is a known, trusted source for nationwide tsunami official alert information. When an unknown term and unfamiliar banner is displayed on this website it can throw these plans into disarray by not conforming to nationally understood, agreed-upon, and trained-to protocols. That international protocols now fall under the purview of a national website for official alert and notification with life-safety ramifications presents some new issues to work through. Questions have arisen and implications could be that questions may continue even in the midst of a tsunami response, precisely when they should not, from coastal city and county emergency managers, duty officers, the public and others.

The screenshot displays the NOAA U.S. Tsunami Warning System website interface. At the top, the NOAA logo and the text "NOAA / National Weather Service U.S. Tsunami Warning System" are visible. A navigation bar includes "Home", "News", "Organization", and a search field. The main content area features a yellow banner with the message: "Message: Non-US/Canada Pacific Threat #1 Issued Fri Sep 08 04:55:19 UTC 2017". Below this is a purple heading "Tsunami Threat". The "Earthquake:" section provides details: Magnitude: 8, Depth: 21 mi., Location: OFF THE COAST OF CHIAPAS MEXICO, and Origin Time: 9/7/2017 9:49:17 PM. A map of the Pacific Ocean shows the earthquake location with a purple pin. The page includes a sidebar with various program links, a legend for alert types (Warning, Advisory, Watch, Threat, Earthquake), and a "Map FAQ" link.

Figure 5 Combined U.S. tsunami warning center website. Note the purple heading "Tsunami Threat" for this website, which has been commonly used in international messaging but not domestic U.S. messaging.

For the west coast of the U.S., the earthquake occurred at 09:49PM PDT on September 7, 2017. Table 4 summarizes the content of the messages sent by the two warning centers for U.S. states and territories around the Pacific:

Table 3 Summary of domestic U.S. tsunami information statements from the PTWC and NTWC.

Tsunami Warning Center and Related Information Statements	Time Message Sent (PDT)	Information about Earthquake	Primary Emergency Response Message about Tsunami
NTWC Statement #1 for U.S. west coast, Alaska, and British Columbia	09:55PM	Event time 09:49PM M7.8 Depth=39km	Tsunami NOT expected for U.S. west coast, Alaska, and British Columbia
PTWC Statement #1 for American Samoa	09:56PM	Event time 09:49PM M8.0 Depth=33km	"Possible tsunami threat" <ul style="list-style-type: none"> <li>• "Tsunami threat...still under investigation"</li> <li>• Potential tsunami arrival times provided</li> </ul>
PTWC Statement #1 for Guam and Northern Marianas	09:57PM	Event time 09:49PM M8.0 Depth=33km	"Possible tsunami threat" <ul style="list-style-type: none"> <li>• "Tsunami threat...still under investigation"</li> <li>• Potential tsunami arrival times provided</li> </ul>
PTWC Statement #1 for Hawaii	10:02PM	Event time 09:49PM M8.0 Depth=33km	"No tsunami threat"
PTWC Statement #2 for American Samoa	10:26PM	Event time 09:49PM M8.2 Depth=33km	"Possible tsunami threat...update" <ul style="list-style-type: none"> <li>• "Tsunami threat...still under investigation"</li> <li>• Potential tsunami arrival times provided</li> </ul>
PTWC Statement #2 for Guam and Northern Marianas	10:27PM	Event time 09:49PM M8.2 Depth=33km	"Possible tsunami threat...update" <ul style="list-style-type: none"> <li>• "Tsunami threat...still under investigation"</li> <li>• Potential tsunami arrival times provided</li> </ul>
PTWC Statement #2 for Hawaii	10:30PM	Event time 09:49PM M8.2 Depth=33km	"No tsunami threat"
PTWC Statement #3 for Hawaii	10:47PM	Event time 09:49PM M8.2 Depth=33km	"No tsunami threat"
PTWC Statement #3 for American Samoa	10:49PM	Event time 09:49PM M8.2 Depth=33km	"Possible tsunami threat...update" <ul style="list-style-type: none"> <li>• "Tsunami threat...still under investigation"</li> <li>• Potential tsunami arrival times provided</li> </ul>
PTWC Statement #3 for Guam and Northern Marianas	10:50PM	Event time 09:49PM M8.2 Depth=33km	"No tsunami threat"
PTWC Statement #4 for Hawaii	11:24PM	Event time 09:49PM M8.2 Depth=33km	"No tsunami threat"
PTWC Statement #4 for American Samoa	11:30PM	Event time 09:49PM M8.2 Depth=33km	"No tsunami threat"

The PTWC identified that there was no tsunami threat within the first 13 minutes after the earthquake for the State of Hawaii. However, a "potential tsunami threat" was indicated for the U.S. territories of American Samoa and the Northern Marianas Islands. After the PTWC analysis was completed, the domestic U.S. statements indicated there was no tsunami threat for the Northern Marianas within 59 minutes after the earthquake, and then for American Samoa after 79 minutes. But based on the international messages (Table 2), there was still an indication that American Samoa could receive tsunami wave heights in the 0.3-meter to 1-meter range, which is the equivalent of a tsunami "Advisory" alert level with the capability to cause strong, damaging currents along the coast and within harbors. Based on feedback from emergency managers and National Weather Service staff in American Samoa, this caused some confusion for communities and the media as to what the true tsunami threat level was.

The State of California is within the area of responsibility of the NTWC. The California Governor's Office of Emergency Services (CalOES) is responsible for coordinating statewide tsunami response information, ensuring coastal county

operational areas are advised about the tsunami threat. The CalOES Earthquake and Tsunami Program duty officer fielded questions about the “Tsunami Threat” banner on the U.S. warning center website, and contacted the NTWC for guidance and clarification. The duty officer confirmed with the NTWC via phone (following on the bulletin stating no threat) there was “No threat to California or the U.S. West Coast.” The tsunami scientist from the California Geological Survey contacted the PTWC within the first couple of hours after the earthquake to request clarification about the potential differences between the international and domestic tsunami alert levels for American Samoa.

The California Office of Emergency Services daily situation report of September 9, 2017 at 1000 hours focused on the following information: **“Mexico Earthquake** On 09/07/17 at 2149 hours, a magnitude 8.1 earthquake occurred 26 miles SW of Tonala, Chiapas, Mexico. Per the Cal OES Assistant Director of International Affairs, 11 states in Mexico felt the earthquake and aftershocks continue. There have been 33 fatalities and infrastructure and homes have been impacted. Mexico’s National Operation Center is activated and the federal government is assisting with response effort. The Cal OES Assistant Director of International Affairs will continue to monitor the situation.

- The National Tsunami Warning Center (NTWC) issued a Tsunami Information Statement for California.
- There is no tsunami danger for the California coast.
- All coastal counties were briefed.
- Cal OES Duty Officers were notified.
- There have been no requests for State assistance.”

## 4 LESSONS LEARNED

The Chiapas earthquake and tsunami provides an opportunity for scientists, engineers, planners, and emergency managers to review the event outcomes and develop a list of potential improvements to their ongoing work. There are several “lessons” and recommendations that the authors would like to note.

### 4.1 Tsunami Science and Engineering

Potential lessons about tsunami science and engineering from this event:

1. The fault rupture during this earthquake was along a high-angle, northeast dipping normal fault within the subducting Cocos tectonic plate, and not along the Middle American megathrust; a normal-fault generated tsunami also occurred during the M6.9 Tohoku Earthquake on November 21, 2016 (Wilson et al., 2017). This situation complicated the tsunami forecast since forecast methods and pre-event modeling are primarily associated with subduction zone earthquakes where the most significant tsunamis are generated. Having said that, dangerous tsunamis can still occur along non-subduction zone sources like reverse and normal faults as well as triggered by submarine and subaerial landslides. This event presents a case for developing and using alternative tsunami detection and forecast systems, such as seafloor cable detection system or coastal radar systems, in areas where non-subduction tsunami sources exist. Likewise, adding non-subduction zone source modeling to the tsunami forecast databases should also be considered and added to conventional warning systems like those run by the U.S.
2. The Chiapas earthquake is one of the largest down-slab normal faulting events ever recorded. Similar normal fault earthquakes have occurred within the subducting Gorda plate beneath Northern California. Two earthquakes in the mid-magnitude 5 range occurred in the past decade (M 5.6 on 2/13/12, M 5.4 on 4/30/08). While these earthquakes are far smaller than the Chiapas earthquake and their on-land epicenters posed no tsunami threat, the Chiapas event does invite inquiry as to the potential for larger down-slab events in the Juan de Fuca slab and if they pose a tsunami threat to the Oregon or Washington coasts.
3. The fact that the Middle American Trench megathrust did not rupture indicates that the stress along this subduction zone within the Tehuantepec seismic gap may still exist. This leads to two potential ideas which should be considered: 1) analysis of historical and paleo-seismic events in this and other regions should try to confirm that past large earthquake events ruptured the megathrust and not subsidiary faults; and 2) regional seismic hazard analyses should consider the potential for multiple earthquake sources within complicated tectonic boundaries like that off the coast of Chiapas. Further detailed work along subduction zone boundaries should evaluate all potential seismic sources and their potential for triggering tsunamis.

4. From an engineering perspective, the damage to Marina Chiapas harbor where floating docks overtopped their piles could have been potentially reduced by increasing the pile heights. Pre-event tsunami modeling can help harbor engineers with evaluations of expected water level fluctuations to determine the correct pile heights and the stability of pile guides. In addition, amplification of the tsunami should be accounted for where narrow channels occur or where small-boat basins are located at the back of a larger harbor.

#### 4.2 Tsunami Warning Notifications and Response

Potential lessons locally within Mexico:

1. Although it appears that a large number of people did not immediately evacuate after feeling strong earthquake ground shaking, some of the local coastal population evacuated away from the coastline when they felt the earthquake or observed the ocean receding. Public education about the “natural” tsunami warning signs, such as ground shaking and receding water along the beach, are of great value to coastal communities, and should be an ongoing process supported by local, state, and federal governments. Emphasis does need to be placed on feeling the earthquake and not waiting to observe additional effects such as waiting to observe a drawdown.
2. The Mexico tsunami notification system has multiple tiers between the CAT and the local coastal population. This led to the delays in and non-delivery of the tsunami alert messaging during the Chiapas event. A recommendation would be to streamline this notification and messaging system so that there is a direct alert from the CAT to the coastal communities and their residents. If not employed already, social media outlets such as Twitter can immediately notify people who are signed up for alert messages.
3. The earthquake magnitude and tsunami alert messages from the PTWC and NTWC were provided to the public within minutes after the earthquake and they turned out to be fairly accurate. Timely magnitude prediction and tsunami forecasting can be essential for sending the initial messaging out to communities near the source region to confirm there is a tsunami threat and evacuation should occur. However, forecasting agencies should also make it clear to the public that many times the earthquake magnitude and tsunami threat can increase because the actual earthquake magnitude and causative fault rupture can be larger than early estimates.

Potential lessons for distant areas, specifically lessons for domestic U.S. regions:

1. Perceived inconsistencies between the international and domestic messaging for American Samoa led to confusion by local communities and the media. One recommendation is to eliminate discussion of domestic U.S. regions (Hawaii, American Samoa, Guam, and the Northern Marianas Islands) from the international messaging. This would require these U.S. regions to only reference and follow the forecasts and instructions within their specific domestic messages. It is the understanding of the authors that the PTWC is considering making this change to help reduce potential confusion in the future.
2. The use of the “Tsunami Threat” banner at the top of the U.S. warning center website confused both officials in U.S. states and communities and members of the public as to whether a tsunami threat existed. Persons familiar with the NTWC site have become familiar with the green (no threat), yellow (Advisory) and red (Warning) color codes. Introducing a new color without a thorough vetting and outreach process adds to already perceived misunderstanding of what alert levels mean. Because the warning centers messages have recently been combined onto one website, the National Weather Service and state tsunami programs have not had time to educate their communities about use of the “Tsunami Threat” banner. A recommendation would be to include full vetting and socialization of the previously unseen (by U.S. customers) TSUNAMI THREAT message. Further education as well as possible clarification in the wording on the new website should help reduce confusion in the future. It was noted after the fact upon further review of the *tsunami.gov website* that the word “international” is at the bottom of the page explaining the purple color in the legend. This information should be made more prominent.
3. More precise (quantitative) tsunami forecast amplitudes/wave heights are provided by the U.S. warning centers for some coastal areas. This information has been very useful to state and community emergency managers to help determine not only the hazard level along the coast but also the potential for flooding in communities. For maximum benefit and consistency, the warning centers should explore providing this more precise information for ALL domestic and international areas.
4. The US tsunami warning centers and the USGS provided initial focal depths estimates for the earthquake (33-39km in warning center messages that turned out to be inaccurate. When the USGS corrected their depth to

70km from the USGS and revised shaking and damage estimates based on the revised depth, both PTWC and NTWC continued to use the original inaccurate focal depths throughout the event. Although this might not seem significant for the general public, the inaccurate, shallower depths could lead scientists to think that the tsunami threat is more significant. Any discrepancy between US agencies in a tsunami event provides another opportunity for confusion and criticism. The PTWC and NTWC need to collaborate more with the USGS on providing a consistent focal depth and magnitude so that all governmental agencies responsible for notifications are on the same page. Ultimately, this will limit confusion for the public.

5. The PTWC and NTWC were accurate with their forecasts and recommendations that there was no tsunami threat for most U.S. regions. State emergency managers work with state tsunami scientists during these events to confirm the tsunami forecasts. Continued consulting with state and university tsunami scientists about the tsunami hazard before, during, and after events helps emergency managers with their decision making, even confirming that there is no tsunami threat.
6. It is recommended that lessons learned and potential follow up actions be discussed via the National Tsunami Hazard Mitigation Program (NTHMP) Warning and Coordination Subcommittee which has served as an effective discussion forum to inform the NTWC and PTWC of issues of concern to states and territories following events. Adding just a couple of words in the purple "Tsunami Threat" bar, that this bar *only applies to non-U.S. international customers* would clarify the messaging. It is noted that this information is in international bulletins. The graphics should conform to what needs to be seen by U.S.-based customers and protocols.

## 5 ACKNOWLEDGEMENTS

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