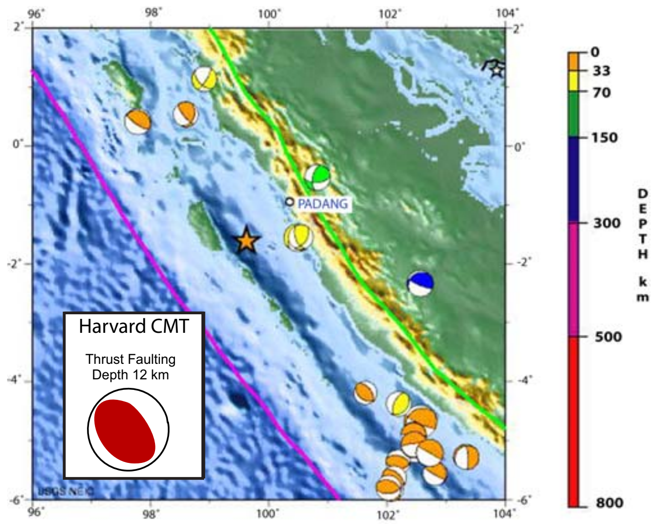
OFF SOUTHERN SUMATRA, INDONESIA, M_W=6.7, 10 APRIL 2005, 11:14 UTC



An earthquake off Southern Sumatra, Indonesia occured on 10 April 2005, measured M_W 6.7 (HRV). It was smaller and further south than the two previous large earthquakes off the coast of Sumatra. (*see Figure 2 in 28 March 2005 section*).

A tsunami with a wave height of 40 cm was observed at Padang, Sumatra. The account cannot be supported with tide records, as the gauge at Padang was out of service at the time of the earthquake.

Figure 1 (left). Historical Moment Tensor Solutions with recent earthquake location marked by orange star. (Map from NEIC).

OFF NORTHERN CALIFORNIA, USA M_W=7.2, 15 JUNE 2005, 02:51 UTC

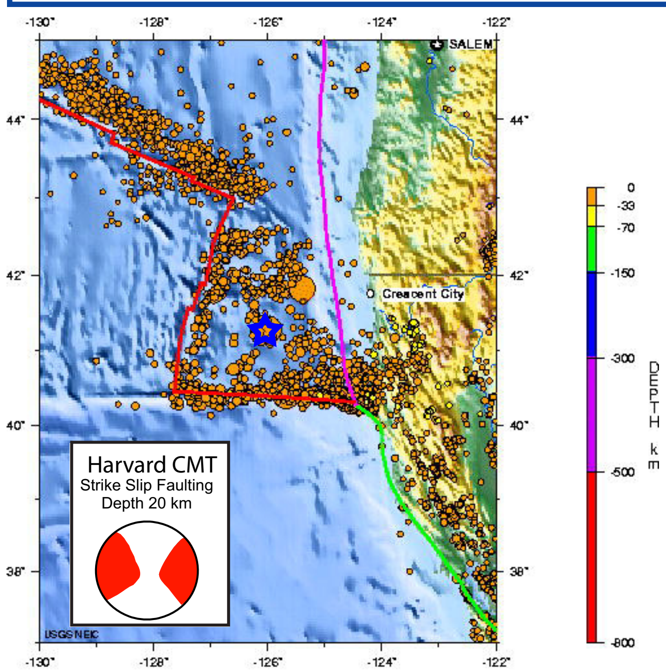


Figure 1. Map showing the location of the earthquake (blue star) and the historic seismicity of the area, with plate boundaries in red and purple. (Map from NEIC).

A major earthquake with a moment magnitude of 7.2 (HRV) occurred at 0251 UTC 15 June (7:51pm 14 June, local time) and was located off the northern coast of California. USA (41.3°N 125.7°W).

The earthquake produced a minor tsunami that was observed at Crescent City, California, USA (41.75°N 124.1°W) approximately 20 cm (p-t) (NOS). (Information posted on the West Coast/Alaska Tsunami Warning Center website, URL: *http://wcatwc.arh.noaa.gov/06-15-05.htm*, which links to the Crescent City tide record and to a raw data file for the earthquake).

Tide gage site	Wave height (cm p-t)	Arrival time (UTC)	ETA (UTC)	Initial motion	Sample Interval (min)	Data File
Crescent City, California, USA	20	approx 0335 06/15	0329 06/15	recession	1	Data (m) starting at 0000 UTC 06-15-05

15 JUNE 2005 EARTHQUAKE AND TSUNAMI

by Dr. Alexander Rabinovich, rabinovicha@pac.dfo-mpo.gc.ca, and Fred Stephenson, Canadian Hydrographic Service, stephensonF@pac.dfo-mpo.gc.ca, both at Institute of Ocean Sciences, P.O. Box 6000, Sidney, B.C. CANADA V8L 4B2.

At 02:51 UTC on 15 June 2005 (14 June at 19:51 local time) an earthquake occurred approximately 145 km northwest of Eureka, California (Figure 1). The magnitude of this earthquake was initially estimated as M_W=7.4, but was later corrected to M_W=7.2 (USGS, CISN). The epicentre coordinates were 41.28ºN, and 125.98ºW (USGS). Based on the earthquake's location and magnitude, the West Coast and Alaska Tsunami Warning Center (WC/ATWC) in Palmer, Alaska issued a Tsunami Warning for all coastal areas from the California – Mexico border to the north end of Vancouver Island (Cape Scott). This warning was issued at 02:56 UTC, i.e. 5 minutes after the main shock. In British Columbia the message was received by the Provincial Emergency Program (PEP), who initiated their tsunami response plan. Within half an hour of there

California, *continued*

being a possibility a wave could hit, 26 communities on the west coast of Vancouver Island were contacted to make sure they were moving on their plans.

Immediately following the earthquake, Dr. Vasily Titov (PMEL/NOAA, Seattle), utilized the prototype of the NOAA Tsunami Forecast System under development by PMEL to predict tsunami amplitudes at five DART stations in the Northeastern Pacific. He sent his first results to the ITIC Tsunami Bulletin Board at 03:16 UTC (20:16 PDT), i.e. 25 minutes after the earthquake. He estimated tsunami heights and travel times for the DART buoy locations and found that even for the closest one (DART 46405) the generated tsunami would have amplitudes less than 1.5 cm.

Tide stations along the west coasts of the US and Canada were monitored for evidence of a tsunami wave, however, no water level changes were observed at coastal sites (Figures 1 and 2). Therefore, based on this information and numerical results by Vasily Titov, the WC/ATWC determined that a destructive tsunami had not been generated and cancelled the Tsunami Warning at 04:09 UTC (21:09 PDT).

In British Columbia, Canadian Hydrographic Service staff continued monitoring six tide stations along the outer B.C. coast and detected weak tsunami waves (greater than 4 cm) at two stations: Tofino and Bamfield (Figure 2). Estimated tsunami arrival time (ETA) to Tofino, 04:57 UTC (20:57 PDT) was in good agreement with the actual tsunami arrival time of 04:51 UTC. This first observed wave was negative (ebb) and the exact trough-to-crest height of this first wave was 3.3 cm. A few minutes later, at 04:56 UTC, a tsunami wave (also negative) arrived at Bamfield with a wave height of 1.8 cm; the maximum wave height at Bamfield (third wave) was 2.6 cm.

The first tsunami waves observed at Tofino were irregular, however, approximately 1 hour after the first arrival (at 05:58 UTC) a train of regular waves with a typical period of about 20 min came to Tofino and were observed there for about four hours (Figure 2). Maximum trough-to-crest wave height was 4.3 cm. It may be assumed that this train of waves was associated with edge waves propagating from the source area northward along the coast of North America. Further intensive analysis of other BC records also identified some tsunami signatures in records of Winter Harbour and Port Hardy, but they were quite small (< 1 cm). For the near-field US coast (Figure 2), tsunami waves were detected in the records of two DART buoys (Figure 3) and four coastal tide gauges (Figure 2).

At Crescent City, California, the station closest to the epicenter the tsunami waves arrived at 03:37 UTC and had a trough-to-crest height of 27.7 cm. The tsunami oscillations at this station were quite steady (Figure 3) with an observed period of about 22 min. At three

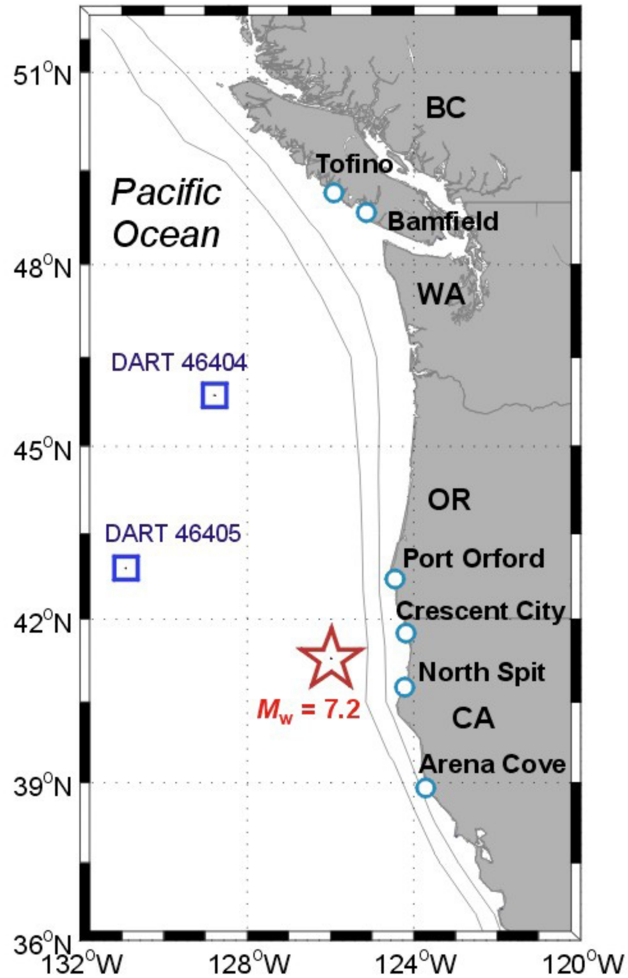


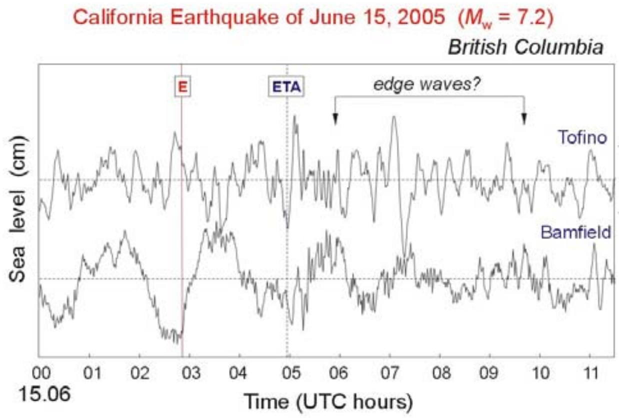
Figure 1. Locations of earthquake, DART systems, and coastal sea level stations recording the 15 June 2005 tsunami.

other stations, Port Orford, North Spit and Arena Cove, the tsunami signal was much weaker. The two latter stations were also very noisy. High-frequency noise associated with infragravity waves (generated by non linear interaction of wind waves and swell) caused serious difficulties in detecting and estimating tsunami arrival times, periods and amplitudes for the North Spit and Arena Cove tide gauges. To reduce this problem, we low-pass filtered the time series with a 6-minute Kaiser-Bessel window. Finally, from the records at these four stations (Figure 2) the following tsunami characteristics were estimated:

	Arrival (UTC)	Travel time (min)	Max wave height (cm)	Period (min)
Port Orford	03:47	56	4.0	17
Crescent City	03:37	46	27.7	22
North Spit	03:19	28	4.7	28
Arena Cove	03:49	58	6.5	irregular

At all four stations the first recorded tsunami wave was negative.

California, *continued*



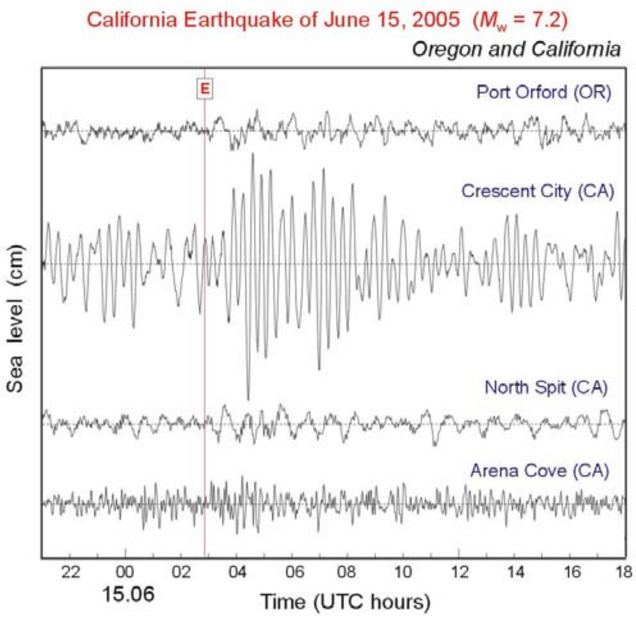


Figure 2. Sea level records from 15 June 2005 tsunami at Tofino and Barmfield, British Columbia, Canada (Data courtesy of Canadian Hydrographic Service), and at stations in Oregon and California, USA (Data courtesy of NOAA). Station locations shown in Figure 1.

Tsunami waves generated by the California earthquake were also recorded by two DART buoys, 46404 and 46405, located in the vicinity of the earthquake epicenter (Figure 1). Actually, both instruments first recorded seismic surface Rayleigh waves that arrived to DART 46405 at approximately 02:53:15 UTC (i.e. about 2 minutes, 21 seconds after the main shock) and to DART 46404 at about 02:53:45 UTC (in 2 minutes, 51 seconds). The ground oscillations at DART 46405 were from -11 cm to +4.5 cm (Figure 4) and these strong oscillations initiated an automatic alarm and 15 second data recording and transmitting. The Rayleigh oscillations at DART 46404 were approximately ±1 cm (Figure 3).

As predicted by Titov's computation, the observed tsunami waves at these offshore locations were quite small. The first tsunami wave arrived to DART 46405 at 03:28:45 UTC (about 38 minutes after the main shock). It was positive (+0.78 cm). The first wave came to DART 46404 at 03:43:45 UTC (in 53 minutes) and it was negative (-0.38 cm).

The warning issued on 15 June 2005 was the first tsunami warning on the B.C. coast since the 1994 M_W=8.2 Shikotan earthquake and tsunami (Southern Kuril Islands) and the first warning after the catastrophic M_W=9.3 megathrust Sumatra tsunami in the Indian Ocean. How has our response changed since that time? The evaluation report compiled following the 1994 event indicates the main challenge was timely communication, both from PTWC to the Member States and, within British Columbia, from the Provincial Emergency Program (PEP) to the various agencies and communities. In British Columbia, messages were sent by fax without prior notification by telephone, and the time between messages (updates) was too long. In 2005, as previously indicated,

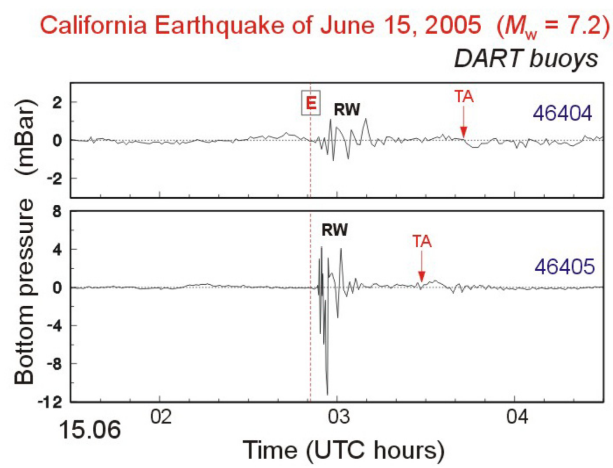


Figure 3. Bottom pressure sensor records from DART system instruments nearest the 15 June 2005 earthquake. Station locations shown in Figure 1. (Data courtesy of NOAA)

the warning information was quickly conveyed to 26 communities at risk. However, communities not at risk were not contacted and in hindsight this was a mistake. All communities want to be informed so that their elected officials and emergency response staff are able to respond to queries from a concerned public. In response to this shortcoming, PEP has upgraded its communications system, installing a new Interactive Voice Response (IVR) system and a high-speed fax server. The present system can now send out up to 1000 messages an hour, providing messages to agencies and communities by the IVR system, but also by fax and e-mail.

The detection and alerting system has also changed significantly since 1994. In 1994 there were very few digital tide gauges in operation and no deep ocean gauges. The earthquake occurred at 1323 UTC, but it was not until 1640 UTC that Bulletin 002 was issued indicating a 3.46m wave at Hanasaki, Japan. Bulletin 004 at 1856 indicated wave heights of 0.15m at Shemya, Alaska and 0.17m at Wake Island, and at

California, *continued*

1940 UTC Bulletin 005 indicated a 0.50m wave at Midway Island. With the observed wave height at Midway Island there was lingering concern of the potential for destructive wave activity in Hawaii and elsewhere. It was not until 2155 UTC that PTWC (Bulletin 006) informed that the tsunami wave height at Hilo, Hawaii had been 0.50m and the Tsunami Warning was cancelled.

On the British Columbia coast our network of tide stations used analogue recorders to measure water levels. Only the tsunami warning stations at Bamfield and Winter Harbour were equipped with digital recorders, and these instruments had to be remotely reset from the standard 15 minute sample interval to a 1 minute sample interval to provide the high sample rate required for tsunami detection. The measured tsunami wave was 22.4 cm at Winter Harbour and 9.2 cm at Bamfield. The analogue records were only recently inspected for evidence of the tsunami and it was determined that three additional stations (Tofino, Port Alberni and Victoria) recorded the tsunami, with the largest wave being 23.7 cm at Port Alberni.

In 1994, the time between the earthquake and the cancellation of the tsunami warning was 8 hours and 32 minutes. Why did it take so long? The location and number of tide gauges able to provide water level information in real-time was a factor, and a denser network of both coastal and deep ocean stations would have been of great benefit. The initial scope of the tsunami warning was too large and was in error, however, the lack of a prediction model integrated with data from deep ocean gauges also compounded the problem.

In 2005, data was received from each of the DART buoys soon after the wave arrival and was used to validate the tsunami model predictions. The tsunami warning was cancelled at 04:09 UTC, shortly after the first observed coastal wave heights were obtained at Crescent City, CA (27.7 cm).

The public's perception of the tsunami warning was also much different in 2005 than in 1994. On 5 October 1994, the front page story in the Victoria newspaper showed people standing on the wharf in Port Alberni waiting for the wave to arrive. A tsunami warning now conveys the horrific images of the December 26th tsunami in the Indian Ocean and the news stories following the June 14, 2005 warning included one of an individual driving out of town at high speed to the top of a mountain more than 1000 feet above sea level! Our tools for detecting and predicting tsunamis are steadily improving, but clearly the need for continued community education is as important as ever.

It should be also emphasized that the California tsunami of 15 June 2005, was probably the first tsunami to be "operationally" numerically simulated, and that the results of this simulation were used to predict tsunami wave heights at several coastal locations. Small predicted values were one of the reasons to cancel the tsunami warning. The prototype source model that was used by Vasily Titov for the 2005 California tsunami simulation gave not only reasonable agreement of observed and predicted wave heights, but also the correct signs of the first wave: negative at coastal sites and positive at DART 46405 supporting the assumption that there was down drop on the coastal side of the source and uplift on the ocean side.

EVALUATION OF U.S. RESPONSE RELEASED

A report evaluating the response to the tsunami potential posed on the evening of 14 June along the Western Coast of the United States, has been published by NOAA's NWS in "*Service assessment West Coast Tsunami Warning, June 14, 2005*". The report's Executive Summary reads as follows:

"At 7:51 p.m. Pacific Daylight Time (PDT) on Tuesday, June 14, 2005, a magnitude 7.2 earthquake occurred 85 miles northwest of Eureka, CA. In accordance with NWS policy, the West Coast and Alaska Tsunami Warning Center (WC/ATWC) issued a tsunami warning at 7:56 p.m. PDT. for areas within a two hour wave travel time of the earthquake. This warning area encompassed coastal areas from the California-Mexico Border to the northern tip of Vancouver Island, British Columbia (BC). The earthquake did produce a small tsunami; a 10-15 centimeter wave was recorded at the Crescent City, CA, tide gage. NOAA tide gage data were received at the Tsunami Warning Centers (TWC) at approximately 9:00 p.m. PDT along with deep-ocean Assessment and Reporting of Tsunamis (DART) buoy data indicating a negligible tsunami. After confirmation that a destructive tsunami did not develop, the WC/ATWC cancelled the warning at 9:09 p.m. PDT.

Emergency management officials at all government levels, media, and citizens in affected communities recognized and appreciated the National Weather Service (NWS) warning efforts. The WC/ATWC quickly disseminated the warning on the National Warning System (NAWAS) as it was circulating through NWS communications to the Weather Forecast Offices (WFOs). Coastal communities who had done preparation work for tsunamis utiltized multiple dissemination system to notify people at risk. The warning prompted the successful evacuation of numerous coastal communities and beaches, created a large amount of public interest, and generated national media coverage. However, not all aspects of the warning system functioned properly during this event.

Due to the relative infrequency of tsunami warnings in the U.S. compared to weather-related hazards, the NWS viewed the 14 June event as an opportunity to improve its role in the tsunami warning system. This

California, *continued*

assessment examines NWS operations and services and provides nineteen recommendations for possible improvements. These suggested courses of action address many facets of the tsunami warning system; from the communications systems used to disseminate information to the effectiveness of the content of the warning messages to the public response to the warning itself.

In summary, the assessment team found that improvements are needed to the tsunami warning product suite in order to provide emergency officials, the media, and the public with information they can understand and quickly act upon. In particular, the format, content, and update cycle should be addressed. Also, procedures at NWS offices need to be formalized and routinely practiced to ensure efficient and consistent tsunami warning operations; likewise, public tests of the tsunami warning system paired with increased outreach through TsunamiReady and other awareness programs will lead to a greater level of community and state-level preparedness for this relatively rare hazard. Finally, enhancements to coordination and collaboration throughout the NWS, and with its partners, are possible to better leverage the knowledge and expertise applied to the tsunami warning process and to the information conveyed to the public. Specific recommendations addressing these issues and others are detailed in the following report."

The chronology of events, as listed in the report's Appendix A, has been incorporated into the following timeline provided by George Crawford (*see below*) The full report is available at *http://www.nws.noaa.gov/om/assessments/pdfs/WestCoastTsunamiFinal.pdf*

Timeline of Emergency Managements Response following the 14 June 2005 Northern California Earthquake

Operational entries (blue) *from NOAA's NWS Service assessment*
"West Coast Tsunami Warning, June 14, 2005,"
(available at http://www.nws.noaa.gov/om/assessments/pdfs/WestCoastTsunamiFinal.pdf)
with Constructive commentary submitted by George Crawford,
Earthquake and Tsunami Program Manager, Washington State Emergency Management Division
Camp Murray, WA 98430-1522 <1>(253) 512-7067, g.crawford@emd.wa.gov.

7:51 PM	A magnitude 7.2 earthquake occurred 85 miles northwest of Eureka, CA (41.4° N, 125.6° W). 7.4 Earthquake, offshore of Crescent City, CA
7:54 PM	Duty personnel arrived at WC/ATWC
7:55 PM	Coordination message sent from PTWC to WC/ATWC
7:56 PM	Tsunami warning issued by WC/ATWC for coastal areas form the California-Mexico border to the northern tip of Vancouver Island, B.C. The Tsunami Warning issued by the West Coast/Alaska Tsunami Warning Center (WC/ATWC) was completed within 5 minutes.
	This warning conflicted with a tsunami warning issued by the Pacific Tsunami Warning Center (PTWC) which stated no tsunami was generated. The PTWC message was intended for international warning system participants.
	Information void between the warning and the cancellation. There is a lack of sea level data available to verify event status.
	Corrective Steps: Tide gauge at Crescent City is being upgraded and additional DART buoys being added along Cascadia.
	Present WC/ATWC hourly updates will be changed to 30 minute updates.
7:57 PM	WC/ATWC initiated National Warning System (NAWAS) announcement of warning. Media received the tsunami warning from the Associated Press (AP).
	Confusion about the WC/ATWC message because PTWC sent a message about 8:00PM saying there was no warning in effect.
	Corrective Steps: Because there is confusion about warnings for Washington, Oregon and California not Hawaii and international participants, a public education plan and program will be developed for the media and public on tsunami warnings.

California, *continued*

7:59 PM	Tsunami Information Bulletin issued by PTWC. State Emergency Operating Centers (EOCs) received Tsunami Warning Message via National Warning System (NAWAS)
	Notified affected jurisdictions via State NAWAS
	Stood by, ready to send a Coastal EAS evacuation warning, via State EAS system if requested by local governments. That request was not received
8:02 PM	NAWAS announcement of WC/ATWC warning was completed.
8:06PM	NWS Seattle tried to transmit a Tsunami Warning Message via Emergency Alert System (EAS) but was unsuccessful because of circuit problems between NWS Seattle and USCG Microwave system to Bahokus Peak, Octopus Mountain and Miller Peak, all on the Olympia Peninsula. The EAS warning was transmitted over their working circuit at Capital Peak to the Grays Harbor area. They tried to transmit the EAS warning message only over coastal NOAA transmitter sites.
	Corrective Steps (actions to be taken by NWS-Seattle office)
	Redundant circuits are being sought to the transmitter sites on the Olympic Peninsula.
	Equipment for Remote On-Air Monitoring (POAM) for all NWS Seattle transmitter sites is to be purchased and installed.
	On September 14, 2005 at 10:45 am, an EAS warning test will be conducted in AK, WA, OR, CA, and HI to test communication protocols.
	NWS Seattle will now transmit Tsunami warnings over all transmitter sites in Western Washington, coding the warning for the 14 counties that may be affected.
8:10 PM	Oregon Warning Point announced PTWC Bulletin on NAWAS –"no tsunami warning is in effect." WFO Medford called Oregon Warning Point and corrected them. The California State Office of Emergency Services (OES) sent a message to the County Emergency Operations Centers (EOCs) that said "no tsunami warning was in effect at 8pm". The exact time of the California OES message could not be verified.
	At approximately 8:10 pm, media interview requests and phone calls began flooding into the offices.
8:11 PM	NWS Portland transmitted a tsunami warning with a header for EAS activation the Pacific County that was received by some NOAA Weather Receivers and the tsunami warning was broadcasted by AM/FM and TV broadcast stations. The lack of receipt of EAS message was due to poor signal quality.
	Corrective Steps: NWS-Portland is taking action to fix poor signal quality in lines by end of July 05.
	Clallam County issued an evacuation order for its county via their Local EAS system. Local AM/FM/TV Broadcasters relayed alert, with one station manually relaying due to receiver problems. Quileute and Makah Tribes evacuated.
	Grays Harbor, Jefferson County, and Pacific Counties elected to not send an EAS message and waited to see what happened in Crescent City. Hoh and Quinault Tribes evacuated. Counties reported that most beaches were cleared as well as self-evacuation.
	About 8:40PM, EMD PIO talked to KOMO Radio and to KING TV. The media asked who should evacuate noting that the WC/ATWC message advised people "on the beach" to seek higher ground while people in "low lying areas" were to await instructions from local authorities. EMD advice for homeowners at Ocean Shores and Long Beach was to heed the warning and move to higher ground.
	Corrective Steps: WC/ATWC developing a new public warning message to eliminate confusion. Local, state and federal officials are discussing how to improve the warning notification system for coastal residents and visitors. Improvements discussed included: Additional All Hazard Alert Broadcasting (AHAB) Radio sirens.
	Expanded dissemination of the warnings through NOAA weather radios, Emergency Alert System broadcasts and AHAB Radio siren systems.

California, *continued*

8:15 PM	Predicted time of arrival of possible tsunami at Cape Mendocino, CA. This was the earliest wave arrival prediction.
8:16 PM	NOAA Pacific Marine Enviornmental Laboratory (PMEL) ran experimental forecast. Forecast predicts one centimeter tsunami at DART Station off the Oregon Coast at 8:40 pm.
8:52 PM	WC/ATWC called PTWC to discuss canceling the warning. PTWC provided evaluation of Crescent City tide data.
9:09 PM	Tsunami warning cancelled by WC/ATWC for coastal areas from the California-Mexico Border to the northern tip of Vancouver Island, B.C.
9:11 PM	Washington State EOC received Tsunami Cancellation Message via National Warning System (NAWAS).
9:12 PM	NAWAS issued announcement of WC/ATWC warning cancellation.
9:17 PM	State EOC relays Tsunami Cancellation Message via National Warning System (NAWAS).
9:52 PM	Tsunami cancellation statement is corrected for errors* by WC/ATWC.

NEAR EAST COAST OF HONSHU, JAPAN M_W=7.2, 16 AUGUST 2005, 02:46 UTC

An earthquake measuring 7.2 M_w (HRV) occured east of the Japanese Island of Honshu on 16 August 2005 at 2:46 UTC (Figure 1). The location of the earthquake was calculated to be 38.2º N and 142.1º E, with a depth of 37km. At least 39 people were injured in Miyagi, nine in Iwate, five in Fukushima and three Saitama Prefectures. One building was destroyed at Kazo and one damaged at Sendai. Power outages and landslides occurred in various locations in northern Japan.

A local tsunami was generated with a wave height of 10 cm on the coast of northern Japan (Figures 2,3 and Table next page). Wave heights were recorded at several tide stations along the coast of Honshu, with the largest wave height of 13 cm recorded at Ayukawa in Miyagi Prefecture.

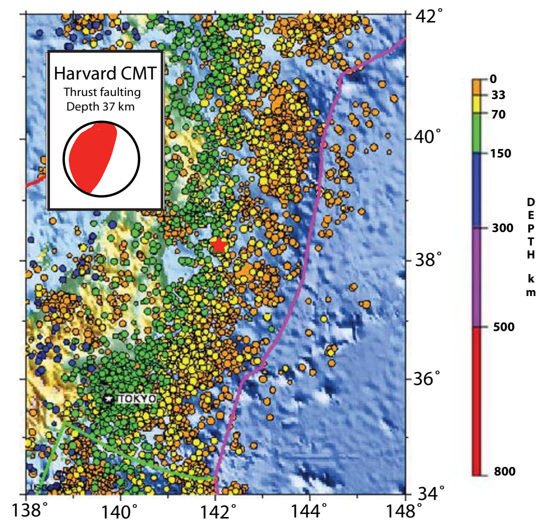


Figure 1. Historical seismicity observed in the region. The epicentre of the 16 August 2005 earthquake is shown by the red star. The purple line indicates the Japan Trench. (Map from NEIC).

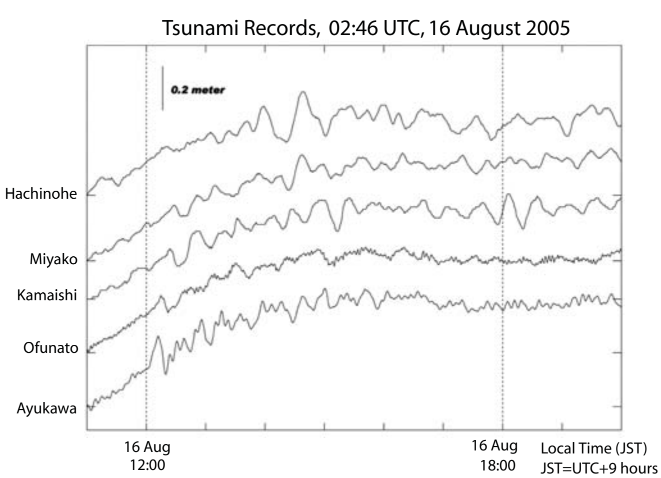


Figure 2. Sea level records recording tsunami. (Data and charts courtesy of JMA).

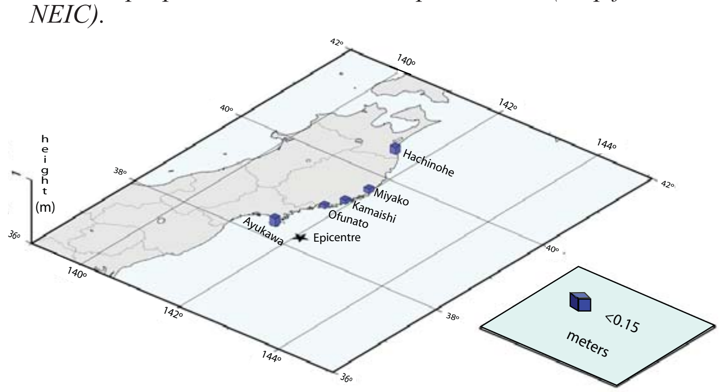


Figure 3. Observed tsunami heights from the 16 August 2005 earthquake as reported by JMA. The map shows the reported run-up heights along the Tohoku Coast. The blue bars indicate maximum wave height of less then 15 cm. above mean sea level.