A summary of the rapid response and analysis of tsunamis in 2012 (from April 2012 to March 2013)

Anawat Suppasri *, Abdul Muhari *, Muzailin Affan ** and Fumihiko Imamura *

1. Introduction

Twelve earthquake generated tsunami events presented in the global historical tsunami database (NGDC, 2013) during April 2012 and March 2013. In this period, the earthquake magnitudes varied from 6.3 to 8.6, and the measured tsunamis were up to 3 m. In this report, we summarize our rapid analysis of four major tsunami events occurring in 2012 (from April 2012 to March 2013), namely, Sumatra tsunami, Indonesia (11th April 2012), Queen Charlotte tsunami, Canada (28th October 2012), Miyagi Sea tsunami, Japan (7th December 2012) and Santa Cruz Islands, and Solomon Islands (6th February 2013), as shown in Fig. 1 and Table 1. These rapid analyses were conducted to provide information regarding the predicted areas that potentially experienced damage and where emergency response may be urgently needed. Additionally, we aim to estimate whether the above events have impacted the area of Japan. Among them, the last event in the Santa Cruz Islands was the only event that caused damage in local areas, including ten deaths. These results were published soon after the event on the Tsunami Engineering Laboratory homepage (http://www.tsunami.civil.tohoku.ac.jp/hokusai3/E/index.html).

For each tsunami event, we summarized the news, impact information, fault type and parameters and the simulated tsunamis. Even though these rapid analyses consist of the preliminary results of numerical simulations, this approach is capable of determining the complexity of recent tsunamis. In this fiscal year, our team, those who participated and performed the analyses, includes research staff and students belonging to the International Research Institute of Disaster Science (IRIDeS), Tohoku University, as shown in Table 2.

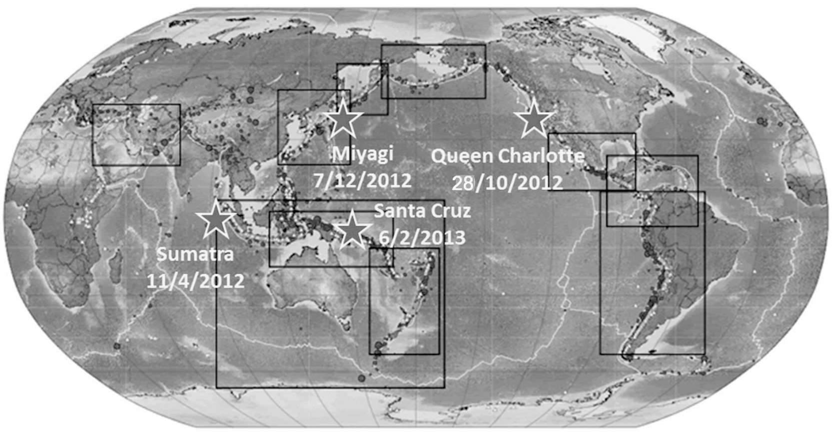

Fig. 1 Major tsunami events in fiscal year 2012 (From April 2012 to March 2013) (Figure source: USGS (2013))

*International Research Institute of Disaster Science,Tohoku University

** Unsyiah University

Table 1 A summary of earthquake generated tsunami events in 2012 (from April 2012 to March 2013)

Date	Time (UTC)	Location	Epicenter	M_w	Depth (km)	Damage	Max. measurement and location (Total damage)
11/4/2012	08:38	Off W. coast of N. Sumatra	2.327N 93.063E	8.6	20	No	1.08 m:Meulaboh port, Sumatra
28/10/2012	03:04	British Columbia	52.788N 132.101S	7.7	14	No	0.76 m: Kahului,Maui, HI
12/7/2012	08:18	Off E. coast of Honshu	37.889N 144.090E	7.3	36	No	1 m: Ishinomaki
6/2/2013	01:12	Santa Cruz Islands	10.738S 165.138E	8.0	29	Yes	3 m: Nela village, Nendo Island (10 deaths 1,060 houses)

Table 2 The identities and divisions of the research members participating in the rapid tsunami analyses in IRIDeS from April 2012 to March 2013

Research division	Research filed	Position	Name
Hazard and risk evaluation	Tsunami Engineering	Professor	Fumihiko Imamura
		Assistant professor	Kentaro Imai
		Research fellow	Abdul Muhari
		Visiting researcher	Hiroyuki Kimura
		Doctoral student	Prasanthi Ranasinghe
		Master student	Soichiro Shimamura
			Yosuke Suda
			Akihiro Hayashi
			Kohei Hashimoto
		Undergraduate student	Akifumi Hisamatsu
			Shigeto Horiuchi
	Remote sensing and geoinformatics for disaster management	Doctoral student	Muzailin Affan
	Science and technology for low-frequency risk evaluation	Assistant professor	Daisuke Sugawara
Disaster information management and public collaboration	Disaster digital archive	Assistant professor	Shosuke Sato
Endowed research division	Earthquake induced tsunami risk evaluation	Associate professor	Anawat Suppasri
		Research associate	Yo Fukutani
		Research associate	Yoshi Abe

2. Sumatra tsunami, Indonesia (11th April 2012)

2.1 Background and impact summary

Approximately eight years after the 2004 Indian Ocean earthquake (M9.3) and tsunami, a doublet outer-rise earthquake of M8.6 and M8.1 occurred near the rupture zone of the 2004 event, causing tsunami warnings in many countries in the Indian Ocean. This is the largest outer-rise event recorded to date by modern equipment. However, due to the strike-slip type of the earthquake, no devastating damage was reported in any country surrounding the Indian Ocean, and only a small tsunami was observed. Even though a tsunami measuring only less than one meter was recorded on the tide gauges in Indonesian territory, and approximately 0.30 meter in Thailand, the strong earthquake prompted people in coastal areas to evacuate.

In Indonesia: In Banda Aceh city, which was devastated during the 2004 Indian Ocean tsunami, the tsunami warning was disseminated 5 minutes after the earthquake. However, the warning was not able to reach the community due to the lack of coordination among the local authorities, the electricity shut-down after the earthquake and the malfunctioning of the siren system. Nevertheless, people evacuated based on their historical memory of the previous strong earthquake. A questionnaire survey was initiated to assess people's behavior during the evacuation in Banda Aceh. A total of 220 respondents were interviewed three weeks after the event. Most of these individuals said that they evacuated soon after the earthquake (Fig. 2) but, unfortunately, that most of them also were trapped in a traffic jam (Fig. 3) because they primarily used motorcycles to evacuate (Fig. 4). The photograph presented in Fig. 5 confirms the above situation, where further mitigation efforts seem to be urgent with regard to avoiding such situations in the future.

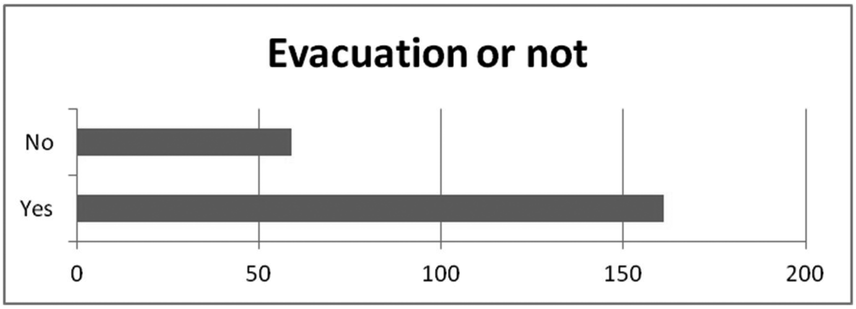

Fig. 2 The number of respondents who did and did not evacuate during the 2012 Indian Ocean earthquake in Banda Aceh

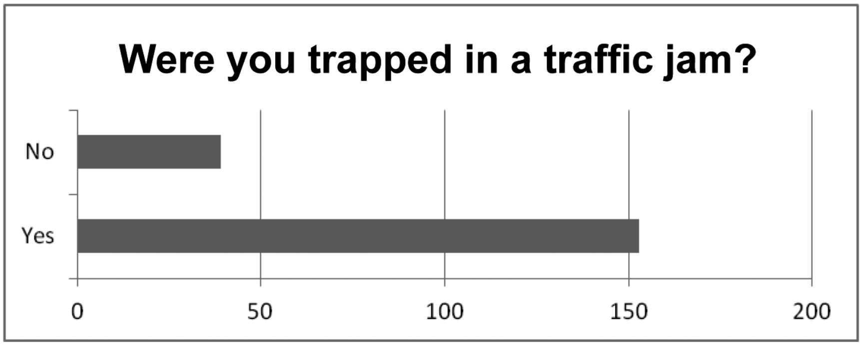

Fig. 3 The number of respondents who were trapped in a traffic jam during the evacuation

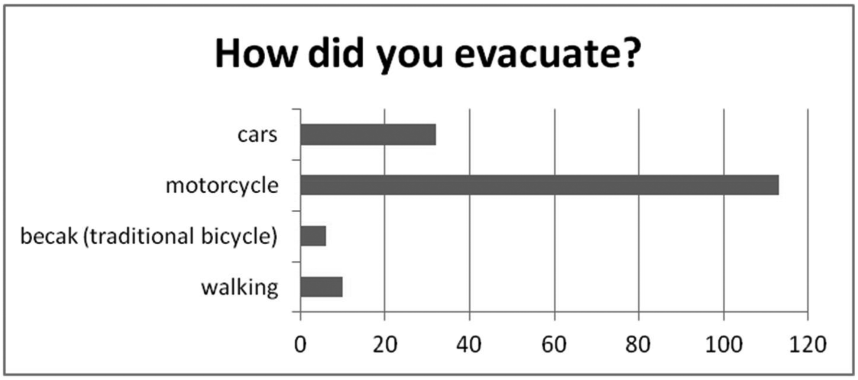

Fig. 4 The condition indicates that most respondents used motorcycles and cars for evacuation

Fig. 5 The traffic situation in an intersection in Banda Aceh City during the evacuation after the 2012 Indian Ocean earthquakes

In Thailand: Thailand also was damaged by the 2004 Indian Ocean tsunami. Although no damage resulted from the tsunami in 2012, it nonetheless created serious traffic jams in the popular tourist areas in Phuket. This situation was similar to that in Banda Aceh city in Indonesia. Patong beach in Phuket is an example in which both tourists and local citizens evacuated soon after using both cars and motorcycles, which caused extensive traffic jams throughout the area. However, no traffic jam occurred in Nam Khem village, which was the area most devastated by the 2004 tsunami. This outcome occurred because the village had established a traffic system, and the staff was well trained for emergency situations. Therefore, the evacuation and traffic were well managed, and the process proceeded smoothly during the 2012 tsunami. For example, in Nam Khem village, the preparedness that was achieved during normal times was able to help decrease the impact during the emergency.

2.2 Tsunami source model and seismic deformation

We used the moment tensor solutions provided by USGS (2012) and the global CMT (2012) project, as summarized in Table 3. These parameters were applied using the equations of Well and Coppersmith (1994) to obtain the rupture dimension as well as the sea floor dislocation that are used to calculate the sea floor deformation, which is performed using a static deformation model (Okada, 1985), where the results are shown in Fig. 6.

Table 3 The Tsunami source model

Parameters	Case 1 (USGS)	Case 2 (USGS)	Case 3 (CMT)
Length / Width (km)	210 / 105	124 / 124	210 / 105
Slip (m)	4.9	7.0	4.9
Strike / Dip / Rake	108 / 87 / 170	199 / 80 / 3	289 / 89 /154
Depth (km)	30	30	40

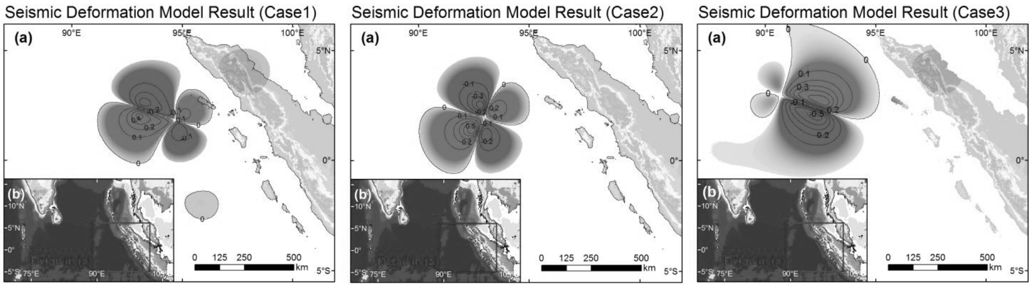

Fig. 6 The modeled seismic deformations

2.3 Simulation conditions and results

We performed tsunami numerical simulations based on linear shallow water equations and using the leap-frog finite difference method (TUNAMI code of the Tohoku University) in a grid size of 1 arc-min. Bathymetry and topography data were obtained from the General Bathymetric Chart of the Oceans (GEBCO) (2012). The distribution of the maximum tsunami height and a comparison between the simulated and observed tsunami waveforms are shown in Figs. 7 and 8, respectively.

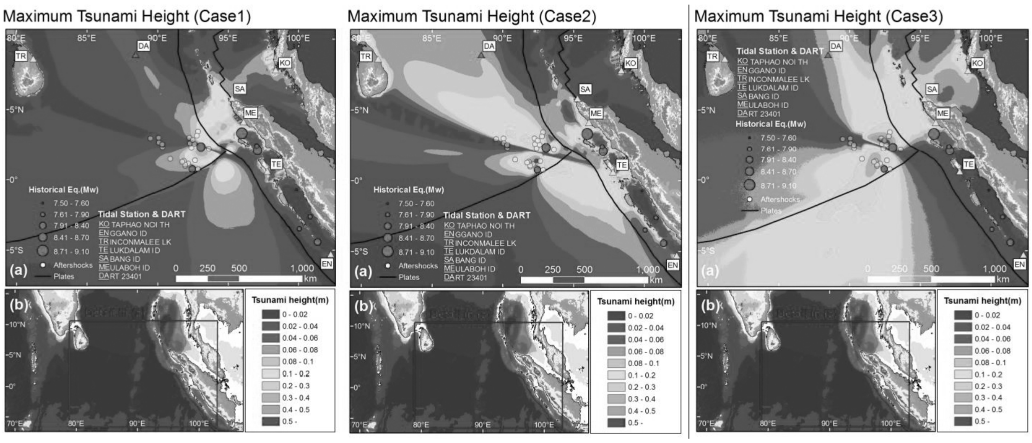

Fig. 7 The simulated maximum tsunami height distributions

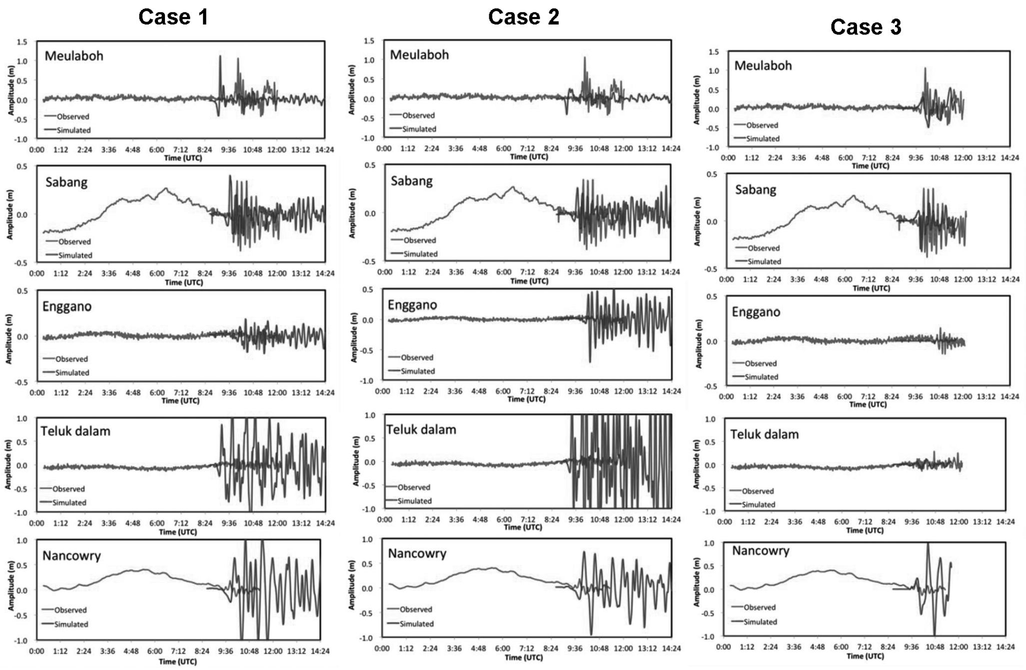

Fig. 8 A comparison between the simulated and observed tsunami waveforms

3. Queen Charlotte Islands tsunami, Canada (28th October 2012)

3.1 Background and impact summary

An earthquake with magnitude M = 7.7 occurred at the Queen Charlotte Islands region, which lines the boundary between the North American Plate and the Pacific Plate. Before the 2012 event, three large earthquakes had occurred in this area within the last hundred years, including M7.0 in 1929, M8.1 in 1949 and 7.4 in 1970. The 1949 event was Canada's largest earthquake ever recorded, since the 1700 Cascadia earthquake. The event in 1949 and other small events in the same area were strike-slip events, but the event in 2012 was a reverse fault event. Consequently, the maximum tsunami recorded (PTWC, 2012) due to the M8.1 earthquake in 1949 was 0.61 m by eyewitness, 0.08 m at a tide gauge station in Alaska and approximately 0.1 m at tide gauge stations in Hawaii. However, the 2012 M7.7 earthquake generated a maximum tsunami as high as 0.46 m in California and 0.76 m in Hawaii, based on the measurements at tide gauge stations. Although no destruction was caused by the tsunami, it nonetheless widely impacted many regions, especially Hawaii. Hawaii was far from the earthquake source but was located directly in the tsunami's propagation direction. Fig. 9 (left) shows examples in Hawaii of people who ignored the tsunami evacuation by waiting to watch the tsunami approach. Additionally, in Fig. 9 (right), many people began storing food and gasoline soon after they heard the tsunami news and warnings.

3.2 Tsunami source model and seismic deformation

We used the solutions provided by USGS and the global CMT project, as summarized in Table 4. The results of the seismic deformation are shown in Fig. 10.

Figure 9 Left: People in Hawaii were waiting to see the tsunami (New Zealand Herald, 2012), Right: People stored gasoline after learning of the tsunami warning (Daily telegraph, 2012)

Table 4 The tsunami source model

Parameters	Case 1 (USGS)	Case 2 (CMT)
Lat. / Lon.	52.769 / 131.93	52.47 / 132.13
Length / Width (km)	95 / 47	95 / 47
Slip (m)	3.2	2.3
Strike / Dip / Rake	118 / 74 / 84	135 / 63 / 79
Depth (km)	11	15

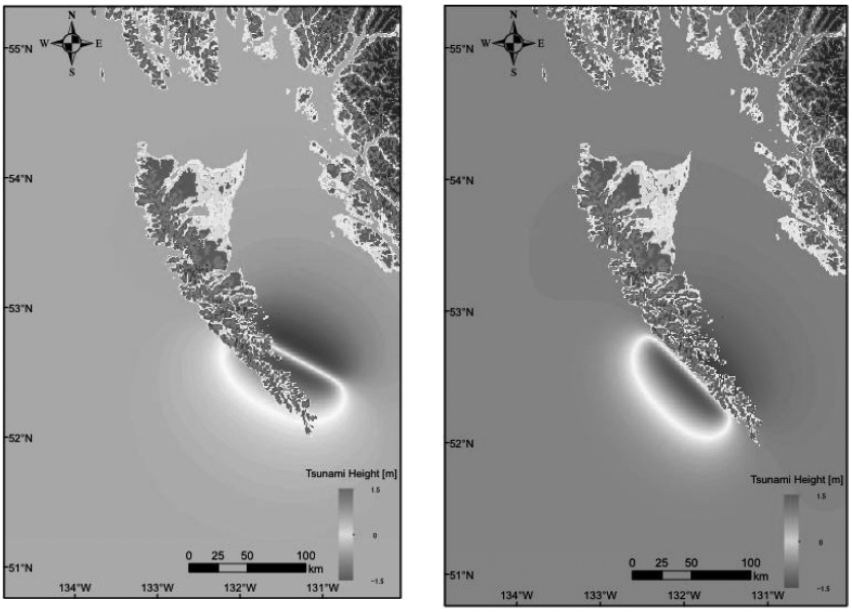

Fig. 10 The results of the seismic deformation model

3.3 Simulation conditions and results

We performed tsunami numerical simulations based on the linear shallow water equations using the leap-frog finite difference method (TUNAMI code of the Tohoku University) with a grid size of 1 arc-min. Bathymetry and topography data were obtained from the GEBCO (2012). The distribution of the maximum tsunami height is shown in Fig. 11.

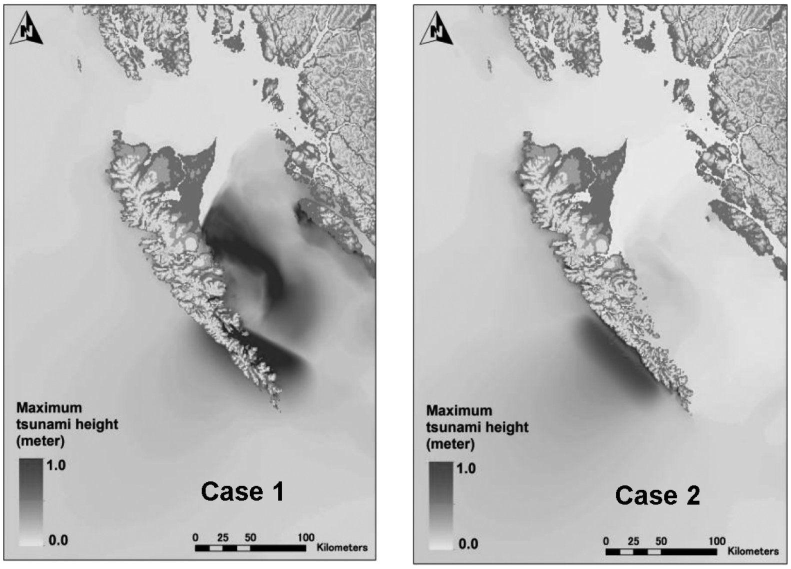

Fig. 11 The simulated maximum tsunami height distribution

4. Off-Miyagi tsunami, Japan (7th December 2012)

4.1 Background and impact summary

Almost two years after the 2011 Great East Japan earthquake (M9.0) and tsunami, an outer-rise normal fault earthquake with M7.2 occurred near the rupture zone of the 2011 event, causing a tsunami warning in the Miyagi prefecture. No devastating damage was reported as a result of this tsunami; however, this tsunami also caused significant traffic in many locations in the Miyagi prefecture, such as Kesennuma city (Fig. 12, Asahi newspaper (2012)), Ishinomaki city (Fig. 12, Kahoku Shinpo newspaper (2012)), Sendai city and Yamamoto town because most of the people evacuated using vehicles. Traffic jam areas occurred inside the inundation zone of the 2011 tsunami. Therefore, significant loss would have occurred if the 2012 earthquake had produced a large tsunami. This problem is similar to that observed in Indonesia and Thailand in April 2012 and must be properly solved.

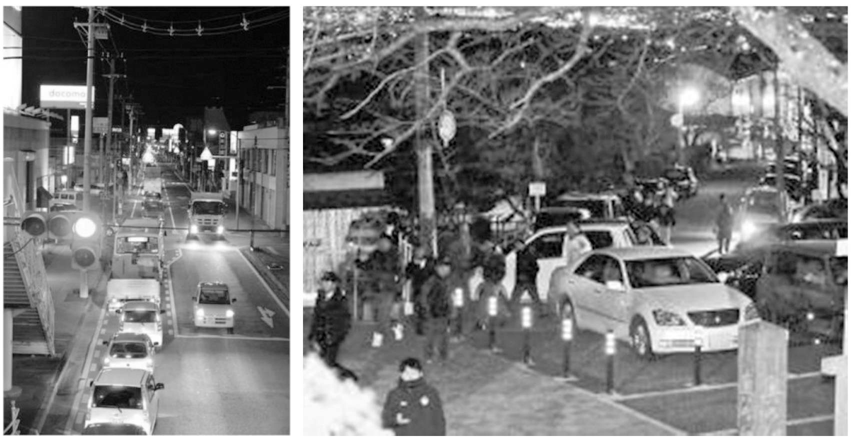

Fig. 12 Traffic jams on the routes to high ground in Kesennuma (Left) and Ishinomaki (Right)

4.2 Tsunami source model and seismic deformation

Several issues regarding earthquake and tsunami generation are discussed. This event is similar to past events, such as the 1933 Showa Sanriku tsunami, which was generated by an outer-rise earthquake that occurred after a thrust fault earthquake, and the Meiji Sanriku earthquake, which generated a large tsunami in 1896. This earthquake was summarized differently among the common internet sources of moment tensor solutions, such as USGS (2012) (reverse fault), GEOFON (2012) (normal fault), NIED (2012) (normal fault) and the global CMT (2012) (doublet earthquake with reverse and normal fault). We used the solutions provided by USGS, GEOFON and the global CMT project, as summarized in Table 5. For the CMT model, we have two cases with two segments for each case. The locations of the two earthquakes are shown in Fig. 13.

Table 5 The Tsunami source model for the Miyagi Sea tsunami, Japan (7th December 2012)

Parameters	Case 1 (USGS)	Case 2 (Geofon)
Lat. / Lon.	37.888 / 144.090	37.650 / 144.590
Length / Width (km)	54 / 27	54 / 27
Slip (m)	2.5	2.2
Strike / Dip / Rake	186 / 85 / 99	23 / 84 / −96
Depth (km)	35	17

Parameters	Case 3 (CMT)		Case 4 (CMT)	
	Segment 1	Segment 2	Segment 1	Segment 2
Lat. / Lon.	38.010 / 144.090	37.770 / 13.830	38.010 / 144.090	37.770 / 13.830
Length / Width (km)	48 / 24	48 / 24	48 / 24	48 / 24
Slip (m)	1.3	1.3	1.3	1.3
Strike / Dip / Rake	38 / 51 /138	18 / 40 /−90	158 / 59 /48	198 / 50 /−90
Depth (km)	57.8	19.5	57.8	19.5

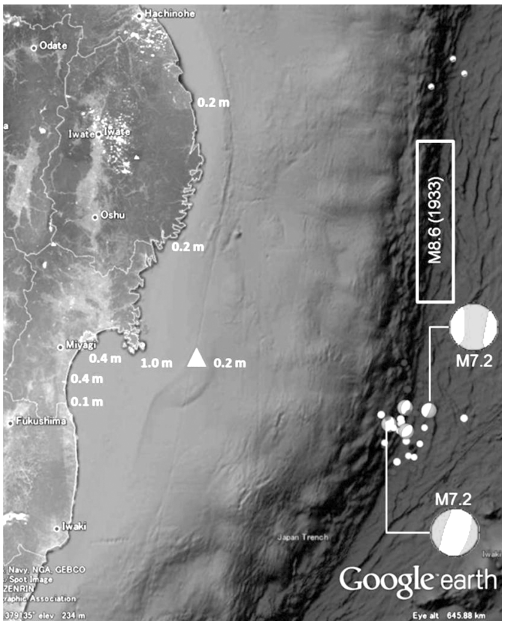

Fig. 13 The location of the doublet earthquakes for the 2012 event and the observed maximum tsunami

4.3 Simulation conditions and results

We performed a tsunami numerical simulation based on the linear shallow water equations using the leap-frog finite difference method (TUNAMI code of the Tohoku University) with a grid size of 2 arc-min. Bathymetry and topography data were obtained from the ETOPO2. The distribution of the maximum tsunami height (Fig. 14) and comparisons between the simulated and observed tsunami waveforms (Fig. 15) and peak tsunami amplitudes (Fig. 16) are shown in the following figures.

5. Santa Cruz Islands tsunami, Solomon Islands (6th February 2013)

5.1 Background and impact summary

An earthquake with M8.0 occurred offshore of the Santa Cruz Islands in the Solomon Islands, generating a local destructive tsunami near the tsunami source. Dozens of foreshocks and aftershocks occurred before and after the main shock. The affected area was mainly in the Temotu Province where the reported tsunami height of 1.5 m damaged or swept away more than a hun-

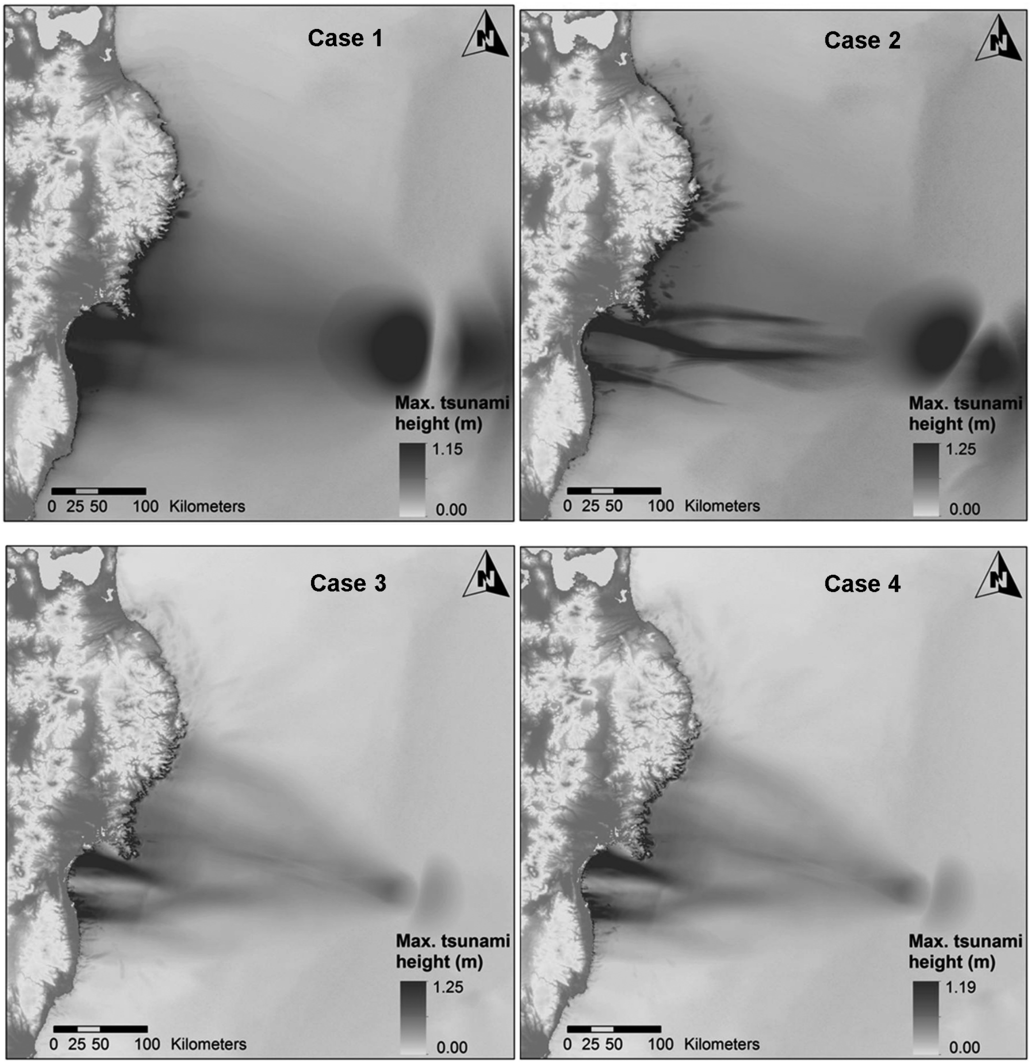

Fig. 14 The simulated maximum tsunami height distribution

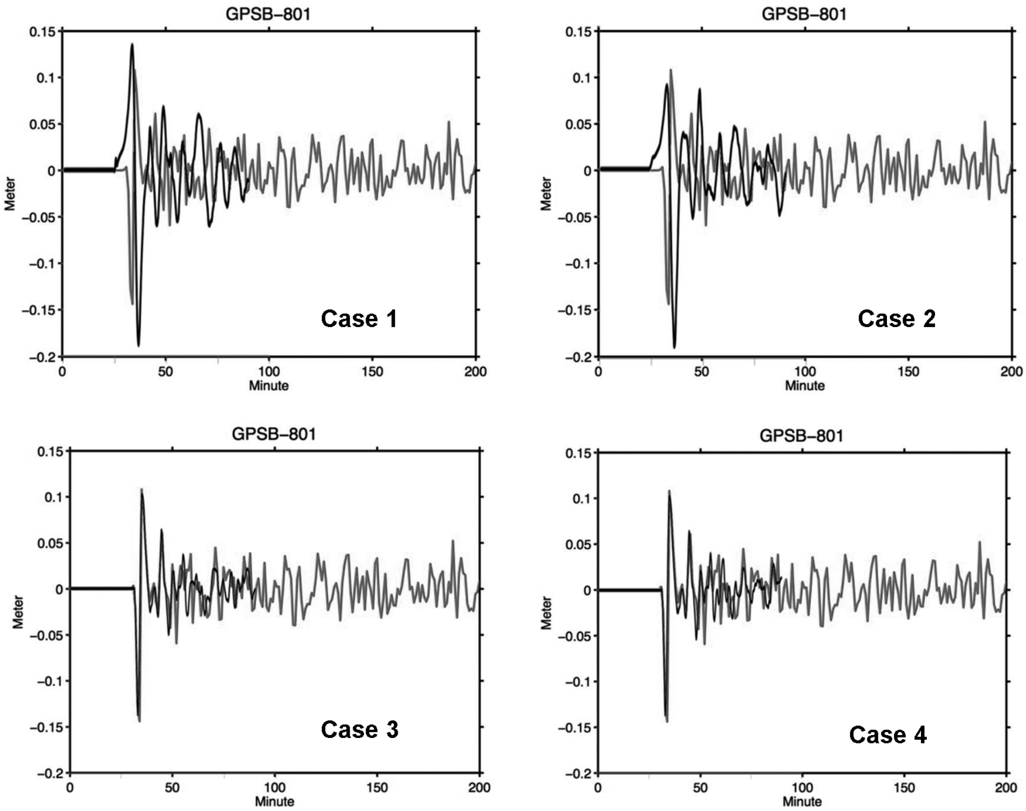

Fig. 15 A comparison between the simulated and observed tsunami waveforms

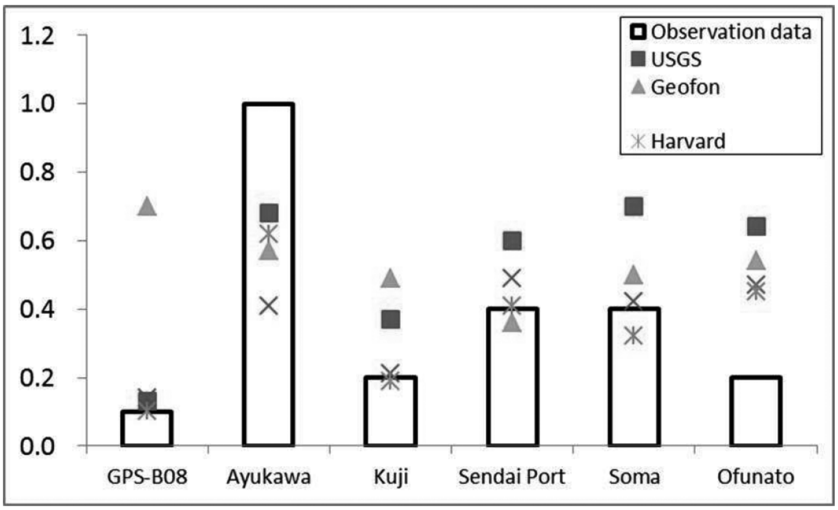

Fig. 16 A comparison between the simulated and observed peak tsunami amplitudes (in meters)

dred houses, claimed at least nine peoples' lives, and displaced more than 3,000 people. In Lata, the capital of the Temotu Province, the airport runway was flooded and the tsunami penetrated inland by approximately 500 m. In total, approximately 1,000 houses were totally or partially destroyed (Fig. 17, OCHA report (2013)). The earthquake and tsunami also caused water and electricity shortages, affecting more than 2,000 people. Smaller tsunamis of 26 cm and 55 cm propagated to Vanuatu and New Caledonia, respectively, whereas a maximum tsunami height of 40 cm was observed in Japan. Tsunami evacuation was observed in some places, such as in the main area of the Solomon Islands and Fiji (Fig. 18, Twitter (2012)), where people evacuated quickly without panic but caused confirmed traffic jams. Evacuation from the far-field tsunami also was observed in Japan. In 2007, the Solomon Islands were struck by a tsunami that was generated by an M8.1 earthquake on 2 April 2007 near the provincial capital of Gizo Island. At that time, the measured maximum tsunami runup was 12 m, which destroyed 900 houses and killed 52 people.

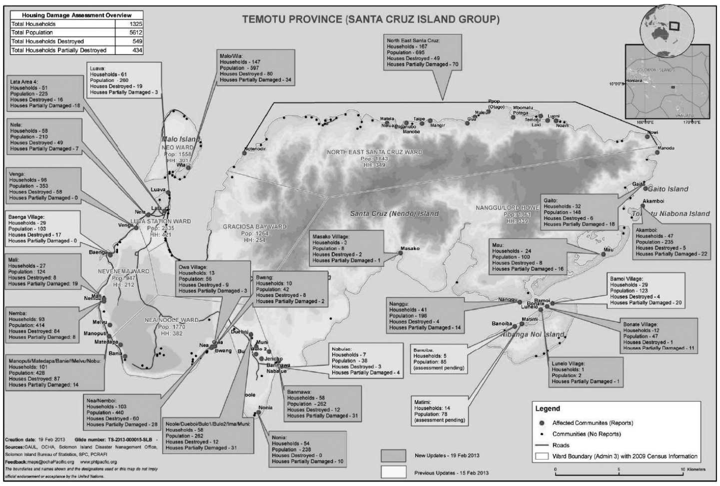

Fig. 17 Damaged houses in the Santa Cruz Islands as of 19 February 2013

Fig. 18 Residents evacuating to higher ground and traffic jams in Fiji

5.2 Tsunami source model and seismic deformation

We used the solution provided by USGS (2013), as summarized in Table 6. The aftershock distribution is shown in Fig.19.

Table 6 The tsunami source model for the Santa Cruz Islands tsunami in the Solomon Islands (6th February 2013)

Parameters	Case 1 (USGS)
Lat. / Lon.	10.751 / 165.088
Length / Width (km)	120 / 60
Slip (m)	5.6
Strike / Dip / Rake	159 / 75 / 99
Depth (km)	11

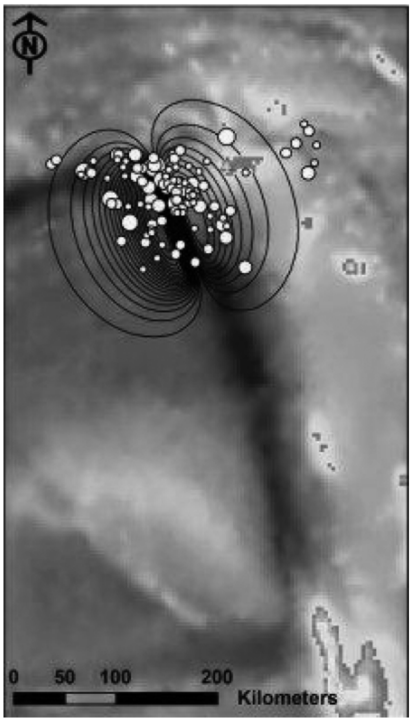

Fig. 19 The aftershock distribution

5.3 Simulation conditions and results

We performed a tsunami numerical simulation based on the linear shallow water equations using the leap-frog finite difference method (TUNAMI code of the Tohoku University) with a grid size of 2 arc-min. Bathymetry and topography data were obtained from the ETOPO2 (2013). The distribution of the maximum tsunami height and a comparison between the simulated and observed tsunami waveforms are shown in Fig. 20.

6. Conclusions

We have reported out results in response to the major earthquake tsunamis that occurred from April 2012 to March 2013, mainly including short discussions of tsunami impact and our tsunami numerical simulations. Among these events, the 2012 Sumatra tsunami and the Off-Miyagi tsunami are similar in that they were the result of an outer-rise earthquake, which occurred following great thrust fault earthquakes in 2004 and 2011, respectively. Both events in 2012 also illustrate examples of the unsolved problems related to tsunami evacuation using vehicles, as seen in Indonesia, Thailand and Japan. The 2012 Off-Miyagi earthquake was modeled using a doublet earthquake mechanism (with rupture time differences and simultaneously) for which satisfactory agreement was found with the observed data. This outcome shows the importance of source model selection in addition to a comparison with the observed waveforms made by the numerical simulation. The 2013 Santa Cruz was the only event that occurred during this one-year period that led to casualties and property damage. The associated field survey activities to estimate the actual impact and lessons are ongoing.

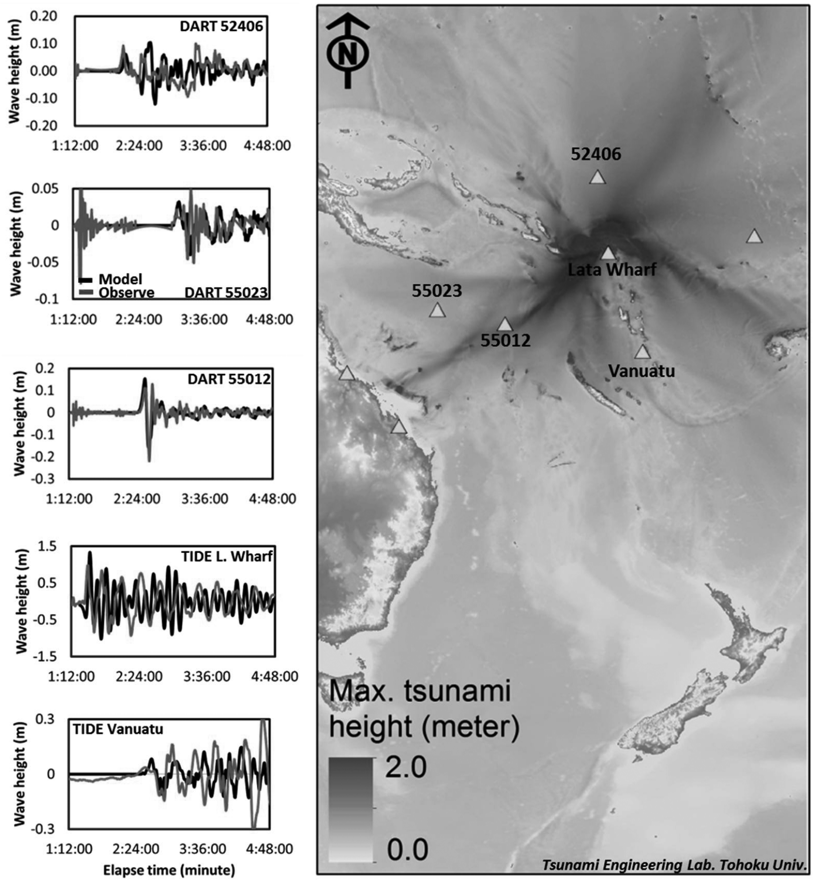

Fig. 20 The simulated maximum tsunami height distribution and a comparison between the simulated and observed tsunami waveforms

References

Asahi newspaper (2012): http://dot.asahi.com/wa/2012121000014.html

Daily Telegraph (2012):
http://www.dailytelegraph.com.au/news/world/tsunami-warning-after-58-canada-quake/story-fnddckzi-1226504780107

General Bathymetric Chart of the Oceans (GEBCO) (2012-2013): http://www.gebco.net/

GEODAS Grid Translator, ETOPO2 (2013): http://www.ngdc.noaa.gov/mgg/gdas/gd_designagrid.html?dbase=grdet1

GEOFON program (2012): http://geofon.gfz-potsdam.de/

Global Centroid Moment Tensor (CMT) Project (2012), Global CMT catalog search: http://www.globalcmt.org/CMTsearch.html

Kahoku Shinpo newspaper (2012) : http://www.kahoku.co.jp/news/2012/12/20121208t73018.htm

National Geophysical Data Center / (NGDC/WDS) Global Historical Tsunami Database, Boulder, CO, USA: http://www.ngdc.noaa.gov/hazard/tsu_db.shtml

National Research Institute for Earth Science and Disaster Prevention (NIED) (2012), Earthquake Mechanism Search: http://www.fnet.bosai.go.jp/event/search.php

New Zealand Herald (2012): http://www.nzherald.co.nz/world/news/article.cfm?c_id=2&objectid=10843568

Office for the Coordination of Humanitarian Affairs (OCHA) (2013) Earthquake and tsunami situation report No.6-Solomon Islands: http://www.phtpacific.org./content/earthquake-and-tsunami-situation-report-no-6

Pacific Tsunami Warning Center (PTWC) (2012): http://ptwc.weather.gov/

Tsunami Engineering Laboratory (TEL) (2013), International Research Institute of Disaster Science, Tohoku University, Modeling the Tsunami of 6 February 2013 in Solomon Islands: http://www.tsunami.civil.tohoku.ac.jp/hokusai3/J/events/Solomon_130206/

Tsunami Engineering Laboratory (TEL) (2012), International Research Institute of Disaster Science, Tohoku University, Modeling the Tsunami of 28 October 2012 in Canada: http://www.tsunami.civil.tohoku.ac.jp/hokusai3/J/events/121028_Canada_2/canada_121028.html

Tsunami Engineering Laboratory (TEL) (2012), International Research Institute of Disaster Science, Tohoku University, Modeling the Tsunami of 11 April 2012 in Sumatra:
http://www.tsunami.civil.tohoku.ac.jp/hokusai3/J/events/Sumatra_120411/sumatra_120411.html

Twitter (2012): https://twitter.com/ArielaZibiah/status/298997606258991105/photo/1

U.S. Geological Survey (USGS) (2012-2013) Earthquake Hazards Program: http://earthquake.usgs.gov/

Wells, D.L. & Coppersmith, K.J., 1994. New empirical relationship among magnitude, rupture length, rupture width rupture area, and surface displacement. Bull. Seismol. Soc. Am., 84(4), 974–1002.

Okada, Y., 1985. Surface deformation due to shear and tensile faults in a half-space. *Bull. Seismol. Soc. Am.*, 75(4), 1135–1154.