# A summary of the rapid response and analysis of tsunami on April 1st, 2014

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## 1. Introduction

An M8.2 earthquake occurred on April 1st, 2014 at 23:46 (UTC) generated a tsunami, and tsunami up to 2.1m (PTWC, 2014). In this report, we summarize our rapid analyses of this tsunami event and a big aftershock as shown in Fig. 1 and Table 1. This rapid analyses was conducted to provide information regarding the predicted areas that could potentially experience damage and where emergency response may be urgently needed. Additionally, we aim to estimate whether the event has impacted the Japan. This tsunami event caused damages in local areas, including six 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) and also reported in a press conference called by Tohoku University's International Research Institute of Disaster Science (IRIDeS).

For this tsunami event, we summarized the news, impact information, fault type and parameters, and the simulated tsunami. In this fiscal year, our team, those who participated and performed the analyses, includes research staff and students belonging to the IRIDeS, as shown in Table 2.

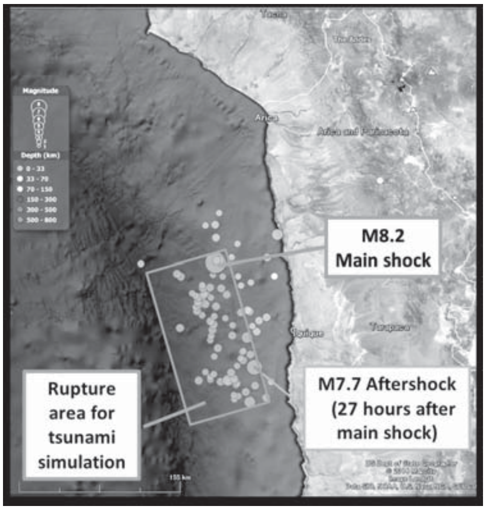


Fig. 1 Main shock and aftershocks (Figure source : USGS,Google Map)

Table 1 A summary of earthquake on April 1st, 2014

| Date | Time(UTC) | Location | Epicenter | Mw | Depth(km) | Damage | Max. tsunami measurement and location(Total damage) |
|---|---|---|---|---|---|---|---|
| 1/4/2014 | 23:46 | Off W. coast of N. Chile | 19.642S 70.817W | 8.2 | 20.1 | Yes | 2.1m:Iquique, Chile (7deaths, 2500houses) |
| 3/4/2014 | 2:43 | Off W. coast of N. Chile | 20.518S 70.498W | 7.7 | 31.1 | No | 0.74m:Iquique, Chile |

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Table 2 The identities and divisions of the research members in IRIDeS, 2014

| Research Division | Reasearch field | Position | Name |
|---|---|---|---|
| Hazard and risk evaluation | Tsunami Engineering | professor | Fumihiko Imamura |
| | | Assistant professor | Kentaro Imai |
| | | Reasearch fellow | Adbul Muhali |
| | | visiting researcher | Yasuo Suzuki |
| | | visiting researcher | Kei Yamashita |
| | | Master student | Shigeto Horiuchi |
| | | | Akifumi Hisamatsu |
| | | | Masashi Watanabe |
| | | | Atsushi Tanobe |
| | | | Fumiyasu Makinoshima |
| | | Undergraduate student | Natsuhiro Kashima |
| | | | Yuuta Hirakawa |
| | | | Tomohiro Yokoyama |
| | Science and Technolo-gyfor low-frequency risk evaluation | Assistant professor | Daisuke Sugawara |
| Disaster information manage-ment and public collaboration | Disaster digital archive | Assistant professor | Shosuke Sato |
| Endowed research division | Earthquake inducedt-sunami risk evaluation | Associate professor | Anawat Suppasri |
| | | research associate | Yo Fukutani |
| | | research associate | Yoshi Abe |

## 2. Background

In the 20th century, there were multiple earthquakes, whose magnitudes ranged from 7.7 to 9.5, occurred along the west coast of Chile. In 1960, a M9.5 earthquake, the largest earthquake in the world occurred and caused approximately 1,655 deaths and $550 million damage in southern Chile (including damages caused by the tsunami), and the resulting tsunami caused 138 deaths and $50 million damage in Japan (USGS, 2014). A M8.8 earthquake in 2010 also generated a tsunami and caused damages in Chile and Japan. In this area where large earthquakes historically occur, the Iquique gap is known as the seismic gap with one of the highest possibility of producing earthquakes (USGS, 2014). However the Iquique gap witnessed no significant earthquake since 1900. On April 1st, 2014 at 23:46 (UTC), a magnitude 8.2 earthquake occurred in the northern part of Chile where the Iquique gap is located. This earthquake generated a tsunami, and tsunami warnings were initially issued for many countries in the west coast of South America but were eventually limited to Chile and Peru. The tsunami also impacted other countries such as the United States (in Hawaii) where the maximum tsunami amplitude of 0.58m was observed (PTWC, 2014) and Japan where at most 0.6m observed (JMA, 2014).

## 3. Impact Summary

*In Chile*: 9 minutes after the earthquake, expanding regional tsunami warnings were issued for coastal countries of South America such as Chile, Peru. Since Chile has been experiencing big earthquakes and tsunamis, nearly one million Chileans evacuated from tsunami (Fig 2). There was no death due to the tsunami, however, many tens of fishing boats are damaged (Fig 3). In this event, most of damages such as road ruptures (Fig 4), building collapse (Fig 5), fire (Fig 6) were caused by strong ground motion (ABC News, 2014). A total of six people were killed after being crushed to death or suffering heart attacks.


Fig. 2 Evacuee in Iquique, Chile (ABC News)

Fig. 3 Tsunami damages in Iquique, Chile (ABC News)

Fig. 4 Ruptued road in Iquique (ABC News)

Fig. 5 Collapsed home in Iquique (ABC News)

Fig. 6 Fire accident in Iquique (ABC News)

A M7.7 aftershock occurred on April 3rd, 2014 at 2:43 (UTC) and generated a tsunami with a height of 0.47m was observed in Iquique (PTWC, 2014).

*In Japan*: Since Japan experienced the Great-East-Japan Earthquake which generated devastating tsunamis in 2011, the Sanriku-oki earthquake in 2012 and the Fukushima-oki earthquake in 2013 which also generated tsunamis, and the tsunamis from Chile in 1960 and 2010, this event attracts a lot of attention in Japan. A tsunami advisory was issued on April 3rd at 3:00 (JST) by JMA and canceled at 18:00 (JST). As a result, some local authorities issued an evacuation advisory and set up shelters. Higashi-Matsushima City issued an evacuation advisory for 1,481 people, 528 households, and set up 15 shelters, however only 12 people used the shelters because of the advisory level. Sendai City issued no advisory but set up shelters which were not utilized by people. The maximum tsunami amplitude observed in Japan was 0.6m observed in Kuji (JMA, 2014), and no injuries or damages are reported. However, considering the tsunami, some businesses in Tohoku region such as shopping malls, railroad operators, and fish markets temporarily suspended their businesses. The Sanriku-Yamada fisherman's association says business loss due to the tsunami will be over 500,000 yen because of the suspension of the oyster culture industry(Kahoku Shimpo).

## 4. Tsunami simulation

A tsunami numerical simulation was performed in order to understand the transoceanic propagation characteristic of this tsunami event as detail shown in following sections.

### 4.1 Tsunami source model and seismic deformation

We used the moment tensor solutions provided by USGS (2014) and the global CMT (2014) project, as summarized in Table 3. These parameters were applied using the equation of Papazachos et al, (2004) to obtain the rupture dimension as well as the sea floor dislocation.

### 4.2 Simulation conditions and results

We performed tsunami numerical simulations based on linear shallow water equations (TUNAMI code of the Tohoku University) in a grid size of 5 arc−min. Table. 4 shows the DART and Tide−gauge location used for the simulation. Bathymetry data was obtained from the ETOPO2 (NOAA, 2014). The distribution of the maximum tsunami amplitude (Table. 5) and a comparison between the simulation (dashed line) and observed (solid line) tsunami waveforms are shown in Figs. 7 and 8, respectively. From the simulation results near the tsunami source, we can see that the first wave was the highest tsunami amplitude that arrived Chilean' s dart within less than 30 min. However, we could not see clearly trend of the waveforms in Japan.

Since these are preliminary results of the simulation in a grid size of 5 arc−min, most of the results of simulation are well matching with observations. However, the maximum tsunami height in japan and the waveform, especially Kamaishi, was lower than the observation. This is due to the calculation condition without non−linear terms.

Table 3 The Tsunami source model

| Parameters | Case 1 (USGS) | Case 2 (CMT) |
|---|---|---|
| Length / Width (km) | 209/8 | 2184/76 |
| Slip (m) | 2.9 | 2.5 |
| Strike / Dip / Rake | 161/79/87 | 157/18/84 |
| Depth (km) | 25.5 | 21.9 |

Table 4 DART and Tide−gauge location

| | Latitude | Longitude |
|---|---|---|
| Caldera | 26.743S | 73.983W |
| Arica | 20.473S | 73.429W |
| Lima | 7.399S | 93.504W |
| Kamaishi | 39.273N | 141.889E |
| Ayukawa | 38.297N | 141.505E |
| Souma | 37.831N | 140.962E |

Table 5 The maximum tsunami height

| | Case1 (USGS) | Case2 (CMT) |
|---|---|---|
| Maximum tsunami height in Chile (m) | 1.74 | 2.79 |
| Maximum tsunami height in Japan (m) | 0.27 | 0.19 |

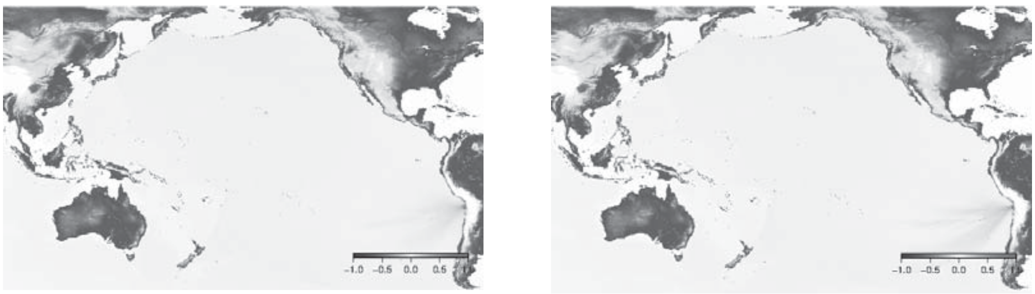

Fig. 7 Ditribution of tsunami height

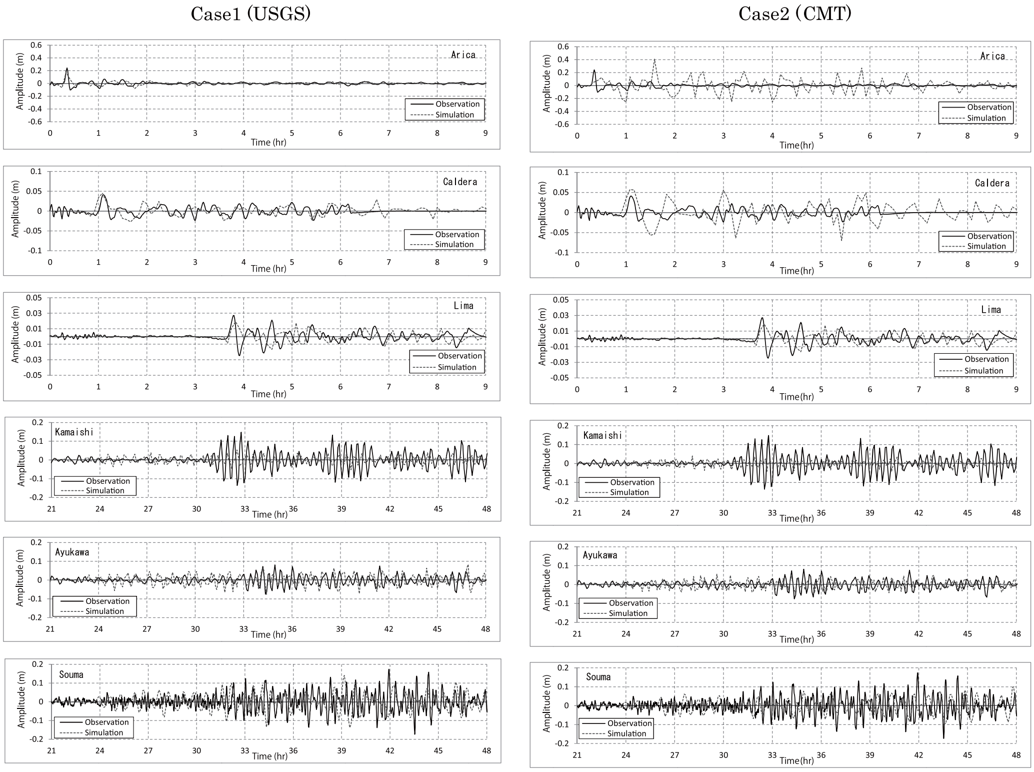


Fig. 8 A comparison between the simulated and observed tsunami waveforms

## 5. Conclusion

We have reported our results in response to the earthquake tsunami that occurred on April 1st, 2014, mainly including short discussions of tsunami impact and our tsunami numerical simulations. Although tsunamis that occur on the west coast of Chile has historically impacted both countries, this is the first time a tsunami that impacted both countries, has occurred since the 2011 Great-East Japan Earthquake. By using historical tsunami lessons learned, many Chileans could promptly evacuate from tsunami, and there were no injuries. In this event, the tsunami height in Japan was low, and there was no damage due to the tsunami, however, this event had disclosed the problem when and how the advisory should be issued.

Since the tsunami simulations in this report are preliminary results, we could at least understand the trend of the tsunami. Future research can focus on non-linear equations using detail topography data might help increasing accuracy of the simulation.

## References

The U.S. Geological Survey (2014): http://www.usgs.gov/

Global Centroid Moment Tensor (CMT) Project (2014), Global CMT catalog search: http://www.globalcmt.org/CMTsearch.html

Japan Meteorological Agency (2014): http://www.jma.go.jp/jma/index.html

ABC News (2014): http://www.abc.net.au/news/2014-04-03/chile-orders-evacuation-after-7-magnitude-aftershock/5364952

Kahoku Shimpo (2014): http://kahoku.co.jp/tohokunews/201404/20140404_73016.html