The Tohoku Earthquake & East Japan Tsunami

11th,March 2011

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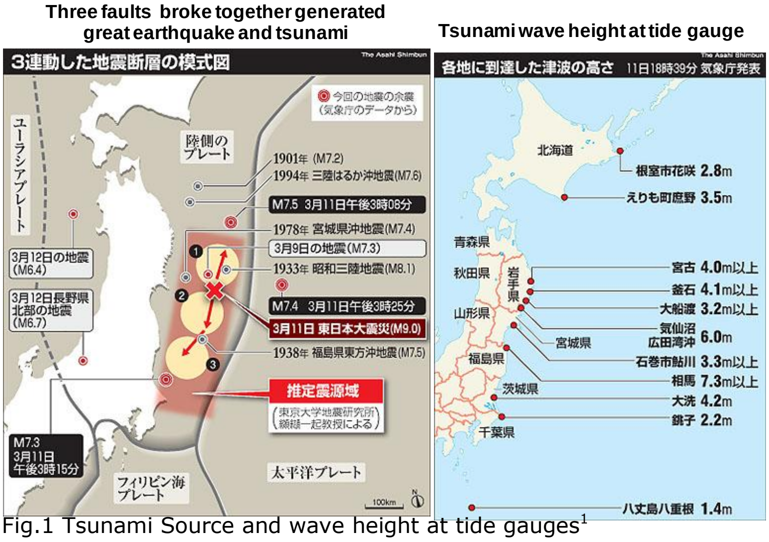
The **Tohoku Earthquake of 11th March 2011** was the fourth largest in the world since 1900. In terms of strength, the U.S. Geological Survey placed the magnitude 9.0 earthquake just behind the 2004 earthquake off the coast of Sumatra, Indonesia.

Great earthquakes ranking:
M9.5: 1960 Chile
M9.2 :1964 Alaska
M9.1 :2004 Indonesia
M9.0 :2011 Japan
M9.0 :1952 Russia


Three faults broke together generated great earthquake and tsunami

Tsunami wave height at tide gauge

Fig.1 Tsunami Source and wave height at tide gauges[1]

Facts about the 2011 tsunami[2]

- A massive fault measuring about 500 kilometers in a north-south direction and about 200 km in an east-west direction moved a maximum of 20 meters along the ocean floor.
- Japan Meteorological Agency officials believe a series of three earthquakes led to the gigantic scale. Shaking continued for about six minutes and was recorded with an intensity of a maximum 7 on the Japanese scale.
- As of Friday 1st April, 2011 there have been over 800 aftershocks with at least a magnitude 4.0 were observed, the largest number ever in Japan.
- Meteorological Agency officials said the number of aftershocks have been decreasing, but warned there was still a 30-percent probability of an aftershock of at least magnitude 7.0 occurring within three days from Friday.

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[1] Source: Asahi newspaper
[2] Ibid

- An analysis by the Geospatial Information Authority found that at least 400 square kilometers of land was flooded by the tsunami, an area equivalent to 20 percent of the area of Tokyo. The tsunami reached a maximum distance of 6 km inland.
- A tsunami, at least 7.3 meters high was observed in Soma, Fukushima Prefecture. A study by researchers of Tohoku University found that the tsunami reached a height of 10 meters in Sendai's Wakabayashi Ward.
- An analysis by experts at the Earthquake Research Institute of the University of Tokyo found that the tsunami hit land as soon as 10 minutes after the earthquake struck.
- Officials of the National Police Agency have confirmed 8,199 deaths as of 4 p.m. Sunday (20/3/2011) with 12,722 unknown, surpassing the 6,434 deaths in the 1995 earthquake that devastated Kobe in western Japan.

Fig.2 Damage from earthquake

At 4 km away from shoreline, we found maximum tsunami flow depth = 55 cm

Fig.3 Tsunami run up and inundation

History of the East Japan Tsunami[3]

Historical records show that Sendai city (Miyagi Prefecture) has faced the risks of giant earthquakes since 1793, with the average return period of 37 years for an earthquake in the magnitude (M) range 7.5 to 8.0. The expected earthquake magnitude from fault A alone is M7.5, and the combination of fault A and B could result in earthquakes of M8.0 (Fig. 4) has a probability of 70% in 10 years and 99% in 30 years. The earthquake of 11th March 2011, with M9.0 was an unforeseen event that generated a 10 meters (m) in height tsunami penetrating 5 kilometers (km) inland into Sendai plain. However, this is not the first event in the history of this region.

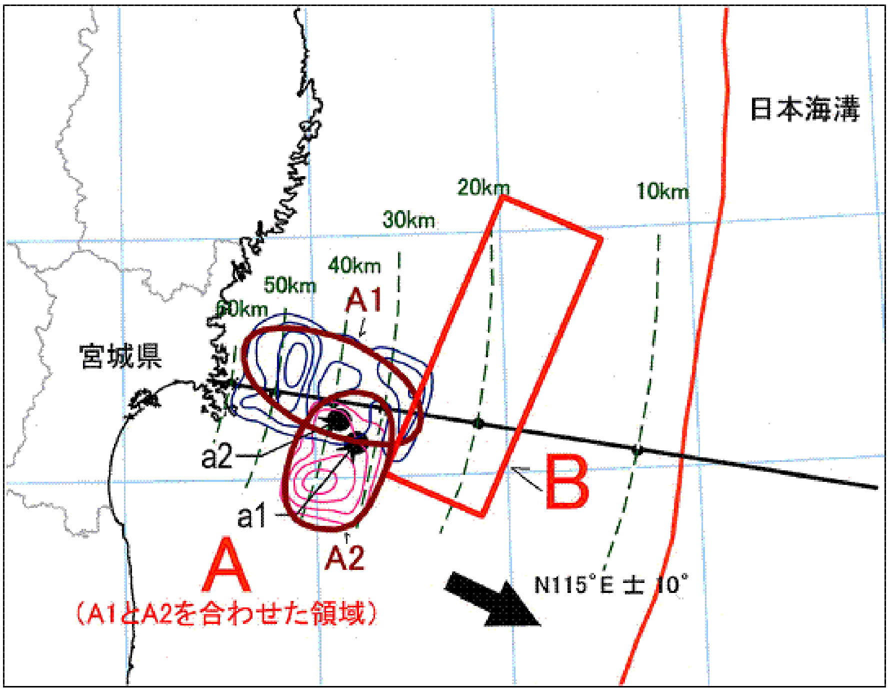

Fig. 4 Expected fault location near Sendai by Japanese Scientists before 11/3/2011

The 869 Jogan tsunami

Historical records found in the Namiwake shrine located near Sendai bay, reveal notes about an earthquake and tsunami in the year 869 or Jogan period. Scientists from Tohoku University (Miura et al, 2001) and Tokyo University (Satake et al., 2008) found tsunami deposits of 10-40 cm around Sendai plain. These studies show that the tsunami inundated 4 km inland and the simulation results show that the tsunami may have reached a height of 8 m. The notes reveal that these deposits may have been transported by the Jogan tsunami of 869. The study by Miura et al.(2001) highlights the high potential of great earthquake occurrence in the current time period as 1,100 years have passed since the Jogan earthquake of 869. The study also concluded that the 11/3/2011 tsunami event might be the recurrence of the Jogan tsunami in 869.

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[3] Dr. Anawat Suppasri Research fellow, Disaster Control Research Center, Tohoku University, Japan
Visiting RIMES during 21-25 March 2011

Additionally, the inundation area derived from the satellite image of the 11/3/2011 tsunami event can be comparatively matched to the simulated inundation area of the Jogan tsunami (Satake et al., 2008) as shown in Fig.5.

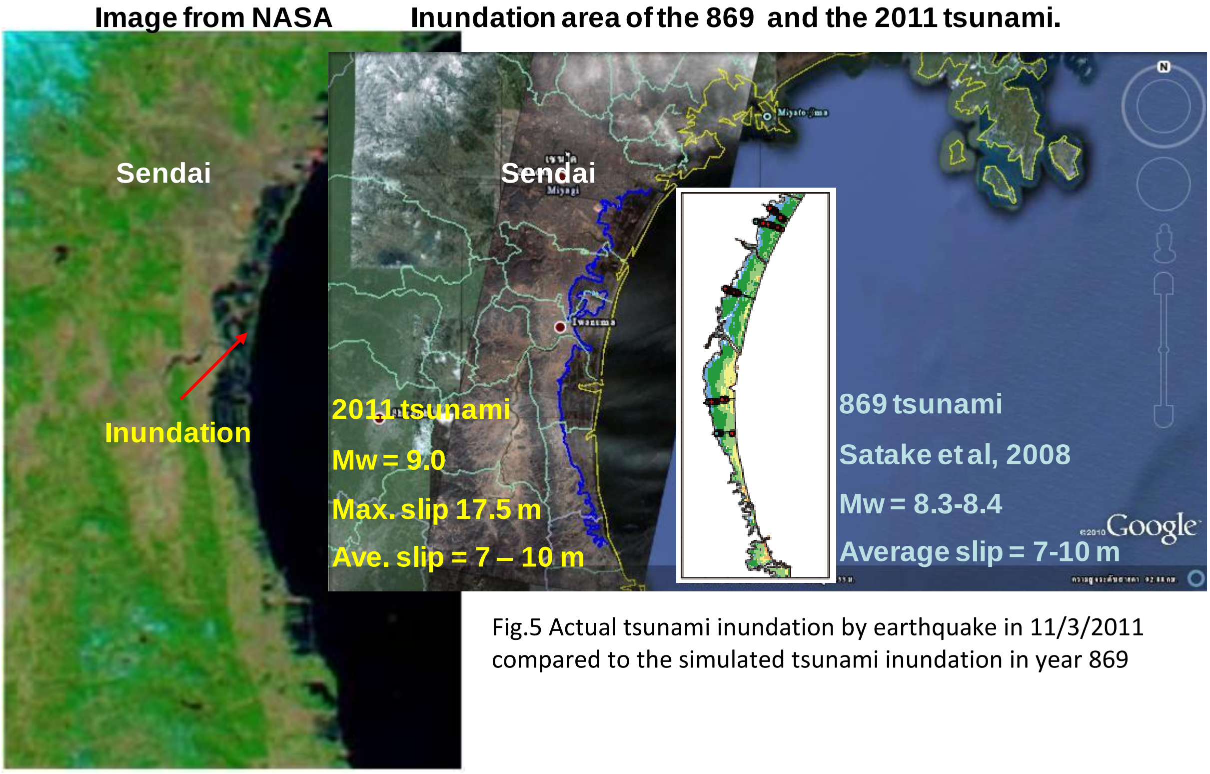


Fig.5 Actual tsunami inundation by earthquake in 11/3/2011 compared to the simulated tsunami inundation in year 869

Effect of Honshu Tsunami to the Indian Ocean and Southeast Asia

Tsunami propagation simulation was carried out during the event by setting the computational domain covering a part of the Pacific Ocean, expanding to the entire Indian Ocean and Southeast Asia and estimating the effect of the tsunami from Honshu Japan to the rest of the region. Model was set up for fast computation with the spatial resolution of 10 arc-minute and simulation for 24 hours of tsunami propagation time. The computation time would take about 10 minutes to present the overall impact of this tsunami event to the region.

The simulated tsunami was generated from a source located at Off Tohoku-Pacific earthquake (38.322°N, 142.369°E, Mw = 8.9 at 5:46:23 UTC according to USGS) on March 11, 2011. The assumed tsunami source is located within the aftershock area with dimension of 500 km × 220 km. The focal mechanisms are strike:193º, dip:14º, slip:81º from the USGS's solution. Simulated maximum tsunami wave amplitude is plotted in Fig.6 compared to the summary of measured tsunami amplitude provided by The National Geophysical Data Center (NOAA/ NGDC).

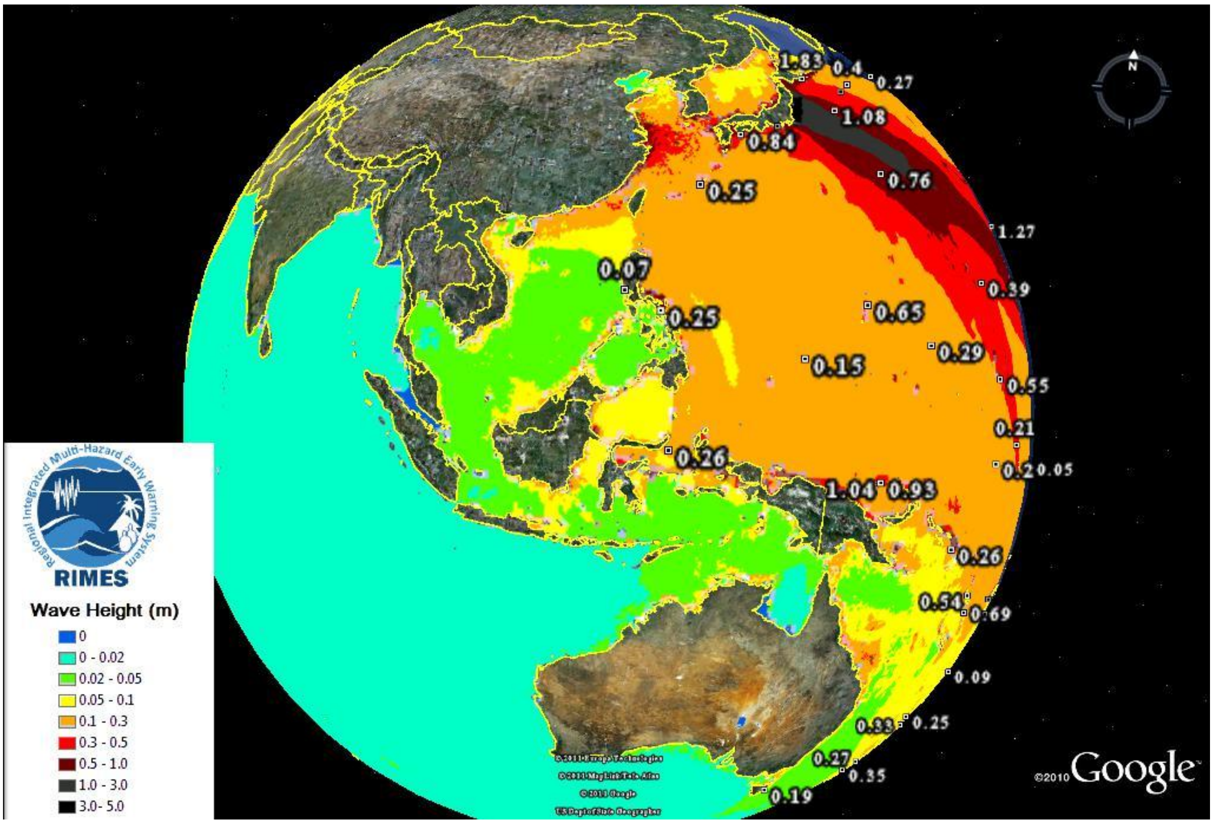
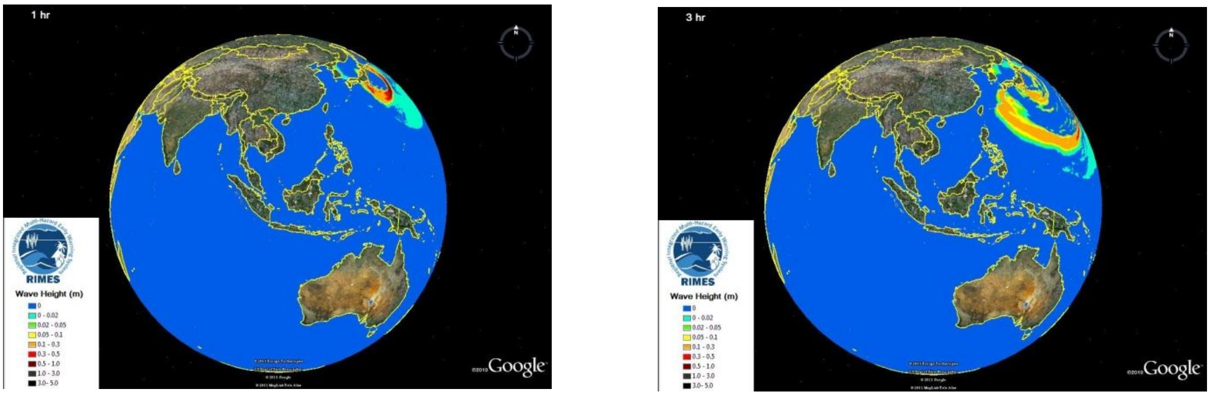
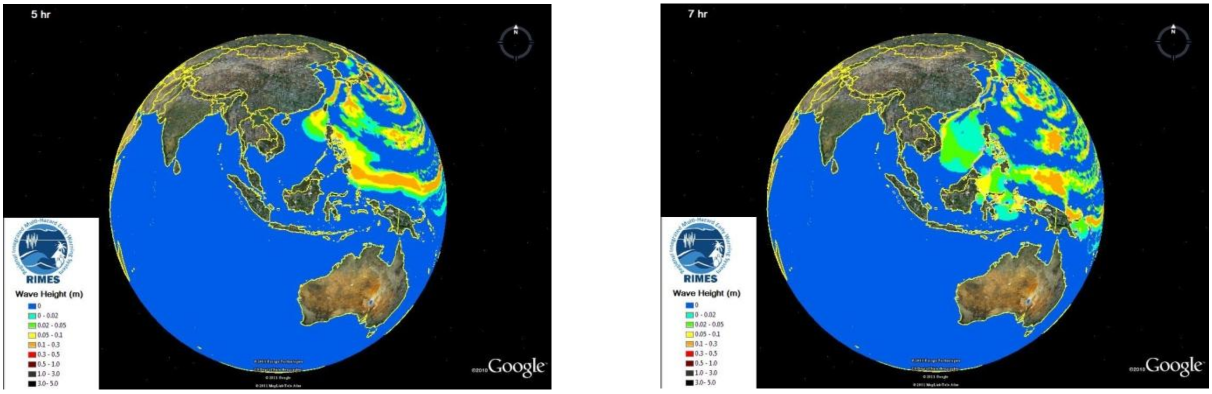


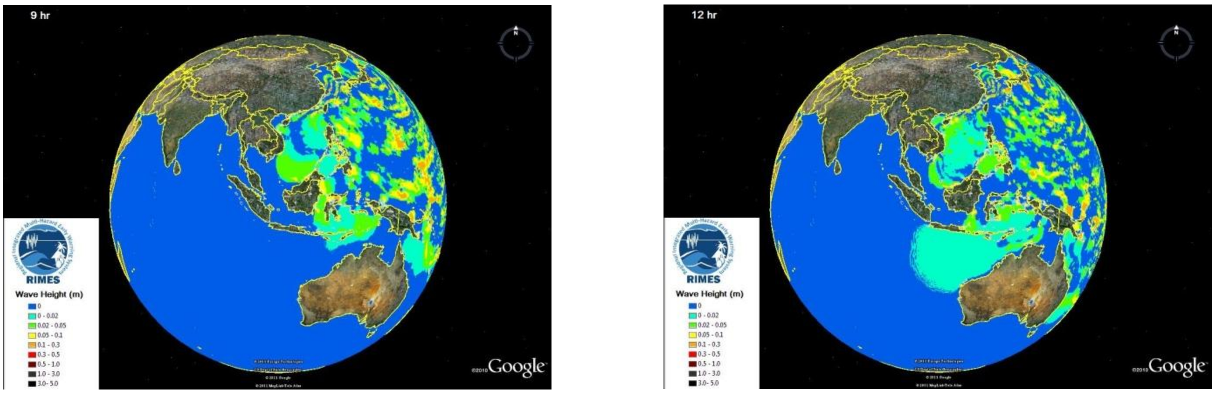
Fig.6 Simulated maximum tsunami amplitude in the Indian Ocean and South East Asia for Honshu tsunami event on 11 March 2011



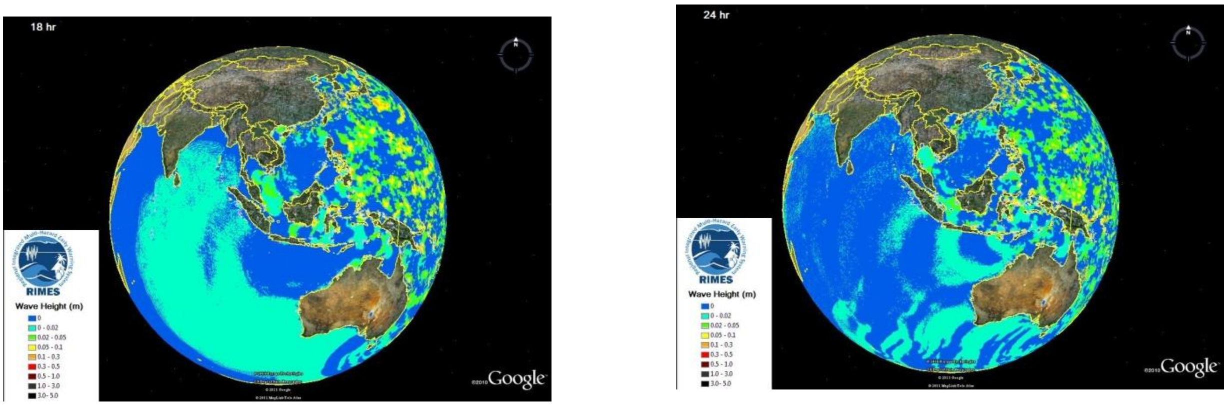
after 1 hour after 3 hours



after 5 hours after 7 hours



after 9 hours after 12 hours



After 18 hours after 24 hours

Fig.7 Snapshot of simulated tsunami wave propagation into the Indian Ocean and the South China Sea after earthquake origin time

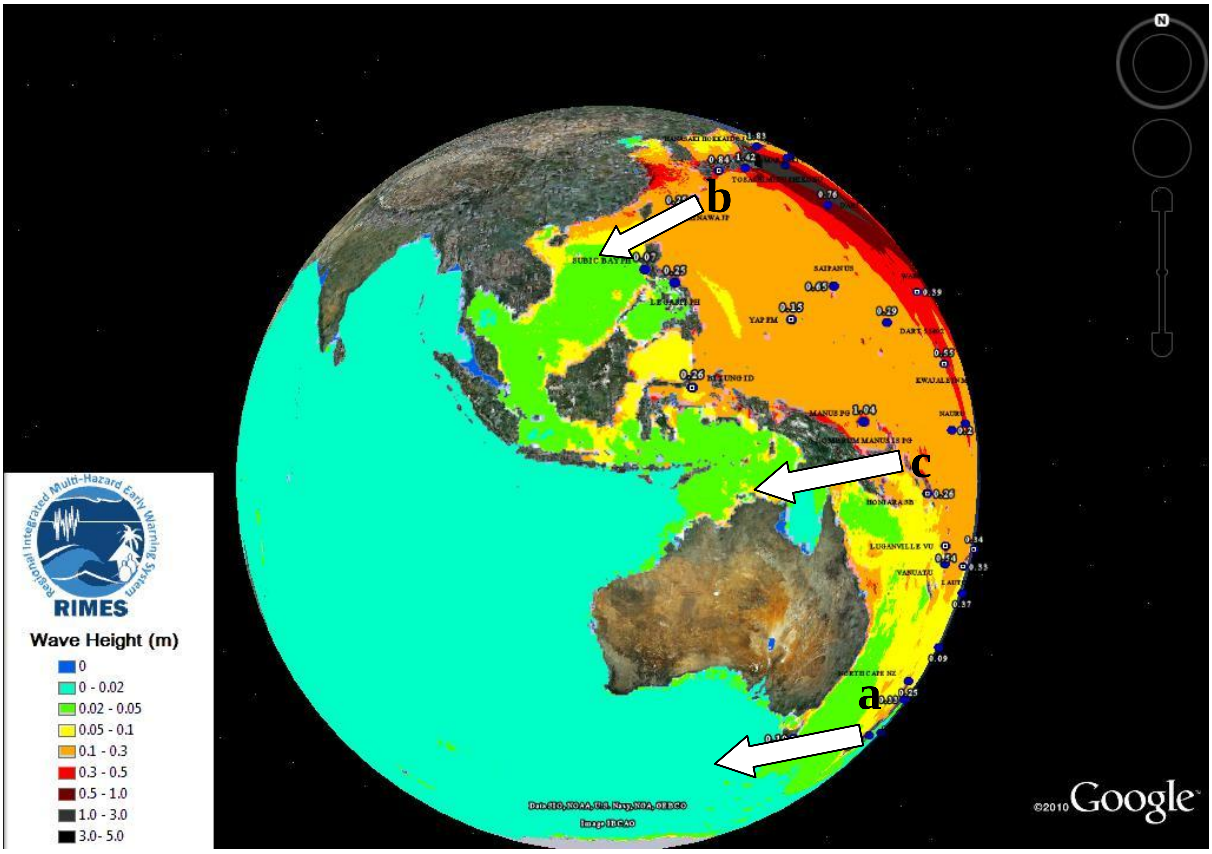


Fig.8 Potential routes of tsunami wave penetration to the Indian Ocean

Simulation results show the potential route of tsunami energy penetration in to the region as follows:

a) Southern Australia (Tasman Sea)

From the sea level observations, 19-cm amplitude of tsunami was observed at Spring Bay station which presents the penetration of tsunami energy across the ocean basin from the Pacific Ocean to the Indian Ocean. From this simulation, the directivity of tsunami penetration to the Indian Ocean was possible along the southeastern side of the Indian Ocean. However, the energy of the tsunami would have been low, as no tsunami signal was observed at Coco Island station and Re-union Island station. It was estimated that the Eastern and Western areas of the Indian Ocean would not experience this effect and sea level sensors did not detect any clear sea level anomaly.

b) South China Sea route

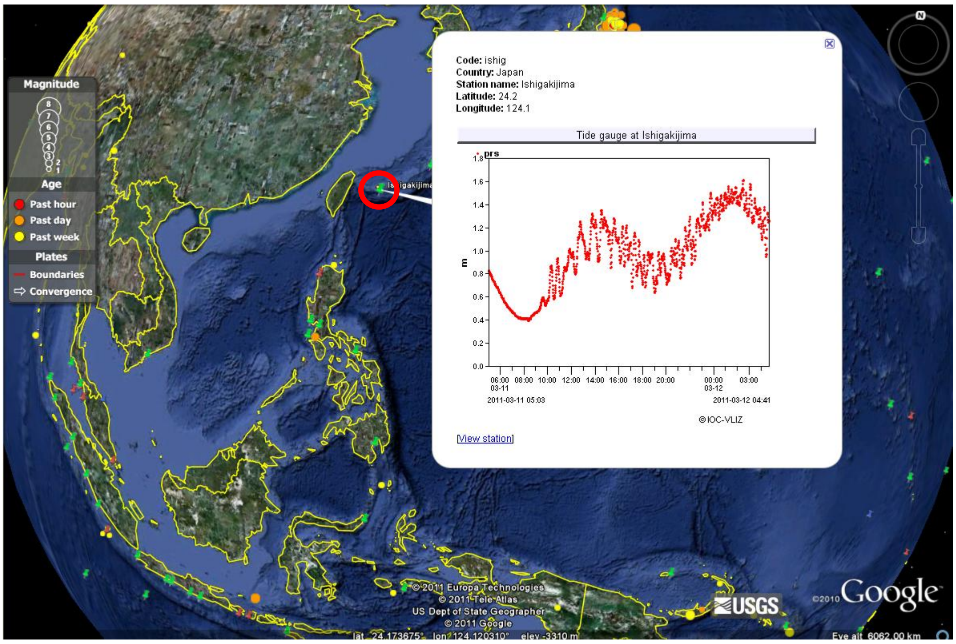
From sea level observation 24 hours after the origin time of the earthquake, some swells with amplitude of less than 25 cm have been observed along the north and east coast entrances to the South China Sea. However, a tsunami wave was not observed on the western side of the South China Sea e.g. Vung Tao station in Vietnam, therefore the energy of tsunami from this event was not strong enough to propagate over the South China Sea and penetrate into the Gulf of Thailand.

c)South of Java Island route (Timor Sea)

From sea level observation 24 hours after the origin time of the earthquake, no Tsunami signal was observed at Rote Station located at the strait connecting Pacific Ocean to the Indian Ocean. Tsunami from the Pacific Ocean did not penetrate this route.

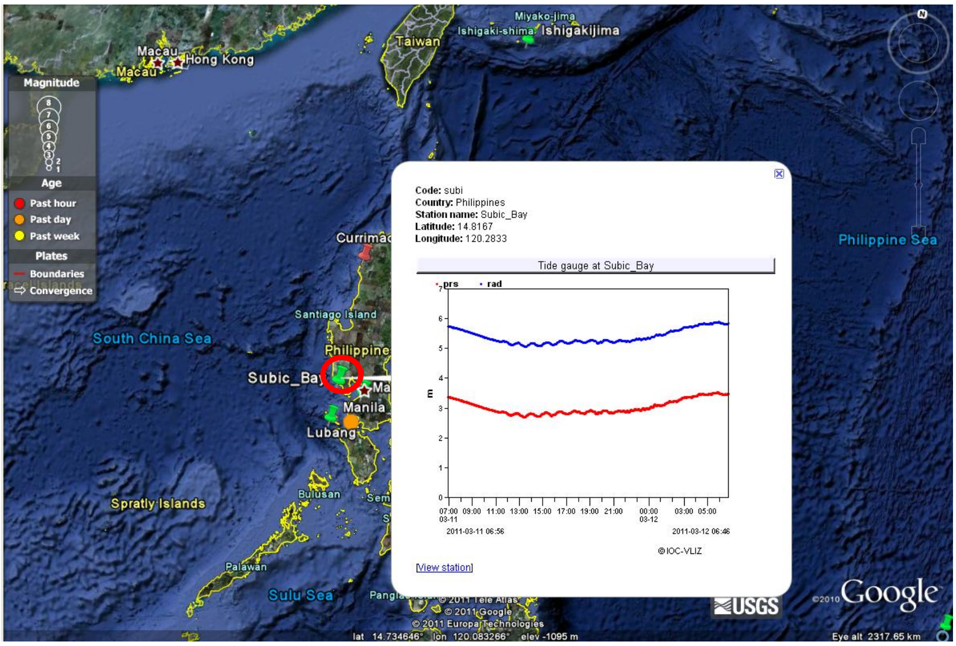
Summary of observed sea level within 24 hours is as follows:

Observed Tsunami Effect on the South China Sea



Code: ishig
Country: Japan
Station name: Ishigakijima
Latitude: 24.2
Longitude: 124.1

Fig.9 Tsunami amplitude within 0.3 m at Ishigakijima station (entrance to the South China Sea)



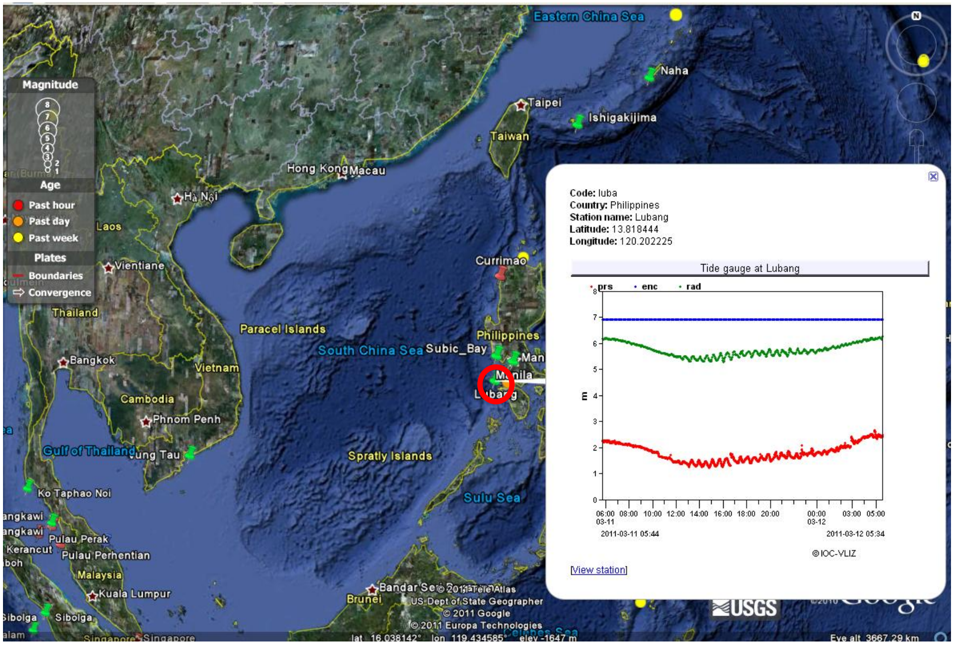
Code: subi
Country: Philippines
Station name: Subic_Bay
Latitude: 14.8167
Longitude: 120.2833

Tide gauge at Subic_Bay

[View station]

Fig.10 Tsunami amplitude within 0.1 m at Subic Bay station

(Eastern rim of the South China Sea)

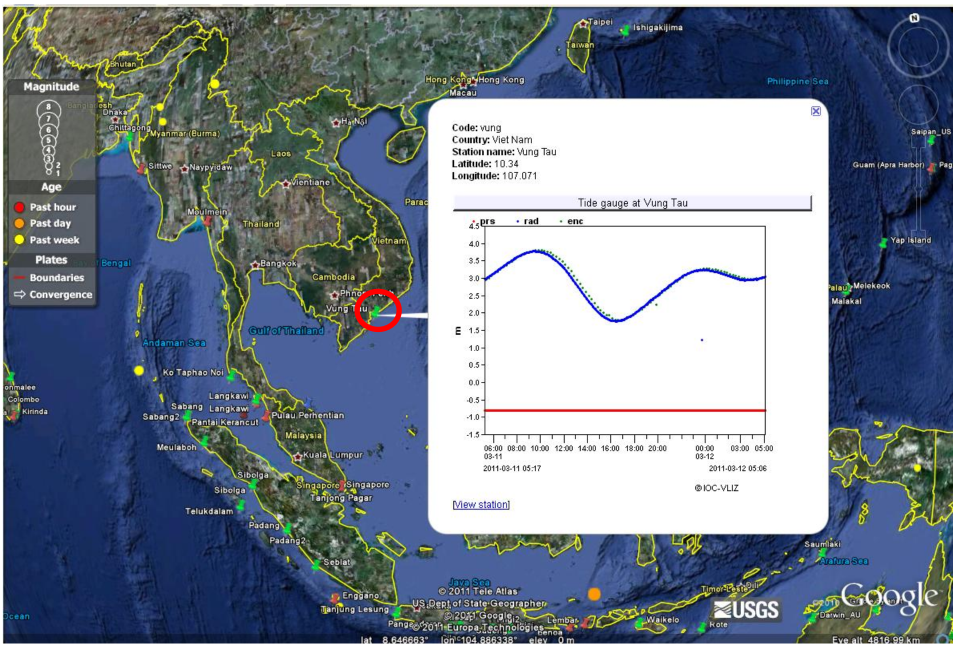


Code: luba
Country: Philippines
Station name: Lubang
Latitude: 13.818444
Longitude: 120.202225

Tide gauge at Lubang

[View station]

Fig. 11 Tsunami amplitude within 0.2 m at Lubang station (Eastern rim of the South China Sea)



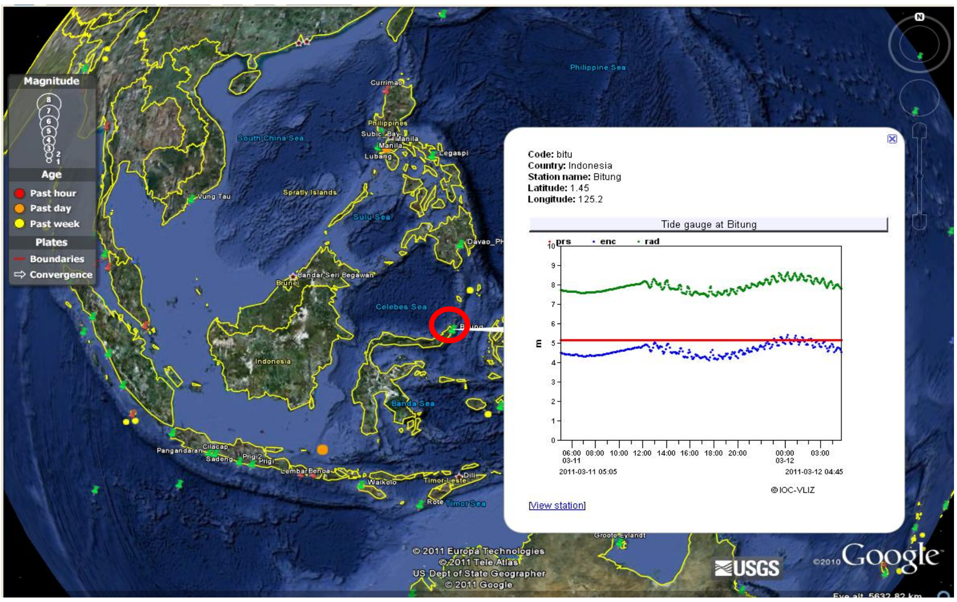
Code: vung
Country: Viet Nam
Station name: Vung Tau
Latitude: 10.34
Longitude: 107.071

Fig. 12 No Tsunami signal at Vung Tao Station (Western rim of the South China Sea) 24 hours after earthquake

Summary:

From sea level observation 24 hours after the origin time of the earthquake, some swells were observed at the entrance and eastern part of the South China Sea. However, a tsunami wave was not observed on the western side of the South China Sea.

Observed Tsunami Effect to the Marginal Sea (Molucca & Celebes Sea)



Code: bitu
Country: Indonesia
Station name: Bitung
Latitude: 1.45
Longitude: 125.2

Fig. 13 Tsunami amplitude within 0.3 m at Bitung station (entrance to the Molucca Sea)

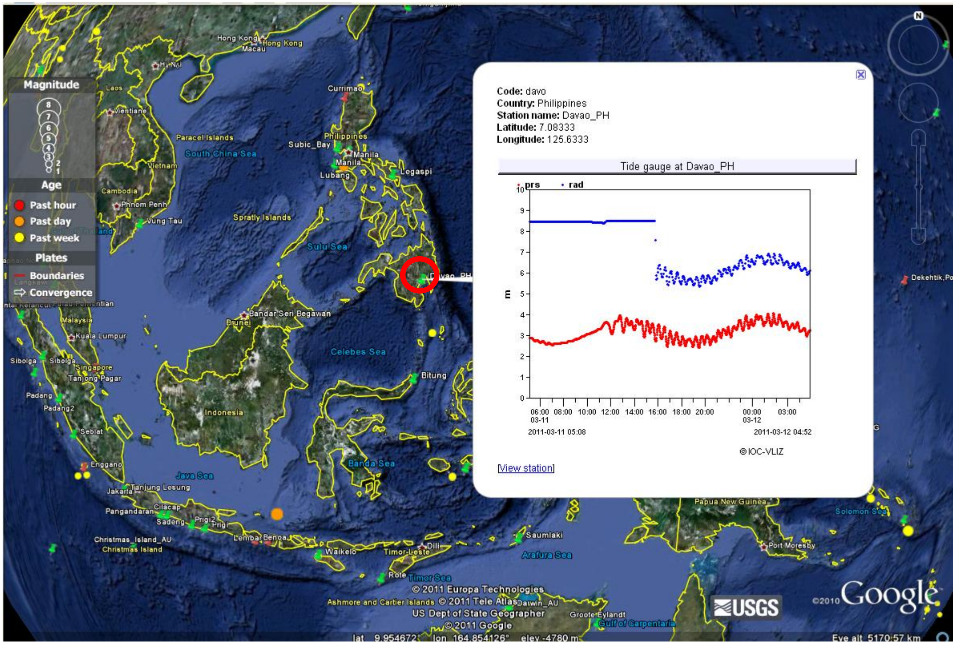

Code: davo
Country: Philippines
Station name: Davao_PH
Latitude: 7.08333
Longitude: 125.6333

Fig.14 Tsunami amplitude within 0.3 m at Davao station (entrance to the Celebes Sea)

Summary:

From sea level observation 24 hours after the origin time of the earthquake and maximum amplitude map from tsunami simulation, some swells were observed along the eastern part of the Celebes Sea and the northern part of the Molucca Sea.

Observed Tsunami Effect to the Indian Ocean

a) Penetration of tsunami through Southern Australia (Tasman Sea)

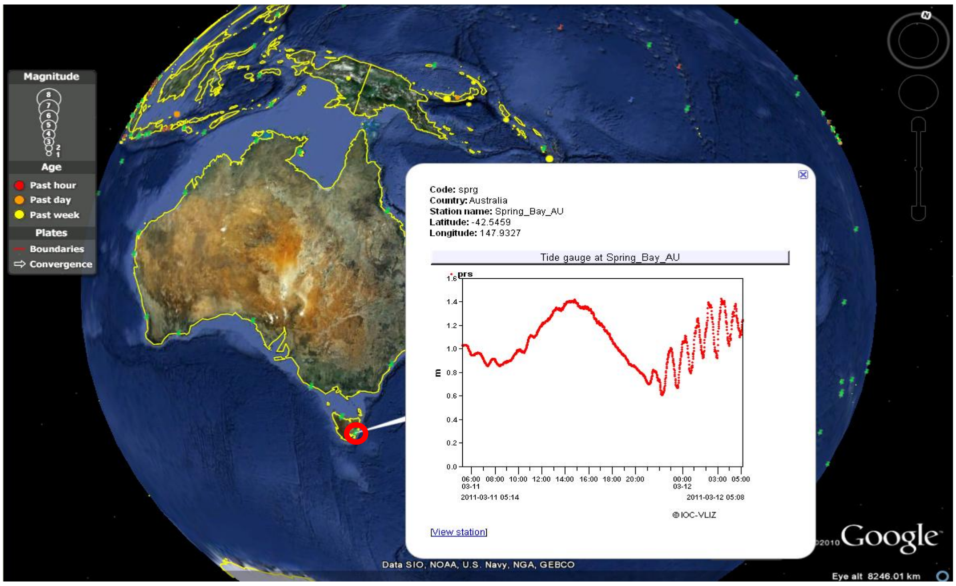
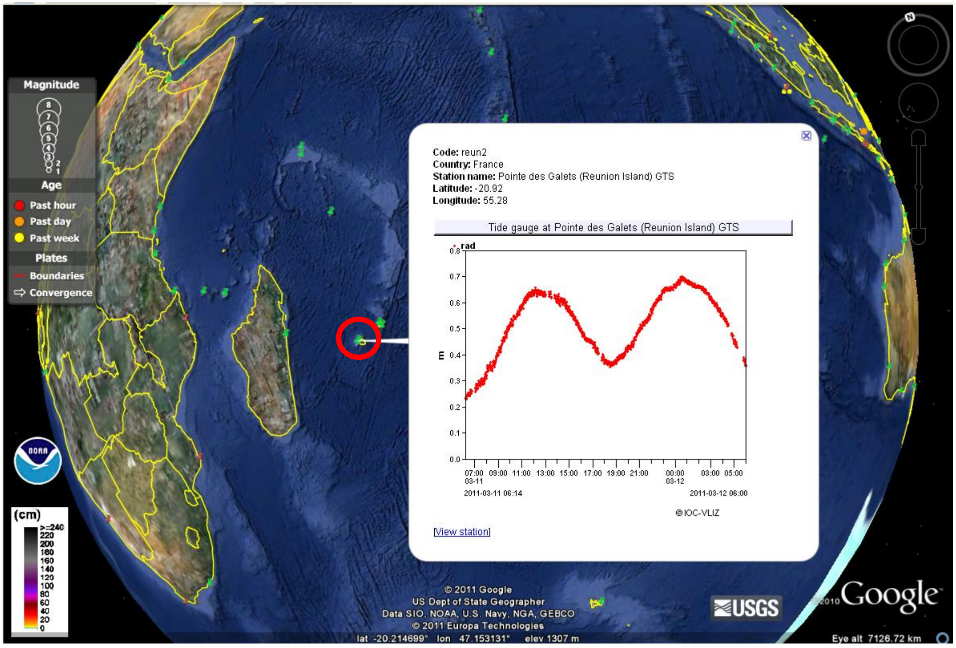

Code: sprg
Country: Australia
Station name: Spring_Bay_AU
Latitude: -42.5459
Longitude: 147.9327

Fig.15 Tsunami amplitude within 0.2 m at Spring Bay station (entrance to the Indian Ocean through the South sea direction)

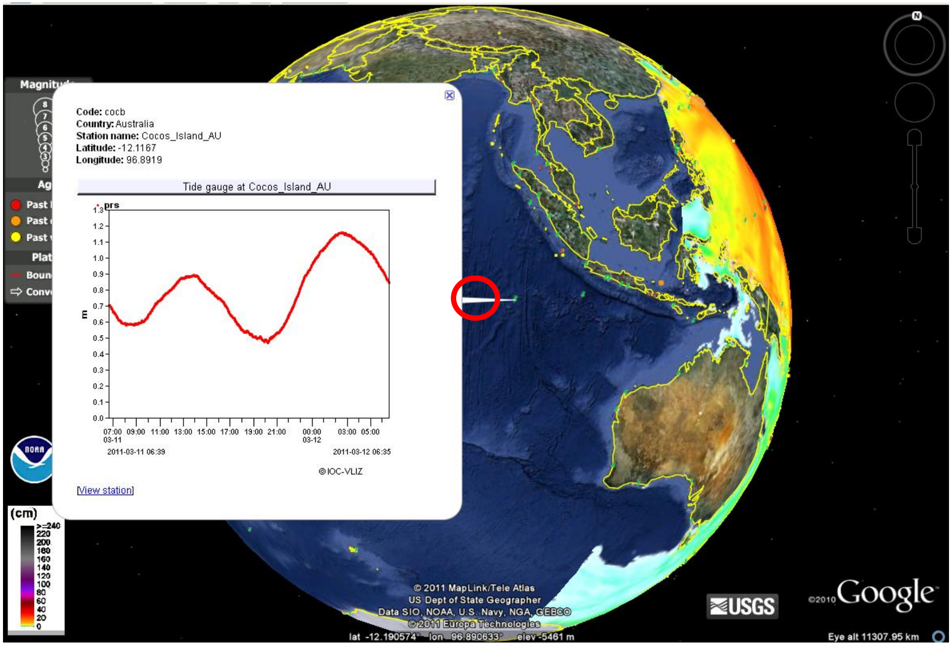


Code: reun2
Country: France
Station name: Pointe des Galets (Reunion Island) GTS
Latitude: -20.92
Longitude: 55.28

Tide gauge at Pointe des Galets (Reunion Island) GTS

[View station]

Fig.16 No significant swell from the tsunami wave is observed at Re-Union Island station



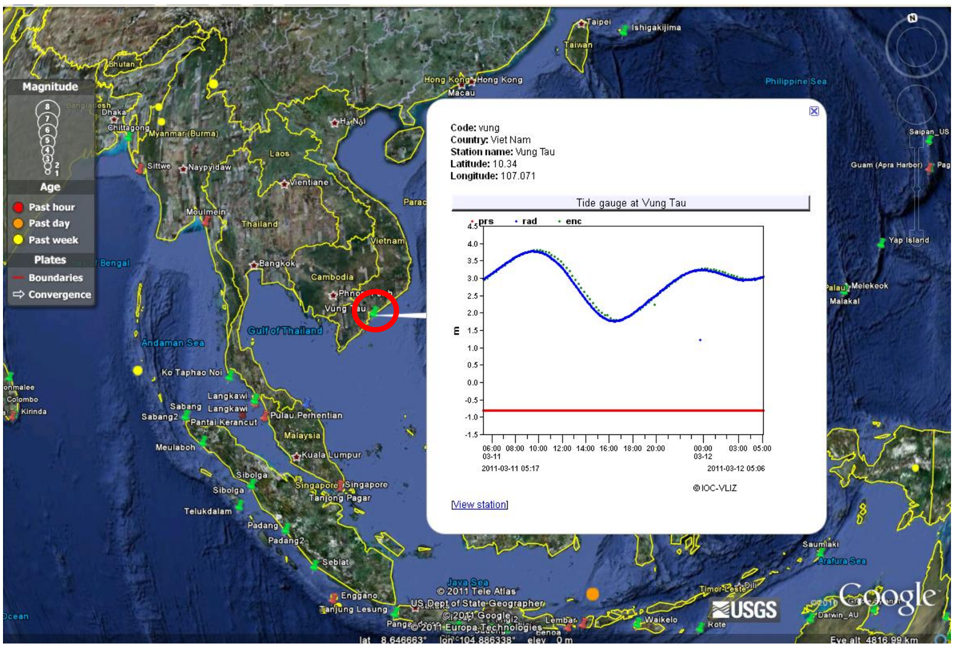
Code: cocb
Country: Australia
Station name: Cocos_Island_AU
Latitude: -12.1167
Longitude: 96.8919

Tide gauge at Cocos_Island_AU

[View station]

Fig.17 No significant swell from tsunami is observed at Cocos Island station

b) Penetration of tsunami through South China Sea direction



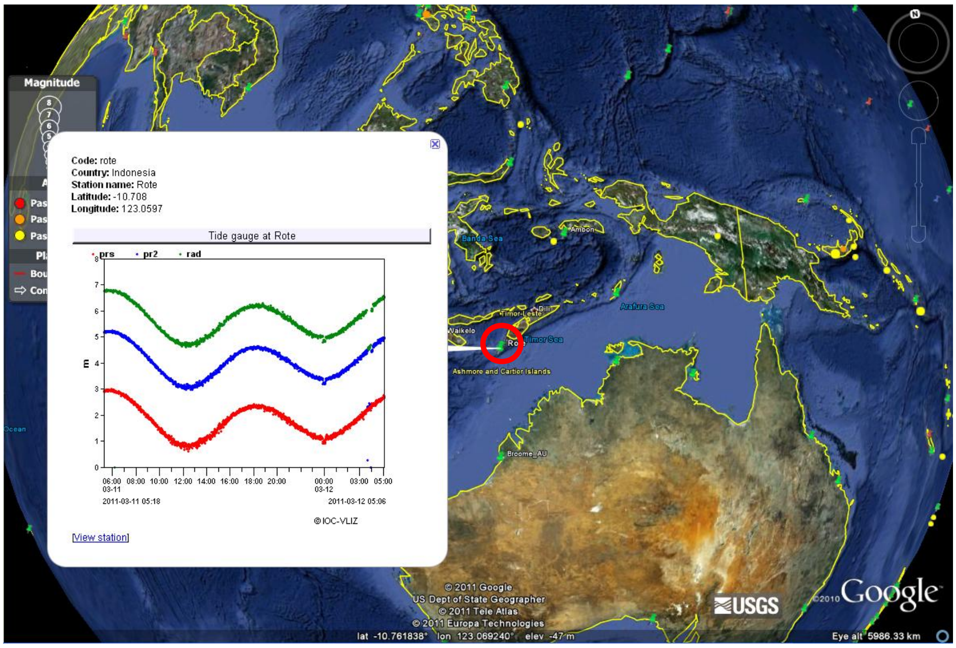
Code: vung
Country: Viet Nam
Station name: Vung Tau
Latitude: 10.34
Longitude: 107.071

Tide gauge at Vung Tau

[View station]

Fig.18 No Tsunami signal at Vung Tao Station (Western rim of the South China Sea)

c) Penetration of tsunami through South of Java Island (Timor Sea)



Code: rote
Country: Indonesia
Station name: Rote
Latitude: -10.708
Longitude: 123.0597

Tide gauge at Rote

[View station]

Fig. 19 No Tsunami signal at Rote Station (entrance to the Indian Ocean through the southern part of Indonesia)

Tsunami inundation simulation for Miyagi Prefecture using INSPIRE

To understand the spatial distribution of tsunami impact to the Miyagi Prefecture, near shore bathymetric and topographic data was combined to generate dataset for tsunami inundation simulation by using INternet based Simulation Platform for inundation and Risk Evaluation (INSPIRE). Data sources used for generated bathymetric and topographic DEMs are GEBCO08 and ASTER GDEM and shoreline derived from SRTM data respectively.

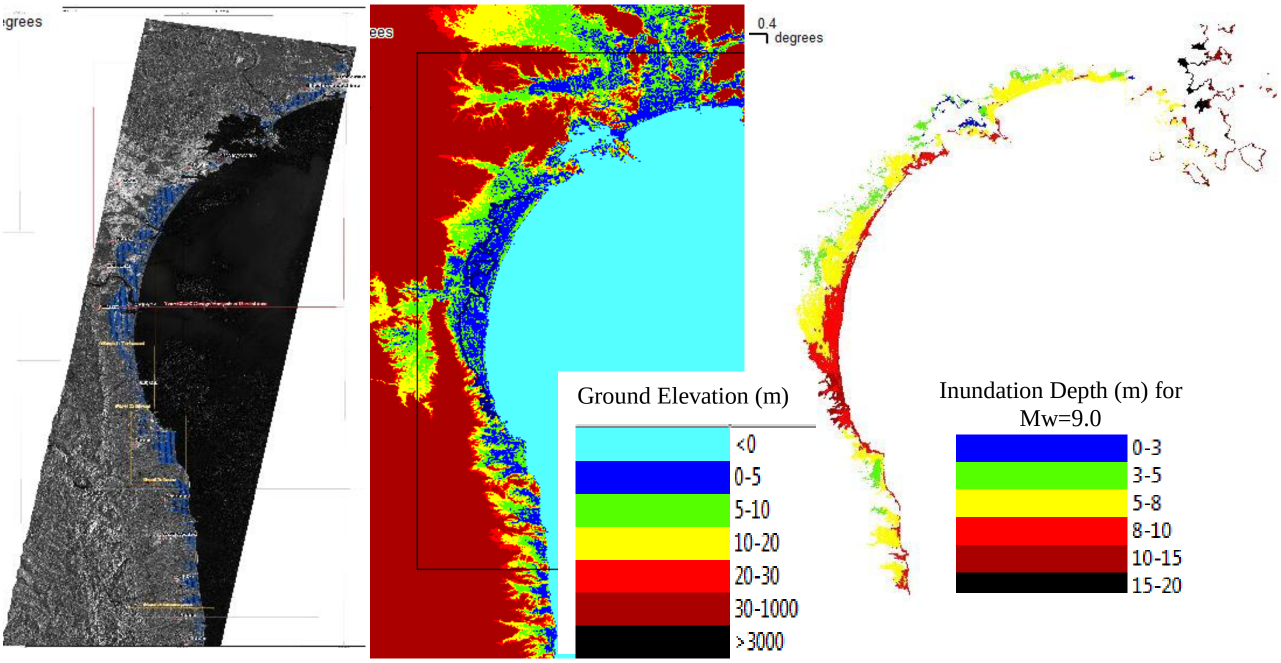
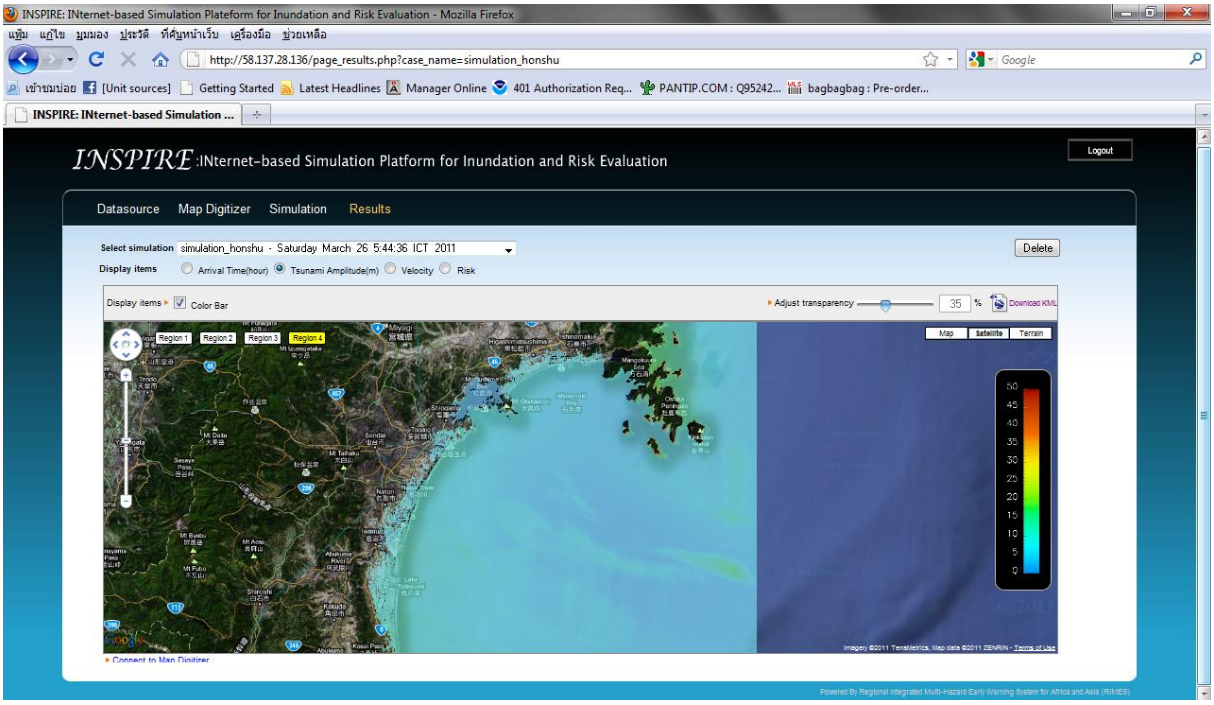


Fig.20 Tsunami inundation area and ground elevation in Miyagi Prefecture, Japan
Left: inundation area from satellite image, Middle: Ground elevation, Right: Simulated Inundation depth by INSPIRE for Mw=9.0)



INSPIRE: INternet-based Simulation Plateform for Inundation and Risk Evaluation - Mozilla Firefox

http://58.137.28.136/page_results.php?case_name=simulation_honshu

INSPIRE :INternet-based Simulation Platform for Inundation and Risk Evaluation

Select simulation: simulation_honshu - Saturday March 26 5:44:36 ICT 2011

Display items: ○ Arrival Time(hour) ● Tsunami Amplitude(m) ○ Velocity ○ Risk

Display items ▸ ☑ Color Bar

▸ Adjust transparency 35 %

Fig.21 Tsunami inundation simulation (50 m-resolution) in Miyagi Prefecture, Japan using INSPIRE for Mw=9.0

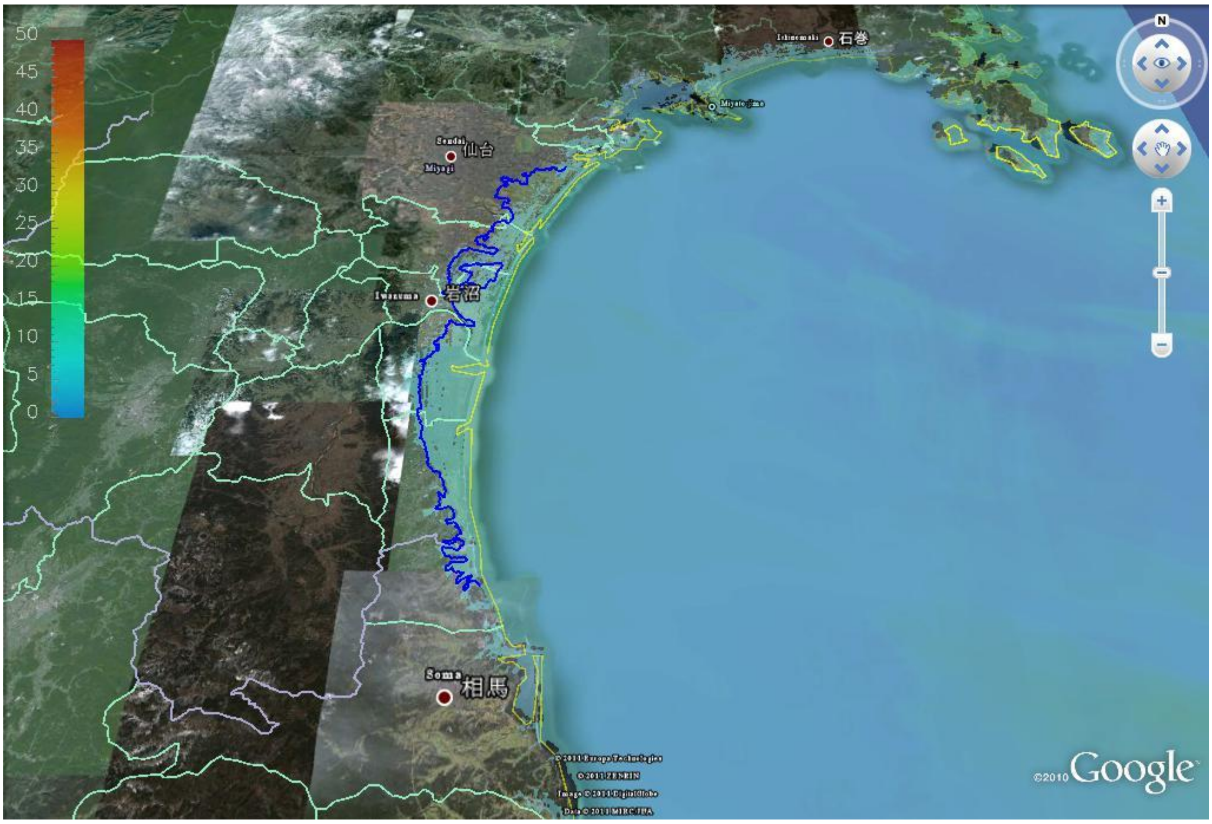


Fig.22 INSPIRE Tsunami inundation simulation of Mw=9.0 plotted on Google Earth compared to inundation line (blue line) derived from post-disaster satellite images

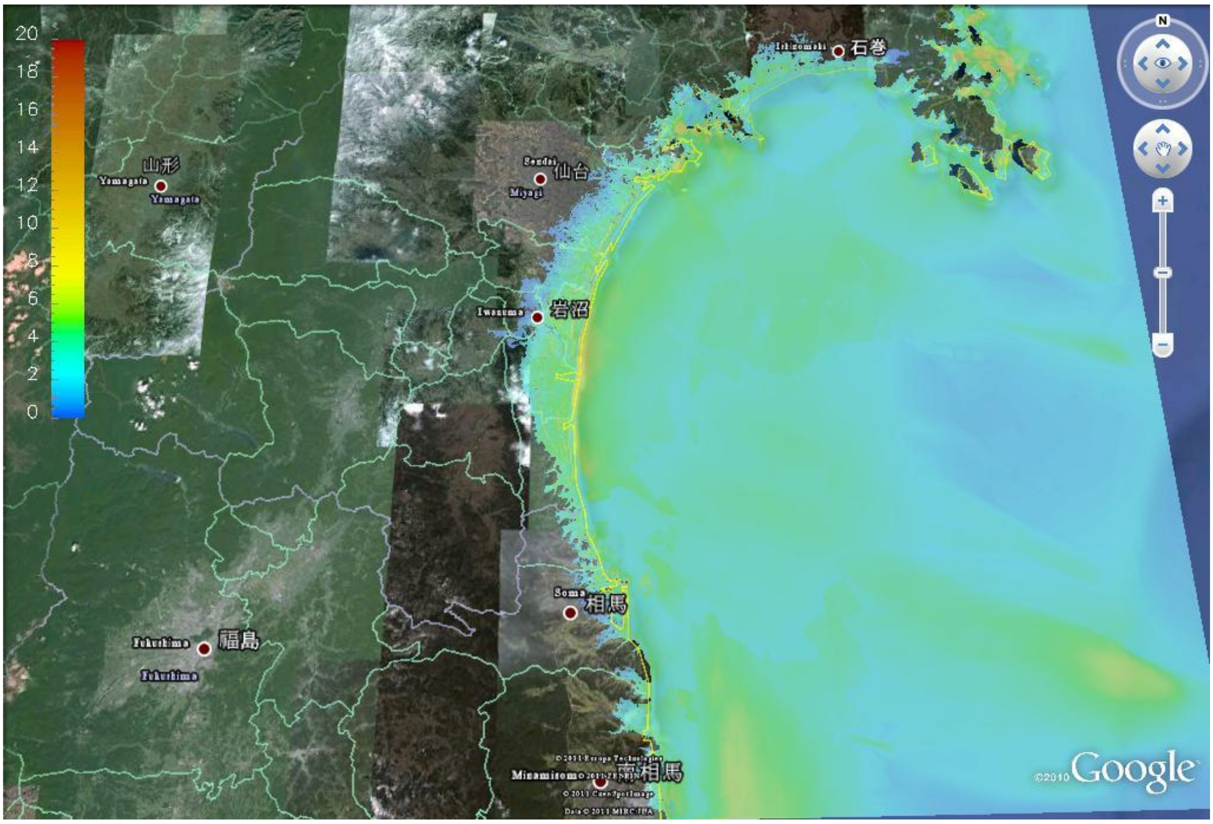


Fig.23 INSPIRE Tsunami current velocity simulation for Mw=9.0 plotted on Google Earth

Since an earthquake with Mw8.0 was expected and prepared for in Japan, INSPIRE was applied to simulate the inundation depth for tsunami generated by Mw 8.0 comparing to recent event with Mw9.0

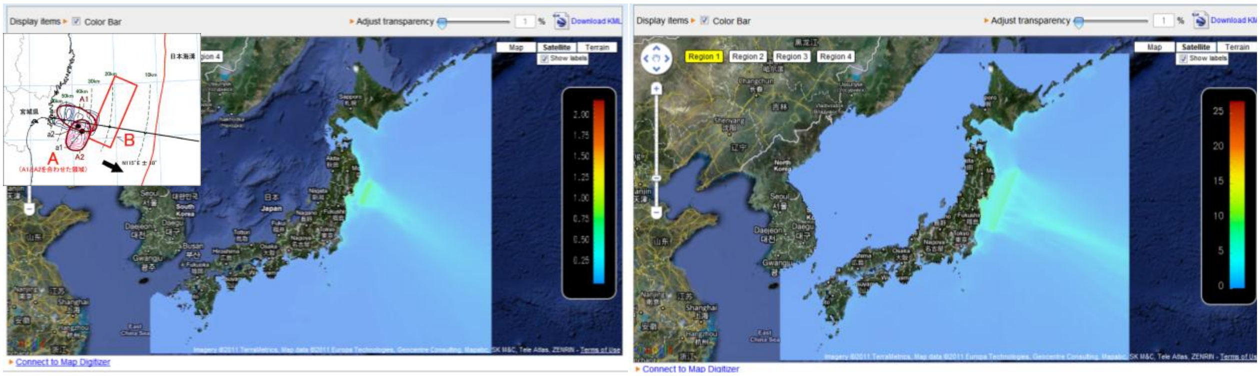


Fig.24 Tsunami source of expected Mw8.0 (left) and actual event with Mw9.0 (right)

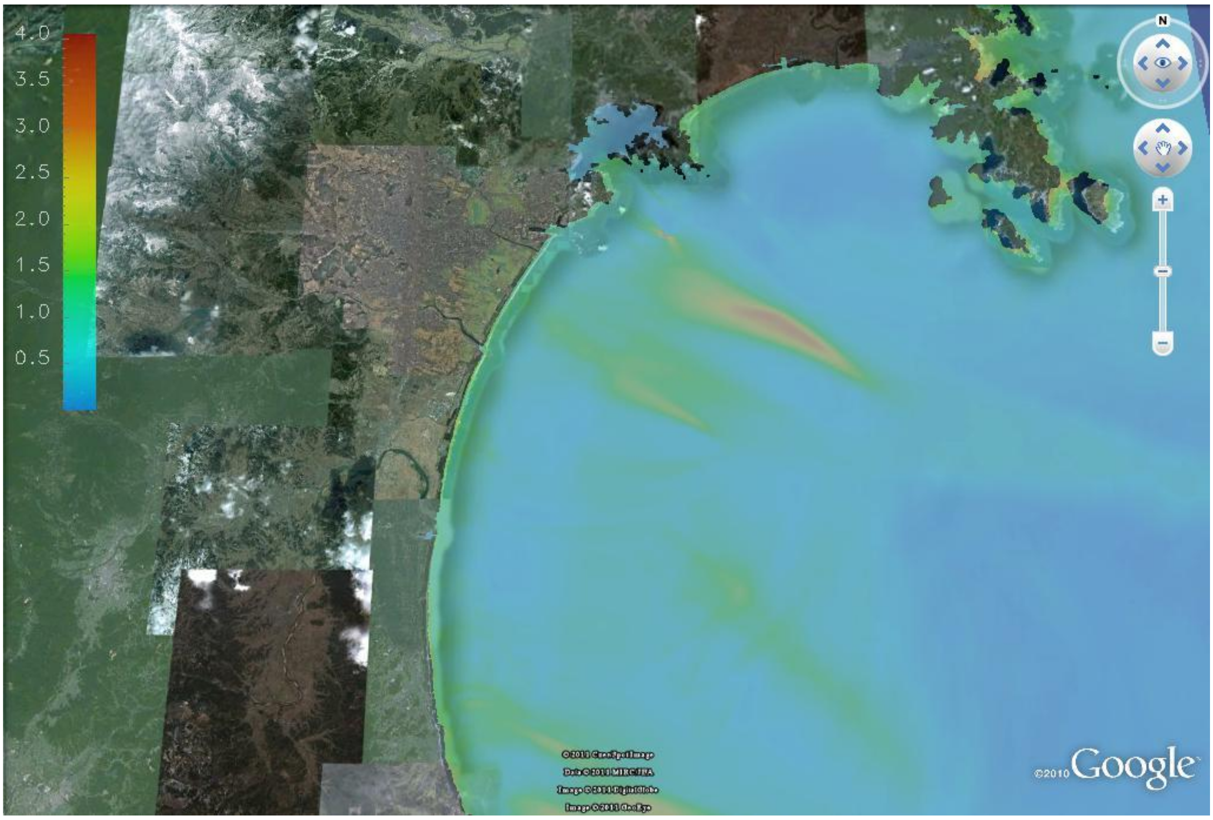


Fig.25 INSPIRE Tsunami inundation simulation for Mw=8.0 plotted on Google Earth

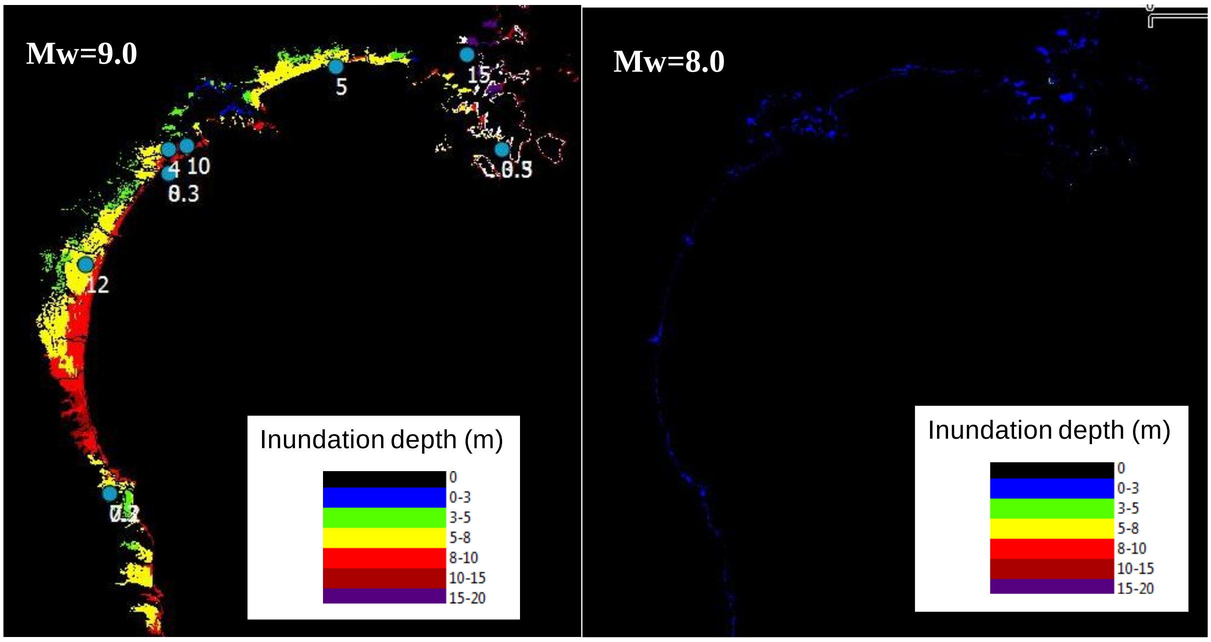


Fig.26 Comparison of inundation depth and extend for Mw 9.0 (with actual measured run up points by NGDC) and Mw 8.0