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The potential tsunami threats from the South China Sea and hazard mitigation

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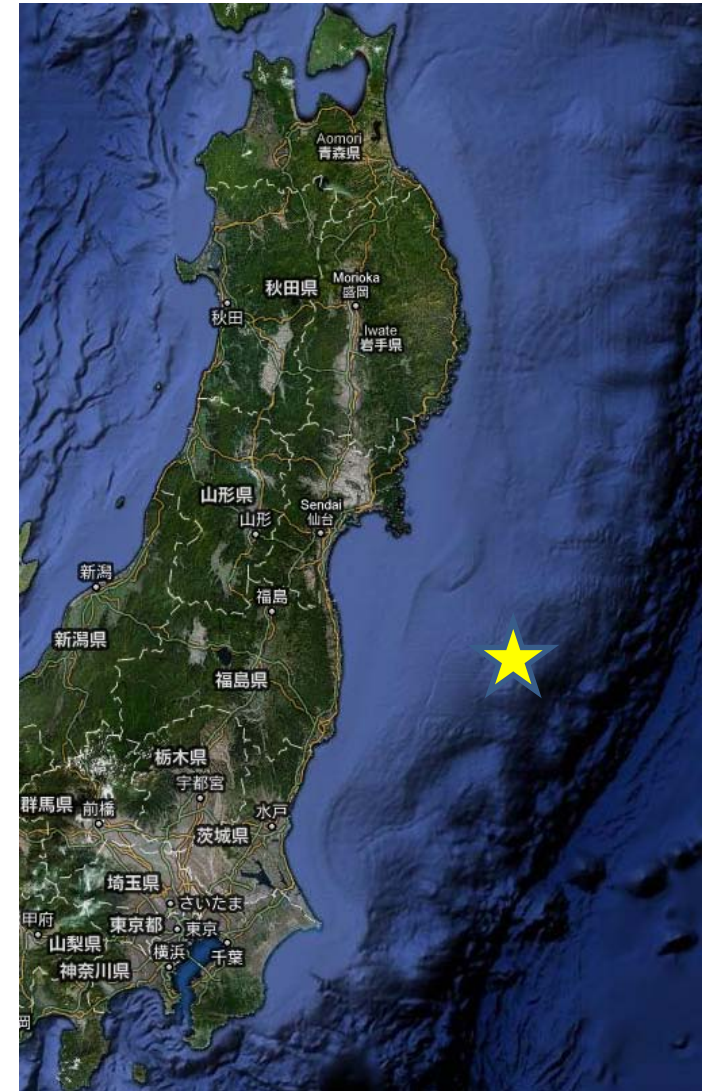
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Introduction

- The 2011 Tōhoku earthquake was a 9.0-magnitude undersea megathrust earthquake off the coast of Japan that occurred at 14:46 JST on Friday 11 March 2011. The epicenter was approximately 72 kilometers (45 mi) east of the Oshika Peninsula of Tōhoku, with the hypocenter at an underwater depth of approximately 32 km (19.9 mi).
- The earthquake triggered extremely destructive tsunami waves of up to 10 meters that struck Japan minutes after the quake, in some cases traveling up to 10 km inland, with smaller waves reaching many other countries after several hours. Tsunami warnings were issued and evacuations ordered along Japan's Pacific coast and at least 20 other countries, including the entire Pacific coast of North America and South America. (Wiki)
- However, the tsunami height in Taiwan was 12cm reported by CWB.



Questions

- Why the tsunami was so devastated in Japan, and only in Japan?
- will the similar scenario present in Taiwan and in the SCS region?
- Strategies for hazard mitigation of the near-source tsunami?

Tsunami Propagation Model

- COMCOT (Cornell Multi-grid Coupled Tsunami Model)

$$\frac{\partial \eta}{\partial t} + \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} = 0 \quad (1)$$

$$\frac{\partial P}{\partial t} + gH \frac{\partial \eta}{\partial x} - f \left(\frac{Q}{H} \right) = 0 \quad (2)$$

$$\frac{\partial Q}{\partial t} + gH \frac{\partial \eta}{\partial y} + f \left(\frac{Q}{H} \right) = 0$$

where: x, y are the horizontal coordinates,
 η is the free-surface displacement,
 $H = \eta + h$ is the total water depth,
 h is the still water depth,
 $P = Hu, Q = Hv$ are the horizontal volume discharges,
 g is gravity, t is time,
 f is the Coriolis coefficient.

$$\frac{\partial \eta}{\partial t} + \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} = 0 \quad (3)$$

$$\frac{\partial P}{\partial t} + \frac{\partial}{\partial x} \left(\frac{P^2}{H} \right) + \frac{\partial}{\partial y} \left(\frac{PQ}{H} \right) + gH \frac{\partial \eta}{\partial x} + \tau_x = 0 \quad (4)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left(\frac{PQ}{H} \right) + \frac{\partial}{\partial y} \left(\frac{Q^2}{H} \right) + gH \frac{\partial \eta}{\partial y} + \tau_y = 0$$

where τ_x and τ_y are the bottom frictions.

The bottom friction comes from Manning's formula and is expressed as:

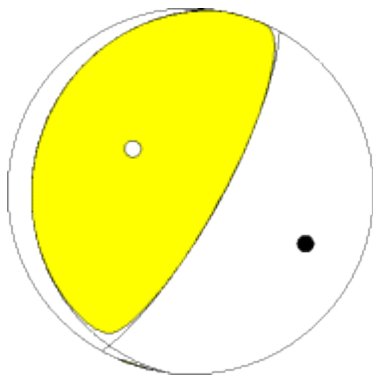
$$\tau_x = \frac{gn^2}{H^{7/3}} P (P^2 + Q^2)^{1/2}, \tau_y = \frac{gn^2}{H^{7/3}} Q (P^2 + Q^2)^{1/2} \quad (5)$$

Features: 1. Nested grid; 2. inundation; 3. nonlinear

地震參數與巢狀網格

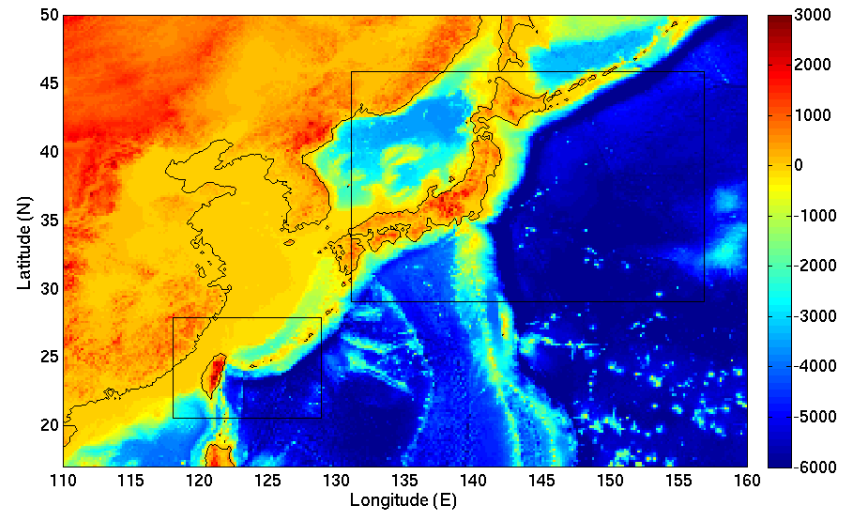
- USGS

- Epicenter: 38.308 142.383
- MW: 9.0
- Depth: 10
- Strike= 187 Dip=14 Slip= 68



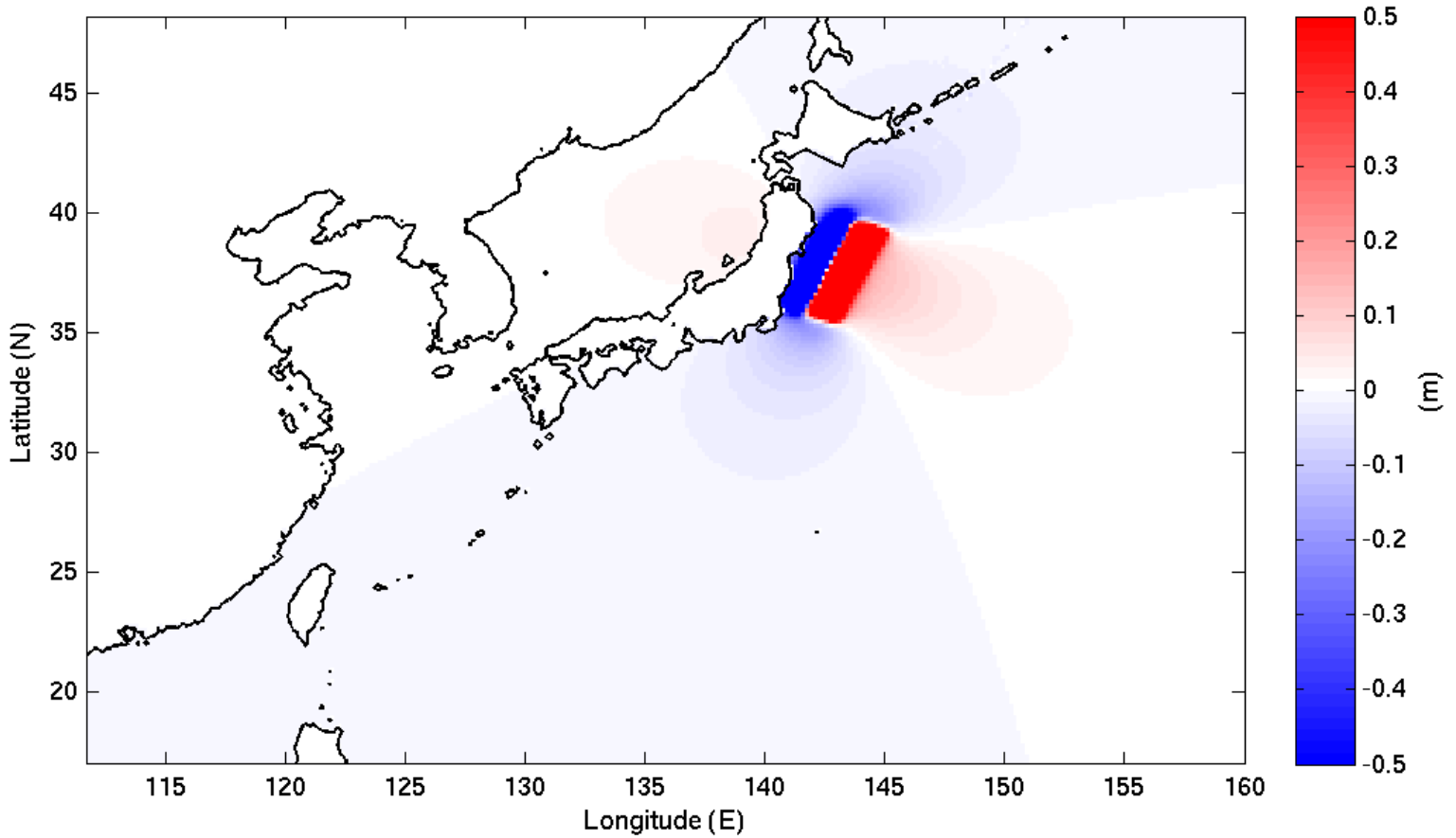
GCMT ★

- Epicenter: 37.52 143.05
- MW: 9.1
- Depth: 20
- Strike= 203 Dip=10 Slip= 88
- L:450km W:150km d:18m

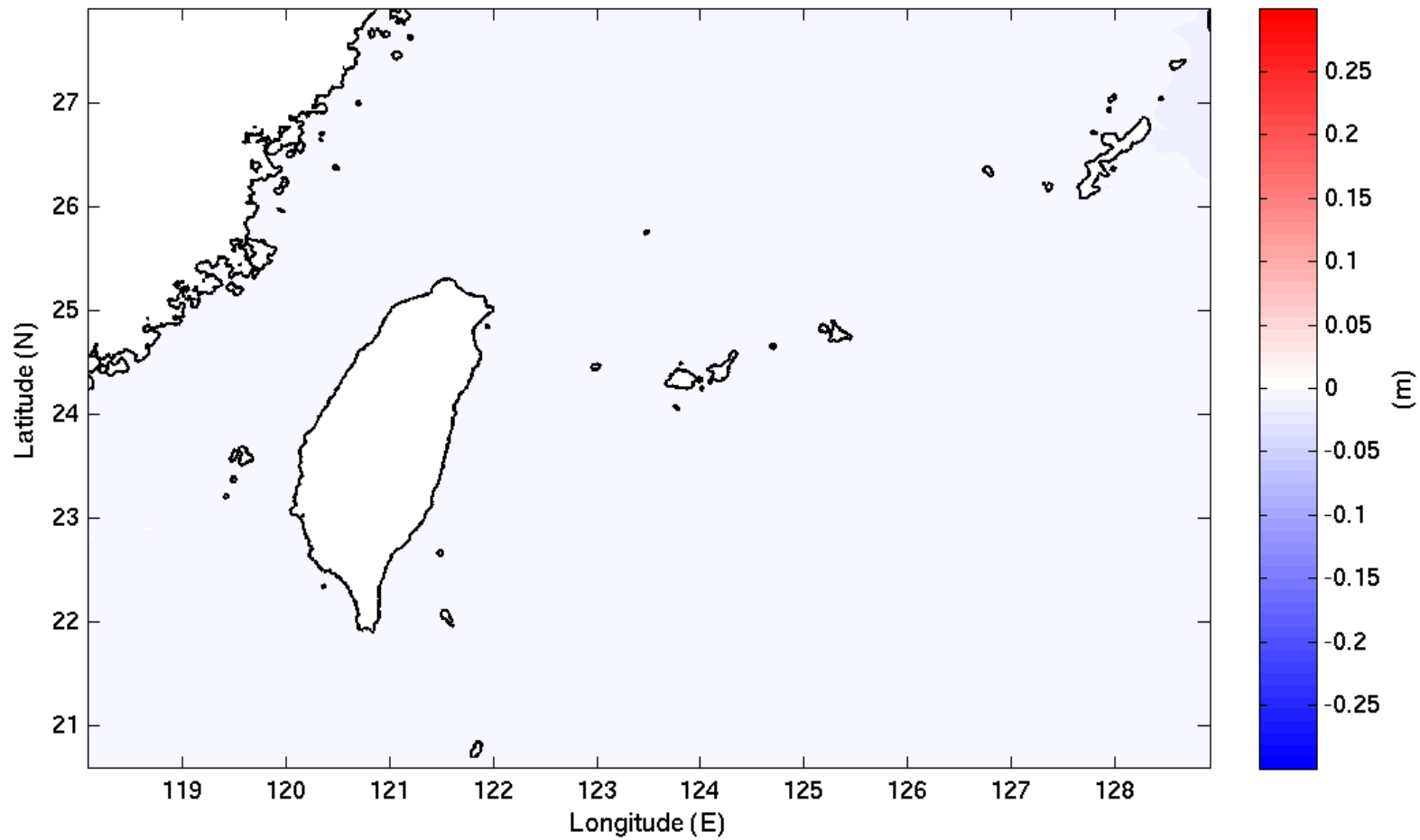


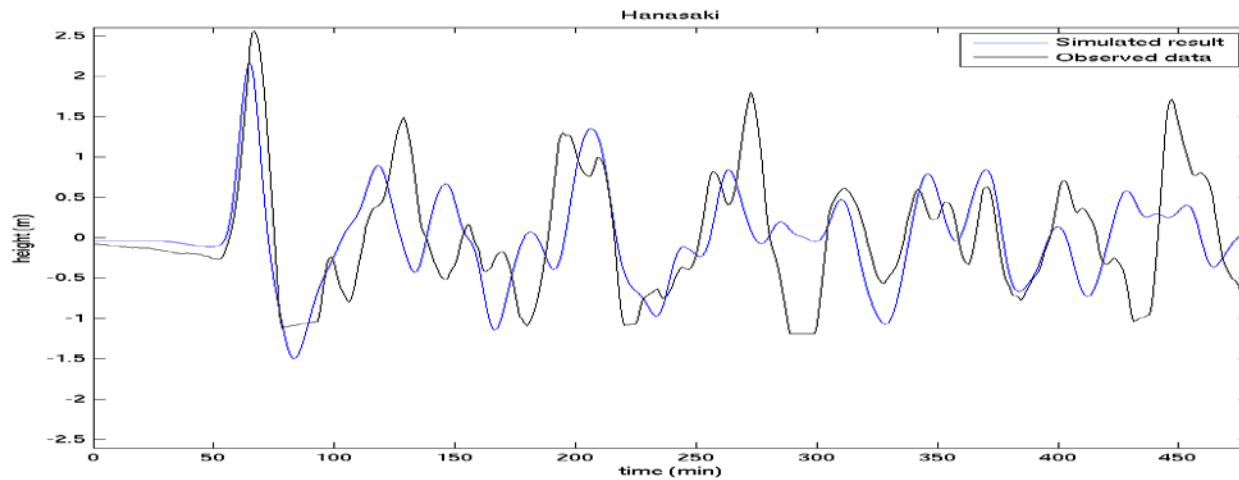
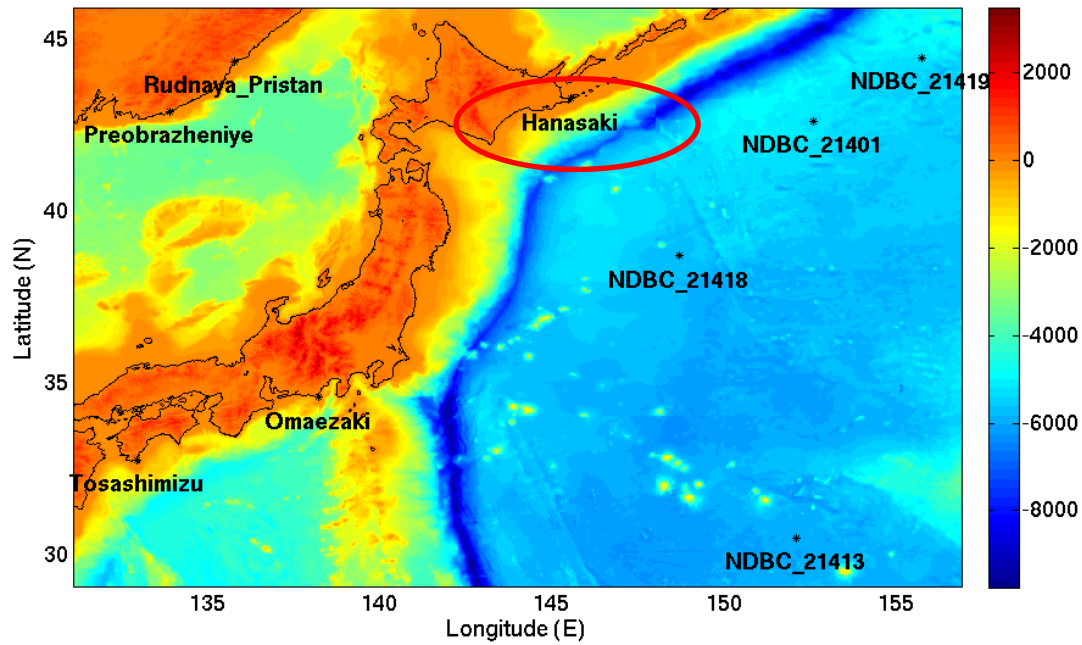
Simulation Results

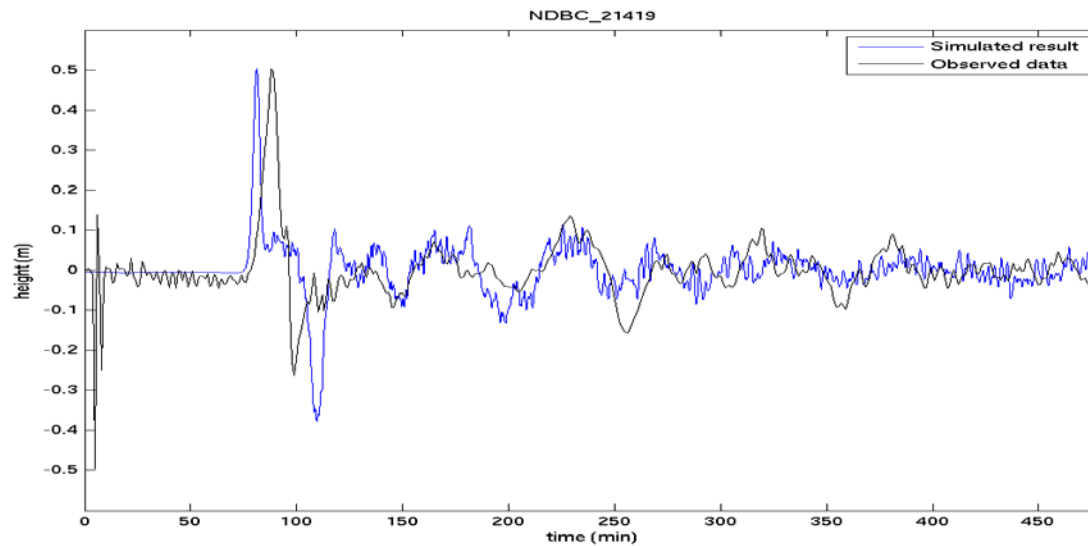
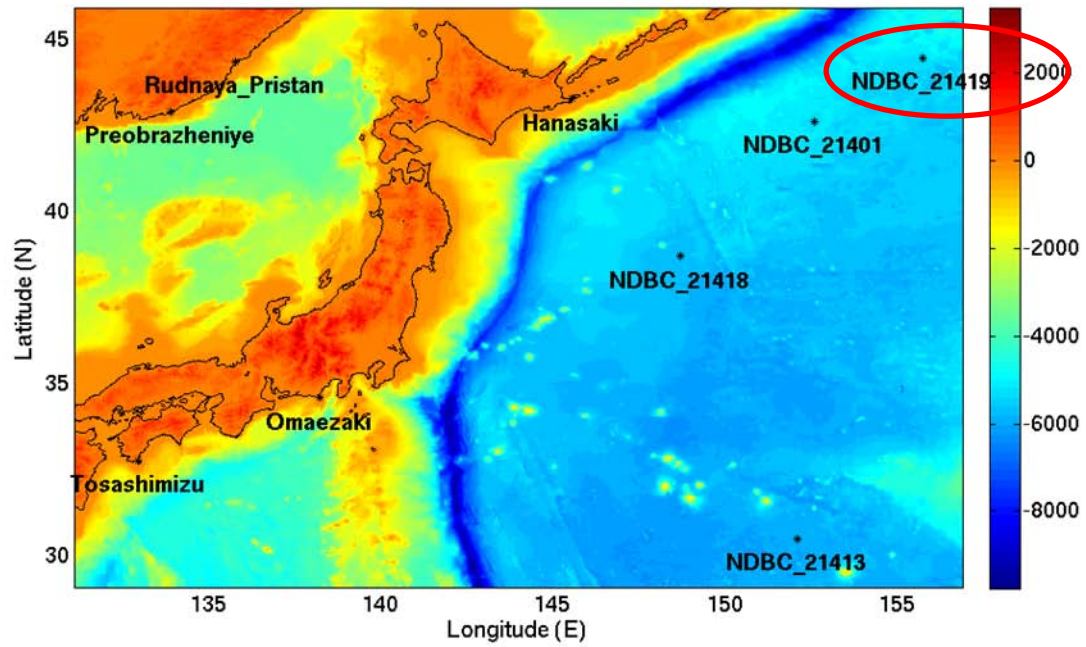
Water elevation
0hr 0min 0sec

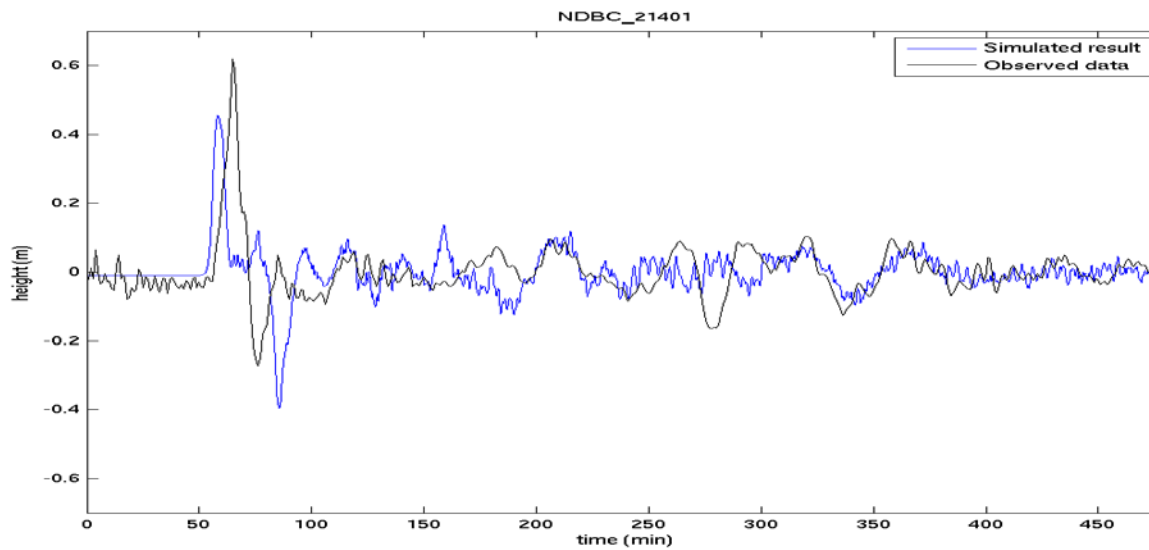
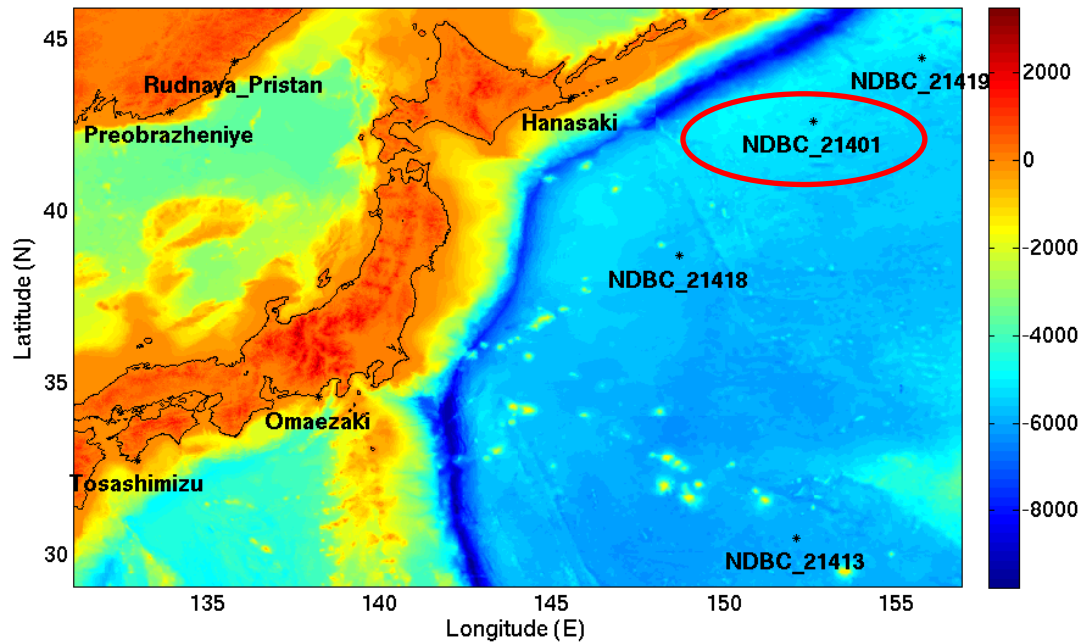


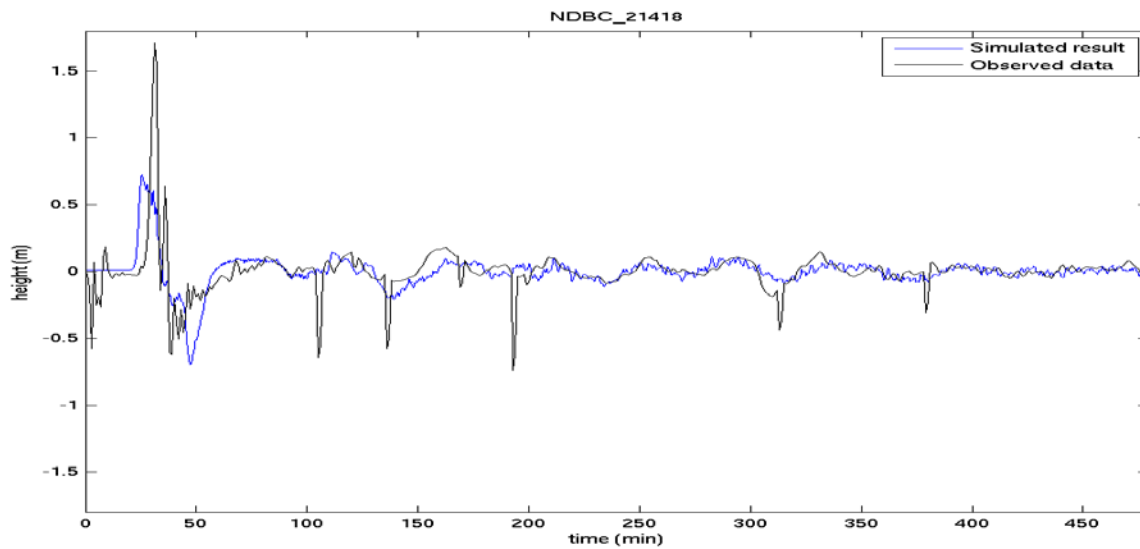
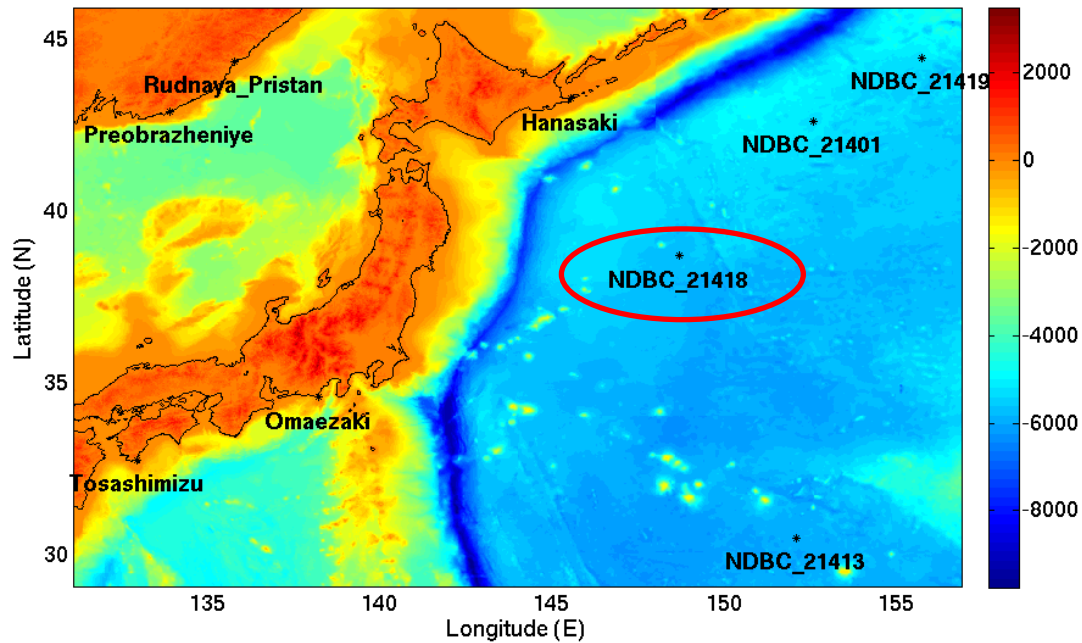
Water elevation
2hr 0min 0sec

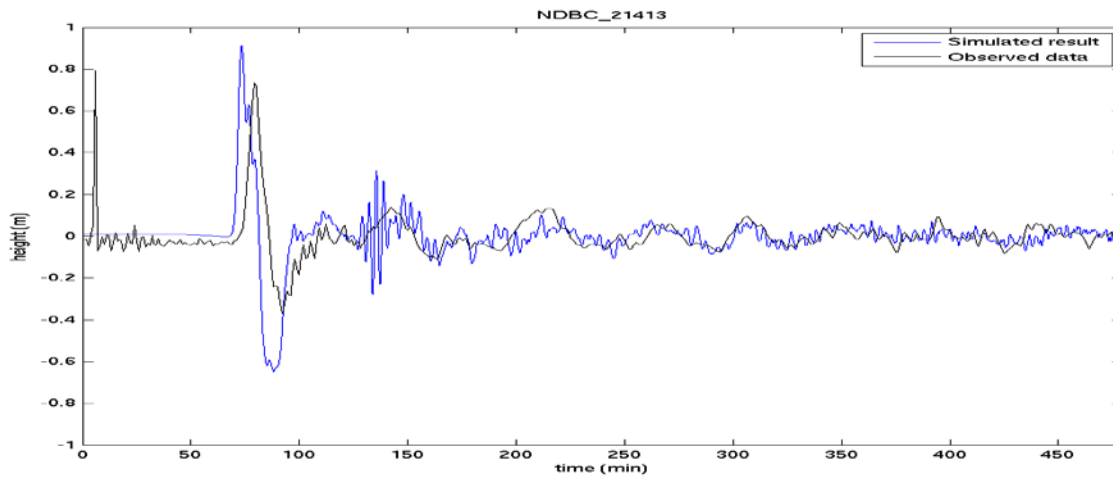
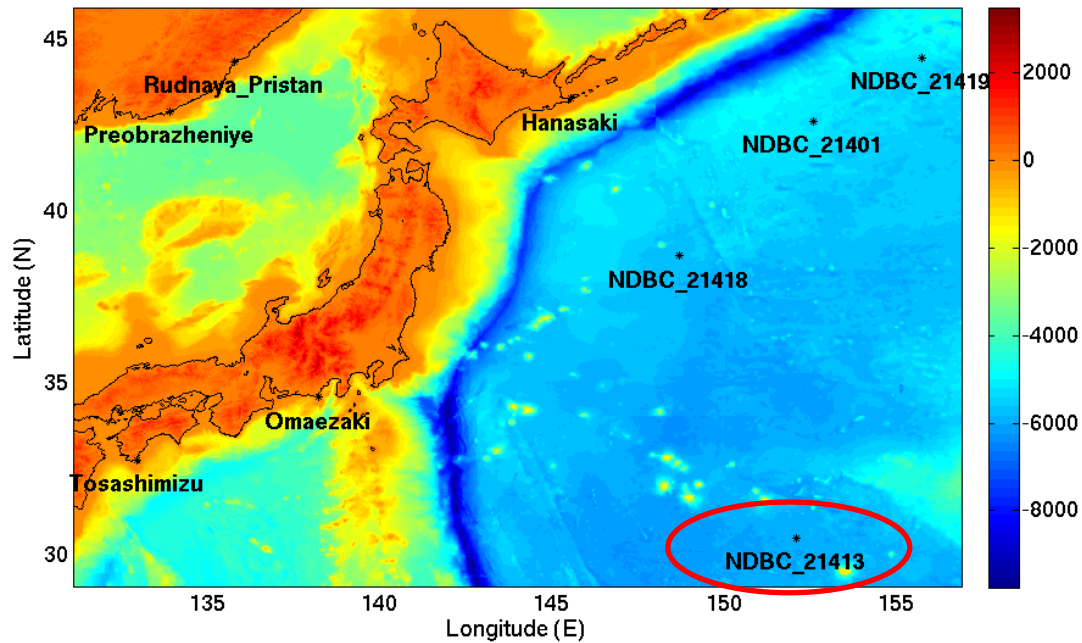


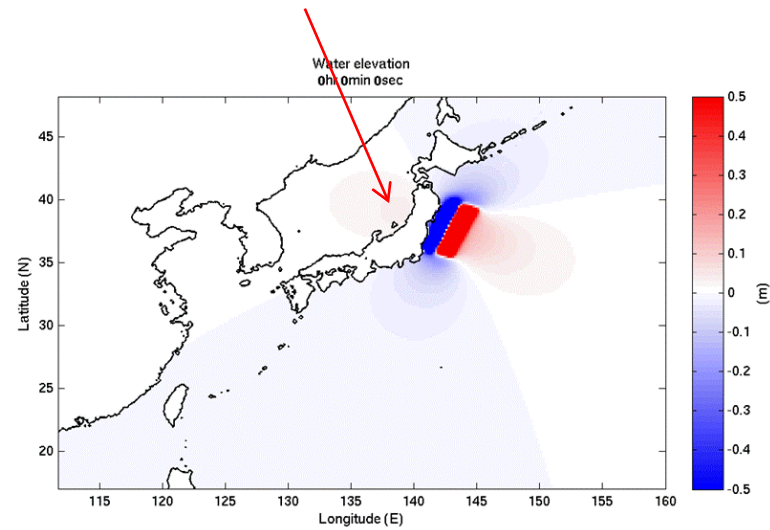
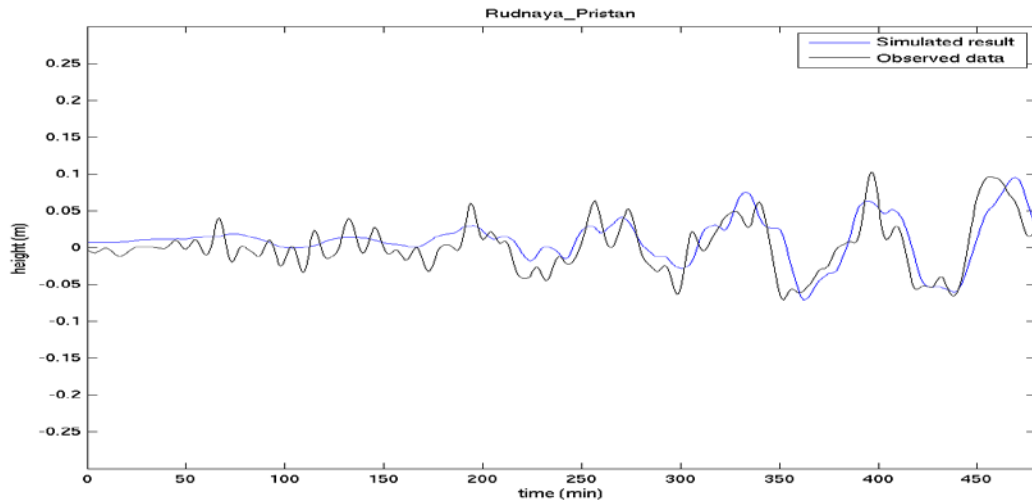
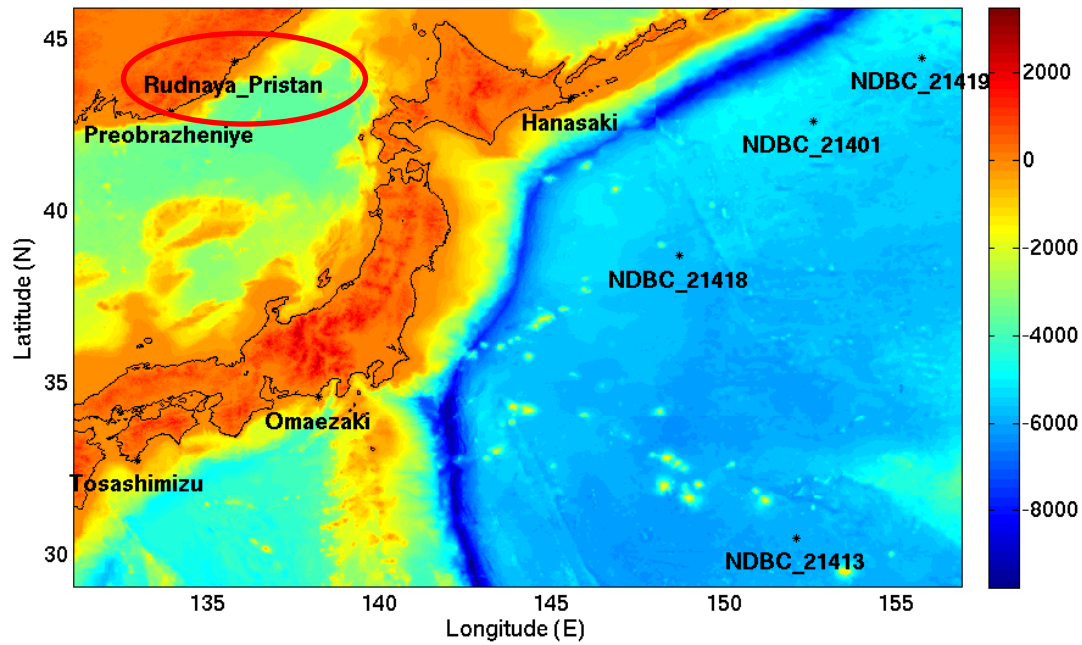




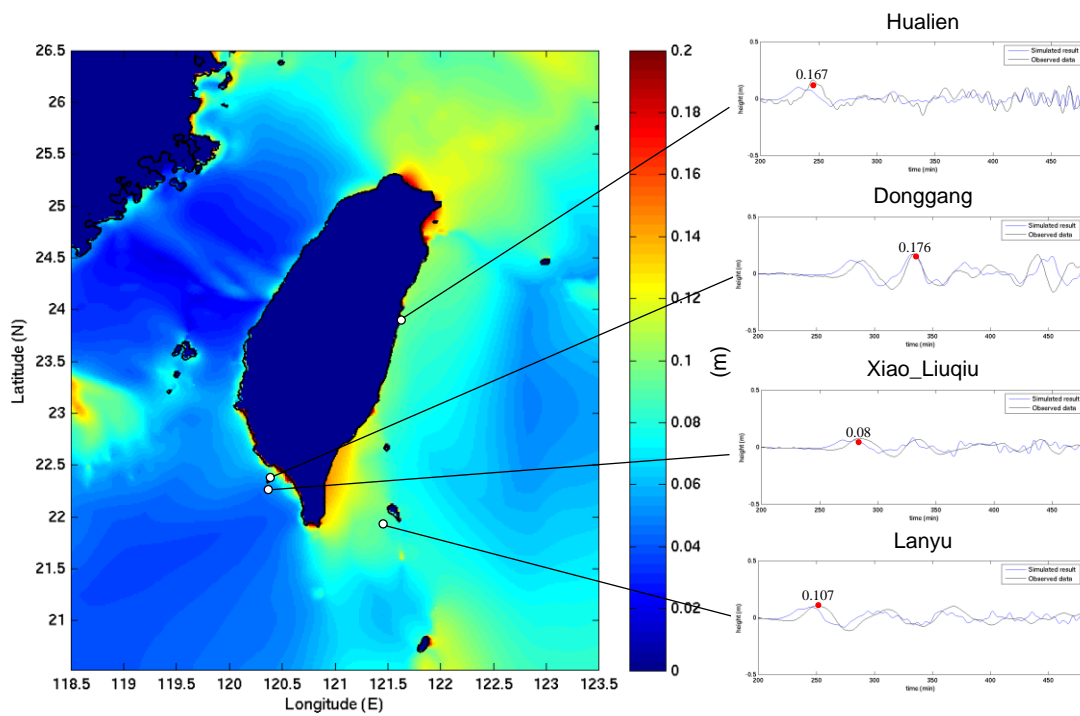
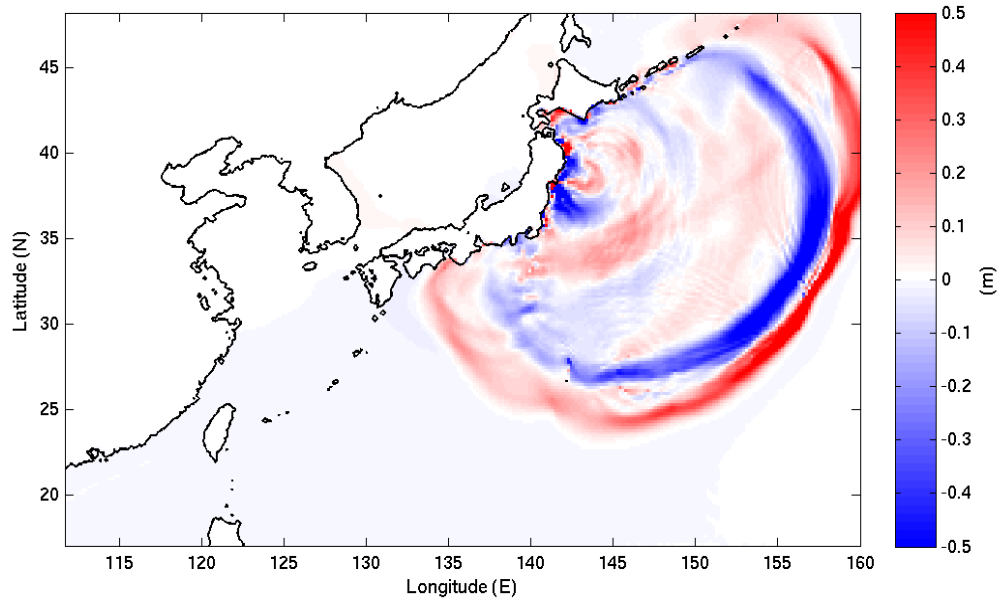




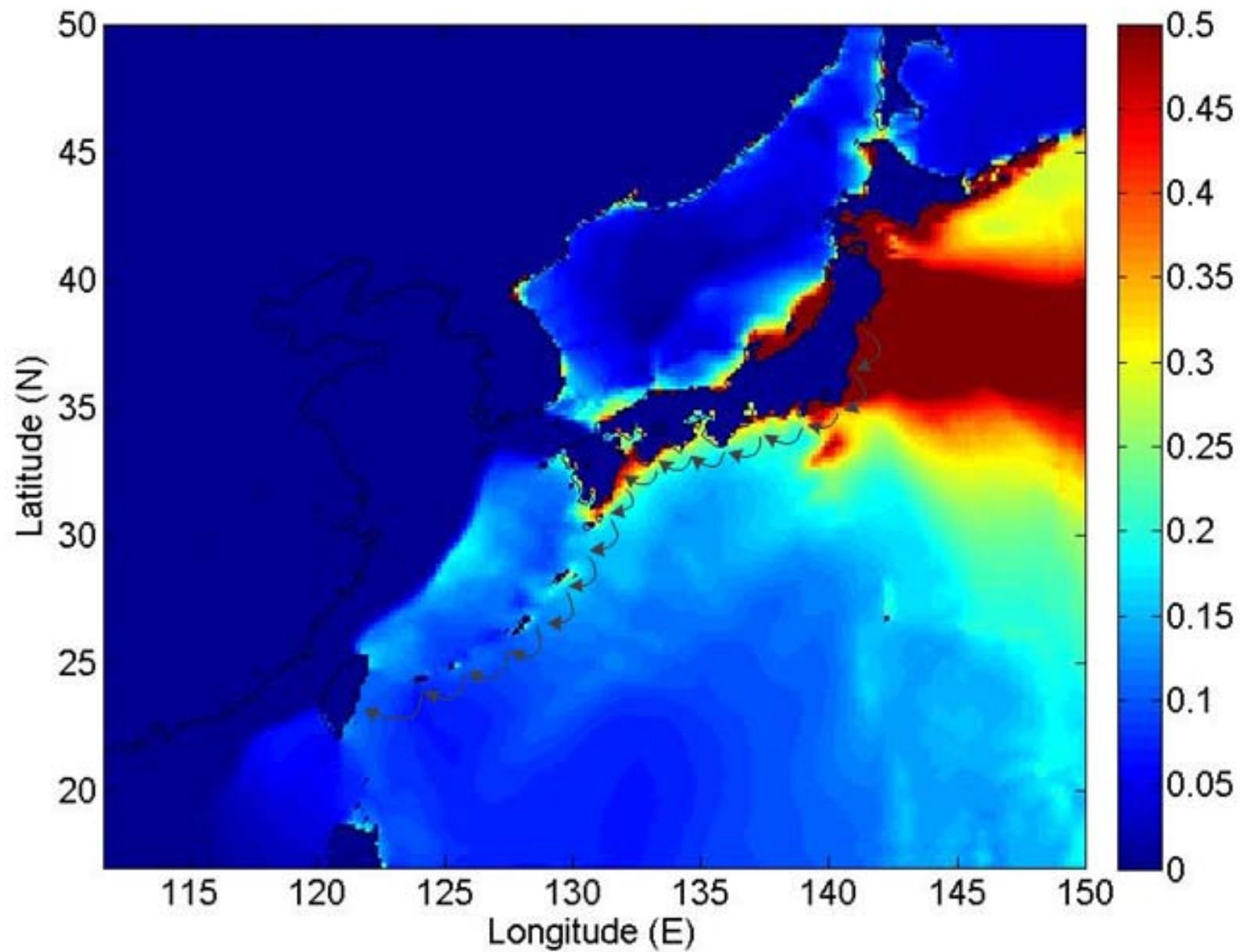




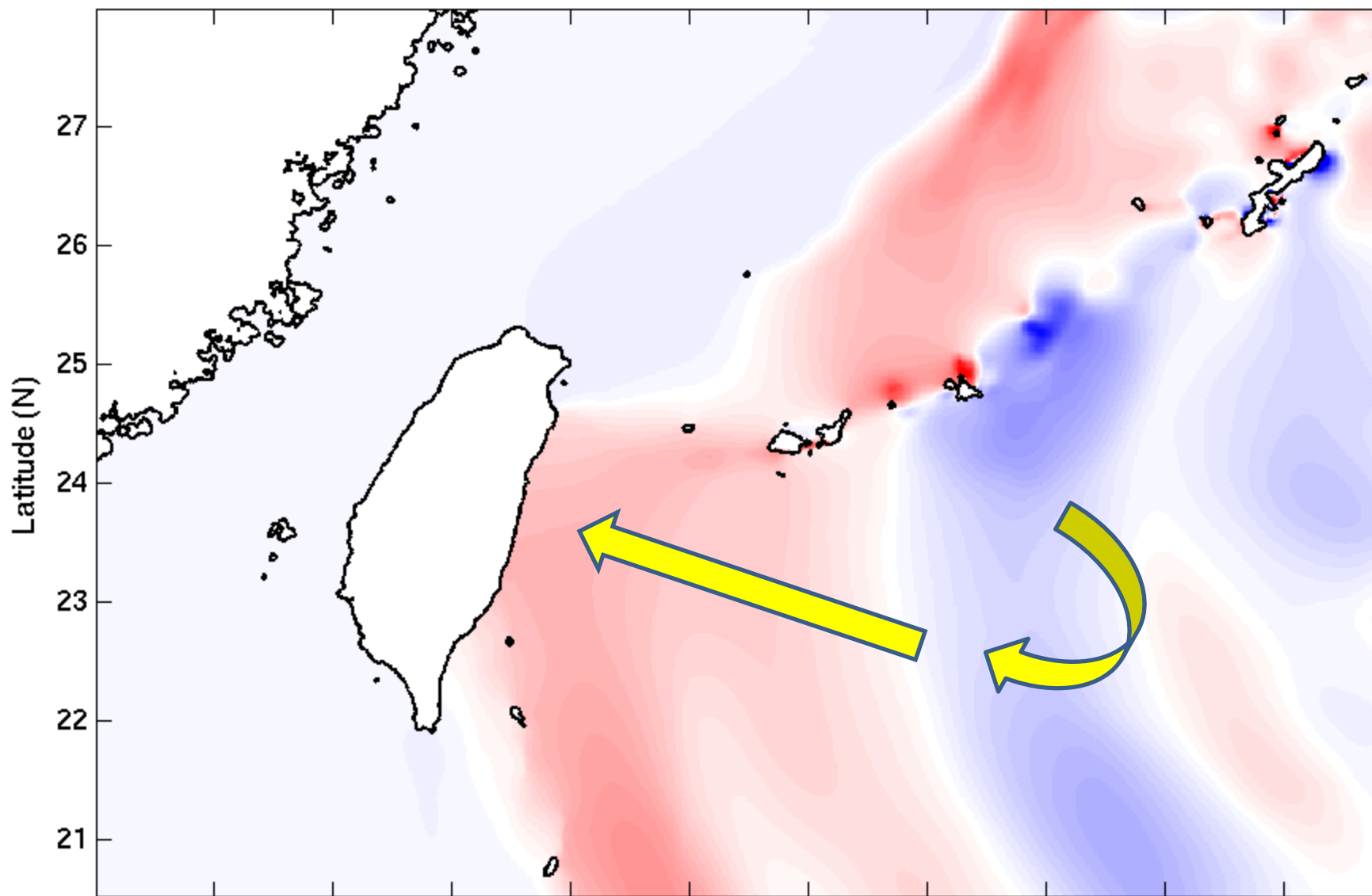
Water elevation
1hr 40min 0sec

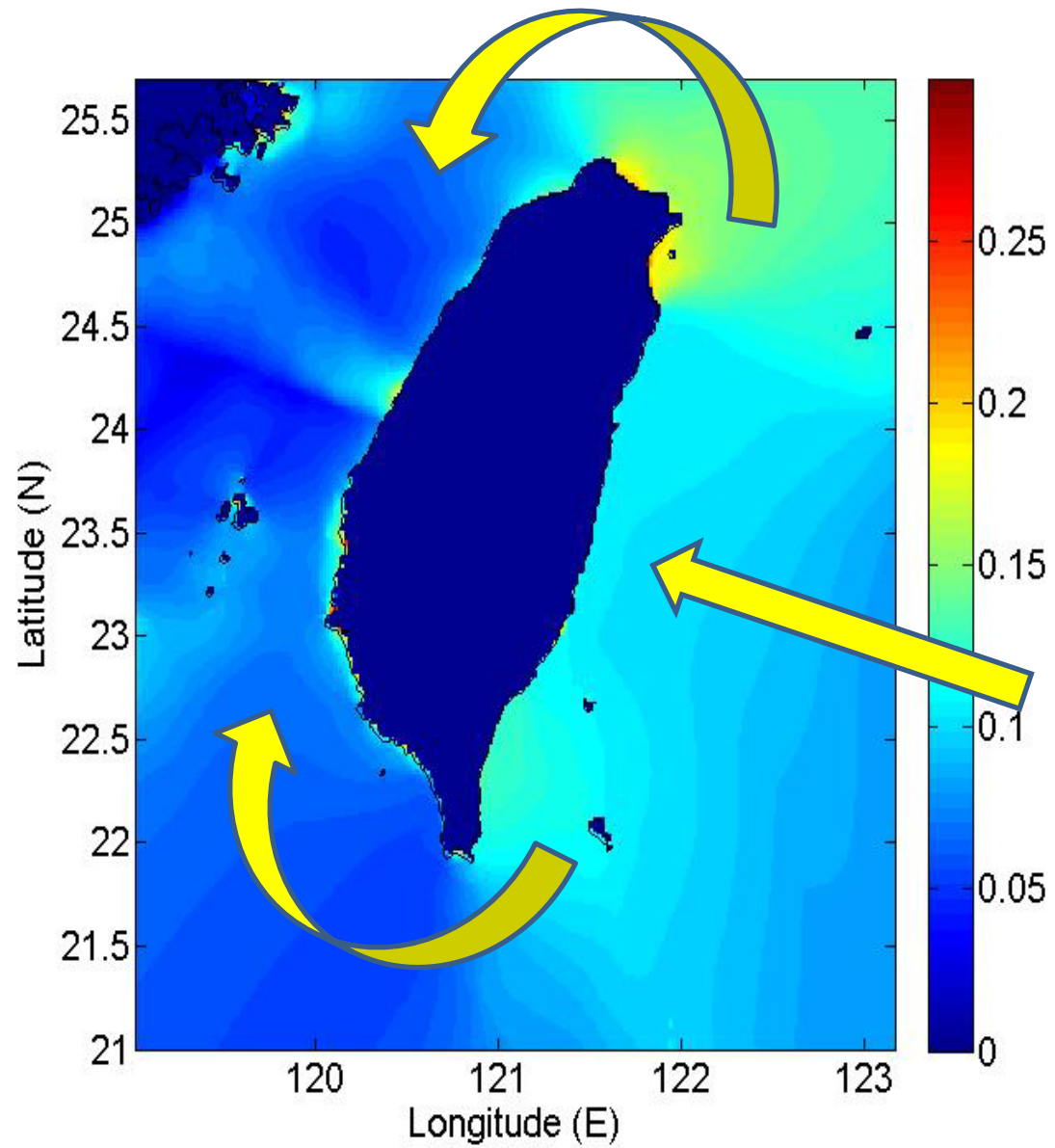






3hr 45min 0sec

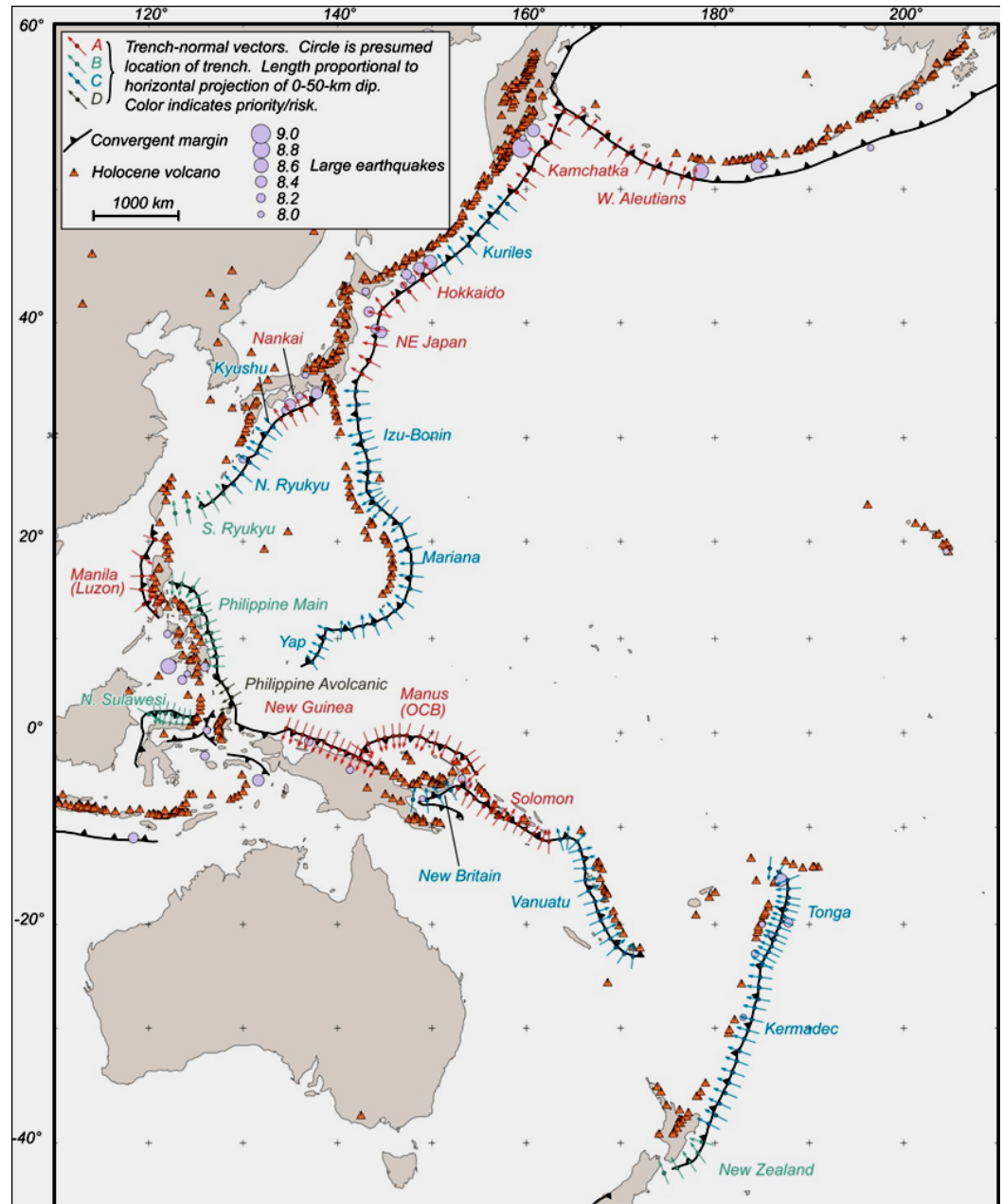


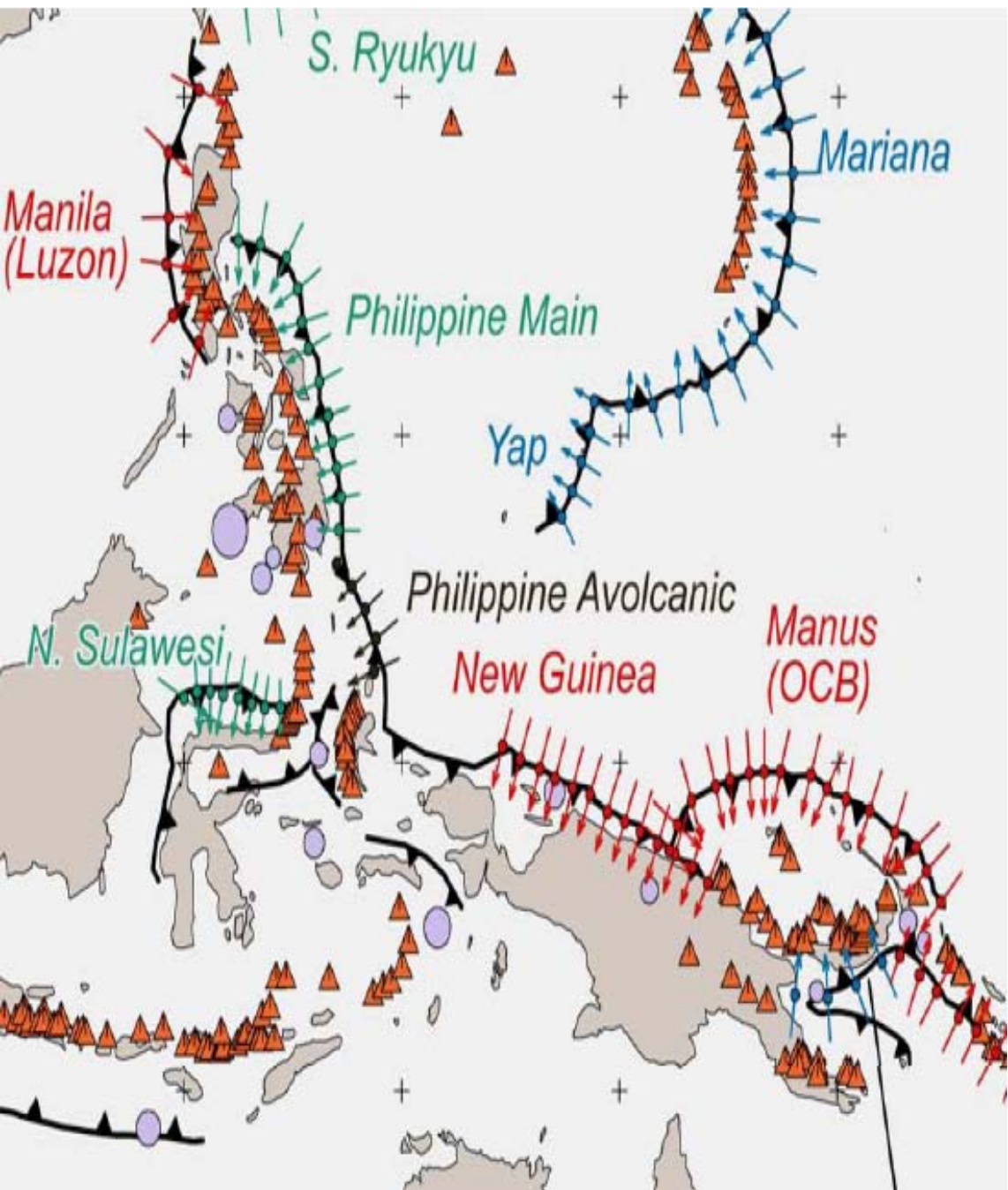


Maximum Wave height

**Tsunami Source
 Characterization for Western
 Pacific Subduction Zones: A
 Preliminary Report
 USGS1 Tsunami Subduction
 Source Working Group**

**BOTTOM LINE
 Hazard appraisal key:
 A: High
 B: Intermediate
 C: Low
 D: Not classified**





Recently the USGS issued a report assessing the potential risk as a tsunami source along the entire Pacific seduction zones. One highly risk zone is identified along the Manila (Luzon) trench, where the Eurasian plate is actively subducting eastward underneath the Luzon volcanic arc on the Philippine Sea plate.

BOTTOM LINE
Hazard appraisal key:
A: High
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South China Sea Region

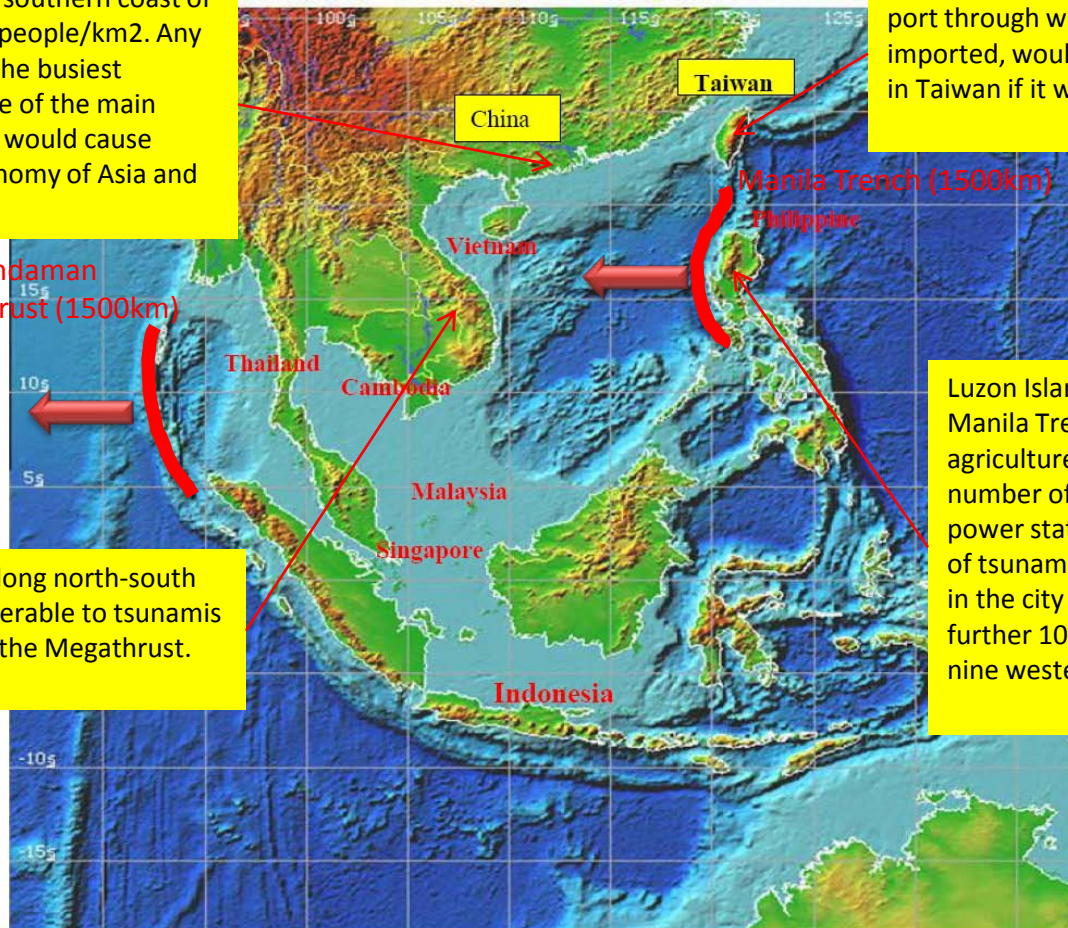
Population density along the southern coast of mainland China is 100 – 200 people/km². Any effect to Hong Kong, one of the busiest seaports in the world and one of the main gateways to and from China, would cause significant impact to the economy of Asia and the world.

Kaohsiung in the southern Taiwan, the major port through which most of Taiwan's oil imported, would paralyze economic activities in Taiwan if it were devastated by tsunami.

Aceh-Andaman
Megathrust (1500km)

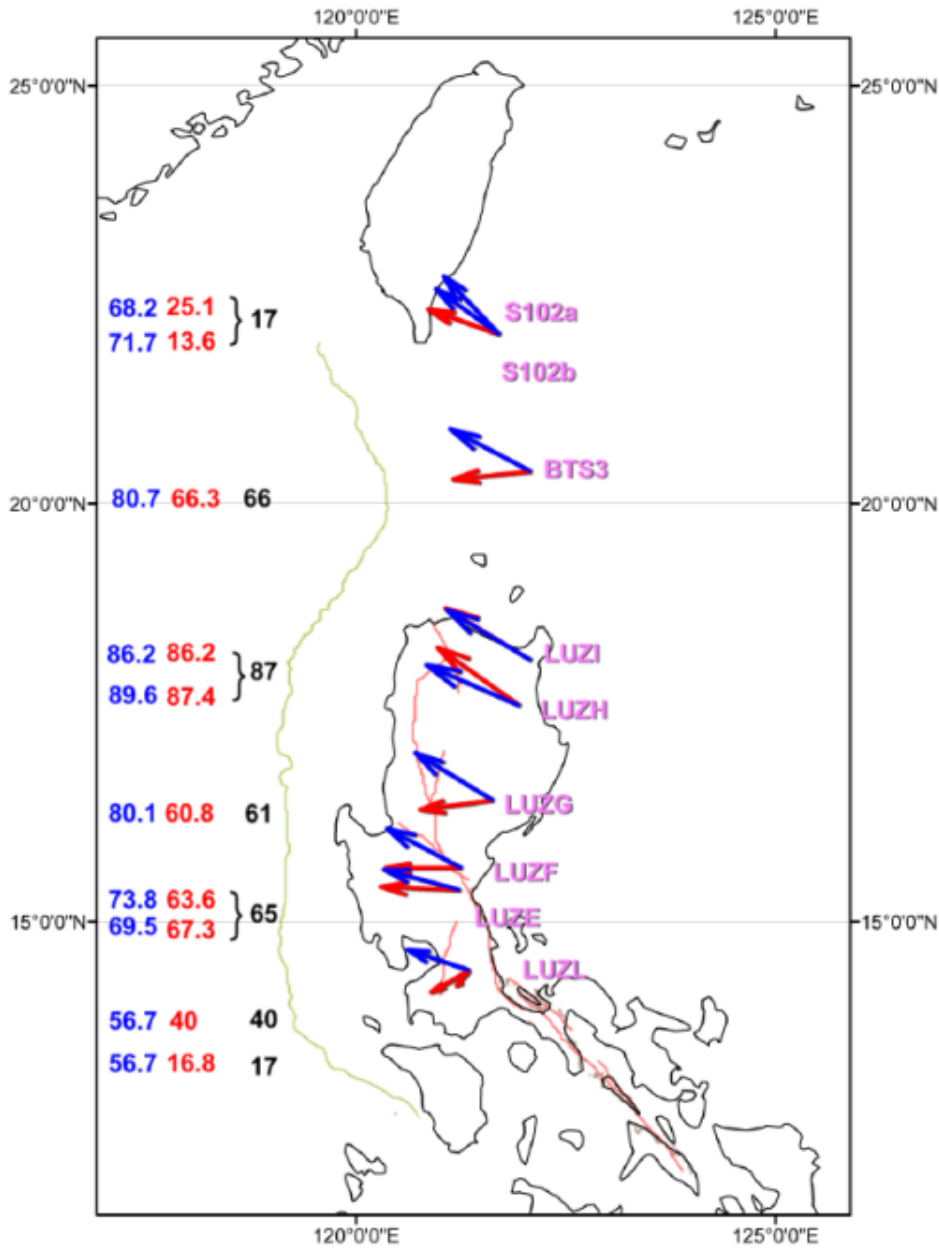
Facing the trench, Vietnam's long north-south profile renders it acutely vulnerable to tsunamis from the southern section of the Megathrust.

Luzon Island, which lies just east of the Manila Trench, is the site for intensive agriculture, industry, tourism, with a number of key sea and air ports and power stations exposed to the threat of tsunami. Over 11 millions people live in the city of Manila alone, with a further 10 million people inhabiting the nine western coast provinces.



The exposure of large population centers bounding the South China Sea to tsunami hazard cannot be understated.

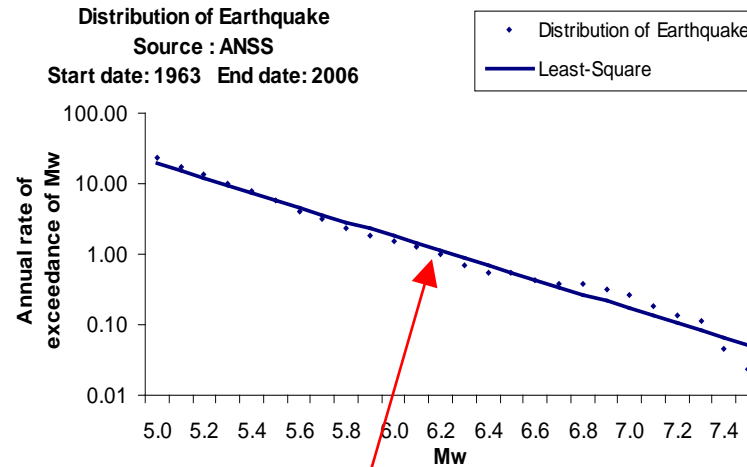
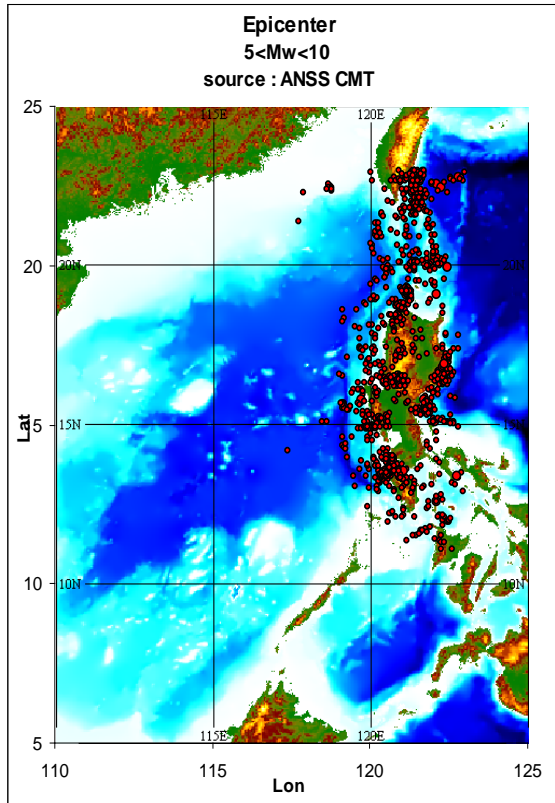
(Megawati et al., 2008)



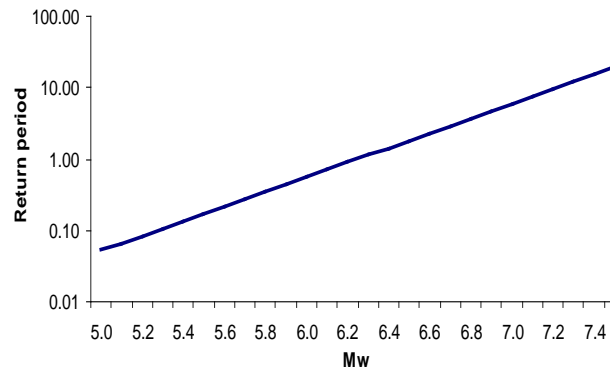
The GPS geodesy measurements show that the convergence rate across the Megathrust is about 8 cm/year. Yu et al. (1999) used 35 GPS stations on Luzon Island and southern Taiwan to calculate the relative motion between Luzon arc and Eurasia. The observation was conducted for two years, from 1996 to 1998. Relative motion is greatest in northern Luzon at 19N, moving 86-90 mm/yr northwestward. The velocities taper gradually towards the north and south as collision regimes pin both ends of the Megathrust.

GPS data (Yu et al., 1999) indicating motion of the converging Eurasian Plate and the Philippines Sea Plate, where the blue arrows and numbers show raw velocity values (mm/yr) taken from Yu et al. (1999), the red arrow and numbers indicate velocity values (mm/yr) resolved in the direction perpendicular to the trench front, and the black numbers give the rounded values (mm/yr) used for slip estimation.

Estimation of Return period



$$\log N = 6.410 - 1.026M$$

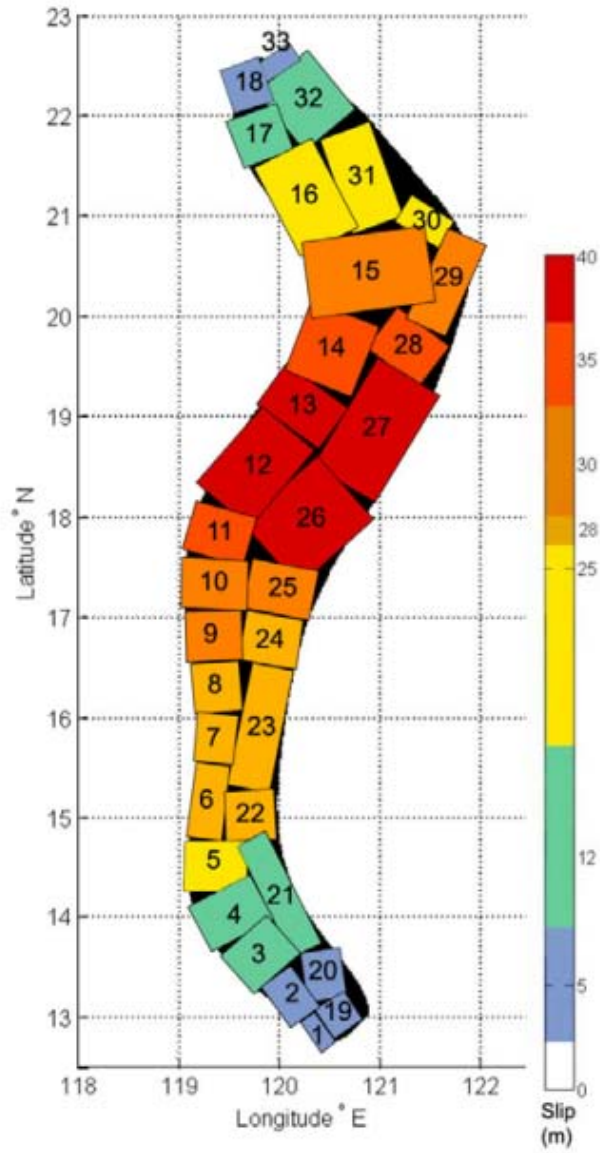


Mw	Return Period (year)
7.0	6
7.5	19
8.0	63
8.5	205
9.0	667

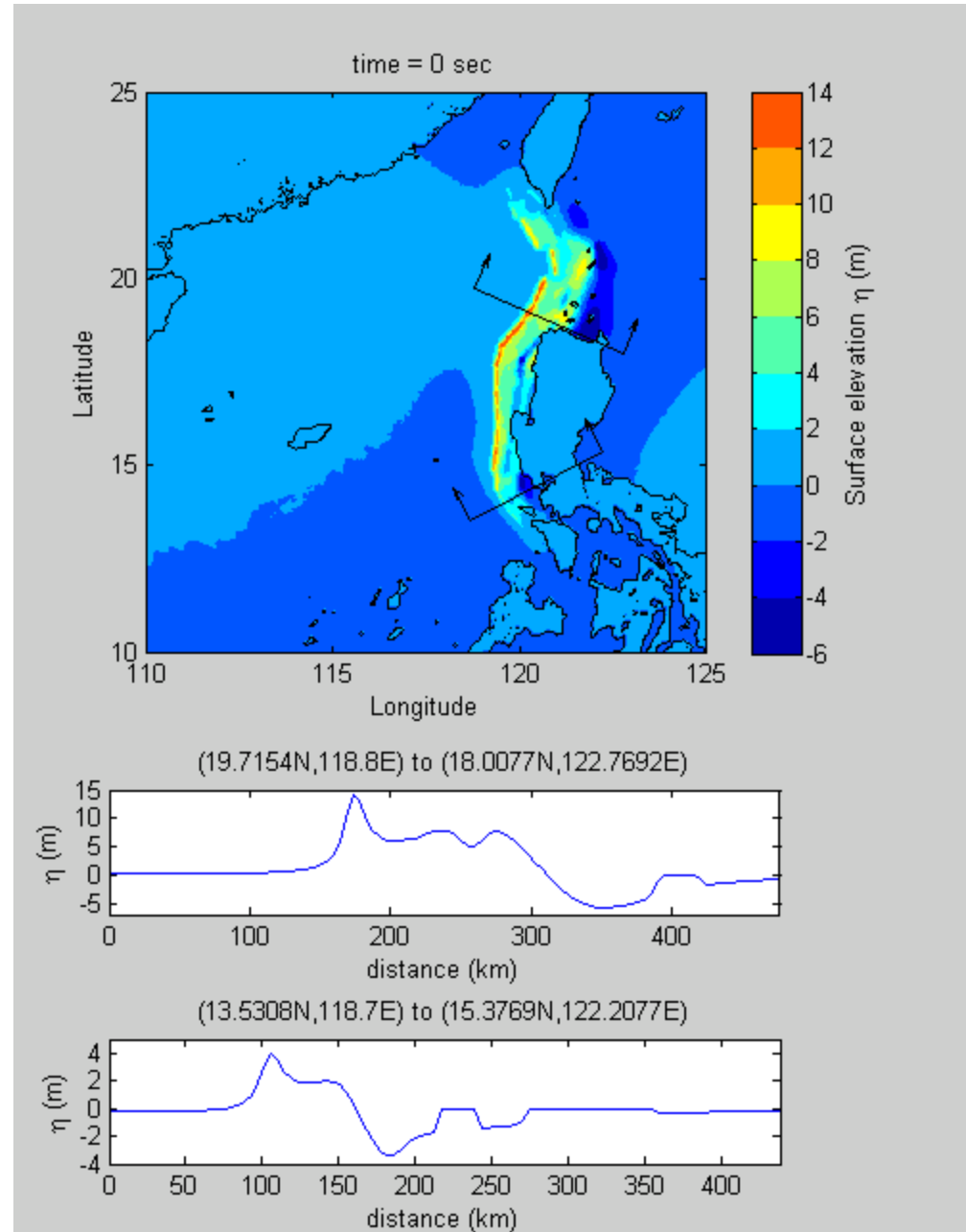
Source:ANSS 1963-2006

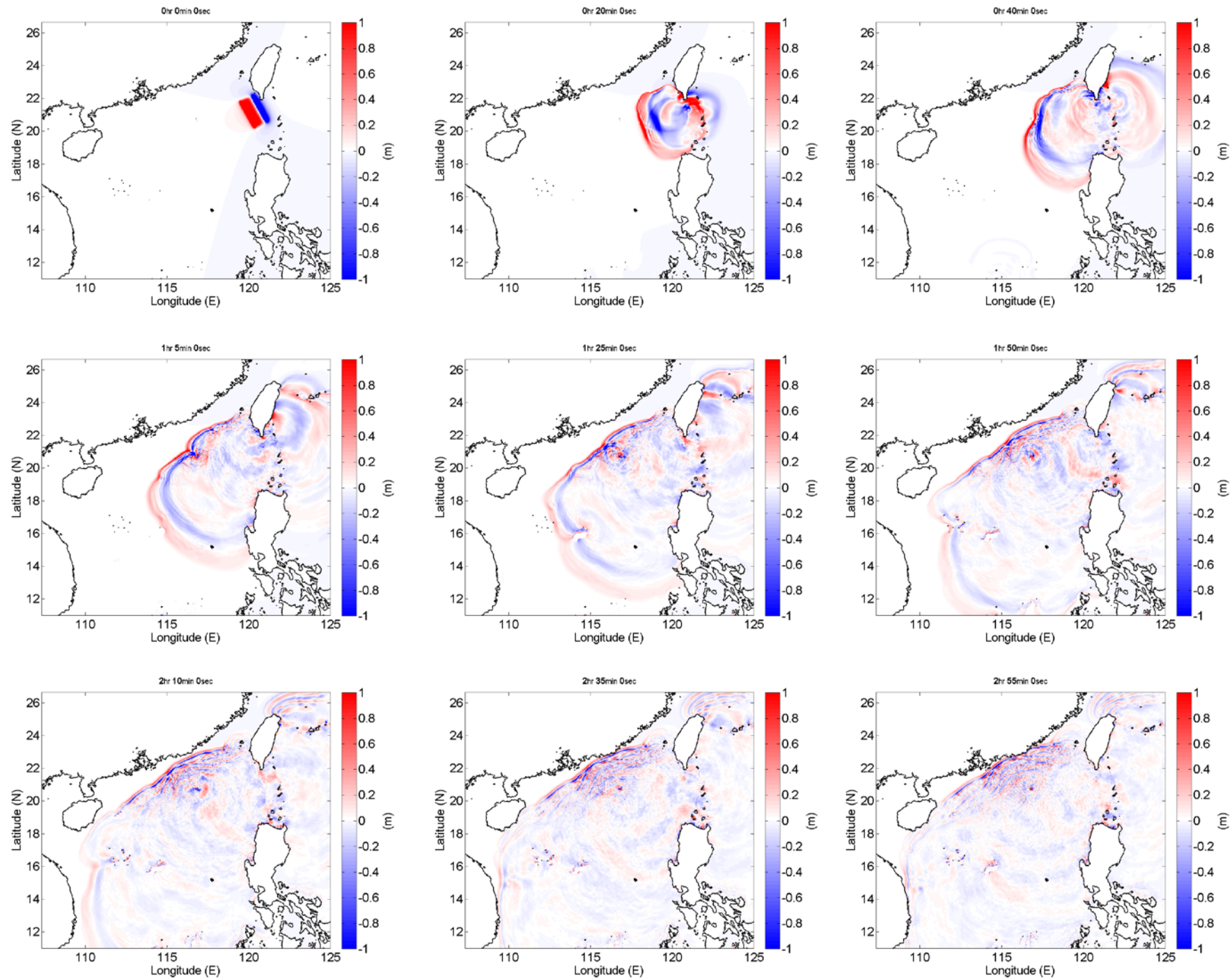
It is significant that since the Spanish colonization of Luzon in the 1560s, no earthquake exceeding magnitude 7.8 has been observed (Repetti, 1946). Conservatively, it can be postulated that very large events on this Megathrust have a recurrence interval exceeding 440 years. Taking a trench-normal convergence velocity of 87 mm/yr, strain of ~38 m would range of plausible scenarios. It is comparable to the 1960 Mw 9.5 Chilean earthquake, in which coseismic slip reached 40 m (Barrientos and Ward, 1990), and larger than 2004 Aceh-Andaman event, which produced 20 m of coseismic slip (Chlieh et al., 2007).

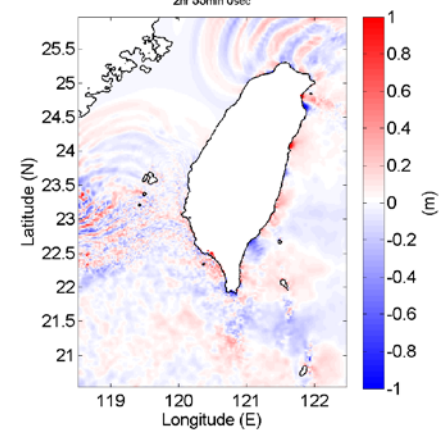
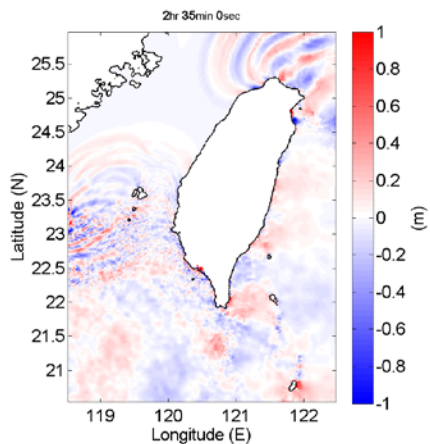
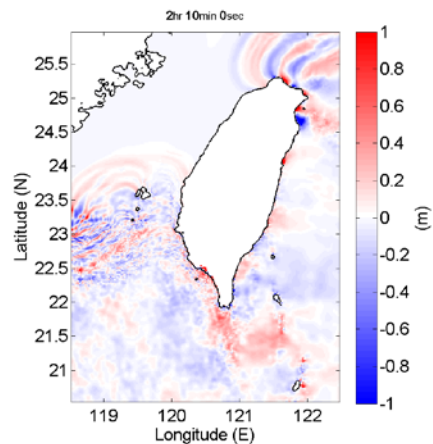
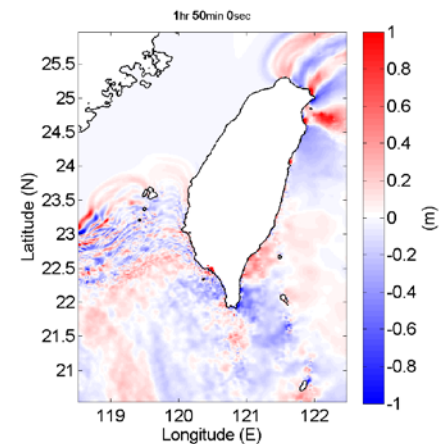
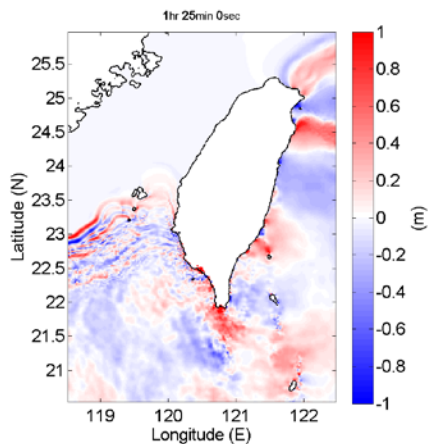
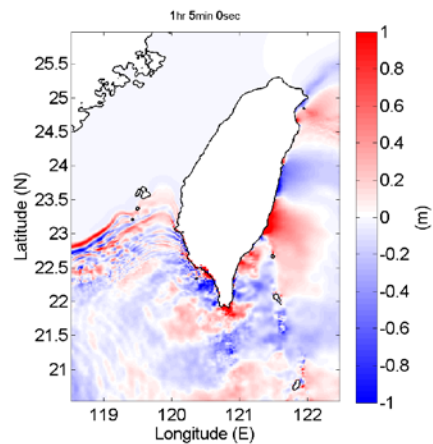
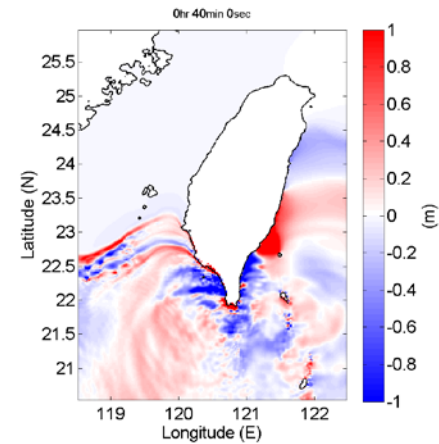
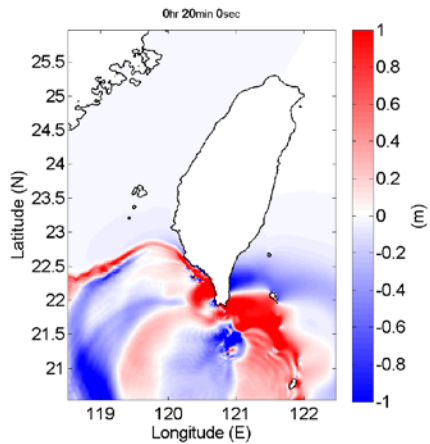
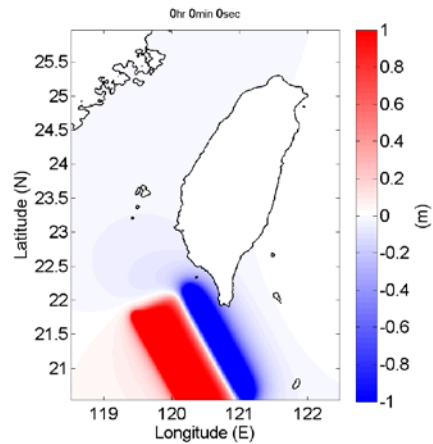
Initial free-surface profile

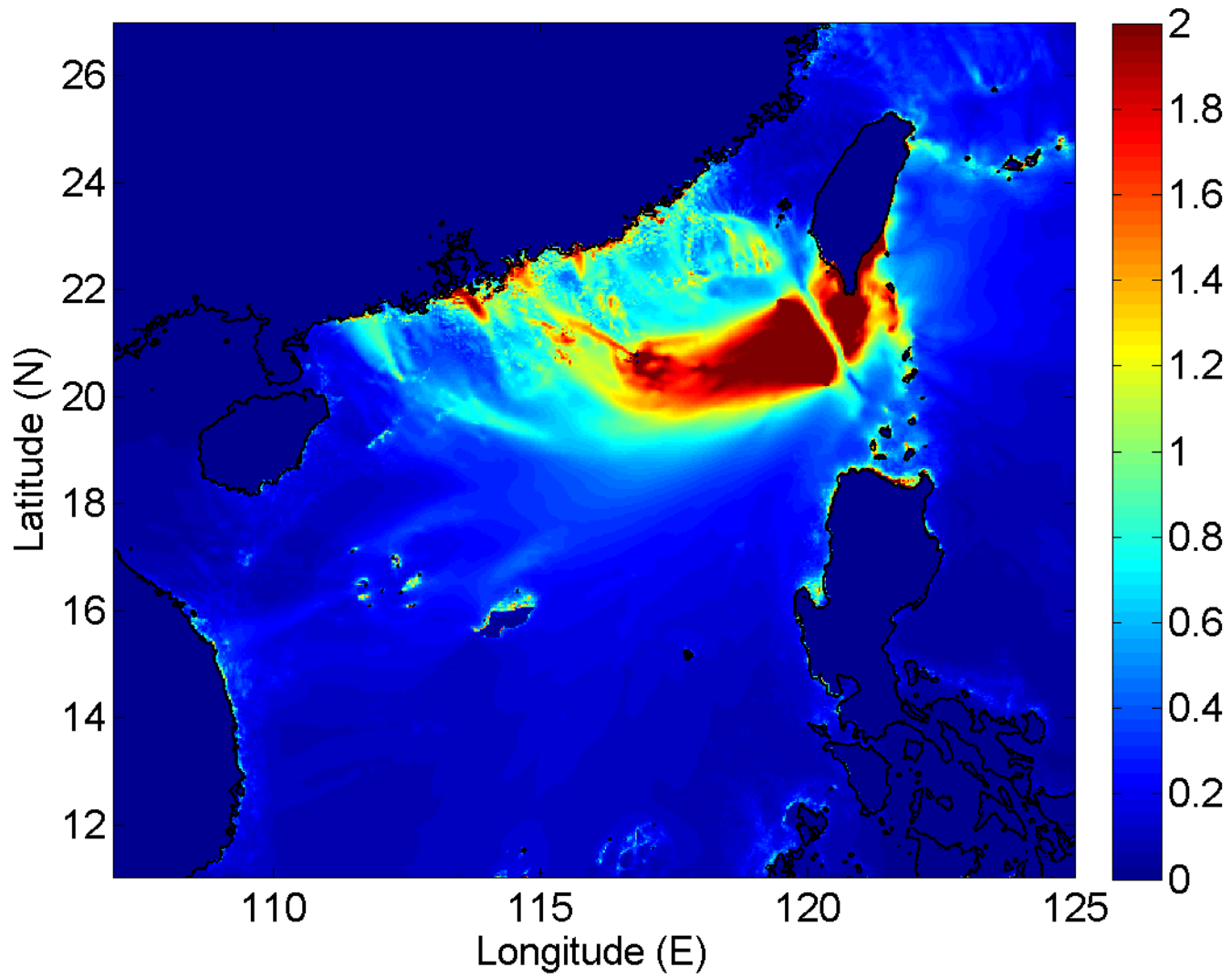


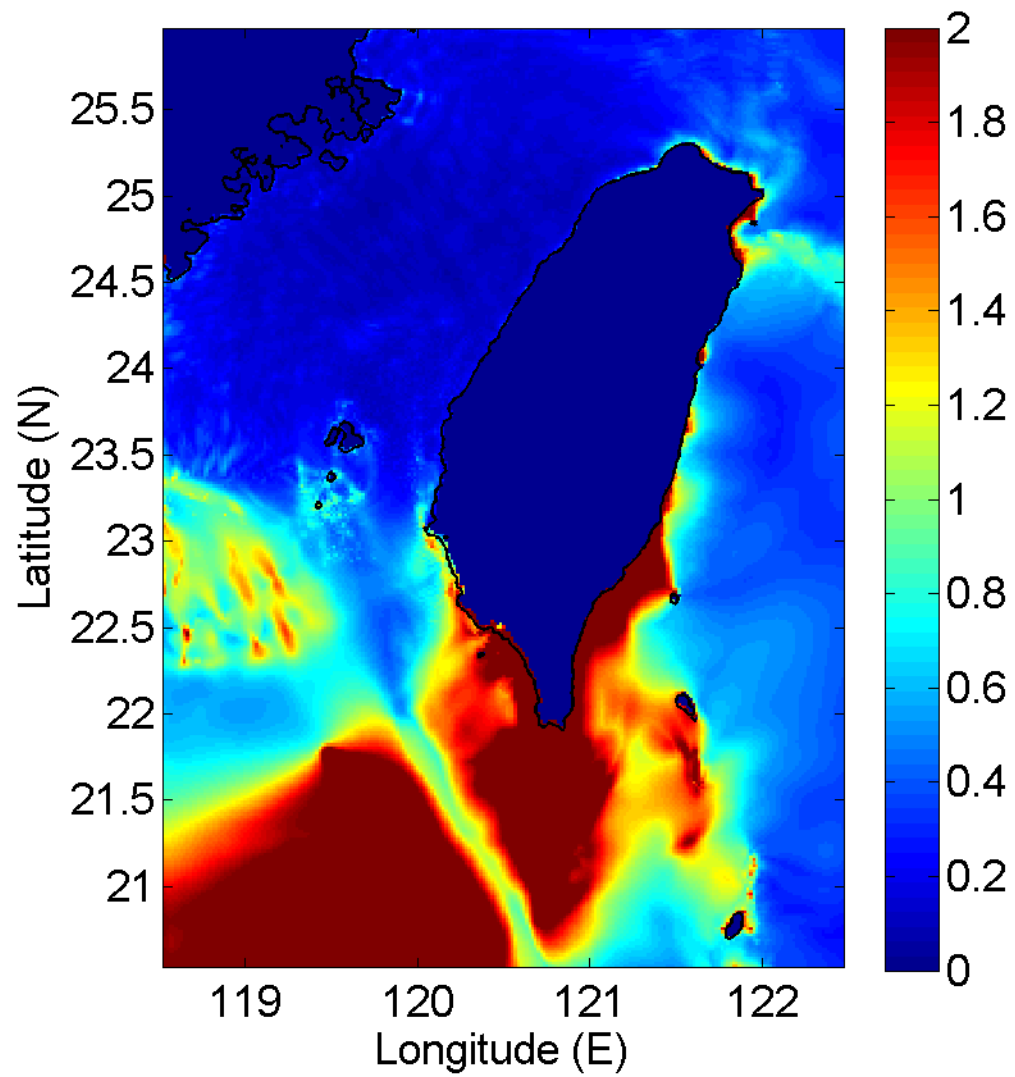
The discretized model for computation of seafloor displacement



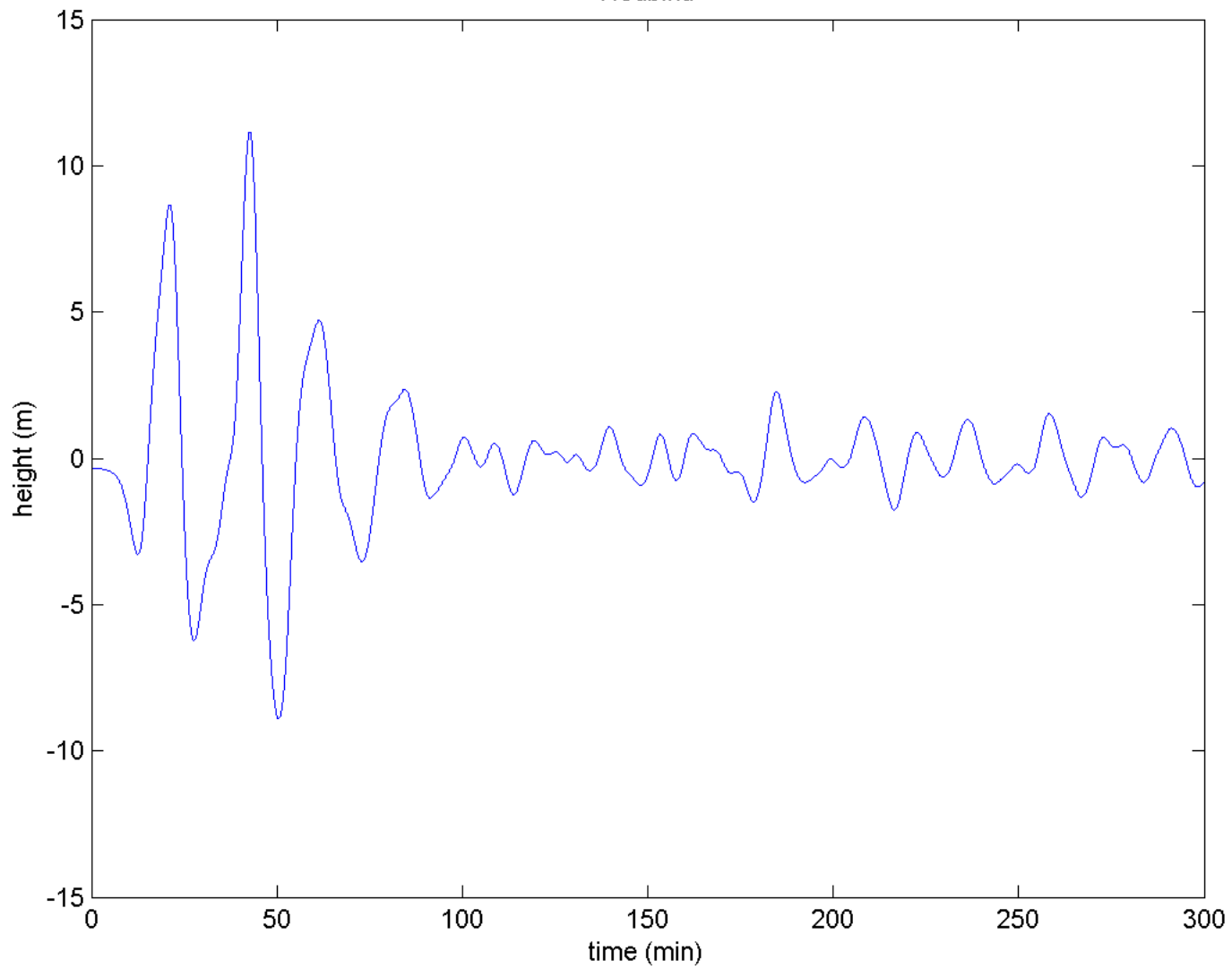


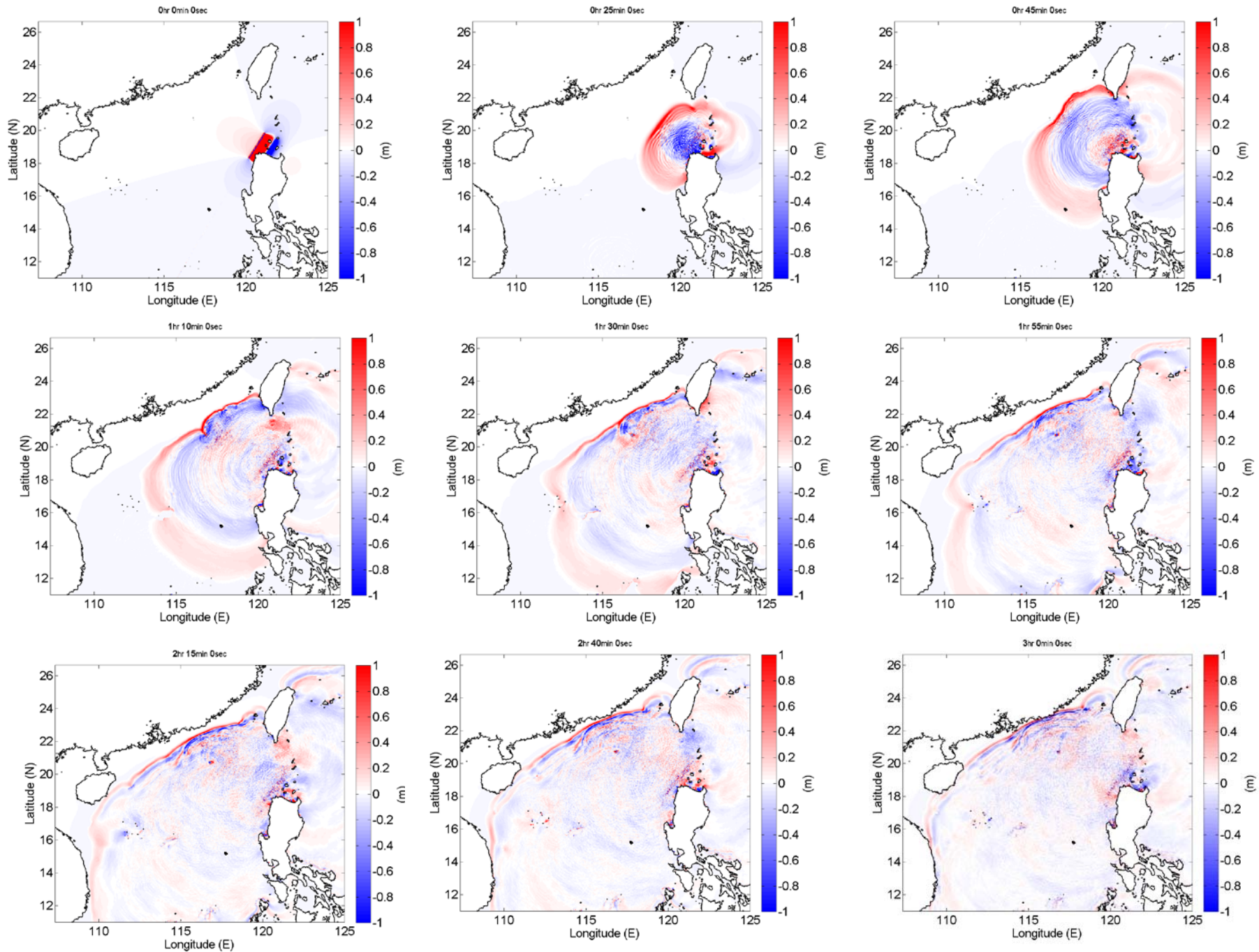


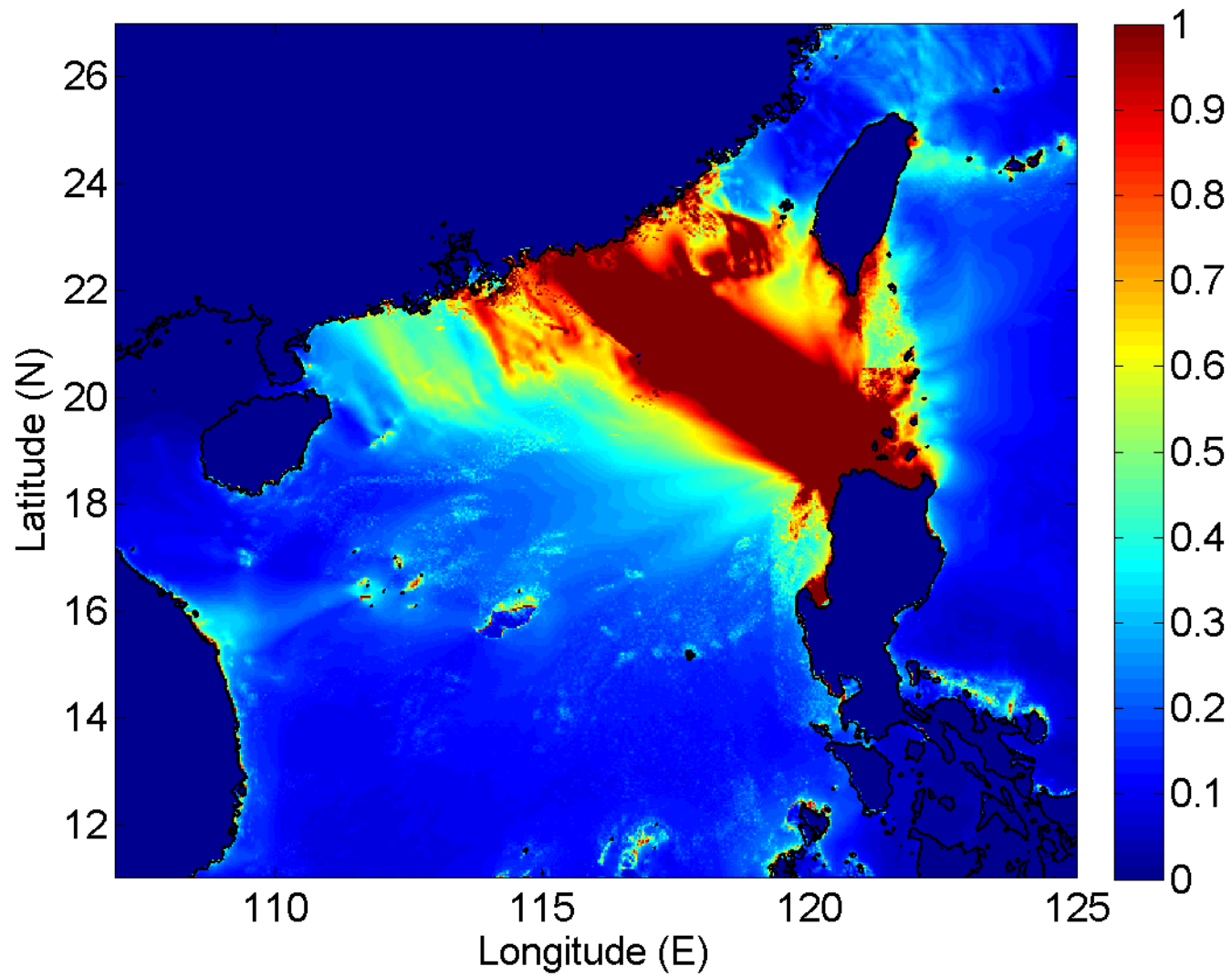


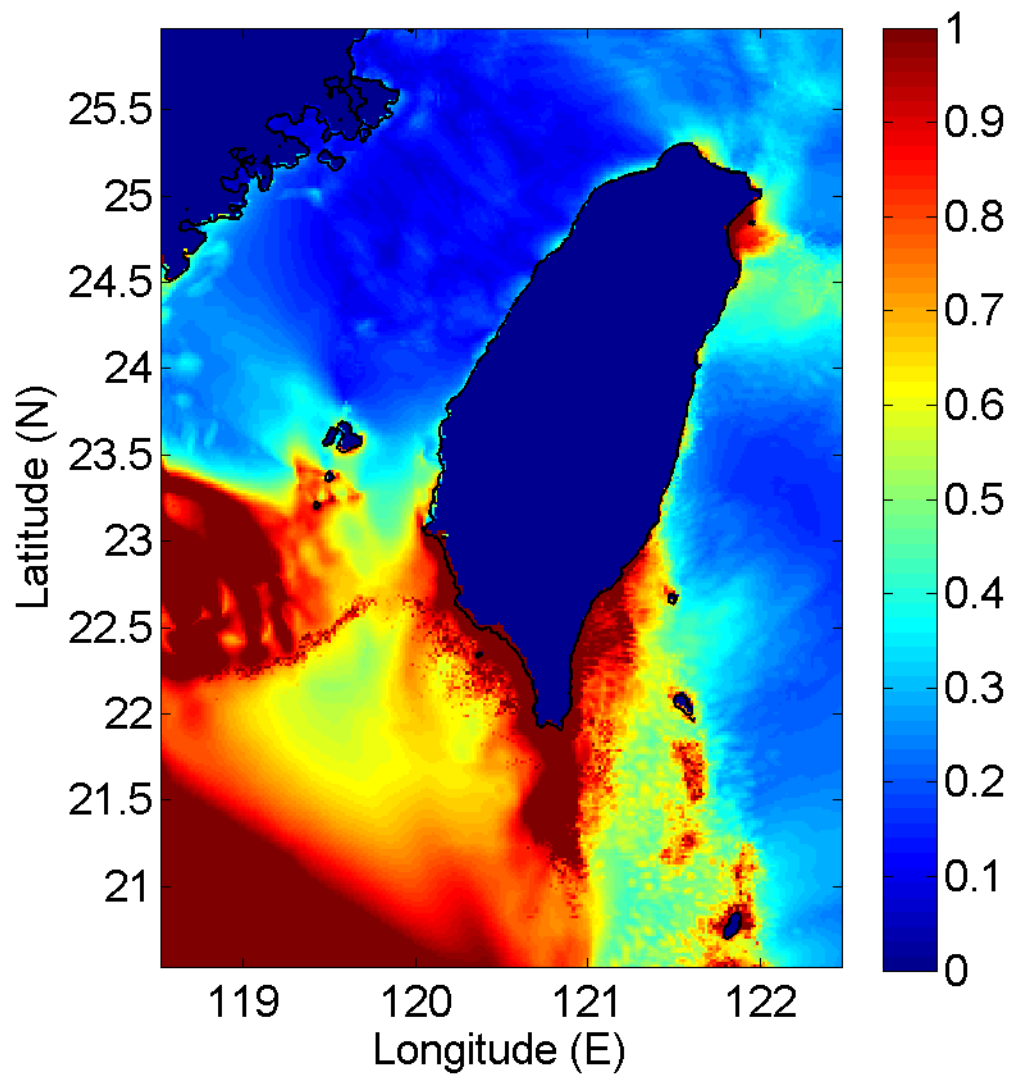


Houbihu









Fault parameters of Manila Megathrust

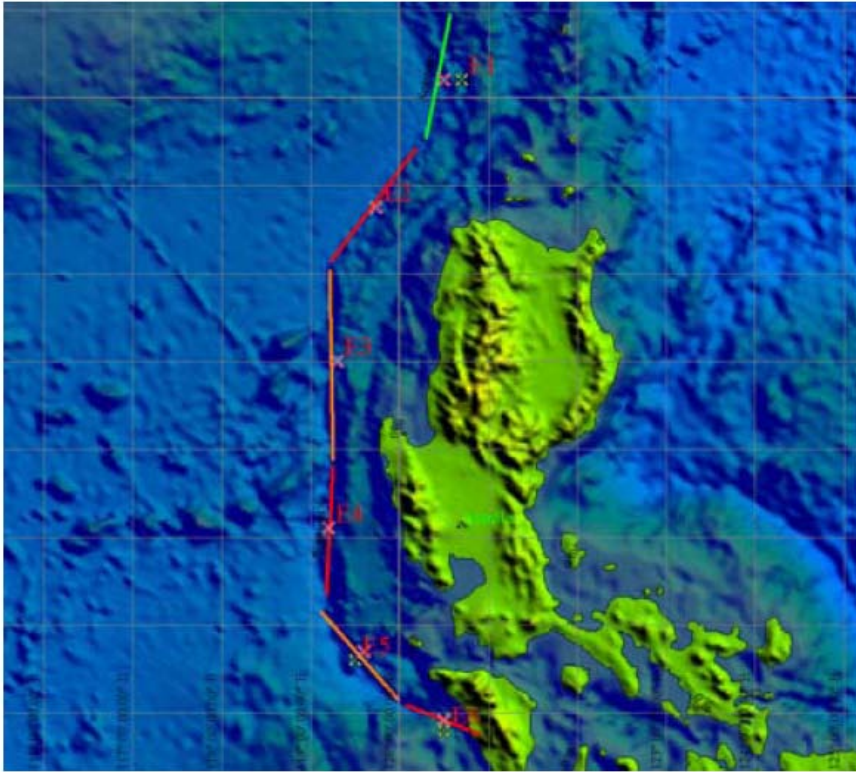
- Earthquake parameters of the three largest tsunami earthquakes. All three earthquakes have similar length varying from 740 to 1300 km, and similar width varying from 200 to 300 km. The earthquake magnitude ranged from $M_w = 9.0$ to 9.5. Using all of the information and referring to the fault geometry, a set of hypothetical fault of Manila Megathrust is nailed down.

Date	Location	(Lon,lat)	M_w	Length (km)	Width (km)	Dislocation (m)	Focal Depth (km)	Maximum water height (m)
1960/5/22	Chile	(74.5,39.5)	9.5	1000	300	No data	60	25
1964/3/28	Alaska	(-147.5,61.1)	9.2	540-740	300	18-22	23	67
2004/12/26	Sumatra	(95.98,3.3)	9	1300	200	20	28.6	50

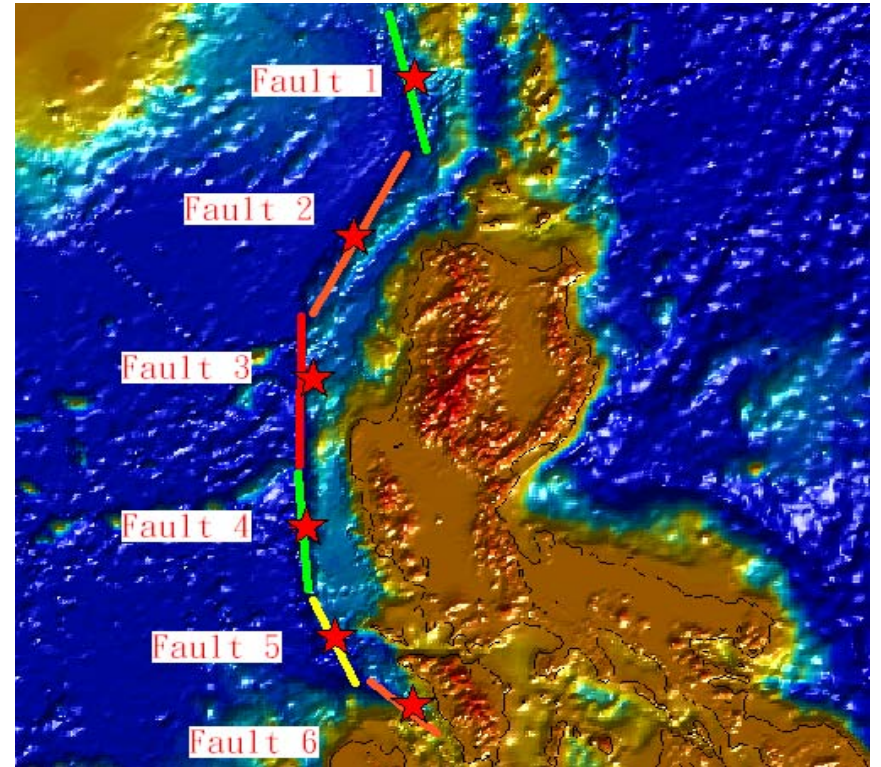
(Data source: Catalog of Tsunamis in the Pacific Ocean, and Harvard CMT)

Manila Fault	M_w	Length (km)	Width (Km)	Dislocation (m)	Depth (km)
Total	9.35	990	200	20	40

The earthquake parameters of Manila Fault



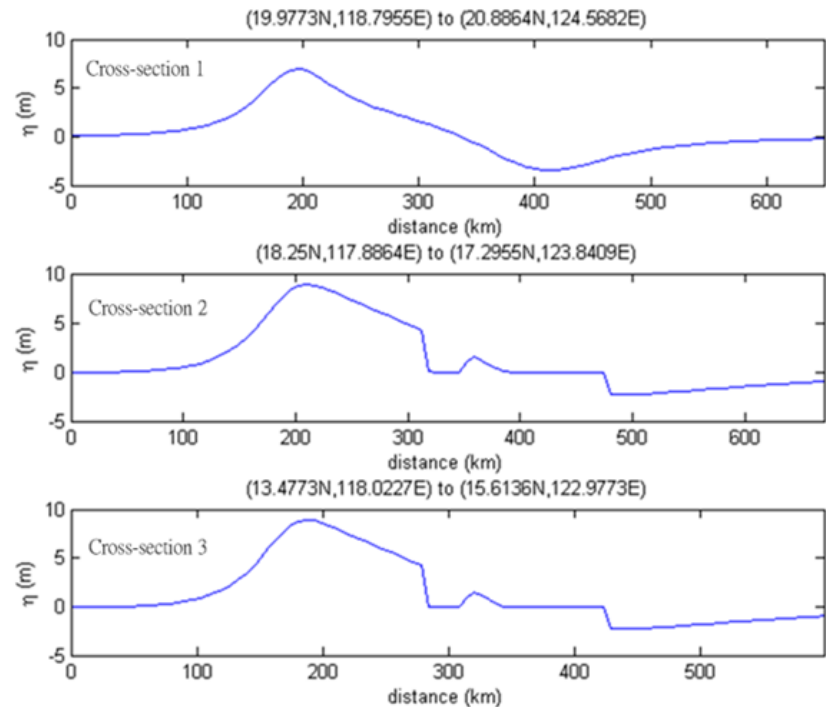
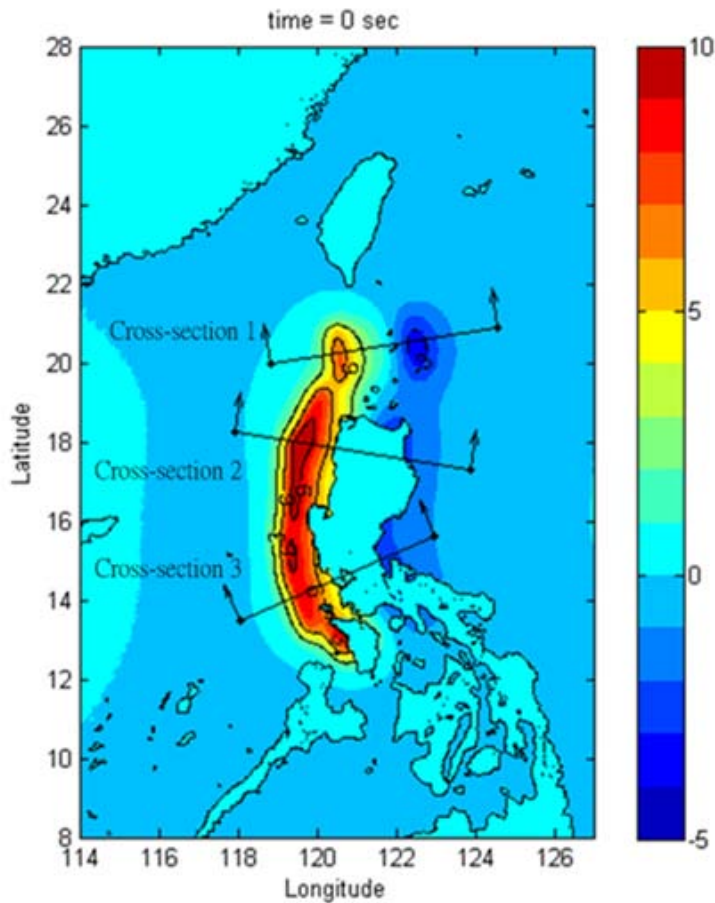
Fault distribution along Manila Trench.
(Map provided by USGS)



Fault distribution along Manila Trench used
in present study.

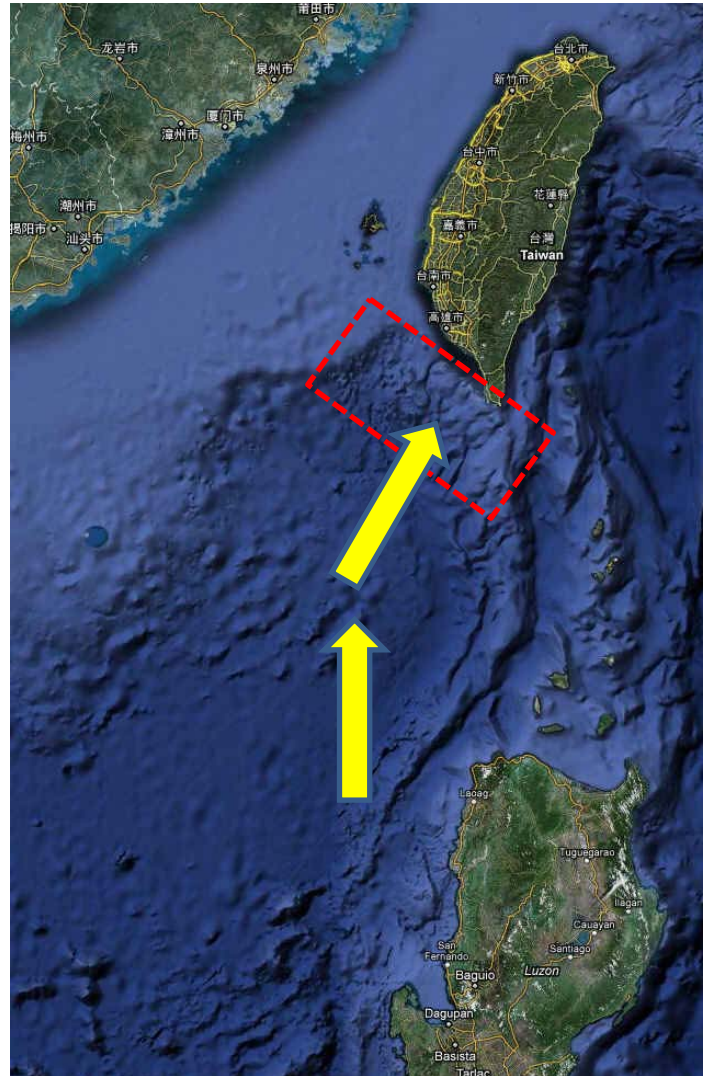
Initial free surface elevation

The tectonic movement is calculated based on the elastic dislocation theory proposed by Mansinha and Smylie (1971).



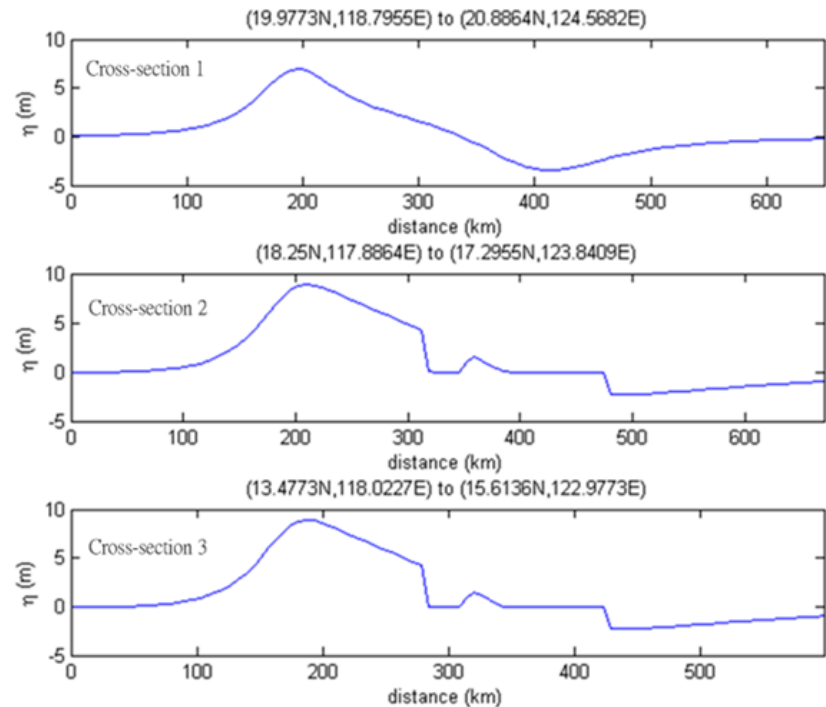
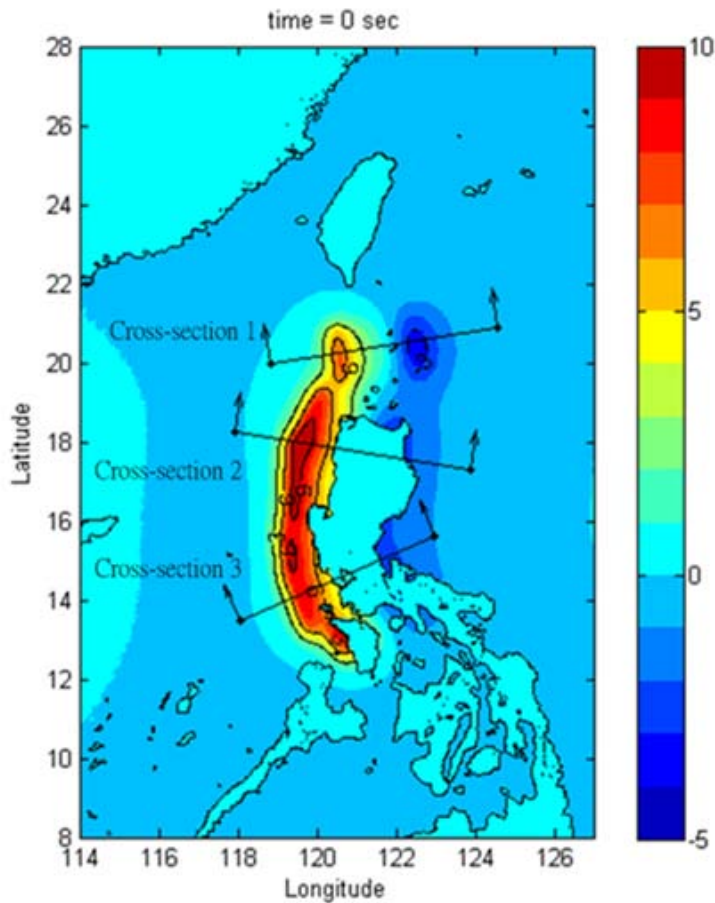
Initial free-surface profile (Left) and three cross-section profiles (Right)

Bathymetry of Taiwan

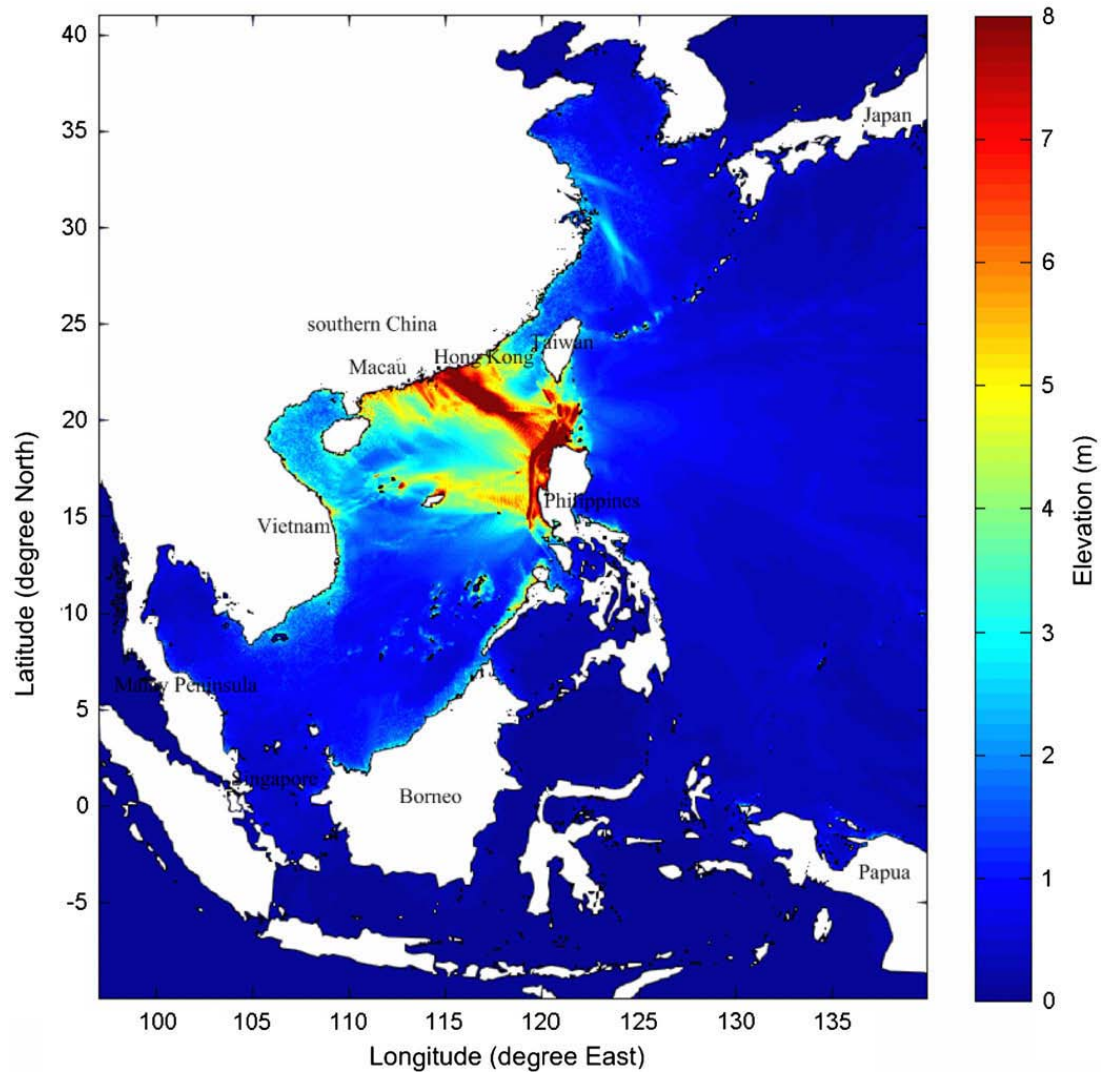


Initial free surface elevation

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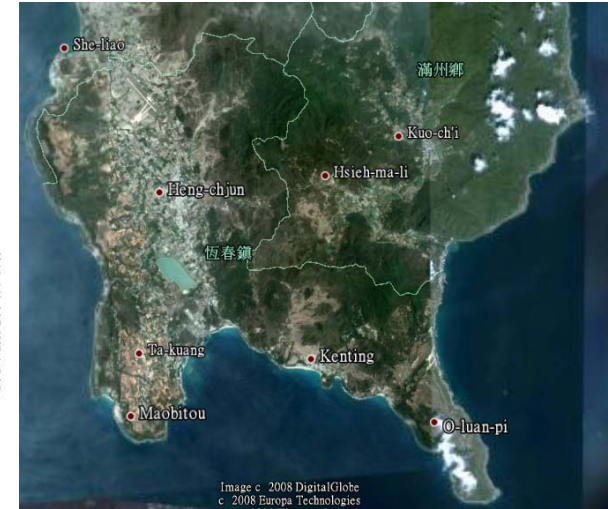
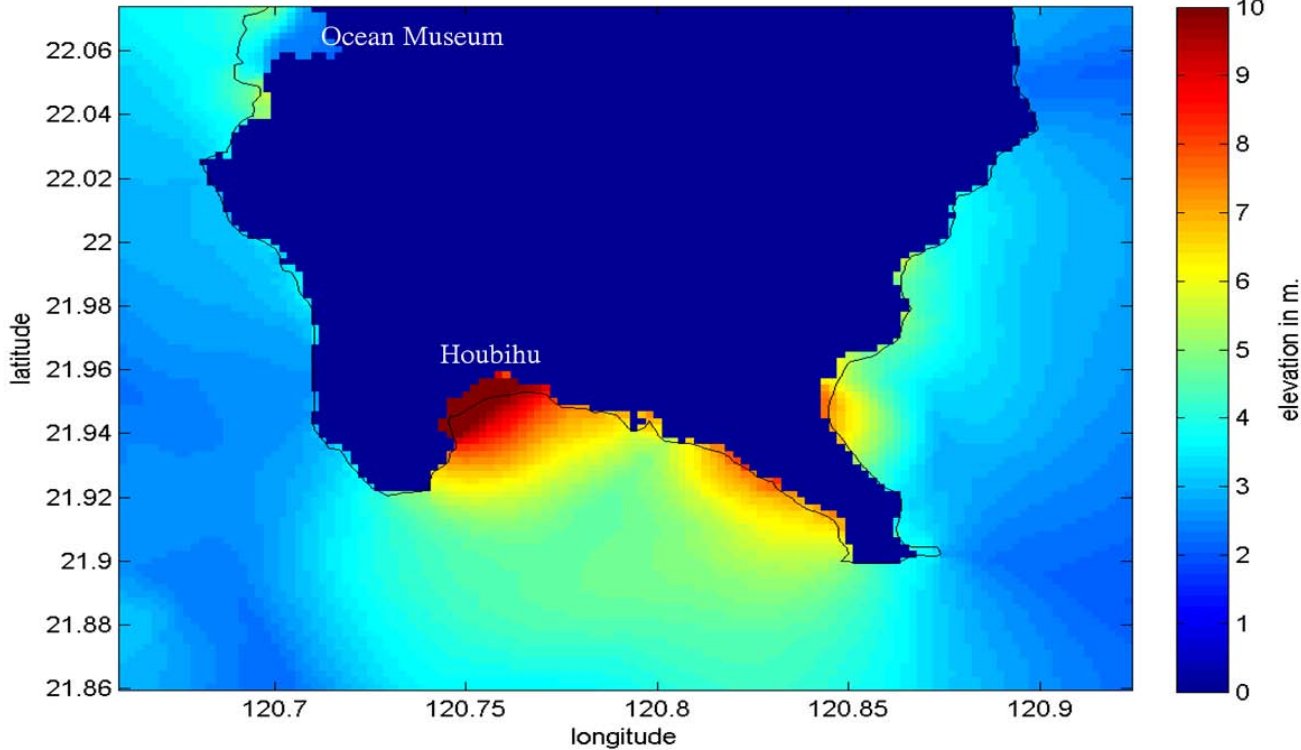
Initial free-surface profile (Left) and three cross-section profiles (Right)



The maximum water-level rise.

Maximum free surface elevation

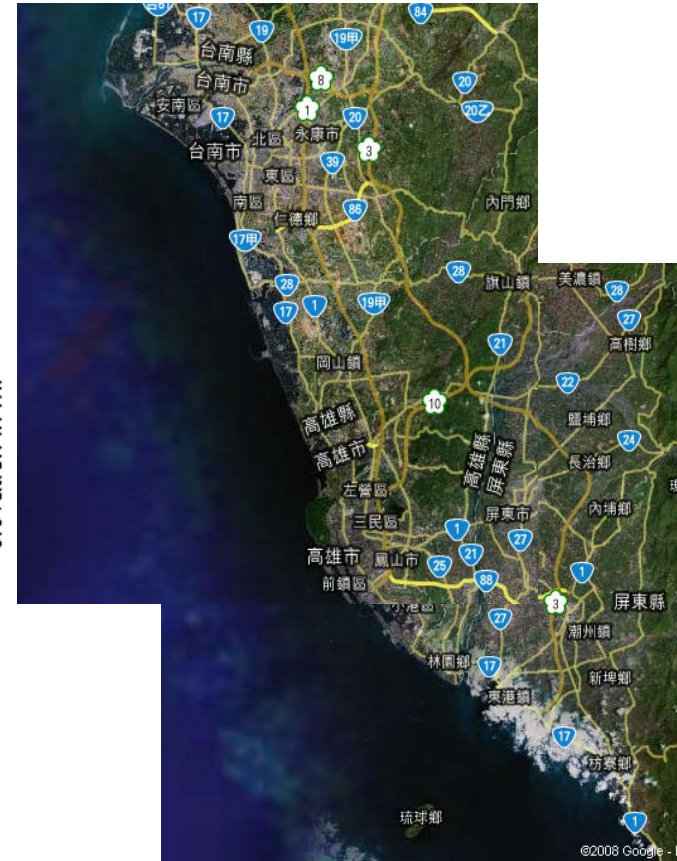
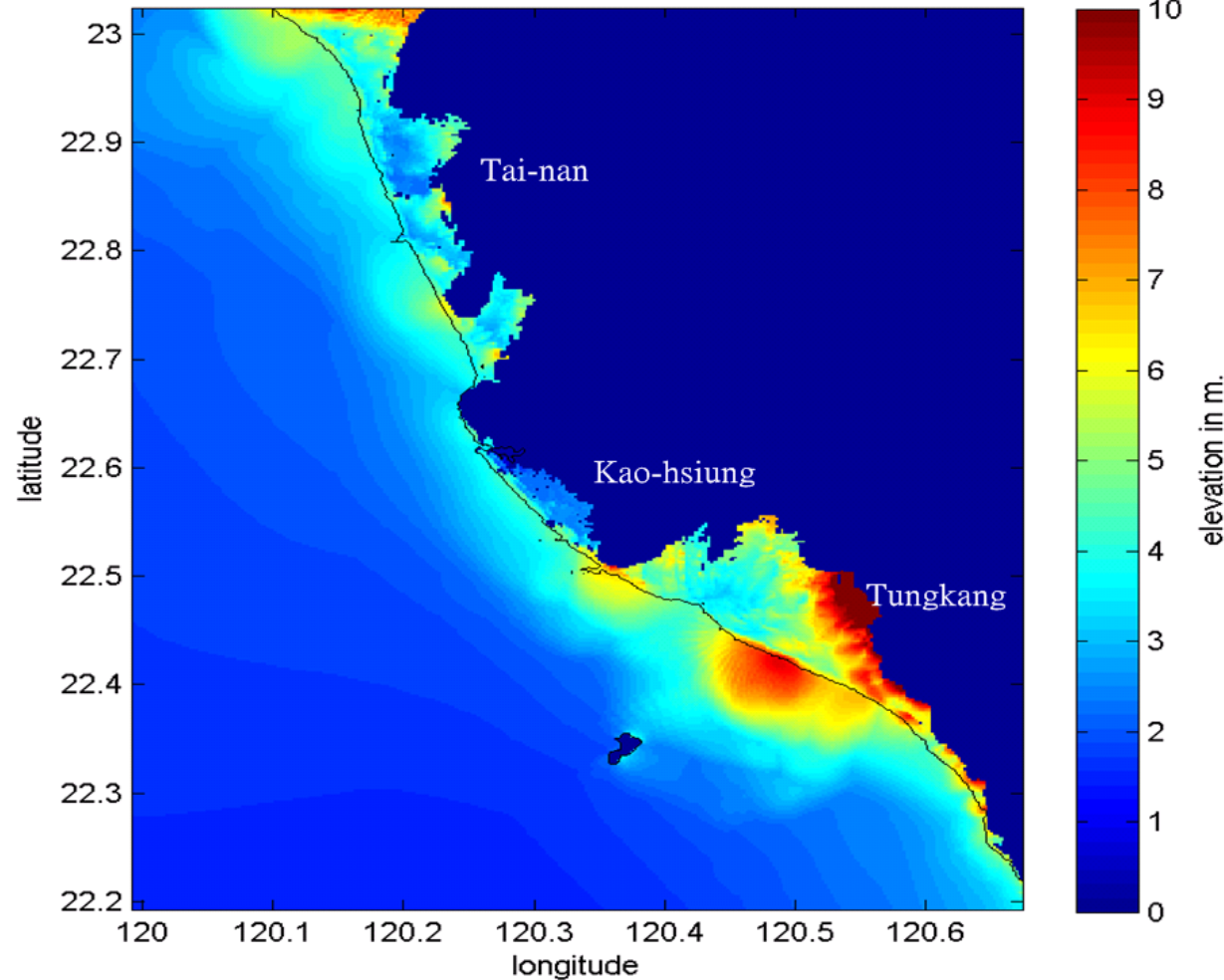
time = 14370 sec



Maximum free-surface elevation and inundation area on Grid 3A

Maximum free surface elevation 2

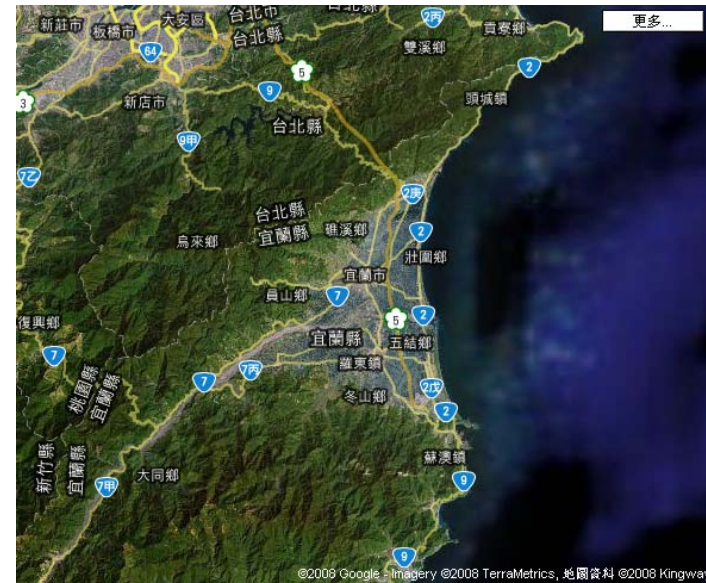
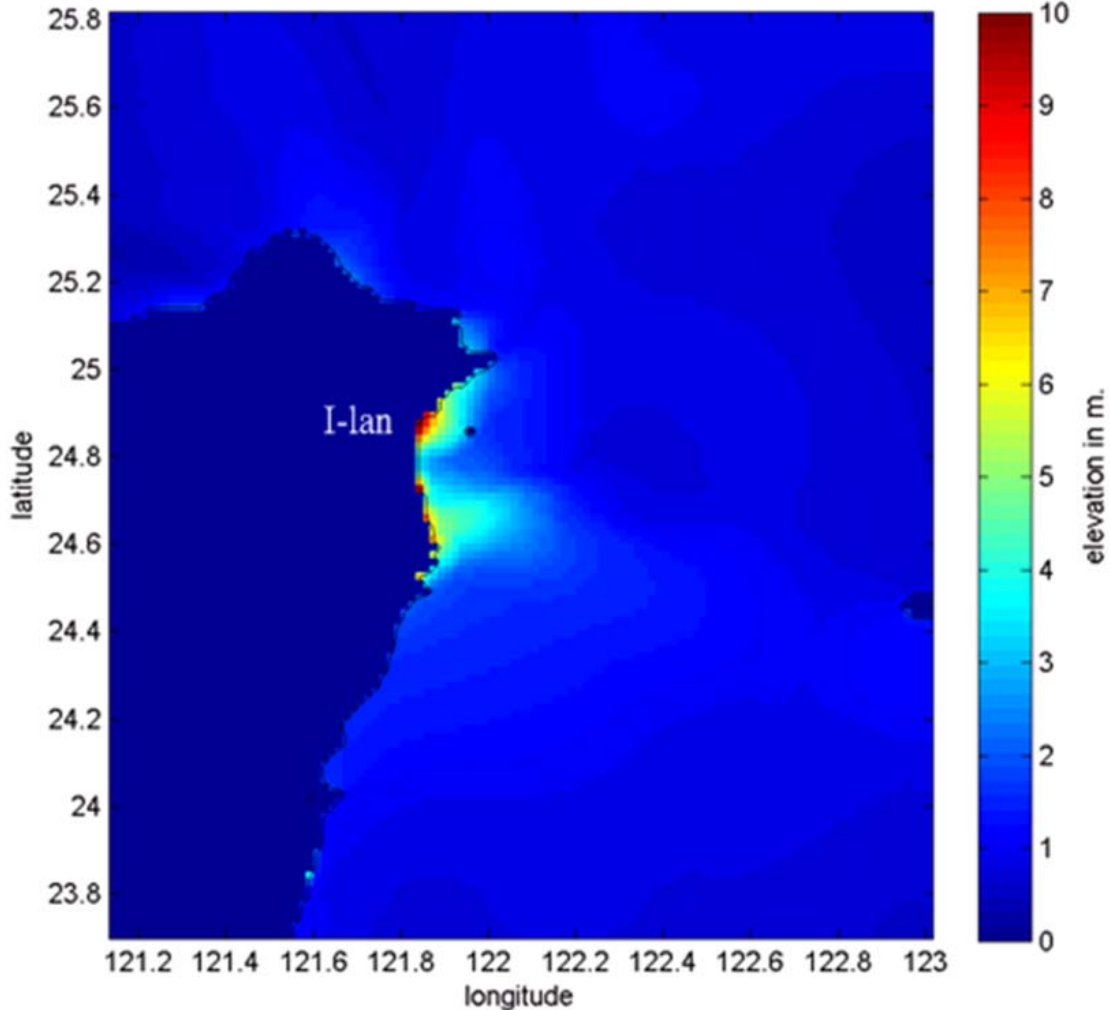
time = 14370 sec



Maximum free-surface elevation and inundation area on Grid 3B

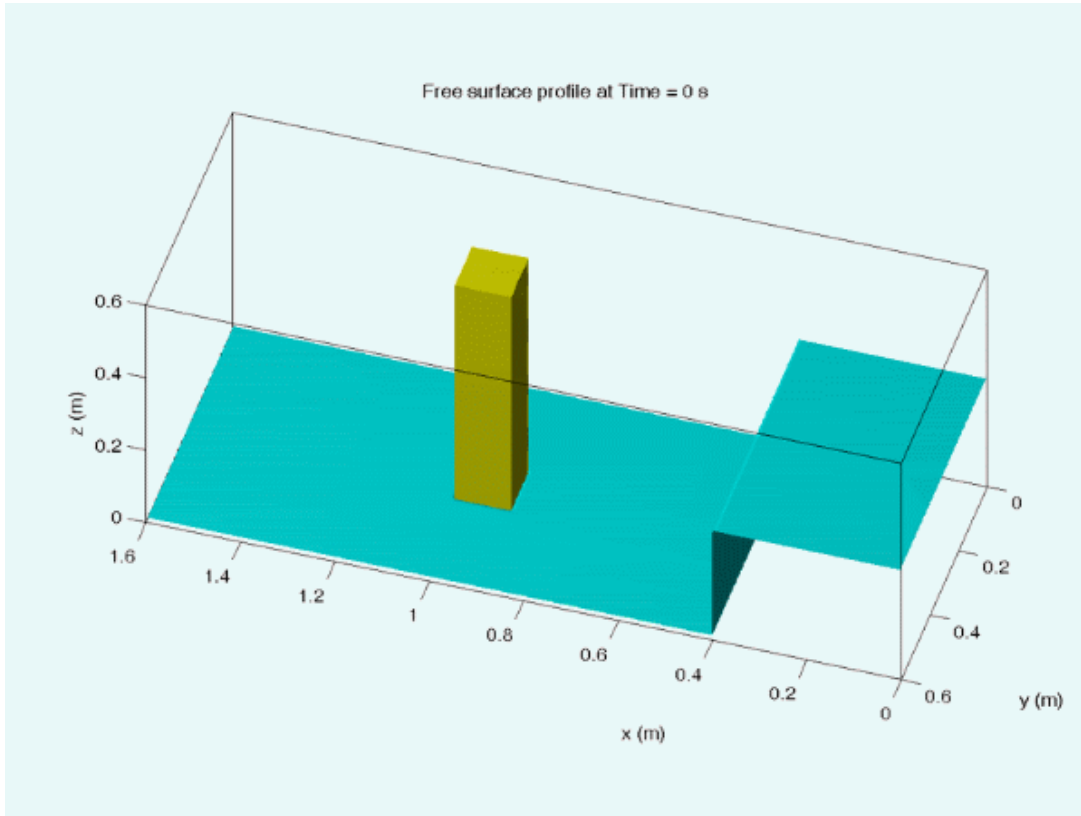
Maximum free surface elevation 3

time = 13770 sec

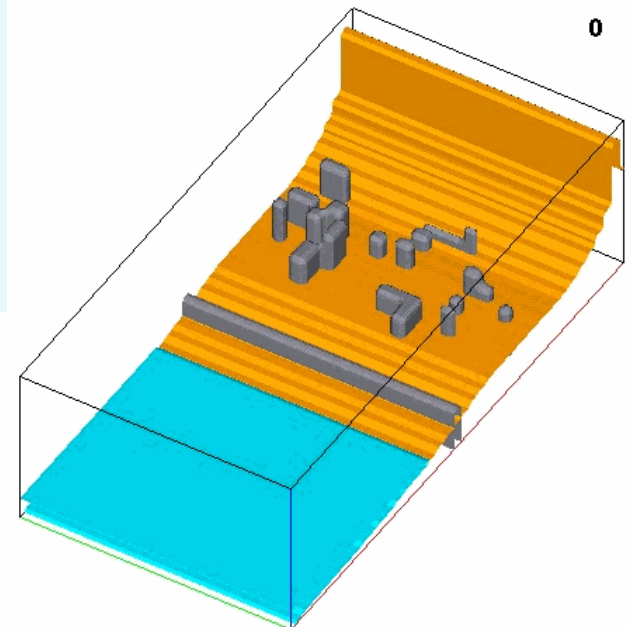


Maximum free-surface elevation on Grid 2

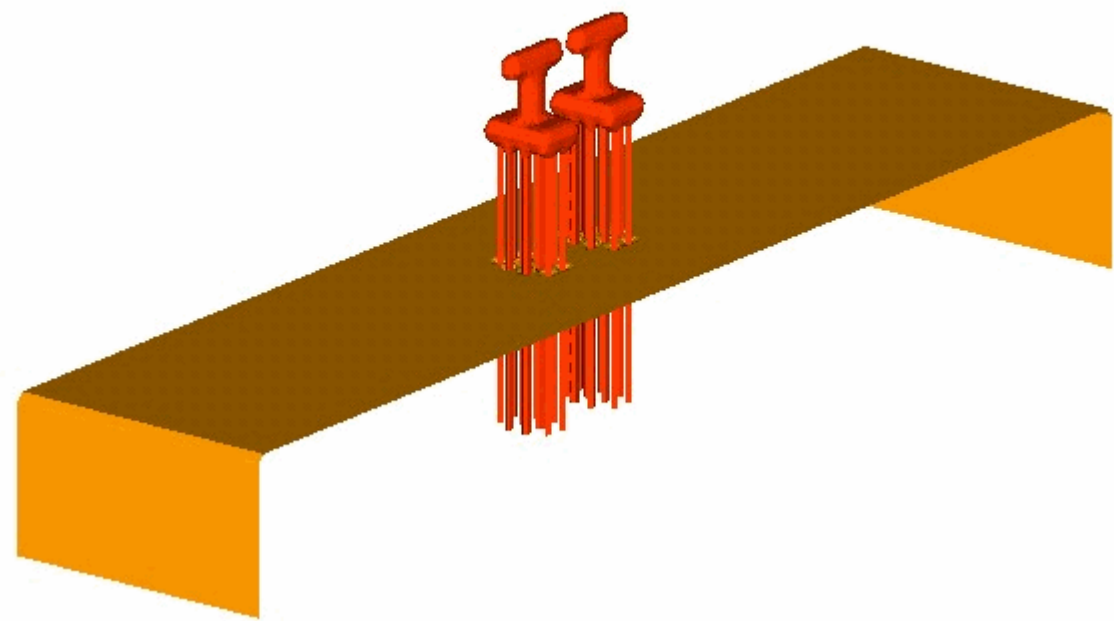
Why the seawall failed?



3月13日，外媒公布海嘯在日本登陸瞬間照片。圖為3月11日，海嘯衝上日本宮古市岸邊的



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Tsunami hazard mitigation strategy

- 3D dynamic calculation is important in the hazard mitigation. Especially for the sensitive facilities such as the nuclear power plant, airport, etc.
- By incorporating with the earthquake early warning system and pre-calculated 2D and 3D results, the active hazard mitigation is able to provide useful information for the near-source tsunami with little warning time.
- The 2D+3D calculations are time and storage consuming. Assist from the grid system is needed.

Thanks for listening. Questions for Dr. Wu?