『台灣地震損失評估系統』講習會
財團法人國家實驗研究院
國家地震工程研究中心
2013/10/ 10:20~11:10

台灣海嘯災防與研究

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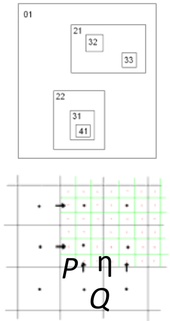
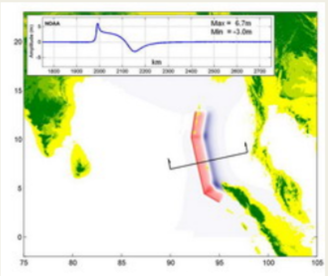


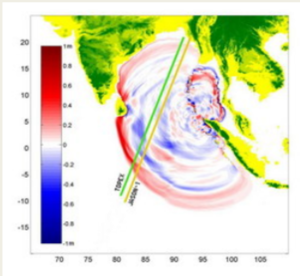
Tsunami Model: COMCOT

(Cornell Multi-grid Coupled Tsunami Model)

COMCOT: A Tsunami Modeling Package



Tsunami Generation



Tsunami Propagation

COMCOT (Cornell Multi-grid Coupled Tsunami Model) is a tsunami modeling package, capable of simulating the entire lifespan of a tsunami, from its generation, propagation and runup/rundown in coastal regions.

- Capable of simulating the entire lifespan of a tsunami, from its generation, propagation and runup/rundown on coastal regions
- A numerical model which solves nonlinear shallow water equation (SWE).
- On both/either Spherical or Cartesian coordinate system.
- Using nested grid to solve multi-scale problems.
- Moving-boundary for inundation calculation
- Parallelized

• Governing Equations

COMCOT was developed based on Shallow Water Equations (SWE) in Spherical Coordinates (*Eq.01*) and Cartesian Coordinates (*Eq.02*). In the equations, ζ denotes free surface elevation; P and Q are volume flux in x and y direction ($P=hu$, $Q=hv$); φ and ψ stand for longitude and latitude, respectively.

$$\frac{\partial \zeta}{\partial t} + \frac{1}{R\cos\varphi}\left[\frac{\partial P}{\partial \psi} + \frac{\partial}{\partial \varphi}(\cos\varphi Q)\right] = 0$$

$$\frac{\partial P}{\partial t} + \frac{gh}{R\cos\varphi}\frac{\partial \zeta}{\partial \psi} - fQ = 0$$

$$\frac{\partial Q}{\partial t} + \frac{gh}{R}\frac{\partial \zeta}{\partial \varphi} + fP = 0$$

Eq.01 SWE in Spherical Coord.

$$\frac{\partial \zeta}{\partial t} + \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} = 0$$

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

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

Eq.02 SWE in Cartesian Coord.

• Moving Boundary Scheme

Moving boundary scheme was also introduced in COMCOT to model the run-up and run-down. The instant "shoreline" is defined as the interface between a dry grid and wet grid and volume flux normal to the interface is assigned to zero.

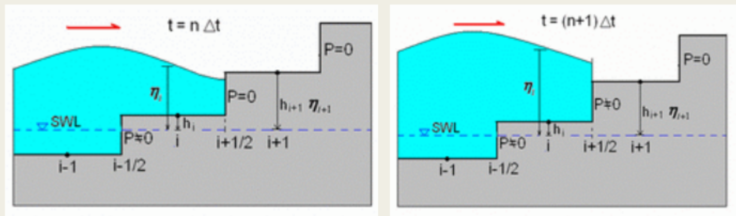


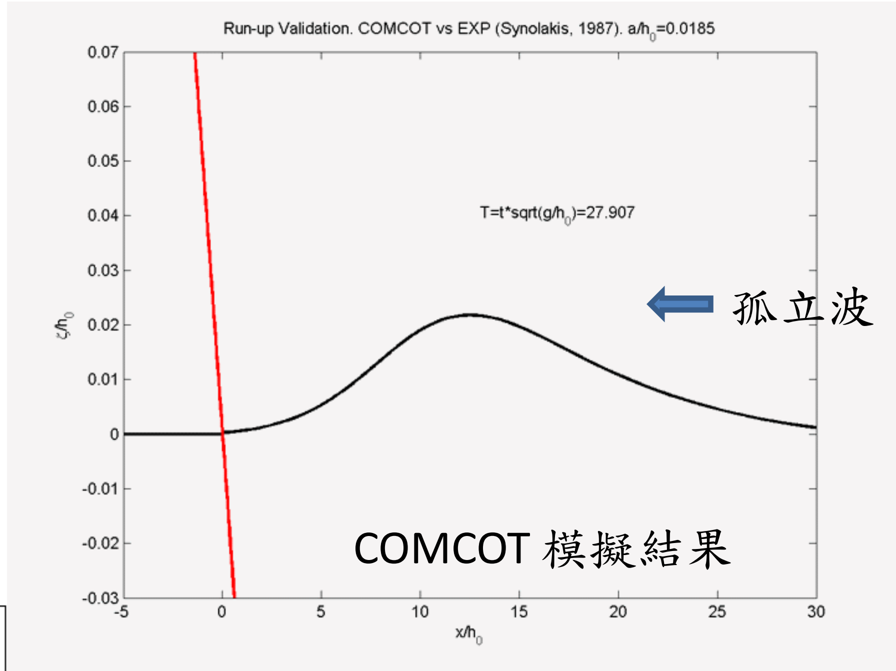
Fig.02 Moving Boundary Scheme

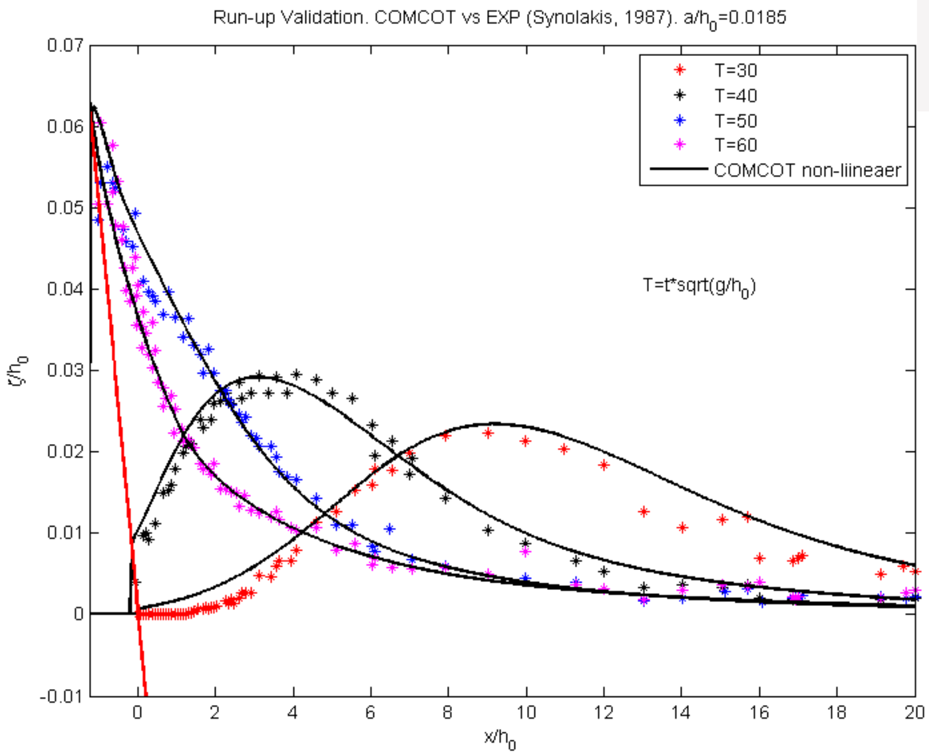
(1). Widely validated

Soliton runup:

Synolakis (1986, 1987)

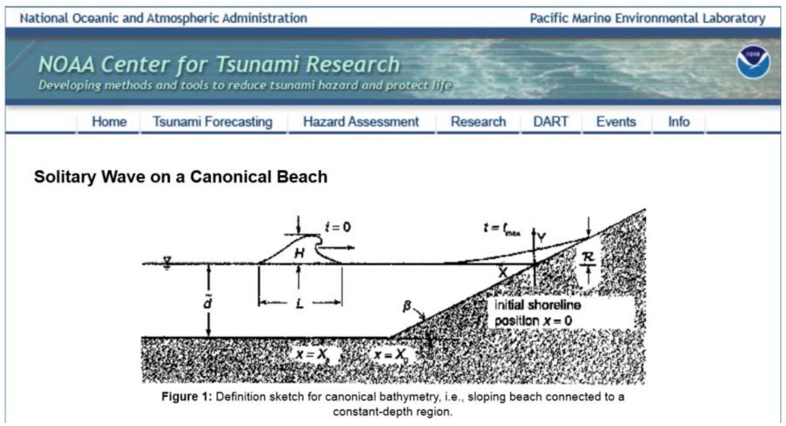
Very accurate results can be seen.





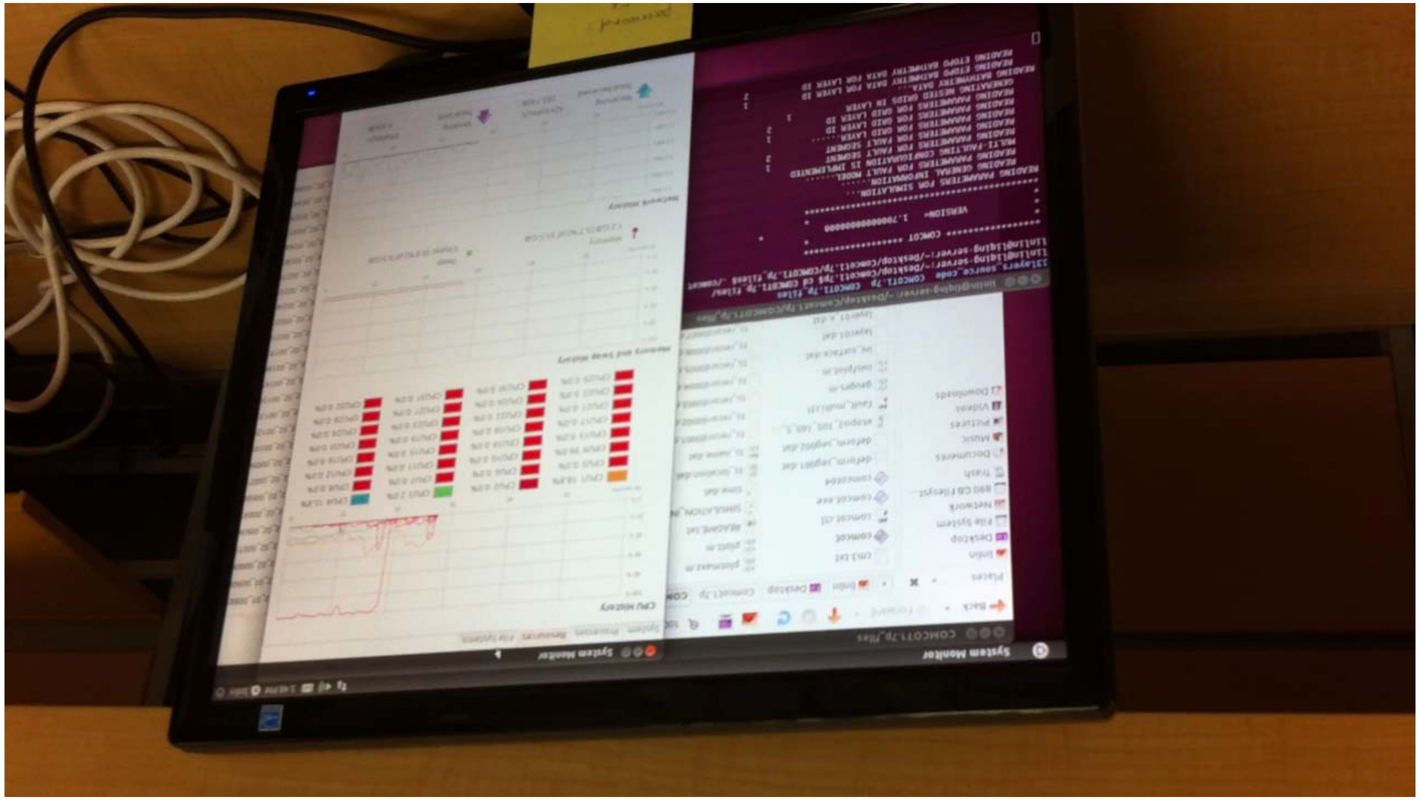
（吳祚任，2012）

Figure 2: Time evolution of H = 0.0185 initial wave over a sloping beach with $\cot\beta = 19.85$ from $t = 25$ to 65 with 10 increments. Constant depth-segment starts at $X_0 = 19.85$. While markers show experimental results of Synolakis (1986, 1987), solid lines show nonlinear analytical solution of Synolakis (1986, 1987) Experimental data is provided from $t = 30$ to 70 with 10 increments.



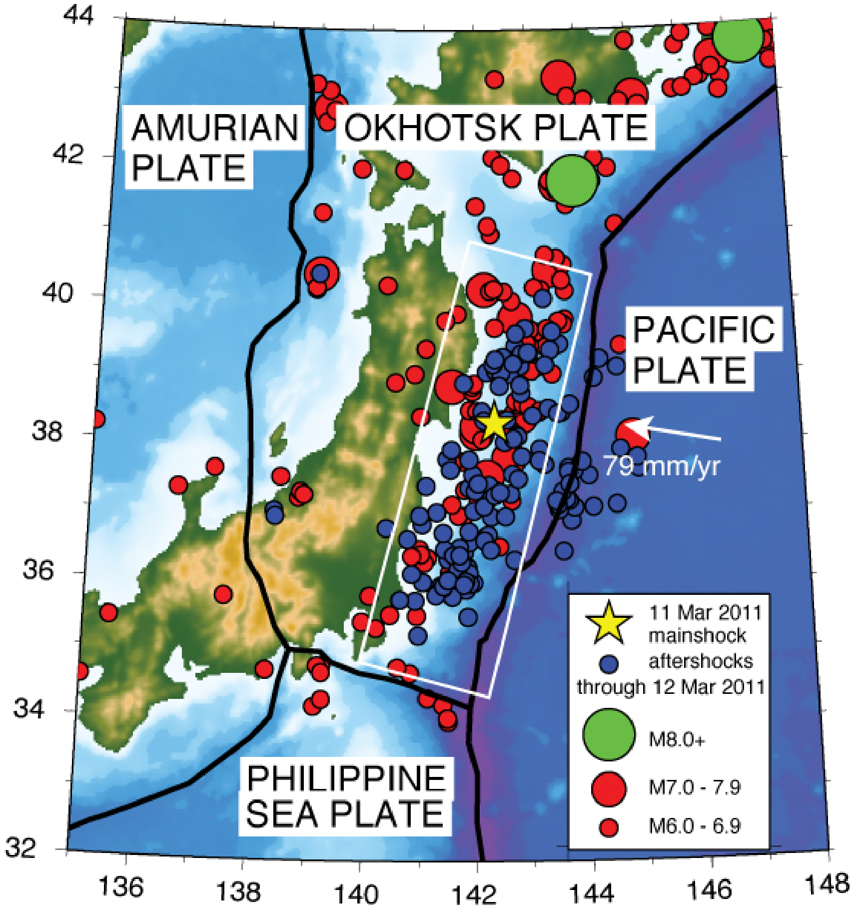
（資料來源：NOAA 官網）

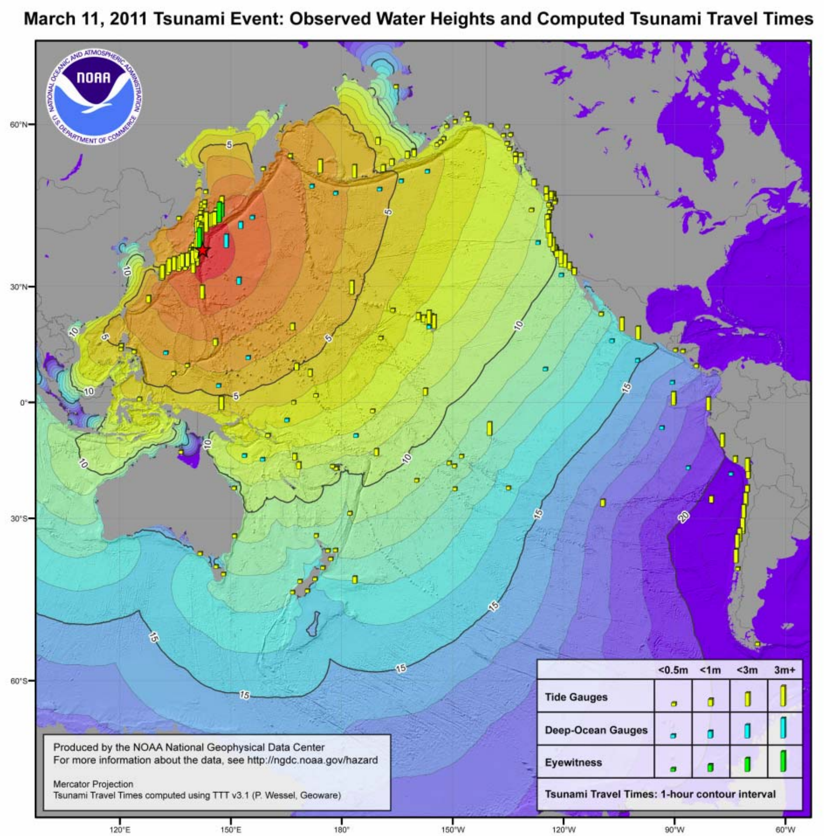
- (2). Stable and Fast。Parallelized by ASGC, COMCOT now is able to use all the mutli-core CPU resources



（We tested COMCOT on a new 32-core server in NTU, Singapore. A case used to be done in 30 minutes can be finished in 2 minutes on the new machine.）

2011 Tōhoku earthquake and tsunami

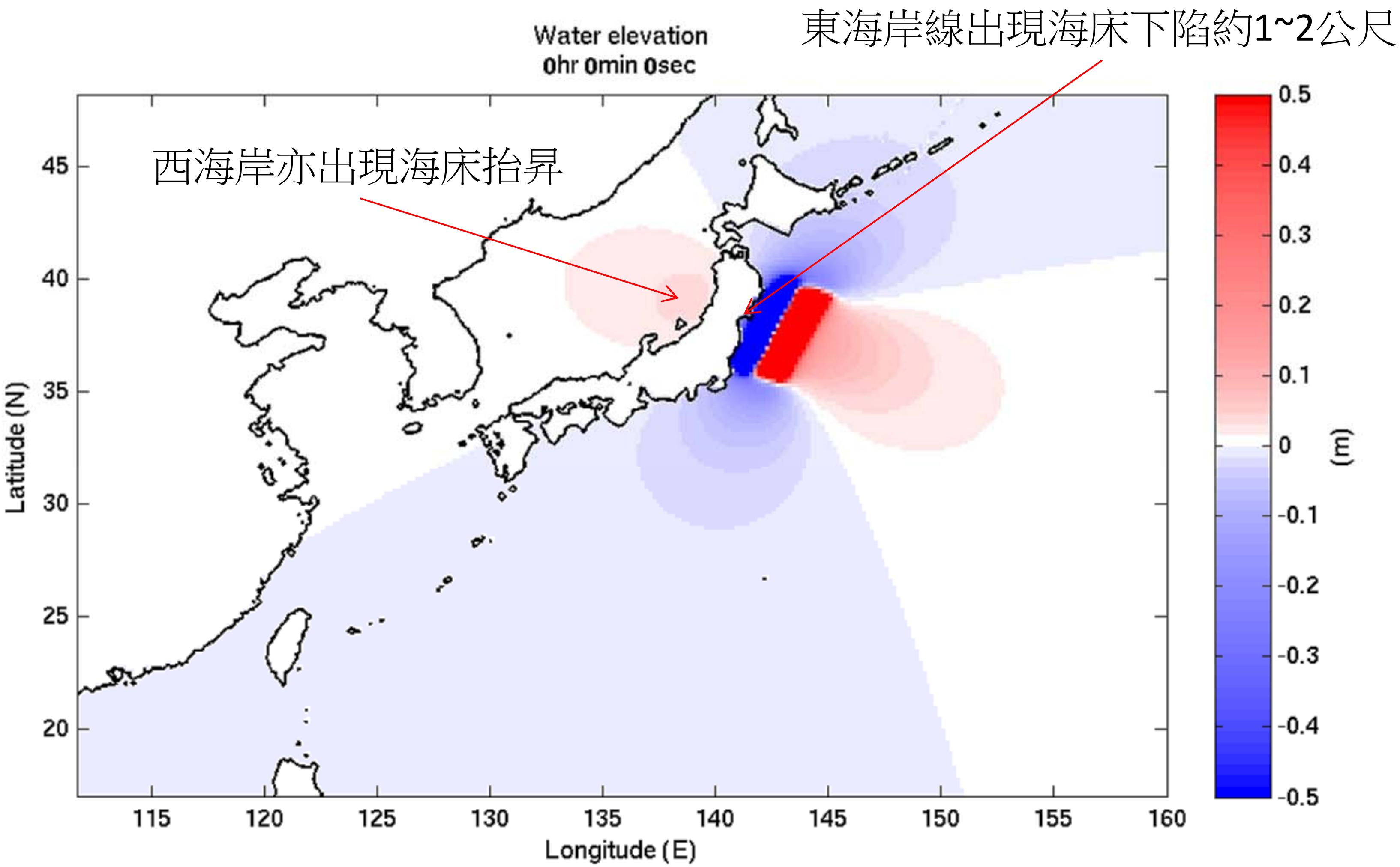




2011 Tōhoku earthquake and tsunami

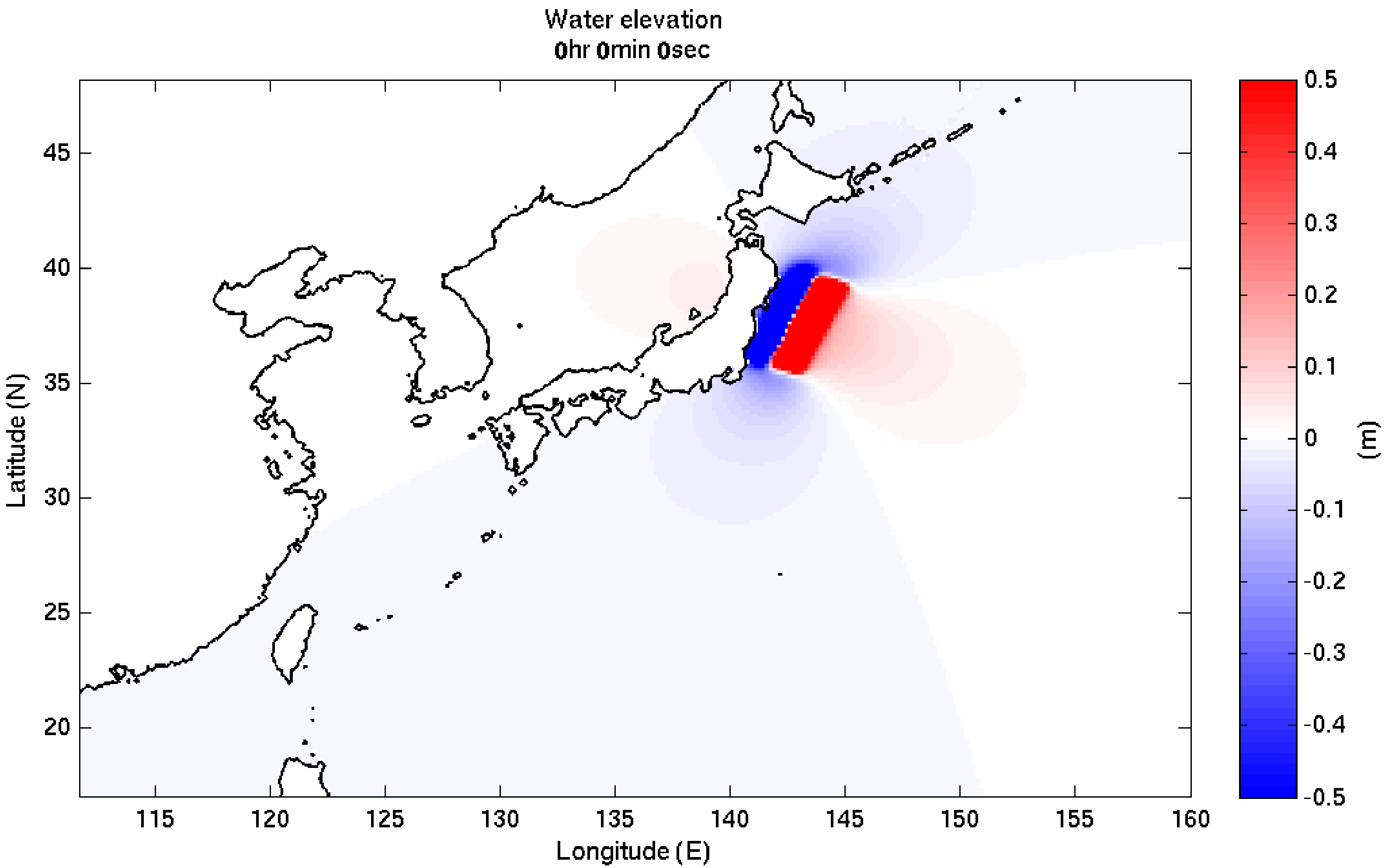
- We spent about 20 mins to prepare, or wait for, the fault parameters
- COMCOT spent about 1 min to finish the tsunami simulation from Japan to Taiwan.
- It is about real-time simulation
- COMCOT predicted that the tsunami wave height was about 12 cm offshore Taiwan.
- Field data also showed about 12 cm.

模式預測之2011日本海嘯波源



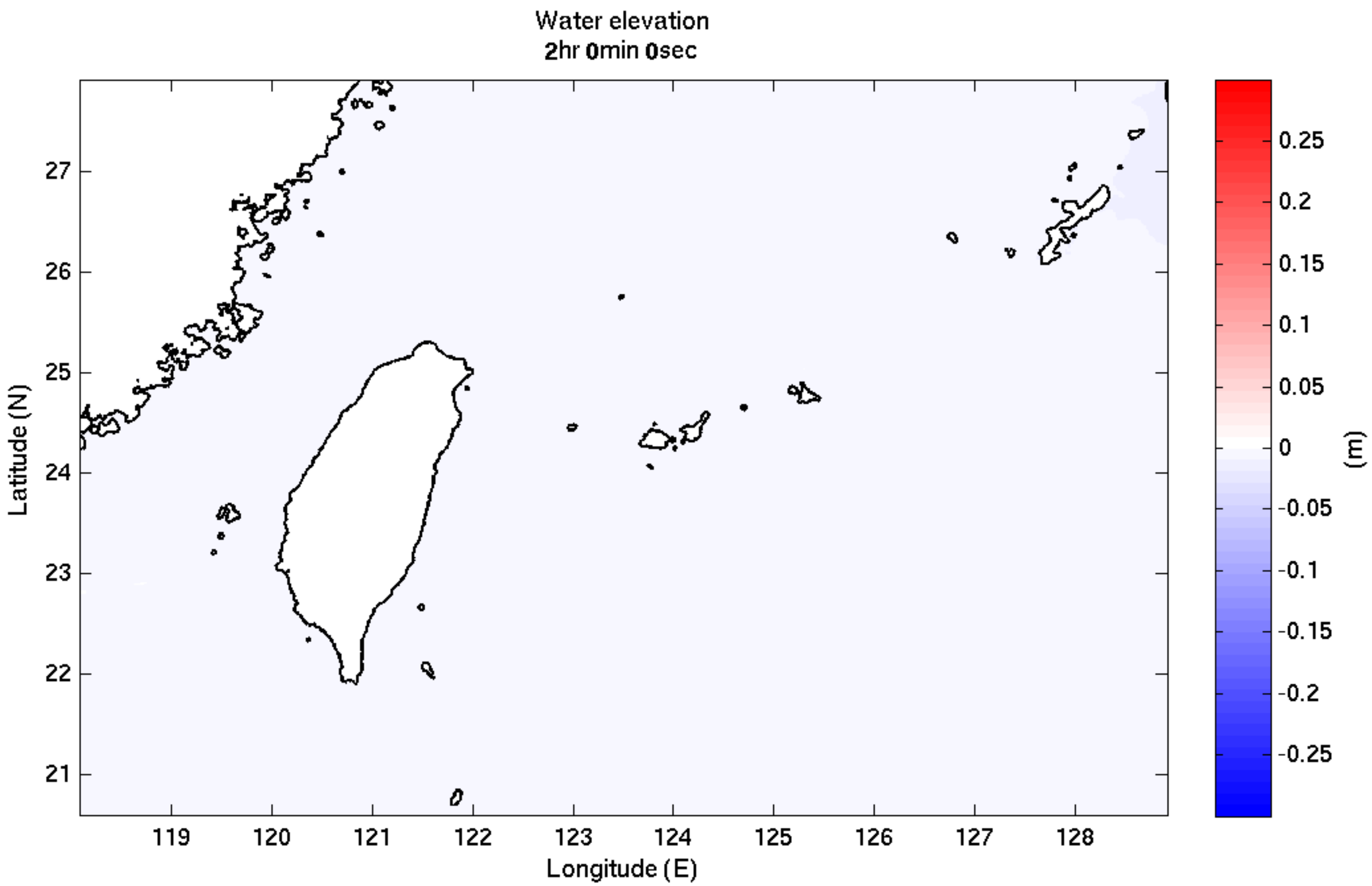
模式預測海床抬昇量為4.5公尺，與實際觀測之5公尺相當接近。

模擬結果：海嘯傳播方式



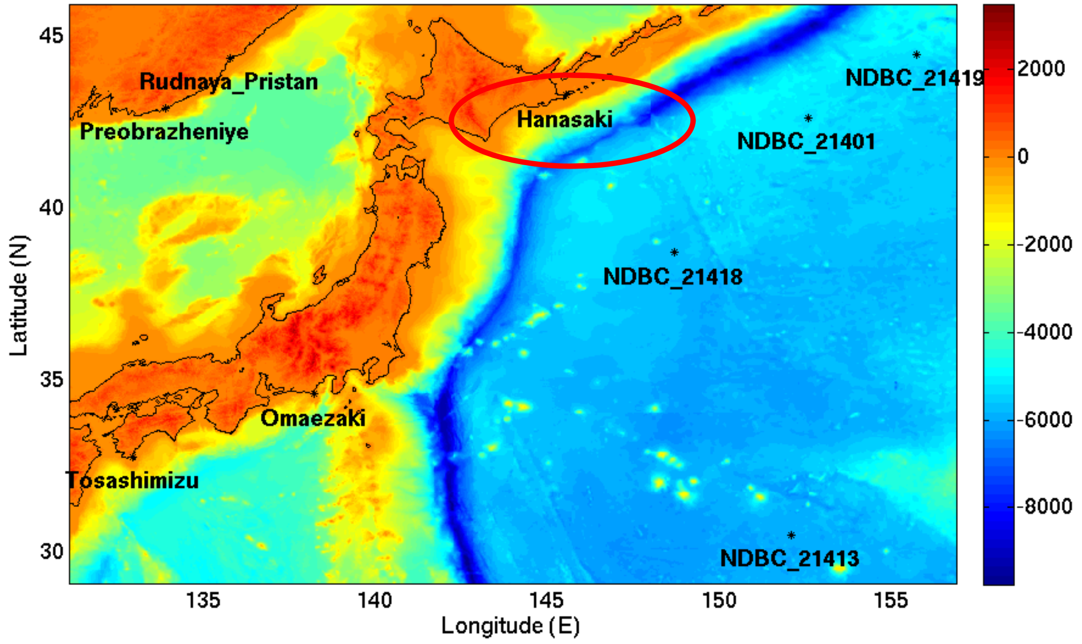
Water elevation
0hr 0min 0sec
Latitude (N)
45
40
35
30
25
20
115
120
125
130
135
140
145
150
155
160
Longitude (E)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
(m)

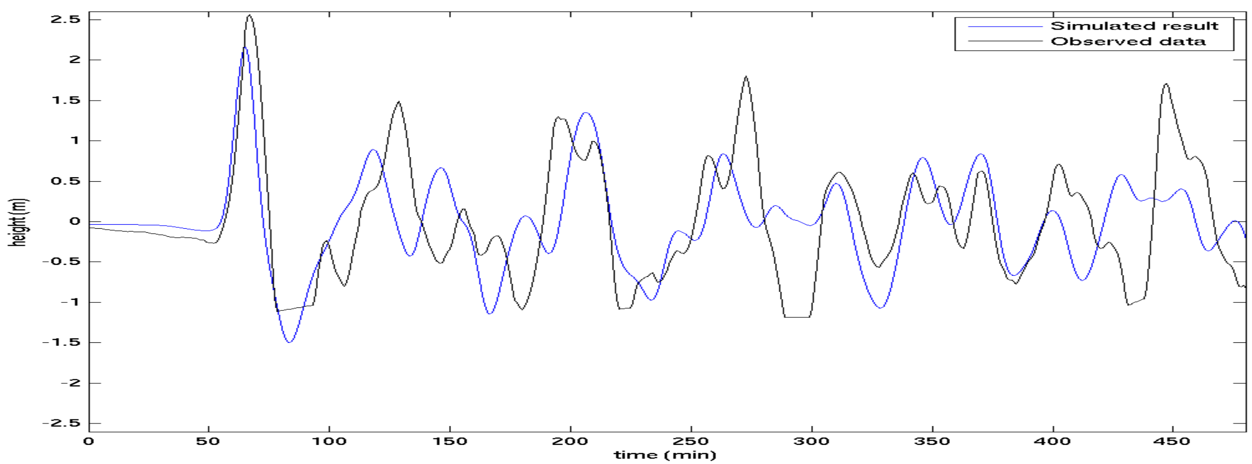
海嘯傳遞至台灣



Water elevation
2hr 0min 0sec
27
26
25
24
23
22
21
Latitude (N)
119
120
121
122
123
124
125
126
127
128
Longitude (E)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
(m)

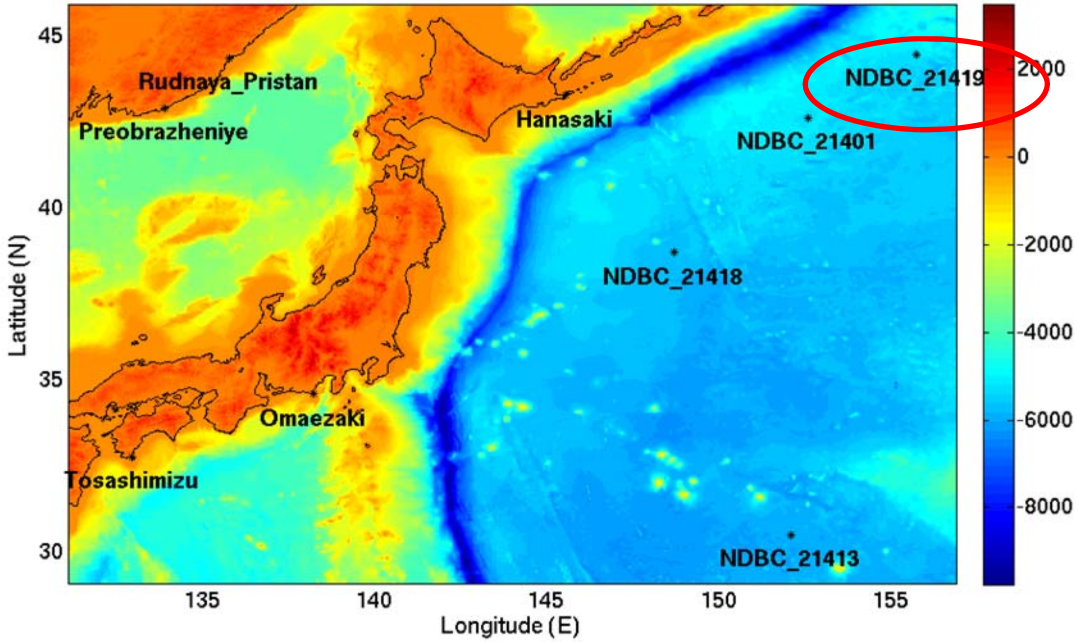
模式預測之海嘯波高與日本潮位站實測比對：Hanasaki

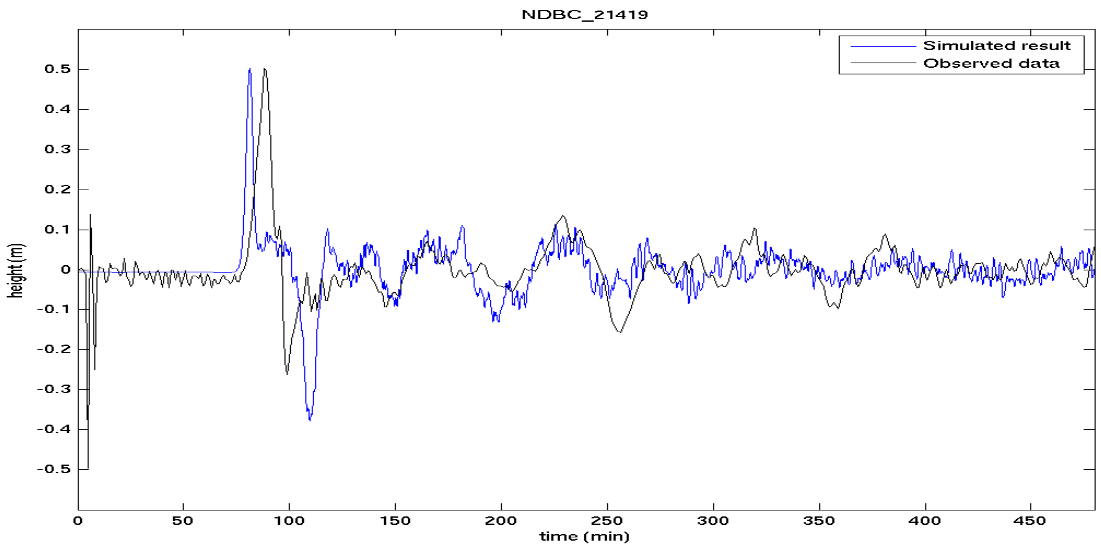




Hanasaki 潮位站比對，藍線為模擬結果，黑線為實測資料。該站位於斜坡部分，模擬結果與實測比對相當一致。

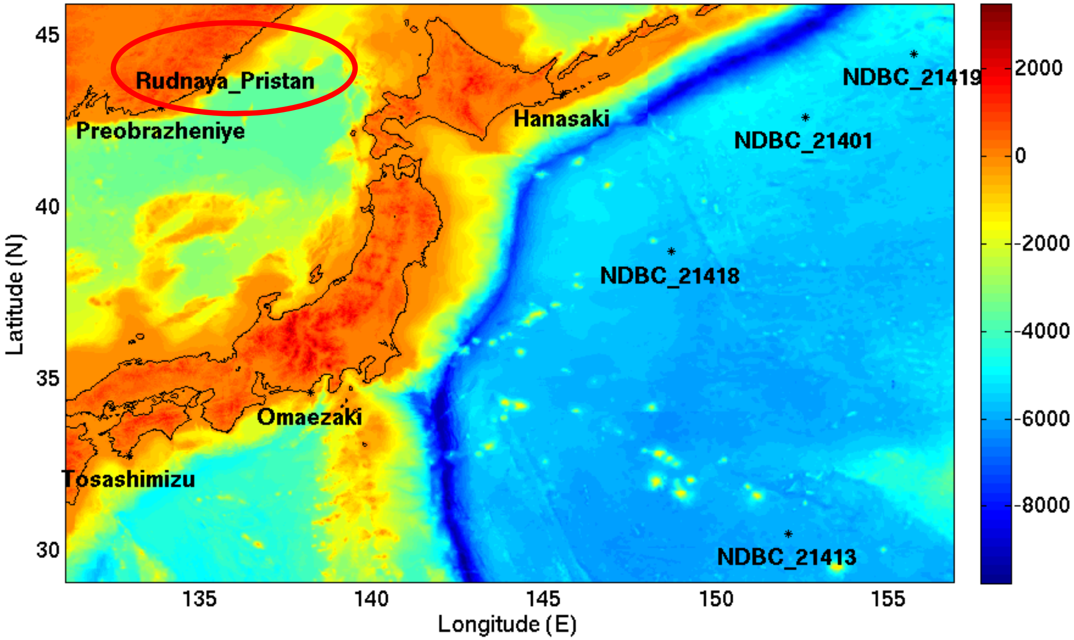
模式預測之海嘯波高與美國NOAA深海浮標實測比對：NDBC_21419



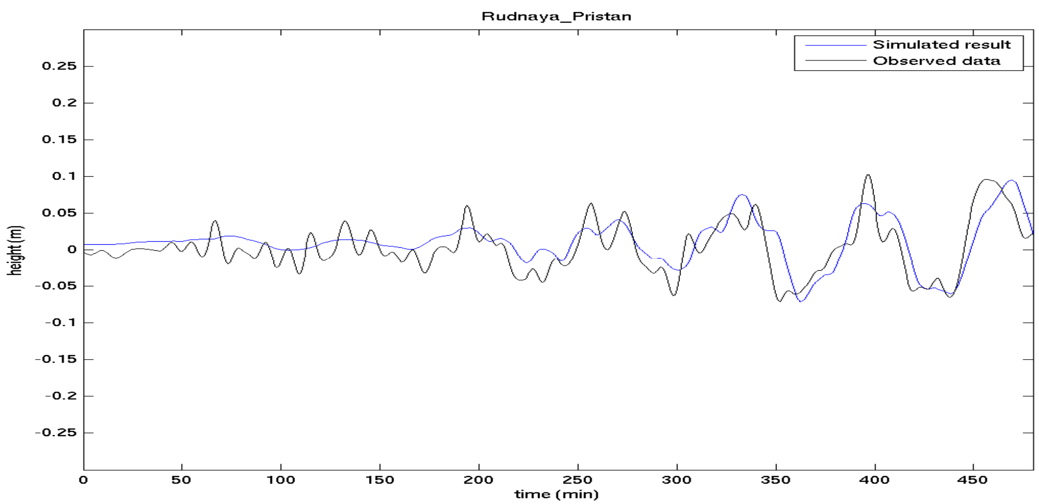


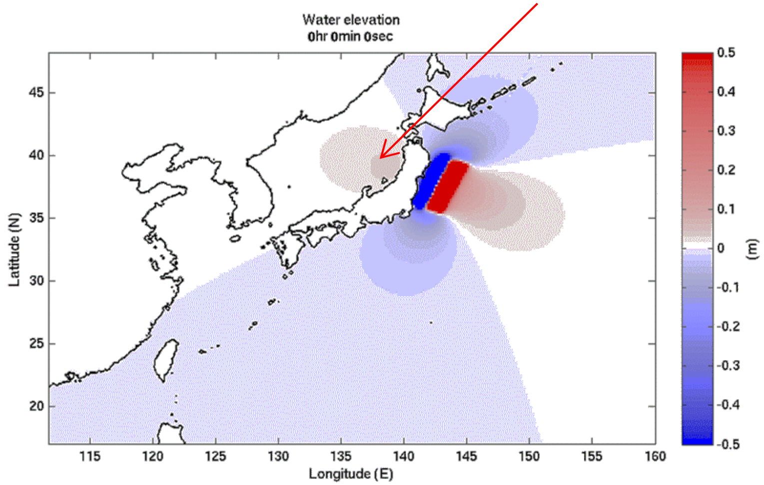
與NOAA浮標資料比對，藍線為模擬結果，黑線為實測資料。模擬結果與實測比對相當一致。

模式預測之海嘯波高與蘇聯潮位站實測比對：Rudnaya Pristan
（日本西岸亦出現海嘯訊號）

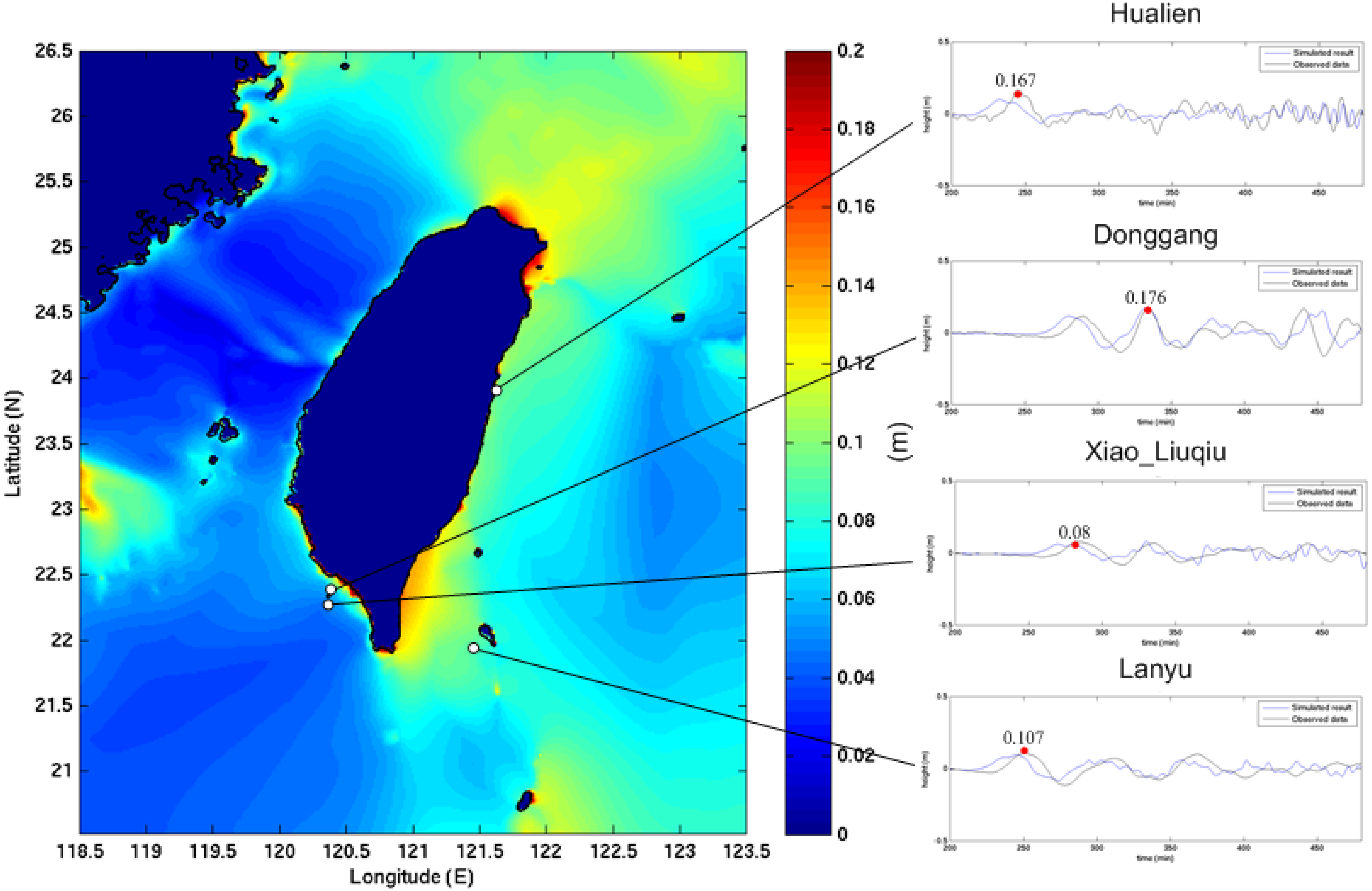


西海岸海床抬昇



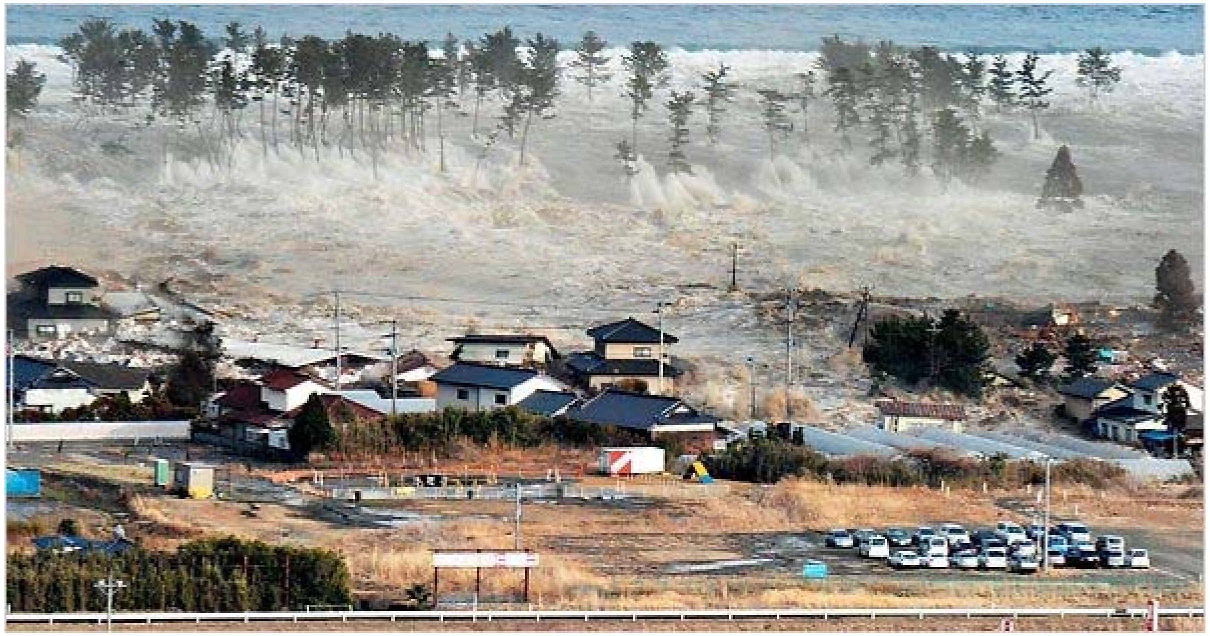


模式預測之海嘯波高中央氣象局潮位站資料比對



台灣測站比對。比對花蓮、東港、小琉球、蘭嶼四個測站，結果相當理想。（藍線為模擬結果，黑線為實測資料，資料提供：中央氣象局）

Disaster pictures are constantly repeated in the media



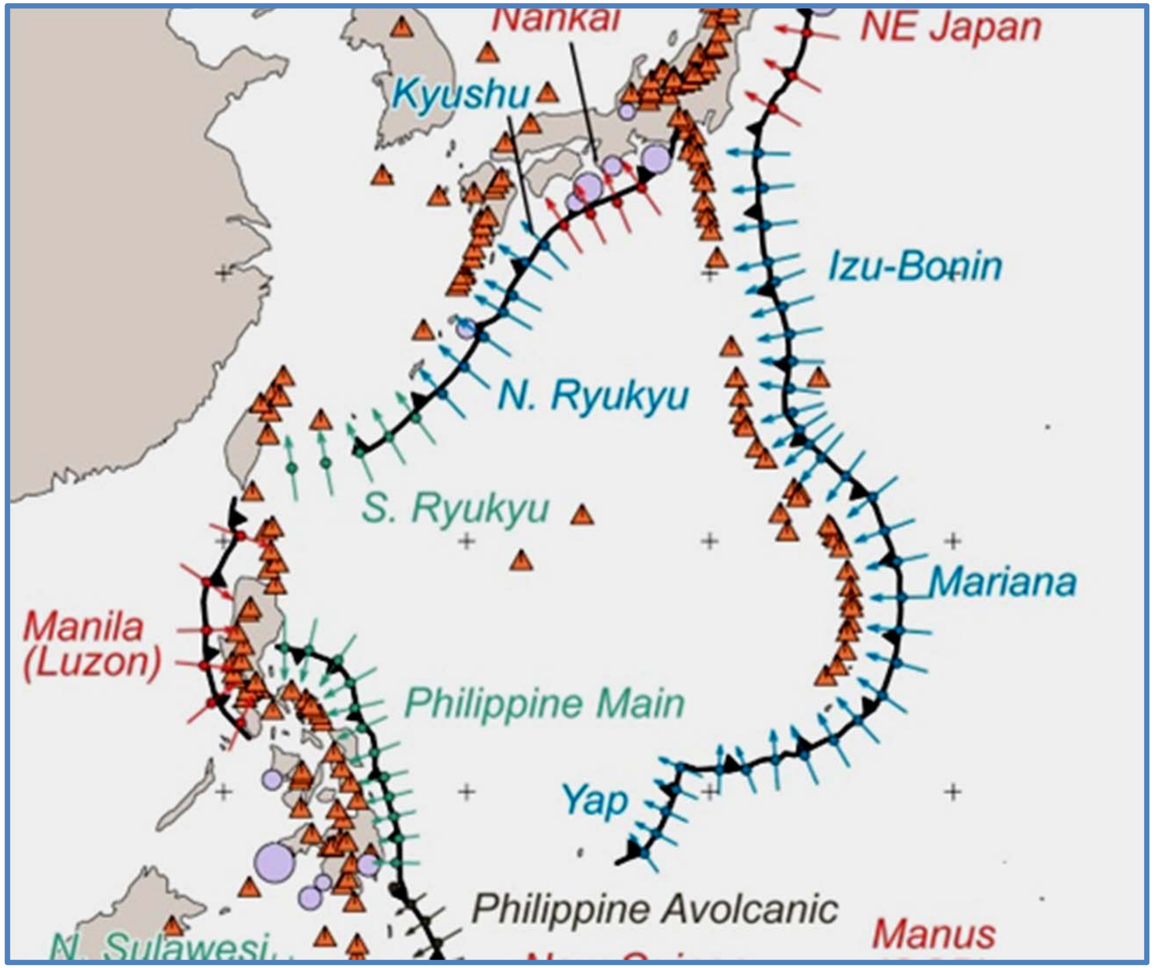
http://majikphil3.blogspot.tw/2011/04/what-is-chance-of-big-one-in-tokyo.html

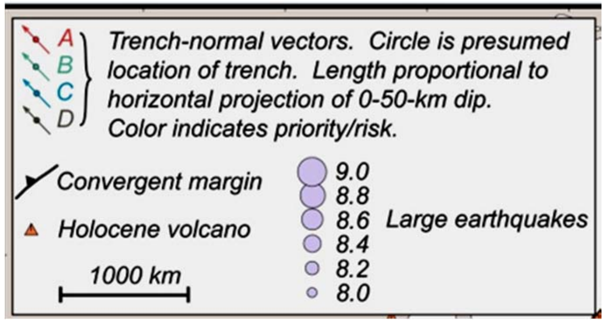
Including the Nuclear Disaster

People in Taiwan wanted to know…

- Will we encounter the same tsunami disaster?
- Can our buildings against the tsunamis?
- Is our government prepared for the tsunami hazard mitigation?
- How about the safety of our nuclear power plants?

Tsunami Sources of 18 Trench and 4 Fault Segments





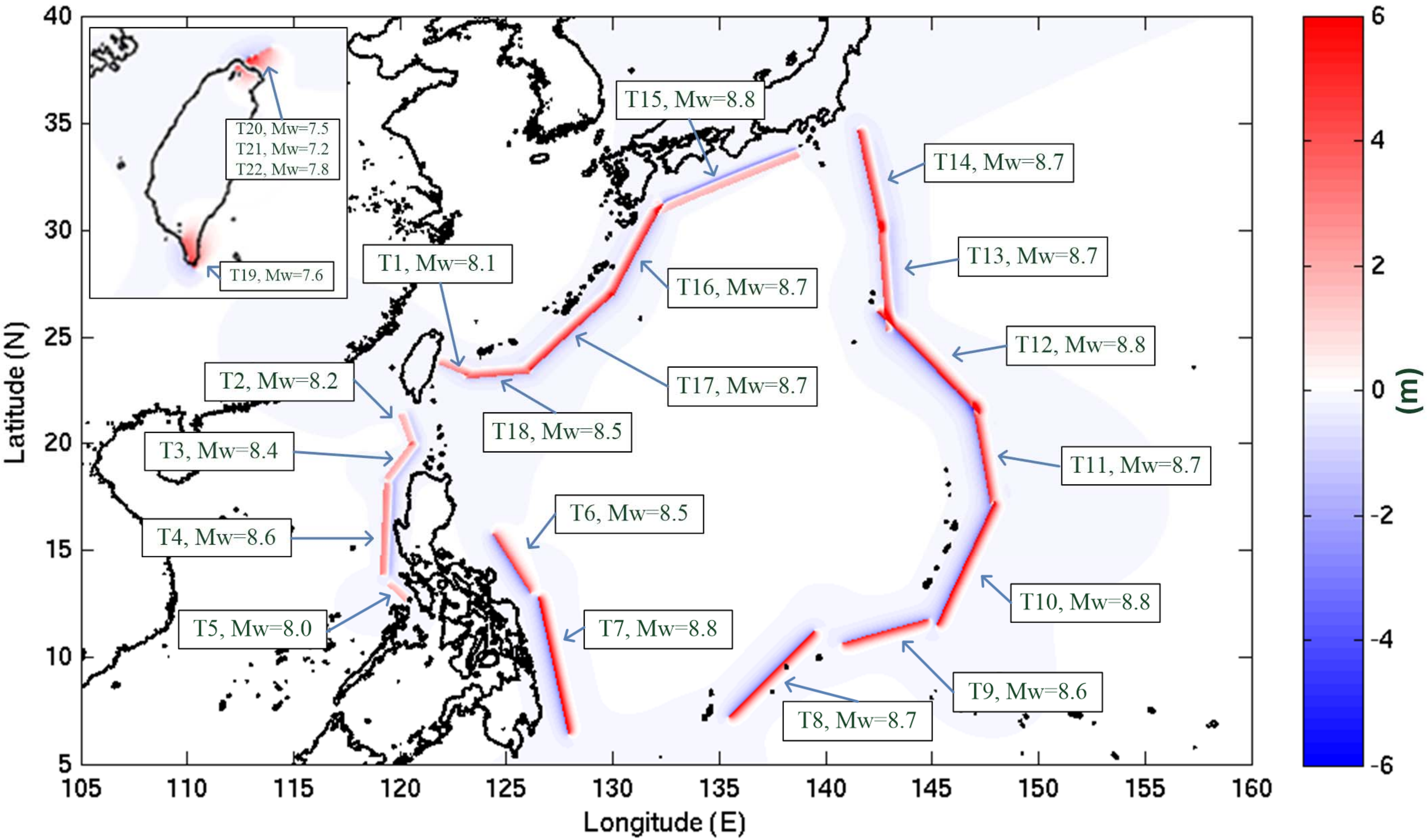
Tsunami Source Characterization for Western Pacific Subduction Zones: A Preliminary Report
USGS1 Tsunami Subduction Source Working Group

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.

Tsunami Sources of
18 Trench and 4 Fault Segments

18 Trench-type tsunami sources（T1~T18） 4 Fault-type tsunami sources（T19~T22）

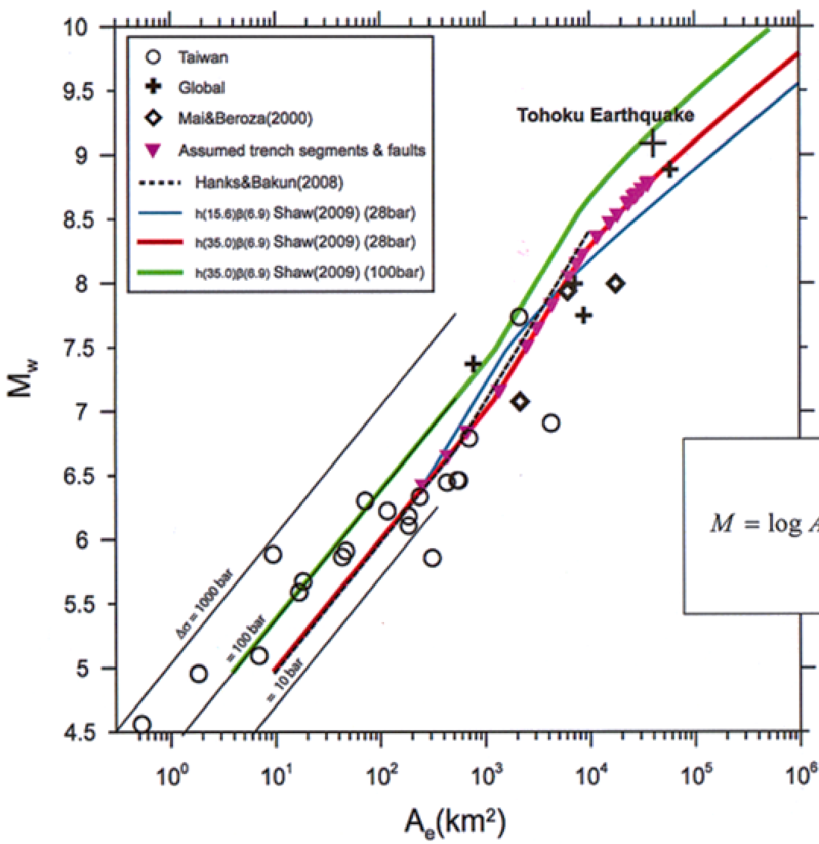


Fault parameters:

1. Length: We consider the topography and geological conditions of trenches and faults, and determine the maximum length based on the uniformity of the geological structure.
2. Width: Reference to the world-class mega-earthquakes, the width is determined.
3. Mw and slip: After obtaining the length and width of the mega-thrust, the area can be determined. Based on the seismic scaling law (Yen and Ma, 2011), the earthquake magnitude (Mw) and slip can be determined.
4. Adopting the half-space homogenous elastic mode (Okada, 1986) to estimate the vertical displacement of the seafloor deformation and the tsunami initial profile.

In practice, the size of a potential earthquake along a given subduction zone could be limited only by the length along which a coherent rupture could take place (Okal et al., 2011). This point was first illustrated by Ando (1975) in the case of the Nankai Trough, and similar conclusions were reached in the growing number of literatures (Nanayama et al., 2003; Cisternas et al., 2005; Okal et al., 2006; Nelson et al., 2006).

Yen Y. T. and K. F. Ma (2011). Source-Scaling Relationship for M 4.6–8.9 Earthquakes, Specifically for Earthquakes in the Collision Zone of Taiwan, *Bull. Seismol. Soc. Am.* **101**, 464-481.

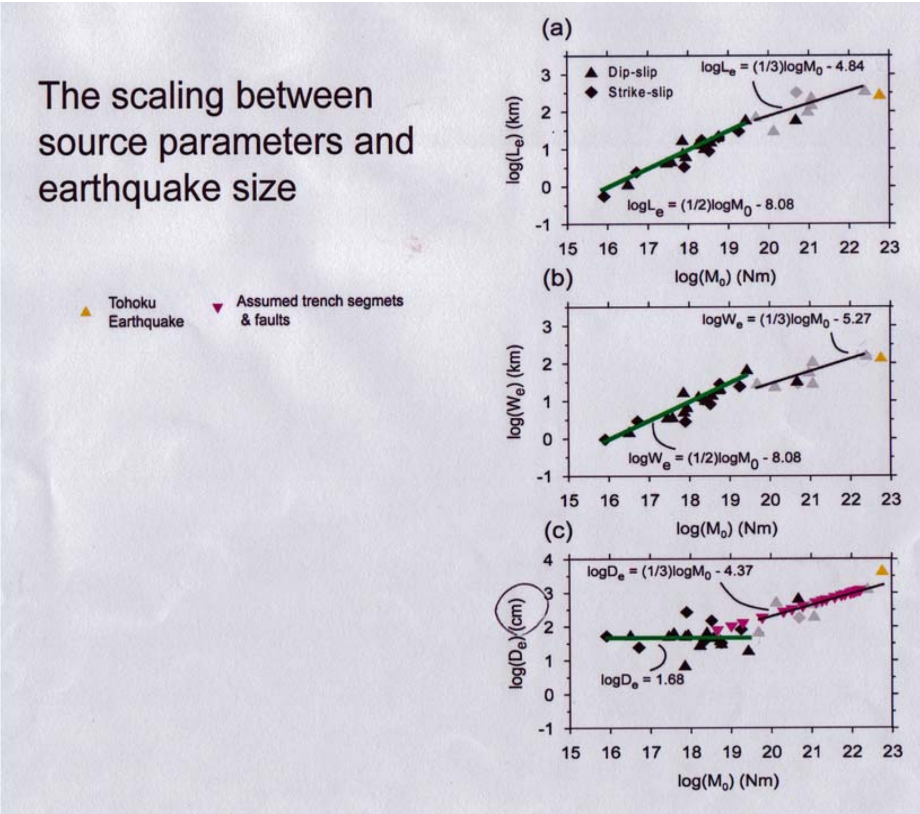


h : seimogenic depth

β : scaling parameter related to the effective fault width

$$M = \log A + \frac{2}{3}\log\frac{\max(1,\sqrt{\frac{A}{H^2}})}{[1+\max(1,\frac{A}{H^2\beta})]/2} + const.$$

(Yen Y. T. and K. F. Ma, 2011)



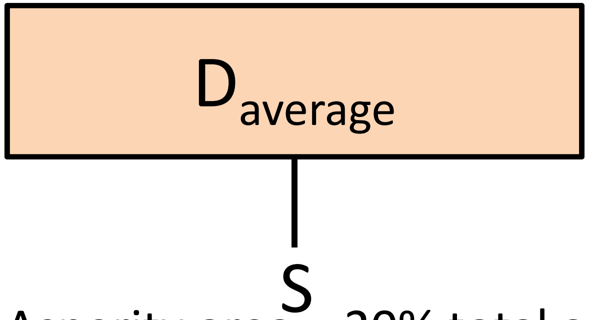
$$M_w = (2/3)\left(\log M_0 - 16.1\right)$$

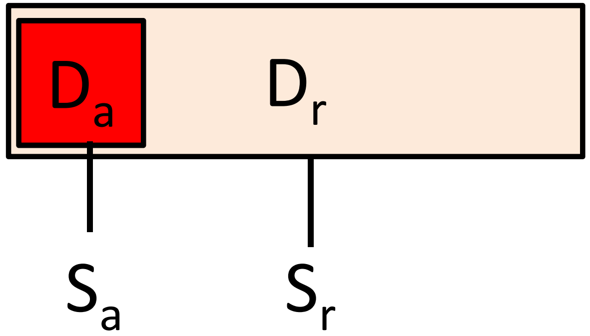
$$\log L_e = (1/2)\log M_0 - 8.08 \quad (\le 10^{20}\ \text{Nm})$$
$$\log W_e = (1/2)\log M_0 - 8.08$$
$$\log D_e = 1.68 \pm 0.33$$

$$\log L_e = (1/3)\log M_0 - 4.84 \quad (> 10^{20}\ \text{Nm})$$
$$\log W_e = (1/3)\log M_0 - 5.27$$
$$\log D_e = (1/3)\log M_0 - 4.37$$

(Yen Y. T. and K. F. Ma, 2011)

- Fault plane





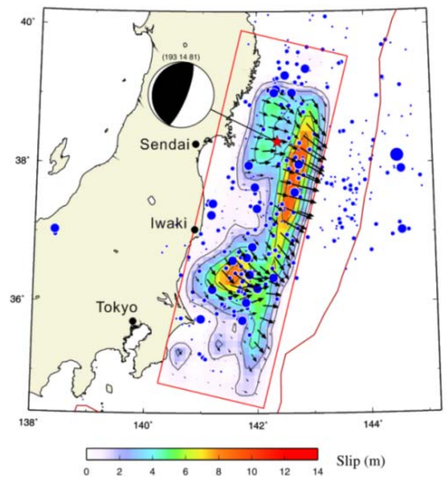
- Asperity area ≈ 20% total area
- Asperity slip ≈ 1.5 average slip
- If we assume asperity slip = 1.5 times average slip, to conserve M_0, the residual slip is 0.875 times average slip.

$$M_0 = M_a + M_r, M_0 = \mu \cdot S \cdot \overline{D}$$

$$\mu \cdot S \cdot \overline{D} = \mu \cdot S_a \cdot D_a + \mu \cdot S_r \cdot D_r$$

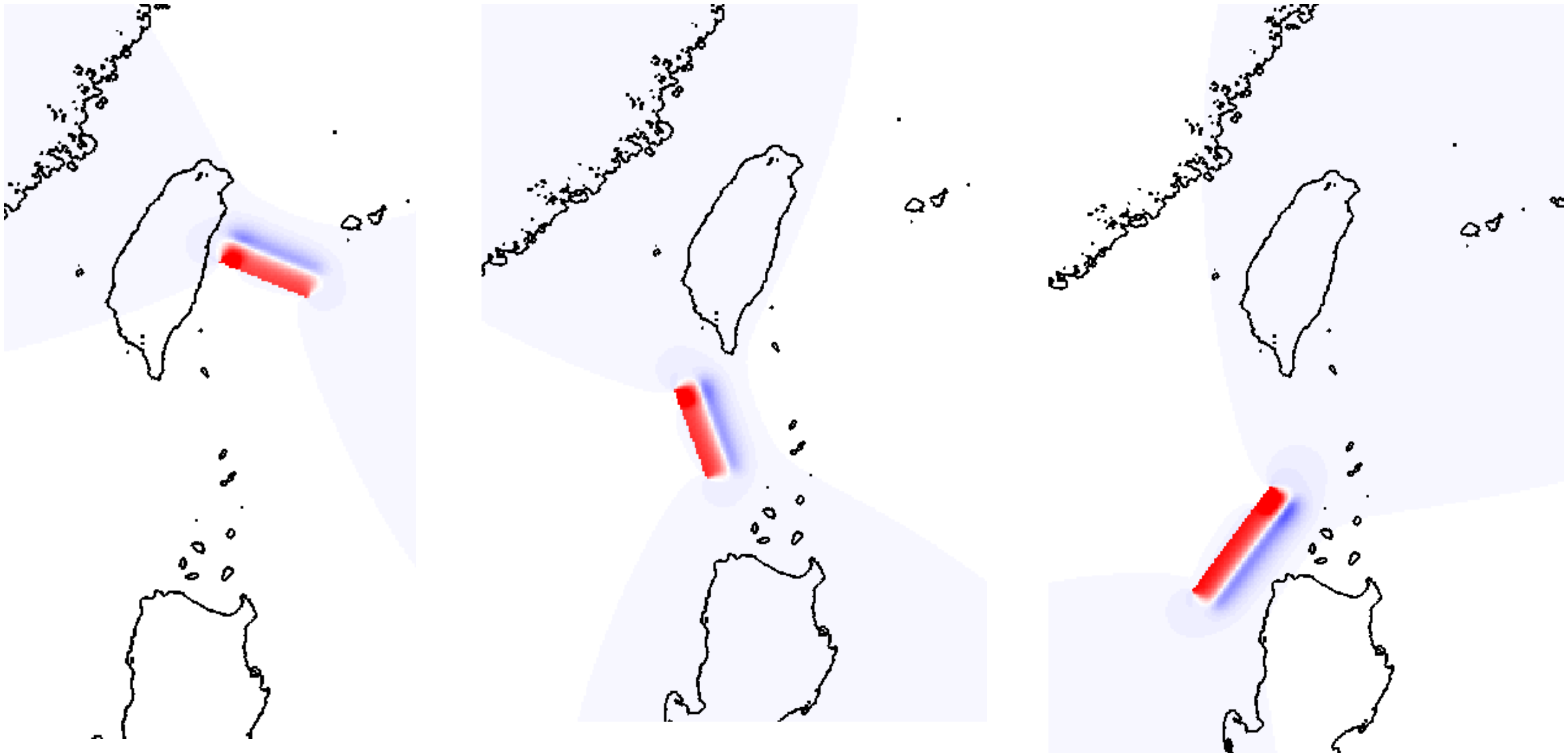
$$S_a = 0.2 \cdot S; \; S_r = 0.8 \cdot S$$

thus $D_r = 0.875 \cdot \overline{D}$

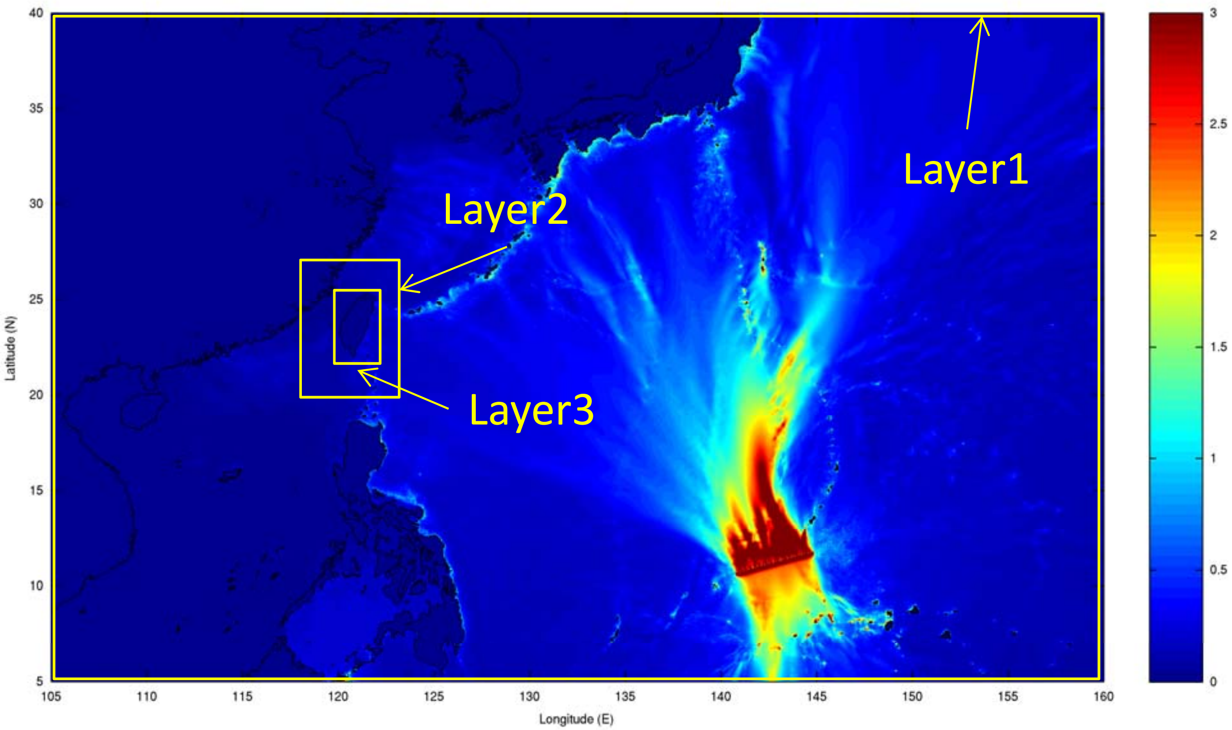


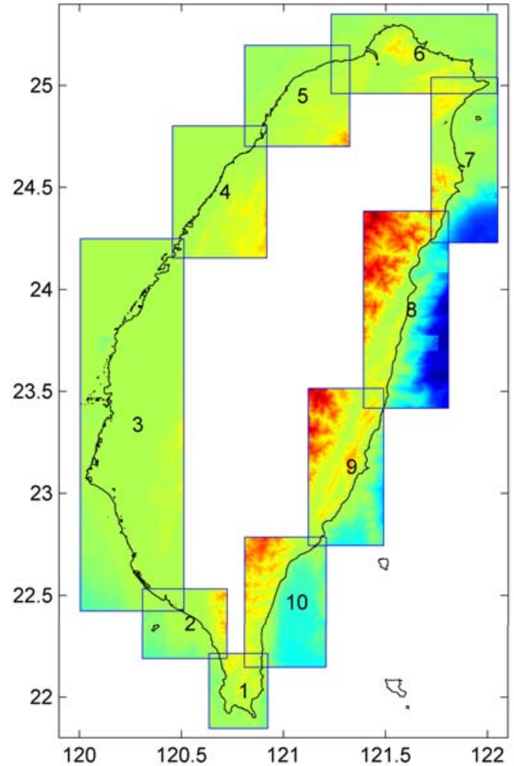
錯動量空間分佈（李憲忠，2011）

An asperity is a region on the fault rupture surface that has a large slip relative to the average slip on the fault (Somerville et al., 1999). The slip is 1.5 or more times larger than the average slip over the fault (Somerville et al., 1999; Asano and Iwata, 2011) and the area is 20% of the total area (Pulido et al., 2004).



Nested Grids



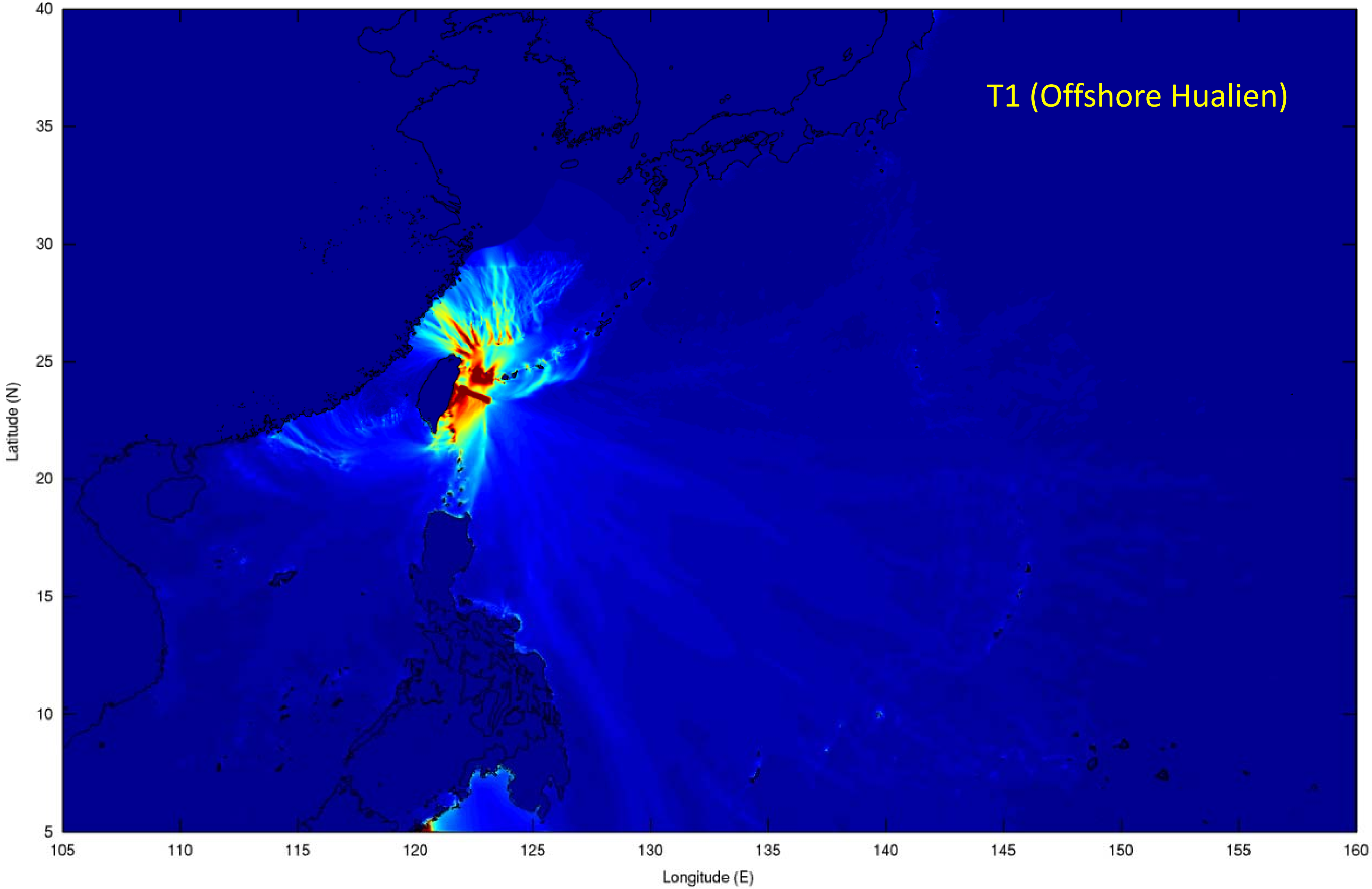


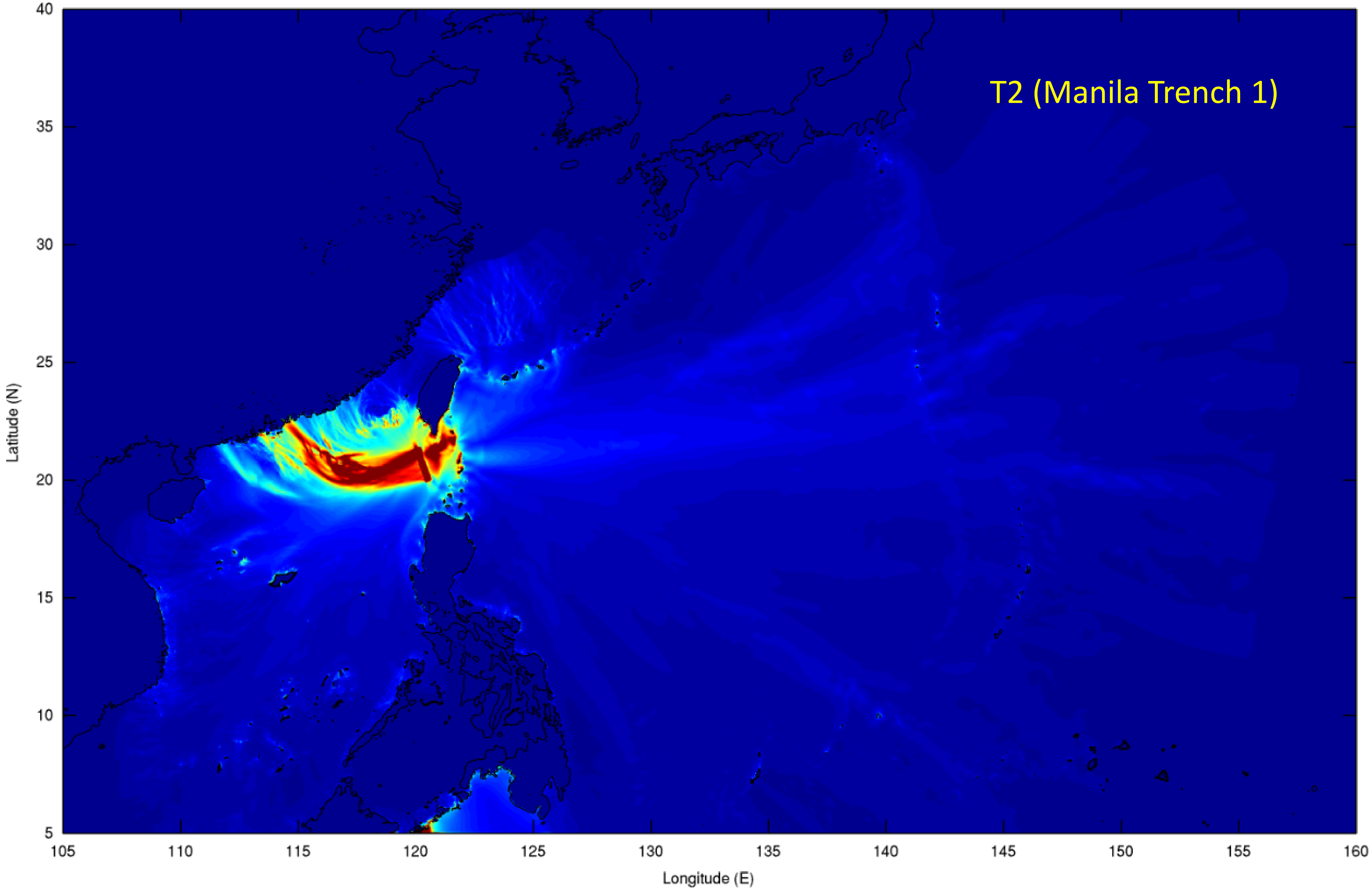
Layer 1: 2 min (~3500m);
Layer 2: ½ min (~900m);
Layer 3: 1/8 min (~200m);
Layer 4: 1/128 min (~50m);
Layer 5: 1/512 min (~10m);
Layer 6: 1/2048 min (~2m);

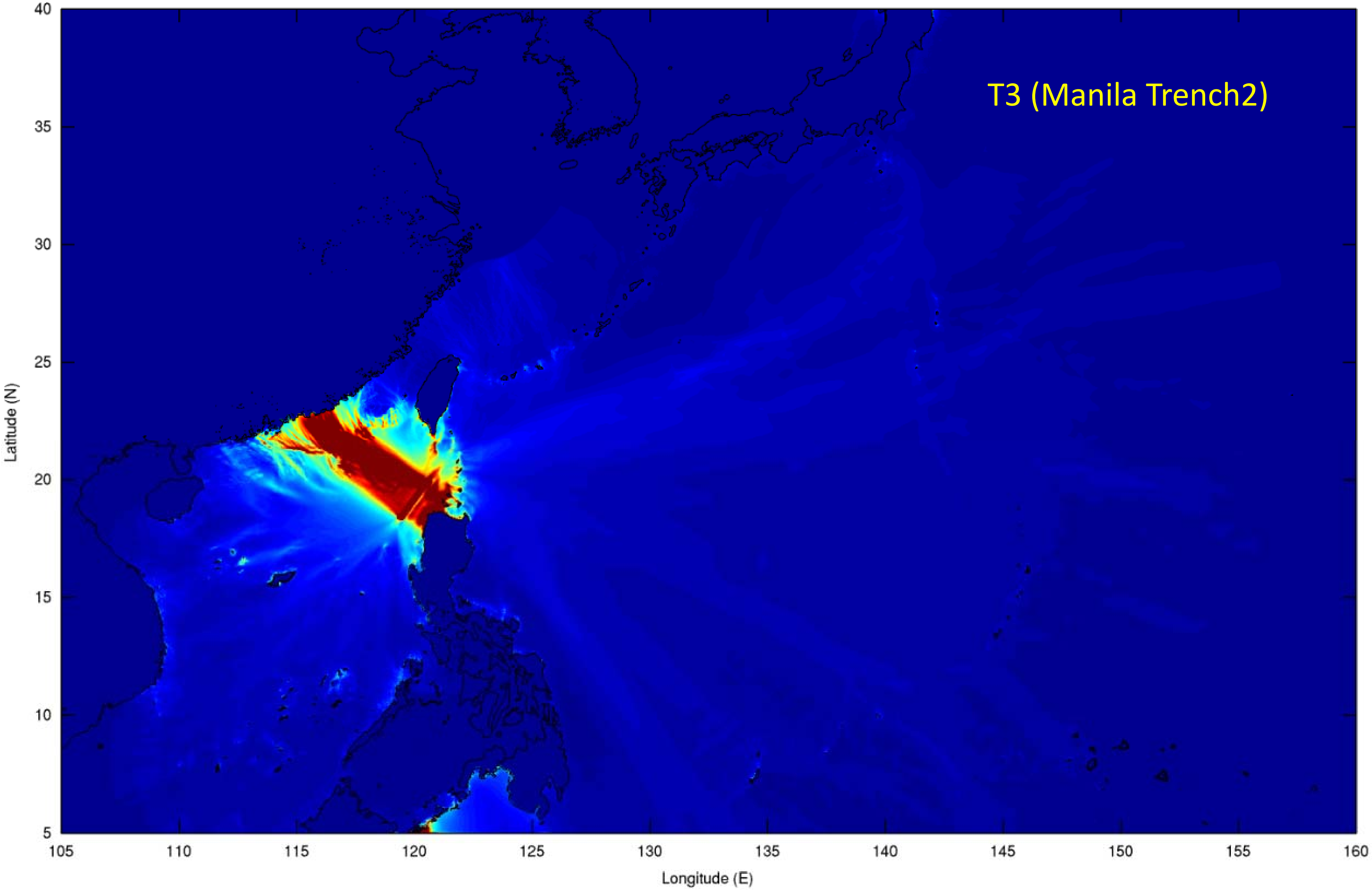
Source of Bathymetry

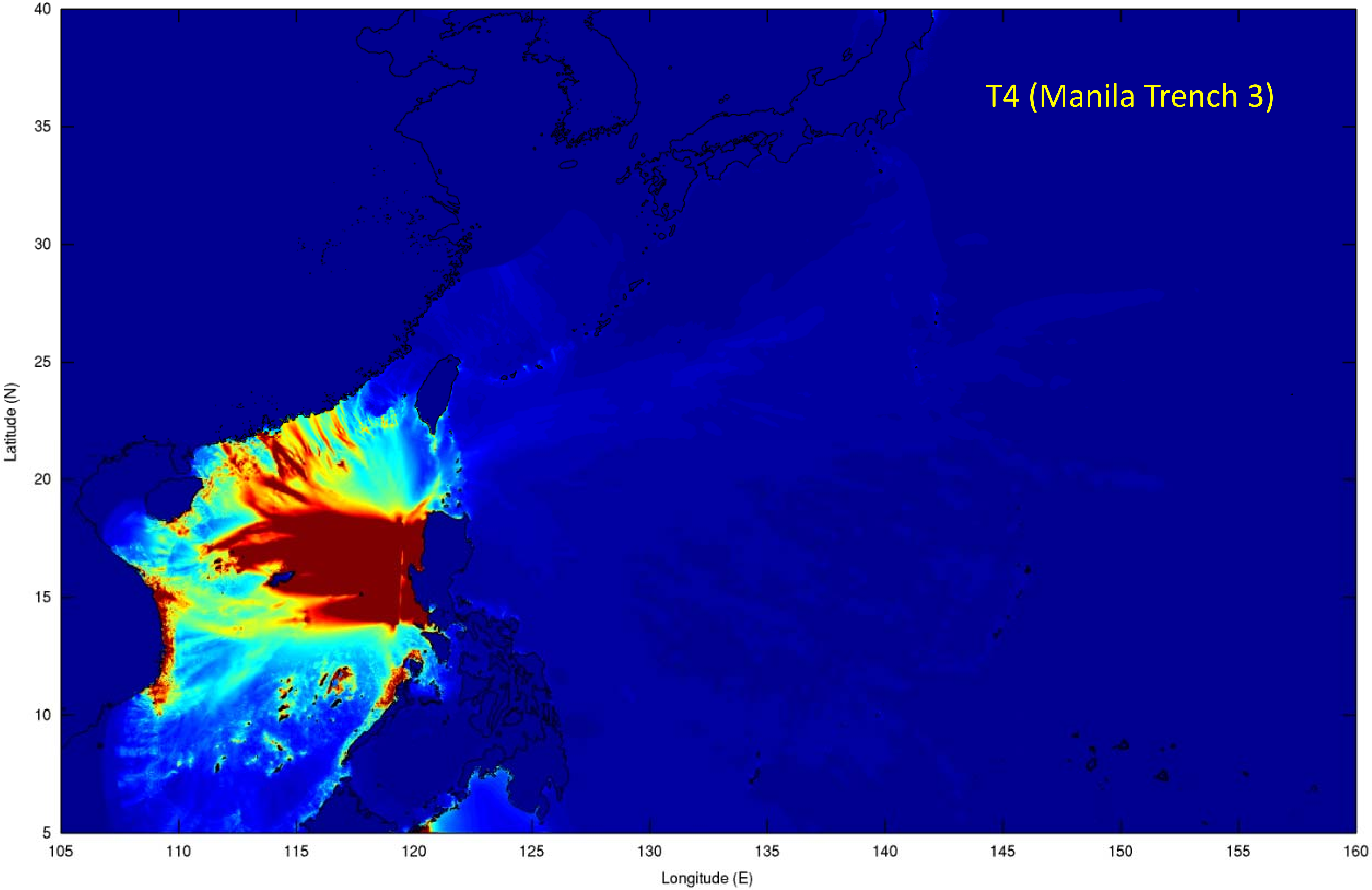
- **ETOTO2:** (2 arc min)
- http://www.ngdc.noaa.gov/mgg/gdas/gd_designagrid.html ，
- **GEBCO:** (0.5 arc min)
- http://www.gebco.net/data_and_products/gridded_bathymetry_data/ 。
- **NAVY**
- **NCU:** 40m DEM 。
- **National Land Surveying and Mapping Center: 10m DEM**
- **Tai Power: 1m DEM**

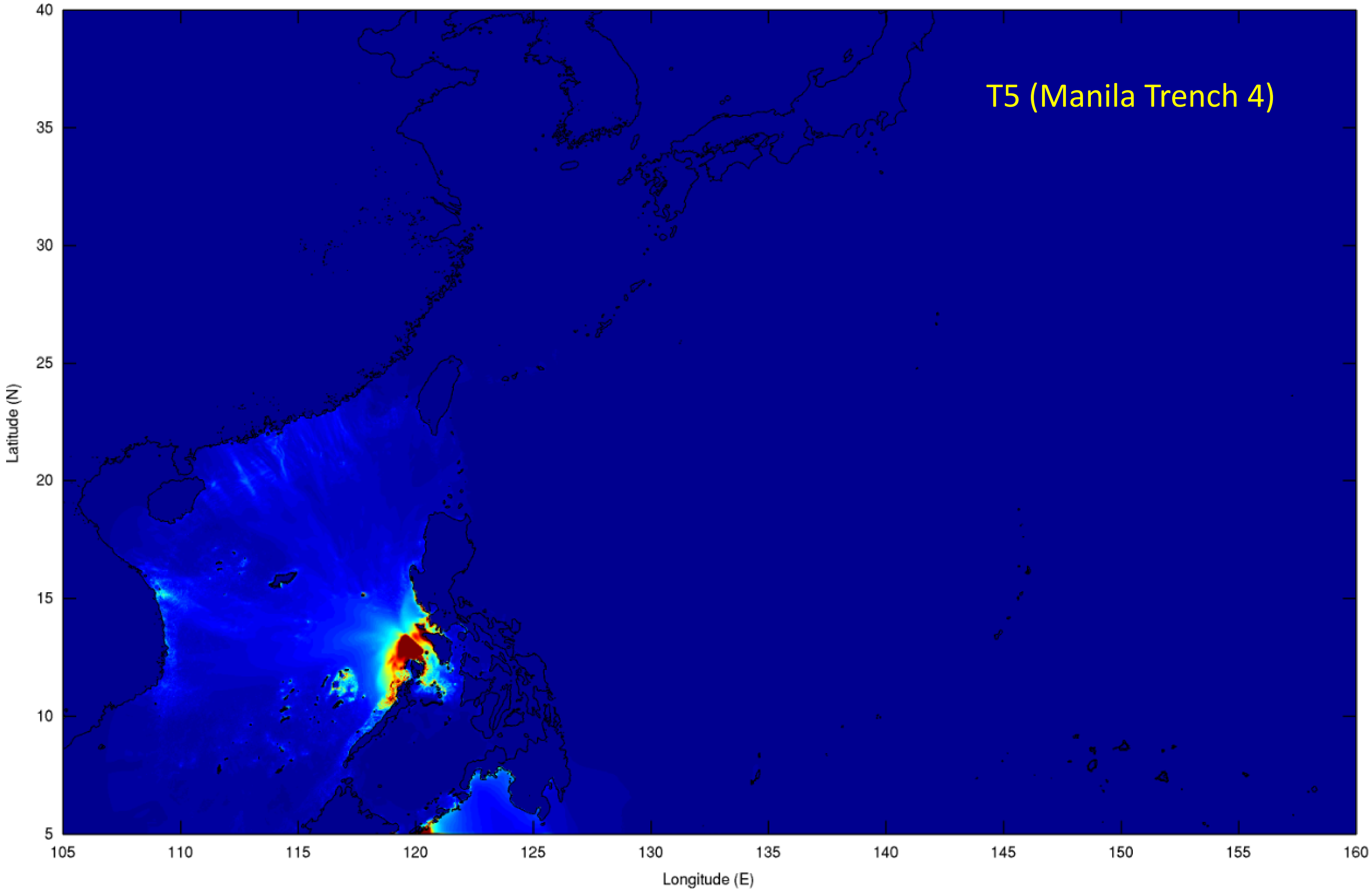
Simulation Results of Tsunamis from 18 Trench Segments

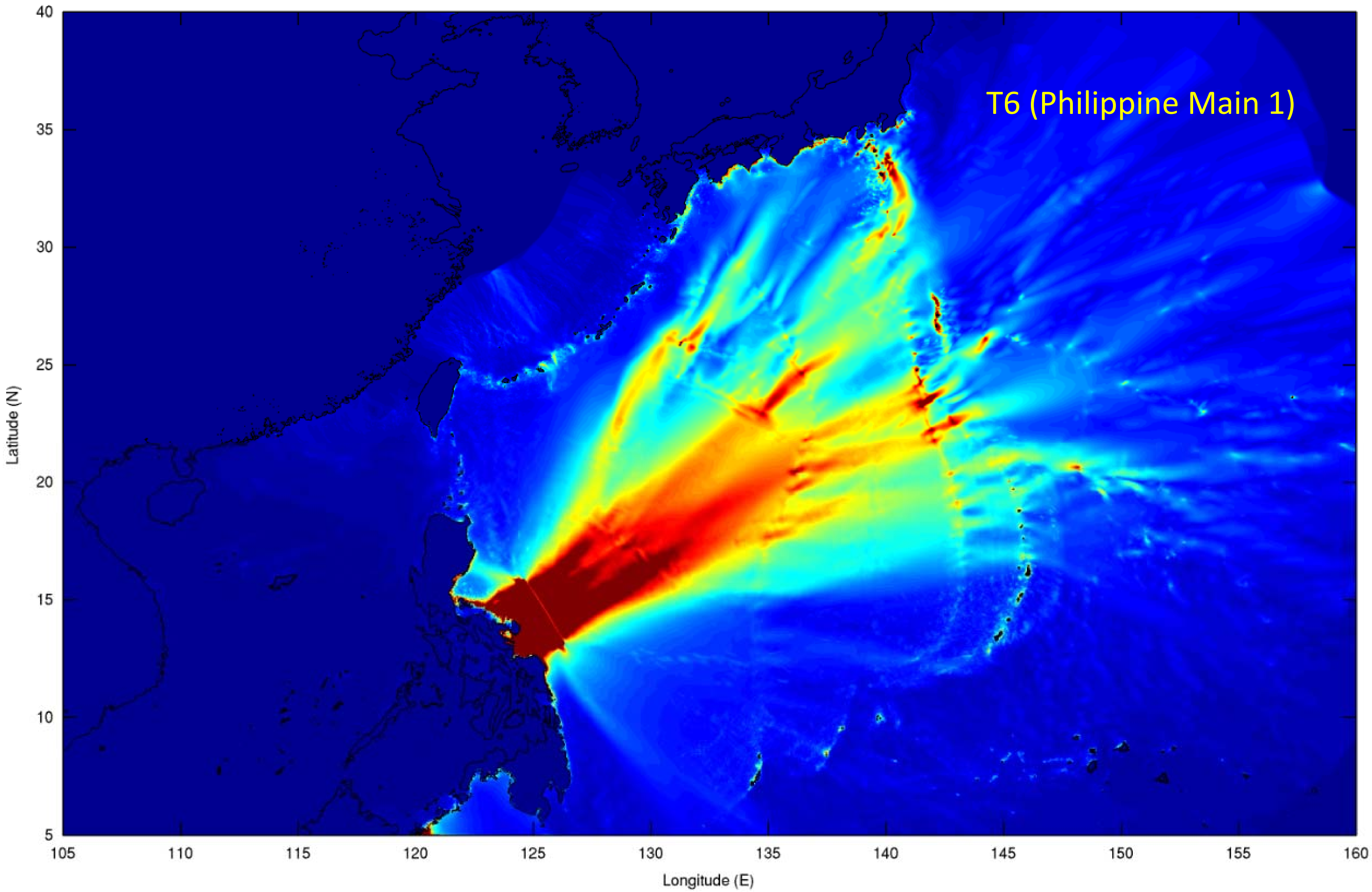

T1 (Offshore Hualien)
Latitude (N)
Longitude (E)
40
35
30
25
20
15
10
5
105
110
115
120
125
130
135
140
145
150
155
160

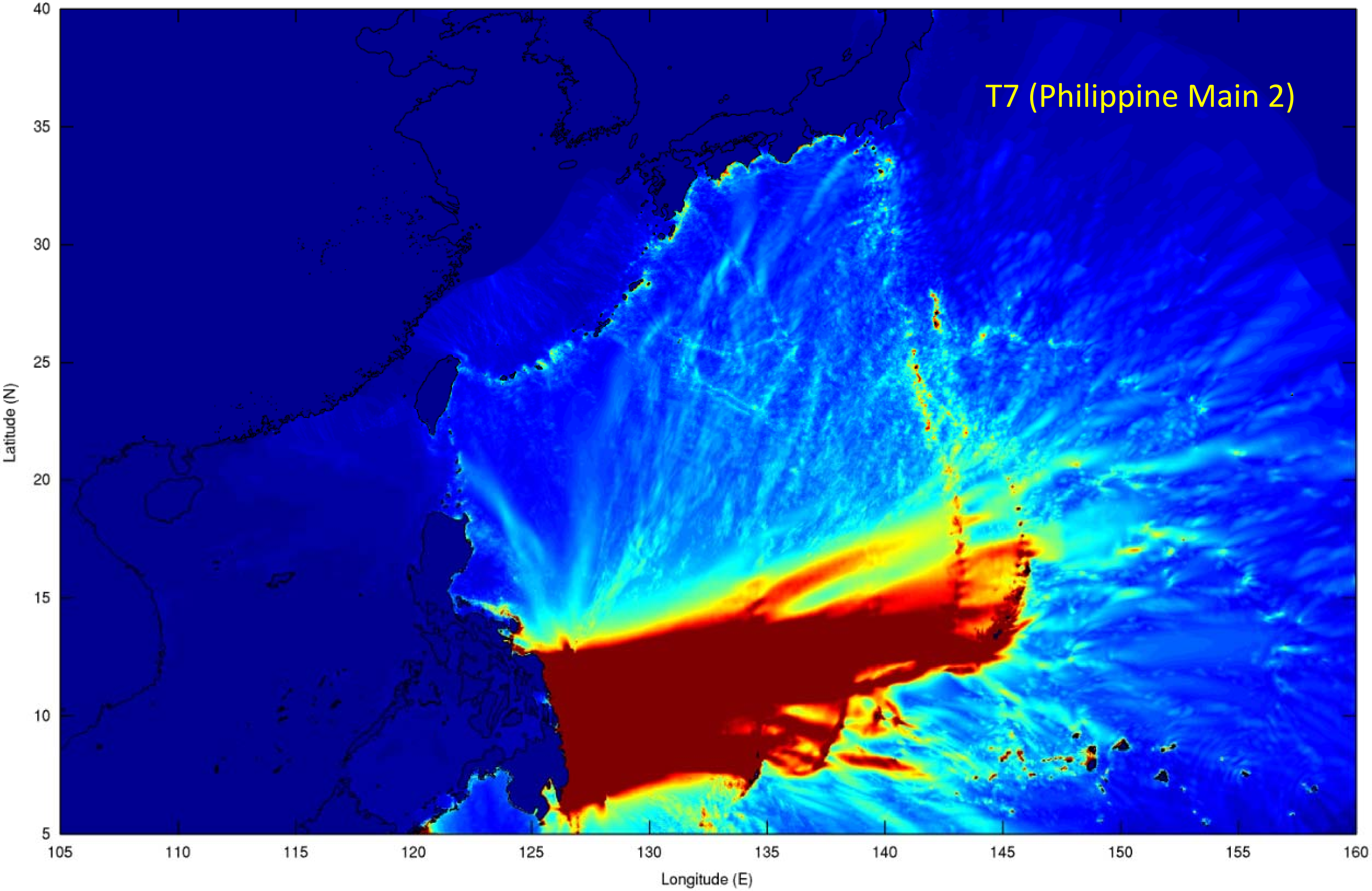

T2 (Manila Trench 1)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)


T3 (Manila Trench2)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)


T4 (Manila Trench 3)
Latitude (N)
Longitude (E)
40
35
30
25
20
15
10
5
105
110
115
120
125
130
135
140
145
150
155
160


T5 (Manila Trench 4)
Latitude (N)
Longitude (E)
40
35
30
25
20
15
10
5
105
110
115
120
125
130
135
140
145
150
155
160


T6 (Philippine Main 1)
Latitude (N)
40
35
30
25
20
15
10
5
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)



T7 (Philippine Main 2)
Latitude (N)
Longitude (E)
40
35
30
25
20
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10
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105
110
115
120
125
130
135
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145
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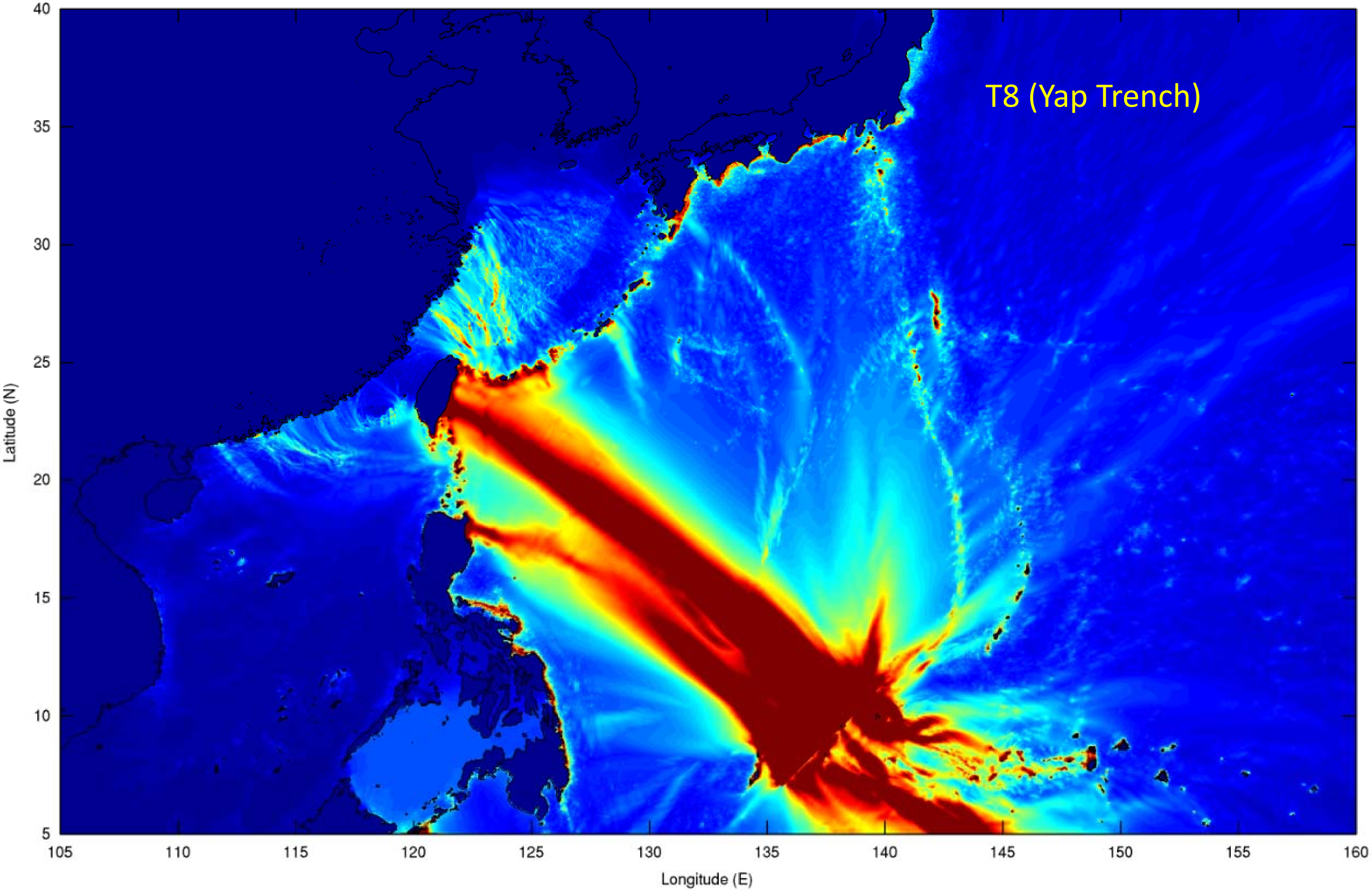
160


T8 (Yap Trench)
Latitude (N)
Longitude (E)
40
35
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25
20
15
10
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105
110
115
120
125
130
135
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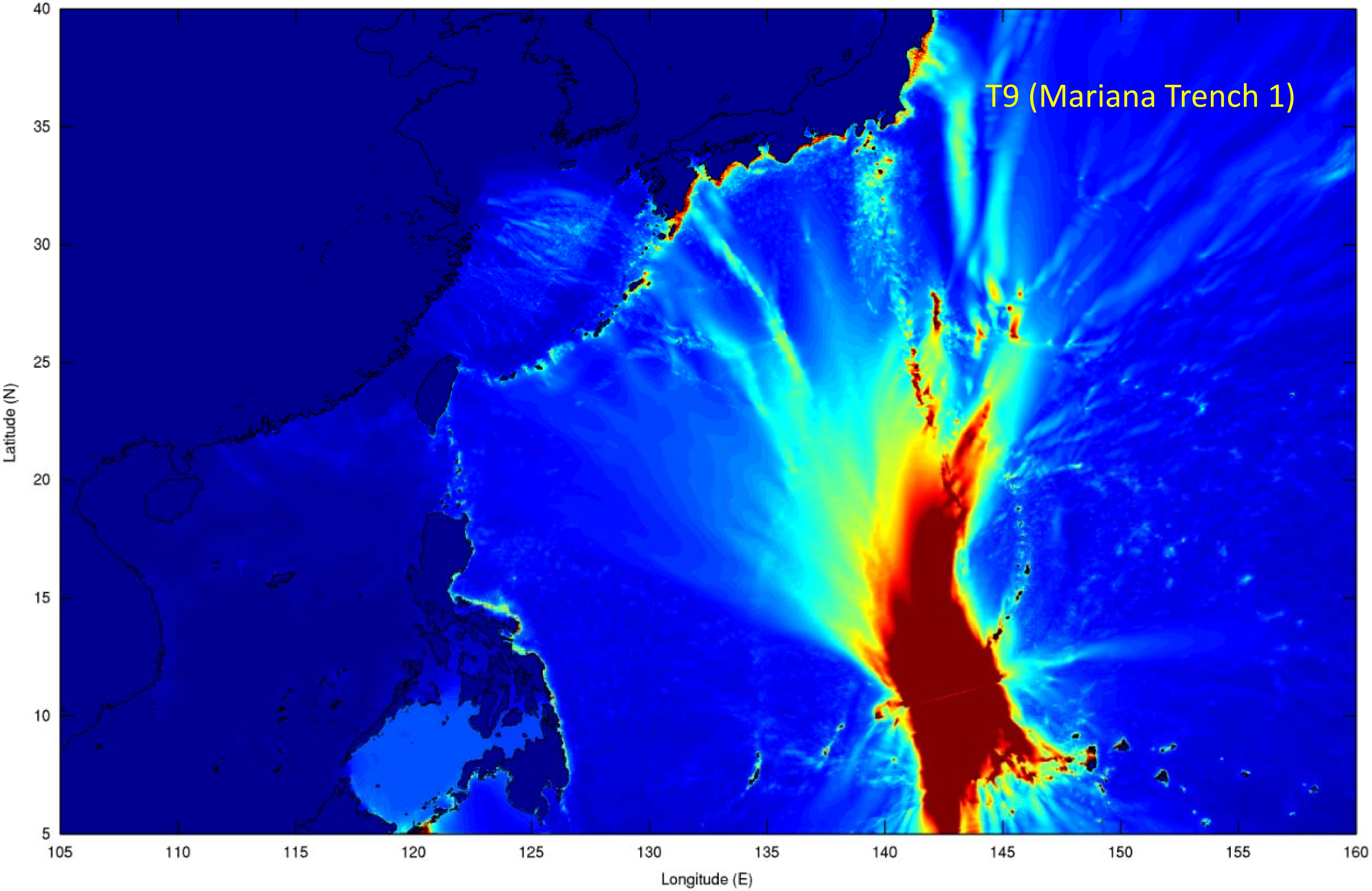
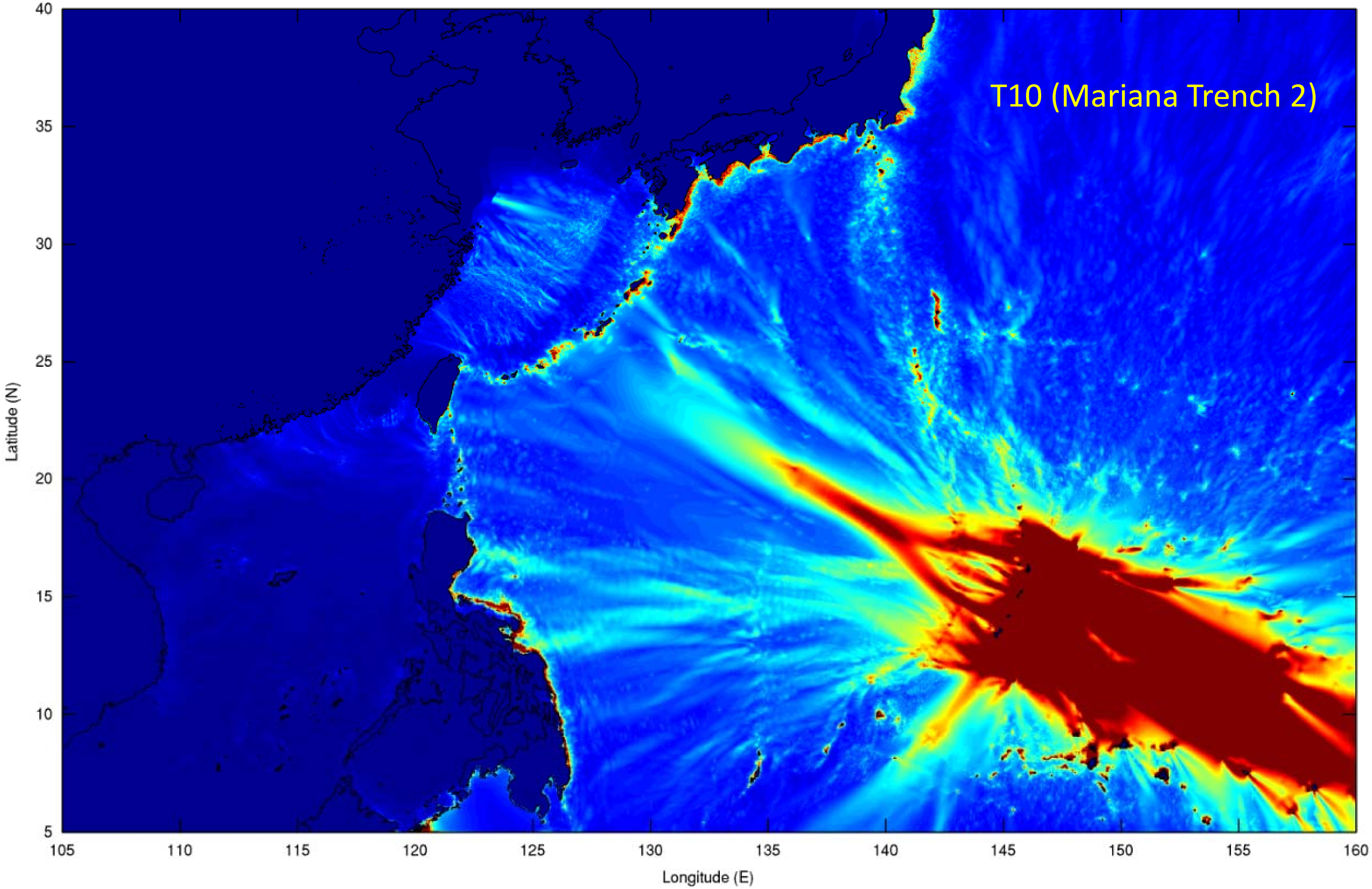
145
150
155
160


T9 (Mariana Trench 1)
Latitude (N)
Longitude (E)
40
35
30
25
20
15
10
5
105
110
115
120
125
130
135
140
145
150
155
160


T10 (Mariana Trench 2)
Latitude (N)
Longitude (E)
40
35
30
25
20
15
10
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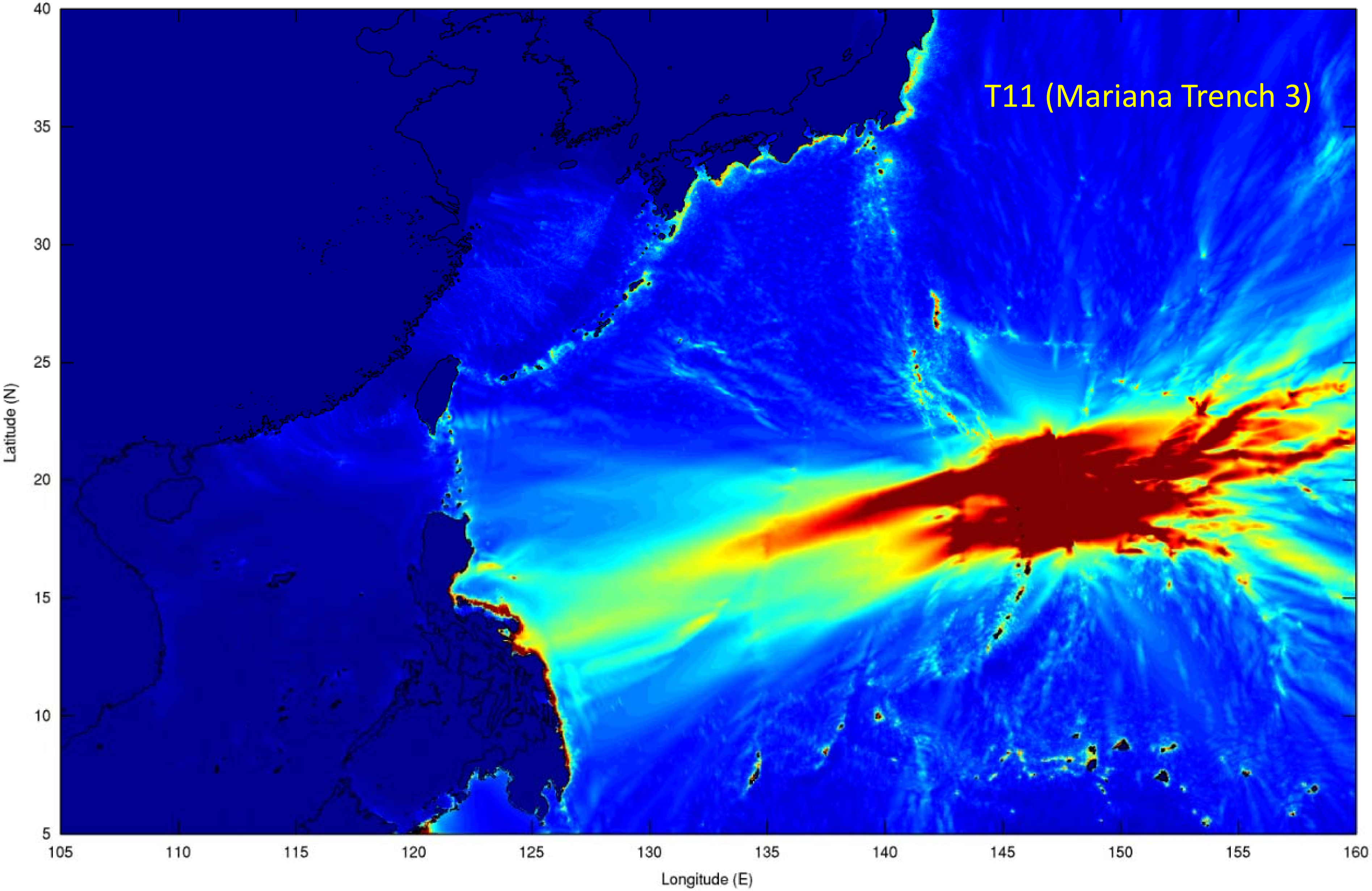
105
110
115
120
125
130
135
140
145
150
155
160


T11 (Mariana Trench 3)
Latitude (N)
Longitude (E)
40
35
30
25
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15
10
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105
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115
120
125
130
135
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145
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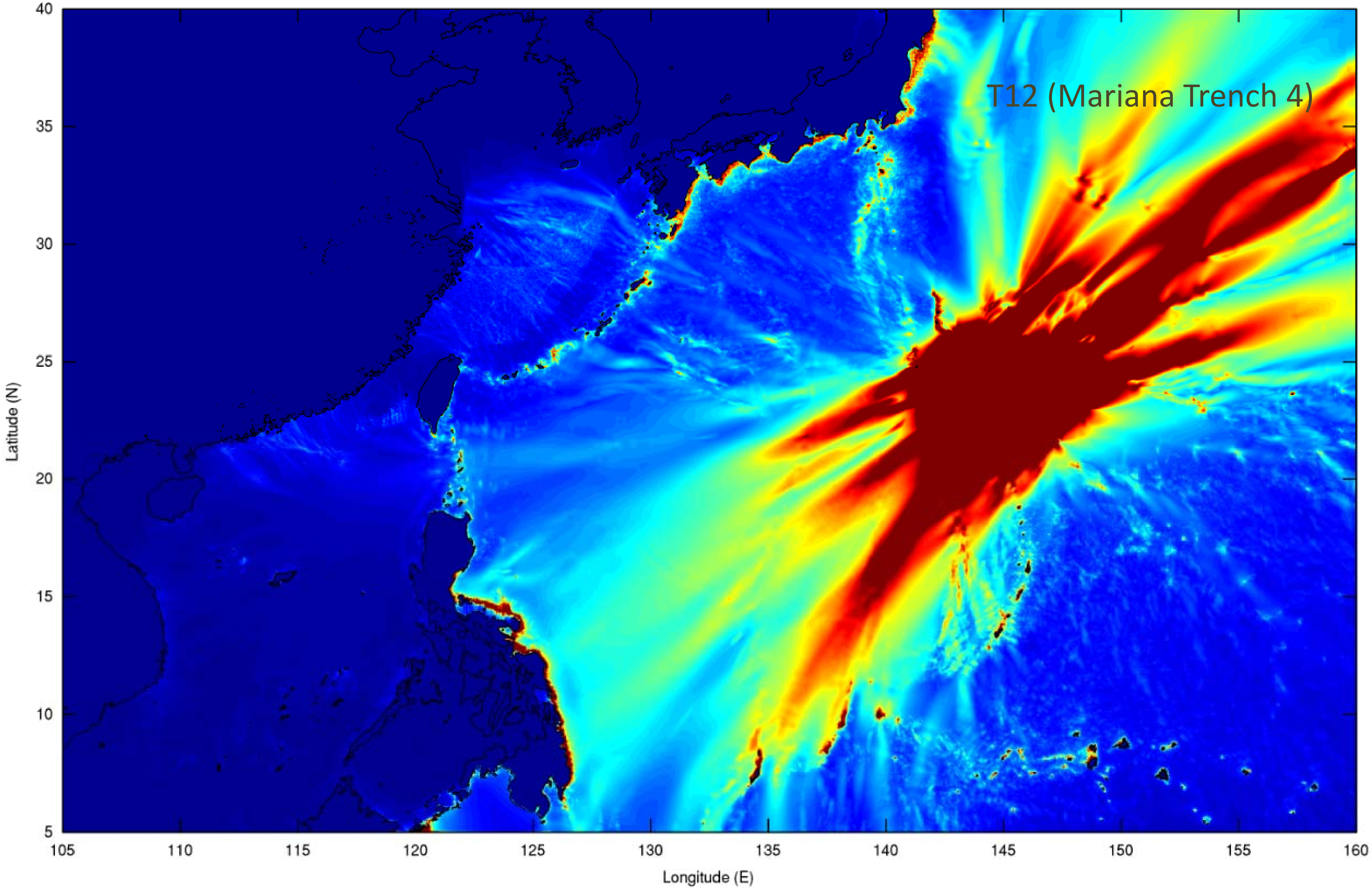
T12 (Mariana Trench 4)
40
35
30
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5
Latitude (N)
105
110
115
120
125
130
135
140
145
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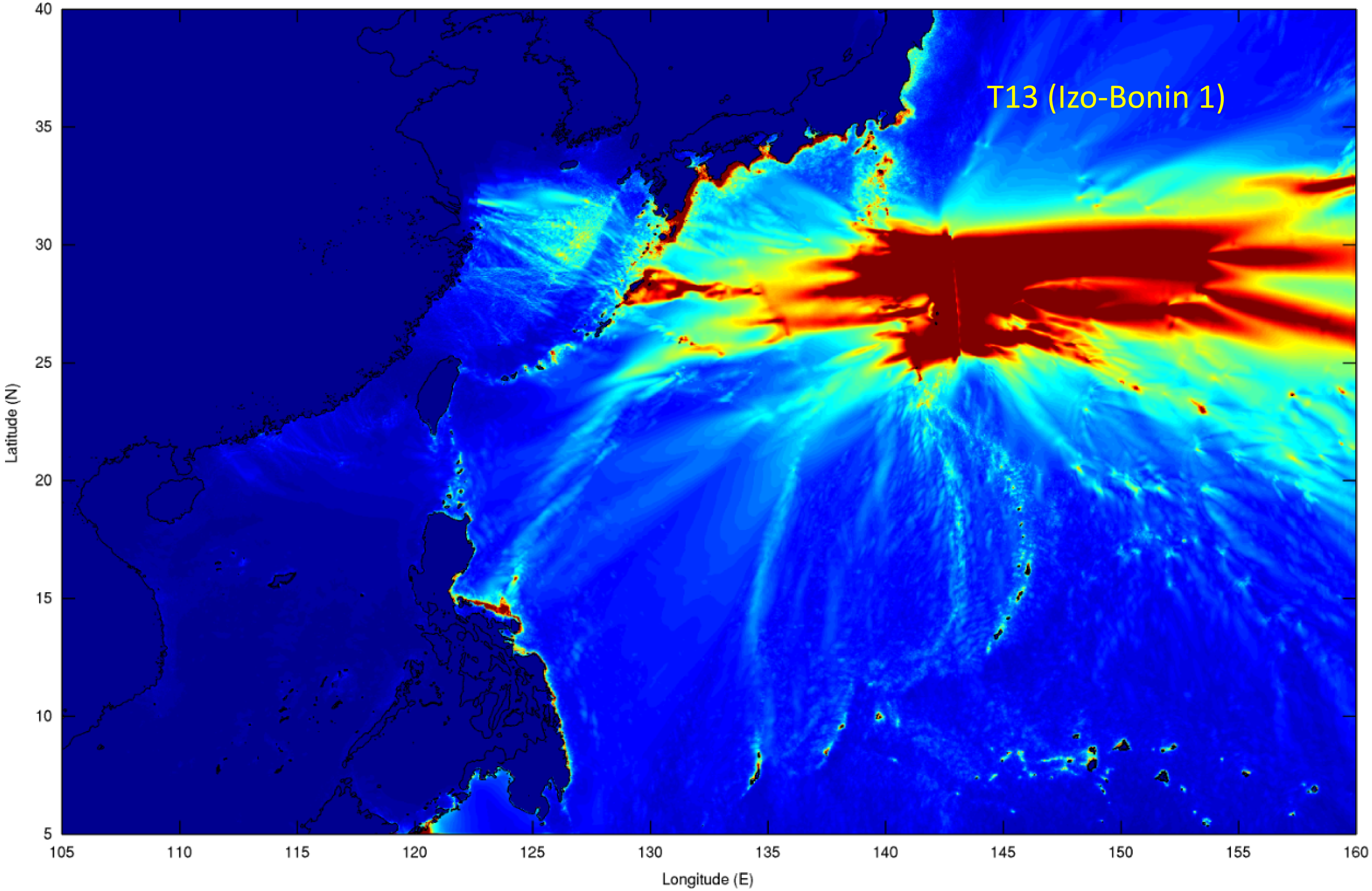
155
160
Longitude (E)



T13 (Izo-Bonin 1)
40
35
30
25
20
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Latitude (N)
105
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115
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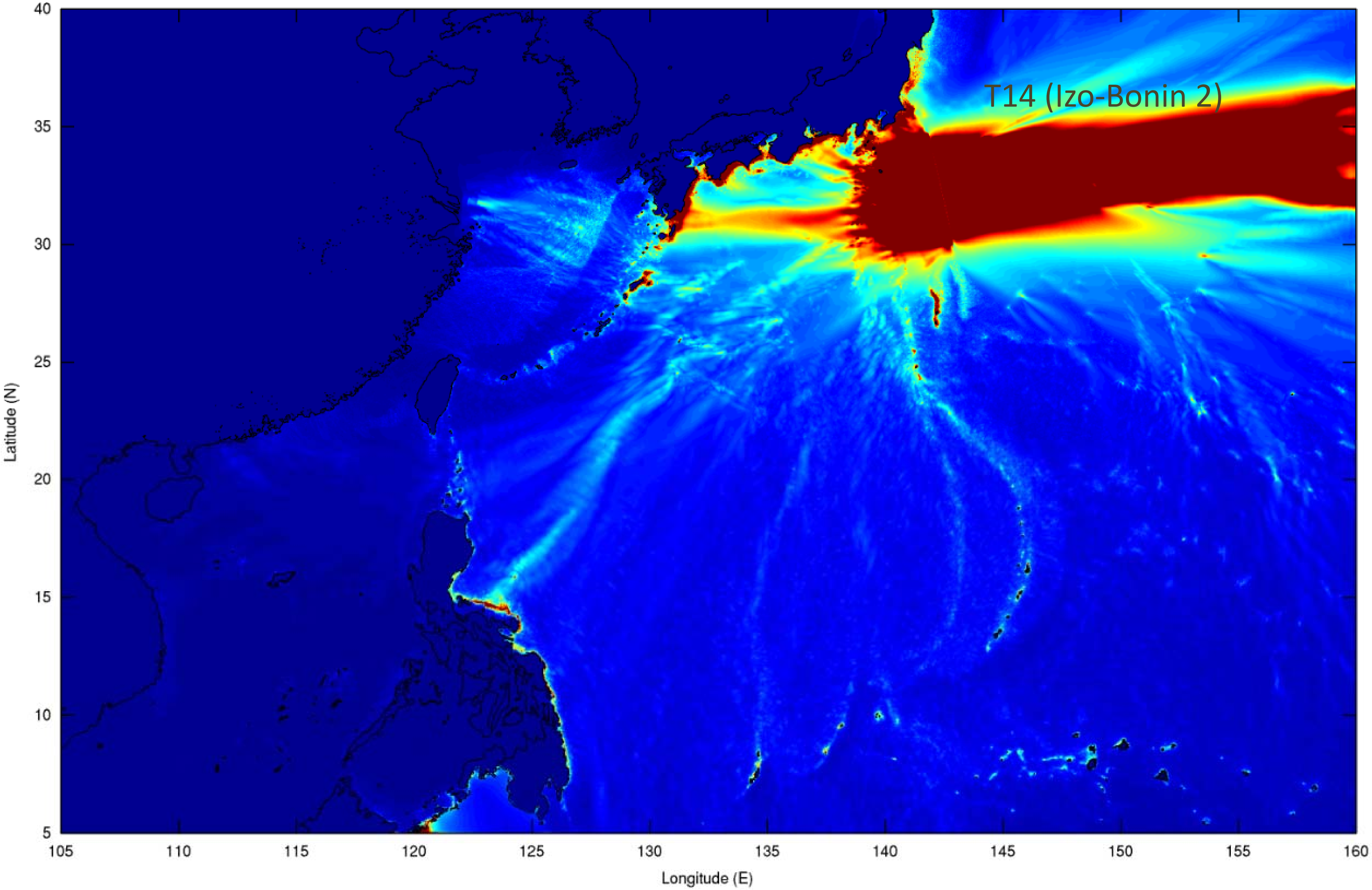
125
130
135
140
145
150
155
160
Longitude (E)


T14 (Izo-Bonin 2)
Latitude (N)
Longitude (E)
40
35
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25
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105
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115
120
125
130
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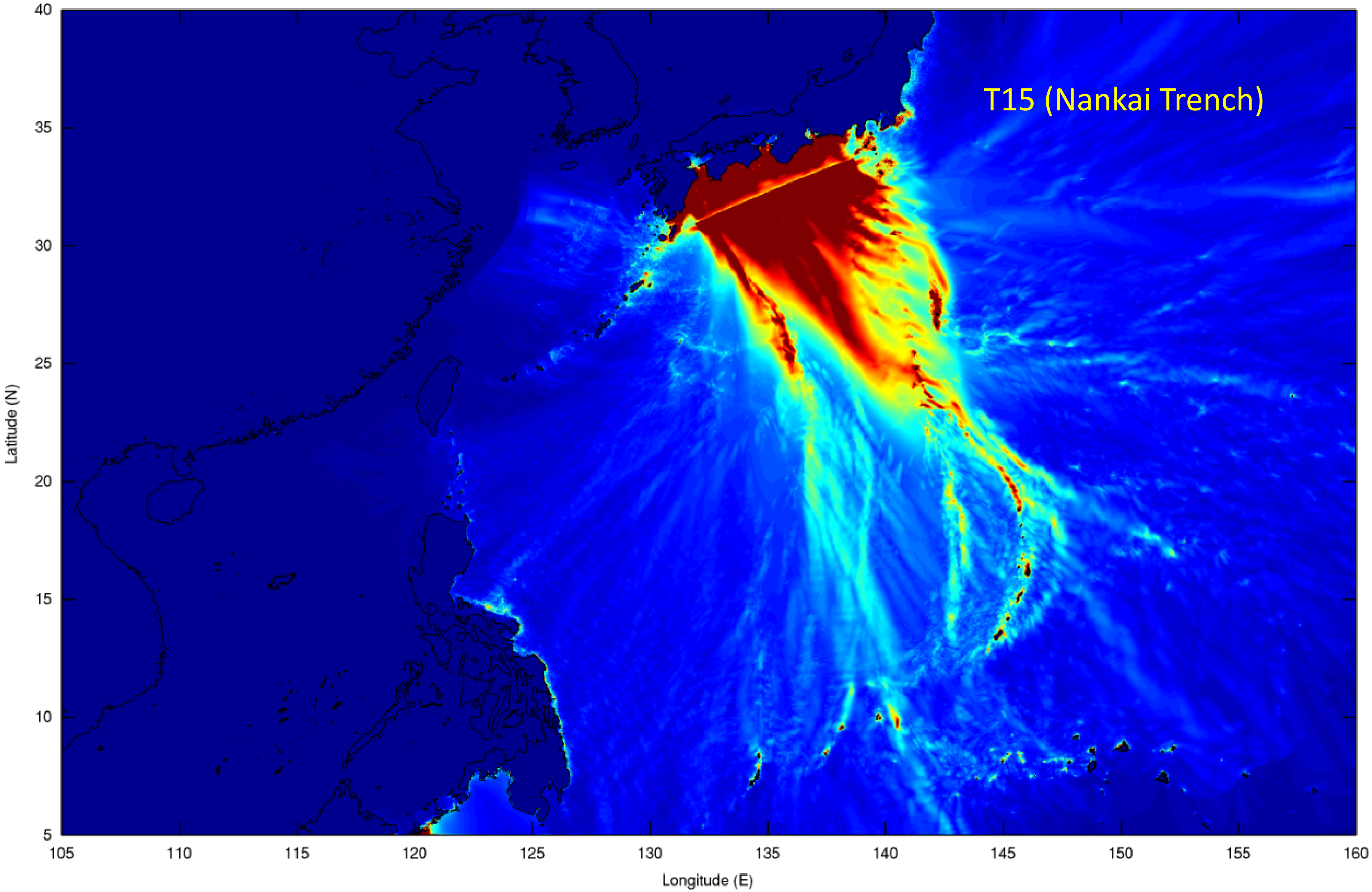
145
150
155
160


T15 (Nankai Trench)
Latitude (N)
Longitude (E)
40
35
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105
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115
120
125
130
135
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145
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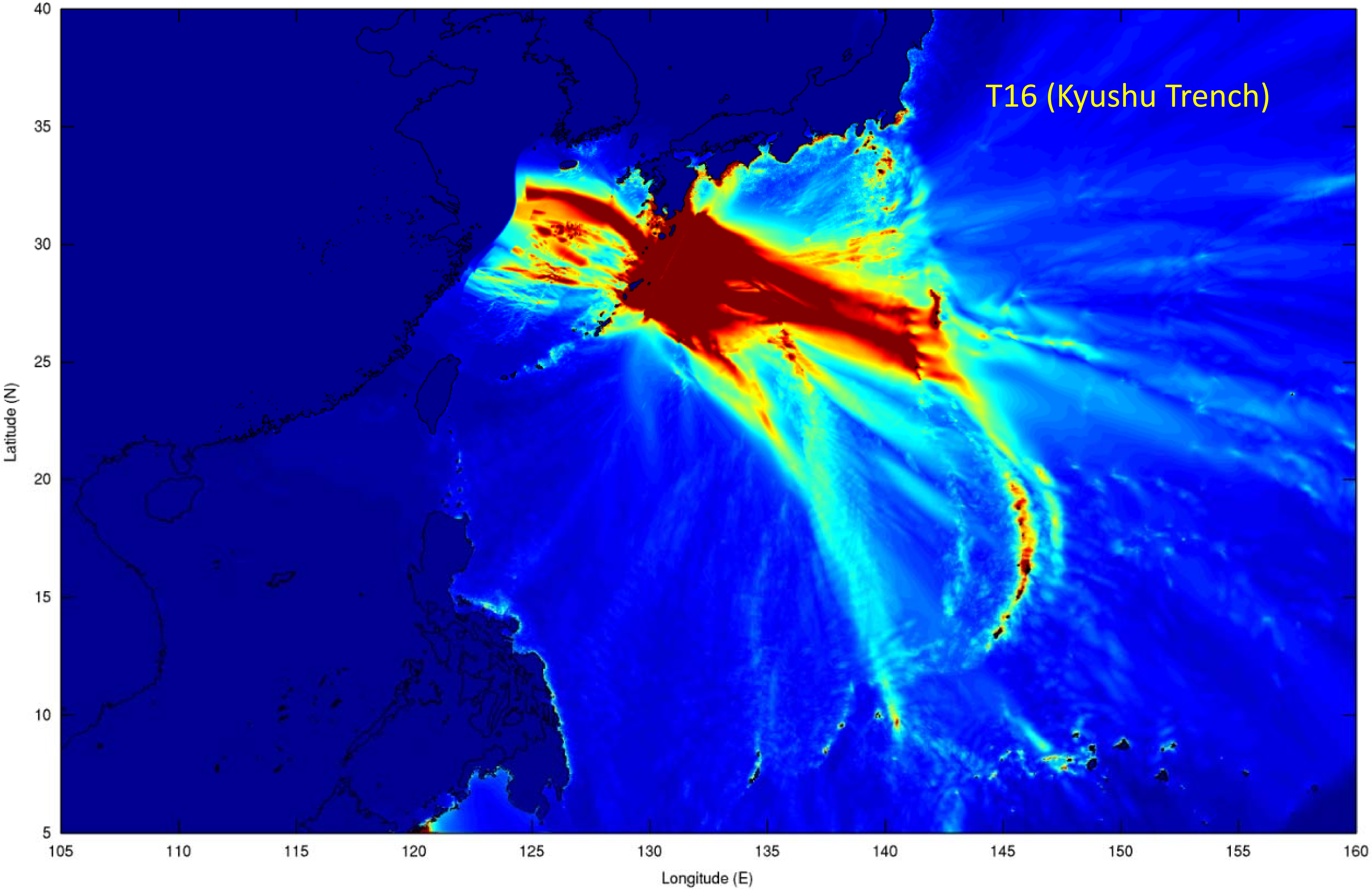
T16 (Kyushu Trench)
Latitude (N)
Longitude (E)
40
35
30
25
20
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105
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115
120
125
130
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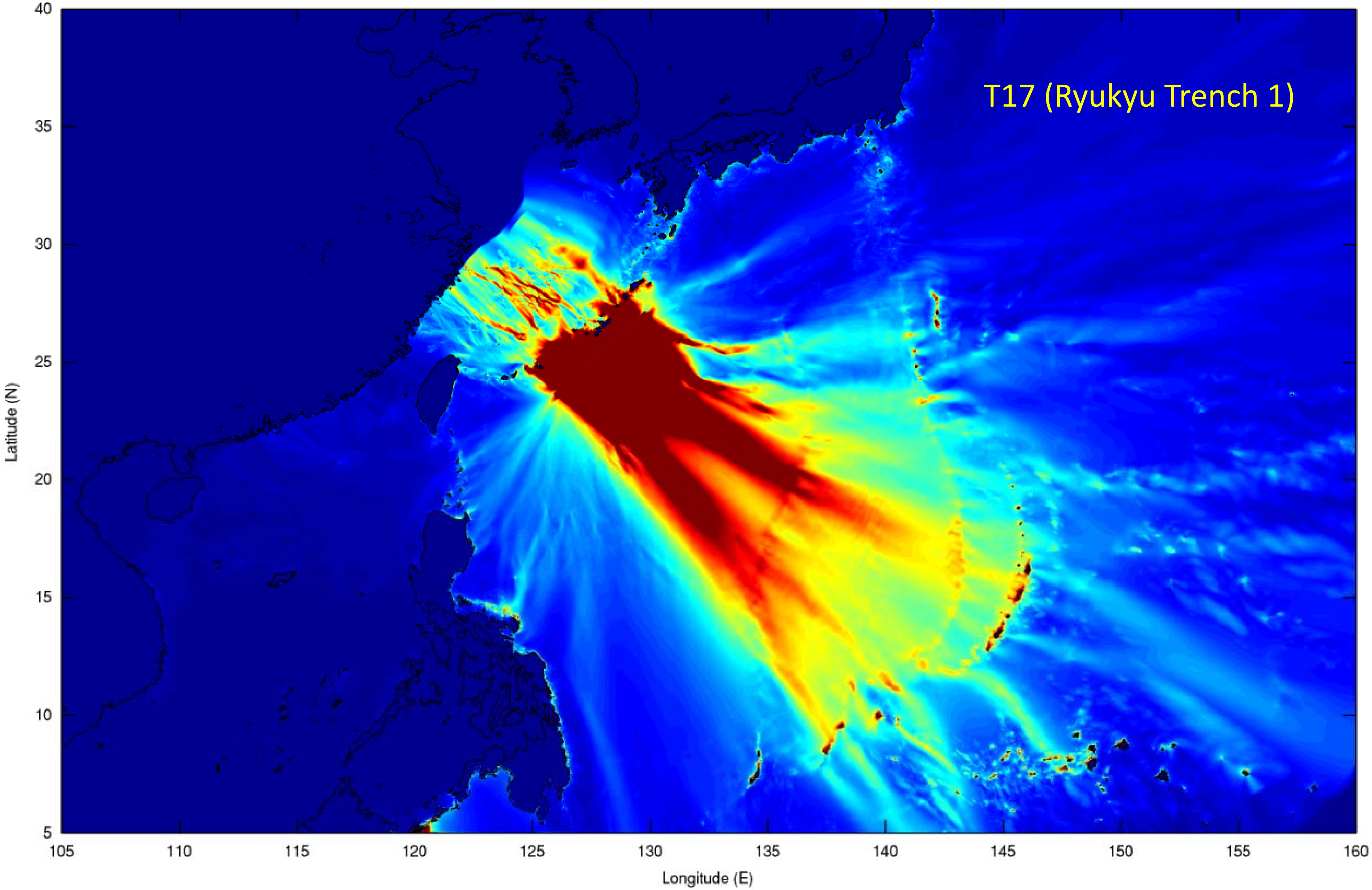
T17 (Ryukyu Trench 1)
Latitude (N)
Longitude (E)
40
35
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115
120
125
130
135
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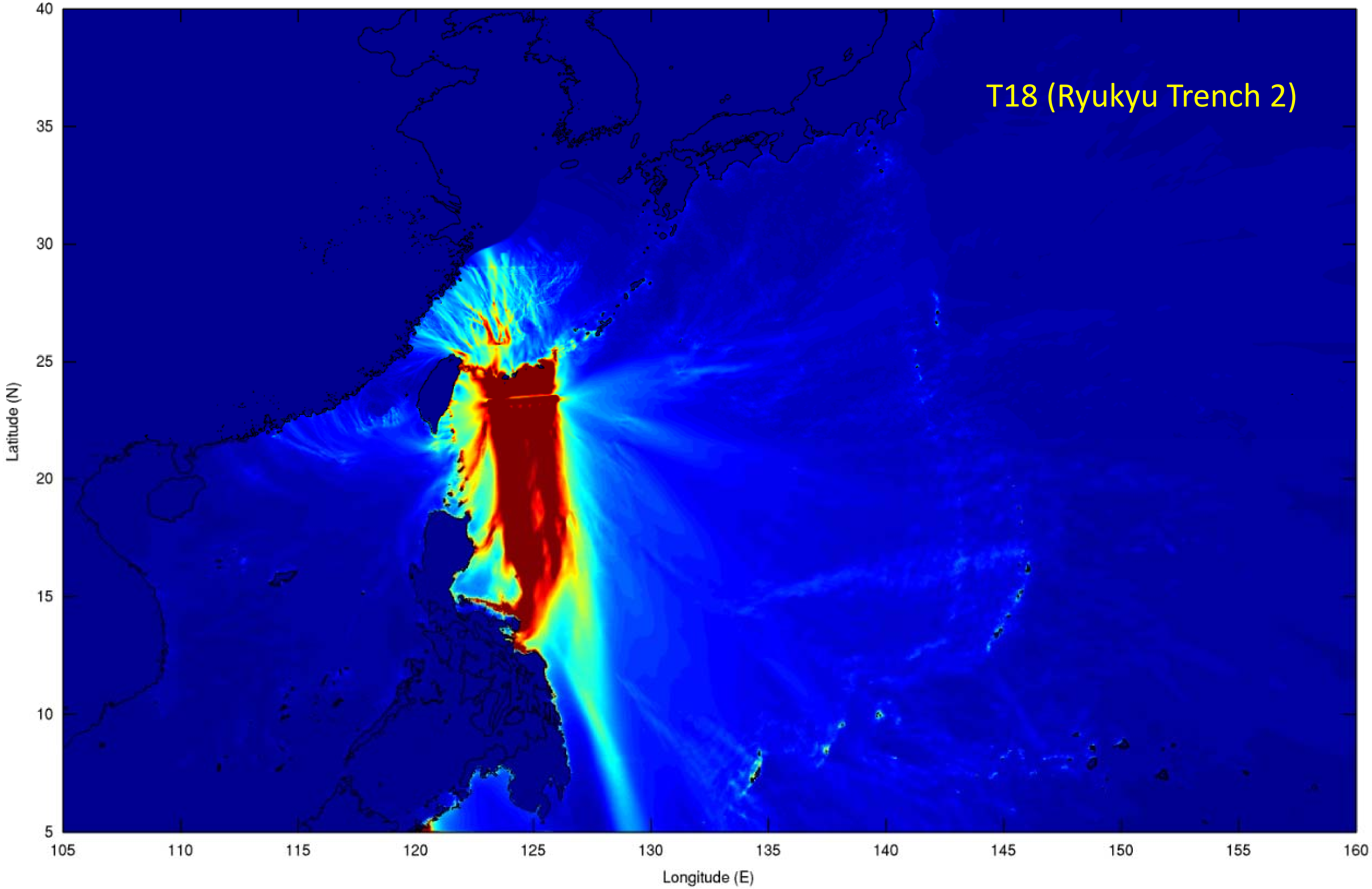
160



T18 (Ryukyu Trench 2)
40
35
30
25
20
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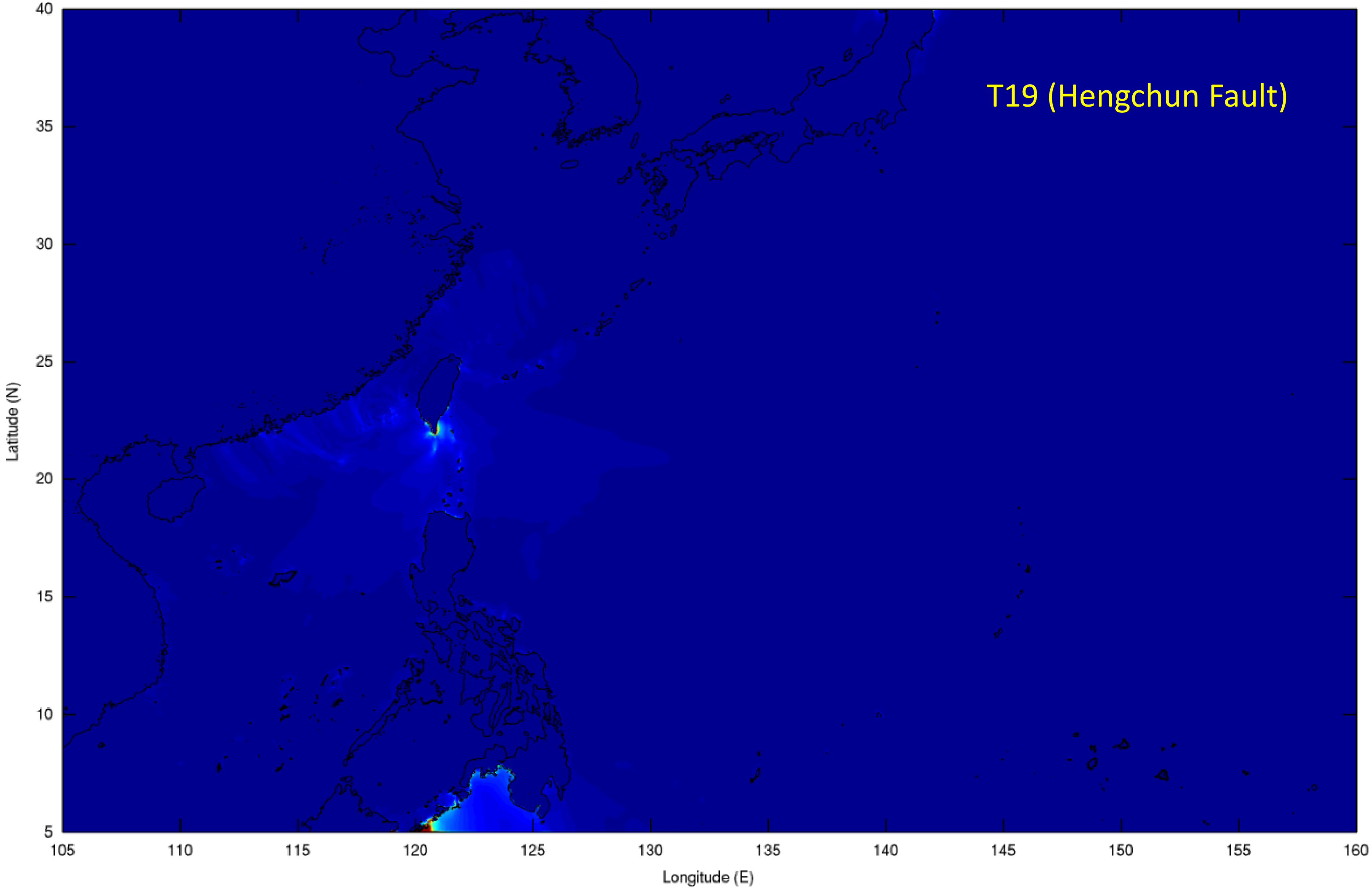
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)



T19 (Hengchun Fault)
Latitude (N)
Longitude (E)
40
35
30
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20
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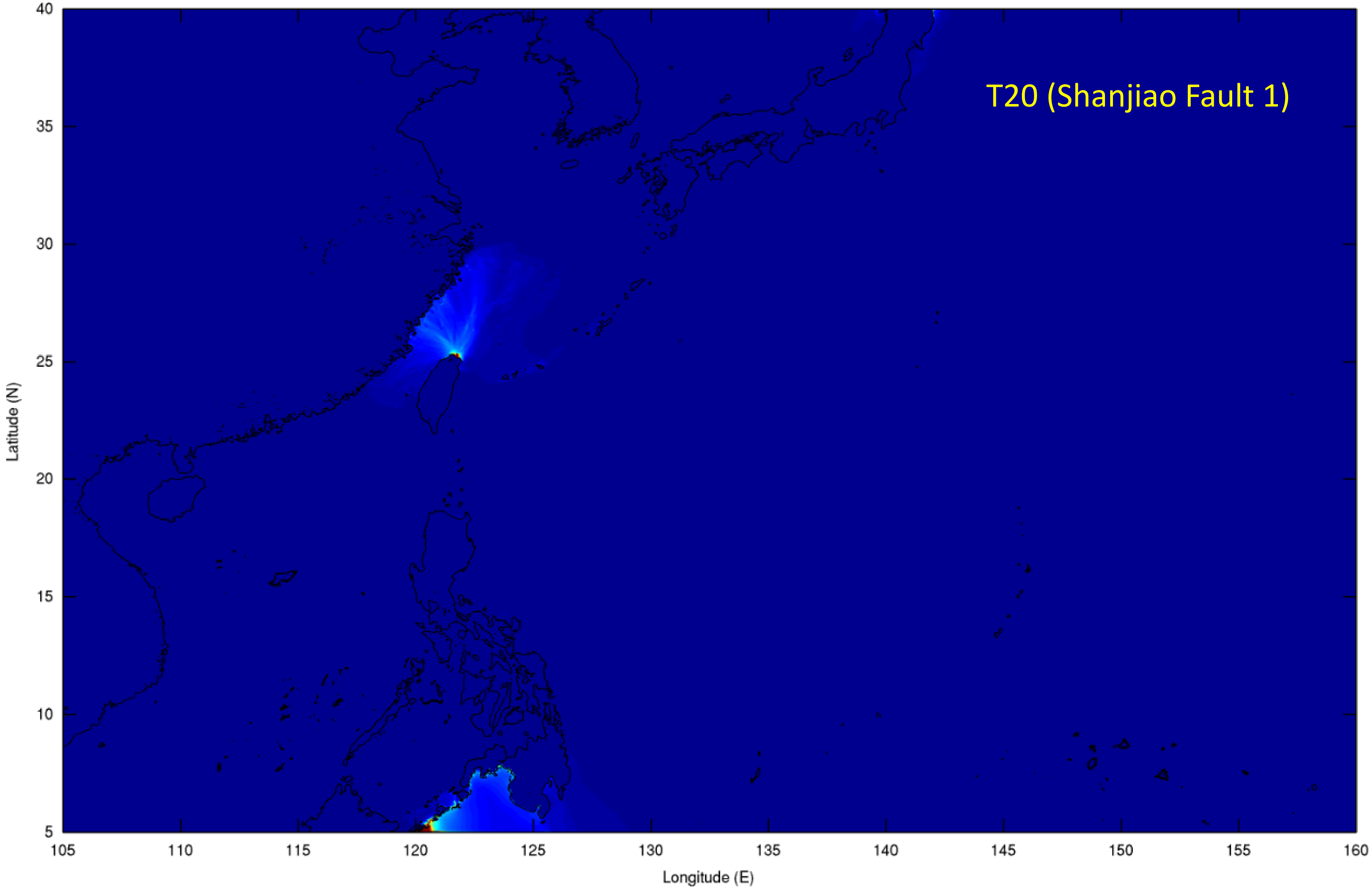
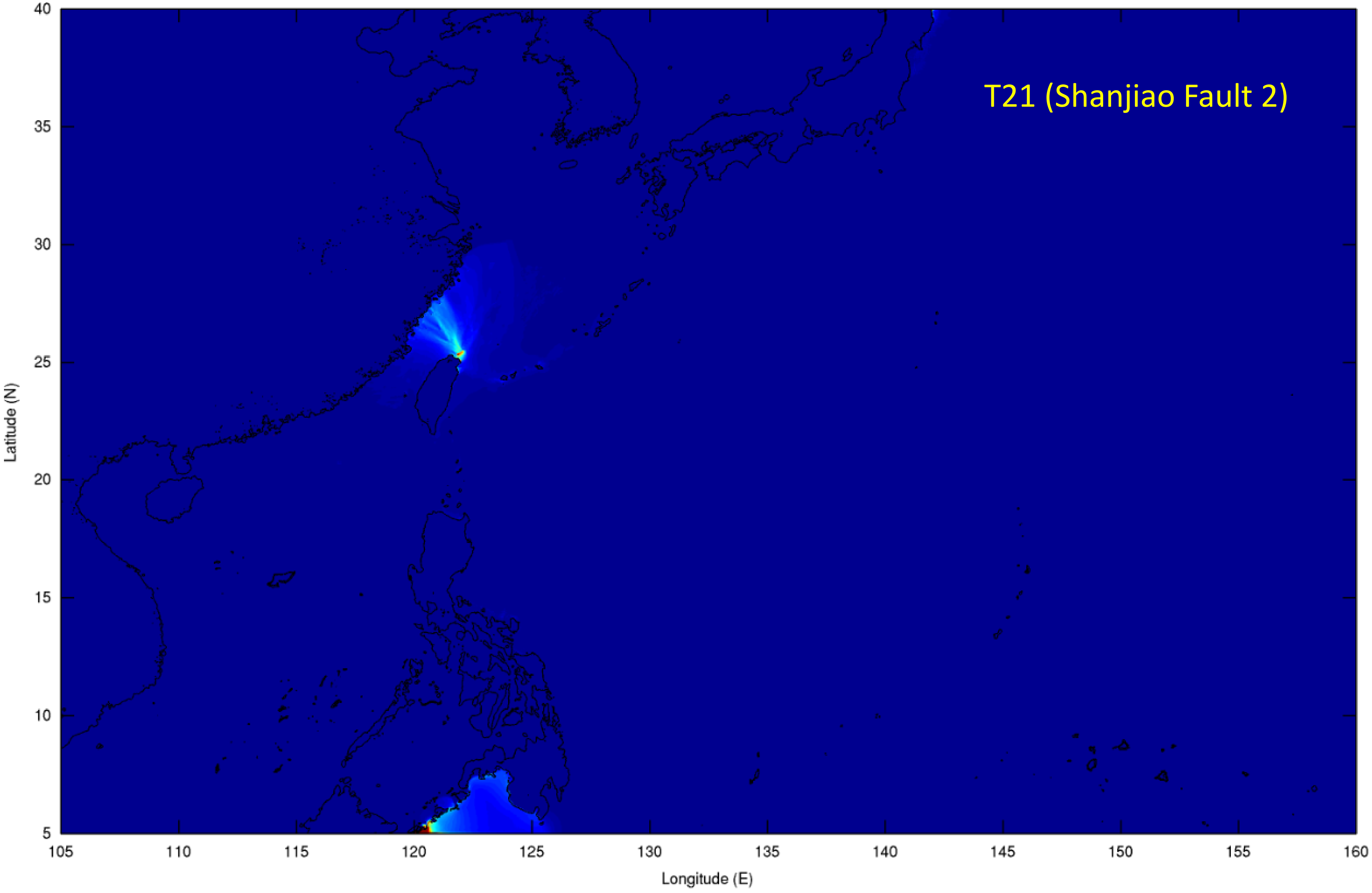
105
110
115
120
125
130
135
140
145
150
155
160


T20 (Shanjiao Fault 1)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)


T21 (Shanjiao Fault 2)
Latitude (N)
Longitude (E)
40
35
30
25
20
15
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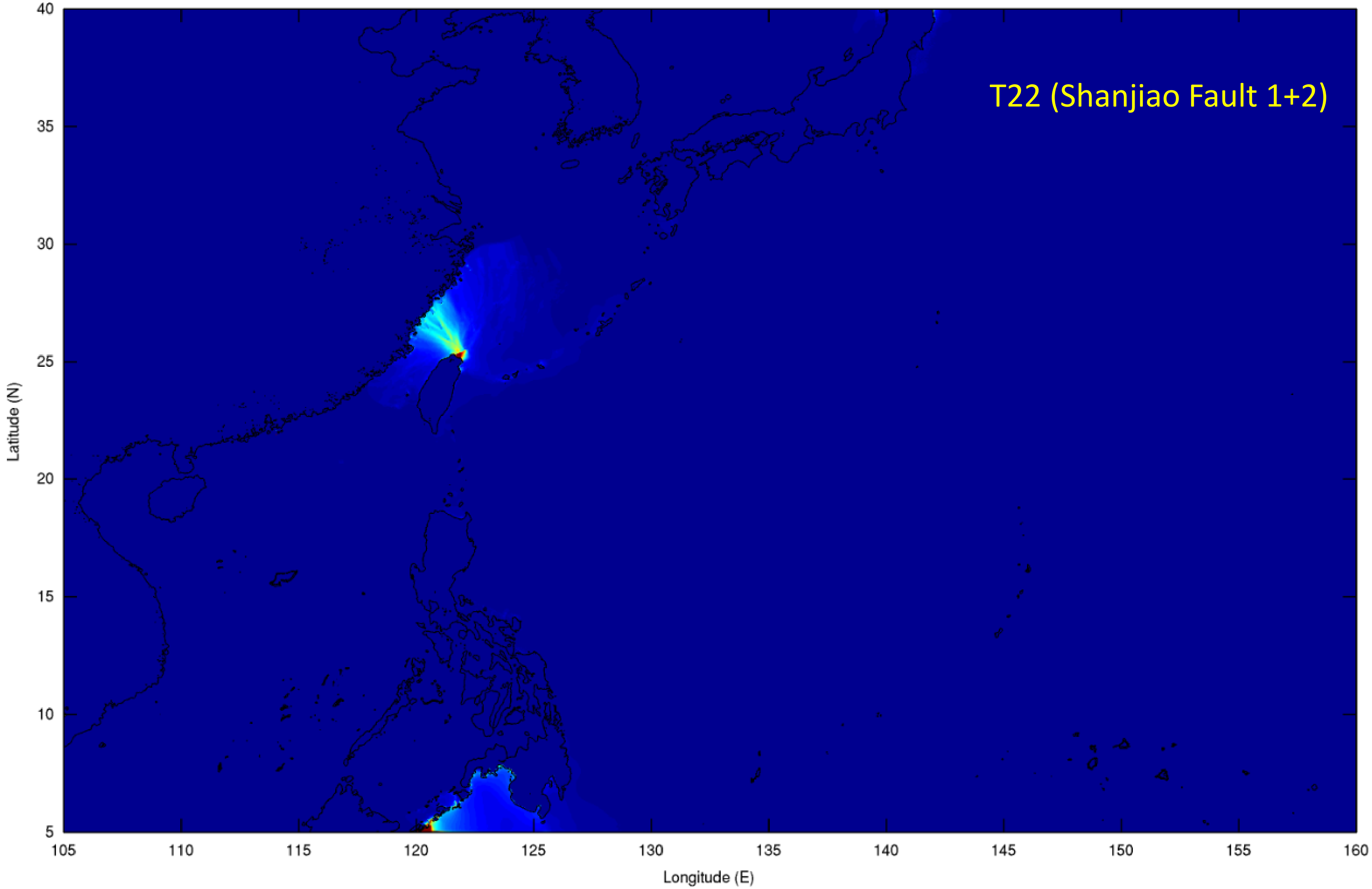
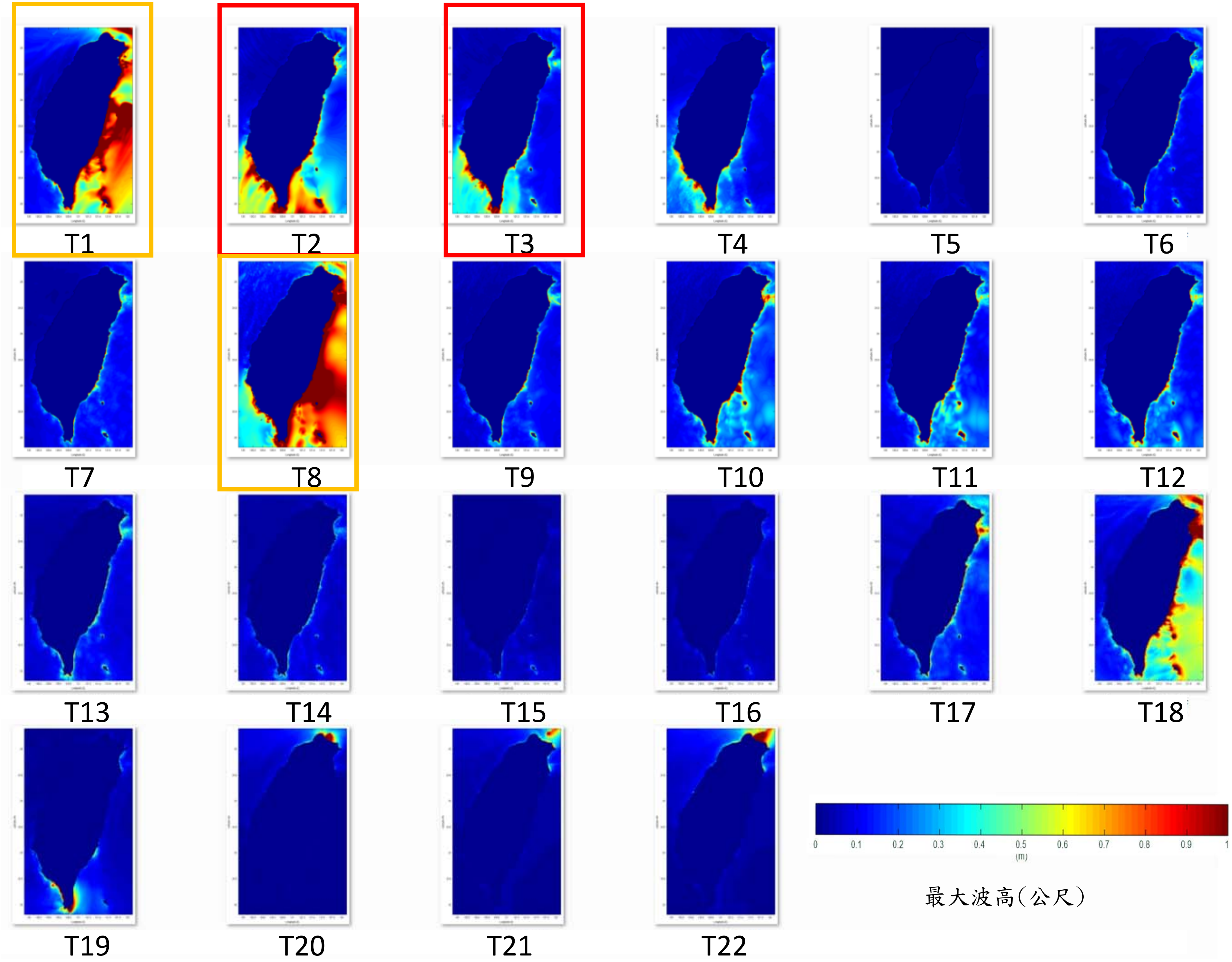
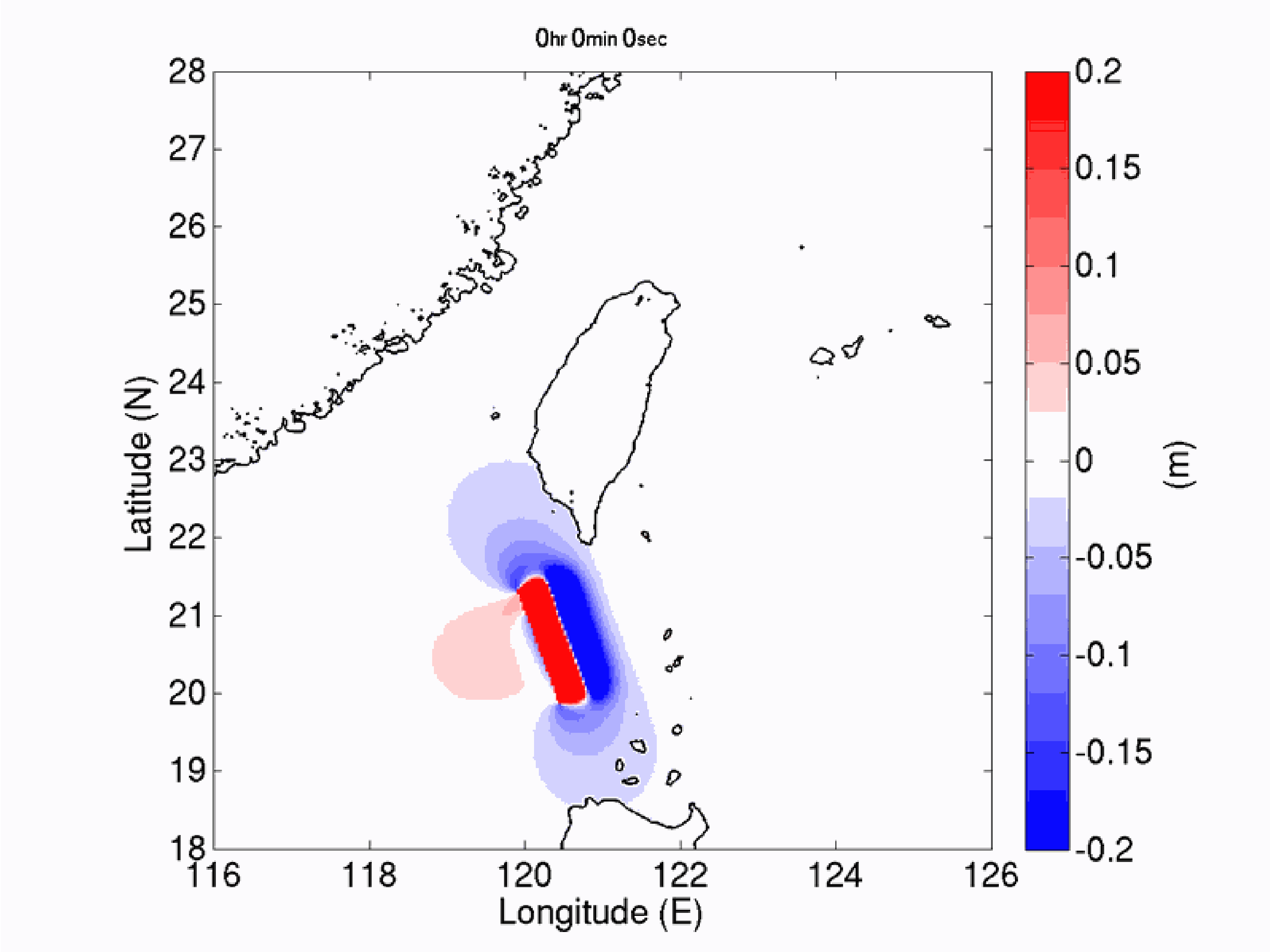
5
105
110
115
120
125
130
135
140
145
150
155
160


T22 (Shanjiao Fault 1+2)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)

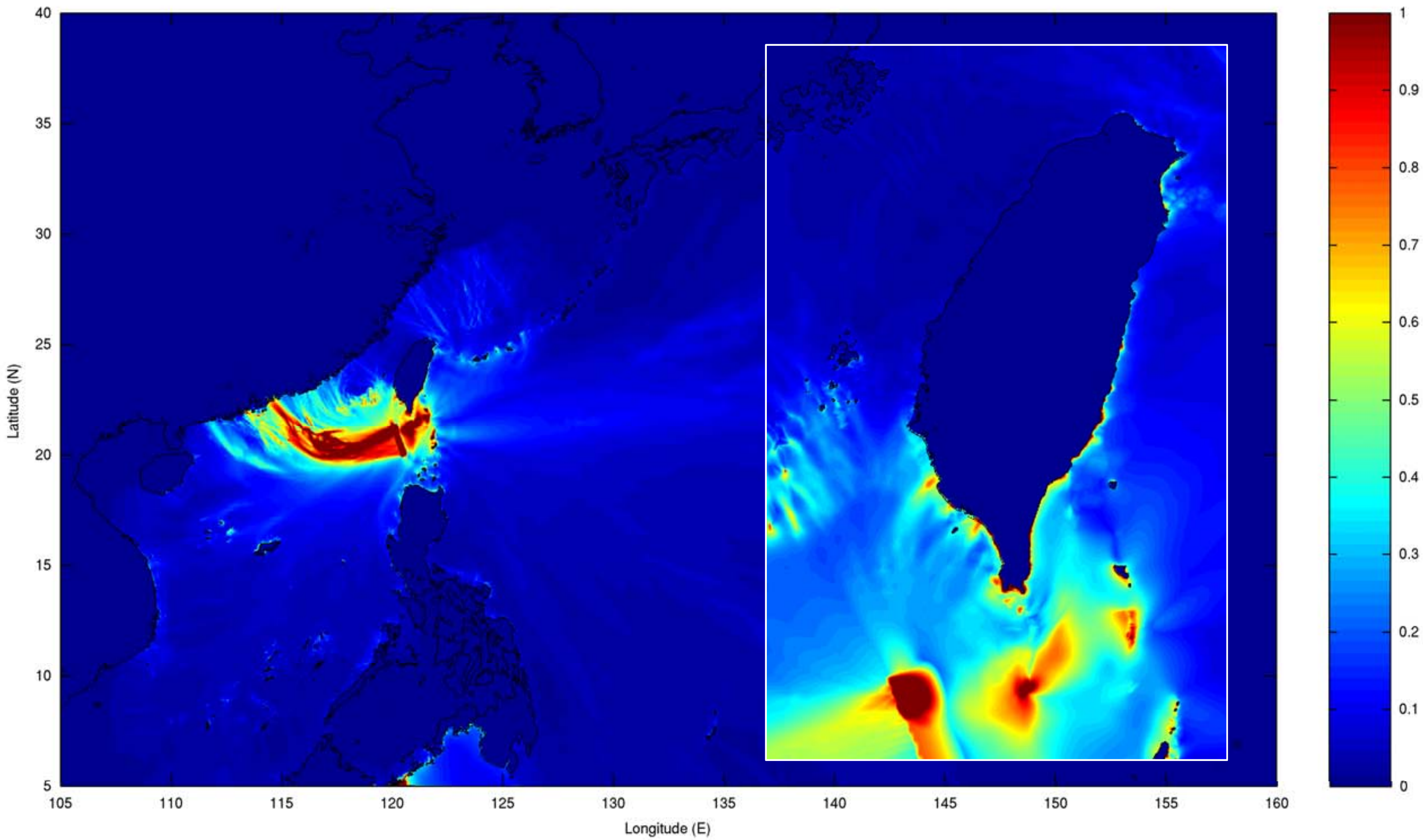
小尺度網格模擬結果


T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
T13
T14
T15
T16
T17
T18
T19
T20
T21
T22
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
(m)
最大波高(公尺)

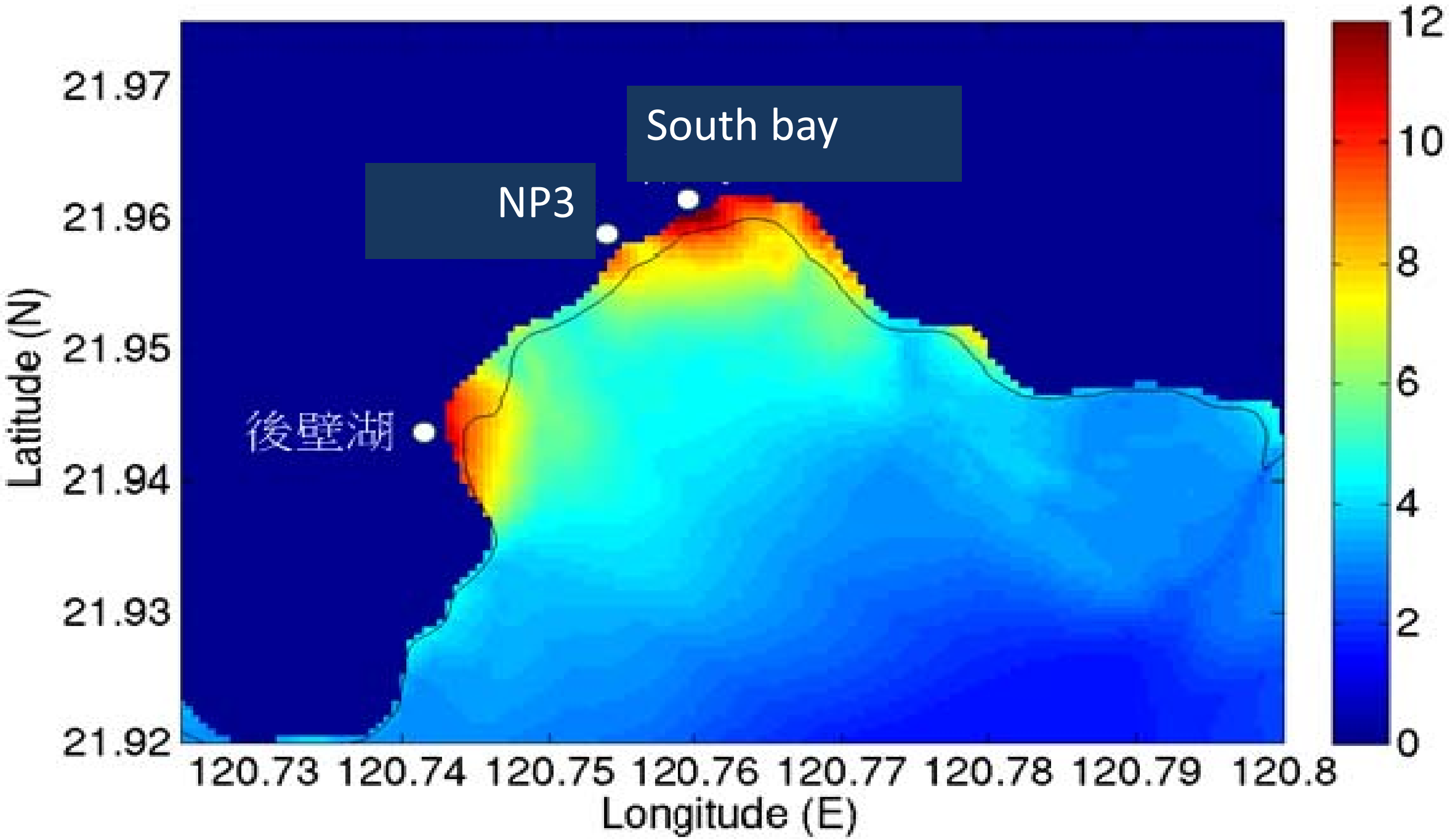
T2 (Manila Trench 1) (Animation)



T02, Inundation and Maximum Runup Height



T02, Nearshore Inundation and Maximum Runup Height



Runup height: NP3: 10~12m; South Bay: 18m

T8 (Yap)

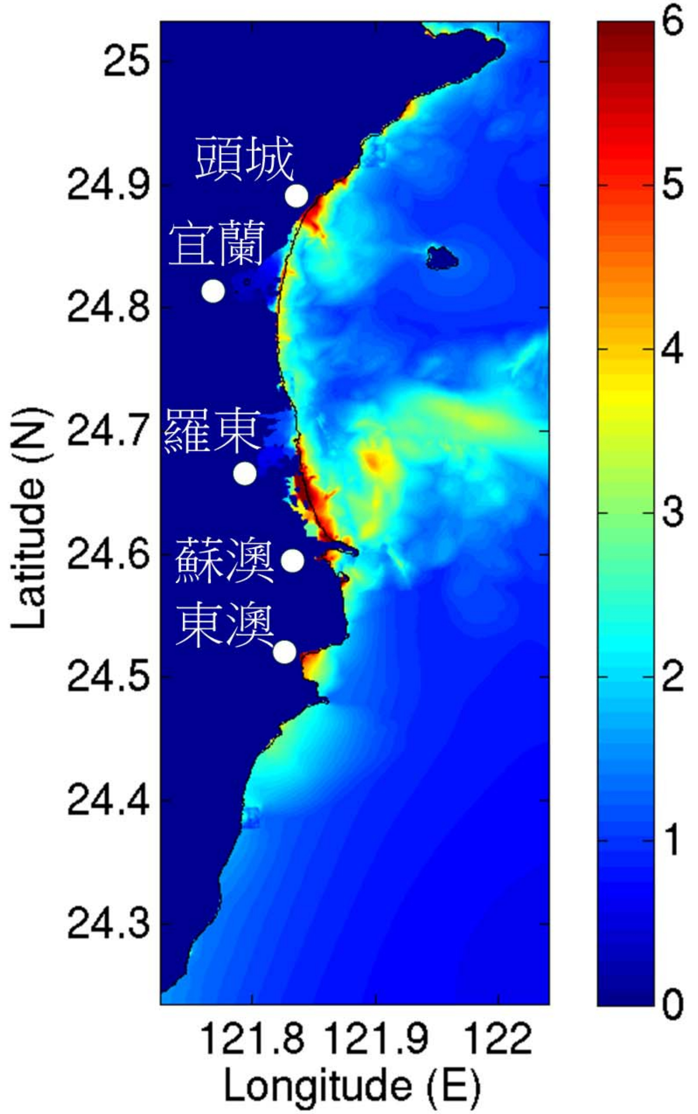


圖5A、T8海嘯源（亞普海溝）最大波高暨淹溢範圍圖。
（A：宜蘭地區；B；花蓮；C：台東；D：恆春半島；E：屏東；F：高雄、台南；G：新北市。）
註：色階（color bar）依各地波高調整，單位：公尺。

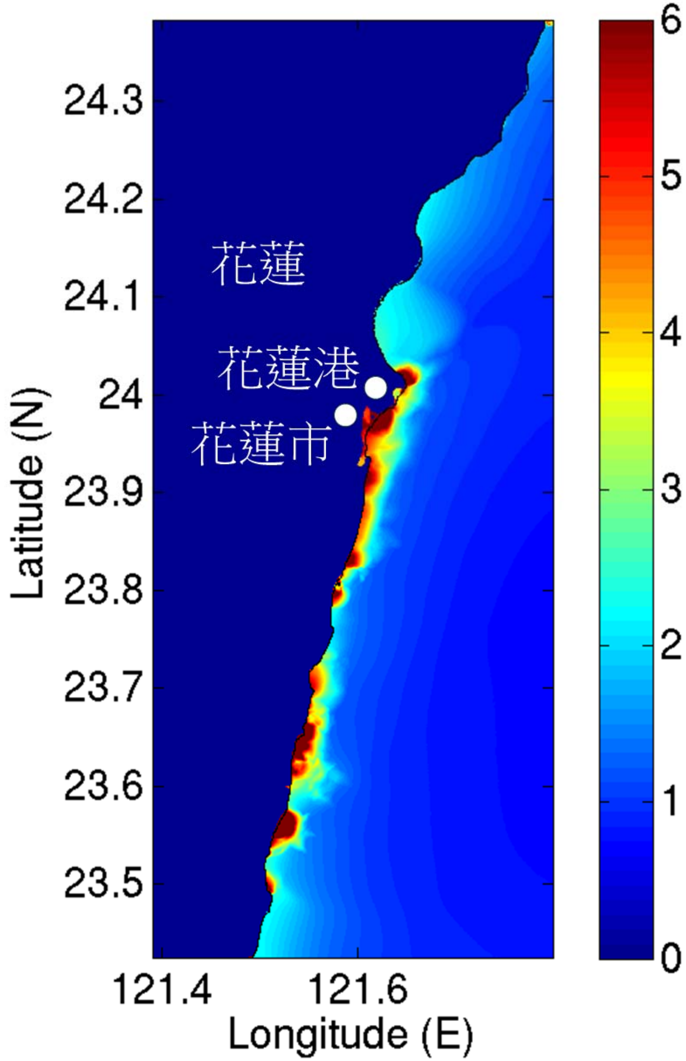
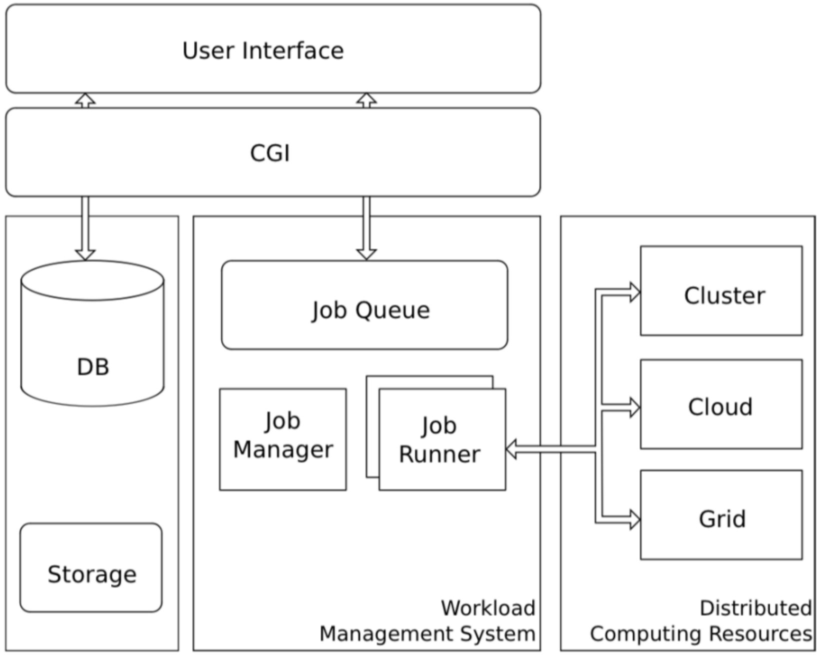


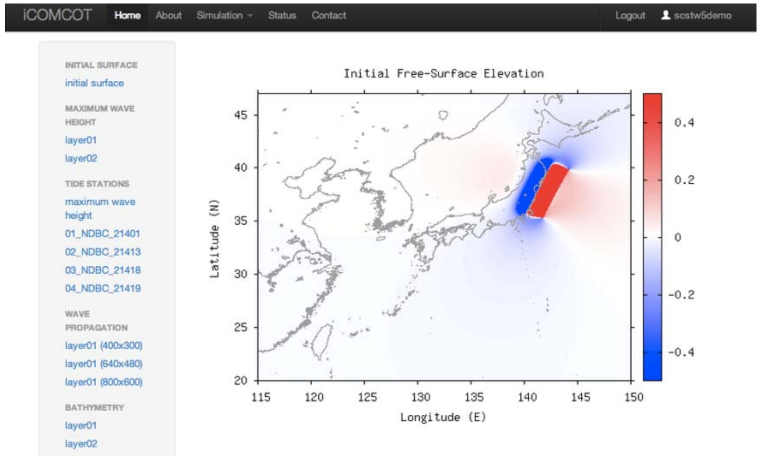
圖5B、T8海嘯源（亞普海溝）最大波高暨淹溢範圍圖。

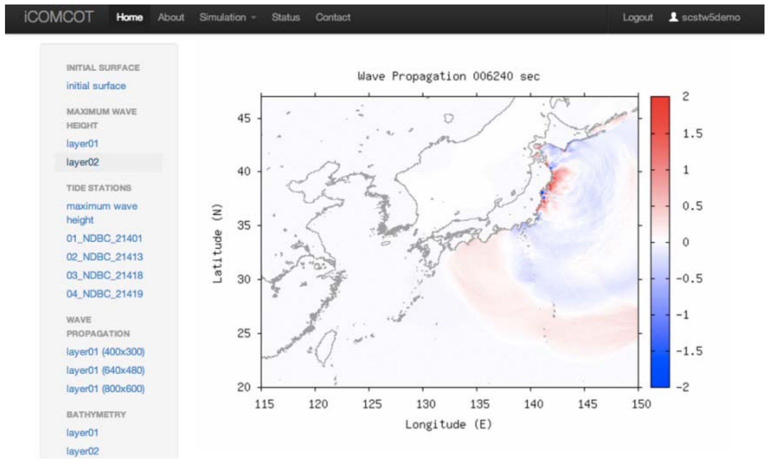
（A：宜蘭地區；B；花蓮；C：台東；D：恆春半島；E：屏東；F：高雄、台南；G：新北市。）

註：色階（color bar）依各地波高調整，單位：公尺。

iCOMCOT:
a grid/cloud-based Tsunami system







在中研院網格中心協助下，將COMCOT模式提昇為雲端系統，以利其他國家之海嘯災防

(1) 2012 Invited Speech at UNESCO
(2) Interviewed by isgtw, London, UK

http://www.isgtw.org/feature/forecasting-wrath-tsunami

isgtw international science grid this week

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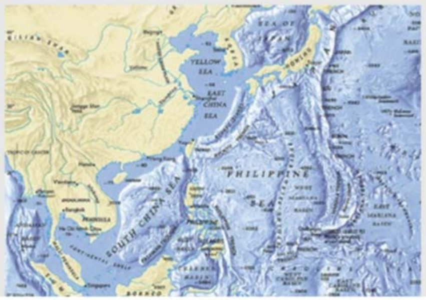
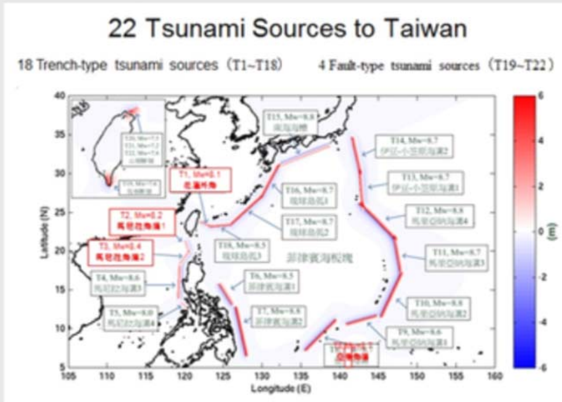
Forecasting the wrath of a tsunami

FEATURE | APRIL 24, 2013 | BY ZARA QADIR



Immediately to the south-west of Taiwan, is the South China Sea and the deep oceanic Manila trench. Roughly every 10 years, the area experiences a moderate earthquake (under 6.9 on the Richter scale). However, there has not been a major earthquake since the 1570s. GPS data and global historical records show that every 700 years an earthquake of magnitude 9.0 is likely to strike the area. The region, therefore, is due one relatively soon (in terms of geological time frames) and if (or *when*) a mega-sized one does strike, people living in the



The spatial distribution of 18 trench-typed tsunami sources (T1-T-18) and 4 fault-typed tsunami sources (T19-T-22). The color bar indicates the seafloor displacement of each tsunami source.Click for large version. Image courtesy Simon Lin, ASGC, from Tso-Ren Wu's paper.

COMCOT (Cornell Multi-grid Coupled Tsunami Model) is a numerical model that allows both simulation and visualization of the whole lifespan of a tsunami. It shows how a wave will travel on the earth and gives an estimate of its arrival time and the level of run up on to dry land. "The original research model focuses on accuracy and not speed; it took between 12 to 24 hours to generate a result. But for the system to be operational, COMCOT needed to simulate a tsunami as fast as real time propagation, from hours to minutes," says Wu.

Usually an operational system sacrifices some level of accuracy, but COMCOT allows both linear and non-linear equations. "A linear system speeds up the operation and is accurate for the deep ocean, but is not precise enough for the near-shore region. When the wave approaches the shoreline its speed diminishes, and it becomes thinner and taller so the curve can no longer be represented linearly. Most tsunami systems ignore this part of the simulation but it is the most important to impact on human life," explains Wu. COMCOT integrates the spherical with a Cartesian coordinate system, which is more accurate for near shore simulations.

Tsunami Impact Force

An overturned building

（Chen, 2011）

（Chen，2011）

（Chen，2011）


蘋果日報

Breaking wave modeling

We adopted the Splash3D numerical model to solve for the breaking wave problems (Wu, 2004; Liu et al., 2005). This model solves 3-dimensional incompressible flow with Navier-Stokes equations. The free-surface is tracked by Volume-of-Fluid (VOF) method. The domain is discretized by finite volume method (FVM). The turbulent effect is closed by large eddy simulation (LES) with Smagorinsky model.

Incompressible continuity equation:

$$\nabla \cdot \boldsymbol{u} = 0$$

Navier-Stokes Equation

$$\frac{\partial(\boldsymbol{u})}{\partial t} + \nabla \cdot (\boldsymbol{u}\boldsymbol{u}) = -\frac{1}{\rho}\nabla P + \frac{1}{\rho}\nabla \cdot \tilde{\tau} + \boldsymbol{g} + \boldsymbol{F}_0$$

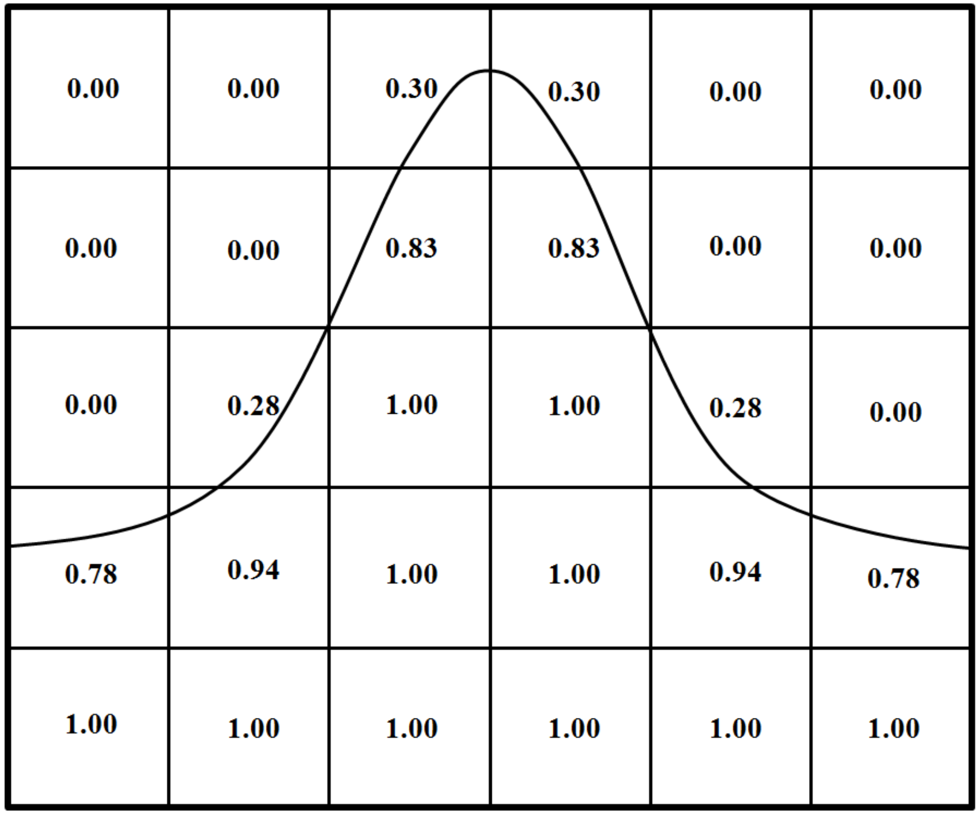
Volume of Fluid (VOF) method

The fluid density is presented in fluid fraction, and the transport equation is used to describe the fluid movement.

$$\frac{\partial \rho_m}{\partial t} + \nabla \cdot (\rho_m \boldsymbol{u}) = \frac{\partial \rho_m}{\partial t} + \boldsymbol{u}\frac{\partial \rho_m}{\partial x} + \boldsymbol{v}\frac{\partial \rho_m}{\partial y} + \boldsymbol{w}\frac{\partial \rho_m}{\partial z} = 0$$

$$\rho = \sum_m f_m \rho_m^0$$

$$\frac{\partial f_m}{\partial t} + \nabla(\boldsymbol{u}_i f_m) = 0$$



Piecewise linear interface calculation (PLIC)

$$\vec{N} \cdot \vec{x}_p - C_p = 0$$

$$F(C_p) = V_{tr}(C_p) - f_m * \forall \approx 0$$

Partial-Cell treatment

$$\forall_{eff} = \left(1 - f_{solid}\right)\forall = \theta\forall$$

$$\partial\frac{\left(\theta f_m\right)}{\partial t} + \nabla\cdot\left(\theta f_m V\right) = 0$$

$$\theta\frac{\partial\left(V\right)}{\partial t} + \nabla\cdot\left(\theta VV\right) = -\frac{\theta}{\rho}\nabla p + \frac{\theta}{\rho}\nabla\cdot\tilde{\tau} + \theta g + \theta F_0$$

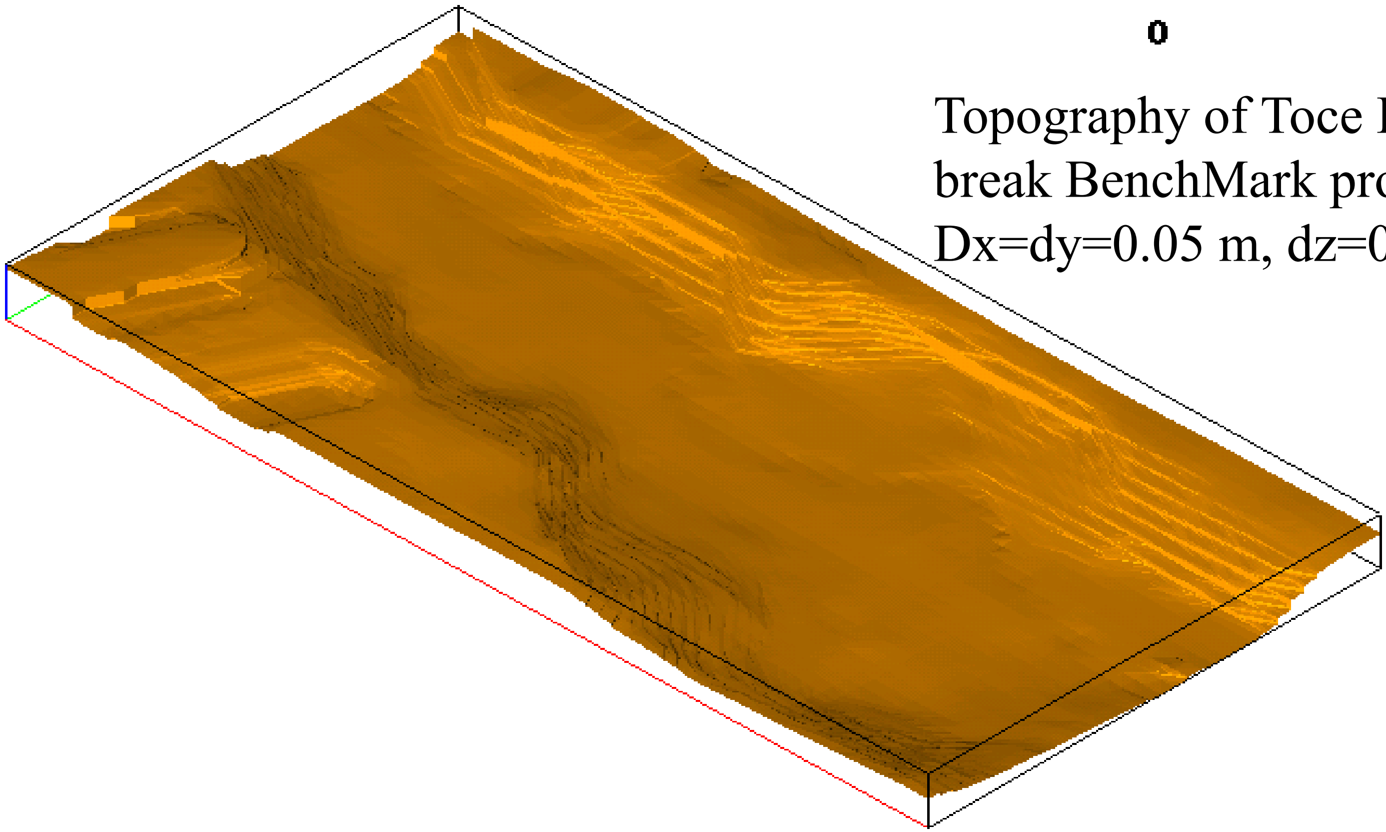
If a cell contains partial volume of solid material, the flow solver has to deal with it. Cell faces are defined either to be entirely closed, or not. Cell faces are “closed” only if at least one of the two immediately neighboring cells is entirely occupied by solid material. If the cell faces are “closed”, the face velocity of the cell is set to zero, and the face pressure is no longer calculated in the pressure solution. On the other hand, if any face between two cells, containing at least a partial cell volume of fluid, is “open”, the code solves the velocities and pressure gradients.

DEM topography module and COMCOT boundary coupling module

DEM topography module

The real topography can be easily constructed in the Splash3D by using PCT.

Example of DEM topography module



Topography of Toce River Valley Dam-break BenchMark problem.
Dx=dy=0.05 m, dz=0.01m.

LES (Large Eddy Simulation) Filtering

A low-pass filtering operation is performed so that the resulting filtered velocity can be adequately resolved on a relatively coarse grid.

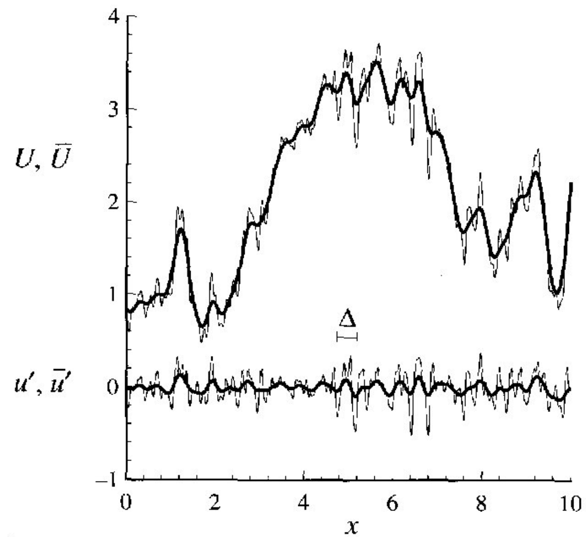


Fig. 13.2. Upper curves: a sample of the velocity field $U(x)$ and the corresponding filtered field $\overline{U}(x)$ (bold line), using the Gaussian filter with $\Delta \approx 0.35$. Lower curves: the residual field $u'(x)$ and the filtered residual field $\overline{u'(x)}$ (bold line).

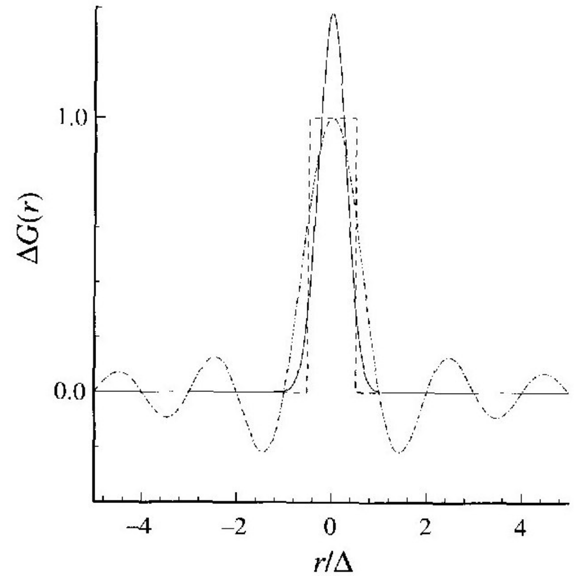


Fig. 13.1. Filters $G(r)$: box filter, dashed line; Gaussian filter, solid line; sharp spectral filter, dot dashed line.

Δ : the filter width

η : the radius

Filtered Conservation Equations

- Continuity equation:

$$\overline{\left(\frac{\partial U_i}{\partial x_i}\right)} = \frac{\partial \overline{U}_i}{\partial x_i} = 0$$

$$\frac{\partial u_i^{'}}{\partial x_i} = \frac{\partial}{\partial x_i}\left(U_i - \overline{U}_i\right) = 0$$

- Conservation of Momentum:

$$k_r \equiv \frac{1}{2}\tau_{ii}^R$$

$$\tau_{ij}^r \equiv \tau_{ij}^R - \frac{2}{3}k_r\delta_{ij}$$

the anisotropic residual-stress tensor is:

$$\tau_{ij}^r \equiv \tau_{ij}^R - \frac{2}{3}k_r\delta_{ij}$$

$$\overline{p} \equiv \overline{P} + \frac{2}{3}k_r$$

$$\frac{\partial \overline{U}_j}{\partial t} + \frac{\partial \overline{U_i U_j}}{\partial x_i} = \nu \frac{\partial^2 \overline{U}_j}{\partial x_i \partial x_i} - \frac{1}{\rho}\frac{\partial \overline{P}}{\partial x_j}$$

$$\because \overline{U_i U_j} \neq \overline{U}_i \overline{U}_j$$

$$\text{Let } \tau_{ij}^R \equiv \overline{U_i U_j} - \overline{U}_i \overline{U}_j$$

$$\frac{\overline{D}\,\overline{U}_j}{\overline{D}t} = \nu \frac{\partial^2 \overline{U}_j}{\partial x_i \partial x_i} - \frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_j} - \frac{\partial \tau_{ij}^r}{\partial x_i}$$

$$\text{where } \frac{\overline{D}}{\overline{D}t} \equiv \frac{\partial}{\partial t} + \overline{\mathbf{U}} \cdot \nabla$$

Smagorinsky Model

$$\tau_{ij}^{r} = -\nu_t \left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i} \right) = -2\nu_t \overline{S}_{ij}$$

$$\nu_t = \ell_S^2 \overline{\mathbf{S}} = \left(C_S \Delta \right)^2 \overline{\mathbf{S}}$$

ℓ_S : Smagorinsky length scale

C_S : Smagorinsky coefficient

Δ : filter width

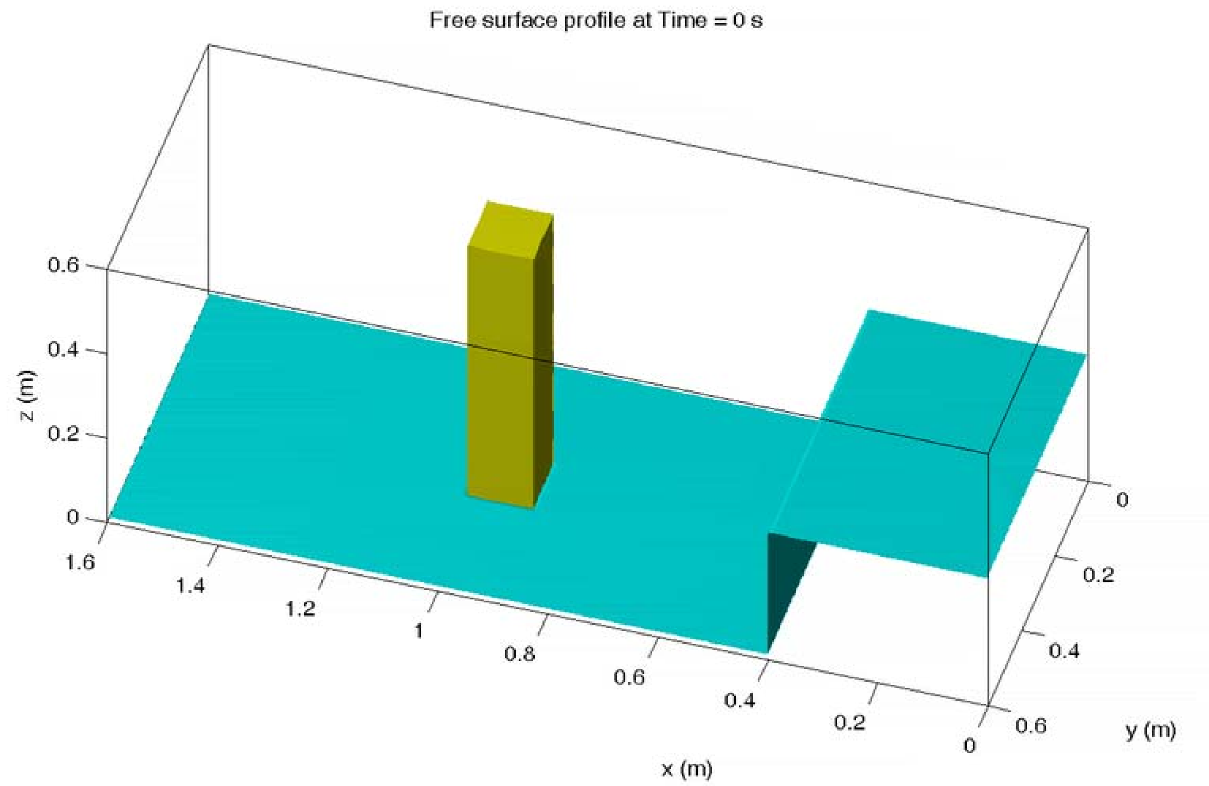
$$\overline{\mathbf{S}} \equiv \left(2\overline{S}_{ij} \overline{S}_{ij} \right)^{1/2}$$: the characteristic filtered rate of strain

$$\Delta = \left(\Delta x_1 \times \Delta x_2 \times \Delta x_3 \right)^{1/3}$$

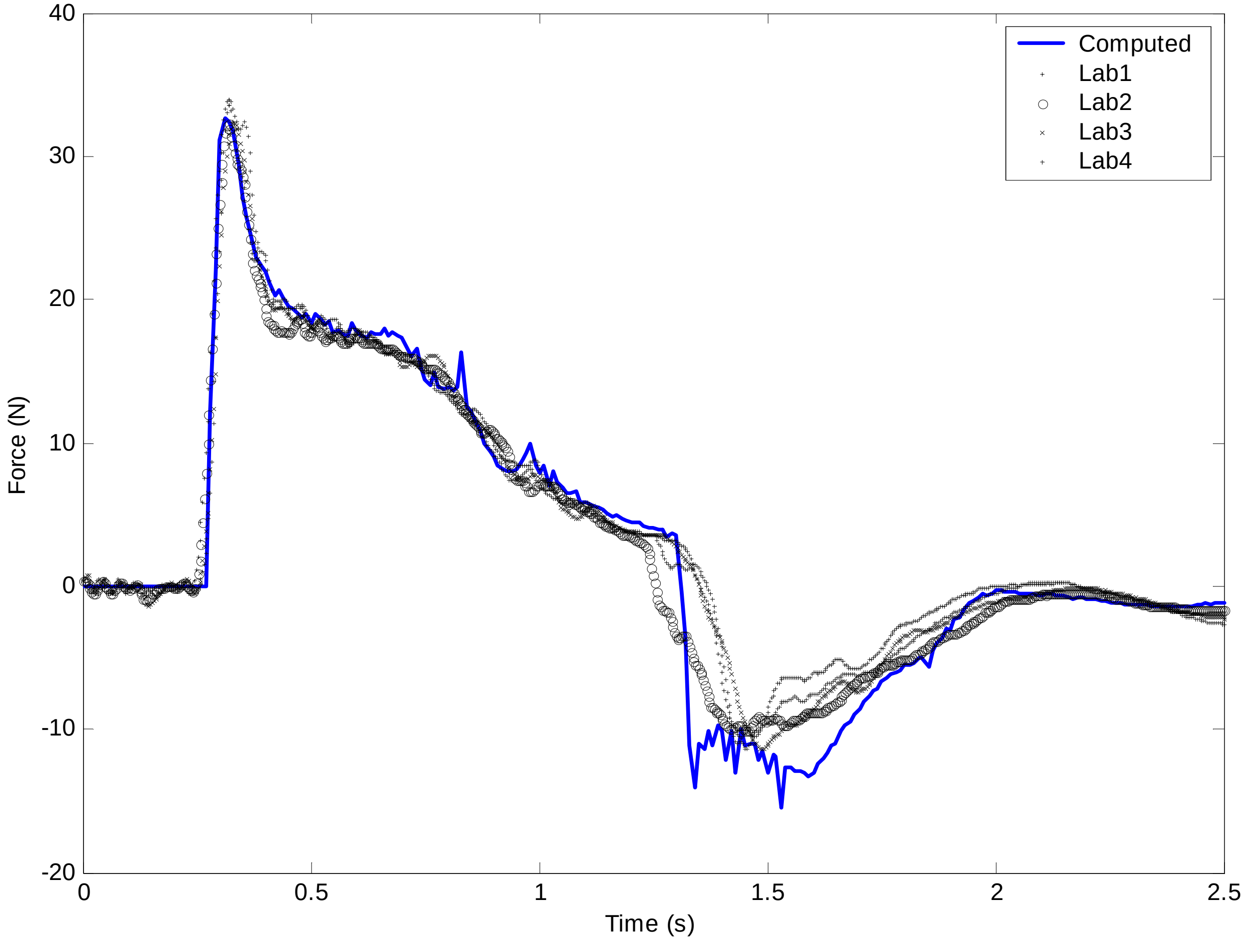
淚望大海「無處去」

葛西先生說，當天強震後，海嘯警報響起，他趕緊與老婆爬到高處避難，起初第一、二波海嘯襲來時，就與漲潮無異，「只是第三波後越來越強，海水激烈衝撞，有一股無形力量將海水都吸到遠方去，幾乎能看到海底，第四波海嘯累積能量後，衝過來打向岸邊發出『砰』的聲音，威力就像一顆炸彈。」

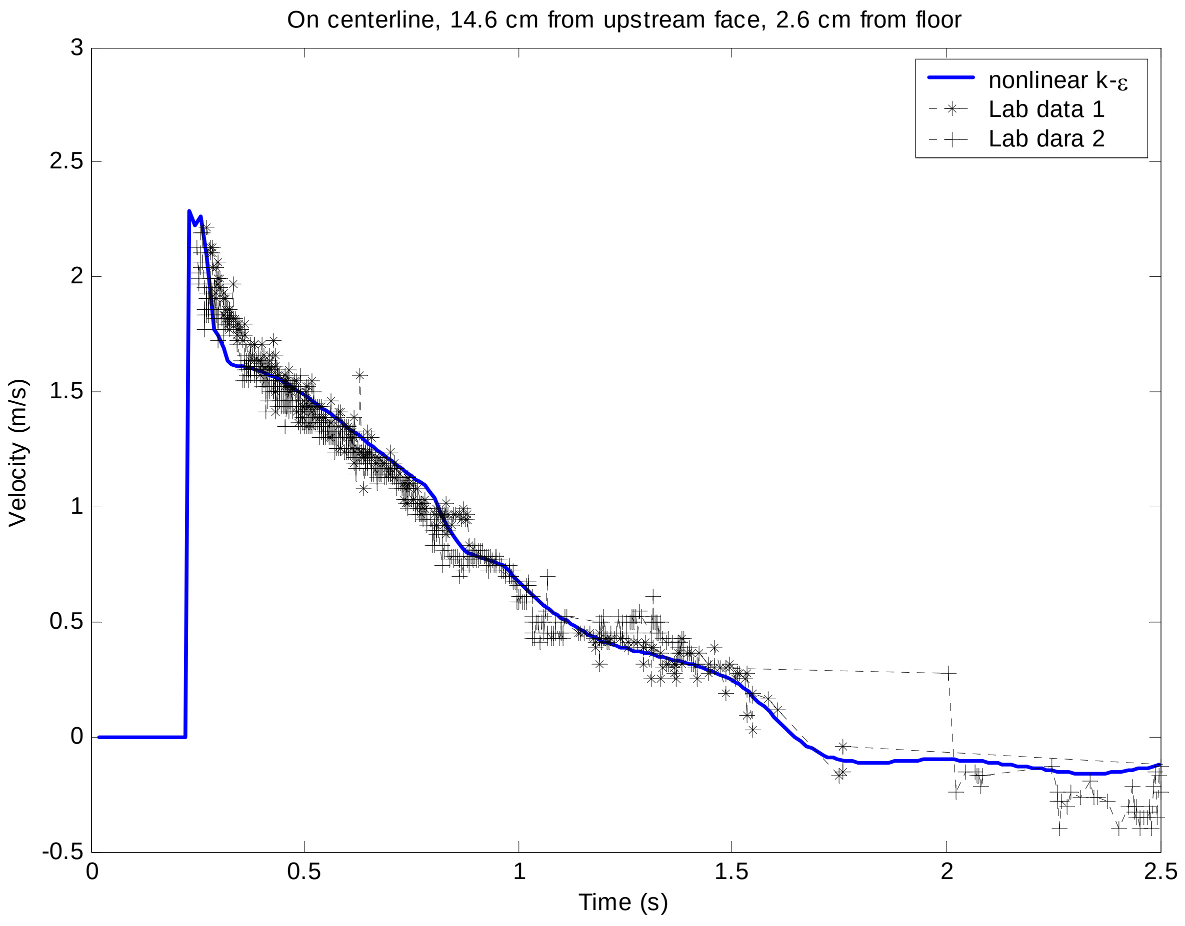
他們親眼目睹岸邊房子瞬間被「炸」毀，2、300人罹難



Total force acting on the square cylinder

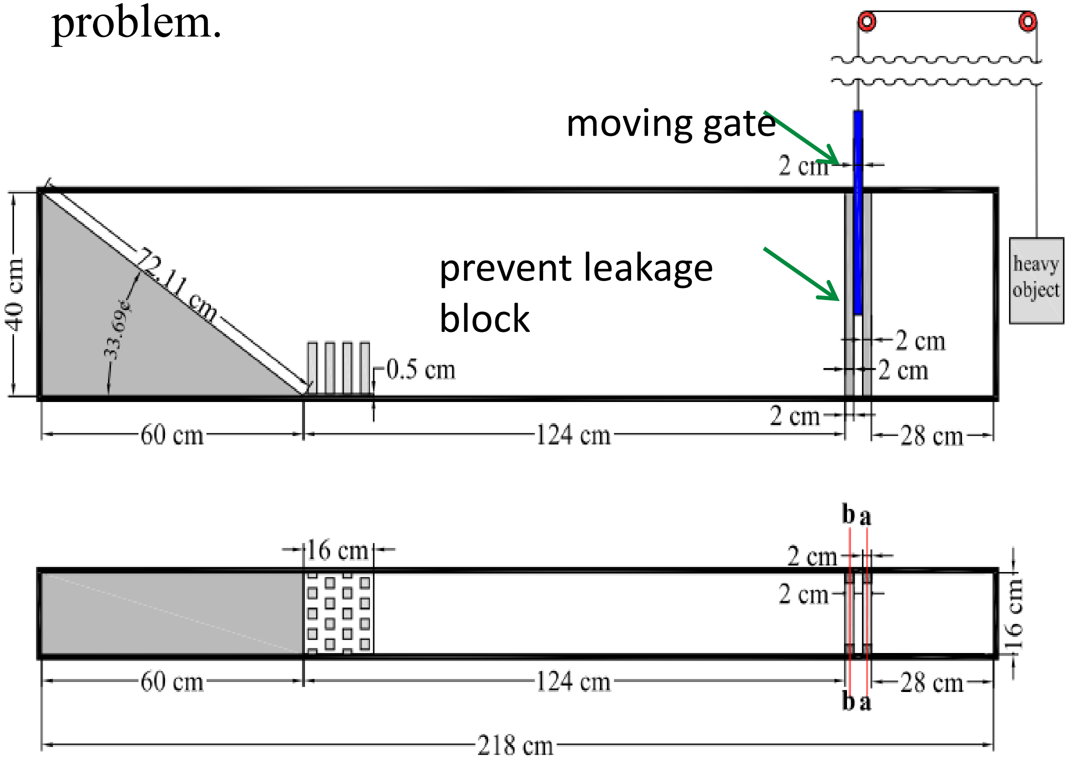


Velocity comparisons

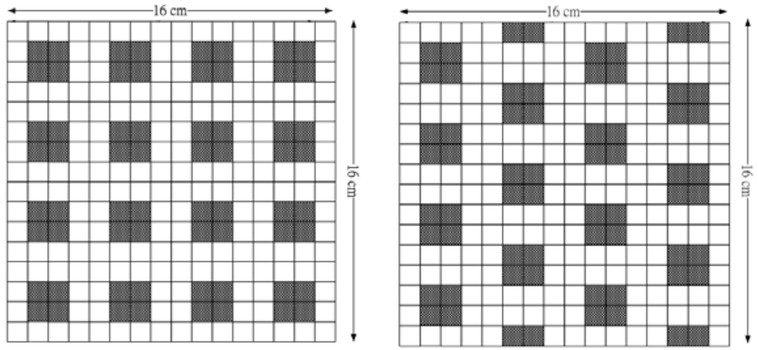


Setup of the Benchmark Problem

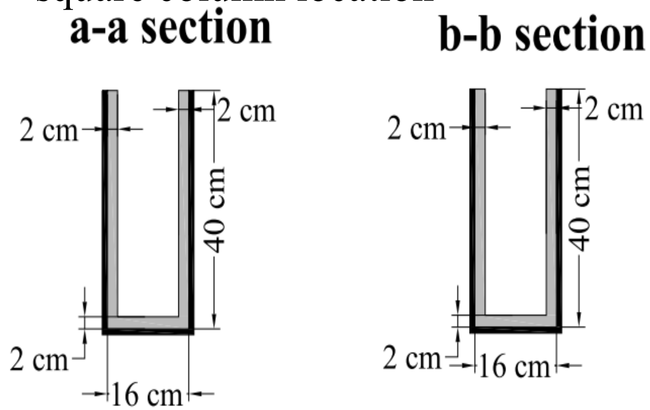
This model shall be easily setup for numerical simulation, and be able to represent the interaction between a bore and a structure array. Moreover, the quantity of dissipated energy shall be easily identified. We focus the comparison on the free-surface kinematics. After the validation, the numerical model can be used to study the real-scale tsunami problem.



Experimental setup: up : lateral view ;down: top view; blue part is moving gate



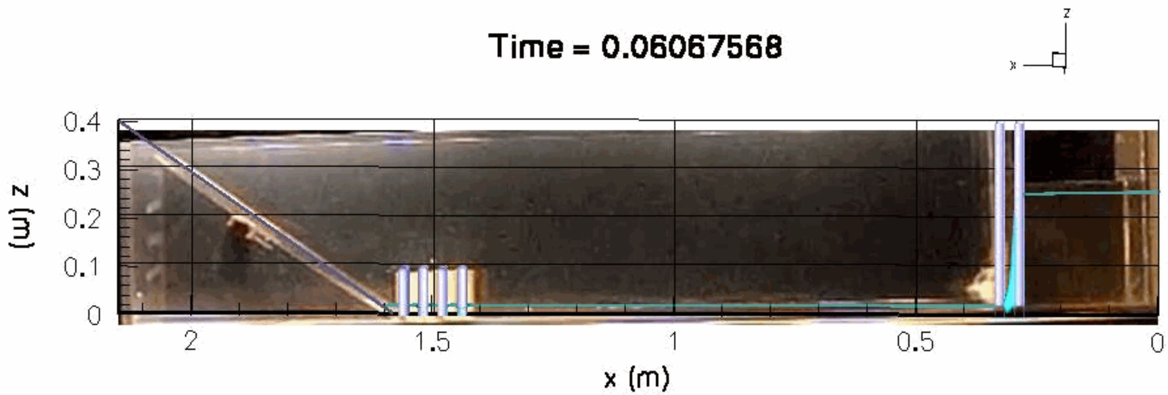
The orthogonal arrange gray part is square column location

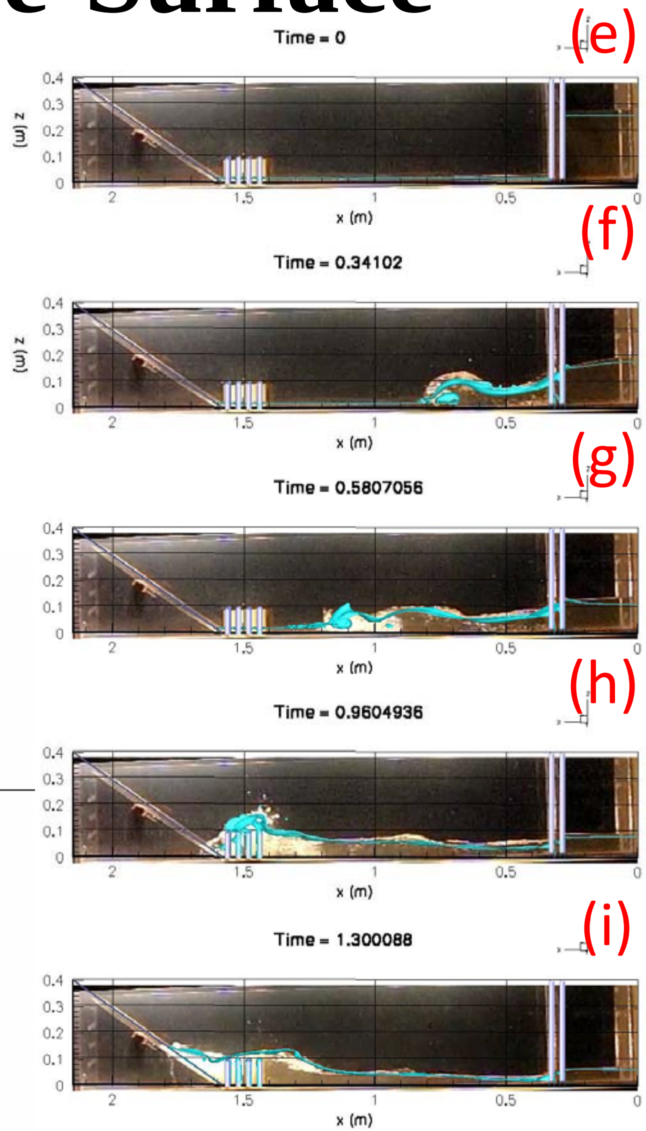


Sectional drawing: gray part is prevent leakage block

Validation on the Free-Surface

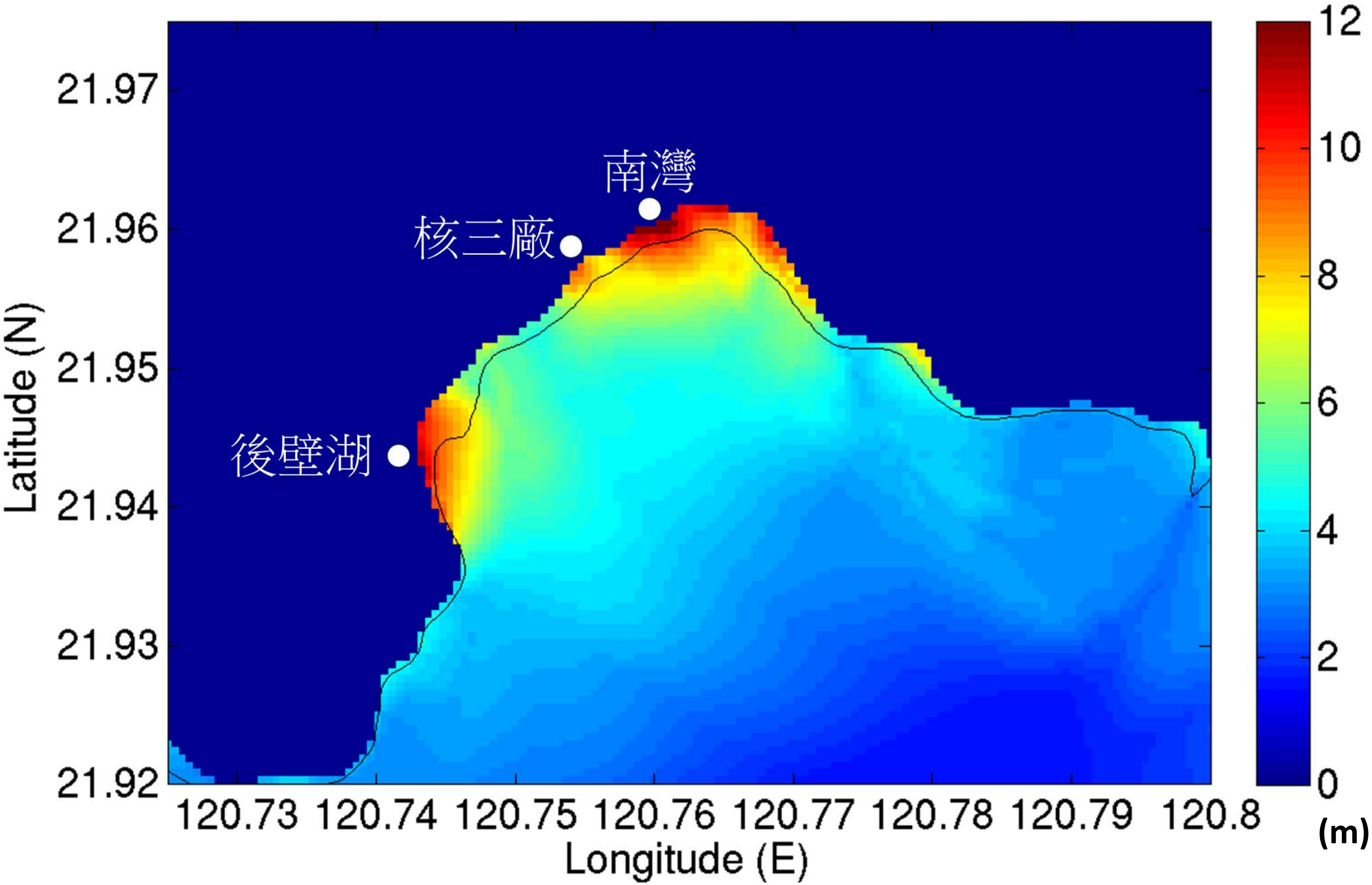
Fig (e) ~ Fig (i) show the free-surface comparisons. Blue indicates the perspective free-surface profile from the numerical simulation. The free-surface profile is overlapped with the experimental snapshots taken by the high-speed camera. After sudden-removal of the gate, the bore soon develops into a plunging wave (Fig (f)). The plunging wave collapses after the first bounce (Fig (g)). When the bore with strong turbulence encounters the cylinder array, splashing waves can be observed (Fig (h)). Finally, the bore reaches the maximum runup height and gets reflected back from the sloping beach (Fig (i)). The free-surface profile predicted by the numerical model is very close to the experimental data. This indicates that the 3D VOF-LES model is able to describe the complex flow field, even when the complex breaking wave presents. After the validation, this model will be used to simulate the real-scale problem on the south-western coast of Taiwan. The result will be presented in the near future.



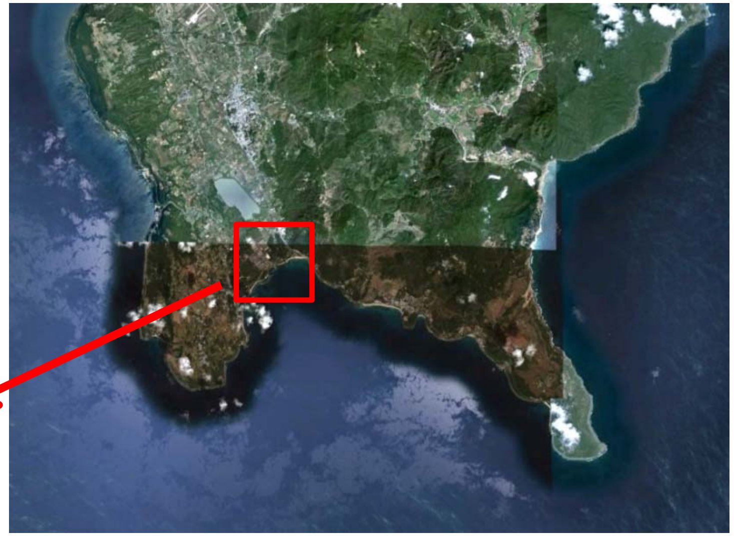


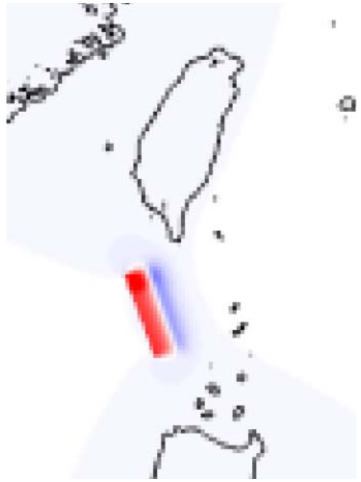
Base maps is experiment snapshot ; Blue is water; purple is structure

T2 (Manila Trench 1) (NP3)



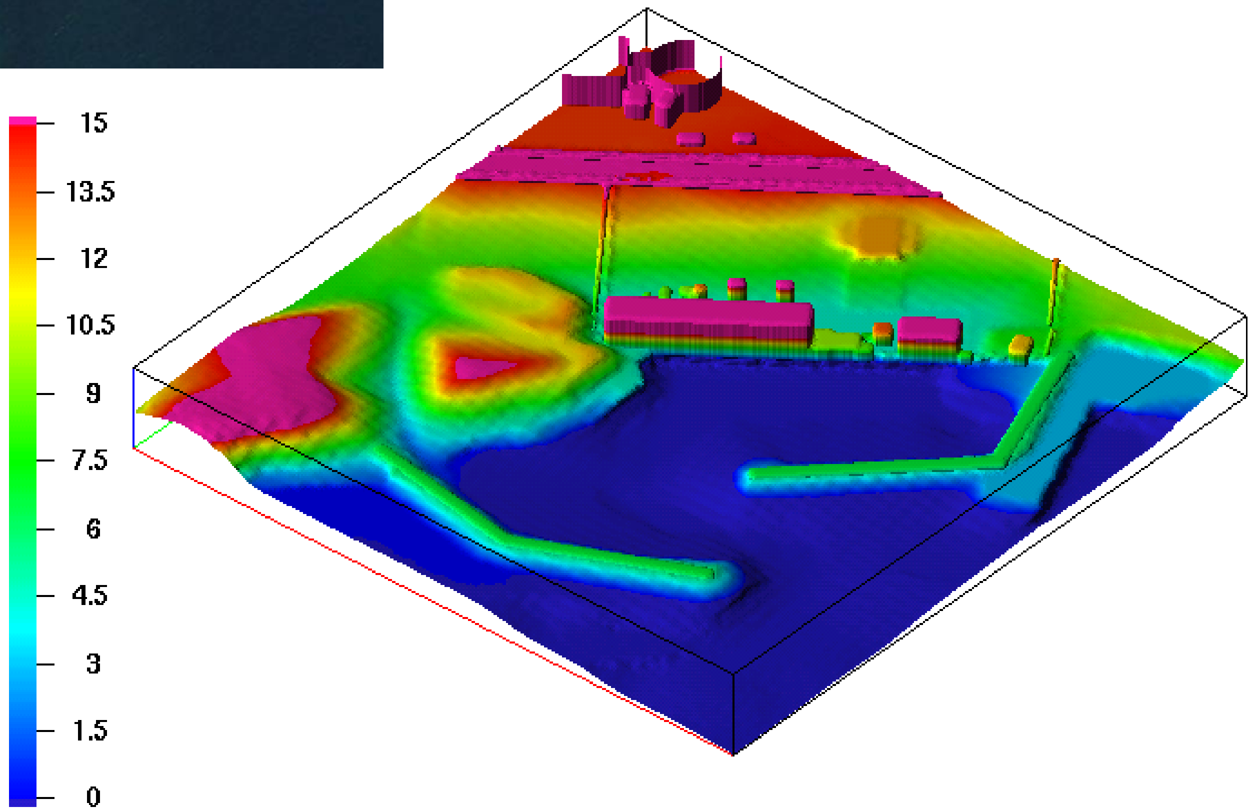
核三廠位址及模擬範圍





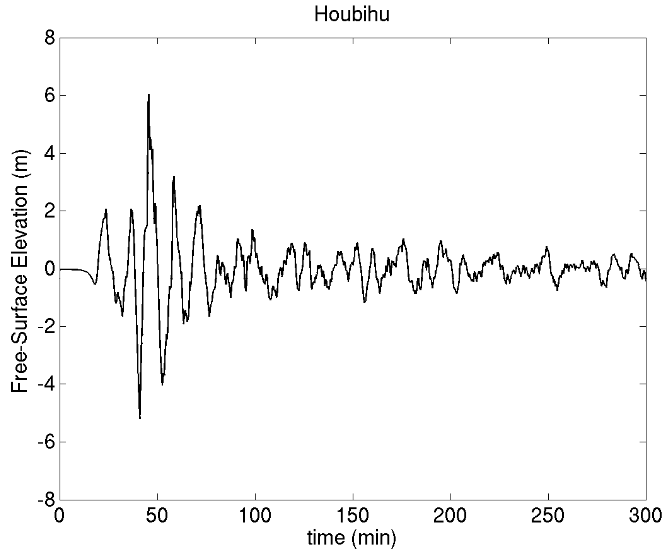
核三廠廠區設施

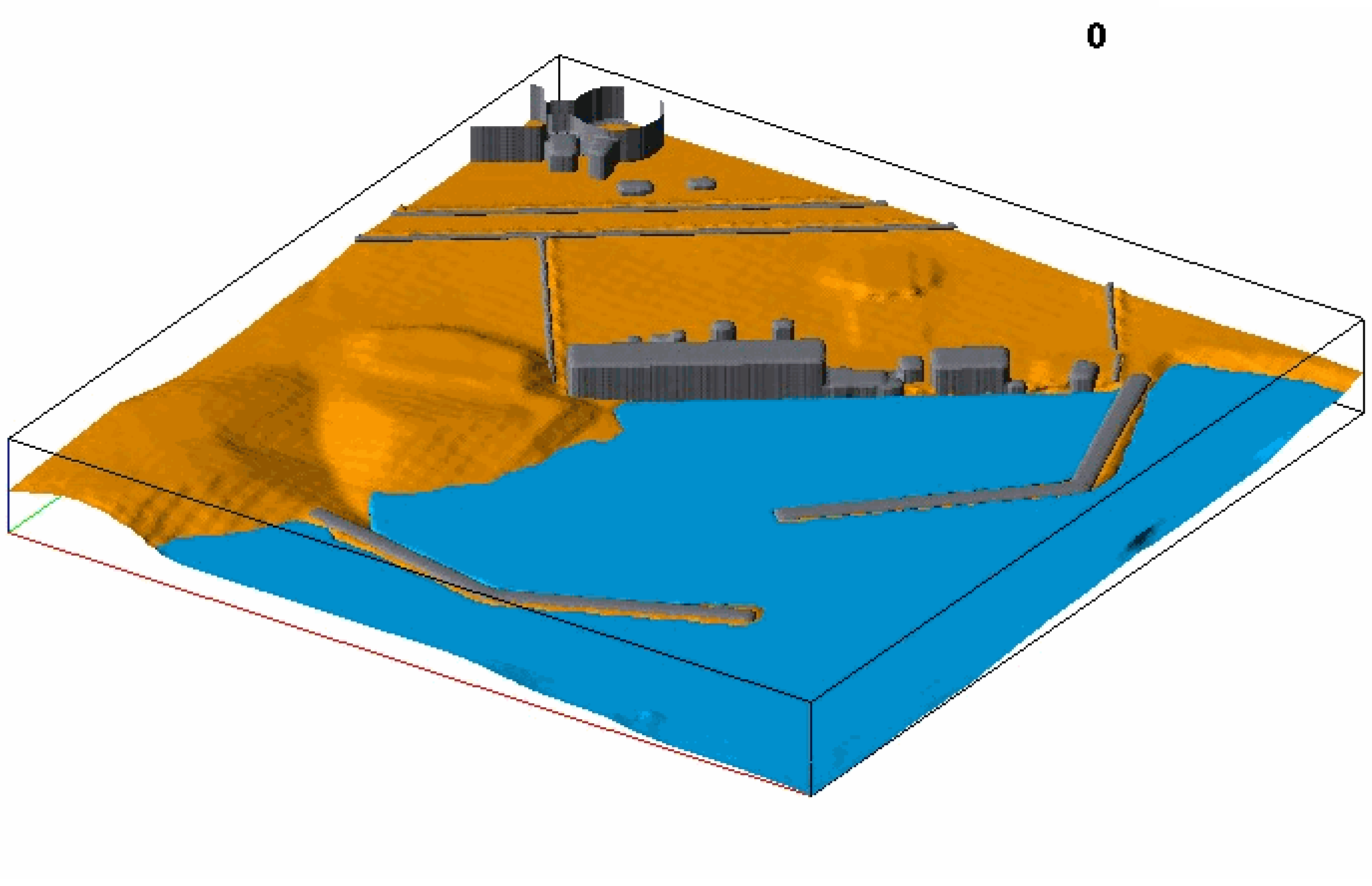
核三廠廠區地形高程



模擬動畫

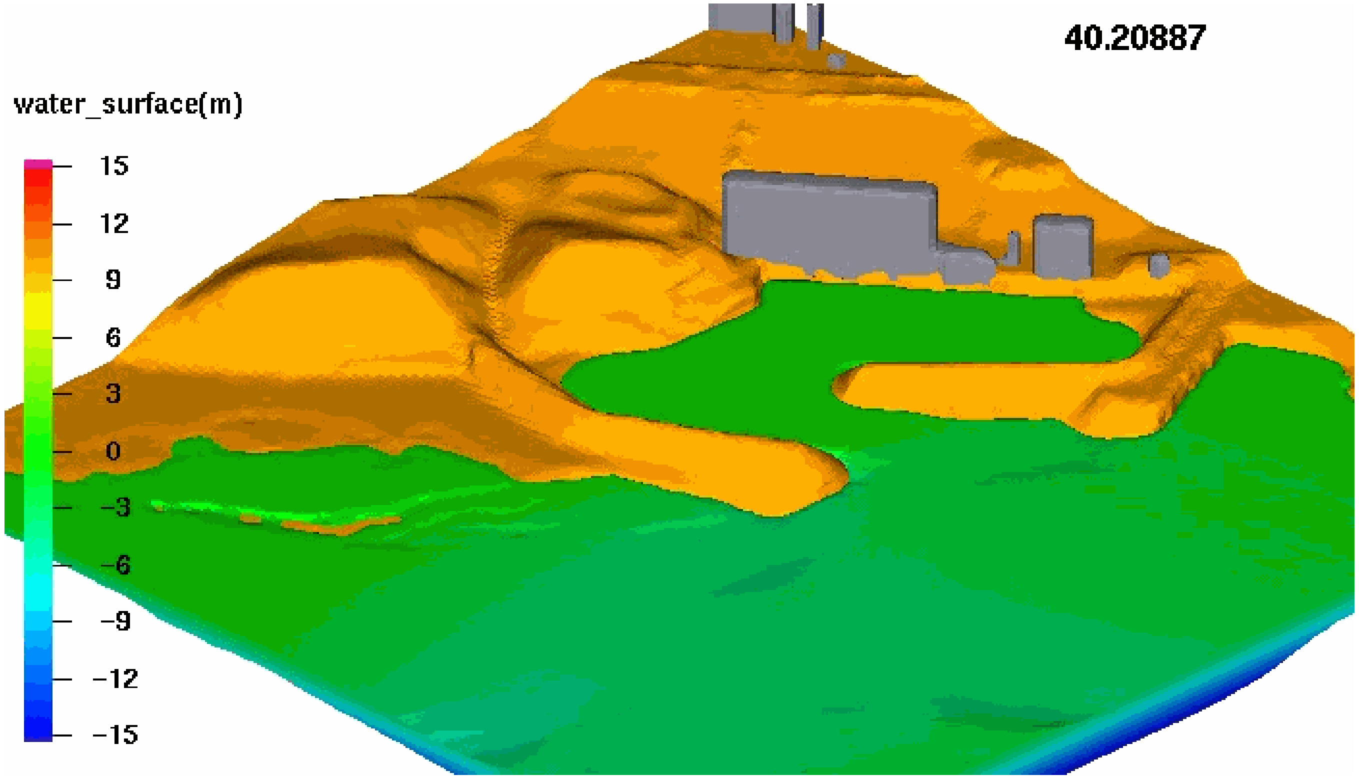
模擬範圍：500*500*55
網格：200*200*55
dx=dy=2.5 m , dz=1 m
波高:6 m
速度:8 m





3D Simulation

Domain	650×650
dx,dy	10m
dz	0.5m
Cells	1,376,000



- SCI Paper
- Liu, P.L.-F.* and Wu, T.-R., 2004/08, Waves generated by moving pressure disturbances in rectangular and trapezoidal channels, Journal of Hydraulic Research, 46(2), 89-107, (SCI RANK: 27/78 in ENGINEERING, CIVIL, Cited:4)
- Hu, Kai Cheng, Shih Chun Hsiao*, Hwung Hweng Hwung and Tso-Ren Wu, 2012/10, Three-dimensional numerical modeling of the interaction of dam-break waves and porous media, Advances in Water Resources, 47, 14–30, (SCI: IF=2.449 RANK: 7/78 in WATER RESOURCES)

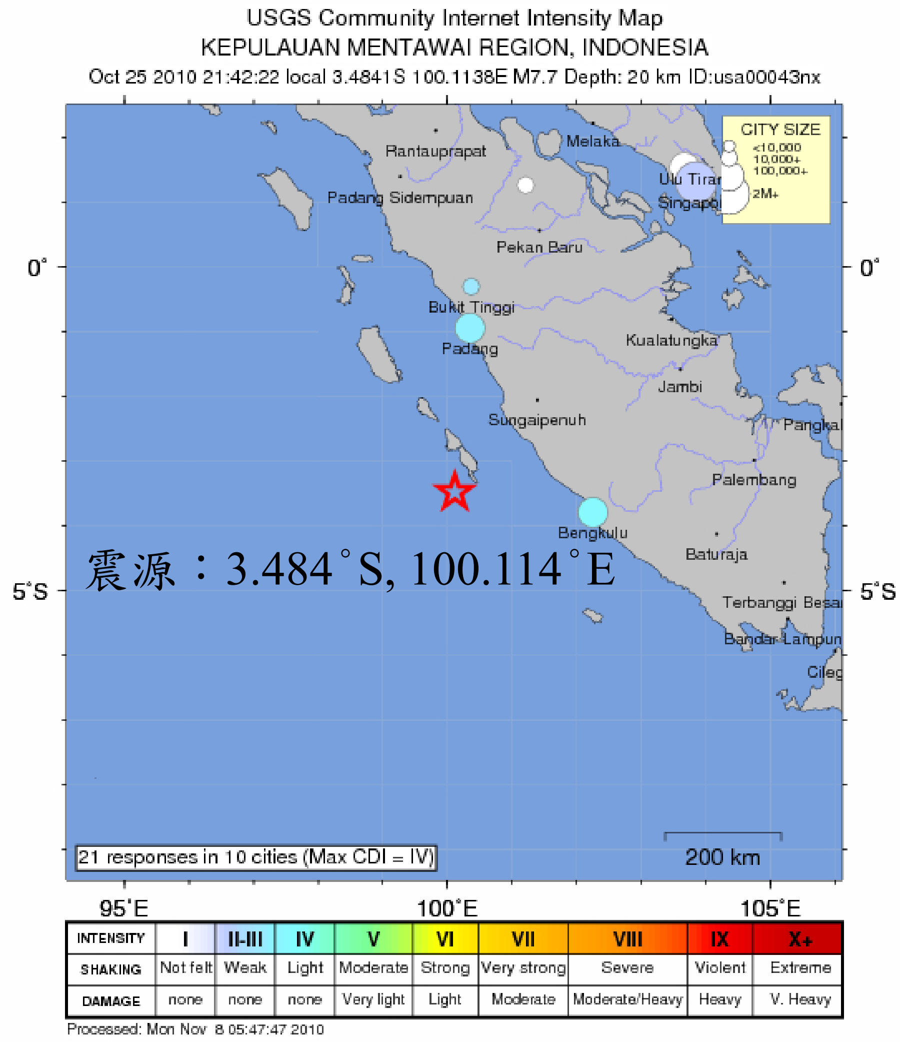
- Book Chapter
- Wu, Tso-Ren and Miao-Shan Wei, "Numerical Analysis on the 3D Bores Interaction with Structures," Tsunami Simulation for Impact Assessment, Penerbit Universiti Sains Malaysia, 239-249, May, 2011.
- Huang, Zhenhua, Tso-Ren Wu, Chunrong Liu and Mei-Hui Chuang, "Experimental and Numerical Study of Solitary Waves Passing Over a Vertical Thin Wall," Tsunami Simulation for Impact Assessment, Penerbit Universiti Sains Malaysia, 95-105, May, 2011.
- Wu, T.-R. and Liu, P. L.-F. , "Numerical study on the three-dimensional dam-break bore interacting with a square cylinder," Nonlinear Wave Dynamics: Selected Papers of the Symposium Held in Honor of Philip L.-F. Liu's 60th Birthday, 281-303, World Scientific, Singapore, 2009.
- Wu, T.-R. and Liu, P. L.-F., "A Large Eddy Simulation Model for Tsunami and Runup Generated by Landslides," Advances in Coastal and Ocean Engineering, Vol. 10, 101-162, Advanced Numerical Models for Simulating Tsunami Waves and Runup, World Scientifics, Singapore, 2008.

2010 Mentawai Earthquake and Tsunami

1. Introduction

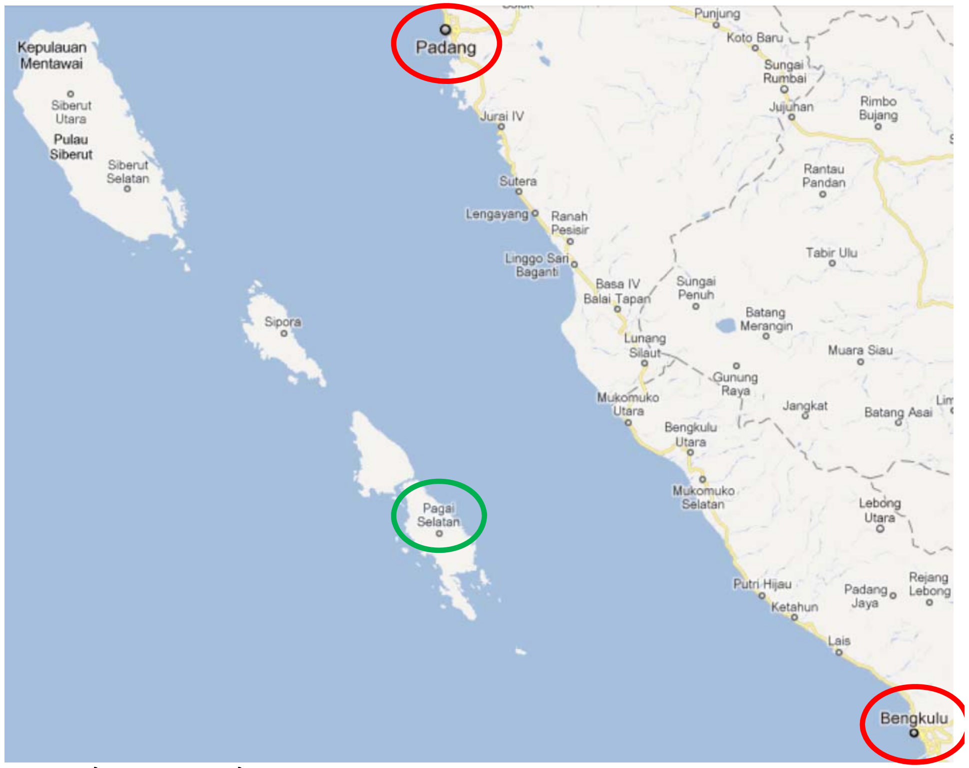
The October 2010 Sumatra earthquake was a magnitude 7.7 Mw earthquake that occurred on 25 October 2010 off the western coast of Sumatra, Indonesia at 21:42 local time (14:42 UTC). The earthquake occurred on the same fault that produced the 2004 Indian Ocean earthquake. It was widely felt across the provinces of Bengkulu and West Sumatra and resulted in a substantial localized tsunami that struck the Mentawai Islands.

Many villages on the islands were affected by the tsunami, which reached a height of 3 m and swept as far as 600 m inland. The tsunami caused widespread destruction that displaced more than 20,000 people and affected about 4,000 households. 435 people were reported to have been killed, with over 100 more still missing.



海嘯震源位置圖

海嘯過後由調查團隊於當地災區調查，其成員有新加坡、美國、紐西蘭和印尼等八位科學家，該調查隊從蘇門答臘南邊Benkulu出發，沿著Pagai、Sipora西邊沿岸地區調查，直至Siberut島之南邊後，再回到蘇門答臘西邊之Padang。該調查主要記錄海嘯入侵沿岸之相關資訊，如海嘯上溯之最大高度(run up height)、溢淹範圍(inundation)、海嘯上溯之來流水深(flow depth)、海嘯破壞程度以及海嘯影響區域大小。該調查發現，Sibigau島被mentawai海嘯衝擊最為嚴重



調查隊調查區域

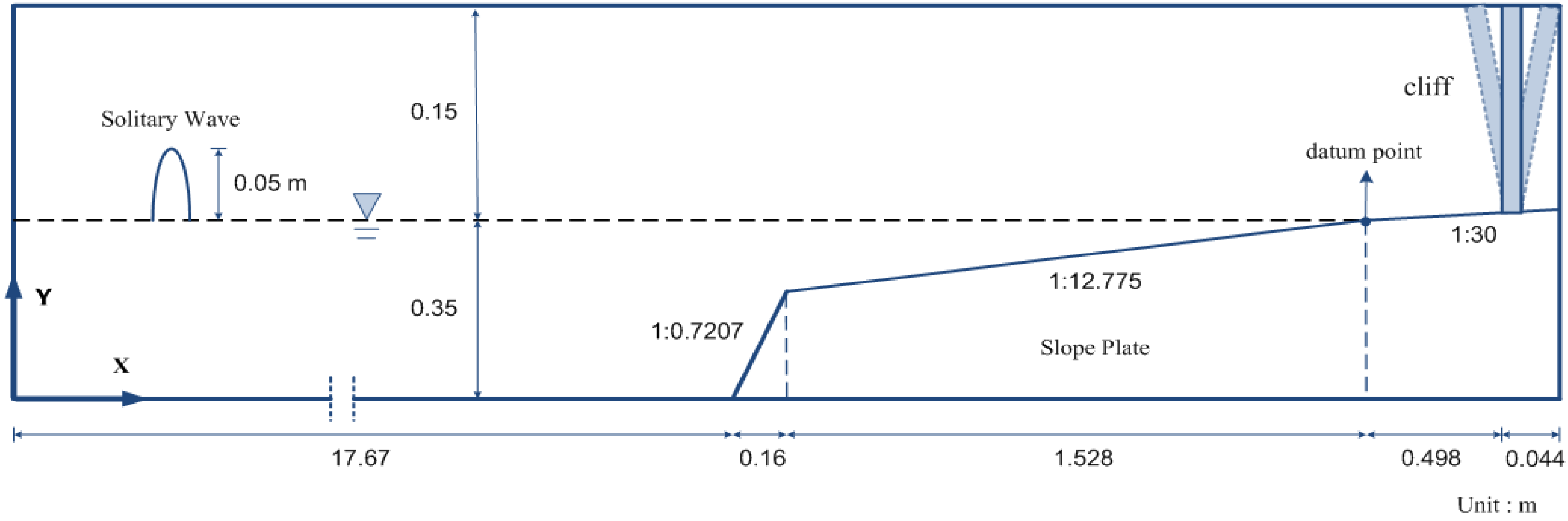
Sibigau島嶼位置

由Jose C. Borrero領隊，調查發現，Sibigau島上植生受到海嘯嚴重破壞，然而特別的是，較內陸之植生幾乎全面被摧毀，反而沿海之植生大幅度存活 。其與一般所觀察到之海嘯災區行為相反。另外由當地地形可發現，較內陸之植生帶後方為較陡峭之山坡。

本研究將針對峭壁地形對海嘯產生之影響進行研究。

Sibigau西邊遭受海嘯衝擊區域

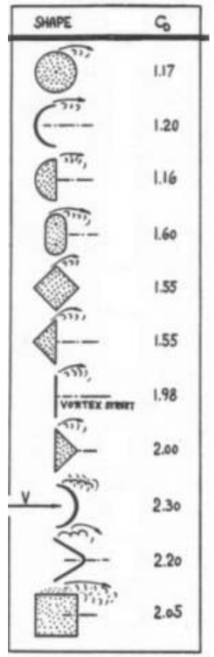
內陸之峭壁，前面植生破壞情形嚴重



force $F(t)=C_D\times0.5(\rho D)\times(h+\eta(t))\times\int_{-\eta(t)}^{\eta(t)}u(z,t)\left|u(z,t)\right|dz$

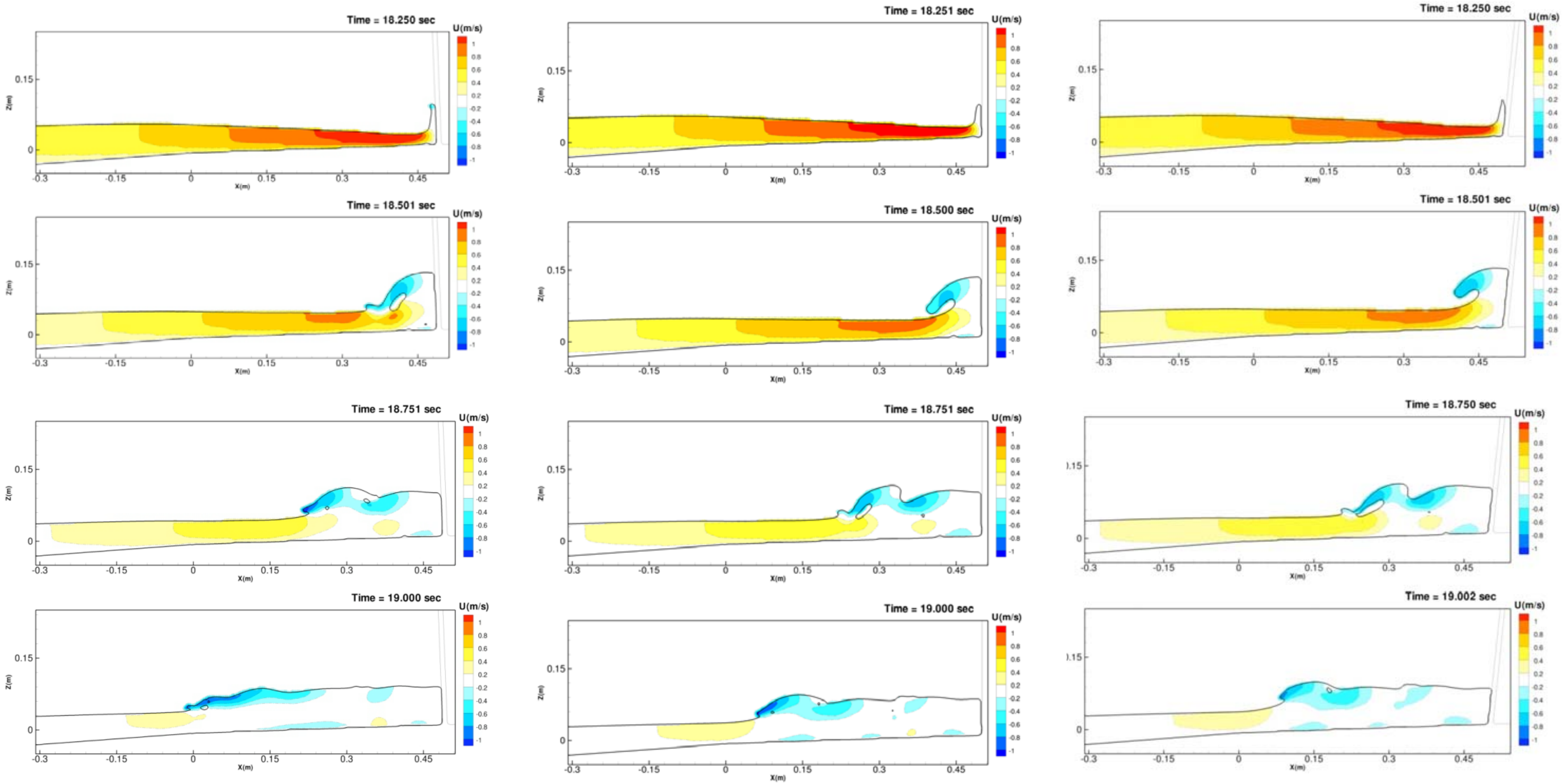
Bending moment $M(t)=C_D\times0.5(\rho D)\times(h+\eta(t))\times\int_{-\eta(t)}^{\eta(t)}u(z,t)\left|u(z,t)\right|(h+z)dz$

柱徑D=0.01, 水密度P.=1000 kd/m^3, 阻滯係數C_D = 0.12



ftp://ftp.colorado.edu/cuboulder/courses/chen3200/Lectures/DragCoef.pdf

Discuss Three inclinations simulation Result

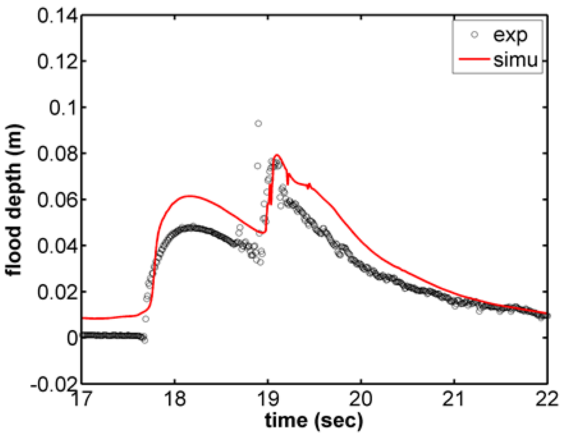


傾斜角度= -1/30　　傾斜角度=0　　傾斜角度= 1/10

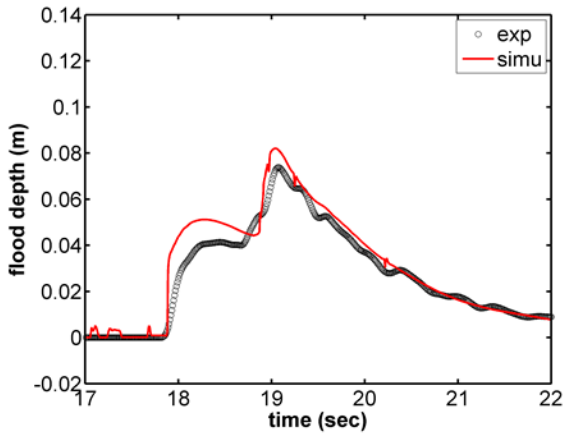
（陳子宇、吳祚任，中大水海所海嘯科學研究室）

Flood Depth Validation

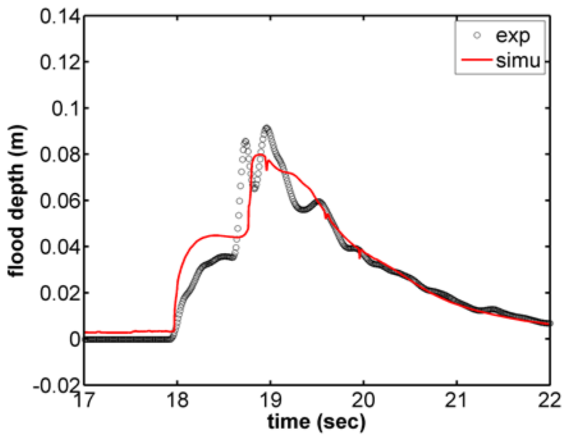
G1



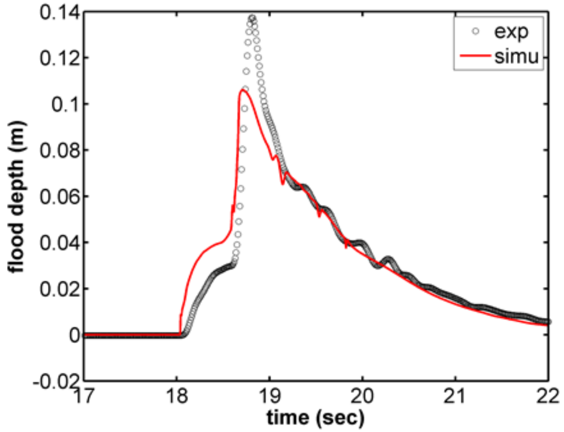
G2



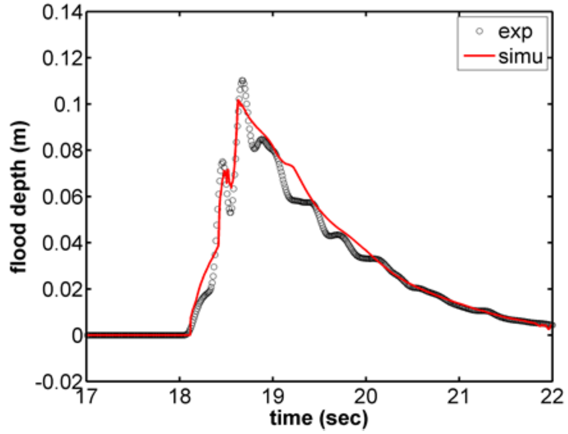
G3



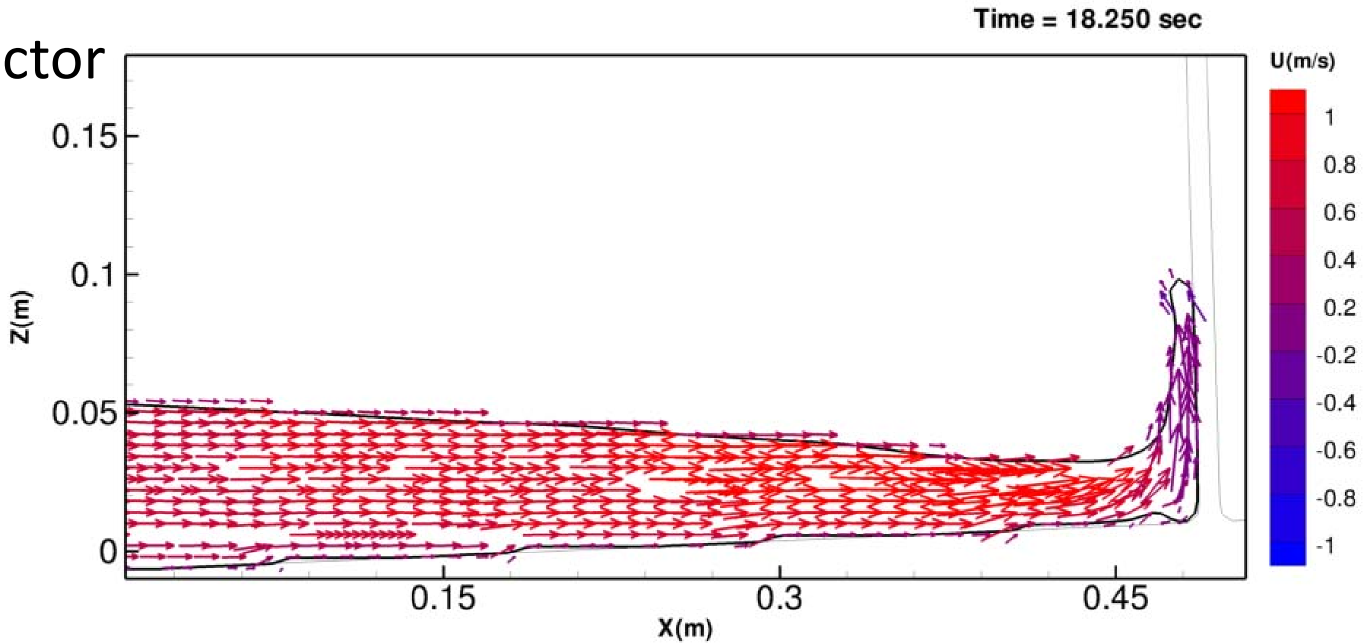
G4

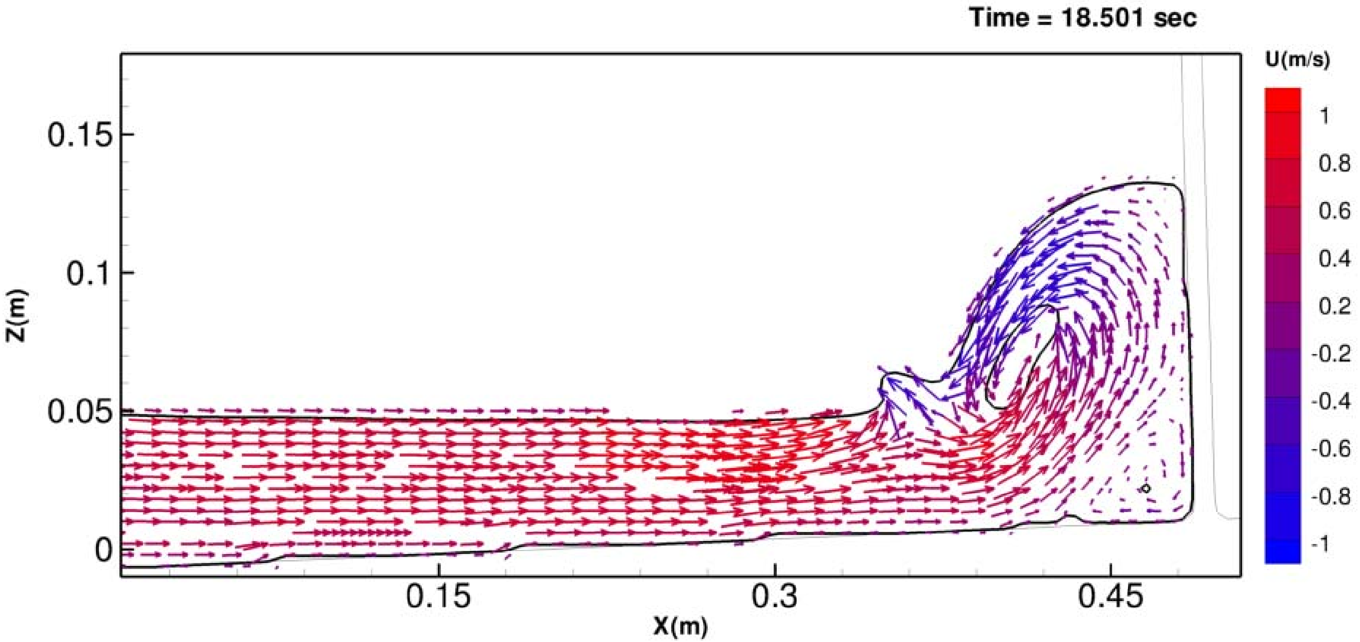


G5



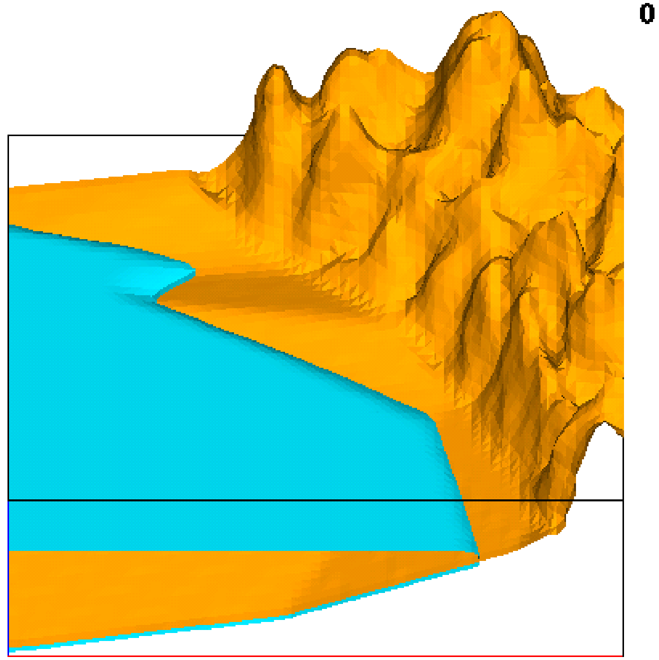
Velocity Vector

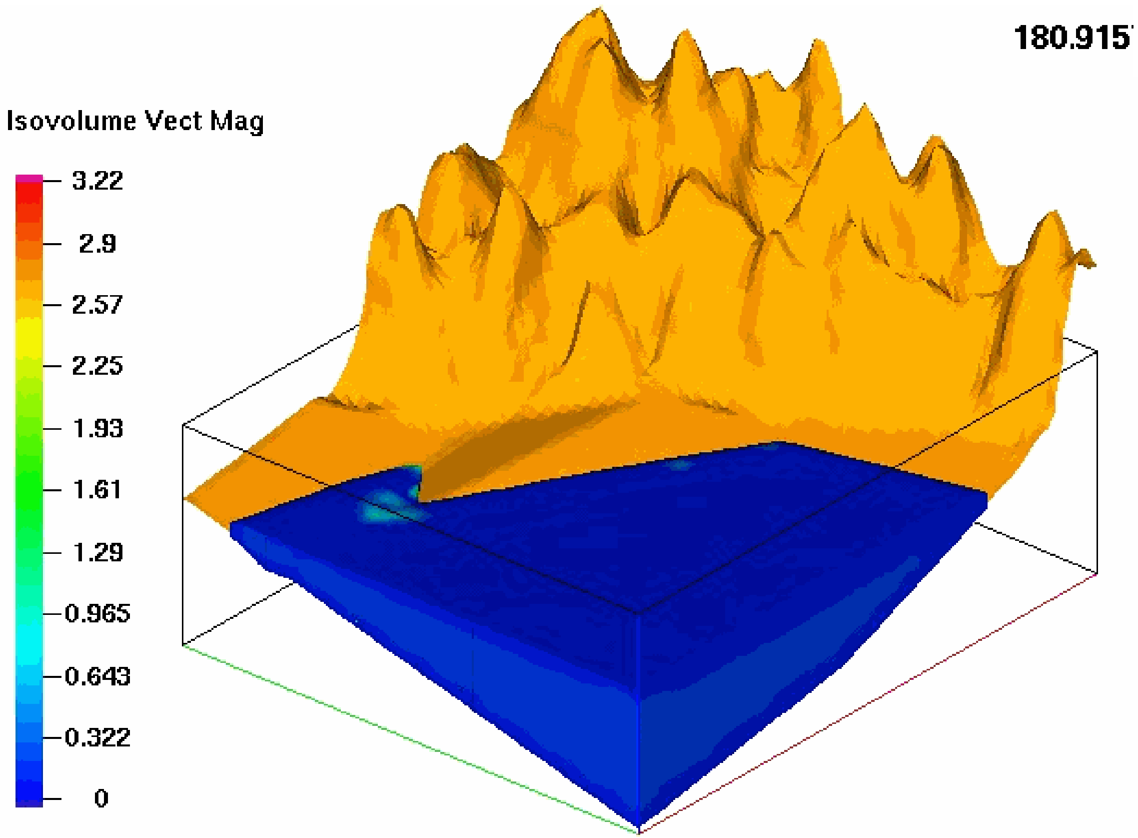




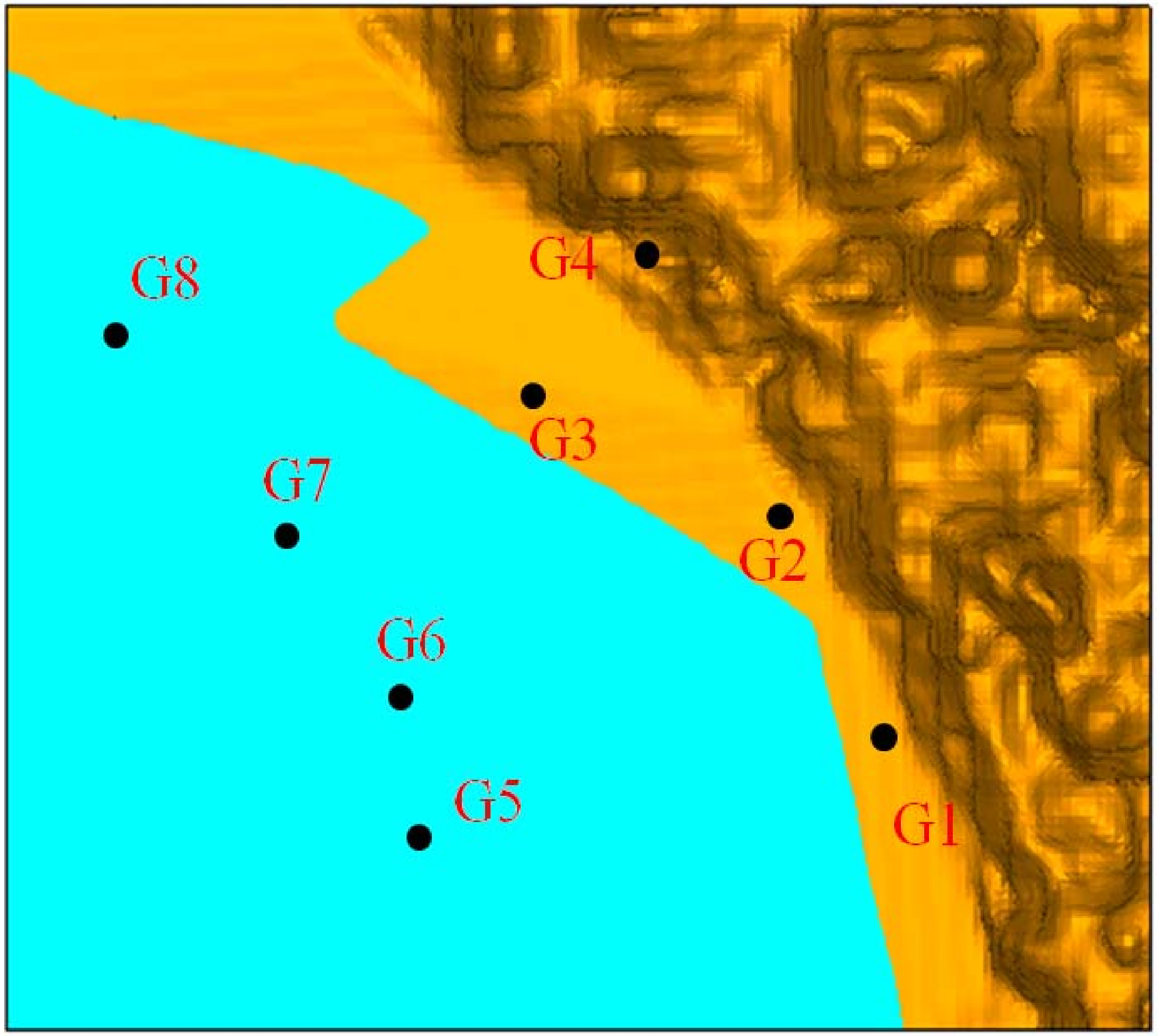
3D Simulation

Domain Area: 1300*1100*32 m^3
Cells: 65*55*32
Time: 800 sec





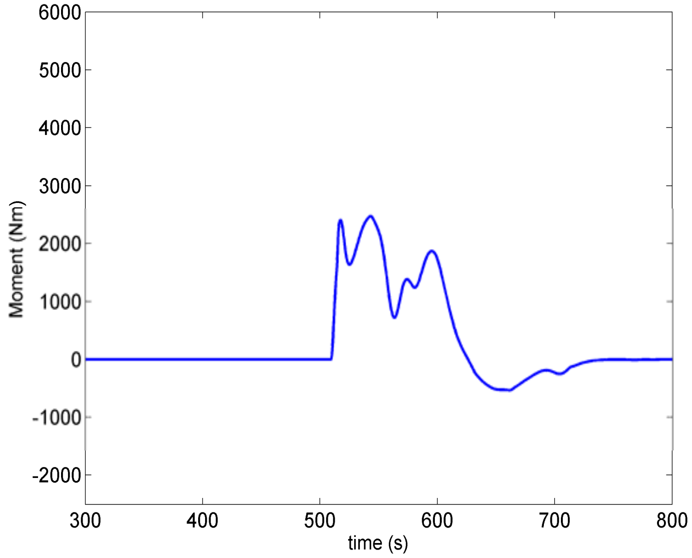
Gauge Distribution



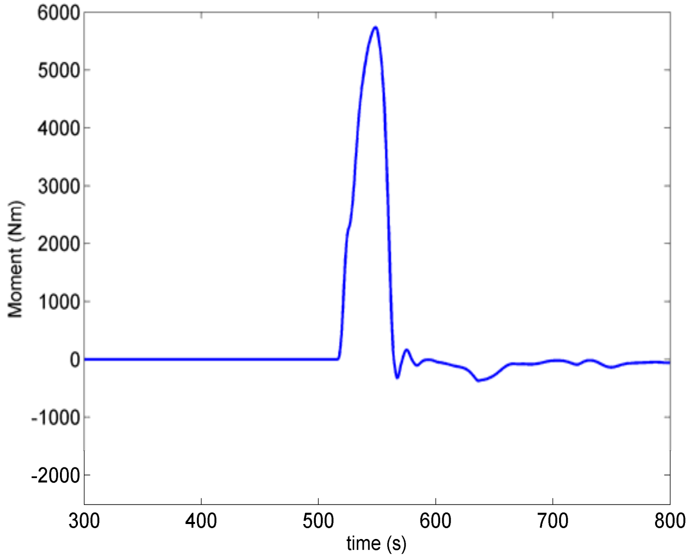
（陳子宇、吳祚任，中大水海所海嘯科學研究室）

Moment

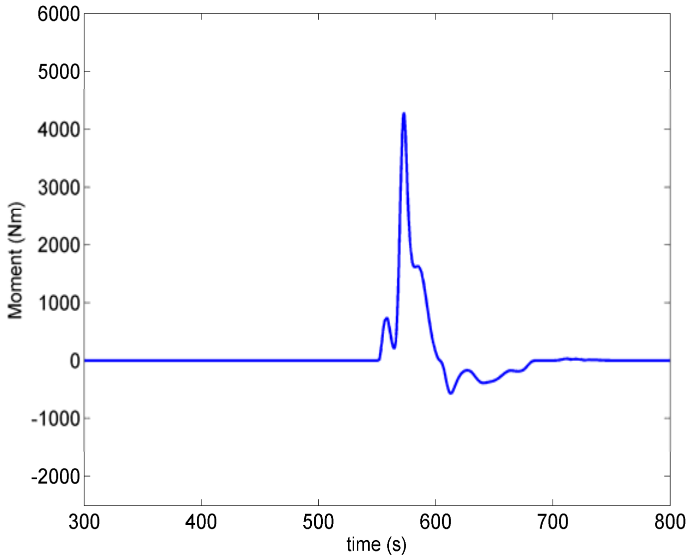
G1



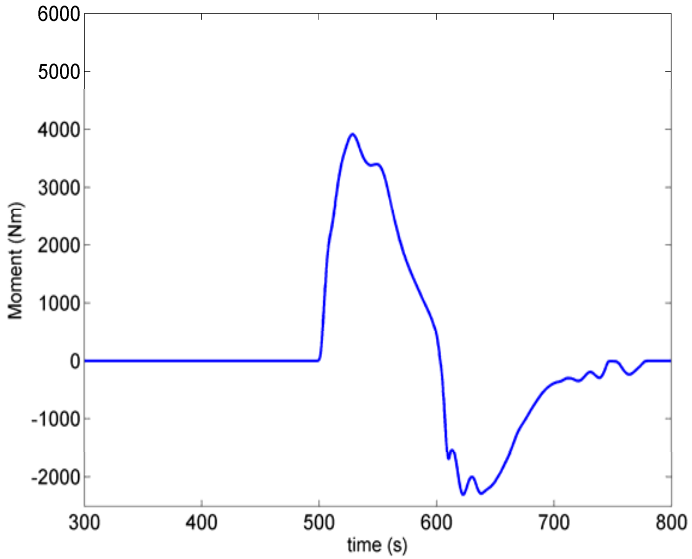
G2



G3

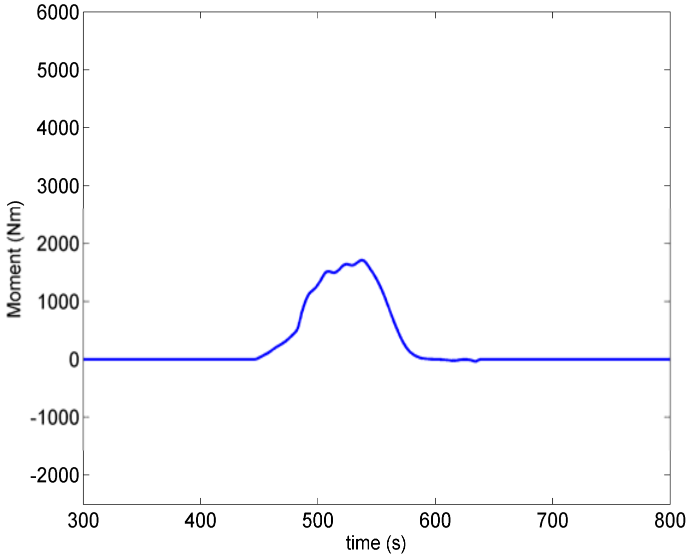


G4

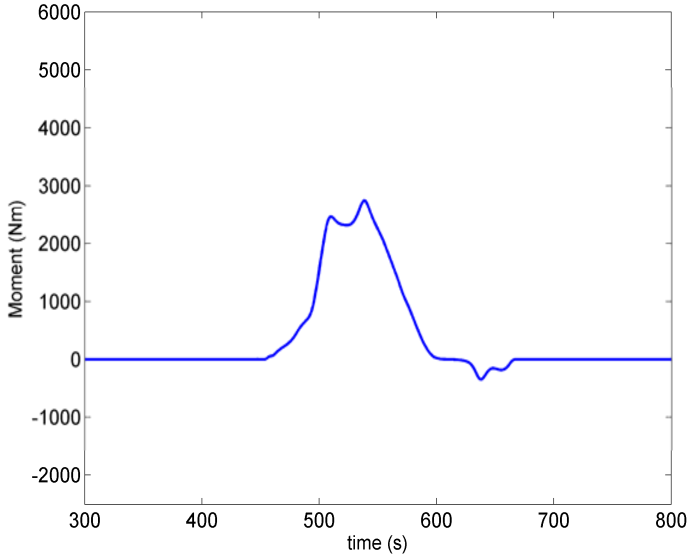


Moment

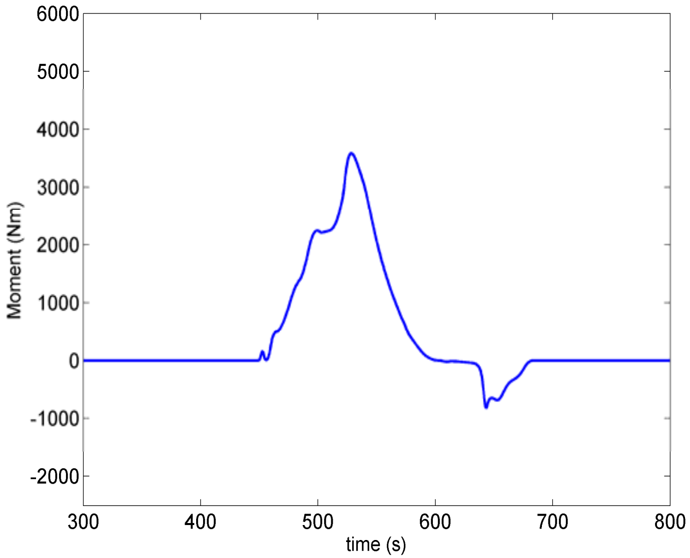
G5



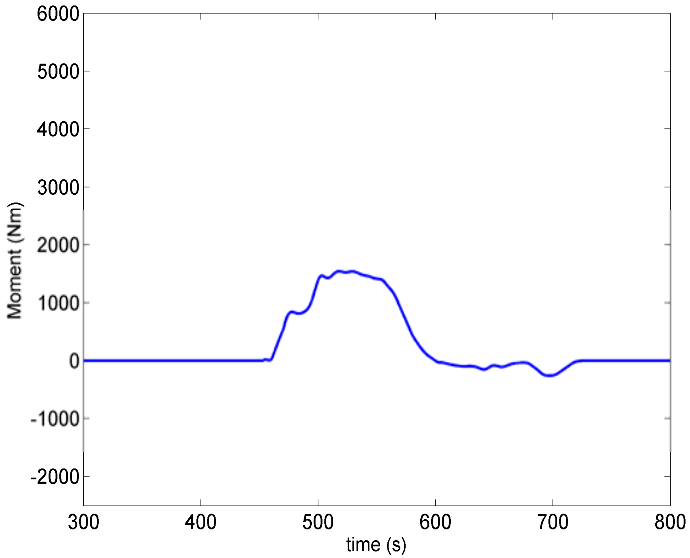
G6



G7



G8



SCI Paper

- Huang, Zhenhua, Tso-Ren Wu, Tzu-Yu Chen and Shawn Y. Sim, 2012/11, A possible mechanism of destruction of coastal trees by tsunamis: A hydrodynamic study on effects of coastal steep hills, Journal of Hydro-Environment Research, 10.1016/j.jher.2012.06.004, (SCI: IF=1 RANK: 41/118 in ENGINEERING, CIVIL)

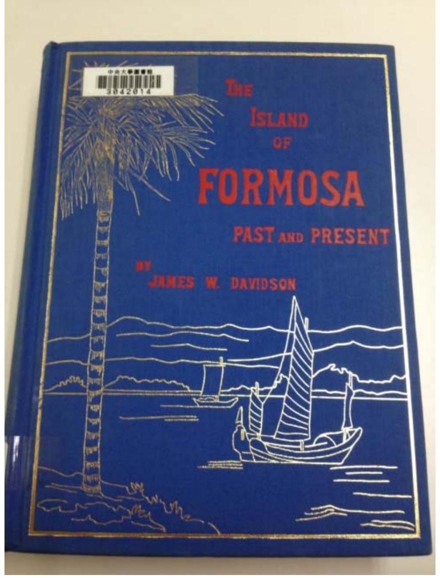
台灣自1661年起之10次台灣歷史海嘯紀錄（2012，吳祚任整理）

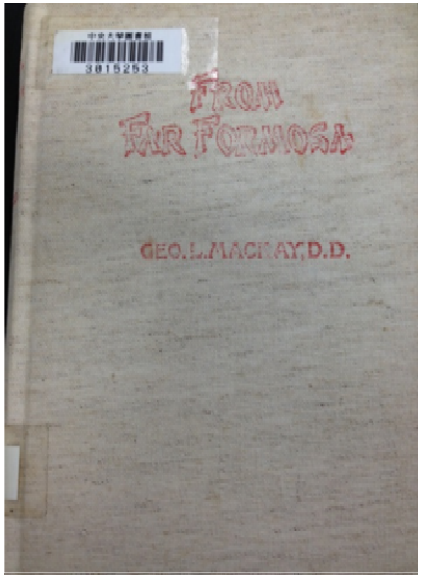
時間	地點	出處	描述	備註
1661年1月	安平	德人海卜脫（Herport）著旅行記	1661年1月某日晨6時開始地震，約歷30分，居民均以為地將裂開。安平房屋倒塌23棟，海地（今安平）城破裂多處。大震之後仍不斷有輕微地震，使人如置身舟中，約3小時，無一人能站穩。其時適有3船入港，在水中亦激烈震動，一若即將覆沒者。此次地震中，有一事最可驚奇，即海水曾被捲入空中，其狀如雲。此次地震，無論海中，在陸上，人身均能感覺，共歷6星期。	與一般地震與海嘯之認知差異甚大。可能為作者誇大描述。
1721年1月5日	台南縣	重修台灣縣志「雜誌。祥異」及明清史料戊編	王必昌，重修台灣縣志「雜誌。祥異」：「12月庚子（1721年1月5日），又震，凡震十餘日，日震數次，房屋傾倒，壓死居民。」。明清史料戊編載朱一貴供詞有云：「因地震，海水冷漲，眾百姓合夥謝神唱戲。」。	有可能為地震海嘯，然而文中對海嘯描述甚少。
1781年4、5月間	高雄、屏東	台灣采訪冊「祥異。地震」	「鳳港西里有加藤港，……乾隆四十六（1781）年四、五月間，時甚晴霽，忽海水暴吼如雷，巨涌排空，水漲數十丈，近村人居被淹，皆攀援而上至尾，自分必死，不數刻，水暴退，人在竹上搖曳呼救，有強力者一躍至地，兼救他人，互相引援而下。間有牧地甚廣及附近田園溝壑，悉是魚蝦，撥刺跳躍，十里內村民提籃挈筒，往爭取焉。……漁者乘筏從竹上過，遠望其家已成巨浸，至水汐時，茅屋數椽，已無有矣。	文中提海水退卻及第二海嘯波，深具科學意義。由內文描述可了解第一海嘯波波高約3m，第二海嘯波約4-5m，與情境分析雷同，可信度高。
1782年5月22日或1682年12月間	台南	Soloviev and Go, 1974	（原俄文，吳祚任、阮芳香譯）「1782年5月22日（1682年12月？）台灣（台南）發生強烈地震並造成嚴重災情，海嘯隨之而來，並以東西向方式攻擊海岸地區。『幾乎全島』超過120公里被海嘯所淹沒。地震和海嘯歷時8小時。該島的三大都市和二十多個村莊先是被地震破壞，隨後又為海嘯浸吞。海水退去後，原本是建築物的地方，只剩下一堆瓦礫。幾乎無人生還。40,000多居民喪生。無數船沉沒或被毀。一些原本伸向大海的海角，已被沖刷，形成新的峭壁和海灣，並造成淹水。安平堡（即熱蘭遮）以及赤崁城堡（台南市赤崁樓舊址）連同其坐落的山包均被沖跑了」	文中精確描述海嘯之8小時歷時以及120公里海岸溢淹範圍，並描述安平及赤崁受災情形。與情境分析雷同，可信度高。然四萬人死亡可能為錯誤之推估。年代亦尚待考證。
1792年8月9日	彰化	「台灣采訪冊」（頁39-40）「祥異，地震」	乾隆壬子歲六月，郡城地震，西定坊新街折一亭，隕一命。次日，聞嘉城地大震，店屋、民房倒壞，而繼之以火。一城惶恐無措，民房燒損過半，死者百餘人。壬子，將赴鄉闈，時六月望，泊舟鹿耳門，船常搖蕩，不為異也。忽無風，水湧起數丈，舟人曰：『地震甚。』又在大洋中亦然，茫茫黑海，搖搖巨舟，亦知地震，洵可異也。.	有可能為地震海嘯，然而文中對海嘯描述甚少。

1866年12月16日晨8時20分	高雄	阿瓦力茲（Alvarez）著「福爾摩薩（Formosa）」	「1866年12月16日晨8時20分，發生地震，約歷一分鐘，樹林、房舍及港中船隻，無不震動；河水陡落3尺，忽又上升，似將發生水災。	文中提及河口海水退卻又急速上升，與一般海嘯現象類似。可信度高。
1867年12月18日	基隆	淡水廳志、Alvarez，Formosa等	「（同治六年）冬十一月，地大震。……二十三日，雞籠頭、金包里沿海，山傾地裂，海水暴漲，屋宇傾壞，溺數百人。」。Alvarez，Formosa：「1867年12月18日，北部地震更烈，災害亦更大，基隆城全被破壞，港水似已退落淨盡，船隻被擱於沙灘上；不久，水又復回，來勢猛烈，船被衝出，魚亦隨之而去。沙灘上一切被沖走。……」	諸多文獻皆明確指出此基隆海嘯，且海嘯高度在6m與7.5m之間。地震規模約為7。可能為地震引發山崩海嘯。
1918年5月1日	基隆	楊春生等（1983）	台電電源開發處之調查報告提到，1918年5月1日台灣東北部海底地震引起海嘯，基隆海嘯溯上約3.7公尺。查鄭世楠、葉永田（1989）一書，該日並無規模大於5之地震。	可能為山崩海嘯。
1960年5月24日	基隆、花蓮	聯合報等	民國49年5月25日聯合報：「基隆測候所的記錄，24日上午6時30分，基隆港內海潮高出海平面1.9公尺，為基隆海潮的最高記錄，上一次的最高記錄是1.5公尺。」；「基隆市區內田寮港運河的尚志橋於上午5時許，被來自淺水碼頭附近港內的漂浮的巨枝柳安木所沖垮，另有崇仁、平等、自由三橋亦被沖壞。……。據昨日目擊當時的市民稱：有一艘小舢舨，被旋轉的海潮捲得直立達數分鐘之久，然後再傾覆。另有三艘舢舨亦被捲覆沒。」；	智利海嘯傳至台灣所致。波高在基隆為66cm花蓮為30cm。
2006年12月26日	屏東後壁湖漁港	吳祚任，中央氣象局	根據中央氣象局後壁湖潮位站資料顯示，屏東外海所發生之規模7.0及6.9之雙地震，於後壁湖港區產生40cm之海海嘯。	地震規模不大，然而海嘯卻達40cm，顯示台灣南端容易造成海嘯波高放大效應。

1867 基隆海嘯

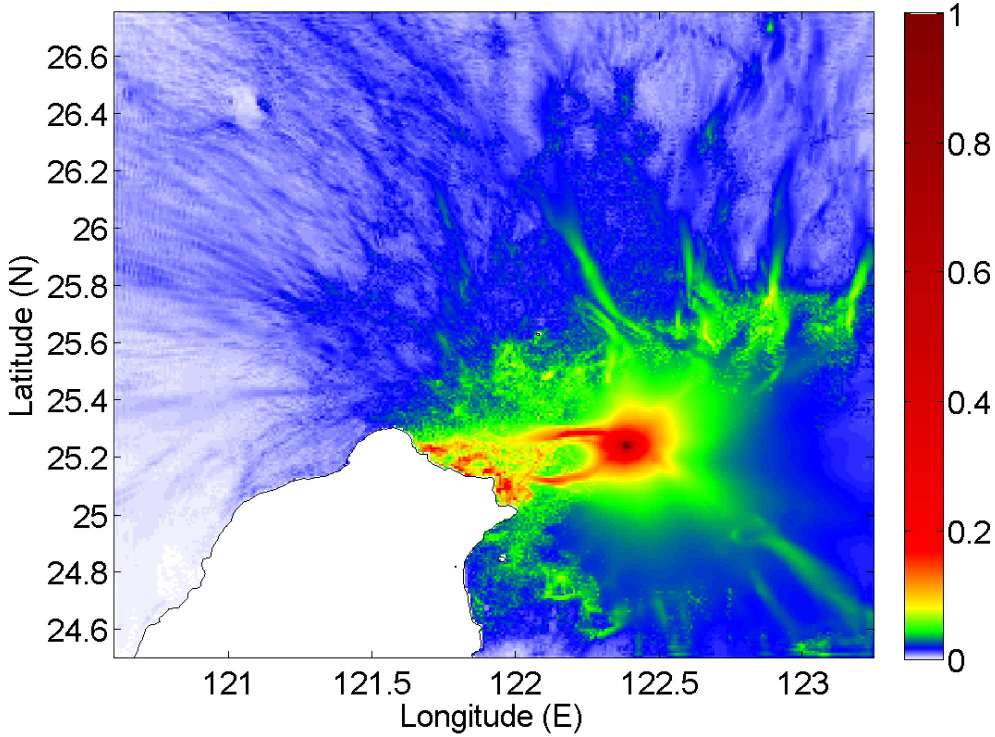
- 字林西報」（North China Dairy News）
  - 「棕櫚島和基隆島之間的海面上有湮霧。海港內的水湧向海外，致使遠至閻王岩的地方有幾秒鐘成為無水地帶，所有的東西都被退去的海水捲走了，然後海水又形成兩個大浪湧回，將舢板和上面的人淹沒，並把帆船擱淺在基隆對岸。海水也不像往常那樣清澈，而是變得又黃又渾。大量的魚被沖到岸上。海水退出港口時，有一個男人從一條帆船上下來，但是在他到達岸上之前，就被回湧的海水淹沒了。無數的煤船傾覆沈沒。一條深埋在沙中多年的舊帆船沖上了岸」。
- 「淡水廳志」
  - 「（同治六年）冬十一月，地大震。…二十三日，雞籠頭、金包里沿海，山傾地裂，海水暴漲，屋宇傾壞，溺數百人」（祥異考）。
- Reports on Trade at the Treaty Ports for the Year, 1864～1881
  - 「1867年地震發生在12月18日，海水從基隆港傾瀉而出，留下了一個乾涸的泊位，但不幾秒鐘，帶著兩個浪頭的海水又洶湧而回，淹沒了舢板和人口。基隆、金包里及巴其那等城鎮部份泡為廢墟。淡水遭到嚴重破壞，好幾百人死亡」。
- 「臺灣遙寄」（From Far Formosa）
  - 「地大震，雞籠頭、金包里沿海，山傾地裂、海水暴漲、屋宇傾壞、溺數百人。北部地震更烈，災害亦更大：基隆城全被破壞。港水似已退落淨盡，船隻被擱于沙灘上。不久，水又復回。來勢猛烈，船被衝出，魚亦隨之而去，砂灘上一切被沖走」。
- 「同治年間於金包里附近的地變」
  - 「地震發生在清同治六年（慶應三年）十一月二十三日上午十點，震前並無徵兆，初時，南邊的硫磺山發出如雷的聲響，聲音由南向北傳遞，繼而地面開始左右劇烈搖晃，約五分鐘後，海面開始暴退，三十分鐘後，海底約裸露四、五町之多，一個鐘頭後，海水暴漲，發生海嘯。磺港、水尾港附近皆受波及，海水暴升兩丈高，金包里街、八斗子均被海水淹沒……. 」





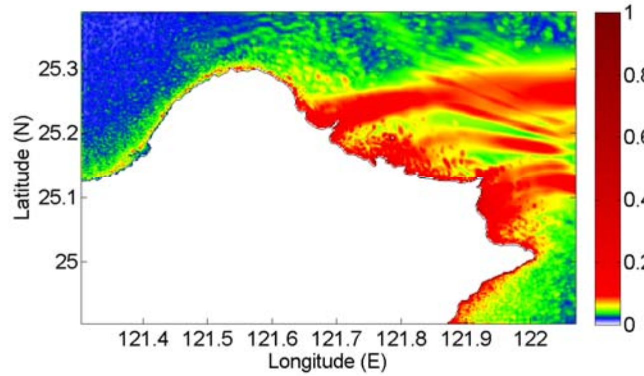
李俊叡整理（中大水海所海嘯科學研究室）

李俊叡模擬（中大水海所海嘯科學研究室）



潛在山崩位置B

主要影響:貢寮、金山、基隆



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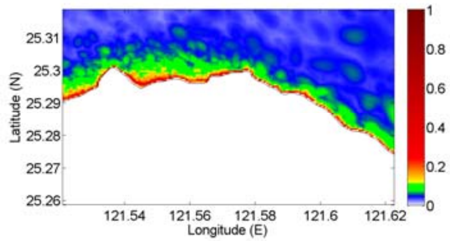

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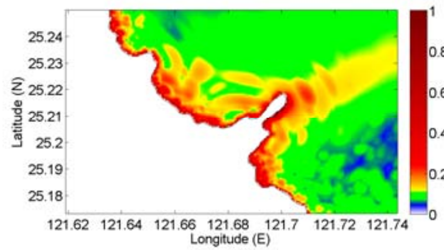

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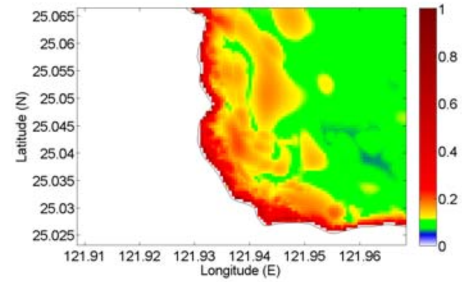
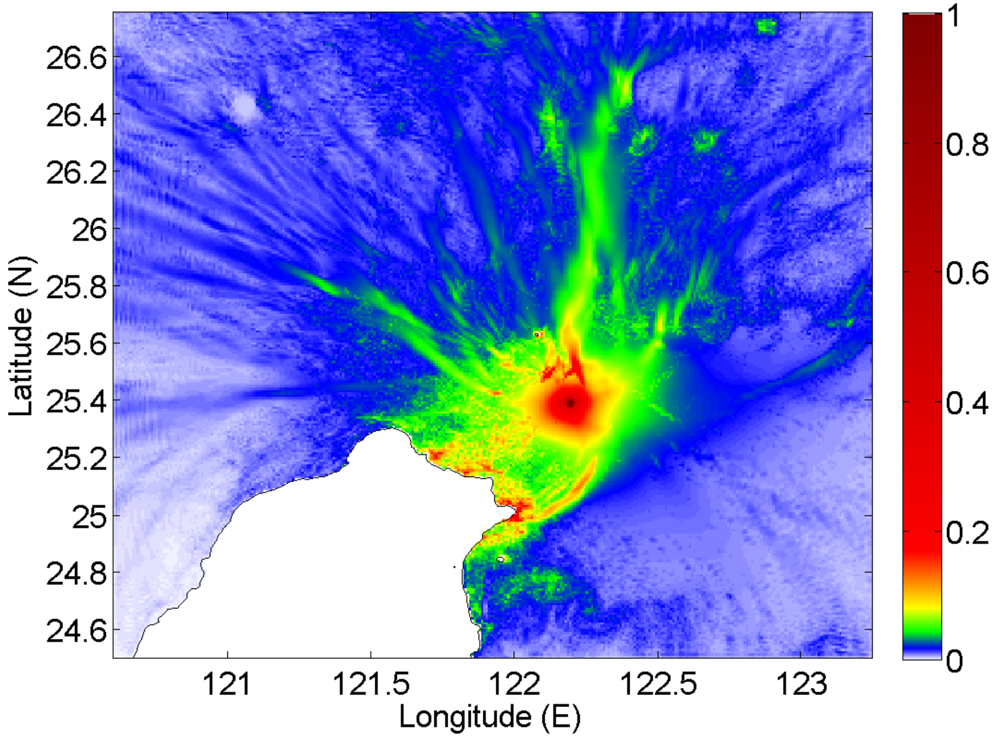
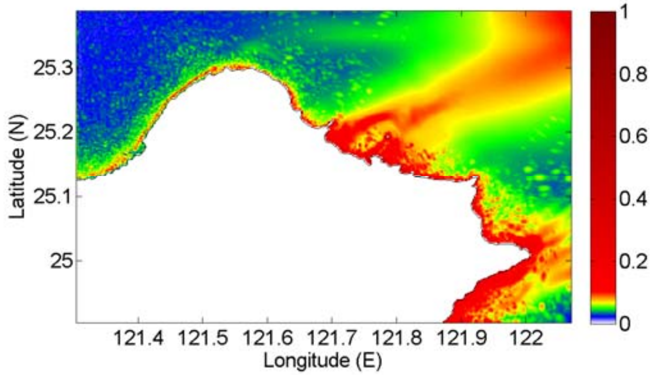


李俊叡模擬（中大水海所海嘯科學研究室）



0801-04潛在火山

主要影響:貢寮、金山、基隆



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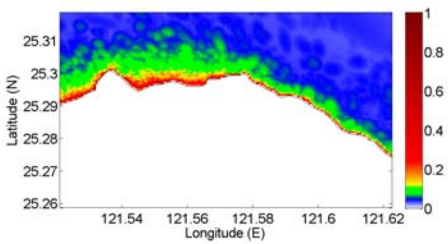

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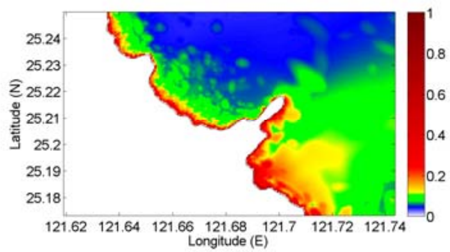

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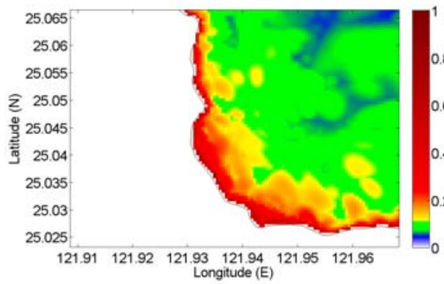
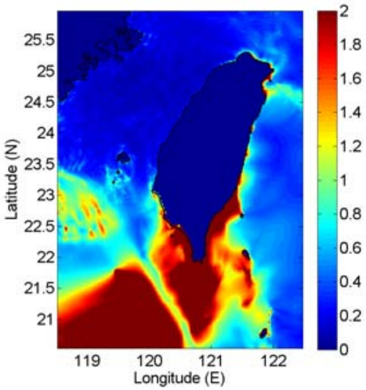
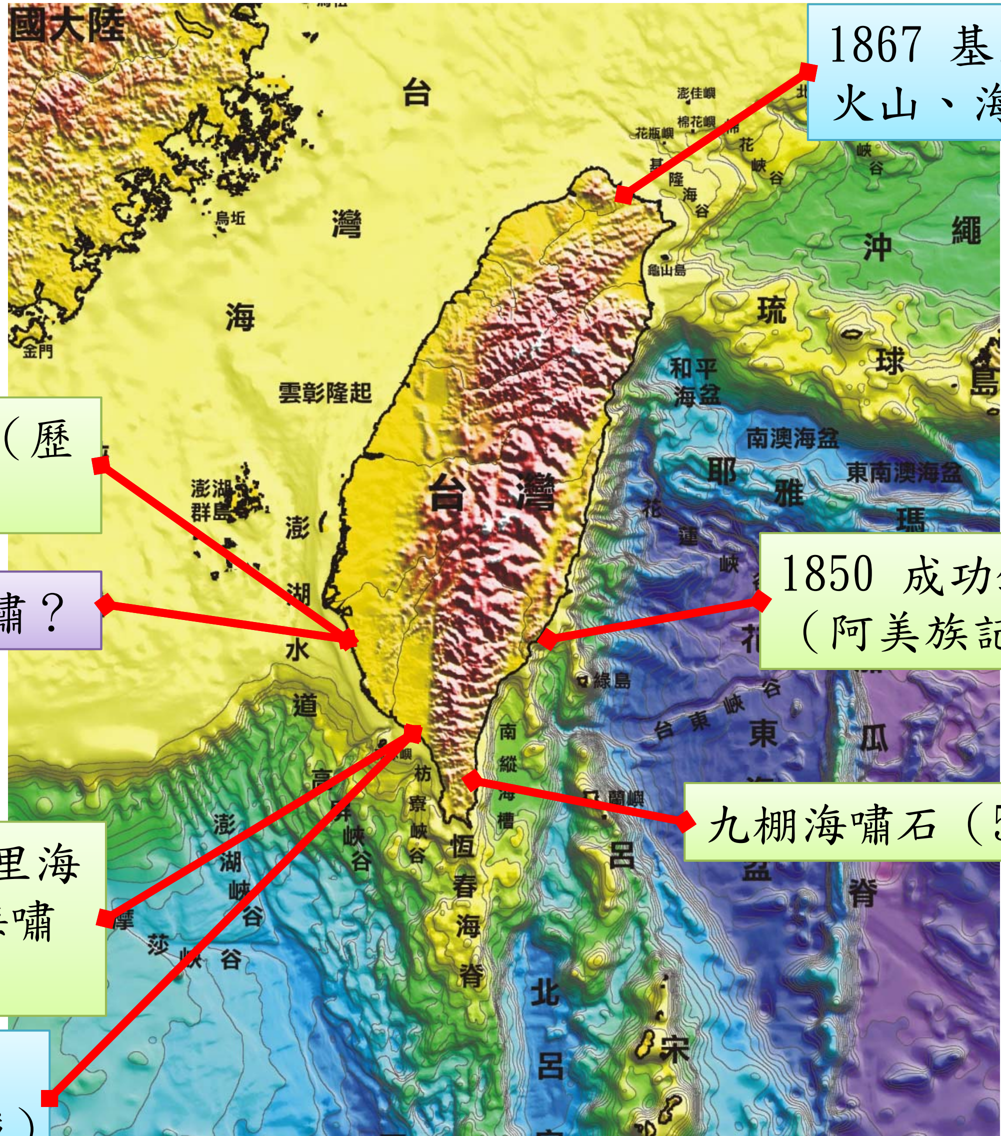






1867 基隆海嘯（地震、火山、海底山崩）

1772 台南海嘯（歷時與地點精確）

1661 鄭成功海嘯？

1850 成功鎮海嘯（阿美族記載）

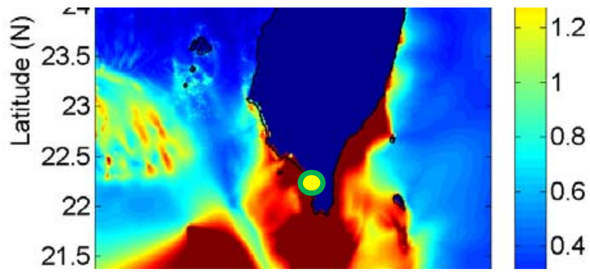
九棚海嘯石（5000年內）

1771 屏東港西里海嘯（記載兩次海嘯波）

1894 東港海嘯（四座宮廟記載）

台灣歷史暨古海嘯事件（吳祚任整理，中大水海所海嘯科學研究室）

1781年（清乾隆46年）5月間（4月24日-6月21日）屏東港西里海嘯



- 「台灣采訪冊」「祥異，地震」：「乾隆四十六年四、五月間，時甚晴霽，忽海水暴吼如雷，巨浪排空，水漲數十丈，近村人居被淹，皆攀援而上至尾，自分必死，不數刻，水暴退，人在竹上搖曳呼救，有強力者一躍至地，兼救他人，互相引援而下。間有牧地甚廣及附近田園句壑，悉是魚蝦，撥刺跳躍，十里內村民提籃挈筒，往爭取焉。聞只淹斃一婦，婦素悍，事姑不孝，餘皆得全活。嗣聞是日有漁人獲兩物，將歸，霎時間波濤暴起，二物竟趣，漁者乘筏從竹上過，遠望其家已成巨浸，至水汐時，茅屋數椽，已無有矣。」。
- 文中描述到第二海嘯波，幾乎可以肯定為海嘯事件。
- 第一波波高約3公尺。第二波約4~5公尺。淹溢範圍約1km。

- "In 1781 around the 4th to 5th month, 46th Qianlong year, the weather was fine. Suddenly the sea roared like thunder. Giant wave appeared. Water rose for tens of zhang high. Villagers nearby were submerged. They climbed upwards, expecting to die. After a few quarters, it ebbed. People were swinging on top of bamboos, crying for help. One strong man jumped to ground, and helped others getting down. Gazing lands, farmlands and gullies were full of leaping fishes. Villagers nearby rushed to collect by baskets. It was heard that one woman was drown. The woman was fierce, and was not filial to her parents in law. Except for the woman, everybody was survived. After collecting the fishes and heading home, **suddenly the sea roared again**. Fishermen lost their fishes. They sailed on top of bamboos on raft, watching their homes submerged from far."

About 3m

About 230 years ago

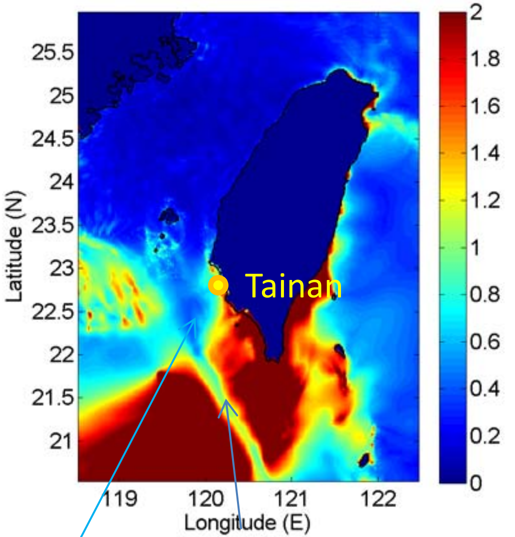
About 4~5m

Second tsunami coming in

About 1km far

（感謝許明光、李昭興、吳季莊提供資料）

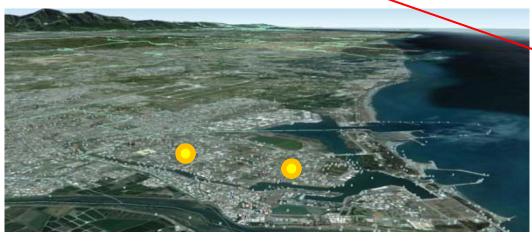
- 「1782年5月22日（1682年12月？）台灣（台南）發生強烈地震並造成嚴重災情，海嘯隨之而來，並以東西向方式攻擊海岸地區。『幾乎全島』超過120公里被海嘯所淹沒。地震和海嘯歷時8小時。該島的三大都市和二十多個村莊先是被地震破壞，隨後又為海嘯浸吞。海水退去後，原本是建築物的地方，只剩下一堆瓦礫。幾乎無人生還。40,000多居民喪生。無數船沉沒或被毀。一些原本伸向大海的海角，已被沖刷，形成新的峭壁和海灣，並造成淹水。安平堡（即熱蘭遮）以及赤崁城堡（台南市赤崁樓舊址）連同其坐落的山包均被沖跑了」

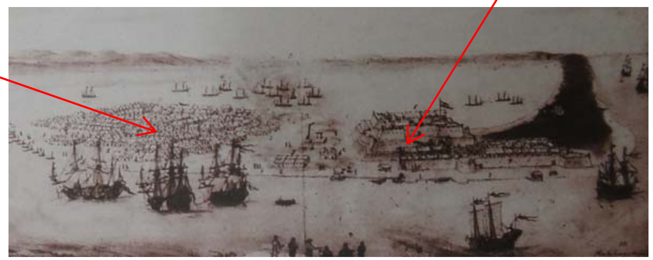


(Epicenter was not far away from Tainan)

In 1782 May 22 (or 1682 December ?), strong earthquake shook the Taiwan (Tanian) and vyzvuzshee (??) and caused severe damage, followed by tsunami waves, attacking the coastal area in the East-West direction. “ Almost the whole island” was flooded **by tsunami for over 120 km**. Earthquake shaking and **tsunami waves lasted for 8 hours.** Three big cities and 20 villages of the island were destroyed by an earthquake at first, and then by the tsunami. After ebbing, the locations where the buildings stood remained only the debris. “There were nobody left alive”. **More than 40,000 inhabitants were killed**. Lots of ships were destroyed or sunk. In the places where some capes were swashed away, fresh slopes and coves appeared, and filled with water. Forts Zealand (Anpin) and Pigchingi were washed away along with the hills on which they are located. (Perrey, 1862c; Mallet, 1854; Iida et al, 1967; Cox, 1970)

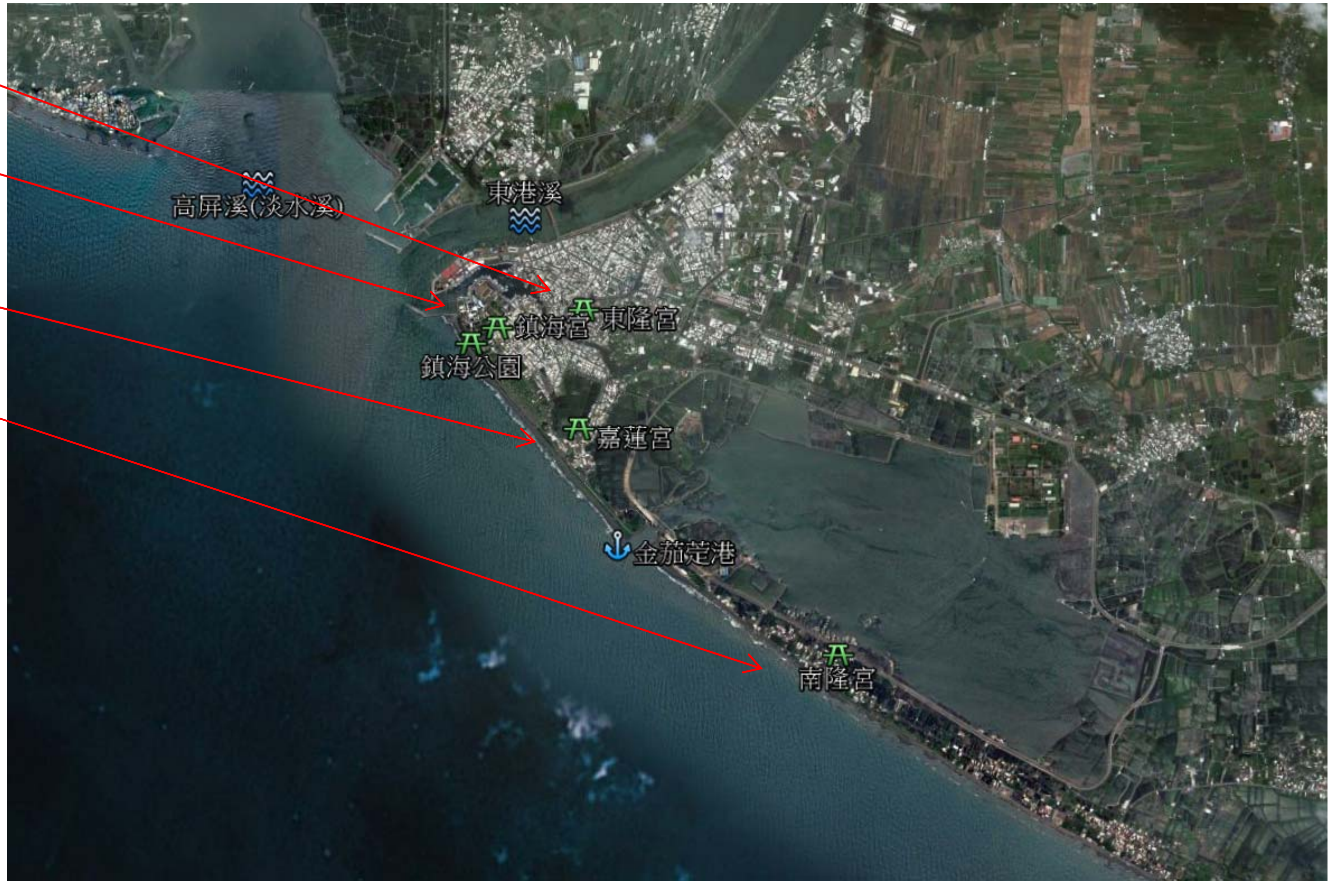
Translated by Prof. NGUYEN NOHG PHUONG (2011/11/16, Hanoi, Vietnam)





1894年東港海嘯
相關地點調查結果

- 東隆宮
- 鎮海宮
- 嘉蓮宮
- 南隆宮



（蔡育霖、李俊叡、柯利鴻提供，中大水海所海嘯科學研究室）

東隆宮

，名聲遠播。

光緒二十年（一八九四年），某天發生海嘯，浪濤翻天，淹沒了當時的太監府，許多居民早已先行避難，只有東隆宮仍陷於波浪濤滾之中，有士紳林合，在刻不容緩的緊急情形之下，發動民衆划竹筏，情願冒著被巨浪吞噬的危險，前去救溫王爺金身神

像，然而前殿因巨浪而

即用開山斧劈穿後殿廟

爺神像脫離危境，剎那

隆一聲，土崩瓦解，全

之間，消逝無影無蹤，

堅信溫王爺之神威。當

海底時，距離現在鎮海

之海中，溫王爺適時顯

沿革誌摘要：

- 光緒二十年(西元1894年)，某天發生海嘯，浪濤翻天，淹沒了當時的太監府，……
- 當時之太監府已沉入海底，距離現在鎮海里大約一公里之海中，……

（蔡育霖、李俊叡、柯利鴻提供，中大水海所海嘯科學研究室）

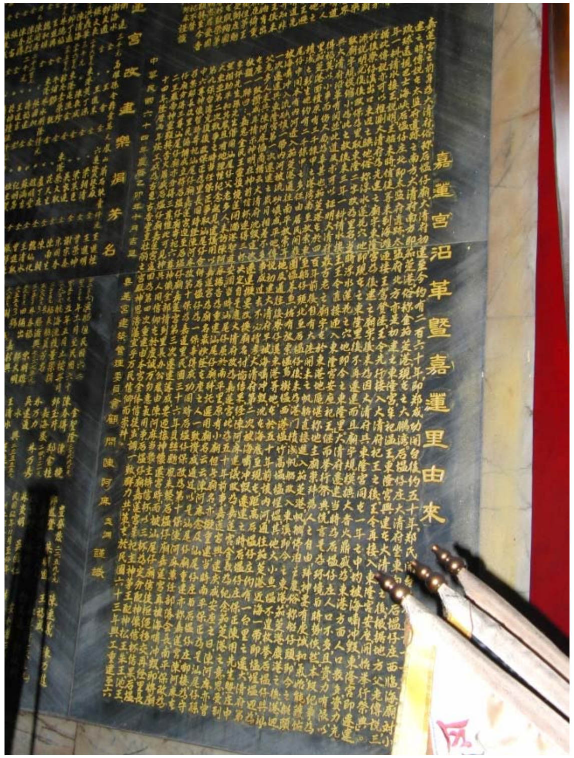
嘉蓮宮

碑文摘要：

- 俗稱大清府，初建之時傳說在太監府遺跡之南方，即茄萣港(現大鵬灣一帶)。
- 曾於與東隆宮同時遭海嘯摧毀。
- 茄萣港一帶泥沙淤積嚴重，然後廢港，帆船改入東溪(今之東港)。
- 約西元1925年左右，原大鵬灣有一內河通往茄萣港近海一帶，因海嘯衝入流砂，該一帶內河被流砂填成平地。

◎碑文上雖無描述時間，但有描述東隆宮遷建後之地點，與之比對，確定為西元1894年之海嘯。

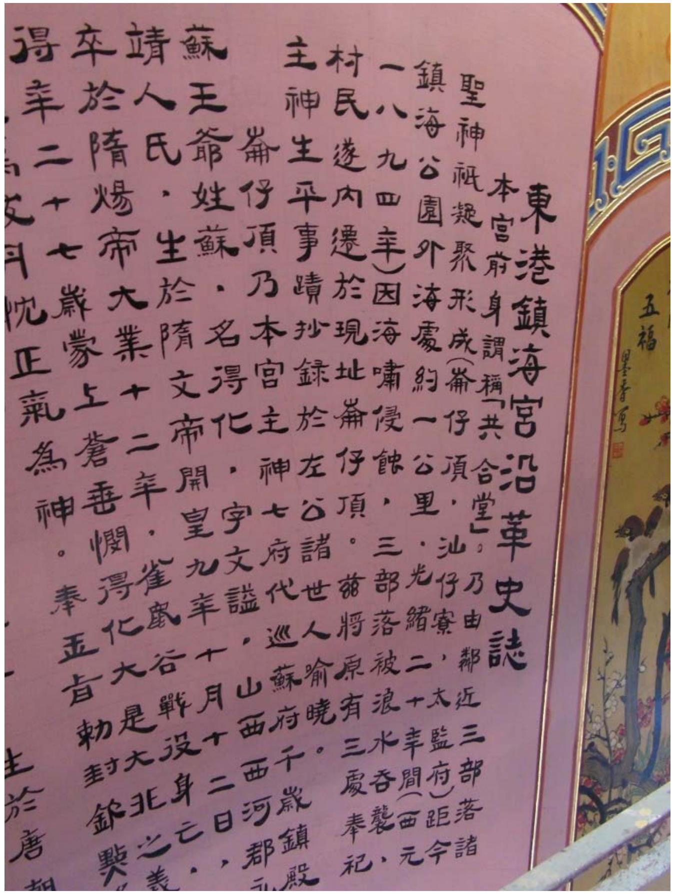
（蔡育霖、李俊叡、柯利鴻提供，中大水海所海嘯科學研究室）



鎮海宮

碑文摘要：

- 崙仔頂(鎮海宮)、汕仔寮、太監府(東隆宮)三個村落在1894年遭海嘯襲擊，盡沉海底。



（蔡育霖、李俊叡、柯利鴻提供，
中大水海所海嘯科學研究室）

南隆宮

碑文摘要：

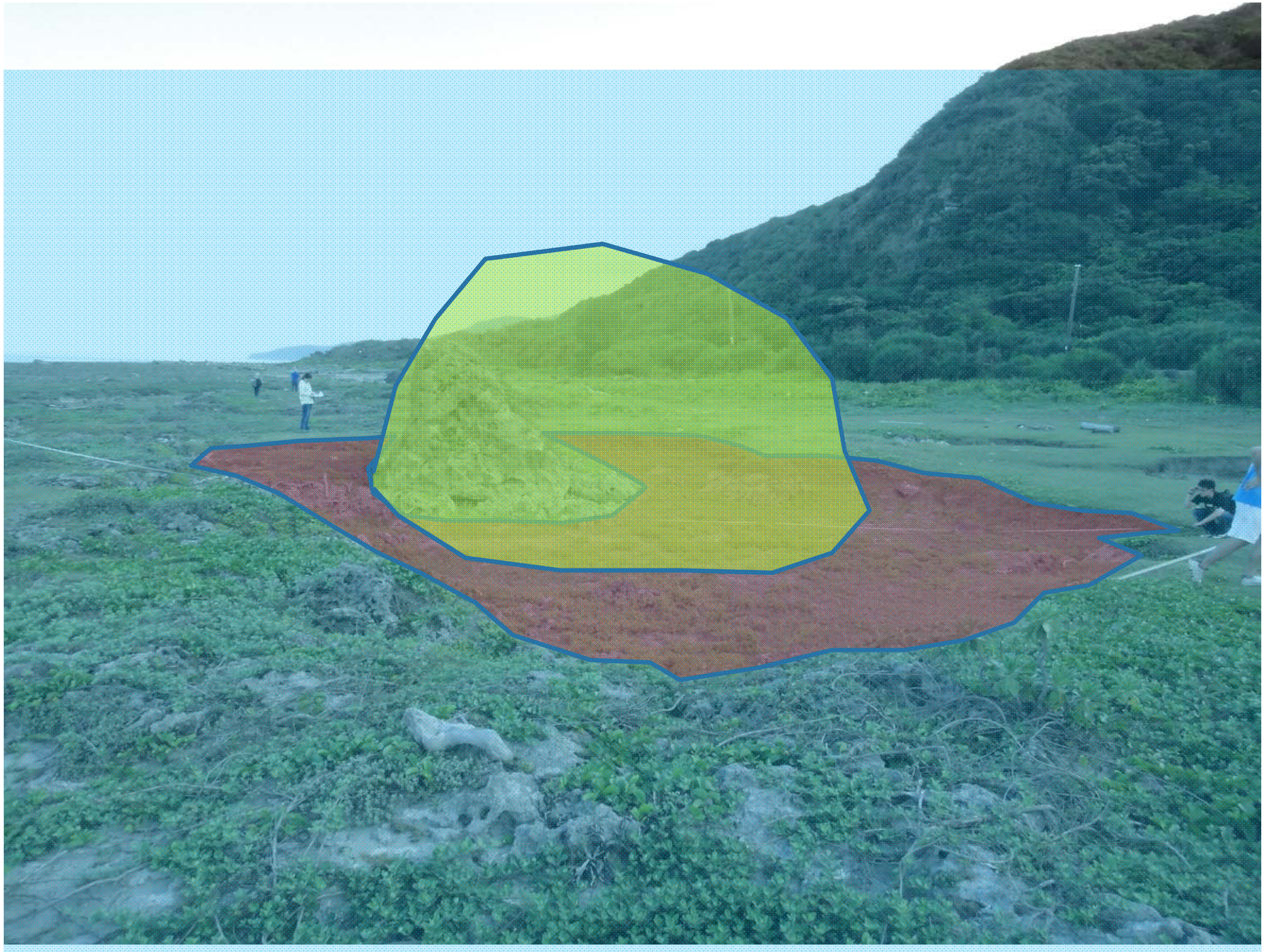
- 緣南平里昔日位處金茄萣港，……
- …大鵬灣港口之中心位置，西面有一顆大松樹，……，其後有紅毛番(荷蘭人)路過，好奇而將古松樹之大樹鬚(根)砍斷，不過三年，連遭天然災變，本庄竟被怒濤吞沒，地勢變動，住民逐漸遷移至現在里址定居，……

（蔡育霖、李俊叡、柯利鴻提供，中大水海所海嘯科學研究室）

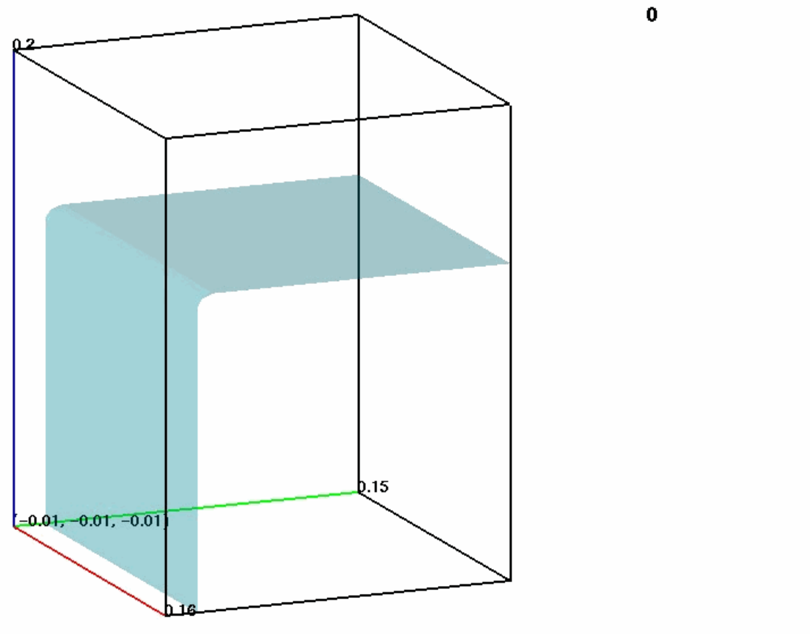
Tsunami Boulders were found in Taiwan

Motivation-2

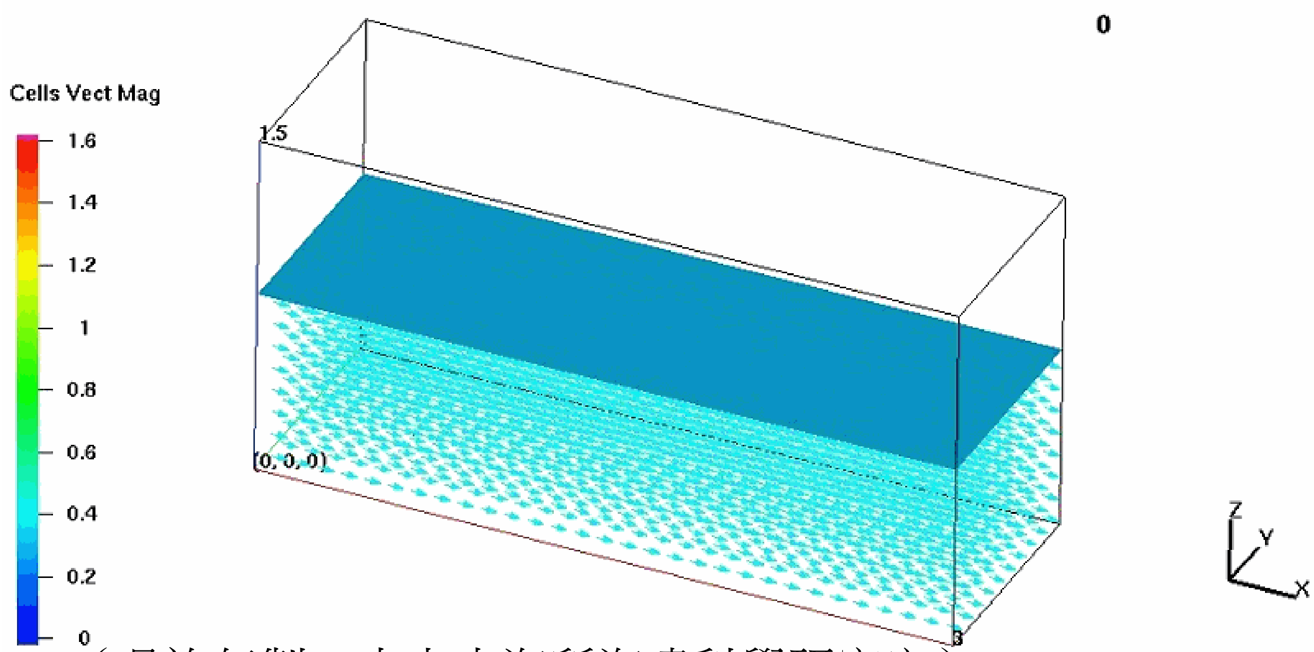
One of them presents a huge scour hole



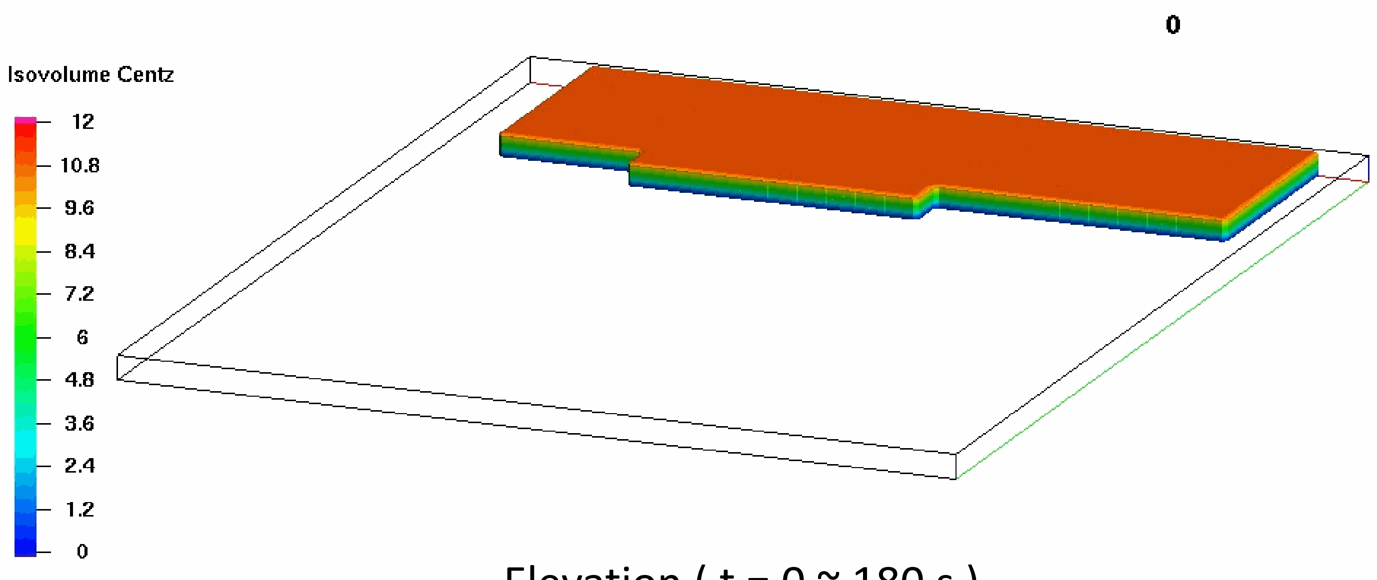
雙向流固耦合



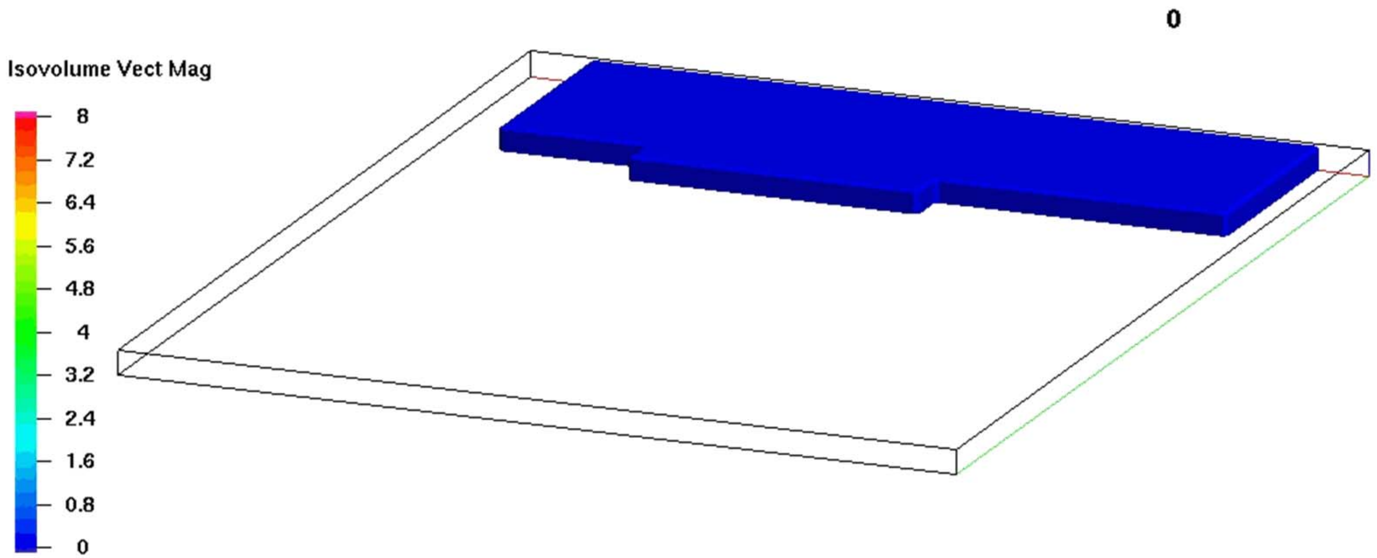
（中大土木所王仲宇教授、黃致榮博士製）



（吳祚任製，中大水海所海嘯科學研究室）



Elevation (t = 0 ~ 180 s)



Velocity Magnitude (t = 0 ~ 180 s)

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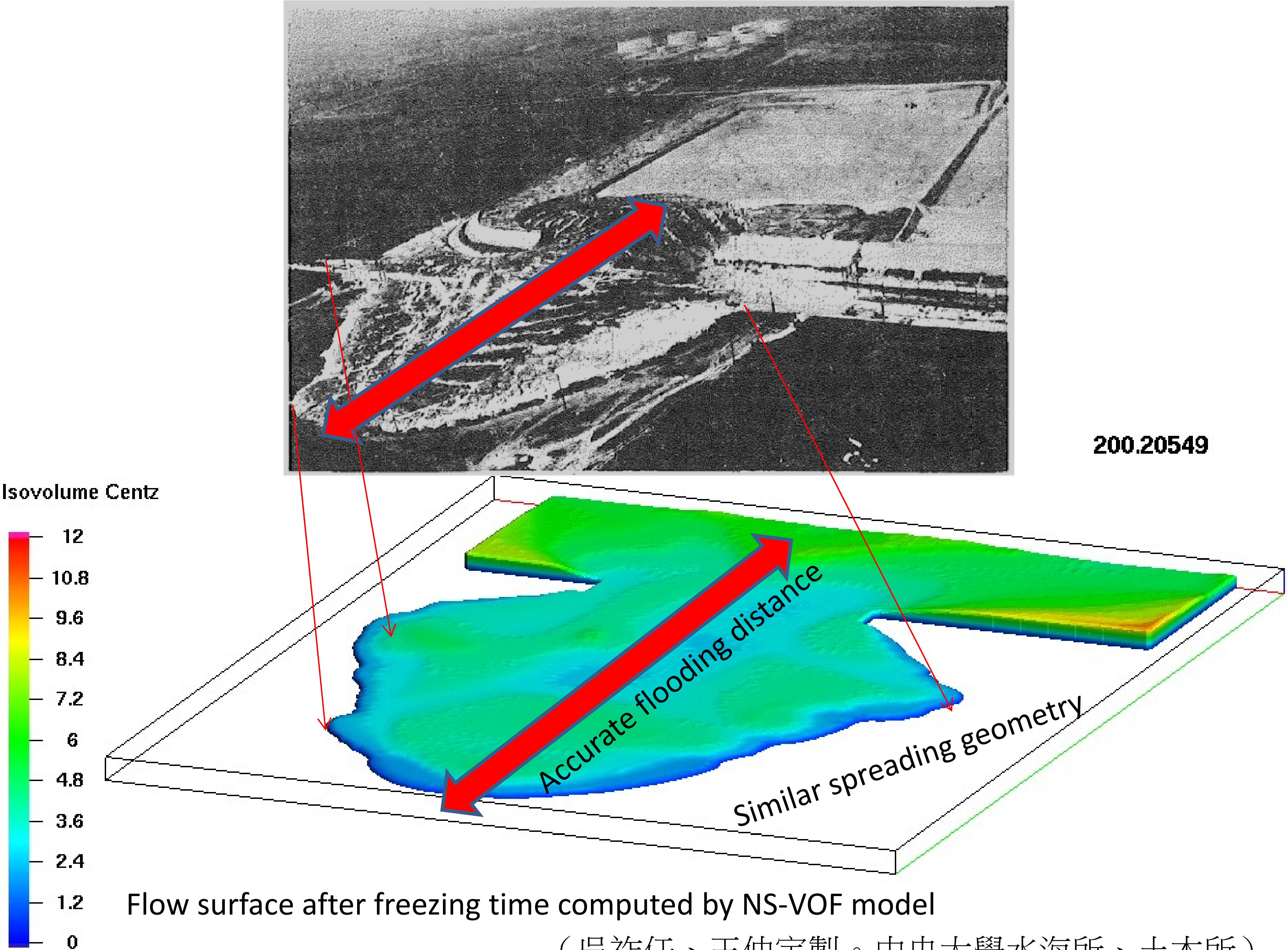

Flow surface after freezing time computed by NS-VOF model

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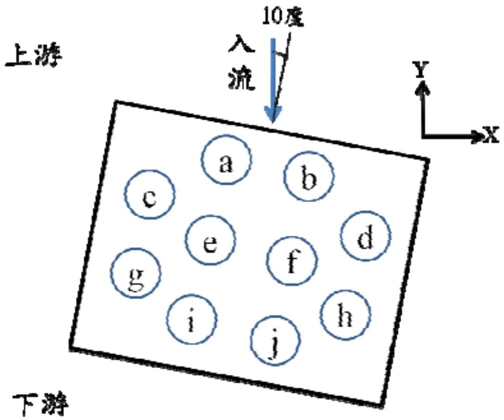
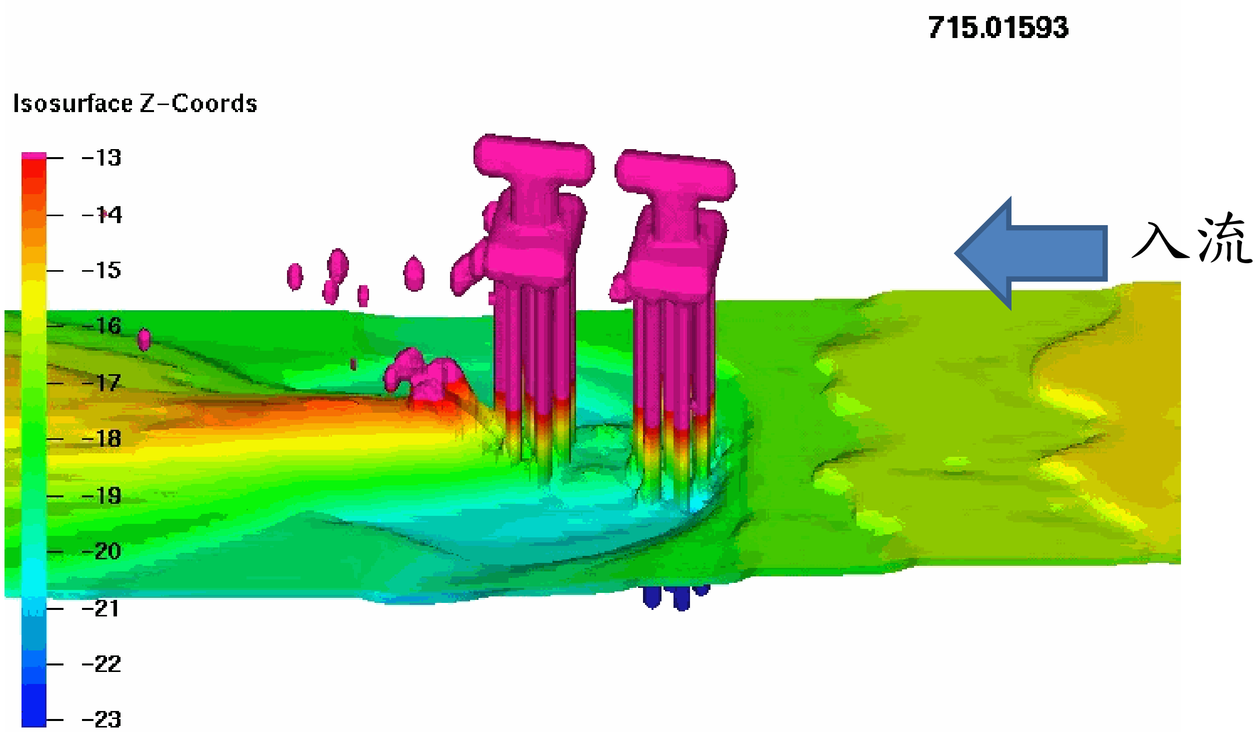
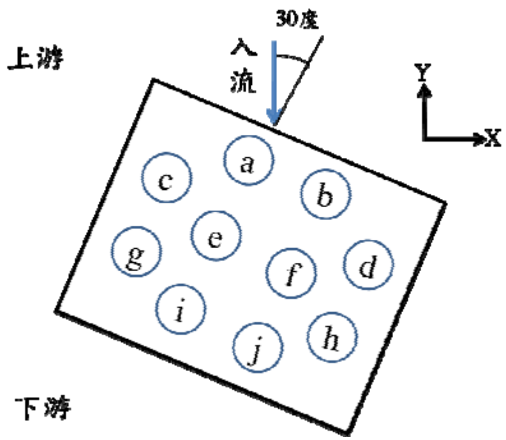
不同攻角問題也有探討

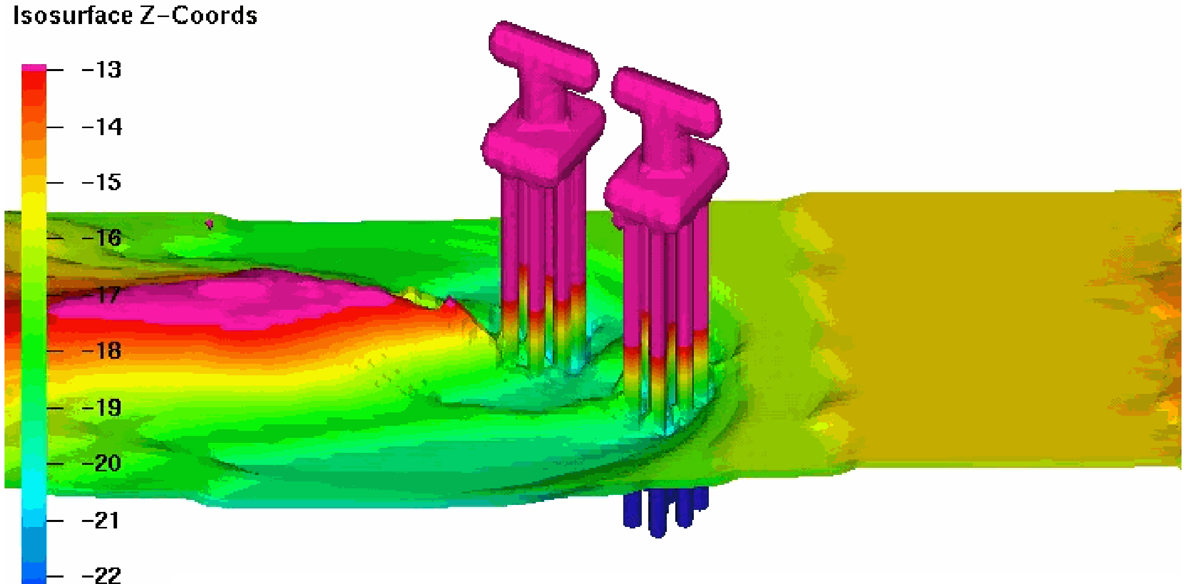
攻角10度





攻角30度





（吳祚任、王仲宇製。中央大學水海所、土木所）

SCI Paper

- Wu, Tso-Ren, Helsin Wang*, Yung-Yen Ko, Jiunn-Shyang Chiou, Shih-Chun Hsieh, Cheng-Hsing Chen, Cheng Lin, Chung-Yue Wang and Mei-Hui Chuang, 2012/09, Forensic Diagnosis on Flood-Induced Bridge Failure, Part II - Framework of Quantitative Assessment, Journal of Performance of Constructed Facilities, 10.1061/(ASCE)CF.1943-5509.0000393, (SCI: IF=0.45 RANK: 35/56 in CONSTRUCTION & BUILDING TECHNOLOGY)
- Wu, Tso-Ren, Mei-Hui Chuang, Chih-Jung Huang, Meng-Zhi Chen, Chung-Yue Wang and Chia-Ren Chu, "Developing a Two-way Coupled of Moving Solid Method for Solving Landslide Generated Tsunamis," Tsunami Simulation for Impact Assessment, Penerbit Universiti Sains Malaysia, 63-73, May, 2011.
- Wu, Tso-Ren*, Chih-Jung Huang, Mei-Hui Chuang, Chung-Yue Wang, and Chia-Ren Chu, 2011/12, Dynamic Coupling of Multi-Phase Fluids With a Moving Obstacle, Journal of Marine Science and Technology-Taiwan, 19(6), 643-650, (SCI: IF=0.483 RANK: 56/90 in ENGINEERING, MULTIDISCIPLINARY)
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- BOOK:
- Chuang, Mei-Hui and Tso-Ren Wu, “Dynamic Coupling of Multiphase Fluids with a Moving Obstacle: Developing a Two-way Coupled Moving Solid Method for Solving Landslide Generated Tsunamis,” VDM Verlag Dr. Müller, June, 2010.

小結

- 應科方案海嘯計畫之成果為中央及地方政府在擬定海岸災防策略時之重要依據。
- 本計畫所研發之海嘯自動化速算技術亦協助鄰近國家進行海嘯災防，並受國際肯定。
- 由本計畫所衍生之沖刷模擬技術可用於土石流及橋墩沖刷等災海模擬。
- 台灣海嘯歷史案例相當多，後續研究尚待努力。

謝謝聆聽！