THE RECENT DEVELOPMENT ON THE TSUNAMI MODELING AND EARLY WARNING

DMCC DISASTER MITIGATION WORKSHOP

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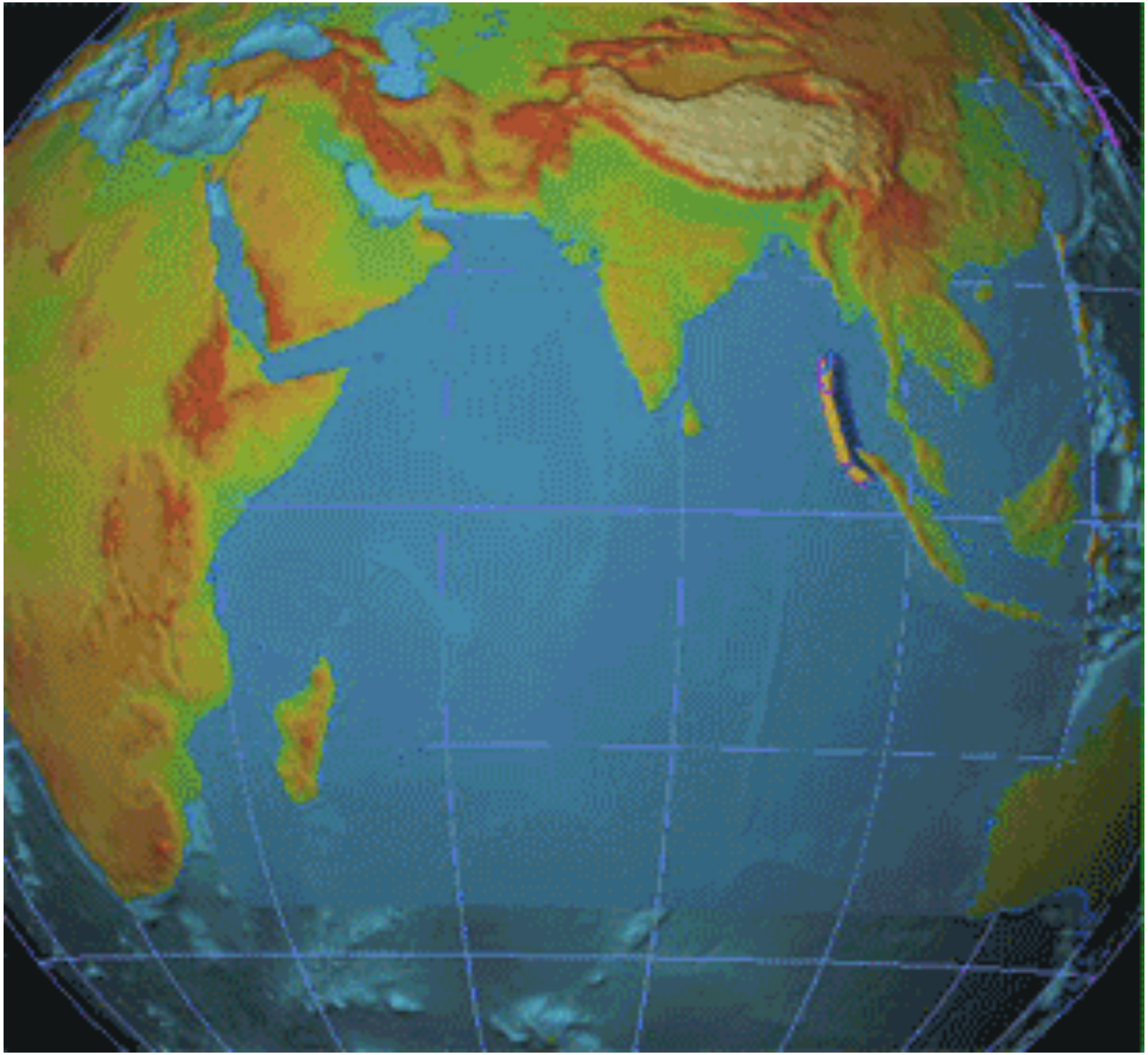
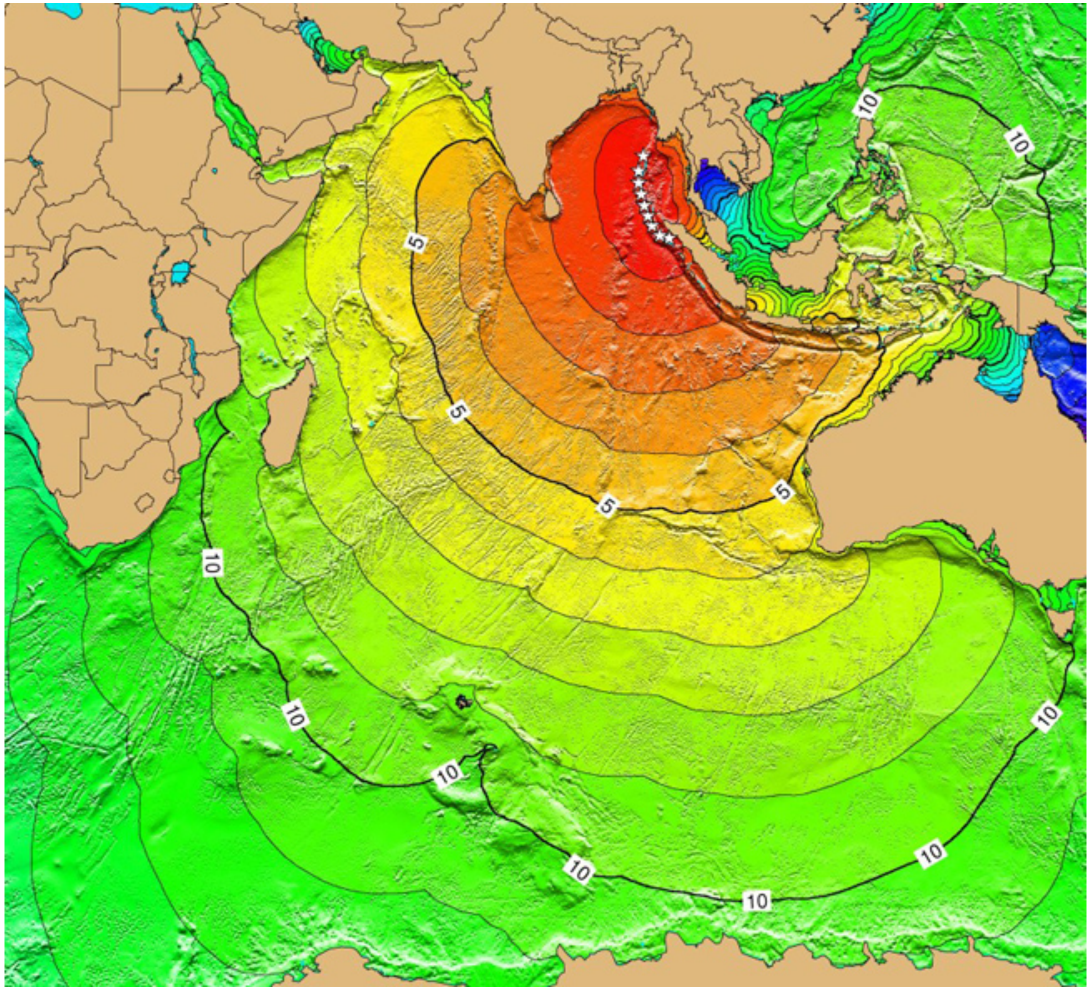
2004 Indian Ocean earthquake and tsunami
Mw=9.3, L=1500KM



Tsunami Arrival Time for 2011 Indian Ocean Tsunami



NOAA's tsunami travel time (TTT) map for the 2004 Indian Ocean tsunami.

290,000 more death toll

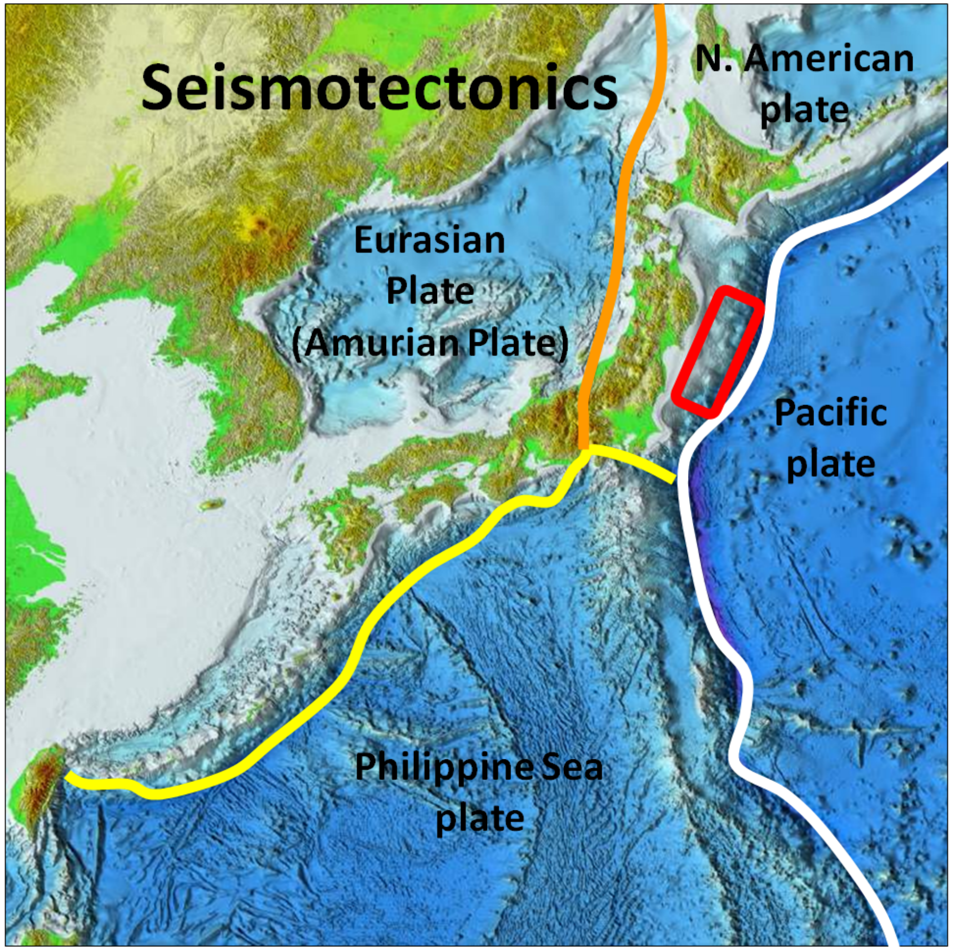

Dont
Broken


35 ft
10 m
30 ft
8 m
25 ft
6 m
20 ft
15 ft
4 m
10 ft
2 m
5 ft

Giant earthquake occurred at a relatively short and sinuous rupture interface

2011年東日本大海嘯，強烈地震發生在相對**短**且**彎曲**之破裂面上

2011 Tohoku earthquake and tsunami, Mw=9.1, L=500 KM



(Copy right: Newton)

Lessons learned from the 2011 2011 Tohoku earthquake and tsunami

2011東日本大海嘯使海嘯災防與研究有許多革新的看法

- A devastating earthquake will occur on a long and straight trench? (毀滅型海嘯不一定發生在超長且平直的海溝上)
  - No, it might not.
  - (例如南中國海東側馬尼拉海溝的海嘯威脅)

Other questions…

- A tsunami disaster can be prevented by the coastal vegetation? （海嘯可以透過海岸植生防治？）
- The reinforced concrete (RC) can against the tsunami waves? (房子不怕海嘯？)
- T海嘯牆可以防範海嘯侵襲？
- 海嘯預警可透過離岸浮標加以監控？
- 海嘯預警模擬到海岸即可，不需要計算到內陸？

海岸植生防海嘯

岩手縣陸前高田市

Rikuzen Takata City

Population: 24,246

Number of households: 8,068

高田松原公園有廣大的松樹植生林
用於防範海嘯侵襲

（Ando, 2011)

Pine tree of hope
希望之松

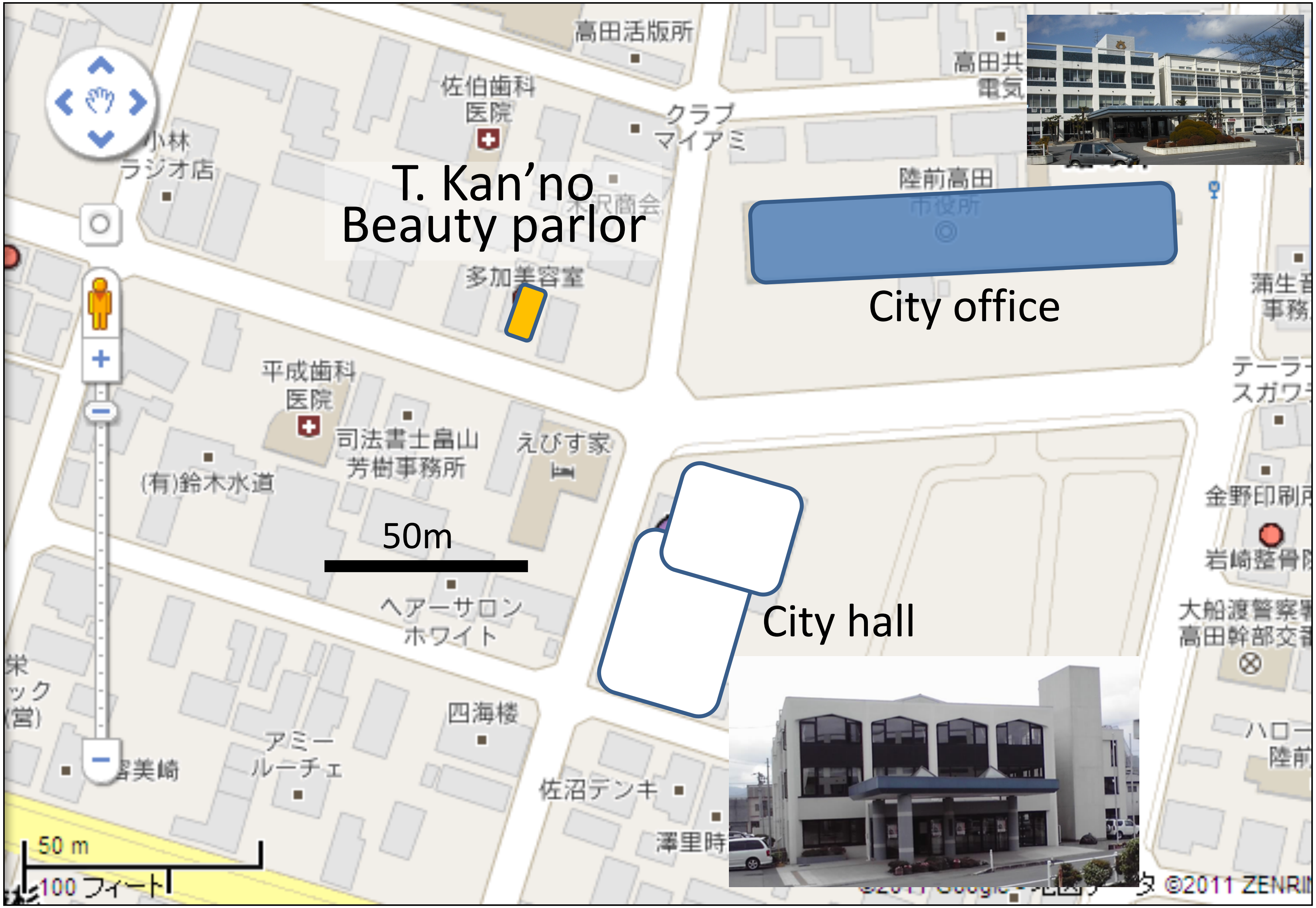
海岸防海嘯松樹林被摧毀
松樹林削減海嘯能量功效不明，
但碎片 卻造成額外的威脅

（Ando, 2011)

RC建築承受不住海嘯衝擊而折斷並翻滾
Turned over two-story RC building

（Ando, 2011)

(Ando, 2011)


T. Kan’no
Beauty parlor
City office
City hall
50m
高田活版所
佐伯歯科
医院
クラブ
マイアミ
陸前高田
市役所
多加美容室
平成歯科
医院
司法書士畠山
芳樹事務所
えびす家
(有)鈴木水道
ヘアーサロン
ホワイト
四海楼
アミー
ルーチェ
佐沼デンキ
金野印刷
大船渡警察署
高田幹部交番
50 m
100 フィート
©2011 ZENRIN

(Ando, 2011)

City Hal (市府大樓)

（Ando, 2011)

City Hall was destroyed
市府大樓被海嘯摧毀

（Ando, 2011）

City Office
市府辦公大樓

（Ando, 2011)

City Office kept the shape. However, it was penetrated by the tsunami debris.
市府辦公大樓外觀大致完整，
但內部已被海嘯與破碎物貫穿

（Ando, 2011)

The seawall sometimes called “The Great Wall” by local residents.
有海上萬里長城之稱的岩手縣釜石市小白浜防耐海嘯海堤

（Ando, 2011）

岩手縣釜石市小白浜防耐海嘯海堤

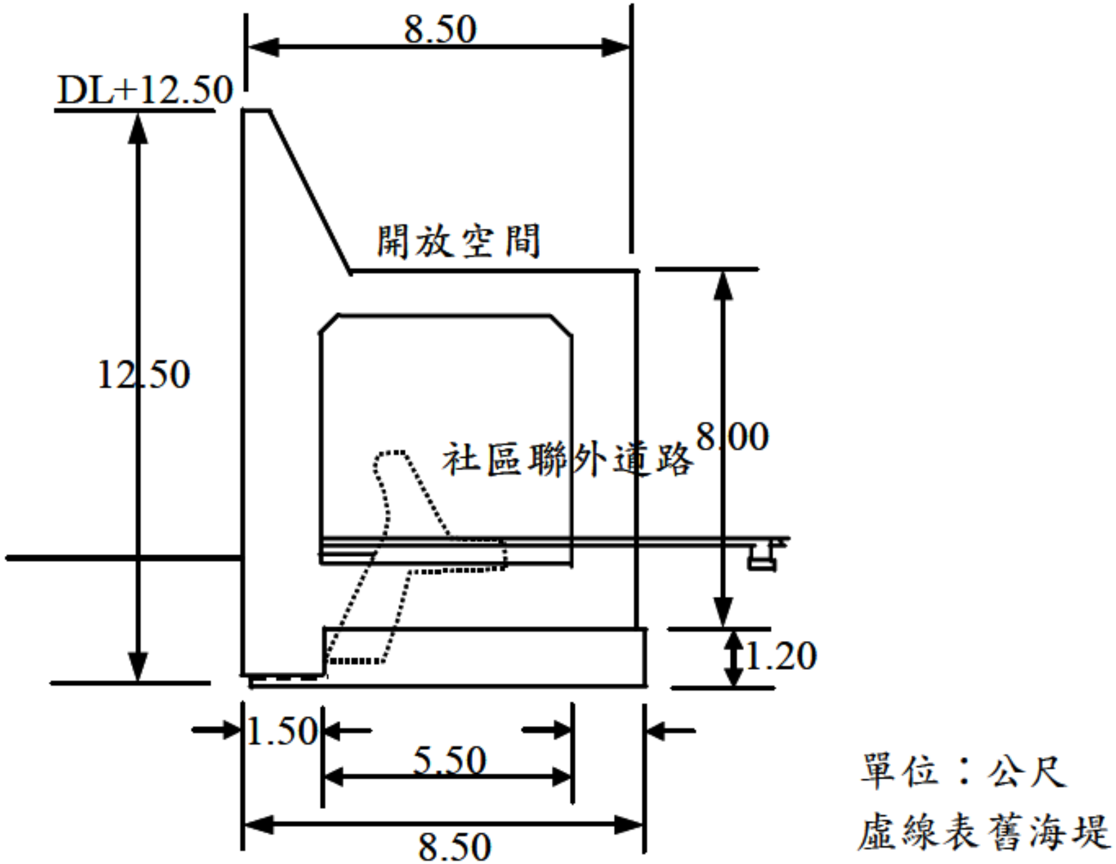


圖2-4-7 日本岩手縣釜石市小白浜地區(Kojirahama)之耐海嘯海堤斷面示意圖(資料來源：Tsunami：Progress in Prediction, Disaster Prevention and Warning，1995)

The great seawall was not tall enough to hold back the tsunami.
有海上萬里長城之稱的防海嘯提，被海嘯摧毀，僅末端保持完整但已喪失防海嘯功能

（Ando, 2011)

(Ando, 2011)

日本岩手縣普代村15公尺海嘯牆完整抵擋海嘯

- 日本岩手縣普代村位於兩個山坡之間，面對大海，大約有兩千多村民。30年前，普代村正在規劃防波堤與水門，而當時村長堅持蓋15公尺而廣受眾人批評。大多數村民都認為15公尺太高了。不過當時村長和村幸得矜持不肯讓步。和村幸得指出，1896年明治三陸海嘯和1933年昭和三陸海嘯造成439人死亡，而明治年間曾經來了15公尺的海嘯，因此堅持要建高。由於同樣在岩手縣，宮古市田老地區也建造舉世聞名的『萬里長程』超級防波堤也僅有10公尺高，因此和村幸得村長的15公尺高的防波堤構想在當時備受詬病。最後防波堤終究市完成。普代村在1967年耗資5800萬日圓，建造15.5公尺高，155公尺長的太田名部防波堤，其後又斥資35億日圓，在1984年建城15.5公尺高，205公尺長的普代水閘。

日本岩手縣普代村15公尺海嘯牆保住村民財產性命。圖片來源：可可日語。

海嘯高度預估是否足夠非常重要

『萬里長程』超級防波堤10公尺高

普代村15公尺海嘯牆

Tragedy of OKAWA Elementary School

- Many public schools were completely destroyed, including Ishinomaki Okawa Elementary School (大川小学校), which lost 70 of 108 students and nine of 13 teachers and staff[11] There is still anger among some of the parents of the dead students because the teachers had wasted precious time in debating whether to evacuate to higher ground. And when the decision was finally made, the teachers had decided to get to higher ground further away from the school which necessitated crossing a nearby river bridge. It was here while crossing the bridge that both the teachers and students were swept away by the tsunami. This decision is deemed unreasonable by many of the parents because there is a hill right behind the school, which they could have reached quickly. One of the teachers had tried to persuade the other teachers to bring the students to safety uphill soon after the earthquake; when he was unsuccessful, he evacuated himself, managing to persuade one of the students to go with him - both survived. One of the teachers who survived the tsunami at the bridge later committed suicide.[12][13][14][15][16]

大川小學依山傍河，風景優美。地震發生於下午2點46分，而海嘯則是於3點30分左右來襲。這當中約有50分鐘的時間可以將學童疏散至後面的山上。然而學童被勒令乖乖排隊在操場等候，而教師則在爭執是否上山避難，部分老師認為地震後樹木有倒下的危險，不應上山，也因此錯失逃生良機。最後海嘯來襲，高度竟然高於校舍的最高點，全校108名學生，僅31名倖存。

致命的第二次錯誤：錯誤的避難地點

有人認為大橋上很安全：結果海嘯順著河川逆流而上，最後海嘯淹過大橋

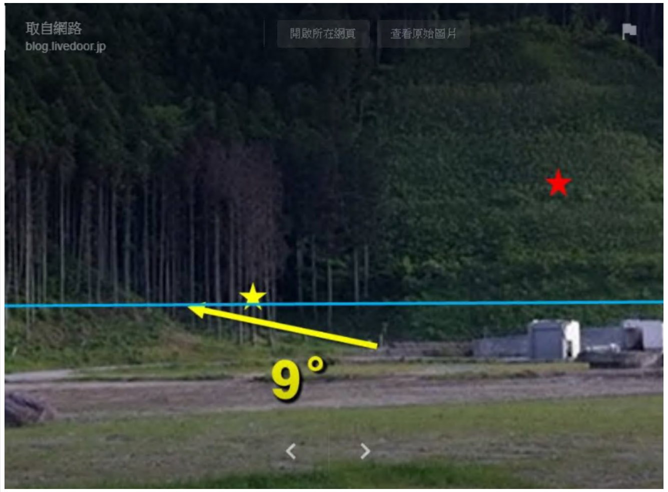
海嘯逃生最基本概念：往高處逃

- **錯誤的海嘯到時，導致民眾誤以為海嘯已經不會來襲**
- **準確的到時，必須考慮海嘯溯昇與溢淹。**
- **需要準確的近岸地形與非線性溢淹模式互相搭配應用**

2011年3月19日大川小學校周邊地理環境。綠色部分及為未受海嘯侵襲之山丘。圖片來源：日本河北新報。


Ishinomaki Shiritsu Okawa Elementary ...
目指した交差点
新北上大橋
50m
北上川
堤防
裏山
児童が通った裏道
富士川
釜谷交流会館
永沼さんが立っていた所
児童の避難経路
校庭
大川小校舎
体育館
三條さんが通った道
新北上大橋
1000m
北上川
大川小
釜谷地区
墓地
長面地区
長面浦
石巻市
追波湾


Ishinomaki Shiritsu Okawa Elementary School
中里俊也
5月 2017


取自網路
blog.livedoor.jp
開啟所在網頁
查看原始圖片
9°


地図
写真
津波の集中
著しい地盤沈下
津波による破壊
© 2012 Cnes/Spot Image
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2012 GeoEye
Google earth

Is Taiwan under the threat of tsunami attract?

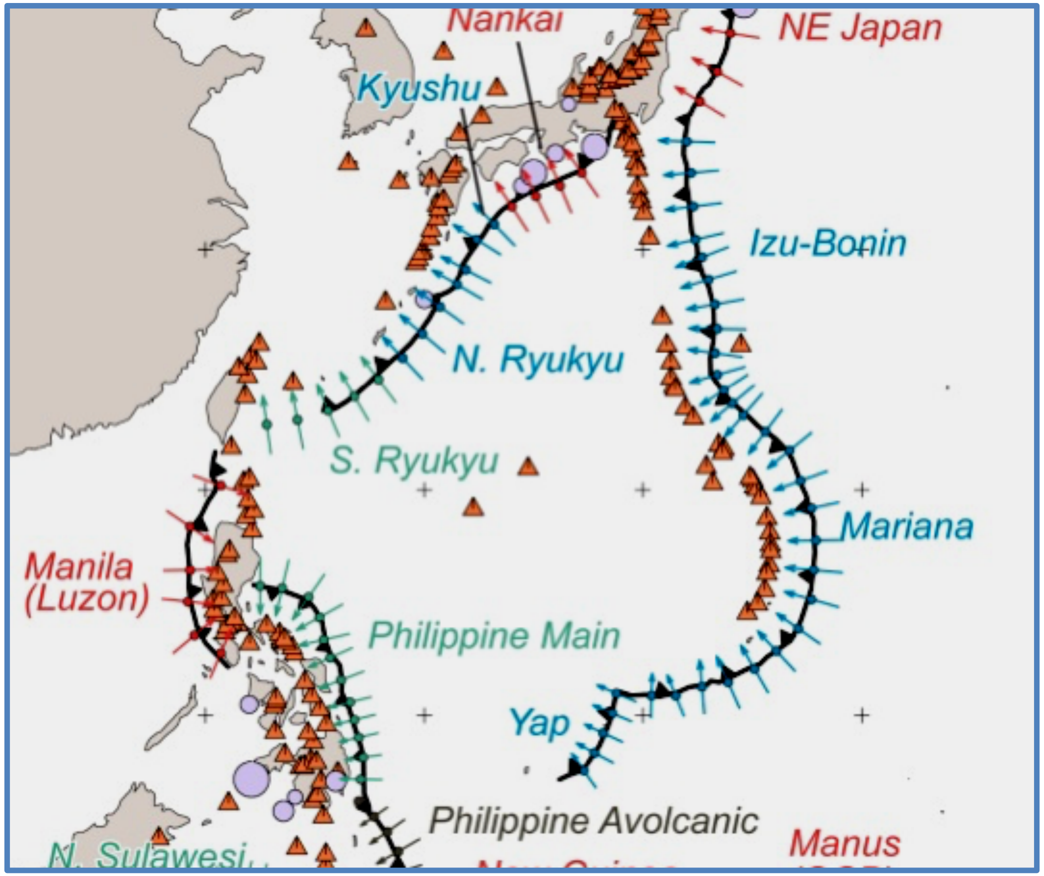
Distribution of trench

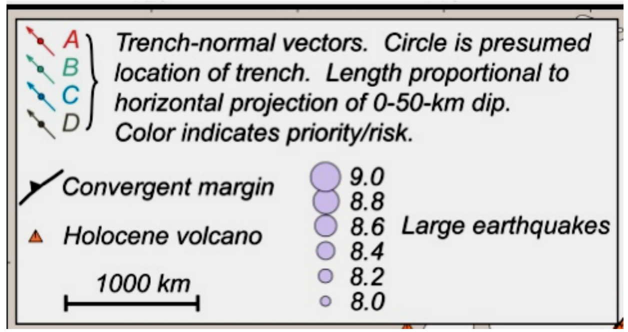
Historical record

Tsunami boulders and sediment deposit

Scenario study

The Trench Distribution around Taiwan (USGS)
台灣周圍海域之海溝分布





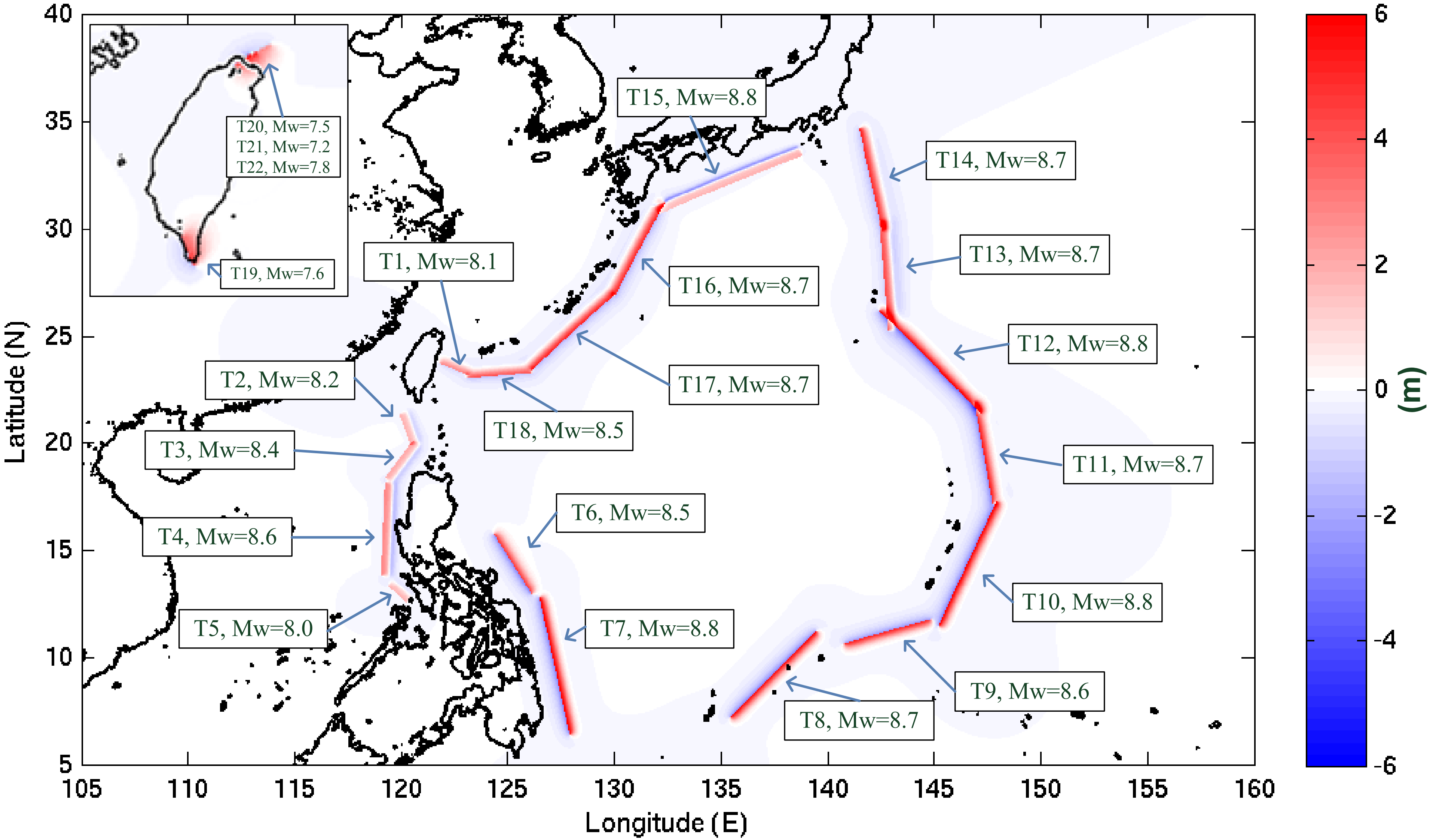
Tsunami Source Characterization for Western Pacific Subduction Zones: A Preliminary Report USGS1 Tsunami Subduction Source Working Group

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

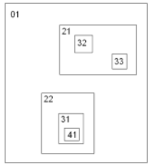
Recently the USGS issued a report assessing the potential risk as a tsunami source along the entire Pacific seduction zones. One highly risk zone is identified along the Manila (Luzon) trench, where the Eurasian plate is actively subducting eastward underneath the Luzon volcanic arc on the Philippine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

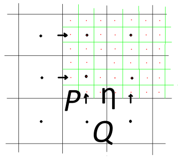
Tsunami Sources of
18 Trench and 4 Fault Segments

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



COMCOT
Tsunami Model



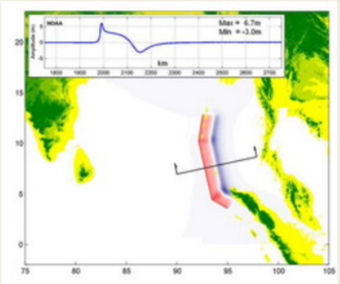


Tsunami Model: COMCOT

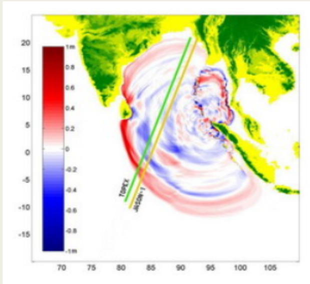
(Cornell Multi-grid Coupled Tsunami Model)

康乃爾大學多重巢狀網格海嘯數值模式

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.

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

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

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

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

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

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

Eq.01 SWE in Spherical Coord. *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.

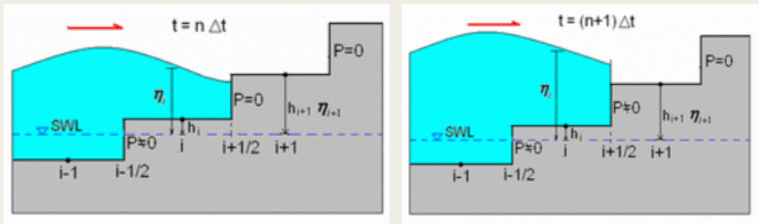


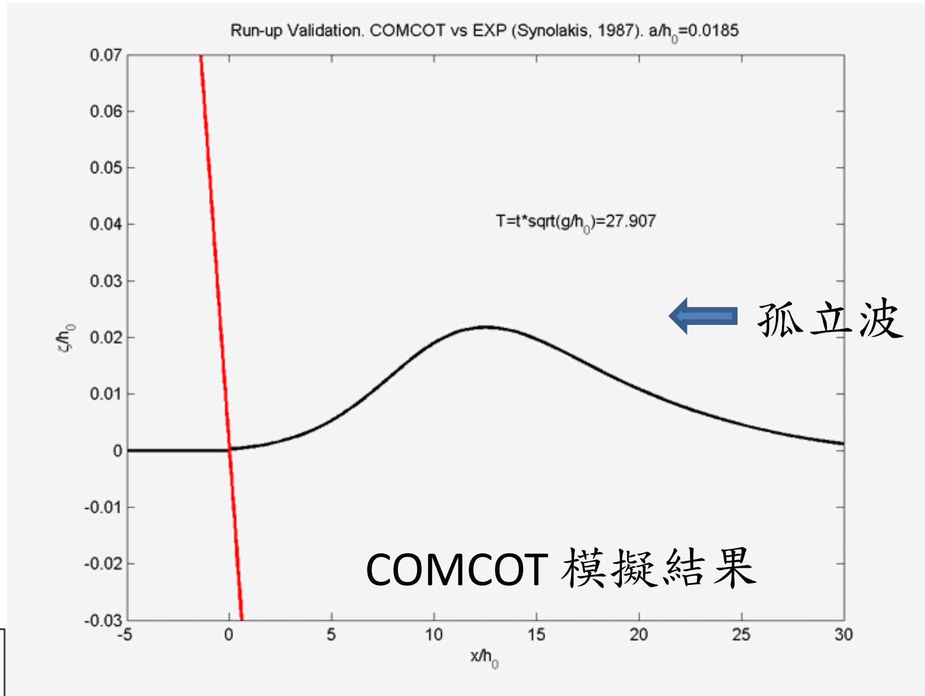
Fig.02 Moving Boundary Scheme

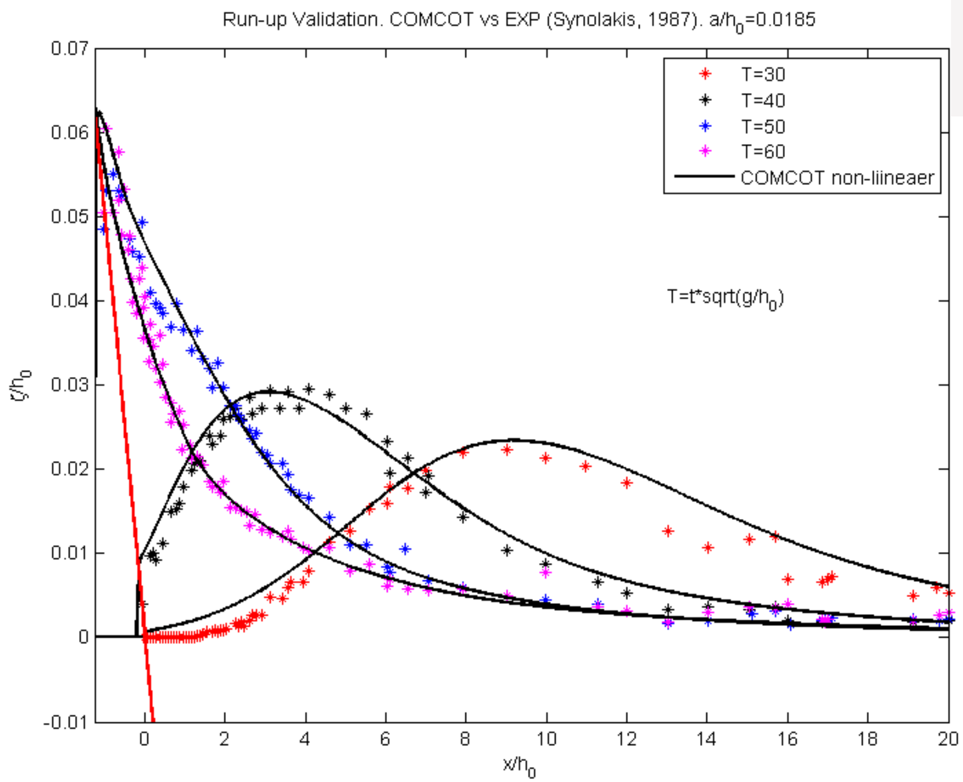
(1). Widely validated

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.

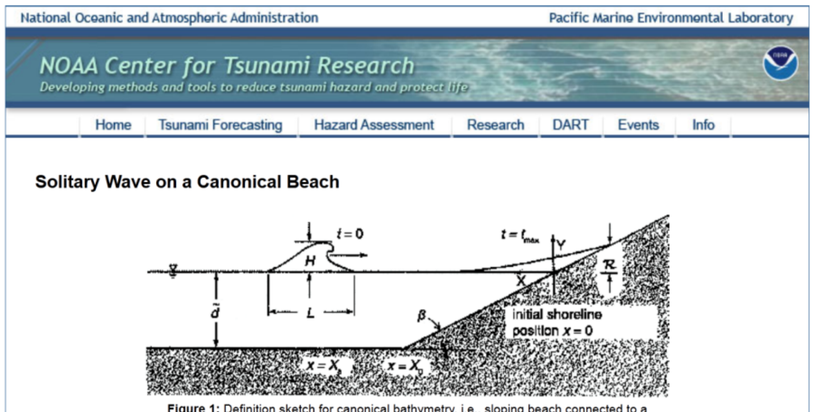
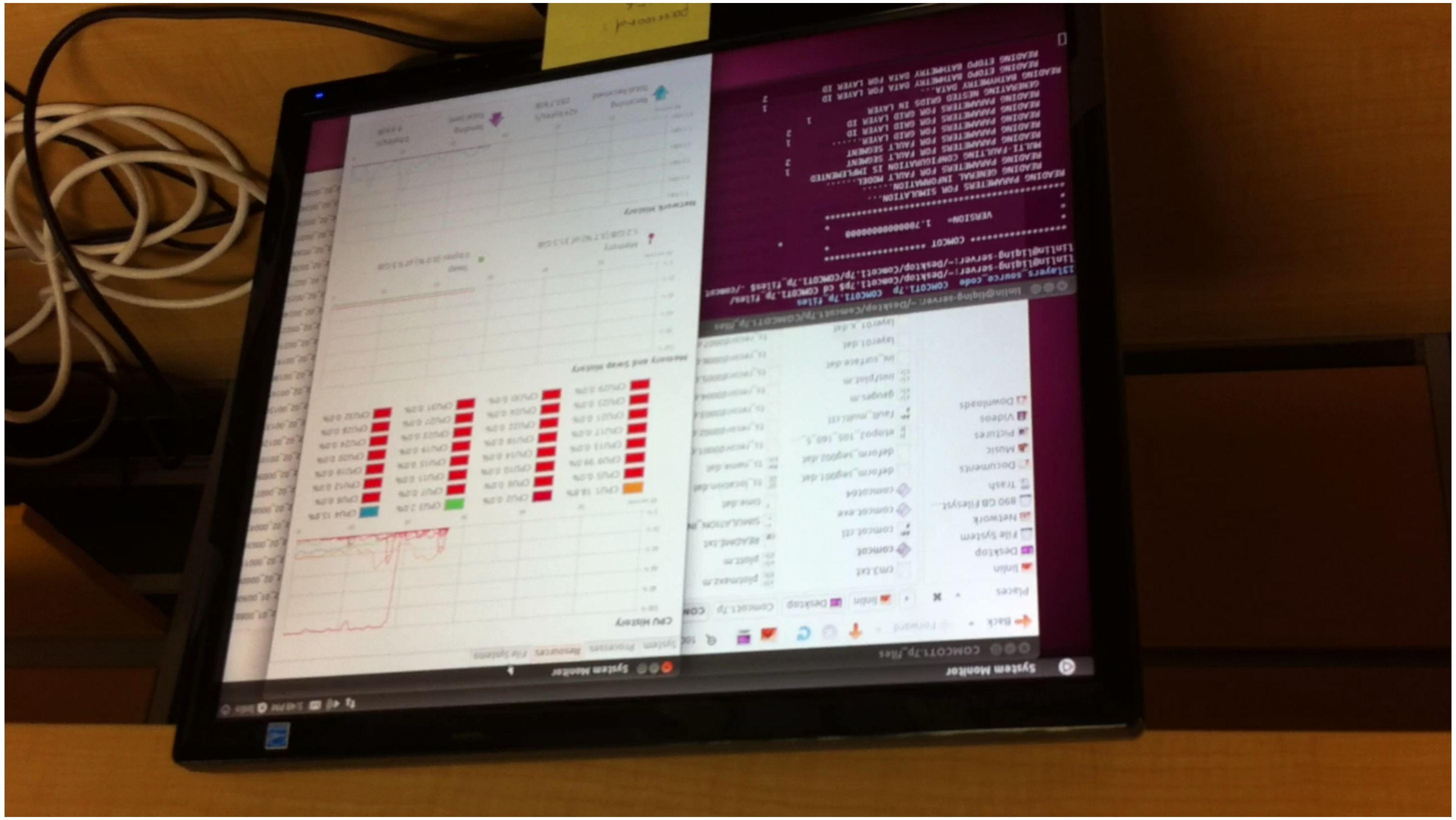


Figure 1: Definition sketch for canonical bathymetry, i.e., sloping beach connected to a constant-depth region.

（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

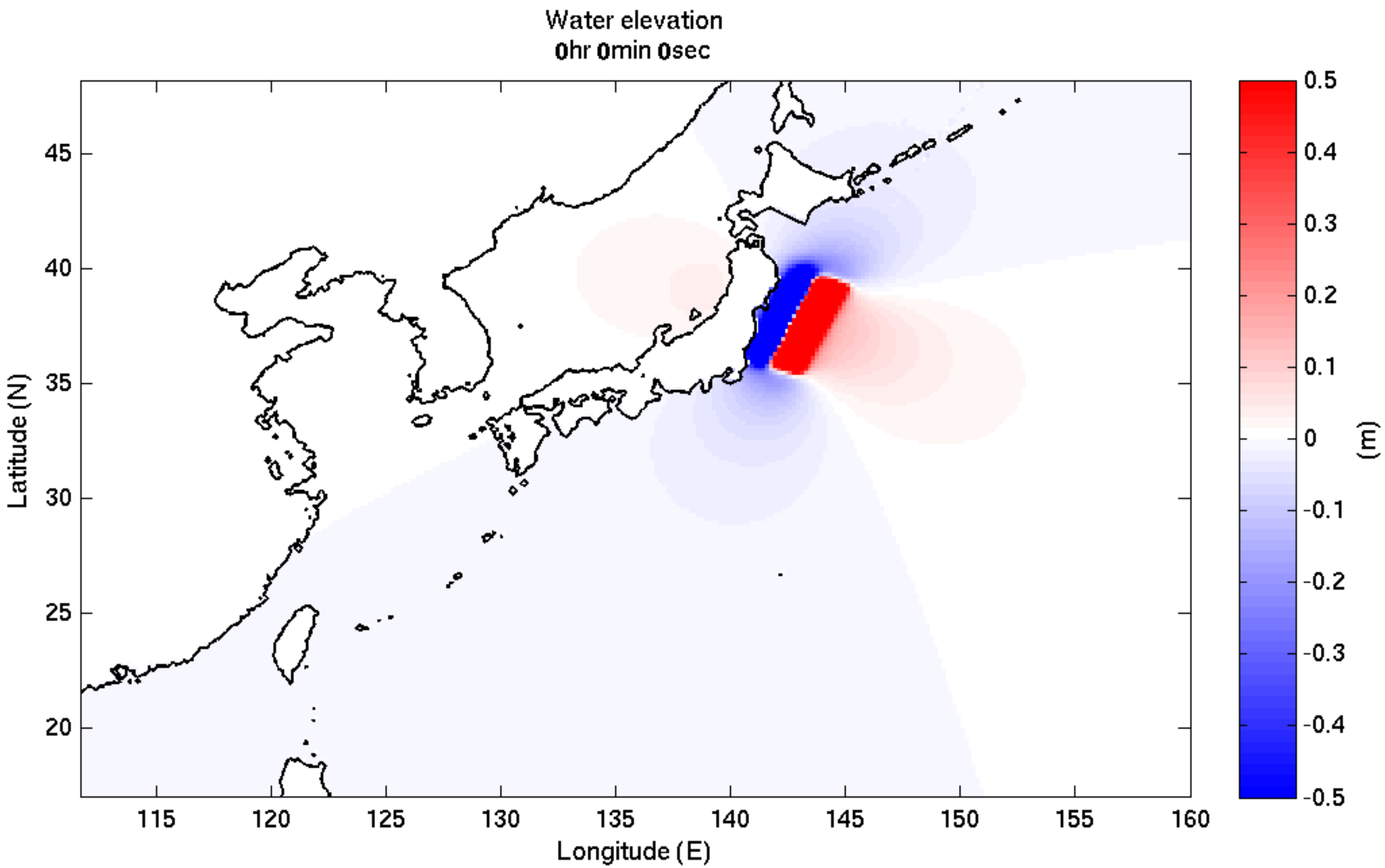


（We tested COMCOT on a new 32-core server in NTU, Singapore. A case used to be done in 30 minutes can be finished in 2 minutes on the new machine.）

2011 Tōhoku earthquake and tsunami

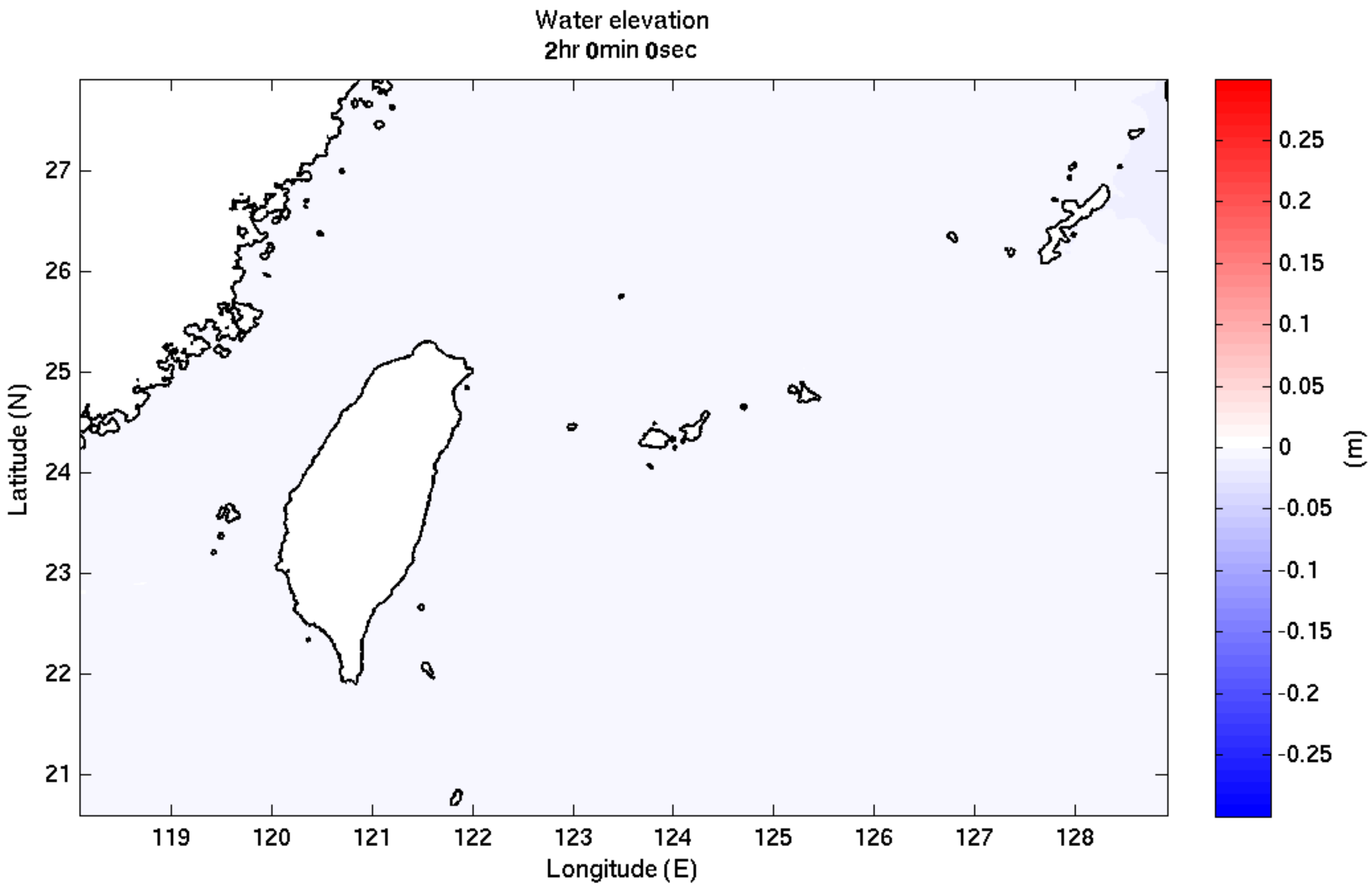
- We spent about 20 mins to prepare, or wait for, the fault parameters
- COMCOT spent about 1 min to finish the tsunami simulation from Japan to Taiwan.
- It is about real-time simulation
- COMCOT predicted that the tsunami wave height was about 12 cm offshore Taiwan.
- Field data also showed about 12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

模擬結果：海嘯傳播方式



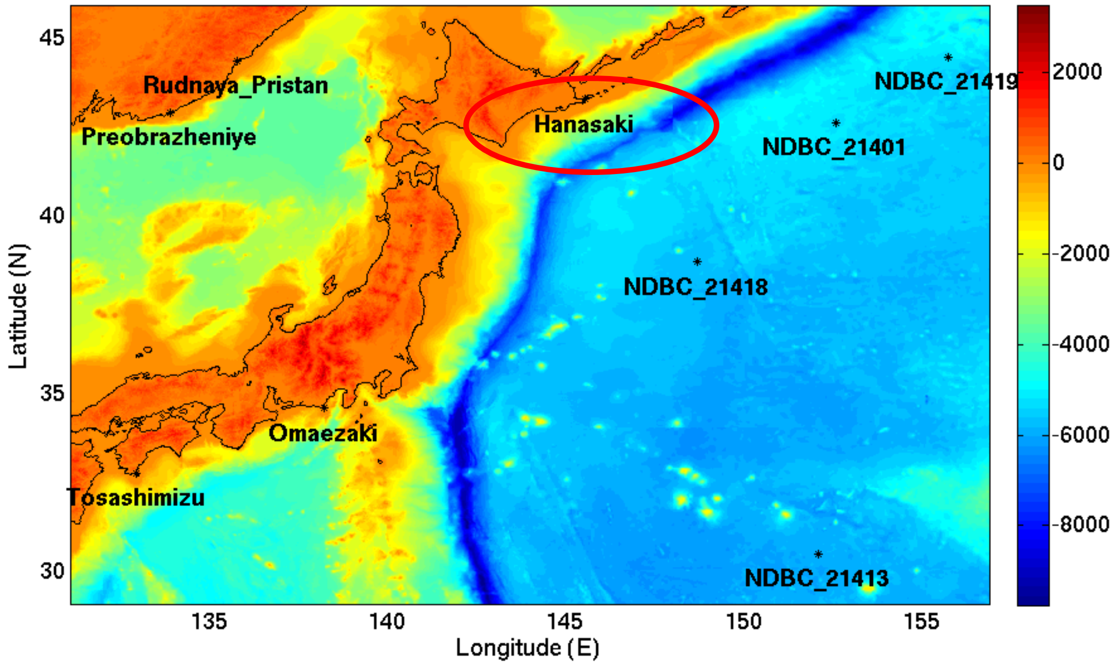
Water elevation
0hr 0min 0sec
45
40
35
30
25
20
Latitude (N)
115
120
125
130
135
140
145
150
155
160
Longitude (E)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
(m)

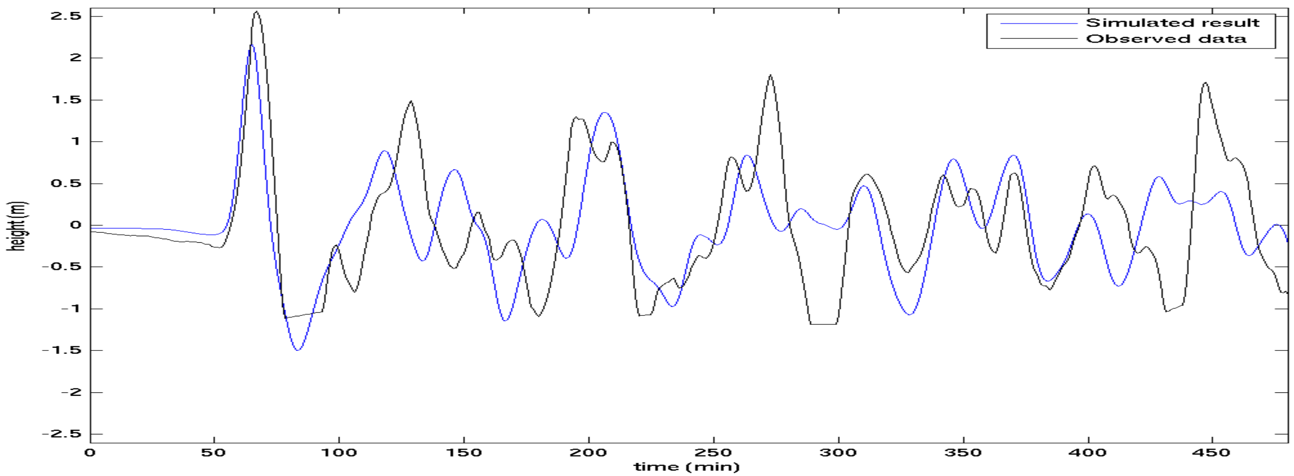
海嘯傳遞至台灣



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)

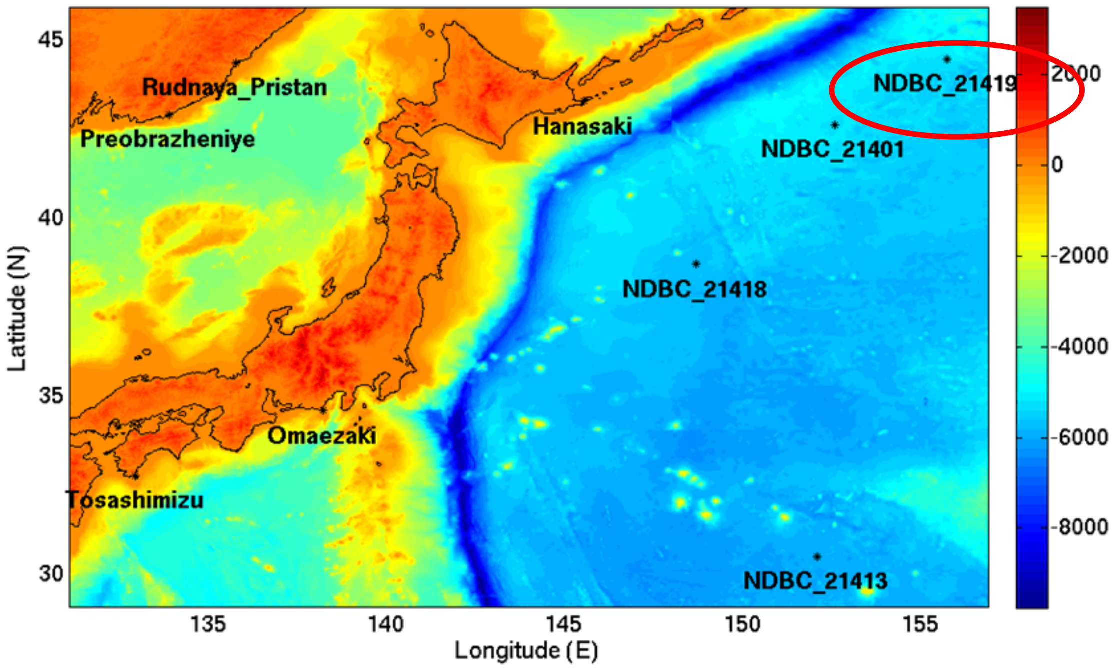
模式預測之海嘯波高與日本潮位站實測比對：Hanasaki

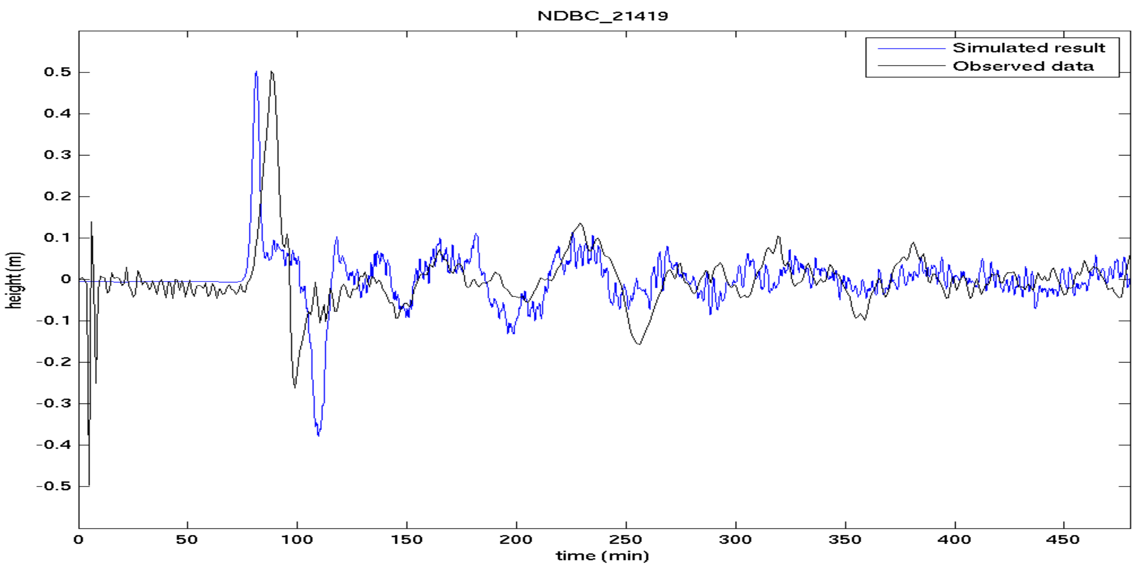




Hanasaki 潮位站比對，藍線為模擬結果，黑線為實測資料。該站位於斜坡部分，模擬結果與實測比對相當一致。

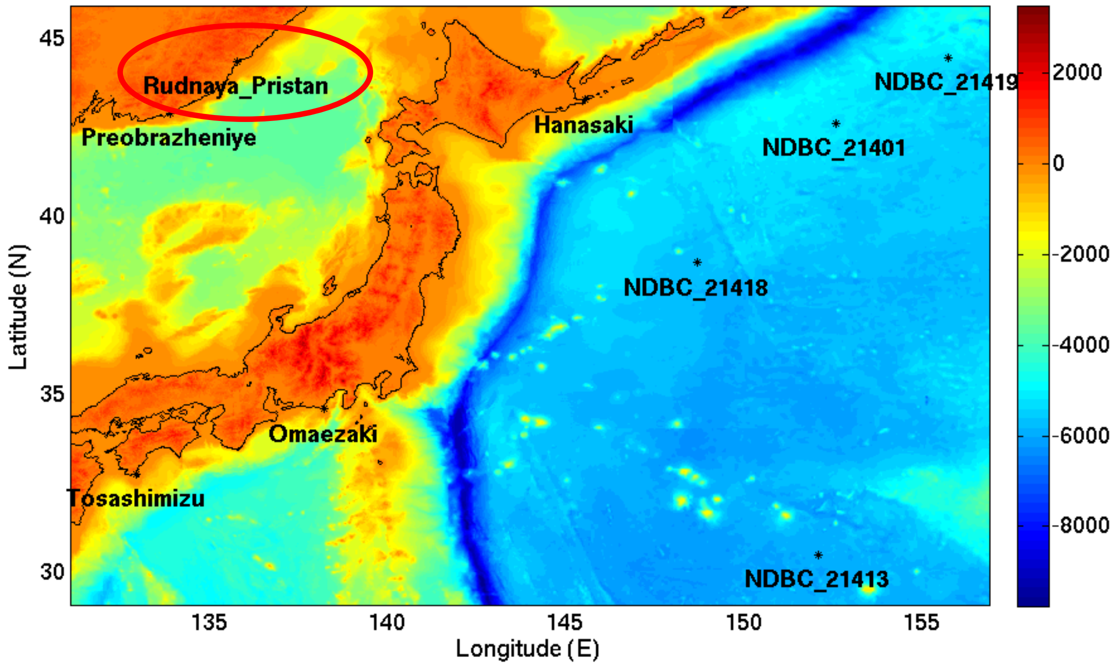
模式預測之海嘯波高與美國NOAA深海浮標實測比對：NDBC_21419



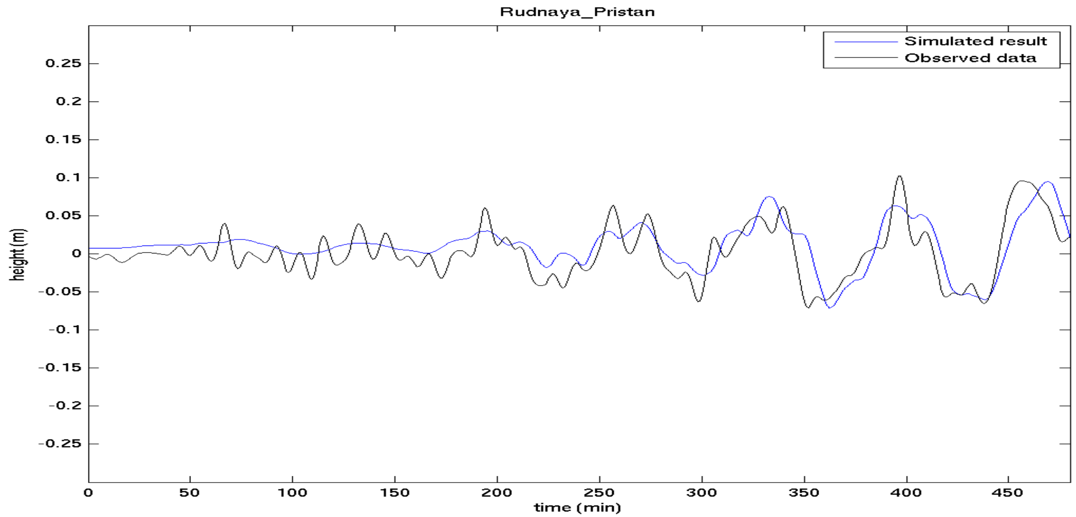


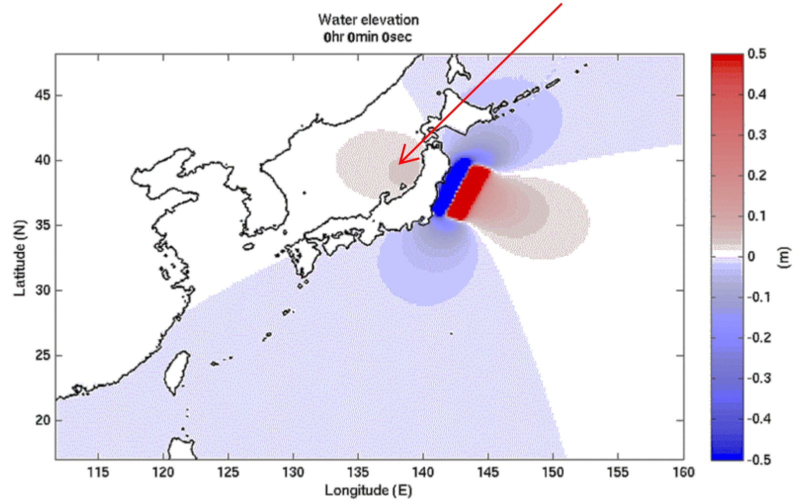
與NOAA浮標資料比對，藍線為模擬結果，黑線為實測資料。模擬結果與實測比對相當一致。

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）

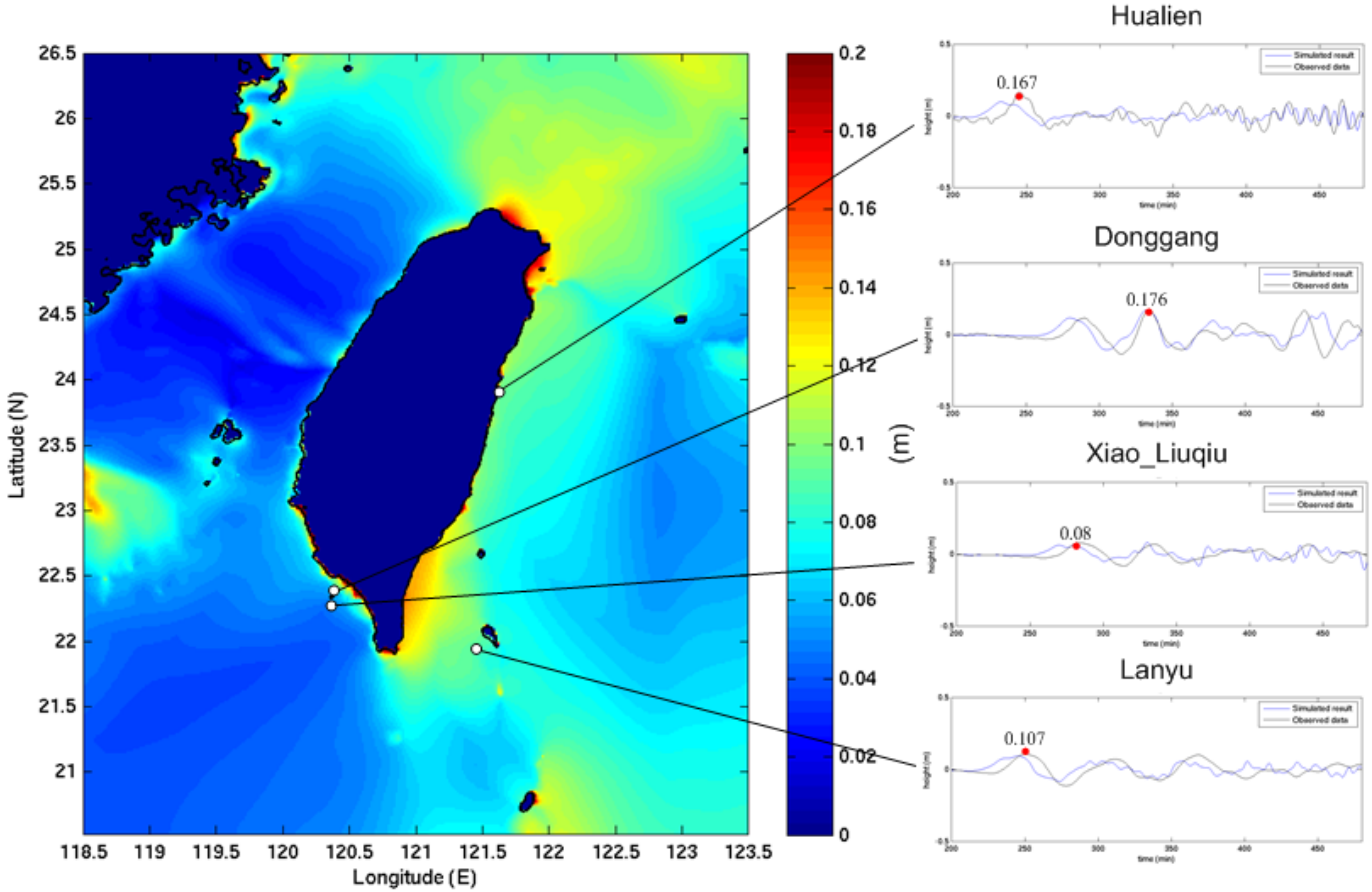


西海岸海床抬昇





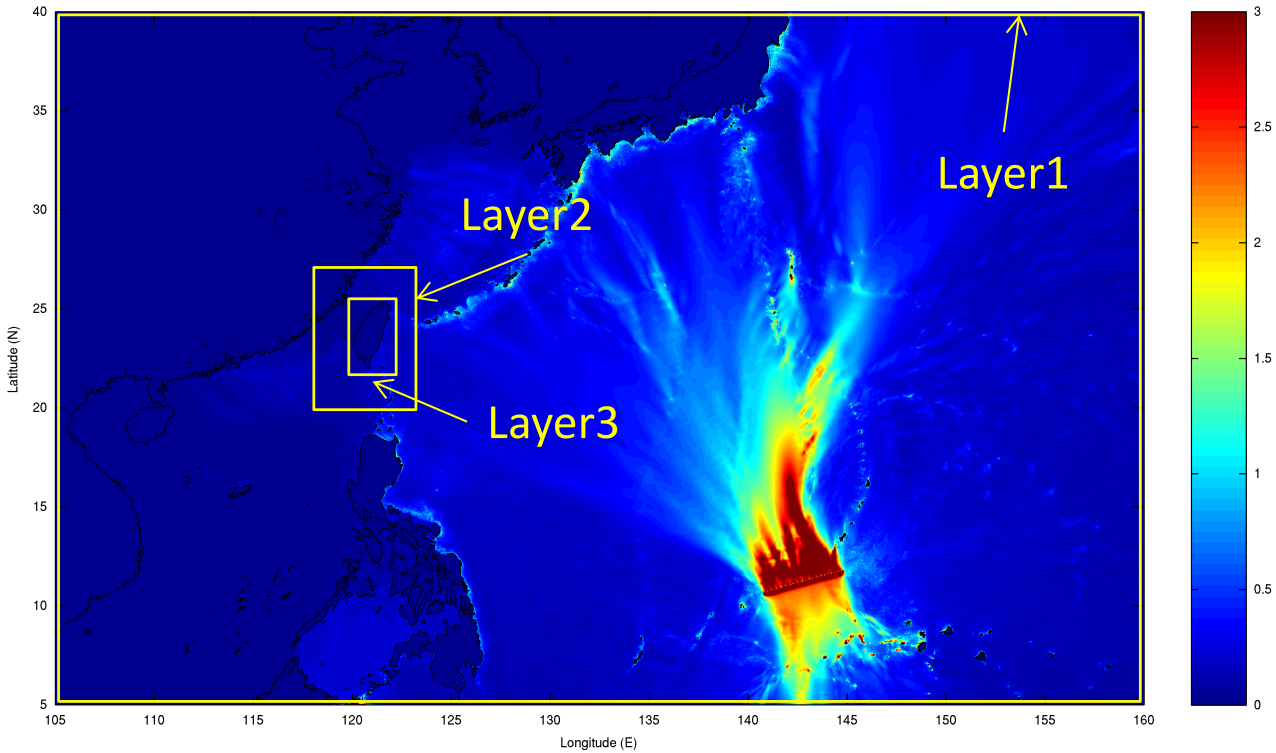
模式預測之海嘯波高中央氣象局潮位站資料比對

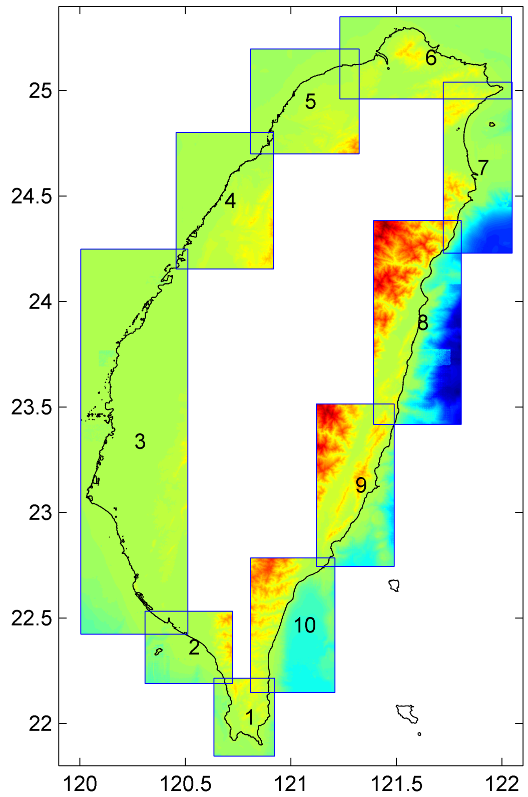


台灣測站比對。比對花蓮、東港、小琉球、蘭嶼四個測站，結果相當理想。（藍線為模擬結果，黑線為實測資料，資料提供：中央氣象局）

Simulation Results of Tsunamis from 18 Trench Segments

Nested Grids

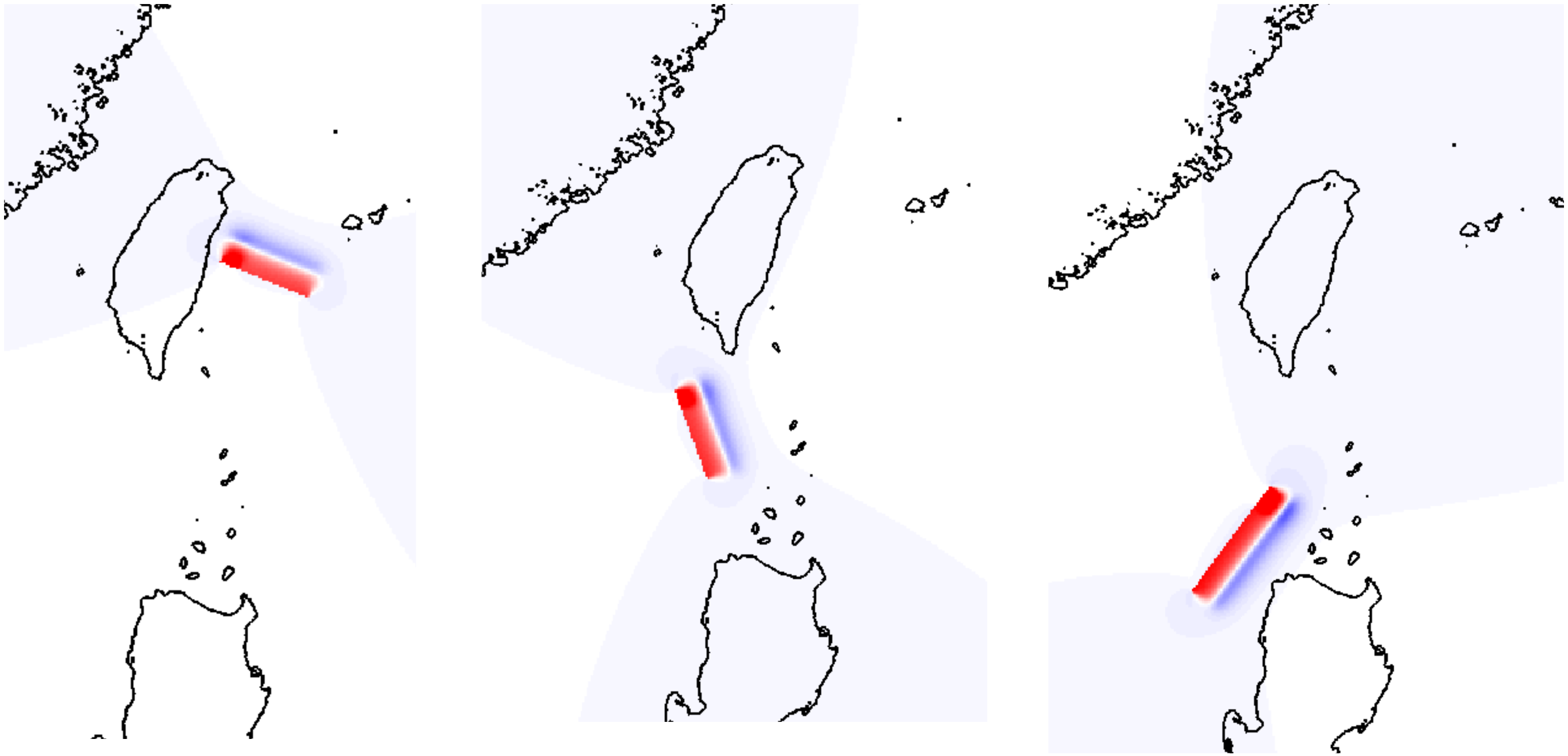


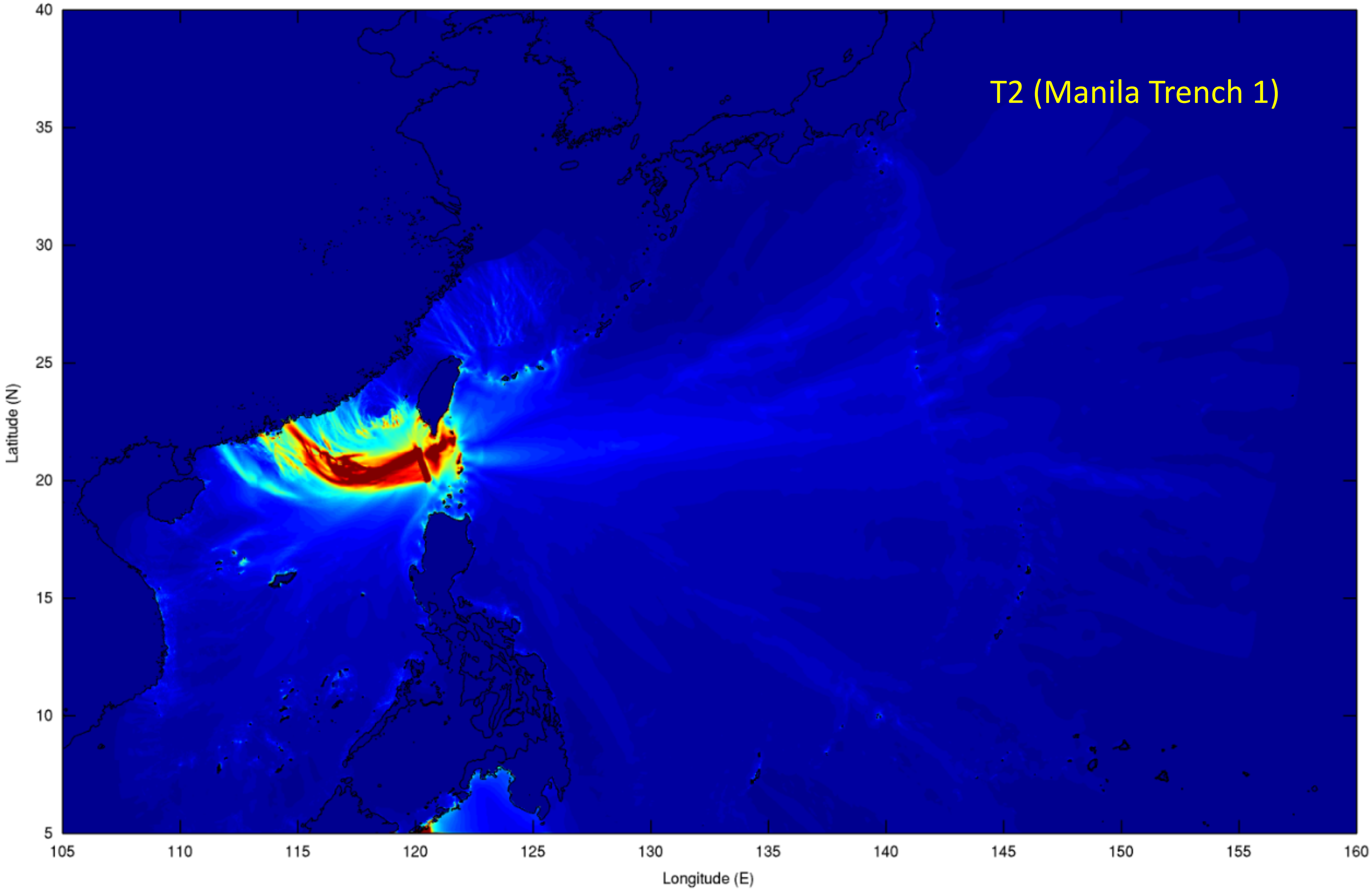


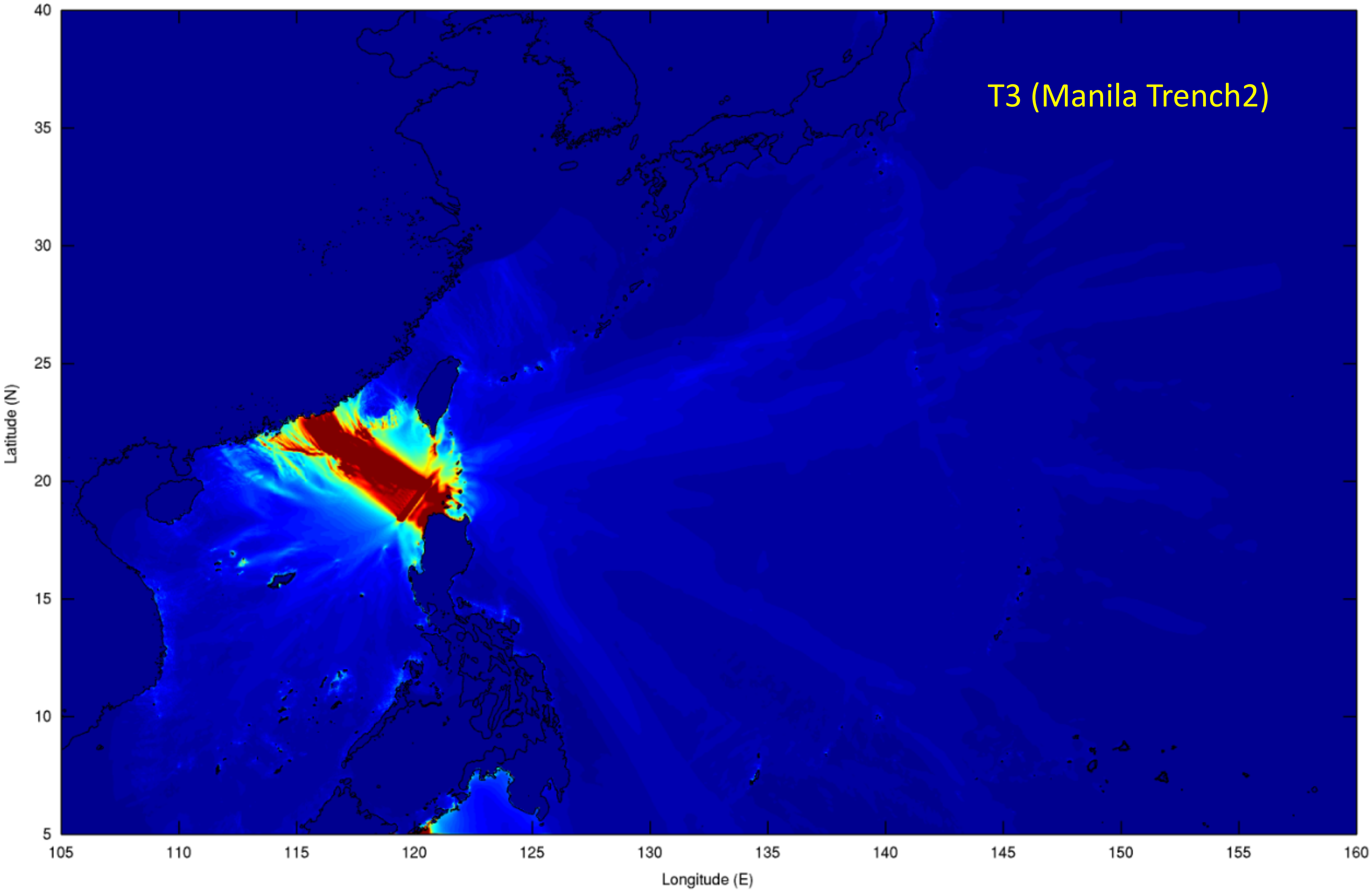
Layer 1: 2 min (~3500m);
Layer 2: ½ min (~900m);
Layer 3: 1/8 min (~200m);
Layer 4: 1/128 min (~50m);
Layer 5: 1/512 min (~10m);
Layer 6: 1/2048 min (~2m);

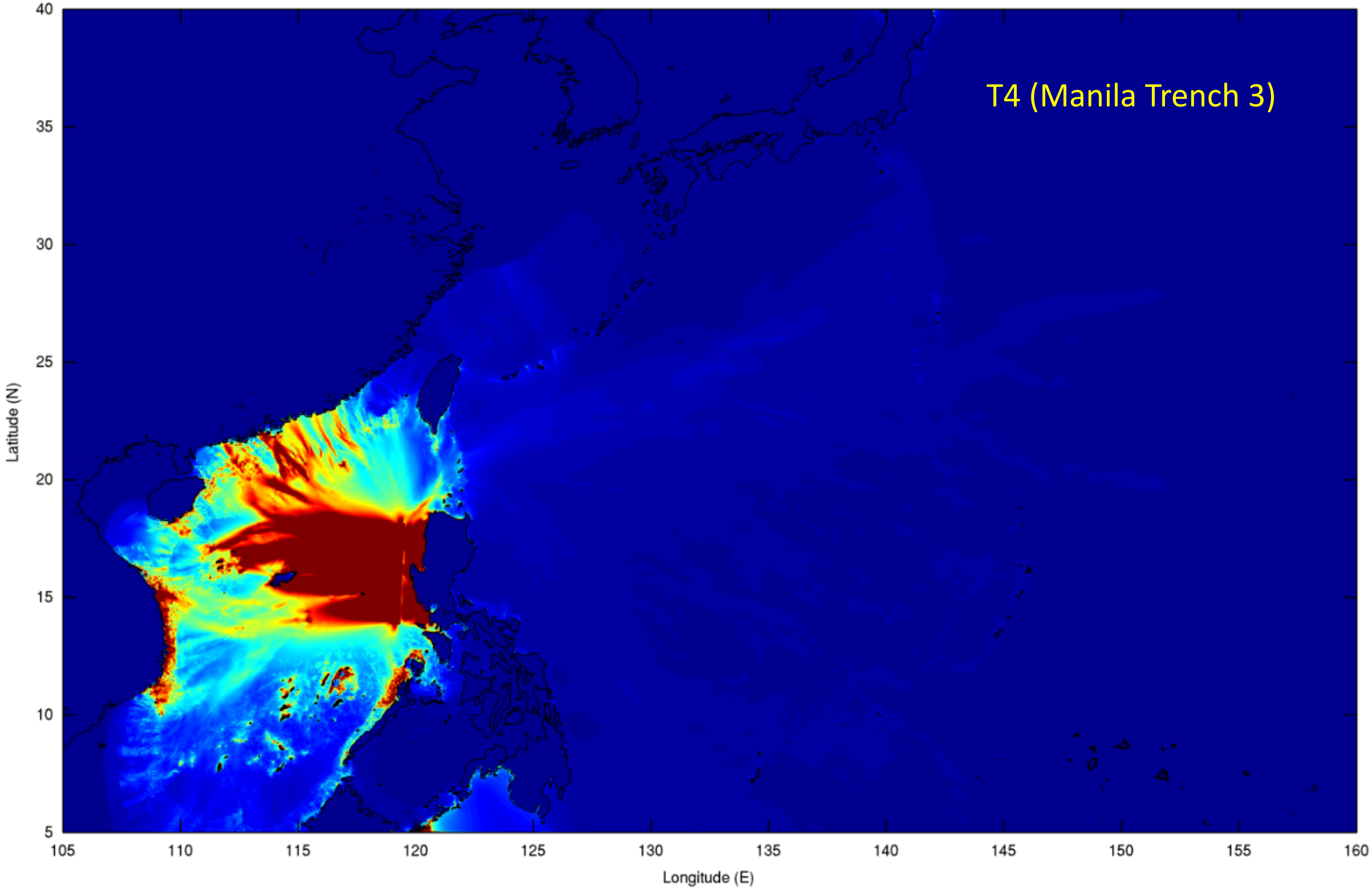
Source of Bathymetry

- **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**




T2 (Manila 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


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)
40
35
30
25
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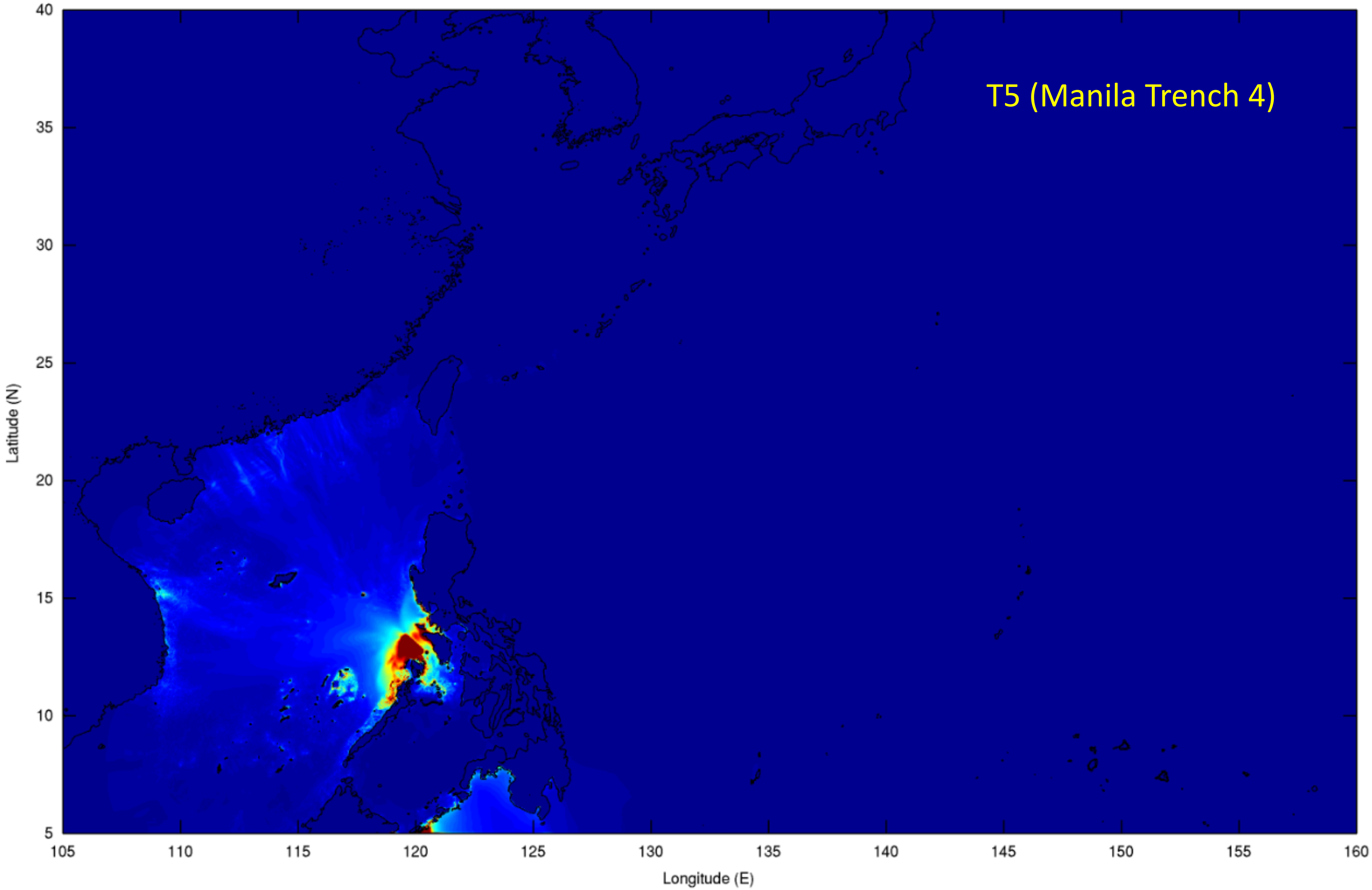
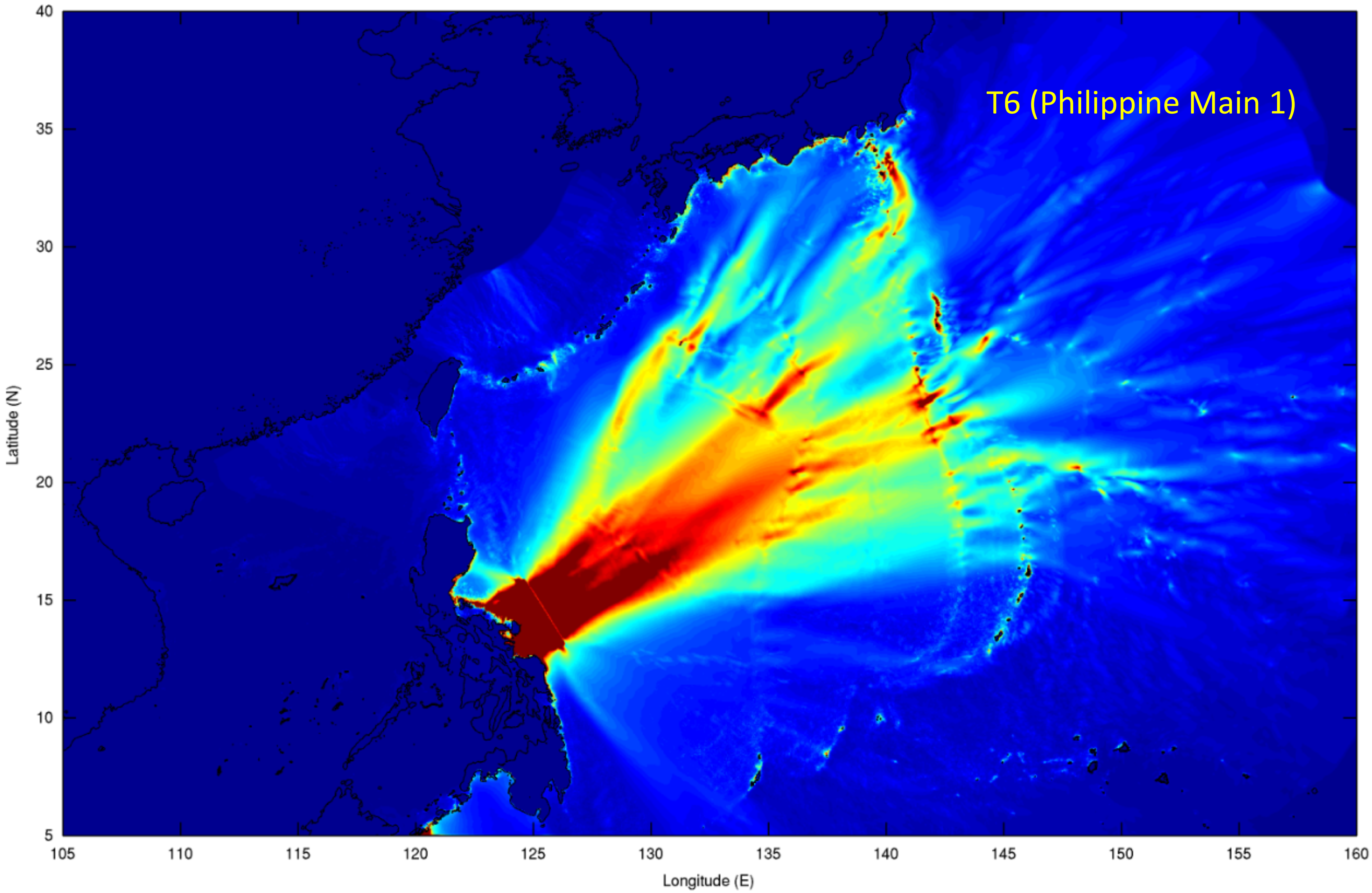
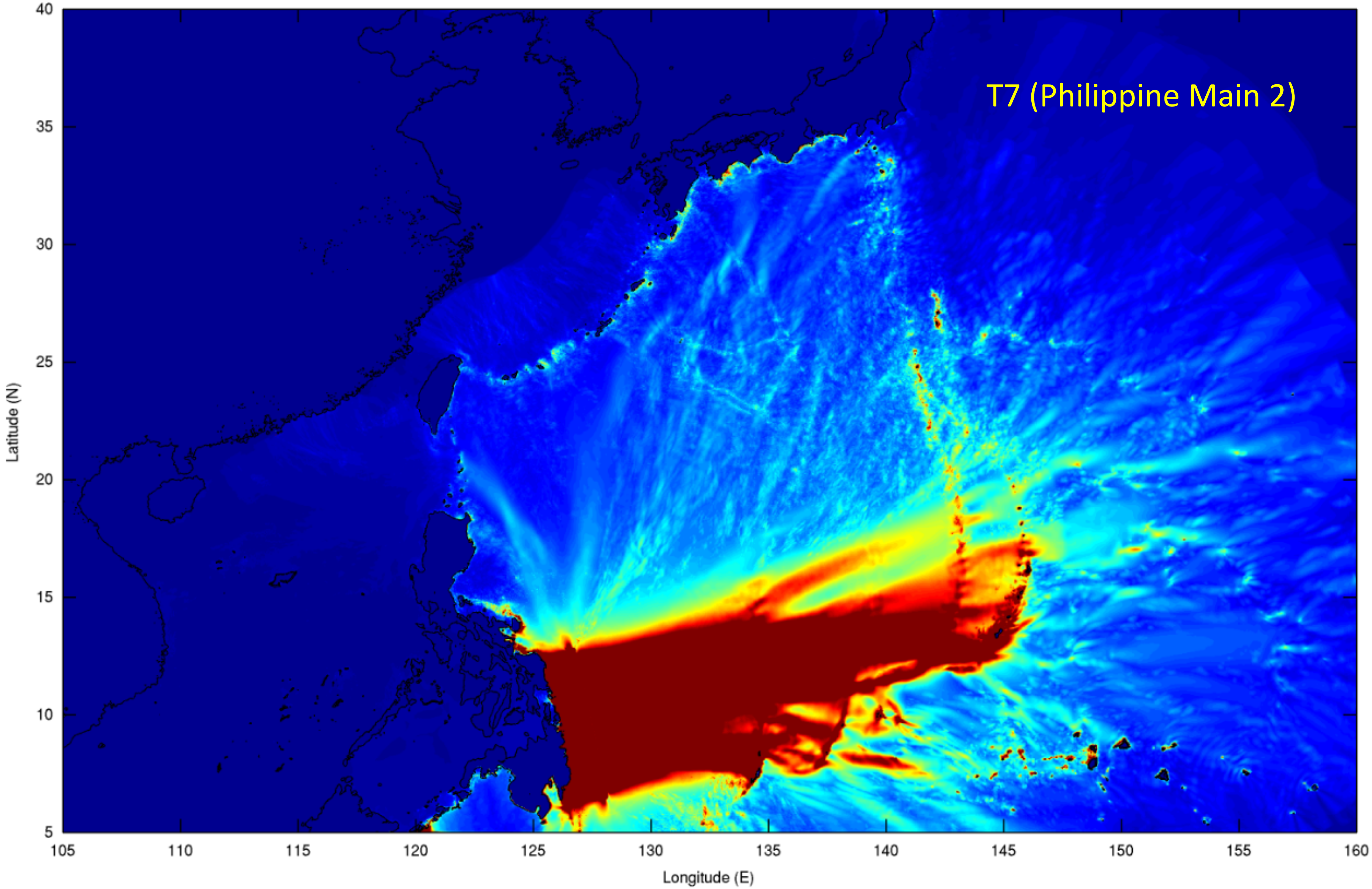
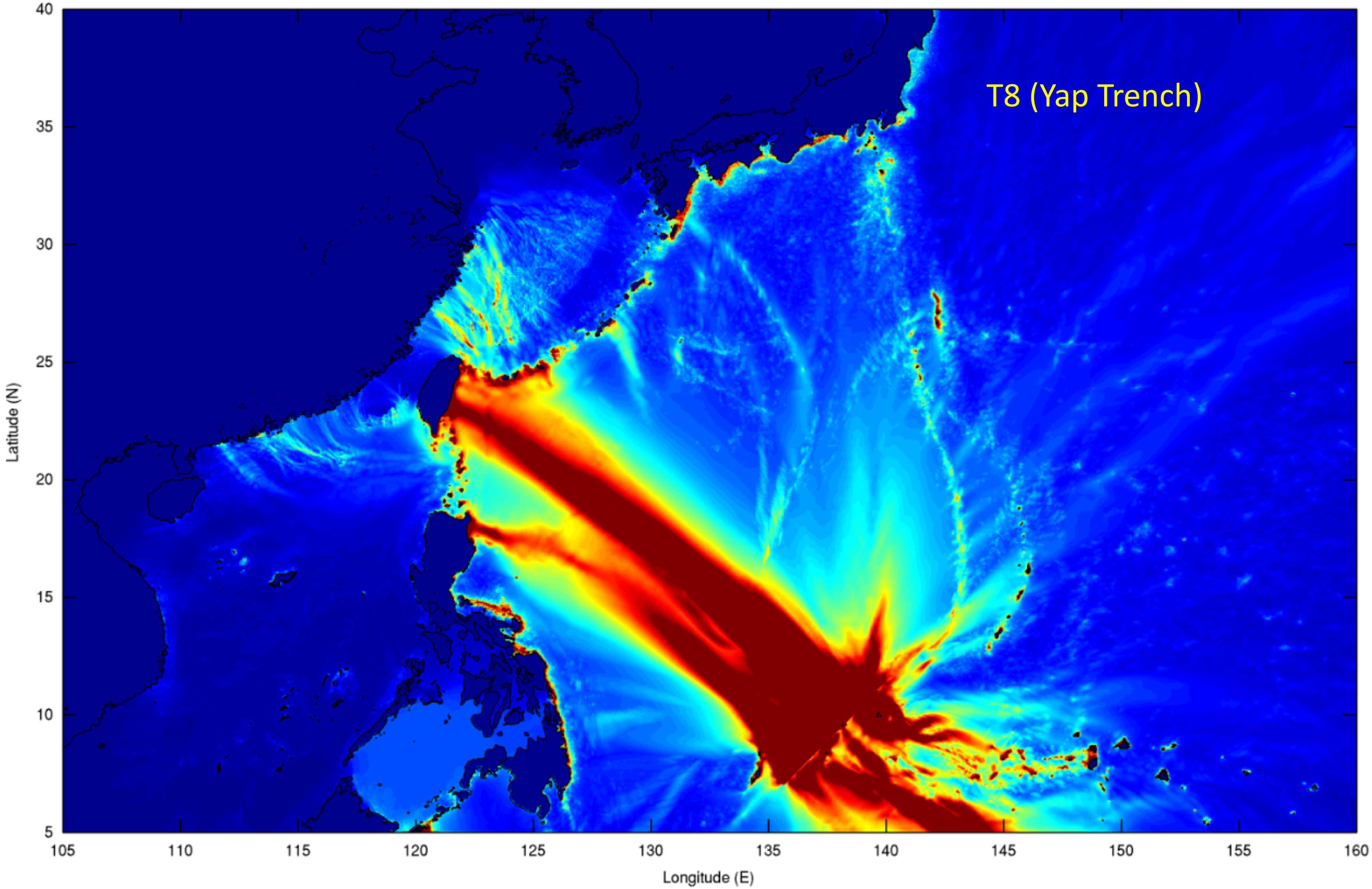
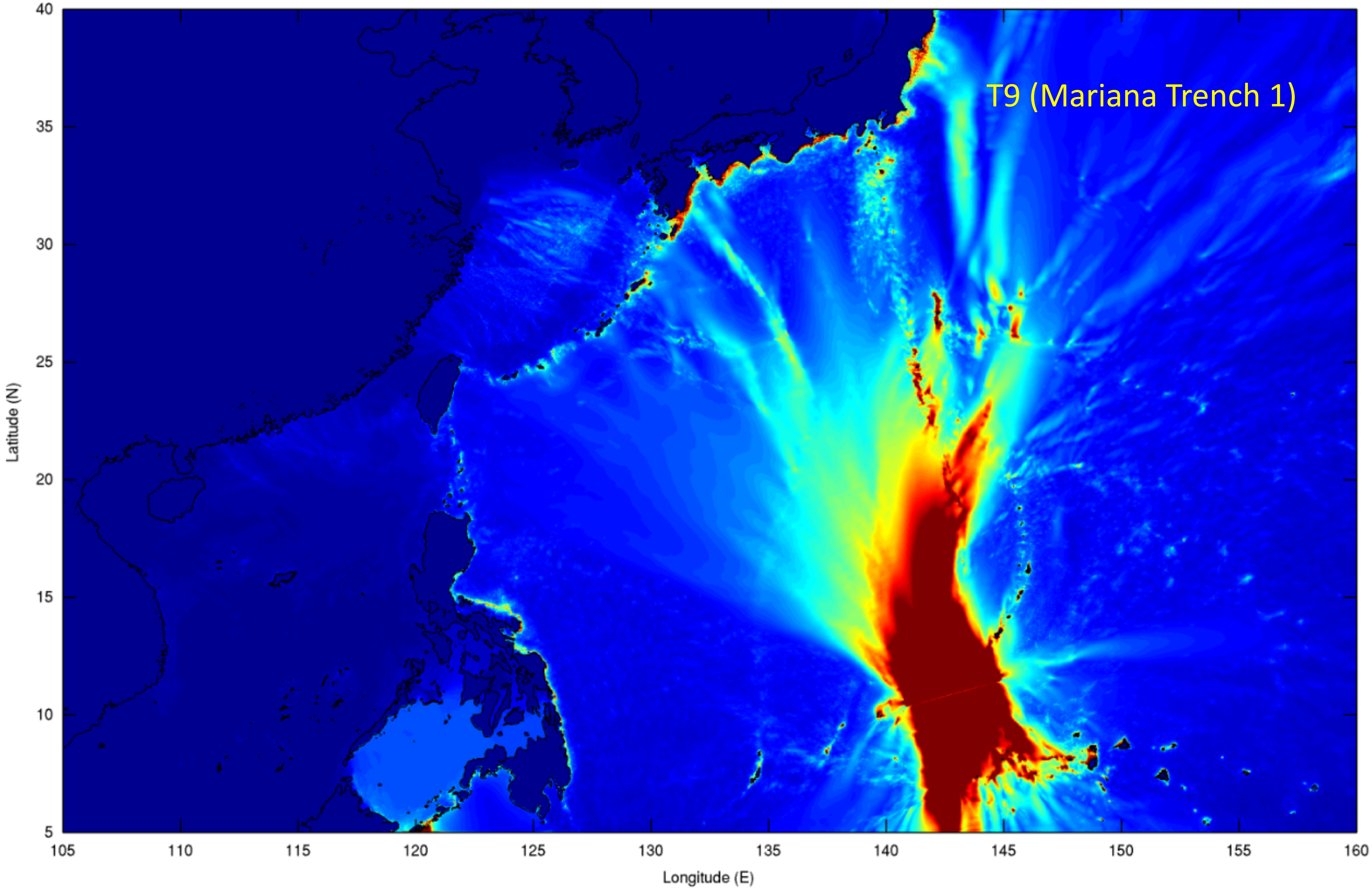
10
5
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)


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

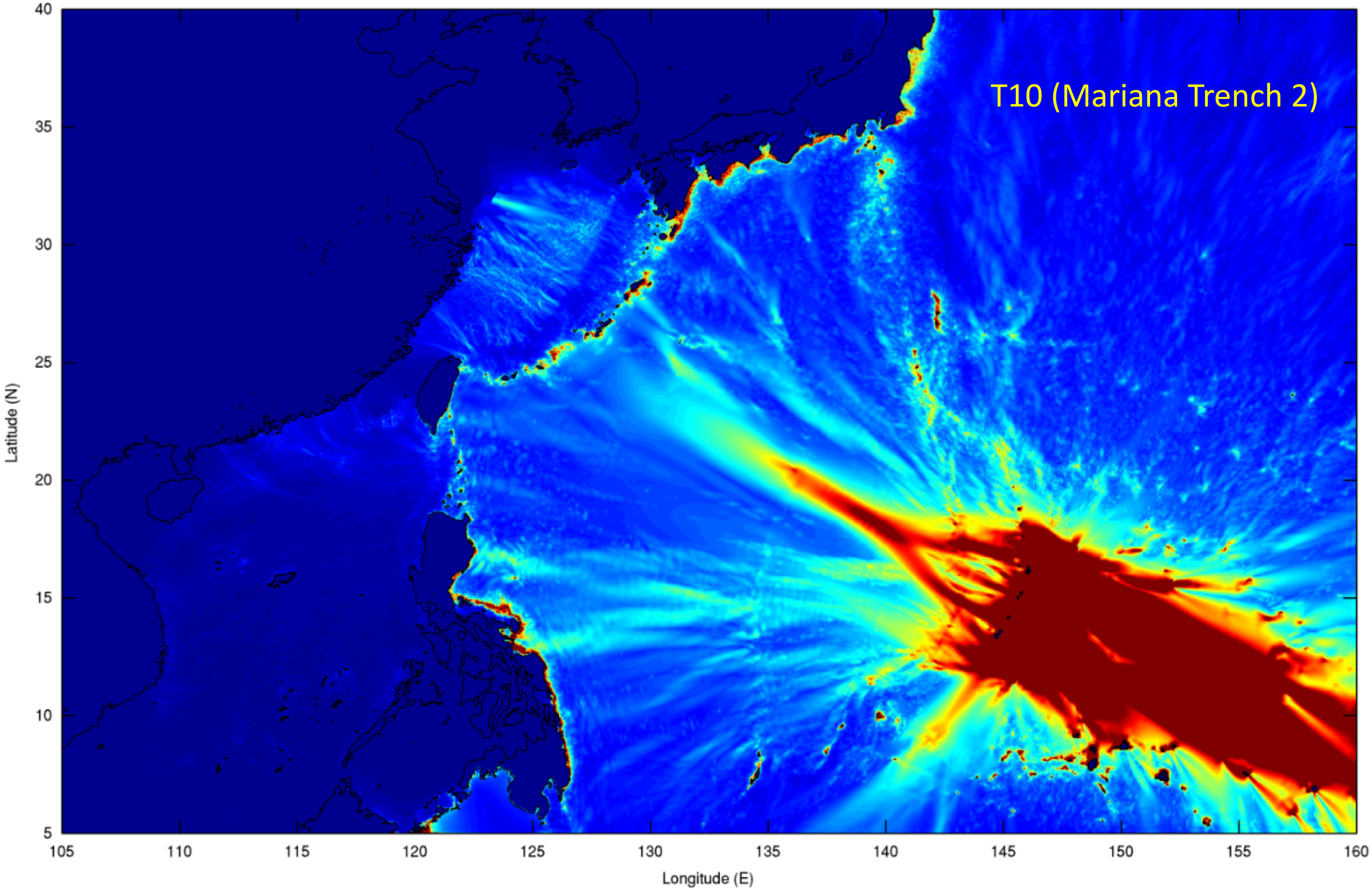

T6 (Philippine Main 1)
Latitude (N)
Longitude (E)
40
35
30
25
20
15
10
5
105
110
115
120
125
130
135
140
145
150
155
160


T7 (Philippine Main 2)
Latitude (N)
Longitude (E)
40
35
30
25
20
15
10
5
105
110
115
120
125
130
135
140
145
150
155
160

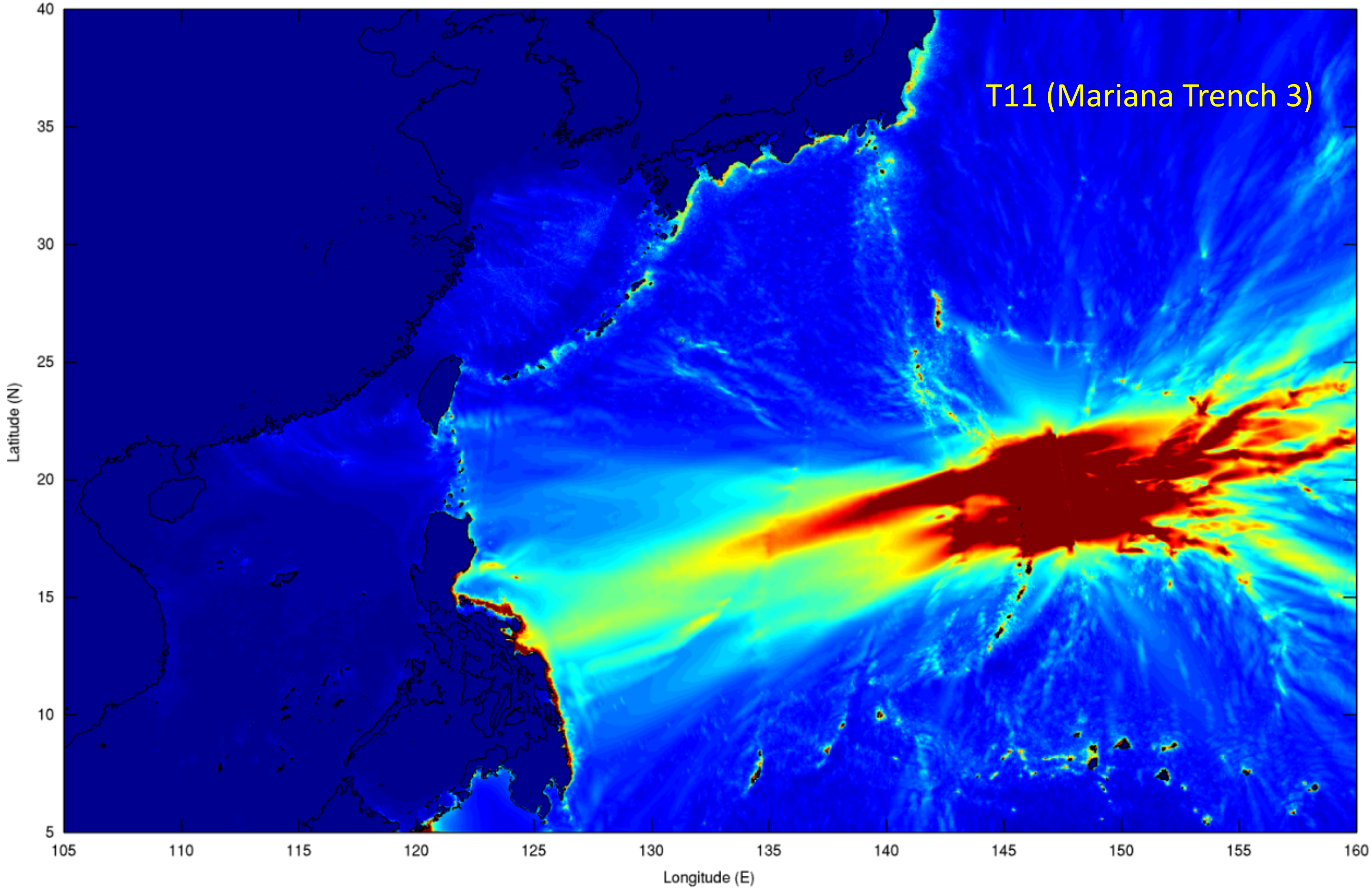

T8 (Yap Trench)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)

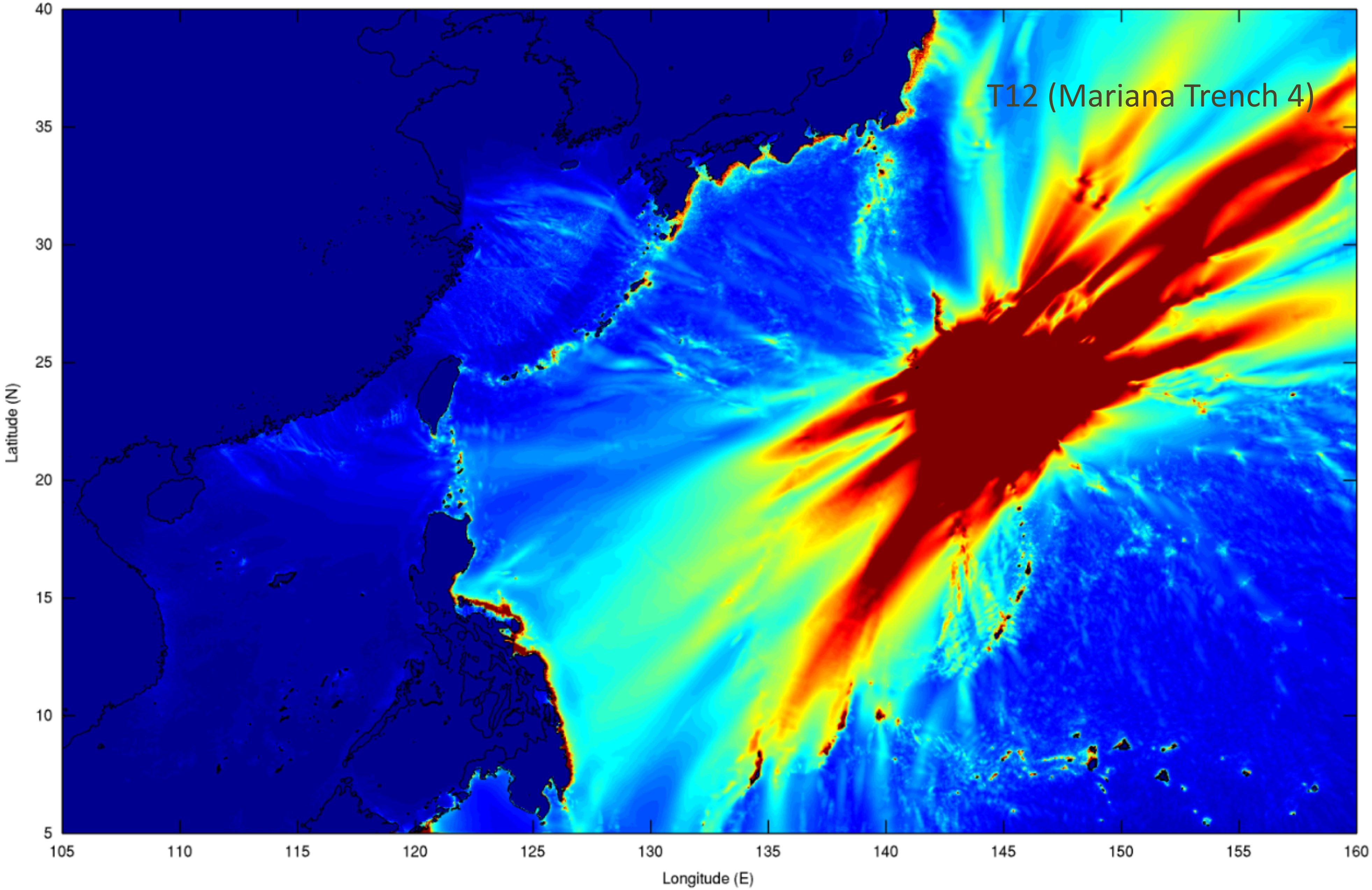


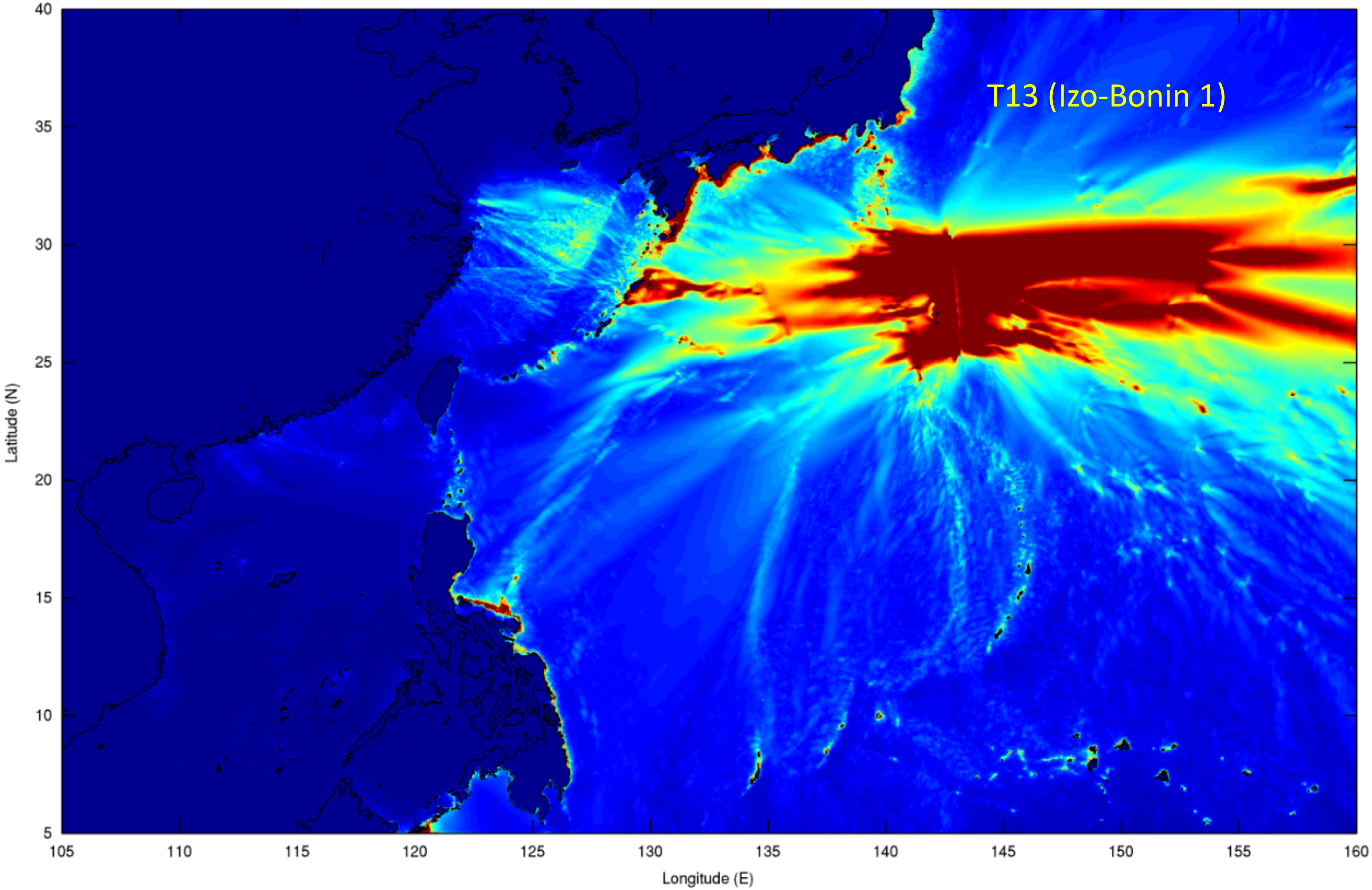
T9 (Mariana Trench 1)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)

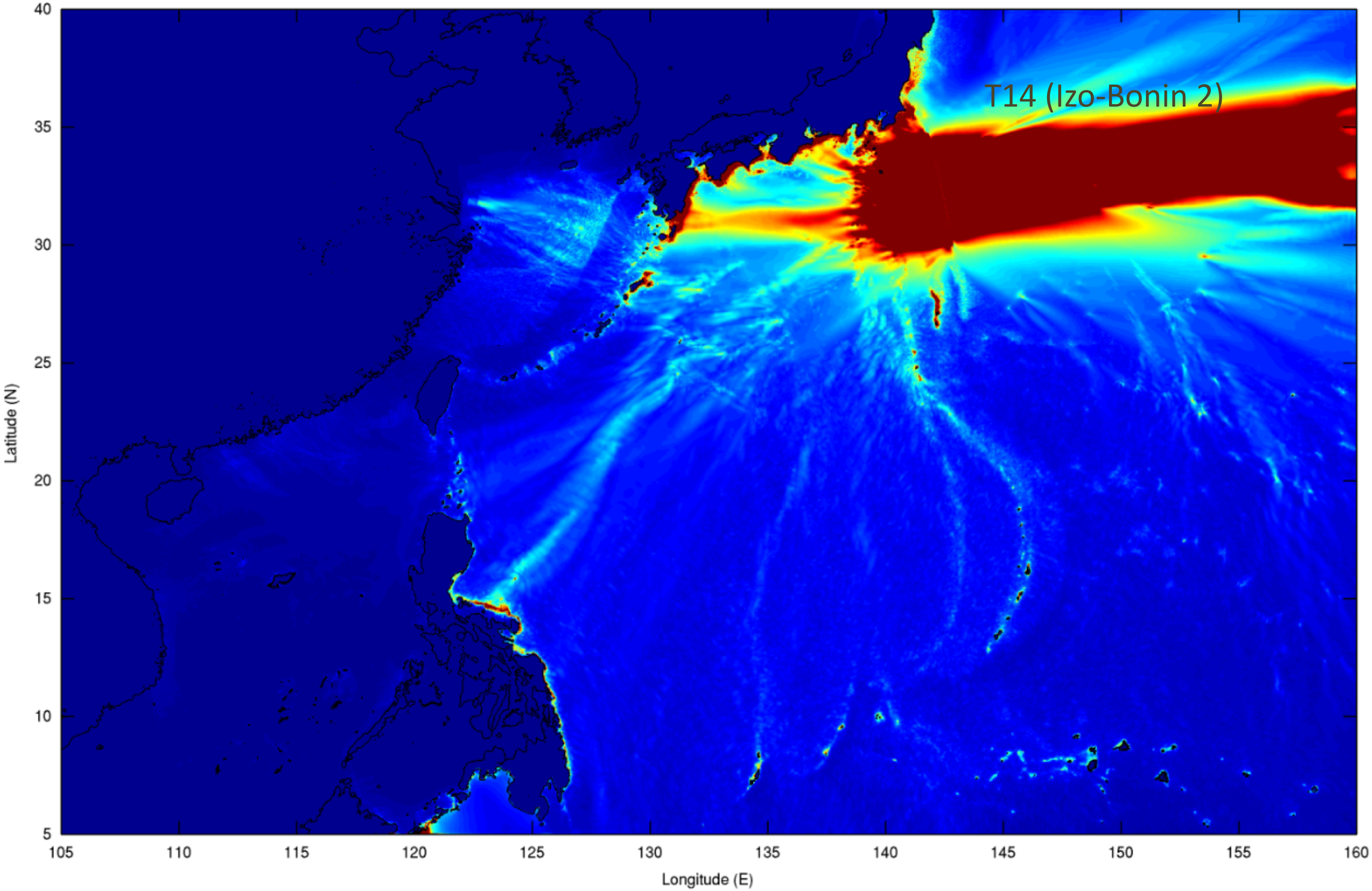


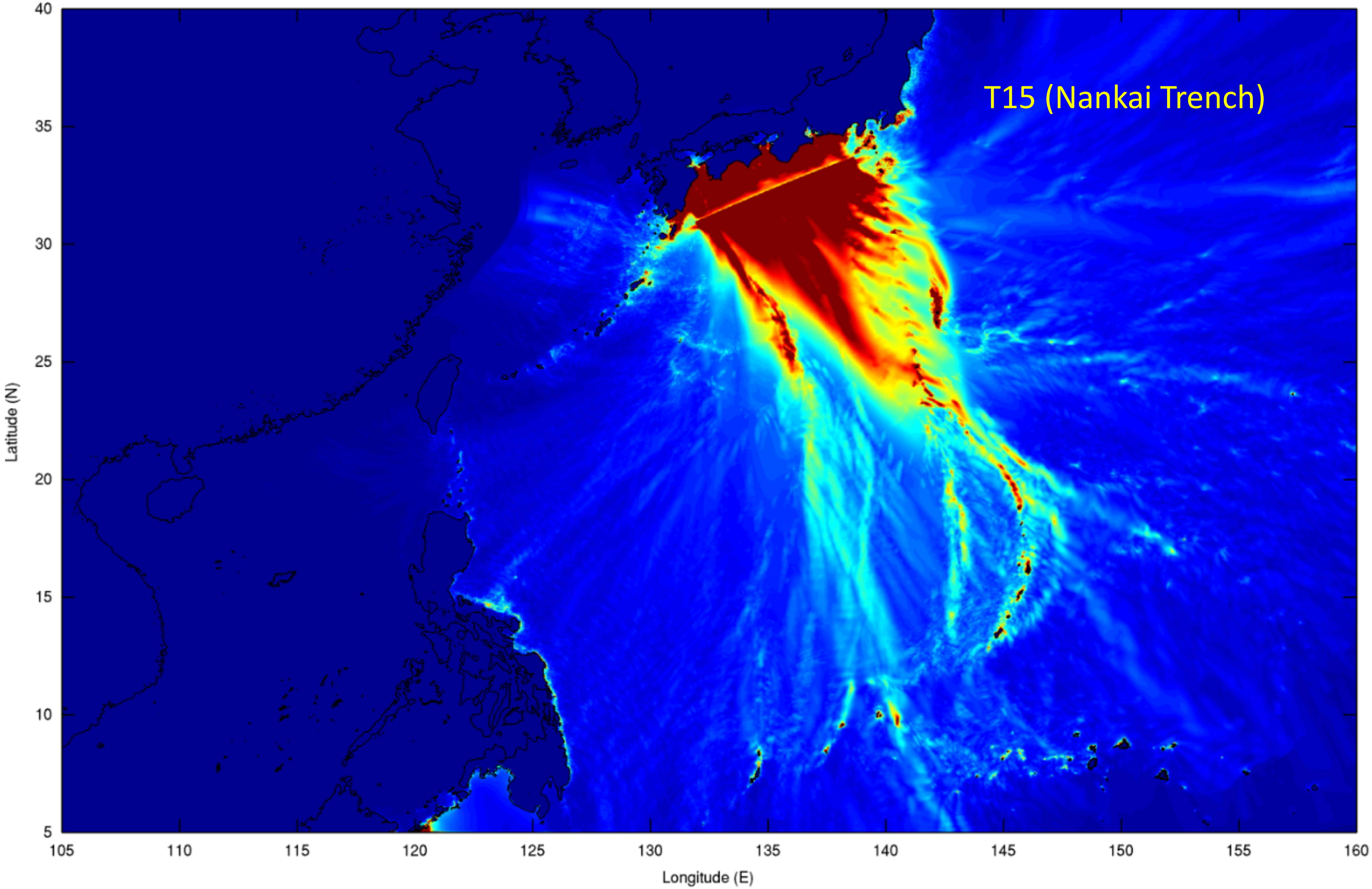
T10 (Mariana Trench 2)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)

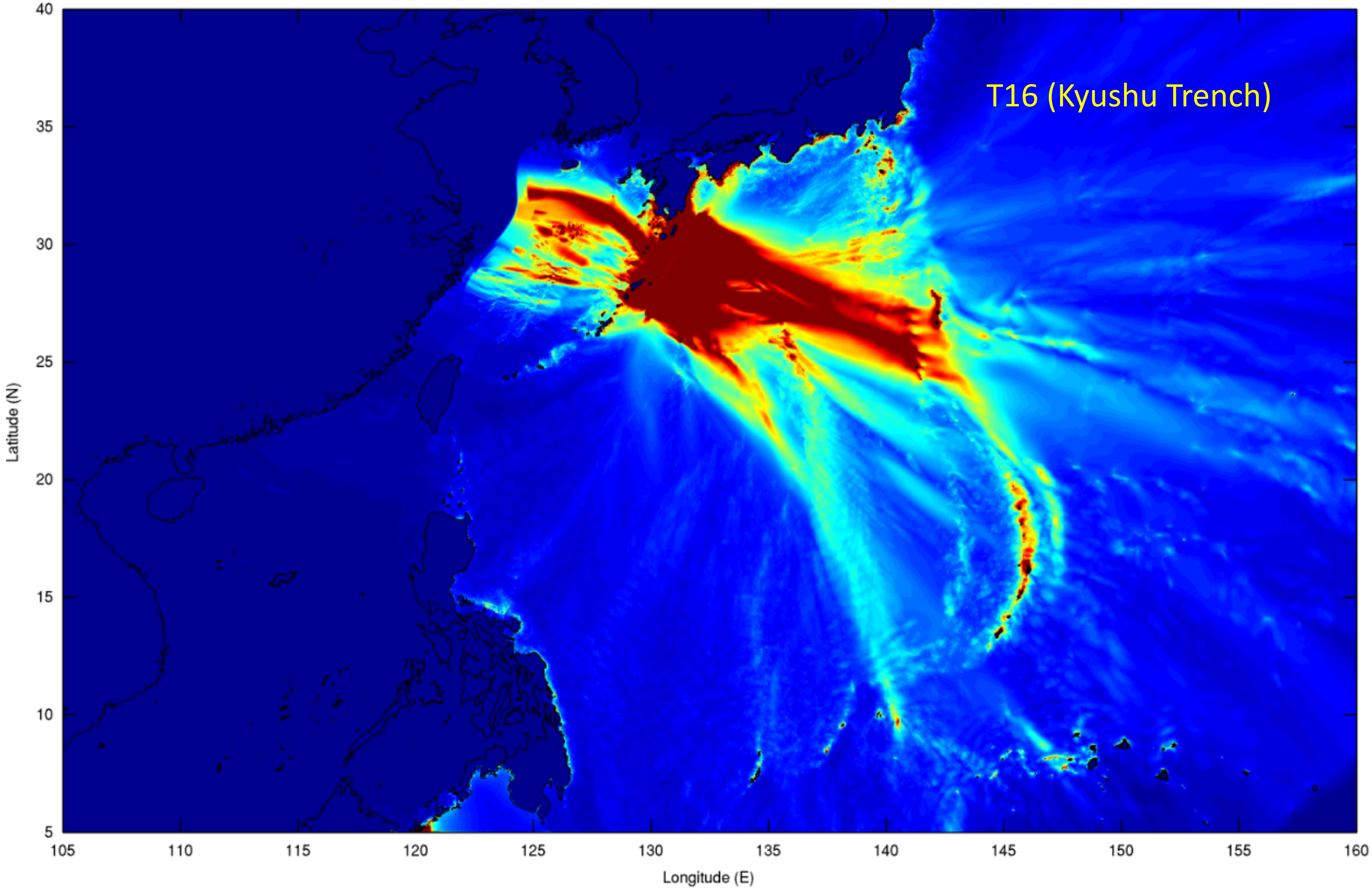

T11 (Mariana Trench 3)
Latitude (N)
Longitude (E)
40
35
30
25
20
15
10
5
105
110
115
120
125
130
135
140
145
150
155
160

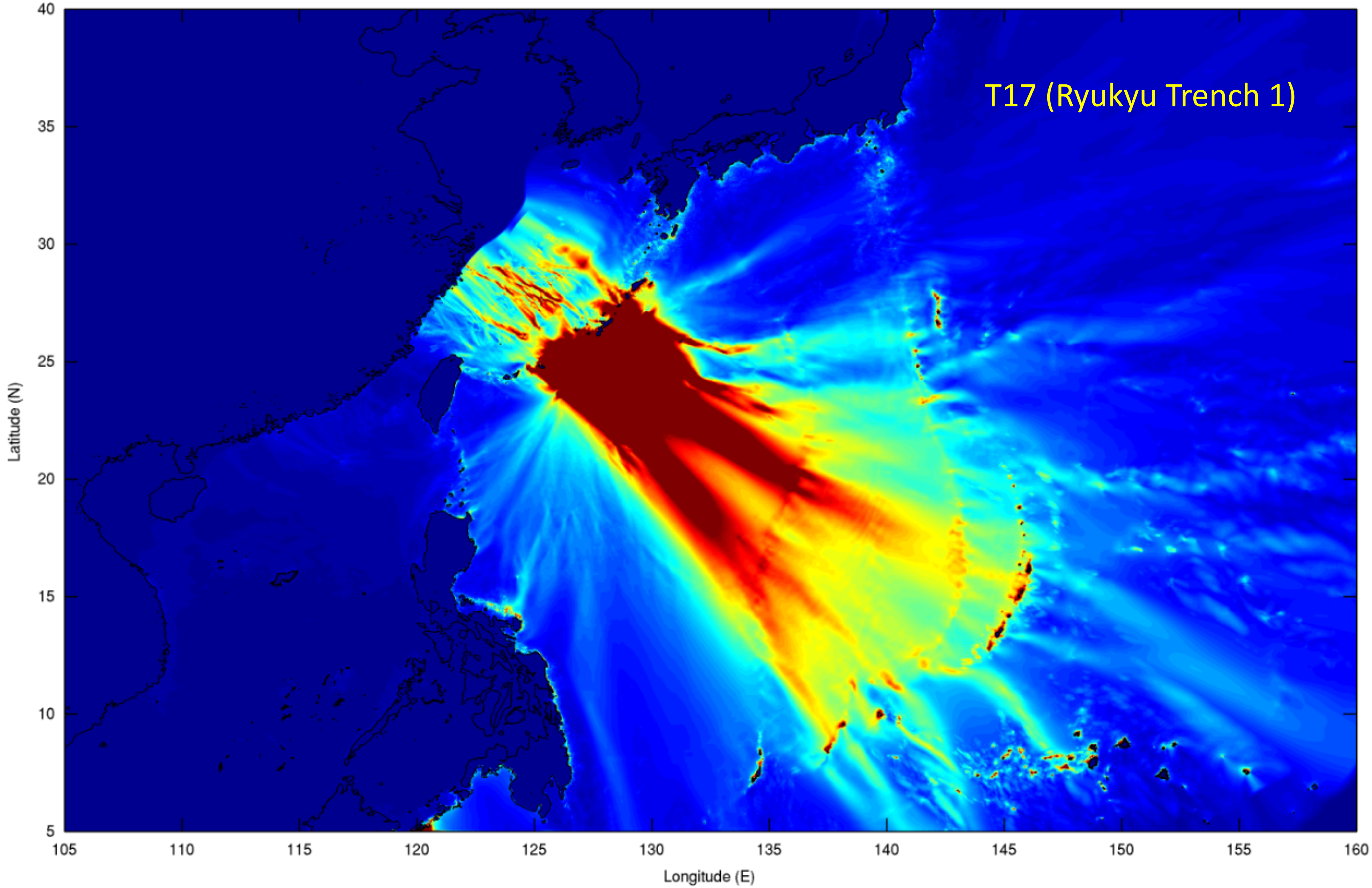

T12 (Mariana Trench 4)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)


T13 (Izo-Bonin 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)

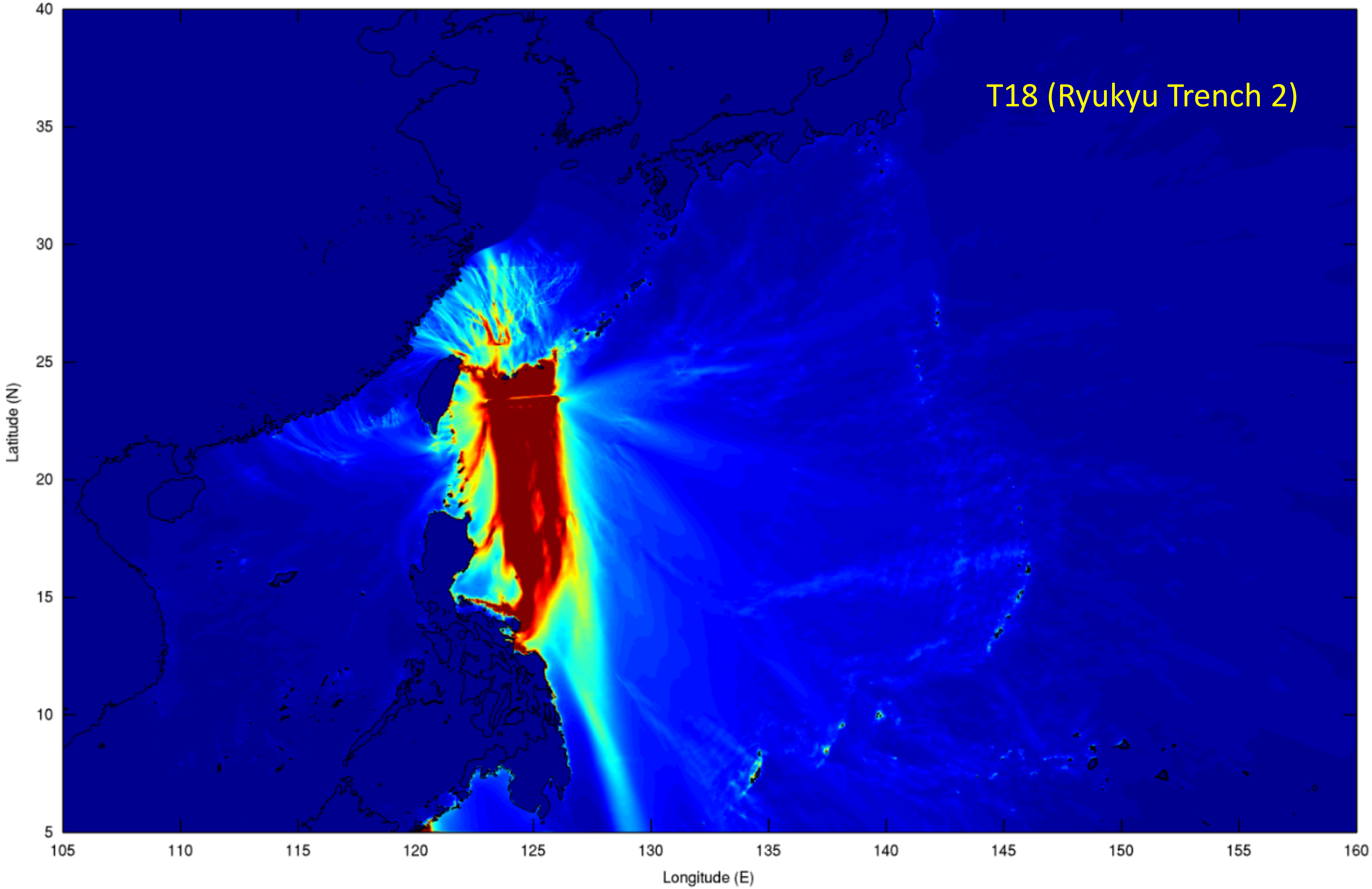

T14 (Izo-Bonin 2)
Latitude (N)
Longitude (E)
40
35
30
25
20
15
10
5
105
110
115
120
125
130
135
140
145
150
155
160

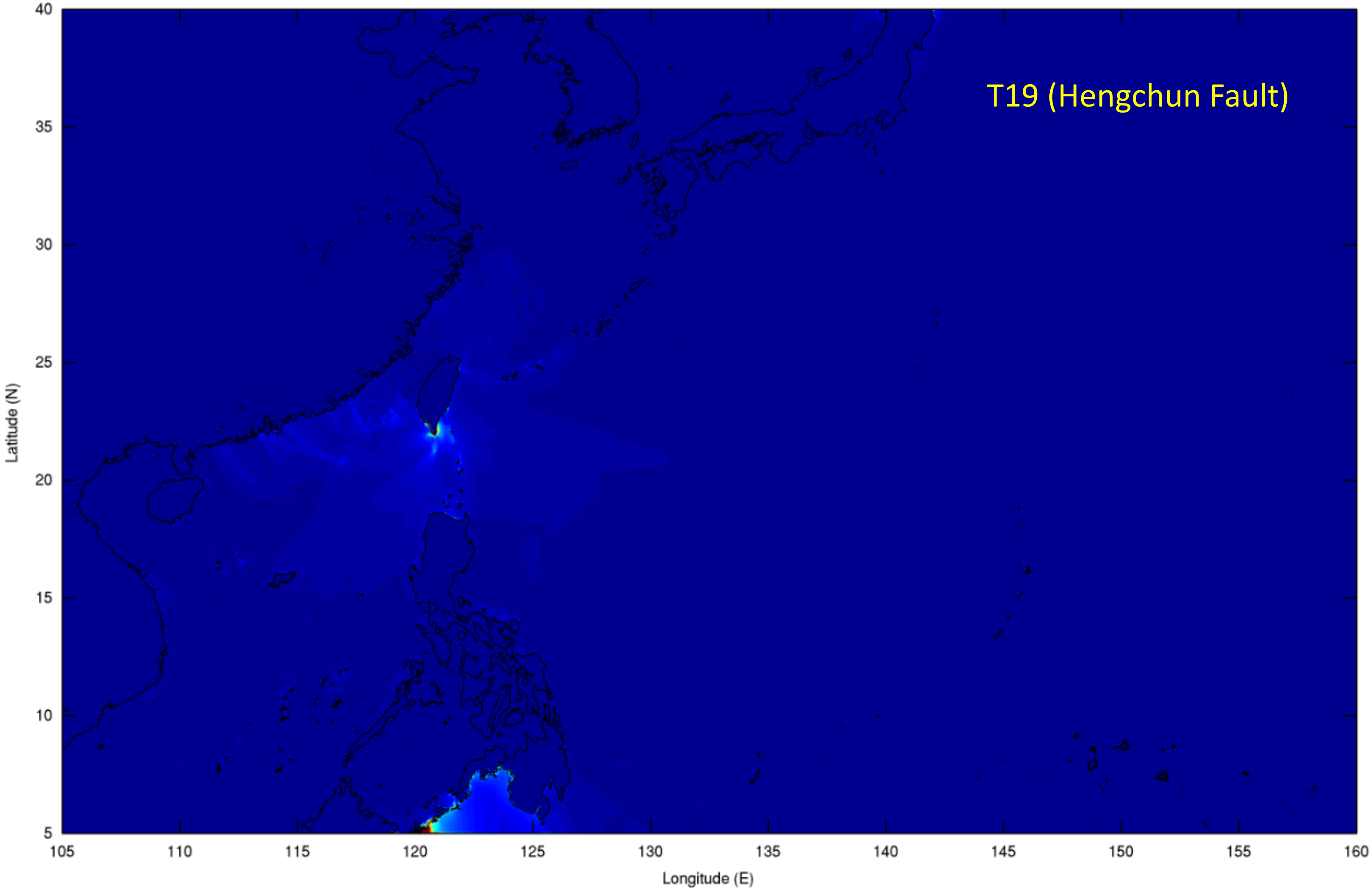

T15 (Nankai Trench)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)


T16 (Kyushu Trench)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)

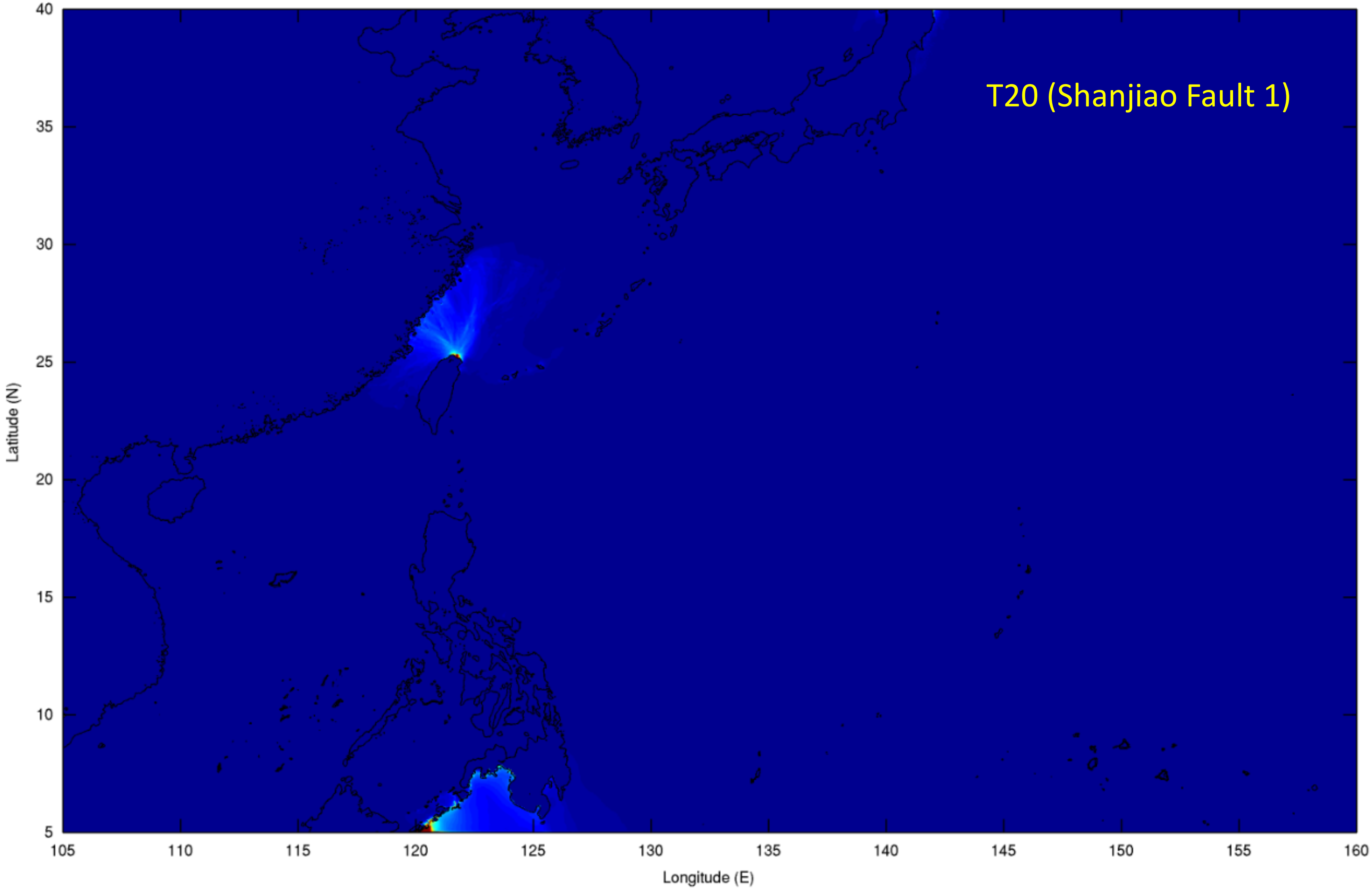


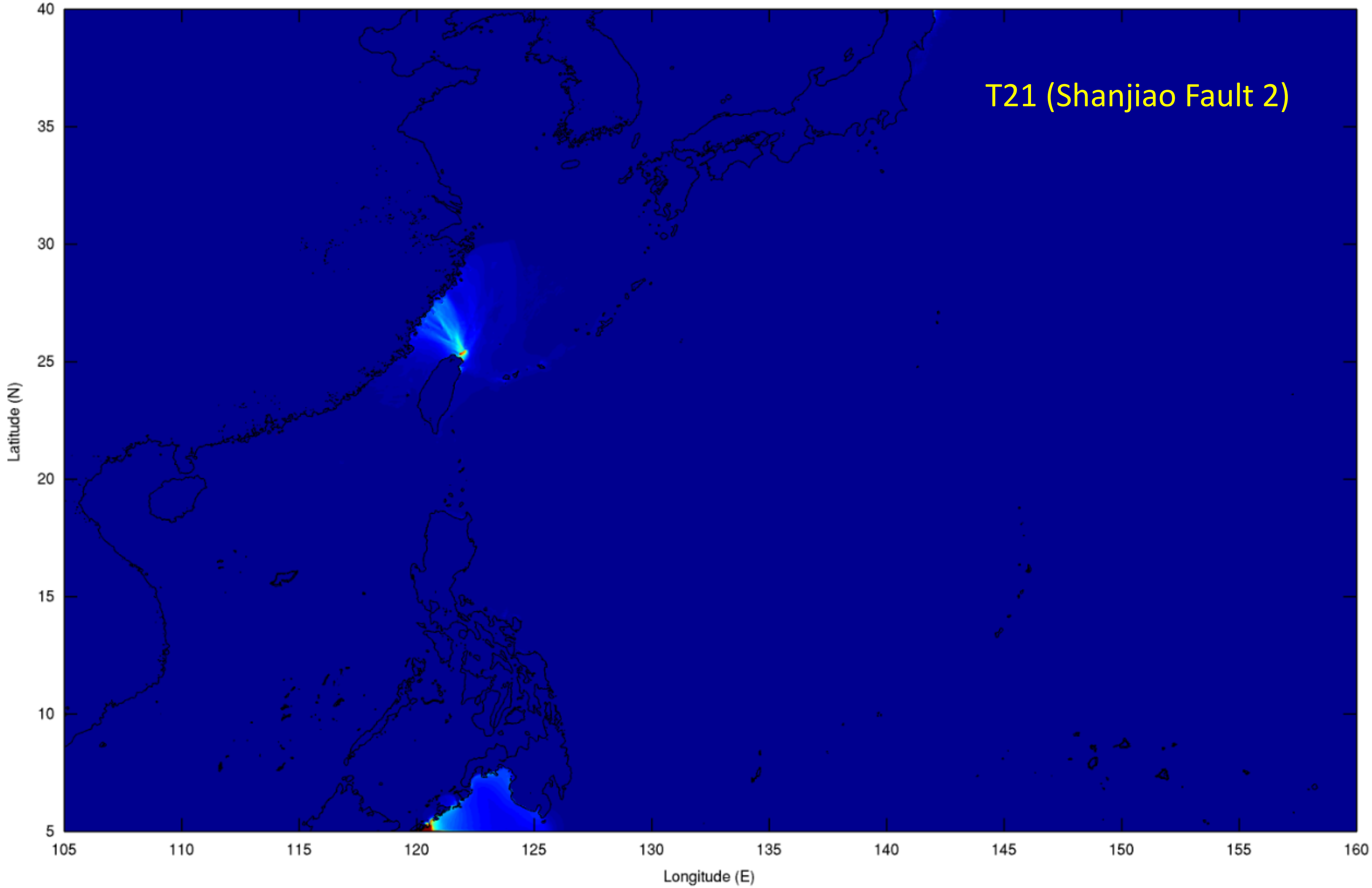
T17 (Ryukyu Trench 1)
Latitude (N)
Longitude (E)
40
35
30
25
20
15
10
5
105
110
115
120
125
130
135
140
145
150
155
160

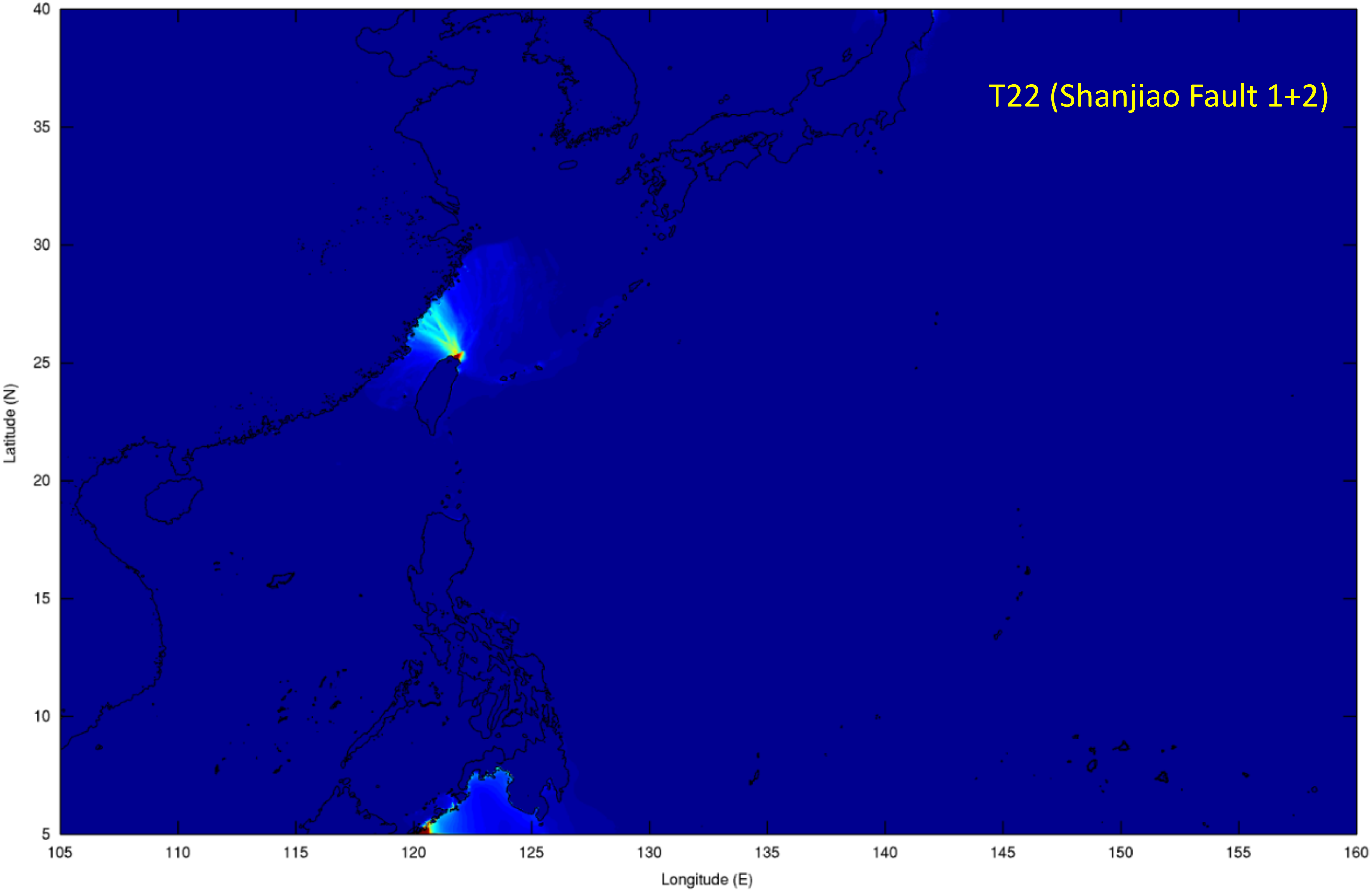

T18 (Ryukyu Trench 2)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)



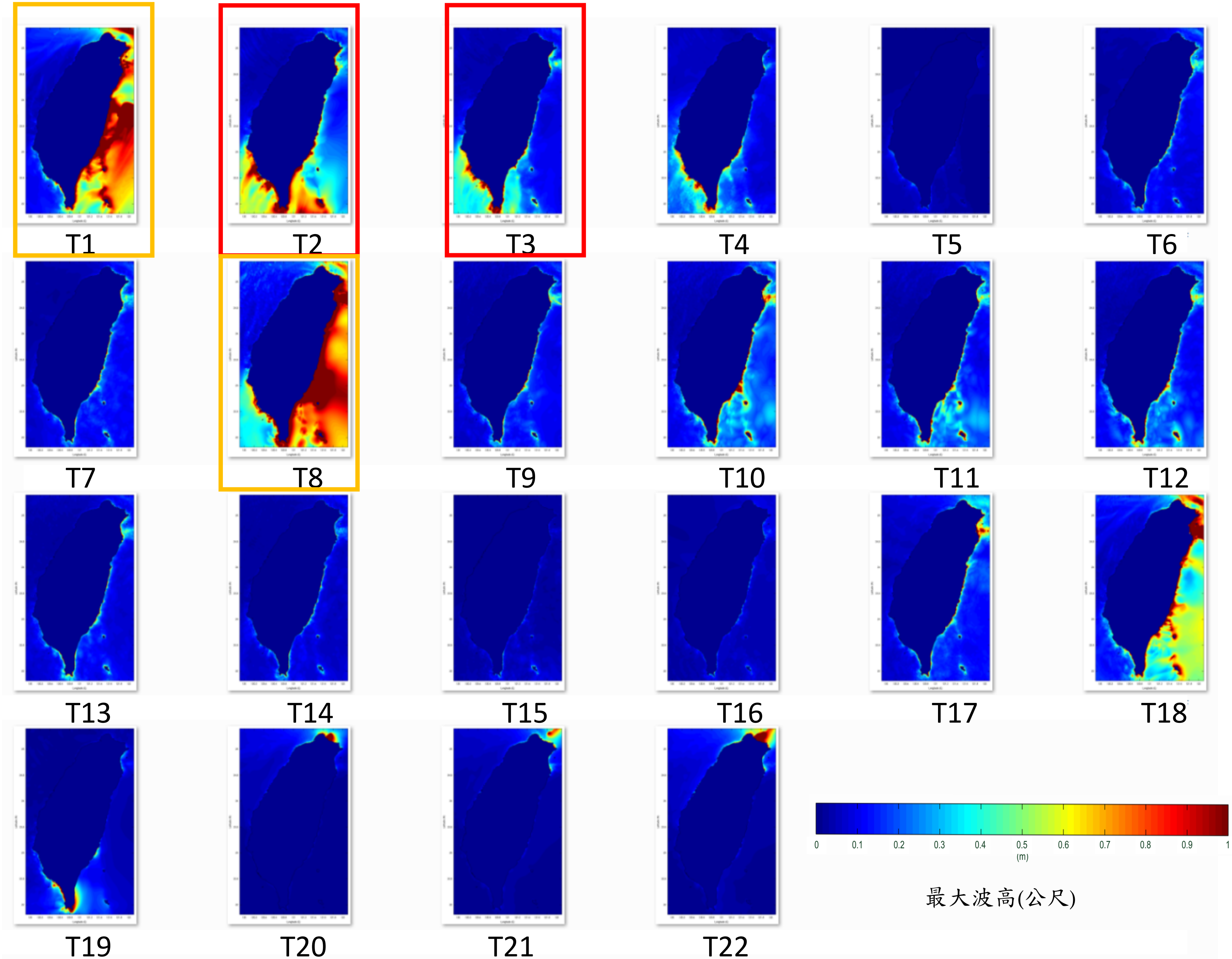
T19 (Hengchun Fault)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)


T20 (Shanjiao Fault 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

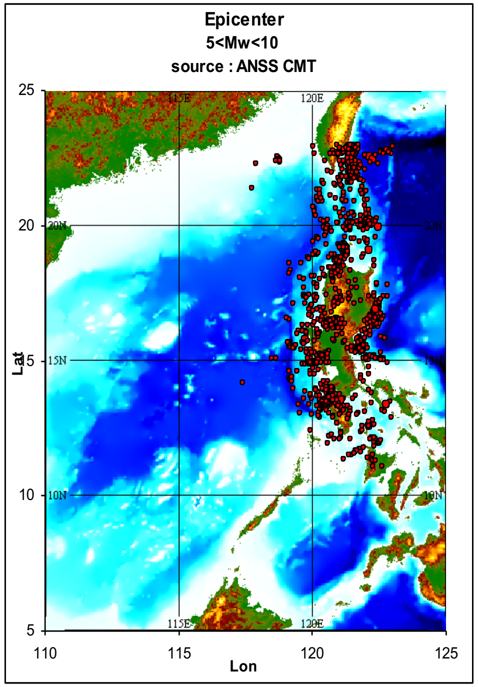

T21 (Shanjiao Fault 2)
40
35
30
25
20
15
10
5
Latitude (N)
105
110
115
120
125
130
135
140
145
150
155
160
Longitude (E)

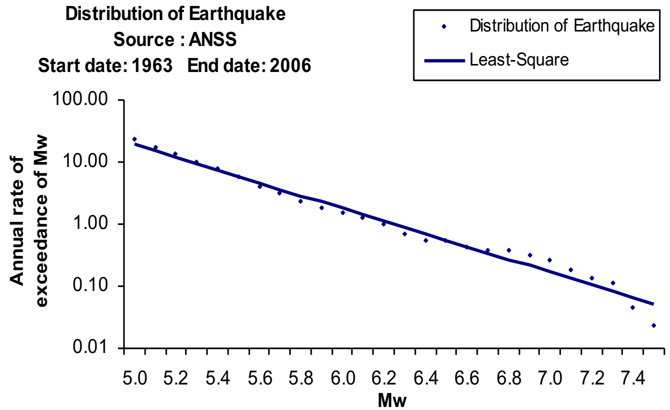

T22 (Shanjiao Fault 1+2)
Latitude (N)
Longitude (E)
40
35
30
25
20
15
10
5
105
110
115
120
125
130
135
140
145
150
155
160

小尺度網格模擬結果

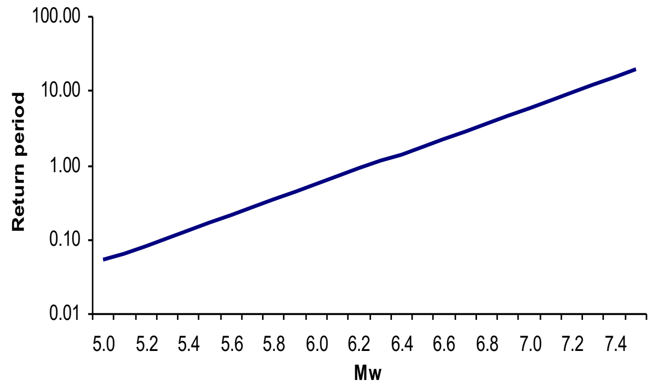

T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
T13
T14
T15
T16
T17
T18
T19
T20
T21
T22
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
(m)
最大波高(公尺)

馬尼拉海溝，地震重現期
Estimation of Return period





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



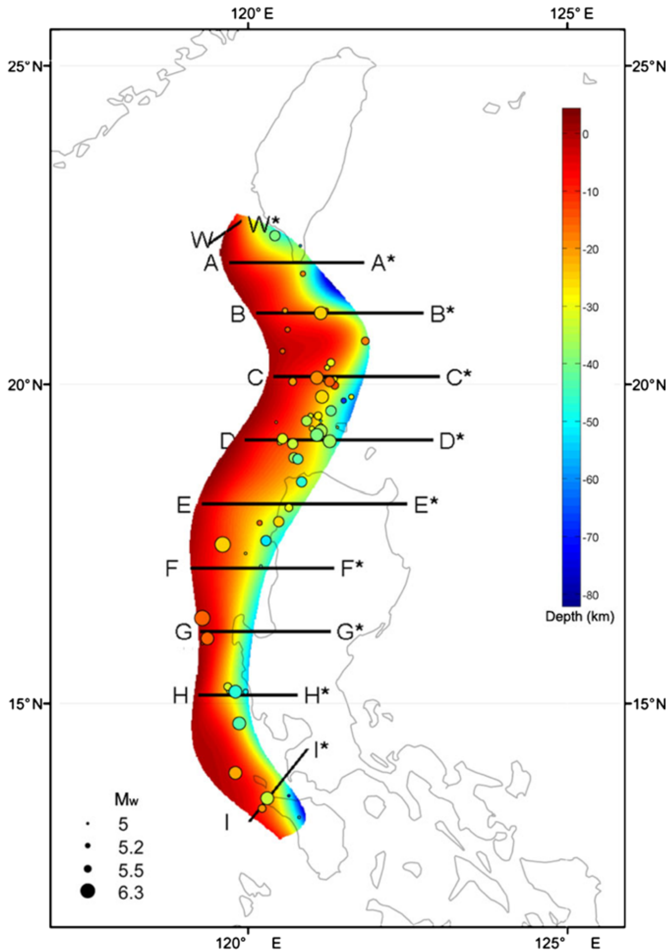
Mw	Return Period (year)
7.0	6
7.5	19
8.0	63
8.5	205
9.0	667

Source:ANSS 1963-2006

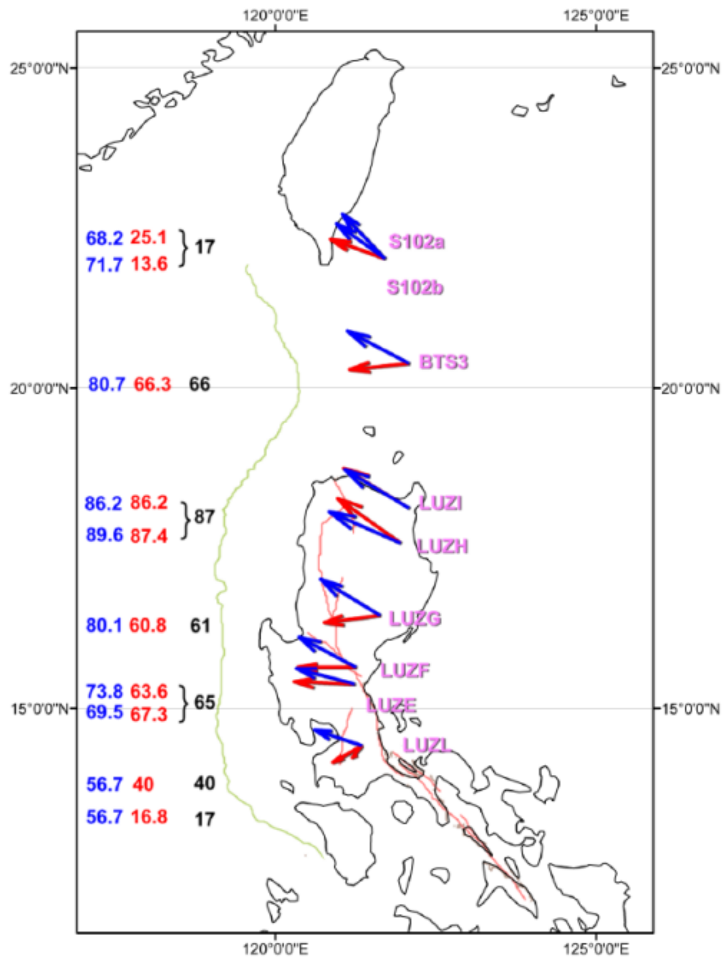
It is significant that since the Spanish colonization of Luzon in the 1560s, no earthquake exceeding magnitude 7.8 has been observed (Repetti, 1946). Conservatively, it can be postulated that very large events on this Megathrust have a recurrence interval exceeding 440 years. Taking a trench-normal convergence 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).

Anat Ruangrassamee (2007)

馬尼拉海溝之板塊位移速度分佈



The sinuous rupture interface of the South China Sea megathrust, together with ten seismic cross sections between latitude 12.5N and 23.5N from the studies by Bautista et al. (2001) and Wu et al. (2007). Epicenters of thrust-faulting earthquakes are plotted to mark the downdip boundary of the rupture interface.



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.

(Megawati et at., 2009)

馬尼拉海溝海嘯情境分析：海嘯源初始波高分布