



國立中央大學
National Central University



水文與海洋科學研究所

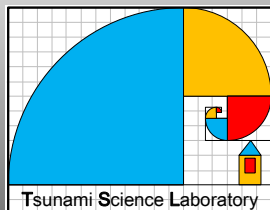
台電教育訓練 台灣海嘯與災防

吳祚任

國立中央大學

水文與海洋科學研究所

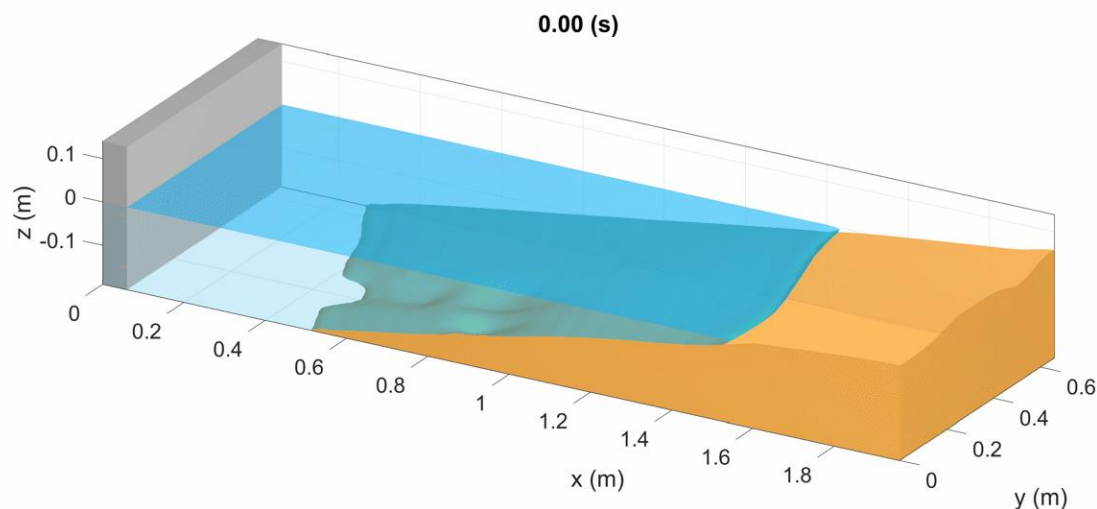
tsoren@ncu.edu.tw



海嘯科學研究室
TSUNAMI SCIENCE LABORATORY

Contact information:

- Prof. Tso-Ren Wu
- 國立中央大學
- 水文與海洋科學研究所
tsoren@ncu.edu.tw
- Facebook: 吳祚任



三維流固耦合模擬造波機所製造之海嘯波
(921地震園區)



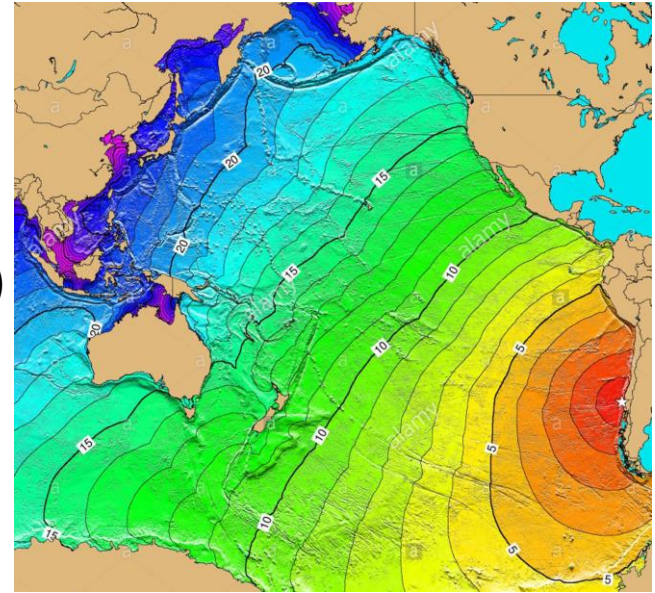
Three largest tsunami events

三大海嘯事件

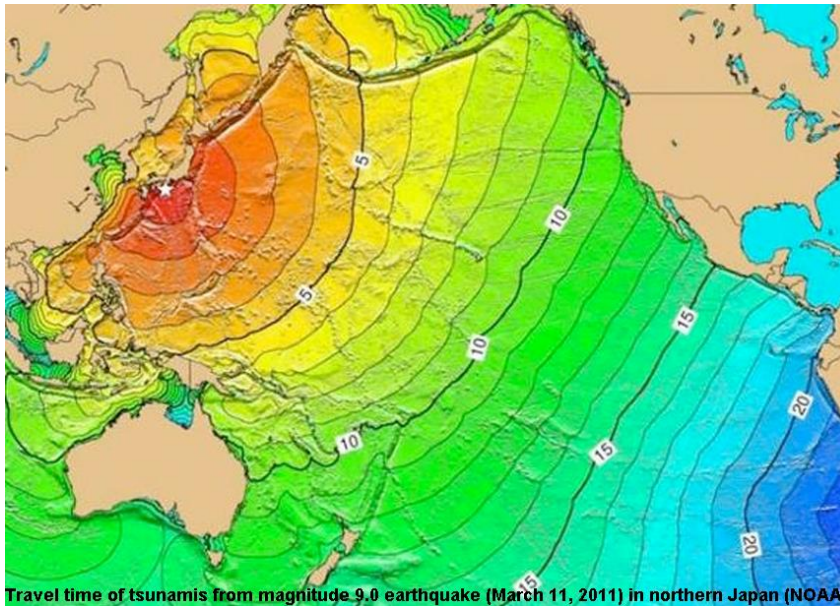
1. 1960 智利海嘯 Chile Tsunami (Mw=9.5)
2. 2004 南亞海嘯 South Asia Tsunami (Mw=9.3)
3. 2011 東日本海嘯 East Japan Tsunami (Mw=9.1)

(Wiki) (NOAA)

1960 智利海嘯 Chile Tsunami

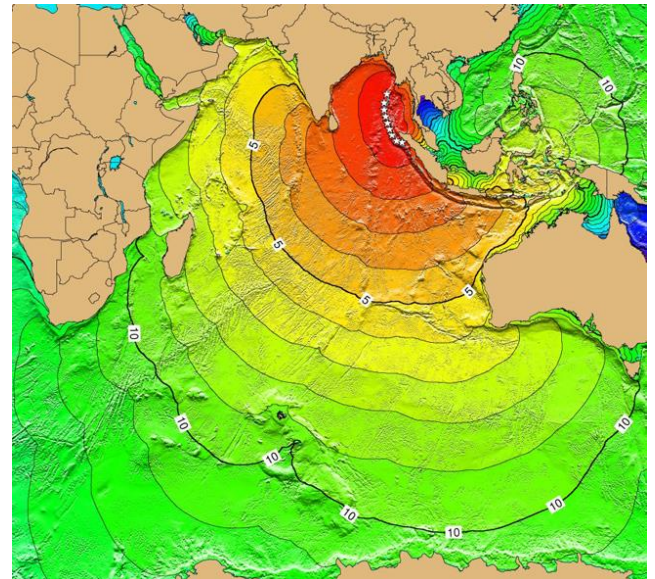


2011 東日本海嘯 East Japan Tsunami



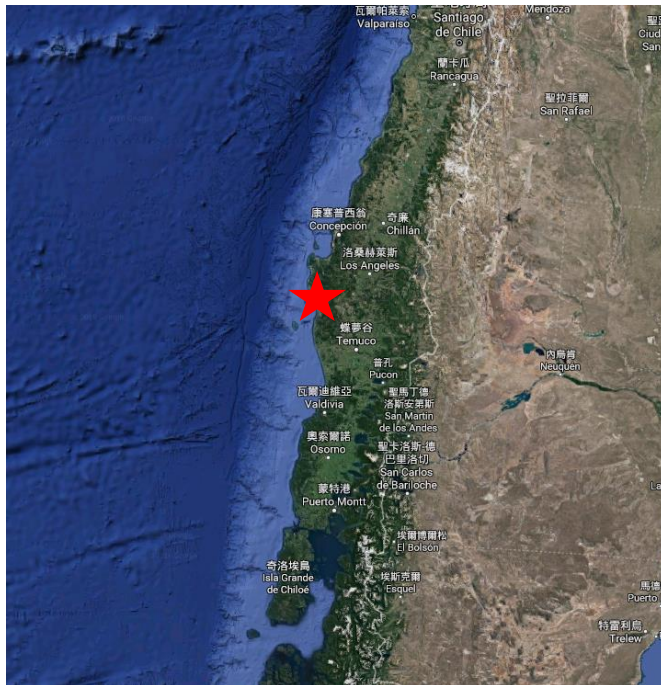
Travel time of tsunamis from magnitude 9.0 earthquake (March 11, 2011) in northern Japan (NOAA)

2004 南亞海嘯 South Asia Tsunami

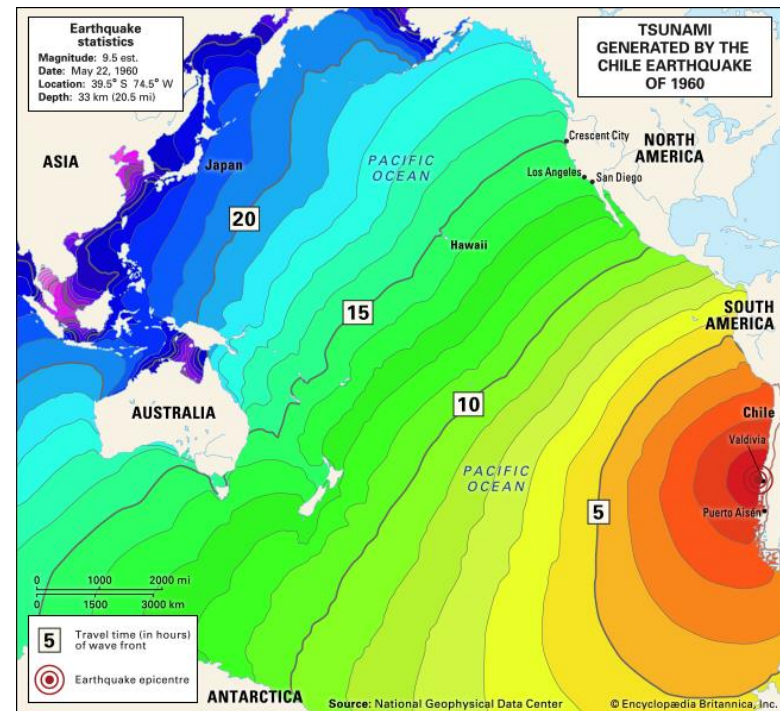


1960 Chile Earthquake Tsunami

On May 22, 1960, Chile recorded the largest earthquake ever recorded. It also known as the 1960 Valdivia Earthquake. The magnitude of the earthquake moment was **9.4 to 9.6**. The epicenter was located at -73.41° W and 38.14° S (USGS). The earthquake caused a severe tsunami on the coast of **Chile, with an run-up height is 25 meters**. Tsunami waves hit **Hawaii**, Pitcairn Island, New Guinea, New Zealand, **Japan**, Okinawa and the Philippines and **Hilo**. (Bryant, 2014).

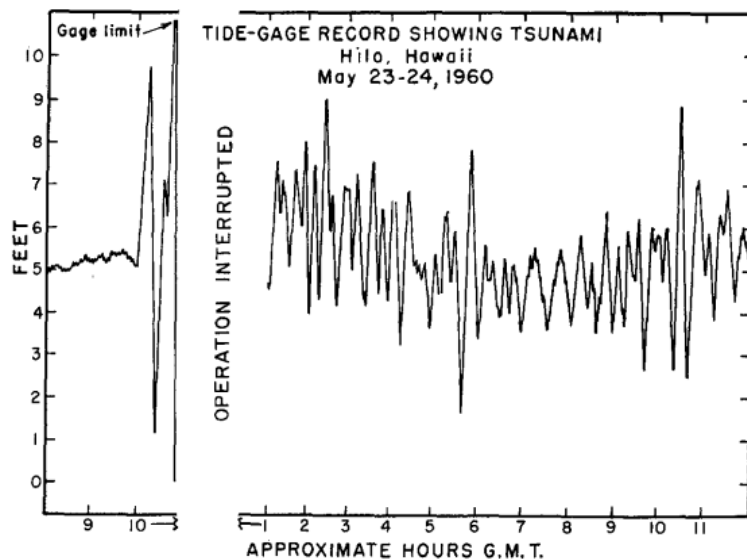


Google map

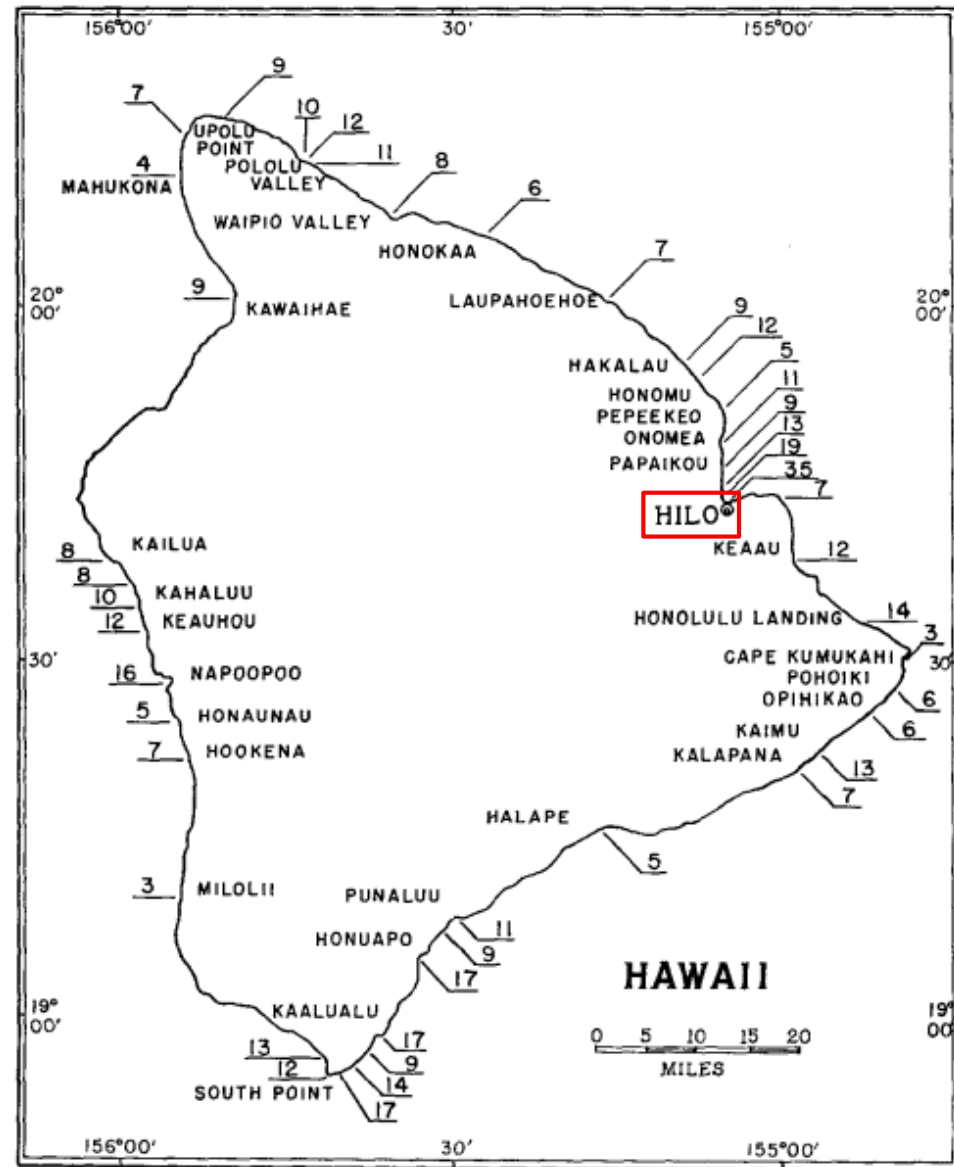


Tsunami travel time Valdivia 1960 (NGDC)

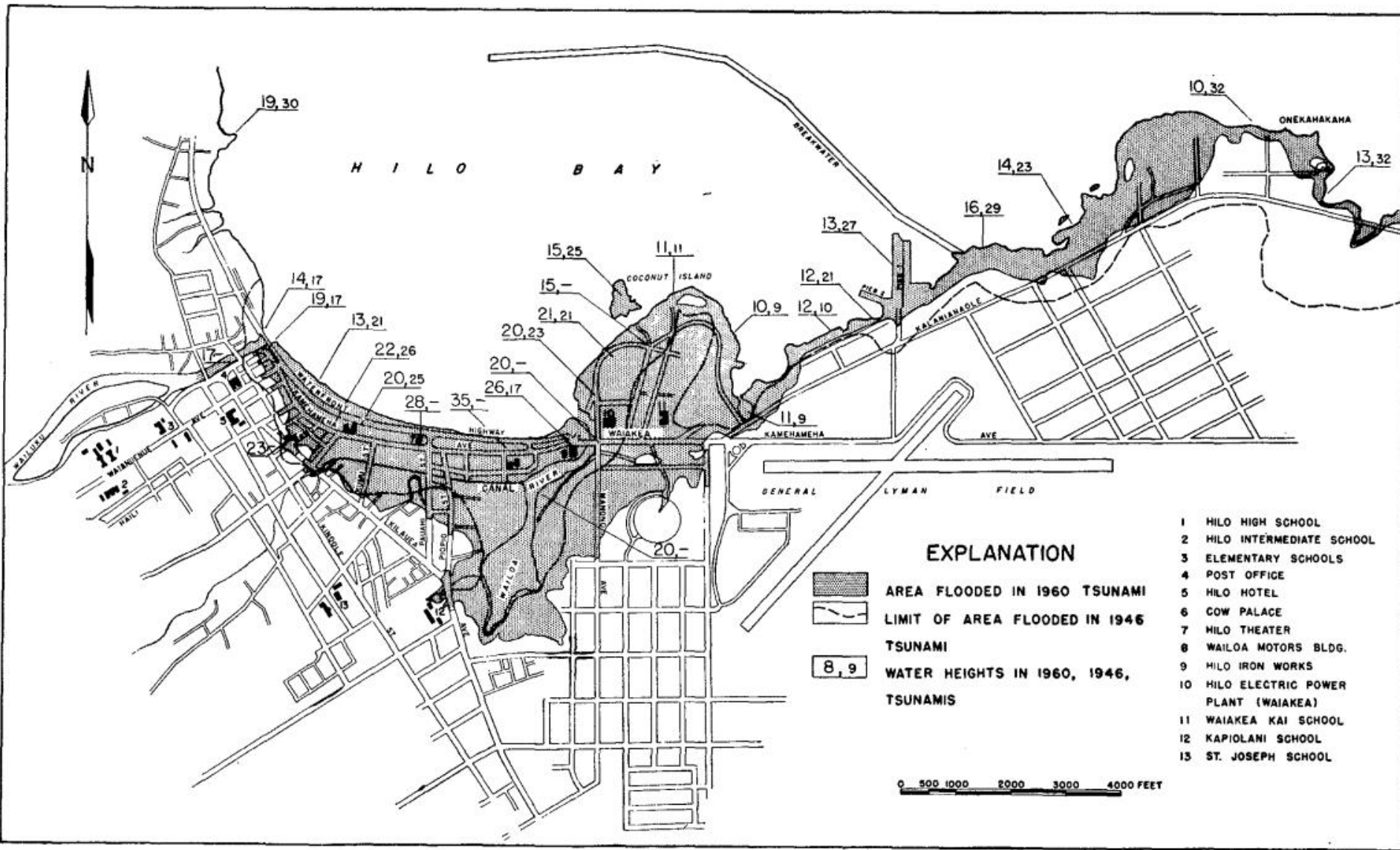
1960 Chile Earthquake Tsunami caused 61 death toll and 282 injured in Hilo, Hawaii. The tsunami caused by the run-up height was about 10.5 m, and the flooded area was about 2.5 km². With the exception of Hilo, the runup heights in other city of Hawaii range from approximately 0.6 to 5.1 m with an 2.7 m average runup height. (Doak et al., 1963)



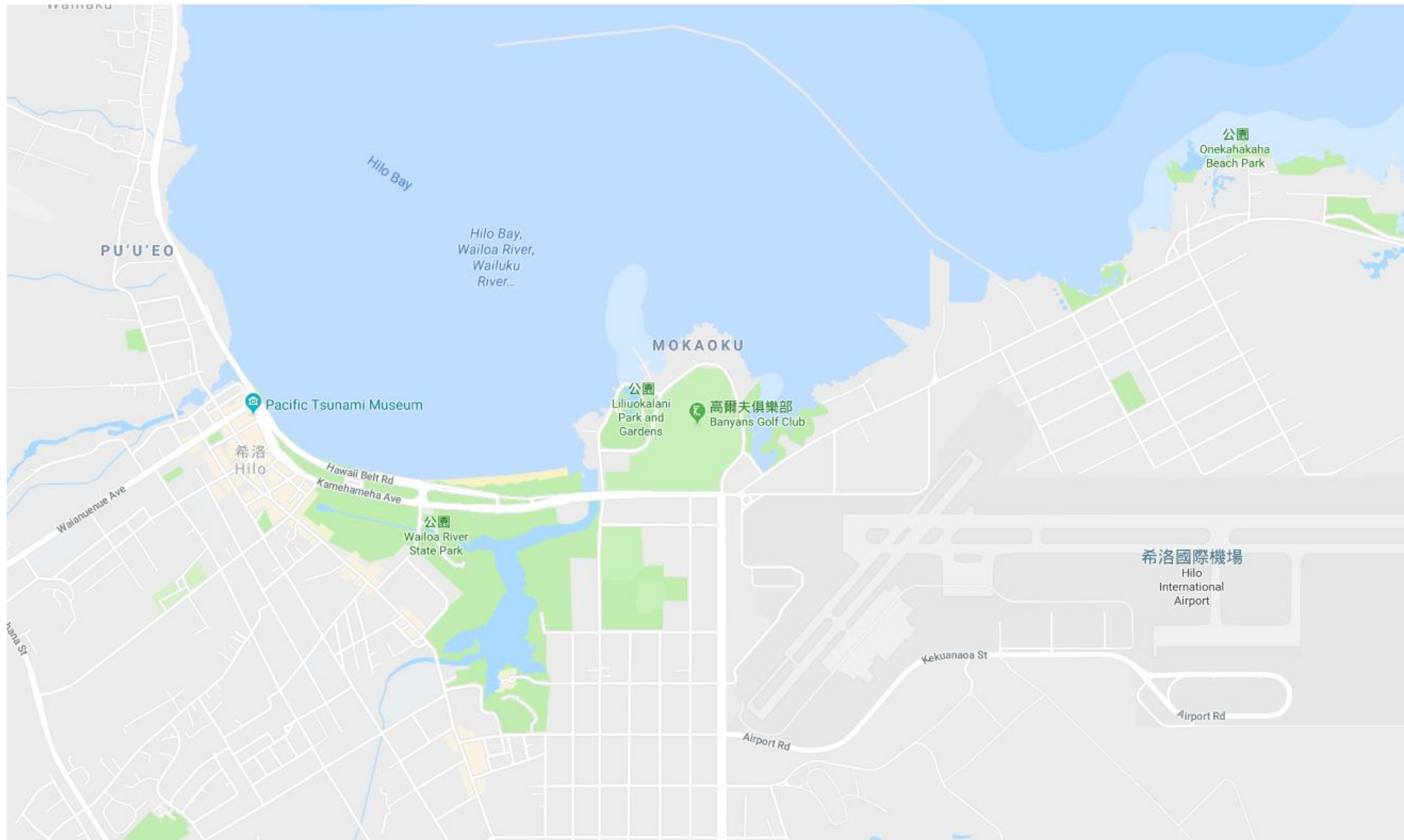
(Symon et al., 1960)



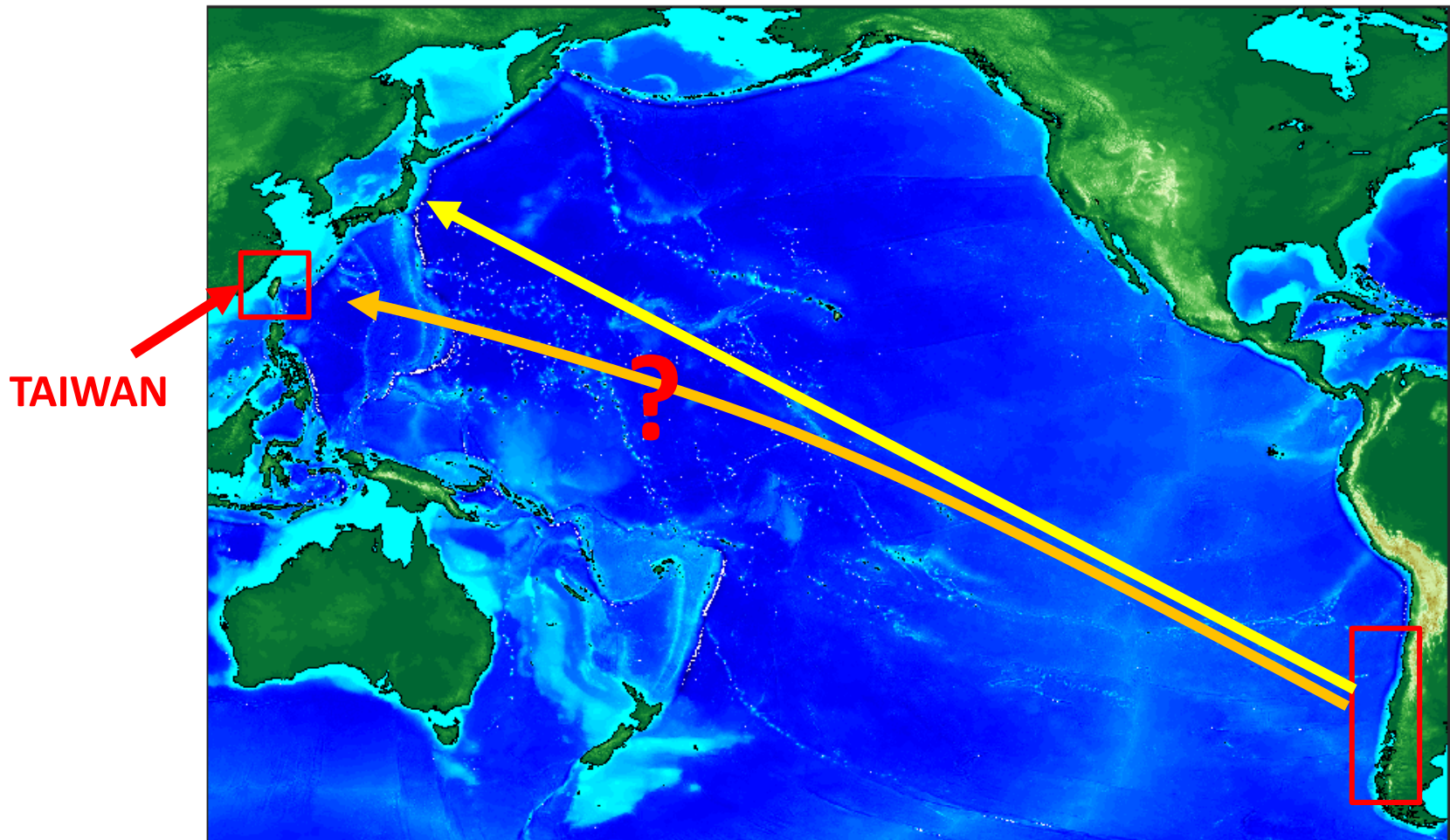
Area flooded by 1960 tsunami



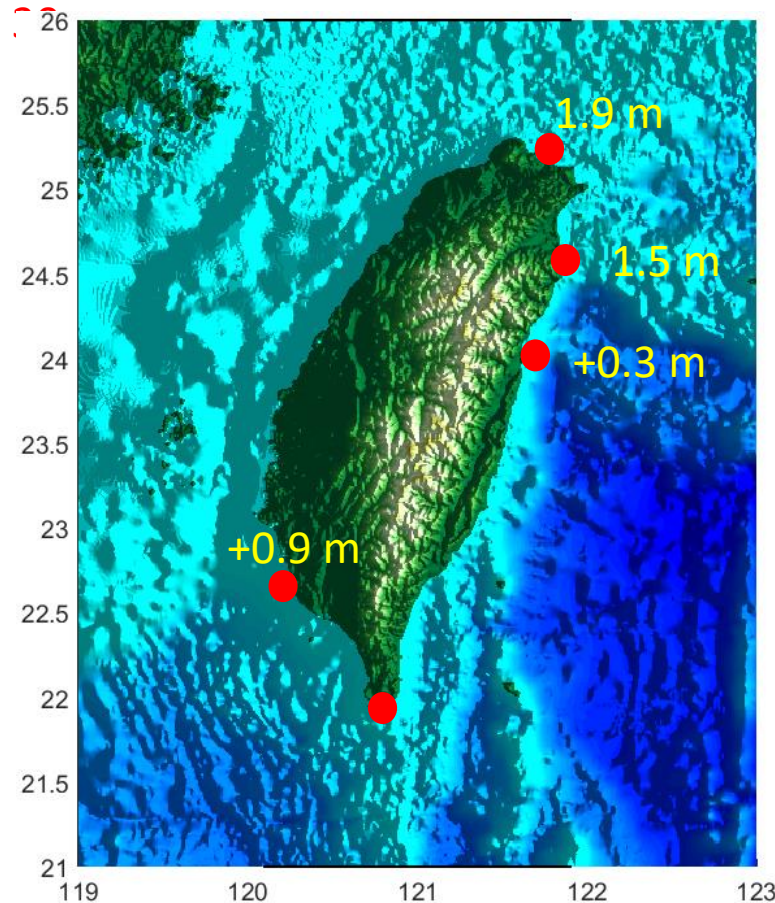
Area flooded in 1960 tsunami



HOW ABOUT THE TSUNAMI FROM CHILE TO TAIWAN?



根據聯合報報導，智利海嘯於基隆港內之潮位記錄達 1.9 m。基隆市內田寮港運河之尚志橋被沖垮。另有崇仁、平等、自由三橋被沖壞。在高雄地區，根據高雄港務局消息，海水已增高三尺（約 90 cm），所幸未造成災害。花蓮地區的潮差則是比平常高約

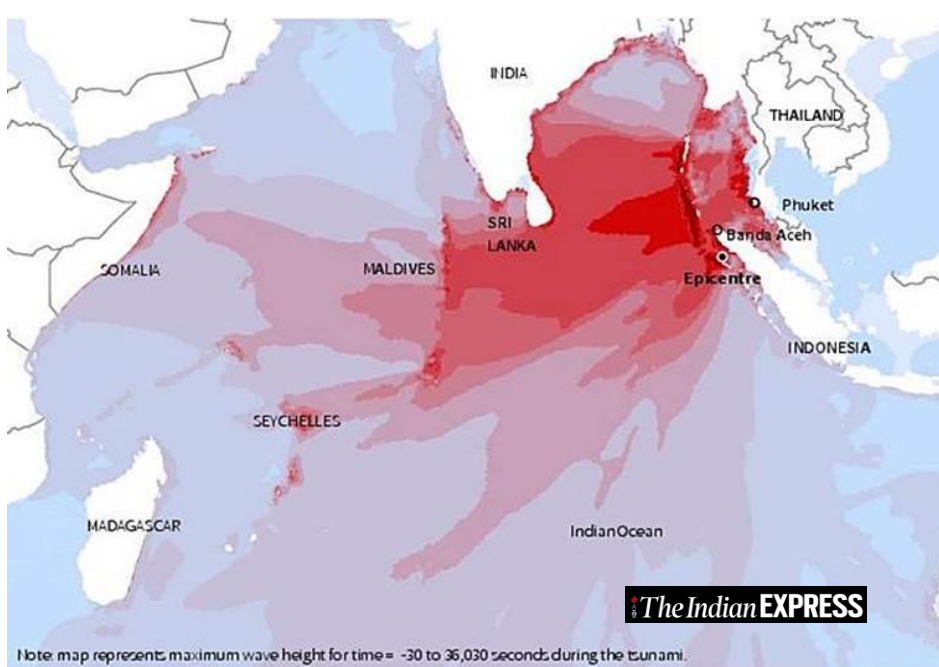


（許明光、李起彤，1996，台灣及其鄰近地區之海嘯，台灣海洋學刊）



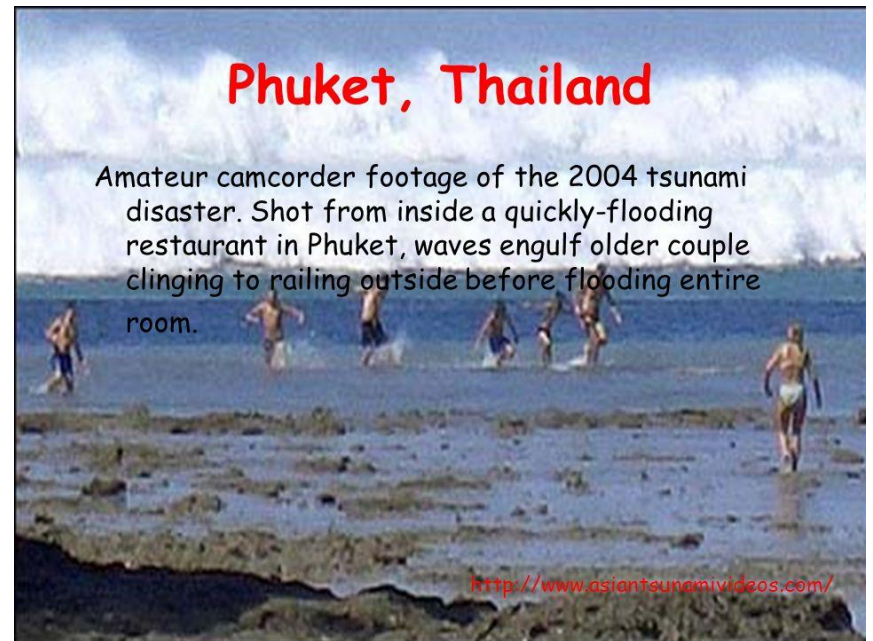
中央日報提到，南方澳漁港於24日凌晨5時許發生海嘯多次。初來時浪潮洶湧，港內海面驟漲起 5 尺餘高（約 1.5 m），去時浪潮急劇下降，每隔 10 分鐘一次，前後六次之多。當海潮第三次來時，適瑞振隆漁船在受檢查時。為浪潮沖走200餘公尺，幸未發生事端。恆春鎮南海里沿海 24 日發生罕見的海嘯奇觀。此一在風平浪靜中突然發生的海嘯，係開始於 24 日 6 時許，其中海水漲得最高的一次約有丈餘，二分鐘後迅速退卻，此後每隔五分鐘，即漲潮一次。2010 年又再次發生規模 8.8 之地震，並於後壁湖及烏石紀錄到 66 公分及 52 公分之海嘯波高，顯示該區域之災害潛勢極高，因此仍須謹慎面對。

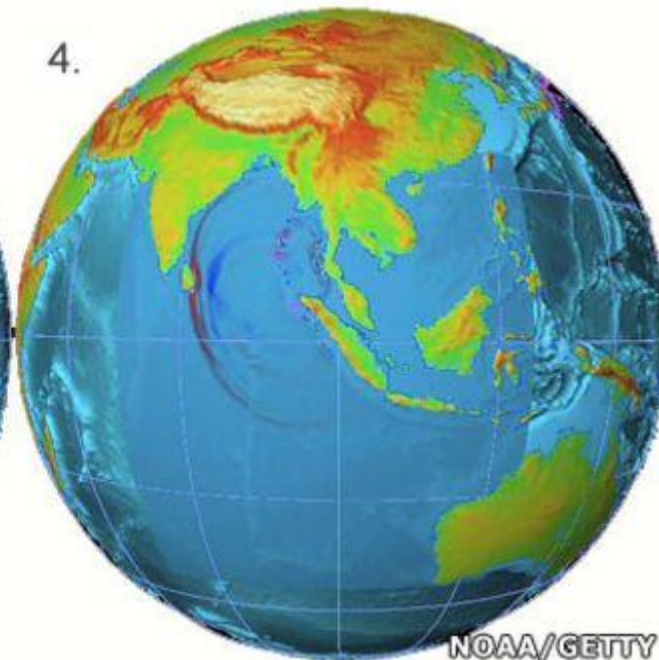
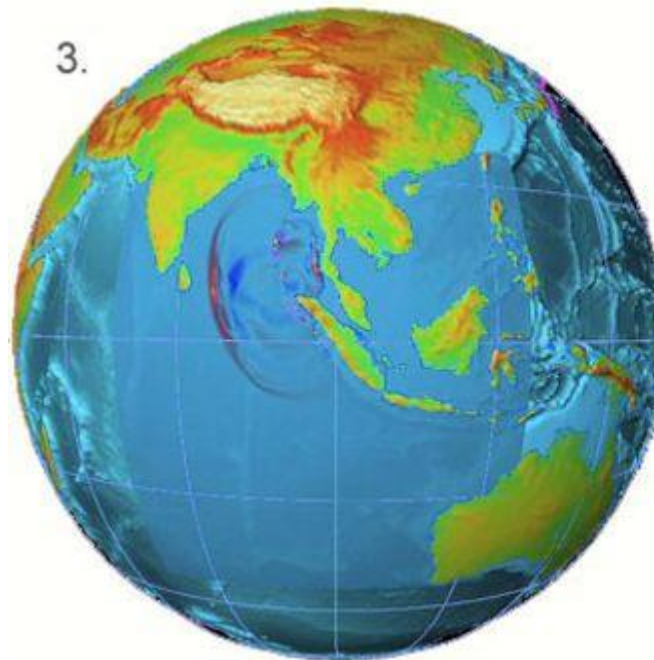
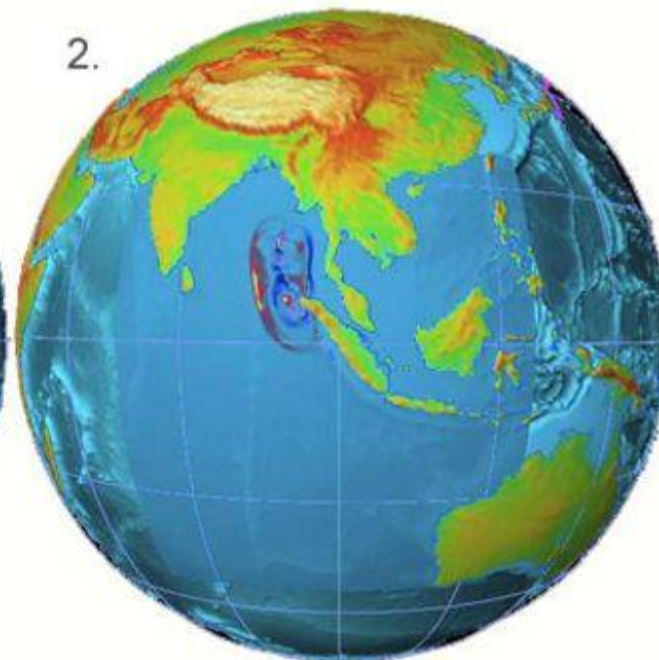
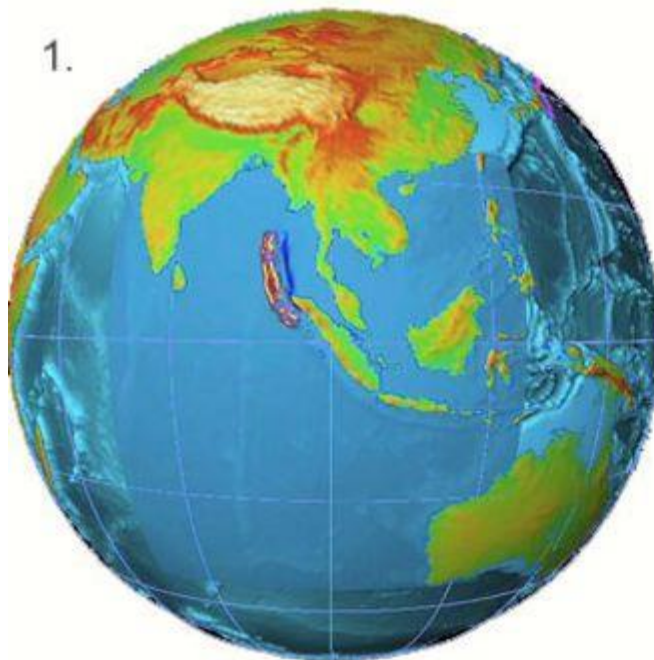
2004 南亞海嘯



Phuket, Thailand

Amateur camcorder footage of the 2004 tsunami disaster. Shot from inside a quickly-flooding restaurant in Phuket, waves engulf older couple clinging to railing outside before flooding entire room.





海嘯來臨時的情景（普吉島）



29萬人死亡 是海嘯史上傷亡人數最高的事件







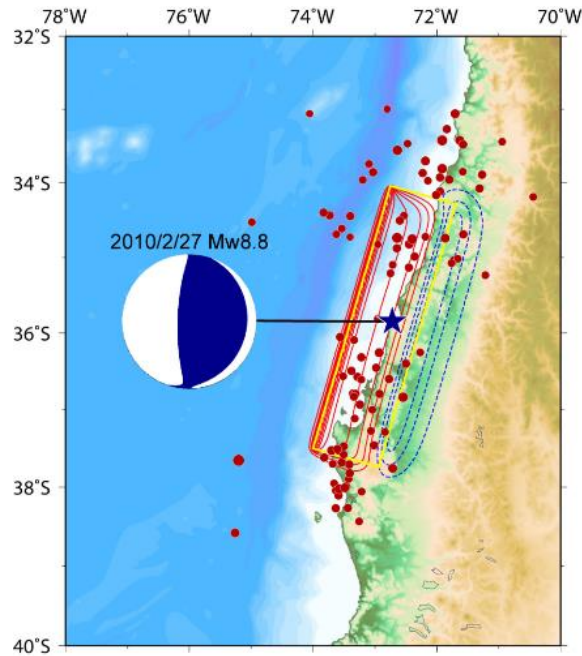




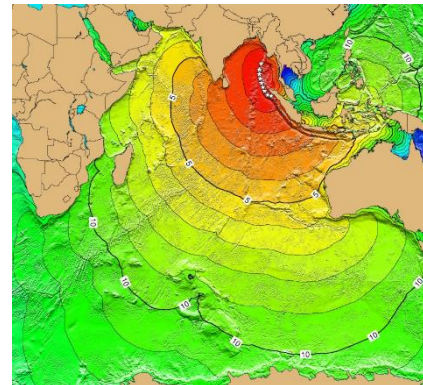
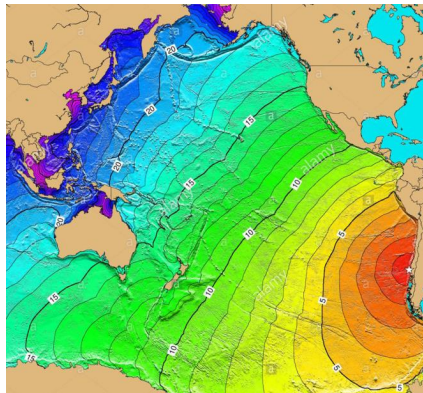
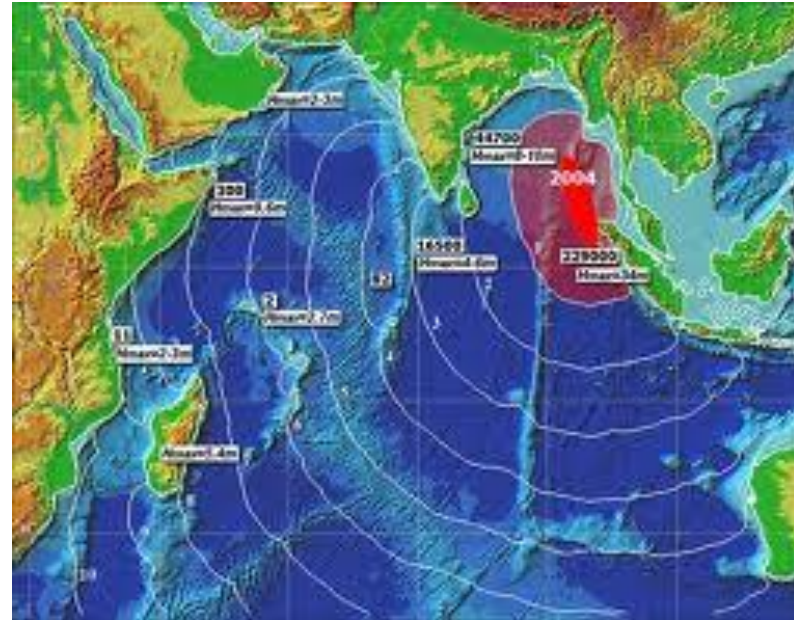


在歷經1960智利大海嘯和2004南亞大海嘯後，科學家普遍認定超級地震 (Mega Earthquake) 會發生在又直又長的海溝上。

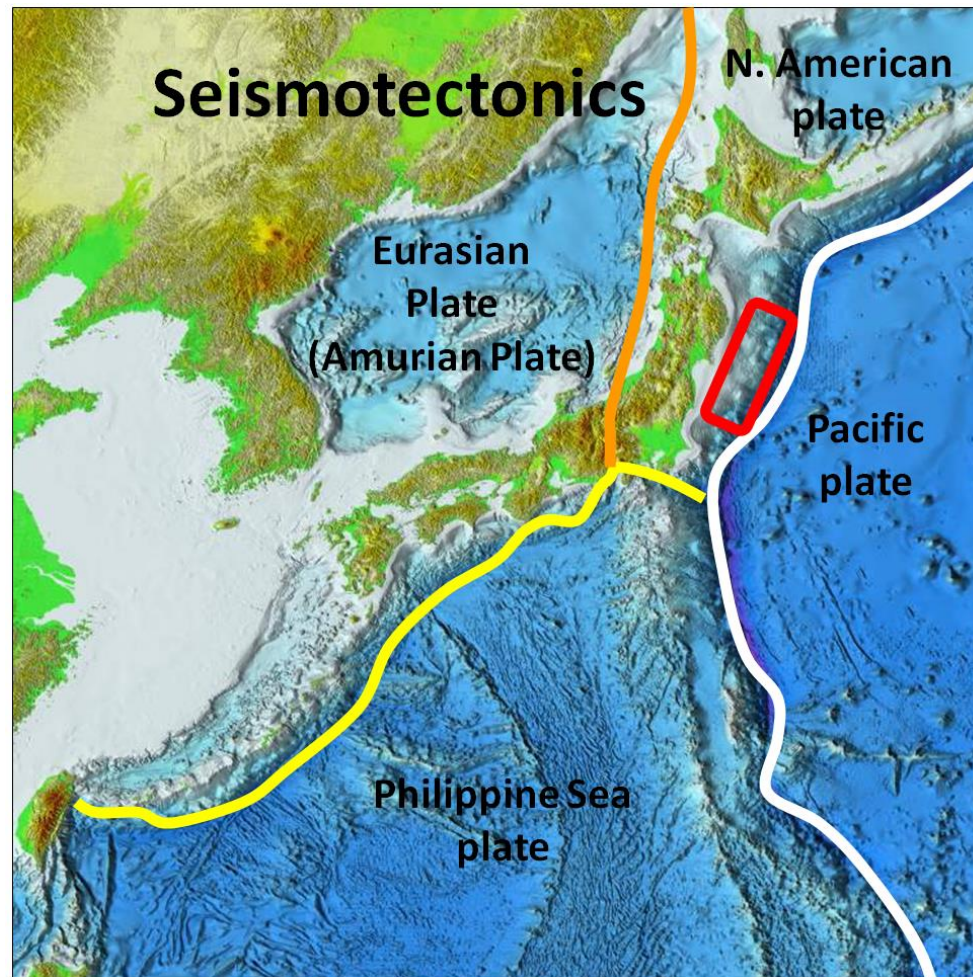
1960智利大海嘯



2004南亞大海嘯



2011年的東日本大地震，規模高達Mw9.1
發生在短且彎曲之破裂面上



(Copy right: Newton)



日本宮古市岸邊



日本宮城縣名取市



日本宮城縣仙台市



日本宮城縣仙台市，仙台機場



日本福島第一核電站爆炸現場



日本日立在地震和海嘯中被毀壞的汽車



本埼玉縣路段



海嘯和地震過後海上形成巨大的漩渦

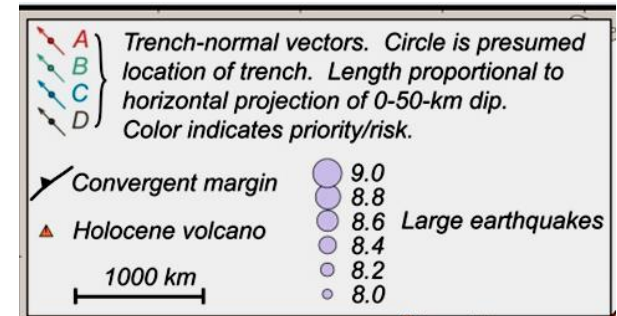
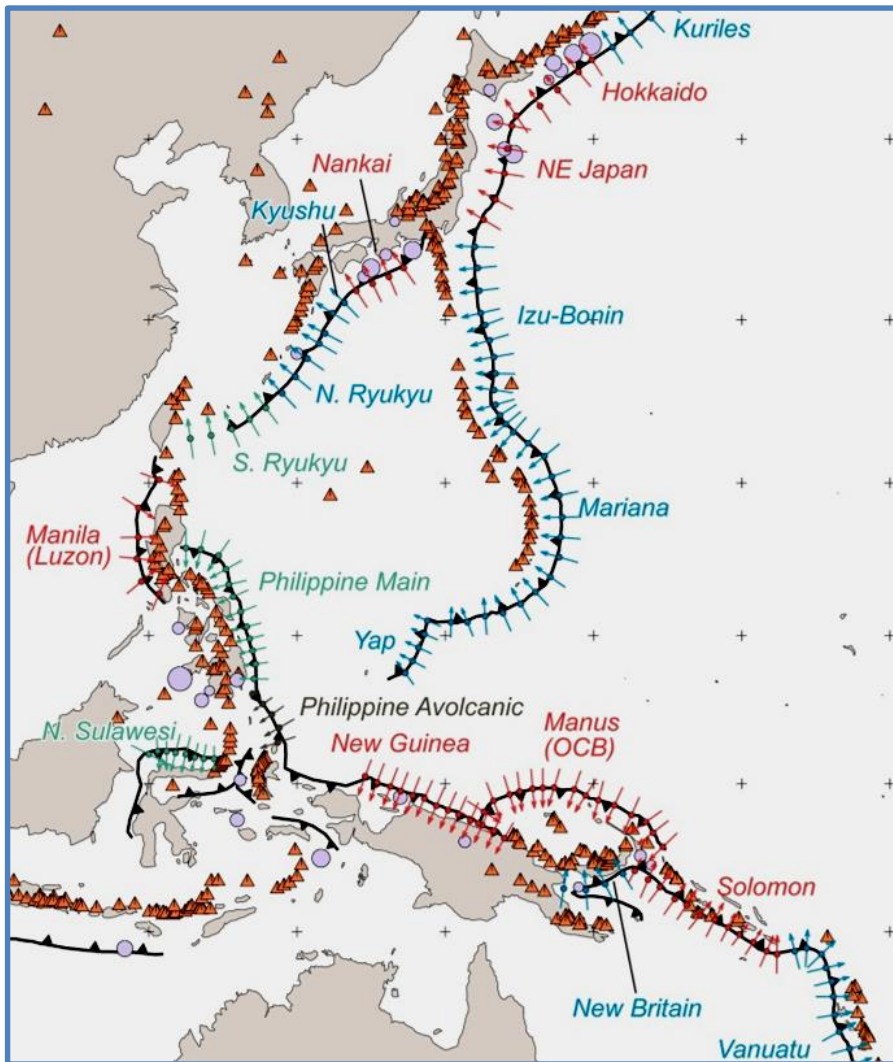


南三陸町

<https://kknews.cc/world/pxlxlrz.html>

台灣是否會有海嘯？

從地理和地質條件來看

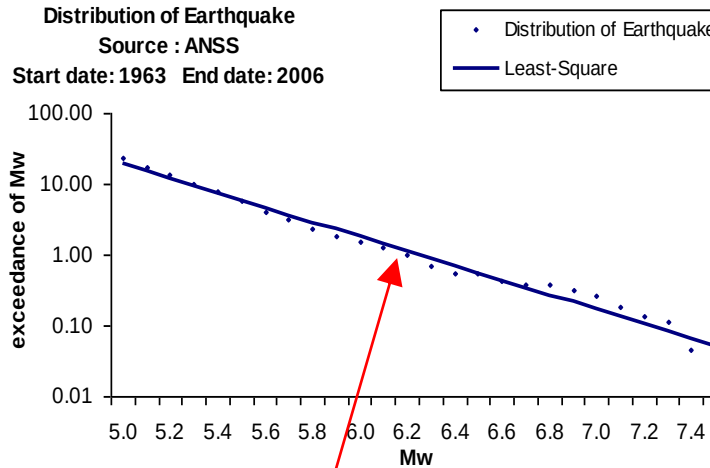
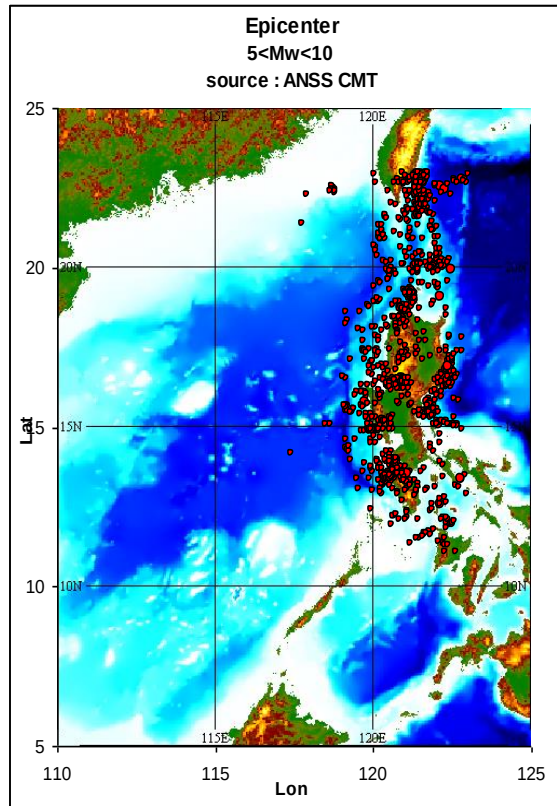


Tsunami Source Characterization for Western Pacific Subduction Zones: A Preliminary Report USGS1 Tsunami Subduction Source Working Group

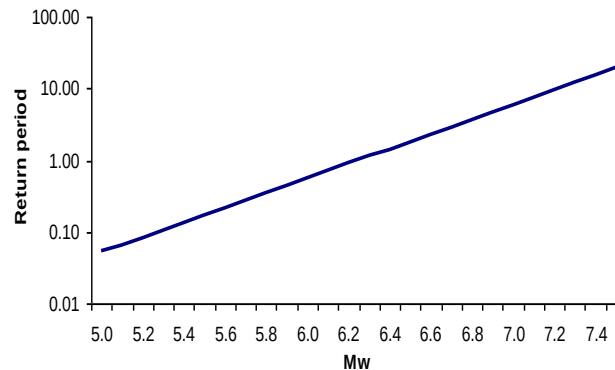
BOTTOM LINE
Hazard appraisal key:
A: High
B: Intermediate
C: Low
D: Not classified

USGS (2006) 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.

Estimation of Return period



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

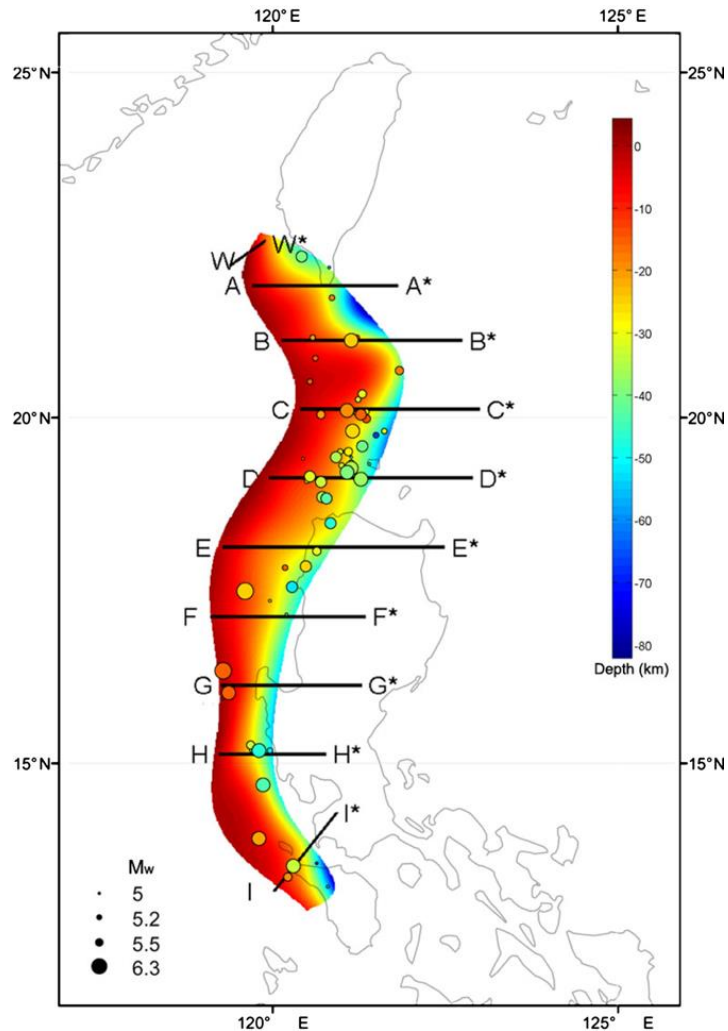


Mw	Return Period (year)
7.0	6
7.5	19
8.0	63
8.5	205
9.0	667

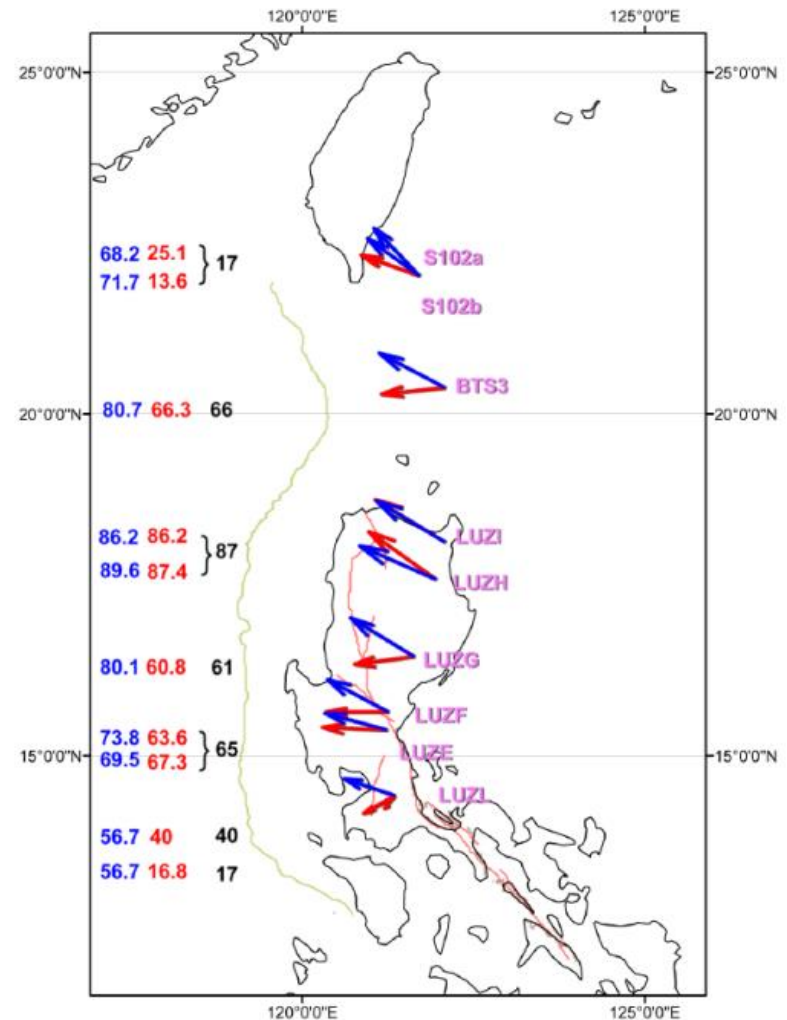
Source:ANSS 1963-2006

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)

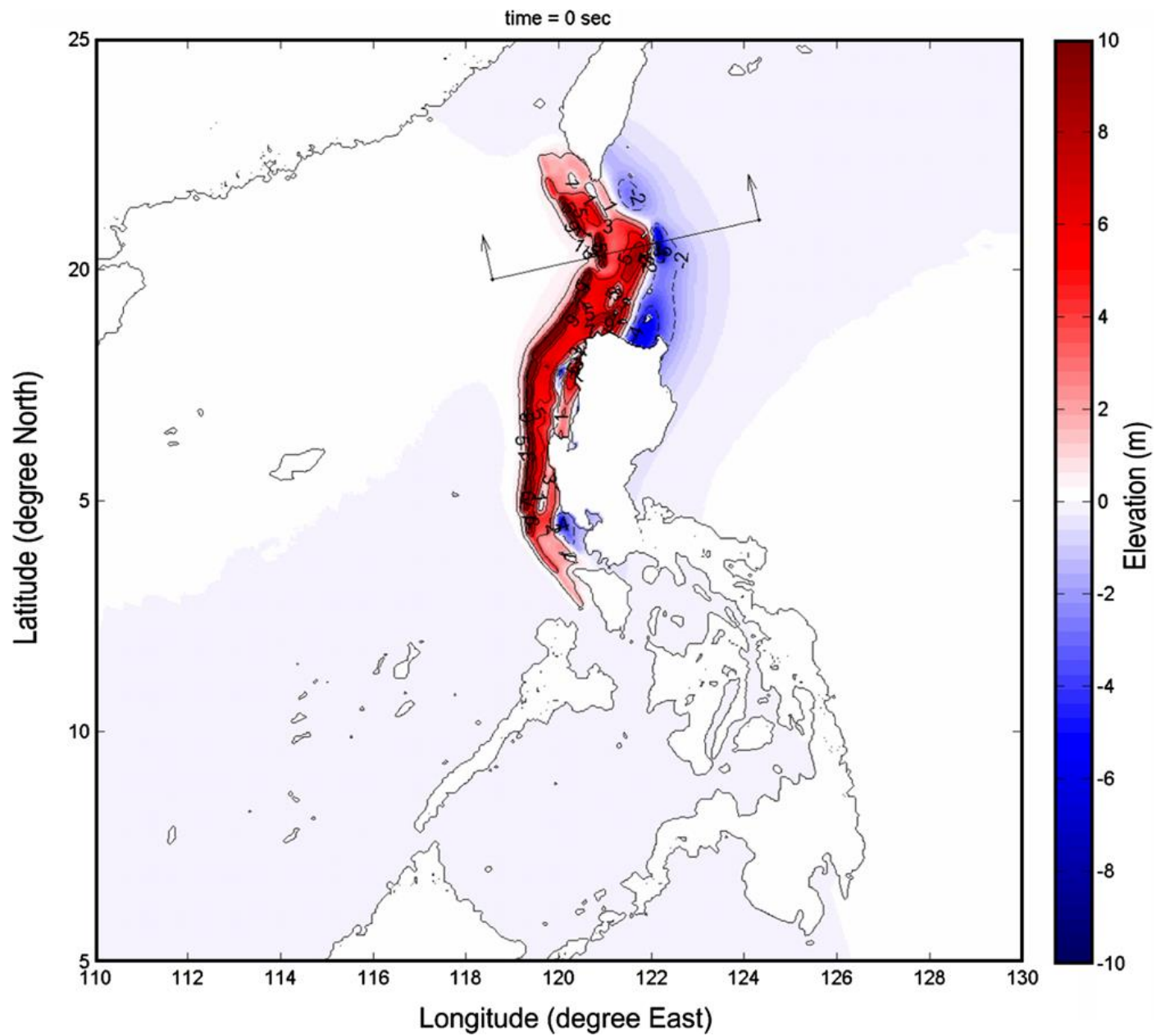


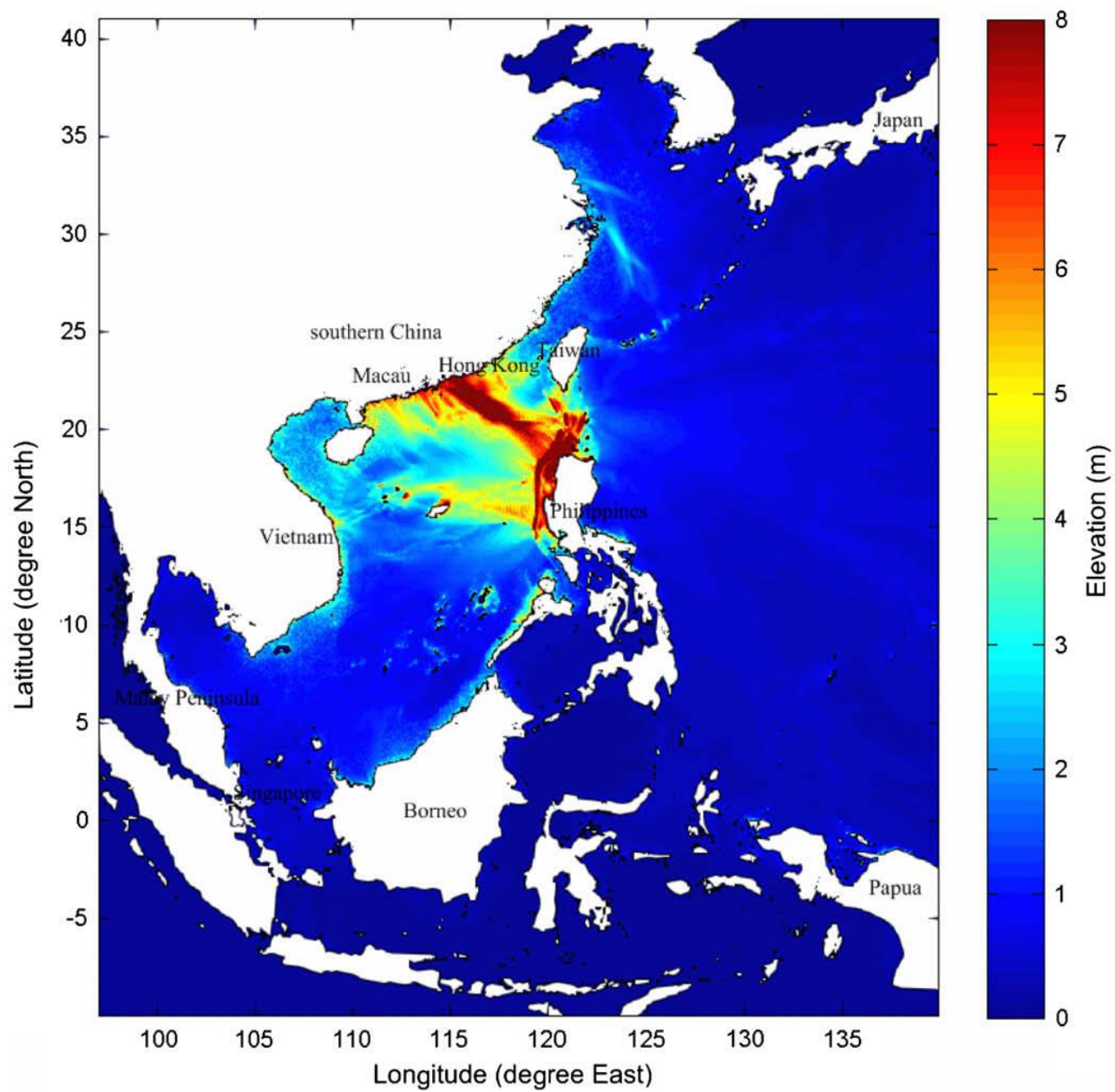
The sinuous rupture interface of the South China Sea megathrust, together with ten seismic cross sections between latitude 12.5°N and 23.5°N from the studies by Bautista et al. (2001) and Wu et al. (2007). Epicenters of thrust-faulting earthquakes are plotted to mark the downdip boundary of the rupture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

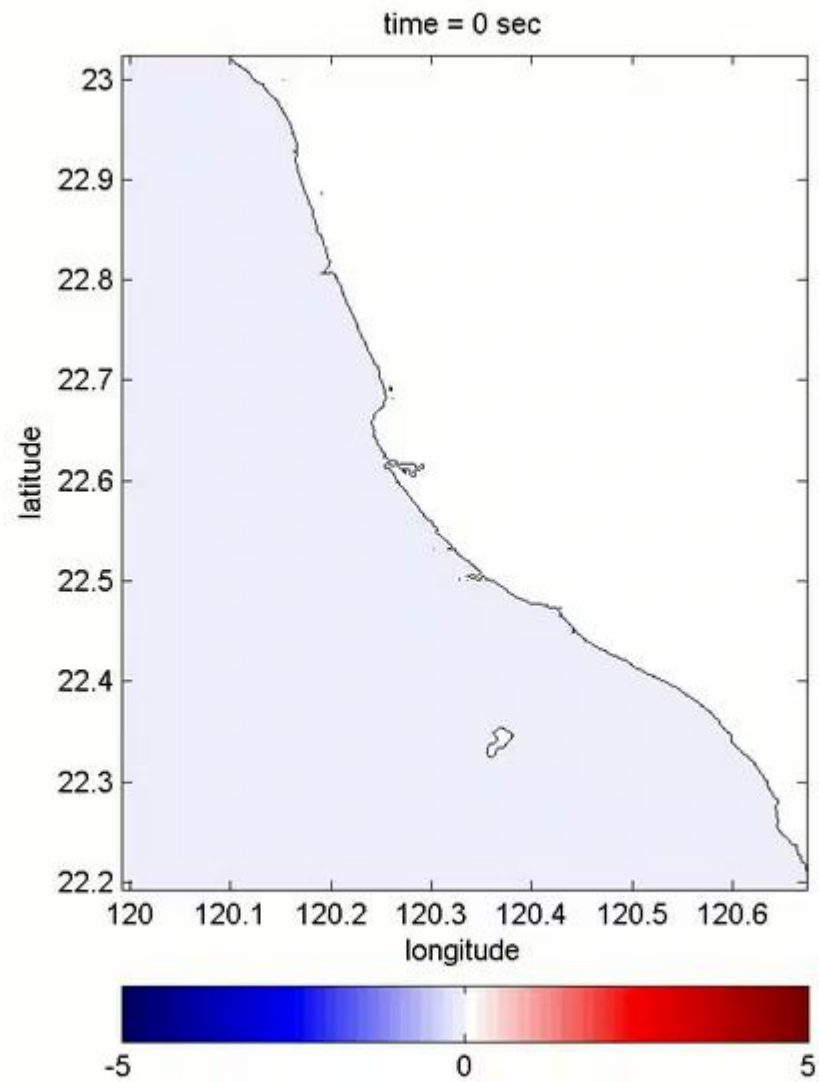


GPS data (Yu et al., 1999) indicating motion of the converging Eurasian Plate and the Philippines Sea Plate, where the blue arrows and numbers show raw velocity values (mm/yr) taken from Yu et al. (1999), the red arrow and numbers indicate velocity values (mm/yr) resolved in the direction perpendicular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

(Megawati et al., 2009)







News Report:

South China Morning Post 創立於1903年

繁體中

新浪微博

微信

騰訊微博

Facebook

香港南華早報

星期四 2014年08月14日

國際

金光大道
度假區



大陸

港澳台

國際

財經

觀點

圖解

南早香港指南

首頁

國際

馬尼拉海溝地震風險加劇 南海爭端阻預測工作

熱門話題: 中國反腐 “福喜肉”事件

國際

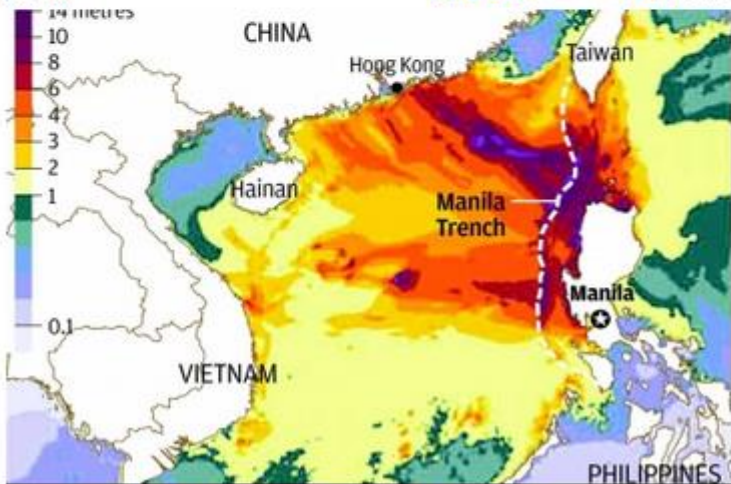
馬尼拉海溝地震風險加劇 南海爭端阻預測工作

一旦海嘯發生，包括香港在內的沿海地區可能會有數萬人喪生，導致損失慘重。

陳冰琳

分享到:      列印

電郵 2014年08月06日 下午1:05



中國大陸、台灣和菲律賓的科學家都認為，南海周邊國家低估了南海海域發生大海嘯的風險。

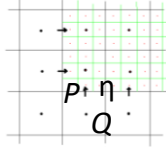
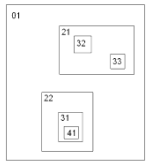
一旦海嘯發生，包括香港在內的沿海地區可能會有數萬人喪生，導致損失慘重。

中國科學院海洋研究所一位科學家稱，他們亟需最新數據來評估海嘯可能爆發的規模和時間，但由於南海主權糾紛，他們無法前赴該區域獲取數據。

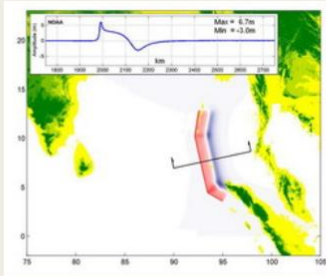
來源：亞洲地球科學期刊

Tsunami Model: COMCOT

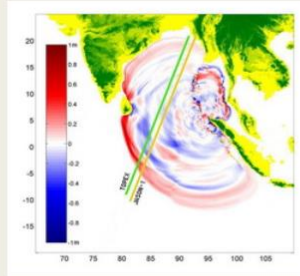
(Cornell Multi-grid Coupled Tsunami Model)



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.

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.

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

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

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

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

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

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

Eq.01 SWE in Spherical Coord.

Eq.02 SWE in Cartesian Coord.

- 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

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.

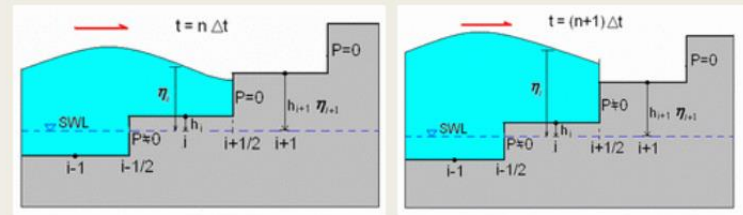


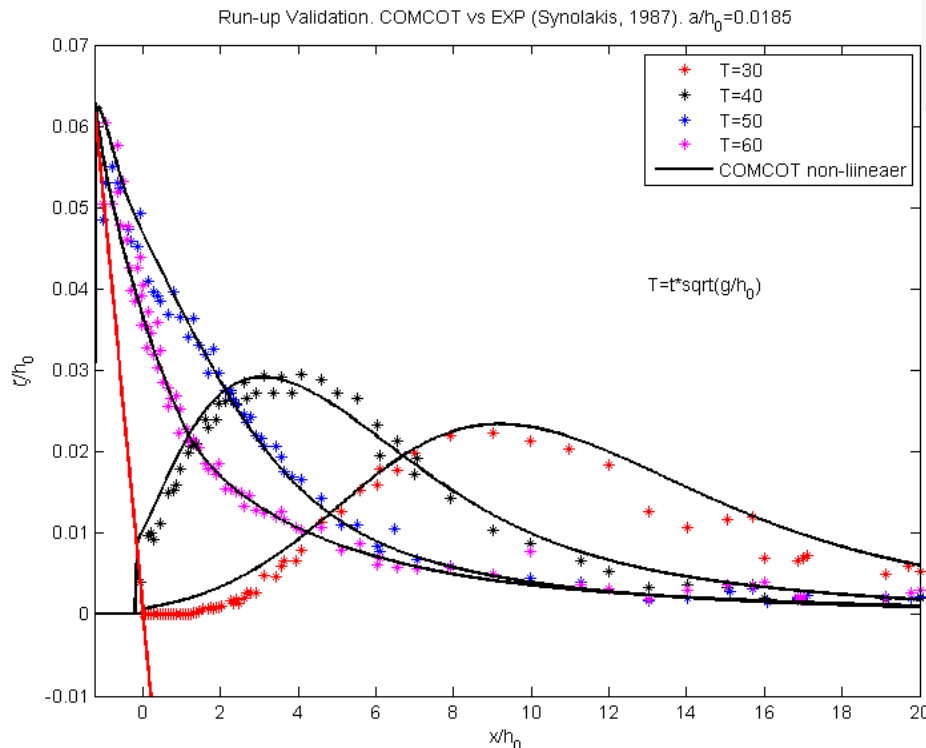
Fig.02 Moving Boundary Scheme

(1). Widely validated

Soliton runup:

Synolakis (1986, 1987)

Very accurate results can be seen.



(吳祚任，2012)

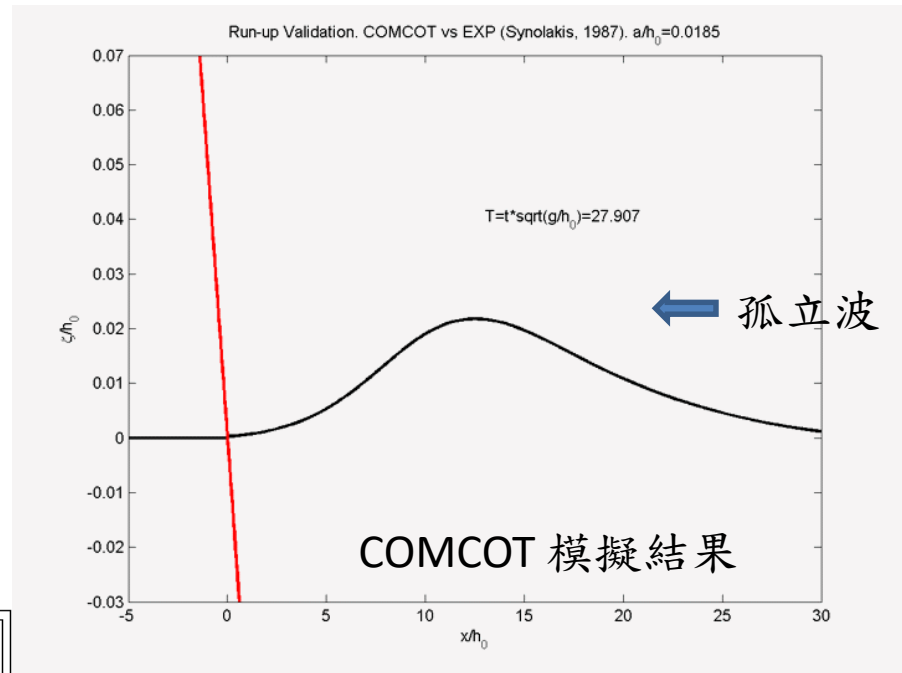
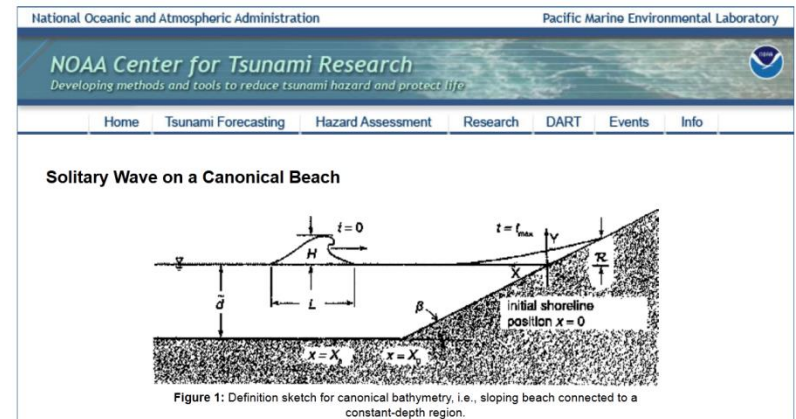


Figure 2: Time evolution of $H = 0.0185$ initial wave over a sloping beach with $\cot \beta = 19.85$ from $t = 25$ to 65 with 10 increments. Constant depth-segment starts at $X_0 = 19.85$. While markers show experimental results of Synolakis (1986, 1987), solid lines show nonlinear analytical solution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



(資料來源：NOAA 官網)

(2). High-speed Calculation

COMCOT-Surge Model can finish 48 hrs forecast in 30 mins on PC-level computational resources and be used for the operational system.

```
!$OMP PARALLEL DO PRIVATE(J,I,ZZZ,DD)
DO J=JS, JE
  DO I=IS, IE
    IF (L%H(I,J) .GT. ELMAX) THEN
      ZZZ = L%Z(I,J,1) - RX*(L%M(I,J,1)-L%M(I-1,J,1)) &
        - RY*(L%N(I,J,1)-L%N(I,J-1,1))
      ZZZ = ZZZ - (L%HT(I,J,2)-L%HT(I,J,1))
      IF (ABS(ZZZ) .LT. EPS) ZZZ = 0.0
      DD = ZZZ + L%H(I,J)
    ...
  ELSE
    ...
  END IF
END DO
END DO
!$OMP PARALLEL DO
```

Parallel Computing on Multi Cores.



Review

Development of a tsunami early warning system for the South China Sea



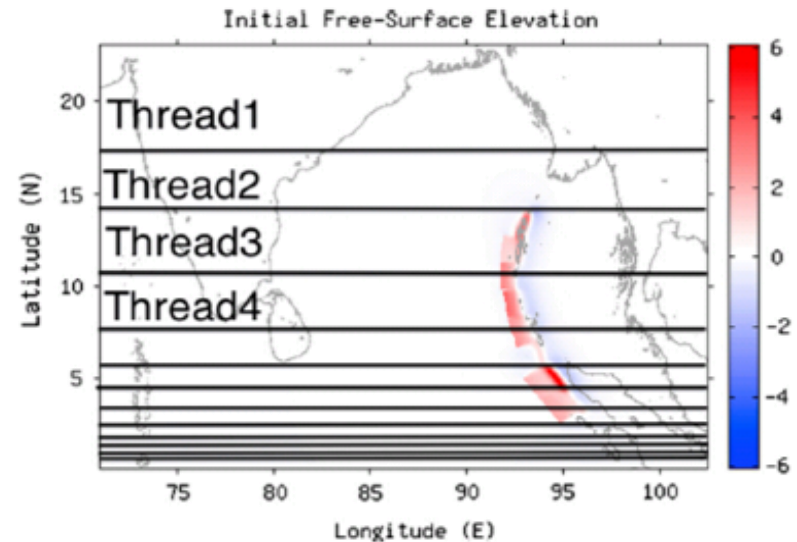
Simon C. Lin^a, Tso-Ren Wu^{c*}, Eric Yen^b, Hsin-Yen Chen^b, John Hsu^a, Yu-Lin Tsai^c, Chun-Juei Lee^c, Philip, L.-F. Liu^{c,d}

^aInstitute of Physics, Academia Sinica, Taipei 11529, Taiwan

^bAcademia Sinica Grid Computing Centre, Taipei 11529, Taiwan

^cInstitute of Hydrological & Oceanic Sciences, National Central University, Jhongli 32001, Taiwan

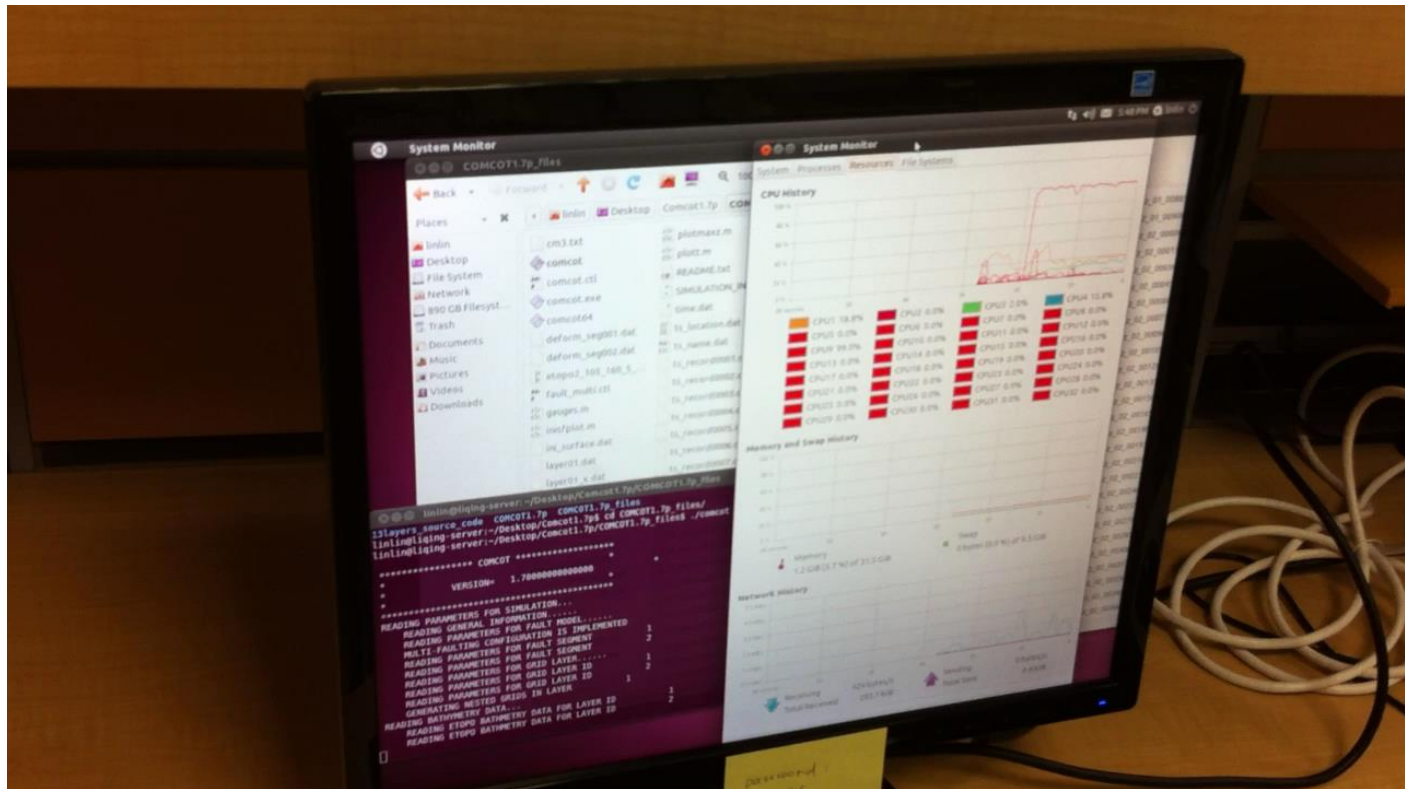
^dSchool of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853, USA



Dynamic resources sharing.

*The results has been published on Ocean Engineering
(Simon C. Lin et al., 2015).*

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



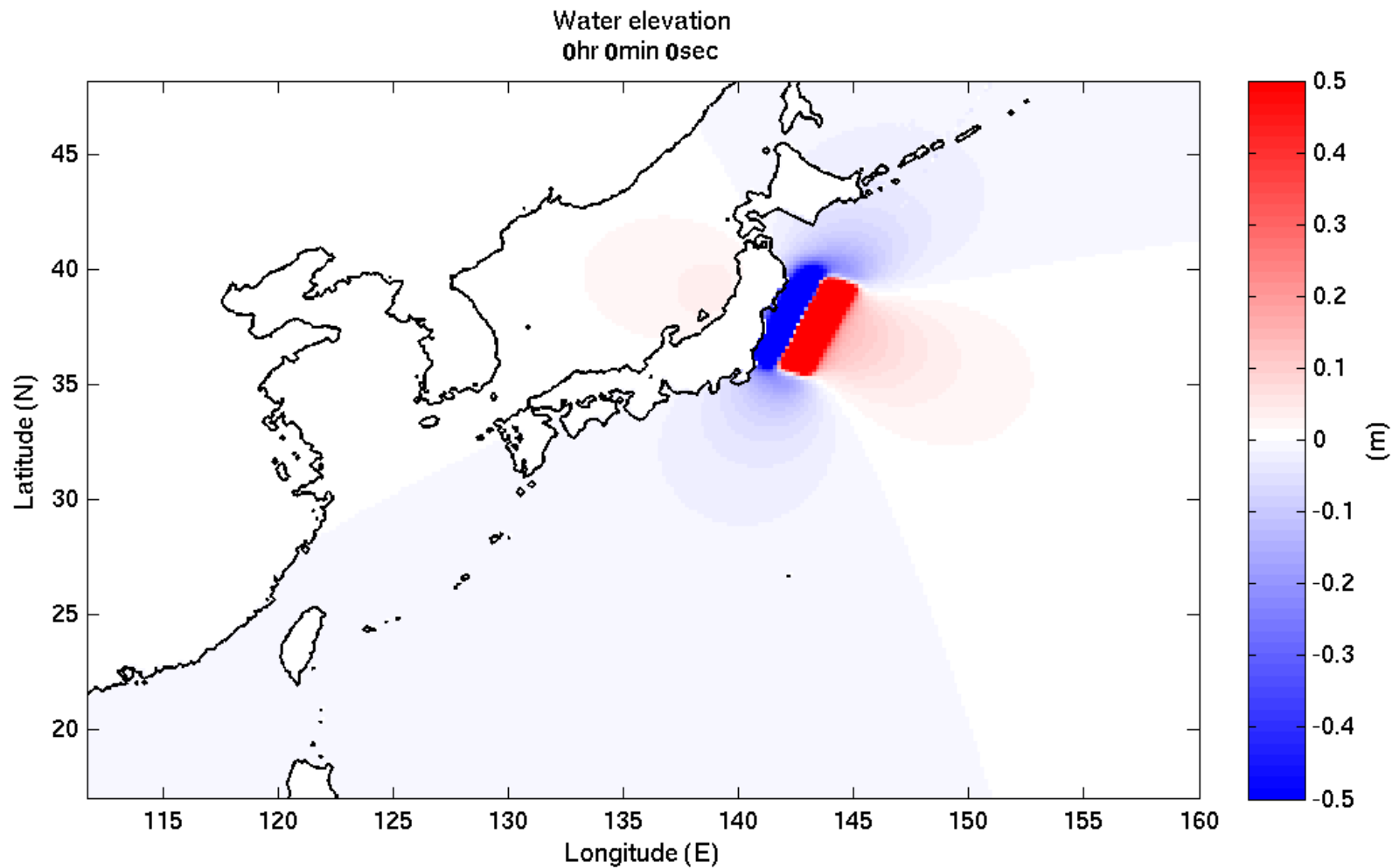
(We tested COMCOT on a new 32-core server in NTU, Singapore. A case used to be done in 30 minutes can be finished in 2 minutes on the new machine.)

2011 Tōhoku earthquake and tsunami

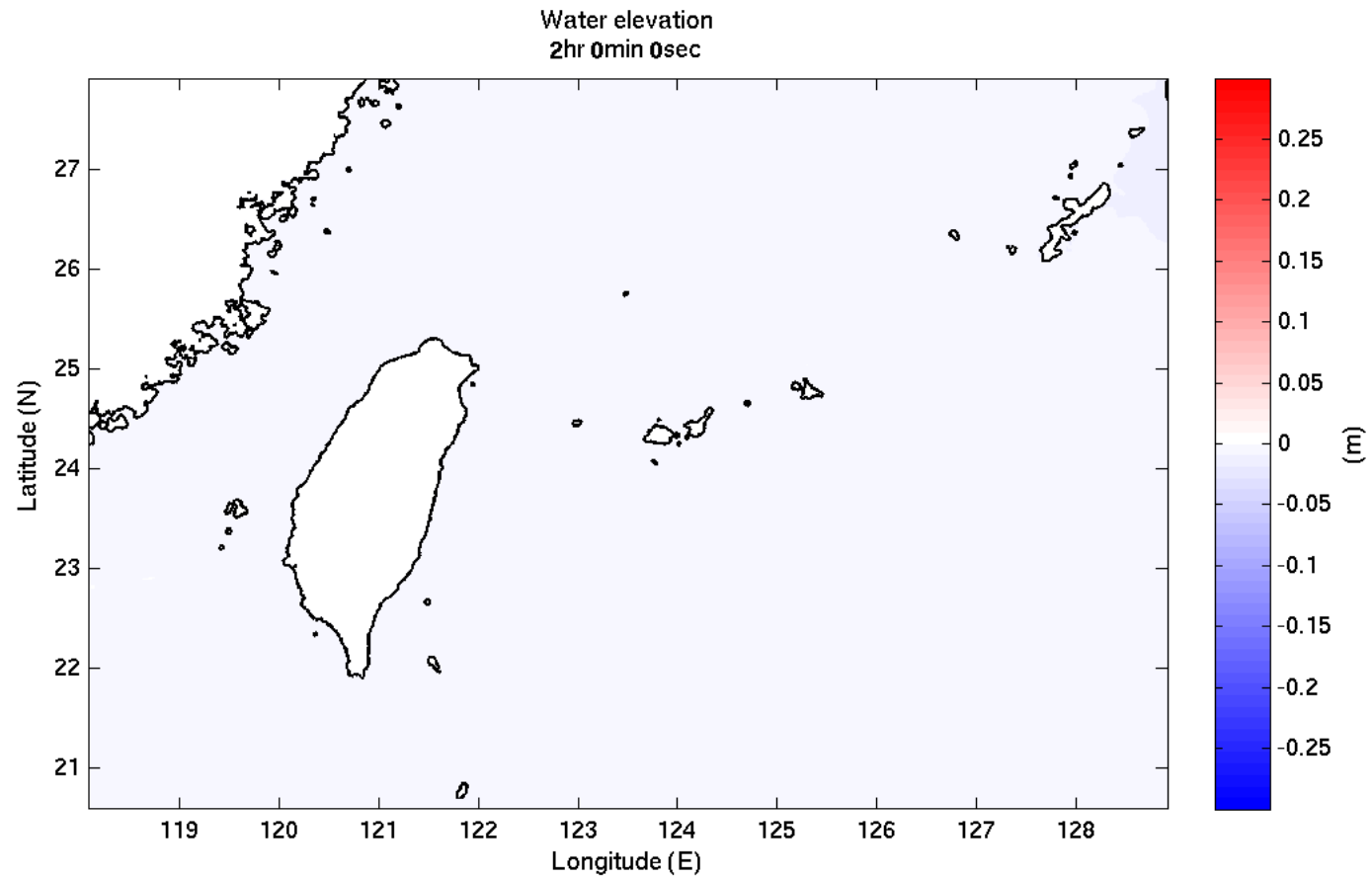
2011東日本海嘯事件

- 我們花了20分鐘等待地震參數
 - We spent about 20 mins to prepare, or wait for, the fault parameters
- COMCOT海嘯模式僅花費1分鐘，就完成日本到台灣的海嘯模擬
 - COMCOT spent about 1 min to finish the tsunami simulation from Japan to Taiwan.
- 這比海嘯跑得還要快很多！
 - It is about real-time simulation
- COMCOT預測海嘯抵達台灣成功浮標站的波高約12 公分
 - COMCOT predicted that the tsunami wave height was about 12 cm offshore Taiwan.
- 後來資料顯示的確是12公分
 - Field data also showed about 12 cm.

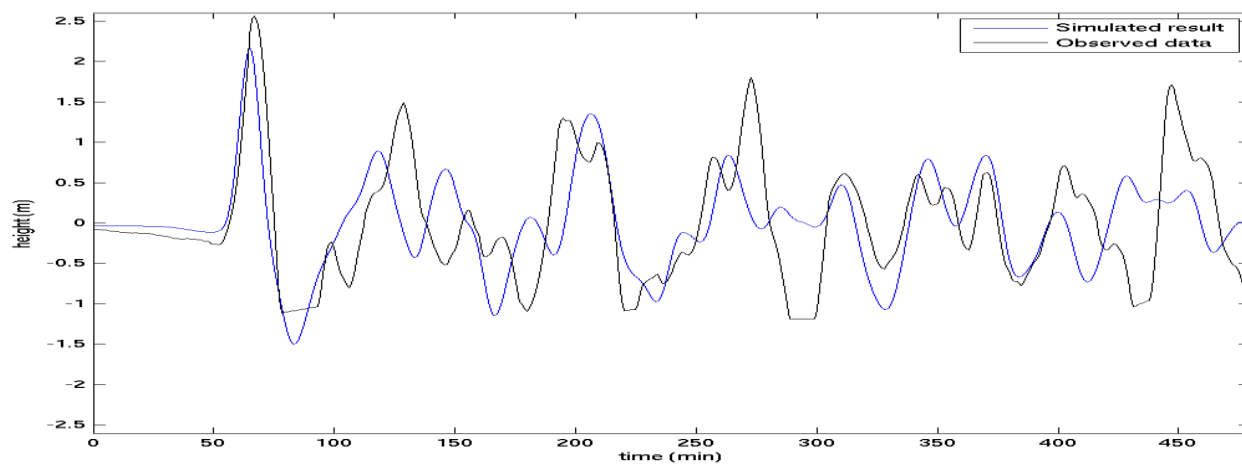
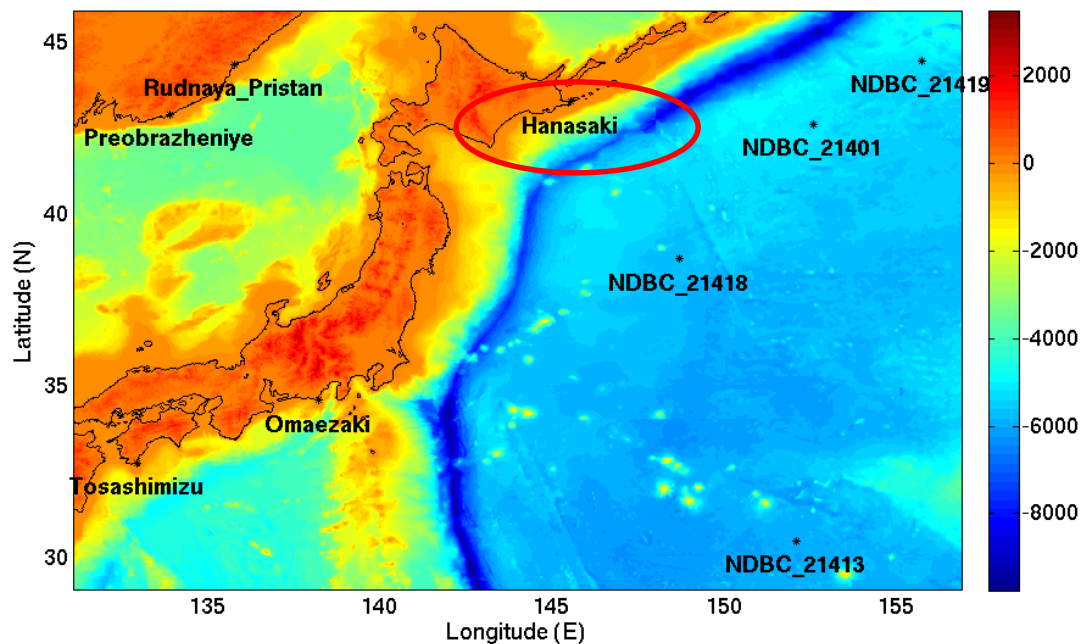
模擬結果：海嘯傳播方式



海嘯傳遞至台灣

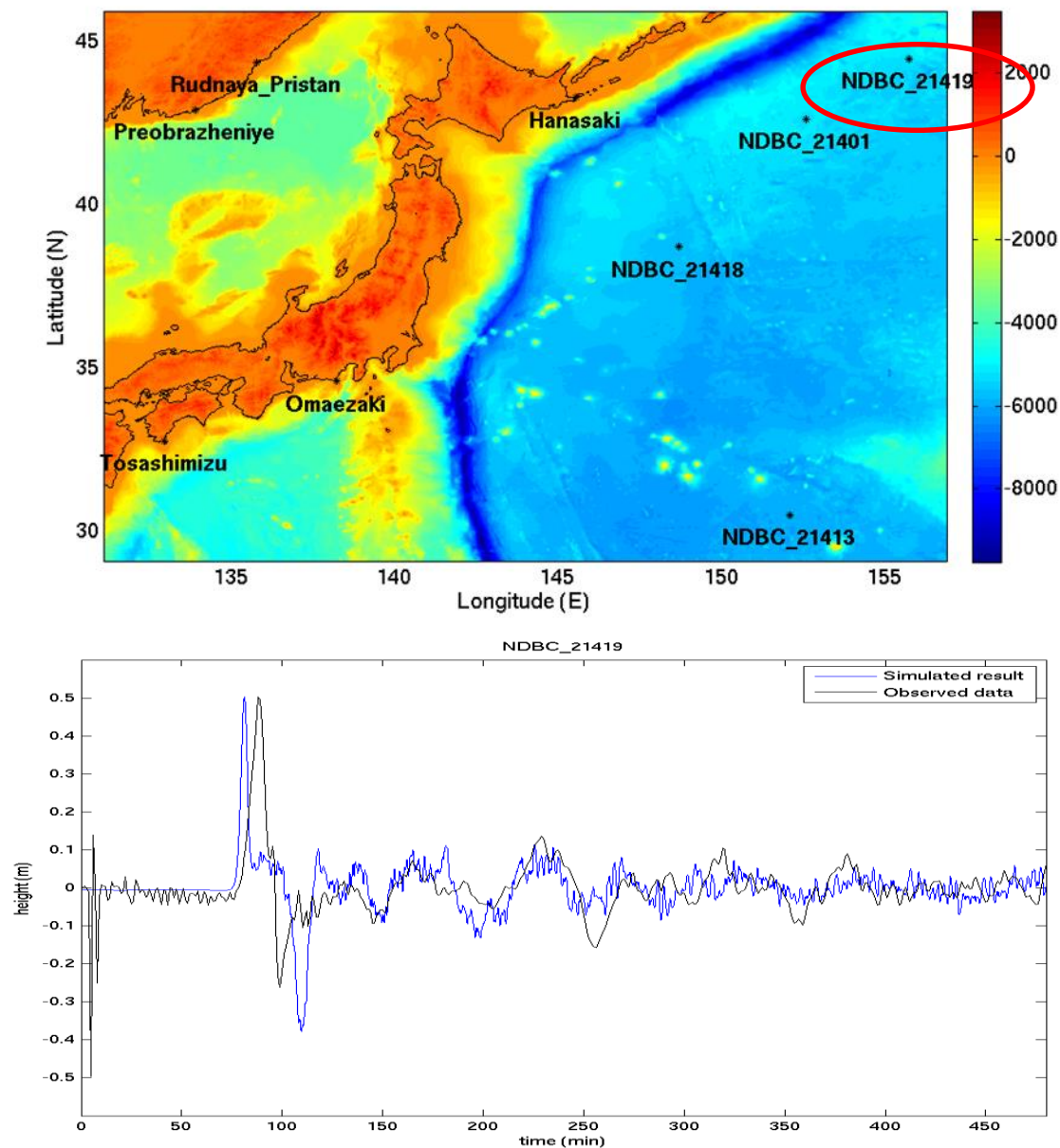


模式預測之海嘯波高與日本潮位站實測比對：Hanasaki



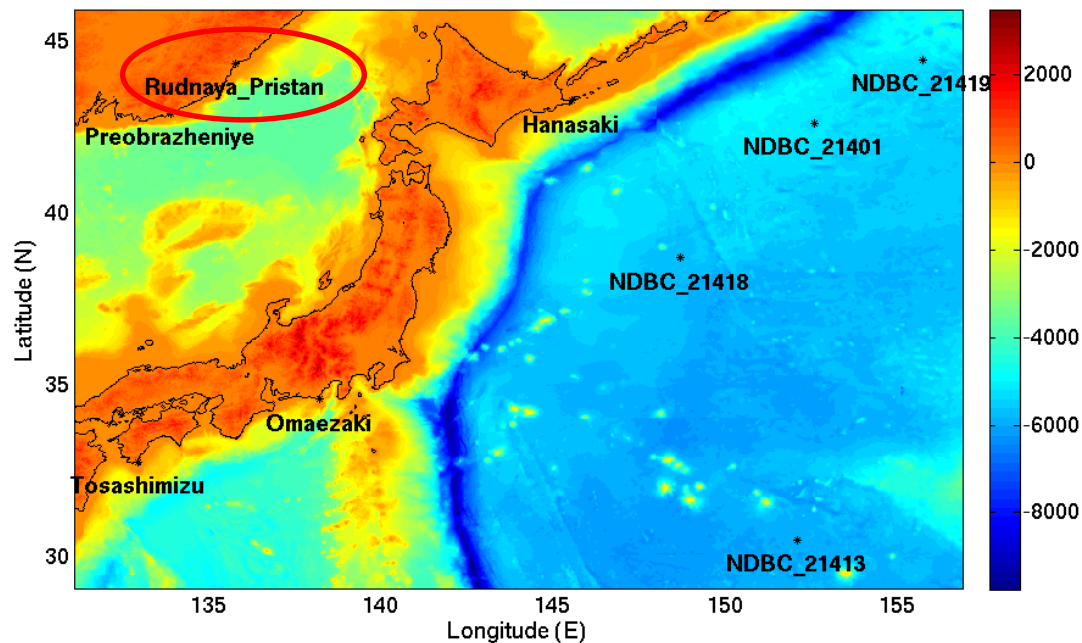
Hanasaki 潮位站比對，藍線為模擬結果，黑線為實測資料。該站位於斜坡部分，模擬結果與實測比對相當一致。

模式預測之海嘯波高與美國NOAA深海浮標實測比對：NDBC_21419

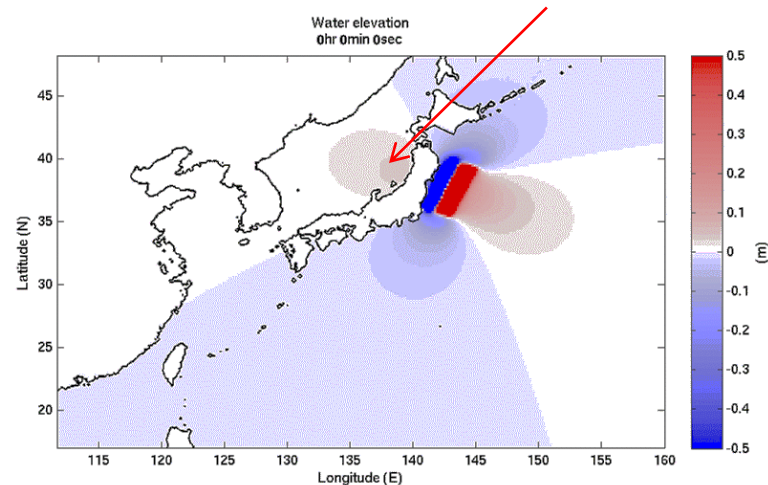
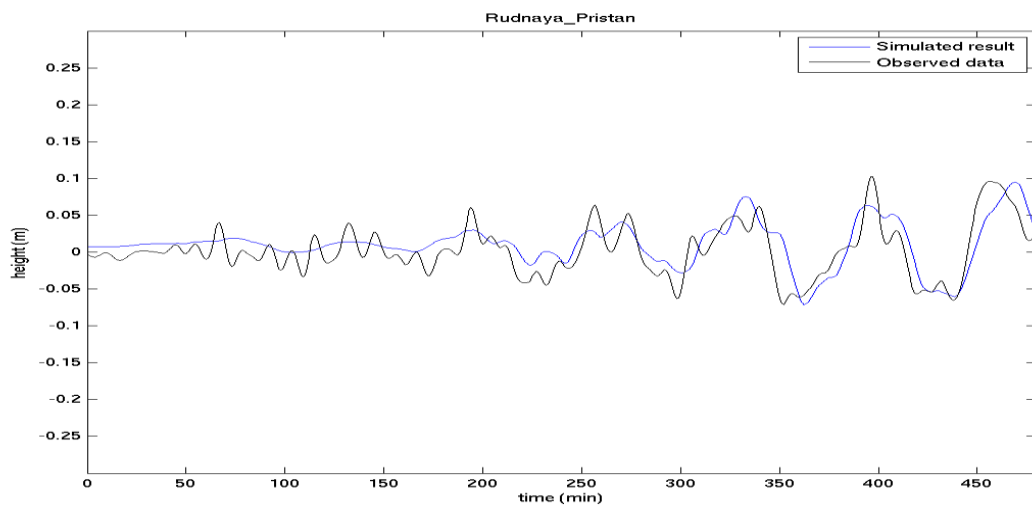


與NOAA浮標資料比對，藍線為模擬結果，黑線為實測資料。模擬結果與實測比對相當一致。

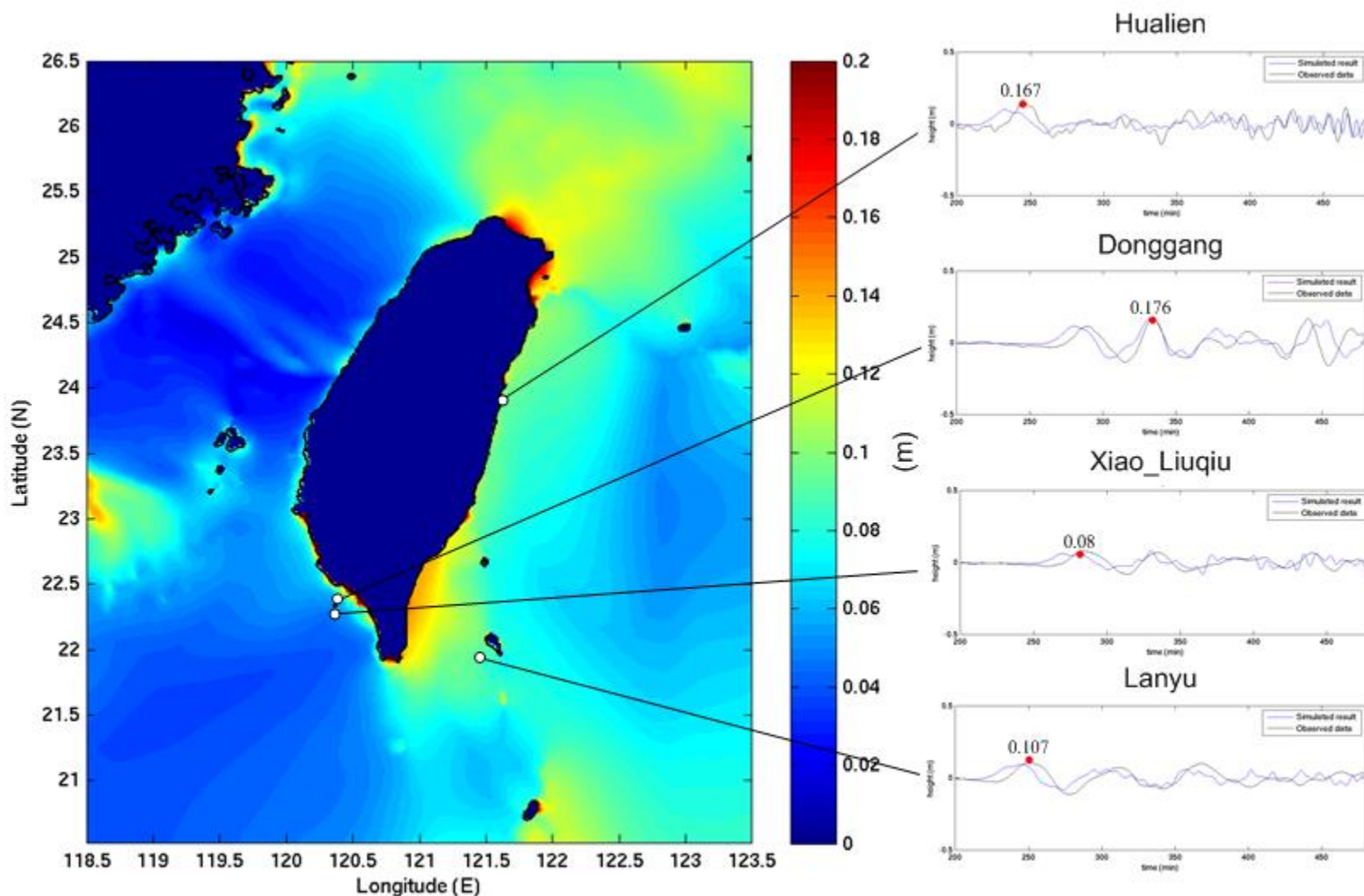
模式預測之海嘯波高與蘇聯潮位站實測比對：Rudnaya Pristan (日本西岸亦出現海嘯訊號)



西海岸海床抬昇



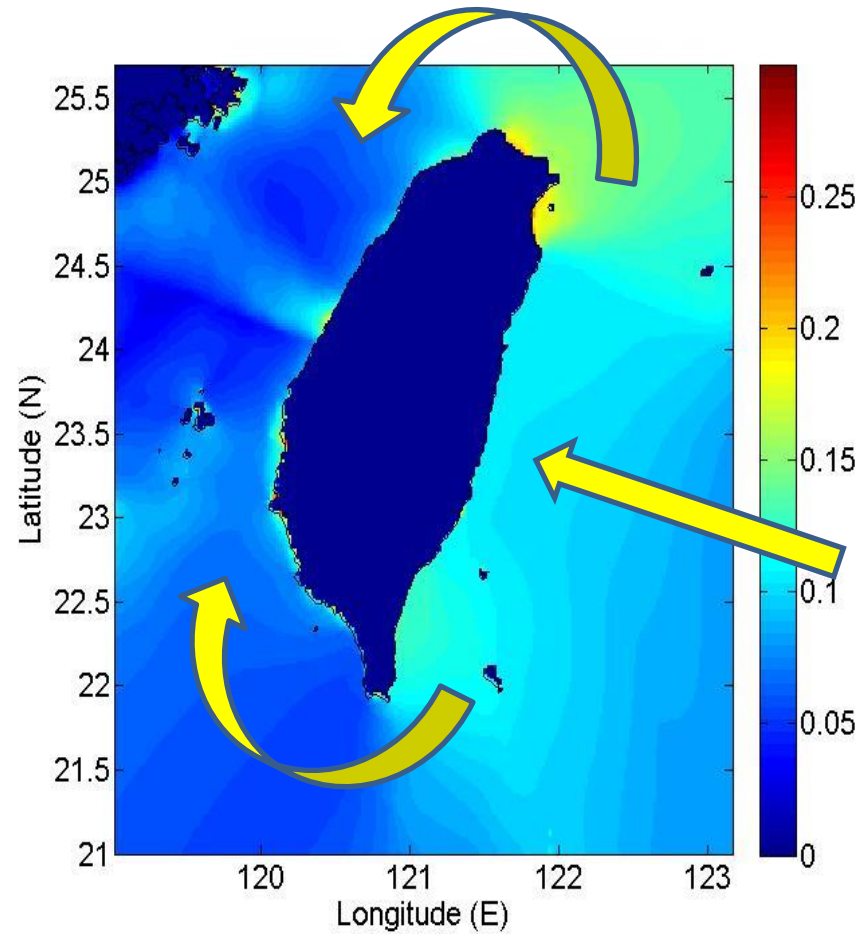
模式預測之海嘯波高中央氣象局潮位站資料比對



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）

哇！好準！

海嘯傳遞至台灣之方式



Maximum Wave height

威脅台灣的
海嘯18套劇本

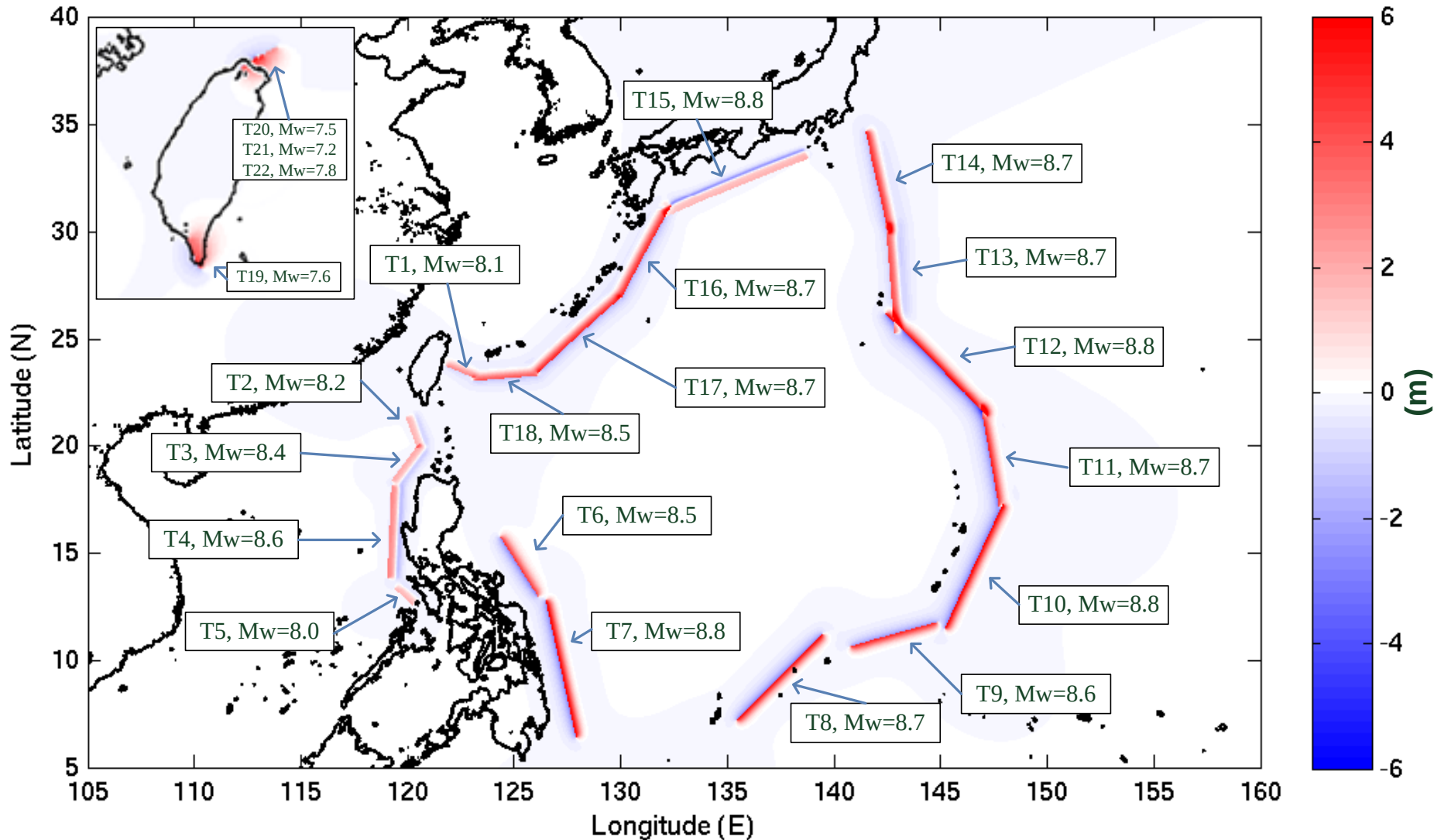
Tsunami Sources of
18 Trench Segments

18個海溝型海嘯源以及4個斷層型海嘯源

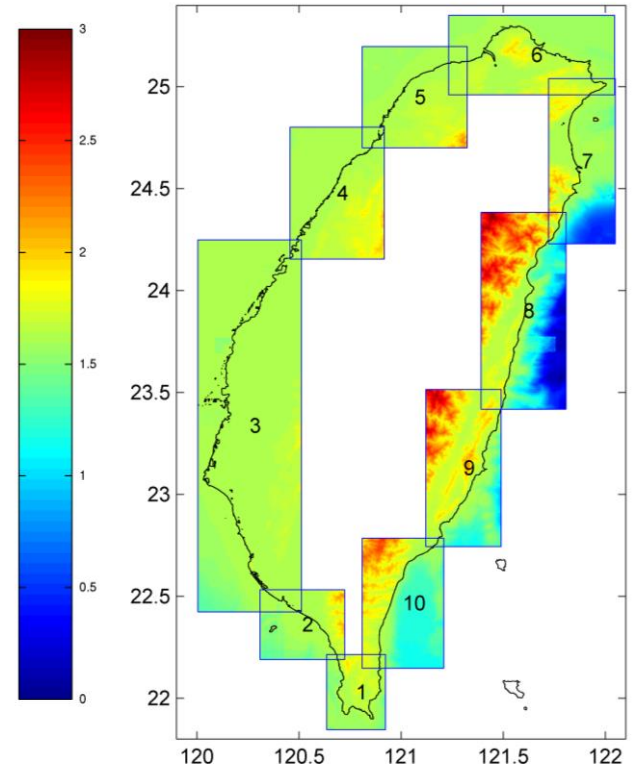
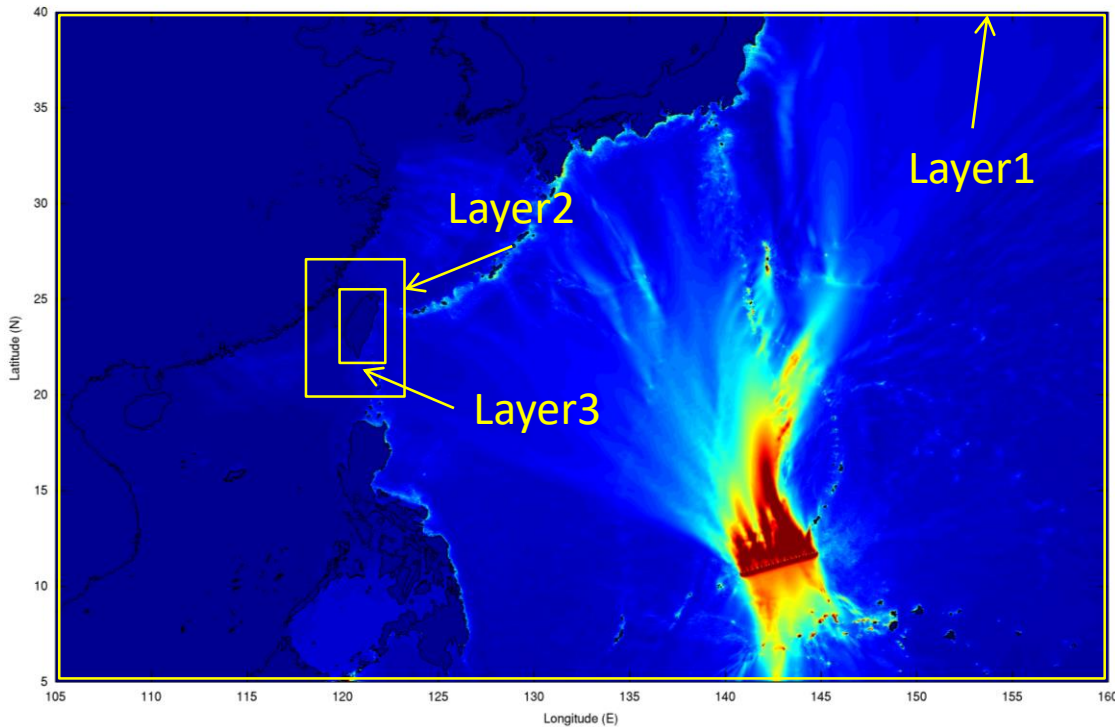
Tsunami Sources of 18 Trench and 4 Fault Segments

18 Trench-type tsunami sources (T1~T18)

4 Fault-type tsunami sources (T19~T22)



Nested Grids

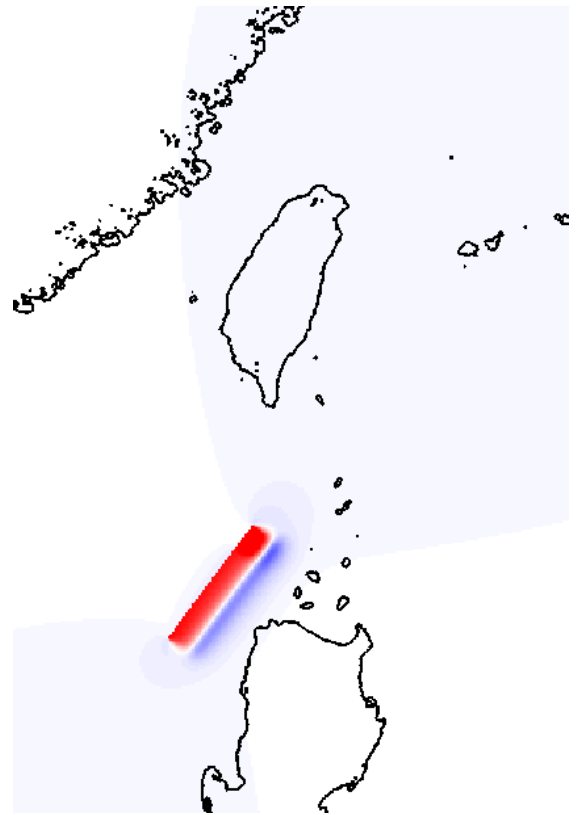
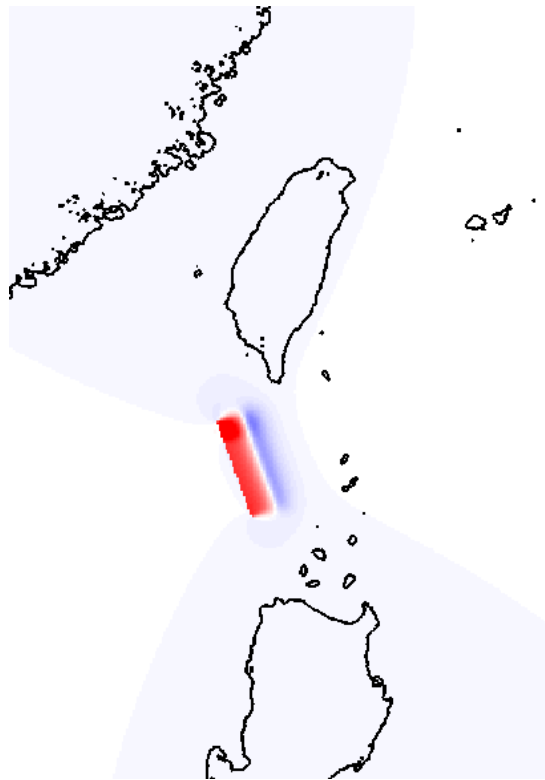
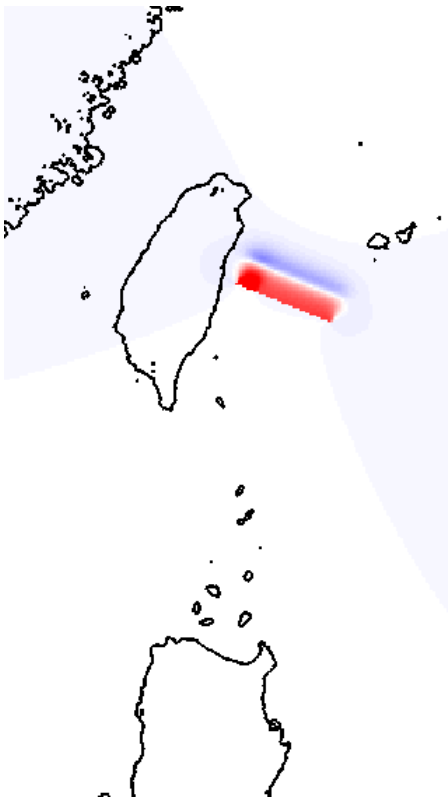


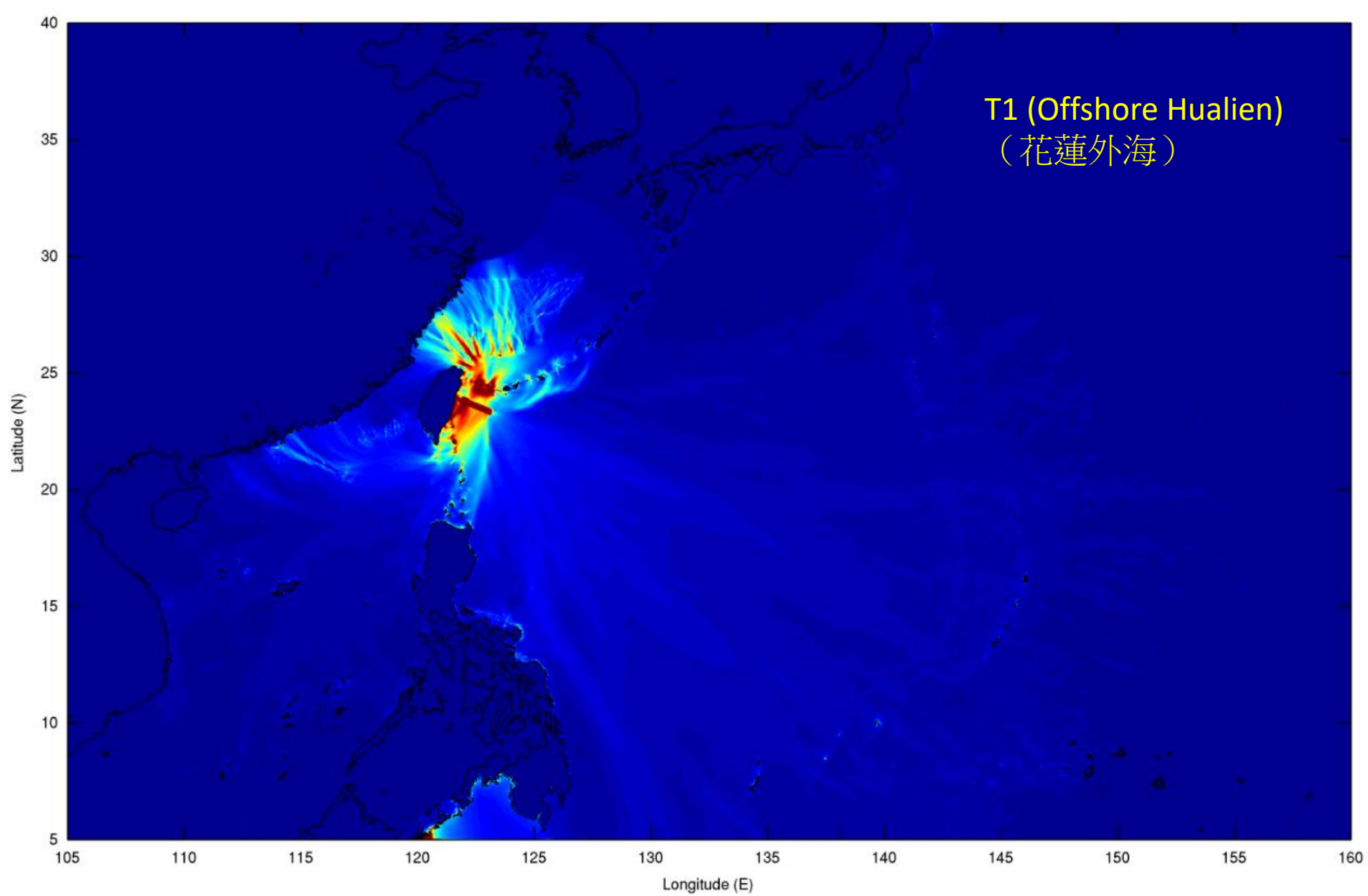
Layer 1: 2 min (~3500m);
Layer 2: $\frac{1}{2}$ min (~900m);
Layer 3: $\frac{1}{8}$ min (~200m);
Layer 4: $\frac{1}{128}$ min (~50m);
Layer 5: $\frac{1}{512}$ min (~10m);
Layer 6: $\frac{1}{2048}$ min (~2m);

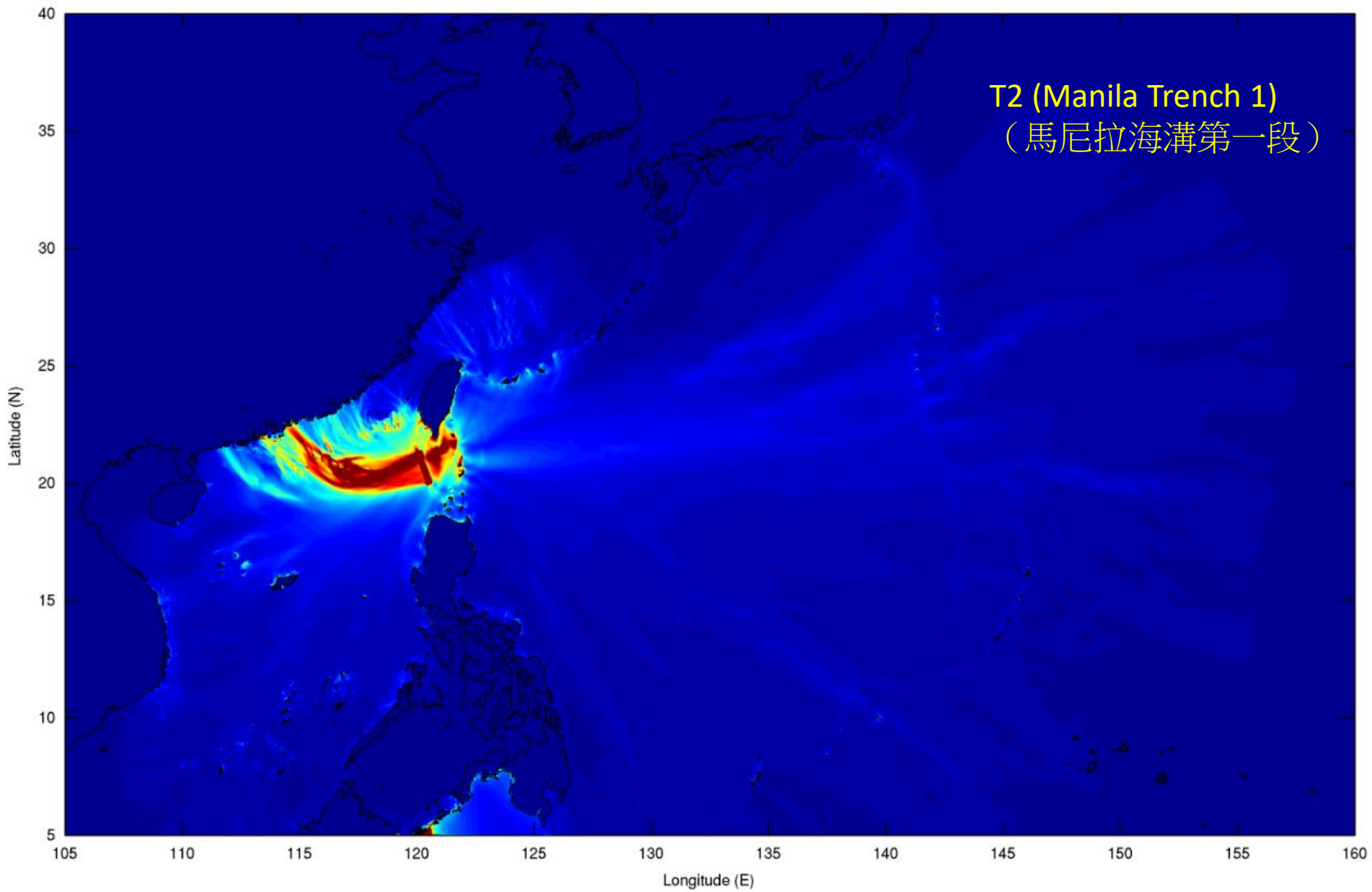
海底地形資料取得

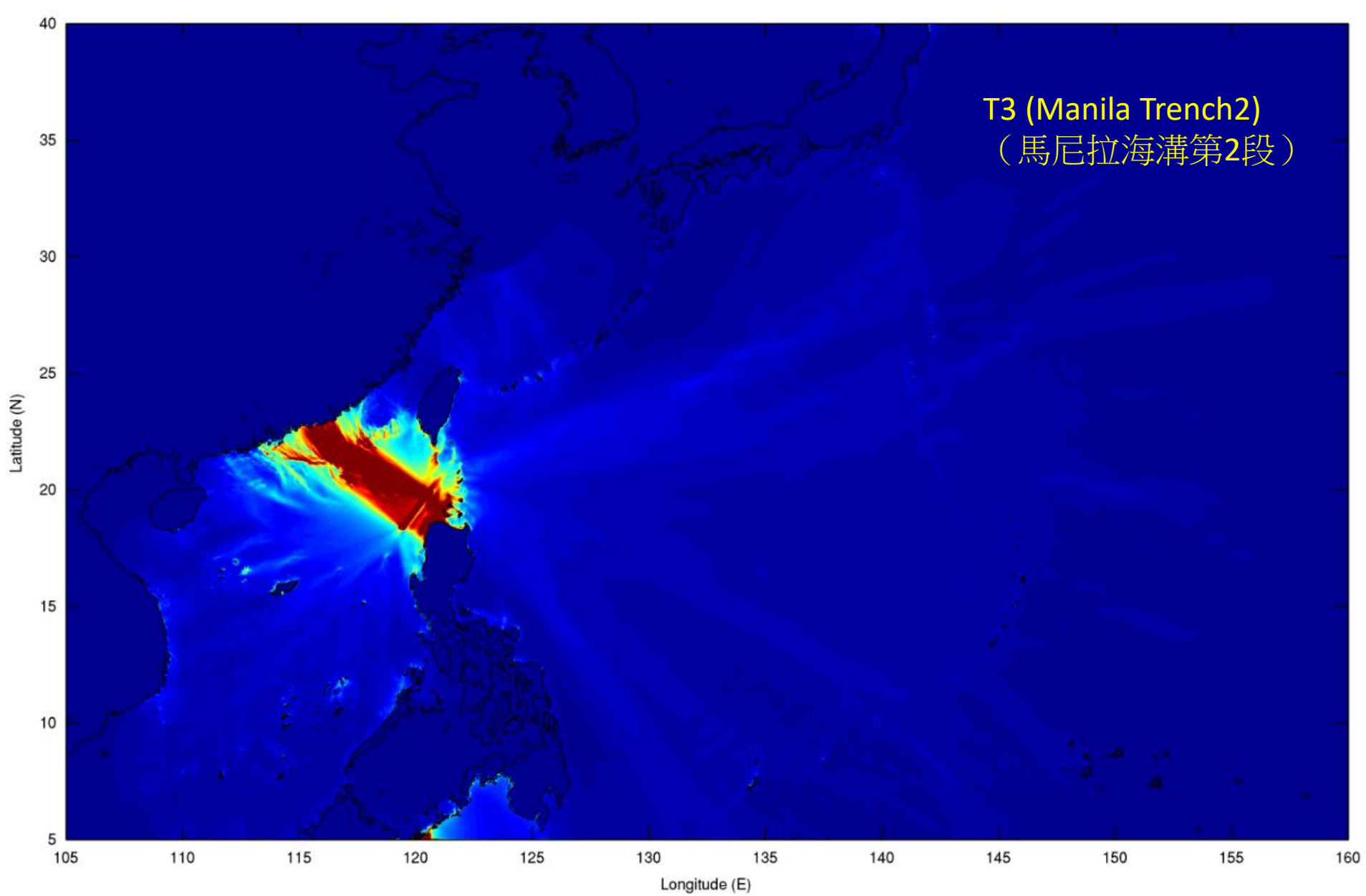
Source of Bathymetry

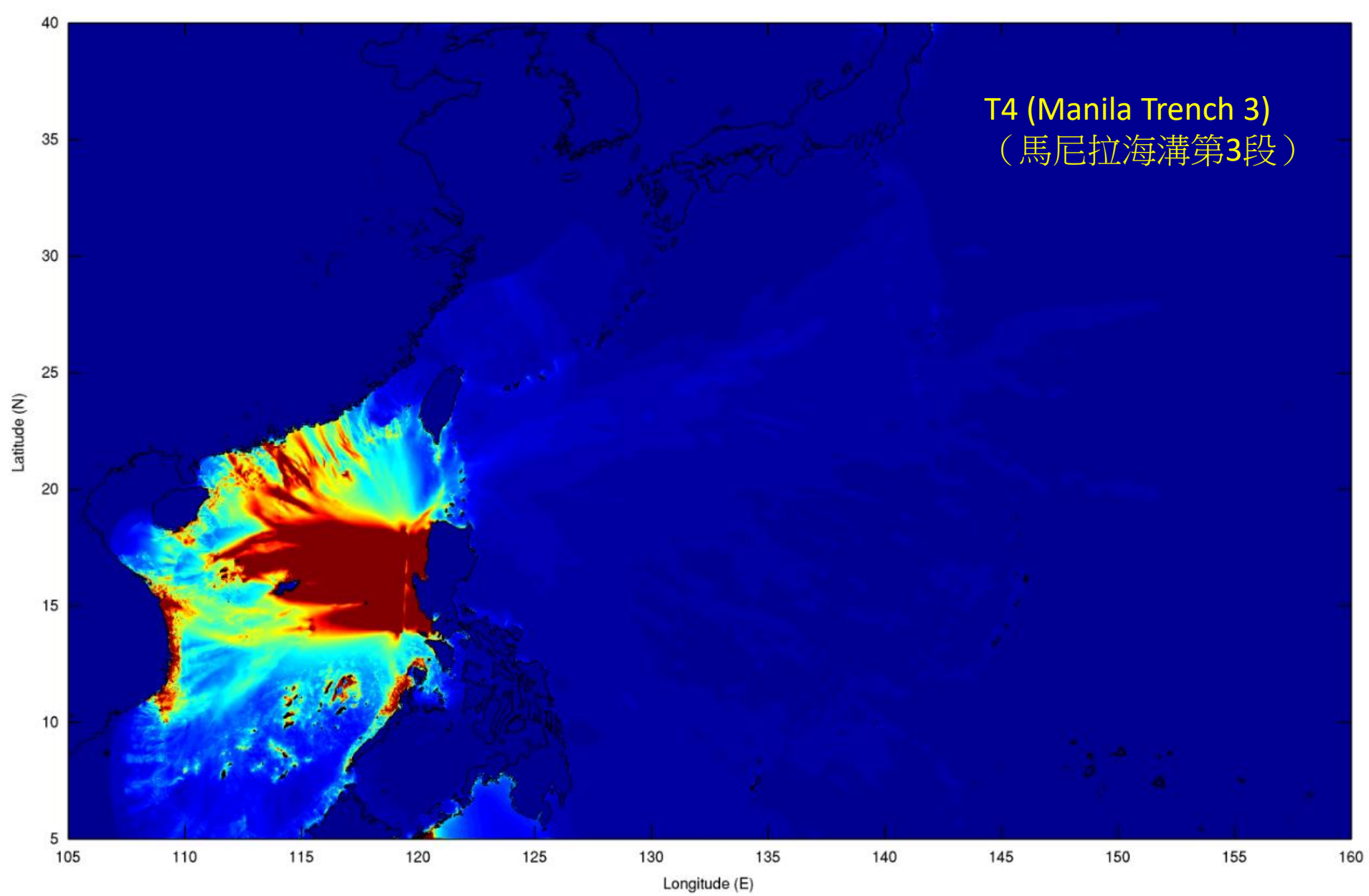
- 全球1弧分 **ETOTO2**: (2 arc min)
 - http://www.ngdc.noaa.gov/mgg/gdas/gd_designagrid.html ,
- **GEBCO**: (0.5 arc min)
 - http://www.gebco.net/data_and_products/gridded_bathymetry_data/ 。
- 中華民國海軍 **NAVY**
- 國立中央大學太空與遙測中心 **NCU**: 40m DEM 。
- 內政部國土測繪中心 **National Land Surveying and Mapping Center**: 10m DEM
- 台電 **Tai Power**: 1m DEM

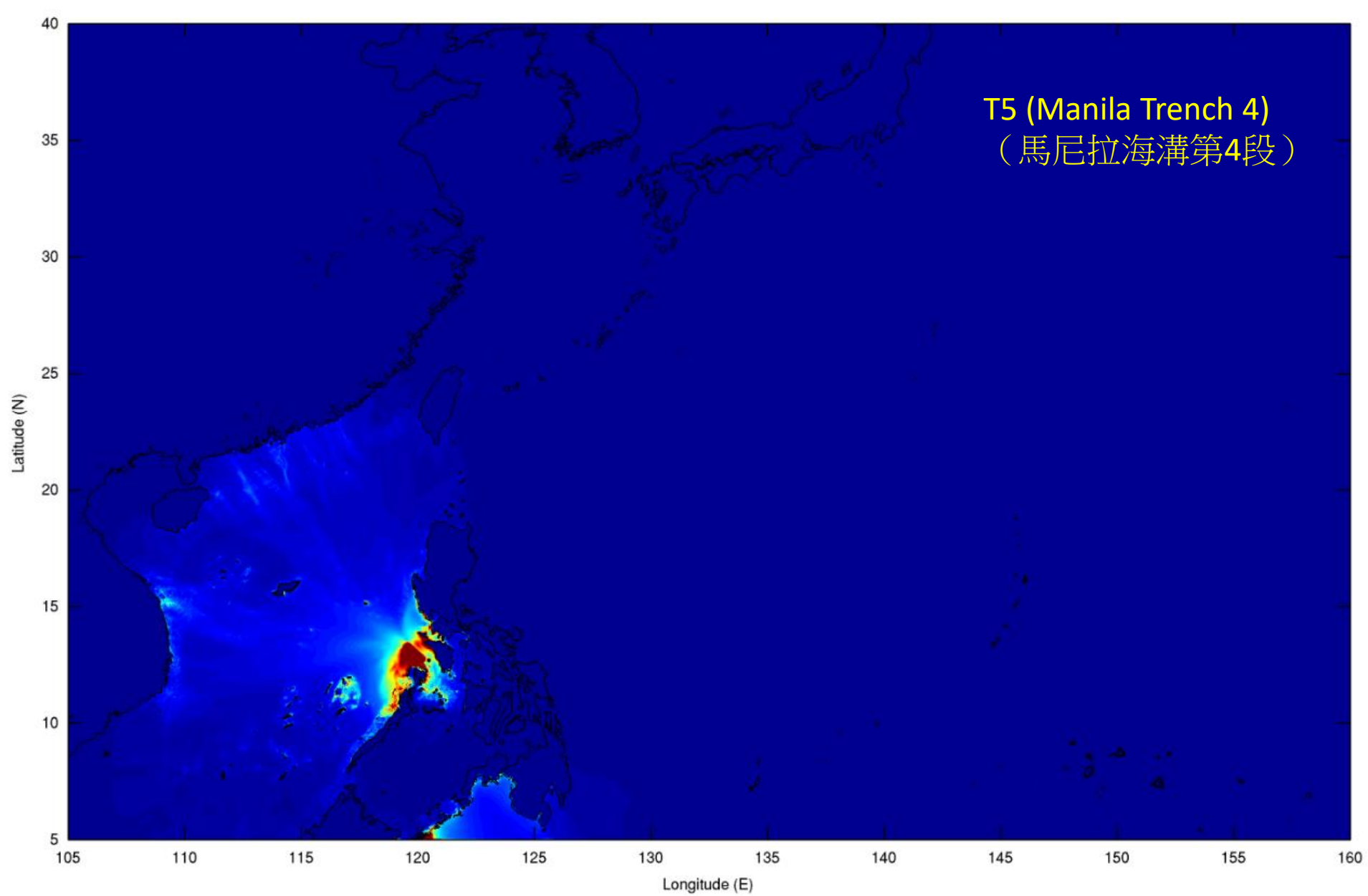


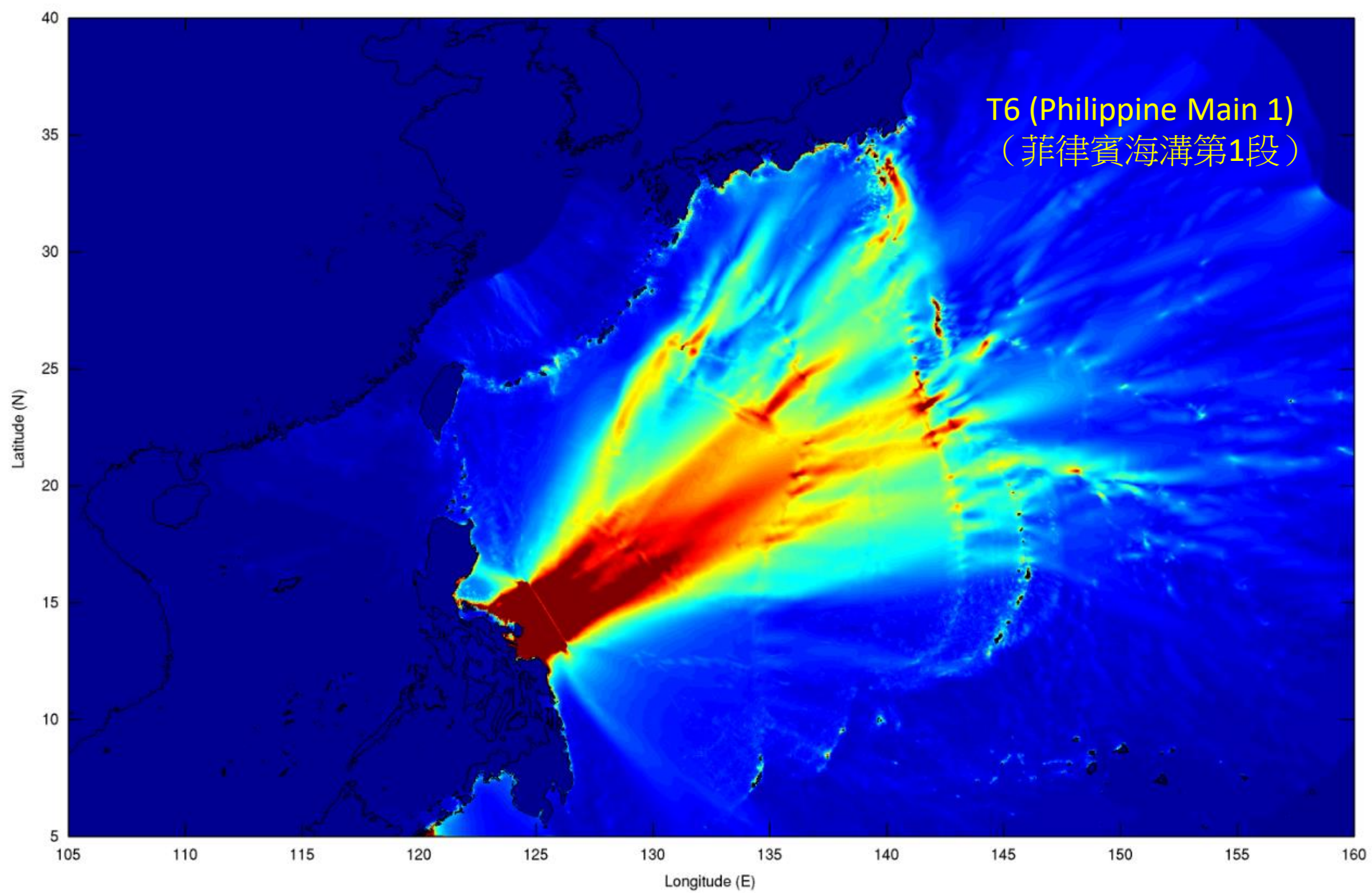


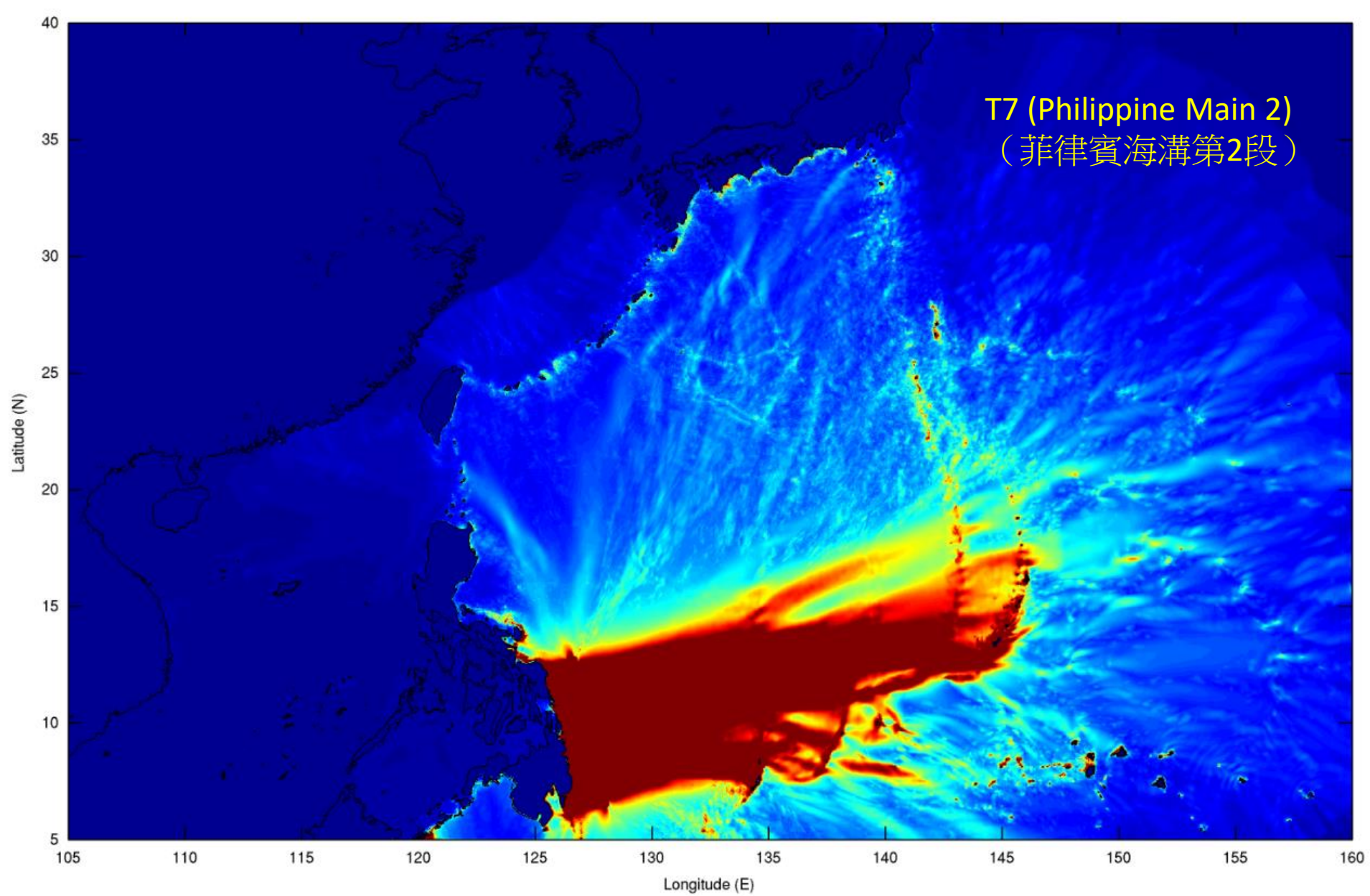


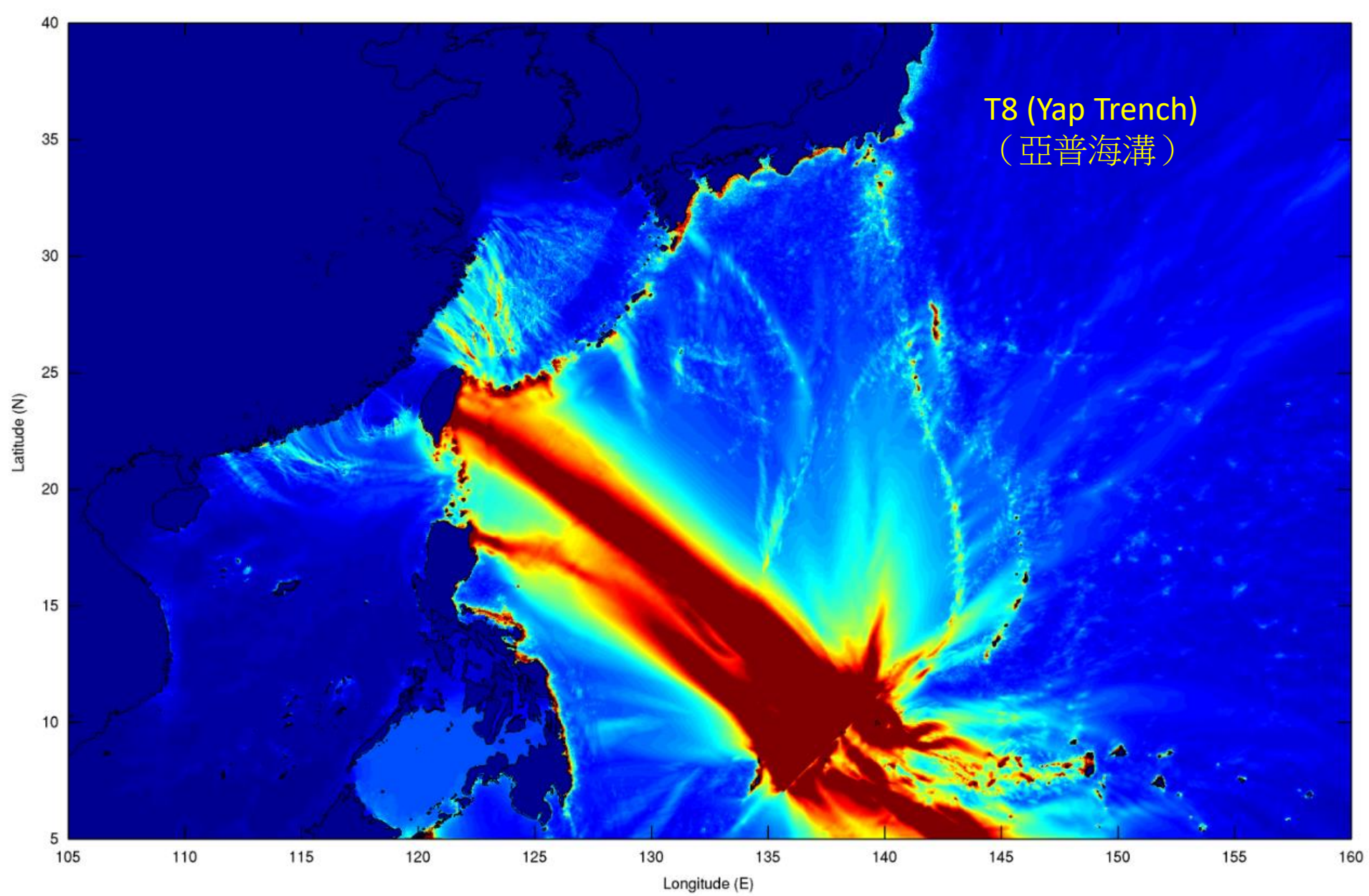


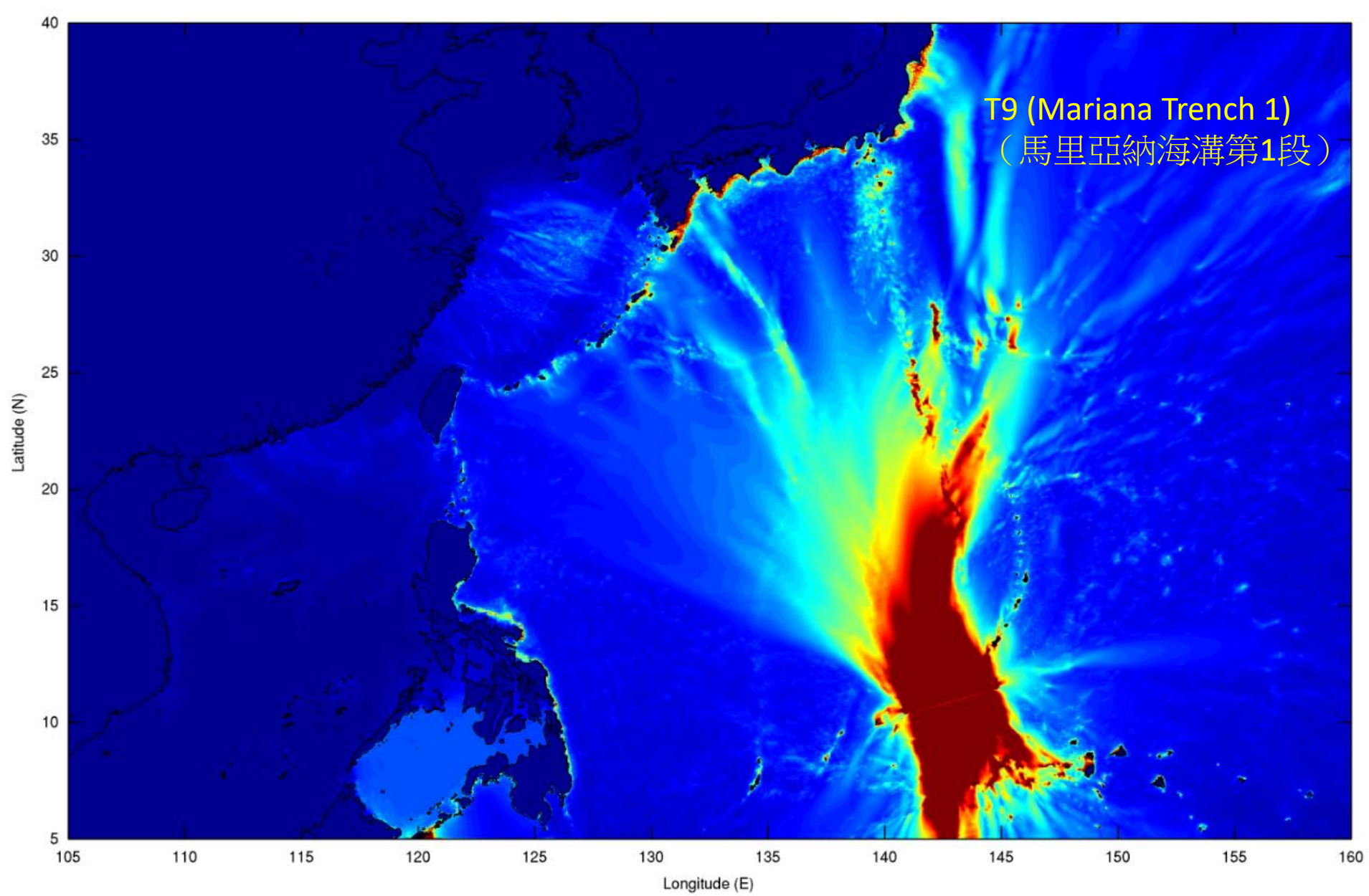


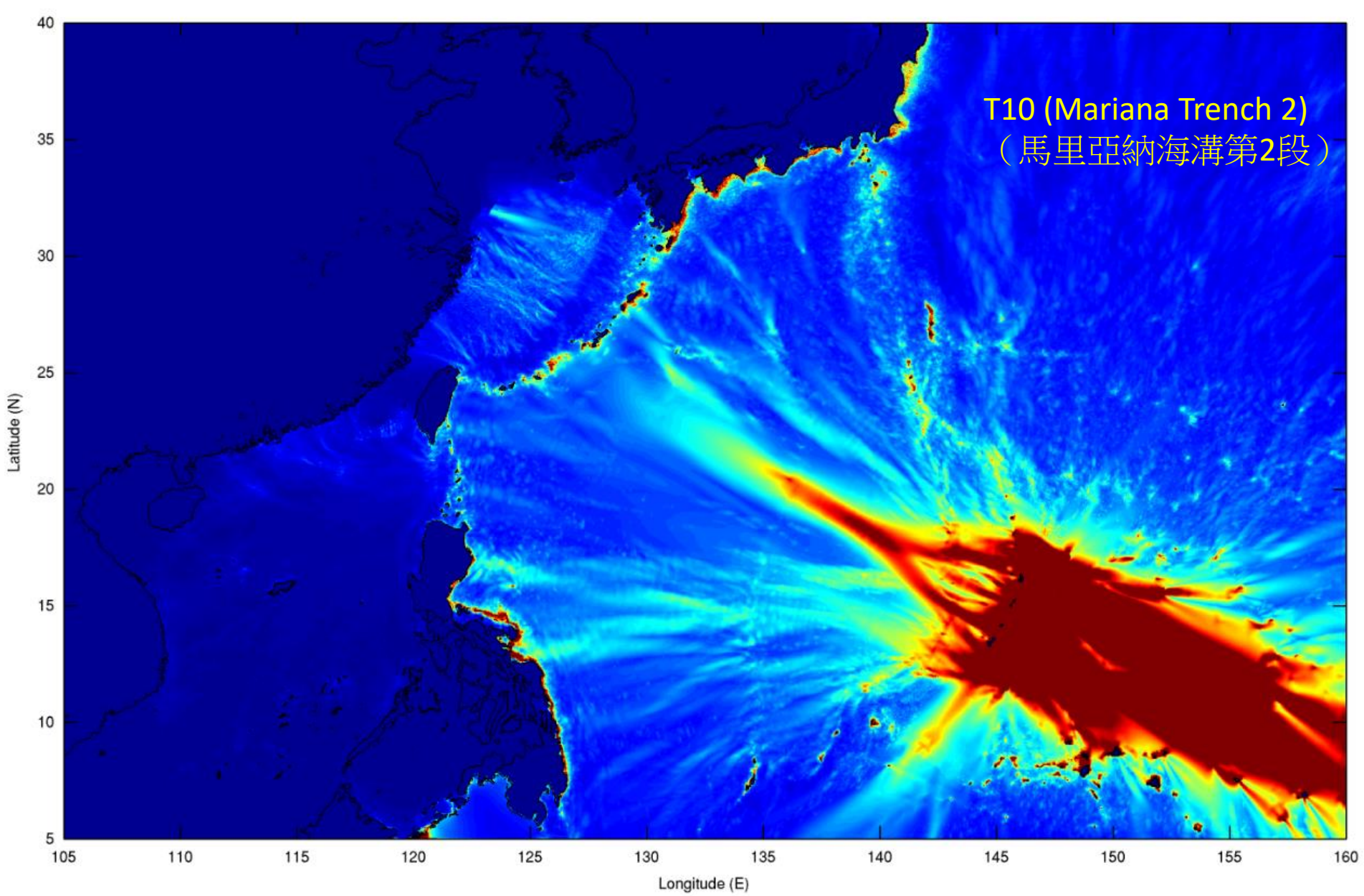


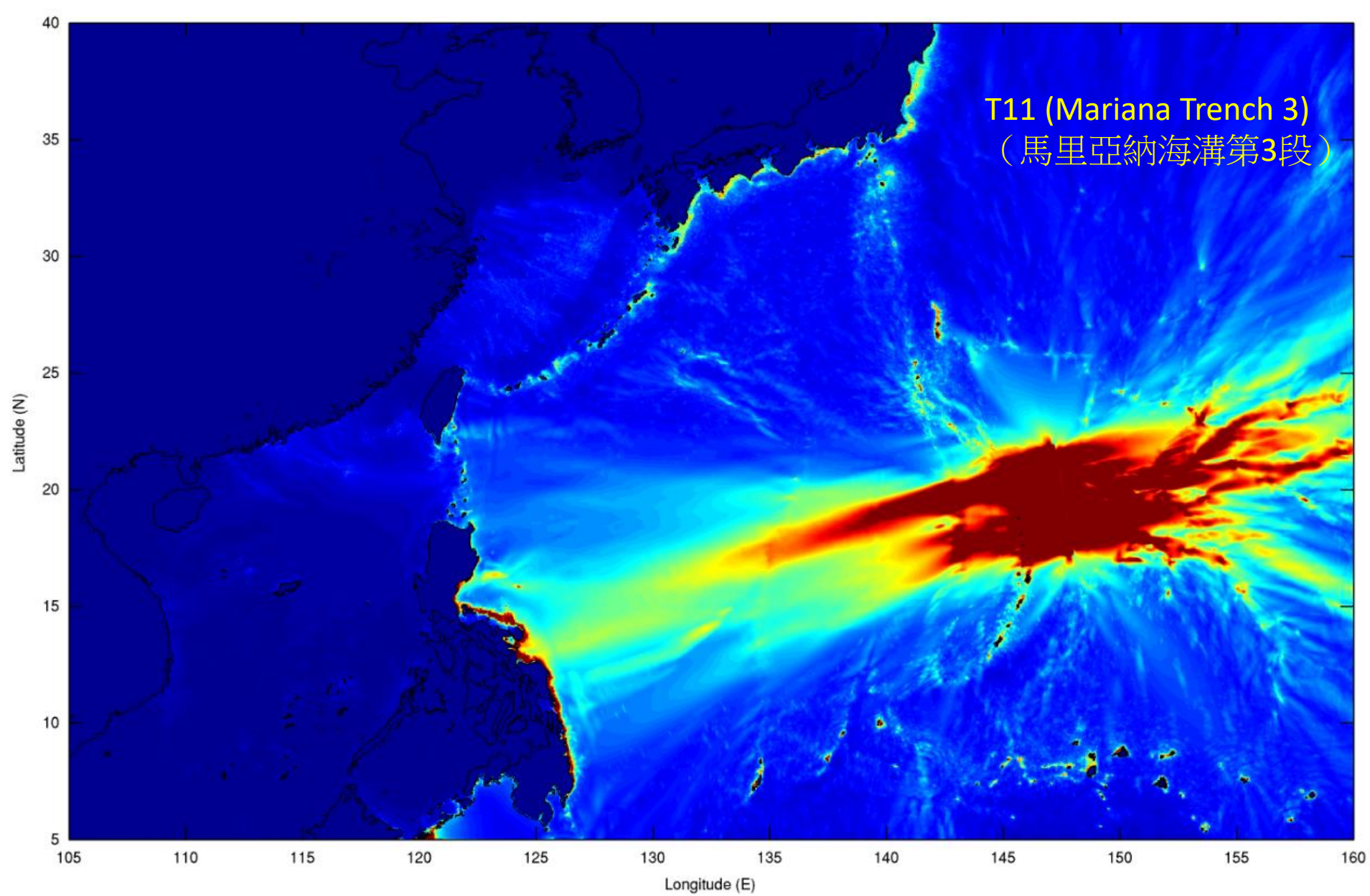


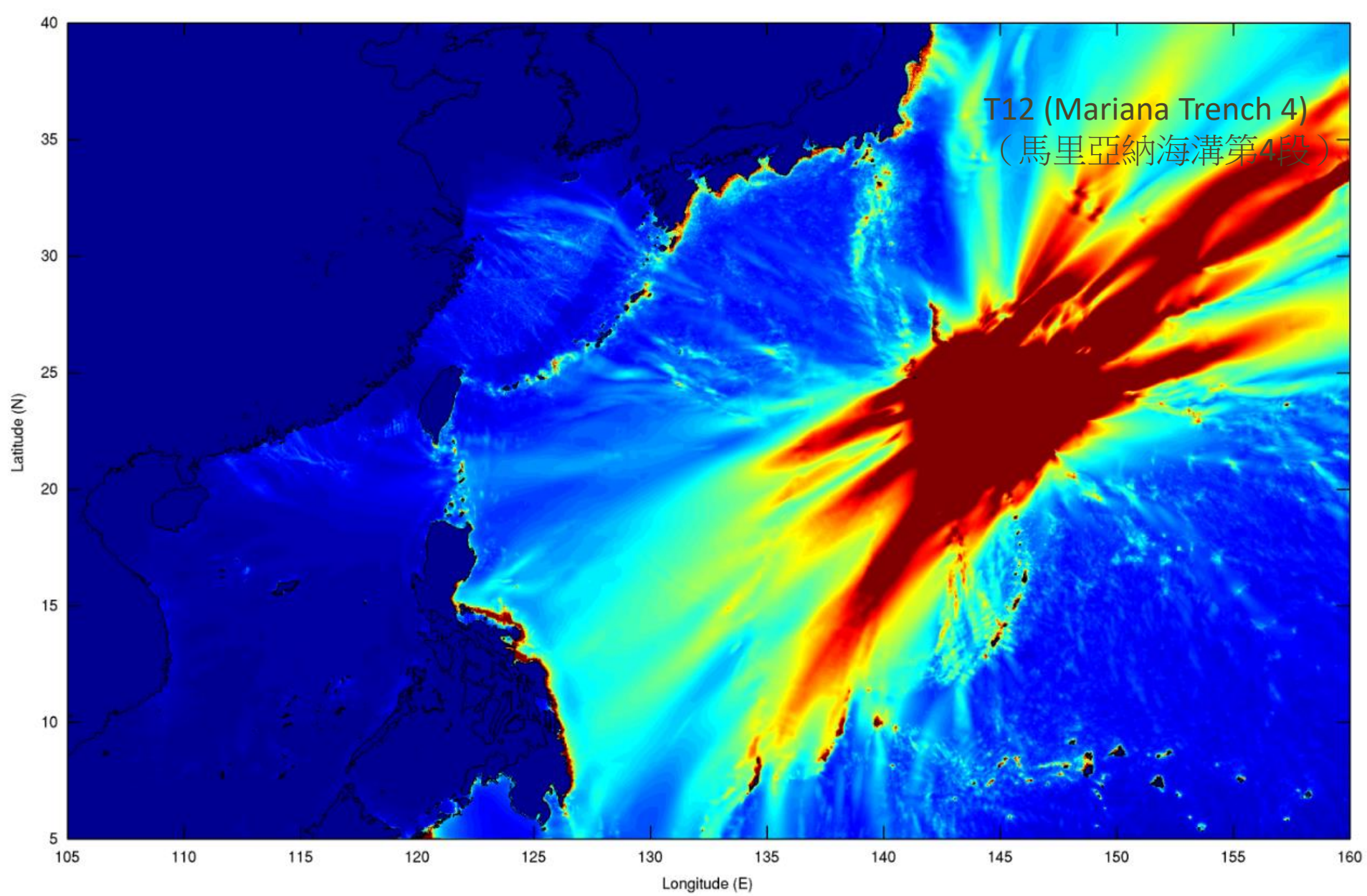


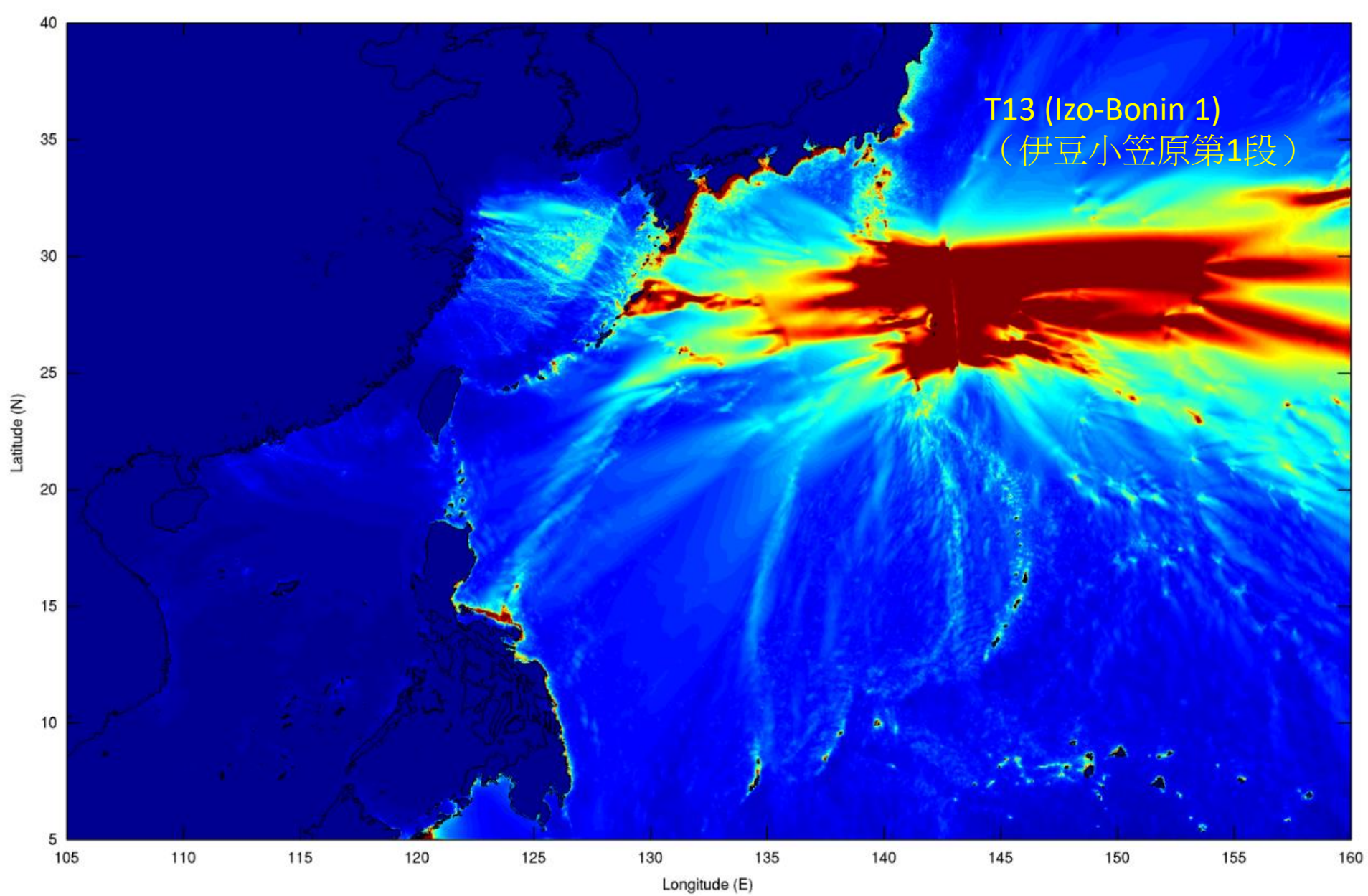


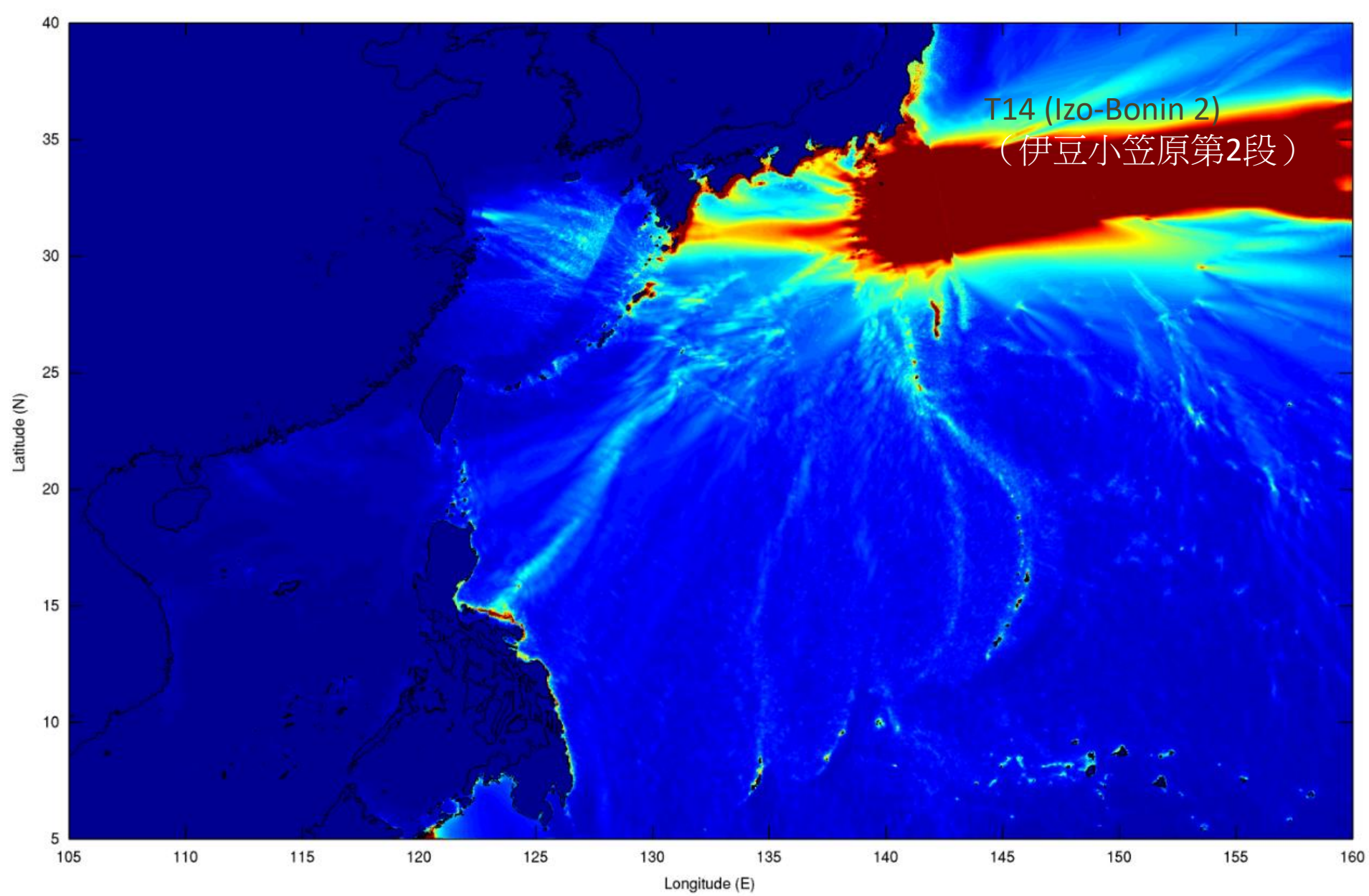


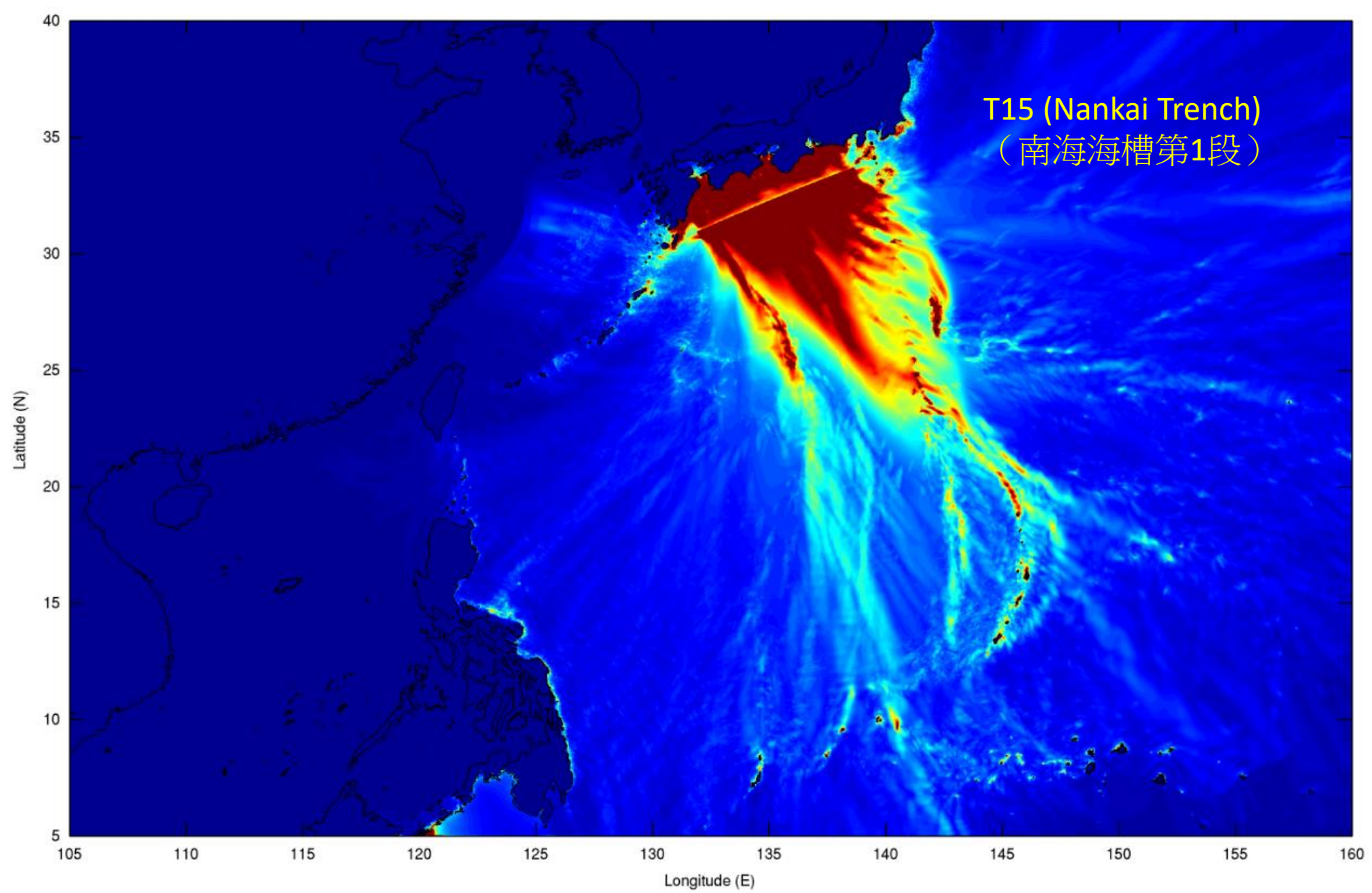


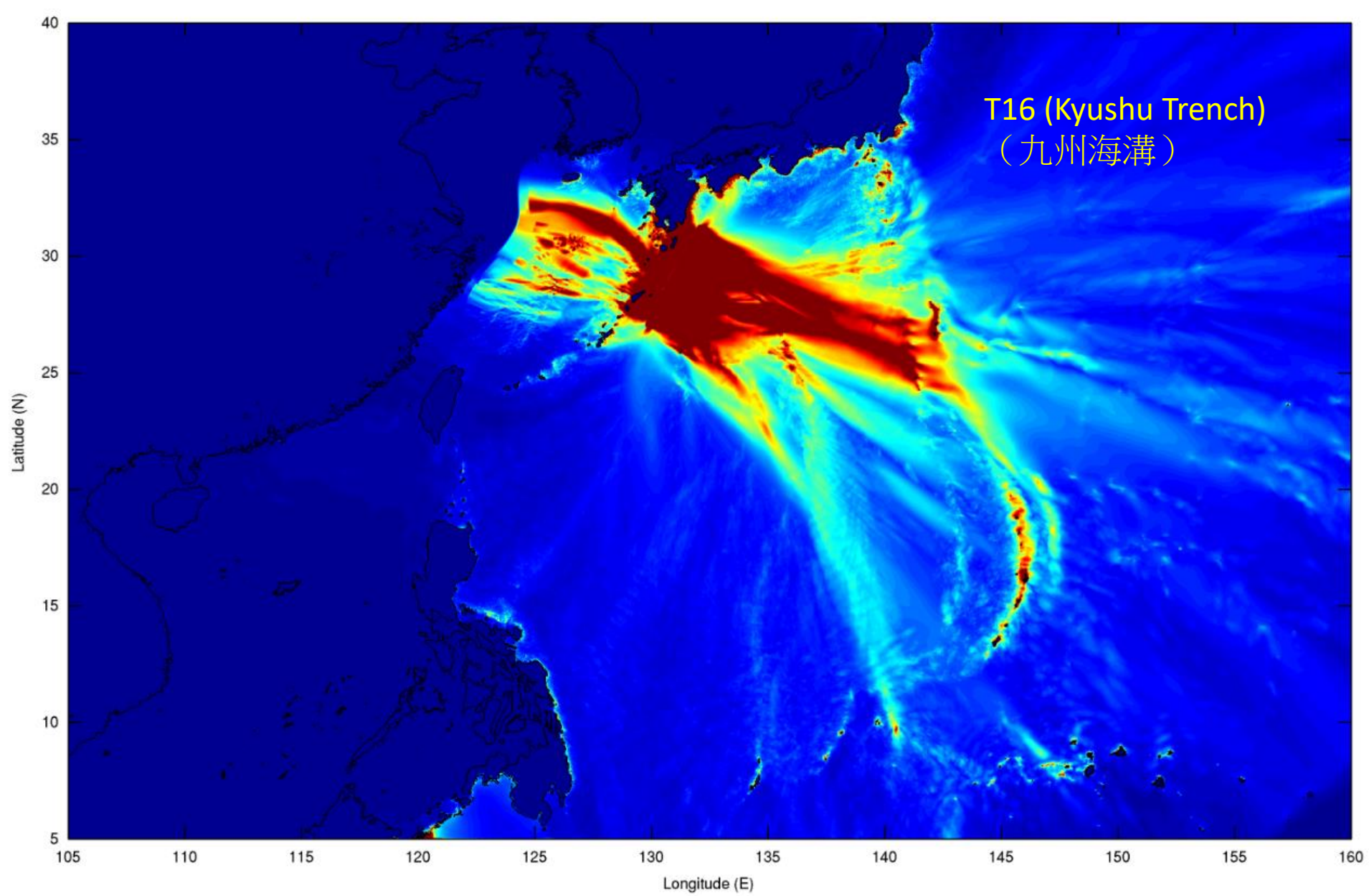


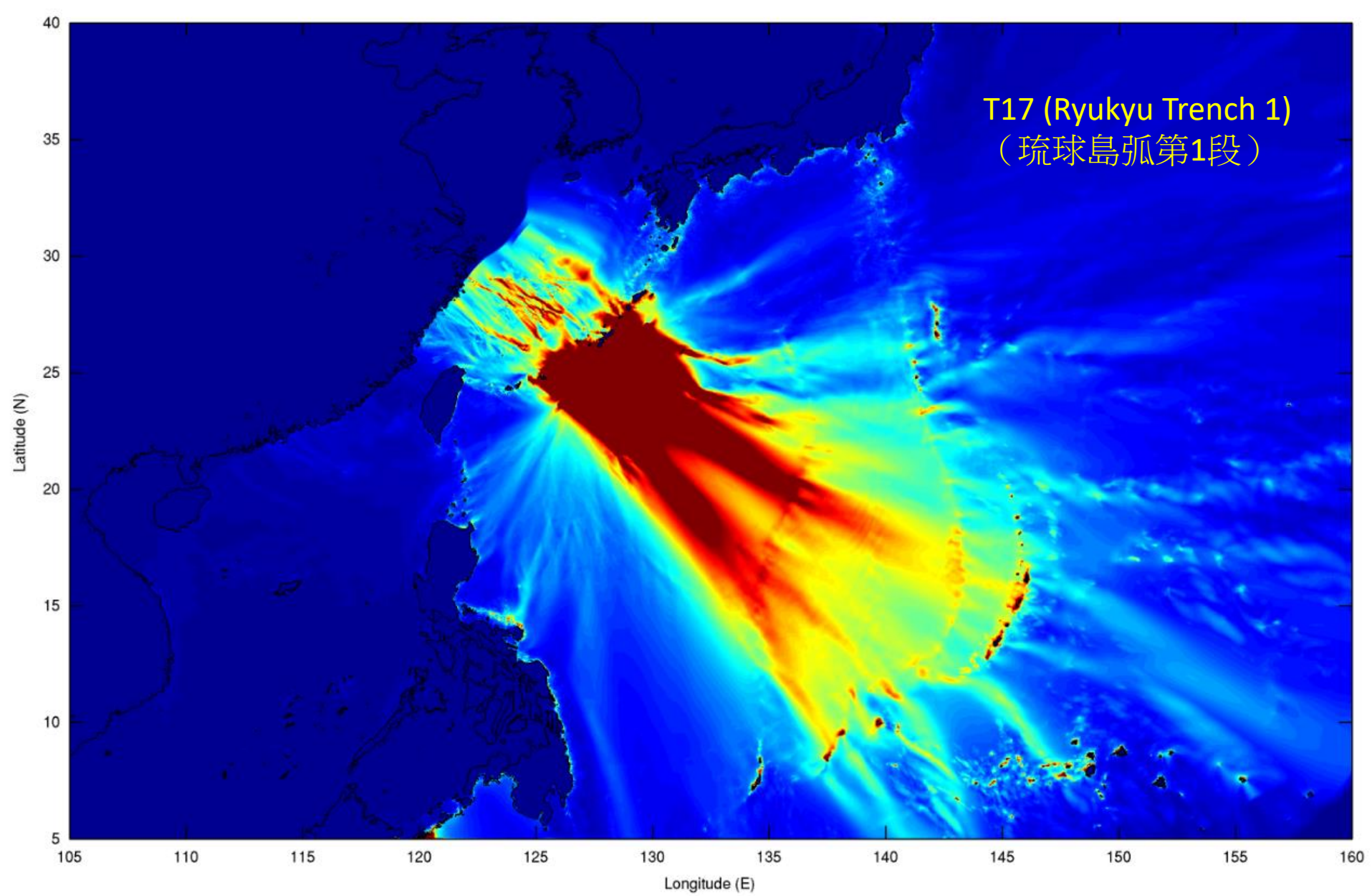


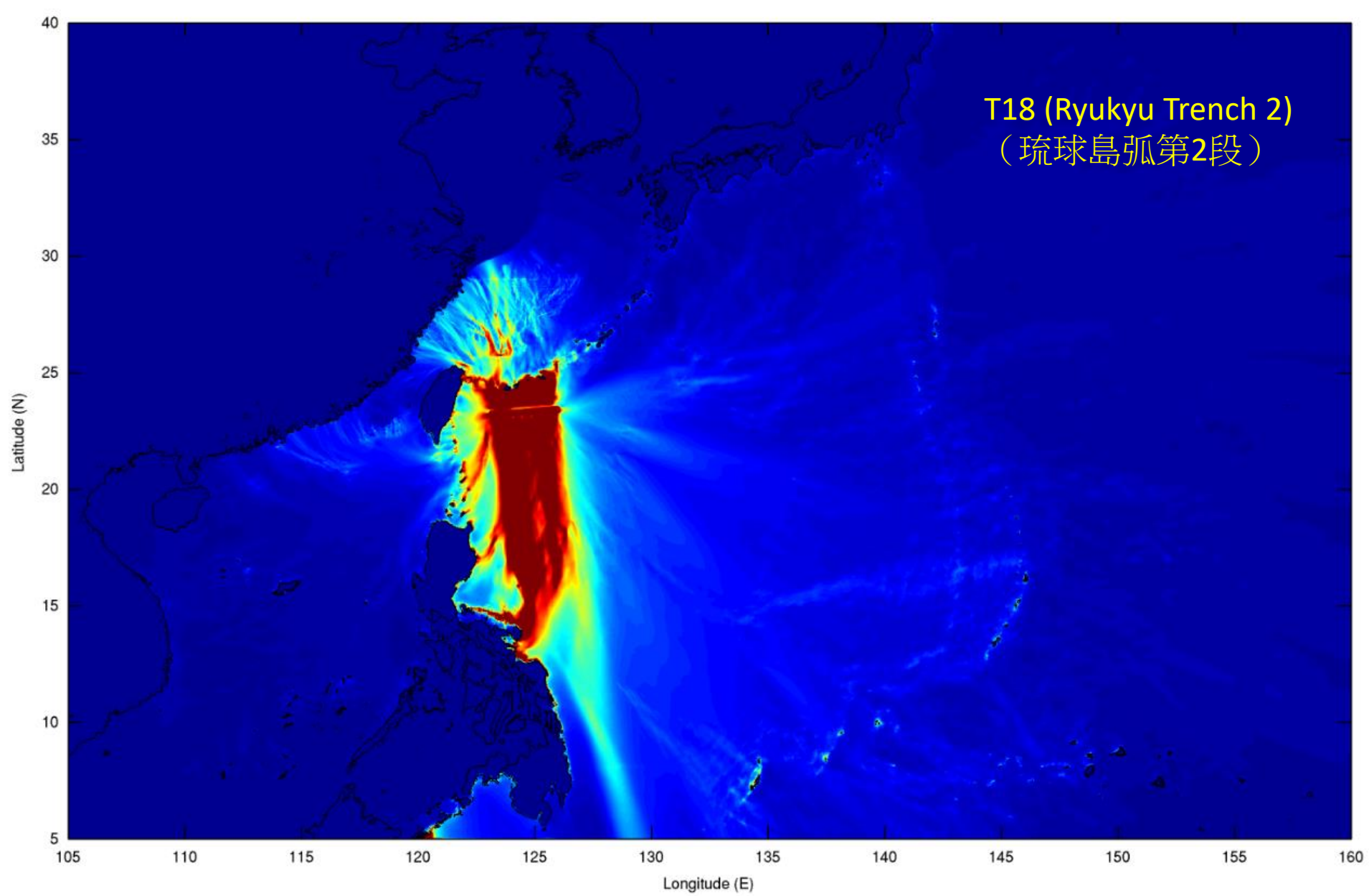






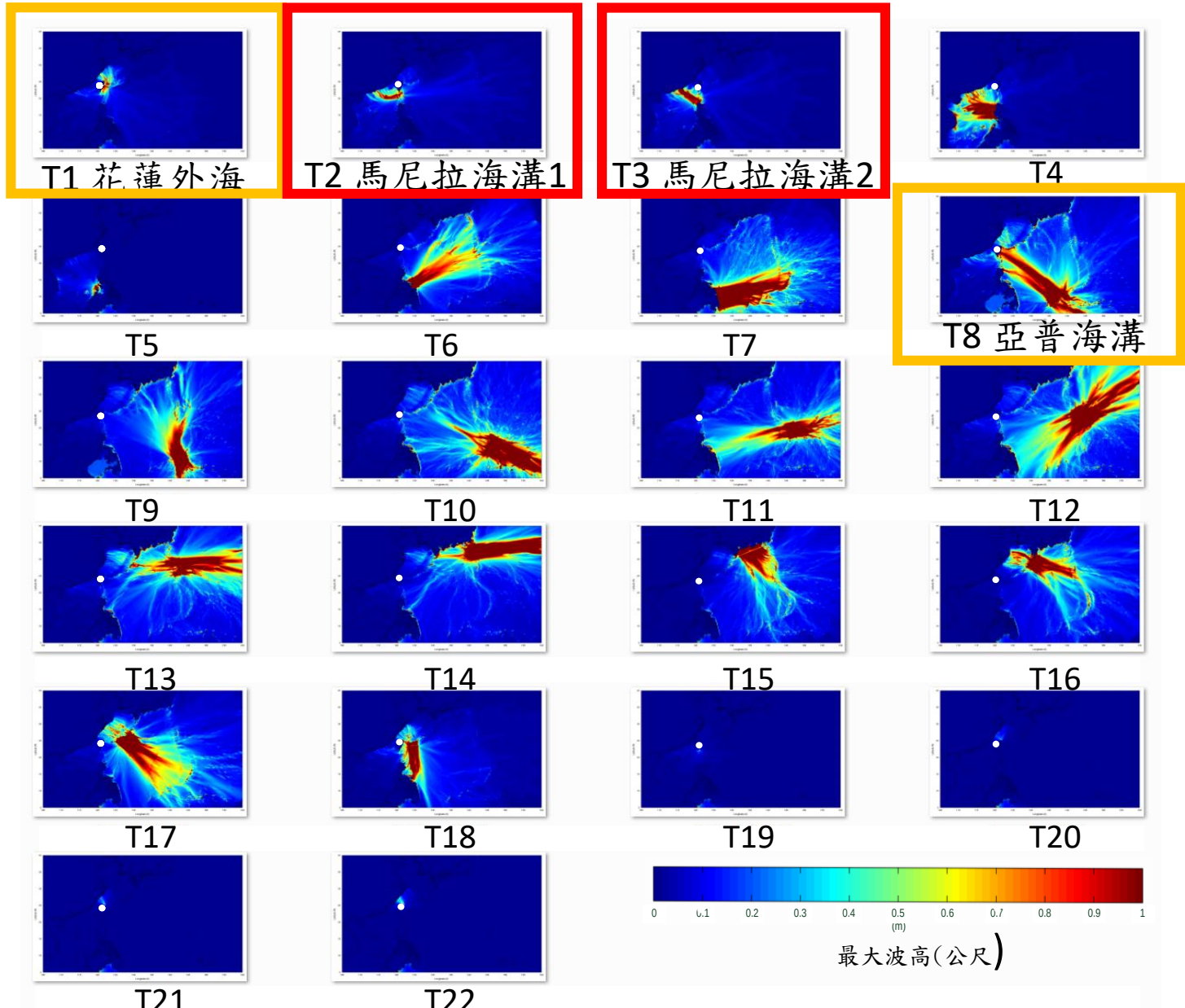






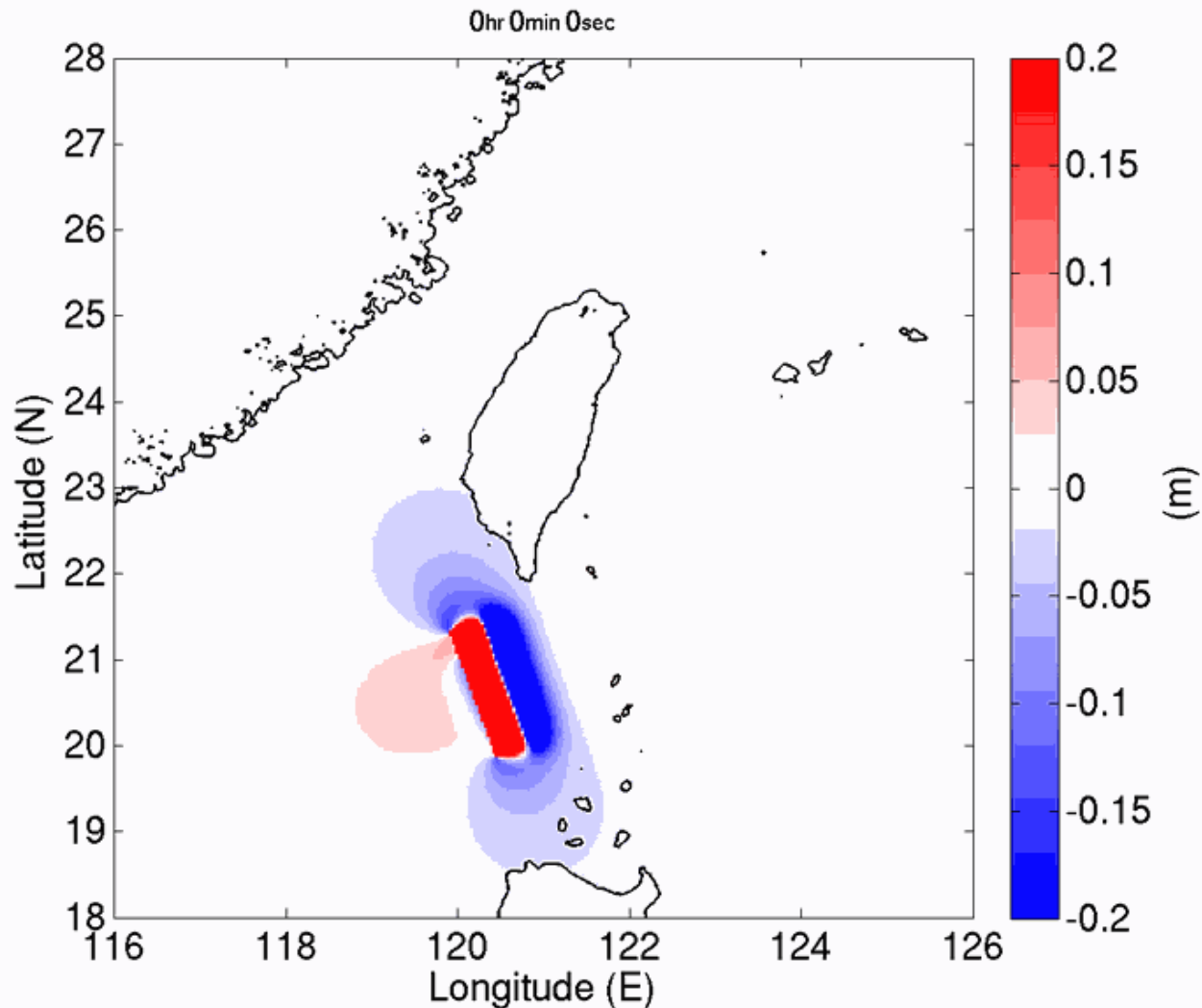
台灣必須特別注意 T1, T2, T3, T8

Taiwan has to be aware of the tsunamis from T1, T2, T3, and T8



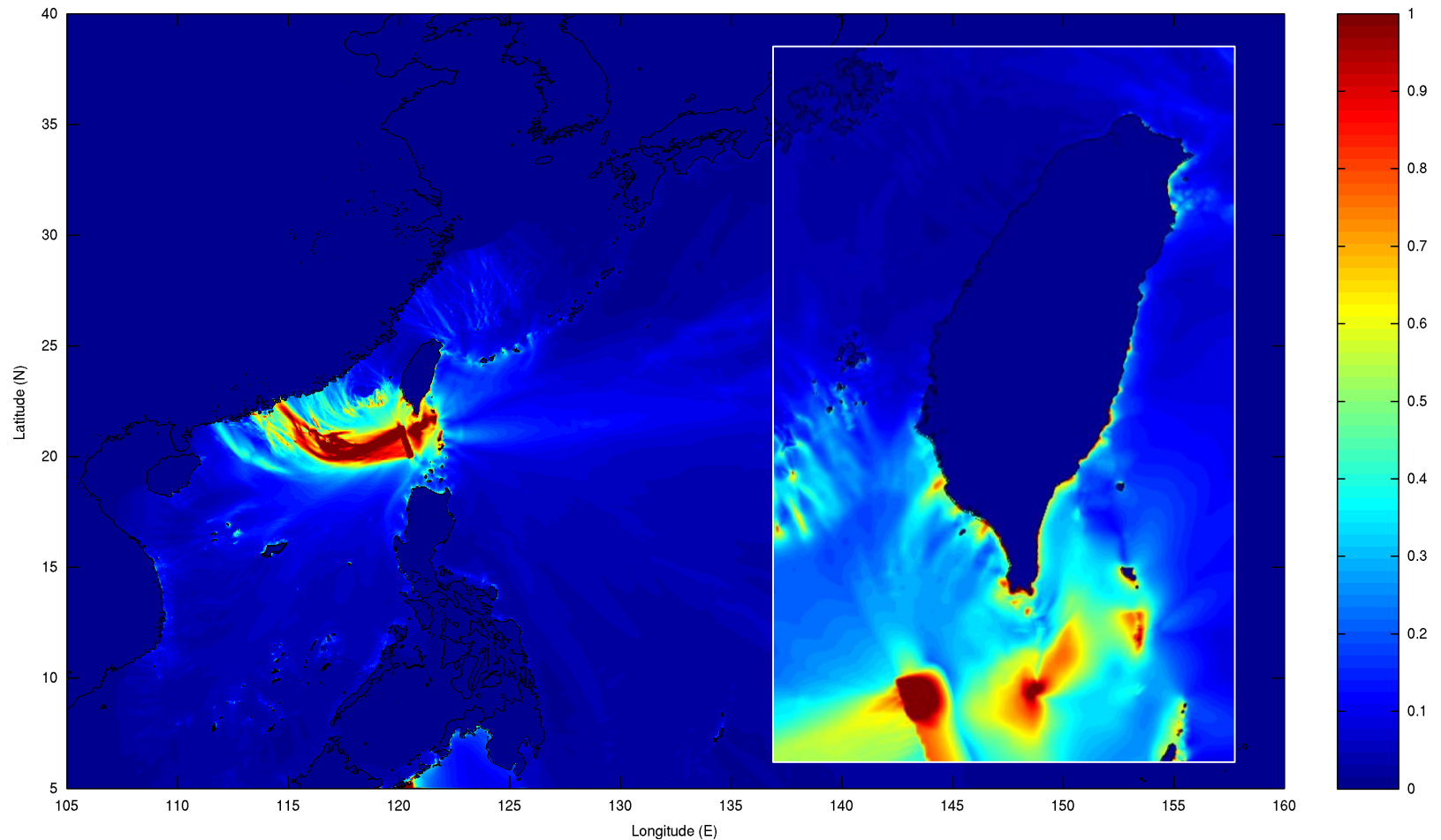
T2馬尼拉海溝第1段海嘯動畫

T2 (Manila Trench 1) (Animation)



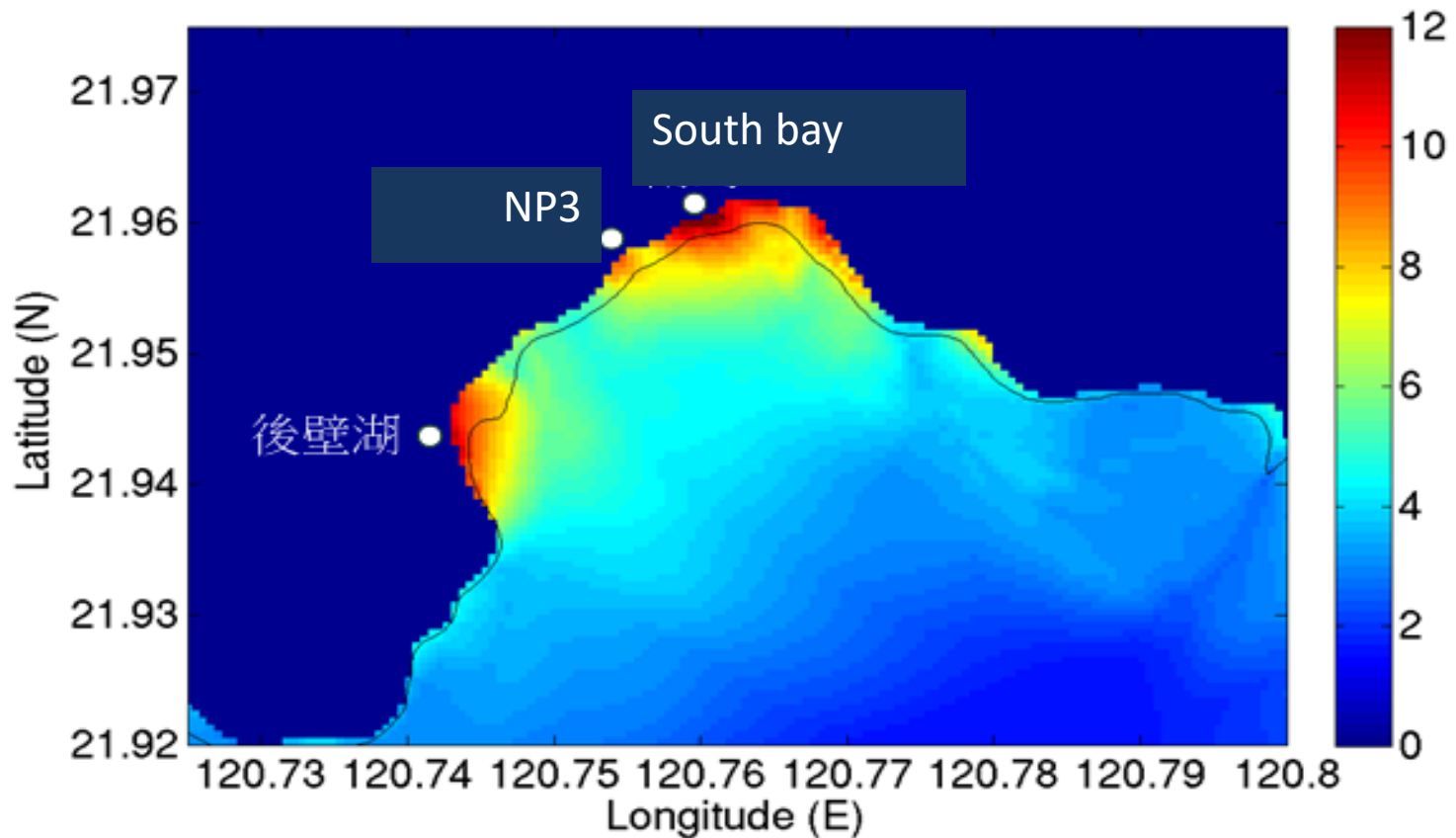
T02 溢淹與最大溯昇高程

T02, Inundation and Maximum Runup Height



T02 近岸溢淹與最大溯昇高程

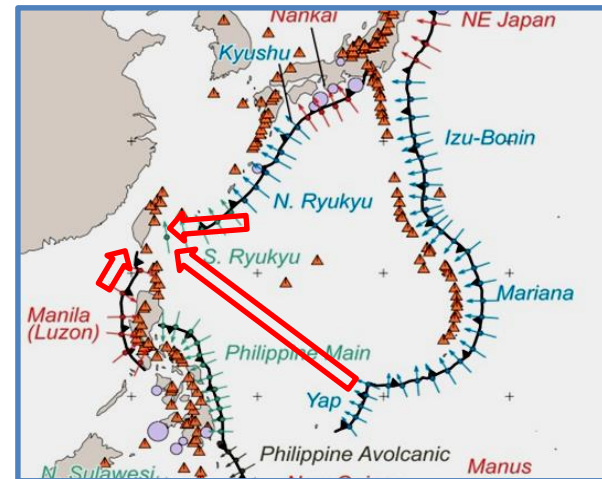
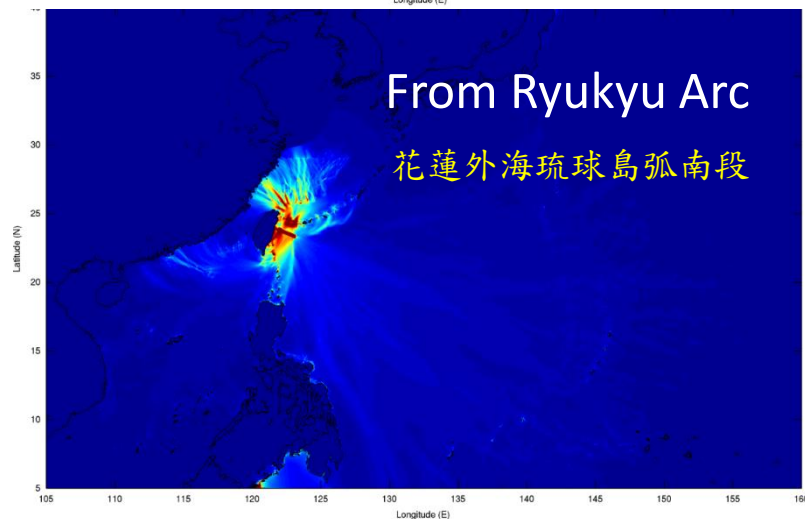
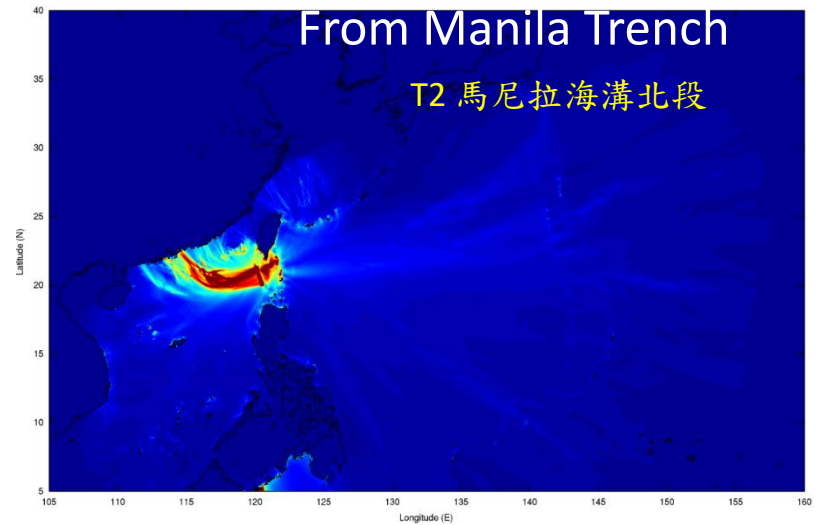
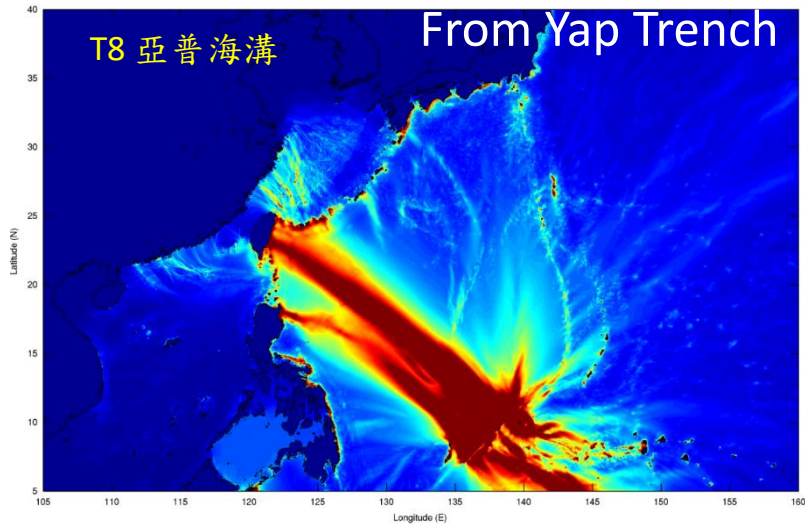
T02, Nearshore Inundation and Maximum Runup Height



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

海灣威脅性海嘯主要來自於亞普海溝、馬尼拉海溝 北段、及花蓮外海之琉球島弧南段

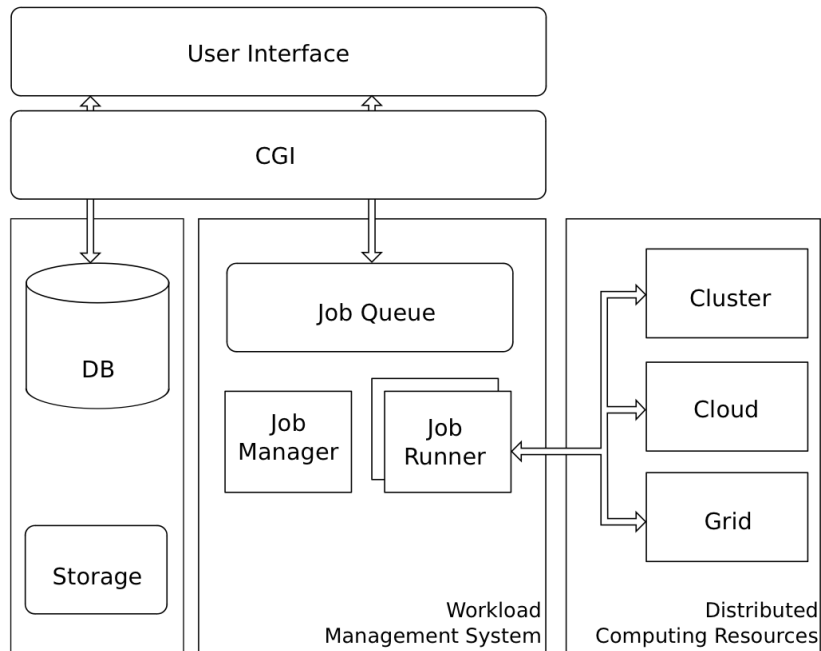
From the geology/trench analysis, three potential tsunami sources were found.



中華民國台灣於2014/9/19舉行有史以來第一次海嘯演習 The First National-wide Tsunami Drill in Taiwan in 2014/9/19



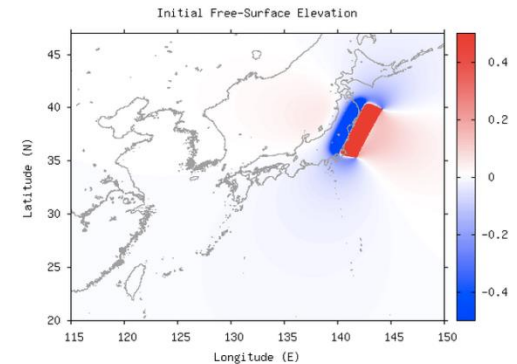
iCOMCOT: 海嘯雲端速算系統 a grid/cloud-based Tsunami system



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

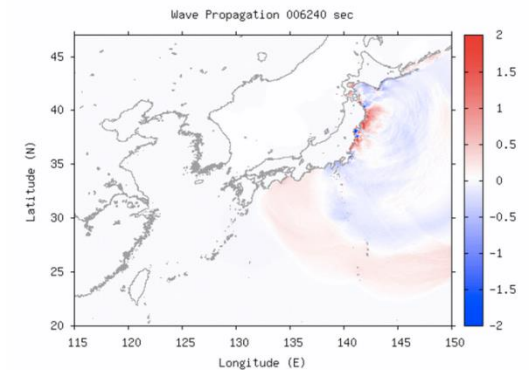
iCOMCOT Home About Simulation - Status Contact Logout user6demo

INITIAL SURFACE
initial surface
MAXIMUM WAVE HEIGHT
layer01
layer02
TIDE STATIONS
maximum wave height
01_NDBC_21401
02_NDBC_21413
03_NDBC_21418
04_NDBC_21419
WAVE PROPAGATION
layer01 (400x300)
layer01 (840x480)
layer01 (800x600)
BATHYMETRY
layer01
layer02



iCOMCOT Home About Simulation - Status Contact Logout user6demo

INITIAL SURFACE
initial surface
MAXIMUM WAVE HEIGHT
layer01
layer02
TIDE STATIONS
maximum wave height
01_NDBC_21401
02_NDBC_21413
03_NDBC_21418
04_NDBC_21419
WAVE PROPAGATION
layer01 (400x300)
layer01 (840x480)
layer01 (800x600)
BATHYMETRY
layer01
layer02



- (1) 2012, 2015 受邀至聯合國教科文組織演講
- (2) 2013 英國倫敦媒體 isgtw 專訪

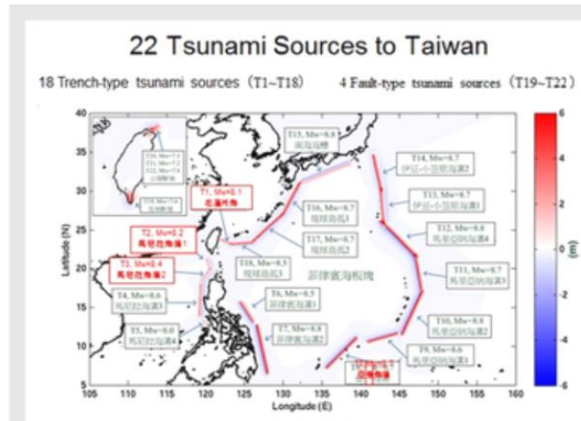
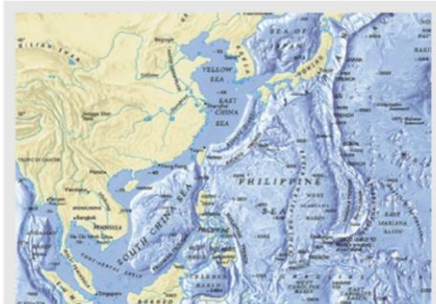
<http://www.isgtw.org/feature/forecasting-wrath-tsunami>



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.

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.

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



台灣海嘯的過去與未來

2016-07-10



20160710

311東日本大震災

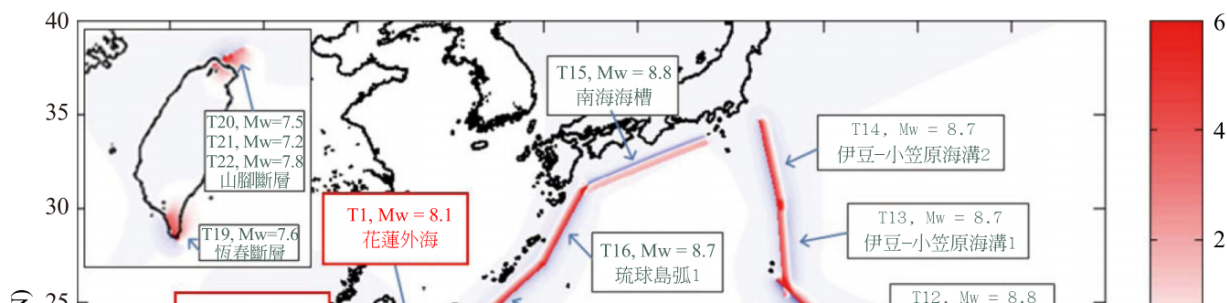
公元**2011**年**3月11**日，當地時間下午**2時46**分，日本東北部海域發生芮氏**9.0**級地震並引發海嘯。根據**2012**年**4**月的日本官方統計，此次地震海嘯共造成**15855**人死亡，**3084**人失蹤，**6025**人受傷。房屋全毀有**129483**戶，半毀與部分毀壞有**952791**戶，是日本有觀測紀錄以來規模最大的一次地震，引發的海嘯也是史上最嚴重的。

台灣的海嘯研究與發展

國立中央大學水文與海洋科學研究所 吳祚任

2011年3月11日，日本宮城大地震引發海嘯，災情震撼全球，而後續的核電災變至今仍未如法徹底解決。台灣四面環海，天然環境甚至人文環境都與日本類似，透過不斷的災區畫面播送，

讓台灣人產生同情與共鳴。也因如此，台灣自此開始重視海嘯的威脅，也希望透過科學的研究，減少台灣的海嘯災害。



1. 震央經度
2. 震央緯度
3. 震源深度
4. 地震規模

1. 震央經度
2. 震央緯度
3. 震源深度
4. 地震規模
5. Strike
6. Dip
7. Slip

1. 震央經度
2. 震央緯度
3. 震源深度
4. 地震規模
5. Strike
6. Dip
7. Slip
8. 斷層破裂長寬
9. 錯動量
10. 其他模擬設定

為中央氣象局建立海嘯速算系統

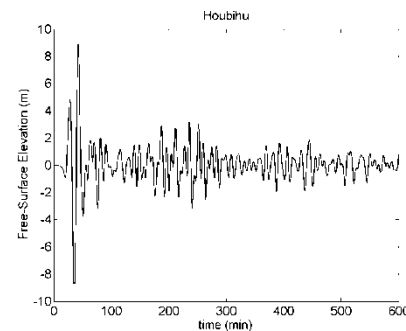
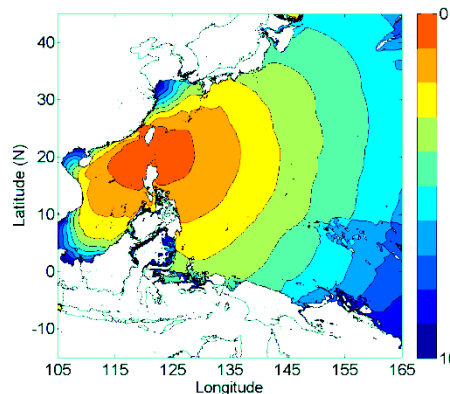
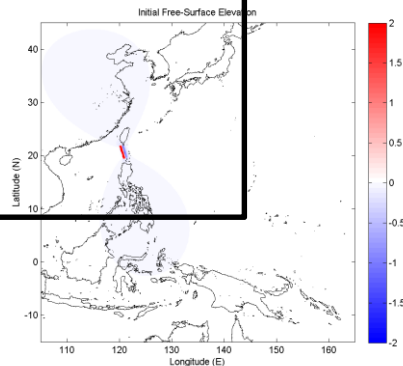
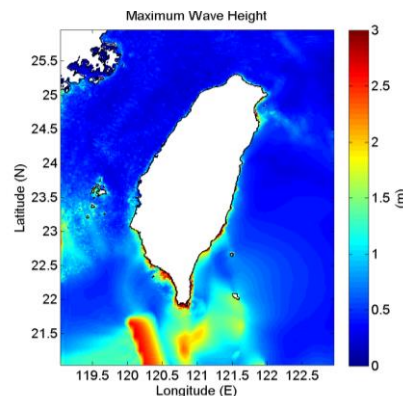
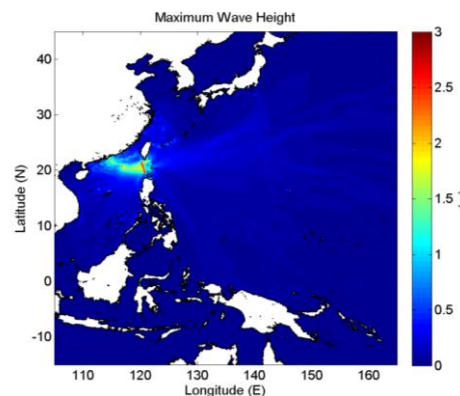
Tsunami Fast Calculation System for CWB in Taiwan.

一鍵式，一分半鐘完成海嘯速算

Fully automatic. One-click to finish them all.

Simulation with the region covers the PS and SCS can be done in 1.5 mins.

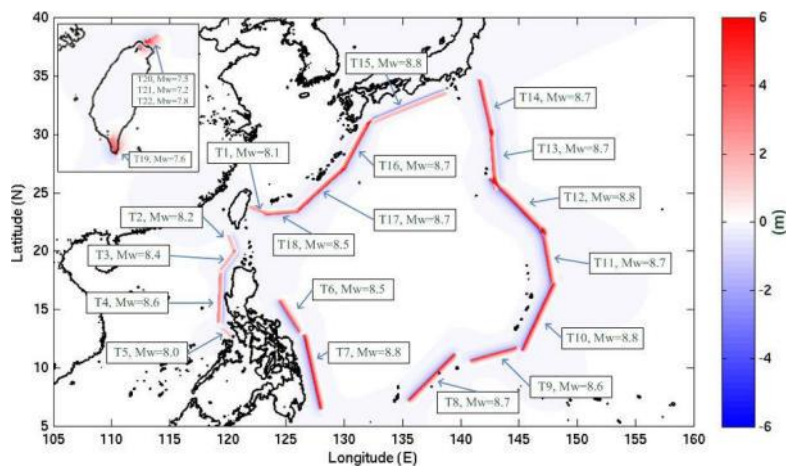
COMCOT
計算&繪圖



增設海溝走向資料庫以提升準確性

Database for earthquake parameters

資料庫參考過去學者針對台灣具有潛在海嘯威脅之海溝所訂定之參數(Wu,2012)所設計。若地震位於資料庫外，則走向平行於台灣海岸線，判斷方式為，以南投虎子山一等三角點代表台灣中心，走向垂直於震源和虎仔山連線方向。



海溝之空間分布(吳祚任，2011)

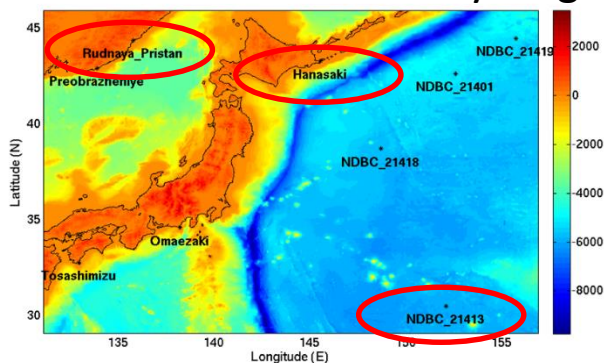
海溝名稱	走向(度)	適用經度範圍(°E)	適用緯度範圍(°N)
T1花蓮外海	-66.2422	121.9 ~123.5	23.8~24.5
T2馬尼拉海溝1	340.7619	119.25~120.75	19.5~22.0
T3馬尼拉海溝2	35.3532	119.0~121.0	17.5~20.0
T4馬尼拉海溝3	2.403	118.5~120.5	13.5~19.0
T5馬尼拉海溝4	313.0466	119.0~121.0	12.5~14.0
T6菲律賓海溝1	328.3928	123.5~125.5	13.5~15.5
T7菲律賓海溝2	347.6032	125.5~127.5	5.5~13.5
T8亞普海溝	44.9191	135.0~140.0	6.0~12.0
T9馬里亞納海溝1	74.3247	141.0~145.5	10.5~13.5
T10馬里亞納海溝2	24.4308	145.5~150.5	12.5~17.5
T11馬里亞納海溝3	-9.6795	146.0~149.0	16.5~22.5
T12馬里亞納海溝4	-42.1025	143.0~149.0	22.5~25.0
T13伊豆-小栗原海溝1	-4.1057	141.0~144.0	26.0~30.0
T14伊豆-小栗原海溝2	-10.9672	140.0~144.0	30.0~35.0
T15南海海溝	-115.806	132.5~140.0	31.0~35.0
T16琉球島弧1	-154.62	130.0~132.5	27.5~31.0
T17琉球島弧2	-134.981	126.0~130.0	23.0~27.5
T18琉球島弧3	-95.1302	123.5~126.0	23.0~24.75

海溝之參數與範圍分布

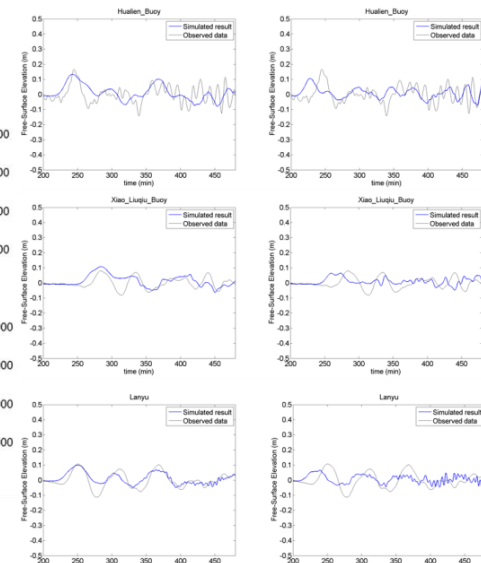
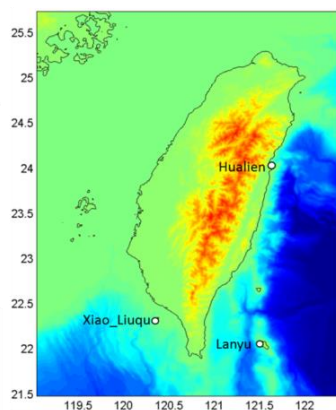
海嘯速算系統驗證

Validation

By assuming that only four parameters were known in the early stage.



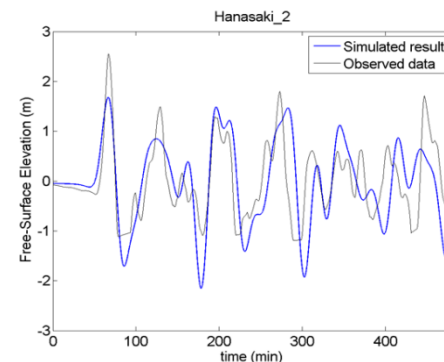
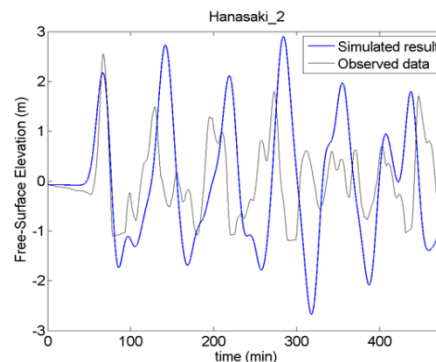
Taiwan 台灣



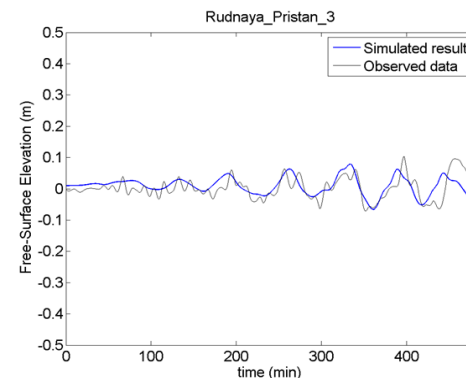
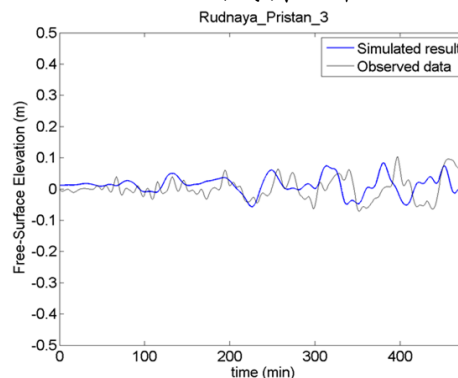
初步參數(present)

較詳細參數(GCMT)

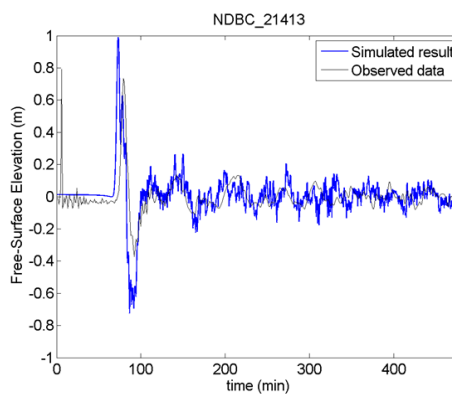
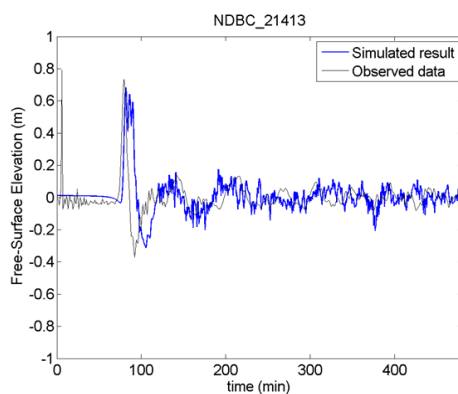
Japan 日本



Russia 俄羅斯



USA 美國



初步參數(present)

較詳細參數(GCMT)

海嘯的特性

人類有史以來第一次在船上拍攝到海嘯

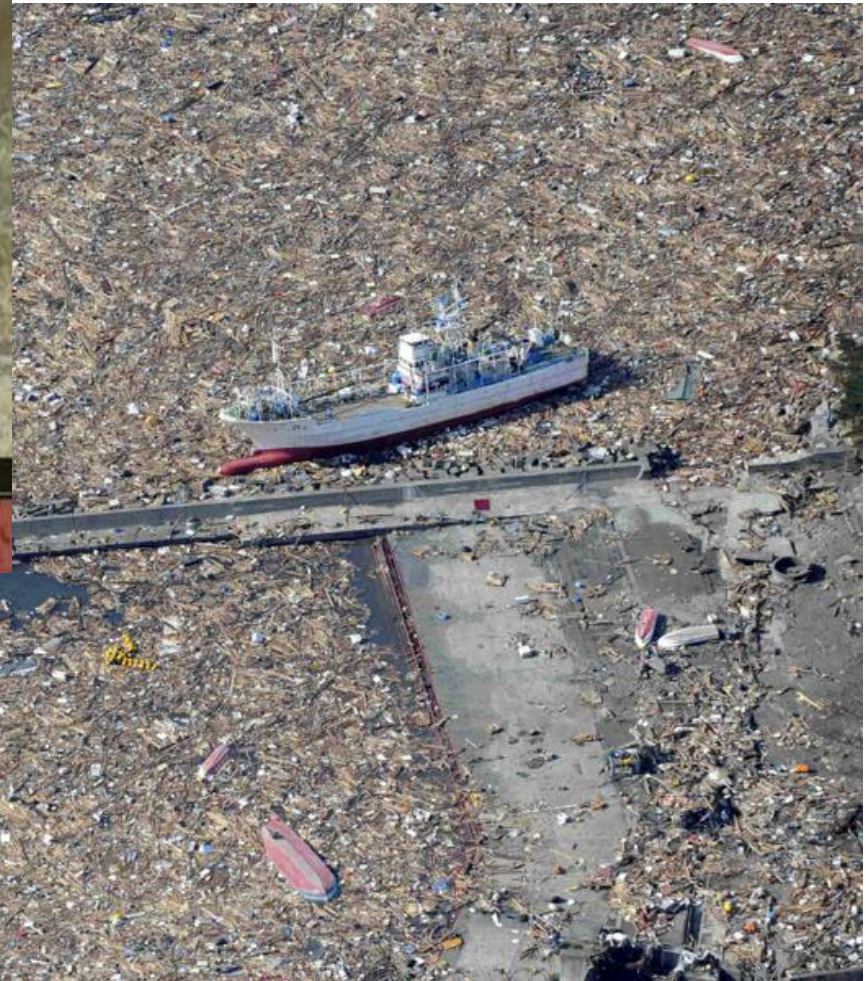


海嘯進入內陸變成海嘯湧潮

- 由原本波浪的傳能不傳質，變成傳能也傳質。

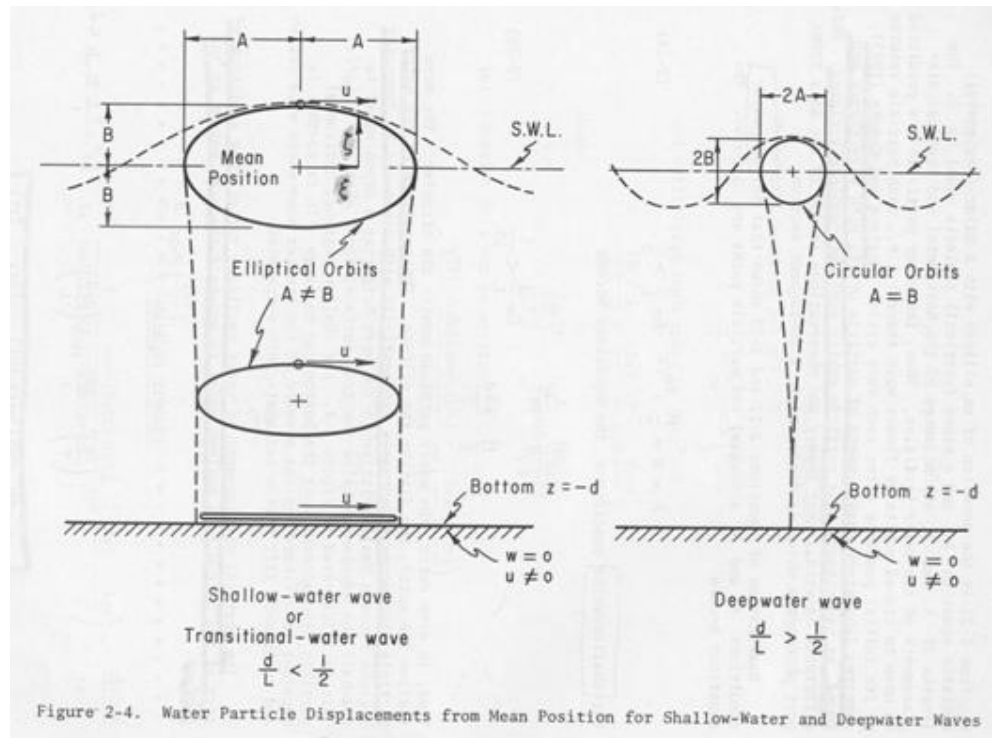


海嘯帶來的不只是洪水，還有… 大量破碎懸浮物

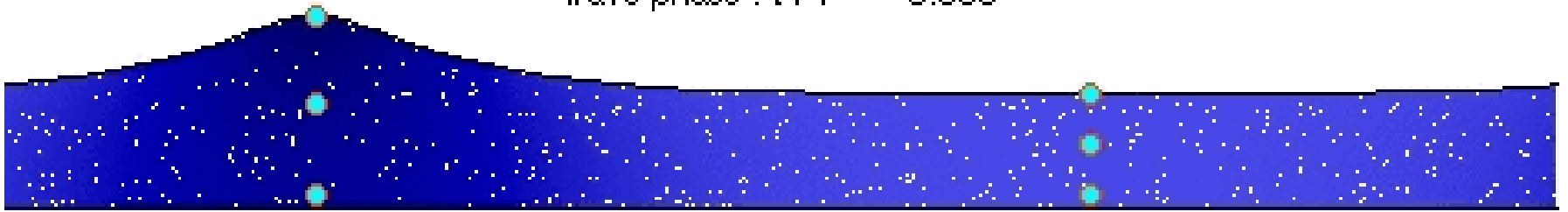


海嘯波特色

- 水分子移動均勻：
 - 沒有扯後腿的隊員，能量不浪費
- 幾乎沒有上下的運動
 - 能量幾乎完全往前傳遞
- 所以可以傳遞很遠
 - 2004南亞海嘯、1960 智利海嘯、抵達夏威夷及日本



wave phase : $t / T = 0.000$



http://en.wikipedia.org/wiki/File:Shallow_water_wave.gif

非線性淺水波方程式

Nonlinear equations:

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

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

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

For both linear and nonlinear equations,

$$P = Hu_x \text{ and } Q = Hu_y.$$

$$H = \eta + h.$$

η is the free surface displacement;

h is the still water depth; and

H is the total water depth.

海嘯的速度

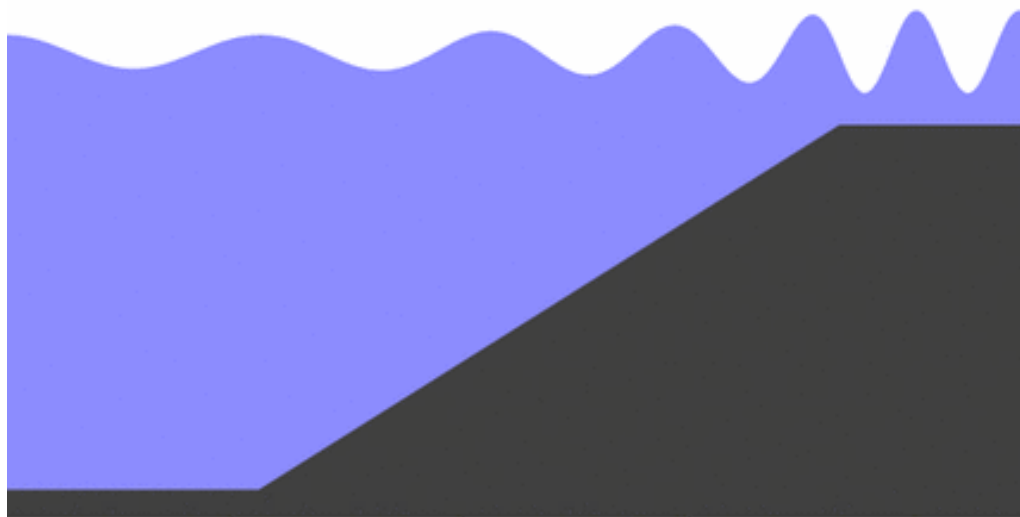
- 海嘯的速度可以由以下的公式簡單算出：
- 根據淺水波理論，海嘯在深海傳遞的波速等於重力加速度乘上水深的開根號。也就是

$$C = \sqrt{gh}$$

（問題：大海嘯跑比較快還是小海嘯？進實驗）

海嘯抵達岸邊的波高放大效應

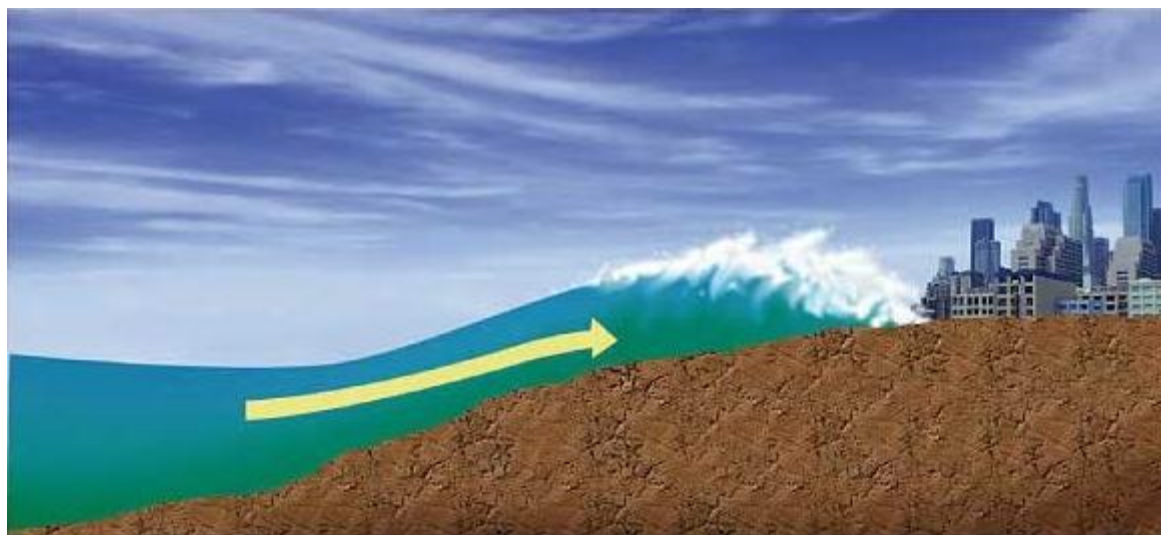
- 當海嘯波運動到彼岸時，地形效應是如何將兩三百公里的海嘯長波累積與集中，造成海嘯波的放大。
 - 如果我們假設水是不可壓縮的流體，在沒有其他化學反應的情況下，質量守恆可以轉換為體積守恆。所謂體積守恆就是體積不會無故消失。所以原本在深海大約四公里深的波浪進入到淺海區的時候，波高就會開始放大，這就如同有一個人由游泳池較深處走向較淺處類似。更糟糕的是，根據淺水波理論，當水深變淺，波前進的速度也會變慢。這就會產生後浪推前浪，後浪騎在前浪上的放大現象。



海嘯抵達岸邊的放大效應。

(http://en.wikipedia.org/wiki/File:Propagation_du_tsunami_en_profondeur_variable.gif)

後浪推前浪，前浪死在沙灘上...

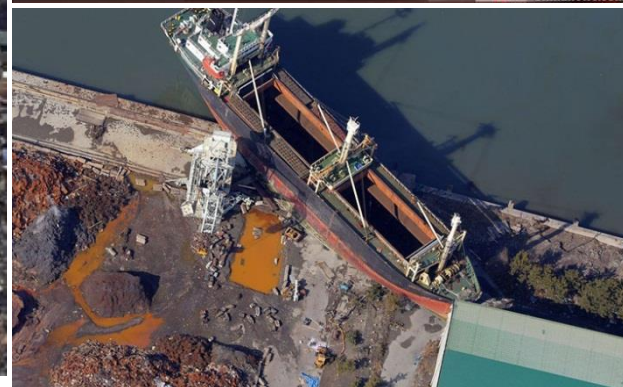


海嘯入侵至內陸時為海嘯湧潮



海嘯來臨時，人與船隻都應儘速離港

- 當海嘯波變成海嘯湧潮時，會產生強大推移力！



海嘯湧潮破壞力驚人 連鋼筋混凝土都遭破壞

- 女川港附近高達三、四樓的鋼骨建築也嚴重倒塌，研判當時承受的海嘯壓力約為一平方公尺五十噸！



颱風巨浪 VS 海嘯湧潮

颱風巨浪



颱風“天兔”襲臺海邊掀起滔天巨浪
(中央社，2013-09-22)

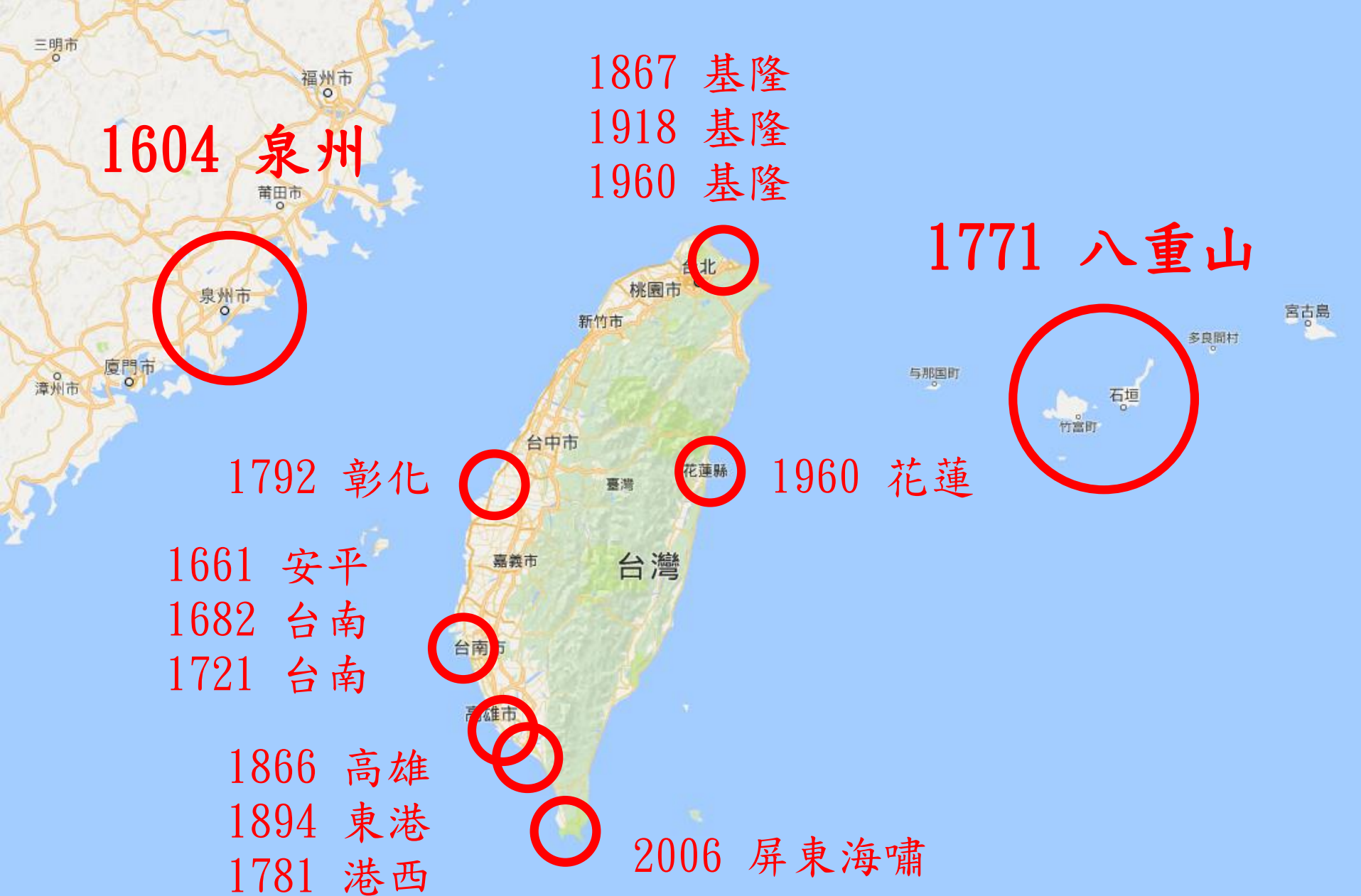


麥德姆颱風來襲，在宜蘭烏石港旁不時出現
狂濤巨浪。(聯合報，2014-07-23)

台灣歷史海嘯紀錄

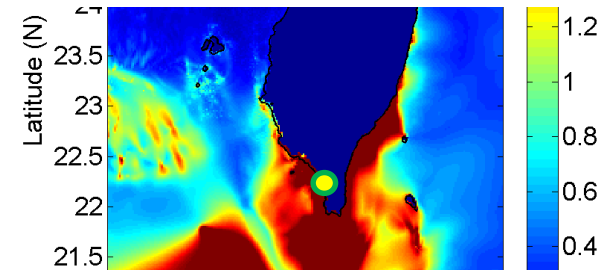
台灣自1661年11起之台灣歷史海嘯紀錄（2013，吳祚任）

時間	地點	出處	描述
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，有3船入港，在水中亦激烈震動
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	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。」。
1781年4、5月間	屏東港西里	台灣采訪冊「祥異。地震」	海水暴吼如雷，巨湧排空，水漲數十丈，近村人居被淹，不數刻，水暴退。
1682年	台南	Soloviev and Go, 1974	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。40,000多居民喪生。
1792年8月9日	彰化	「台灣采訪冊」（頁39-40）「祥異，地震」	嘉城地大震，忽無風，水湧起數丈，舟人曰：『地震甚。』
1866年12月16日晨8時20分	高雄	阿瓦力茲（Alvarez）著「福爾摩薩（Formosa）」	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。
1867年12月18日	基隆	淡水廳志、Alvarez，Formosa等	雞籠頭、金包里沿海，山傾地裂，海水暴漲，屋宇傾壞，溺數百人。
1894年	屏東東港	記載於東隆宮、鎮海宮、嘉蓮宮、南隆宮之廟誌及碑文上	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
1918年5月1日	基隆	楊春生等（1983）	台灣東北部海底地震引起海嘯，基隆海嘯溯上約3.7公尺
1960年5月24日	基隆、花蓮	聯合報等	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
2006年12月26日	屏東後壁湖漁港	吳祚任，中央氣象局	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之海嘯。



台灣自1661年11起之台灣歷史海嘯紀錄（2013，吳祚任）

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，十里內村民提籃契筒，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 drowned. 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

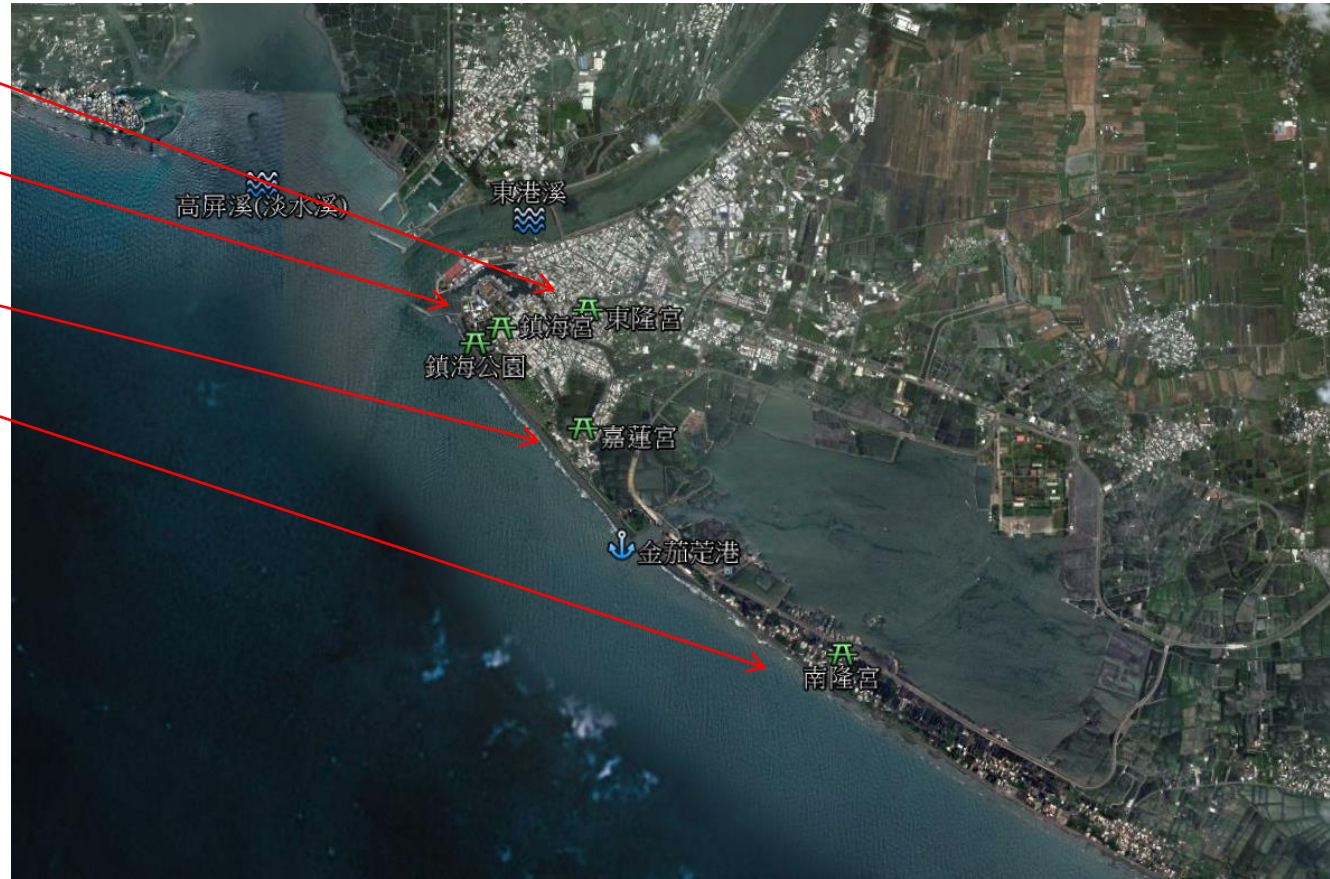
About 4~5m

Second tsunami coming in

About 1km far

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



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)

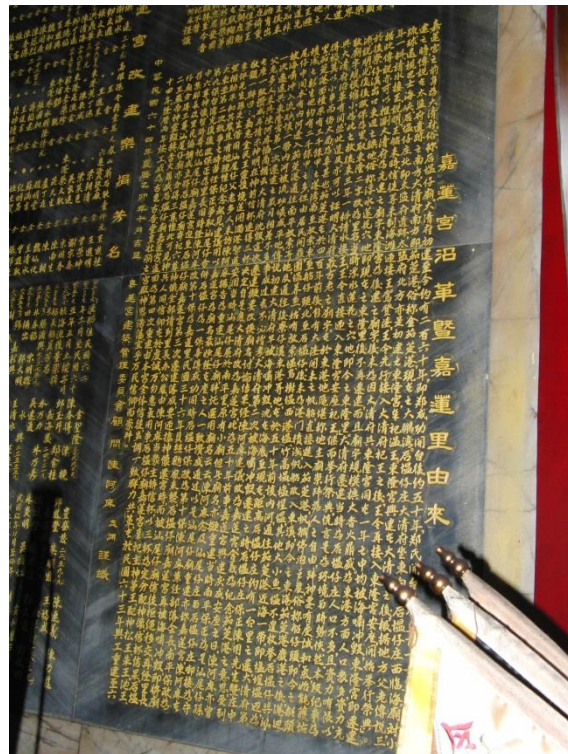
嘉蓮宮

碑文摘要：

- 俗稱大清府，初建之時傳說在太監府遺跡之南方，即茄荳港(現大鵬灣一帶)。
- 曾於與東隆宮同時遭海嘯摧毀。
- 茄荳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荳港近海一帶，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。

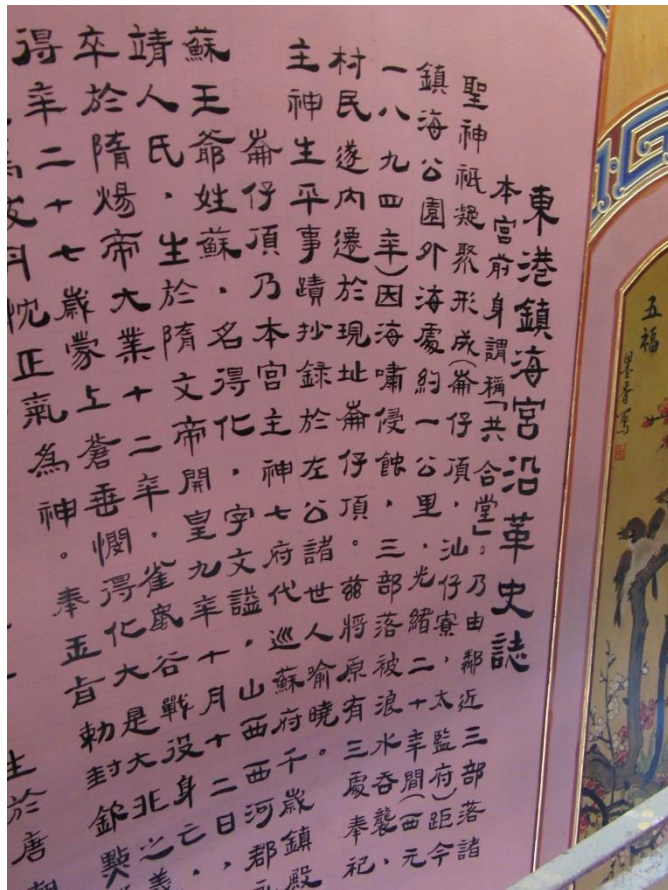
(蔡育霖、李俊叡、柯利鴻提供，中大水海所海嘯科學研究室)



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。



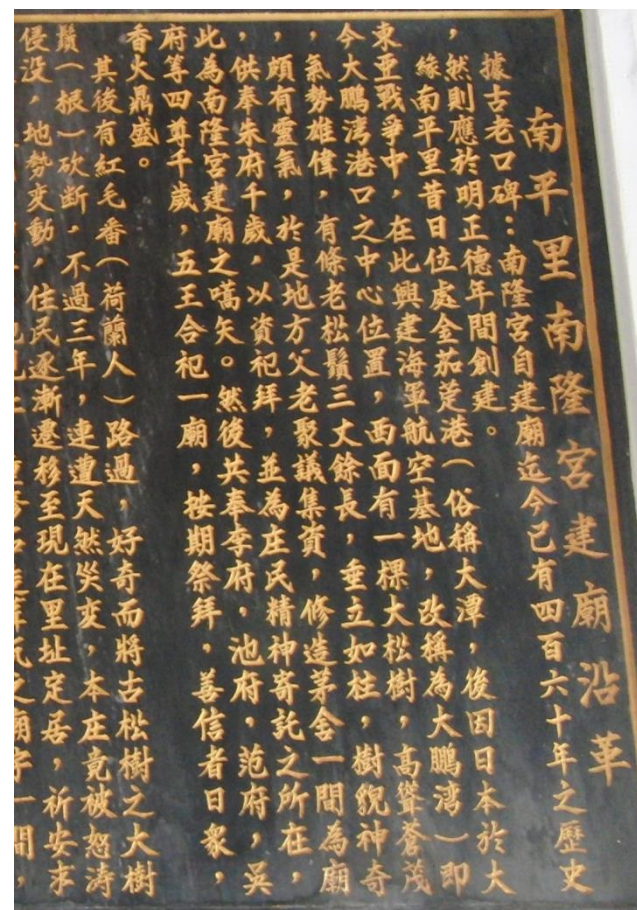
(蔡育霖、李俊叡、柯利鴻提供，
中大水海所海嘯科學研究室)

南隆宮

碑文摘要：

- 緣南平里昔日位處金茄荳港，.....
- ...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)



海嘯災防的首要工作是找出歷史海嘯與古海嘯的來源

For tsunami hazard mitigation, the first thing first, is to figure out where did those historical or paleo tsunamis come from?



其中 1867 基隆海嘯最令學者困惑

One event bothering us is the 1867 Keelung Tsunami



1867年基隆海嘯事件之還原

Reconstructing the 1867 Keelung Tsunami Event

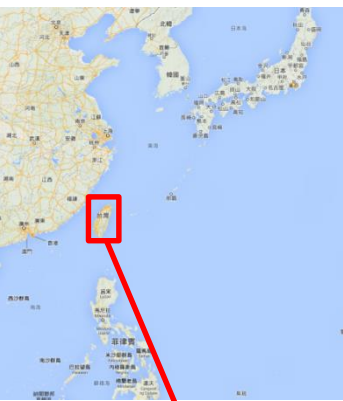


Tsunami deposit were found on the Hoping Island, Keelung,
Taiwan (Liberty Times, 2012)

基隆和平島海嘯沉積物考察 (自由時報，2012)

為何1867 基隆海嘯如此重要？

Why the 1867 Keelung tsunami event is important?



1867基隆海嘯是目前唯一政府認證的台灣歷史海嘯事件
It is the only tsunami event officially recognized by Taiwan government, so far.

1867 基隆海嘯事件有不同語言的文獻記載

This event was documented by multiple literatures with multiple languages

1. 《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」
2. 《字林西報》：「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，致使遠至閩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」
3. 《1881年通商各關貿易報告》：「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」
4. 《同治年間於金包里附近之地變》「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」
5. From Far Formosa和The Island of Formosa中亦有描述到當日地震和海嘯之情境，但無更進一步之較具體之海嘯物理現象描述。

文獻描述

Historical records

- 1867年12 December
- 有地震 Earthquakes
- 有煙塵 Smoke observed
- 有海嘯 Tsunami
 - 6~7m tsunami height
 - seabed exposed
- 基隆和金山受災
Tsunami impact at
Jinshan and Keelung
- 數百人死亡 Hundreds death toll



學者研究大致認為該地震規模約 Mw 7.2~7.2

Earthquake magnitudes proposed by
previous studies were Mw 6.2~Mw 7.2

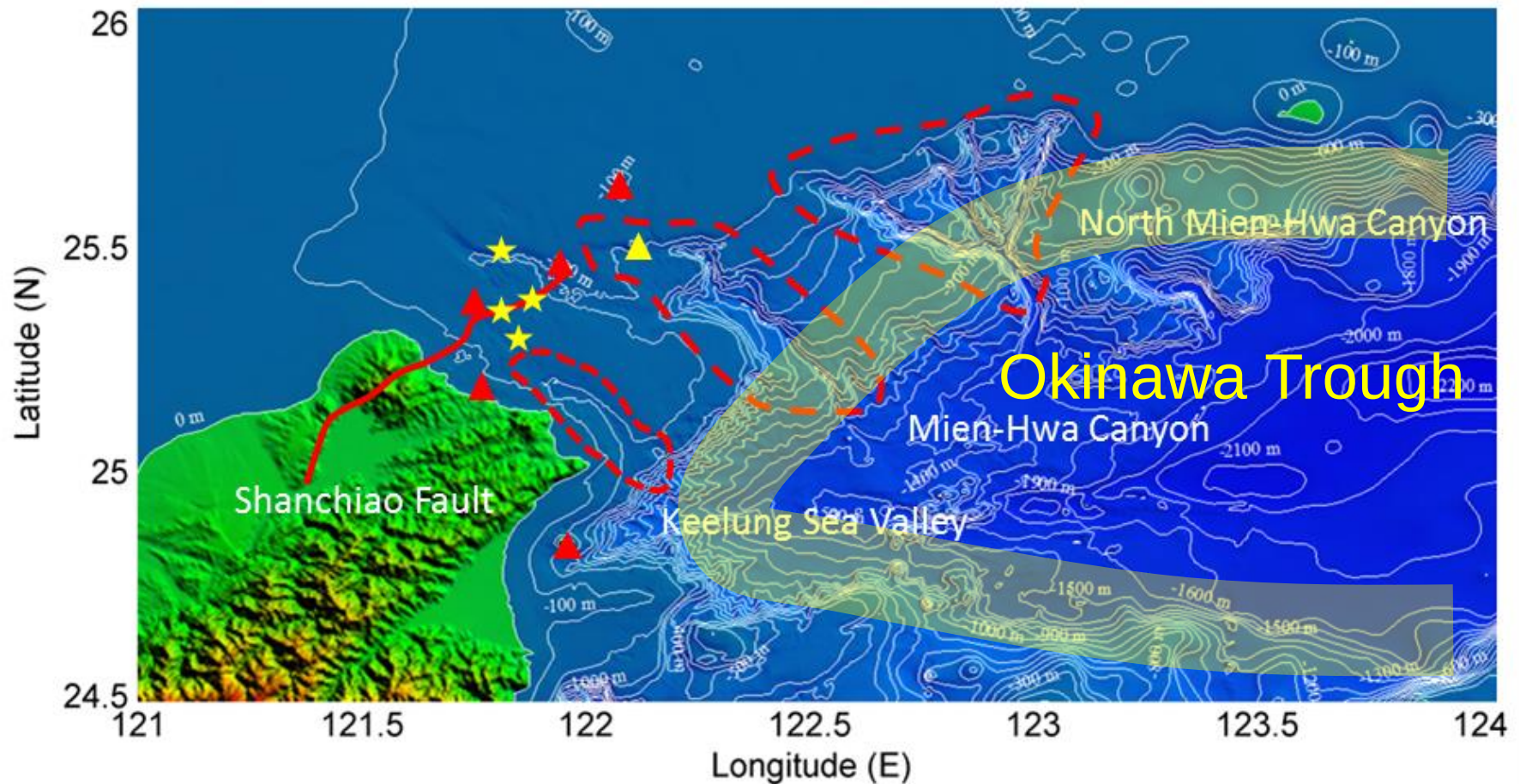
但是，這樣的地震只能產生半公尺不到的海嘯

However, the simulated tsunami heights are less than 0.5m

	Longitude	Latitude	Magnitude
Lee et al., 1976	121.7	25.5	Mw=6.2
Hsu, 1981	121.8	25.2	Mw=7.0
Tsai, 1985	121.7	25.3	Mw=7.0
Ma and Lee, 1997	121.7	25.5	Mw=6.9~7.2
Lin, 2006	121.7	25.3	Mw=7.0
Cheng, 2013	121.91	25.34	Mw=7.0

鄰近海底地形有陡峭的斜坡和海底火山

Steep slope and volcanos are presented in the near-field region



▲ : 海底火山 Volcano ——— : Fault - - - - : Submarine canyon

▲ : 噴發過的海底火山 Erupted record volcano (Chen et al., 2005)

★ : 震央位置 Epicenters of previous studies
(Lin et al., 2006, Zheng et al, 2011, Tsai et al., 1985 & Ma et al., 1997)

如果進行情境分析，必須考慮太多因素。

We are going to perform the scenario studies. However, there are numerous of scenarios if we considered possible slope angels, lengths, depth, and locations.....etc.



有沒有方法可以快速且系統性的分析潛在海嘯源？

We want to develop a method that can help us analyzing the potential tsunami sources systemically.

為此，我們發展出新的方法，由研究地點向外去尋找海嘯源
So, instead of simulating all possible scenarios from the sources to the study area, we want to trace back from the study area to the sources.



過去學者在研究可能的海嘯源時，往往以距離來判斷。這樣可行嗎？

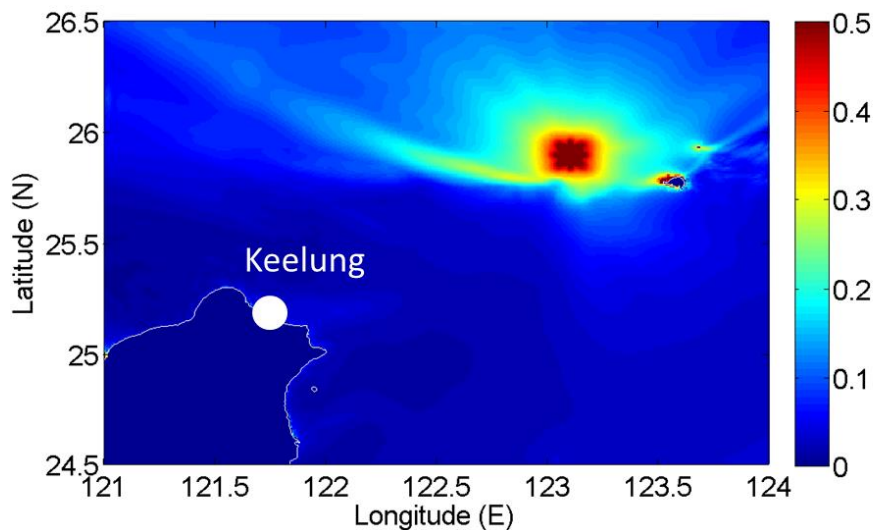
風險很大

Can we identify a potential tsunami source based on the intuition or distance?

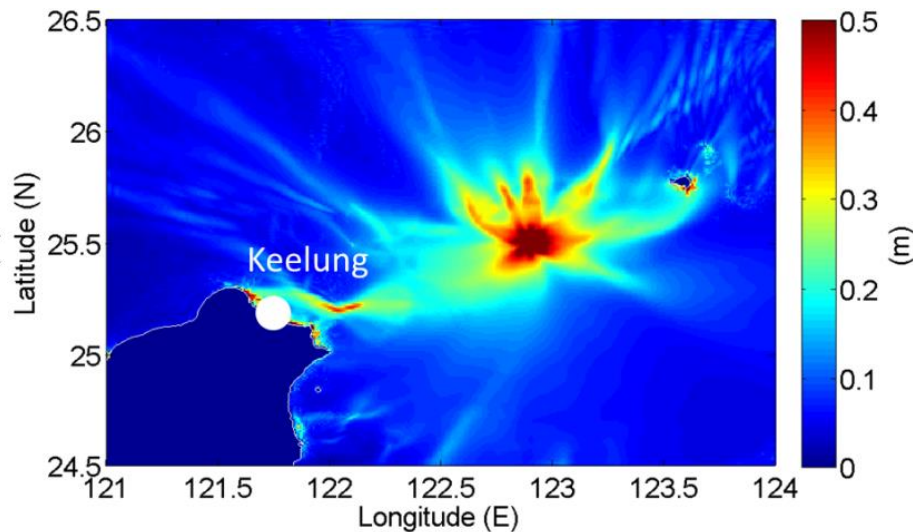
Maybe yes, but risky.

Within 100 km, two sources present different results.

海嘯源A



海嘯源B

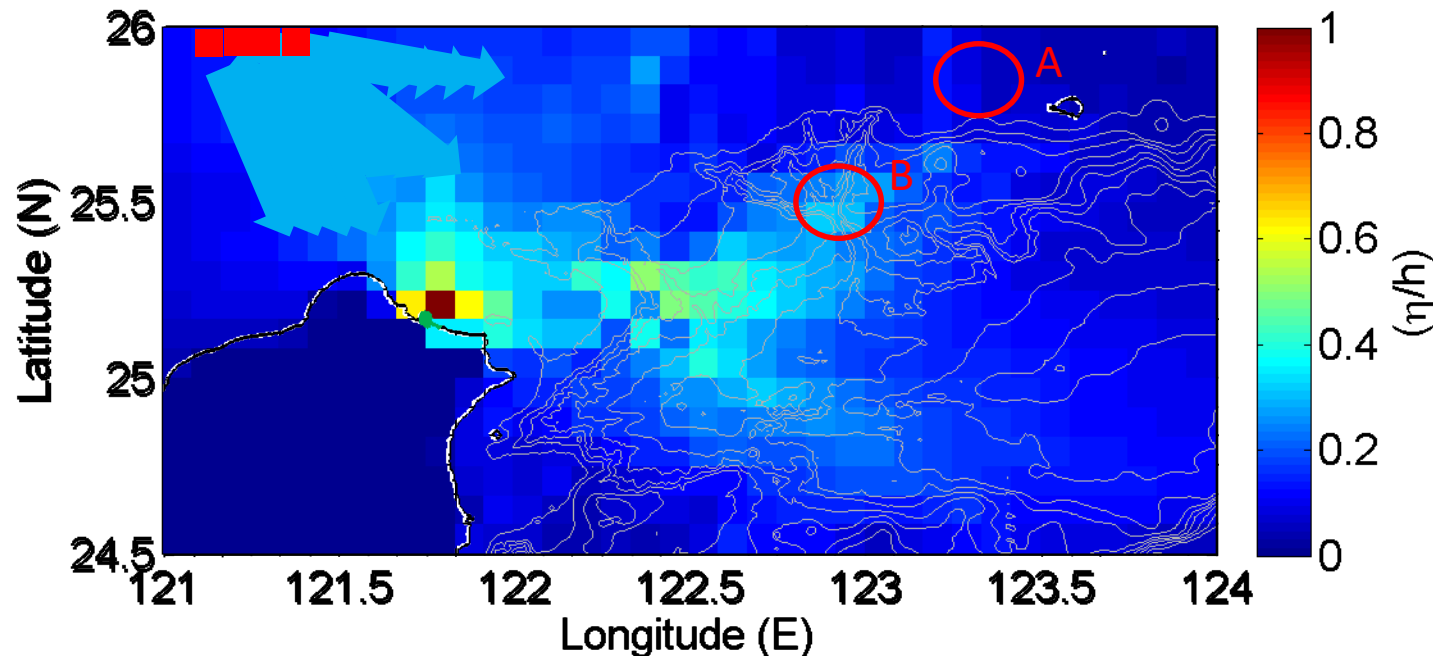


本案例中，海嘯源A與海嘯源B皆位於基隆港外海不遠處，然而其對基隆港之卻有極大差異。海嘯源A之能量主要朝北部傳遞，對基隆港幾乎無影響，然而海嘯源B之能量卻主要傳遞至基隆，對基隆港危害極大。

此案例突顯情境分析法之缺點，亦即有挂一漏萬之疑慮。

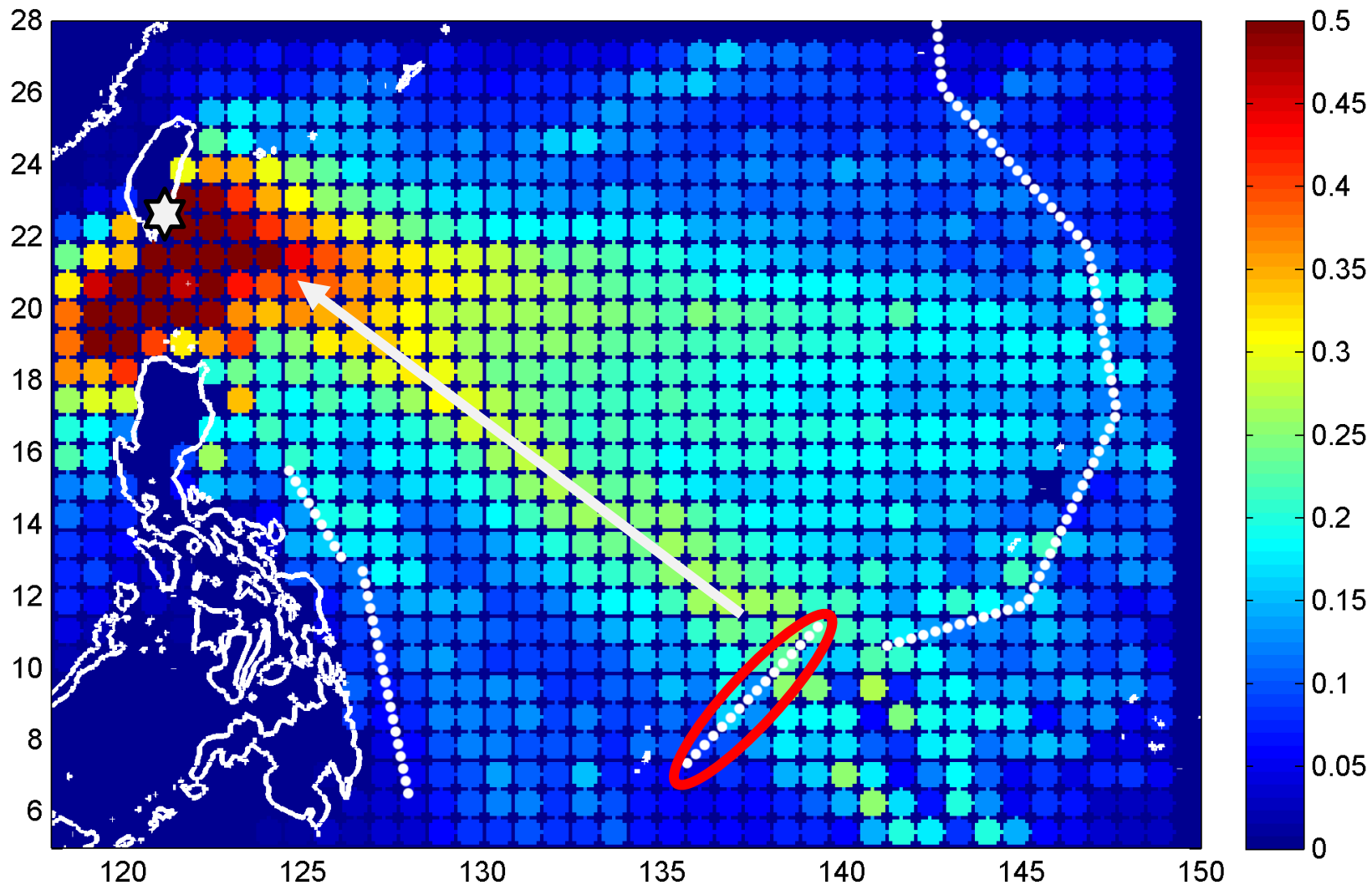
Method of Impact Intensity Analysis (IIA)

1. Discretized the computational domain into small uniform source regions
2. Calculate the wave propagation from each source region. (This requires high performance computation)
3. Record the maximum wave height (MWH) at the study area
4. Place the MWH value on the corresponding source region

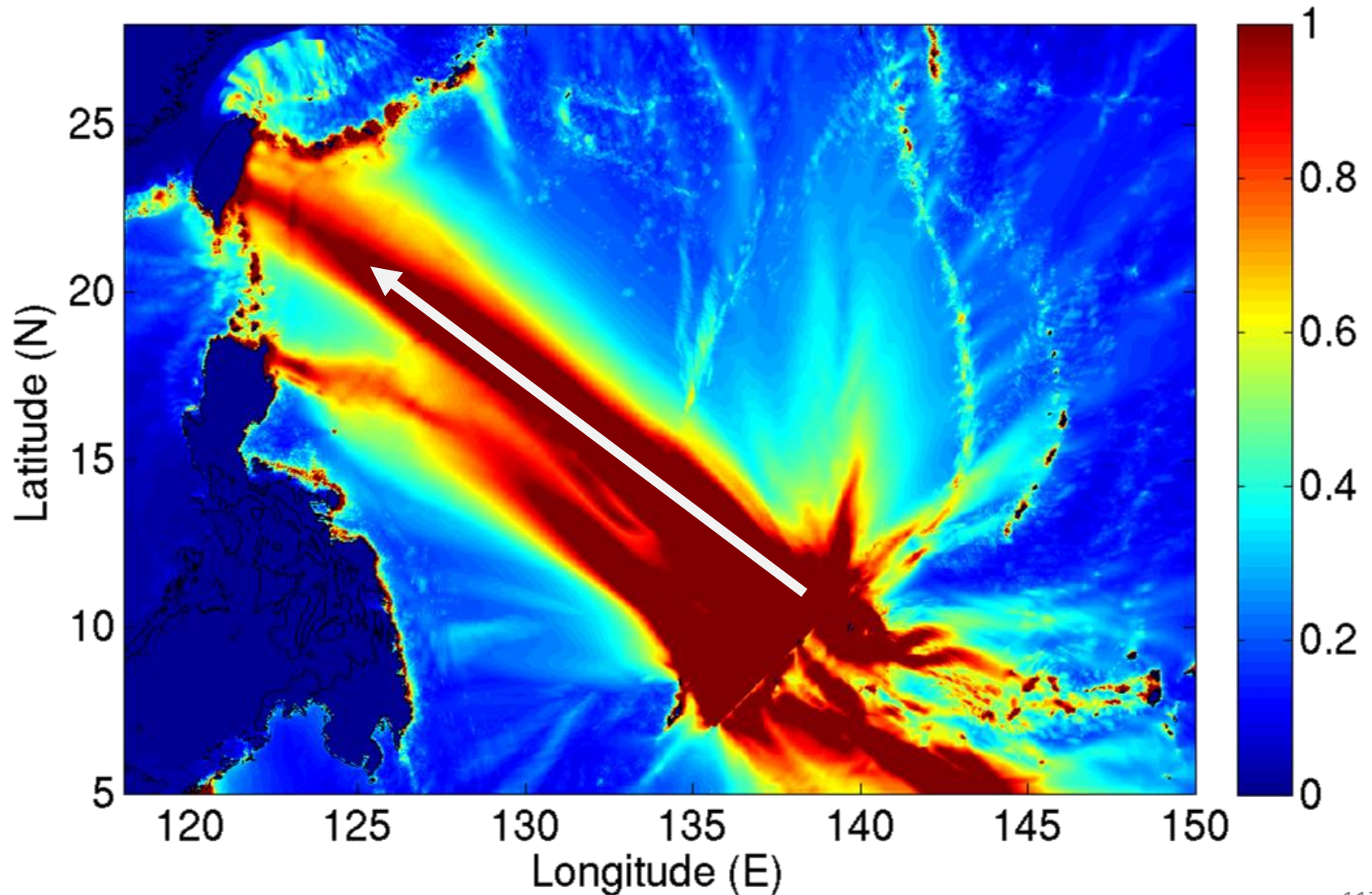


IIA: Jiu Peng (九鵬)

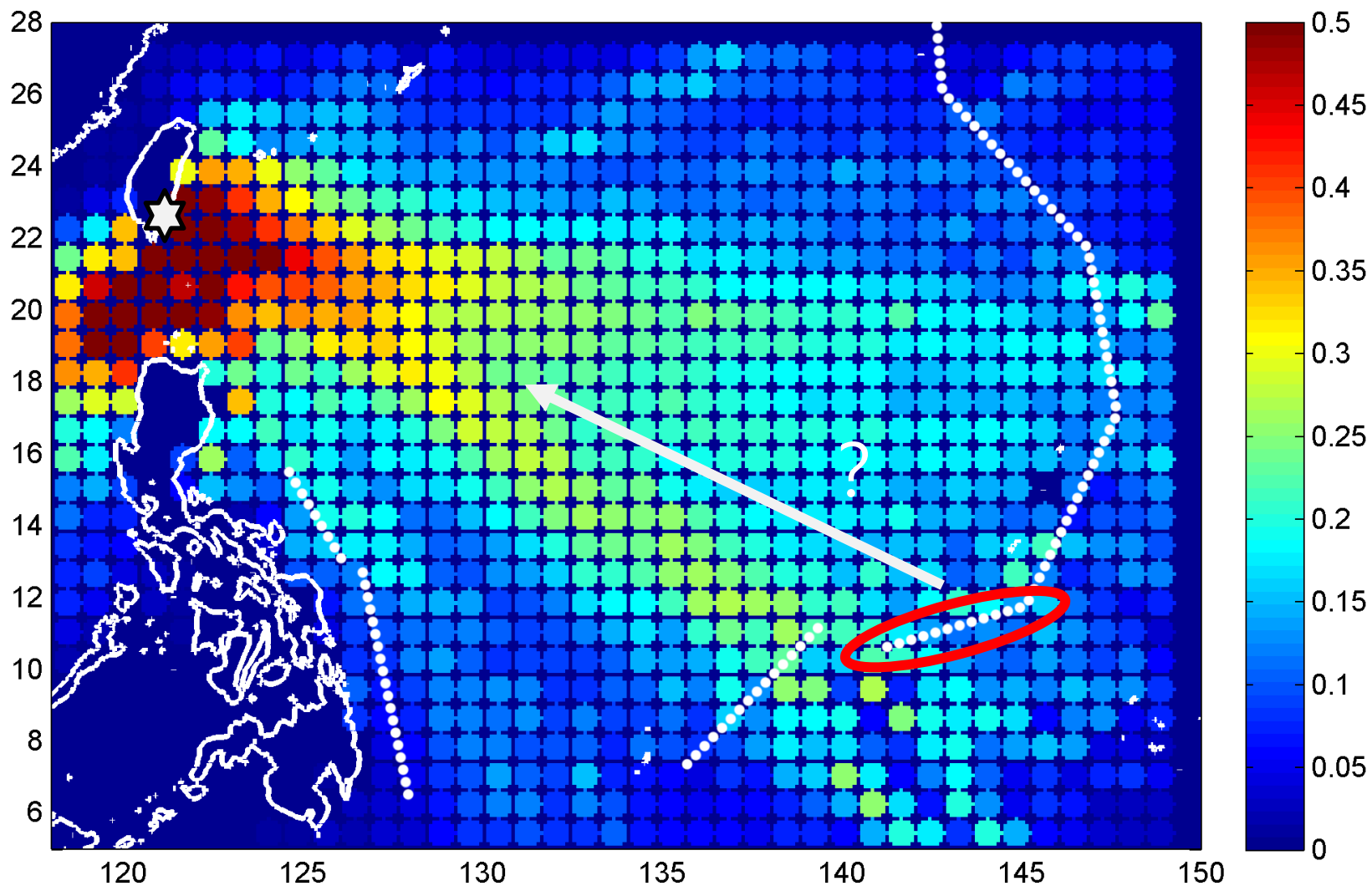
(22.124520, 120.894662)



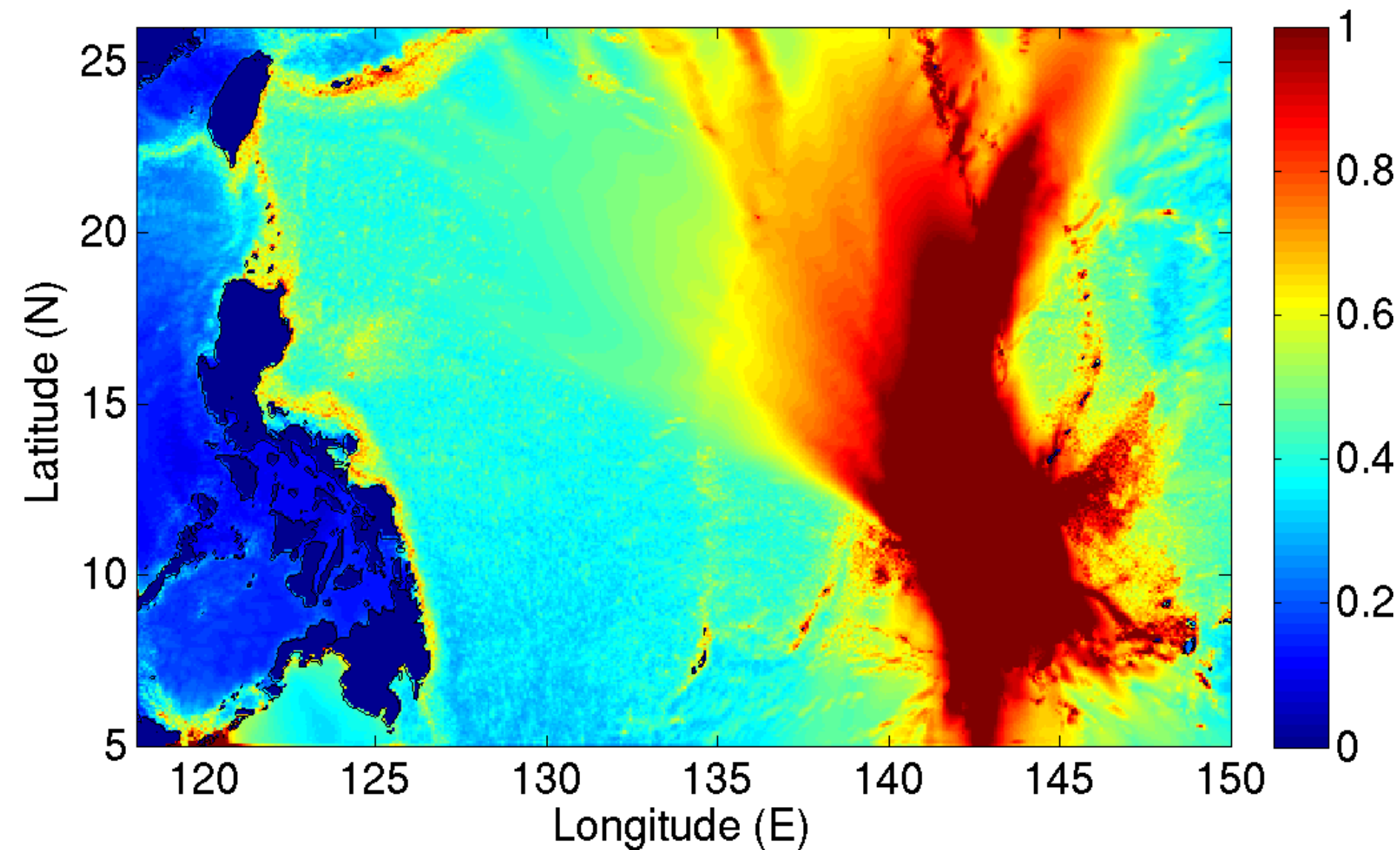
T08, Yap Trench (亞普海溝)



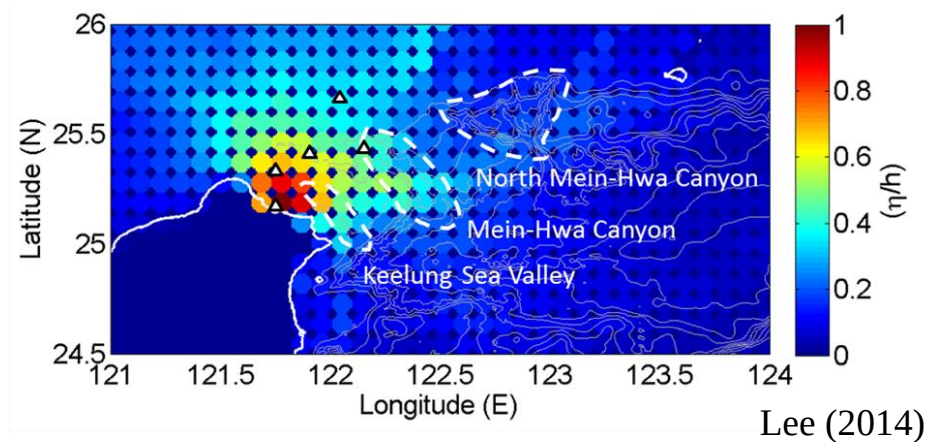
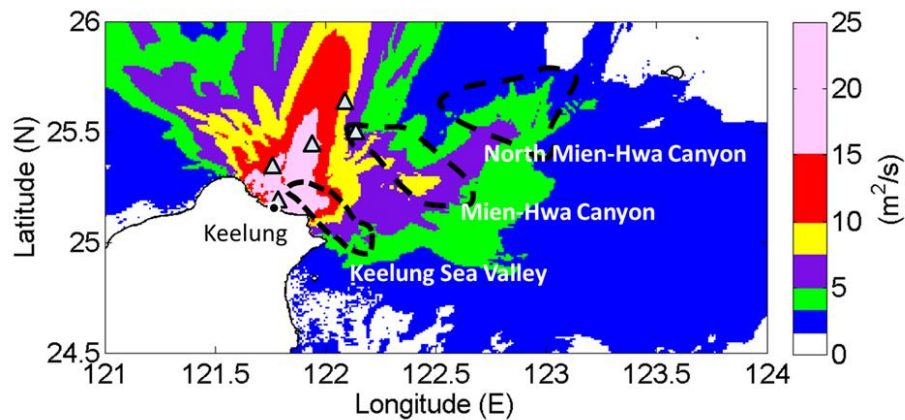
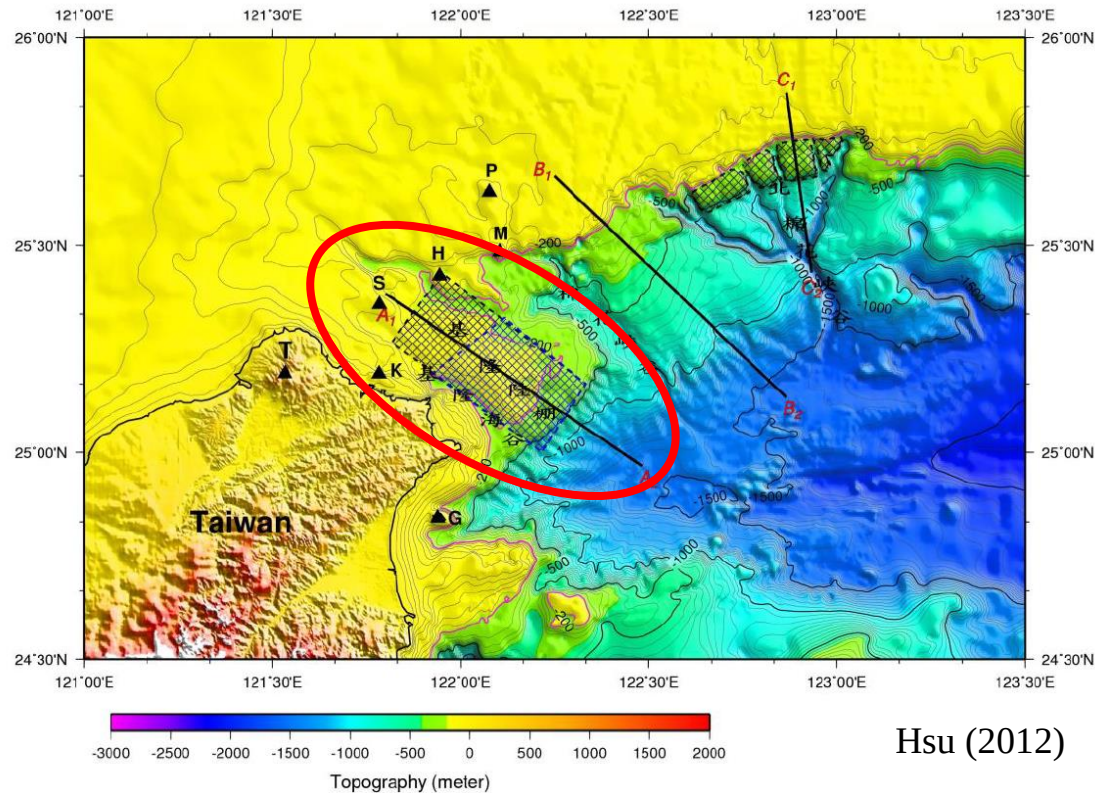
IIA :Jiu Peng (九鵬)

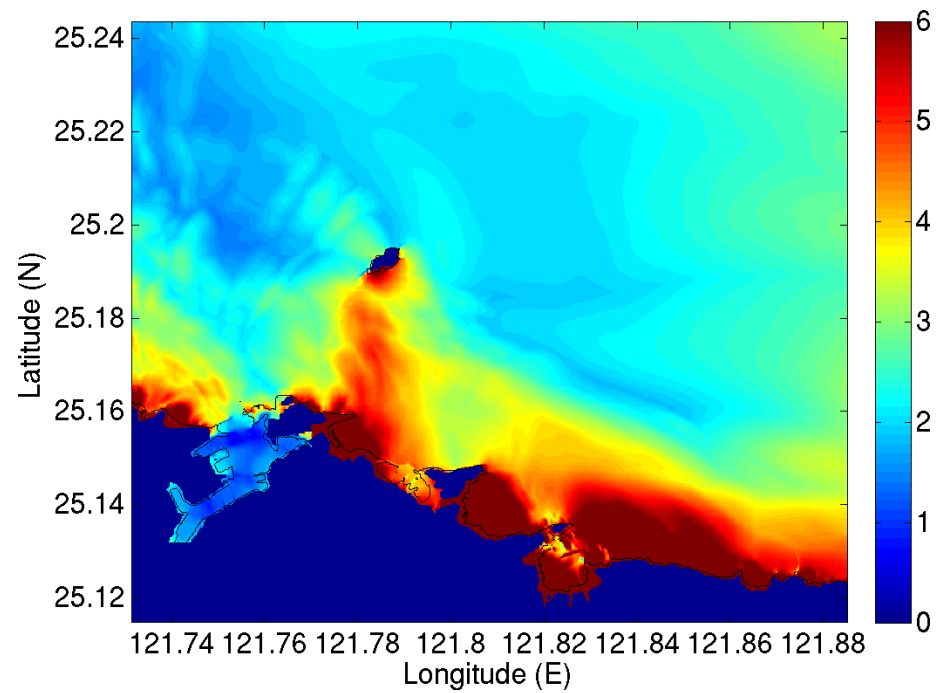
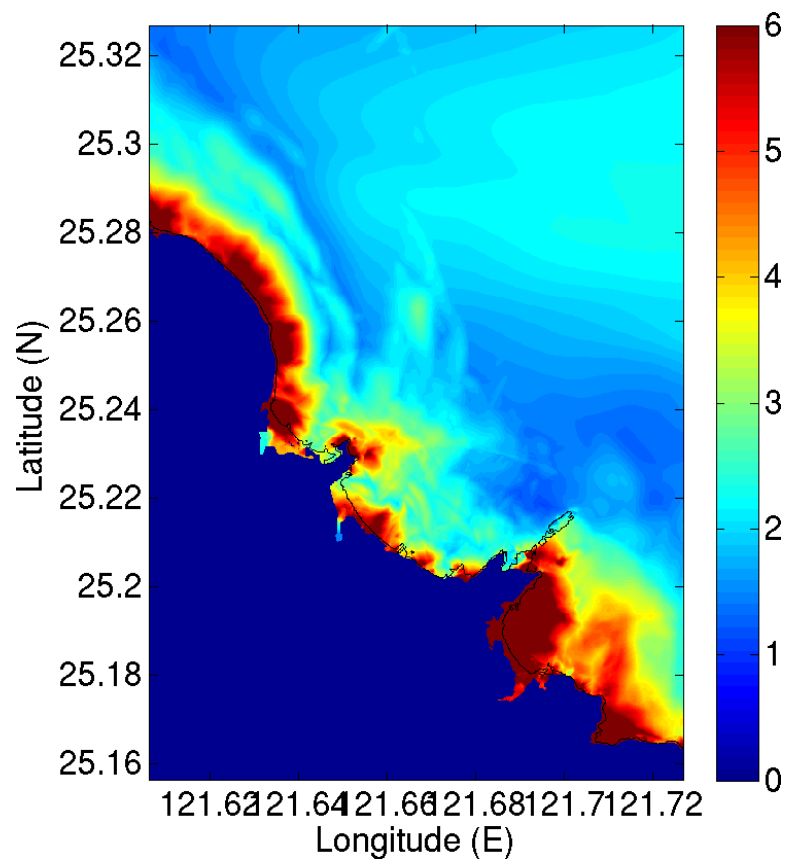
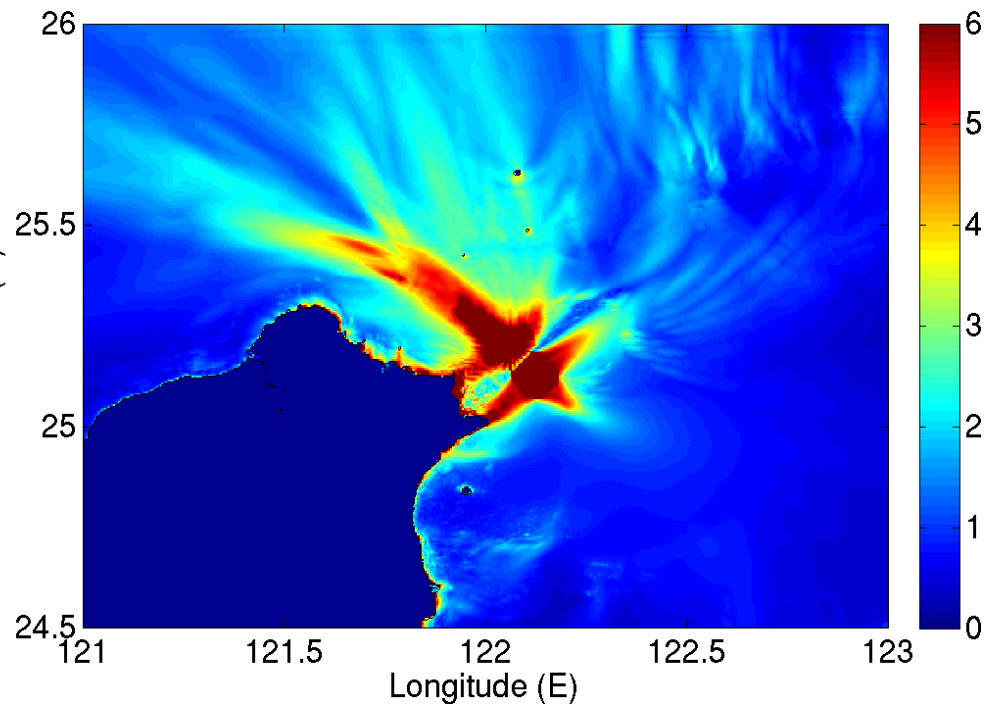
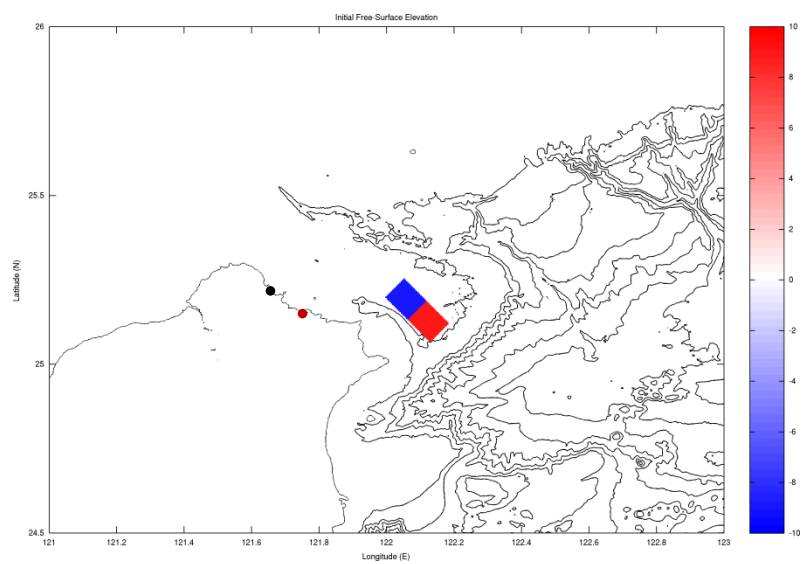


馬里亞納T09

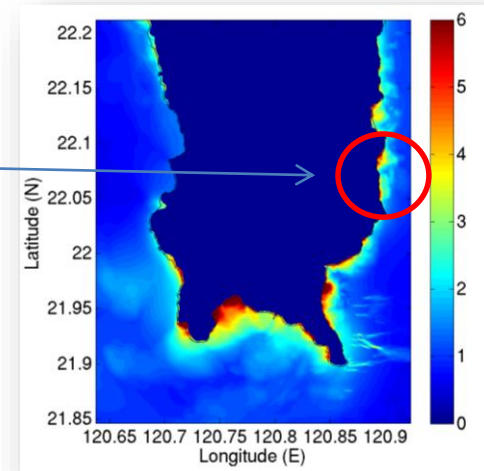
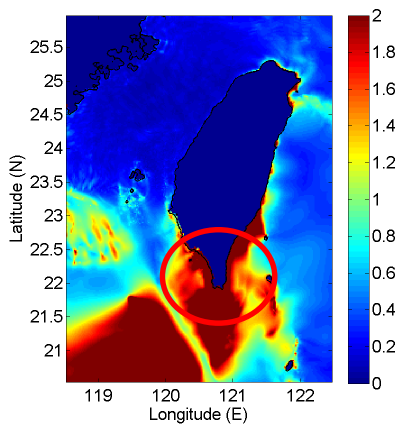


1867年基隆海嘯之還原與分析





台灣九鵬第一次發現海嘯石 Tsunami Boulders were found in Taiwan



海嘯沉積物 Tsunami Deposits



歷史沿革

成功鎮由阿美族、西拉雅族及漢人的聚落組成。阿美族最早於清初就已移居本地而形成聚落，原名「麻荖漏」，阿美族語：「東西在火上烤乾之意」。相傳早年阿美族聚落於1850年左右曾遭海嘯侵襲，草木皆枯死，極似被火烤乾，因有此名。其後，漢人於成功北方狀似「蟬管」之小海灣登岸移墾，閩人皆稱為「澳」，故得「蟬廣澳」之名，後轉為「成廣澳」，為漢人最早開發後山的據點。日治時期因修築漁港而改稱為「新港」，光復後，為紀念鄭成功開發台灣之功績，且「成功」與「成廣」之音相近，遂定名「成功鎮」迄今。

The original name of Chenggong town is "Ma-Lau-Lo", means **"basked by the fire"**. There was a **tsunami came 150** years age. The grass and trees were died and looked like burned by the fire.

【2010/03/16 聯合報】

台東新聞

成功150年前海嘯？ 跨國調查

記者羅紹平／台東報導／聯合報

民間傳說台東成功鎮150年前曾遭海嘯侵襲？為了解傳說真假，我國與日本、新加坡學者跨國合作，在成功鎮進行地質鑽探，希望取得發生海嘯的具體證據，做為建構台灣海嘯預警制度參考。

這項研究由目前在台大地質所進行博士後研究的松多信尚主導，松多為名古屋大學地震火山研究所博士。團隊成員包括中央研究院地科所、台大地質系主任陳文山、新加坡南洋理工學院地科所教授亞當·史威茲等人。

松多信尚表示，台灣是否曾遭遇海嘯襲擊，缺乏歷史文獻佐證；但台灣學術界及氣象局普遍樂觀認為，台灣東海岸因地形影響，發生海嘯機率不高。日本學術界認為，「台灣上下都這麼認為，是很危險的事」。

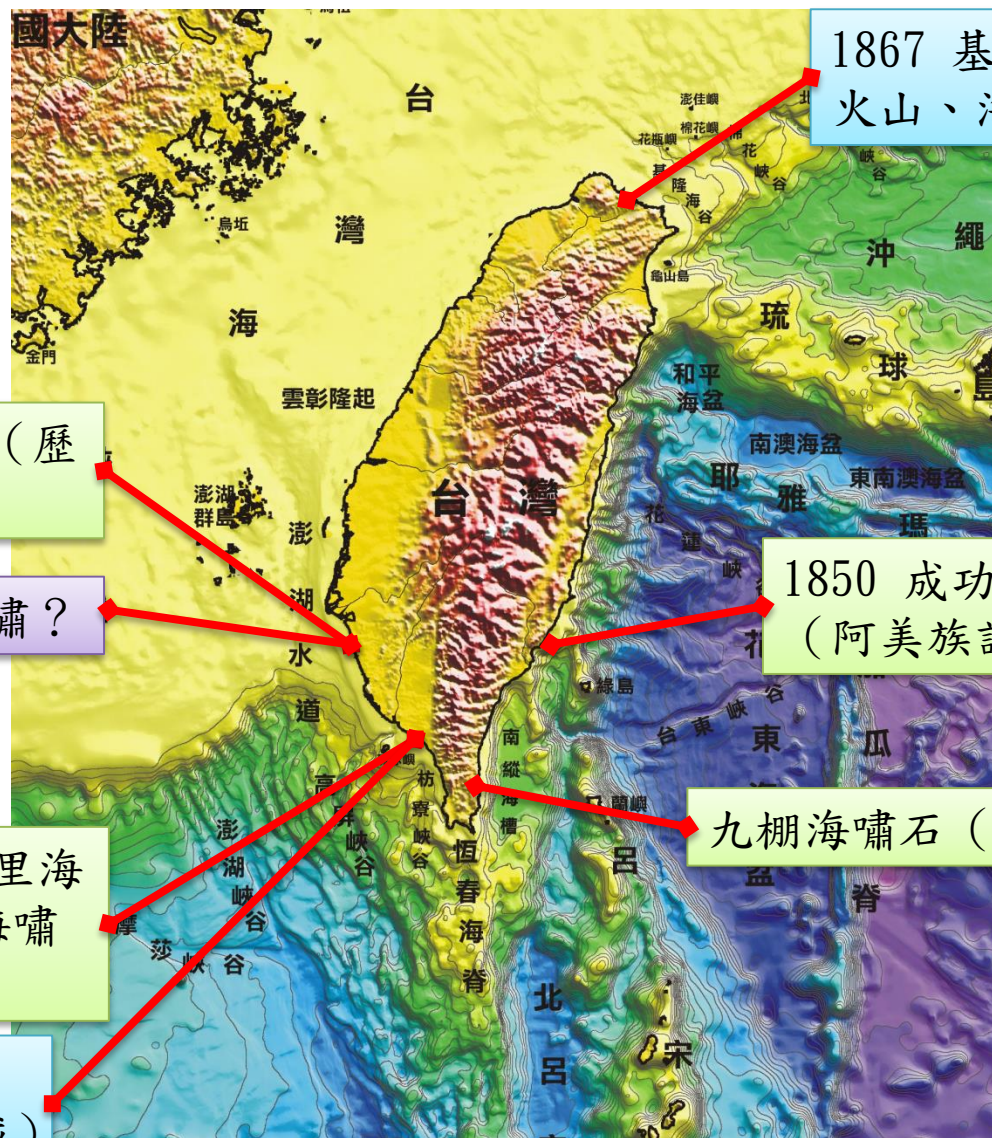
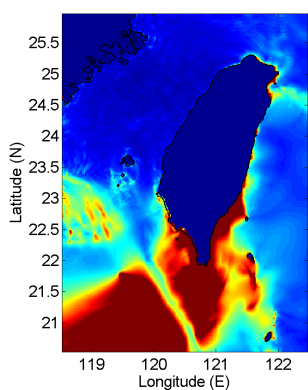
研究團隊本月9日至13日，根據地表階地特性，選擇成功鎮新港國中、署立台東醫院成功分院等六個點鑽探，採集地表下兩公尺至三公尺的土壤樣本。

採取的土壤樣本，部分送往美國做碳14鑑定，另在台大進行土壤成分分析，透過土壤中矽藻、花粉、沙子、貝殼等數十種含量分析，可研判這些成分是隨地殼造山運動從海底隆起？還是因海嘯被大浪捲上岸堆積形成。

松多信尚透過翻譯表示，他及研究團隊很期待鑽探結果，若能驗證成功鎮確實曾遭海嘯侵襲的傳說，除可提醒台灣別再對海嘯掉以輕心，同時還可藉由科學實驗，了解當年海嘯威力有多大？侵襲陸地的範圍有多廣？協助台灣建構海嘯預警機制。



原住民傳說，150年前成功鎮曾有海嘯，我與日本、新加坡學者跨國合作，在成功鎮地質鑽探求證。



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）

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）

九棚海嘯石（5000年內）

海嘯湧潮 Tsunami Bore



A tsunami strikes northeast Japan after the 2011 Tohoku Earthquake, generating waves up to 133 feet high along some areas of the coast. Although the Japan Meteorological Agency issued a warning, the tsunami was responsible for more deaths and more damage than the earthquake itself. (Courtesy S. Tomizawa)

Breaking wave modeling, **Splash3D (史百力士3D)**

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.

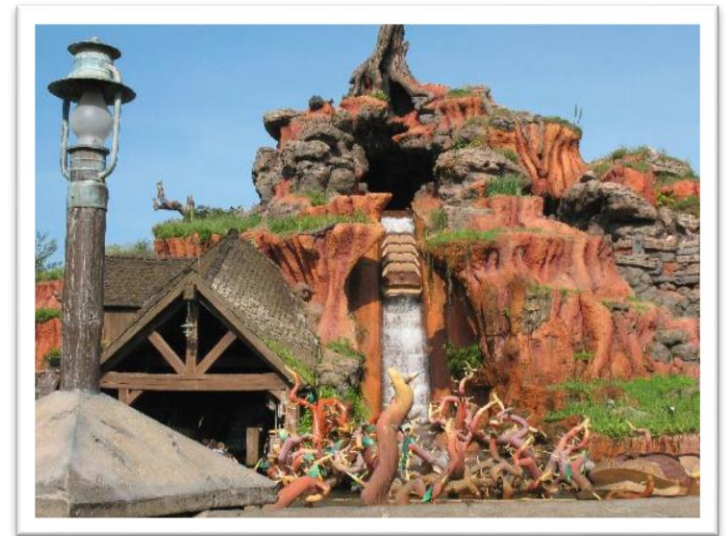
Incompressible continuity equation:

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

Navier-Stokes Equation

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

Splash: 飛濺



Disney **Splash** Mountain
迪士尼 **史百力士**山

Development of Fluid-Solid Coupling

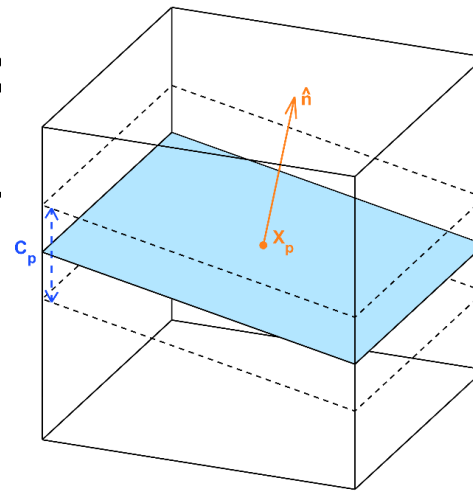
Numerical Method of Fluid

- **Volume of Fluid (VOF) Method** calculate volume fraction of each cell

- **Piecewise Linear Interface Calculation (PLIC)**

0	0	0	0	0	0	0
0.58	0.54	0.42	0.29	0	0	0
1	1	1	1	0.20	0	0
1	1	1	1	0.60	0	0
1	1	1	1	0.95	0.08	0
1	1	1	1	1	0.69	0.03
1	1	1	1	1	1	0.64

$$f_k = \frac{V_k}{V}$$

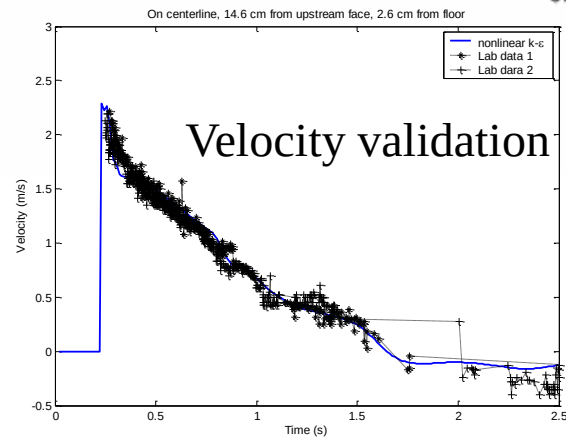
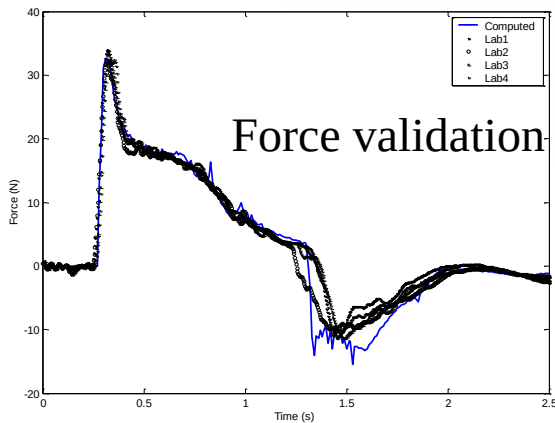
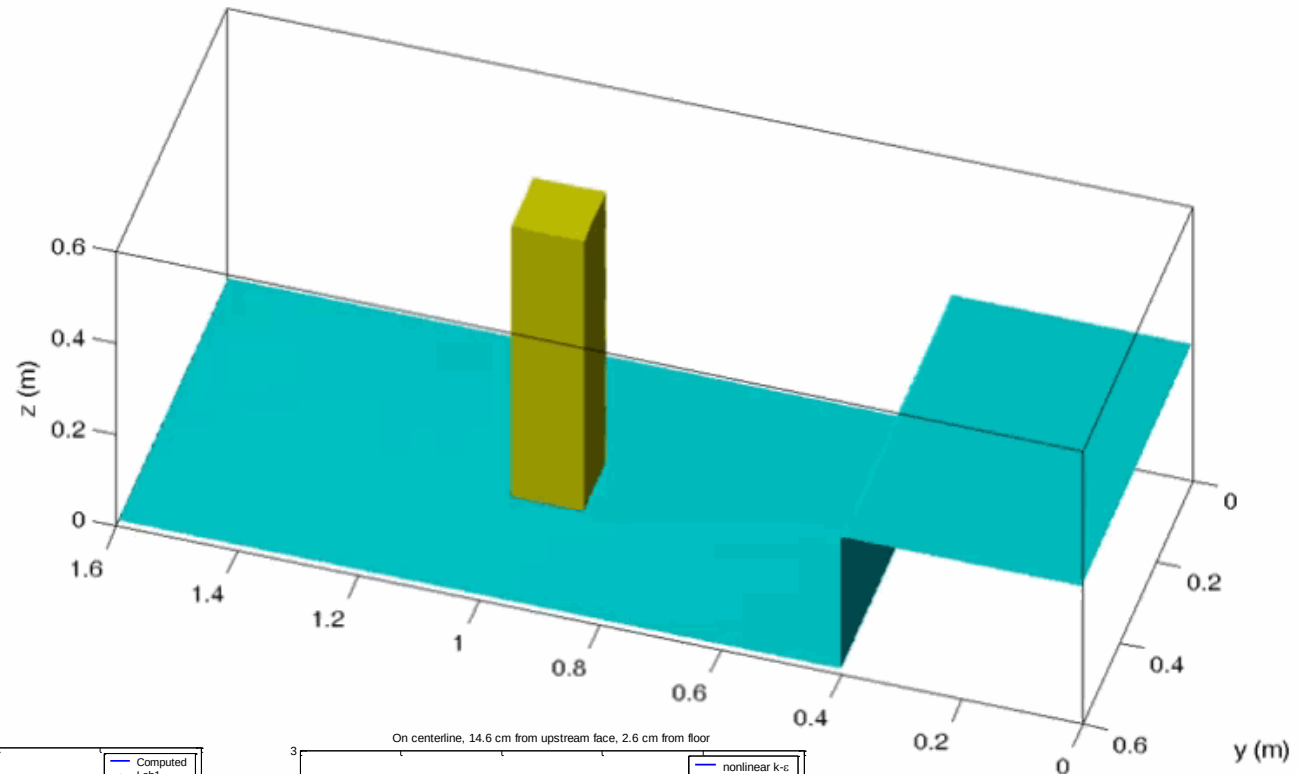


(PLIC)

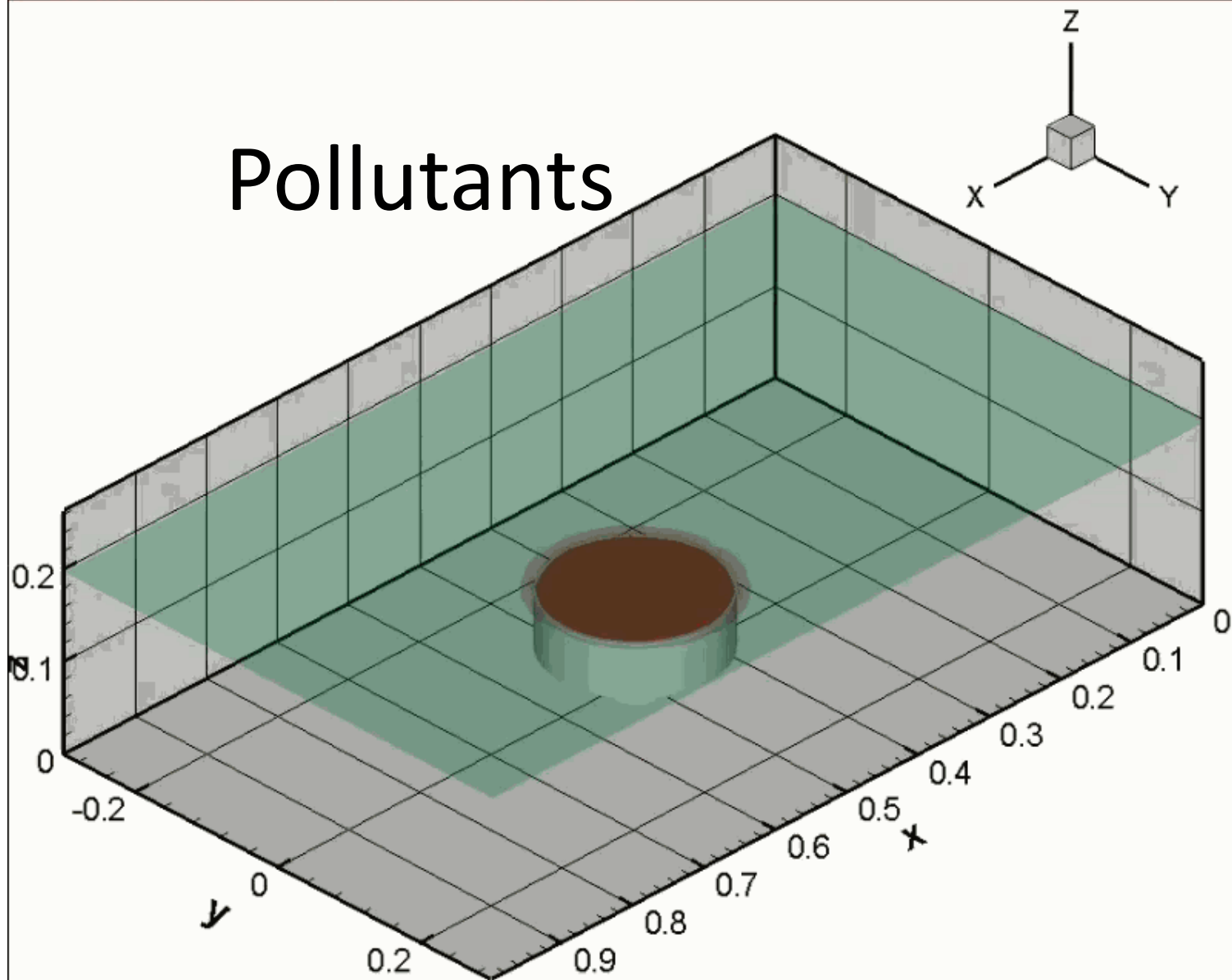
$$\hat{n} = \frac{\nabla f_k}{|\nabla f_k|}$$

Model Validation 1: Dam-break bore impinging a square cylinder

Free surface profile at Time = 0 s

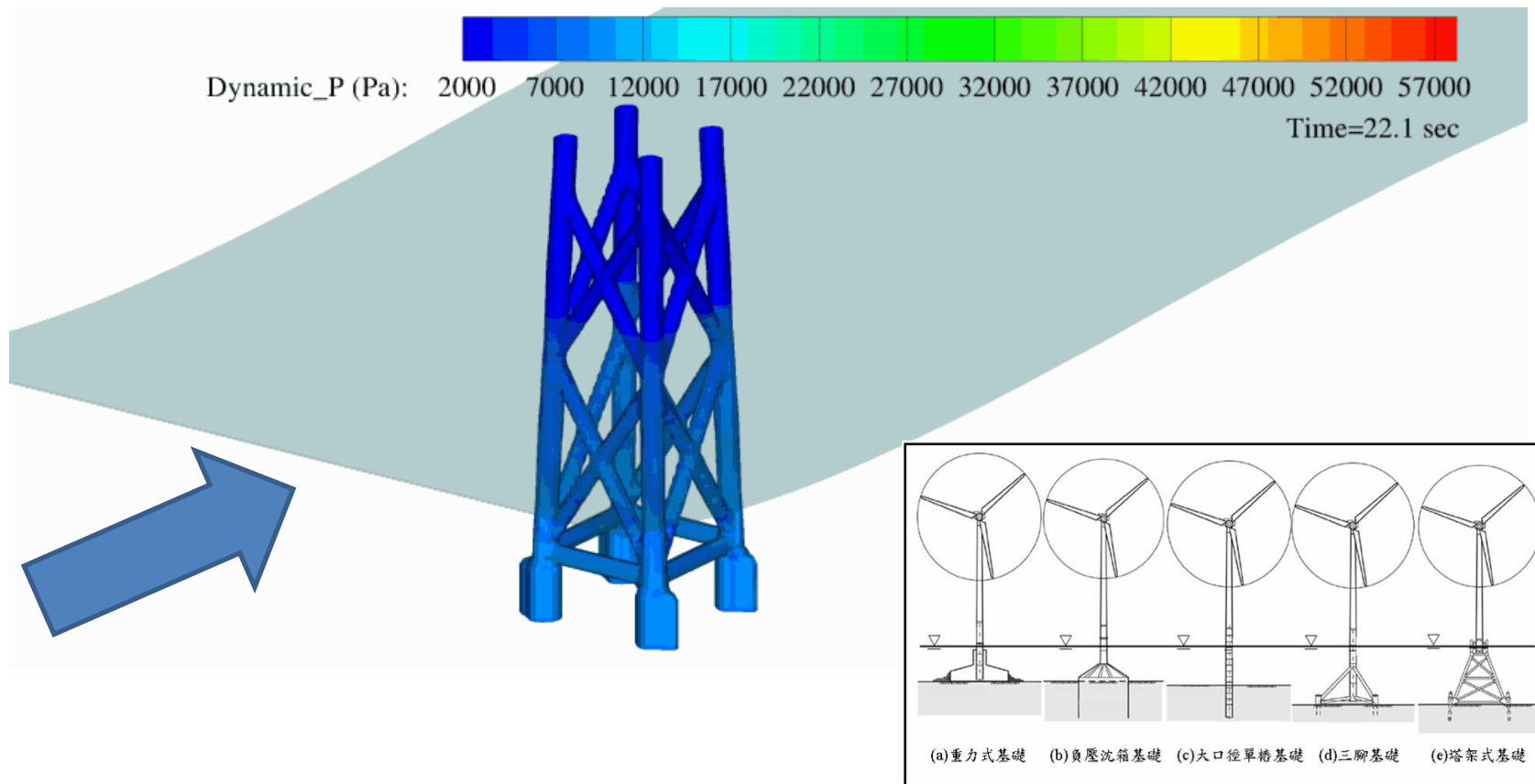


Pollutants

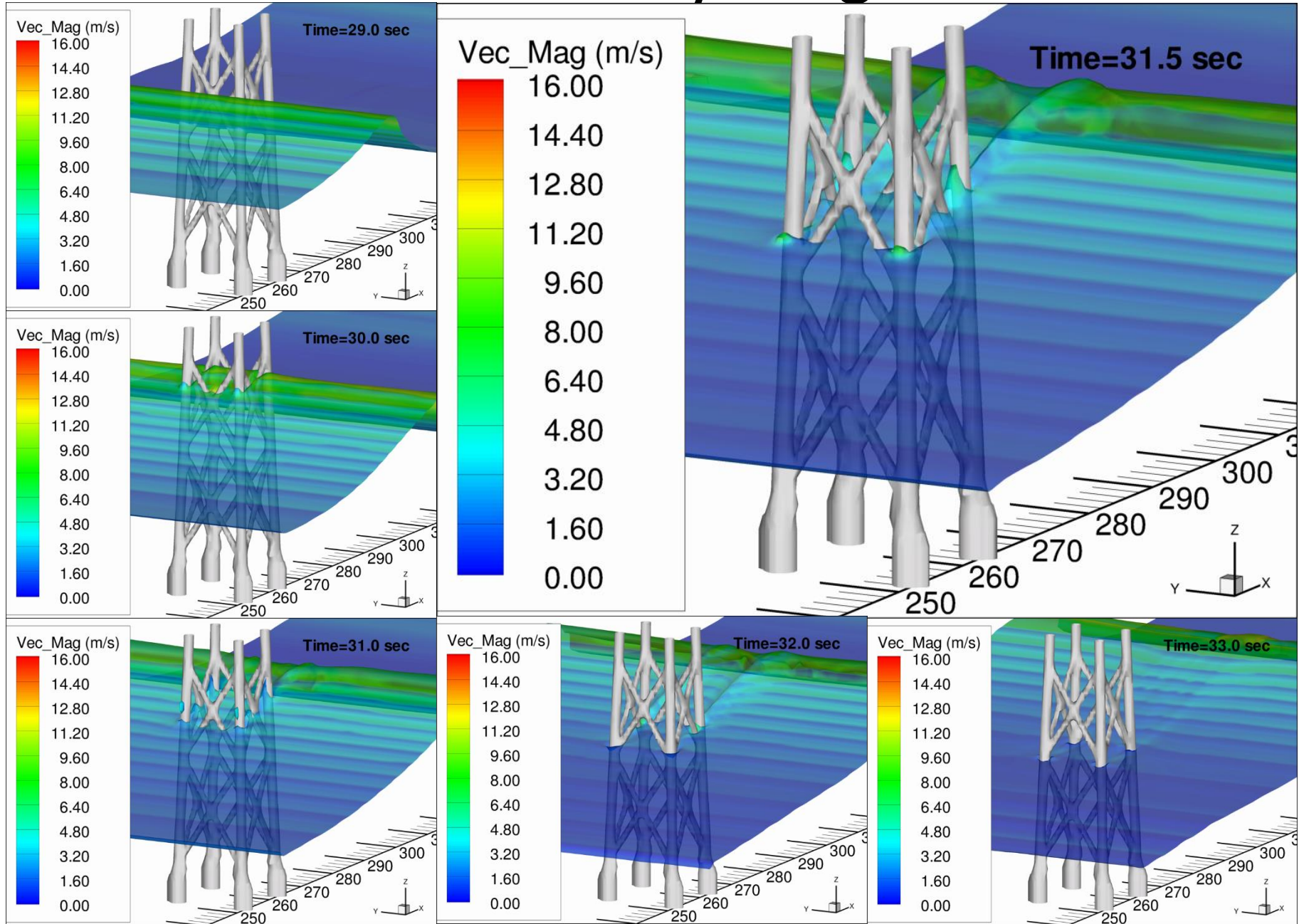


Wave + Current + Truss

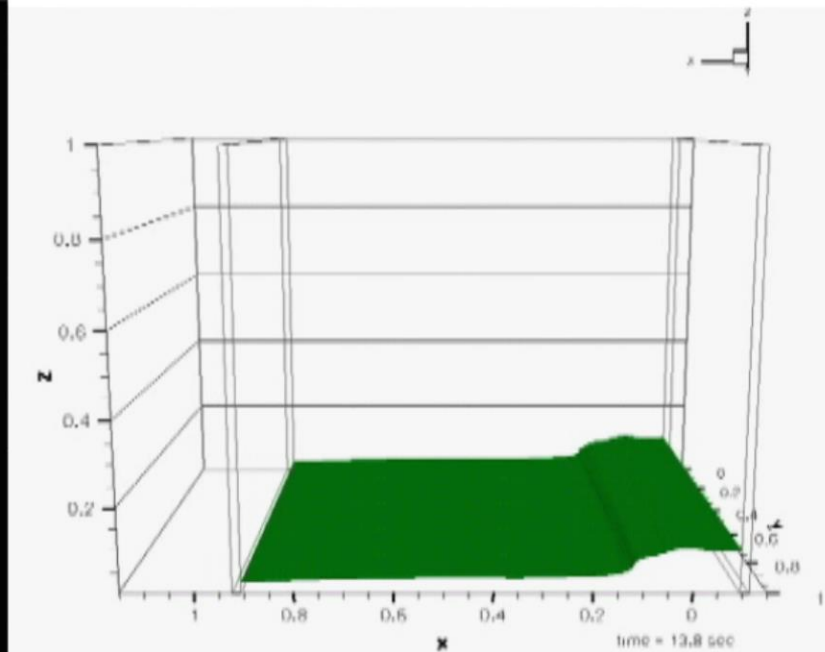
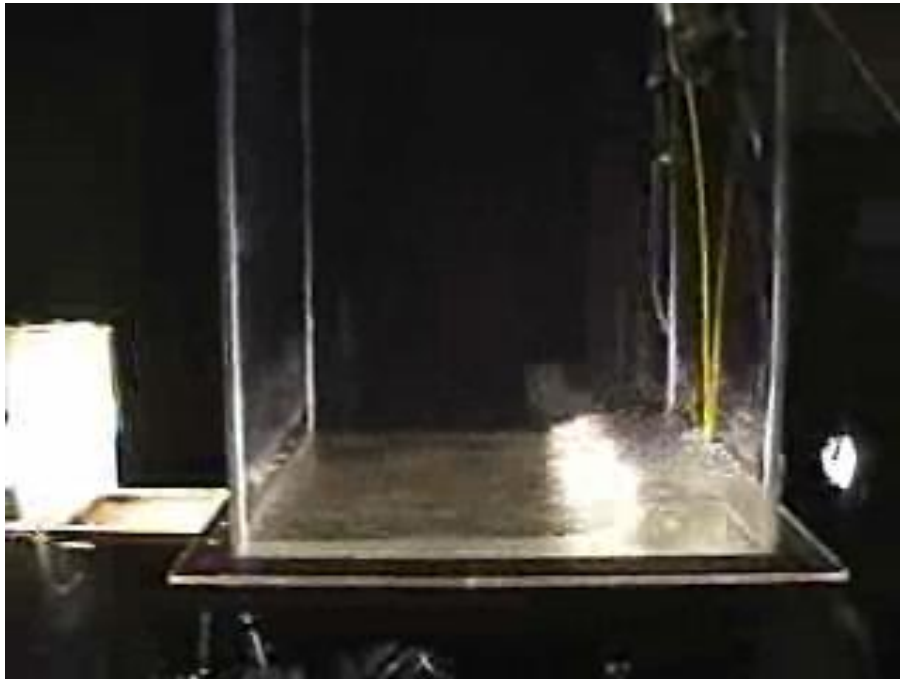
Surface Elevation and Dynamic Pressure



Surface Velocity Magnitude



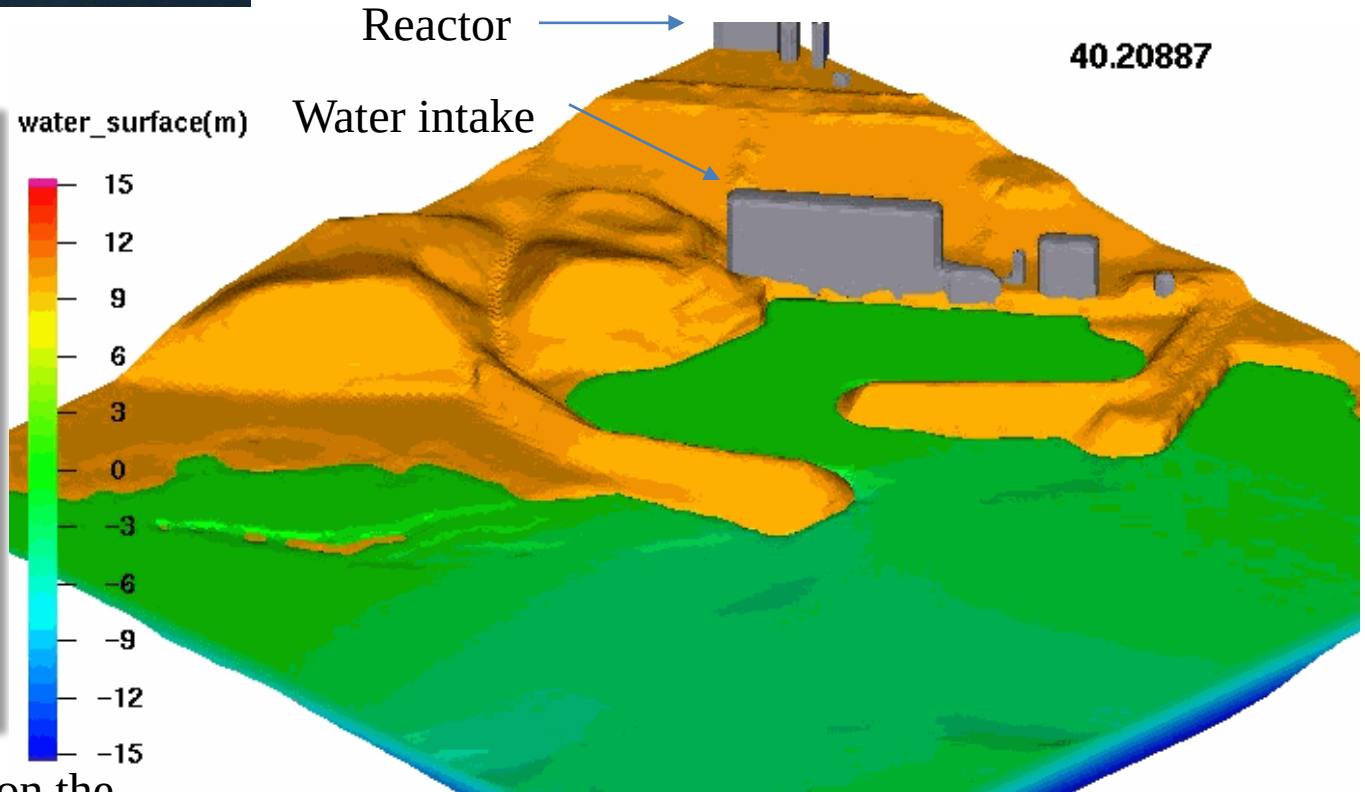
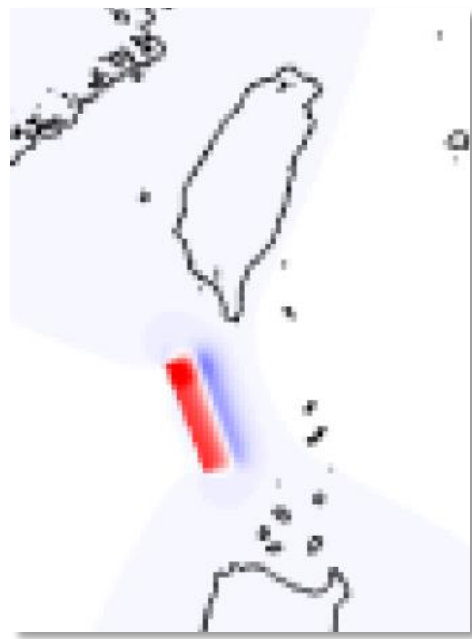
Application: Sloshing Problem





Potential tsunami impact on the Nuclear Power Plant (NPP) No.3 in Taiwan.

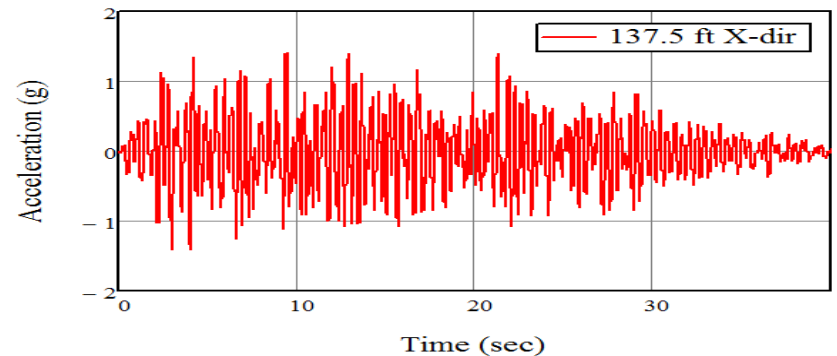
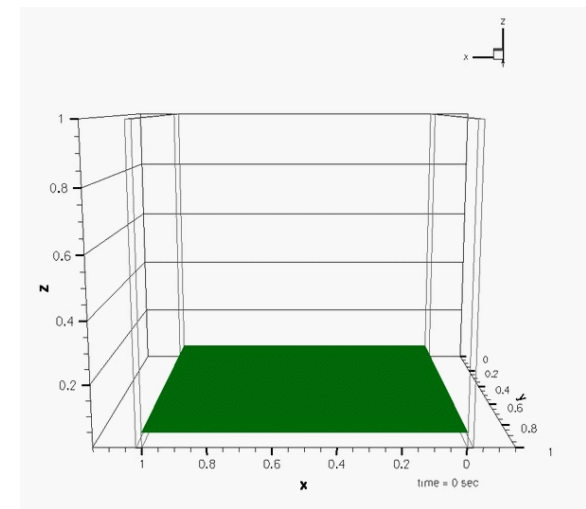
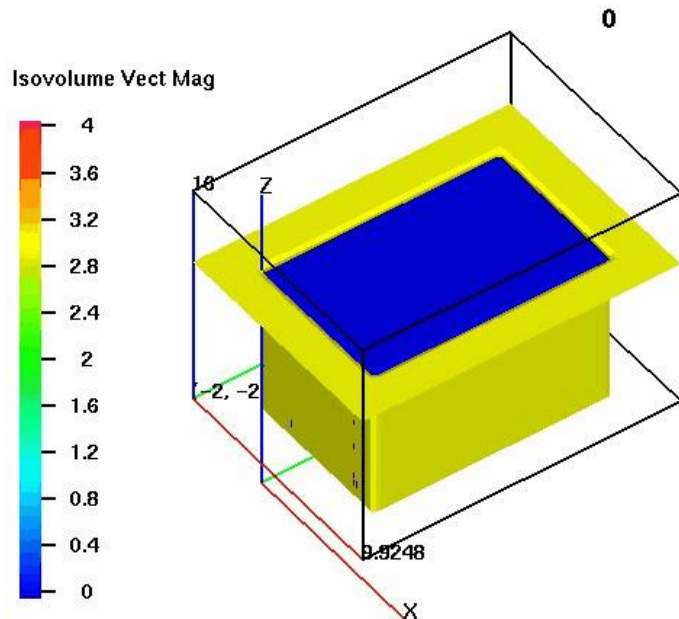
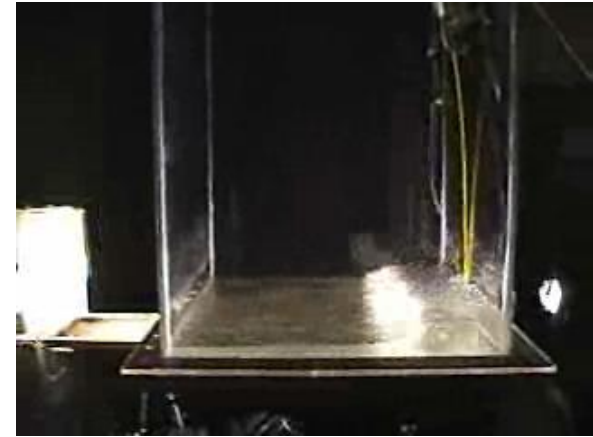
Splash3D Coupled with the result of 2D COMCOT tsunami model

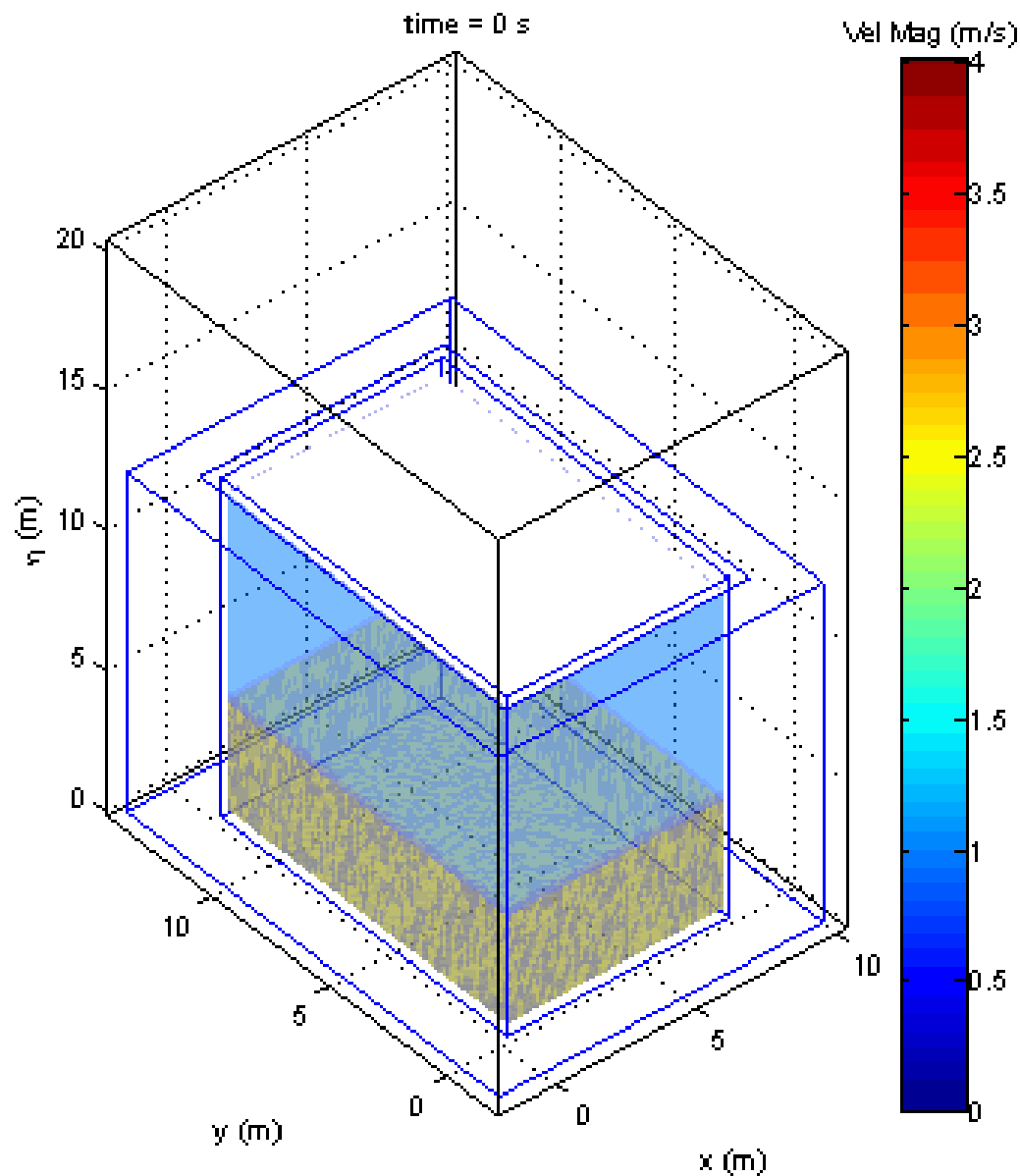
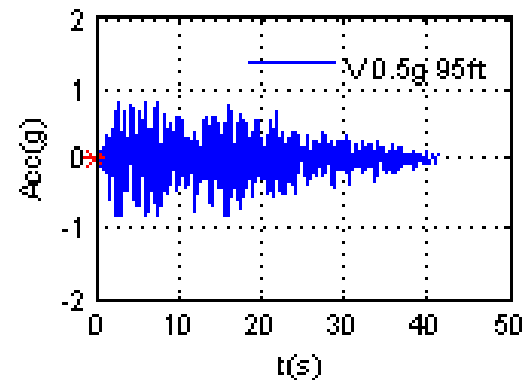
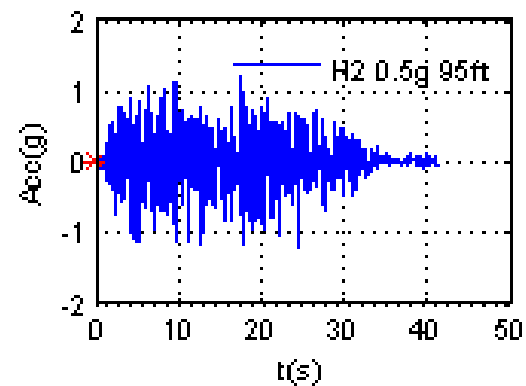
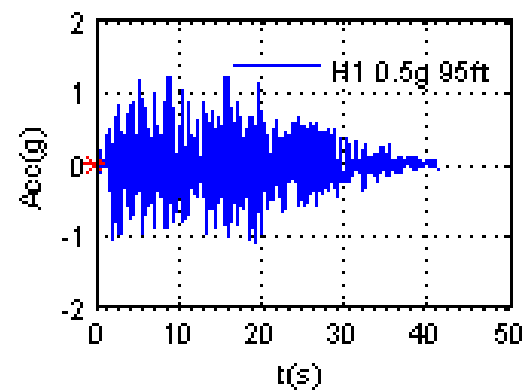


Scenario tsunami source on the northern Manila Trench

Sloshing Problem

2015 Nepal Earthquake, Swimming pool.

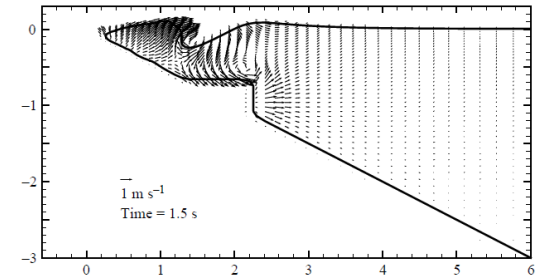




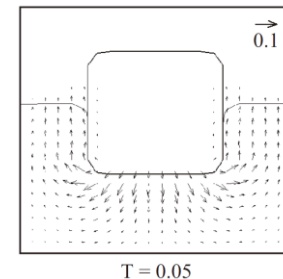
Development of Fluid-Solid Coupling

Literature Review

- **Development of Moving Solid Algorithm**
- The first Version is developed by Wu (2004)
 - Publish in Liu and Wu (2005) ;
 - Girolamo, Wu and Liu et al. (2006)
- The second Version is developed by Chuang (2009)
 - Publish in Wu, Huang and Chuang et al. (2011) ;
 - Wu and Chu et al. (2014)



Liu and Wu (2005)

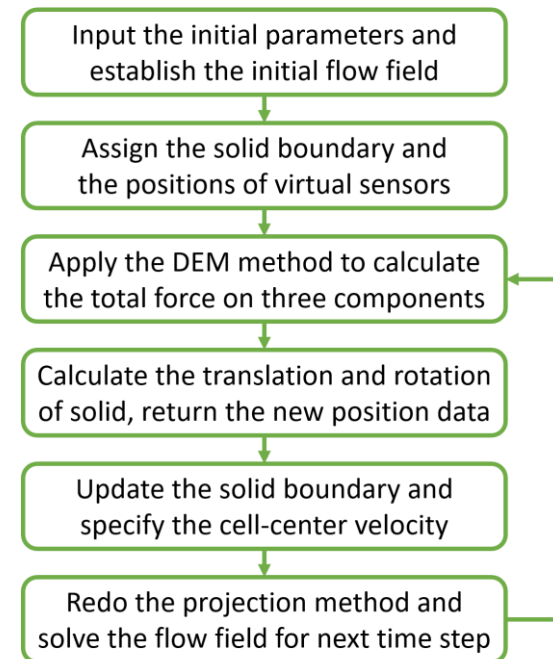
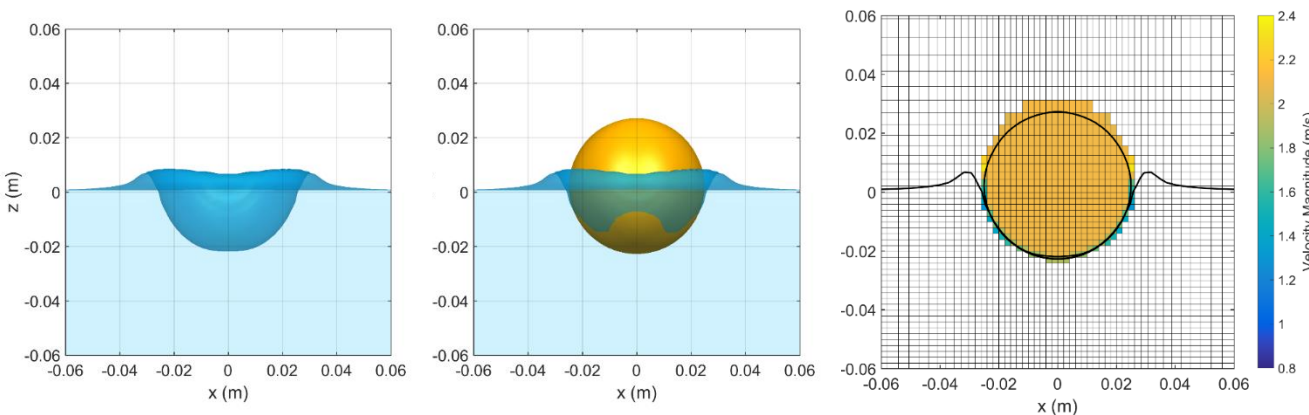


Wu, Huang and Chuang et al. (2011)

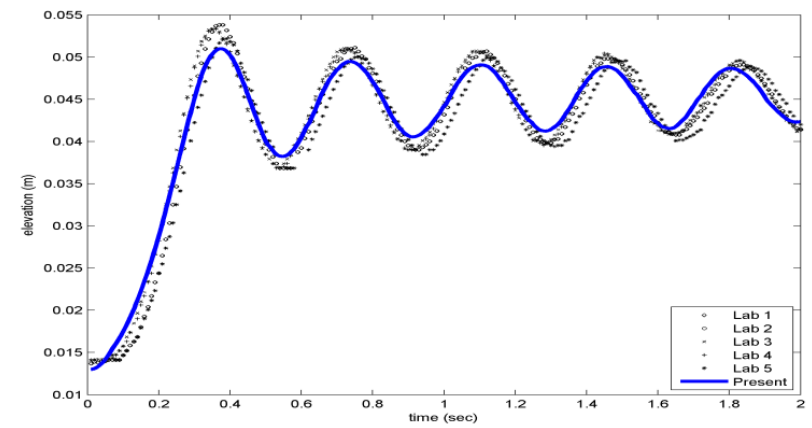
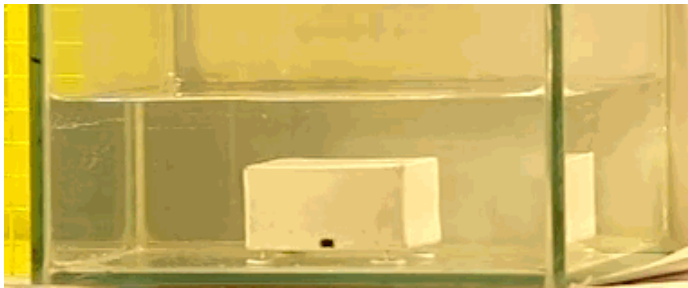
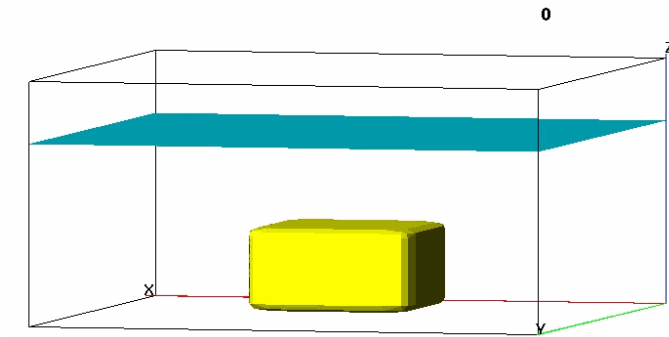
Development of Fluid-Solid Coupling

The Newest Moving Solid Algorithm

- The third version is named **Rigid-Water Method (RFM)**



Simulation on a Floating Obstacle



(莊美惠製)

- 渠槽大小：15 × 14 cm、30 × 30 cm
- 網格大小：0.33 × 0.33 × 0.25 cm
- 楔形體：4.8 × 4.9 × 2.4 cm
- 變動條件：渠槽大小

Example 1

- Parameters

- $L1=L3=0.01\text{m}$

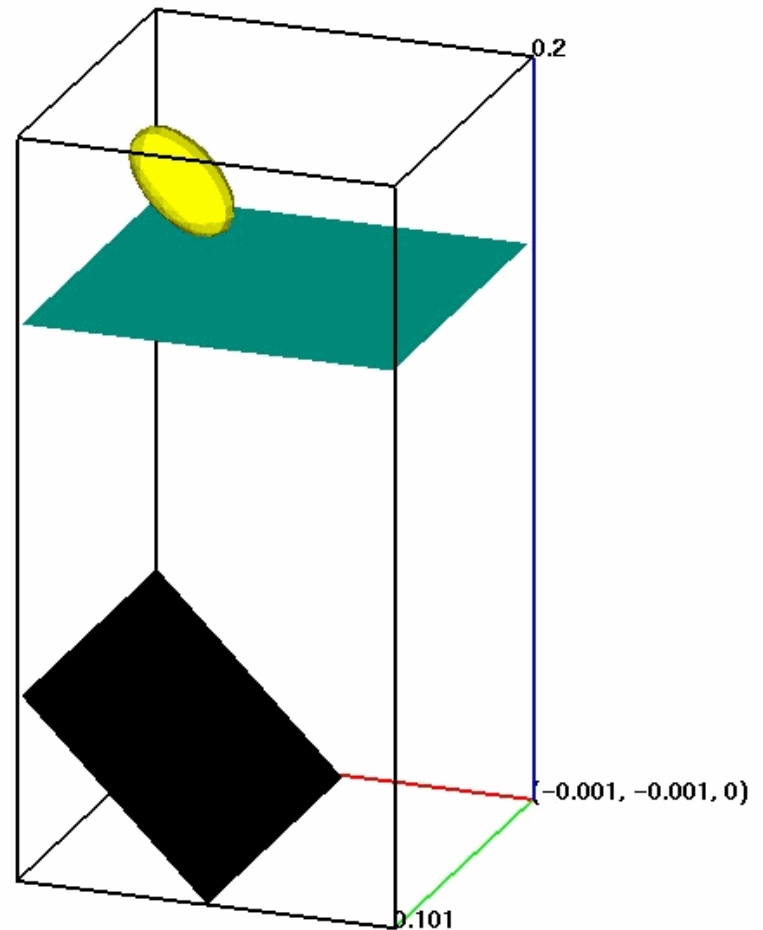
- $R1=R3=0.0075\text{m}$

- $\text{Beta}=60^\circ$

- $\text{Density}=1300\text{kg/m}^3$

- $\text{Flud Grid}=30\times30\times60$

- Normal vector of plane= $(0.707,0,0.707)$



Example 2

- Parameters

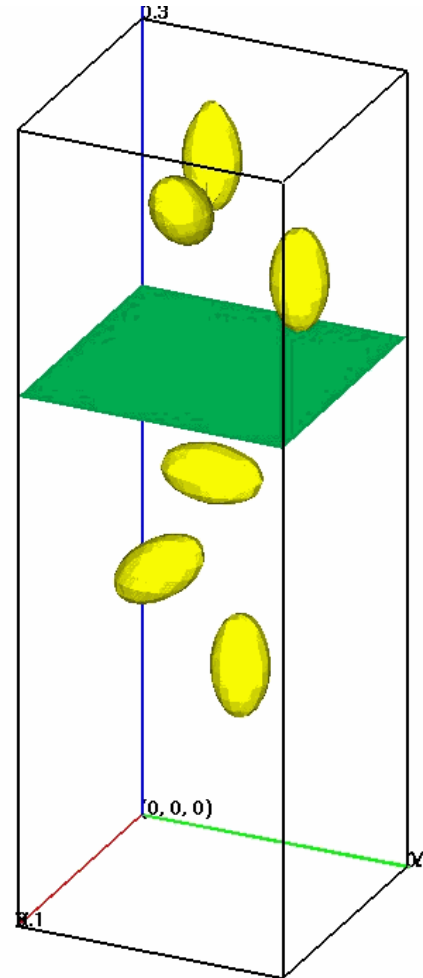
- $L1=L3=0.0125\text{m}$

- $R1=R3=0.0075\text{m}$

- $\text{Beta}=60^\circ$

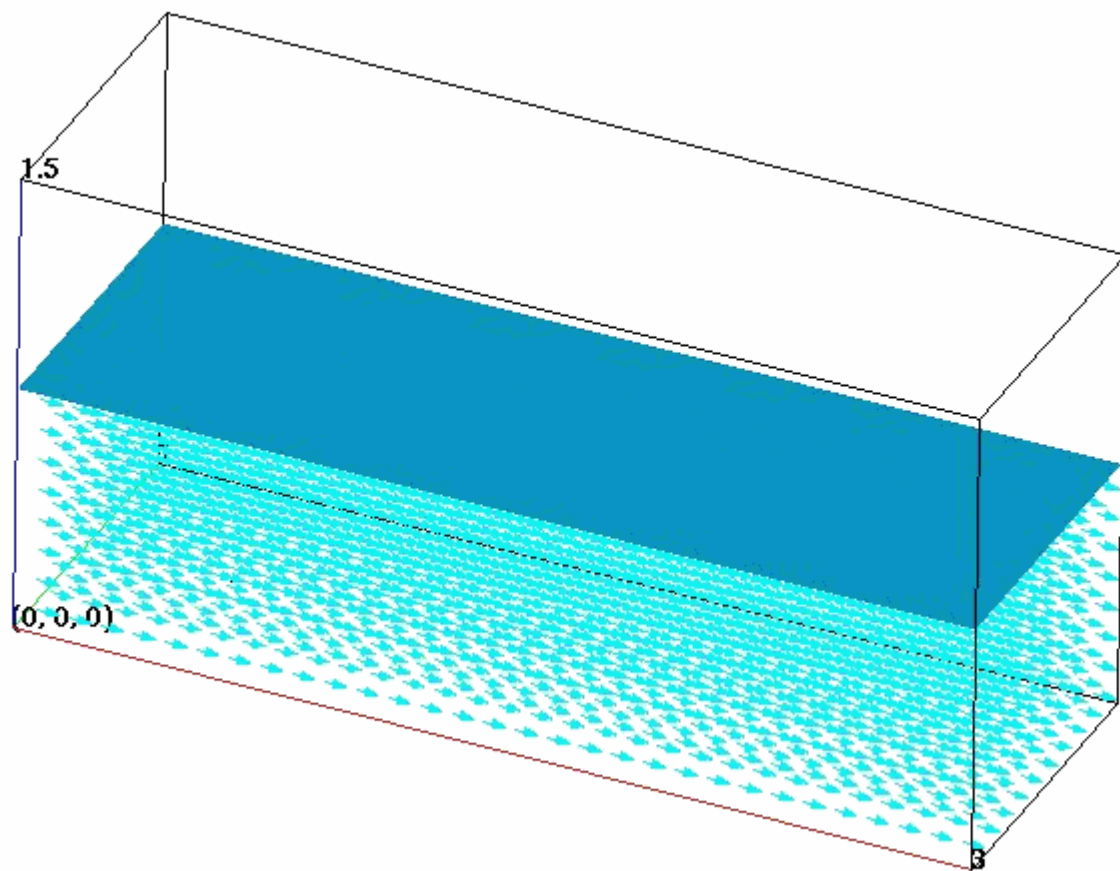
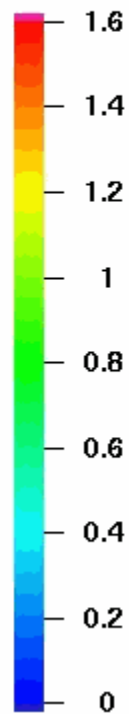
- $\text{Density1}=1300\text{kg/m}^3$

- $\text{Flud Grid}=30\times30\times60$

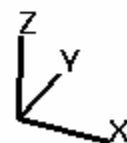


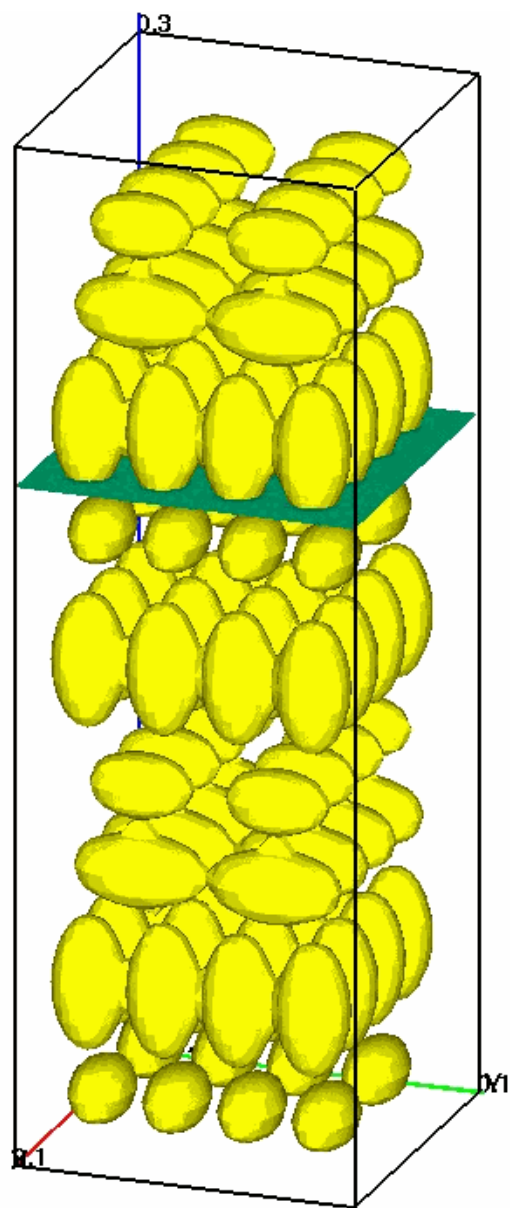
0.0129159

Cells Vect Mag



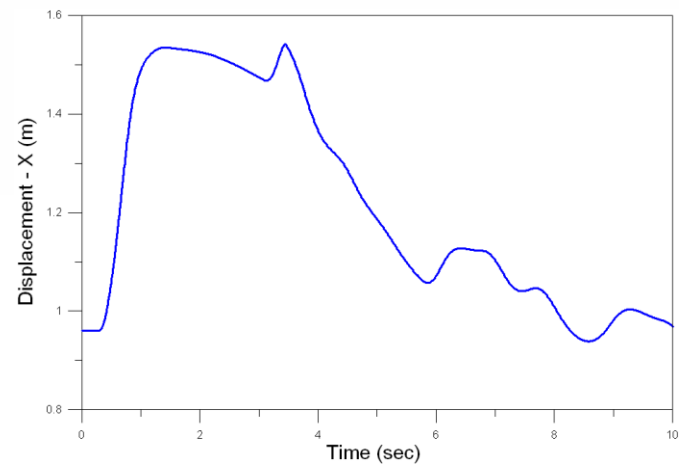
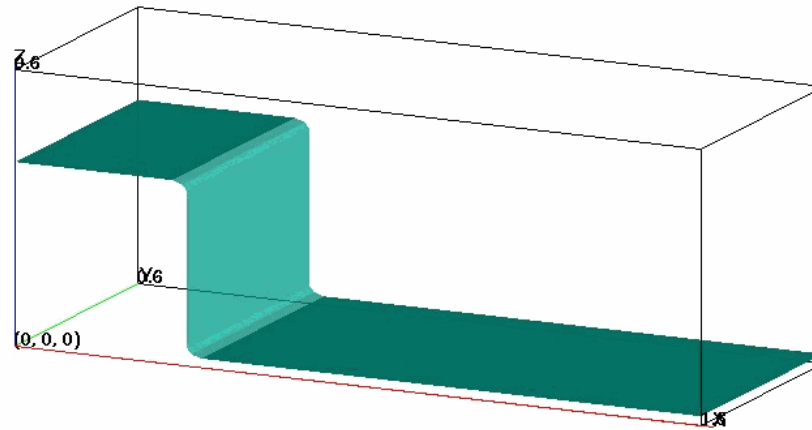
0





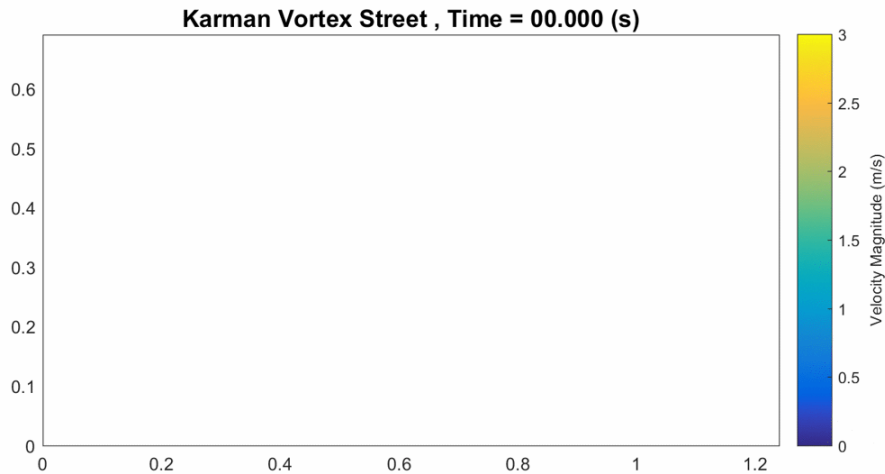
0.0129159

0

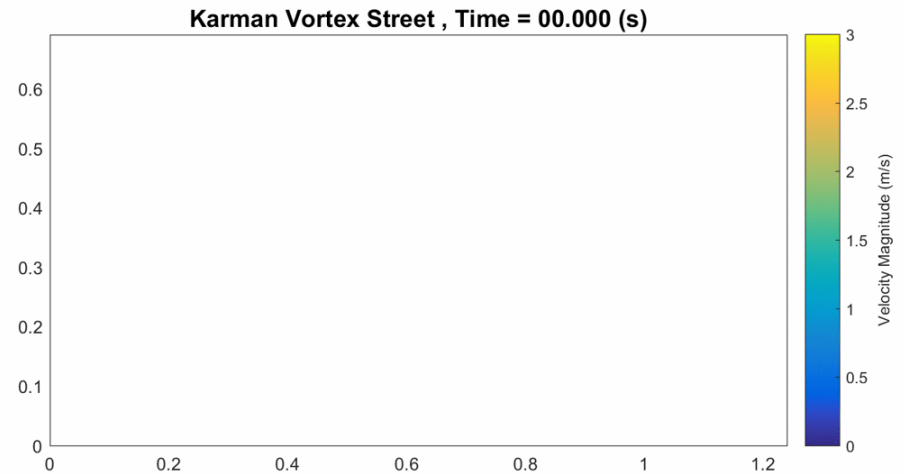


Model Validation

Karman Vortex Street



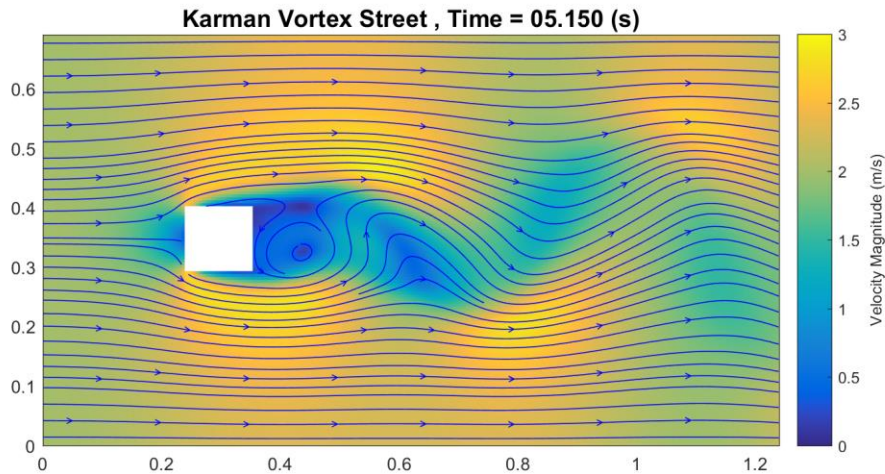
Rigid-Water Method



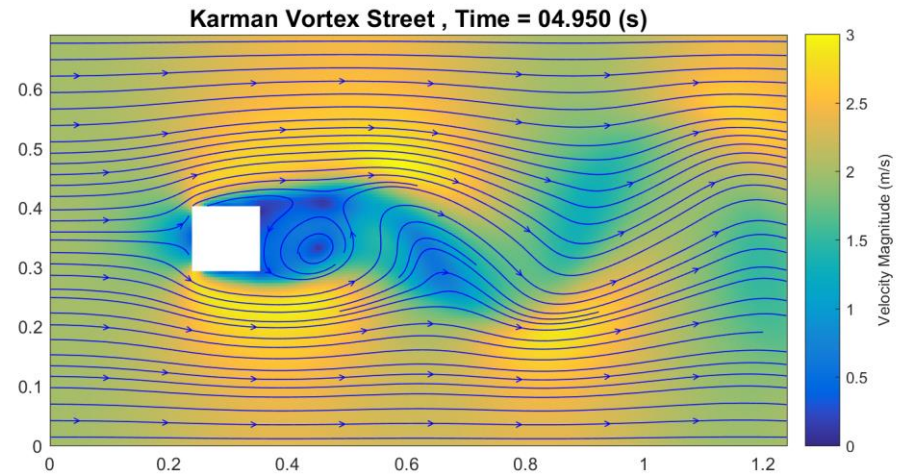
Partial Cell Treatment

Model Validation

Karman Vortex Street



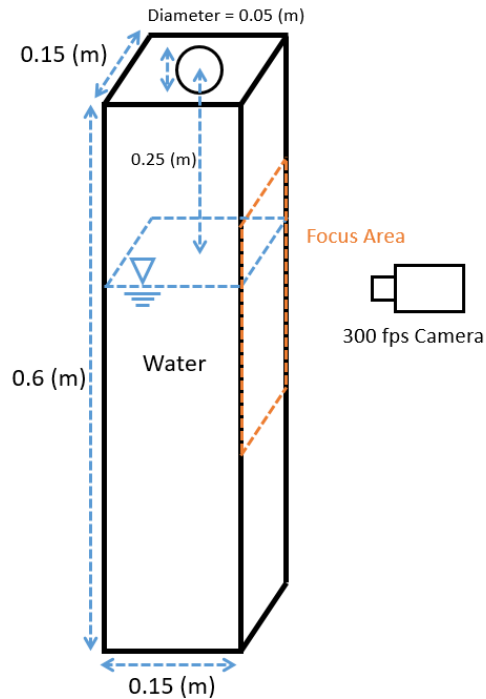
Rigid-Water Method



Partial Cell Treatment

Model Validation

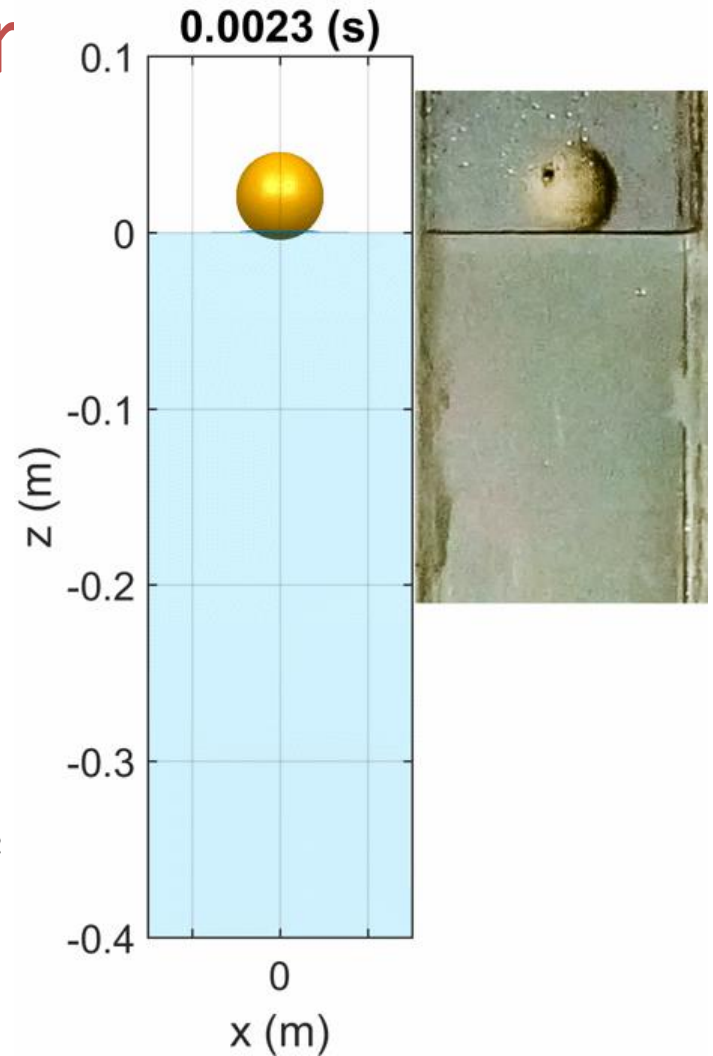
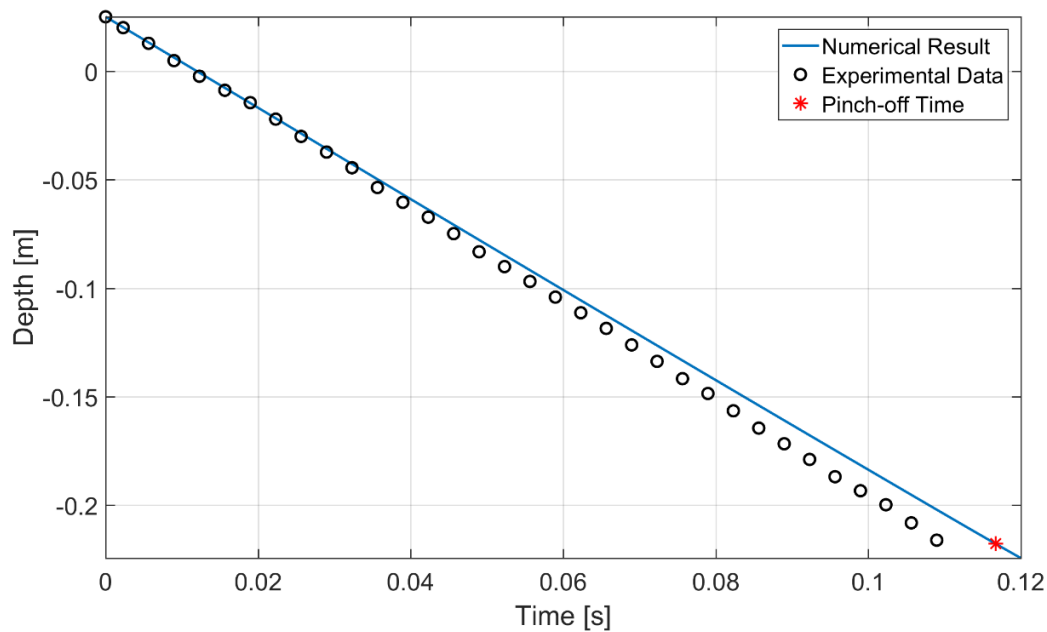
Water Entry Problem



網格數	55 × 55 × 160格	水之密度	998.0 (kg/m ³)
總網格數	484000格	水之黏滯係數	1.0e-3 (Pa·s)
最細解析度	0.002 (m)	空氣之密度	1.2 (kg/m ³)
Courant Number	0.5	空氣之黏滯係數	1.8e-5 (Pa·s)
輸出時間步長	1/900 (s)	球體密度	3946.0 (kg/m ³)
模擬時長	0.2 (s)	上邊界條件	壓力定值=0.0 (Pa)
球體直徑網格數	25格	其餘邊界條件	Free-Slip

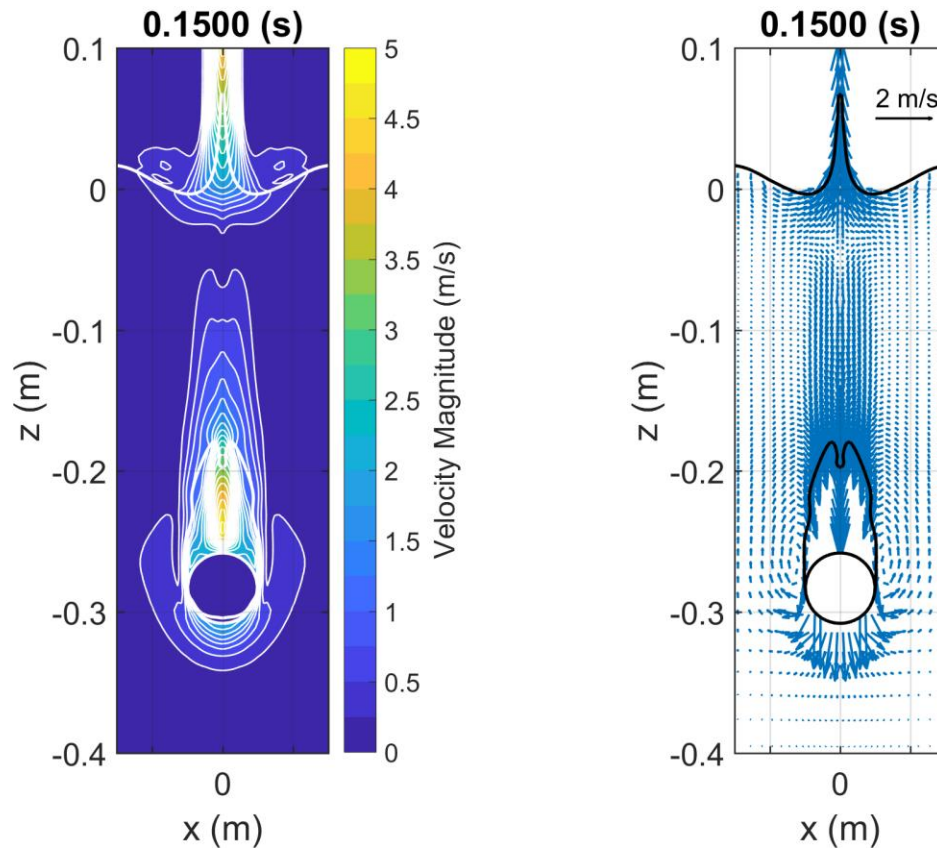
Model Validation

Water Entry Pressure



Model Validation

Water Entry Problem

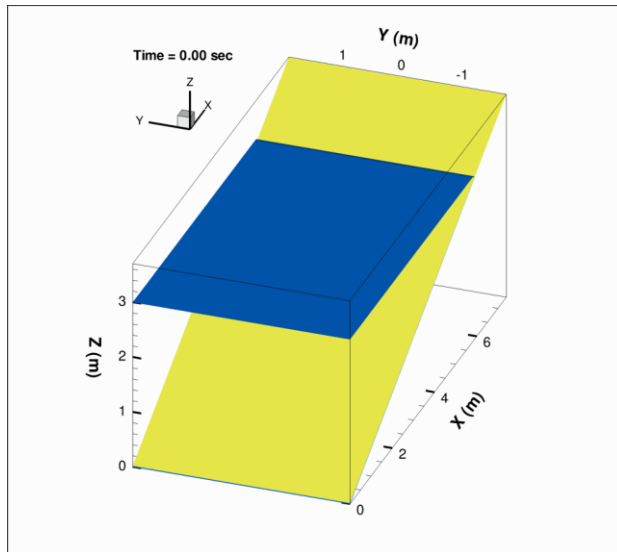


Hemisphere Landslide Tsunami

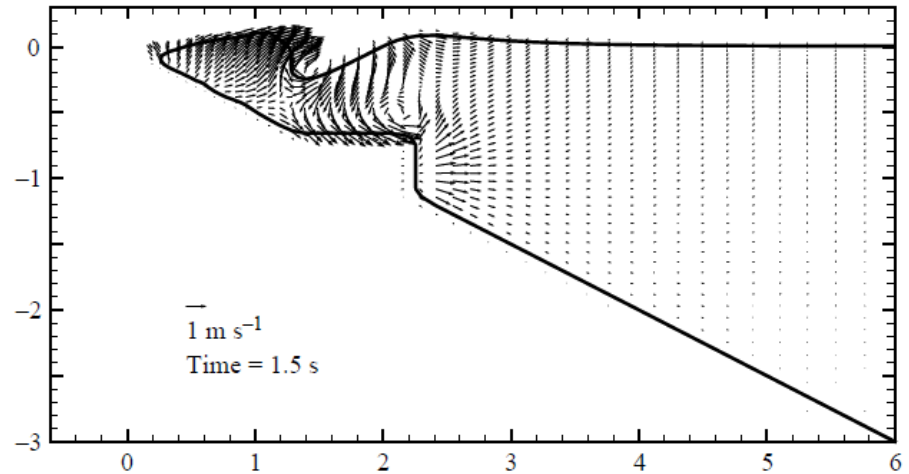
Literature Review

- 山崩海嘯實驗：Liu and Wu (2005)

Lee (2015)



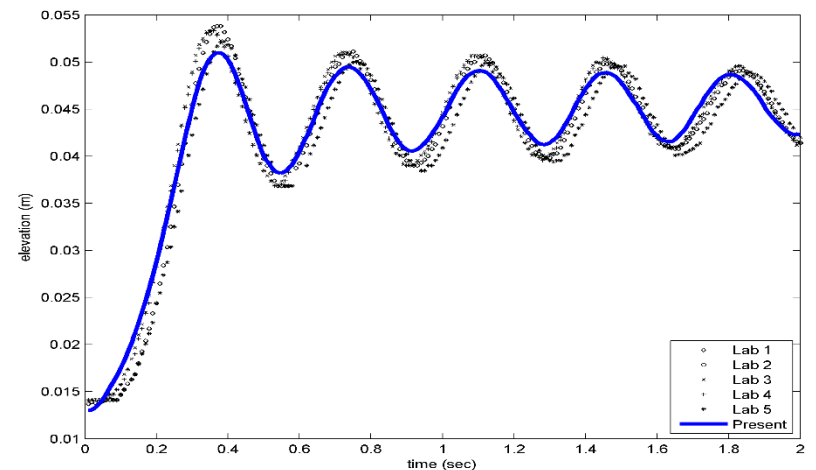
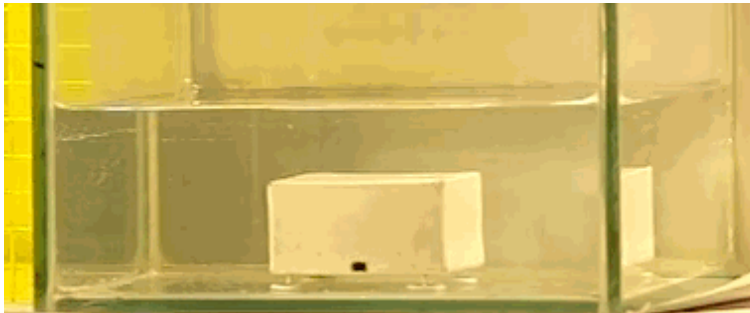
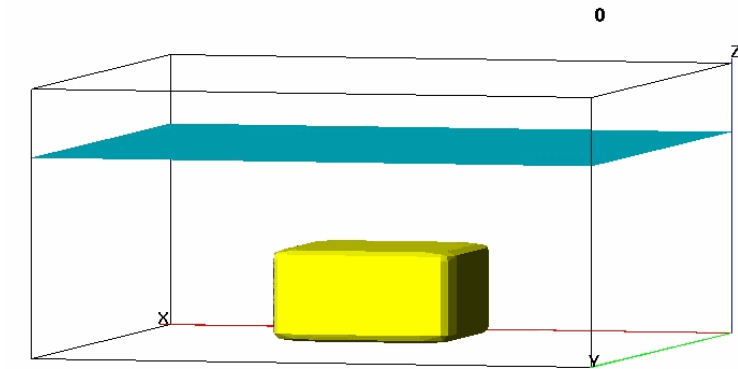
Liu and Wu (2005) --> One Way Coupling
Chuang (2009) --> Two Way Coupling



- Watts et al. (2003) 將山崩海嘯分類為塊體崩落 (Slides) 與泥沙崩塌 (Slumps)，本文之重點為模擬塊體崩落型山崩海嘯。
- 山崩海嘯之研究常用Watts et al. (2005) 之經驗公式求解，但參數有適用範圍之限制。

Model Validation

Simulation on a Floating Obstacle



(莊美惠製)

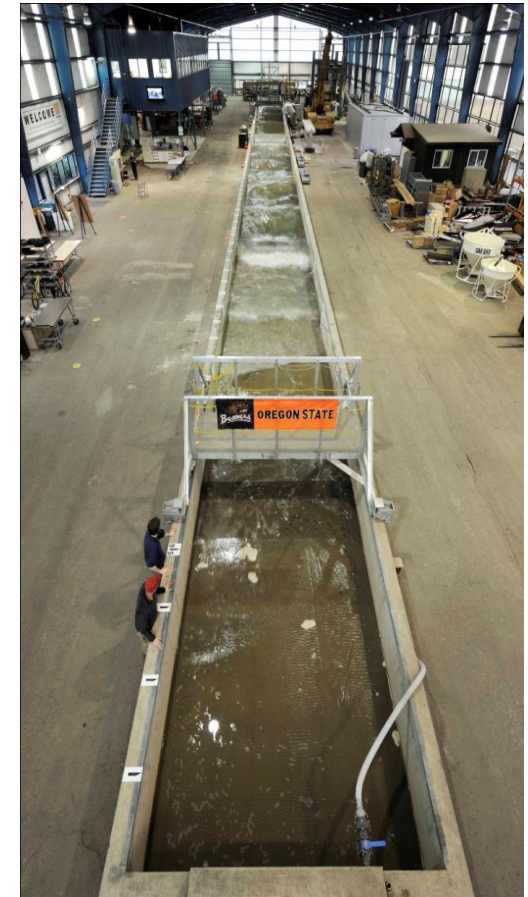
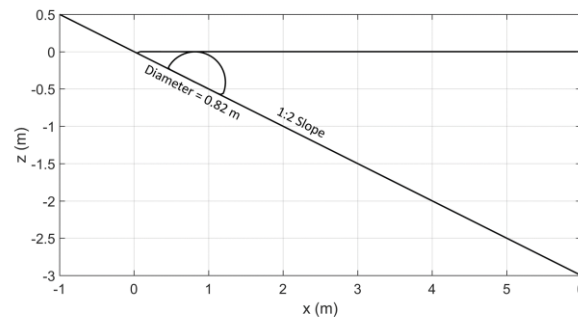
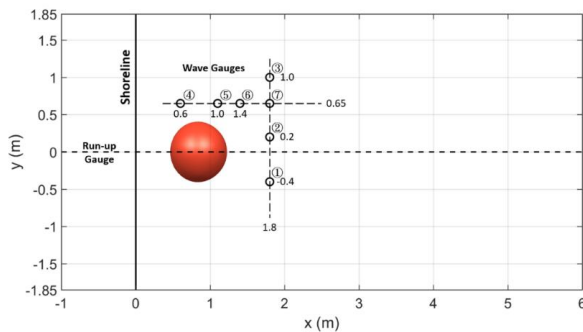
Water Tank : 15×14 cm 、 30×30 cm

Cell Size : $0.33 \times 0.33 \times 0.25$ cm

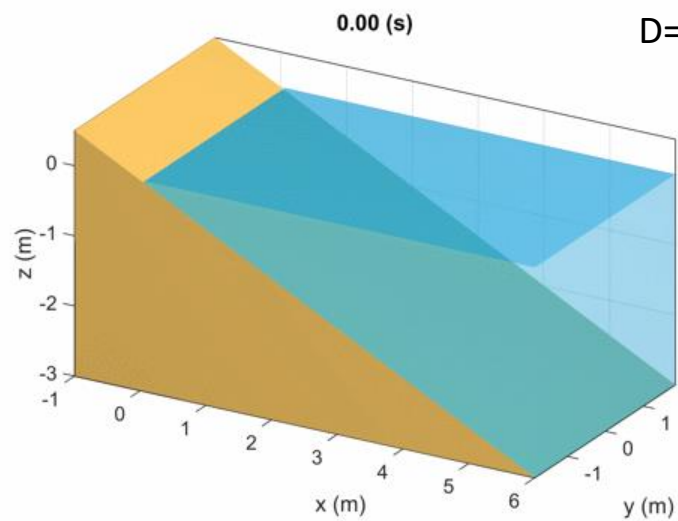
Wedge body : $4.8 \times 4.9 \times 2.4$ cm

Hemisphere Landslide Tsunami

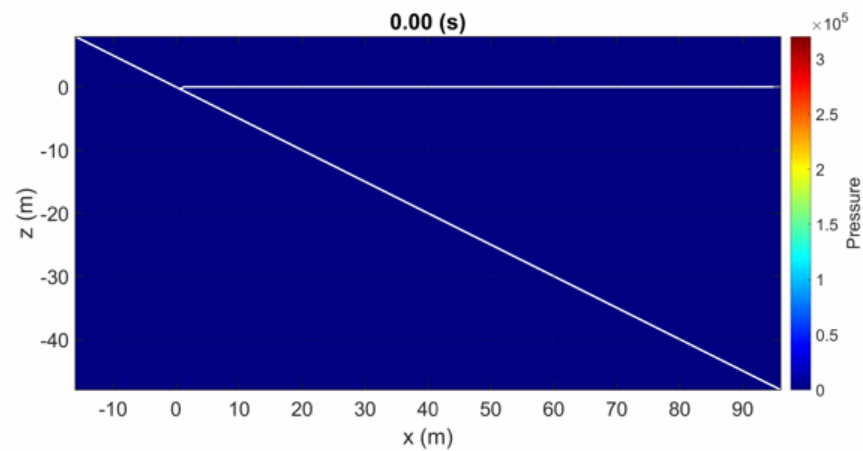
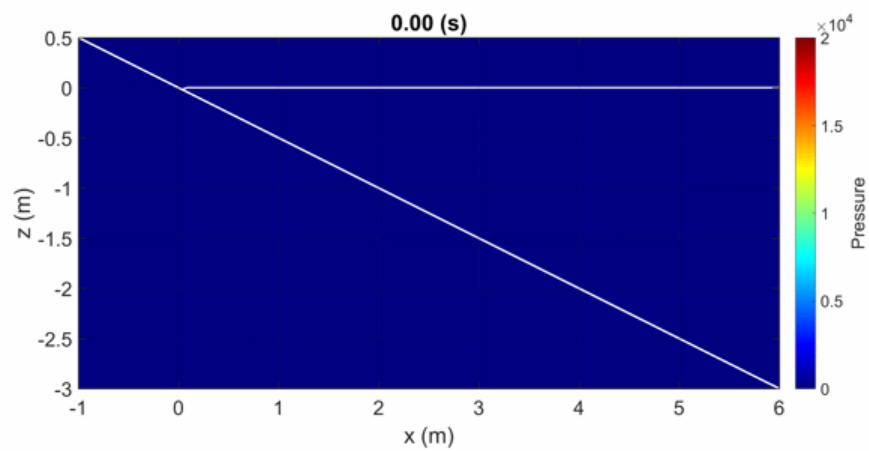
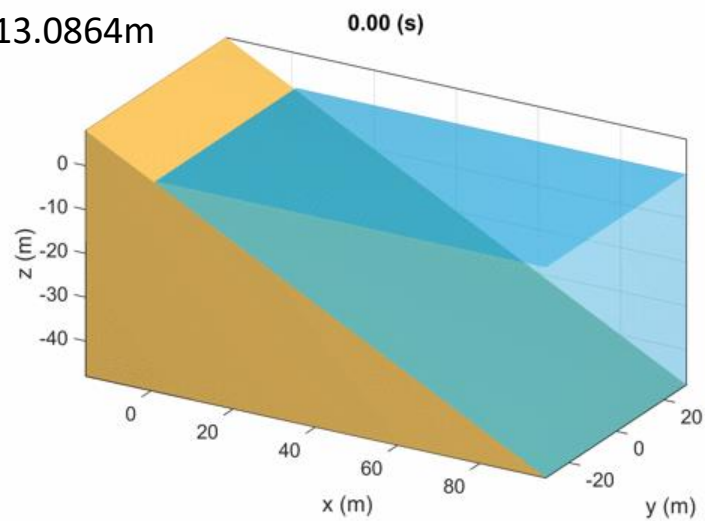
Numerical and Experimental Setup



網格數	120 × 80 × 120格	水之密度	1000.0 (kg/m ³)
總網格數	1152000格	水之黏滯係數	1.0e-3 (Pa·s)
最細x, y解析度	0.04 (m)	空氣之密度	1.2 (kg/m ³)
最細z解析度	0.02 (m)	空氣之黏滯係數	1.8e-5 (Pa·s)
Courant Number	0.5	球體密度	4447.6 (kg/m ³)
輸出時間步長	0.02 (s)	上邊界條件	壓力定值=0.0 (Pa)
模擬時長	4.0 (s)	其餘邊界條件	Free-Slip
圓球直徑網格數	18格	斜坡摩擦係數	0.1

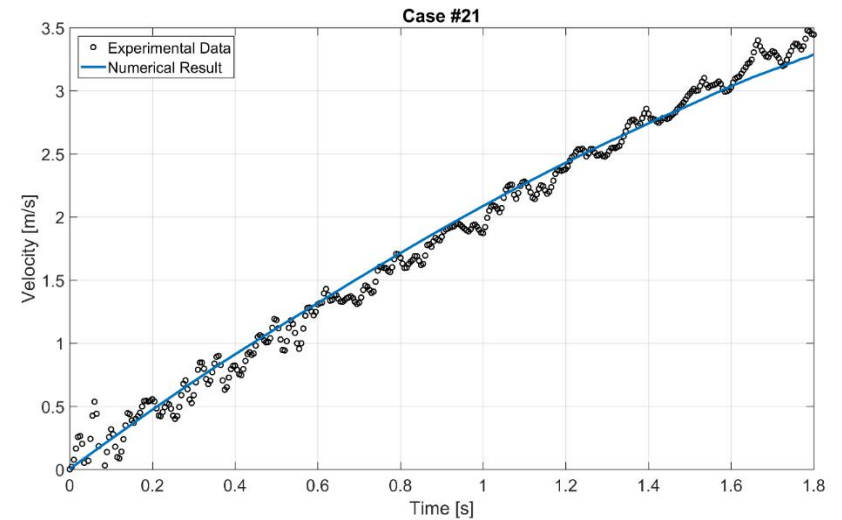
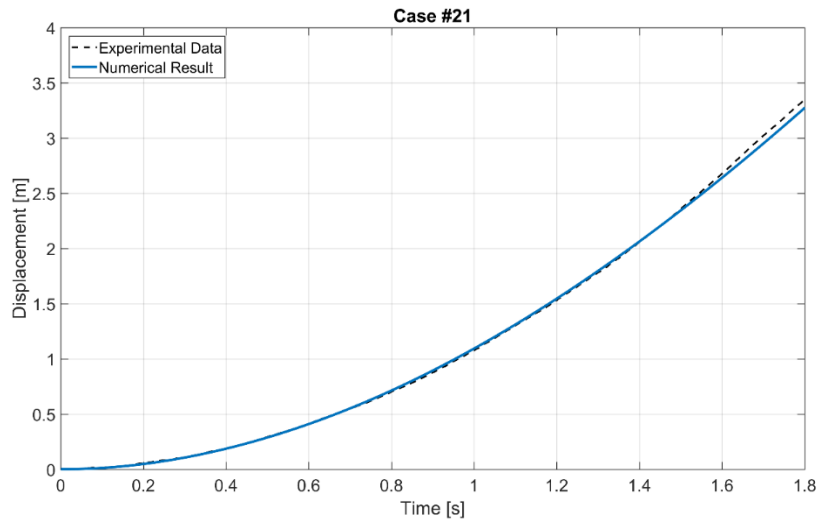


D=0.8179m D=0.130864m



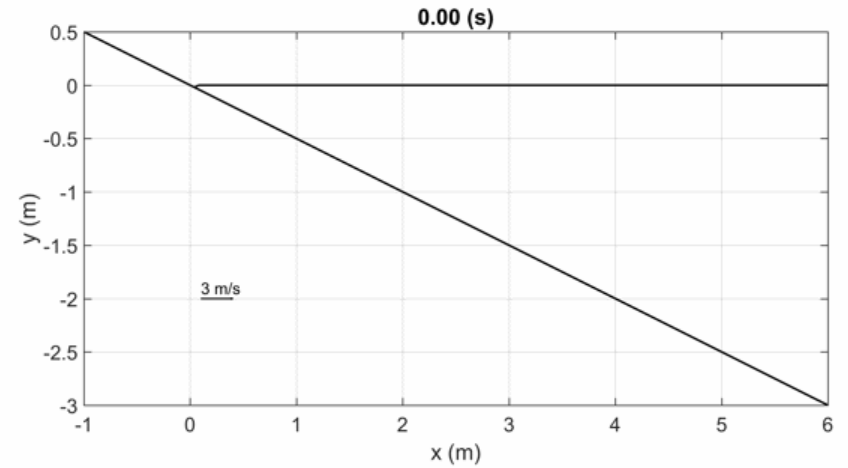
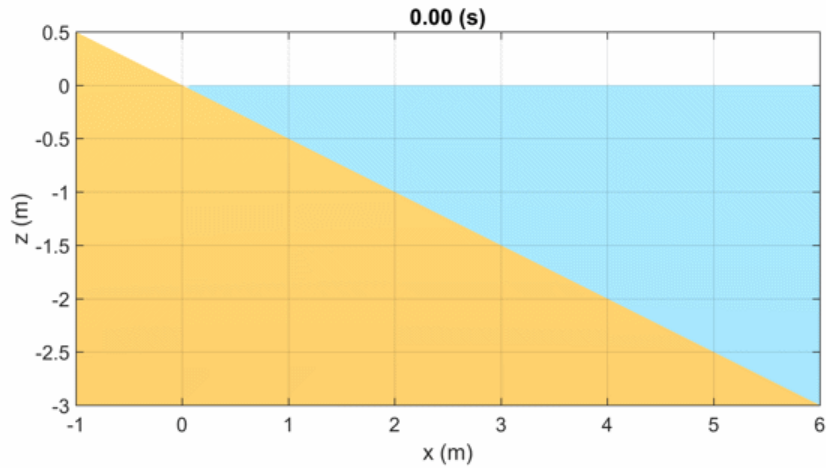
Hemisphere Landslide Tsunami

Discussion



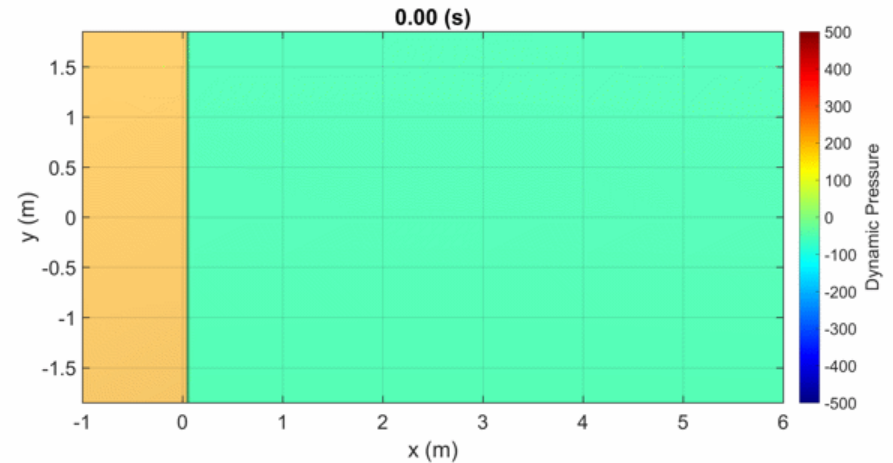
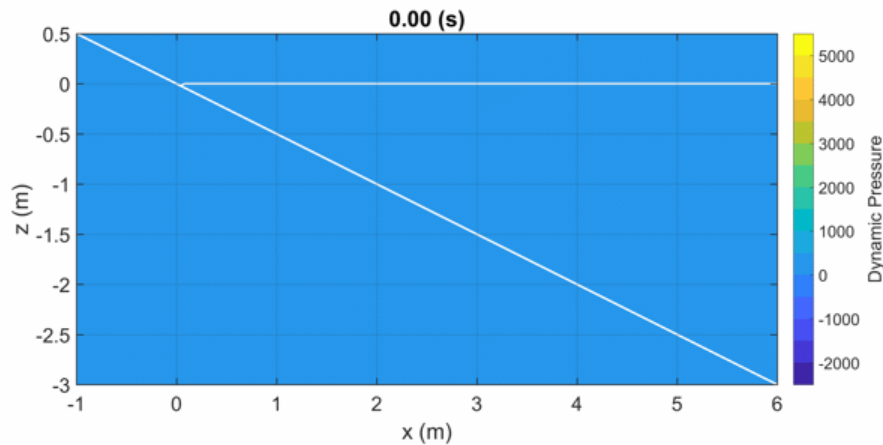
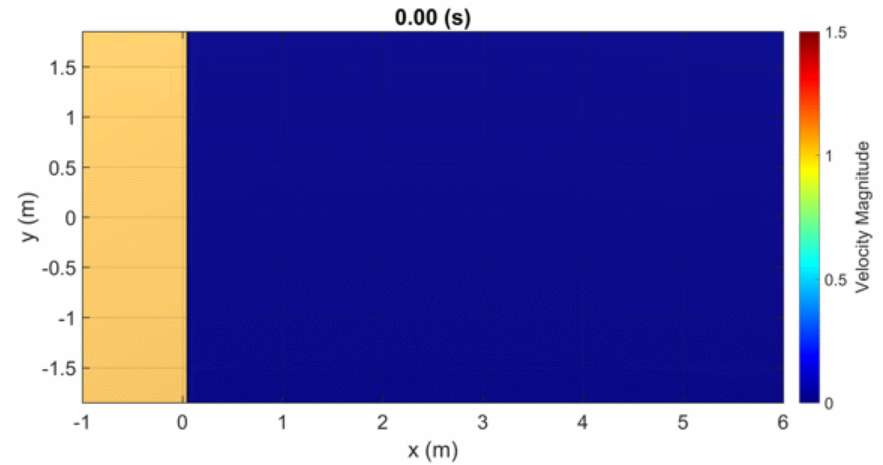
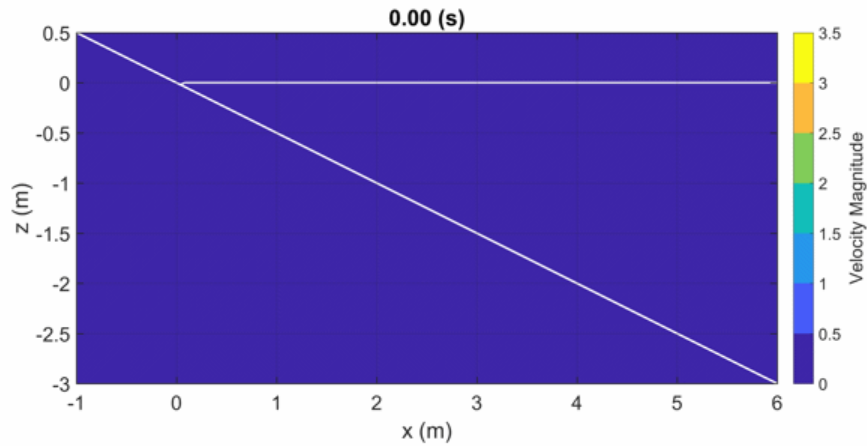
Hemisphere Landslide Tsunami

Discussion



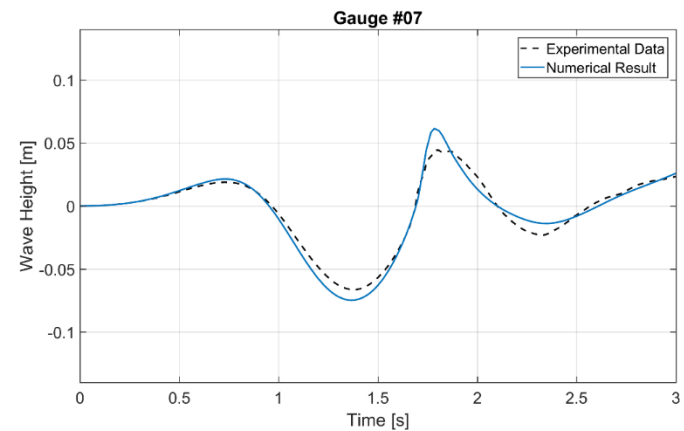
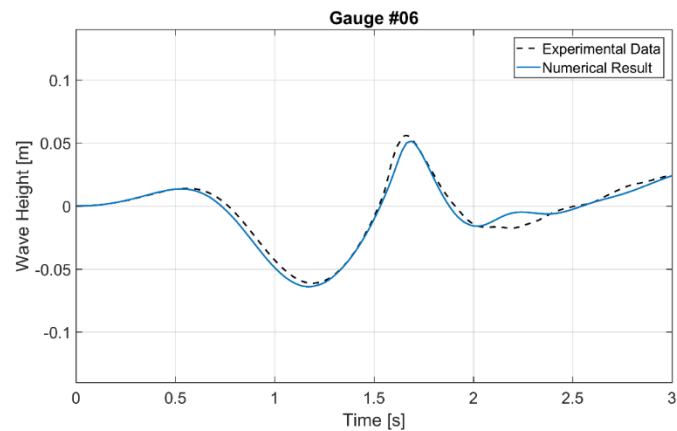
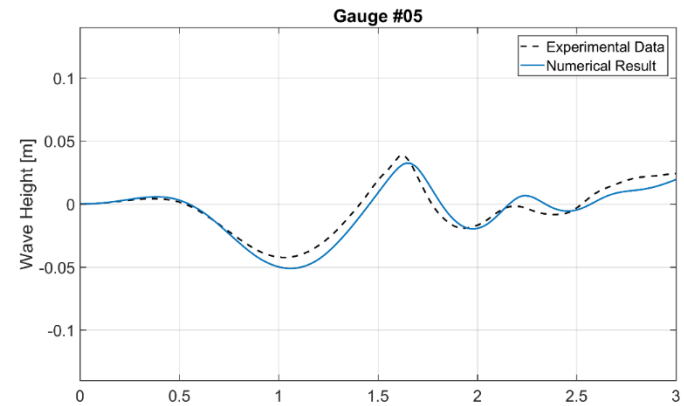
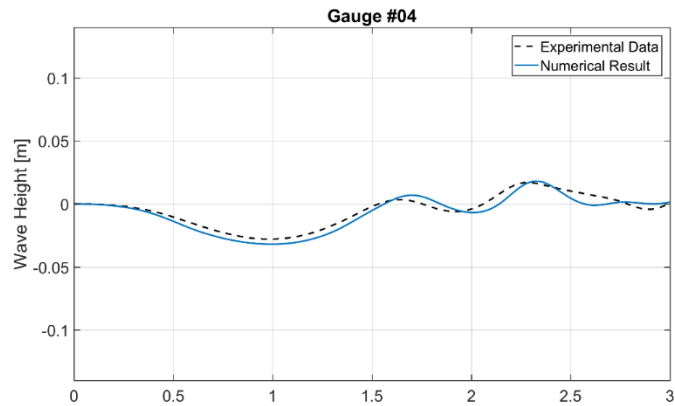
Hemisphere Landslide Tsunami

Discussion



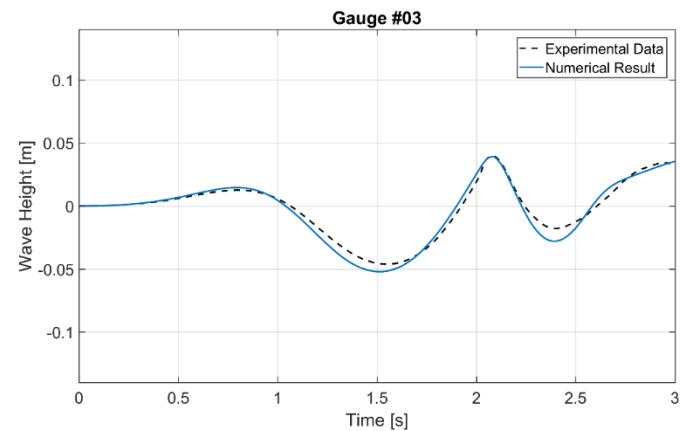
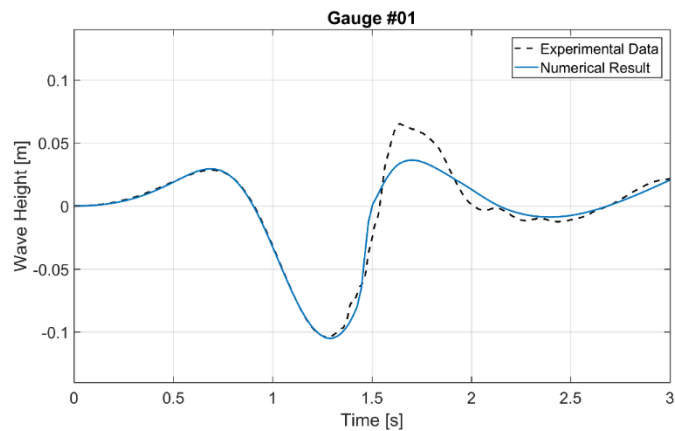
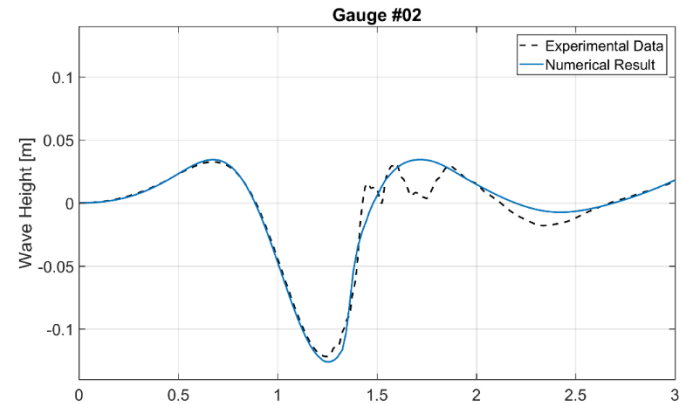
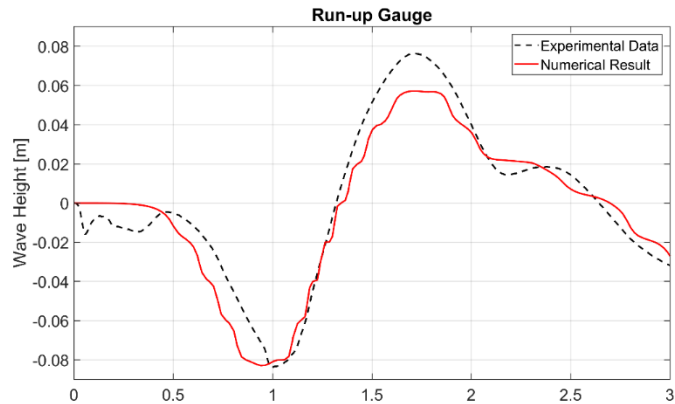
Hemisphere Landslide Tsunami

Discussion



Hemisphere Landslide Tsunami

Discussion



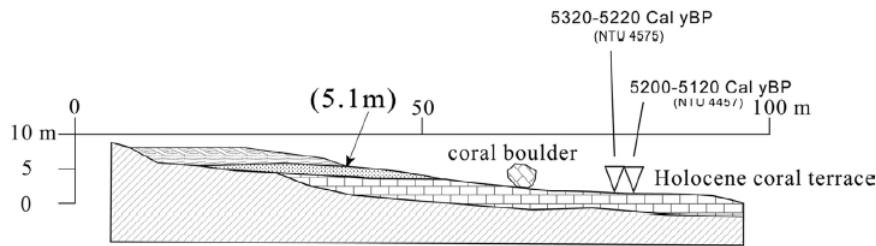
Movement of the Tsunami Boulders at Jiu Peng

Literature Review

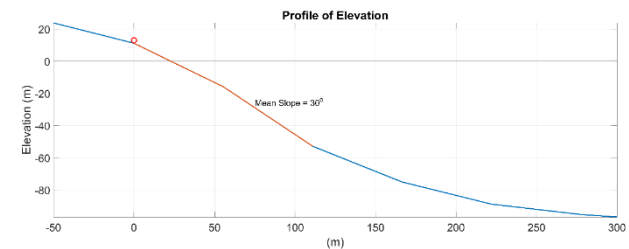
- Imamura et al. (2008) 以潰壩衝擊斜坡上之方塊固體之實驗，模擬海嘯湧潮衝擊海嘯石之情境，斜坡坡度為1:10，發現方塊之運動模式並非滑動，而是滾動與跳動。
- Goto et al. (2010) 利用數值模式估算出2004南亞海嘯在泰國Pakarang Cape搬運上岸之海嘯石，來自水深10公尺左右，以及海嘯波高約為7公尺。
- 珊瑚礁生長環境之重要依據之一為日照深度，日照深度平均至少能達9公尺之水深 (Kleypas et al., 1999)
- $\sqrt{gh}$ 、 $\sqrt{2gh}$ 、 $2\sqrt{gh}$ 為研究海嘯湧潮常用之波高與波速關係式 (Al-Faesly et al., 2011)
- $2\sqrt{gh}$ 為海嘯波流經乾底床之最大流速 (Camfield, 1980)

Movement of the Tsunami Boulders at Jiu Peng

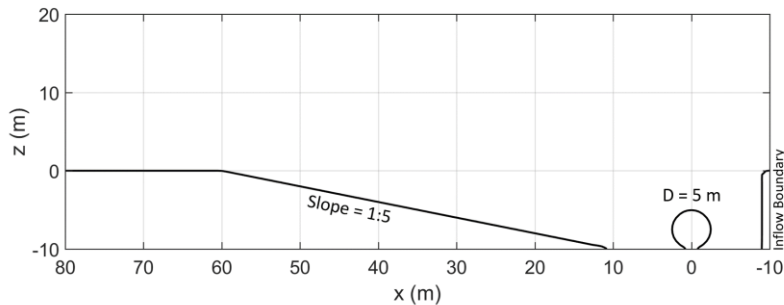
Numerical Setup



Matta et al. (2013)



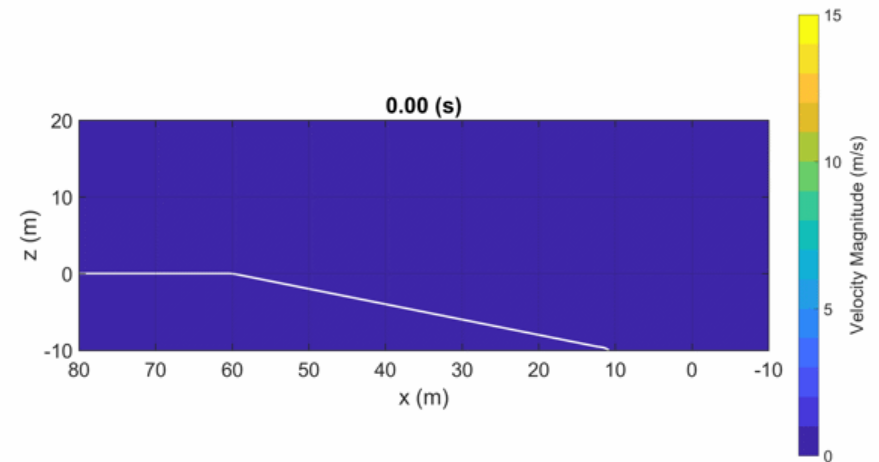
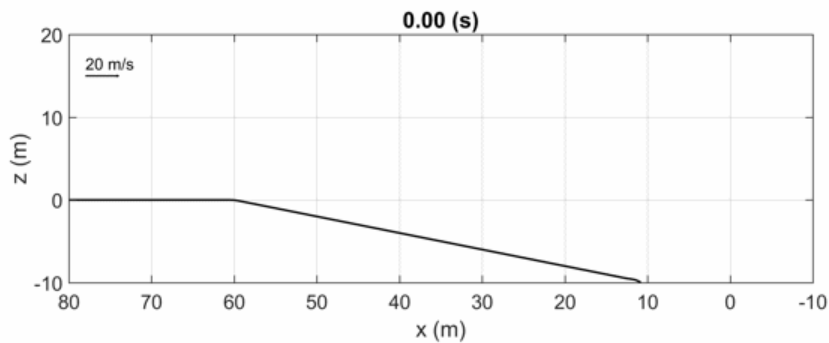
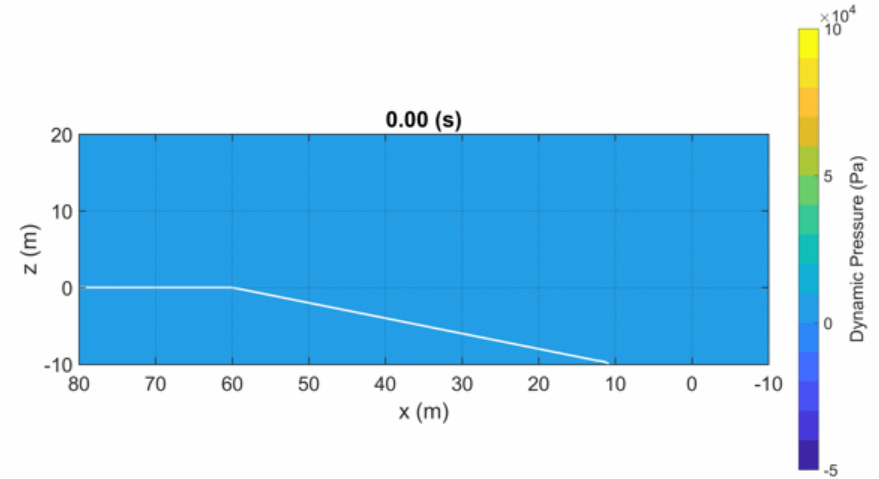
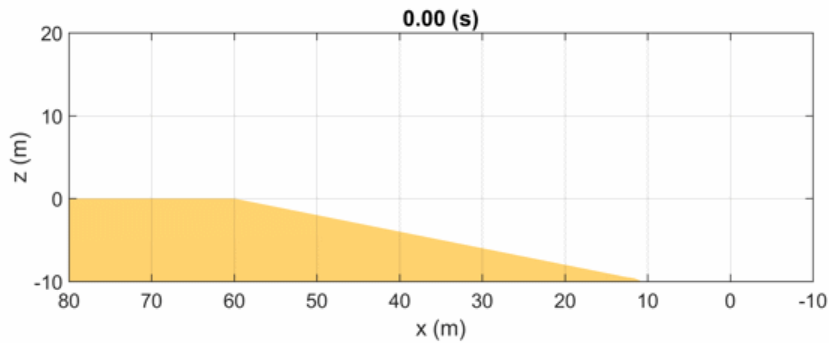
100 m resolution DEM



網格數	180 × 40 × 50格	水之密度	1000.0 (kg/m ³)
總網格數	360000格	水之黏滯係數	0.0 (Pa·s)
最細解析度	0.5 (m)	空氣之密度	0.0 (kg/m ³)，真空
Courant Number	0.8	空氣之黏滯係數	0.0 (Pa·s)
輸出時間步長	0.1 (s)	海嘯石密度	2600.0 (kg/m ³)
模擬時長	20.0 (s)	上邊界及下游邊界	壓力定值=0.0 (Pa)
海嘯石直徑網格數	10格	上游邊界	速度定值 (詳內文)
底床邊界條件	No-Slip	其餘邊界條件	Free-Slip

Movement of the Tsunami Boulders at Jiu Peng

Discussion



Movement of the Tsunami Boulders at Jiu Peng

Discussion

湧潮高度	波速關係式	到達時間	最大高度	最大速度	可否被搬運至斜坡上
0.5D	$\sqrt{gh}$	20.00 (s)	0.00	1.18	X (4.95 m/s)
0.5D	$\sqrt{2gh}$	9.78 (s)	0.25	2.28	X (7.00 m/s)
0.5D	$2\sqrt{gh}$	9.60 (s)	1.35	3.36	X (9.90 m/s)
1.0D	$\sqrt{gh}$	10.24 (s)	2.02	3.62	X (7.00 m/s)
1.0D	$\sqrt{2gh}$	11.47 (s)	3.60	4.10	X (9.90 m/s)
1.0D	$2\sqrt{gh}$	14.25 (s)	6.81	5.82	X (14.00 m/s)
1.5D	$\sqrt{gh}$	12.88 (s)	5.27	4.67	X (8.58 m/s)
1.5D	$\sqrt{2gh}$	20.00 (s)	10.00	6.11	O (12.13 m/s)
1.5D	$2\sqrt{gh}$	9.31 (s)	10.00	8.70	O (17.16 m/s)
2.0D	$\sqrt{gh}$	15.82 (s)	10.00	6.00	O (9.90 m/s)
2.0D	$\sqrt{2gh}$	10.43 (s)	10.00	7.43	O (14.00 m/s)
2.0D	$2\sqrt{gh}$	6.88 (s)	10.00	11.04	O (19.80 m/s)

Conclusion

Model Validation

- （1）本研究為驗證新開發之RWM，提出卡門渦街案例與圓球入水案例，分別驗證RWM應用於靜態與動態固體之數值模擬結果。
- （2）藉由卡門渦街案例，驗證RWM可準確模擬靜止固體於流場中之影響，產生相似之渦流形狀與速度，準確度與Splash 3D原生之PCT法相當。
- （3）由圓球入水案例，驗證RWM於可準確計算圓球入水後之軌跡，且拖曳出形狀相似之空氣柱，並可準確預測空氣柱斷裂之時間，Aristoff et al.（2010）表示準確之空氣柱斷裂時間為模式驗證之重要指標。

Conclusion

Hemisphere Landslide Tsunami

- (1) 半圓球山崩之模擬結果與實驗相當符合，無論崩落體移動之軌跡、速度，或是各水位計量測之波高以及溯上高度，皆相當準確，驗證以斜面將移動固體截切之計算方法可行。
- (2) 半圓球山崩之側向流速將逐漸增大，俯視之波型由圓弧形逐漸擴展為新月形，且塊體浸沒深度達2.5倍半圓球直徑後，已難影響上層之流場。
- (3) 將半圓球山崩模擬之尺度放大後，模擬結果遵守福祿數相似，時間、流速、動壓、合力等參數皆符合福祿數相似時之倍數關係。

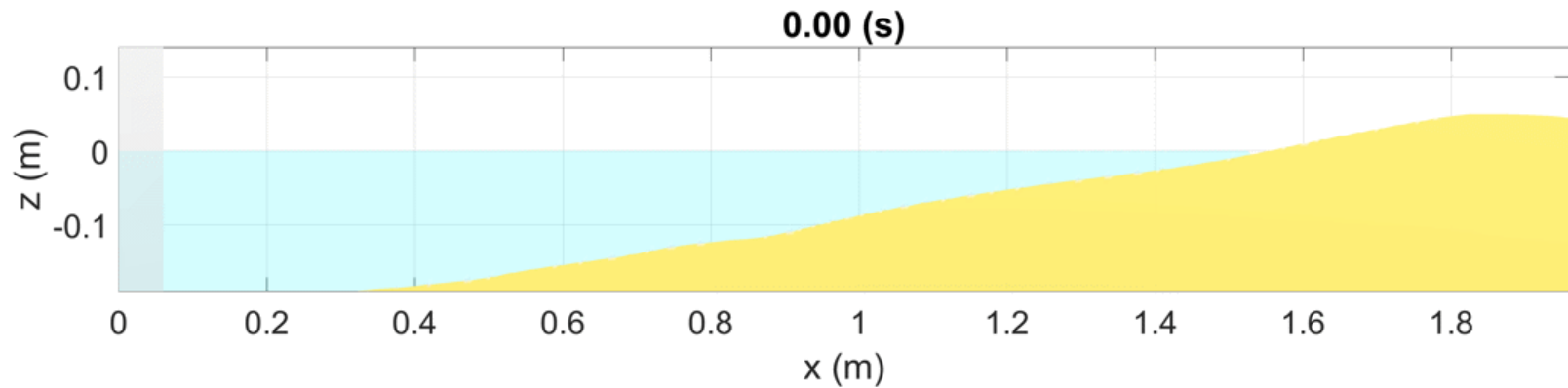
Conclusion

Movement of the Tsunami Boulders at Jiu Peng

- (1) Splash 3D經前述章節充分驗證後，可對流固耦合計算提供準確之速度與位移，並可推估受海嘯湧潮衝擊之搬運過程。
- (2) 在1:5坡度條件下，海嘯石搬運之條件為至少1.5倍直徑波高之湧潮，以及至少 $\sqrt{2gh}$ 之流速。
- (3) 海嘯湧潮因有溯上之極限，當流速無法繼續支撐其高度，將產生回溯，以及降低流場中之流速，產生低速區。海嘯石必須通過低速區後依然維持一定速度，否則將被回溯之湧潮往回帶。

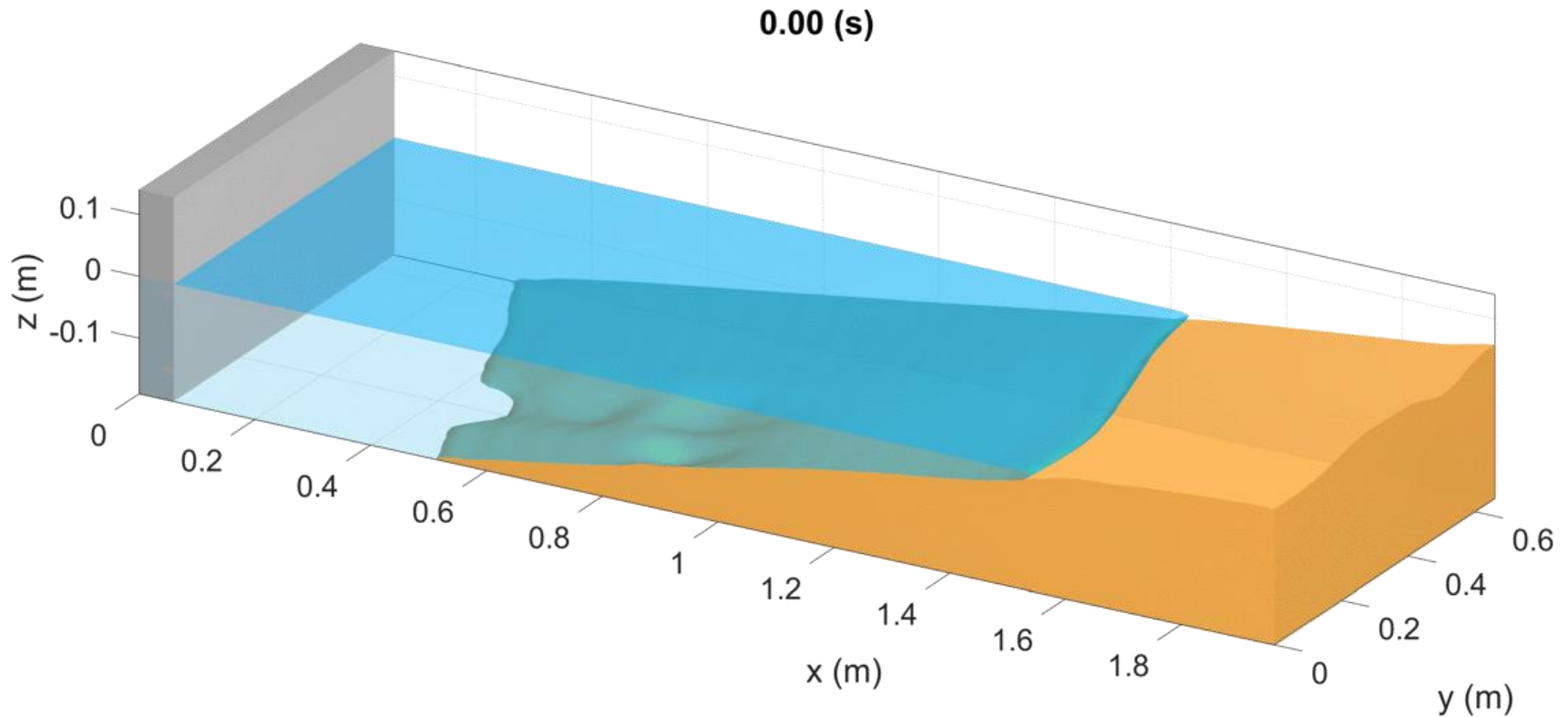
Moving Solid Algorithm Generation Forth

Future Work



Moving Solid Algorithm Generation Forth

Future Work



海嘯災防要點

- 過去沒發生過海嘯，不見得以後不會發生
 - 大規模海嘯事件幾乎都是由大規模地震所引起，而此類地震通常規模大於Mw 8.0，並且發生於海溝。此類地震重現期往往長達200年到500年或更長，因此即便是創校於1874年的大川小學，也遠短於海嘯的重現期。
- 過去曾發生過海嘯，就一定會再發生
 - 歷史上若有海嘯之記載，就必須更審慎擬定海嘯災防策略。
- 料敵從寬是唯一的態度
 - 由於大規模海嘯的重現期太長，因此必須以更嚴肅的態度面對。千萬不可以過去沒有發生而斷論未來也不會發生。
- 海嘯容易沿河川而進入內陸
 - 因此即便是遠離海洋的學校，仍須謹慎面對海嘯之威脅。
- 海嘯的避難方式與地震迥異
 - 海嘯需逃往高處，而地震則是留在寬闊的地面。因此事先擬定逃生策略相當重要。
- 適當的防護是必須的
 - 海嘯並非無法消弭的災害，只要事先有正確的評估，海嘯是可以防範的。

結語

- 台灣北部之海嘯源較複雜，海底地震、海底山崩或海底火山皆有可能
- 台灣西南沿海需小心來自馬尼拉海溝北段之地震型海嘯
- 台灣東南沿海需小心來自亞普海溝之海嘯
- 台灣海嘯逃生以垂直避難為主，想辦法逃到頂樓就對了。
- 台灣的確有海嘯的紀錄，而且還不少。（特別在短短350年以內），但台灣近期都沒有海嘯，因此要更加小心。
- 海嘯科學是很有趣的。
- 最後一點最重要，請拿筆抄下來：
 - 歡迎大家報考：
 - 中央大學地球科學院
 - 水文與海洋科學研究所（水海所）
- 感謝聆聽！問題請問 吳祚任老師