海嘯與海嘯災害應變

澎湖縣災害防救深耕5年中程計畫(100年度) 教育訓練課程(一)
海嘯/颱風災害應變與資訊整合應用

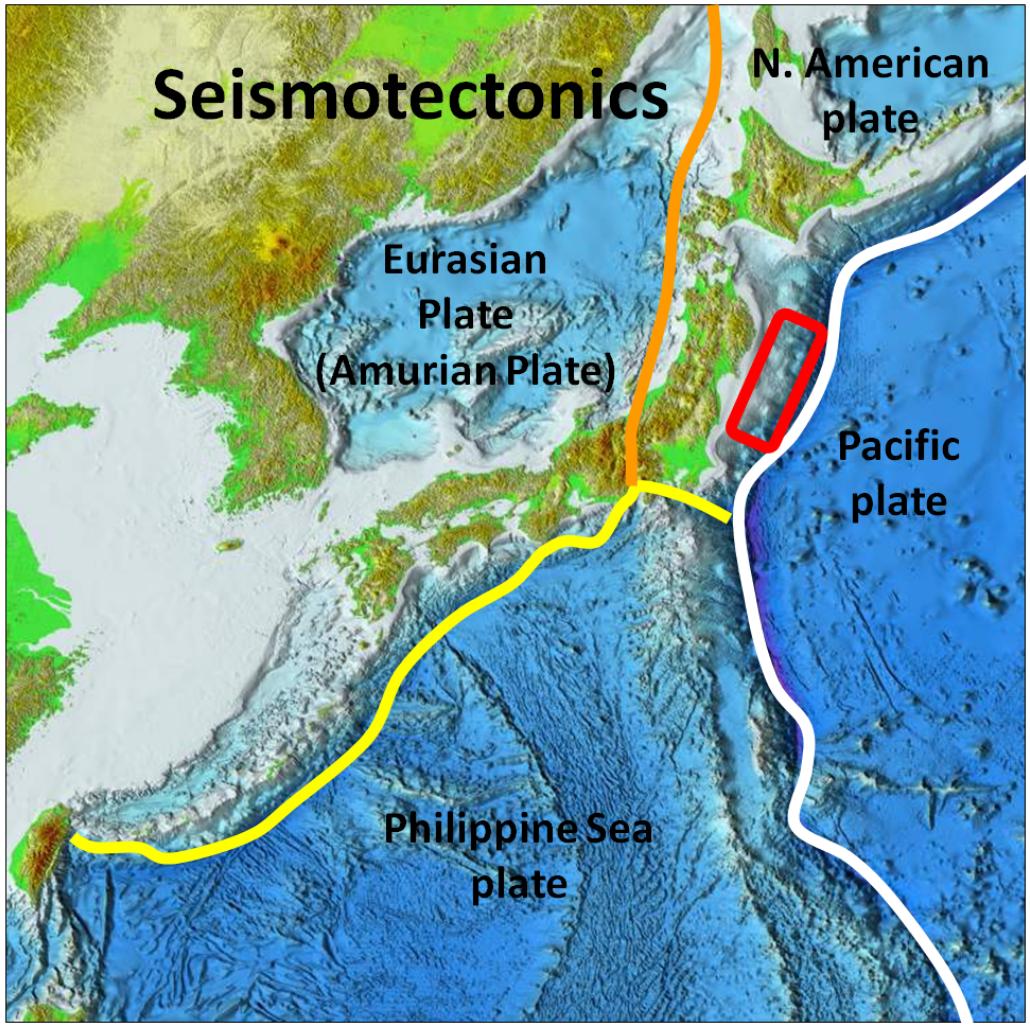
主辦單位：澎湖縣政府消防局
承辦單位：南亞技術學院協力機構
講習對象：縣政府與各鄉市公所　防救災業務承辦主管與人員
講習時間：100年9月19日(上午0910~10:30)
講習地點：澎湖科技大學 活動中心會議室

吳祚任 老師

國立中央大學

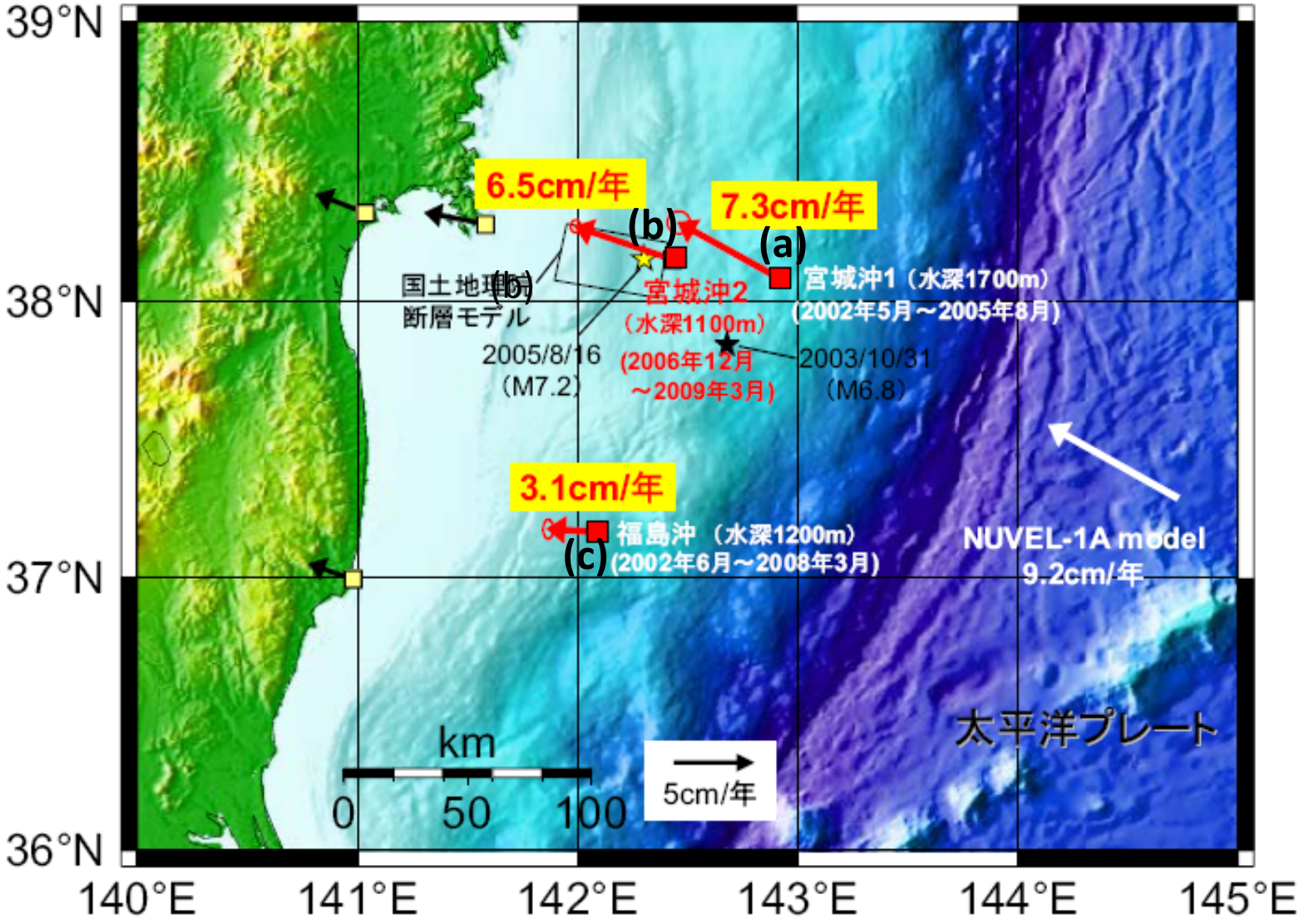
水文與海洋科學研究所

Giant earthquake occurred at a relatively short and sinuous rupture interface



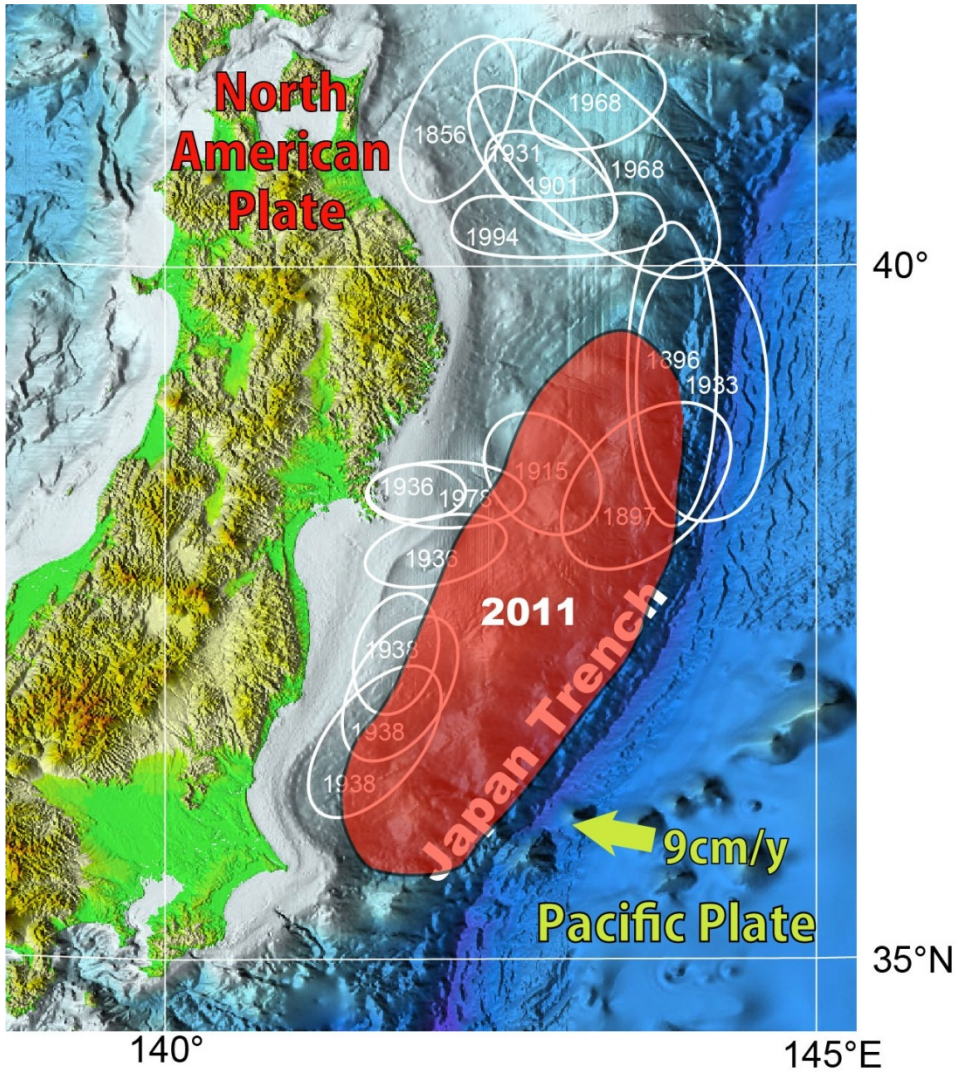
(Copy right: Newton)

Seafloor geodetic survey, Japan Coast Guard



（Ando, 2011）

日本東北外海歴史地震



(by Masanobu SHISHIKURA)

Major focal areas along the Japan Trench

Only M 7-8 class earthquakes was known in this area.

Unpredictable M9 earthquake occurred!

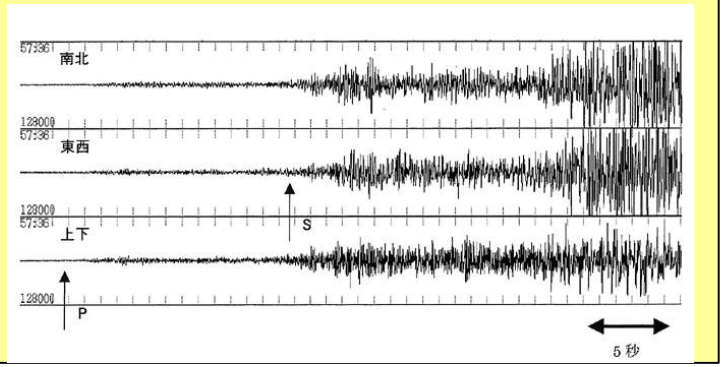
However similar past giant earthquake has been recorded into geology.

➡ **869 Jogan earthquake**

How to predict future giant earthquake and tsunami, and mitigate disaster.

→ We have to know the past.

However we cannot obtain instrumental observation data before the last century.



Historical records are also very few before several century ago.





Tsunami deposit is one of the best evidences to evaluate past tsunami.



(by Masanobu SHISHIKURA)



Tsunami deposit



Tsunami deposit

- Tsunami deposit can reconstruct the inundation area of past tsunami. → Prediction of magnitude
- Tsunami deposit can reconstruct the history of repeated tsunami. → Prediction of approximate timing

However, some evidences are suggesting the possibility of a giant earthquake

- GPS shows large slip deficit (6-10cm/y)
- Historical documents on the AD869 tsunami
- Tsunami sediments (>1000 yrs) were excavated 2-3km inland from the coast

In Taiwan, do we receive the signs of a giant earthquake?

Rikuzen Takata City

Population: 24,246
Number of households: 8,068







(Ando, 2011)



Pine tree
of hope





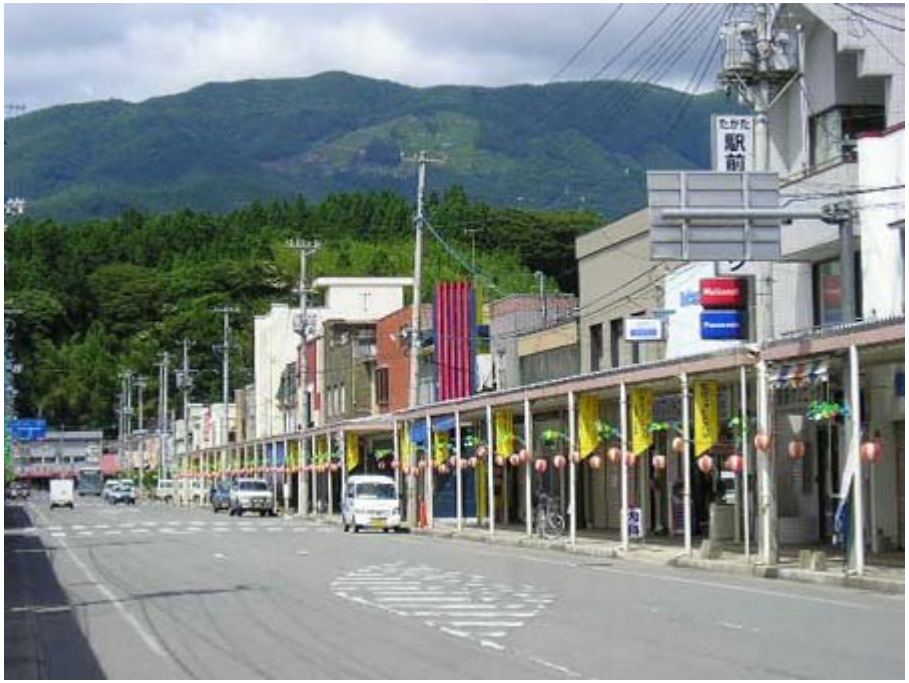




（Ando, 2011）









（Ando, 2011）



（Ando, 2011）

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
小林
ラジオ店
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
50 m
100 フィート
©2011 ZENRI

(Ando, 2011)



（Ando, 2011）





(Ando, 2011)



（Ando, 2011）



(Ando, 2011)







如來神掌？

（陳慧慈，2011）



基礎嚴重淘刷



淘刷後基座懸空

（陳慧慈，2011）



如來神掌，兩枚

（陳慧慈，2011）



（陳慧慈，2011）



土壤液化+海嘯沖刷+海嘯撞擊＝翻滾的房子

（陳慧慈，2011）

驚人的海嘯衝擊力



房子



（陳慧慈，2011）









（Ando, 2011）



(Ando, 2011)



(Ando, 2011)

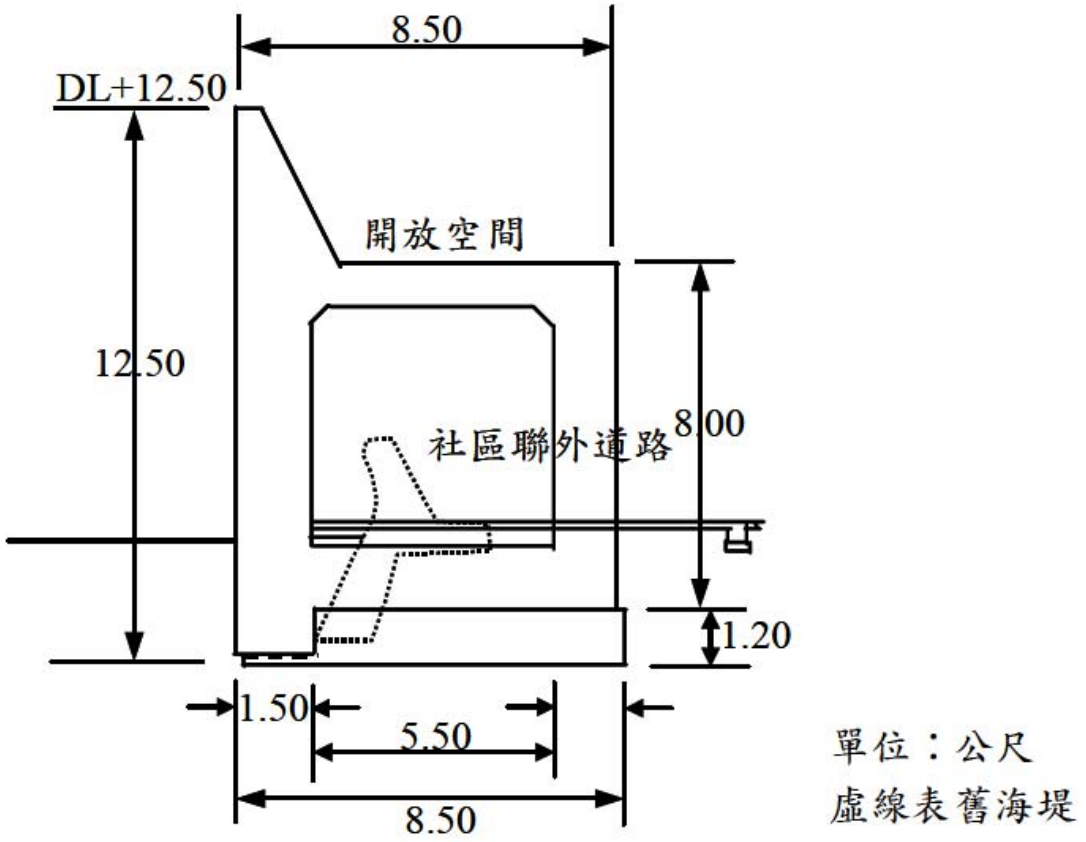


圖2-4-7　日本岩手縣釜石市小白浜地區(Kojirahama)之耐海嘯海堤斷面示意圖(資料來源：Tsunami：Progress in Prediction, Disaster Prevention and Warning，1995)

疏散情況

- 居民不想疏散。
  - 由於日本氣象廳每年發佈2~6次海嘯警報，導致居民對海嘯警報警覺性降低。
  - 海嘯牆讓人誤解以為很安全。

- 居民開車疏散，導致致命的塞車情形

（Ando, 2011）

探討

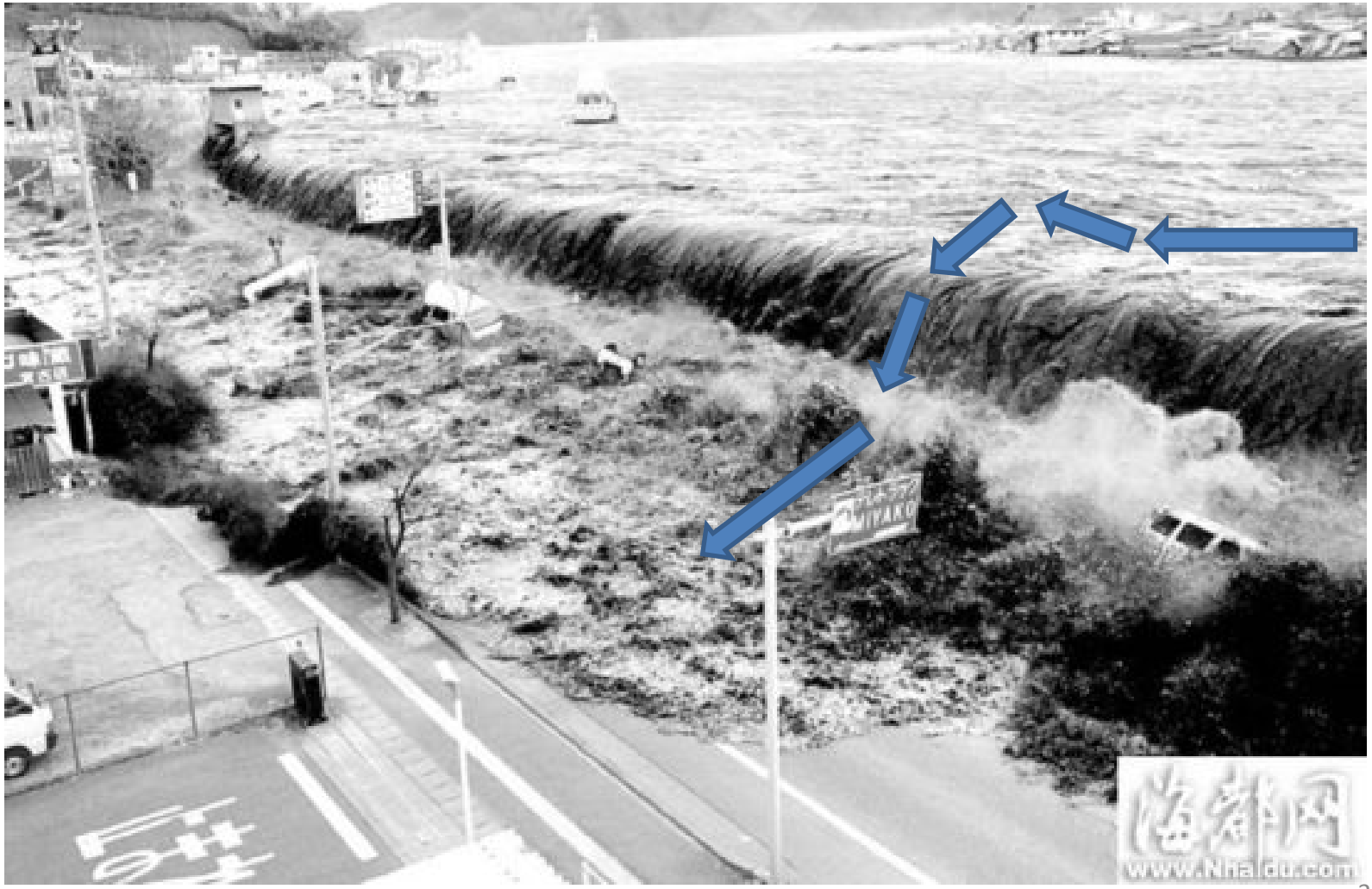
- 日本海嘯其實有徵兆可循，台灣呢？有沒有徵兆？
- 海嘯衝擊可以模擬嗎？
- 台灣有沒有可能遭受海嘯攻擊？

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。



海嘯動能會使海嘯翻牆而過
僅考慮溢淹高度是危險的



海嘯帶來的不只是洪水，還有...
大量破碎懸浮物





還有大船（兩艘）



貨輪



三菱物流所租用的亞洲欣和號貨輪，被海嘯沖上岩手縣釜石港碼頭

什麼是海嘯？



真正的海嘯







來臨時像是一面水牆

淹上岸像是大洪水

更重要的是，海嘯波長很長，往往可達100~200公里長

人類有史以來第一次在船上拍攝到海嘯



海嘯來臨時，船隻應儘速離港

- 當海嘯波變成海嘯湧潮時，會產生強大推移力！







海嘯入侵至內陸時為海嘯湧潮



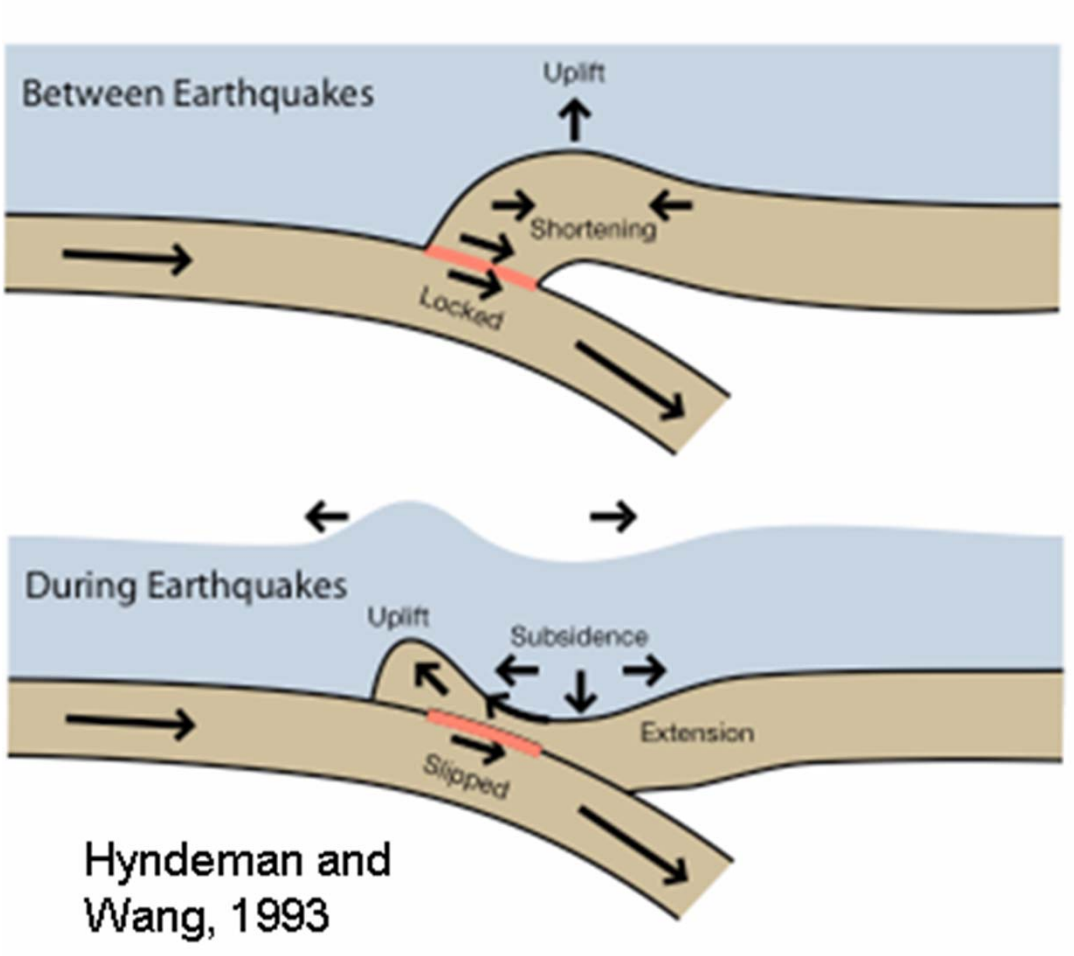
海嘯湧潮破壞力驚人
連鋼筋混凝土都遭破壞

- 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！



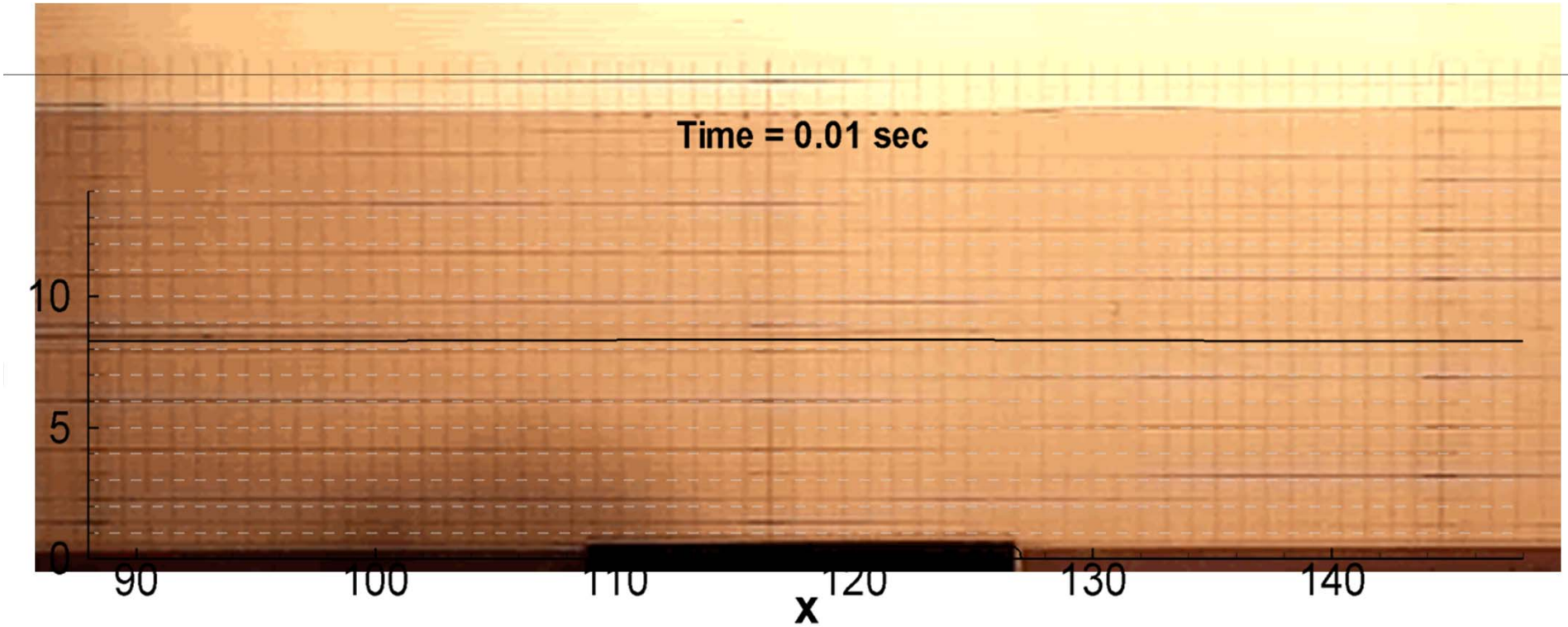
地震引發海嘯的方法

- 地震的震源深度在地表下30公里以內
- 地震規模大於芮氏7.2級（通常為逆斷層或正斷層）
- 深海



實驗動畫(矩形抬升):

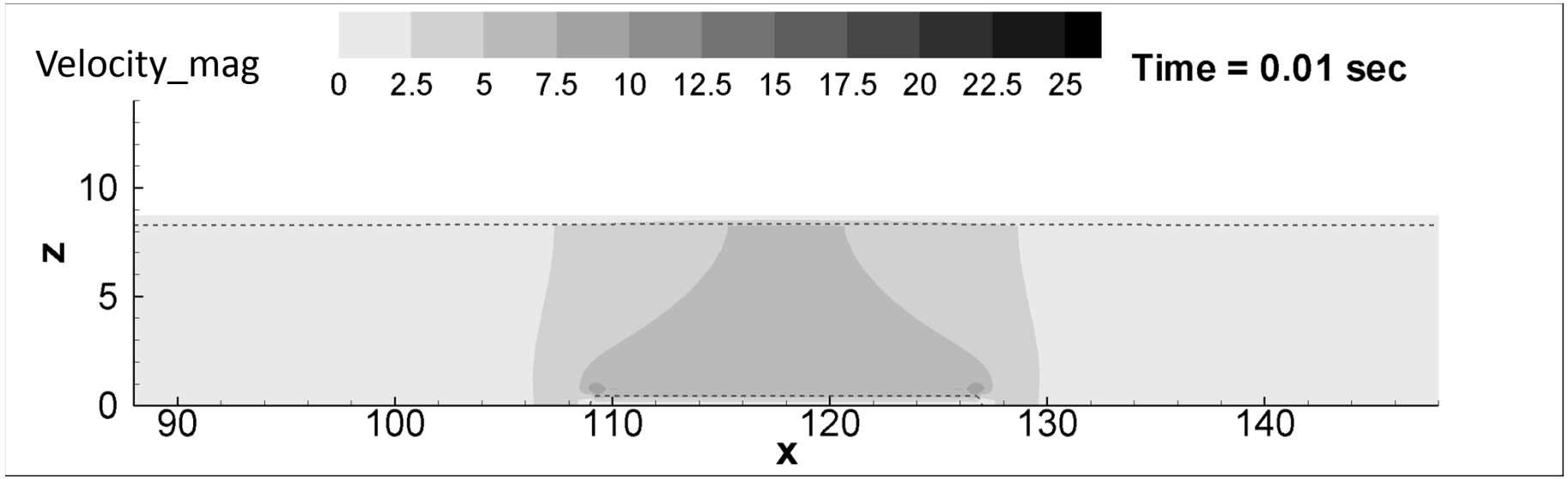
地震海嘯生成機制



（黑線：數值模擬結果）

（鄭喆宇製）

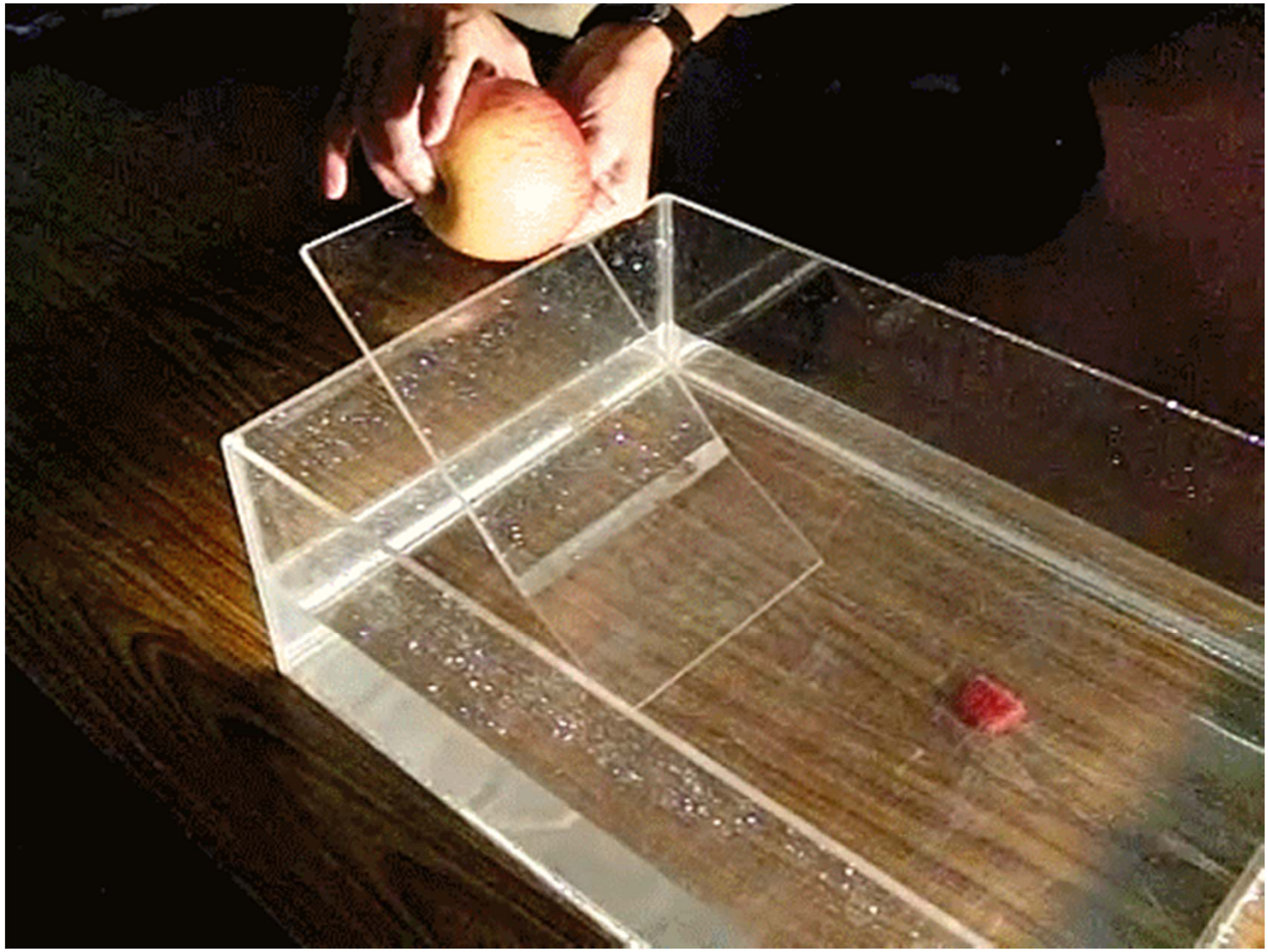
Ncells 944,1,60
DOMAIN 236, 10, 15 單位:公分
dx=dz=0.25



（鄭喆宇製）

山崩海嘯

山崩海嘯生成機制



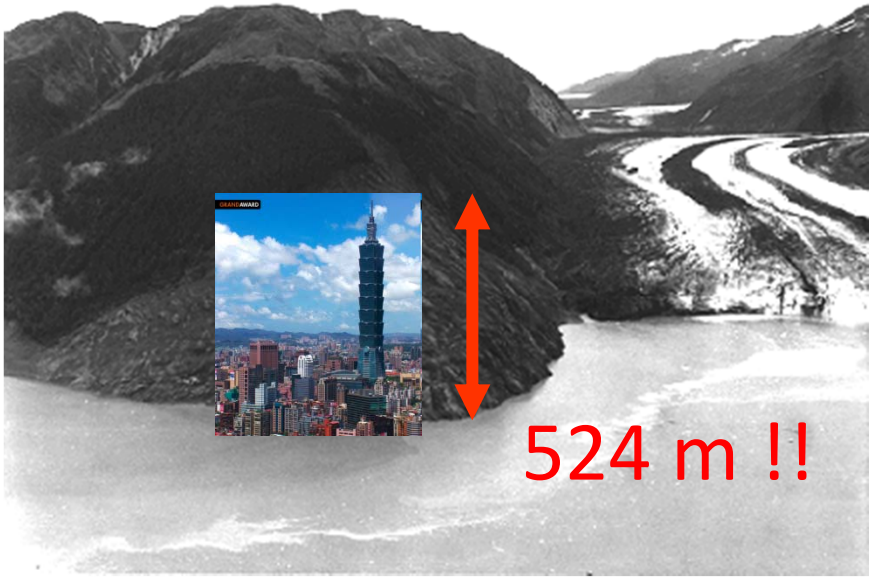
海嘯能有多高？

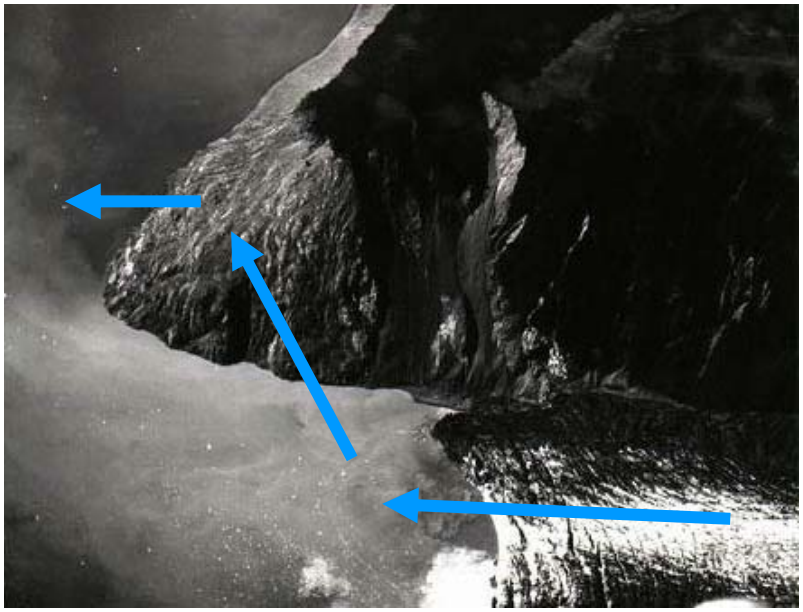




歷史上最高的海嘯波：由山崩引發

The Giant Tsunami Generation in Lituya Bay on July 9, 1958.





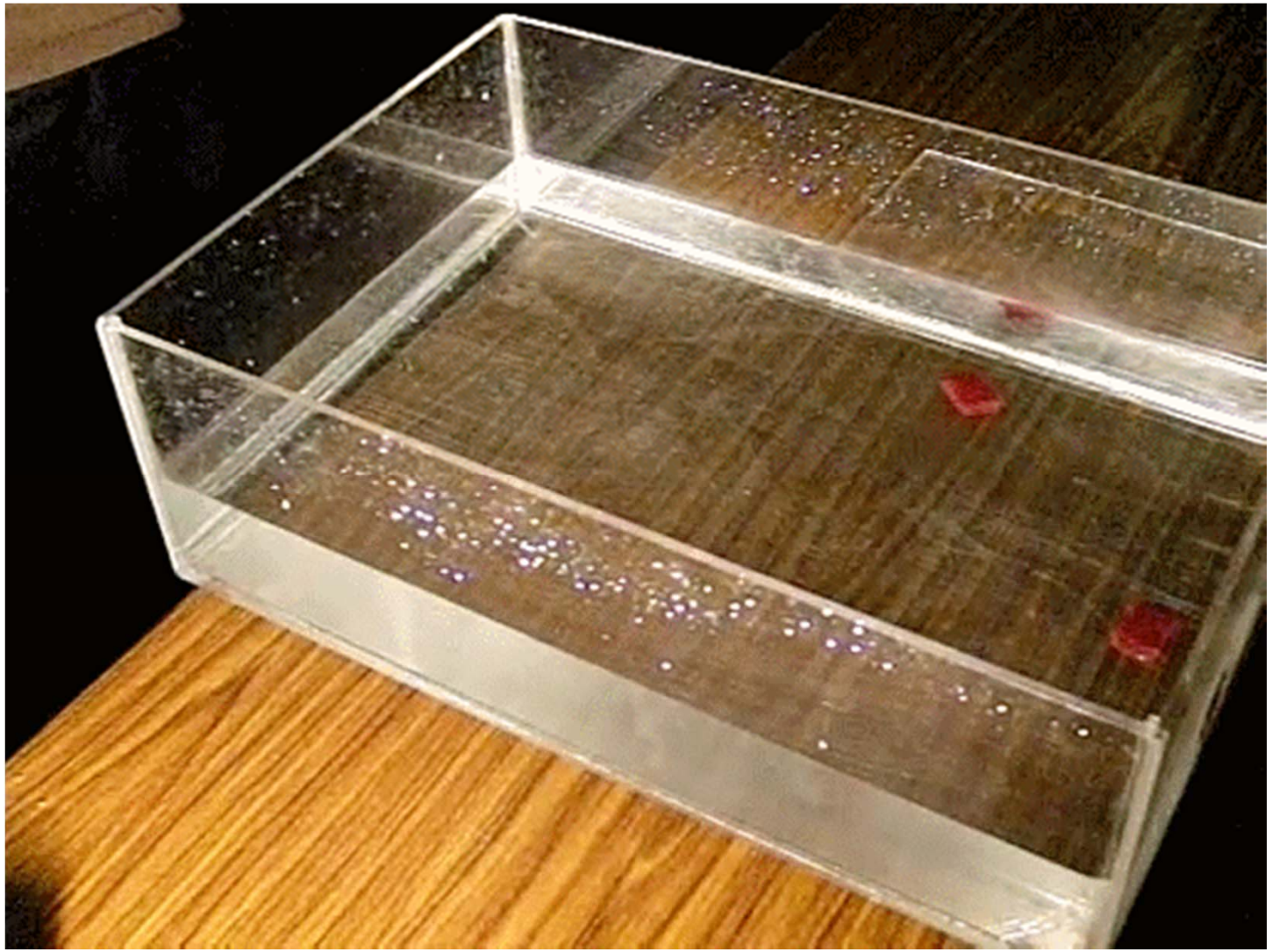
This photo shows a view of the Gilbert Inlet, located in the northeastern corner of Lituya Bay, which serves as the terminus of the Lituya Glacier (also shown in the photo). The barren patch of rock along the point, shown in the center of the photo, is the result of the initial giant splash of water generated by the rockslide, which occurred directly opposite the inlet. The extent of runup at this location, marked by the vertical elevation of the barren rock face, was an amazing 1,720 feet (524 m) above sea level! The highest ever recorded.



http://www.usc.edu/dept/tsunamis/alaska/1958/webpages/lituyacloseup.html

隕石撞地球

隕石撞地球



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

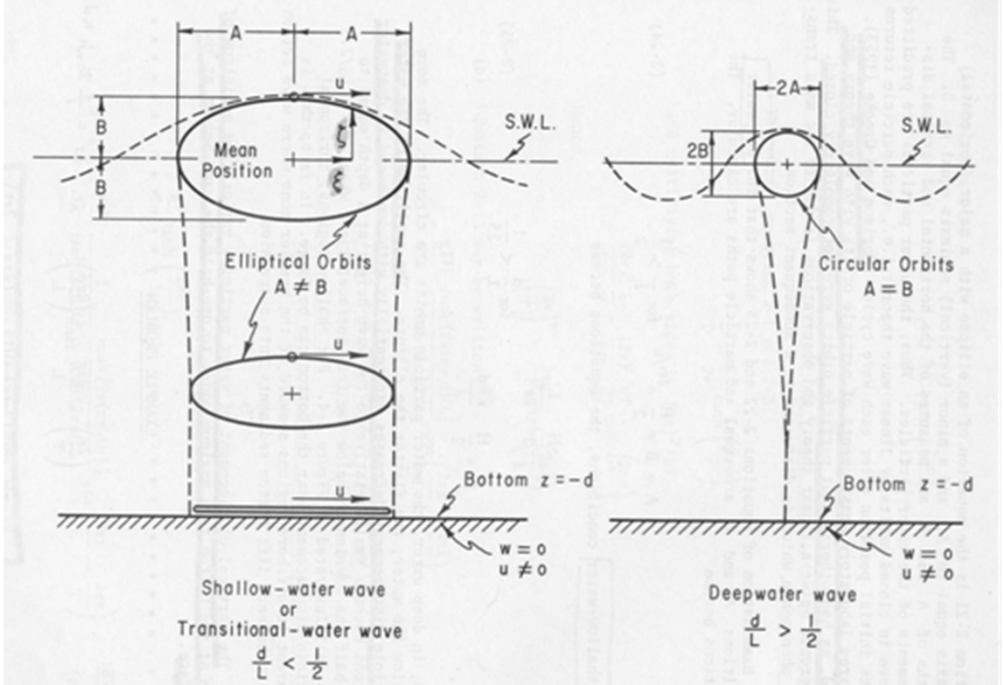
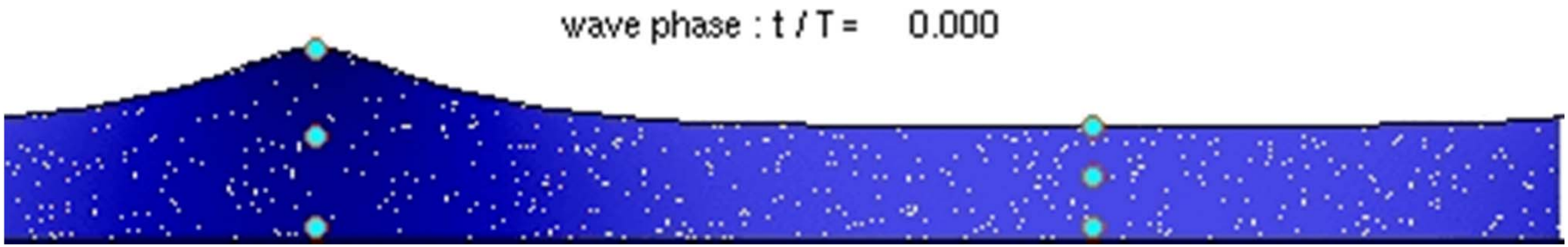


Figure 2-4. Water Particle Displacements from Mean Position for Shallow-Water and Deepwater Waves



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,

$P=Hu_x$ 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.

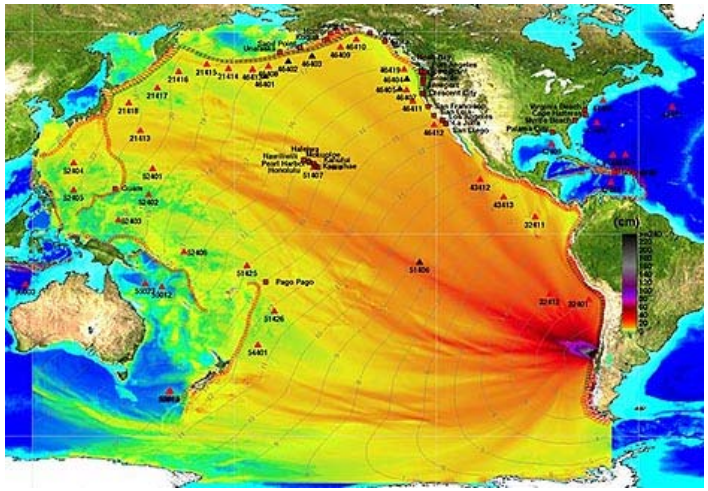
海嘯的速度

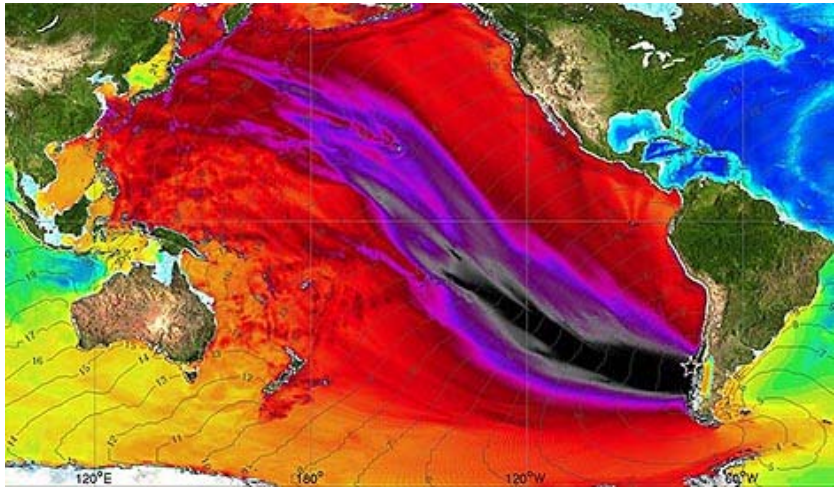
- 海嘯的速度可以由以下的公式簡單算出：
- 根據淺水波理論，海嘯在深海傳遞的波速等於重力加速度乘上水深的開根號。也就是

$$C = \sqrt{gh}$$

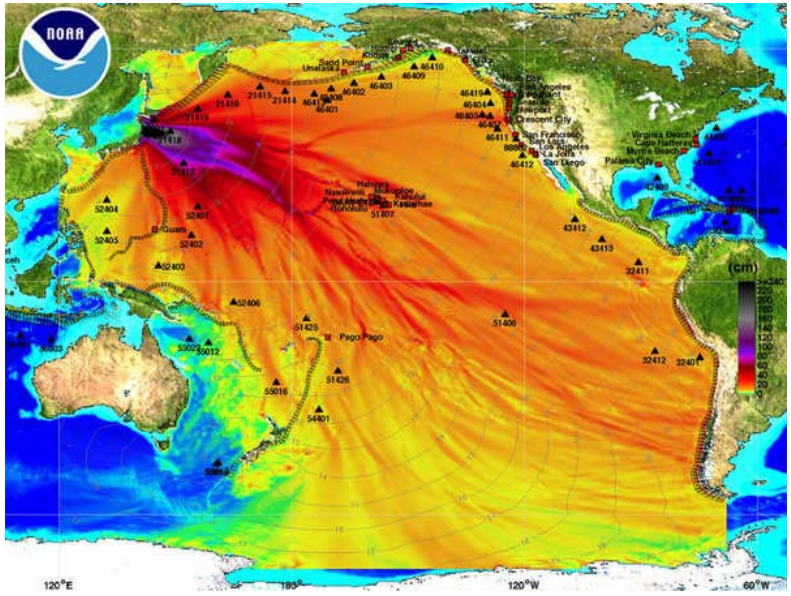
（問題：大海嘯跑比較快還是小海嘯？進實驗）

2010 智利海嘯　1960 智利海嘯





2011 日本海嘯



為什麼海嘯傳遞路徑這麼相似？
日本海嘯還會對台灣有影響嗎？

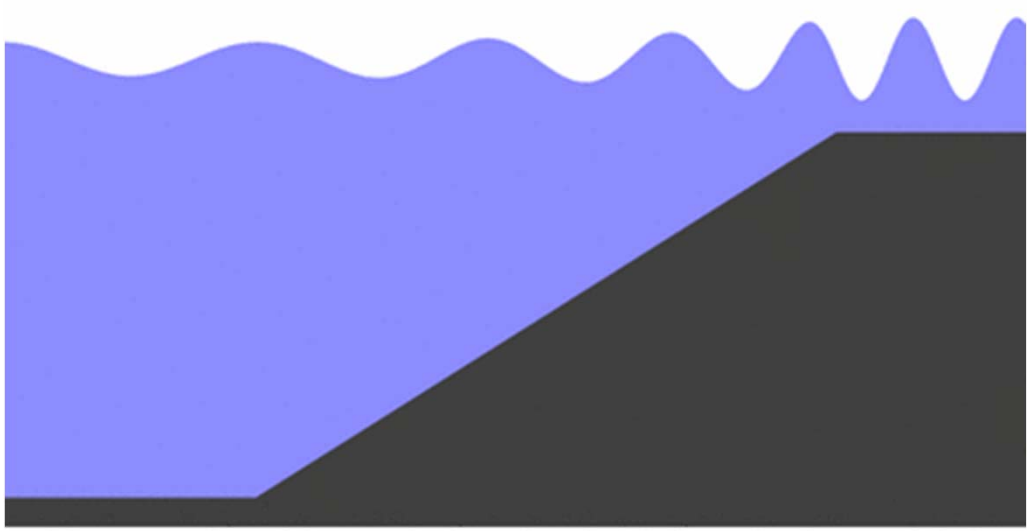
水越深，海嘯越快

- 所以，海嘯會往水淺的地方轉彎
- 所以，海灘不會有直線條的海浪

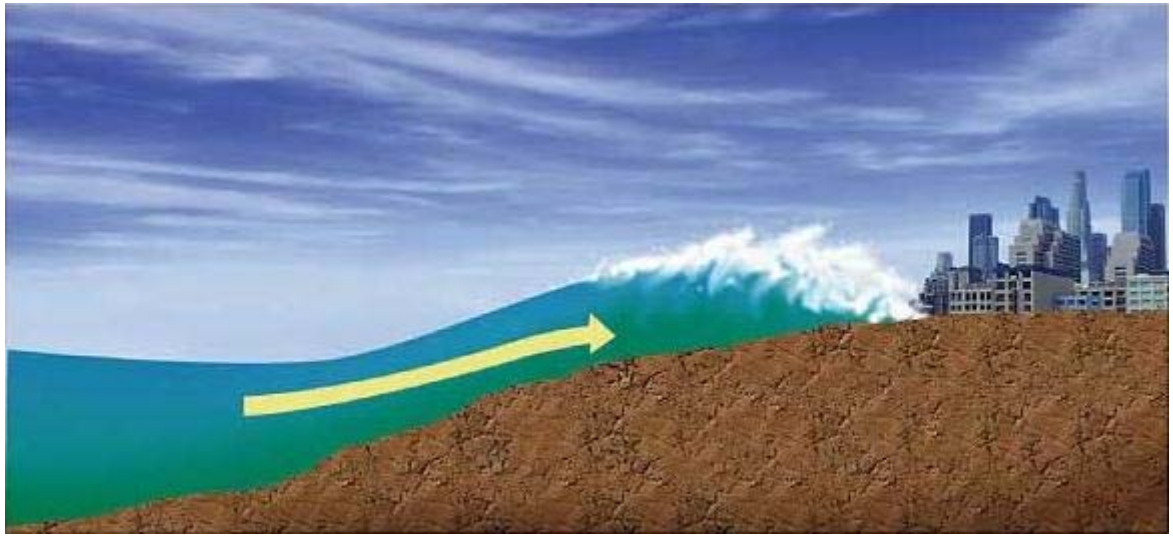


海嘯抵達岸邊的波高放大效應

- 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）



科學家們如何研究海嘯？

- 推導公式
  - 淺水波方程式，布氏定理
- 做實驗





- 現地量測、親身體驗
- 數值模擬

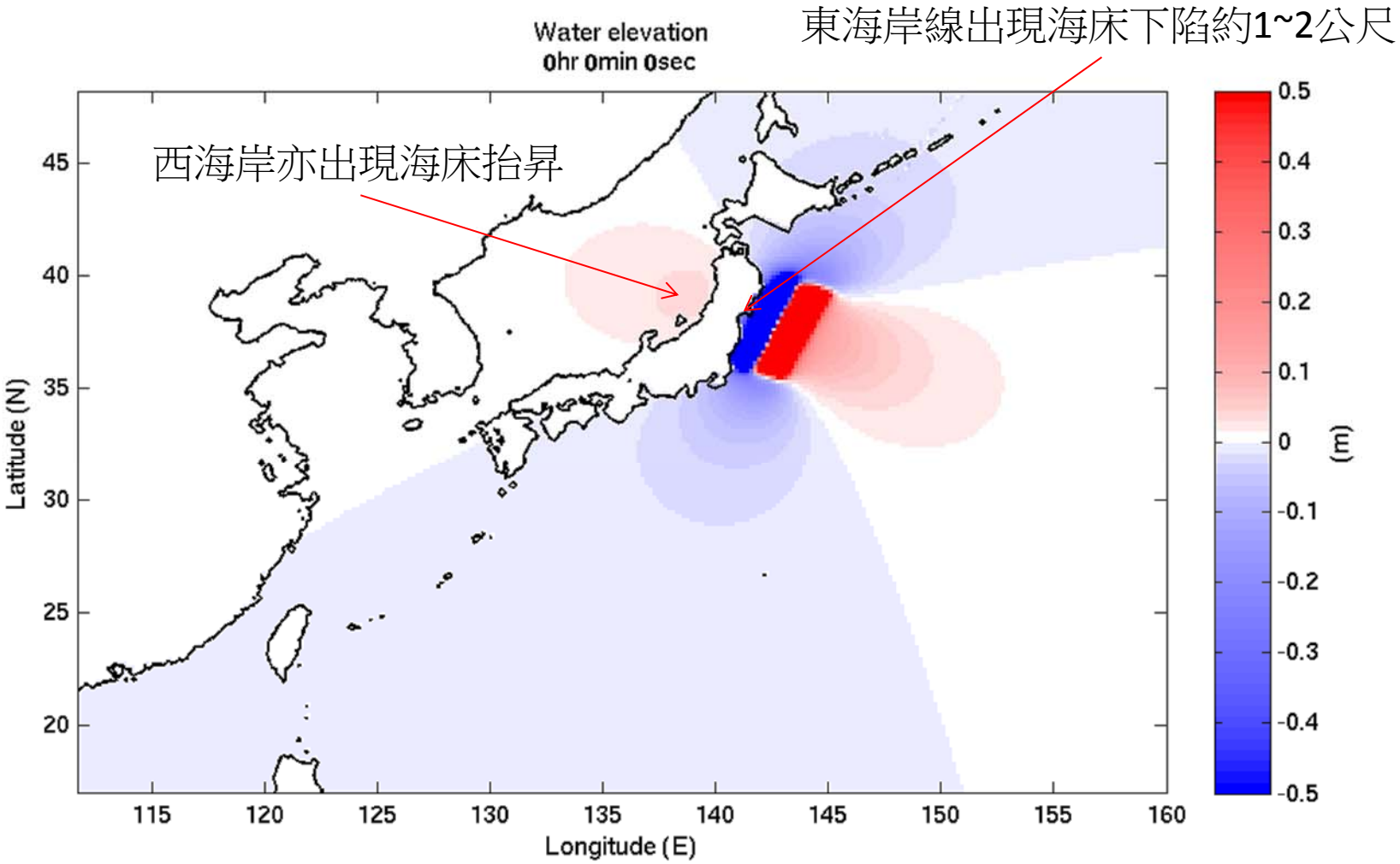


做實驗的好處



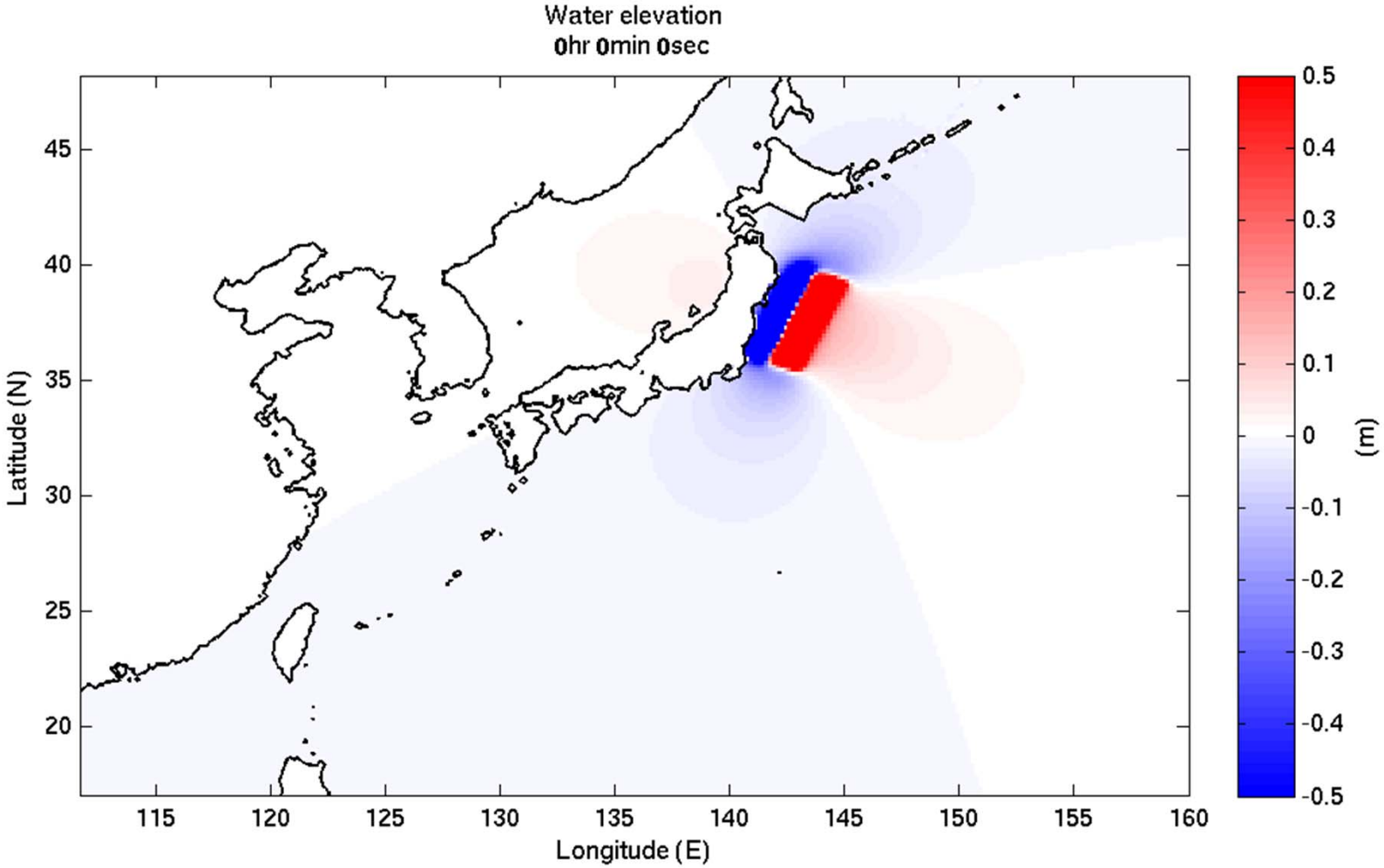
海嘯波數值模擬

模式預測之2011日本海嘯波源

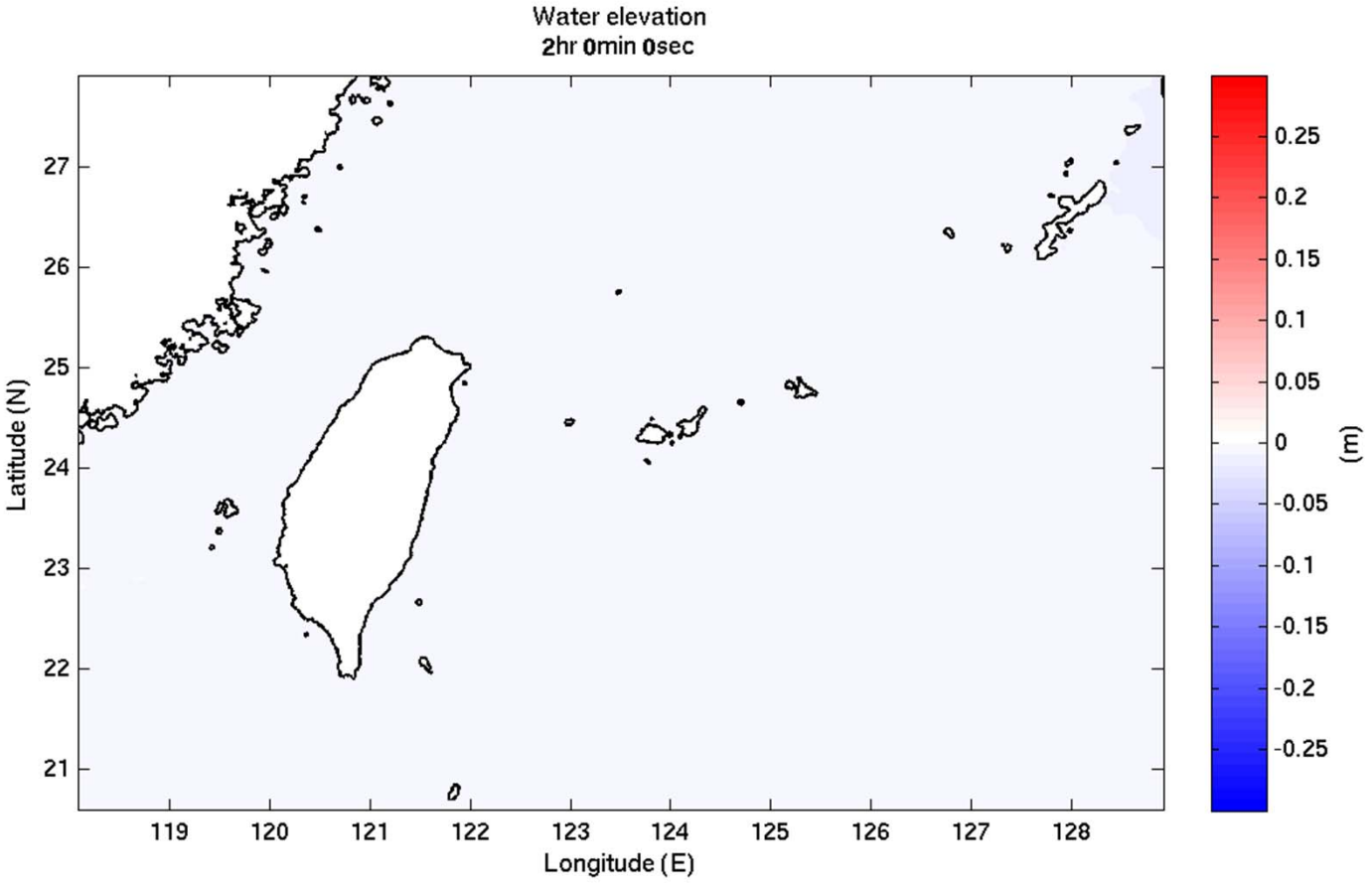


模式預測海床抬昇量為4.5公尺，與實際觀測之5公尺相當接近。

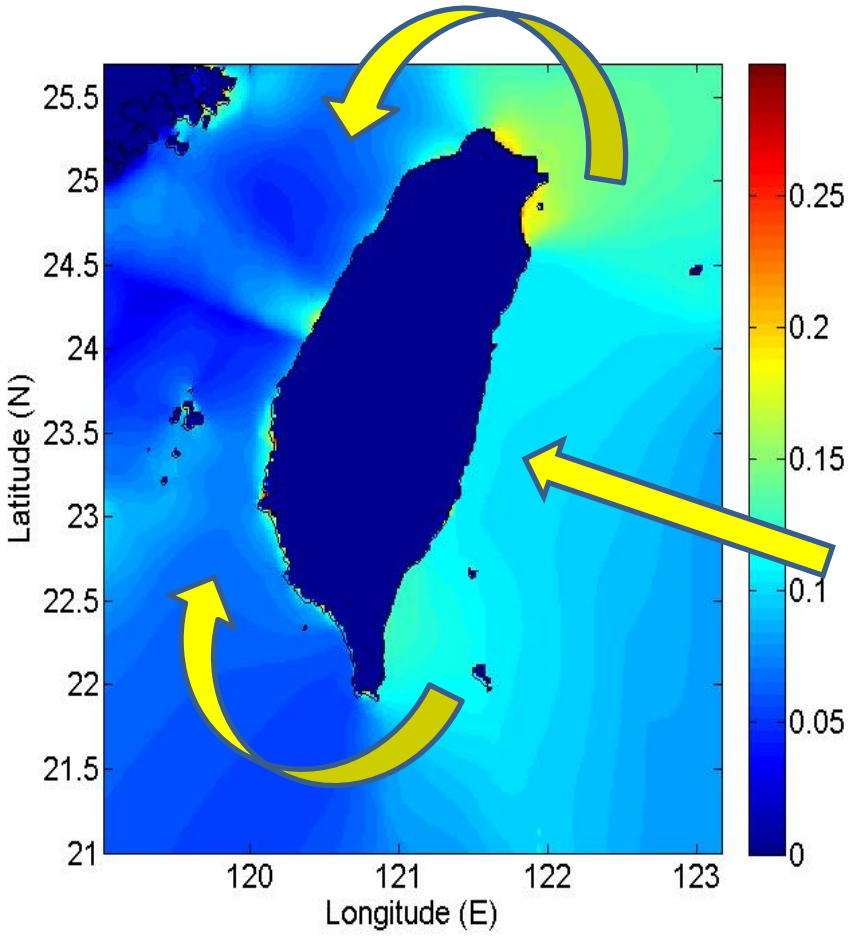
模擬結果：海嘯傳播方式


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

海嘯傳遞至台灣

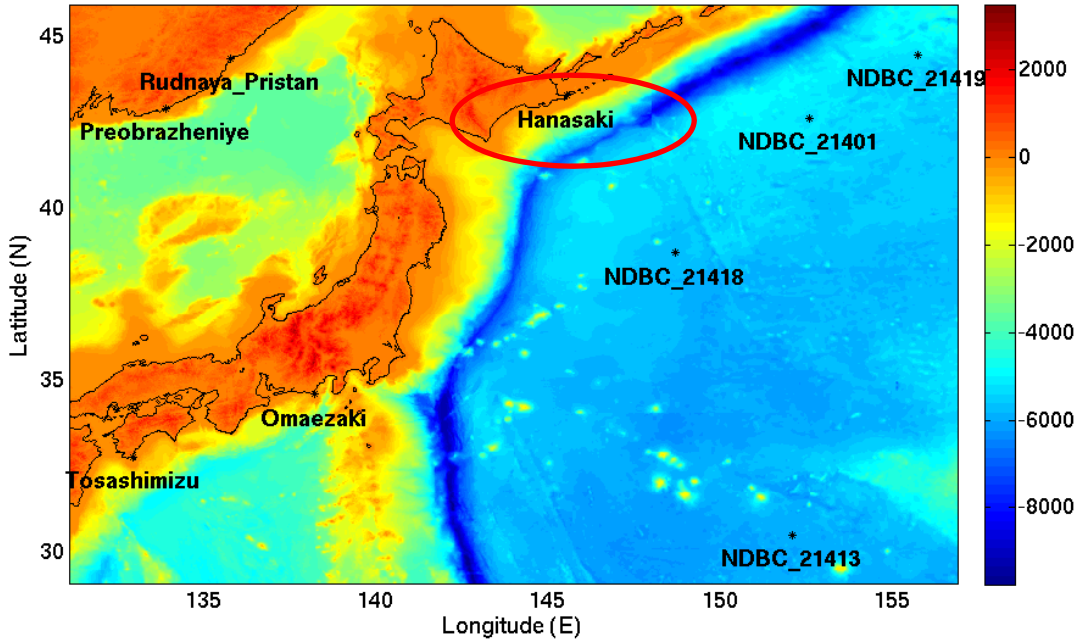

Water elevation
2hr 0min 0sec
Latitude (N)
Longitude (E)
27
26
25
24
23
22
21
119
120
121
122
123
124
125
126
127
128
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
(m)

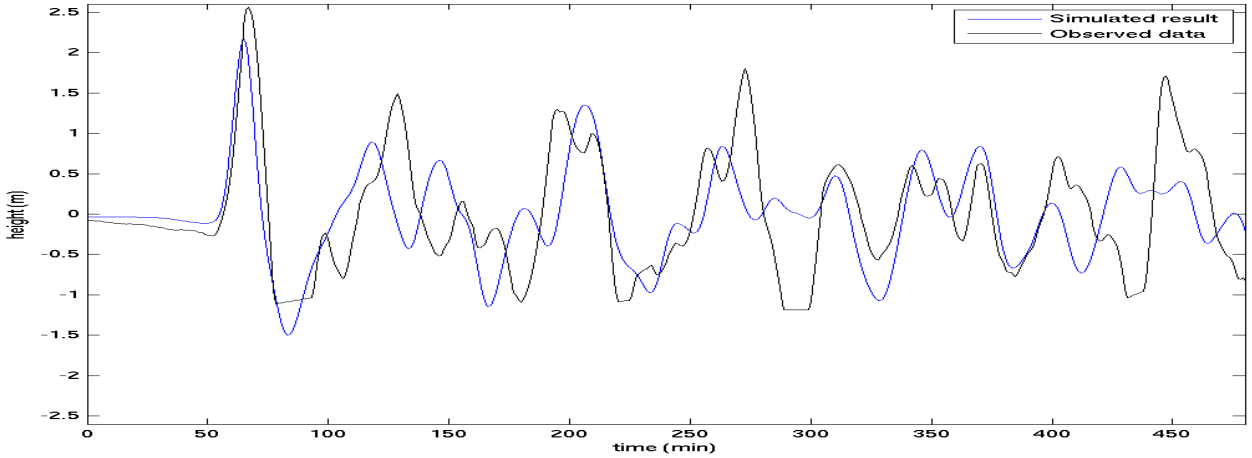
海嘯傳遞至台灣之方式



Maximum Wave height

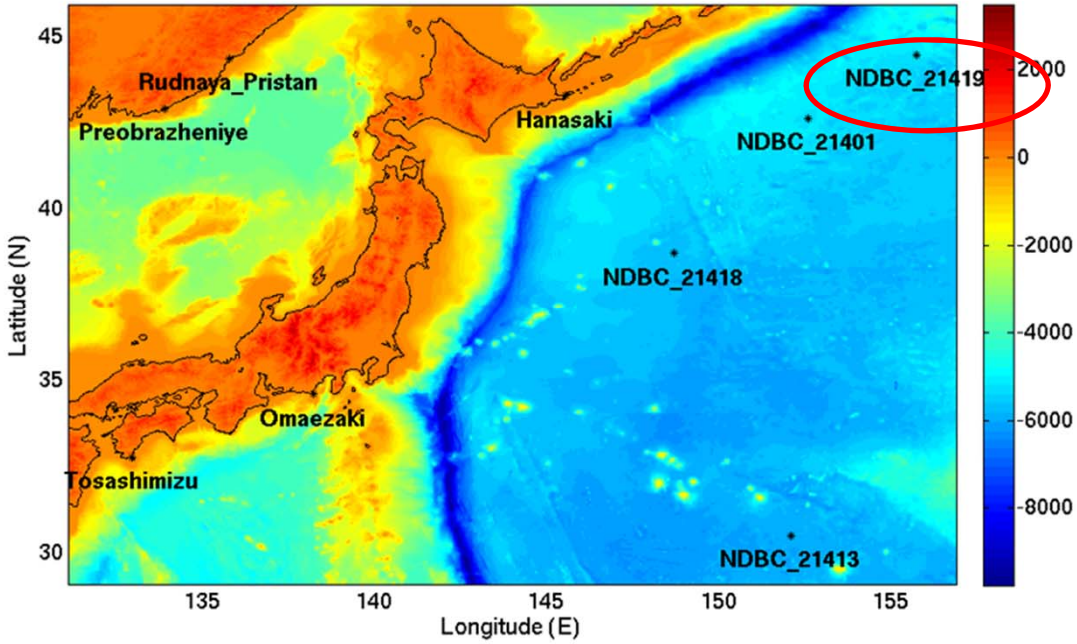
模式預測之海嘯波高與日本潮位站實測比對：Hanasaki

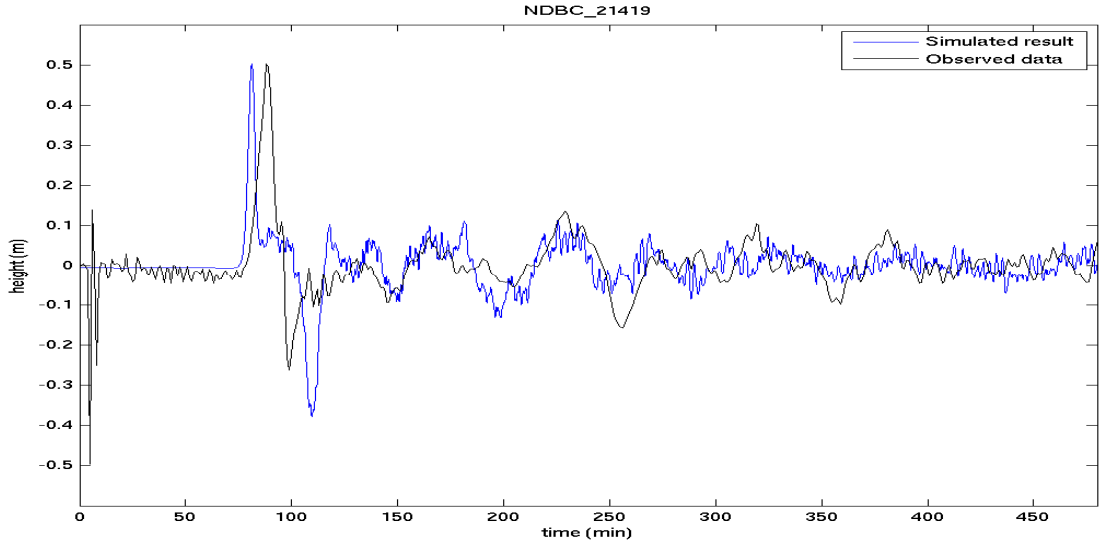




Hanasaki 潮位站比對，藍線為模擬結果，黑線為實測資料。該站位於斜坡部分，模擬結果與實測比對相當一致。

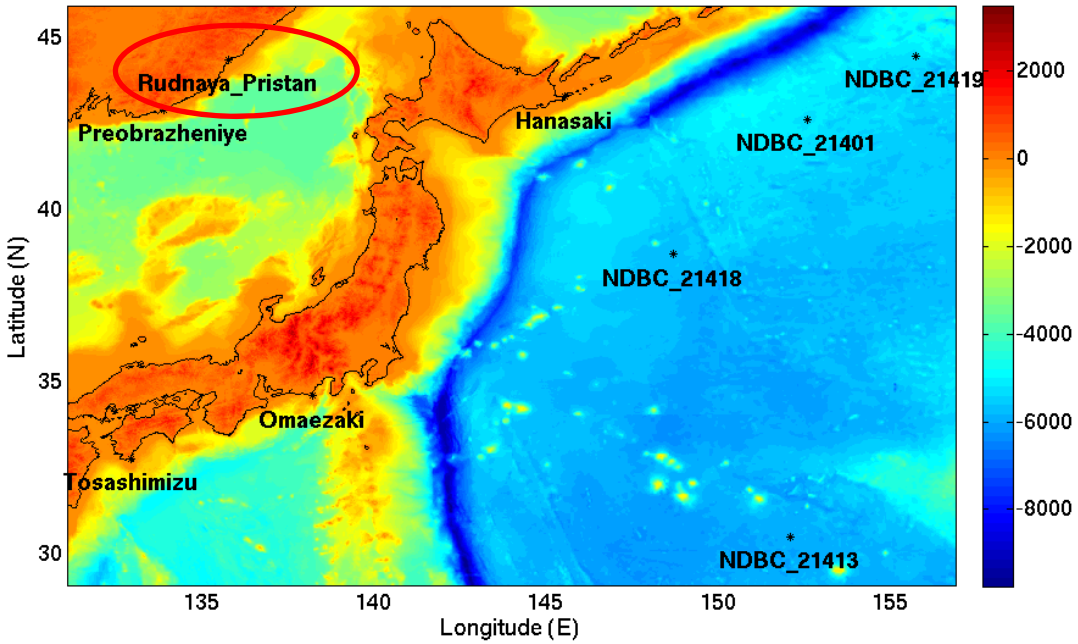
模式預測之海嘯波高與美國NOAA深海浮標實測比對：NDBC_21419



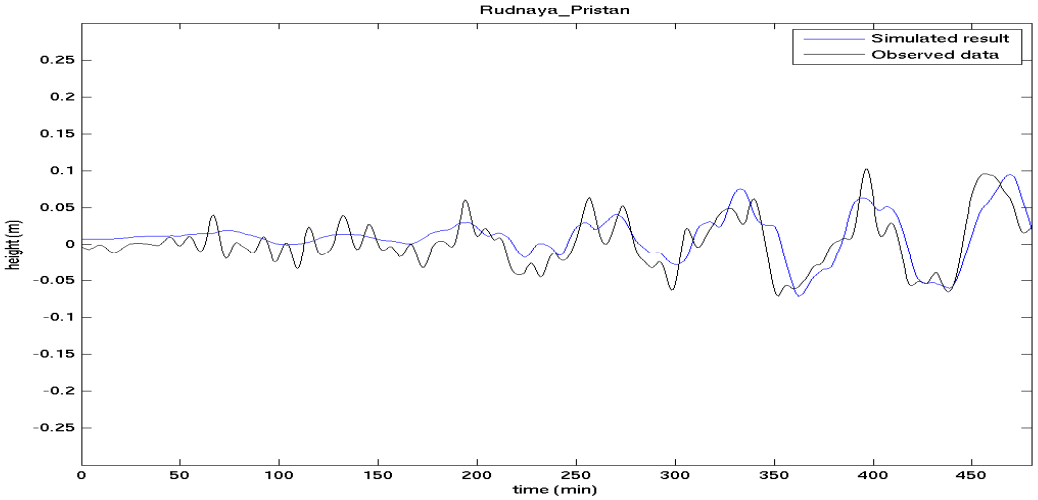


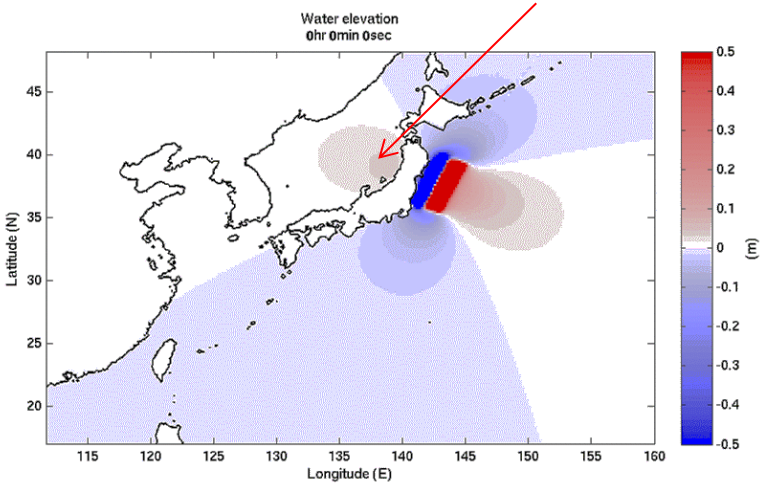
與NOAA浮標資料比對，藍線為模擬結果，黑線為實測資料。模擬結果與實測比對相當一致。

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）

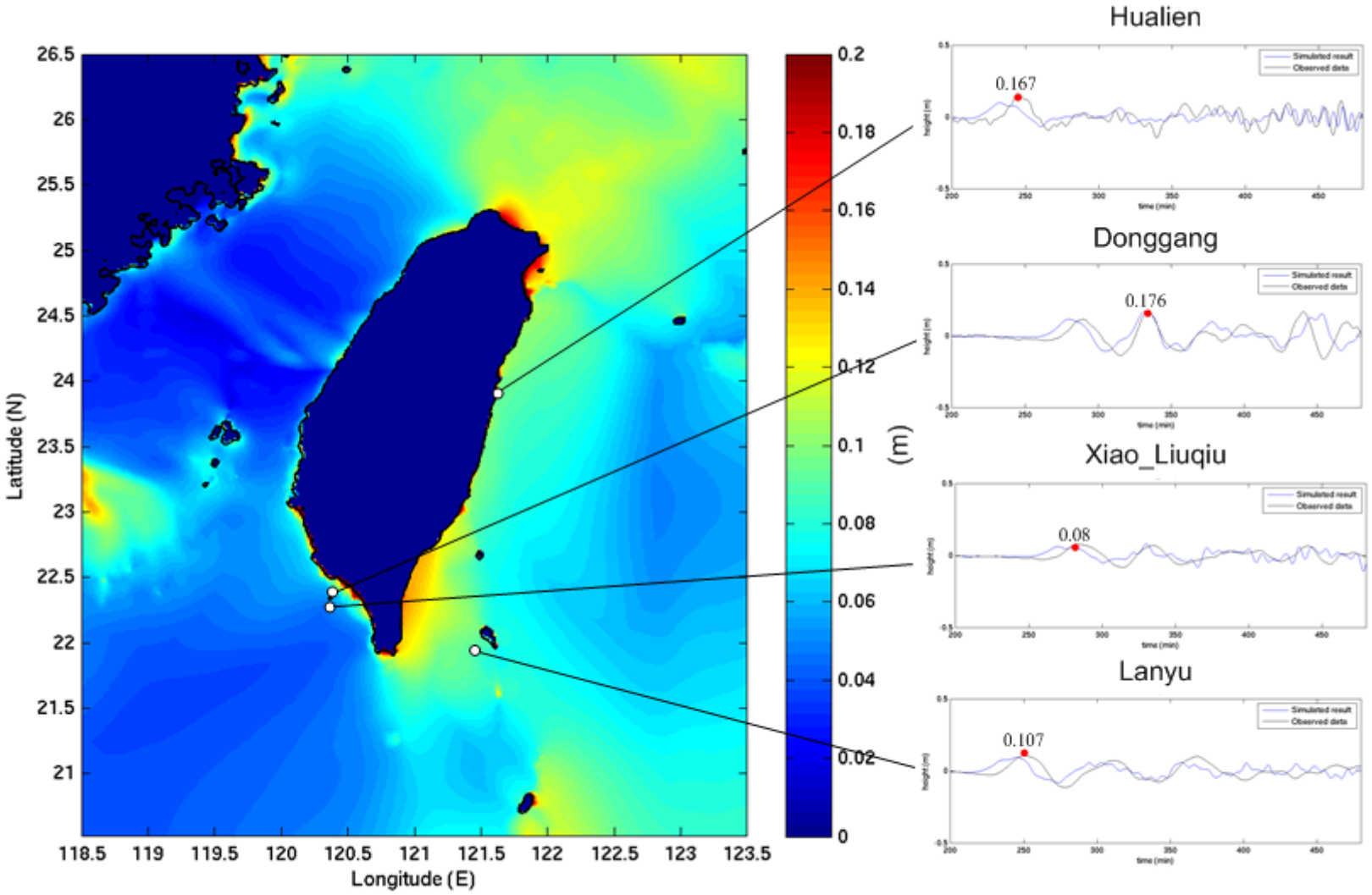


西海岸海床抬昇





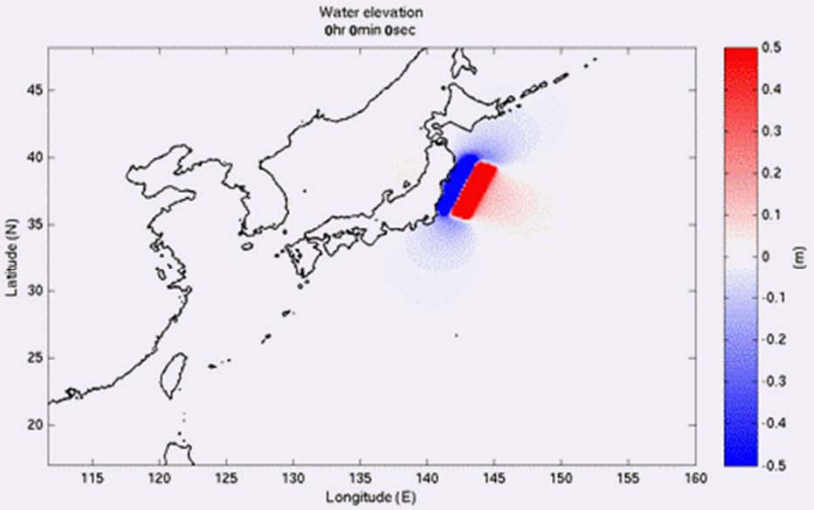
模式預測之海嘯波高中央氣象局潮位站資料比對

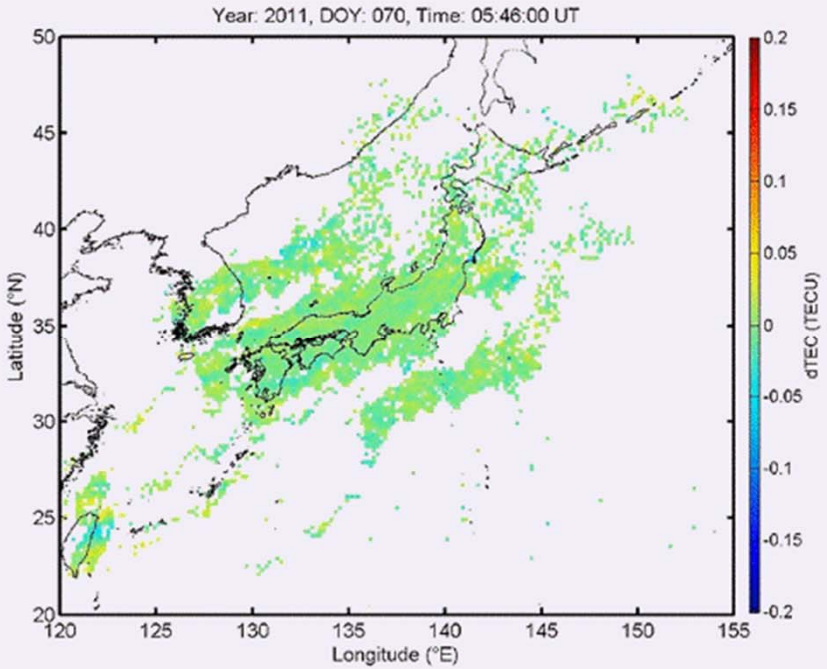


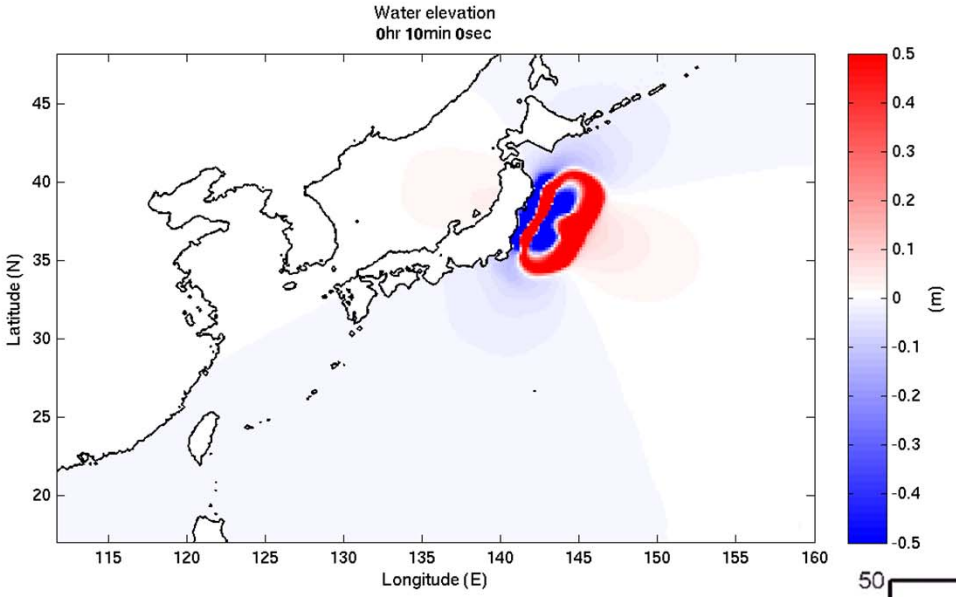
台灣測站比對。比對花蓮、東港、小琉球、蘭嶼四個測站，結果相當理想。（藍線為模擬結果，黑線為實測資料，資料提供：中央氣象局）

好準！

海嘯模擬與電離層訊號比對

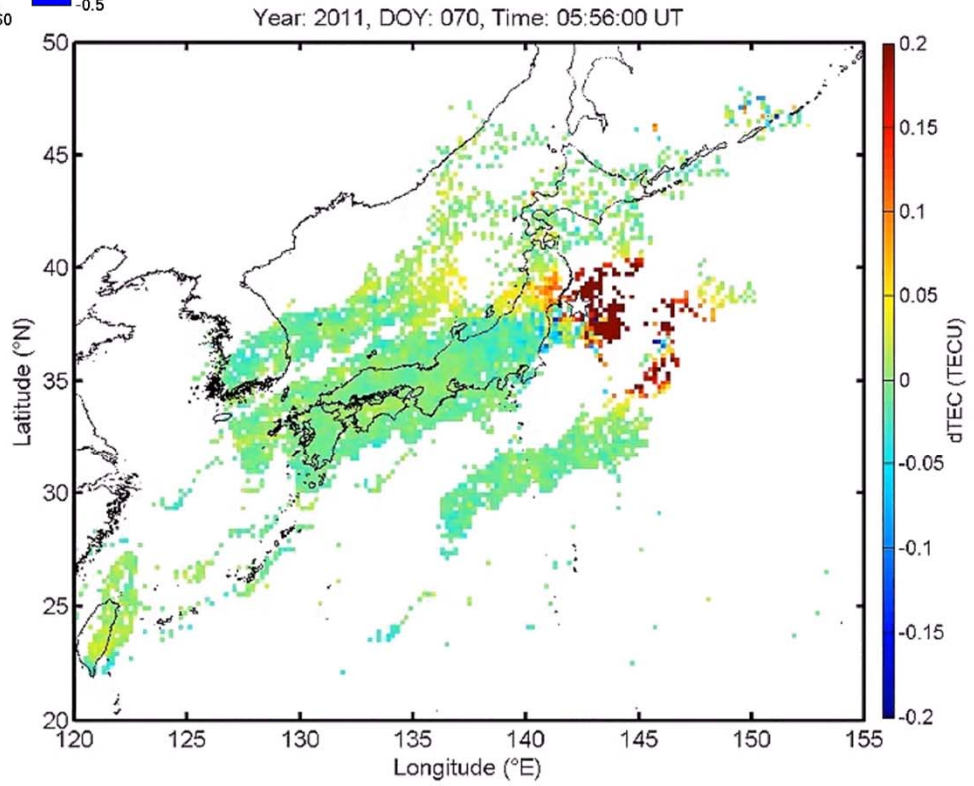


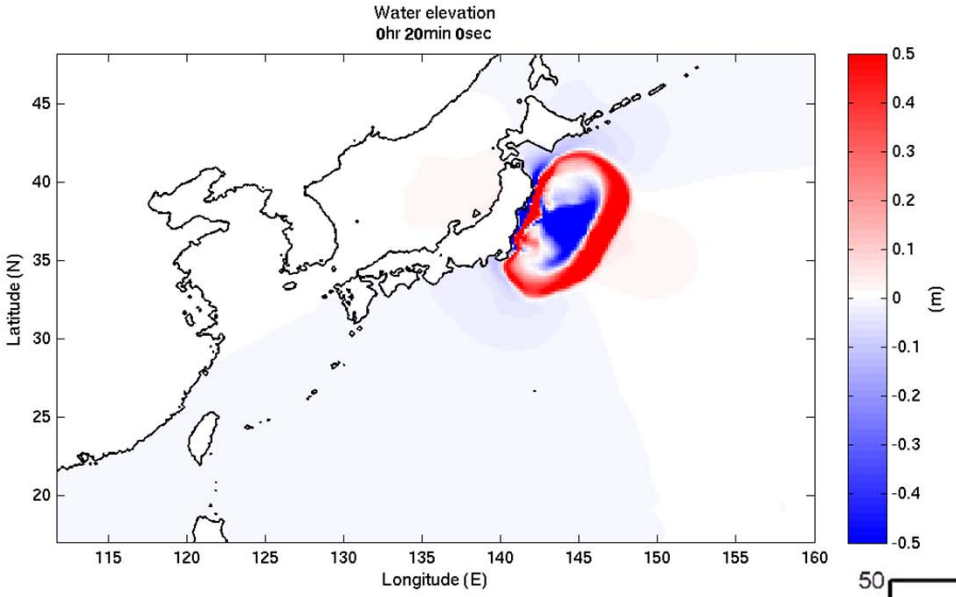




地震後10分鐘

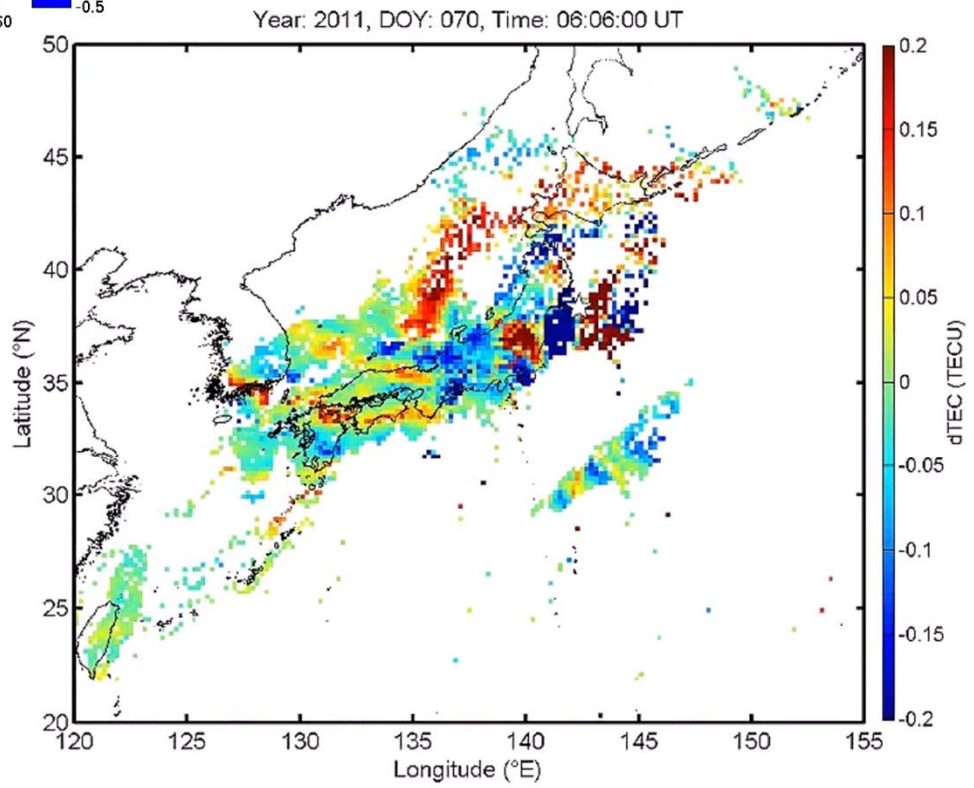
地震初期，電離層訊號包含地震波與海嘯波。

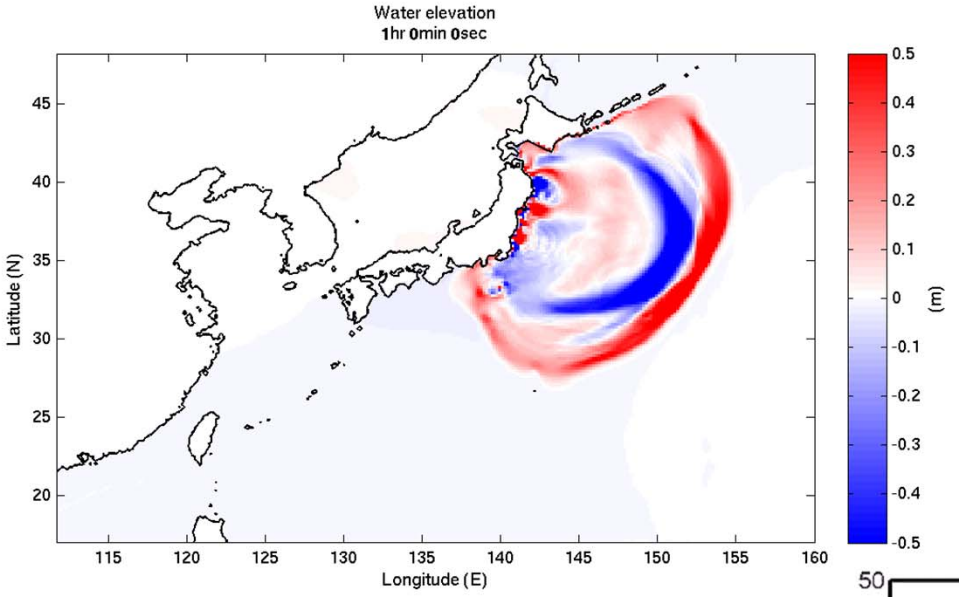




地震後20分鐘

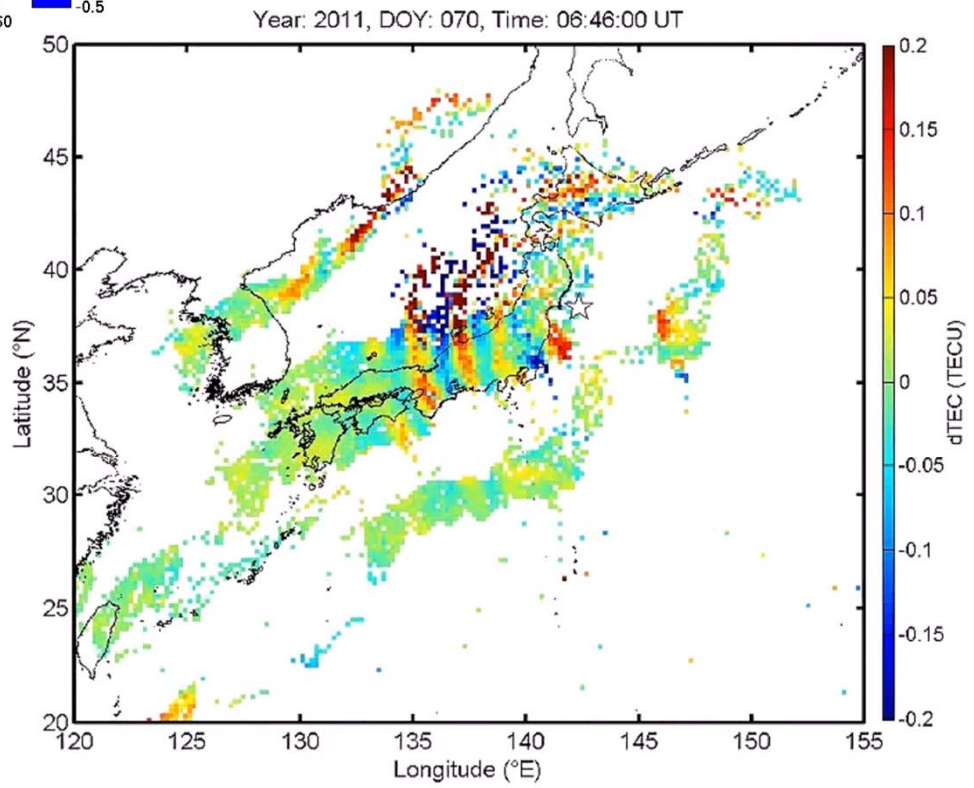
地震發生20分鐘後，地震波迅速向外傳播，海嘯波則傳遞致福島外海。電離層之訊號明顯顯示此現象。

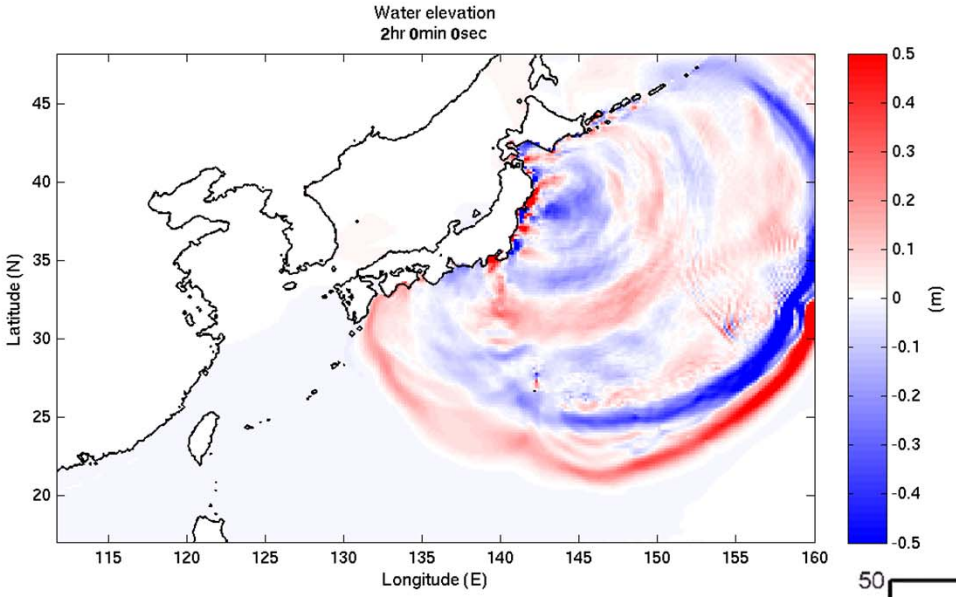




地震後1小時

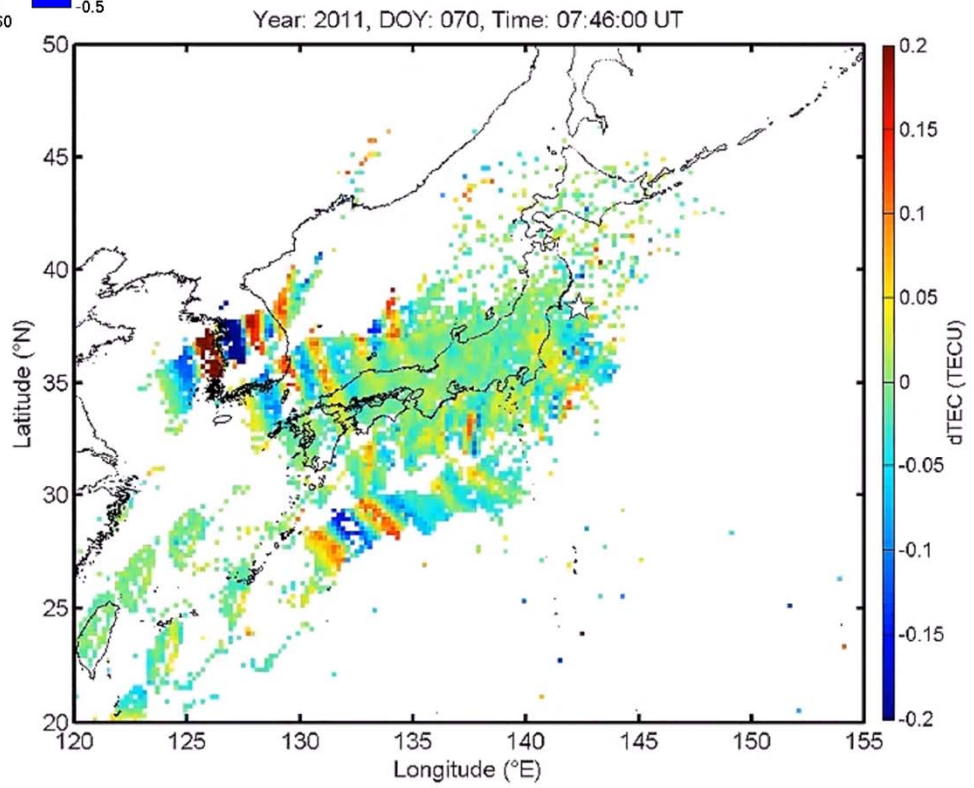
地震發生後1小時，海嘯持續往南傳遞，電離層之訊號與海嘯波訊號相當吻合。





地震後2小時

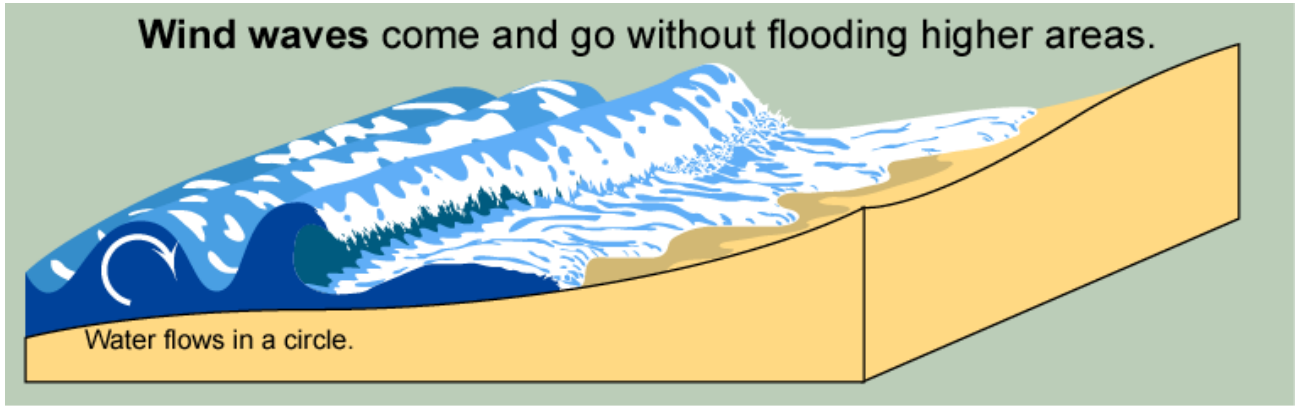
地震發生後2小時，海嘯傳遞至琉球島弧，電離層之訊號與海嘯波訊號亦相當吻合。

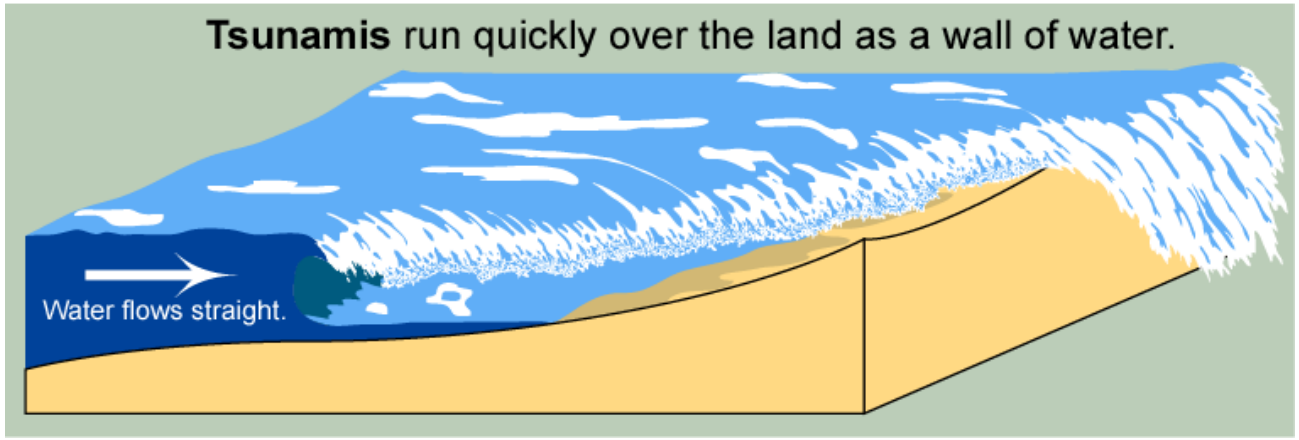


但是這樣就夠了嗎？
盲點在哪裡？

- 只能知道海嘯到達岸邊的浪高，卻無法知道海嘯進入內陸的情形
- 哪一部分才是跟人們有直接關係？

海嘯上岸後即由長波轉換成像水牆的湧潮
此時破壞力最強，然而計算上卻極為困難
（謎之音：電影上不是已經有很多動畫了嗎？怎麼會難呢？）





求解牛頓第二運動定律

- F=ma
  - 適合於追蹤有限體積固體運動
- 雷諾轉置後
  - Navier-Stokes equations

$$\frac{\partial u_i}{\partial x_i} = 0$$

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial \rho u_i u_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} + \rho g_i$$

$$\tau_{ij} = \mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$$

海水運動具有海表面，
然而海表面的位置也是答案的一部分
為此，我們採用流體體積法（VOF）追蹤海表面運動

$$\frac{\partial \rho_m}{\partial t} + \nabla \cdot (\mathbf{u} \rho_m) = 0$$

$$\rho_m = \frac{M_m}{V} = \left(\frac{V_m}{V}\right) \cdot \left(\frac{M_m}{V_m}\right) = f_m \rho_m^0$$

$$\frac{\partial f_m}{\partial t} + \nabla \cdot (\mathbf{u} f_m) = 0$$

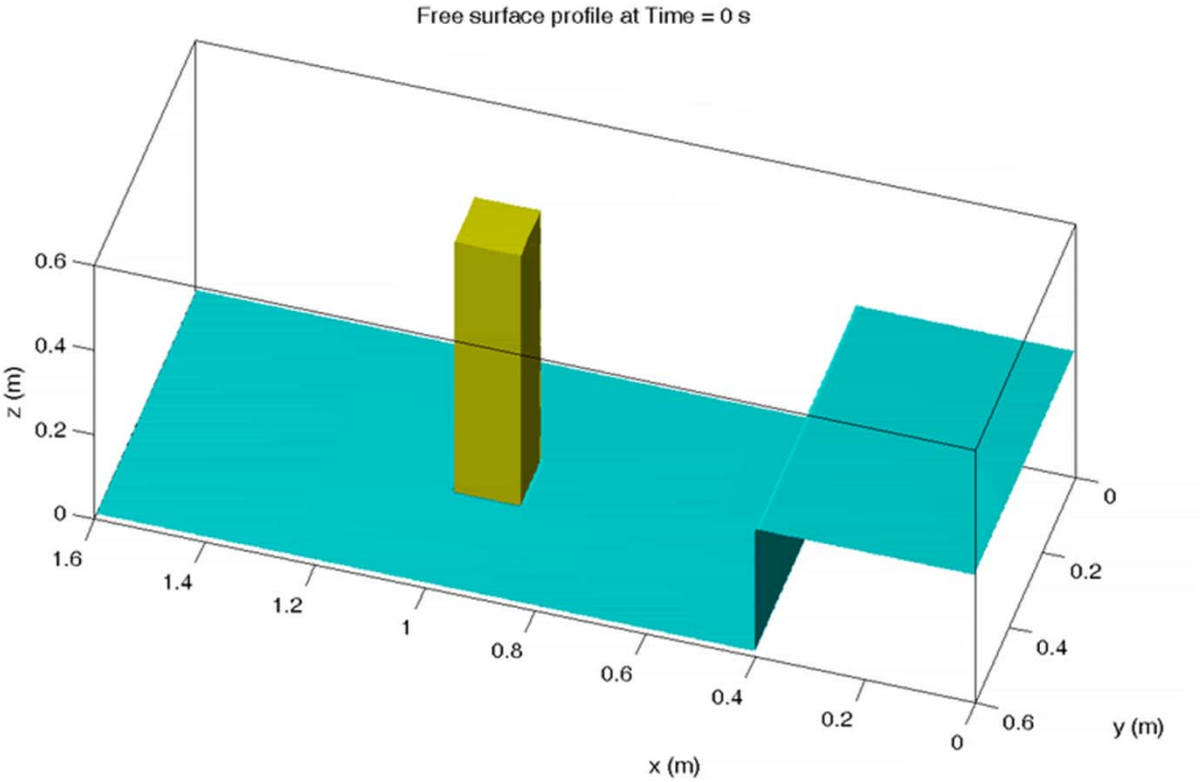
$$\rho = \sum_m \rho_m^0 f_m$$

.2	.02	0	0
1	.8	.7	.5
f =1	1	1	1

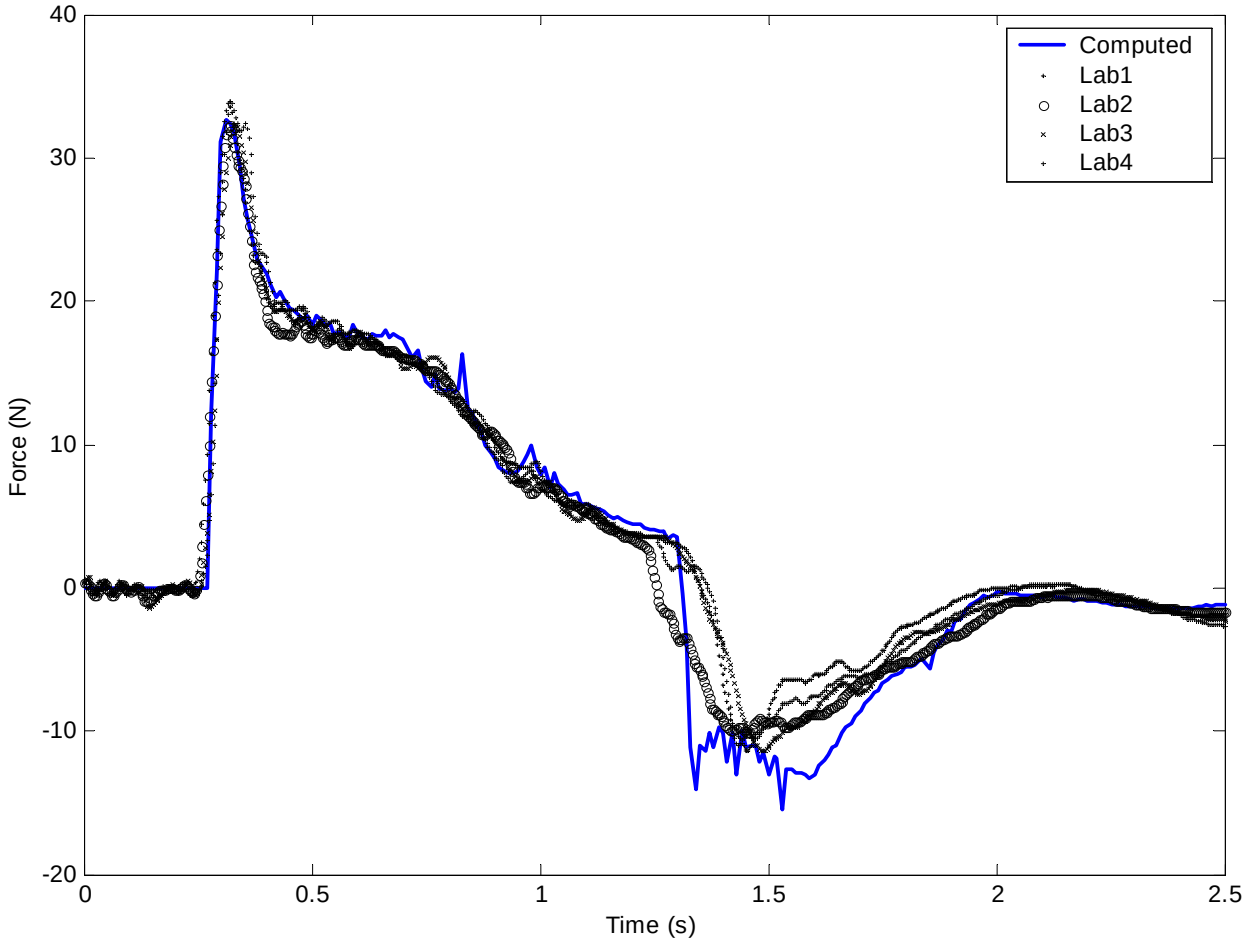
淚望大海「無處去」

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

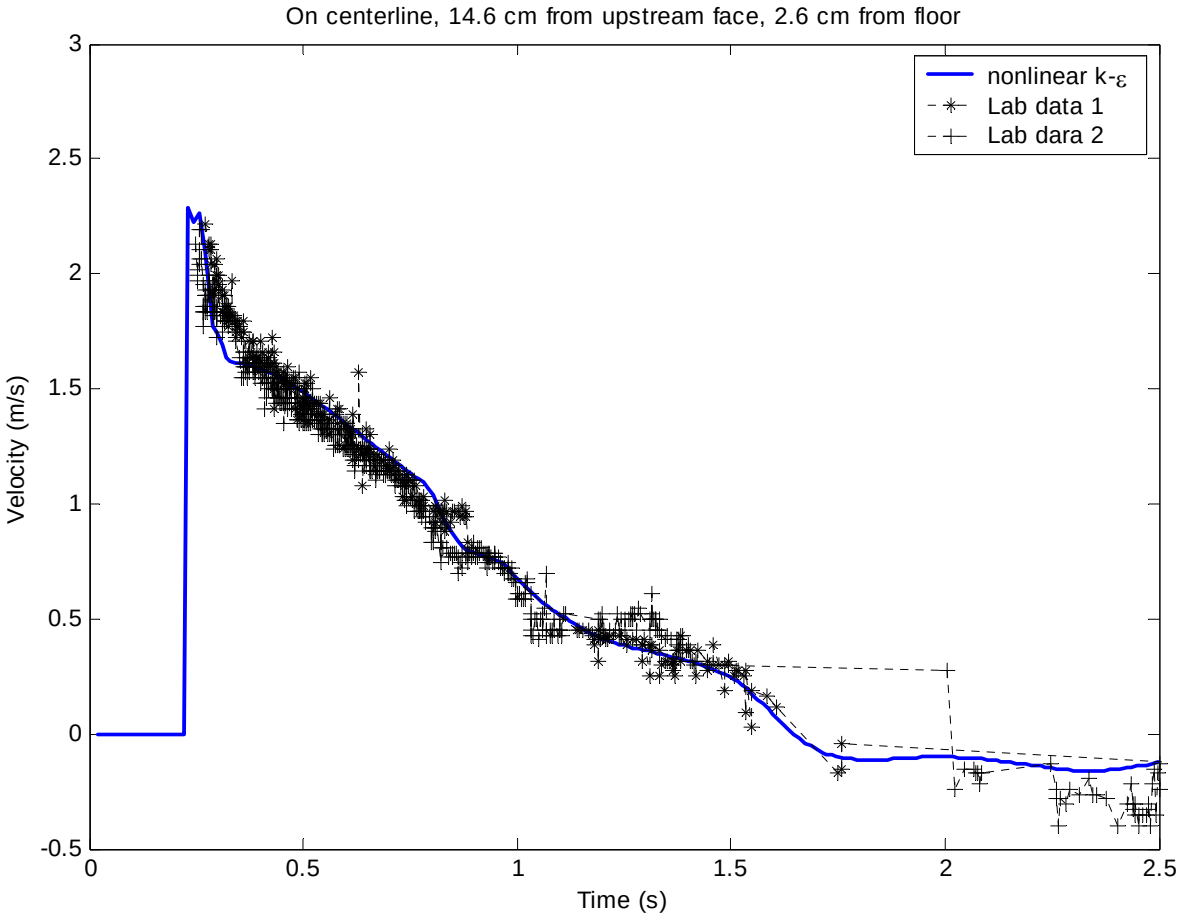
他們親眼目睹岸邊房子瞬間被「炸」毀，2、300人罹難



Total force acting on the square cylinder

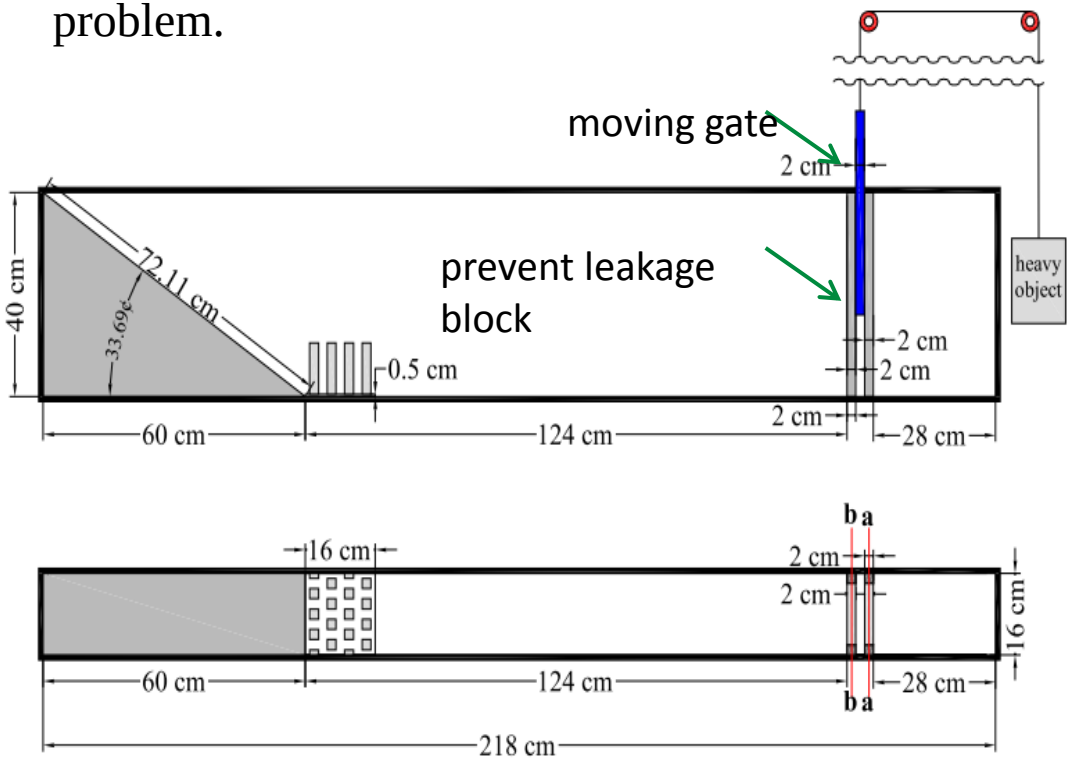


Velocity comparisons

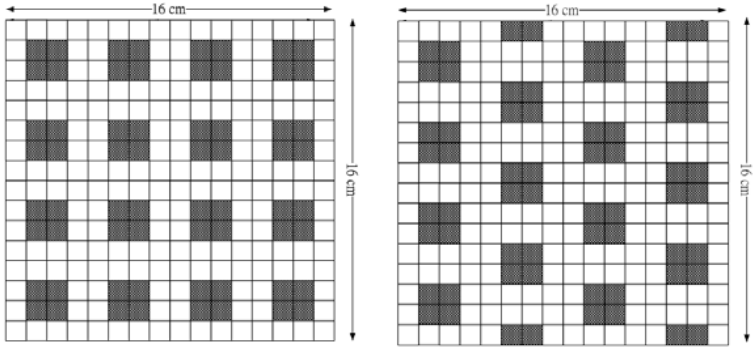


Setup of the Benchmark Problem

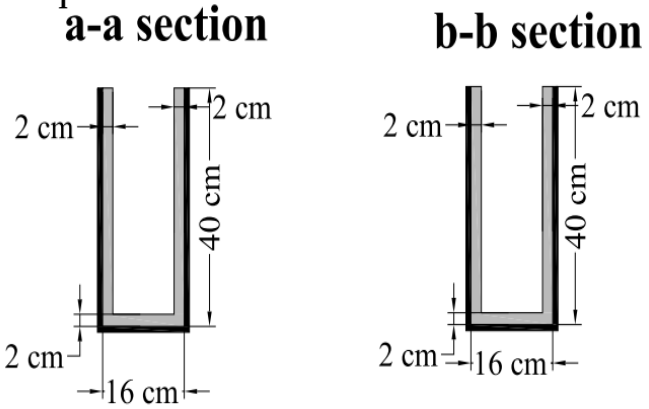
This model shall be easily setup for numerical simulation, and be able to represent the interaction between a bore and a structure array. Moreover, the quantity of dissipated energy shall be easily identified. We focus the comparison on the free-surface kinematics. After the validation, the numerical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



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



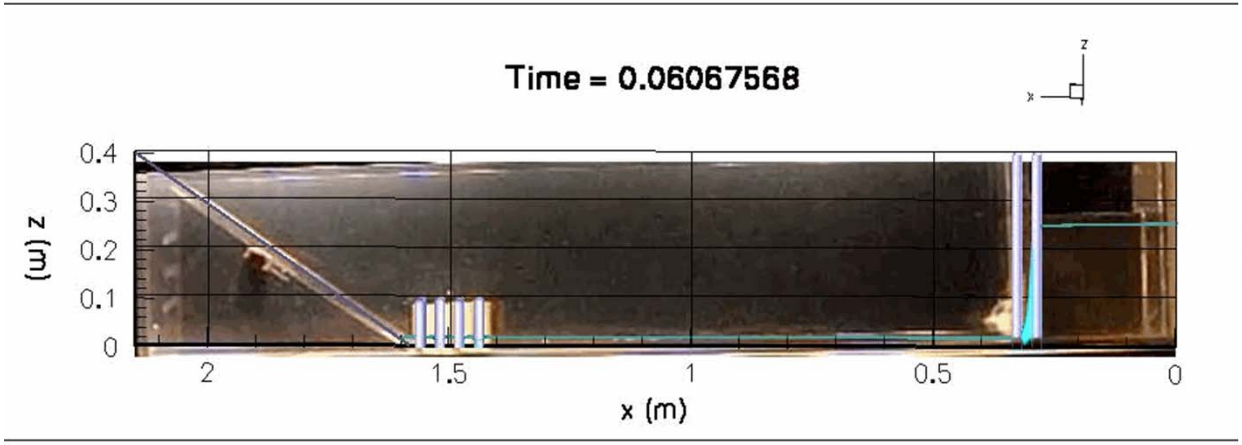
The orthogonal arrange gray part is square column location

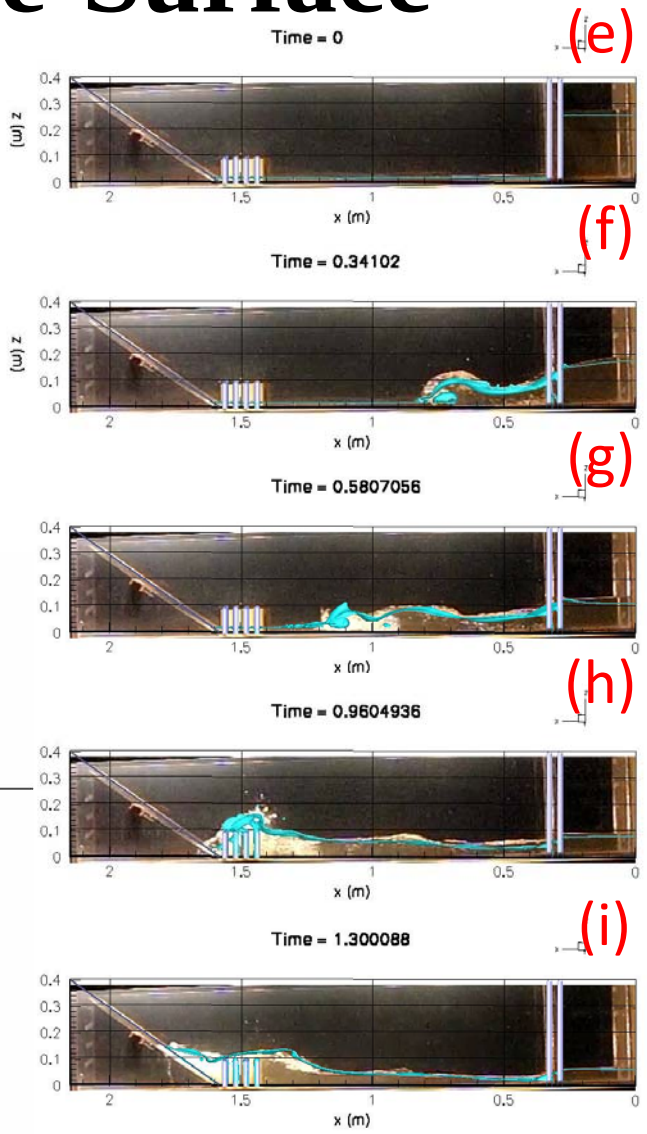


Sectional drawing: gray part is prevent leakage block

Validation on the Free-Surface

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





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

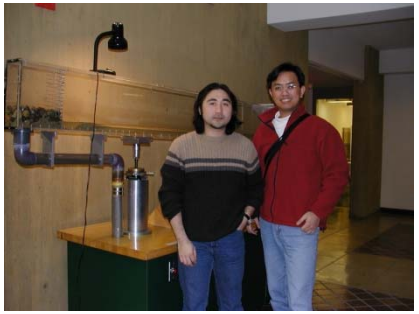
神準！

海嘯淘刷



Serious scouring problem during the tsunami inundation (Photo by Prof. Philip Liu)

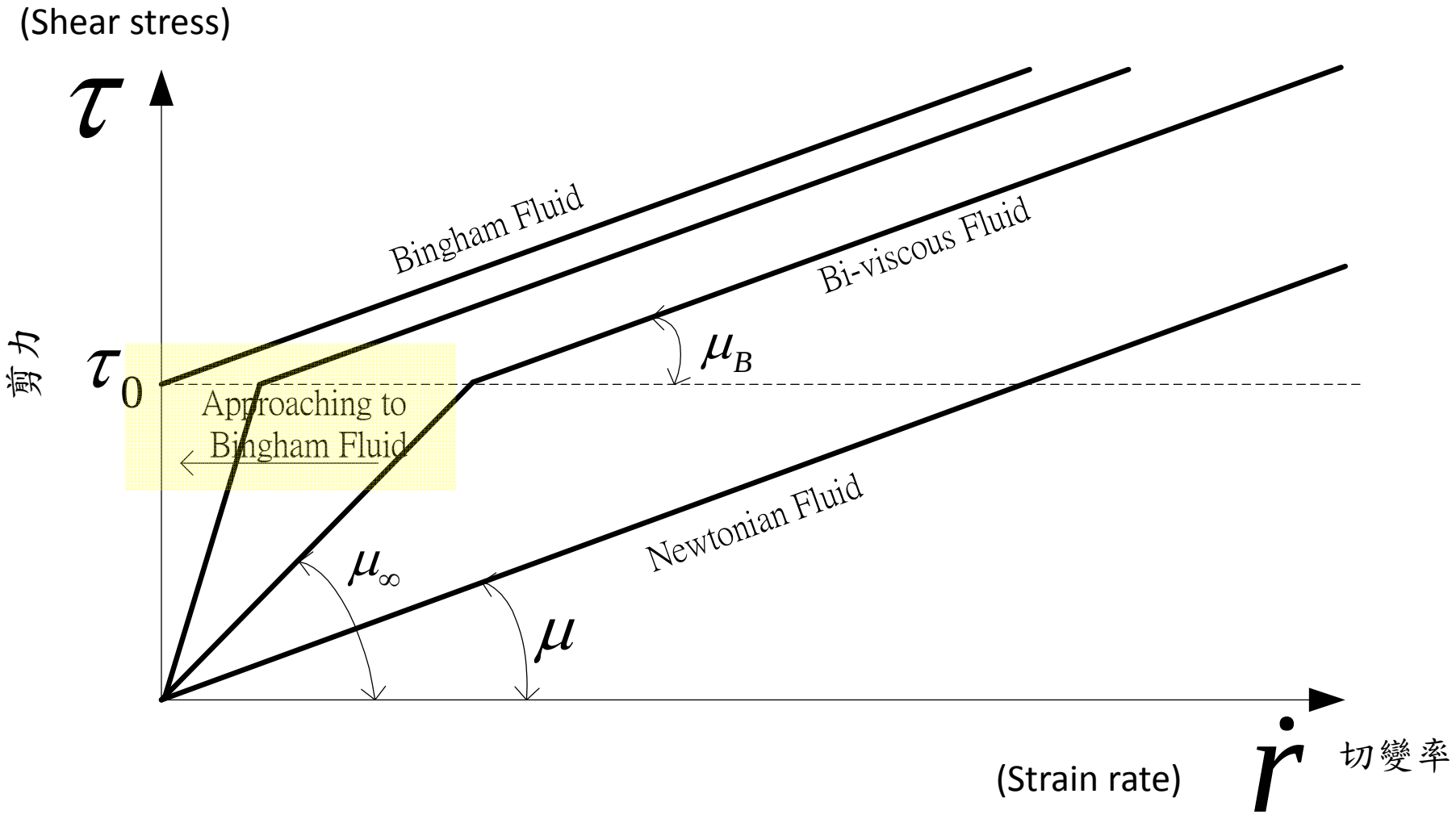




(2002 at Cornell)

Bingham and Bi-viscous Fluids

Bi-viscous becomes Bingham as Mu_inf goes infinite



Bingham Constitutive Model

Shear stress

strain rate

$$\tau = 2\mu(\bar{D})\bar{D}$$

Bingham viscosity

Yield stress (Bingham yield)

$$\mu(\bar{D}) = \begin{cases} \mu_B + \dfrac{\tau_0}{2\sqrt{\frac{1}{2}\bar{D}:\bar{D}}} & \text{if } \frac{1}{2}\tau:\tau > \tau_0^2 \\ \mu_\infty \text{ and } \bar{D} = 0 & \text{if } \frac{1}{2}\tau:\tau \le \tau_0^2 \end{cases}$$

A large number indicating the solid behavior

Model Validation (1): with Analytical Solution

Pressure Gradient Channel Flow (Bird et al. 1983)

Newtonian Fluid

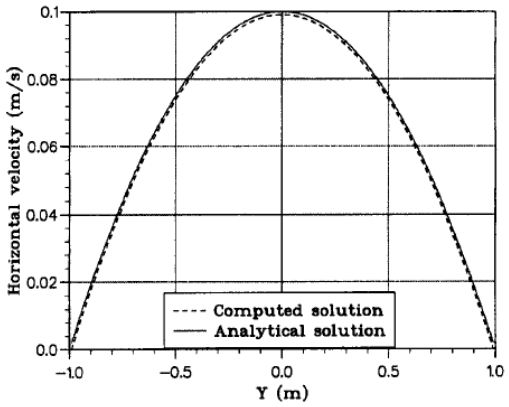


FIG. 2. Comparison between Computed and Analytical Velocity Profiles for Newtonian Fluid

Bingham Fluid

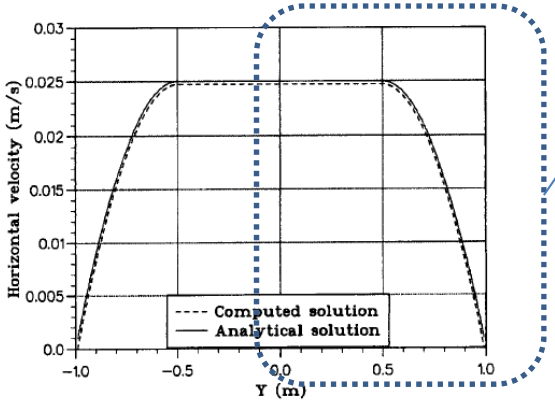
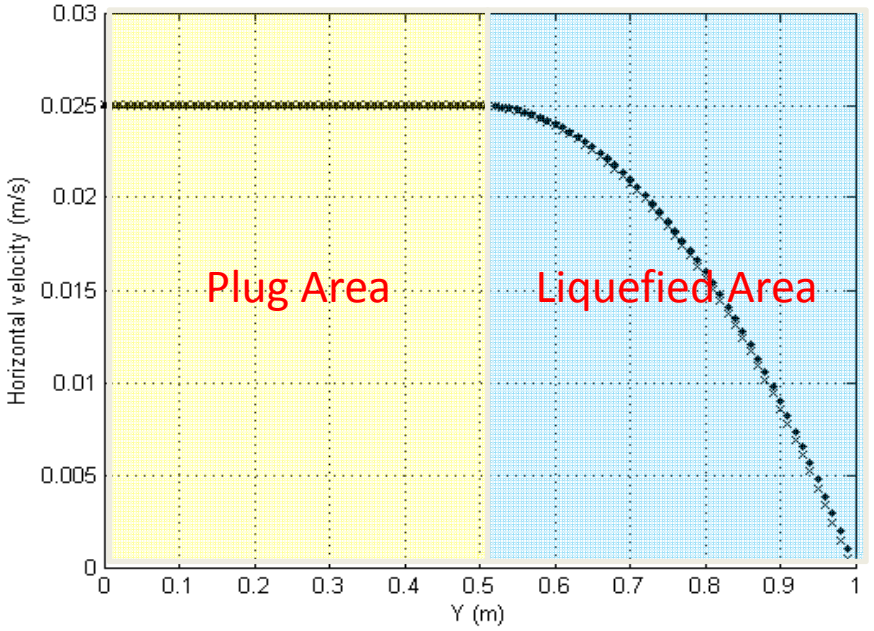


FIG. 3. Comparison between Computed and Analytical Velocity Profiles for Bingham Fluid

Analytical Solution of Bingham Fluid in a Channel

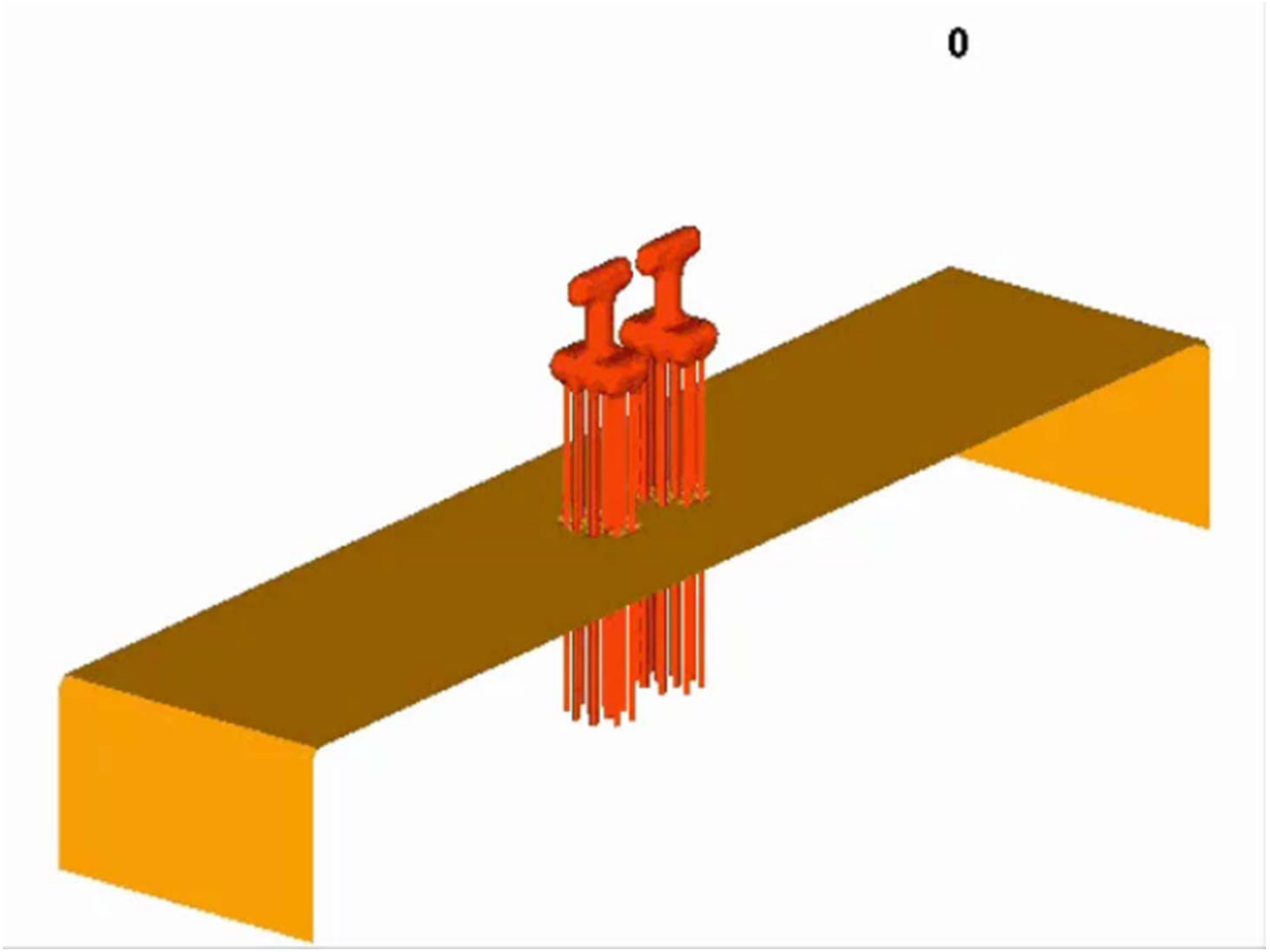
$$u(y)=\frac{(P_0-P_L)B^2}{2\mu_B L}\left[1-\left(\frac{y}{B}\right)^2\right]-\frac{\tau_0 B}{\mu_B}\left(1-\frac{y}{B}\right) \qquad y_0 \le y \le B$$

$$u(y)=u(y_0)=u_M \qquad 0 \le y \le y_0$$



$\mu_B = 5.0\ \text{Pa}\cdot\text{s}$ $\tau_0 = 0.5\ \text{Pa}$

$$\mu_\infty = 1e6\ \text{Pa}\cdot\text{s}$$


0

髒水入侵？



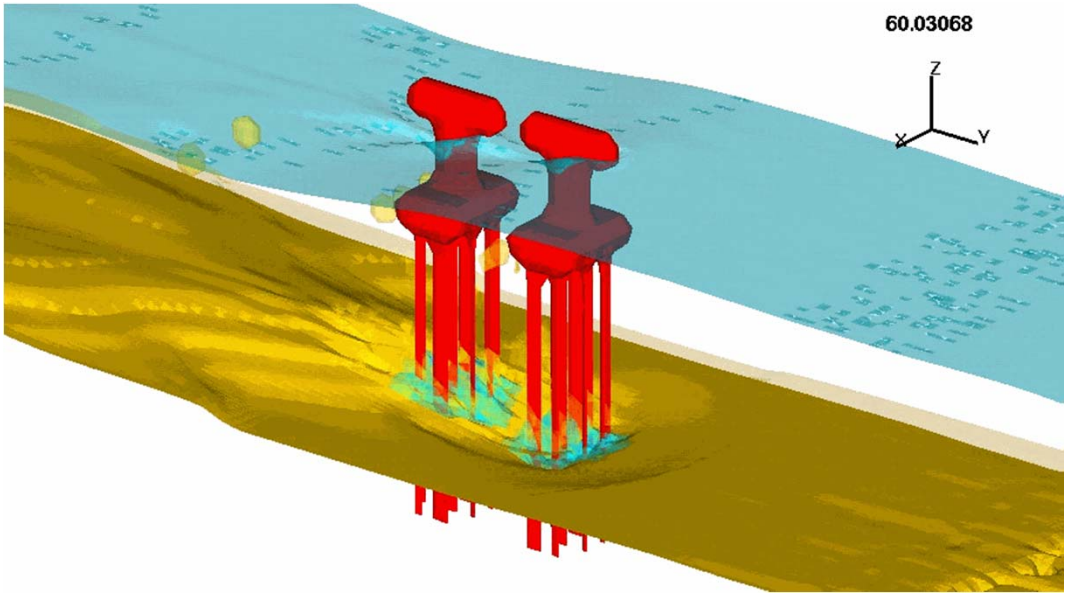
Simulation on
THE FAILURE OF SHUAN-YUAN BRIDGE

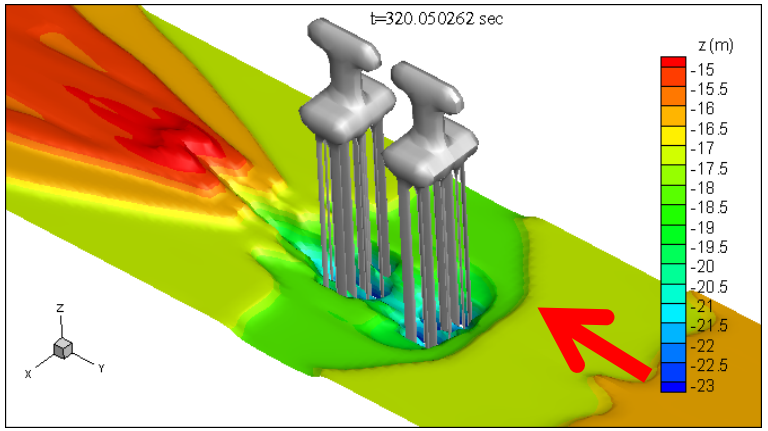
in the event of 2009 Typhoon Morakot

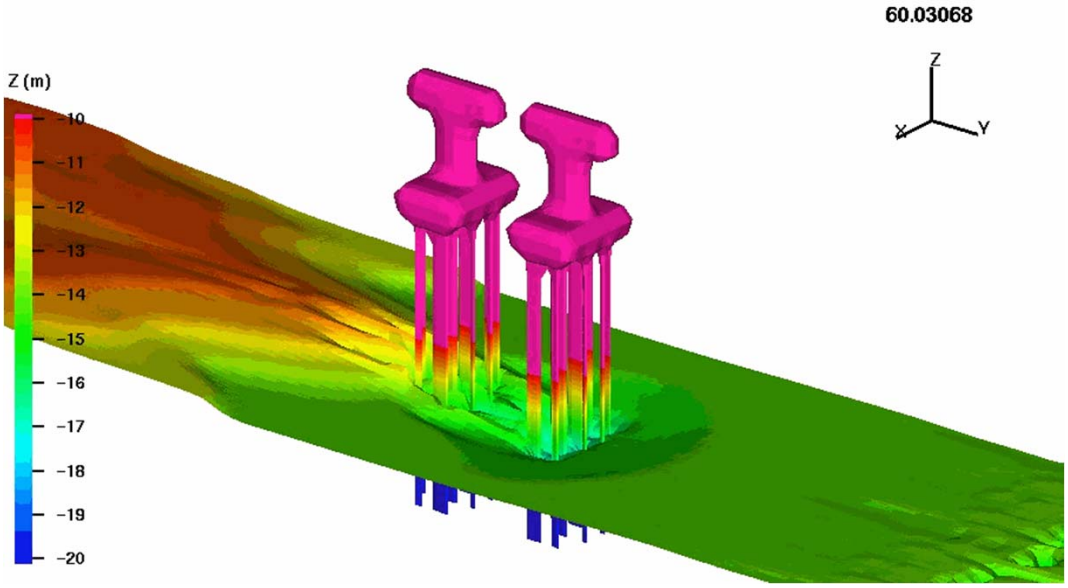


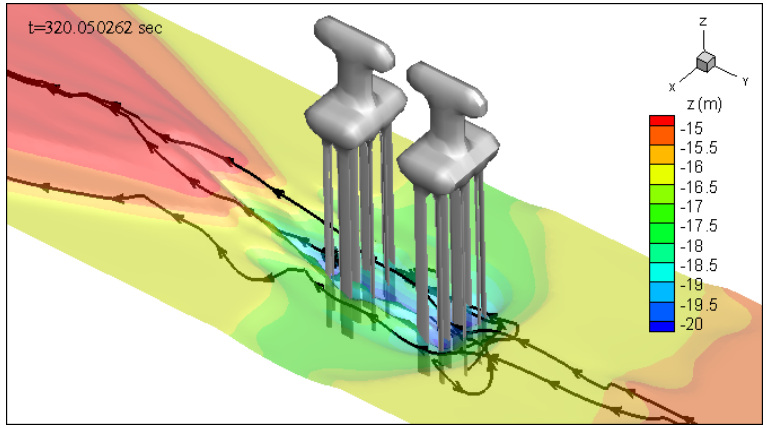
洪水對於橋梁的沖刷

mud_vof =0.05









（陳孟志製）

Comparison to the Field Survey Data

Maximum Scour Depth:

Right in front of the bridge piers:

Field survey: about 23 m.

Numerical: 23 m.

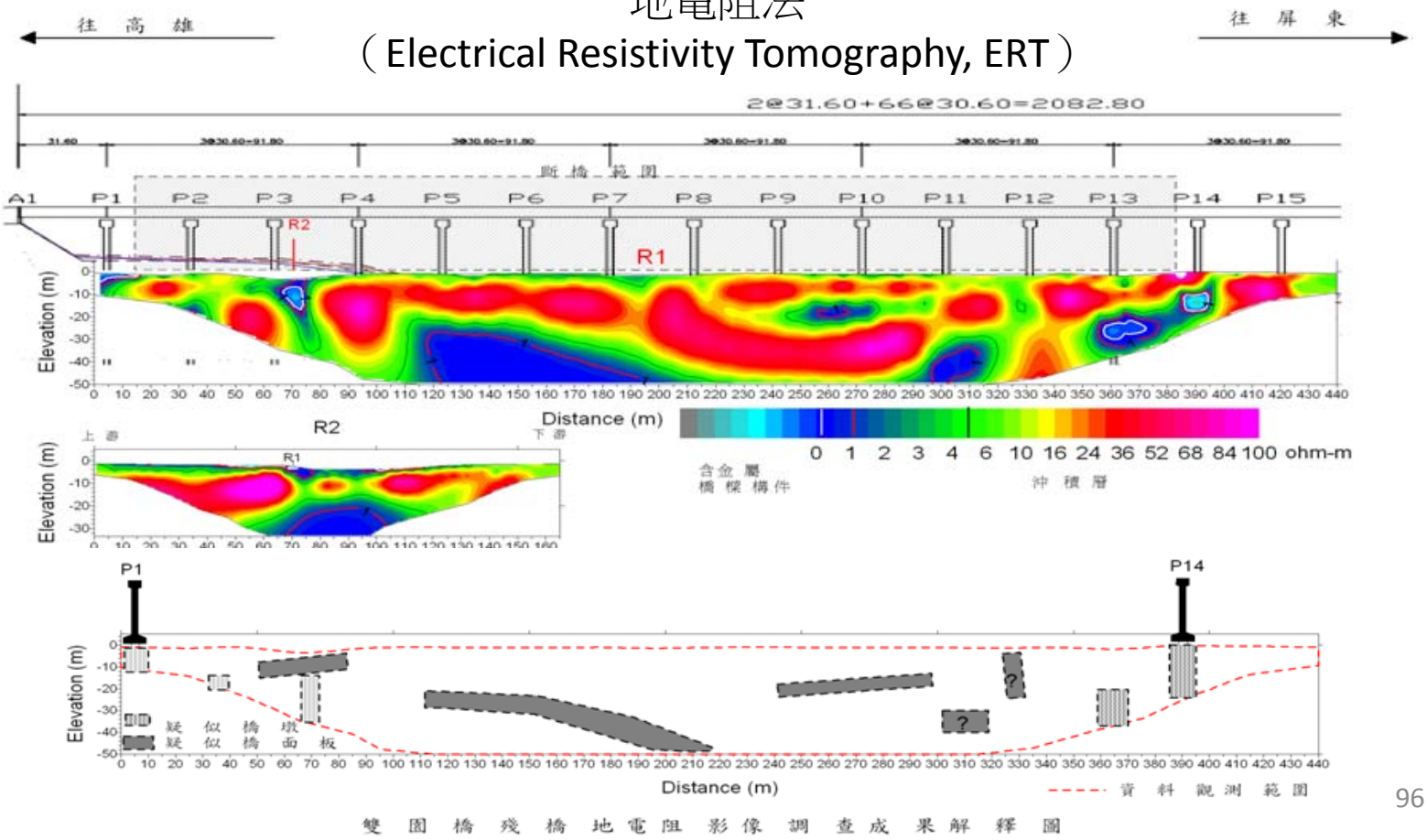
30 m upstream away from the bridge piers:

Field survey: 15 m

Numerical: 15 m

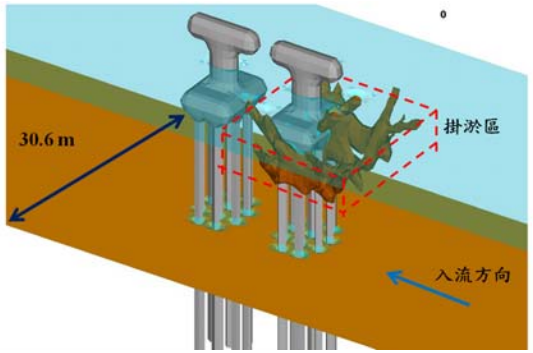
地電阻法

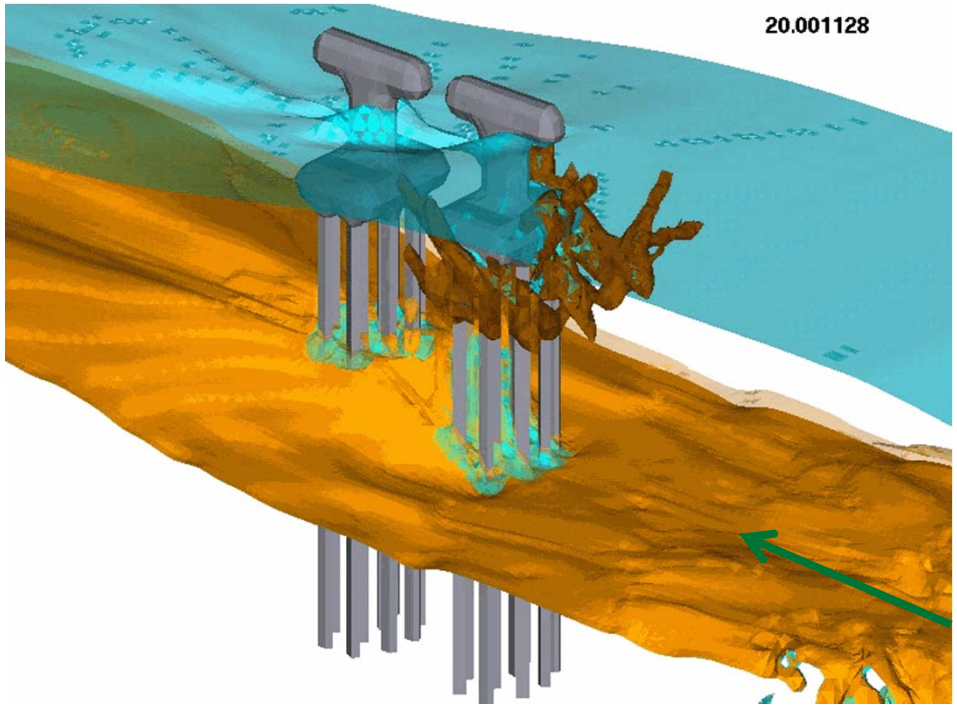
（Electrical Resistivity Tomography, ERT）

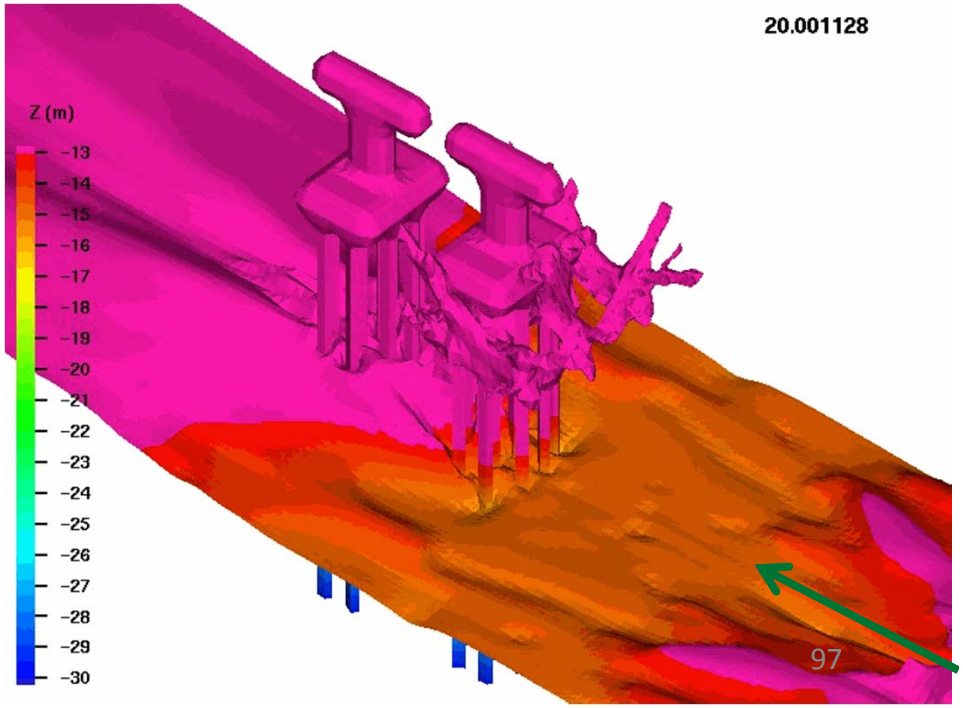


雙 園 橋 殘 橋 地 電 阻 影 像 調 查 成 果 解 釋 圖

可精確模擬沖刷坑之發展，
甚至連浮木掛淤的影響都可模擬



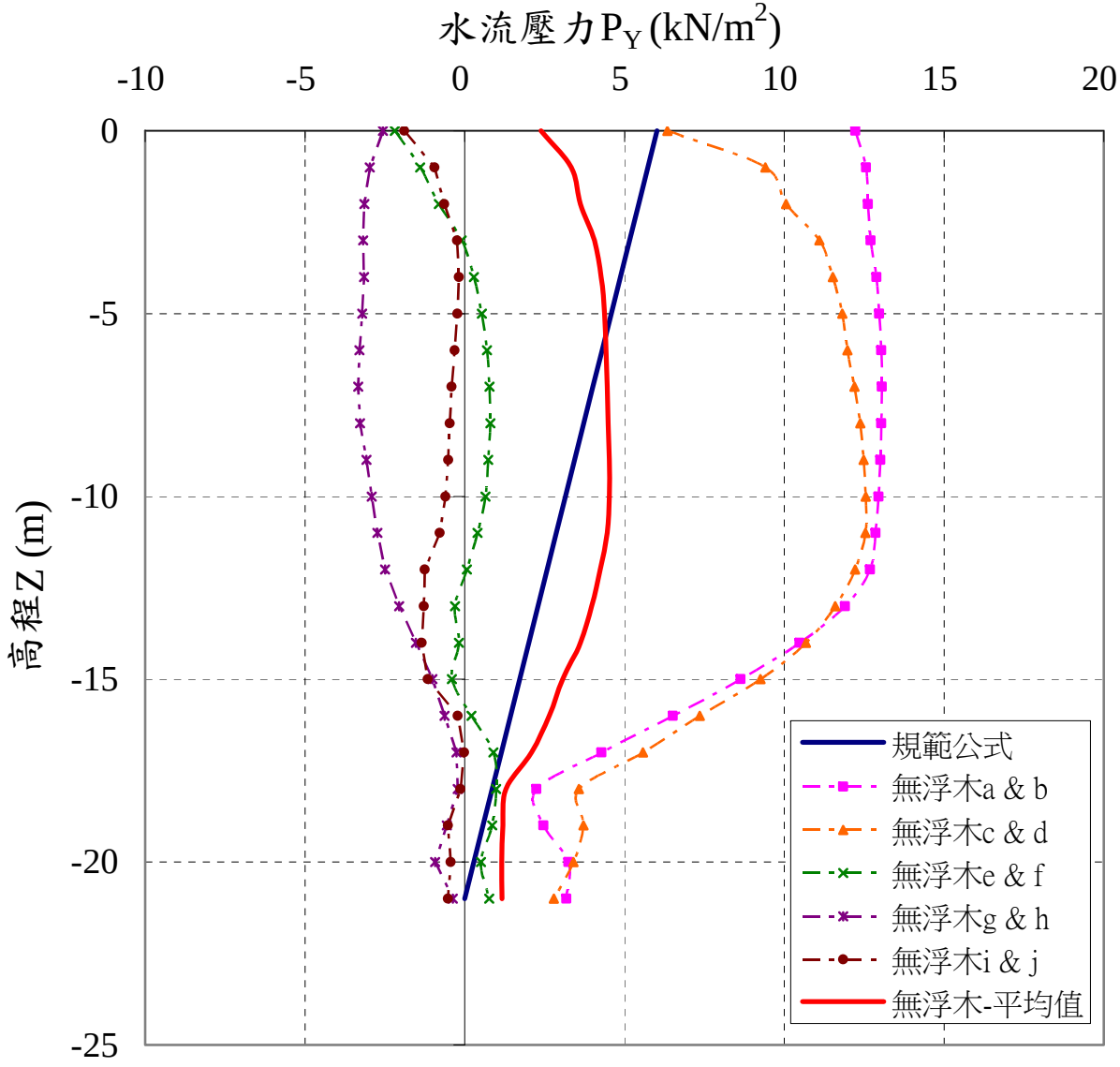


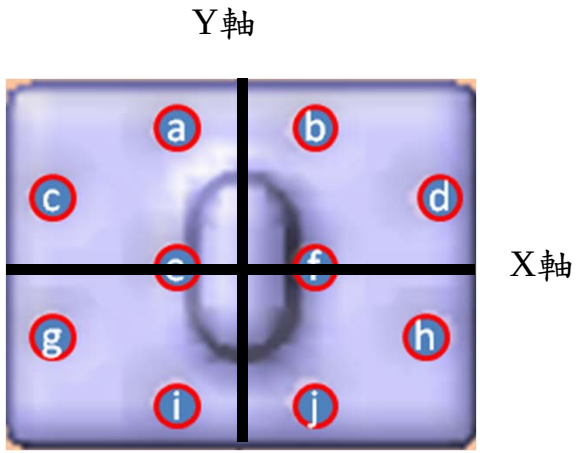


圖中平均值係為 a ～ j 之水流壓力平均值。

基樁水流壓力（無浮木）

傳統受力公式僅能提供平均值，無法掌握局部受力





原有基樁 ：

a、b；e、f；i、j

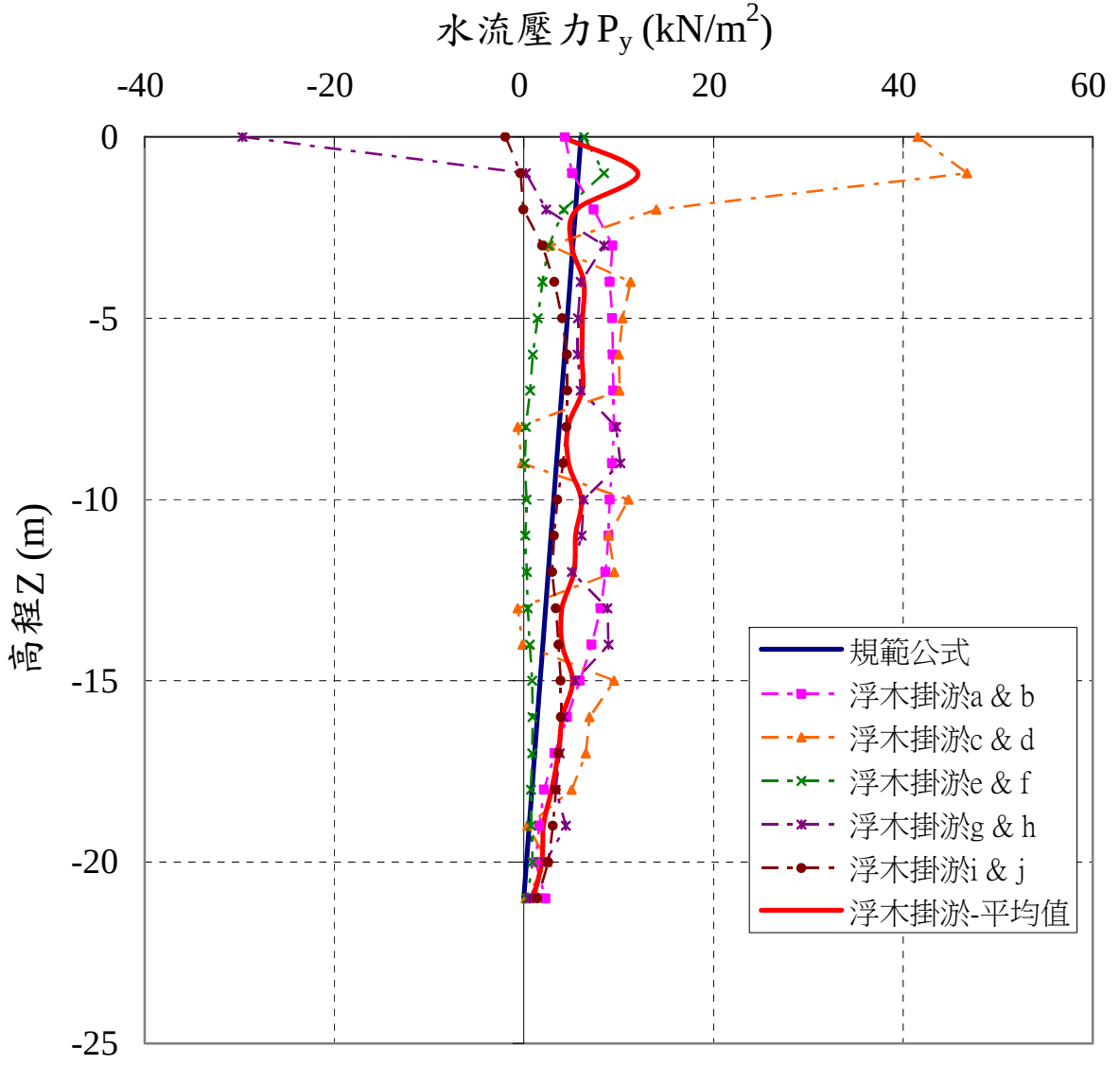
補強新增基樁：

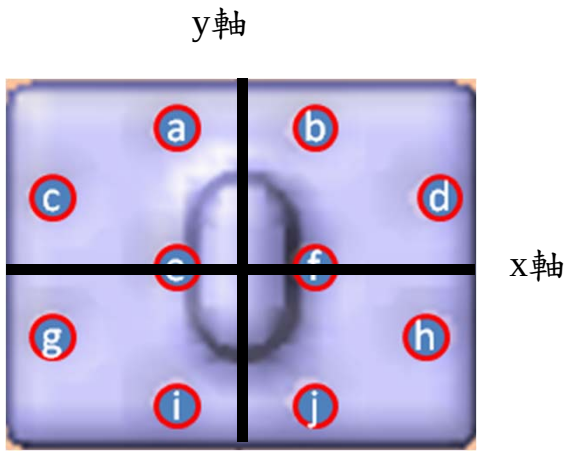
c、d；g、h

基樁水流壓力（含浮木掛淤）

含浮木掛淤時，基樁局部受力變異更為驚人

圖中平均值係為 a ～ j 之水流壓力平均值。





原有基樁 ：

a、b；e、f；i、j

補強新增基樁：

c、d；g、h

浮體（浮木、石塊）運動模擬

固體置於流場中

- 不規則貼壁網格
- 規則網格＋部分網格法(Partial-Cell Treatment)

$$V_{eff} = (1 - f_{solid})V = \theta V$$

$$\theta \frac{\partial(V)}{\partial t} + \nabla \cdot (\theta V V) = -\frac{\theta}{\rho}\nabla p + \frac{\theta}{\rho}\nabla \cdot \tilde{\tau} + \theta \mathbf{g} + \theta \mathbf{F}_0$$

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

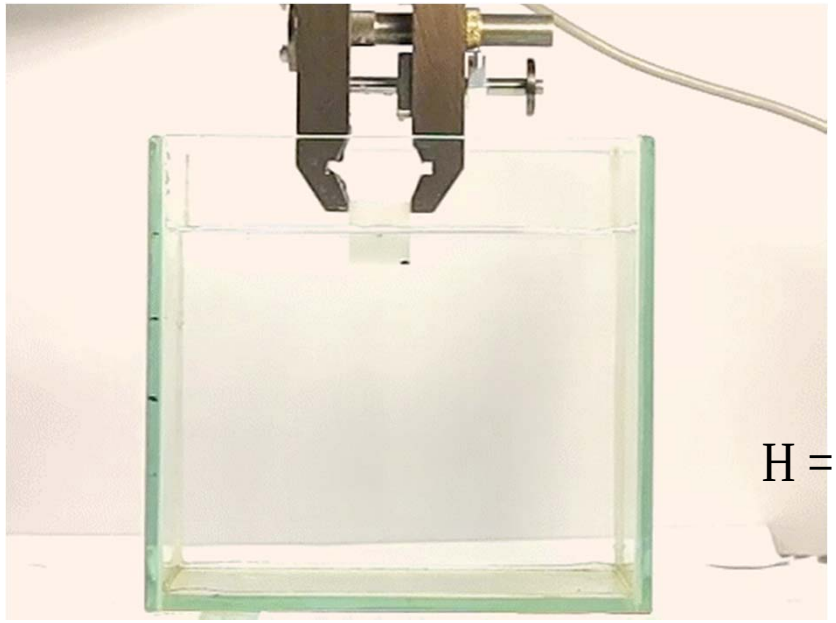
θ為有效體積分率

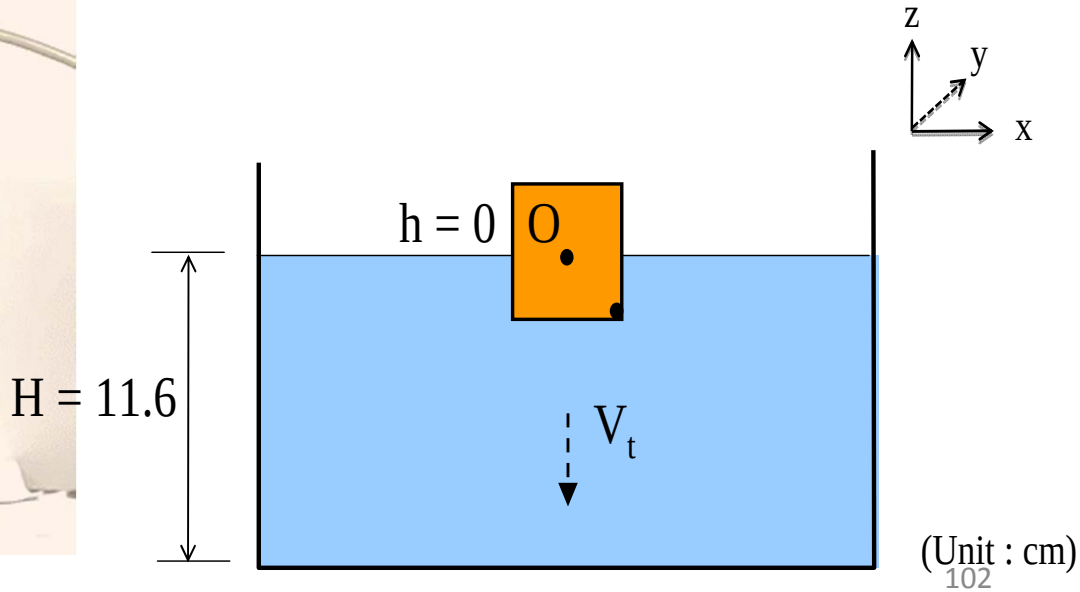
部分網格法優點：

1. 減輕複雜固體時網格建立之困難度
2. 採用孔隙介質概念，可減輕不規則邊界之鋸齒效應

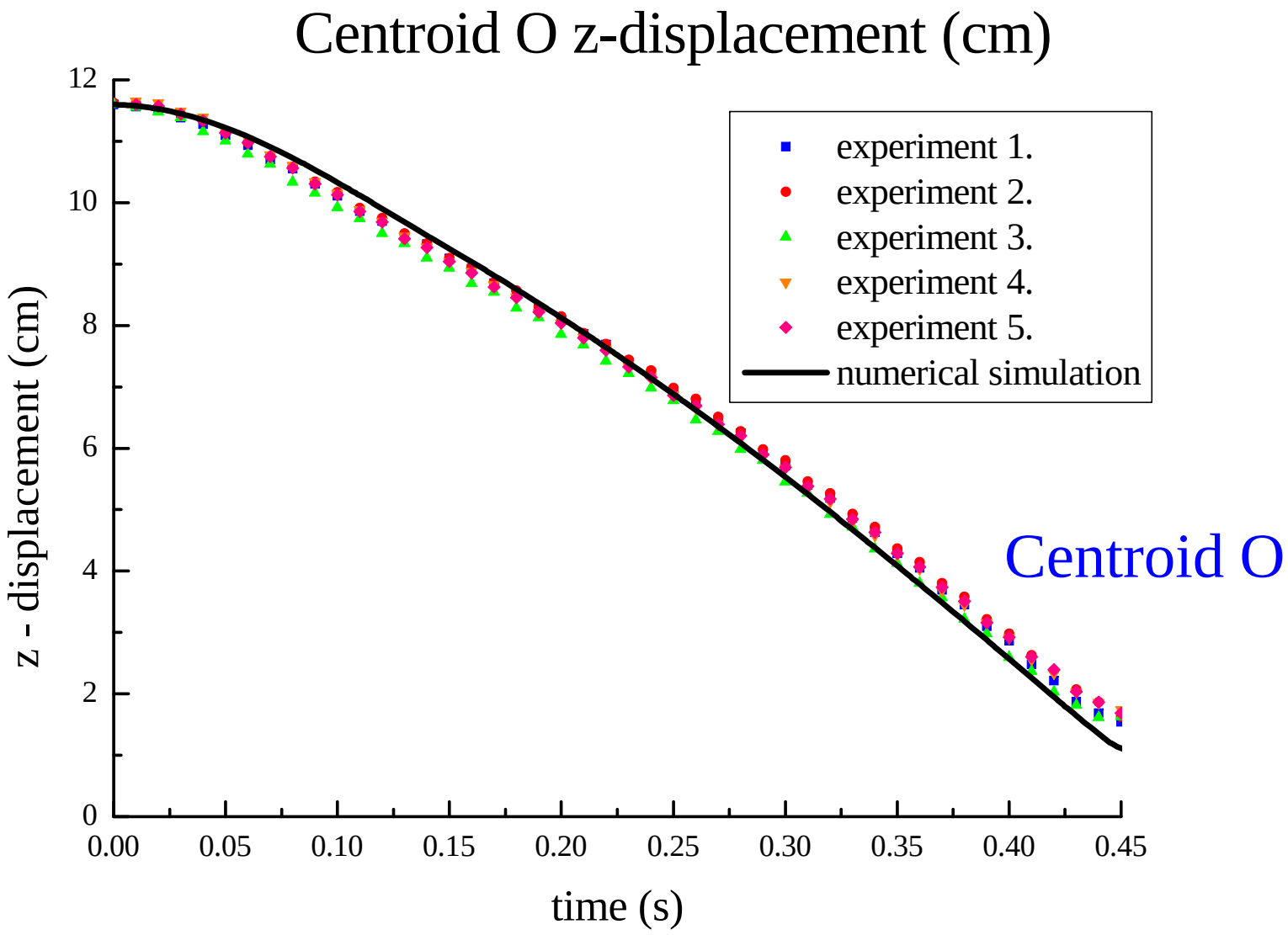
落體試驗 試驗配置

- Water Tank: 15 x 14 x 14 cm
- X = 6.8 cm ; Y = 7.2 cm ; **Z = 11.6 cm**
- Cube: 2.0 x 2.0 x 2.1 cm
- ρs = 1.41 g cm-3
- Temperature: 24.5 ℃ (ρw= 997.22 kg m-3)



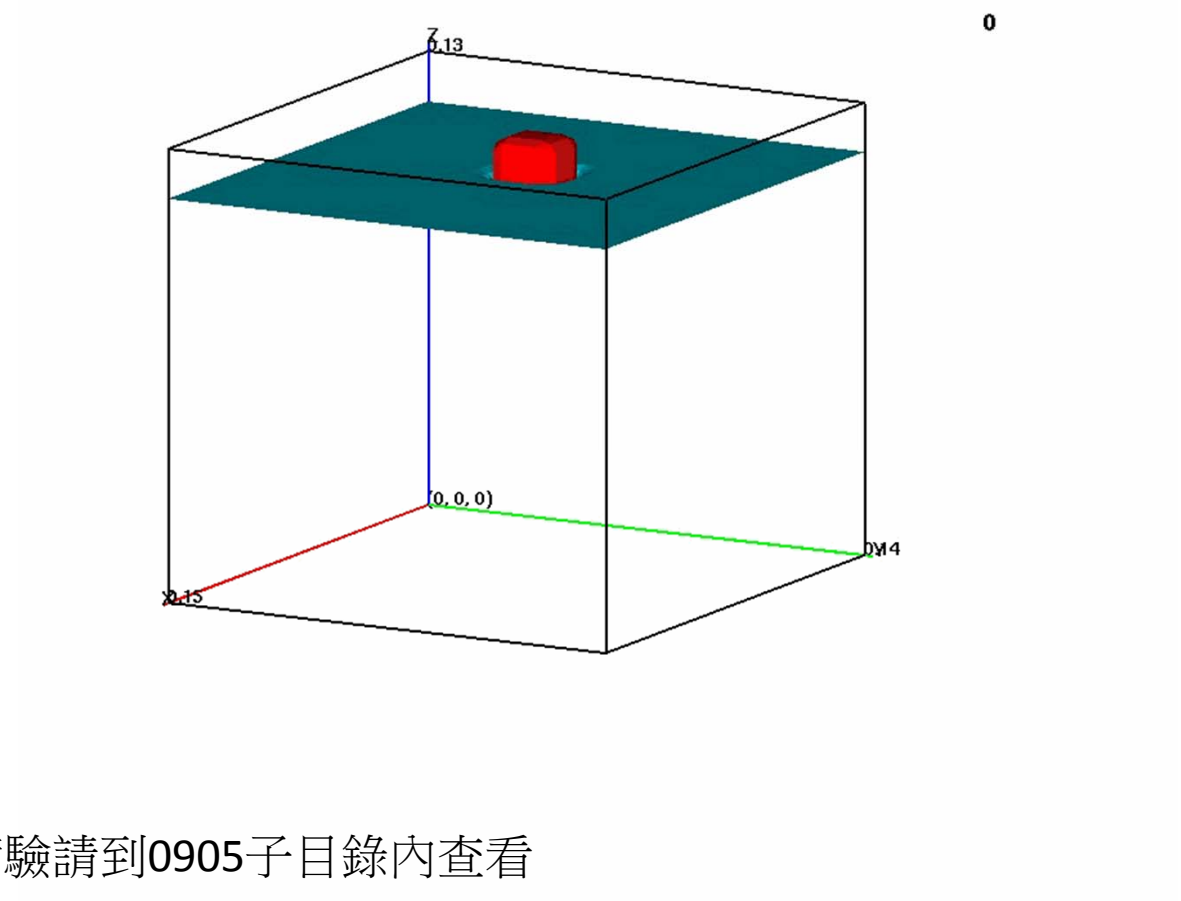


軌跡 z-dir.



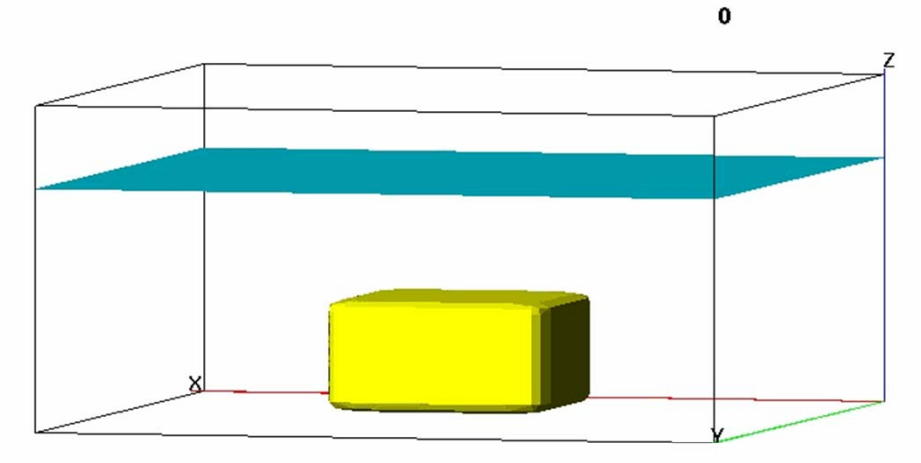
Centroid O

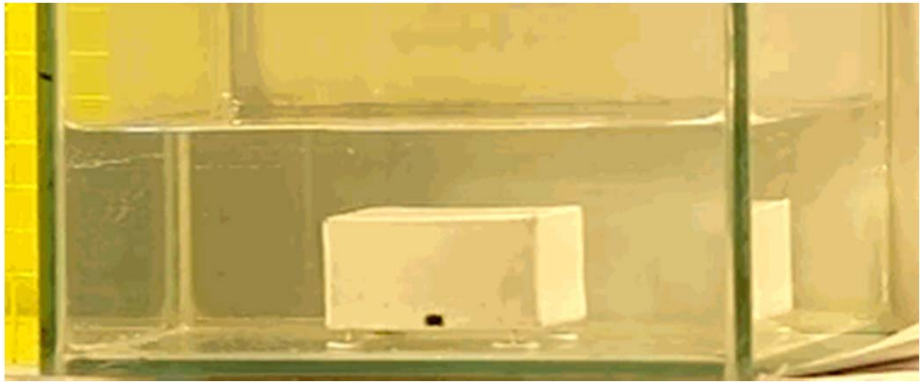
數值分析結果

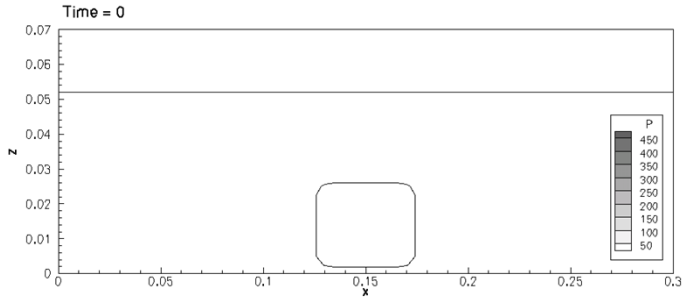


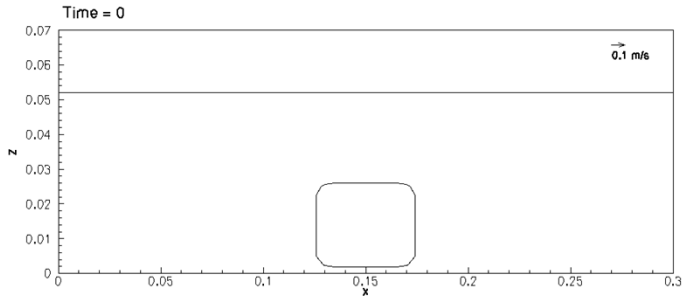
實驗請到0905子目錄內查看

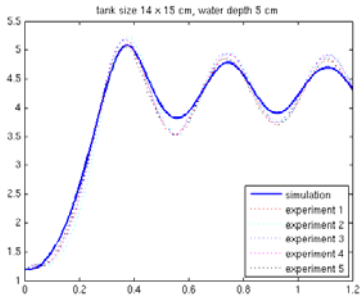
浮體運動模擬

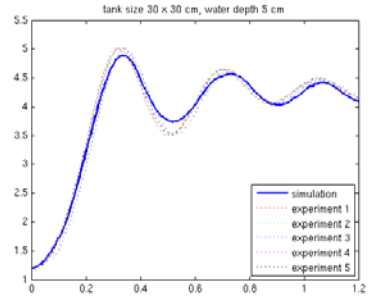












- 渠槽大小：15 x 14 cm、30 x 30 cm
- 網格大小：0.33 x 0.33 x 0.25 cm
- 楔形體：4.8 x 4.9 x 2.4 cm
- 變動條件：渠槽大小

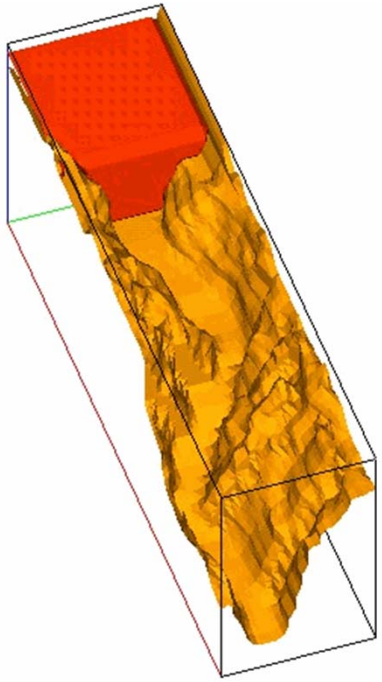
（莊美惠製）

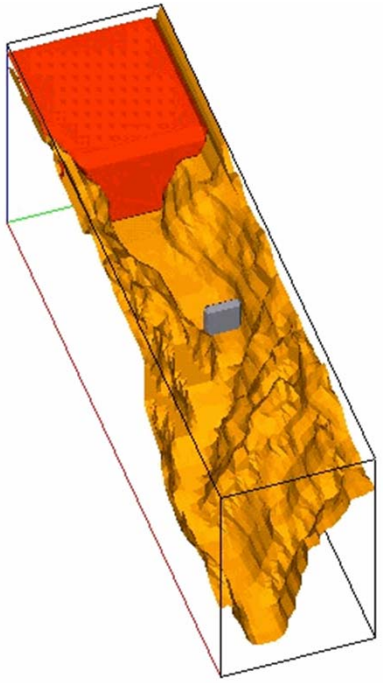
平行電腦配置
上述計算需要高速平行計算

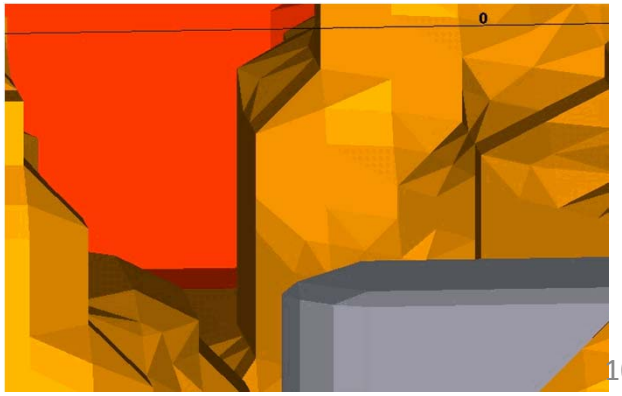


	規格
中央處理器	英特爾 Core i5-750 2.66GHz
主機板	華碩 P7P55D LE
記憶體	金士頓 8G DDR3-1333
顯示卡	技嘉 N210 512MB DDR2
硬碟機	WD 160G
電源供應器	全漢 藍金鑽 400W

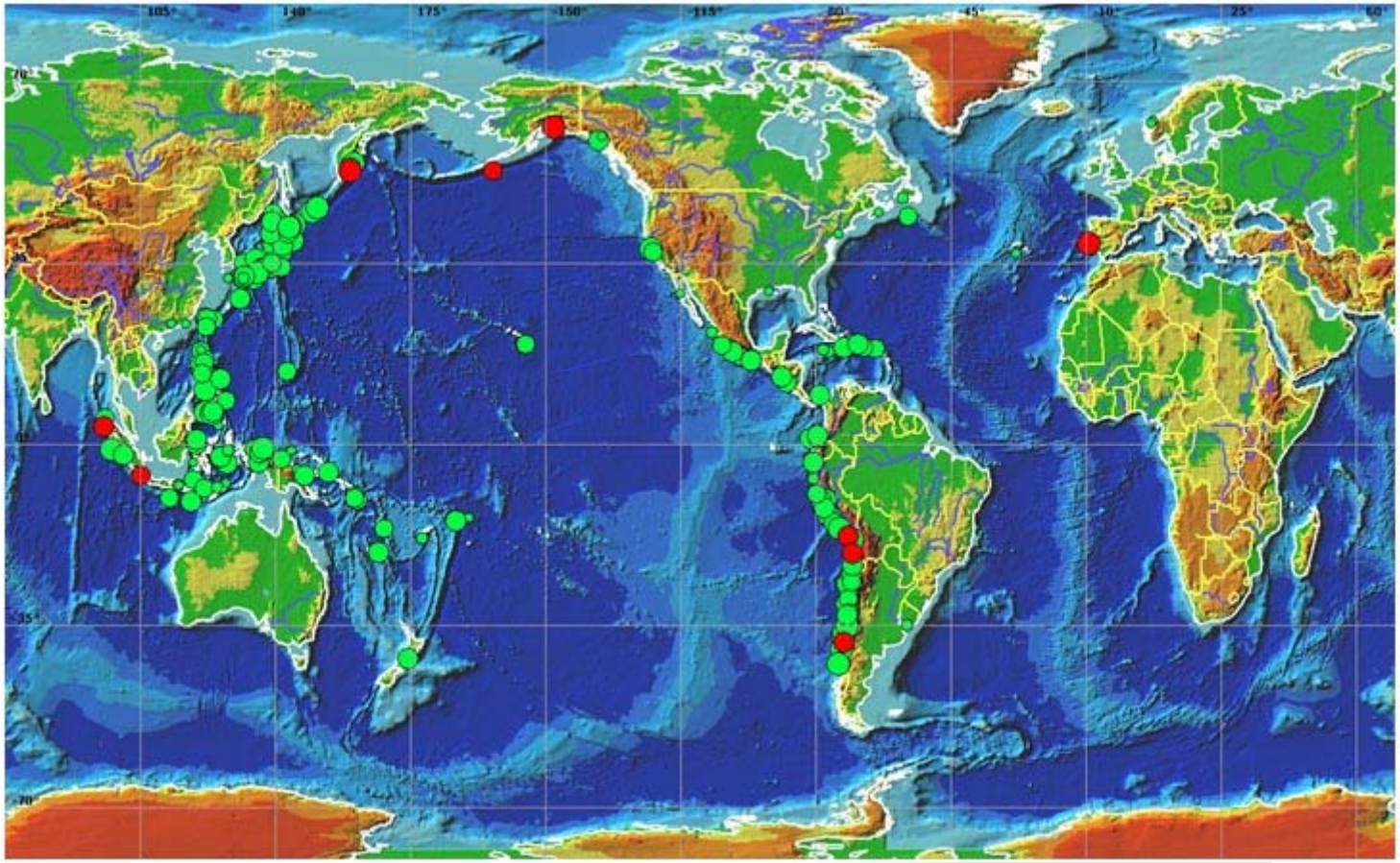
土石流之模擬（賓漢雙黏性流模式）



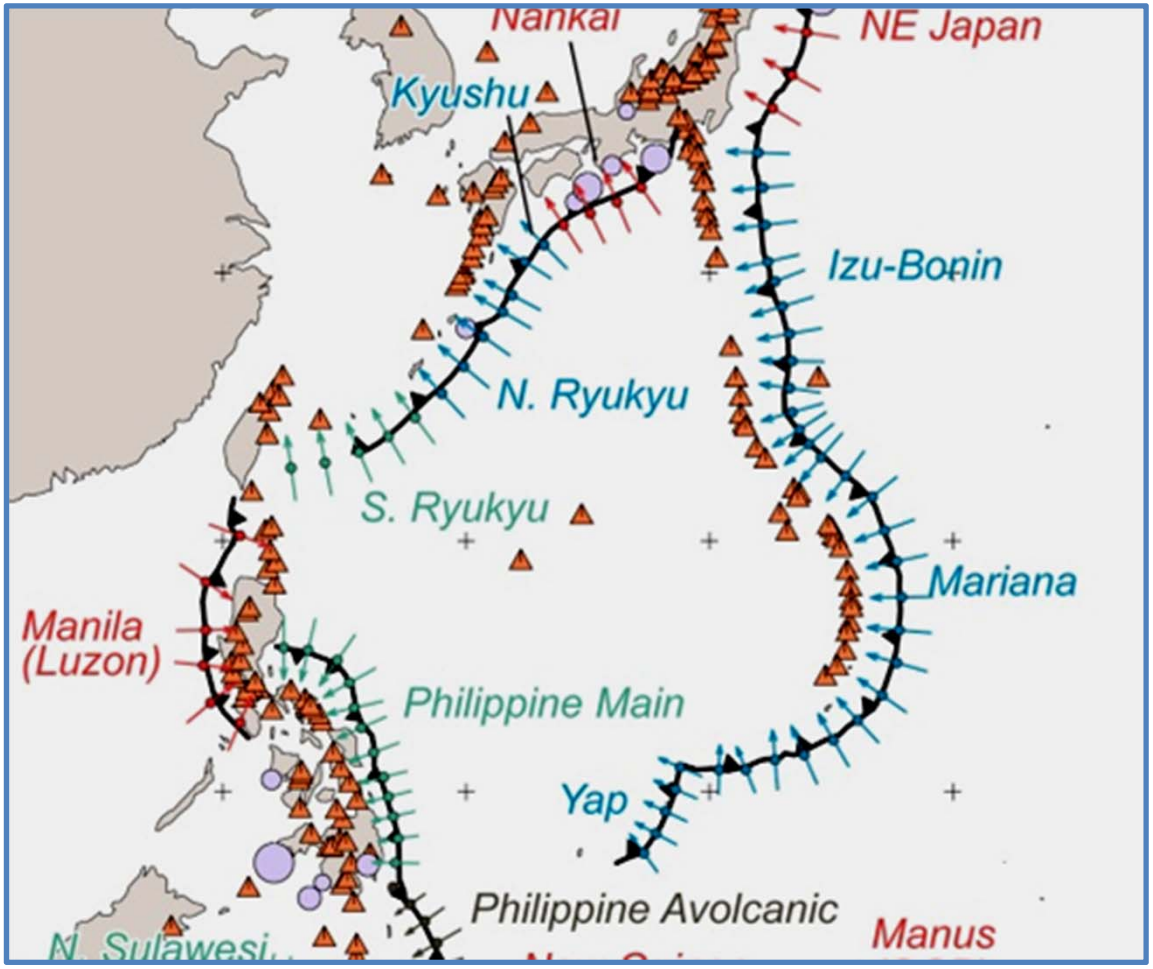


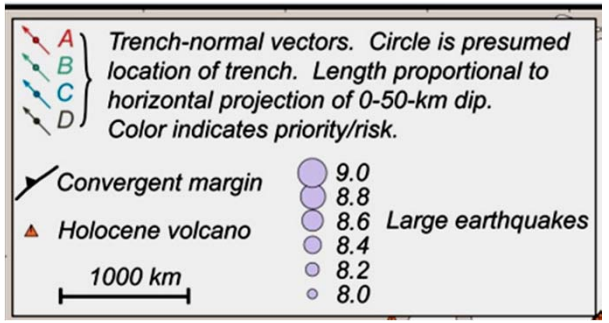


雙黏性流參數
Tao_0=500
Mu_b=1e4
Mu_Max=1e10
密度=2500



Date and place	Magnitude	Max run-up near the source, m	Max run-up in the far-field, m	Fatalities
November 1, 1755 Lisbon	8.5	18	7.0	40000
November 7, 1837 Chile	8.5	8	6.0	many
August 13, 1868 Chile	9.1	18	10	3000
August 27, 1883 Krakatau		36	1.5	36000
February 3, 1923 Kamchatka	8.3	8	6.1	some
April 1, 1946 Aleutians	7.4	42	18	165
November 4, 1952 Kamchatka	9.0	18	9.1	>10000
March 9, 1957 Aleutians	9.1	15	10	none
May 22, 1960 Chile	9.5	18	12	1180
March 28, 1964, Alaska	9.2	68	6.0	123
December 26, 2005 Sumatra	9.3	34	9.1	280000

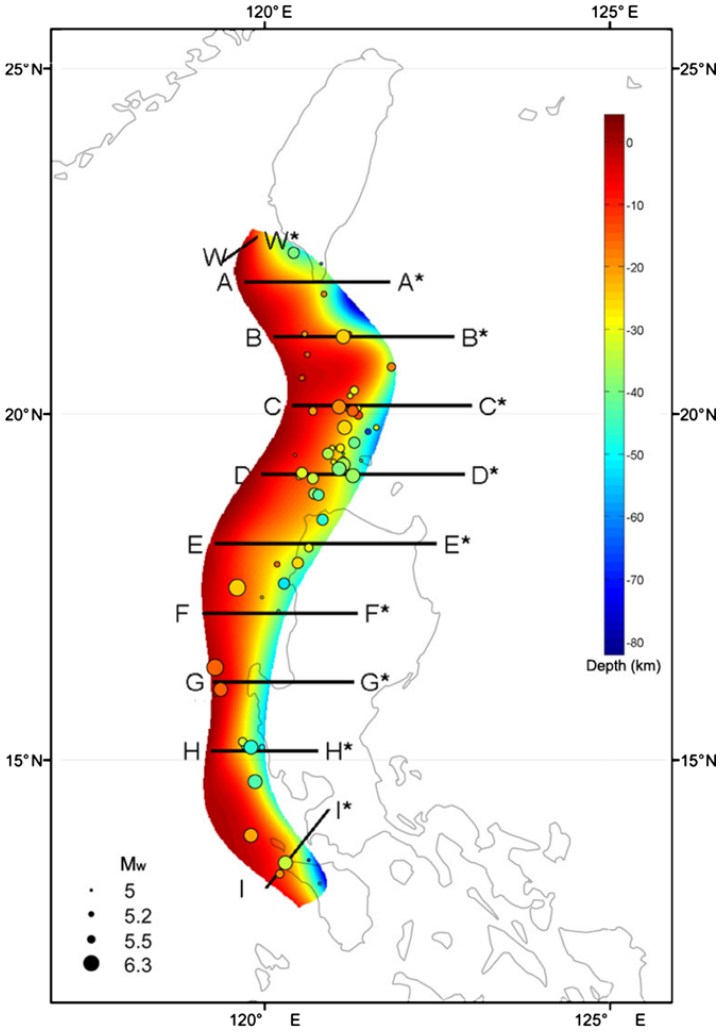




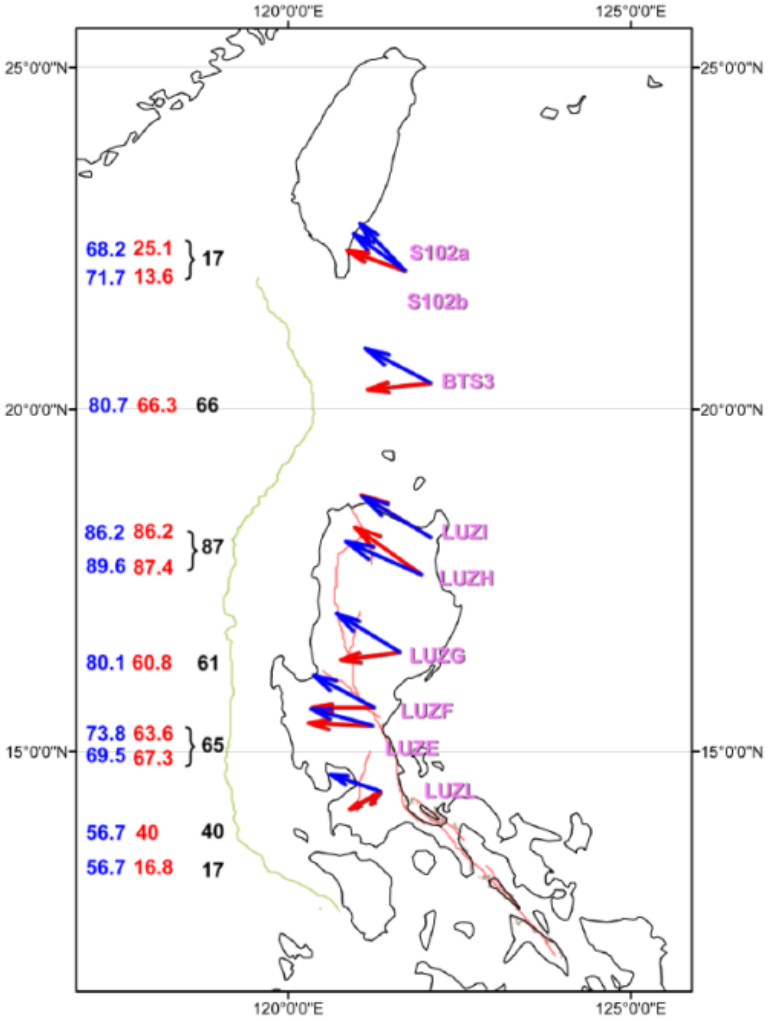
Tsunami Source Characterization for Western Pacific Subduction Zones: A Preliminary Report
USGS1 Tsunami Subduction Source Working Group

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.

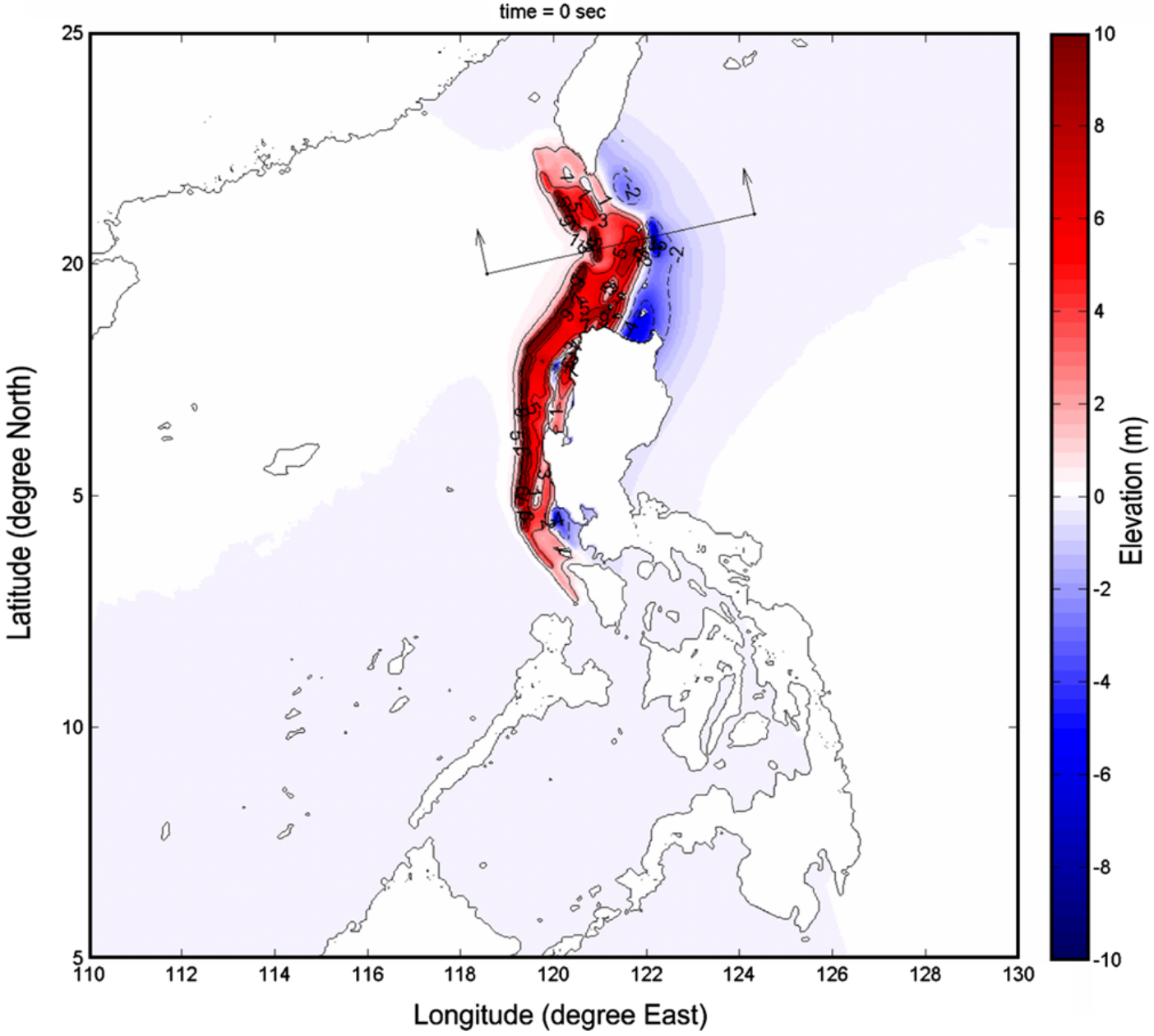


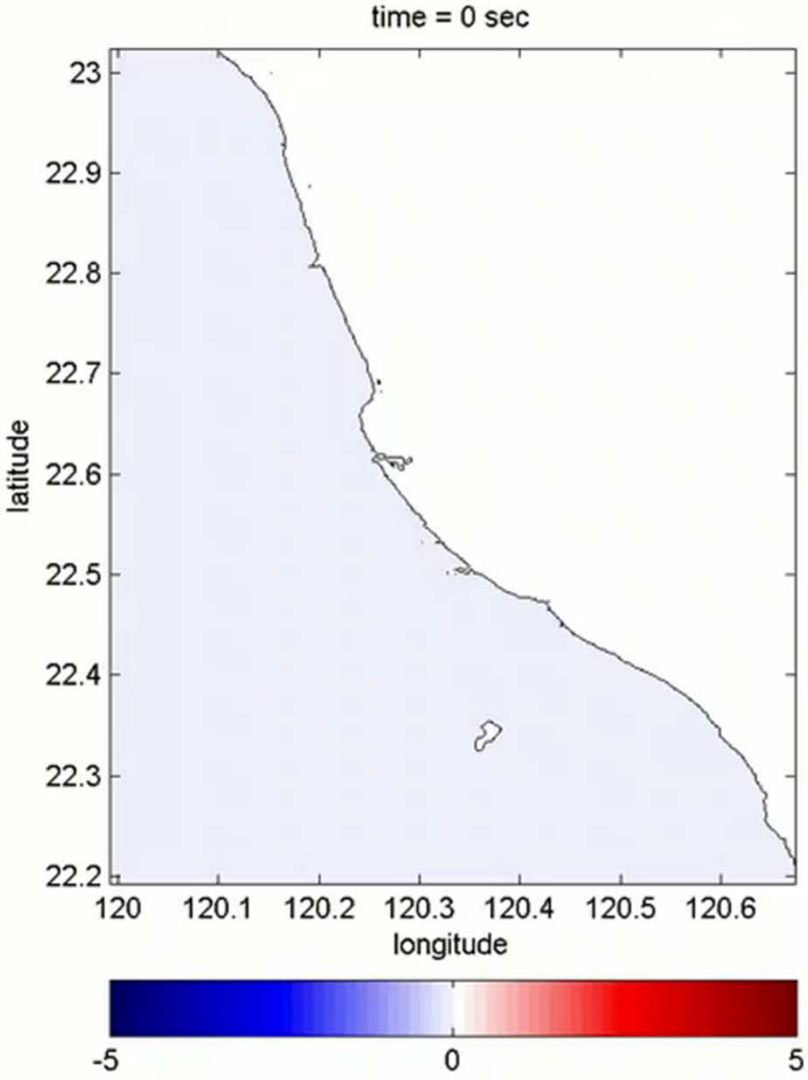
The sinuous rupture interface of the South China Sea megathrust, together with ten seismic cross sections between latitude 12.5N and 23.5N from the studies by Bautista et al. (2001) and Wu et al. (2007). Epicenters of thrust-faulting earthquakes are plotted to mark the downdip boundary of the rupture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

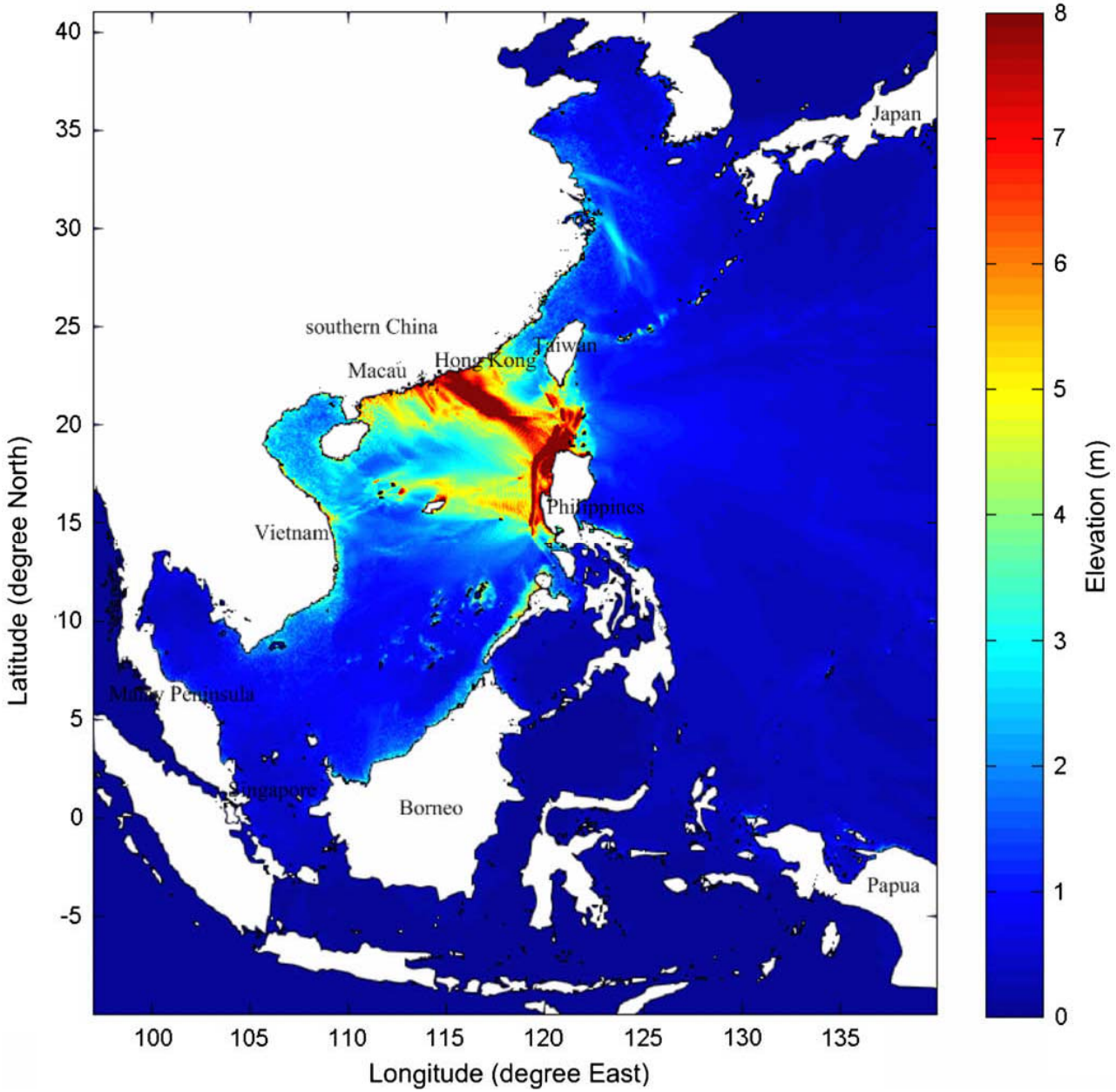


GPS data (Yu et al., 1999) indicating motion of the converging Eurasian Plate and the Philippines Sea Plate, where the blue arrows and numbers show raw velocity values (mm/yr) taken from Yu et al. (1999), the red arrow and numbers indicate velocity values (mm/yr) resolved in the direction perpendicular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

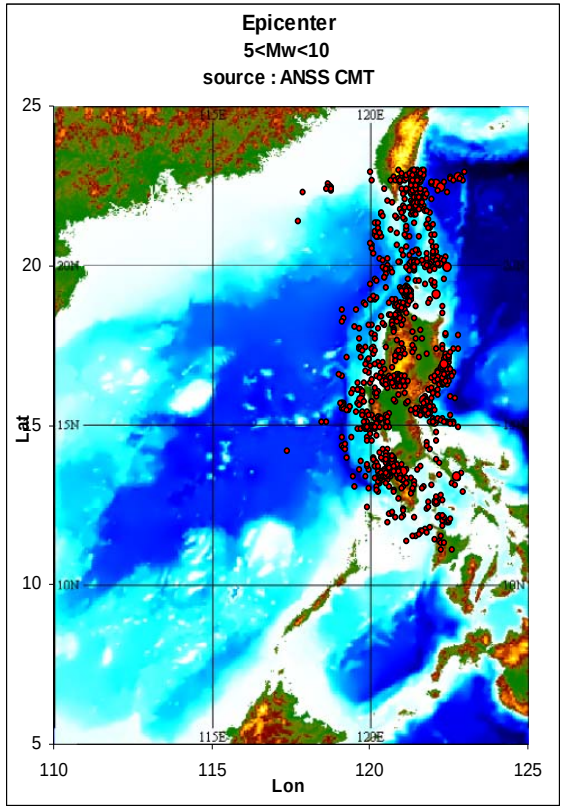
(Megawati et at., 2009)

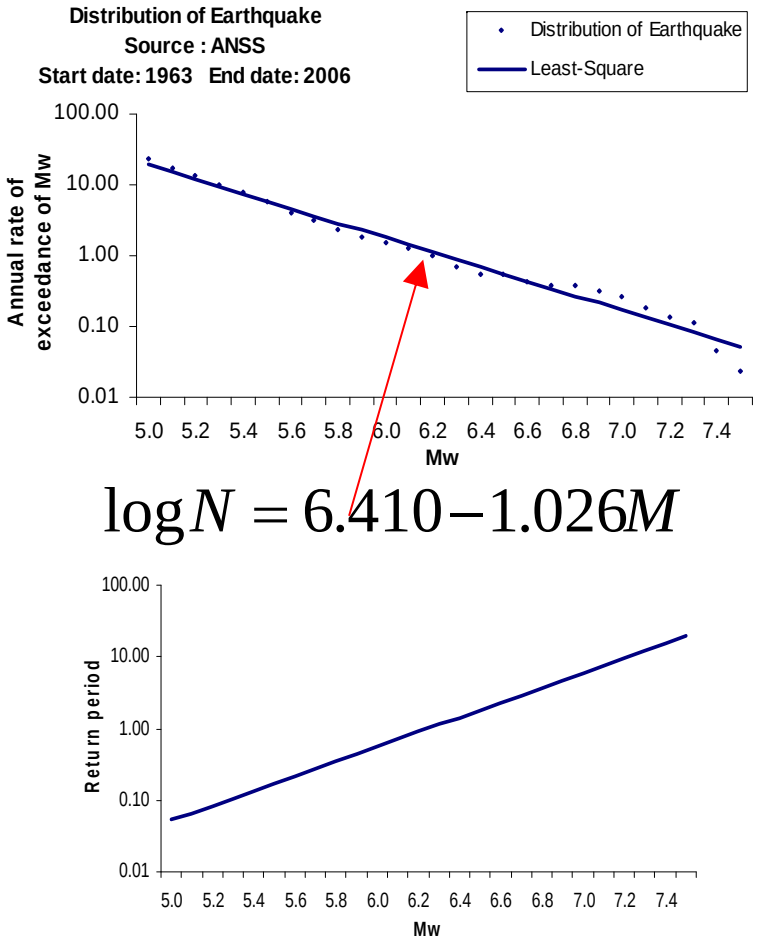

time = 0 sec
Latitude (degree North)
Longitude (degree East)
Elevation (m)
25
20
5
10
5
110
112
114
116
118
120
122
124
126
128
130
10
8
6
4
2
0
-2
-4
-6
-8
-10


time = 0 sec
23
22.9
22.8
22.7
22.6
22.5
22.4
22.3
22.2
latitude
120
120.1
120.2
120.3
120.4
120.5
120.6
longitude
-5
0
5


Japan
southern China
Taiwan
Macau
Hong Kong
Philippines
Vietnam
Malay Peninsula
Singapore
Borneo
Papua
Latitude (degree North)
Longitude (degree East)
Elevation (m)
40
35
30
25
20
15
10
5
0
-5
100
105
110
115
120
125
130
135
8
7
6
5
4
3
2
1
0

Estimation of Return period





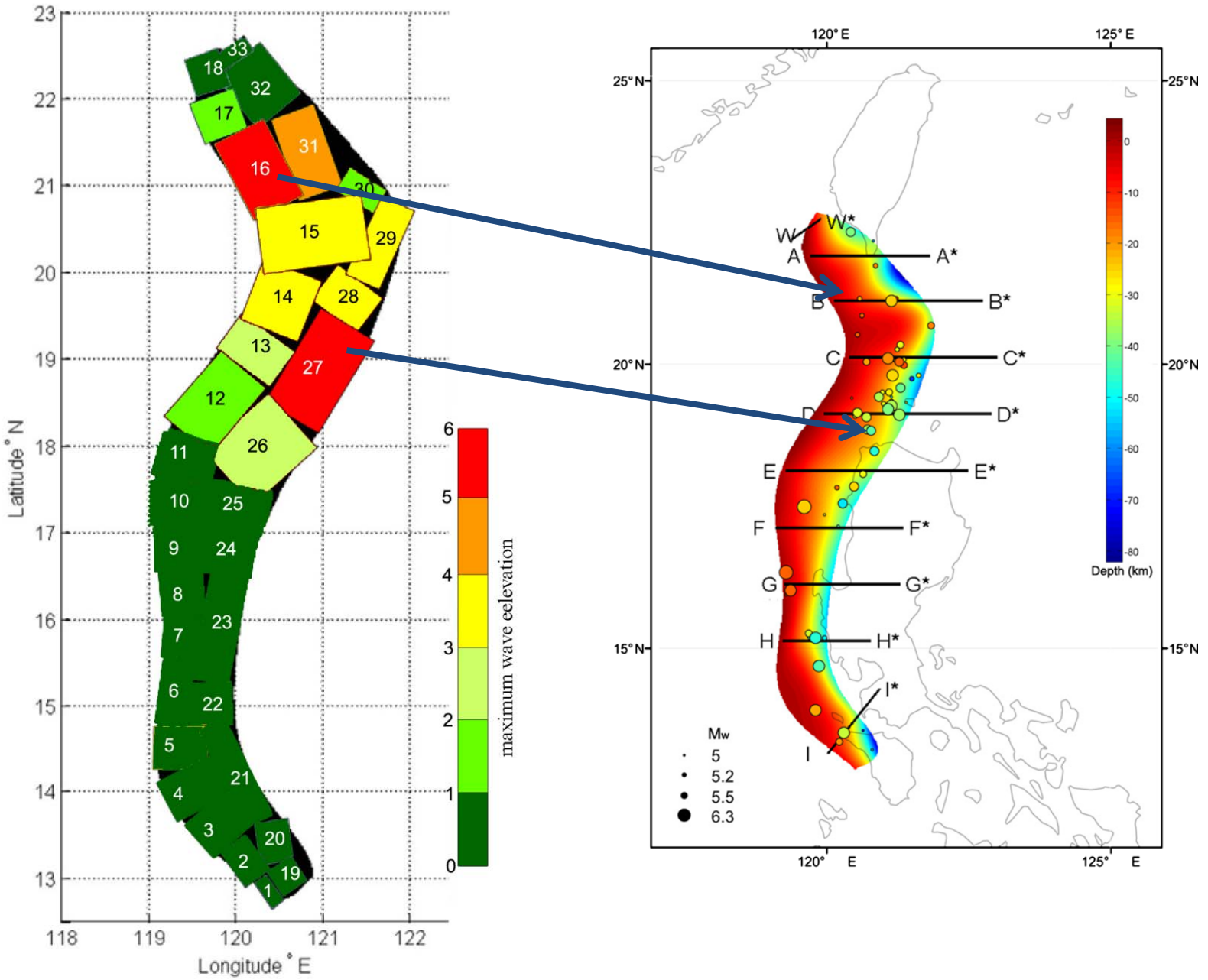
$$\log N = 6.410 - 1.026M$$

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).

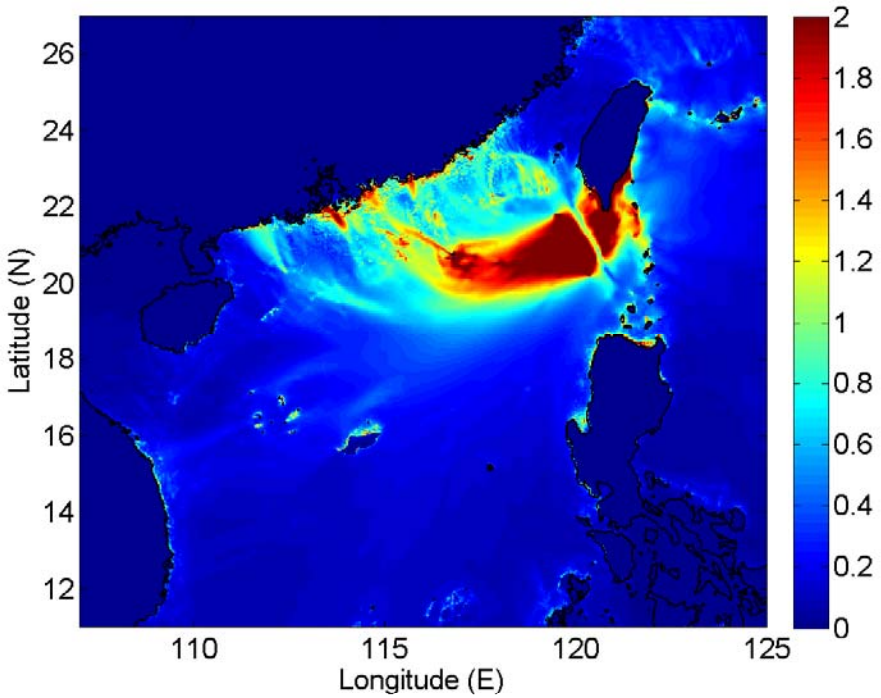
Anat Ruangrassamee (2007)

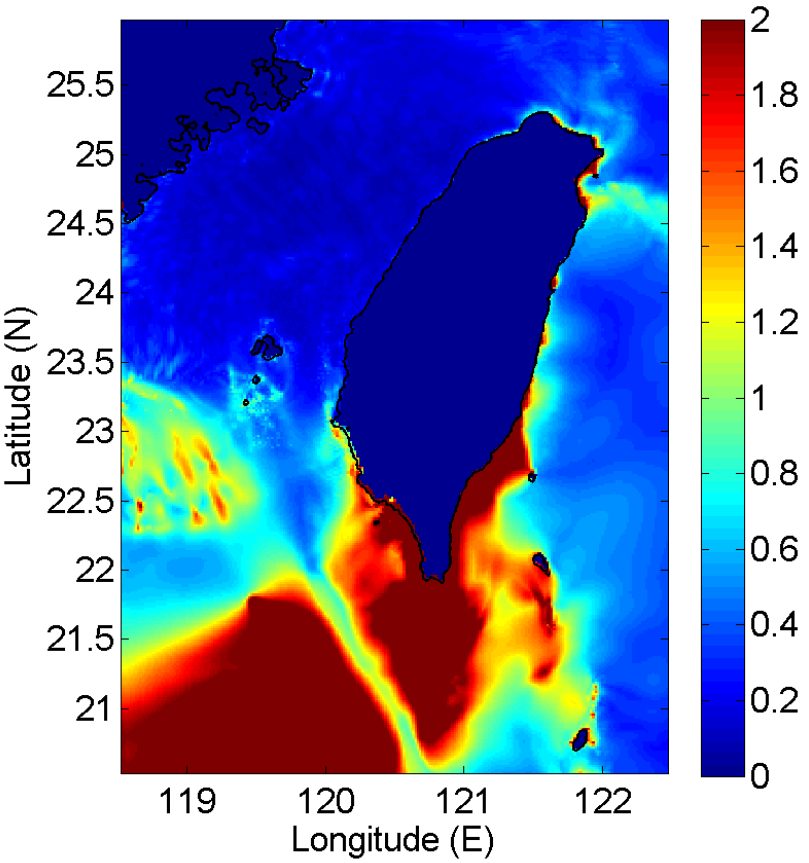

Latitude ° N
Longitude ° E
maximum wave eelevation
Depth (km)
Mw
5
5.2
5.5
6.3
120° E
125° E
25° N
20° N
15° N

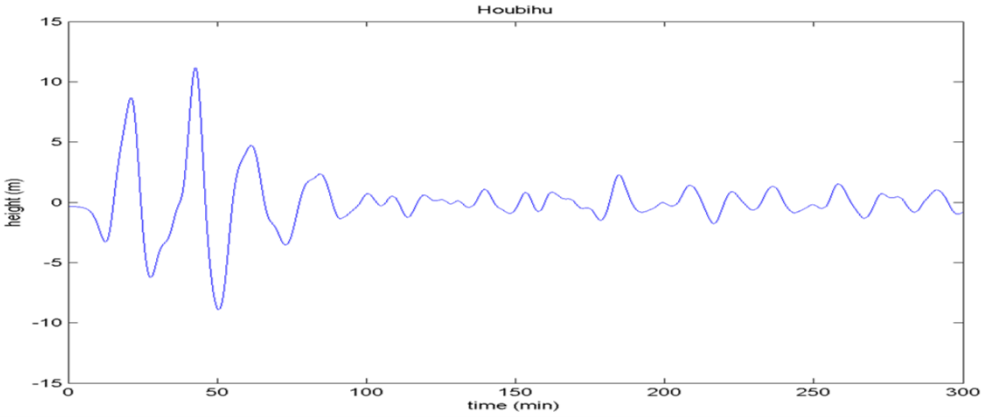
No. 16 sub-fault，Mw = 8.5

Feature:

1. Epicenter is close to Taiwan.
2. The tsunami mainly propagates toward Taiwan and SCS.





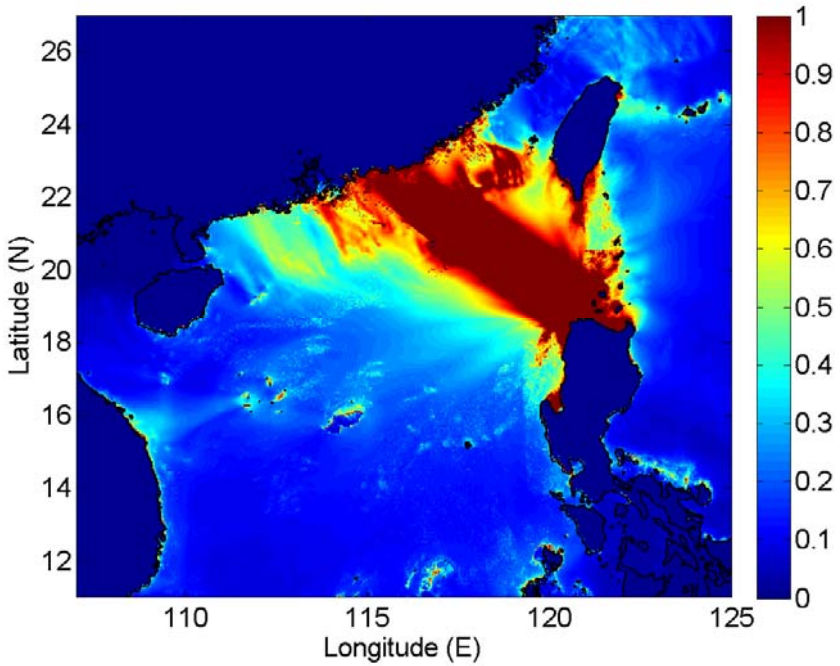


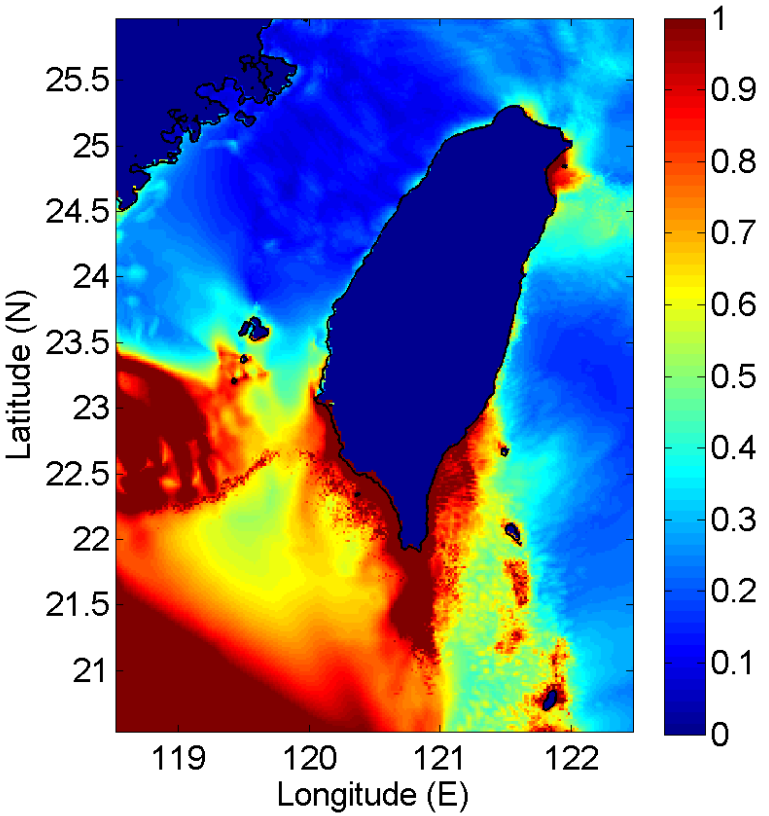
Large wave height is recorded at Houbihu.

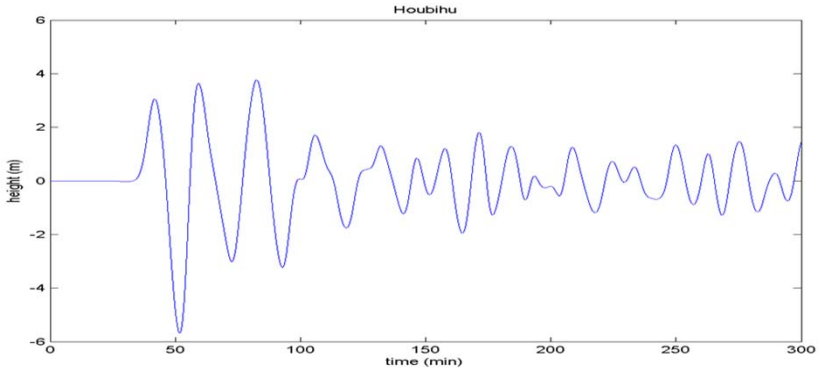
No. 27 sub-fault，Mw = 8.5

Feature:

1. Epicenter is close to North Luzon Island.
2. The tsunami mainly propagates toward Hong Kong and Macao.





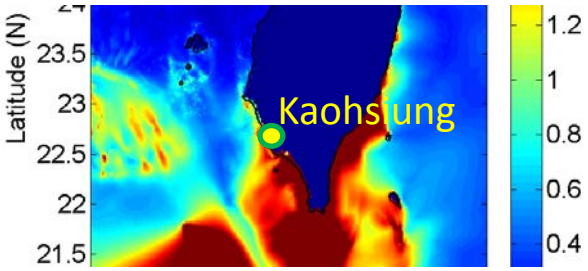


However, some evidences are suggesting the possibility of a giant earthquake

- GPS shows large slip deficit (6-10cm/y) ✓
- Historical documents on the AD869 tsunami ?
- Tsunami sediments (>1000 yrs) were excavated 2-3km inland from the coast

In Taiwan, do we receive the signs of a giant earthquake?

1781年（清乾隆46年）5月間（4月24日-6月21日）高雄海嘯
1781, Kaohsiung tsunami



- 「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，撥剌跳躍，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 drown. The woman was fierce, and was not filial to her parents in law. Except for the woman, everybody was survived. After collecting the fishes and heading home, **suddenly the sea roared again**. Fishermen lost their fishes. They sailed on top of bamboos on raft, watching their homes submerged from far.”

About 3m

About 230 years ago

About 4~5m

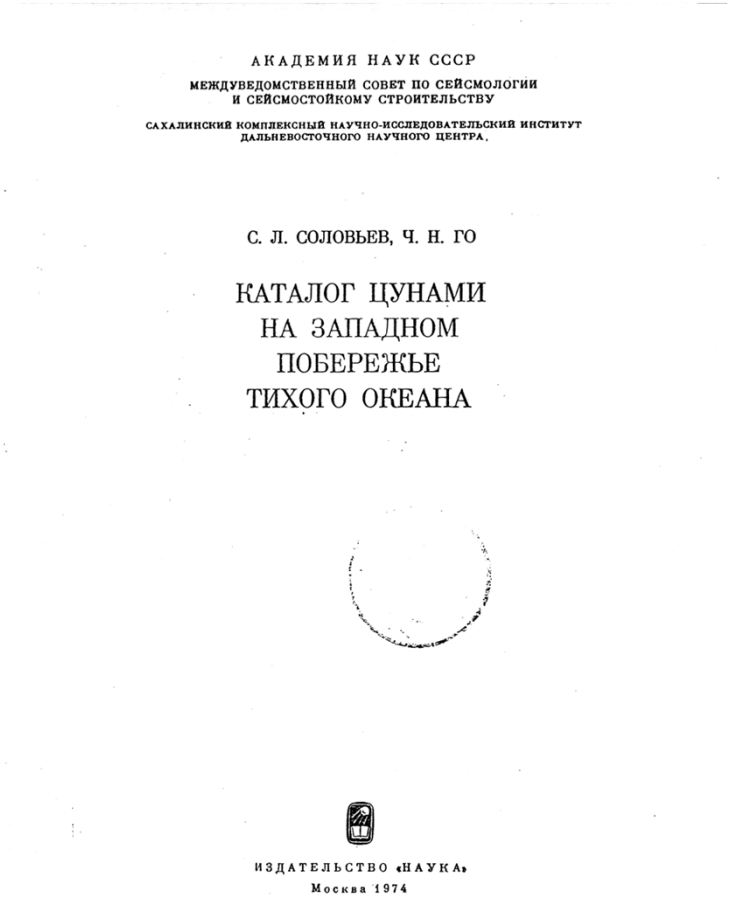
Second tsunami coming in

About 1km far

Next year (1782, 1682?) Tainan Tsunami

(Soloviev and Go, 1974).

This tsunami is also listed by Bryant (2008) as resulting in “the second largest death toll from tsunami in the Pacific and Indian Oceans over the last 2000 years”



АКАДЕМИЯ НАУК СССР

МЕЖДУВЕДОМСТВЕННЫЙ СОВЕТ ПО СЕЙСМОЛОГИИ И СЕЙСМОСТОЙКОМУ СТРОИТЕЛЬСТВУ

САХАЛИНСКИЙ КОМПЛЕКСНЫЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ ДАЛЬНЕВОСТОЧНОГО НАУЧНОГО ЦЕНТРА

С. Л. СОЛОВЬЕВ, Ч. Н. ГО

КАТАЛОГ ЦУНАМИ НА ЗАПАДНОМ ПОБЕРЕЖЬЕ ТИХОГО ОКЕАНА

ИЗДАТЕЛЬСТВО «НАУКА»

Москва 1974

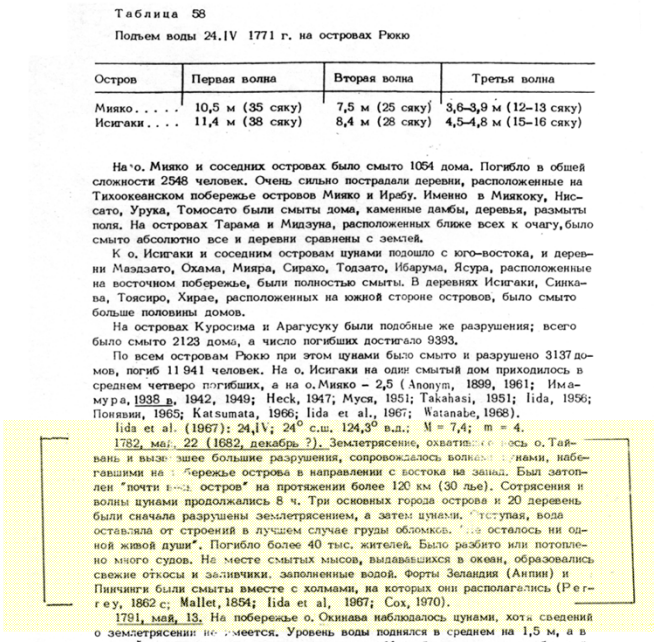


Таблица 58

Подъем воды 24.IV 1771 г. на островах Рюкю

Остров	Первая волна	Вторая волна	Третья волна
Мияко	10,5 м (35 сяку)	7,5 м (25 сяку)	3,6–3,9 м (12–13 сяку)
Исигаки . . .	11,4 м (38 сяку)	8,4 м (28 сяку)	4,5–4,8 м (15–16 сяку)

На о. Мияко и соседних островах было смыто 1054 дома. Погибло в общей сложности 2548 человек. Очень сильно пострадали деревни, расположенные на Тихоокеанском побережье островов Мияко и Ирабу. Именно в Миякоку, Нисато, Урука, Томосато были смыты дома, каменные дамбы, деревья, размыты поля. На островах Тарама и Мидзуна, расположенных ближе всех к очагу, было смыто абсолютно все и деревни сравнены с землей.

К о. Исигаки и соседним островам цунами подошло с юго-востока, и деревни Маэдзато, Охама, Мияра, Сирахо, Тодзато, Ибарума, Ясура, расположенные на восточном побережье, были полностью смыты. В деревнях Исигаки, Синкава, Тоясиро, Хирае, расположенных на южной стороне островов, было смыто больше половины домов.

На островах Куросима и Арагусуку были подобные же разрушения; всего было смыто 2123 дома, а число погибших достигало 9393.

По всем островам Рюкю при этом цунами было смыто и разрушено 3137 домов, погиб 11 941 человек. На о. Исигаки на один смытый дом приходилось в среднем четверо погибших, а на о. Мияко – 2,5 (Anonym, 1899, 1961; Имамура, 1938 в, 1942, 1949; Heck, 1947; Муся, 1951; Takahasi, 1951; Iida, 1956; Поняви, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968).

Iida et al. (1967): 24,1V; 24° с.ш. 124,3° в.д.; M = 7,4; m = 4.

1782, май, 22 (1682, декабрь ?). Землетрясение, охватившее весь о. Тайвань и вызвавшее большие разрушения, сопровождалось волнами, набегавшими на побережье острова в направлении с востока на запад. Был затоплен "почти весь остров" на протяжении более 120 км (30 лье). Сотрясения и волны цунами продолжались 8 ч. Три основных города острова и 20 деревень были сначала разрушены землетрясением, а затем цунами. Отступая, вода оставляла от строений в лучшем случае груды обломков. Не осталось ни одной живой души". Погибло более 40 тыс. жителей. Было разбито или потоплено много судов. На месте смытых мысов, выдававшихся в океан, образовались свежие откосы и заливчики, заполненные водой. Форты Зеландия (Антин) и Пинчинги были смыты вместе с холмами, на которых они располагались (Pfeiffer, 1862 c; Mallet, 1854; Iida et al, 1967; Cox, 1970).

1791, май, 13. На побережье о. Окинава наблюдалось цунами, хотя сведений о землетрясении не имеется. Уровень воды поднялся в среднем на 1,5 м, а в порту Йонабару, на юго-востоке острова, до 11 м благодаря воронкообразной форме бухты. Были разрушены четыре гавани. По мнению Имамура, это было цунами от удаленного землетрясения (Имамура, 1938 в, 1942, 1949; Муся, 1951; Takahasi, 1951; Iida, 1956; Iida et al., 1967).

Iida (1956): m = 1.

1853, октябрь, 29. Подводное извержение у восточного побережья о. Тайвань. Очевидец события, офицер американского военного корабля, рассказывал: "Когда мы перестали видеть вулкан, извержение еще было в полном разгаре. Вулкан исчез полностью в направлении от нас на северо-северо-восток, когда мы удалились от него на 20 км. Это было в 15 ч. На горизонте не было видно никаких судов. Позднее, когда мы проходили еще раз поблизости от вулкана, океан был настолько взволнован и бушевал так сильно, что вахтенный и другие офицеры сначала предположили, что судно попало в буруны. Затем мы

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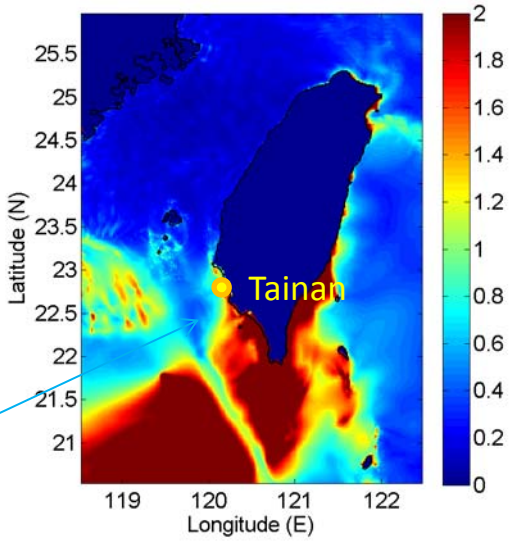
（感謝許明光、李昭興、吳季莊提供資料）

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1782, май 22 (1682, декабря?) землетрясение, охватишь о Тайвань и вызвузшее большие разрушения, сопровождалось волнам, цунами набегавшими на бережье острова в направлении с востока на запад. Был затоплен 'почти остров' на протяжении более 120 км(30лье). Сотрясения и волны цунами продолжались 8 ч. Три основных города острова и 20 деревень были сначала разрушены землетрясением, а затем цунами. Отступая, вода оставляла от строений в лучшем случае груды обломков. 'Не осталось ни одной живой души'. Погибло более 40 тыс. жителей. Было разбито или потоплено много судов. На месте смытых мысов, выдававшихся в океан, образовались свежие откосы и заливчики. заполненные водой. Форты Зеландия (Анпин) и Пигчинги были смыты вместе с холмами, на которых они располагались(Perrey, 1862c Mallet, 1854; lida et al, 1967;

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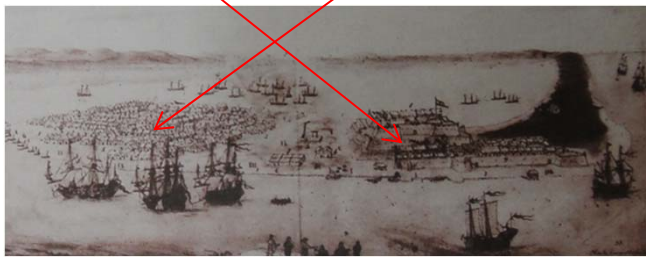
- 「1782年5月22日（1682年12月？）發生地震，台南和vyzvuzshee？？受創嚴重，海嘯接踵而來。海嘯將沿海島嶼自西向東淹沒。台灣全島受海嘯淹沒達120公里。地震和海嘯歷時8小時。該島的三個重鎮和二十餘個村莊，先是被地震破壞，隨後又為海嘯浸吞。海水退去後，原本是建築物的地方，只剩下一堆瓦礫。幾乎無人生還。40,000多居民喪生。無數船沉沒或被毀。一些原本伸向大海的海角，已被沖刷，形成新的峭壁和海灣，並造成淹水。安平堡（即熱蘭遮）以及赤崁城堡（台南市赤崁樓舊址）連同其坐落的山包均被沖跑了」



(Epicenter was not far away from Tainan)

In 1782 May 22 (or 1682 December ?), strong earthquake occurred, and caused severe damage in Tainan and vyzvuzshee (??). The tsunami arrived after the earthquake. The tsunami wave propagated from west to east and inundated the small islands in the coastal area. The whole Taiwan was flooded **by tsunami for over 120 km**. Earthquake **and tsunami lasted for 8 hours**. The three main islands of the city and 20 villages were destroyed by an earthquake at first, and then the tsunami. After ebbing, the locations where the buildings stood remained only the debris. Almost nobody survived. 40,000 more inhabitants were killed. Lots of ships were destroyed or sunk. Some of the capes were swashed away and became fresh slopes and coves, and filled with water. Forts Zealand (Anpin) and Pigchingi were washed away along with the hills on which they are located. (Perrey, 1862s Mallet, 1854; lida et al, 1967; Cox, 1970)





However, some evidences are suggesting the possibility of a giant earthquake

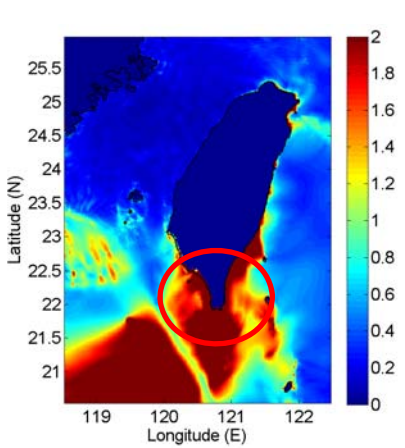
- GPS shows large slip deficit (6-10cm/y) ✓
- Historical documents on the AD869 tsunami ✓
- Tsunami sediments (>1000 yrs) were excavated 2-3km inland from the coast ?

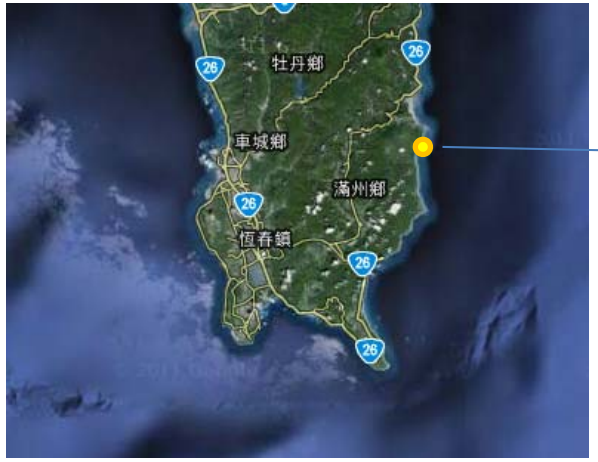
In Taiwan, do we receive the signs of a giant earthquake?

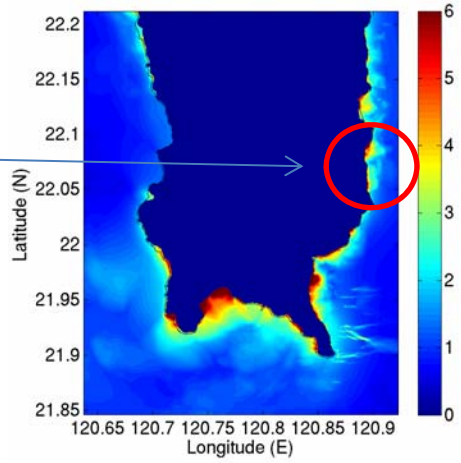
Tsunami Boulders were found in Taiwan











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「蟳管」之小海灣登岸移墾，閩人皆稱為「澳」，故得「蟳廣澳」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。



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。

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。

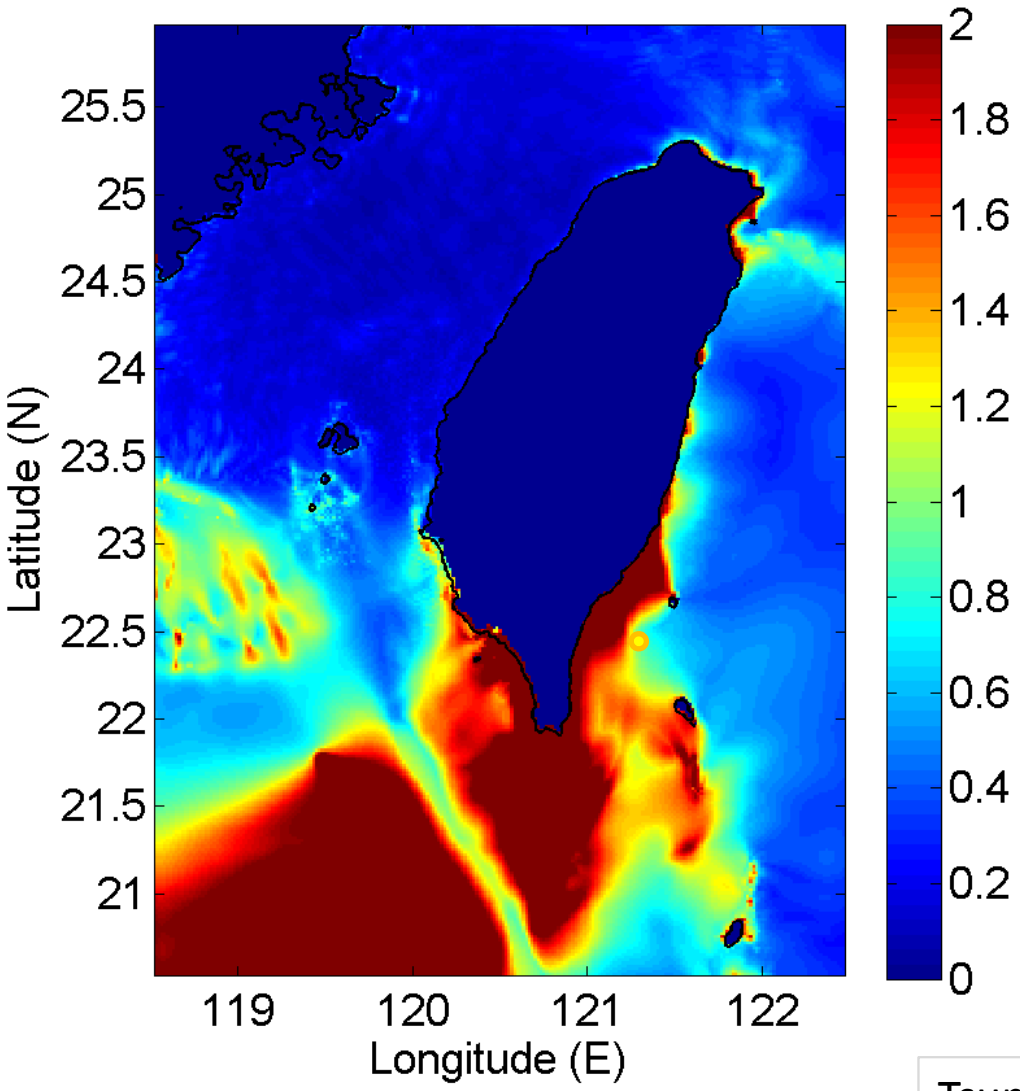
松多信尚表示，台灣是否曾遭遇海嘯襲擊，缺乏歷史文獻佐證；但台灣學術界及氣象局普遍樂觀認為，台灣東海岸因地形影響，發生海嘯機率不高。日本學術界認為，「台灣上下都這麼認為，是很危險的事」。

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。

評論





Tsunami from Manila Trench propagates along the sea mountain ridge to Chenggong Town.

Similarity

- Tohoku earthquake:
  - No giant earthquake in the last 400 yrs
  - Large slip deficit (6-10 cm/y) from GPS
  - Historical documents on the AD869 tsunami
  - Tsunami sediments (>1000 yrs) were excavated 2-3km inland from the coast
- Taiwan:
  - No giant earthquake in the last 400 yrs along the Manila Trench
  - Large slip deficit (7-8 cm/y) from GPS
  - Historical documents on the 1781 and 1782 tsunami
  - Tsunami sediments and tsunami boulders were found from the coast

Summary

- The descriptions on 1781 Kaohsiung tsunami and 1782 (1682) Tainan Tsunami are very close to the simulation result of No. 16 sub-fault of Manila Trench. The estimated earthquake magnitude is about 8.3 – 8.6.
- The estimation of earthquake return period in Manila Trench is about 205 years for Mw = 8.5 which is overdue already.
- The tsunami boulders and tsunami deposits show tsunami events in the past.
- Taiwan shall be aware of the tsunami threat from Manila Trench.