An Overview of Current Tsunami Activities in Taiwan

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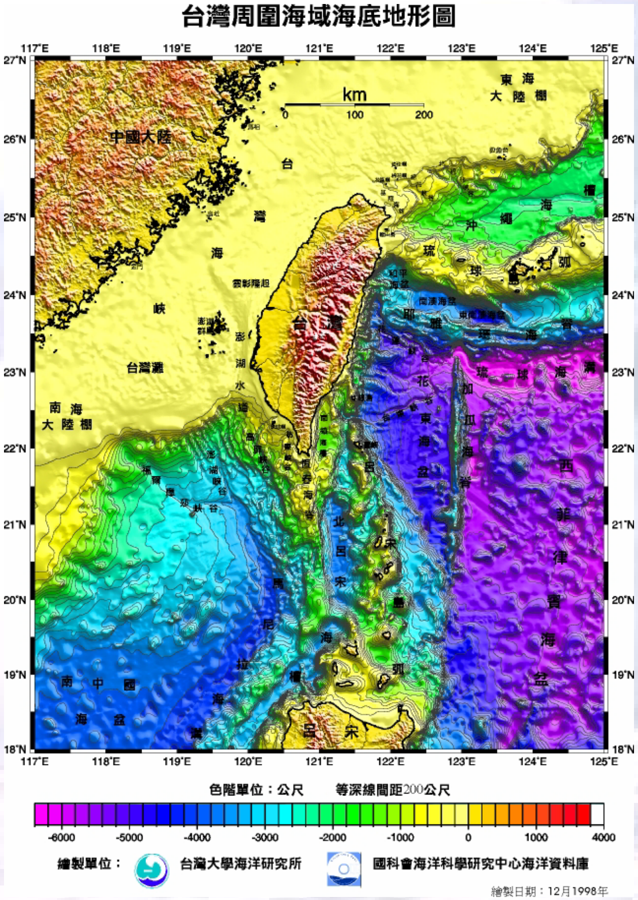
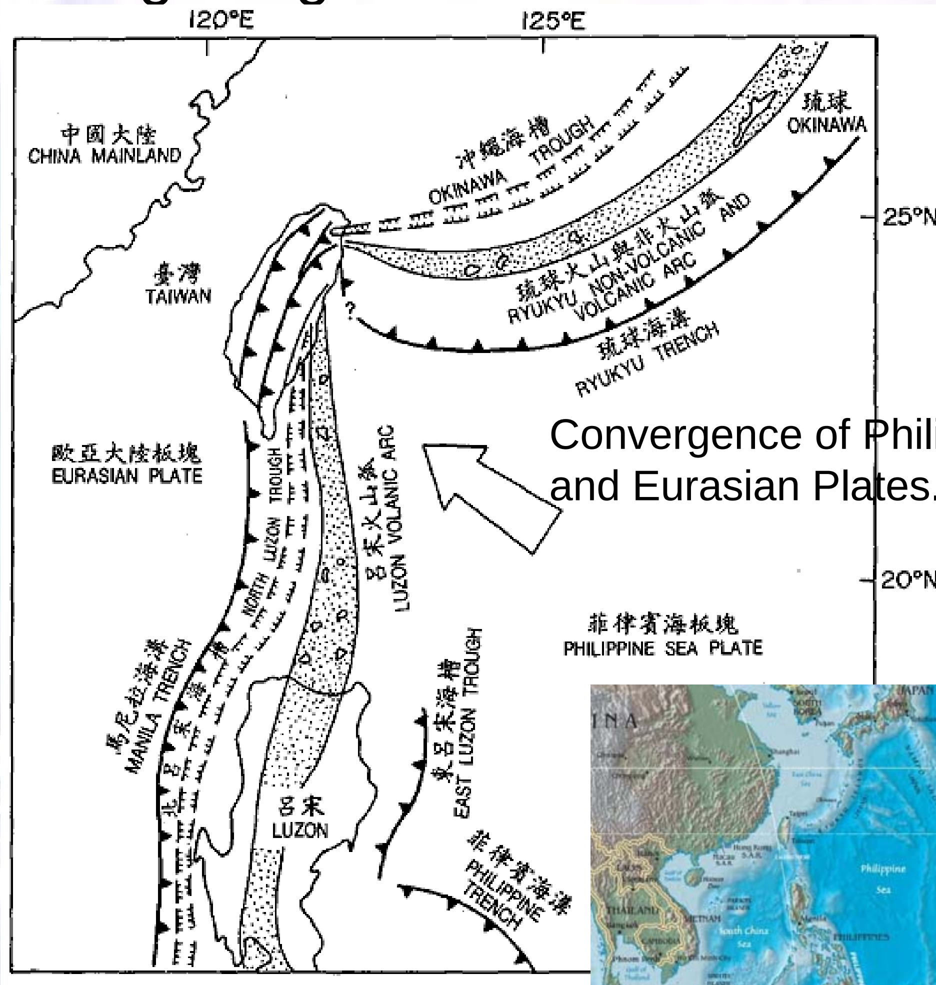
Outline

- The geographical and geological features of Taiwan
  - 台灣地理與地質特色
- Historical Tsunamis
  - 歷史海嘯
- The budget of tsunami research activities in Taiwan
  - 台灣海嘯相關學術活動與經費
- The tsunami early warning system in Taiwan
  - 台灣之海嘯預警及防治手段
- Current development of Tsunami research in National Central University
  - 中大海嘯發展
- Numerical simulations on 1226 Ping-tung dual earthquakes
  - 數值海嘯模擬示範，以屏東雙地震爲例
- Numerical simulation on the SCS tsunamis
  - 南中國海地震模擬
- 3D simulations on the breaking waves
  - 近岸碎波模擬

台灣地理與地質的特色
The geographical and geological features of Taiwan



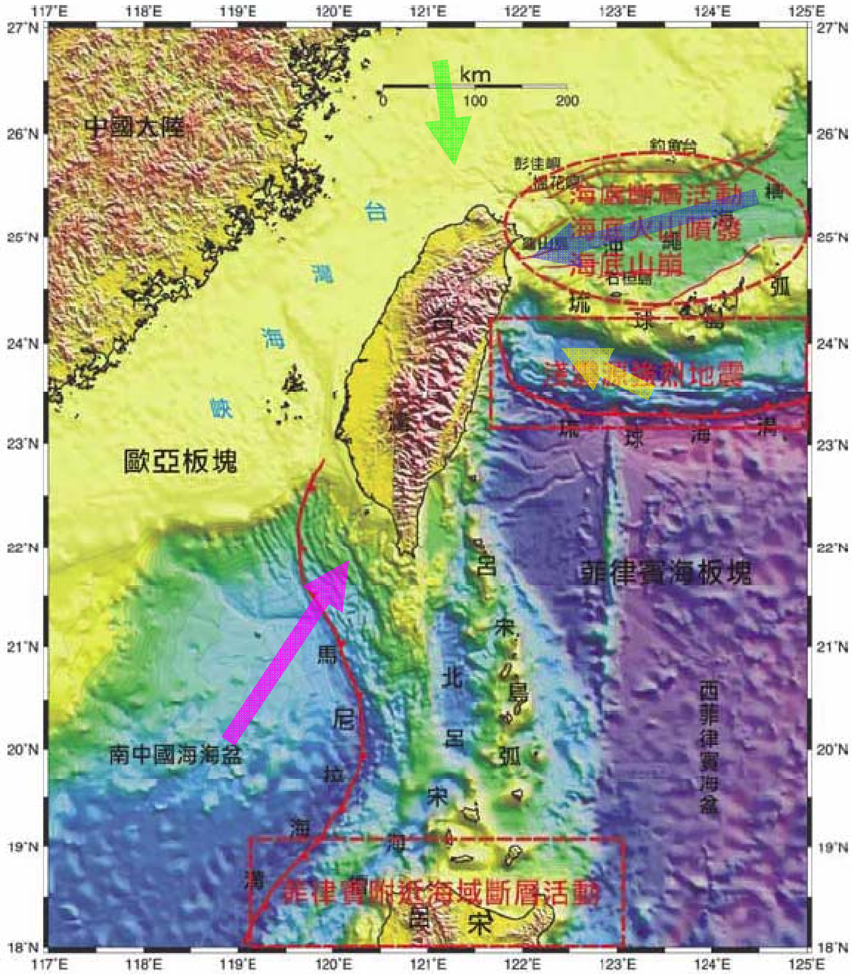


Convergence of Philippine sea and Eurasian Plates.

- Shallow water on the west coast. Cliff slope on the east coast. Mild on the south-west coast.
- 西岸淺灘，東岸陡坡，西南斜坡

Most of the tsunamis are near-source tsunamis
台灣海嘯的特色：威脅性海嘯多為近源海嘯

- Earthquake: Manila Trench and Shallow earthquake on the east coast.
  - 地震：馬尼拉海溝、東部淺源地震
- Submarine landslide: North-east and south-west coasts.
  - 海底山崩：位於台灣東北沖繩海槽的張裂區域和台灣西南大陸斜坡區域。
- Submarine volcanic eruption: North-east coast.
  - 台灣東北海域，有許多海底火山。
- Sea-floor collapse: gas hydrate found on the south-east coast.
  - 海床崩塌：台灣西南岸，蘊藏豐富的天然氣水合物。天然氣水合物所產生的氣泡不斷的逸散，有可能會造成該地區的海床崩陷。



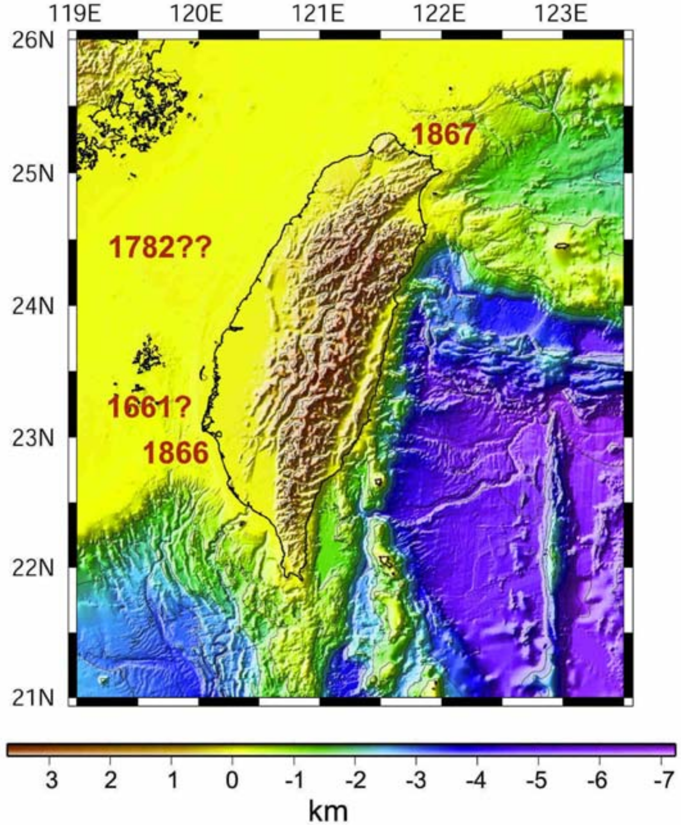
圖三 台灣附近海域可能發生海嘯的區位及因素
（海底地形圖資料來源：國家海洋科學研究中心）

Steep slope on the west coast: Reflect back tsunami energy

東岸峭壁：阻擋太平洋的海嘯威脅

台灣歷史海嘯紀錄

Figure 2. Historical "tsunami" events in Taiwan.



1661 (Jan. 8 or 9). Island of Formosa (Taiwan)?

"The sea was violently agitated" (Mallet, 1852).

1782 (May 22). Taiwan Strait??

This event is highly questionable, as no known historical record of this big casualty dimension can be found in official Taiwan documents. Before the Sumatra earthquake/tsunami, this event (may be erroneously listed to have caused 50,000 death) was listed as the most deadly tsunami of the world (Bryant, 2001, p. 21, Table 1.5; and two major online websites).

Bryant (2001) credited the NOAA National Geophysical Data Center as the source, which in turn cited Iida et al. (1967) and Soloviev and Go (1974), both credited Mallet (1853) and Perrey (1862) as their sources. We have so far not able to locate any supporting Chinese source.

"On the 22nd [May, 1782] the sea rose with great violence on the coast of Formosa and the adjacent part of China, and remained eight hours above its ordinary level; having swept away all the villages along the coast, and drowned immense numbers of people. No shock is mentioned" (Mallet, 1853).

1866 (December 16). Kaohsuing (SW Taiwan)

"Ground shook for about 1 minute, river water fell 3 feet and suddenly rose" (KBTEQ, 2005).

1867 (December 18). Kelung (Northern Taiwan)

"At Kelung the whole harbour was left dry for a few moments; and the water returning in one vast wave, rushed into the town itself. Large landslips have taken place, and several villages between Kelung and Tamsuy have been destroyed." (Holt, 1868).

1868-present: No significant tsunamis reported in Taiwan.

1867 基隆大海嘯

[by 馬國鳳]

Tsunami Warning for Distance Tsunamis

International Cooperation

國際合作

- 國際海嘯資料中心
  International Tsunami Information Center
- 太平洋海嘯預警中心
  Pacific Tsunami Warning Center
- 海嘯預警系統
  - 近岸海嘯監測站
    Sea level stations
  - 深水域海嘯監測站
    Deep-ocean Assessment and Reporting of Tsunamis

[from 中央氣象局徐月娟主任]

Tsunami Warning for Near-Source Tsunamis

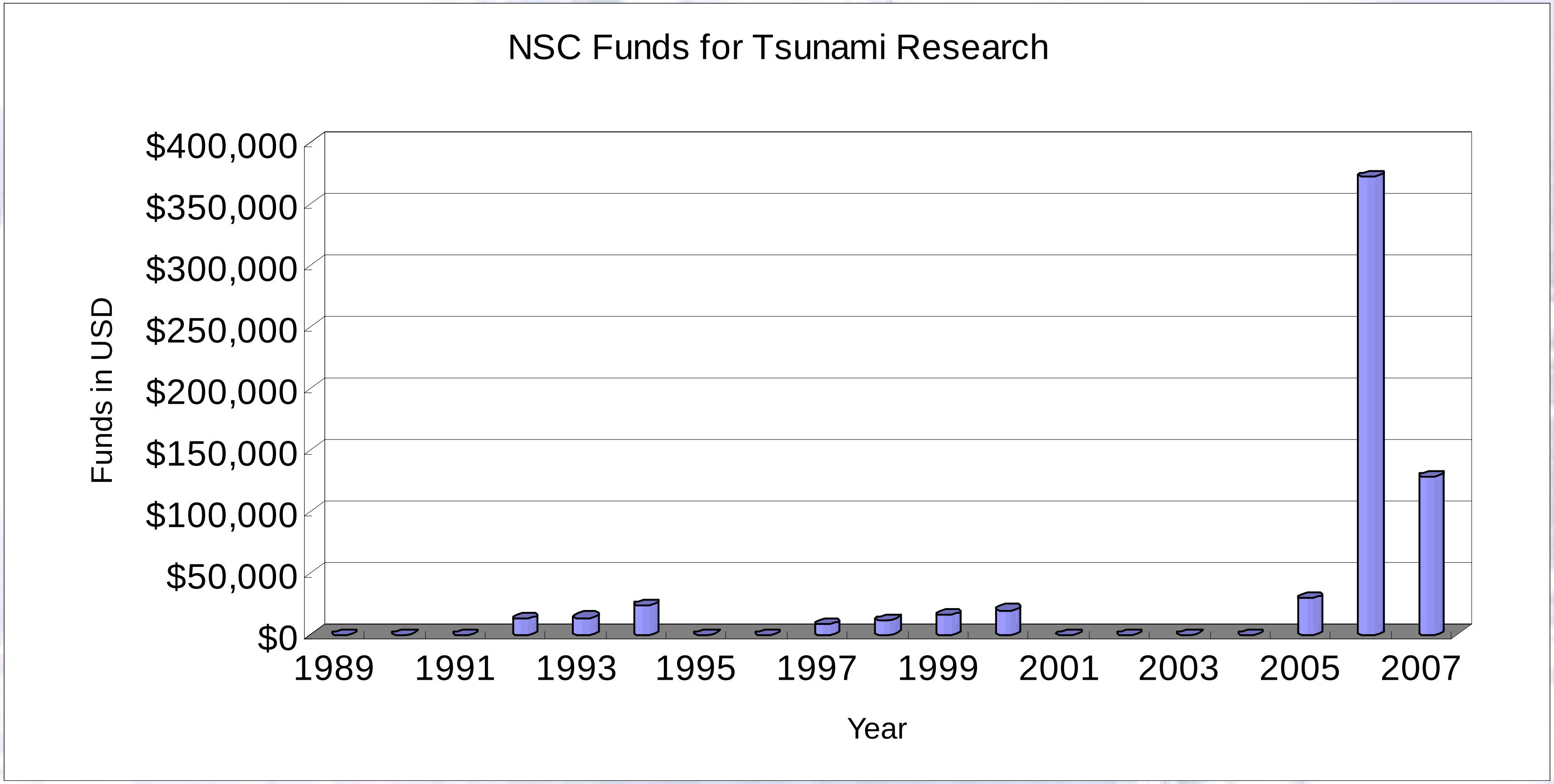
海嘯警報發布作業規定(續)

- 近海地震所引起海嘯通報：
  - 當中央氣象局地震速報系統偵測到台灣近海發生地震規模6.0以上，震源深度淺於35公里之淺層地震時，在地震報告中加註沿岸地區應防海水位突變。
  - 當中央氣象局地震速報系統偵測到台灣近海發生地震規模7.0以上，震源深度淺於35公里之淺層地震時，將發布海嘯警報，透過簡訊或傳真等方式迅速傳達給相關單位以及大眾傳播媒體，籲請沿岸居民準備因應海嘯侵襲。
- 海嘯警報發布後，根據太平洋海嘯警報中心或潮位站資料，適時發布海嘯警報解除。

Tsunami warning will be issued if Mw > 7.0 and the focal depth < 35 KM

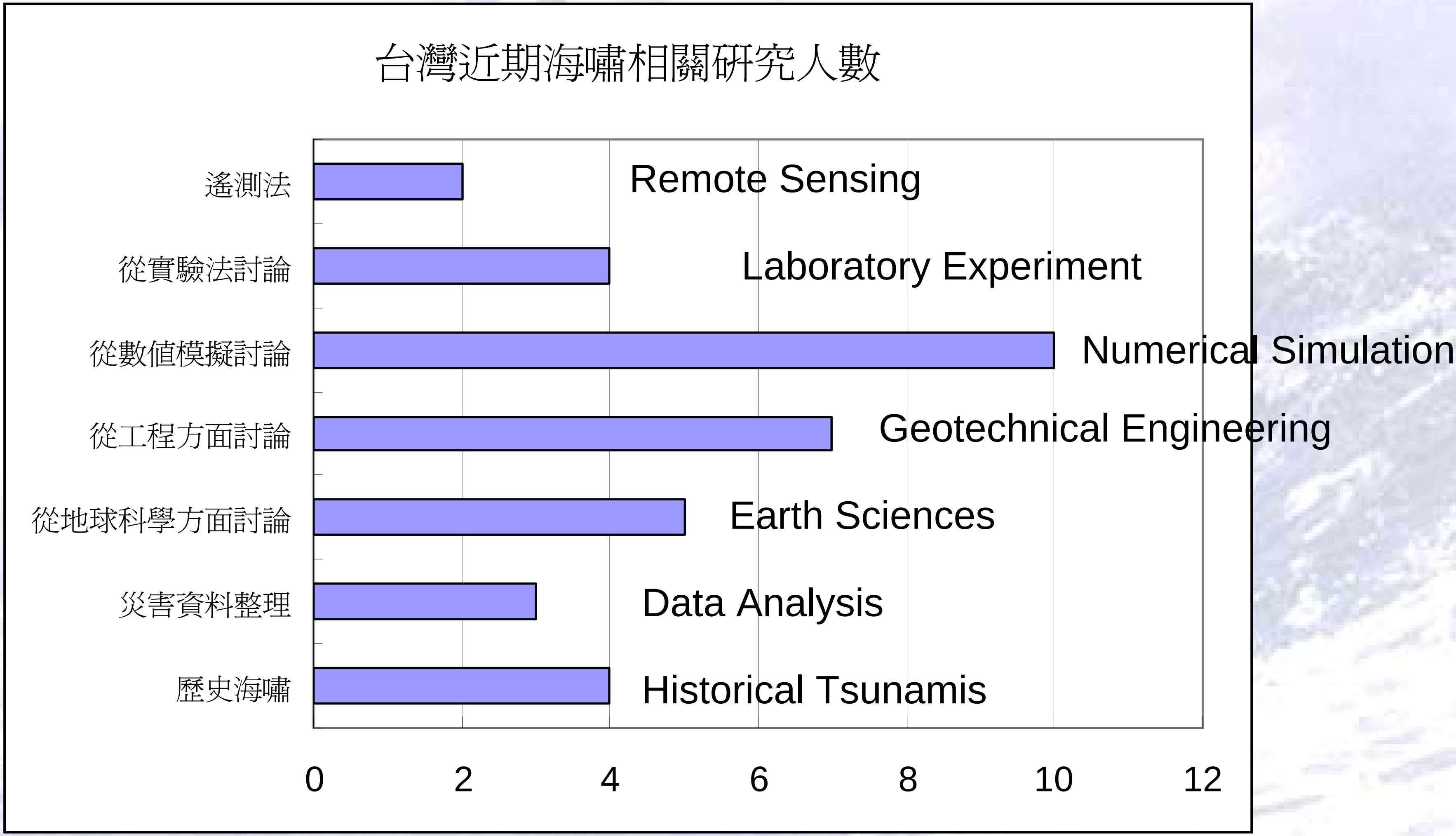
[from 中央氣象局徐月娟主任]

Support from NSC
國科會歷年補助海嘯研究經費



國科會補助下海嘯研究人員數： 10人

台灣具有從事海嘯相關研究之人力
Numbers of researchers in Tsunami-related topics in Taiwan



總人數：35人

The Development of Tsunami Sciences at NCU
中央大學海嘯科學發展

- Bathymetry Data 地形資料取得
  - 利用海底聲納回聲剖面儀精密探測台灣周遭的海底地形Hsu, Su-Kun 。
  - 利用遙測量測近海淺灘水域地形 Determination of shallow water depth between isles by using optical satellite images. Chang, Chung-Pai.
  - 海底電纜架設以提供地震、海嘯、及海底火山監測預警Hsu, Su-Kun 。The establishment of submarine cable observatories off eastern Taiwan can provide real-time earthquake, tsunami, and submarine volcano information,
- Source Identification 海嘯生成
  - 研究地震活動，模擬推估大地震發生之機率、範圍及地點 Ma, Kuo-Fong; Chen, Po-Fei
- Tsunami propagation, shoaling, runup, and inundation 海嘯傳播，放大、溯昇、與淹溢
  - Using COMCOT to calculate the tsunami propagation, shoaling, runup and inundation. Liu, Philip L.-F.; Tsai, Wu-Ting; Wu, Tso-Ren; Ma, Kuo-Fong; Chen, Po-Fei
  - 利用COMCOT 來建立台灣淹溢模式、災害潛勢圖、以及研究曾經侵襲台灣的海嘯，並瞭解台灣地形對於海嘯之影響
- Tsunami generated by the subaerial and submarine landslide
  - 海床崩移地點及山崩海嘯之模擬 Hsu, Su-Kun; Tsai, Wu-Ting; Wu, Tso-Ren
  - Using 3D numerical model to simulate the landslide generated tsunamis. Wu, Tso-Ren
- Tsunami force
  - Using 3D numerical model to calculate the shear stress, normal stress and force under the tsunami disaster. 海嘯破壞 Wu, Tso-Ren
  - 利用三維數值模式計算海嘯進入內陸之後所產生之紊流、壓力、剪力、及對底床及結構物之破壞力
- Science popularization 科普教育
  - 積極參與並推廣青少年對於海嘯之科學知識
  - Benjamin Fong Chao (Dean); Wu, Tso-Ren; Ma, Kuo-Fong;

Determination of shallow water depth between isles by using optical satellite images. Chang, Chung-Pai.

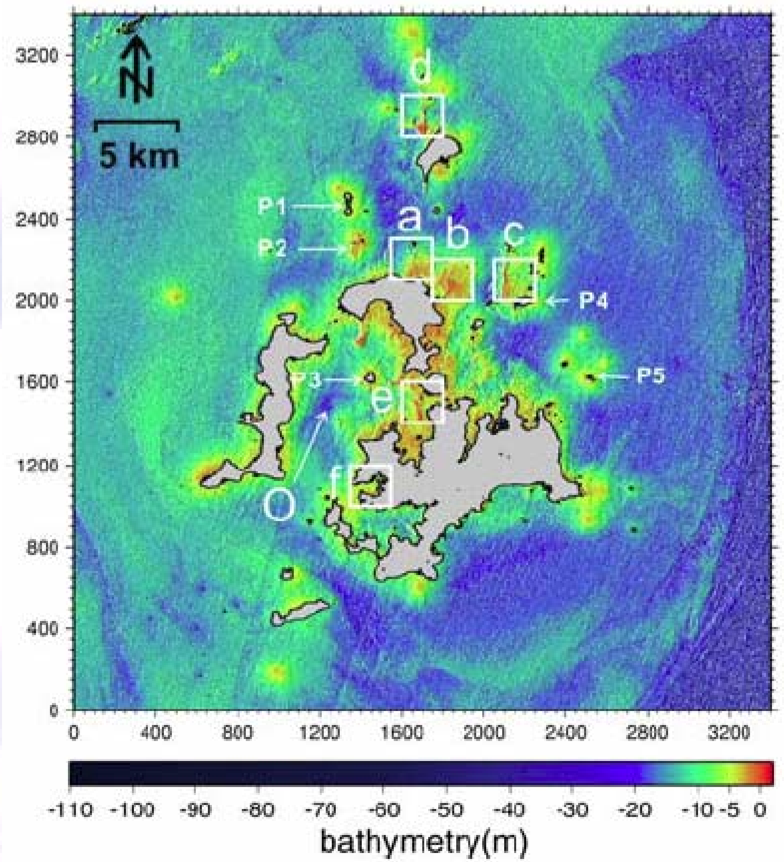


Fig. 1. Resulted bathymetry of the Penghu archipelago by using optical method. Rectangular frames a ~ f : detail bathymetric maps shown in Figure 2.

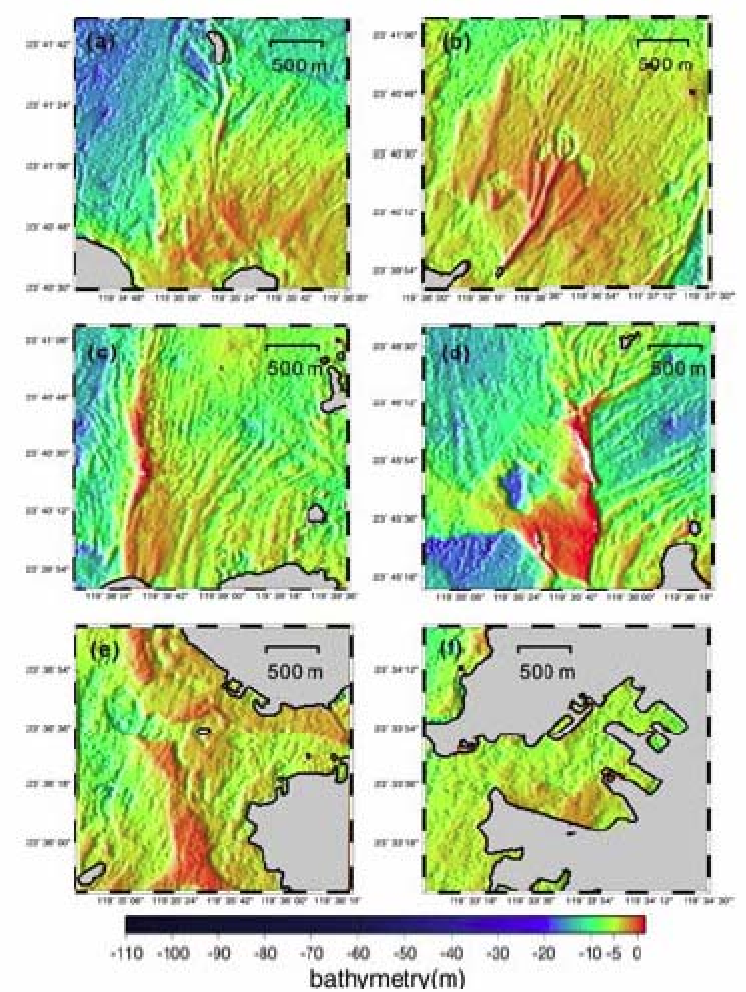
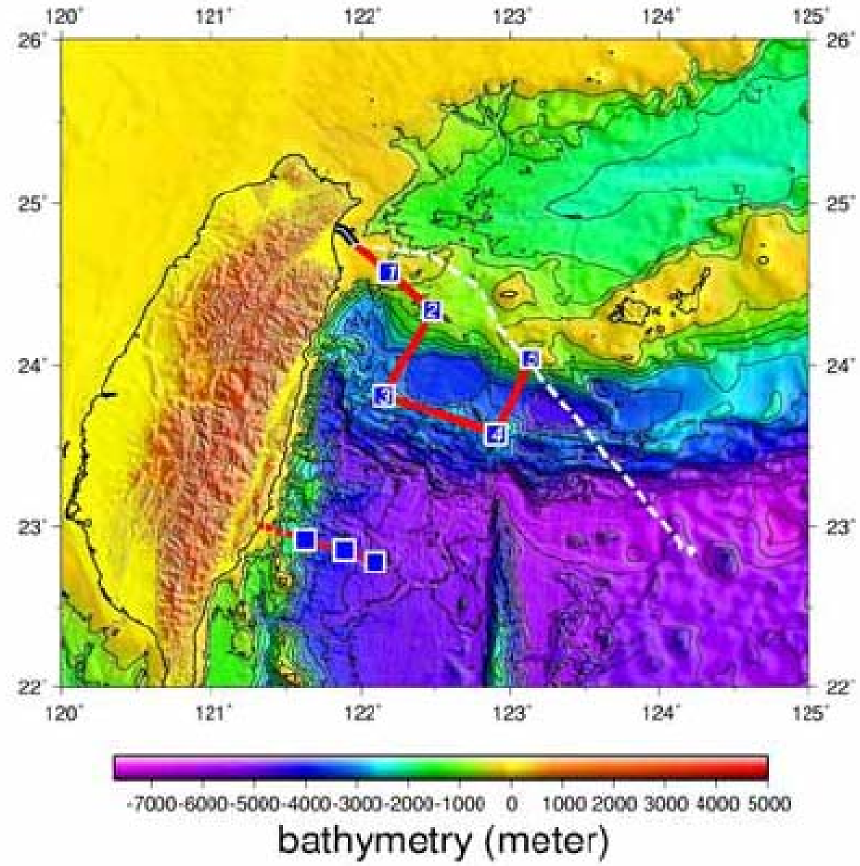


Fig. 2. Detail bathymetric maps of the study area.

The establishment of submarine cable observatories off eastern Taiwan can provide real-time earthquake, tsunami, and submarine volcano information.

- Hsu, Su-Kun



圖五、台灣東部海域海底觀測系統建置的構想圖。數字1-4代表海底觀測站位置，數字5的位置為終端設置。黑色虛線為APC纜線位置，紅色虛線為第二期海底觀測系統可能路徑。

Science Popularization 科普教育

[Students at 7th grade]

數值計算，以2006屏東地震為例
2006 Ping-Tung Earthquake

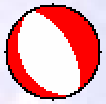
[東森新聞 2006]

[by Tso-Ren Wu, 2007/11/21]

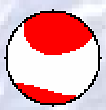
20061226 屏東雙地震特色 The uniqueness of Ping-Tung earthquake.

- Two earthquakes with a similar magnitude happened one after the other.
  - 連續兩場主震
- Tension fault
  - 第一場地震爲張裂型地震
- No records of strong earthquakes shown in the past.
  - 過去一百年來該地沒有記錄到大規模地震，資料缺乏
- Very close to the shore.
  - 極近岸地震，適合校正海嘯模式
- Accessible tidal gauge data from CWB.
  - 中央氣象局可提供潮位站資料

Earthquake Information
兩場主震，四種可能組合



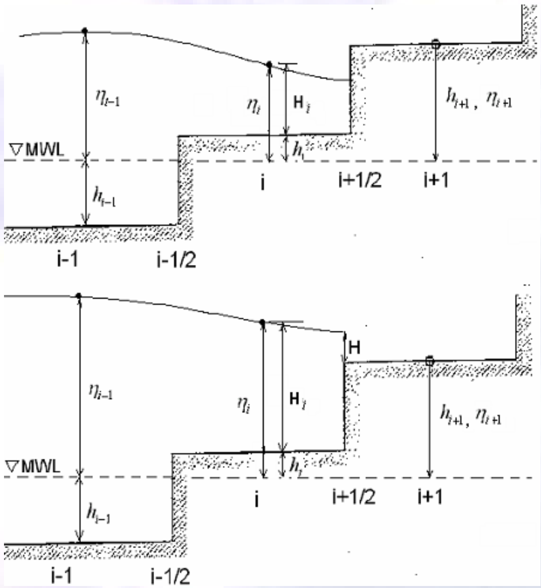
200612261226A TAIWAN REGION
Date: 2006/12/26 Centroid Time: 12:26:29.0 GMT Lat= 21.81 Lon= 120.52
Depth= 19.6 Half duration= 7.6 Centroid time minus hypocenter time: 7.9
Moment Tensor: Expo=26 -3.160 0.419 2.740 1.230 -1.550 -1.230
Mw = 7.0 mb = 6.4 Ms = 7.3 Scalar Moment = 3.78e+26
Fault plane: strike=165 dip=30 slip=-76 Case 11
Fault plane: strike=329 dip=61 slip=-98 Case 12



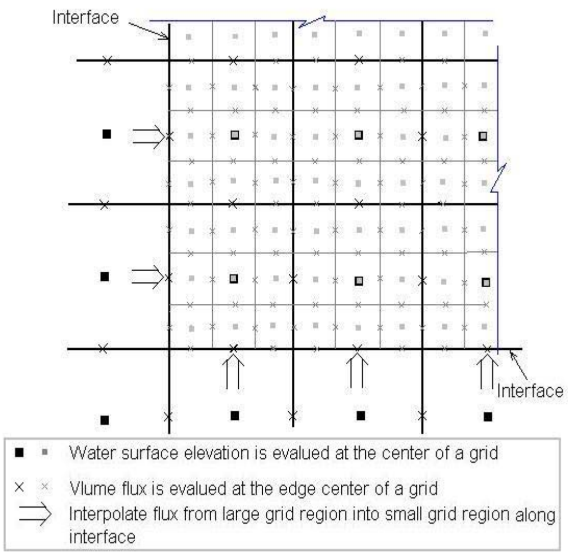
200612261234A TAIWAN REGION
Date: 2006/12/26 Centroid Time: 12:34:22.3 GMT Lat= 22.02 Lon= 120.40
Depth= 32.8 Half duration= 6.9 Centroid time minus hypocenter time: 8.5
Moment Tensor: Expo=26 -0.377 2.210 -1.830 2.110 0.145 -0.806
Mw = 6.9 mb = 6.5 Ms = 7.1 Scalar Moment = 2.87e+26
Fault plane: strike=151 dip=48 slip=0 Case 21
Fault plane: strike=61 dip=90 slip=138 Case 22

Tsunami propagation: COMCOT

Moving boundary scheme



Nested grids



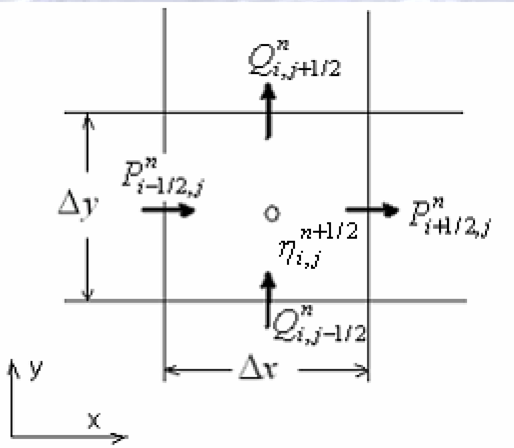
Moving boundary applies When $H_i>0$ and $H_{i+1}<=0$:

1. If $h_{i+1} + \eta_i<0$, shoreline at i+1/2 and $P_{i+1/2}=0$.
Total water depth is 0 at cell i+1.

2. If $h_{i+1} + \eta_i>0$, shoreline moves between i+1 and i+2. $P_{i+1/2}$ may have a none-zero value.
Total water depth is $H=h_{i+1} + \eta_i$ at cell i+1.

Explicit leap-frog scheme :

The free surface elevation is evaluated at the center of a grid cell on the *(n+1/2)-th* time step;
The volume flux components, P and Q, are evaluated at the center of four sides of the grid cell on the *n-th* time step.
The differencing schemes are shown in the right figure.



$$\frac{\partial \eta}{\partial t} = \frac{\eta^{n+1/2}_{i,j} - \eta^{n-1/2}_{i,j}}{\Delta t}; \quad \frac{\partial \eta}{\partial x} = \frac{\eta^{n+1/2}_{i,j} - \eta^{n+1/2}_{i,j}}{\Delta x}; \quad \frac{\partial \eta}{\partial y} = \frac{\eta^{n+1/2}_{i,j} - \eta^{n+1/2}_{i,j}}{\Delta y}$$

$$\frac{\partial P}{\partial t} = \frac{P^{n+1}_{i+1/2,j} - P^{n}_{i+1/2,j}}{\Delta t}; \quad \frac{\partial Q}{\partial t} = \frac{Q^{n+1}_{i,j+1/2} - Q^{n}_{i,j+1/2}}{\Delta t}$$

$$\frac{\partial P}{\partial x} = \frac{P^{n}_{i+1/2,j} - P^{n}_{i-1/2,j}}{\Delta x}; \quad \frac{\partial Q}{\partial y} = \frac{Q^{n}_{i,j+1/2} - Q^{n}_{i,j-1/2}}{\Delta y}$$

$$\frac{\partial \eta}{\partial t} + \sqrt{gh}\,\frac{\partial \eta}{\partial \vec{n}} = 0$$

where $\vec{n}$ is the normal to the open boundary.

Shallow Water Equations

$$\frac{\partial \eta}{\partial t} + \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} = 0 \quad (1.1)$$

$$\frac{\partial \eta}{\partial t} + \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} = 0 \quad (1.3)$$

$$\begin{aligned} &\frac{\partial P}{\partial t} + gH\frac{\partial \eta}{\partial x} = 0 \\ &\frac{\partial Q}{\partial t} + gH\frac{\partial \eta}{\partial y} = 0 \end{aligned} \quad (1.2)$$

$$\begin{aligned} &\frac{\partial P}{\partial t} + \frac{\partial}{\partial x}\left(\frac{P^2}{H}\right) + \frac{\partial}{\partial y}\left(\frac{PQ}{H}\right) + gH\frac{\partial \eta}{\partial x} + \tau_x = 0 \\ &\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{PQ^2}{H}\right) + \frac{\partial}{\partial y}\left(\frac{Q^2}{H}\right) + gH\frac{\partial \eta}{\partial y} + \tau_y = 0 \end{aligned} \quad (1.4)$$

x, y are the horizontal coordinates,

η is the free-surface displacement,

$H = \eta + h$ is the total water depth,

h is the still water depth,

$P = Hu$, $Q = Hv$ are the horizontal volume discharges,

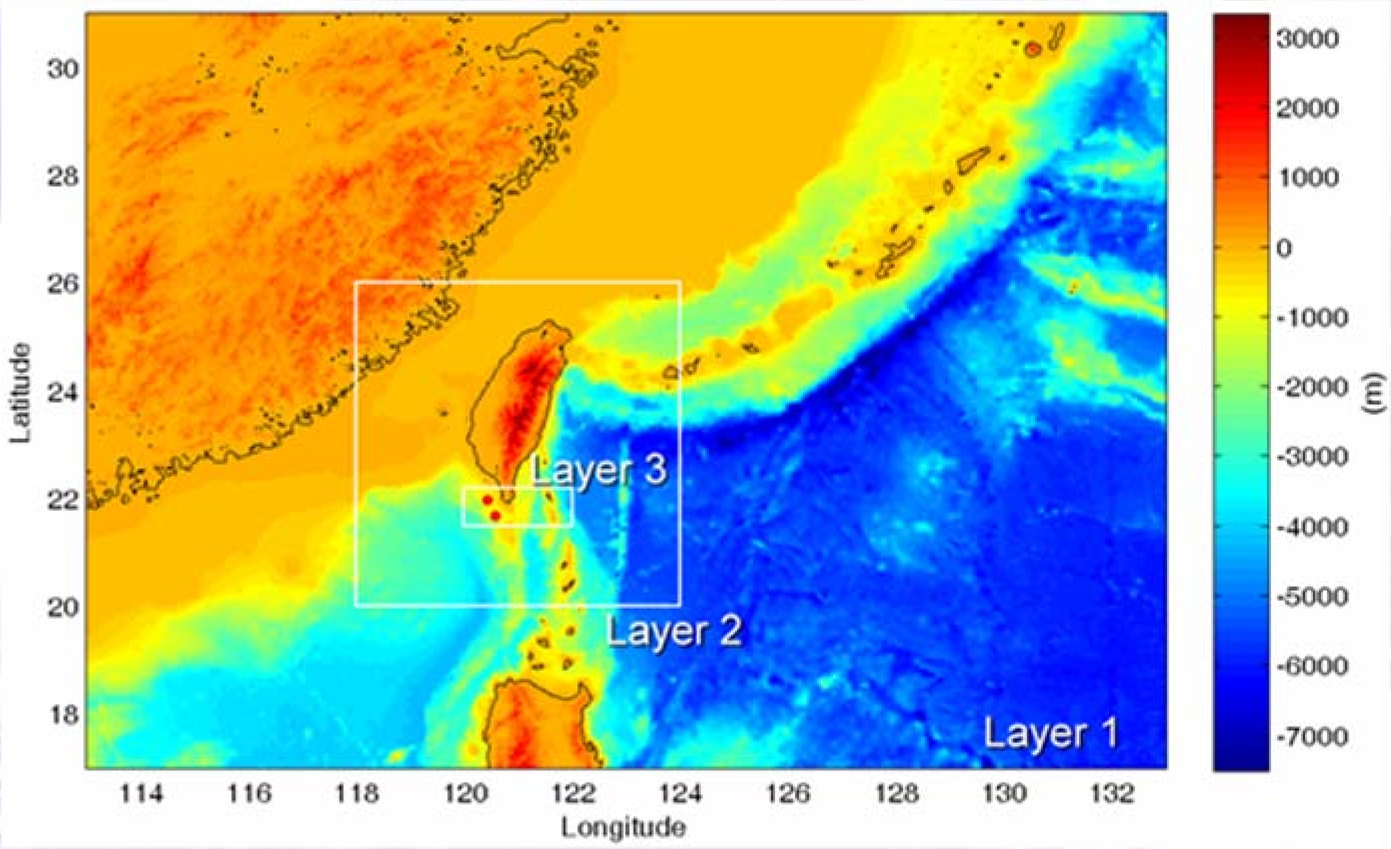
g is gravity, t is time.

where τ_x and τ_y are the bottom frictions.

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

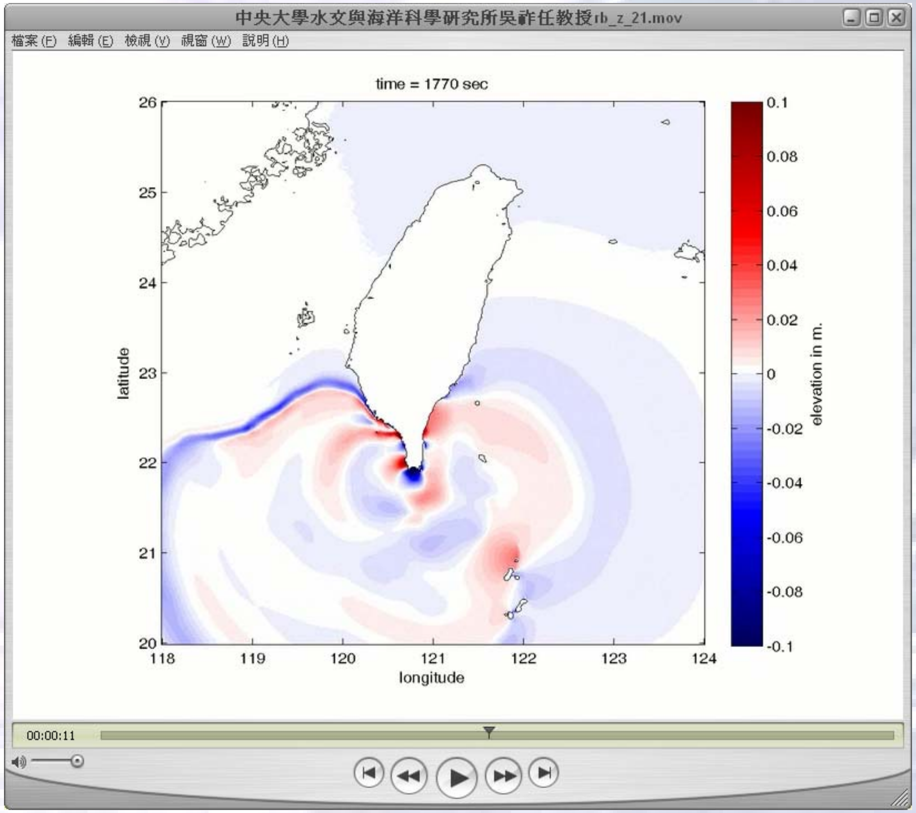
$$\begin{aligned} \tau_x &= \frac{gn^2}{H^{7/3}} P\left(P^2 + Q^2\right)^{1/2} \\ \tau_y &= \frac{gn^2}{H^{7/3}} Q\left(P^2 + Q^2\right)^{1/2} \end{aligned} \quad (1.5)$$

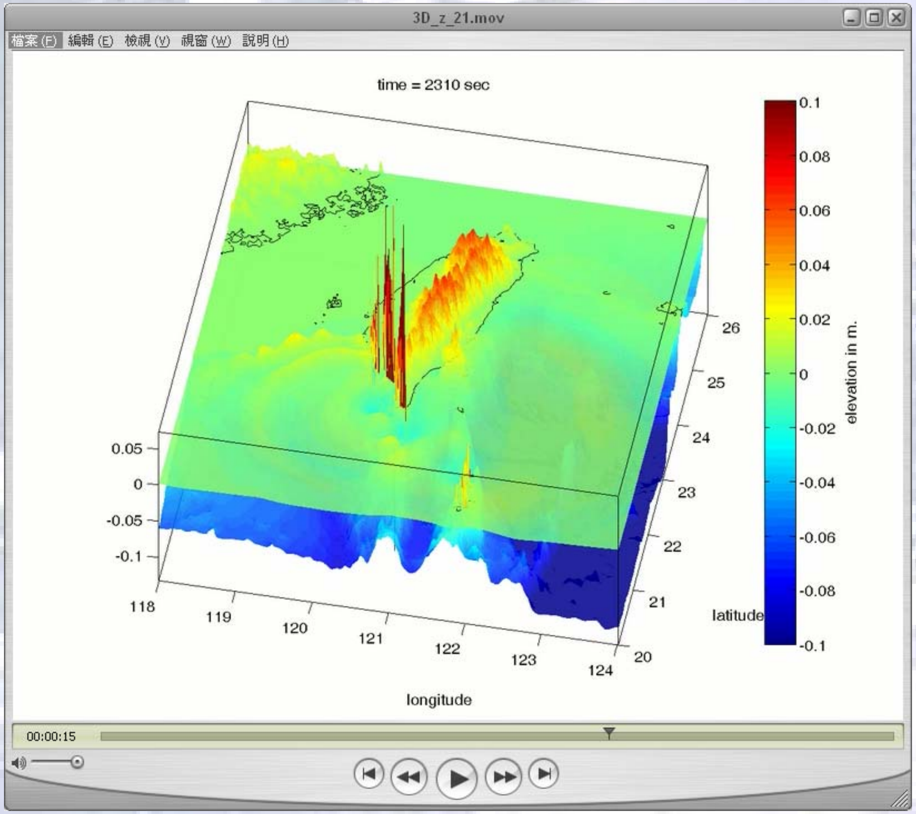
Computational Domain:
三層巢狀網格



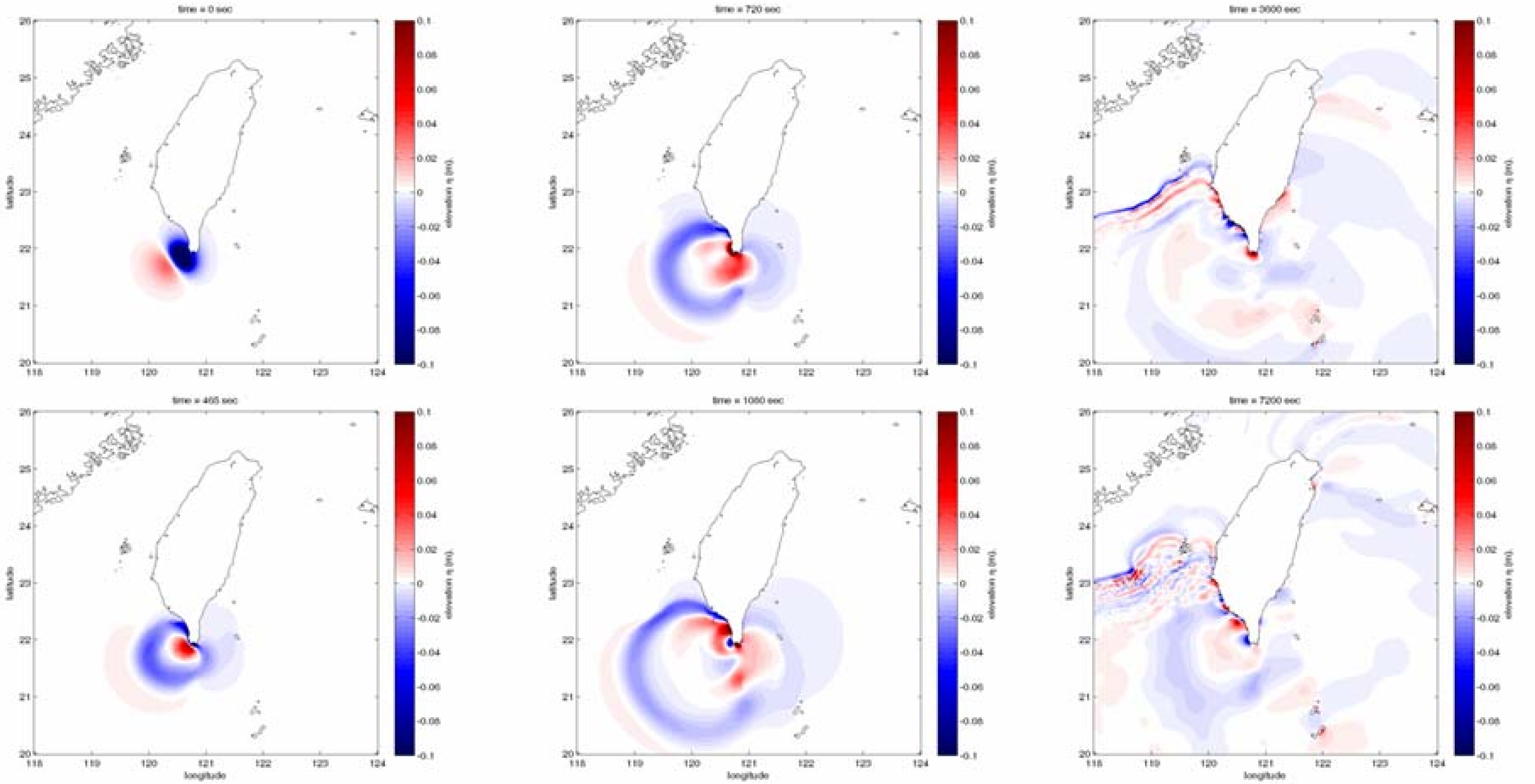
1#: dx= 2 min; 2#: 1 min; 3: 1/8 min

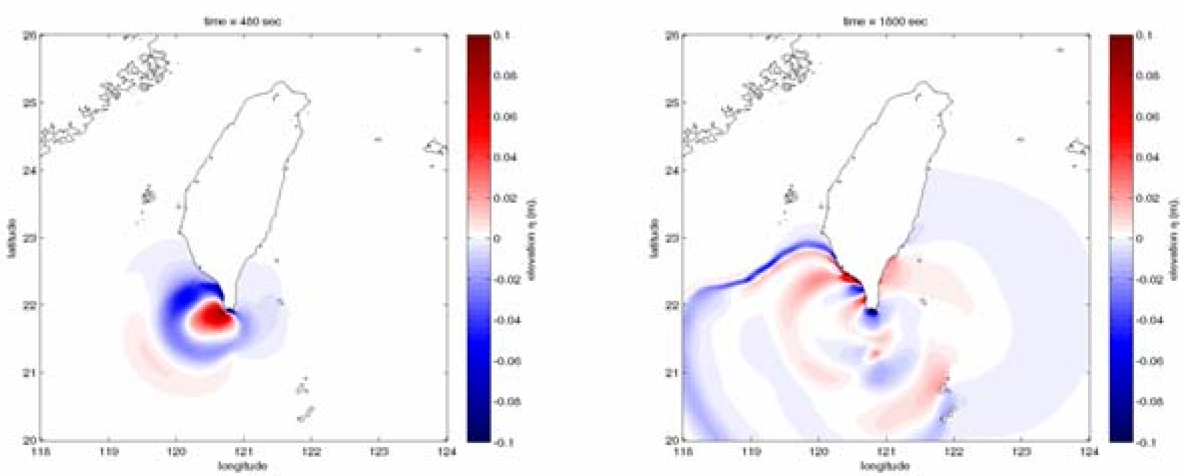
海嘯波傳之數值模擬





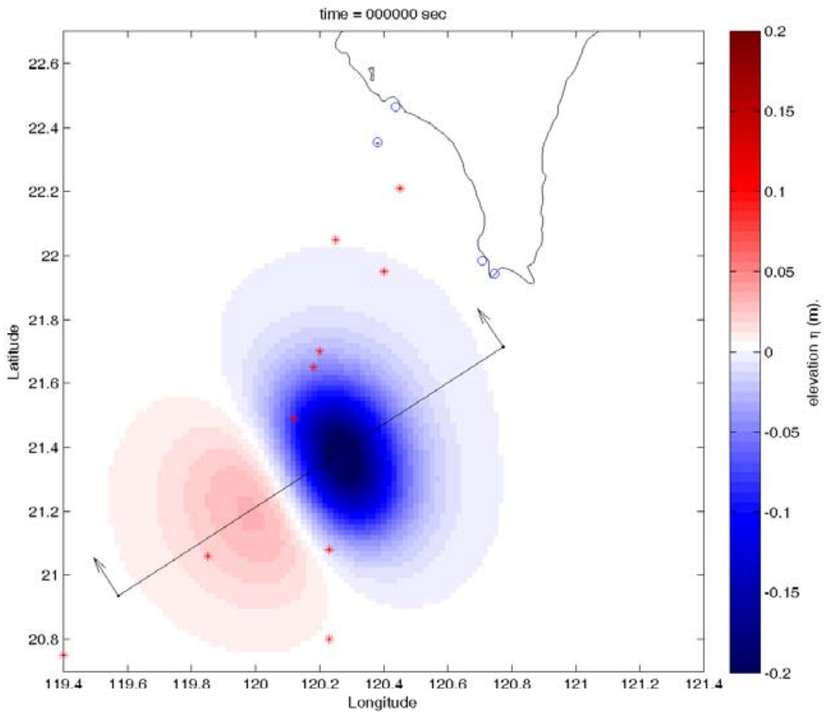
吳祚任老師實驗室對於2006年屏東海嘯傳播之模擬。

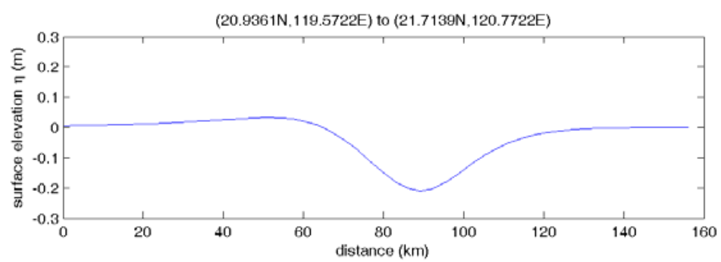




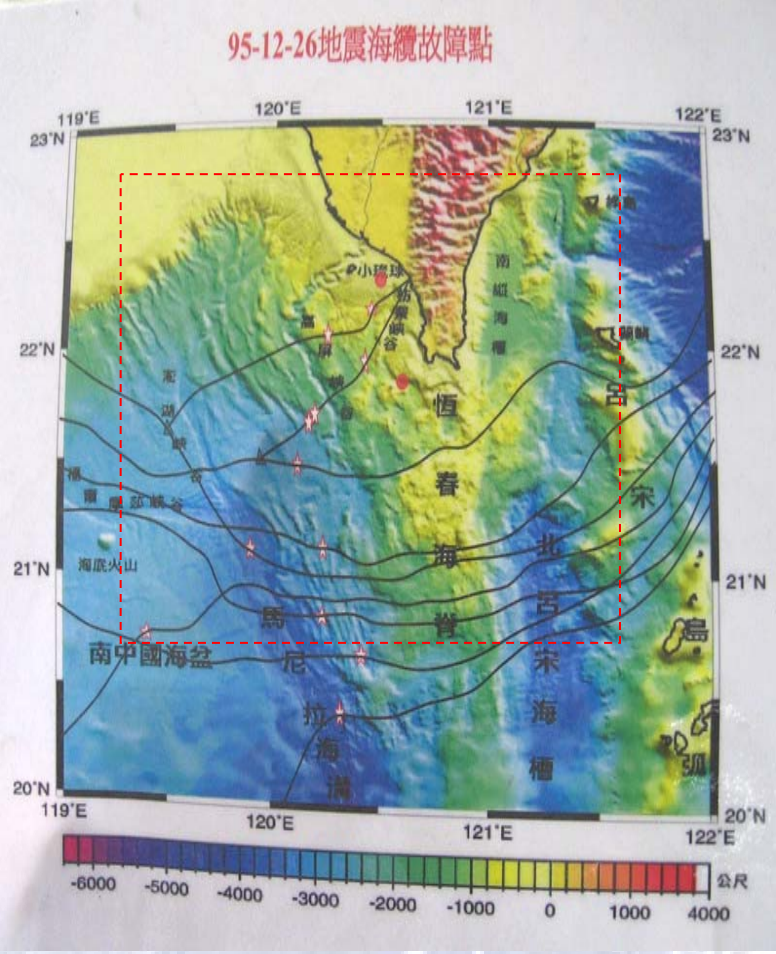
Simulation result:
Case 11+22

Source Calibration





紅色星號爲海底電纜斷纜位置



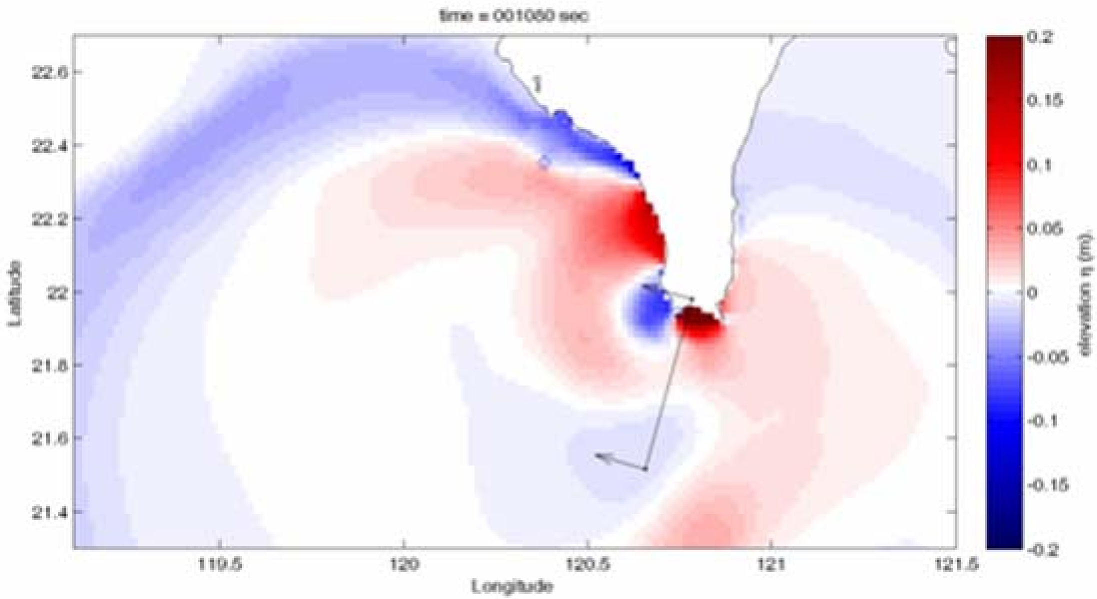
New Epicenters:
1#: (21.36N, 120.31E)
2#: (21.76N, 120.25E)

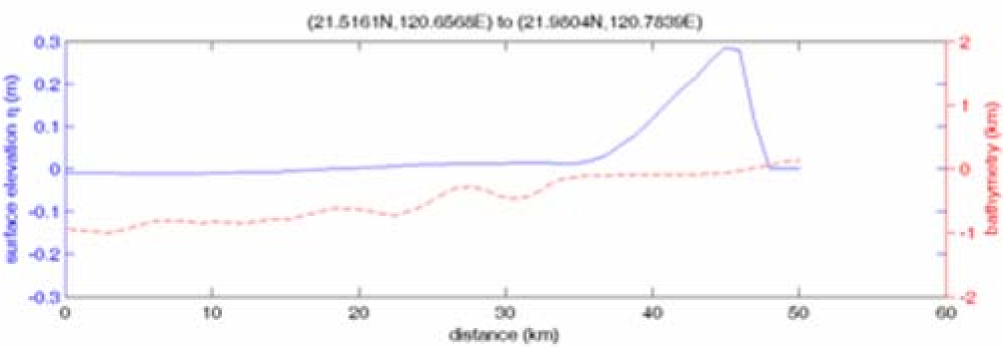
Note: old epicenters:
1#: (21.81N, 120.52E)
2#: (21.97N, 120.42E)

Shoaling effect

20 km mild slope is perfect for tsunami shoaling and amplification

台灣南灣有近20公里的緩坡，適合海嘯放大與溯昇

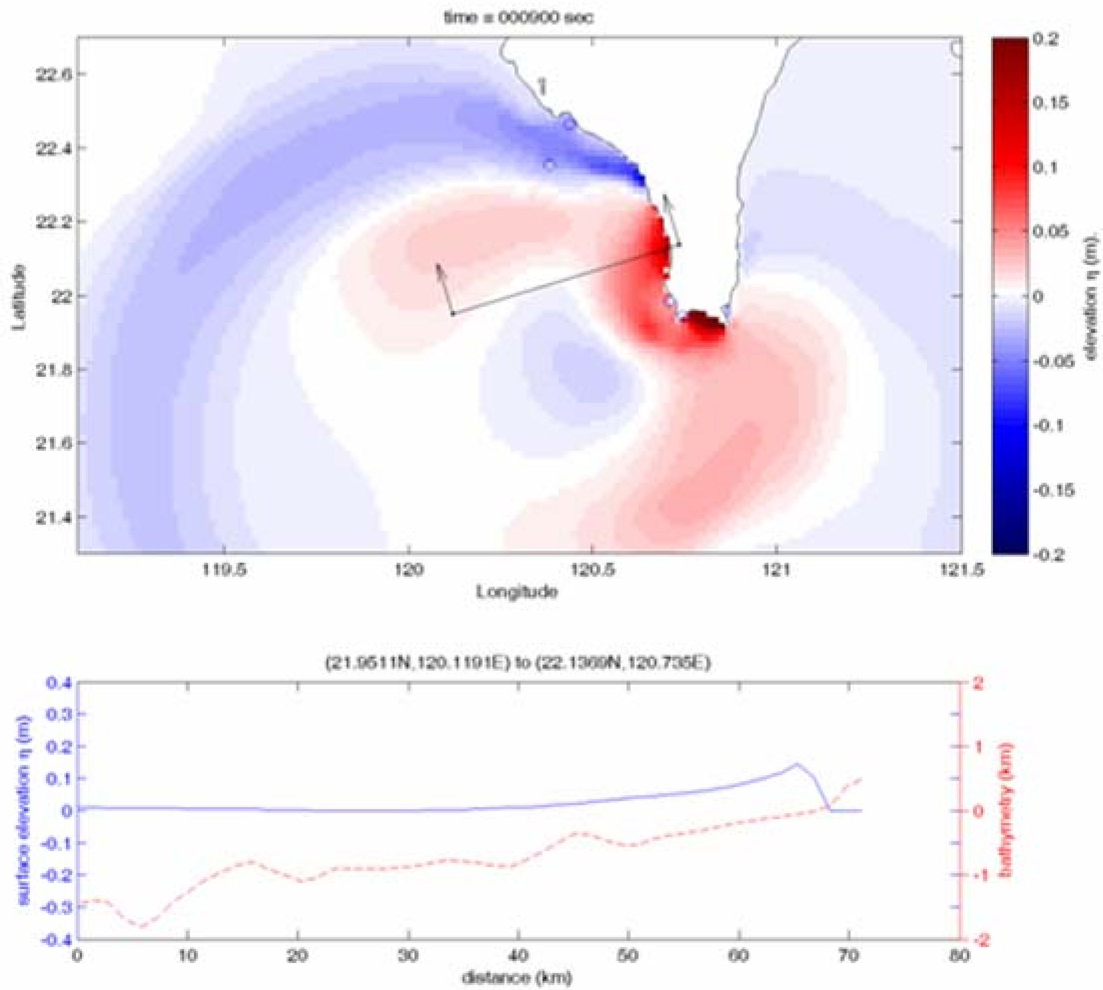




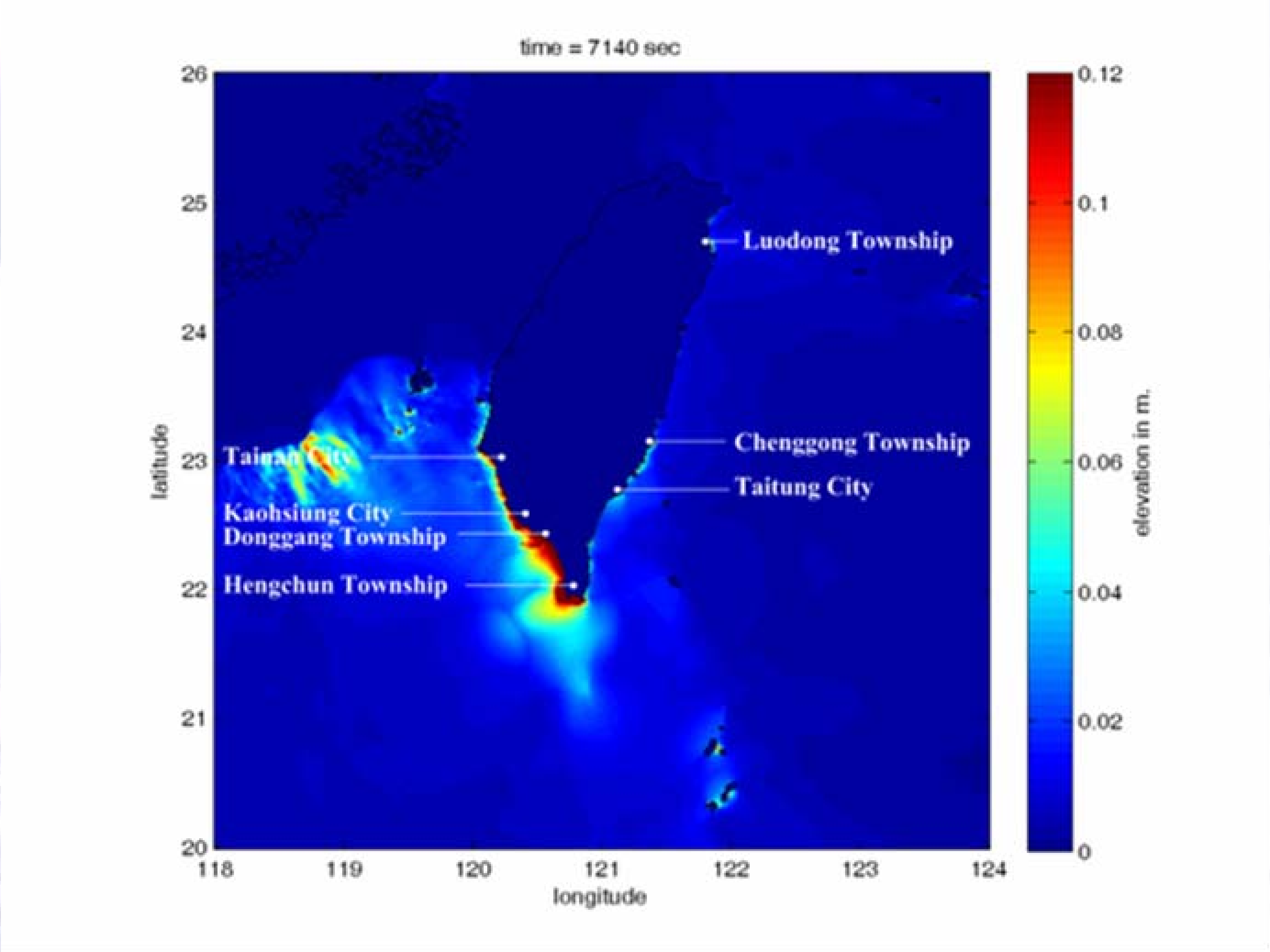
後壁湖漁港

Edge wave effect

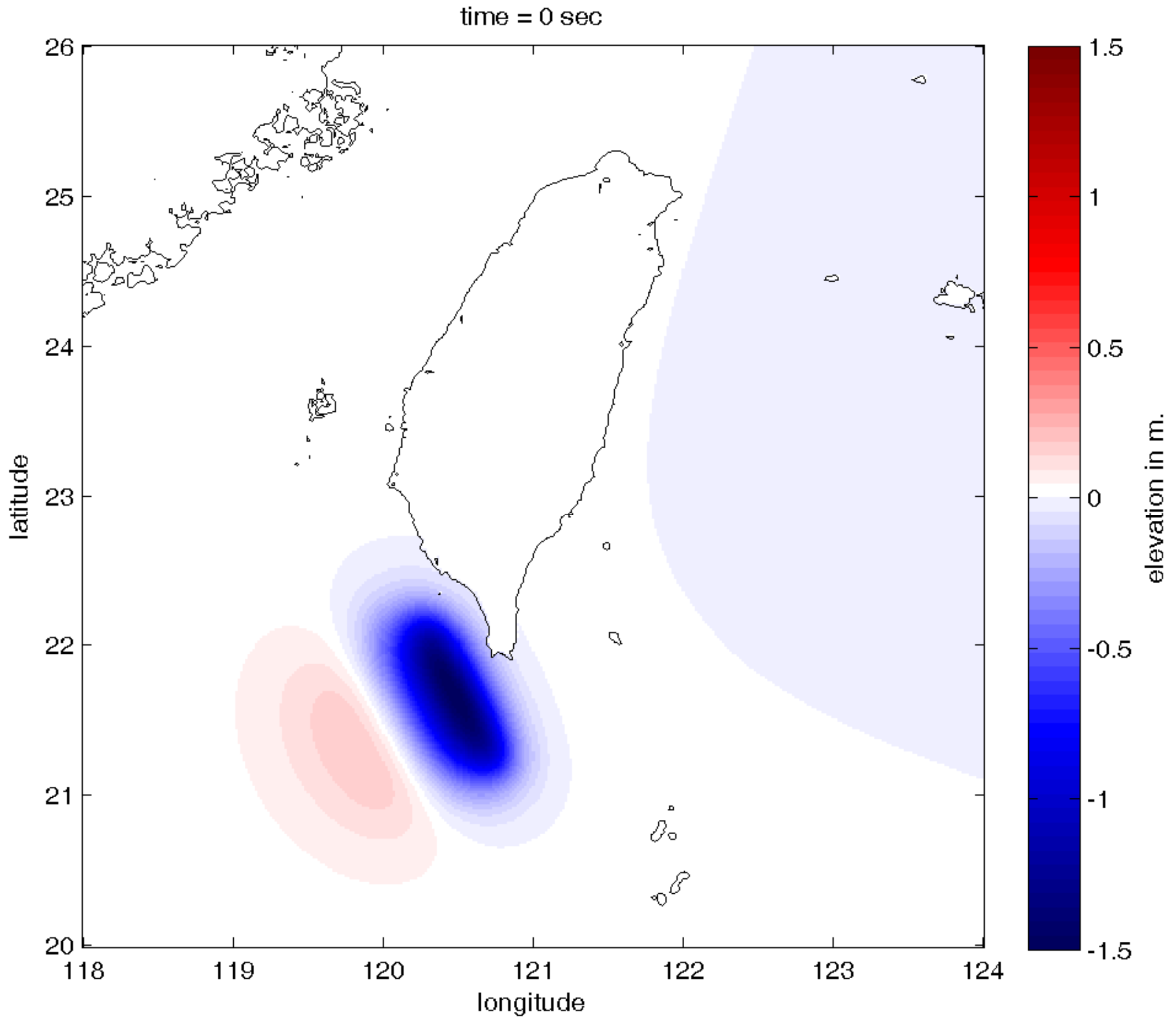
西南岸之緩坡有利海嘯折射，產生邊緣波效應



Maximum surface elevation
最大波高示意圖

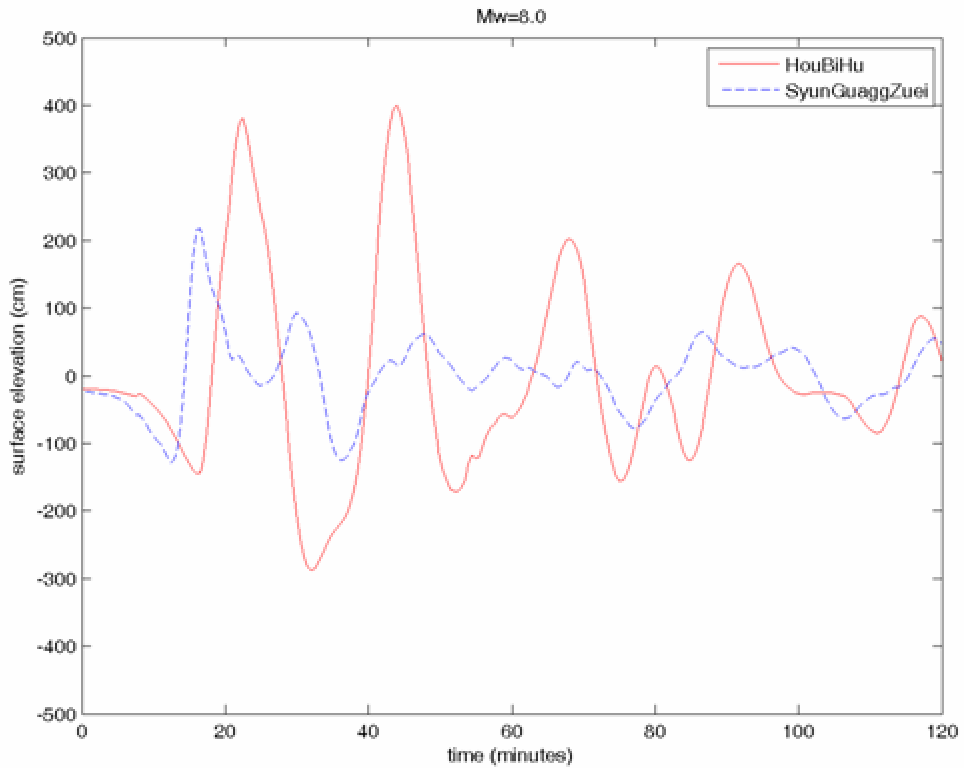


What if we are not that lucky. Say if the earthquake is stronger. Mw=8.0. What's going to happen?

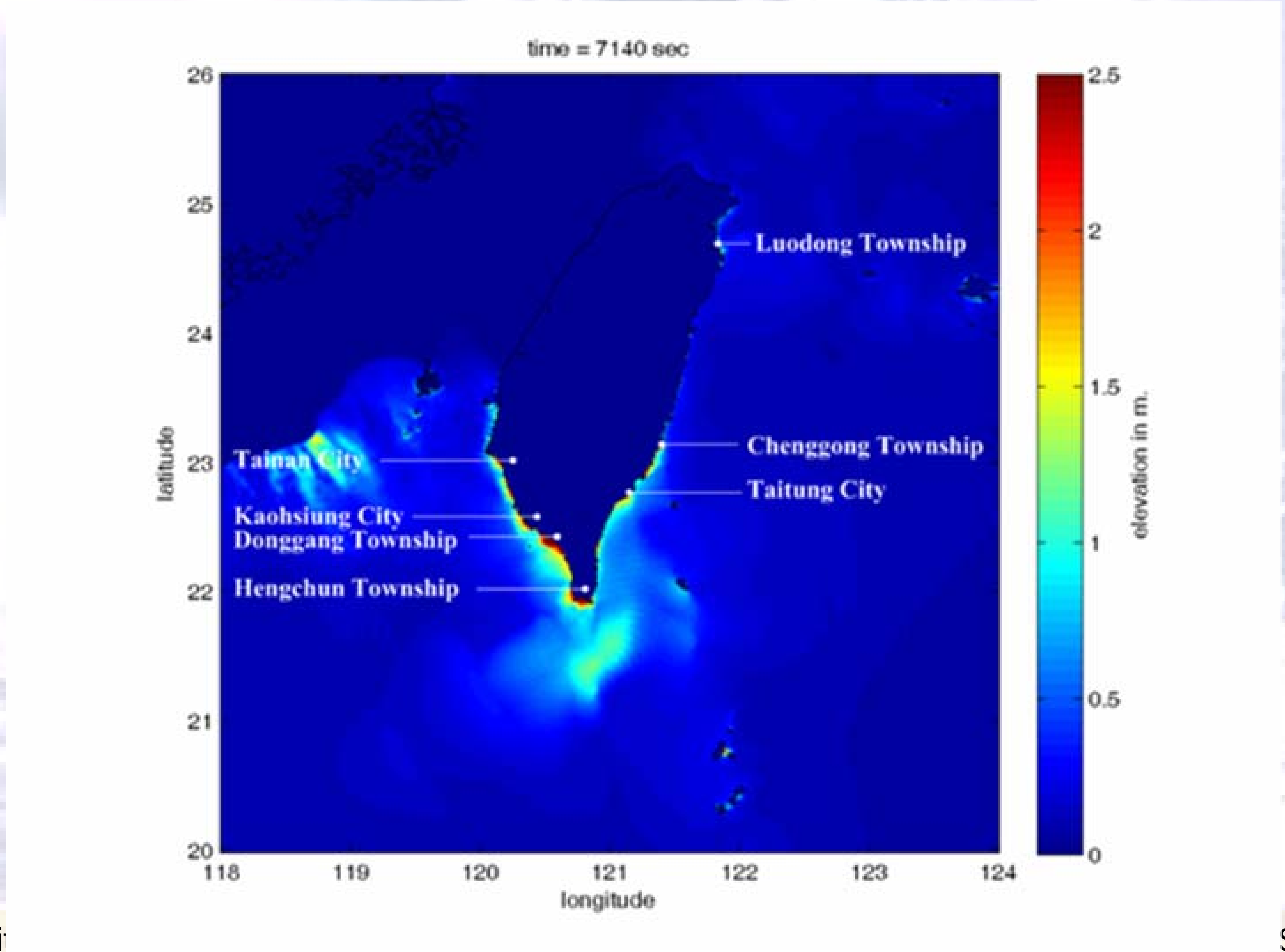


Mw=8.0

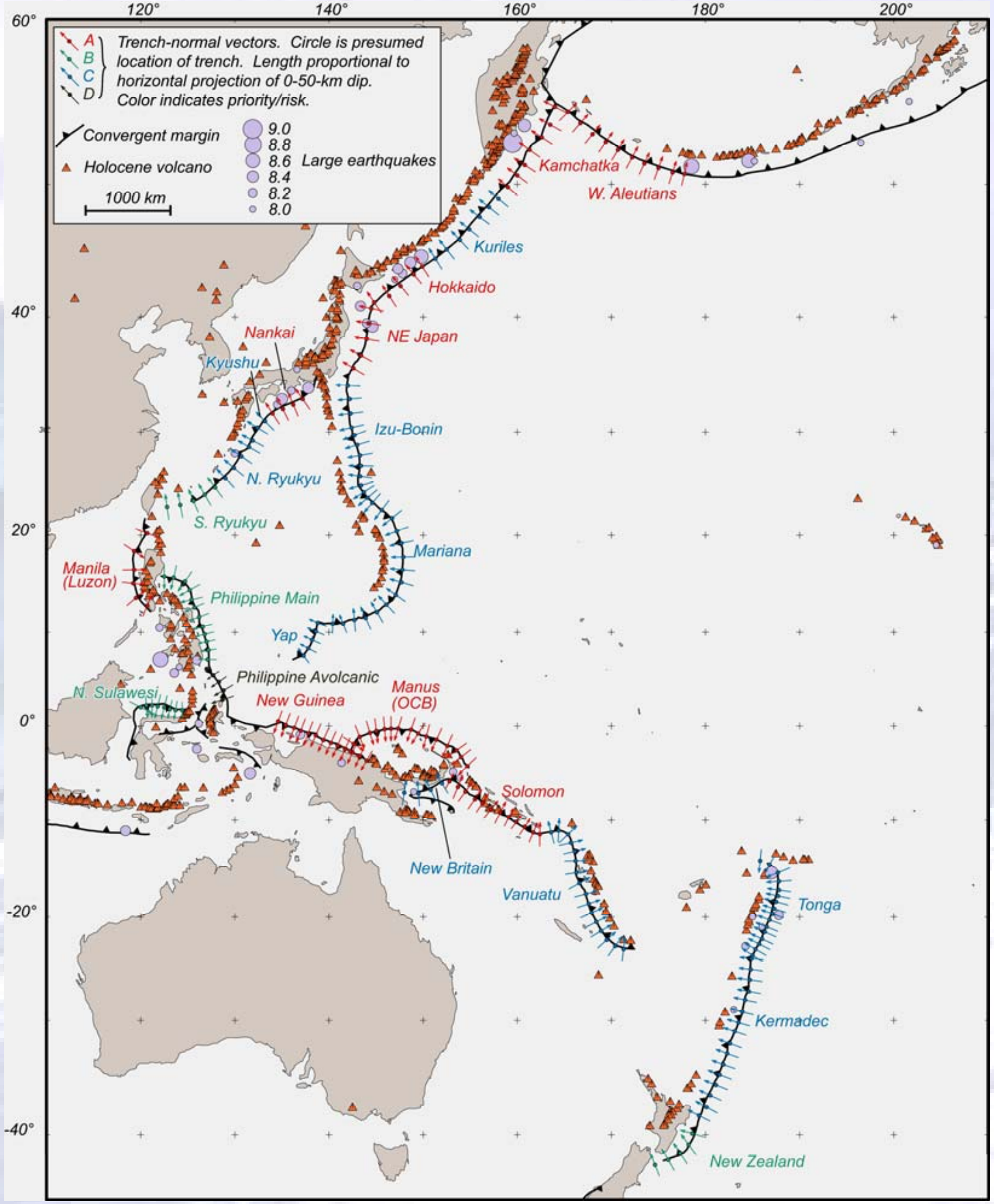
最大波高高達4m。
Maximum wave height is 4 m.



Maximum surface elevation 最大波高圖 (Mw=8.0)



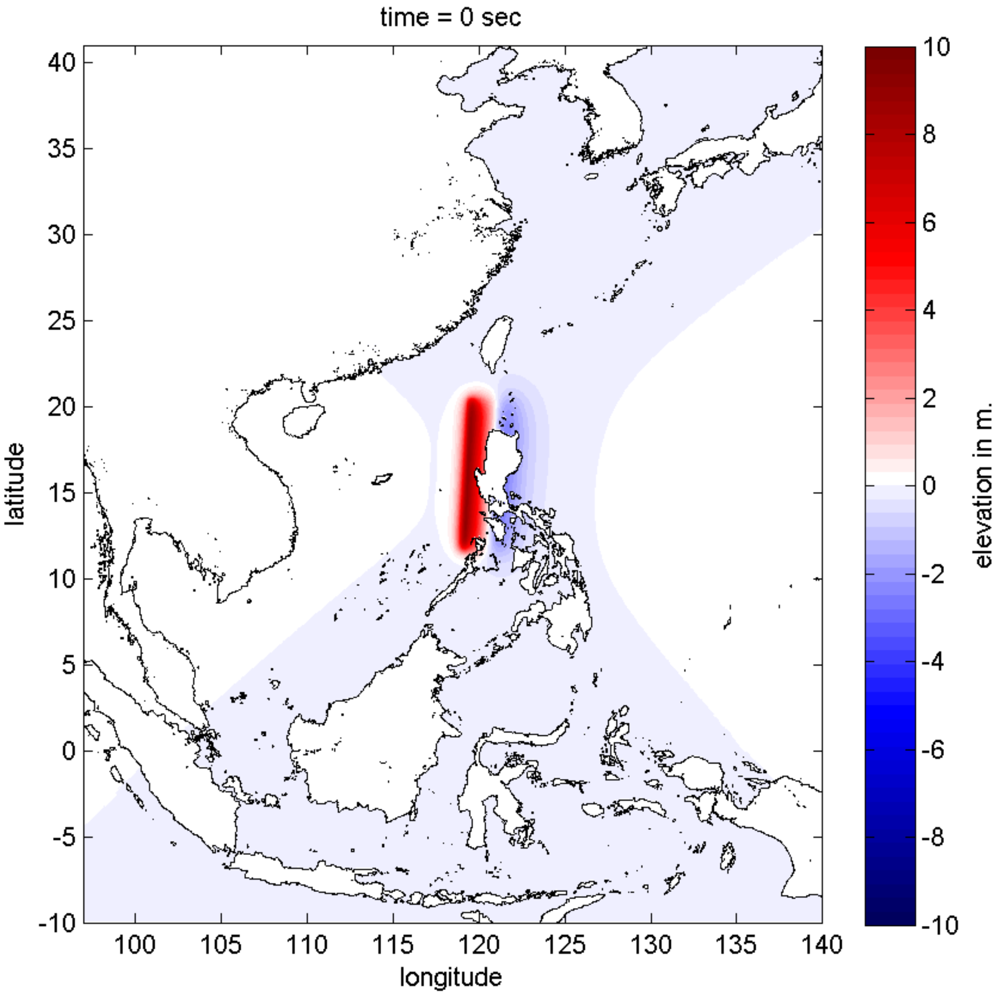
Tsunami Source Characterization for Western Pacific Subduction Zones: A Preliminary Report
USGS1 Tsunami Subduction Source Working Group

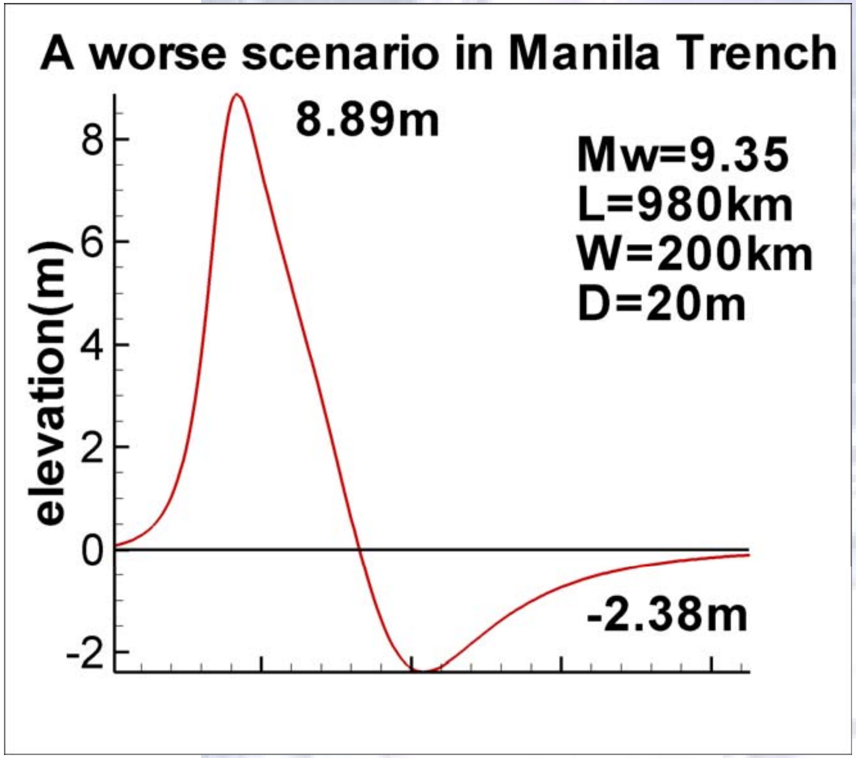


BOTTOM LINE
Hazard appraisal key:
A: High
B: Intermediate
C: Low
D: Not classified

Simulation result

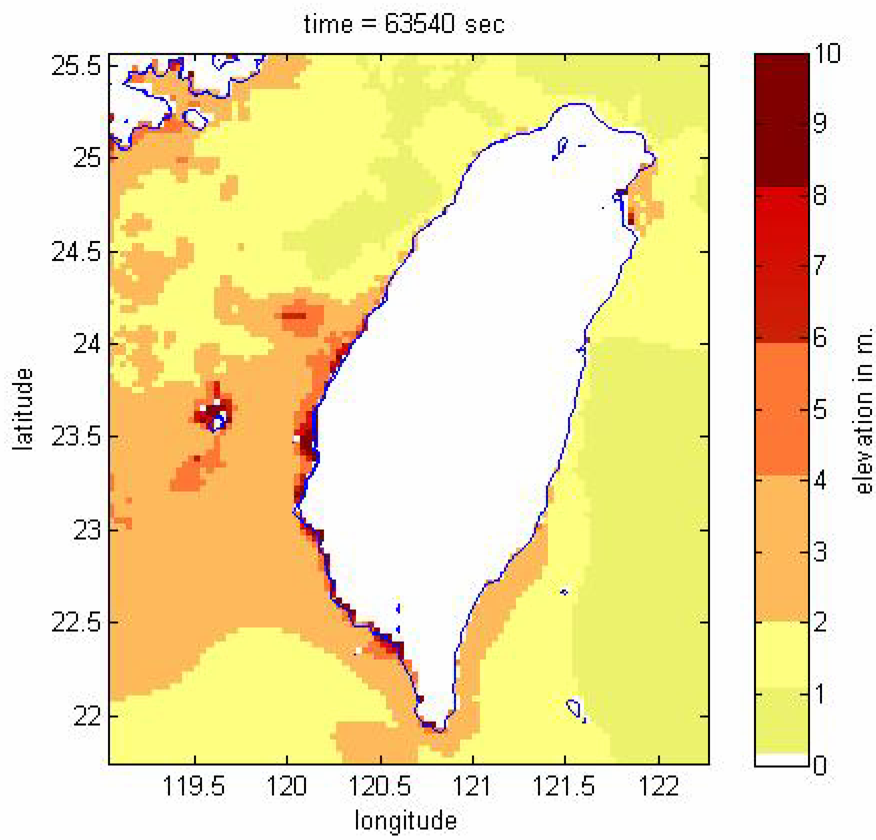
所以推測	總長	推測寬度	推測dislocation	規模	推測深度	其他參數		
Manila trench	980	200.00	20.00	M=9.35	40(or 30or 50)	strike=3	dip=23	slip=90
	經度	緯度						
	119.25	**16.05**						



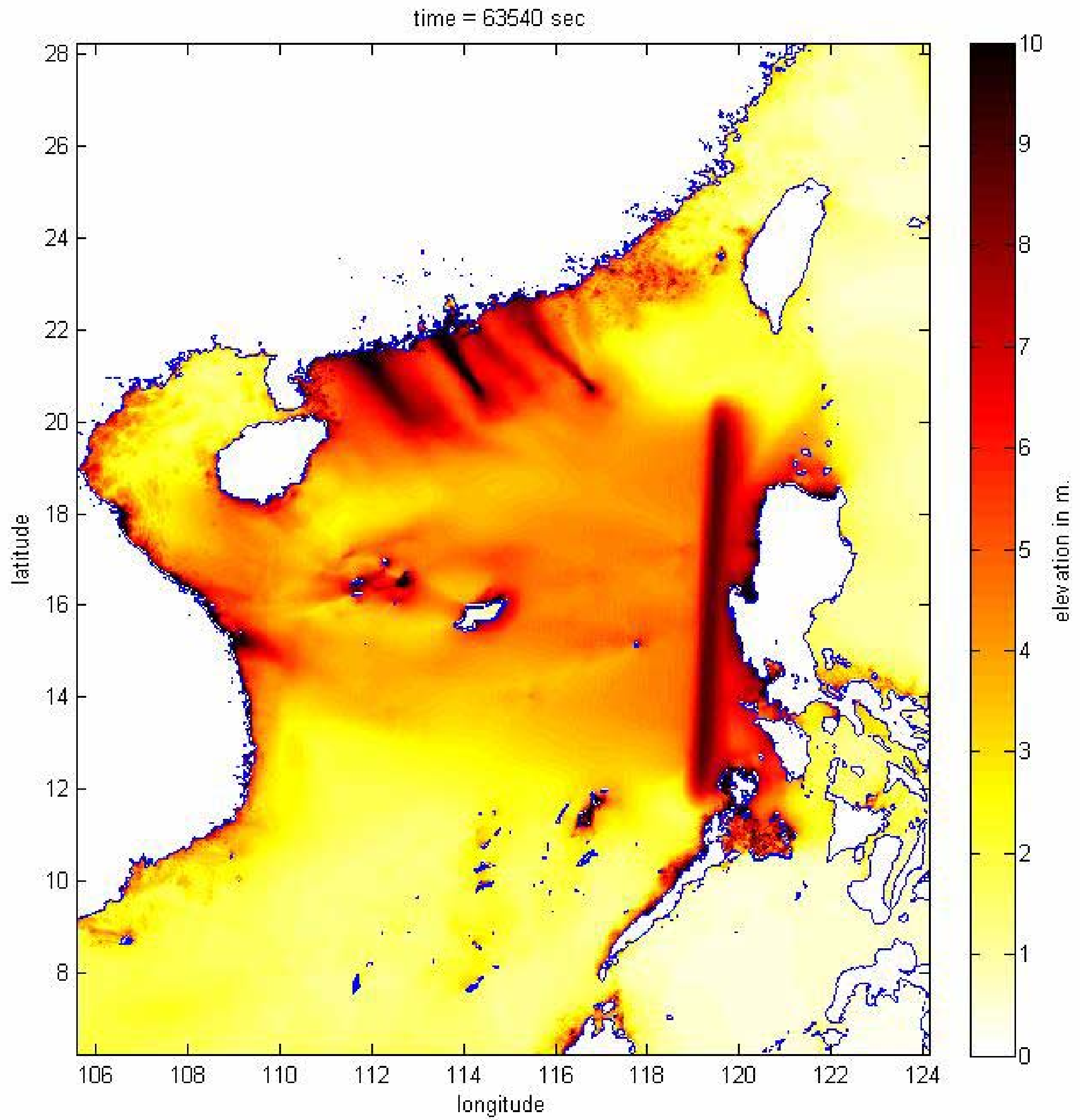


[by 中央大學 黃惠絹]

馬尼拉海溝地震
最大波高圖



[by 中央大學 黃惠絹]

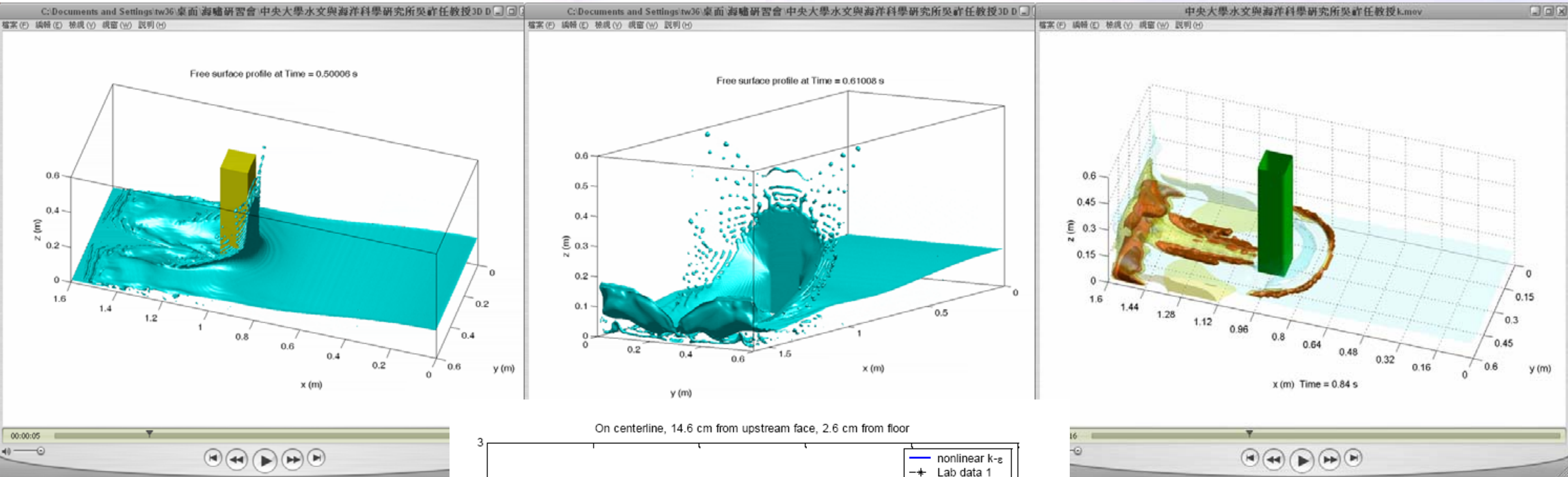


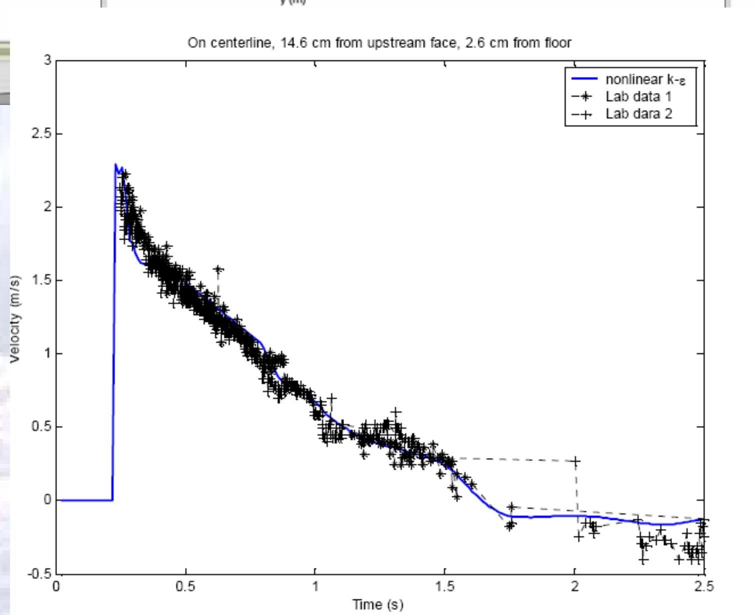
[by Hui-Chuan Huang]

Breaking Waves and Scouring Problem

海嘯溯昇過程中，將對地表產生嚴重的濤刷作用。（from Prof. Philip Liu）

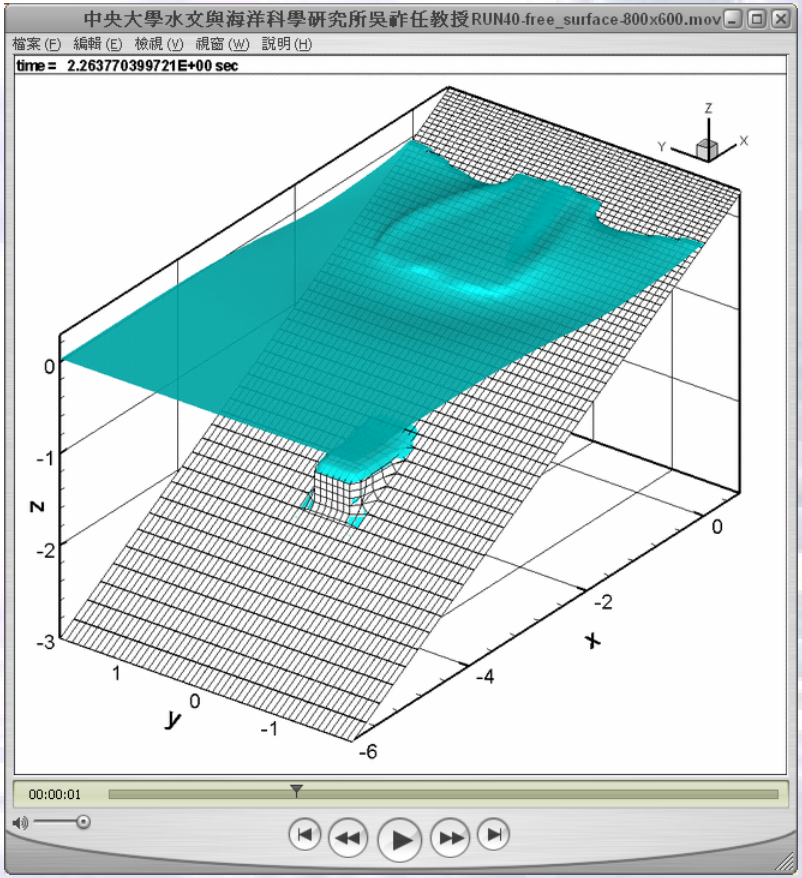
三維碎浪數值模擬

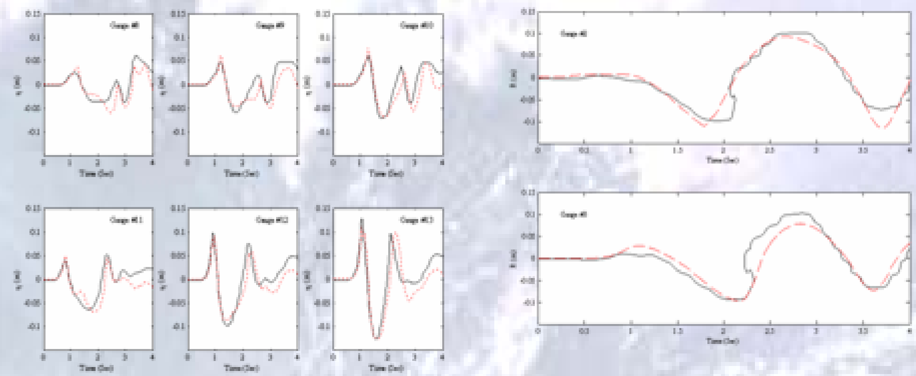


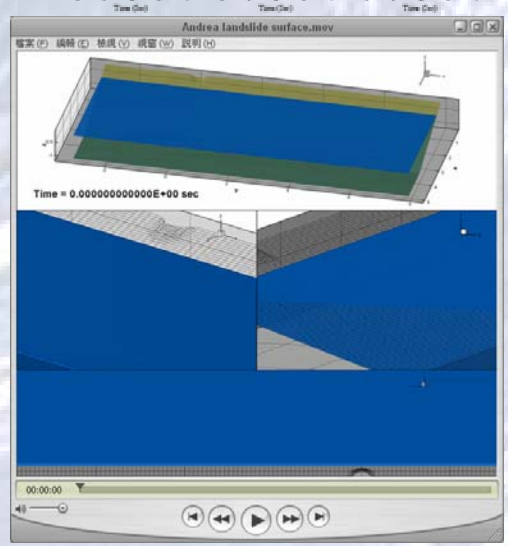


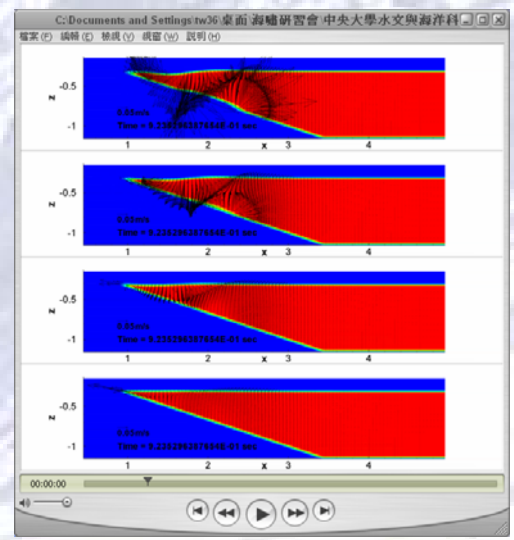
吳祚任老師海嘯實驗室所發展之三維數值模式可以精確計算海嘯湧潮對於結構物之影響。

3D Landslide Tsunamis
三維山崩海嘯









吳祚任老師海嘯實驗室所發展之三維數值模式可真實計算固體墜落所引發之山崩海嘯。

- We are seeking for the international cooperation on the Tsunami research.
- Tso-Ren Wu
- tsoren@ncu.edu.tw

- Thank you for listening!