Source Characterization for Tsunamegenic Earthquakes in Taiwan Region

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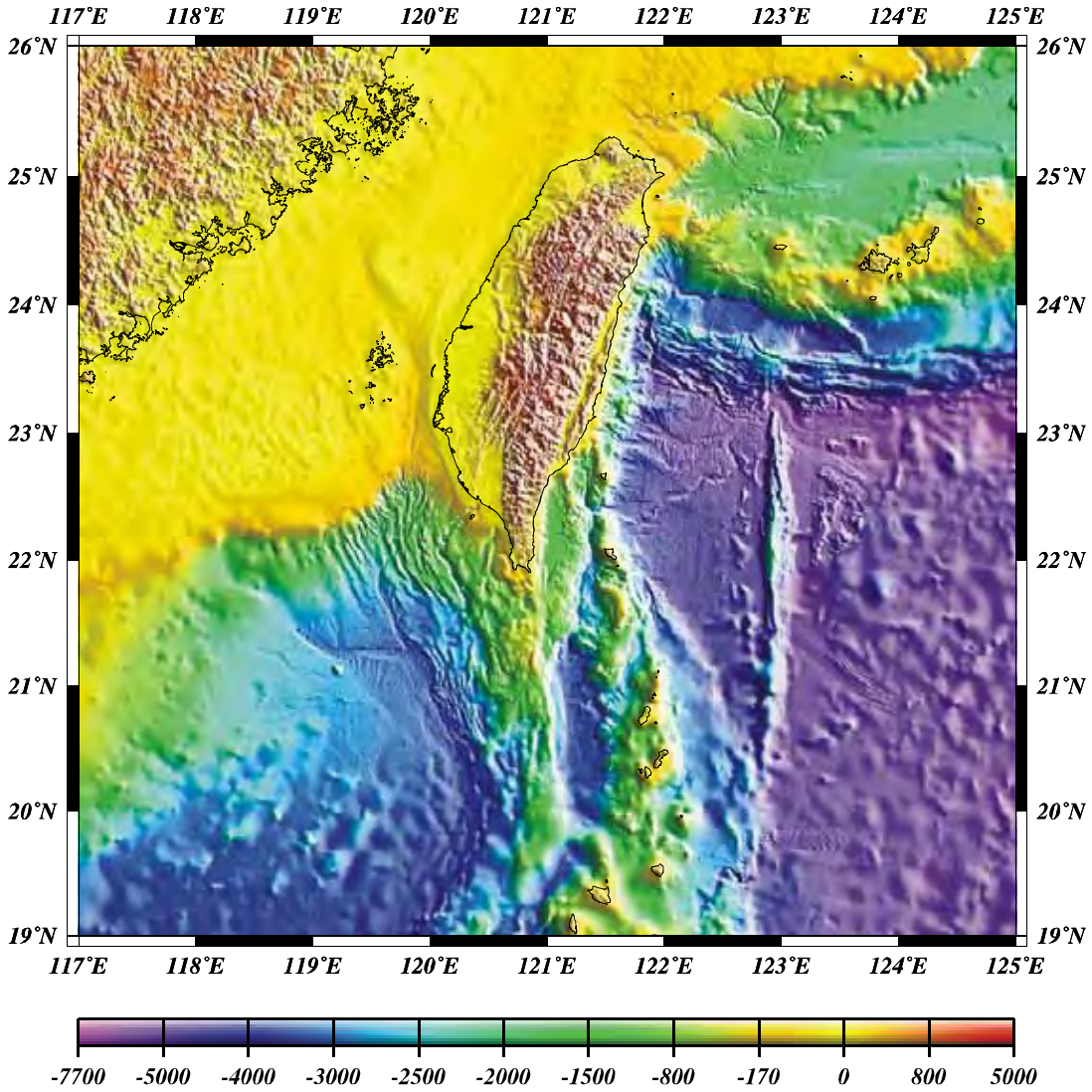
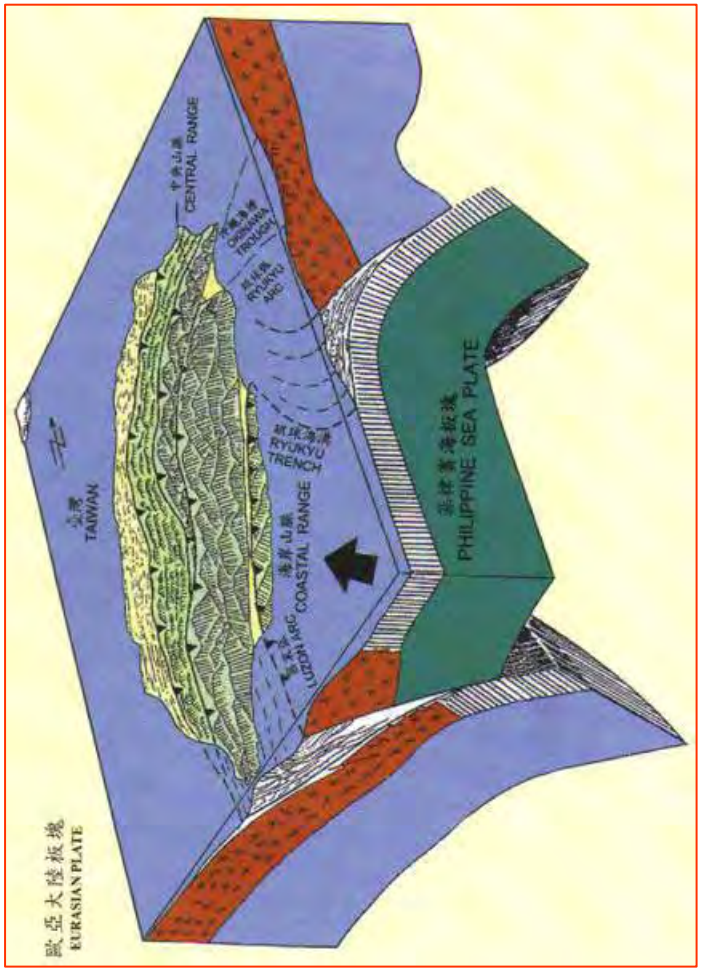
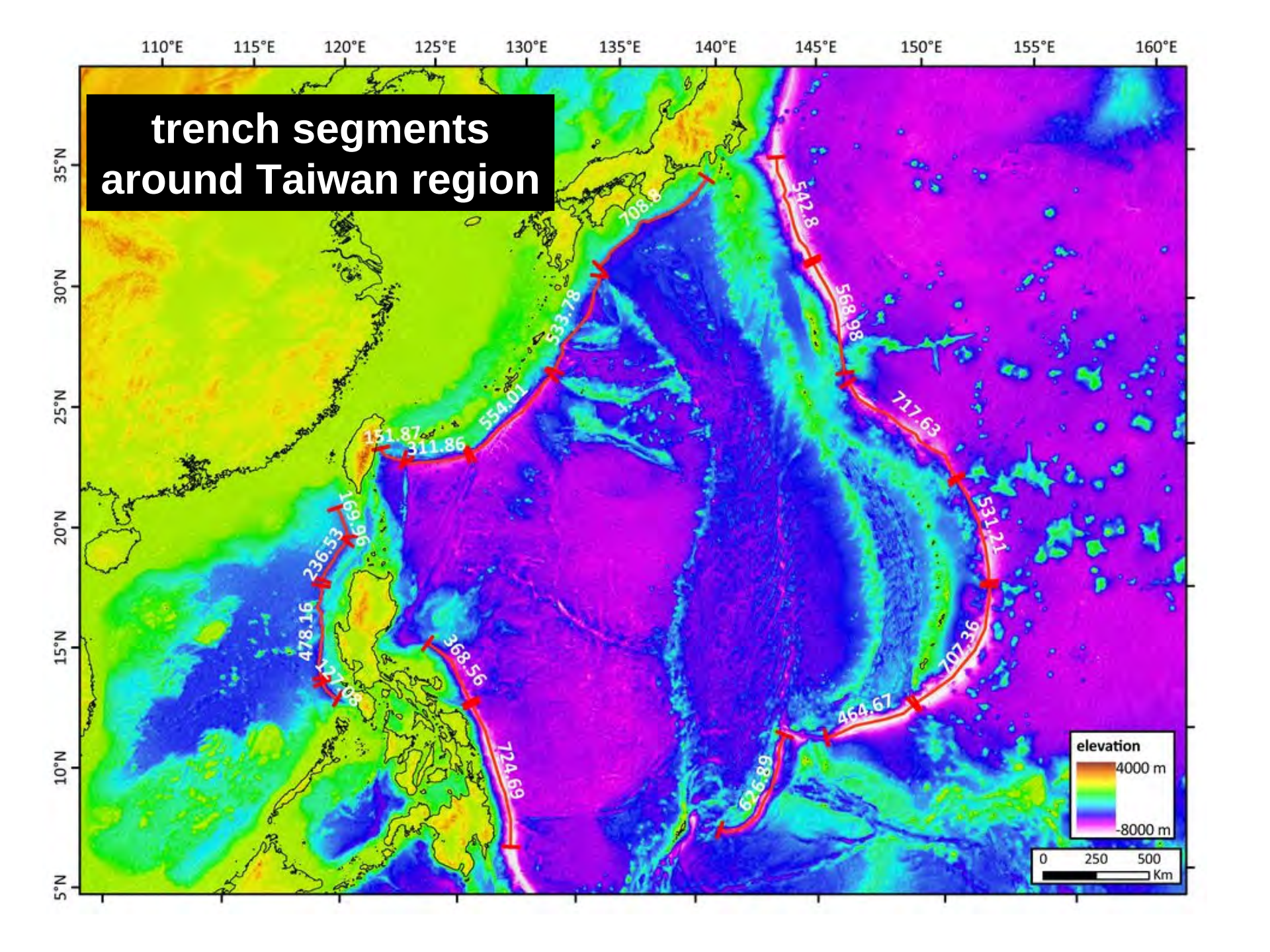
Bathymetry and Tectonic Setting near Taiwan

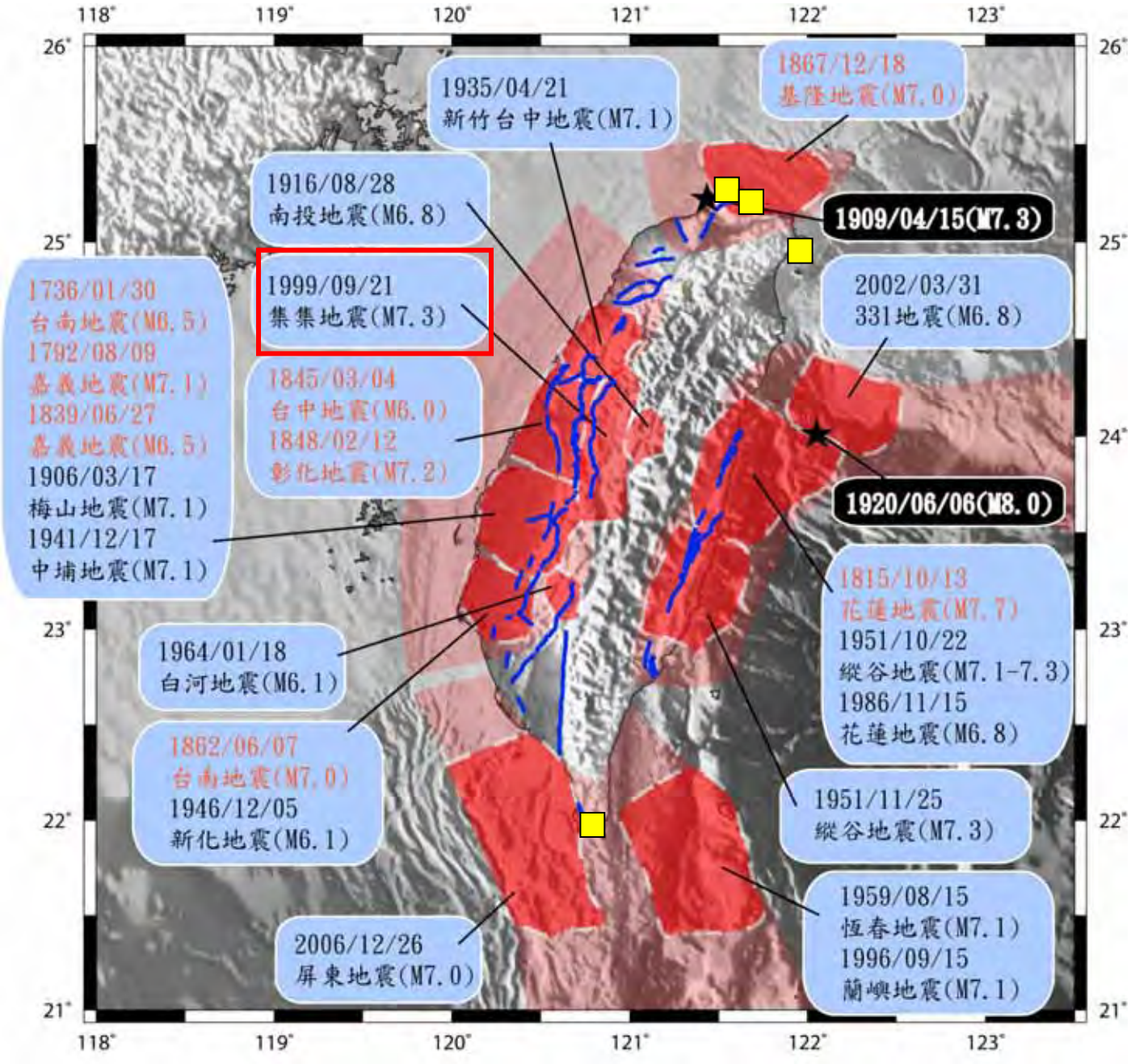
Tsunami: off-shore faults, and subduction zones






trench segments
around Taiwan region
110°E
115°E
120°E
125°E
130°E
135°E
140°E
145°E
150°E
155°E
160°E
35°N
30°N
25°N
20°N
15°N
10°N
5°N
542.8
708.8
568.98
533.78
717.63
554.01
531.21
151.87
311.86
169.96
236.53
478.16
127.98
368.56
707.36
464.67
724.69
626.89
elevation
4000 m
-8000 m
0
250
500
Km

Damaging Earthquakes in Taiwan since 1700s

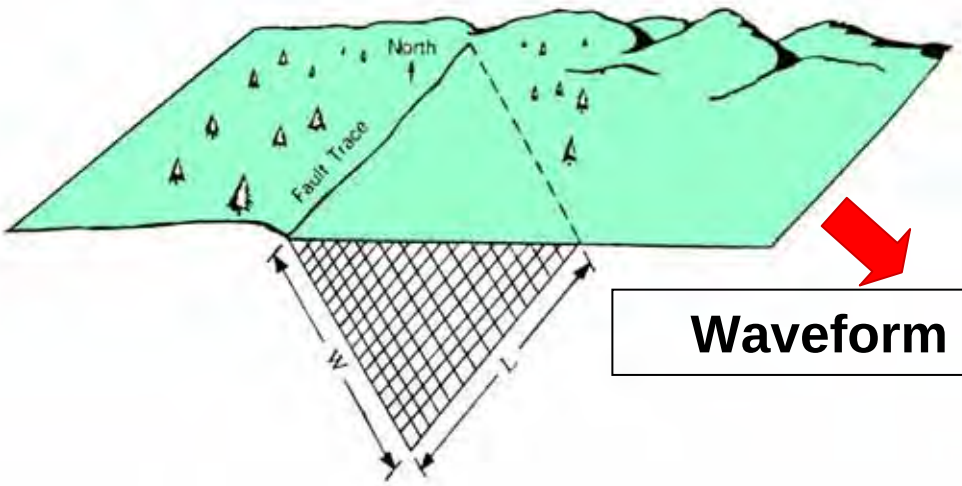


Building up earthquake scaling for earthquake and tsunami sir

Determination of Slip Distribution on the Fault

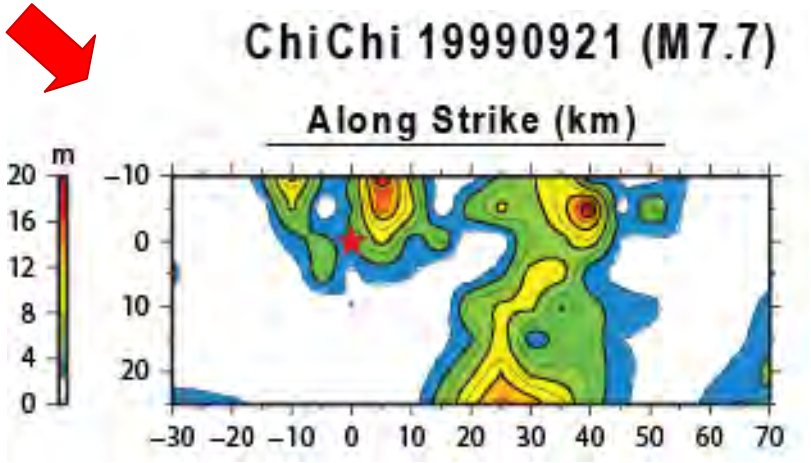
Waveform Inversion for Finite-Fault: Strike, Dip, Rake

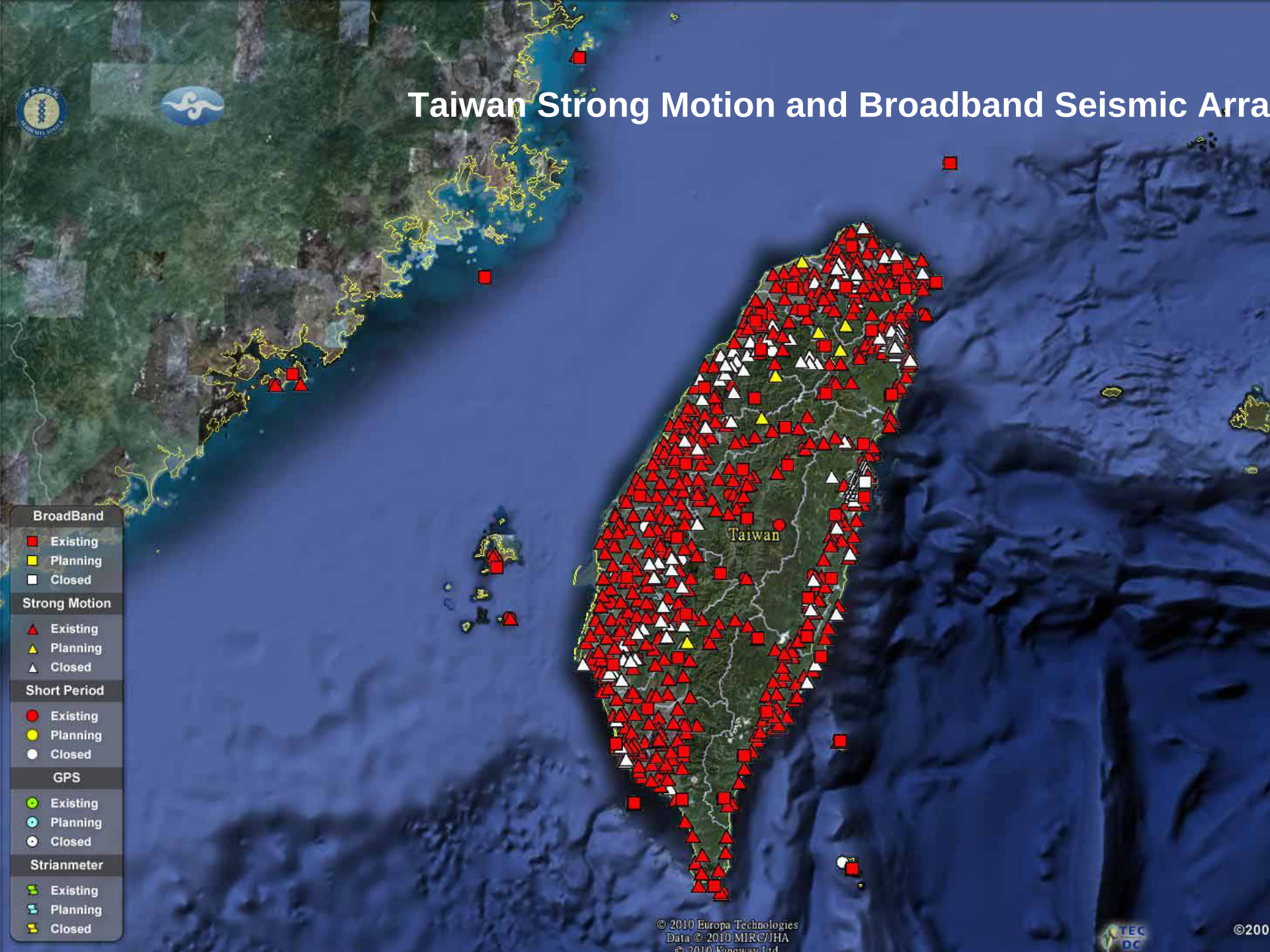
Length, Width and Slip



Waveform Inversion

$$A\,x = B$$




Taiwan Strong Motion and Broadband Seismic Arra
Taiwan
BroadBand
Existing
Planning
Closed
Strong Motion
Existing
Planning
Closed
Short Period
Existing
Planning
Closed
GPS
Existing
Planning
Closed
Strianmeter
Existing
Planning
Closed
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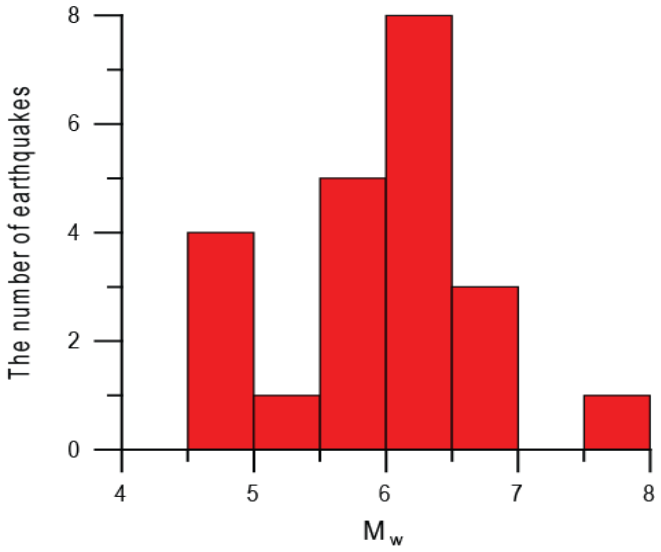
Earthquake Source Scaling for Modeling of Earthquake/Tsunami Scenario

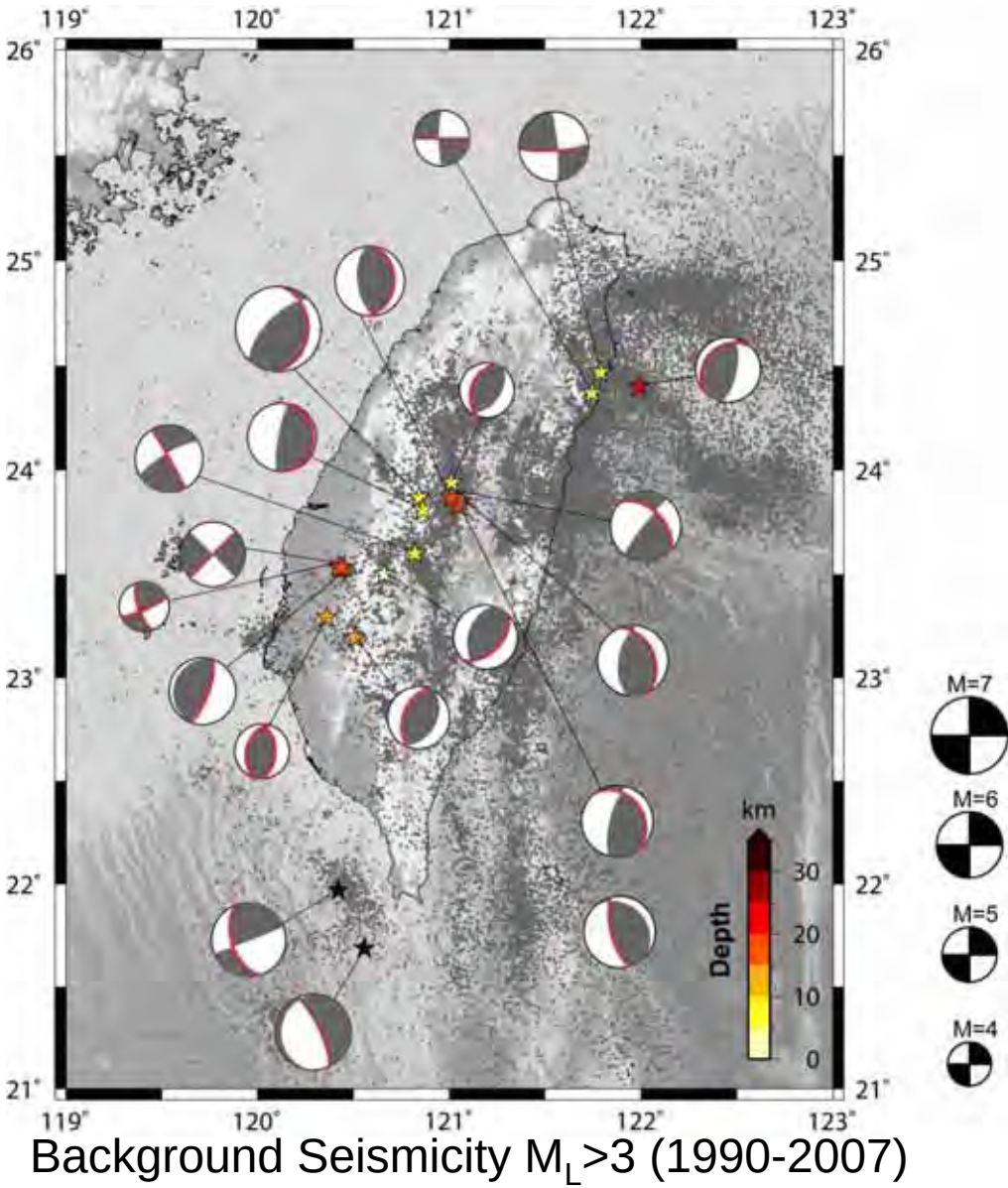


Total event number : 19

Fault type		num.	eq.
Strike		8	7
Dip	Reverse (13)	14	12
	Normal (1)		

7.75 x 10^{15} Nm M_w(4.6)

~ 3.79 x 10^{20} Nm M_w(7.7)



Background Seismicity M_L>3 (1990-2007)

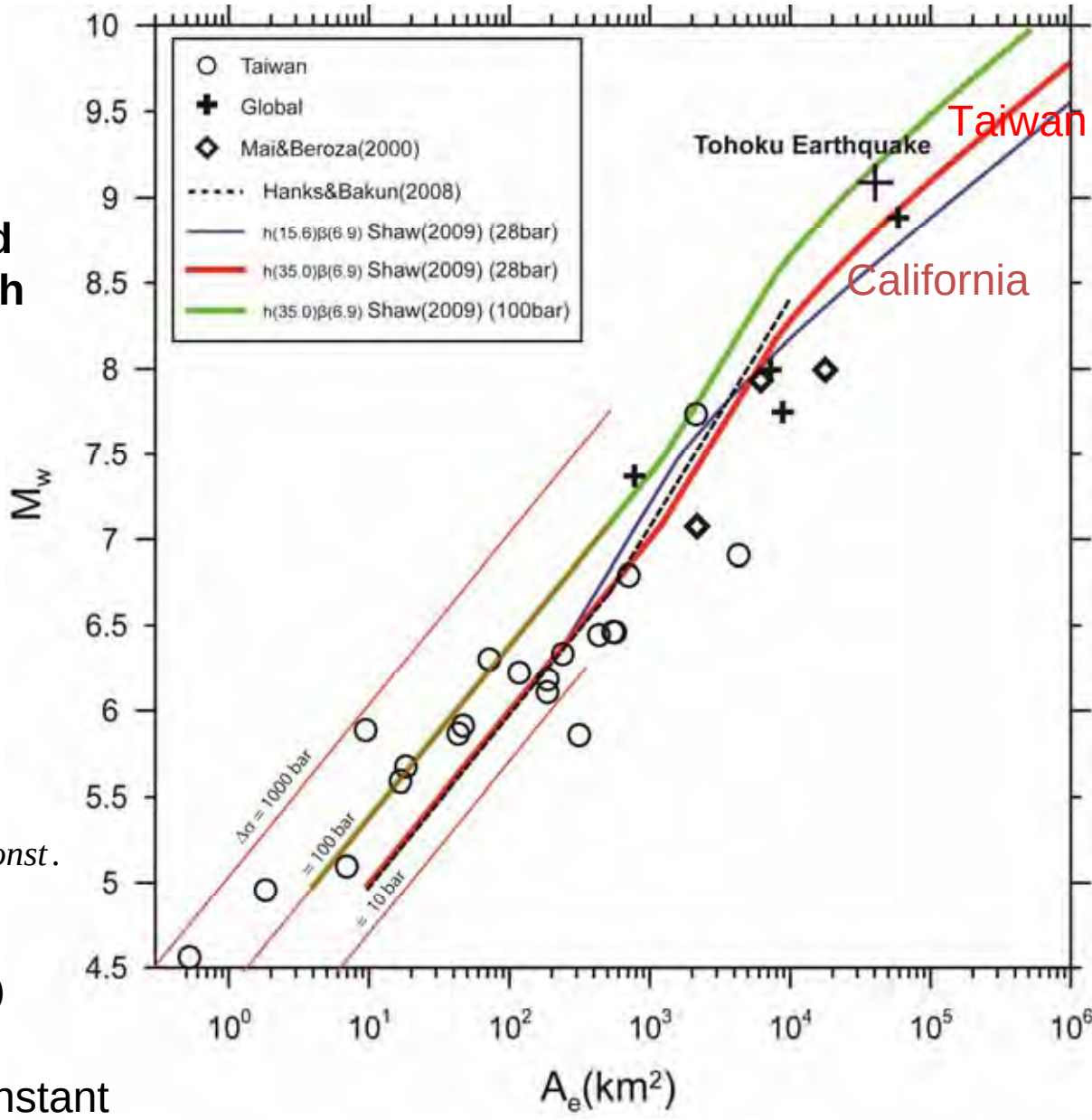
Scaling using AREA

h : seimogenic depth
β : scaling parameter related to the effective fault width

- Small-Moderate earthquakes
  Mw ~ LogA
- Large earthquakes
  Mw ~ 4/3logA
- Extra largest earthquakes
  Mw ~ 2/3logA

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

(Shaw, 2009)



Const.: Stress drop related constant

Empirical Scaling Relationship

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

1. M=> A A: Rupture area
2. W=H/sin(δ), δ: dip angle, H: seismogenic depth
3. L=A/W
4. M=> Mo,
5. D=Mo/μ*A, μ: rigidity (D: average slip on the fault)
6. Sa=0.2*A

   Da=1.5*D, Dr=rest of the slip to the total moment

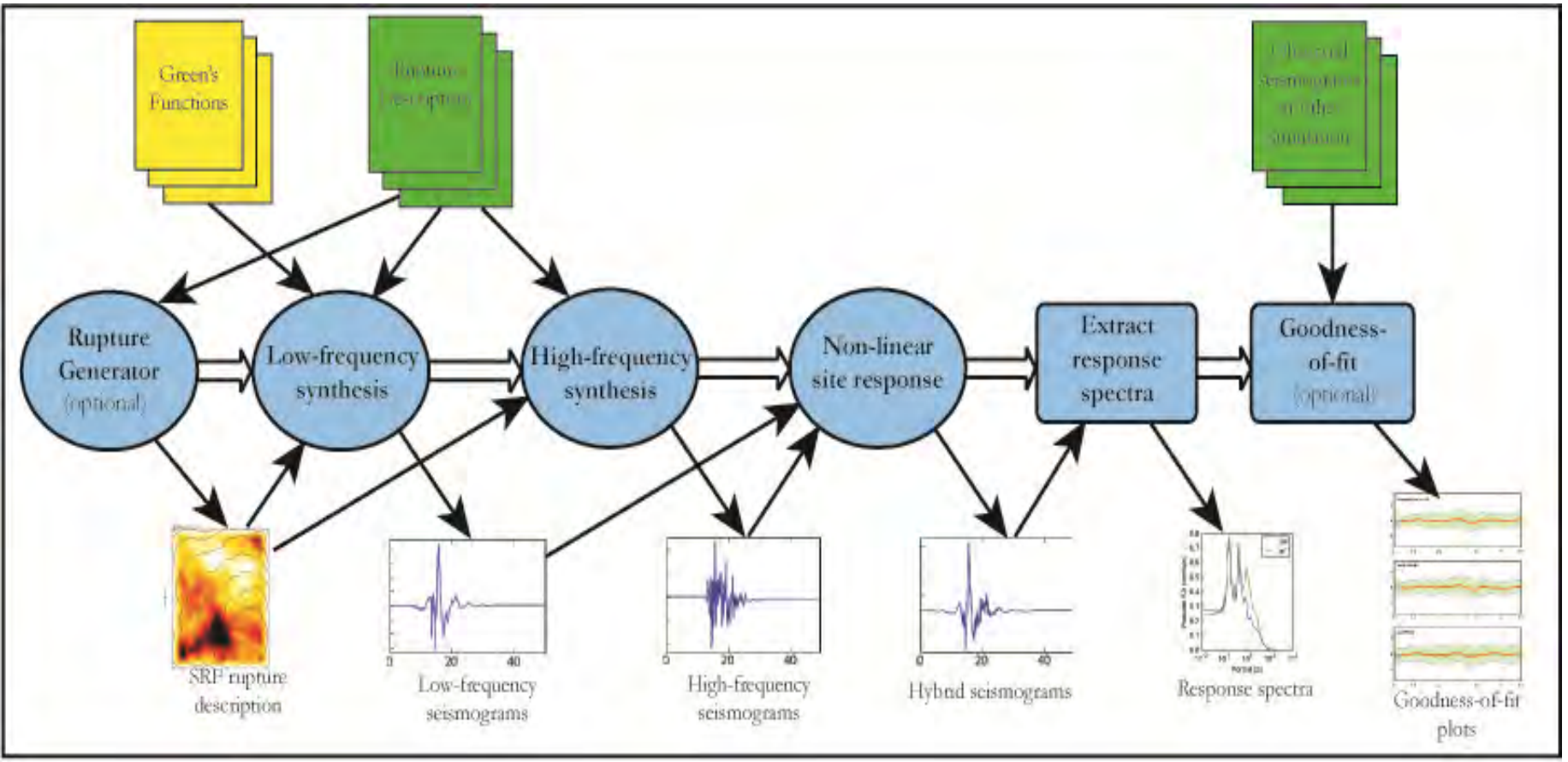
- **Geometry (strike and dip) + Style of faultings**

=> Earthquake and Tsunami simulations

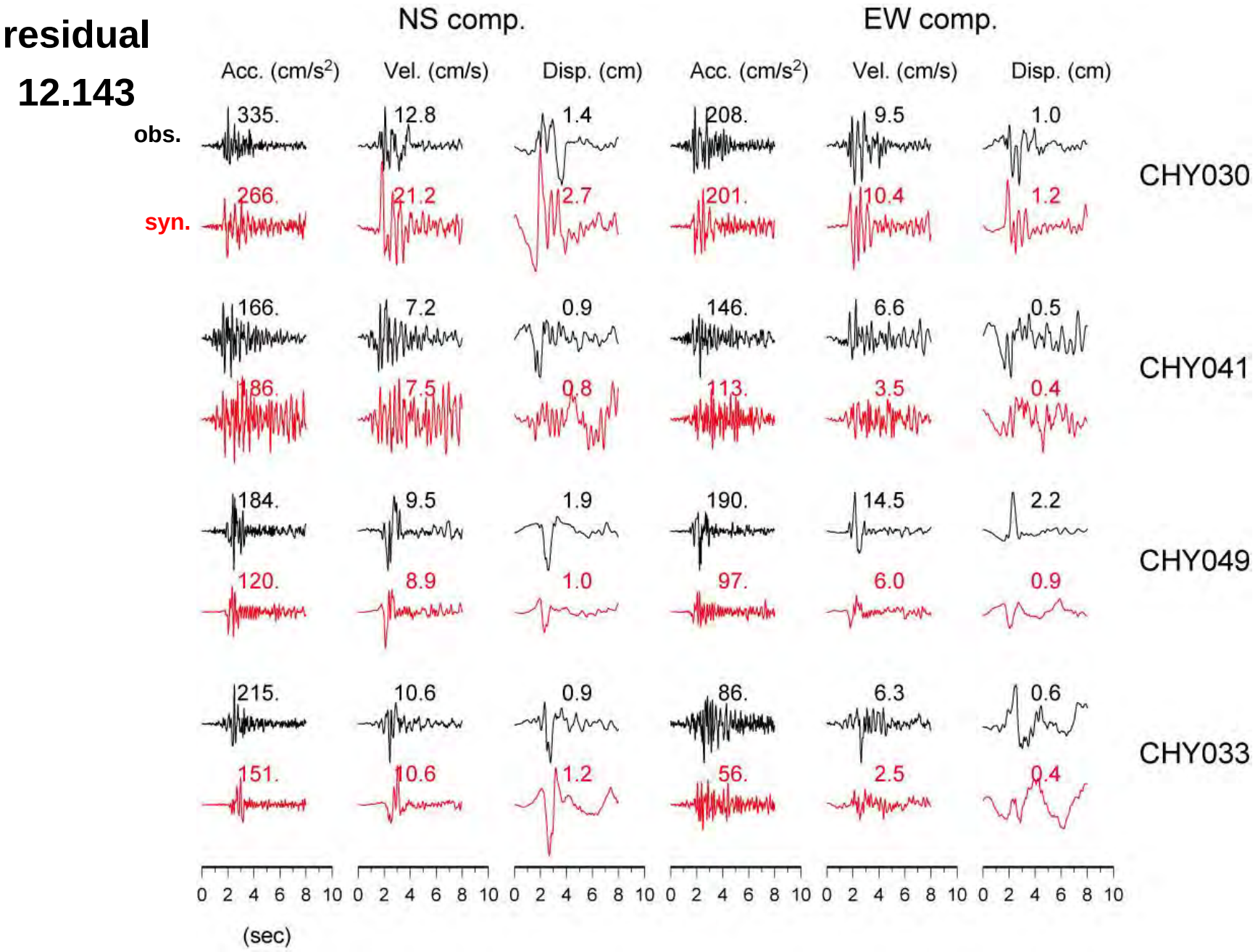
Ground Motion Prediction:
Simulation of seismograms from 0-20Hz
GMPE: NGA

EGF
Stochastic
Hybrid, 3D wave propagation

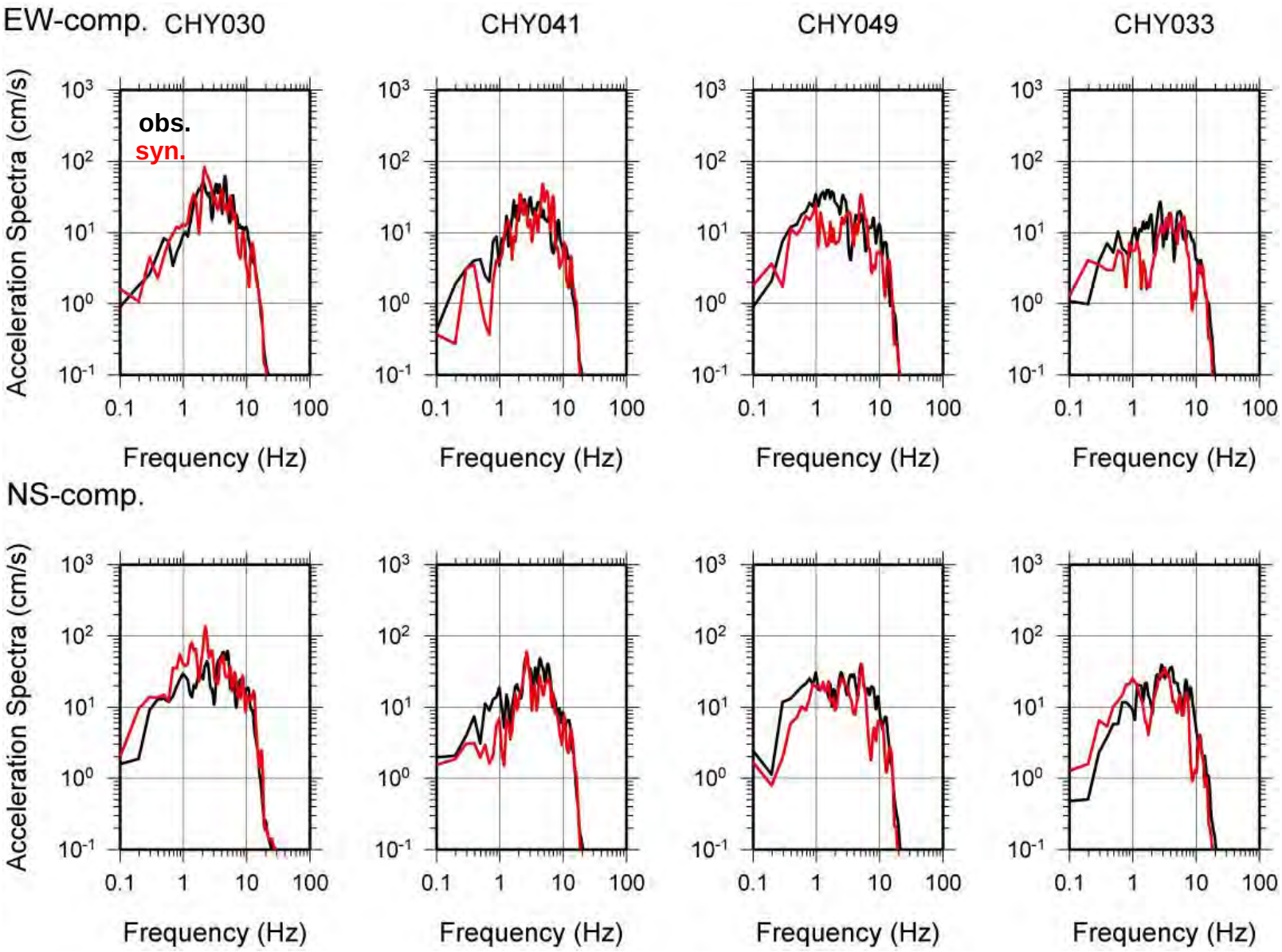
Scaling Laws:
Finite-Fault
Sa distribution



Hybrid full waveform simulation of the 1999/10/22 M6.0 earthquake from M4.0 EGF



Spectra simulation of the 1999/10/22 M6.0 earthquake from M4.0 EGF

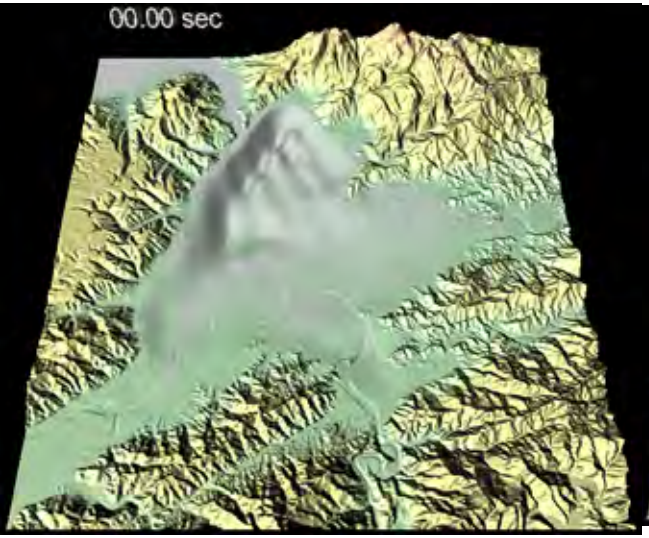


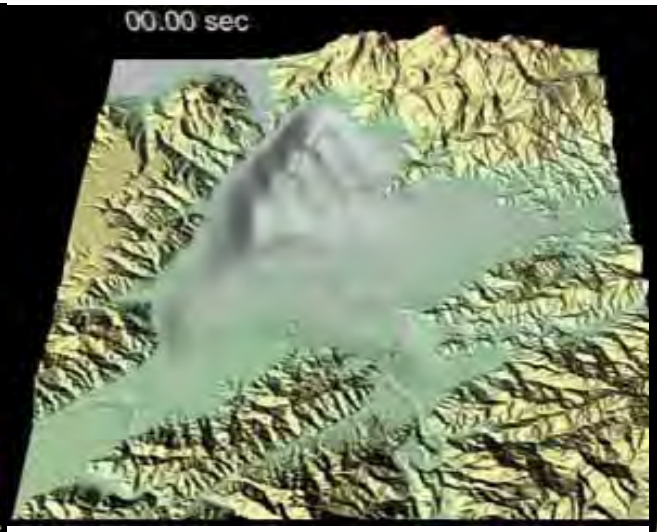
3D Ground Motion Simulation For Taipei Basin in different Models

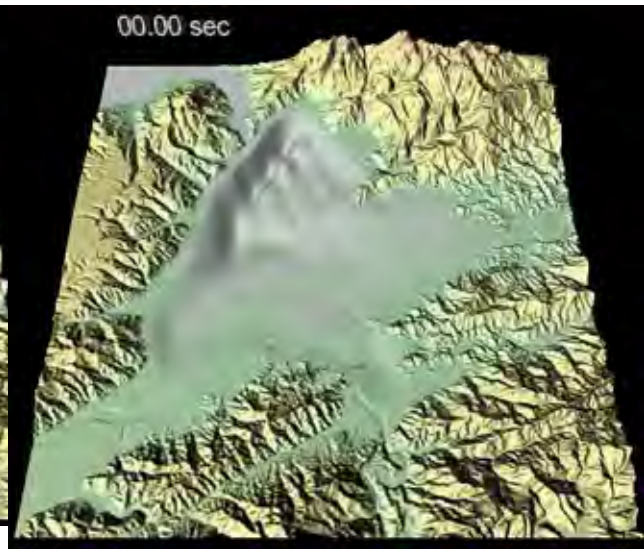
Basement + SunShang Formation

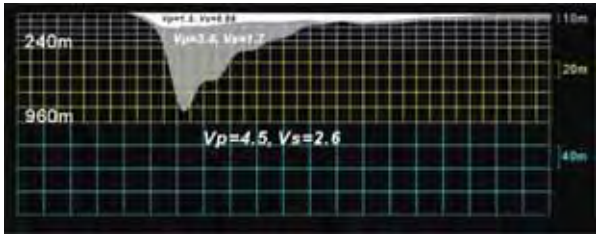
Only Basement

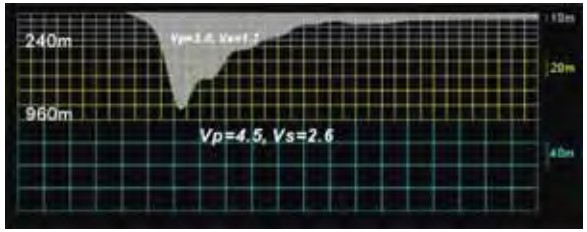
Layered Half-Space

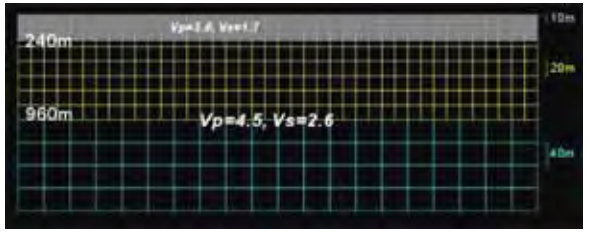




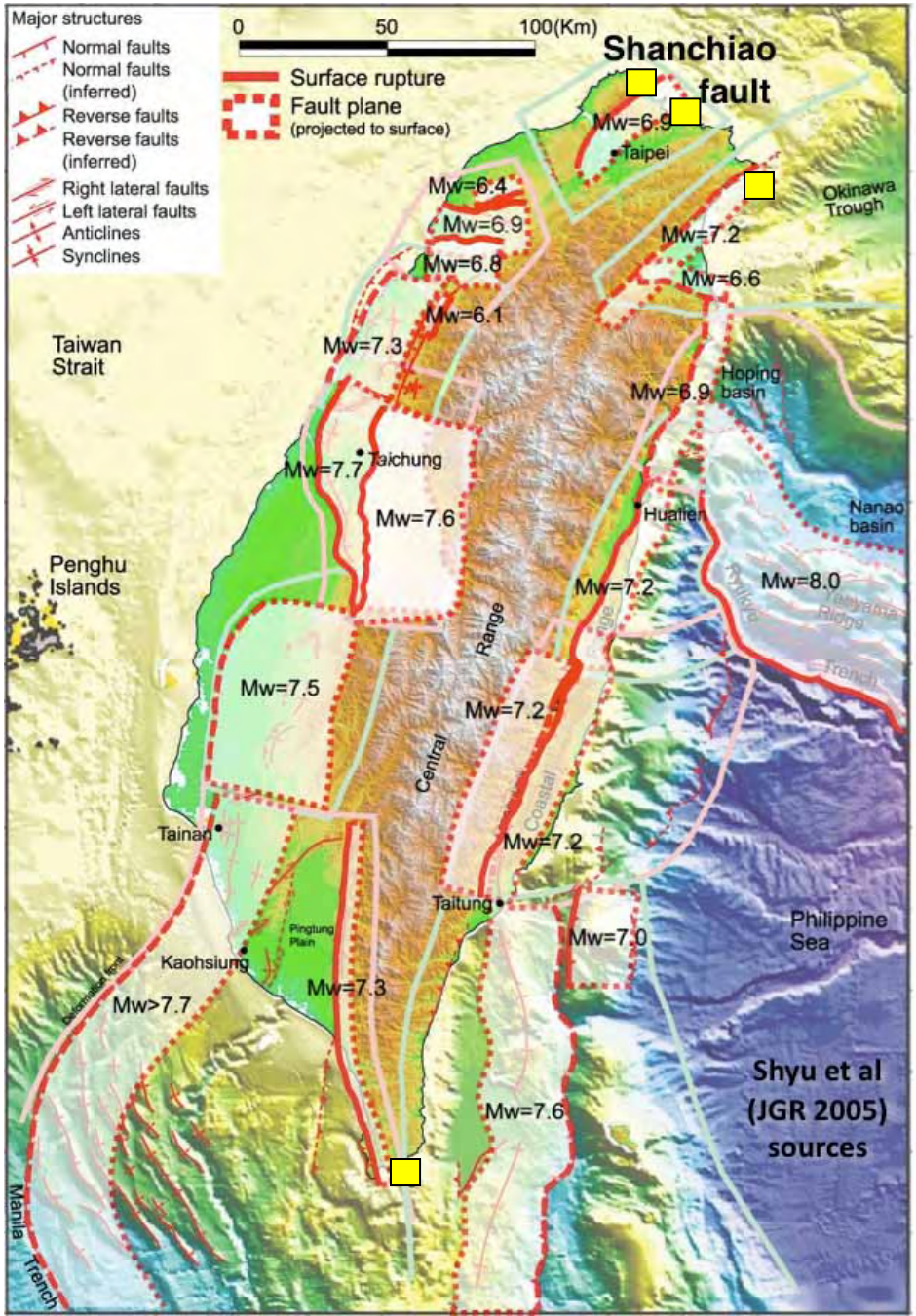








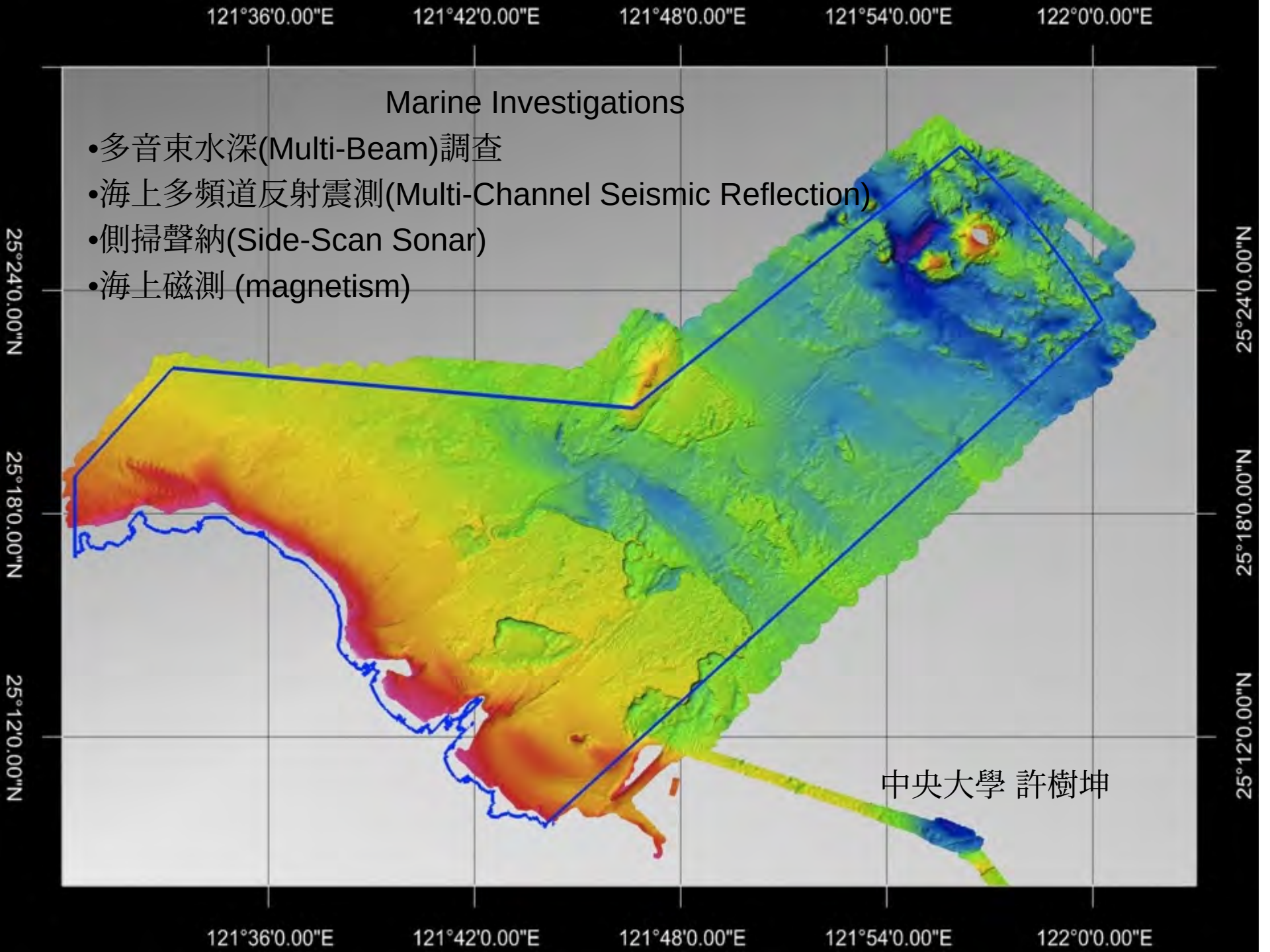
By 李憲忠 Lee et al. (2009)

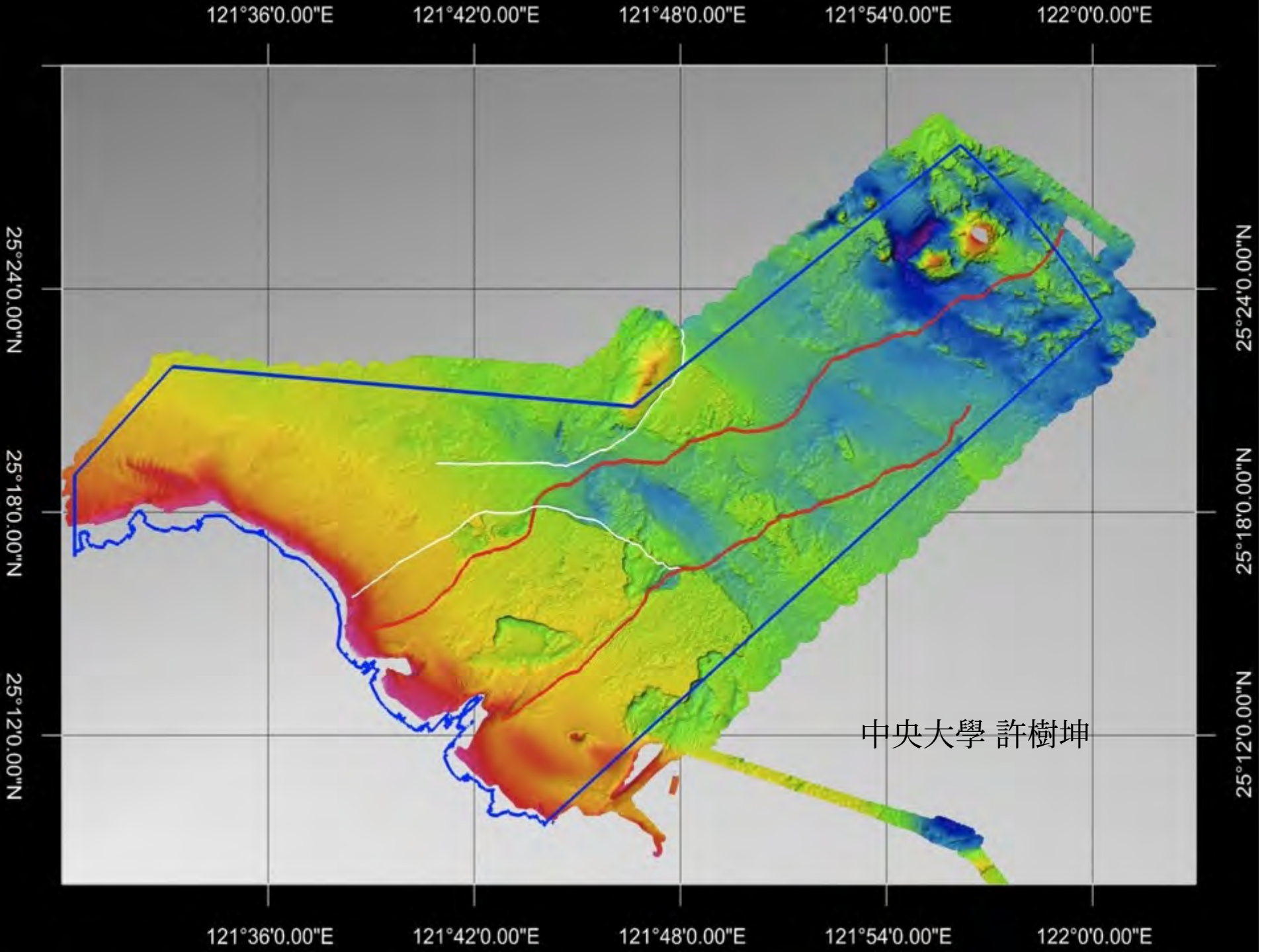


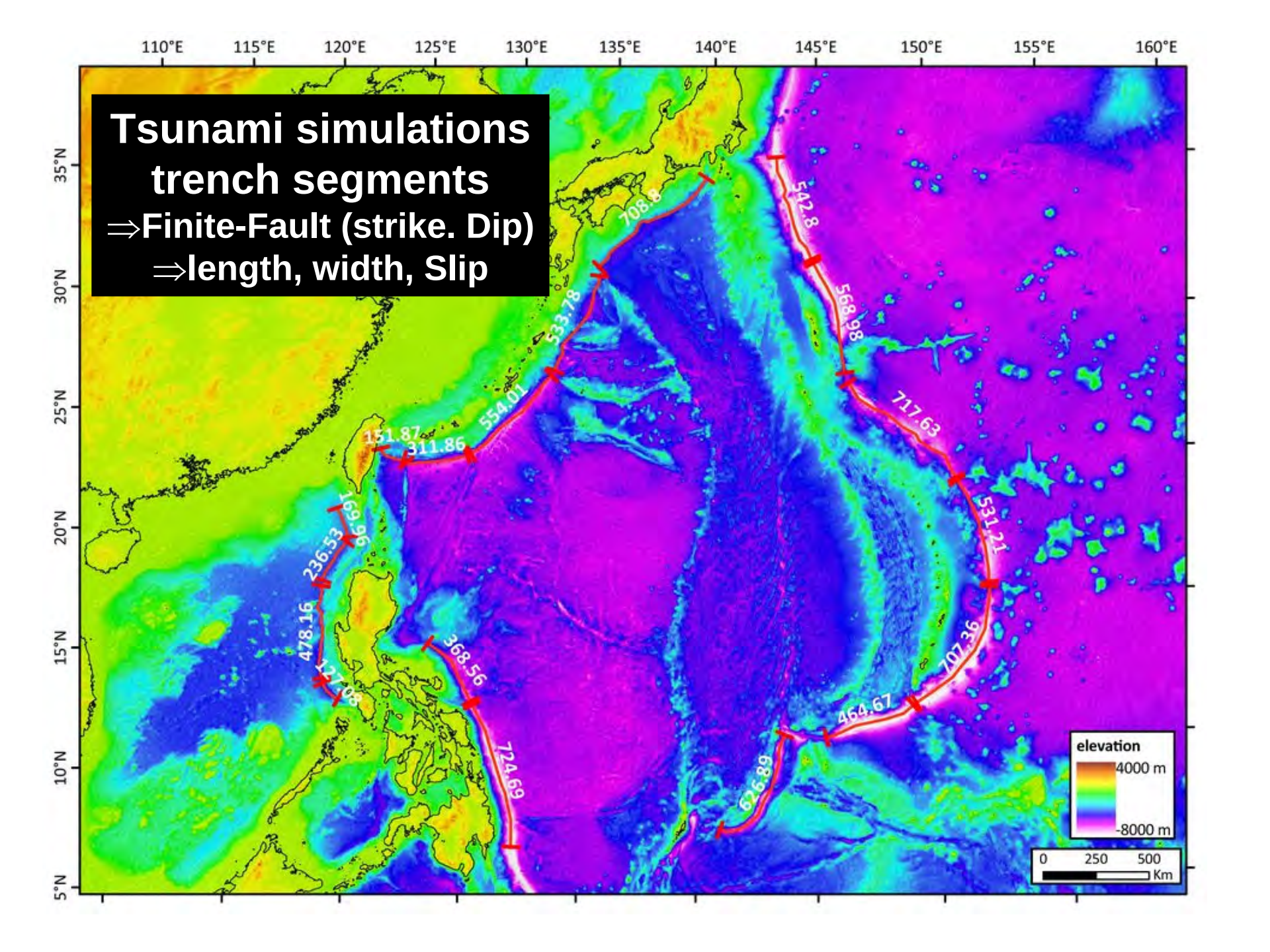
-Ground Motion Prediction of NPPs (faults and subduction zones)

-Tsunami run-up heights near/at NPPs (off-shore faults, subduction zones, volcanos and submarine landslide)

-Scenario (Deterministic)
-Probability

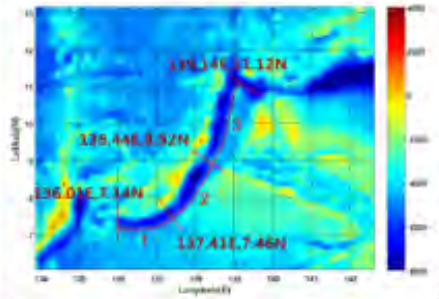

121°36'0.00"E
121°42'0.00"E
121°48'0.00"E
121°54'0.00"E
122°0'0.00"E
25°24'0.00"N
25°18'0.00"N
25°12'0.00"N
Marine Investigations
•多音束水深(Multi-Beam)調查
•海上多頻道反射震測(Multi-Channel Seismic Reflection)
•側掃聲納(Side-Scan Sonar)
•海上磁測 (magnetism)
中央大學 許樹坤


121°36'0.00"E
121°42'0.00"E
121°48'0.00"E
121°54'0.00"E
122°0'0.00"E
25°24'0.00"N
25°18'0.00"N
25°12'0.00"N
中央大學 許樹坤


Tsunami simulations
trench segments
⇒Finite-Fault (strike. Dip)
⇒length, width, Slip
110°E
115°E
120°E
125°E
130°E
135°E
140°E
145°E
150°E
155°E
160°E
35°N
30°N
25°N
20°N
15°N
10°N
5°N
542.8
568.98
717.63
531.21
707.36
464.67
626.89
724.69
368.56
127.98
478.16
236.53
169.96
151.87
311.86
554.01
533.78
706.8
elevation
4000 m
-8000 m
0
250
500
Km

Tsunami Sources

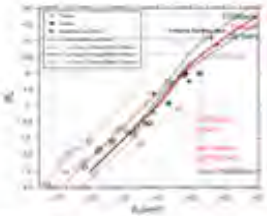
地震源搜尋及海域調查
(1)遠震海嘯源
(2)近震海嘯源
(3)山崩海嘯源
(4)火山海嘯源



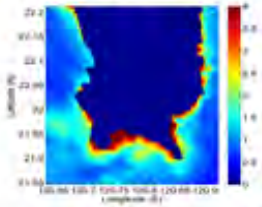
Under-going Project for
Probability Tsunami Hazard Analysis
PTHA

Model and Calculations

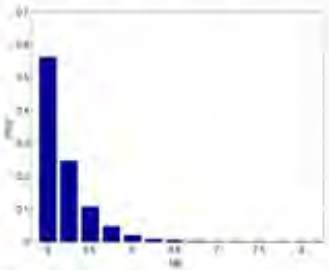
(1)決定海嘯地震源模型



(2)計算海嘯波高及浪高



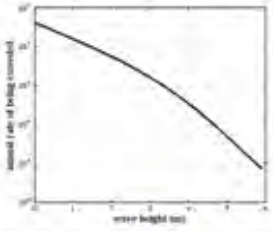
評估地震發生率
(1)分析歷史地震活動度
(2)估算地震週期(Poisson process)



Probability

Tsunami Hazard Curve

海嘯波高之機率分布圖



災害評估

Tsunami Hazard Curves

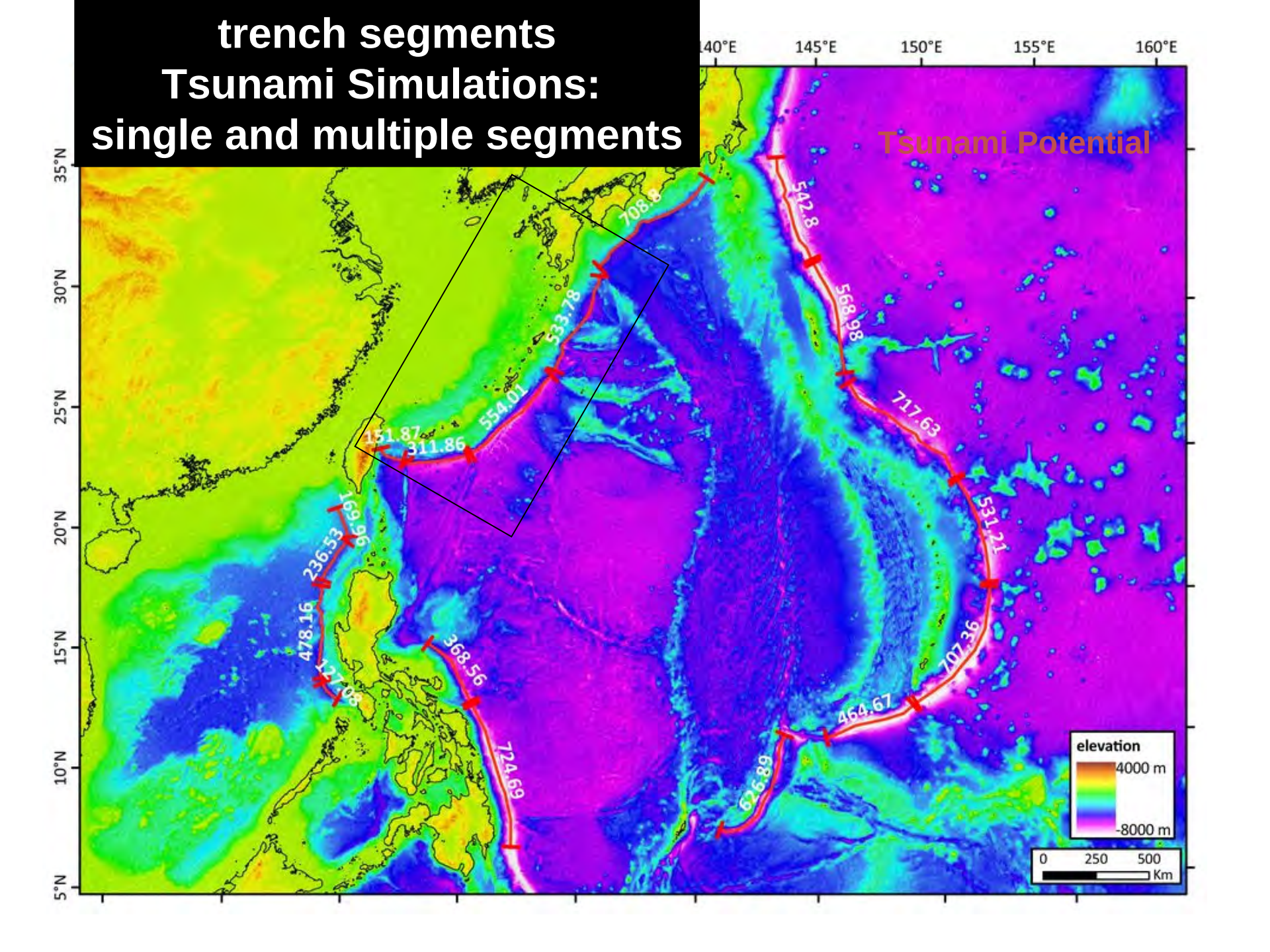
Regional events

-Ryukyu Trench

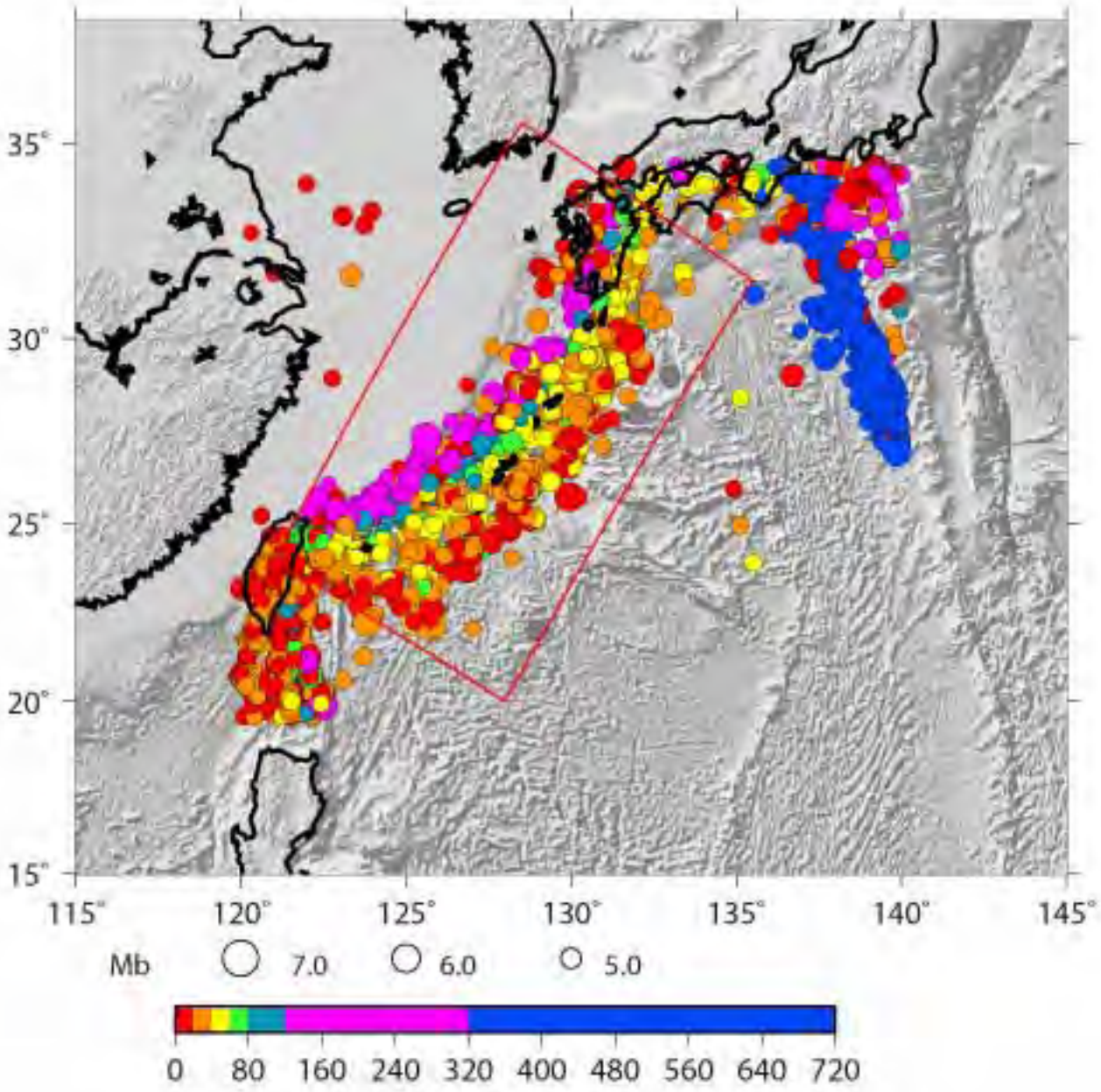
-Shanchiao fault

Teleseismic events

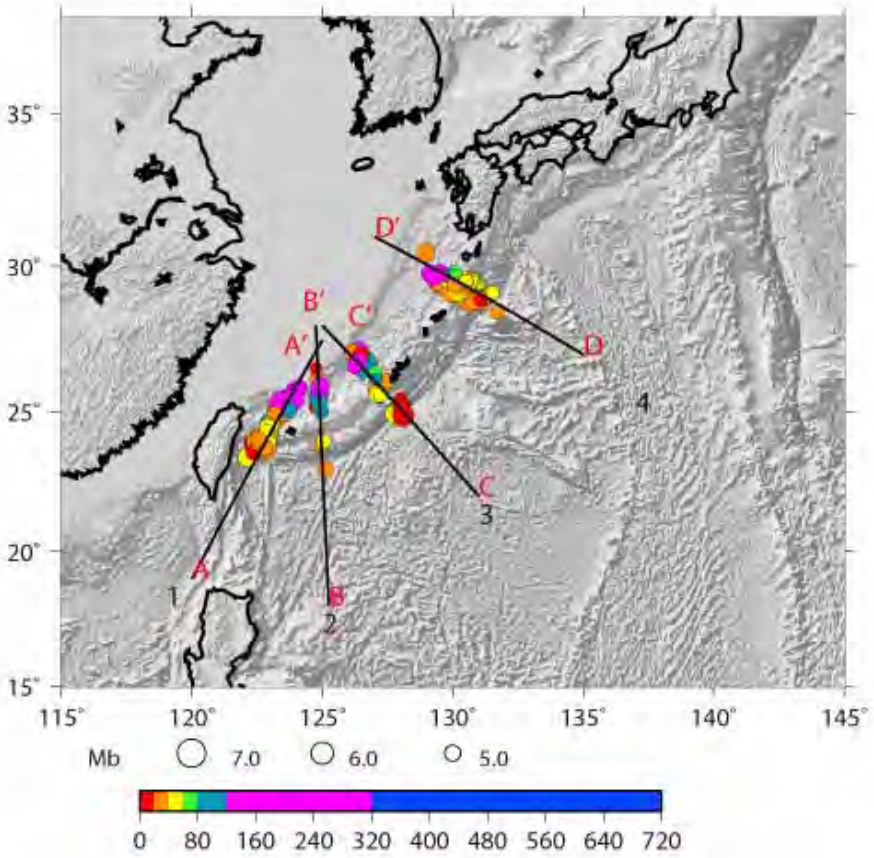
-Yapu trench

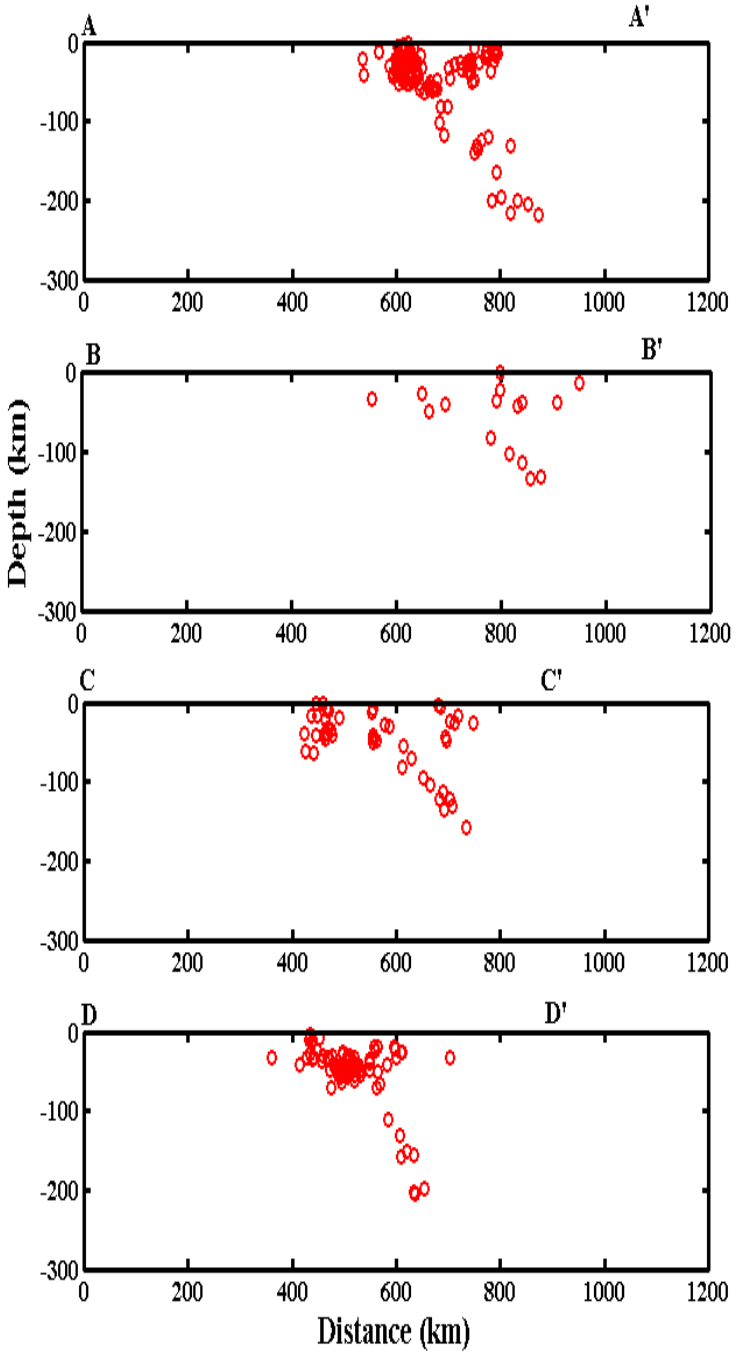

trench segments
Tsunami Simulations:
single and multiple segments
Tsunami Potential
140°E
145°E
150°E
155°E
160°E
35°N
30°N
25°N
20°N
15°N
10°N
5°N
542.8
568.98
717.63
531.21
707.36
464.67
626.89
724.69
368.56
127.98
478.16
236.53
169.96
151.87
311.86
554.01
533.78
706.8
elevation
4000 m
-8000 m
0
250
500
Km

Ryuku Trench



Ryukyu Trench: dips and widths





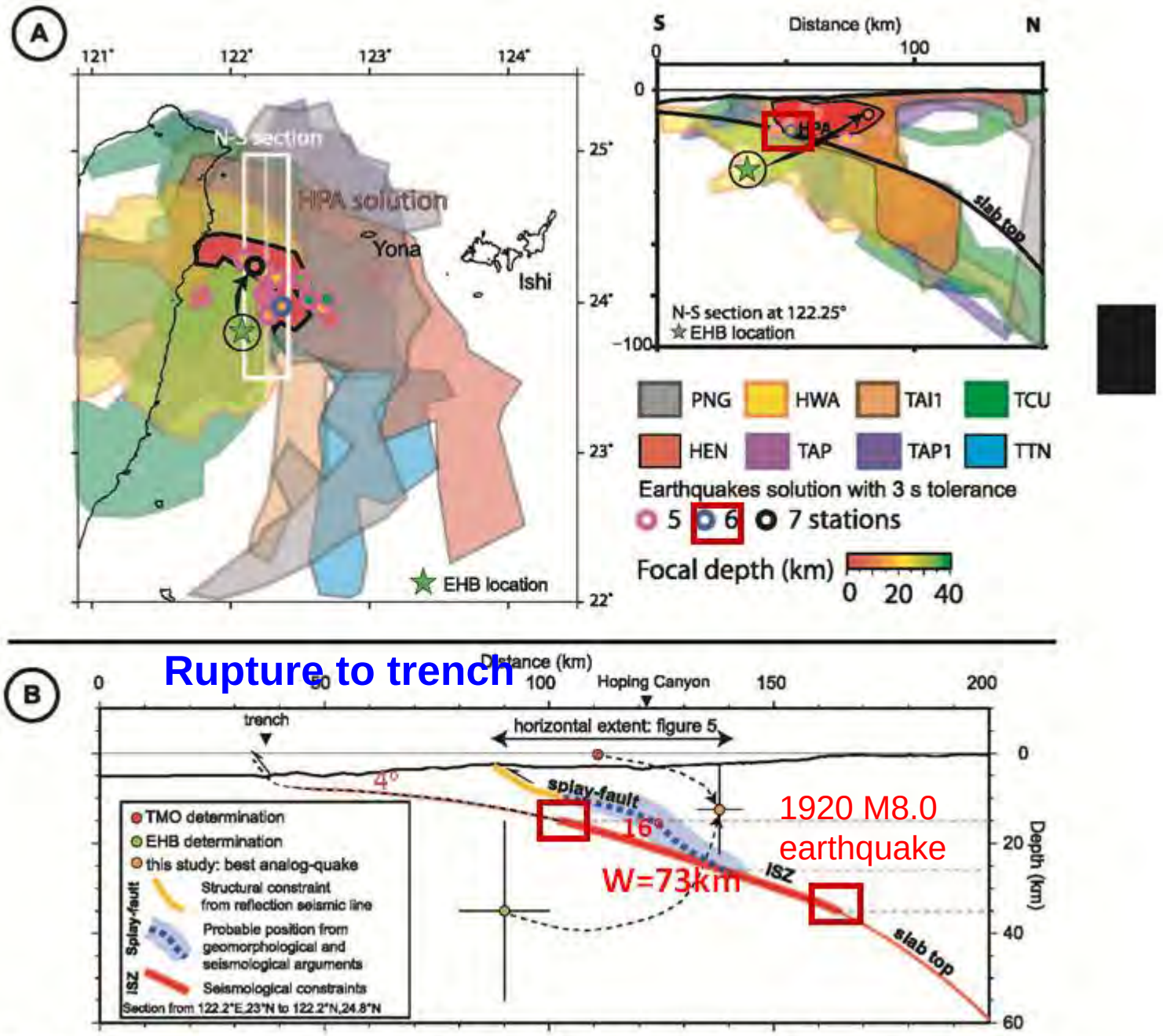


Figure 4. (a) Determination of the high probability area (HPA) where the M_W^L 7.7 1920 earthquake occurred and (b) location of the best analogue-quake from Font *et al.* (2004) compared to the position of the ISZ and the possible splay fault. The tolerance for each envelope is ± 3 s (see text for more details). The best '1920 analogue-quake' (1994/10/09) solution is unique. Other earthquakes are selected with the same maximum 3 s tolerance on SP_{RES} but with less correlated stations. The area defined in surface is more extended than in section because all envelopes do not cross in depth to the north. The slab top is built

PTHA Steps

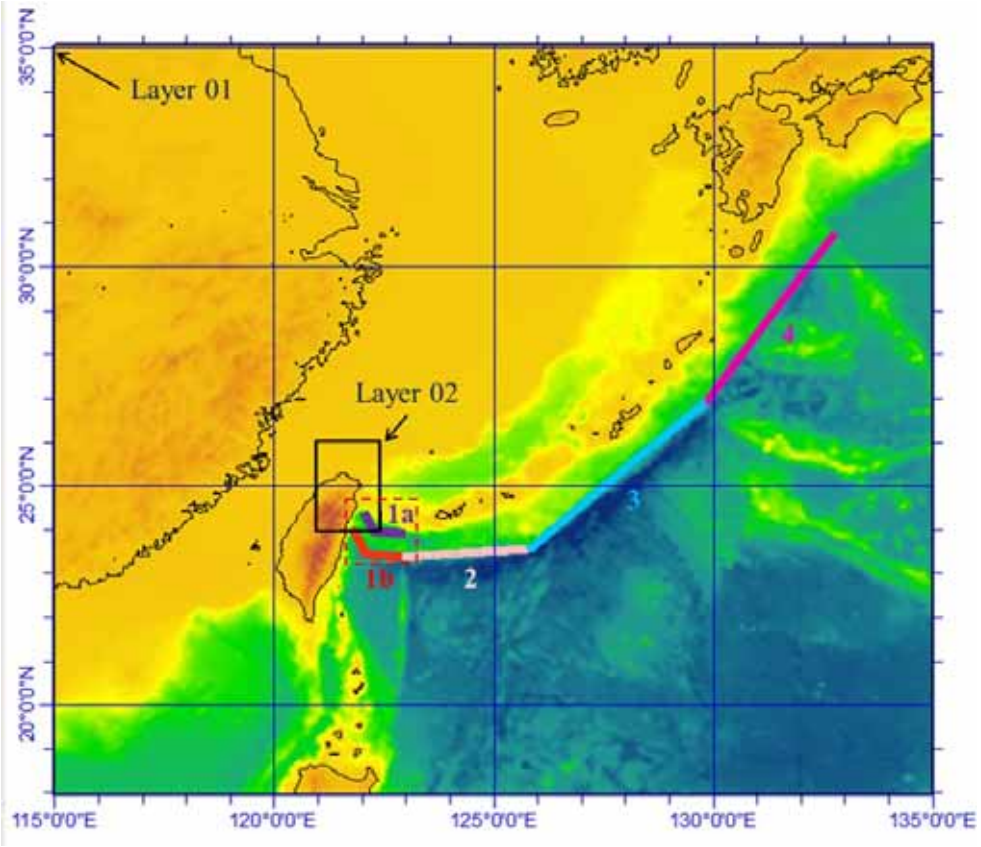
•segments and seismicity (PPT using excel)

1.Length (Lt), Width (from seismicity and dip angle of the seismicity,
W=Ds/sin(delta), Ds: deepest depth delta, dip angle of the seismicity

- Width (Wt), Ds/sin(delta)
- Le=0.8Lt, We=0.8Wt => Ae
- (program eq8.f /home/fong7/TEMPprogram/eq8.f)
- Ae-Mw regression relationship for Mw and D

2. input Lt, Wt to get Ae and Mw, D, Mw1, D1
(Mw, D, for stress drop of 28bars, Mw1, D1 for stress drop of 100 bars)
eq8.f from Yen and Ma (2010), B=6.9, H=35km,
LogDe=logMo/s.0-4.37, where Mo is in nt-m

3.Mo from logMo=1.5ML+16.1, here Mo is dyne-cm
(10**7 dyne-cm=1 nt-m)



Tsunami Simulation (Grids setting)

Total Run Time: 18000 seconds

Pro. T.R. Wu

- Layer 1: 4 minute (M1Layer01)
- Layer 2: 1 minute (M1Layer02)
- Layer 3: 1/40 minute
  - NPP 1 (M1Layer24)
  - NPP 2 (M1Layer25)
  - NPP 4 (M1Layer27)

地形資料由國科會應科方案

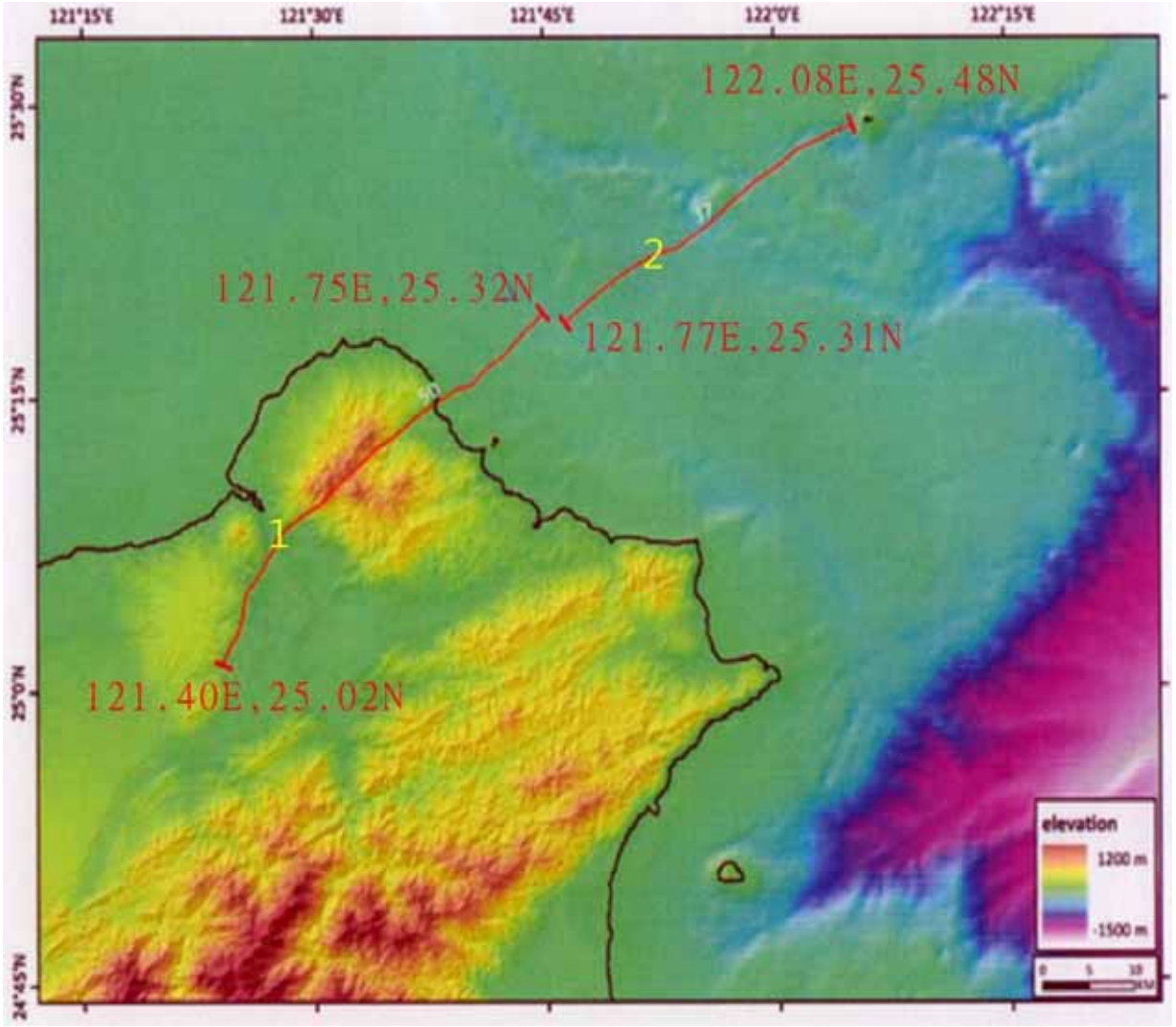
葉錦勳、吳祚任、廖建明、林瑞國

「海嘯預警及災損資料庫建置計畫」提供

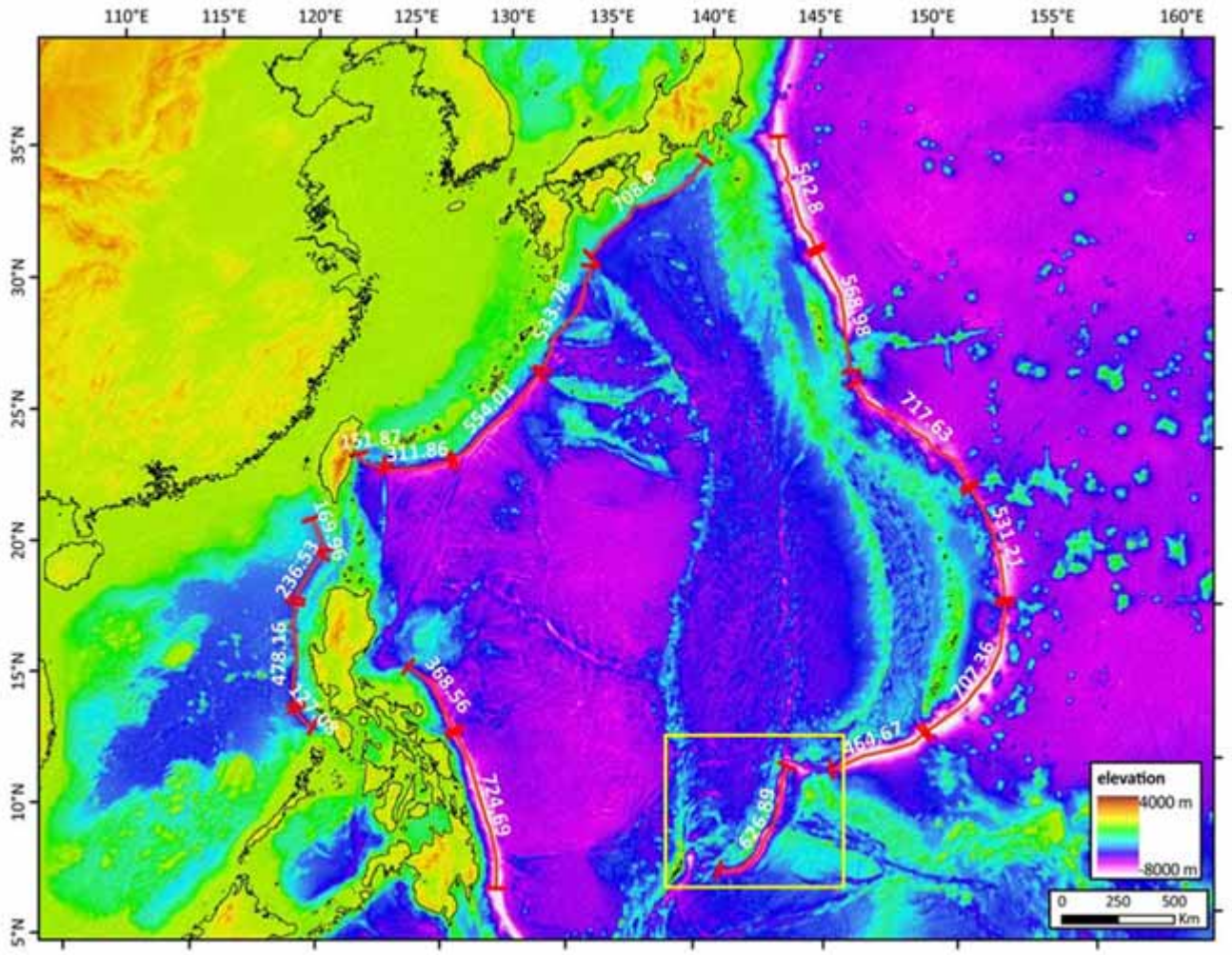
斷層編號	SJ1	SJ1_1	SJ12	SJ12_1	R1a	R1a_1	R1b	R1b_1	R2	R2_1	R3	R3_1	R4	R4_1
長度(km) Length	50		87		總長159.1 km 第一段 67.88	第二段 91.22	總長159.1 km 第一段 67.88	第二段 91.22	320		571		538	
寬度(km) Width	15		15		73		73/71		200		162		162	
中心經度 Longitude	121.58°E		121.93°E		122.0684 72°E	122.6195 25°E	121.9667 28°E	122.5143 79°E	124.375975°E		127.838750°E		131.314000°E	
中心緯度 Latitude	25.17°N		25.40°N		24.24333 2°N	23.94199 1°N	23.69391 3°N	23.39002 6°N	23.449290°N		25.230470°N		28.833770°N	
走向角 Strike	49°		61°		-27°	-86°	-27°	-86°	-94°		-130°		-143°	
傾角 Dip	90°		90°		16°		16° /4°		30°		18°		18°	
滑移角 Rake	-90°		-90°		90°		90°		90°		90°		90°	
位移量(m)	1.0	1.56	1.33	2.06	5.36	8.30	7.60	11.77	11.7	18.12	13.47	20.86	13.17	20.40

Shanjiao

Fault sedments	Fault length
Shanjiao1	50.27 km
Shanjiao2	37.21 km
Shanjiao12	87.48 km



Telesemsic tsunami: Yapu Trench

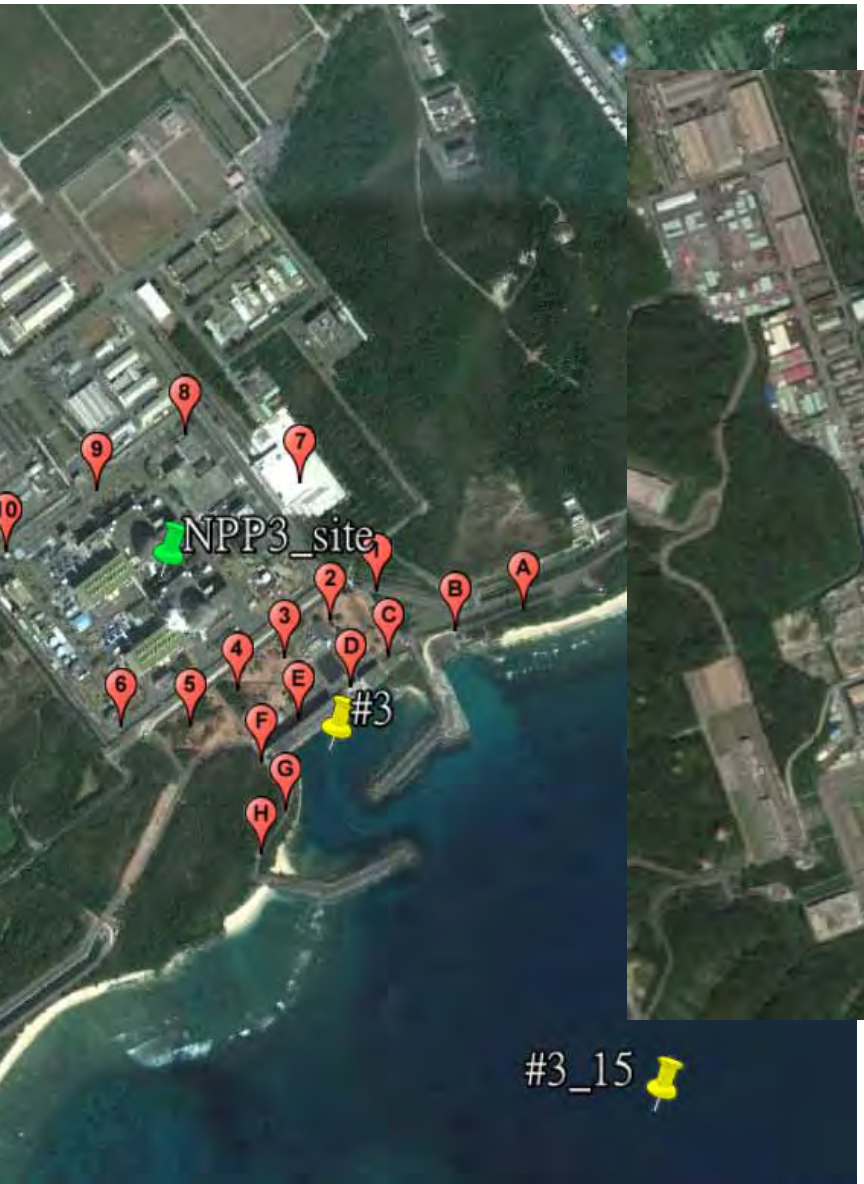


核一廠
NPP1

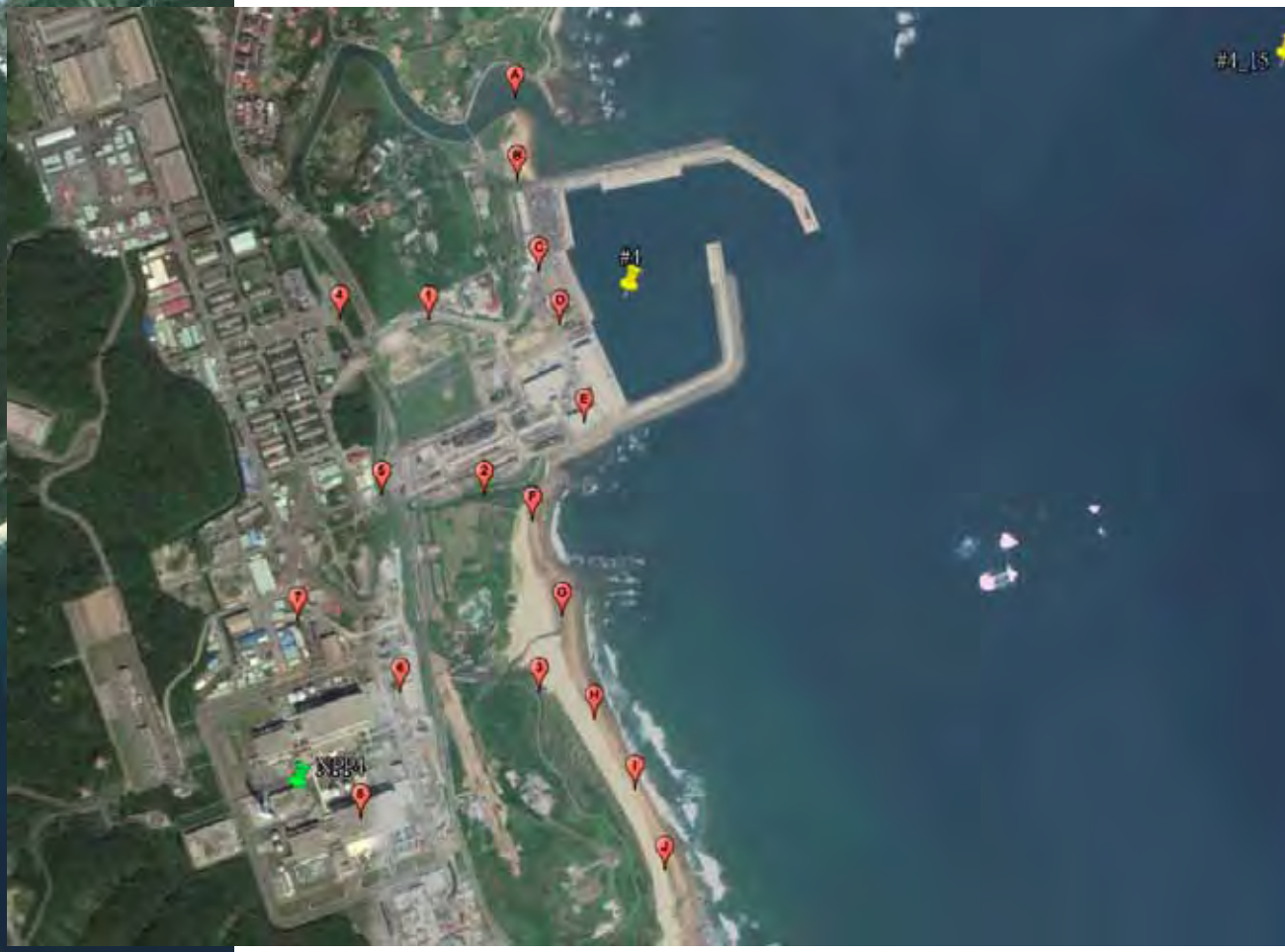
Stations
-15m water depth, Outlet
(出水口), Coast, SITE

核二廠
NPP2

核三廠
NPP3

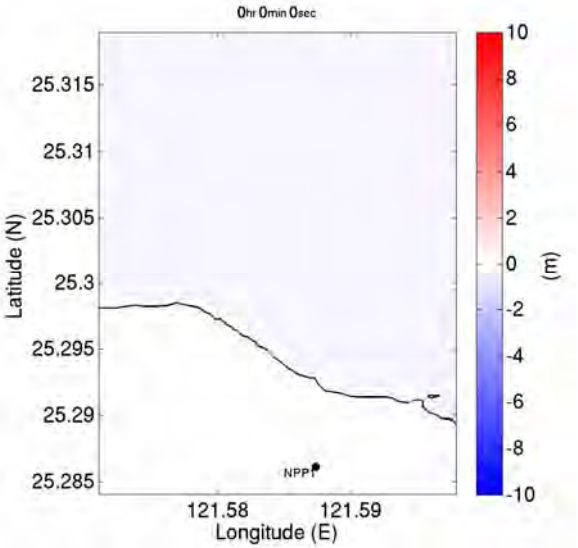


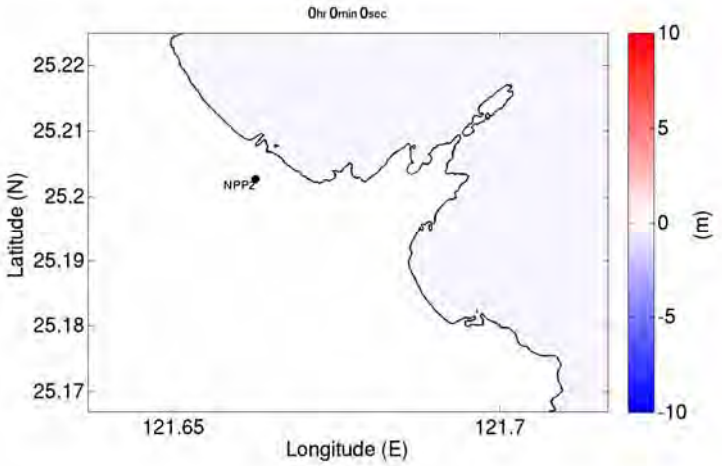
核四廠
NPP4

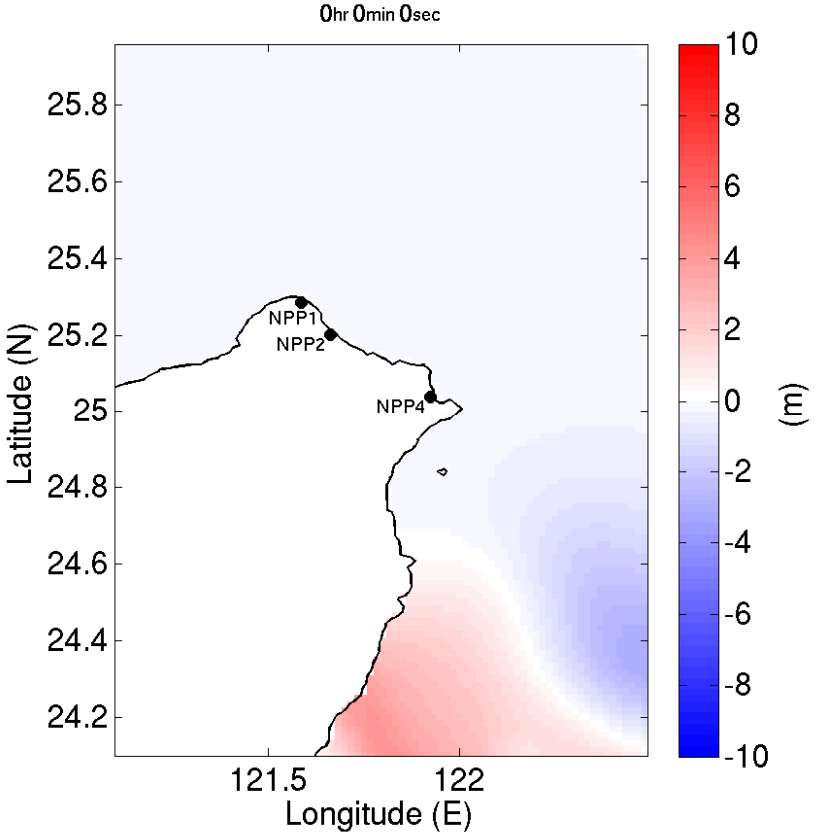


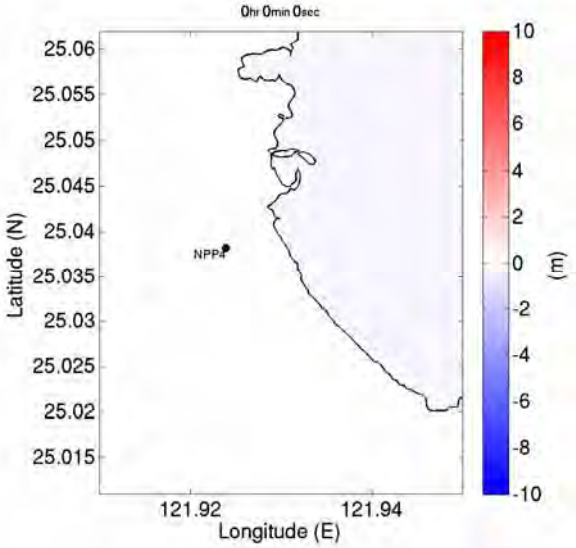
R1b_1 Mw=8.81

Tsunami wave propagation

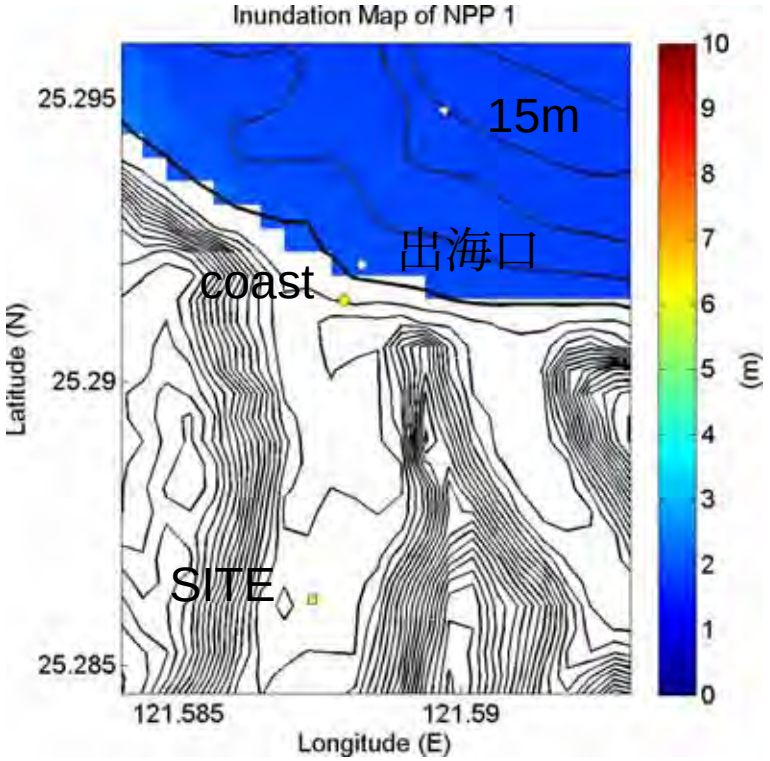


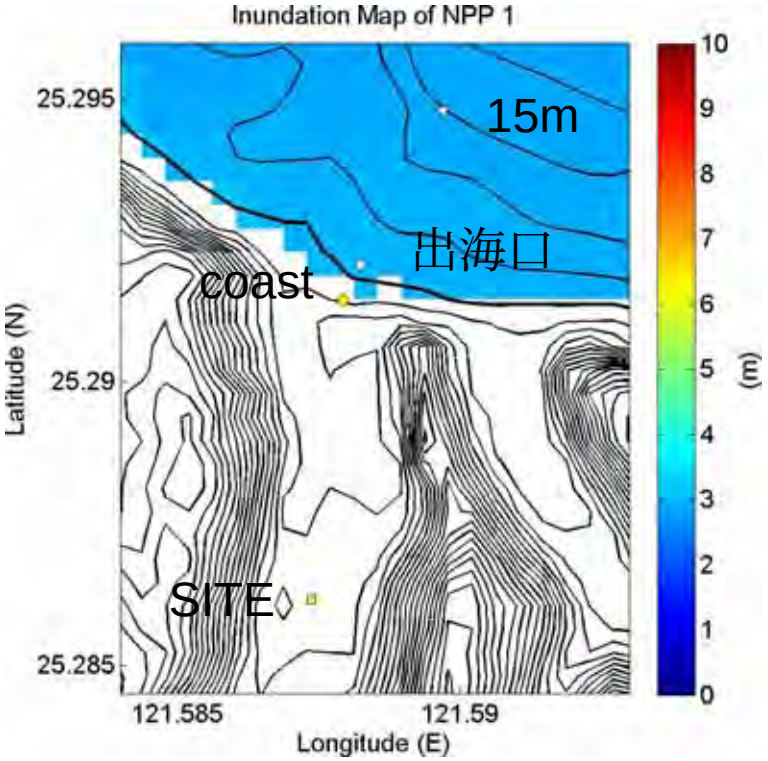


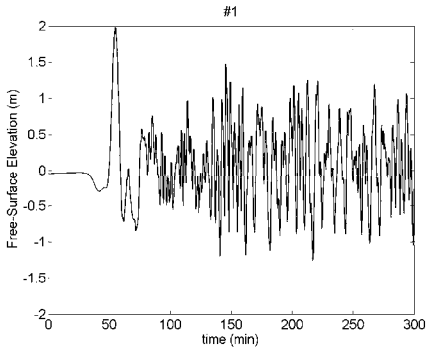


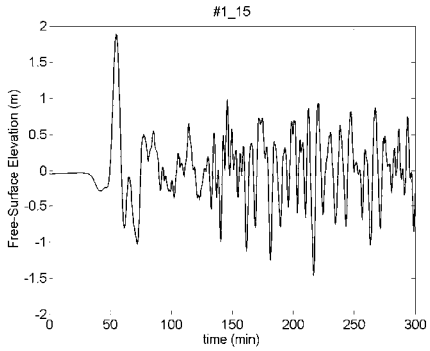


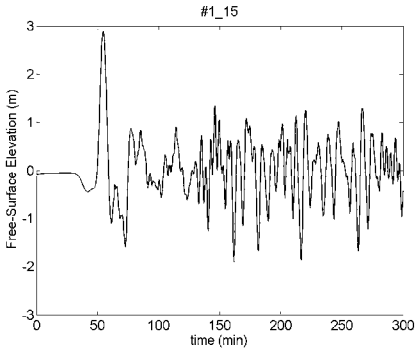
NPP1, R1b (Mw=8.43, Mw=8.81)

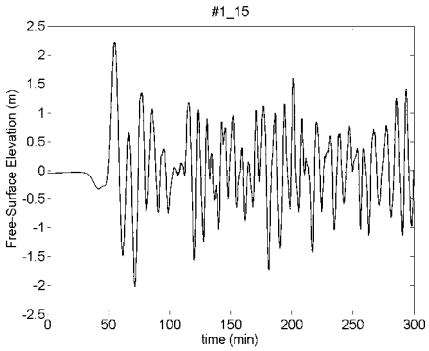




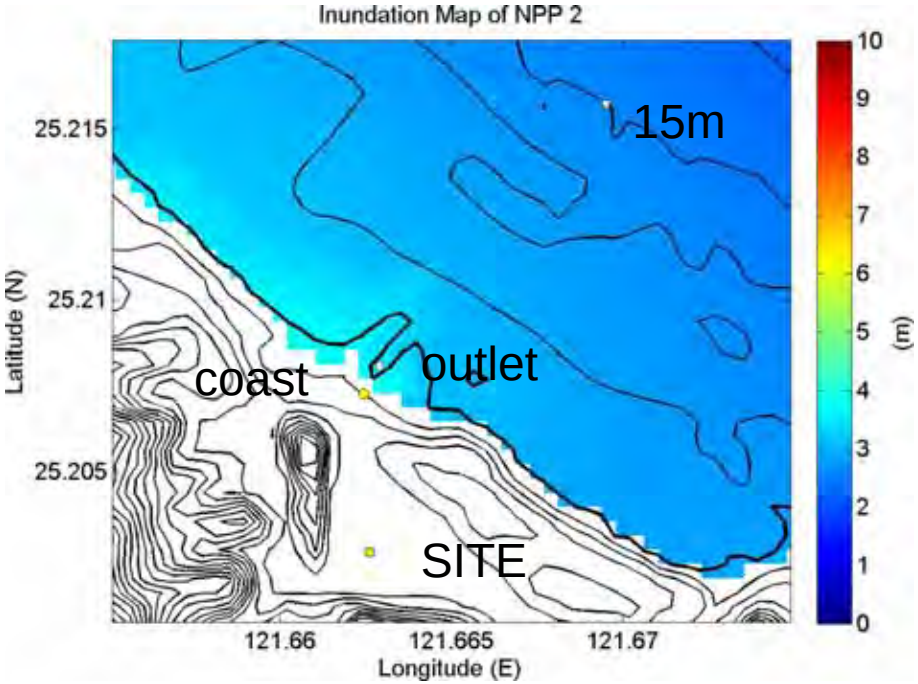


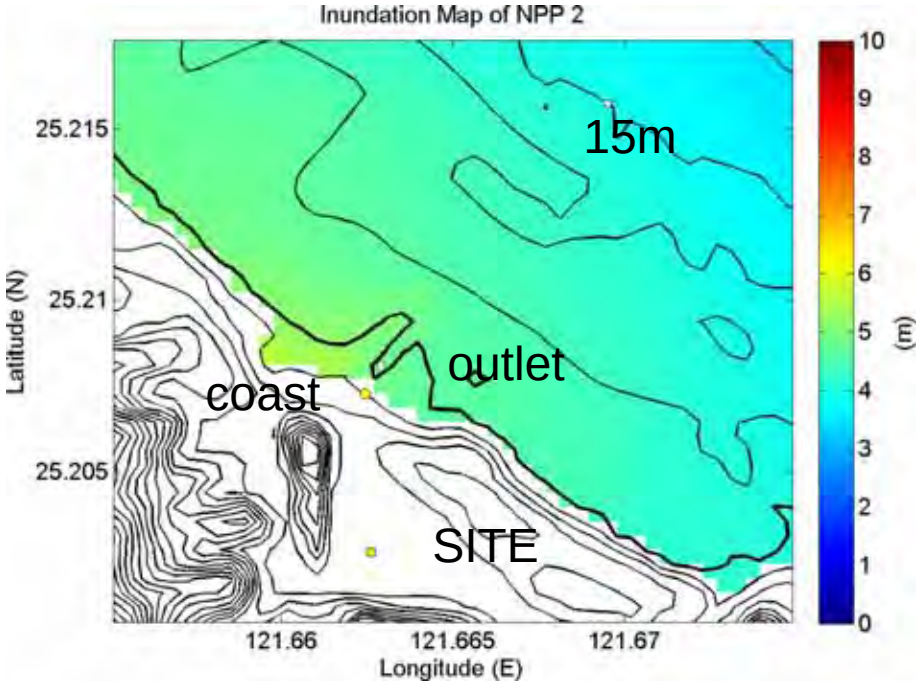


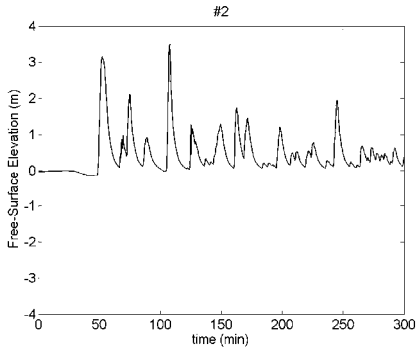


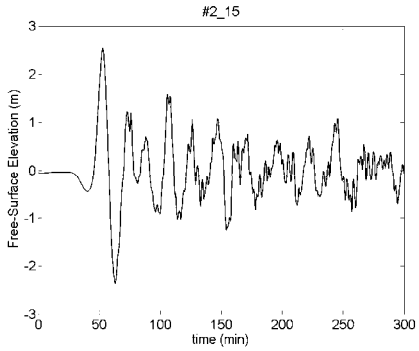


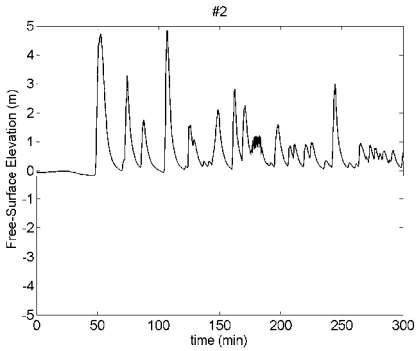
NPP2, R1b (Mw=8.43, Mw=8.81)

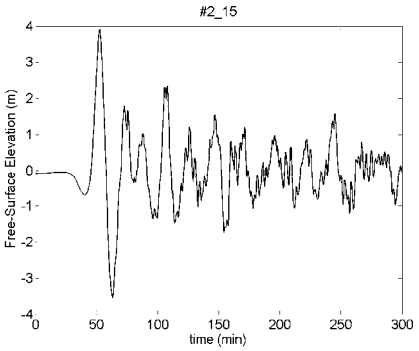




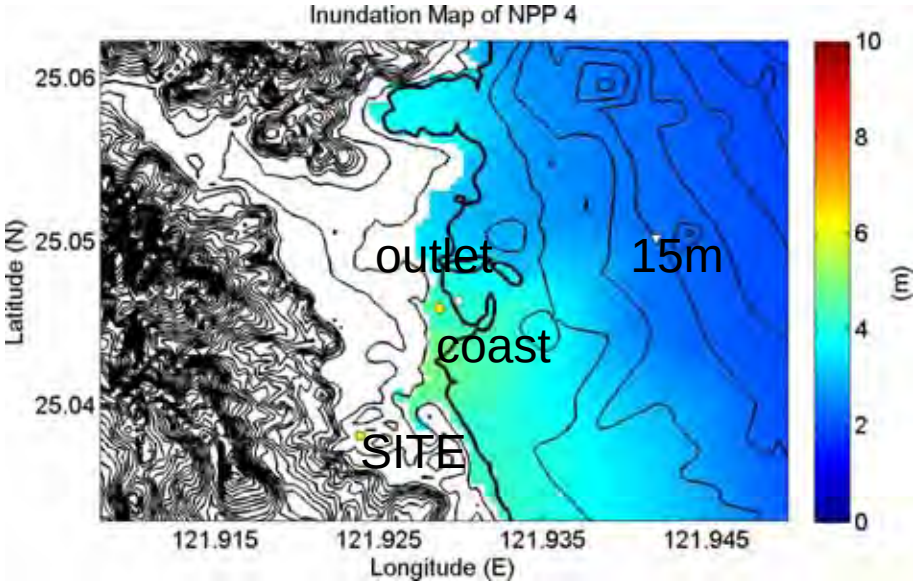


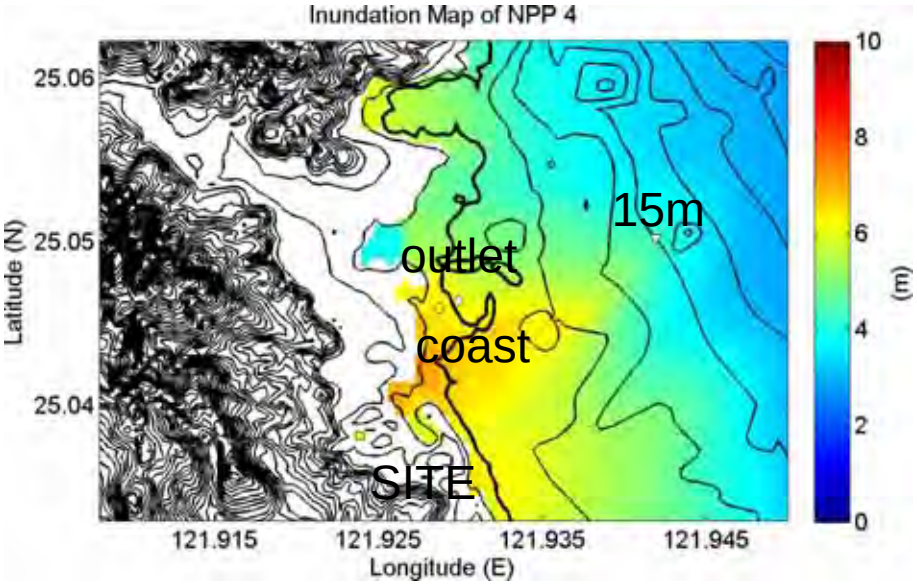


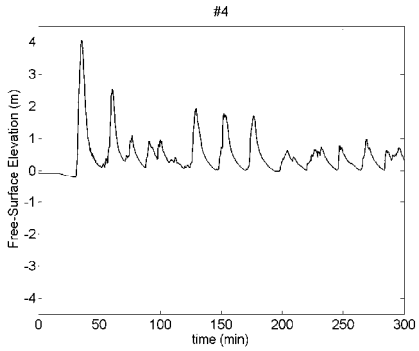


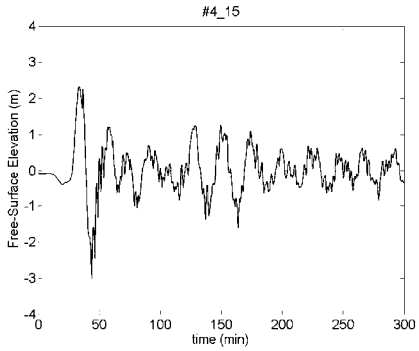


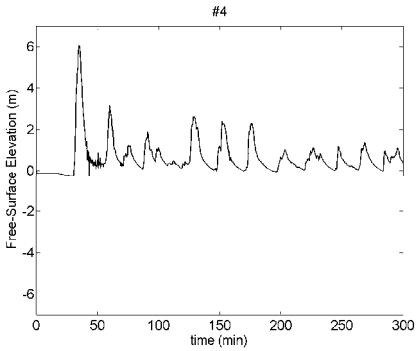
NPP4, R1b (Mw=8.43, Mw=8.81)

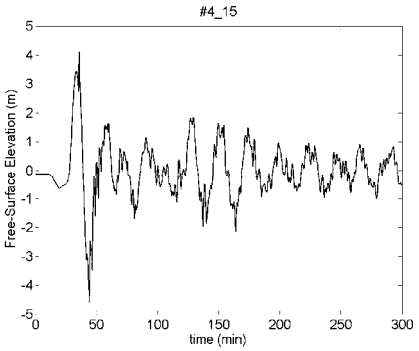












R1b
Mw8.43
(stress drop=30 bars)

	出水口 (outlet)			水深15 m處 (15m)		
	核一 NPP1	核二 NPP2	核四 NPP4	核一 NPP1	核二 NPP2	核四 NPP4
初始波到時	54 min	52 min	35 min	54 min	53 min	33 min
初始波波高 (m)	2.03	3.15	4.15	1.93	2.59	2.41
最大波到時	54 min	1 hr 47 min	35 min	54 min	53 min	33 min
最大波波高 (m)	2.03	3.54	4.15	1.93	2.59	2.41
	沿岸 (coast)			重點設施 (SITE)		
	核一 NPP1	核二 NPP2	核四 NPP4	核一 NPP1	核二 NPP2	核四 NPP3
最大波到時	0 min	1 hr 47 min	35 min	0 min	0 min	0 min
最大波波高(m)	0.0	0.35	2.42	0.0	0.0	0.0

Initial Height Peak Height

R1b_1
Mw8.81
(stress drop=100 bars)

	出水口 (outlet)			水深15 m處 (15m)		
	核一 NPP1	核二 NPP2	核四 NPP4	核一 NPP1	核二 NPP2	核四 NPP4
初始波到時	54 min	52 min	35 min	54 min	52 min	35 min
初始波波高(m)	3.08	4.71	6.19	2.96	4.0	4.24
最大波到時	54 min	1 hr 47 min	35 min	54 min	52 min	35 min
最大波波高(m)	3.08	4.90	6.19	2.96	4.0	4.24
	沿岸 (coast)			重點設施 (SITE)		
	核一 NPP1	核二 NPP2	核四 NPP4	核一 NPP1	核二 NPP2	核四 NPP4
最大波到時	54 min	1 hr 47 min	34 min	0 min	0 min	0 min
最大波波高(m)	0.14	0.68	4.54	0.0	0.0	0.0

組合模擬 – 琉球海溝

Multi-segments- Ryukyu Trench

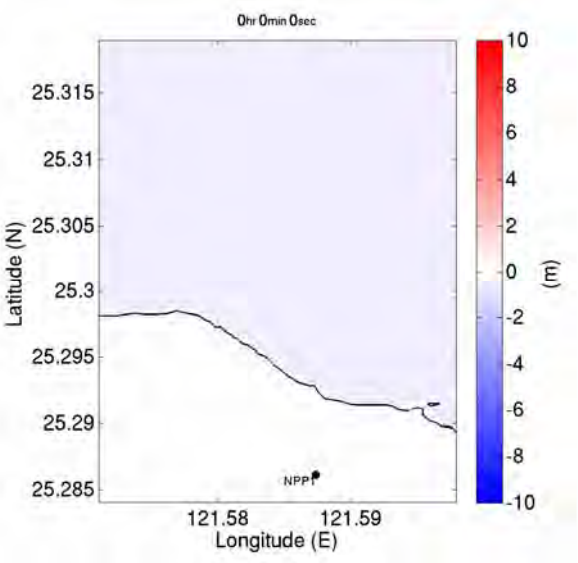
斷層編號	SJ1	SJ1_1	SJ2	SJ2_1	R1a	R1a_1	R1b	R1b_1	R2	R2_1	R3	R3_1	R4	R4_1
長度(km)	50		87		總長159.1 km		總長159.1 km		320		571		538	
					第一段	第二段	第一段	第二段						
					67.88	91.22	67.88	91.22						
寬度(km)	15		15		73		73/71		200		162		162	
中心經度	121.580000°E		121.930000°E		122.0684 72°E	122.6195 25°E	121.9667 28°E	122.5143 79°E	124.375975°E		127.838750°E		131.314000°E	
中心緯度	25.170000°N		25.400000°N		24.24333 2°N	23.94199 1°N	23.69391 3°N	23.39002 6°N	23.449290°N		25.230470°N		28.833770°N	
走向角	49°		61°		-27°	-86°	-27°	-86°	-94°		-130°		-143°	
傾角	90°		90°		16°		16° /4°		30°		18°		18°	
滑移角	-90°		-90°		90°		90°		90°		90°		90°	
位移量(m)	1.00	1.56	1.33	2.06	5.36	8.30	7.60	11.77	11.7	18.12	13.47	20.86	13.17	20.40

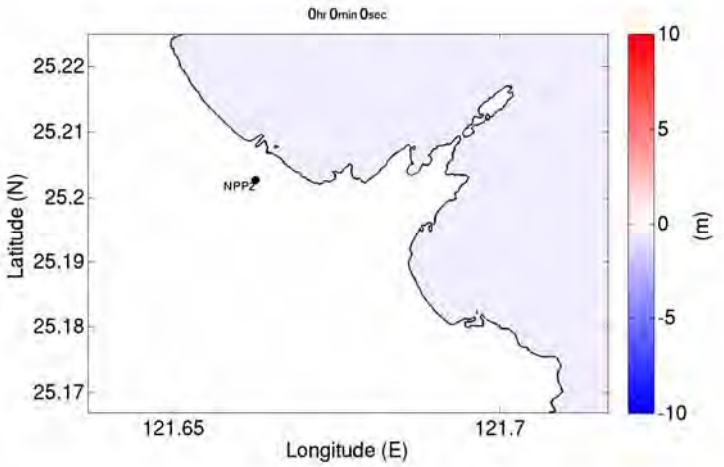
Mw=8.94 Mw=9.32 Mw=9.14 Mw=9.52 Mw=9.14 Mw=9.52

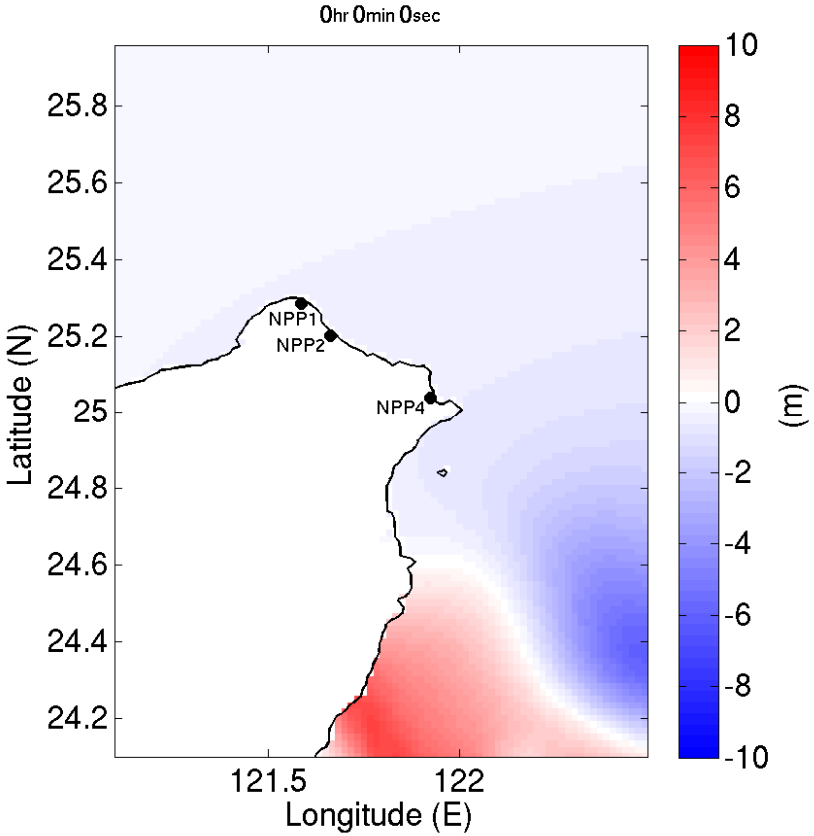
組合編號	R1b2	R1b2_1	R23	R23_1	R34	R34_1
位移量(m)	13.65	21.14	17.11	26.5	17.16	26.58
組合編號	R1b23	R1b23_1	R234	R234_1	R1b234	R1b234_1
位移量(m)	18.14	28.09	20.2	31.29	20.96	32.47

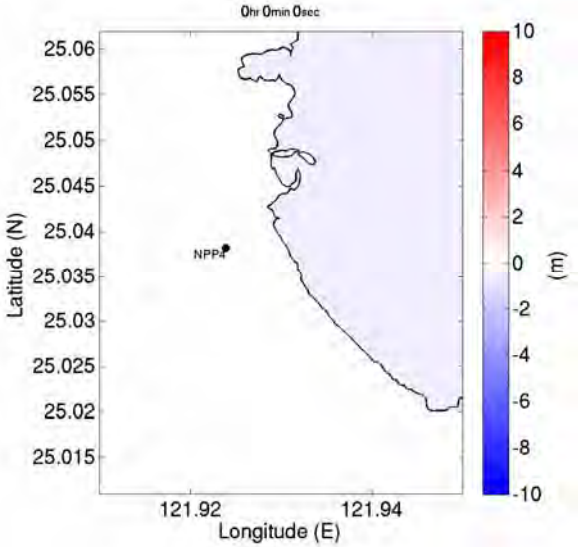
Mw=9.19 Mw=9.57 Mw=9.28 Mw=9.66 Mw=9.32 Mw=9.70

R1b2_1
Mw9.32

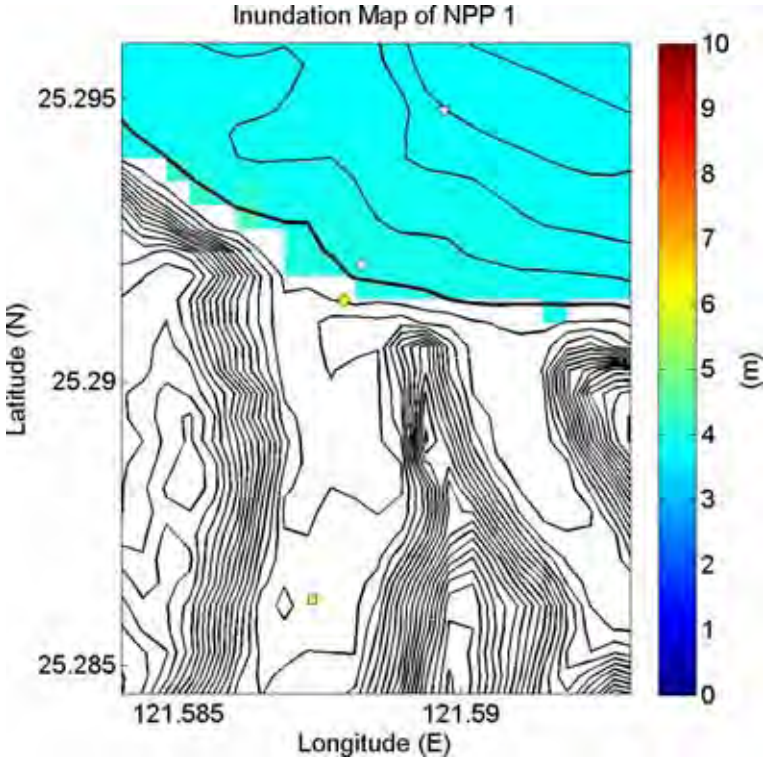

0hr 0min 0sec
25.315
25.31
25.305
25.3
25.295
25.29
25.285
Latitude (N)
NPP1
121.58
121.59
Longitude (E)
10
8
6
4
2
0
-2
-4
-6
-8
-10
(m)

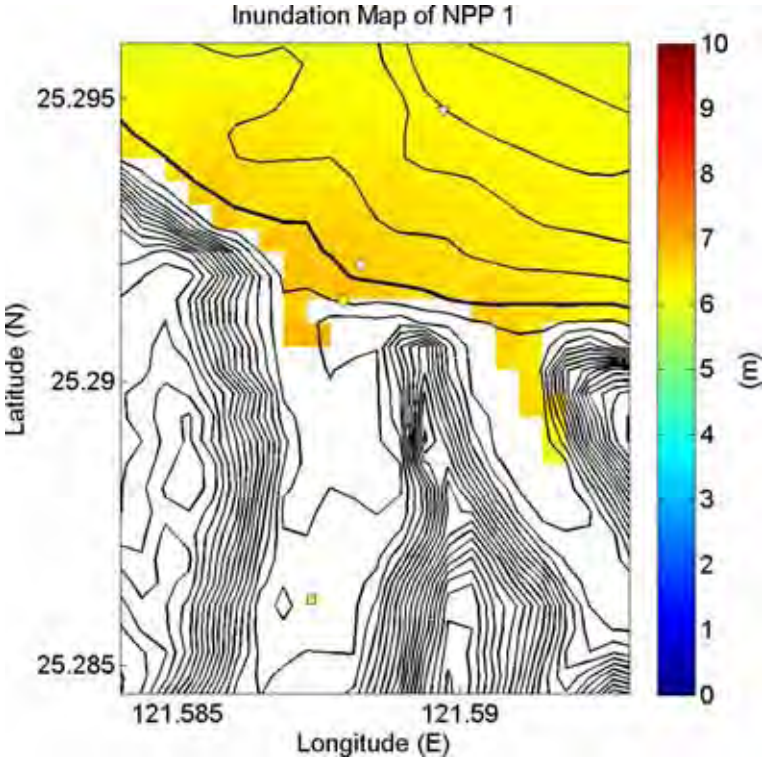

0hr 0min 0sec
25.22
25.21
25.2
25.19
25.18
25.17
Latitude (N)
NPP2
121.65
121.7
Longitude (E)
10
5
0
-5
-10
(m)

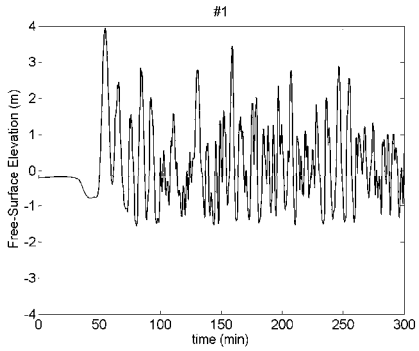

0hr 0min 0sec
25.8
25.6
25.4
25.2
25
24.8
24.6
24.4
24.2
Latitude (N)
NPP1
NPP2
NPP4
121.5
122
Longitude (E)
10
8
6
4
2
0
-2
-4
-6
-8
-10
(m)

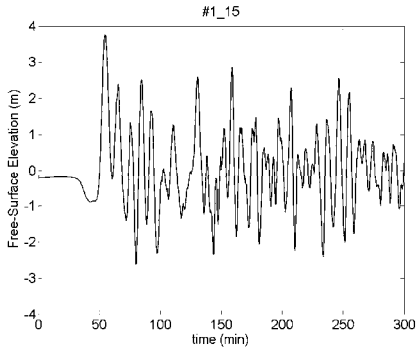

0hr 0min 0sec
25.06
25.055
25.05
25.045
25.04
25.035
25.03
25.025
25.02
25.015
Latitude (N)
NPP4
121.92
121.94
Longitude (E)
10
8
6
4
2
0
-2
-4
-6
-8
-10
(m)

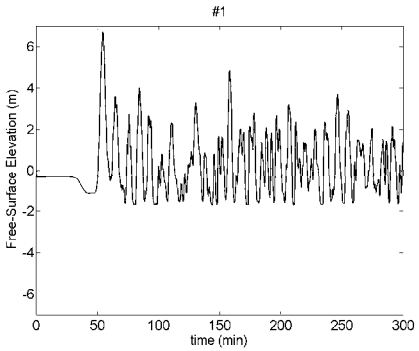
R1b2 & R1b2 _1 NPP 1

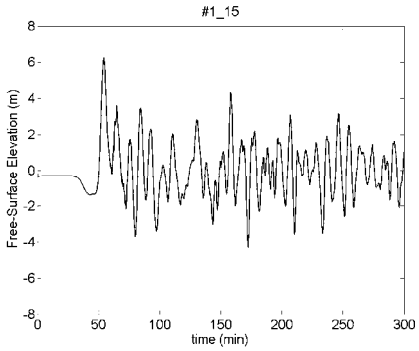




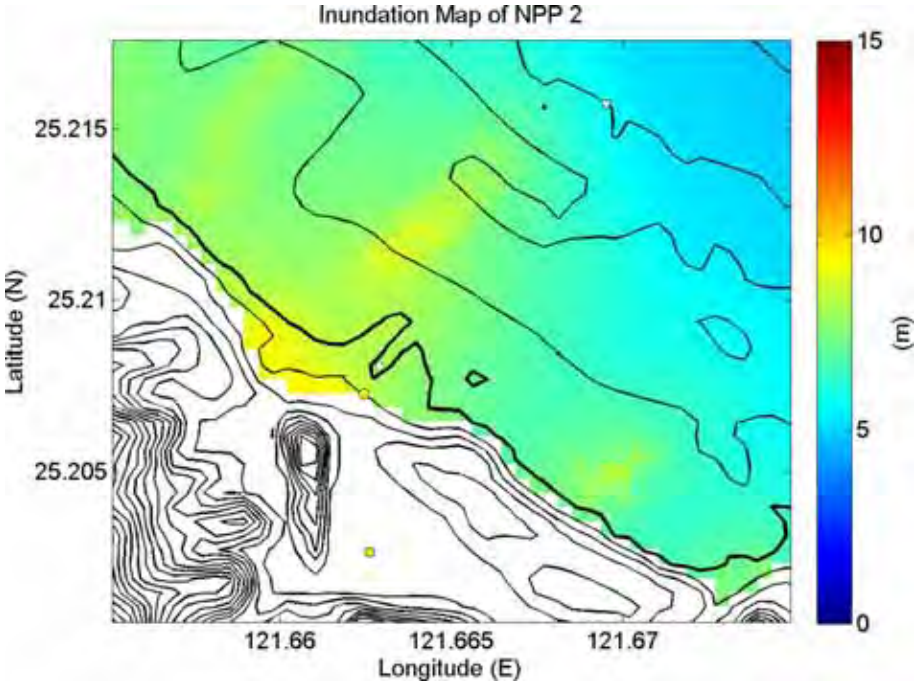


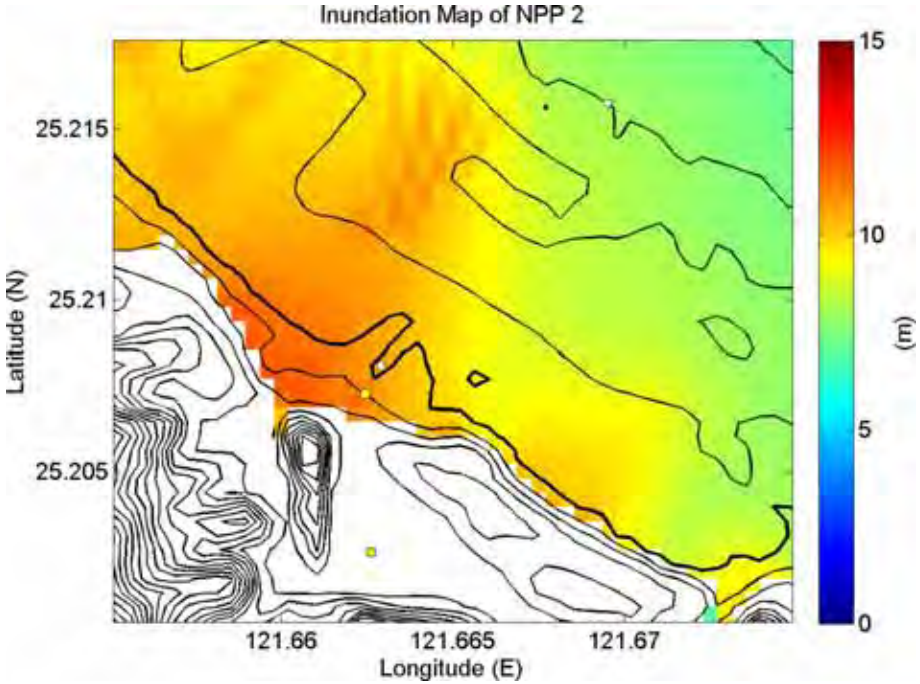


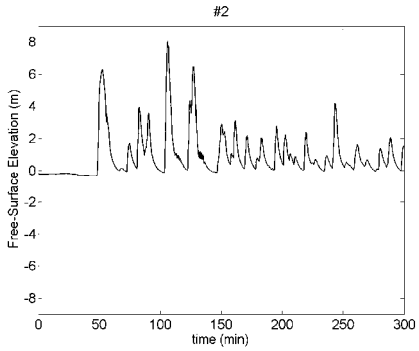


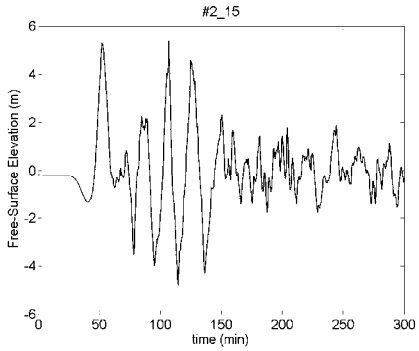


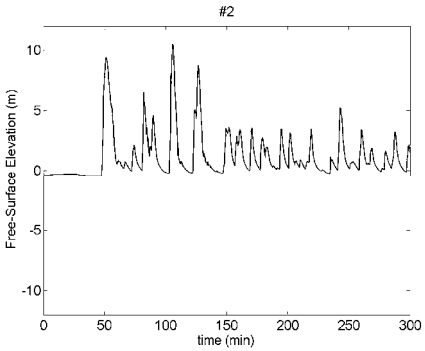
R1b2 & R1b2 _1 NPP 2

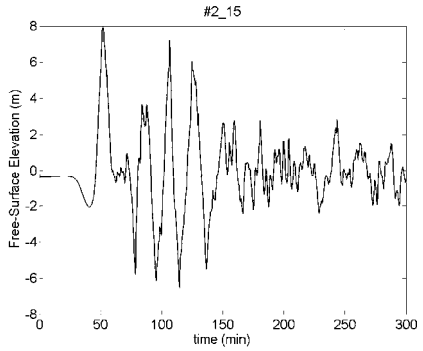




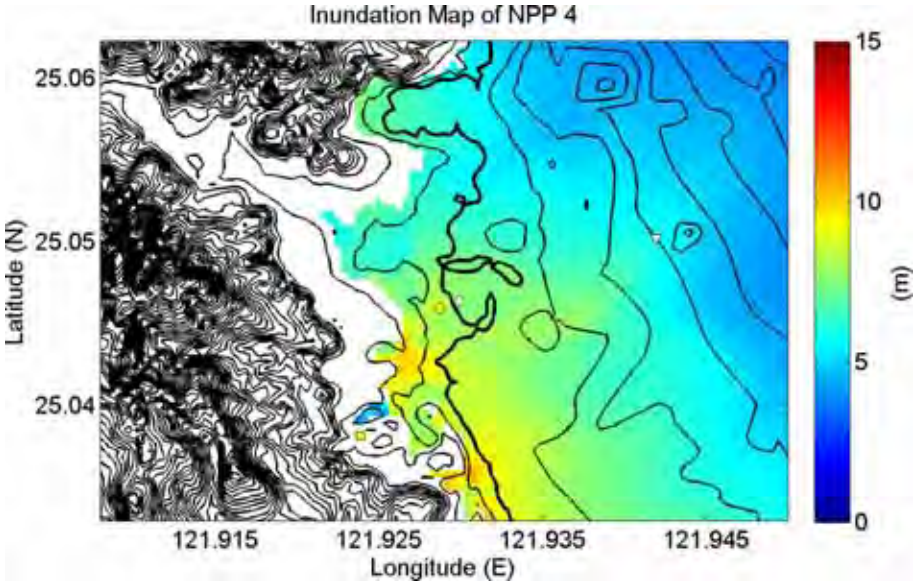


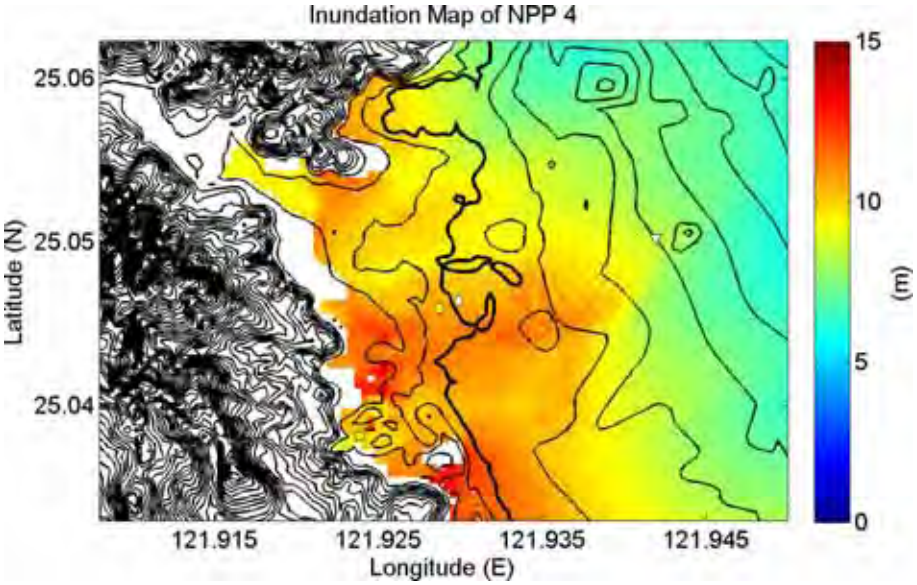


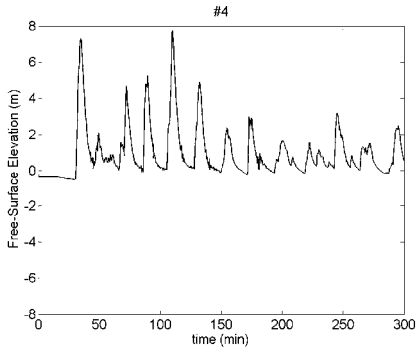


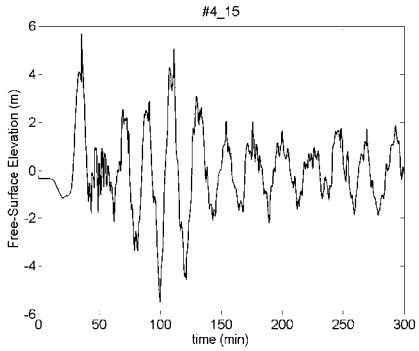


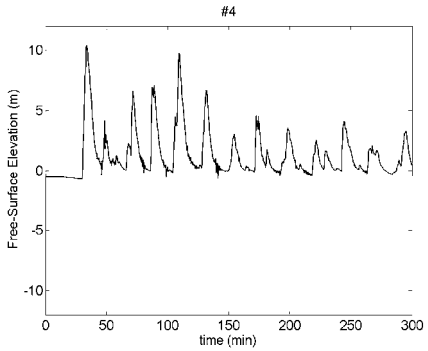
R1b2 & R1b2 _1 NPP 4

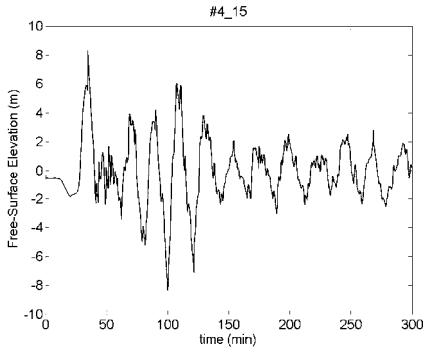












R1b2 (30bars)
Mw=8.94

	出水口 outlet			水深15 m處		
	核一	核二	核四	核一	核二	核四
初始波到時	54 min	52 min	46 min	54 min	52 min	35 min
初始波波高(m)	4.17	6.50	7.80	3.98	5.60	6.04
最大波到時	54 min	1 hr 46 min	1 hr 50 min	54 min	1 hr 46 min	35 min
最大波波高(m)	4.17	8.30	8.08	3.98	5.63	6.04
	沿岸			重點設施 SITE		
	核一	核二	核四	核一	核二	核四
最大波到時	54 min	1 hr 46 min	1 hr 49 min	0 min	0 min	0 min
最大波波高(m)	0.75	3.53	6.79	0.0	0.0	0.0

R1b2 (100bars)
Mw=9.32

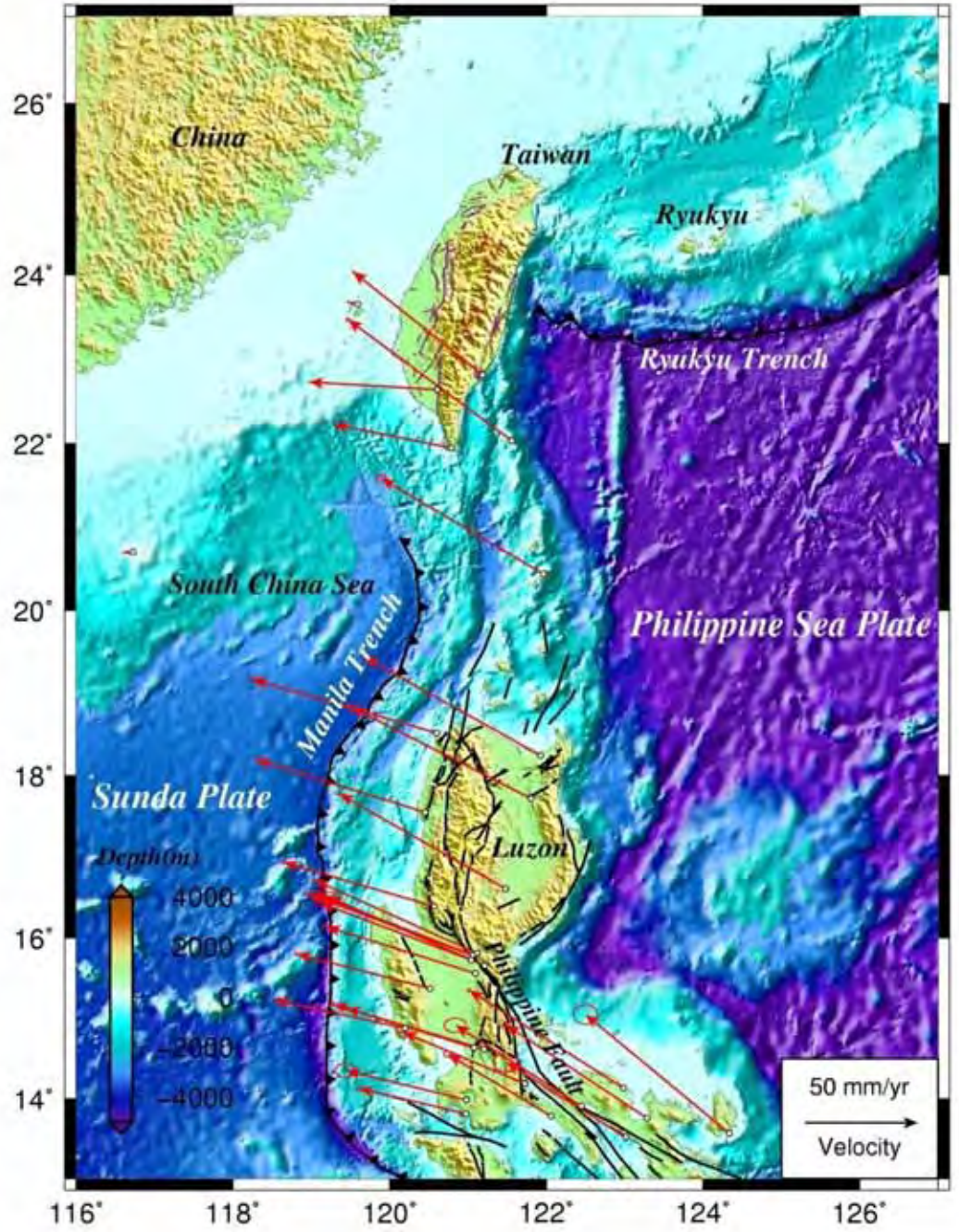
	出水口 Outlet			水深15 m處		
	核一	核二	核四	核一	核二	核四
初始波到時	54 min	52 min	33 min	54 min	52 min	34 min
初始波波高(m)	7.04	10.0	10.97	6.60	8.36	8.96
最大波到時	54 min	1 hr 45 min	33 min	54 min	52 min	34 min
最大波波高(m)	7.04	10.89	10.97	6.60	8.36	8.96
	沿岸			重點設施 SITE		
	核一	核二	核四	核一	核二	核四
最大波到時	54 min	1 hr 45 min	33 min	0 min	0 min	1 hr 51 min
最大波波高(m)	3.32	6.32	9.28	0.0	0.0	4.34

Manila Trench Tectonic setting

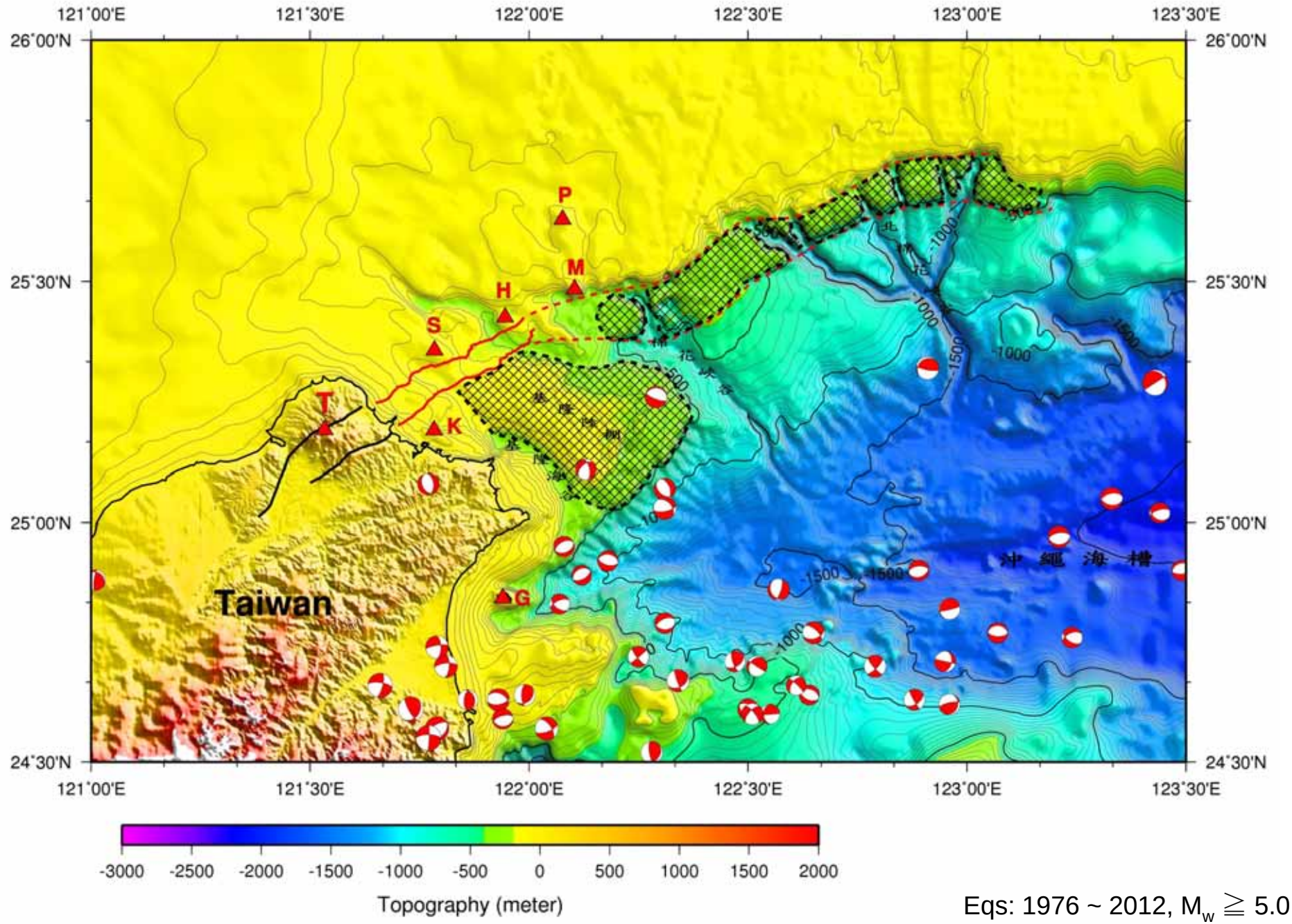
GPS horizontal velocity w.r.t the Sunda Plate gradually decrease from north to south along the western Luzon at rates of 81 to 50 mm/yr in the west-northwest direction.

(1996-2008)

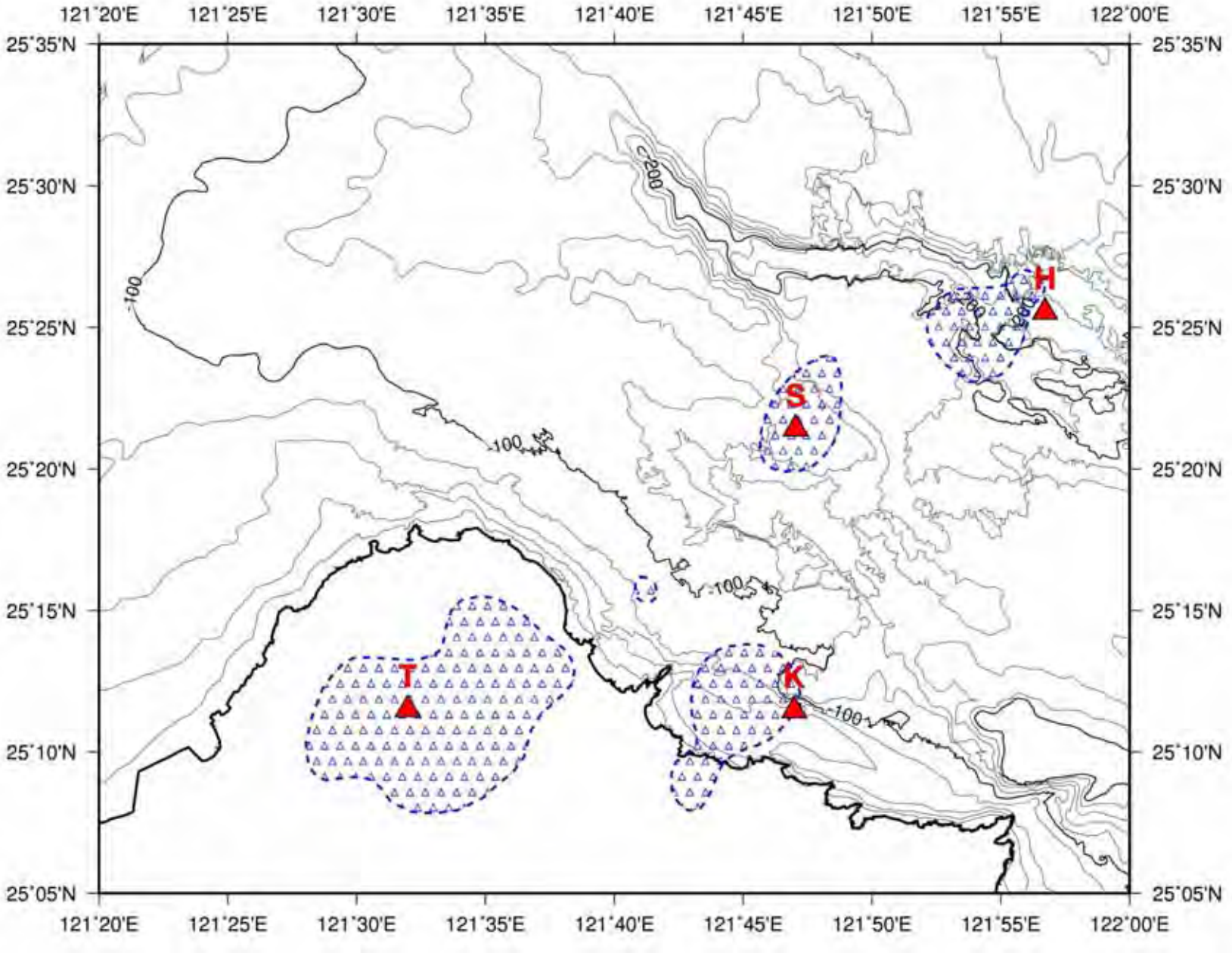
Under-going



Submarine Landslide and Volcanoes (Still under invetigations)



Eqs: 1976 ~ 2012, $M_w \geqq 5.0$


121°20'E
121°25'E
121°30'E
121°35'E
121°40'E
121°45'E
121°50'E
121°55'E
122°00'E
25°35'N
25°30'N
25°25'N
25°20'N
25°15'N
25°10'N
25°05'N
-200
-100
H
S
T
K

Continue Efforts

- Manila Trench, Historical Tsunamis
- Volcanoes and Submarine Landslide
- Earthquake with Submarine Landslides
- More detail mapping in submarine landslide and volcanoes
- How to deal with Mmax
- How to deal with the uncertainty and probabilities
- First attempt in Taiwan PTHA, needing international platform for construction of PTHA

Thank you for your attention