Earthquake Monitoring in Taiwan

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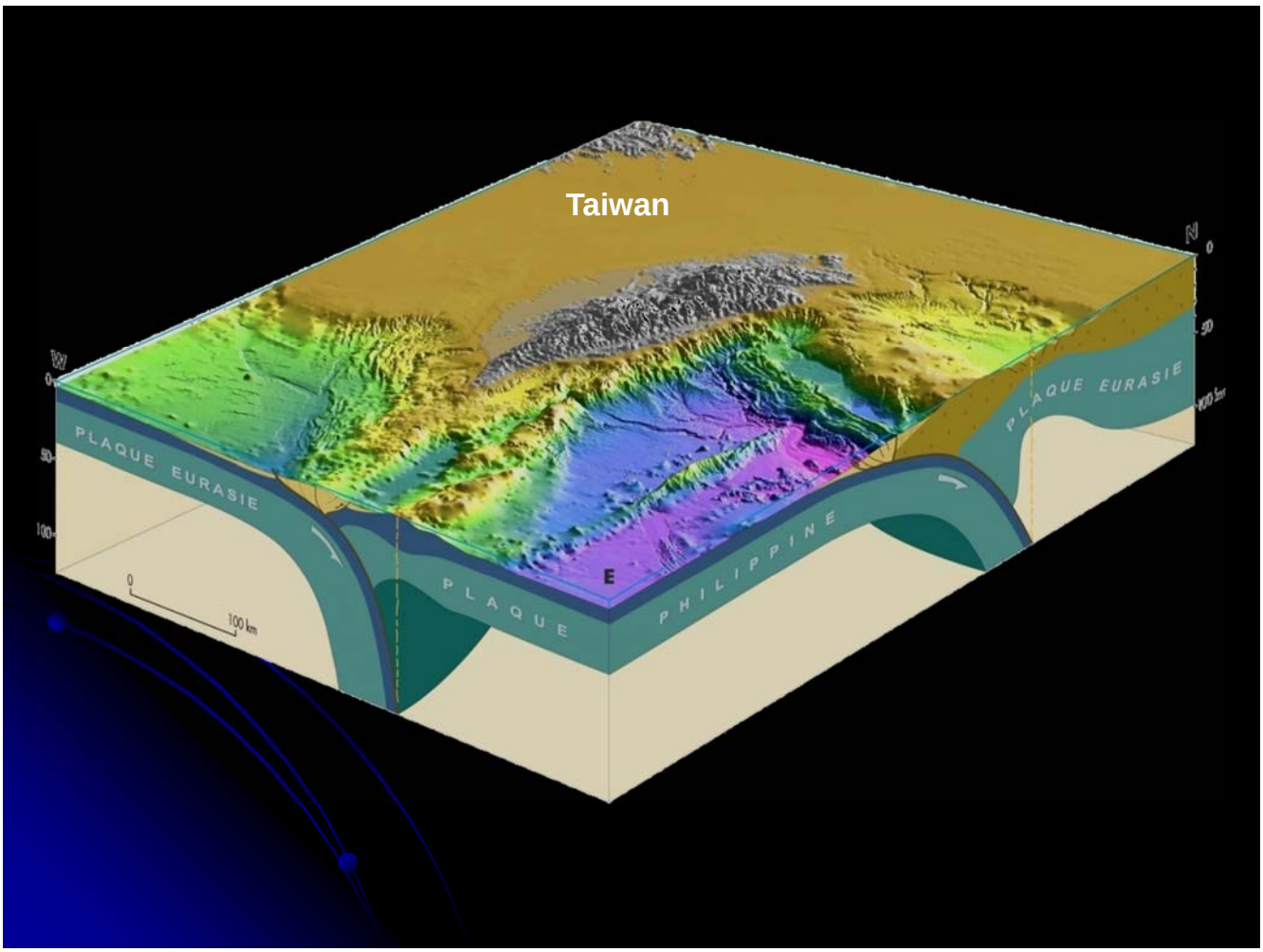
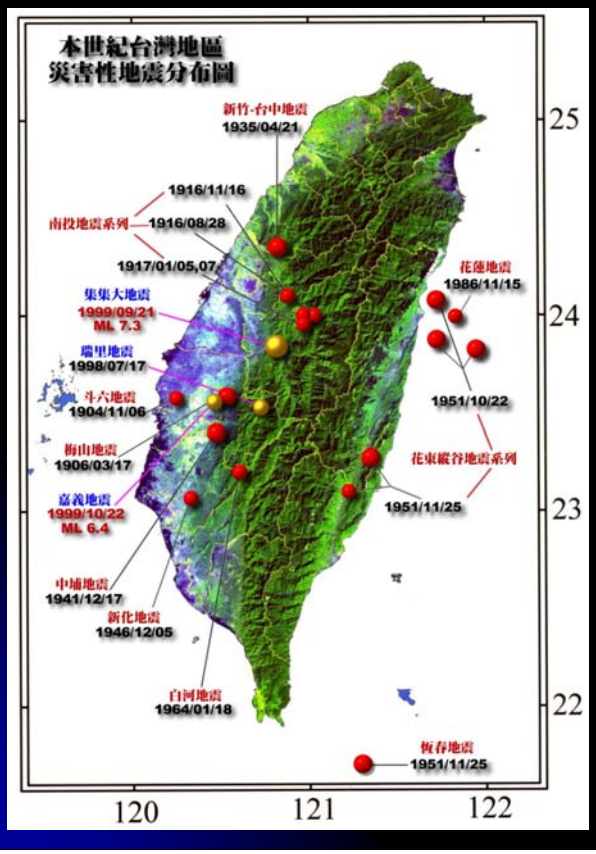
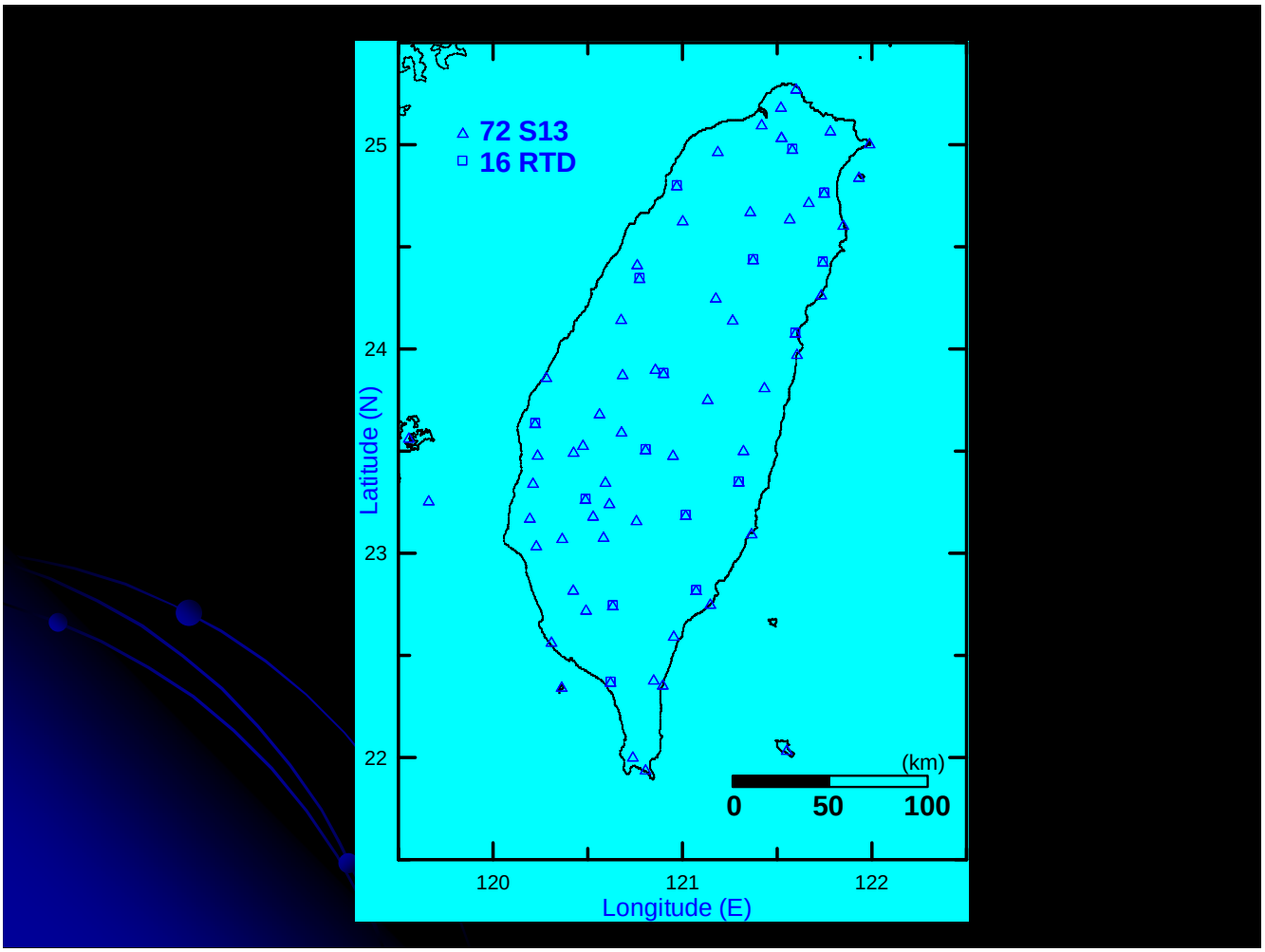


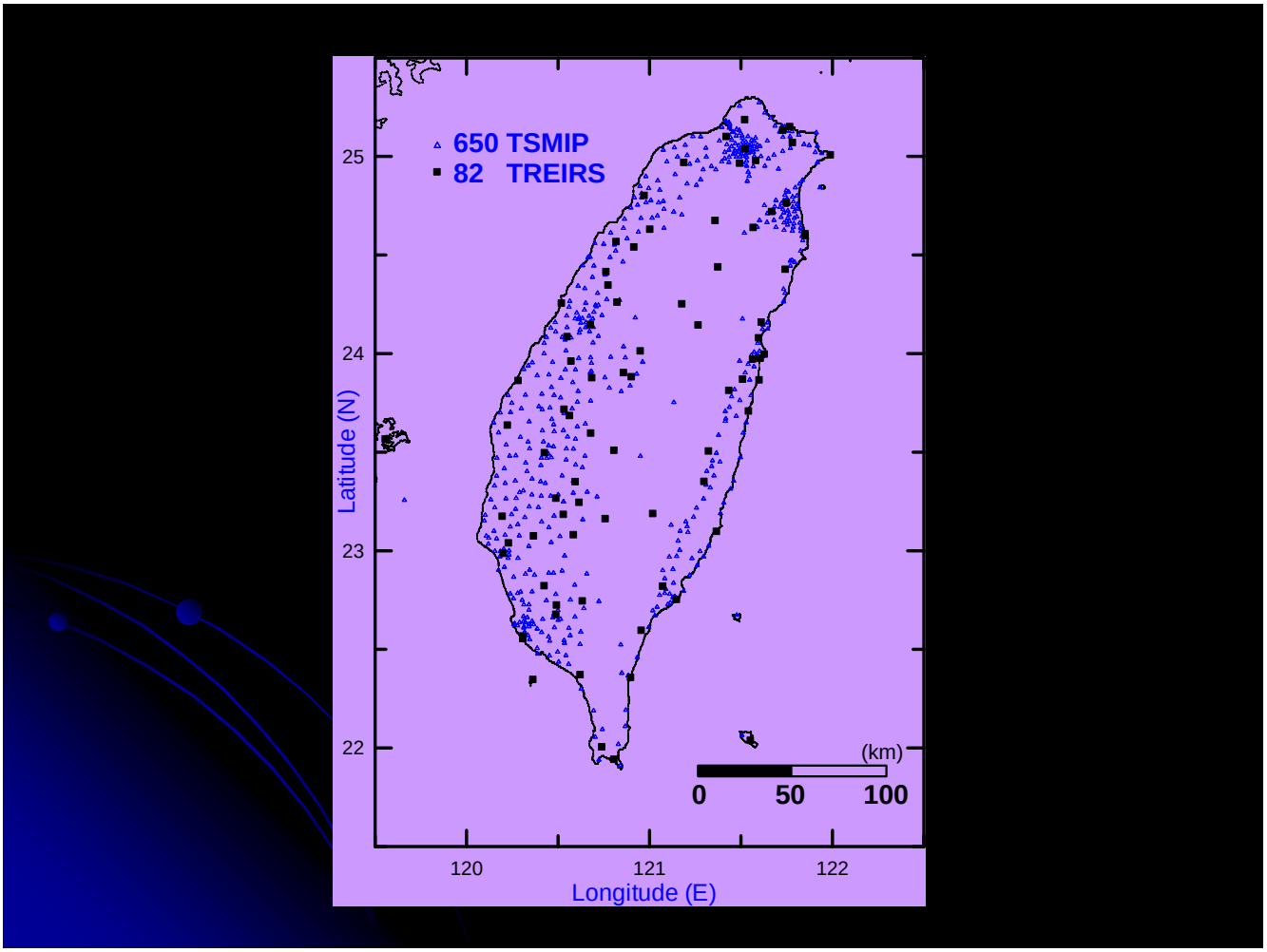
Historical Disastrous Earthquakes

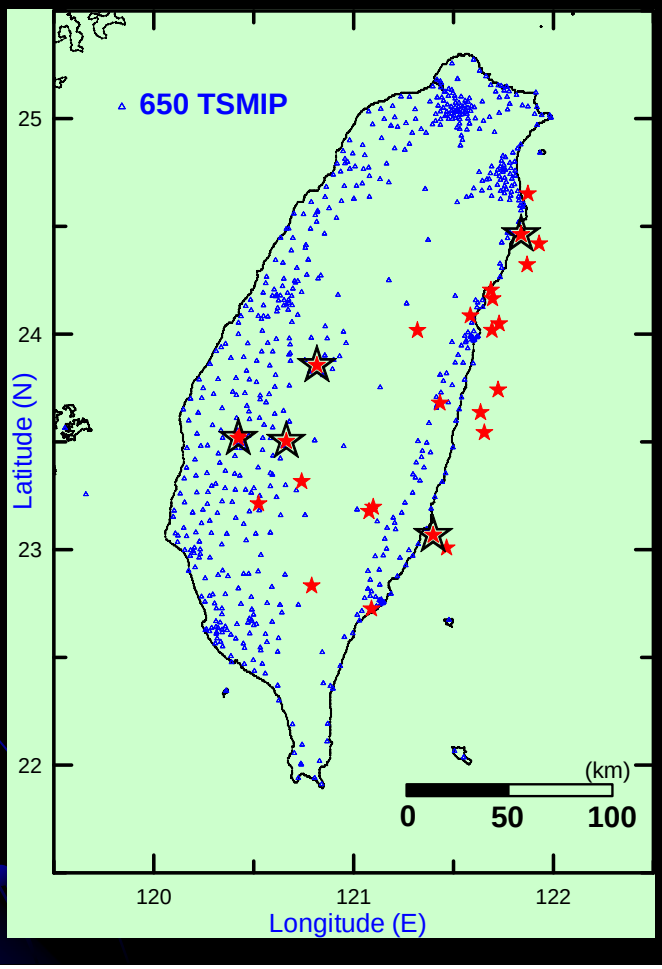


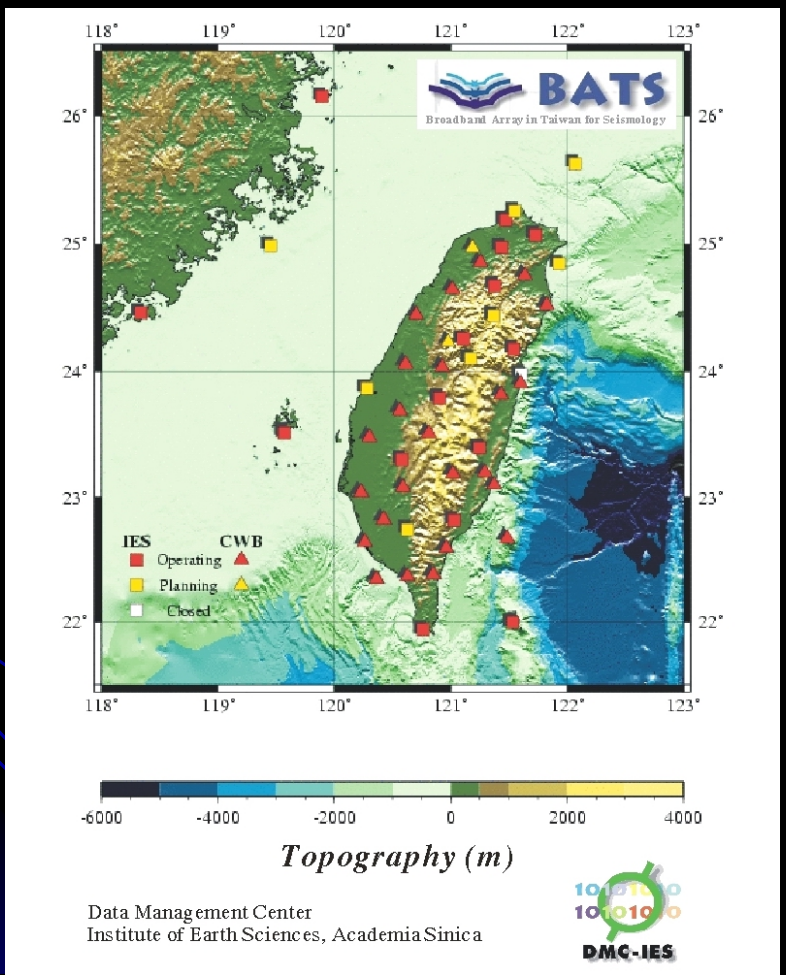
Seismic networks of Taiwan

- Central Weather Bureau Seismic Network
  - S13 Short-Period high gain 71 stations
  - Real time strong motion network 110 stations
    - EWS seismic early warning system
    - RRS seismic rapid reporting system
  - TSMIP Taiwan Strong Motion Instrumentation Program 800 stations
  - BATS+CWB Broadband Array in Taiwan for Seismology 60 stations

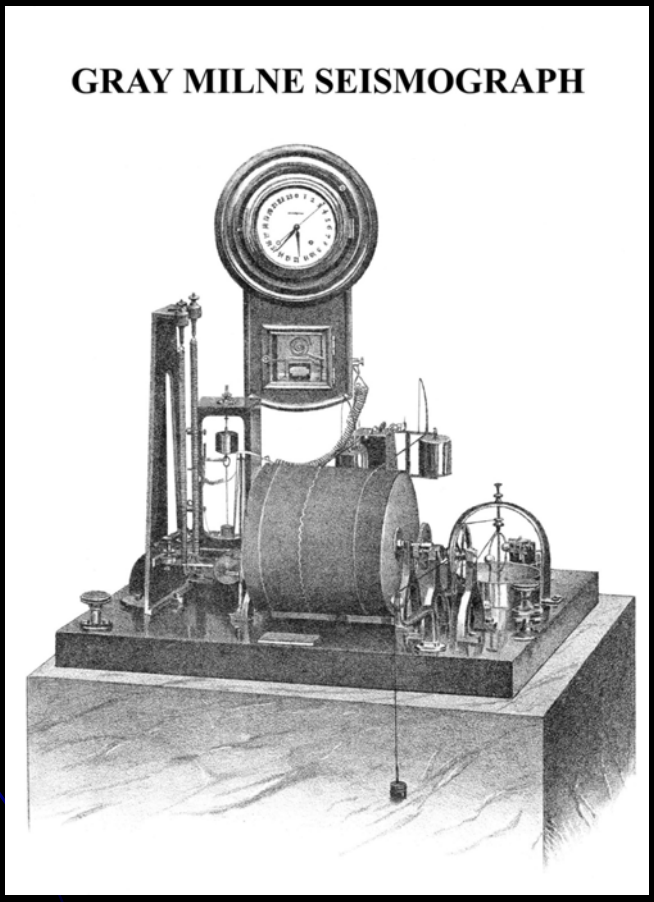

72 S13
16 RTD
25
24
23
22
Latitude (N)
(km)
0
50
100
120
121
122
Longitude (E)

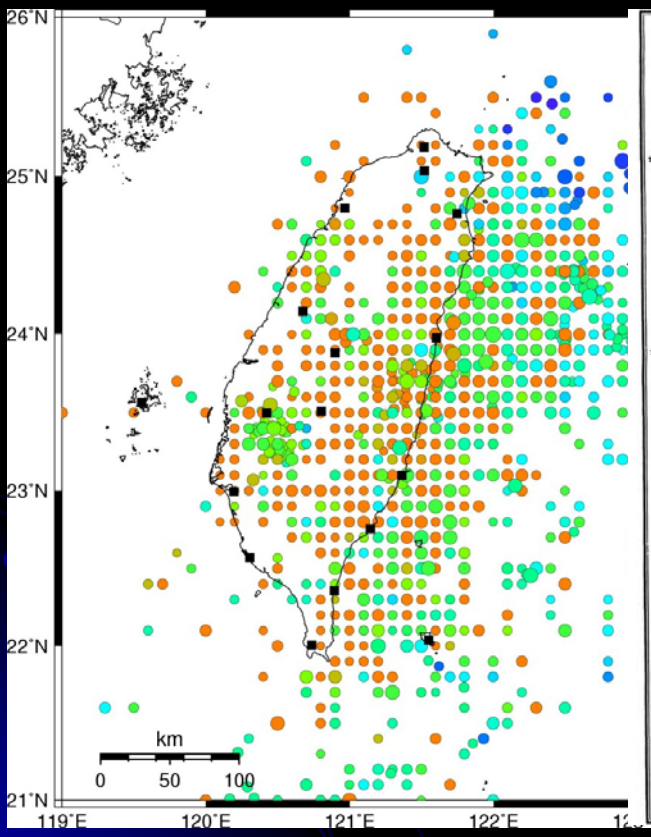

650 TSMIP
82 TREIRS
25
24
23
22
Latitude (N)
(km)
0
50
100
120
121
122
Longitude (E)

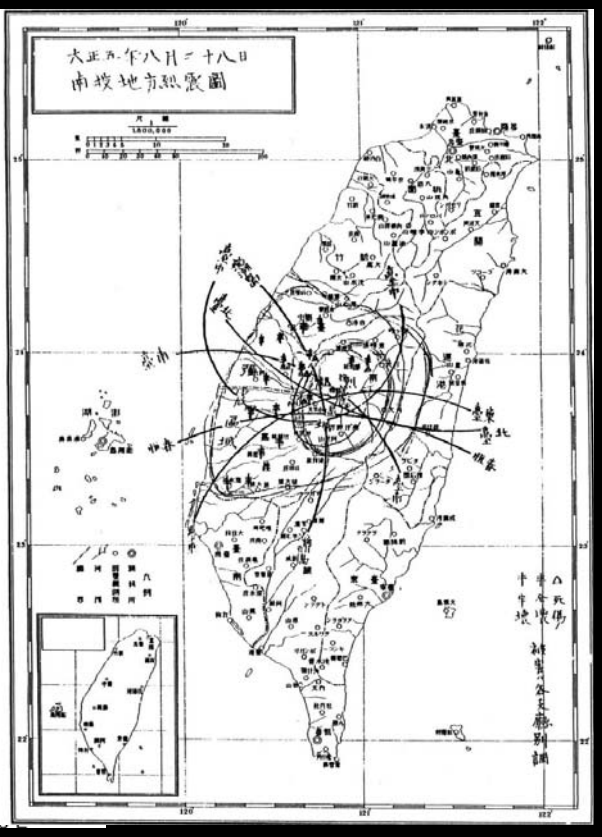

650 TSMIP
25
24
23
22
Latitude (N)
120
121
122
Longitude (E)
(km)
0
50
100


118°
119°
120°
121°
122°
123°
26°
25°
24°
23°
22°
BATS
Broadband Array in Taiwan for Seismology
IES
CWB
Operating
Planning
Closed
-6000
-4000
-2000
0
2000
4000
Topography (m)
Data Management Center
Institute of Earth Sciences, Academia Sinica
DMC-IES

1897-1972
CWB

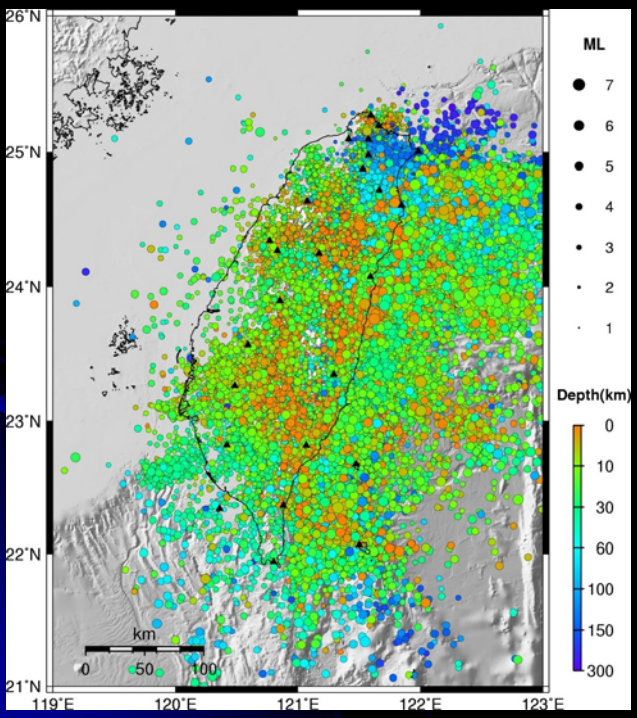


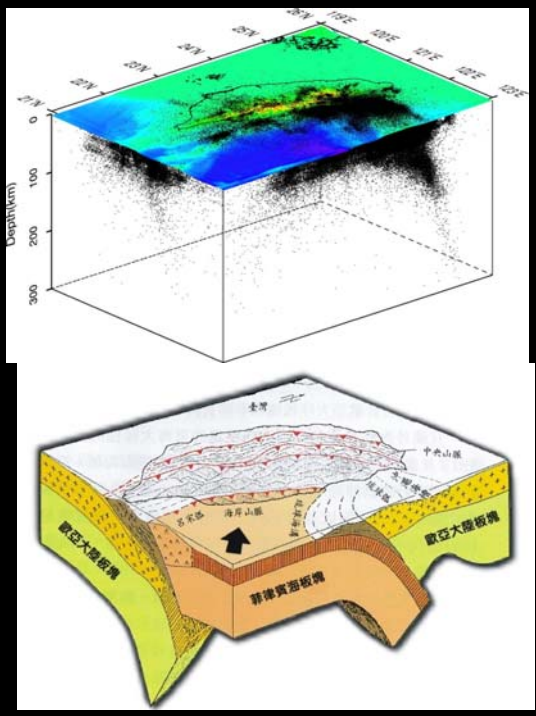




Taiwan Telemetry Seismic Network (1973~1990) 23 stations

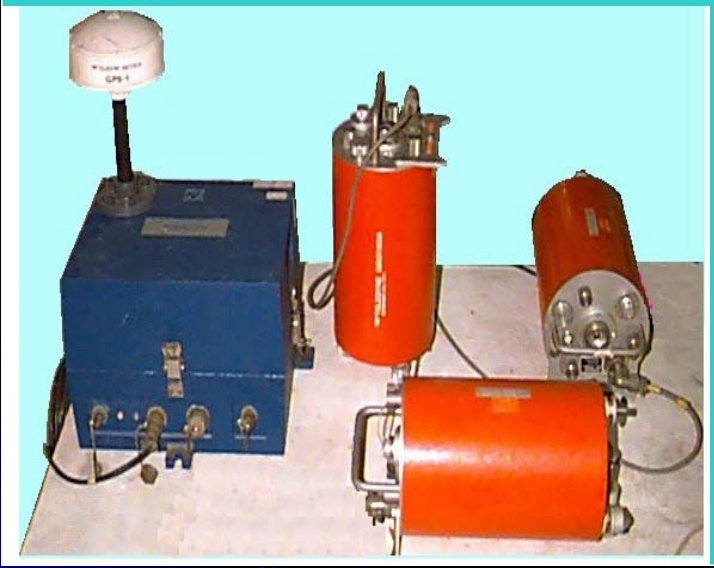
中央研究院地球科學研究所





Central Weather Bureau Seismic Network (1991-)

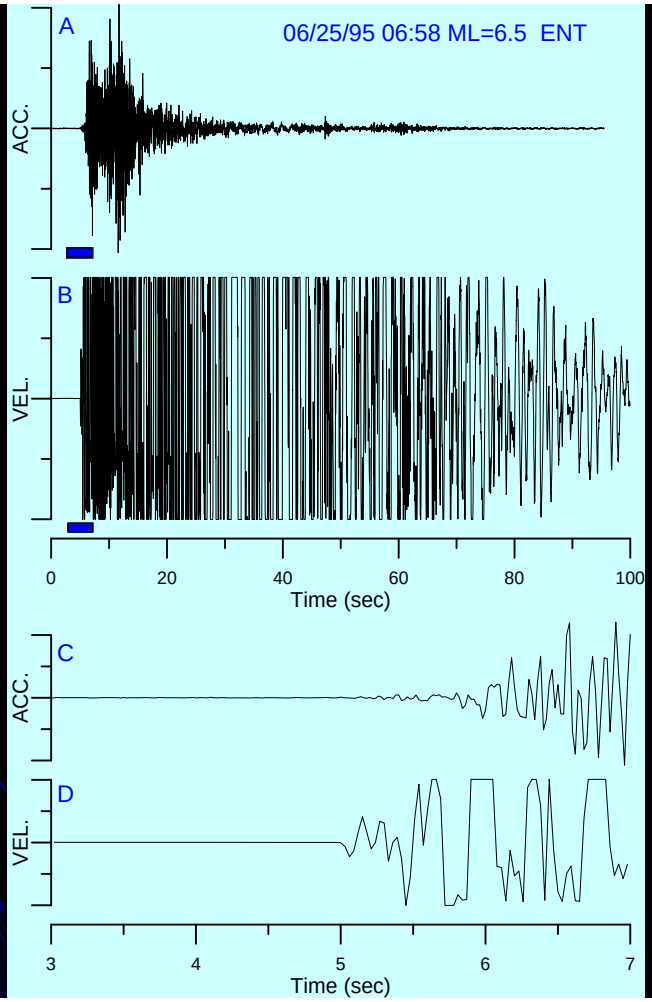
Station Instrument A900 & S13

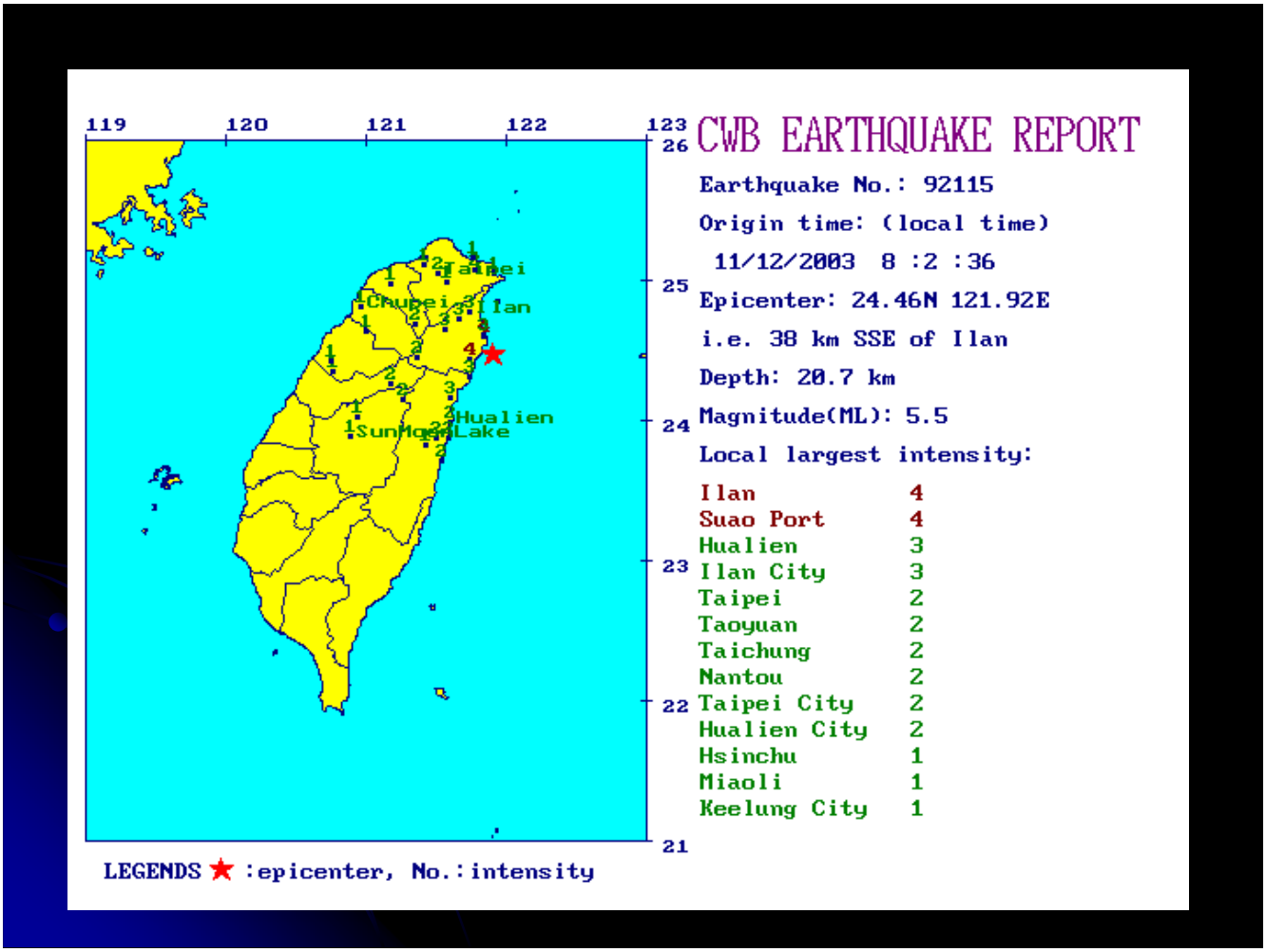


Real-time strong motion and weak motion sensors for earthquake monitoring

Real-time Telemetry

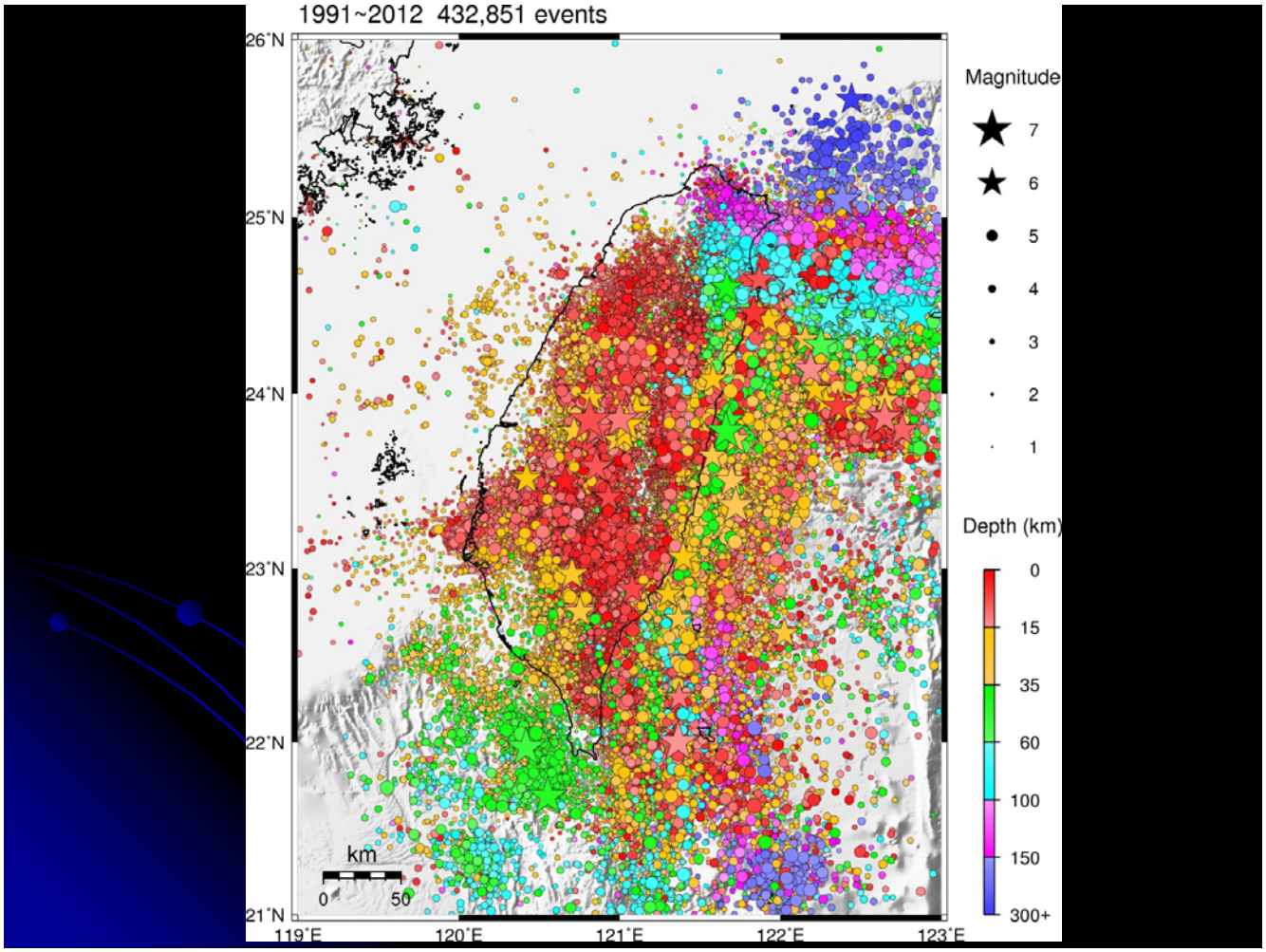
- Digital Telephone Lines and T1 lines
- Network with Satellite backup

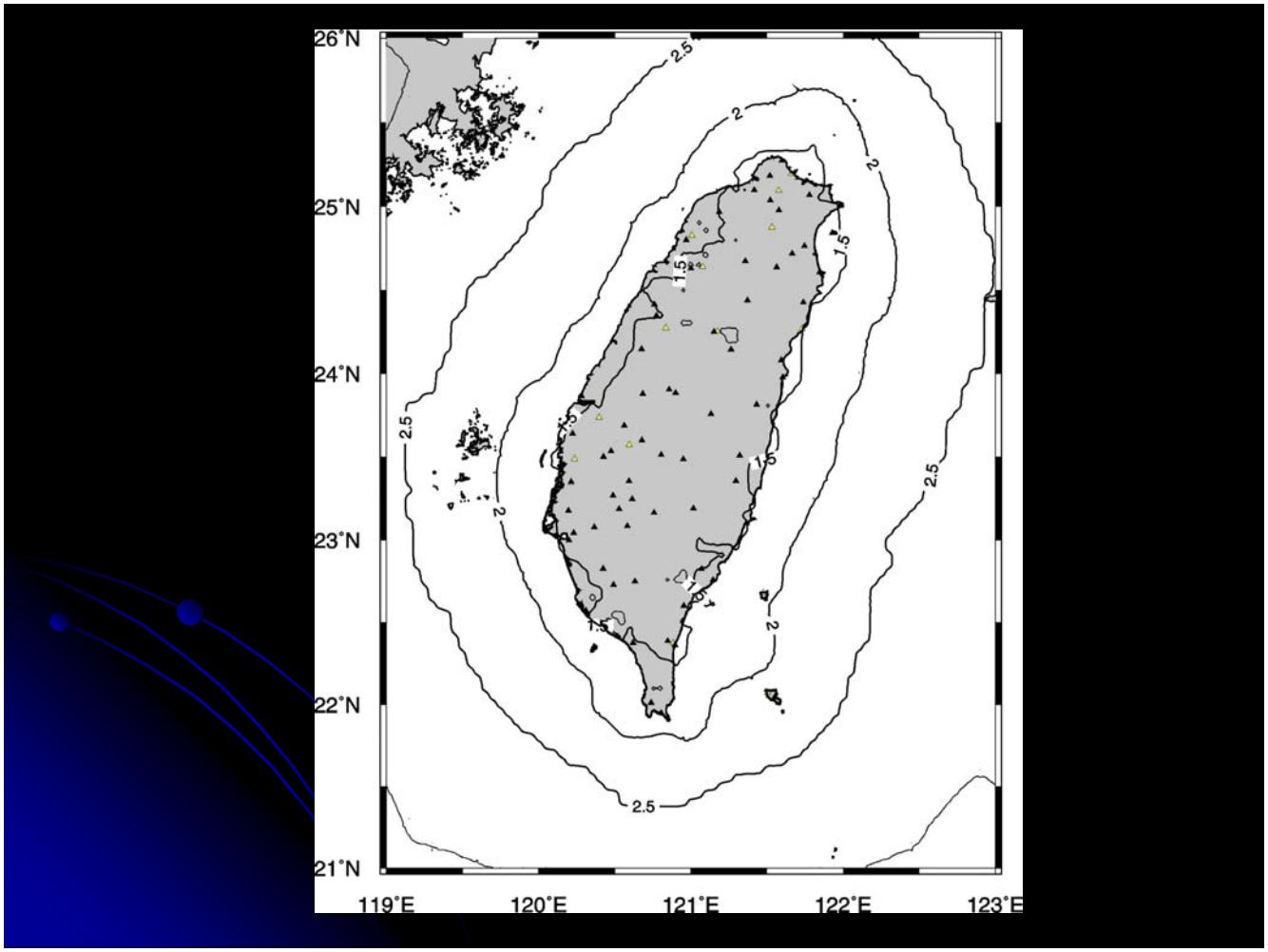




Using of the S13 data

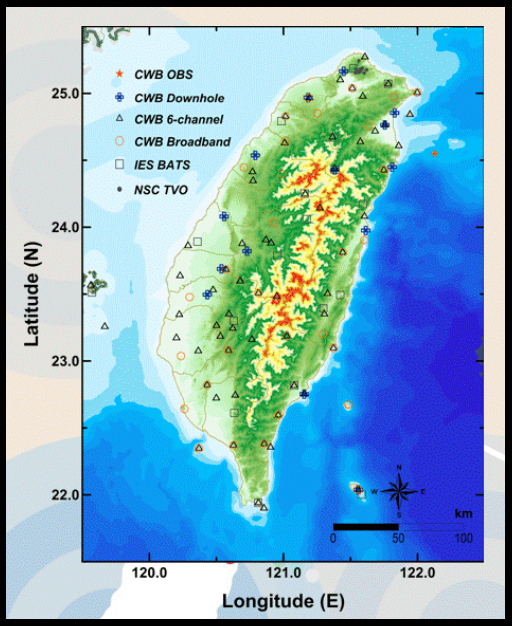
- Picking P and S arrivals for earthquake location
- Picking P wave first motion for determination focal mechanism


1991~2012 432,851 events
26°N
25°N
24°N
23°N
22°N
21°N
119°E
120°E
121°E
122°E
123°E
km
0
50
Magnitude
7
6
5
4
3
2
1
Depth (km)
0
15
35
60
100
150
300+


26°N
25°N
24°N
23°N
22°N
21°N
119°E
120°E
121°E
122°E
123°E
2.5
2
1.5

CWBSN improved since 2012~

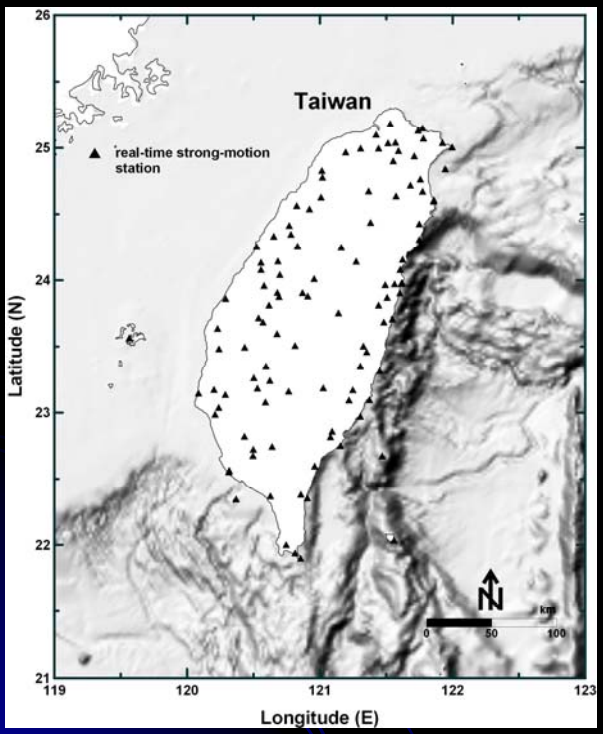
- ✓ Resolution of the 24 bits and sampling rate is 100 sps
- ✓ Combination of different instruments (short-period, strong-motion and broadband data) and different sites (surface, borehole and cable-based OBS) in operation
- ✓ GPS timing marks on-site
- ✓ A total of 150 stations in real-time operation



Earthquake Early Waning and Rapid Reporting Systems

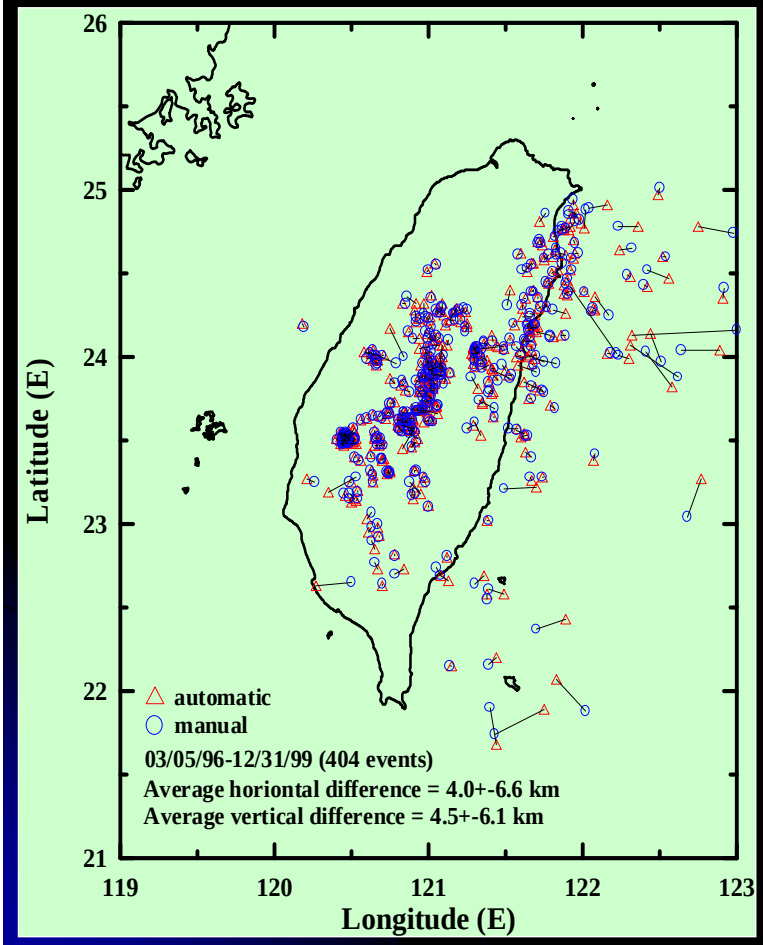
- Before Strong Ground motion
  - Early Waning System (EWS)
  - Predicts Shaking
- Before Damage is Discovered
  - Rapid Reporting System (RRS)
  - Predicts Damage
  - Focusing seismic rescue efforts

Real-time strong-motion network



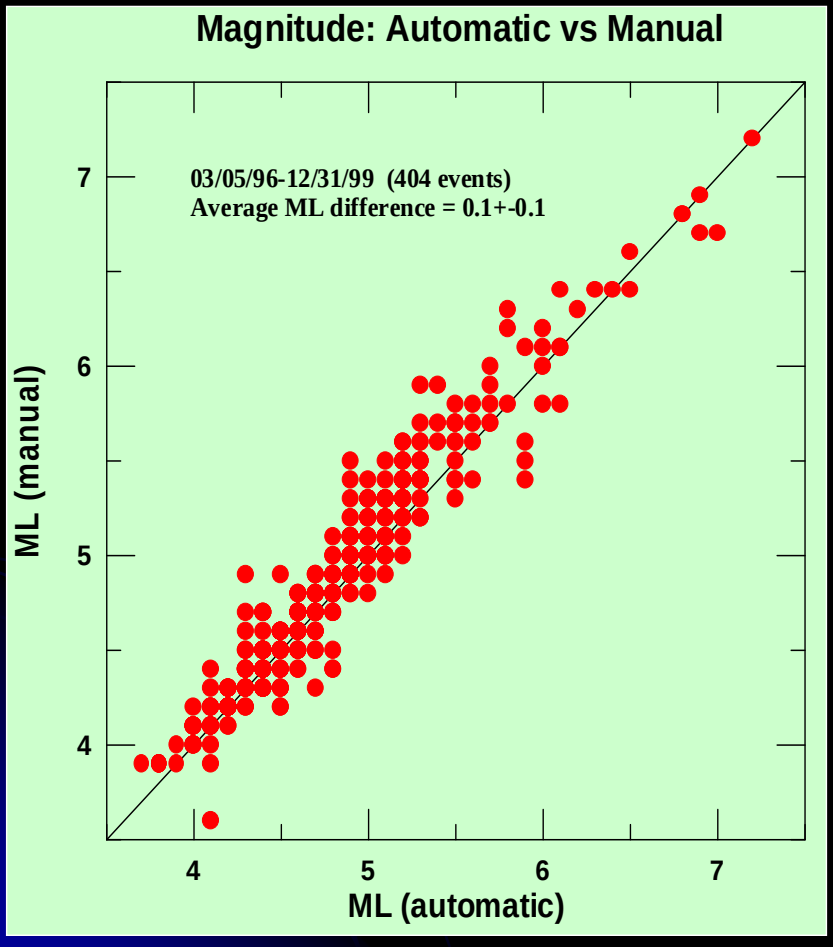
- Accelerometer -
  - 102 stations (20km averaged spacing)
  - 16 bits resolution
  - ± 2g Max. amplitude
- Telemetry -
  - Real-time data stream (RTD)
  - 4.8K dedicated telephone line
  - Sampling rate 50 sps
  - 0.2 sec averaged delay
- Data processing -
  - Taipei data center
  - Windows-based workstation

RRS about one minute



Location Precision

- On-line V.S. Off-line
- Epicenter
  - 4.0+- 6.6 km
- Depth
  - 4.5 +- 6.1 km
- 1996-1999 404 events

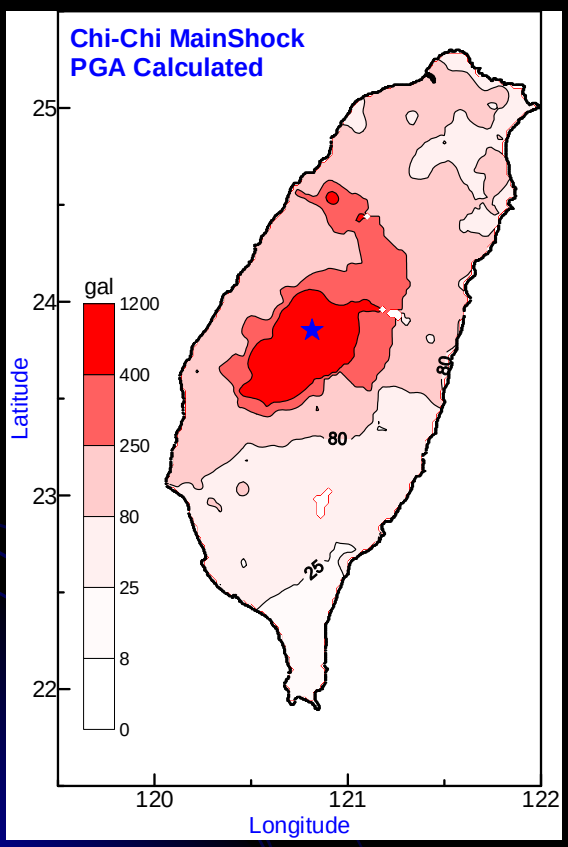


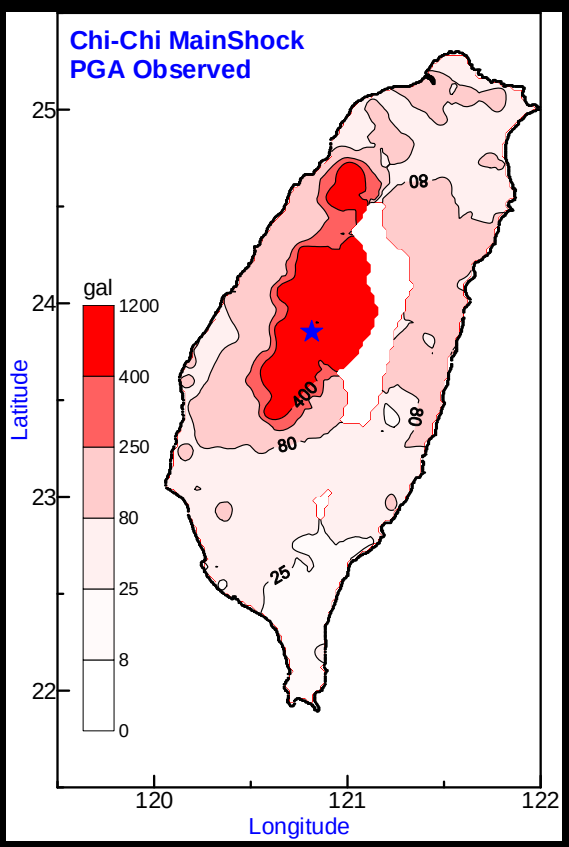
Magnitude Precision

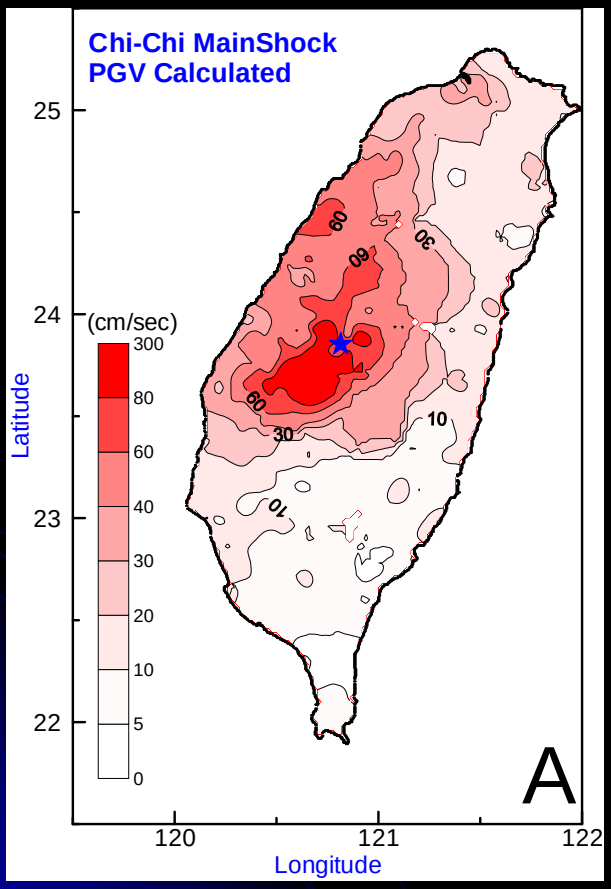
- On-line V.S. Off-line
- 0.1 +- 0.1

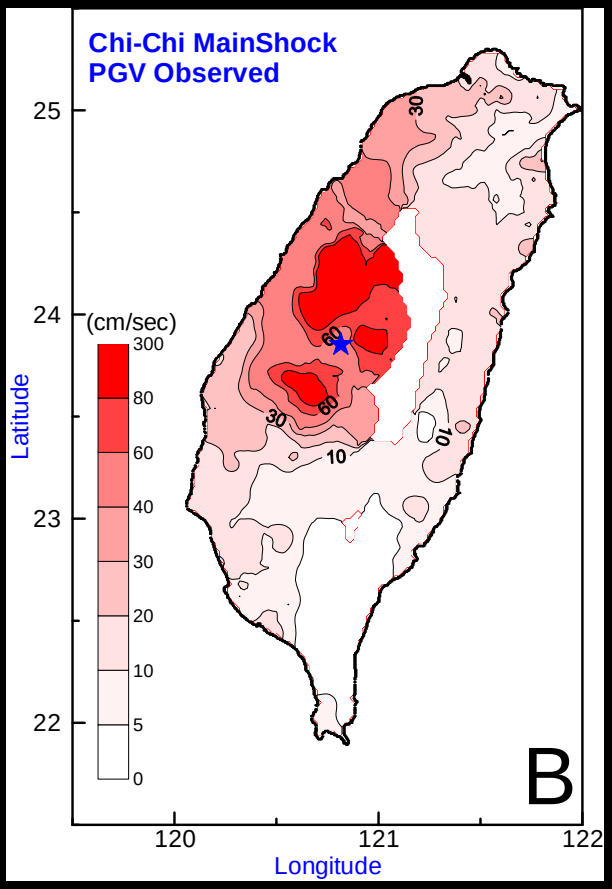
Shake Maps

- Two minutes PGA and PGV maps
- Combination site factors, attenuation relationships, real-time observed values.



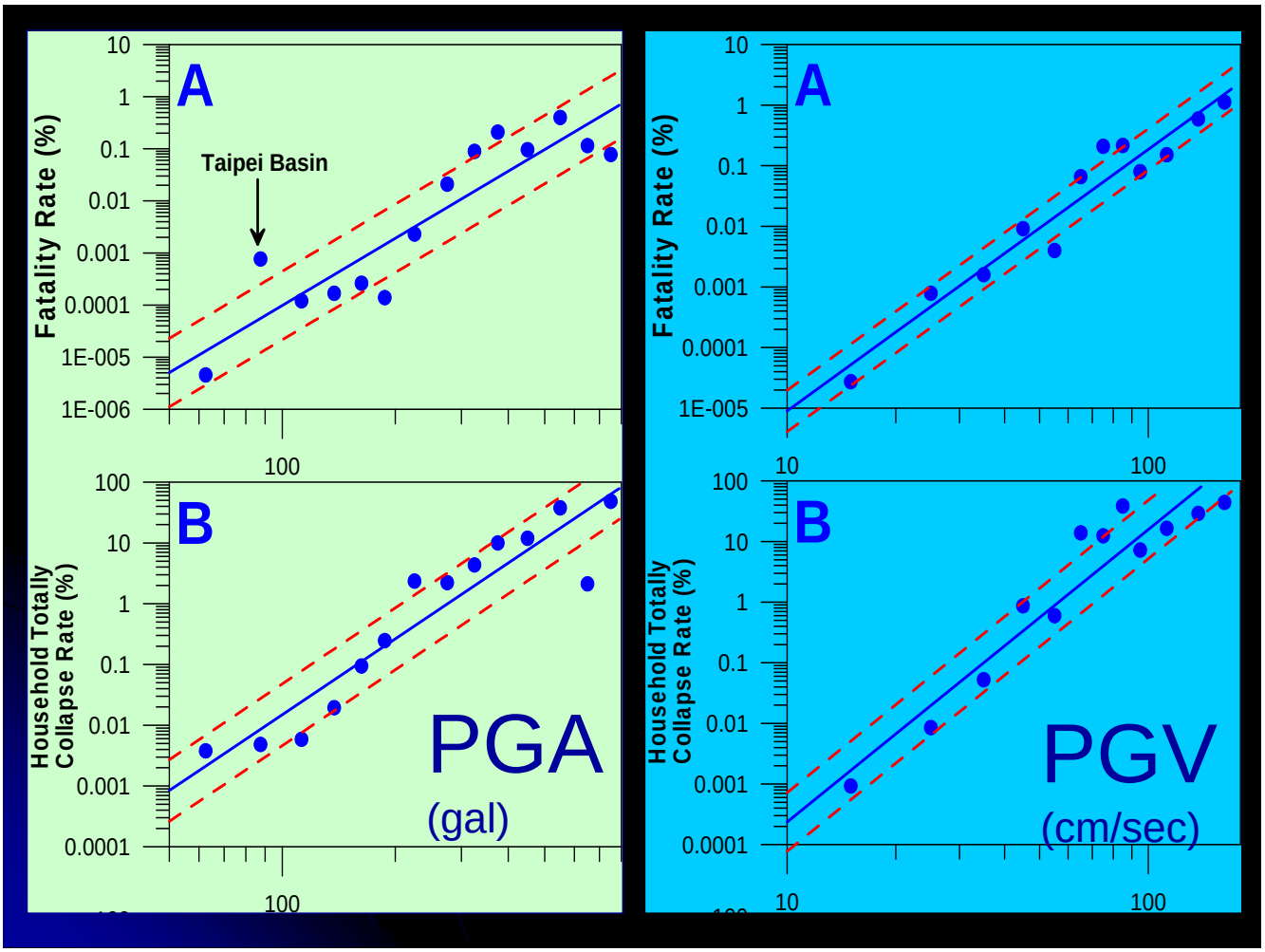






Rapid Potential Damage Assessment

- Two minutes
- Base on the Relationships between 1999 Chi-Chi earthquake damage data and PGA & PGV values.

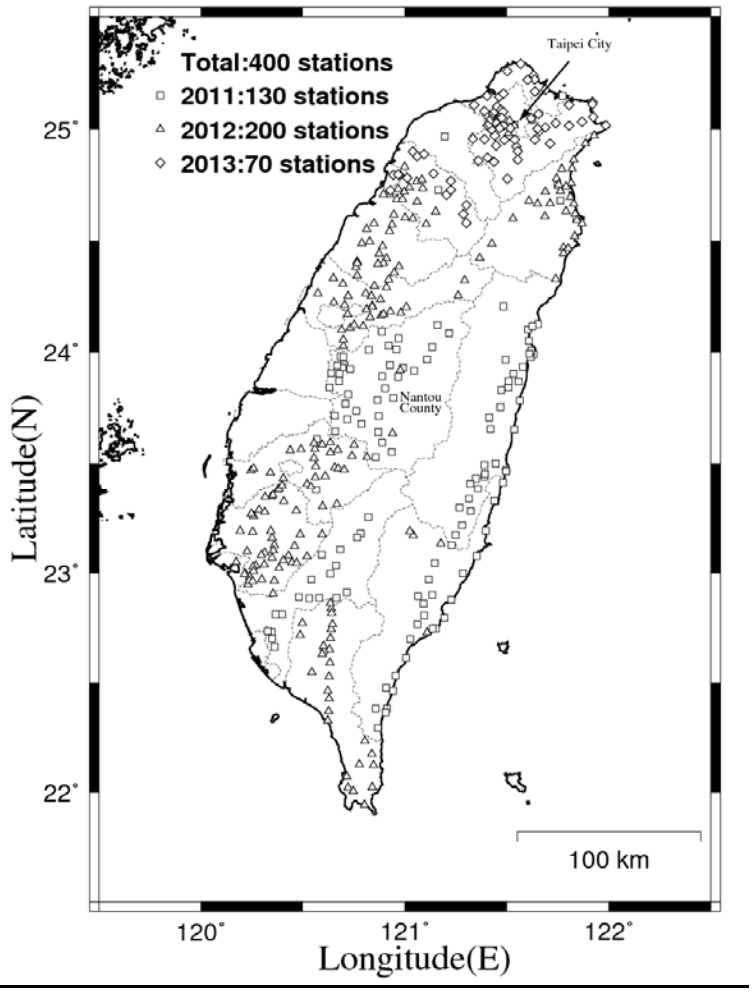


Summary for currently RRS

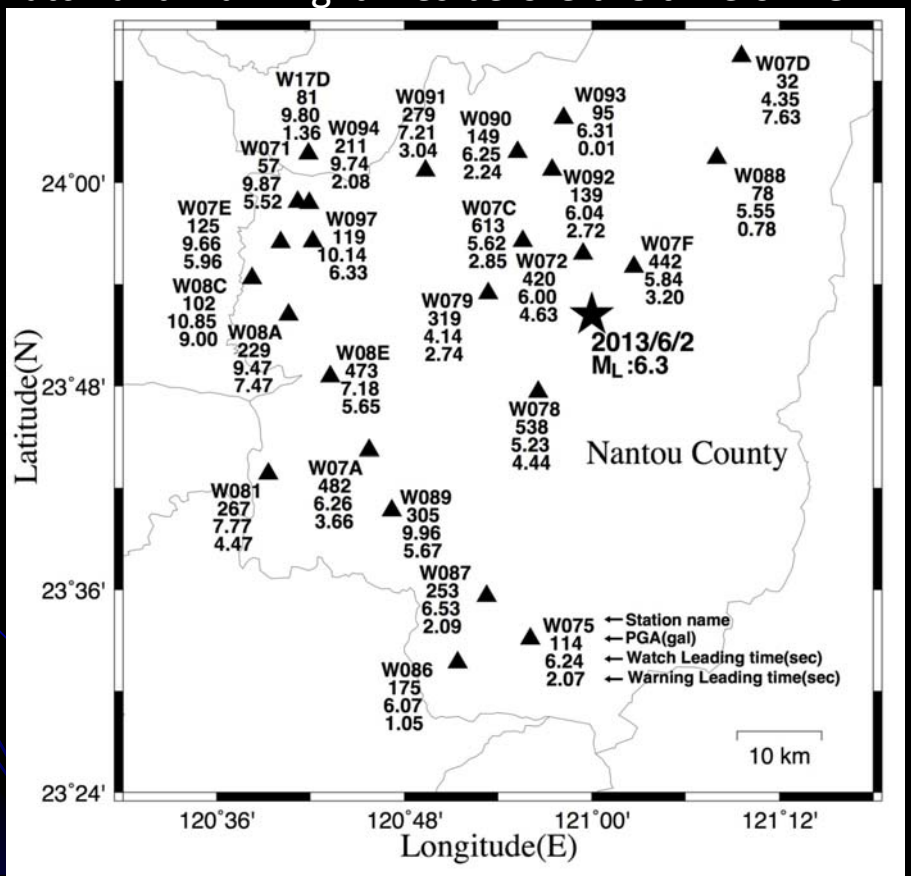
- One minute – hypocenter, M_L, intensities
- Two minutes - large event magnitude (M_{ew}), shake maps and potential damage assessment

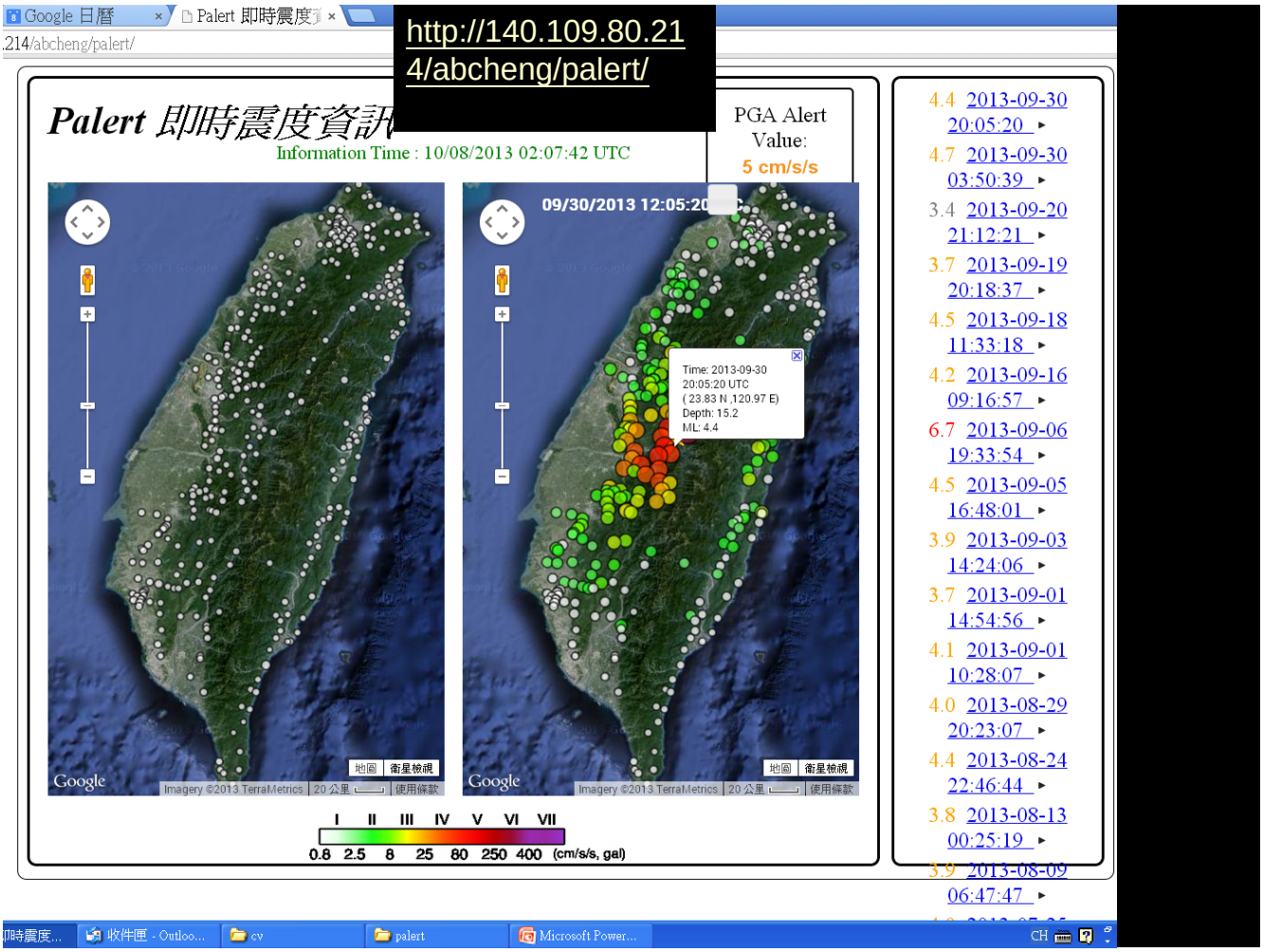
Palert system, for both onsite & regional early warning purposes, P-wave warning before S-waves
http://140.109.80.214/abcheng/palert/

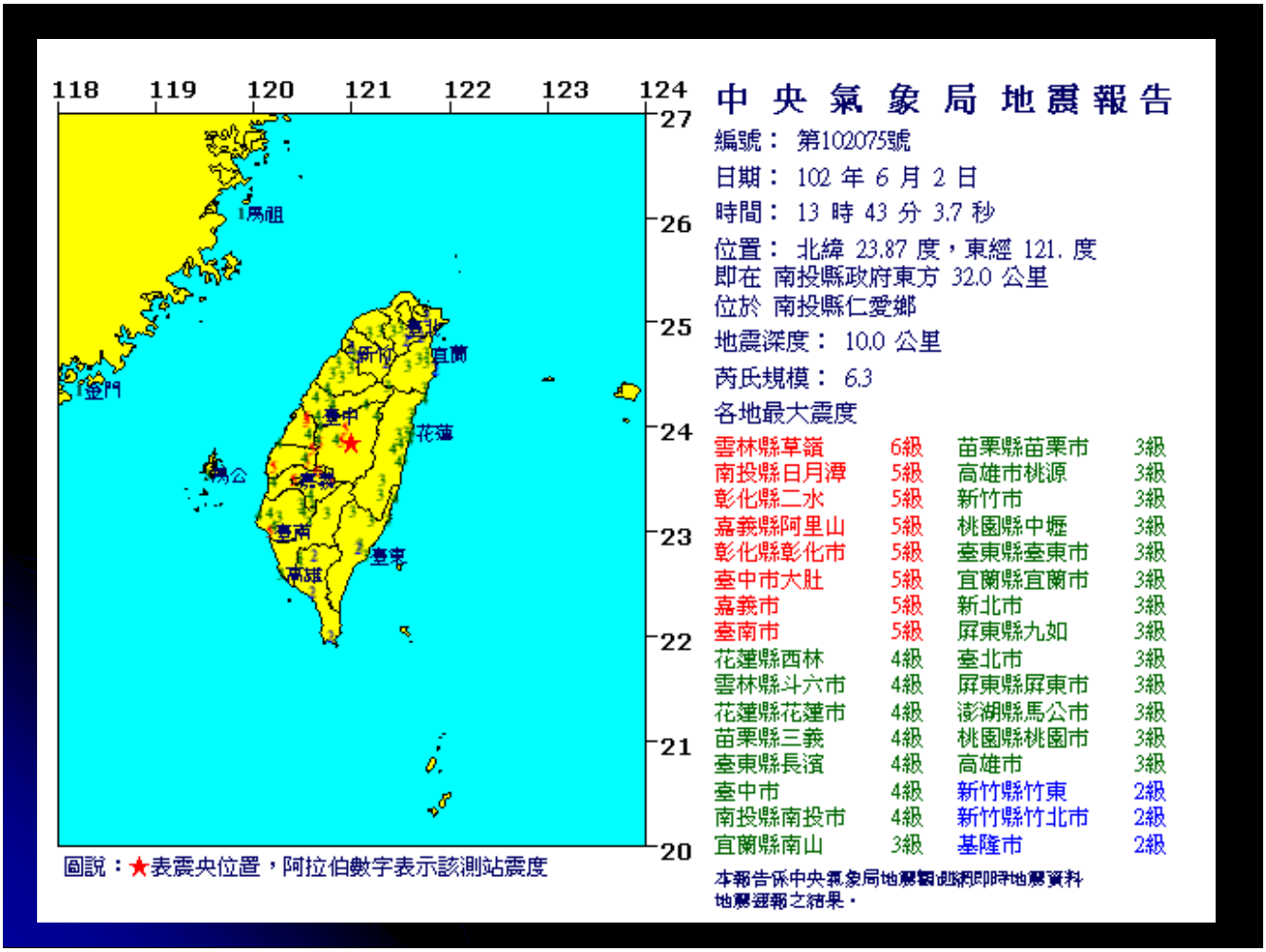
台灣大學地質系

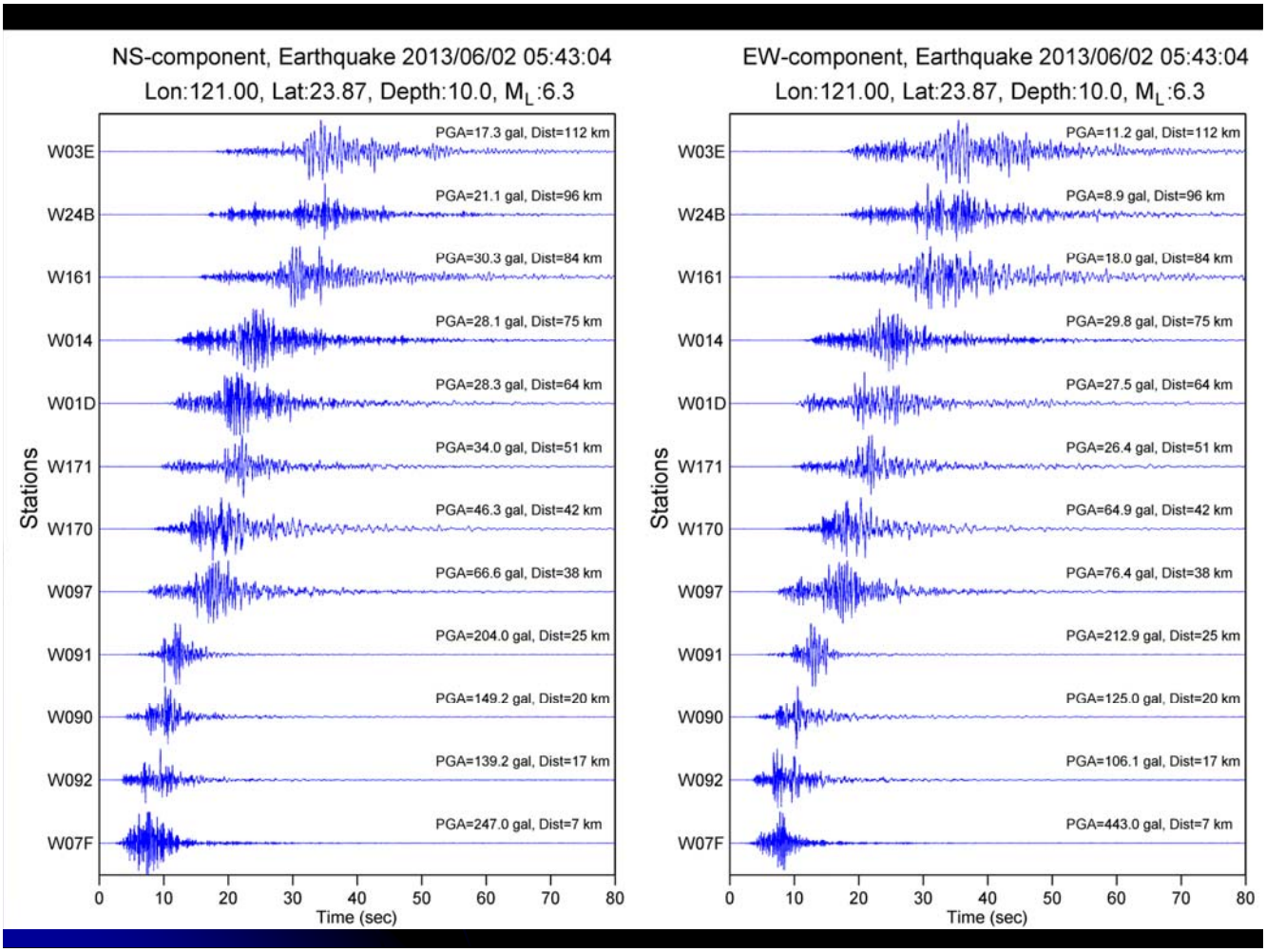


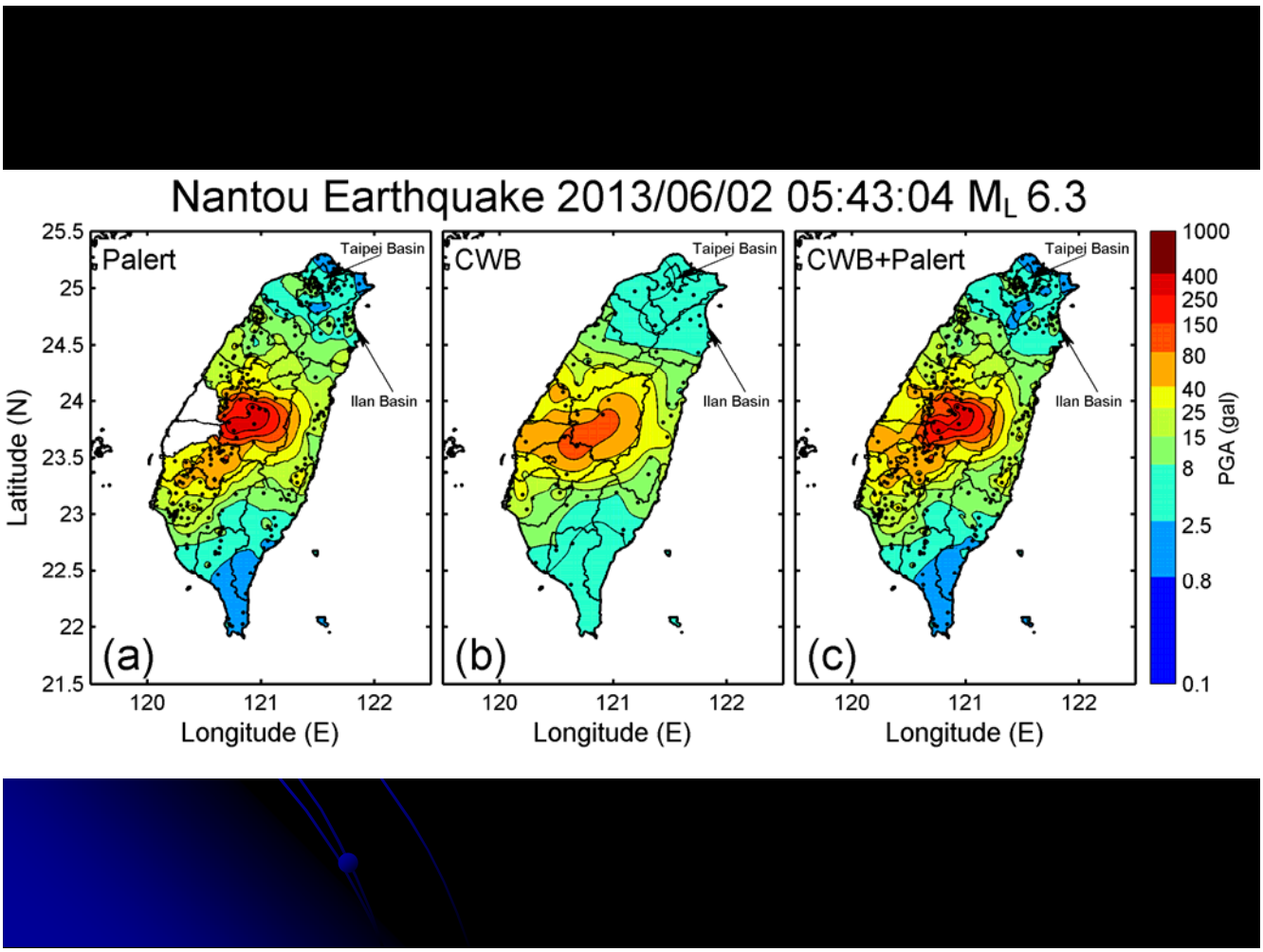
Results from 2013/06/02 Nantou Earthquake, Figure shows each station Palert's watch and warning times before the time of PGA.

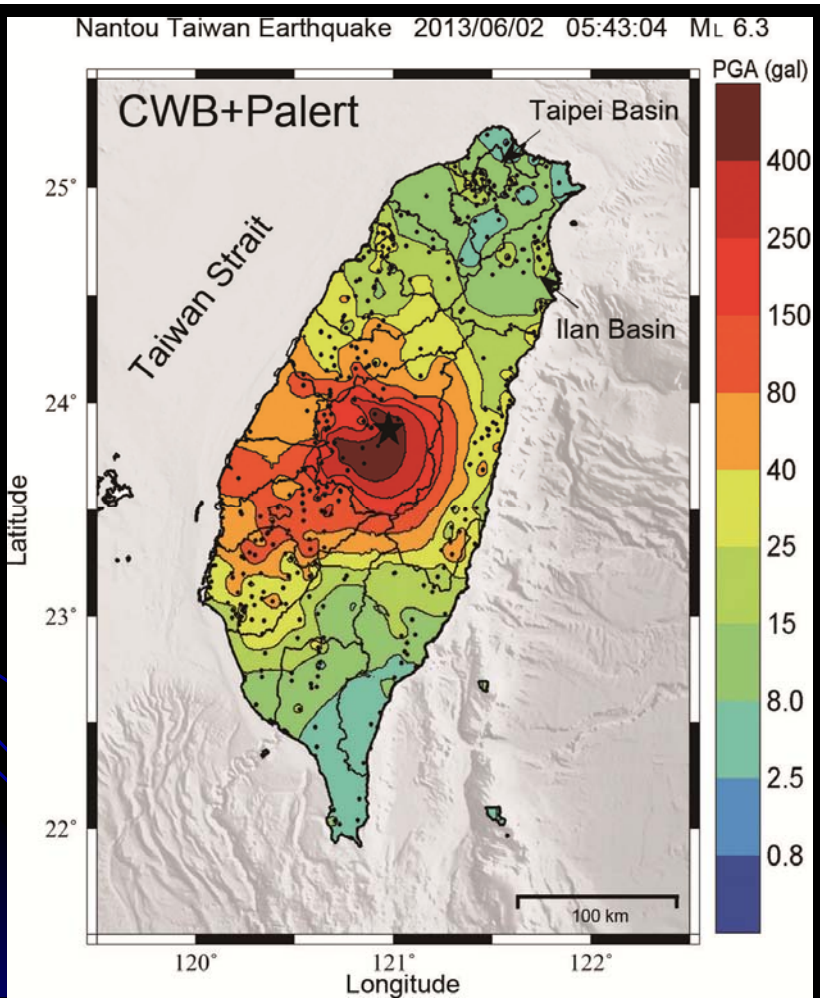



http://140.109.80.214/abcheng/palert/
Palert 即時震度資訊
Information Time : 10/08/2013 02:07:42 UTC
PGA Alert Value:
5 cm/s/s
09/30/2013 12:05:20
Time: 2013-09-30 20:05:20 UTC
(23.83 N ,120.97 E)
Depth: 15.2
ML: 4.4
I II III IV V VI VII
0.8 2.5 8 25 80 250 400 (cm/s/s, gal)
4.4 2013-09-30 20:05:20
4.7 2013-09-30 03:50:39
3.4 2013-09-20 21:12:21
3.7 2013-09-19 20:18:37
4.5 2013-09-18 11:33:18
4.2 2013-09-16 09:16:57
6.7 2013-09-06 19:33:54
4.5 2013-09-05 16:48:01
3.9 2013-09-03 14:24:06
3.7 2013-09-01 14:54:56
4.1 2013-09-01 10:28:07
4.0 2013-08-29 20:23:07
4.4 2013-08-24 22:46:44
3.8 2013-08-13 00:25:19
3.9 2013-08-09 06:47:47


118 119 120 121 122 123 124
27 26 25 24 23 22 21 20
馬祖
金門
臺北
宜蘭
臺中
花蓮
澎湖
臺南
臺東
南投
圖說：★表震央位置，阿拉伯數字表示該測站震度
中 央 氣 象 局 地 震 報 告
編號： 第102075號
日期： 102 年 6 月 2 日
時間： 13 時 43 分 3.7 秒
位置： 北緯 23.87 度，東經 121. 度
即在 南投縣政府東方 32.0 公里
位於 南投縣仁愛鄉
地震深度： 10.0 公里
芮氏規模： 6.3
各地最大震度
雲林縣草嶺 6級
南投縣日月潭 5級
彰化縣二水 5級
嘉義縣阿里山 5級
彰化縣彰化市 5級
臺中市大肚 5級
嘉義市 5級
臺南市 5級
花蓮縣西林 4級
雲林縣斗六市 4級
花蓮縣花蓮市 4級
苗栗縣三義 4級
臺東縣長濱 4級
臺中市 4級
南投縣南投市 4級
宜蘭縣南山 3級
苗栗縣苗栗市 3級
高雄市桃源 3級
新竹市 3級
桃園縣中壢 3級
臺東縣臺東市 3級
宜蘭縣宜蘭市 3級
新北市 3級
屏東縣九如 3級
臺北市 3級
屏東縣屏東市 3級
澎湖縣馬公市 3級
桃園縣桃園市 3級
高雄市 3級
新竹縣竹東 2級
新竹縣竹北市 2級
基隆市 2級
本報告係中央氣象局地震觀測網即時地震資料
地震經報之結果。

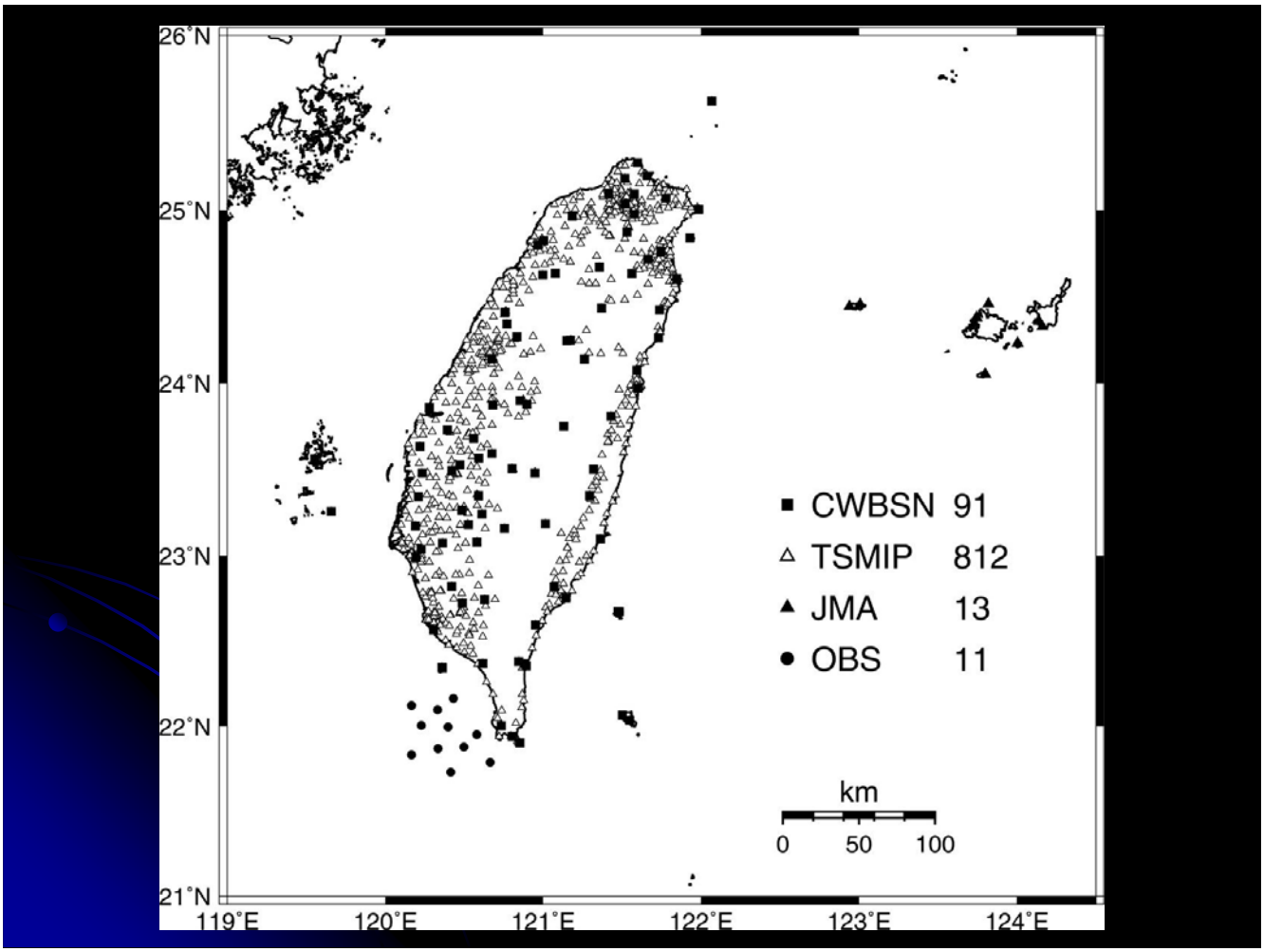

NS-component, Earthquake 2013/06/02 05:43:04
Lon:121.00, Lat:23.87, Depth:10.0, M_L:6.3
EW-component, Earthquake 2013/06/02 05:43:04
Lon:121.00, Lat:23.87, Depth:10.0, M_L:6.3
Stations
W03E
W24B
W161
W014
W01D
W171
W170
W097
W091
W090
W092
W07F
PGA=17.3 gal, Dist=112 km
PGA=21.1 gal, Dist=96 km
PGA=30.3 gal, Dist=84 km
PGA=28.1 gal, Dist=75 km
PGA=28.3 gal, Dist=64 km
PGA=34.0 gal, Dist=51 km
PGA=46.3 gal, Dist=42 km
PGA=66.6 gal, Dist=38 km
PGA=204.0 gal, Dist=25 km
PGA=149.2 gal, Dist=20 km
PGA=139.2 gal, Dist=17 km
PGA=247.0 gal, Dist=7 km
PGA=11.2 gal, Dist=112 km
PGA=8.9 gal, Dist=96 km
PGA=18.0 gal, Dist=84 km
PGA=29.8 gal, Dist=75 km
PGA=27.5 gal, Dist=64 km
PGA=26.4 gal, Dist=51 km
PGA=64.9 gal, Dist=42 km
PGA=76.4 gal, Dist=38 km
PGA=212.9 gal, Dist=25 km
PGA=125.0 gal, Dist=20 km
PGA=106.1 gal, Dist=17 km
PGA=443.0 gal, Dist=7 km
0 10 20 30 40 50 60 70 80
Time (sec)

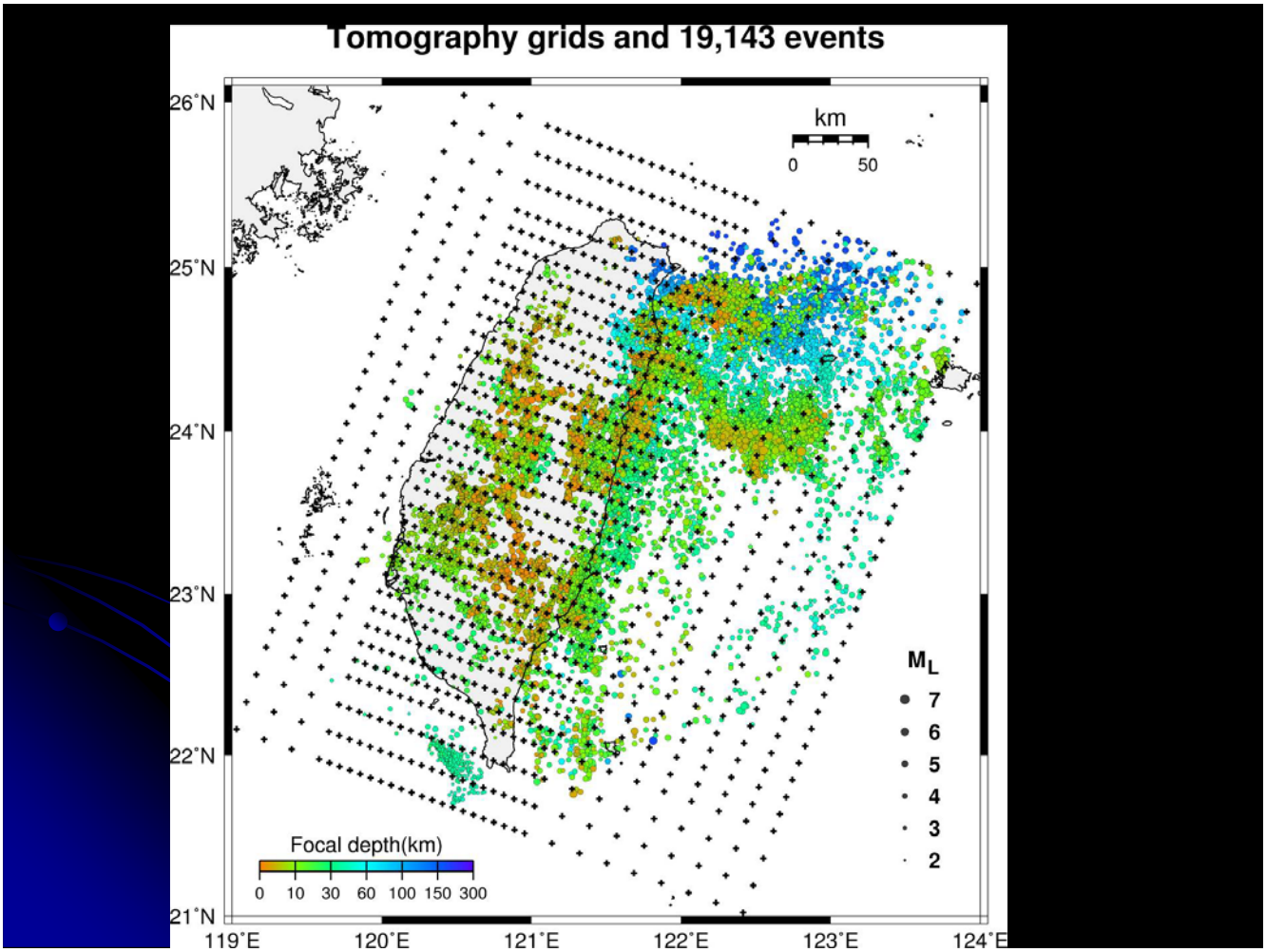

Nantou Earthquake 2013/06/02 05:43:04 M_L 6.3
Palert
CWB
CWB+Palert
Taipei Basin
Ilan Basin
(a)
(b)
(c)
Latitude (N)
25.5
25
24.5
24
23.5
23
22.5
22
21.5
120 121 122
Longitude (E)
PGA (gal)
1000
400
250
150
80
40
25
15
8
2.5
0.8
0.1



Earthquake data used for Seismotectonics

- Local tomography (structures of Vp & Vp/Vs)
- Focal mechanism (stress)
- Relocated Seismicity (Fault structures)


26°N
25°N
24°N
23°N
22°N
21°N
119°E
120°E
121°E
122°E
123°E
124°E
CWBSN 91
TSMIP 812
JMA 13
OBS 11
km
0 50 100

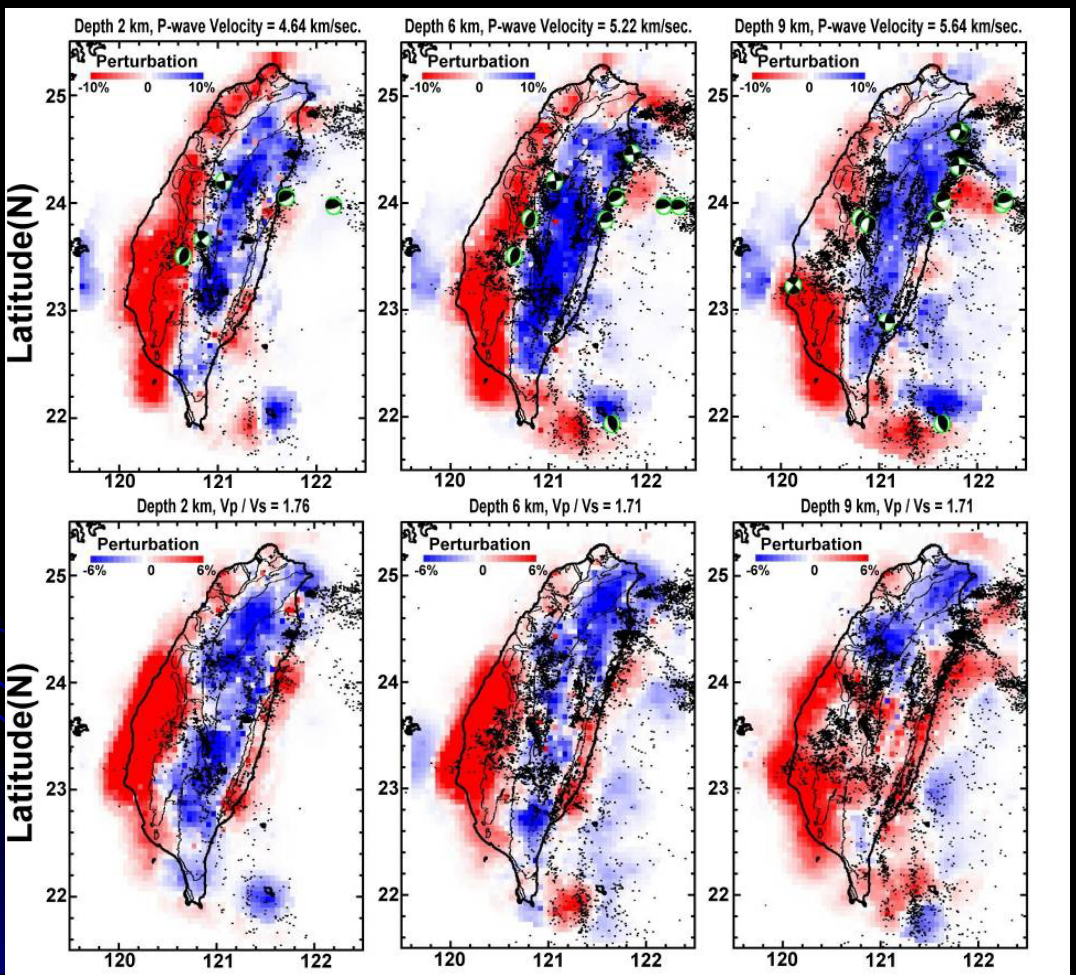

Tomography grids and 19,143 events
26°N
25°N
24°N
23°N
22°N
21°N
119°E
120°E
121°E
122°E
123°E
124°E
km
0 50
M_L
7
6
5
4
3
2
Focal depth(km)
0 10 30 60 100 150 300

Vp & Vp/Vs results

Wu et al. (JGR, 2007)

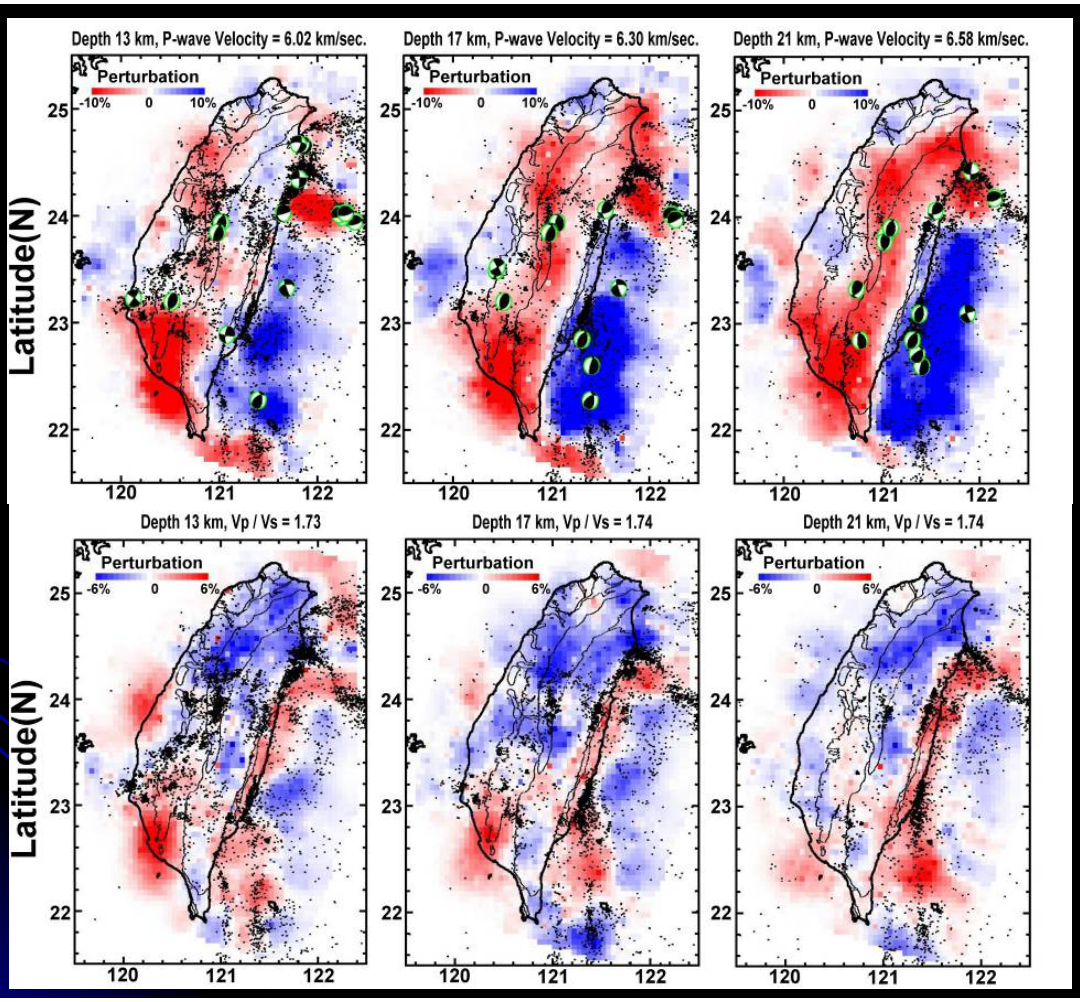
Vp

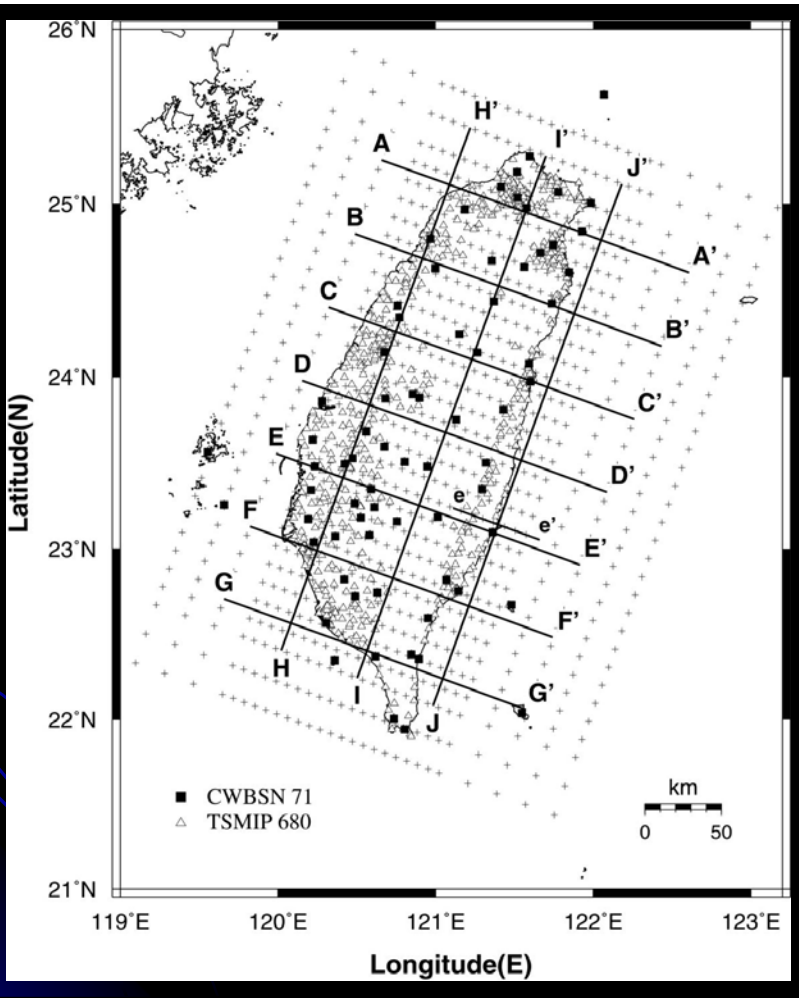
Vp/Vs

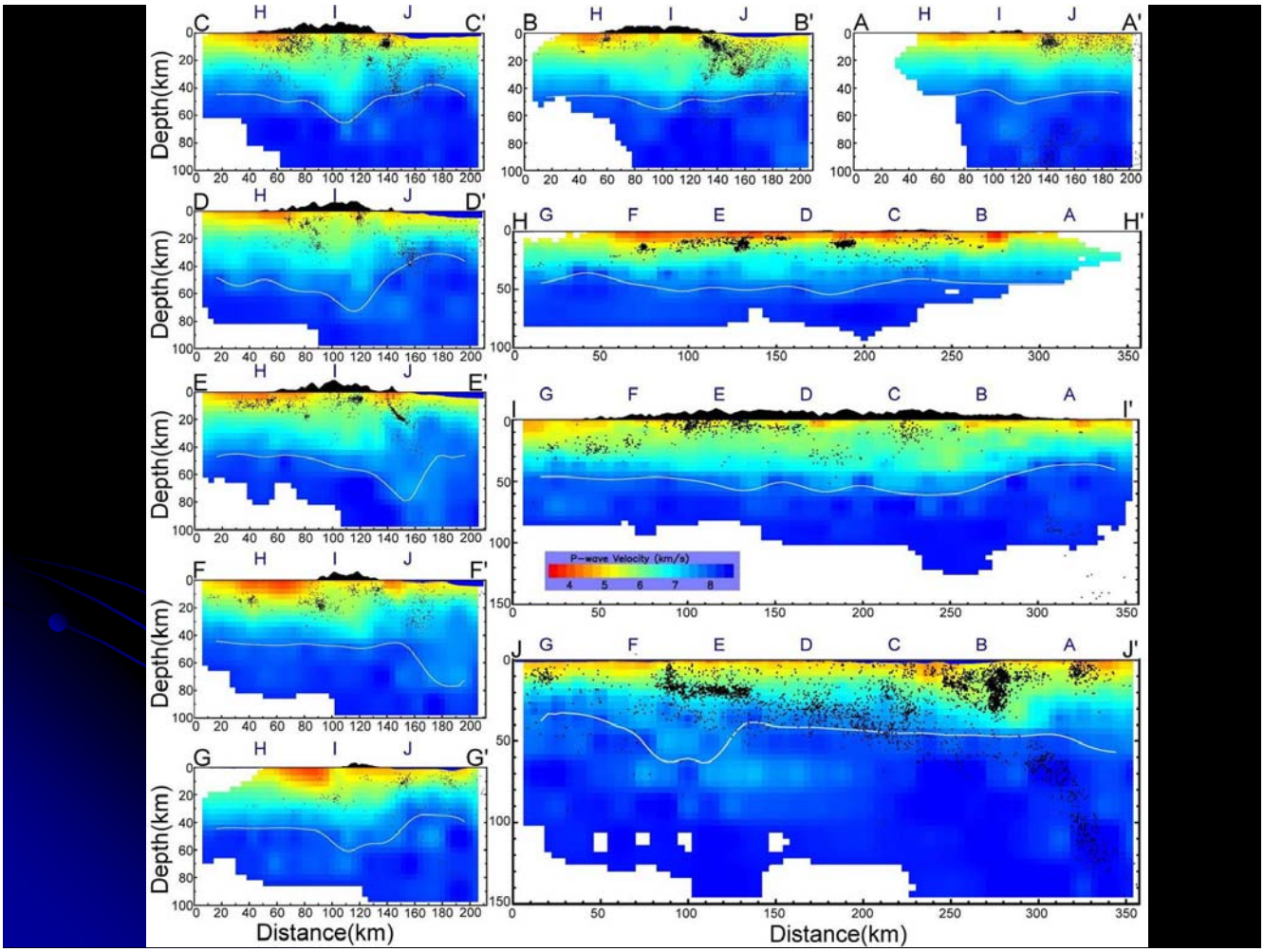


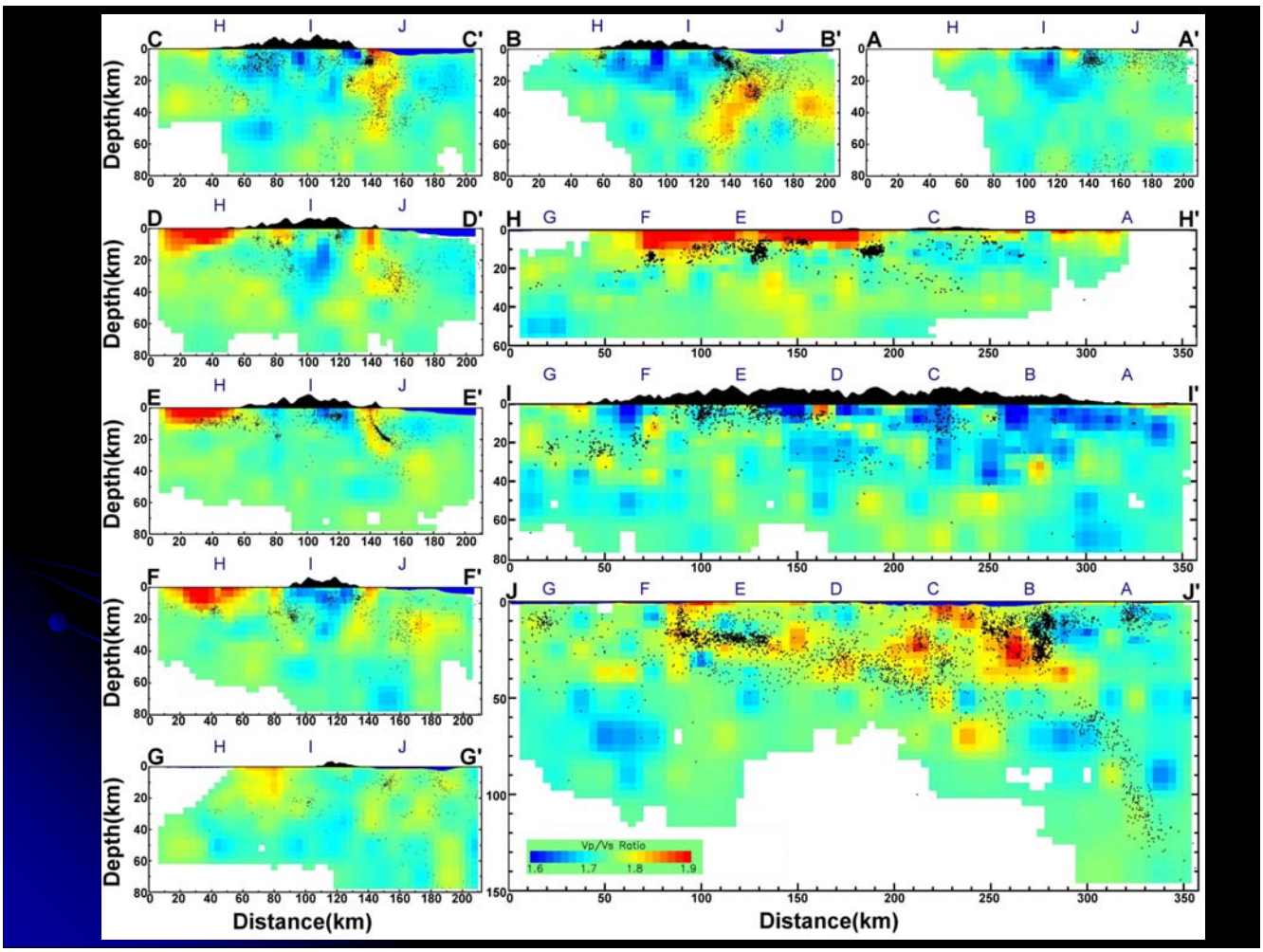
Vp

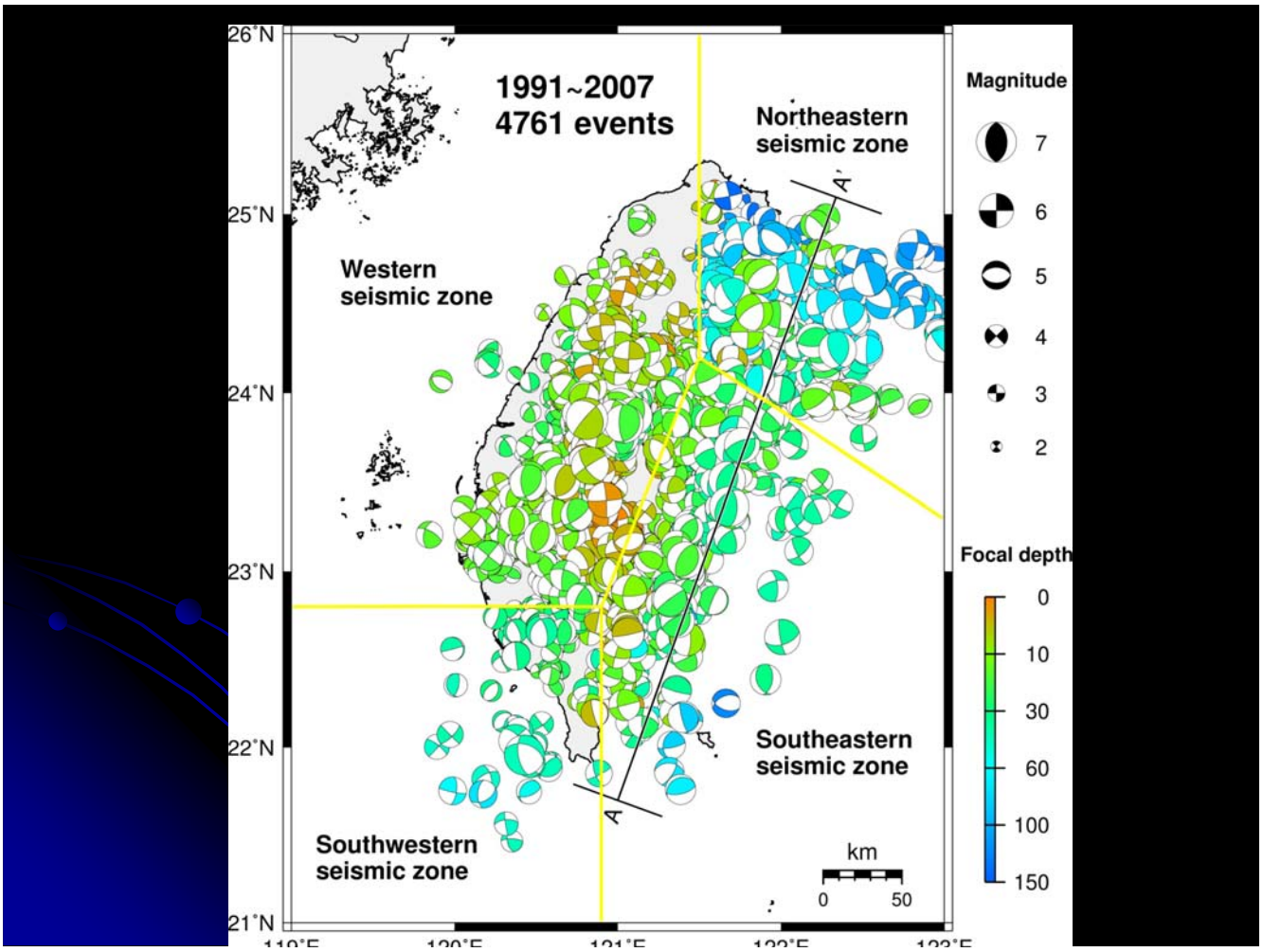
Vp/Vs

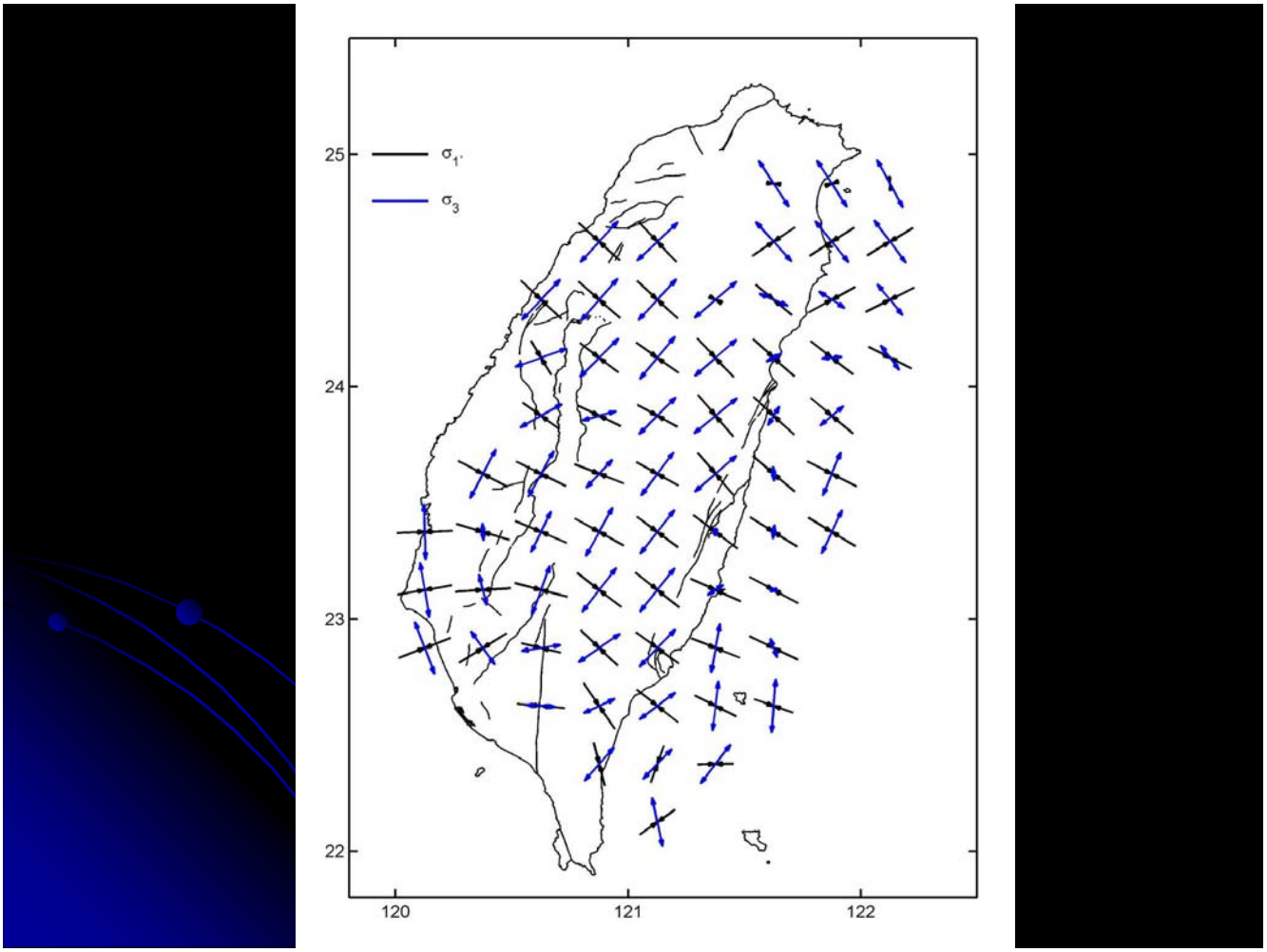

Depth 13 km, P-wave Velocity = 6.02 km/sec.
Depth 17 km, P-wave Velocity = 6.30 km/sec.
Depth 21 km, P-wave Velocity = 6.58 km/sec.
Perturbation
-10%
0
10%
Depth 13 km, Vp / Vs = 1.73
Depth 17 km, Vp / Vs = 1.74
Depth 21 km, Vp / Vs = 1.74
-6%
6%
Latitude(N)
25
24
23
22
120
121
122

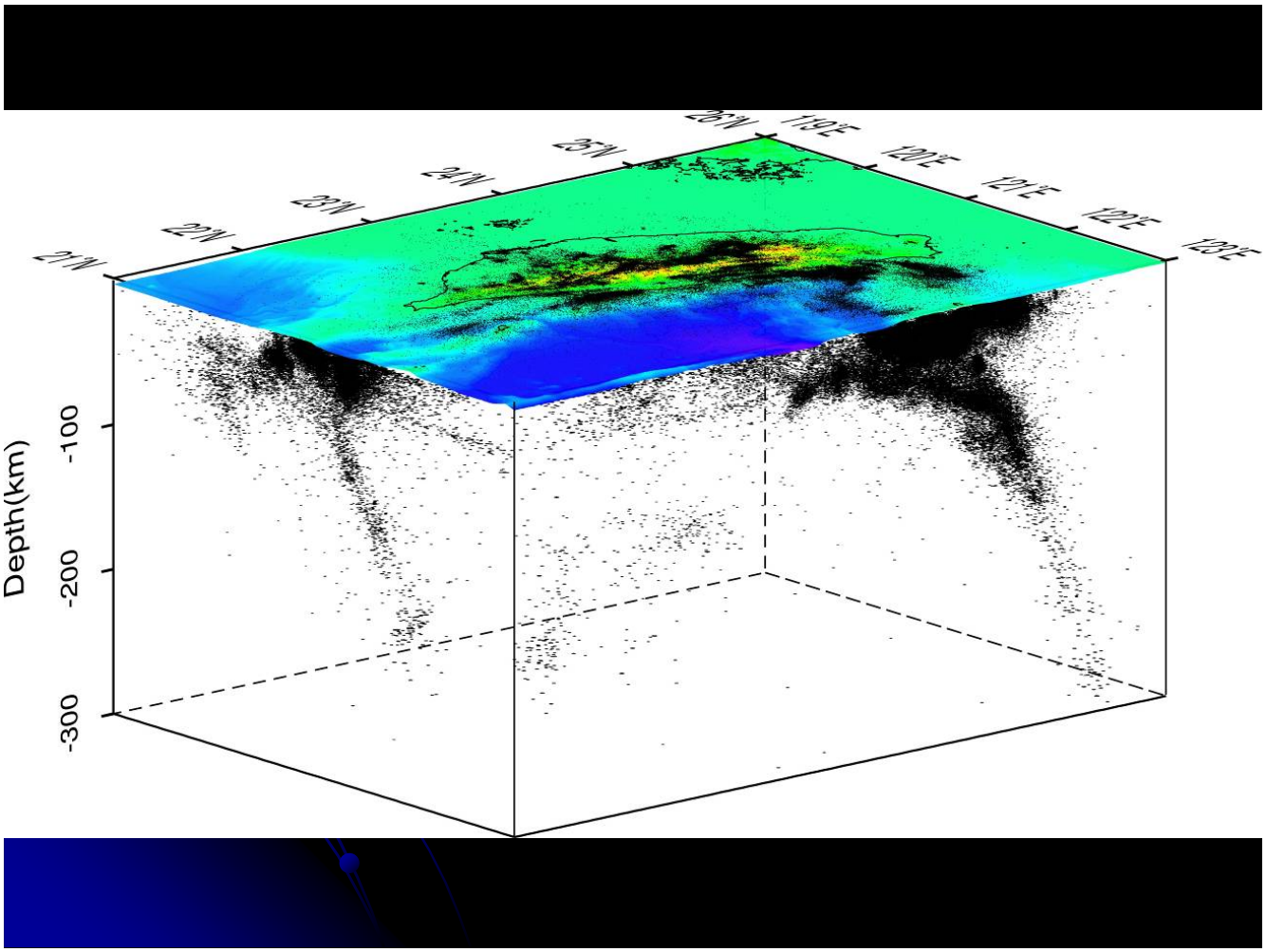

26°N
25°N
24°N
23°N
22°N
21°N
119°E
120°E
121°E
122°E
123°E
Latitude(N)
Longitude(E)
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
H
H'
I
I'
J
J'
e
e'
CWBSN 71
TSMIP 680
km
0
50

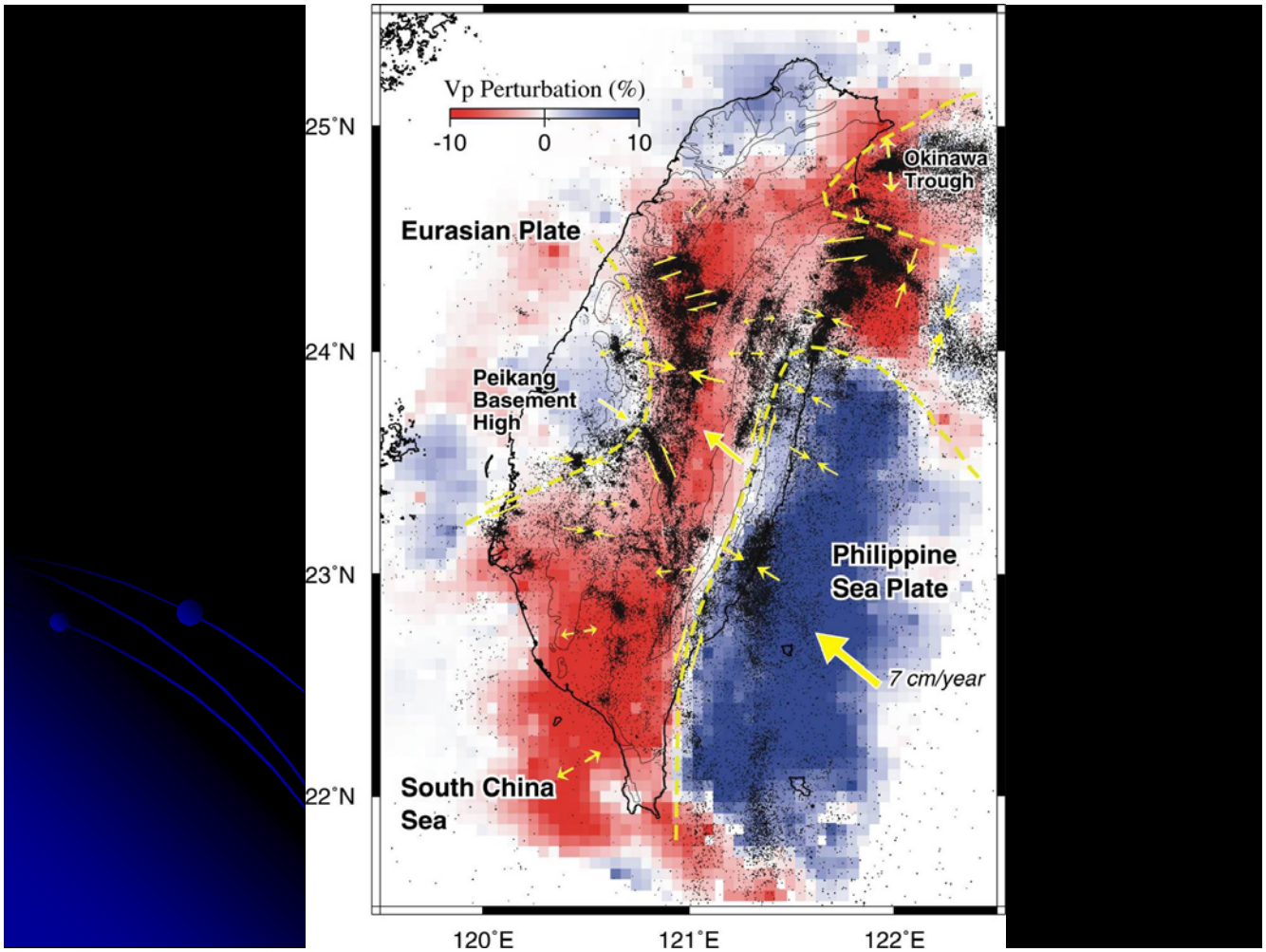

C H I J C'
B H I J B'
A H I J A'
D H I J D'
H G F E D C B A H'
E H I J E'
G F E D C B A I'
F H I J F'
J G F E D C B A J'
G H I J G'
P-wave Velocity (km/s)
4 5 6 7 8
Depth(km)
Distance(km)

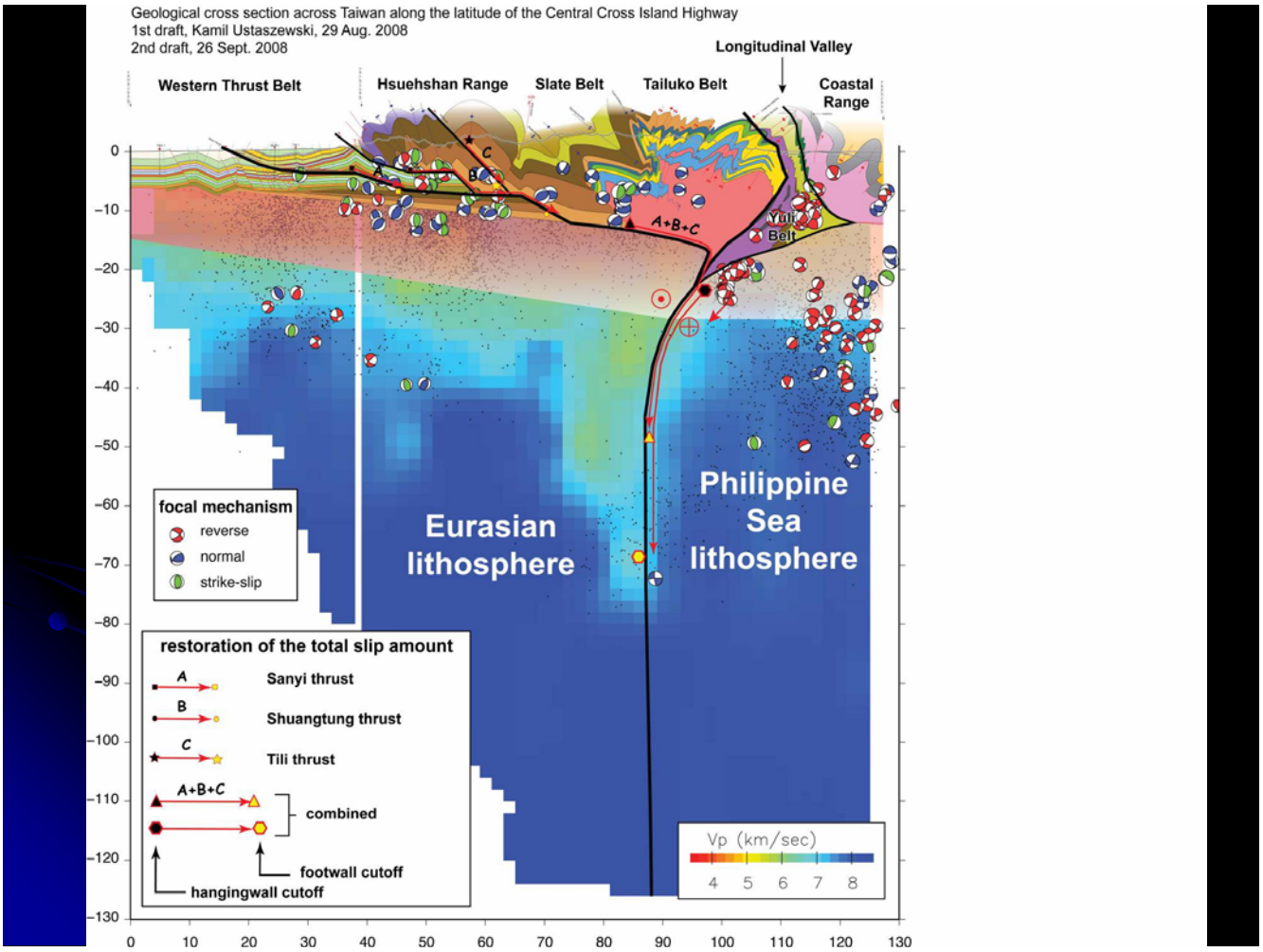

C H I J C'
B H I J B'
A H I J A'
D H I J D'
H G F E D C B A H'
E H I J E'
I G F E D C B A I'
F H I J F'
J G F E D C B A J'
G H I J G'
Vp/Vs Ratio
1.6 1.7 1.8 1.9
Depth(km)
Distance(km)

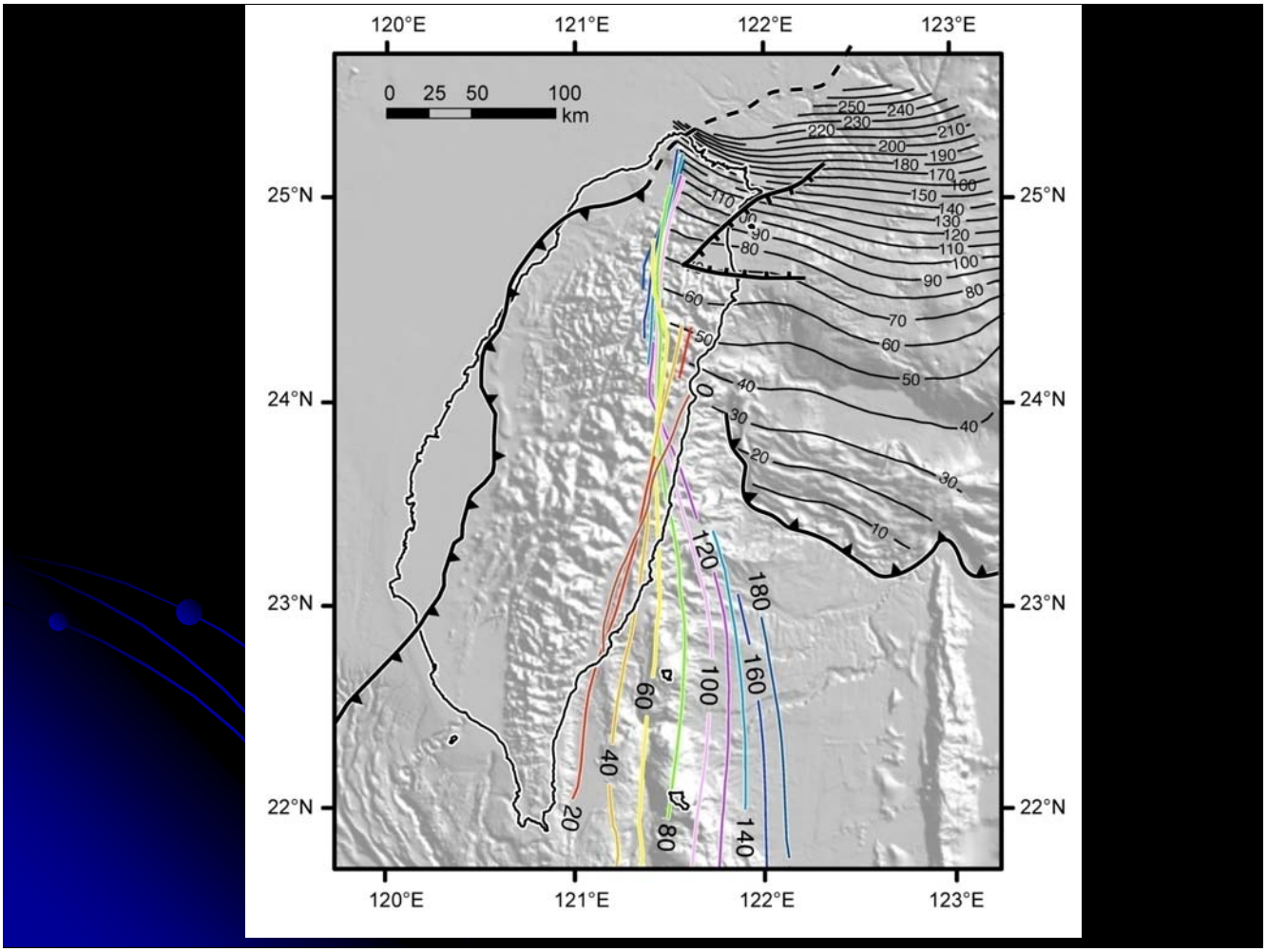

1991~2007
4761 events
Northeastern
seismic zone
Western
seismic zone
Southeastern
seismic zone
Southwestern
seismic zone
A
A'
Magnitude
7
6
5
4
3
2
Focal depth
0
10
30
60
100
150
km
0
50
26°N
25°N
24°N
23°N
22°N
21°N

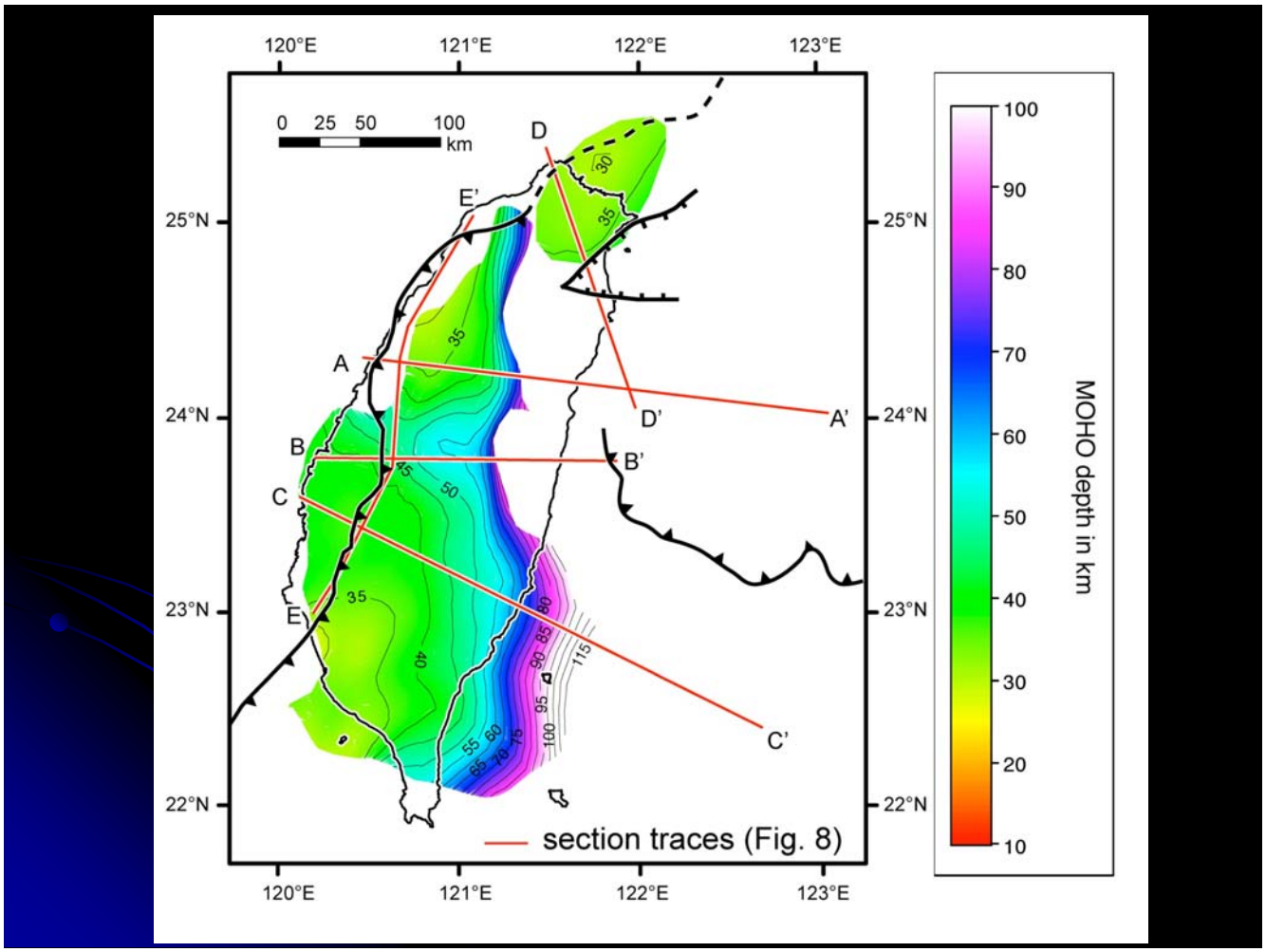

σ1
σ3
25
24
23
22
120
121
122

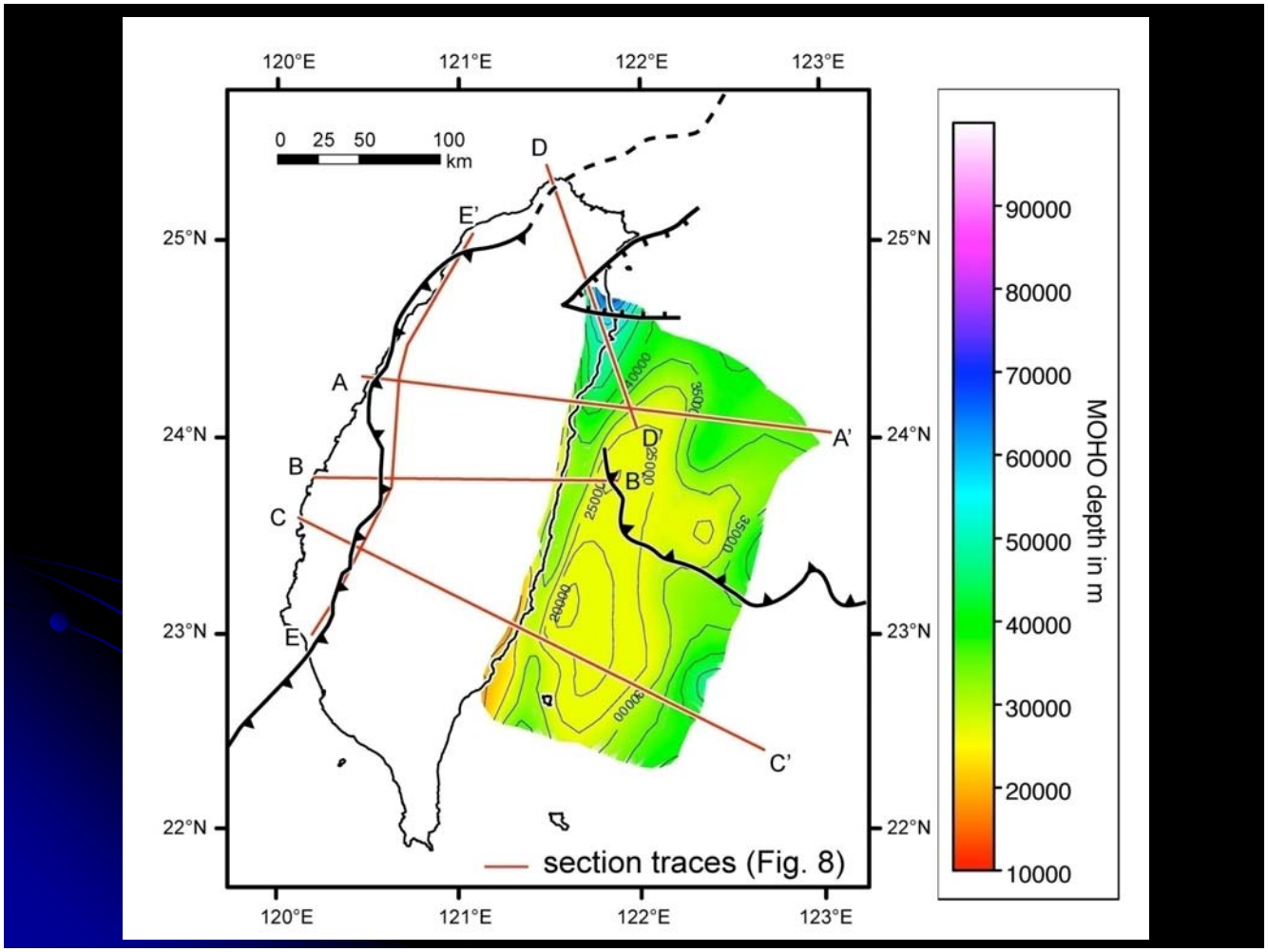

Depth(km)
-100
-200
-300
21°N
22°N
23°N
24°N
25°N
26°N
119°E
120°E
121°E
122°E
123°E

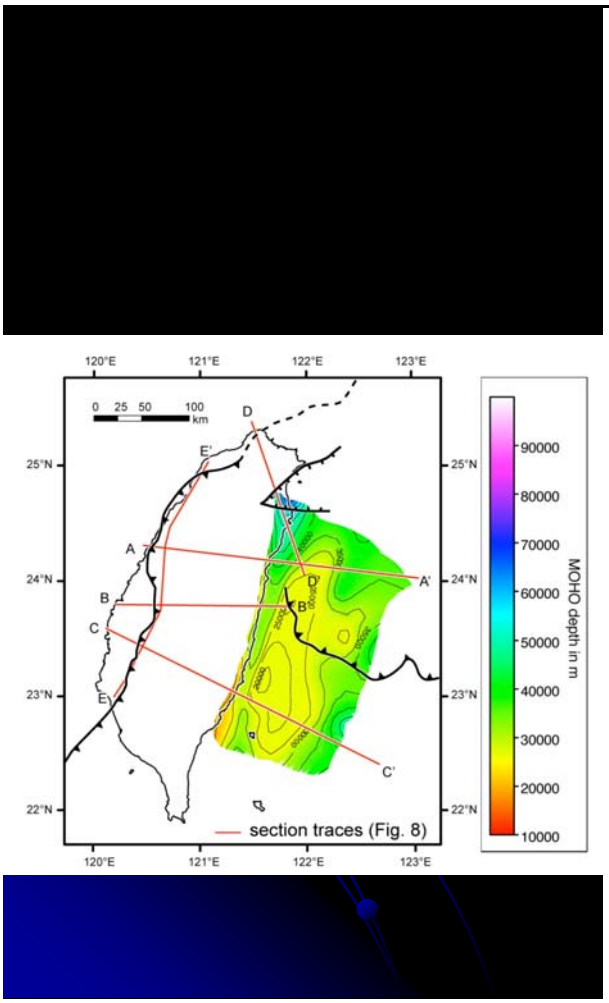

Vp Perturbation (%)
-10
0
10
Okinawa Trough
Eurasian Plate
Peikang Basement High
Philippine Sea Plate
7 cm/year
South China Sea
25°N
24°N
23°N
22°N
120°E
121°E
122°E

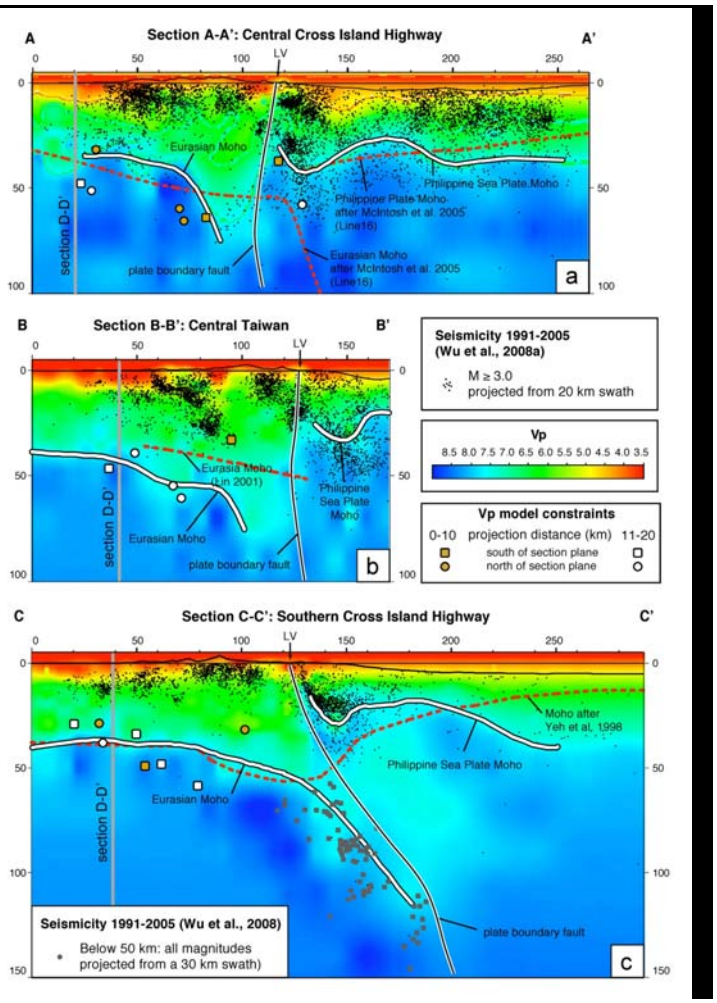

Geological cross section across Taiwan along the latitude of the Central Cross Island Highway
1st draft, Kamil Ustaszewski, 29 Aug. 2008
2nd draft, 26 Sept. 2008
Longitudinal Valley
Western Thrust Belt
Hsuehshan Range
Slate Belt
Tailuko Belt
Coastal Range
A
B
C
A+B+C
Yuli Belt
Eurasian lithosphere
Philippine Sea lithosphere
focal mechanism
reverse
normal
strike-slip
restoration of the total slip amount
Sanyi thrust
Shuangtung thrust
Tili thrust
combined
footwall cutoff
hangingwall cutoff
Vp (km/sec)
4 5 6 7 8

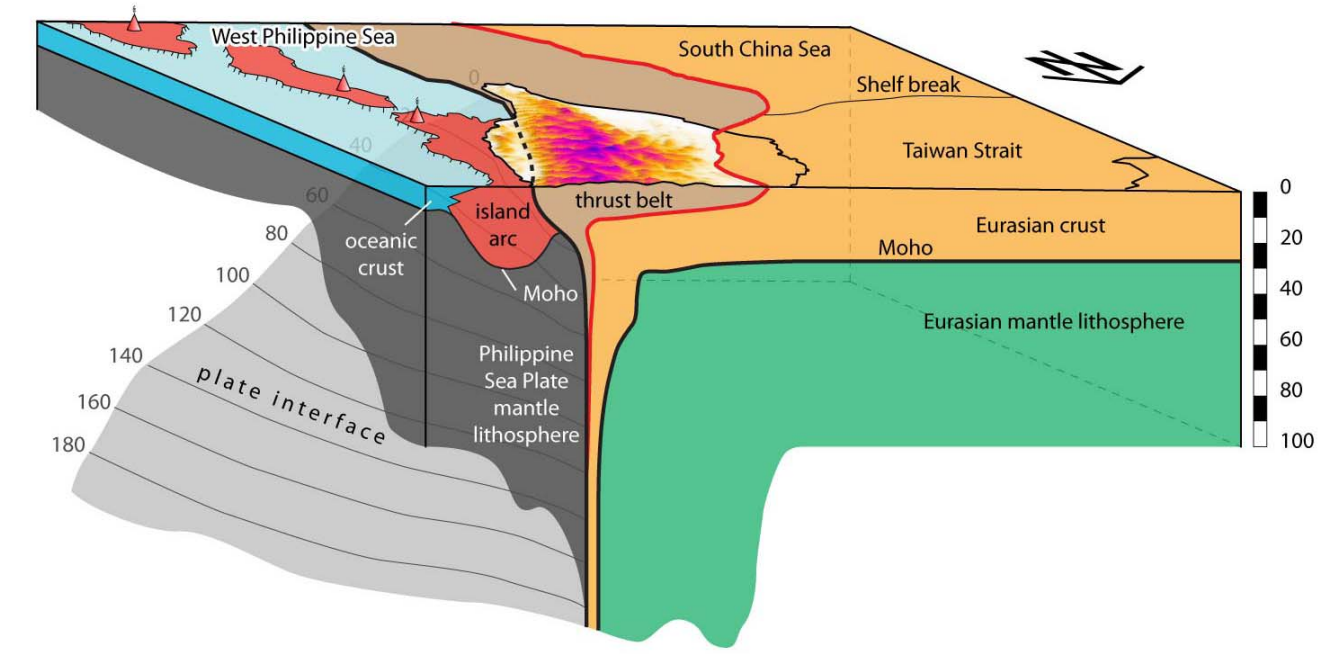

120°E
121°E
122°E
123°E
25°N
24°N
23°N
22°N
0 25 50 100 km


120°E
121°E
122°E
123°E
25°N
24°N
23°N
22°N
0 25 50 100 km
A
A'
B
B'
C
C'
D
D'
E
E'
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
115
section traces (Fig. 8)
MOHO depth in km
100
90
80
70
60
50
40
30
20
10


120°E
121°E
122°E
123°E
25°N
24°N
23°N
22°N
0 25 50 100 km
A
A'
B
B'
C
C'
D
D'
E
E'
section traces (Fig. 8)
MOHO depth in m
90000
80000
70000
60000
50000
40000
30000
20000
10000


120°E
121°E
122°E
123°E
25°N
24°N
23°N
22°N
0 25 50 100 km
A
A'
B
B'
C
C'
D
D'
E
E'
section traces (Fig. 8)
MOHO depth in m
90000
80000
70000
60000
50000
40000
30000
20000
10000


A
Section A-A': Central Cross Island Highway
A'
LV
Eurasian Moho
Philippine Sea Plate Moho
Philippine Plate Moho after McIntosh et al. 2005 (Line16)
Eurasian Moho after McIntosh et al. 2005 (Line16)
plate boundary fault
section D-D'
a
B
Section B-B': Central Taiwan
B'
Eurasian Moho (Lin 2001)
Philippine Sea Plate Moho
Eurasian Moho
plate boundary fault
b
Seismicity 1991-2005 (Wu et al., 2008a)
M ≥ 3.0 projected from 20 km swath
Vp
8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5
Vp model constraints
0-10 projection distance (km) 11-20
south of section plane
north of section plane
C
Section C-C': Southern Cross Island Highway
C'
Moho after Yeh et al. 1998
Philippine Sea Plate Moho
Eurasian Moho
plate boundary fault
c
Seismicity 1991-2005 (Wu et al., 2008)
Below 50 km: all magnitudes projected from a 30 km swath)


West Philippine Sea
South China Sea
Shelf break
Taiwan Strait
thrust belt
island arc
oceanic crust
Moho
Eurasian crust
Moho
Eurasian mantle lithosphere
Philippine Sea Plate mantle lithosphere
plate interface
0
40
60
80
100
120
140
160
180
0
20
40
60
80
100

Thanks for your attention