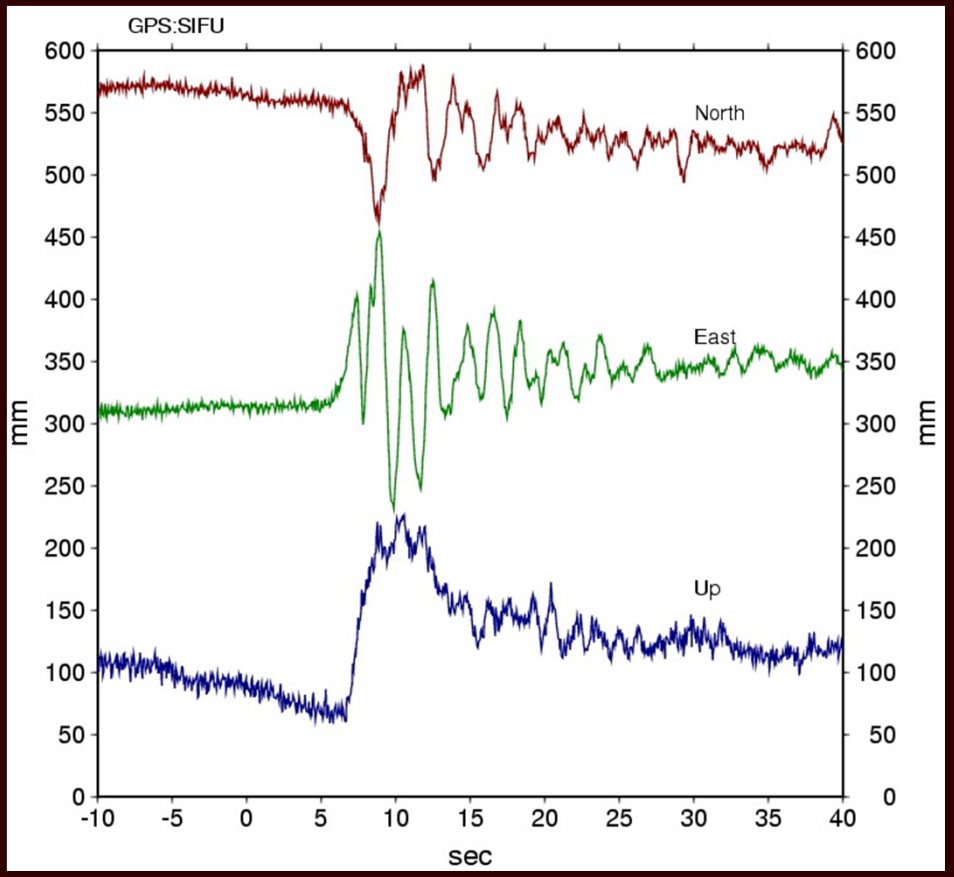
National Cheng Kung University

Nov. 1st, National Central University

Seismic waves from Taiwan dense high-rate GPS network

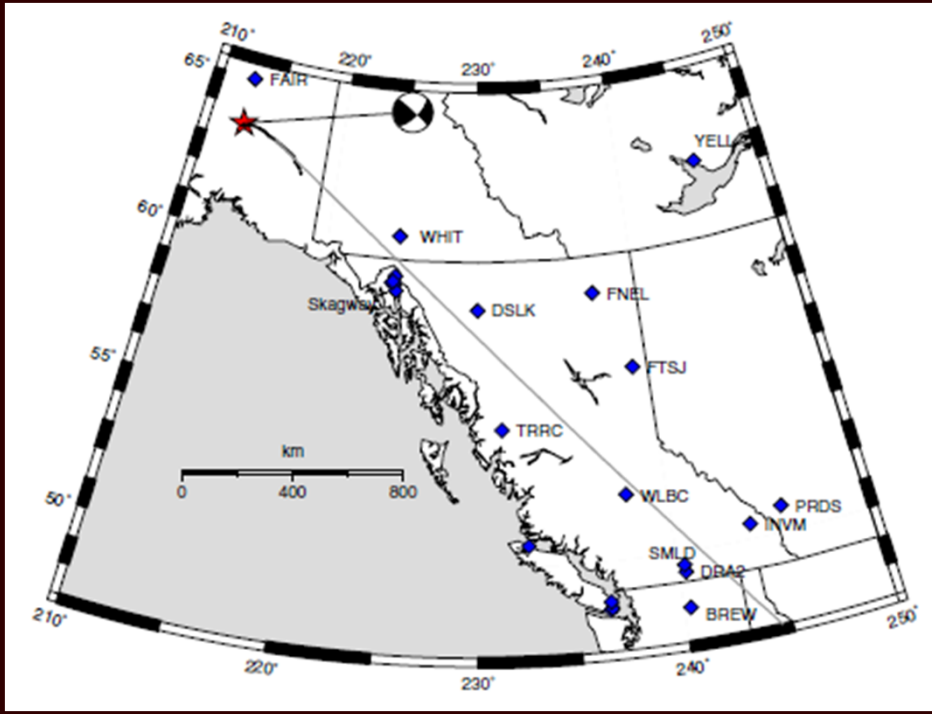


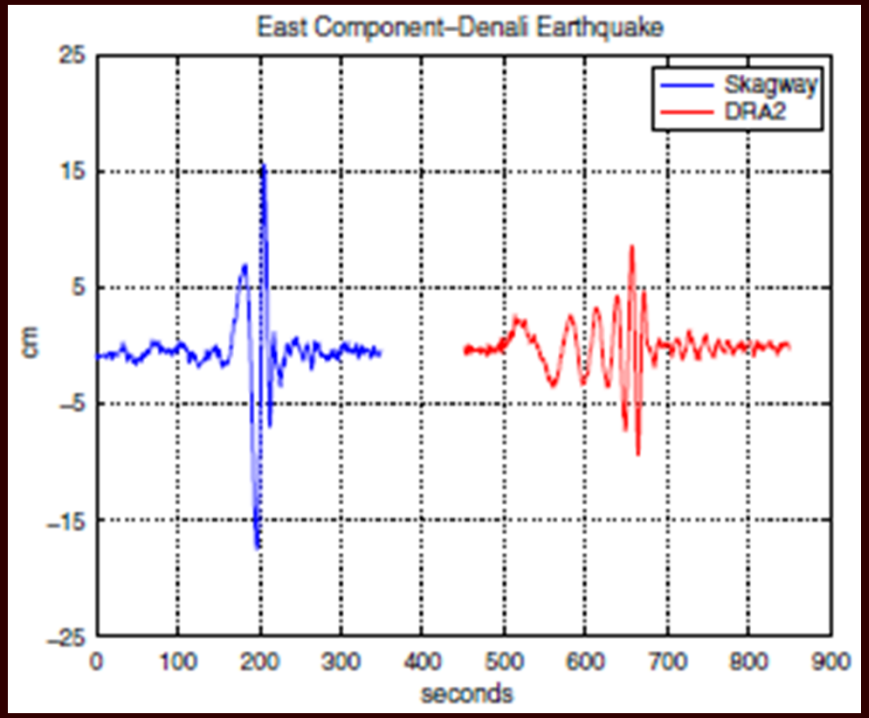
2013/10/31 EQ

Huang-Kai Hung
Department of Earth Sciences

GPS Seismology

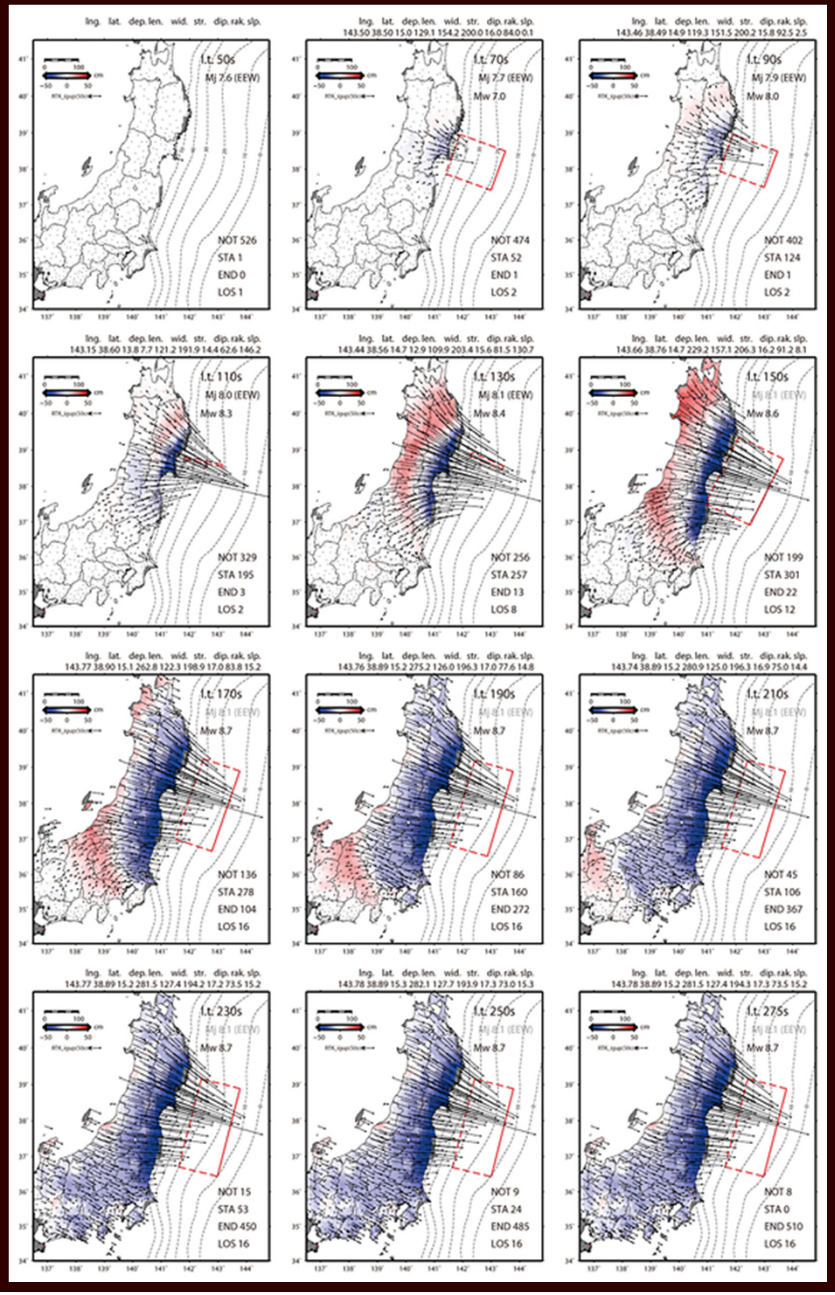
- GPS seismology uses convential geodetic models to analyze GPS data at ***high sampling rates***, such as 1 Hz [Larson, 2009].
- First case: Denali, M7.9, 2002 Nov 3rd



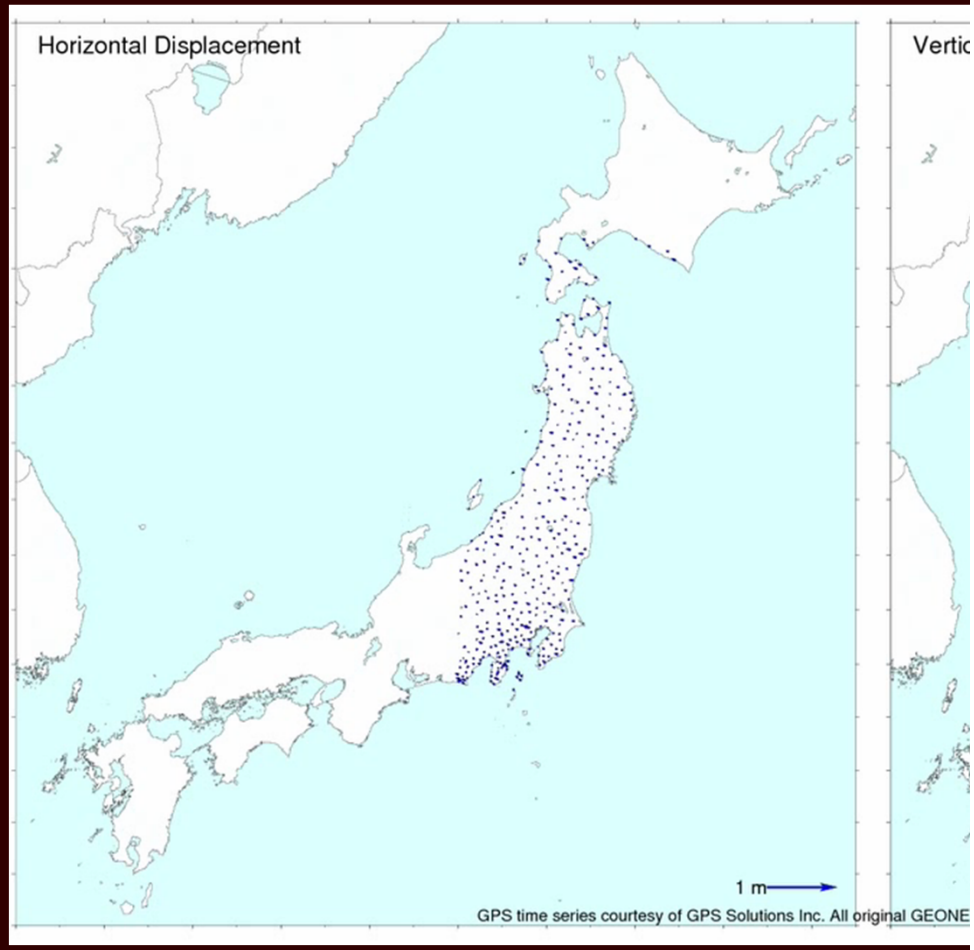


[Larson, 2009]

Tohoku-Oki earthquake - GEONET

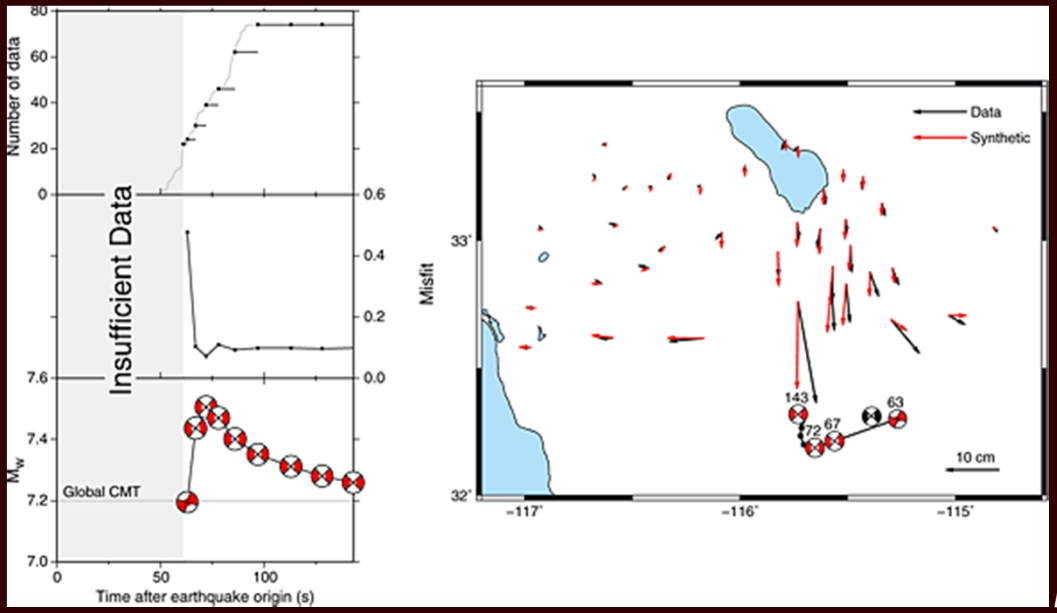


[Ohta et al., 2012]



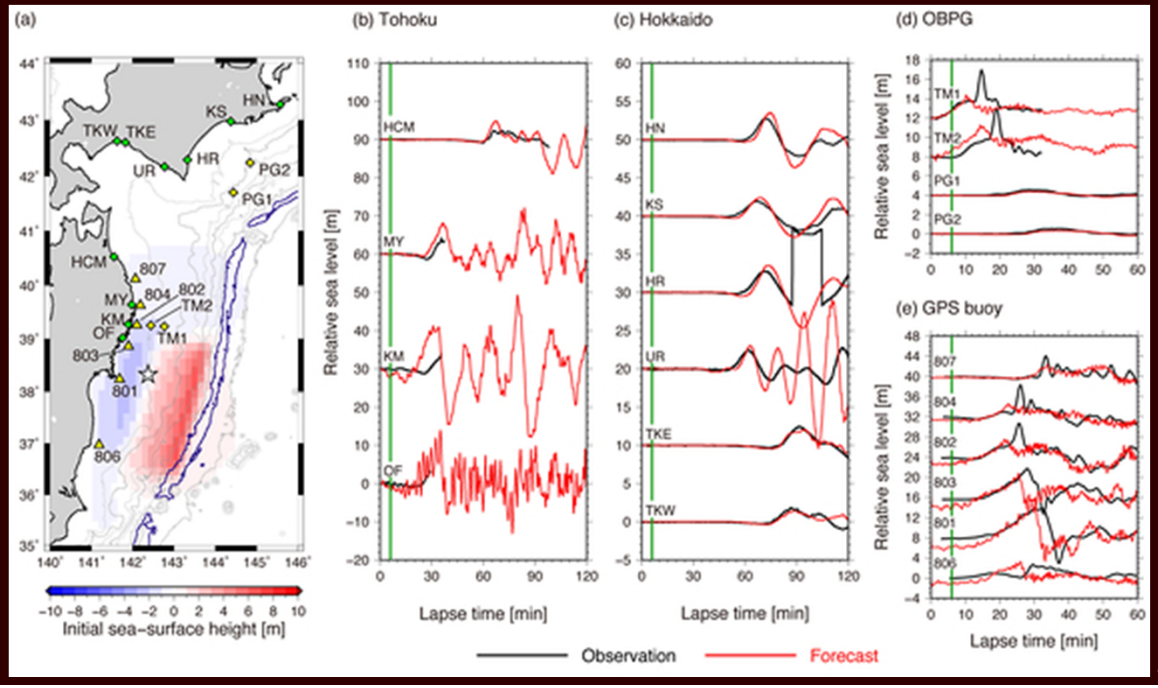
[Grapenthin et al., 2011]

Real-time high-rate GPS applications



Real-time source inversion for El Mayor-Cucapah earthquake

[O'Toole et al., 2012]



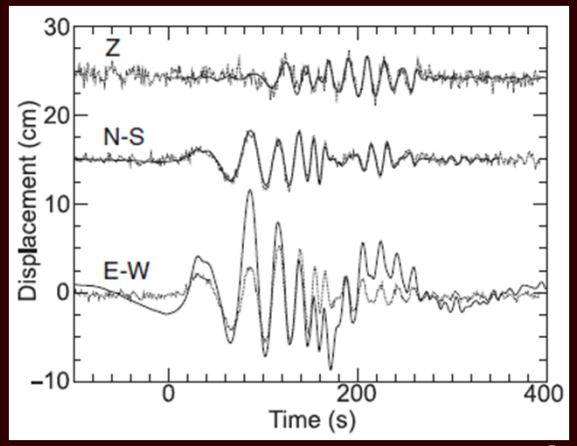
Tsunami forecast from near-real-time fault model of Tohoku earthquake

[Ohta et al., 2012]

Advantage and disadvantage for GPS seismology

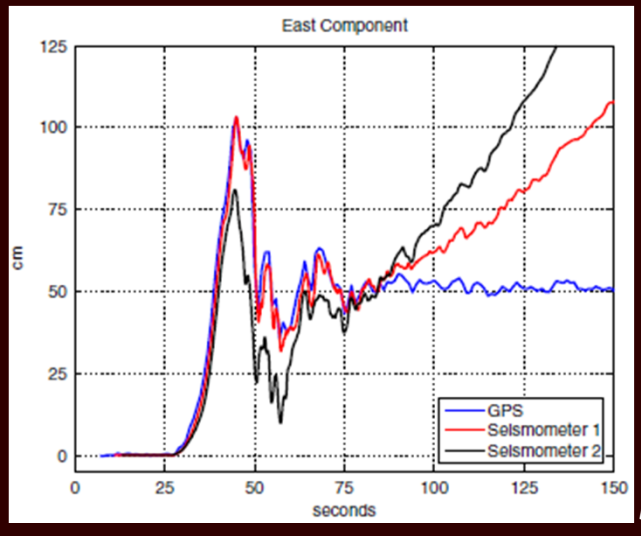
Advantages

- No clip and tilt



[Bilich et al., 2008]

- True displacements



[Larson, 2009]

Disadvantages

- More noisy
- Position of the GPS antenna

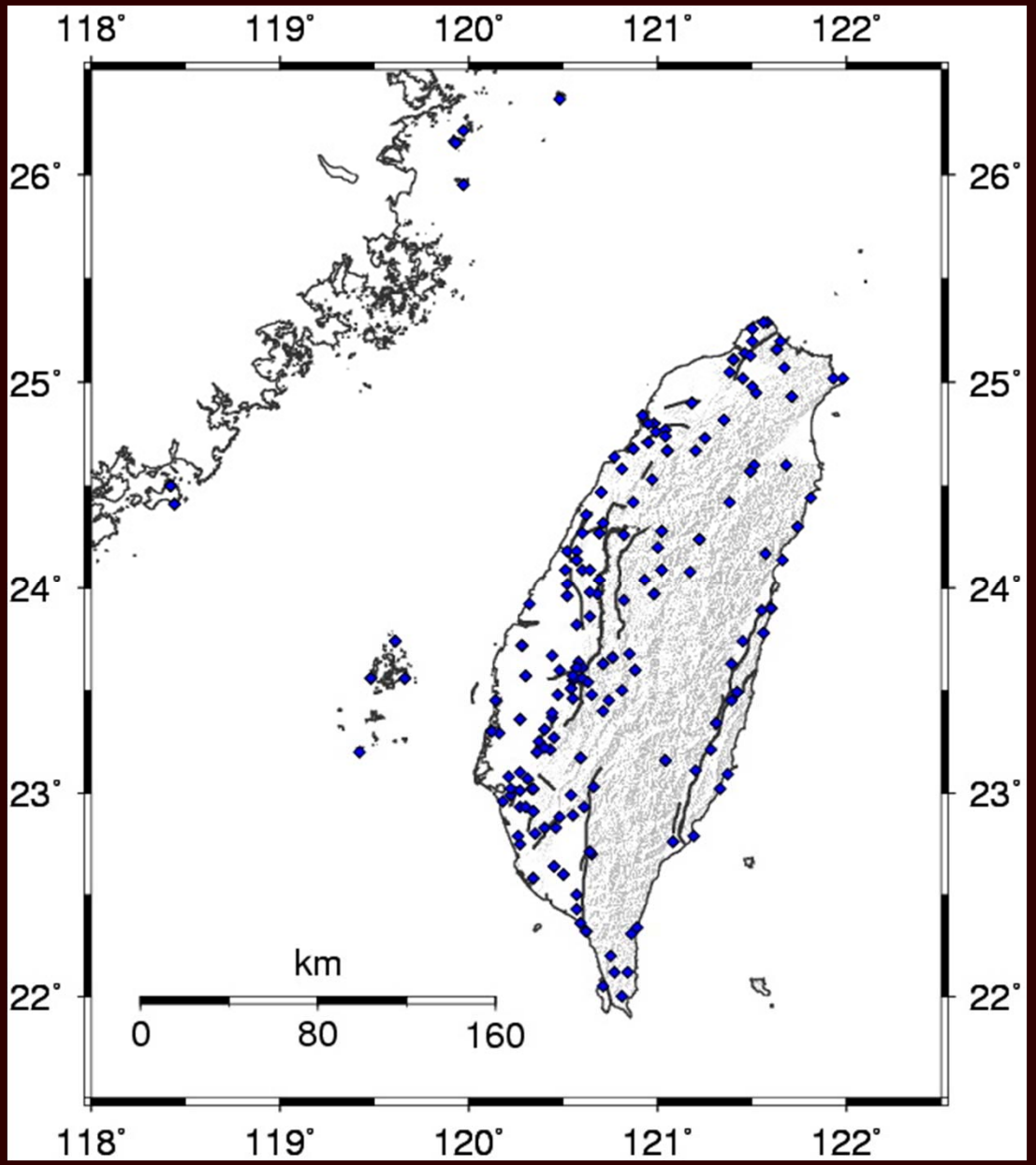
Taiwan dense high-rate CGPS network

- Total 220 CGPS stations for 1-Hz observations

- CWB 中央氣象局
- CGS 中央地調所
- IES 中研院地球所
- NLSC 國土測繪中心
- NCCU 中正大學
- IGS station - TWTF
- Other institutions

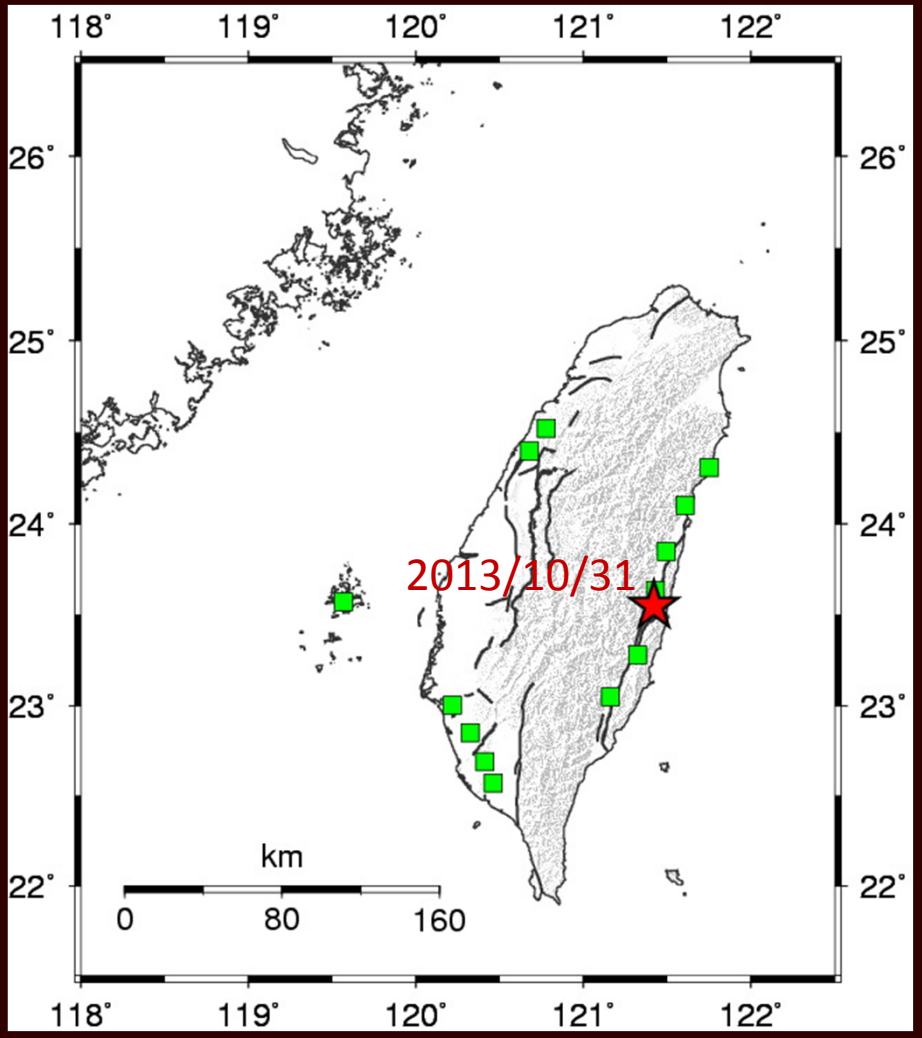
- ***For real-time applications***

NLSC, e-GPS system



Ultra-high-rate CGPS network in Taiwan (NCKU-IES)

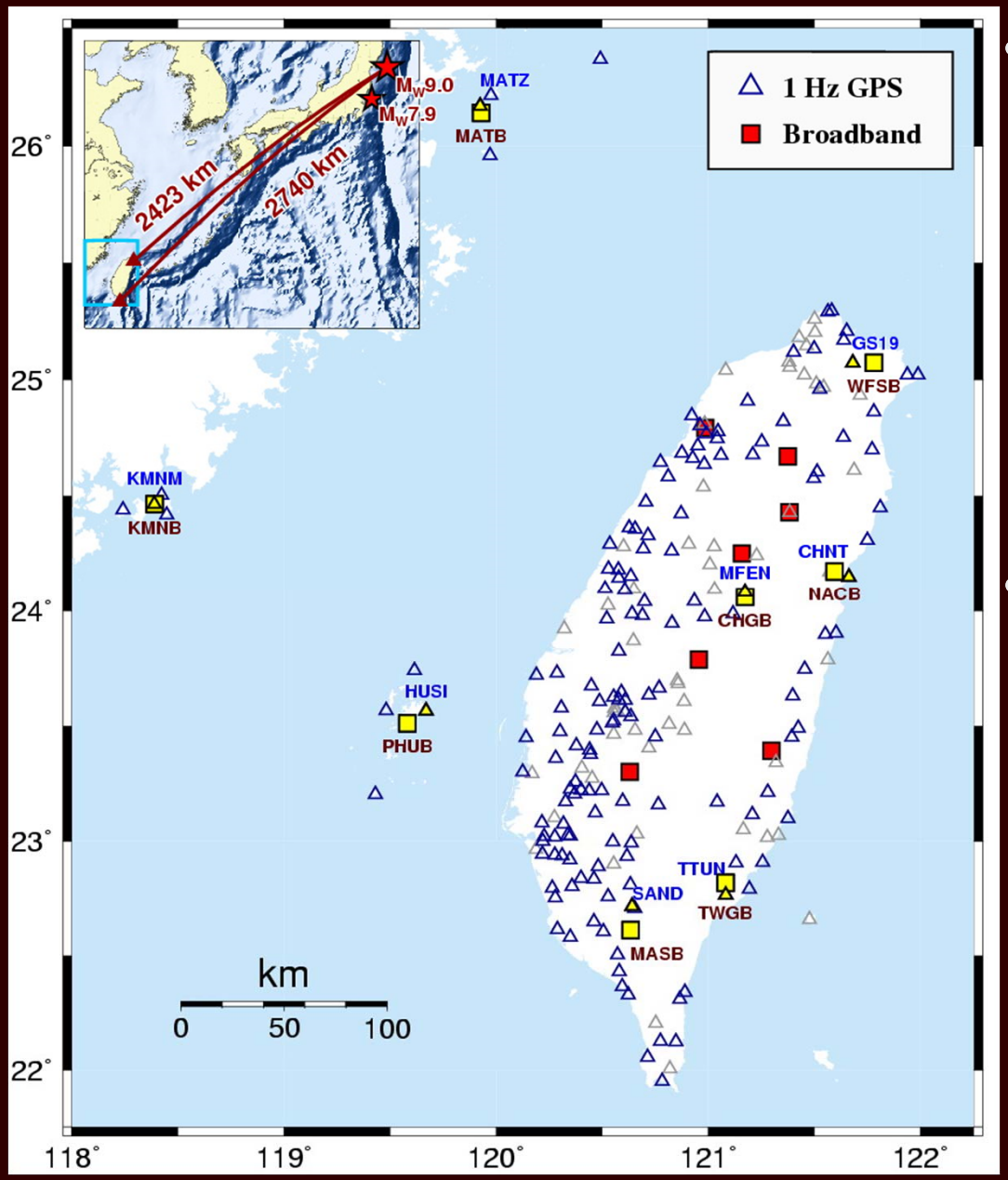
- 20-Hz observations
- Receiver type: TRIMBLE NETR8
- Antenna type:
- Mounted on the roof



GPS Seismology in Taiwan

- 2011 Tohoku earthquake (1-Hz, 2400-2800 km)
- 2010 Jiashian earthquake (1-Hz, 10 -120 km)
- 2013 Nantou earthquake (20-Hz)
- 2013/10/31 Hualien earthquake (20-Hz)

Datasets for Tohoku EQ (GPS & seismic data)



- *High-rate continuous GPS sites (210 stations)*

  CWB, CGS, NLSC, NCCU

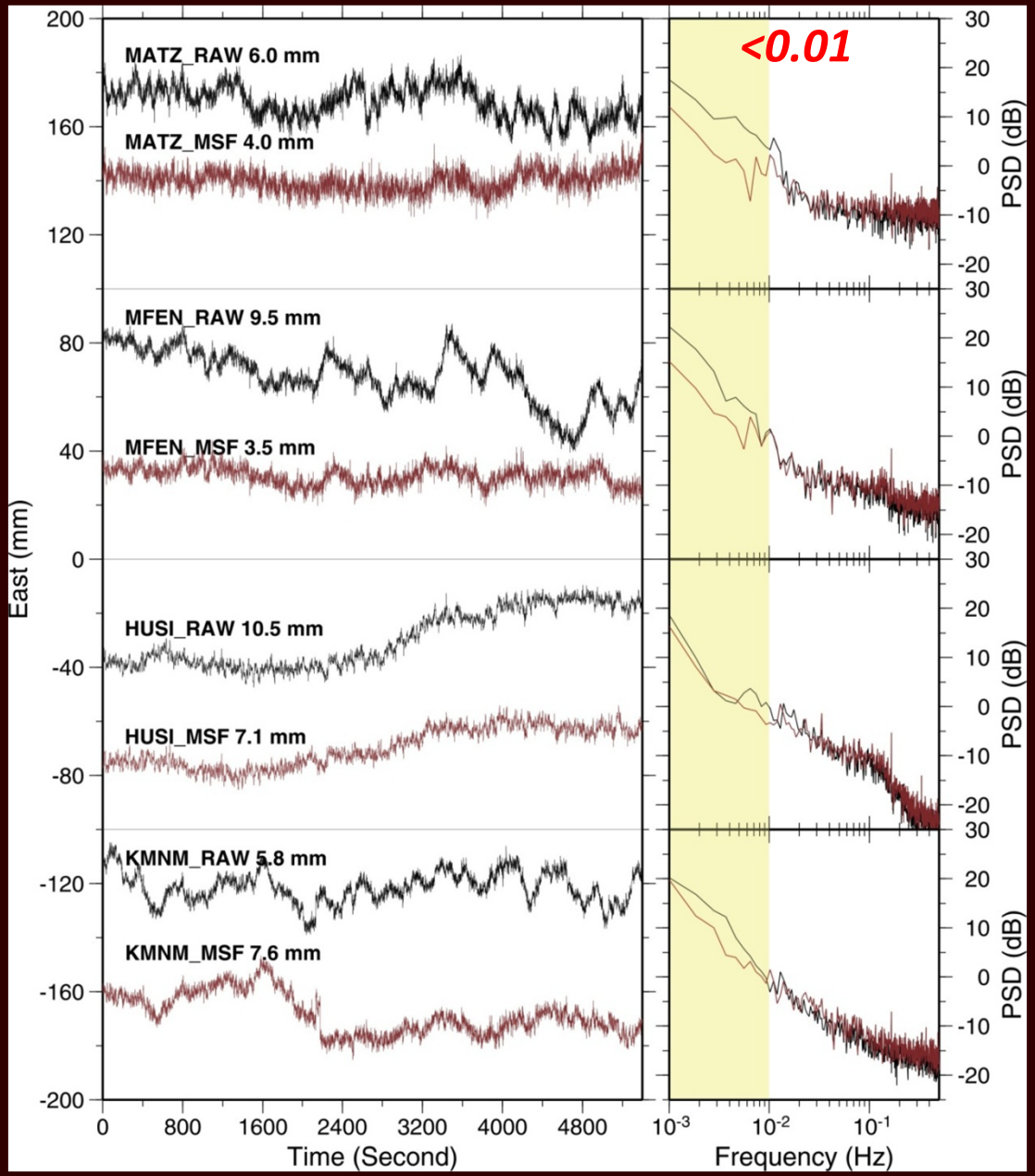
  1-Hz, 7-11 March, 2011

- *Broadband seismometers (15)*

  BATS, IES, 20-Hz

- ***8** co-located pairs for comparison*
- *PPP*
- *MSF applying*

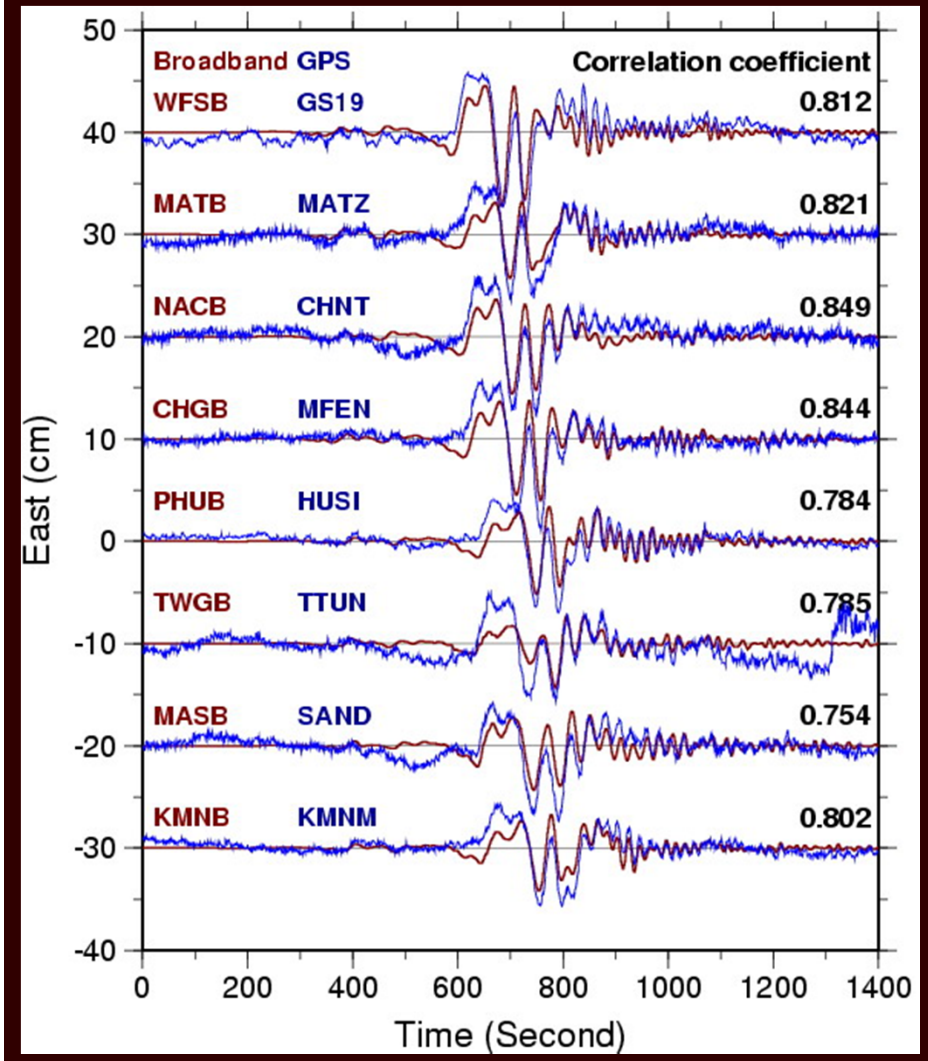
RESULTS – PRECISION OF HIGH-RATE GPS



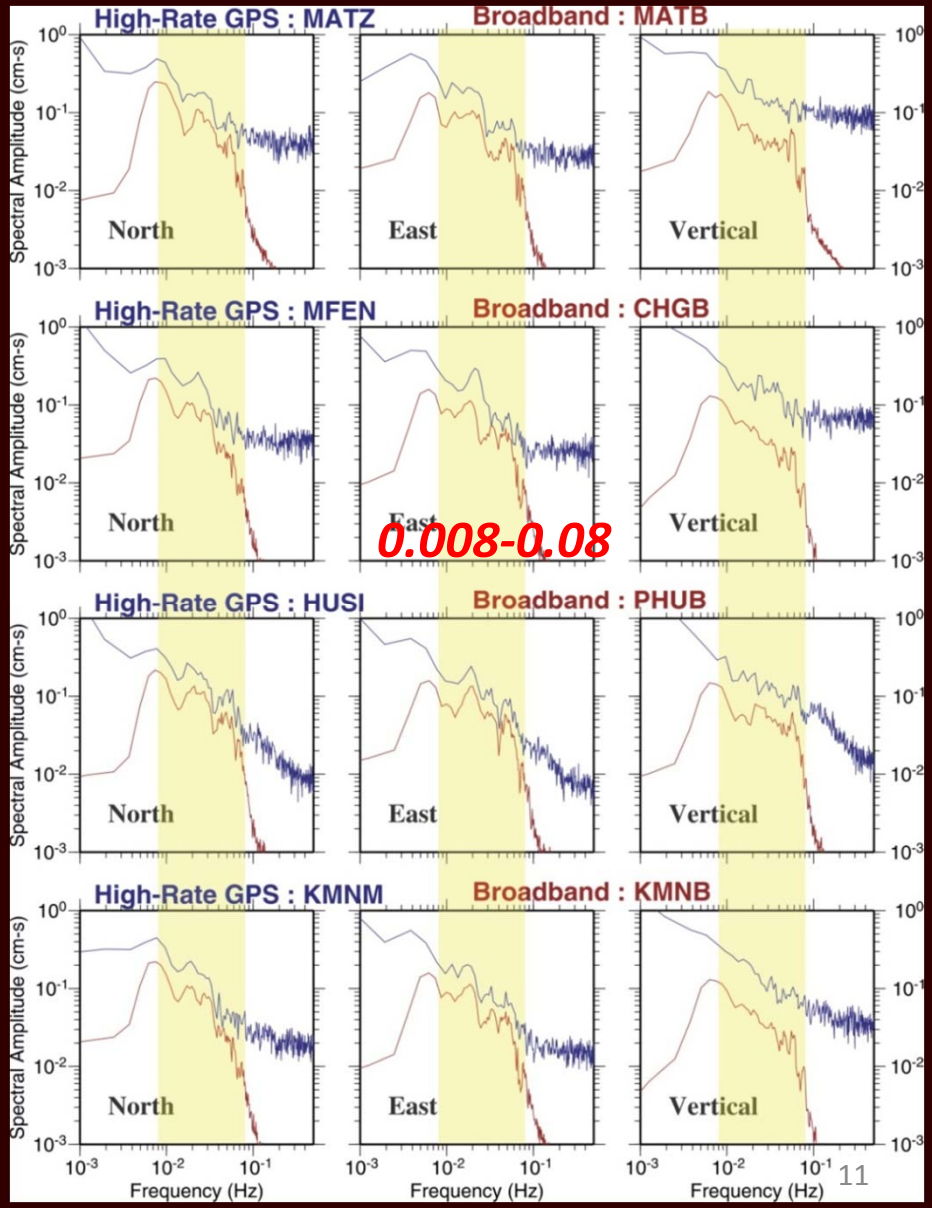
N, E precision: ~5mm
Vertical: ~30 mm

High-rate GPS v.s. Broadband seismometers

Displacements

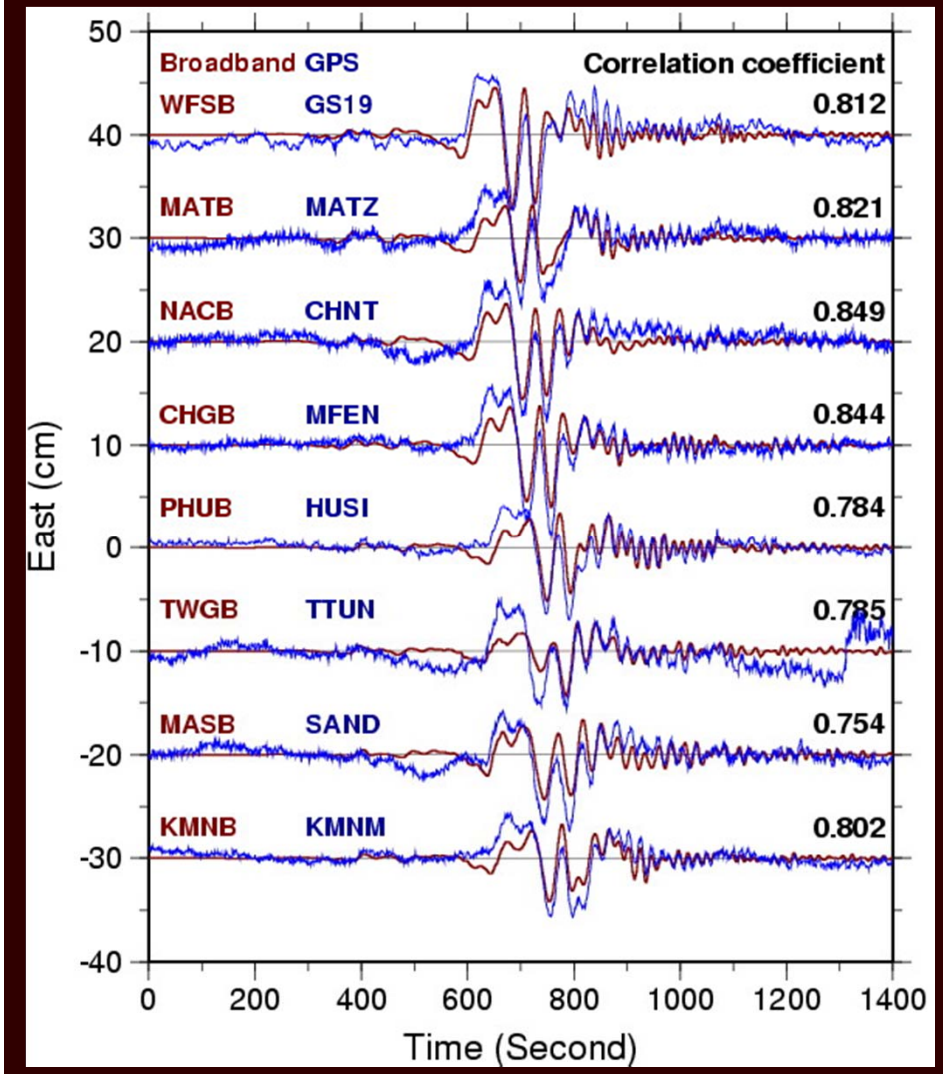


Spectral analysis

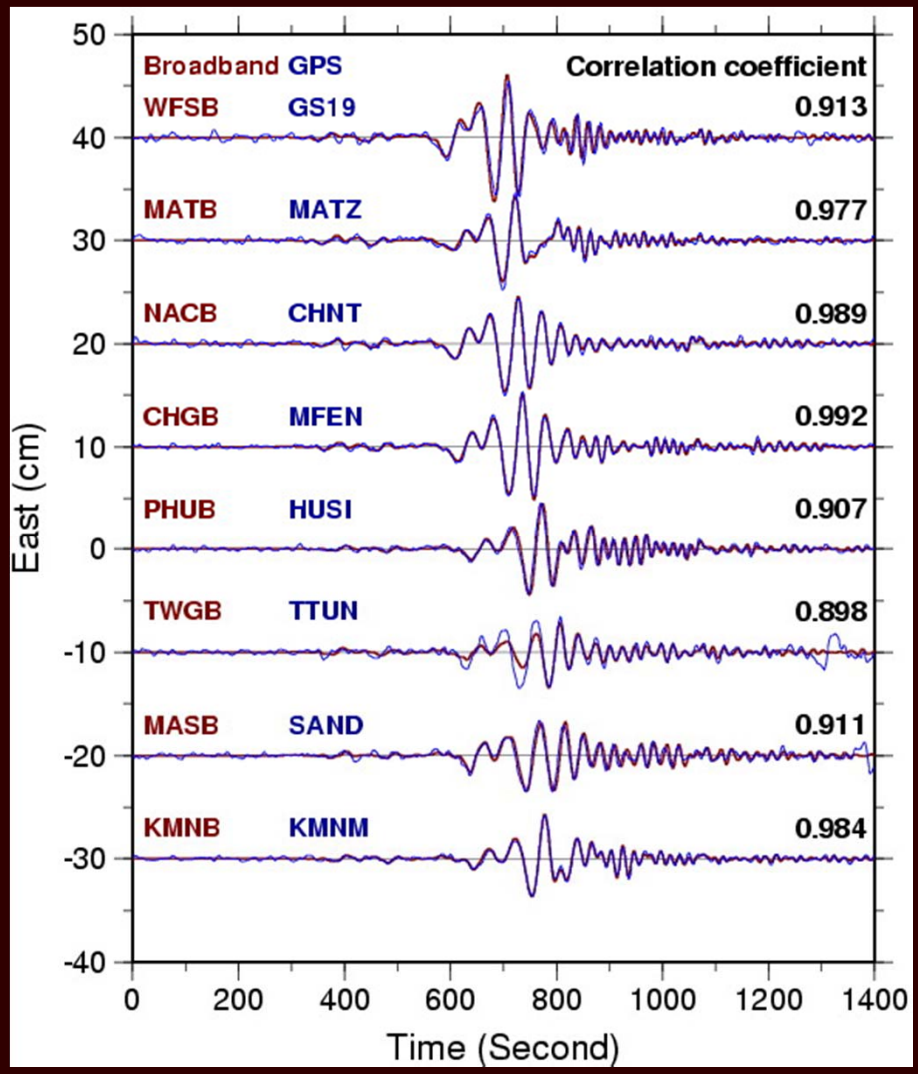


Comparison between high-rate GPS and broadband data

Unfiltered

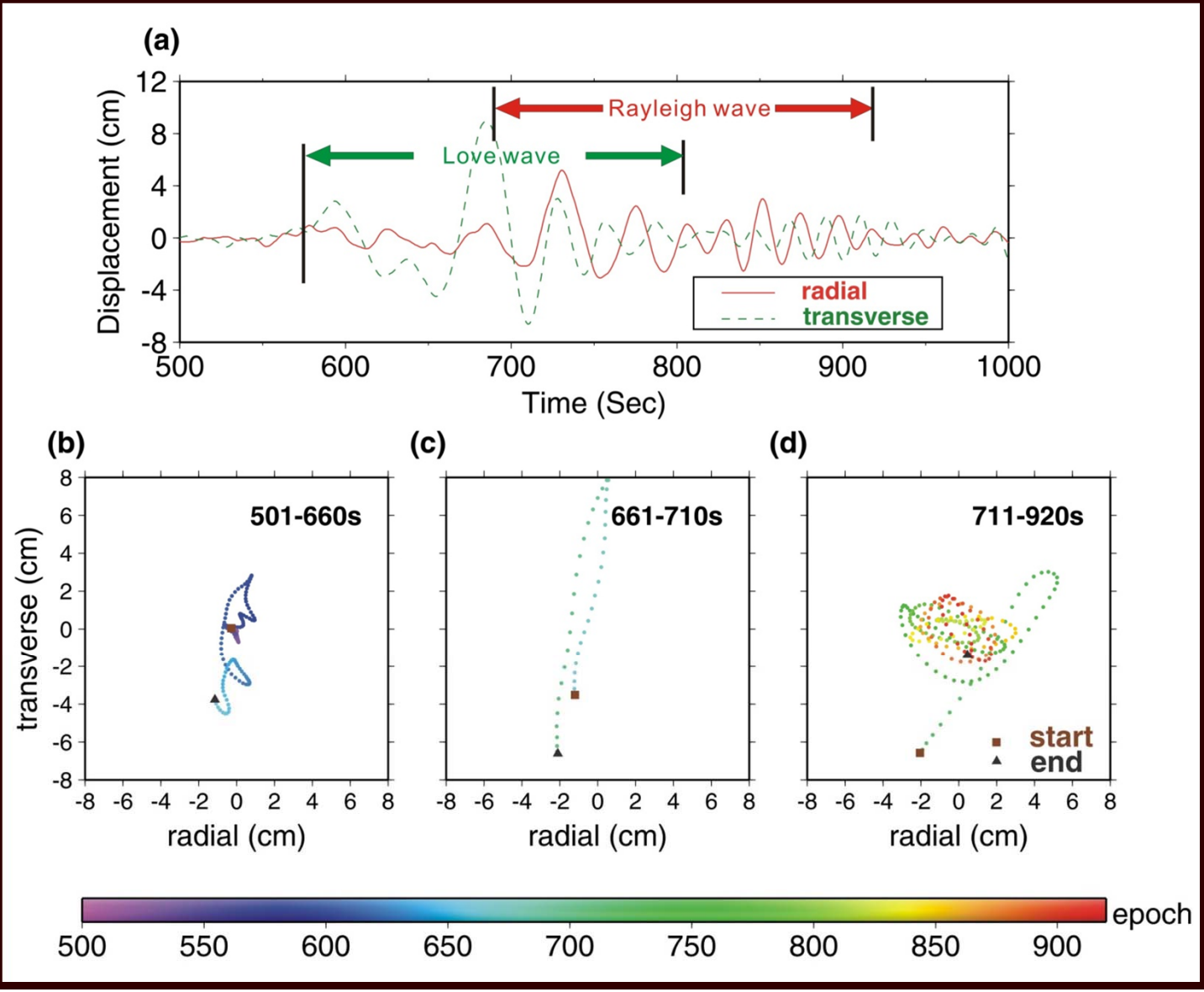


0.008 – 0.08 Hz bandpass filter



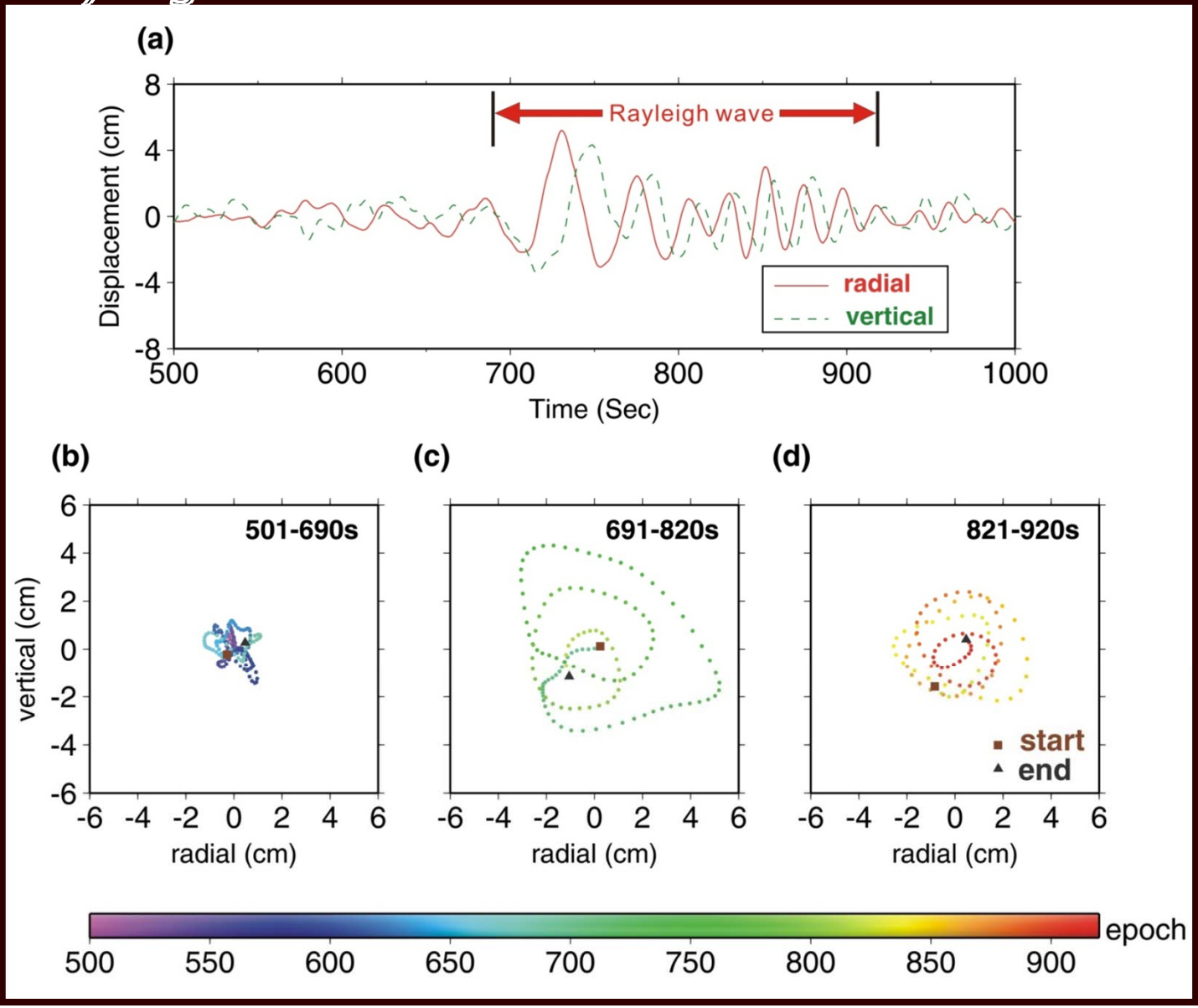
Surface waves from Tohoku earthquake

Love waves

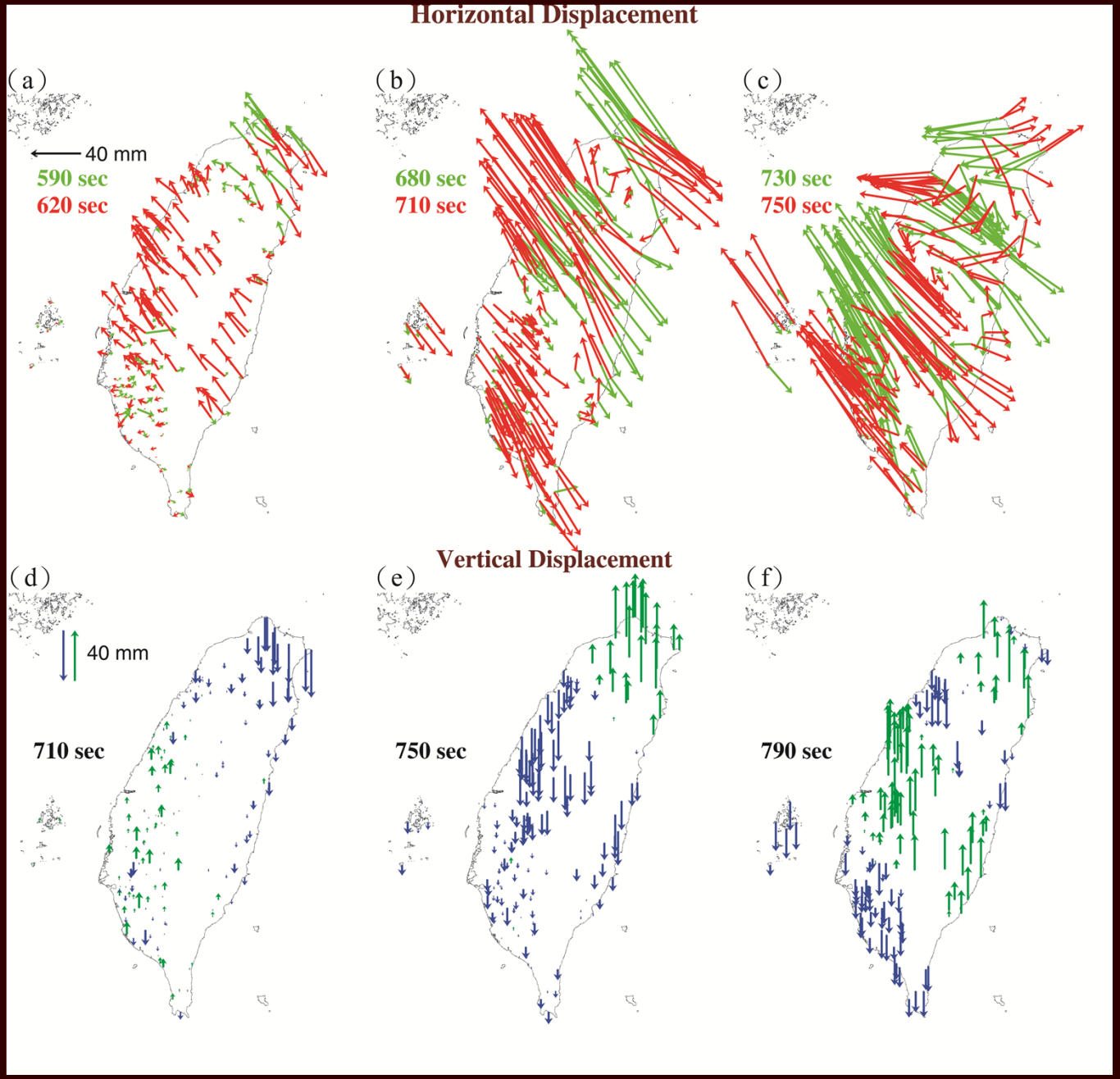


Surface waves from Tohoku earthquake

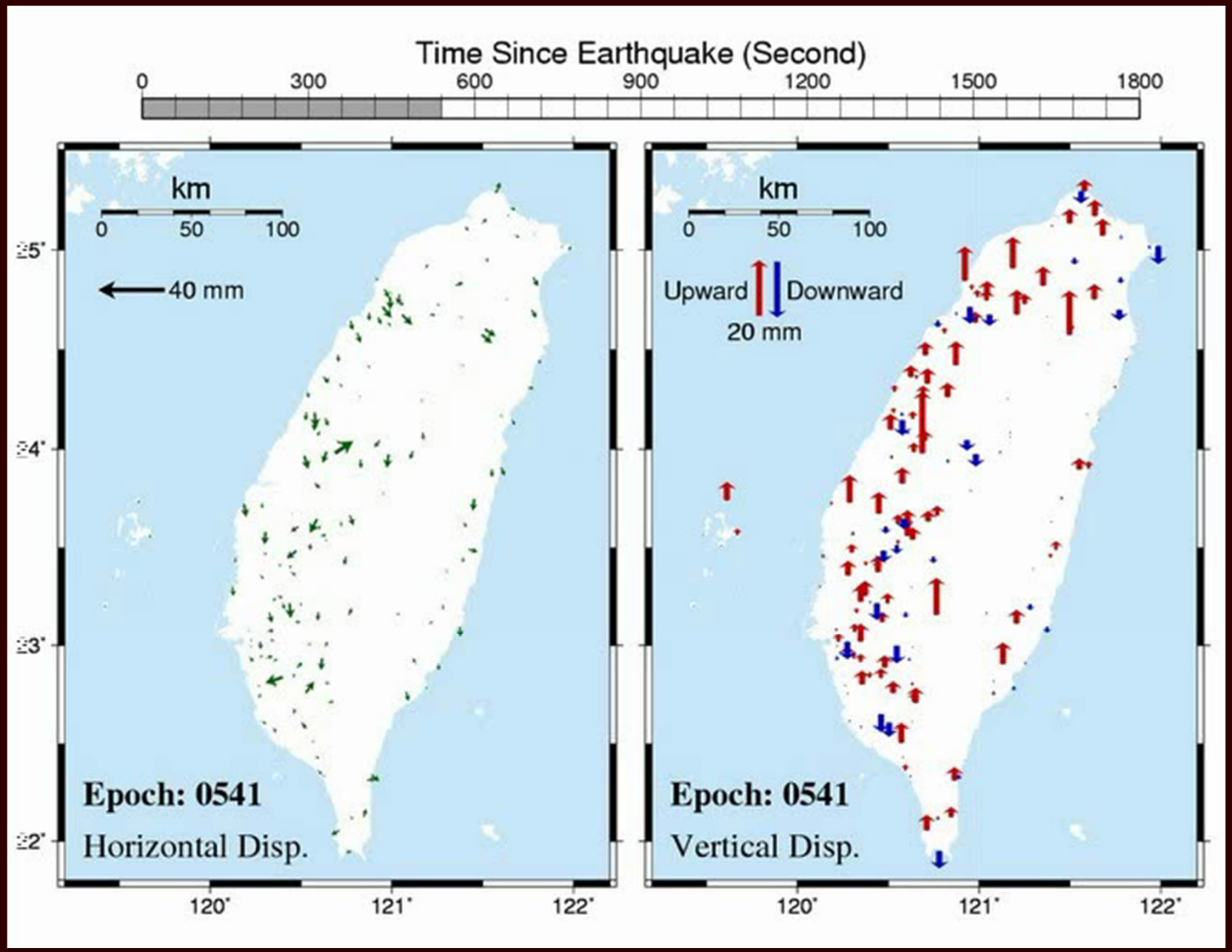
Rayleigh waves



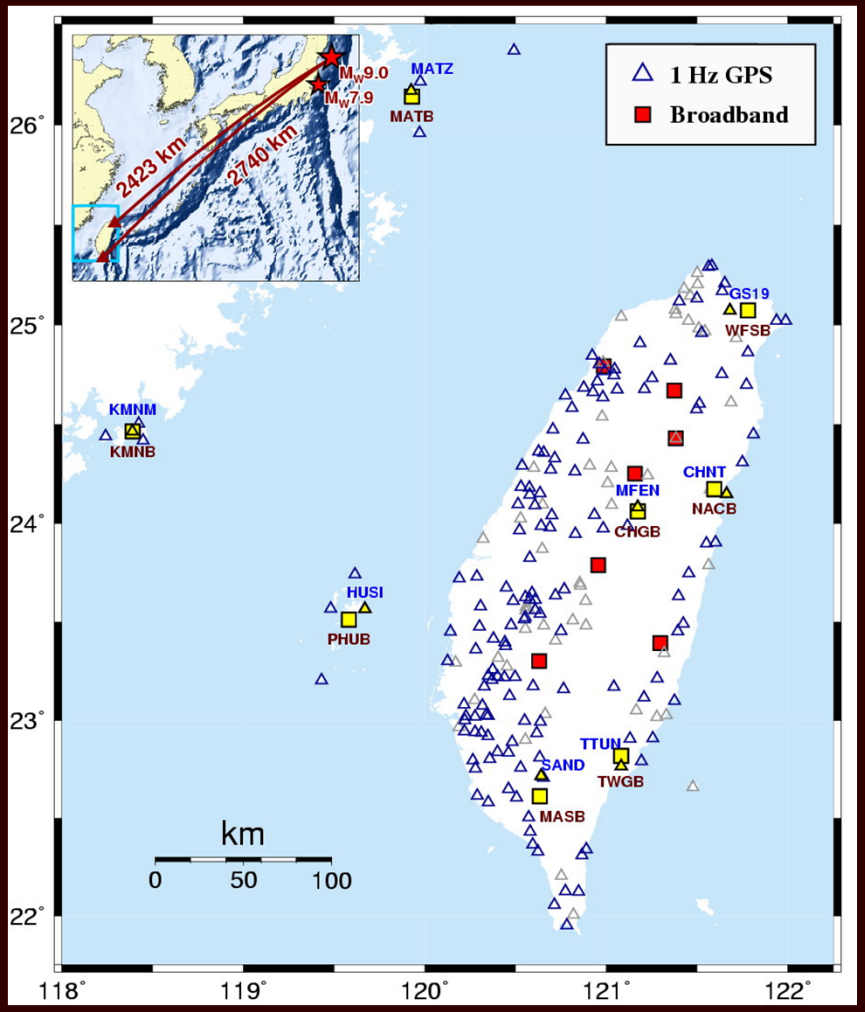
Displacement field from CGPS and BB

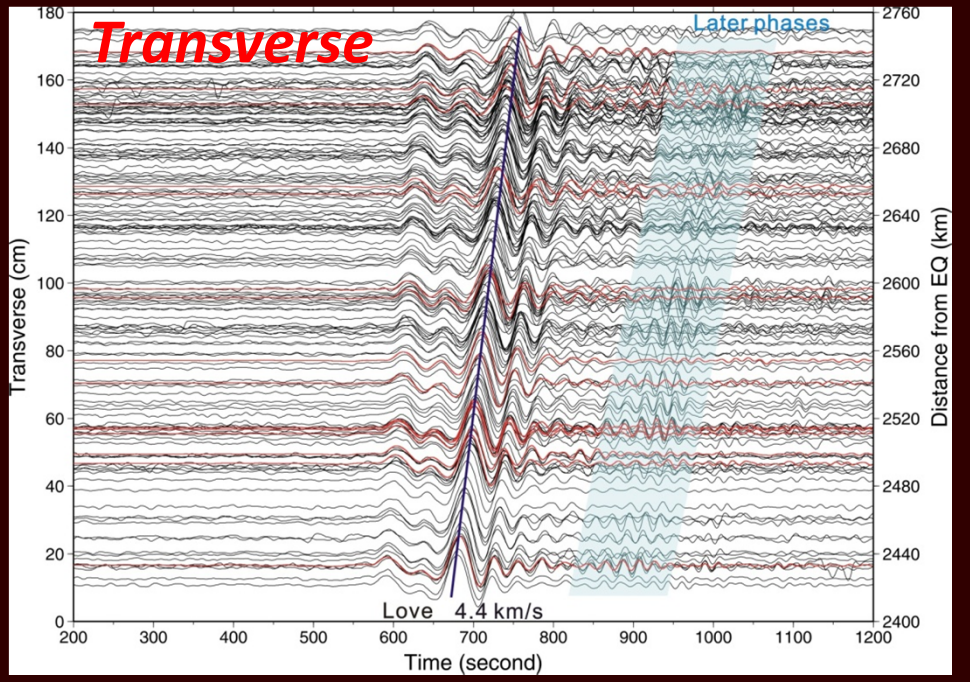


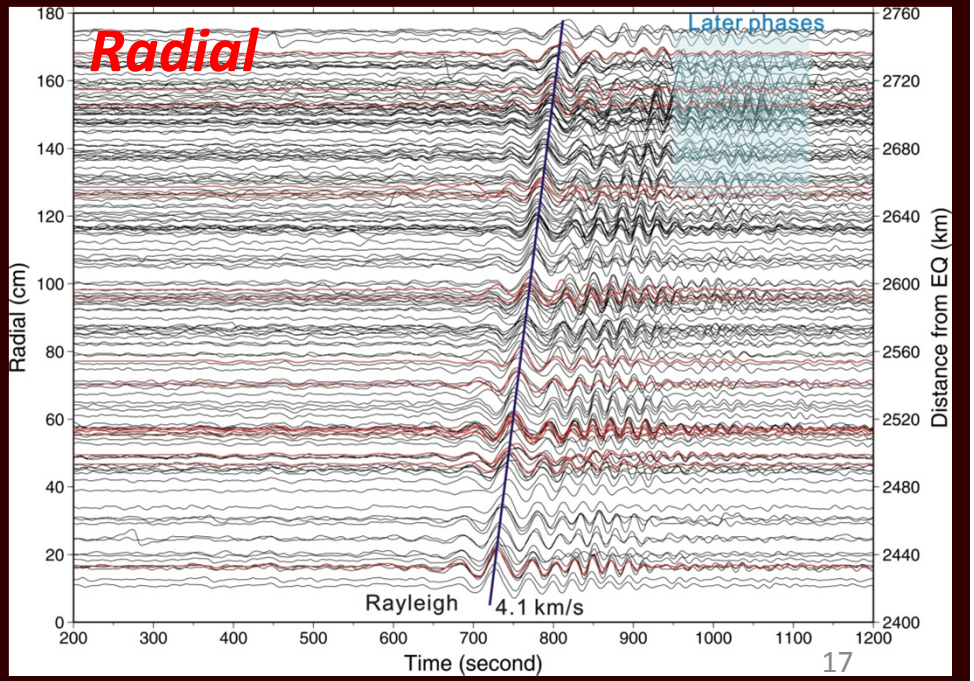
Animation for CGPS and BB motions



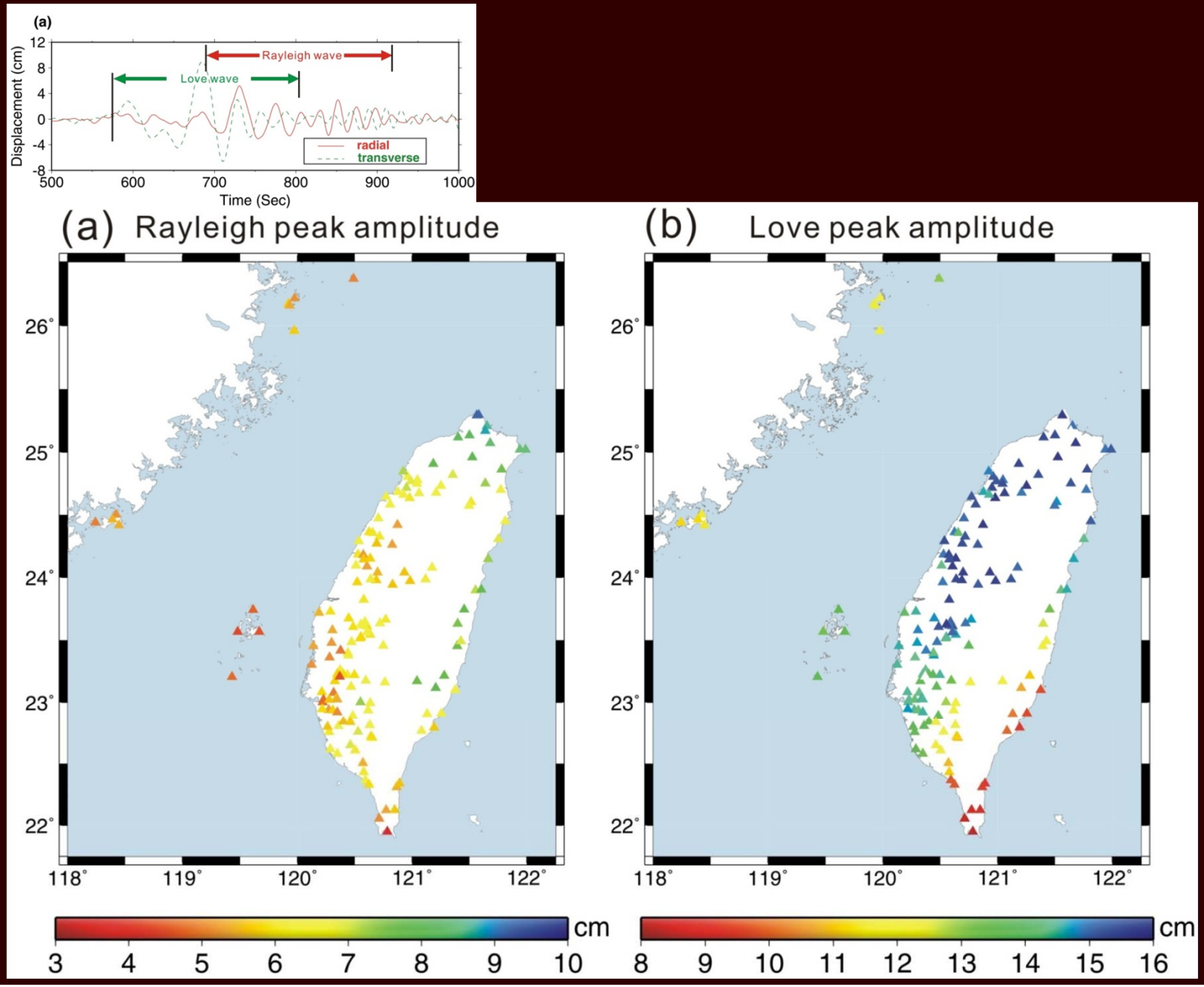
SURFACE WAVES DERIVED FROM 156 CGPS STATIONS AND 15 BROADBAND SEISMOMEERS



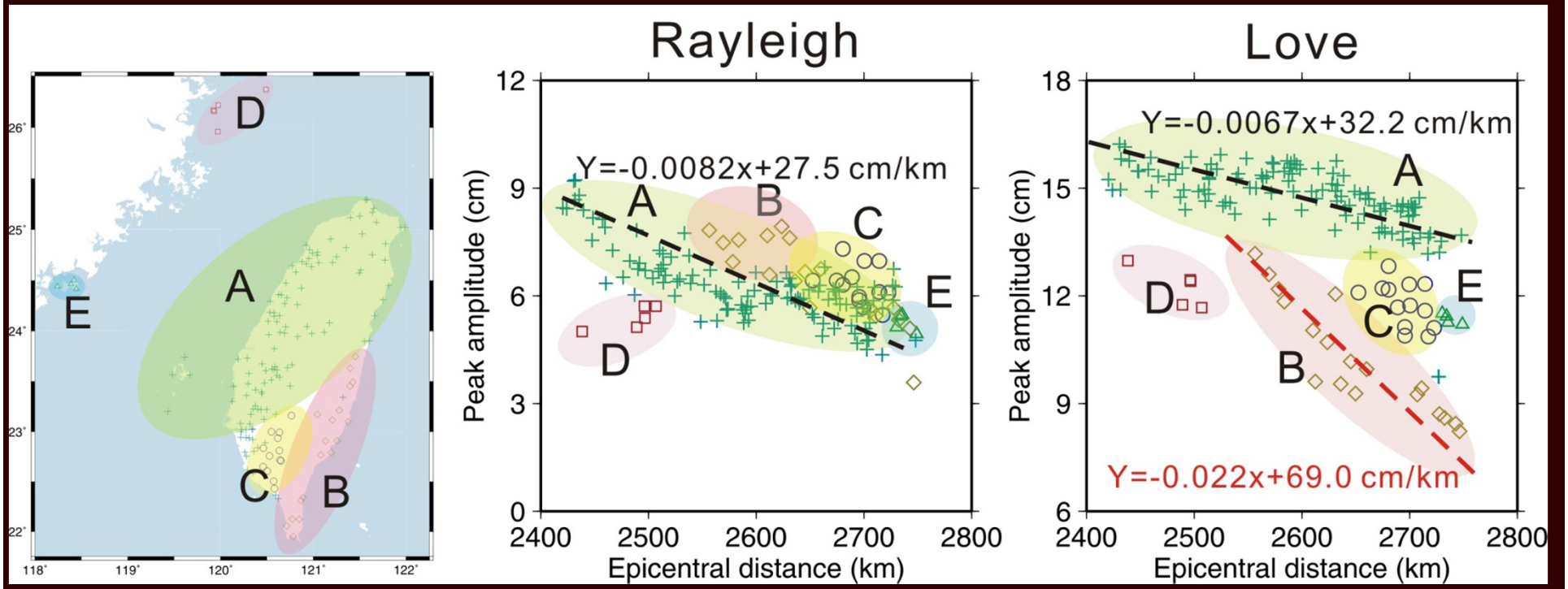




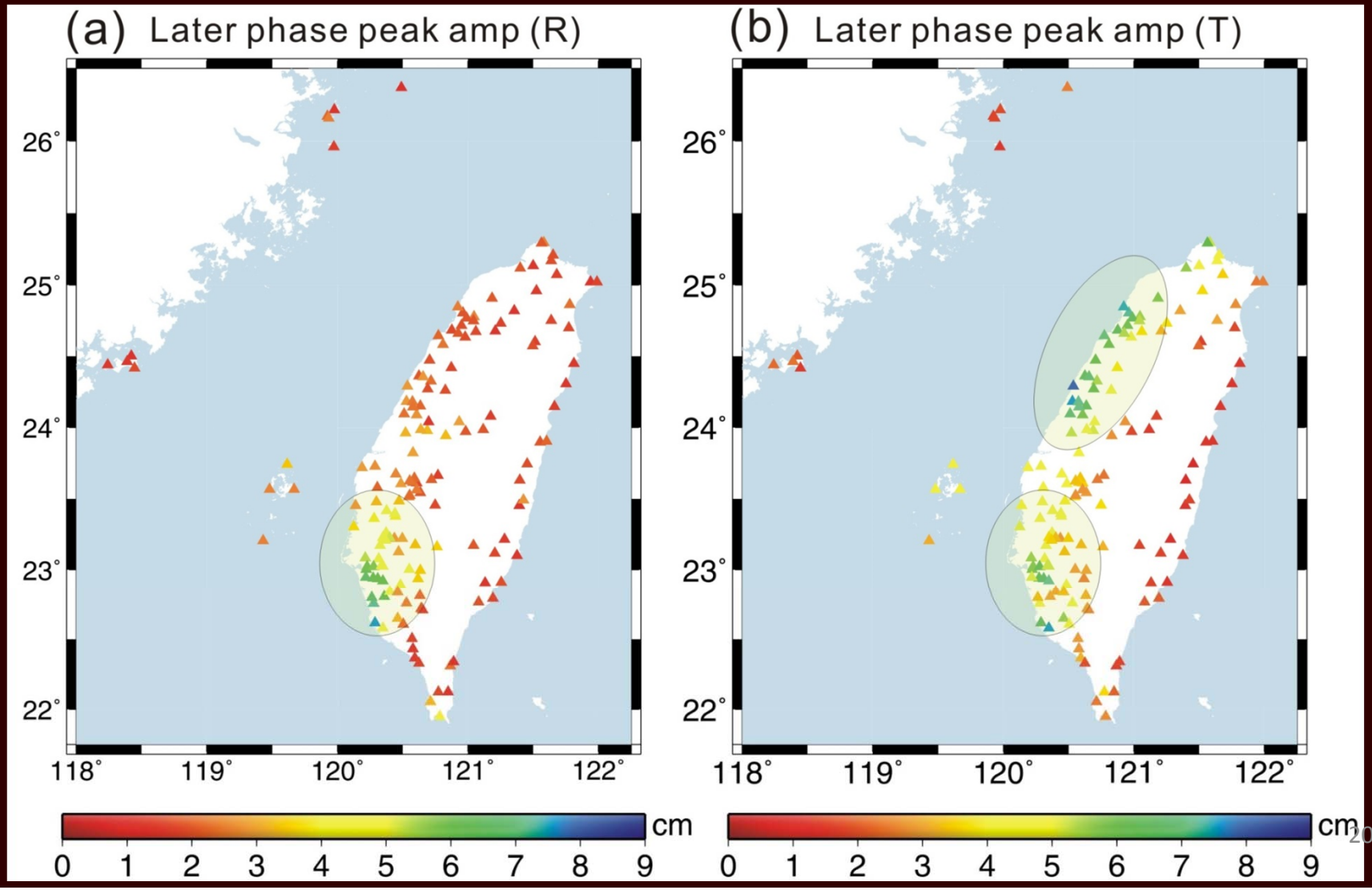
Maximum peak-to-peak amplitude



MAXIMUM PEAK-TO-PEAK AMPLITUDE



MAXIMUM PEAK-TO-PEAK AMPLITUDE OF THE LATER PHASES

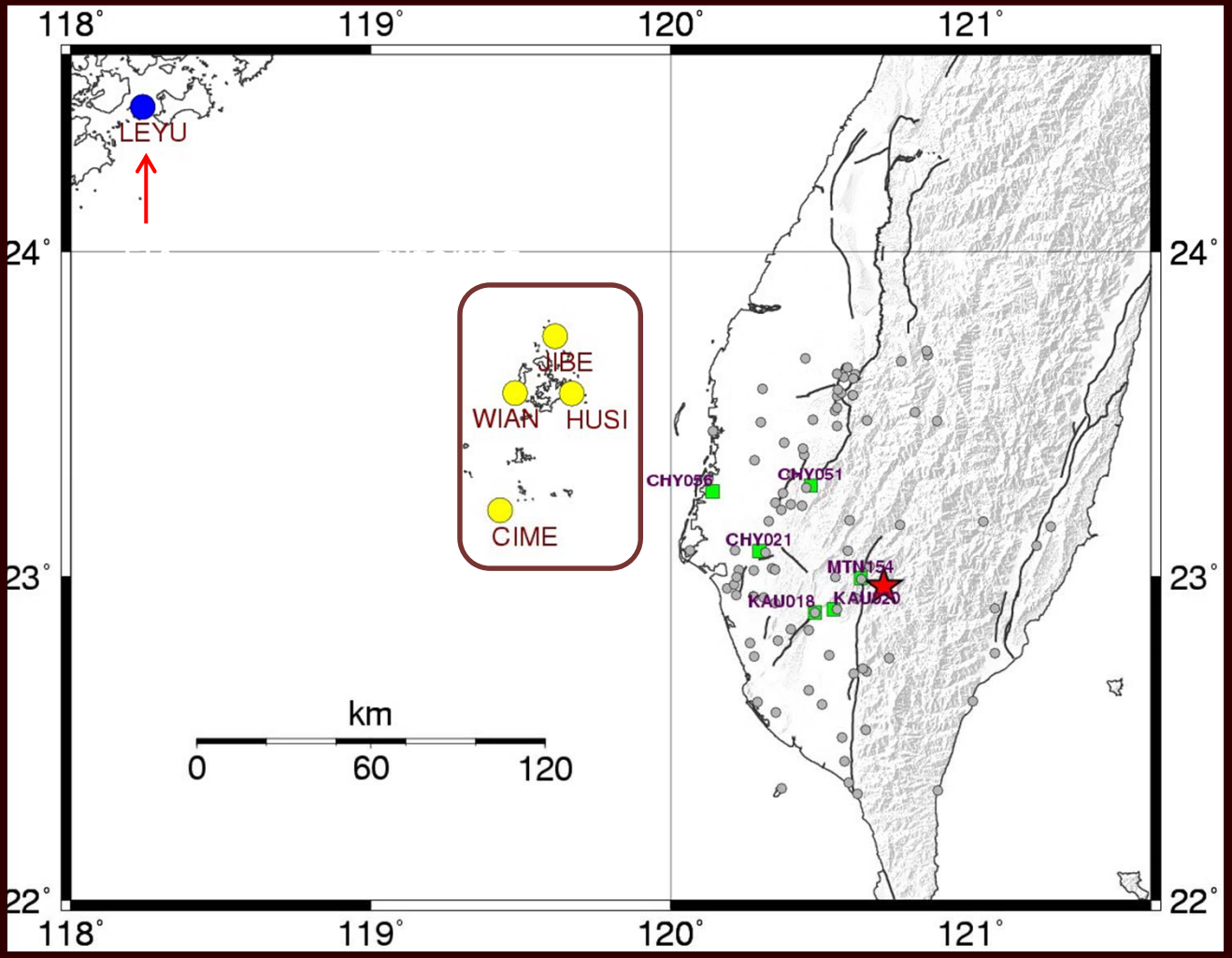


GPS Seismology in Taiwan

- 2011 Tohoku earthquake (1-Hz, 2400-2800 km)
- 2010 Jiashian earthquake (1-Hz, 10 -120 km)
- 2013 Nantou earthquake (20-Hz)

High-rate GPS for near-field earthquake in Taiwan (Jiashian earthquake)

- Jiashian earthquake (M_L6.4), 4th March, 2010
- 89 CGPS stations
- 6 pairs of CGPS-SM
- Kinematic positioning (TRACK 1.26)
- Fix stations - ***LEYU*** (金門)
- Filtering - 4 stations ***JIBE, WIAN, HUSI, CIME (澎湖)***



Distribution of the high-rate CGPS stations in Jiashian earthquake

Modified sidereal filtering (MSF) & Spatial Filtering (SP)

MSF

$$(mp_i)_d = \sum_{k=d-3}^{k=d-1}\left[\frac{(x_i)_k}{(\sigma_i^2)_k}\right] \Big/ \left[\sum_{k=d-3}^{k=d-1}\frac{1}{(\sigma_i^2)_k}\right]$$

$$(x_i)_d^{flt} = (x_i)_d - (mp_i)_d$$

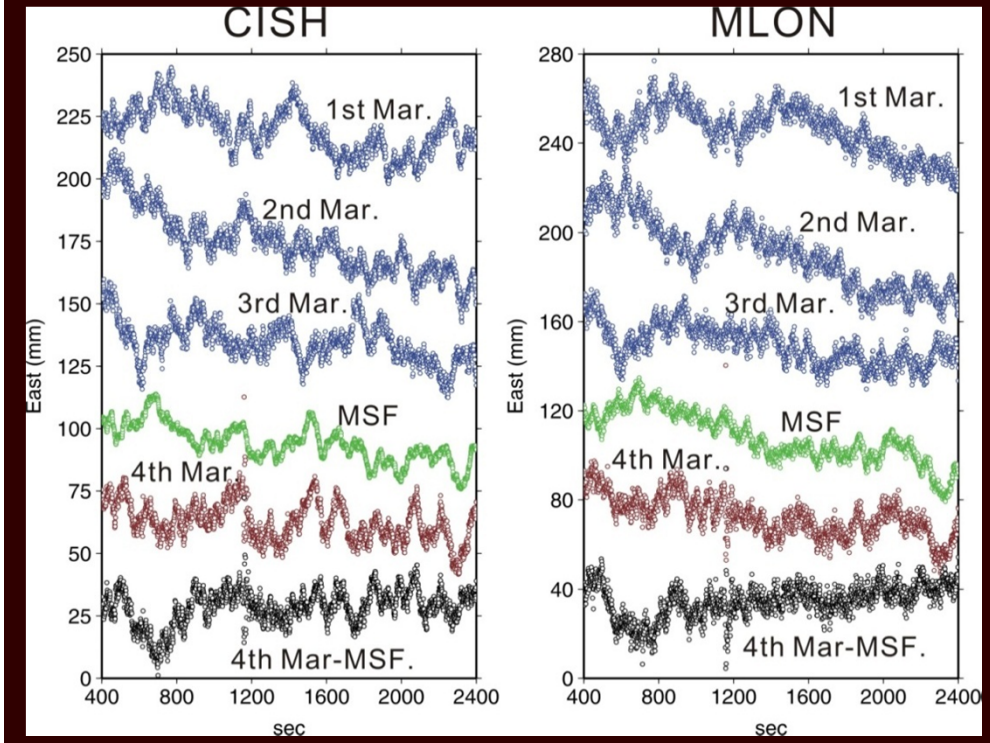
SP

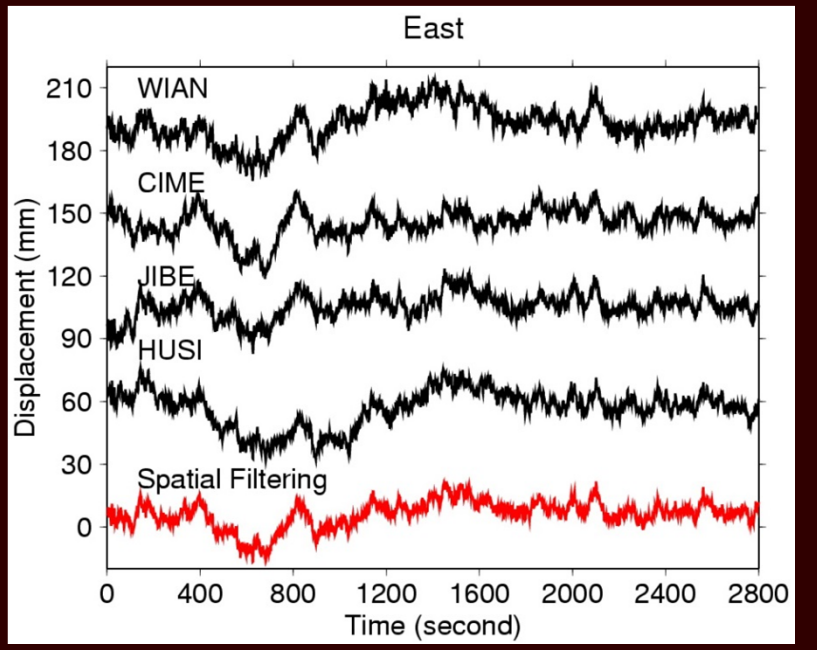
$$\bar{\varepsilon}(d) = \frac{\sum_{S=1}^{N}\varepsilon_s(d)}{N}$$

[Choi et al., 2004]

$$\hat{O}_s(d) = O_s(d) - \bar{\varepsilon}(d)$$

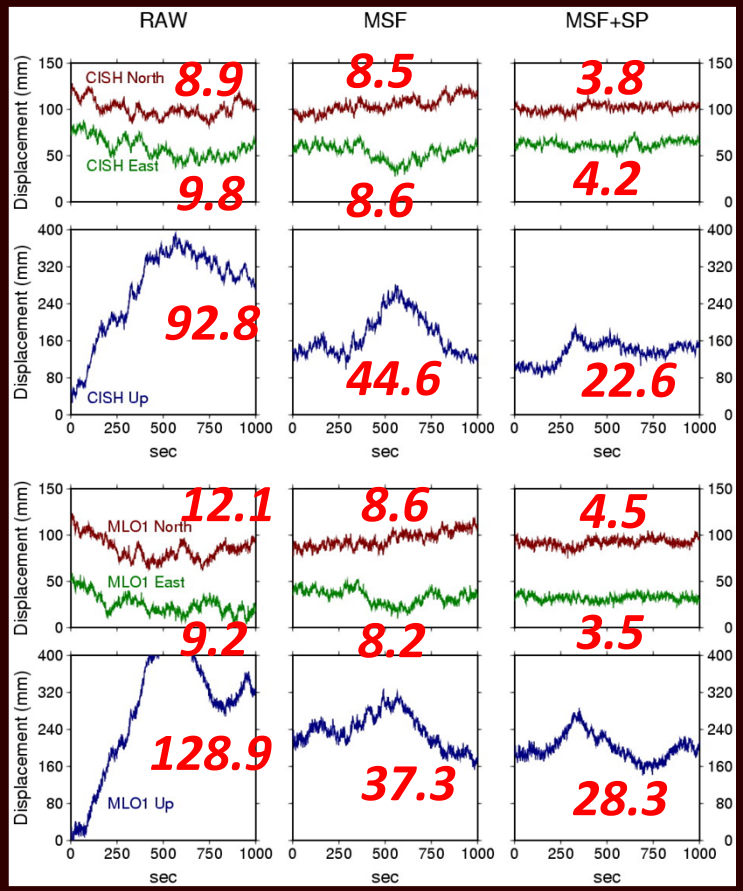
[Wdowinski et al., 1997]





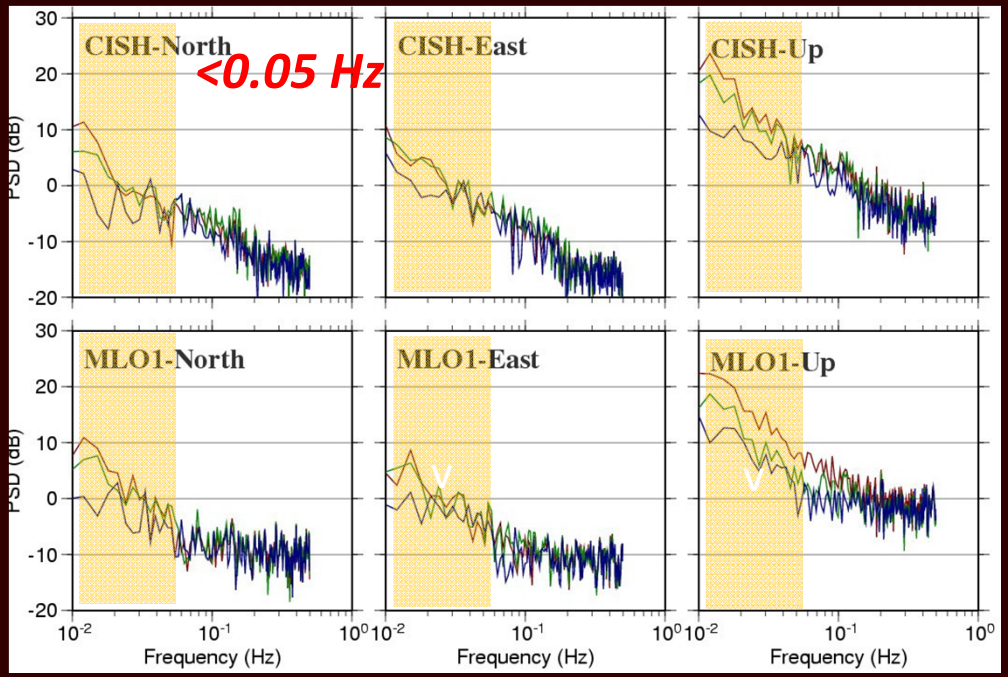
Results – displacement precision (79 CGPS STATIONS)

	RAW			RAW-MSF			RAW-(MSF+SP)		
	n (mm)	e (mm)	u (mm)	n (mm)	e (mm)	u (mm)	n (mm)	e (mm)	u (mm)
AVG	10.7	10.7	92.0	9.8	9.3	62.2	6.2	5.3	52.8
STD	2.2	2.8	30.5	3.9	1.9	27.5	3.2	3.3	30.6



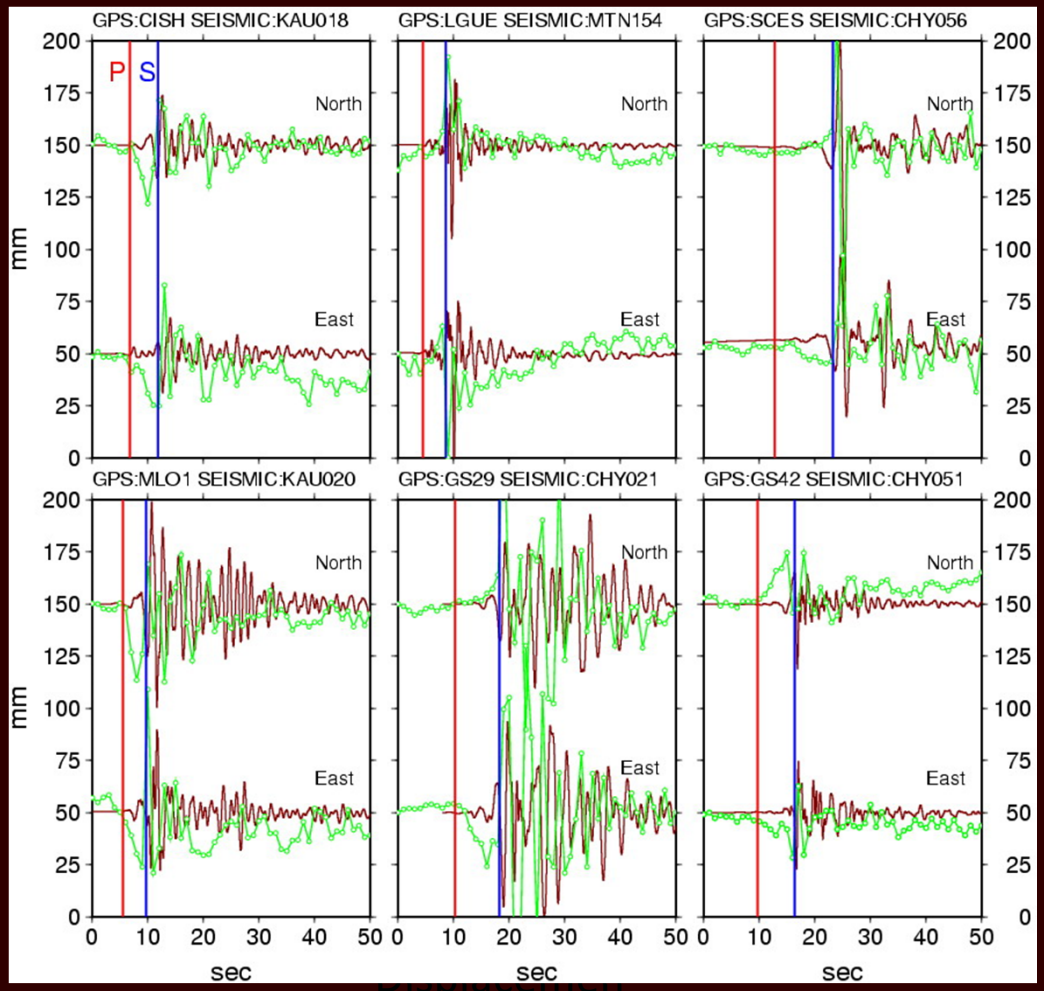
Displacements

Red: RAW, Green: RAW-MSF, Blue: RAW-(MSF+SP)

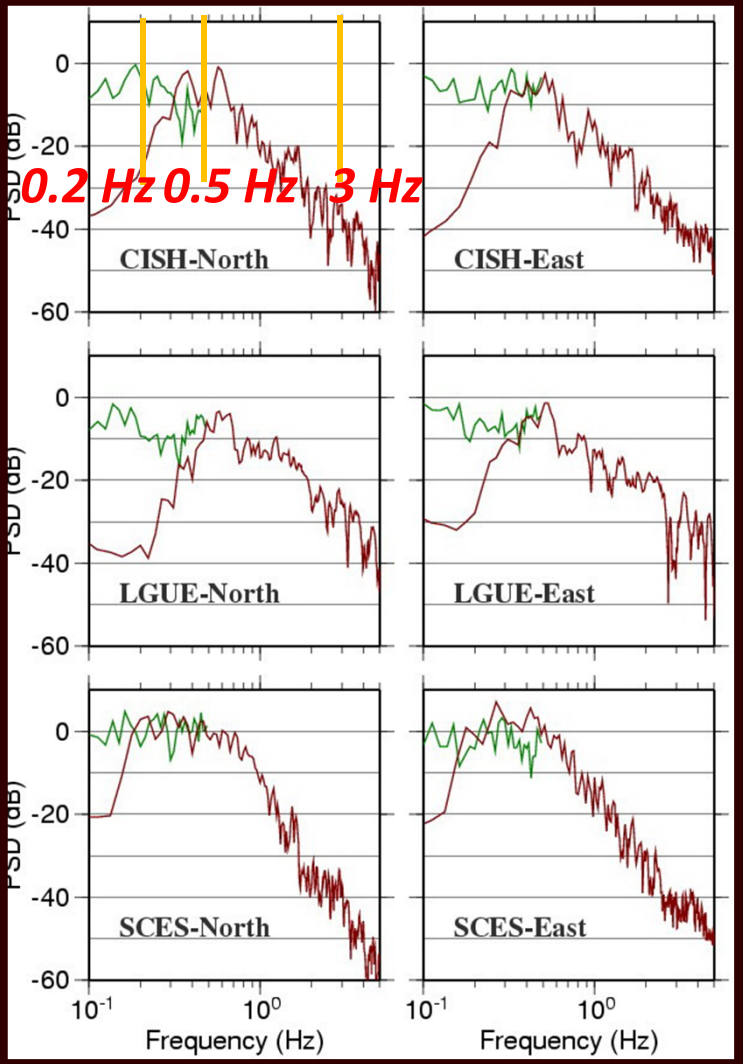


Power spectral density

GPS v.s. Strong Motion Data

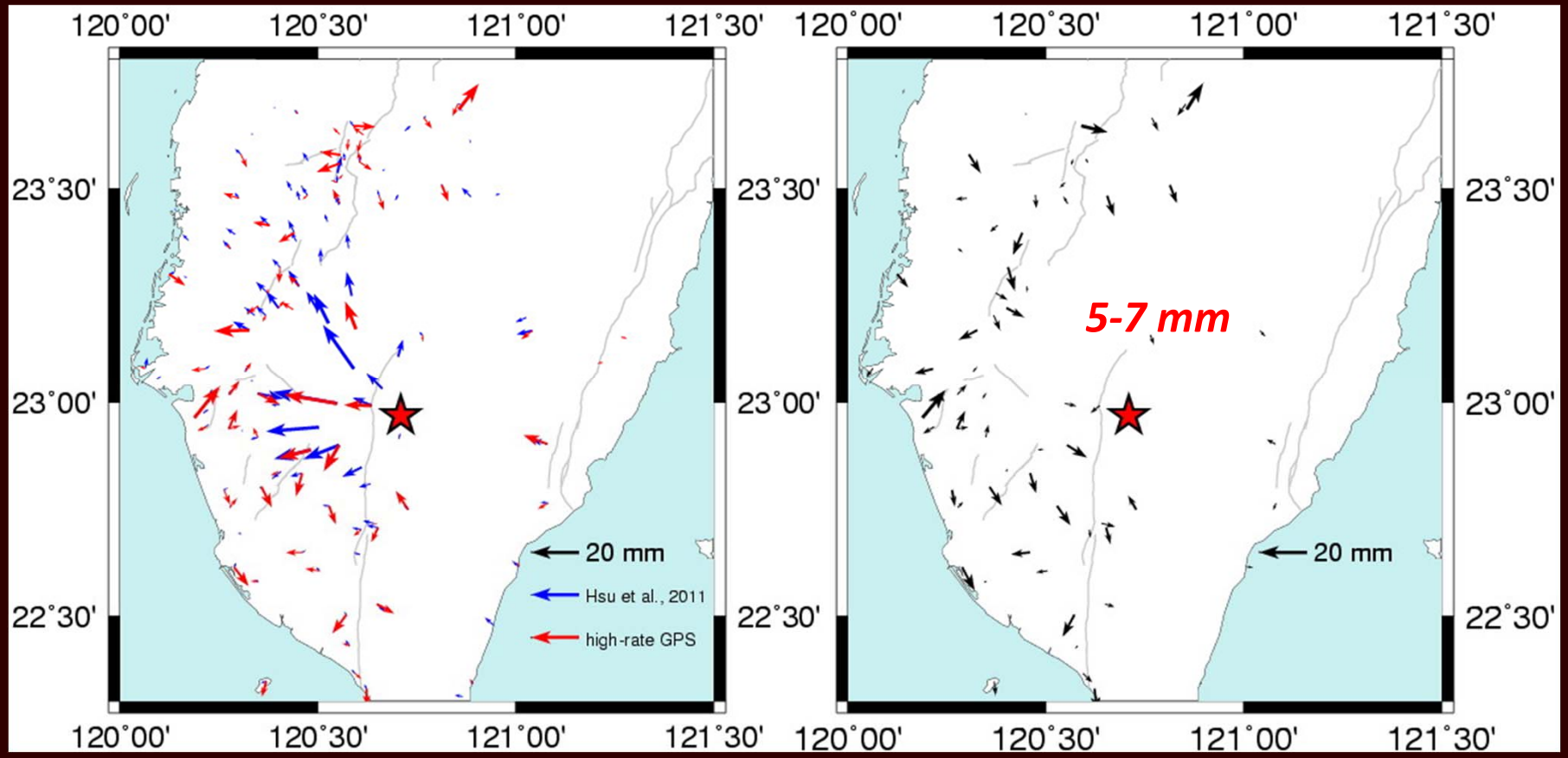


Displacements



Power spectral density

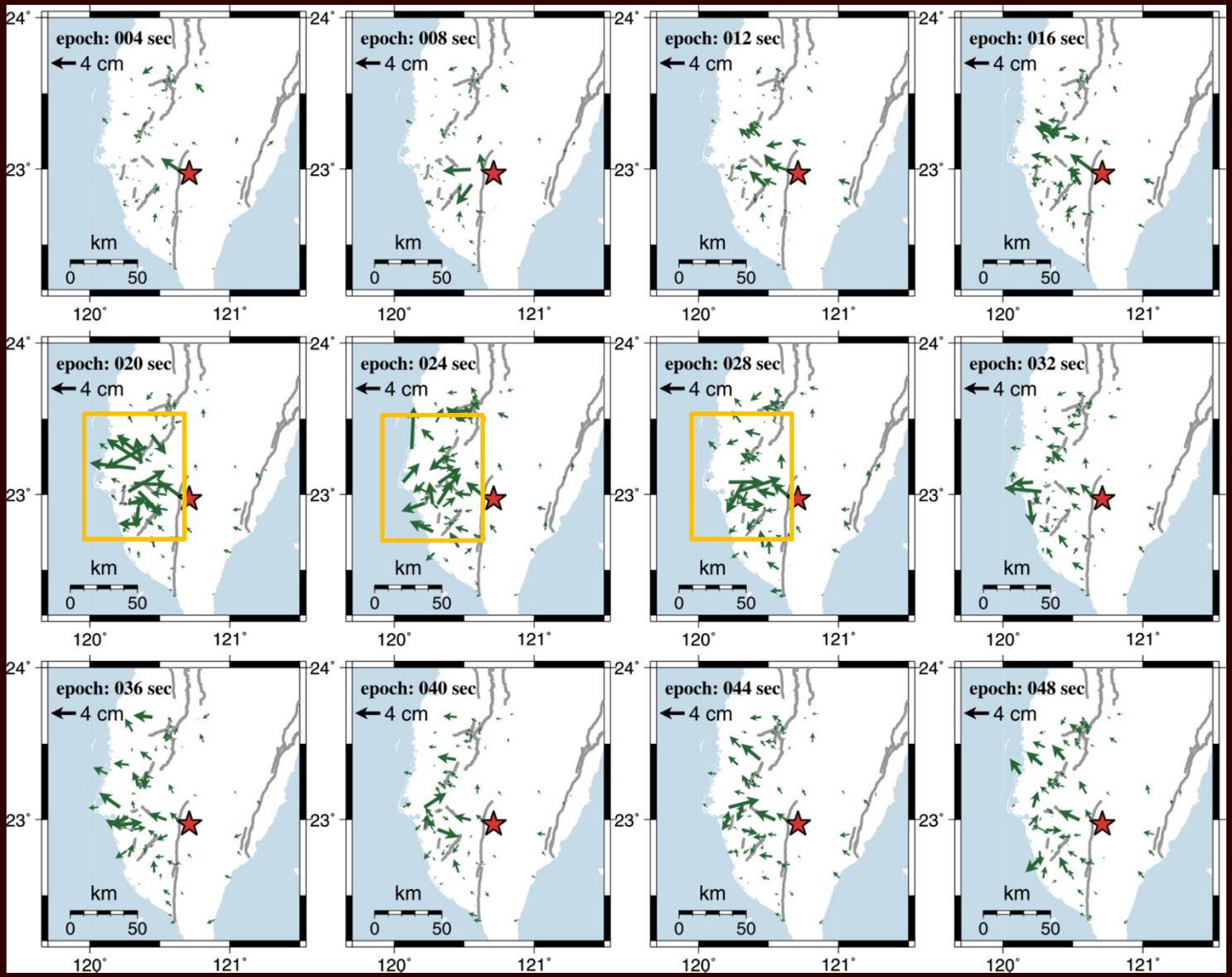
Coseismic displacements in daily and epoch-by epoch solutions



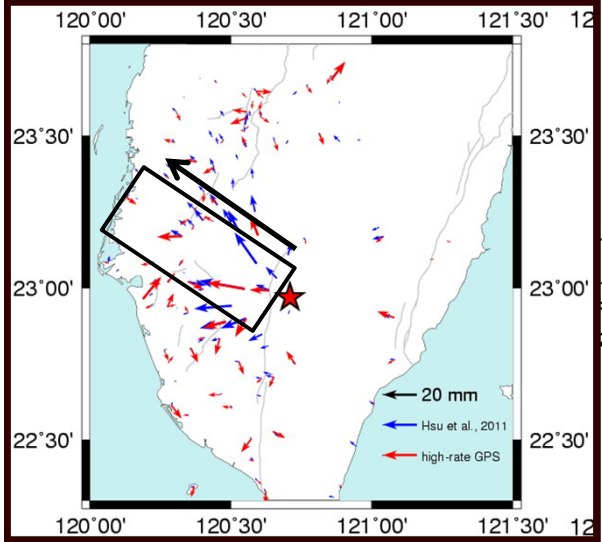
Coseismic displacements in daily and epoch-by-epoch solutions

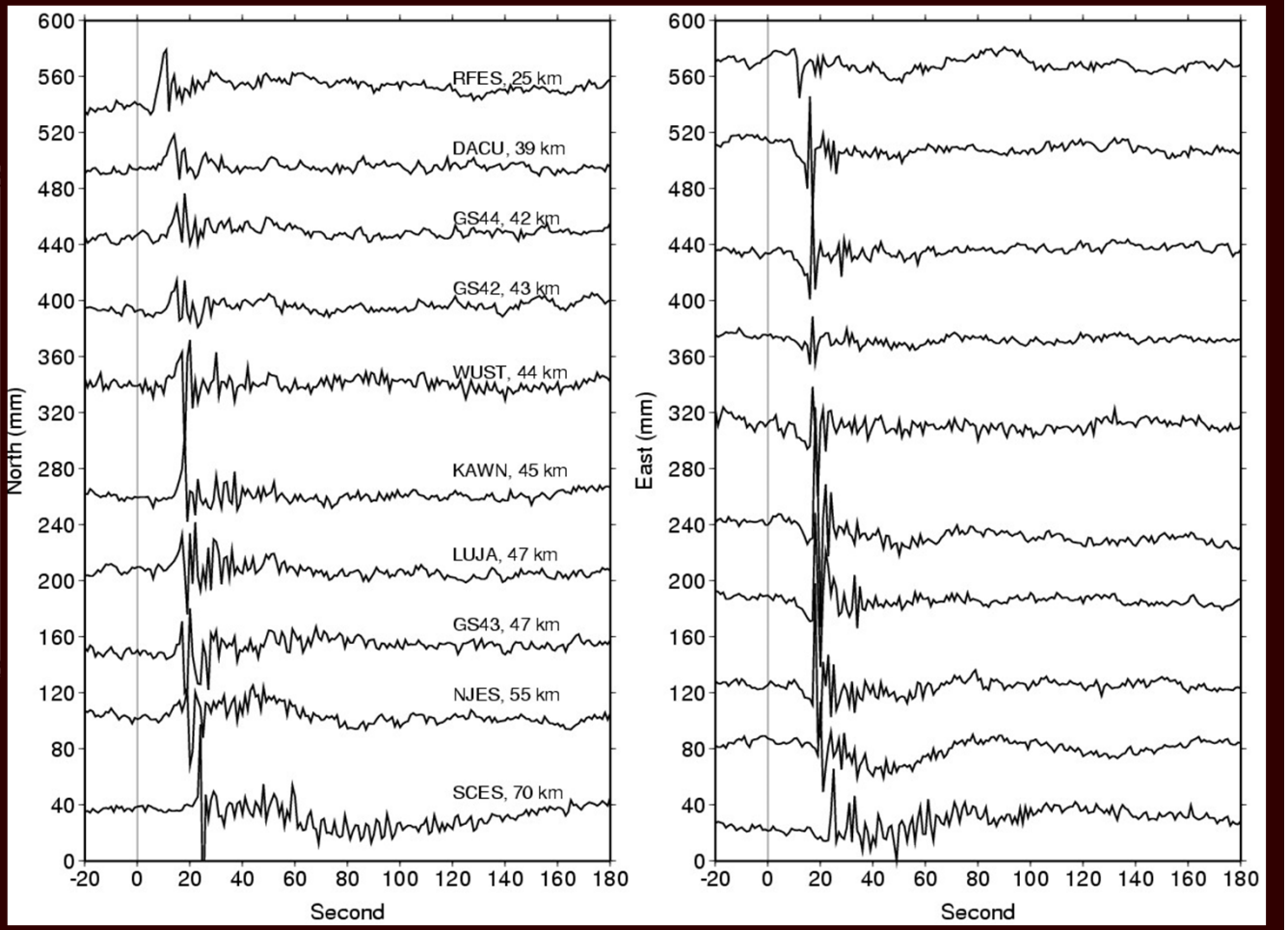
Differences between two observations

Displacement field from 0-48 seconds



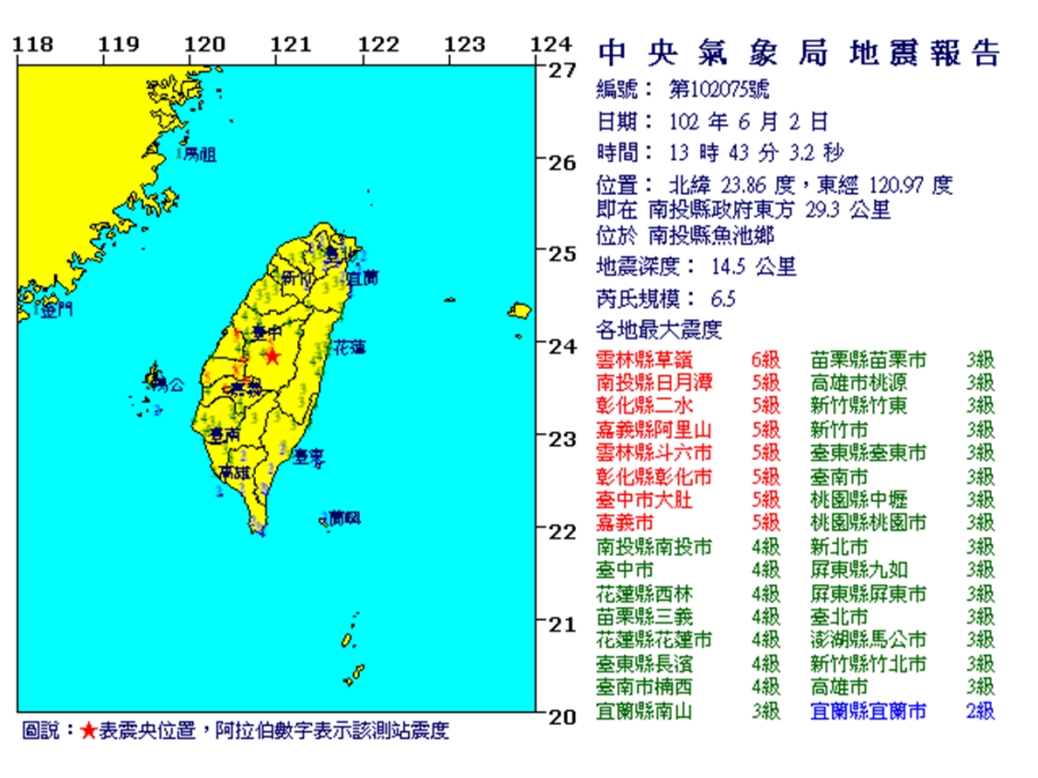
Horizontal CGPS displacements

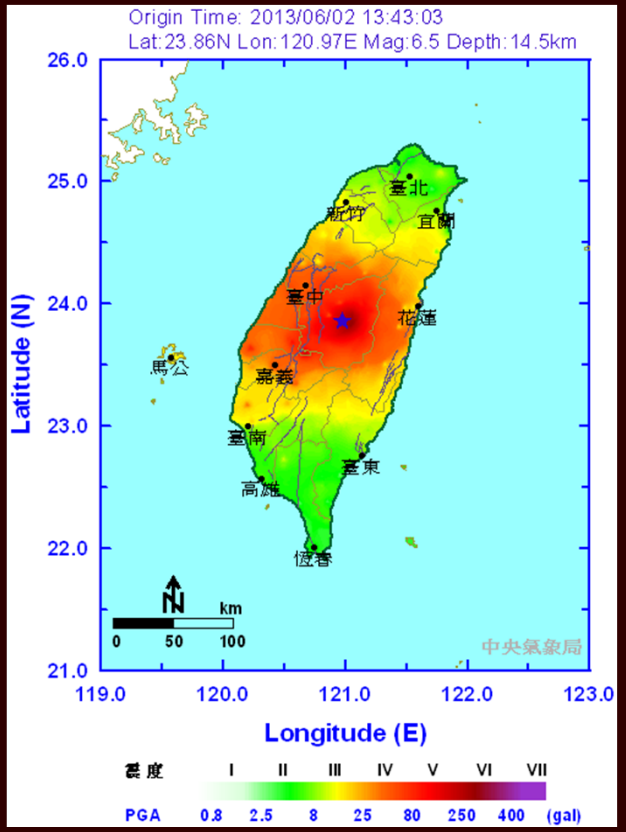




GPS Seismology in Taiwan

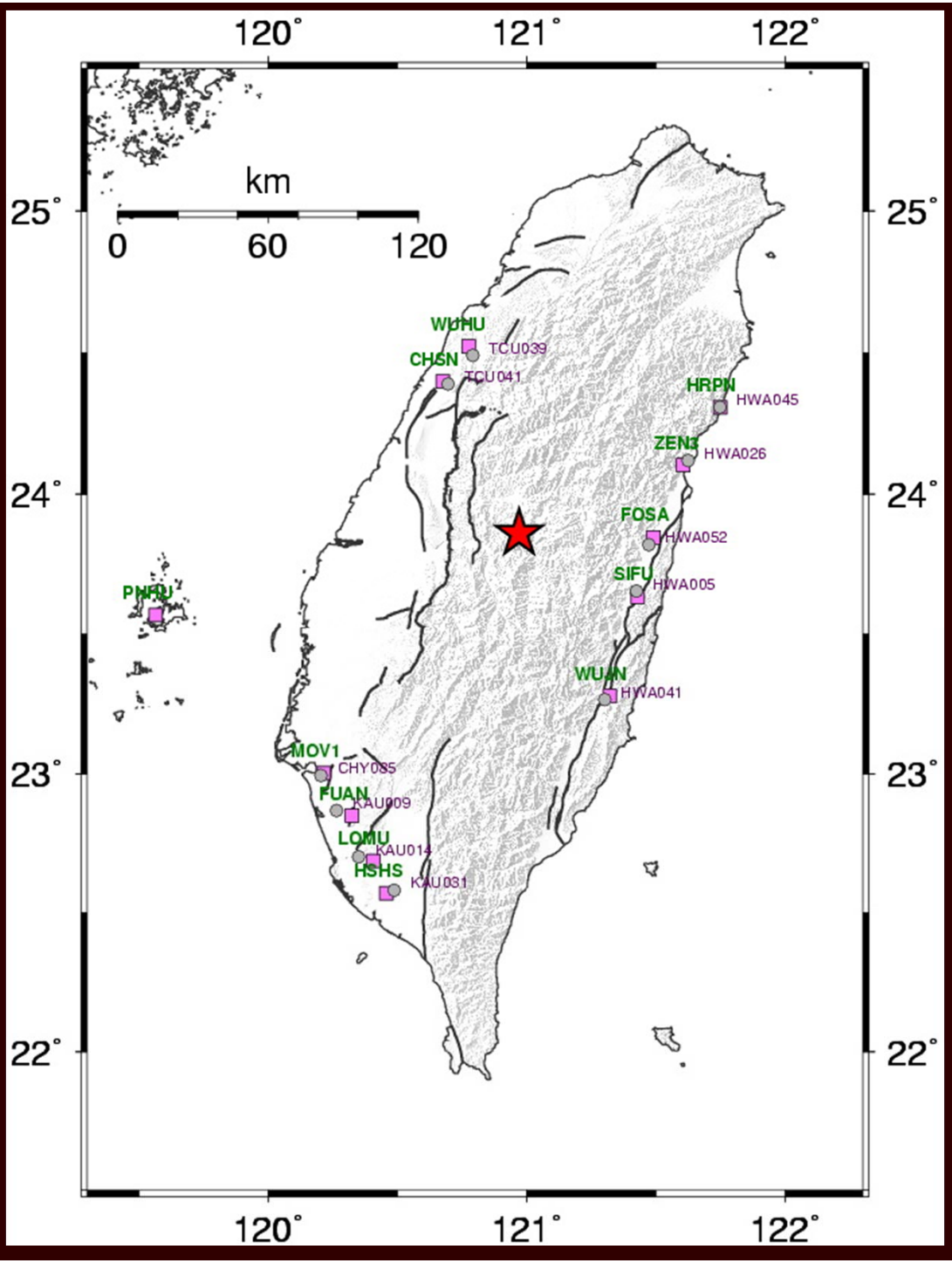
- 2011 Tohoku earthquake (1-Hz, 2400-2800 km)
- 2010 Jiashian earthquake (1-Hz, 10 -120 km)
- 2013 June 2nd Nantou earthquake (20-Hz)



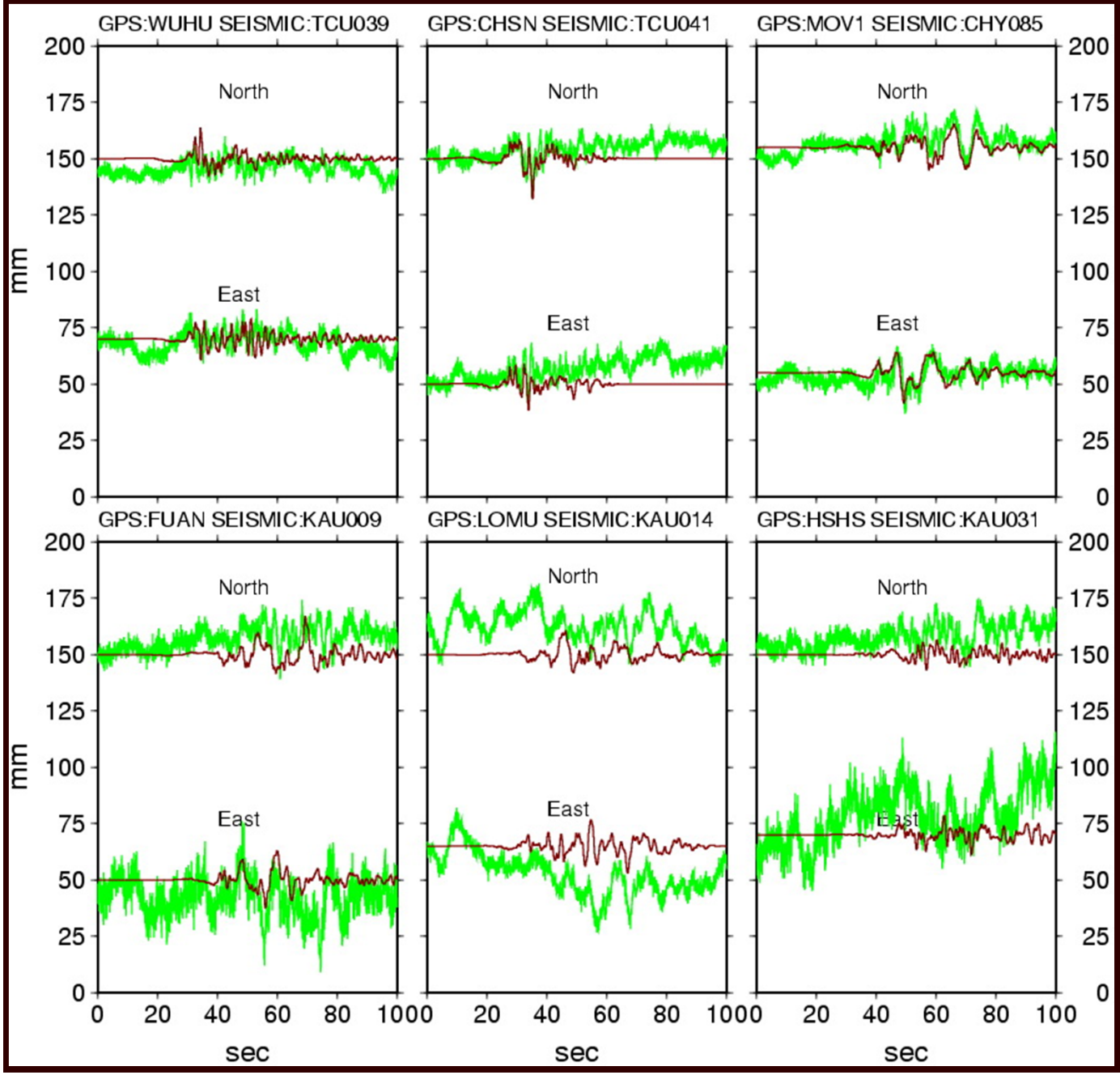


Nantou EQ

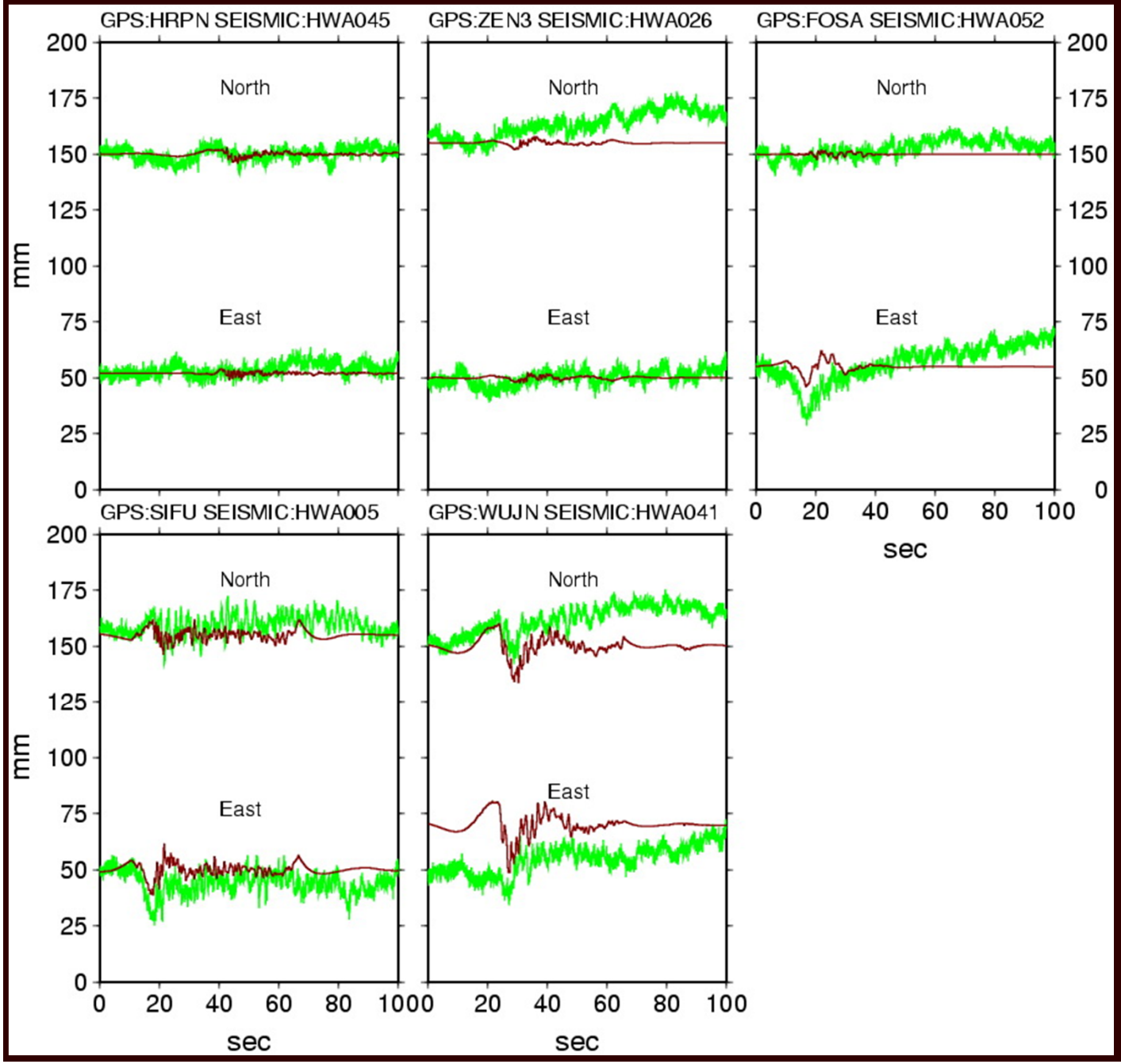
- 12 CGPS stations (20-Hz)
- PNHU – FIX stations (澎湖)
- 11 strong motion data (200-Hz)

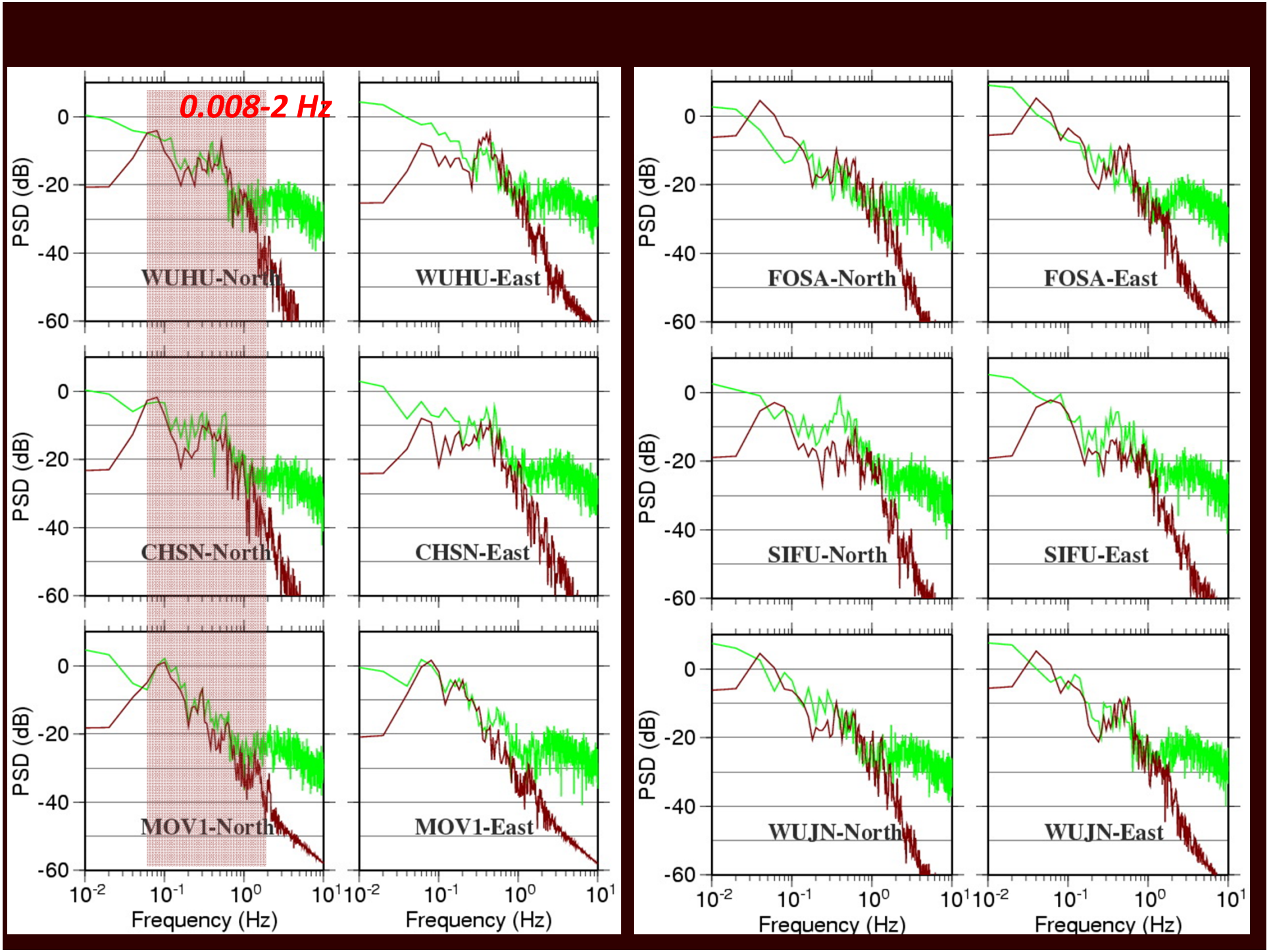


Ultra-high-rate GPS displacements (western Taiwan)



Ultra-high-rate GPS displacements (eastern Taiwan)




0.008-2 Hz
WUHU-North
WUHU-East
FOSA-North
FOSA-East
CHSN-North
CHSN-East
SIFU-North
SIFU-East
MOV1-North
MOV1-East
WUJN-North
WUJN-East
PSD (dB)
0
-20
-40
-60
10^{-2}
10^{-1}
10^{0}
10^{1}
Frequency (Hz)

Discussion- capacity of 1-Hz CGPS data

Amplitude

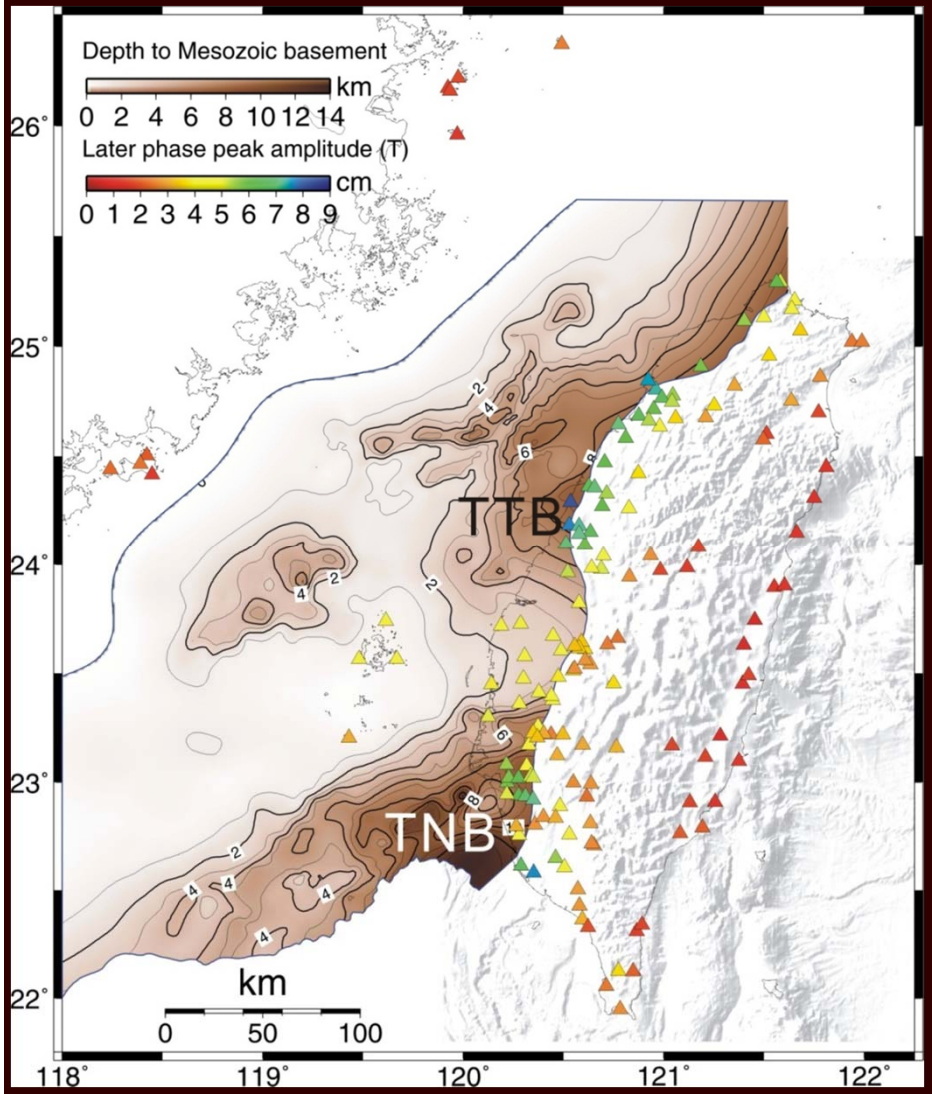
- PPP positioning - ~0.5 cm horizontal, ~3 cm vertical
- Differential positioning - ~0.6 cm horizontal, ~5 cm vertical
- Least amplitude we can detect using high-rate GPS is 6 mm for horizontal

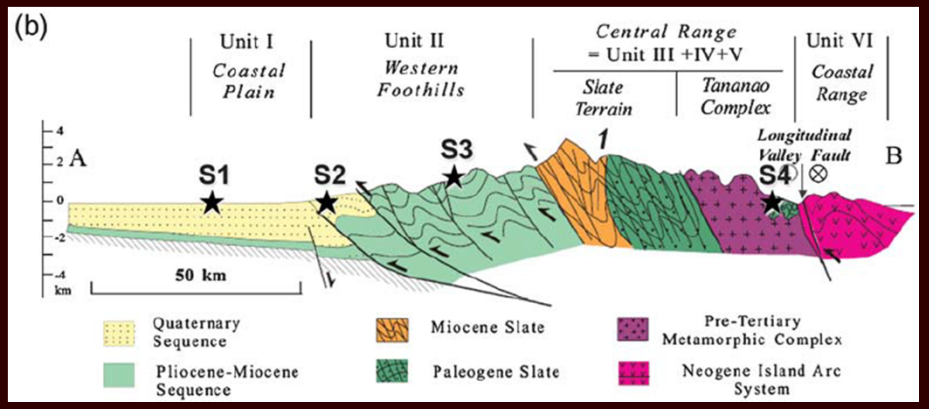
Frequency

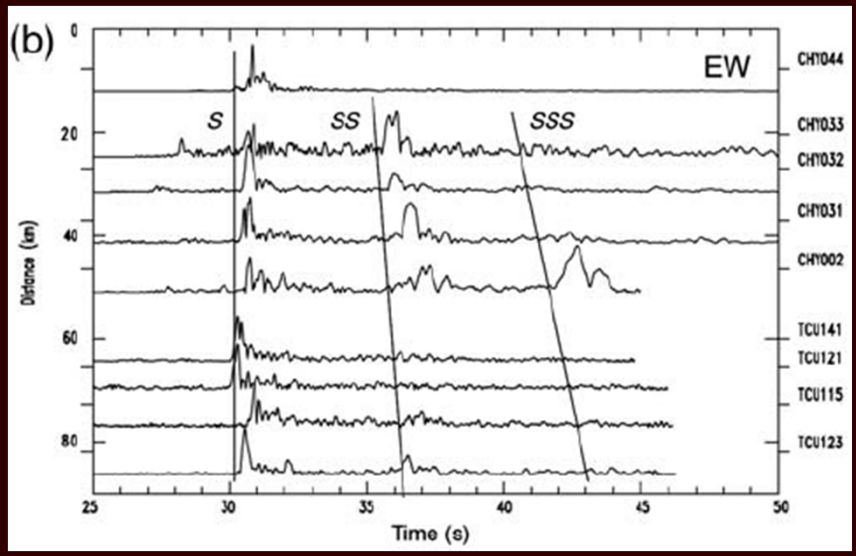
- Tohoku earthquake – 0.008-0.08 Hz
- Jiashian earthquake – 0.2-3 Hz
- Nantou earthquake – 0.008-2 Hz

- 1-Hz sampling data, Nyquist frequency f_n = 0.5 Hz (good for Tohoku, not enough for Jiashian)
- 5-Hz signal, f_n = 10-Hz (least sampling rate for near-field earthquakes)

Behavior of later phase in west coastal region





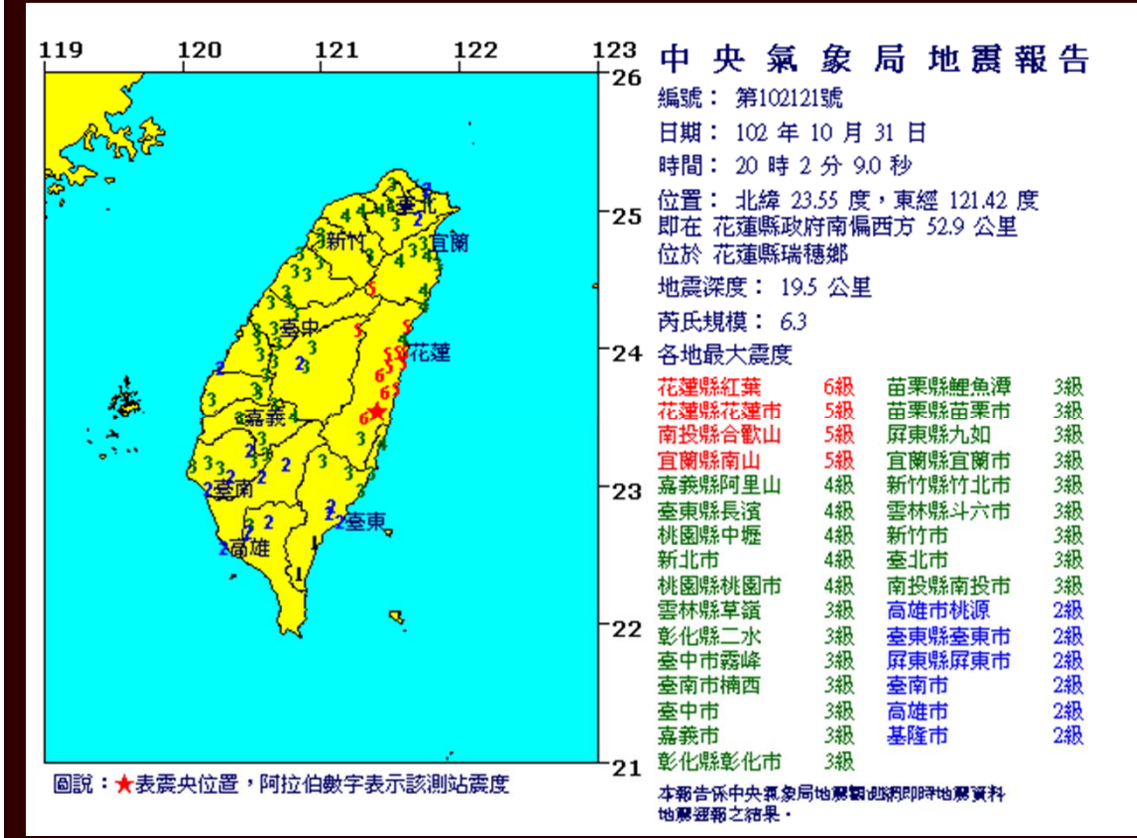


[Huang et al., 2013]

Conclusions

- For near-field earthquake
  - are capable of detecting the co-seismic displacement at the earthquake origin time
  - the frequency of seismic motions is too high to well detect by 1-Hz GPS solutions (10-Hz should be better)
  - Densely CGPS array indicates the propagations of the seismic waves
- For far-field earthquake
  - highly agreement between CGPS and BB displacements
  - clear attenuation and propagation of the surface waves
  - animation provides good opportunity for the scientific educations

2013-10/31 earthquake



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102121號

日期： 102 年 10 月 31 日

時間： 20 時 2 分 9.0 秒

位置： 北緯 23.55 度，東經 121.42 度
即在 花蓮縣政府南偏西方 52.9 公里
位於 花蓮縣瑞穗鄉

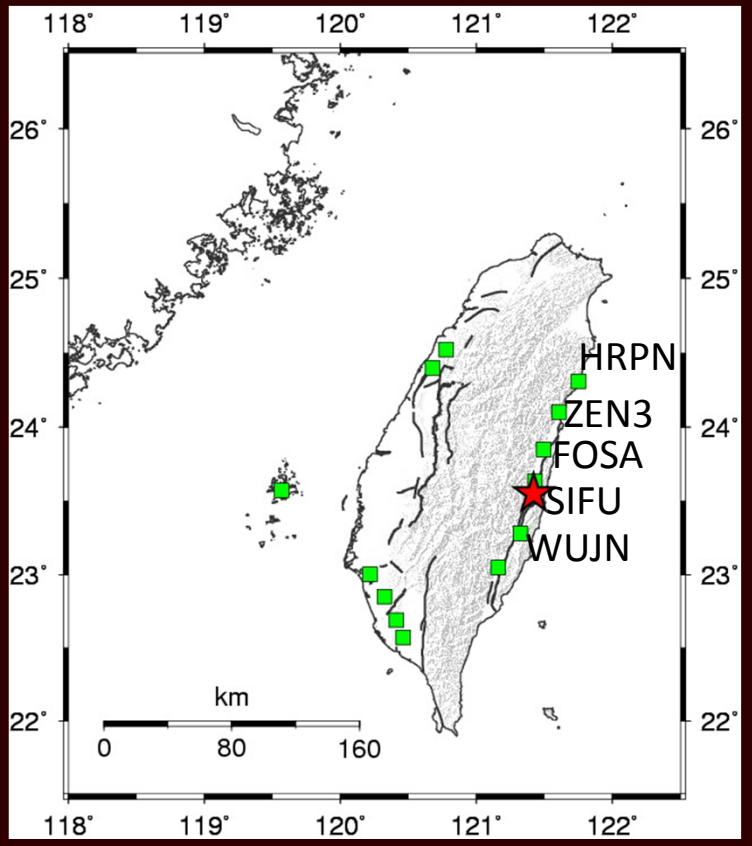
地震深度： 19.5 公里

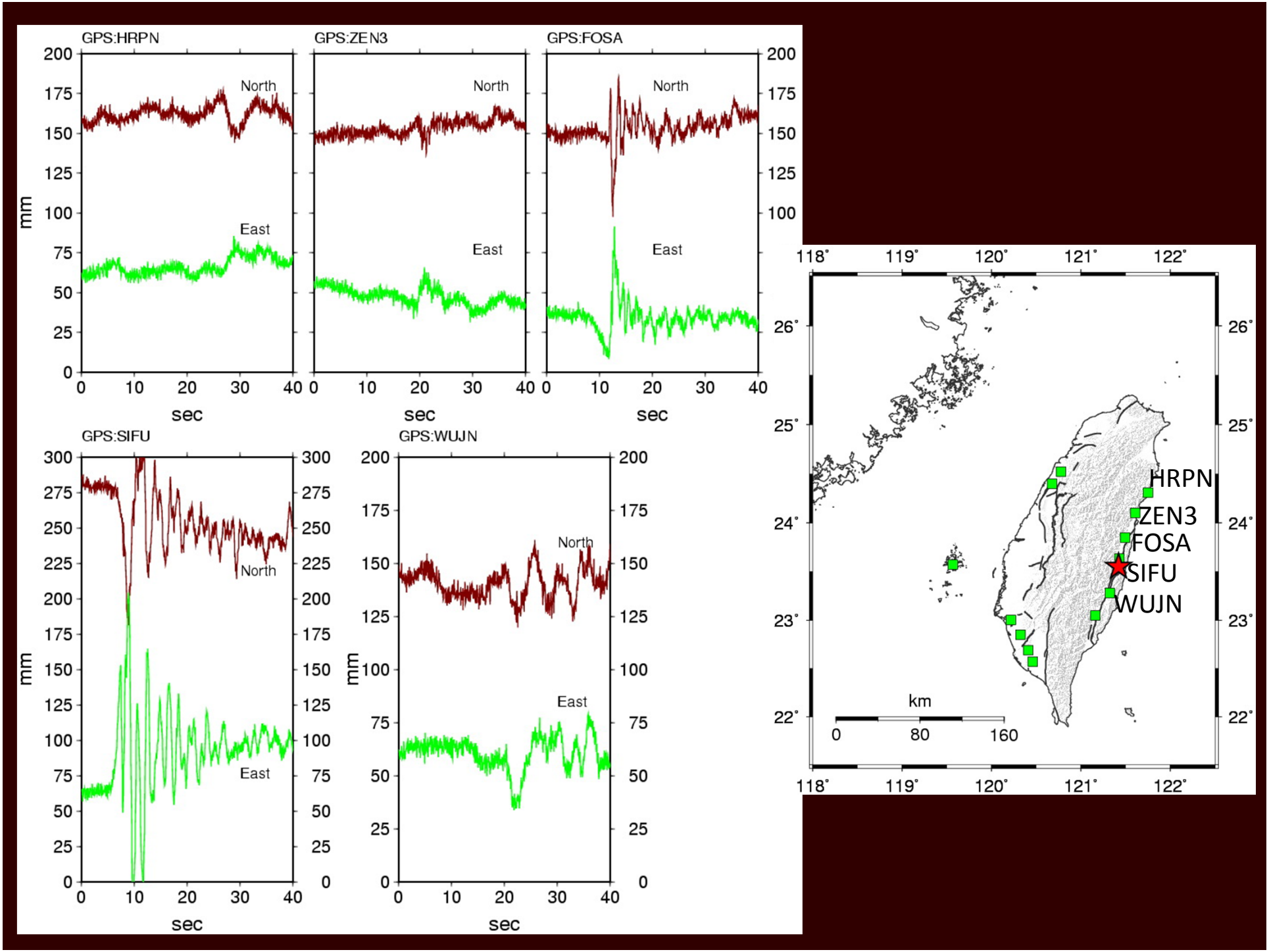
芮氏規模： 6.3

各地最大震度

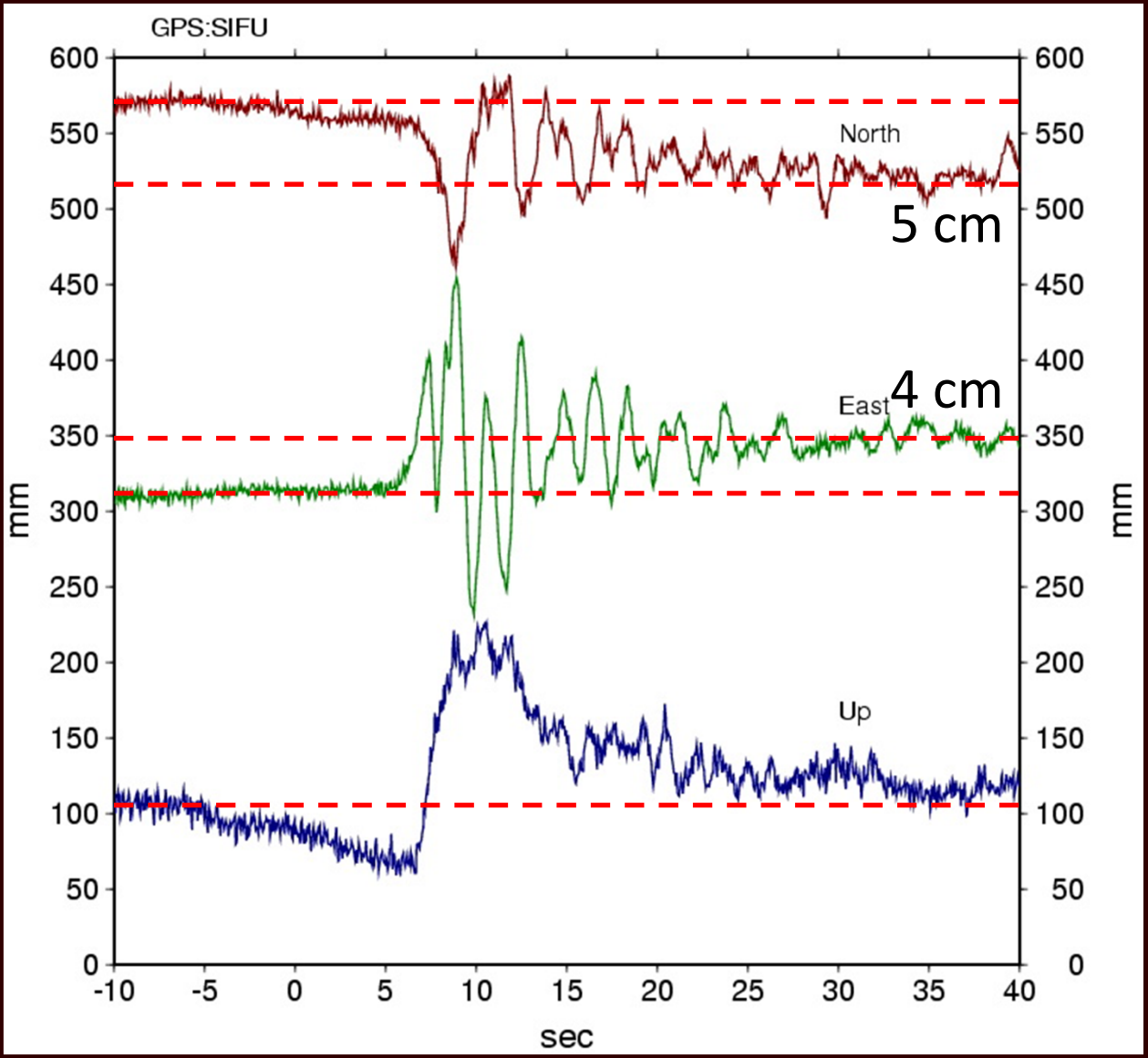
花蓮縣紅葉	6級	苗栗縣鯉魚潭	3級
花蓮縣花蓮市	5級	苗栗縣苗栗市	3級
南投縣合歡山	5級	屏東縣九如	3級
宜蘭縣南山	5級	宜蘭縣宜蘭市	3級
嘉義縣阿里山	4級	新竹縣竹北市	3級
臺東縣長濱	4級	雲林縣斗六市	3級
桃園縣中壢	4級	新竹市	3級
新北市	4級	臺北市	3級
桃園縣桃園市	4級	南投縣南投市	3級
雲林縣草嶺	3級	高雄市桃源	2級
彰化縣二水	3級	臺東縣臺東市	2級
臺中市霧峰	3級	屏東縣屏東市	2級
臺南市楠西	3級	臺南市	2級
臺中市	3級	高雄市	2級
嘉義市	3級	基隆市	2級
彰化縣彰化市	3級		

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。




GPS:HRPN
GPS:ZEN3
GPS:FOSA
GPS:SIFU
GPS:WUJN
North
East
mm
sec
HRPN
ZEN3
FOSA
SIFU
WUJN
km
0
80
160
118°
119°
120°
121°
122°
22°
23°
24°
25°
26°

SIFU


GPS:SIFU
North
East
Up
5 cm
4 cm
mm
sec
600
550
500
450
400
350
300
250
200
150
100
50
0
-10
-5
0
5
10
15
20
25
30
35
40