利用時序方法研究
日本311地震震前的地殼變形

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大綱

- 台灣的地殼變形觀測
- 地震前的地殼變形研究(Chen et al., 2011)
- 時間異常轉換至空間異常(Chen et al., 2013a)
- 震前地殼變形與地下水(Chen et al., 2013b)、電磁異常之耦合
- 日本Tohoku地震震前地殼變形異常
- 結論

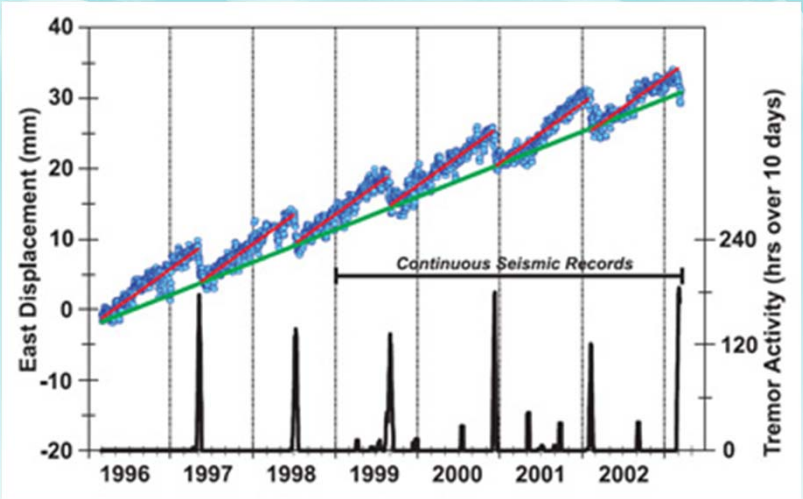
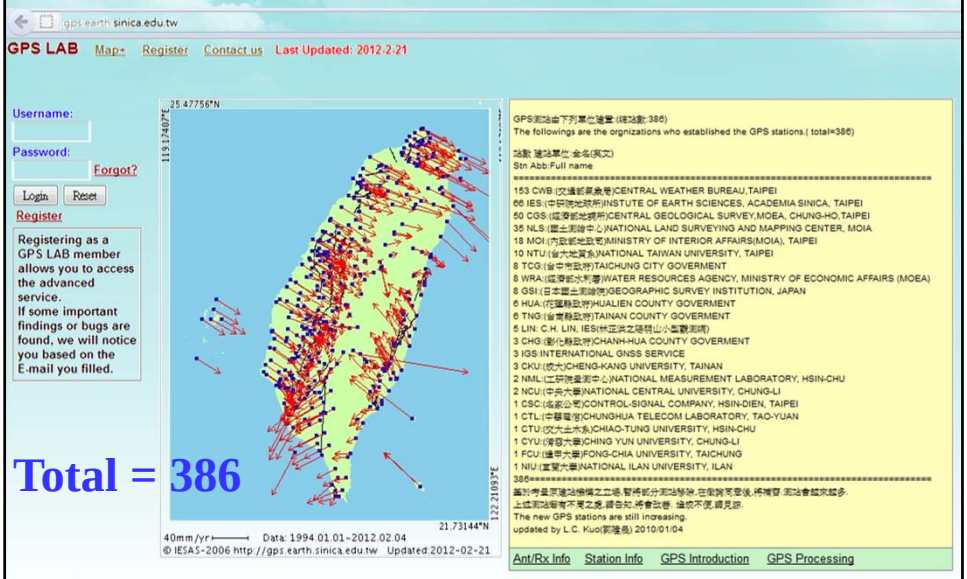
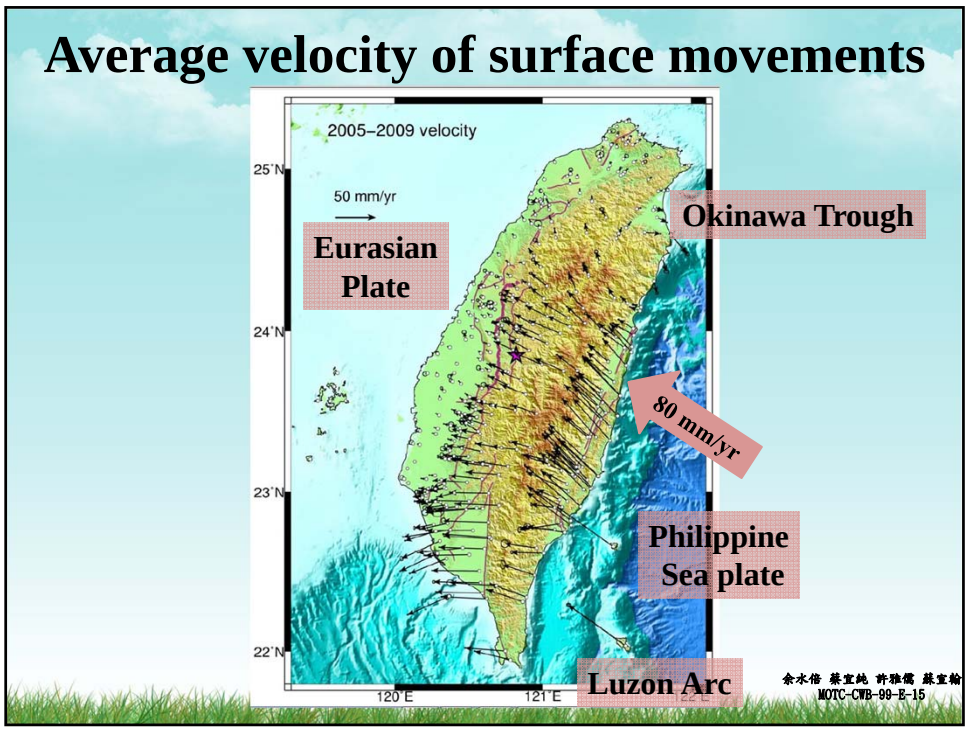
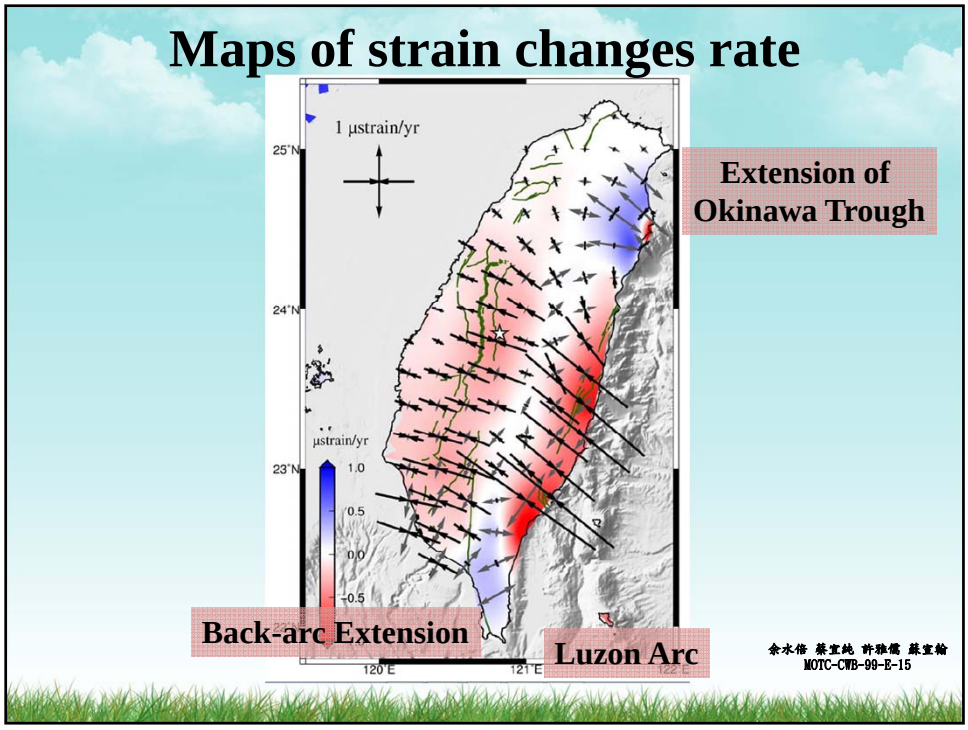


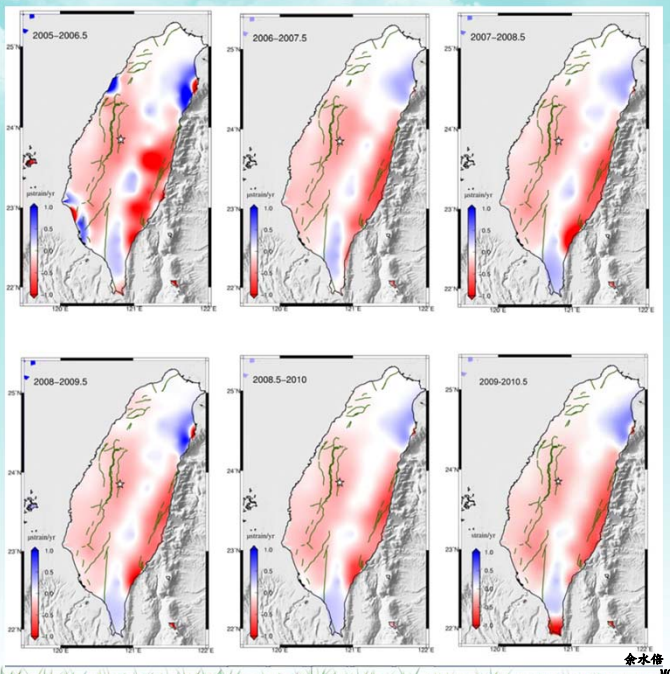
Figure 1 - Image of episodic tremor and slip. Garry Rogers and Herb Dragert, Episodic Tremor and Slip on the Cascadia Subduction Zone: The Chatter of Silent Slip, Science Express on 8 May 2003 and Science 20 June 2003:, Vol. 300. no. 5627, pp. 1942 – 1943, DOI: 10.1126/science.1084783.

GPS stations in Taiwan



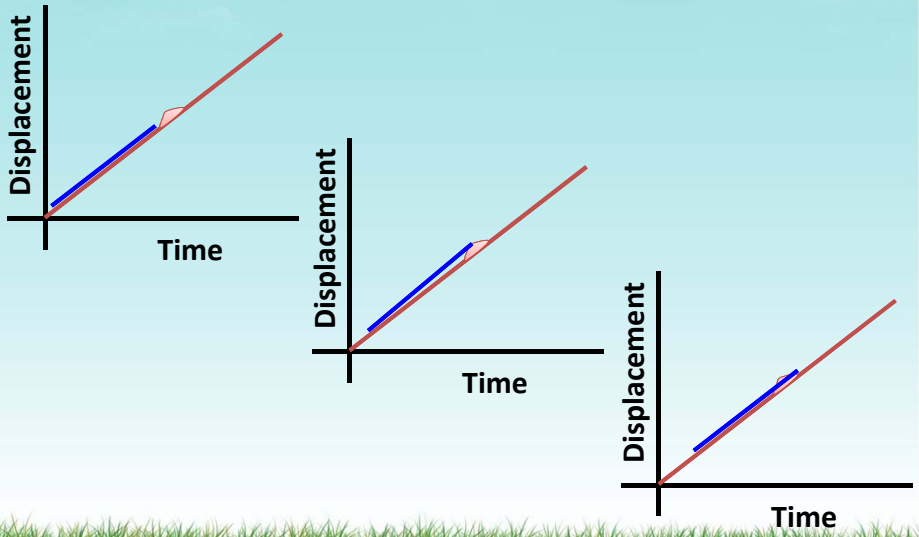

Average velocity of surface movements
2005–2009 velocity
50 mm/yr
Eurasian Plate
Okinawa Trough
80 mm/yr
Philippine Sea plate
Luzon Arc
25°N
24°N
23°N
22°N
120°E
121°E
余水倍 蔡宜純 許雅儒 蘇宜翰
MOTC-CWB-99-E-15


Maps of strain changes rate
1 μstrain/yr
Extension of Okinawa Trough
μstrain/yr
1.0
0.5
0.0
-0.5
Back-arc Extension
Luzon Arc
25°N
24°N
23°N
120°E
121°E
余水倍 蔡宜純 許雅儒 蘇宜翰
MOTC-CWB-99-E-15



余水倍 蔡宜純 許雅儒 蘇宜翰
MOTC-CWB-99-E-15

持續時間不明 → 無法得到決定參考點與觀測點
位移大小不明 → 長期板塊運動掩蓋了訊號



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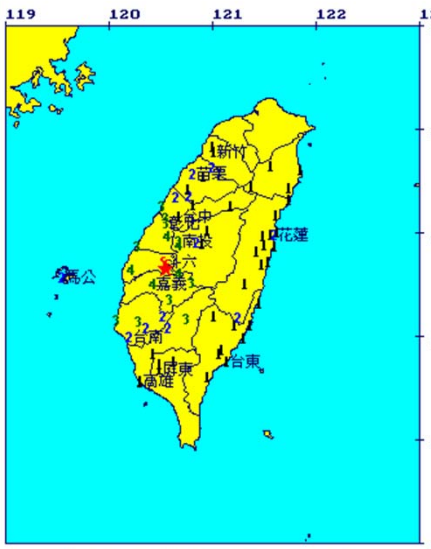
Case study



中央氣象局地震報告

編號： 第950178號
日期： 95 年 3 月 9 日
時間： 12 時 7 分 28.8 秒
位置： 北緯 23.64 度，東經 120.56 度
即在 雲林古坑地震站南方 4.6 公里
地震深度： 9.9 公里
芮氏規模： 5.1

各地最大震度

雲林古坑	5級	花蓮市	2級
斗六市	5級	台中市	1級
嘉義市	4級	台東利稻	1級
南投名間	4級	屏東三地門	1級
彰化員林	4級	屏東市	1級
嘉義阿里山	3級	台東市	1級
南投市	3級	宜蘭南山	1級
彰化市	3級	高雄市	1級
台中大肚	3級	新竹市	1級
高雄桃源	3級	新竹竹北	1級
台南善化	3級		
苗栗鯉魚潭	2級		
台南市	2級		
花蓮富里	2級		
澎湖馬公	2級		
苗栗市	2級		

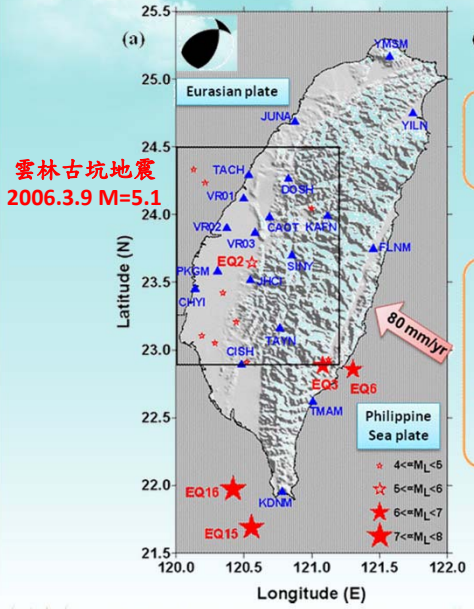
圖說：★表震央位置，阿拉伯數字表示該測站震度

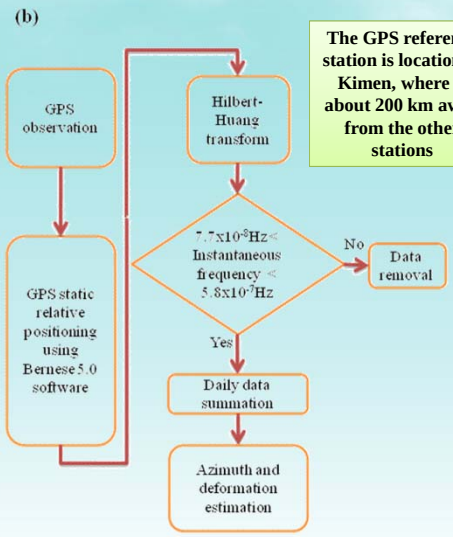
Chen et al. (2011), Surveys in Geophysics

Comparisons among the FFT、WT and HT

	Fourier	Wavelet	Hilbert-Huang
Basis	A priori	A prior	Adaptive
Frequency	Global uncertainty	Regional uncertainty	Local uncertainty
Presentation	Energy-frequency	Energy-time-frequency	Energy-time-frequency
Nonlinear	No	No	Yes
Non-stationary	No	Yes	Yes
Feature Extraction	No	discrete : No Continuous : Yes	Yes
Theoretical base	Theory complete	Theory complete	empirical

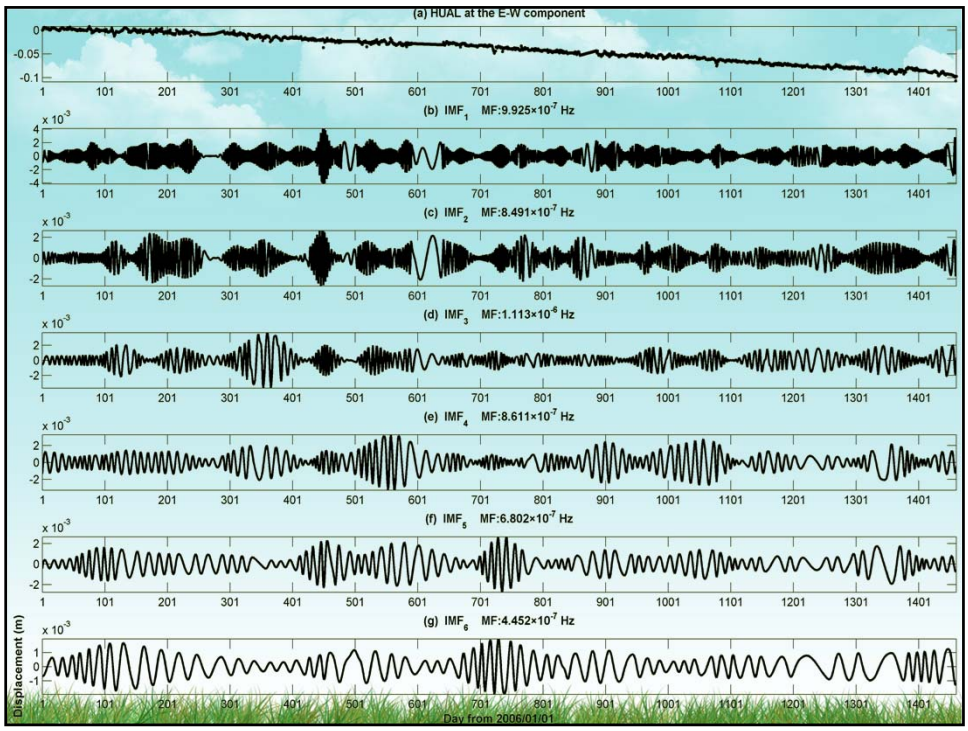
地震引起之地殼變形異常分析

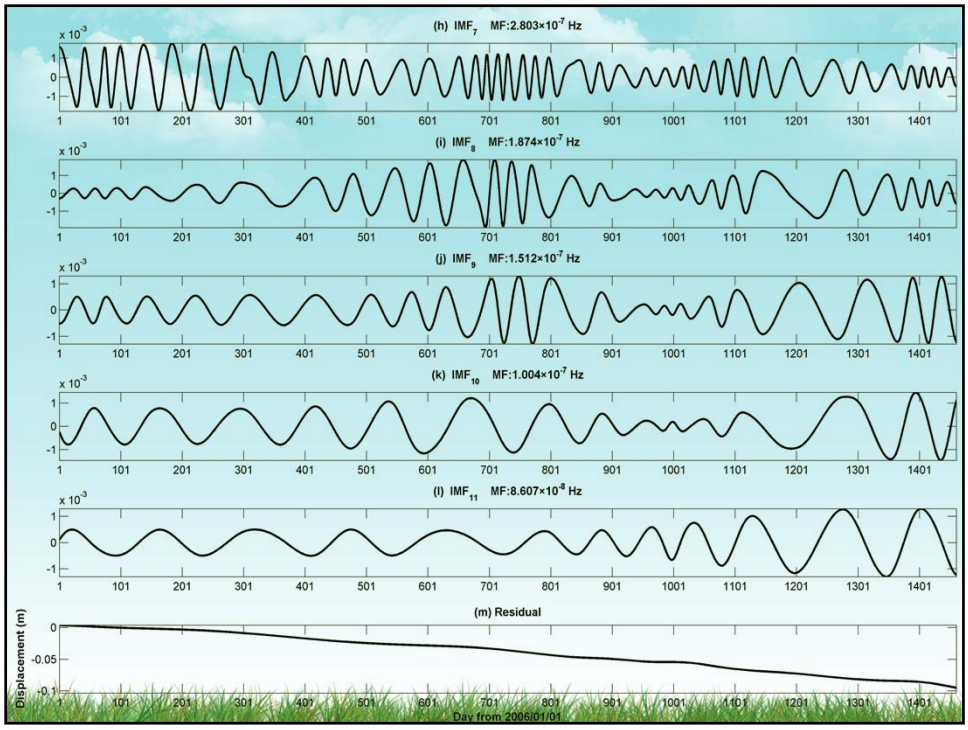




The GPS reference station is location in Kimen, where is about 200 km away from the other stations

Chen et al., (2011) Survey in Geophysics

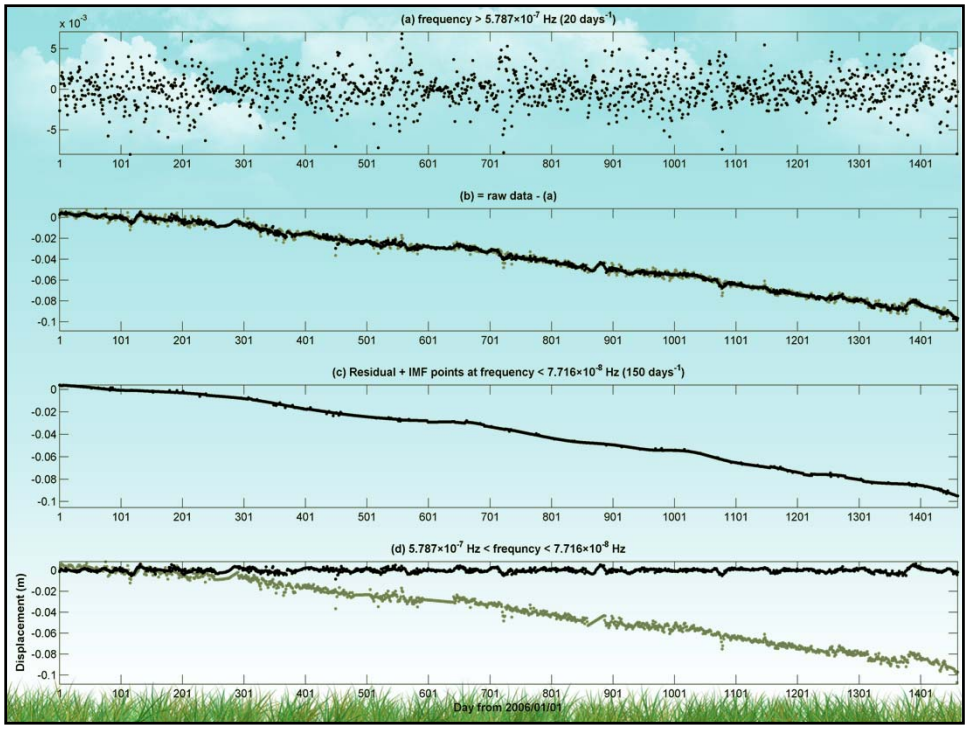

(a) HUAL at the E-W component
(b) IMF1 MF:9.925×10-7 Hz
(c) IMF2 MF:8.491×10-7 Hz
(d) IMF3 MF:1.113×10-6 Hz
(e) IMF4 MF:8.611×10-7 Hz
(f) IMF5 MF:6.802×10-7 Hz
(g) IMF6 MF:4.452×10-7 Hz
Displacement (m)
Day from 2006/01/01

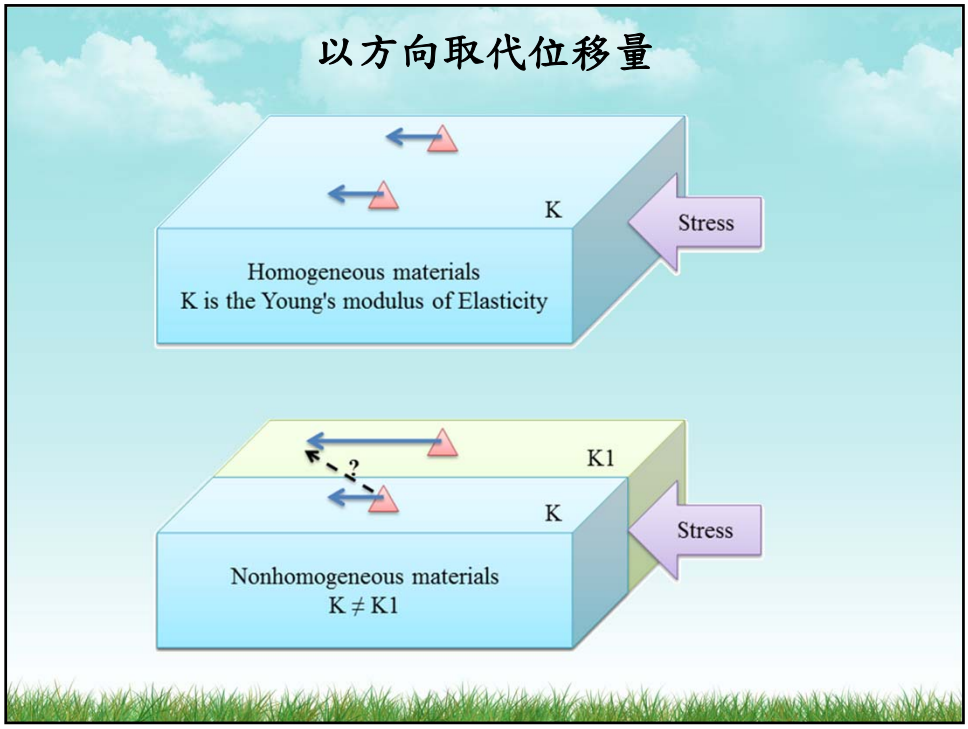

(h) IMF7 MF:2.803×10-7 Hz
(i) IMF8 MF:1.874×10-7 Hz
(j) IMF9 MF:1.512×10-7 Hz
(k) IMF10 MF:1.004×10-7 Hz
(l) IMF11 MF:8.607×10-8 Hz
(m) Residual
Displacement (m)
Day from 2006/01/01

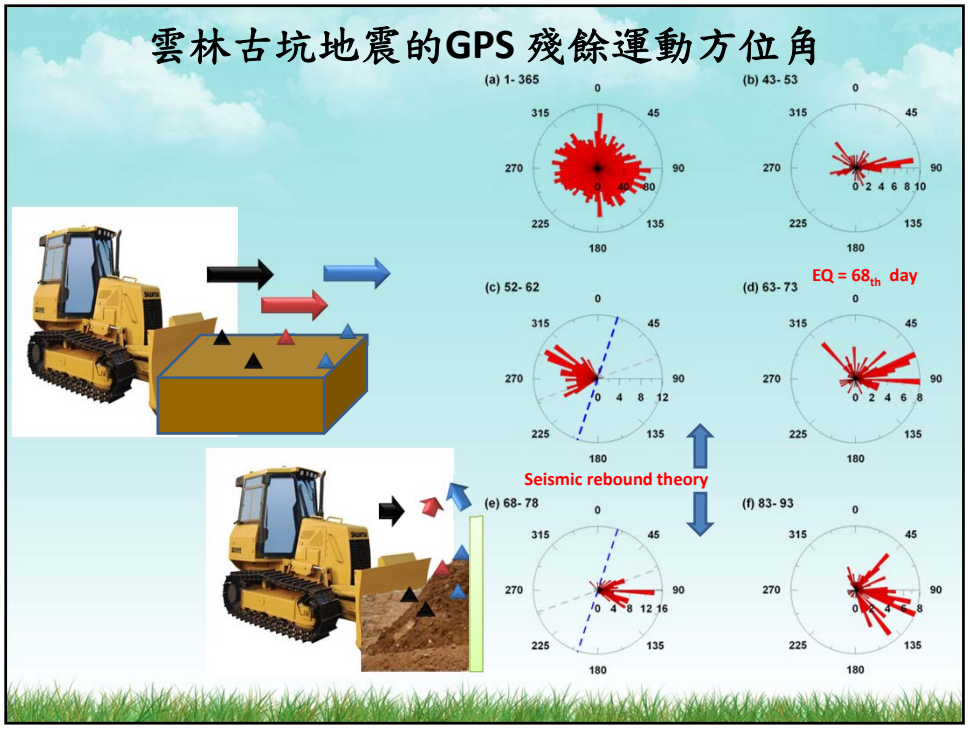
Median frequency and period of the IMFs in the EW component at the HOUL station

IMFs	Median frequency (Hz)	Median period (day)
1	9.9249×10^{-7}	11.7
2	8.4907×10^{-7}	13.6
3	1.1127×10^{-6}	10.4
4	8.6112×10^{-7}	13.4
5	6.8018×10^{-7}	17.1
6	4.4520×10^{-7}	26.0
7	2.8028×10^{-7}	41.3
8	1.8737×10^{-7}	61.8
9	1.5120×10^{-7}	76.5
10	1.0041×10^{-7}	115.3
11	8.6075×10^{-8}	134.5

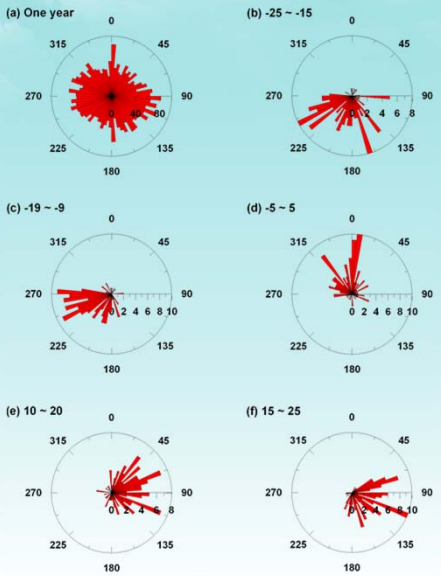
Chen et al. (2011), Surveys in Geophysics




以方向取代位移量
K
Stress
Homogeneous materials
K is the Young's modulus of Elasticity
K1
?
K
Stress
Nonhomogeneous materials
K ≠ K1

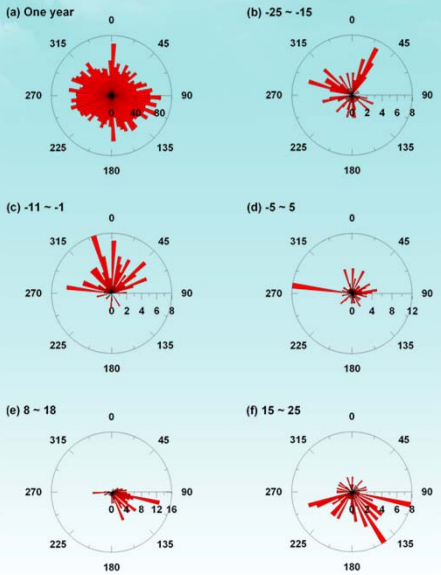

雲林古坑地震的GPS 殘餘運動方位角
(a) 1- 365
(b) 43- 53
(c) 52- 62
(d) 63- 73
EQ = 68th day
Seismic rebound theory
(e) 68- 78
(f) 83- 93

EQ224



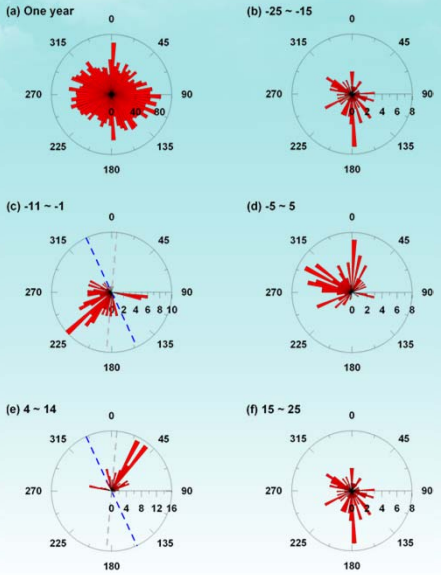
Chen et al. (2011), Surveys in Geophysics

EQ310

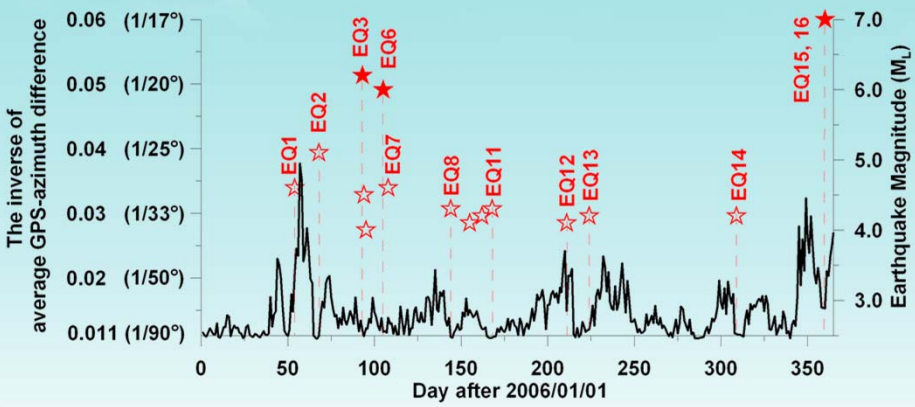


Chen et al. (2011), Surveys in Geophysics

M7 屏東地震



Chen et al. (2011), Surveys in Geophysics



Chen et al. (2011), Surveys in Geophysics

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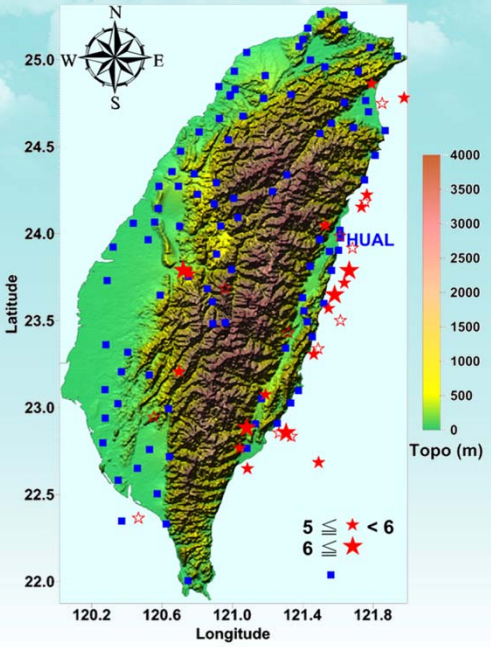
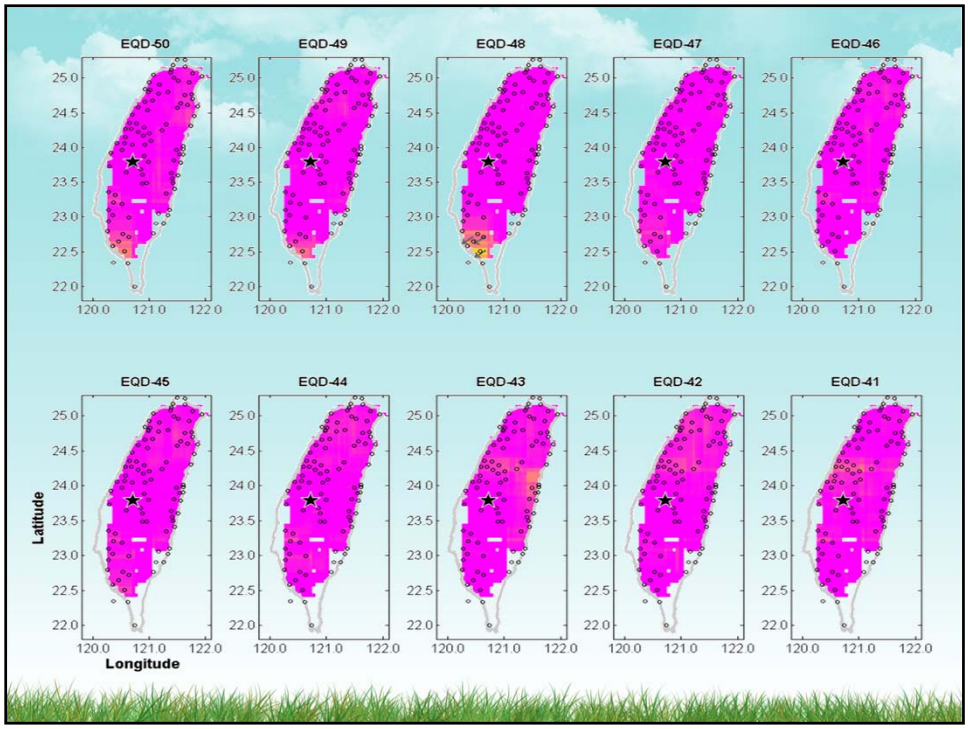
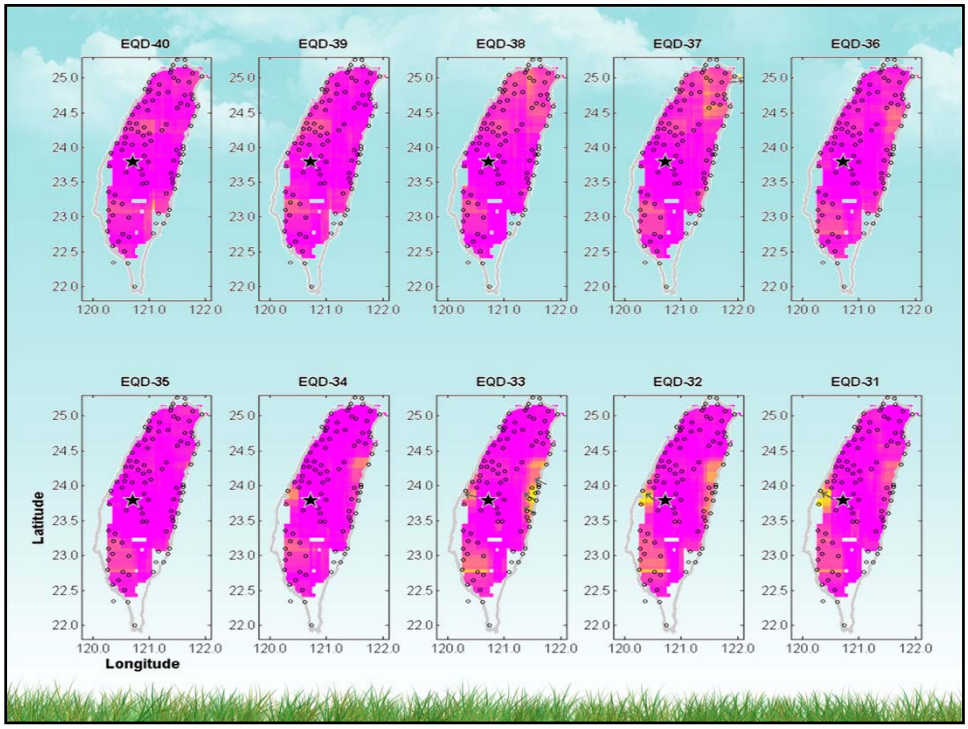
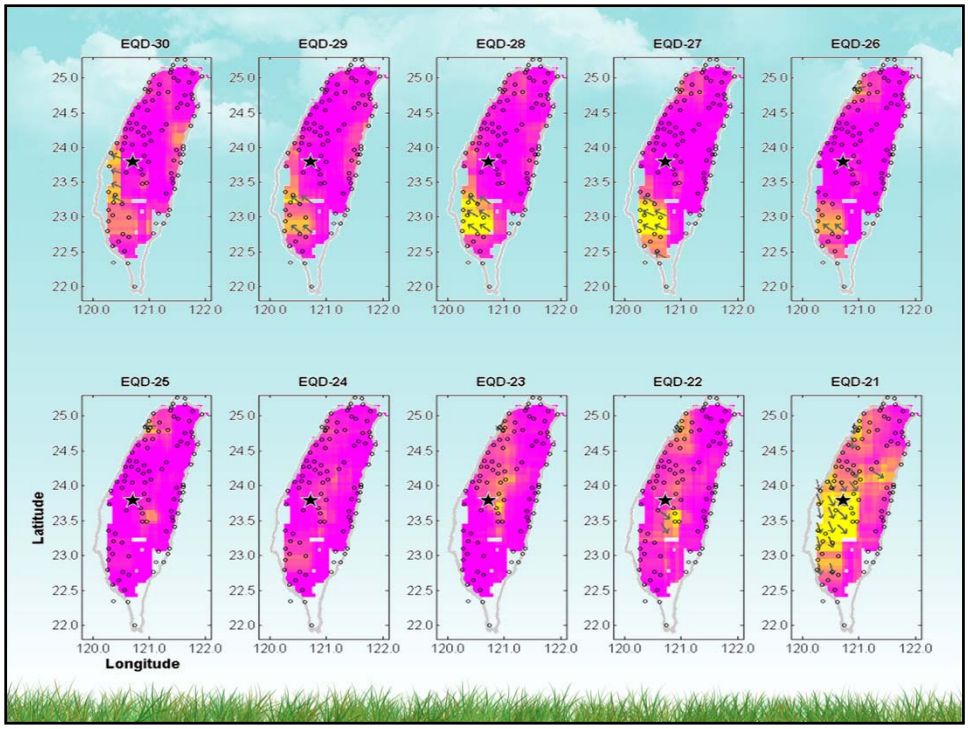


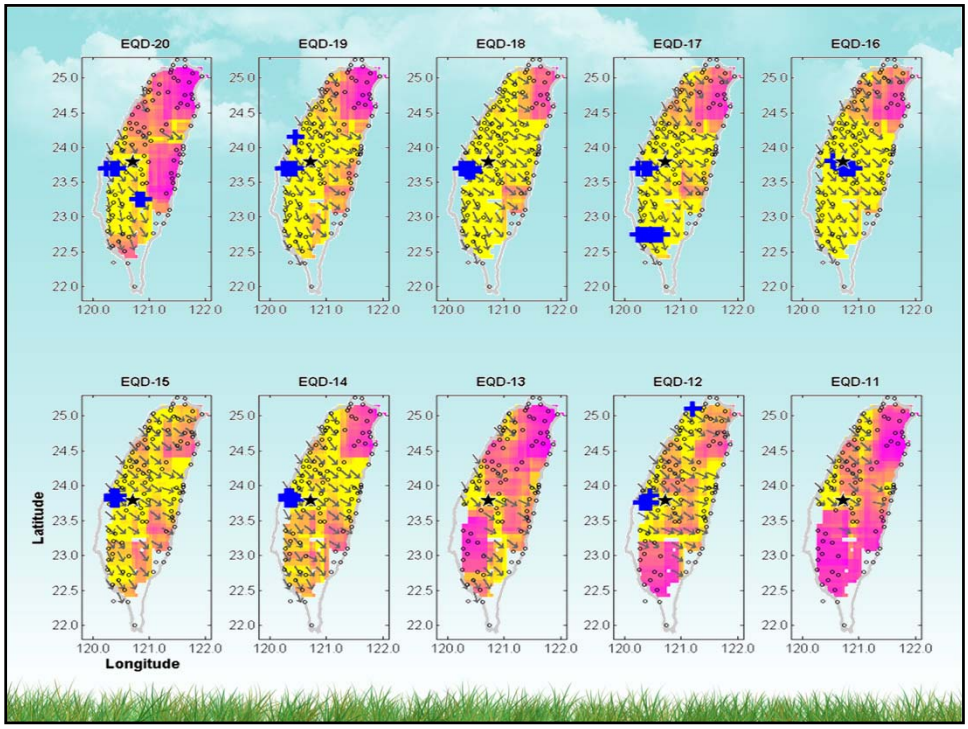
Event survey

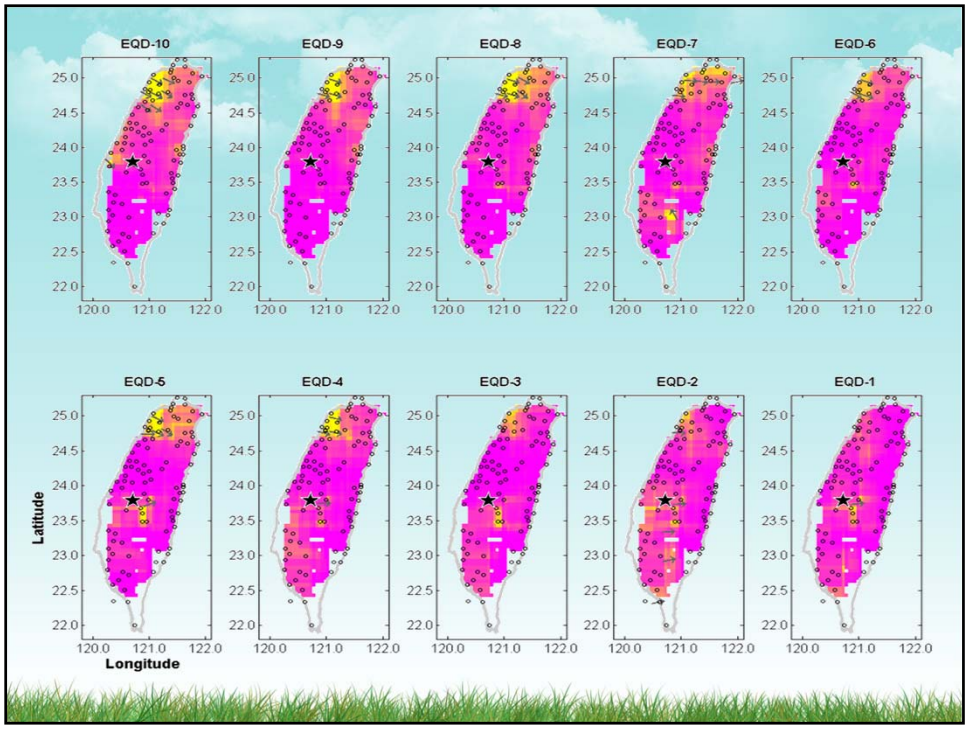
名間地震
(2009.11.5 M=5.7)



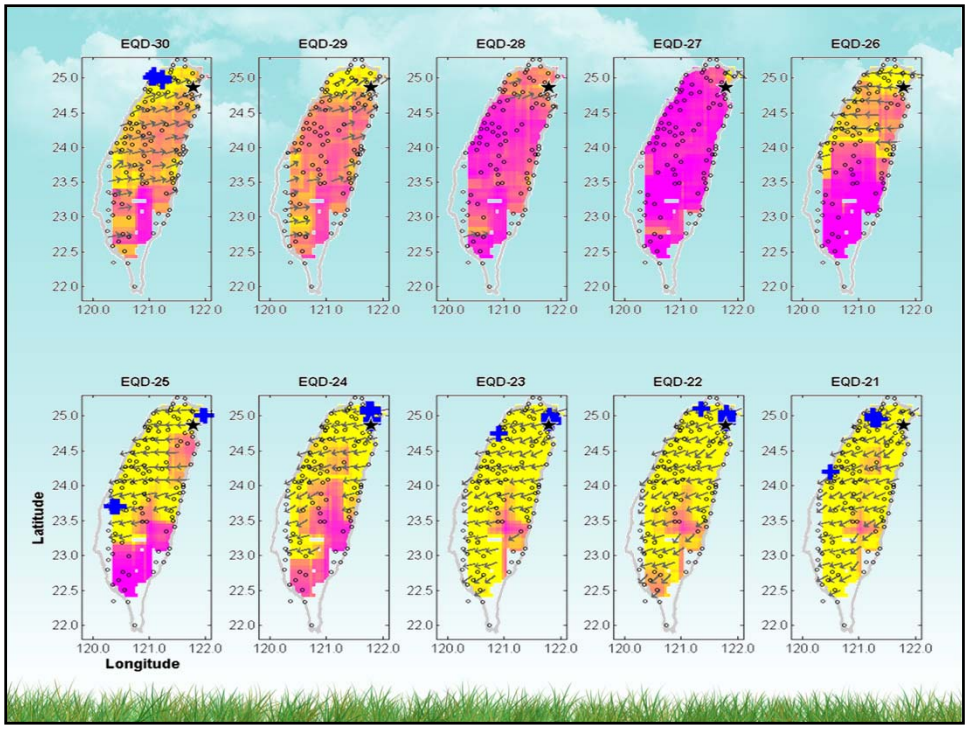

EQD-40
EQD-39
EQD-38
EQD-37
EQD-36
EQD-35
EQD-34
EQD-33
EQD-32
EQD-31
Latitude
Longitude

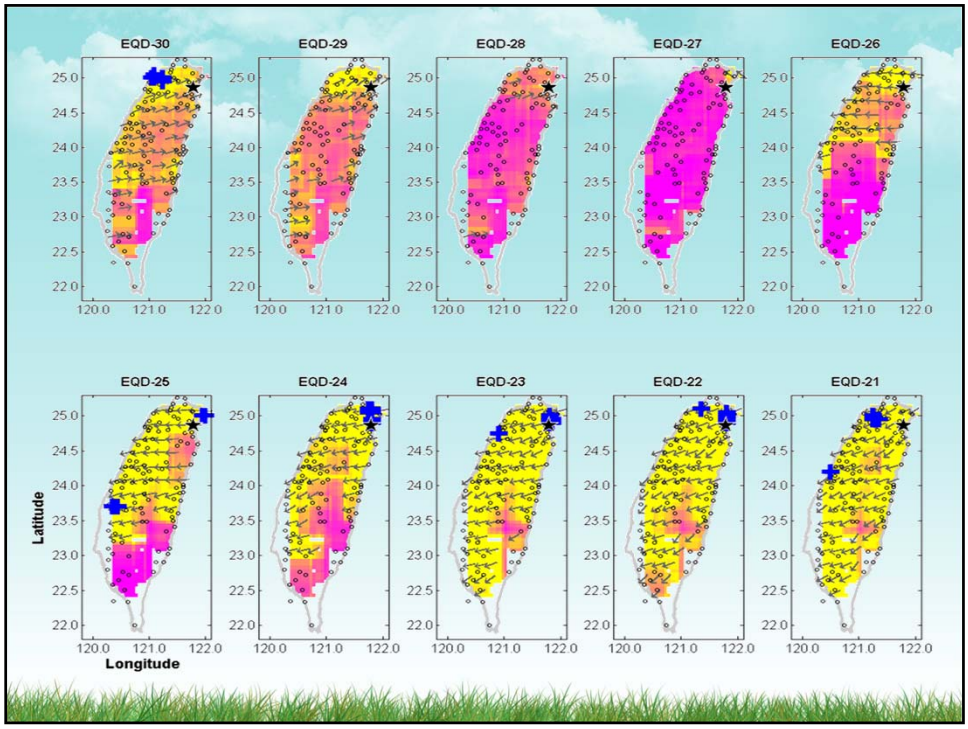

EQD-30
EQD-29
EQD-28
EQD-27
EQD-26
EQD-25
EQD-24
EQD-23
EQD-22
EQD-21
Latitude
Longitude

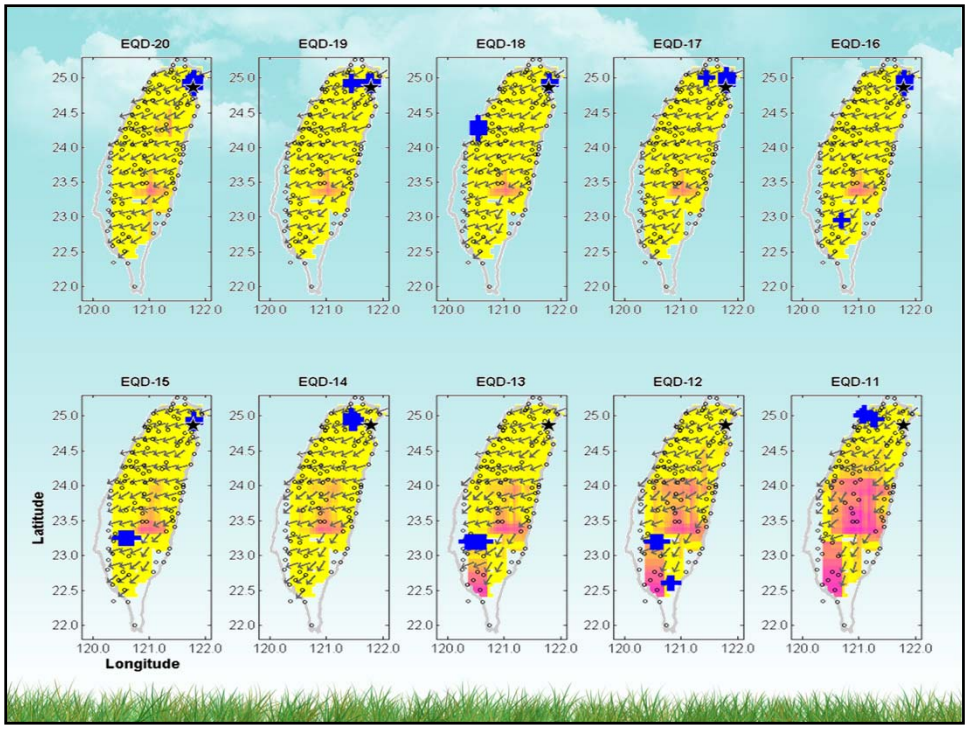

EQD-20
EQD-19
EQD-18
EQD-17
EQD-16
EQD-15
EQD-14
EQD-13
EQD-12
EQD-11
Latitude
Longitude

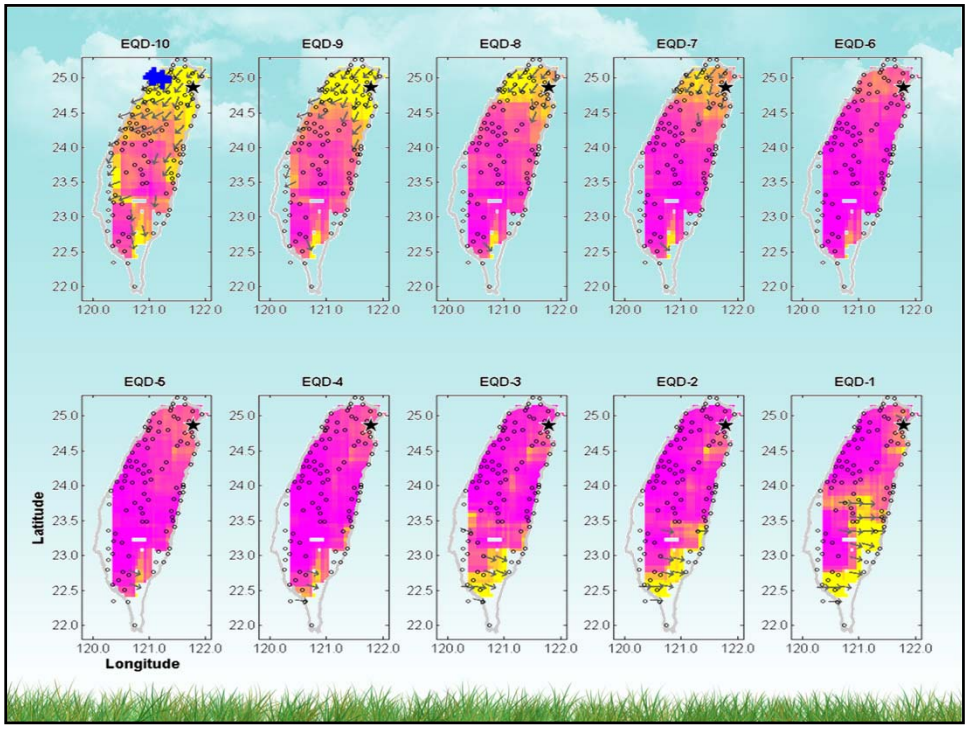

EQD-10
EQD-9
EQD-8
EQD-7
EQD-6
EQD-5
EQD-4
EQD-3
EQD-2
EQD-1
Latitude
Longitude

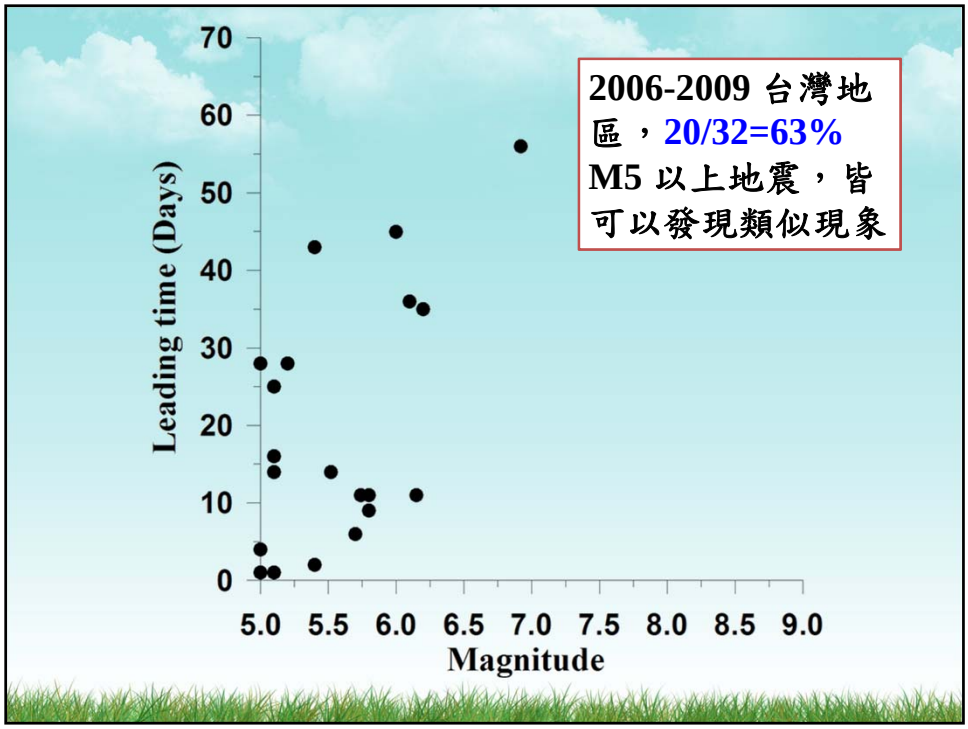
(2008.6.1 M=5.8)


EQD-30
EQD-29
EQD-28
EQD-27
EQD-26
EQD-25
EQD-24
EQD-23
EQD-22
EQD-21
Latitude
Longitude


EQD-30
EQD-29
EQD-28
EQD-27
EQD-26
EQD-25
EQD-24
EQD-23
EQD-22
EQD-21
Latitude
Longitude


EQD-20
EQD-19
EQD-18
EQD-17
EQD-16
EQD-15
EQD-14
EQD-13
EQD-12
EQD-11
Latitude
Longitude


EQD-10
EQD-9
EQD-8
EQD-7
EQD-6
EQD-5
EQD-4
EQD-3
EQD-2
EQD-1
Latitude
Longitude


2006-2009 台灣地區，20/32=63%
M5 以上地震，皆可以發現類似現象
Leading time (Days)
Magnitude

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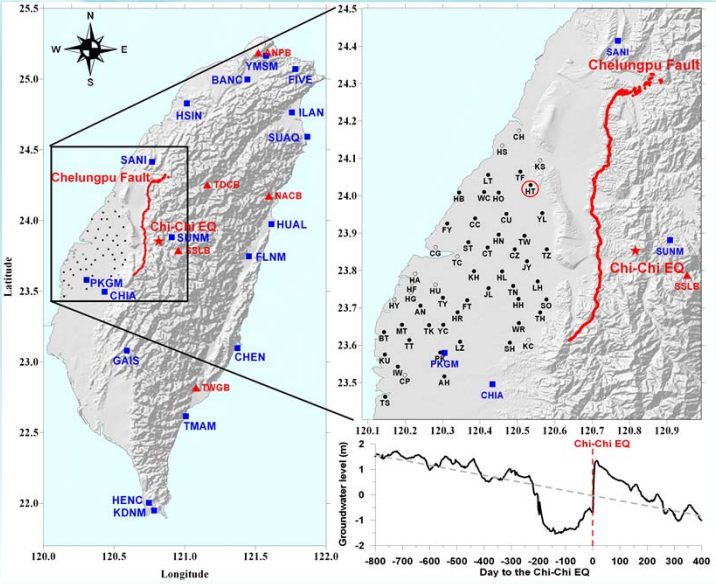
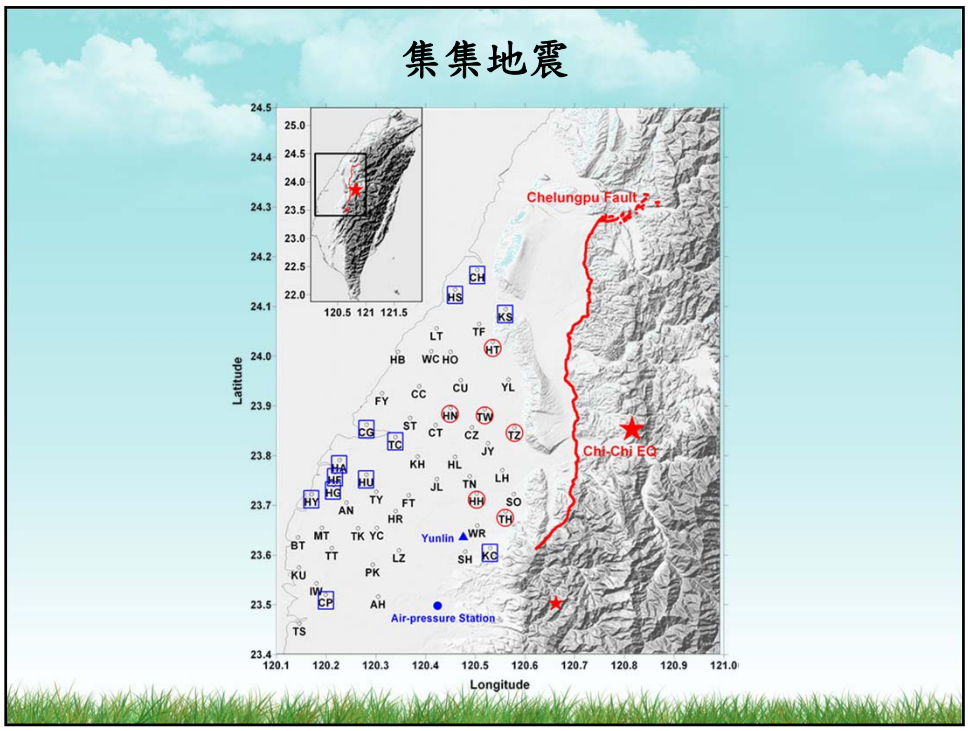
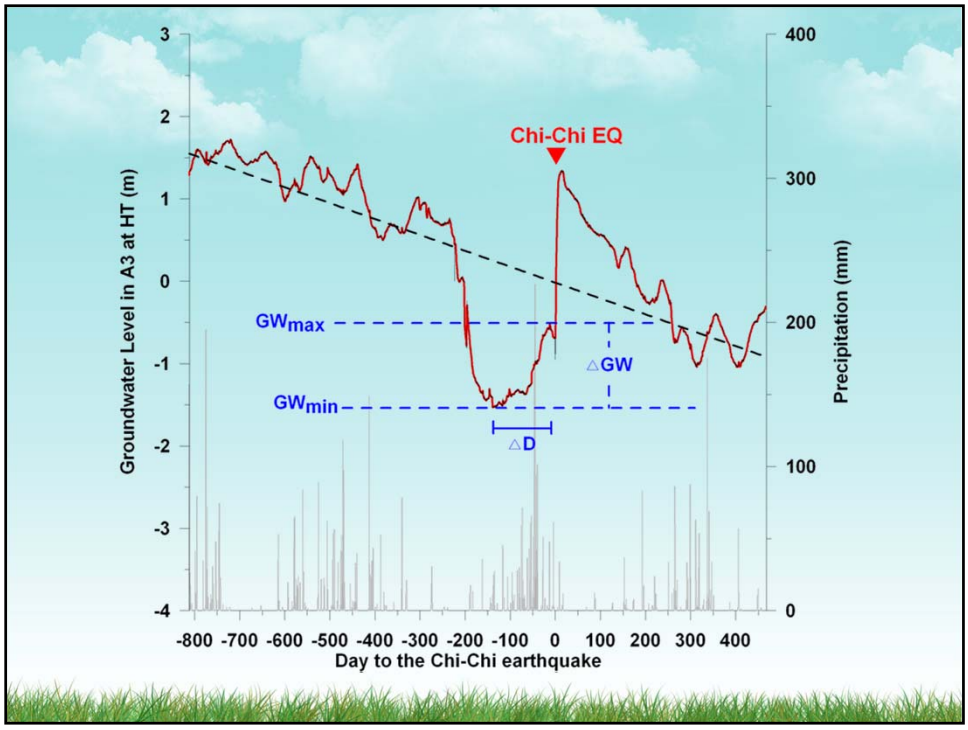
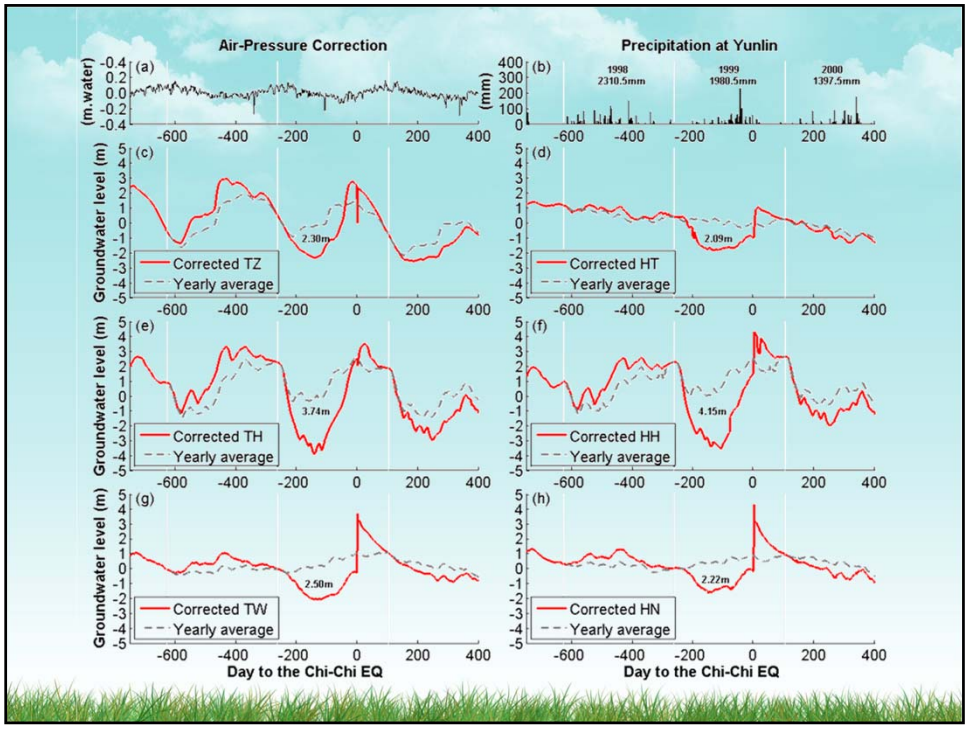
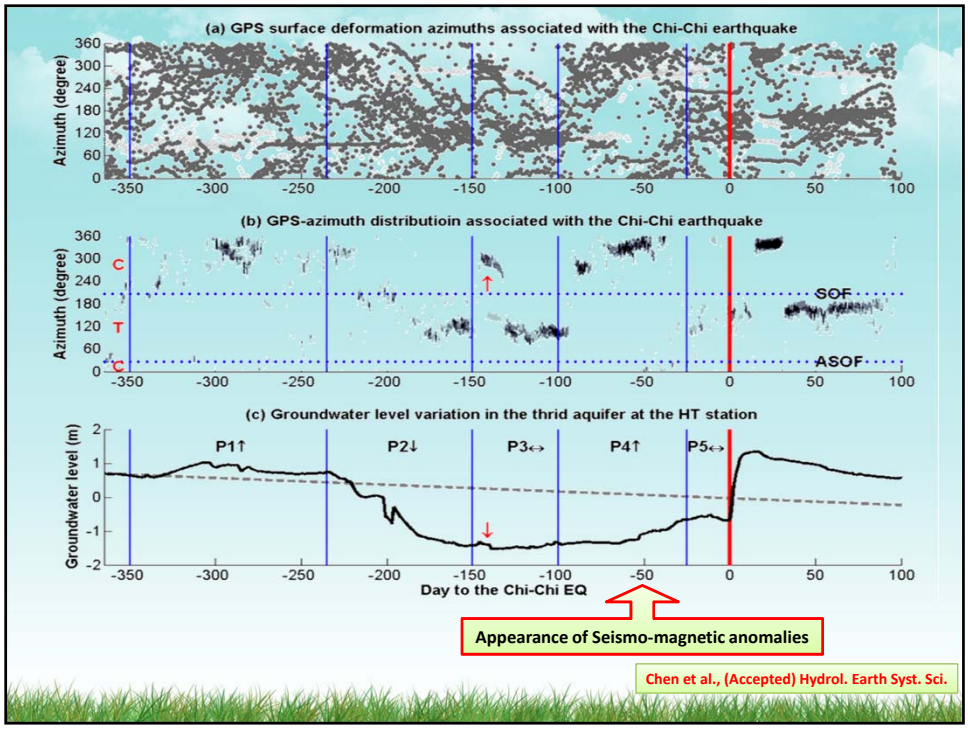
地下水、地殼變形與地磁異常之耦合




集集地震
Chelungpu Fault
Chi-Chi EQ
Yunlin
Air-pressure Station
Latitude
Longitude


Chi-Chi EQ
GWmax
GWmin
△GW
△D
Groundwater Level in A3 at HT (m)
Precipitation (mm)
Day to the Chi-Chi earthquake


Air-Pressure Correction
Precipitation at Yunlin
(m.water)
(mm)
1998 2310.5mm
1999 1980.5mm
2000 1397.5mm
Groundwater level (m)
Corrected TZ
Yearly average
2.30m
Corrected HT
2.09m
Corrected TH
3.74m
Corrected HH
4.15m
Corrected TW
2.50m
Corrected HN
2.22m
Day to the Chi-Chi EQ


(a) GPS surface deformation azimuths associated with the Chi-Chi earthquake
Azimuth (degree)
(b) GPS-azimuth distributioin associated with the Chi-Chi earthquake
C
T
C
SOF
ASOF
(c) Groundwater level variation in the thrid aquifer at the HT station
Groundwater level (m)
P1↑
P2↓
P3↔
P4↑
P5↔
Day to the Chi-Chi EQ
Appearance of Seismo-magnetic anomalies
Chen et al., (Accepted) Hydrol. Earth Syst. Sci.

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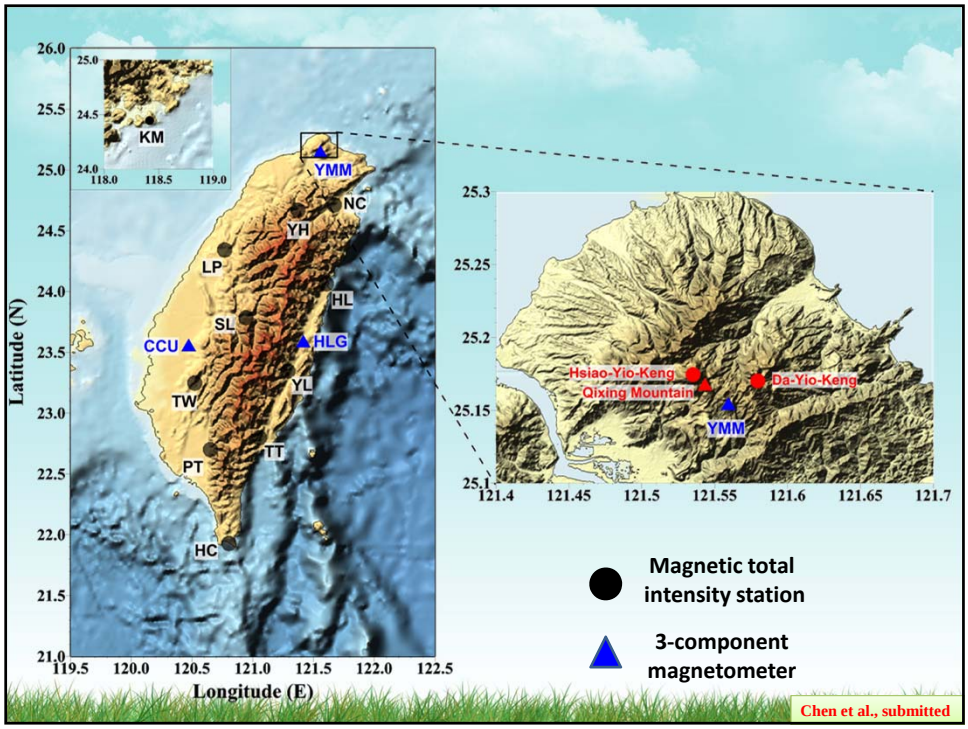
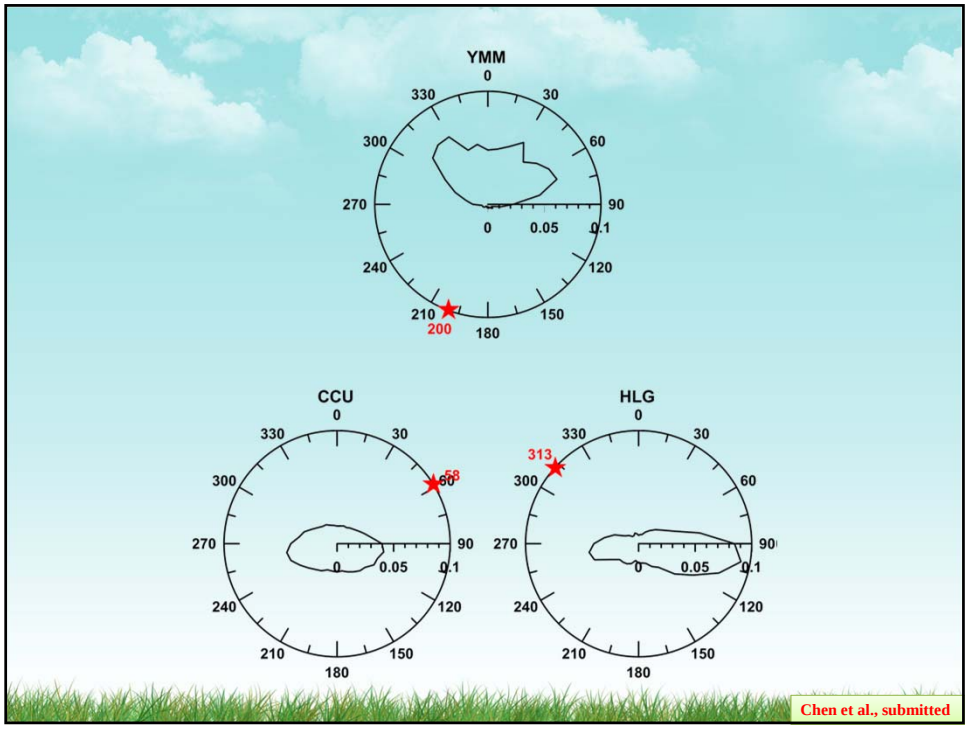
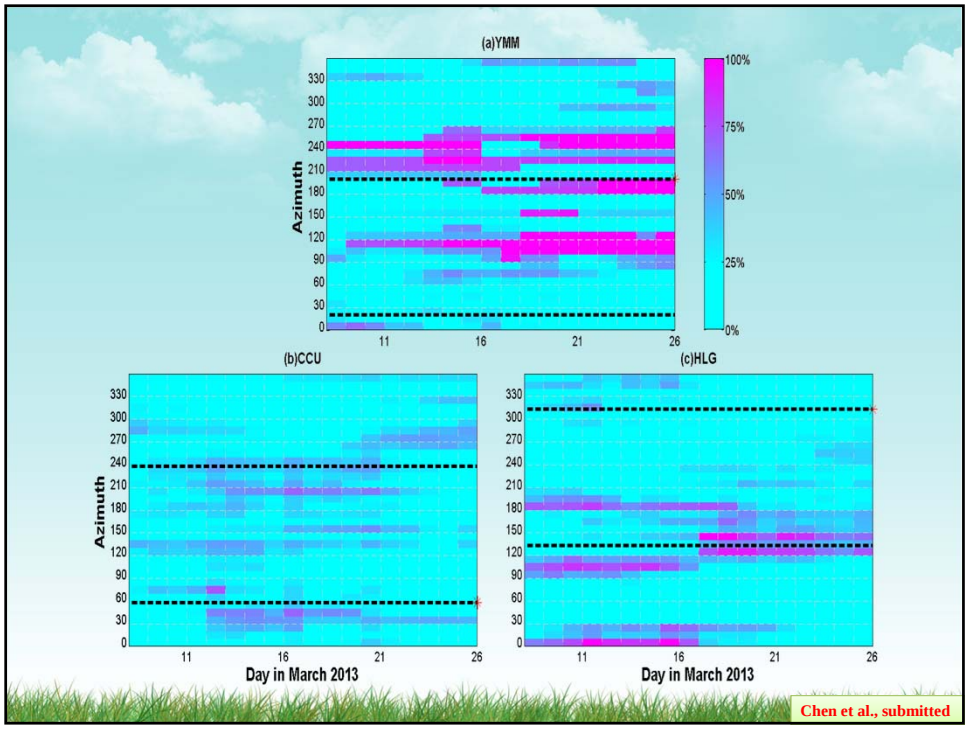
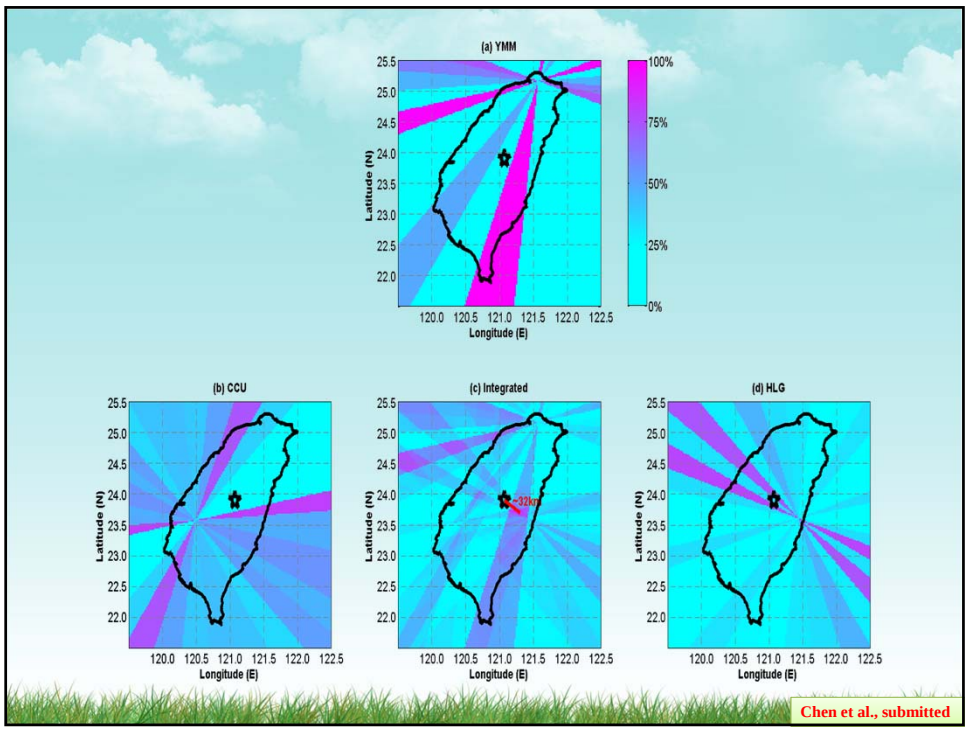
- 日本Tohoku地震震前地殼變形異常
- 結論




YMM
CCU
HLG
200
58
313
Chen et al., submitted

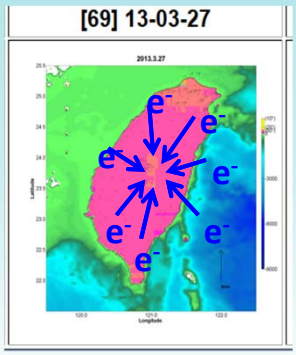

(a)YMM
(b)CCU
(c)HLG
Azimuth
Day in March 2013
Chen et al., submitted

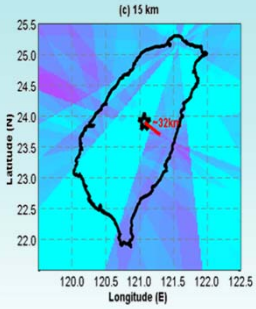


Conclusions

Pre-earthquake dislocations & Conductivity enhancement

3.22 – 3.27

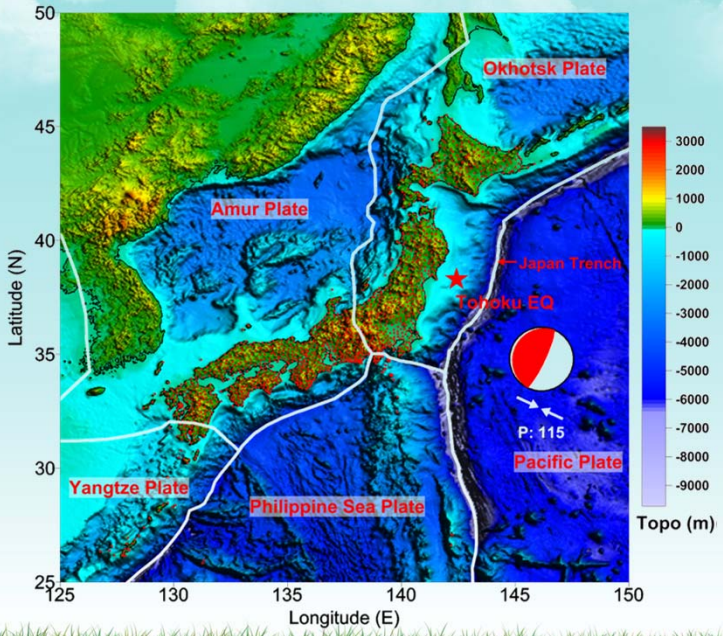


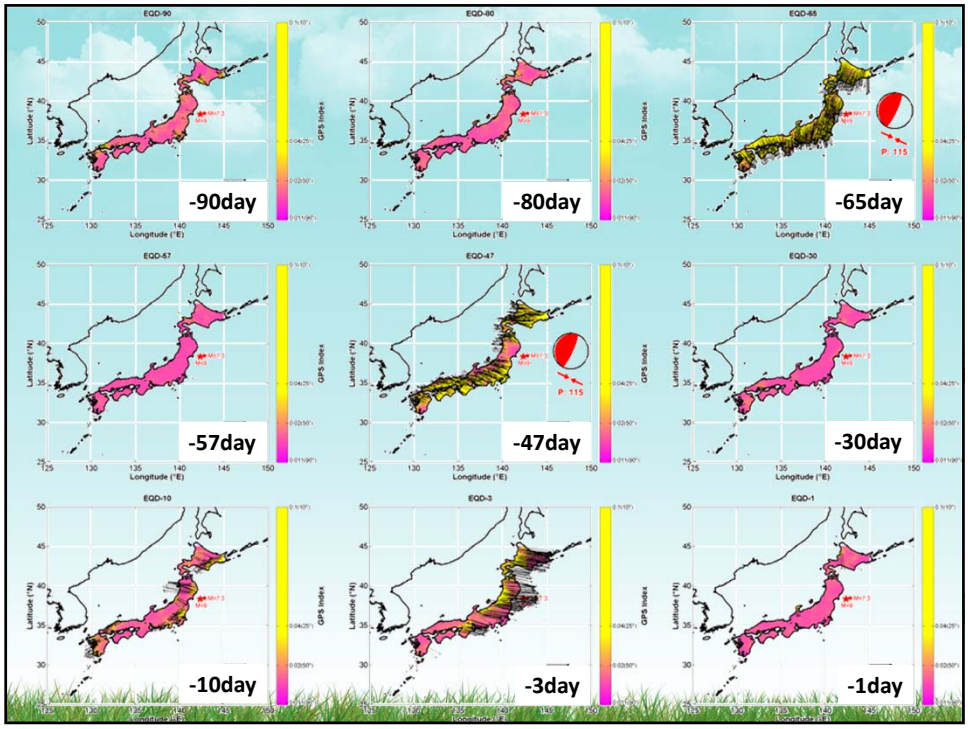


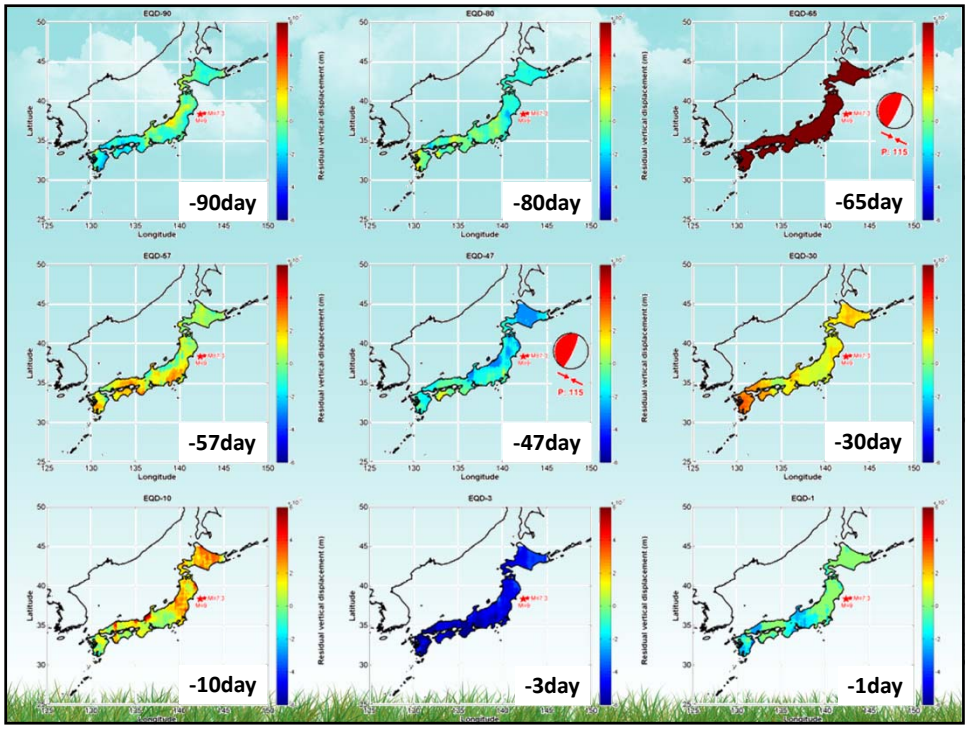
大綱

- 台灣的地殼變形觀測
- 地震前的地殼變形研究(Chen et al., 2011)
- 時間異常轉換至空間異常(Chen et al., 2013a)
- 震前地殼變形與地下水(Chen et al., 2013b) 、電磁異常之耦合
- 日本Tohoku地震震前地殼變形異常
- 結論

2011 M9 Tohoku Earthquake




-90day
-80day
-65day
-57day
-47day
-30day
-10day
-3day
-1day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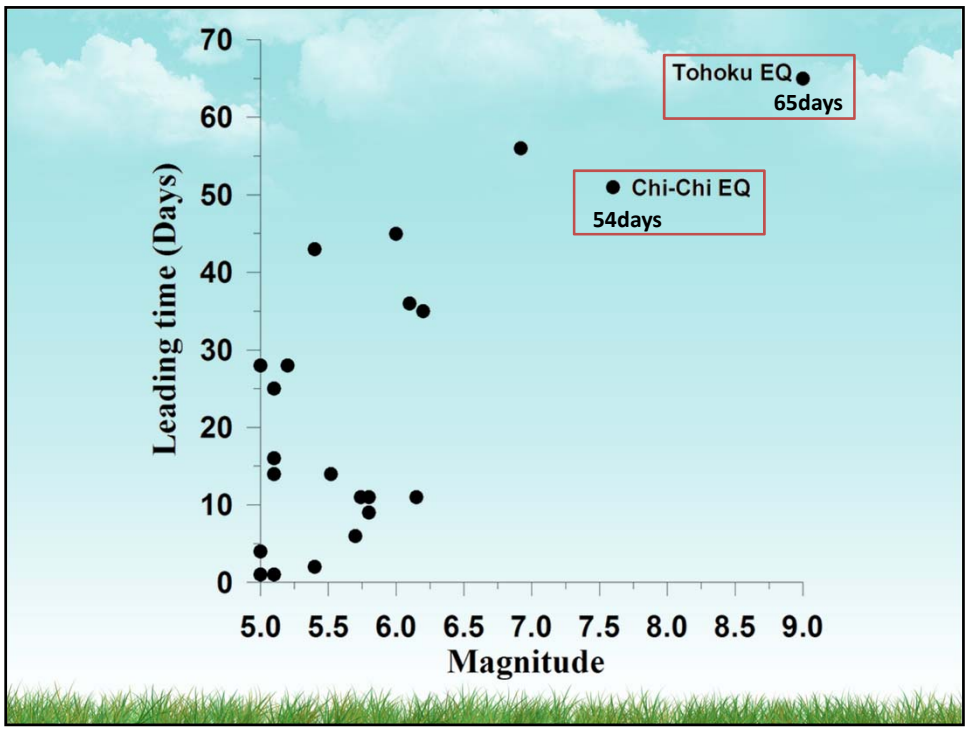
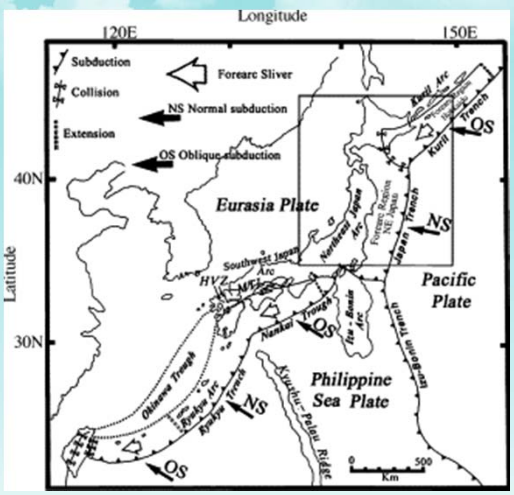
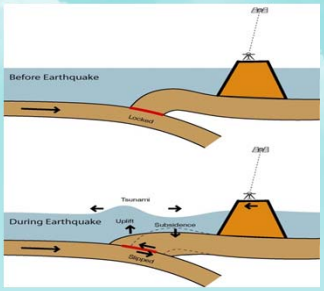
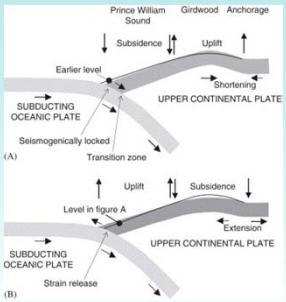




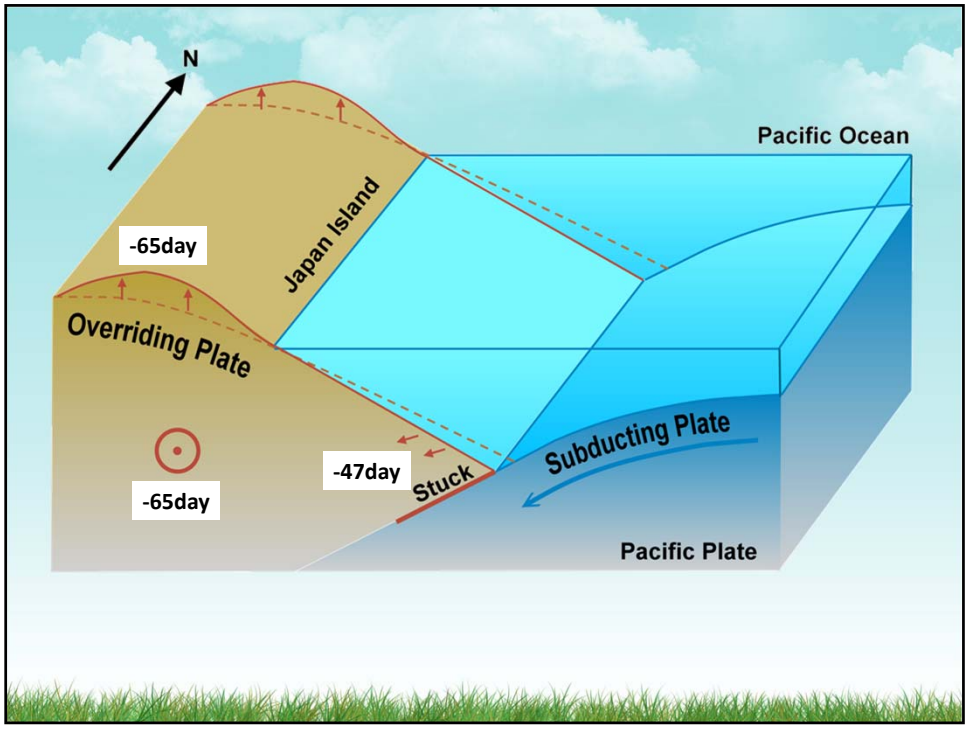
Wang and Zhao, 2005
DOI:10.1016/j.pepi.2005.06.010

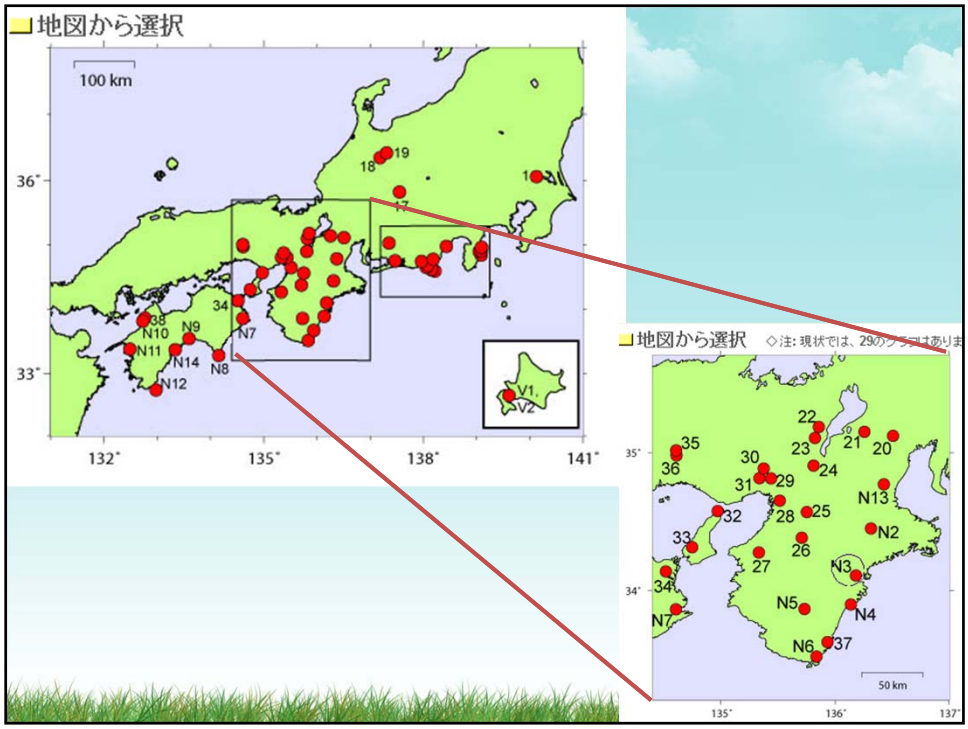


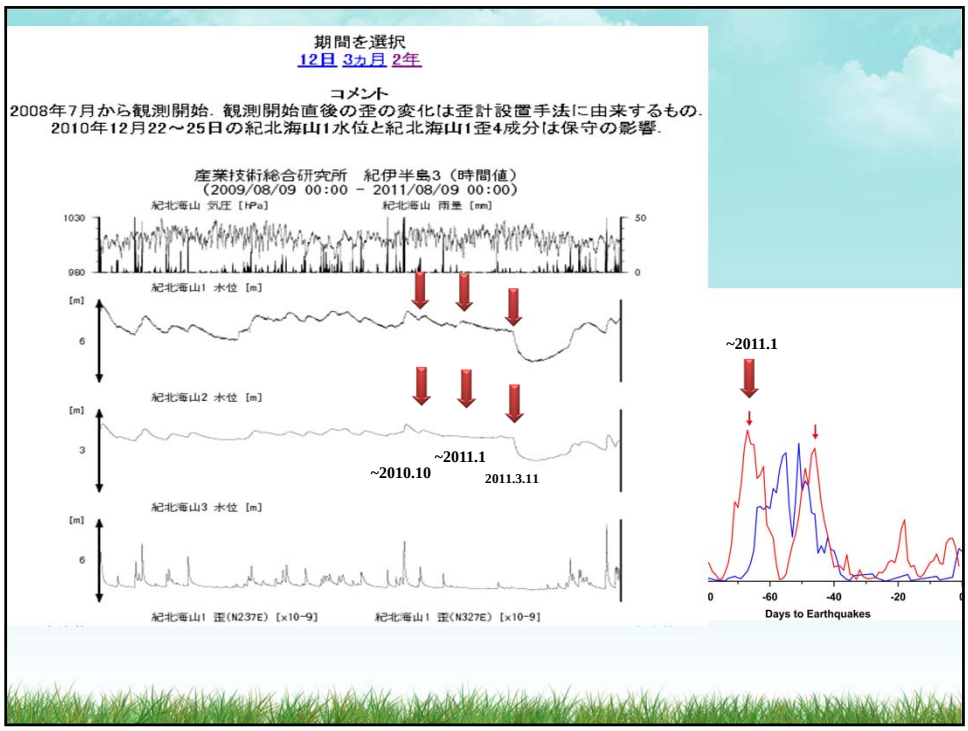
http://www.earth.northwestern.edu/people/seth/research/sumatra.html



Hamilton and Shennan, 2005
DOI:10.1016/j.quascirev.2004.11.003


N
Pacific Ocean
Japan Island
-65day
Overriding Plate
-65day
-47day
Stuck
Subducting Plate
Pacific Plate


地図から選択
100 km
36°
33°
132°
135°
138°
141°
地図から選択
50 km
35°
34°
135°
136°
137°



結論

- HHT能截取FFT或WT可能無法發現的訊號
- 與可能物理機制比對確認訊號的來源
- 了解震前的地殼變形將有助於地震前兆研究

THANK YOU FOR
YOUR ATTENTION