# Analysis of strain anomalies by strainmeters in Taiwan

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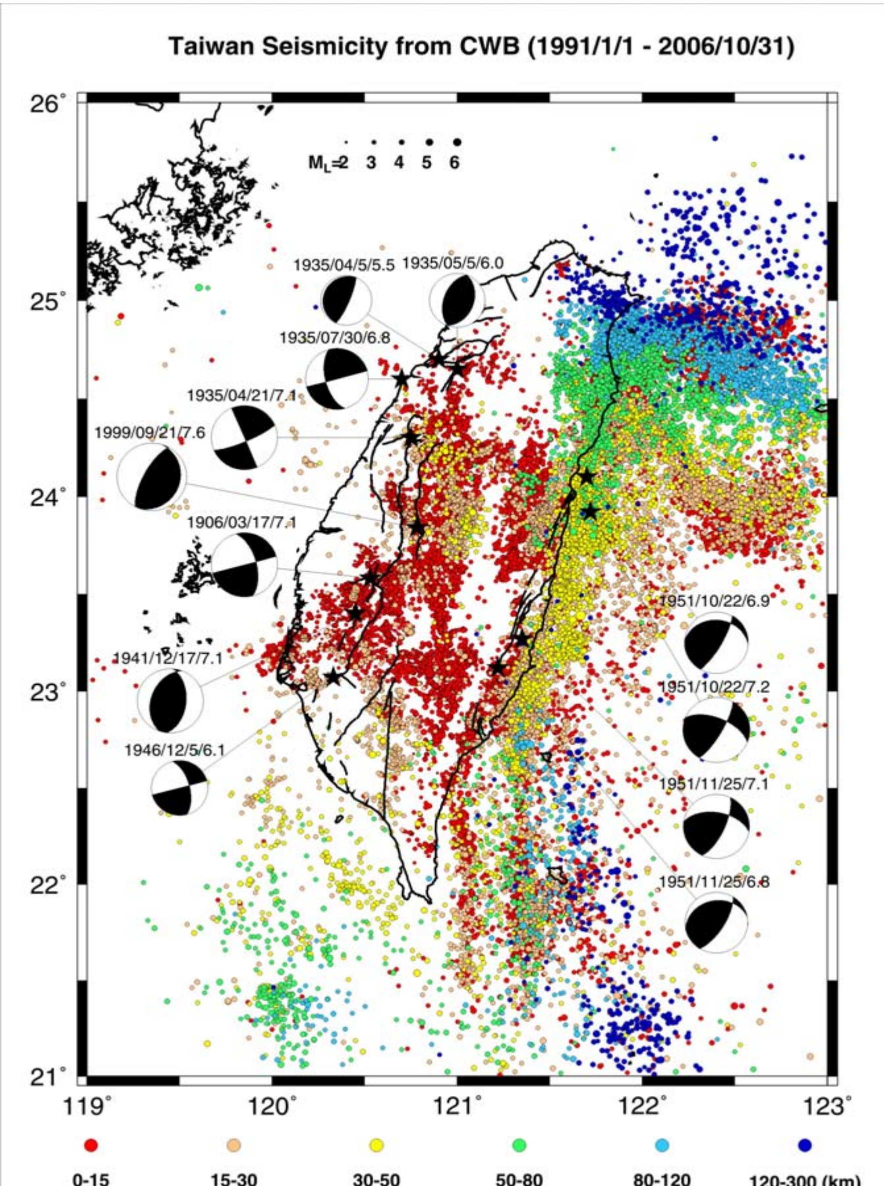
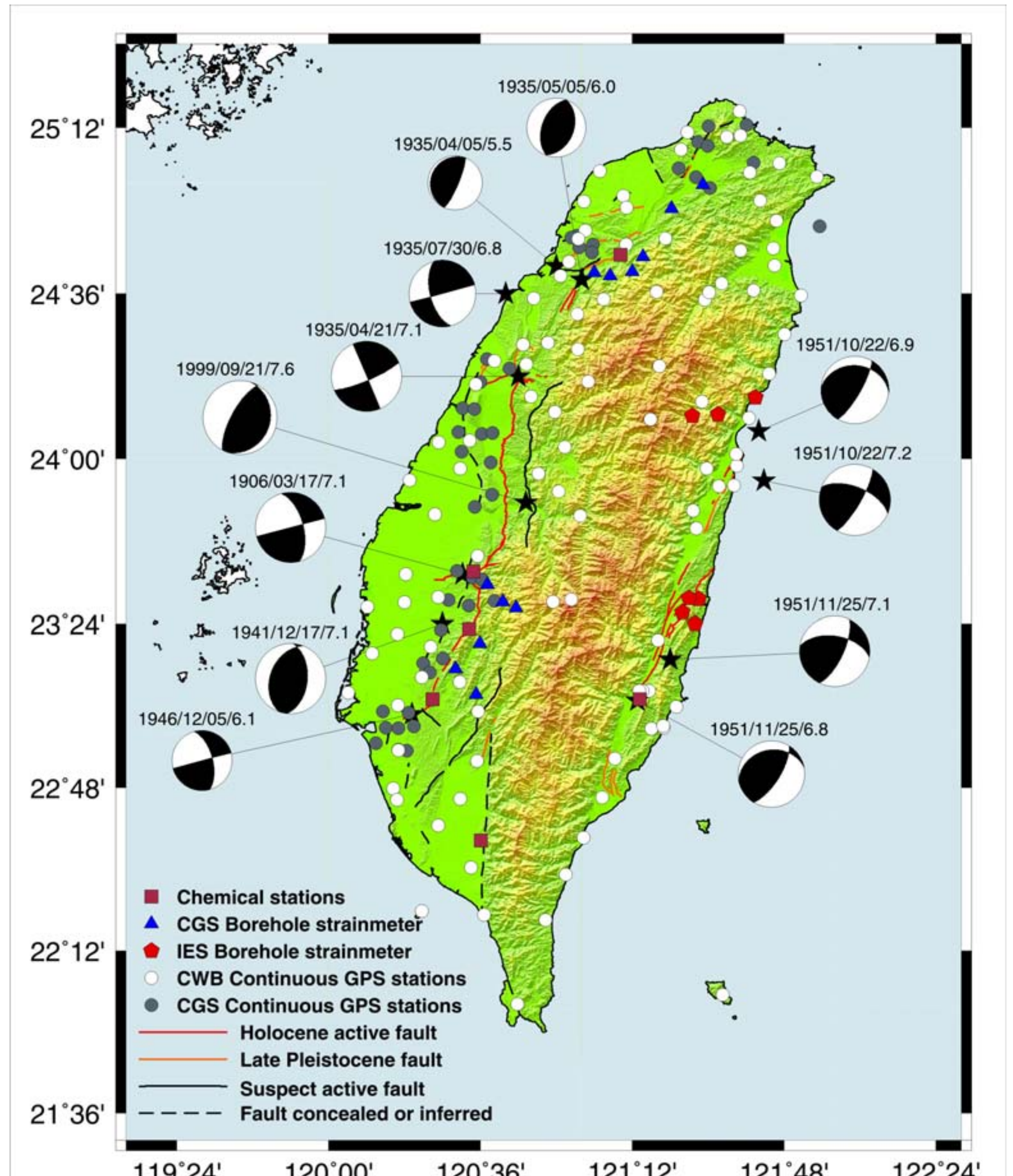
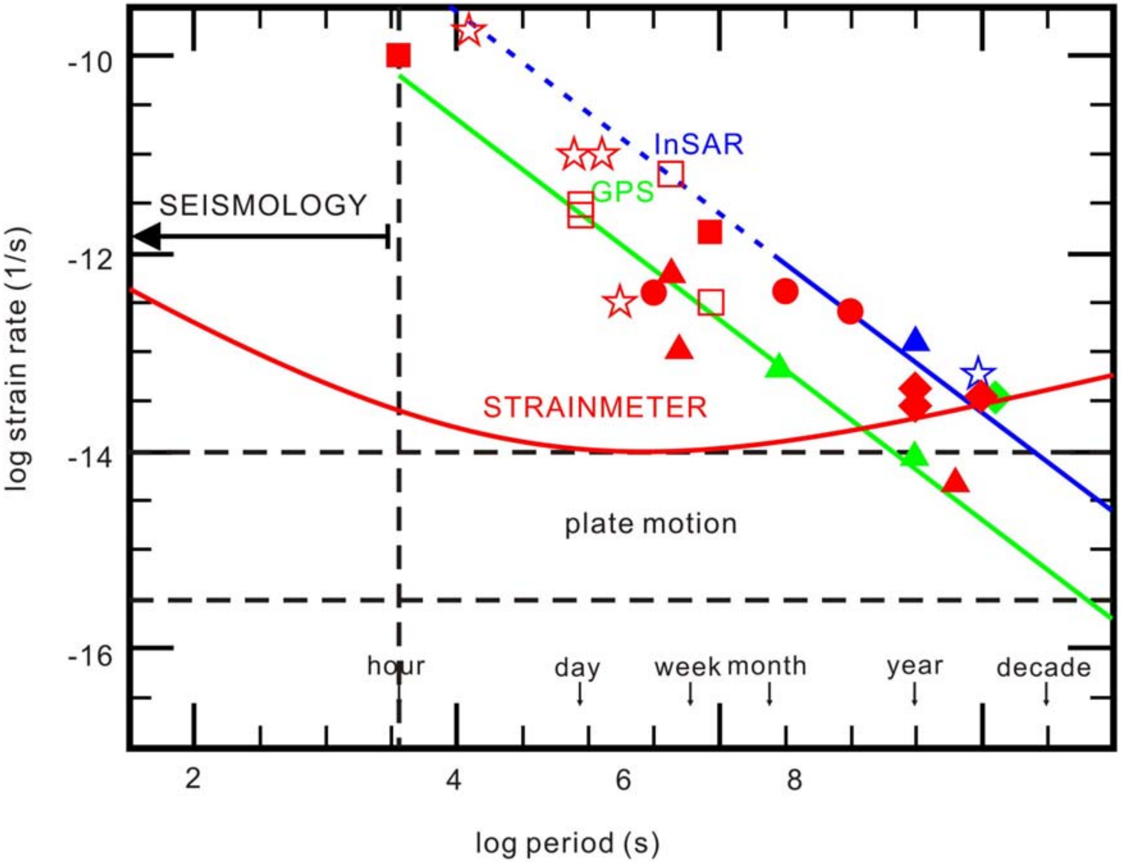
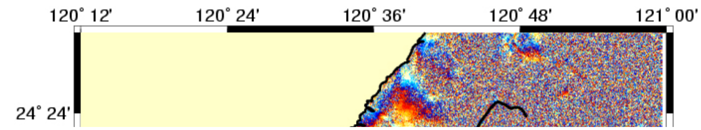
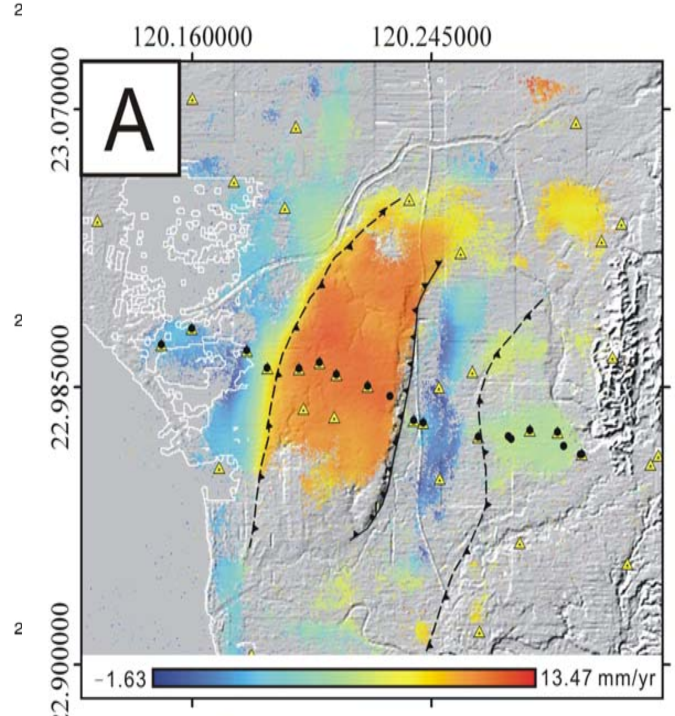
# Monitoring of active faults: Continuous GPS, Borehole strainmeters and Geochemical monitoring stations



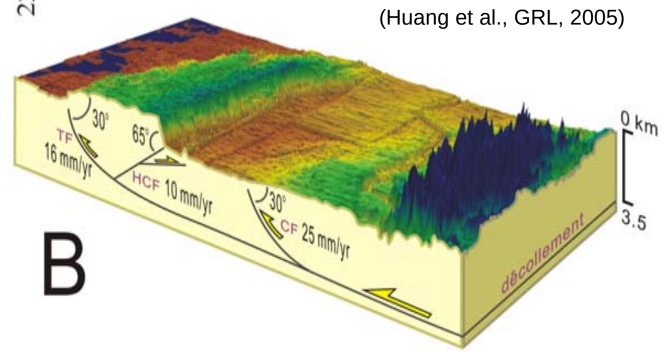





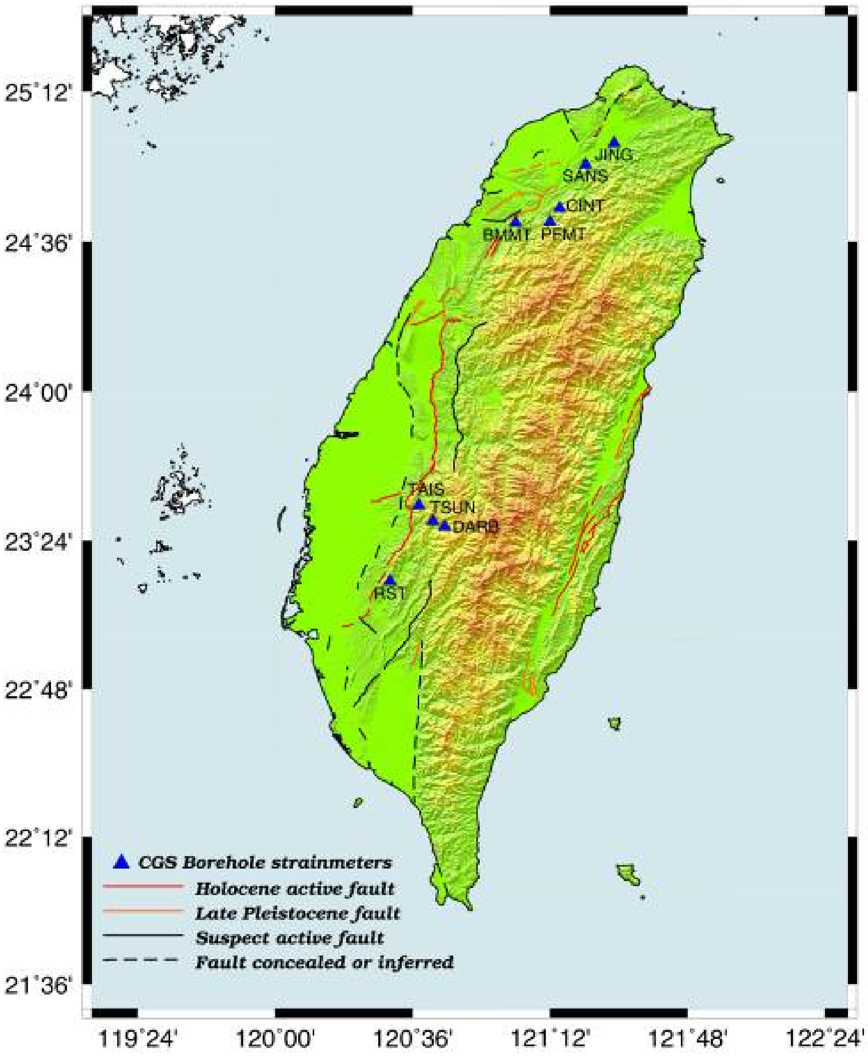



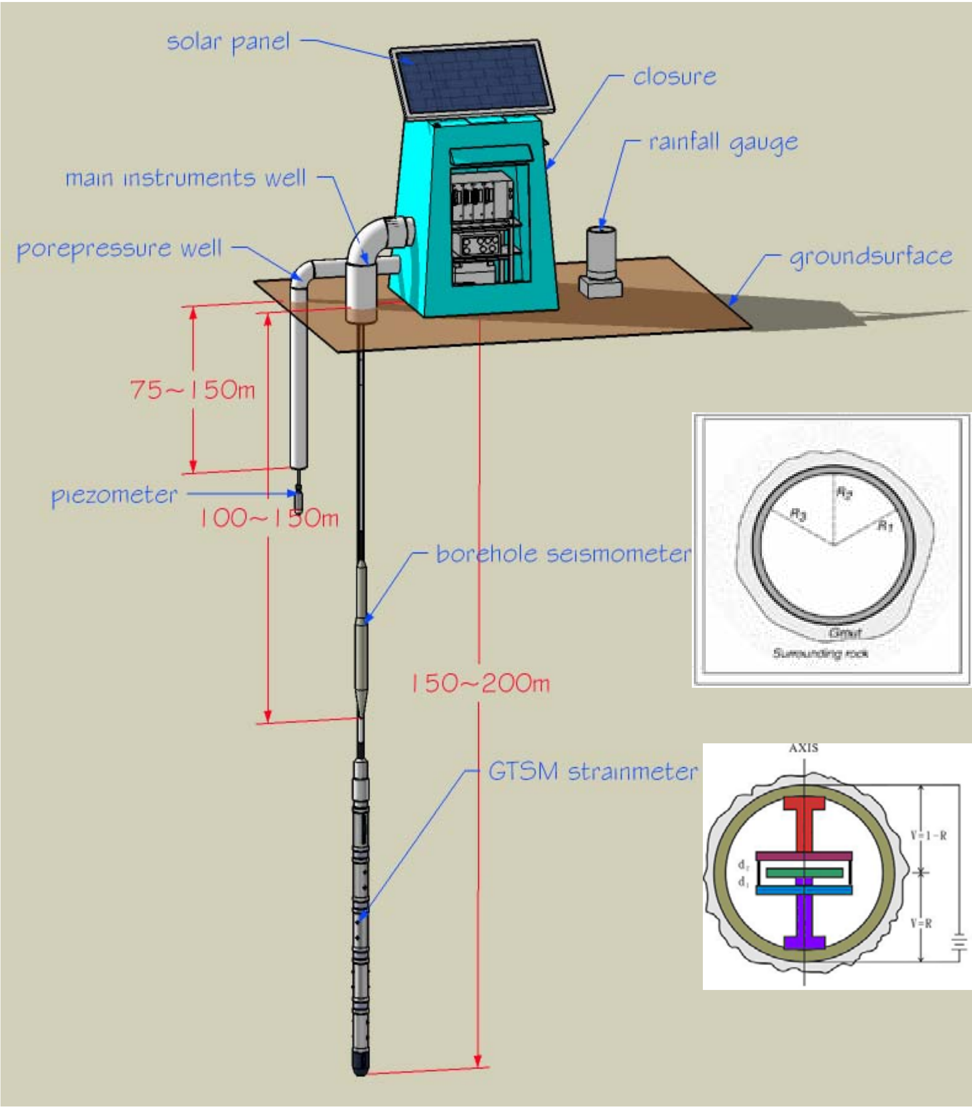

(Huang et al., GRL, 2005)



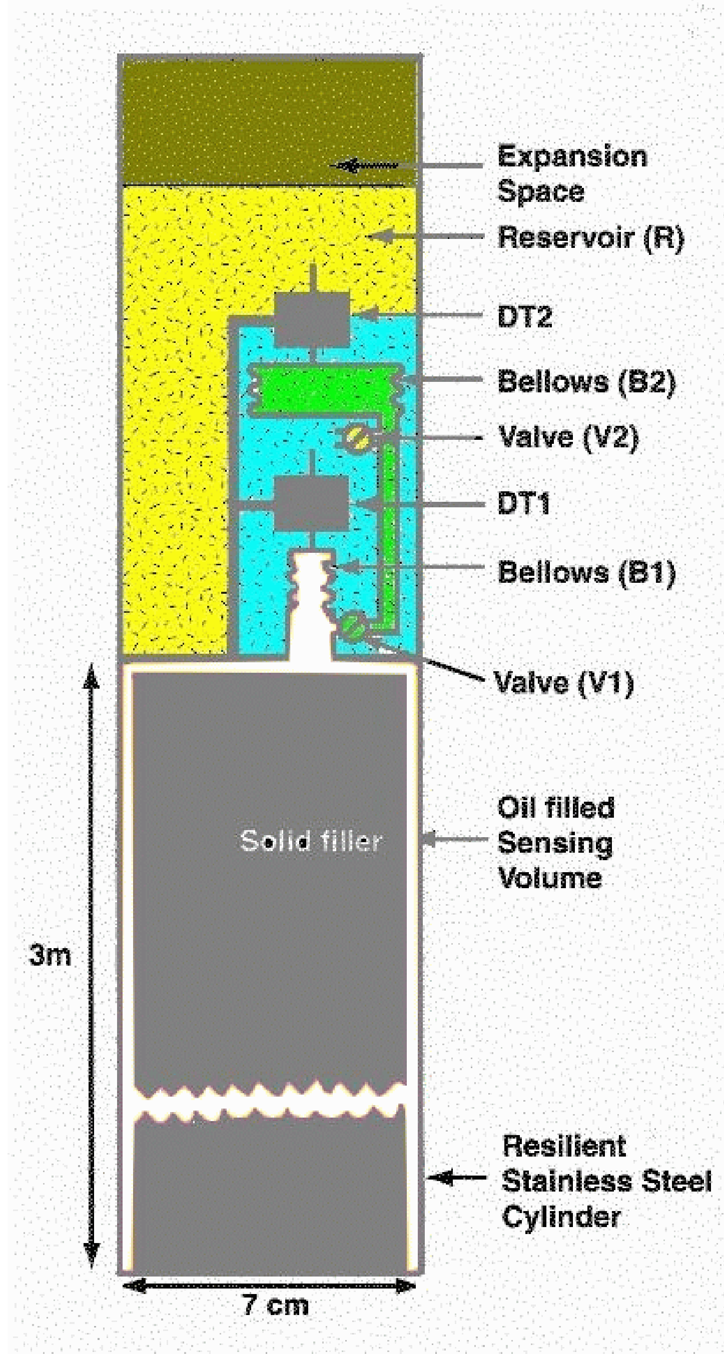

- Bridging the sensitivity and frequency g seismic and GPS measurements.
- Detecting aseismic deformation rate ch to earthquake

# Gladwin TSM Strainmeters in Taiwan



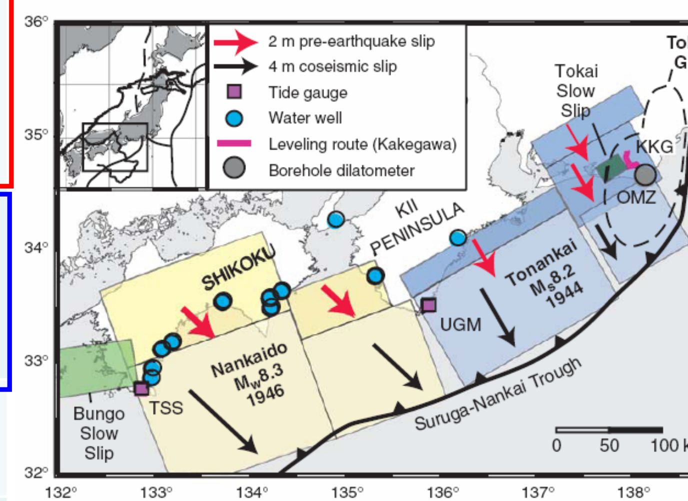



# Sacks-Evertson Starinmeter



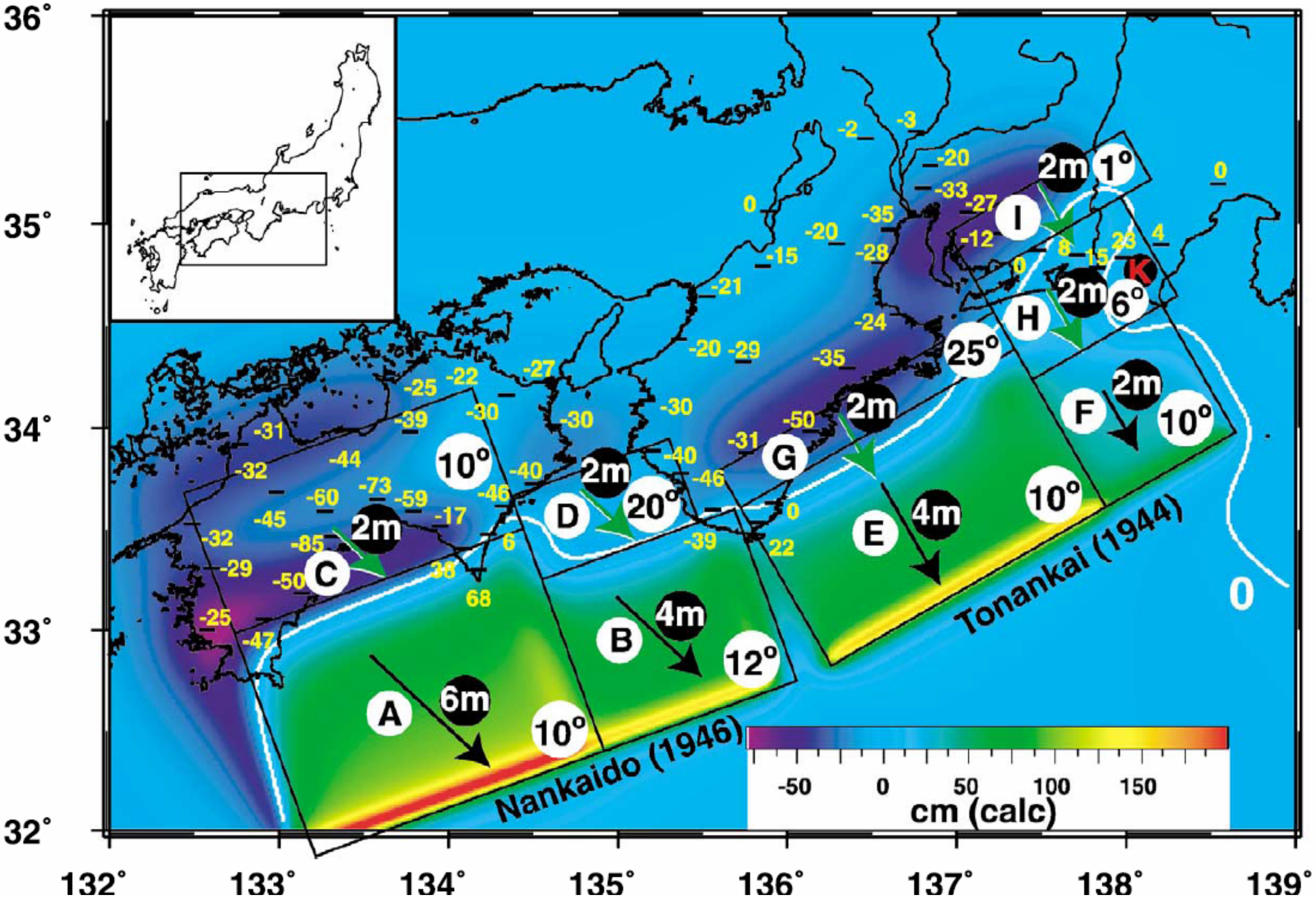
| | Type | Method of observation | Start time (prior to mainshock) | Equivalent moment Magnitude of pre-earthquake slip | References |
|---|---|---|---|---|---|
| M9 Cascadia, USA and Canada January 29, 1700 | CONVERGENT MARGIN | Microfossils | Unknown | Unknown | Shennan et al. 1998 |
| Ms8.2 Tonankai, Japan December 7, 1944 | CONVERGENT MARGIN | Leveling | 1 day | 7.8 | Sagiya 1998, Linde & Sacks 2002 |
| Mw8.3 Nankaido, Japan December 20, 1946 | CONVERGENT MARGIN | Tide gauges,water wells | 3 days | 7.9 | Sato 1982, Linde & Sacks 2002 |
| Mw9.2 Chile May 22, 1960 | CONVERGENT MARGIN | Long-period seismometer | 14–20 min | 8.9–9.1 | Cifuentes & Silver 1989 |
| Mw9.2 Prince William Sound, Alaska March 28, 1964 | CONVERGENT MARGIN | Microfossils | 10–12 years | (0.12 ± 0.13 m uplift) | Hamilton & Shennan 2005 |
| M7.0 Izu-Oshima-Kinkai, Japan January 14, 1978 | TERRESTRIAL | Leveling, groundwater levels, geodolite, tide gauges | 2 years | (15 cm uplift) | Inouchi & Sato 1979, Wakita 1981 |
| Ms6.8 | | | | | Taylor et al. |

# 11 events, 1700-2002




Roeloffs, 2006, Annu. Rev. Earth Planet. Sci.

# Slow earthquake and great earthquakes along the Nankai trough

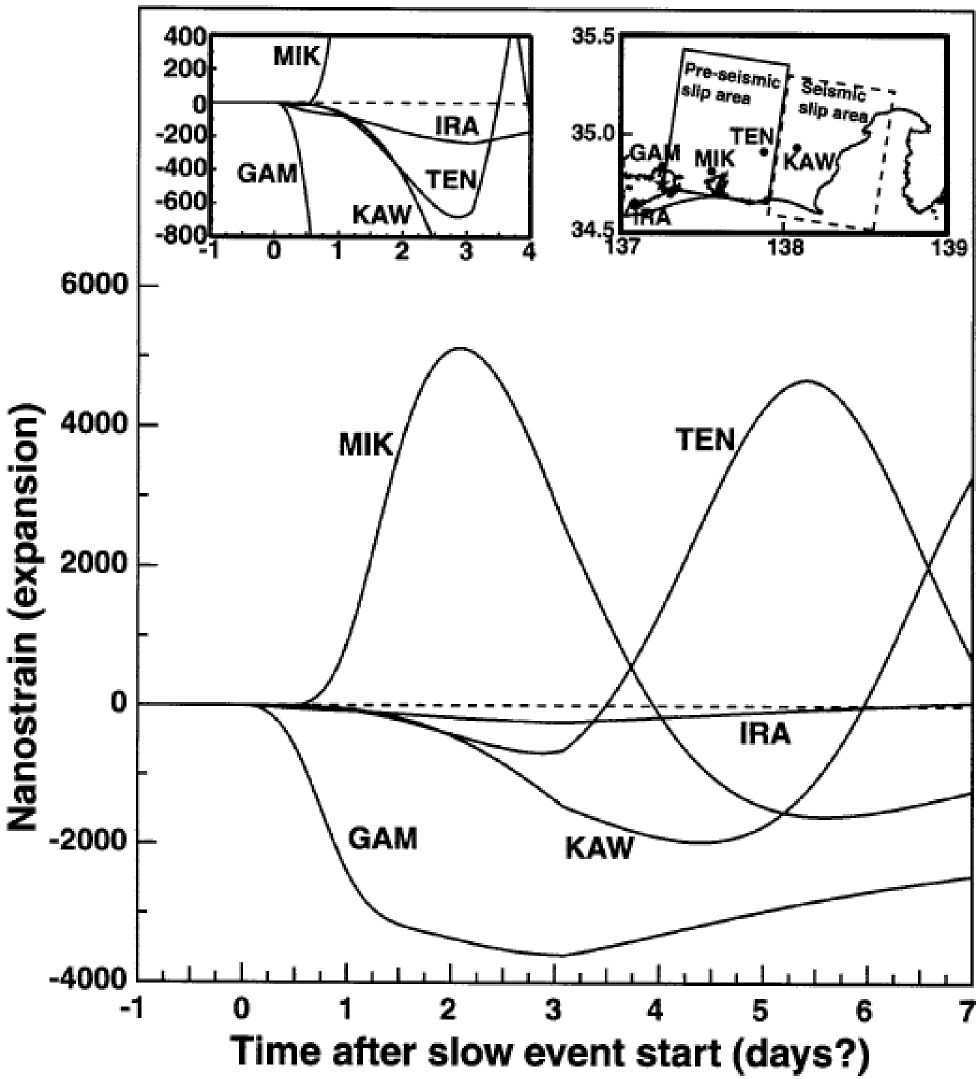



Pre-slip: slow slip on the subduction interface, downward extension of seismic rupture zonrs

Kakegawa leveling lines

Linde and Sacks, 2002, EPSL

# Slow earthquake and great earthquakes along the Nankai trough




Recognition of significance of the strain changes with time

Detection Capability:

Noise level: order of 10 nanostrain

Strain amplitudes calculated: thousands of nanostrain

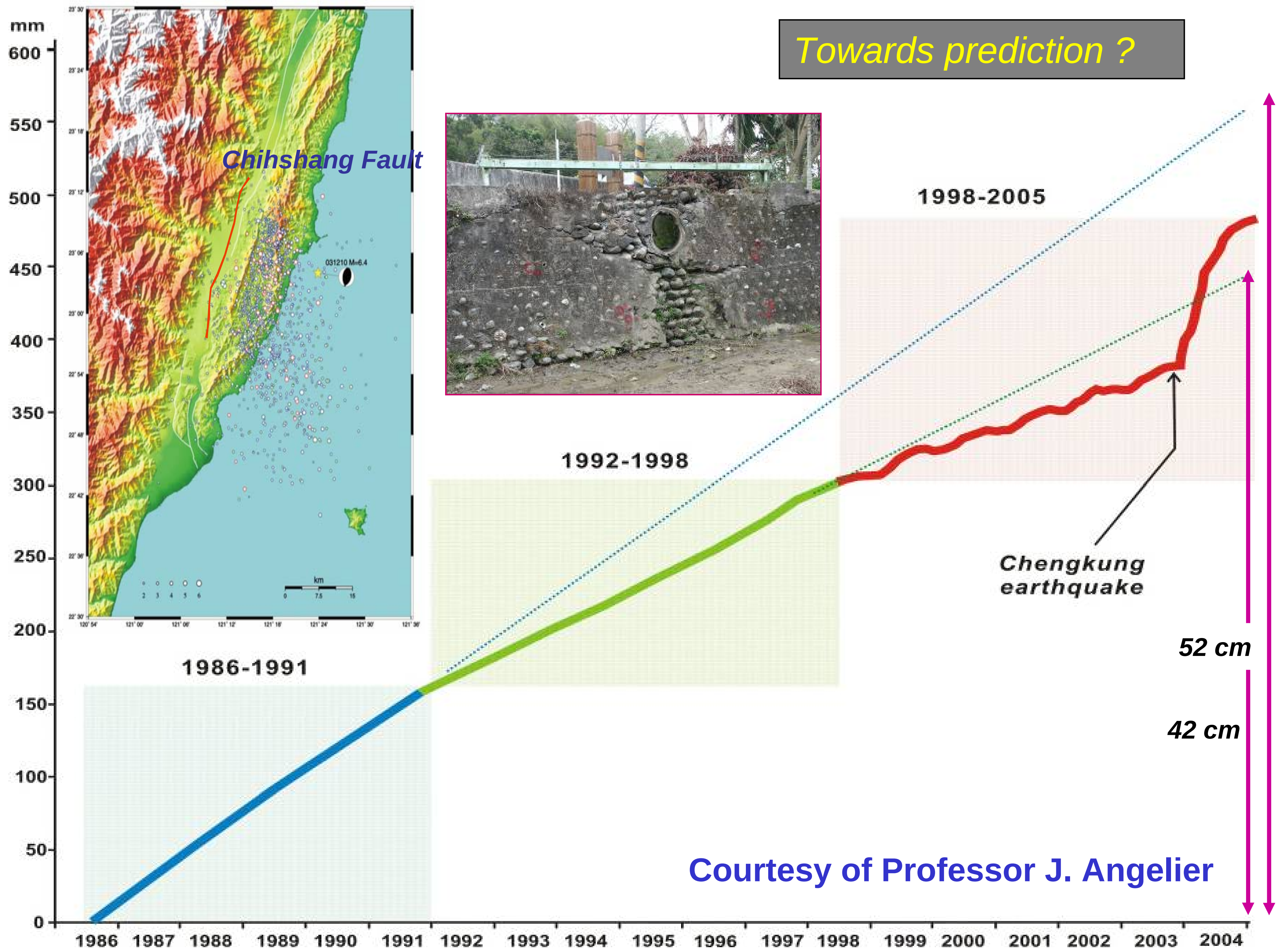
Network of Japan Meteorological Agency

Linde and Sacks, 2002, EPSL

| | Type | Type of data (distance) | Allowable moment of pre-earthquake slip | References |
|---|---|---|---|---|
| Mw6.9 Loma Prieta, California October 18, 1989 | TERRESTRIAL | Borehole strainmeters (40 km), Campaign GPS (0–31 km) | *<M5.4* | Lisowski et al. 1993 |
| Mw7.3 Landers, California June 28, 1992 | TERRESTRIAL | Pinon Flat strainmeters, GPS (68 km), Dilatometer (100 km) | *<M4.8 (Pinon Flat laser* strainmeter) | Wyatt et al. 1994, Johnston et al. 1994 |
| Mw7.6 ChiChi, Taiwan September 21, 1999 | TERRESTRIAL | CGPS (10 km) | *<M6* | Yu et al. 2001 |
| Mw7.1 Hector Mine, California October 16, 1999 | TERRESTRIAL | CGPS (25 km), InSAR | *<M6.4 (CGPS), <M5 (InSAR)* | Mellors et al. 2002 |
| Mw8.4 Peru June 23, 2001 | CONVERGENT MARGIN | CGPS (300 km) | *<M7.6* | Melbourne &Webb 2002 |
| Mw8.3 Tokachi-oki, Japan September 25, 2003 | CONVERGENT MARGIN | CGPS (30 km from fault plane, 70 km from epicenter) | *<M7* | Irwan et al. 2004 |
| Mw6.0 Parkfield, California September 28, 2004 | TERRESTRIAL | Borehole strain (10km) | *<M3.2* | Langbein et al. 2005 |

Roeloffs, 2006, Annu. Rev. Earth Planet. Sci.

# Towards prediction ?




Courtesy of Professor J. Angelier

# *How well can aseismic deformation be measured?*

- For ten earthquakes: credible published accounts of pre-earthquake deformation-rate changes lasting hundreds of seconds to more than a decade.

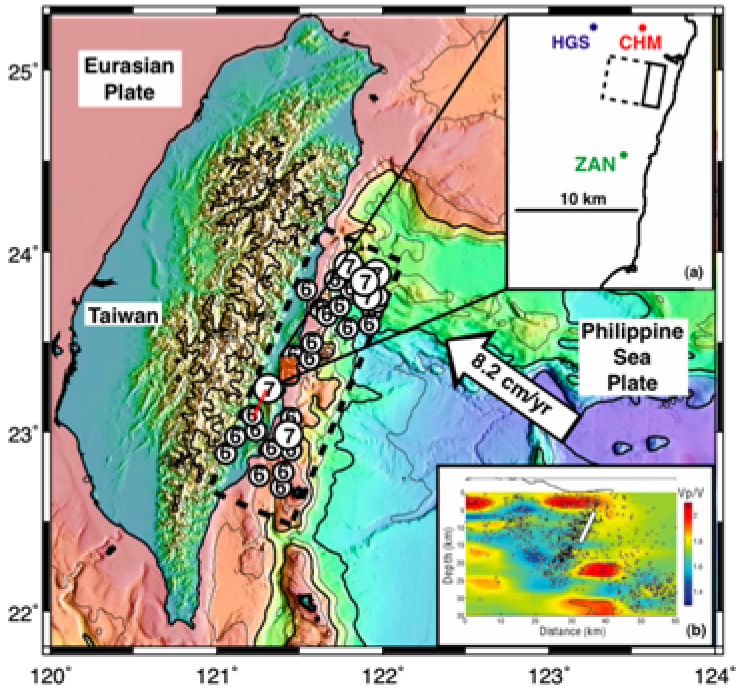
- Although most M> 7.5 earthquakes without detectable pre-earthquake deformation:

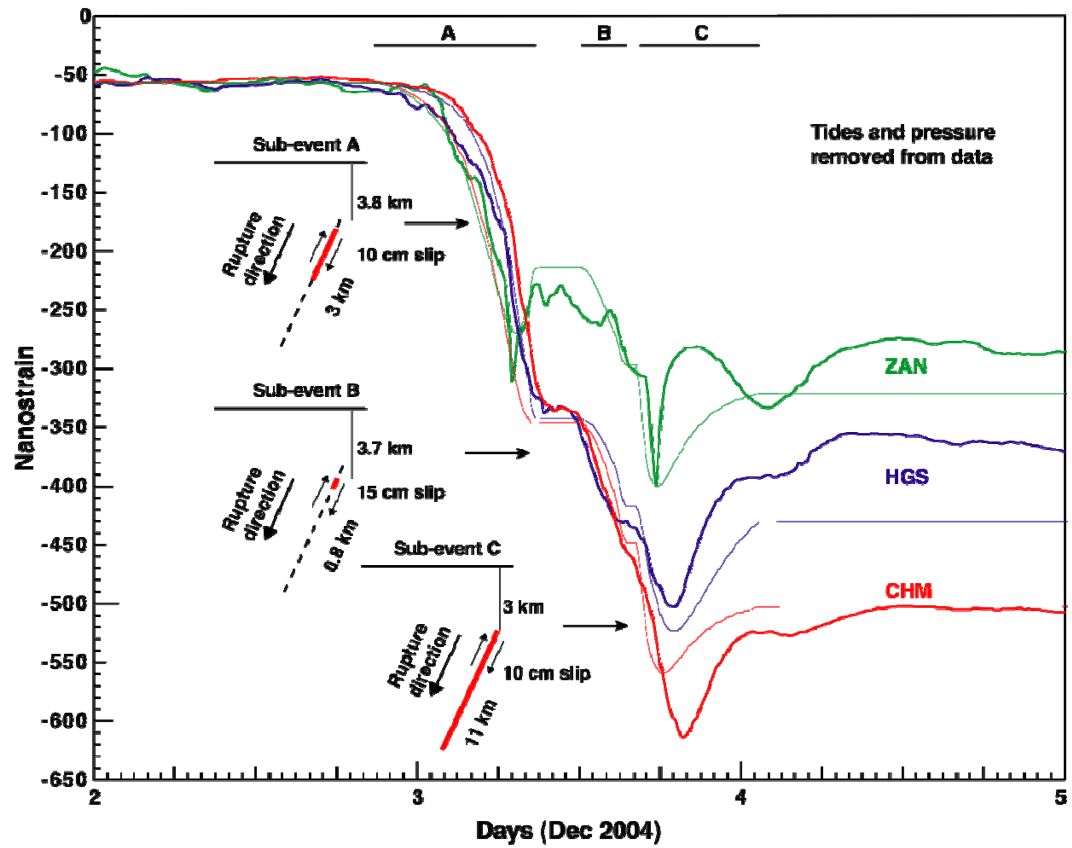
detection threshold for aseismic deformation remains high, in that aseismic slip with moment equivalent to an M5 earthquake would in most (although not all) cases have been missed.

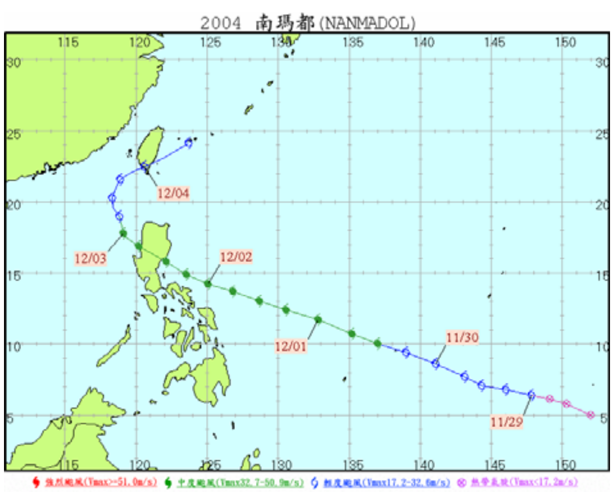
# Motivation and Scientific Goals

- Slow  earthquake triggered by typhoon
- Strain seismography (e.g., 2005 Wenchuan earthquake)
- Perturbation and permutation of principal strain in southern Taiwan
- *Aseismic deformation rate changes prior to earthquake?*

# Coupling with environment: slow earthquake triggered by 2004 Nanmadol Typhoon

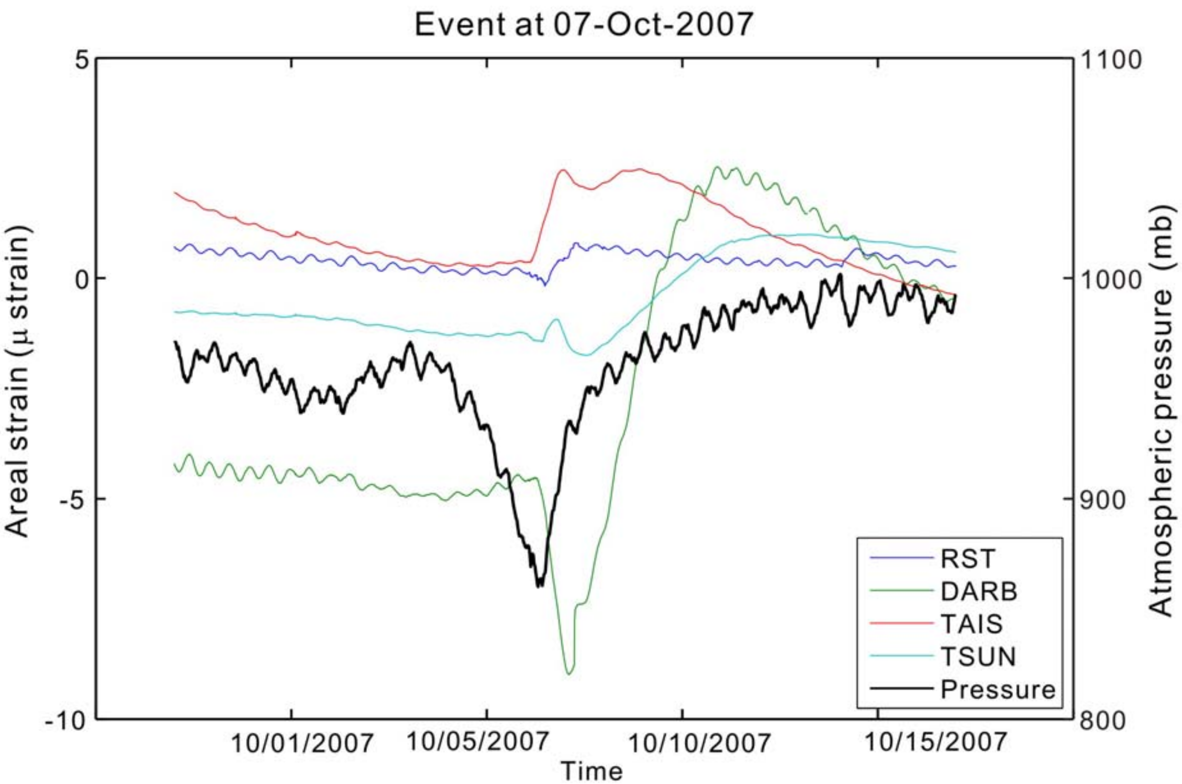


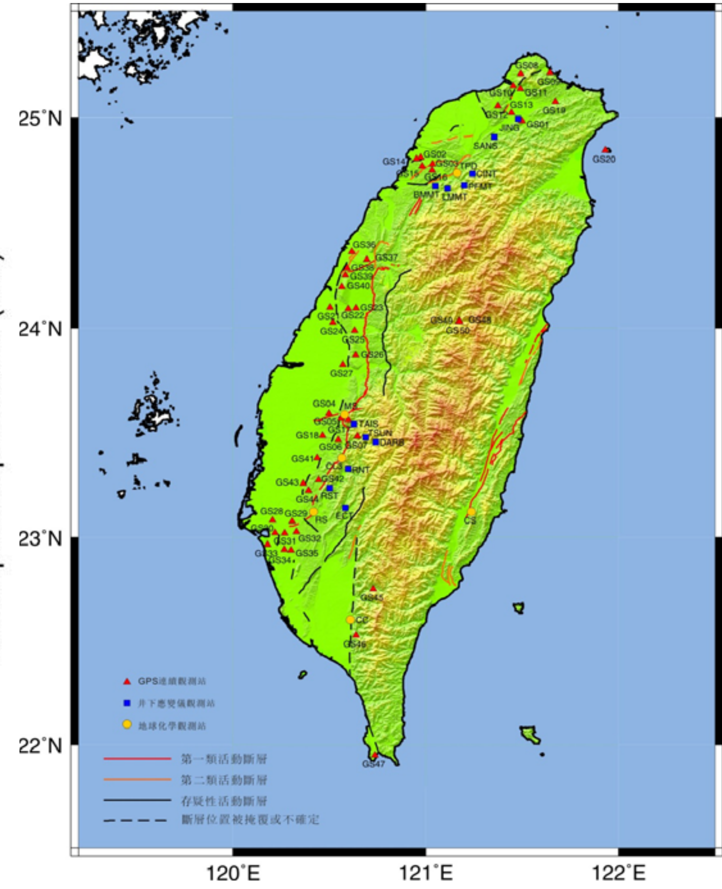



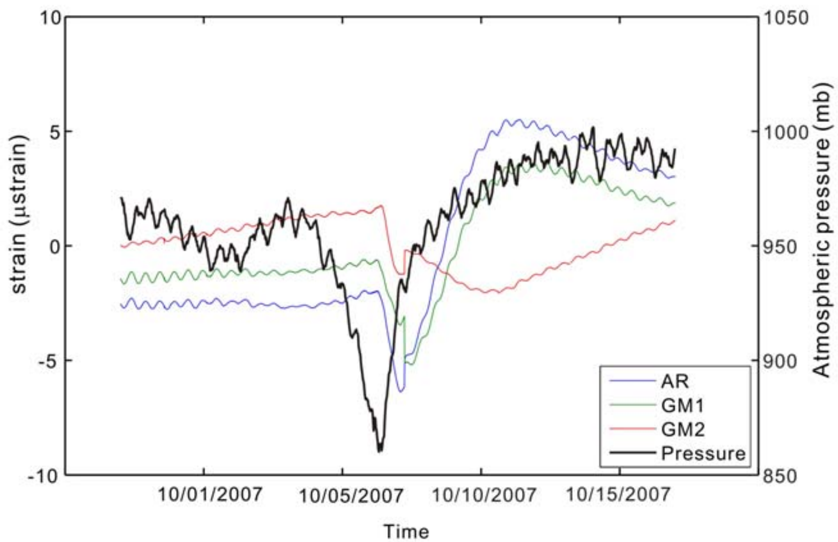

Liu et al., 2009 Nature 2004/12/3 02:30 -2004/12/4 14:30

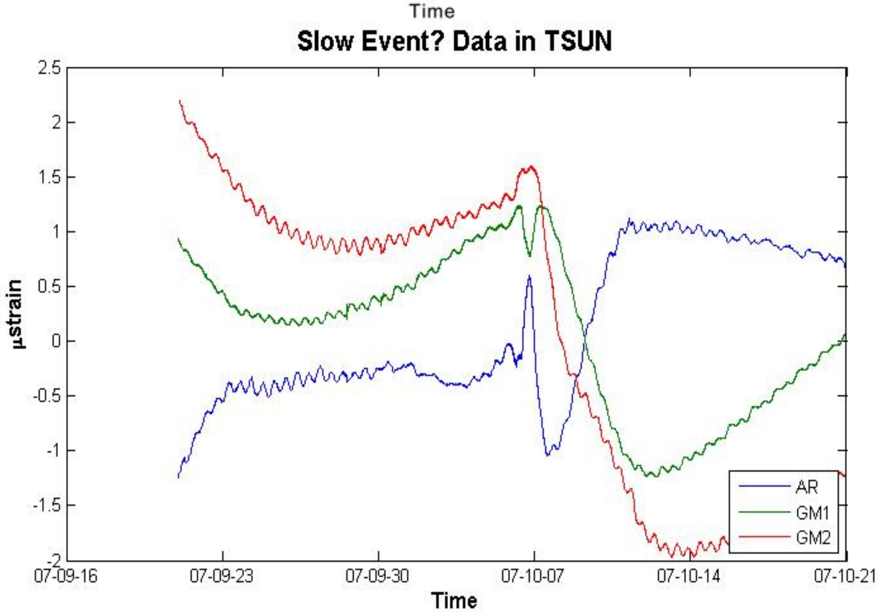
# Strain anomaly at 2007/10/06: Slow EQ triggered by Typhoon Krosa?

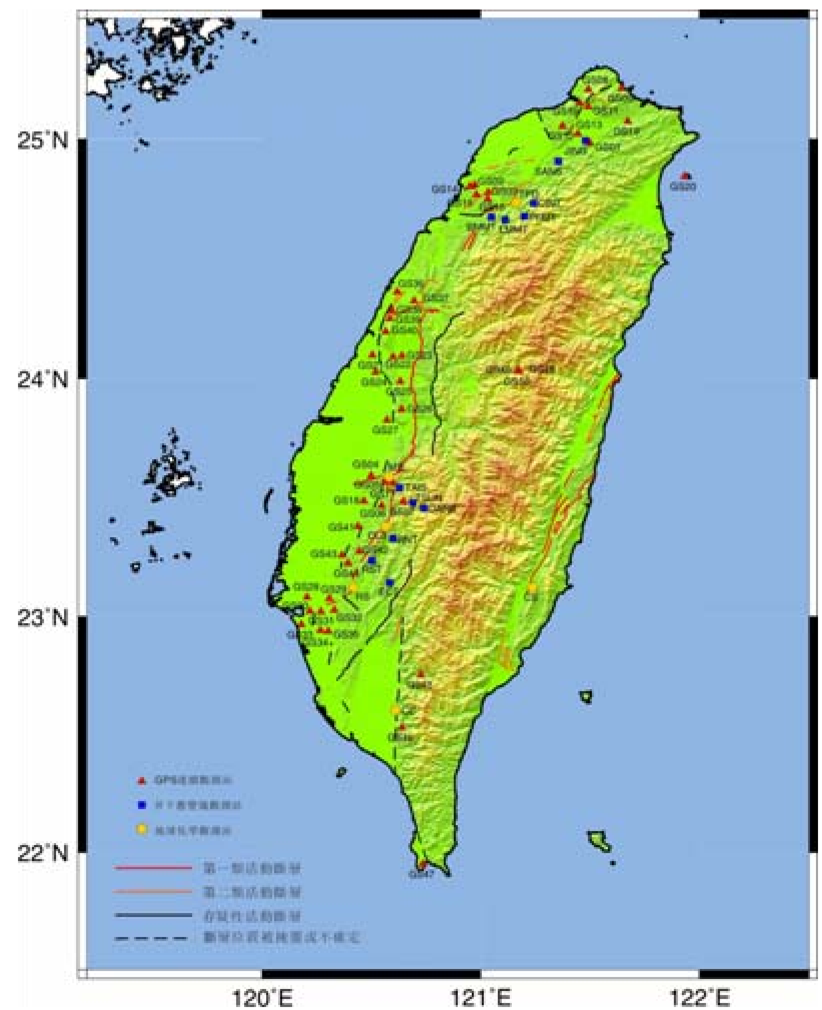


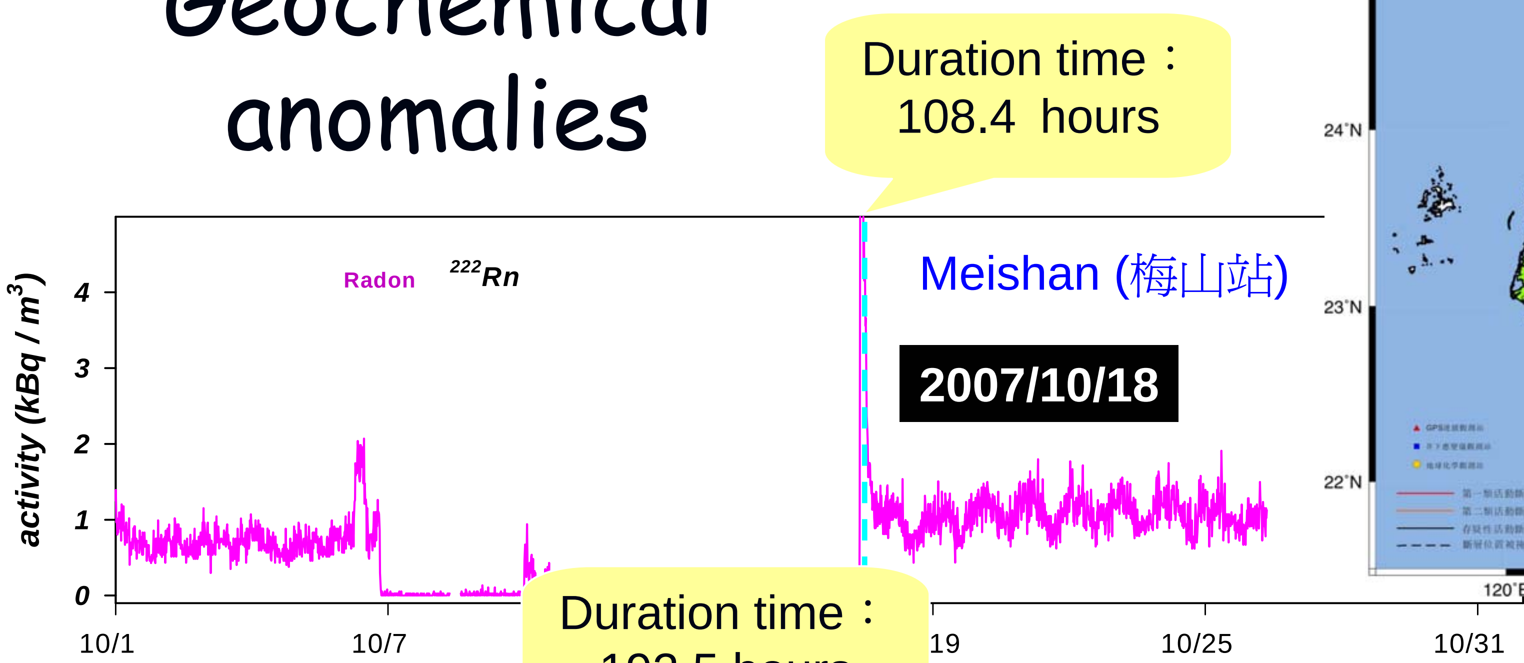
# Areal strain and shear strain changes at DARB (達邦) and TSUN (中興國小)

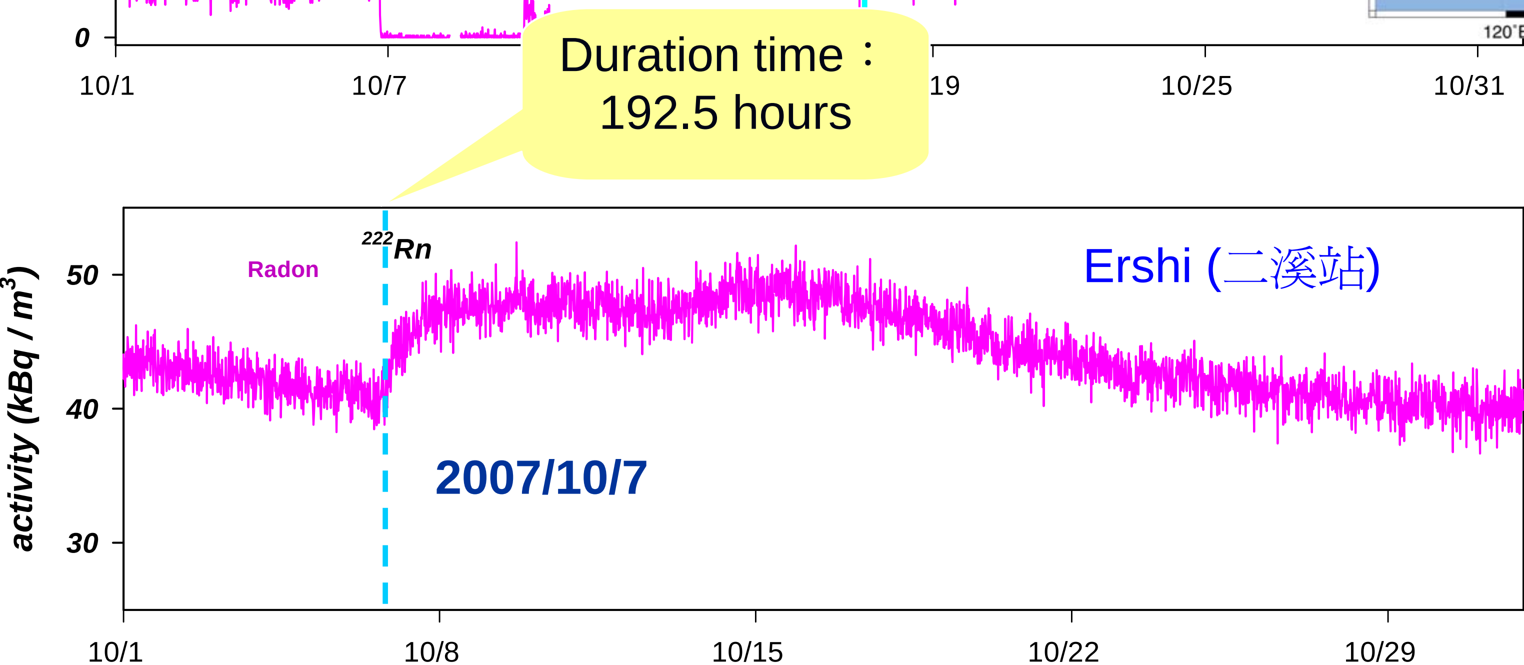


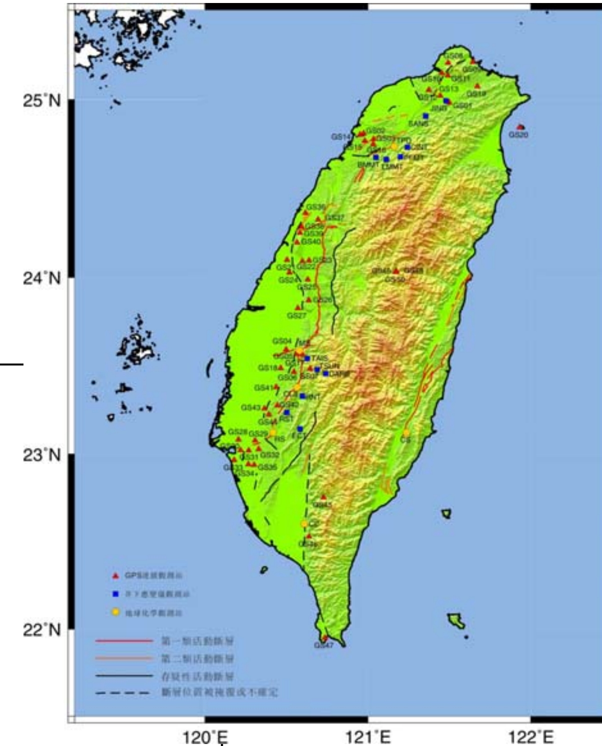



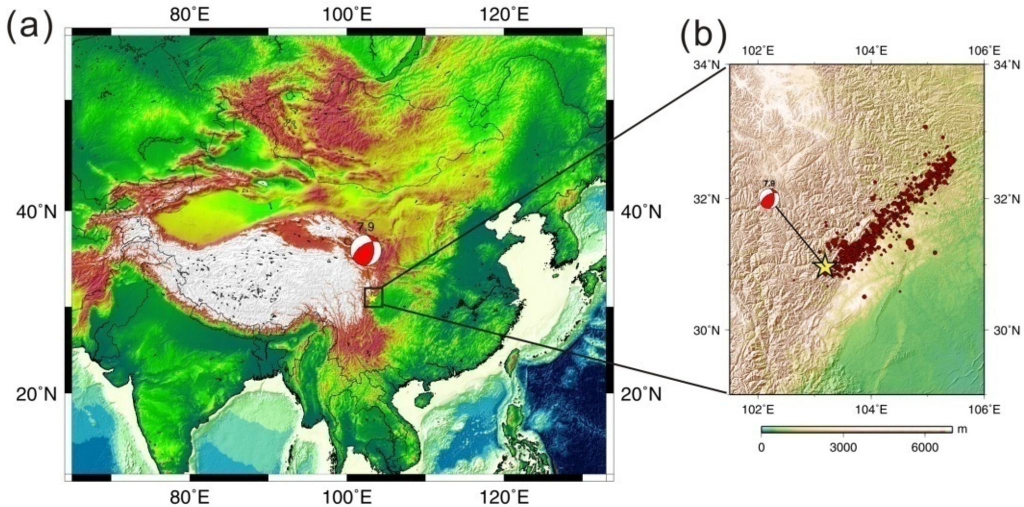
# Geochemical anomalies

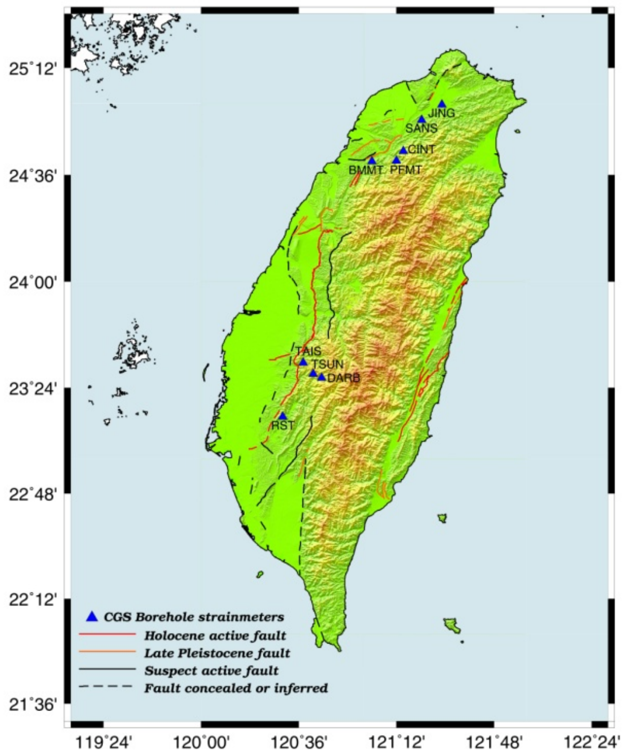


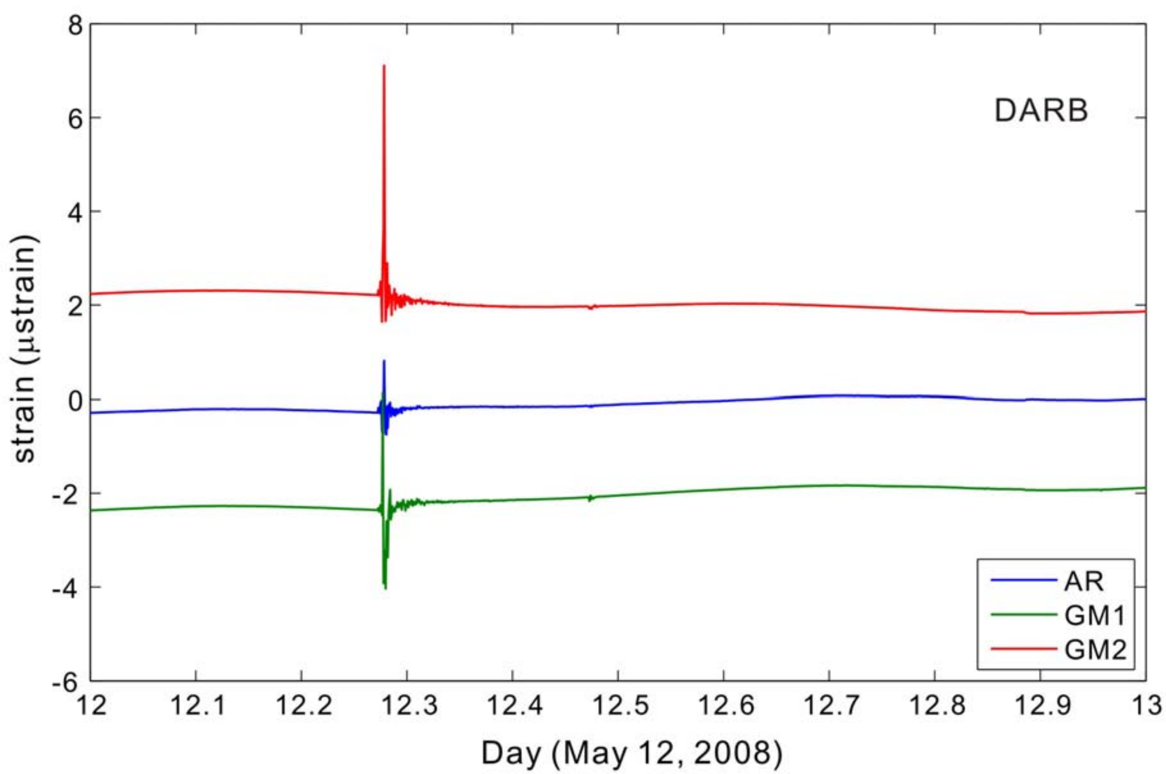



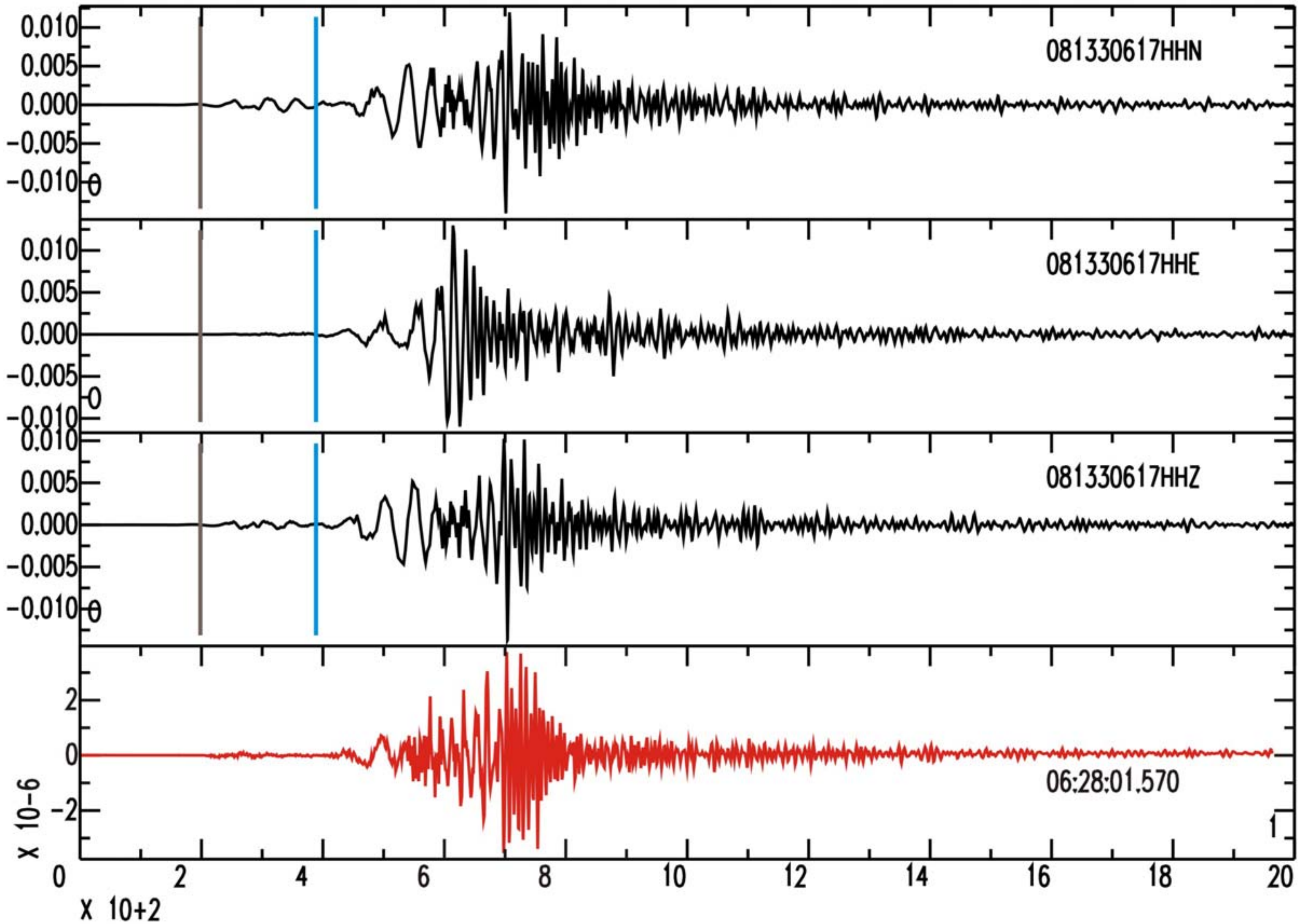
# Strain seismography



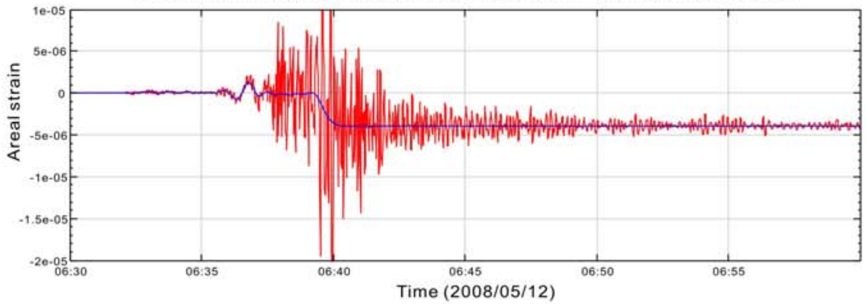



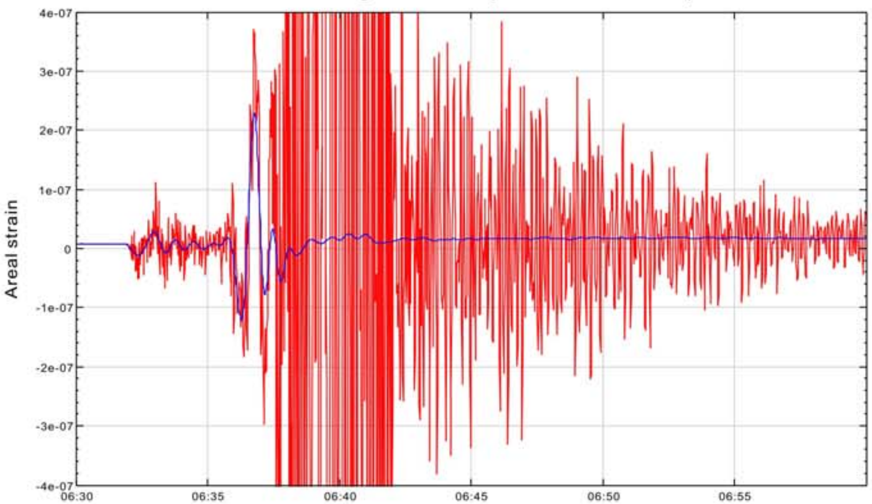
# Seismogram and strain of Wenchuan Earthquake at DARB



Areal strain change induced by Wenchuan Earthquake in SANS

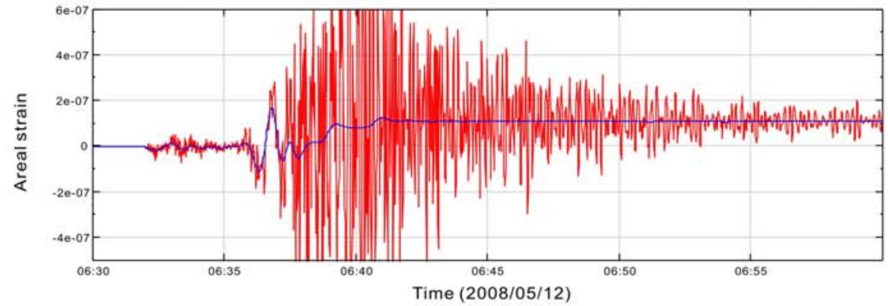



Areal Strain change induced by Wenchuan Earthquake in TAIS

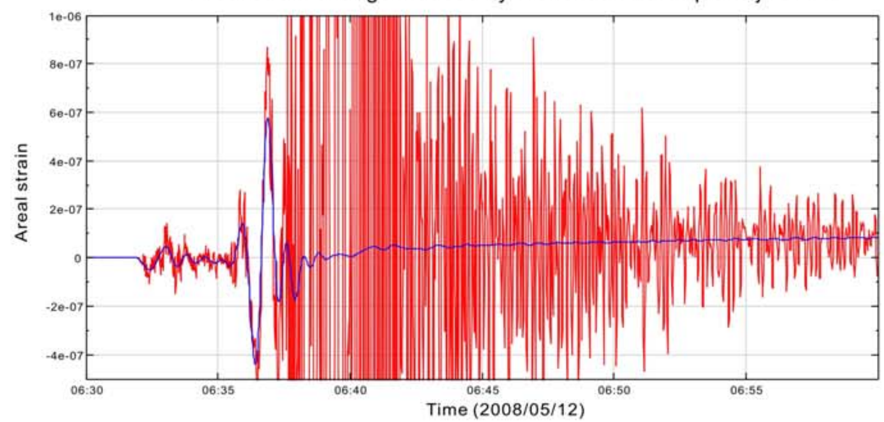



Time (2008/05/12)

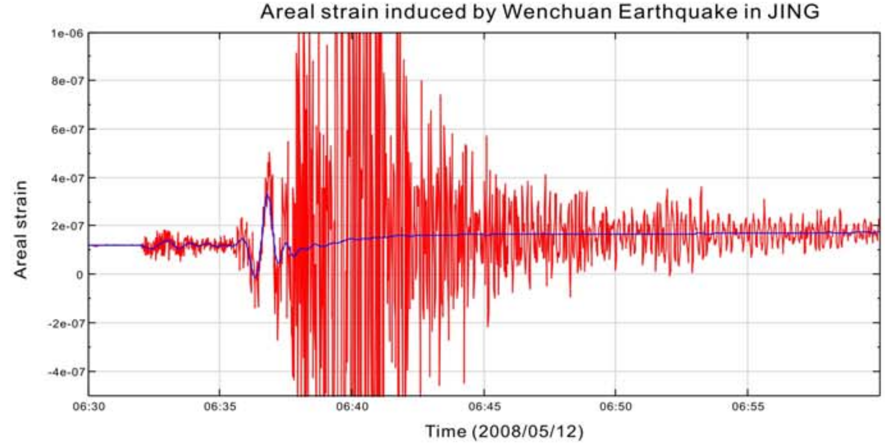
Areal strain change induced by Wenchuan Earthquake jn TSUN



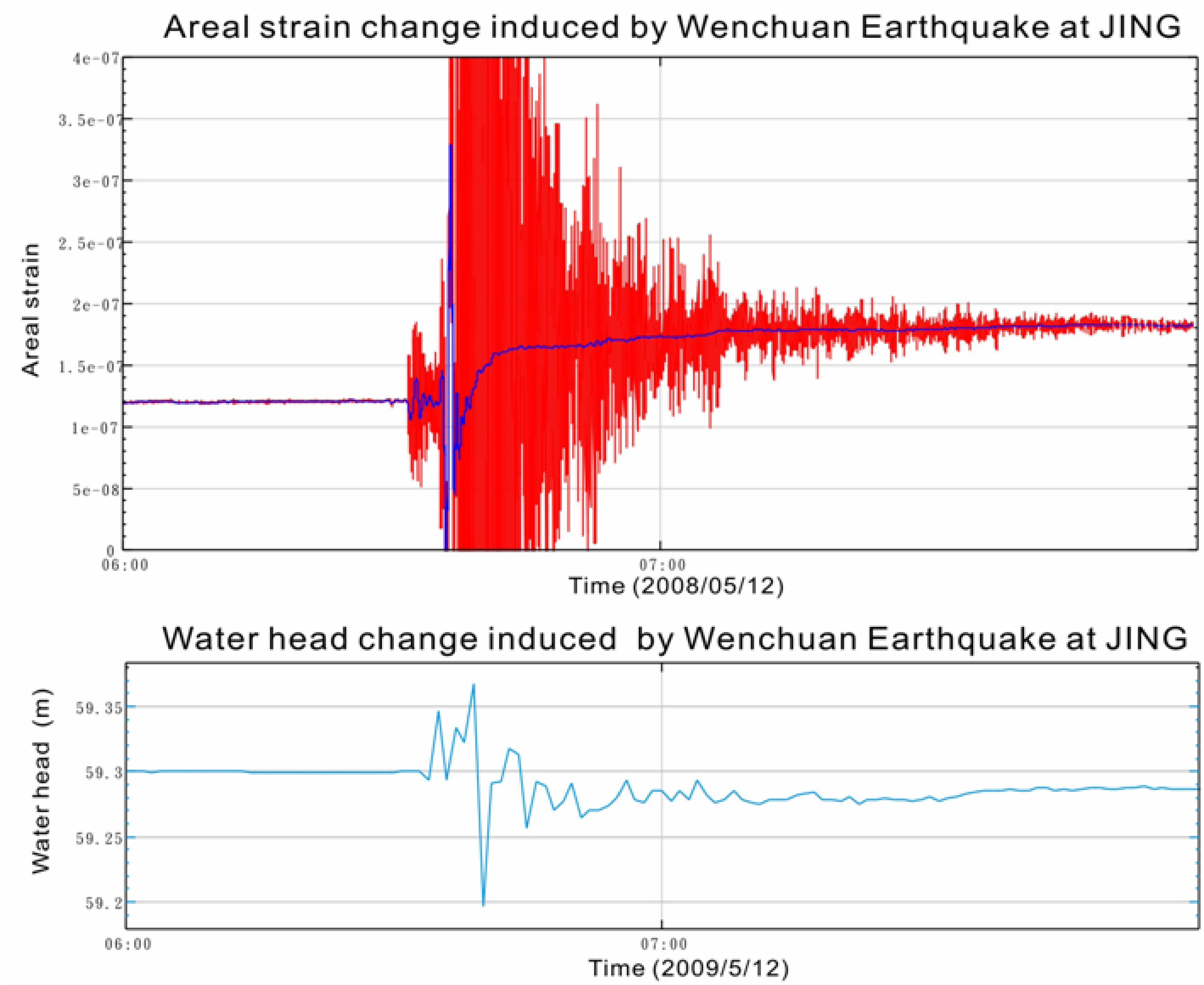

Areal strain change induced by Wenchuan Earthquake jn DARB



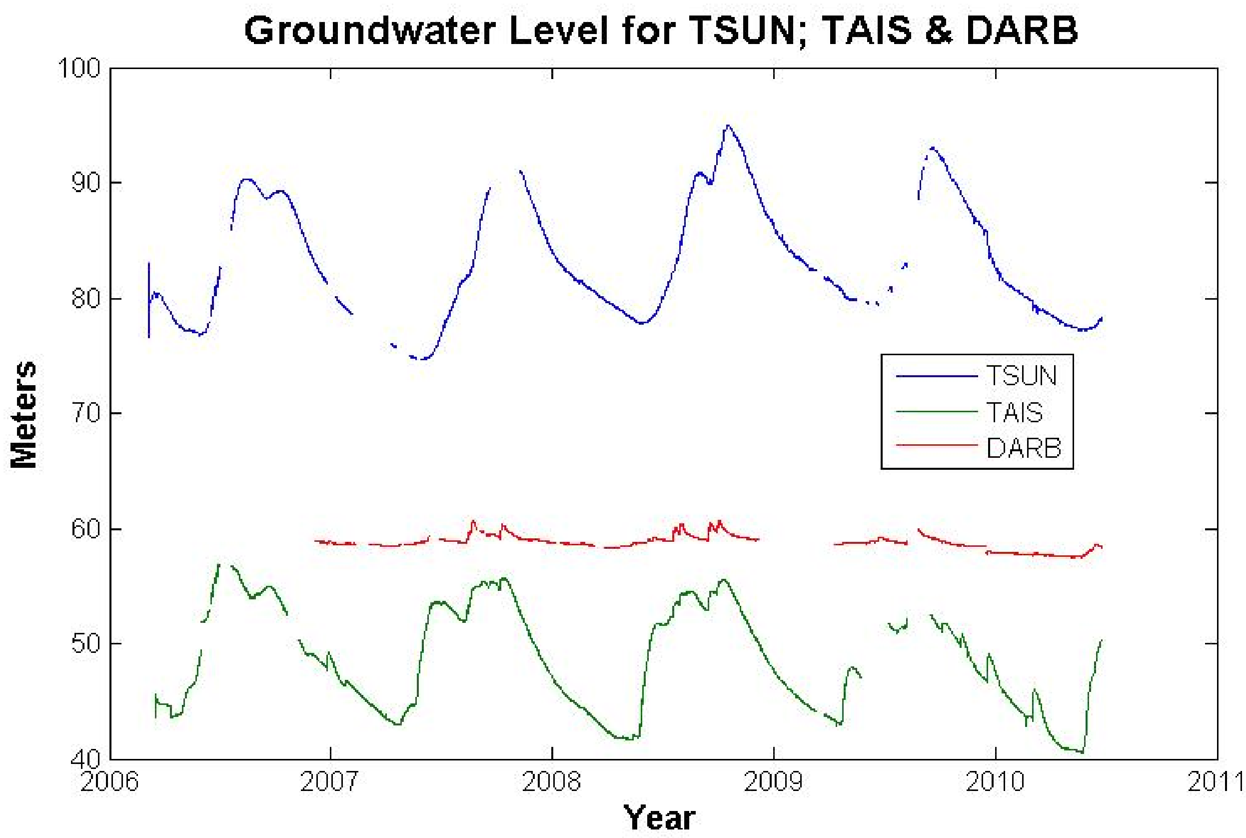

Areal strain induced by Wenchuan Earthquake in JING

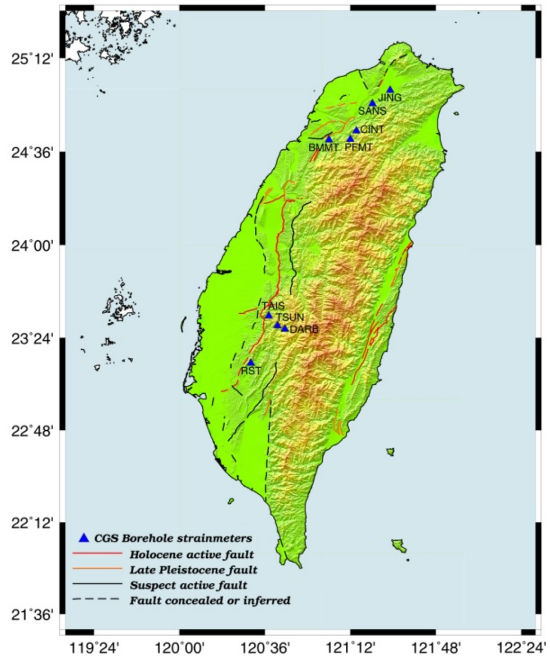


# Areal strain and water head changes

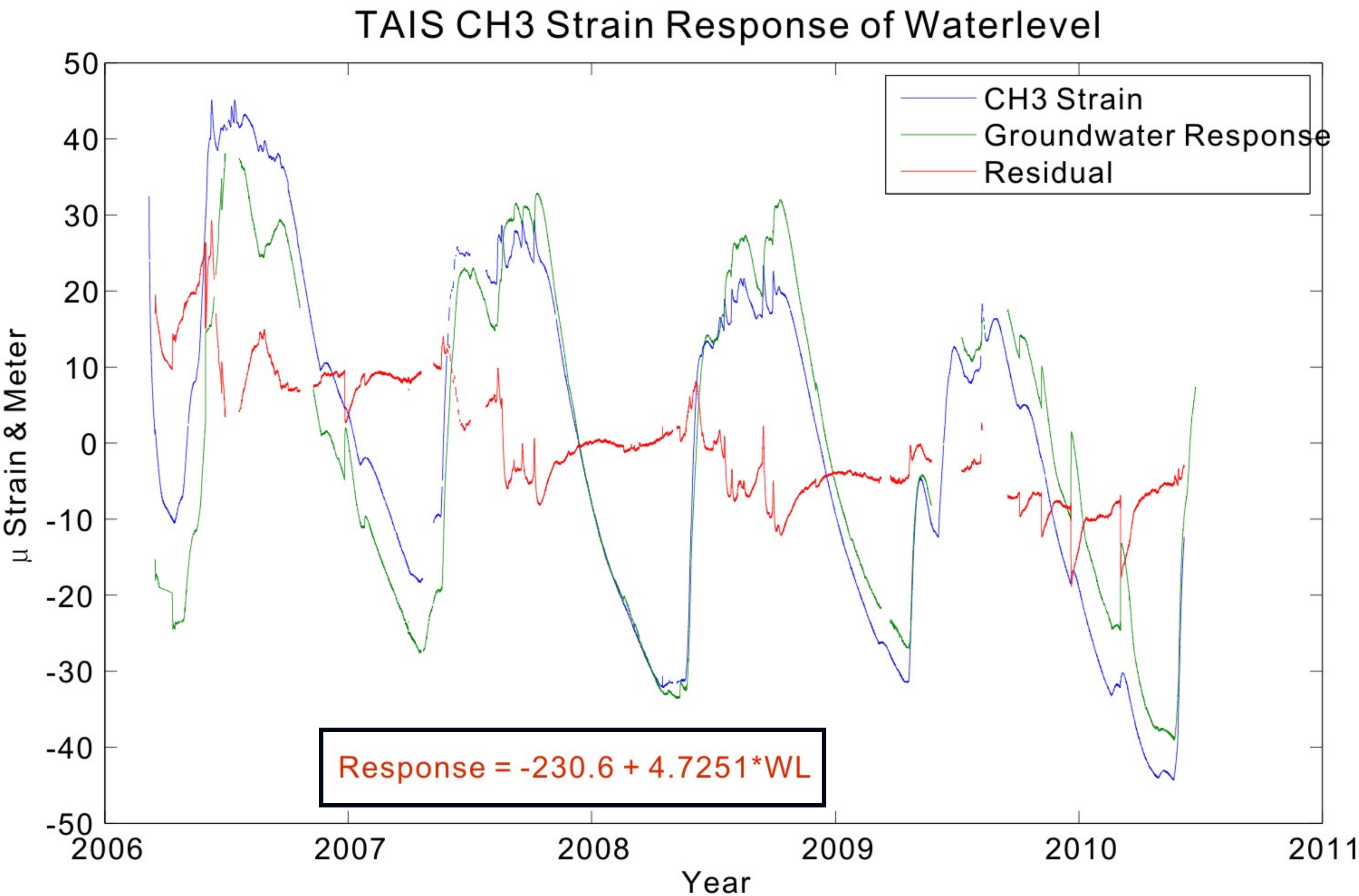


# Environmental parameters: Coupling of Groundwater Level



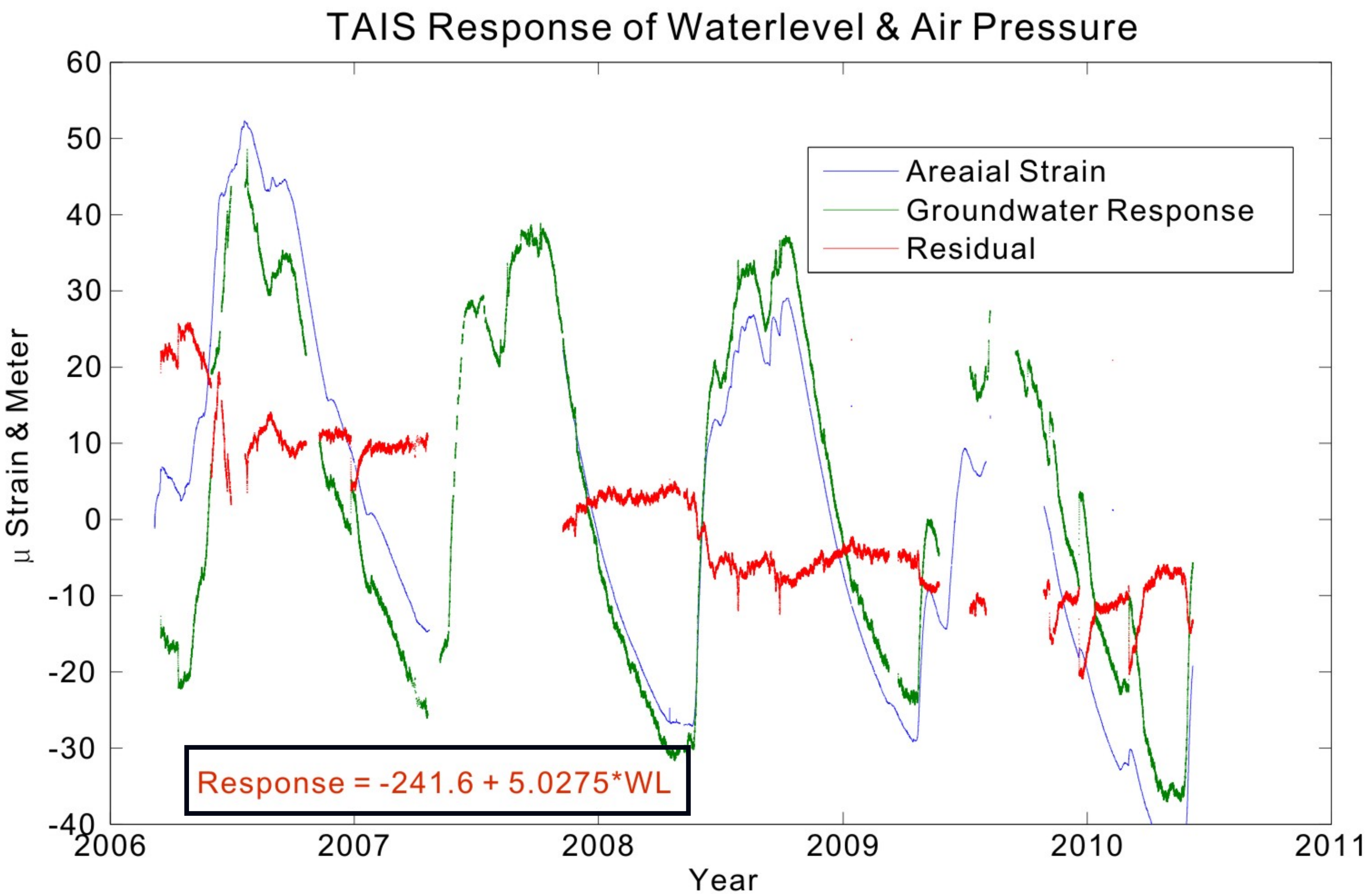



# Environmental parameters: Coupling of Strain and Groundwater Level



# Environmental parameters: Coupling of Strain and Groundwater Level

1m of groundwater level induces about 5 micorstrain change



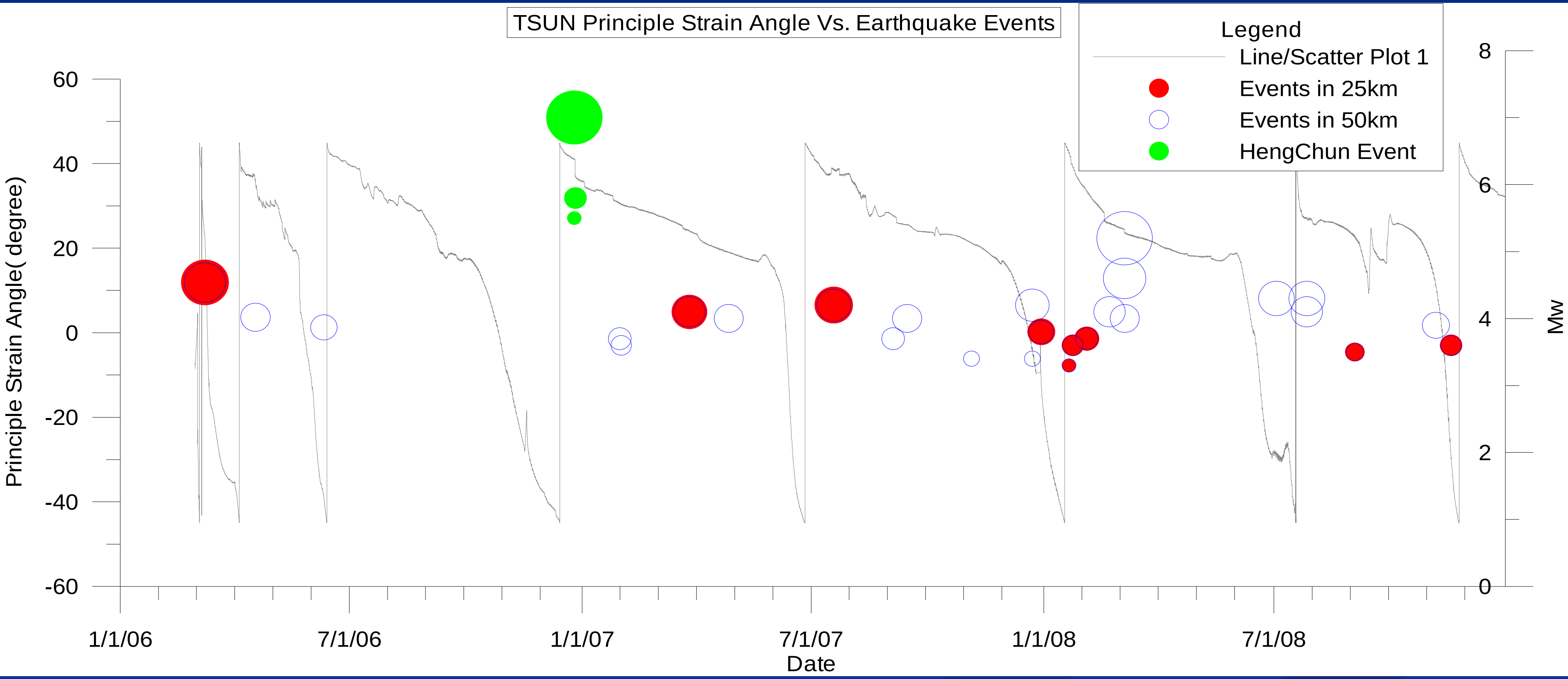
# Summary

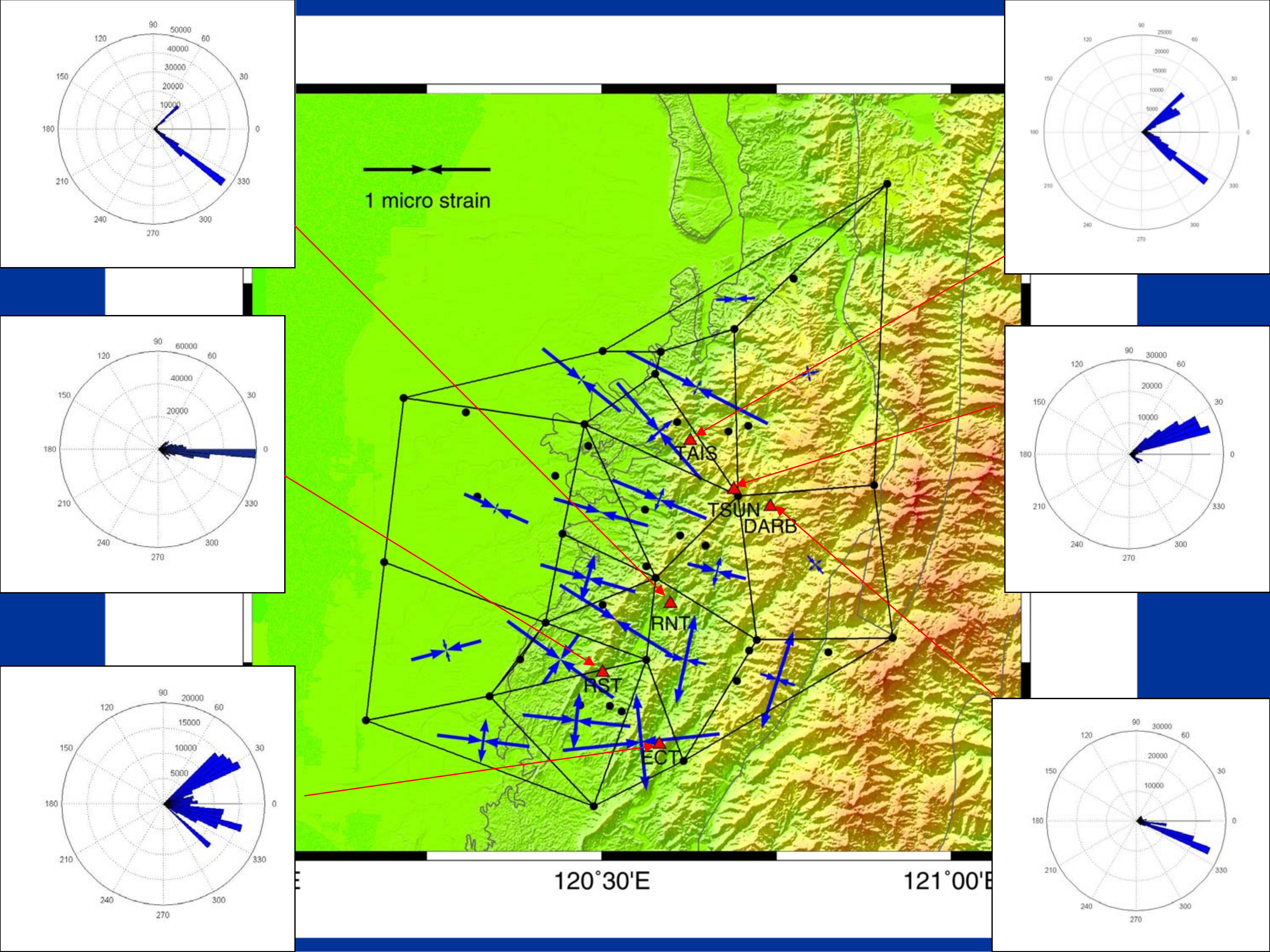
| Site | installed depth (m) | head before(m) | head after (m) | induced head (m) | induced strain ($\mu$ strain) |
|---|---|---|---|---|---|
| JING | 59.6 | 59.299 | 59.277 | -0.022 | +0.05 |
| SANS | 68.3 | 68.054 | 68.051 | -0.003 | -4 |
| BMMT | 155 | 145.65 | 145.63 | -0.02 | -0.2 |
| LMMT | 135 | 129.52 | 129.51 | -0.01 | - |
| CINT | 75 | 62.153 | 62.245 | 0.092 | +0.2 |
| TAIS | 180 | 41.721 | 41.765 | 0.044 | +0.01 |
| TSUN | 159.3 | 78.219 | 78.199 | -0.02 | +0.1 |
| DARB | 150 | 58.580 | 58.586 | 0.06 | +0.05 |

# How could seismic train induce permanent (step-like) deformation ?

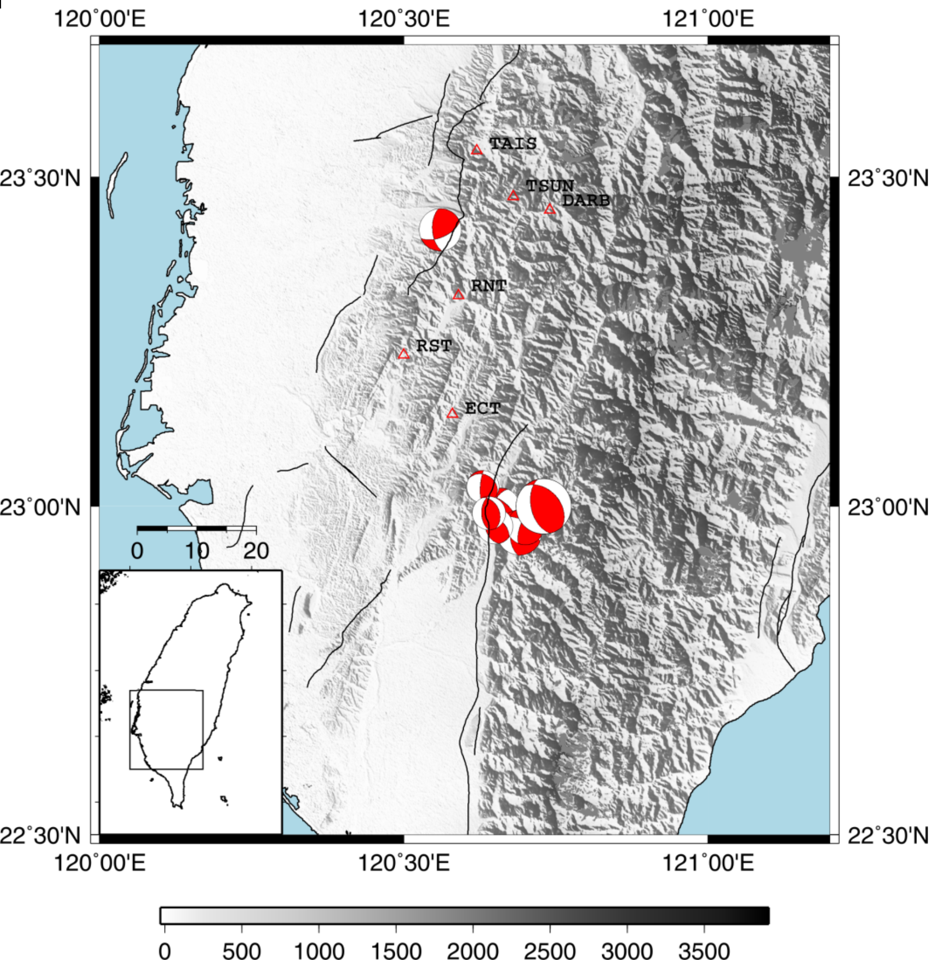
- Instrumental problem?
- Remote-triggering and reactivation of local fault?
- Poroelastic effects?

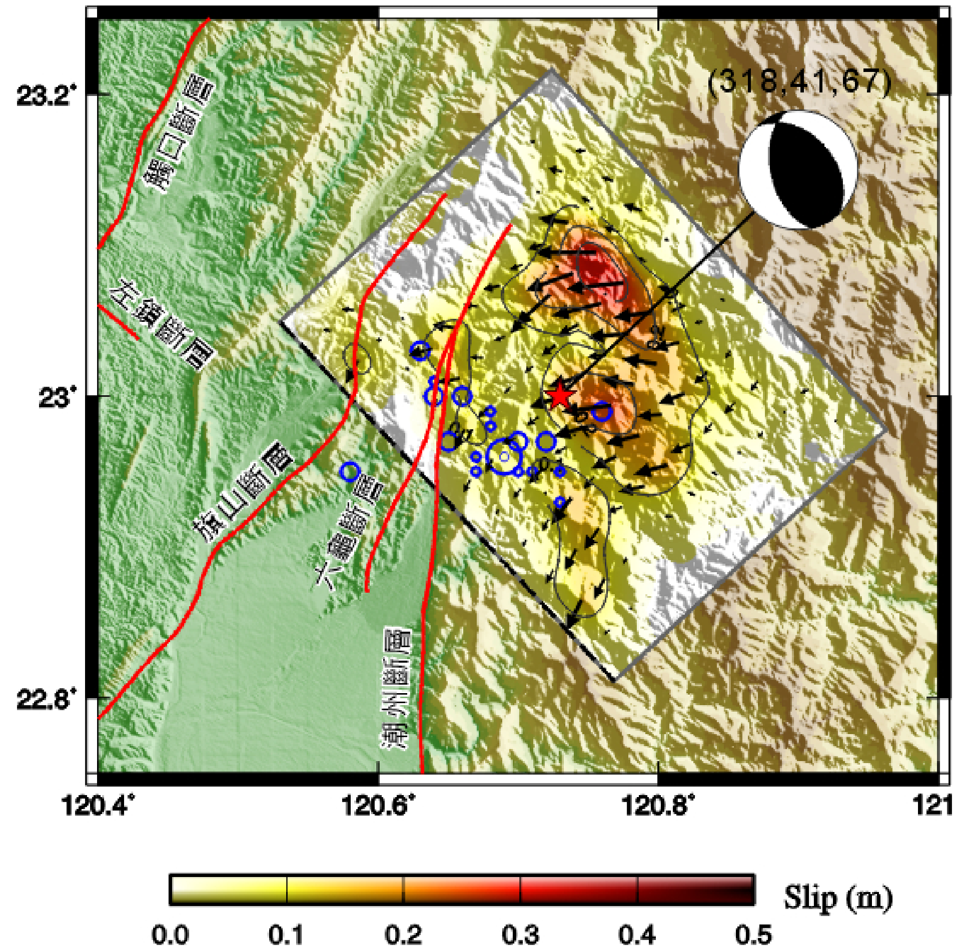
# Permutation of principal strain



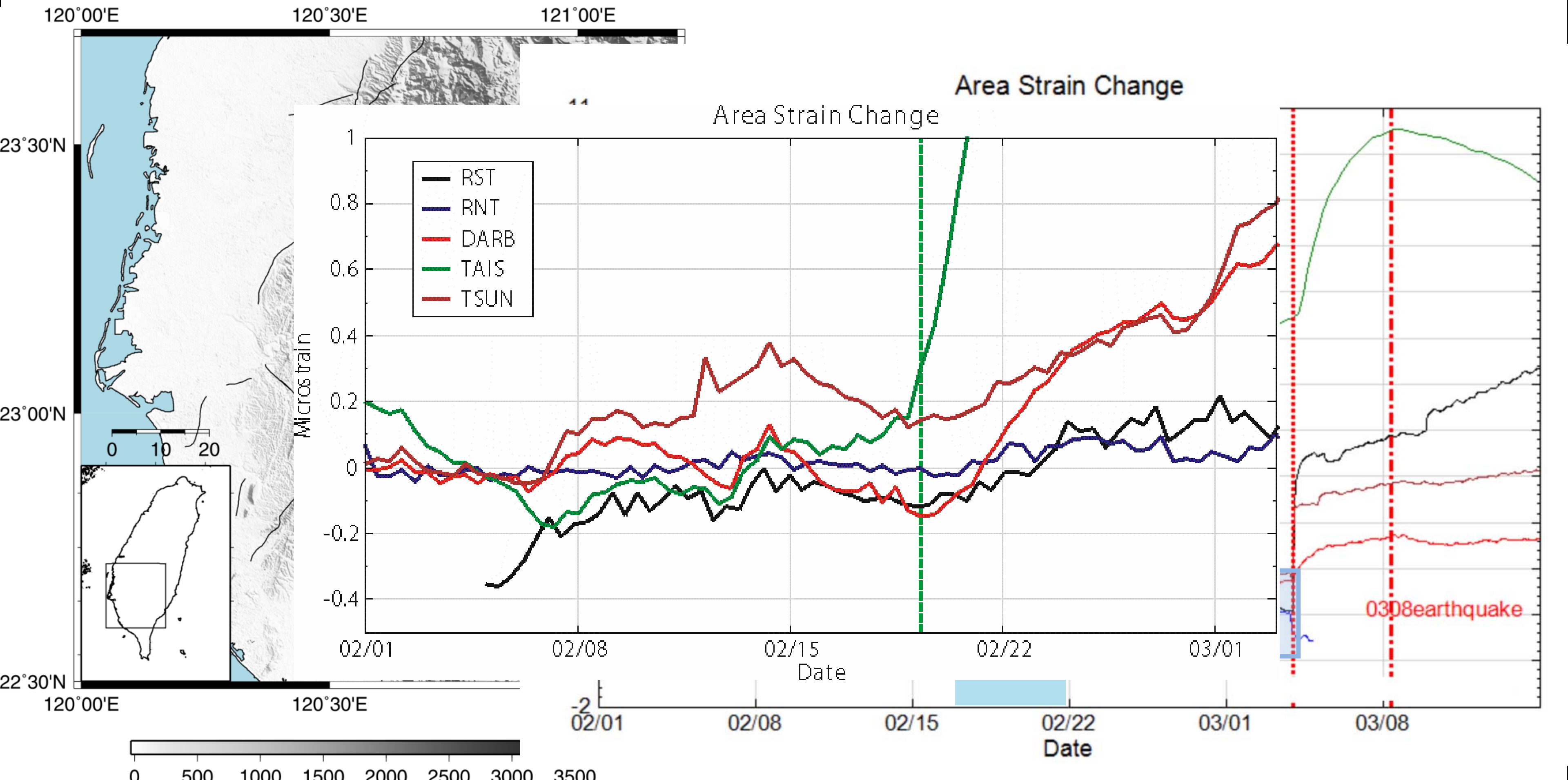

1 micro strain
TAIS
TSUN
DARB
RNT
RST
ECT
120°30'E
121°00'E

# Jiasian earthquake: $M_L$ 6.4, March 4, 2010

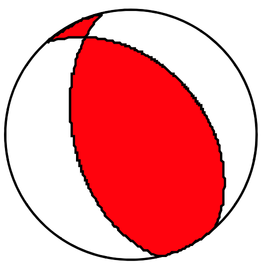


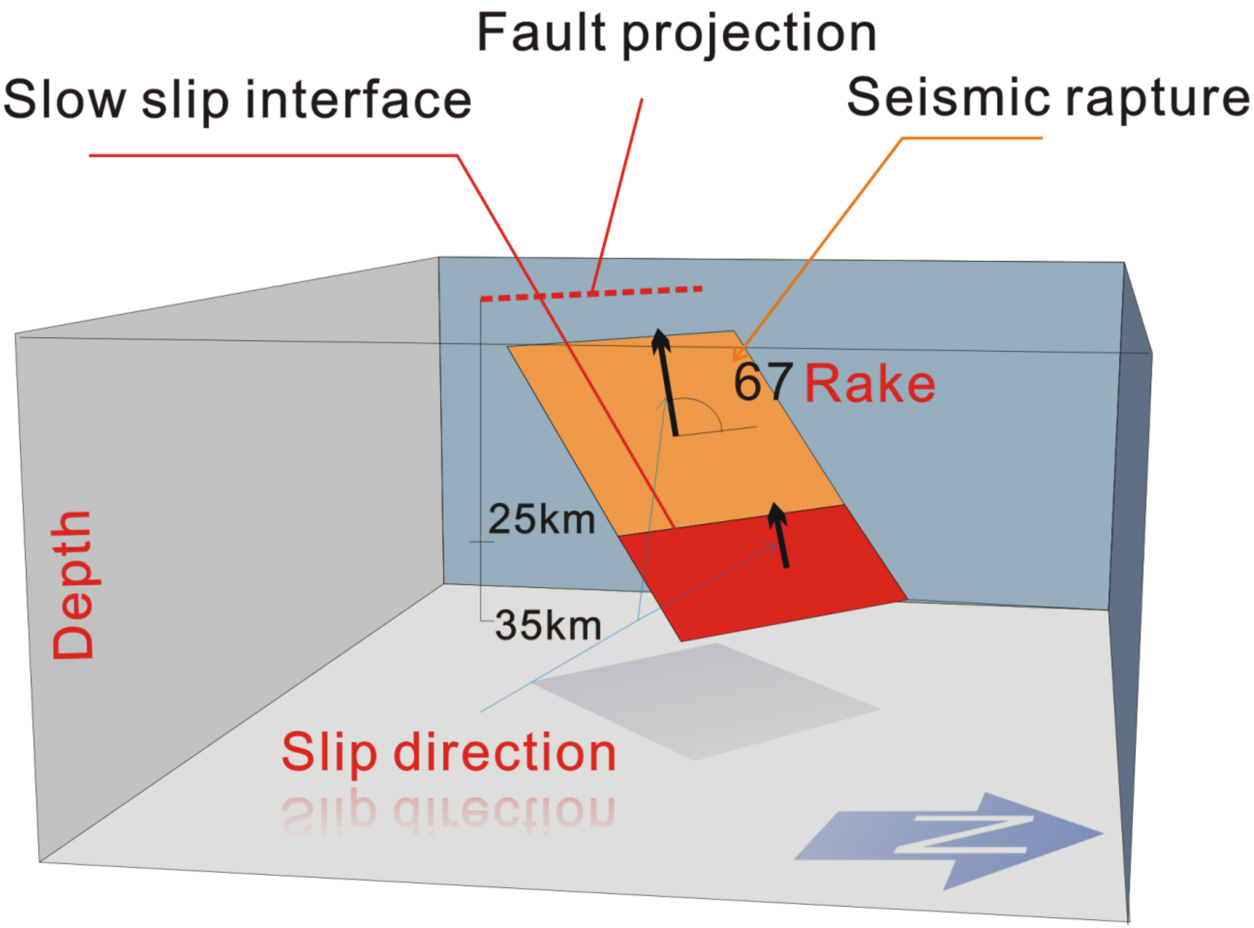
# Possible precursory pre-slip event observed from borehole



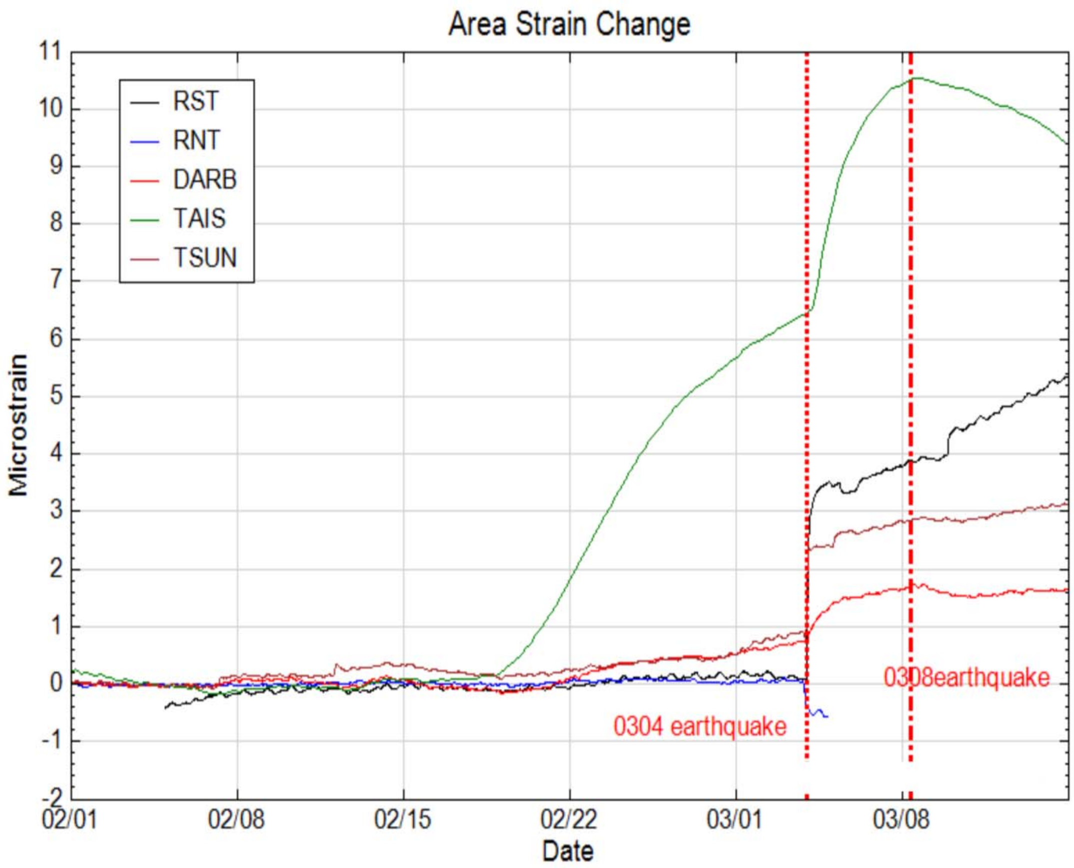
# Modeling of pre-slip and coseismic events

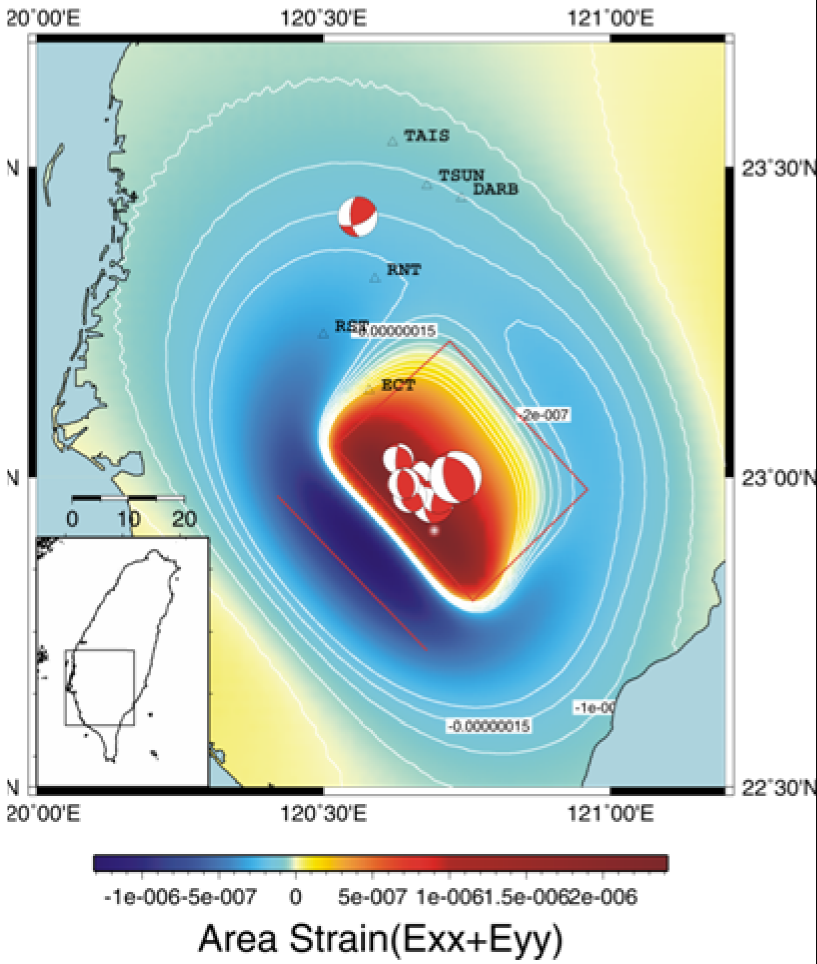


(318,41,67) BATS

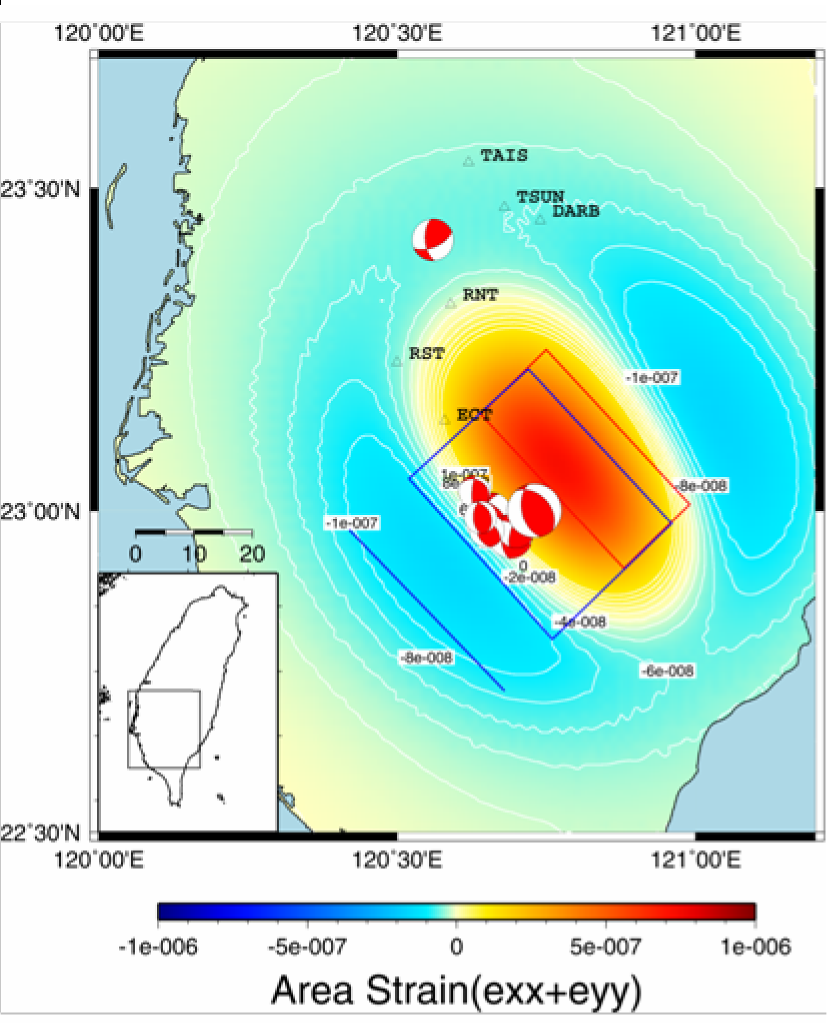


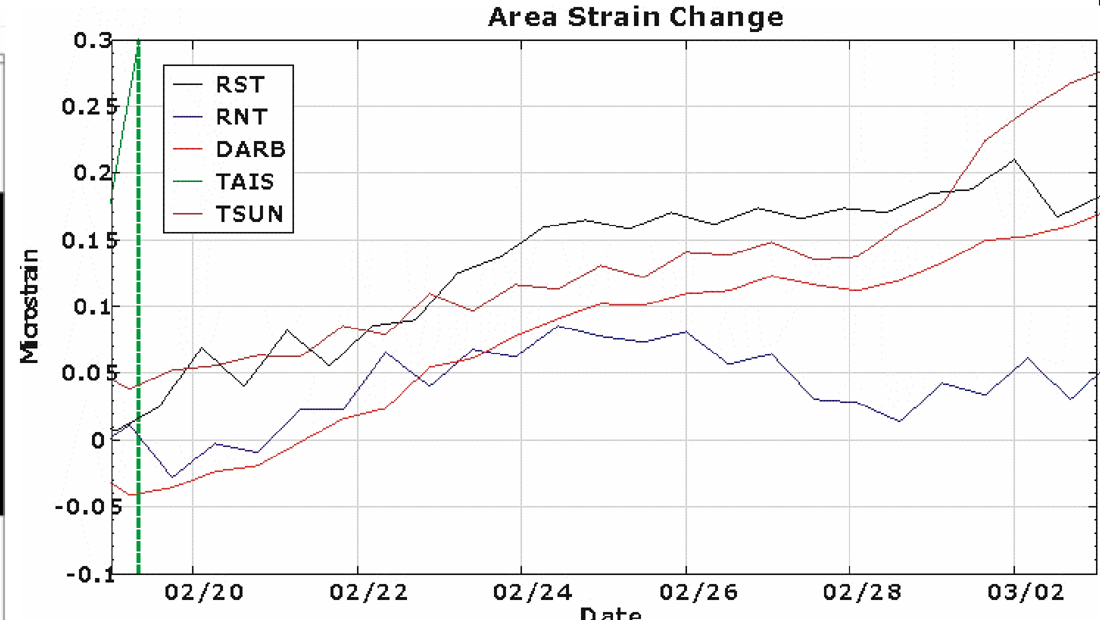
# Coseismic-induced areal strain (exx+eyy) change

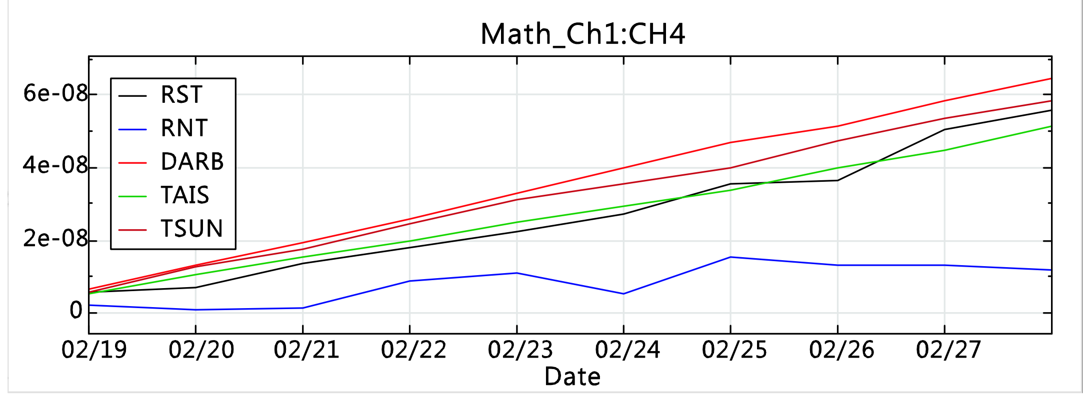


# Pre-slip  areal strain change



# Prospect: Cooperation with GSJ, AIST

## Active faults and Earthquake Research Center

Coupling with environmental parameters and calibration

Fault activity monitoring

Strain seismography

**Can aseismic deformation rate changes prior to earthquake be detected in Taiwan?**

Tremor & slow earthquake

Permutation of principal strain