

# 快速時頻分析在井下應變儀之初步 研究

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<sup>1</sup>臺灣大學地質科學系

<sup>2</sup>中央研究院地球科學研究所

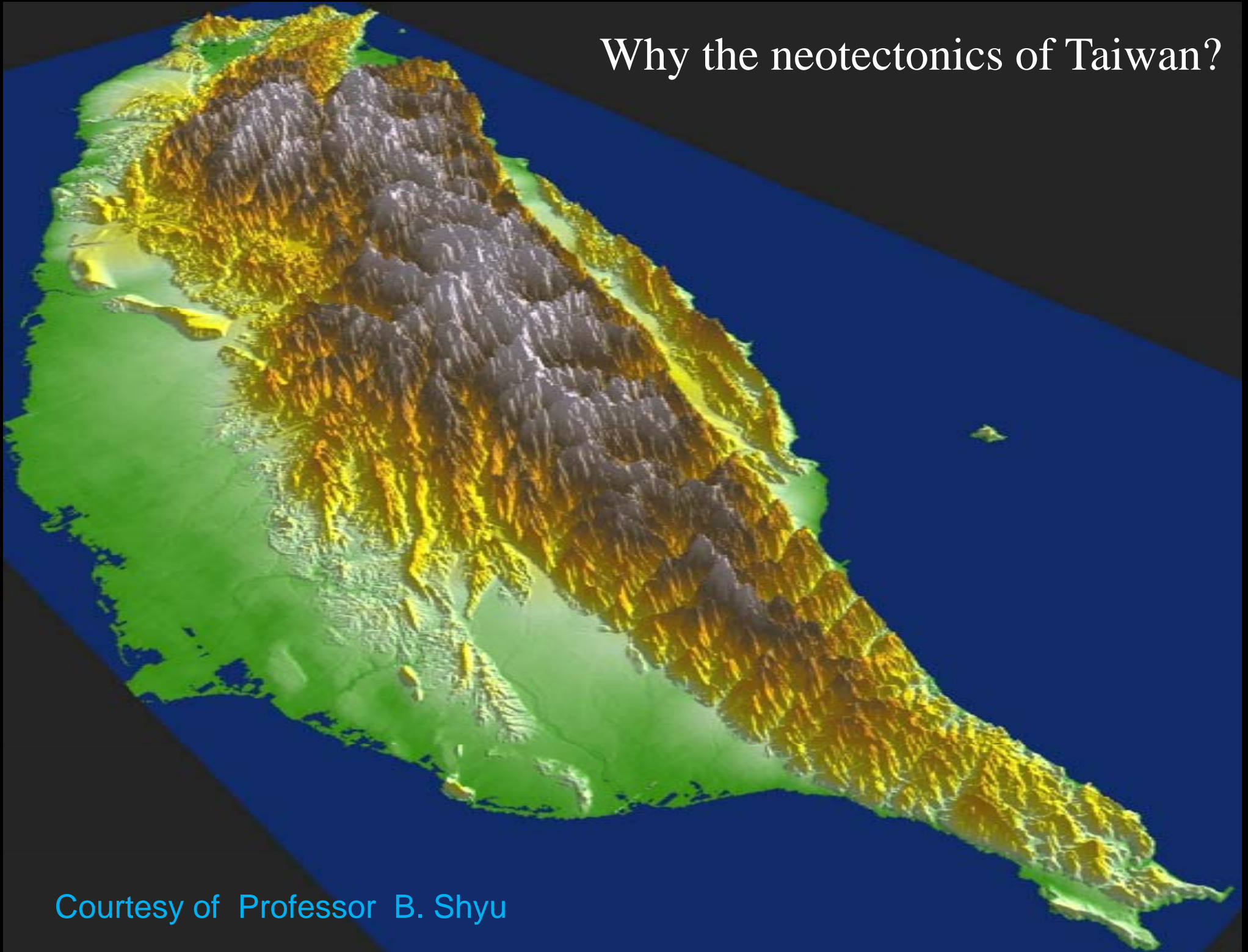
<sup>3</sup>經濟部中央地質調查所

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<sup>5</sup>中央大學地球科學系

<sup>6</sup>師範大學地球科學系

# Why the neotectonics of Taiwan?



Courtesy of Professor B. Shyu

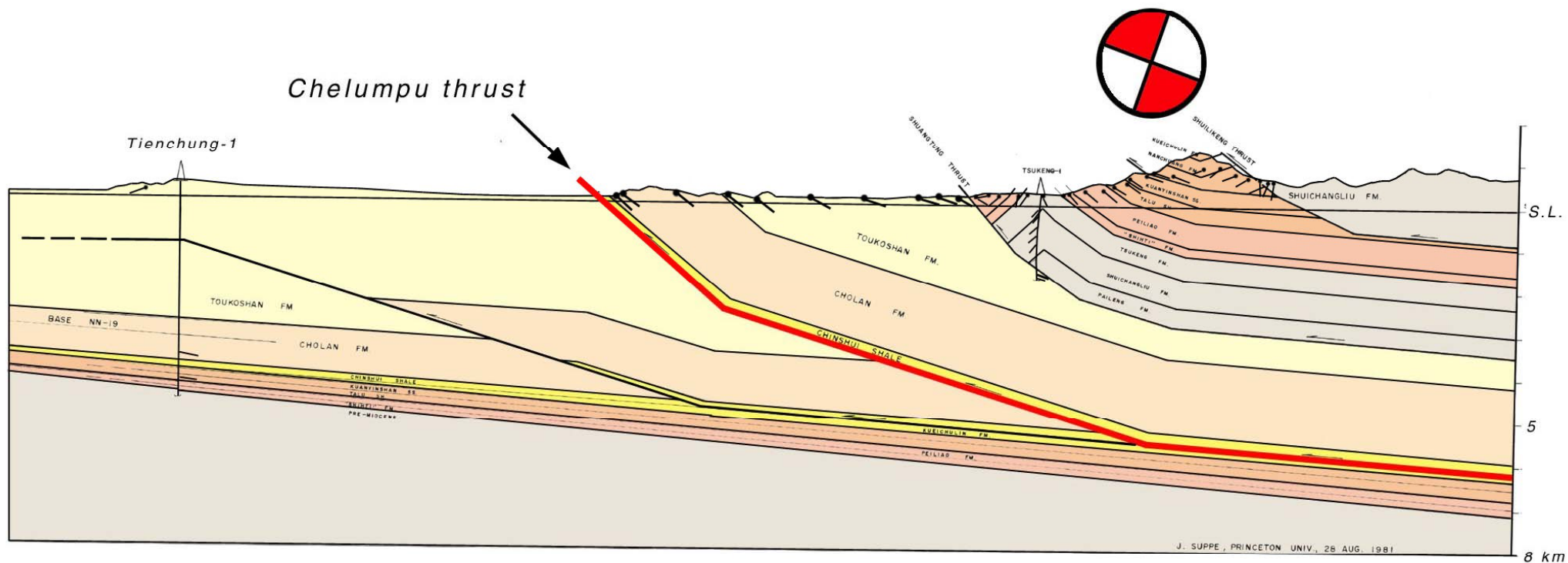
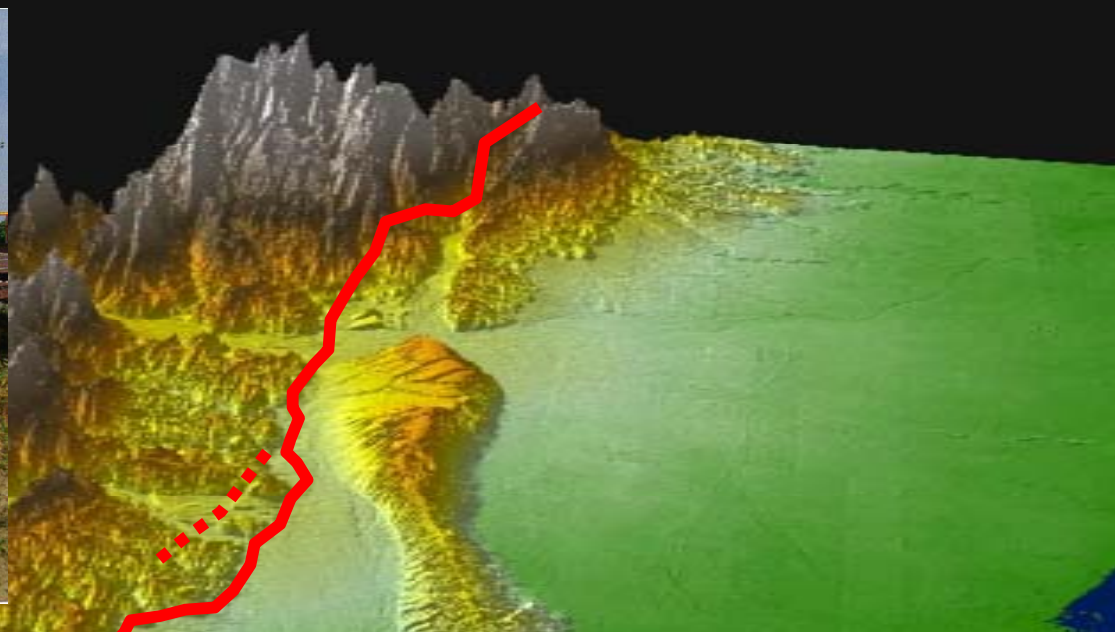


The 1999 Chi-Chi earthquake!



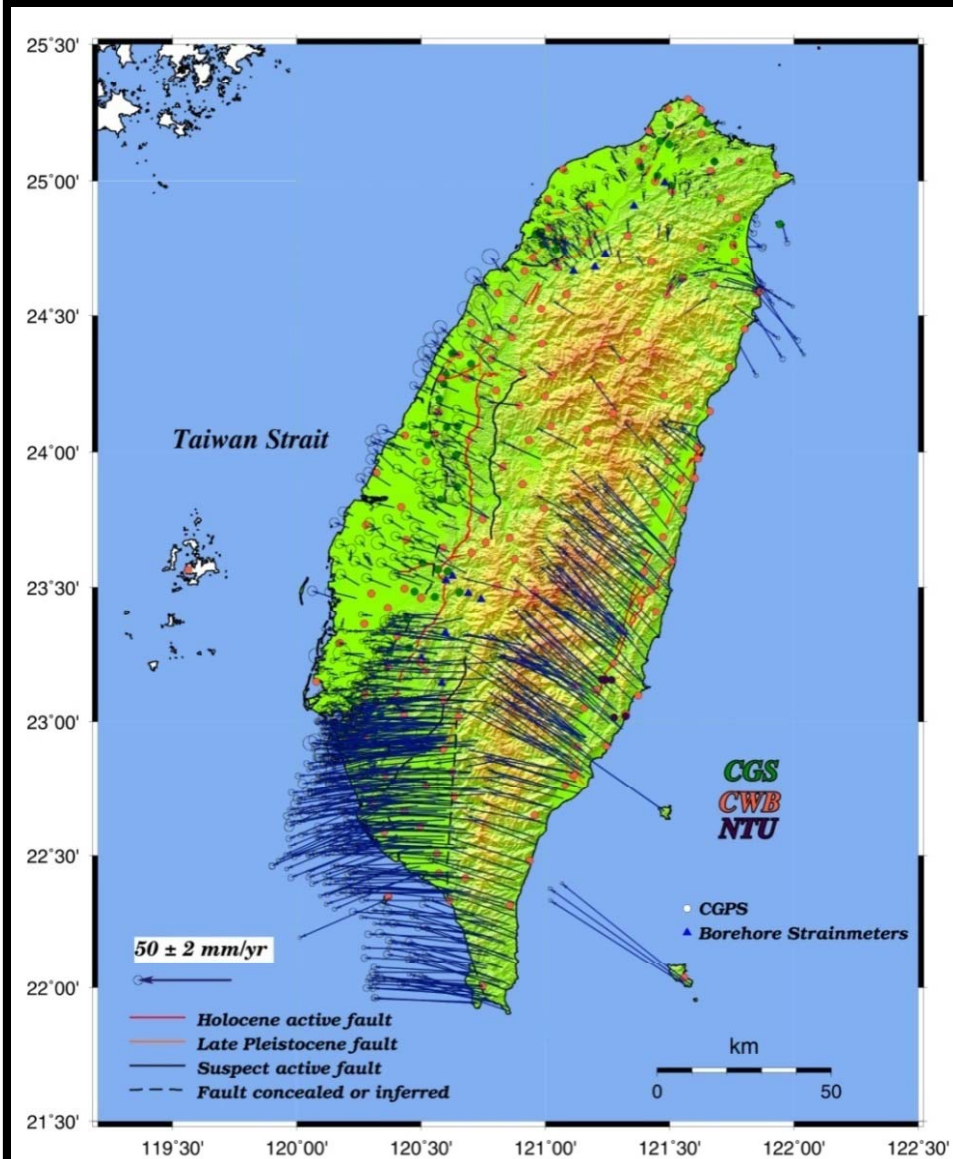
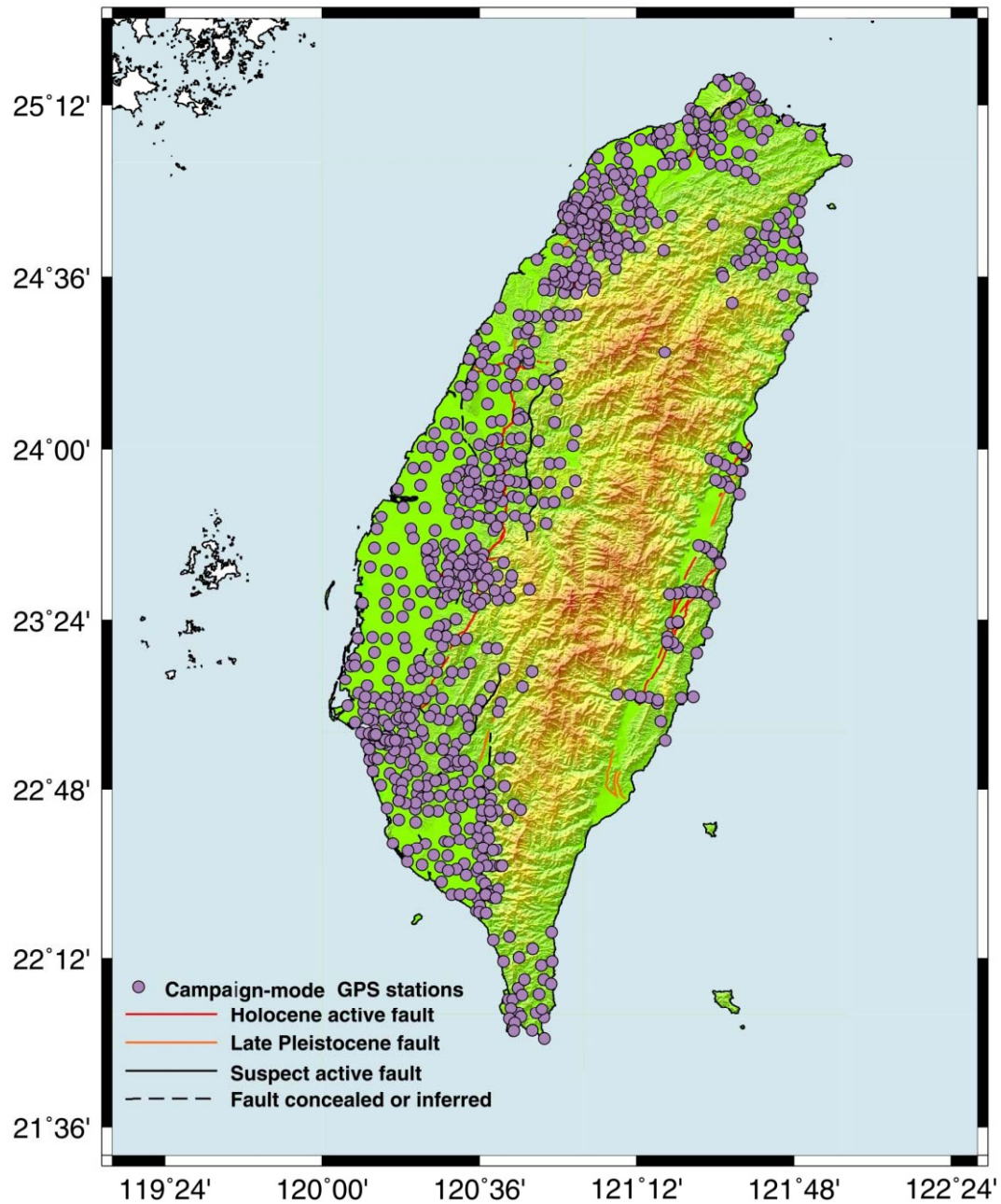
Courtesy of Professor B. Shyu



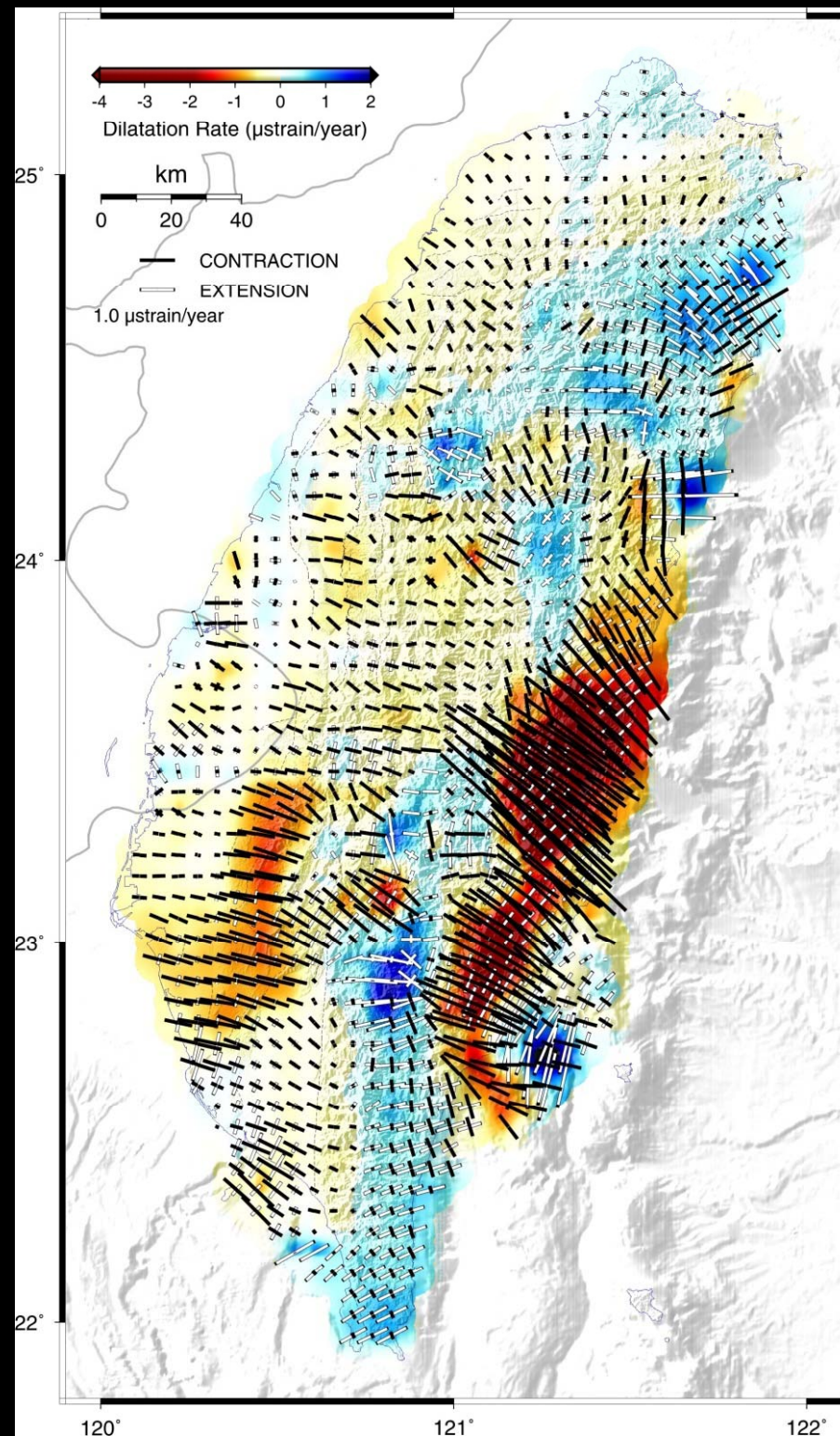
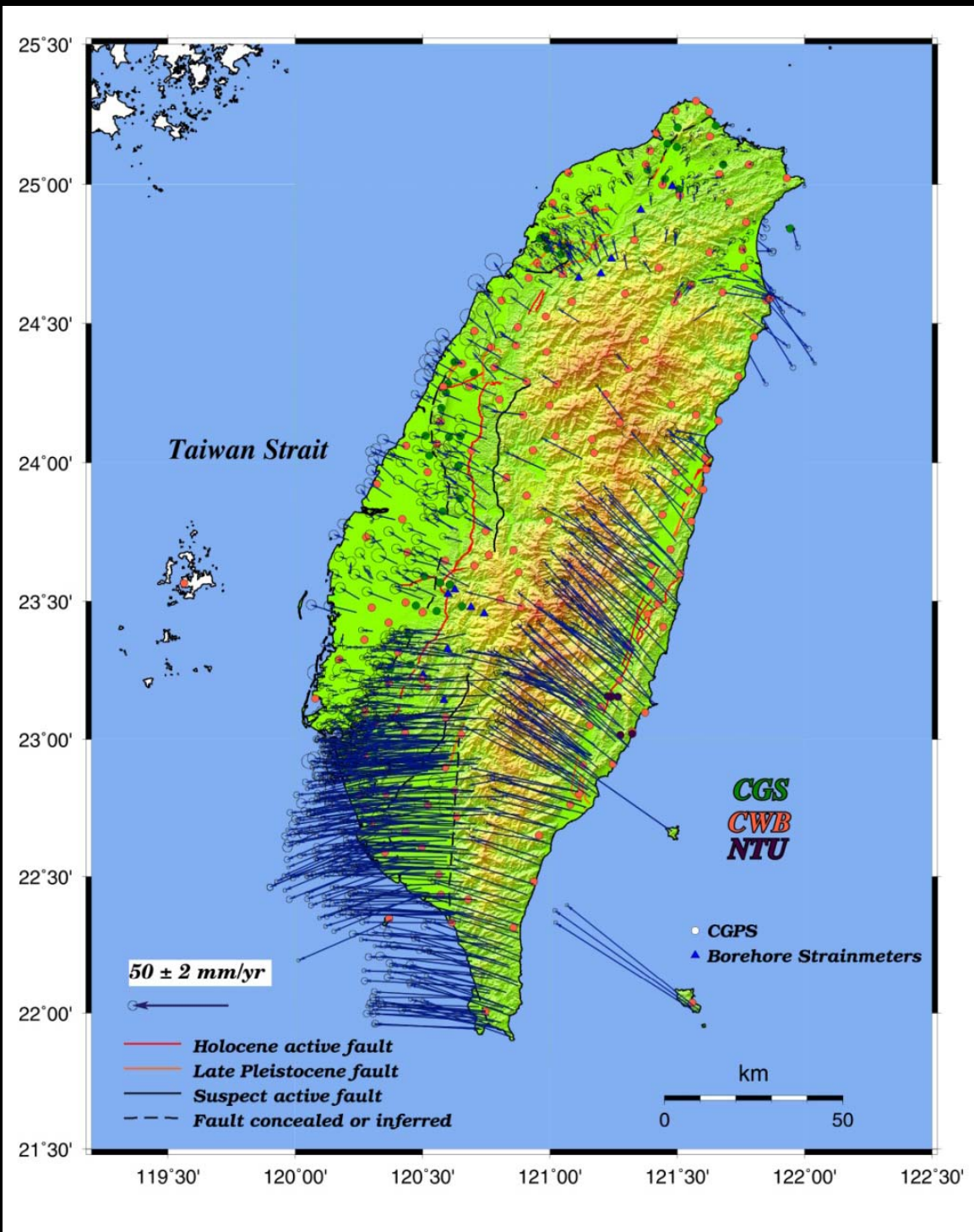


(Suppe, 1981)



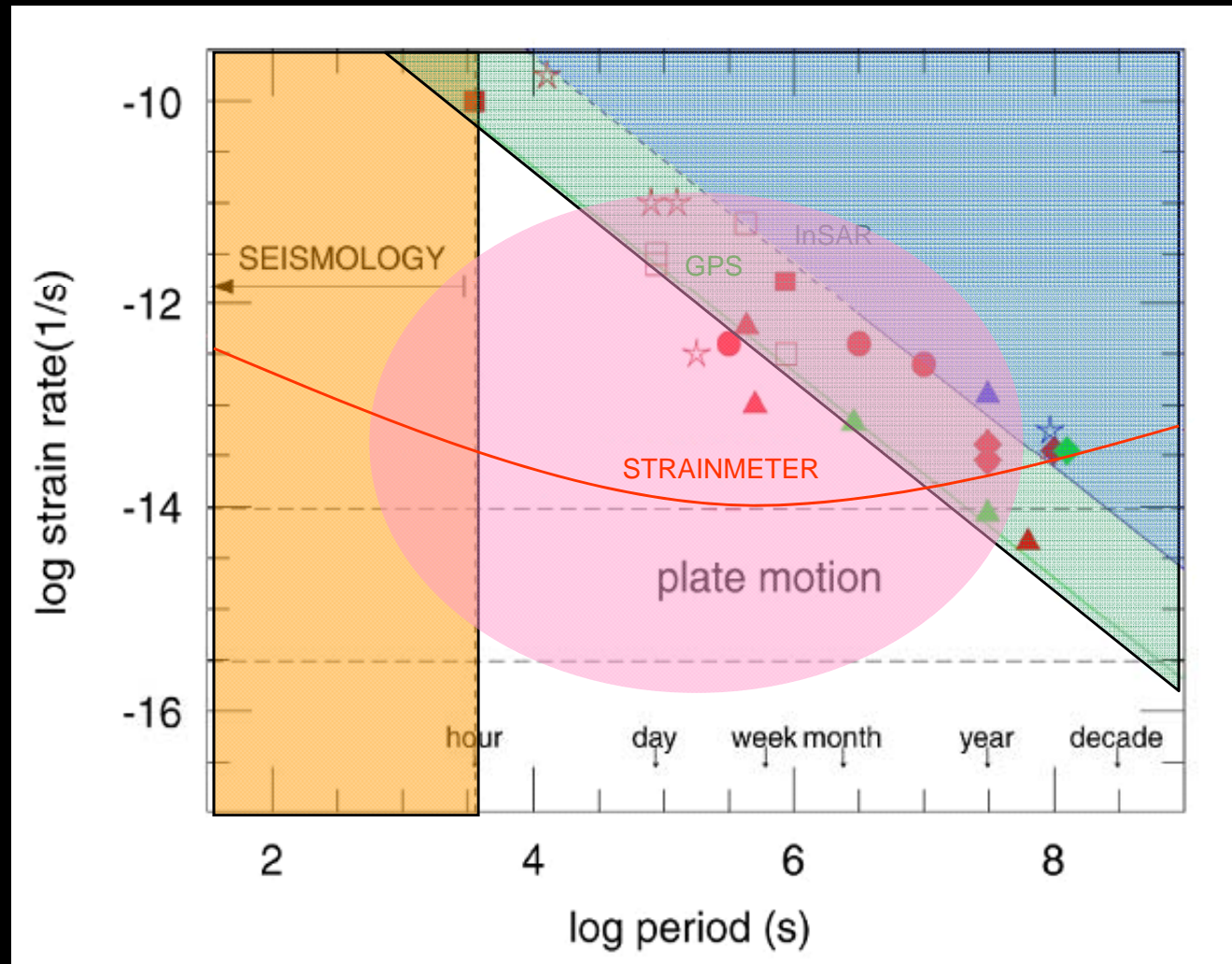








# Crustal Deformation and Monitoring



- Bridging the sensitivity and frequency gap between seismic and GPS measurements.
- Detecting aseismic deformation rate changes prior to earthquake

	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 Urakawa-oki, Japan March 21, 1982	CONVERGENT MARGIN	Leveling	3–11.5 years	(0.4 m slip)	Taylor et al. 1991; Iio et al. 2002; Murai et al. 2003
Ms7.8 Japan Sea May 26, 1983	CONVERGENT MARGIN	Leveling, tide gauges, borehole strain	14 years	7.7	Iio et al. 2002, Mogi 1985
Mw6.1 Kettleman Hills, California August 4, 1985	TERRESTRIAL	Water levels, borehole strain	3 days	5.4	Roeloffs & Quilty 1997
Mw7.6 Peru July 7, 2001	CONVERGENT MARGIN	CGPS	18 h	7.8	Melbourne & Webb 2002



	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	Pi ~ non Flat strainmeters, GPS (68 km), Dilatometer (100 km)	<M4.8 ( <i>Pi ~ non Flat laser strainmeter</i> )	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 ( <i>CGPS</i> ), <M5 ( <i>InSAR</i> )	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

# *How well can aseismic deformation be measured?*

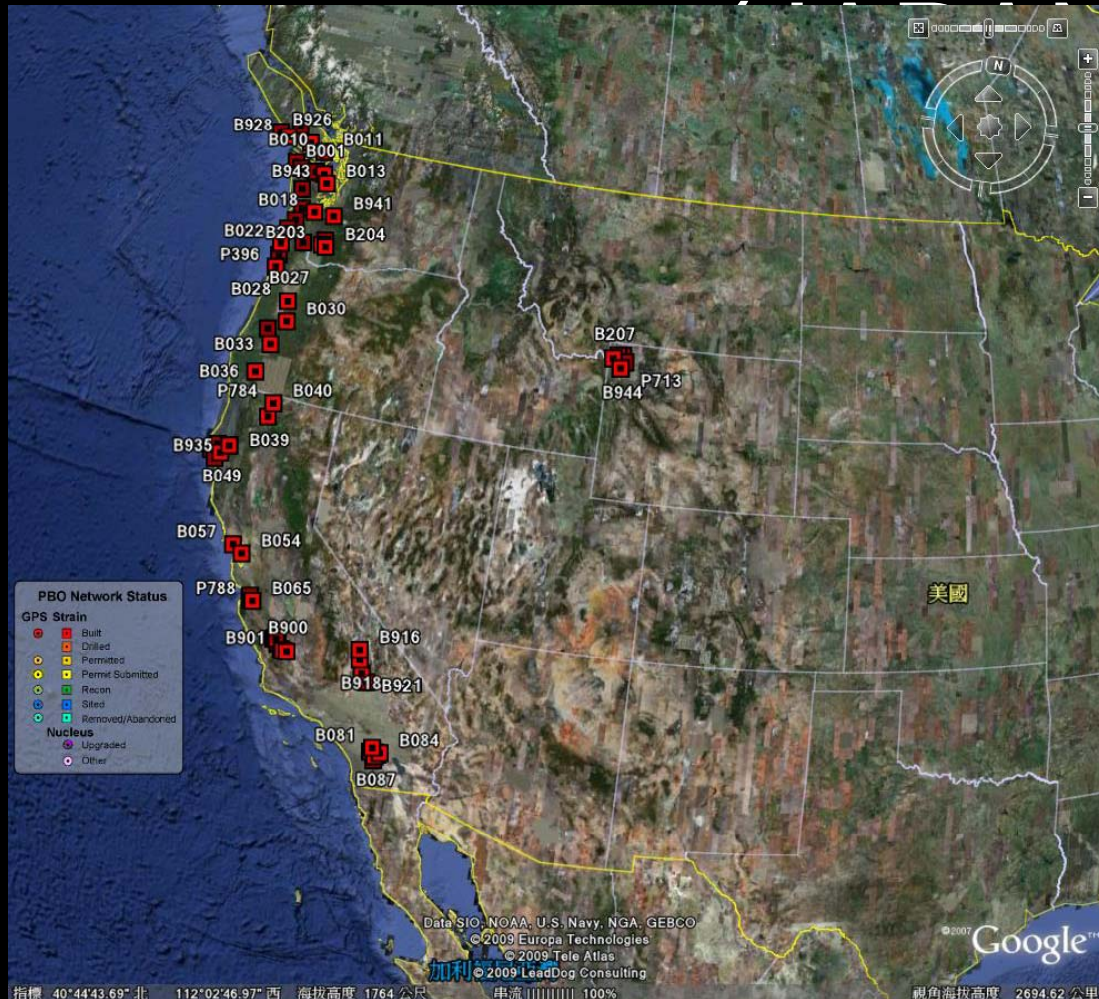
- For ten earthquakes in nonmagmatic settings, there are credible published accounts of **pre-earthquake deformation-rate changes** lasting hundreds of seconds to more than a decade.
- Although most  $M > 7.5$  earthquakes have occurred without detectable pre-earthquake deformation, the **detection threshold 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

- Coupling with environment
- Episodic Tremor and Slip (ETS)
- Strain seismography
- Variation of principal strain
- Aseismic deformation rate change prior to earthquake

# PBO (US) and Tokai Scheme

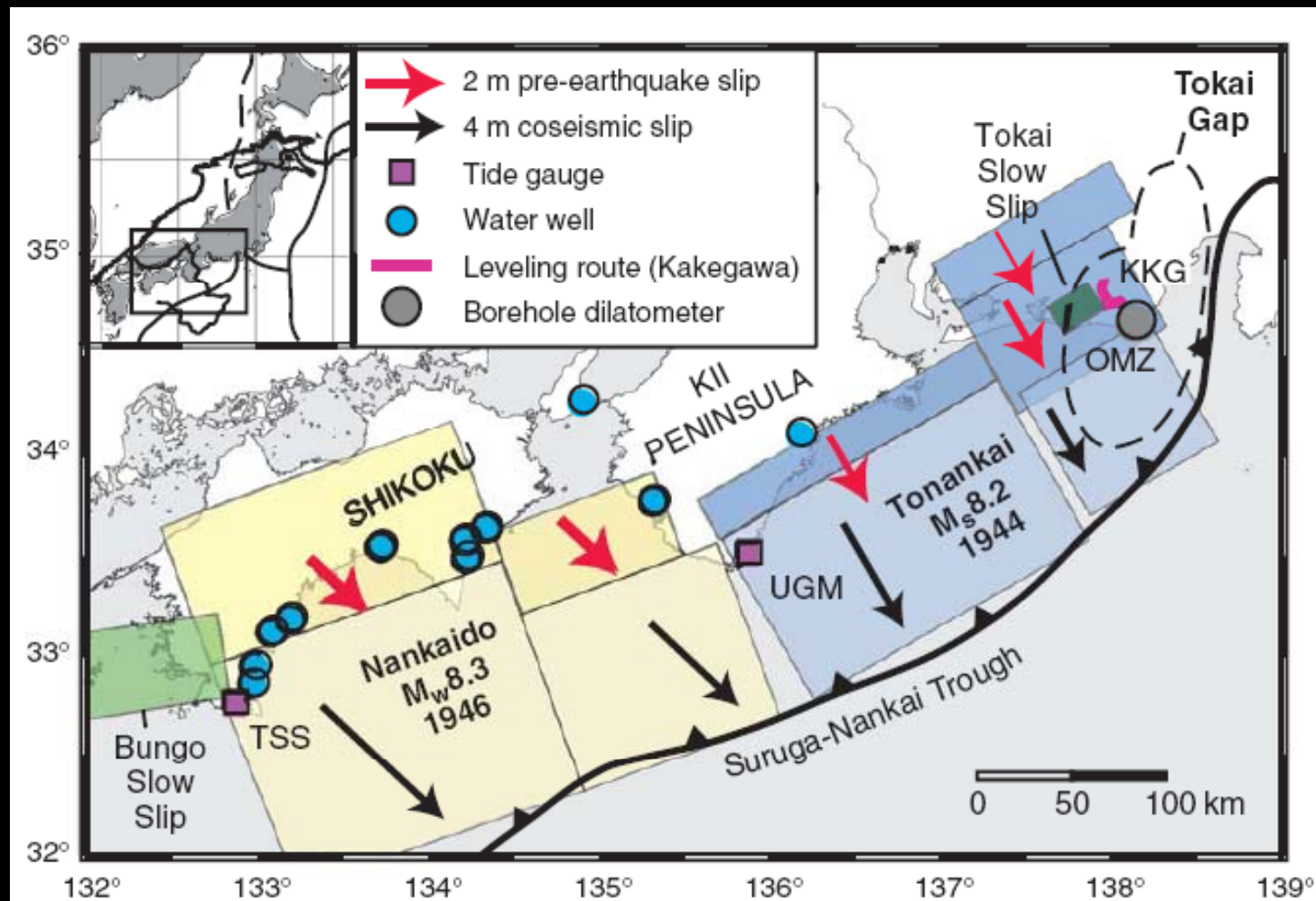


875 GPS, 103 borehole strainmeter,  
5 laser strainmeter installed in 5 yrs

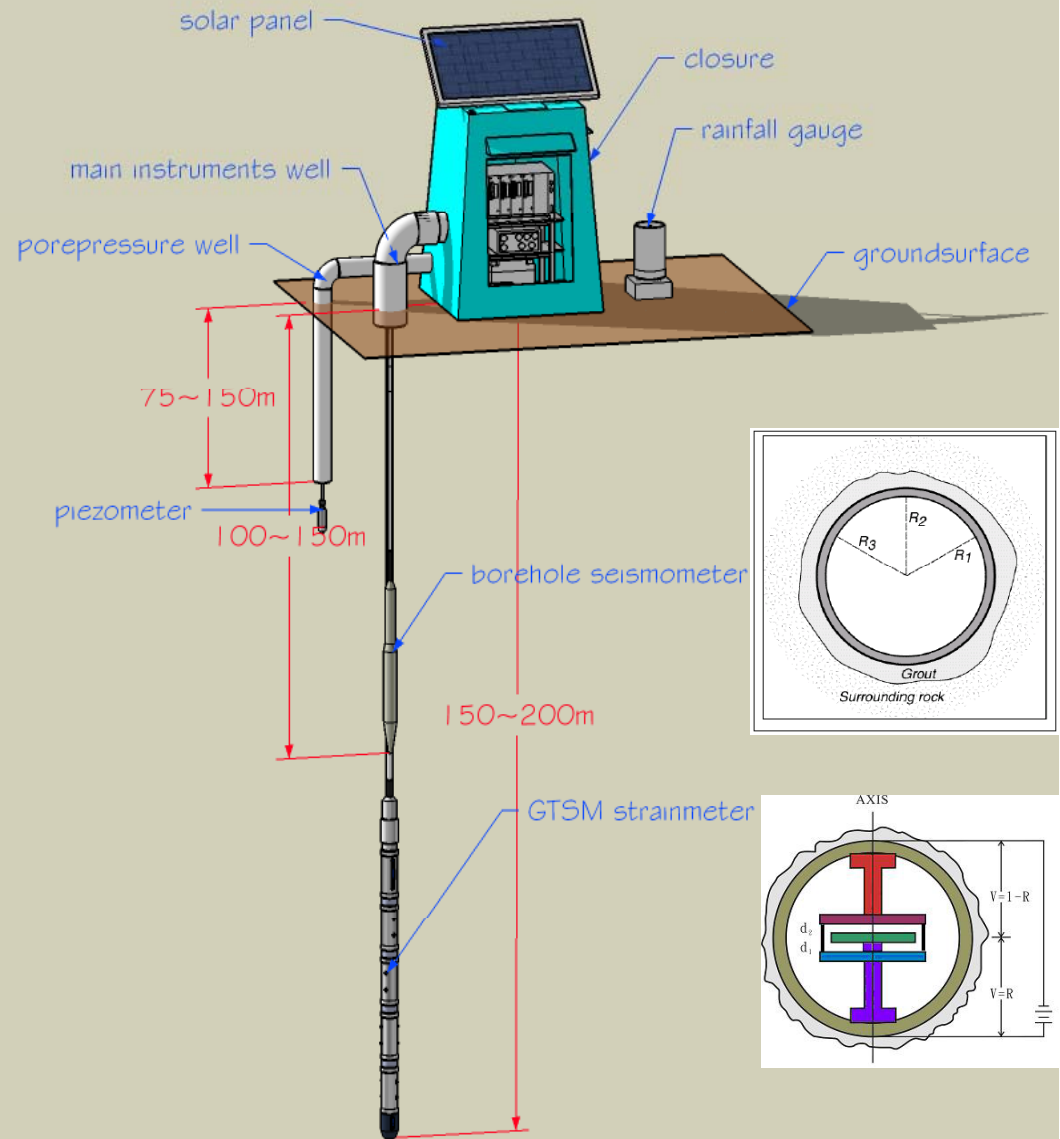
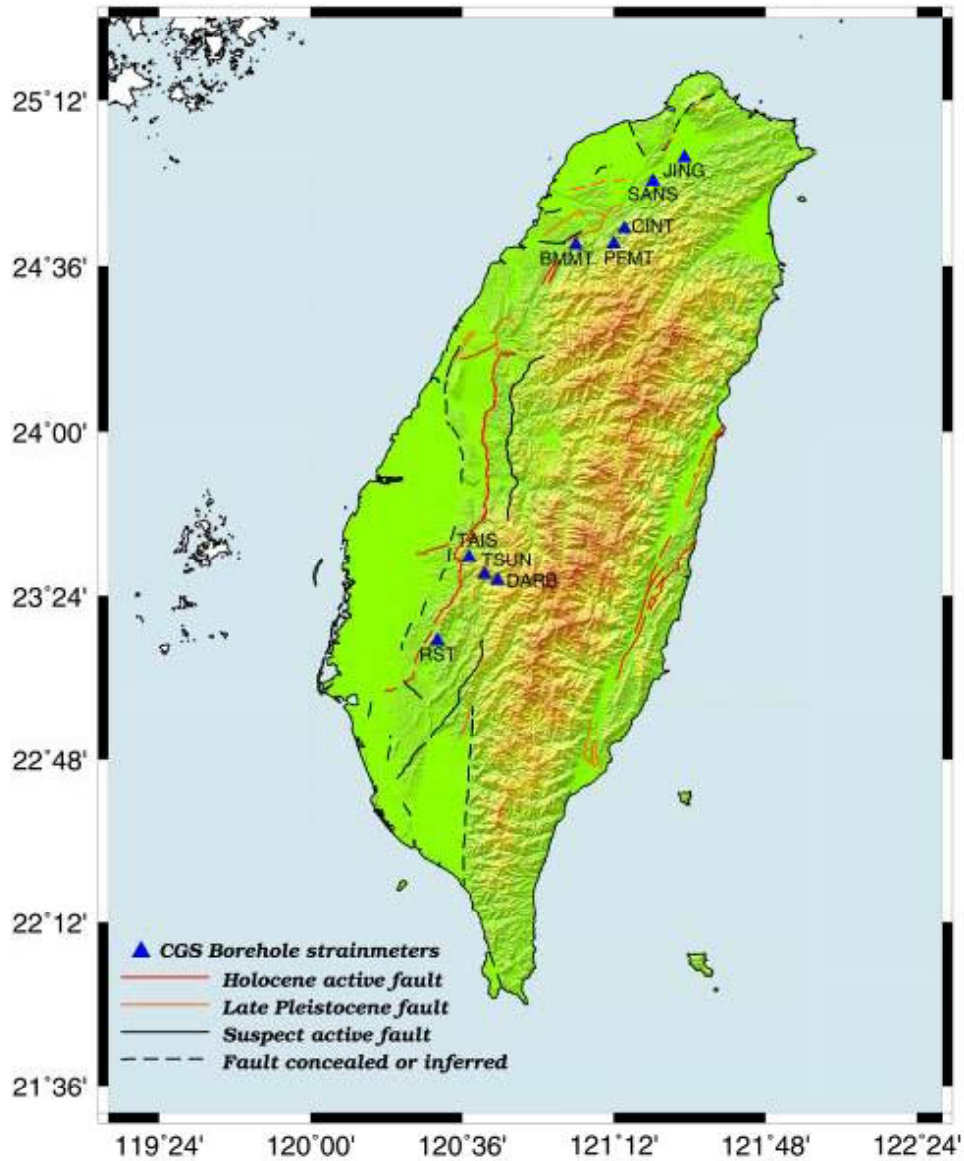


# CONVERGENT MARGIN EARTHQUAKES

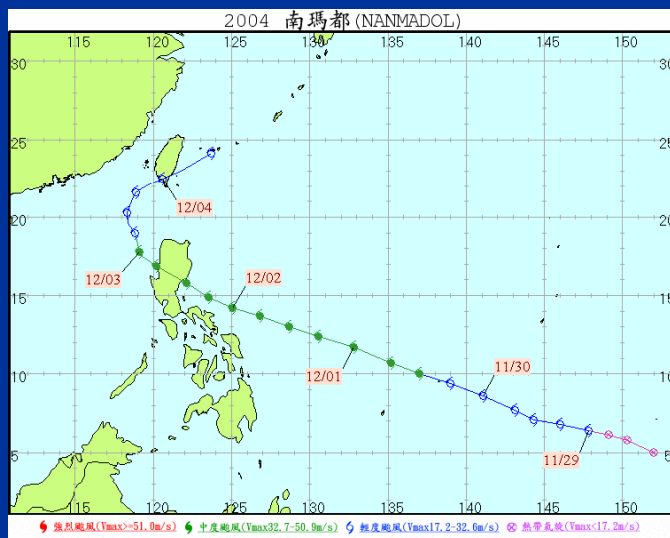
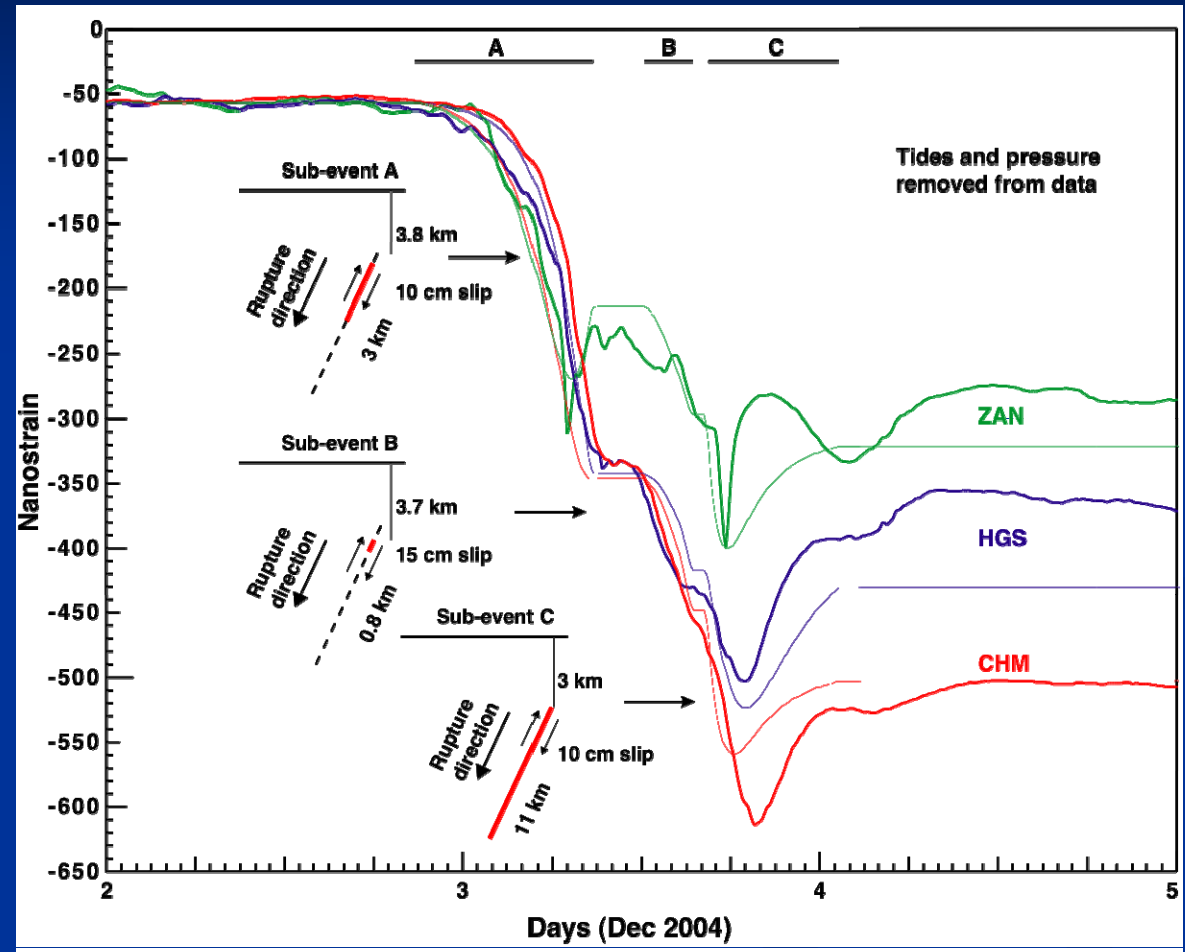
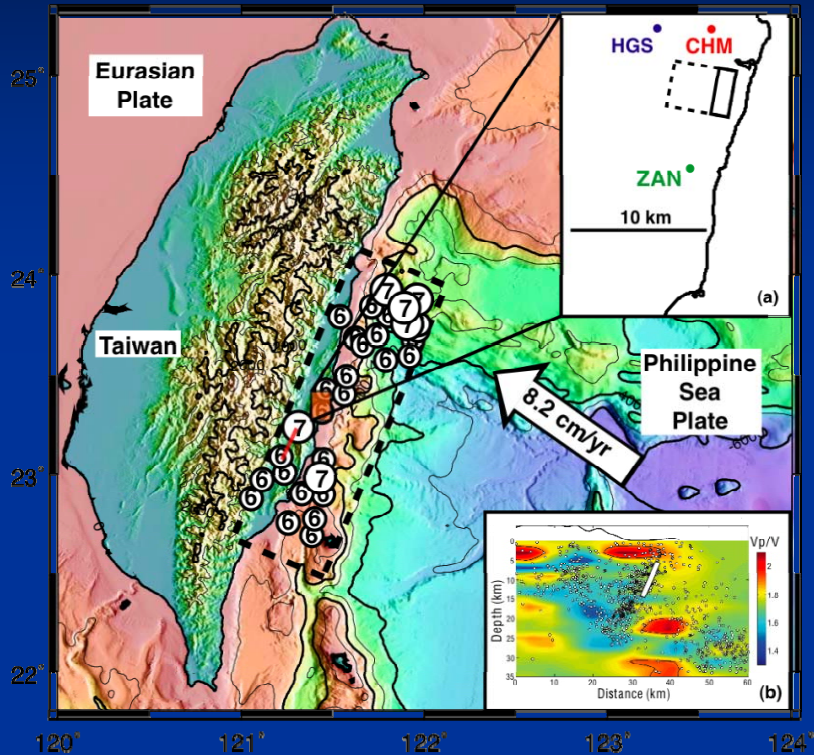
- The 1944 Tonankai ( $M_s 8.2$ ), 1946 Nankaido ( $M_w 8.3$ ), and the Anticipated Tokai Earthquakes



# Strainmeter in Taiwan



# Coupling with environment

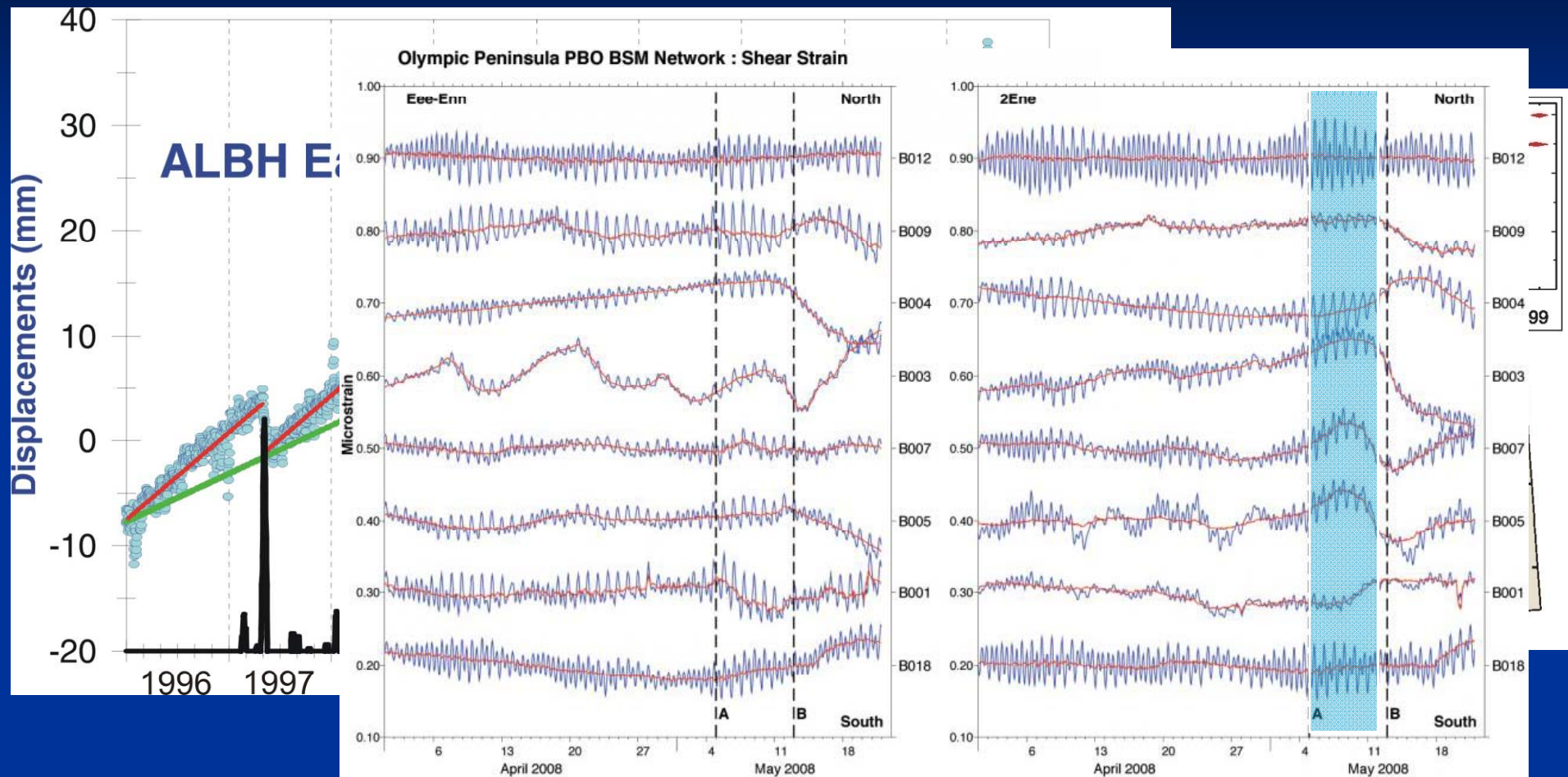


Liu et al., 2009 Nature, accepted  
Nanmadol Typhoon

2004/12/3 02:30 -2004/12/4 14:30

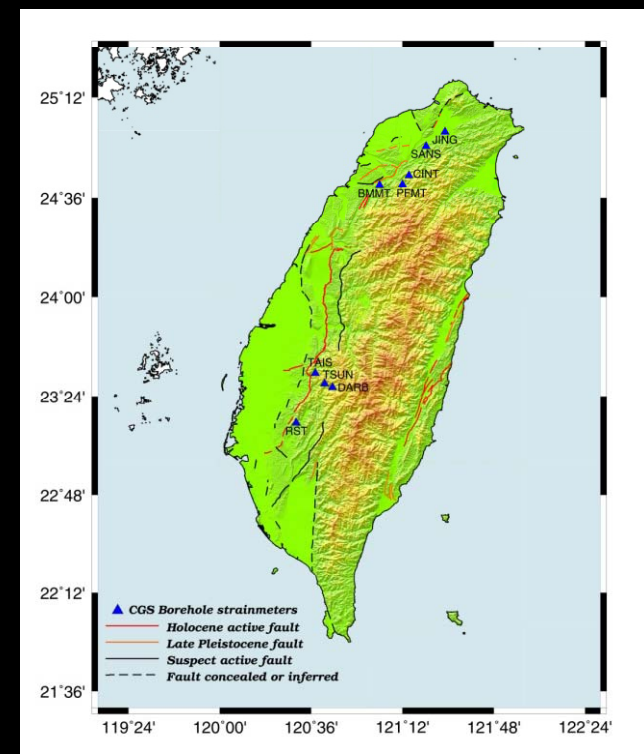
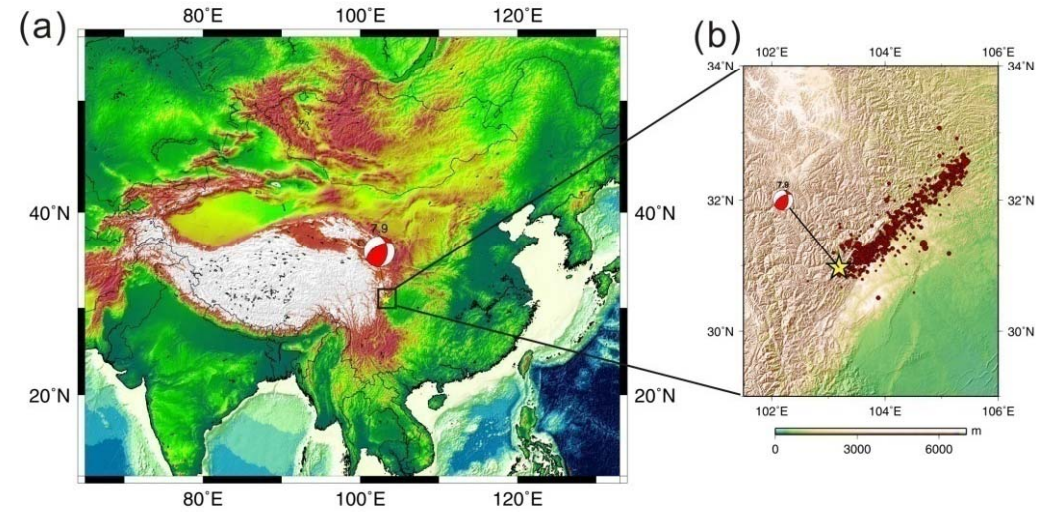
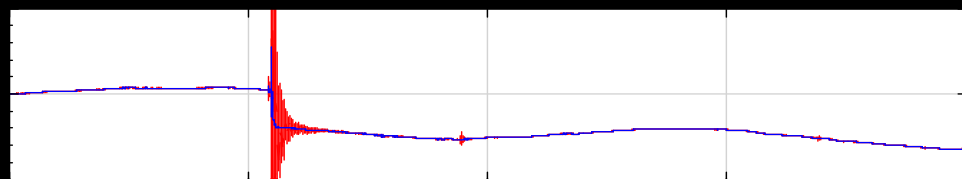
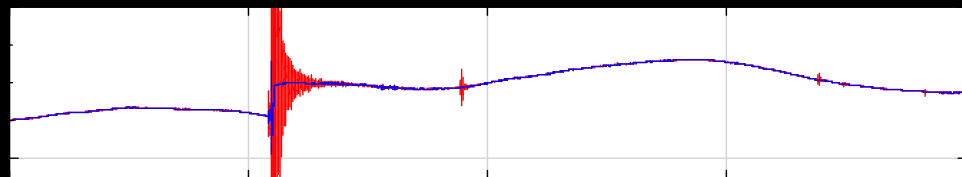
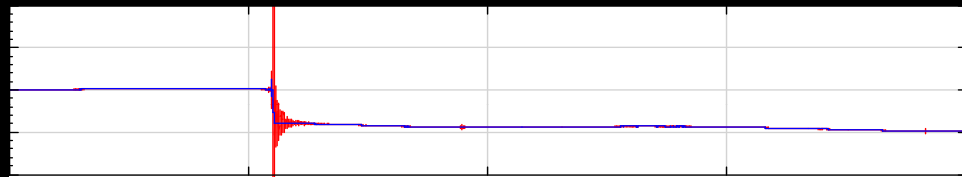
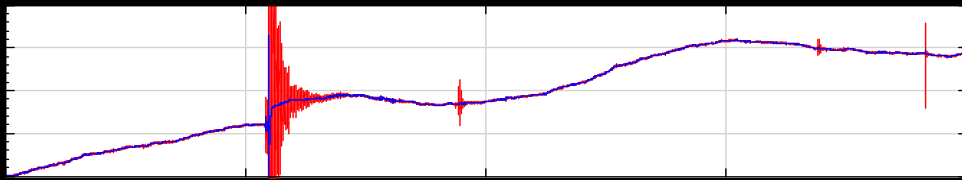


# Correlation of Tremor & Slip in the Victoria Area

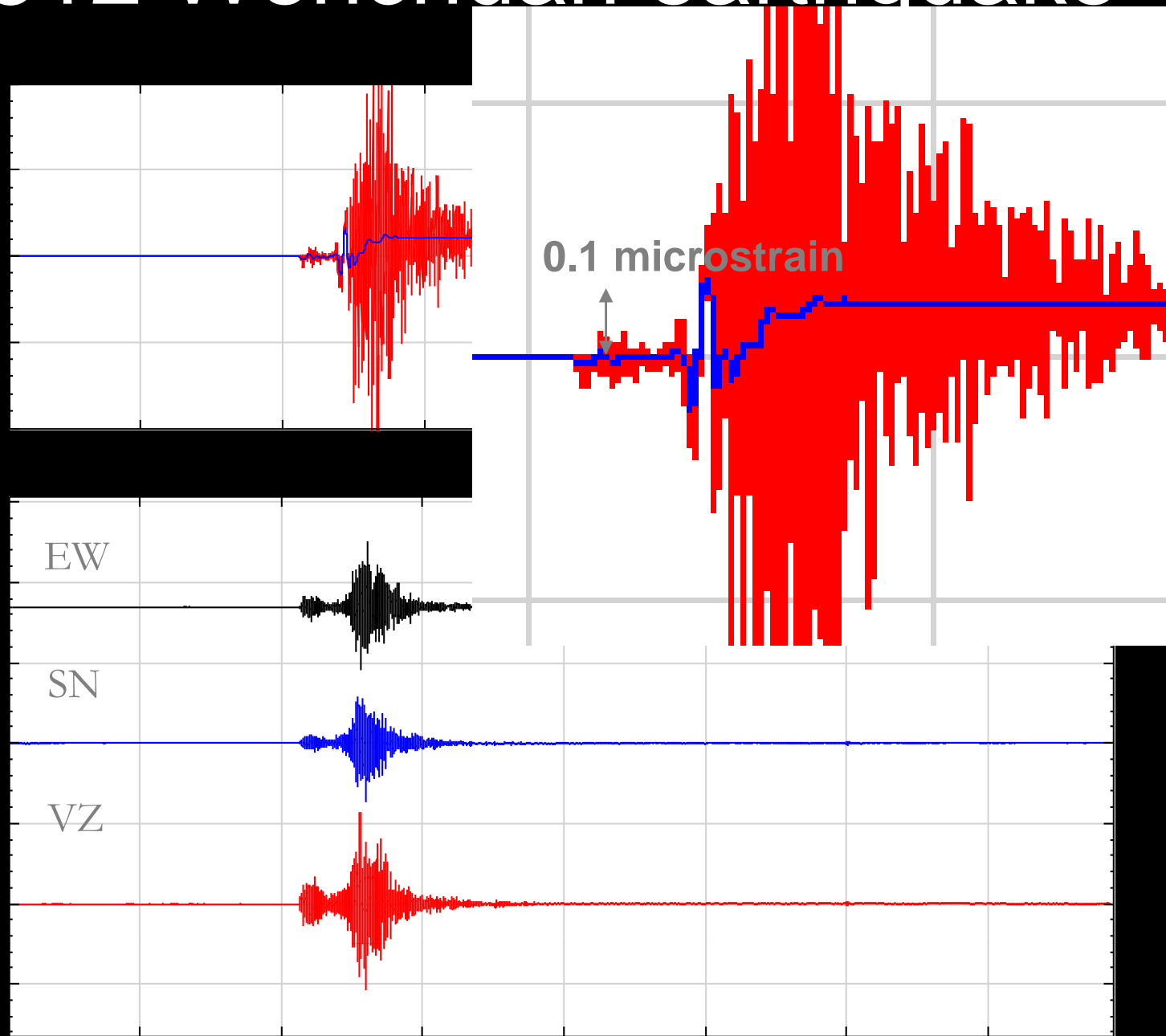


- Blue dots show GPS east component at Victoria
- Black graph shows total # of hrs with tremor activity in a 10-day window
- The strong correlation prompted the naming “Episodic Tremor & Slip”

# Strain seismography



# 512 Wenchuan earthquake



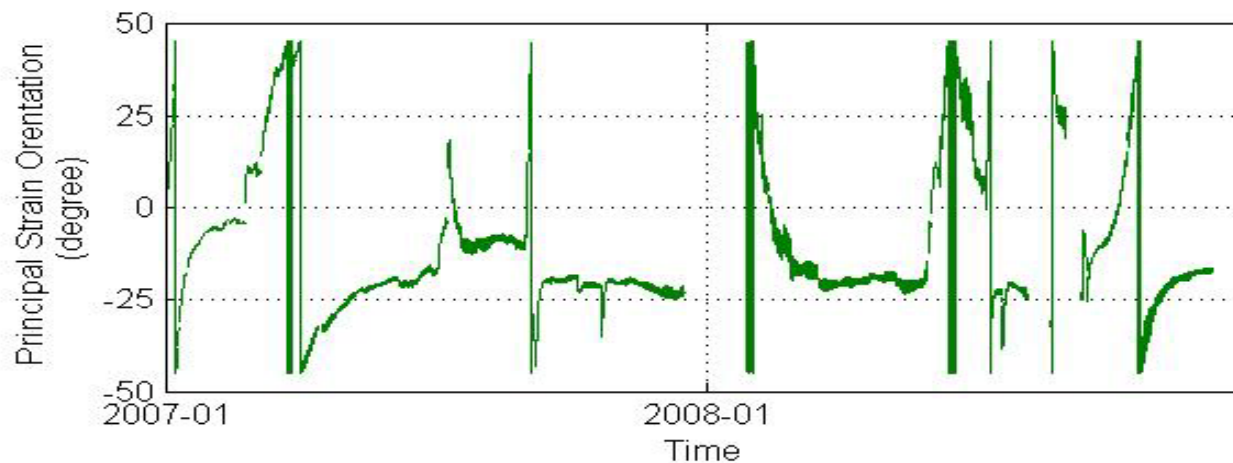
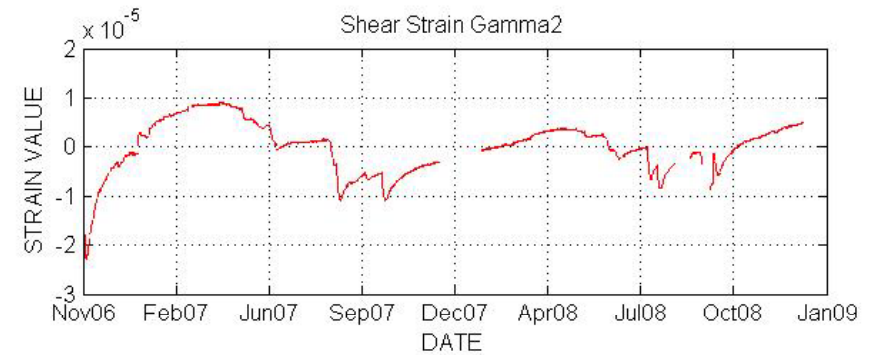
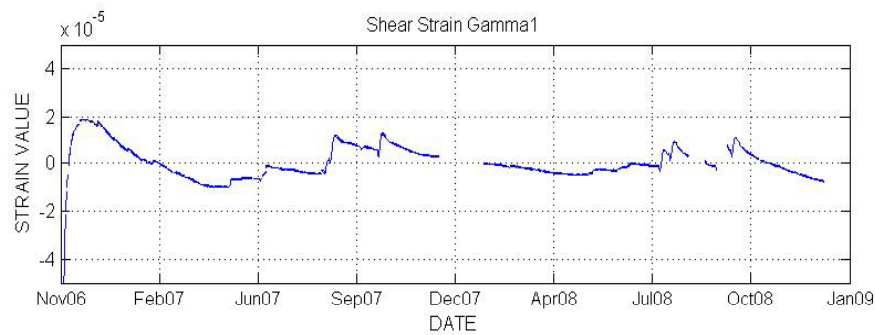


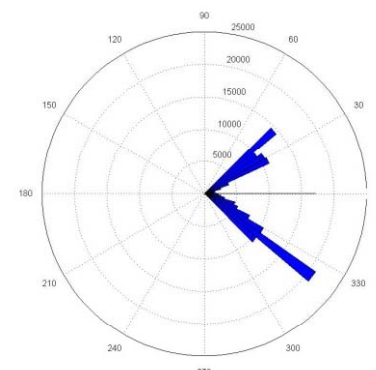
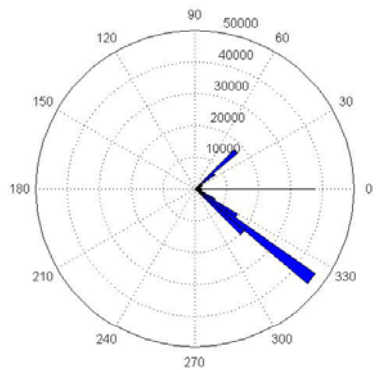
# Principal strain

$$\tan 2\varphi_o = \frac{\gamma_2}{\gamma_1}$$

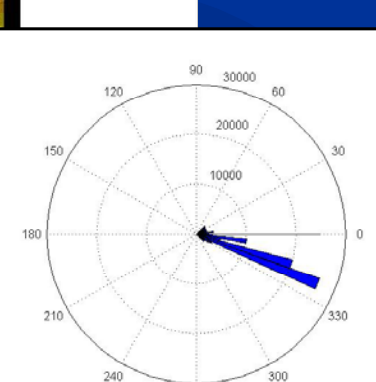
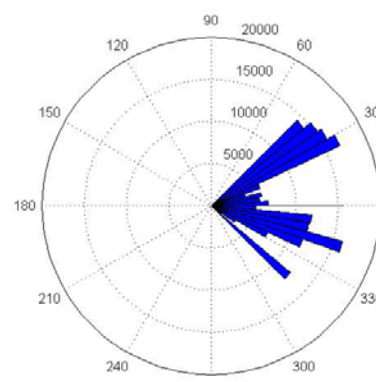
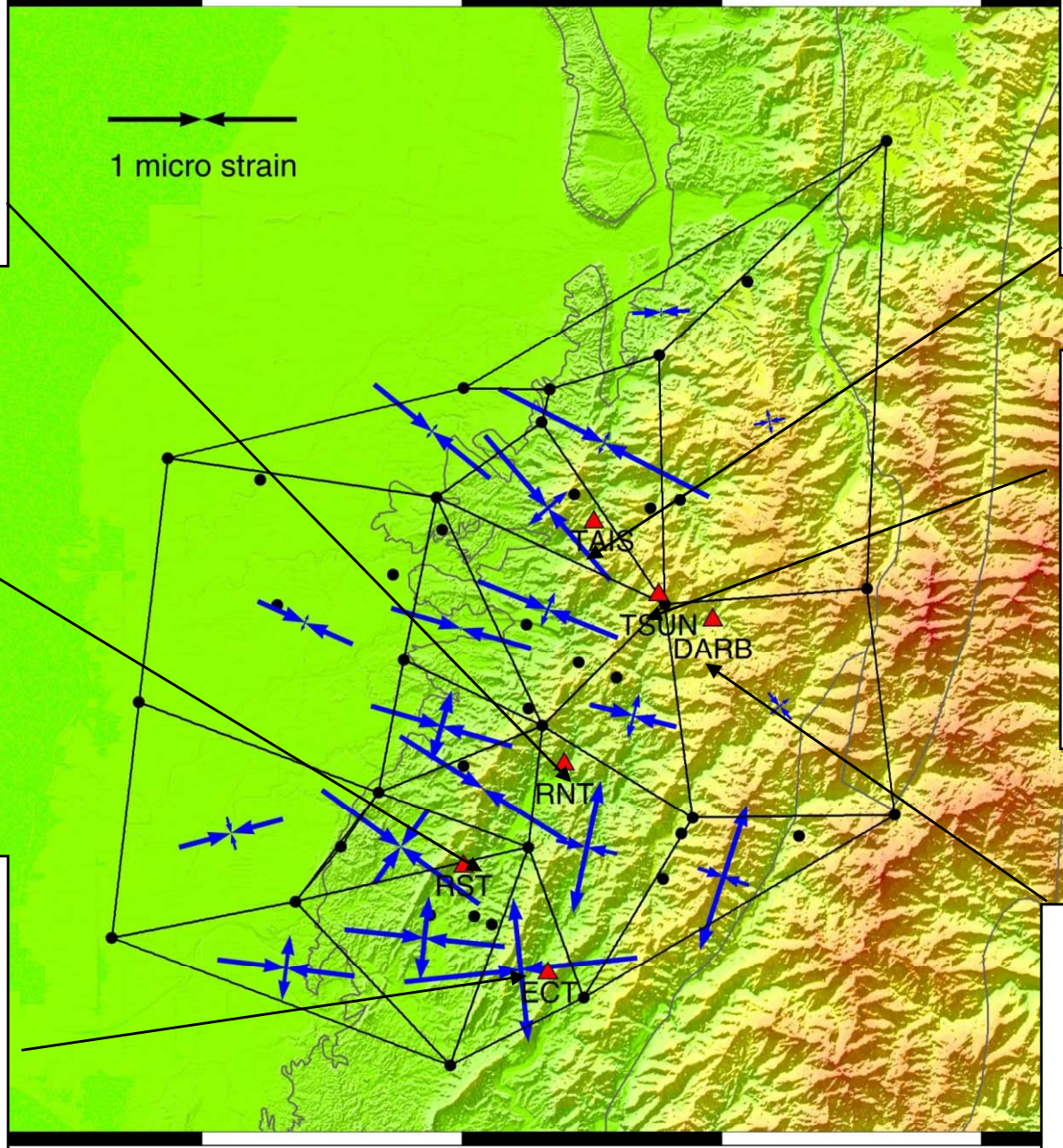
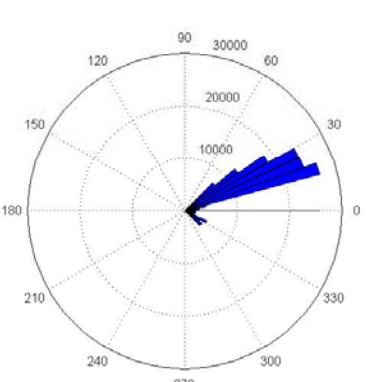
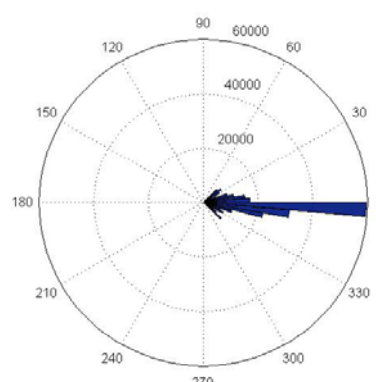
$$S = \frac{1}{2} \sqrt{\gamma_1^2 + \gamma_2^2}$$

$$P = \frac{1}{2}(\varepsilon_{xx} + \varepsilon_{yy}) = \frac{1}{2} \varepsilon_a$$





1 micro strain



120°30'E

121°00'E

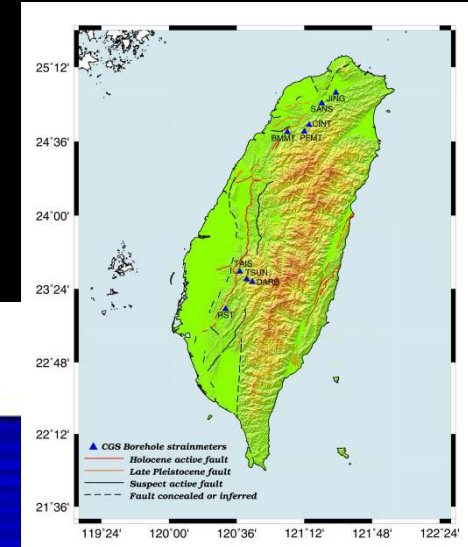




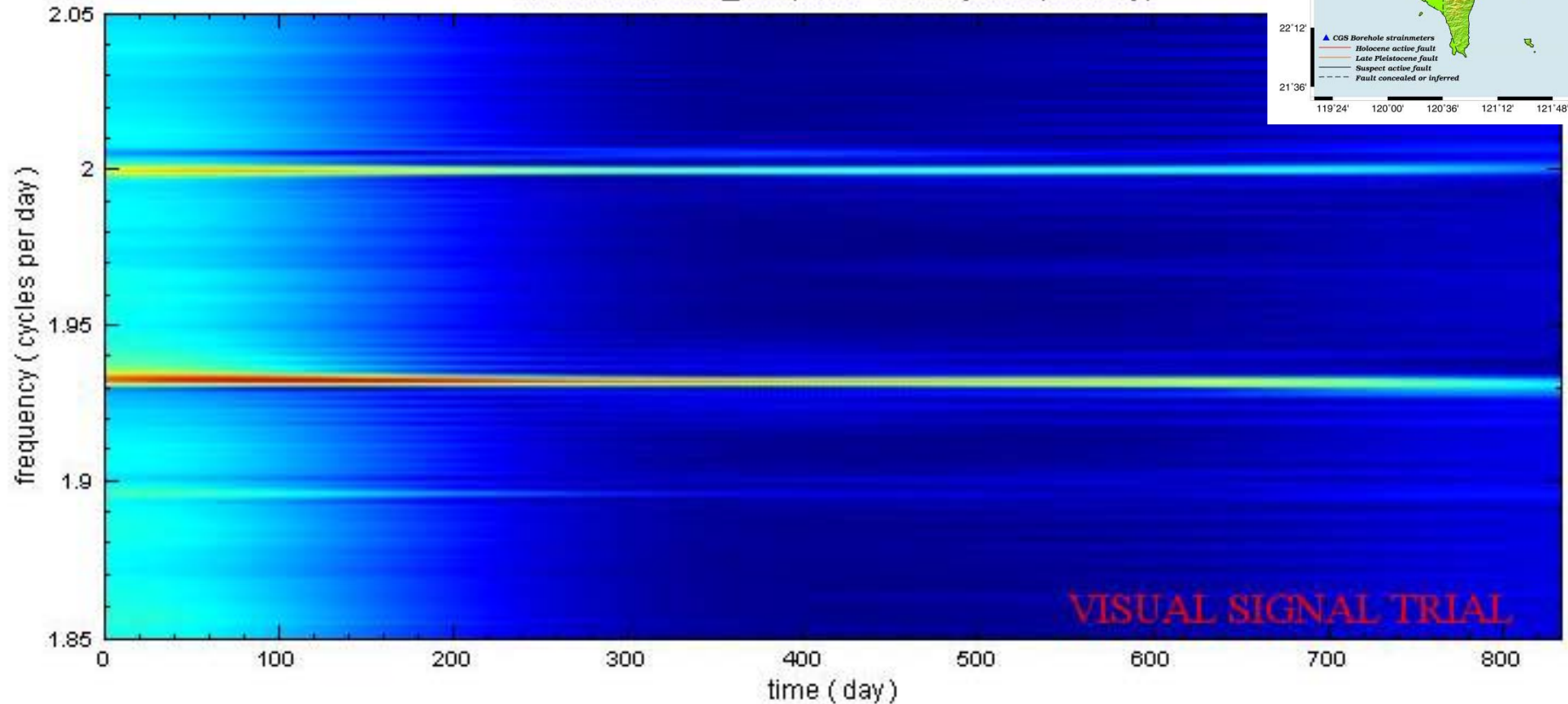


# Semi-diurnal tides: M2 (1.9323), S2 (2.0000)

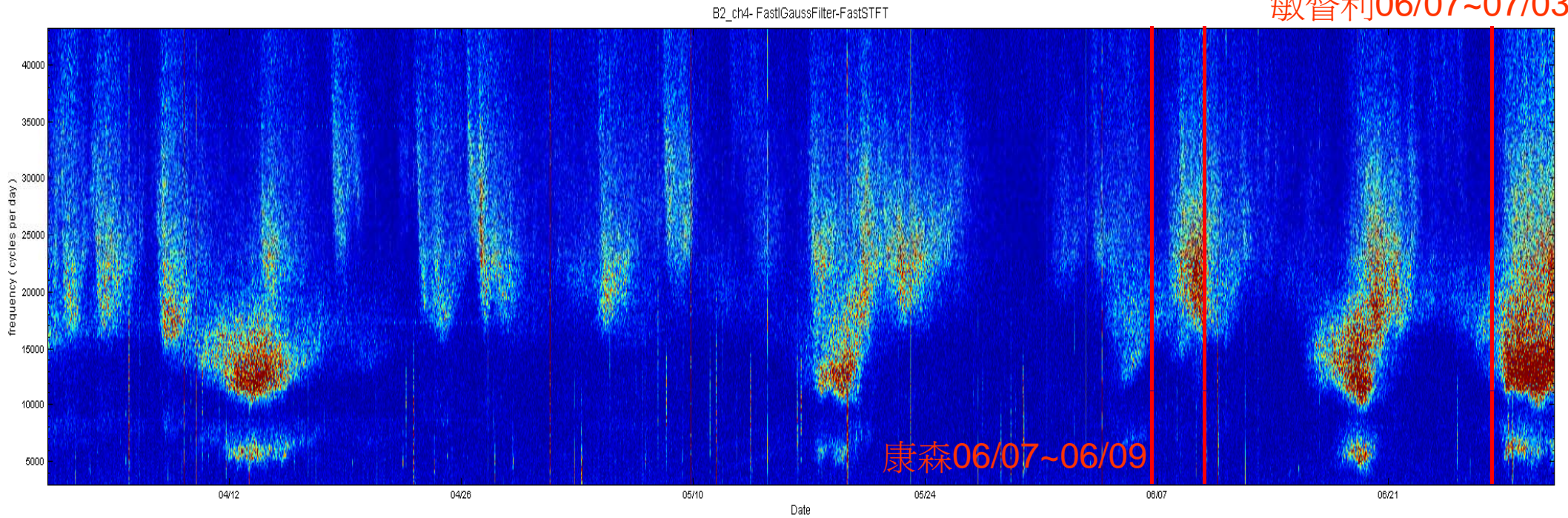
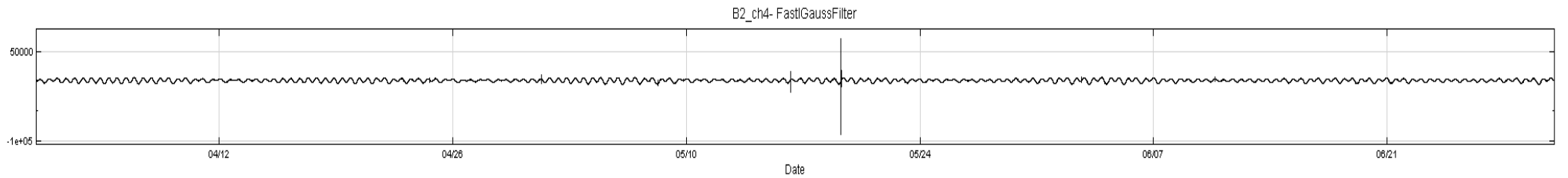
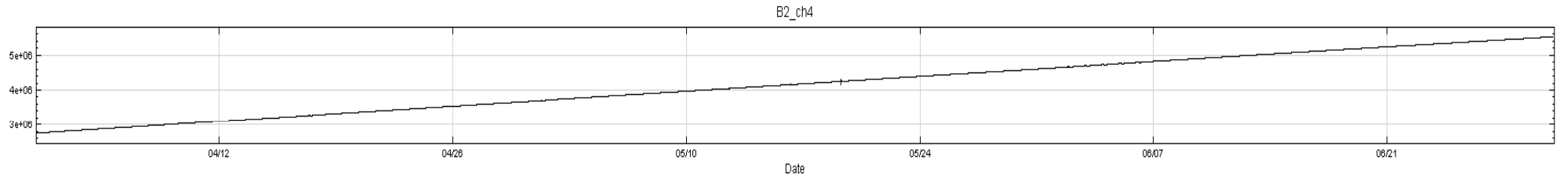
DARB station



DARB0709CH1\_min(1.85~2.05 cycles per day)

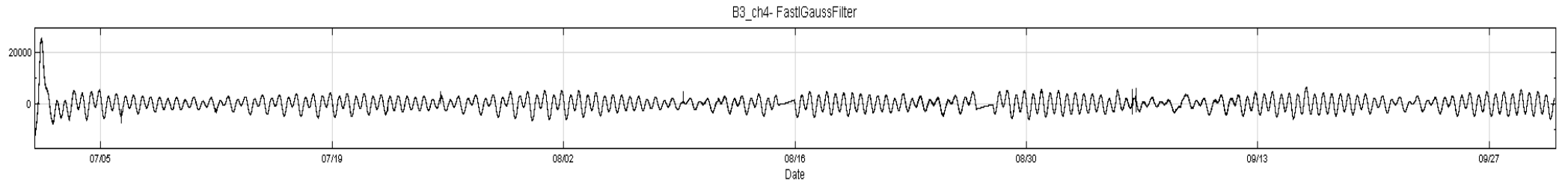
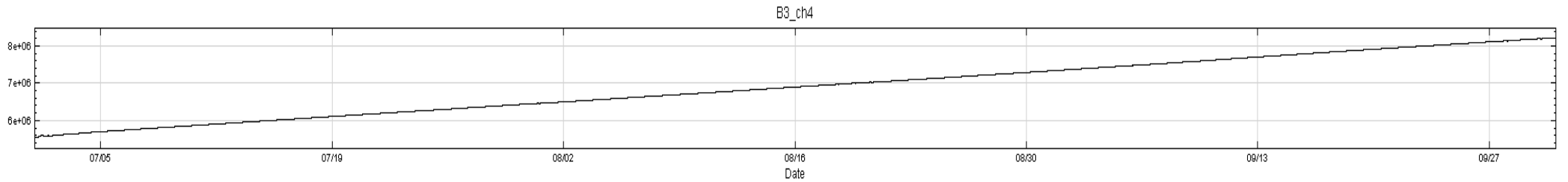


# CHMB2004年4~6月





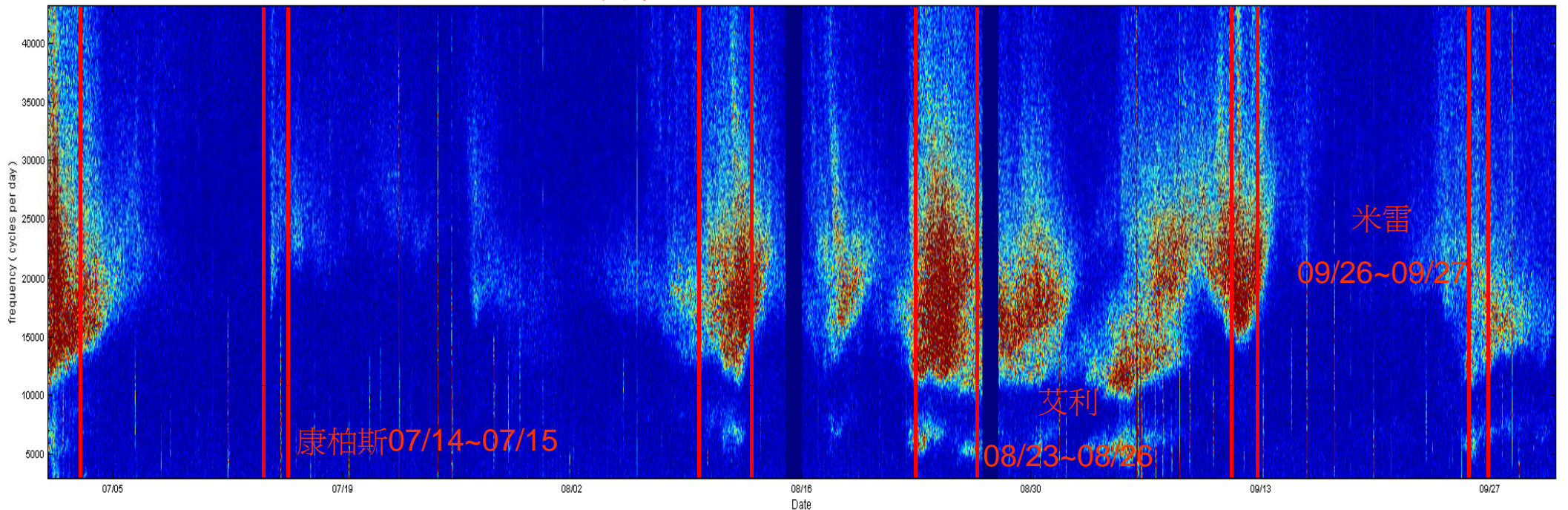
# CHMB2004年7~9月



敏督利06/07~07/03

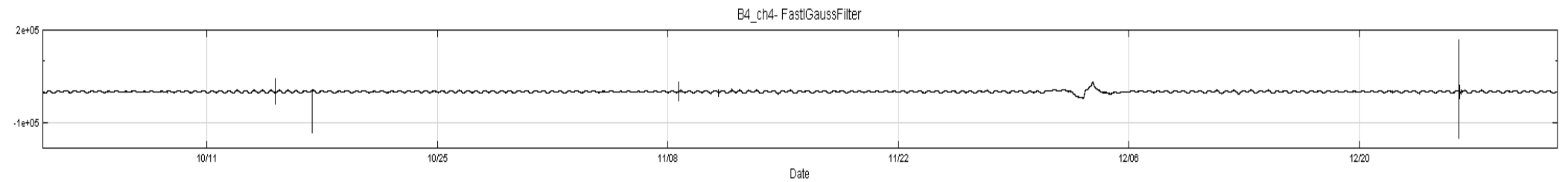
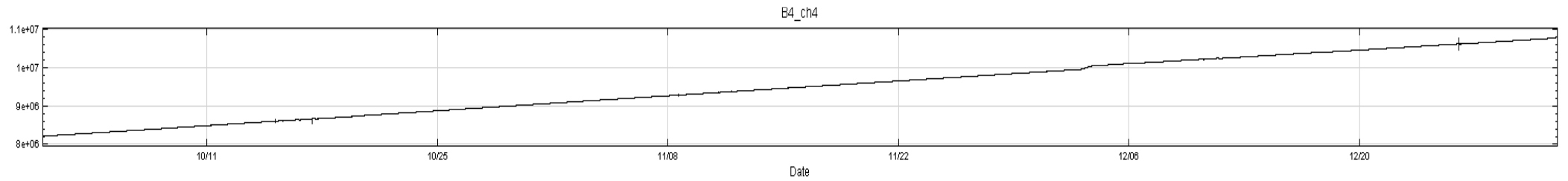
蘭寧08/10~08/13

海馬09/11~09/13





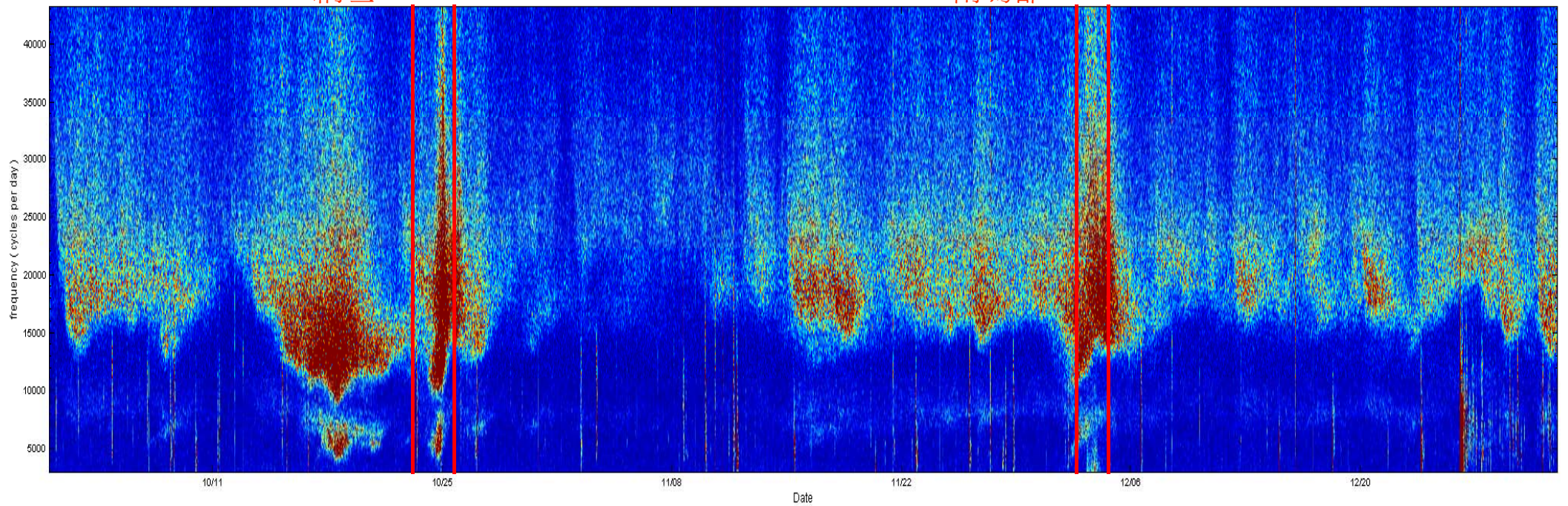
# CHMB2004年10~12月



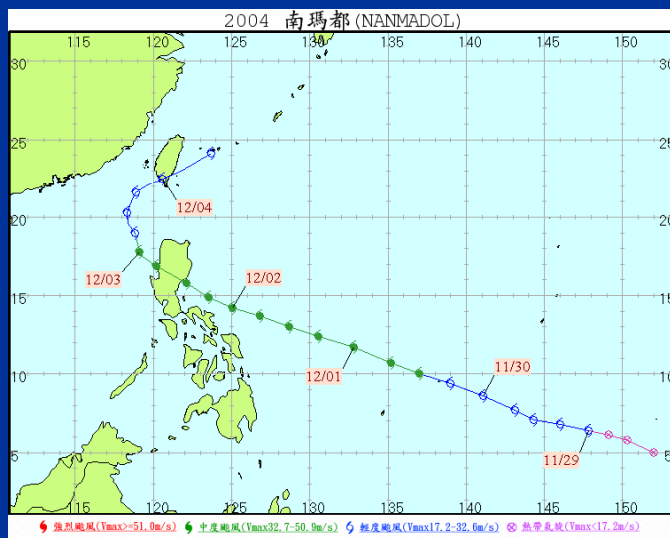
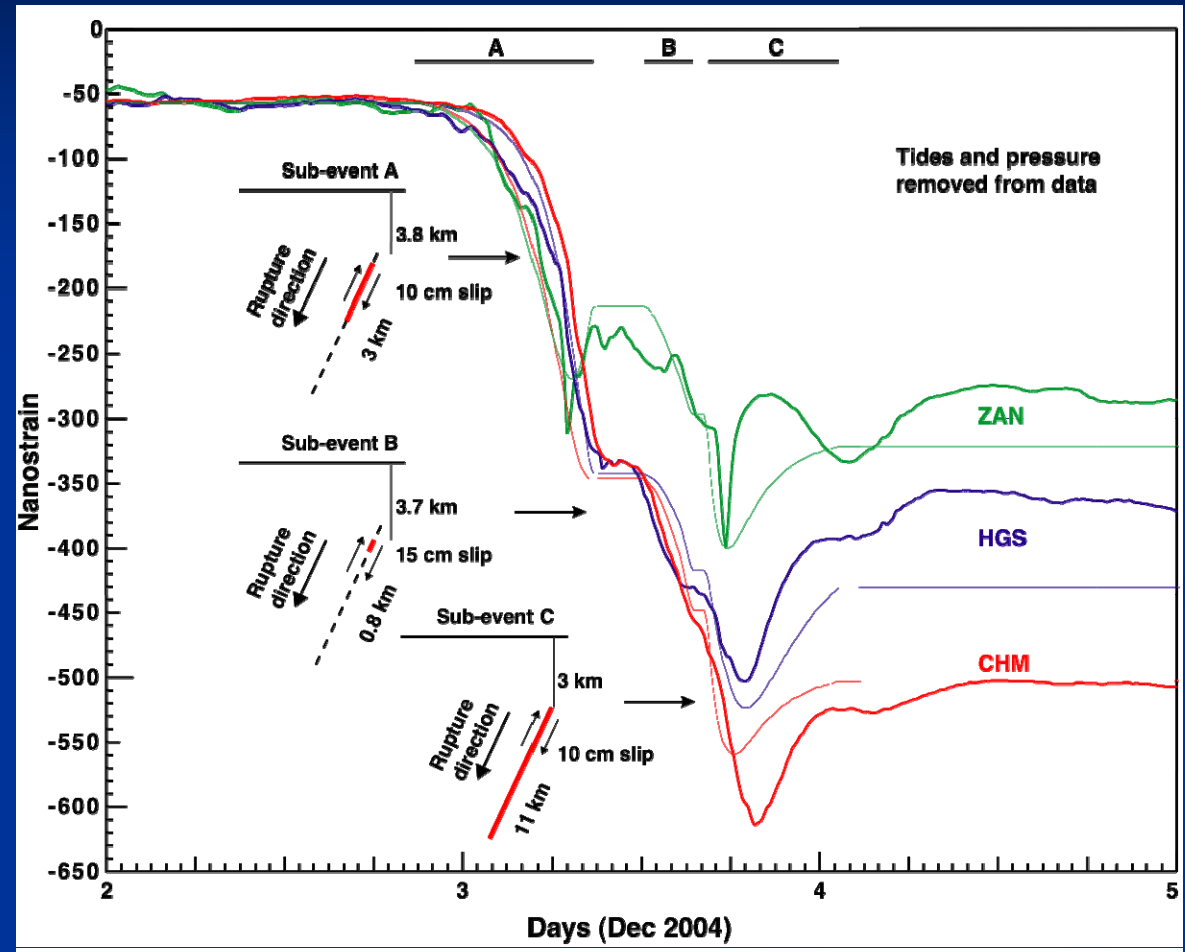
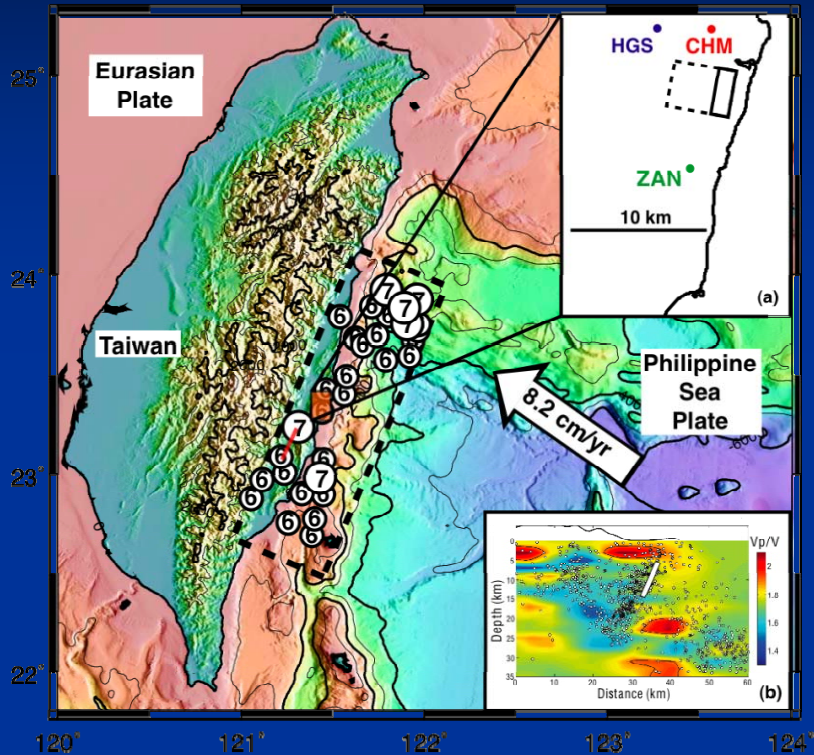
納坦10/23~10/26

B4\_ch4- FastlGaussFilter-FastSTFT

南瑪都12/03~12/04



# Coupling with environment

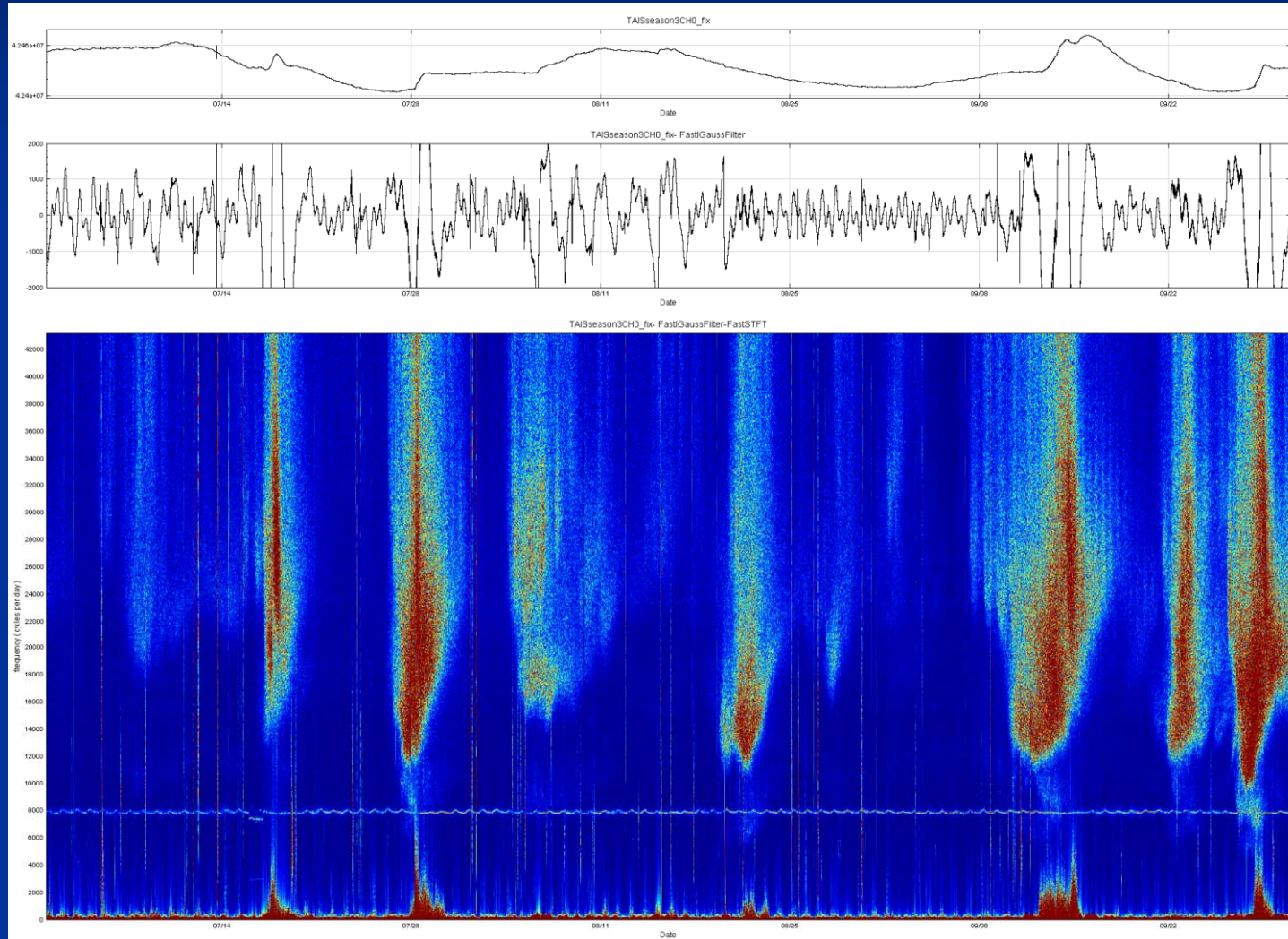


Liu et al., 2009 Nature, accepted  
Nanmadol Typhoon

2004/12/3 02:30 -2004/12/4 14:30



# 嘉義太興 Autumn 2008, ch0



27

↑  
卡玫基 (中)

↑  
鳳凰 (中)

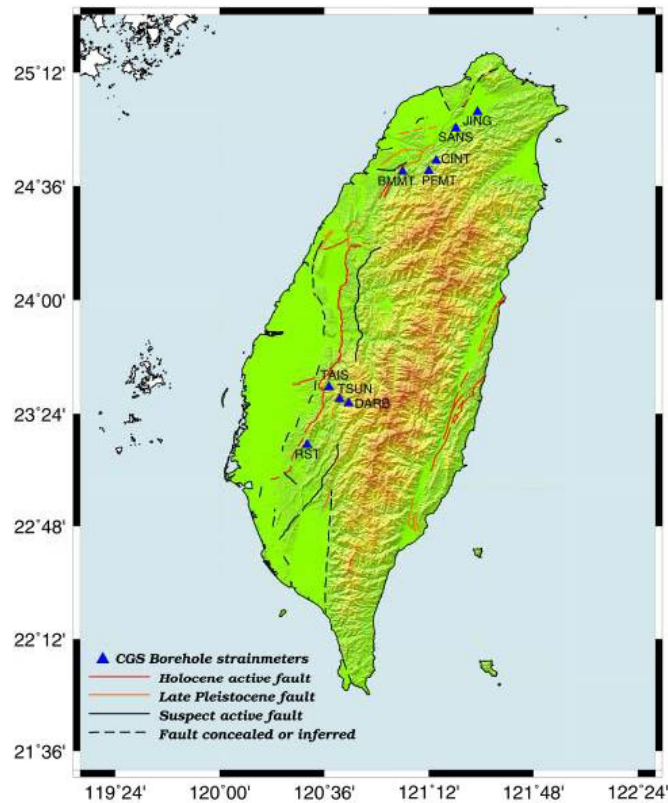
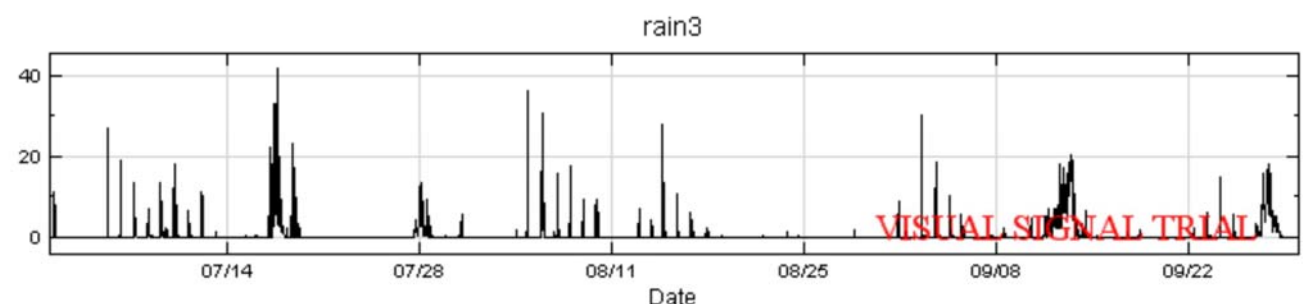
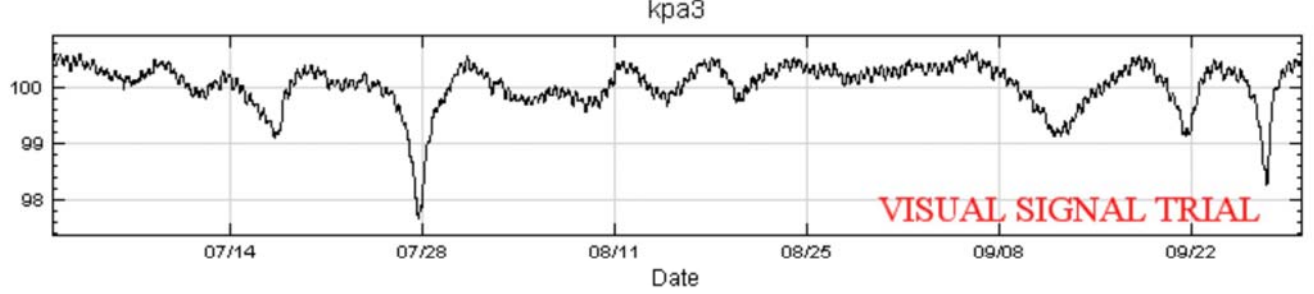
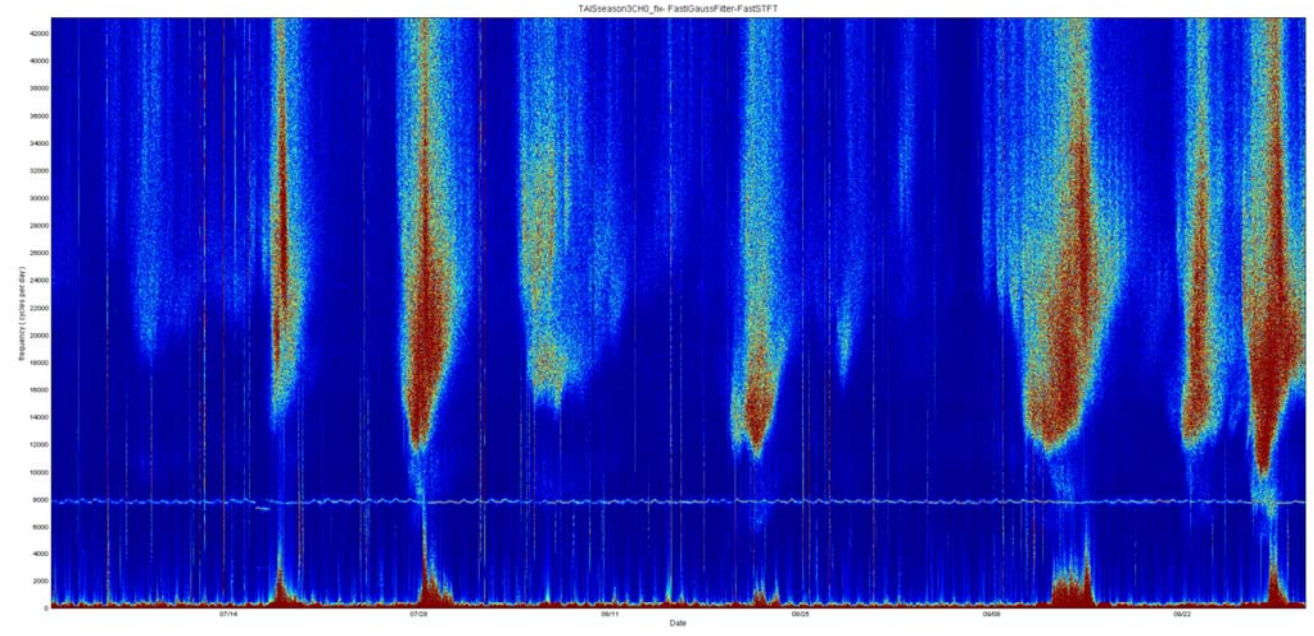
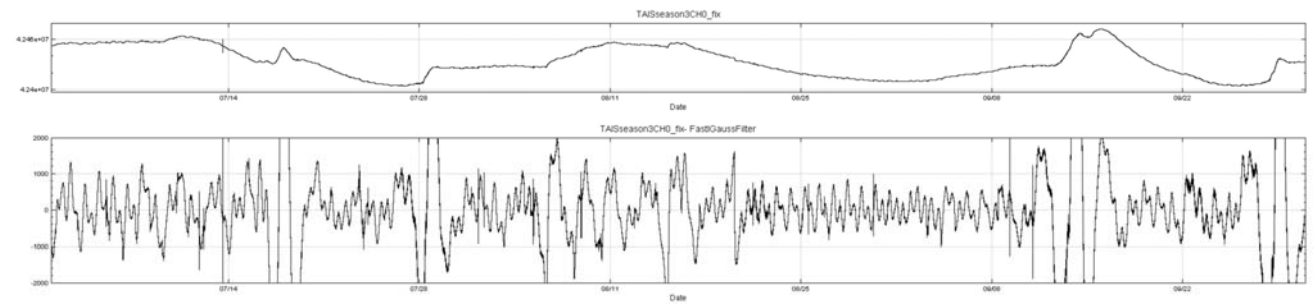
↑  
如麗 (中)

↑  
辛樂克 (強)

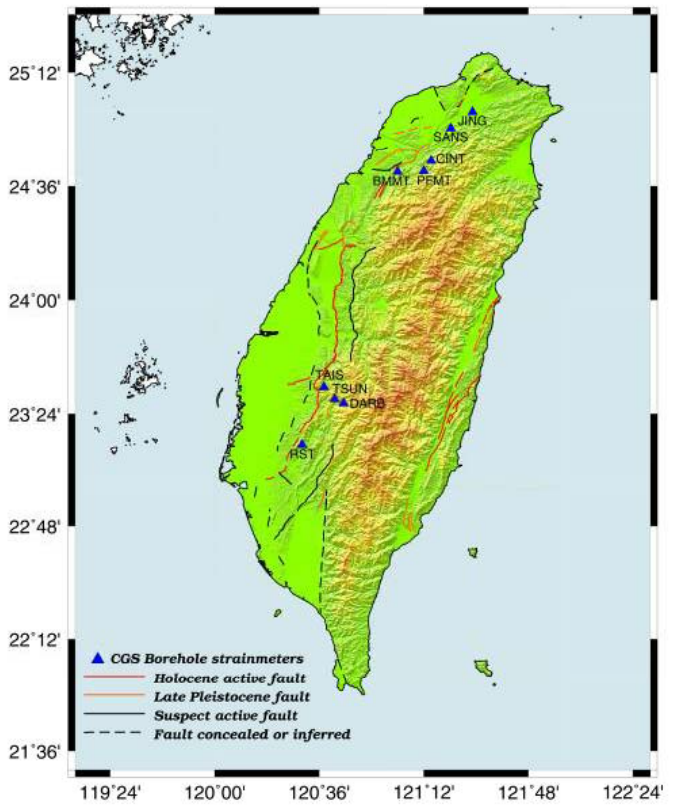
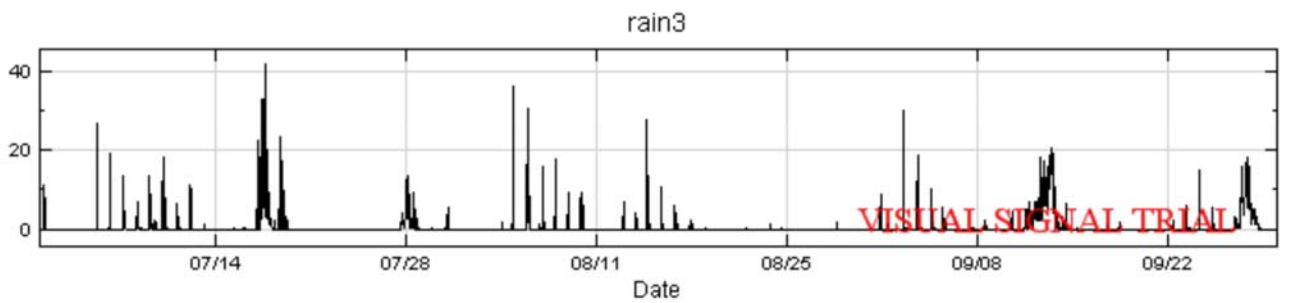
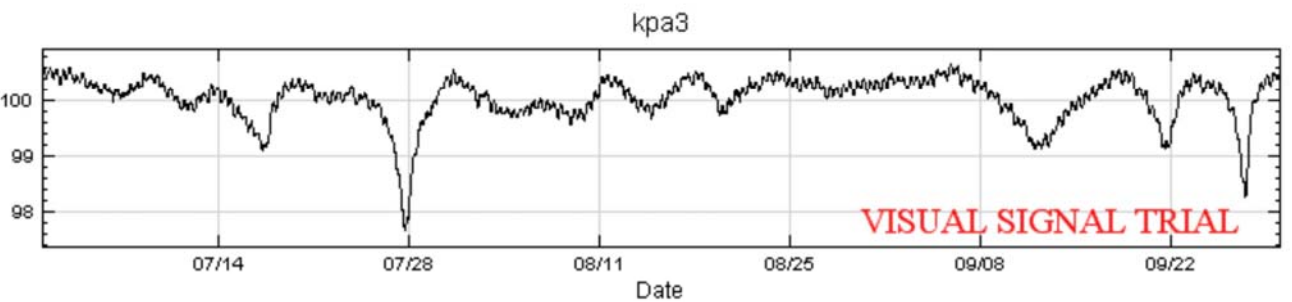
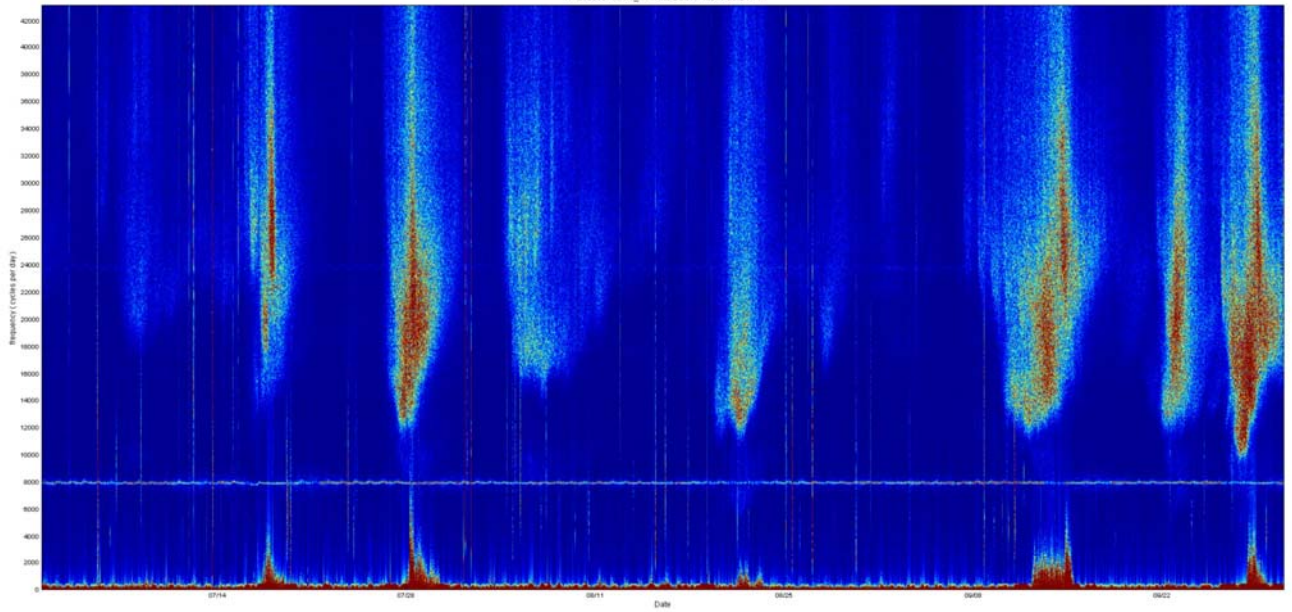
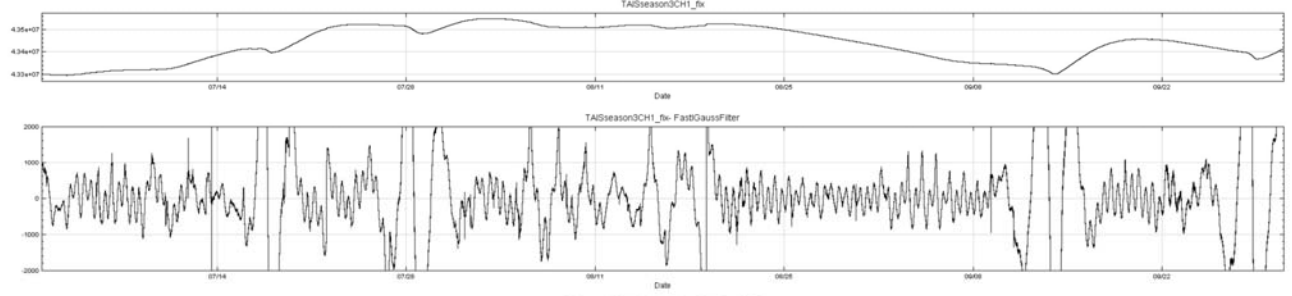
↑  
哈格比 (強)  
↑  
蓄蜜 (中)



# TAIS Season 3 Ch0

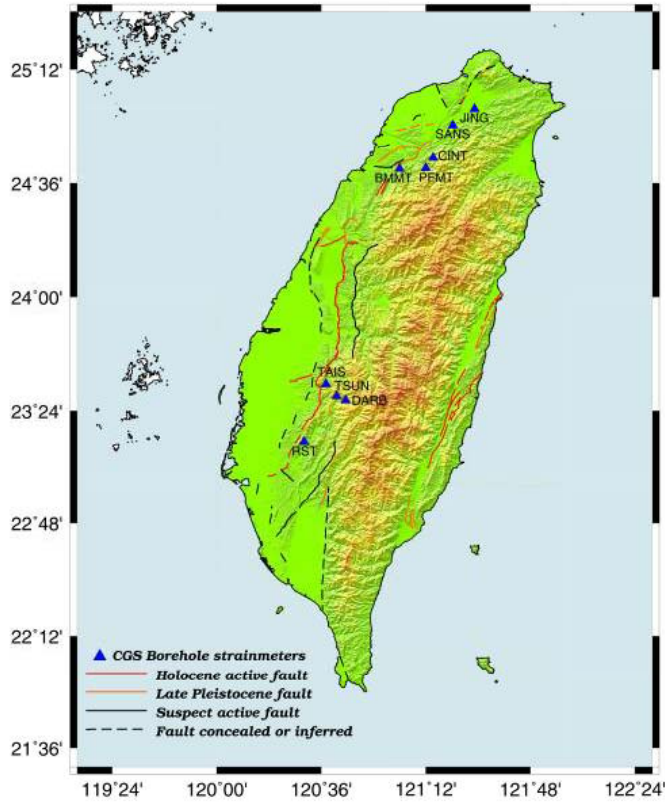
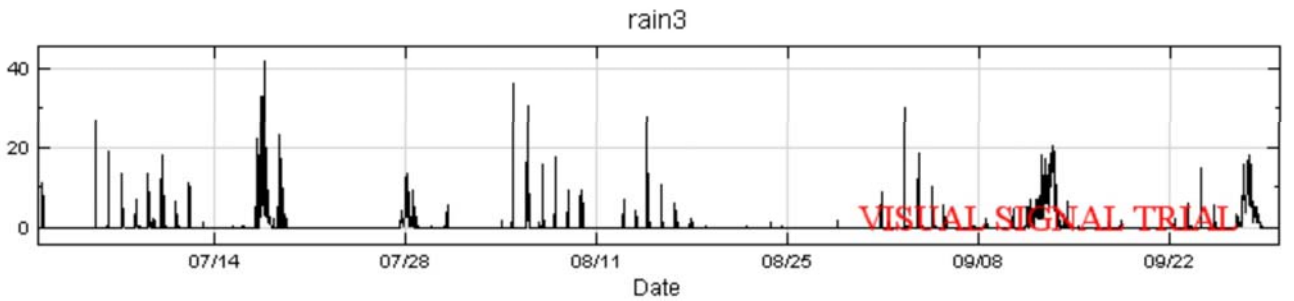
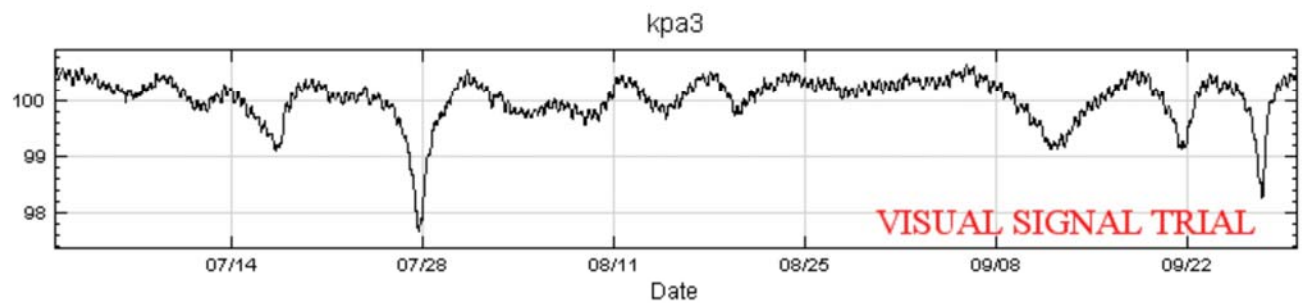
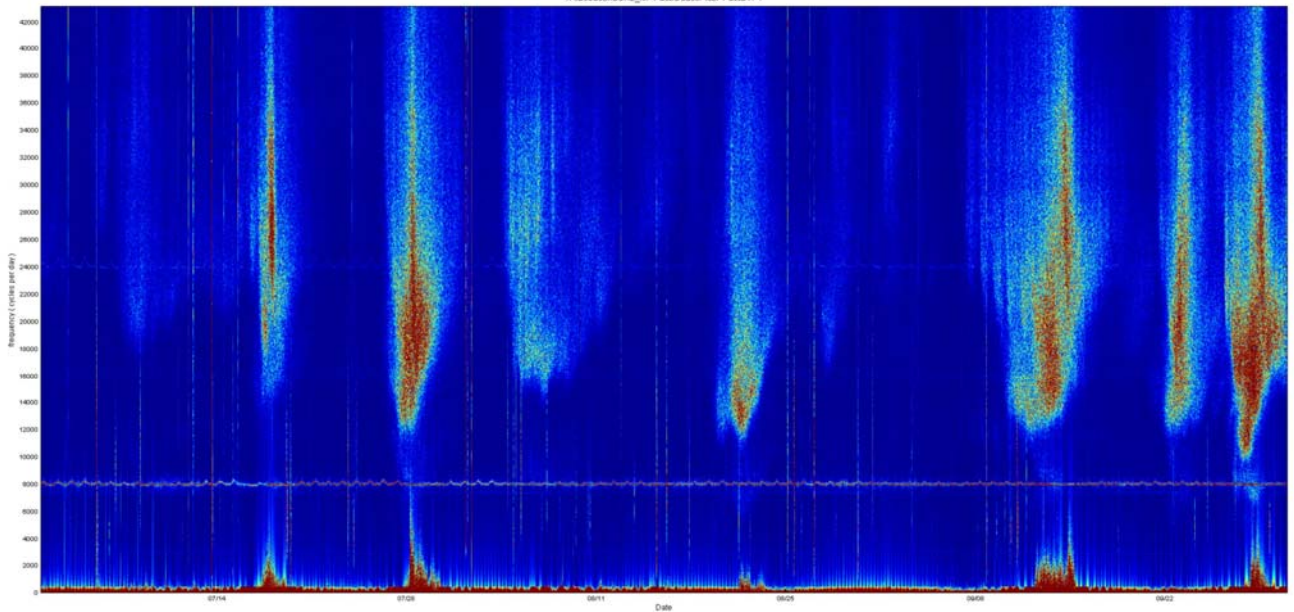
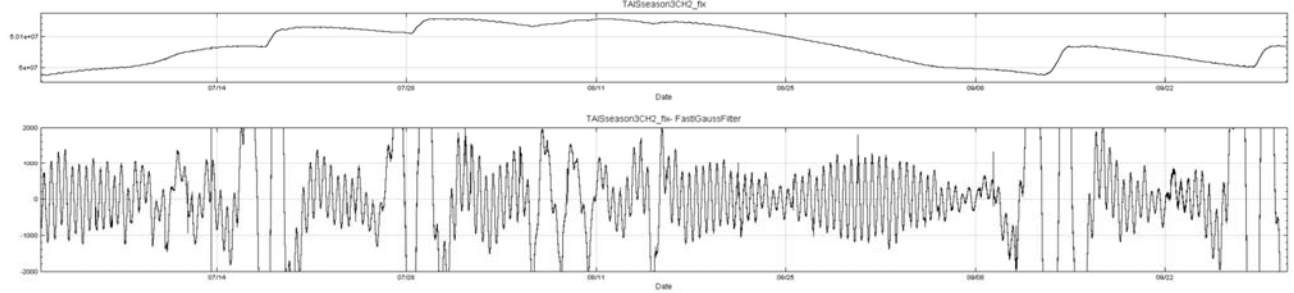


# TAIS Season 3 Ch1



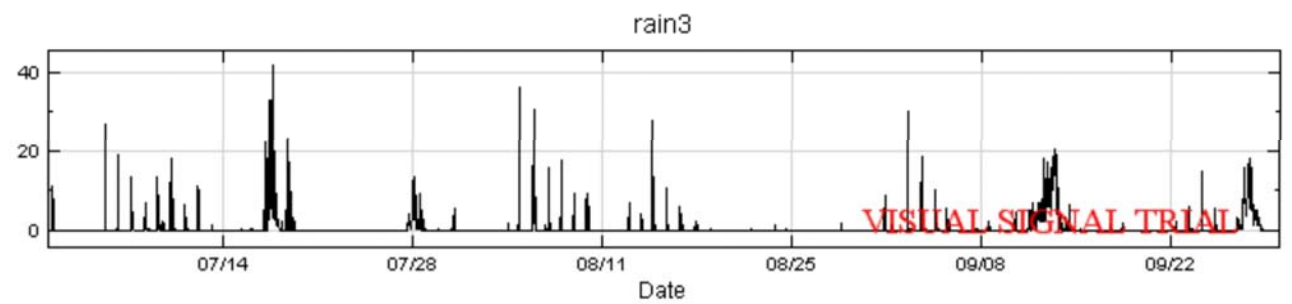
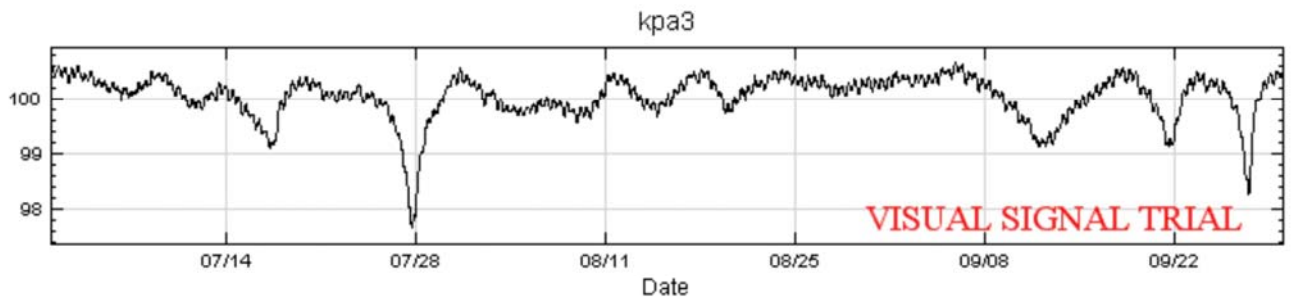
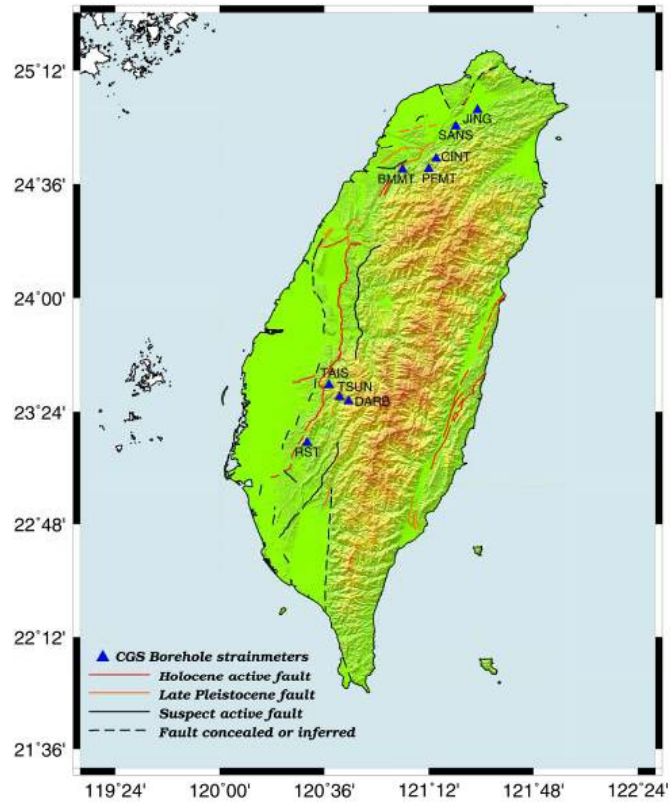
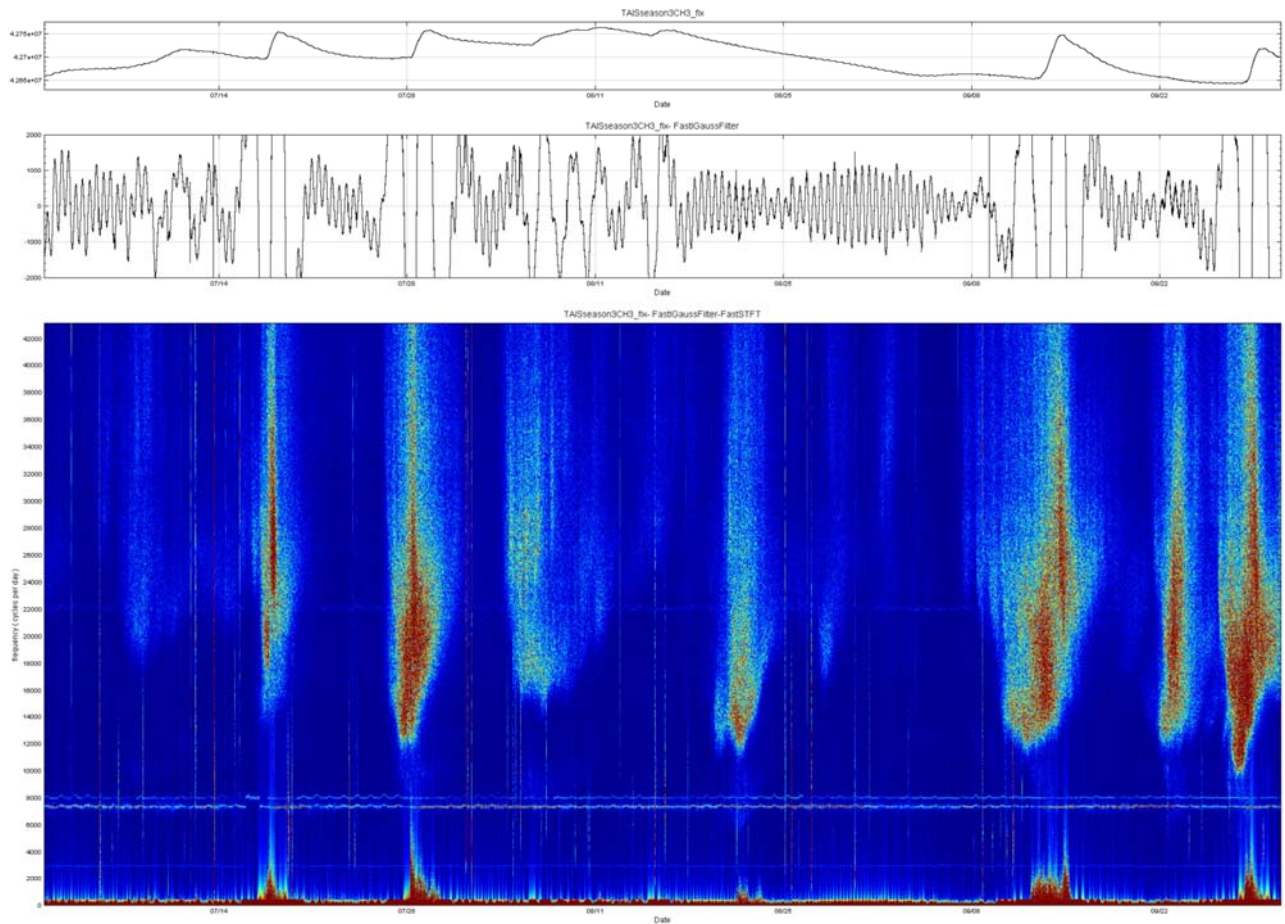


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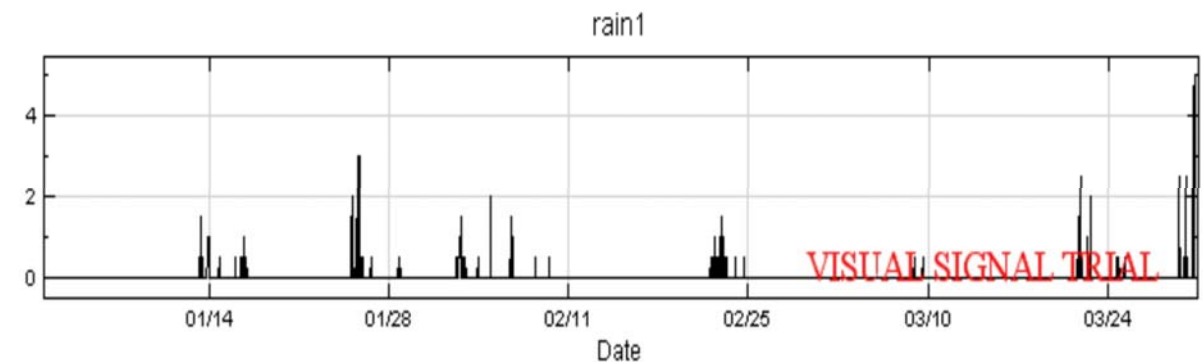
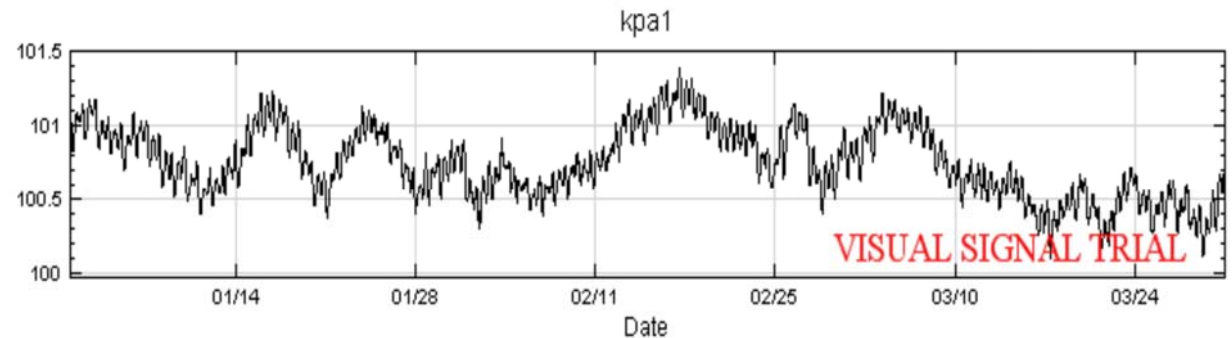
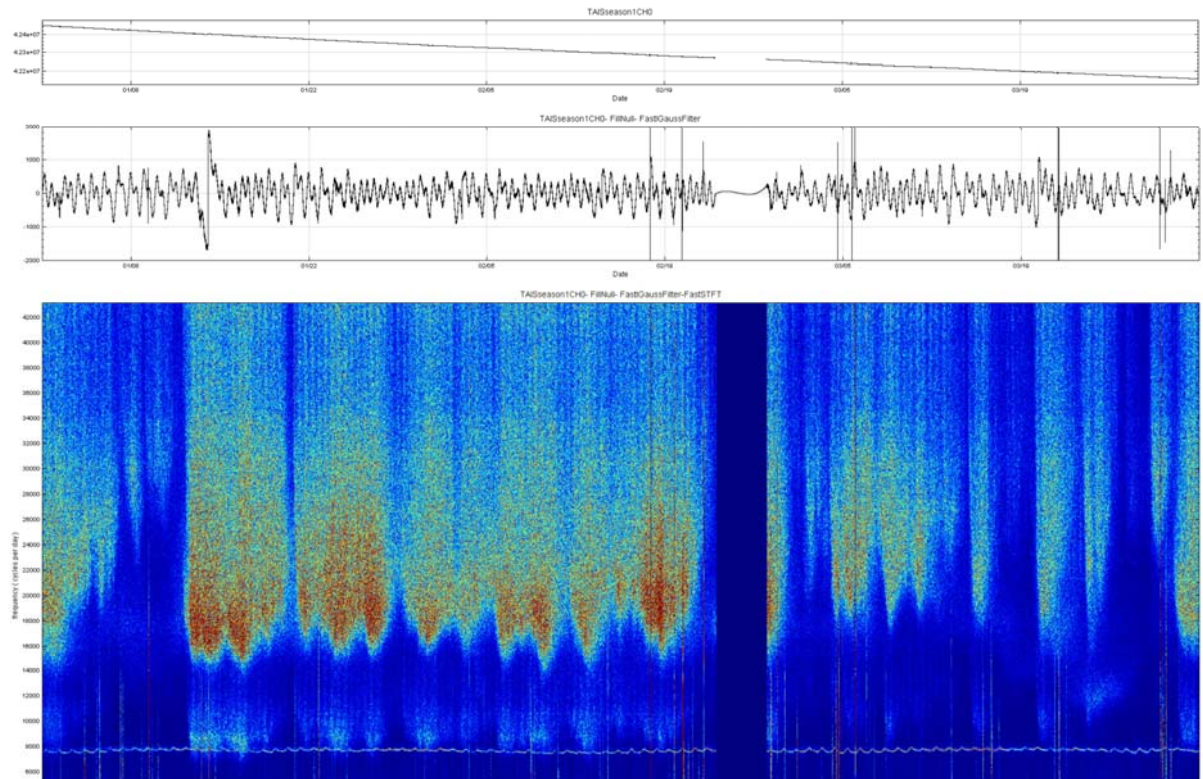
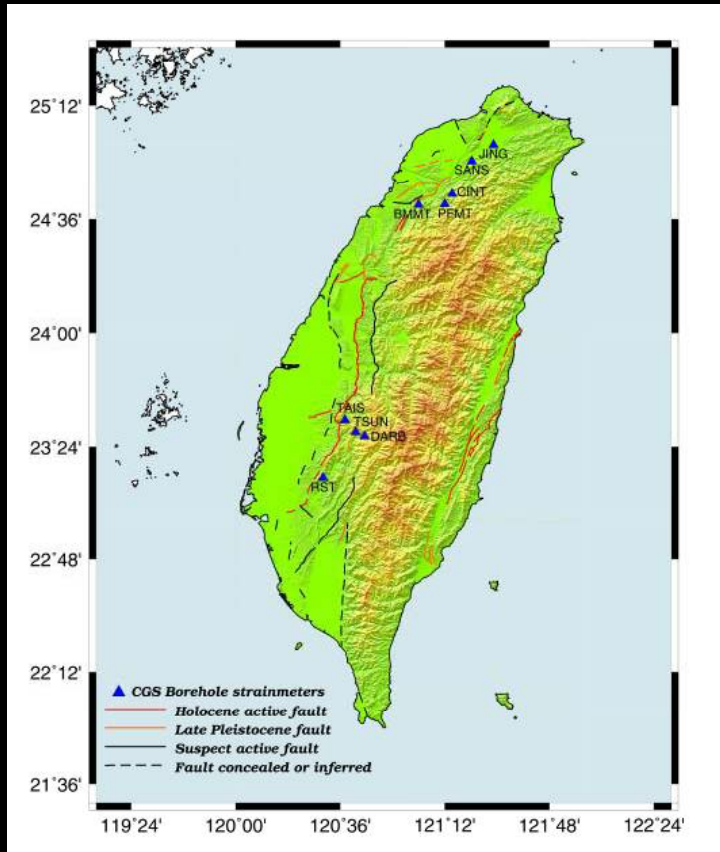




# TAIS Season 3 Ch3

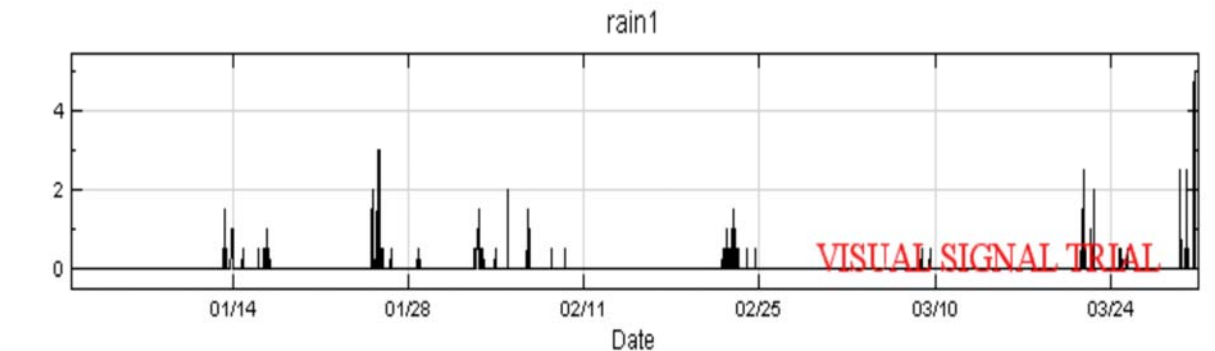
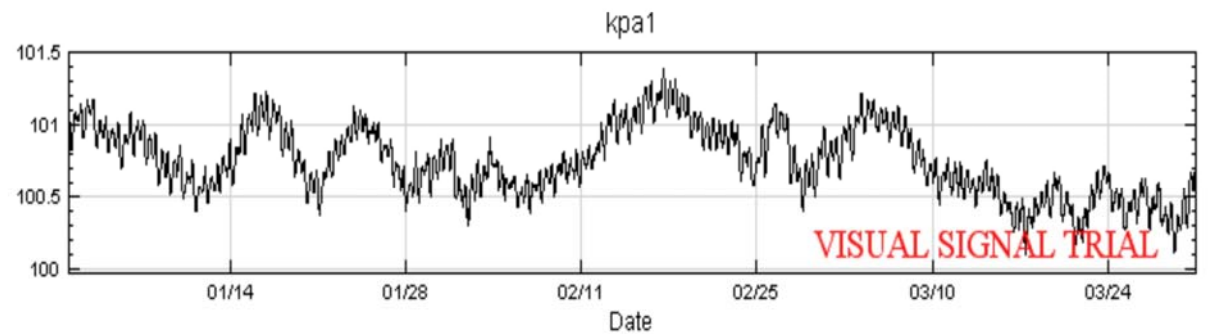
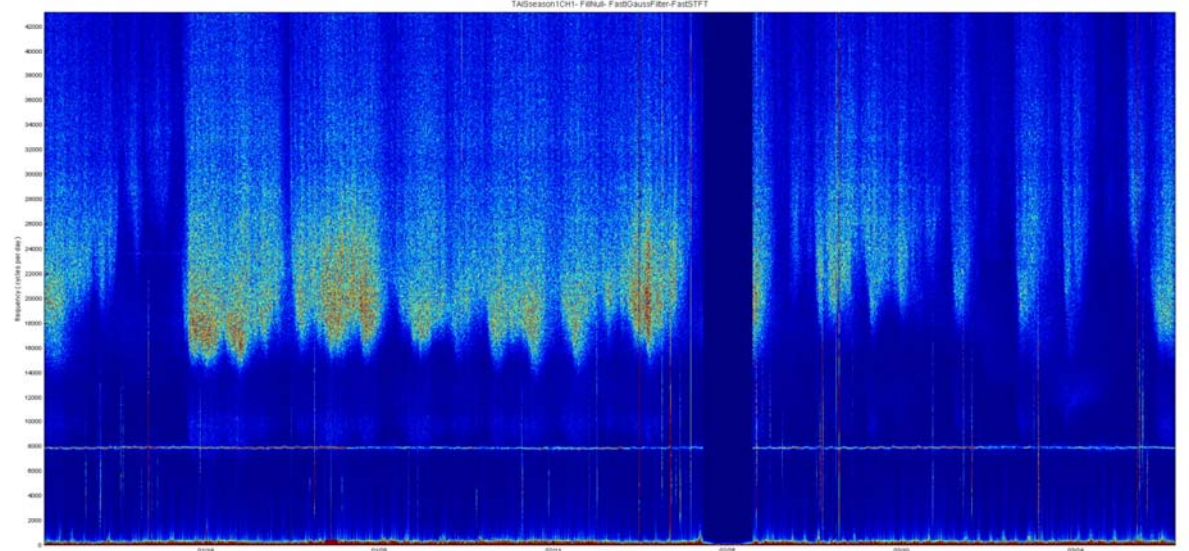
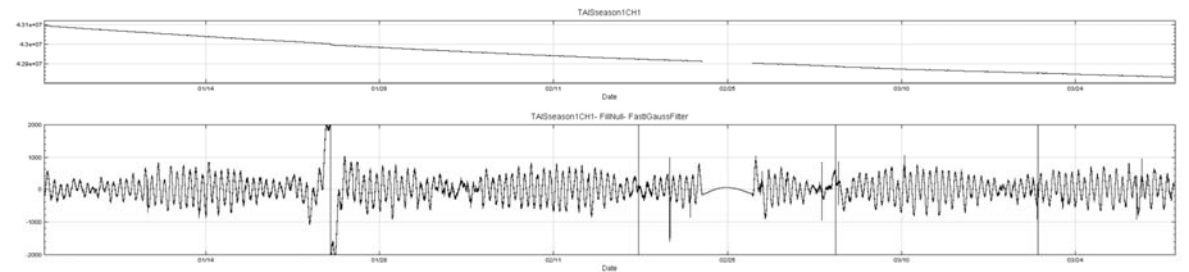
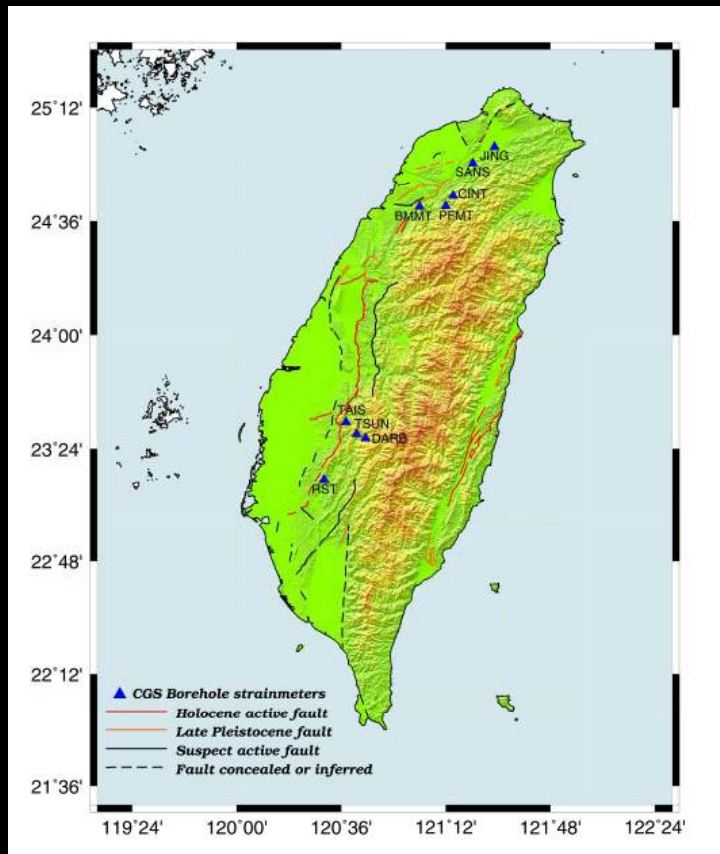


# TAIS Season 1 Ch0



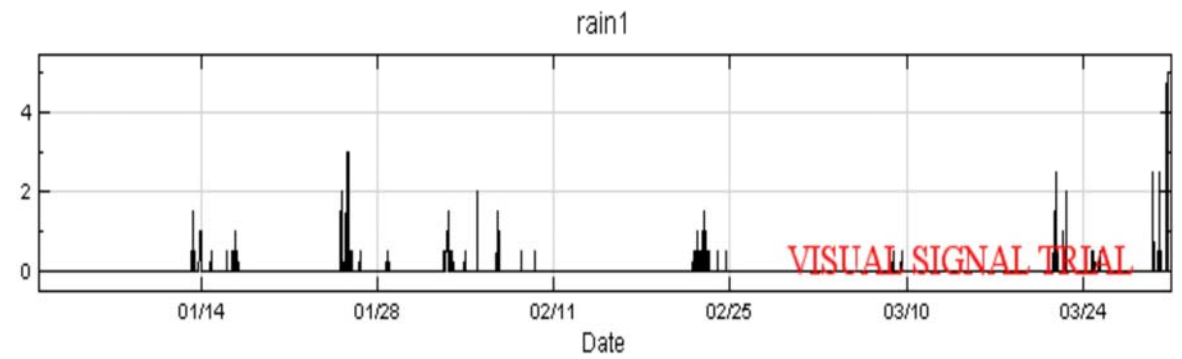
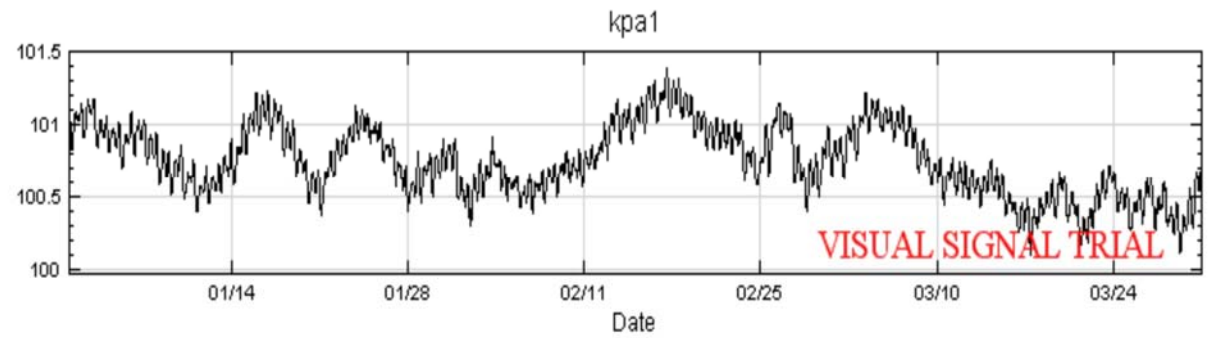
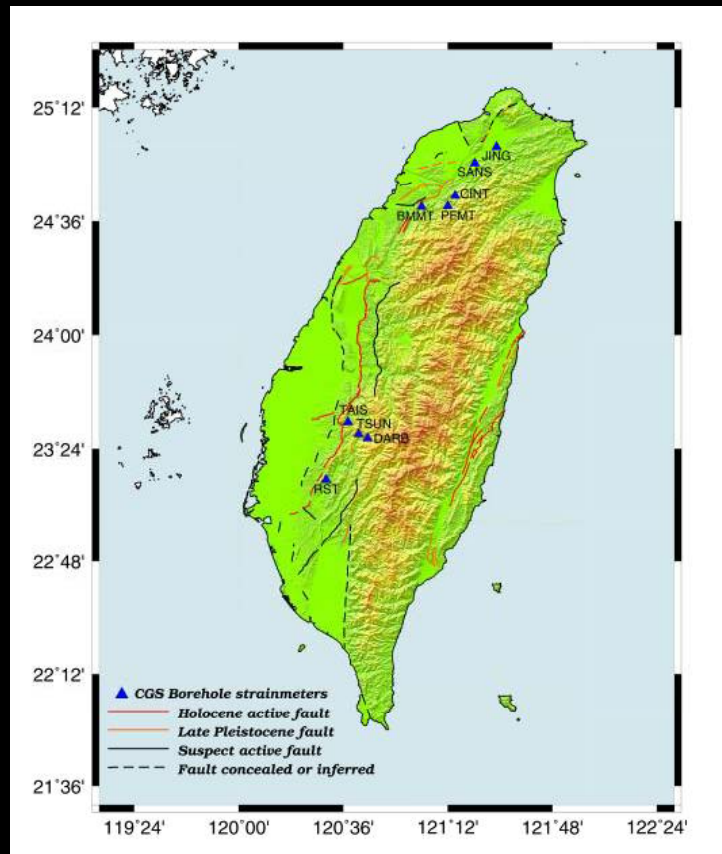
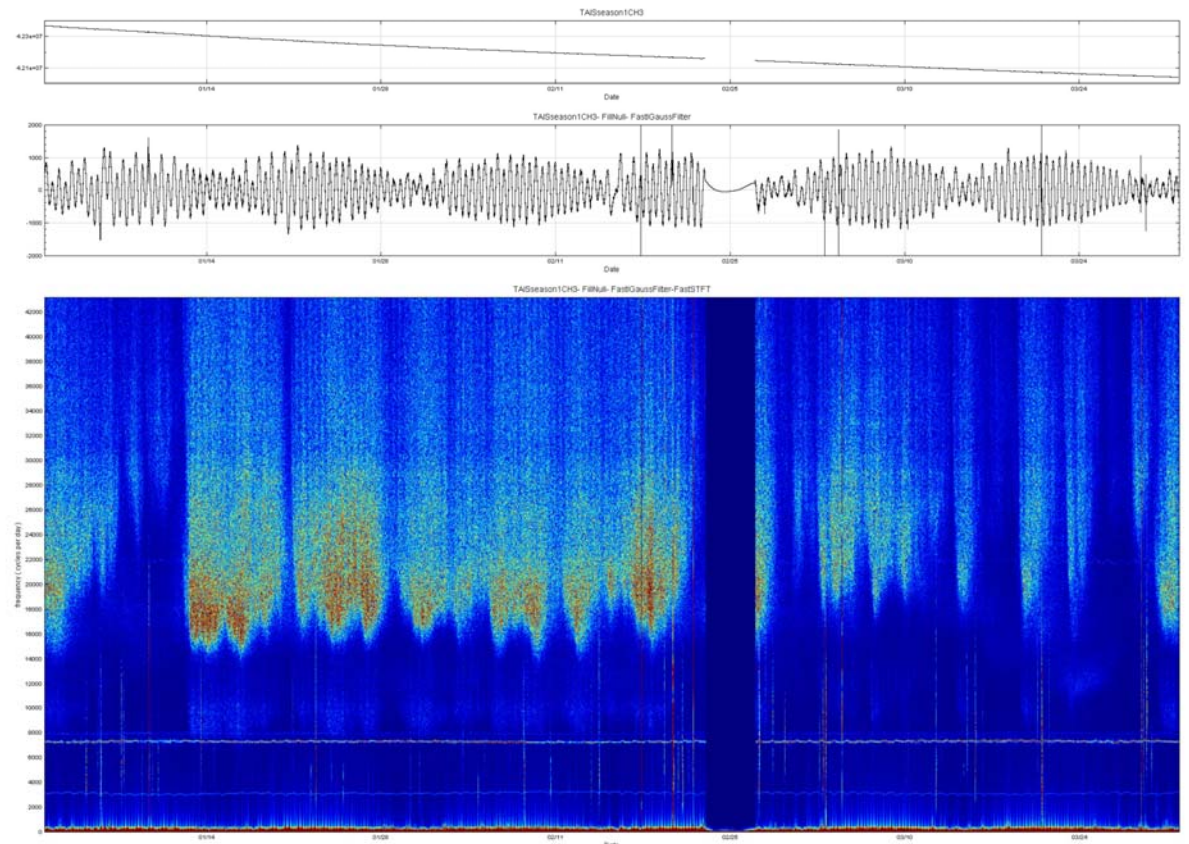


# TAIS Season 1 Ch1

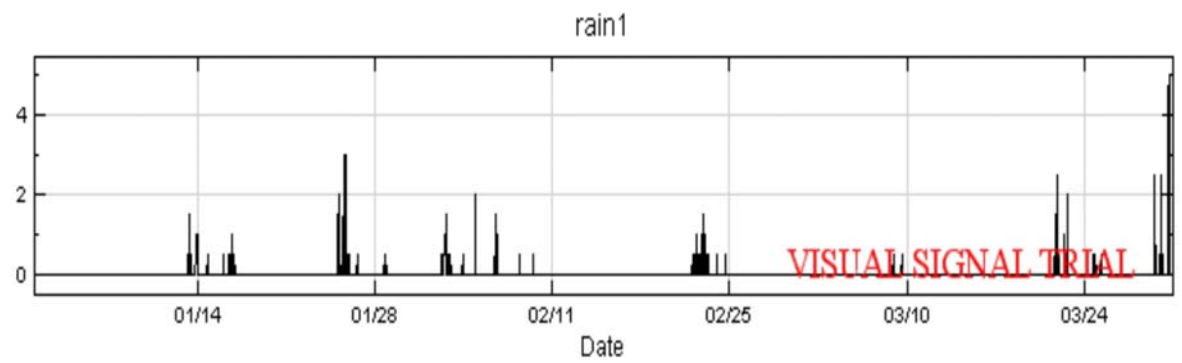
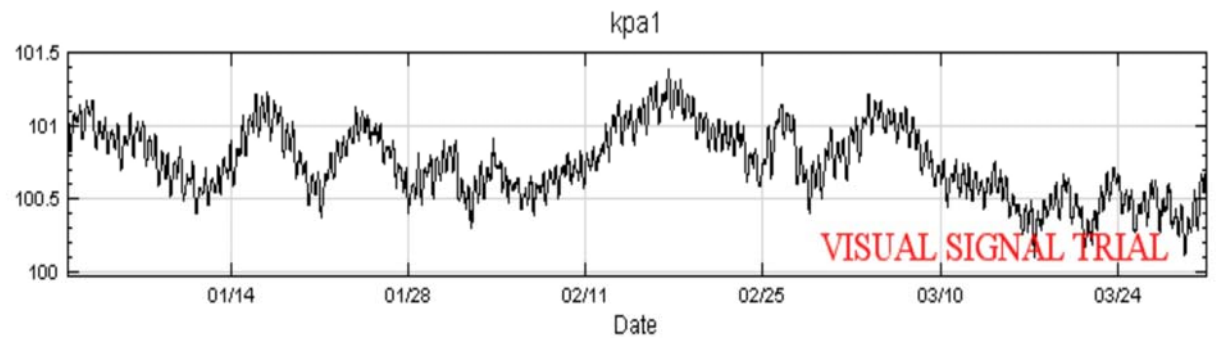
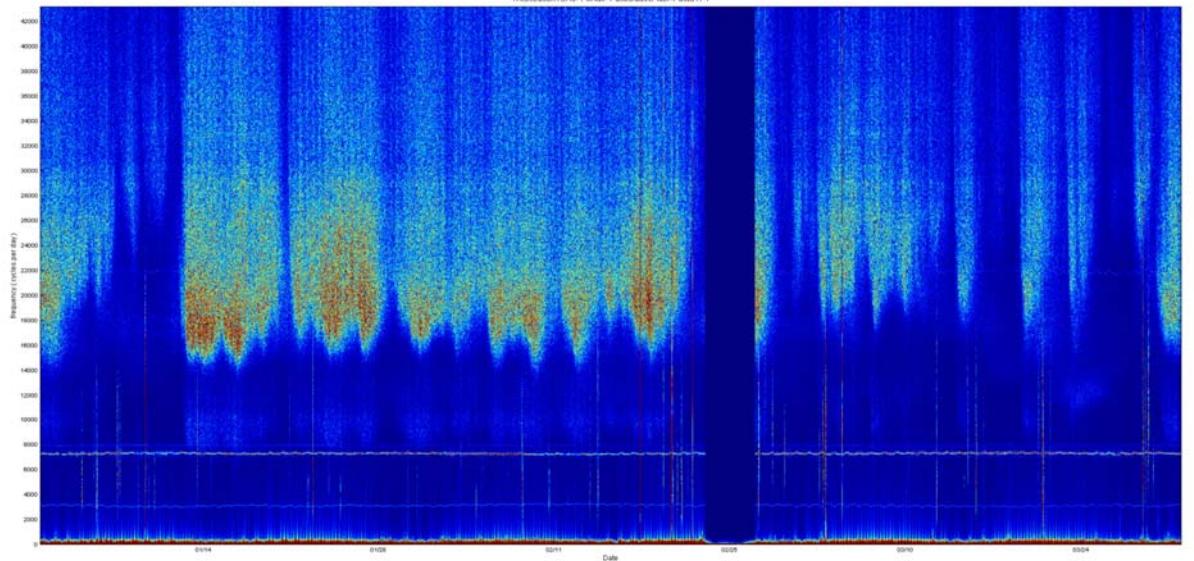
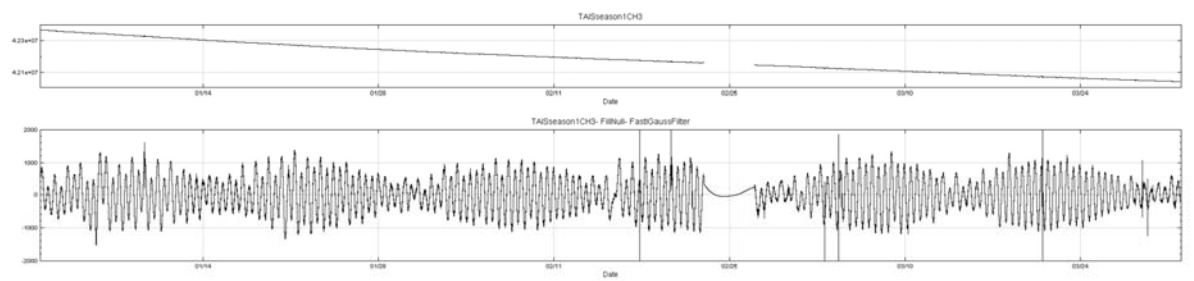
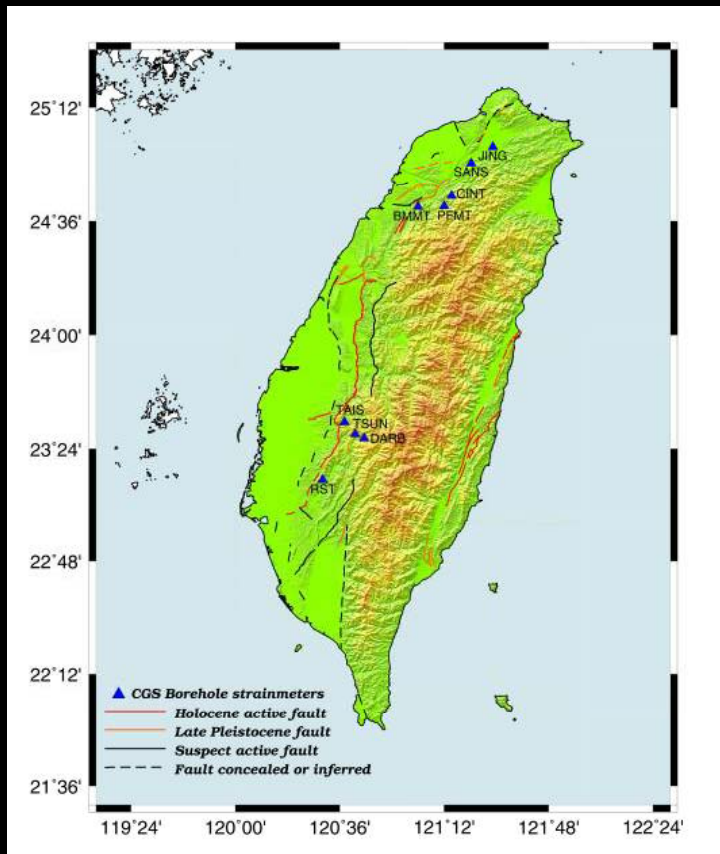




# TAIS Season 1 Ch2

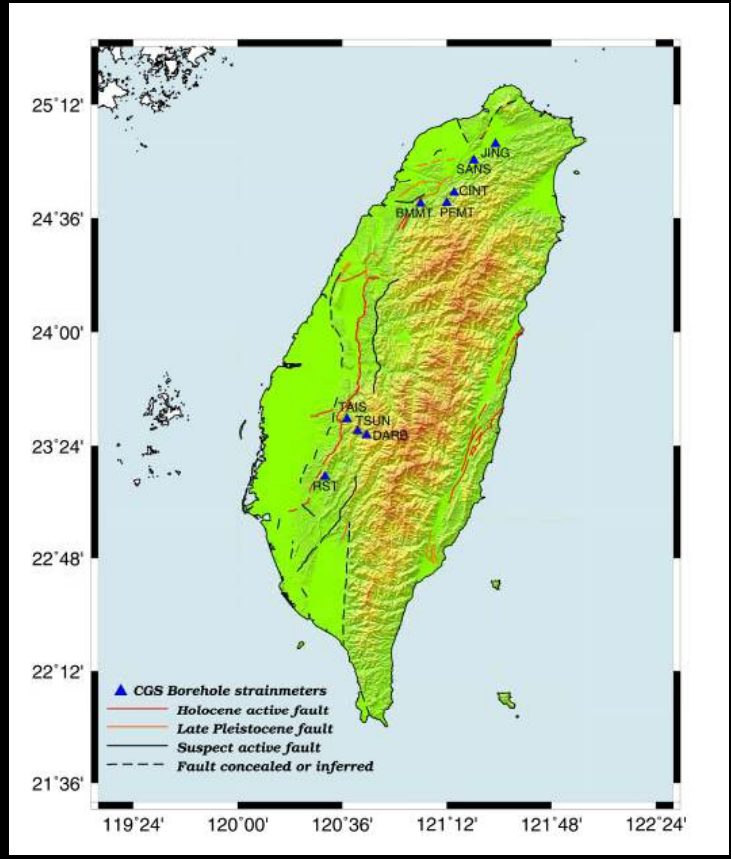
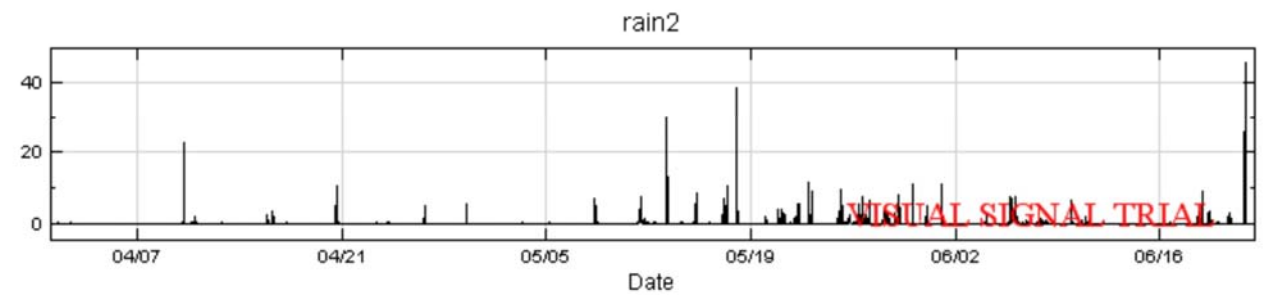
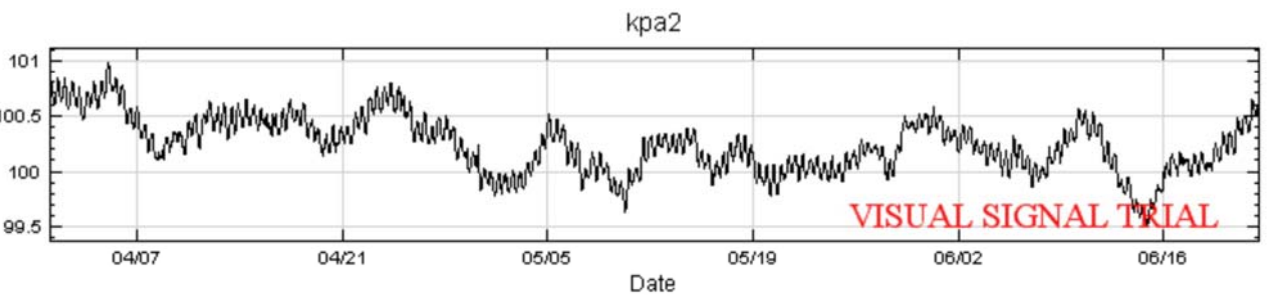
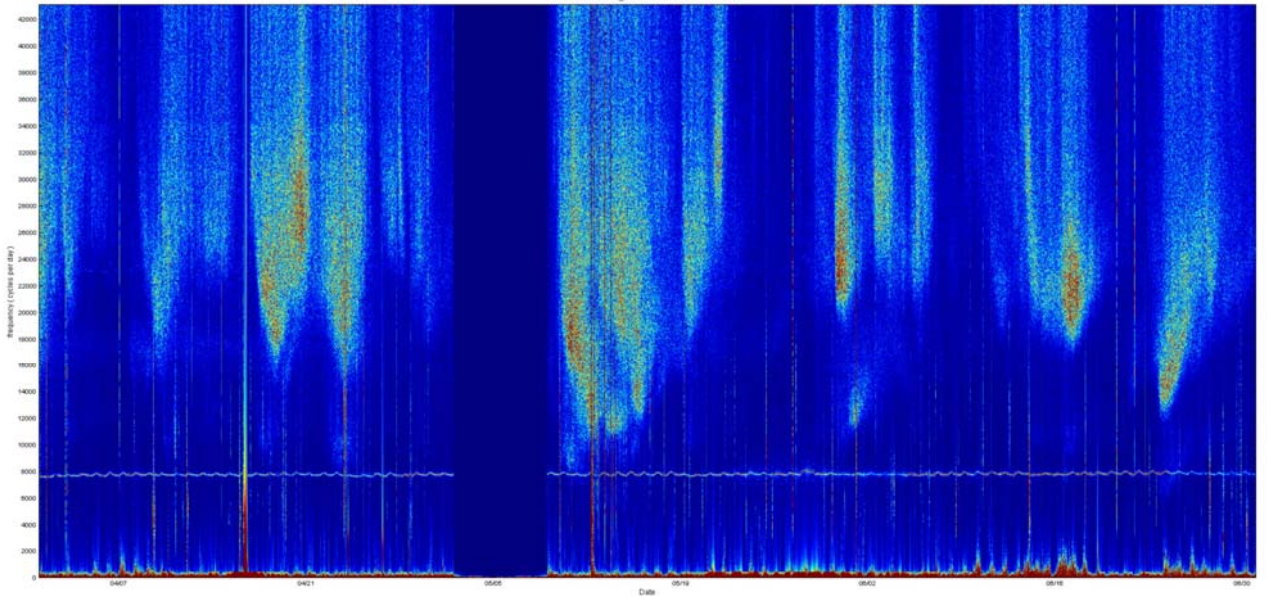
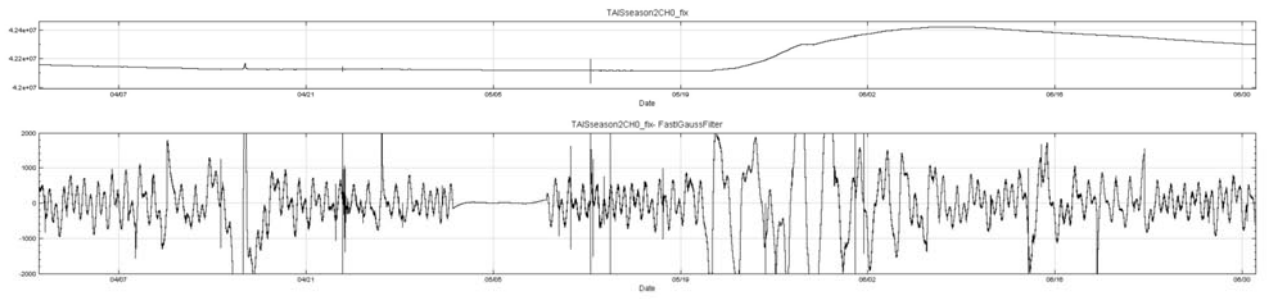


# TAIS Season 1 Ch3



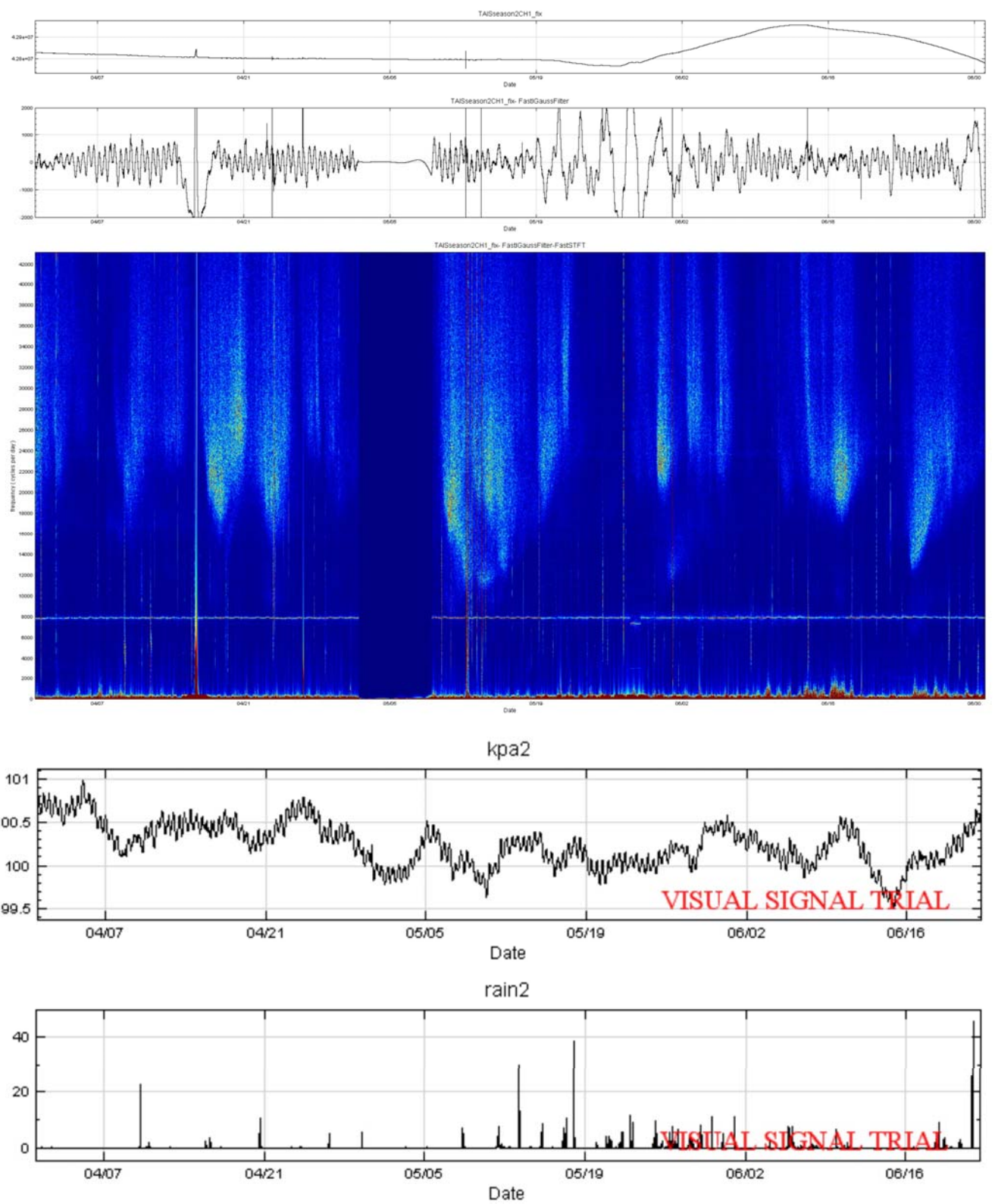
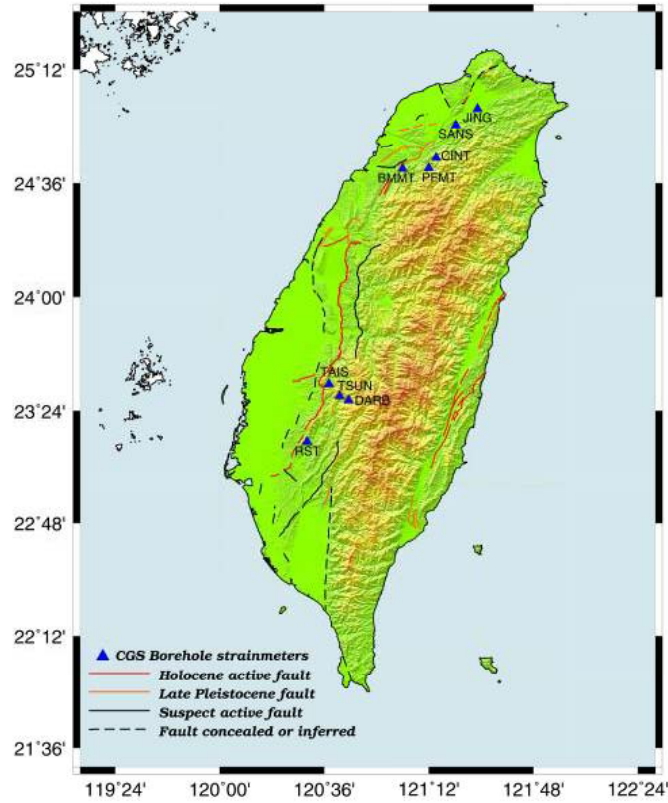


# TAIS Season 2 Ch0

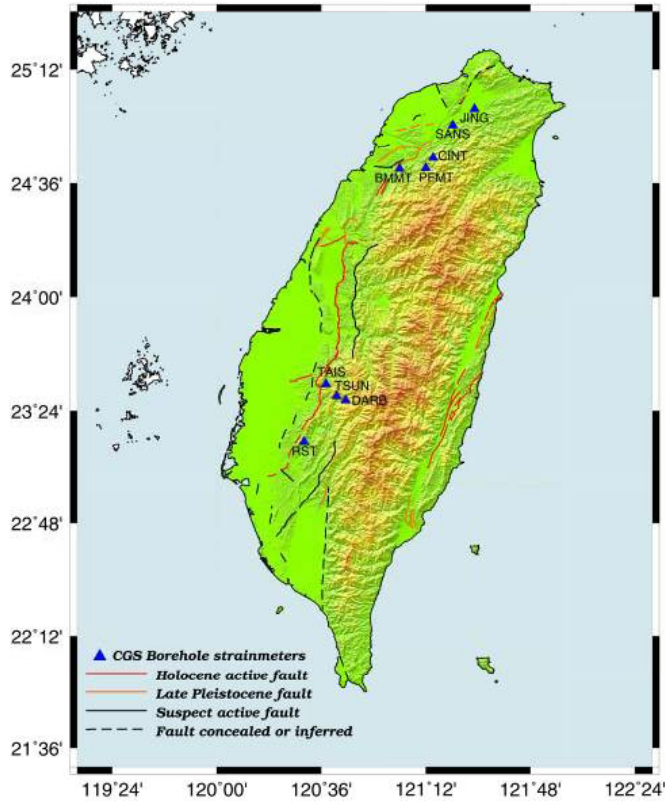
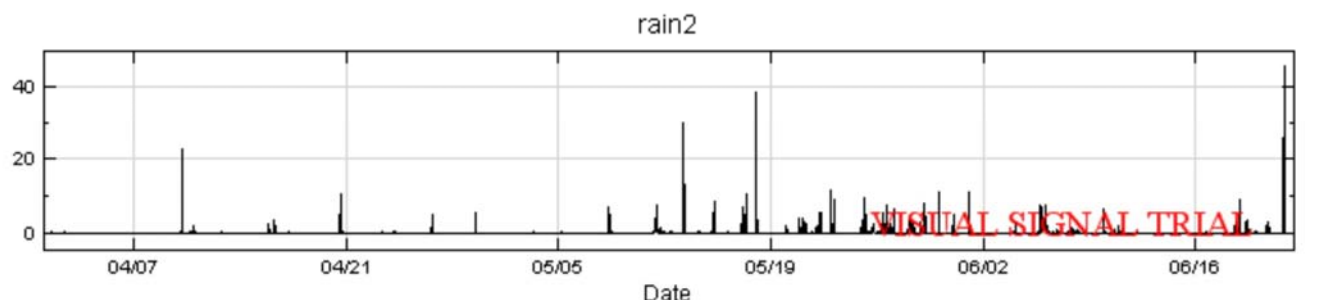
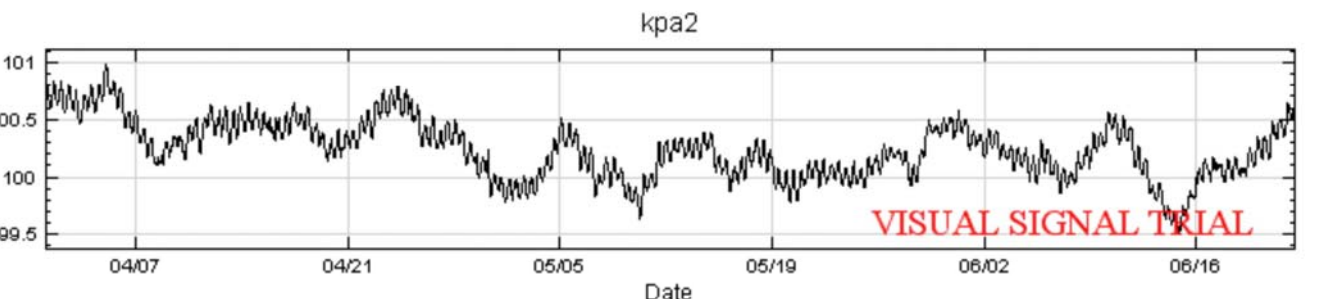
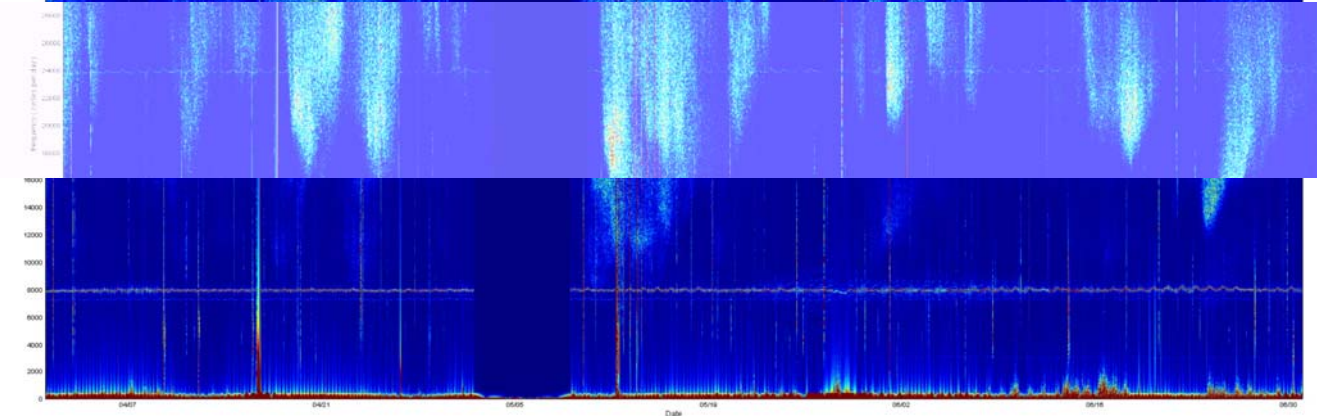
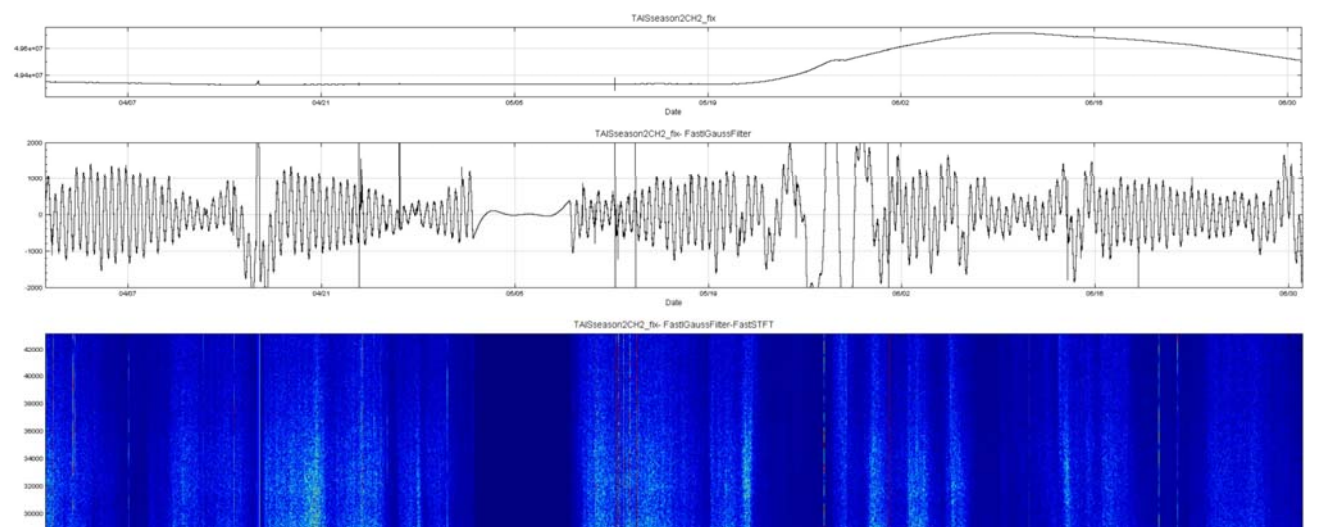




# TAIS Season 2 Ch1

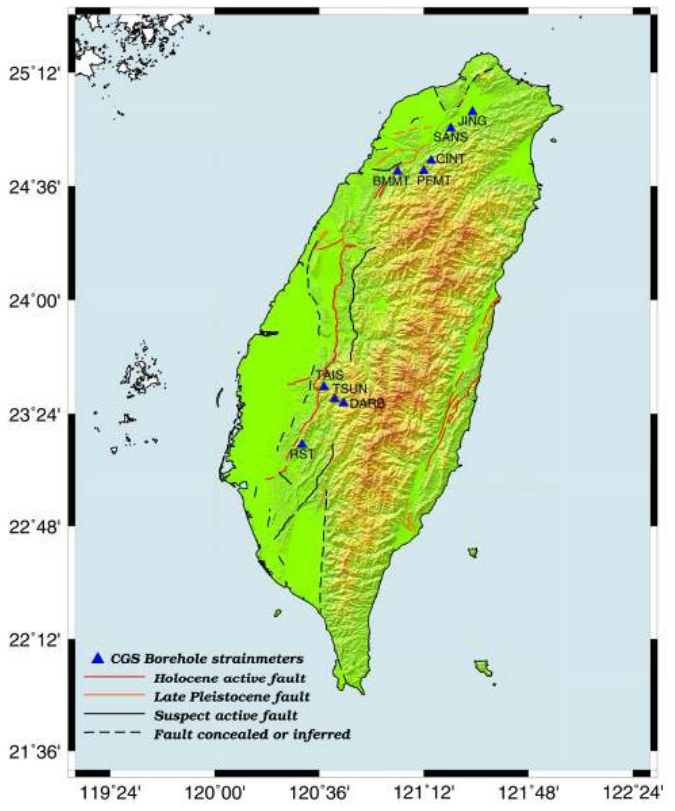
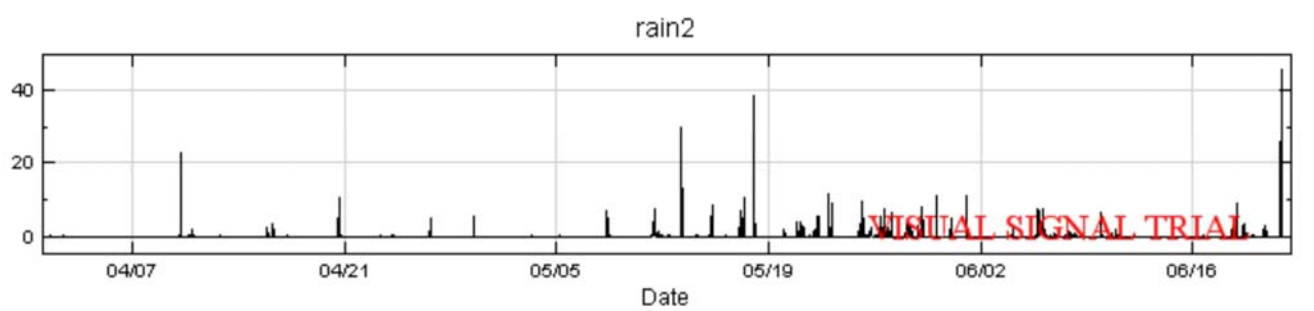
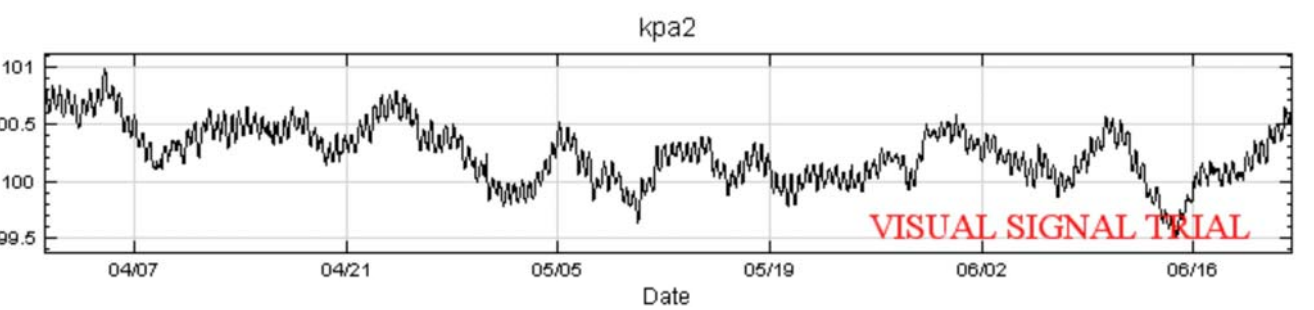
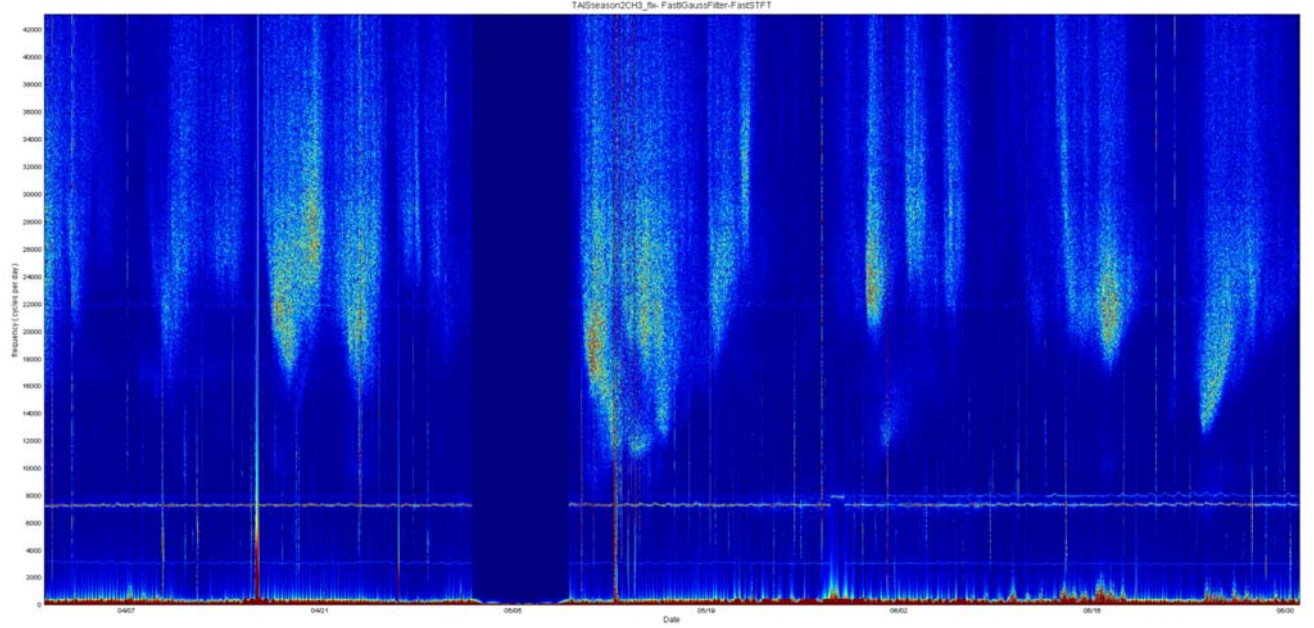
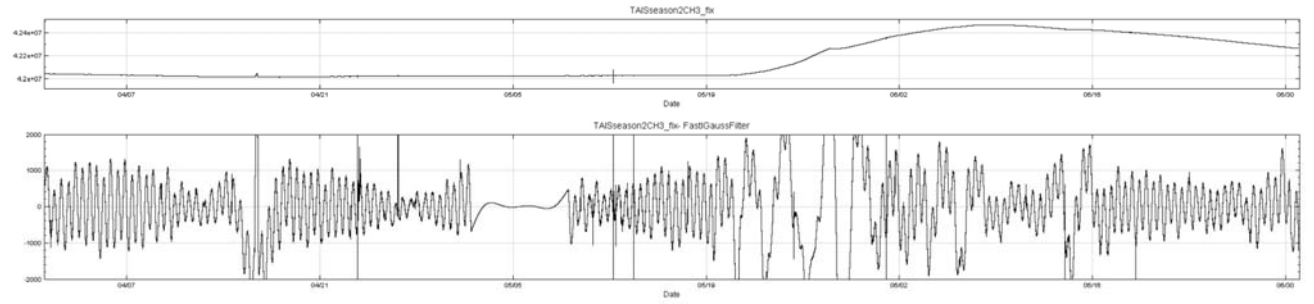


# TAIS Season 2 Ch2

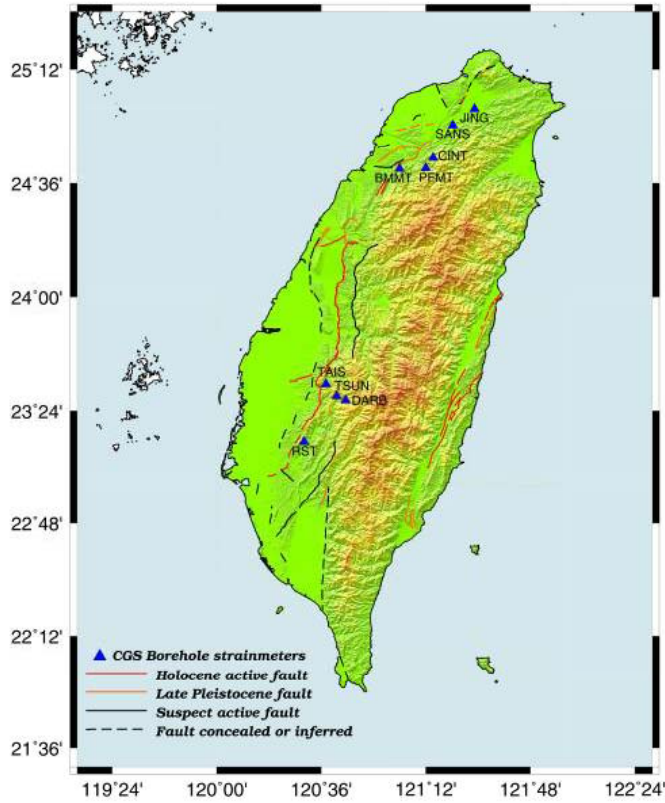
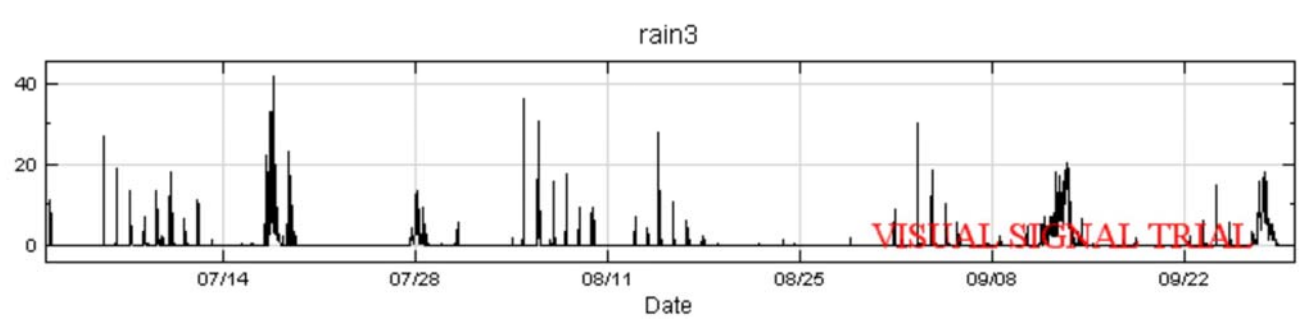
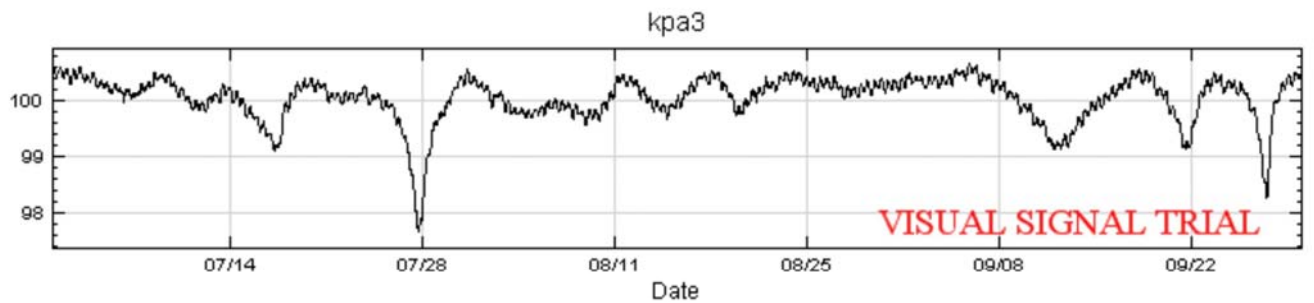
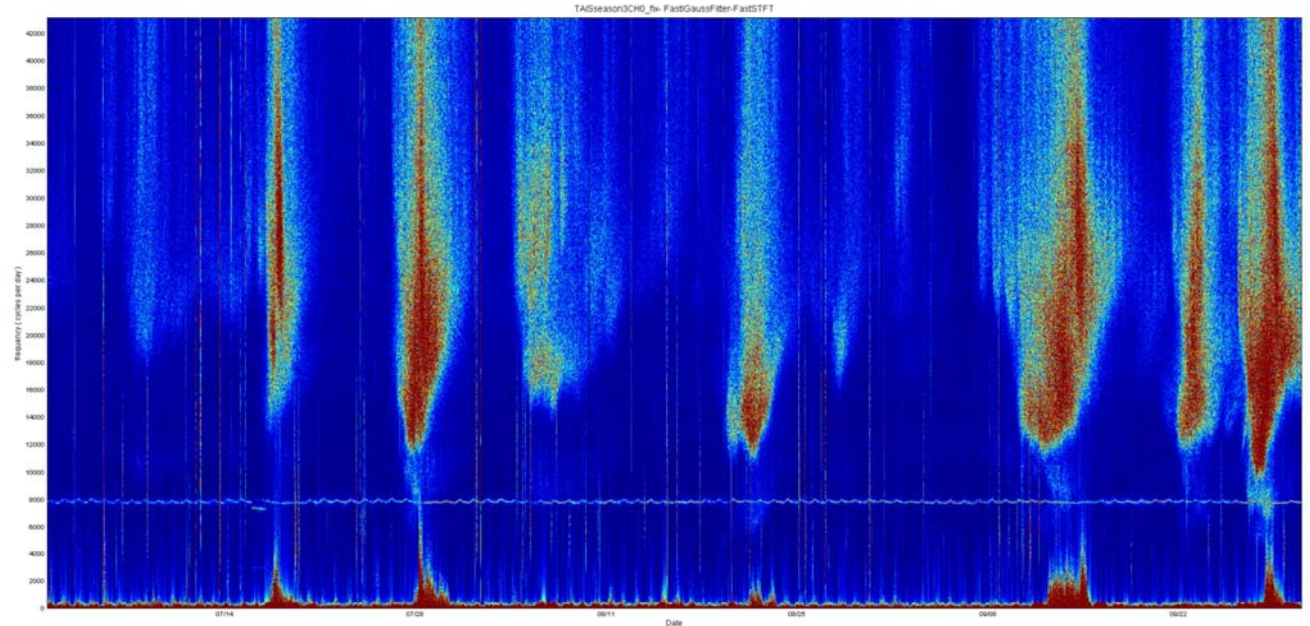
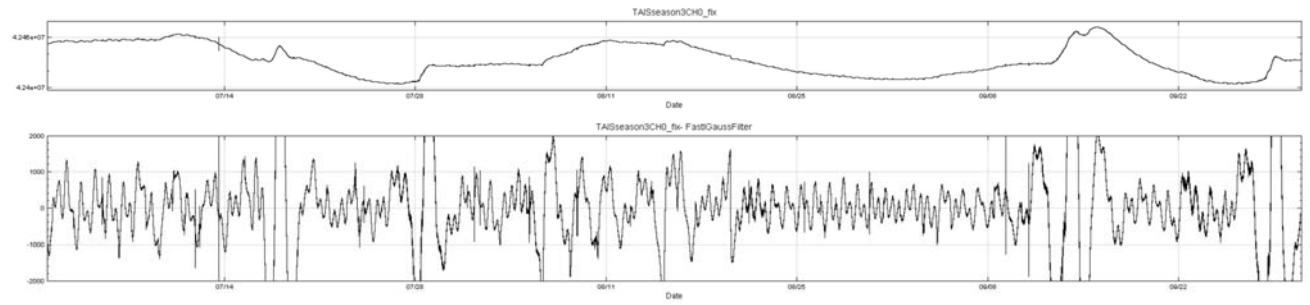




# TAIS Season 2 Ch3

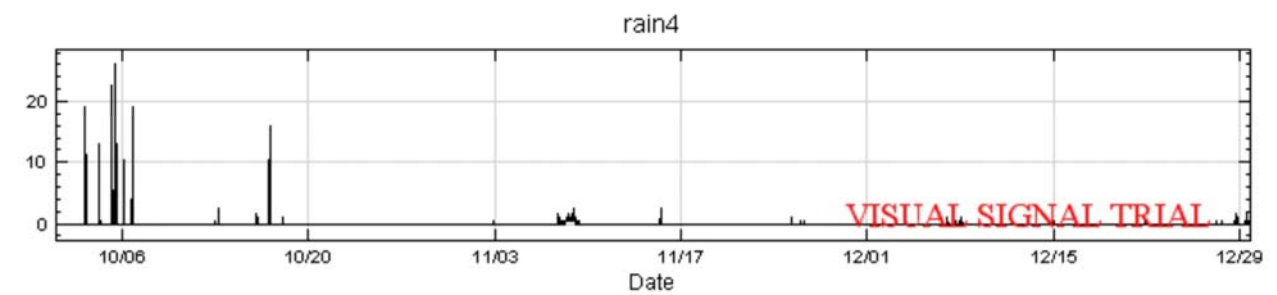
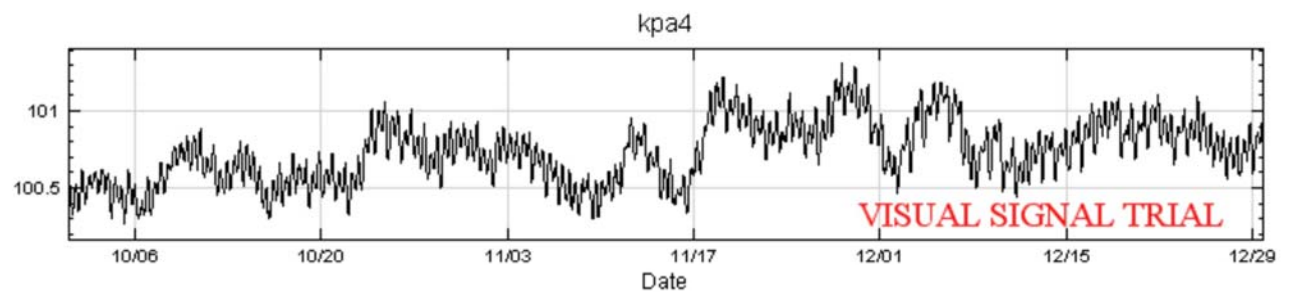
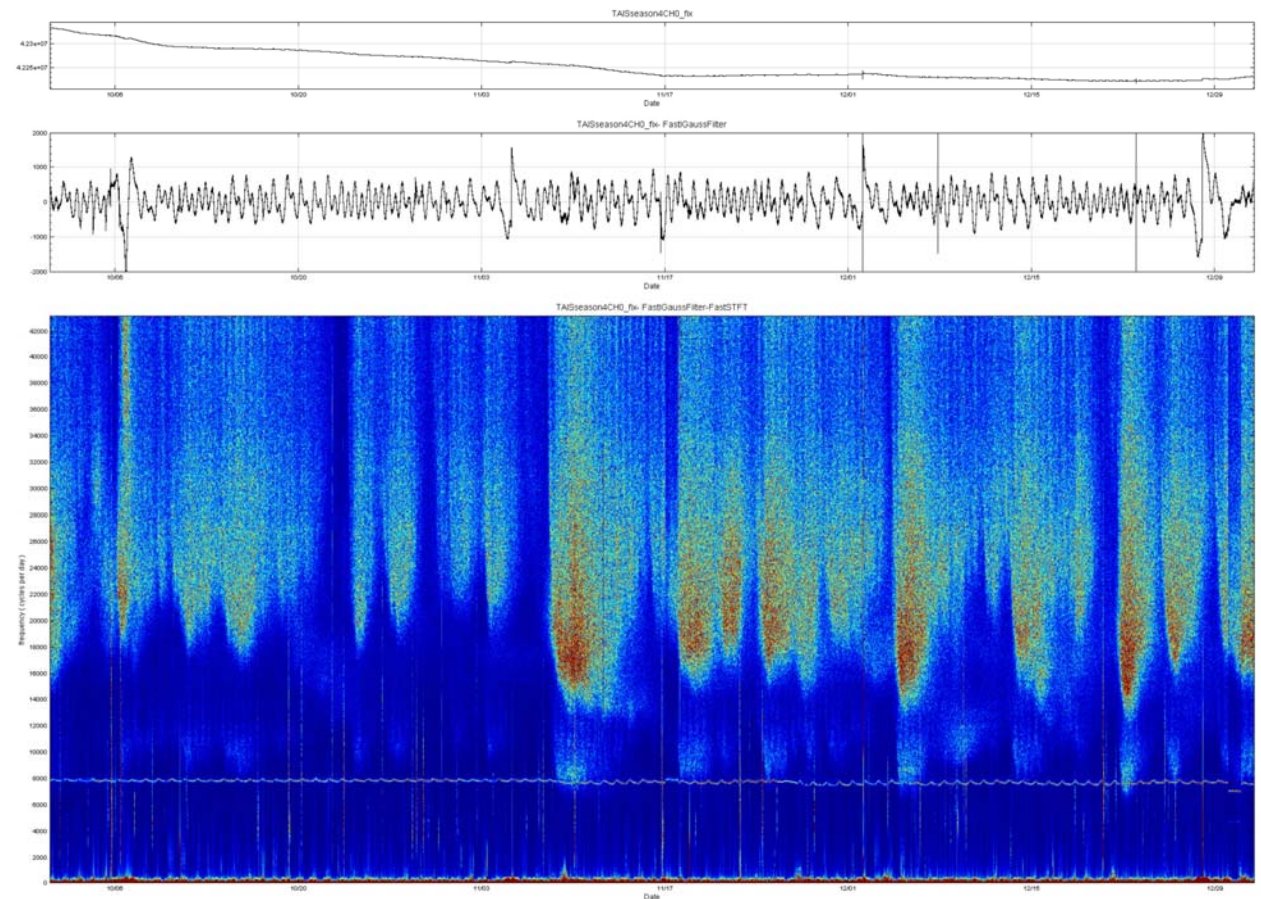
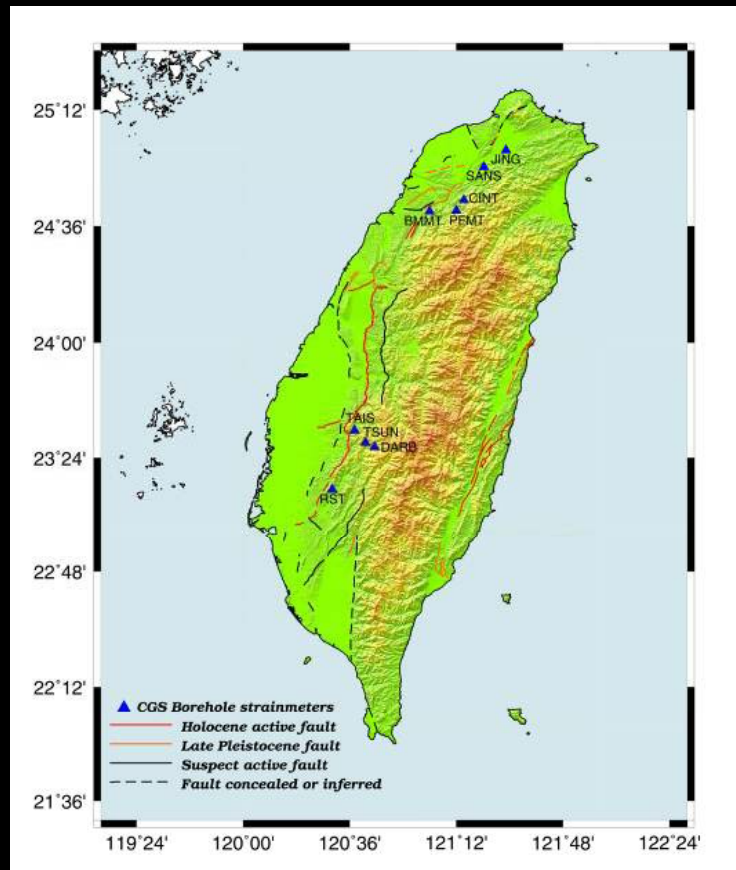


# TAIS Season 3 Ch0

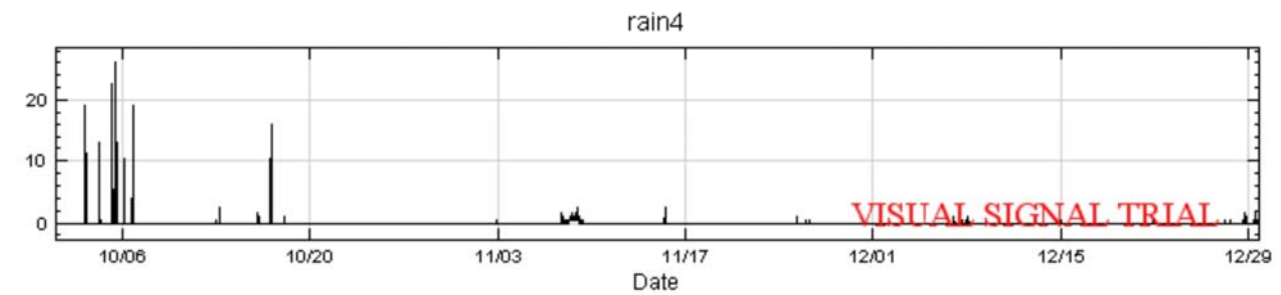
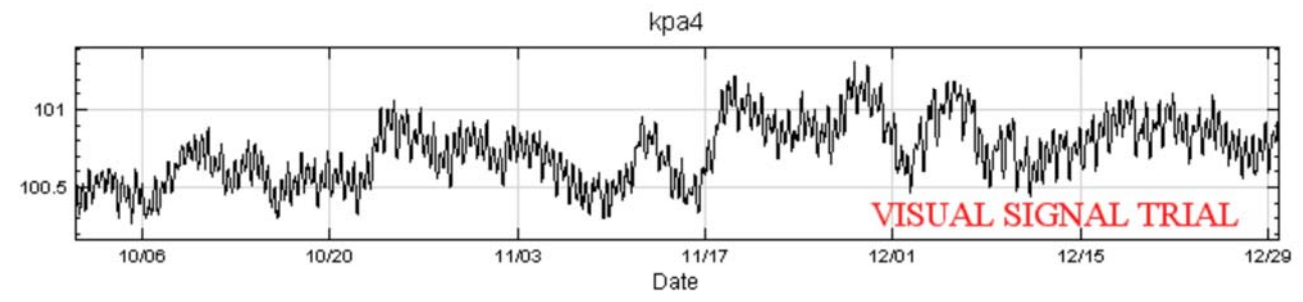
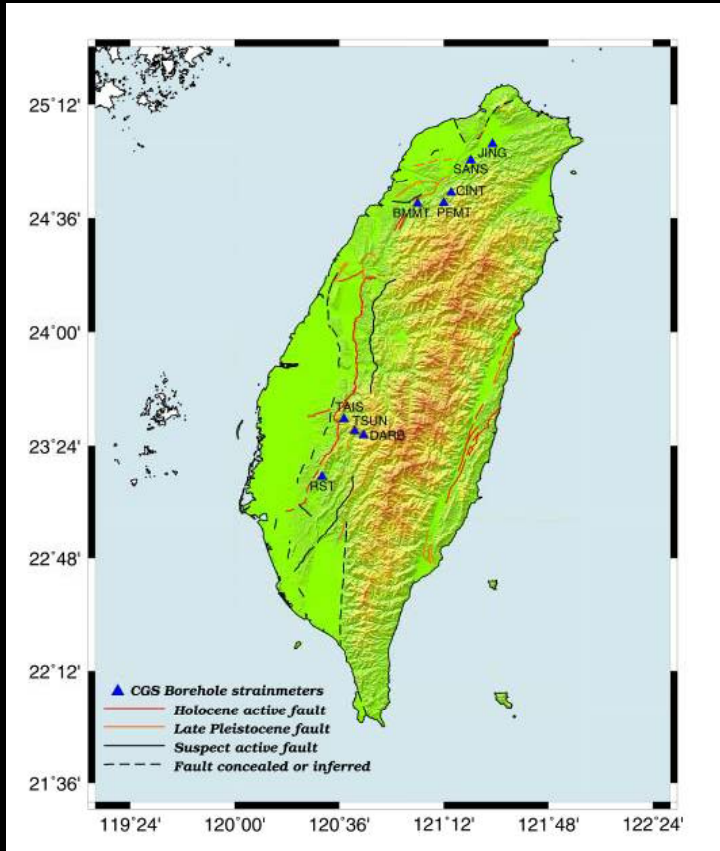
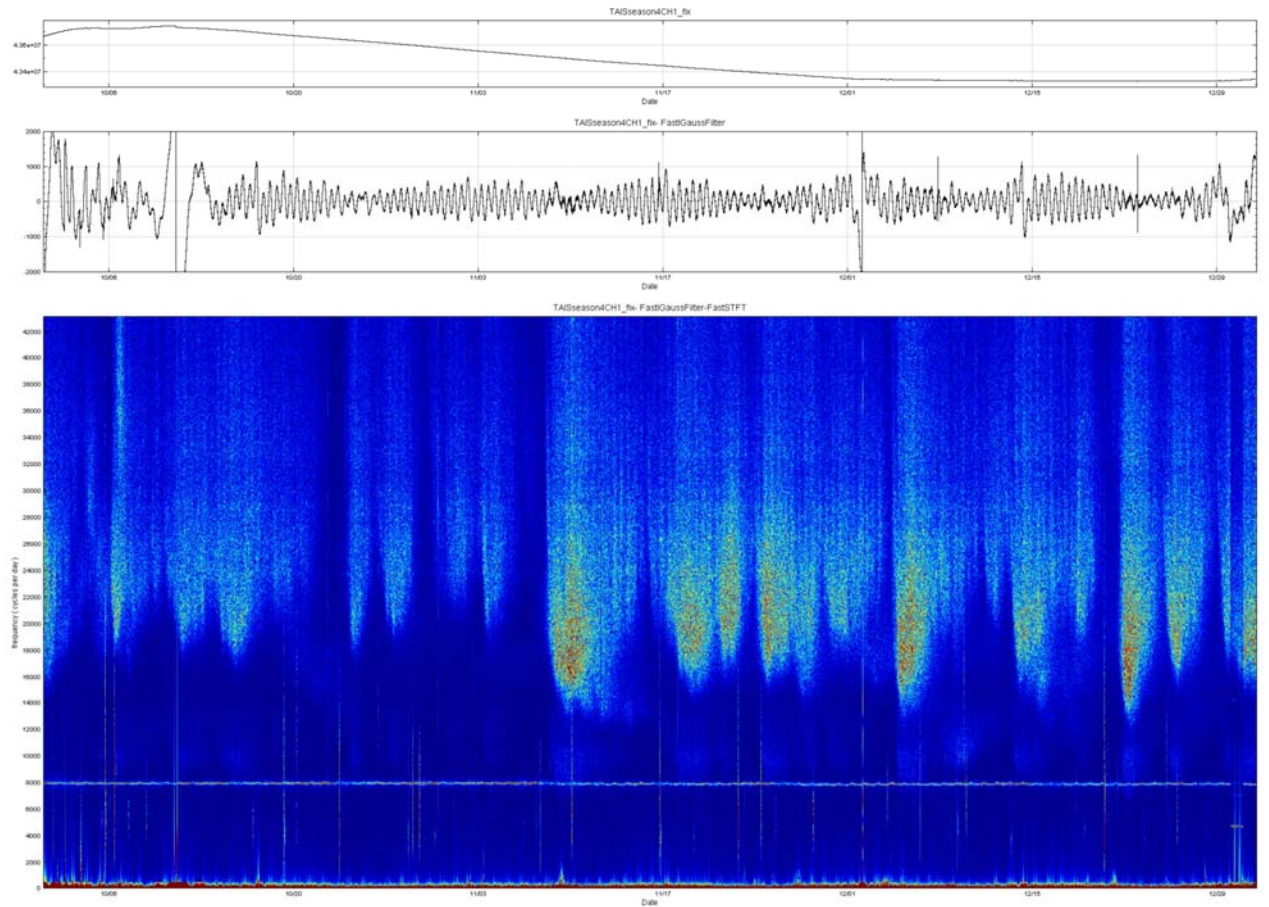




# TAIS Season 4 Ch0

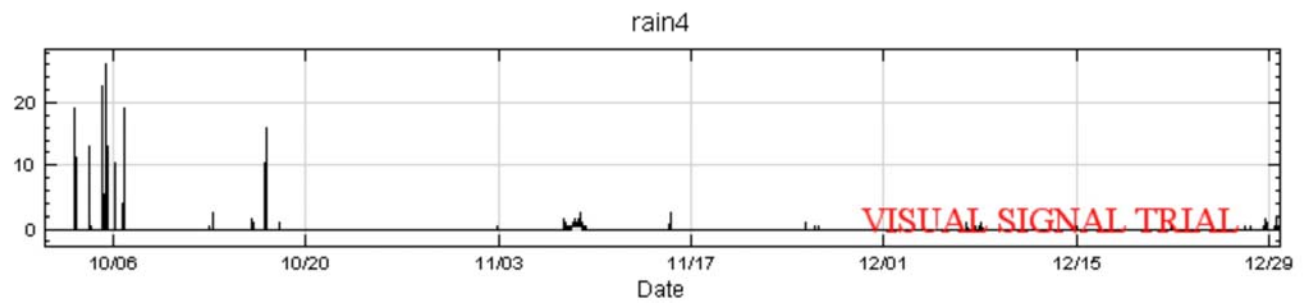
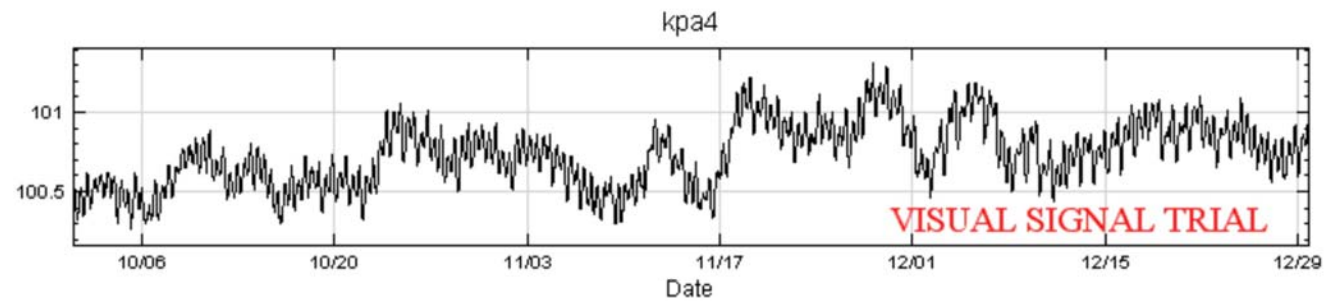
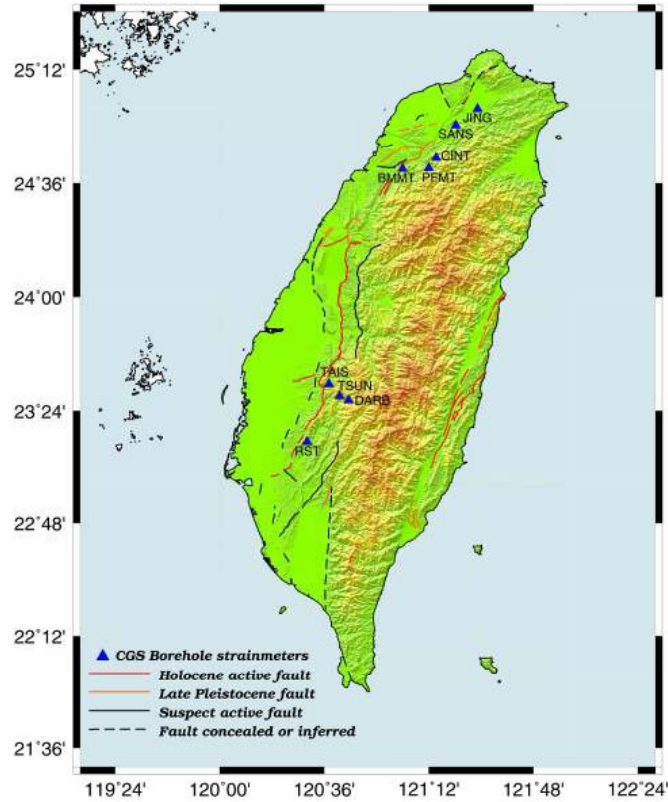
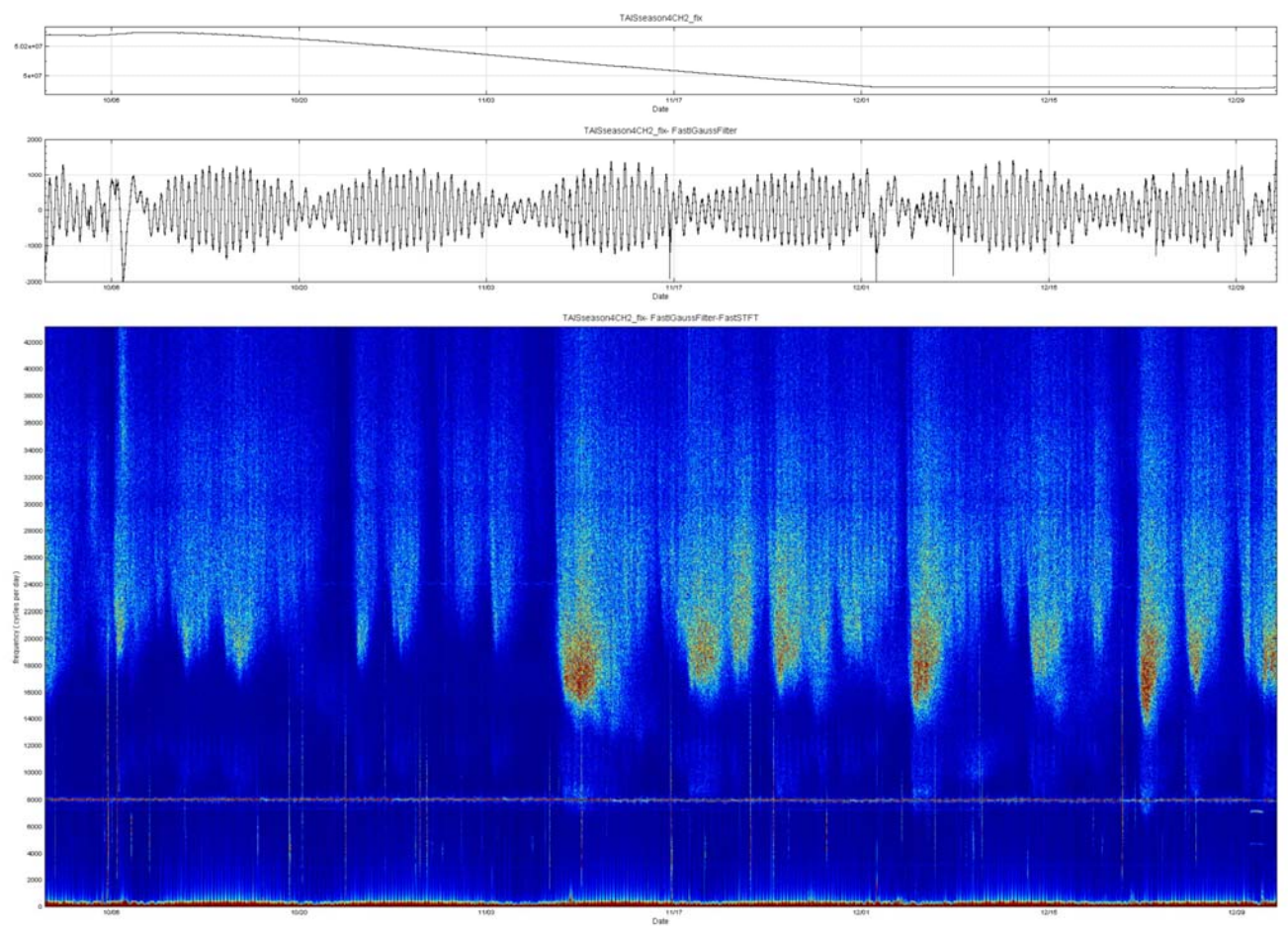


# TAIS Season 4 Ch1

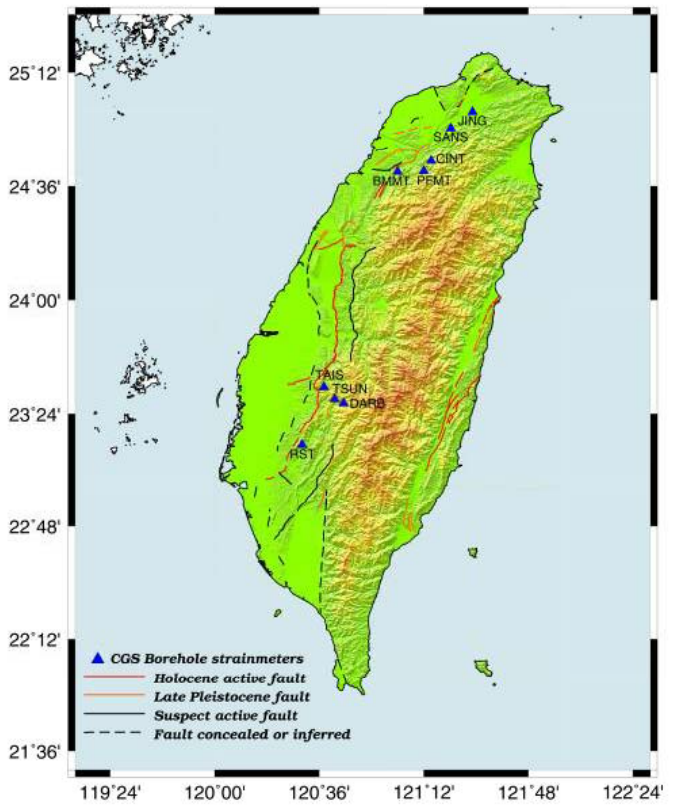
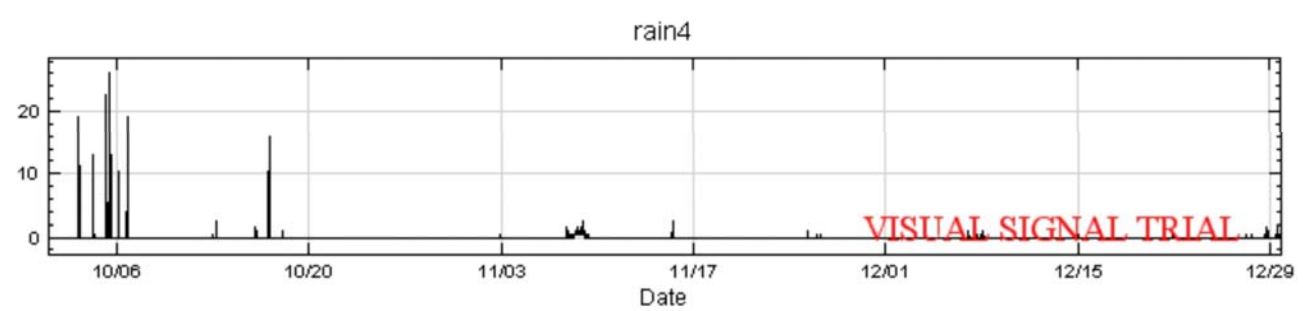
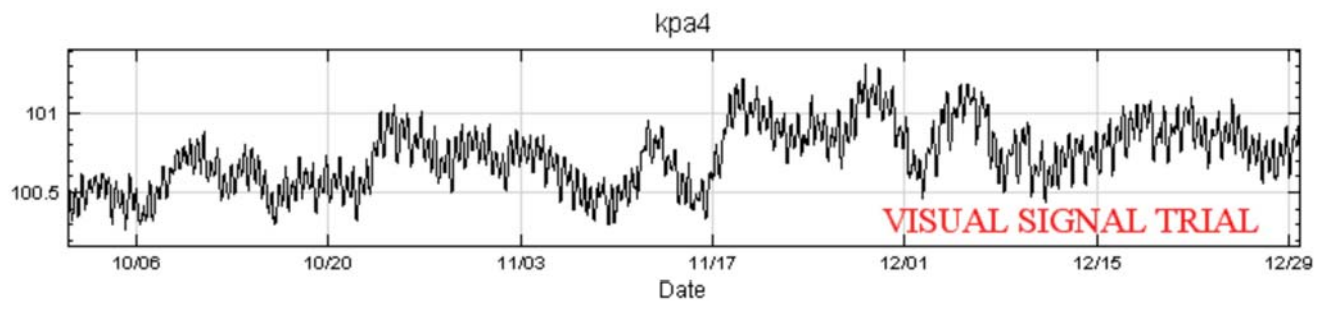
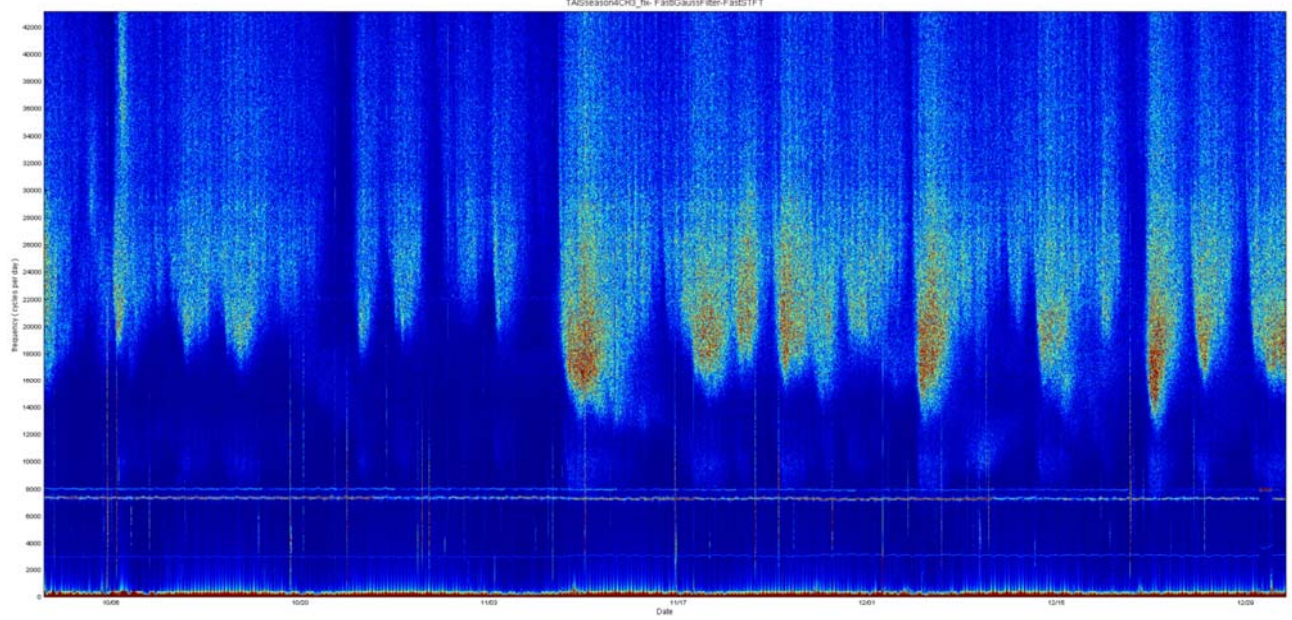
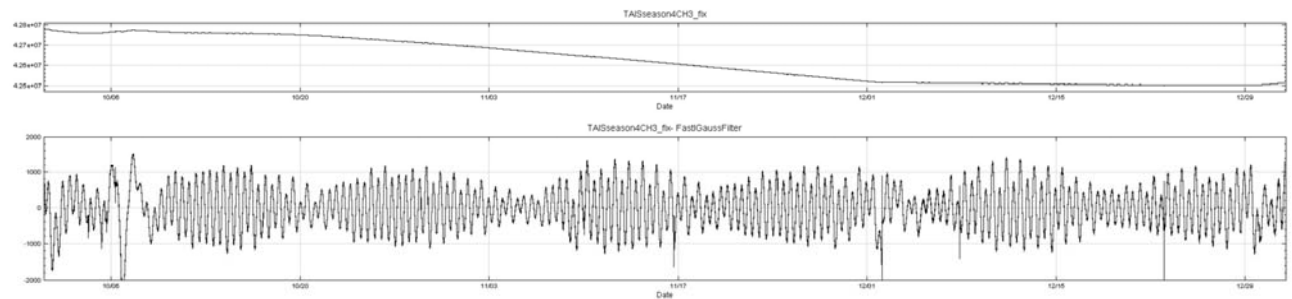




# TAIS Season 4 Ch2



# TAIS Season 4 Ch3





# Prospect

Coupling with environment

Fault activity

Strain seismography

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

Permutation of principal strain

Tremor & slow earthquake

