DPRC
Disaster Prevention Research Center,
National Cheng Kung University, Taiwan

Tectono-Hydrology Research Group
AIST The National Institute of Advanced Industrial Science and Technology
Geological Survey of Japan

# The Observation of the Tidal Deviation of Groundwater Level Act as the Precursory Changes of Earthquakes

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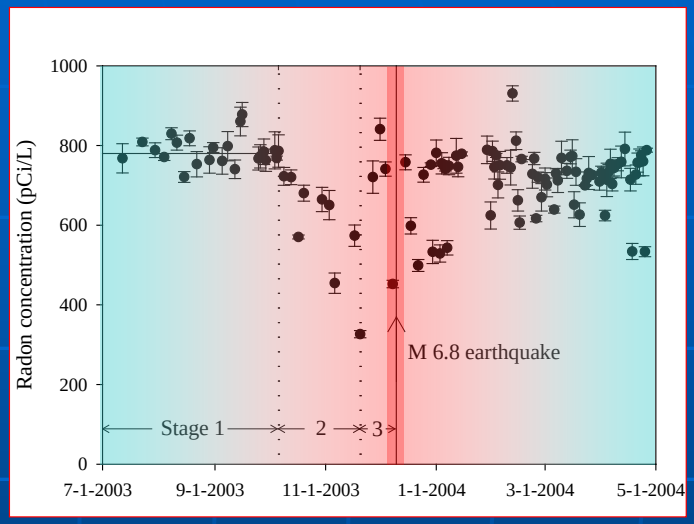
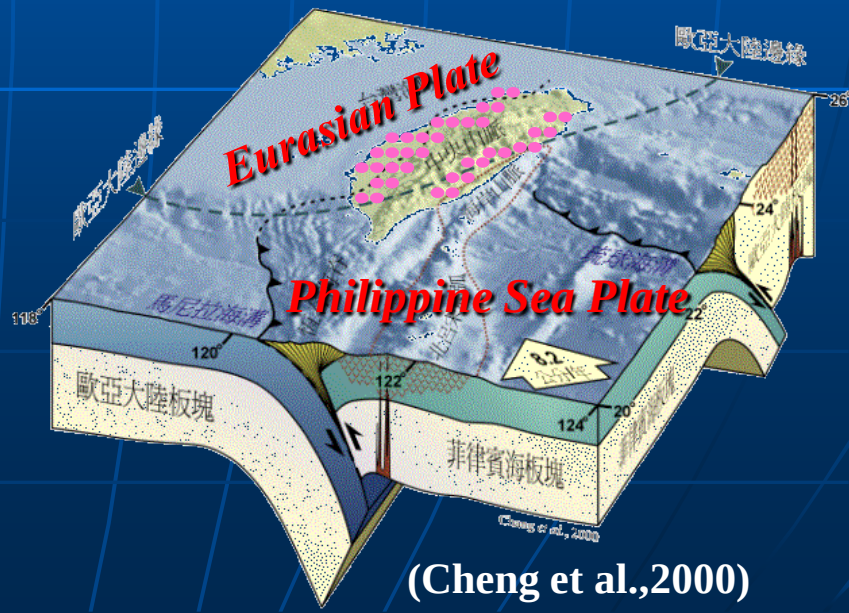
# I. Introduction

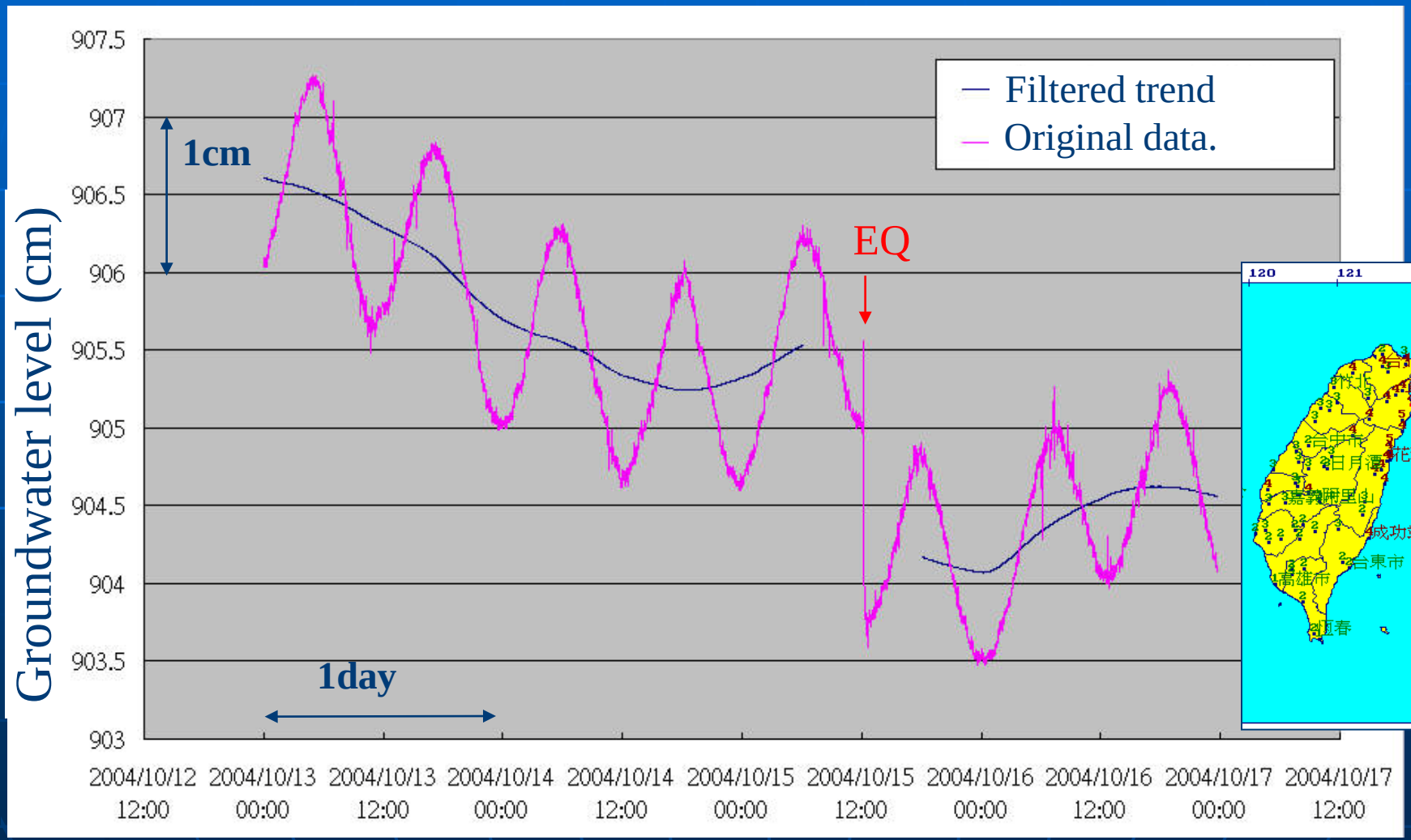
- Tectonic Setting of Taiwan.
  - On-land plate boundary
  - Highly deformation rate
  - Active fault in thick alluvial layers
- Highly Seismic hazard risk.
- Advantage of the research
  - High density monitoring network for water resources Groundwater Monitoring Networks of Taiwan
  - High density seismic monitoring network.
  - High seismic activity




(Cheng et al.,2000)

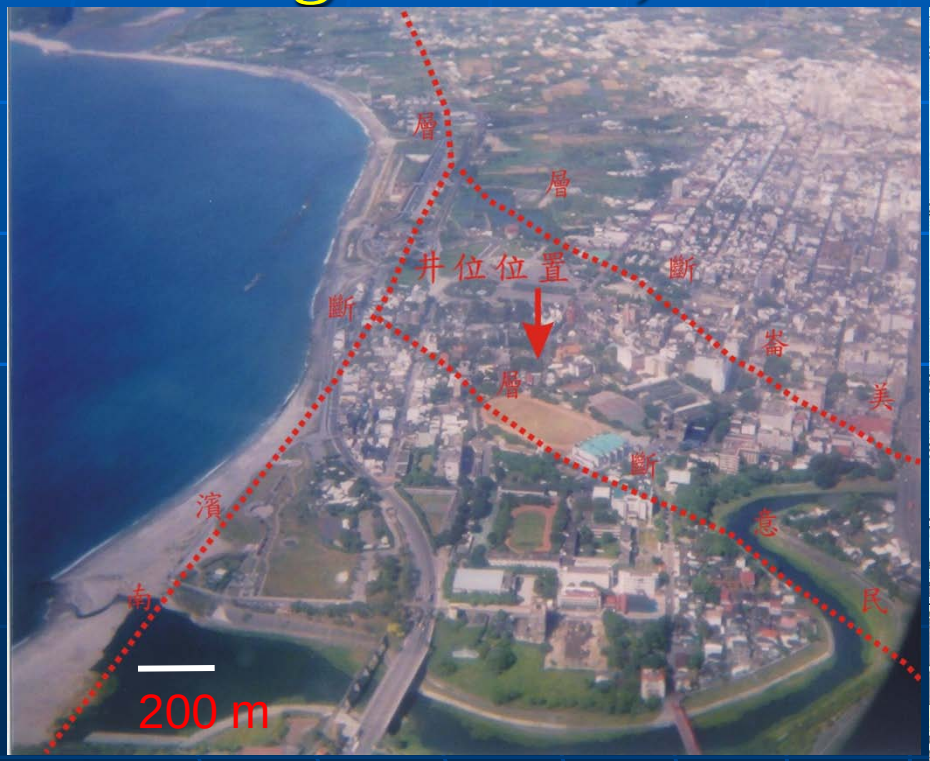
# Pre-seismic Groundwater Level Changes

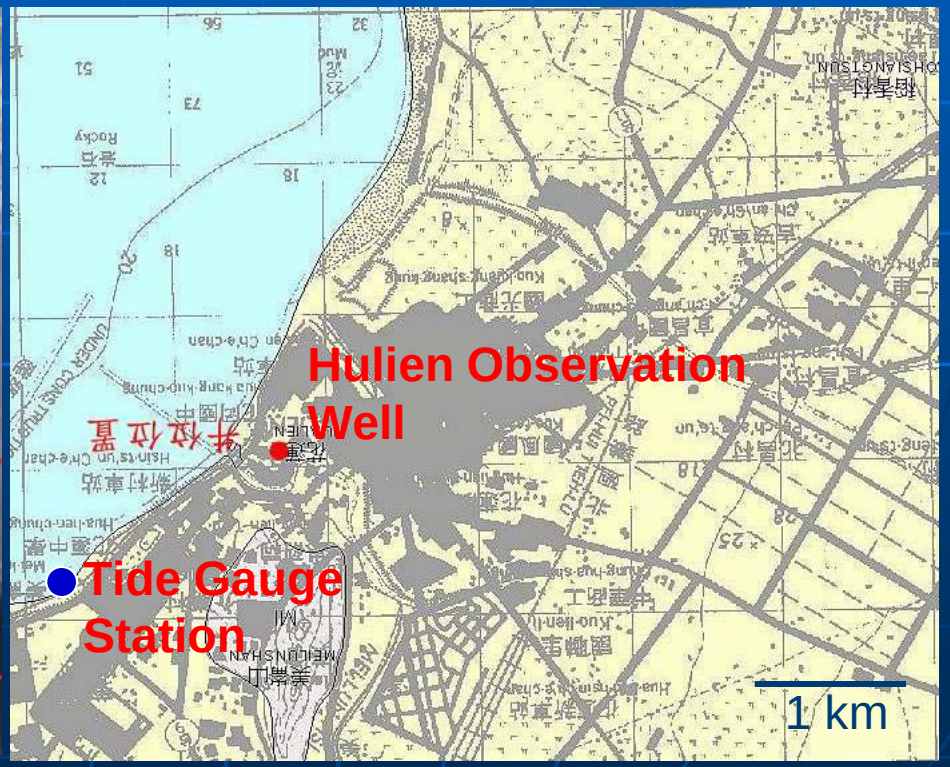



2004/10/15 Ilan Earthquake, M7.0

# II. Observation

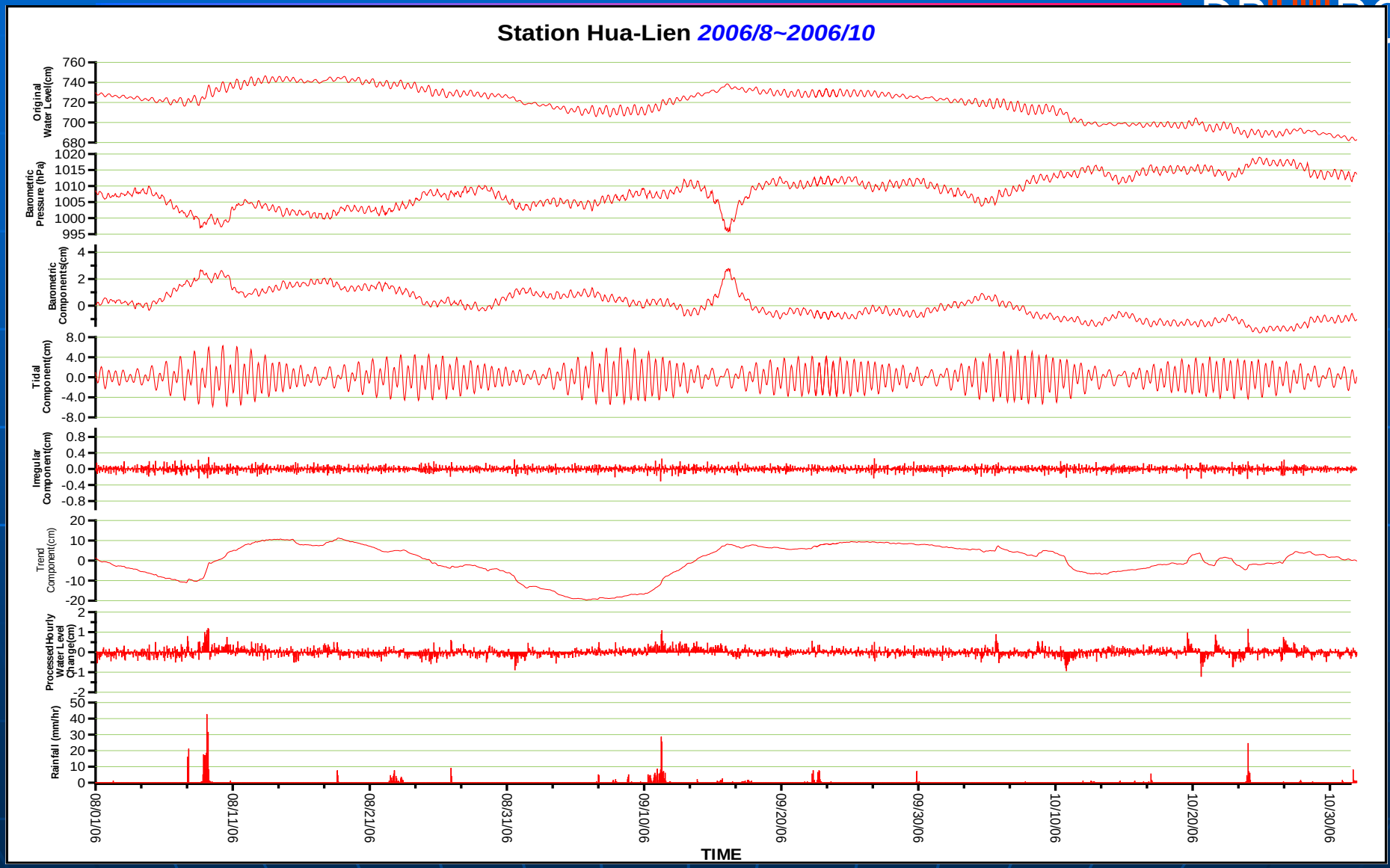
- Effected by ocean tide
- Located on Pleistocene ~ Quaternary Conglomerate, Situated inside the fault zones.



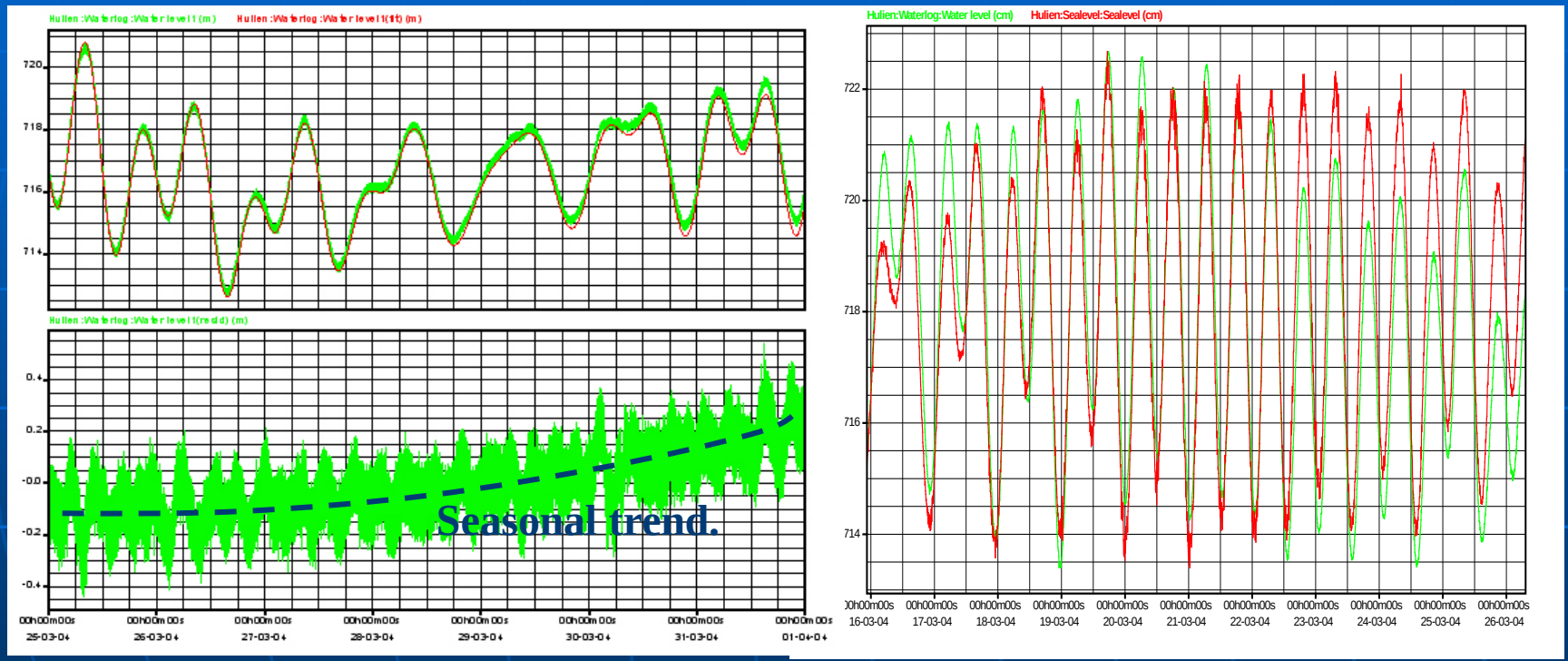




Location of Hulien observation well and tidal gauge station

# Typical Hydrograph of observation



# Comparison of Sea Level and Groundwater Level Observation

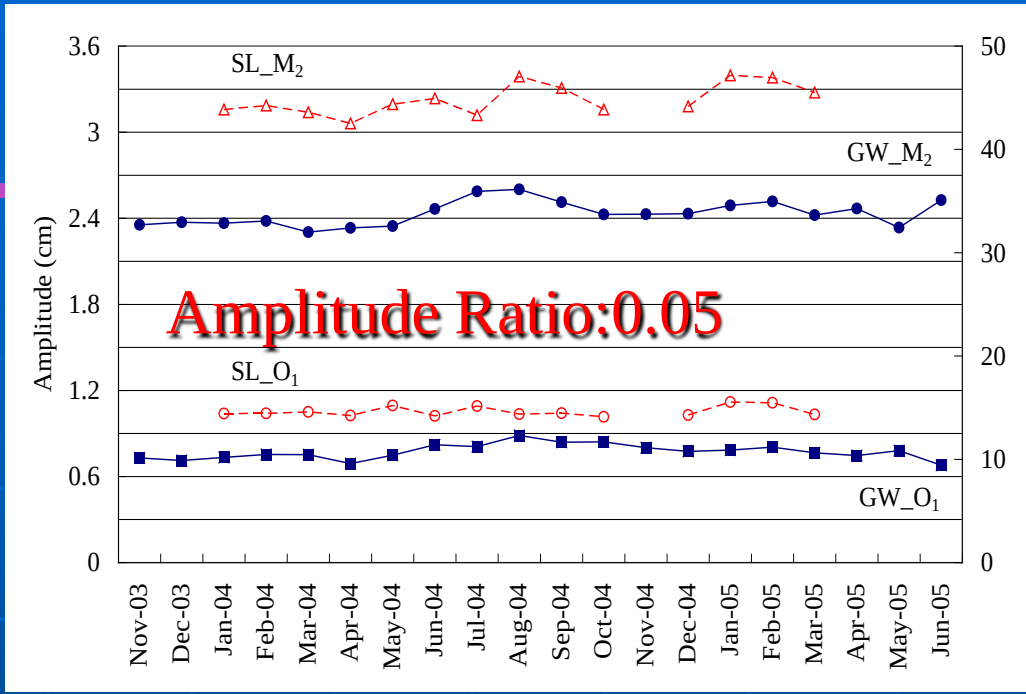


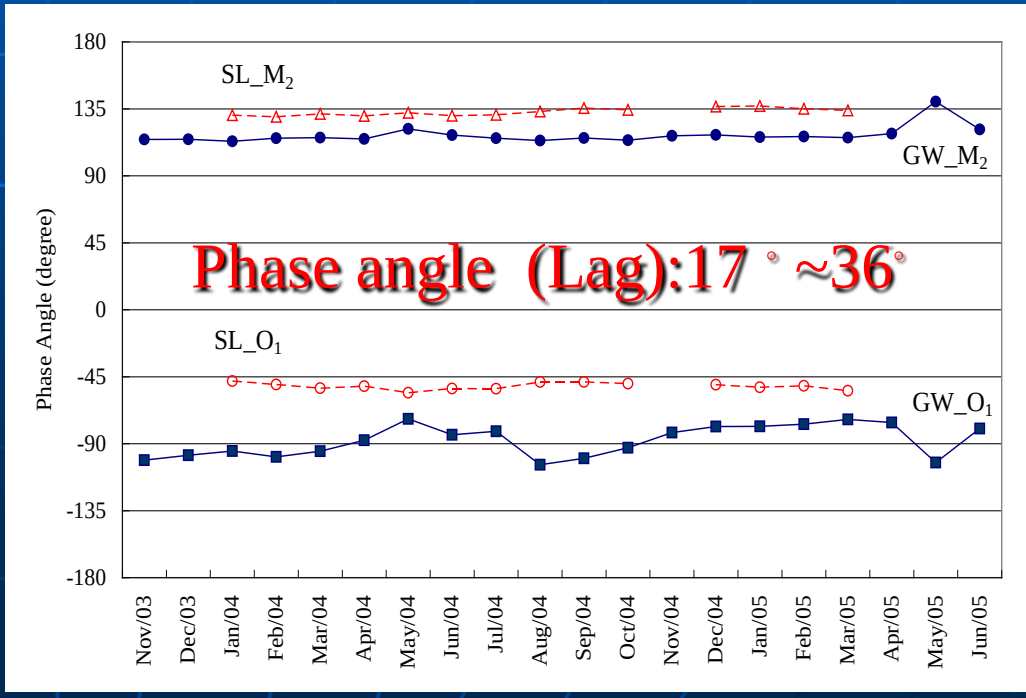

Red: sea level observation in Huilen Harbor (6 min)

Green: Groundwater level observation in Huilen Observation(2 min)

# Ocean Tidal Loading

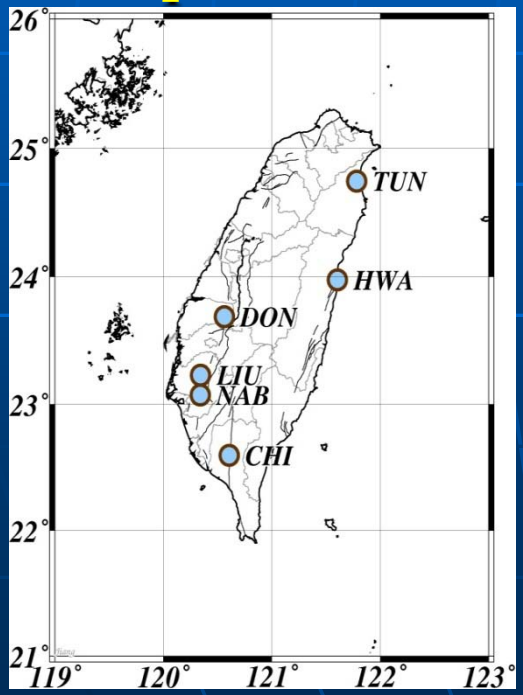
- The loading efficiency (amplitude ratio) is 0.05, time lag (phase angle difference) is 17 ° ~36 ° (8~10 min were stable for the whole period.
- The results support the "Predictable" groundwater level responses except to other non-seasonal factors.



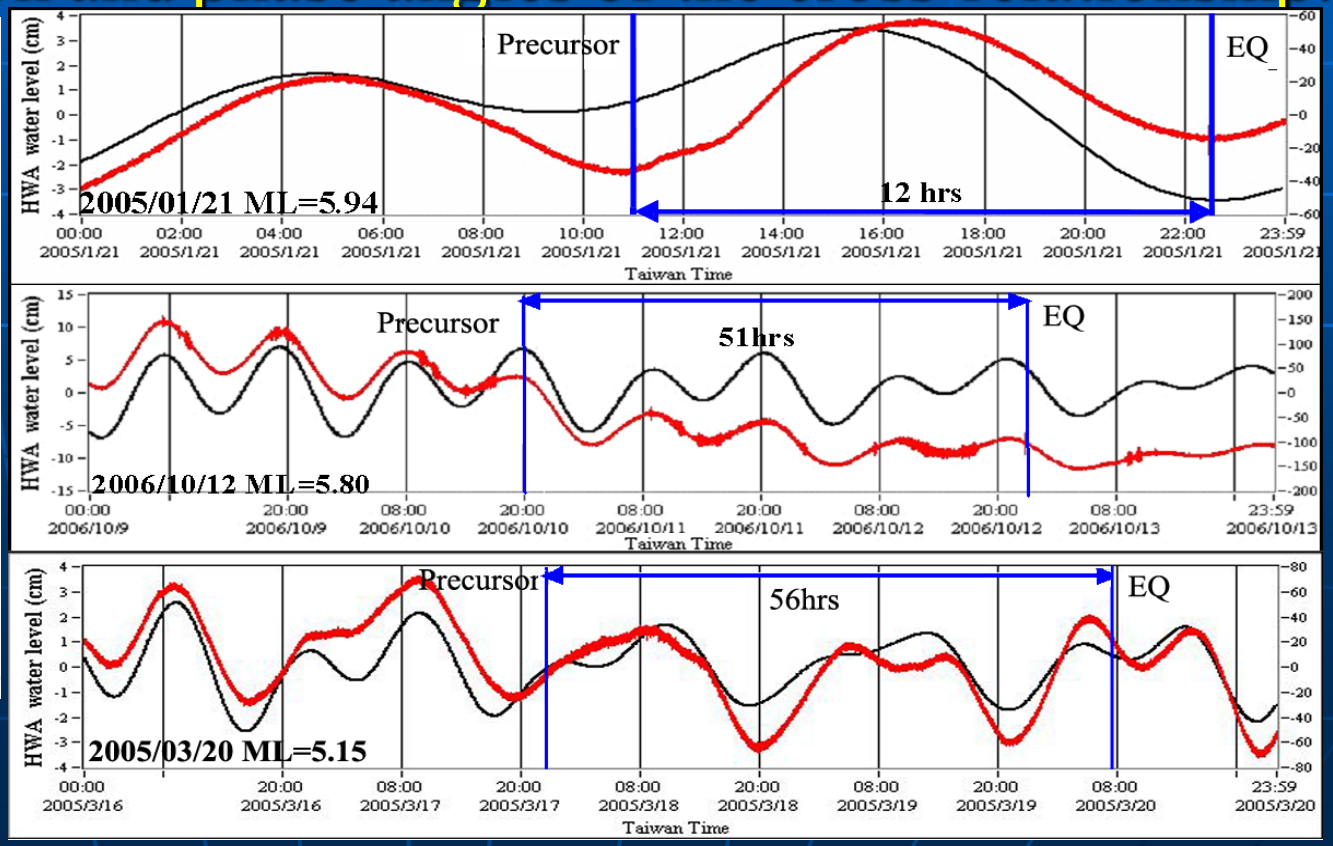



# III. Anomalies ( Tidal Deviation )

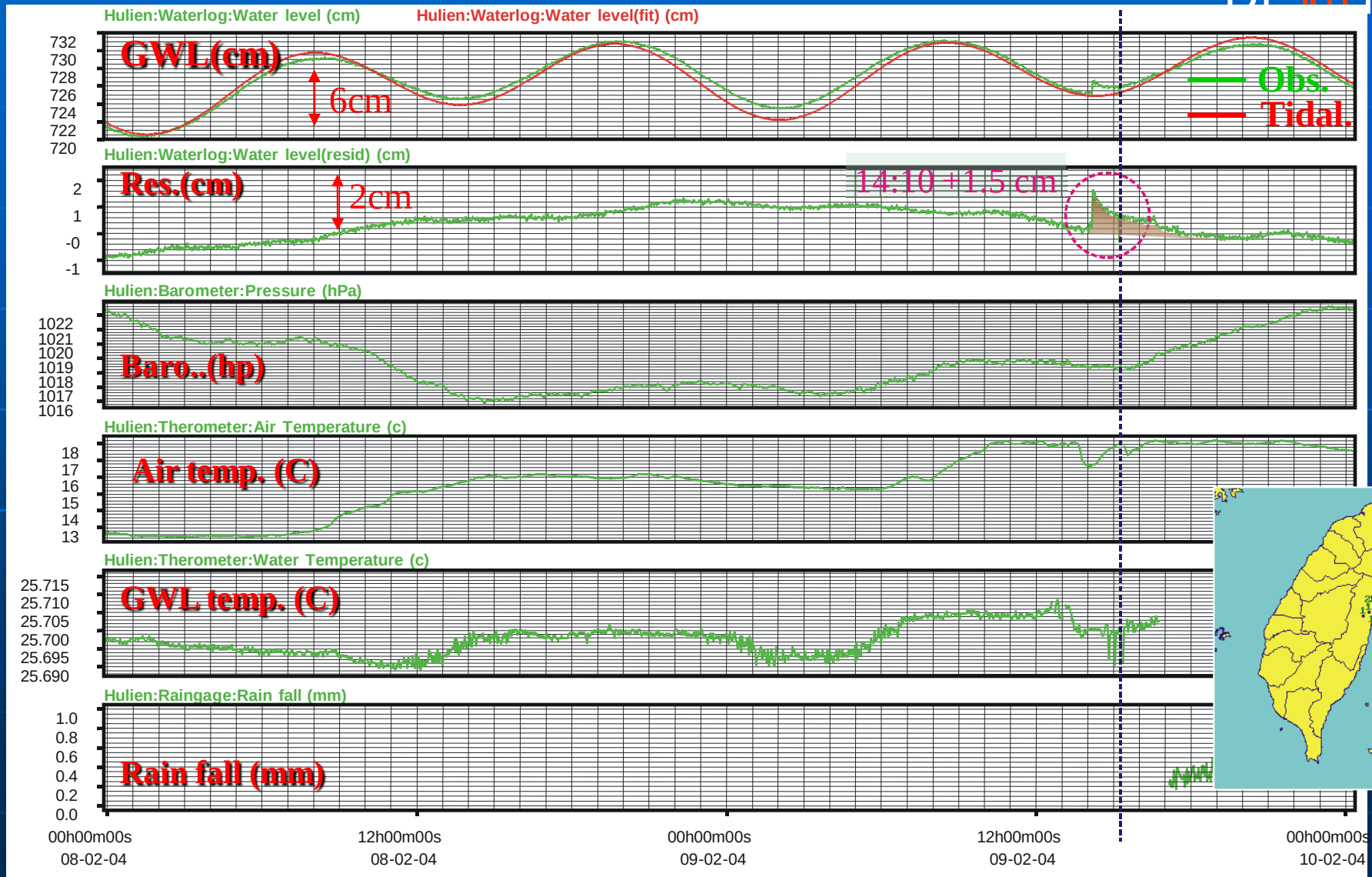
- The comparison between the S.L. / G.W.L. are base on the observation in Hulien.
- The anomalies detecting criteria had been defined by the amplitude ration and phase angles of the cross-relationship.



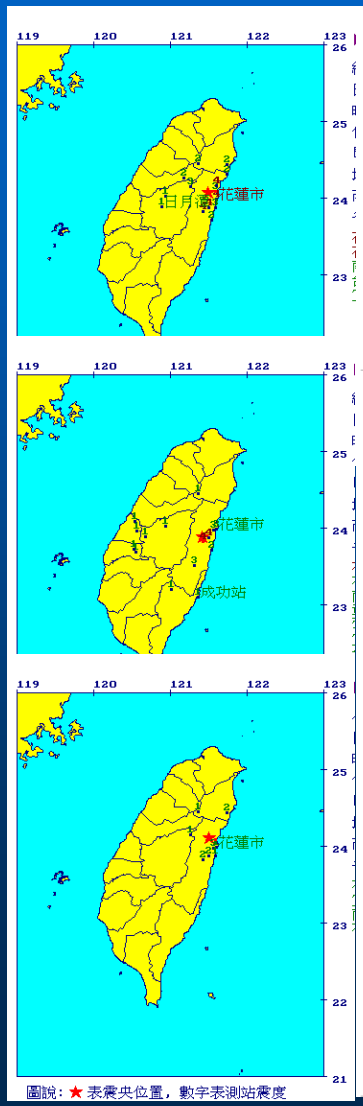

CWB Observation

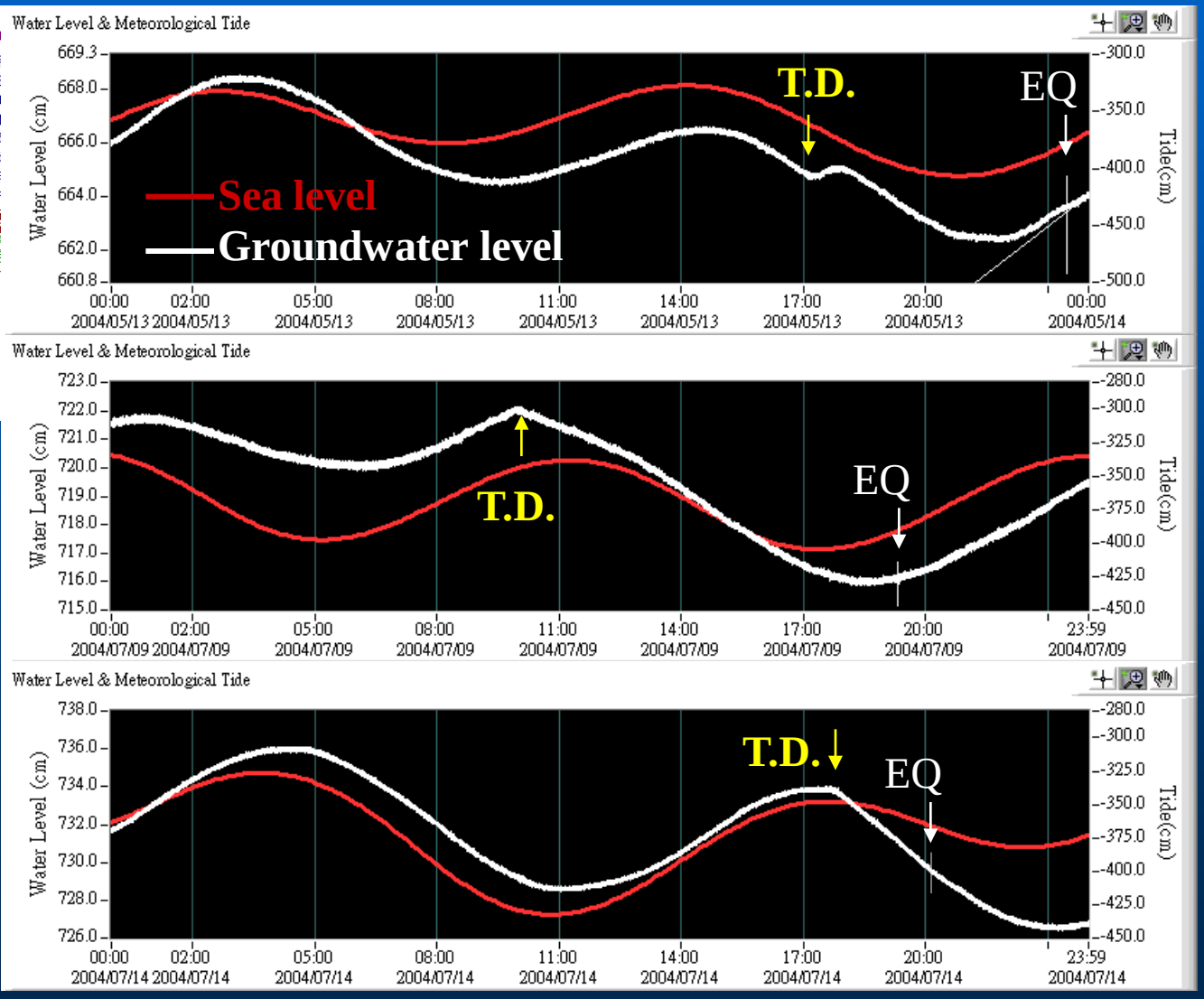


# Feb. 9 15:14, 2004, Hulien Earthquake, (M=4.3 Depth 27.6 Km)



| No. | Occ. Time | $M_L$ | Lon. | Lat. | Depth (km) | Distance (km) | Obs. Sta. | Intens. |
|---|---|---|---|---|---|---|---|---|
| 93053 | 2004/05/13 23:28:47 | 4.6 | 121.51 | 24.05 | 18.9 | 13.3 | HUL | 4 |
| 93069 | 2004/07/09 19:19:29 | 4.8 | 121.43 | 23.86 | 19.5 | 23.3 | HUL | 3 |
| - | 2004/07/14 20:04:30 | 4.1 | 121.52 | 24.09 | 21.1 | 15.7 | HUL | 1 |



# Seismic swarms in April ~ May, 2005

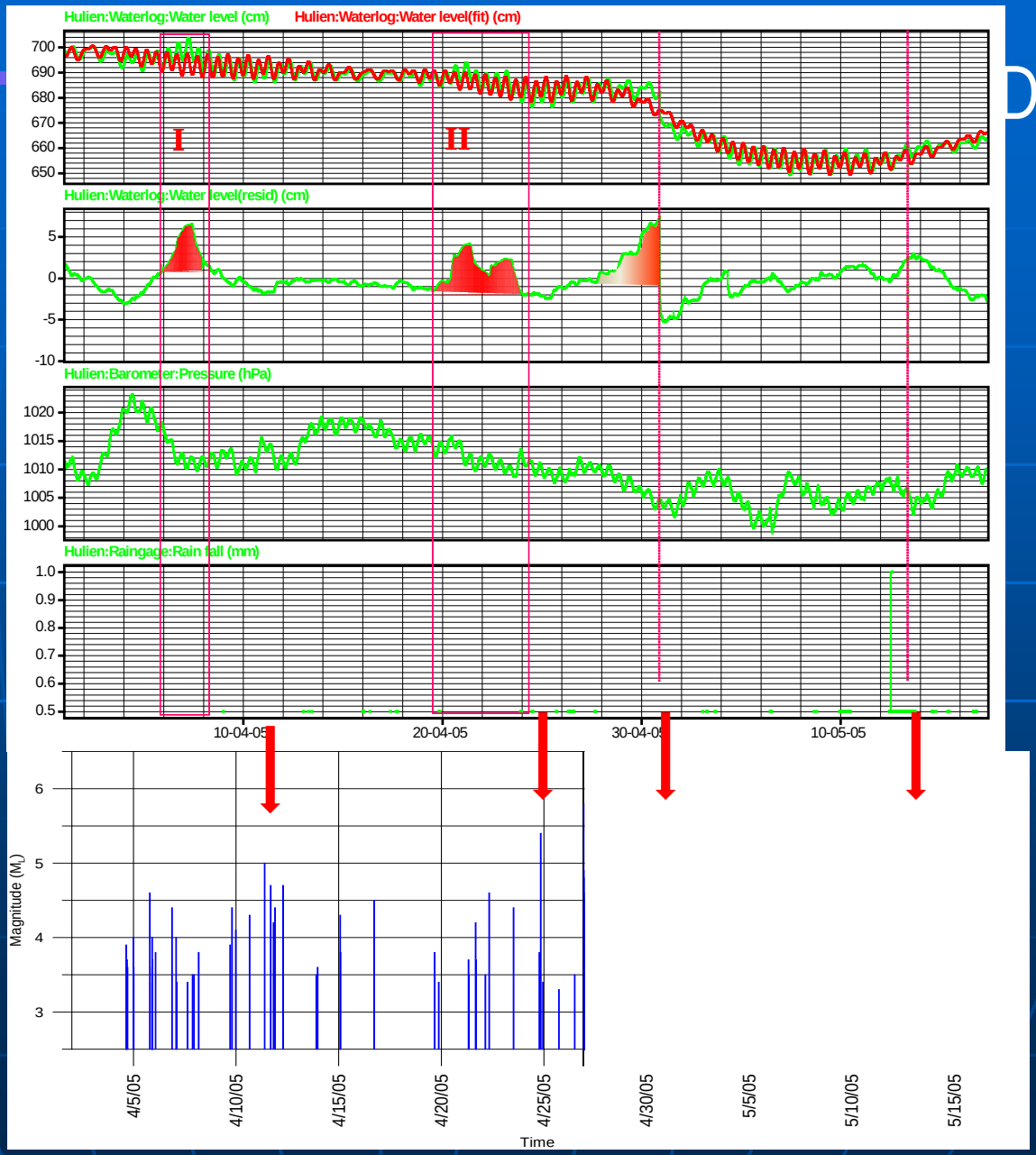
Orig. GW(Green)
Fitted GW(Red)

**Residual ( Orig-Fit )**
**( cm )**

**Barometric Pressure**
( hPa )

Rainfall
( mm )

Earthquake
($M_L$)



# 2005/4/5~4/8 Anomalies with Seismic swarm

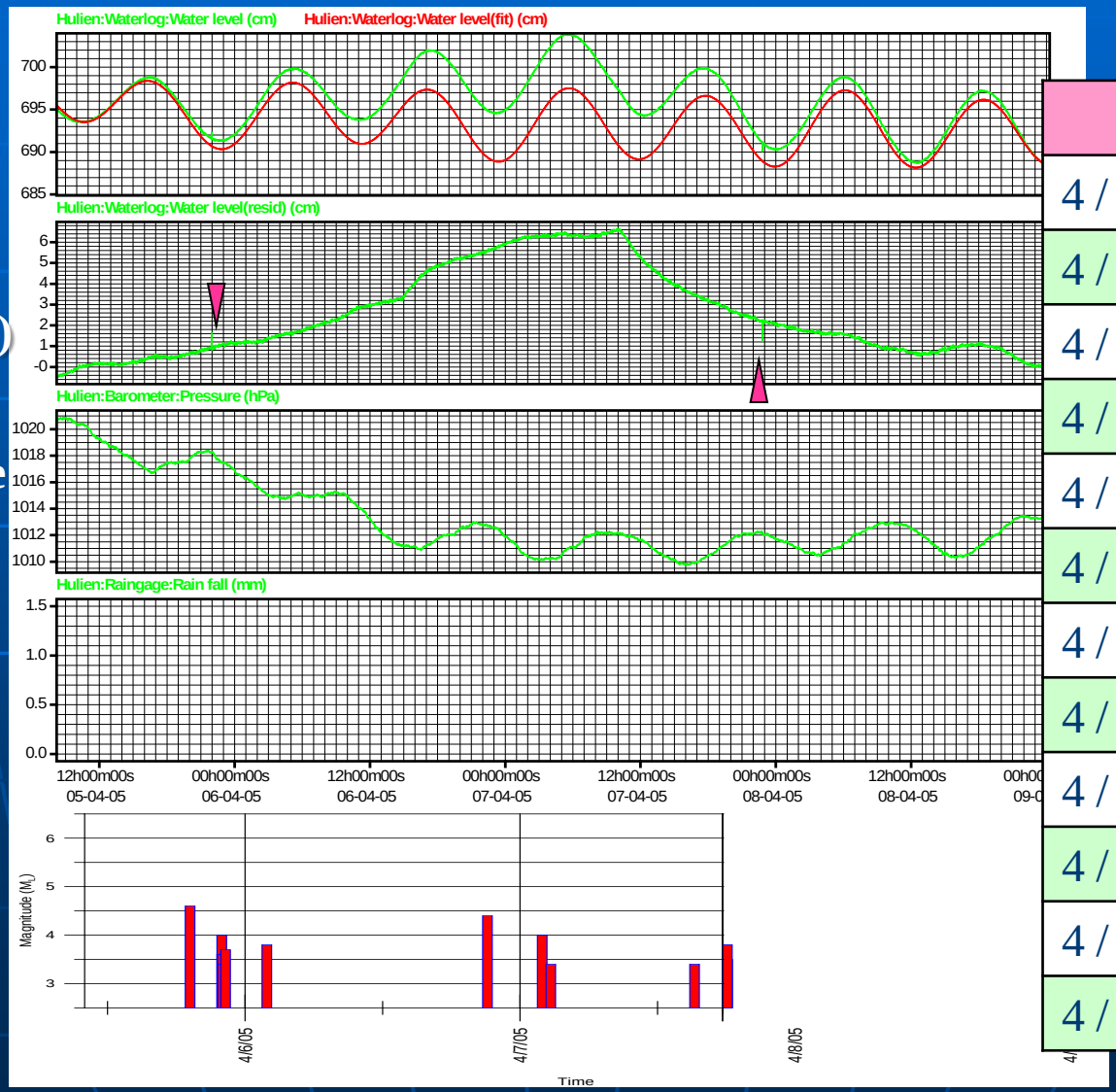
Orig. GW(Green)
Fitted GW(Red)

**Residual ( Orig-Fit )**
**( cm )**

**Barometric Pressure**
( hPa )

Rainfall
( mm )

Earthquake
($M_L$)




| Time | $M_L$ |
|---|---|
| 4 / 05 00 : 16 | 3.1 |
| 4 / 05 21 : 58 | 3.0 |
| 4 / 05 21 : 58 | 4.0 |
| 4 / 05 22 : 01 | 2.9 |
| 4 / 05 22 : 02 | 2.5 |
| 4 / 05 22 : 18 | 3.0 |
| 4 / 06 01 : 54 | 2.8 |
| 4 / 07 02 : 41 | 2.8 |
| 4 / 07 15 : 14 | 2.5 |
| 4 / 07 21 : 13 | 3.0 |
| 4 / 07 22 : 50 | 3.0 |
| 4 / 08 04 : 19 | 3.2 |

# 2005 /4/20 ~24 Anomalies with Seismic swarm

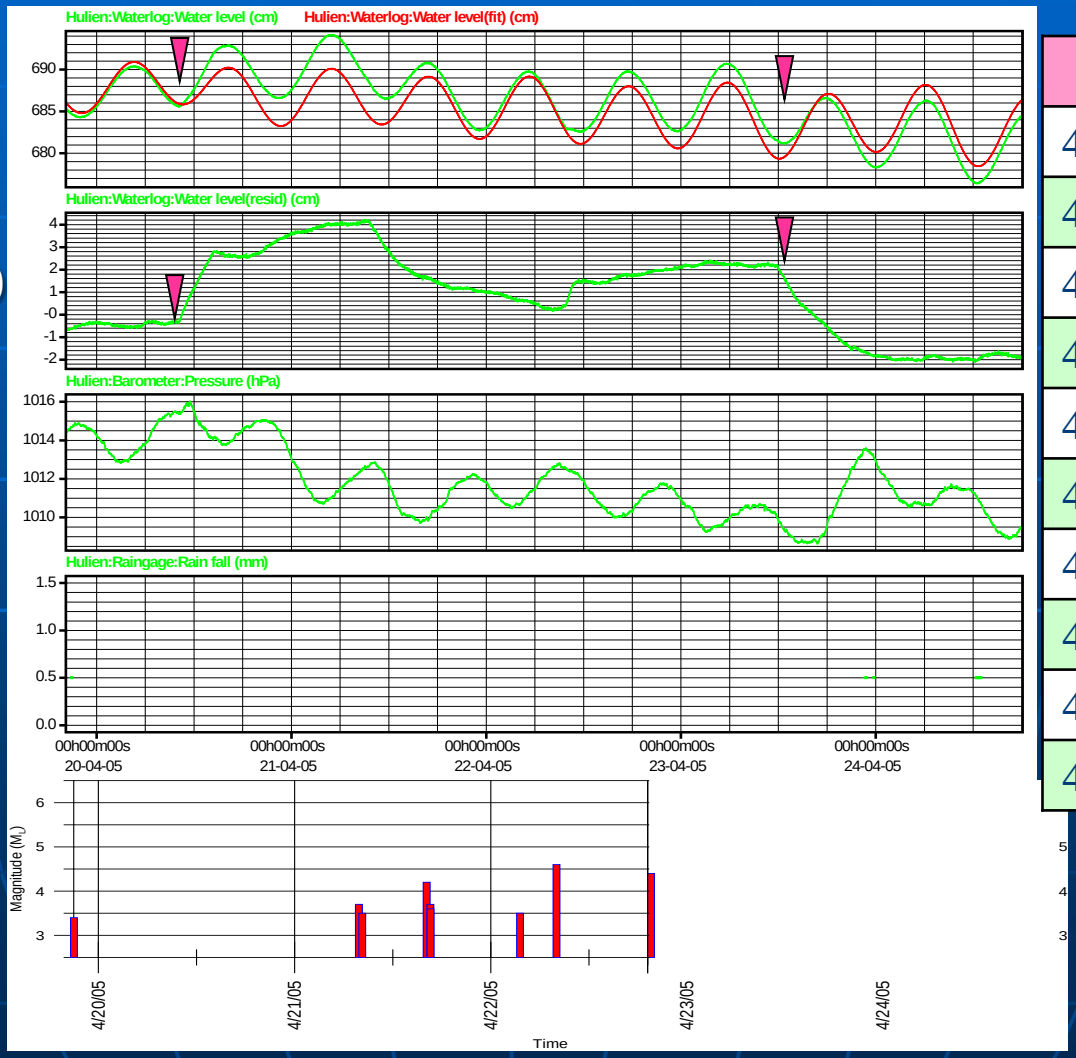
Orig. GW(Green)
Fitted GW(Red)

**Residual ( Orig-Fit )**
**( cm )**

**Barometric Pressure**
**( hPa )**

Rainfall
( mm )

Earthquake
($M_L$)




| Time | $M_L$ |
|---|---|
| 4 / 21 07 : 52 | 3.1 |
| 4 / 21 08 : 16 | 2.8 |
| 4 / 21 16 : 09 | 3.8 |
| 4 / 21 16 : 36 | 3.3 |
| 4 / 21 16 : 37 | 3.0 |
| 4 / 22 03 : 34 | 3.0 |
| 4 / 22 08 : 01 | 4.2 |
| 4 / 23 12 : 29 | 3.5 |
| 4 / 24 18 : 36 | 2.9 |
| 4 / 24 22 : 52 | 2.7 |

# IV. Verification

- Spatial Verification - Another Stations

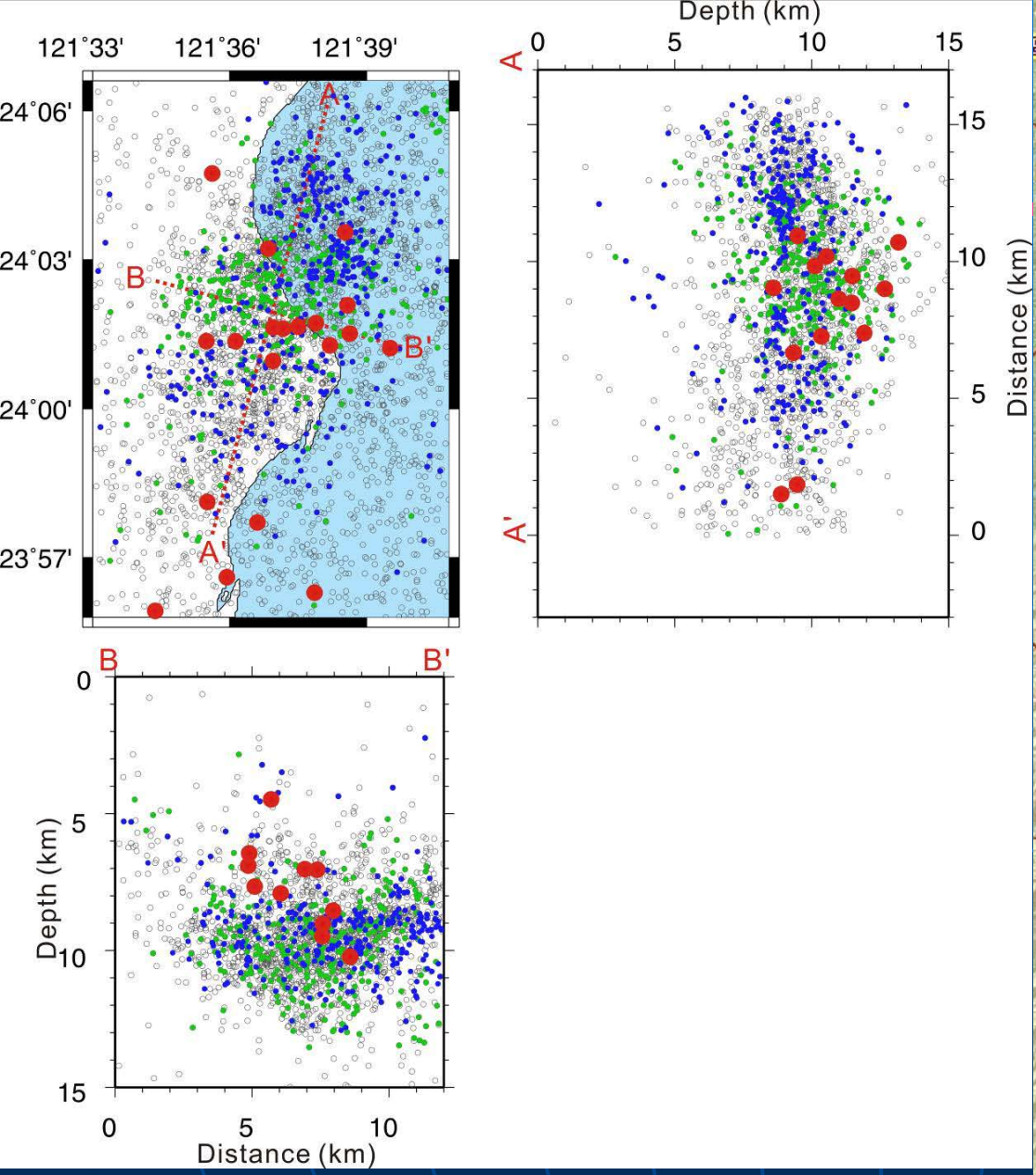
  we choose the other stations beside the HUL station with similar responses.

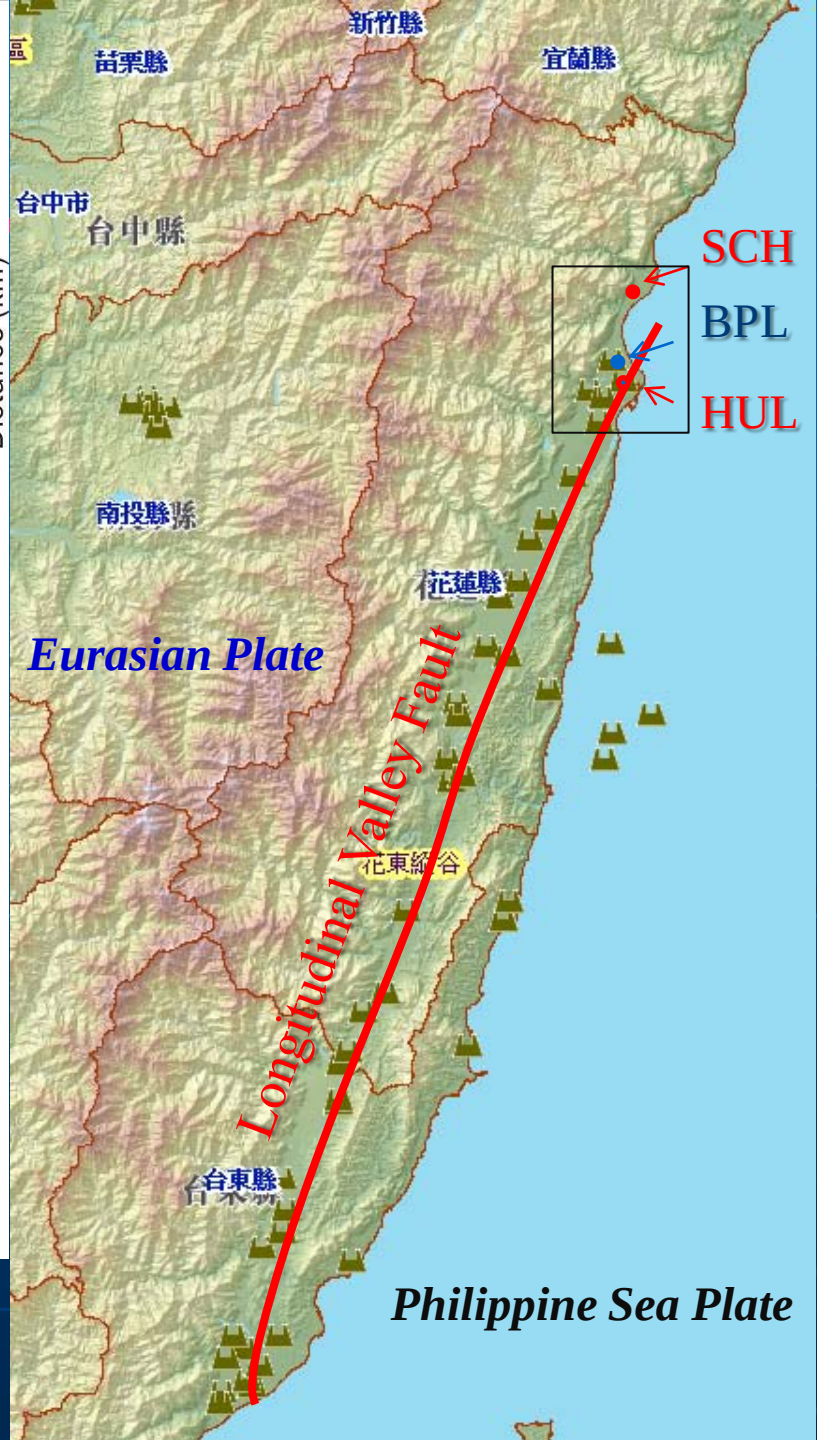
  *~ Sincheng station, Beipu station*

- Time Verification-Another event

  we choose the untested events of the HUL station to check the responses.

  *~ Seismic swarm of May ~ June, 2012*




**Precursory swarms of moderate-sized earthquakes in eastern Taiwan, Rau (2009)**

# Well Choosing

| 井名 | 康樂 | 豐田 | 豐里(1) | 豐里(2) | 復興 | 關山 | 月眉 | 瑞源 | 池上 | 慈濟(1) | 慈濟(2) | 大榮 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 井號 | 14010111 | 14010211 | 14010311 | 14010321 | 14010411 | 14030111 | 14030211 | 14050111 | 14060111 | 15010211 | 15010221 | 15020111 |
| 地下水分區 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 |
| 井別 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 |
| 設置日期 | 20071031 | 20071231 | 20071108 | 20071108 | 20071017 | 20071029 | 20071005 | 20071022 | 20071231 | 20071229 | 20071229 | 20071023 |
| 水位高(公尺) | 18.6 | | 8.9 | 8.7 | 4.6 | 1.4 | 19.2 | 27.8 | | 5.2 | 5.2 | |
| 距地面高(公尺) | | | | | | | | | | | | |
| 井頂高(公尺) | 29 | 59.5 | 15.8 | 15.8 | 6.4 | 223.6 | 208.6 | 184 | 287.8 | 24.5 | 24.4 | 93 |
| 井管口徑(英吋) | 6 | 6 | 6 | | | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 井深(公尺) | 100 | 110 | 60 | 130 | 54 | 40 | 40 | 90 | 110 | 94 | 176 | 93 |
| 完鑿日期 | 20071031 | 20071231 | 20071108 | 20071108 | 20071017 | 20071029 | 20071005 | 20071022 | 20071231 | 20071229 | 20071229 | 20071023 |
| 完鑿深度 | 100 | 110 | 130 | 130 | 54 | 40 | 40 | 90 | 150 | 176 | 176 | 93 |
| X座標 (TWD67) | 262134.6 | 258416 | 262508.9 | 262508.9 | 265665.5 | 266871.6 | 265274.2 | 265977.1 | 270150 | 309763.5 | 309763.5 | 297624.7 |
| Y座標 (TWD67) | 2517120 | 2519249 | 2515115 | 2515115 | 2516238 | 2549799 | 2545275 | 2539514 | 2557325 | 2654667 | 2654667 | 2627964 |

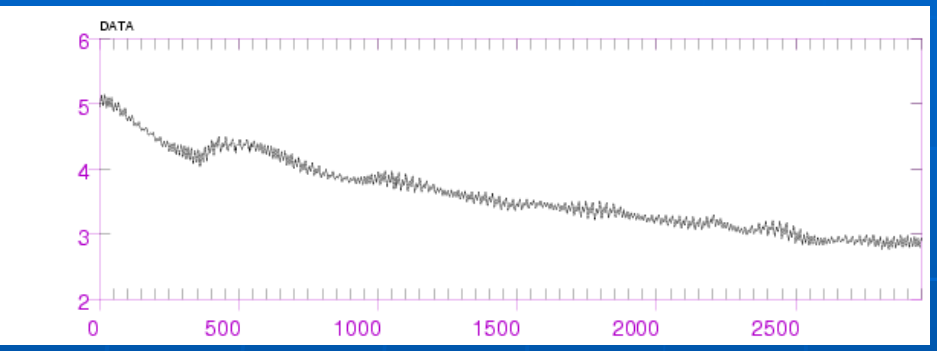
| 井名 | 長橋 | 中城 | 新城 | 北埔(1) | 北埔(2) | 南華 | 吳全(1) | 吳全(2) | 大富 | 瑞穗(1) | 瑞穗(2) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 井號 | 15020211 | 15030111 | 15040111 | 15040211 | 15040221 | 15050111 | 15060111 | 15060121 | 15070111 | 15090111 | 15090121 |
| 地下水分區 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 | 花東縱谷 |
| 井別 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 | 自計站 |
| 設置日期 | 20071116 | 20071202 | 20071014 | 20071016 | 20071016 | 20071229 | 20051107 | 20051107 | 20071103 | 20051024 | 20051024 |
| 水位高(公尺) | 14.4 | 2.9 | 13.4 | 9.1 | 9.1 | | 0 | 0 | 32.3 | 0 | 0 |
| 距地面高(公尺) | | | | | | | 0 | 0 | | 0 | 0 |
| 井頂高(公尺) | 141.8 | 131.7 | 17 | 17.5 | 17.4 | 72.5 | 25.1 | 25 | 182.6 | 102.7 | 102.7 |
| 井管口徑(英吋) | 6 | 6 | 6 | 6 | 6 | 4 | 6 | 6 | 6 | 6 | 0 |
| 井深(公尺) | 90 | 100 | 86 | 30 | 130 | 67 | 50 | 128 | 107 | 65 | 146 |
| 完鑿日期 | 20071116 | 20071202 | 20071014 | 20071016 | 20071016 | 20071229 | 20051107 | 20051107 | 20071103 | 20051024 | 20051024 |
| 完鑿深度 | 90 | 100 | 86 | 130 | 130 | 74 | 158 | 158 | 107 | 146 | 146 |
| X座標 (TWD67) | 292829 | 282369 | 316146.6 | 311645.1 | 311645.1 | 305738.7 | 304958.1 | 304958.2 | 289829.4 | 287511.4 | 287511.4 |
| Y座標 (TWD67) | 2622803 | 2580319 | 2669306 | 2658701 | 2658701 | 2649155 | 2642791 | 2642791 | 2611611 | 2599609 | 2599609 |

# Sincheng Station

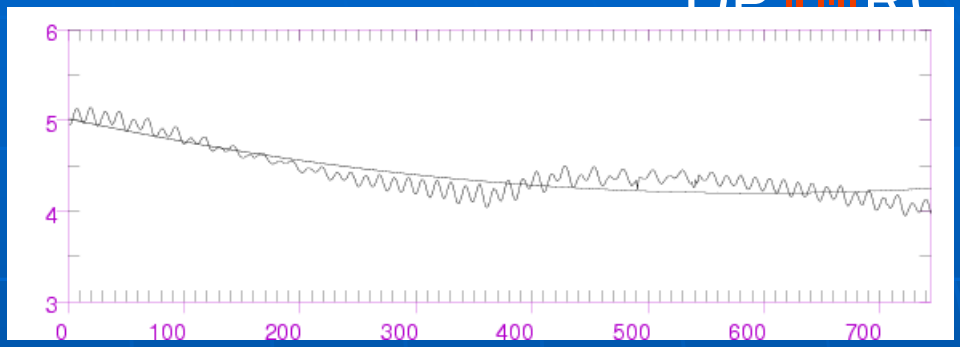
# Sincheng Station

# Background Analysis

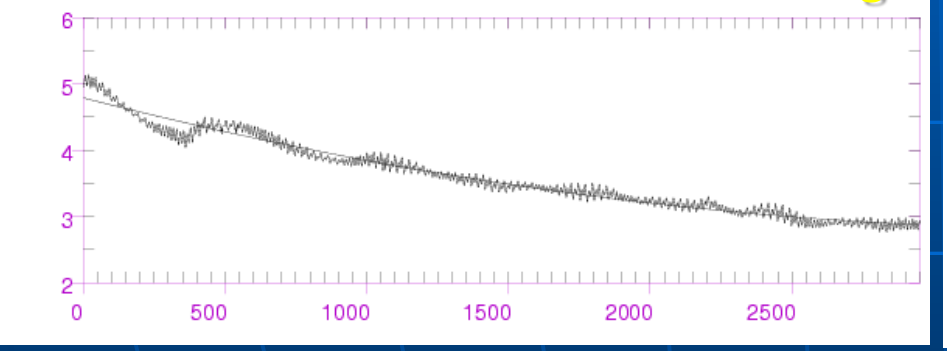
**2011/11/1 ~2012/5/31 Original**



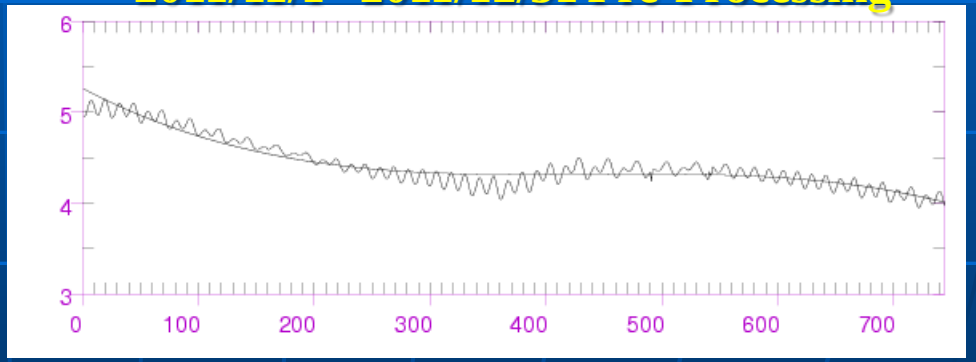

**2011/11/1 ~2011/12/31 Original**



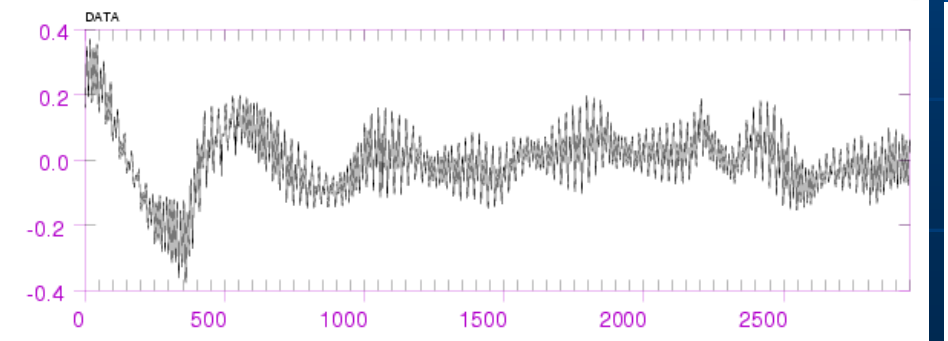

**2011/11/1 ~2012/5/31 Pre-Processing**



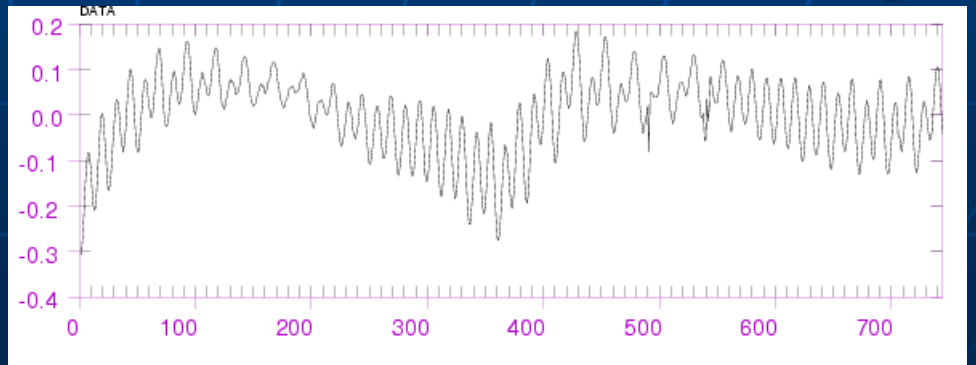

**2011/11/1 ~2011/12/31 Pre-Processing**




**2011/11/1 ~2012/5/31 Trend-removing**




**2011/11/1 ~2011/12/31 Trend-removing**

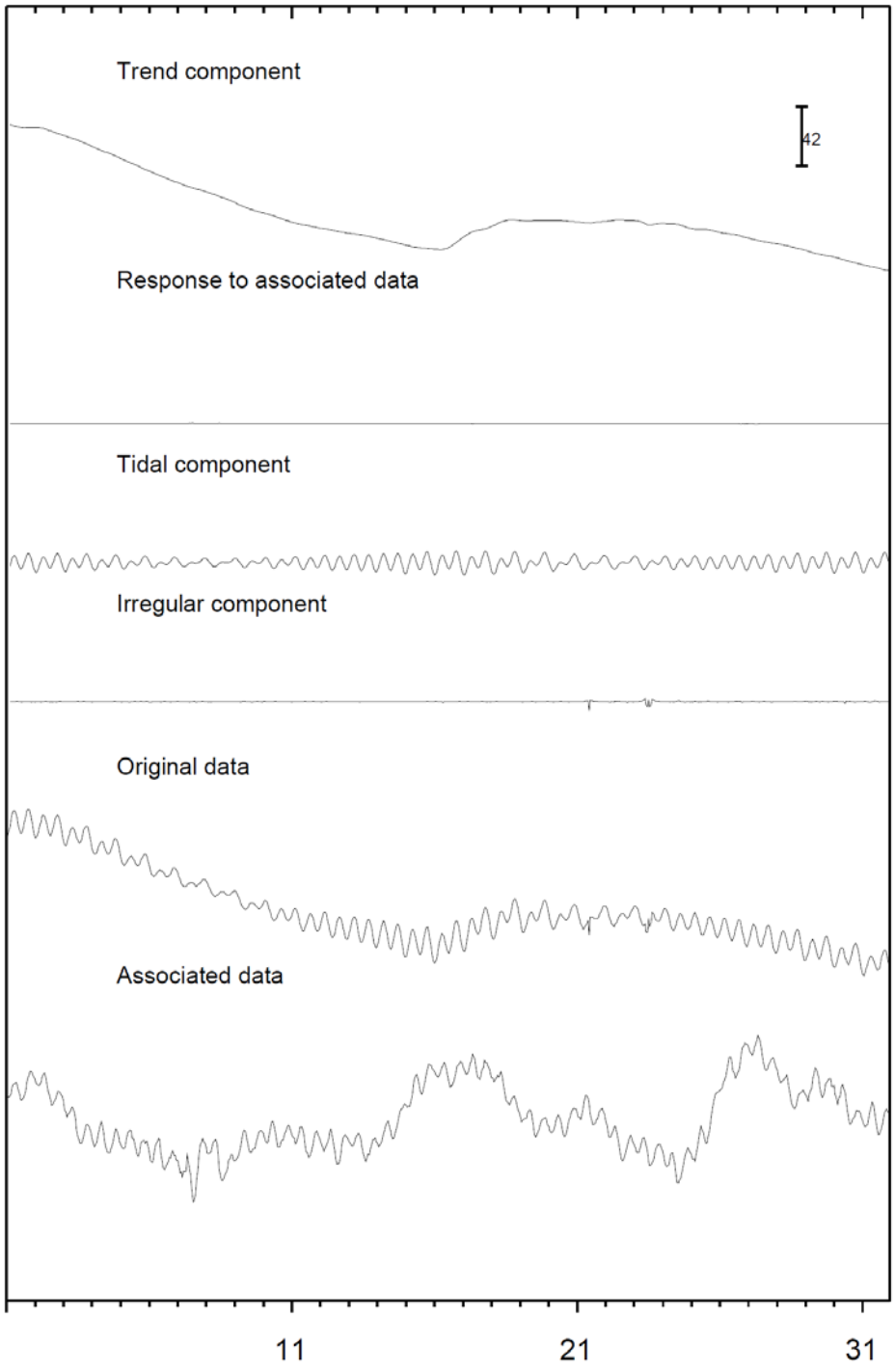


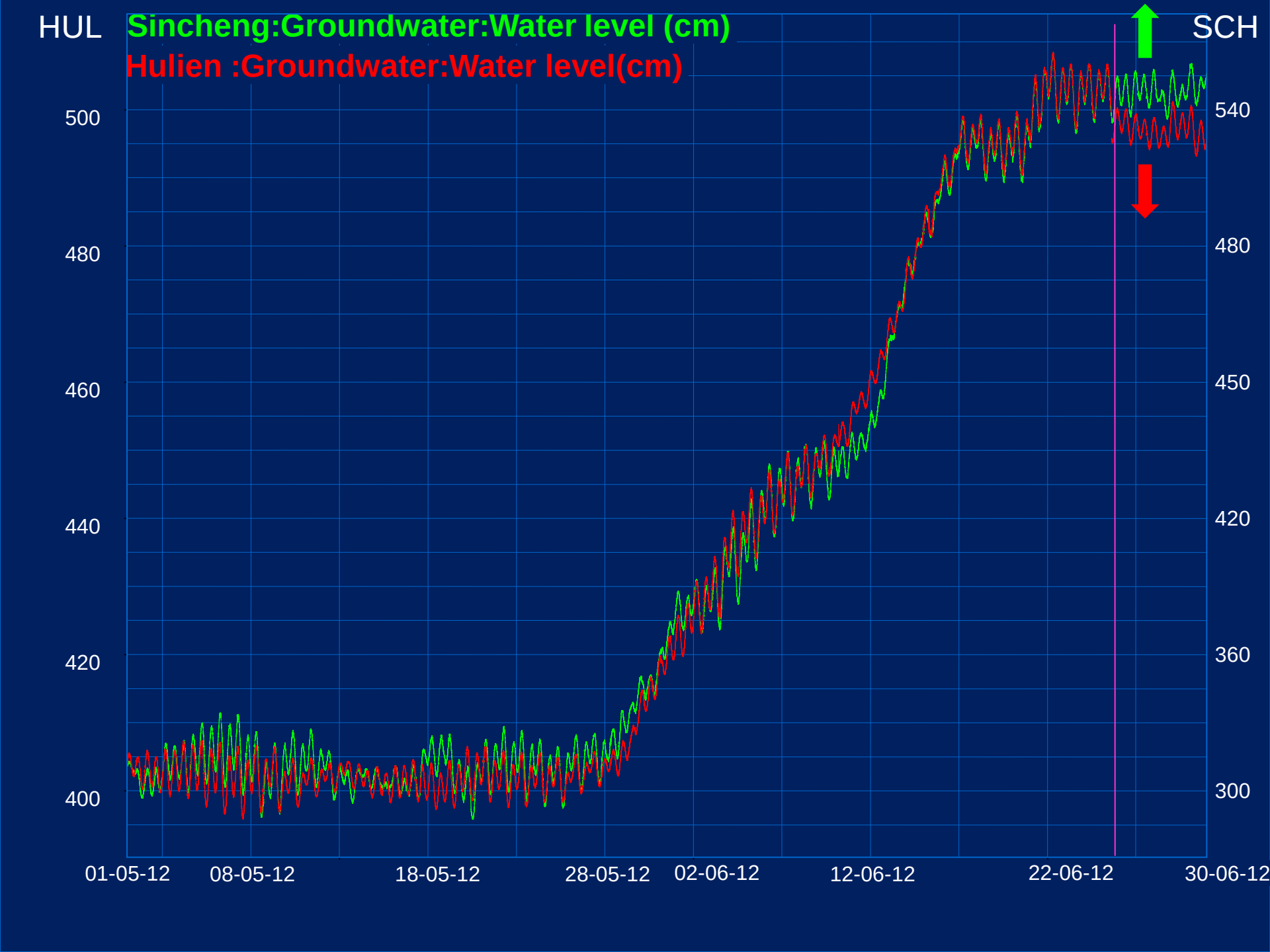
# Decomposition

- Clearly ocean tidal responses

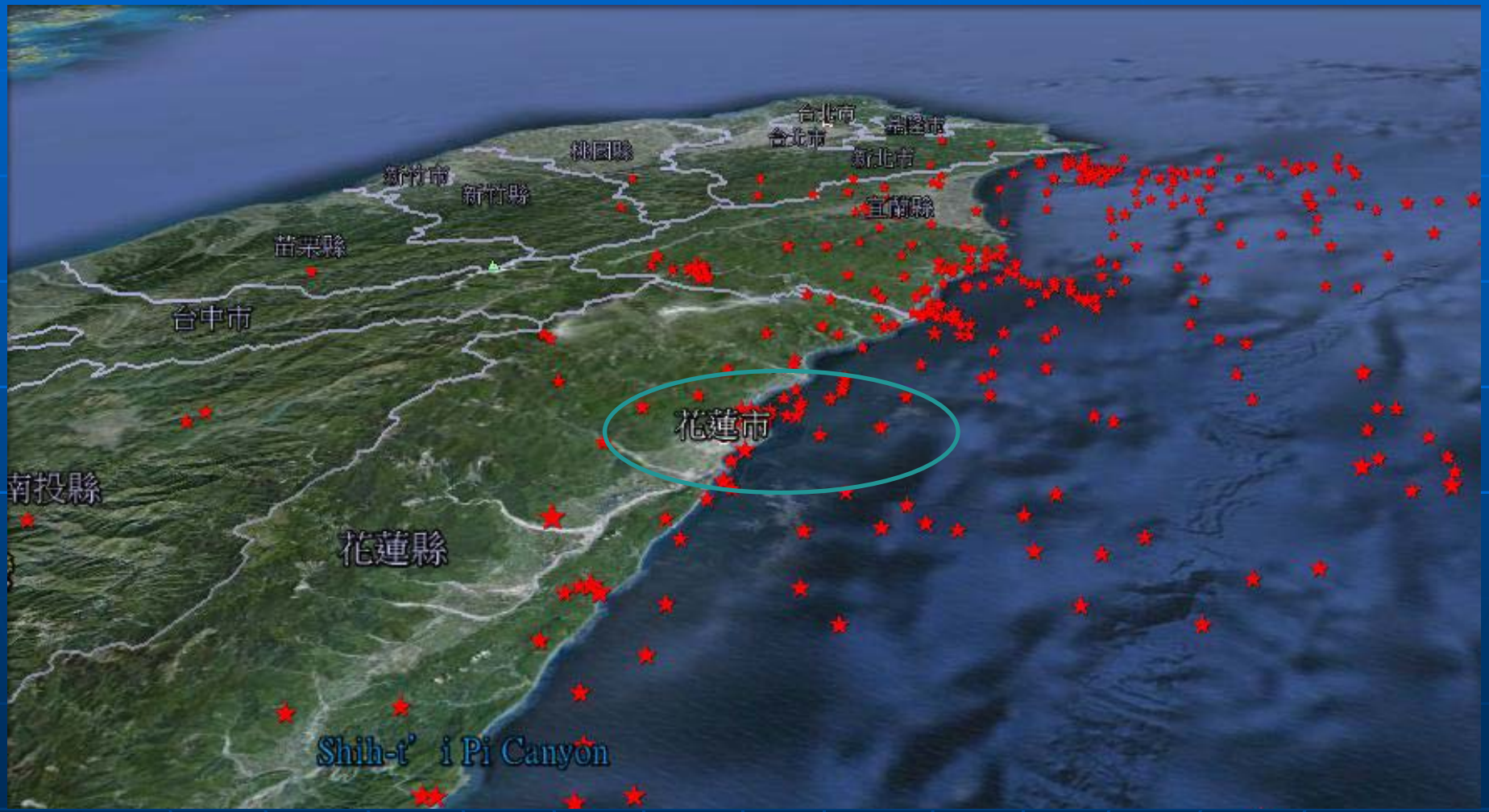
| GROUP | SYMBOL | FACTOR (RMSE) | PHASE (RMSE) (LOCAL, LAG:NEGATIVE) | AMPLITUDE (RMSE) |
|---|---|---|---|---|
| 1 | ( 1-143 : Q1 ) | 0.15034 ( 0.01553) | -7.620 ( 5.938) | 0.663 ( 0.069 ) |
| 2 | (144-201 : O1 ) | 0.10380 ( 0.00270) | -34.901 ( 1.494) | 2.392 ( 0.062 ) |
| 3 | (202-249 : M1 ) | 0.20844 ( 0.04569) | -26.308 ( 12.593) | 0.378 ( 0.083 ) |
| 4 | (250-305 : P1S1K1 ) | 0.06951 ( 0.00238) | -59.580 ( 2.136) | 2.252 ( 0.077 ) |
| 5 | (306-345 : J1 ) | 0.06575 ( 0.03142) | -132.026 ( 27.375) | 0.119 ( 0.057 ) |
| 6 | (346-450 : OO1 ) | 0.12590 ( 0.03658) | -45.727 ( 16.645) | 0.125 ( 0.036 ) |
| 7 | (451-549 : 2N2 ) | 0.14077 ( 0.02076) | 19.867 ( 8.439) | 0.223 ( 0.033 ) |
| 8 | (550-599 : N2 ) | 0.09193 ( 0.00353) | 8.306 ( 2.199) | 1.103 ( 0.042 ) |
| 9 | (600-655 : M2 ) | 0.10127 ( 0.00068) | 6.414 ( 0.389) | 6.344 ( 0.043 ) |
| 10 | (656-681 : L2 ) | 0.16283 ( 0.02518) | -7.115 ( 8.870) | 0.288 ( 0.045 ) |
| 11 | (682-827 : S2K2 ) | 0.09295 ( 0.00292) | -11.254 ( 1.831) | 2.709 ( 0.085 ) |
| 12 | (828-909 : M3 ) | 0.04942 ( 0.03447) | 122.029 ( 39.992) | 0.056 ( 0.039 ) |

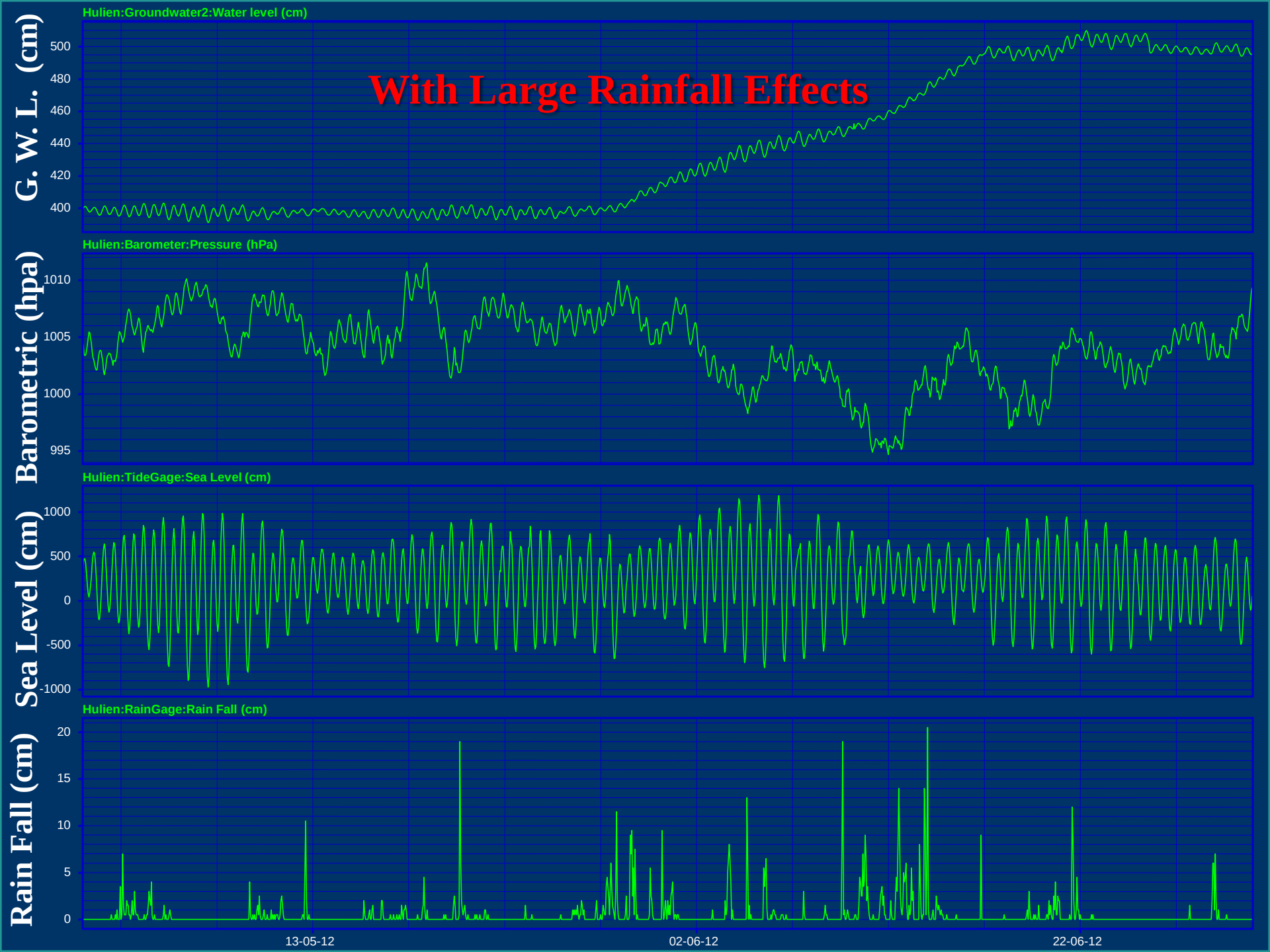
- The loading efficiency (amplitude ratio) is 0.18, time lag (phase angle difference) is 6 ° ~35 ° (1~10 min were stable for the whole period.



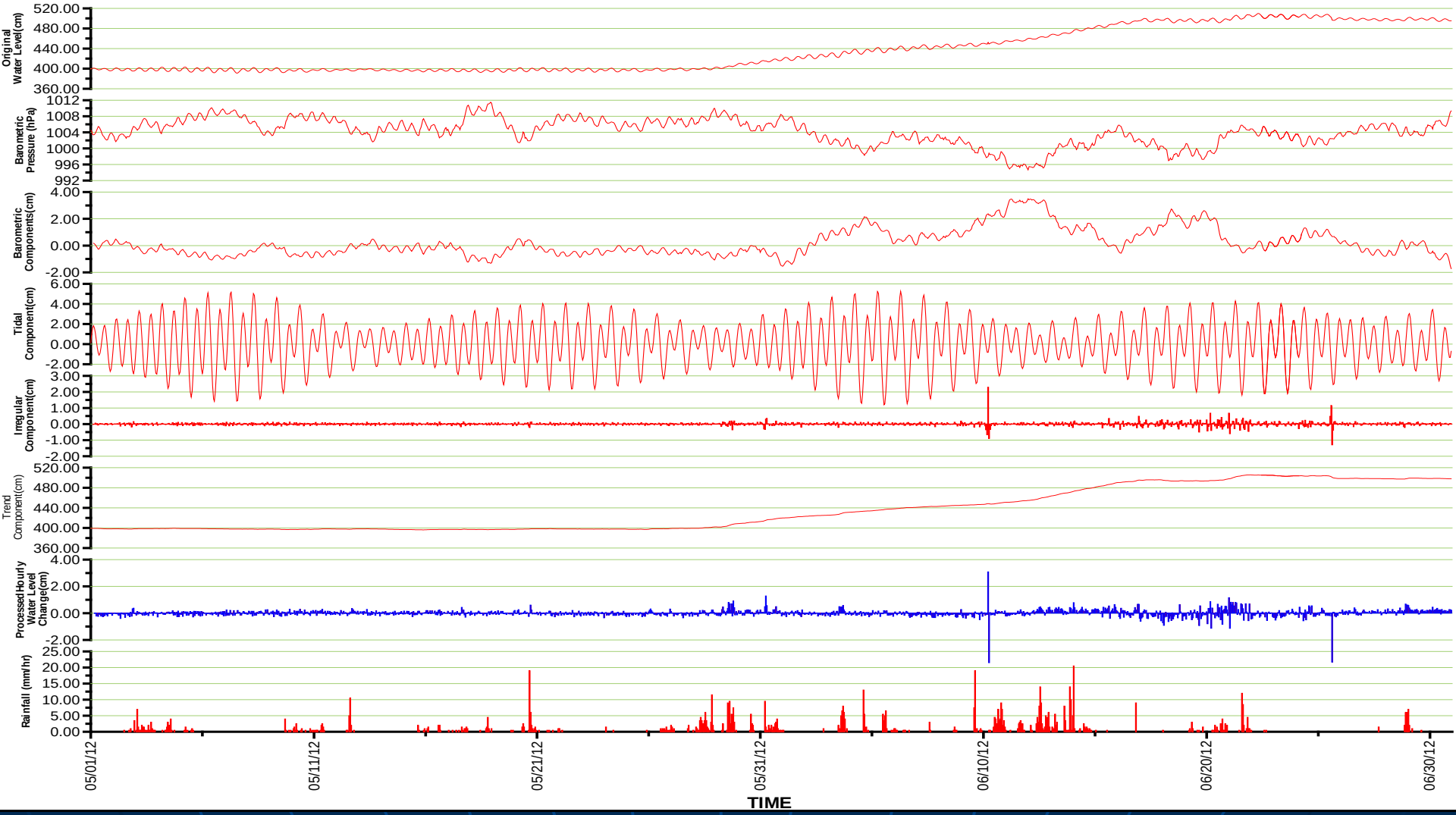

HUL
Sincheng:Groundwater:Water level (cm)
Hulien :Groundwater:Water level(cm)
SCH
500
480
460
440
420
400
540
480
450
420
360
300
01-05-12
08-05-12
18-05-12
28-05-12
02-06-12
12-06-12
22-06-12
30-06-12

# Seismic swarms in May ~ June, 2012

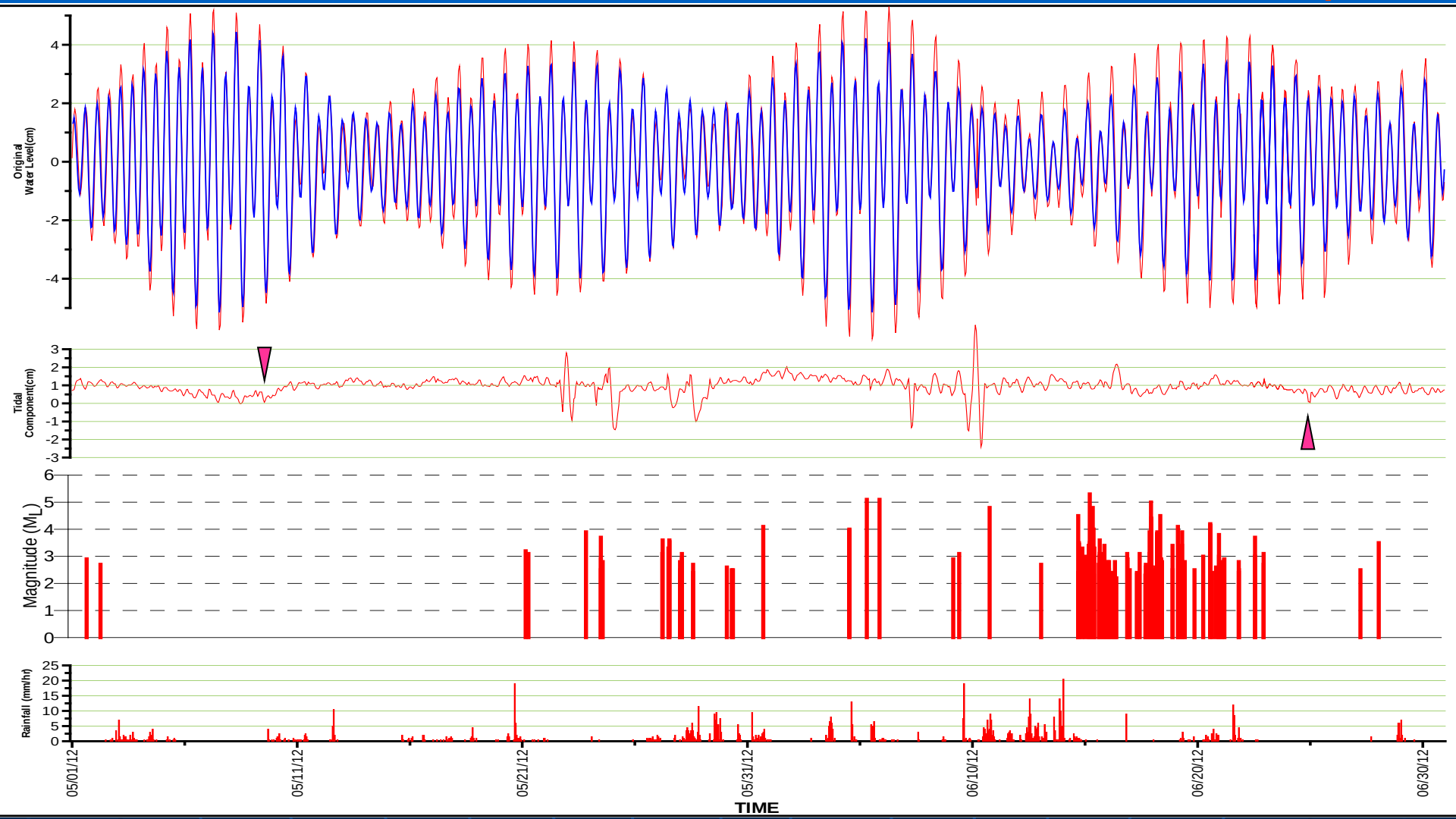



Hulien:Groundwater2:Water level (cm)
G. W. L. (cm)
500
480
460
440
420
400
With Large Rainfall Effects
Hulien:Barometer:Pressure (hPa)
Barometric (hpa)
1010
1005
1000
995
Hulien:TideGage:Sea Level (cm)
Sea Level (cm)
1000
500
0
-500
-1000
Hulien:RainGage:Rain Fall (cm)
Rain Fall (cm)
20
15
10
5
0
13-05-12
02-06-12
22-06-12

# Decomposition of the G.W.L.

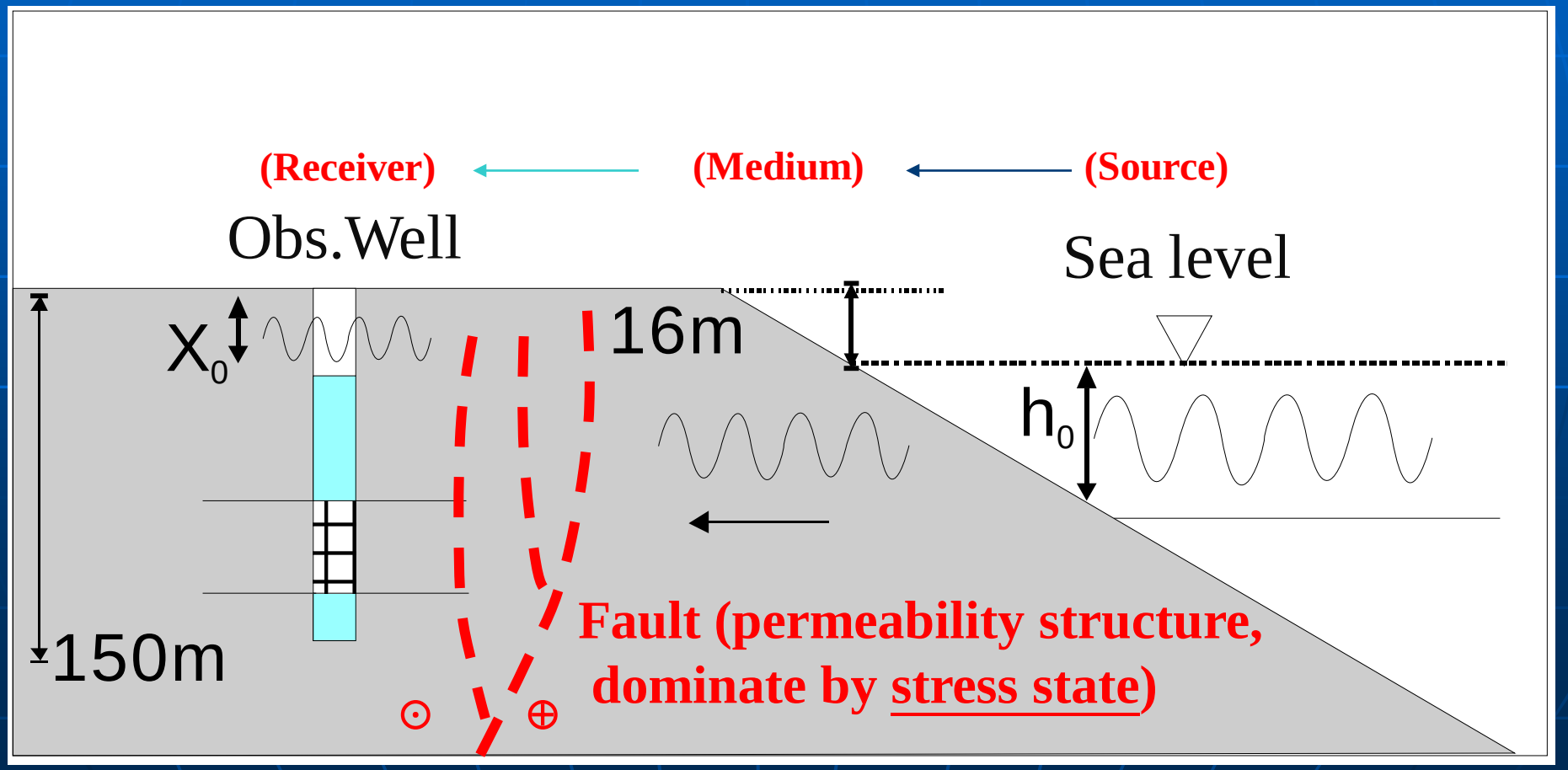


# Seismic swarms in May ~ June, 2012



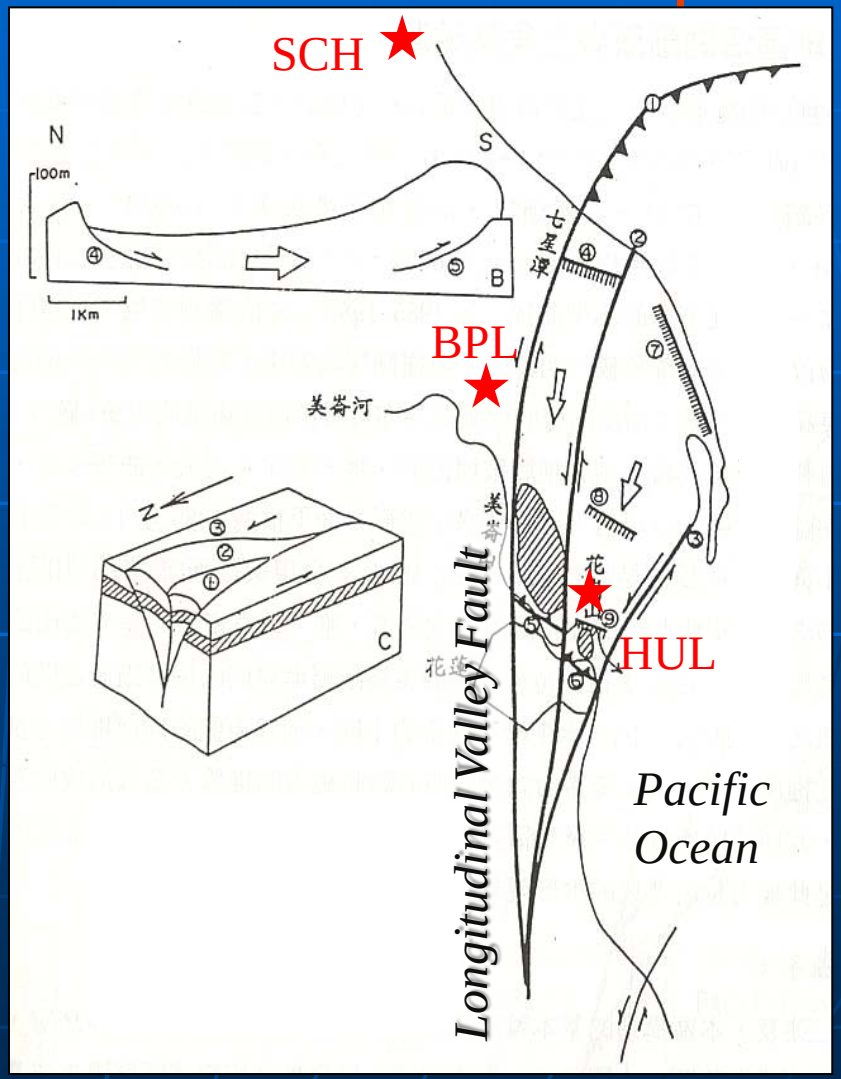
# V. Discussion: Possible Mechanism of Observation in Hulien Observation Well

- Wave Propagation Model (fault permeability structure)



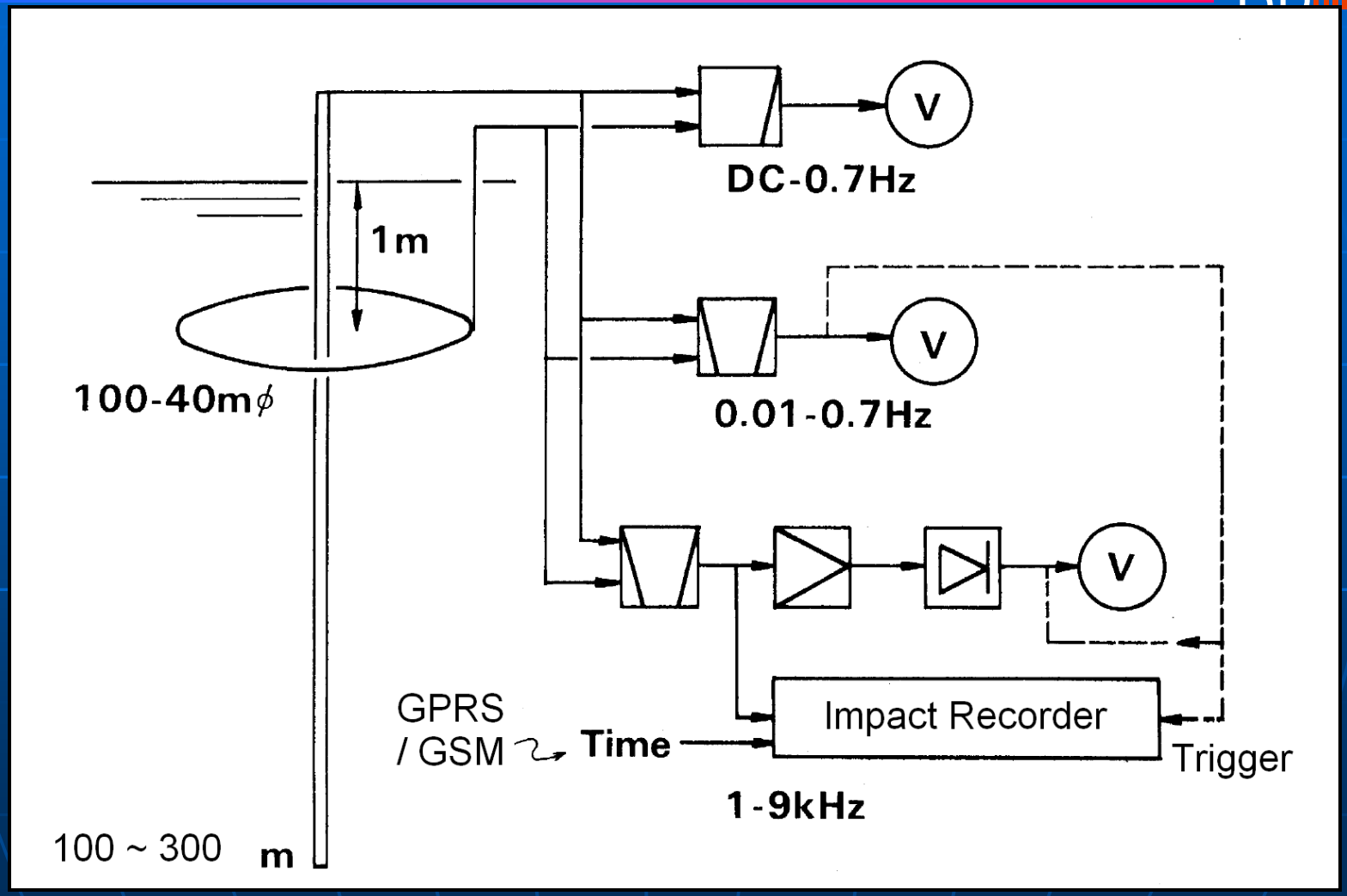
# Structural-Sensitive Zone

- Located inside the Longitudinal Valley Fault ( Plate Boundary Fault).
- Sustained highly stress – concentrated state ( 82mm/yr)
- Ocean tidal forces act as natural detecting sources apply to G.W.L. responses.
- The “predictable” responses to the non-structural disturbances to G.W.L. is the key factor.



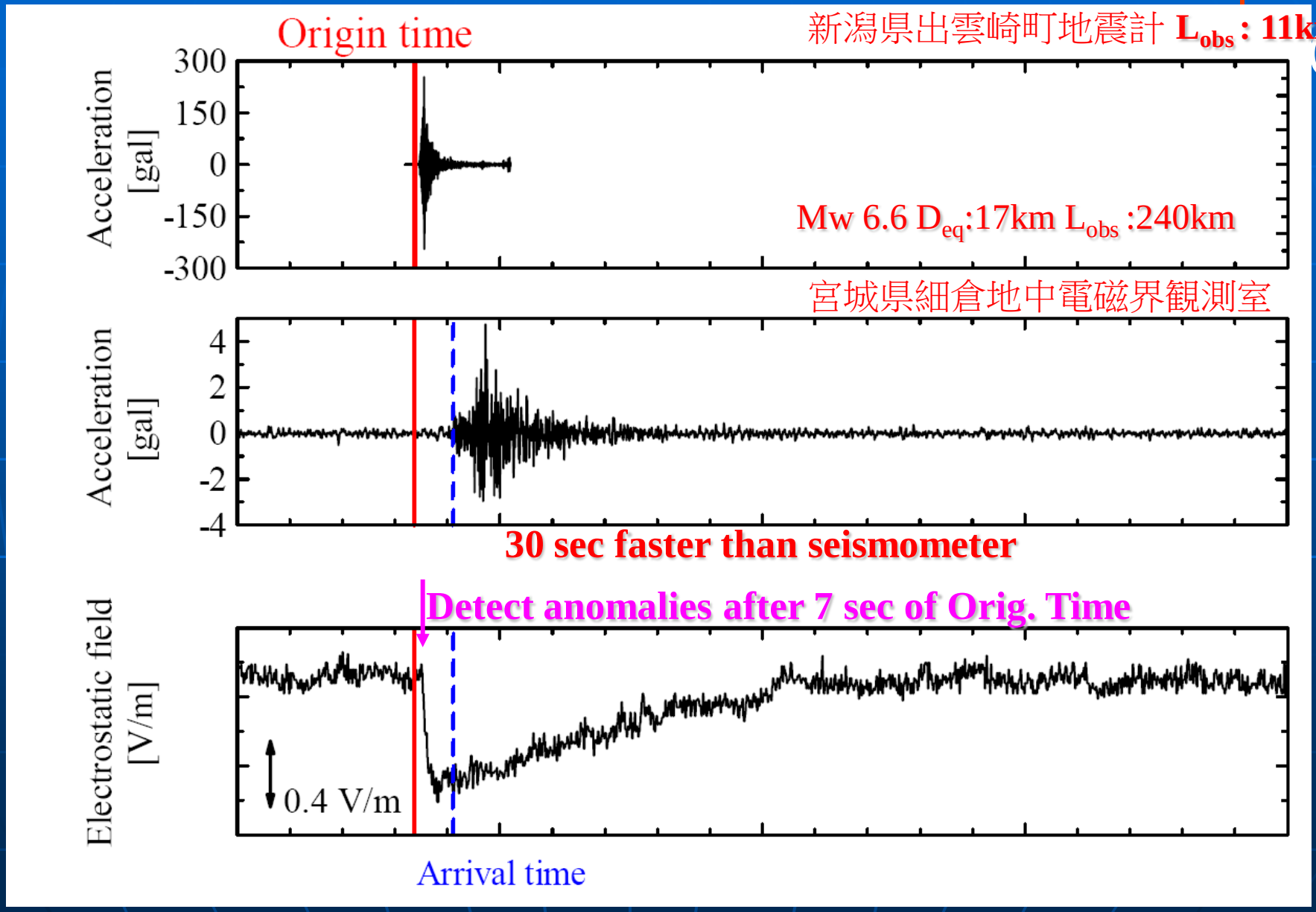

Modify from (Lin, 1994)

# Research on going：Deep Flow Detection




Detection device of the underground electric field anomalies
(Fujinawa and Takahashi, 1994)

# Example: Niigata Chuetsu-oki Earthquake, 2007/7/16



# Waveform（DC）

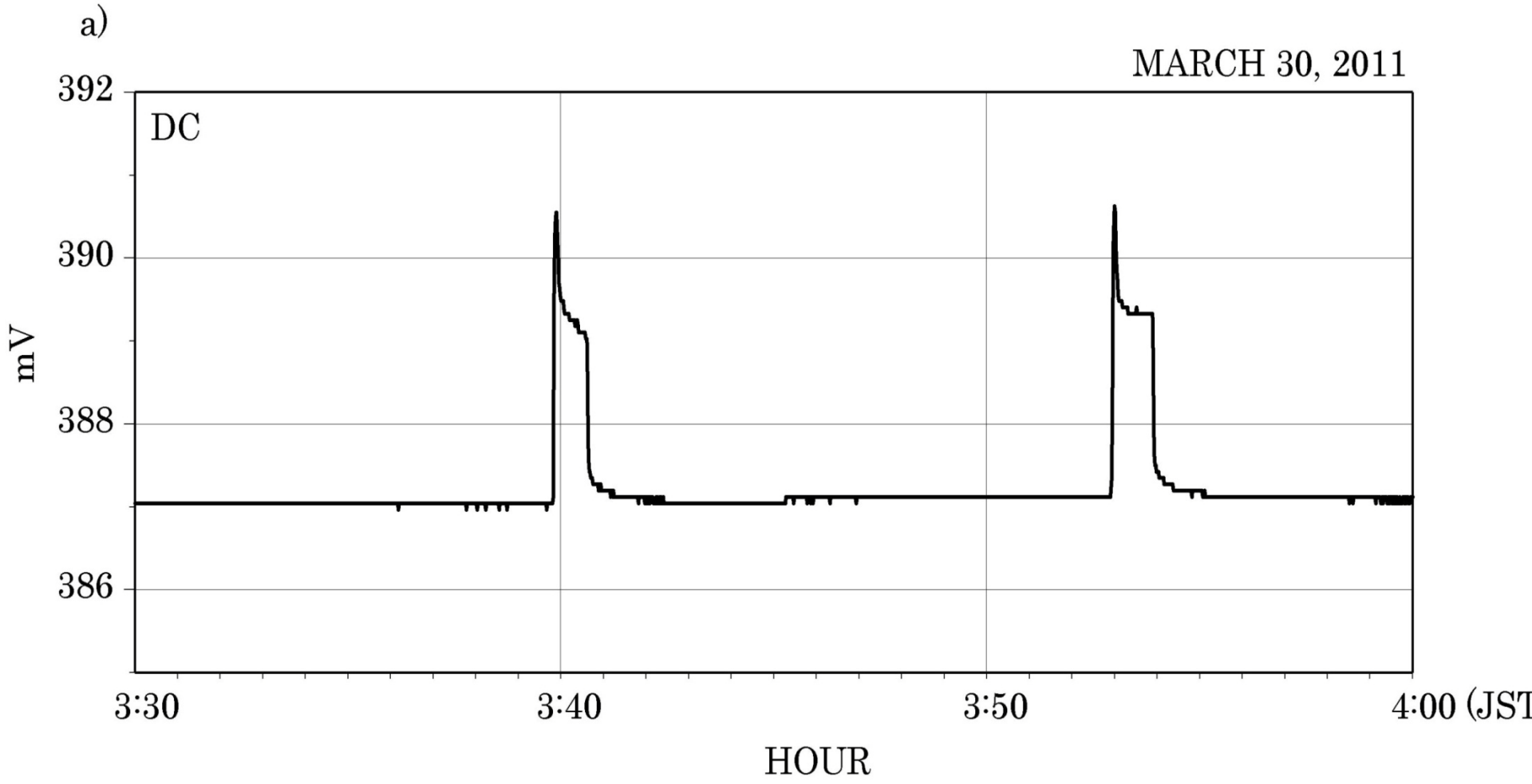
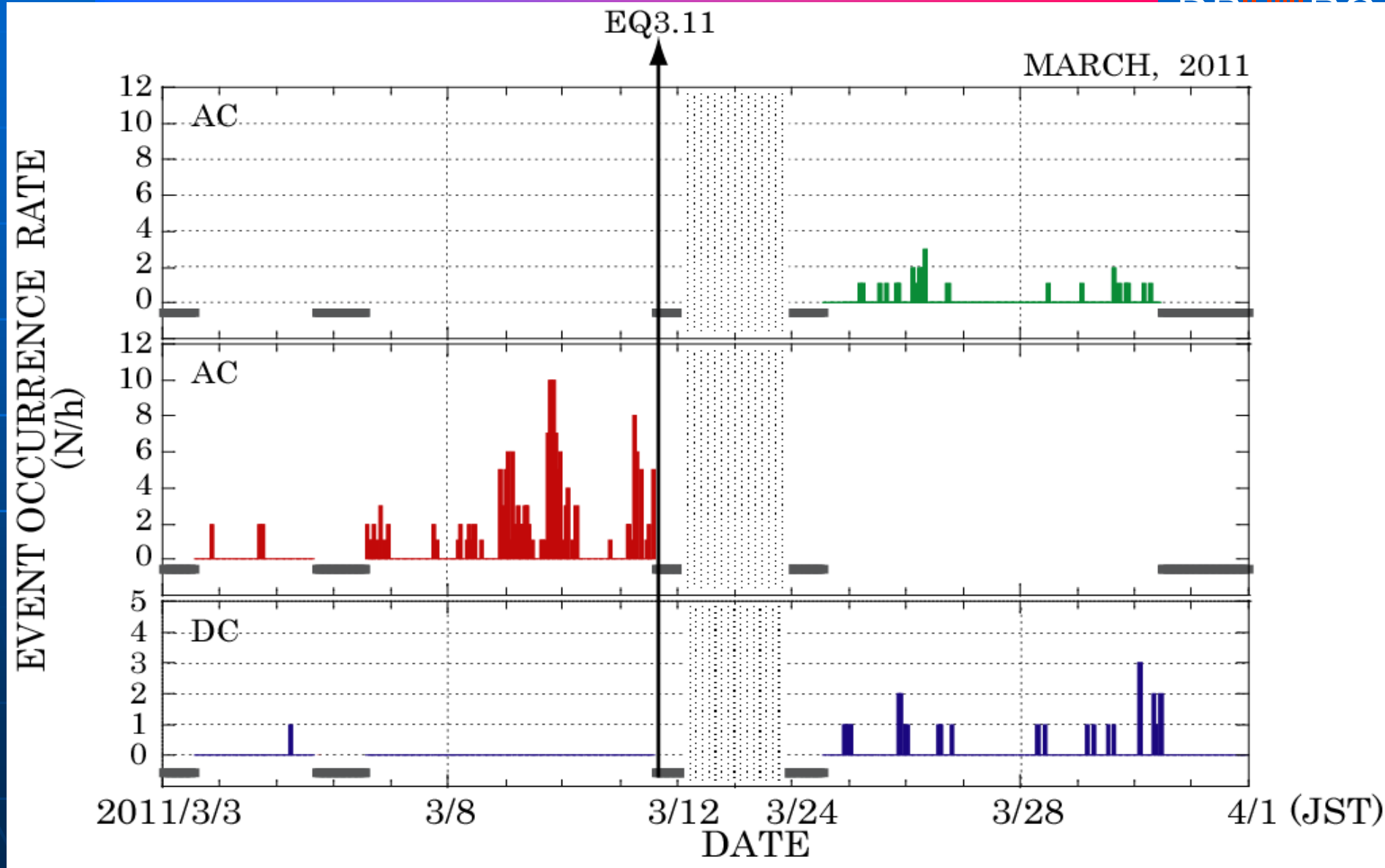



Figure. 3a (Fujinawa et al.2012)

# Example: Eastern Japan Earthquake, 2011/3/11



# VI. Summary

DPRC

- Using the ocean tidal force to act as naturally recurring stimuli to provide a sufficiently varied distribution of excitations in time and space
- The results support the "Predictable" groundwater level responses except to other non-structural factors.
- Curiously pre-seismic groundwater level changes in the pattern of tidal deviation occurred repeatedly in several local seismic events nearby the HUL.
- The Wave Propagation Model and Structural-Sensitive Zone were issued from HUL observation results.

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AIST The National Institute of Advanced Industrial Science and Technology
Geological Survey of Japan

# Thank you !