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Tectono-Hydrology Research Group
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Geological Survey of Japan

Precursory and Coseismic Groundwater Level Changes with Earthquakes of Taiwan, 2003~2004

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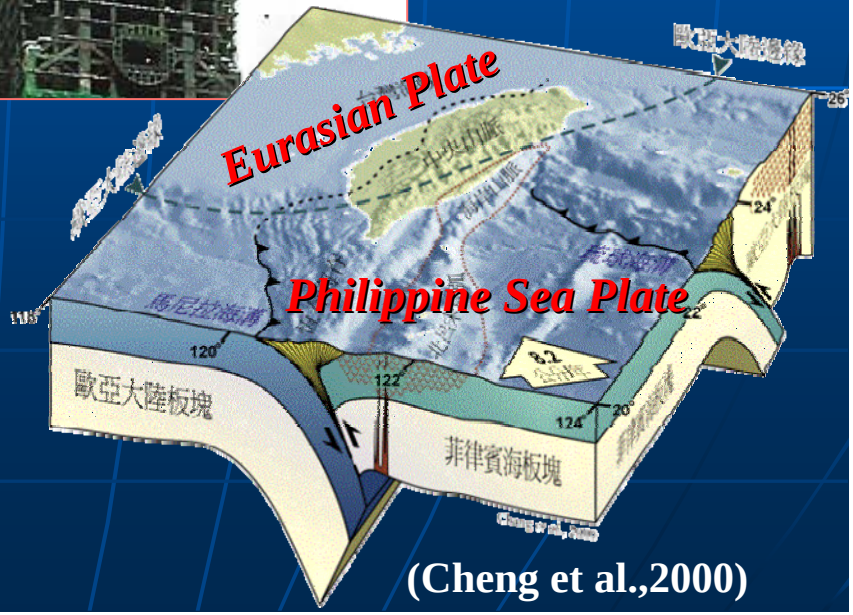
I. Introduction

- Tectonic Setting of Taiwan.
- 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
- Good quality observation

→ ***Waiting for good news…***

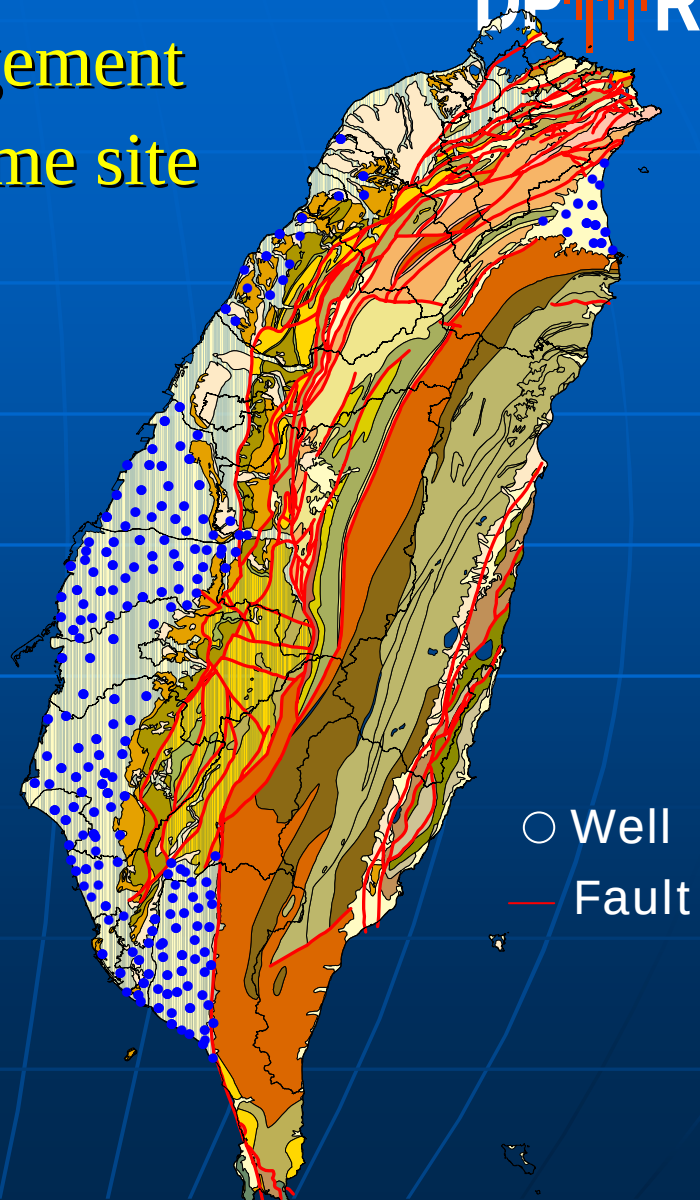


(Cheng et al.,2000)

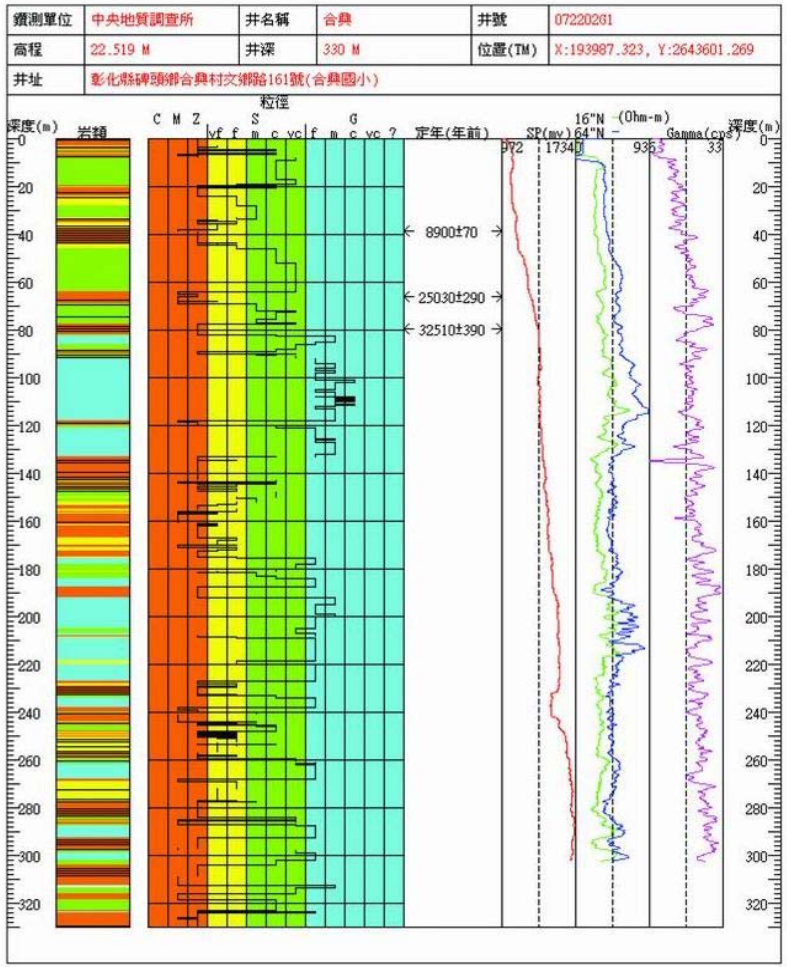
Taiwan Groundwater Monitoring Network (1992~2003)

- Design for water resources management
- Monitoring different aquifer in same site

Sub-Province	Site	Well
Taipei Basin	12	30
Taoyuan Tableland	5	10
Hsinchu-Miaoli Area	16	35
Choshui River Alluvial Fan	70	193
Chiayi-Tainan Area	40	105
Pingtung Plain	55	132
Ilan Plain	30	45
Total	228	560

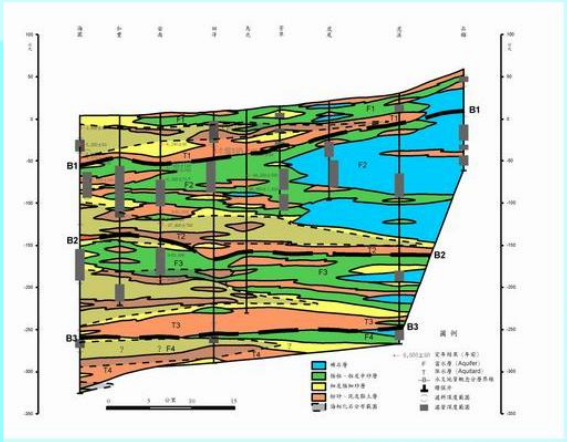


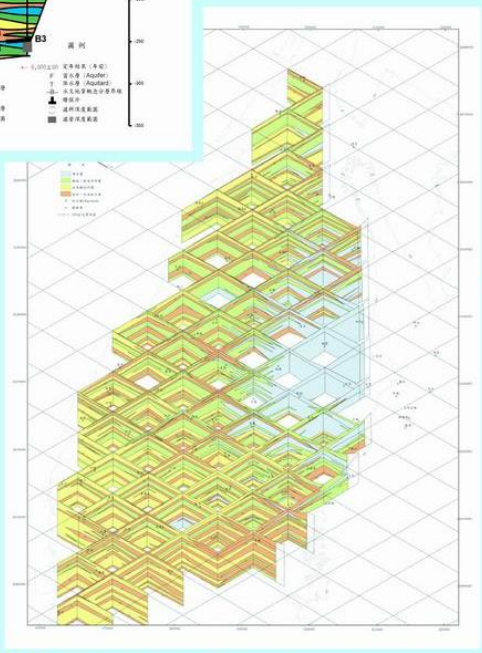
Taiwan Groundwater Monitoring Network: Detail Hydrogeological Database



地質柱狀圖 **The Geological Column**

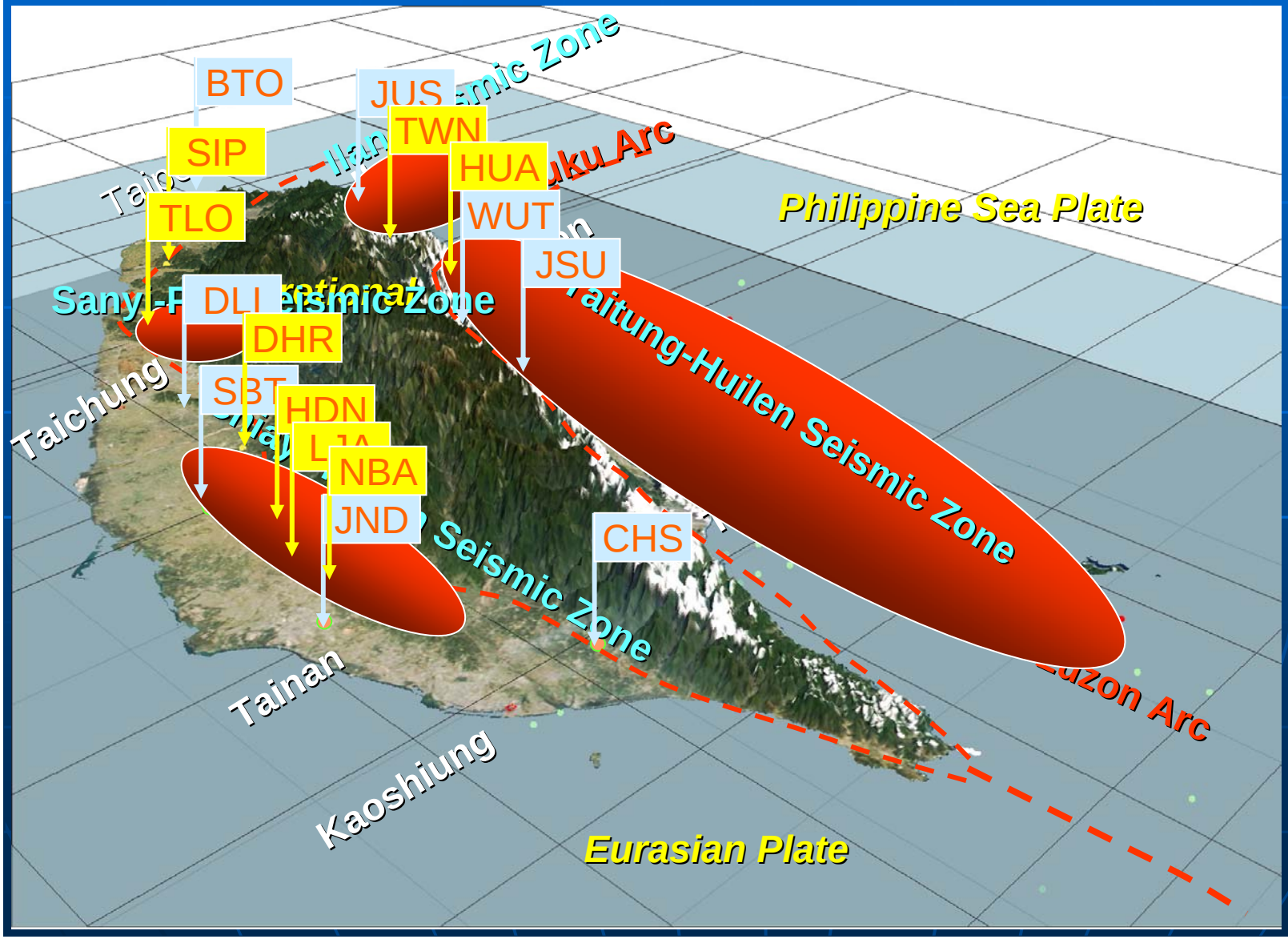
濁水溪沖積扇之地質剖面圖
Geological Cross for Choshui River Alluvial Fan





濁水溪沖積扇之水文地質屏狀圖
Geological Fence Diagram of Choshui River Alluvial Fan

Observation Network



Well Location

XXX

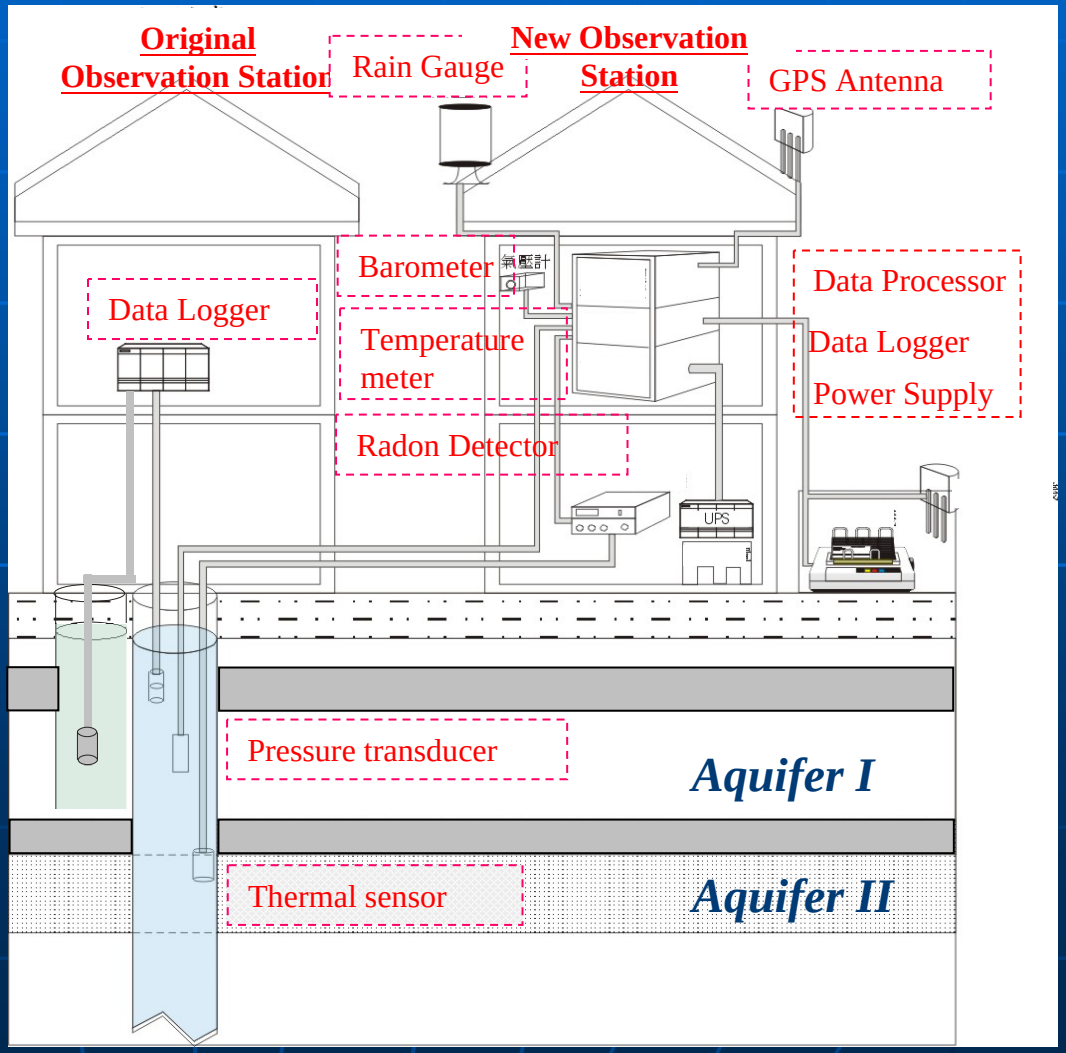
Before 2004

XXX

After 2004

II. Observation

- Observation and Instruments setting

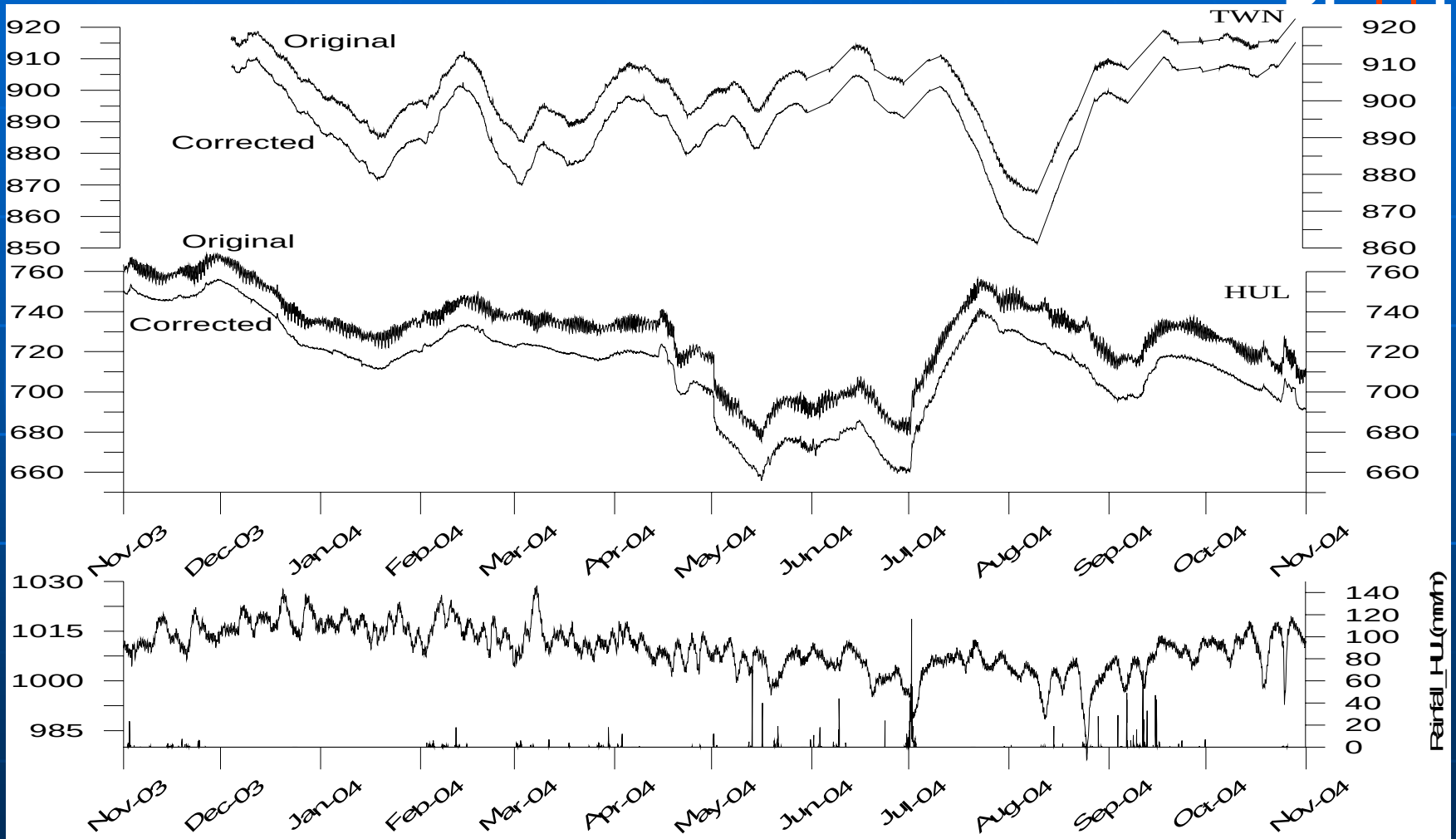


Description of observation wells

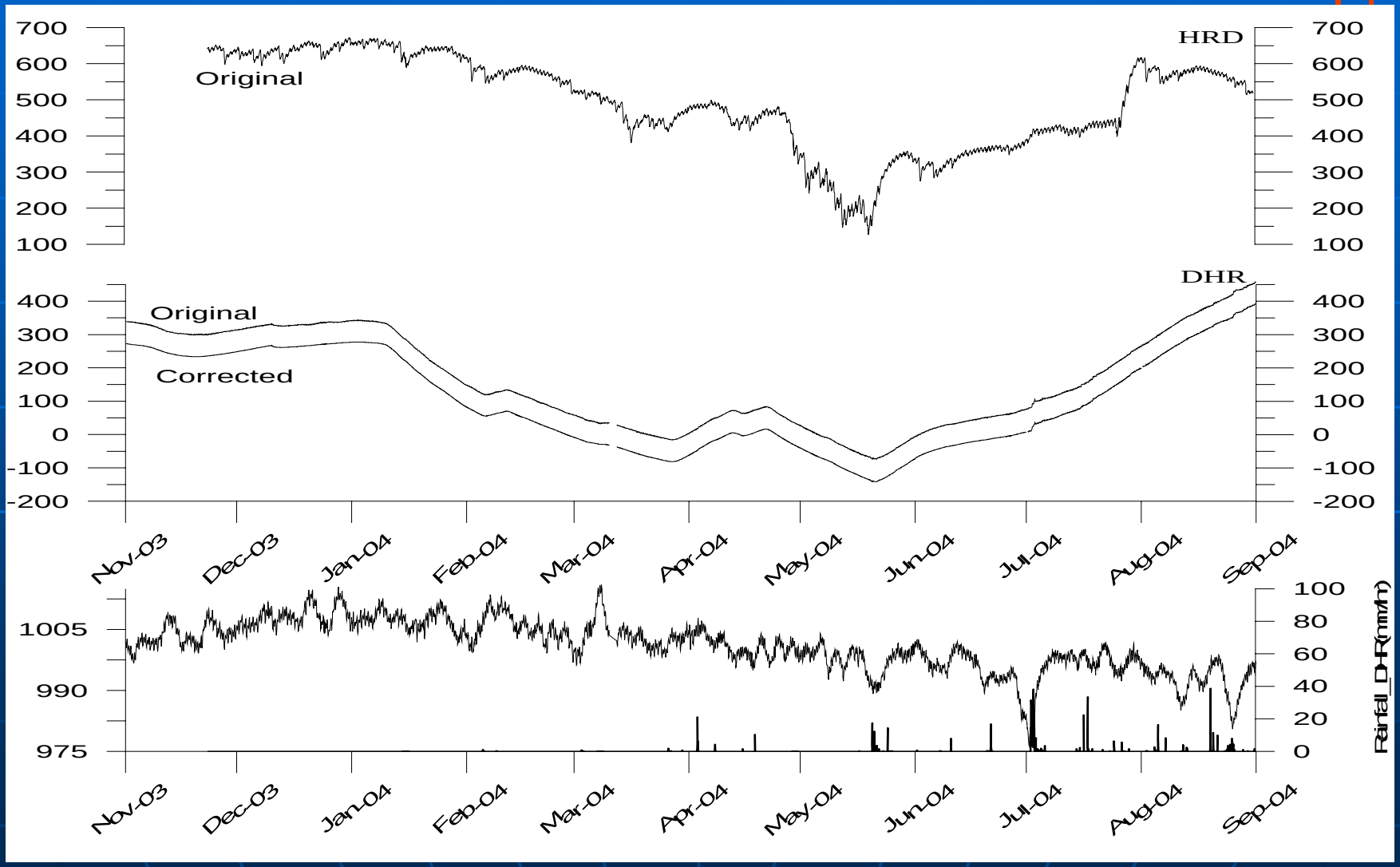
Site	Location		Elevation (m)	Depth (m)	Screened Depth (m)	Geology	Wells
	Longitude	Latitude					
SIP	121.071	24.831	78.86	150	132-144	Qg, Qs	3
DHR	120.561	23.688	75.41	258	222-252	Qg	3
LUJ	120.342	23.227	26.87	228	204-222	Qs, Qm	3
NBA	120.340	23.071	42.77	153	135-147	Qs	3
TWN	121.782	24.746	3.79	130	130-150	Qs, Qm	3
TLO	120.784	24.491	156.54	99	80-99	Qs	2
HUL	121.605	23.977	16.09	205	140-160	Qc	1
HRD	120.429	23.347	43.77	300	220-250	Qm, Qs	1

Qc: Quaternary conglomerate, Qg: Quaternary gravel, Qs: Quaternary sandstone, Qm: Quaternary shale and mudstone

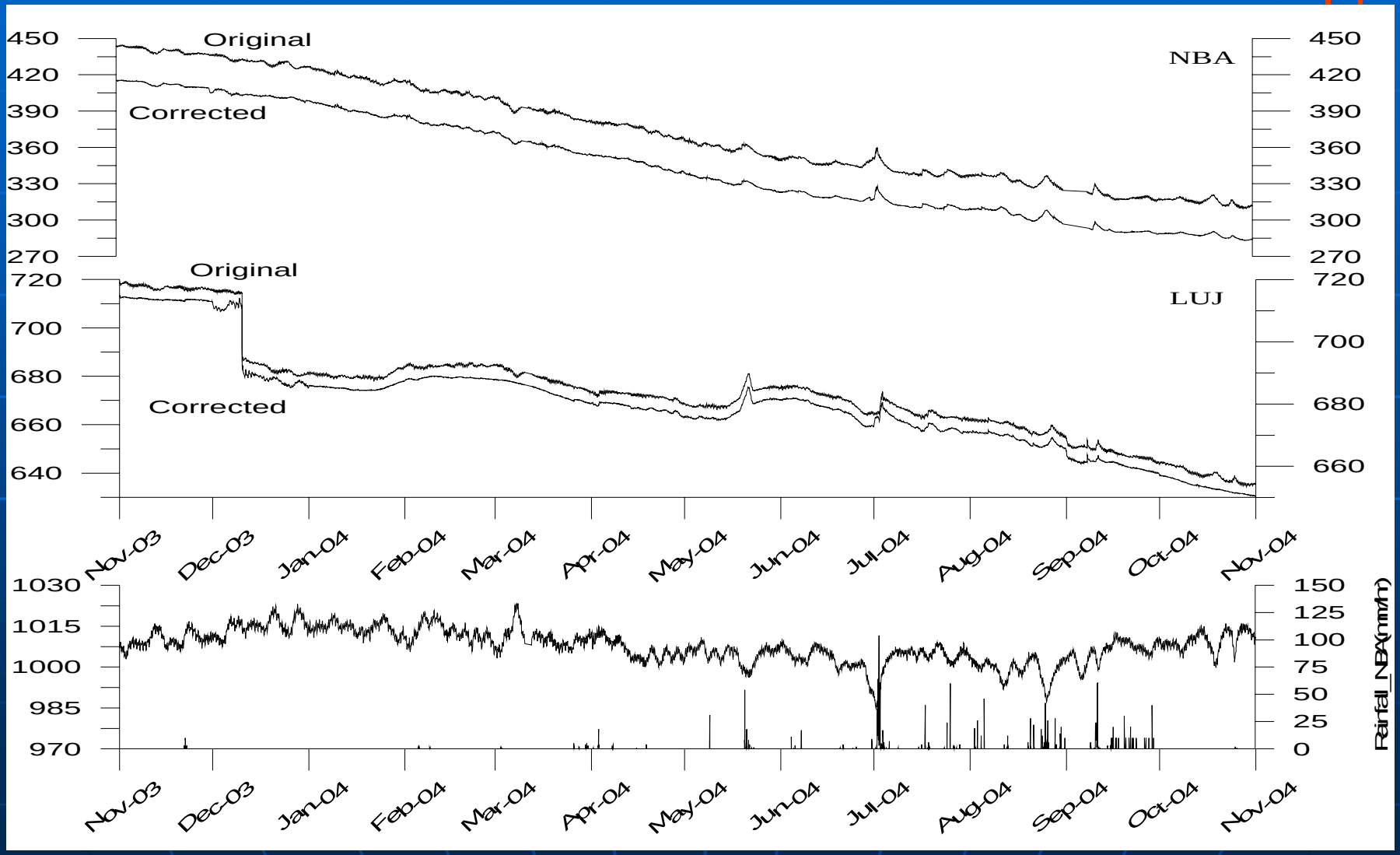
Observation hydrograph- Eastern



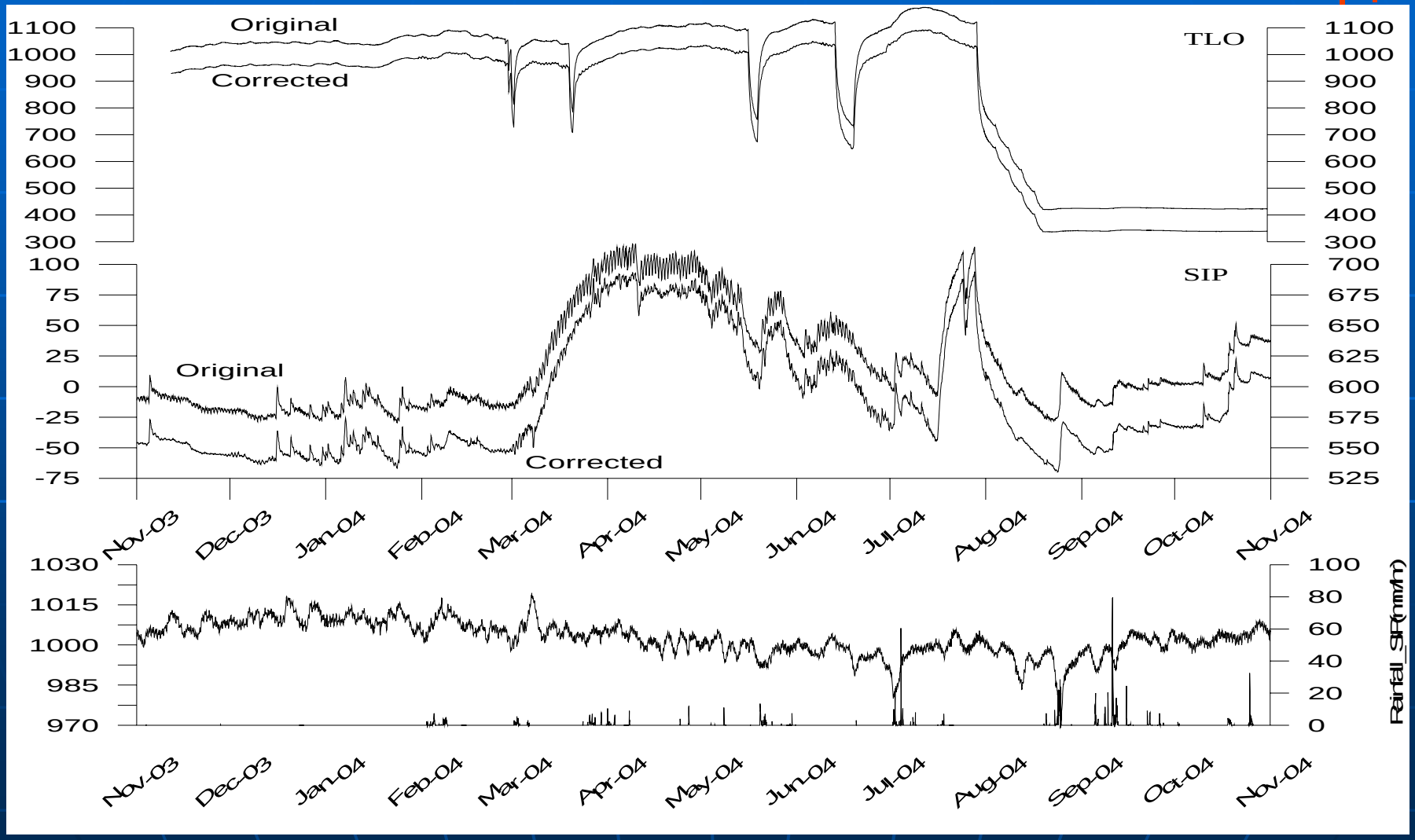
Observation hydrograph- Central



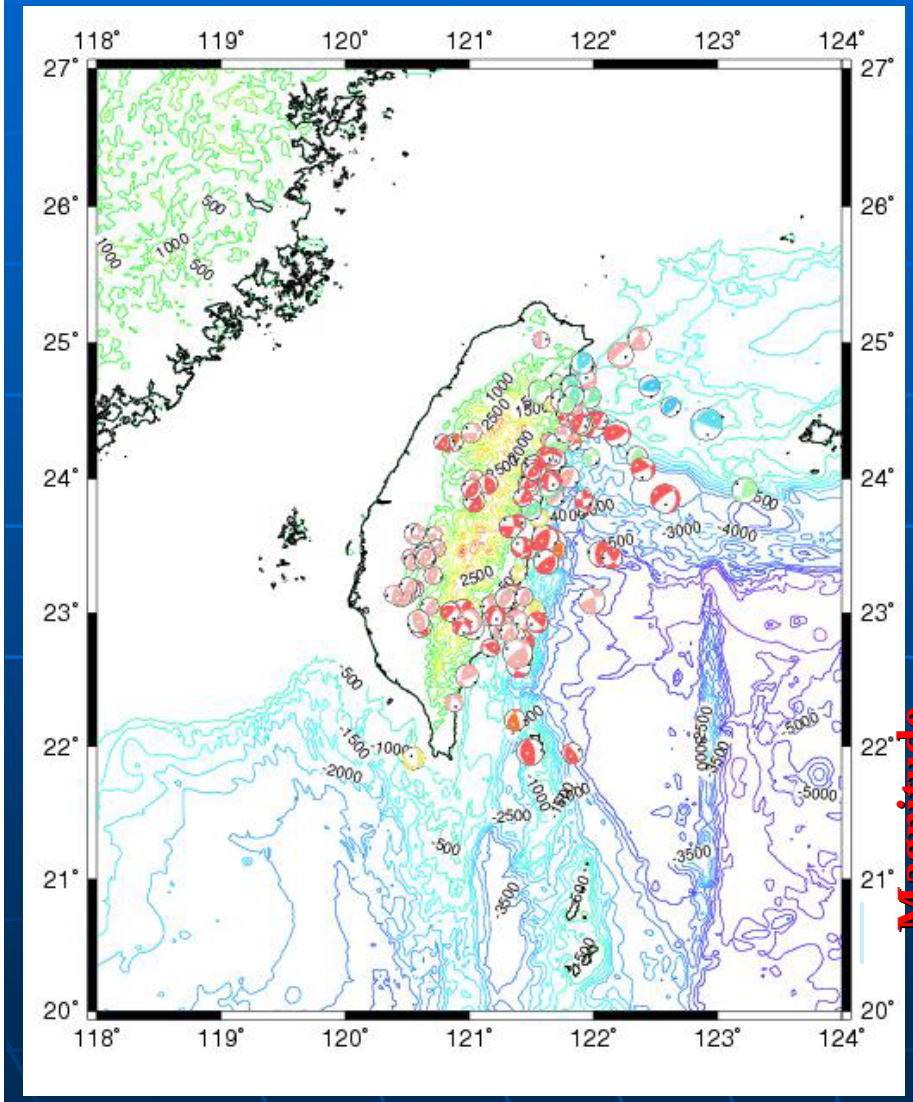
Observation hydrograph- Southern



Observation hydrograph- Central



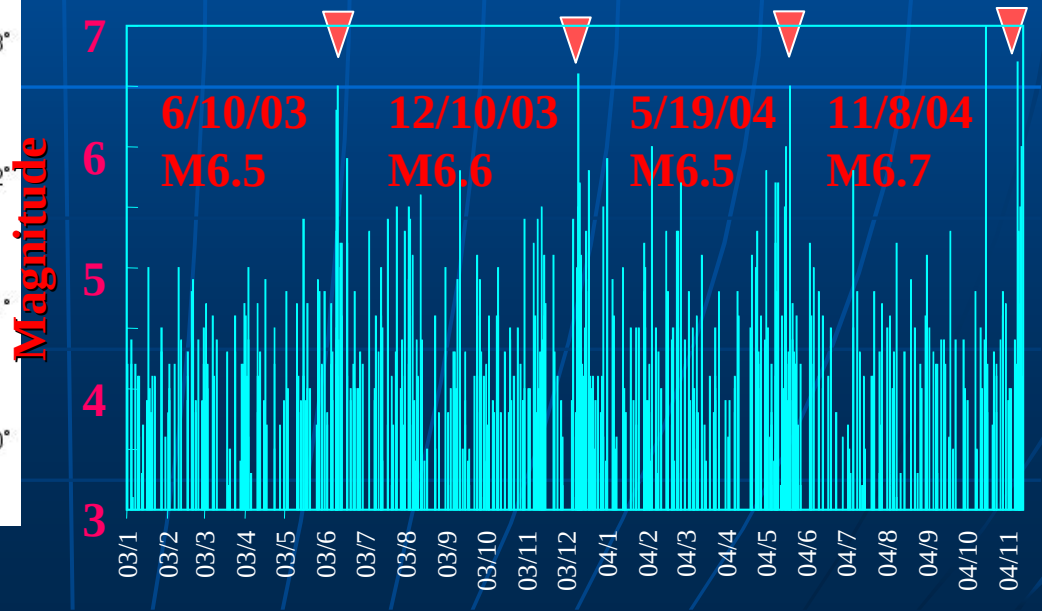
III. Results and Discussions



12 CMT solution and distribution of events

Events of the earthquake M_L >3 in Taiwan 03'~04'

M_L	3	4	5	6
2003	118	181	43	3
2004	86	125	25	5
Events	204	306	68	8

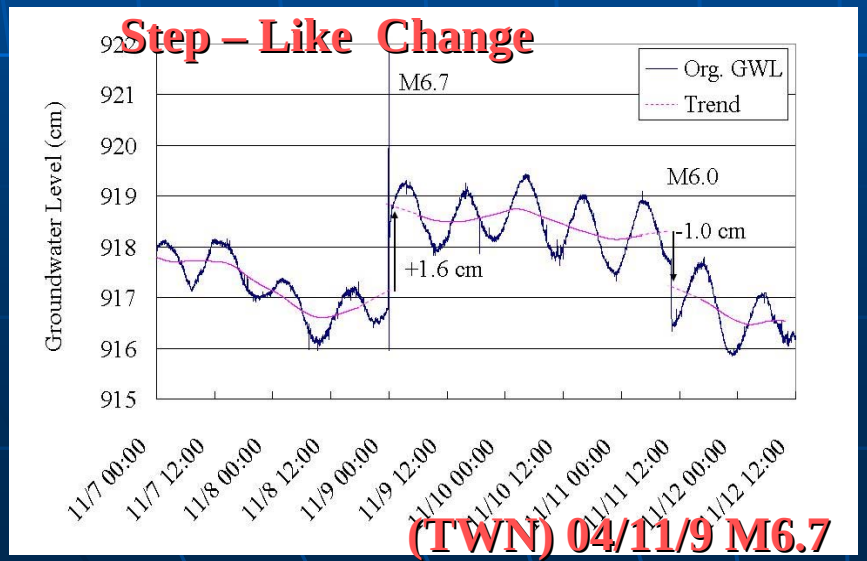


Observed coseismic events (03'~04')

- Total 68 Observation, step changes (S) 21events, oscillation (O) 27 events, O+S 20 events

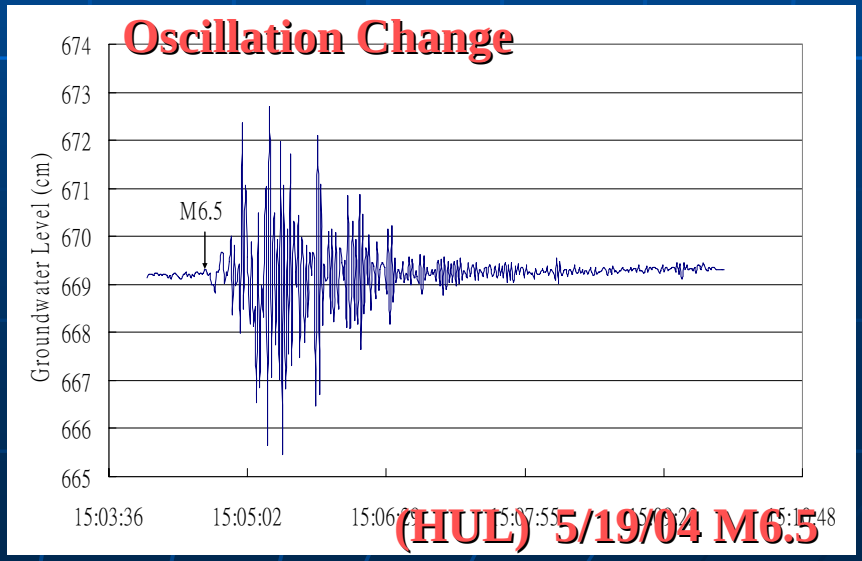
Catalog	Events	HUL	TWN	LUJ	NAB	HRD	DHR	TLO	SIP
2003/4/3 Tainan, M=4.9	2			S	S				
2003/6/10 Taitung, M=6.5	4			S	O		O+S		O
2003/6/17 Taitung , M=5.9	2				O				O
2003/12/10 Taitung , M=6.6	7	O+S	O+S	S		S	O+S	O+S	O
2003/12/11 Taitung, M=5.7	1				S				
2003/12/18 Taitung, M=5.8	1	O							

Step – Like Change



(TWN) 04/11/9 M6.7

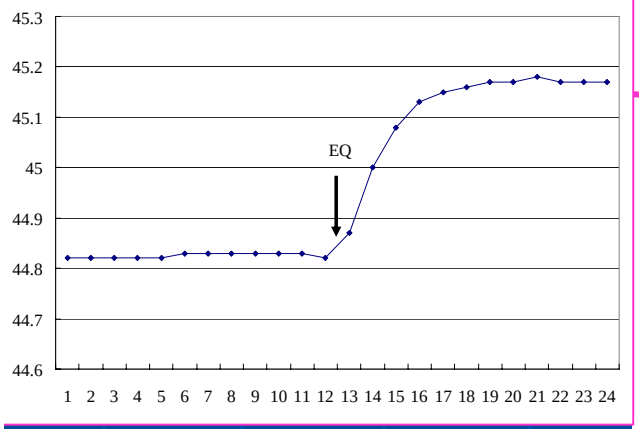
Oscillation Change



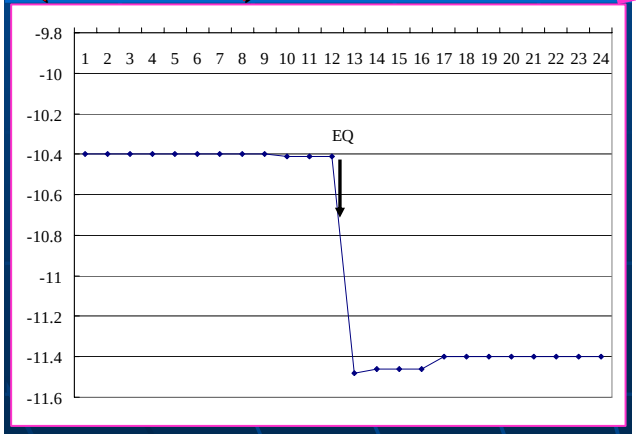
(HUL) 5/19/04 M6.5

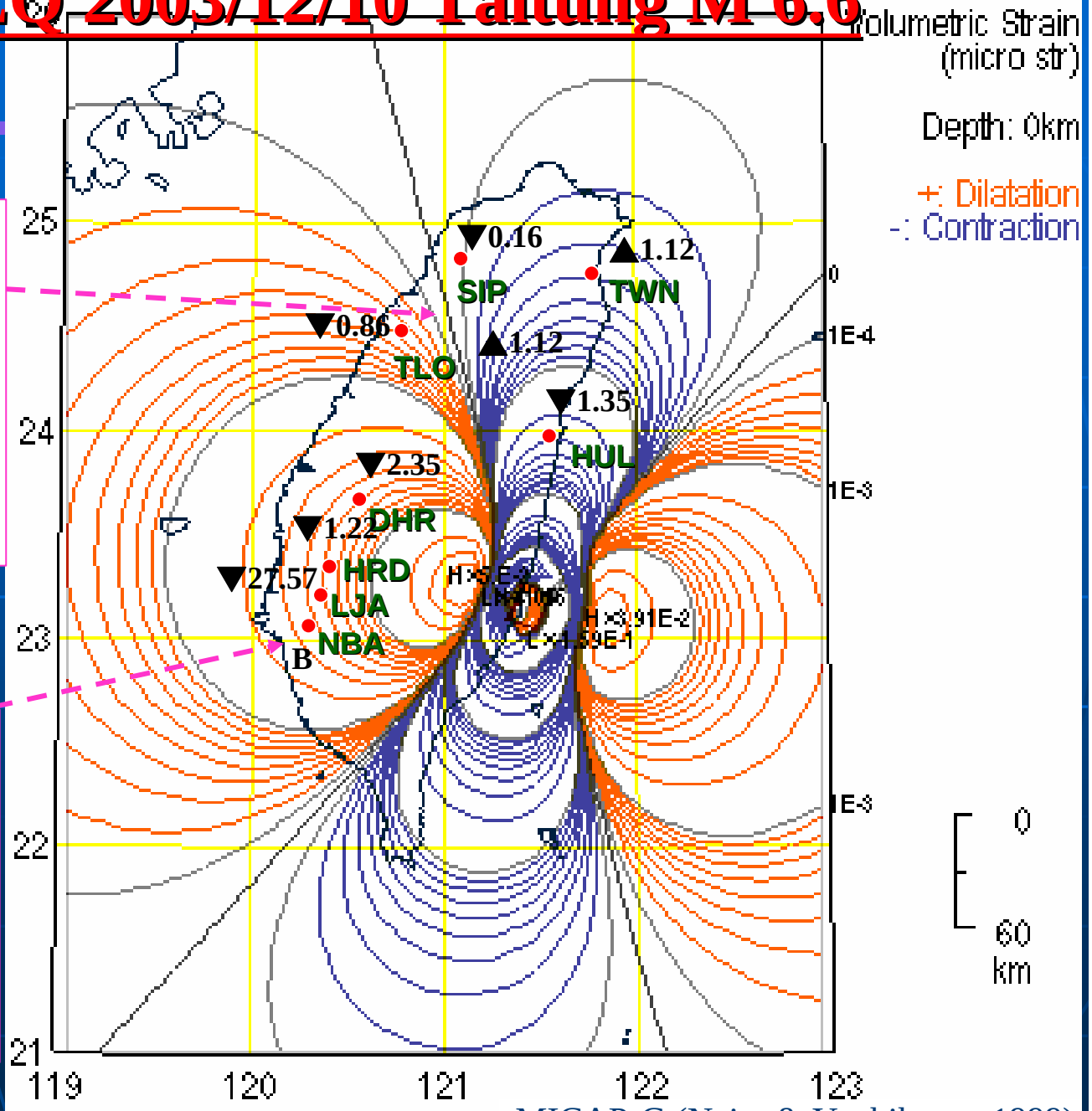
EQ 2003/12/10 Taitung M 6.6

2 wells increase in Miaoli area (6cm~35 cm)



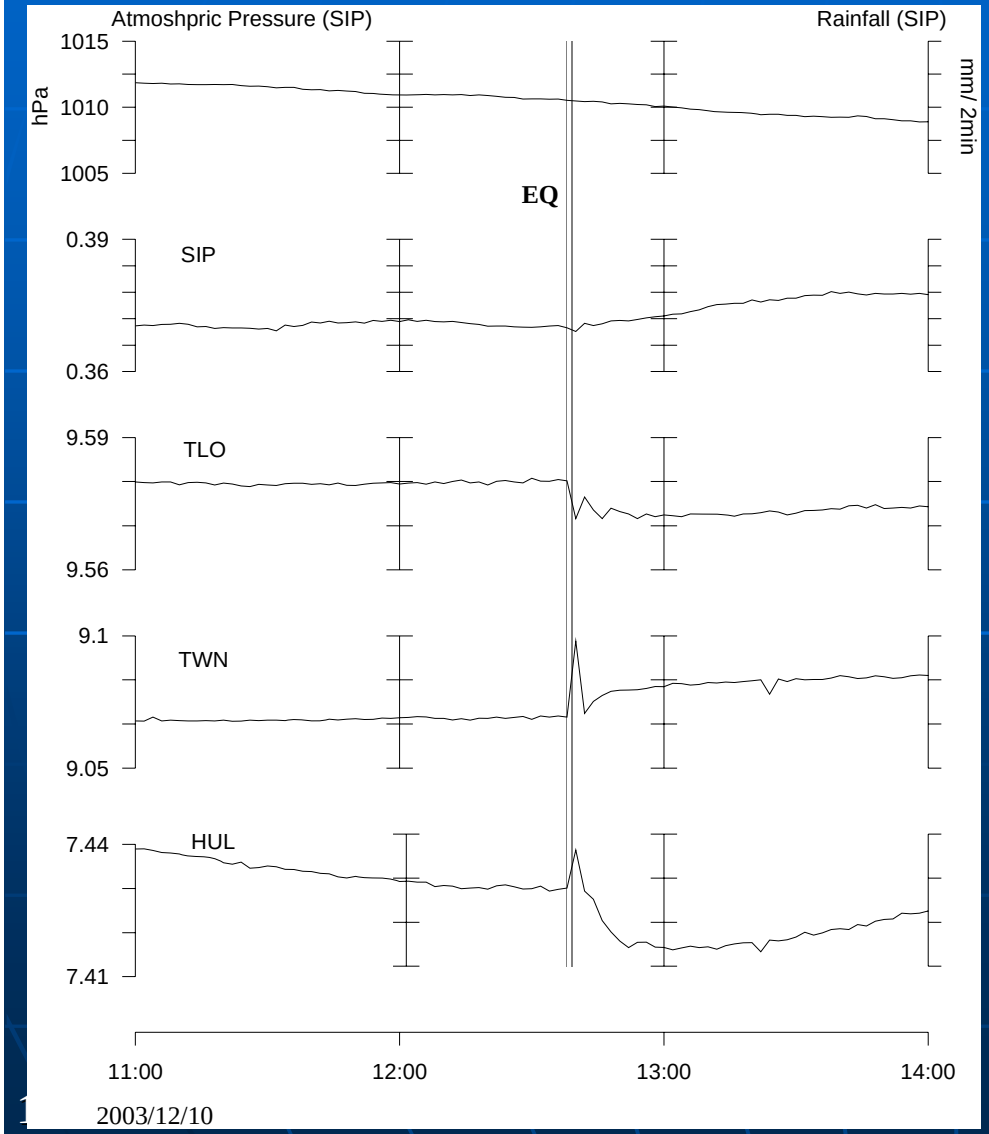
21 Wells decrease in Tainan-Kaoshiung Area (3~107 cm)

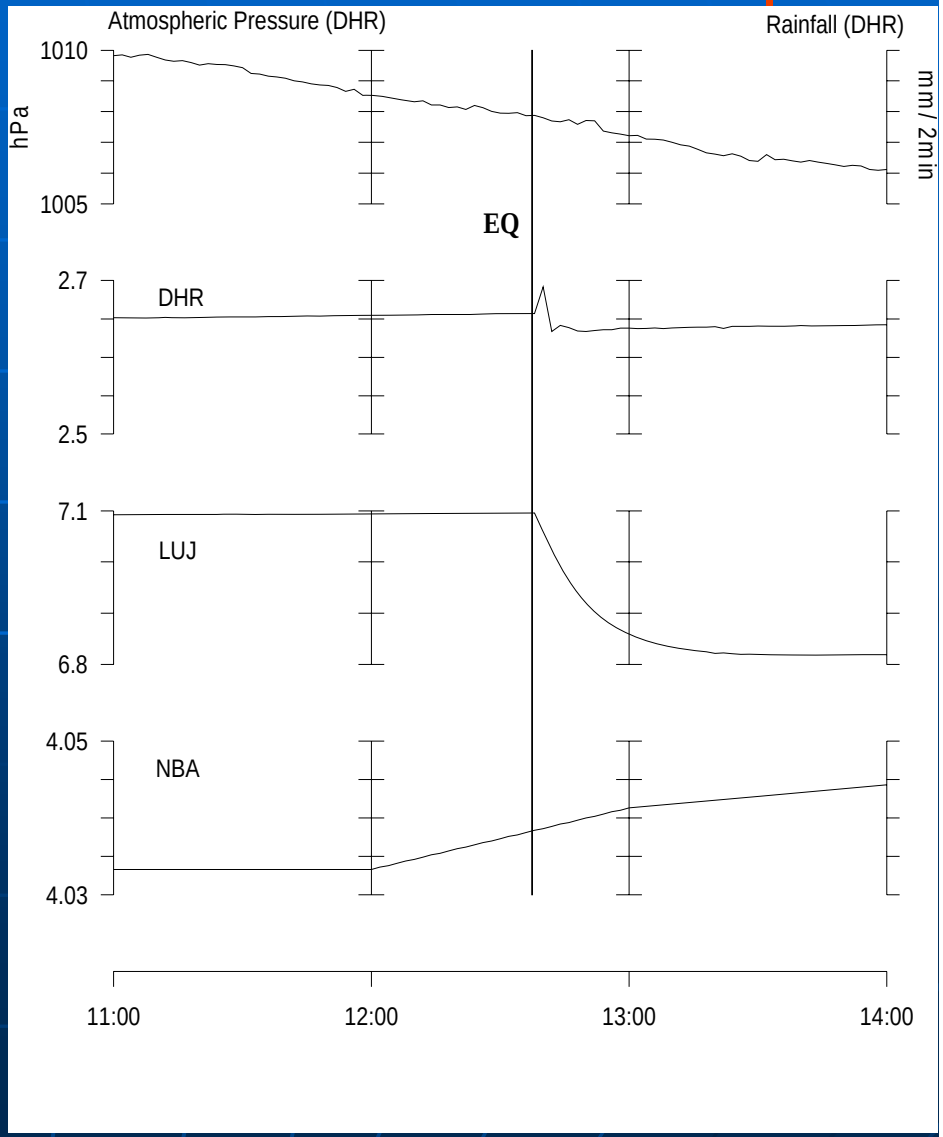




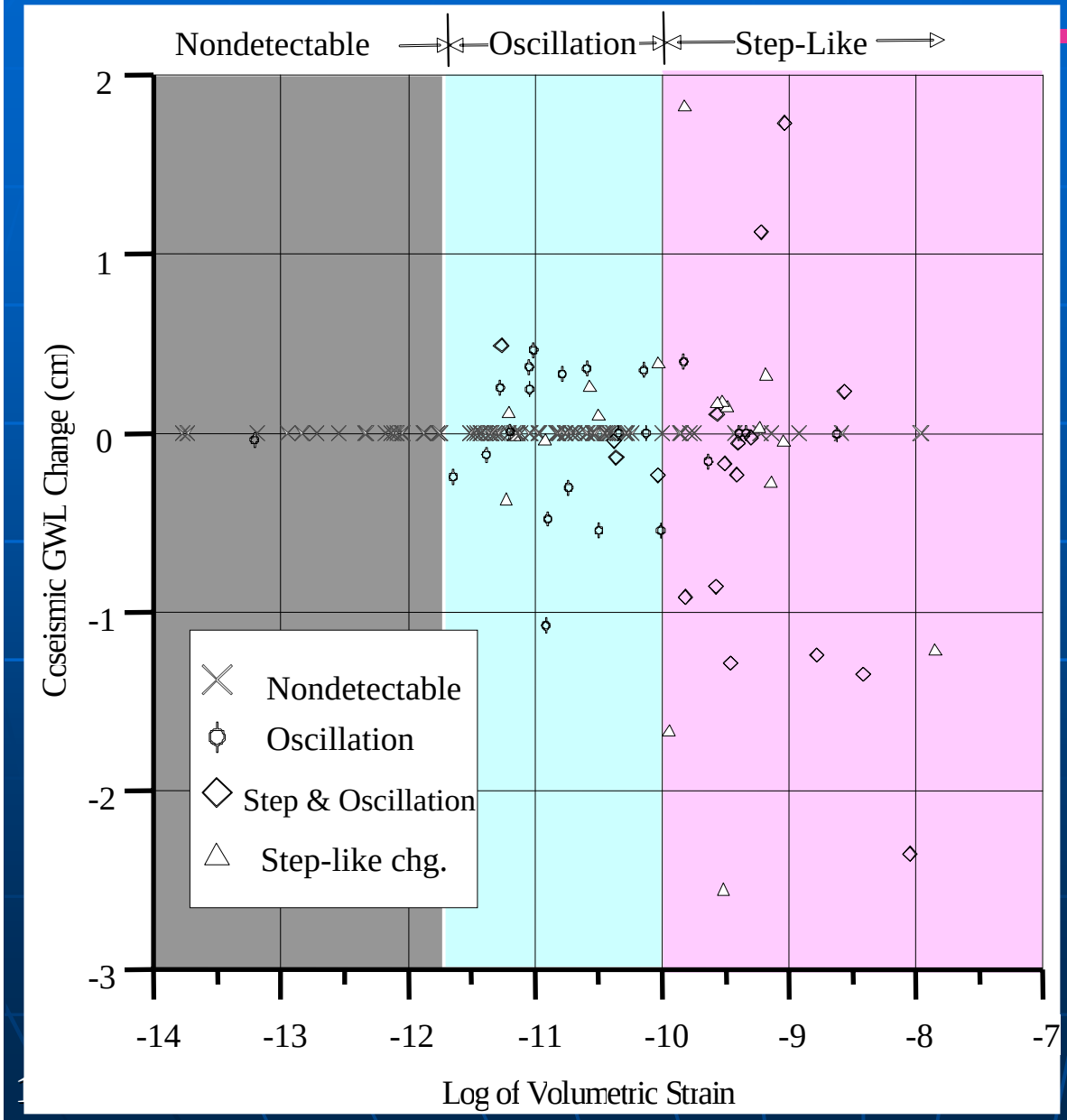
MICAP-G (Naito & Yoshikawa, 1999)

The coseismic groundwater level changes records, eastern Taiwan, Dec. 10, 2003





Criteria of the Coseismic Changes



DPRC

- **Step-Like Chg.**
  - Vol. Strain: $>10^{-10}$
  - Amplitude: $\pm$3 cm
- **Oscillation**
  - Vol. Strain: $10^{-10}>>10^{-12}$
  - Amplitude: $\pm$1 cm
- **Nondetectable**
  - Vol. Strain: $10^{-12}>$
  - Amplitude: : >1 mm

Estimation of the theoretic responses

- Using Baytap-G Program to estimate the Tidal component of observed groundwater level
- Calculate the theoretic tidal potential from GOTIC II Program
- Derived the static strain sensitivity by

  static strain sensitivity = (tidal responses ÷ tidal potential)

- Calculate the coseismic static volumetric strain using MICAP-G program
- Derived the predicted amplitude estimated from tidal response by

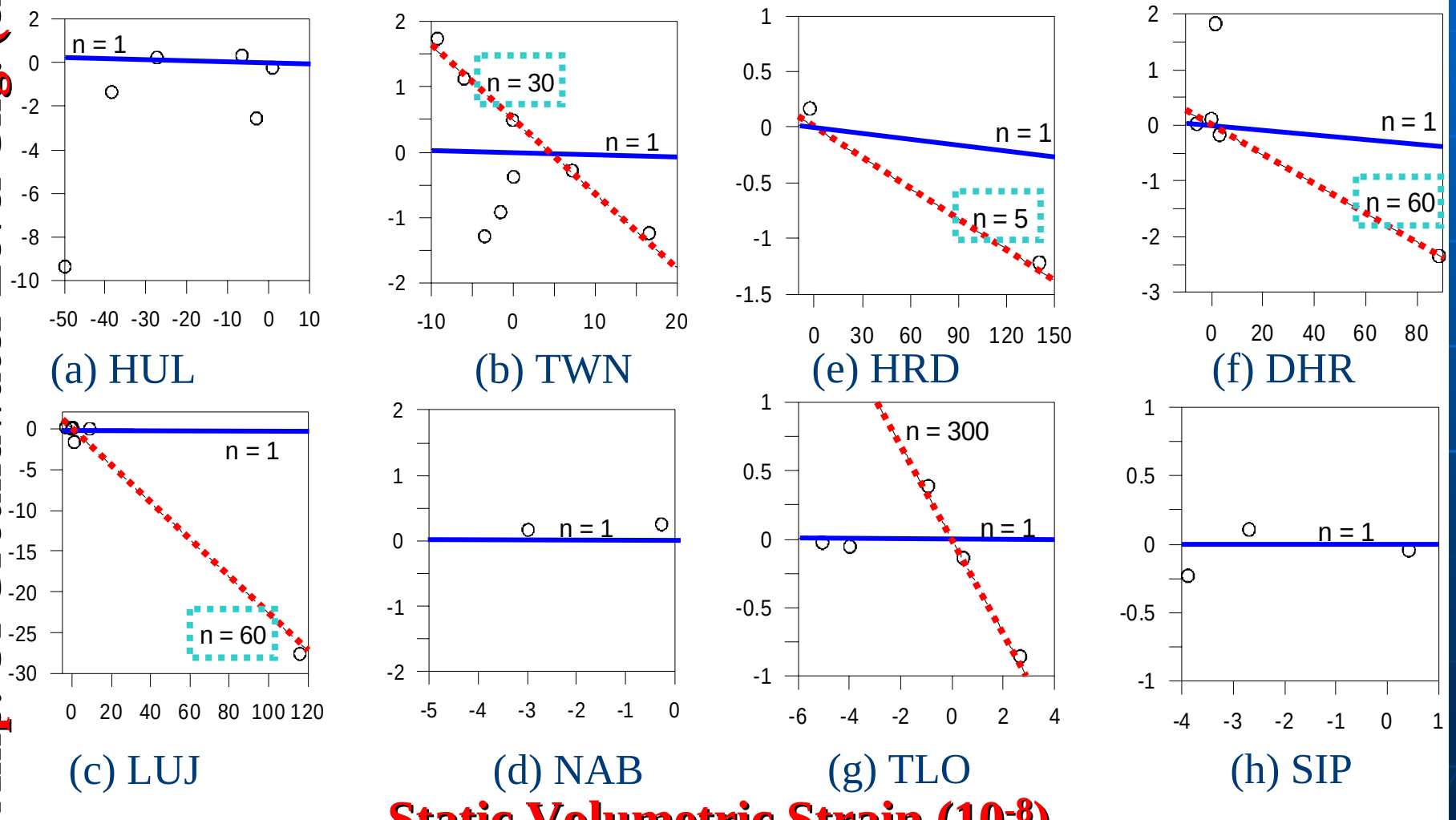
  Amp. Of Chg.= (calculated volumetric strain × strain sensitivity)

Static Volumetric Strain Sensitivity

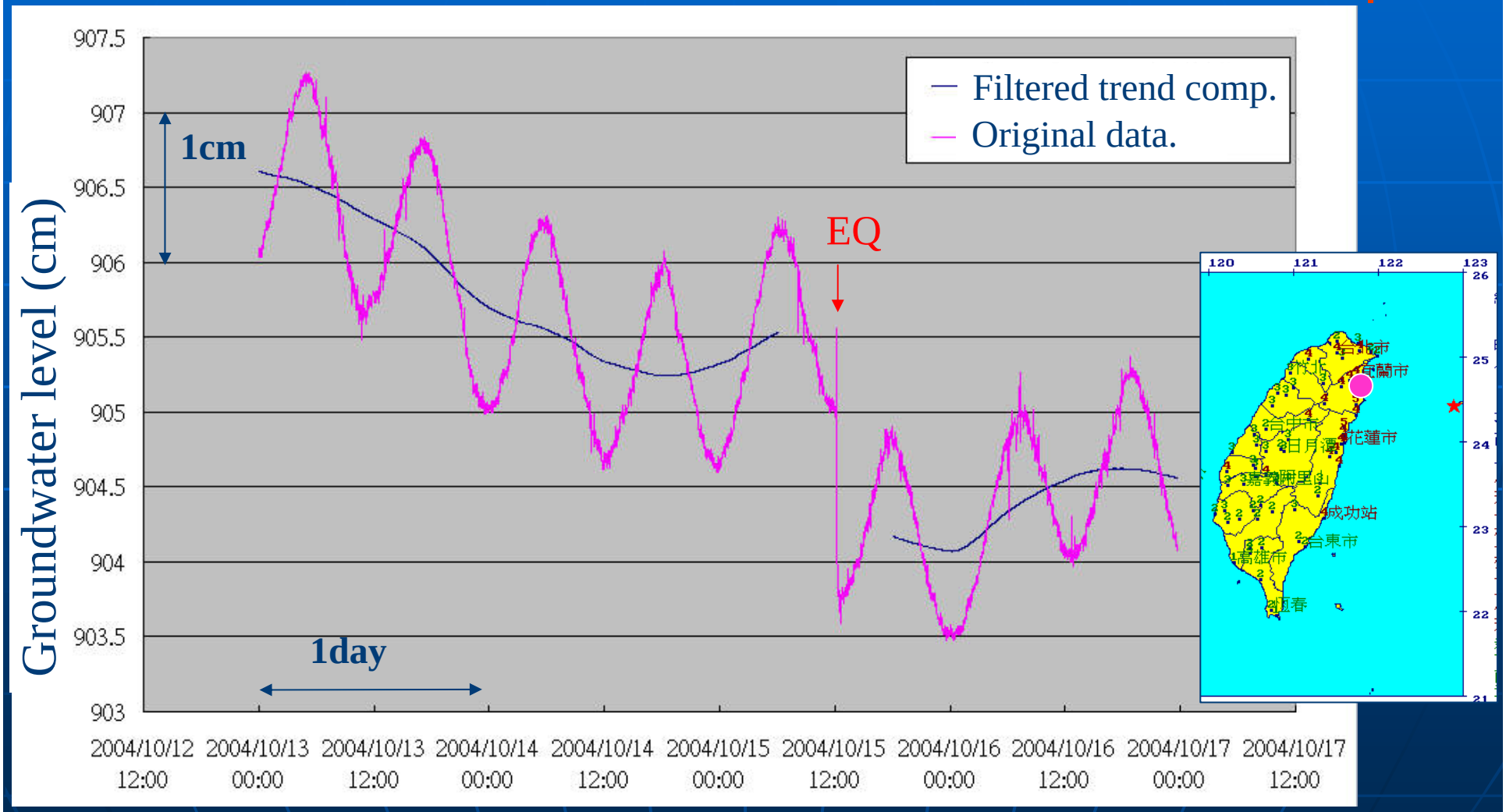
	SIP	TLO	DHR	HRD	LUJ	NBA	TWN	HUL
	Amplitude (10^{-8}) [Phase Shift (degree)]							
Vol. starin by M_2 earth tide, $\mathbf{t_e}$	1.35 [0]	1.35 [0]	1.37 [0]	1.38 [0]	1.38 [0]	1.38 [0]	1.35 [0]	1.37 [0]
Vol. starin by M_2 oceanic tidal loading, $\mathbf{t_o}$	1.11 [-314]	2.08 [-321]	0.18 [-276]	0.14 [-283]	0.11 [-290]	0.11 [-301]	0.60 [-227]	6.10 [-184]
Vol. starin by earth + oceanic tide, $\mathbf{t_t=t_e + t_o}$	2.27 [-340]	3.25 [-336]	1.40 [-352]	1.42 [-355]	1.42 [-356]	1.45 [-356]	1.04 [-335]	4.73 [-185]
M_2 amplitude of water level, $\mathbf{t_w}$	5.19±0.45 [-323±24]	3.72±0.67 [-282±49]	6.17±0.60 [-339±23]	2.61±1.05 [-252±18]	2.54±0.59 [-350±34]	4.24±0.29 [-349±15]	3.93±0.27 [-272±21]	23.77±0.50 [-21±6]
Strain sens. by M_2 tide, Ws = $\mathbf{t_w/t_t}$ **(mm/10^{-8})**	**2.28**	**1.14**	**4.39**	**1.84**	**1.78**	**2.92**	**3.78**	**5.02**

*Negative phase shifts denote lags.

Comparison of the theoretic and observed responses

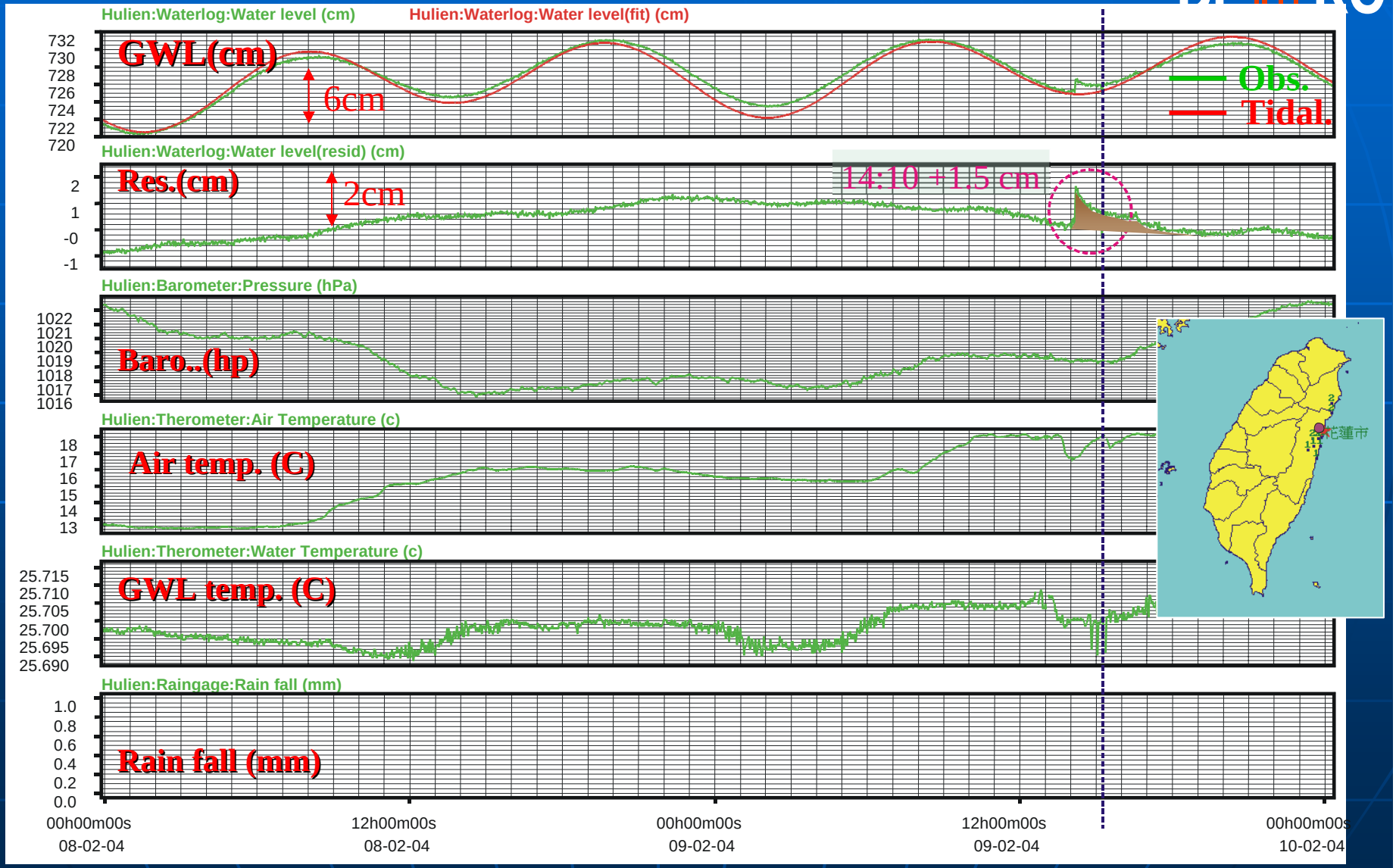


Pre-seismic Groundwater Level Changes

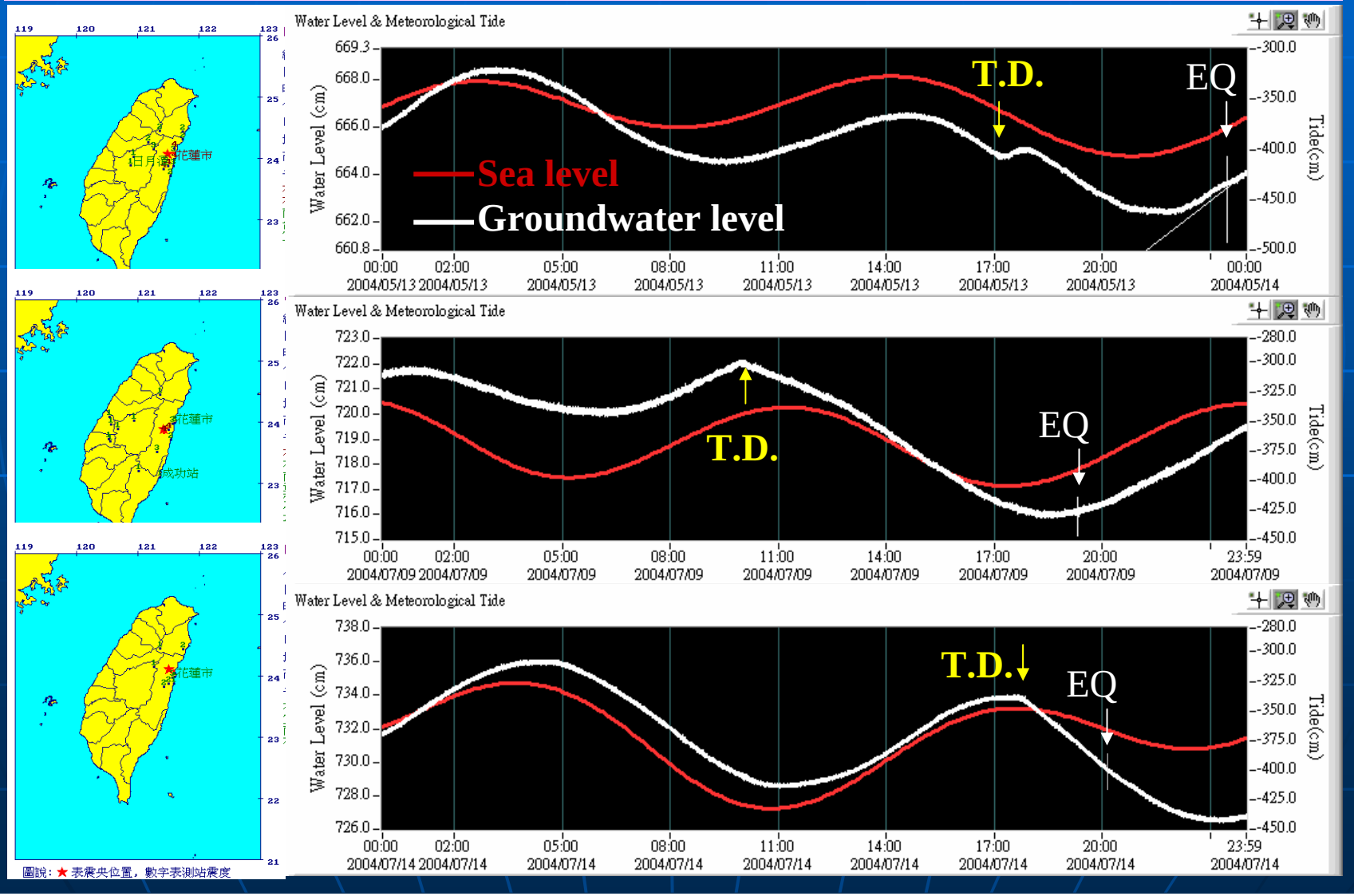


2004/10/15 Ilan Earthquake, M7.0 (TWN)

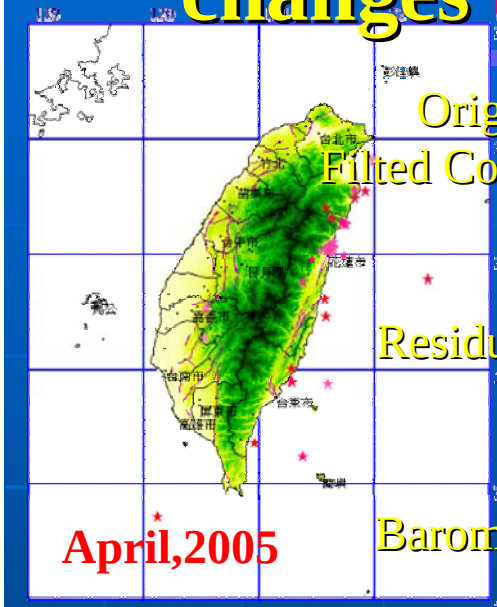
Feb. 9 15:14, 2004, Hulien Earthquake, (M=4.3 Depth 27.6 Km)



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 activity and the groundwater level changes (April~May, 2005)



April,2005

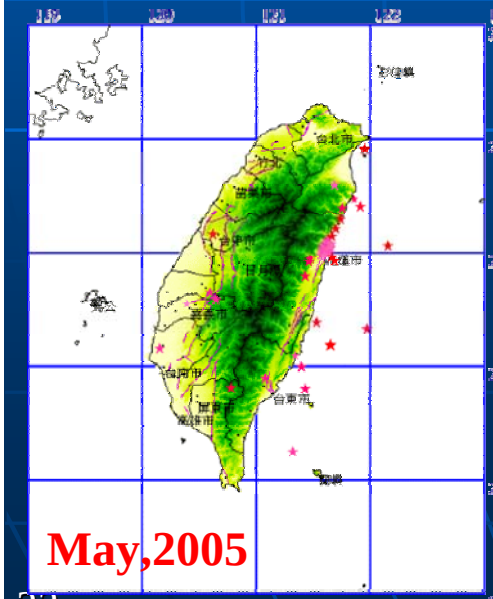
Orig. WL. (green)
Filted Components(red)

Residual water level (cm)

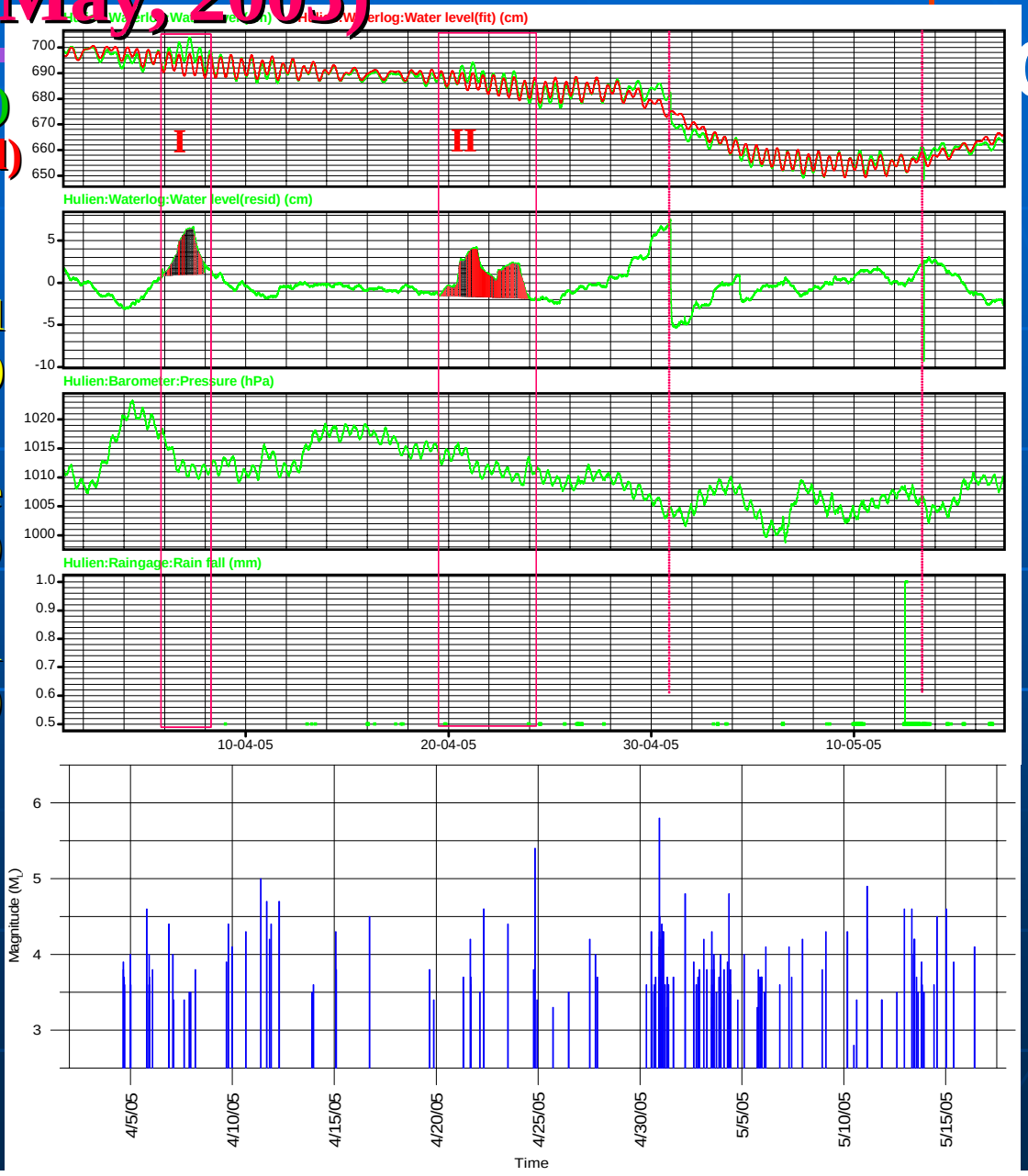
Barometric Pressure (hpa)

Rainfall (mm)

Seismicity (M_L)

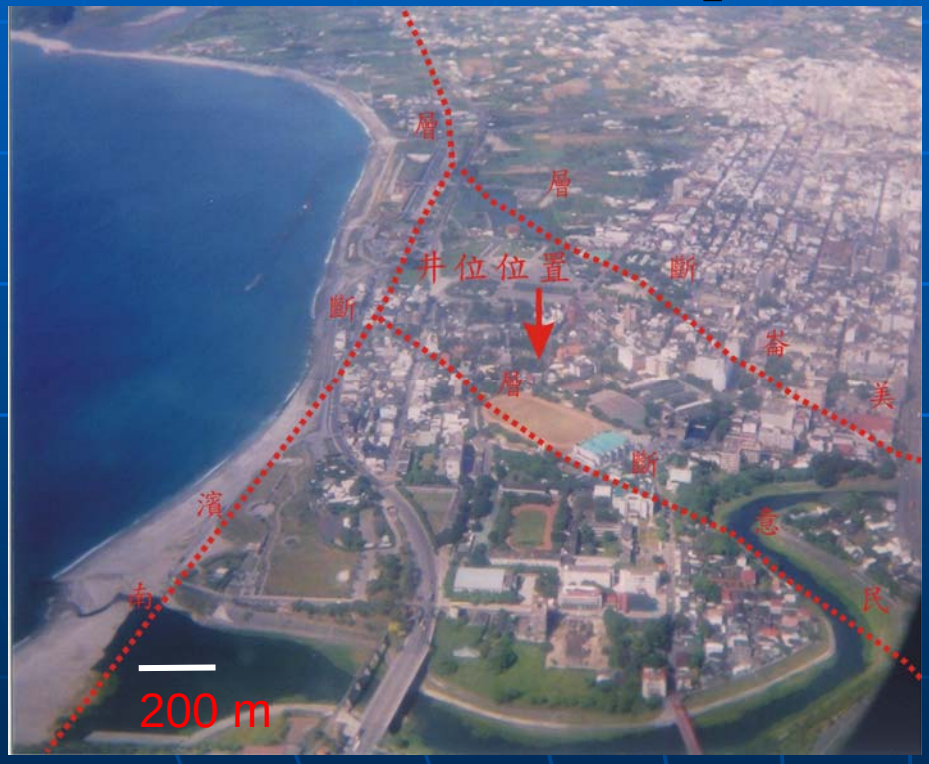


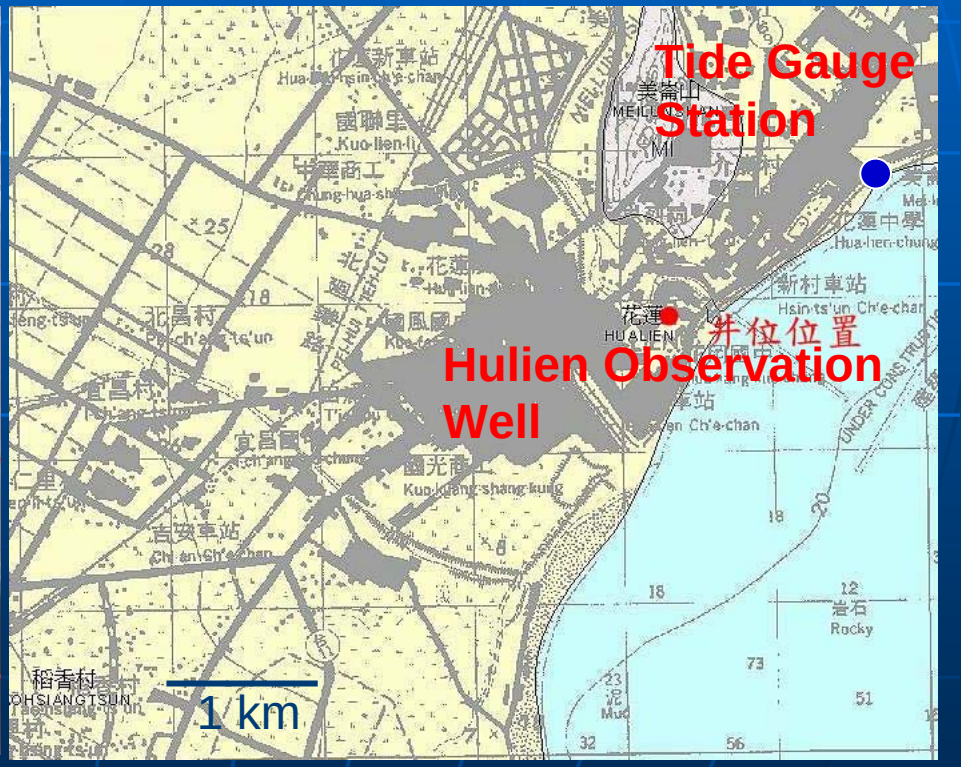
May,2005



Discussion: *Possible Mechanism of Observation in Hulien Observation Well*

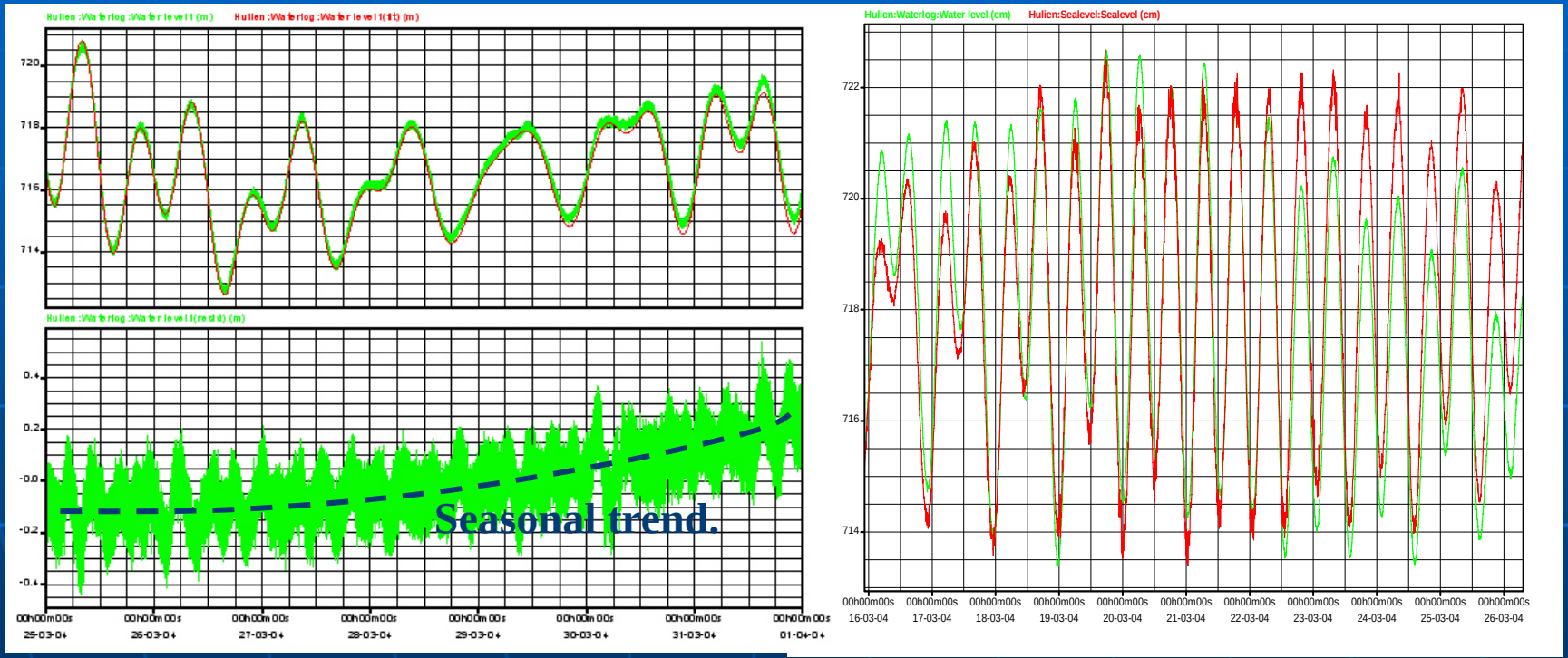
- Effected by ocean tide
- Located on complex fault zone





Location of Hulien observation well and tidal gauge station

Comparison of Sea Level and Groundwater Level Observation

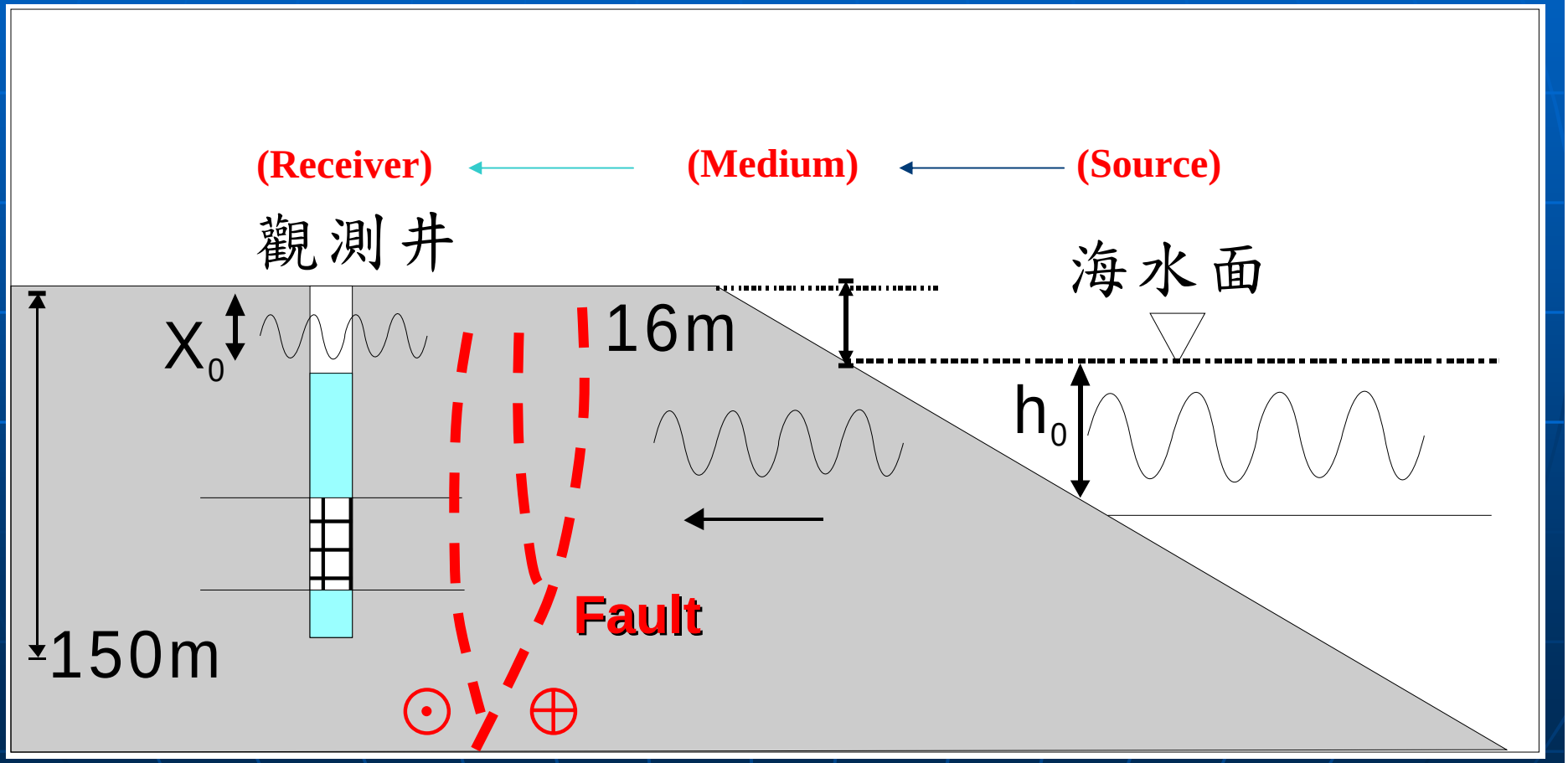


Red: sea level observation in Huilen Harbor (6 min)

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

Possible Mechanism of Observation in Hulien Observation Well

- Wave Propagation Model



Summary

- Valuable information of earthquake induced Groundwater level changes derived from dense "Groundwater Monitoring Networks of Taiwan"
- Observed coseismic patterns can fit to poroelastic behavior, but the amplitudes are amplify compare to the static strain sensitivity estimated from tidal response.
- 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 were issued from HUL observation results.