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 study of seismic-induced groundwater level changes in porous sediment and sedimentary rock

Wen-Chi Lai[1,2], Chjeng-Lun Shieh[1], Kuo-Chyng Chang[3], Kai-Wen Kuo[4], Norio Matsumoto [5], Naoji Koizumi [5]

1. Disaster Prevention Research Center, NCKU, Taiwan
2. Department of Resources Engineering, NCKU, Taiwan
3. Water Resource Agency, MOEA, Taiwan
4. Central Weather Bureau, MOEA, Taiwan
5. Geological Survey of Japan, AIST, Japan

1.Review of NCKU-GSJ Cooperation

- 1999~2000

  The Case Study of 1999 Chi-Chi Earthquake

- 2000~2003

  Establishment of the observation network

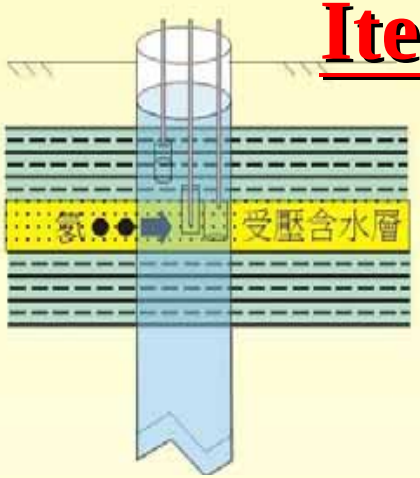
- 2003~2005

Studies of observation results: coseismic and preseicmic

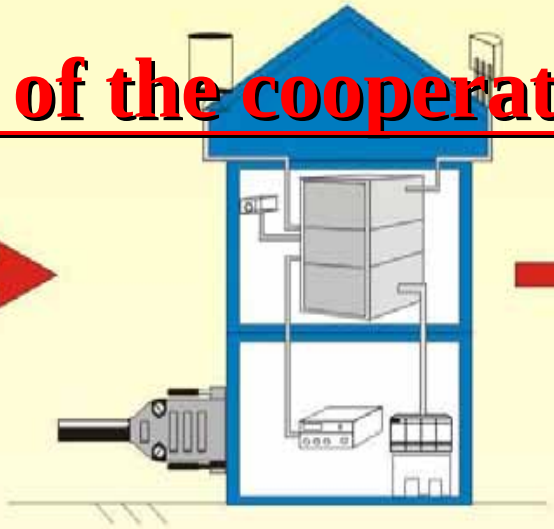
- 2006~2009

  Future scopes and plan

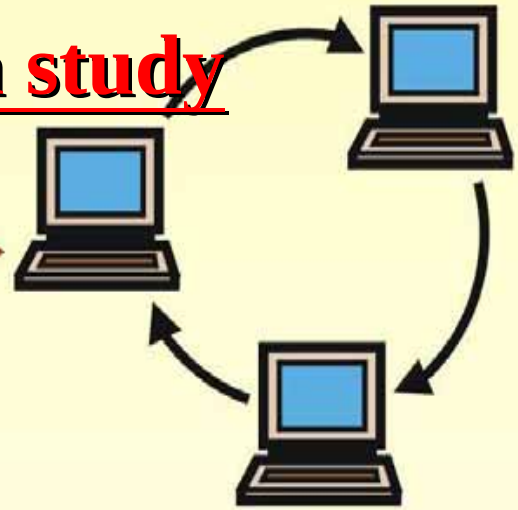
Items of the cooperation study



Observation well selection



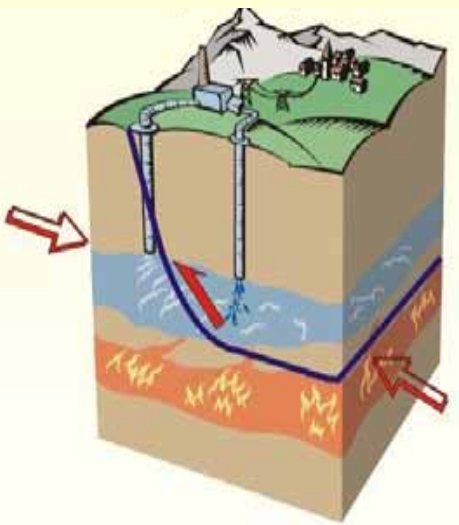
Observation instruments installation



Data transfer and record network

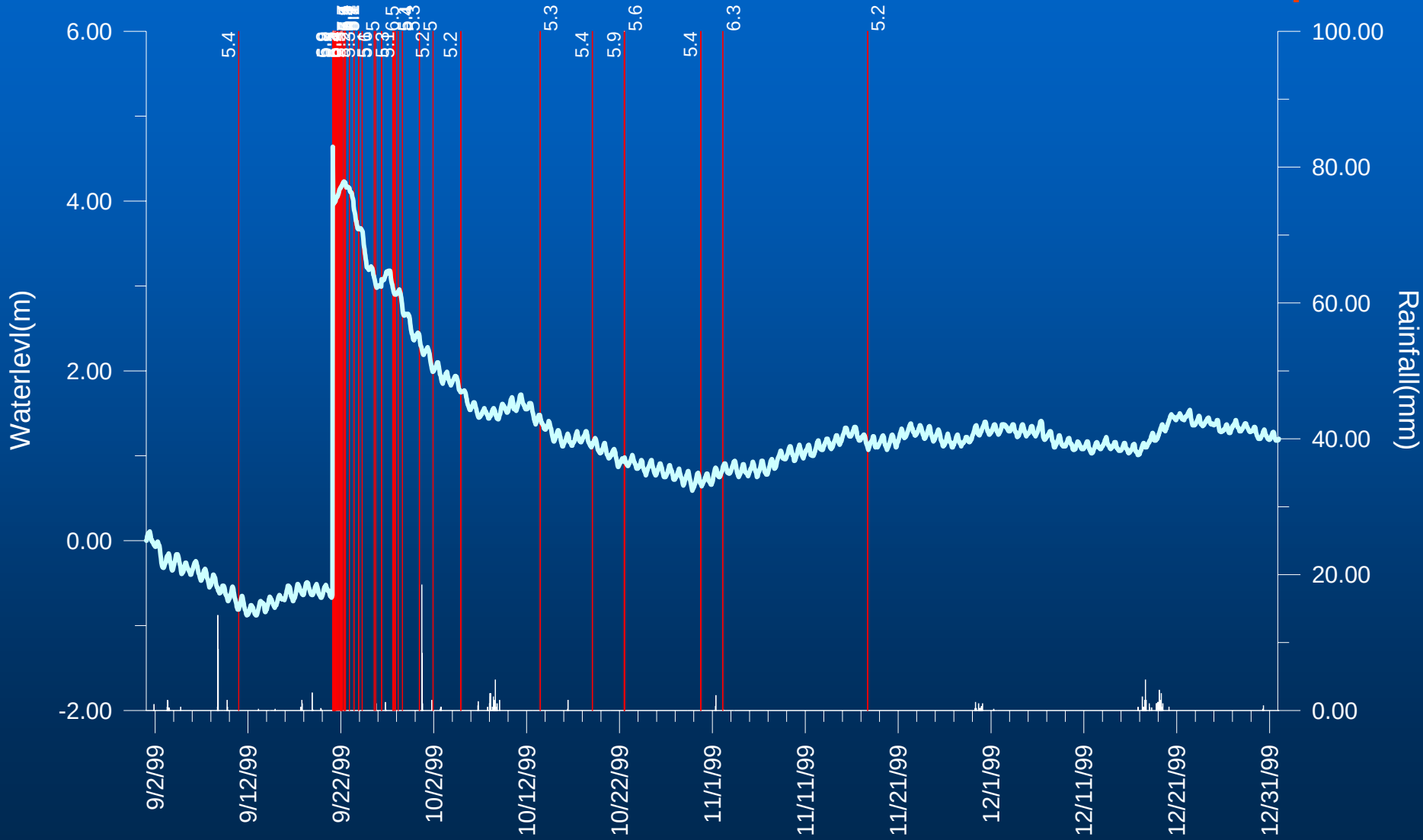
Data correction and analysis technique

Data publish Information system



Related earthquake prediction study

Coseismic Groundwater Level Changes in 1999 Chi-Chi Earthquake



Observation wells


Jiousi Hot Spring

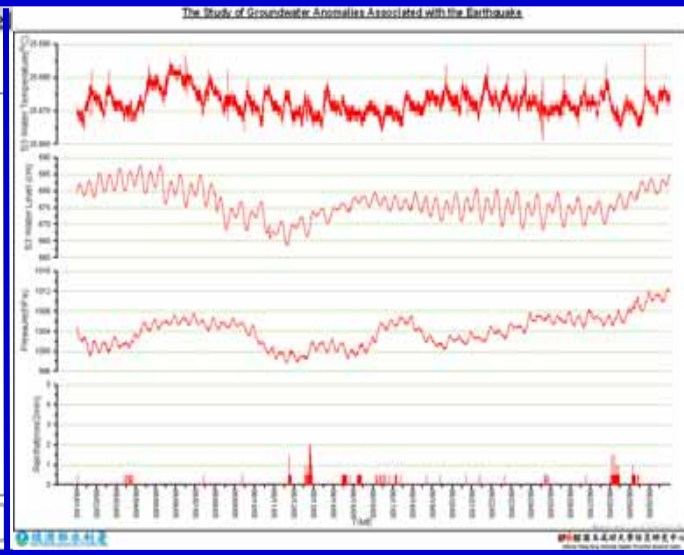

Siabantien St.


Jender St.

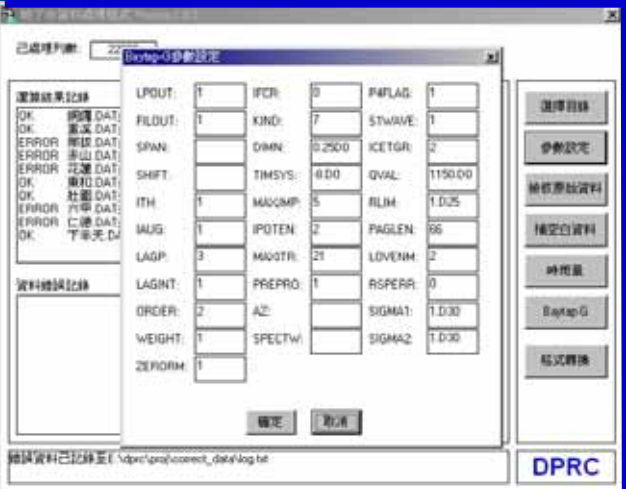

Chishan St.

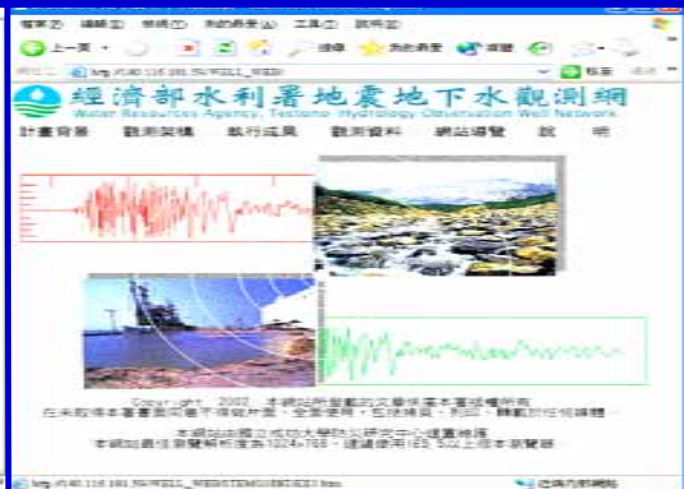
Automatic recording, analysis and anomalies detecting system

1.Recording → 2.QC, pre-processing → 3.Daily plots & reprot



4.Data filting → 5.Anomaly Dete. → 6.Results publication

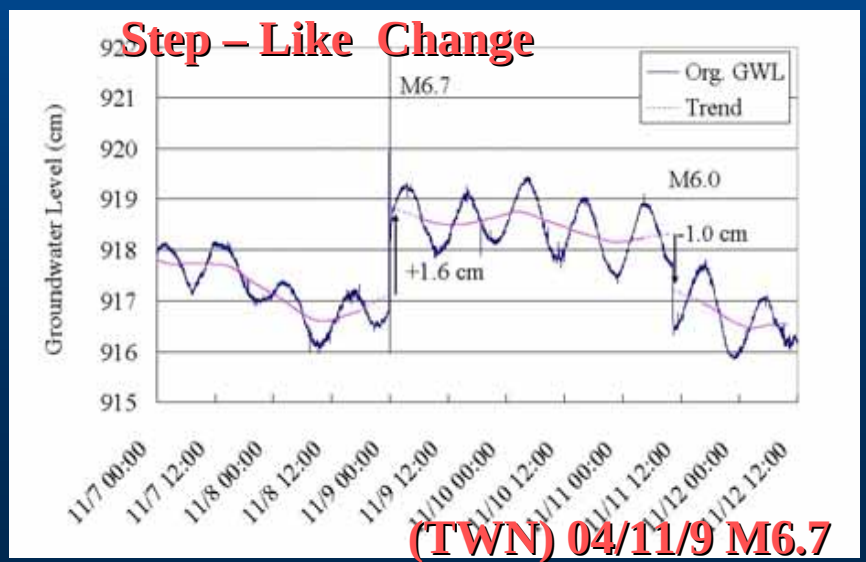


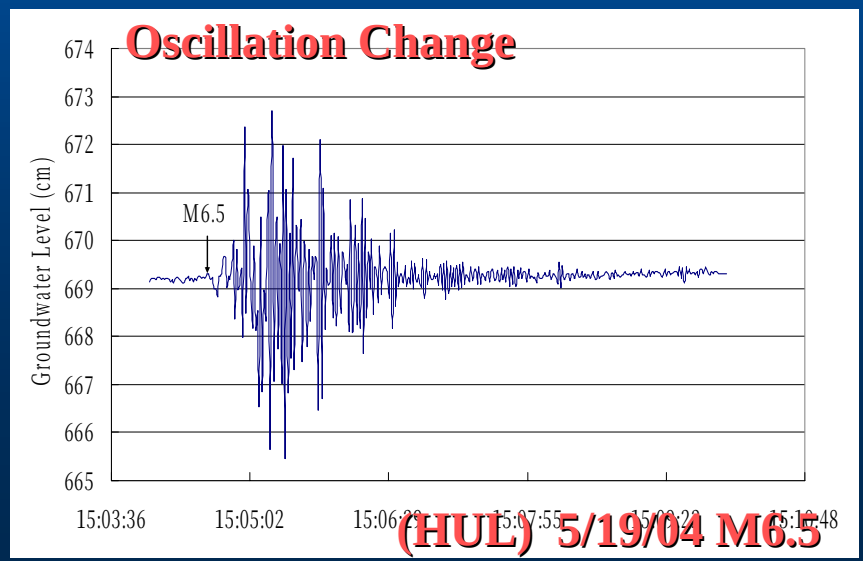


Observed coseismic events (03'~05')

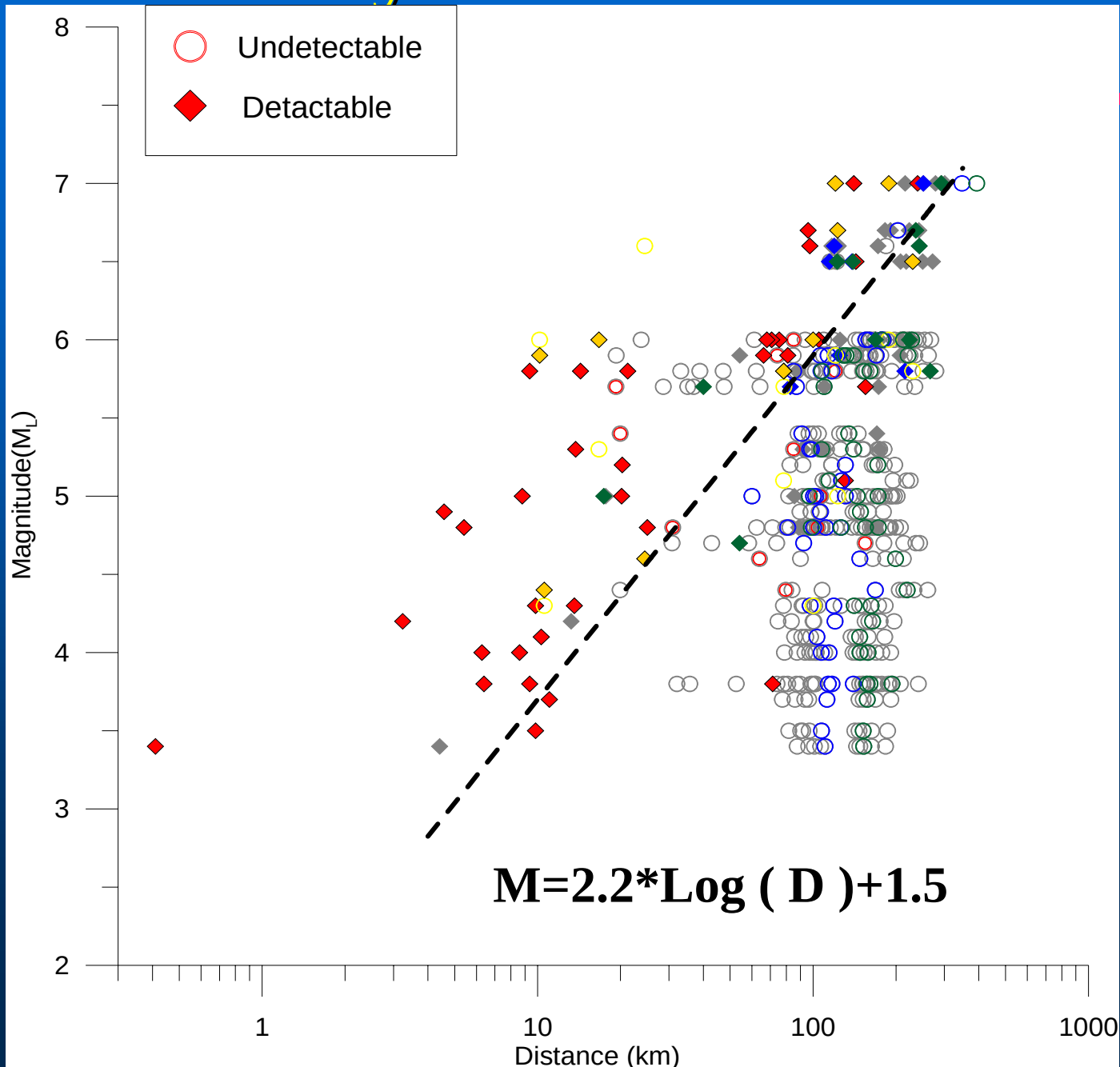
- Total 130 Observation, step changes (S) 32events, oscillation (O) 56 events, O+S 42 events

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	@	@	@	@	@	@	@





Criteria by the Moments & Distances



Obs. well

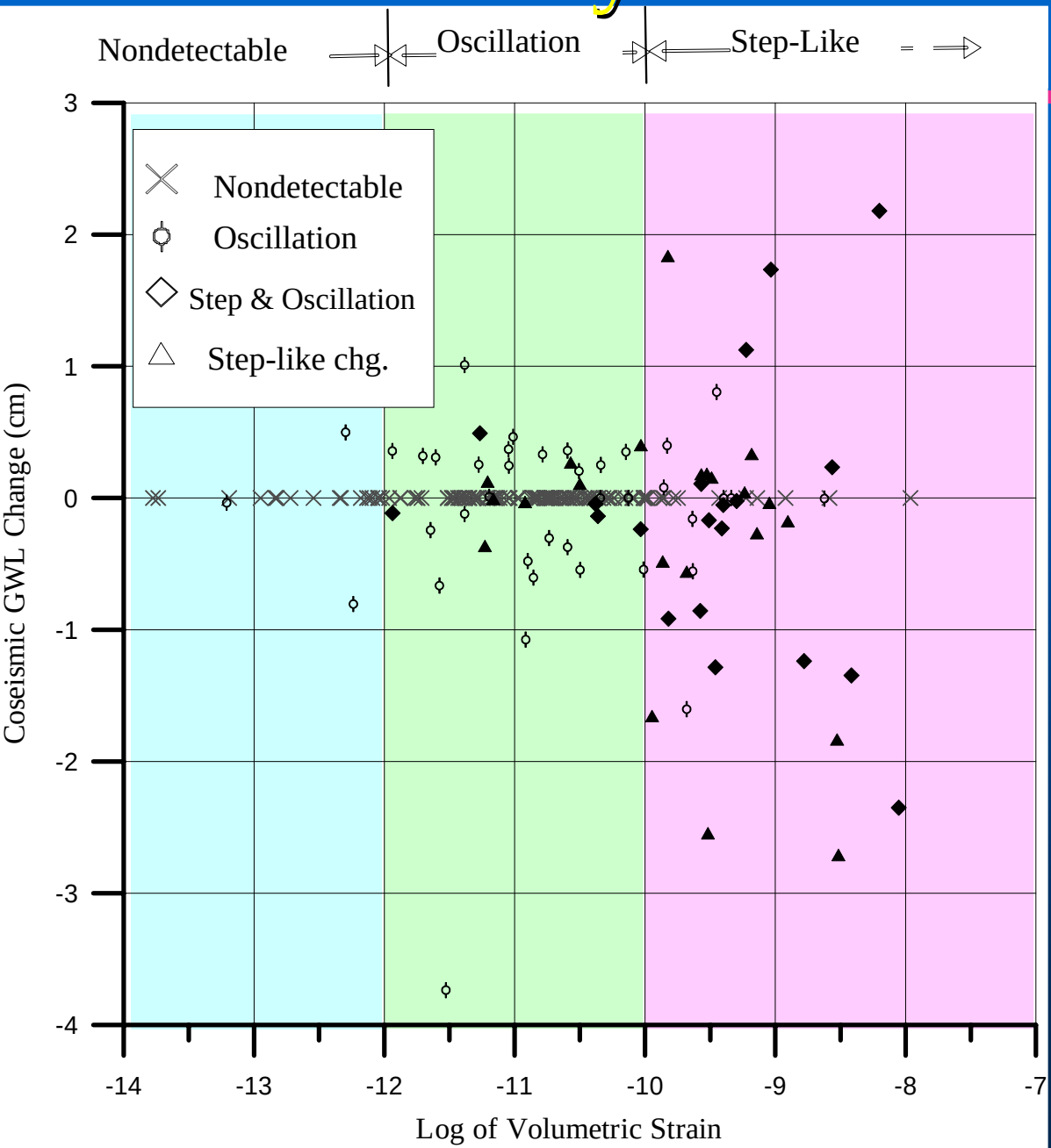
HUL

DHR

TWI

LUJ

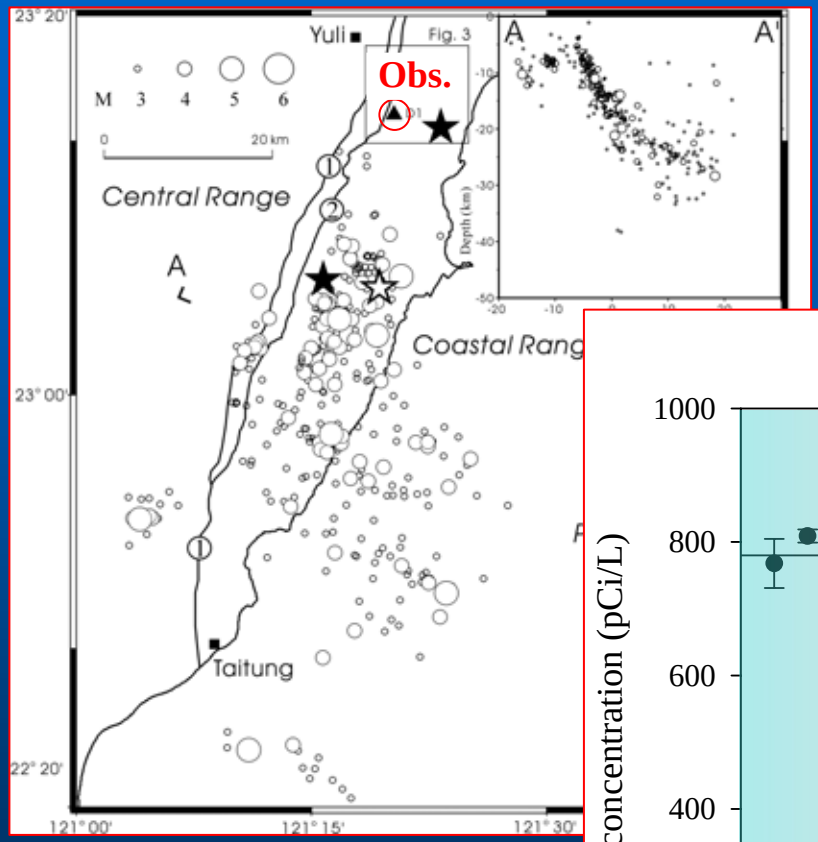
Criteria by the Volumetric Strain



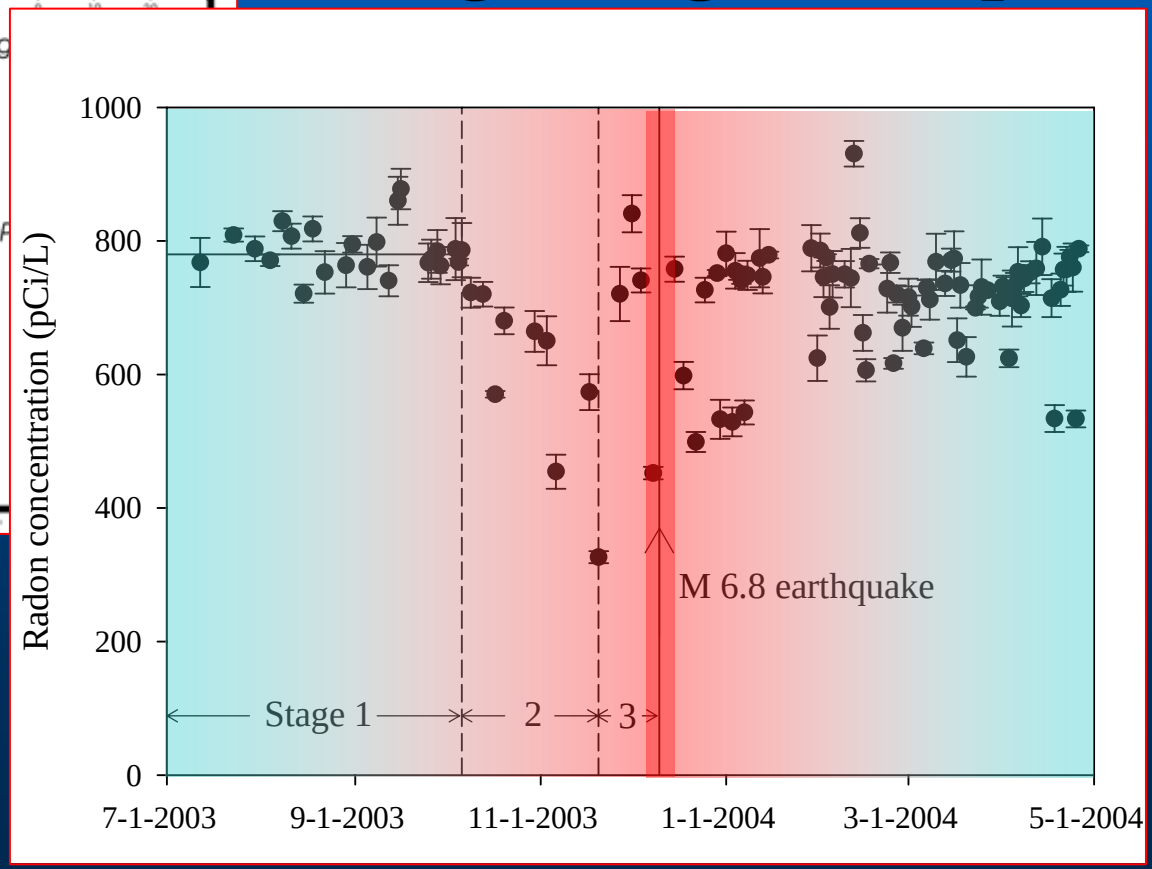
DPRC

- **Step-Like Chg.**
  - Vol. Strain: $>10^{-10}$
  - Amplitude: §1~3 cm
- **Oscillation**
  - Vol. Strain: $10^{-10}>>10^{-12}$
  - Amplitude: §0.2~1 cm
- **Nondetectable**
  - Vol. Strain: $10^{-12}>$
  - Amplitude: : >1 mm

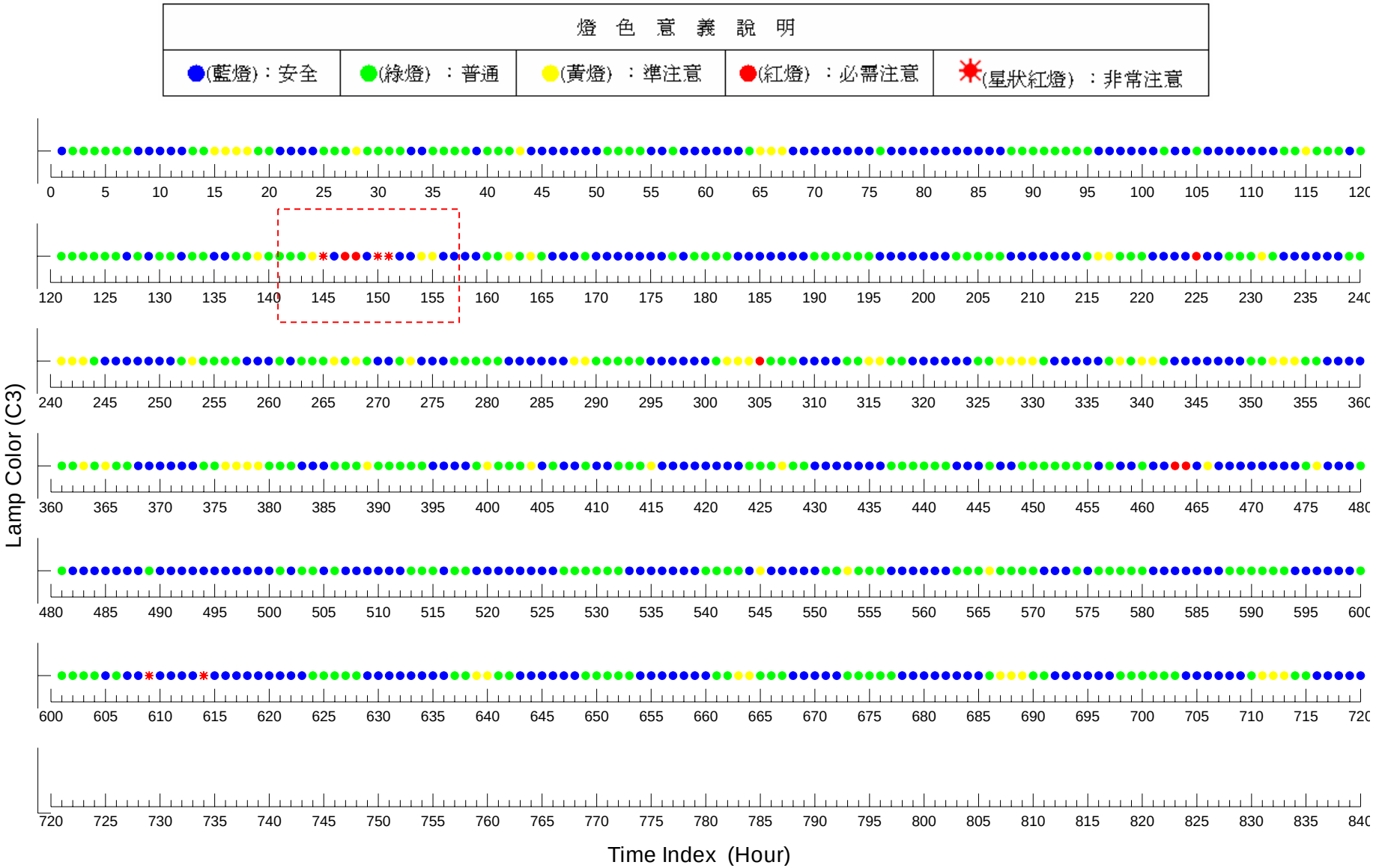
Preseismic anomaly: Radon



2003/12/10 M6.8
Cheng Kung Earthquake

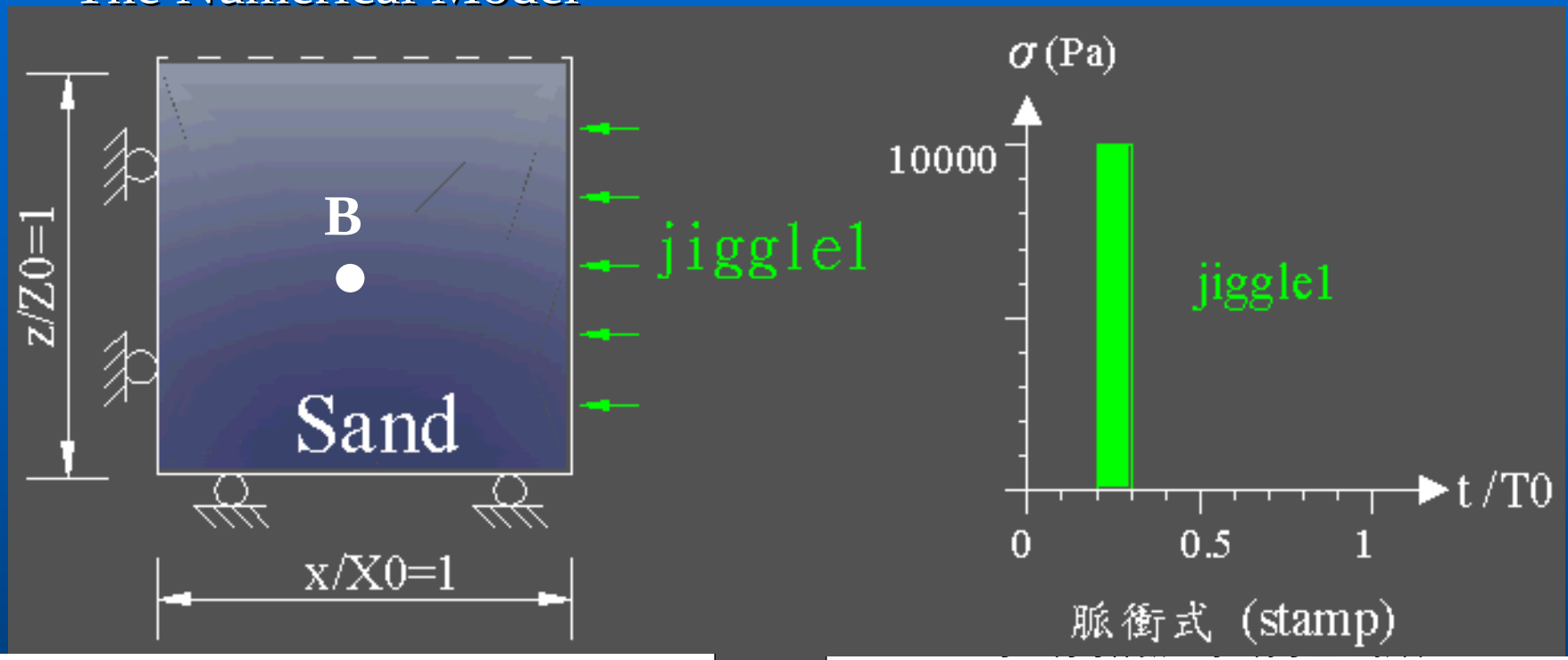


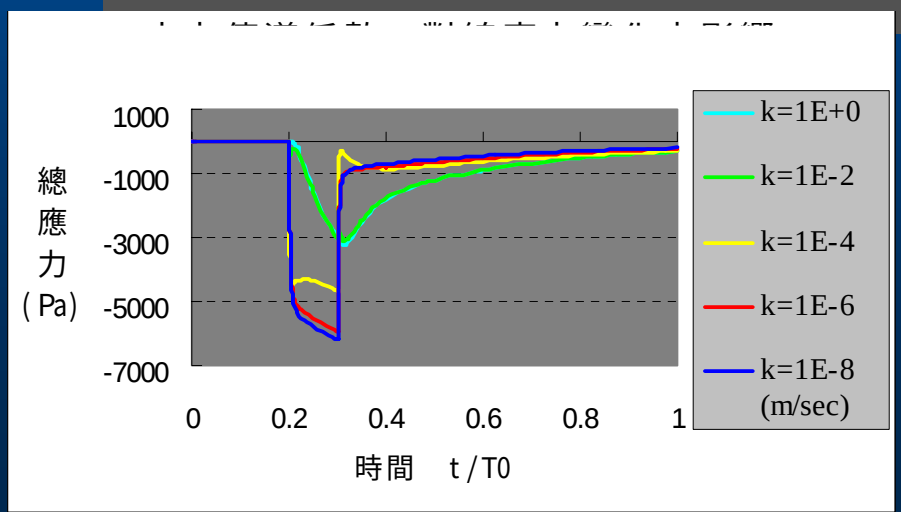
Item One: Time series anomaly detecting

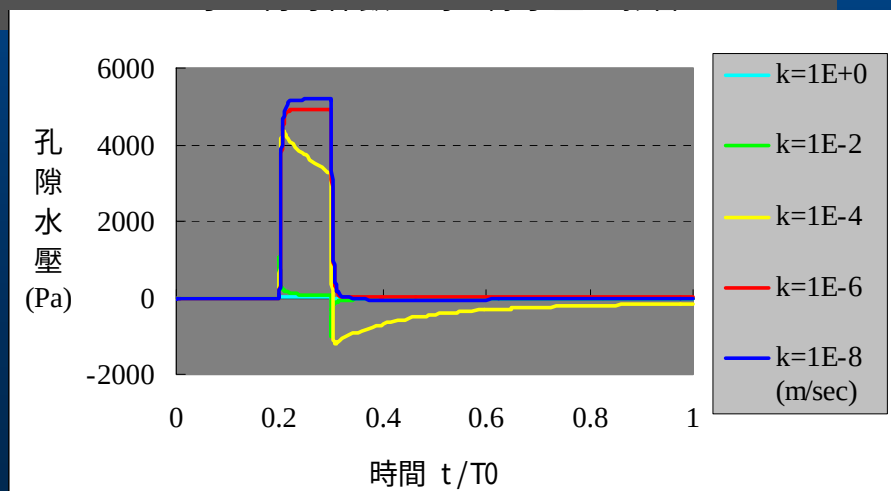


Item Two: Study of effects of ground motion

The Numerical Model

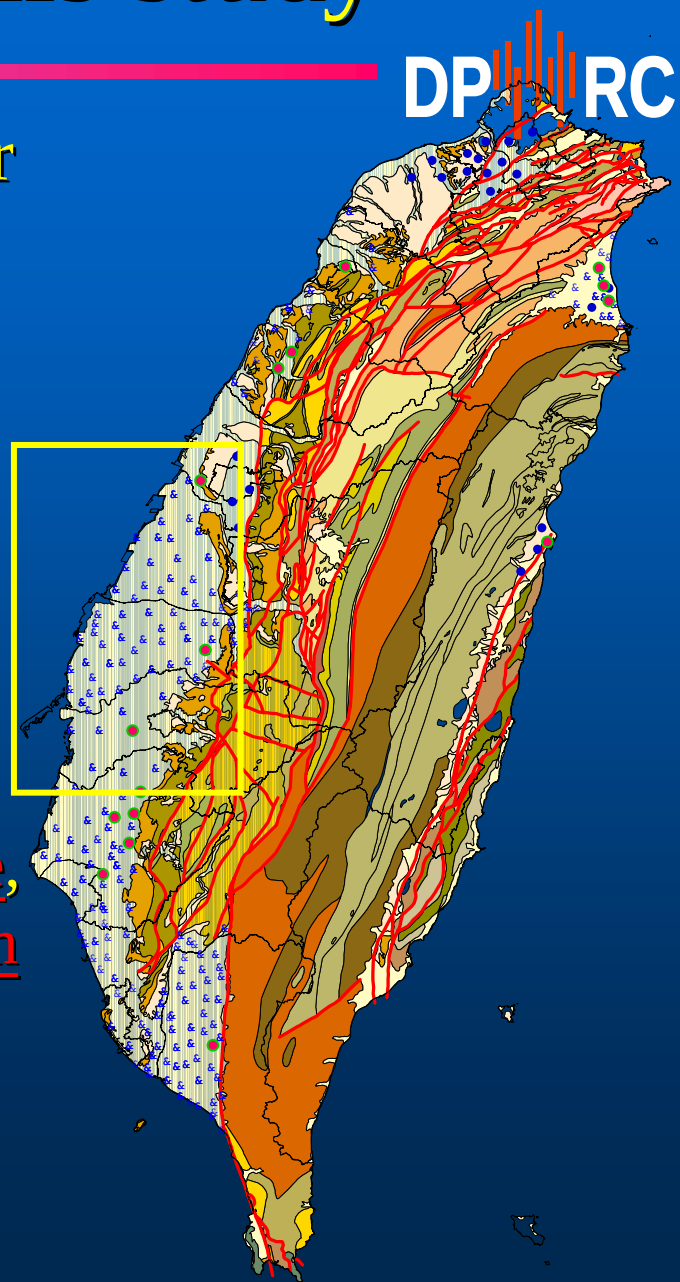






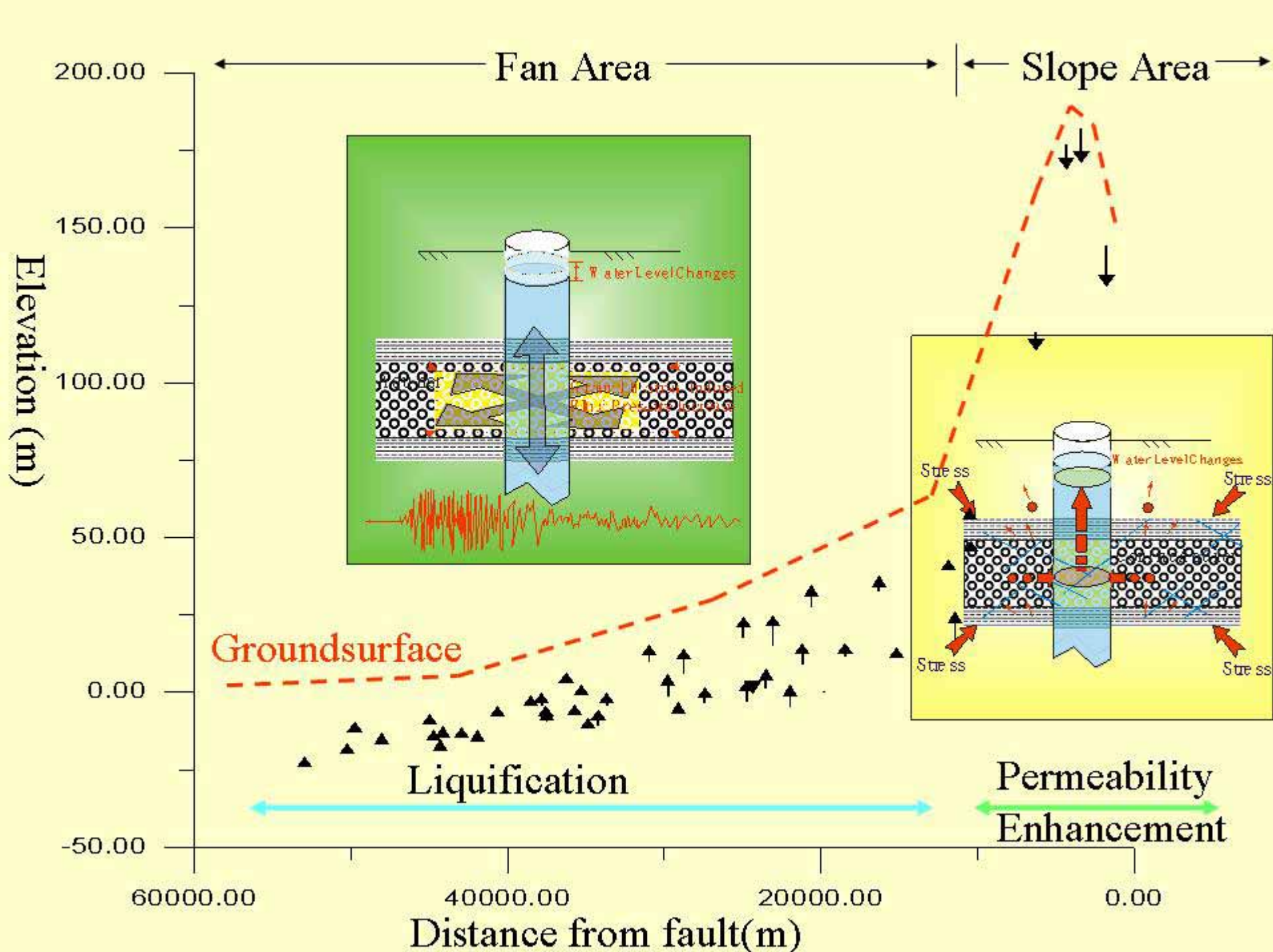
2.Introduction of this study

- High density monitoring network for water resources Groundwater Monitoring Networks of Taiwan
- Continuous observation from **1991**, management by Water Resource Agency and local divisions.
- The abundant observation dataset (water level, ground-motion, seismic wave, hydraulic conductivity, crustal deformation et al.,) in Sep. 21, 1999 Earthquake.



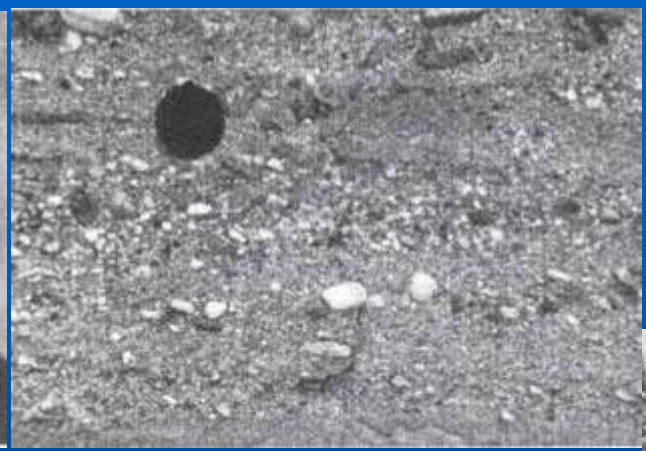
3.Motivation

- Previously work (Lai et al., 2004) the coseimic water level changes were contributed by the liquefaction in fan area, and the permeability enhancement in the slope area.
- This study will focus on the quantitative analysis of the similarity in the spatial distribution of each parameter.
- This study want to examine the spatial relationship between well level change/ volumetric strain/ ground motion/ hydraulic conductivity, to testify the mechanism of the coseismic groundwater level changes in Chi-Chi Earthquake, Sep. 21, 1999.


Fan Area
Slope Area
200.00
150.00
100.00
50.00
0.00
-50.00
Elevation (m)
Water Level Changes
Groundsurface
Stress
Stress
Stress
Stress
Liquification
Permeability
Enhancement
60000.00
40000.00
20000.00
0.00
Distance from fault(m)

3.Motivation: Heterogeneity in the nature

Darcy scale 1cm



Local scale, 1m

Field scale 100m

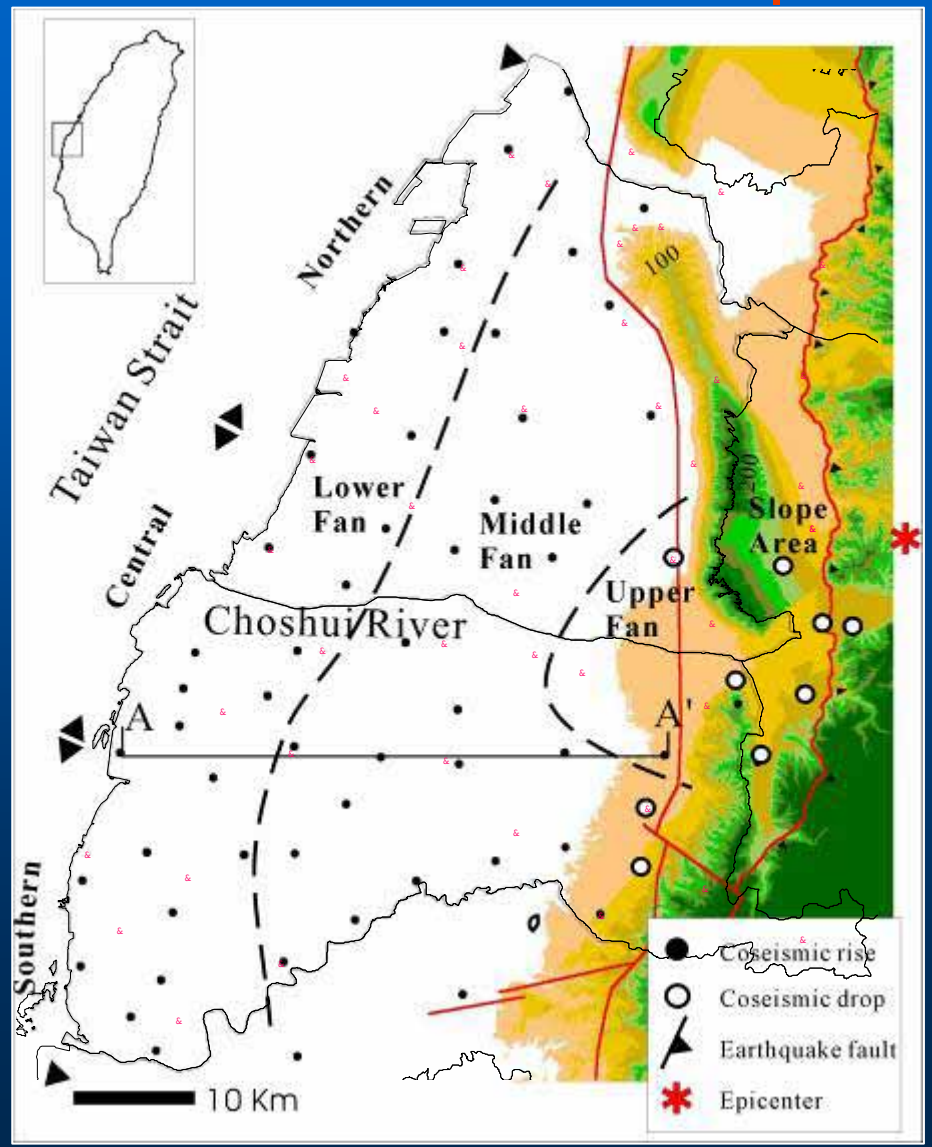
Basin scale, 10-100km

Sub-Basin scale, 1km

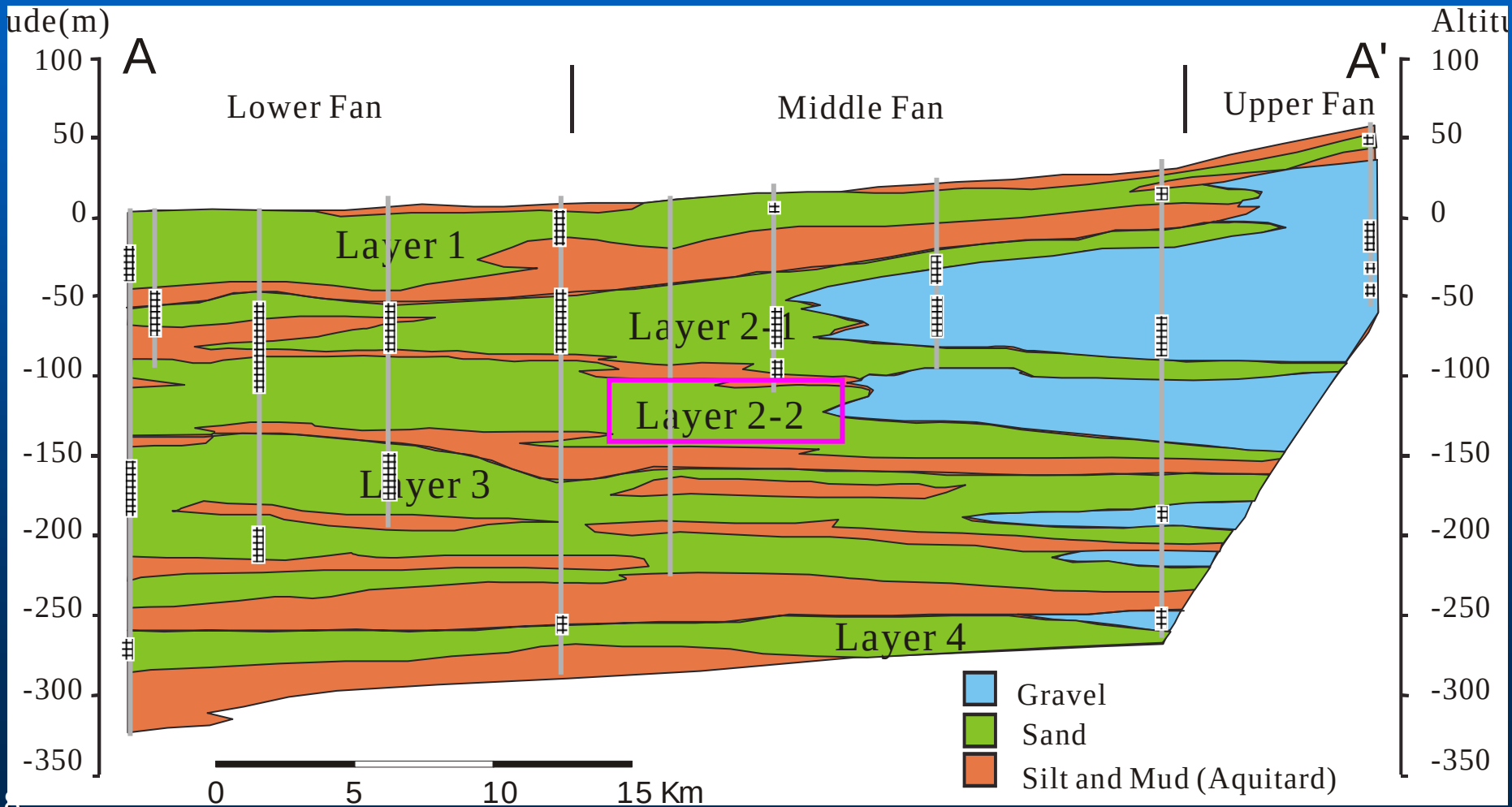
(Harter, 2001)

Study Area: Choshui river alluvial fan

- Location: Choshui river, Central Taiwan
- Dimension: typical fan shape, 90 km in length, 40km in width ⨯ the area around 2000 km^2 ·
- Observation: totally 177 wells in 70 observation station. 46 ground accelerator installed in the area.

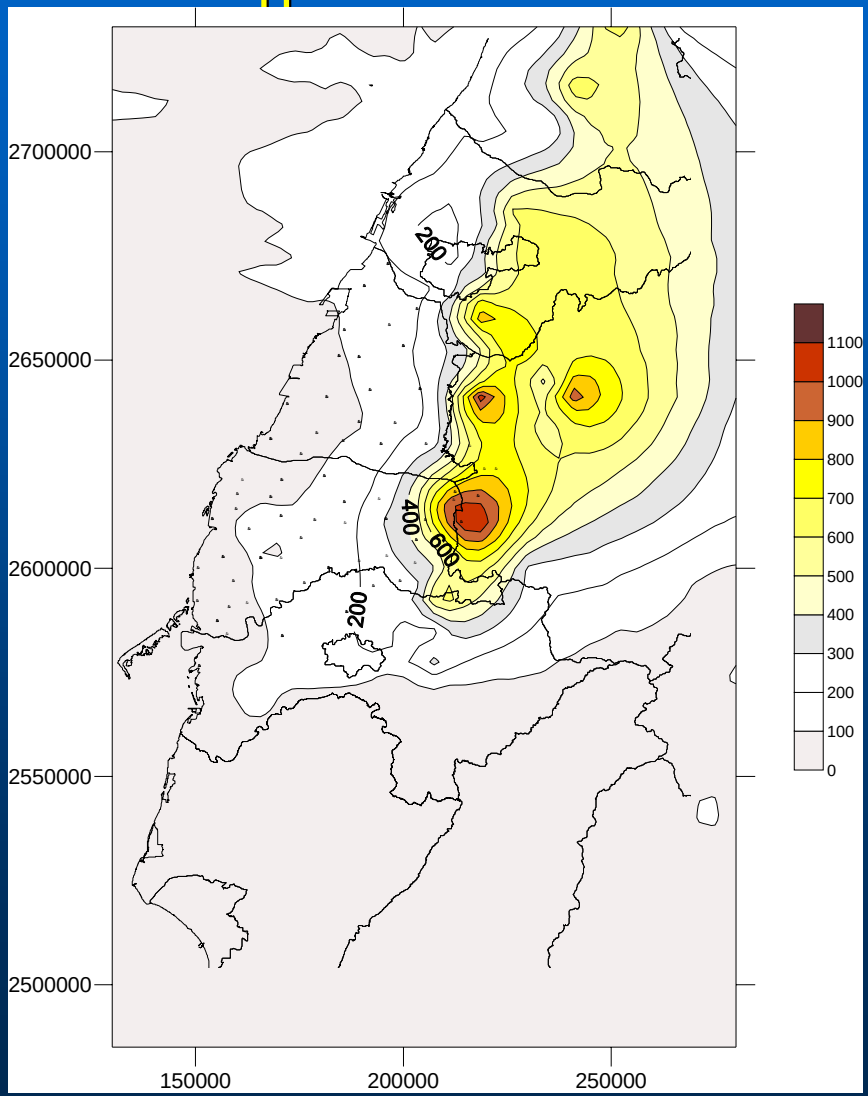


Hydrogeology of Choshui river alluvial fan

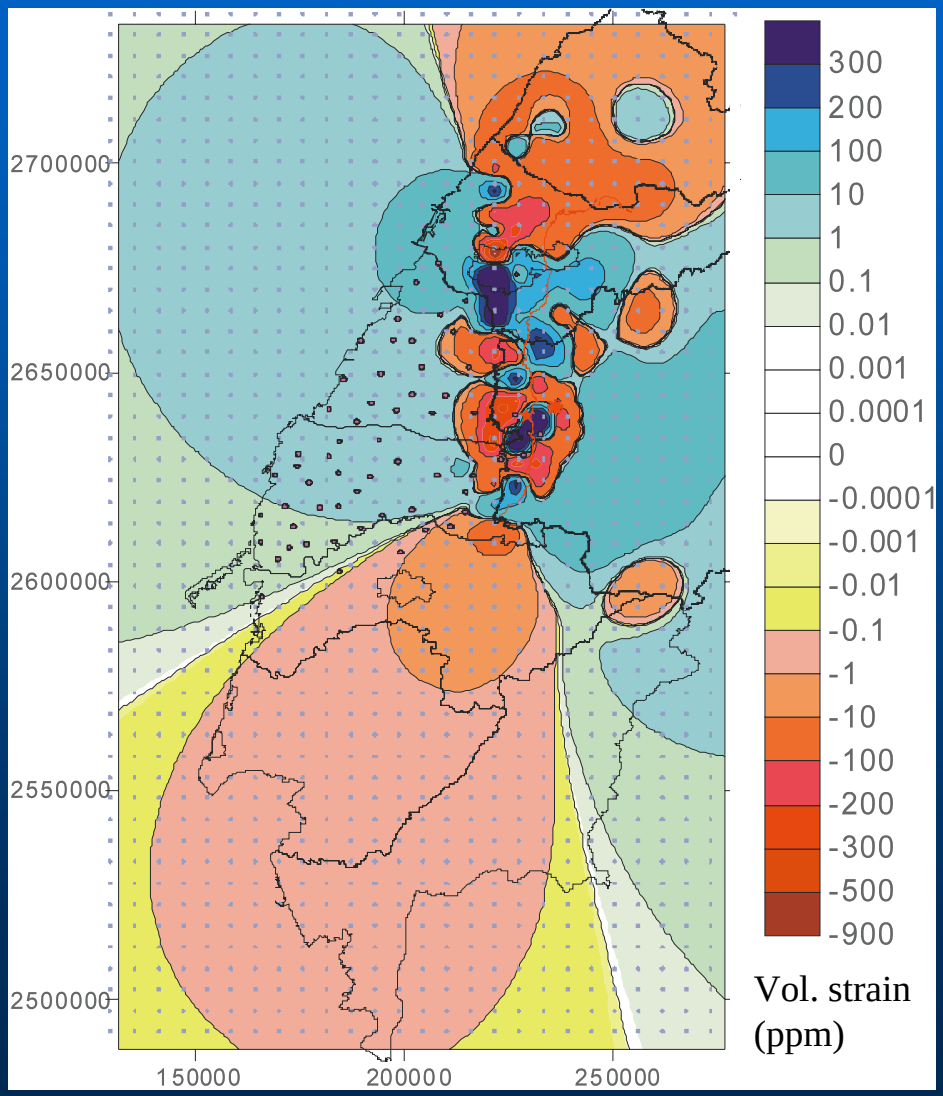


Spatial distribution (P.G.A. and Vol. strain)

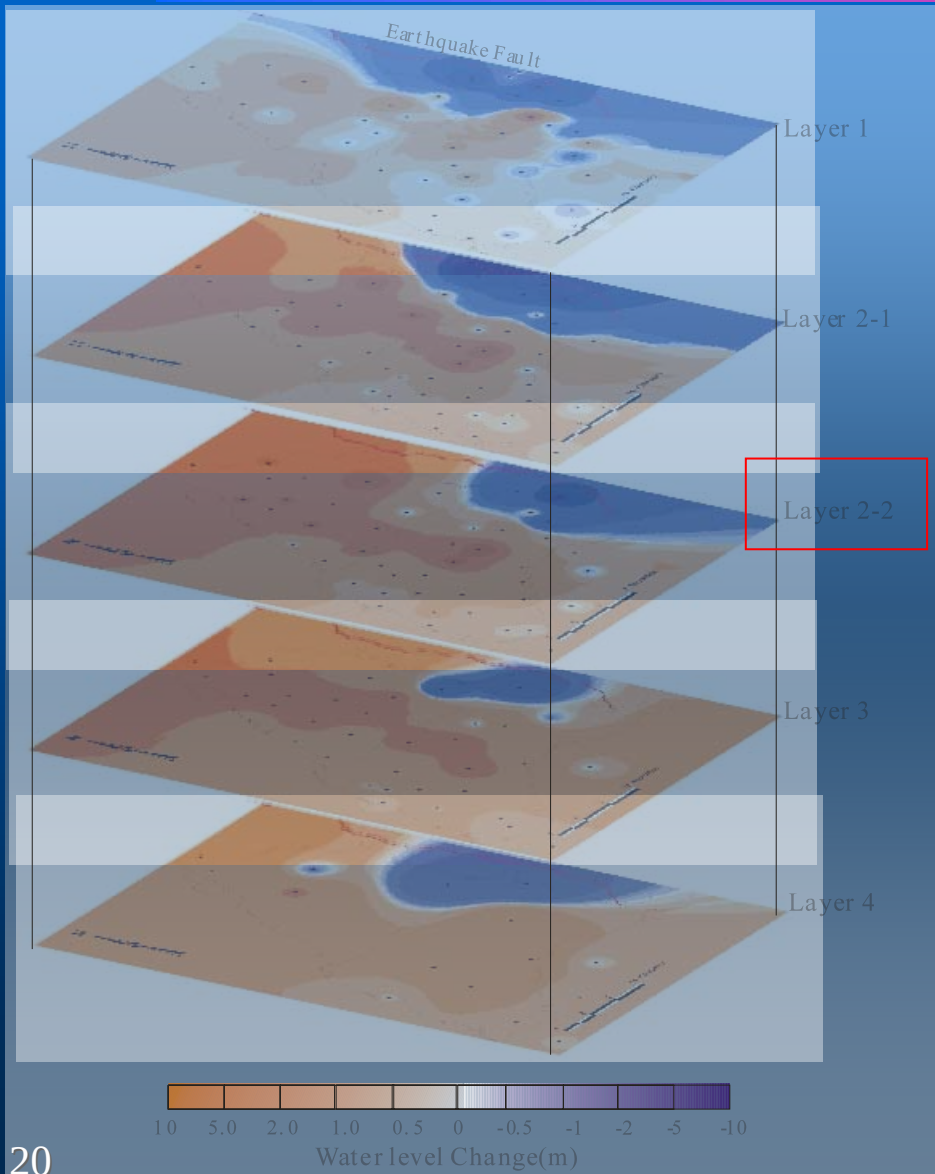
- PGA_H

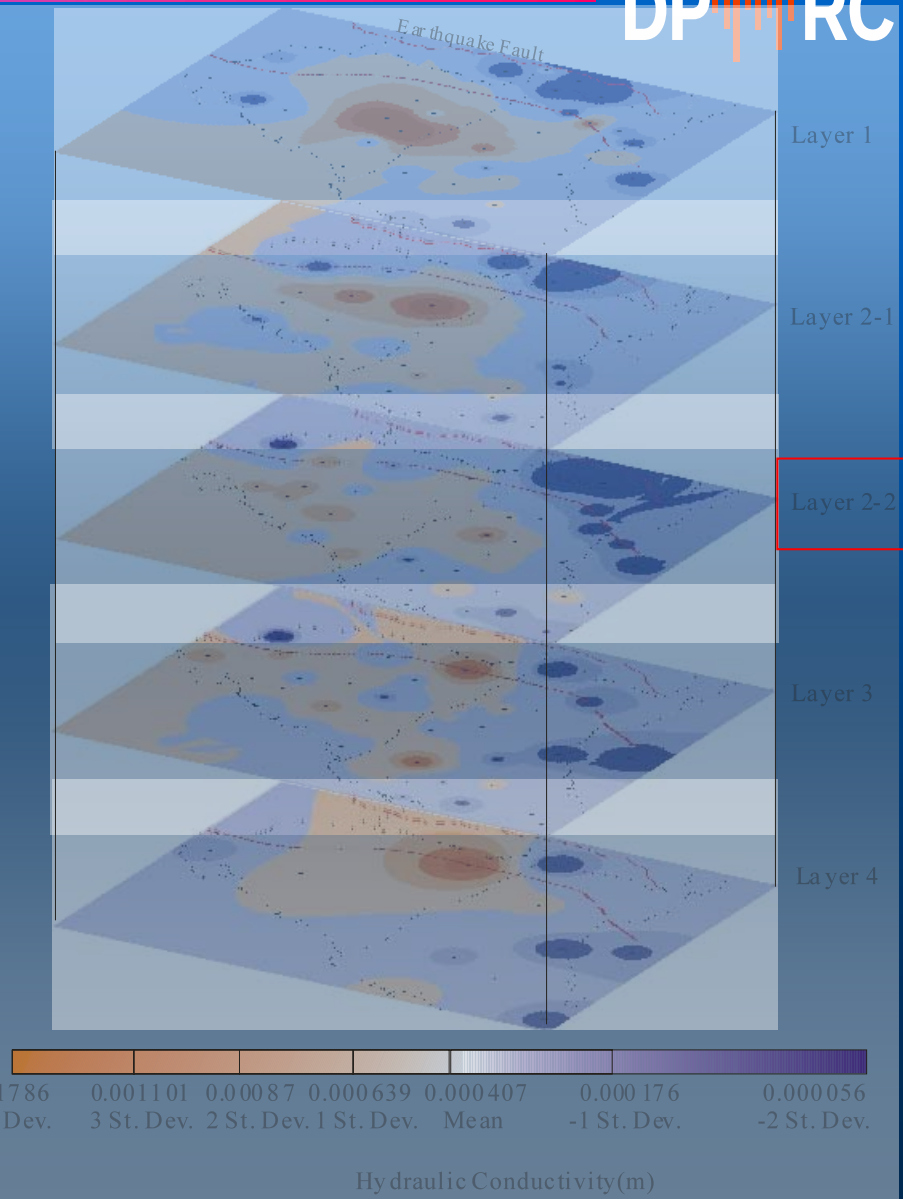


- Volumetric strain



Spatial distribution(G.W.L. and K)



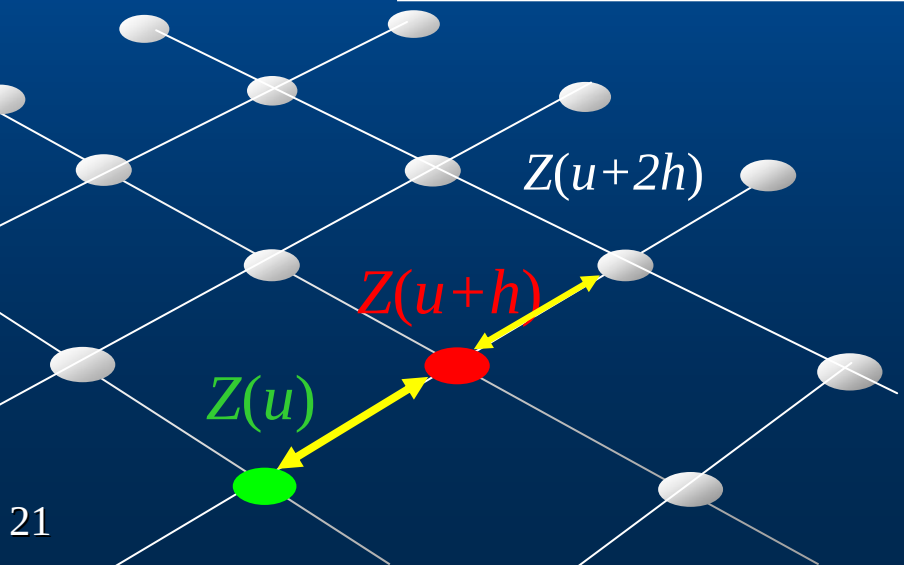


4.Methdology (1/2)

- **Variogram (~ autocorrelation in space)**

The variogram is a measure of dis-similarity between two points in space separated by a distance *h*.

$$2\gamma(h) = Var\left[Z(u+h) - Z(u)\right] \quad (1)$$



2末(*h*): Variogram value

Z(*u*): value of the specified variate

Z(*u*+*h*): value with spacing *h*

Var [ ]: variance operator

4.Methdology (2/2)

- **Cross semi-variogram and correlogram**

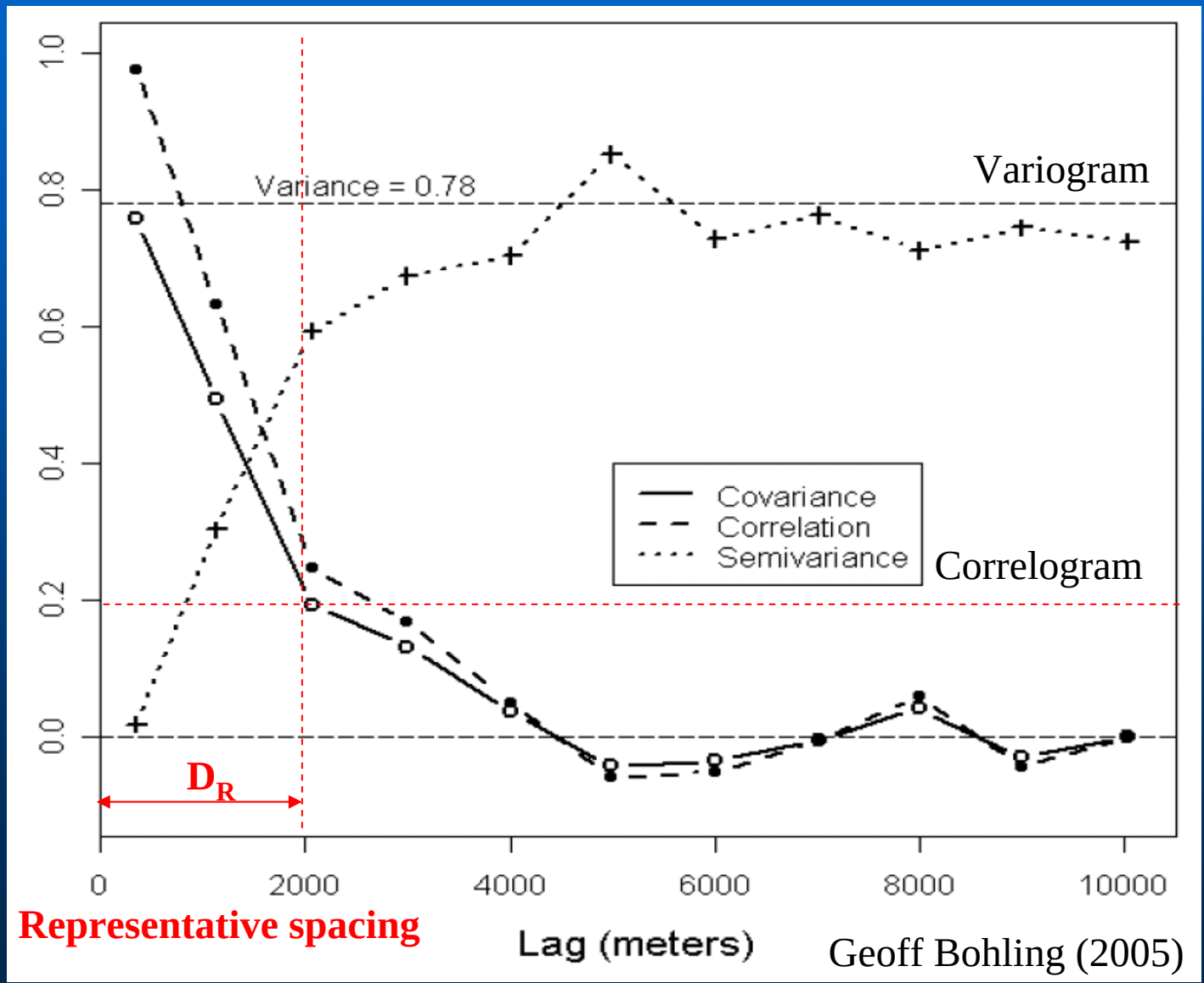
(~ cross correlation in space)

The cross semivariogram measure the variability of two different attributes and cross correlogram measures the similarity. The correlogram are defined for two different attributes X and Y as

$$\rho(h) = \frac{C(h)}{\sigma_{-h}\sigma_{+h}} = \frac{\frac{1}{N(h)}\sum_{i=1}^{N(h)} x_i y_i - m_{-h}m_{+h}}{\sqrt{\frac{1}{N(h)}\sum_{i=1}^{N(h)} x_i^2 - m_{-h}^2}\sqrt{\frac{1}{N(h)}\sum_{i=1}^{N(h)} y_i^2 - m_{+h}^2}} \quad (2)$$

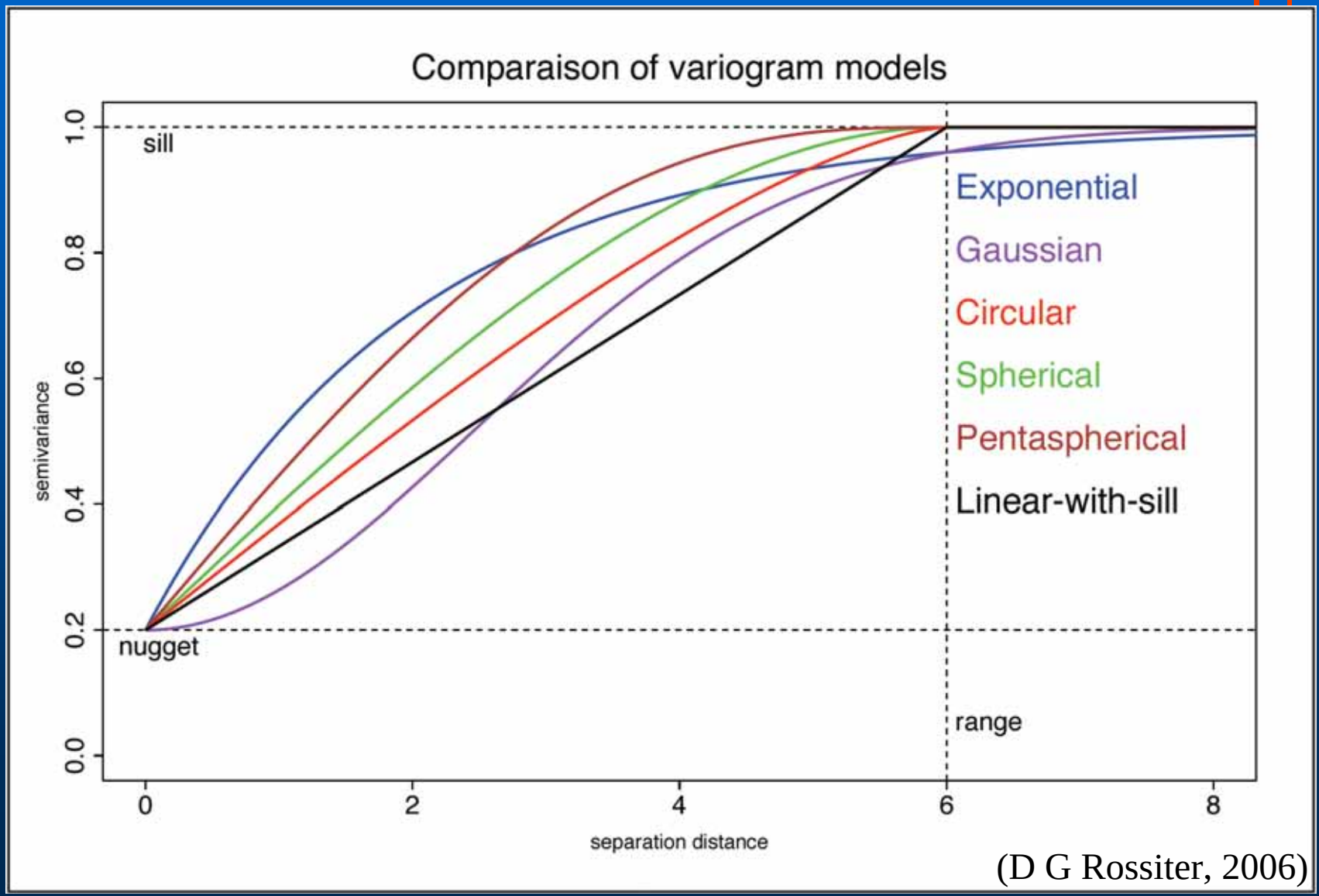
Where m_{-h}, m_{+h} is the mean values of X and Y in spacing h, respectively.

Example of the variogram & correlogram



Geoff Bohling (2005)

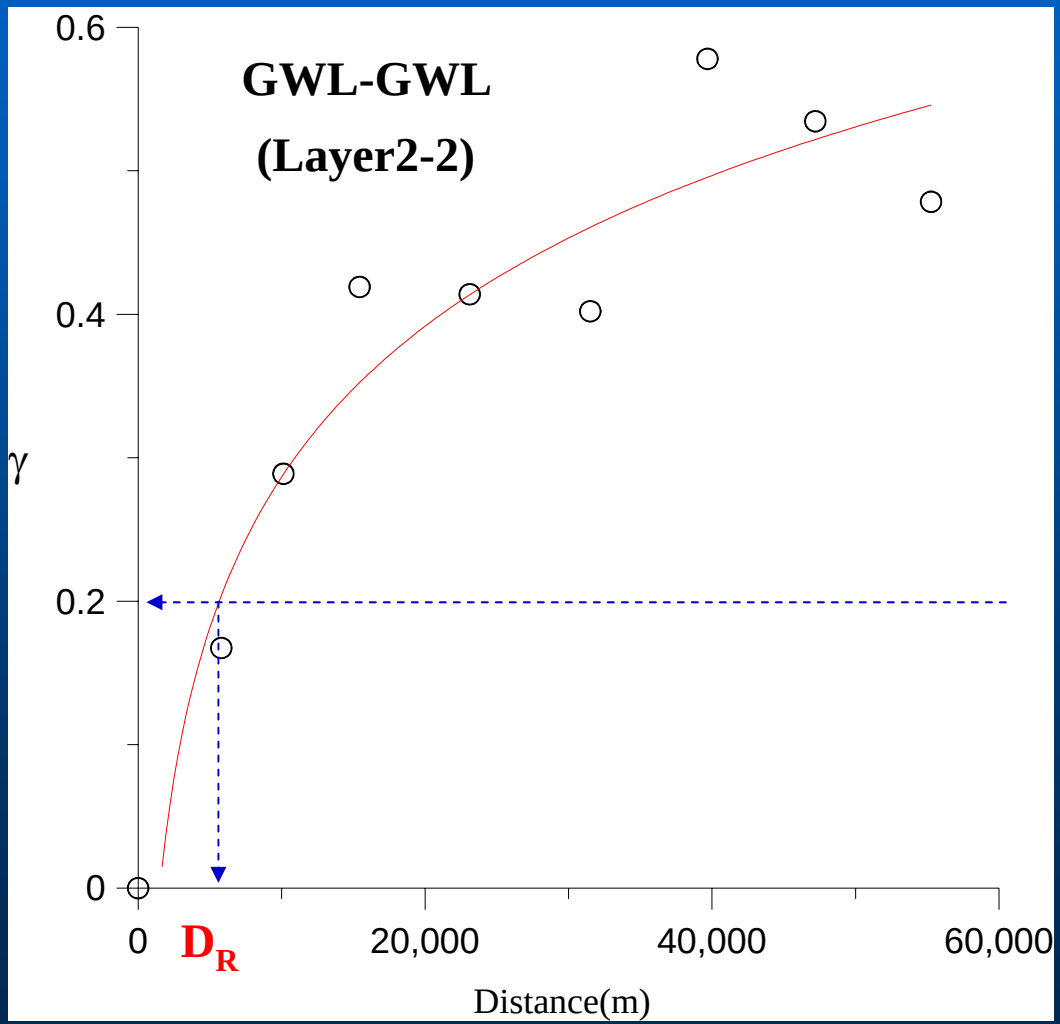
Type of the variogram



(D G Rossiter, 2006)

5. Variogram: Well level change

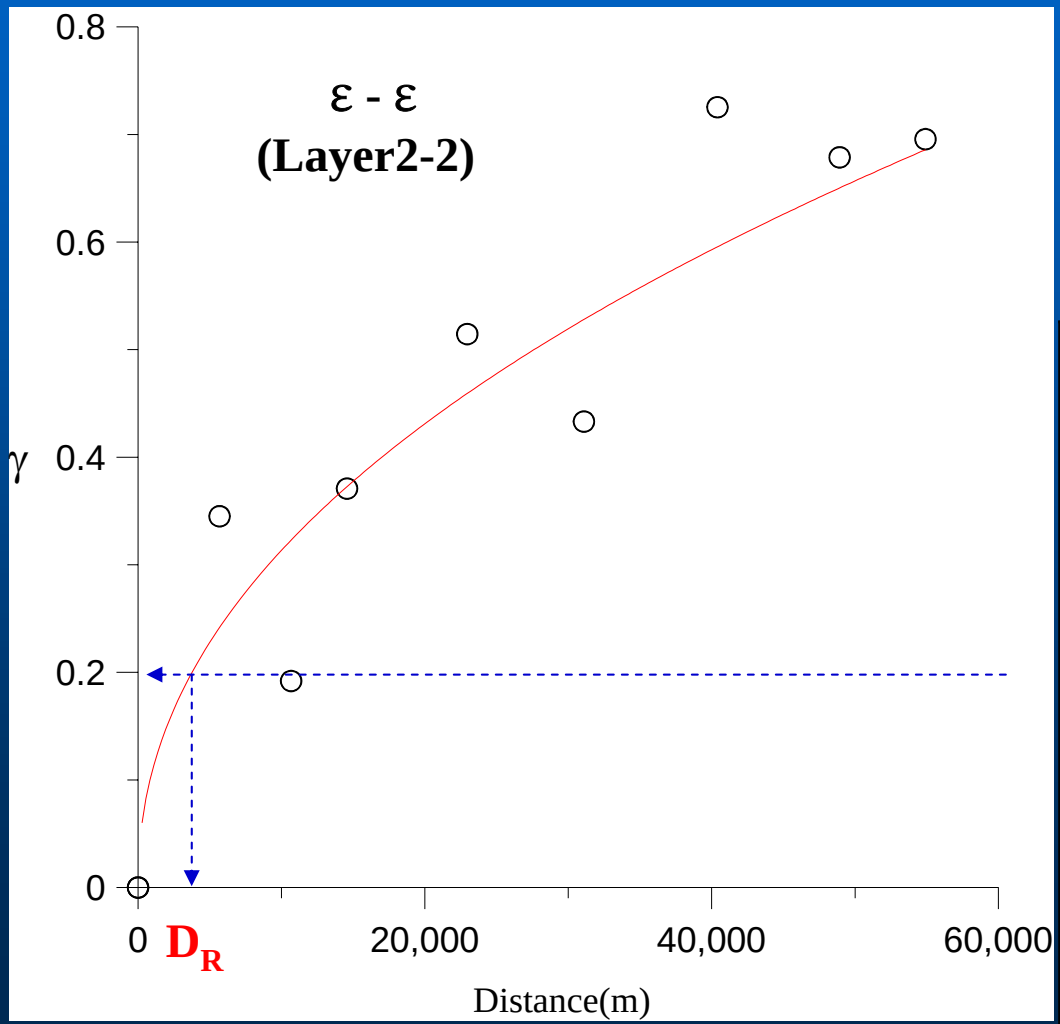
- Type: Exponential
- D_R: ~ 5000 m



Lag	Distance	Variogram	Pairs_lag
1	0	0	33
2	5795.773	0.1674	4
3	10126.78	0.28881	19
4	15435.23	0.41905	29
5	23111.16	0.41393	24
6	31512.47	0.40208	19
7	39681.22	0.57805	18
8	47196.69	0.53454	16
9	55261.96	0.4784	11

5. Variogram: Volumetric strain

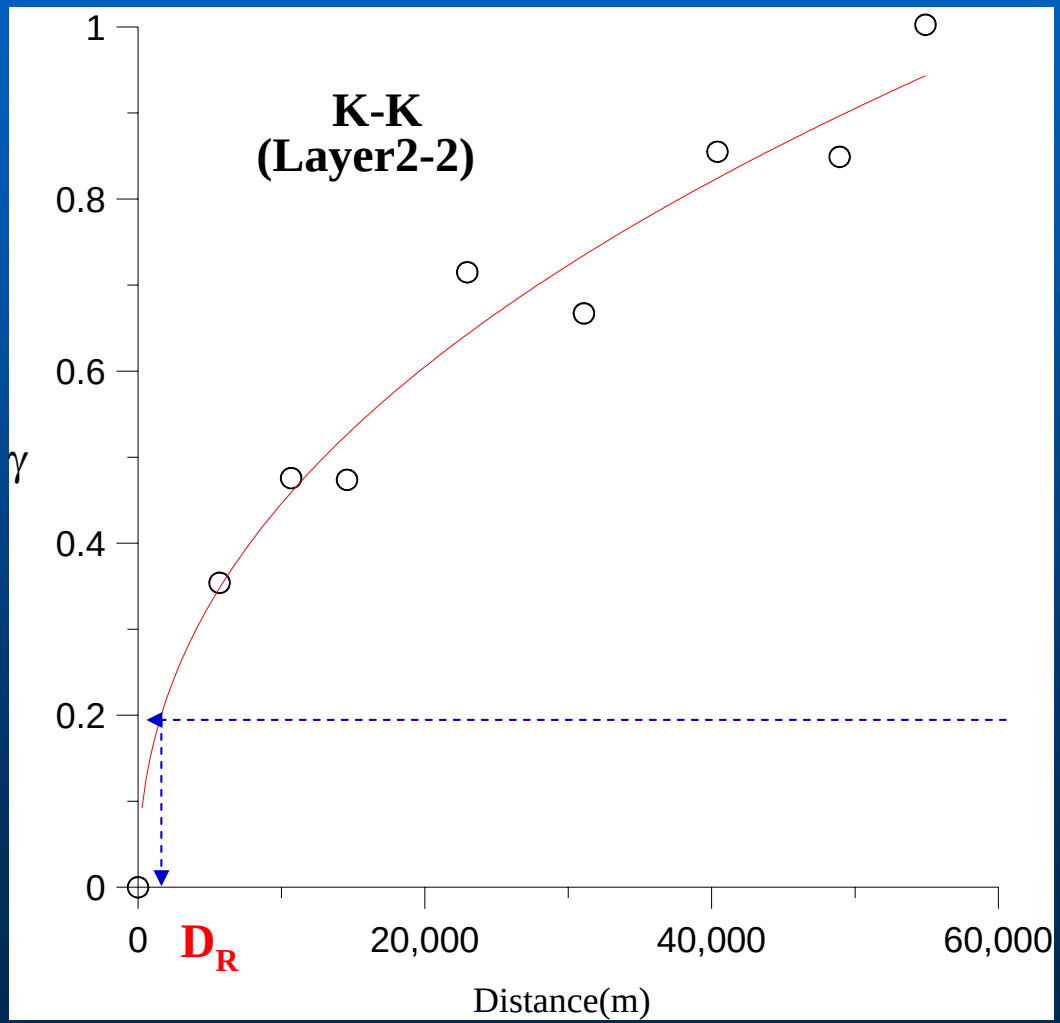
- Type: Exponential
- D_R: ~ 3000 m



Lag	Distance	Variogram	Pairs_lag
1	0	0	33
2	5685.103	0.34508	3
3	10674.23	0.19197	15
4	14573.2	0.37081	20
5	22960.27	0.5144	16
6	31096.73	0.43309	13
7	40407.7	0.7253	9
8	48924.89	0.67873	11
9	54913.88	0.69555	11

5.Variogram: Hydraulic conductivity

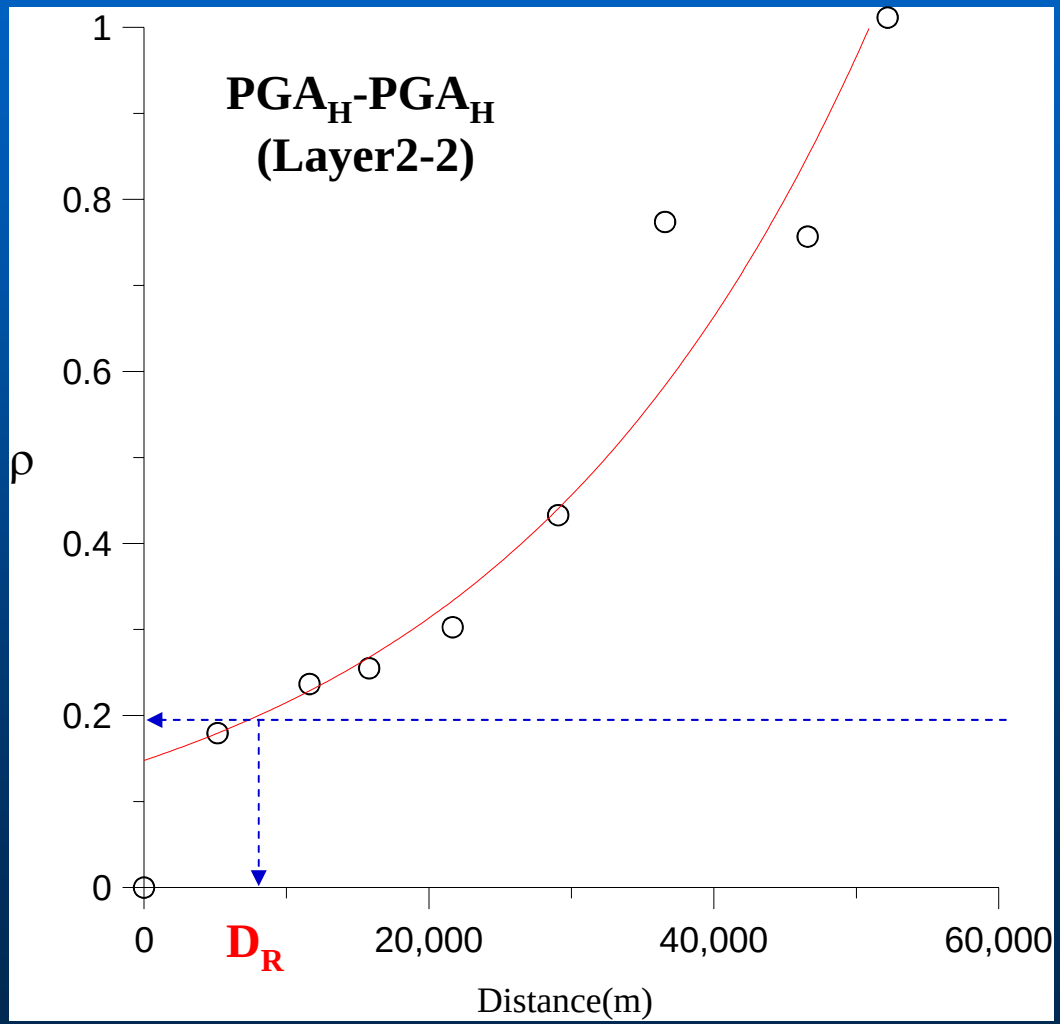
- Type: Exponential
- D_R: **~ 1500 m**



Lag	Distance	Variogram	Pairs_lag
1	0	0	33
2	5685.103	0.35394	3
3	10674.23	0.4756	15
4	14573.2	0.47363	20
5	22960.27	0.71492	16
6	31096.73	0.66709	13
7	40407.7	0.85502	9
8	48924.89	0.84909	11
9	54913.88	1.00261	11

5.Variogram: Peak Ground Acceleration

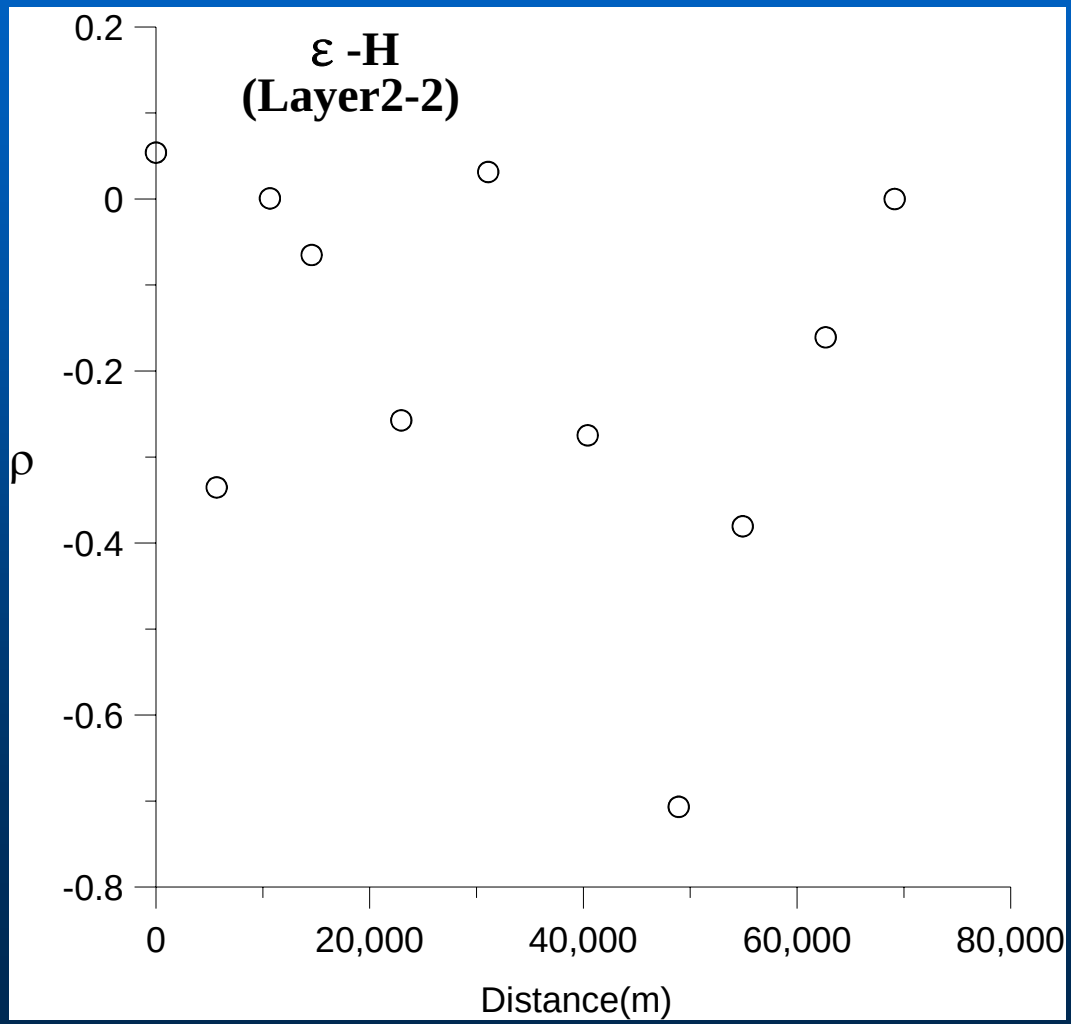
- Type: **Gaussian**
- D_R: **~ 8000 m**



Lag	Distance	Variogram	Pairs_lag
1	0	0	33
2	5163.839	0.17954	2
3	11616.95	0.23664	11
4	15804.24	0.25486	19
5	21666.09	0.30264	16
6	29074.08	0.43286	8
7	36575.18	0.7737	3
8	46582.96	0.75673	2
9	52197.47	1.01129	1

6. Correlgram: Volumetric strain-Water level

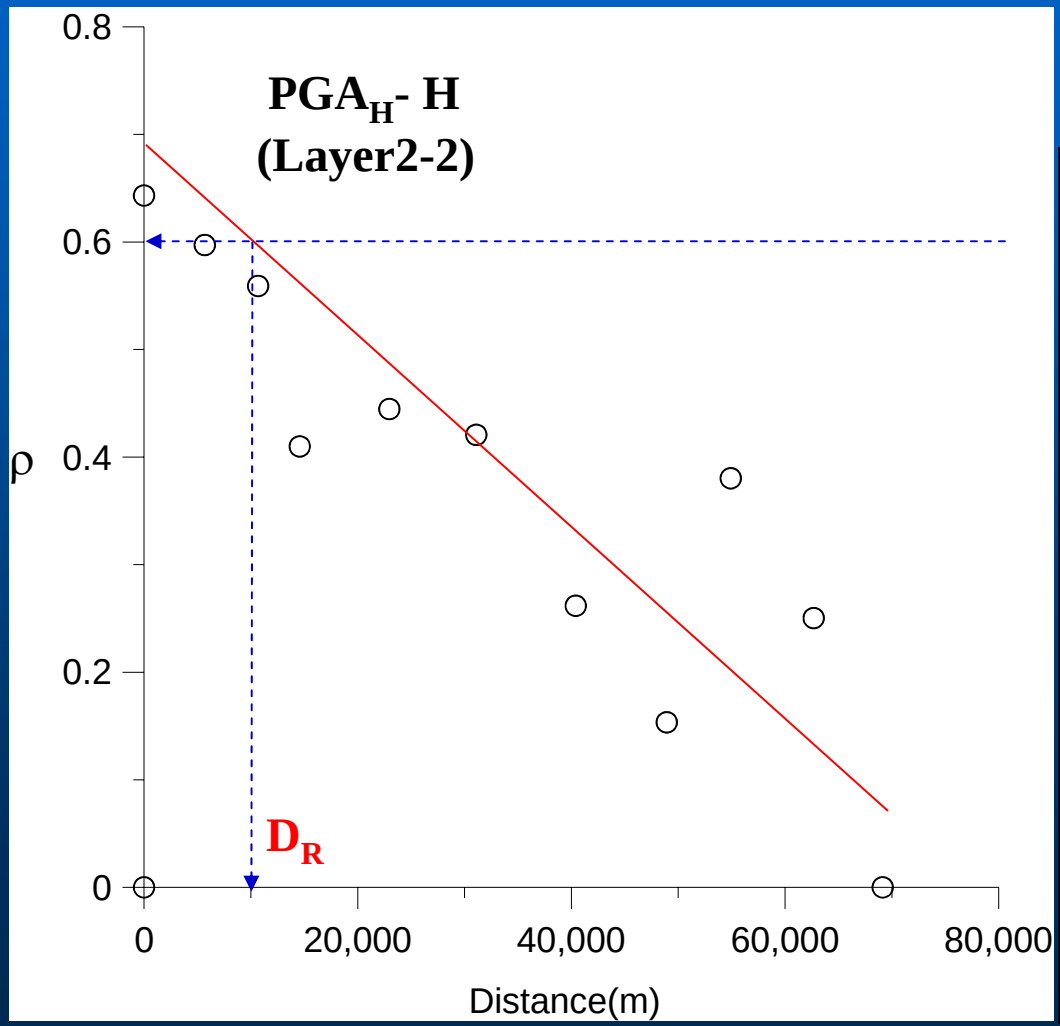
- Type: **None**
- D_R: **None**



Lag	Distance	Correlogram	Pairs_lag
1	0	0.05395	33
2	5685.103	-0.33529	3
3	10674.23	0.00074	15
4	14573.2	-0.06506	20
5	22960.27	-0.25735	16
6	31096.73	0.03143	13
7	40407.7	-0.27478	9
8	48924.89	-0.7067	11
9	54913.88	-0.38053	11
10	62676.08	-0.16081	5
11	69131.2	0	1

6. Correlgram: PGA_H-GWL

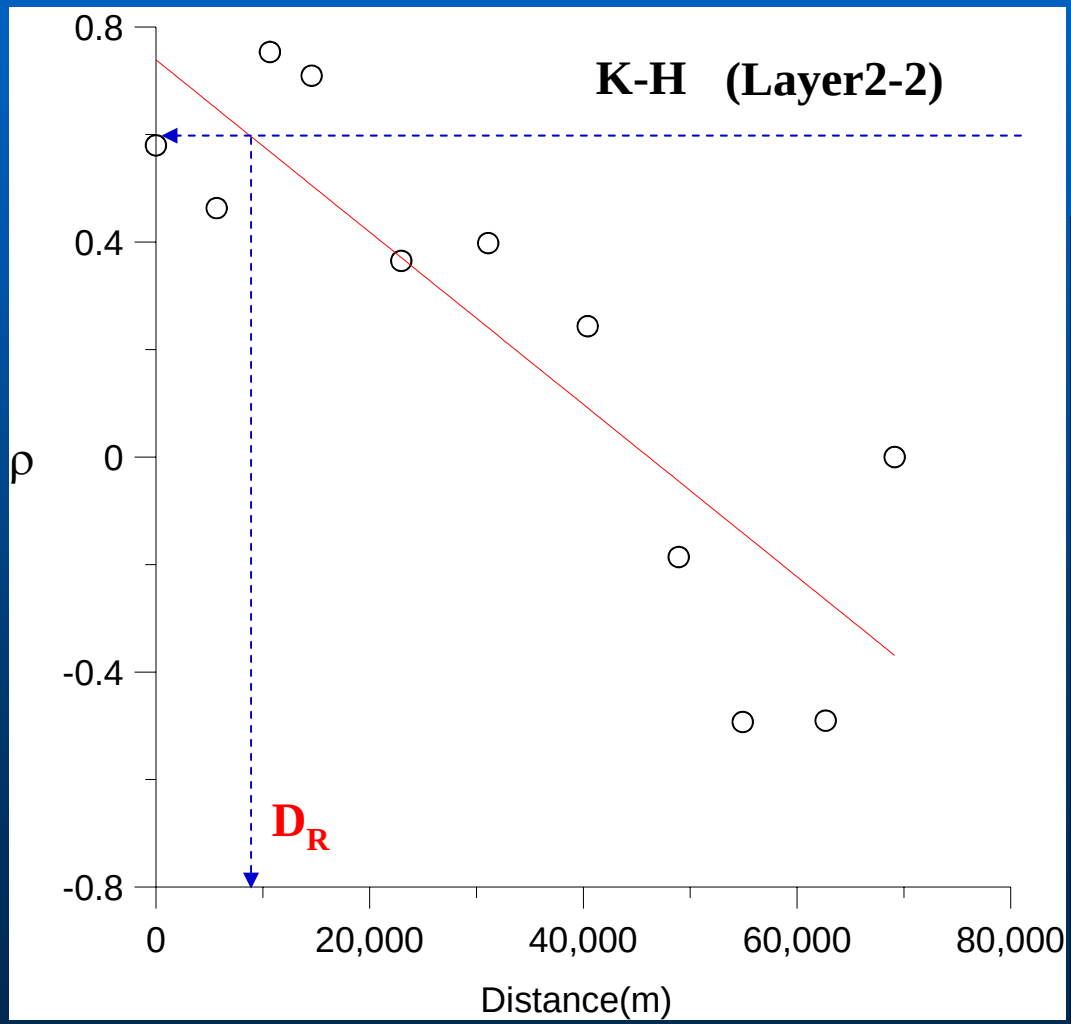
- Type: **Linear**
- D_R: **~ 10000 m**



Lag	Distance	Correlogram	Pairs_lag
1	0	0.64321	33
2	5685.103	0.59717	3
3	10674.23	0.55913	15
4	14573.2	0.40993	20
5	22960.27	0.44469	16
6	31096.73	0.42073	13
7	40407.7	0.26178	9
8	48924.89	0.15343	11
9	54913.88	0.38031	11
10	62676.08	0.25034	5
11	69131.2	0	1

6.Correlgram: Hydraulic conductivity-Water level

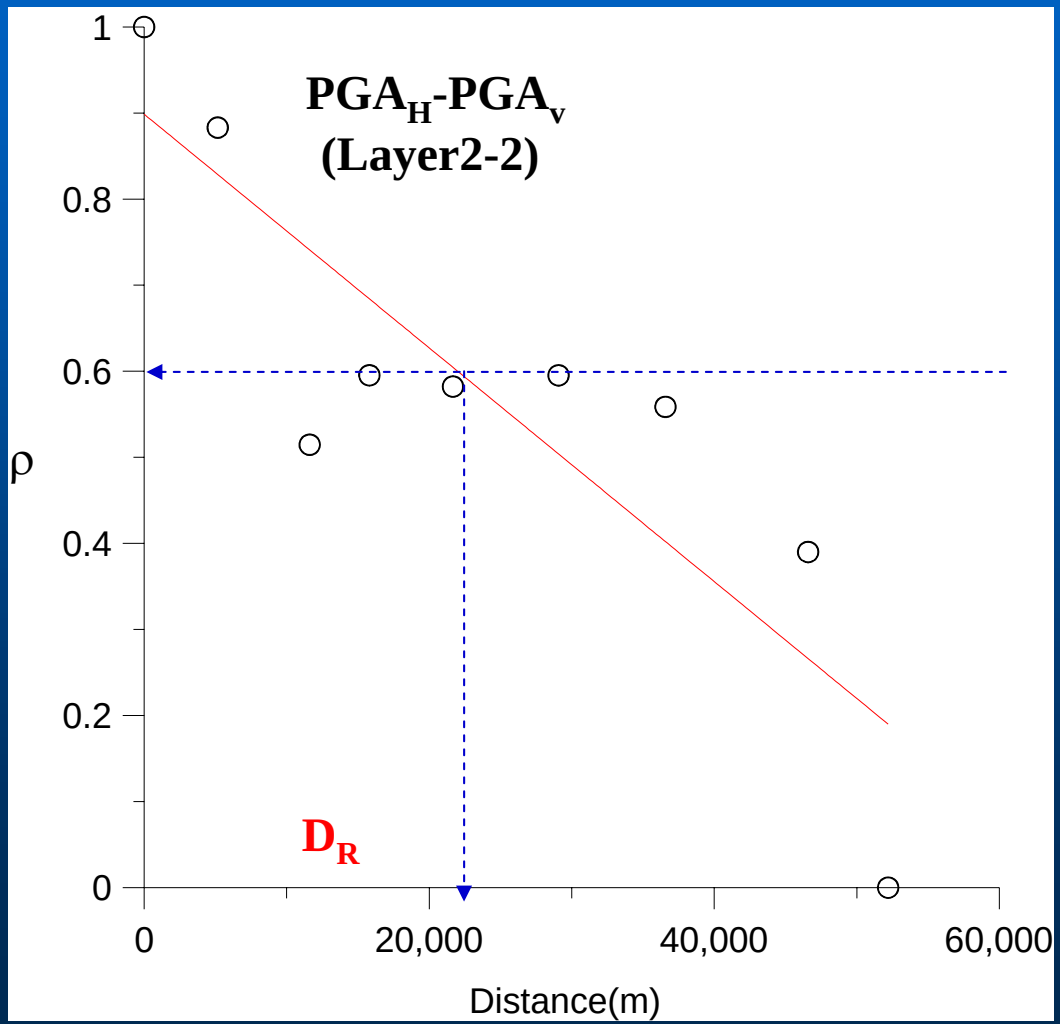
- Type: **Linear**
- D_R: **~ 9000 m**



Lag	Distance	Correlogram	Pairs_lag
1	0	0.5798	33
2	5685.103	0.46311	3
3	10674.23	0.7535	15
4	14573.2	0.70942	20
5	22960.27	0.36489	16
6	31096.73	0.39801	13
7	40407.7	0.24337	9
8	48924.89	-0.18597	11
9	54913.88	-0.49289	11
10	62676.08	-0.49036	5

6. Correlgram: PGA_V-PGA_H

- Type: **Linear**
- D_R: **~ 22000 m**



Lag	Distance	Correlogram	Pairs_lag
1	0	1	33
2	5163.839	0.88309	2
3	11616.95	0.51465	11
4	15804.24	0.5953	19
5	21666.09	0.58222	16
6	29074.08	0.59526	8
7	36575.18	0.55868	3
8	46582.96	0.39	2
9	52197.47	0	1

7.Summary

- The amplitudes and the types of the spatial similarity of the GWL/ PGA/ K been testify by variogram and correlgram. The relationship of the volumetric strain been rejected.
- The characteristic representative spacing been defined by each variogram and correlogram, these spacing should be choose as the grid size for simulation.
- Heterogeneity should be consider for study the hydrological response to earthquakes in the alluvial deposit and porous sedimentary rock.