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How to choose the sensitive site to earthquakes?

Studies of spatial sensitivity of the hydrological response to earthquakes

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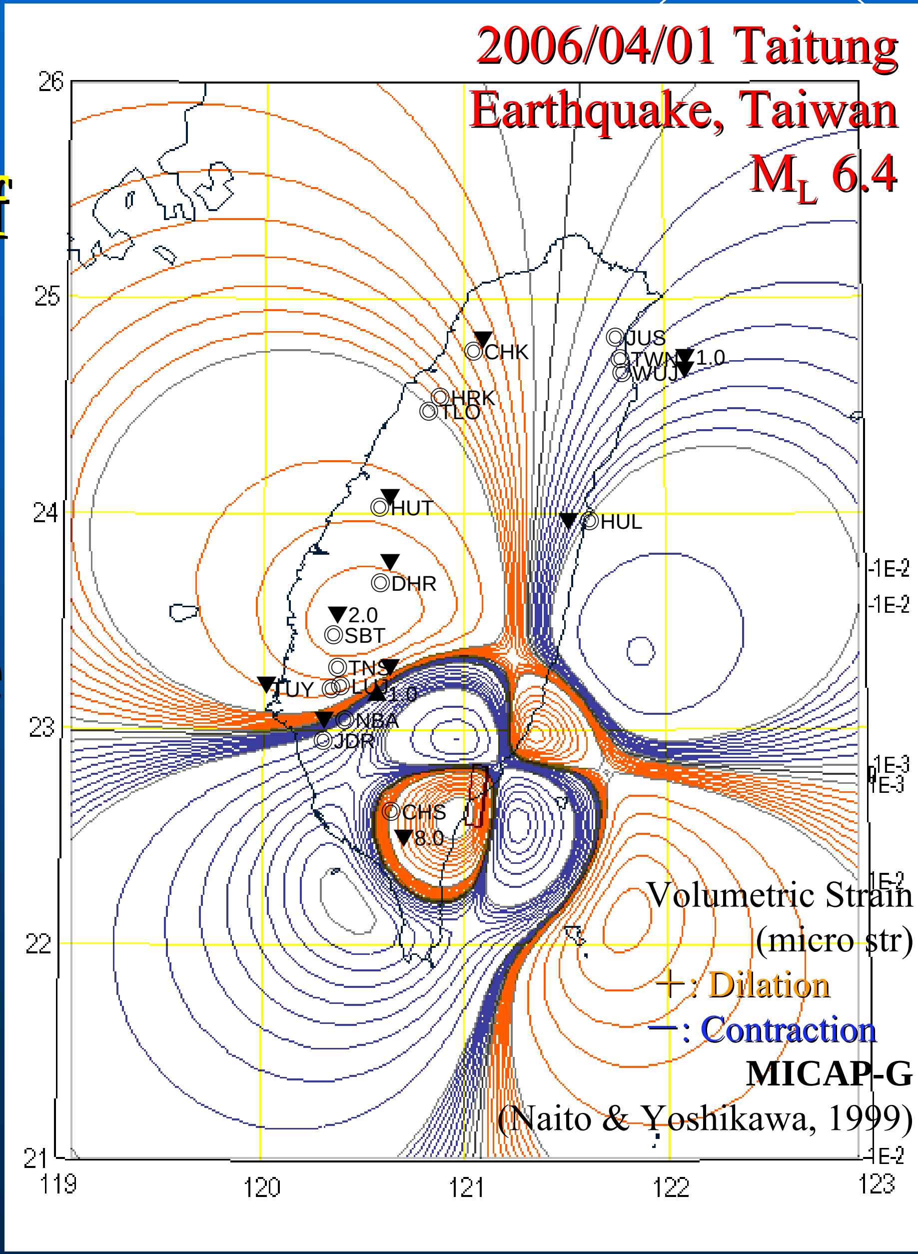
1. Motive

- Choosing the sensitive wells for best coverage of the seismic activity area.
- Some wells seems more sensitive to some special area, and not so sensitive to others.
- Most observed changes fitted to strain field, but some wells always not.



2.Objective

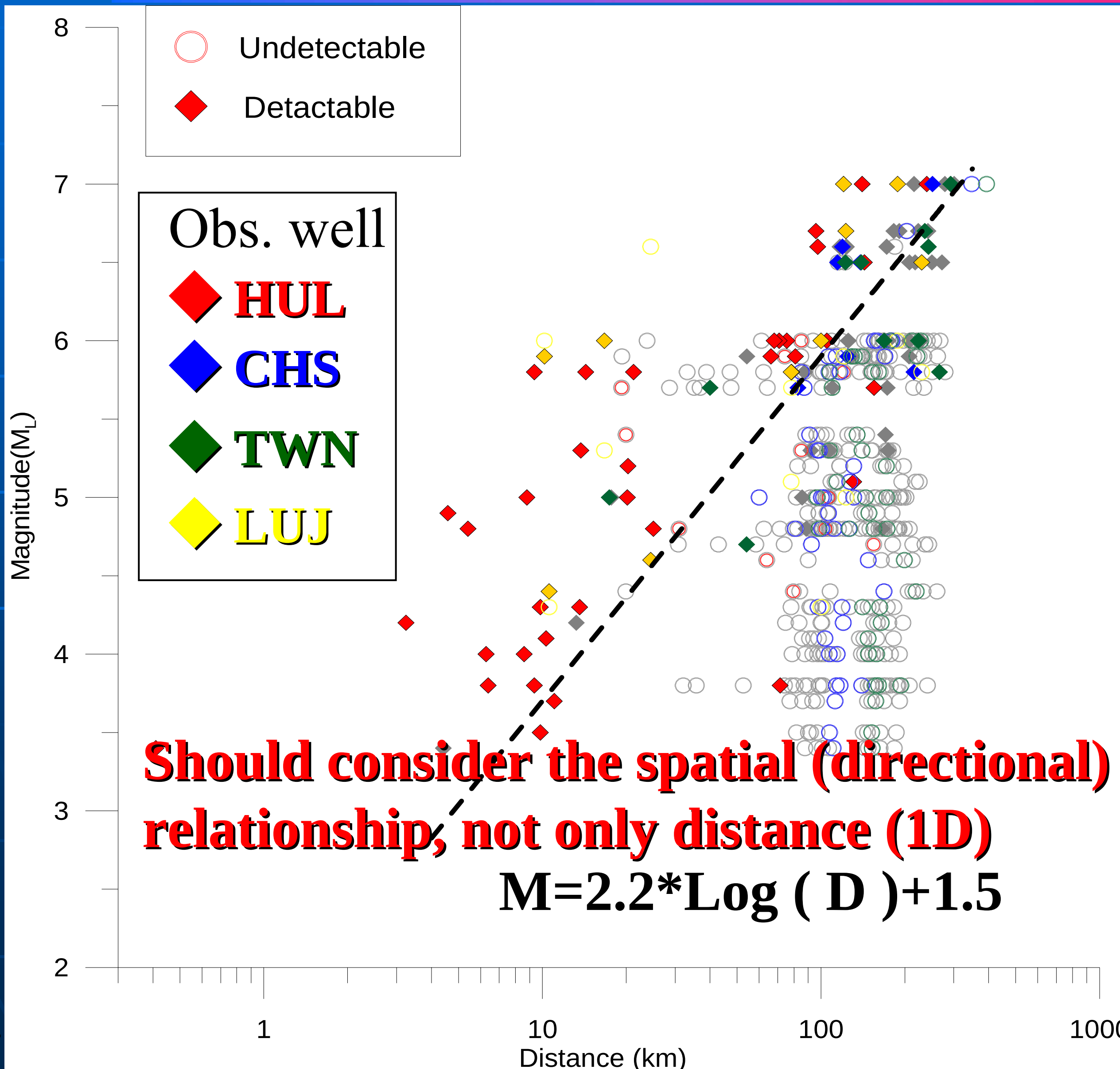
Use the recorded coseismic groundwater level changes to study the three problems:

包$_1$ ①Why the cosesimic groundwater level changes happen in some earthquakes and didn’t in other earthquakes? ~ Criteria of the detectability.

Q_2 ①Where are the high / low sensitivity areas? ~ Spatial distribution of the detectability.

Q_3 ① What the reasons made the different responses to the earthquake? ~ Structural anisotropy / mechanical heterogeneity

Criteria by the Moments & Distances



Should consider the spatial (directional) relationship, not only distance (1D)

M=2.2*Log (D)+1.5

Data Period:

2003~2005

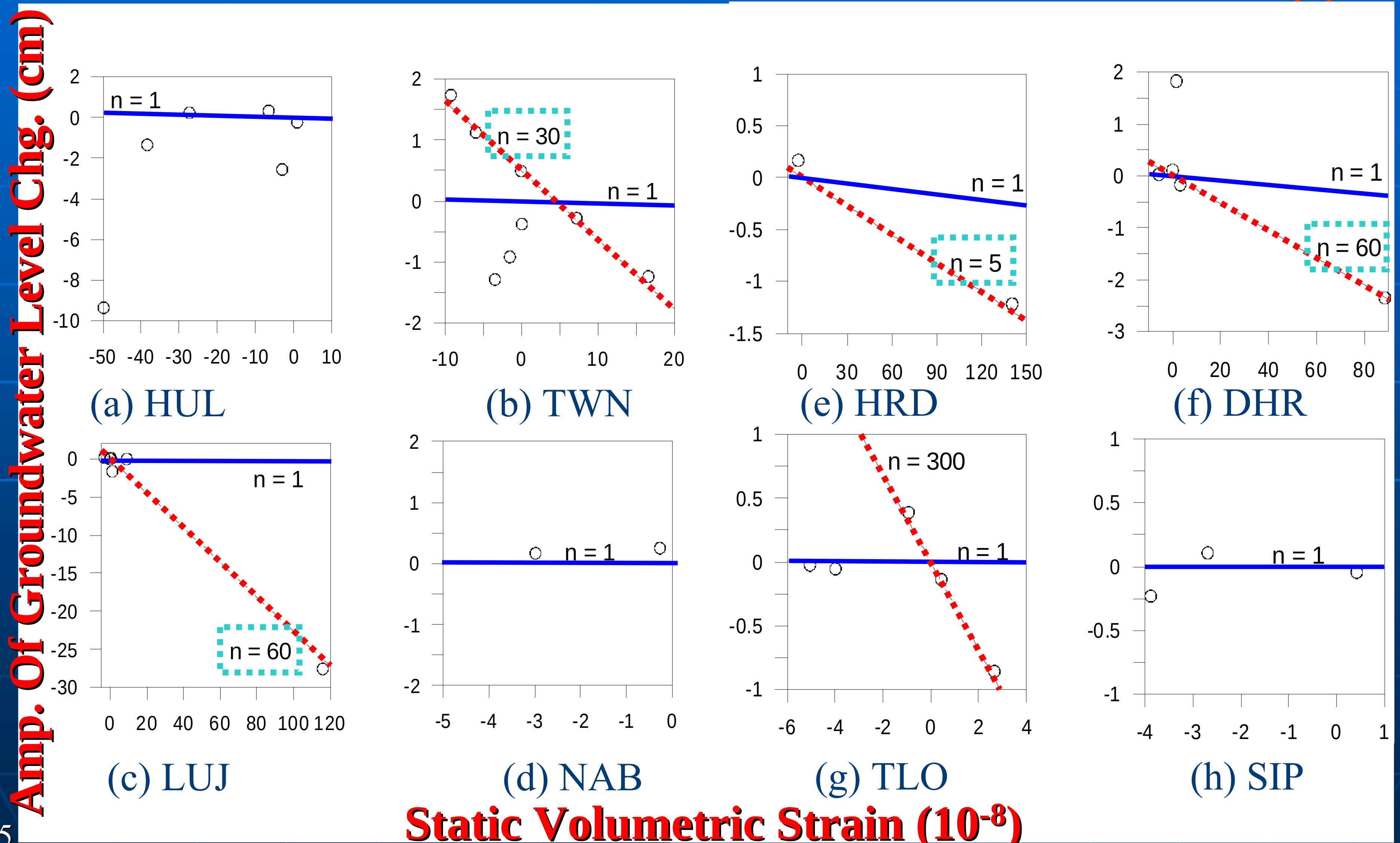
Detected records:

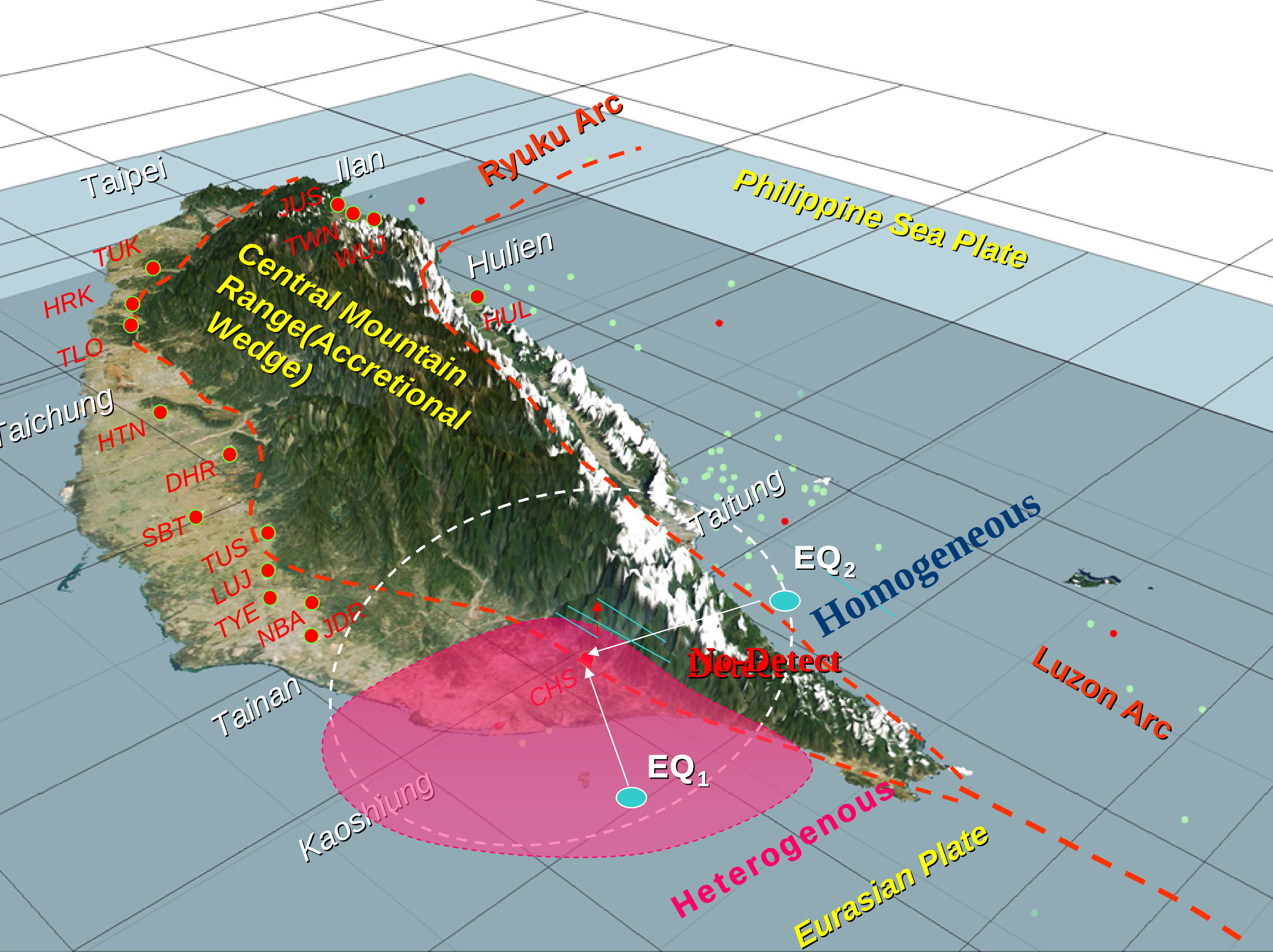
103

Earthquake events:

125

Comparison of the theoretic and observed responses





Taipei
Ilan
Ryuku Arc
Philippine Sea Plate
JUS
TWN
WUJ
TUK
HRK
TLO
Central Mountain Range(Accretional Wedge)
Hulien
HUL
Taichung
HTN
DHR
SBT
TUS
LUJ
TYE
NBA
JDP
Taitung
EQ$_2$
Homogeneous
No-Detect
Detect
CHS
Tainan
EQ$_1$
Kaoshiung
Luzon Arc
Heterogenous
Eurasian Plate

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→ **Strategy of sensitive sites choosing**

3.Observation

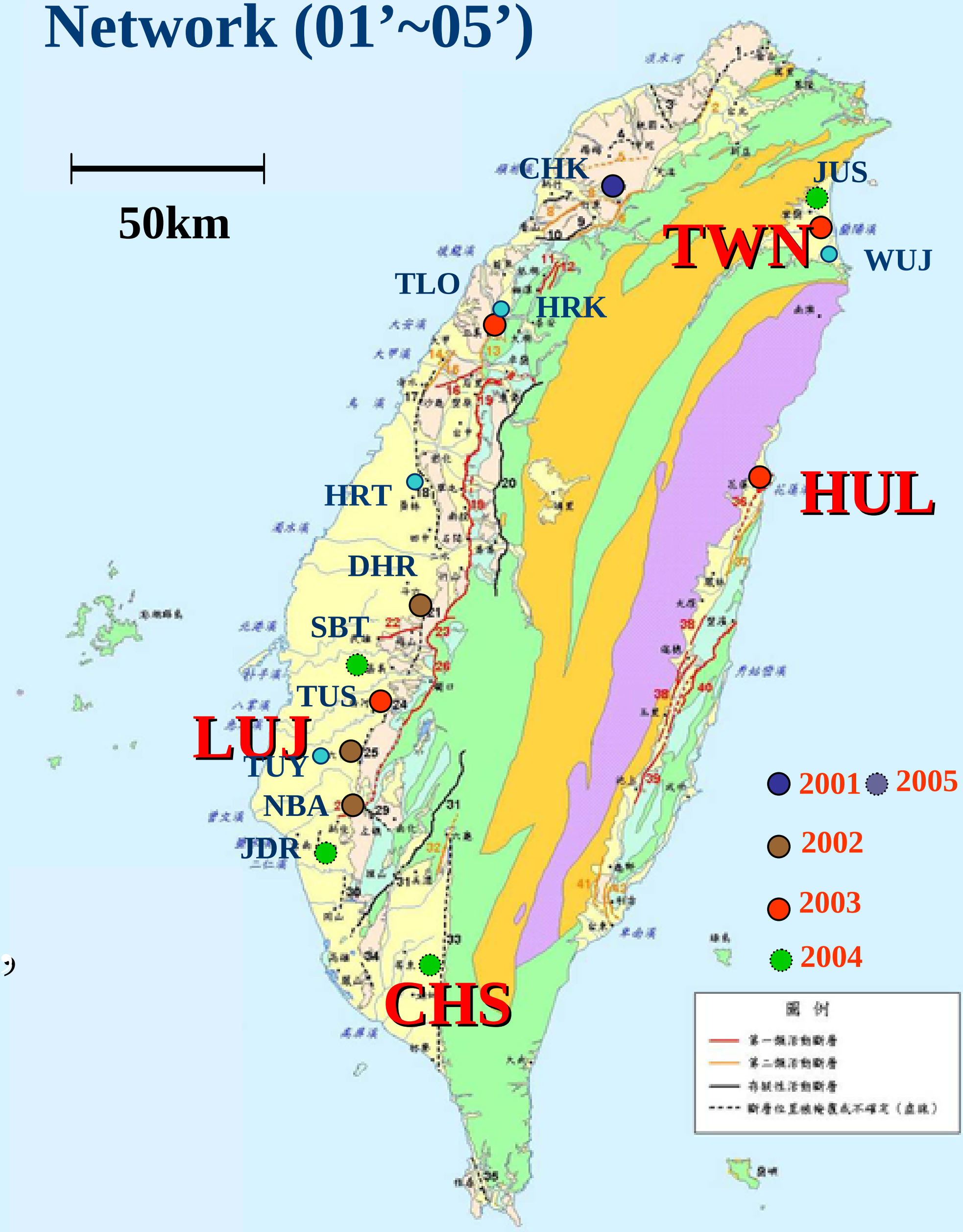
Observation Well

- **4** observation well 上**15** detectable records

Observation Period

- 2003-2006 **M_L上5** Earthquake×Total **125** Events.
- Total **83** coseismic changes, step changes (S) **45** records, oscillation (O) **38** records

Observation Network (01'~05')

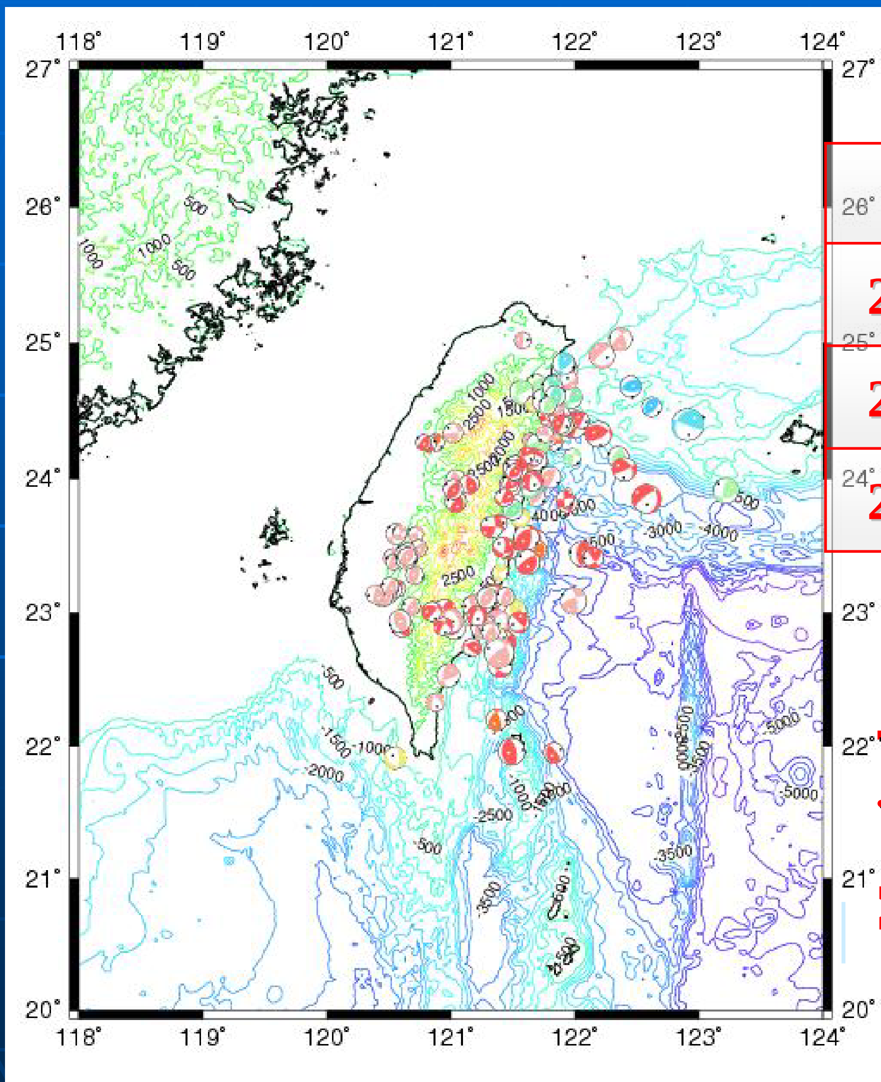


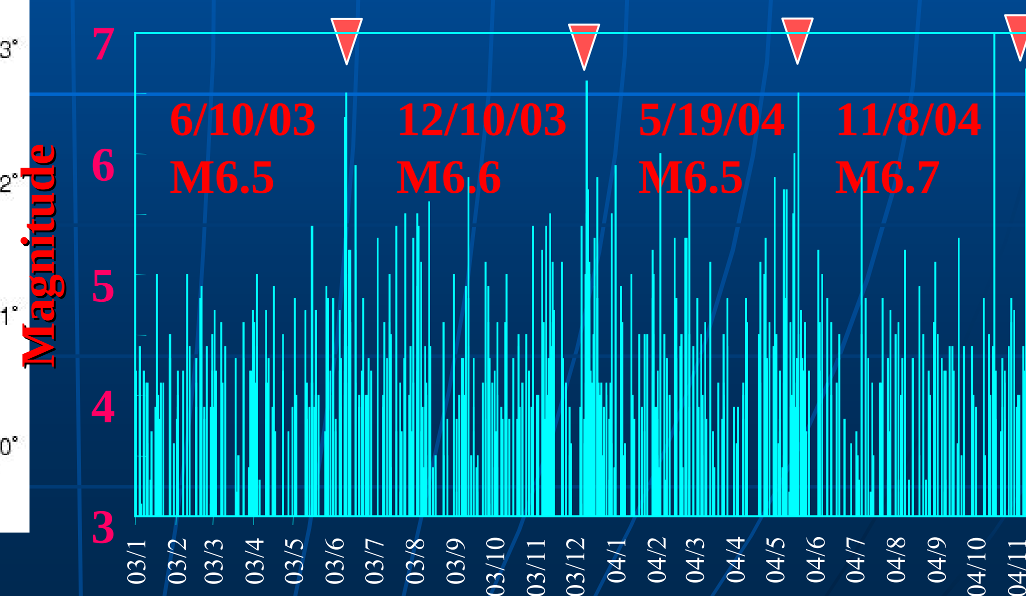
3.Observation

DPRC

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

M_L	3~3.9	4~4.9	5~5.9	上6.0
2003	118	181	43	3
2004	86	125	25	5
2005	277	140	24	3





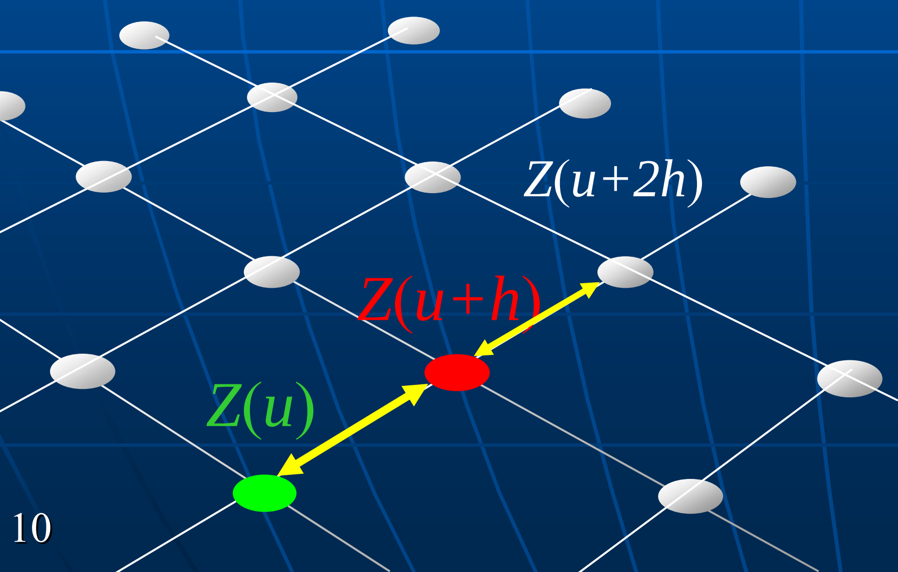
CMT solution and distribution of events

4.Methdology (1/3)

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

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

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



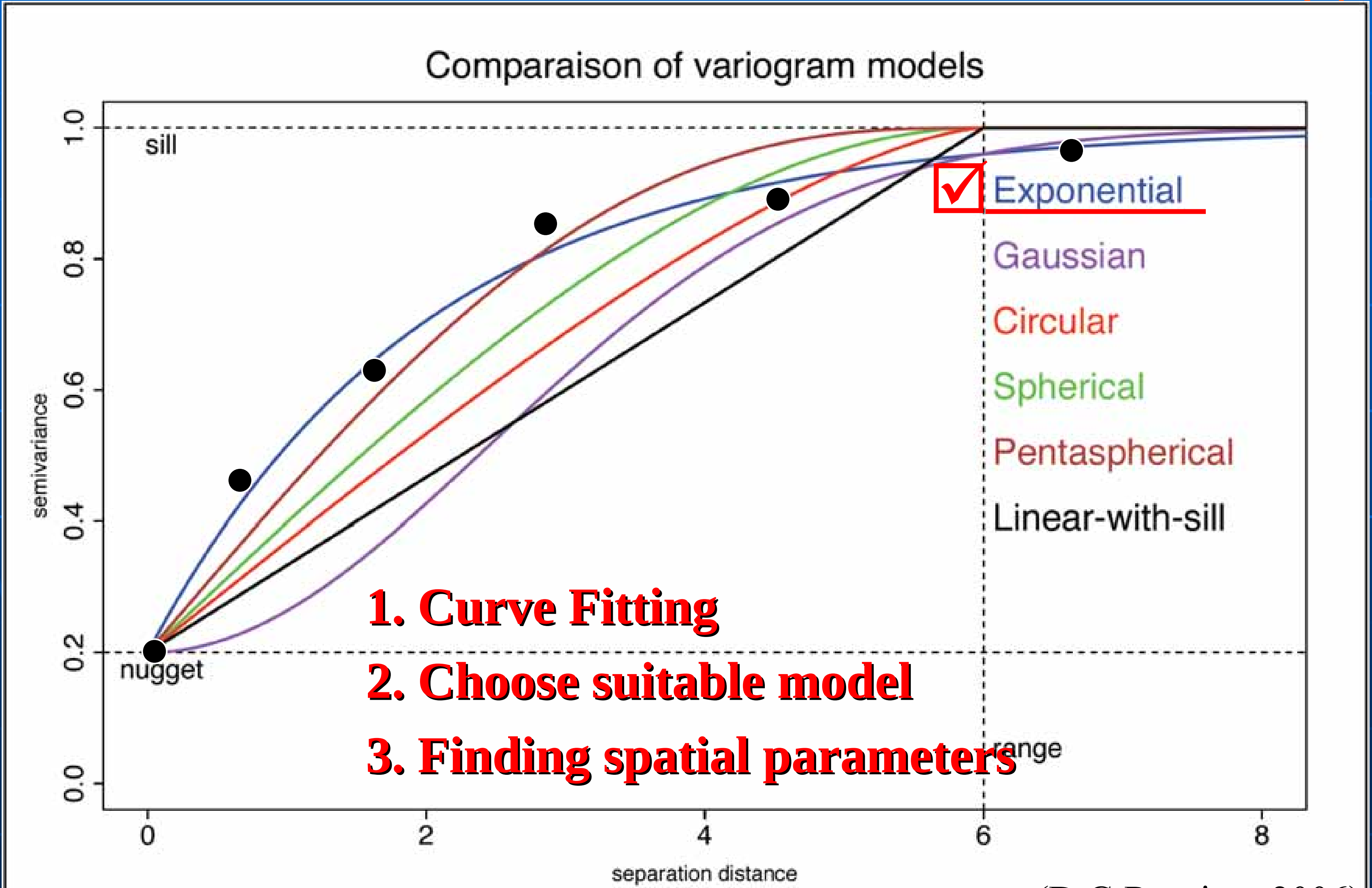
2末(*h*): Variogram value

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

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

Var [ ]: variance operator

Distribution models of the variogram



1. Curve Fitting
2. Choose suitable model
3. Finding spatial parameters

(D G Rossiter, 2006)

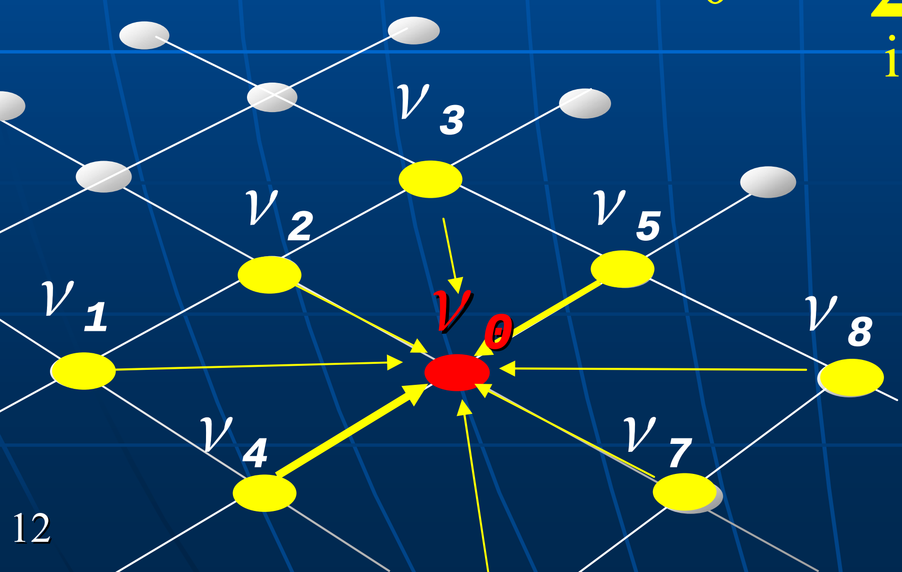
4.Methdology (2/3)

- **Kriging** **(Matheron, G., 1962)**

(~ Interpolation data by distribution model)

The Kriging methods are for data interpolation in **Best, Linear, Unbiased, Estimate** (**BLUE**) assumption.

$$\nu_0 = \sum_{i=1}^{N(\nu_0)} \omega_i \nu_i \qquad \ldots\ldots. (2)$$



犯$_0$: estimate value

N(犯$_0$): numbers of neighborhood

甲$_i$: weighting

犯$_i$: sample value

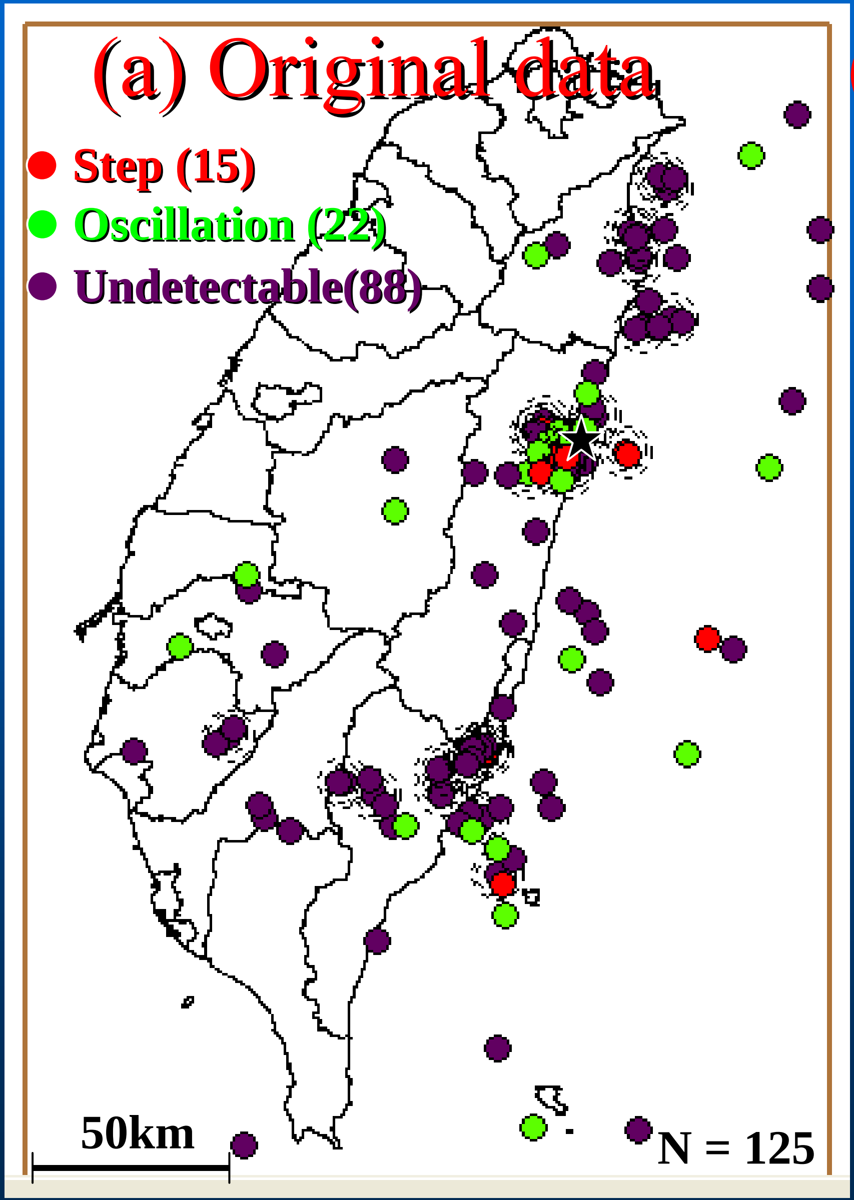
4.Methdology (3/3)

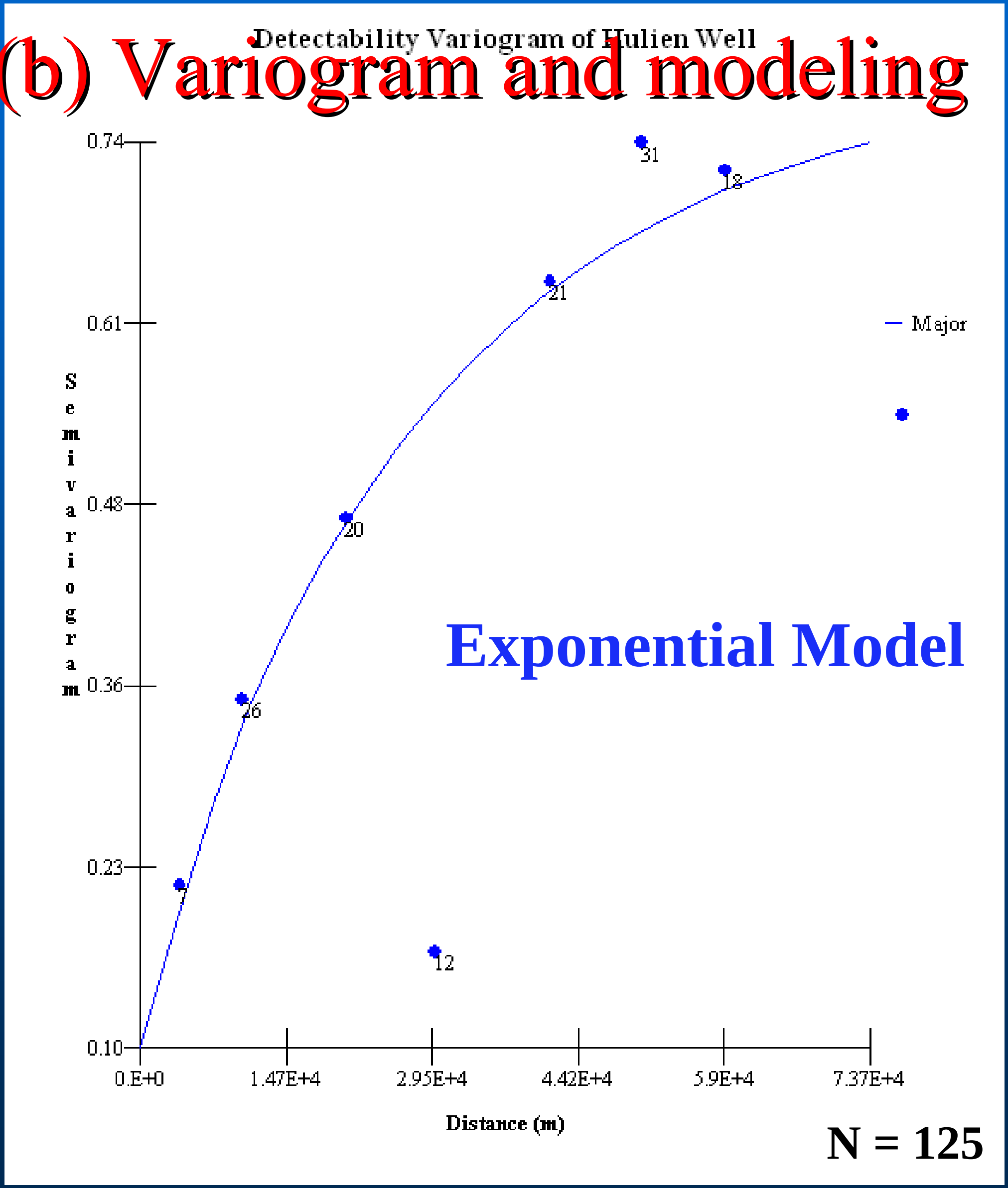
● **Indicator Kriging** **(Journel, 1983)**

The main difficult of the spatial analysis is the **samples number is limited (又20~30)**. We solve the problem by consider the undetectable events, then the samples increase to all earthquakes **(125)**.

Indicator Kriging's made index transfer (**Yes: 1 ㄩ No: 0**) result shows **Probabilities** (the probability that the grade is above the detect criteria: exp. **1**) or **Proportions** (the proportion of the block above the detect criteria : exp. **1** on data support).

5.Result: HUL well (1/2)

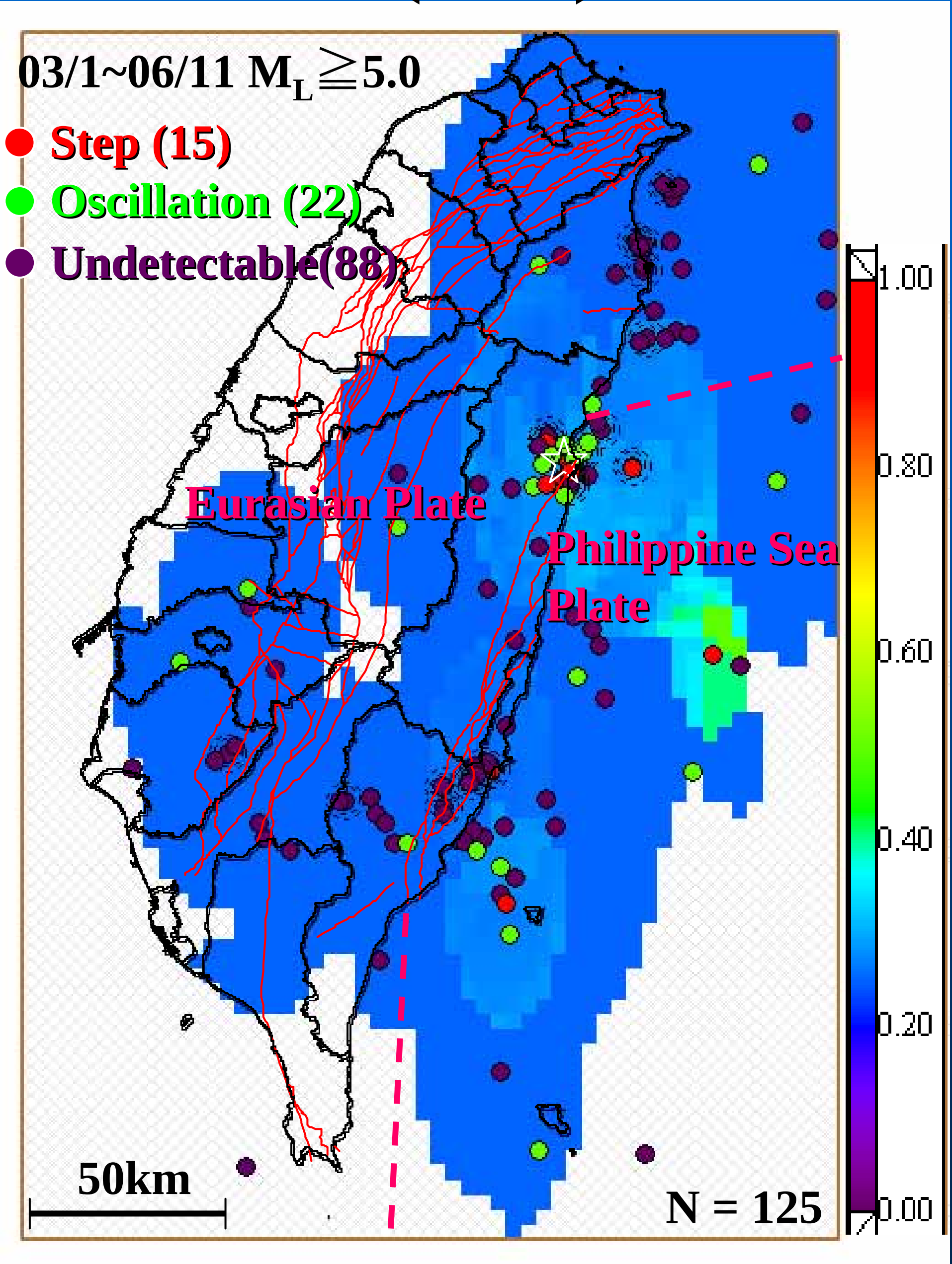




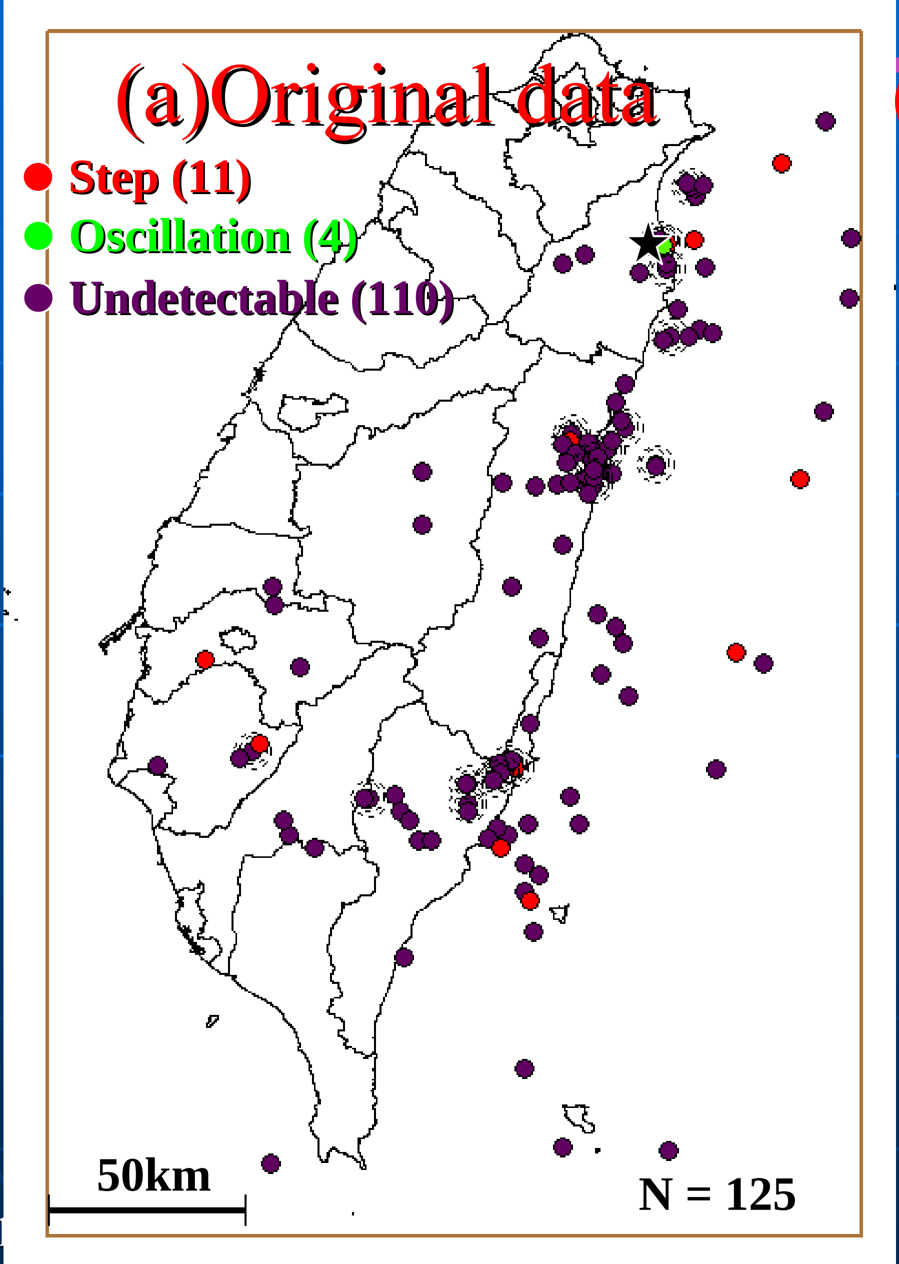
5.Result: HUL well (2/2)

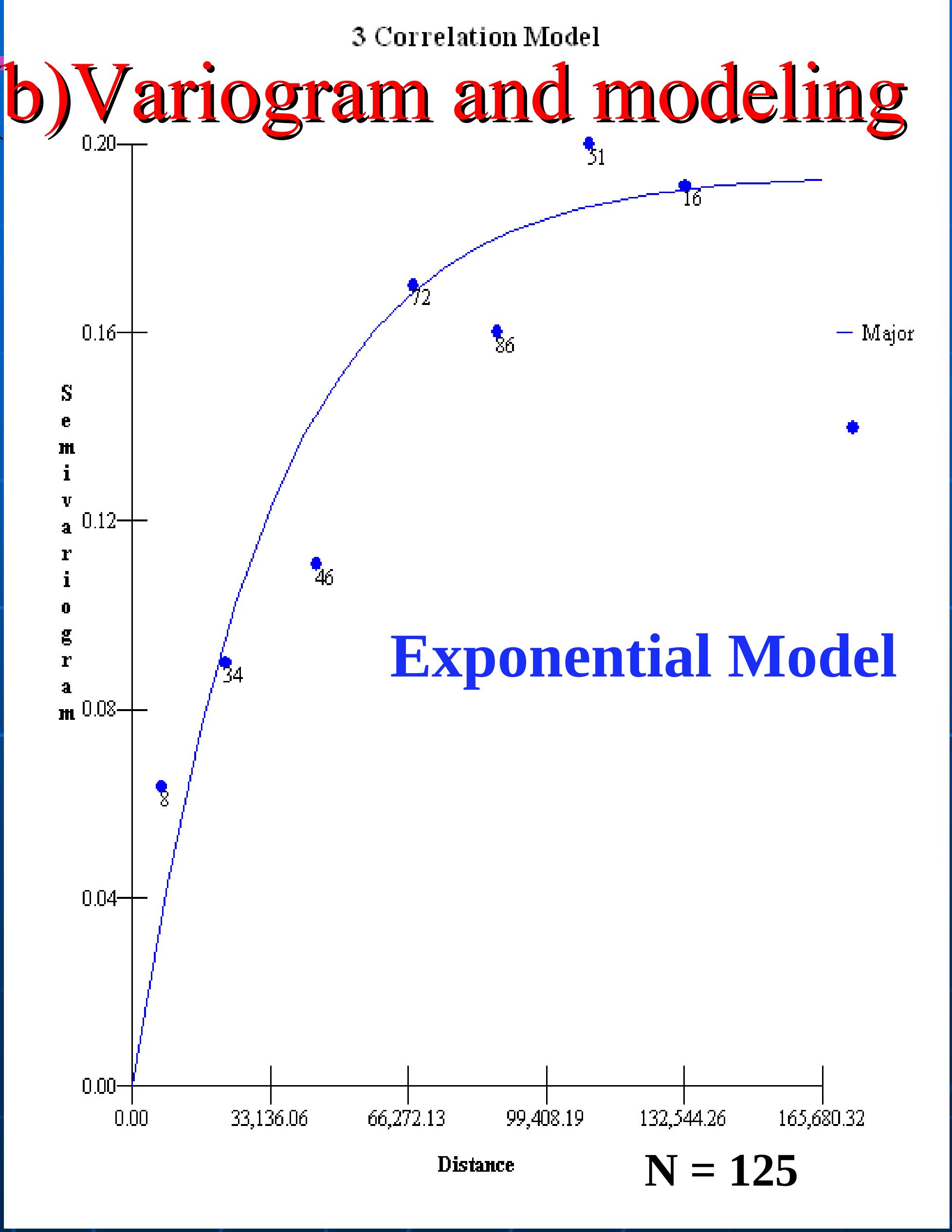
Tectonic control case

- Mostly < **30%** for M5
- Sensitive to eastern offshore(**50%**), low to western Taiwan.
- Low sensitive to northern Taiwan
- Difference responses in Philippine Sea Plate and Eurasian Plate



5.Result: TWN well (1/2)

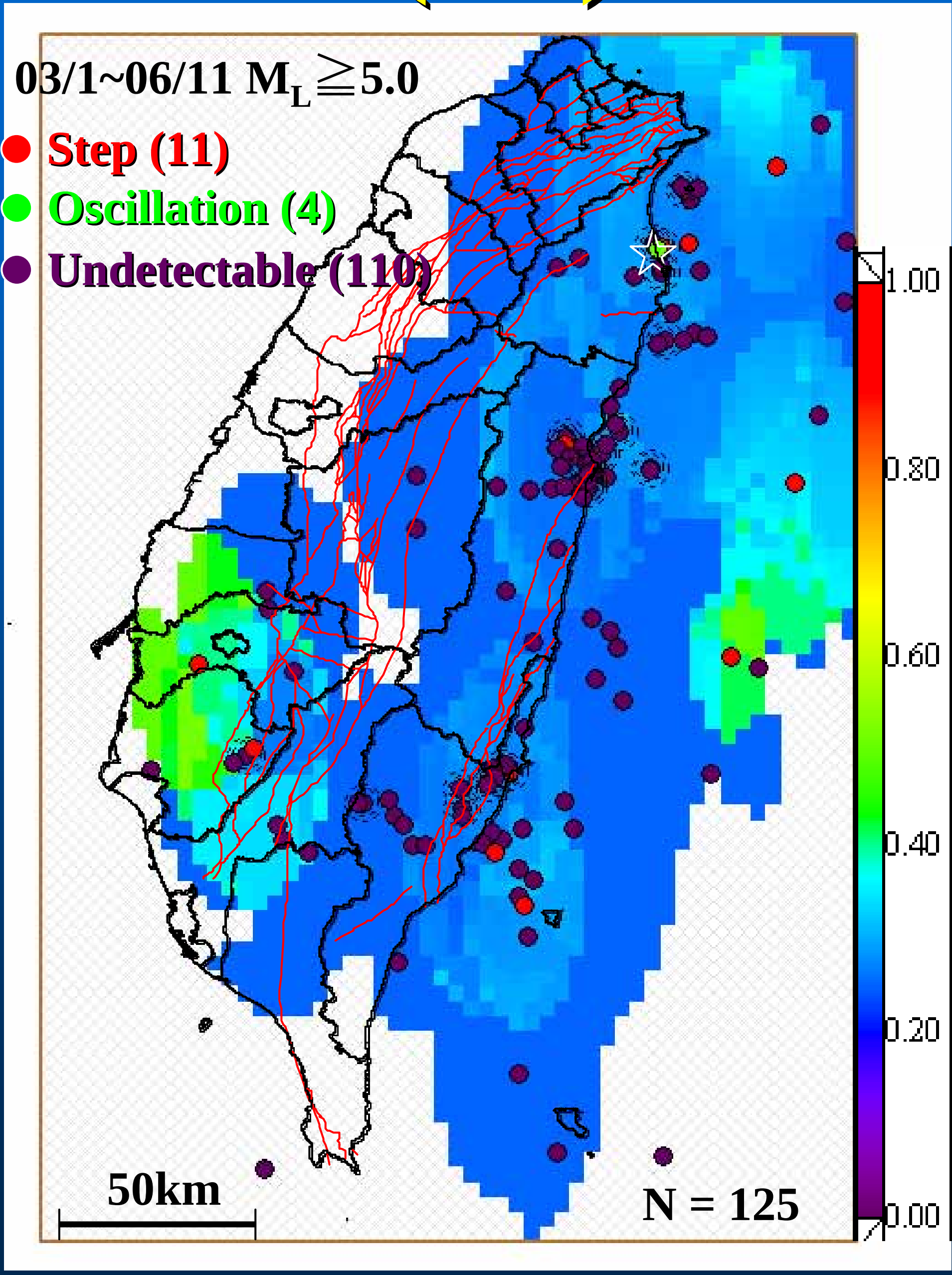




5.Result: TWN well (2/2)

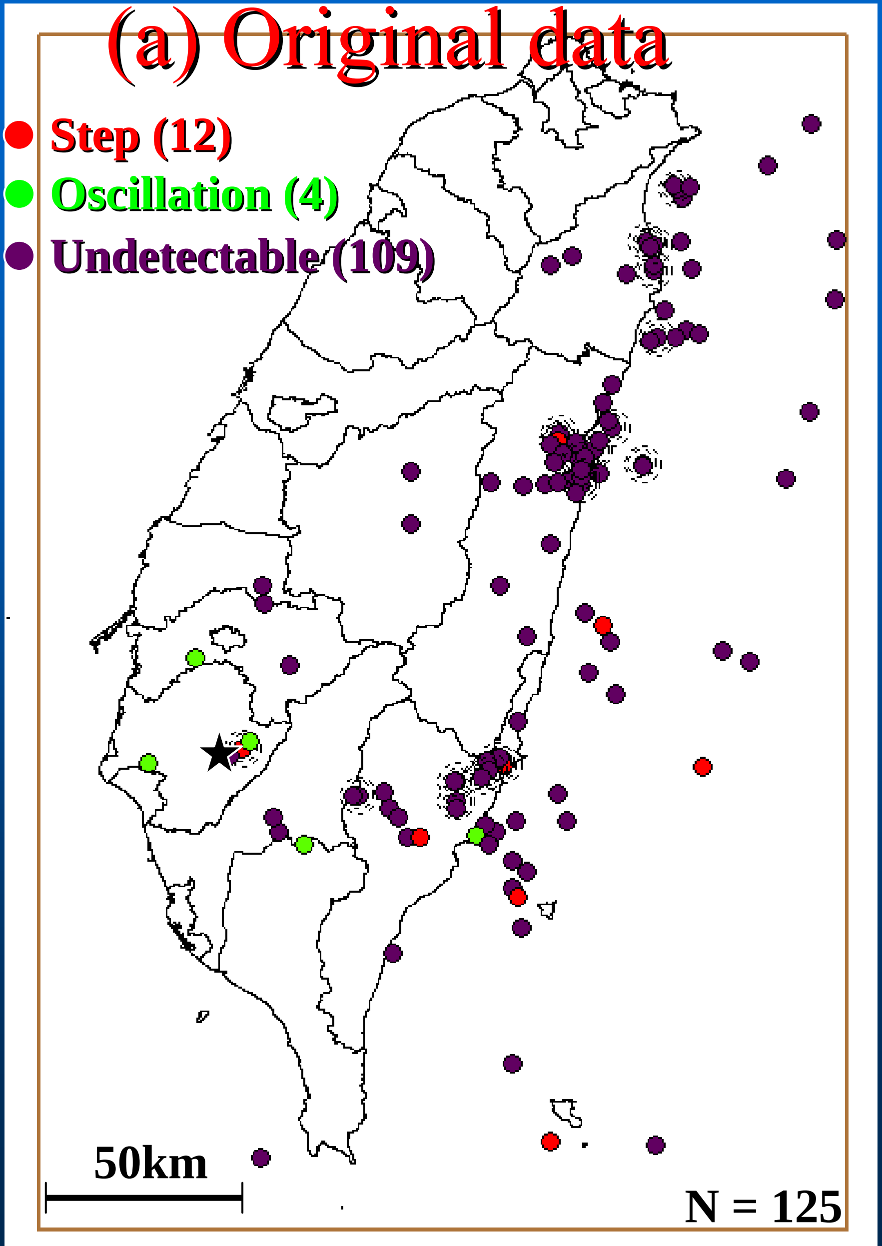
Homogeneous case

- Sensitive to **eastern offshore area (40%)**.
- Responses to south-western earthquakes.
- **Homogeneous response** to crustal strain.
- Sensitive well, low noise and few oscillation record (ground motion)

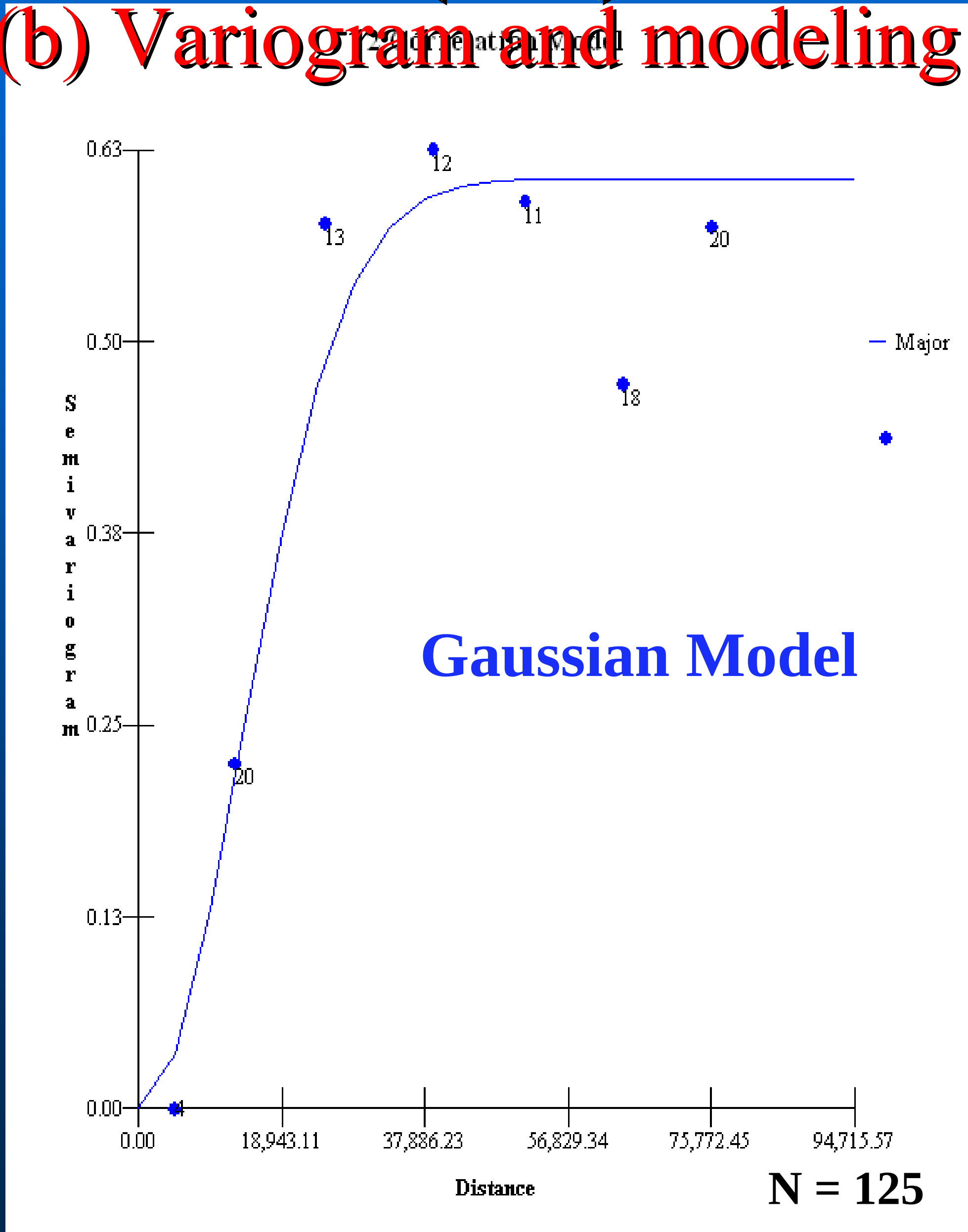


5.Result: LUJ well (1/2)

(a) Original data



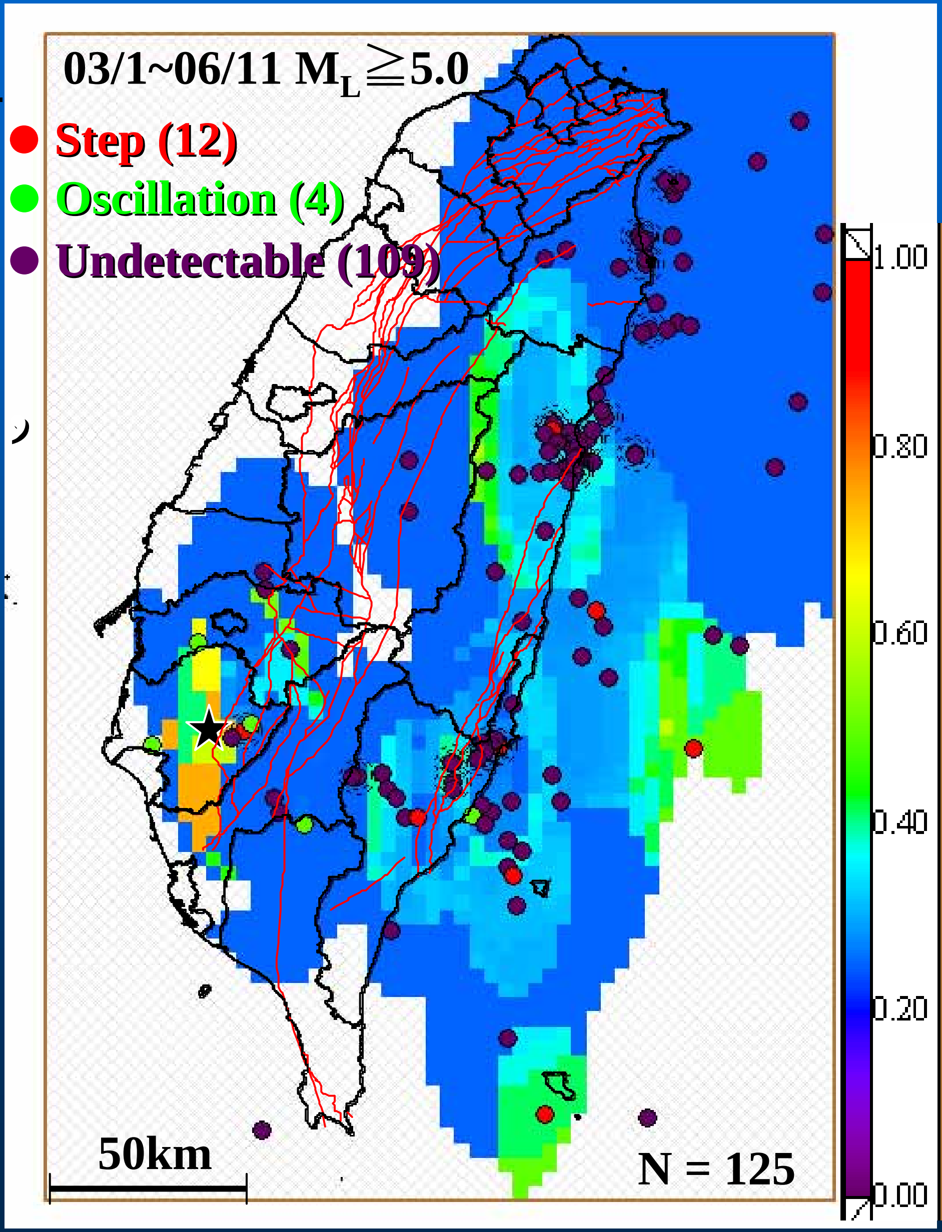
(b) Variogram and modeling



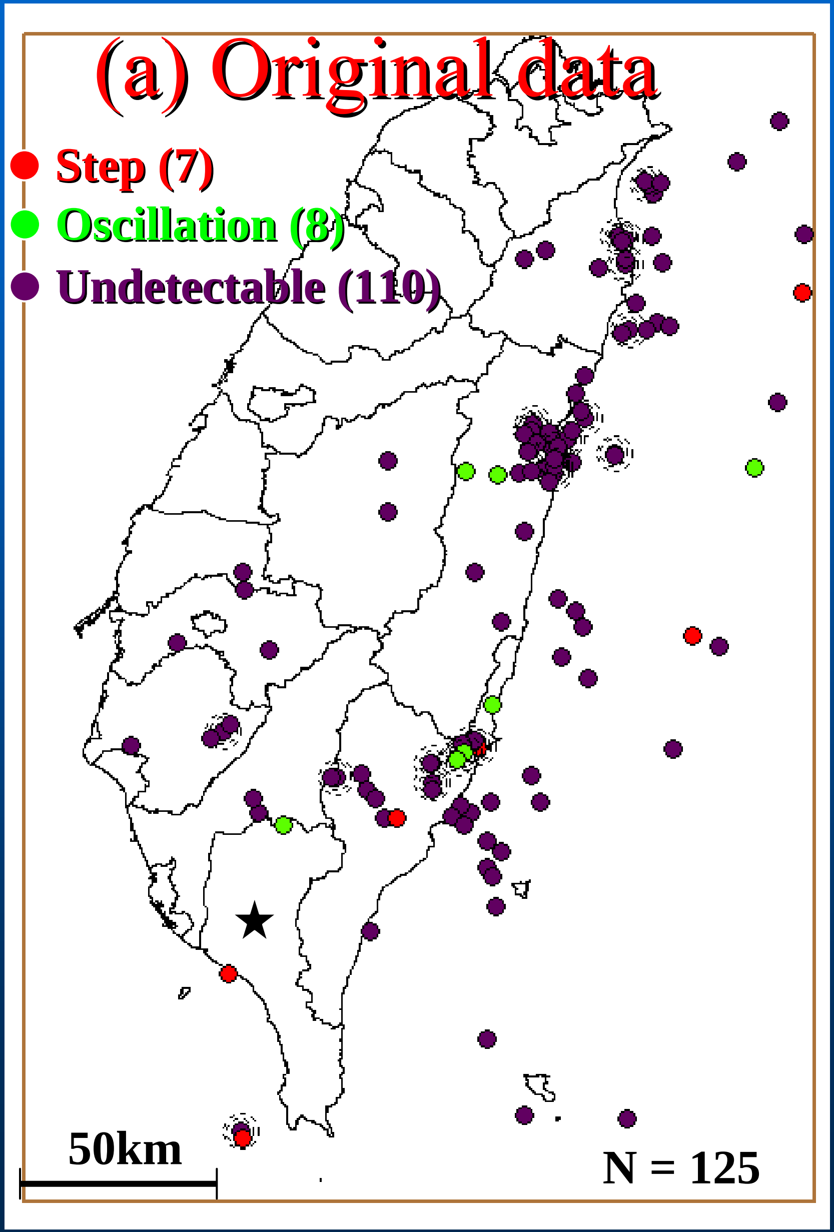
5.Result: LUJ well (2/2)

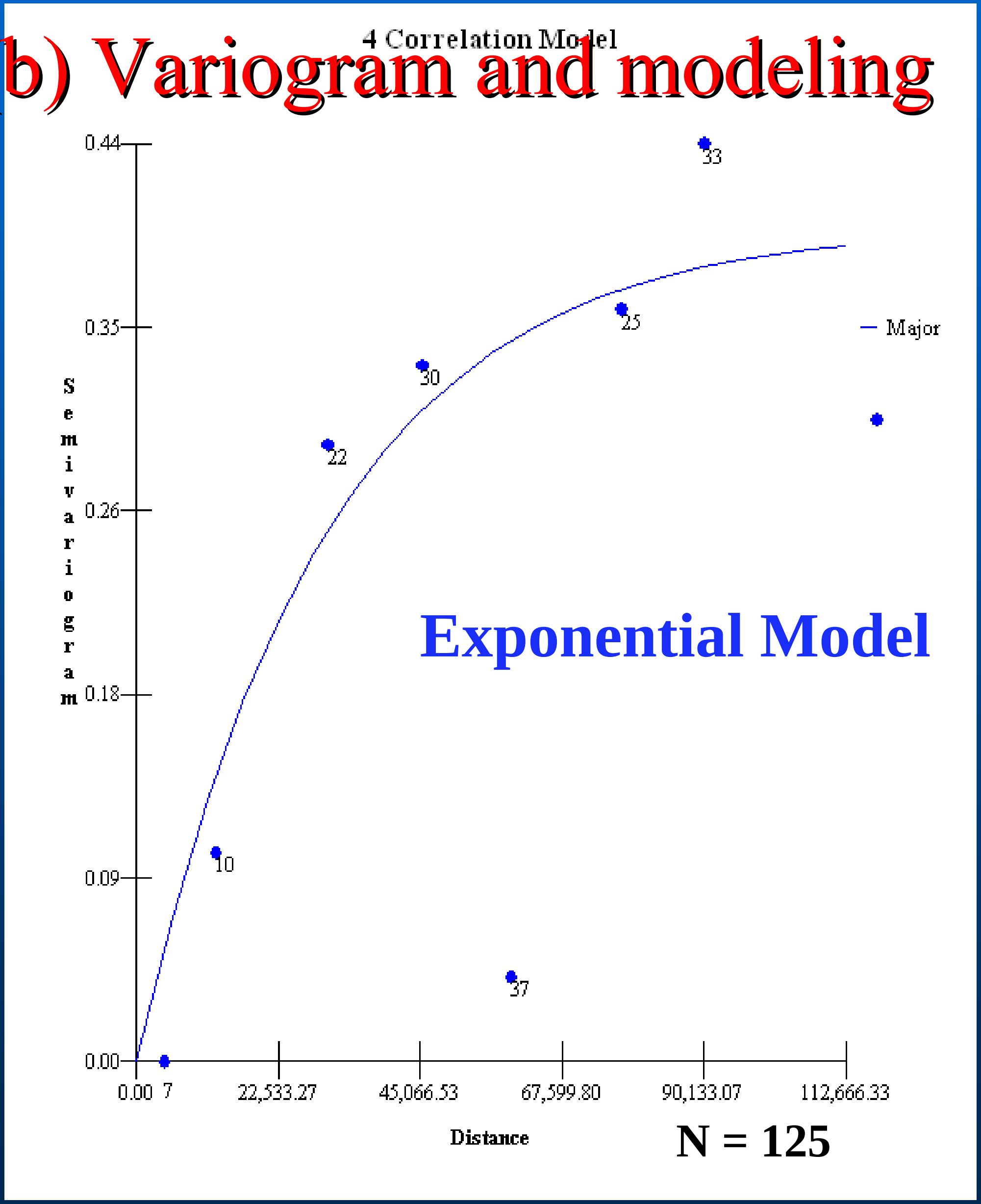
Structural control case

- Mostly **20~40%** for M5
- Sensitive to south-western Taiwan(**>60%**) low in east-west trend.
- Sensitive well, low noise and few oscillation record (ground motion)
- **Fault-Barrier effect**
- **Fault-Conduit effect**



5.Result: CHS well (1/2)

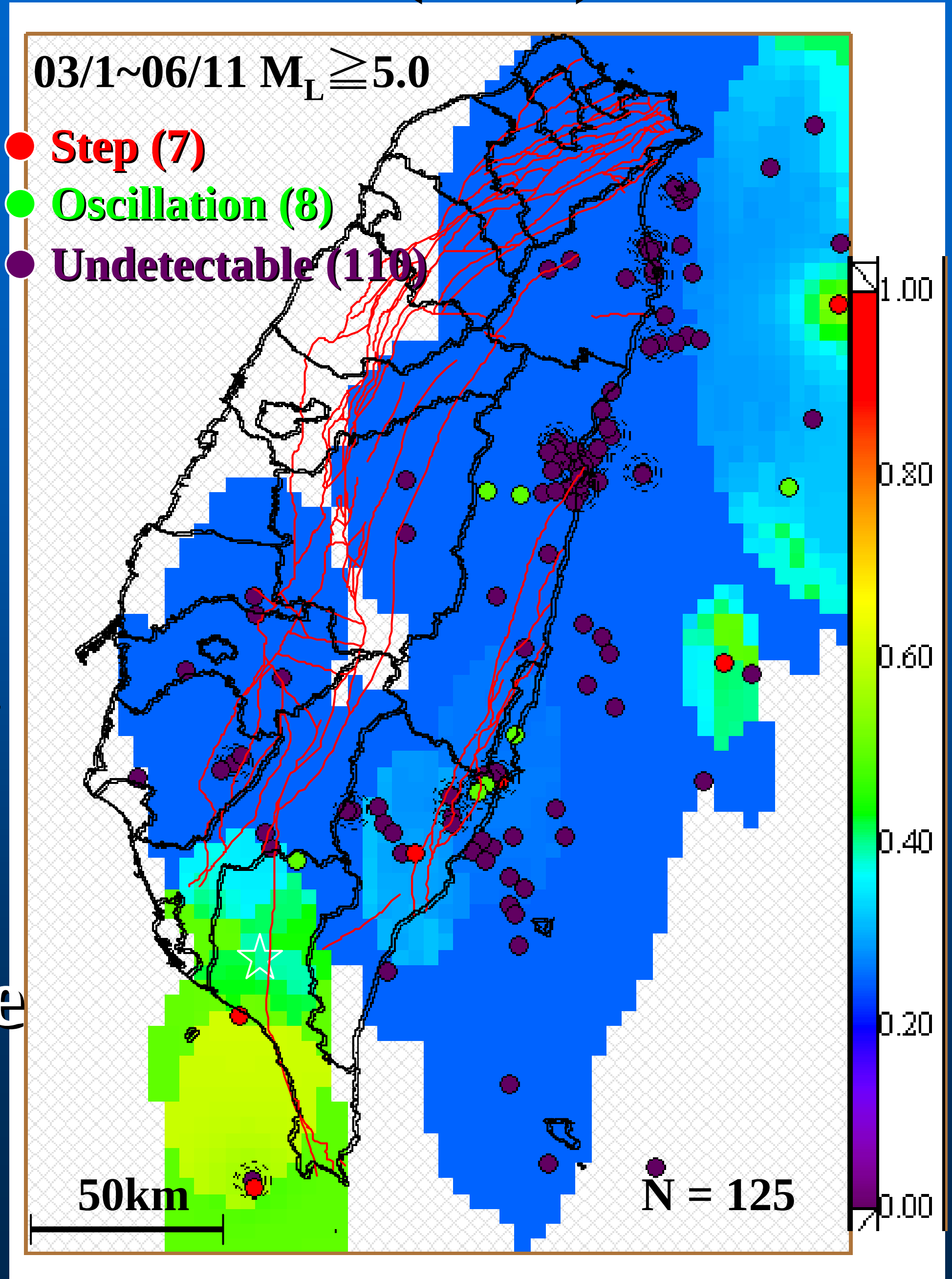




5.Result: CHS well (2/2)

Structural control case

- Mostly ＜30% for M5
- Sensitive to southern Taiwan (50~70%).
- Sensitive well, larger noise and lots oscillation record (ground motion)
- **Fault-Barrier effect**, made low transmit of the strain.



6.Conclusion

- From the spatial analysis of the detectability, they shows the **highly anisotropy and heterogeneity** in three wells. They could partly explain the different responses of earthquake induced groundwater changes.
- **Tectonic and structural geology** setting could be the main reason control the spatial difference of earthquake induced groundwater changes (**Fault-Barrier Effect**).
- **The strain model** usually could explain the type of the coseismic change, but the amplitudes usually not fit to the homogeneous assumption. The **Structural anisotropy and mechanical heterogeneity** should be consider to improve the volumetric strain estimation.