2nd Taiwan-Japan Joint Workshop on Hydrological Research for Earthquake Prediction

Intervention Pattern and Detection Analysis for Anomaly Groundwater Level Time Series

T.-Y. Lee, S.-C. Lin, W.-C. Chen, F.-S. Chiu and Y.-P. Lee

Sep. 22-23, 2003

Acknowledgement

This work was supported in part by the Water Resources Agency (WRA).

We would like to thank the Disaster Protection Research Center (DPRC) for kindly permitting us to participate the team of project.

ABSTRACT

- Introduction (Motive/Purpose)
- Theory of Intervention Analysis (IA) Model
- Statistical Methods for Anomaly Detection
- Case Studies
- Concluding Remarks

Introduction (Motive/Purpose)

- To explore the anomaly pattern of seismic groundwater level by the quantitative method and the specific function may be used to explain the transfer mechanism.
- A series of statistical methods are used to detect and test the anomaly of groundwater level. It may be served as an information for pre-cursor.

Intervention Analysis (IA)

- The Intervention analysis is to study a time series structural change due to external events. It is a special case of the transfer function model.
- The opportunity to use the IA:
  - The starting-point of intervention event is clear。
  - Specify the possible pattern of intervention impact.

Intervention Analysis (IA)

- A single external event is considered:

$$Z_t = V_t + N_t = \frac{\omega(B)}{\delta(B)} B^b I_t + \frac{\theta(B)}{\phi(B)} a_t$$

V_t=dynamic component or transfer from the N_t
N_t=static component

I_t=intervention time series assembled by 0 and 1

ω; δ; θ ; φ =unknown parameters

B=backward shift operator

a_t=noise

Anomaly Detection

- A rapid (sharp; sudden; abrupt) variation of statistical property from one to the other.
- The main procedure is to compute the mean and standard deviation of series, then the anomaly is checked by the abrupt change or not。

Methods for Anomaly Detection

- Parametric Testing Method:
  - (1) Moving *t* Testing
  - (2) Cramer's Method
  - (3) Yamamoto Method
- Non-Parametric Testing Method:
  - (4) Moving *T*max Testing
  - (5) Mann-Kendall Method
  - (6) Pettitt Method

For Example: Moving *t* Testing

One Series		Two Series	Data Number
x	divide →	x_1 ; x_2	n_1; n_2

$$t = \frac{\overline{x_1} - \overline{x_2}}{s * \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

where $s = \sqrt{\frac{n_1 s_1^2 + n_2 s_2^2}{n_1 + n_2 - 2}}$

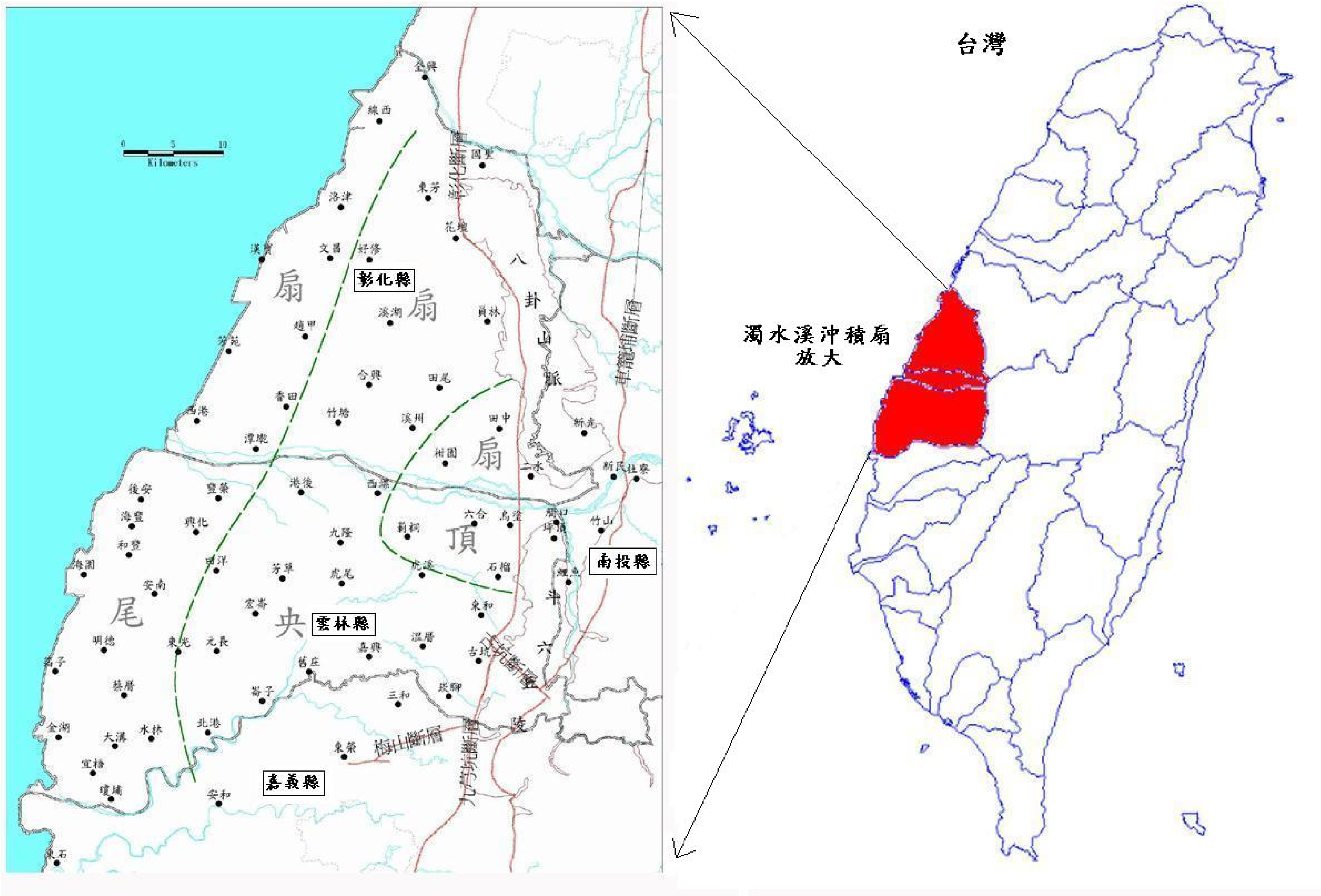
Case Studies for Dynamic Groundwater Level

- Statistics for Anomaly Variability - Part (I)
- Intervention Analysis for Real-Case - Part (II)
- Simulation and Real-Case for Anomaly Detection - Part (III)

Research Scope

- Location
  - Alluvial Fan of Cho-Shui Stream Watershed
  - 188 Observation Wells in 70 Stations
- Data
  - Sep. 1 ~ Oct. 31, 1999 (921 Chi-Chi Earthquake)
  - Mar. 1 ~ Apr. 30, 2002 (331 Cha-I Earthquake)
  - Data (Groundwater Level) Recording by Hourly Time Interval

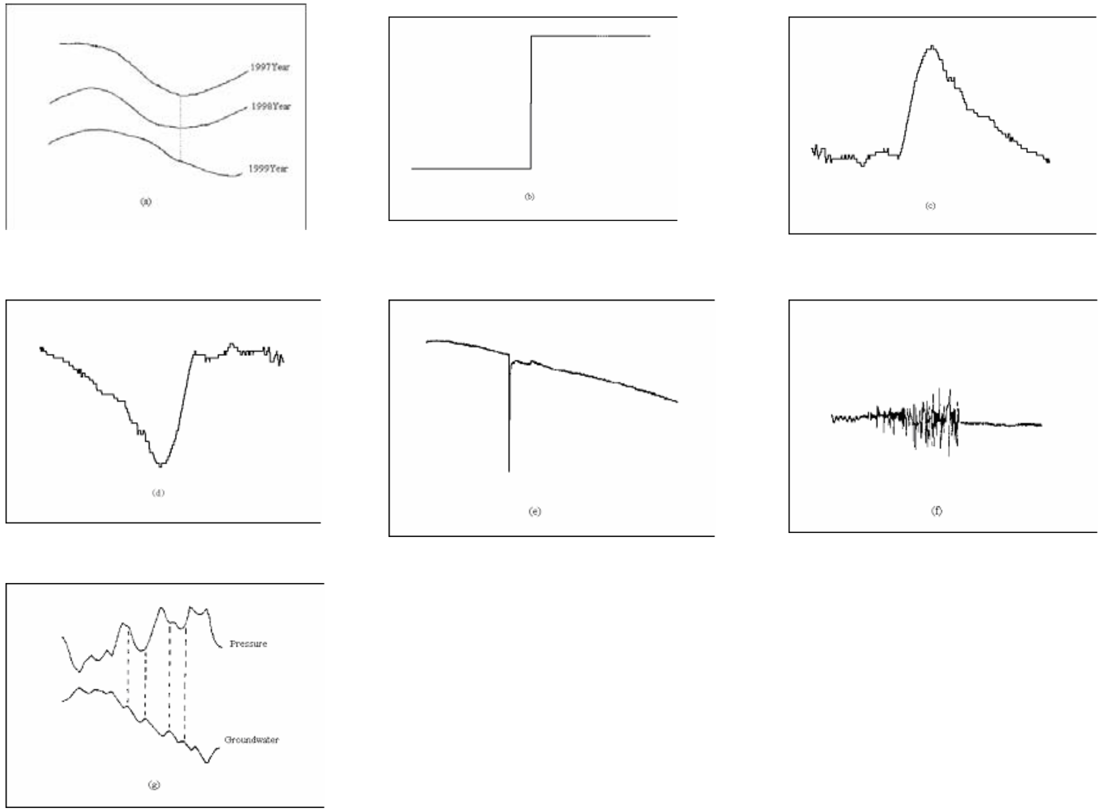
Part (I) - Statistics for Anomaly Variability [2/8]



Data and Map Source: WRA/CWB

Classification of Anomaly Pattern for Groundwater Level

- Dynamic Pattern
- Leap
- Rise
- Decline
- Pulse
- Vibration
- (Solid Tide) Distortion



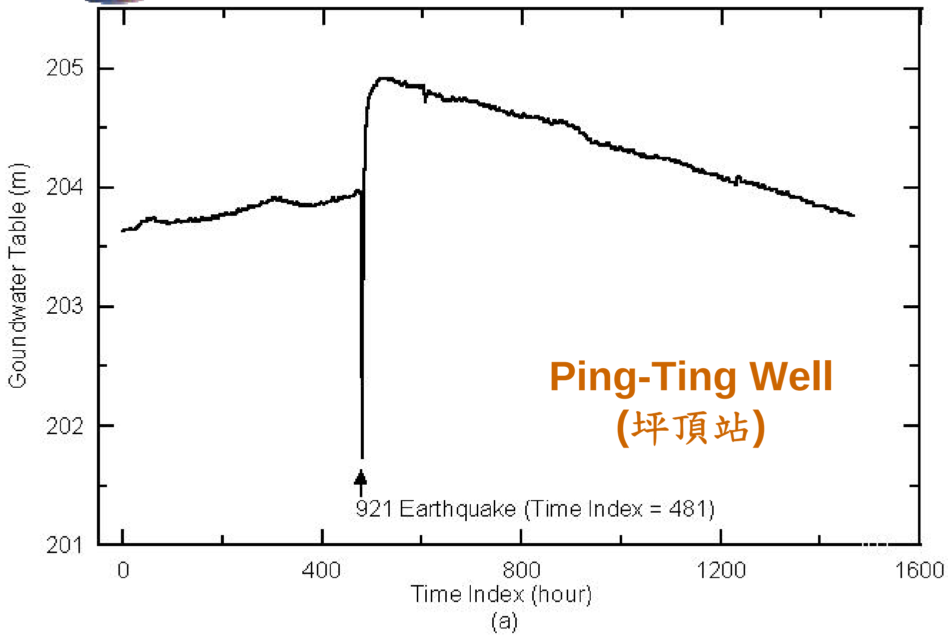
Anomaly Pattern Statistics for 921 and 331 Earthquakes

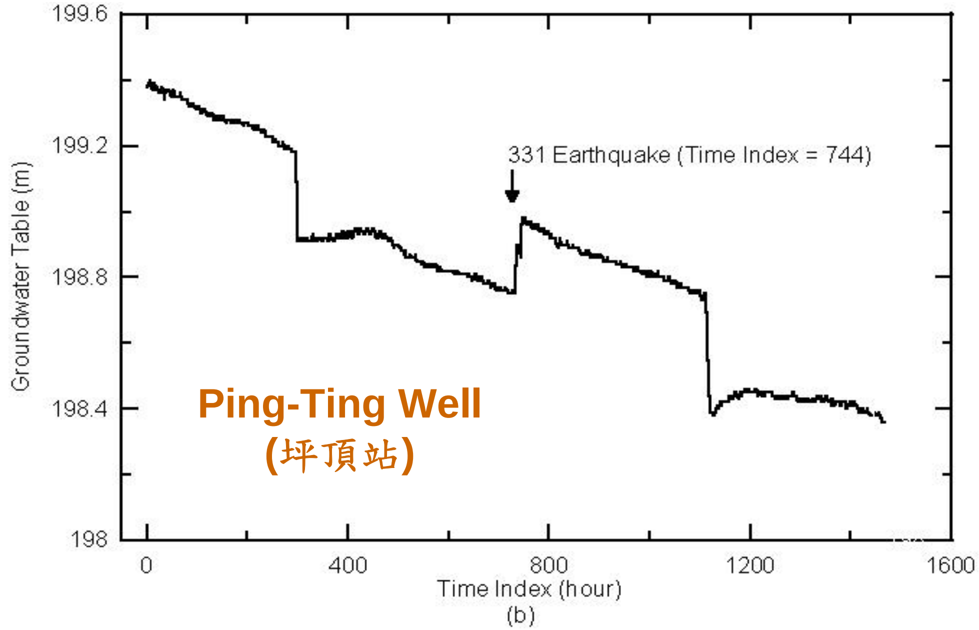
Item	921 Earthquake	331 Earthquake
Wells in Total	190	199
Interrupt and Damage	22	3
Net Number for Analysis	168	196
Anomalies in Total	112	24
Counting for Leap	99	19
Counting for Pulse	13	-
Counting for Rise	-	5

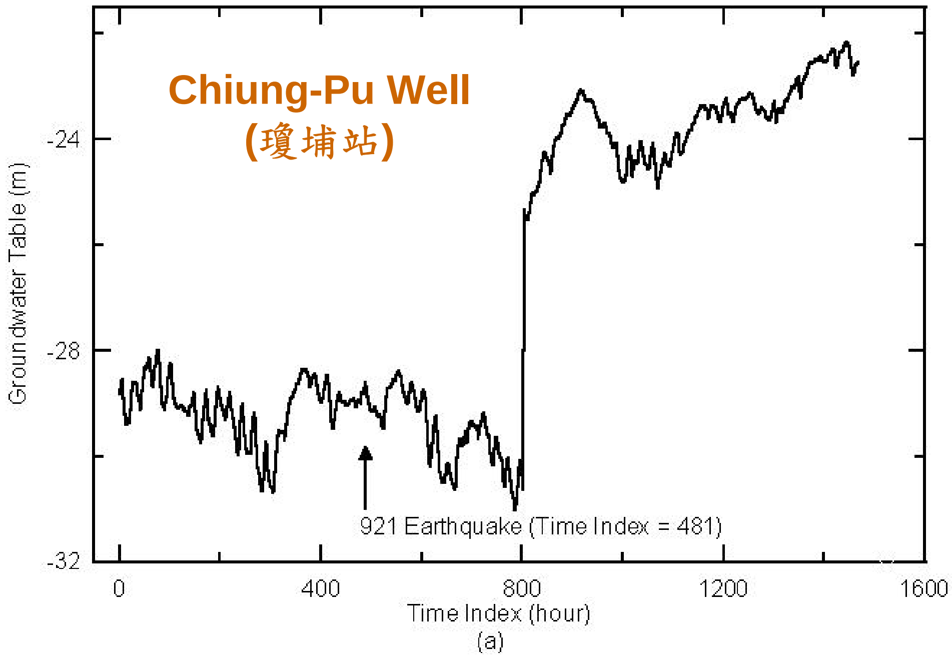
Anomaly Comparison Between 921 and 331 Earthquakes

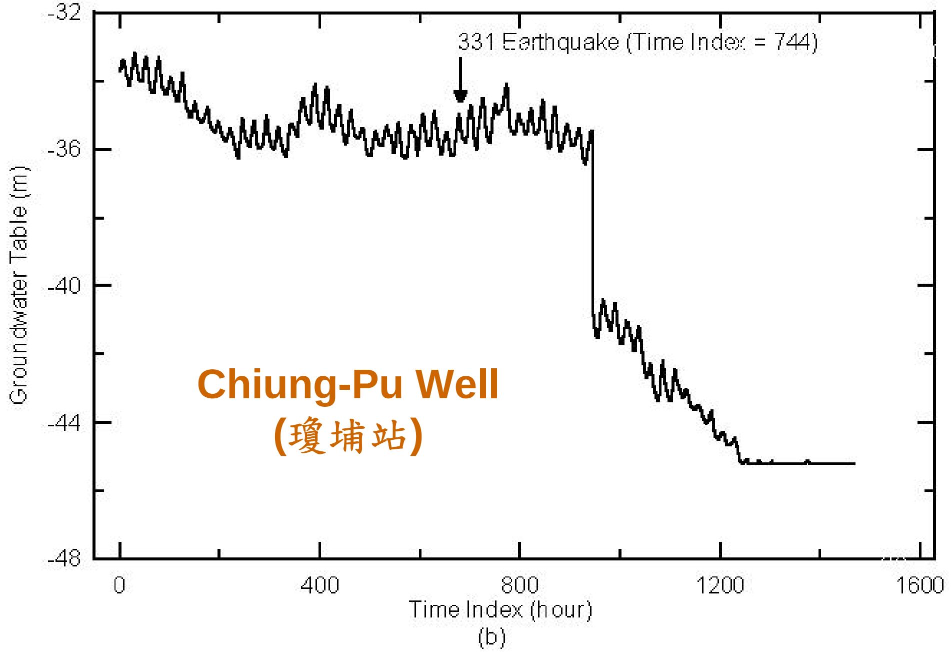
Anomaly Well 921	331	Counting	Percent(%)
YES	YES	10	6
NO	NO	42	25
YES	NO	102	61
NO	YES	14	8

Part (I) - Statistics for Anomaly Variability [7/8]

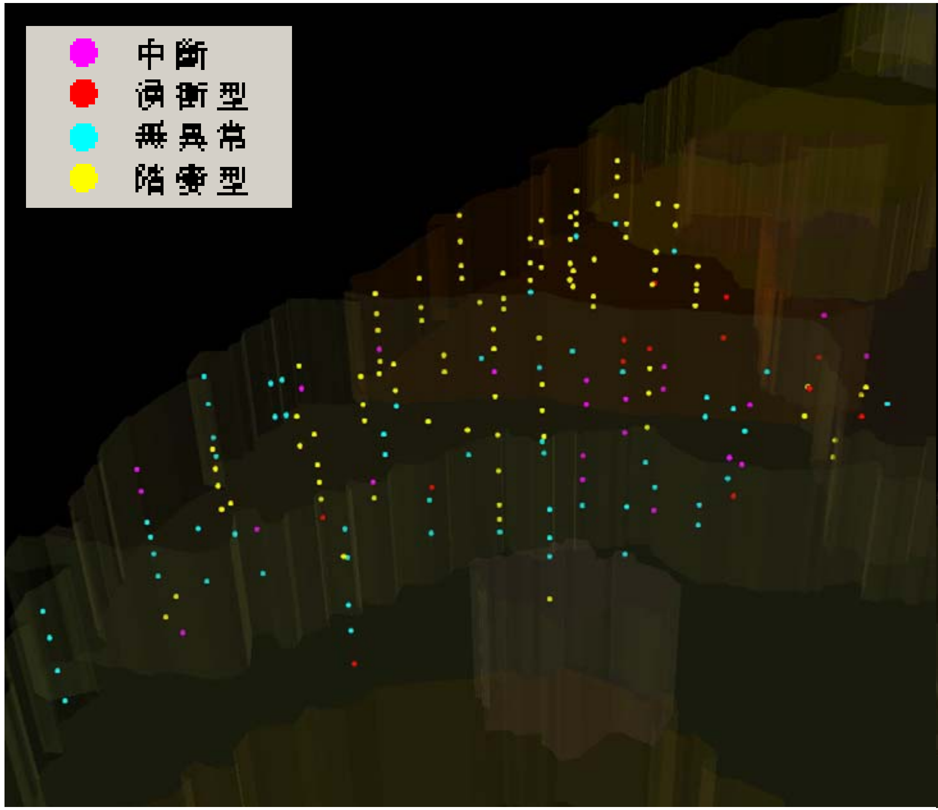




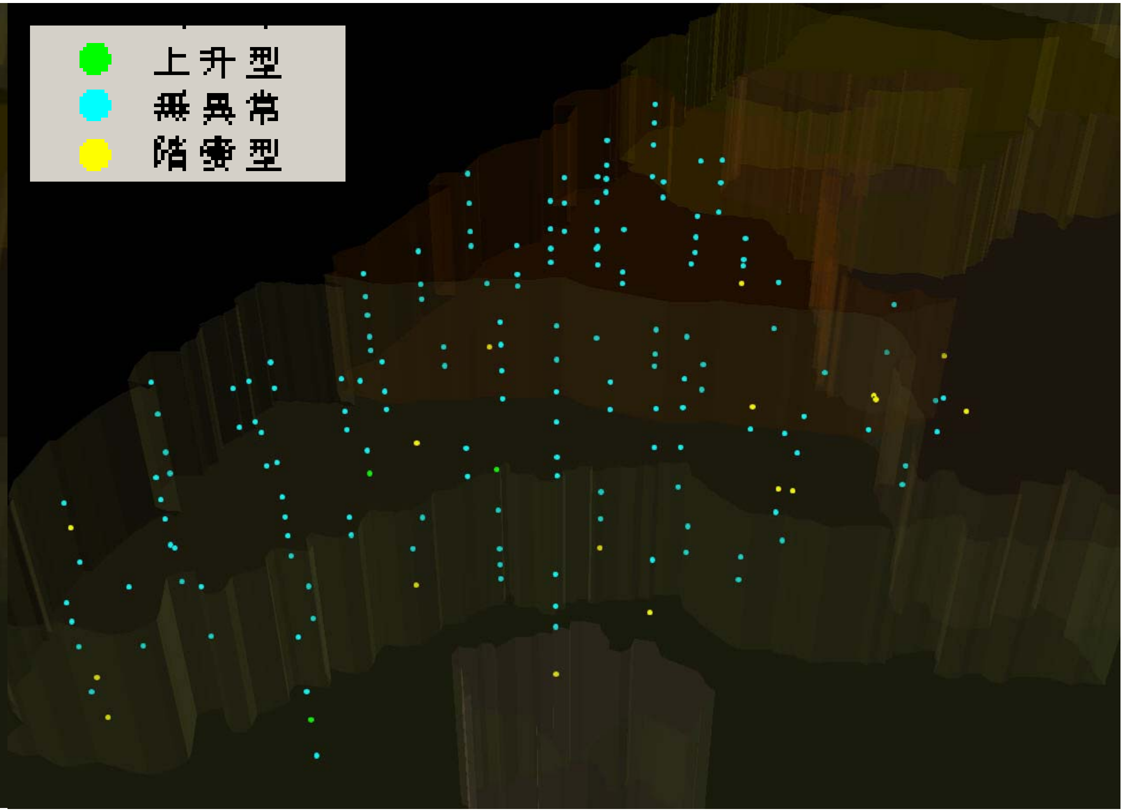




Well Map for Water-Level Anomaly Pattern



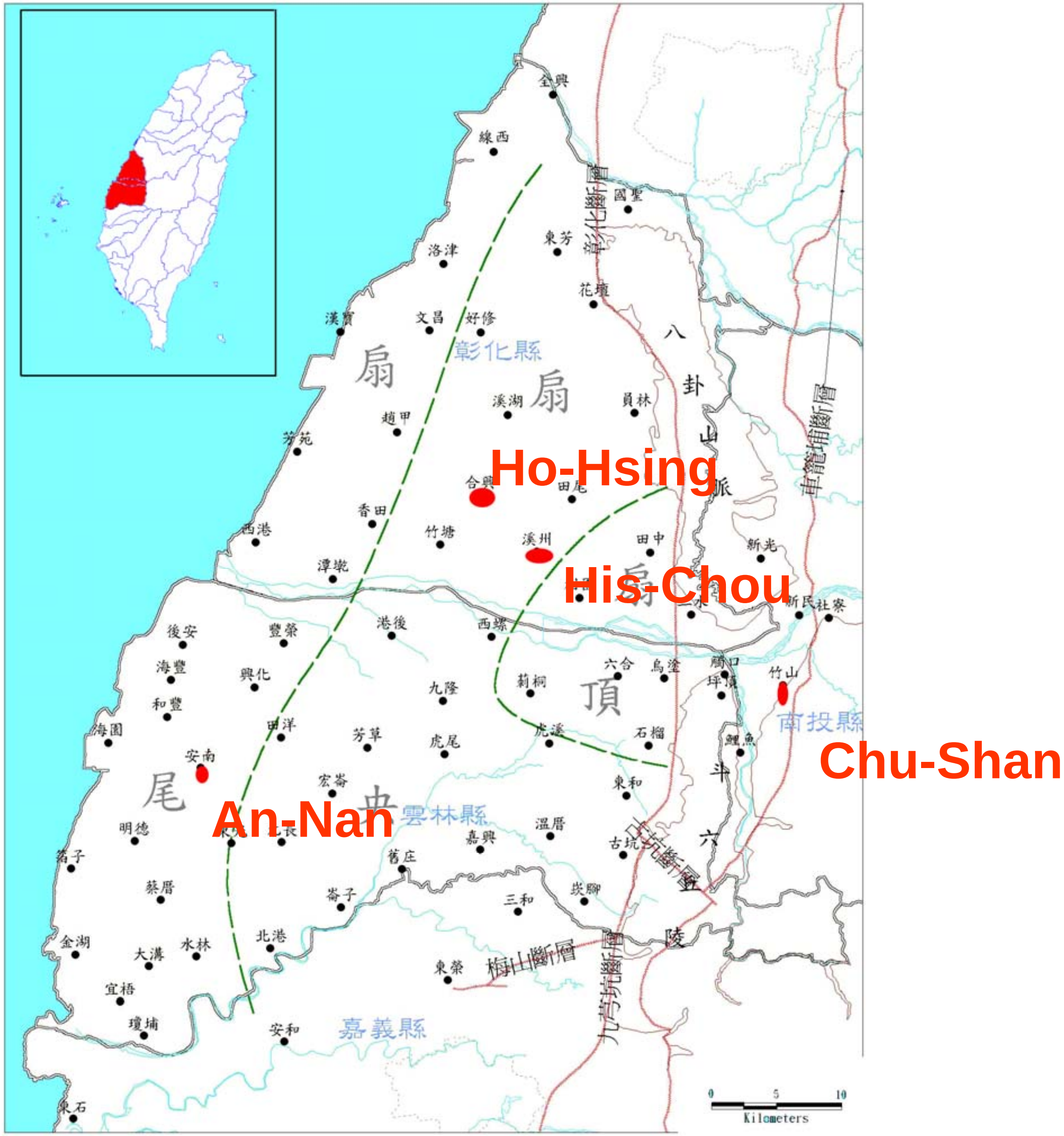
921 Earthquake



331 Earthquake

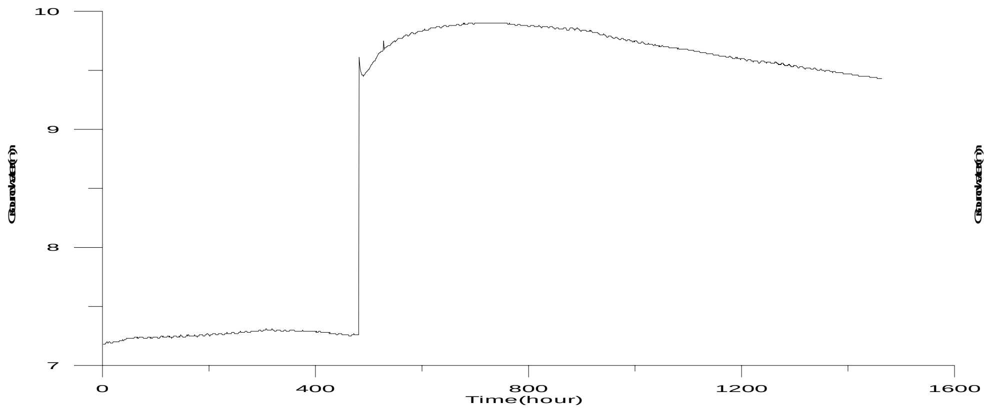
Part (II) – Intervention Analysis for Real-Case [1/3]

Four wells are selected to build the IA model.

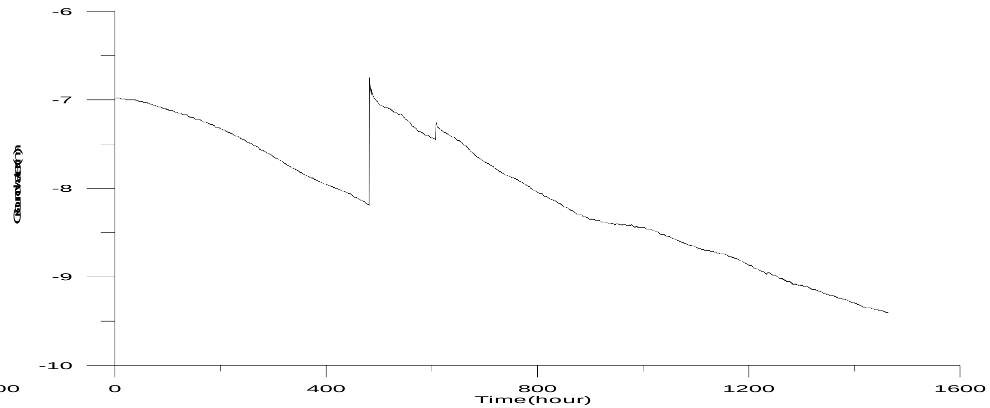


Part (II) – Intervention Analysis for Real-Case [2/3]

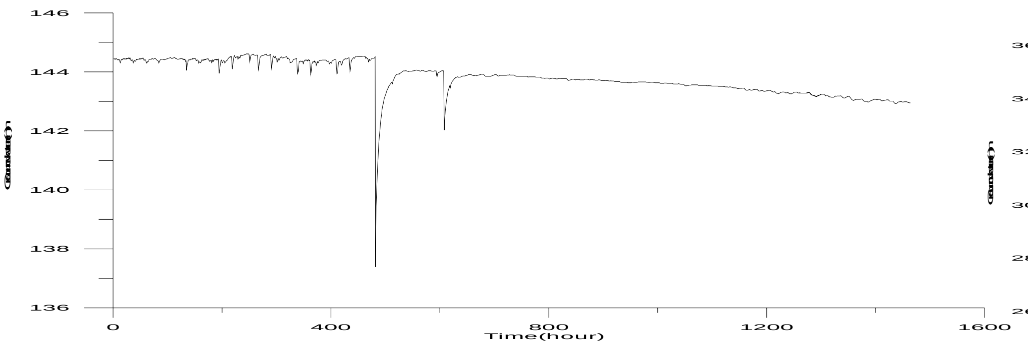
Leap Anomaly for Ho-Hsing Well (282m)



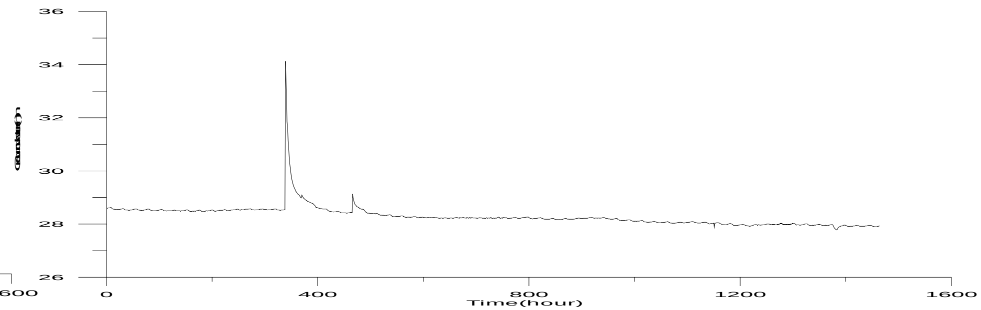
Leap Anomaly for An-Nan Well (201.9m)



Pulse Anomaly for Chu-Shan Well (72m)



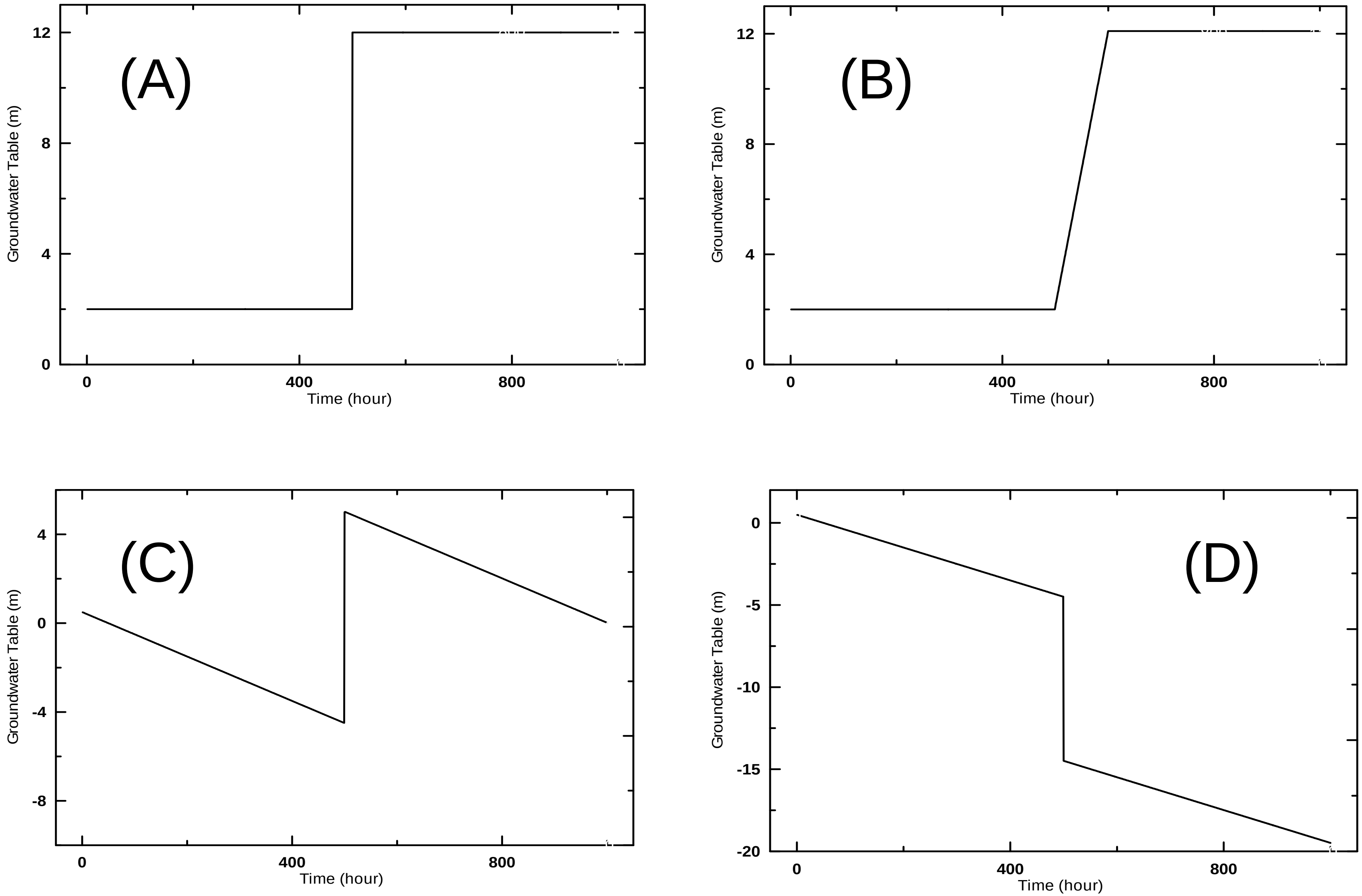
Pulse Anomaly for His-Chou Well (133m)



IA Model for Several Cases

#	Well	IA Model
1	Ho-Hsing(3)	$X_t - X_{t-1} = \frac{(W)}{(1-\delta * B)} P_t + \frac{(1-\theta_1 B)}{(1-\phi_1 B - \phi_2 B^2)} a_t$
2	An-Nan(2)	$X_t - X_{t-1} = \frac{(W)}{(1-\delta * B)} P_t + \frac{(1-\theta_1 B)}{(1-\phi_1 B - \phi_2 B^2)} a_t$
3	Chu-Shan(1)	$X_t - X_{t-1} = (W) P_t + (1-\theta_1 B) a_t$
4	His-Chou(3)	$X_t - X_{t-1} = (WB^{142}) P_t + \frac{(1-\theta_1 B)}{(1-\phi_1 B)} a_t$

Simulation of Leap Anomaly

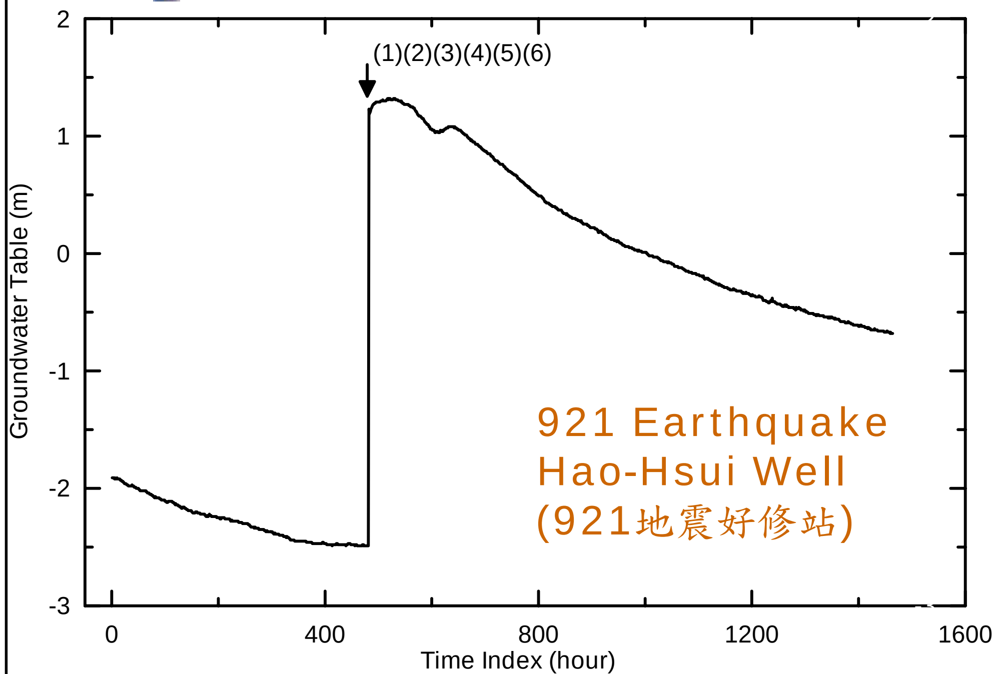


Simulation of Leap Pattern for Anomaly Detection

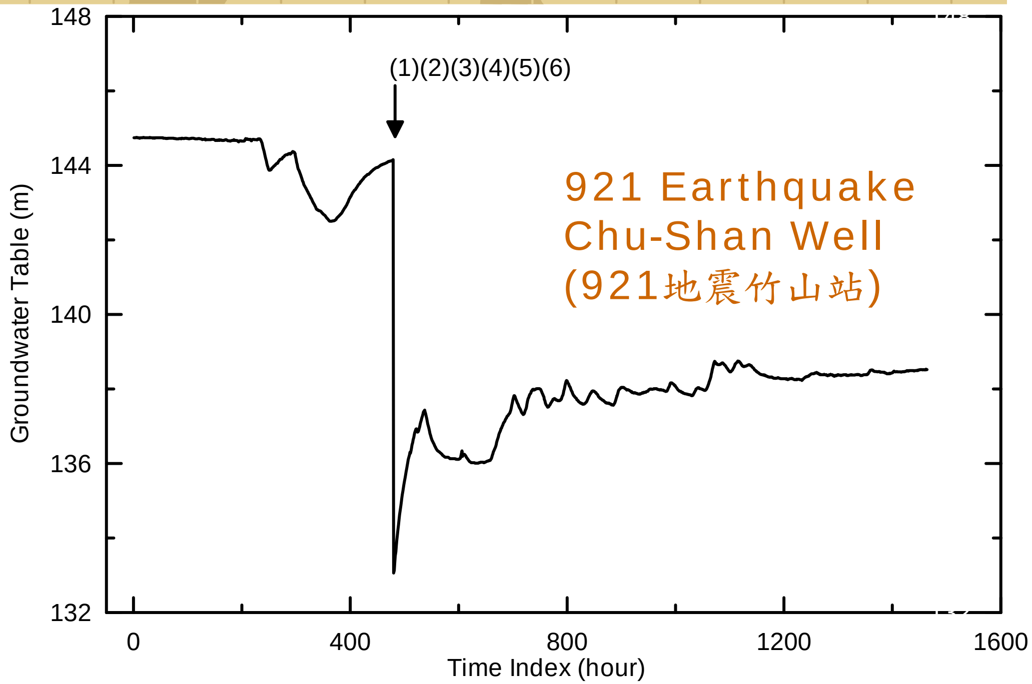
Anomaly Pattern		Leap											
Case		(A)			(B)			(C)			(D)		
Detection Method		1	2	3	1	2	3	1	2	3	1	2	3
(1) Moving *t* Testing	N=2	498	498	498	599	599	599	499	499	499	499	499	499
	N=50	499	498	500	575	575	575	465	499	499	499	499	499
	N=100	499	498	500	549	549	549	566	499	499	499	499	499
(2) Cramer's Method	N=2	*	*	*	599	599	599	*	*	499	*	*	*
	N=50	499	499	499	599	599	599	*	*	499	*	*	*
	N=100	499	499	499	599	599	599	*	*	499	*	*	*
(3) Yamamoto Method	N=2	498	498	498	599	599	599	499	499	499	499	499	499
	N=50	499	498	500	587	587	587	467	499	499	499	499	499
	N=100	499	498	500	549	549	549	434	499	499	499	499	499
(4) Moving *T*max Testing		499	500	500	549	549	549	512	786	499	499	499	499
(5) Mann-Kendall Method	UF	499	499	499	449	499	499	*	499	499	*	*	*
	UB	*	*	*	*	*	*	*	499	499	*	*	*
(6) Pettitt Method		499	499	499	599	599	599	*	*	499	*	*	*

The symbol "*" means the anomaly is not detected by the method for the case.

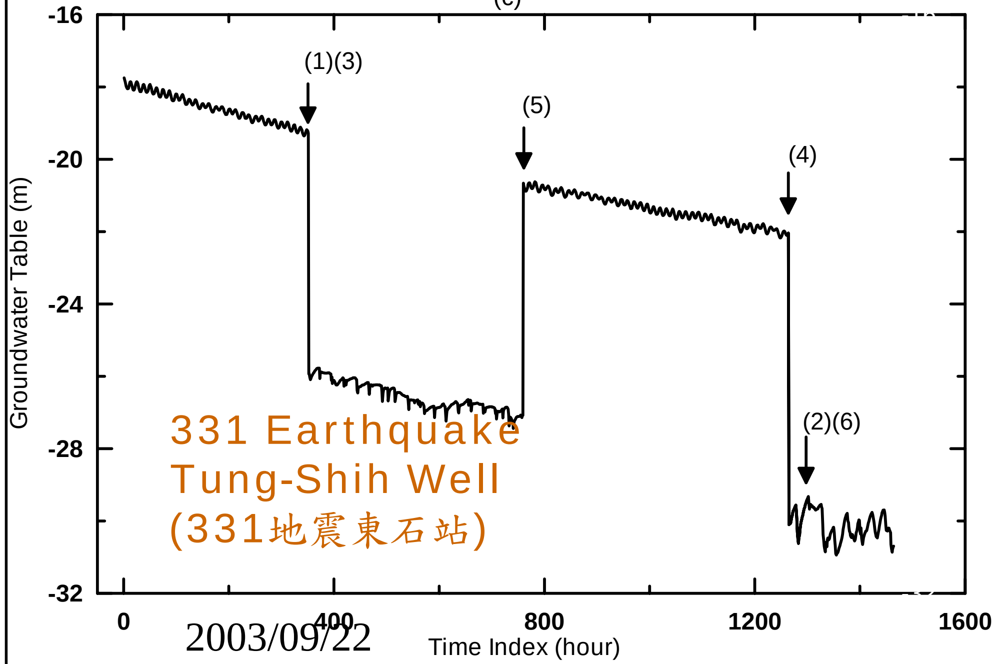
Part (III) – Simu. & Real-Case for Anomaly Detection [3/5]



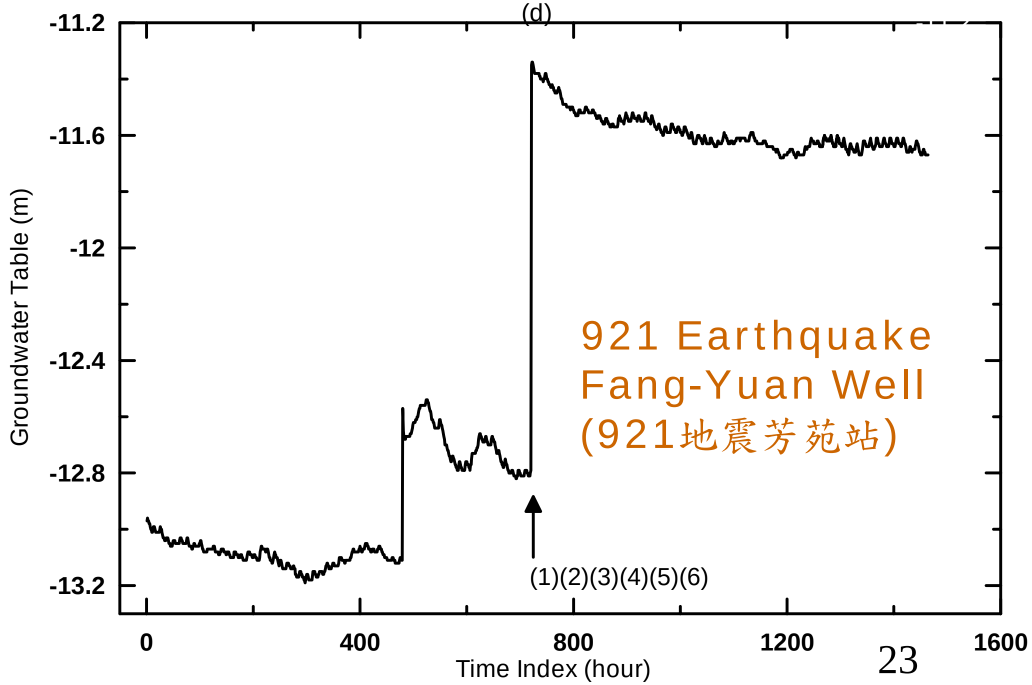
(c)



(d)

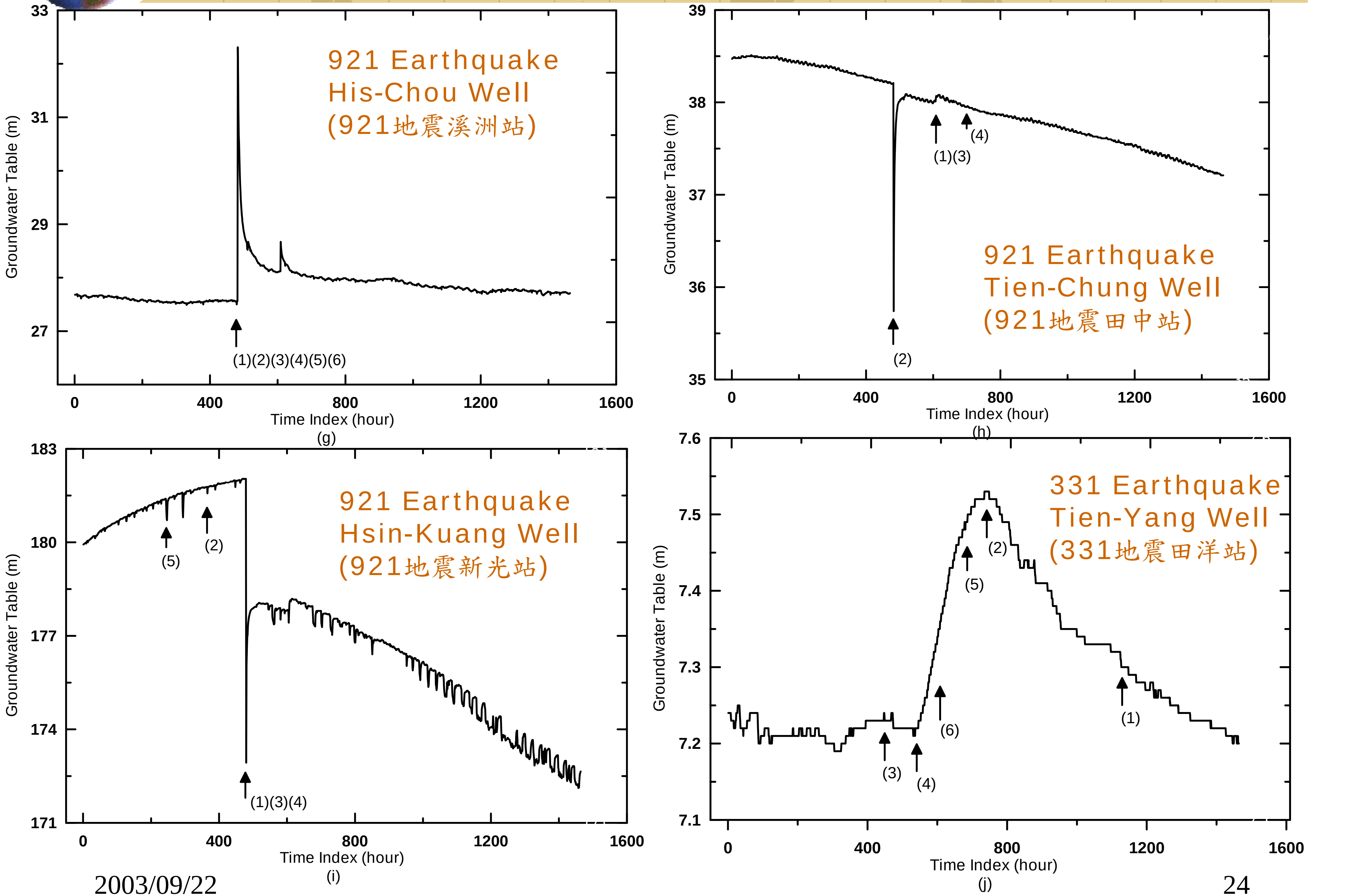


(e)



(f)

Part (III) – Simu. & Real-Case for Anomaly Detection [4/5]



Percent (%) of Anomaly Detection for Groundwater Level

Method	921 Earthquake		331 Earthquake
	Leap	Pulse	Leap
Moving *t* Testing	100%	43%	100%
Cramer's Method	55%	86%	28%
Yamamoto Method	100%	43%	100%
Moving *T*max Testing	76%	58%	78%
Mann-Kendall Method	69%	14%	28%
Pettitt Method	67%	14%	17%

Concluding Remarks [1/2]

- Many cases show that the anomaly pattern of seismic groundwater level is so complicated and multiplex, but there is the possibility on the reappearance of anomaly pattern in the same well.
- The leap and pulse pattern of groundwater level by two earthquakes can obtain the specific transfer function of intervention model.

Concluding Remarks [2/2]

- The moving *t* testing and Yamamoto method are suitable to detect the leap anomaly and the Cramer's method is suitable to detect the pulse anomaly.
- A further study is focused on the topics as follows:
  To develop the testing procedure of anomaly detection.
  Automatic algorithm for detecting the time-point of anomaly.

THANKS FOR YOUR ATTENTION AND COOPERATION