成功大學
資源工程

Estimating the Anomalous Stress-source Area by Using Earthquake-triggered Groundwater Fluctuations

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Introduction

- Earthquakes often cause changes in spring and stream discharge, water levels, geyser behavior, hydyogeochemical anomalies.

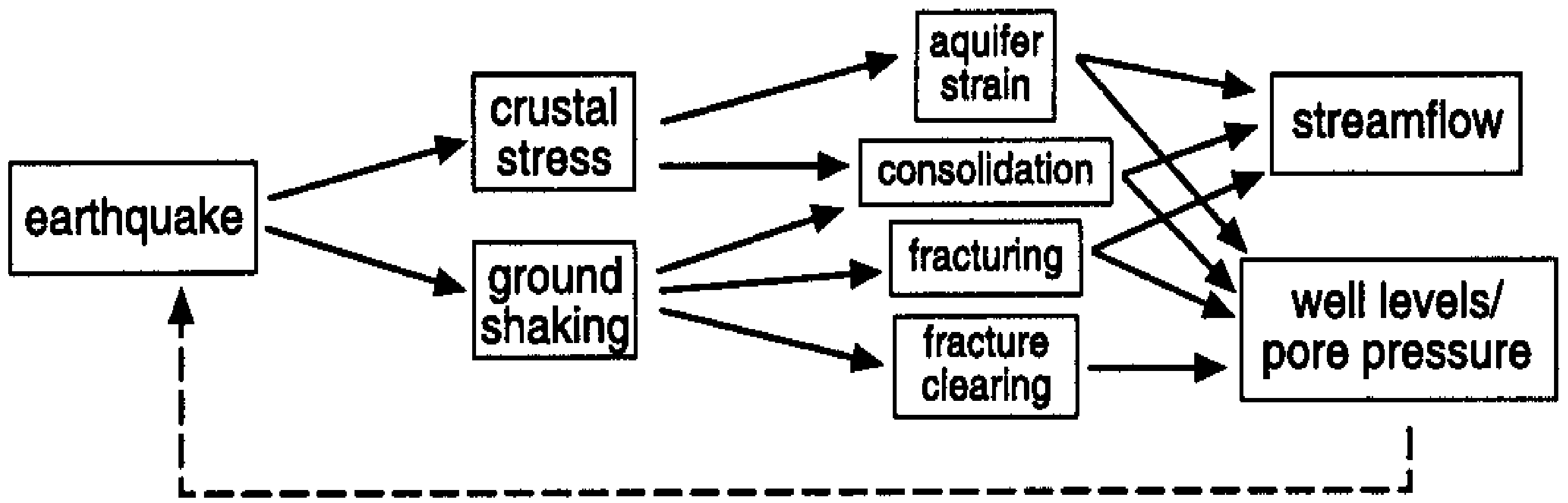
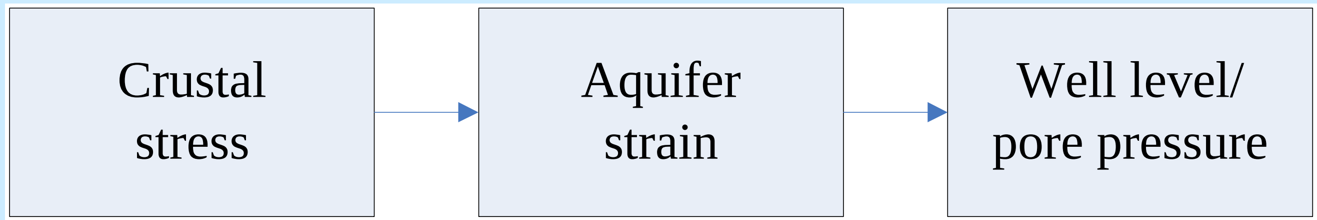


Fig. 1. Interactions between earthquakes and hydrological processes.

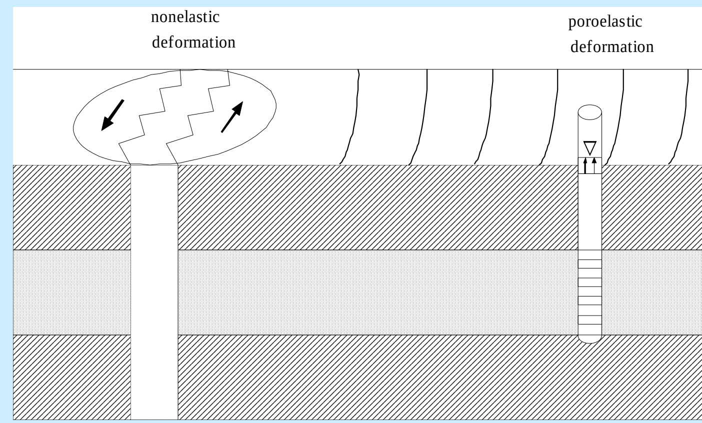
(Montgomery and Manga, 2003)

What can the groundwater level be used for?

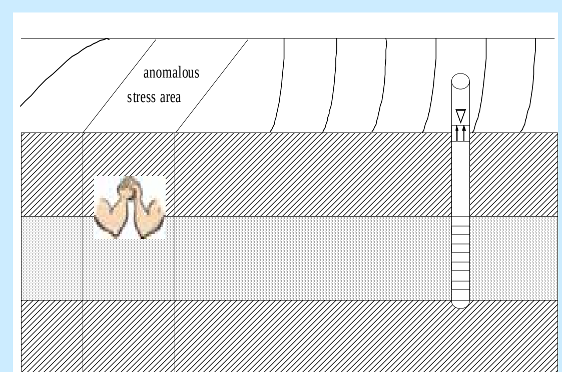
- It may reflect the strain state of the aquifer.



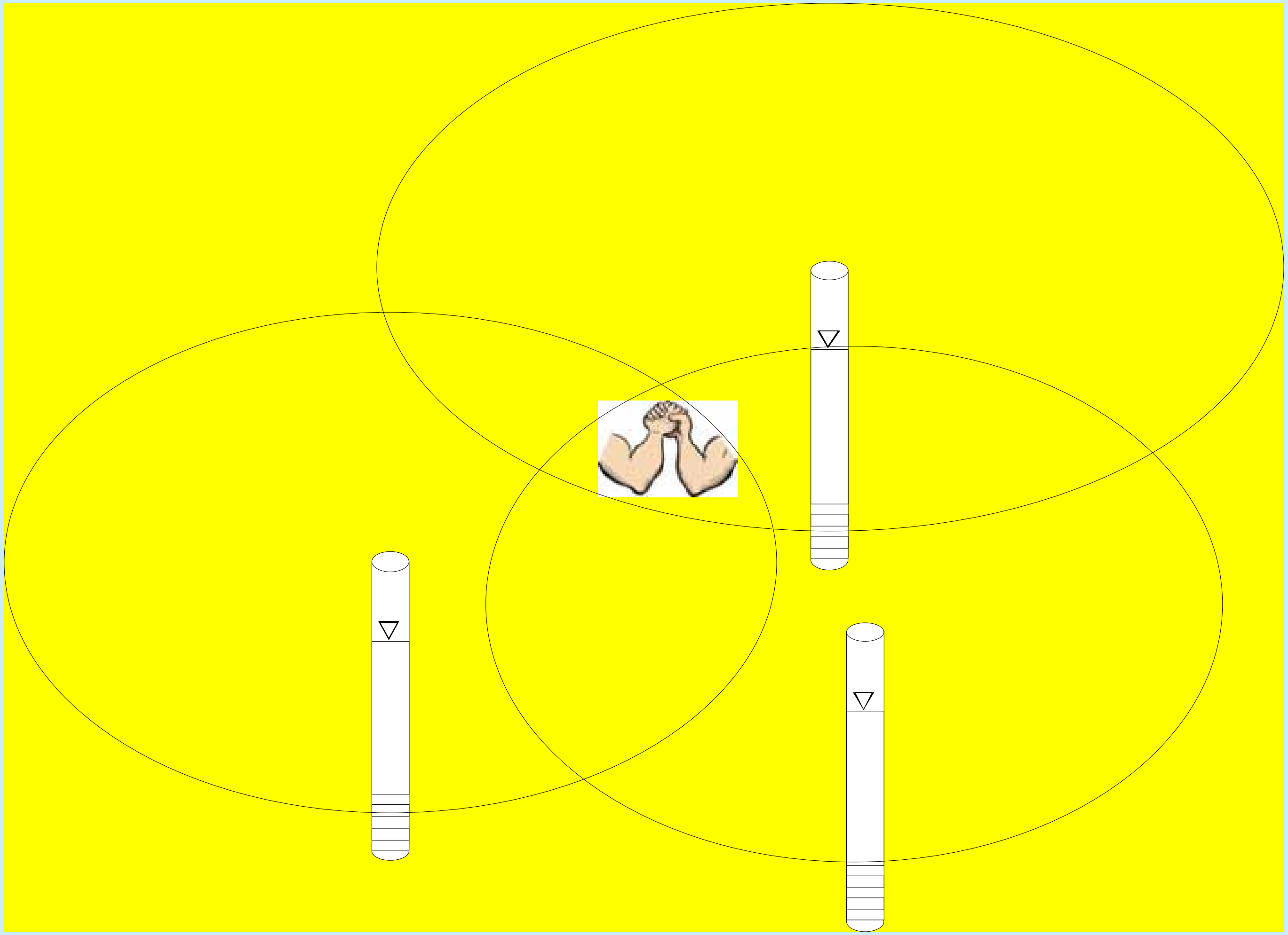
- If so, can it be used to infer the location of anomalous stress area?
  - The assumption may be validated through coseismic events.



  - There are more implications for preseismic conditions.



From groundwater level fluctuation to the stress anomalous area



Theory of Linear Poroelasticity: linear constitutive equations

$$\varepsilon = a_{11}\sigma + a_{12}p$$

$$\zeta = a_{21}\sigma + a_{22}p$$

$$a_{11} = \left.\frac{\delta\varepsilon}{\delta\sigma}\right|_{p=0} \equiv \frac{1}{K}$$

$$a_{12} = \left.\frac{\delta\varepsilon}{\delta p}\right|_{\sigma=0} \equiv \frac{1}{H}$$

$$a_{21} = \left.\frac{\delta\zeta}{\delta\sigma}\right|_{p=0} \equiv \frac{1}{H_1}$$

$$a_{22} = \left.\frac{\delta\zeta}{\delta p}\right|_{\sigma=0} \equiv \frac{1}{R}$$

Theory of Linear Poroelasticity: governing equations

Force equilibrium

$$G\nabla^2 u_i + \frac{G}{1-2\nu}\frac{\partial^2 u_k}{\partial x_i \partial x_j} = \alpha\frac{\partial p}{\partial x_i} - F_i$$

Fluid continuity

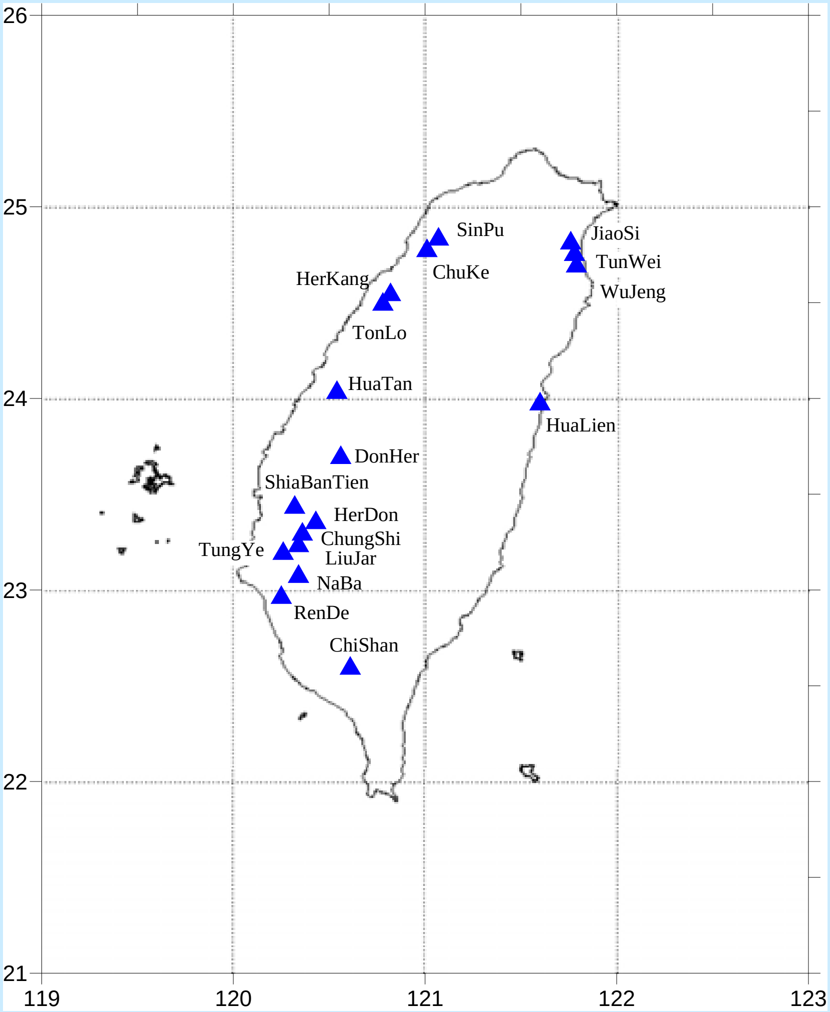
$$\frac{\alpha}{KB}[\frac{B}{3}\frac{\partial \sigma_{kk}}{\partial t} + \frac{\partial p}{\partial t}] - \frac{k}{\mu}\nabla^2 p = Q$$

Analytical Solution (吕志宗,1991）

- Three dimensions
- A constant radial force
- Observed in the horizontal plane

$$\Delta h = \frac{C_0 F}{r^2}\left[erf\left(\bar{D}^{\frac{1}{2}} \right) - \left(\frac{4\bar{D}}{\pi} \right)^{\frac{1}{2}} exp\left(-\bar{D}\right) \right]$$

$$\bar{D} = r^2 / 4Dt$$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HerKang
TonLo
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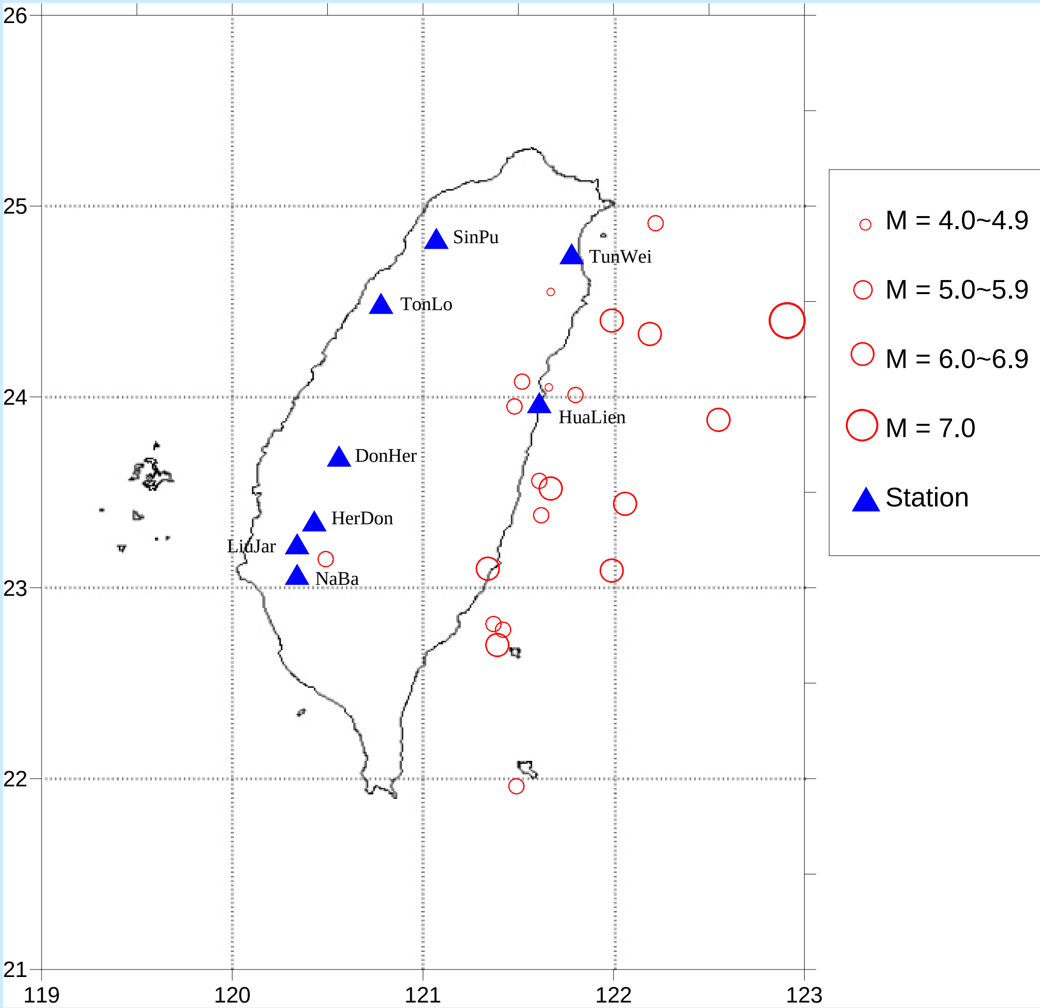
HuaLien
DonHer
ShiaBanTien
HerDon
ChungShi
TungYe
LiuJar
NaBa
RenDe
ChiShan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TonLo
HuaLien
DonHer
HerDon
LiuJar
NaBa
M = 4.0~4.9
M = 5.0~5.9
M = 6.0~6.9
M = 7.0
Station

Earthquake events used in this research and the groundwater level responses

Time	Magnitude	Hypocentral depth (km)	Position		Epicentral distance km (response)							
			Longitude	Latitude	LiuJar	NaBa	DonHer	SinPu	HuLien	TunWei	TonLo	HerDon
2003/04/03 14:59:33.7	5.0	14.5	120.5	23.2	17(S)	18(S)	60	195	—	—	—	—
2003/06/09 09:52:52.6	6.3	21.3	122.0	24.4	212(O)	223	165(O)	104(S)	—	—	—	—
2003/06/10 16:40:32.7	6.5	27.6	121.7	23.5	140(S)	145(S)	115(OS)	157(O)	—	—	—	—
2003/06/17 02:33:39.9	5.9	18.8	121.6	23.6	135	141(O)	108	151	—	—	—	—
2003/12/10 12:38:15.2	6.6	10.0	121.3	23.1	103(S)	102	103(OS)	194(O)	—	—	—	—
2003/12/11 08:01:49.8	5.7	12.6	121.4	22.8	121	115(O)	133	230	—	—	—	—
2004/01/01 11:15:18.5	5.9	17.8	121.6	23.4	132	135	113	170	66(O)	152(O)	150	122(O)
2004/01/06 08:55:33.5	4.6	54.9	121.7	24.6	199	213	148	68	64	24(O)	90	184
2004/01/13 17:29:00.8	5.0	19.8	121.8	24.0	172	182	131	117	20(S)	82	116	158
2004/02/04 11:24:00.5	6.0	4.1	122.1	23.4	177	181	155	184	75(O)	147(O)	175(O)	167(O)
2004/02/09 15:13:49.6	4.3	37.8	121.7	24.1	162	173	119	105	10(O)	78	102	148
2004/04/20 01:51:24.7	5.1	43.4	121.4	22.8	115	109	128	226	131(O)	218(O)	196	113(O)
2004/04/24 23:20:31.2	5.3	20.7	121.5	24.0	141	152	98	106	13	93	93(O)	126
2004/05/01 15:56:13.3	5.8	17.8	121.5	24.1	153	164(O)	107	95	15(S)	78(S)	88(O)	138
2004/05/08 16:02:48.4	5.7	6.2	121.5	22.0	183	171	214	321	223(O)	310	289(O)	188
2004/05/16 14:04:08.3	6.0	12.5	122.0	23.1	169	169	160	214(O)	106(O)	185	198	162
2004/05/19 15:04:12.0	6.5	8.7	121.4	22.7	122	115(O)	138(OS)	238(O)	143(O)	230(OS)	208(S)	122(S)
2004/07/06 15:32:03.3	5.8	9.8	122.2	24.9	267	279	216	116	121	48(S)	153	251
2004/10/15 12:08:50.2	7.0	58.8	122.9	24.4	292(O)	300(O)	—	192(O)	141(O)	121(OS)	216(O)	278(O)
2004/11/08 23:54:58.8	6.7	10.0	122.6	23.9	237(O)	243(O)	—	—	97(O)	124(OS)	192(O)	224(O)
2004/11/11 10:16:44.4	6.0	13.9	122.2	24.3	224(O)	235	180	—	71(O)	62(S)	144	210

$$d = 0.090 \times 10^{0.4785M}$$

(2003~2004 Taiwan's earthquake data)

For M=7 earthquake, the detectable distance is about 200 km.

For M=5 earthquake, the detectable distance is only about 22 km.

Assume sandstone material,

Parameters	Values	Units
Young's modulus	1.00×10^{8}	N/m^2
Poisson ratio	0.25	none
Porosity	0.375	none
Water compressibility	4.40×10^{-10}	m^2/N
Specific weight of water	9810	N/m^3
Hydraulic conductivity	1.00×10^{-4}	m/s

Using water level fluctuation and distance to Epicenter, force is calculated and is related to earthquake magnitude as

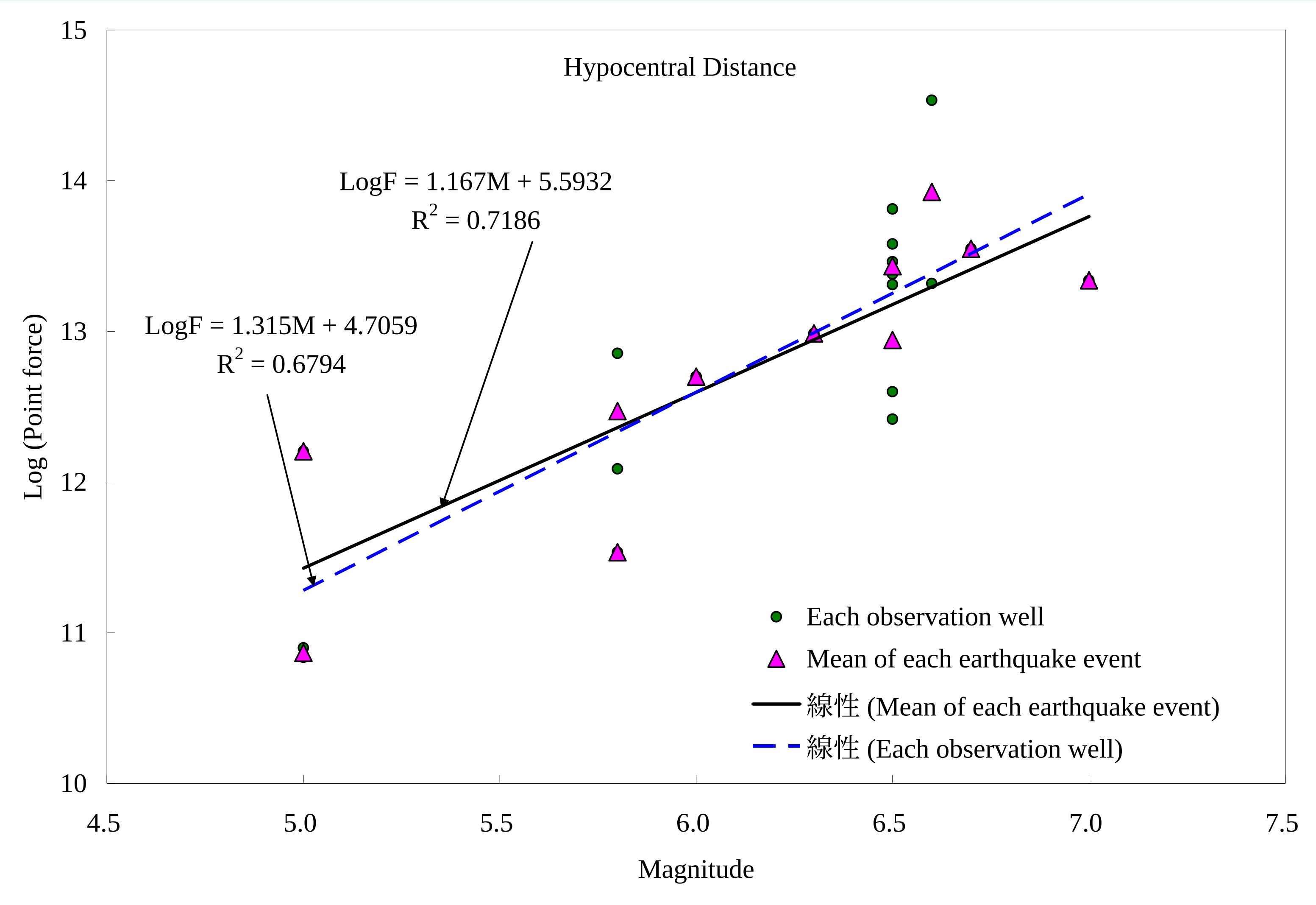
$$F = 126590\times10^{1.2477M}$$

From model

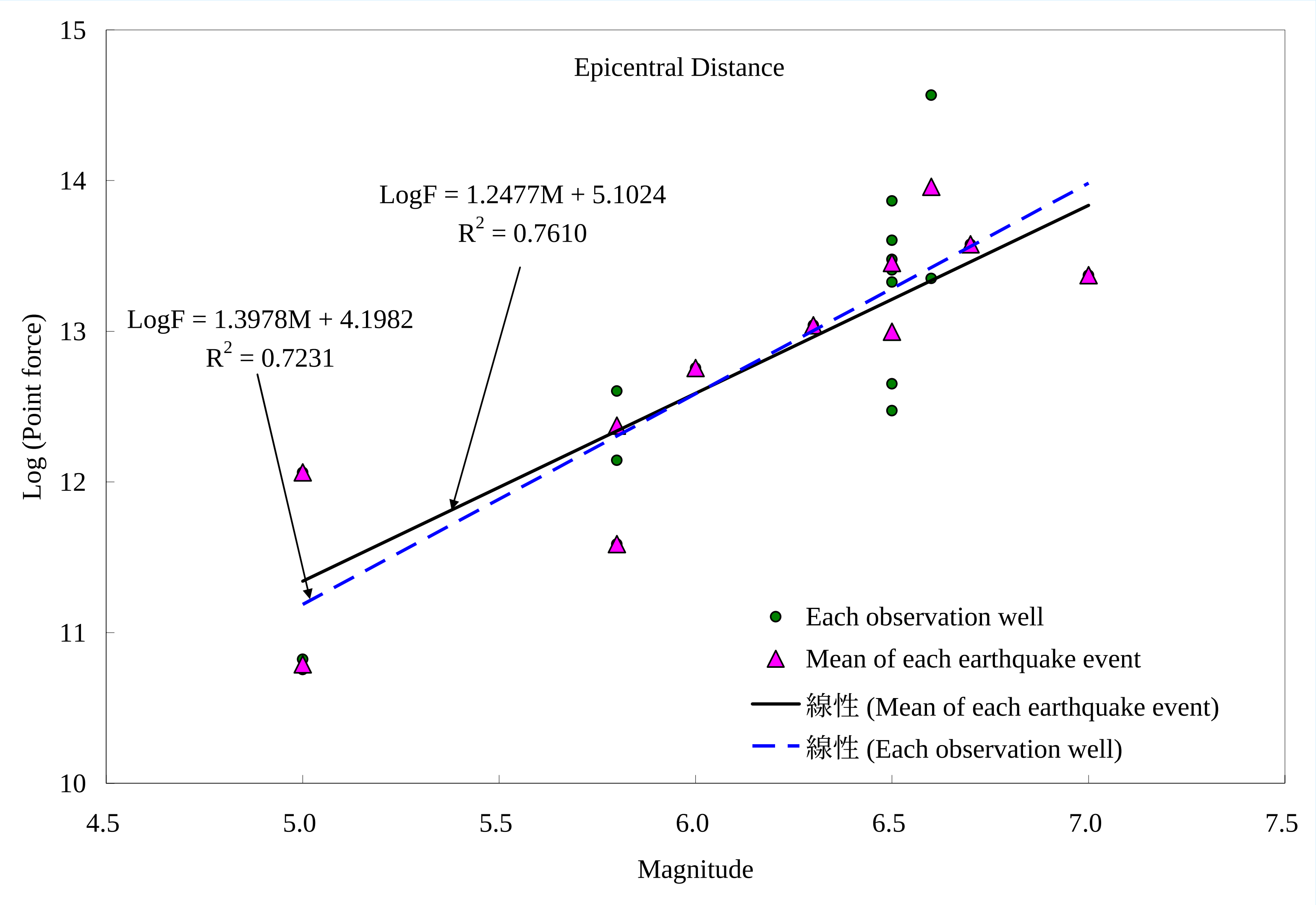
$$\log(r) = -0.5\log(\Delta h) + 0.62385M + 0.001503$$

From data regression

$$\log(r) = -0.1613\log(\Delta h) + 0.5934M + 0.8960$$

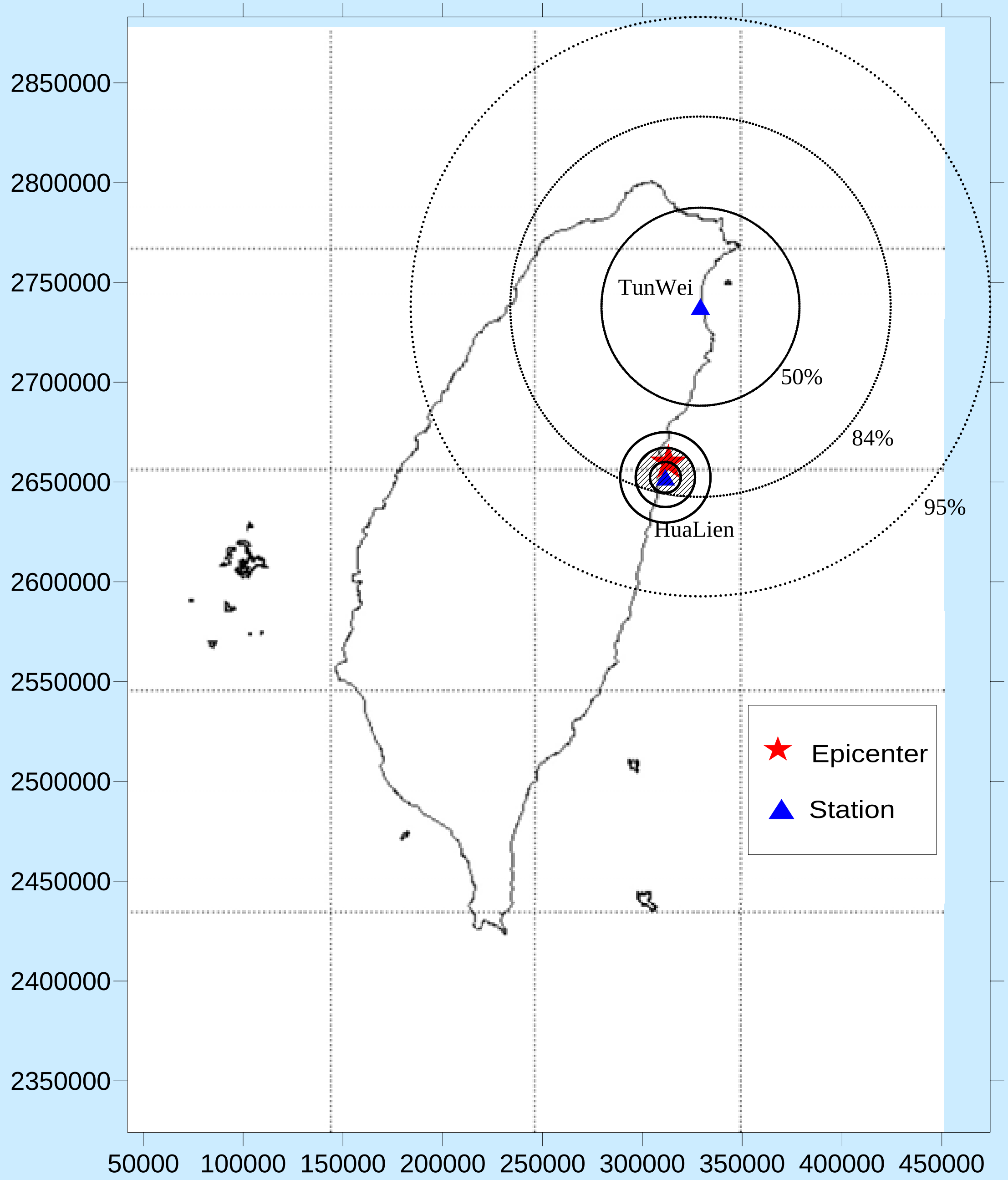


The relationship between point force and earthquake magnitude under three-dimensional model

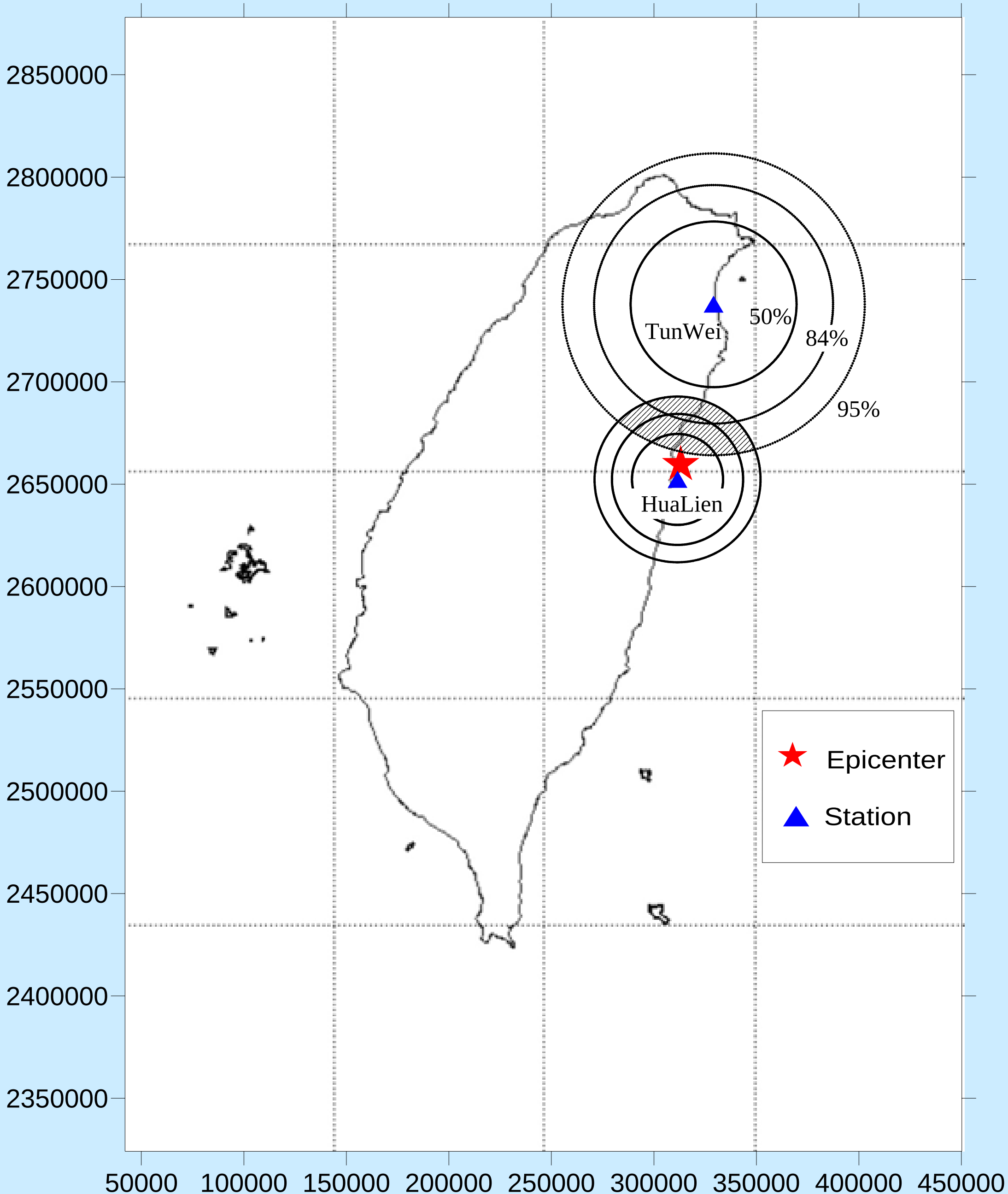


The relationship between point force and earthquake magnitude under two-dimensional model

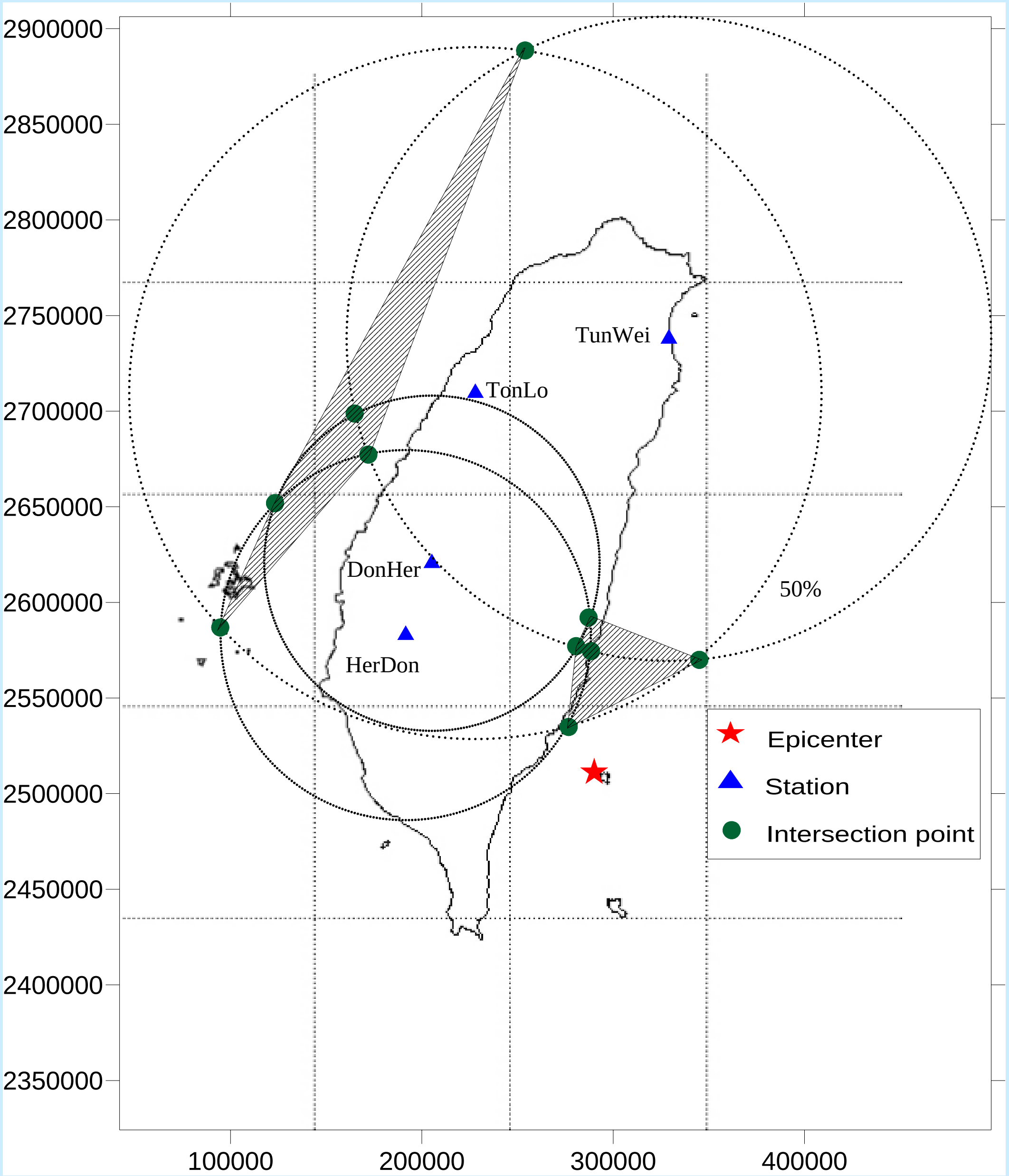
The model I result of 5.6 magnitude earthquake triggered on April 30, 2005



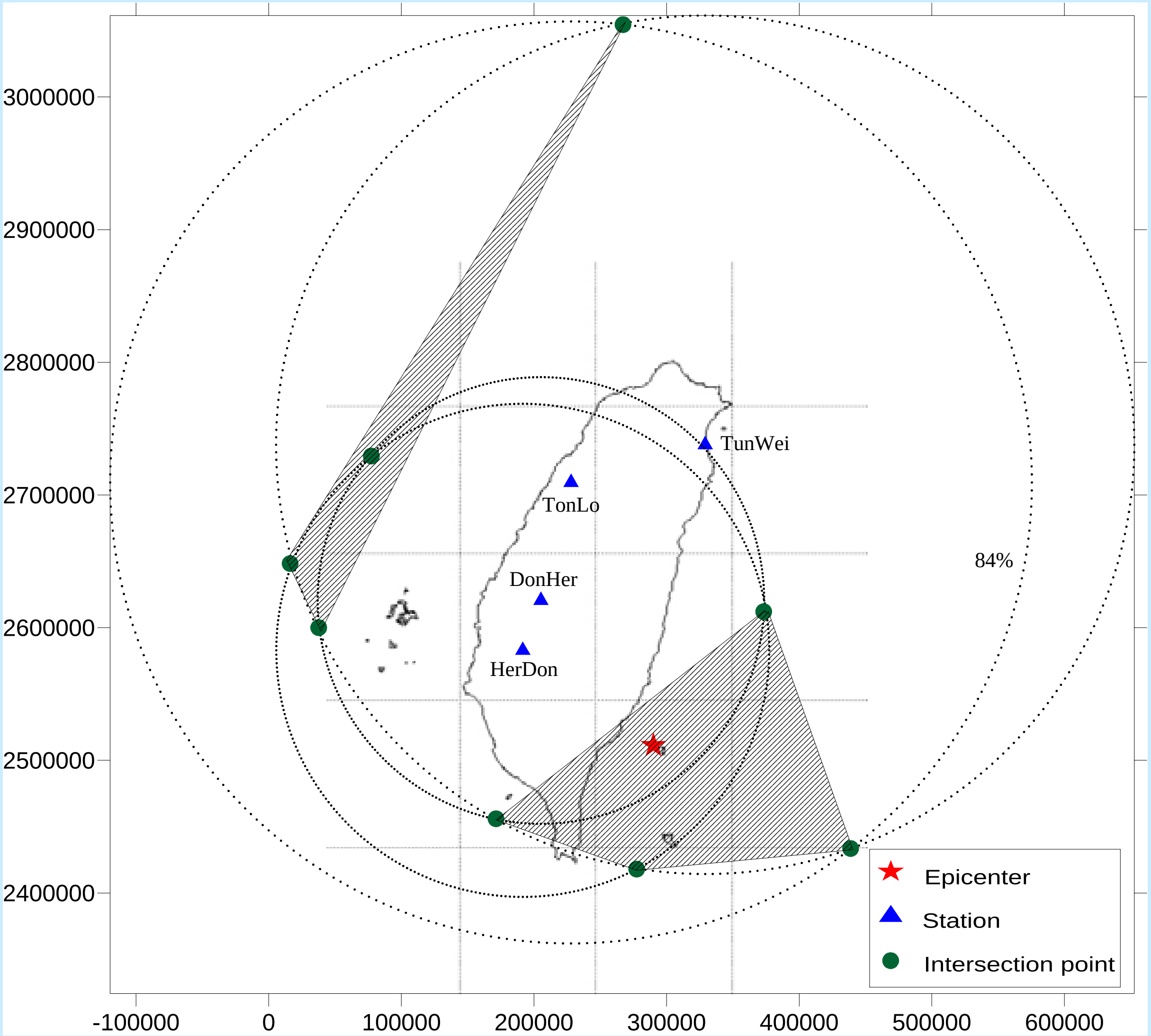
The model II result of 5.6 magnitude earthquake triggered on April 30, 2005



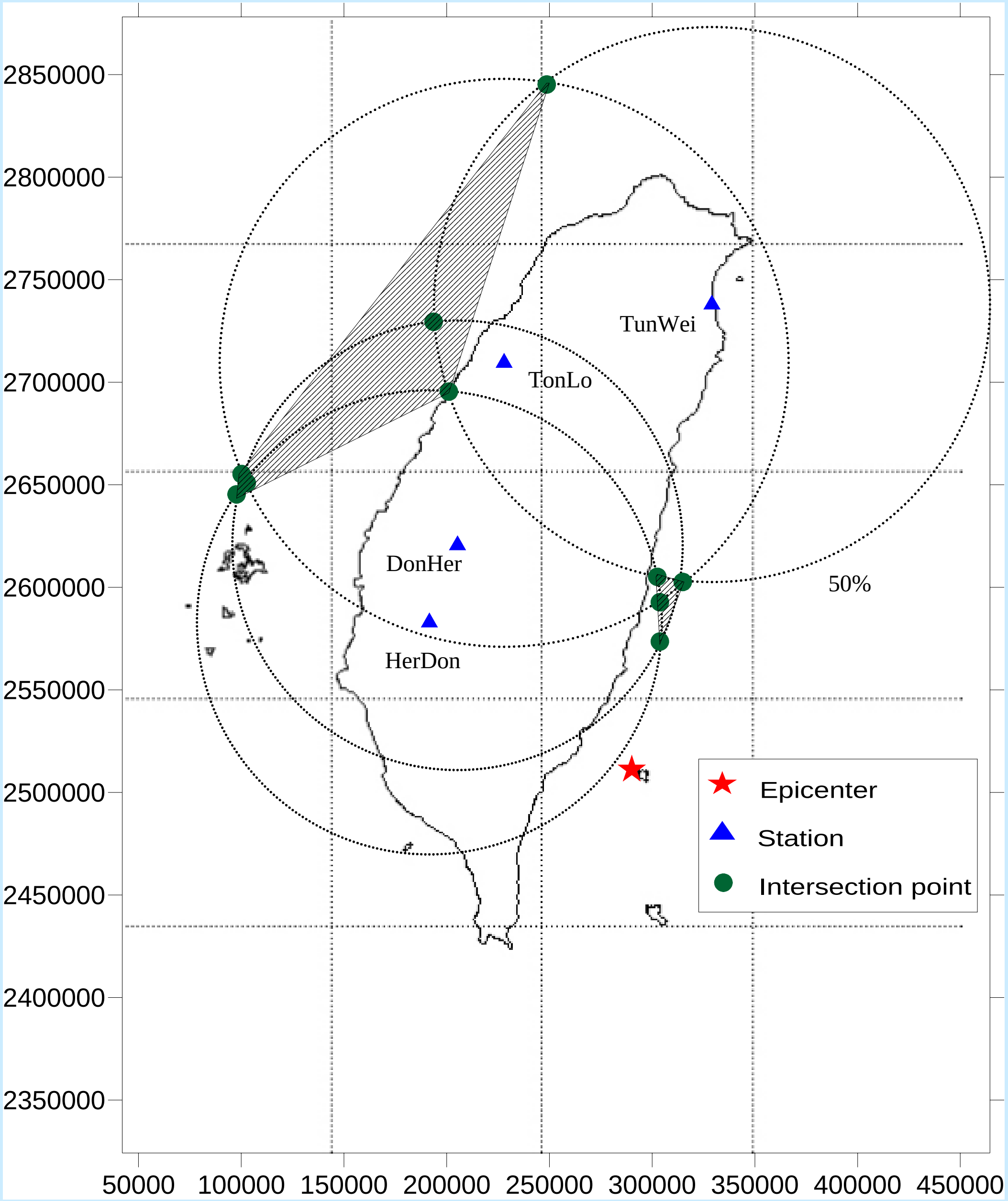
The model I result of 50% confidence of point force distance in 6.5 magnitude earthquake triggered on May 19, 2004



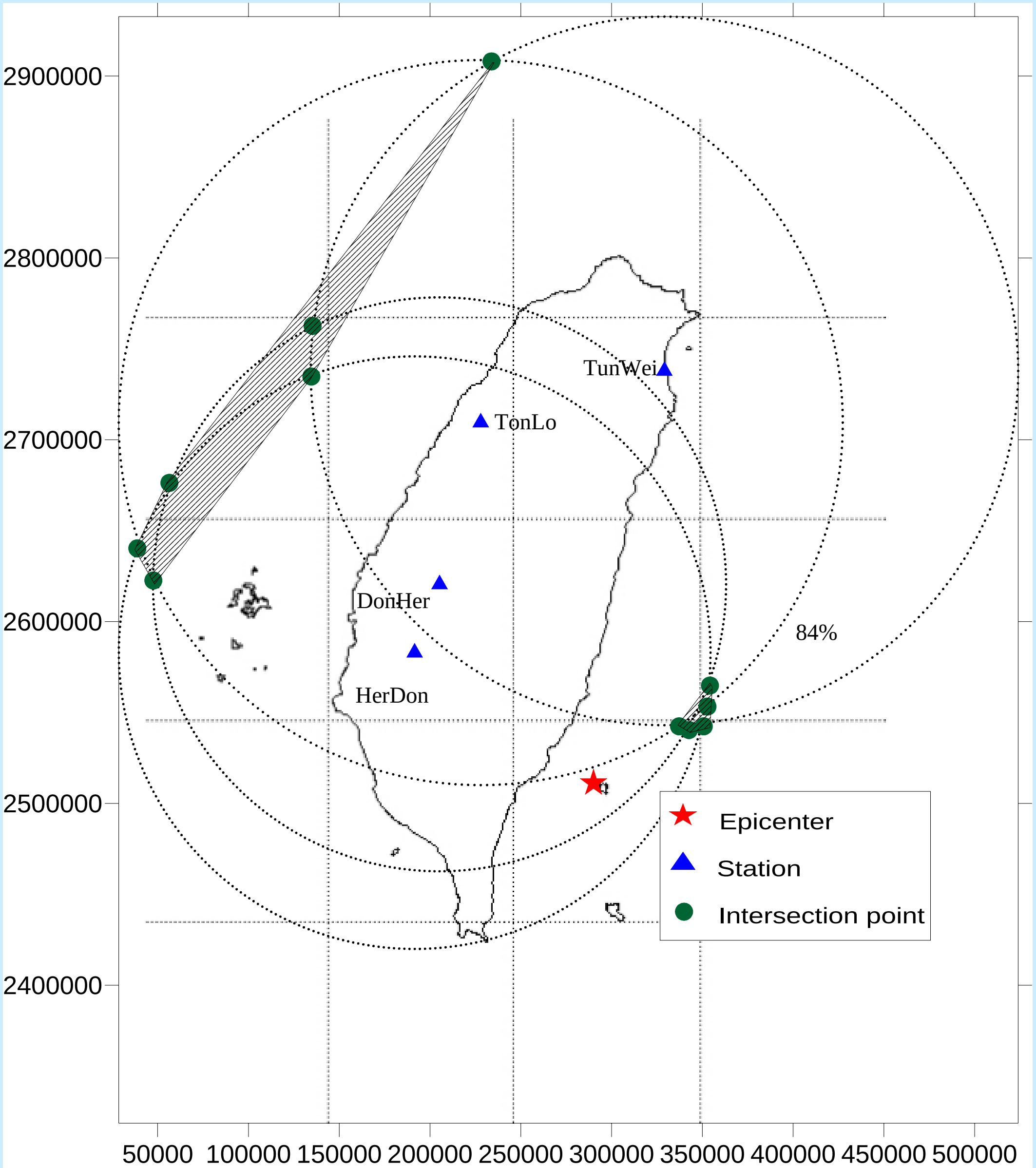
The model I result of 84% confidence of point force distance in 6.5 magnitude earthquake triggered on May 19, 2004



The model II result of 50% confidence of point force distance in 6.5 magnitude earthquake triggered on May 19, 2004



The model II result of 84% confidence of point force distance in 6.5 magnitude earthquake triggered on May 19, 2004



Conclusions

- Water level fluctuations may reflect the status of changed strain which is caused by anomalous stress from far distance.
- Using the semi-analytical analysis the anomalous stress area can be detected using at least three monitoring wells
- The analyzed results show that the direction and distance of the anomalous stress area can be correctly estimated but the accuracy still need to be improved.