The implications of the empirical strong shocking durations equation for 1909、1920 earthquakes

Ya-Ting Lee, Kuo-Fong Ma

1999/09/21 Chi-Chi earthquake M_L=7.3

2,412 deaths

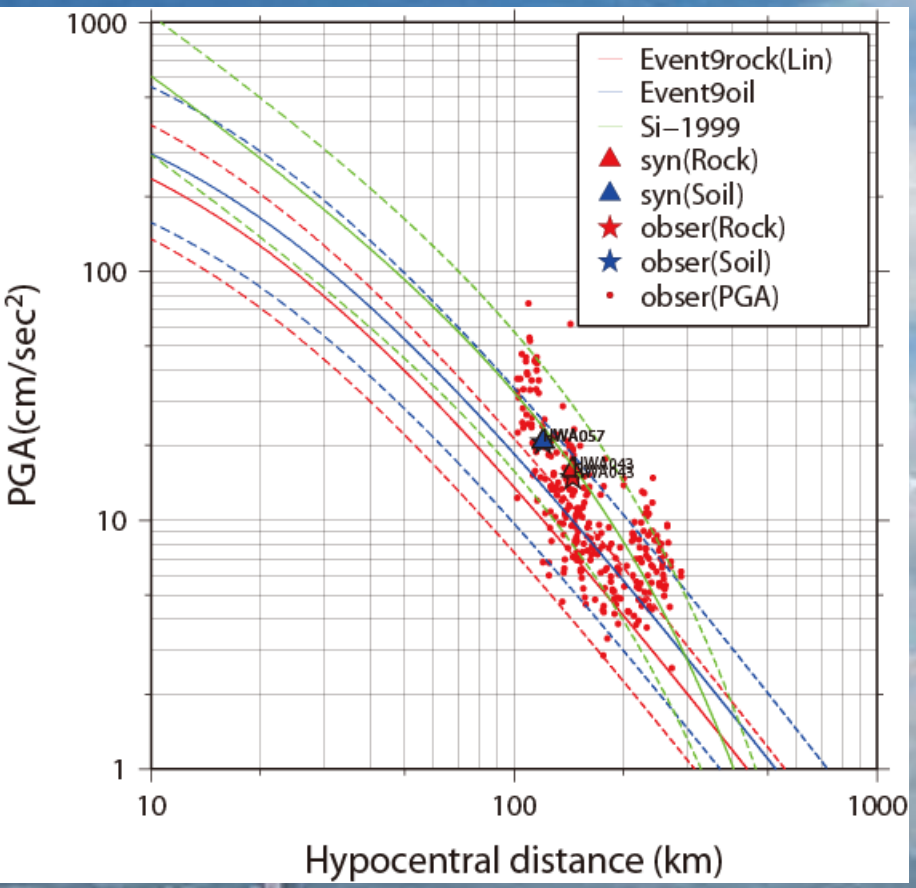
11,305 injured

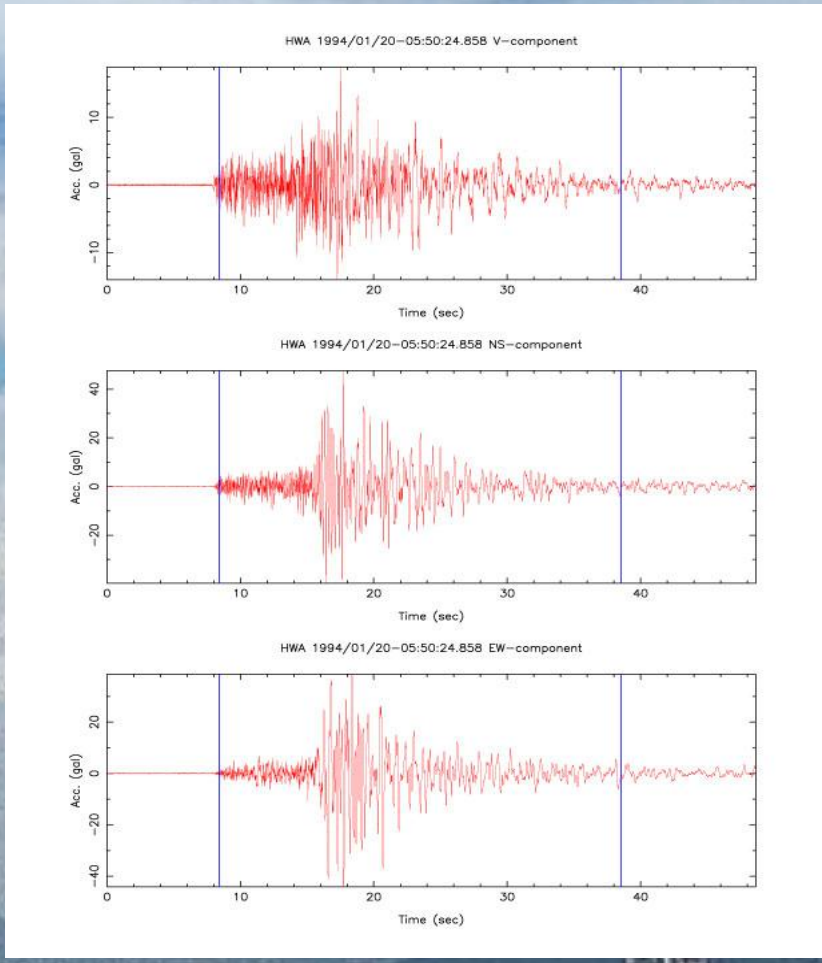
thousands of houses collapsed

more than 100,000 people were left homeless

http://aaling.pixnet.net/blog/post/2226629

http://gogohsu.blogspot.tw/2009/05/blog-post.html





http://mbainlife.blogspot.tw/2011/04/101.html

Strong shocking duration studies

- Bisztricsany (1958) analyzed the earthquakes at Budapest(匈牙利布達佩斯), Prague(捷克布拉格), and Warsaw(波蘭華沙).

$$M_E(\tau) = 2.25\log(\tau_{sur}) - 0.001\Delta + 2.92$$

- Tsumura (1967) analyzed the earthquakes in Japan.

$$M_E(\tau) = 2.25\log(\tau_{F-P}) + 0.0014\Delta - 2.53$$

- Lee et al.(1972) analyzed the earthquakes in central California

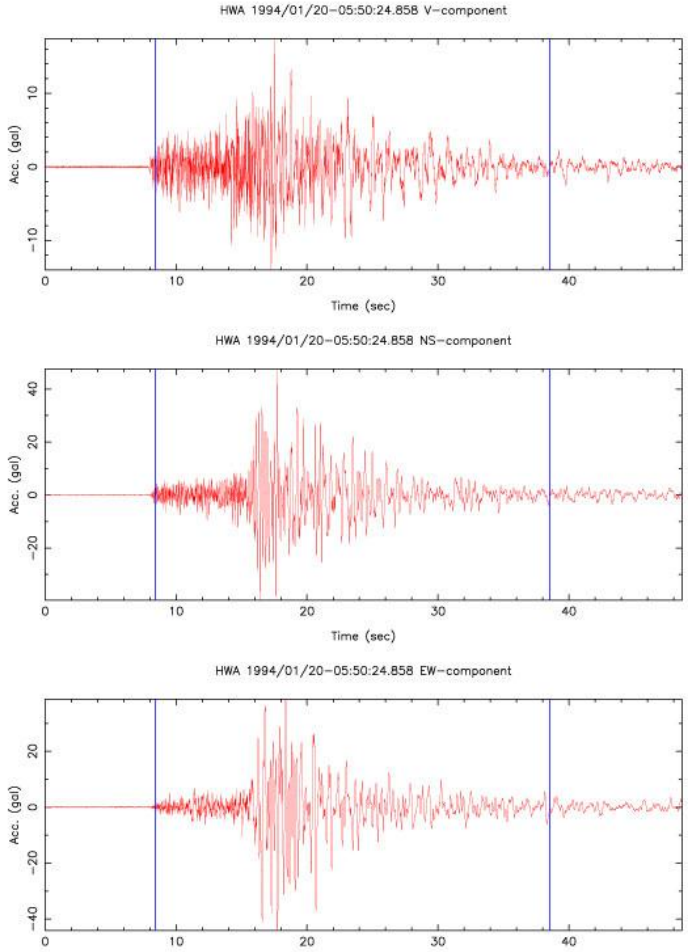
$$\hat{M} = -0.87 + 2.00\log(\tau) + 0.0035\Delta$$

Definitions of duration

- **Bolt(1973) and Page et al. (1975)**: duration as the time interval between the first and last peaks equal to or greater than a given level on the accelerogram.
- **Husid et al. (1969) and Trifunac and Brady (1975):** duration is the time interval required to accumulate a prescribed fraction of the total energy (integrating square accelerations), for 95% or 90%

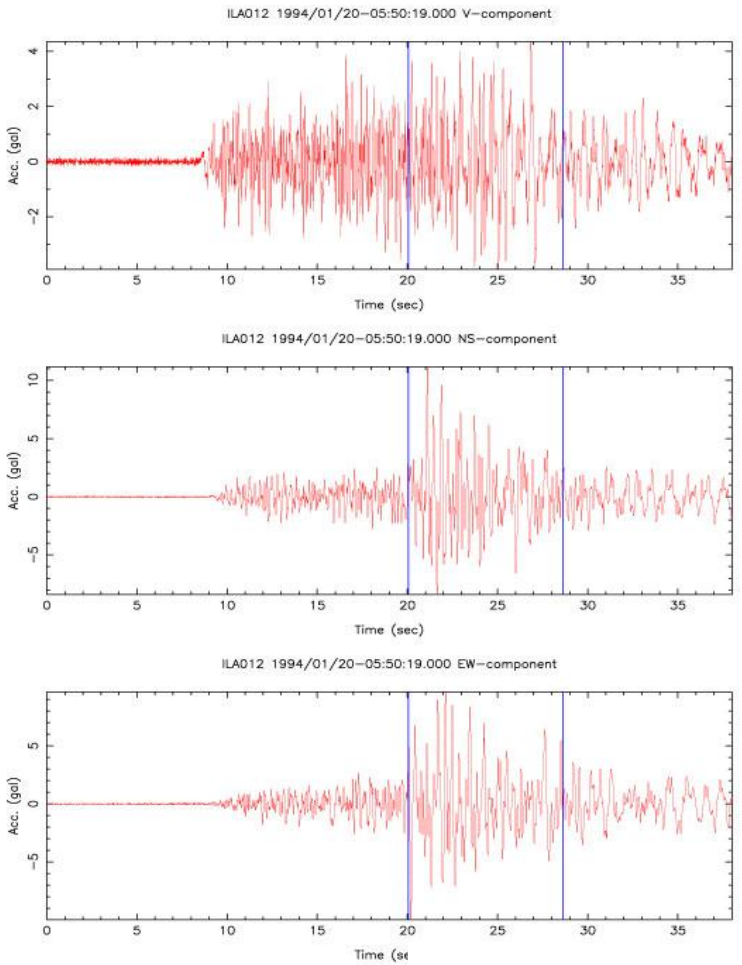
Pick Waveform Duration Time (amplitude >5.0gal)

M=5.58; D=26.94 km (Dc=56.7km)



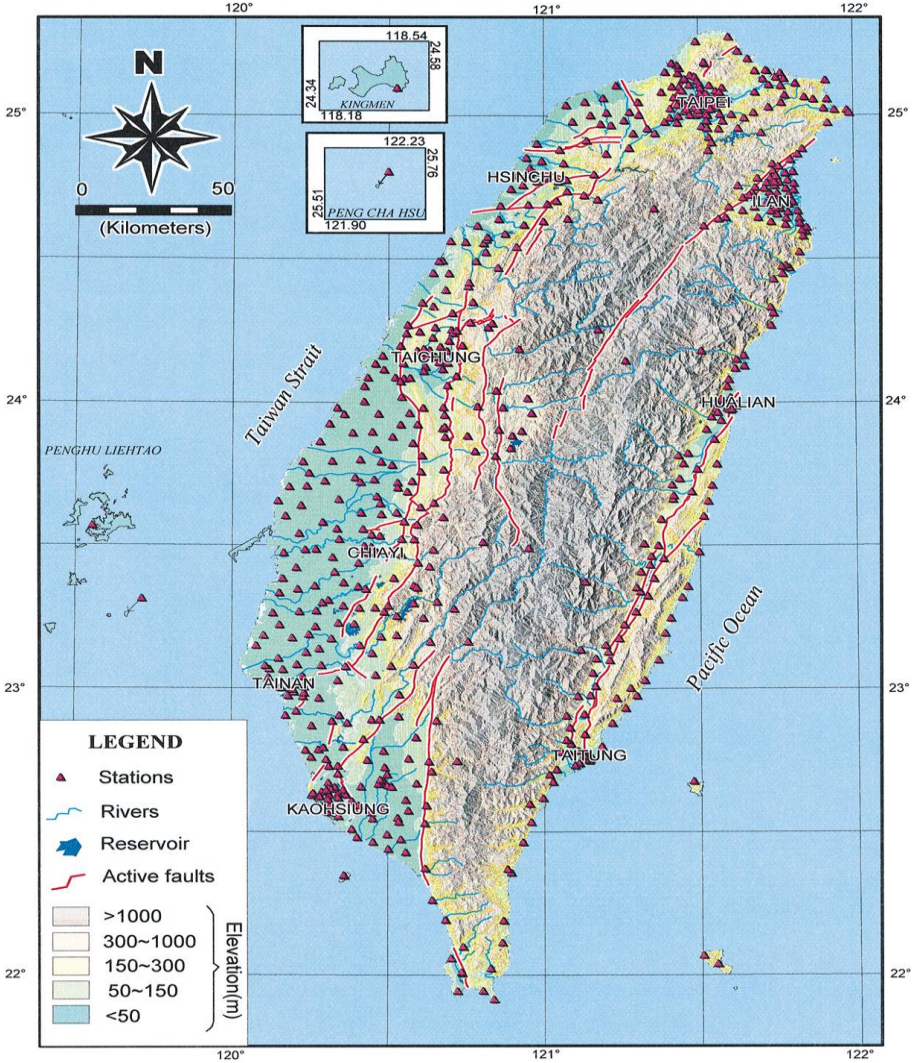
30 sec

M=5.58; D=80.19km (Dc=94.5km)

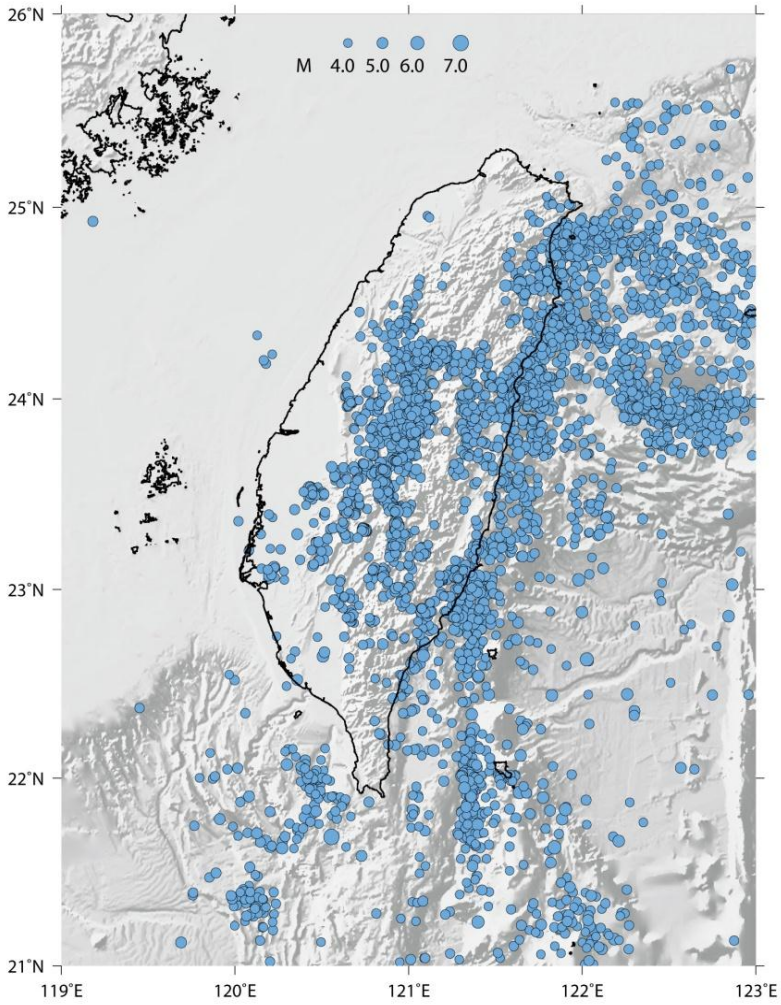


8.7 sec

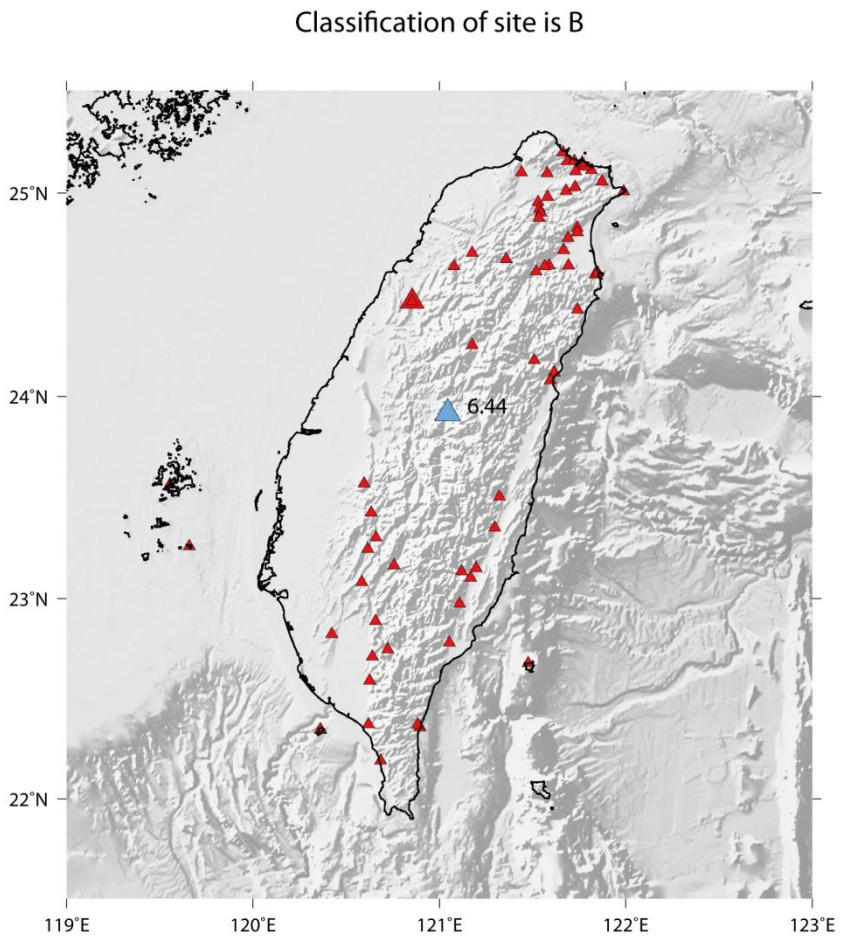
Taiwan Strong Motion Instrumentation Program (TSMIP) network comprises about 700 modern digital accelerographs at free field sites



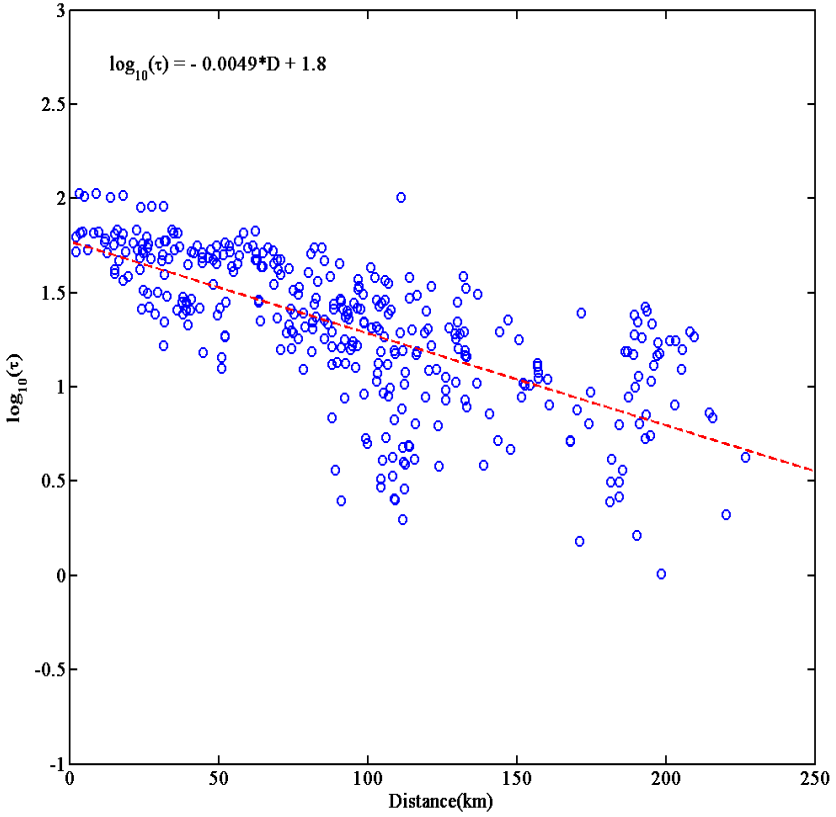
1994~2010 ; Total: N=2016 ; M>4.0



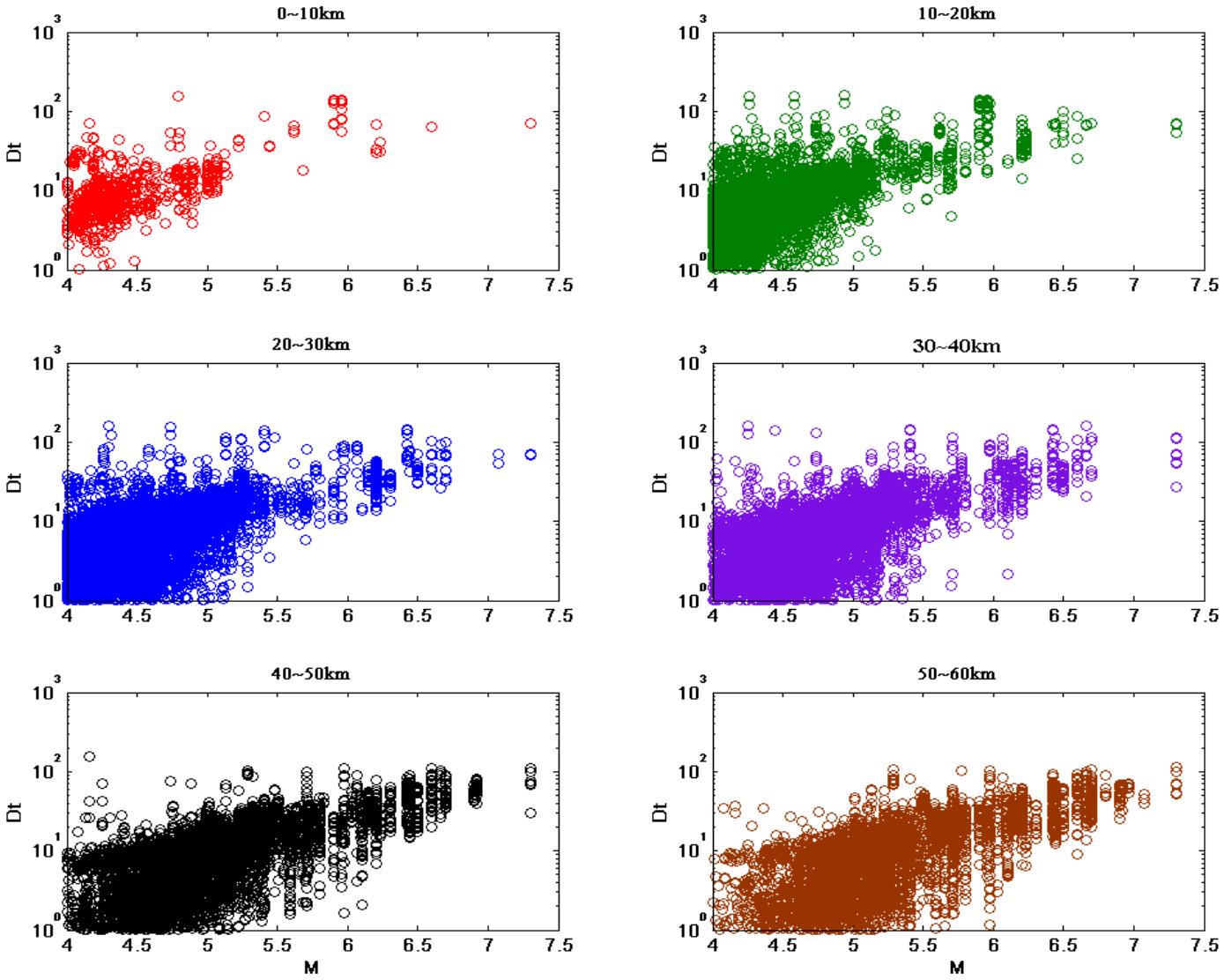
Duration time decay with Distance



1999/10/22 M_L=6.44
Lon: 121.0450 ; Lat: 23.9167



Duration time decay with Magnitude (1994~2010)



A method of estimating magnitude of local earthquakes from signal duration

Empirical formula

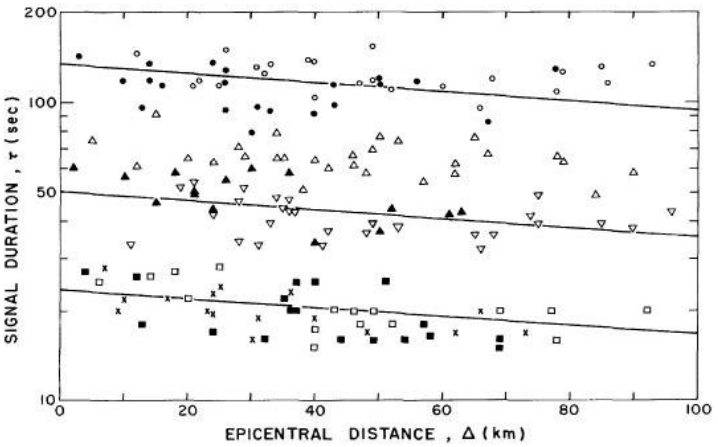
- **Epicentral distance**

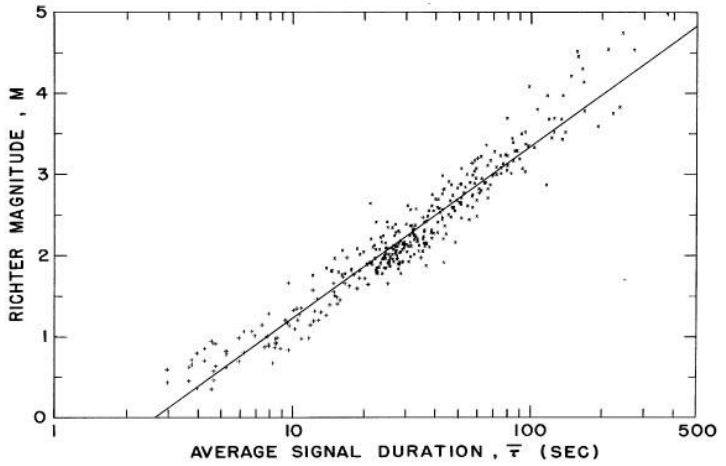
$$\log(\tau_o) = \log(\tau_\Delta) + 1.5 \times 10^{-3}\ \Delta$$

- **Magnitude**

$$M(\tau_o) = -1.2 + 2.2\ \log(\tau_o)$$

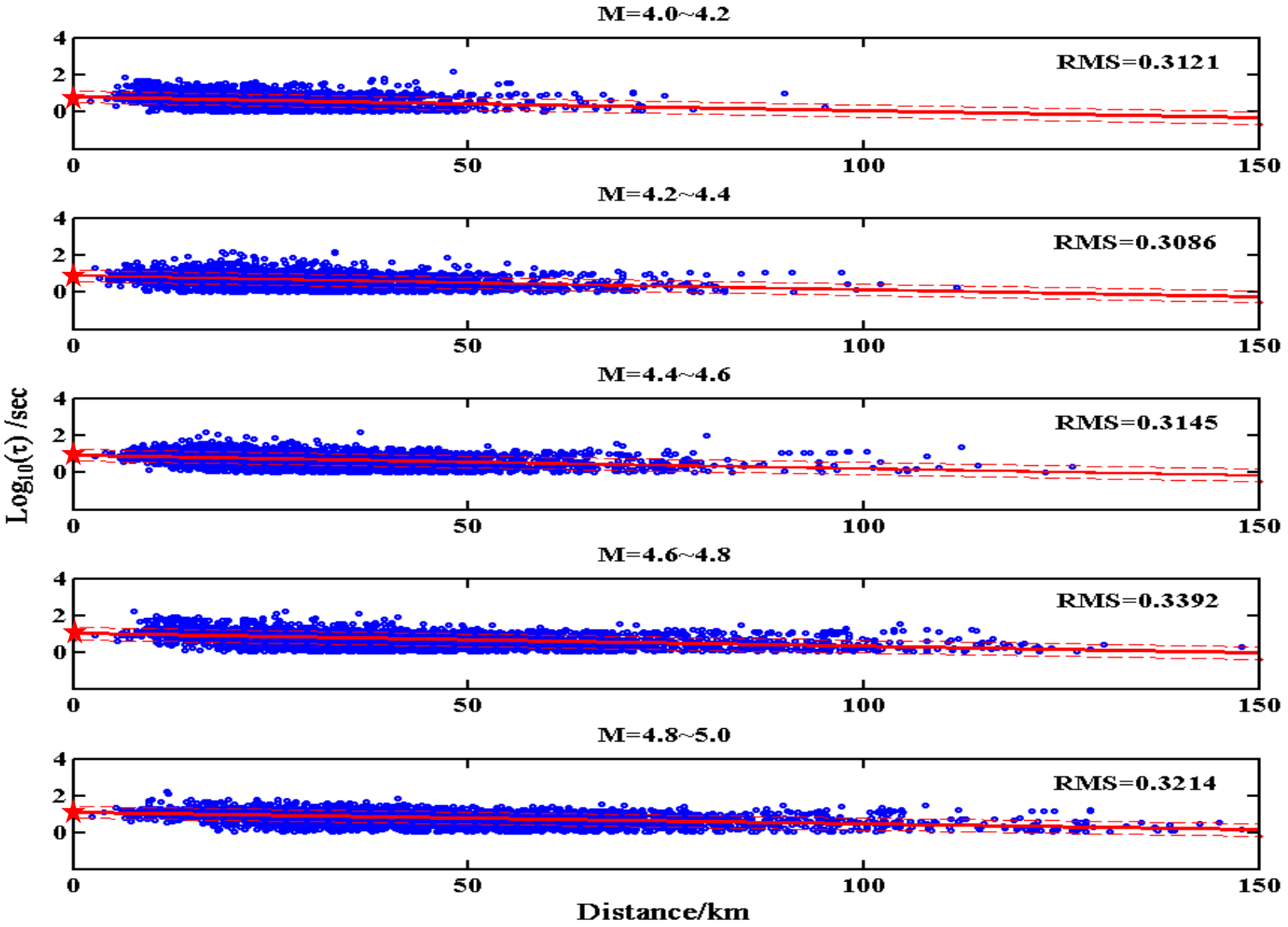
$$M(\tau_\Delta) = -1.2 + 2.2\ \log(\tau_\Delta) + 0.0033\ \Delta$$

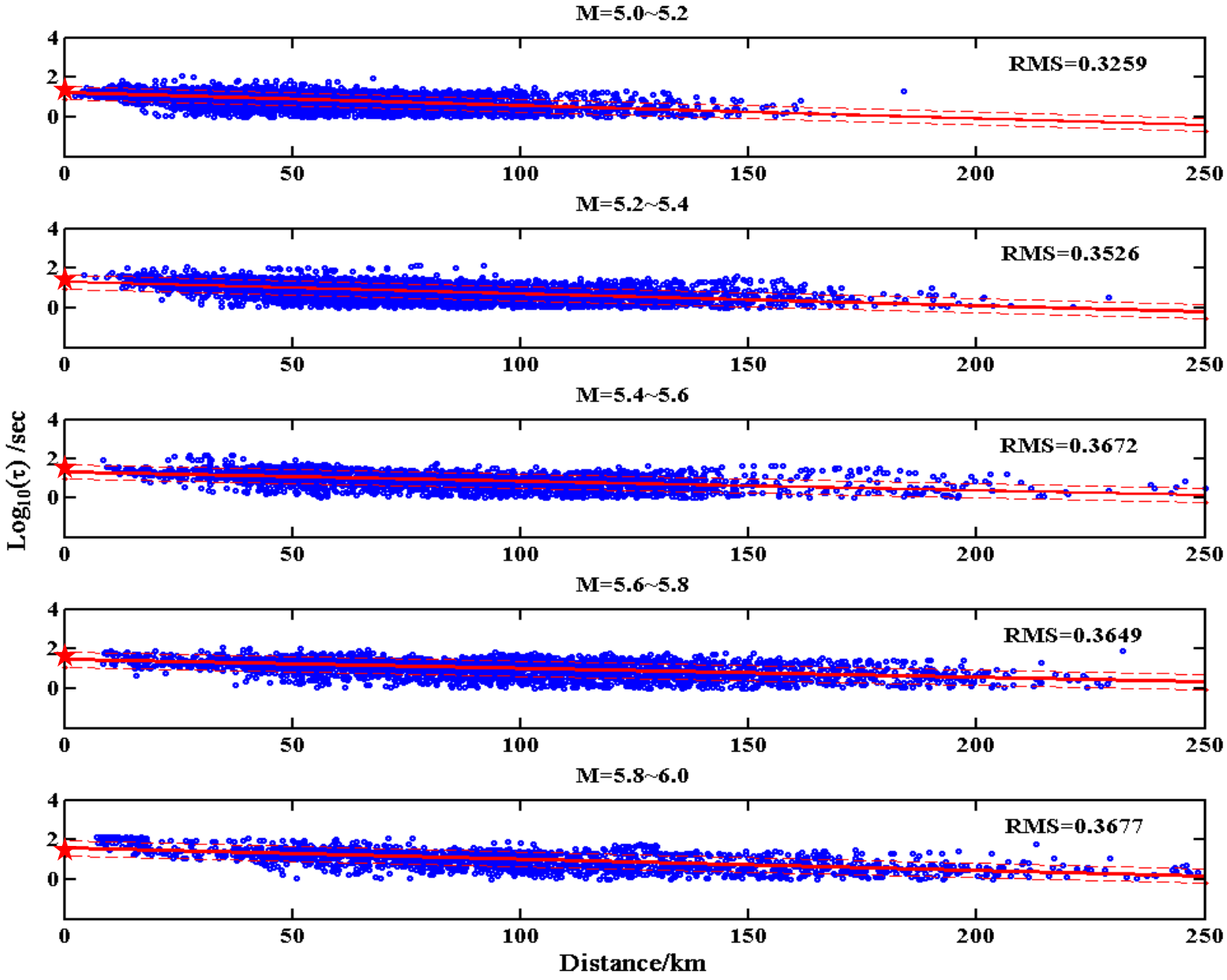


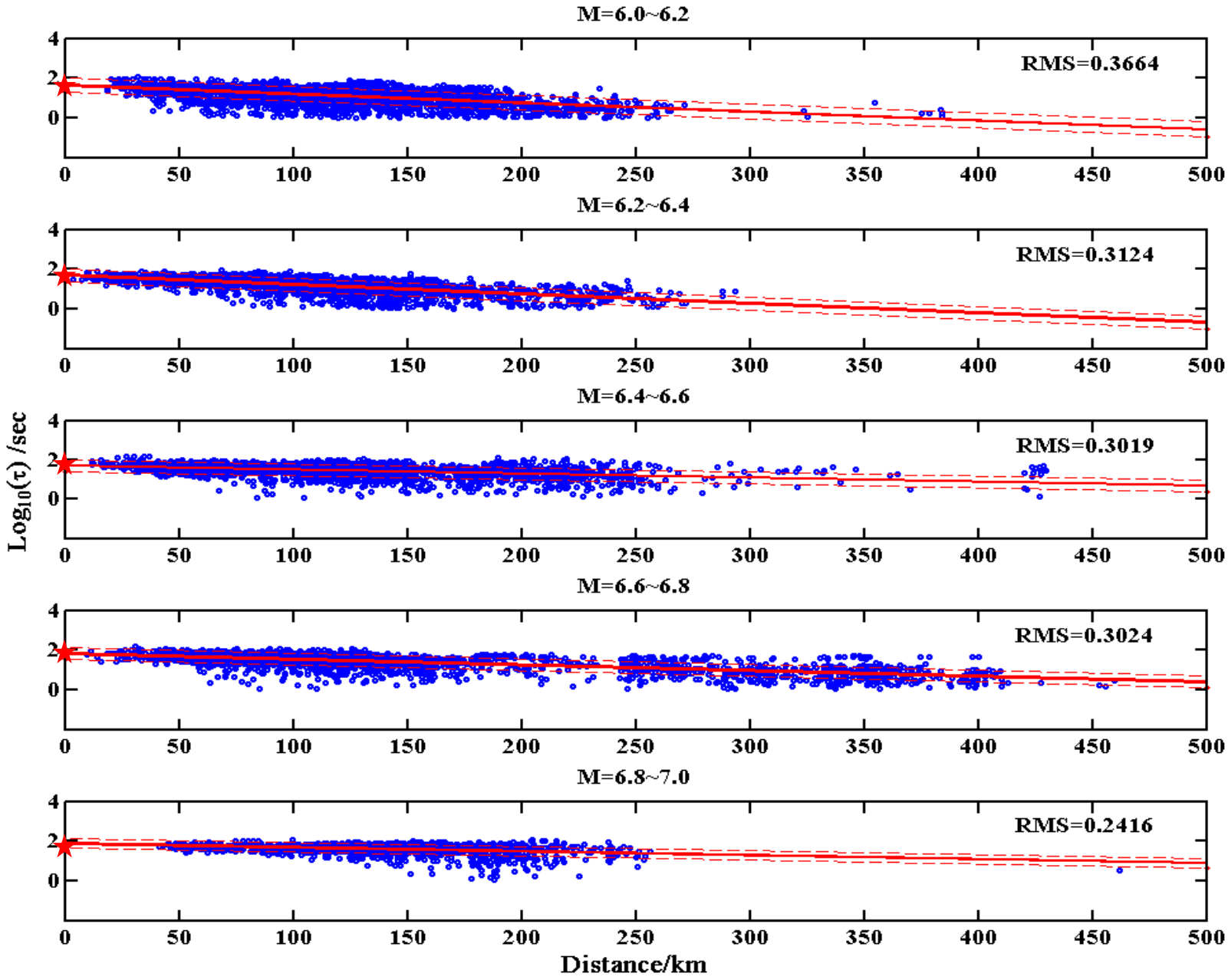


[Lee et al. 1972]

$$\log(\tau_0) = \log(\tau) + c\Delta$$




M=5.0~5.2
RMS=0.3259
M=5.2~5.4
RMS=0.3526
M=5.4~5.6
RMS=0.3672
M=5.6~5.8
RMS=0.3649
M=5.8~6.0
RMS=0.3677
Log10(τ) /sec
Distance/km
0
50
100
150
200
250
2
4


M=6.0~6.2
RMS=0.3664
M=6.2~6.4
RMS=0.3124
M=6.4~6.6
RMS=0.3019
M=6.6~6.8
RMS=0.3024
M=6.8~7.0
RMS=0.2416
Log10(τ) /sec
Distance/km
0
50
100
150
200
250
300
350
400
450
500
2
4

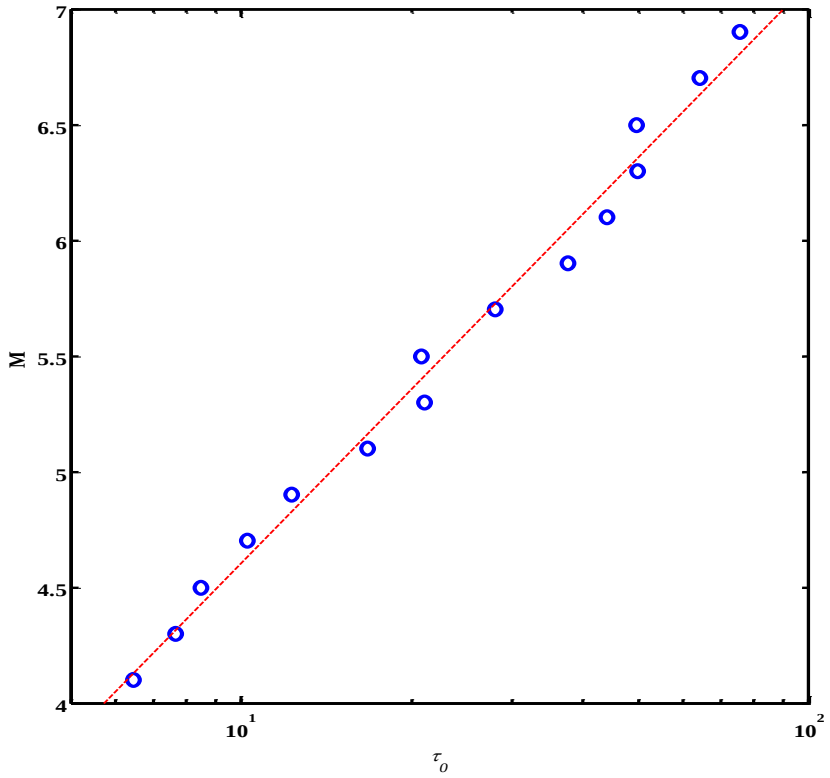
$$\log(\tau_0) = \log(\tau) + c\Delta$$

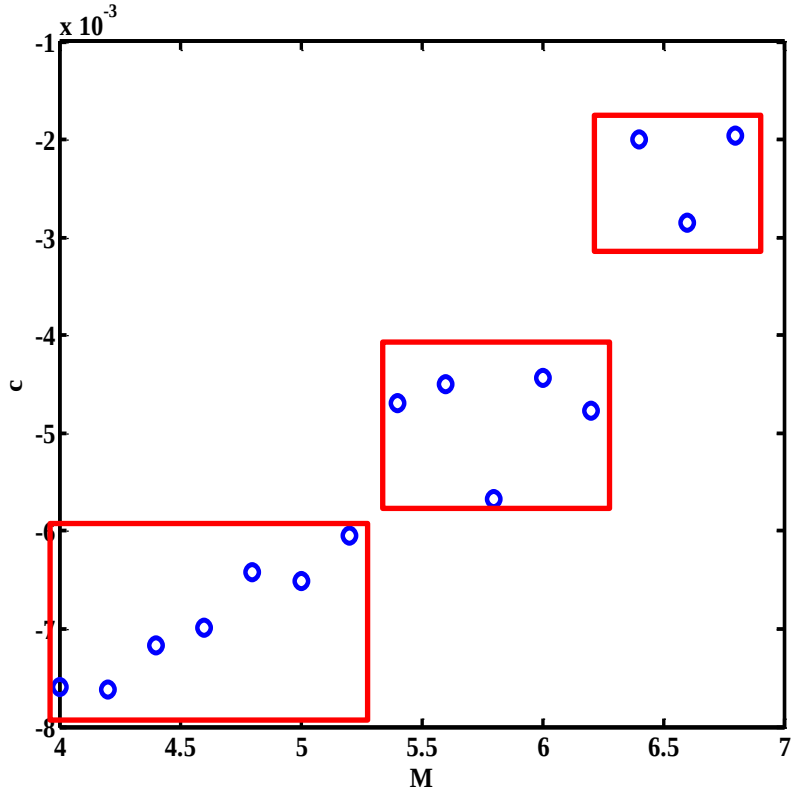
M	c	Log(τ_0)	RMS	N
4.0~4.2	**-0.0076**	**0.8103**	**0.3121**	**505**
4.2~4.4	**-0.0076**	**0.8833**	**0.3086**	**423**
4.4~4.6	**-0.0072**	**0.9285**	**0.3145**	**342**
4.6~4.8	**-0.0070**	**1.0109**	**0.3392**	**242**
4.8~5.0	**-0.0064**	**1.0890**	**0.3214**	**148**
5.0~5.2	**-0.0065**	**1.2228**	**0.3259**	**115**
5.2~5.4	**-0.0060**	**1.3219**	**0.3526**	**79**
5.4~5.6	**-0.0047**	**1.3170**	**0.3672**	**42**
5.6~5.8	**-0.0045**	**1.4475**	**0.3649**	**35**
5.8~6.0	**-0.0057**	**1.5756**	**0.3677**	**22**
6.0~6.2	**-0.0044**	**1.6445**	**0.3664**	**22**
6.2~6.4	**-0.0048**	**1.6978**	**0.3124**	**10**
6.4~6.6	**-0.0020**	**1.6964**	**0.3019**	**9**
6.6~6.8	**-0.0028**	**1.8085**	**0.3024**	**11**
6.8~7.0	**-0.0020**	**1.8775**	**0.2416**	**7**

$$\log(\tau_0) = \log(\tau) + c\Delta$$

$$M(\tau_0) = 2.5064\log(\tau_0) + 2.1028$$

$$c = -0.001 \sim -0.008$$





A method of estimating magnitude of local earthquakes from signal duration

$$\overline{M} = a + b\log(\bar{\tau}) + c\bar{\Delta}$$

Empirical formula

- **Epicentral distance**

$$\log(\tau) = \log(\tau_0) + c\Delta$$

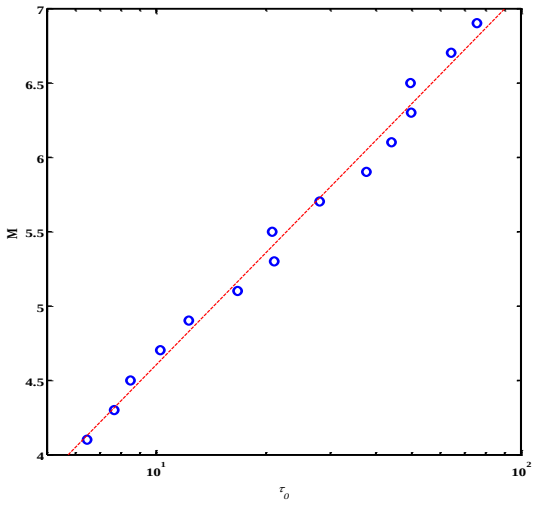
- **Magnitude**

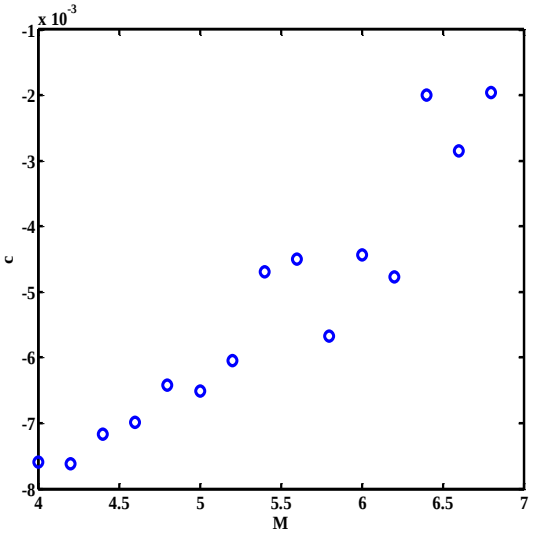
$$M(\tau_0) = 2.5064\log(\tau_0) + 2.1028$$

$$M(\tau) = 2.5064[\log(\tau) - c\Delta)] + 2.1028$$

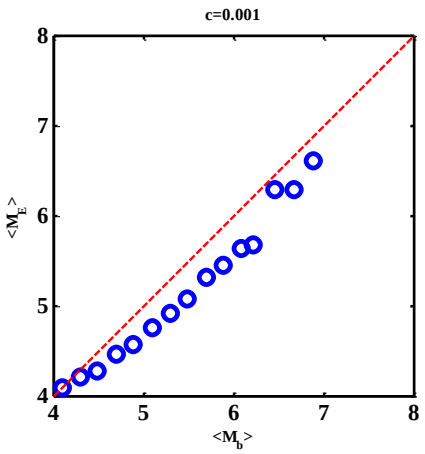
$$c = -0.001 \sim -0.008$$

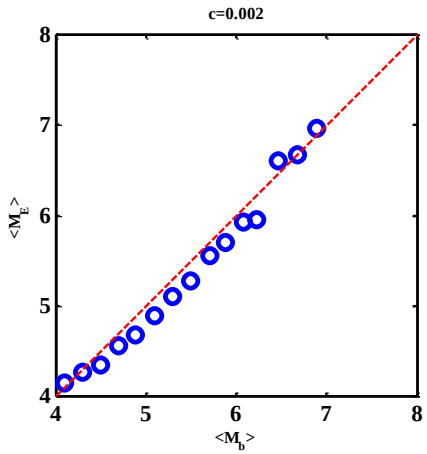
$$M_E(\tau) = 2.5064[\log(\tau) + (c\Delta)] + 2.1028$$

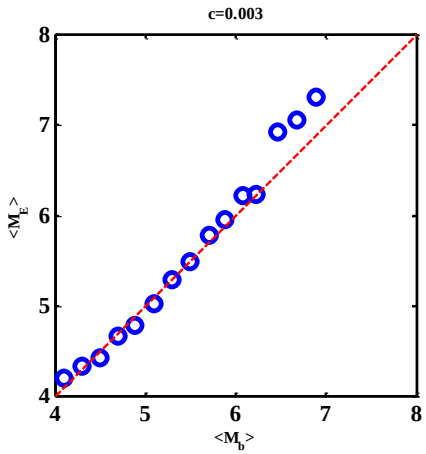


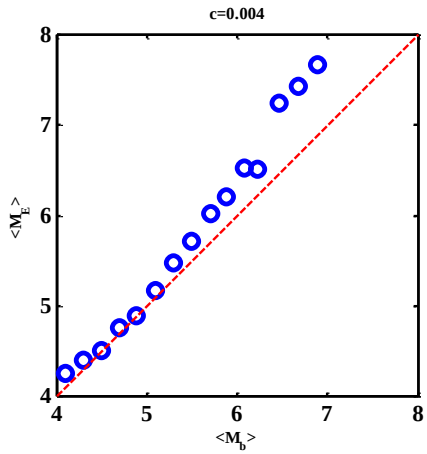


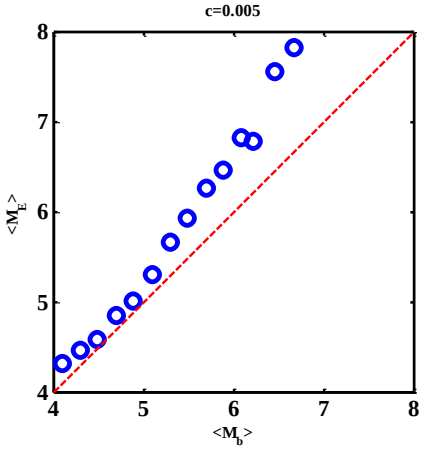
c	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008
RMS	0.058	0.013	0.020	0.08	0.19	0.36	0.57	0.84

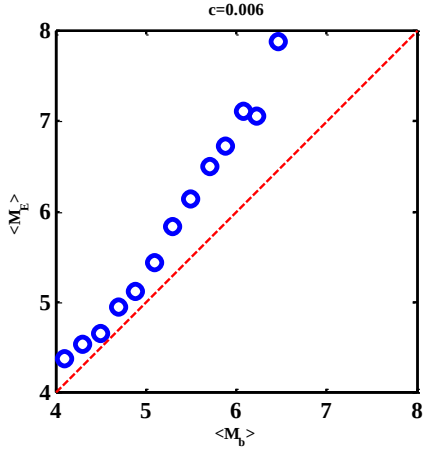


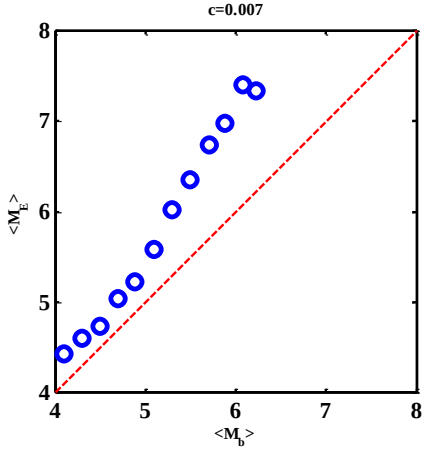


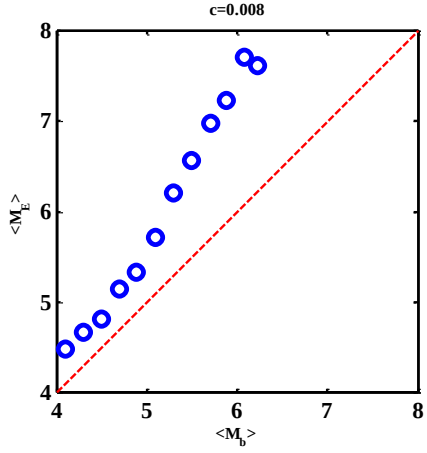










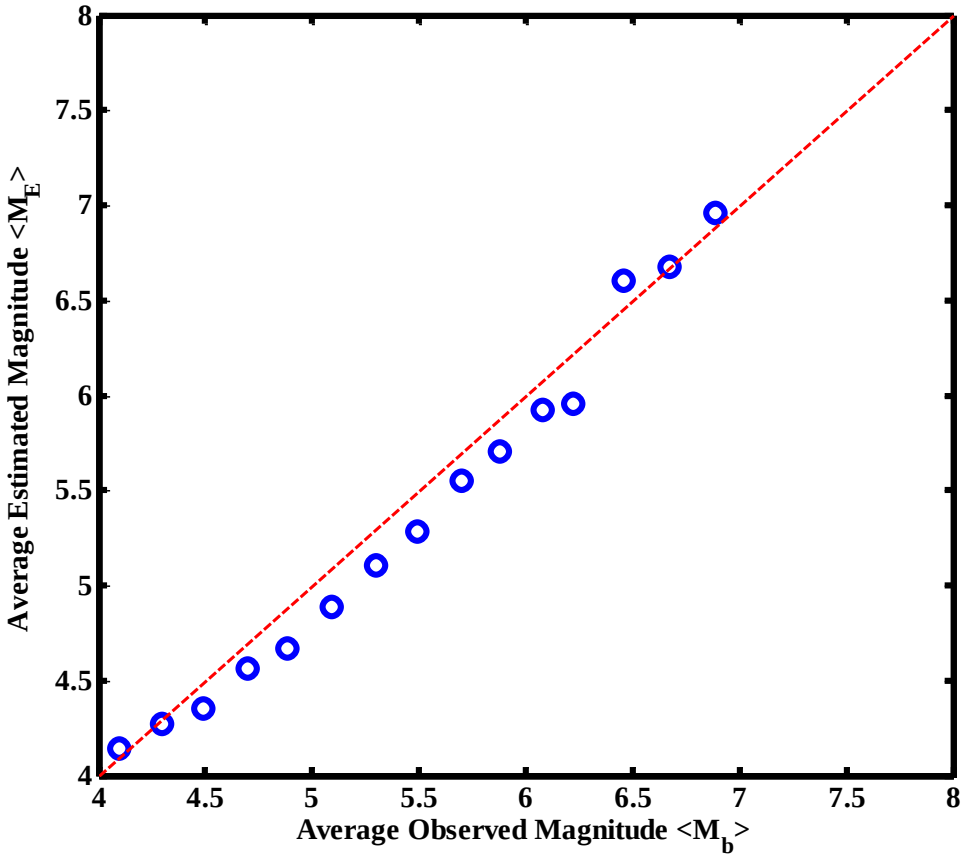


$$M_E(\tau) = 2.5064[\log(\tau) + (c\Delta)] + 2.1028$$

$$\overline{M} = a + b\log(\bar{\tau}) + c\bar{\Delta}$$

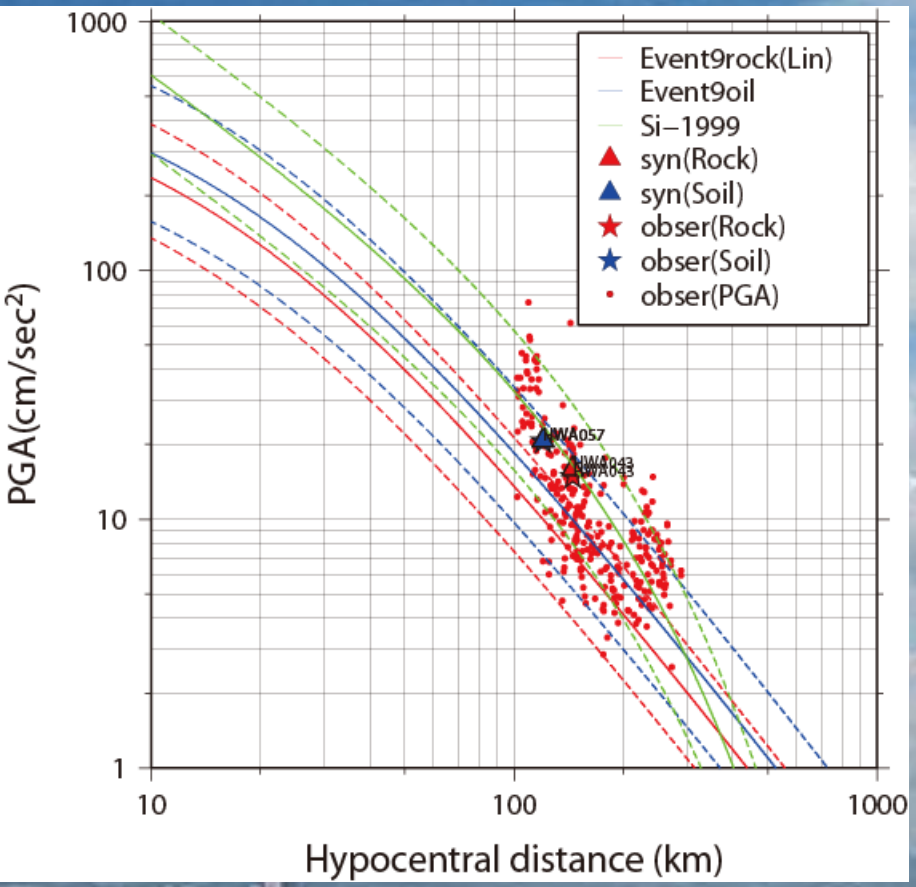
c	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008
RMS	0.058	0.013	0.020	0.08	0.19	0.36	0.57	0.84

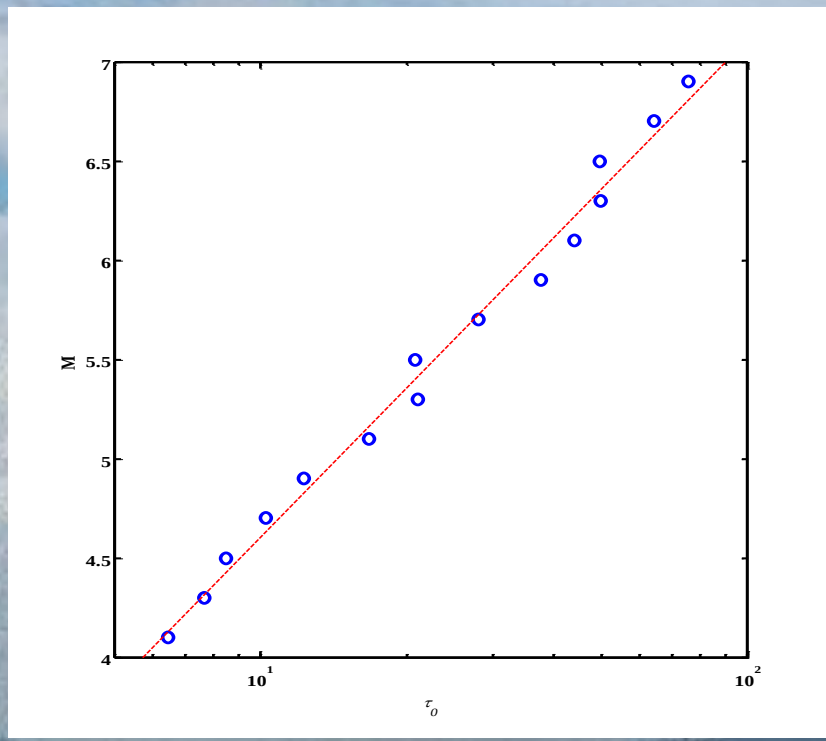
$$M_E(\tau) \equiv 2.5064[\log(\tau) + (0.0052\Delta) + 2.1028$$



M	$\bar{\tau}$	$\bar{\Delta}$	M_E
4.0~4.2	5.90	22.18	4.15
4.2~4.4	6.48	26.28	4.27
4.4~4.6	6.84	30.56	4.35
4.6~4.8	8.03	38.19	4.56
4.8~5.0	8.65	43.86	4.67
5.0~5.2	10.04	55.04	4.89
5.2~5.4	11.22	73.49	5.10
5.4~5.6	12.54	85.00	5.28
5.6~5.8	15.34	94.52	5.55
5.8~6.0	17.20	101.02	5.71
6.0~6.2	19.46	118.21	5.93
6.2~6.4	20.69	110.54	5.95
6.4~6.6	34.82	126.78	6.60
6.6~6.8	33.05	151.97	6.67
6.8~7.0	45.61	139.73	6.96

$$M_E(\tau) = 2.5064\log(\tau) + 0.005\Delta + 2.1028$$

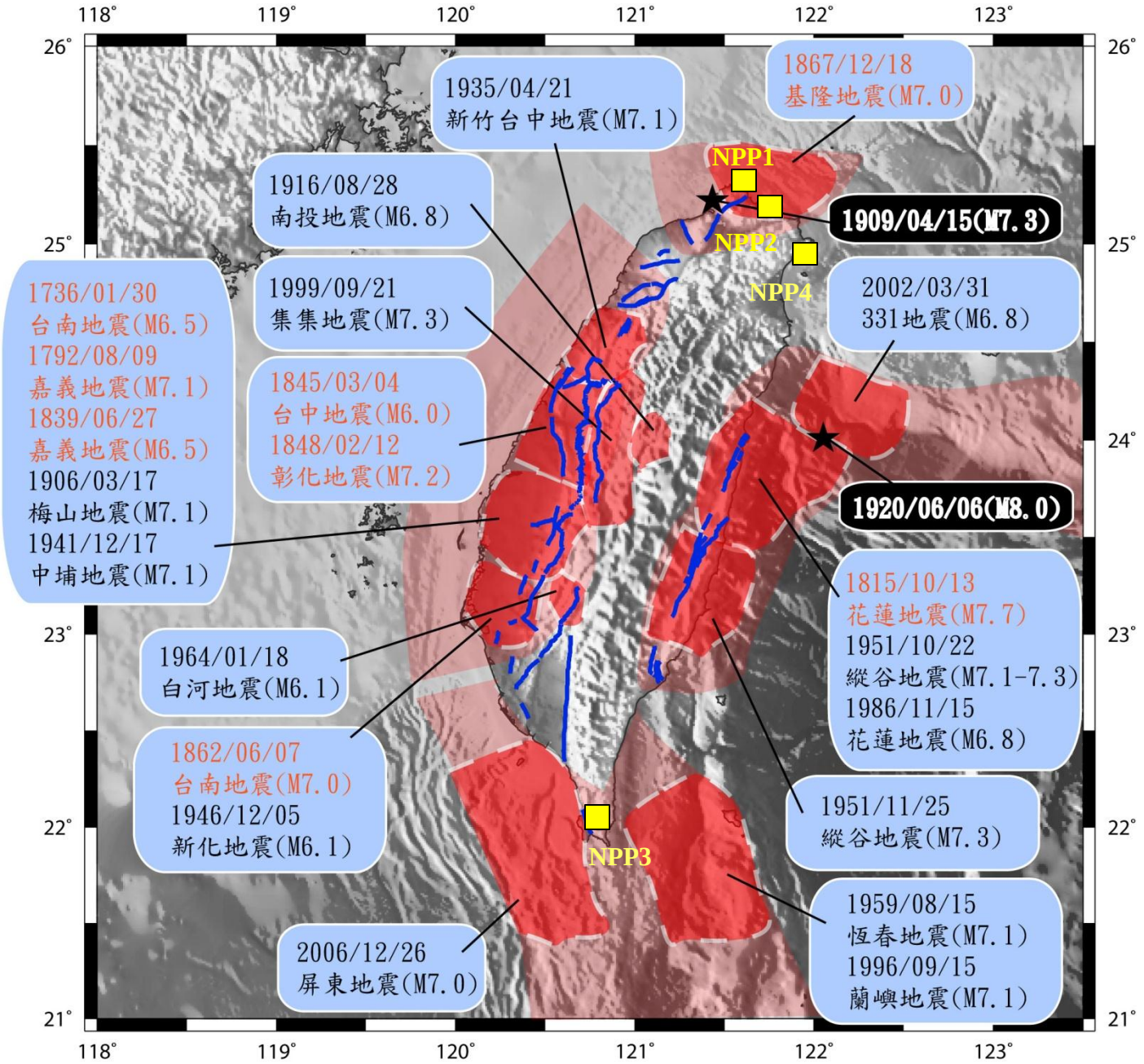




[Yang, and Ma (2012)]

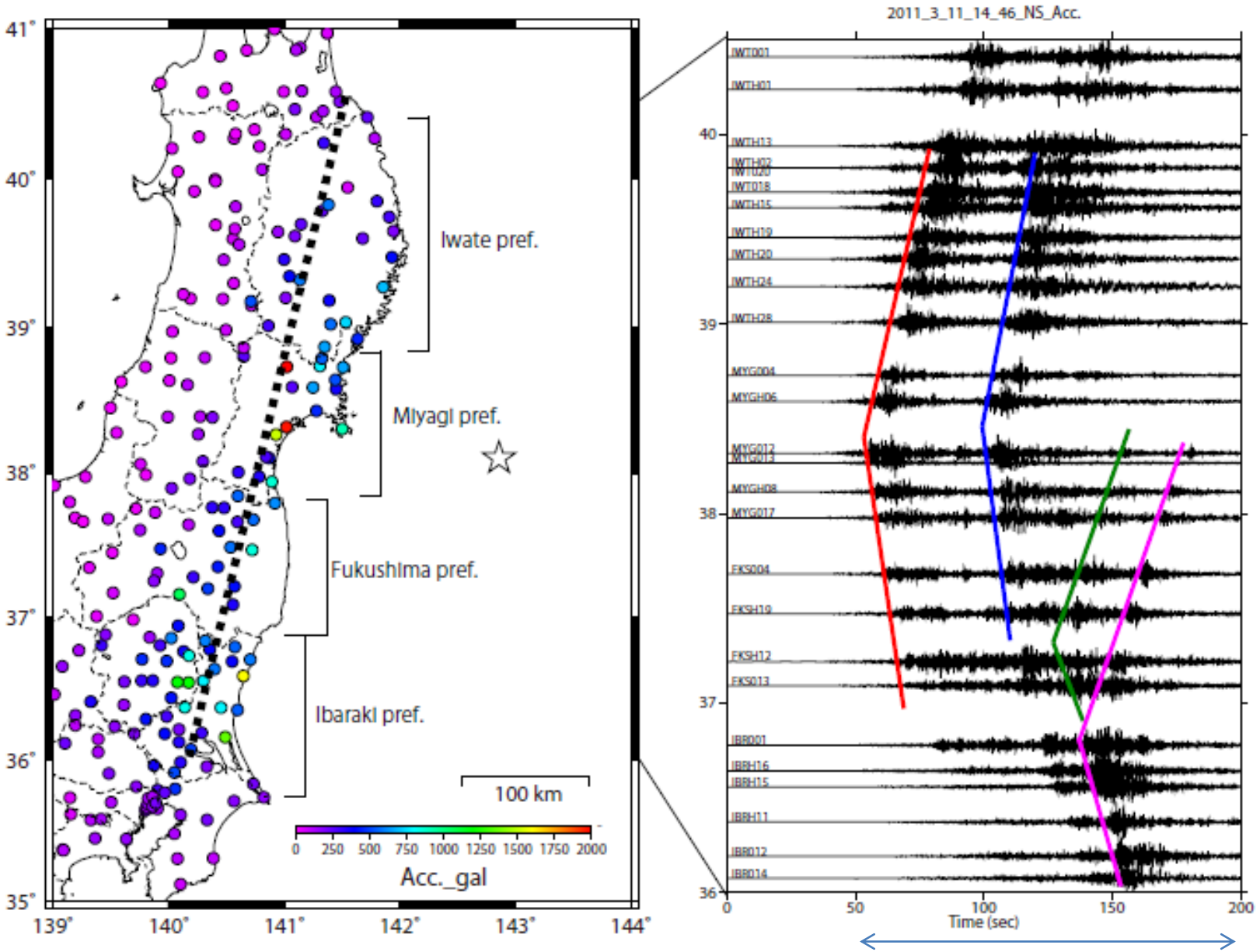
http://mbainlife.blogspot.tw/2011/04/101.html

Damaging Earthquakes in Taiwan since 1700s



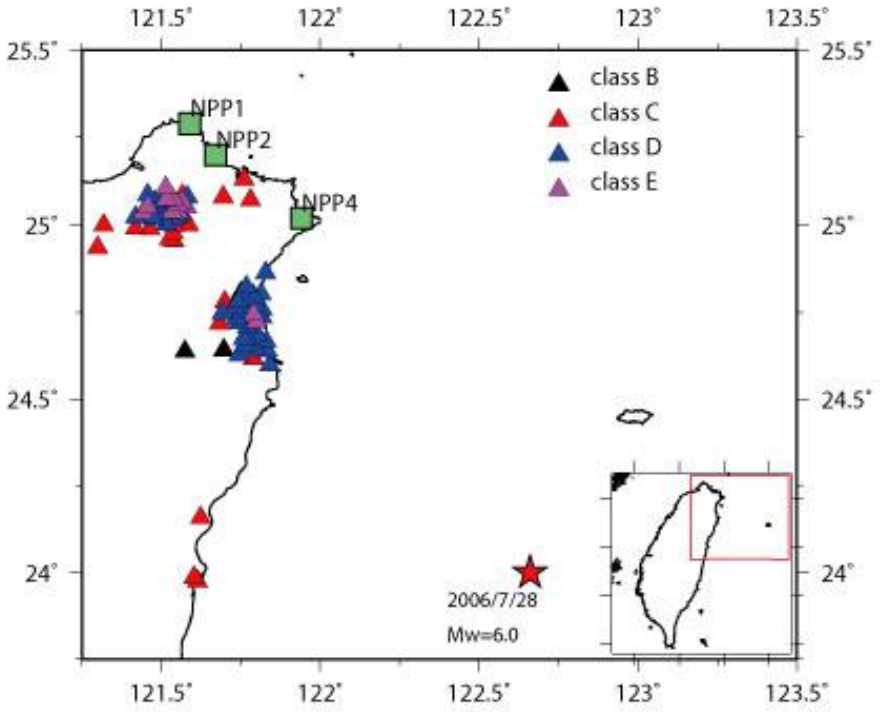
$$M_E(\tau) = 2.5064\log(\tau) + 0.005\Delta + 2.1028$$

1909/04/14 Taipei earthquake M_L=7.3, Lon: 121.52° E, 25.28° N, Dep:75km				
nuclear power plant	Longitude	Latitude	hypocenter distance (km)	Estimated duration (sec)
NPP1	121.590	25.290	75.348	83.73
NPP2	121.670	25.200	77.060	83.07
NPP3	120.740	21.956	384.063	20.20
NPP4	121.940	25.020	86.856	79.41
1920/06/05 Hualien earthquake M_L=8.0, Lon: 122.125° E, 23.925° N, Dep:25km				
nuclear power plant	Longitude	Latitude	hypocenter distance(km)	Estimated duration (sec)
NPP1	121.590	25.290	162.685	106.5336
NPP2	121.670	25.200	150.750	112.5528
NPP3	120.740	21.956	261.142	67.6975
NPP4	121.940	25.020	125.259	126.5722


Iwate pref.
Miyagi pref.
Fukushima pref.
Ibaraki pref.
100 km
0 250 500 750 1000 1250 1500 1750 2000
Acc._gal
41°
40°
39°
38°
37°
36°
35°
139°
140°
141°
142°
143°
144°
2011_3_11_14_46_NS_Acc.
IWT001
IWTH01
IWTH13
IWTH02
IWTH18
IWTH15
IWTH19
IWTH20
IWTH24
IWTH28
MYG004
MYGH06
MYG012
MYGH08
MYG017
FKS004
FKSH19
FKSH12
FKS013
IBR001
IBRH16
IBRH15
IBRH11
IBR012
IBR014
40
39
38
37
36
0
50
100
150
200
Time (sec)

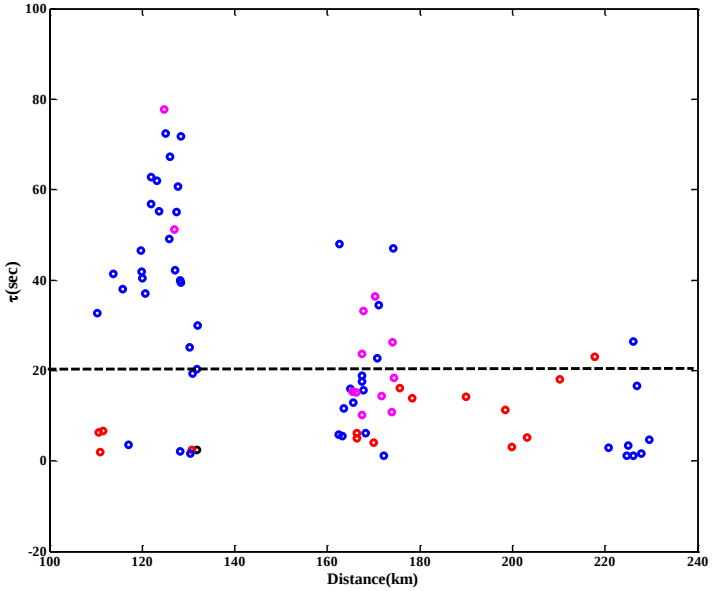
150 SEC

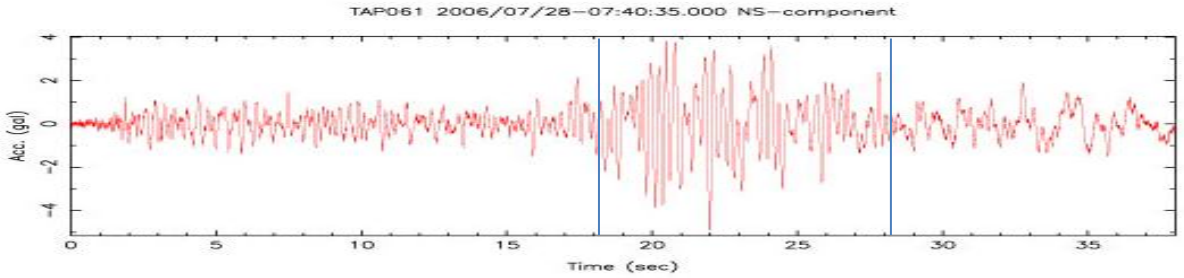
2006/7/28 Mw=6.0, lon:122.66° E, lat:24° N



$$M_E(\tau) = 2.5064\log(\tau) + 0.005\Delta + 2.1028$$

τ_e = 15~20 (sec)





2006/7/28

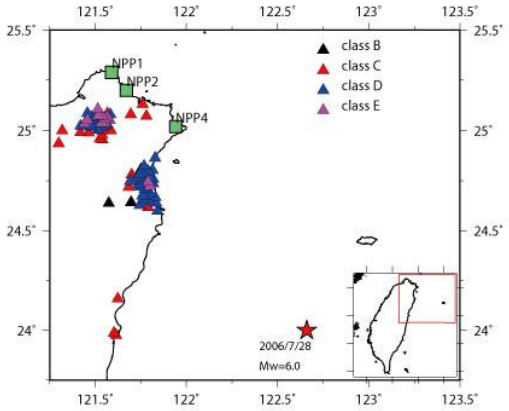
10 sec

Class C: Lon:121.76, Lat:25.13

Affects the amplitude of the ground motion

- Site effect
- The state of stress

  (extensional or compressional)
- Source mechanism
- Wave propagation characteristics



[Spudich P. et al. BSSA, 1999]

CONCLUSION

- **We define the duration time by picking the magnitude of PGA larger than 5 gal.**
- **We got the relation between τ_0 and M is**

$$M(\tau_0) = 2.5064\log(\tau_0) + 2.1028$$

The theory equation of M and τ can be shown as

$$M_E(\tau) = 2.5064\log(\tau) + 0.005\Delta + 2.1028$$

- **For the 1909, 1920 earthquakes, the τ calculated from the empirical equation is about 80sec and 120sec for the north three nuclear power plants.**
- **For 2006/7/28 earthquake (M_L=6.0) , the τ_0 calculated from the empirical equation is about 15~20 sec that is comparable to the record of the τ in Rock site stations.**

Thank you!