Seismology based ground motion attenuation relationship for the demonstration region of China in the joint project

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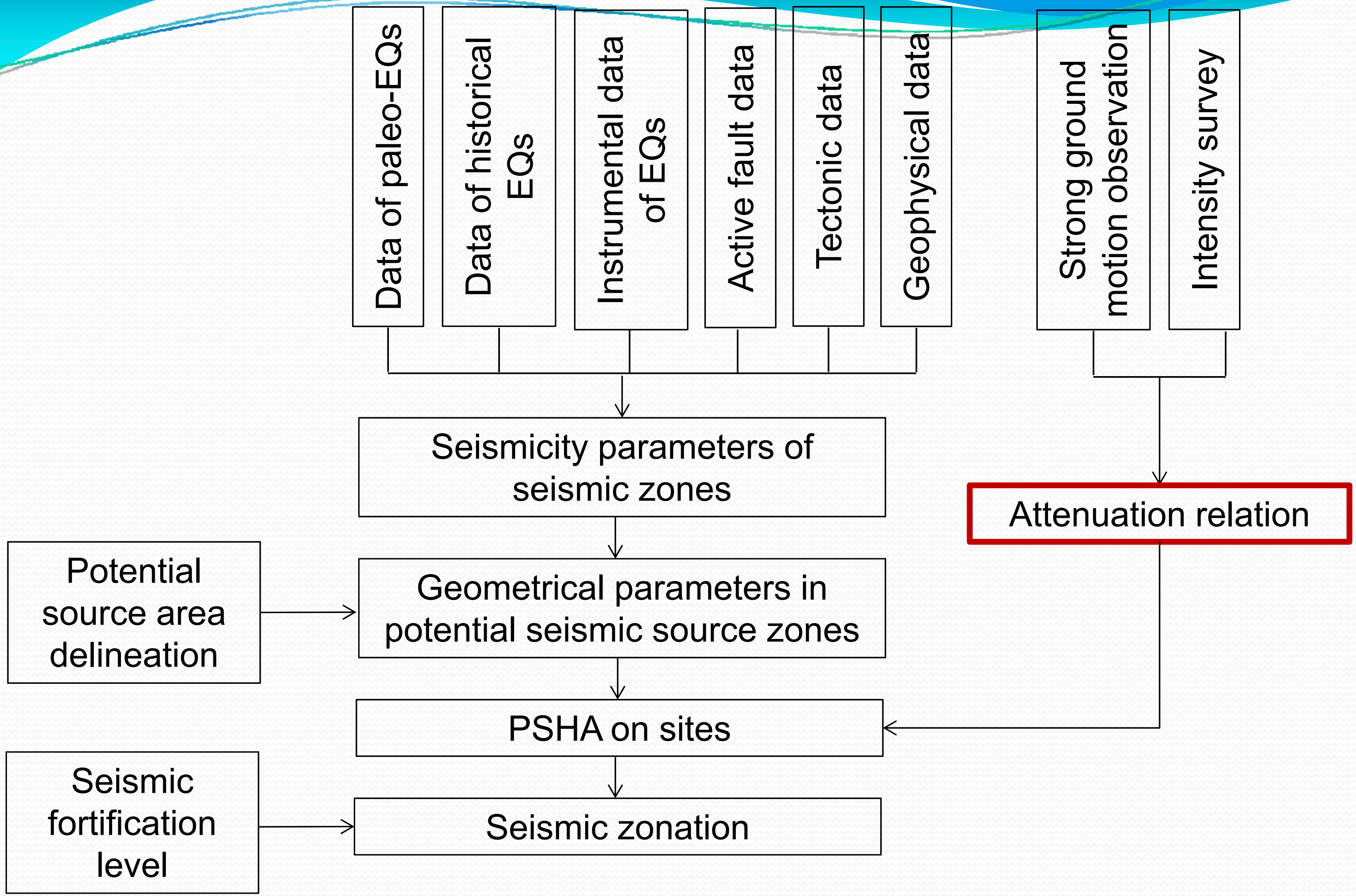
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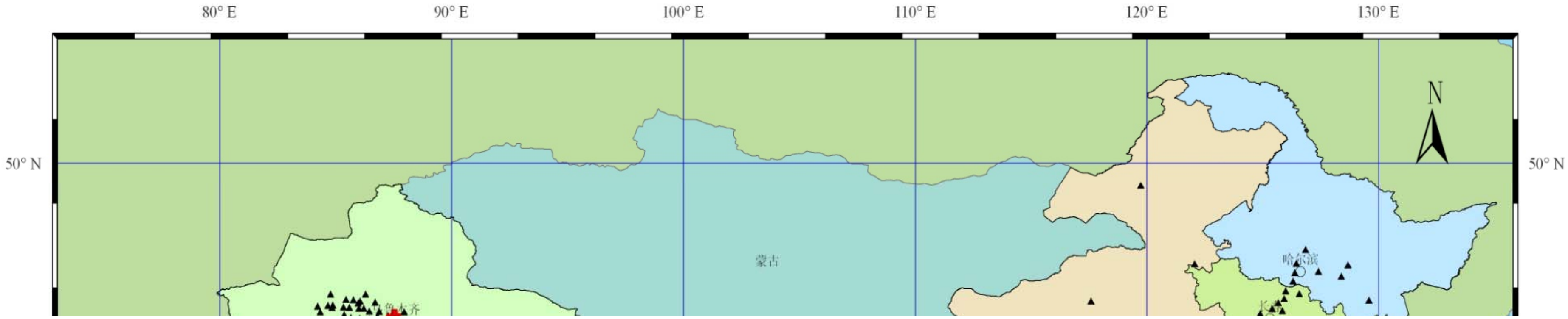
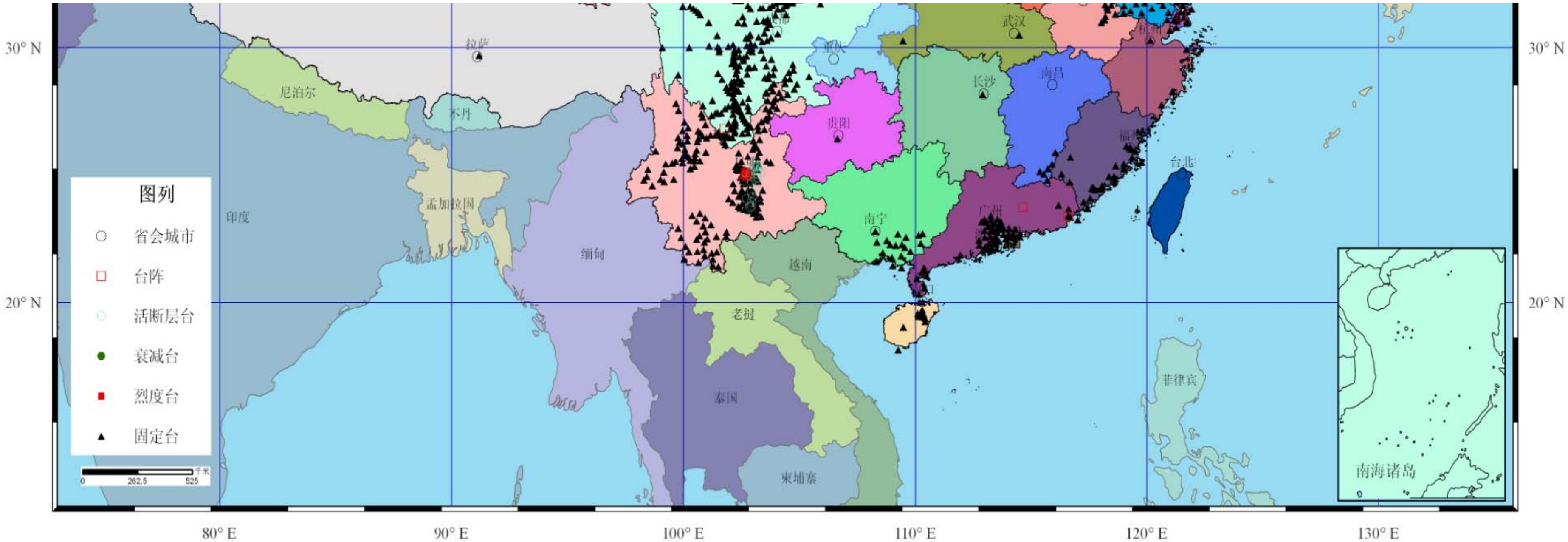
中国数字强震动台网分布图



How to establish relationships for regions with few or without strong ground motion records?



- In China, strong ground motion records are not enough now.
- Mapping method (Hu, 1980s):

This method assumes that, for region A of enough acceleration observation data and a region B of few such data, earthquake pairs (M_A, R_A; M_B, R_B) exist in the intensity attenuation curves $I_A(M_A, R_A)$ of region A and $I_B(M_B, R_B)$ of region B, so that they give the same intensity I and ground motion Y.

$$P(M_A, R_A) \rightarrow [I_A(M_A, R_A) = I_B(M_B, R_B)] \rightarrow Q(M_B, R_B)$$

$$\ln Y_a(M_A, R_A) \rightarrow \boxed{\qquad\qquad} \rightarrow \ln Y_B(M_B, R_B)$$

Western US:

$$I = 0.514 + 1.500M - 0.00659R - 2.014\log(R+10), \sigma = 0.274, R < 300\,km$$

$$\log(PGA) = 1.297 + 0.566M - 1.723\log[R + 1.046e^{0.451M}], \sigma = 0.240$$

Eastern China:

$$\begin{cases} I_a = 5.019 + 1.446M - 4.136\lg(R+24) \\ I_b = 2.240 + 1.446M - 3.070\lg(R+9) \end{cases}, \quad \sigma = 0.517$$

Western China:

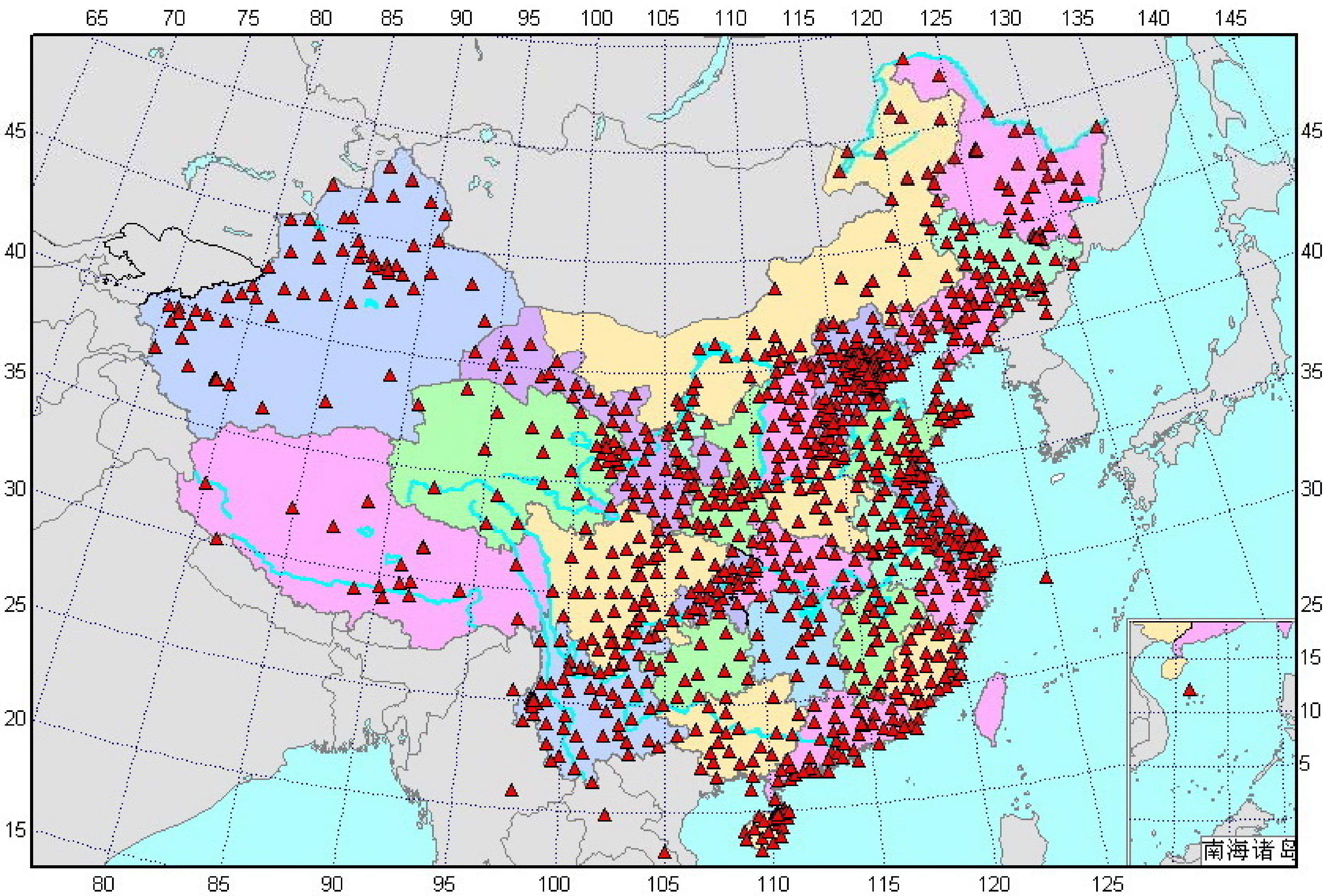
$$\begin{cases} I_a = 5.253 + 1.398M - 4.164\lg(R+26) \\ I_b = 2.019 + 1.398M - 2.943\lg(R+8) \end{cases}, \quad \sigma = 0.632$$

Eastern China:

$$\begin{cases} \log(PGA)_a = 2.027 + 0.548M - 1.902\log[R + 1.700e^{0.425M}] \\ \log(PGA)_b = 1.035 + 0.519M - 1.465\log[R + 0.381e^{0.525M}] \end{cases}, \quad \sigma = 0.240$$

Western China:

$$\begin{cases} \log(PGA)_a = 2.206 + 0.532M - 1.954\log[R + 2.018e^{0.406M}] \\ \log(PGA)_b = 1.010 + 0.501M - 1.441\log[R + 0.340e^{0.521M}] \end{cases}, \quad \sigma = 0.240$$



China Earthquake Data Center

Methodology

Source Fourier spectrum of ground motion *FA*(M_0, *f*, *R*) from a point source can be described as

$$FA(M_0, f, R) = C \cdot S(M_0, f) \cdot G(R) \cdot D(R, f) \cdot A(f) \cdot P(f) \cdot I(f)$$

where, *C* is proportion factor; *S*(M_0, *f*) is source spectrum for a specified seismic moment; *G*(*R*) is geometric spreading function; *D*(*R*, *f*) is anelastic attenuation function; *A*(*f*) is the amplification factor of near surface amplitude; *P*(*f*) is a high-cut filter that rapidly reduces amplitudes at high frequencies; *I*(*f*) is spectrum shape parameter, used to shape the spectrum to correspond to the particular ground-motion measure of interest.

$$C = \frac{R_{\theta\phi} F V}{4\pi R_0 \rho_s \beta_s^3}$$

$$D(R, f) = \exp\left(-\frac{\pi f R}{Q\beta} \right)$$

$$S(M_0, f) = \frac{M_0}{1 + \left(\frac{f}{f_0} \right)^2}$$

$$Q = Q_0 f^{\eta}$$

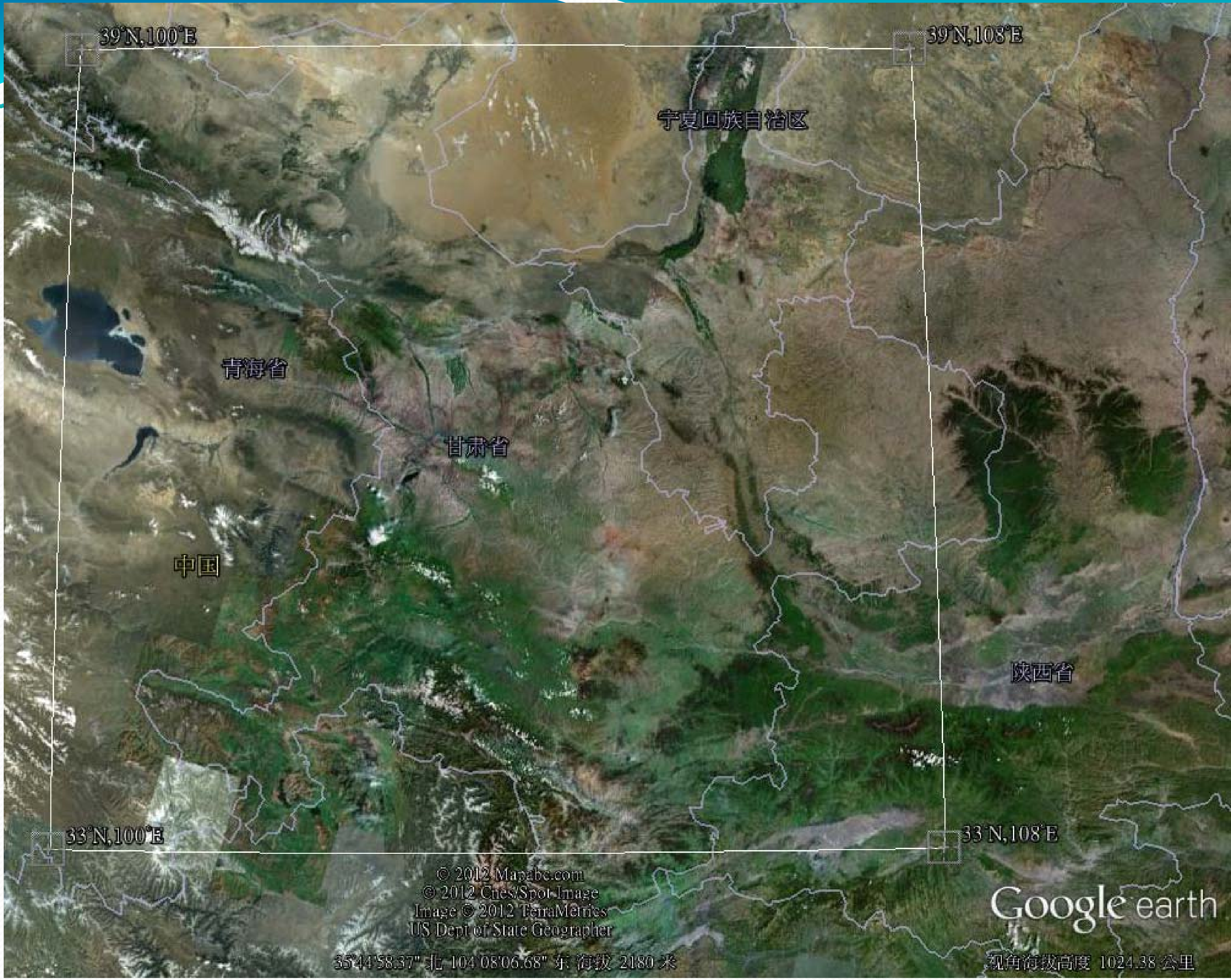
$$f_0 = 4.9 \times 10^6 \beta (\Delta\sigma / M_0)^{1/3}$$

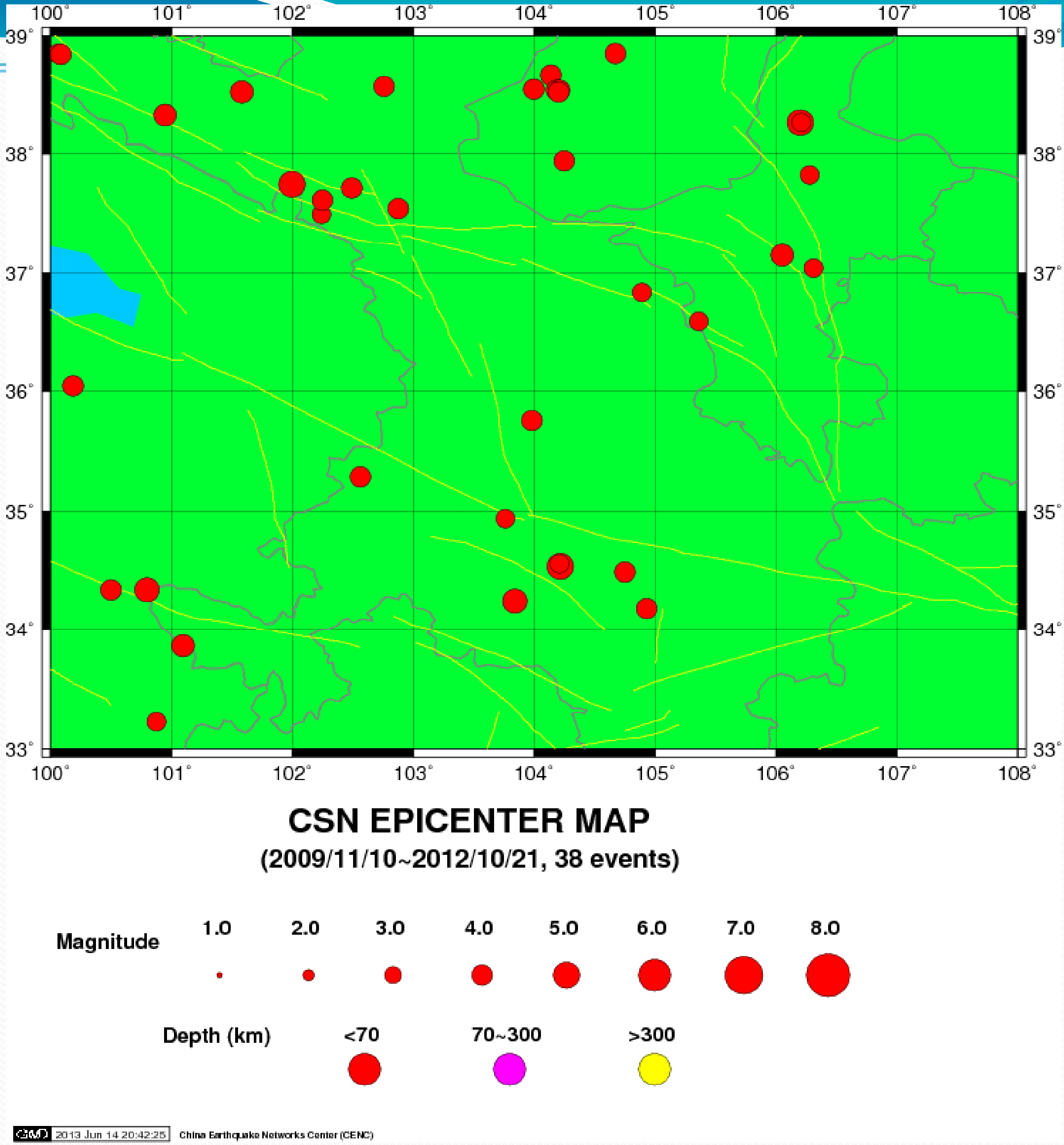
$$P(f) = \left[1 + \left(\frac{f}{f_{\max}} \right)^8 \right]^{-1/2}$$

$$G(R) = \begin{cases} \frac{1}{R} & R \le R_1 \\ \frac{1}{R_1} & R_1 < R < R_2 \\ \frac{1}{R_1}\sqrt{\frac{R_2}{R}} & R \ge R_2 \end{cases}$$

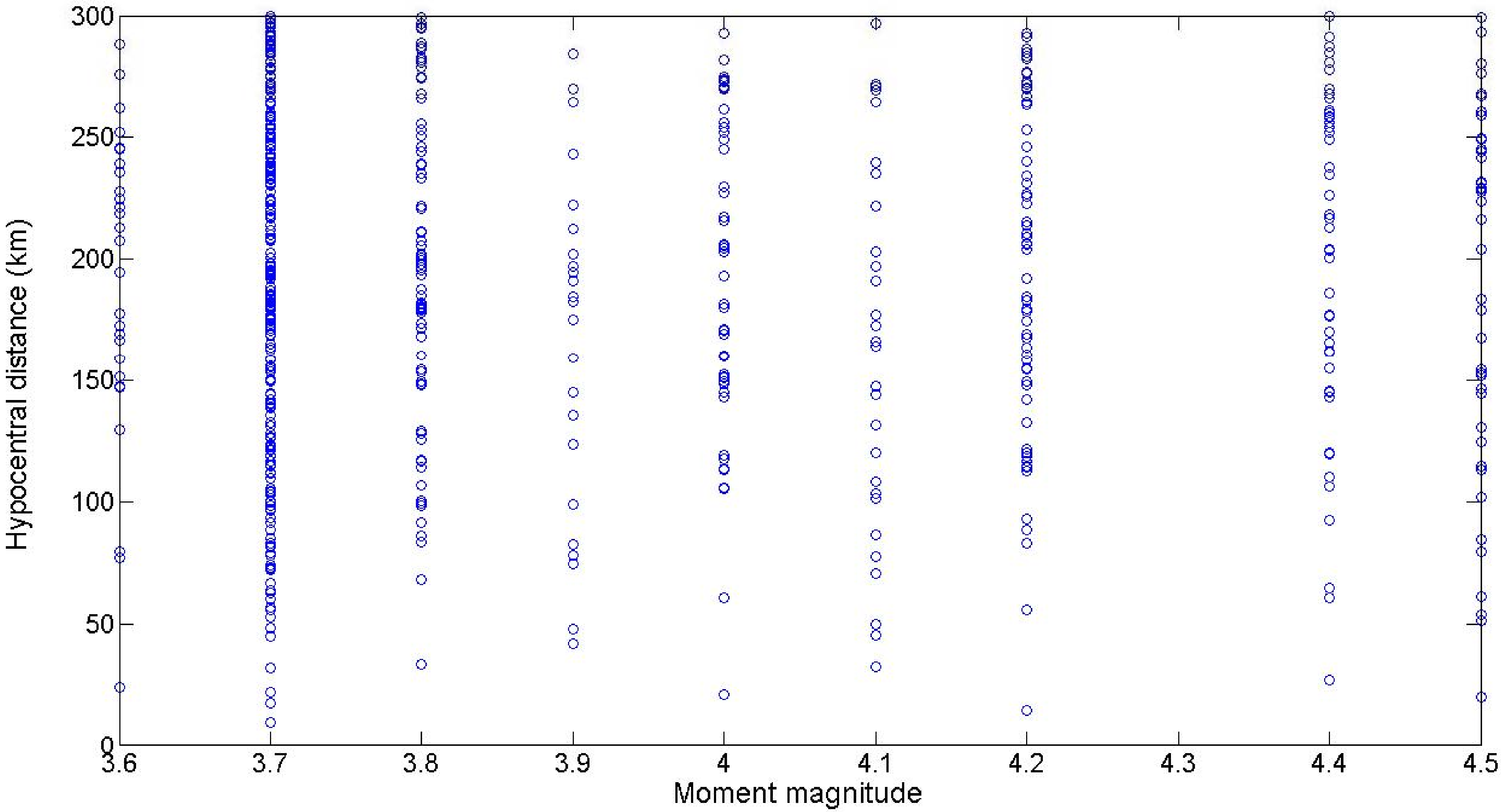
$$I(f) = (2\pi f)^z$$

No available values

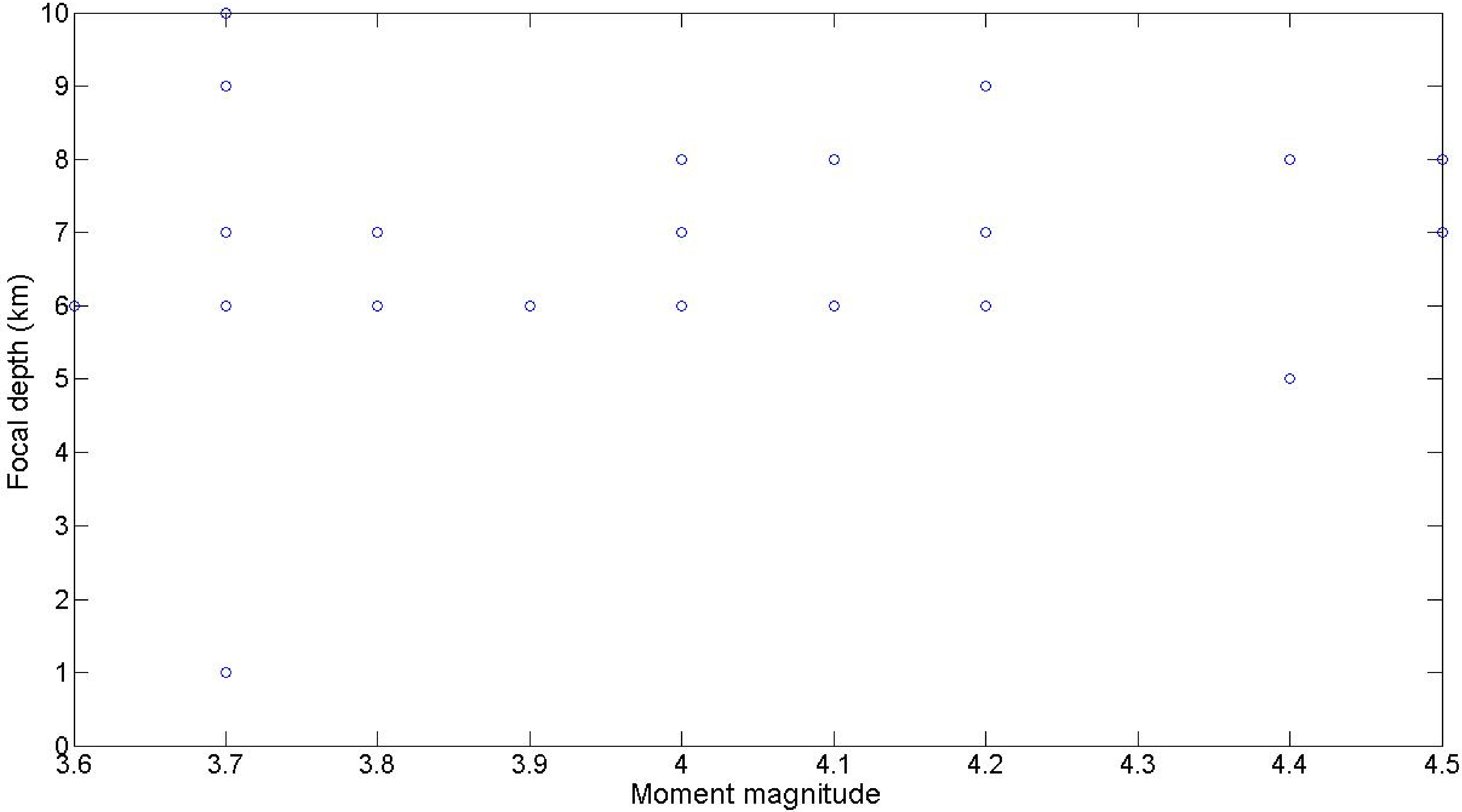

39°N,100°E
39°N,108°E
宁夏回族自治区
青海省
甘肃省
中国
陕西省
33°N,100°E
33°N,108°E
© 2012 Mapabc.com
© 2012 Cnes/Spot Image
Image © 2012 TerraMetrics
US Dept of State Geographer
35°44'58.37" 北 104°08'06.68" 东 海拔 2180 米
Google earth
视角海拔高度 1024.38 公里



33 events,
50 stations,
592 records - CENC



Hypocentral distance (km)
300
250
200
150
100
50
0
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4
4.5
Moment magnitude


Focal depth (km)
Moment magnitude
0
1
2
3
4
5
6
7
8
9
10
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4
4.5

Inversion strategy

- μGA is developed from GA, the main procedure is similar.
- In μGA, there still retain selection and crossover, but no variation, at the same time, it retains the optimal individual.
- Objective function

$$\phi_j = \sum_m \sum_n [FA_0(m,n) - FA_j(m,n)]^2$$

- Fitness

$$F_j = e^{-\beta\phi_j}$$

Inversion ranges

$\Delta\sigma$ (bars)	Q_o	η	R_1 (km)	R_2 (km)
1~200	200~700	0.2~0.6	50~100	100~150

Inversion results

$\Delta\sigma$ (bars)	Q_o	η	R_1 (km)	R_2 (km)
90.99	324.98	0.39	65.30	119.28

Time-domain simulation

- Combined with random phase spectra, the Fourier spectra can be transformed into the time domain.
- In time-domain simulations, these time series are windowed by

$$f(t) = \begin{cases} (t/t_1)^2, & 0 \le t \le t_1 \\ 1.0, & t_1 < t \le t_2 \\ e^{-c(t-t_2)}, & t_2 < t \end{cases}$$

where, t_1 and t_2 are the starting point and finishing point of the stable section, c is the attenuation rate.

ß An envelop curve on bedrock (Huo and Hu, 1991) is adopted.

$$\begin{cases} \lg t_1 = -1.074 + 1.005 \lg(R + 10) \\ \lg t_2 = -2.268 + 0.3262 M_W + 0.5815 \lg(R + 10) \\ \lg c = 1.941 - 0.2817 M_W - 0.5870 \lg(R + 10) \end{cases}$$

- The windowed time histories are transformed into the frequency domain.
- Complex spectra are transformed back to the time domain.
- Attenuation curves, which show mean levels, can be constructed after mean PGAs from 50 different random phase spectra are calculated.

Strong motion data from CSMNC

- 1987.9.12-2011.11.2
- 18 events
- 21 stations

- Mw=5.0, 33 records
- Mw=6.0, 5 records
- Mw=7.0, 1 record

Empirical relations

1989-2012
Seven sets of relations-empirical
Western China, Loess region of China

- Zoning map, Western China (2001)

$$\ln(PGA) = 5.912 + 1.836M - 2.846\ln(R + 3.400 \cdot e^{0.451M})$$

$$\ln(PGA) = 2.509 + 1.36M - 1.791\ln(R + 1.046 \cdot e^{0.451M})$$

- Model 1 (2012)

$$\log_{10}(PGA) = 0.617 + 1.163M - 0.046M^2 - 2.207\log_{10}(R + 1.694 \cdot e^{0.446M})$$

$$\log_{10}(PGA) = -0.644 + 1.08M - 0.043M^2 - 1.626\log_{10}(R + 0.255 \cdot e^{0.57M})$$

- XIAO Liang (2010)

$$\log_{10}(PGA) = 1.204 + 0.632M - 1.928\log_{10}(R + 1.046 \cdot e^{0.451M})$$

- YU Yanxiang and WANG Suyun (Western China, 2006)

$$\log_{10}(PGA) = 2.206 + 0.532M - 1.954\log_{10}(R + 2.018 \cdot e^{0.406M})$$

$$\log_{10}(PGA) = 1.01 + 0.501M - 1.441\log_{10}(R + 0.340 \cdot e^{0.521M})$$

- DING Boyang, TIAN Shaobo and LEI Zhongsheng (Loess region of China, 1991). Circle model, IR and IM

$$\ln(PGA) = 1.066 + 0.559M - 2.012\ln(R + 17) - 0.00387(R + 17)$$

$$\ln(PGA) = 0.071 + 0.500M - 1.502\ln(R + 17)$$

- DING Boyang, LEI Zhongsheng and FANG Shulan (Loess region of China, 1989). Circle model

$$\ln(PGA) = -3.066 + 0.2347M - 0.4137\ln R - 0.00127R$$

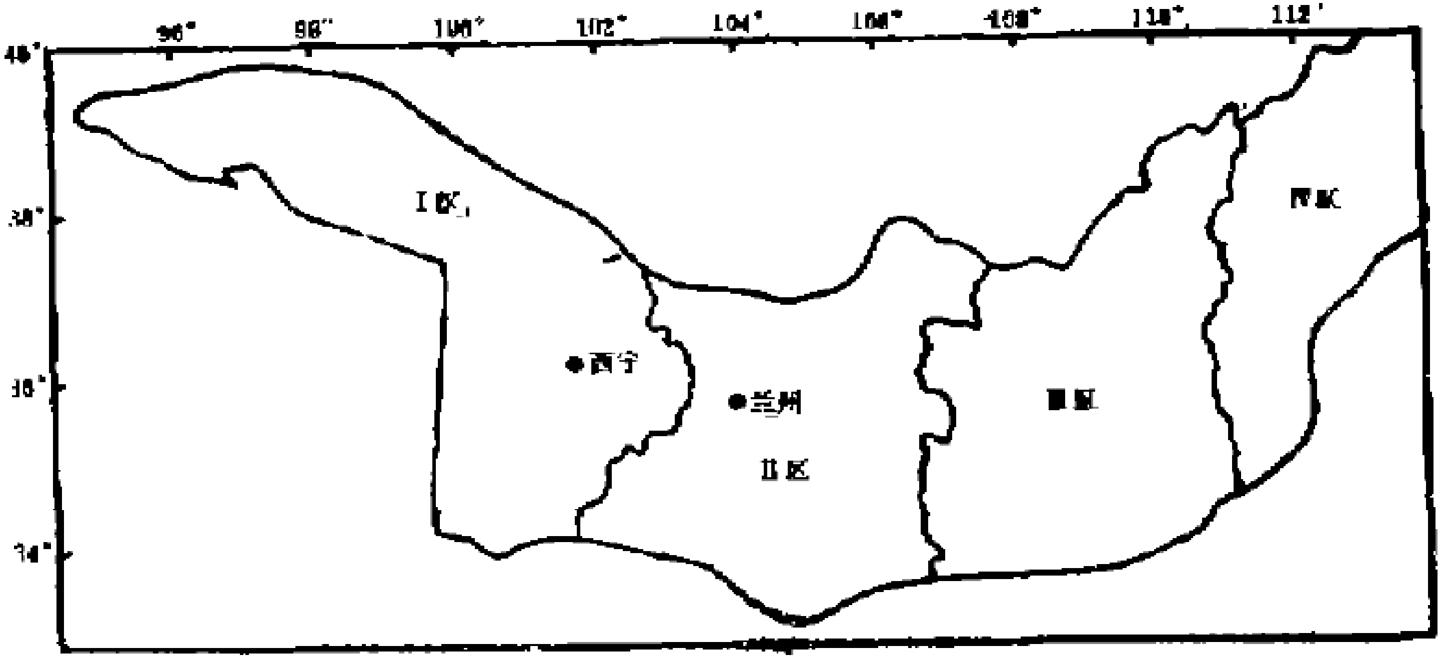


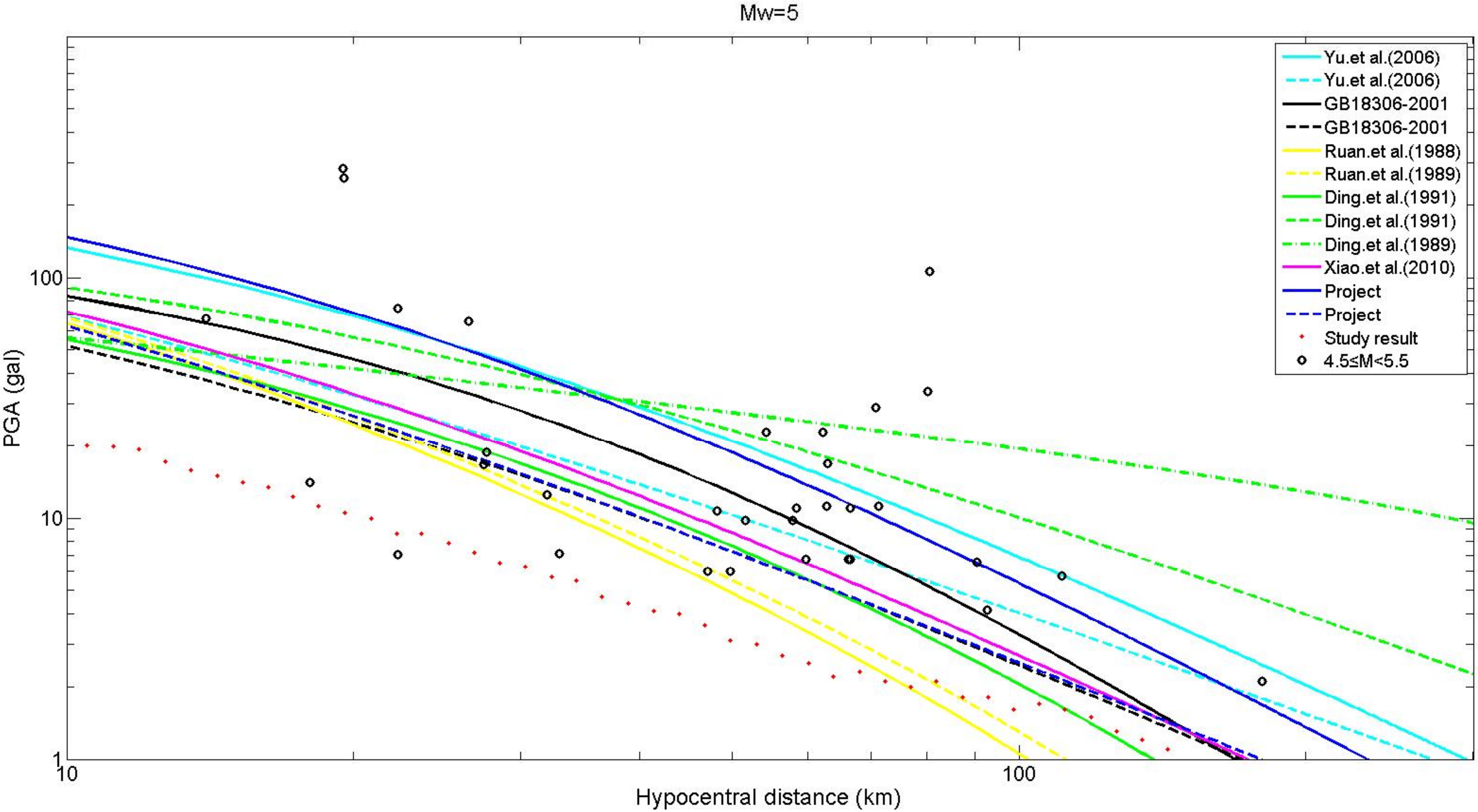
图 2　西北黄土地区构造分区示意图

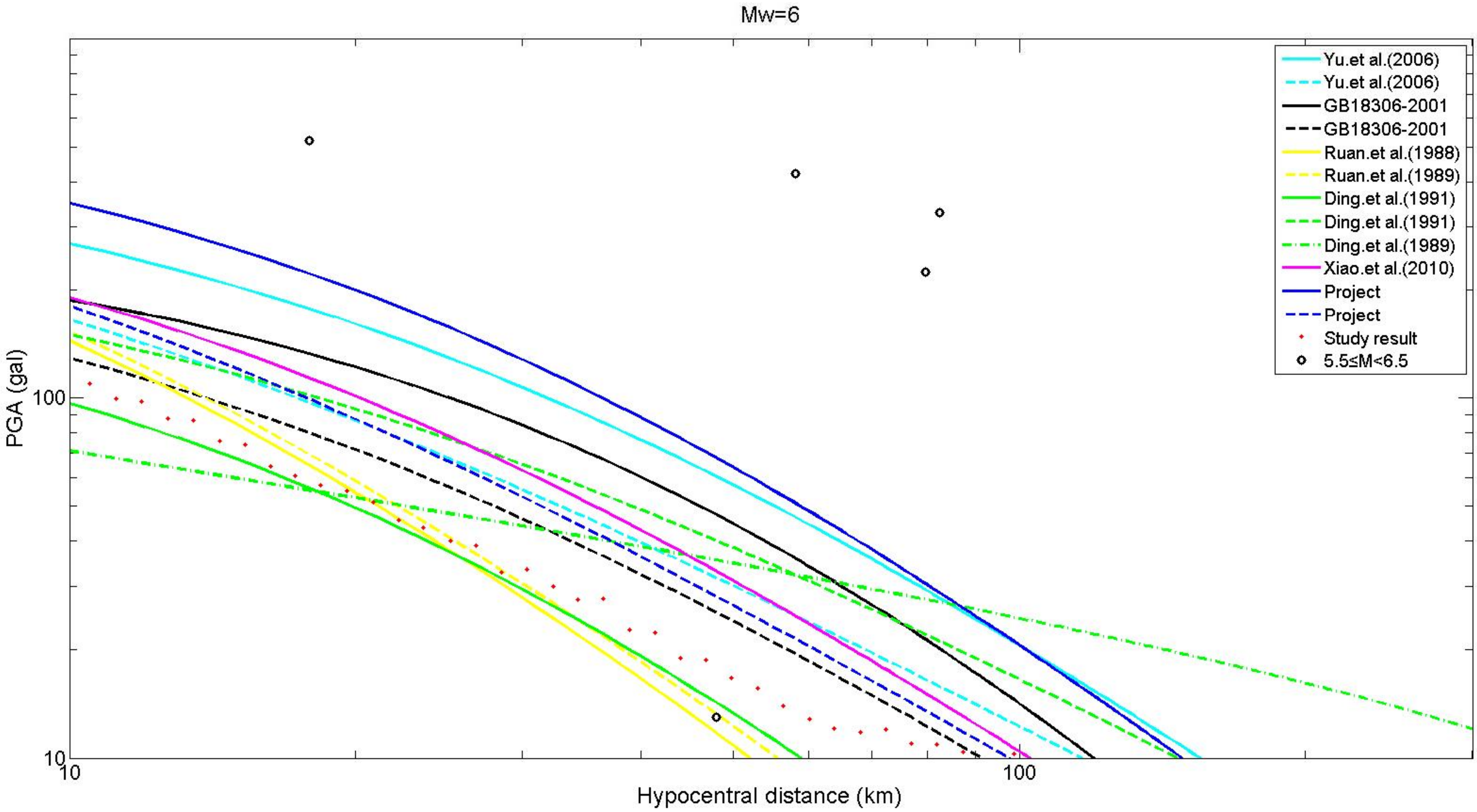
Fig. 2　The loess area and its subregions in the Northwest China

RUAN Aiguo and SUN Congshao, A study on attenuation law of seismic ground motion in the loess region of the Northwest China, 1989

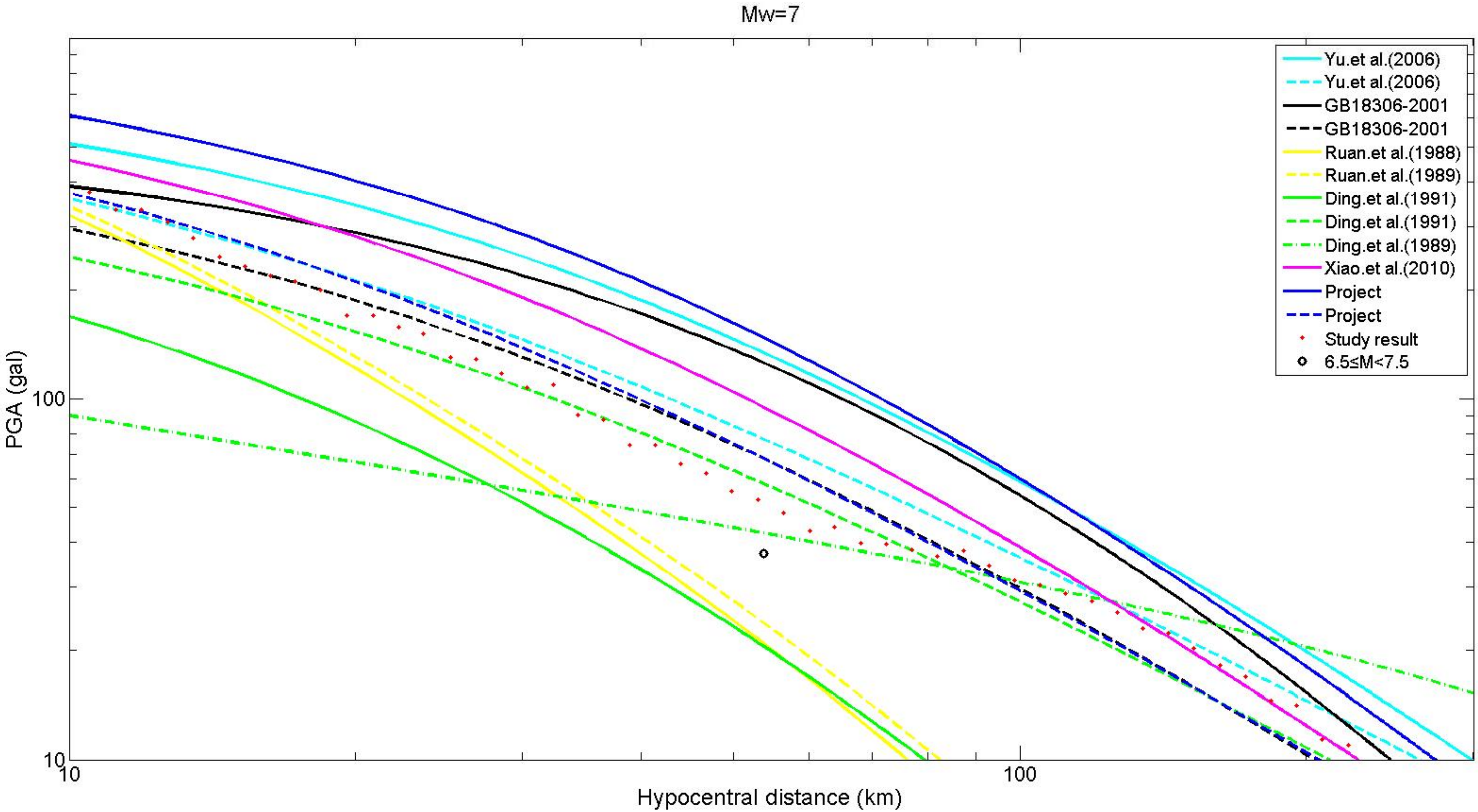
$$\ln(PGA) = -2.9169 + 0.8028M - 1.508\ln\sqrt{R^2+36} - 0.00985\sqrt{R^2+36}$$

$$\ln(PGA) = -2.888 + 0.8038M - 1.507\ln\sqrt{R^2+36} - 0.00815\sqrt{R^2+36}$$


Mw=5
PGA (gal)
100
10
1
Hypocentral distance (km)
10
100
Yu.et al.(2006)
Yu.et al.(2006)
GB18306-2001
GB18306-2001
Ruan.et al.(1988)
Ruan.et al.(1989)
Ding.et al.(1991)
Ding.et al.(1991)
Ding.et al.(1989)
Xiao.et al.(2010)
Project
Project
Study result
4.5≤M<5.5

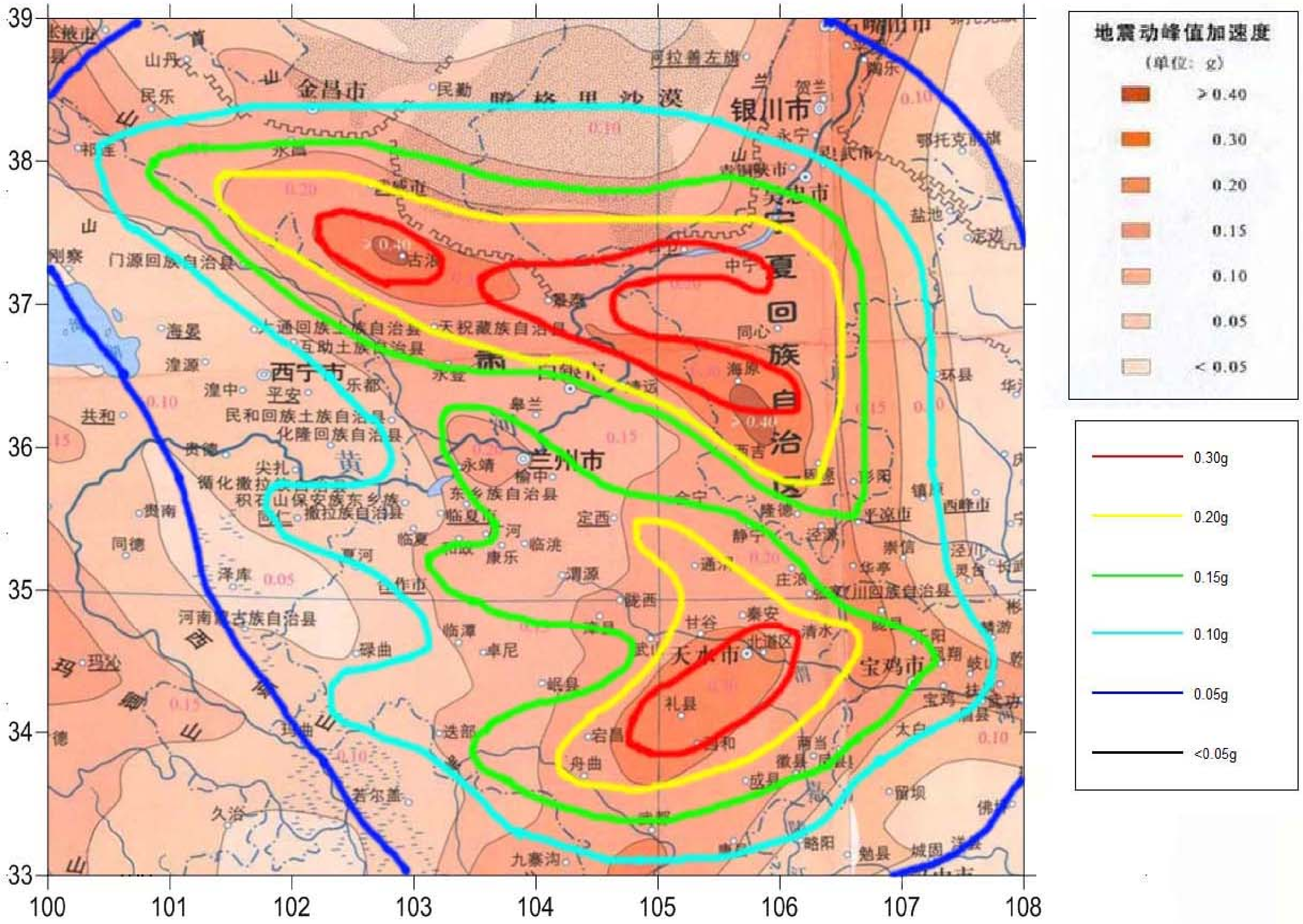


Mw=6
PGA (gal)
100
10
10
100
Hypocentral distance (km)
Yu.et al.(2006)
Yu.et al.(2006)
GB18306-2001
GB18306-2001
Ruan.et al.(1988)
Ruan.et al.(1989)
Ding.et al.(1991)
Ding.et al.(1991)
Ding.et al.(1989)
Xiao.et al.(2010)
Project
Project
Study result
5.5≤M<6.5


Mw=7
PGA (gal)
Hypocentral distance (km)
10
100
10
100
Yu.et al.(2006)
Yu.et al.(2006)
GB18306-2001
GB18306-2001
Ruan.et al.(1988)
Ruan.et al.(1989)
Ding.et al.(1991)
Ding.et al.(1991)
Ding.et al.(1989)
Xiao.et al.(2010)
Project
Project
Study result
6.5≤M<7.5

Application in PSHA

M \ R	20.9	22.2	23.6	25.2	26.8	28.5	30.3	32.3	34.3	36.5
5.5	24.8	21.9	20.2	19.2	17.3	16.6	15.2	14.4	12.9	12.1
5.6	29	24.8	24.3	22.4	21.1	18.4	18.6	16.6	15.3	14.9
5.7	32.7	29.5	29.2	25.3	25.2	22.6	20.5	20.6	17.7	15.8
5.8	38.4	35.6	32.9	32.3	27.5	26.5	23.3	22.2	20.3	19.6
5.9	43.5	40.2	36.7	35.3	31.9	31.7	27	26.3	23.6	21.8
6.0	51.4	45.8	43.7	40	38.8	32.9	33.5	30	27.6	27.8


地震动峰值加速度
（单位：g）
> 0.40
0.30
0.20
0.15
0.10
0.05
< 0.05
0.30g
0.20g
0.15g
0.10g
0.05g
<0.05g
39
38
37
36
35
34
33
100
101
102
103
104
105
106
107
108
金昌市
银川市
西宁市
兰州市
天水市
宝鸡市
宁夏回族自治区

Conclusions

- In the demonstration region of this project, five regional parameters are inversed from small earthquakes by μGA.
- Strong ground motion attenuation relationship is constructed from small earthquake records by China Earthquake Network.
- The relation is expressed as a 2D table and is adopted in PSHA.
- The seismic zoning map of the demonstration is compared with the national map to prove the validation.

The end

Thanks