Selection and weighting of ground motion prediction equations for seismic hazard analysis in Taiwan

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Ground-motion prediction equations (GMPEs) are one of the key elements of seismic hazard analysis. With the increasing of ground-motion databases, the development of GMPE has fast grown up and the selection of GMPE in seismic hazard analysis has become an issue. Several methods has been proposed for select and ranking GMPE in seismic hazard analysis as likelihood (LH) and log-likelihood (LLH) methods proposed in Scherbaum et al. (2004, 2009) and Euclidean distance-based ranking (EDR) method proposed in Kale Ö. and S. Akkar (2013).

In order to select the proper GMPE in developing the seismic hazard map in Taiwan, we first compiled a database using strong ground-motion data collected by Taiwan Strong-motion Instrumentation Program (TSMIP) (Liu et al., 1999). Then, a set of local GMPEs developed with only Taiwan's ground-motion data and a set of global GMPEs developed with global ground-motion data are collected to be the candidate GMPEs for seismic hazard analysis. Using the method proposed by Scherbaum et al. (2004, 2009) and Kale Ö. and S. Akkar (2013) with the ground-motion database, the most proper GMPEs for seismic hazard analysis in Taiwan will be identified and weighting will be assigned.

References

Kale Özkan and Sinan Akkar (2013), A New Procedure for Selecting and Ranking Ground-Motion Prediction Equations (GMPEs): The Euclidean Distance-Based Ranking (EDR) Method, Bulletin of the Seismological Society of America, Vol. 103, No. 2A, pp. 1069 – 1084.

Liu, K.-S., T.-C. Shin, and Y. B. Tsai (1999), A free-field strong-motion network in Taiwain: TSMIP, *Terr. Atmos. Ocean. Sci.* 10, no. 2, 377 – 396.

Scherbaum F, Cotton F, Smit P (2004), On the use of response spectral reference data for the selection and ranking of ground-motion models for seismic hazard analysis in regions of moderate seismicity: the case of rock motion. *Bull Seismol Soc Am* 94(6) 1 – 22.

Scherbaum, F., E. Delavaud, and C. Riggelsen (2009), Model selection in seismic hazard analysis: An information-theoretic perspective. *Bull Seismol Soc Am* 99 (6), 3234–3247.

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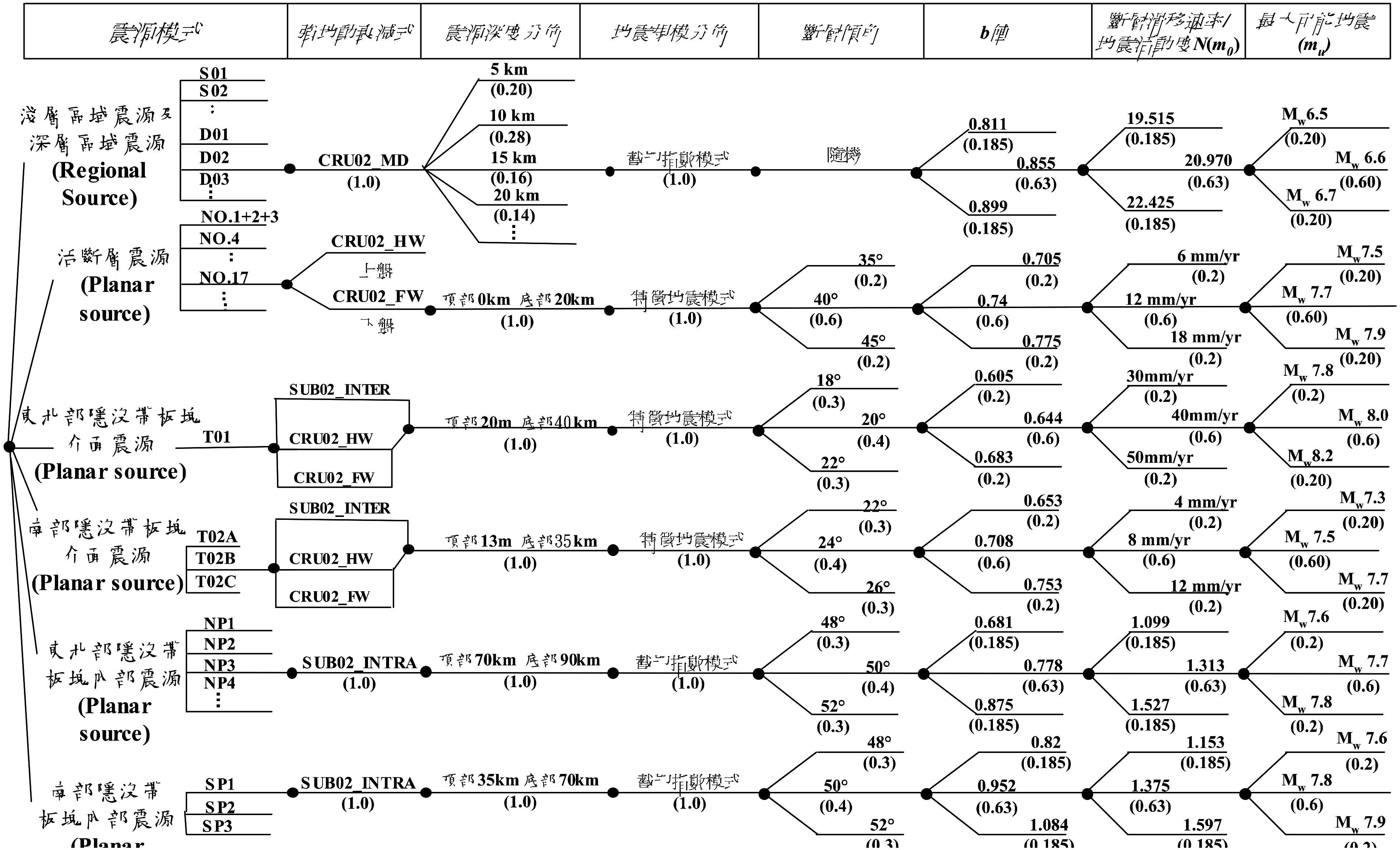
Outline

- Introduction
- Method
- Database
- GMPE models
  - Crustal earthquake
  - Subduction zone earthquake
- Analysis results
- Conclusion
- Future work

Introduction



Introduction

- Probabilistic seismic hazard analysis (PSHA)
  - Selection and ranking(weighting) of ground-motion prediction equations (GMPEs) for PSHA is important.
  - How to select GMPEs in logic tree ?
- Ground-motion prediction equation
  - How the GMPEs perform with the database?
  - How to compare GMPEs with each other?

Method

- Likelihood (LH) method (Scherbaum et al., 2004)
  - LH = 0~1, median = 0.5
  - larger is better
- Log-likelihood(LLH) method (Scherbaum et al., 2009)
  - Smaller is better
- Euclidean distance-based ranking (EDR) mothod (Kale and Akkar, 2012)
  - Smaller is better

Method

- Likelihood (LH) method (Scherbaum et al., 2004)

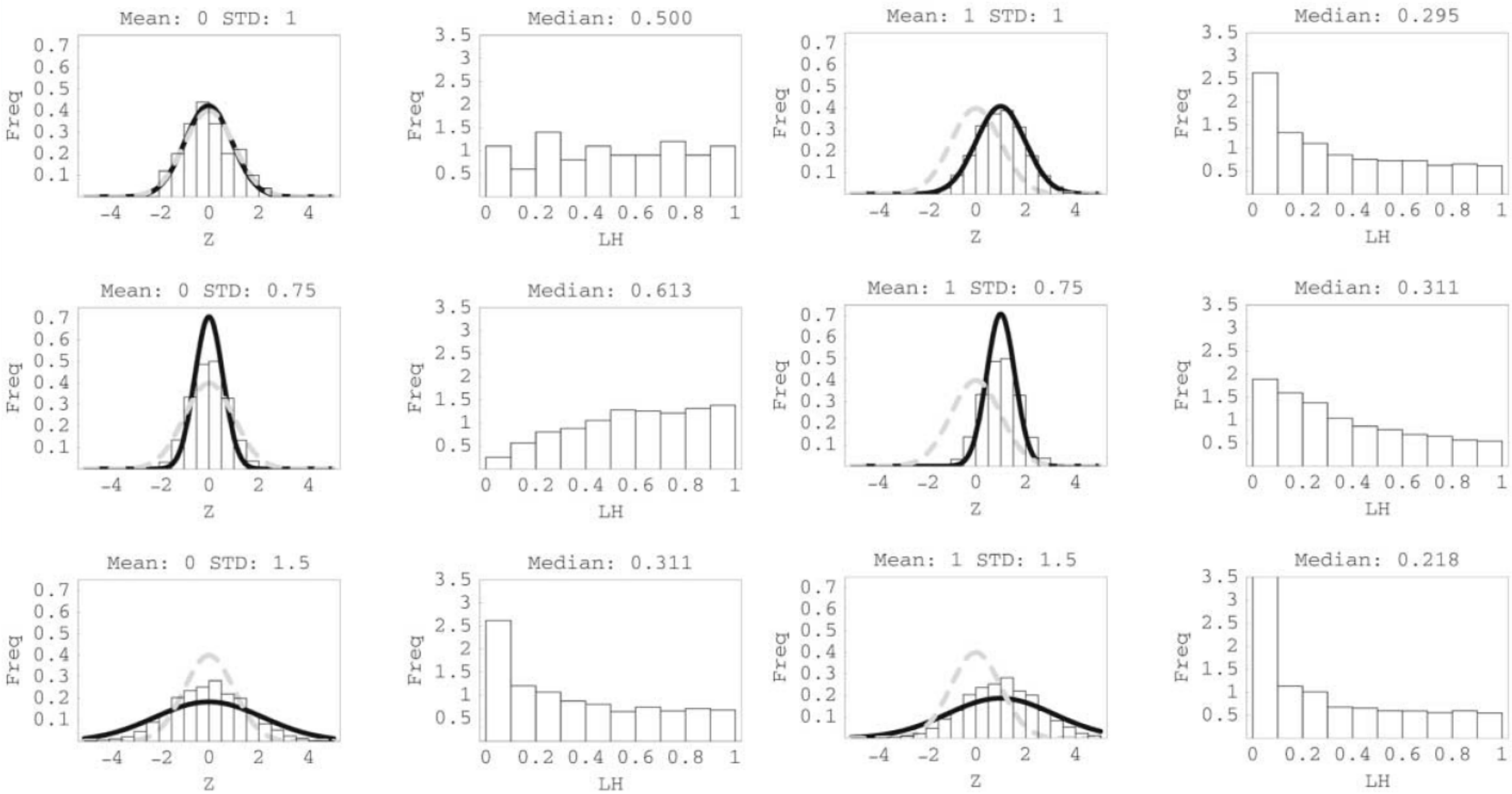
$$\mathrm{LH}(|z_0|) = 2 \cdot u(|z_0|) = Erf\left(\frac{|z_0|}{\sqrt{2}}, \infty\right) = \frac{2}{\sqrt{2\pi}} \int_{|z_0|}^{\infty} \exp\left(\frac{-z^2}{2}\right) dz$$

–LH reaches its maximum value of 1 for $|z_0| = 0$, in other words, for an observation that coincides with the mean value of the model.

–The LH value decreases with increasing distance from the mean (decreasing quality of the fit). For $|z_0| = \infty$ we obtain $\mathrm{LH} = 0$.

–If the model assumptions are matched exactly, in other words, for samples drawn from a normal distribution with unit variance, the samples of the random variable LH are evenly distributed between 0 and 1

Method - LH


Mean: 0 STD: 1
Median: 0.500
Mean: 1 STD: 1
Median: 0.295
Mean: 0 STD: 0.75
Median: 0.613
Mean: 1 STD: 0.75
Median: 0.311
Mean: 0 STD: 1.5
Median: 0.311
Mean: 1 STD: 1.5
Median: 0.218
Freq
Z
LH
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.5
1
1.5
2
2.5
3
3.5
-4
-2
0
2
4
0
0.2
0.4
0.6
0.8
1

Method

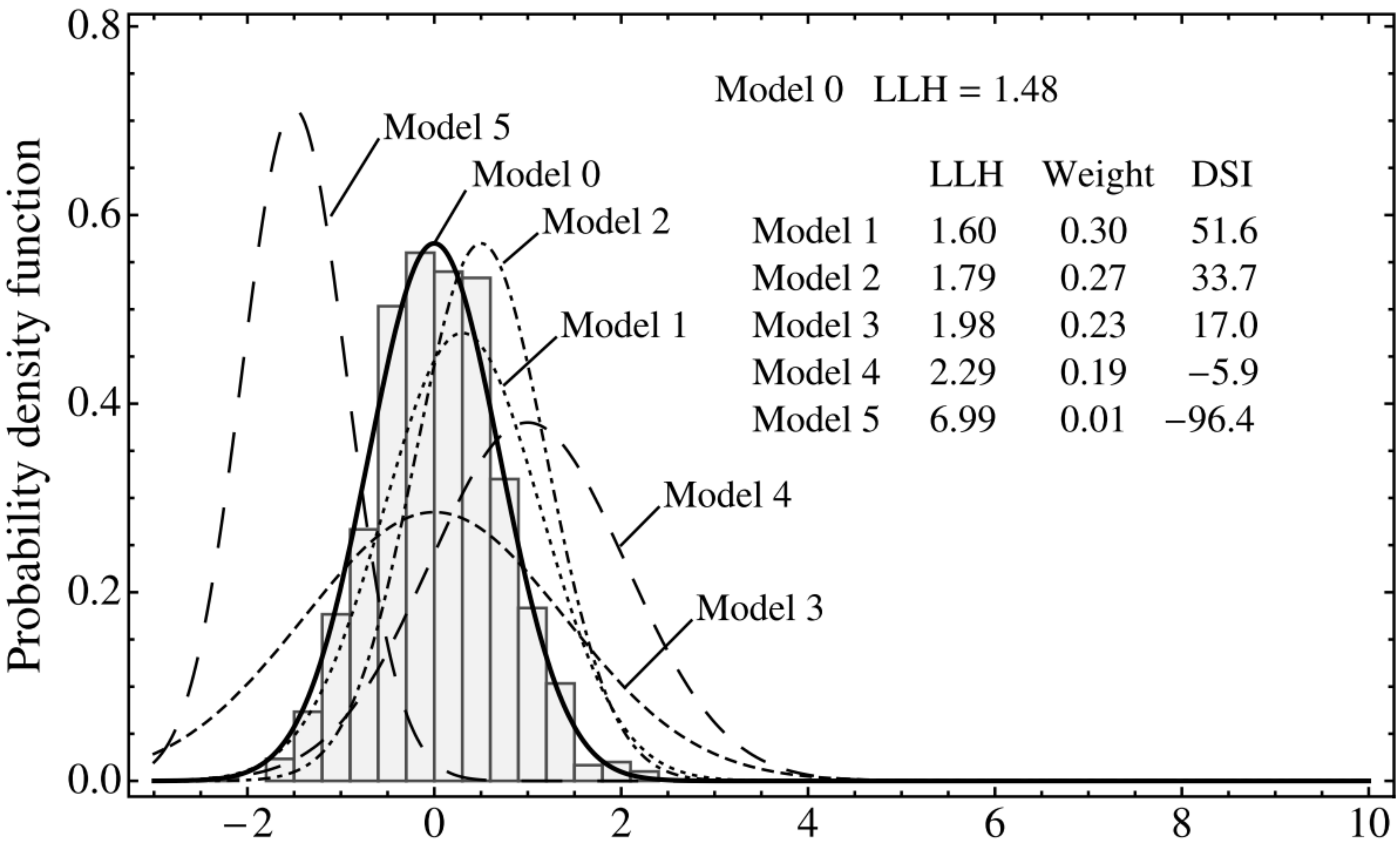
- Log-likelihood(LLH) method (Scherbaum et al., 2009)
  - The negative average sample log-likelihood (LLH), defined by:

$$\mathrm{LLH}(g,\mathbf{x}) = -\frac{1}{N}\sum_{i=1}^{N}\log_2(g(x_i))$$

Where $\mathbf{x}$= { x_i } ,i=1,…,N are the empirical data and $g(x_i)$ is the likelihood that model g has produced the observation x_i. In the case of GMPE selection, g is the probability density function given by an earthquake defined by **M** (and other parameters) at site I that is located at distance **R** from the source. (Delavaud et al., 2012)

  - Smaller is better

Method - LLH



Delavaud et al. (2012) BSSA.

Method-EDR

- Euclidean distance-based ranking (EDR) mothod (Kale and Akkar, 2012)
  - Smaller is better

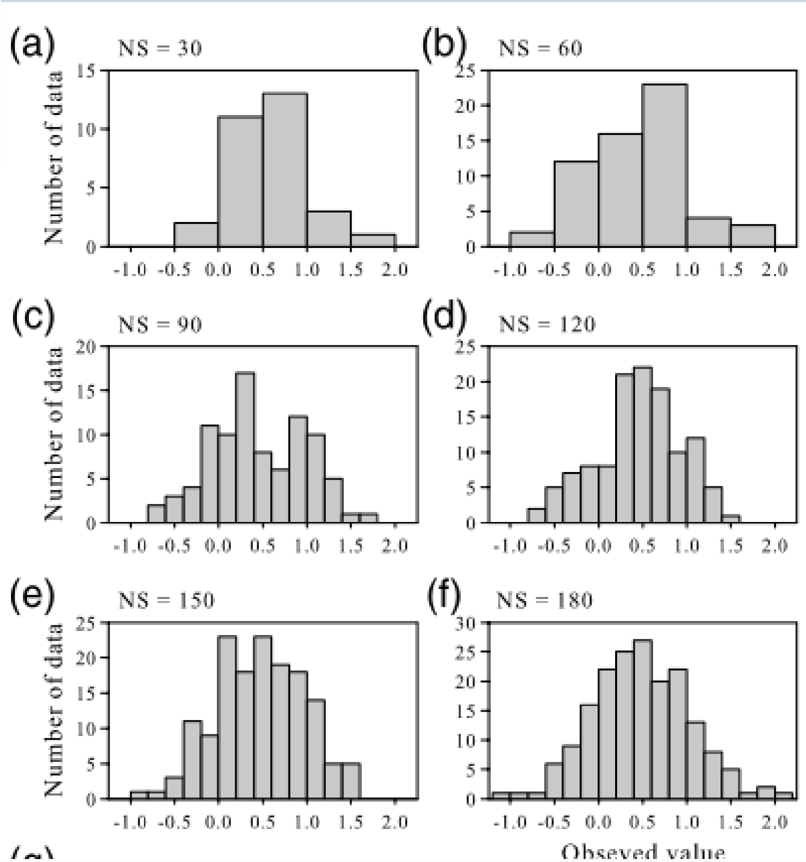
$$DE^2 = \sum_{i=1}^{N} (p_i - q_i)^2$$

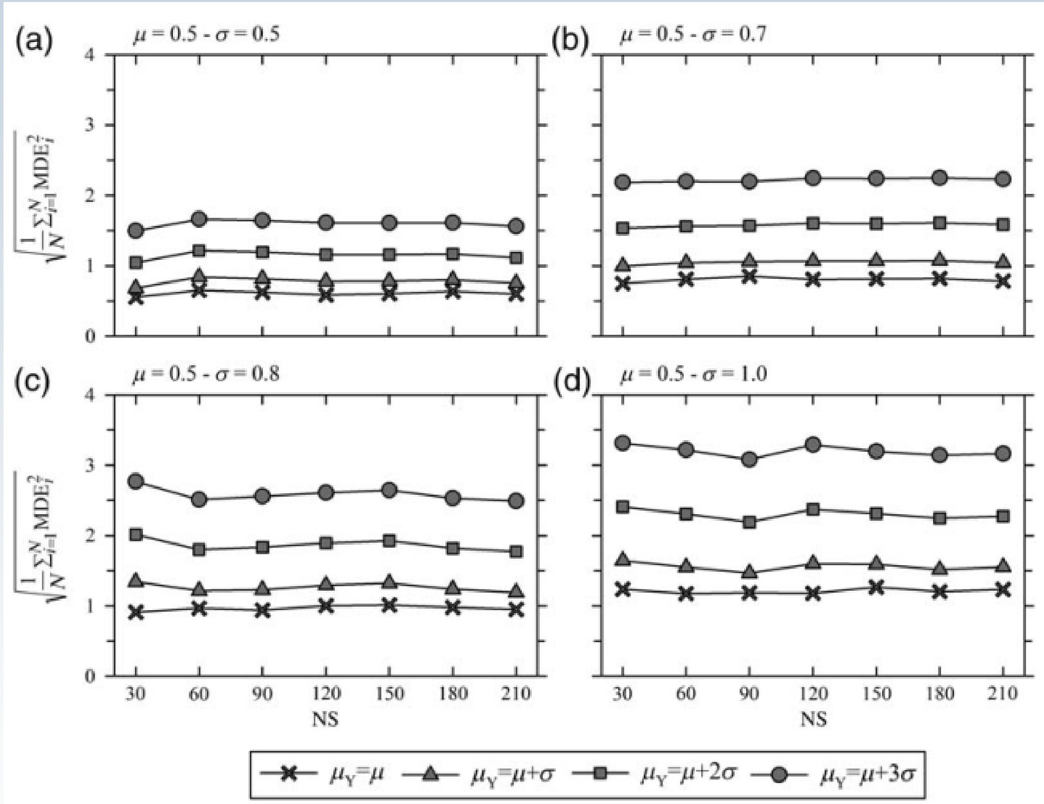
$$MDE_d = \sum_{j=1}^{N} |d_j| \Pr(|D| < |d_j|)$$

$$EDR = \sqrt{\kappa \times \frac{1}{N} \times \sum_{i=1}^{N} MDE_i^2}$$

$$\kappa = \frac{DE_{original}}{DE_{corrected}}$$

Method-EDR



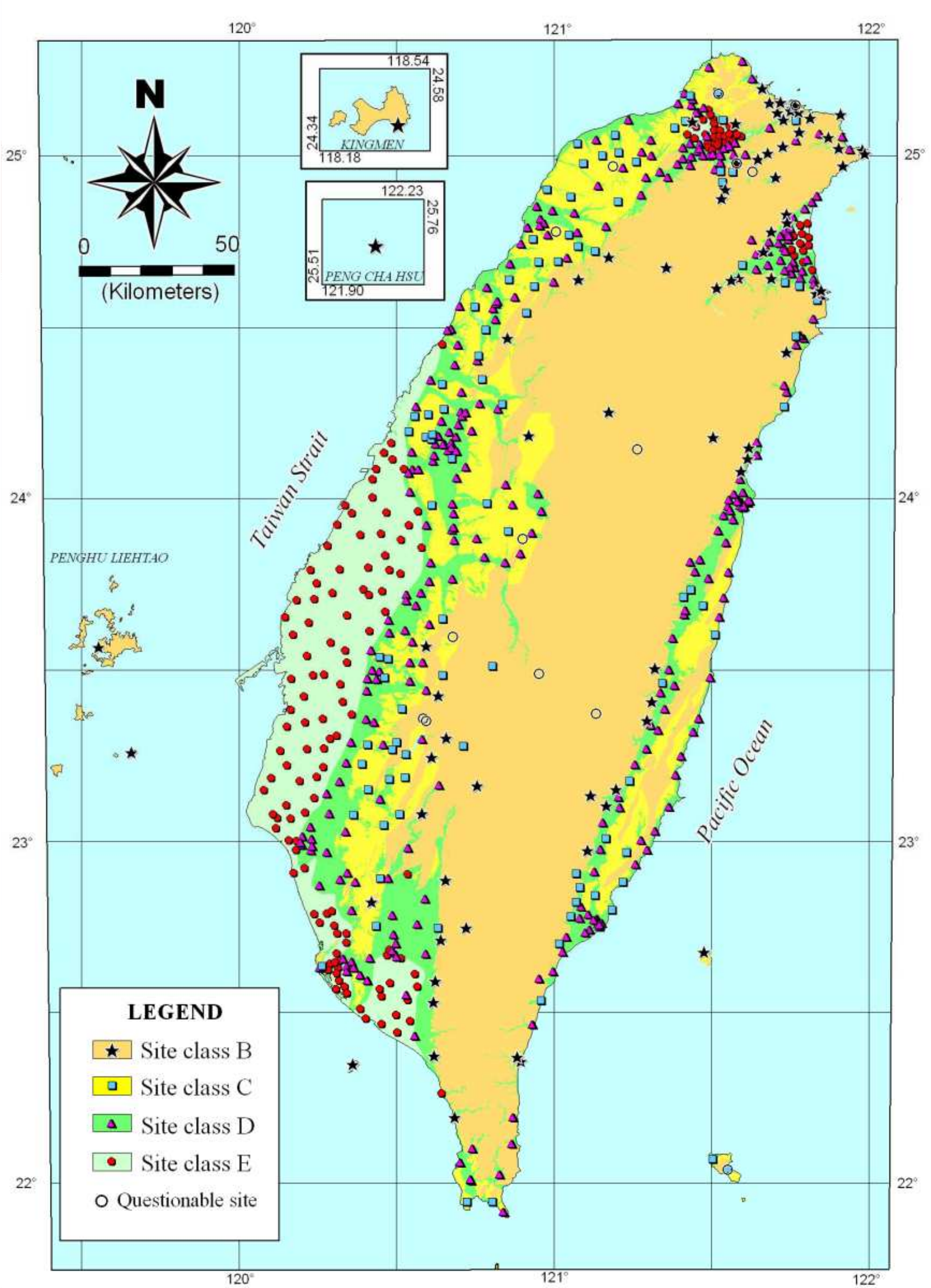


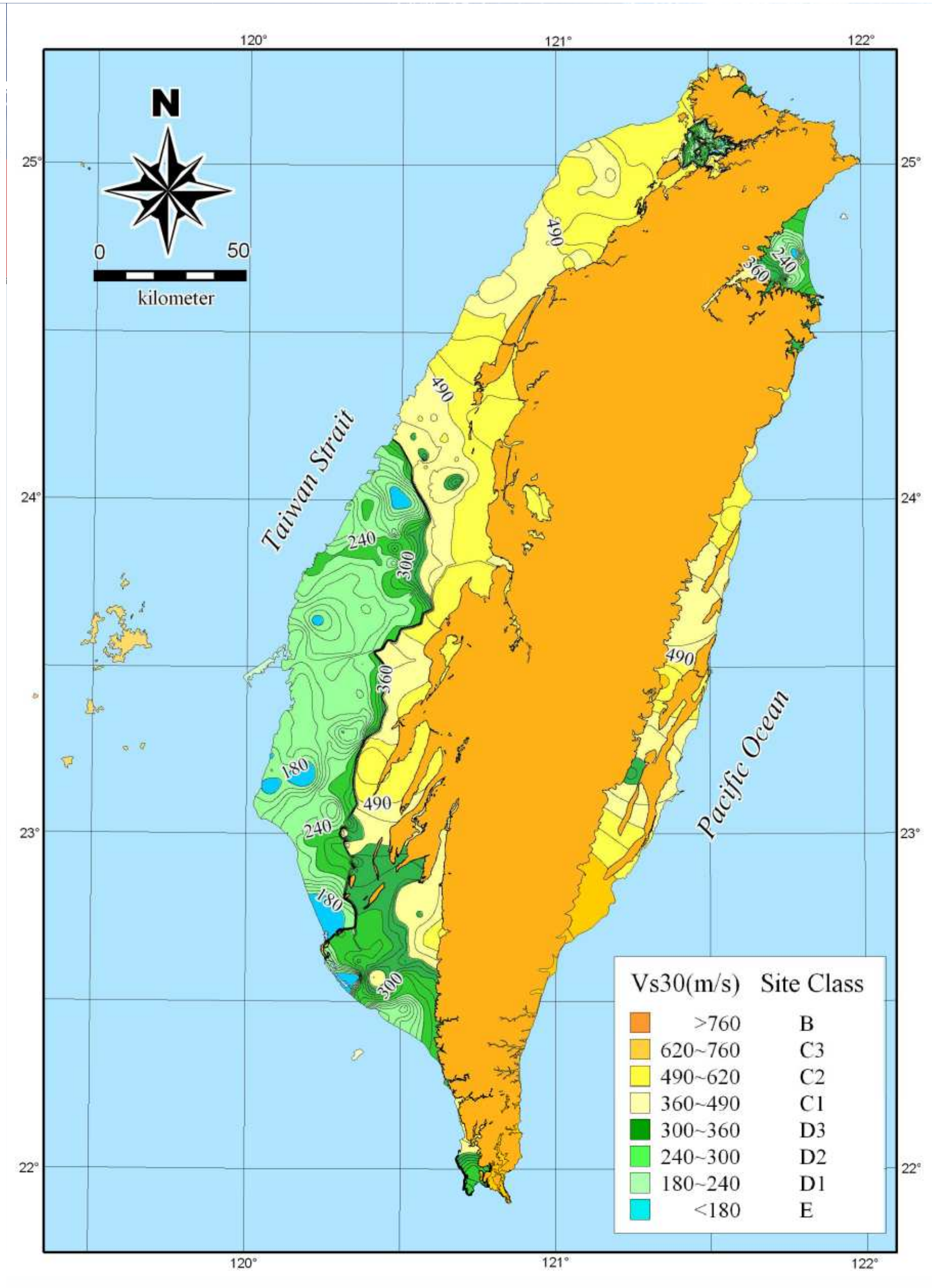
MDE is independent of data size from the plots.

(Kale and Akkar, 2012)

Ground-motion database

- Shallow crustal earthquakes
  - 91 earthquakes
  - 9676 records
- Subduction zone earthquakes
  - 61 earthquakes (11 interface events, 50 intraslab events)
  - 7547 records

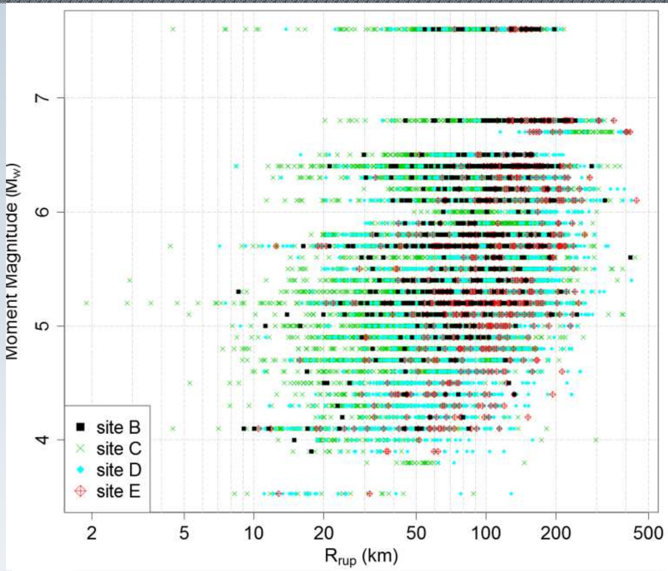


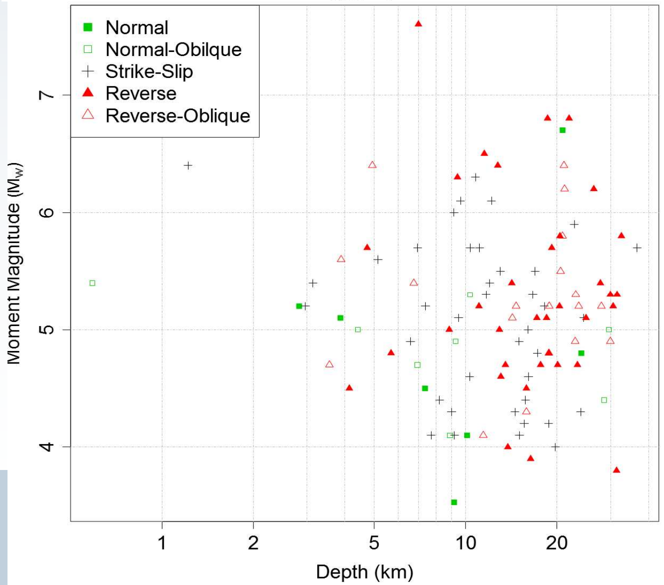


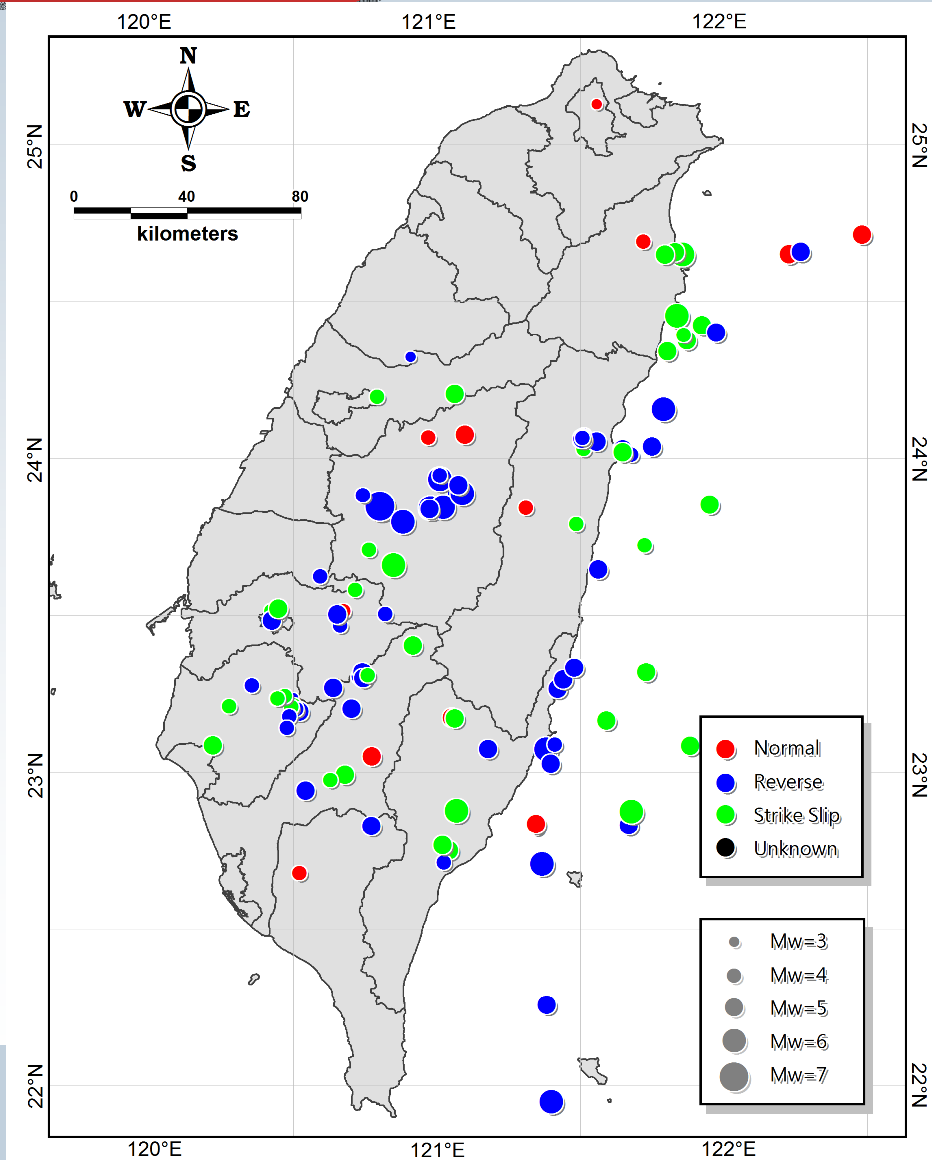
Lee et al. (2001)

Lee and Tsai (2008)

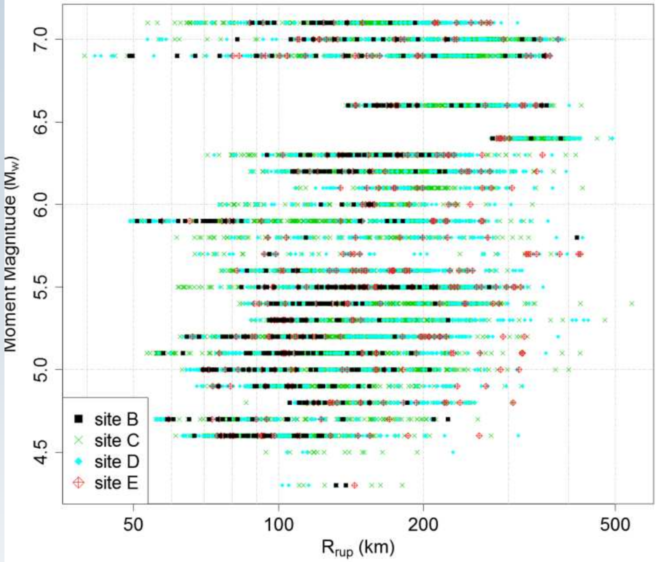
Strong-motion data for GMPE – Crustal

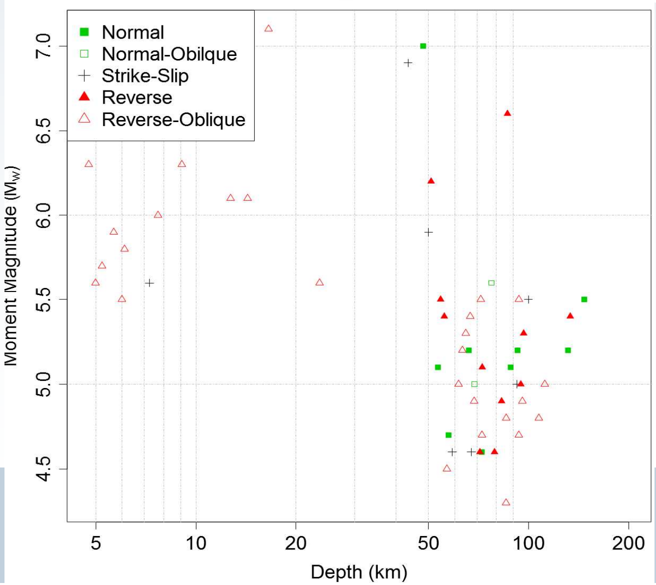


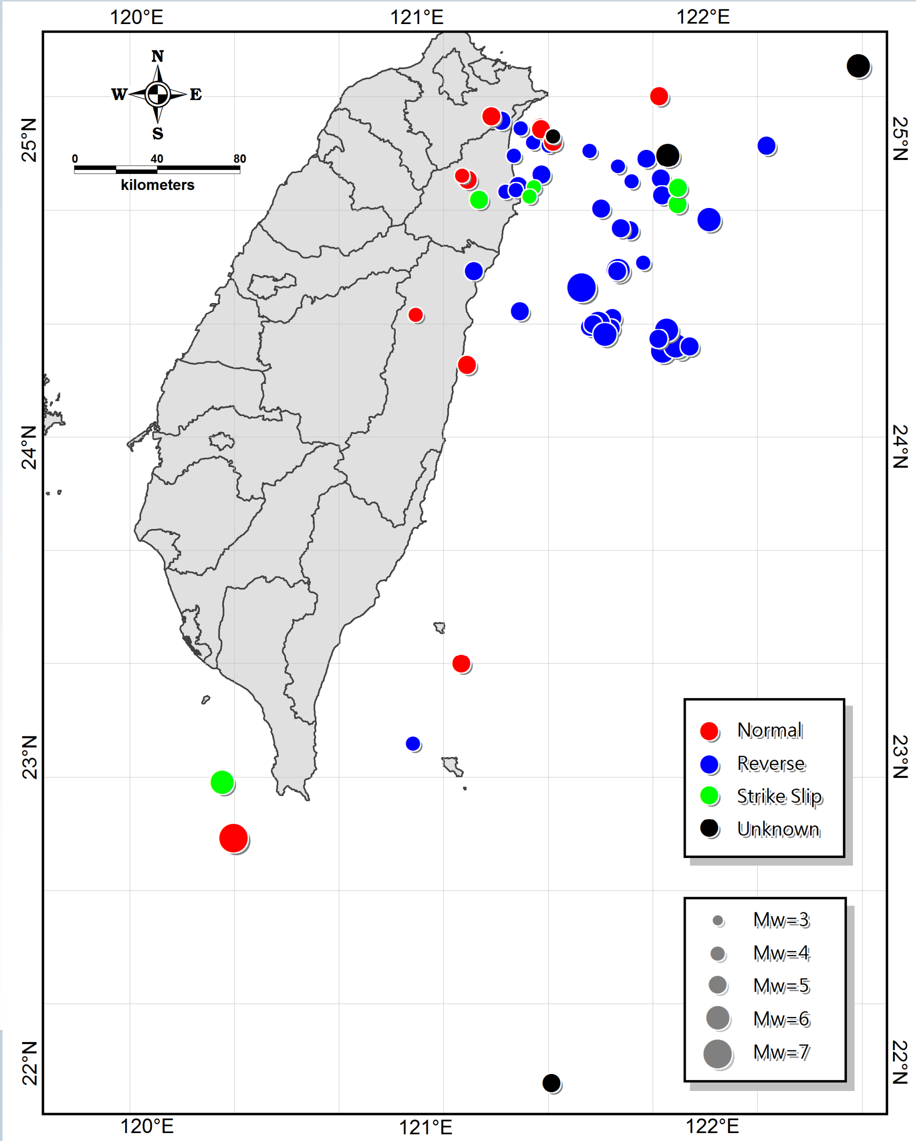




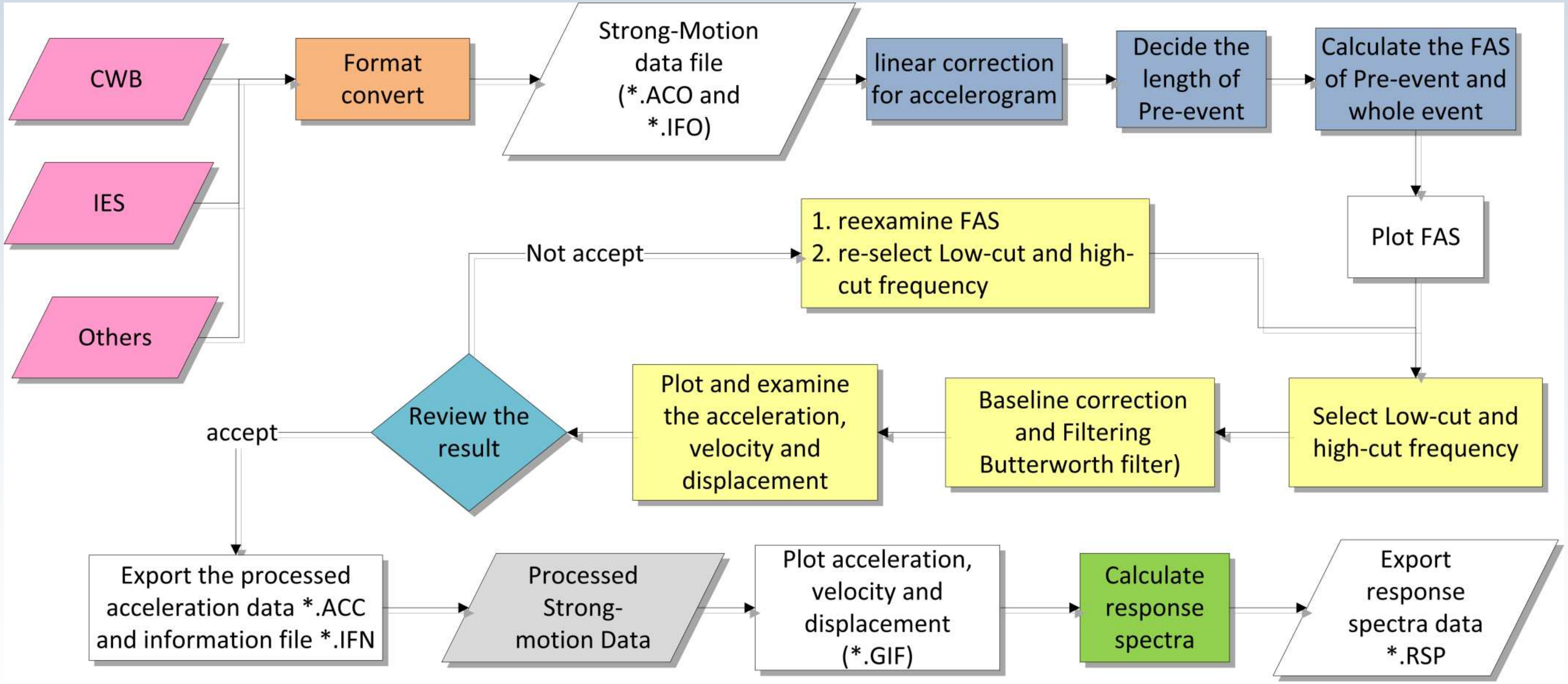
Strong-motion data for GMPE – Subduction





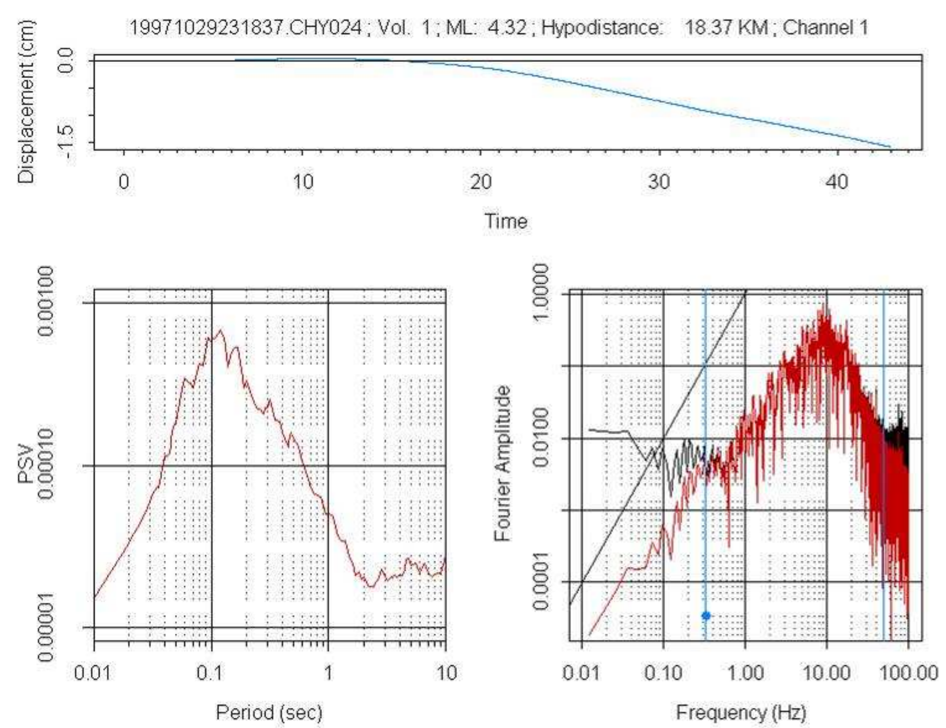


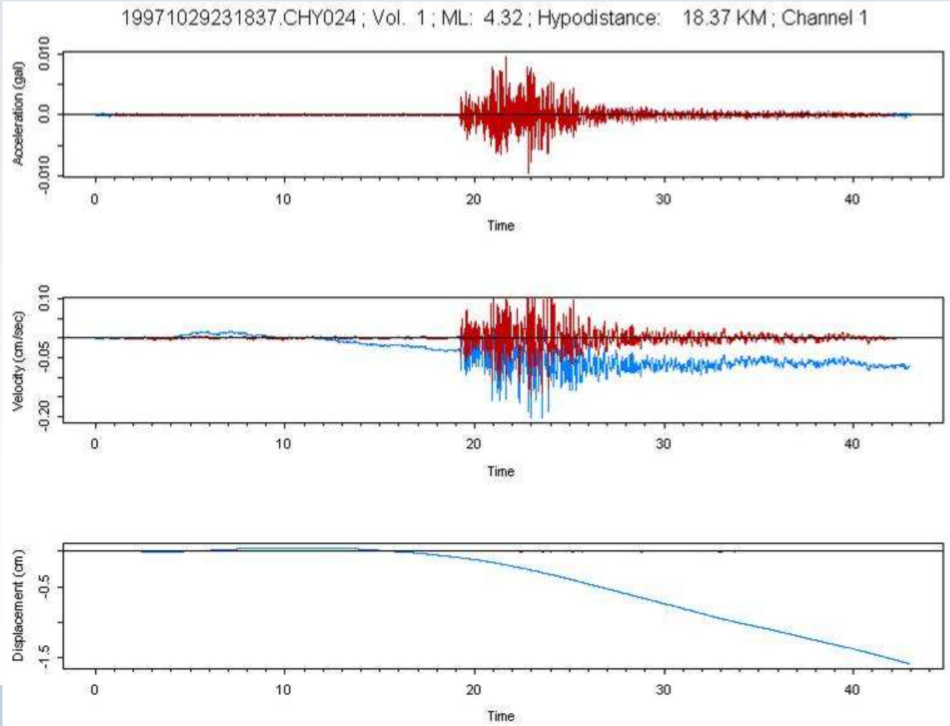
The flow chart of strong-motion data process



An example of strong-motion data process result

- Each strong-motion waveform data was processed with baseline correction and band-pass filter
- The selection of filter range was base on pseudo spectral velocity (PSV) spectra and Fourier amplitude spectral





GMPE models for crustal earthquake

- Wu et al.(2001)
- Chang et al.(2001)
- NCREE (2004)
  - Campbell's form
  - Joyner and Boore's form
  - Kanai's form
  - Japan Rock Site's form
- Liu and Tsai (2005)
- Tsai et al. (2006)
- NCREE (2011)
- Lin et al.(2011)
- Lin (2009)
- Sinotech (2011)

GMPE models for crustal earthquake

GMPEs	Acronym
Wu et al.(2001)	WU2001
Chang et al.(2001)	CB
NCREE (2004) Campbell's form	JB
NCREE (2004) Joyner and Boore's form	JR
NCREE (2004) Kanai's form	KA
NCREE (2004) Japan Rock Site's form	CH2001
Liu and Tsai (2005)	LT2005
Tsai et al. (2006)	TS2006
NCREE (2011)	NCREE2011
Lin et al.(2011)	Lin2011
Lin (2009)	PS2009
Sinotech (2011)	TNGA

GMPE models for subduction zone earthquake

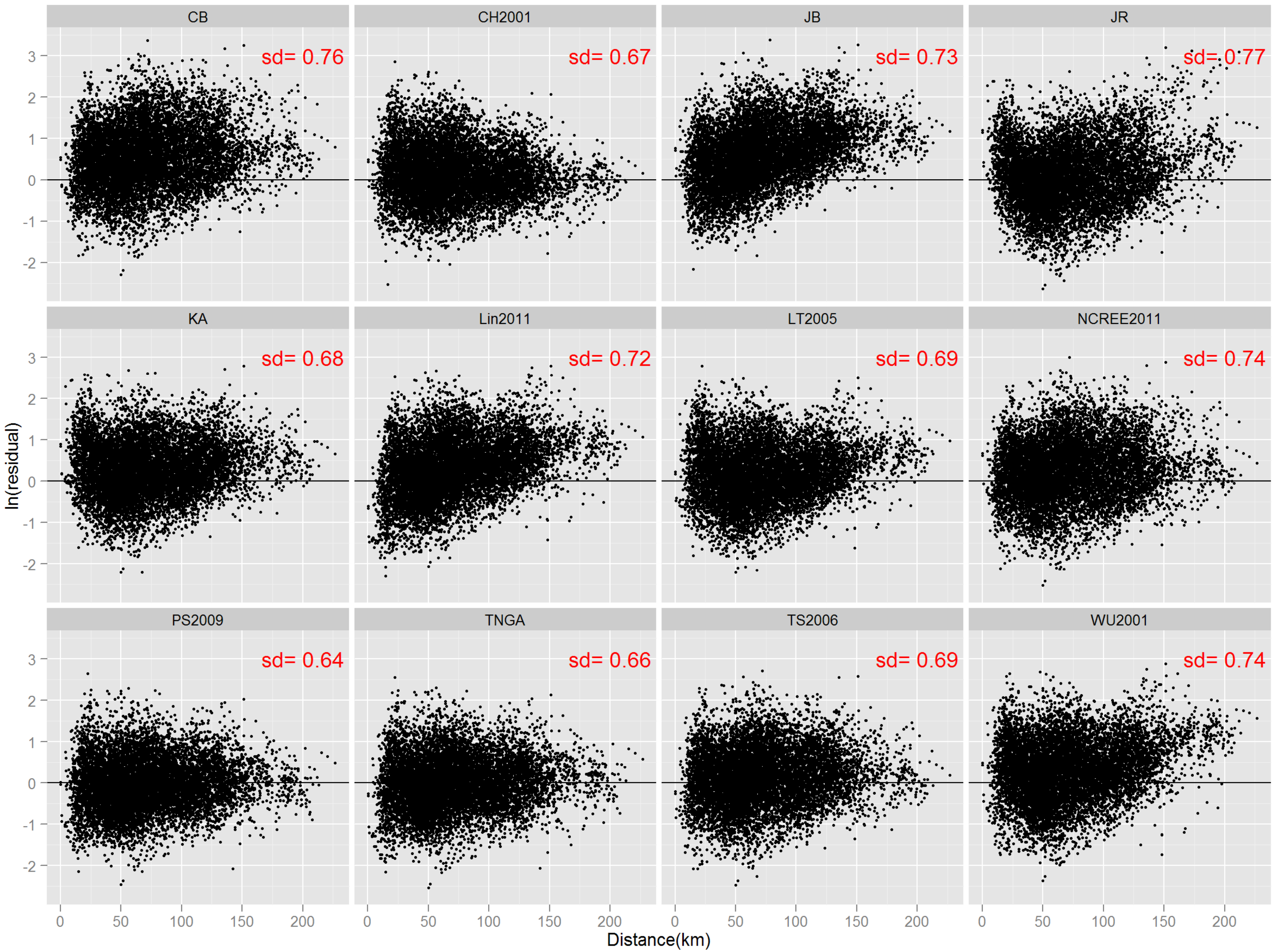
- Youngs et al.(1997)
- Si and Midorikawa (1999)
- Chang et al.(2001)
- Atkinson and Boore (2003)
- Kanno et al. (2006)
- Lin and Lee (2008)
- Sinotech(2011)

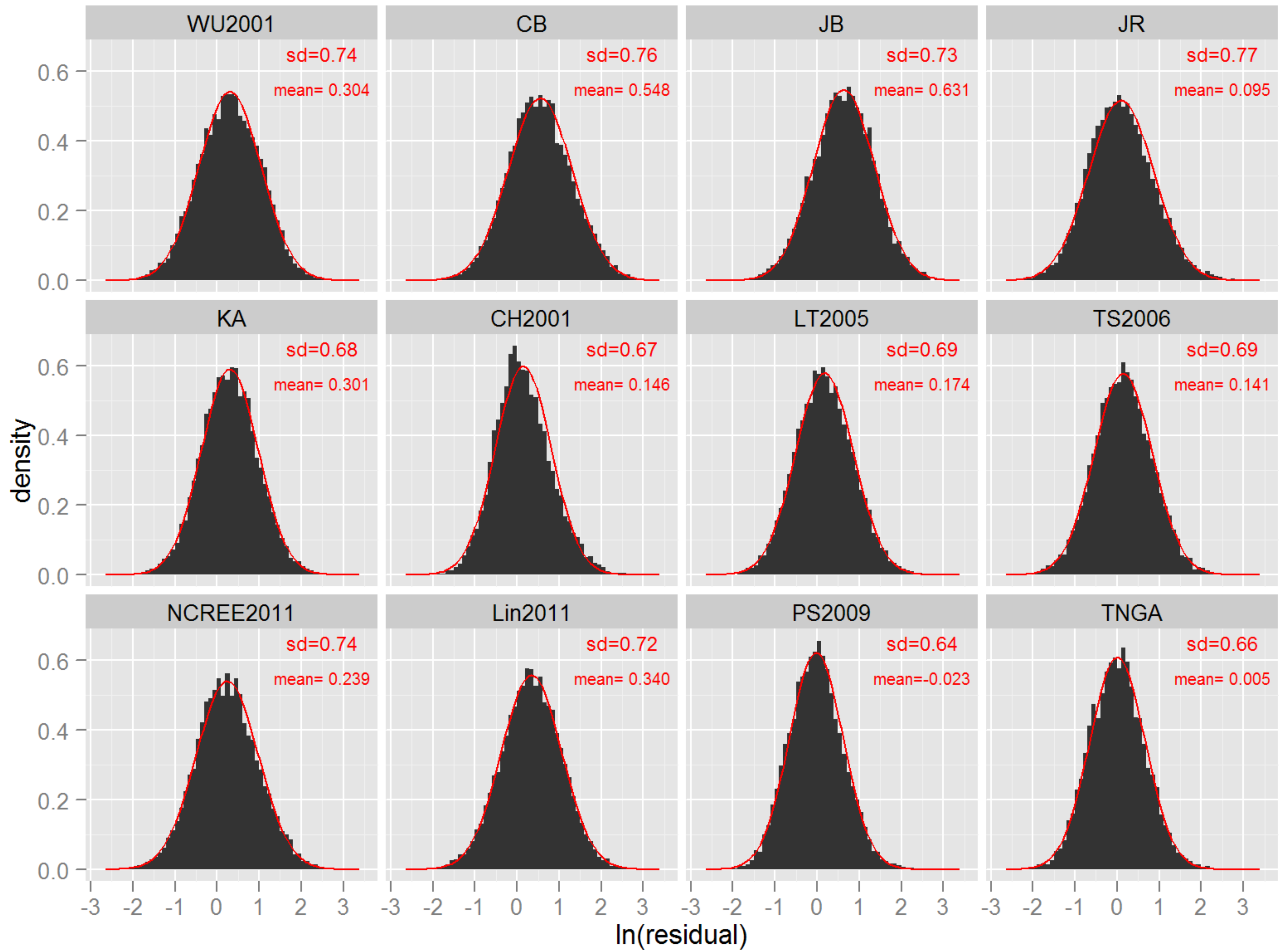
GMPE models for subduction zone earthquake

GMPEs	Acronym
Youngs et al.(1997)	YG1997
Si and Midorikawa (1999)	SM1999
Chang et al.(2001)	CH2001D
Atkinson and Boore (2003)	AB2003
Kanno et al. (2006)	Kan2006
Lin and Lee (2008)	LL2008
Sinotech(2011)	TNGA.Sub

Analysis results

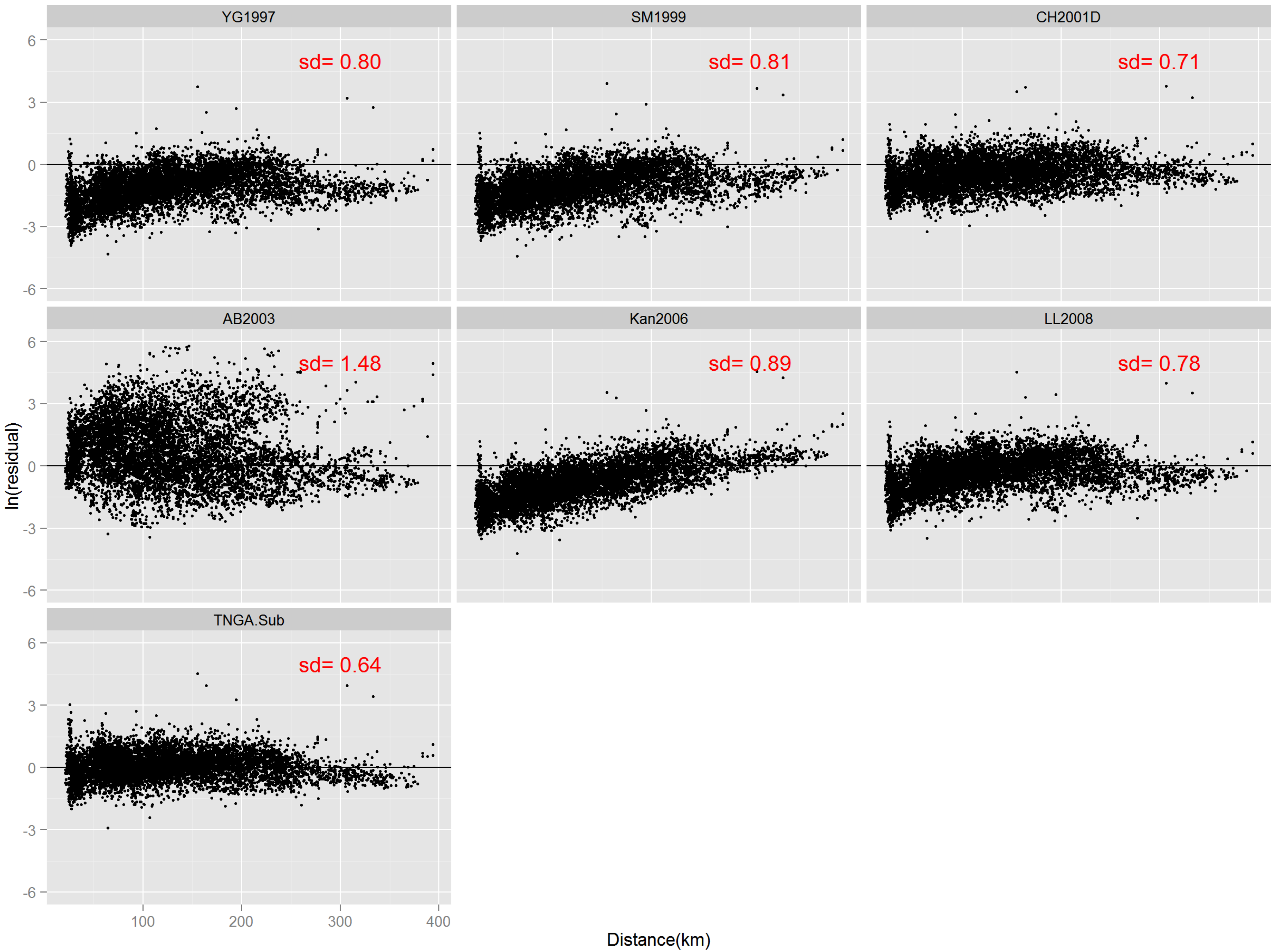
- Residual calculate
  - $\ln(\text{residual}) = \ln(PGA_{observed}) - \ln(PGA_{predicted})$
- Residual distribution
- LH index calculate
- LLH index calculate
- EDR index calculate

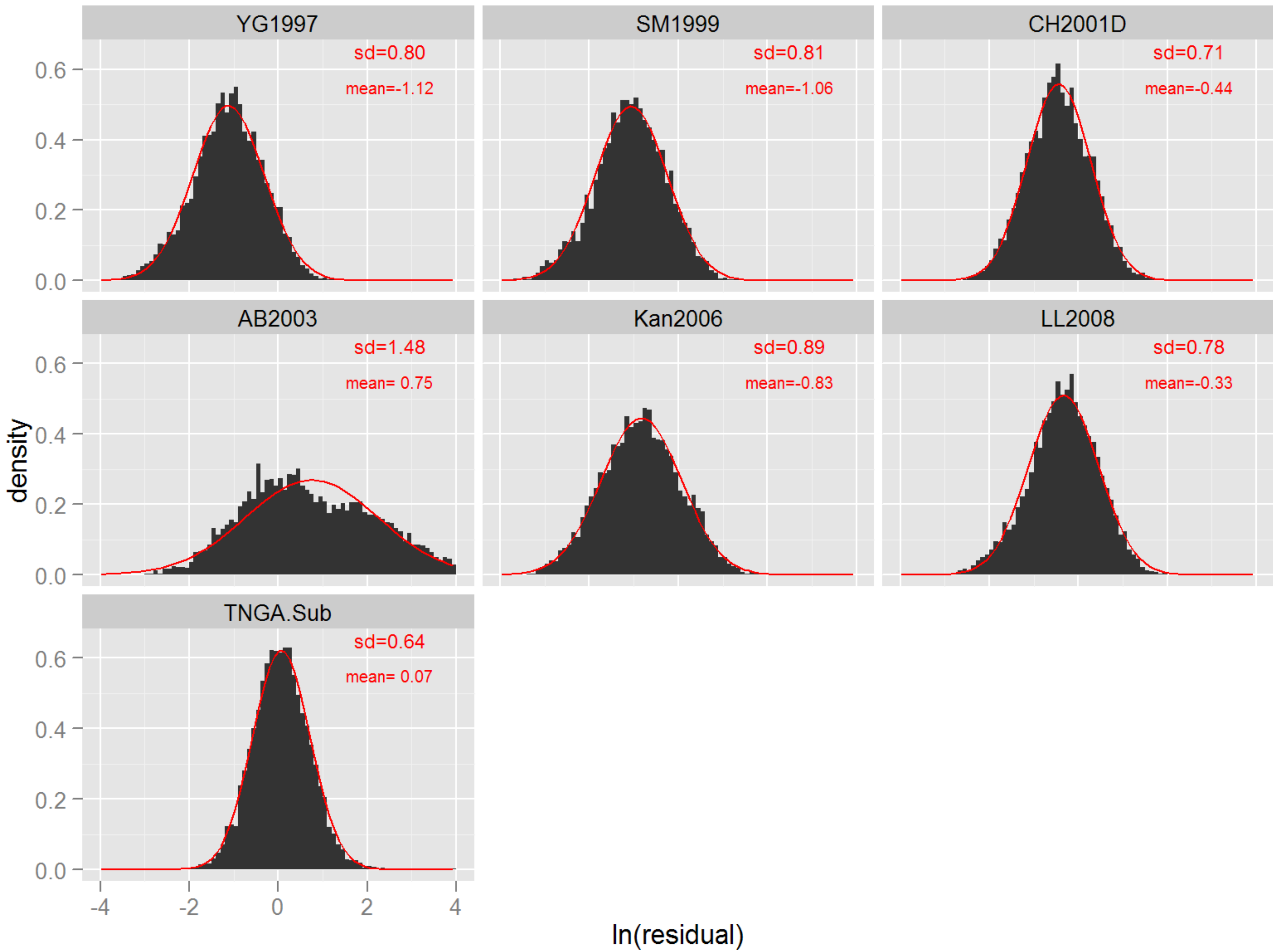

CB
sd= 0.76
CH2001
sd= 0.67
JB
sd= 0.73
JR
sd= 0.77
KA
sd= 0.68
Lin2011
sd= 0.72
LT2005
sd= 0.69
NCREE2011
sd= 0.74
PS2009
sd= 0.64
TNGA
sd= 0.66
TS2006
sd= 0.69
WU2001
sd= 0.74
ln(residual)
Distance(km)


WU2001
sd=0.74
mean= 0.304
CB
sd=0.76
mean= 0.548
JB
sd=0.73
mean= 0.631
JR
sd=0.77
mean= 0.095
KA
sd=0.68
mean= 0.301
CH2001
sd=0.67
mean= 0.146
LT2005
sd=0.69
mean= 0.174
TS2006
sd=0.69
mean= 0.141
NCREE2011
sd=0.74
mean= 0.239
Lin2011
sd=0.72
mean= 0.340
PS2009
sd=0.64
mean=-0.023
TNGA
sd=0.66
mean= 0.005
density
0.0
0.2
0.4
0.6
-3 -2 -1 0 1 2 3
ln(residual)

Crustal GMPE performance

GMPEs	Acronym	SD	Mean	LH	LLH	EDR
Wu et al.(2001)	WU2001	0.7366	0.3042	0.5824	1.6059	0.9966
NCREE (2004) Campbell's form	CB	0.7619	0.5476	0.5245	1.6547	1.1796
Joyner and Boore's form	JB	0.7281	0.6311	0.4802	1.5892	1.3160
Kanai's form	JR	0.7711	0.0950	0.6064	1.6720	0.9651
Japan Rock Site's form	KA	0.6755	0.3013	0.6221	**1.4811**	0.9963
Chang et al.(2001)	CH2001	**0.6652**	**0.1462**	**0.6619**	**1.4588**	0.9881
Liu and Tsai (2005)	LT2005	0.6880	0.1742	0.6347	1.5074	0.9510
Tsai et al. (2006)	TS2006	0.6893	0.1411	0.6412	1.5101	**0.8849**
NCREE (2011)	NCREE2011	0.7392	0.2393	0.6125	1.6111	0.9582
Lin et al.(2011)	Lin2011	0.7165	0.3396	0.5852	1.5660	1.0095
Lin (2009)	PS2009	**0.6419**	**-0.0227**	**0.6660**	**1.4075**	**0.8421**
Sinotech (2011)	TNGA	**0.6566**	**0.0053**	**0.6566**	**1.4401**	**0.8306**


YG1997
SM1999
CH2001D
AB2003
Kan2006
LL2008
TNGA.Sub
sd= 0.80
sd= 0.81
sd= 0.71
sd= 1.48
sd= 0.89
sd= 0.78
sd= 0.64
ln(residual)
Distance(km)
6
3
0
-3
-6
100
200
300
400


YG1997
sd=0.80
mean=-1.12
SM1999
sd=0.81
mean=-1.06
CH2001D
sd=0.71
mean=-0.44
AB2003
sd=1.48
mean= 0.75
Kan2006
sd=0.89
mean=-0.83
LL2008
sd=0.78
mean=-0.33
TNGA.Sub
sd=0.64
mean= 0.07
density
0.0
0.2
0.4
0.6
-4
-2
0
2
4
ln(residual)

Subduction GMPE performance

GMPEs	Acronym	SD	Mean	LH	LLH	EDR
Youngs et al.(1997)	YG1997	0.8025	-1.1229	0.2691	1.7296	1.9960
Si and Midorikawa (1999)	SM1999	0.8061	-1.0631	0.2898	1.7361	1.8795
Chang et al.(2001)	CH2001D	**0.7146**	-0.4367	**0.5652**	**1.5623**	**1.1483**
Atkinson and Boore (2003)	AB2003	1.4837	0.7491	0.2903	2.6162	2.0357
Kanno et al. (2006)	Kan2006	0.8938	-0.8347	0.3736	1.8850	1.5882
Lin and Lee (2008)	LL2008	**0.7814**	**-0.3311**	**0.5828**	**1.6912**	**1.1014**
Sinotech(2011)	TNGA.Sub	**0.6422**	**0.0668**	**0.6738**	**1.4082**	**0.8985**

Conclusion

- For crustal earthquake GMPE, Chang et al.(2001), Lin (2009) and Sinotech (2011) have better performance with the database used in this study.
- For subduction zone earthquake GMPE, Chang et al.(2001), Lin and Lee (2008) and Sinotech(2011) have better performance with the database used in this study.

Future work

- Select worldwide GMPEs for comparison.
  - NGA、NGA-west2
- Comparison of GMPE for different spectral period(Sa).
  - Crustal earthquake
  - Subduction zone earthquake

Thank you for your attention.