Single-Station and Small-Source Regions GMPEs

■ Abstract ■

The results of the probabilistic seismic hazard analysis (PSHA) are sensitive to the standard deviation for empirical ground-motion prediction models (GMPEs), and, even small reductions in sigma may have a significant impact on the hazard level especially with long return periods. Recent studies have proved that the variability decomposition cannot reduce the hazard level, when we move the epistemic uncertainty into the logic tree. So, how to reduce the total uncertainty directly is a critical issue.

In this study, we use 960 crustal earthquakes with moment magnitudes greater than 3.5 obtained from the Taiwan Strong Motion Instrumentation Program network to build the single-station and small-source regions GMPEs. Not only consider the single-station condition, but also set up the different source zones parameters into a GMPE to do the regression analyses. The results show the sigma of the single-station and small-source regions GMPEs is ranging from 0.402 to 0.526 which is far less than the total sigma (0.626 in ln unit), in other words, the total uncertainty can be reduced from 12% to 25% by this approach. Finally, we further use this sigma in PSHA, and we found the hazard level could be reduced about 27% in 475 return period, and 36% in 2475 return period.

■ Introduction ■

The results of PSHA are very sensitive to the standard deviation GMPEs, and, even small reductions in sigma may have a significant impact on the hazard level especially with long return periods, which is shown in **Figure 1** (Bommer and Abrahamson, 2006). Later studies (Anderson and Brune, 1999a,b; Anderson *et al*., 2000) suggested that one reason why the PSHA may be overstated is that of a mixing of the aleatory variability with epistemic uncertainty.

Some researches have devoted to analyzing the variability decomposition, to separate the total variability into different components and quantify the contributions of variability (Chen and Tsai, 2002., Tsai *et al.*, 2006; Al Atik *et al*., 2010; Lin *et al.*,2011). But the variability decomposition cannot reduce the hazard level, when we move the epistemic uncertainty into the logic tree (Strasser *et al*.,2009; Abrahamson and Hollenback, 2012).

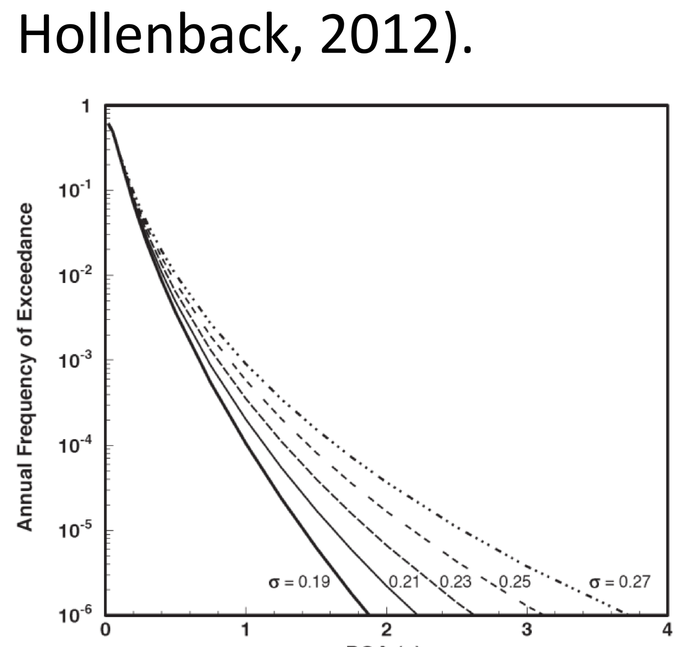

Figure 1. Different sigma results in different hazard level. (Bommer and Abrahamson, 2006)

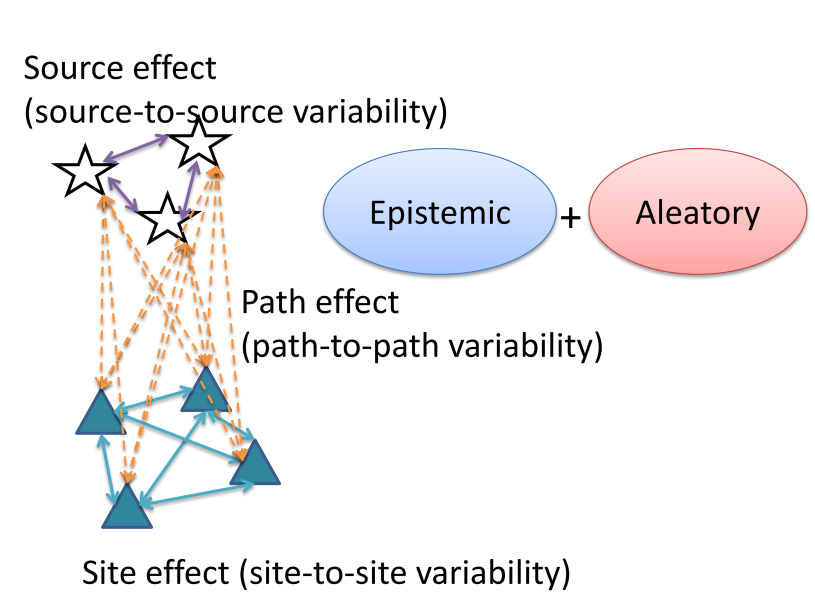

Figure 2. The reason for seismic hazard overestimation.

The past PSHA usually consider more variability of predicted ground motions from different sources to multiple sites, that will increase seismic hazard estimates (**Figure 2**). So, we only focus on the ground motions which were recorded from small-source region to one station to do the GMPE in here, that will solve the seismic hazard overestimation.

■ Data ■

Ground-motion data are collected from the dense TSMIP network. There are 30602 records from 150 crustal earthquakes (Mw ≥ 4.0) during the period from 1991 to 2014 are selected (**Figure 3a**). Baseline correction and filtering of the data are performed according to the standard procedures suggested by the Pacific Earthquake Engineering Research Center (PEER) (Darragh *et al*., 2005).

Most of the moment magnitude data are obtained from the Broadband Array in Taiwan for Seismology, with a few being derived from equation 1 in Lin and Lee (2008), which was used to convert the local magnitude to the moment magnitude (**Figure 3b**). Most of the Vs30 parameters are taken from Lee and Tsai (2008), and few are obtained from Engineering Geological Database for TSMIP (Kuo *et al*., 2012) (**Figure 3c**).

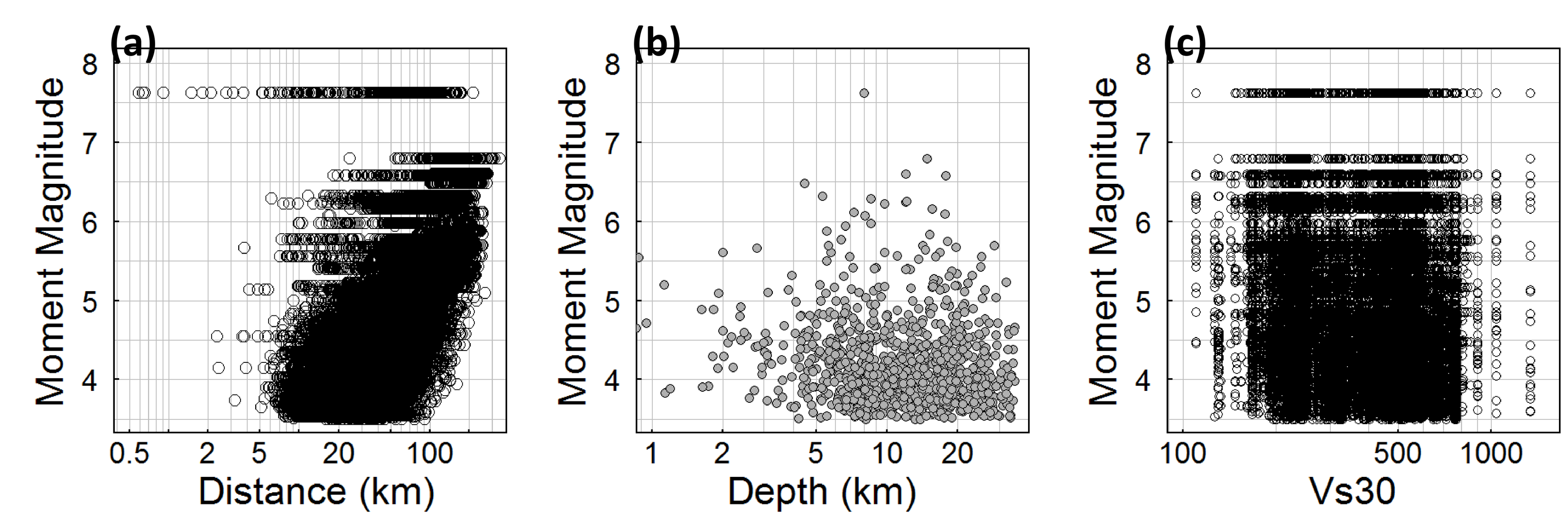

Figure 3. The final selected dataset in this study, **(a)** distribution of magnitude versus distance, **(b)** distribution of magnitude versus depth, and **(c)** distribution of magnitude versus Vs30.

■ Attenuation Model ■

1. Regional GMPE

The maximum likelihood estimation (MLE) and mixed-effects model are adopted in the nonlinear regression in Equation 1 using the whole data (Figure 3). The processing was done using the "nlme" module in the statistical software R (Pinheiro *et al*., 2015).

$$\ln y = C_1 + C_2M + C_3M^2 + C_4\ln(R + C_5e^{C_6M}) + C_7\ln(\frac{Vs30}{Vref}) + C_8F_n + C_9F_R \quad (1)$$

where *y* is the ground-motion parameter (g); *M* is the moment magnitude; R is the distance (km); *VS30* is the average shear-wave velocity in the upper 30 meters of the soil profile (m/s); *Vref* is equal to 1,130 m/s; *FN* and *FR* are indicator variables for the fault types (both being 0 for strike slip faults, 1 and 0 for normal faults, and 0 and 1 for reverse or reverse-oblique faults, respectively).

2. Single-station GMPE

The form is same as the regional GMPE (Equation 1), but the regression data which is recorded by one single station. In here, we only analysis four individual stations and show their results.

3. Single-station and small-source GMPE

We refer the seismic source zonation for shallow earthquakes in Taiwan (Cheng, 2002) to add this factor (source zone, ***Zsi***) in the regional GMPE, there are 25 source zone are shown in **Figure 4**.

$$\ln y = C_1 + C_2M + C_3M^2 + C_4\ln(R + C_5e^{C_6M}) + C_7\ln(\frac{Vs30}{Vref}) + C_8F_n + C_9F_R + C_{Si}Z_{Si} \quad (2)$$

where *Zsi* is indicator variables for the small-source zone; the index *i* indicates the number of source zone which is from 1 to 21. If the earthquake locates in the 21 zone, the Zs_{21}=1 and others are equal to 0.

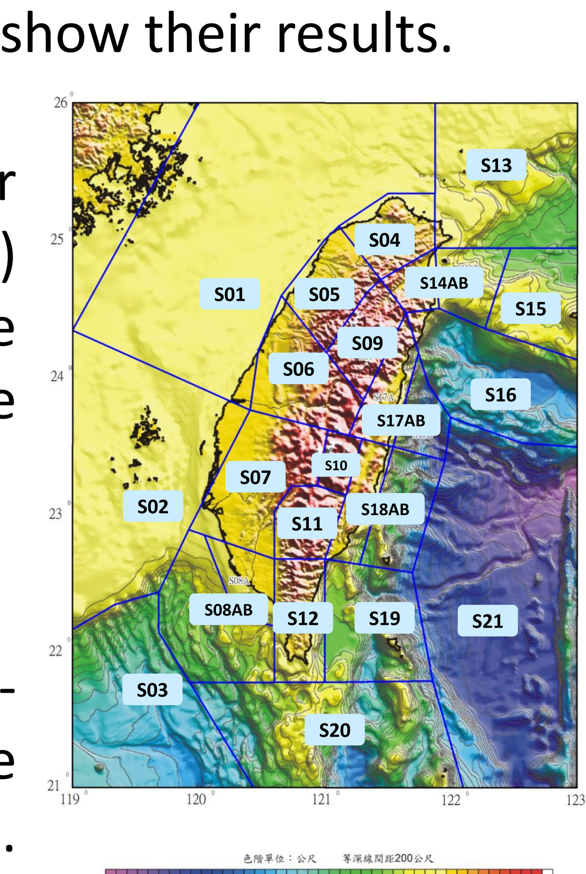

Figure 4. seismic source zonation for shallow earthquakes.

Chih-Hsuan Sung, Graduate Institute of Applied Geology, National Central University, Taiwan (R.O.C.), (karen@gis.geo.ncu.edu.tw)
Jia-Cian Gao, Graduate Institute of Applied Geology, National Central University, Taiwan (R.O.C.), (coolcoke228@gmail.com)
Chyi-Tyi Lee, Graduate Institute of Applied Geology, National Central University, Taiwan (R.O.C.), (ct@gis.geo.ncu.edu.tw)

■ Results & Discussions ■

1. Regional GMPE vs. Single-station GMPEs

The total residuals which are the misfit between the observation (in ln unit) and best-fit prediction, as shown in **Figure 5a**. In a log-normal histogram (**Figure 5b**) there may be a shift of the median values from zero for the total residuals. In here, we only select four stations (HWA028, HWA025, TTN041 and TAP022) (**Figure 6**) to do the single-station GMPE analyze and compare their results with the regional GMPE. **Table 1** presents the regression coefficients of the regional GMPE, four single-station GMPEs, and their standard deviation (σ_T, σ_{SS}). The results show that, for the single-station approach, the sigma for single-station GMPEs are about 10-20% smaller than the regional GMPE for PGA.

Table 1. Regression coefficients and variability for the GMPEs (Equation 1) in this study.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	Sigma	Reduction
Regional	-4.686	1.282	-0.0092	-1.540	0.238	0.623	-0.261	-0.031	0.055	**0.626**	
HWA028	-4.523	1.082	-0.0092	-1.341	0.129	0.623	-0.261	-0.056	0.119	**0.542**	**13.4%**
TTN041	-3.668	1.102	-0.0092	-1.401	0.243	0.623	-0.261	-0.056	0.119	**0.520**	**16.9%**
HWA025	-4.245	1.371	-0.0092	-1.836	0.271	0.623	-0.261	-0.056	0.119	**0.566**	**9.6%**
TAP022	-4.575	1.359	-0.0092	-1.491	0.698	0.623	-0.261	-0.056	0.119	**0.512**	**18.2%**

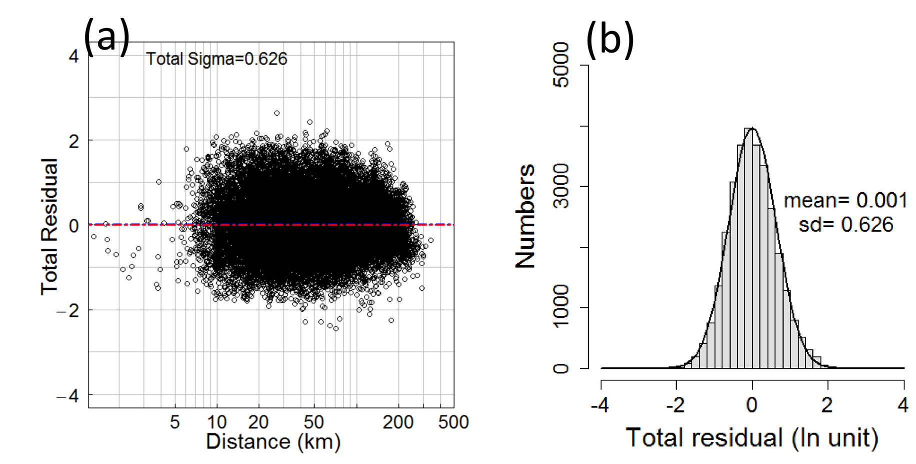

Figure 5. (a) The distribution of total residuals versus distance for regional GMPE, (b) log-normal histogram.

We plot the residuals for HWA028 single-station GMPE in **Figure 7a**, and finding that we always consider more variability at a site in the past. **Figure 7b** shows the comparison of attenuation curves between regional GMPE and HWA028 single-station GMPE, they are very similar but not the same.

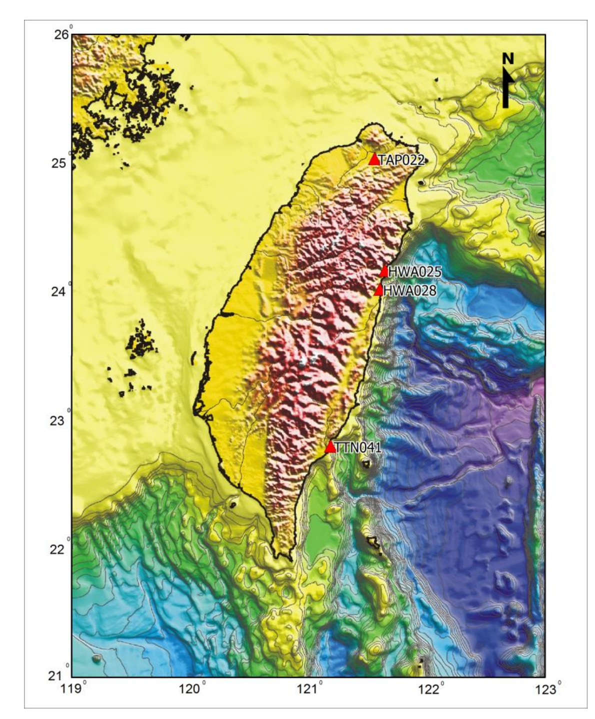

Figure 6. The location for four stations (red triangles).

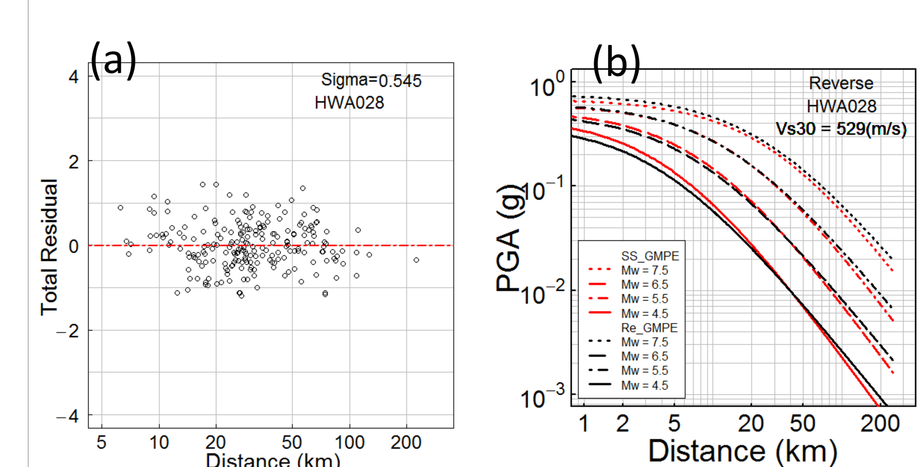

Figure 7. (a) The distribution of single-station residuals versus distance for HWA028 GMPE, (b) the comparison of attenuation curves, regional GMPE vs. HWA028 GMPE .

2. Single-station & small-source GMPEs

We also select the same stations (HWA028, HWA025, TTN041 and TAP022 to do the single-station & small-source GMPE study and compare their results with the single-station GMPEs. **Table 2** shows the regression coefficients of four single-station & small-source GMPEs and their standard deviation ($\sigma_{SS\&SE}$).

Table 2. Regression coefficients and variability for the GMPEs (Equation 2) in this study.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	CS01	CS02	CS03	CS04	CS05	CS06	CS07	CS08A	CS08B
HWA028	-4.097	1.309	-0.0092	-1.722	0.287	0.623	-0.261	-0.056	0.119	0	0	0	0	0	0.297	-0.033	0	0
TTN041	-3.668	1.102	-0.0092	-1.401	0.243	0.623	-0.261	-0.056	0.119	0	0	0	0	0	0.640	0.358	0	0
HWA025	-3.990	1.371	-0.0092	-1.836	0.271	0.623	-0.261	-0.056	0.119	0	0	0	0	0	-0.368	-1.011	0	0
TAP022	-4.575	1.359	-0.0092	-1.491	0.698	0.623	-0.261	-0.056	0.119	0	0	0	0	0	1.289	0	0	0
	CS09	**CS10**	**CS11**	**CS12**	**CS13**	**CS14A**	**CS14B**	**CS15**	**CS16**	**CS17A**	**CS17B**	**CS18A**	**CS18B**	**CS19**	**CS20**	**CS21**	**Sigma**	**Reduction**
HWA028	-0.073	0	0	0	0	0.114	0	0	-0.416	0.173	0.147	-0.192	-0.339	-0.494	0	0	**0.489**	**21.9%**
TTN041	0.568	0.812	0.578	0	0	0	0	0	0.096	1.155	0	0.789	0.892	0.894	0	1.431	**0.483**	**22.8%**
HWA025	-0.662	0	0	0	0	0.211	0.288	-0.163	-0.263	-0.248	-0.165	0.683	0	0	0	0	**0.549**	**12.3%**
TAP022	0.157	0	0	0	0.151	0	0.425	0	0.681	0.936	0.400	0.521	0	0	0	0	**0.467**	**25.4%**

Taking HWA028 station as an example to plot the location of earthquakes (red points) shown in **Figure 8**, there are only ten source zones includes earthquakes; that's why some regression coefficients of source zone are equal to zero. **Figure 9** shows the comparison of residual distributions between single-station GMPE (black circles) and single-station & small-source GMPE (red circles) for HWA028 station. When we add the factor of source zone into GMPE, the result will be better than the single-station GMPE.

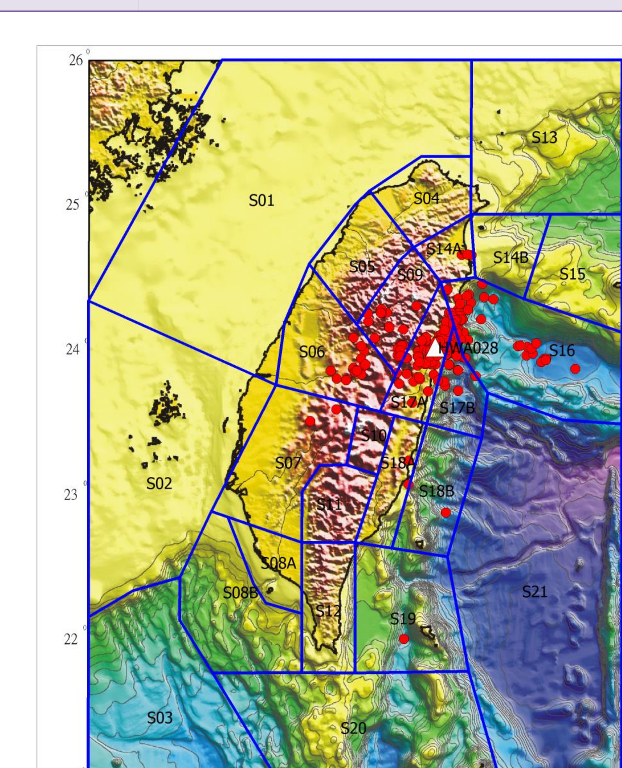

Figure 8. The location for earthquakes (red points) which recorded by HWA028 station (a white triangle).

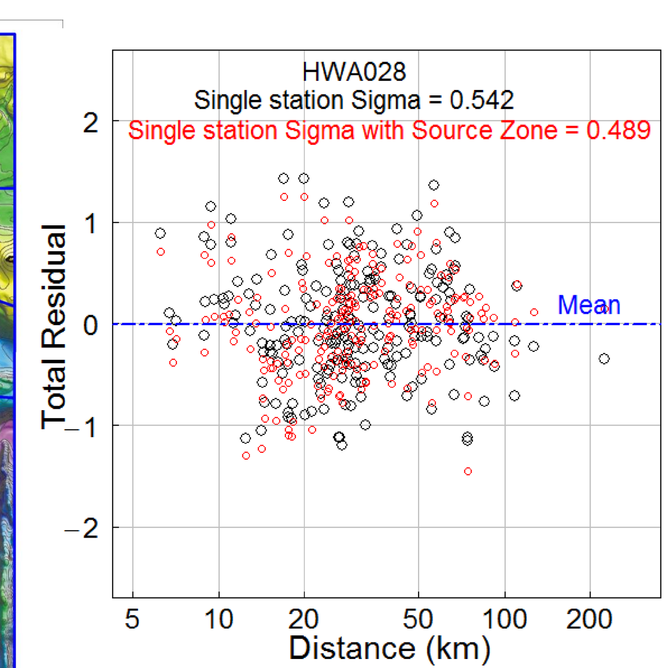

Figure 9. The comparison of residual distributions, single-station GMPE (black circles) vs. single-station & small-source GMPE (red circles) for HWA028 station.

3. The comparison of PSHA for the different sigma of GMPEs

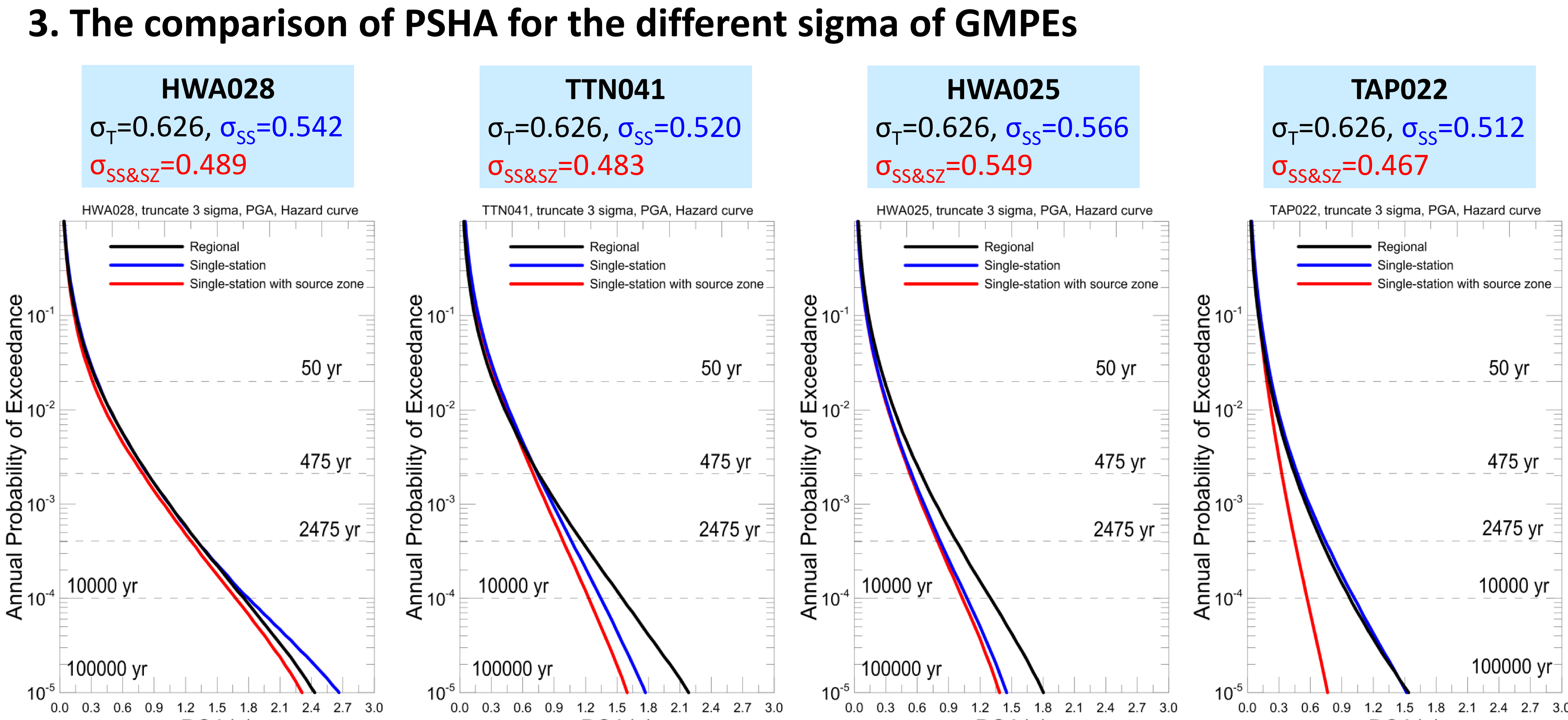

Figure 10. The comparison of hazard curves for different sigma and stations, black line indicates the hazard curve uses the total sigma to do the integration analyze, blue means using single-station sigma and red means adopting single-station & small-source sigma.

Table 3. The reduction of hazard level for different return period when using the single-station & small-source sigma to do the integration analyze.

Return period	Reduce(%) in 475yr	Reduce(%) in 2475yr	Reduce(%) in 10^4yr	Reduce(%) in 10^5yr
HWA028	5.25%	4.34%	6.56%	13.02%
TTN041	1.36%	10.37%	16.07%	22.48%
HWA025	16.39%	18.66%	20.52%	23.23%
TAP022	27.11%	35.80%	41.50%	49.74%