A new local magnitude scale was developed for South Korea using seismograms of 269 earthquakes selected in the magnitude range 2.0 to 5.8 that occurred in and around the Korean Peninsula from 2001 to 2016. The peak amplitudes of synthetic Wood-Anderson seismograms were measured from three components of 6,327 observations recorded at distances of 10 to 600 km by 89 broadband seismic stations in South Korea. The vertical peaks and geometrical means of the horizontal peaks were used separately for both nonparametric and parametric methods. The empirical attenuation curve, station corrections, and magnitudes of the earthquakes were estimated simultaneously using each method, which yielded very similar results. The resulting parametric attenuation curves are

\[ \log A_0 = -0.5869 \log(R/100) - 0.001680(R-100) - 3 \]

for the horizontal component and

\[ \log A_0 = -0.5107 \log(R/100) - 0.001699(R-100) - 3 \]

for the vertical component, where R is the epicentral distance in kilometers. The application of these attenuation curves to the dataset showed that there was no trend in the magnitude residual with distance. The spatial variation of the station corrections generally correlated with the geological features underlying the seismic stations. The station corrections for the horizontal component varied more than those for the vertical component, suggesting that geological or local site effects have a stronger influence on horizontal amplitudes than on vertical ones. We found that ML from this study correlates well with Mw determined from S-wave source spectra.
A LOCAL MAGNITUDE SCALE FOR SOUTH KOREA

DONG-HOON SHEEN*, TAE-SEOB KANG, AND JUNKEE RHIE

Dong-Hoon Sheen
Department of Geological Environment, Faculty of Earth Systems and Environmental Sciences, Chonnam National University, Gwangju, 61186, South Korea
(dhsheen@jnu.ac.kr)

Tae-Seob Kang
Pukyong National University, Busan, 48513, South Korea

Junkee Rhie
Seoul National University, Seoul, 08826, South Korea
Abstract

A new local magnitude scale was developed for South Korea using seismograms of 269 earthquakes selected in the magnitude range 2.0 to 5.8 that occurred in and around the Korean Peninsula from 2001 to 2016. The peak amplitudes of synthetic Wood-Anderson seismograms were measured from three components of 6,327 observations recorded at distances of 10 to 600 km by 89 broadband seismic stations in South Korea. The vertical peaks and geometrical means of the horizontal peaks were used separately for both nonparametric and parametric methods. The empirical attenuation curve, station corrections, and magnitudes of the earthquakes were estimated simultaneously using each method, which yielded very similar results. The resulting parametric attenuation curves are

\[ \log A_0 = -0.5869 \log R/100 - 0.001680(R - 100) - 3 \]

for the horizontal component and

\[ \log A_0 = -0.5107 \log R/100 - 0.001699(R - 100) - 3 \]

for the vertical component, where \( R \) is the epicentral distance in kilometers. The application of these attenuation curves to the dataset showed that there was no trend in the magnitude residual with distance. The spatial variation of the station corrections generally correlated with the geological features underlying the seismic stations. The station corrections for the horizontal component varied more than those for the vertical component, suggesting that geological or local site effects have a stronger influence on horizontal amplitudes than on vertical ones. We found that \( M_L \) from this study correlates well with \( M_W \) determined from S-wave source spectra.
Introduction

Local magnitude ($M_L$), which was defined by Richter (1935), is the fundamental magnitude scale used most widely in earthquake catalogs. Although it is only an empirical estimation of the relative sizes of earthquakes, it has improved our understanding of the seismic characteristics and seismic hazard in a region.

The original $M_L$ scale was developed for crustal earthquakes that occurred in southern California using the peak amplitudes of the seismic waves. Therefore, to follow Richter’s definition in other areas with different seismo-tectonic environments, it is necessary to calibrate the scale considering local attenuation characteristics.

In South Korea, the Korea Meteorological Administration (KMA) and Korea Institute of Geoscience and Mineral Resources (KIGAM) provide their own parameters, such as the location, origin time, and magnitude, for earthquakes in and around the Korean Peninsula. However, neither institute uses magnitude relationships calibrated specifically for South Korea. KMA has officially monitored earthquakes occurring in the Korean Peninsula region since 1978 and has used a magnitude formula proposed by Tsuboi (1954) for determining the magnitude (Kim and Park, 2002). After digital recordings became available in 1999, the formula was modified (Kim and Park, 2002). KIGAM also uses a modified formula (Sheen, 2015), which was originally developed for Japan by Kanbayashi and Ichikawa (1977) and Takeuchi (1983).

The first digital seismic network in South Korea started in the mid-1990s and the number of stations has increased greatly since then. Several studies examined a local magnitude scale for the southern Korean Peninsula with seismograms obtained during the first few years of operation of the digital seismic networks (e.g., Hong et al., 2000; Kim and Park, 2002; Shin et al., 2005). Because of the low to moderate seismicity of the peninsula (i.e., Sheen et al., 2017), the number of events, quantity of data, and range of earthquake magnitudes were likely insufficient for magnitude scaling studies. Therefore, the results of these initial studies might be incomplete for official use.

Recently, Sheen (2015) showed that the station magnitudes of KMA and KIGAM increase with epicentral distance. This indicates that the $M_L$ scales used by both institutes do not represent the characteristics of seismic attenuation in the southern Korean Peninsula accurately. Therefore, this
study developed an $M_L$ scale that represents the attenuation properties of seismic waves in the southern Korean Peninsula using a large dataset from earthquakes that occurred in the peninsula region from 2001 to 2016.

Data and Preliminary Analysis

The seismograms used in this study (see Data and Resources) comprise 6,327 observations from 89 stations of 269 earthquakes that occurred in the Korean Peninsula region from 2001 to 2016. Note that this study included only observations with records of all three components, to use the same information to compare the attenuation characteristics and station correction for the horizontal and vertical components. The initial dataset was based on 10,076 observations for 533 earthquakes and subject to quality screening, as described in more detail below. The seismic stations are operated by KMA, KIGAM, and the Korea Institute of Nuclear Safety (KINS), and are equipped with one of three sensor types: STS-1, STS-2 or 2.5, and CMG-3T or 3TB sensors. In total, 63 of the stations used in this study belong to KMA, 22 to KIGAM, and 4 to KINS. Figure 1 shows the locations of the seismic stations and epicenters, resulting in ray paths covering the southern Korean Peninsula and adjacent areas.

The KMA has cataloged earthquakes greater than or equal to magnitude 2.0 since 1978, among which we selected only those that occurred between 2001 and 2006 and had magnitudes of at least 3.5. This is because there was a small number of broadband stations operating between 2001 and 2006 and only a few seismograms from broadband stations were available for earthquakes of small magnitudes. From 2007, we considered all events in the KMA catalog, whose magnitudes are greater than or equal to 2.0, but excluded aftershocks of the Mw 5.6 2016 Gyeongju earthquakes with magnitudes less than 3.5 (Son et al., 2018) because there were too many small aftershocks.

After careful visual inspection of the broadband seismograms, clipped, cut, or noisy seismograms were identified and excluded. Only observations with seismograms of all three components were selected, which resulted in 10,076 observations initially. After removing the mean and linear
trend, the waveforms were filtered with a 0.5-10 Hz, six-pole Butterworth band-pass filter to suppress microseismic noise, corrected from their instrument responses, and convolved with a revised Wood-Anderson instrument response according to Uhrhammer and Collins (1990).

The zero-to-peak amplitude was measured for each synthesized Wood-Anderson seismogram of the three components in a velocity window of 4.0-2.0 km/s, corresponding to the Sg or Lg phases. Only amplitudes greater than twice the pre-P-noise, averaged for a 1-second window of the pre-P signal, were used. Observations lacking amplitude measurements for all three components were again excluded. The horizontal peak amplitudes were obtained from the geometric mean of two horizontal peaks. Finally, this study used only events and stations with at least 10 observations at a distance ranging from 10 to 600 km, which resulted in 6,327 observations for 269 earthquakes recorded at 89 stations. Of the data, 50 % are at distances between 80 and 230 km and 64 % are in the magnitude range from 2.5 to 3.5 magnitude units (Fig. 2).

### Nonparametric Method

Richter (1935) defined a local magnitude scale with the form

\[ M_L = \log A - \log A_0 + S \]  

(1)

where \( A \) is the peak amplitude in millimeters measured from a Wood-Anderson seismogram, \( \log A_0 \) is an empirically derived attenuation correction term depending on the epicentral distance, and \( S \) is the station correction. The attenuation correction term converts the peak amplitude into a measurement at an epicentral distance of 100 km and anchors an amplitude of 1 mm at a distance of 100 km to be magnitude 3.0.

The nonparametric method for local magnitude introduced by Savage and Anderson (1995) was rewritten (1) in the following form:

\[ a_i \log A_0(R_i) + b_j M_j - c_k S_k = \log A_{jk}(R), \]  

(2)

where the indices \( j \) and \( k \) represent events and stations, respectively; \( M \) and \( S \) are the magnitudes and station corrections, respectively; and \( R \) is the epicentral distance in kilometers. In this study,
the attenuation correction term $\log A_0$ at distances from each node of $R_i$ are interpolated linearly to represent the peak amplitudes, $\log A_{jk}$, measured at arbitrary distances, $R$, using the coefficients $a_i = (\log R_{i+1} - \log R_i)/(\log R_{i+1} - \log R_i)$, $a_{i+1} = 1 - a_i$, and all other $a = 0$. The distance intervals for the nodes, $R_i$, can be equal or unequal. Coefficients $b_j$ and $c_k$ are also weighting factors, defined as $b_j = 1$ for event $j$ and all other $b = 0$, and $c_k = 1$ for station $k$ and all other $c = 0$, respectively. The inversion was performed using a least-squares procedure with the constraints $\sum S_k = 0$, $\log A_0(100) = -3$, and $\log A_0(R_{i-1}) - 2\log A_0(R_i) + \log A_0(R_{i+1}) = 0$ (Savage and Anderson, 1995). Then, this method yields the solution of equation (1) as the attenuation corrections, $\log A_0(R_i)$, at given distance nodes, event magnitudes, $M_j$, and station corrections, $S_k$.

To consider the effect of the choice of distance interval on the attenuation corrections, nonparametric inversion was performed for both regular and irregular distance intervals. Figure 3 shows the differences in the distribution of the data corresponding to the choice of distance interval and the results are given in Figure 4. As a regular interval, a distance of 50 km was used, although the shortest distance nodes had an interval of 40 km. As expected from Figure 2, most of data used for the inversion with the regular interval were distributed from 50 to 300 km. Irregular intervals were used to balance the amount of data within each interval and the average number of data was $667 \pm 47$ in each interval for distances less than 400 km (see Fig. 3b).

**Parametric Method**

The parametric method (Bakun and Joyner, 1984) introduces parameters that consider geometrical spreading and the attenuation of seismic waves and rewrites the attenuation correction $\log A_0$ in eq (1) as:

$$- \log A_0 = n \log \left( \frac{R}{100} \right) + K (R - 100) + 3,$$

where $n$ and $K$ are parameters for geometrical spreading and attenuation, respectively, and $R$ is the hypocentral or epicentral distance in kilometers.
To determine \( n \) and \( K \) from the observed data, equation (3) is formulated as

\[
n \log R + K R + b_j M_j - c_k S_k + C = \log A_{jk}(R),
\]

where \( R \) is epicentral distance in km. \( C \) is a constant for scaling to Richter’s definition at 100 km, which is not formulated explicitly in equation (4), but is determined after inverting the observations (Ottemöller and Sargeant, 2013). The summation of station corrections is constrained as 0, which is the same as in the nonparametric method.

**Result and Discussion**

Figure 4 plots the attenuation curves obtained from this study. The symbols and lines show that Richter’s definition is imposed by setting \( \log A_0 \) to -3 at 100 km. The symbols and solid lines represent the results from the nonparametric and parametric inversions in this study, respectively. The attenuation corrections for the horizontal and vertical components are shown in red and black, respectively. For comparison, the figure also shows the attenuation curves from several other studies (Hutton and Boore, 1987; Kim, 1998; Ortega and Quintanar, 2005; Miao and Langston, 2007), plotted with dashed lines. The attenuation curves from the current study were intermediate between those from the central United States (Miao and Langston, 2007) and southern California (Hutton and Boore, 1987), but are very close to that from the Basin of Mexico (Ortega and Quintanar, 2005), which was obtained for hypocentral distances less than about 250 km.

The attenuation corrections at distance nodes for the nonparametric method are represented by diamonds and circles, which refer to the results using regular and irregular intervals, respectively (see Fig. 3). There are no significant differences in the attenuation corrections between regular and irregular distance intervals, which suggests that the discretization used for the nonparametric method has a minimal effect on the results of this study.

With the parametric method, the attenuation curves for the horizontal and vertical components are represented by red and black lines, respectively, and are given by

\[
- \log A_0 = 0.5869 \log(R/100) + 0.001680(R - 100) + 3 \quad \text{for horizontal},
\]

\[
- \log A_0 = 0.5869 \log(R/100) + 0.001680(R - 100) + 3 \quad \text{for vertical}.
\]
\[ -\log A_0 = 0.5107 \log(R/100) + 0.001699(R - 100) + 3 \] for vertical, \hspace{1cm} (6)

where \( R \) is the epicentral distance in km.

The attenuation curves obtained with the parametric method are very similar to the attenuation corrections at distance nodes with the nonparametric method (see Fig. 4). The difference between the results of the two methods increased slightly beginning at a distance of about 400 km and reached about 0.2 magnitude units at 600 km. However, the difference in the event magnitudes between the two methods is only 0.049 ± 0.012 magnitude units for the horizontal component and 0.015 ± 0.012 magnitude units for the vertical component, as shown in Figures 5a and 5b, respectively. This is because the event magnitude is determined by averaging the station magnitudes at all distance ranges. Therefore, the discrepancy in the attenuation corrections between the nonparametric and parametric methods at distances exceeding 400 km is negligible.

For both the nonparametric and parametric methods, the attenuation corrections for the horizontal component are slightly larger than those for the vertical component at distances greater than 100 km, but the differences are still less than 0.1 magnitude units. Figure 5 compares the magnitudes of the events obtained with each method. The magnitudes from the horizontal component are slightly larger than those from the vertical component for both inversions. The difference in event magnitudes between the horizontal and vertical components is 0.085 ± 0.041 magnitude units for the nonparametric inversion and 0.051 ± 0.042 magnitude units for the parametric inversion (Figs. 5c and 5d).

All magnitude scaling relationships developed in this study give very similar event magnitudes for the horizontal and vertical components, which implies that this study provides a consistent way to measure earthquake magnitudes in the Korean Peninsula region.

Figure 6 compares the station corrections obtained from each inversion. The corrections for the horizontal component vary over a wider range than those for the vertical component. The station corrections vary between -0.54 and 0.27 magnitude units for the horizontal component and -0.29 and 0.26 magnitude units for the vertical component, suggesting that local site or geological effects have a stronger influence on the horizontal amplitudes than on the vertical ones. Note also that the
nonparametric and parametric methods yield very similar station corrections for each component and those for the horizontal and vertical components are generally proportional to each other.

Figure 7 shows the spatial distributions of the station corrections. The corrections are generally large and negative in the southeastern part of the peninsula and Jeju Island, which correspond to the Gyeongsang (GB) and Yeonil (YB) basins, and the Quaternary Jeju volcanic terrain (JVT), respectively. Kang and Shin (2006) showed that the distribution of the Rayleigh wave group-velocity correlates very well with the geological characteristics of the southern Korean Peninsula. Considering that the sedimentary basins (e.g., GB and YB) and volcanic and metasedimentary rocks (JVT) were represented by regions with low velocities, the station corrections obtained from this study could also be explained by the correlation with the geological features underlying the seismic stations.

Figure 8 shows the $M_L$ residual distributions as a function of epicentral distance for the horizontal and vertical components. The residual measures the difference between the magnitude at a single station and the event magnitude obtained as the average of the individual station magnitudes. Note that the station magnitudes for this figure were determined by the results of the parametric inversion, i.e., eqs. (5) and (6), and the event magnitudes determined using the truncated mean correspond to an iterative drop in station magnitude of 0.5 magnitude units above or below the arithmetic mean of the station magnitudes. The dashed lines indicate the results of the linear regression. These showed no particular trend with respect to either distance or logarithmic distance and imply that the attenuation characteristics in and around the southern Korean Peninsula are well represented by the results. Note that the station corrections help to reduce the variances of the residuals. The variances of the residuals for the horizontal and vertical components are reduced by 28 % and 13 %, respectively, and the standard deviations of the residuals for both are decreased to about 0.17 magnitude units. The differences between the event magnitudes with and without station corrections are 0.026 and 0.0091 magnitude units for the horizontal and vertical components, respectively, which shows that the introduction of station corrections has little effect on the determination of the event magnitude. However, this would be important for small earthquakes.
with few observations (e.g., Ottemöller and Sargeant, 2013) and, especially, for the determination
from the horizontal component.

Figure 9 compares the event magnitudes obtained from this study with $M_W$ of Rhee and Sheen
(2016). Rhee and Sheen (2016) determined $M_W$ of an earthquake from the vector sum of three
components of S-wave source spectra. Note that Rhee and Sheen (2016) considered only events
between 2001 and 2014; as a result, 170 earthquakes are shown in the figure. The orthogonal
linear regression based on the principal component analysis gives the following equations for the
$M_L$-$M_W$ relationship:

$$M_L = 1.076M_W - 0.4014 \quad \text{for horizontal,}$$  
(7)

and

$$M_L = 1.086M_W - 0.4772 \quad \text{for vertical,}$$  
(8)

with standard deviations of 0.1051 and 0.1049 magnitude units for the horizontal and vertical
components, respectively. $M_L$ from the current study correlates well with $M_W$ determined from
S-wave source spectra. However, our $M_L$-$M_W$ relationships differ slightly from the relation in
Hanks and Kanamori (1979) and our $M_L$ estimation tends to underestimate the size of small earth-
quakes. Other studies (e.g., Hanks and Boore, 1984; Ben-Zion and Zhu, 2002; Bindi et al., 2005;
Miao and Langston, 2007; Edwards et al., 2010; Ross et al., 2016; Deichmann, 2017) reported
similar observations for small events and Edwards et al. (2010) explained this by the interaction of
attenuation, the stress-drop, and the Wood-Anderson filter.

Figure 10 shows the relationships between the horizontal and vertical $M_L$ values from the current
study and those from the KMA catalog. Note that the KMA determined $M_L$ from the largest
horizontal peak amplitude, while we determined it from the geometric mean of the horizontal
peaks. The relationships were also obtained using orthogonal linear regression, given by

$$M_L = 0.9187M_{L}^{KMA} + 0.3906 \quad \text{for horizontal,}$$  
(9)

and

$$M_L = 0.9234M_{L}^{KMA} + 0.3262 \quad \text{for vertical,}$$  
(10)
with standard deviations of 0.1932 and 0.1980 magnitude units for the horizontal and vertical components, respectively. In comparison with Figure 9, the correlation is rather weak, especially for small earthquakes, which implies that $M_L$ from our study correlates better with $M_W$ than the catalog of the KMA. We also found that KMA tends to underestimate the size of small earthquakes with greater uncertainty, which agrees quite well with what we expect from Sheen (2015).

Conclusion

In this study, we developed a local magnitude scale for South Korea using 6,327 horizontal and vertical peak amplitudes from 269 earthquakes in the magnitude range 2.0 to 5.8 that occurred in and around the Korean Peninsula from 2001 to 2016. Seismograms were recorded at 89 broadband seismic stations within distances of 10-600 km. The zero-to-peak amplitudes were measured from three components of synthetic Wood-Anderson seismograms and the geometric mean of two horizontal peaks was used for the horizontal peak amplitude.

We used nonparametric and parametric methods to estimate the attenuation curves, station corrections, and magnitudes of earthquakes; both approaches yielded very similar results. The magnitude residuals between the individual station magnitudes and the event magnitudes that were measured with attenuation curves in this study showed no trends with distance for either component, which implies that the attenuation characteristics around the southern Korean Peninsula were well represented in this study. The station corrections for the horizontal and vertical components are generally proportional to each other. They varied between -0.54 and 0.27 magnitude units for the horizontal component and -0.29 and 0.26 magnitude units for the vertical component. However, it was found that the introduction of station corrections had little effect on the determination of event magnitude.

The event magnitudes determined in this study were compared with $M_W$ from S-wave source spectra and $M_L$ in the KMA catalog. There was a good correlation between $M_L$ in this study and $M_W$. The size of small events in the KMA catalog appeared to be underestimated with large uncertainty, probably because of a poorly constrained attenuation curve. Therefore, we recommend that the local magnitude scale from this study be used to determine the local magnitudes of earthquakes...
occurring in and around the southern Korean Peninsula, and that the catalog for South Korea be recomputed using the results of this study.

Data and Resources

The earthquake information was obtained from the Korea Meteorological Administration (KMA) using http://www.kma.go.kr/weather/earthquake_volcano/domesticlist.jsp. (last accessed on Feb. 1, 2017). Seismic records data are available on the websites of KMA and Korea Institute of Geoscience and Mineral Resources (KIGAM, https://quake.kigam.re.kr/pds/db/db.html, last accessed May 2016). All figures were generated using Generic Mapping Tools Wessel et al. (2013). The geotectonic lines were obtained from KIGAM (https://mgeo.kigam.re.kr/, last accessed May 2016).

Acknowledgments

We thank Won-Young Kim for valuable discussion while preparing this manuscript. This work was funded by the Korea Meteorological Administration Research and Development Program under grants KMIPA 2016-3010 and KMIPA 2017-4030.

References


**Figure 1.** The distribution of the ray paths used in this study between earthquakes (circles) and stations (triangles). The size of each circle is proportional to the earthquake magnitude obtained from the KMA catalog. The gray lines represent the great circle paths of the event-station pairs.

**Figure 2.** Magnitude and distance distribution of the data used in this study.

**Figure 3.** Histograms of the distance distribution of data corresponding to the distance intervals for the nonparametric method. (a) Distance distribution corresponding to regular intervals. (b) Distance distribution corresponding to irregular intervals.

**Figure 4.** The attenuation correction curves obtained from this study. Symbols and solid lines represent the nonparametric and parametric results, respectively. Diamonds and circles are the attenuation correction terms at the distance nodes of regular and irregular intervals for the nonparametric method. The results for the horizontal and vertical components are shown in red and black, respectively. The dashed lines are attenuation curves from other studies.

**Figure 5.** Comparison of $M_L$ estimates obtained from this study. (a) and (b) Nonparametric versus parametric methods for the horizontal and vertical components, respectively. (c) and (d) Horizontal versus vertical components for the nonparametric and parametric methods, respectively.

**Figure 6.** Comparison of the station corrections. (a) Station corrections from the parametric versus nonparametric methods. (b) Station corrections for the vertical versus horizontal components.

**Figure 7.** Spatial distribution of the station corrections for the horizontal (left) and vertical (right) components. Both were obtained with the parametric method. The color and size of the triangles represent the scale of the correction and the amount of data used for each station, respectively. Tectonic boundaries are denoted by thick solid lines (PB, Pyeongnam Basin; OB, Ongjin Basin; IB, Imjingang Basin; GM, Gyeonggi Massif; OFB, Okcheon fold belt; YM, Yeongnam Massif; GB, Gyeongsang Basin; YB, Yeonil Basin; JVT, Jeju volcanic terrain).

**Figure 8.** Magnitude residual distribution as a function of epicentral distance for the horizontal (upper) and vertical (lower) components. Plus symbols and circles represent the results with and without station correction, respectively. The colors of the histograms correspond to those of the plus symbols, which divide the distance range of the observations. The red and black dashed lines were obtained from linear regressions of the results with the corrections for linear and logarithmic distance scales, respectively.
FIGURE 9. Comparison of the magnitudes between $M_L$ from this study and $M_W$ from Rhee and Sheen (2016). The orthogonal linear regression results are plotted with red solid lines and red dashed lines indicate one standard deviation.

FIGURE 10. Comparison of the magnitudes between $M_L$ from this study and $M_L$ from the KMA catalog. The orthogonal linear regression results are plotted with red solid lines and red dashed lines indicate one standard deviation.
Figure 1. The distribution of the ray paths used in this study between earthquakes (circles) and stations (triangles). The size of each circle is proportional to the earthquake magnitude obtained from the KMA catalog.
Figure 2. Magnitude and distance distribution of the data used in this study.
Figure 3. Histograms of the distance distribution of data corresponding to the distance intervals for the nonparametric method. (a) Distance distribution corresponding to regular intervals. (b) Distance distribution corresponding to irregular intervals.
Figure 4. The attenuation correction curves obtained from this study. Symbols and solid lines represent the nonparametric and parametric results, respectively. Diamonds and circles are the attenuation correction terms at the distance nodes of regular and irregular intervals for the nonparametric method. The results for the horizontal and vertical components are shown in red and black, respectively. The dashed lines are attenuation curves from other studies.
Figure 5. Comparison of $M_L$ estimates obtained from this study. (a) and (b) Nonparametric versus parametric methods for the horizontal and vertical components, respectively. (c) and (d) Horizontal versus vertical components for the nonparametric and parametric methods, respectively.
Figure 6. Comparison of the station corrections. (a) Station corrections from the parametric versus nonparametric methods. (b) Station corrections for the vertical versus horizontal components.
Figure 7. Spatial distribution of the station corrections for the horizontal (left) and vertical (right) components. Both were obtained with the parametric method. The color and size of the triangles represent the scale of the correction and the amount of data used for each station, respectively. Tectonic boundaries are denoted by thick solid lines (PB, Pyeongnam Basin; OB, Ongjin Basin; IB, Imjingang Basin; GM, Gyeonggi Massif; OFB, Okcheon fold belt; YM, Yeongnam Massif; GB, Gyeongsang Basin; YB, Yeonil Basin; JVT, Jeju volcanic terrain).
Figure 8. Magnitude residual distribution as a function of epicentral distance for the horizontal (upper) and vertical (lower) components. Plus symbols and circles represent the results with and without station correction, respectively. The colors of the histograms correspond to those of the plus symbols, which divide the distance range of the observations. The red and black dashed lines were obtained from linear regressions of the results with the corrections for linear and logarithmic distance scales, respectively.
Figure 9. Comparison of the magnitudes between $M_L$ from this study and $M_W$ from Rhee and Sheen (2016). The orthogonal linear regression results are plotted with red solid lines and red dashed lines indicate one standard deviation.
Figure 10. Comparison of the magnitudes between $M_L$ from this study and $M_L$ from the KMA catalog. The orthogonal linear regression results are plotted with red solid lines and red dashed lines indicate one standard deviation.