Statistical Analysis of JMA Seismic Intensity Differences Using Seismometer Array Records

Hidenori Mogi and Hideji Kawakami, Saitama University, Japan

Introduction

The JMA (Japan Meteorological Agency) seismic intensity scale has been playing an important role in earthquake engineering. Since 1996, seismic intensity meters have been densely installed by JMA and many local governments for automatic and rapid announcement of seismic intensities in the region. However, it has been pointed out that the variation of the instrumental seismic intensity at neighboring sites is not small. Therefore, the spatial stochastic properties of the instrumental seismic intensity should be examined for proper utilization of the seismic intensity scale as the regional intensity of seismic ground motions.

In this study, seismic intensity difference (SID), the difference between instrumental seismic intensity observed at two sites during each earthquake, was introduced and investigated to examine the statistical characteristics of the instrumental seismic intensity.

Probability Distribution Model for SIDs

The seismic intensity difference (SID) has been defined as

$$Z = |Z'| \,, \qquad Z' = X_1 - X_2, \tag{1}$$

where X_1 and X_2 are the instrumental seismic intensity observed at two sites during the same earthquake. Since the seismic intensity can be considered as a Gaussian random variable, the probability distribution of the SIDs is also Gaussian distribution whose probability distribution is given by

$$f_Z(z) = \frac{2}{\sqrt{2\pi}\sigma_{Z'}} \exp\left(-\frac{z^2}{2\,\sigma_{Z'}^2}\right), \quad z \geq 0, \tag{2}$$

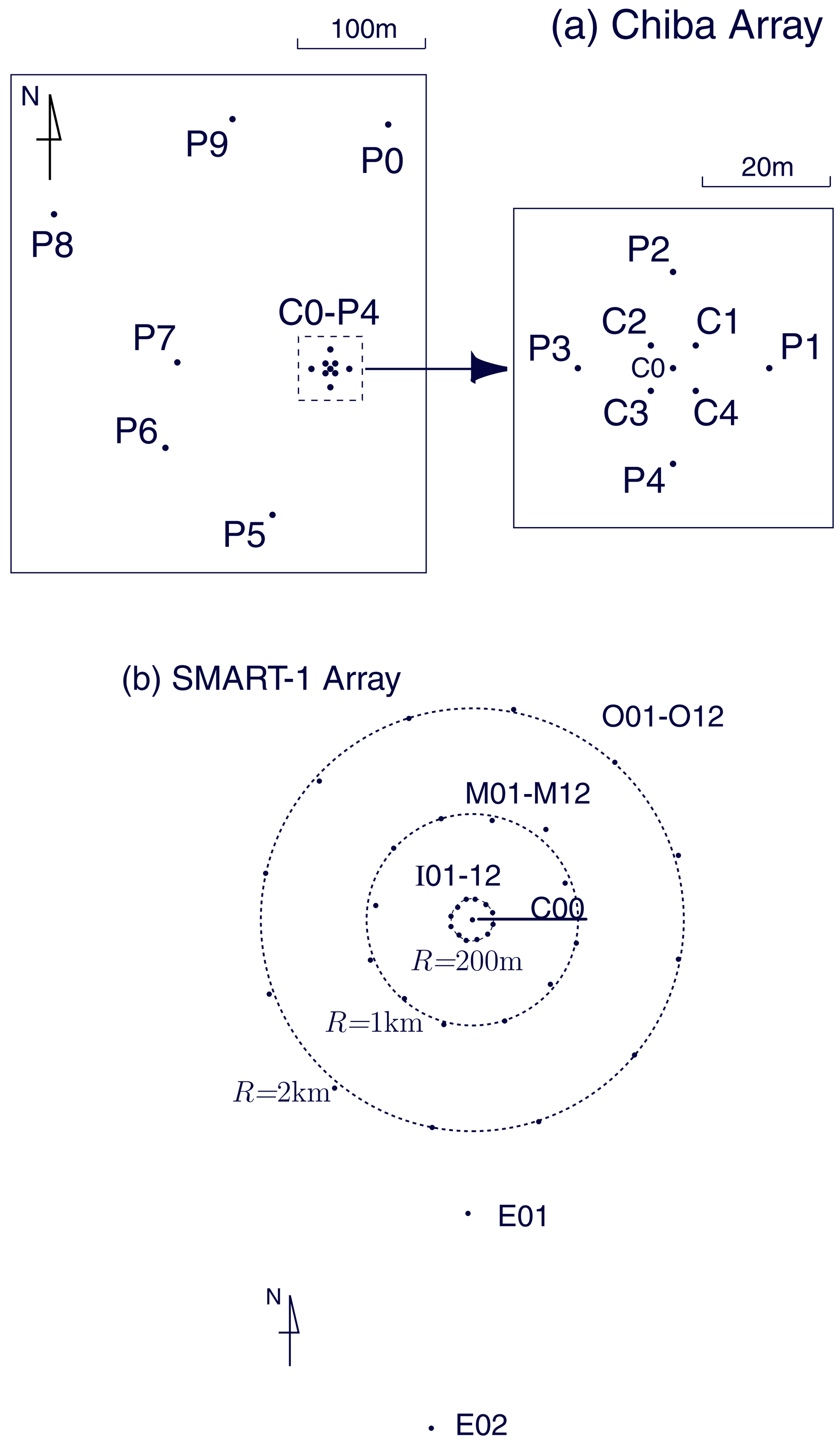
where $\sigma_{Z'}$ is the standard deviation of Z'. As shown in Eq.(2), using the SIDs makes it unnecessary to estimate average μ_X, which depends on individual earthquakes.

Based on Eq.(2), the probability of occurrence of a different n in seismic intensity scale can be expressed as

$$P(n) = \int_{\max(0,\,n-1)}^{n+1} f_Z(z)\, W_n(z) dz, \tag{3}$$

where $P(n)$ is the probability of occurrence and $W_n(z)$ is the weight function given by

$$W_n(z) = \begin{cases} z-(n-1) & (0 \leq n-1 \leq z < n) \\ 1-(z-n) & (n \leq z < n+1). \end{cases} \tag{4}$$



Seismometer Arrays and Site Effect Correction

Accelerograms observed at the Chiba and SMART-1 seismometer arrays were used for stochastic analyses of SIDs. The station pairs with separation distances up to 300 m are available in the Chiba array database, and up to 7 km in the SMART-1 database.

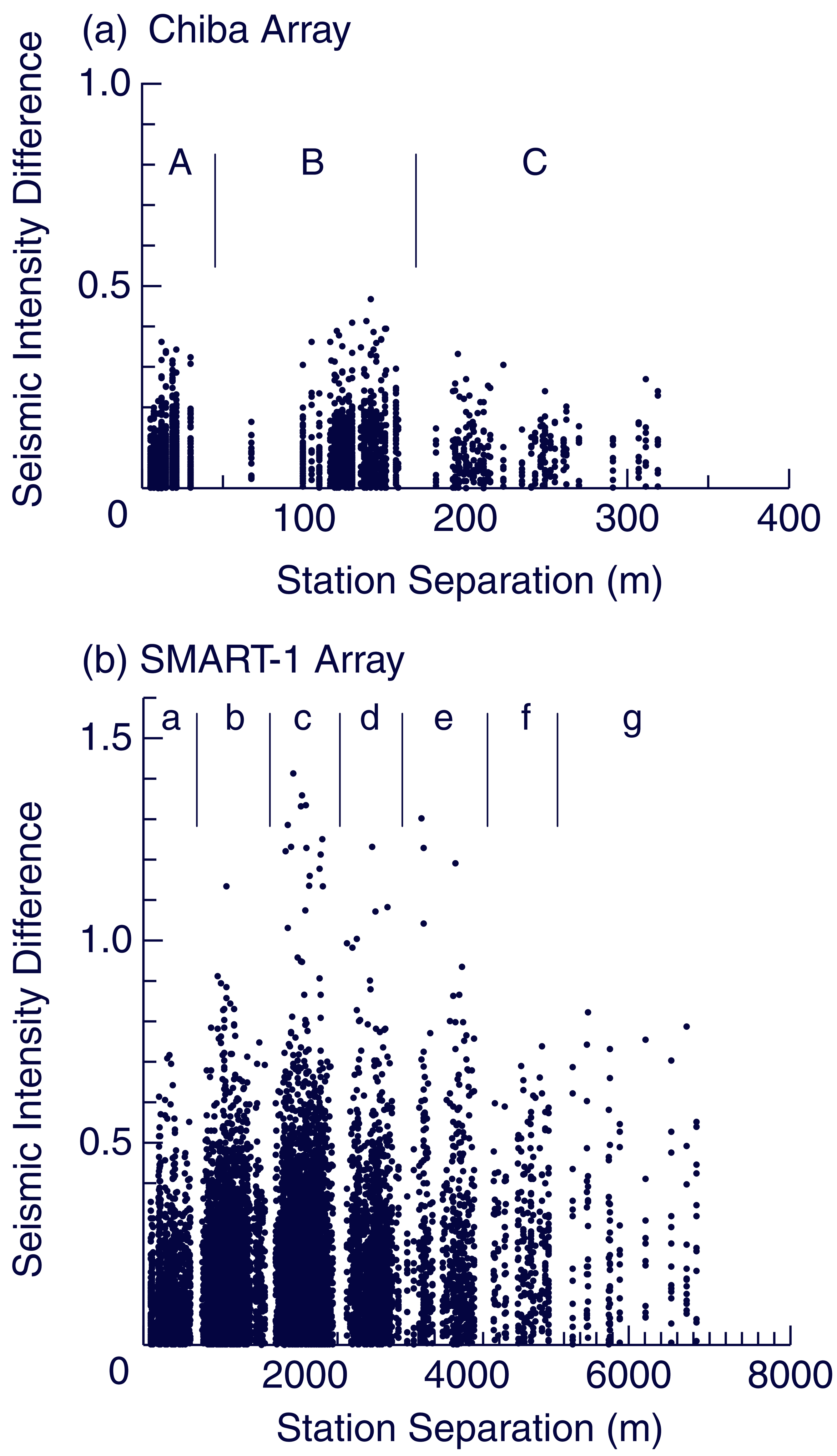
To eliminate the difference due to site effect, the observed seismic intensity was corrected by a site factor. The site factor was estimated as follows:

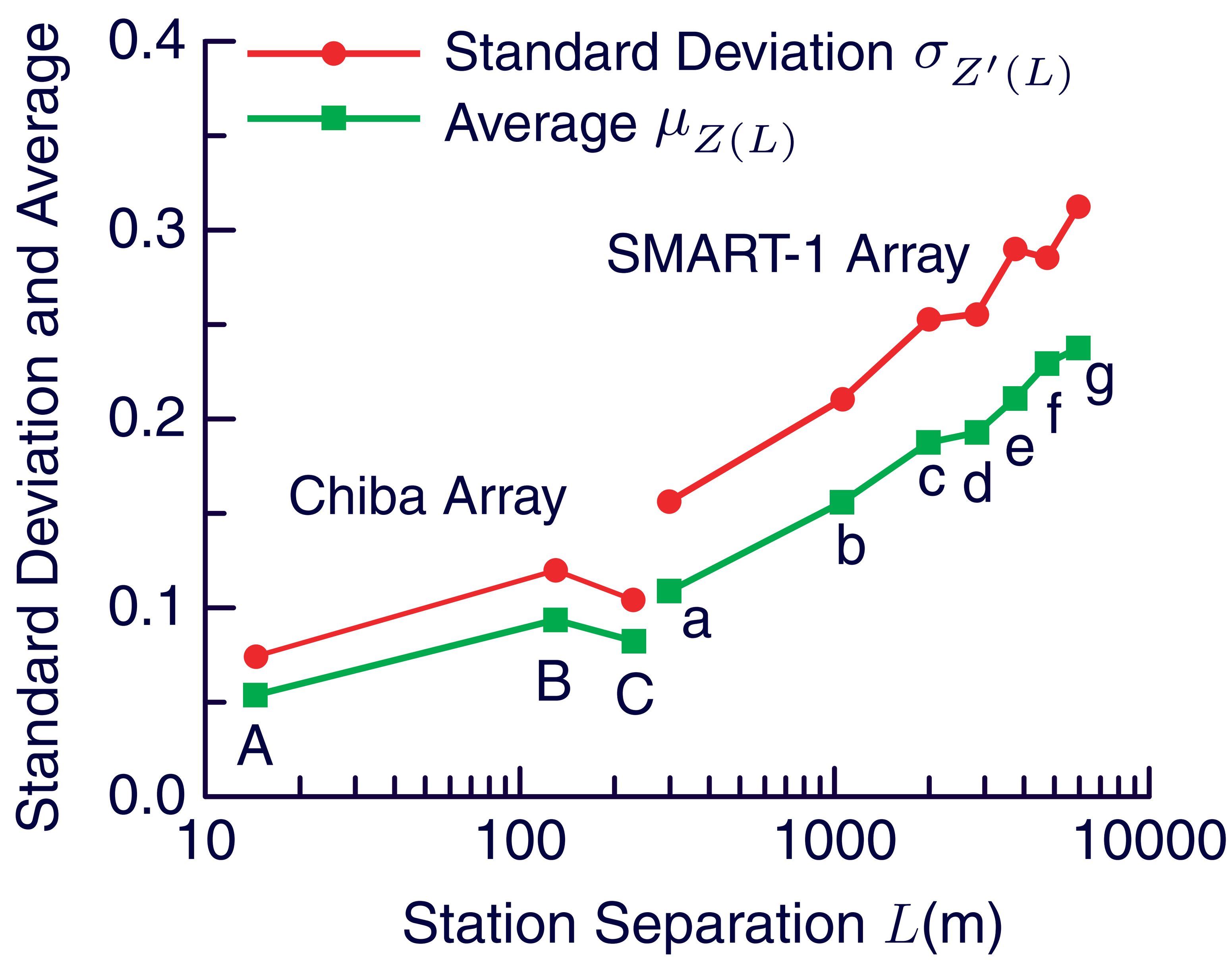
1) The stationwise average of seimic intensity for each earthquake was calculated.
2) The average of the difference between observed seismic intensity and aforementioned stationwise average was calculated as the site factor.

Scatter of SIDs

These figures shows the scatter of the SIDs against the station separation. In the figure for the Chiba array, the SIDs of about 0.4 were observed even for the closest pairs separated by 10 m or less. Also the SIDs more than 1.0 were observed in the results of the SMART-1 array because of its large station separations.

In this study, we have estimated the standard deviation, $\sigma_{Z'}$, and average μ_Z for each station separation group, **A** to **C** for the Chiba array and **a** to **g** for the SMART-1 array. These station separation groups are shown at the top of the figures.





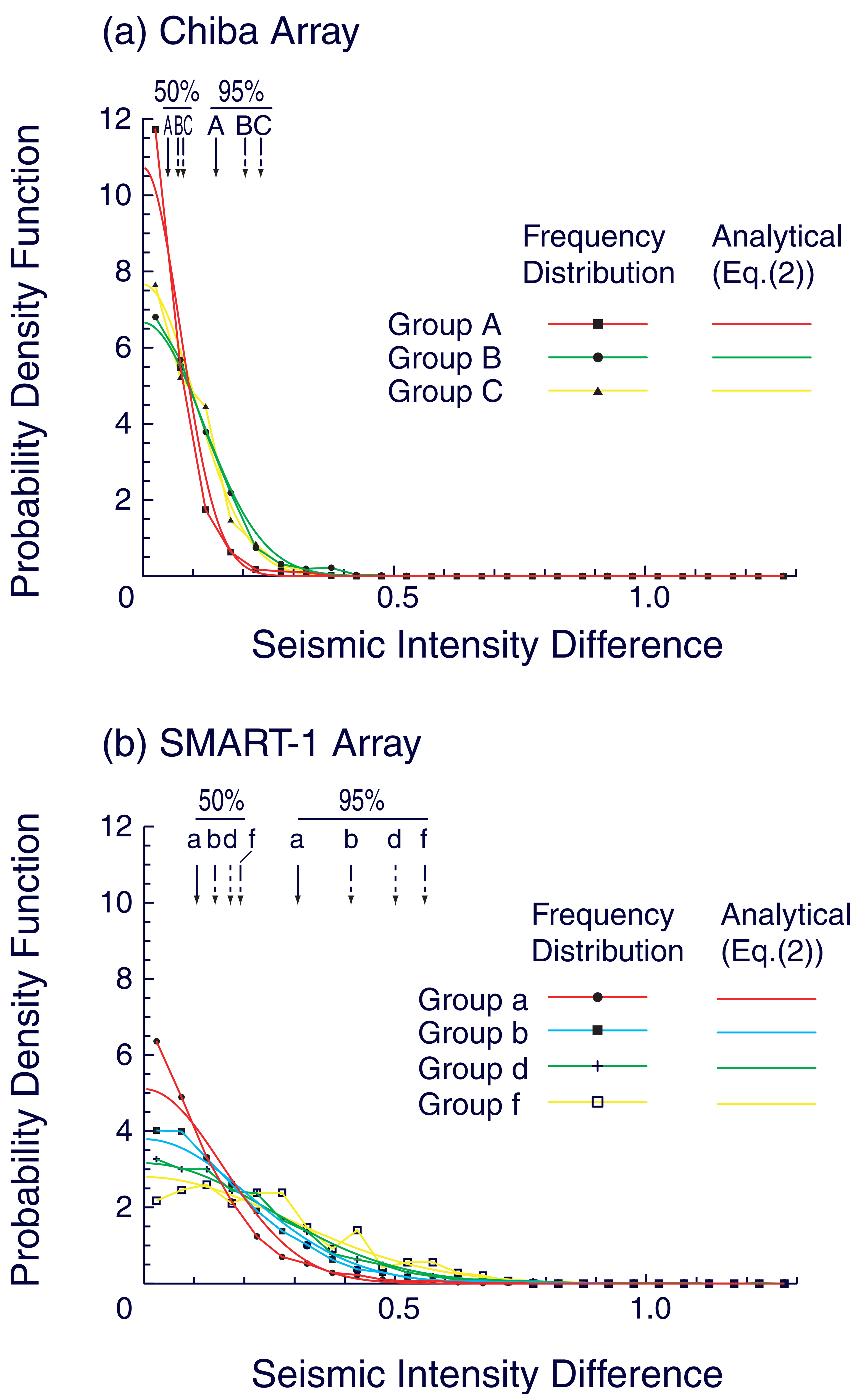
Standard Deviation and Average of SIDs

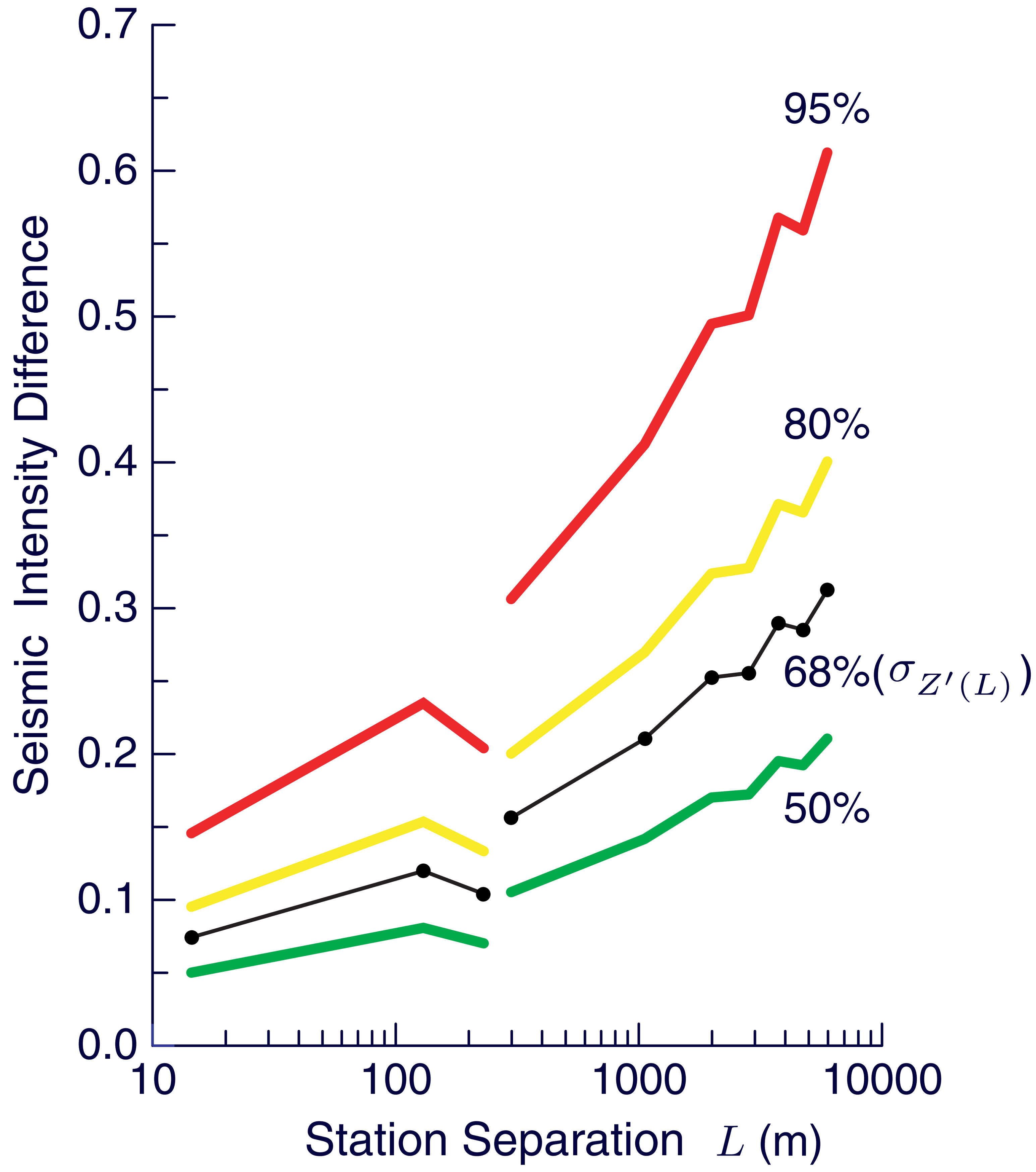
This figure shows the standard deviation $\sigma_{Z'}$ and average μ_Z of the SIDs against the station separation. In this figure, we can find monotonic increases of the standard deviation and average with increasing station separation. Also continuous relationships between two different arrays have to be noted.

Probability Density Functions of SIDs

The probability density functions (PDFs) of the SIDs estimated by frequency of occurrence (lines with symbols) and by Eq.(2) with the estimated standard deviation $\sigma_{Z'}$ (smooth lines) are shown.

Since the shapes of the PDFs estimated by the frequency of occurrence and by Eq.(2) are similar to each other, it can be comfirmed that the Gaussian distribution is applicable to the probability distribution of SIDs. The steep shapes of the PDFs for the Chiba array are indicative of small scatter of the SIDs. For the SMART-1 array, we can find the probability of occurrence of the SIDs of 0.5 or more.





Percentiles of SIDs

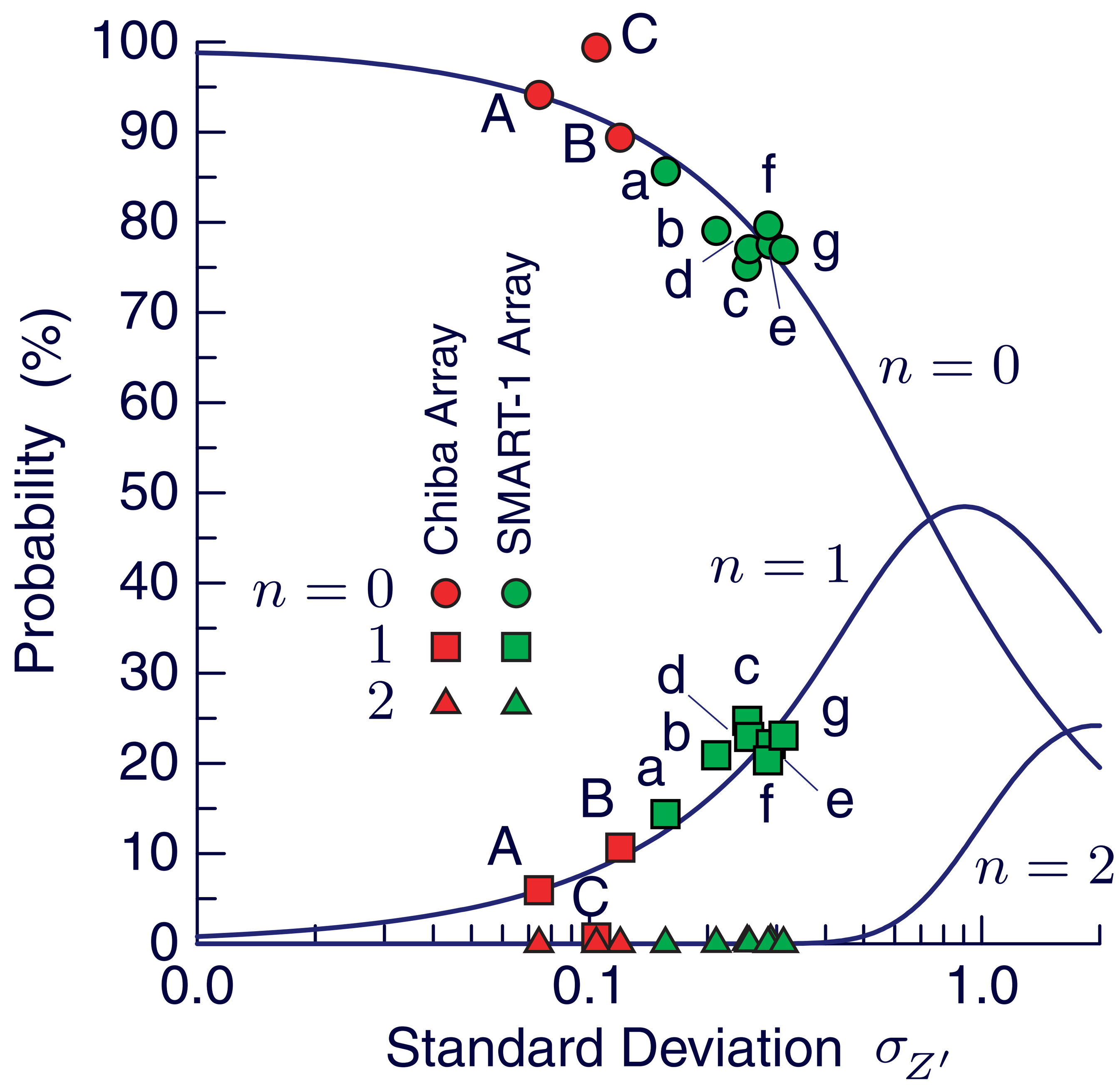
This figure shows 50th, 68th, 80th and 95th percentiles of the SIDs. The 95th percentiles can be considered as the largest value of SIDs (ie., the 95% significance level is assumed). From these results, the followings are revealed:

1) For the station pairs separated by 40 m or less, there is a 50% probability that the SID will be less than 0.05 and a 95% probability that it will be less than 0.15.
2) If the stations are separated by almost 1 km, there is a 50% probability that it will be less than 0.15, and a 95% probability that it will be less than 0.4-0.45.
3) If the stations are separated by almost 5 km, there is a 50% probability that it will be less than 0.2, and a 95% probability that it will be less than 0.55-0.65.

Probability of Occurrence of a Difference in Seismic Intensity Scale

The probability of the occurrence of a difference n in seismic intensity scale estimated from the array records and Eq.(3) are shown in this figure. From this result, the followings can be pointed out:

1) The same seismic intensity scale will be observed with a 95% probability for the station pair separated by several ten meters, and a 75-80% probability for the pair separated by several kilometers.
2) There is no possibility of occurrence of different seismic intensity scales by two at the station pairs separated by within several kilometers.



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