NOTE AND CORRESPONDENCE

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Fractal Characterization of Seismic Networks in Taiwan

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ABSTRACT

The fractal dimension is calculated for the geometrical distributions of the seismic stations of three networks (the old CWB seismic network, the TTSN and the CWBSN) in Taiwan based on the correlation integral algorithm proposed by Hirata *et al.* (1987). Results show that the distribution of the data points of correlation integral for the old CWB seismic network distribute very irregularly and cannot be approximated by a fractal set point. The fractal dimesion value for the TTSN (1.18±0.02) is less than that for the CWBSN (1.56±0.01). This indicates that the dimension resolution and the detectability of sparse phenomena are lower for the former than the latter.

(Key words: Seismic network, Correlation integral, Fractal dimension)

Fractal properties are commonly found with natural phenomena (Mendelbrot, 1983). In 1986 Lovejoy and his associates (Lovejoy *et al.*, 1986a, b; Lovejoy and Schertzer, 1986) reported that the World Meteorological Station Network (9563 stations) constitutes a 1.75-dimensional fractal set on the 2-D surface of the Earth, the French Climatological Network (3593 stations) a 1.8-dimensional set, and the Canadian Meteorological Network (414 stations) only a 1.5-dimensional set. Lovejoy *et al.* (1986a) also stated that to detect phenomena, not only must a network have sufficient spatial resolution, but it must also have sufficient dimensional resolution. Whenever the fractal dimension D_f is less than the Euclidian dimension D_e of the embedding space, sparsely distributed phenomena with a dimension of less than D_e-D_f cannot be detected. Korvin *et al.* (1990) stated that the spatial distribution of the South Australian gravity station network (over 65000 stations) can be approximated by a fractal point set of correlation dimension D=1.4.

The collision of the Philippine Sea and Eurasian plates together with the spreading of the Okinawa Trough have resulted in high seismicity in the Taiwan region. To monitor the earthquake occurrences, at the end of the last century the Japanese started to install seismic stations, and finally constructed a network consisting of 17 stations by 1950. Since then, this network has been operated by the Central Weather Bureau (CWB), of the ROC (Yeh *et al.*, 1989). This network is referred to as the old CWB seismic network in this study. In order to

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improve earthquake location, the Taiwan Telemetered Seismographic Network (TTSN) has been installed by the Institute of Earth Sciences, Academia Sinica since the end of 1972. A detailed description of this network can be found in Wang (1989). This network provides a good data base for earthquakes. Since 1990 other new seismic stations have been installed by the Central Weather Bureau. To unify the observation of earthquakes, since 1992 the TTSN has been merged into the CWB seismic network. Hence, the new CWB seismic network consists of the old CWB seismic network, the TTSN and the newly-installed stations of the CWB and is known as the CWBSN. The coordinates of the TTSN stations are reported in Wang (1989), and those of the CWBSN stations can be found in each volume of the Seismological Bulletin published by the CWB. All the stations of the CWBSN are plotted in Figure 1: solid circles for the old CWB seismic network station, open circles for the newly-installed CWBSN stations, and open triangles for the TTSN stations. Most of the stations are located on the main island of Taiwan, but a few are on nearby small islands. Except for five, all of the stations of the two networks have an elevation of less than 1000 m. Station YUS at Yushan, the highest mountain of Taiwan, is the highest one (elevation 3844.8m). Since the distance between any two stations is generally greater than 10 km and there are so few stations with an elevation greater than 1 km, the possible effect due to elevation is not taken into account. In this study, the fractal dimension is measured for the old CWB seismic network, the TTSN, and the CWBSN as determined by correlation integrals.

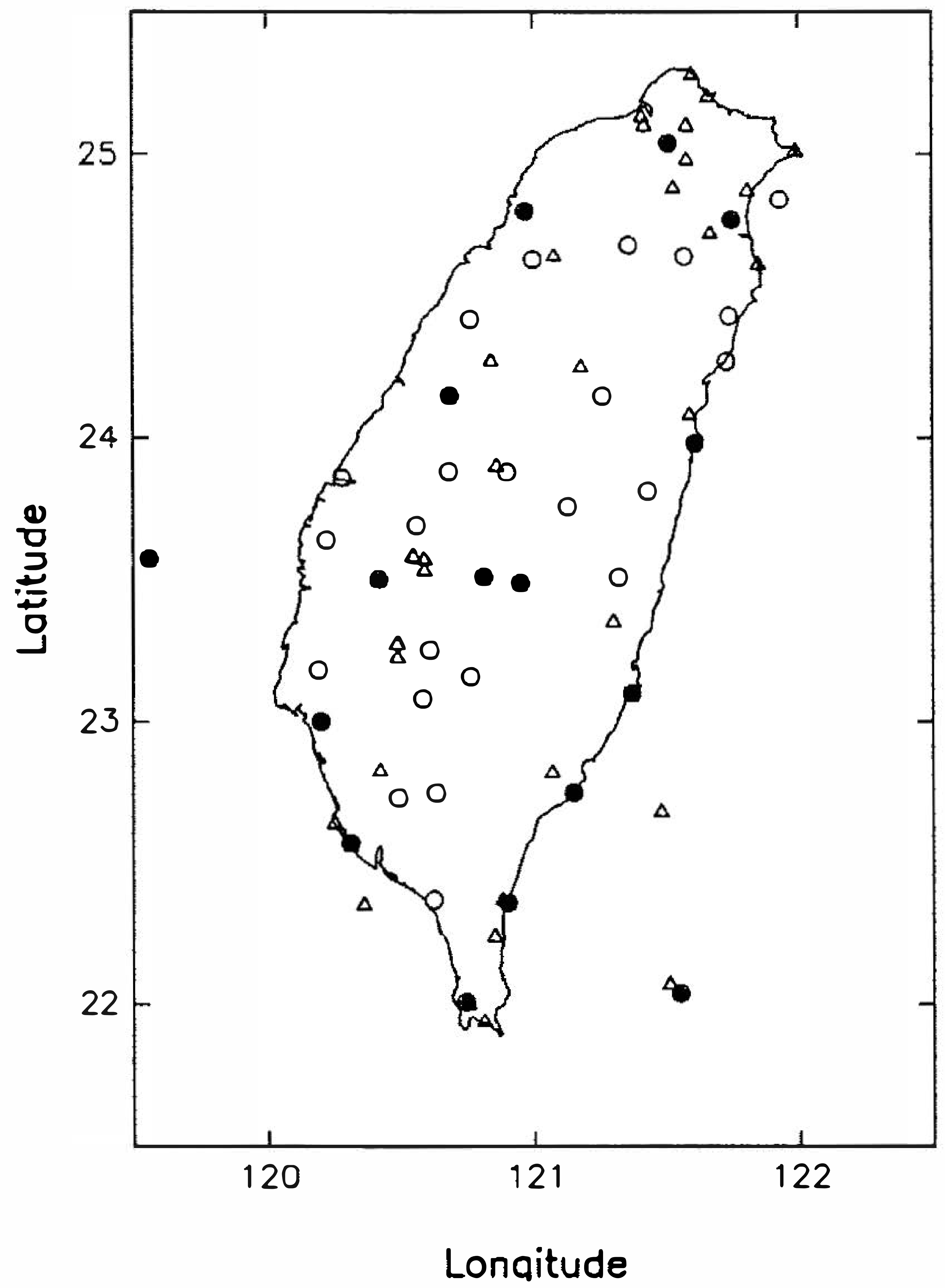

Fig. 1. The locations of stations used in this study: solid circles for the stations of the old CWB seismic network, open triangles for those of the TTSN and open circles for the newly-installed stations of the CWBSN.

The correlation integrals C(r) for the location distributions (h_1, h_2, h_3, ..., h_N) are calculated with the following formula (cf. Hirata *et al.*, 1987):

$$C(r)=2Nr(R<r)/N(N-1), \tag{1}$$

where Nr(R<r) is the number of pairs (h_i, h_j) with a distance smaller than r, and N is the number of stations used. If the distribution has a fractal structure, C(r) is expressed by:

$$C(r) \sim r^D, \tag{2}$$

where D is the correlation fractal dimension.

The number of stations used is individually 17 for the old CWB seismic netwok, 25 for the TTSN and 65 for the CWBSN. The correlation integral versus the distance for the location distribution of stations is plotted on a double natural logarithmic scale in Figure 2.

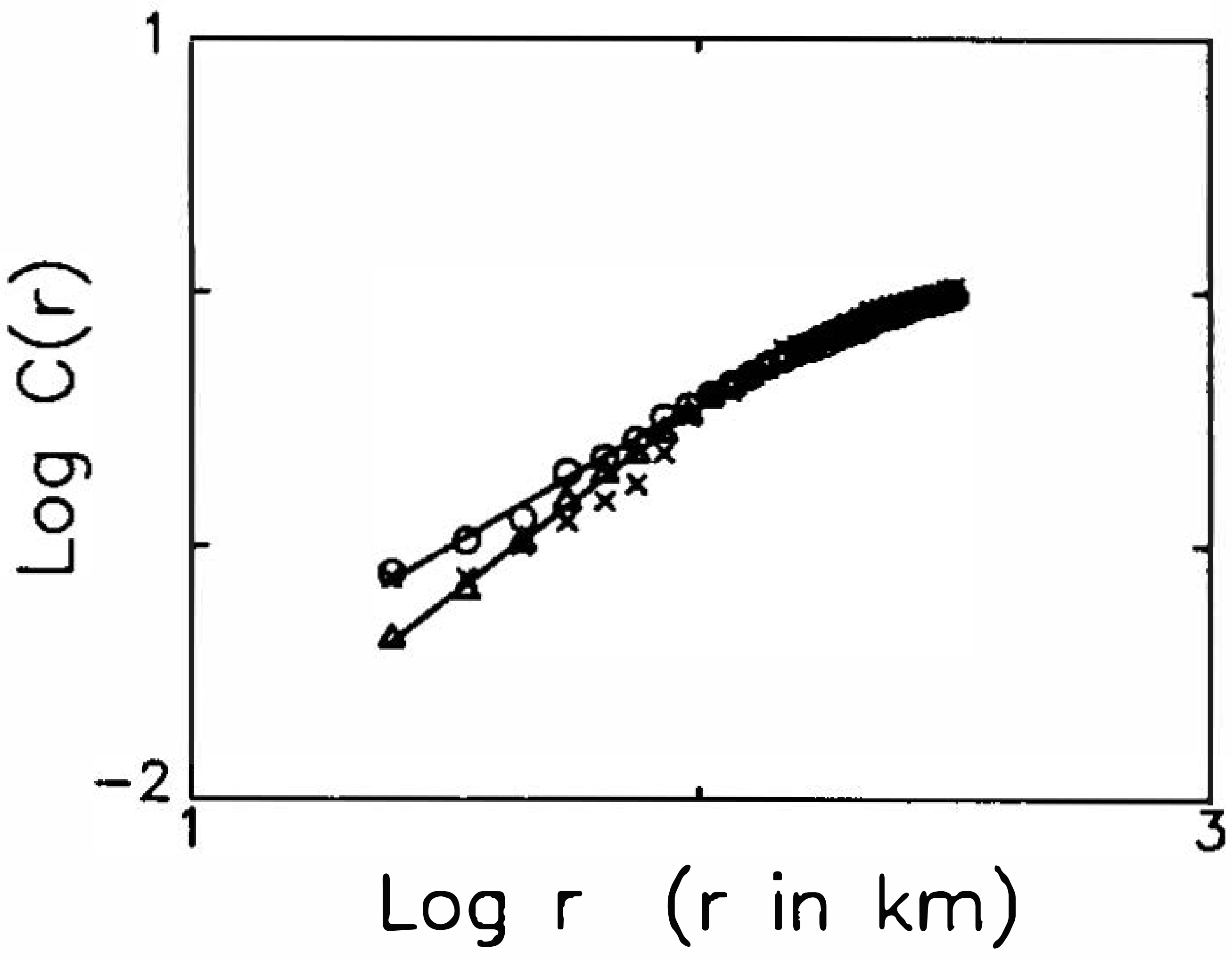

Fig. 2. The data points of log C(r) vs. log r: crosses for the old CWB seismic network, open circles for the TTSN and open triangles for the CWBSN. The solid lines represent the regression lines of the data points with r less than r_c=100 km (or log r_c=2).

The crosses, open circles and open triangles denote the data points for the old CWB seismic network, the TTSN and the CWBSN, respectively. It can be seen that for the TTSN and CWBSN when the distance is less than a certain critical value r_c, the data points mostly distribute along a straight line; in contrast, when the distance is greater than that a value, the two patterns of data points bend downward. Such a critical value is about 100 km, or log(r_c)=2.0. For $r<r_c$, the data points of the three networks separate remarkably; while for $r>r_c$ all data points are close to one another. However, the data points for the old CWB seismic network distribute very irregularly and cannot be fitted by a straight line. Consequently, the distribution of stations of the old CWB seismic network cannot be approximated by a fractal point set. The bending of the pattern of data points for the TTSN and CWBSN indicates that the C(r) value for $r>r_c$ is less than the value estimated from the regression equation deduced from the data points with $r<r_c$. From Figure 1, it can be seen that the r_c value is almost equal to the size of Taiwan Island in the east-west direction. The correlation integral algorithm is based on a circle in two-dimensional space as in the present study or a sphere in three-dimensional space. The length (along the north-south direction) and the largest width (along the east-west direction) of Taiwan Island are about 400 km and 100 km, respectively.

Hence, almost all of the stations used are located on a rectangular surface of 400 km length and 100 km width. When the r value is greater than the width of the rectangle, the number of the pairs of stations counted from the rectangle must be less than the expected value based on a circle with a radius of r. Therefore, the size of the width of the rectangle would cause a so-called finite-size effect on the computed results. For the present situation, the critical size is the width of Taiwan Island. The use of a non-circle distribution of stations limits the reliability of the results. In other words, the fractal dimension can only be estimated from the data points with $r<r_c$. For the data points with $r<r_c$, the slope values (i.e. the D values) inferred from the data points are 1.18±0.01 and 1.56±0.01 for the TTSN and the CWBSN, respectively.

A non-integer value of fractal dimension represents the existence of voids in the object or set. From the viewpoint of the distribution of the seismic stations, the existence of voids indicates the existence of areas where no station is installed. The smaller the value of fractal dimension, the larger the number of voids or the higher the degree of heterogeneity of the object. Hence, the fact that the D value for the TTSN is smaller than that for the CWBSN displays a more heterogeneous distribution of stations for the former than for the latter. From Figure 1, it can be seen that most of the TTSN stations distribute along the two sides of the Central Range, and only a few stations are located on the Central Range. On the other hand, although most of the CWBSN stations distribut along the two sides of the Central Range, a large number of the stations is at the Central Range. Hence, there is a less homogeneous distribution of stations for the TTSN than for the CWBSN over Taiwan Island. In other words, the distribution of the CWBSN stations is more two-dimensional than that of the TTSN stations. Therefore, the fractal dimension is larger for the former than the latter. In addition, according to the concept proposed by Lovejoy and associates, the dimension resolution and the detectability of sparse phenomena of the CWBSN are higher than those of the TTSN.

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REFERENCES

Hirata, T., T. Statoh, and K. Ito, 1987: Fractal structure of spatial distribution of microfracturing in rock. *Geophys. J. R. Astro. Soc.*, **90**, 369-374.

Korvin, G., D. M. Boyd, and R. O'Dowd, 1990: Fractal characterization of the South Australian gravity station network. *Geophys. J. Int.*, **100**, 535-539.

Lovejoy, S., and D. Schertzer, 1986: Scale invariance, symmetries, fractals and stochastic simulations of atmospheric phenomena. *Bull. Am. Meteor. Soc.*, **67**, 21-32.

Lovejoy, S., D. Schertzer, and P. Ladoy, 1986a: Fractal characterization of inhomogeneous geophysical measuring networks. *Nature*, **319**, 43-44.

Lovejoy, S., D. Schertzer, and P. Ladoy, 1986b: Outlook brighter on weather forecasts. *Nature*, **320**, p.401.

Mandelbrot, B. B., 1983: The Fractal Geometry of Nature, W. H. Freeman, New York, 468pp.

Wang, J. H., 1989: The Taiwan Telemetered Seismographic Network. *Phys. Earth Planet. Inter.*, **58**, 9-18.

Yeh, Y. T., C. C. Liu, and J. H. Wang, 1989: Seismic networks in Taiwan. *Proc. Natl. Sci. Council, Part A: Phys. Sci. and Engin.*, **13**, 23-31.