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# Growing correlation length of moderate-sized earthquakes prior to two great earthquakes near Sumatra Island

Rong Dailu and Li Yarong

*Lanzhou Institute of Seismology, China Earthquake Administration, Lanzhou 730000, China*

**Abstract**: Seismic correlation length for moderate earthquakes prior to two great earthquakes in the northern sea area of Sumatra Island (*M*w9.1 in 2004 and *M*s8.6 in 2012) has been studied, using method of Single-Link-Cluster (SLC) analysis, and found to show a power-law growth about two years before their occurrences. No such growth was found for a magnitude 7 earthquake in the same area. This result suggests the occurrence of a physical process of critical-point characteristics in the source area before the great earthquakes.
**Key words**: northern sea area of Sumatra Island; earthquake; critical-point characteristics; seismic spatial-correlation length; single-link cluster analysis (SLC)

## 1 Introduction

The preparation and occurrence of a large earthquake may be characterized by a self-organized critical phenomenon, in which the stress field simultaneously reaches the critical points at a long segment of an active fault, so that a small rupture can jump over barriers and grow into a large earthquake. When such criticality is reached, the system may show accelerated seismic release in the form of increased occurrence of smaller earthquakes at increasing inter-epicentral distances[1], or a growth of "correlation length" in space. Thus to measure the growth in correlation lengths in observed smaller earthquakes may be a possible approach to detect the reaching of critical point for a large earthquake.

In this study, we investigated the seismic activity before and near two great earthquakes that occurred in the northern sea area of Sumatra Island (*M*w9.1 on December 26, 2004 and *M*s8.6 on April 11, 2012) to see whether the correlation length might show such a growth.

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Corresponding author: Rong Dailu, E-mail: shzhsh@qq.com.

## 2 Theory and method

If a system approaches the critical point, the correlation length $\zeta$ is expected to grow according to the power law[2]

$$\zeta(t) \sim (t_f - t)^{-k} \tag{1}$$

where $k$ is a positive constant and $t_f$ is the failure time (earthquake occurrence). The method we used to extract correlation length from earthquake catalogs is the single-link-cluster (SLC) analysis introduced by Frohlich and Davis[3]. SLC has a wide-range of application in many fields (such as social science, taxonomy, astronomy, etc.). Some researchers in China have used this method to study the relationship between seismicity characteristics, geological structures[4] and the seismic activity in certain area[5]. This method can provide a characteristic scale for defining clusters and finding isolated events at both global and local levels. It expresses a mathematical relationship between individual events and between different groups of events. Also, the results of SLC method form a linear chain that is quite appropriate for earthquakes, which often occur along some linear structures (such as large faults). For earthquakes distributed in a region, a characteristic scale for inter-epicentral distances is correlation length.

When estimating the correlation length $\zeta(t)$ by SLC analysis for $N$ earthquakes distributed in a selected area, we link each event with its nearest event in space to form a small cluster; we then link each cluster with its nearest cluster and repeat this process recursively until all $N$ events are connected with $N-1$ links. Here the length of the link is the epicentral distance between two earthquakes (only 2-D condition is considered here). In this way, we can obtain a sequence of $(N-1)$ links. The correlation length is defined by using the criterion that the probability is 0.5 for the link smaller than or equal to $\zeta$.

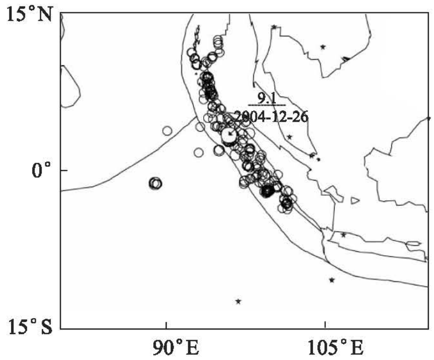
In order to obtain the time series of correlation length, the method of sliding window was used for a sequence of earthquakes before the main shock (several years in general) in a selected space range. If the time series was characterized by an accelerated growth, we tried to fit it with a power law given by equation (1).

Zoller et al[6] analyzed systematically all earthquakes of $M \geqslant 6.5$ in California since 1952, and found growing correlation length in most cases. Rong Dailu et al[7] found similar results for moderate earthquakes in Gansu of China and nearby areas. Zoller selected a circular region with radius $R$ around the main-shock epicenter as the space window. In this study, we selected an elliptical region with the major axis parallel to the strike of the seismogenic fault as the space window, and optimized it in order to provide the best observation for a growing correlation length.

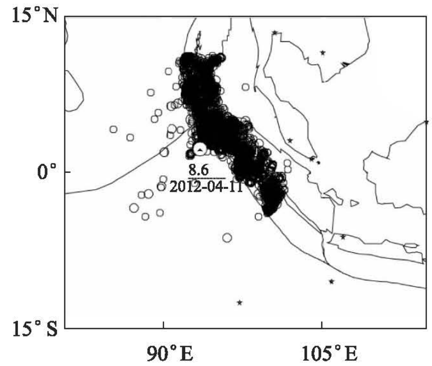
## 3 The earthquakes

The earthquakes used in this study are located within 1000 km of the earthquake epicenters during a 5-year period before the main shocks, according to the catalogs provided by National Earthquake Information Center (NEIC) (Fig. 1).

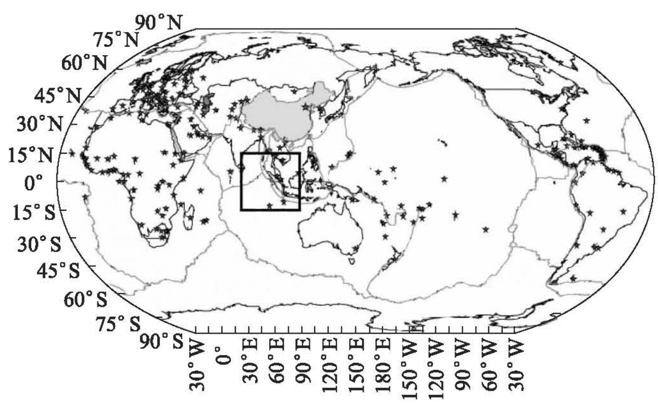
We used values given by NEIC, and selected 5.0 and 4.5 as the minimum magnitudes for the earthquakes of $M$w9.1 and $M$s8.6, respectively. The Gutenberg formulae (magnitude-frequency plots) show completeness of the catalogs above magnitude $m_b = 4.5$ for both main shocks (Fig. 2).




(a) Main shock:Dec.26.2004 $M$w9.1 (from Jan. 1, 1999 to Dec. 26, 2004, $M$min=5.0($m_b$))

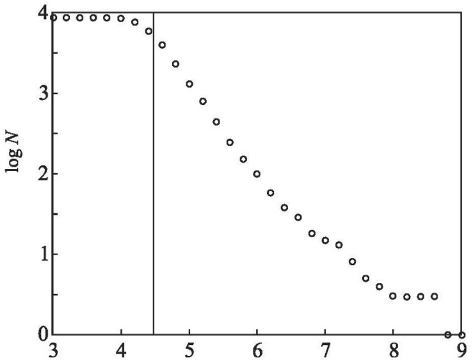



(b) Main shock:April 11,2011 $M$s8.6 (from Jan. 1, 2007 to April 11, 2012, $M$min=4.5($m_b$))

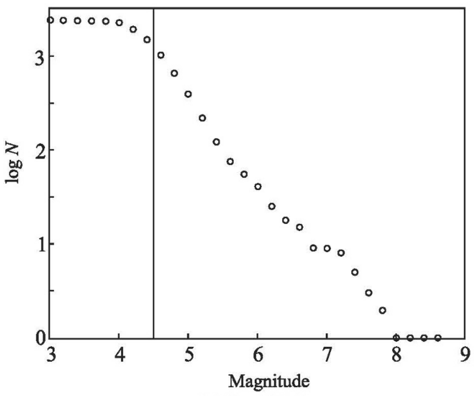



(c) The Location of Seismic region(the black square frame in figure)

Figure 1 Earthquake distribution within 1000 km of the earthquake epicenters




(a) For *Ms*9.1




(b) For *Ms*8.6

Figure 2 Magnitude-frequency plots

# 4 Optimization procedure and results

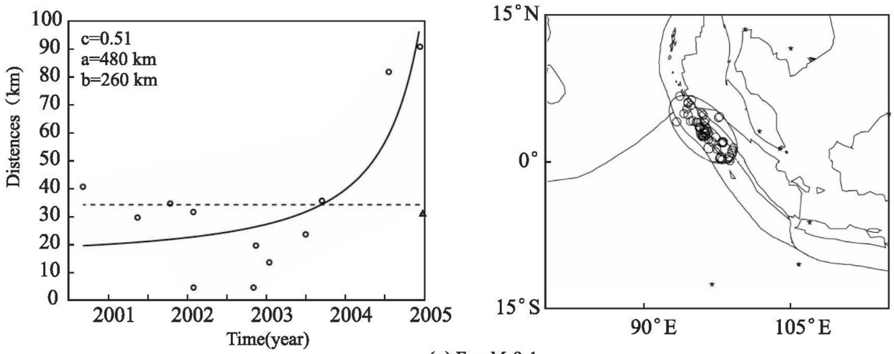
For each main shock, we calculated the time series of the correlation length of the selected earthquakes within elliptical areas of different sizes and azimuth angles and different beginning time, and fitted the series with both a power law and a constant. We then used the ratio between their root-mean-squares errors

$$c = \frac{(RMS)_{\text{powerlaw}}}{(RMS)_{\text{const}}} \tag{2}$$

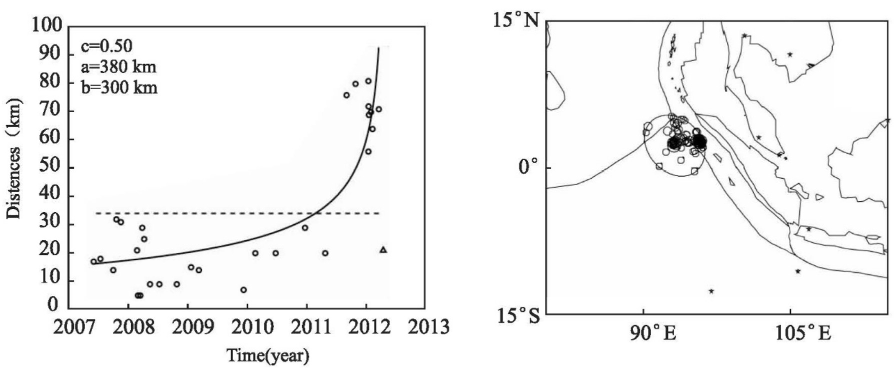
to test the goodness of fit for the power law. A smaller $c$ values indicates a better fit.

Figure 3 shows the constant fits (dashed lines) and the best power-law fits (solid lines) for the correlation-length time series and the corresponding earthquake distributions prior to the main shocks.

where the triangles indicate the main-shock occurrences. With $c$ values of 0.51 and 0.50, respectively, the results show good fits of the power law and thus increased correlation length for both earthquakes.




(a) For *Ms*9.1




(b) For *Ms*8.6

Figure 3 Time series of correlation length (left) and distribution of selected earthquakes (right)

## 5 Test for results

To test the validity of this procedure, Zoller et al[6] used some synthetic catalogs. Their conclusion is that the null hypothesis that the observed pattern (i. e. the-power law increase of correlation length prior to main shock) may occur in a random catalog can be rejected with 99.3% confidence.

In this study we took a different approach, by selecting a time interval before the main shocks in which no great earthquake (great than magnitude *M*s7.0) occurred and using the same procedure to see whether the correlation length showed any power-law increase.

Taking the *M*w9.1 earthquake as an example, figure 4 shows a magnitude versus time (*M-T*) plot of earthquakes since 1973 within 1000 km of the epicenter.

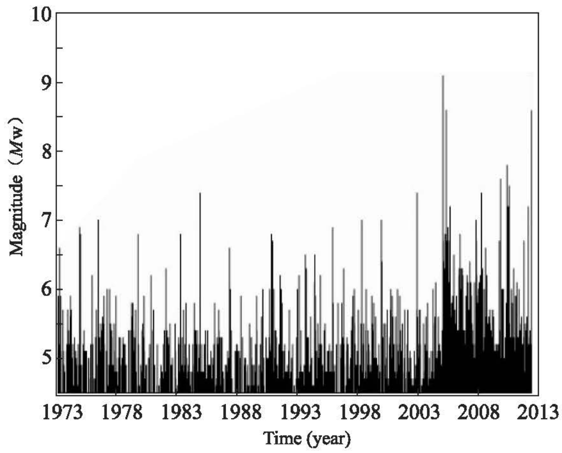



Figure 4 A *M-T* plot for the earthquakes of 4.5 and greater since 1973 within 1000 km the of the epicenter of the *M*w9.1 event

Since no earthquake greater than magnitude 7 occurred during 1988 – 1993 and an earthquake of magnitude 6.9 occurred on Nov. 8, 1995, we selected the earthquakes during 1988 – 1993 for analysis.

Figure 5 shows two histograms of *c* values for the earthquakes prior to *M*w9.1 and during 1988 – 1993, respectively.

It may be seen that the *c* values are much smaller in the case of the *M*w9.1 event (mostly less than 0.7 with a minimum 0.51, whereas the c values are mostly distributed greater than 0.90 with minimum 0.59 during 1988 – 1993). Two time series of correlation length for earthquakes during 1988 – 1993 are shown in figure 6.

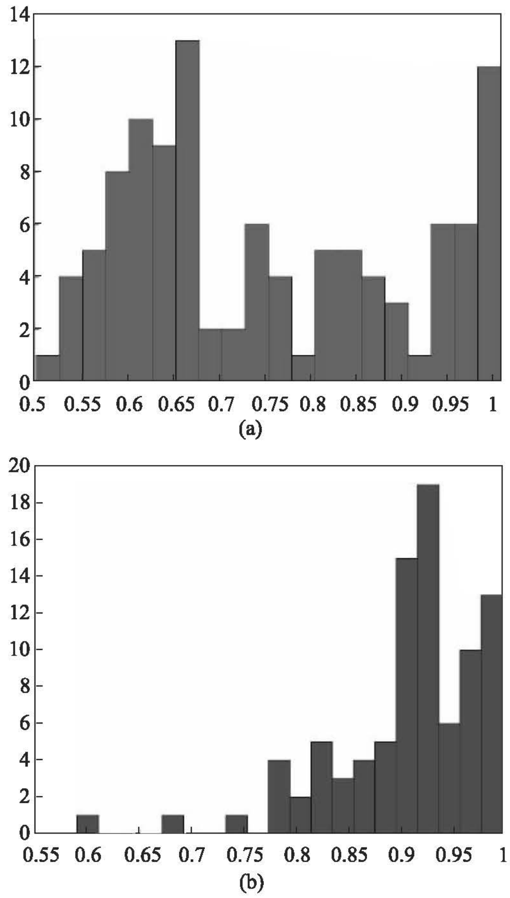



Figure 5 Histograms of *c* values((a) Left, prior to *M*w9.1; (b), during 1988 – 1993)

## 6 Conclusions

1) By using the SLC method, our study of correlation length of moderate earthquakes prior to the *M*w9.1 and *M*s8.6 earthquakes in the northern sea area of Sumatra Island show a two-year power-law growth for both events.

2) By using the same method, no such growth is observed for smaller earthquakes in the same region, indicating that such growth may represent a physical process only in the source areas of great earthquakes in this region.

3) Such growth may be a good indication of the occurrence of a self-organized critical phenomenon prior to the great earthquakes.

4) Similar study should be carried out and compared

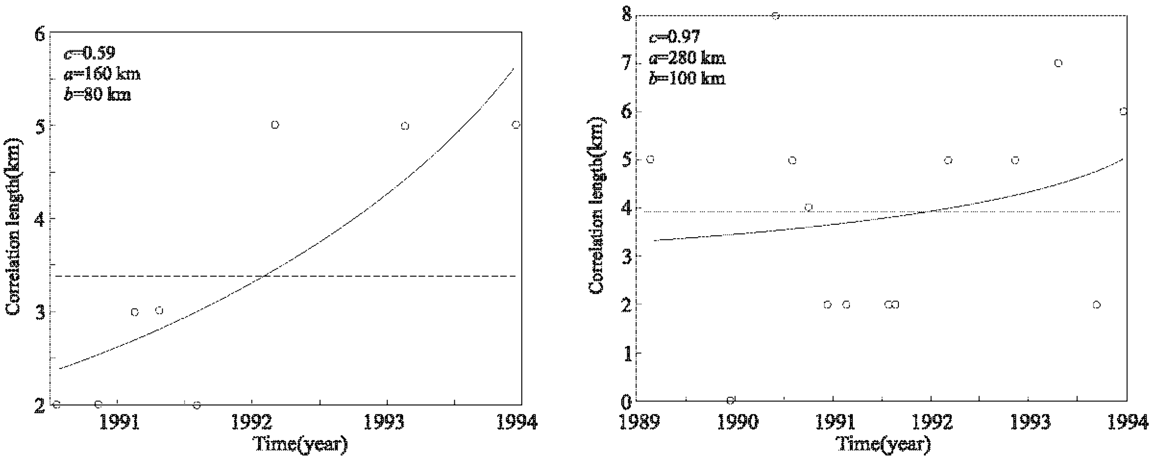



Figure 6 Time series of correlation length for earthquakes during 1988 – 1993
(Left, for minimum *c* value; right: an example for most conditions)

with other studies in the future.

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