บทความวิจัย

INVESTIGATION OF THE INTERNATIONAL EARTHQUAKE CATALOGUES IN THE MAINLAND SOUTHEAST ASIA

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ABSTRACT

The research aimed to study the quality of earthquake catalogue of the National Earthquake Information Center (NEIC) and the International Seismological Center (ISC), with respect to the seismicity patterns of the mainland Southeast Asia. The readymade relationships between the different magnitude scales were derived to allow their convenient interconversion. Earthquake declustering was performed in order to screen the main shocks from the foreshocks and aftershocks. The NEIC's network has gone through periods of station expansion, change in the seismic measurement system but the only major periods of rate changes were found. The ISC catalogue has gone through periods of change in seismic measurement system but the only major periods of rate changes were found. Therefore, the NEIC's catalogue and the ISC's catalogue ware sufficient for hazardous earthquake investigations. The results of the NEIC's catalogue were sufficient for hazardous earthquake investigations that were recorded during 2014.0185-2017.6086 for Mw > 4.5. The FMD investigation using EMR revealed Mc of 4.5, 4.6, 4.8 and 4.5 for the 4 bulk data set. And the results of the ISC catalogue were sufficient for hazardous earthquake investigations that were recorded during 1995.2115 –2014.4836 for mb > 4.0. The FMD investigation using EMR revealed Mc of 4.1, 4.0 and 4.4 for the 3 bulk data set.

Keywords: earthquake catalogue, frequency-magnitude distribution, Southeast Asia

Introduction

The earthquake catalogue is the earthquake data recorded instrumentally 1) the location (latitude, longitude, and depth), 2) occurrence time (year, month, day, hour, minute, and second), including the earthquake magnitude. Conceptually, the data reported in the earthquake catalogue are simple but quite useful for any seismotectonic investigation. For the Mainland Southeast Asia, an alternative earthquake catalogue is provided currently in the International Seismological Center (ISC) and the National Earthquake Information Center (NEIC). Both of them have potential advantages and abroad scope of recordable magnitudes, particularly for small-to large-sized earthquakes. Especially, the data derived from earthquake catalogues are regularly inhomogeneous and deficient in respect to the limitation of detection change, including the manmade changes (Habermann, 1987). Consequently, the earthquake catalogues were misinterpreted of the tectonically related activities. Therefore, this study aimed mainly to clarify qualitatively the ISC and the NEIC catalogue. The ready-to-use procedures for homogenizing and assessing the completeness of the catalogue are proposed. The obtained results will be useful for further seismicity and seismic hazard investigations, in particular within the Mainland Southeast Asia.

Tectonic setting of the mainland southeast asia

Southeast Asia is a region of various tectonic, between the Eurasian and Indo-Australian plate, and the Philippines and West Pacific plates. There are surrounded by convergent margins (Figure 1), It comprises the Burma oblique subduction zone to the northwest, Andaman thrust and Sunda Arc to the west and the south, respectively. The Cenozoic tectonics of Thailand and The South East Asia as a whole, are a consequence of collision of India with Eurasia collision began about 50 Ma and have resulted in 2,000 to 3,000 kilometers shortening across the Himalayan orogeny. As India drove into the southern margin of Eurasia, Indochina was rotated clockwise for about 25o and extruded to the southeast by approximately 800 kilometers along the Red River and the Three Pagoda fault zones during the first 20-30 million years of the collision (Peltzer & Tapponnier, 1988). The present tectonic stress regime in Thailand is one of transtension, with opening along north-south oriented basins and right-lateral and left-lateral slips on northwest-and northeast-striking faults, respectively (Polachan, 1991).

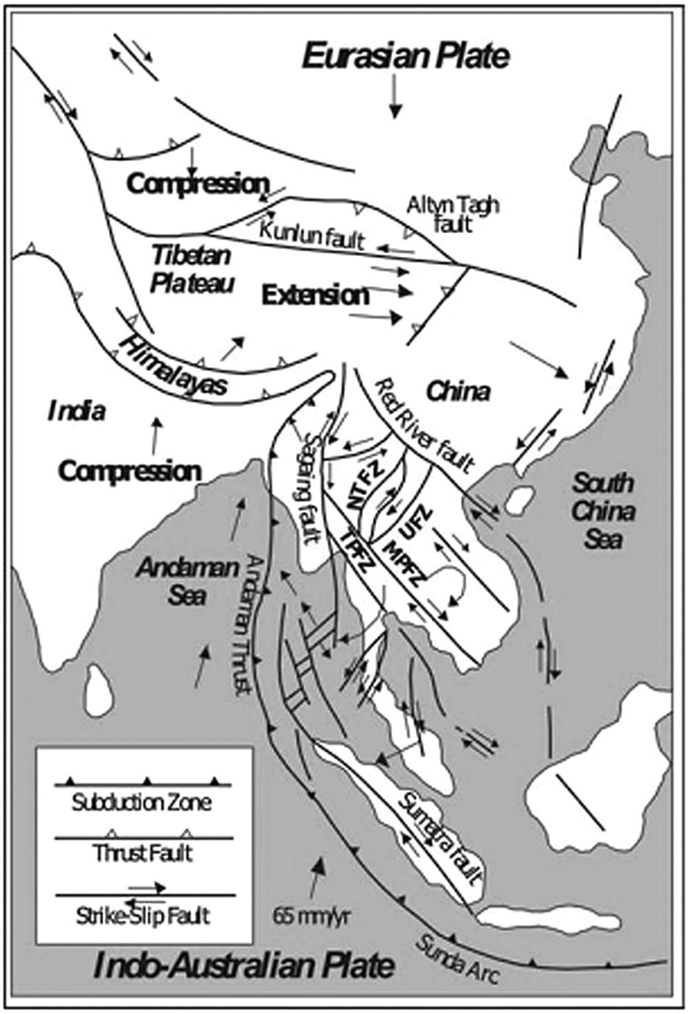


Figure 1 Major tectonic elements in Southeast Asia and Southern China.
Arrows show relative directions of motion of crustal blocks during the Late Cenozoic.
MPFZ-Mae Ping Fault Zone; NTFZ-Northern Thailand Fault Zone;
TPFZ-Three Pagodas Fault Zone; UFZ-Uttaradit Fault Zone (Polachan, 1991).

Method

This study focused on the seismicity in Thailand and adjacent areas. (Latitude 0°-25°N and Longitude 90°-110°E) (Figure 9). The data set from 2 catalogues of instrumentally recorded earthquake events in study areas. There are the ISC and the NEIC catalogues. The first of this is catalogue improvement including:

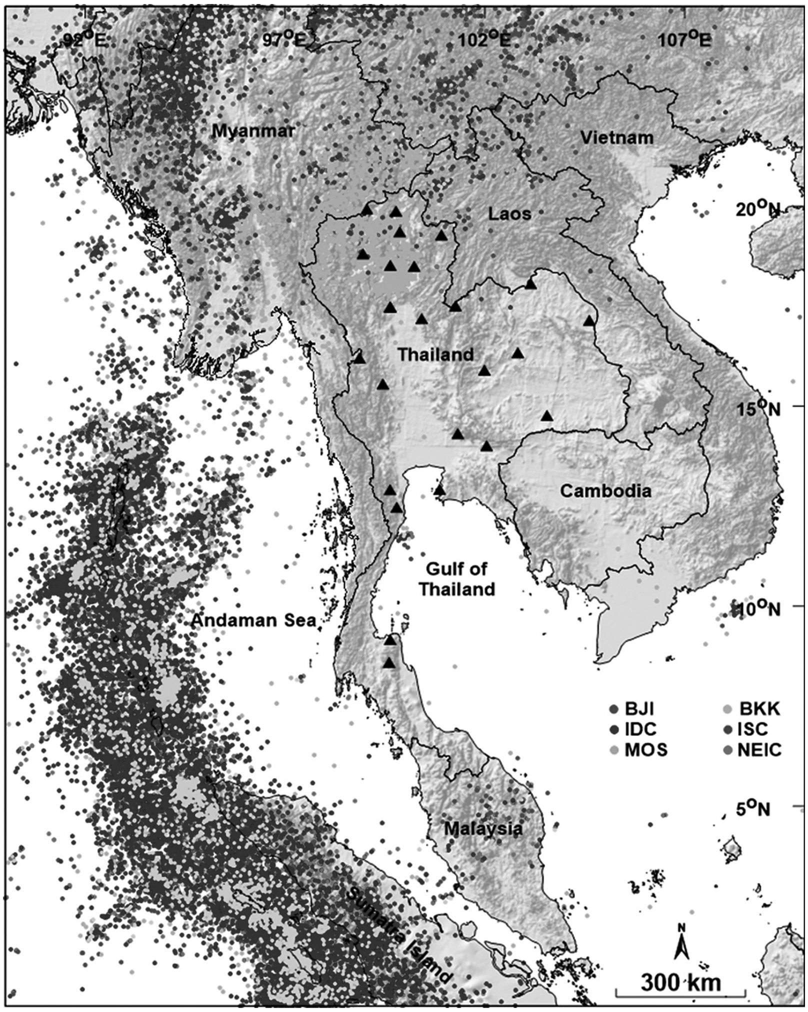


Figure 2 Map of the Mainland Southeast Asia demonstrated the distributions of earthquakes followed by the TMD and derived from the (1) China Digital Seismic Network (BJI), (2) TMD, Bangkok (BKK), (3) International Data Center (IDC), (4) International Seismological Center (ISC), (5) Institute of Physics of the Earth, Moscow, Russia (MOS), and (6) the NEIC. The triangles identify the locations of the persistent seismic recording stations of the TMD (Pailoplee, 2014).

1. Catalogue Collection

Due to the fact that, the earthquake catalogue in each network around the world has different advantages and limitations for example, the NEIC in Figure 3a and the ISC in Figure 3b. Therefore, this investigation is to obtain the best earthquake catalogue in terms of quality and quantity. In the first step of the earthquake catalogue is updated to be used in statistical analysis of seismology and then tries to create a new earthquake catalogue. By collecting the most earthquake data reported in various catalogue, in the case of repeated earthquake measurements in each catalogue, it selects only the most reliable catalogue to represent each earthquake (Suckale & Grünthal, 2009). The result is a new earthquake catalogue with longer measurement time. The distribution of the magnitude scale is more widely measured and covers more study areas.

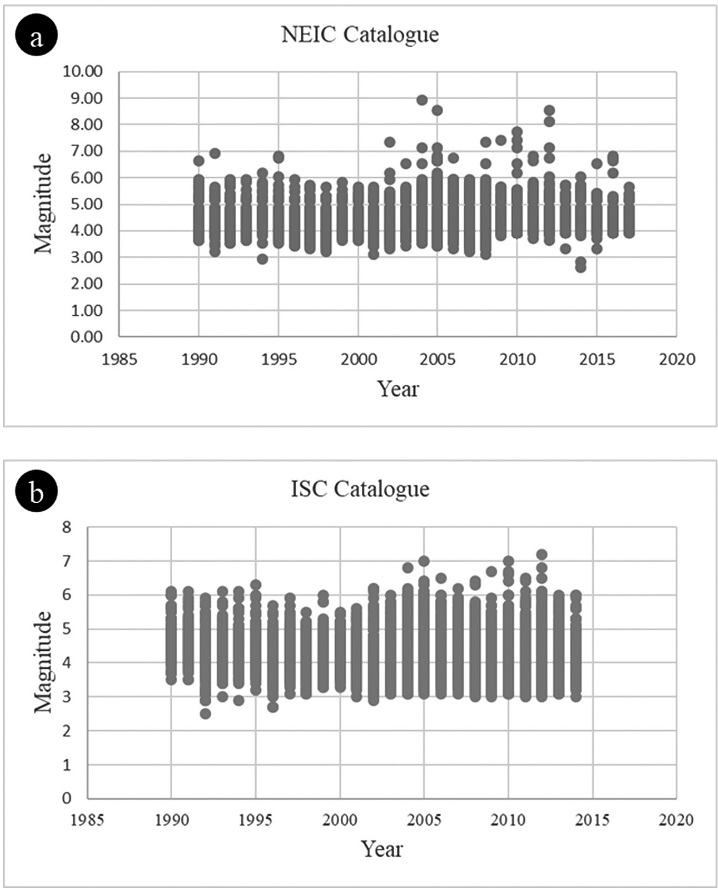


Figure 3 The relationship between magnitude and time of the earthquake occurrence in the Mainland Southeast Asia on a major earthquake recorded in (a) the NEIC and (b) the ISC.

2. Magnitude Conversion

The earthquake catalogue can be recorded from various areas in the world of various organizations. Each earthquake is reported the different magnitudes depending on the suitability and the limitations of measurements, so the same earthquake event can be calculated from different magnitude scales (i.e. mb, Ms, ML and Mw), and may be also reported in different magnitude scale as well.

According to Kagan & Knopoff (1980), it was found that the measurement of large earthquakes with amplitude exceeds the limit of the earthquake measuring instruments usually reported in “mb”, “Ms”, and “ML” lower than reality, called saturation of earthquake magnitude. Each section has different saturation levels. Therefore, it has to calibrate the relationship between various magnitude scales. By bringing the data that has reported the earthquake magnitude of more than 1 magnitude scale of each earthquake, it can be used to create a relationship graph between various magnitude scales of the earthquake (Figure 4). The relationship graph obtained above is used to convert the earthquake magnitude in the same study area into equivalent data. The selection of magnitude scales has 2 principles: 1) convert other magnitude scales to be the most reported magnitude scale in the original catalogue because they do not want to change or make an impact on the original catalogue. 2) convert magnitude scale into moment magnitude (Mw) because it is the only magnitude scale that estimates the magnitude of the earthquake from the variables that represent the energy that the earthquake actually released (Hank & Kanamori, 1979)

After the conversion of the magnitude scale, the earthquake catalogue reports the magnitude of the earthquake only one magnitude scale.

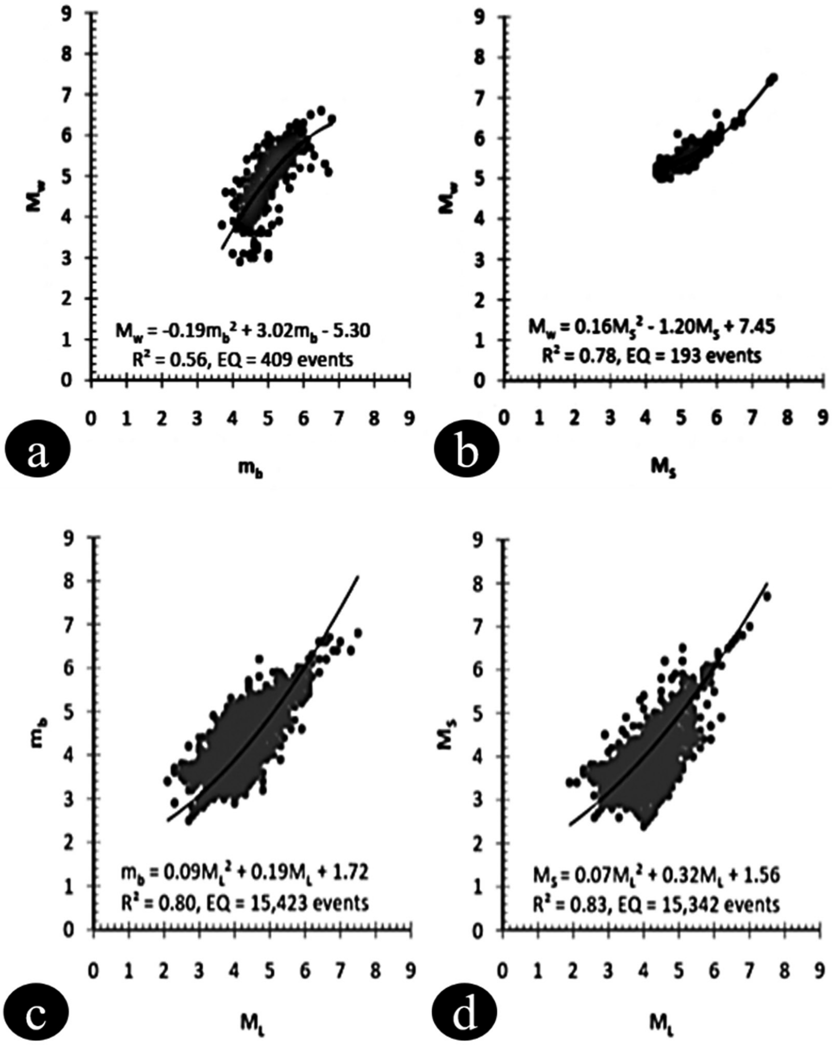


Figure 4 Empirical relationships of the different magnitude scales used for the TMD's earthquake catalogue; showing that for (a) Mw-mb, (b) M w-MS, (c) m b-ML, and (d) M S-ML. The best fit regression line, its equation and R2 value are shown (Pailoplee, 20140).

3. Earthquake Clustering

In the past, from the study of the global catalogue (Aki, 1965) and local catalogue (Knopoff, 1964) it was found that the recorded earthquake data can be classified according to the mechanism and occurrence of earthquakes into 3 types: 1) foreshocks 2) mainshocks and 3) aftershocks. The mainshocks are caused by the stress in the plate tectonics directly. The foreshocks were caused by preparation before the mainshocks. Therefore, having earthquake clustering eliminates foreshocks and the aftershocks. An earthquake catalogue contains only the mainshock which indicates the behavior of earthquakes caused by seismotectonic directly. At present, the 3 popular conditions are used in terms of relationship: 1) size, 2) distance and, 3) time of occurrence during the earthquake. Both foreshocks and the aftershocks, which are meaningless in seismotectonic investigation, were identified and removed by using assumption reported by Gardner & Knopoff (1974) as implemented in the ZMAP program (Wiemer, 2001). The various color lines are the distance (kilometer) and the time (day).

The earthquake pair that considers the distance difference near or below the specified color line of the distance graph and there is a difference in the duration of the earthquake, shorter or lower than the specified line of the time graph, is considered to be the same earthquake clustering events. After that the largest earthquake in each cluster is selected as the mainshock events (Figure 5).

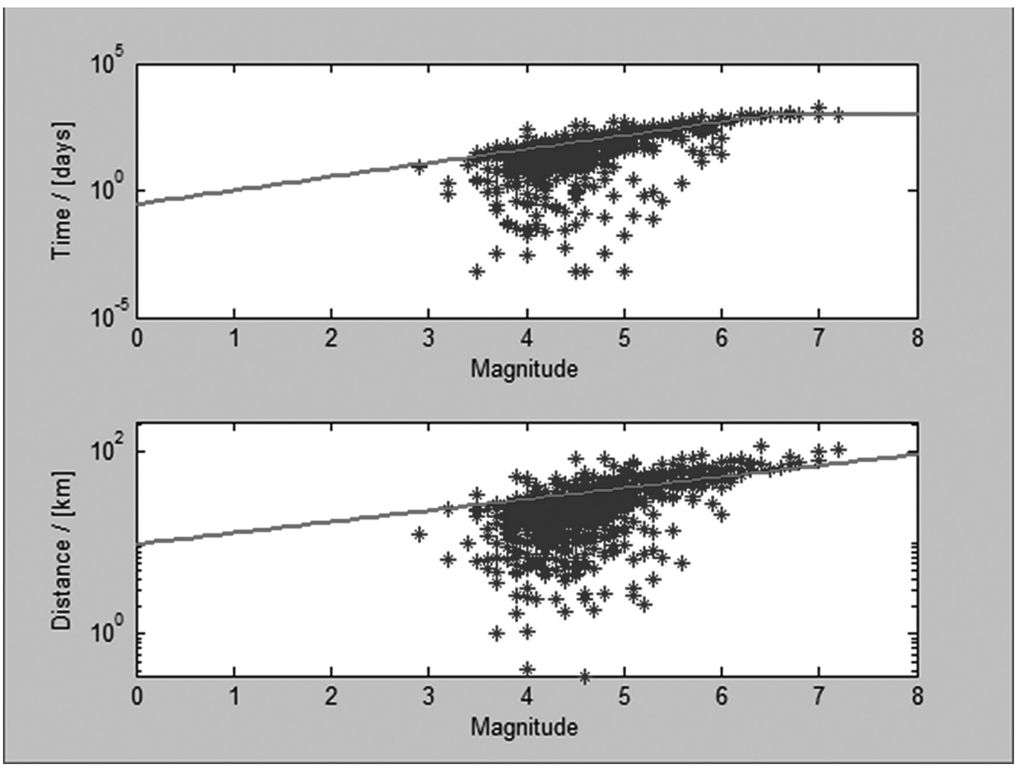


Figure 5 Show the result of earthquake catalogue declustered of the assumption reported by Gardner and Knopoff (1974) and as implemented in the ZMAP program (Wiemer, 2001).

4. Detection System Change

From the studies of seismologists, (Reasenberg & Simpson, 1992; Dieterich & Okubo, 1996; Wyss & Martyrosian, 1998) there found that most earthquake databases were affected by changes in seismic measurement systems from a variety of causes including 1) detection change means the increasing the number of seismic stations, enabling better seismic measurements and, checking the large earthquake measurements that have been completed as before. For example, in 1964 the World-Wide Standardized Seismographic Network (WWSSN) was installed, causing the NEIC catalogue to increase measurement rate especially, small earthquakes. In addition, in some areas it was found that the rate of seismic measurements decrease which was often associated with the disabling of earthquake stations in some stations as well. 2) reporting changes based on the study of Harbermann & Wyss (1984) was found that the earthquake behavior in California was caused by an earthquake data set that did not identify an earthquake magnitude which is often found in the early stages of earthquake database records and in the remote earthquake database. 3) magnitude change was first detected by studying the earthquake database in the central part of California (Hermann & Wyss, 1984) caused by the change of form or software to calculate the earthquake magnitude. Therefore, they invented and presented the principles of analyzing the earthquake rate change to eliminate many problems from detection system change by Wiemer (2001) that proposed the Genetic Network Analysis System (GENAS) algorithm in Figure 6 developed and applied the principle of (Habermann ,1987) to analyze the change in the rate of earthquakes in each earthquake size range and sub-periods of earthquake data recording.

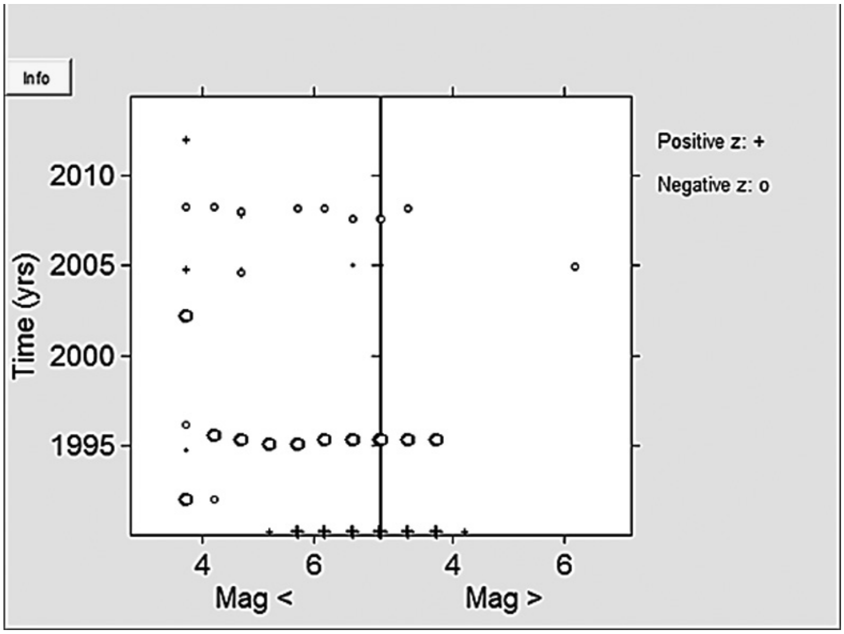


Figure 6 GENAS window illustrating the time of significant rate changes as a function of time of the ISC catalogue. Circles indicate rate increases and crosses rate decreases.

5. Frequency - magnitude Distribution

Frequency-magnitude distribution (FMD) Equation is a basic relationship for any seismicity studies (Ishimoto & Iida, 1939; Gutenberg & Richter, 1944) It explains the relationship between the frequency of occurrence and the magnitude of earthquakes.

$$\mathrm{Log10}\ N\ (M) = a\text{-}bM \qquad \text{Equation (1)}$$

Where N is the cumulative number of earthquakes having magnitudes larger than ‘’M’’, and ‘’a’’ and ‘’b’’ are the constant units. The b-value describes the relative size of the events and is determined by either linear least squares regression or by maximum-likelihood analysis considering as the Mc (Utsu, 1965). Because of the changes in the Mc affecting the obtained a-and b-values, before proceeding in such that the frequency-magnitude distribution investigations and it is essential to examine and report on the spatial and temporal completeness of the catalogue. Therefore, in this study, the Mc (Figure 7) was estimated according to the Entire Magnitude Range method (EMR) (Woessner & Wiemer, 2005) based on Ogata and Fatsura (1993). We estimate Mc use the entire data set, including the range of magnitude reported incompletely because the method is stable under most condition and shows a superior performance when applied to synthetic test cases or real data from regional and global earthquake catalogues.

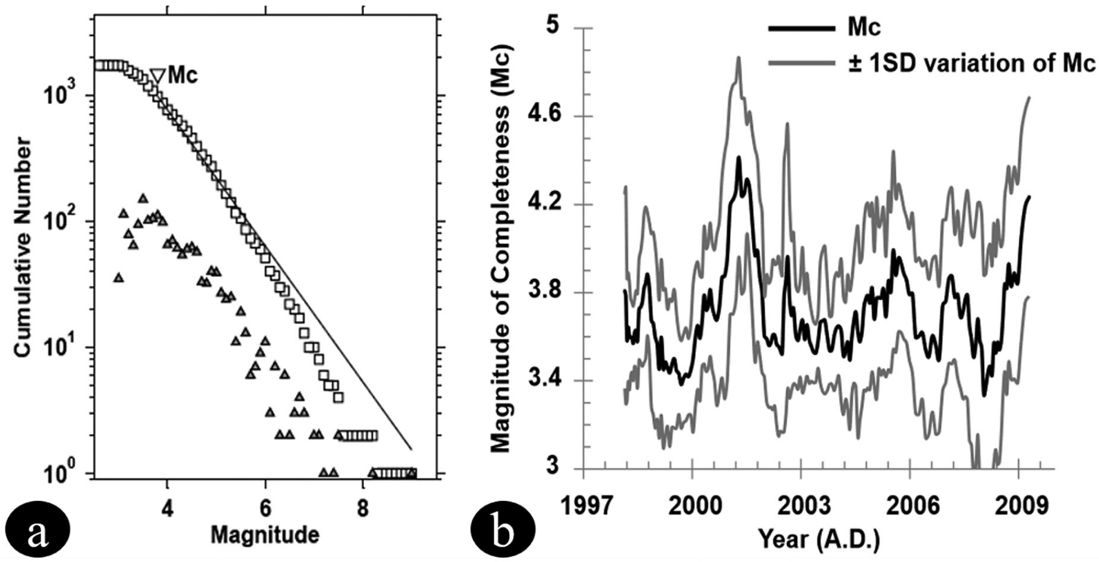


Figure 7 (a) The diagram showing the frequency-magnitude distribution (FMD) plot of the seismicity data recorded from the Thailand Meteorological Department (TMD) mb ≥ 3.0 during 1998.31-2009.01 (Pailoplee, 2014). Triangles indicate the number of earthquakes of each magnitude; squares represent the cumulative number of earthquakes equal to or larger than each magnitude. Solid lines are the lines of best fit according to Woessner & Wiemer (2005) Mc is defined as the magnitude of completeness. (b) Temporal variations of the Mc as a function of time since 1998-2009 (Pailoplee, 2014).

Results and discussion

The NEIC catalogue showed the outputs of the GENAS algorithm as the times of significant rate changes. There are four obvious rate changes in the reported events and the Mc is estimated according to the Entire Magnitude Range method (EMR) (Woessner & Wiemer, 2005). The Data set 4 is the best data to show the rate change increases with Mw > 4.0 in 1990.0191 and Mw > 9.0 in 2017.6086. The FMD plot, ‘’a’’ is 6.77 and ‘’b’’ is 0.845±0.03. By the EMR method, the estimated Mc for the bulk data was found to be approximately 4.5 Mw and the variations of Mc as a function of time during 1990-2017 reveal that the temporal Mc throughout these 7 years varied between 4.0-9.0 Mw. There are some promimences that decreases in Mc in 1991, 1997, 2008, 2012 and 2015 and increases in 1992, 2000, 2004, 2005, 2007, 2010 and 2017.

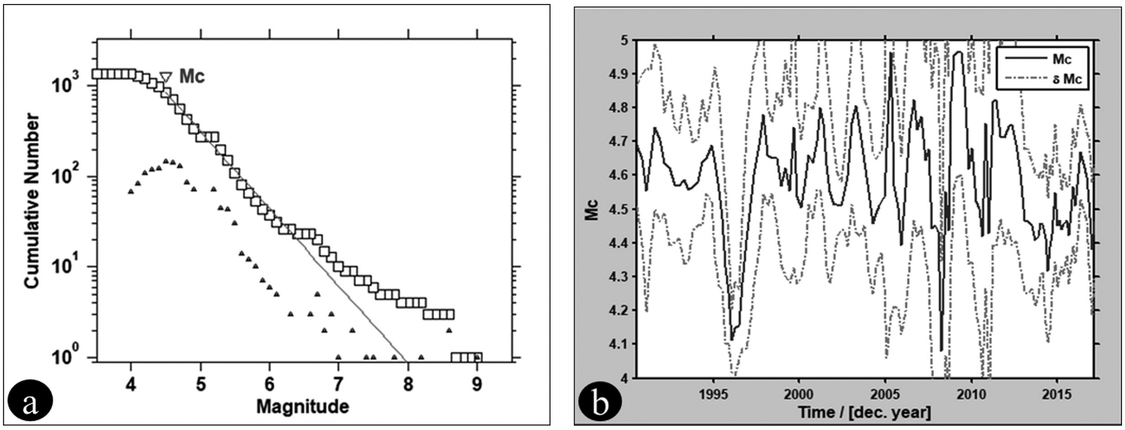


Figure 8 (a) FMD plot of the seismicity data recorded rate changes increases with Mw > 4.0 in 1990.0191 and Mw > 9.0 in 2017.6086. Triangles indicate the number of earthquakes of each magnitude; squares represent the cumulative number of earthquakes equal to or larger than each magnitude. Solid lines are the lines of best fit according to Woessner & Wiemer (2005) Mc is defined as the magnitude of completeness. (b) Temporal variations of the Mc as a function of time since 1990-2017.

In addition, the obtained Mc map reveals that the areas of Thailand-Laos-Myanmar border shows a high earthquake detection capability with the lowest Mc ranging from 4.0-5.0 Mw, which is reasonable enough for seismic hazard analysis recognizing earthquakes with Mw ≥ 4.0 as the hazard (Kramer, 1996). However, the Gulf of Thailand and Andaman Sea, the earthquake data of the NEIC catalogue were weak with the highest Mc up to 5.0-5.5 Mw. Based on statistical analysis as mentioned above it can shows the accuracy of the FMD relationship equation analysis which shows the percentage of the consistency between the mathematical model and the actual data of the FMD relationship equation (% of goodness fit of FMD).The percentage of goodness fit of FMD, that were more than 80% indicated that the assessment results are statistically reliable.

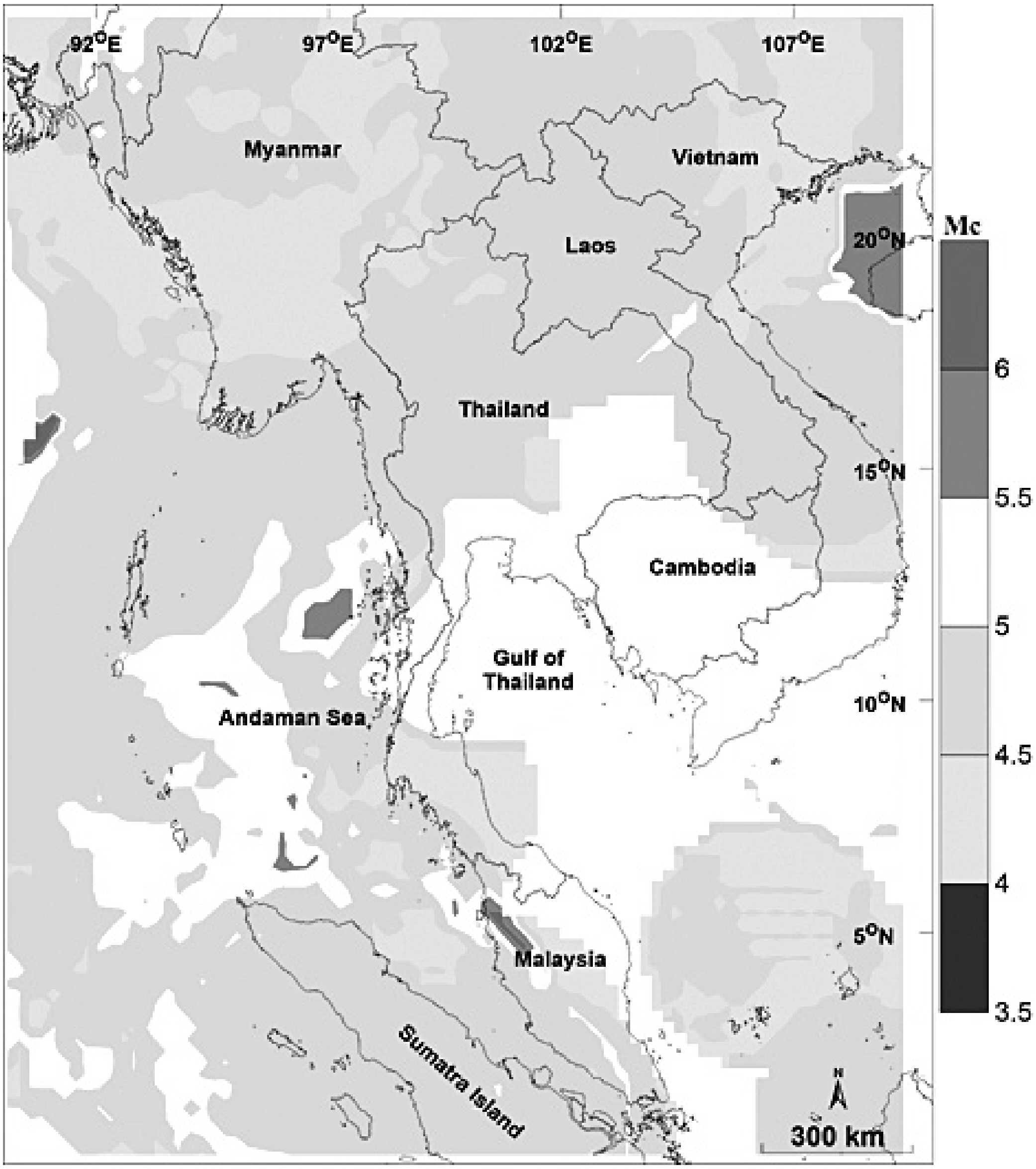


Figure 9 Map Dataset 4 showing the spatial distribution of Mc analyzed from dataset 4. The circles illustrate the 300 km radius from four specific areas where the FMD plots are demonstrated in Figure 10.

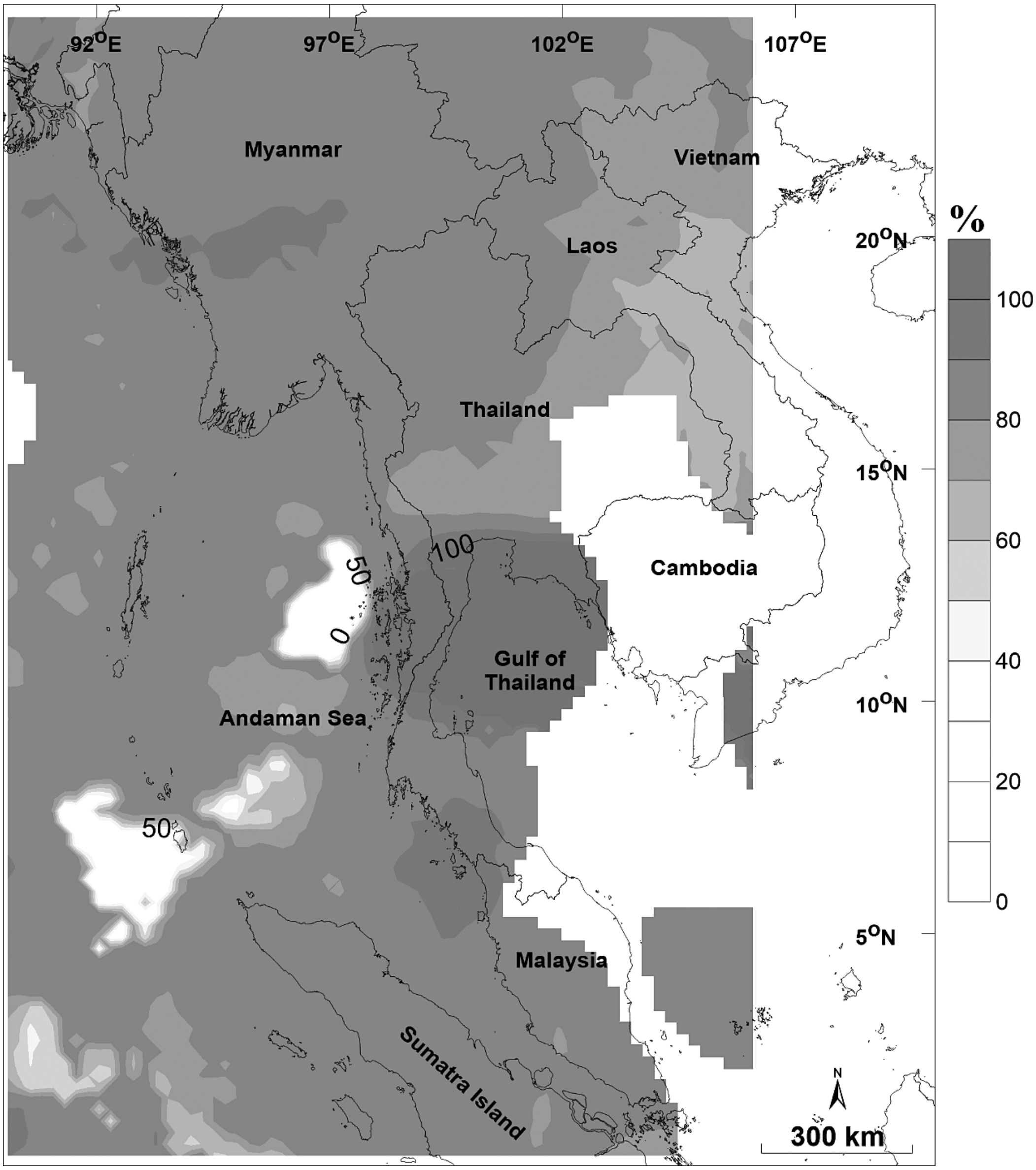
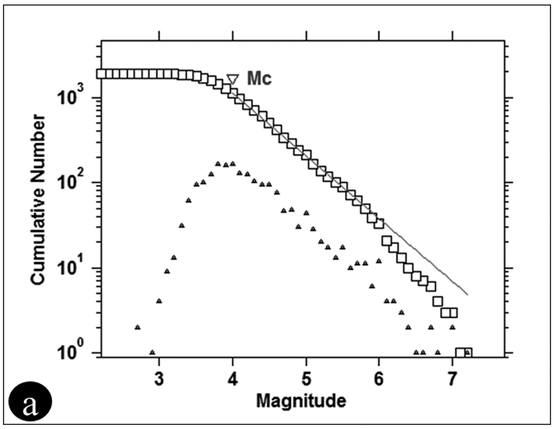


Figure 10 Map Dataset 4 showing percentage of the consistency between the mathematical model and the actual data of the FMD relationship equation (% of goodness fit of FMD).

The ISC catalogue shows the output of the GENAS algorithm as the times of significant rate changes. There are three obvious rate changes in the reported events. The Mc was estimated according to the Entire Magnitude Range method (EMR) (Woessner & Wiemer, 2005). The Data set 2 is the best data showing the rate changes increases with rate changes increases with mb > 2.7 in 1995.2115 and mb > 7.2 in 2014.4836. The FMD plot, a is 6.00 and b is 0.737±0.02. By the EMR method, the estimated Mc for the bulk data was found to be approximately 4.0 mb and the variations of Mc as a function of time during 1990-1994 reveal that the temporal Mc throughout these 4 years varied between 2.9-6.1 mb. There are some prominent decreases in Mc in 1991.5, 1993 and 1994 and increases in 1991, 1992.5 and 1993.5.



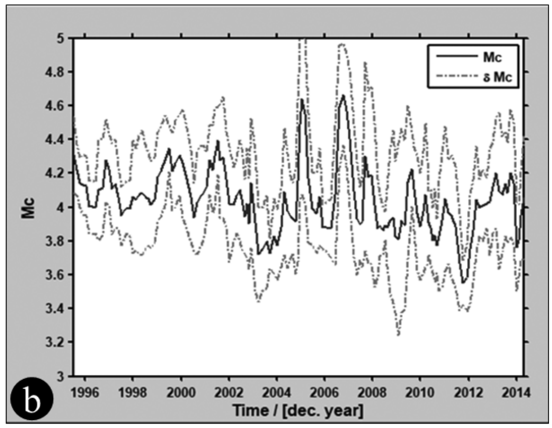


Figure 11 (a) FMD plot of the seismicity data recorded mb > 2.7 in 1995.2115 and mb > 7.2 in 2014.4836. Triangles indicate the number of earthquakes of each magnitude; squares represent the cumulative number of earthquakes equal to or larger than each magnitude. Solid lines are the lines of best fit according to Woessner Wiemer (2005). 00Mc is dfined as the magnitude of completeness. (b) Temporal variations of the Mc as a function of time since 1995-2014.

In addition, the obtained Mc map revealed that the areas of Thailand-Laos-Myanmar border Malaysia and Sumatra Island showed a high earthquake detection capability with the lowest Mc ranging from 3.5 to 4.5 mb, which is reasonable enough for seismic hazard analysis recognizing earthquakes with Mw ≥ 4.0 as the hazard (Kramer, 1996) However, for the Gulf of Thailand and Andaman Sea, the earthquake data of the ISC catalogue were weak with the highest Mc up to 4.5-5.0 mb. Based on statistical analysis as mentioned above, it can show the accuracy of the FMD relationship equation analysis which shows the percentage of the consistency between the mathematical model and the actual data of the FMD relationship equation (% of goodness fit of FMD). The percentage of goodness fit of FMD, that were more than 80 %, indicates that the assessment results are statistically reliable.

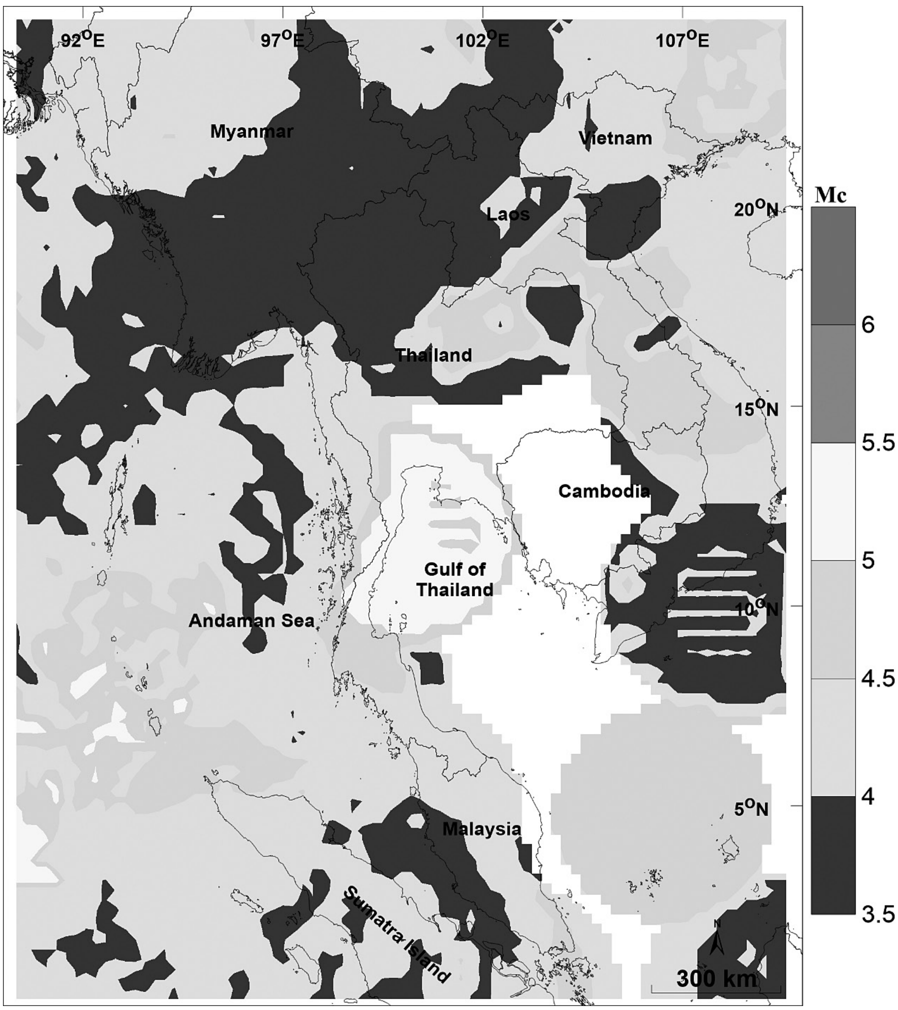


Figure 12 Map of Dataset 2 showing the spatial distribution of Mc analyze from Dataset 2. The circles illustrate the 300 km radius from four specific areas where the FMD plots are demonstrated in Figure 13.

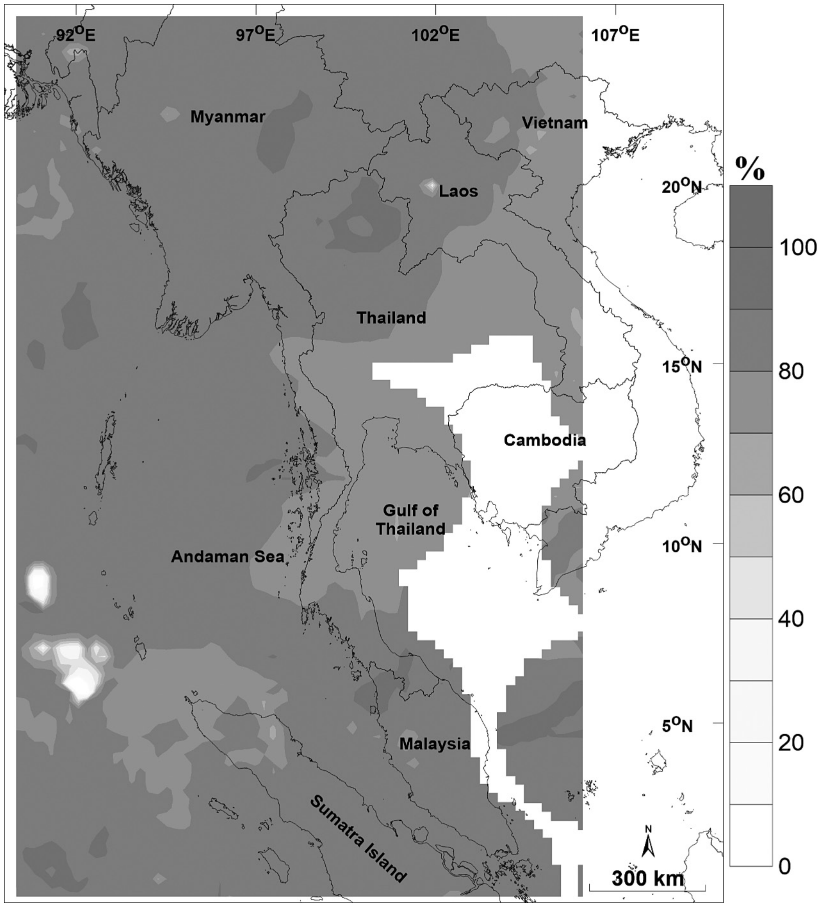


Figure 13 Map Dataset 2 showing percentage of the consistency between the mathematical model and the actual data of the FMD relationship equation (% of goodness fit of FMD).

Conclusions

In this study, the NEIC catalogue was investigated to report on the potential inhomogeneities and artifacts that could distort the earthquake catalogue which may provide further insight when examining in detail of the seismicity patterns. The magnitude scale, earthquake cluster, man-made impact, and the limitation of detection were evaluated. Also, the guidelines for improvement are provided. From these investigations, the following outcomes were obtained.

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