

THE ECAT SOFTWARE PACKAGE TO ANALYZE EARTHQUAKE CATALOGUES

Tuba Eroğlu Azak

Akdeniz University, Department of Civil Engineering, Antalya Turkey

tubaeroglu@akdeniz.edu.tr

Abstract: Earthquakes are one of the most damaging natural disasters. Accordingly, earthquake phenomenon has been an important subject in seismology and earthquake engineering. In order to have insight on earthquakes, they have been compiled over the past years in databases called as earthquake catalogues. In seismic hazard studies, earthquake catalogues are of prime importance as they provide the most important features of earthquakes such as date, time, location, magnitude, depth etc. Accordingly, earthquake catalogues are often utilized to model seismicity. However, before such an implementation, earthquake catalogues need to be undergone several analyses such as seismic declustering, assessment of completeness periods and calculation of magnitude recurrence parameters. In order to perform these analyses, several software packages are available for users on different programming platforms. Vast majority of these software are only applicable to earthquake catalogues that are complete over the time period they extend. However, most of the earthquake catalogues are incomplete in terms of small and moderate size events particularly in the early years of instrumental period. This paper illustrates some of the useful features of the software package called as ECAT that is generated to compute completeness and magnitude recurrence parameters of earthquake catalogues whose completeness periods are unequal for different magnitudes.

Keywords: Earthquake Catalogue, Catalogue Completeness, Calculation of Magnitude Recurrence Parameters

Introduction

Turkey is located on a highly seismically active region where many devastating earthquakes take place. Only in the last 20 years, more than 10 earthquakes with $M_w \geq 6$ hit the country. Among them, in particular, Kocaeli and Düzce earthquakes served as a landmark for a better understanding of earthquake hazard and earthquake risk in Turkey. Accordingly, considerable effort has been given on assessment of seismic hazard on the basis of continually updated and improved seismic data. Considering seismic data, the contribution of earthquake catalogues in earthquake engineering is significant as the most important information on earthquakes such as location, time, magnitude and depth are compiled in these documents. Accordingly, seismic catalogues are often utilized to model and investigate seismic sources. To achieve this goal, however, further analysis steps such as seismic declustering, completeness analysis and magnitude-recurrence model analysis are essential. Considering these tasks, computer software is considerably necessary due to the utilized methods that either require back and forth computation or reapplication of the procedure several times for different sets of data and condition. Moreover earthquake catalogues are often lack of some small and moderate size events. This fact is mainly attributed to poor seismic networks in the early years of instrumental period. Accordingly, completeness periods of small, moderate or big size events in an earthquake catalogue may differ. Although there exist several methods to deal with the catalogues with unequal completeness periods, handy computer programs that incorporate such methods are either limited or not very well-known.

Recently, a national project supported by AFAD (Disaster and Emergency Management Authority of Turkey) has been completed with the collaboration of several universities and public institutions. As the final product, probabilistic seismic hazard maps for peak ground acceleration (PGA) and 5 % damped spectral acceleration (SA) at $T=0.2s$ and $1.0s$ were produced for 475- and 2475-year return periods considering the administrative borders of Turkey. These maps were generated by considering two different sets of seismicity models namely 1-area source model and 2-fault source + smoothed seismicity model that were developed under the light of the updated Turkish earthquake catalogue and active fault map of the region. In line with the demands encountered during the course of the project, a software package called as ECAT (Earthquake Catalogues Analysis Tools) has been developed for assessing completeness periods of the Turkish earthquake catalogue and calculating magnitude recurrence parameters of earthquakes.

This study presents some of the useful features of the ECAT software that is applicable to earthquake catalogues

with unequal completeness periods. In the first part of the paper, capabilities of the software will be presented overall while the developed tools will be addressed in the subsequent sections.

General capabilities of the ECAT Software Package

The ECAT software is developed by making use of MATLAB® programming language and it provides a user-friendly environment for earthquake catalogue operations while letting users filter events in terms of date, location, magnitude and hypocentral depth. The main window of the software is based on a map in geospatial format that covers Turkish territory and its surroundings. The opening window of the software first asks for a catalogue file in the desired file format. Accordingly, all the events in the catalogue are plotted on the map in the main window of the program. Figure 1 illustrates the general view of the main window of the ECAT software.

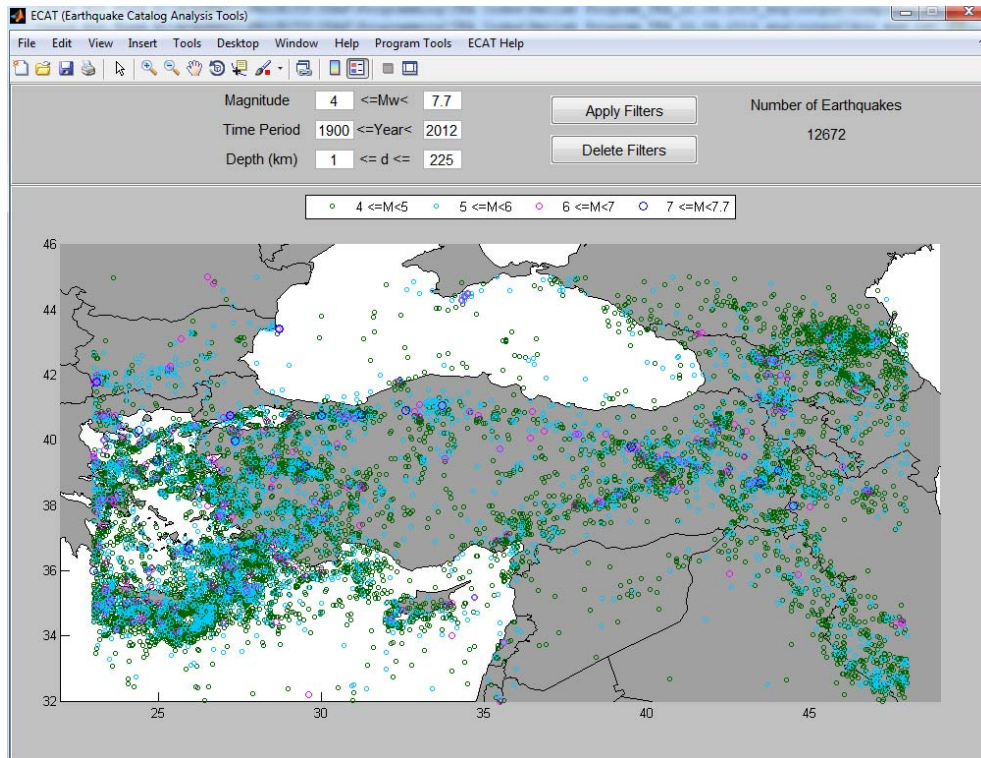


Figure 1. Main window of the ECAT software

As it can be seen in Figure 1, the earthquakes are plotted in terms of magnitude bins that are established with unit magnitude by default. On the upper panel, the extents of the selected catalogue are presented with upper and lower values in terms of magnitude, time and hypocentral depth. The user can limit and replot the earthquakes in terms of these 3 constraints with the “Apply Filters” and “Delete Filters” buttons. Upon the each mouse click on “Apply Filter” and “Delete Filter” buttons, the earthquakes on the map are replotted. Similarly, the number of events that fulfil the selected criterion are automatically refreshed on the right hand side of the buttons.

The developed tools within the ECAT software are grouped under the “Program Tools” menu on the menu bar. Under the “Program Tools” menu, the tools for region selection, completeness analysis and magnitude recurrence analysis are available. The general view of the “Program Tools” menu and cascading view of the “Select Region” menu are given in Figure 2. The operations related with these tools will be presented in the following sections.

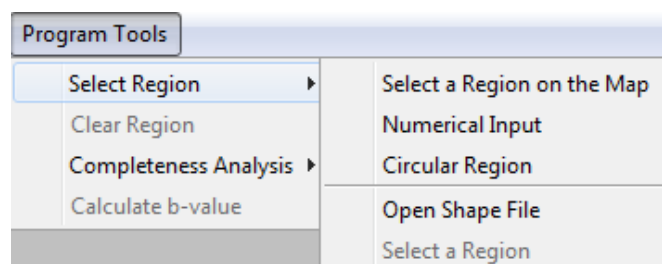


Figure 2. The submenus under “Program Tools” menu

Selection of a region

The ECAT software provides 4 different options for region selection. As the first option under the menu, users can define a region with an arbitrary shape by selecting the “Select a region on the map” command. By this command any shape with any number of points can be defined by clicking on the mouse buttons. A sample view of a user-defined region is presented in Figure 3.

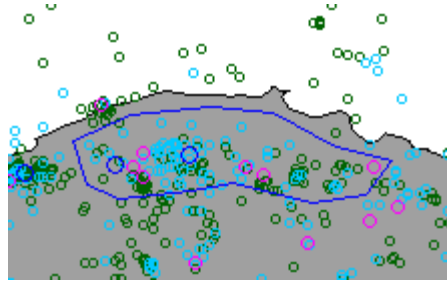


Figure 3. Region with an arbitrary shape

As the secondary option, users can define a rectangular region by selection the “Numerical input” command. Figure 4 illustrates the pop-up window where corner points of a rectangle can be entered.

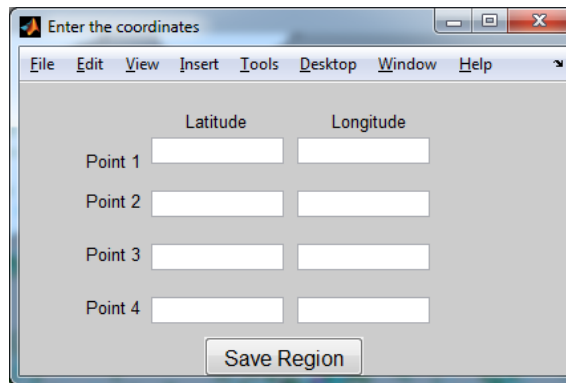


Figure 4. Rectangular region definition

The ECAT software also enables to define circular regions. By clicking on the “Circular region” option under the region selection menu, a pop-up window appears. On this window, users can define the central coordinates of a circle either by keyboard entry or mouse click on the main window. The radius of the circle is also defined on the circular region pop-up window.

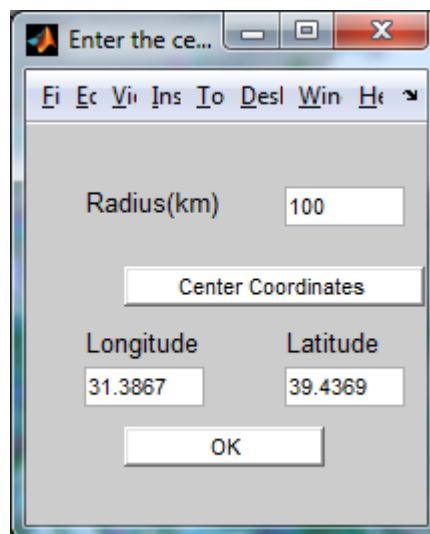


Figure 5. Pop-up menu for circular region selection

As the last option, region data can also be loaded from geospatial data files. Figure 6 illustrates a sample view of a loaded shape file that is plotted on top of the earthquake map. As it can be seen from the pop-up window

appearing in front of the main window, the program allows users to select a region out of several regions. Thus, a loaded shape file does not necessarily have to incorporate single region data.

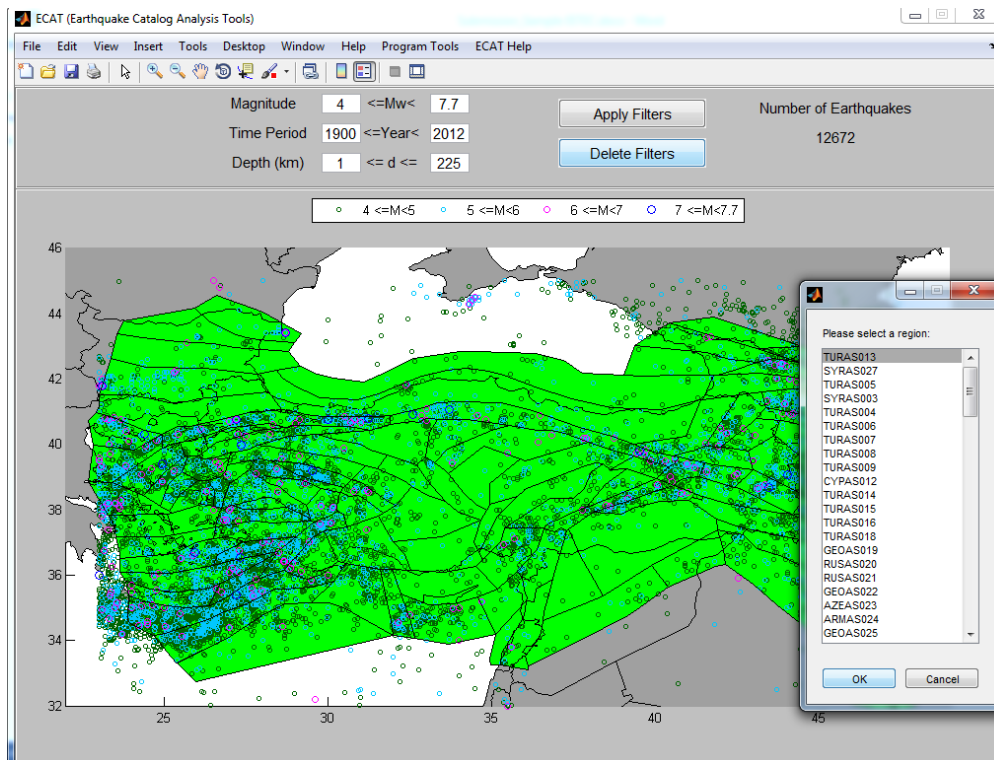


Figure 6. Selection of the region from a loaded shape file

After defining a region, users can proceed with the completeness analysis and magnitude recurrence relation tool.

Completeness Analysis Tool

As mentioned in the previous sections, earthquake catalogues are often lack of some events particularly in the early period of instrumental period. This fact complicates determination of completeness periods of catalogues as in this case one needs to investigate catalogue events in terms of subgroups of magnitude classes. Bearing on this idea, Stepp (1972) proposed a method to assess completeness periods of catalogues with unequal completeness periods. According to this method, the mean earthquake rate of each magnitude class is calculated for expanding time windows established from the last record backwards the first one. Then, scatter plots of standard deviation of the mean of the annual number of events are plotted against sample lengths for each magnitude class. Finally, completeness period of each magnitude class is assessed upon the stability of the estimates in the subintervals. The ECAT software enables users to decide on the duration of temporal window as well as magnitude interval to establish magnitude classes. The default values of these parameters are considered as 5 years and M_w 0.5 for time and magnitude increments respectively. The program also asks for lower, intermediate and upper magnitudes to be considered while constructing magnitude bins. Here, the intermediate magnitude is intended to separate moderate and big size events so that a single magnitude class can be established for big events regardless of the bin size. Figure 7 illustrates the main window of completeness analysis tool. On this window, users can zoom in and out on the plots and decide on the completeness periods of each magnitude class with the help of the auxiliary tools that can be utilized to draw/clear reference lines and trace on data.

The secondary method integrated into the ECAT software to assess completeness periods is based on the study by Mulargia et al. (1987). Similar to Stepp (1972) method, all selected earthquakes are grouped in terms of magnitude classes that are established according to the user's definitions. Then, cumulative number of events in each magnitude class is plotted against time starting from the first record towards the last one. Completeness period of each magnitude class is decided upon the stationarity of cumulative number of events. A sample plot of completeness analysis tool is illustrated in Figure 8 if the method by Mulargia et al. (1987) is selected.

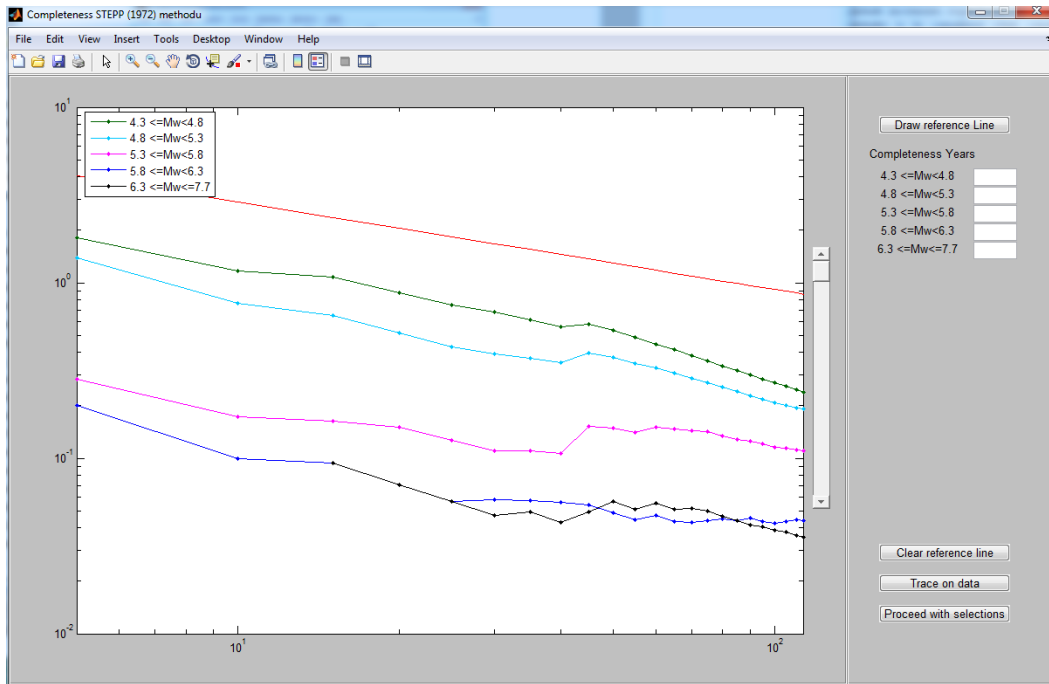


Figure 7. The main window of completeness tool for Stepp (1972) method

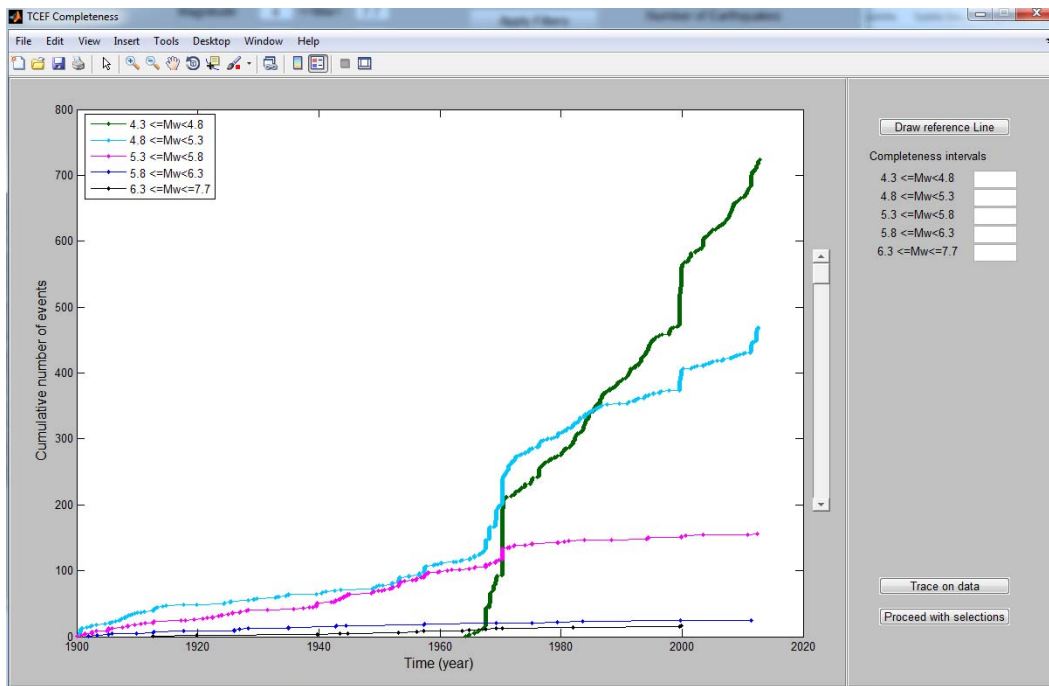


Figure 8. The main window of completeness tool for Mulargia et al. (1987) method

For both methods, completeness analysis is completed if “Proceed with selections” button is pressed. After this selection, the completeness analysis results are saved automatically as a text file under the main folder of the program. This file updates itself if the completeness analysis repeated. Once completeness analysis is completed, users can proceed with the magnitude recurrence tool.

Magnitude Recurrence Relation Tool

The ECAT software provides 3 methods for calculation of magnitude recurrence parameters. Among these methods, two of them can be applied to catalogues with unequal completeness periods. In the program, the magnitude recurrence tool can be accessed under the “Program Tools” menu. After choosing this tool, a pop-up window appears (Figure 9). On this window, the required inputs differ in accordance with the selected method.

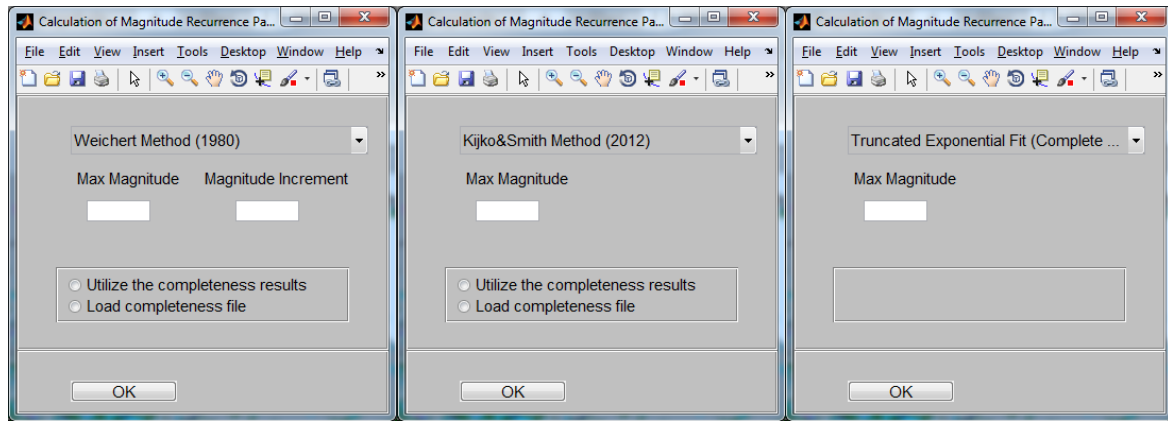


Figure 9. Appearance of the input window of magnitude recurrence tool in case (from left to right) Weichert (1980), Kijko and Smith (2012) and Truncated Exponential Fit method is selected.

According to Weichert (1980) method, maximum likelihood method is utilized to estimate magnitude recurrence parameters (ν and β) that are connected to the constants (a and b) of the Richter's (1958) equation (Eq. 1) for exponential distribution of earthquake magnitudes. Readers are referred to McGuire (1977) for the equivalent form of Eq.1 in case the equation is rearranged in terms of ν and β .

$$\text{Log}_{10}N(m) = a - bM \tag{Eq.1}$$

As one can infer from Figure 9, for the case of Weichert (1980) method maximum magnitude and magnitude increment values are decided by the user. Here, the user can either utilize the completeness analysis results of the latest completeness analysis or load a previously saved completeness file. In this method, the magnitude increment that is utilized to construct successive magnitude bins is considerable important. According to Bender (1983), the magnitude increment must be kept small enough in order to not create bias in estimates. To this end, the value of magnitude increment is considered as 0.1 M as default. However, users can define values different than the default value. Another important parameter utilized in Weichert (1980) method is the maximum magnitude. It is well known that maximum magnitude has a great effect on magnitude recurrence parameters. In this sense, decision on maximum magnitude needs to be made under the light of state-of-art geological and seismological (McGuire, 1977). After deciding on magnitude related entries and selecting completeness file, maximum likelihood estimates of magnitude recurrence model is calculated. After that, the exponential fit is illustrated together with earthquake recurrence data on a new window as given in Figure 10.

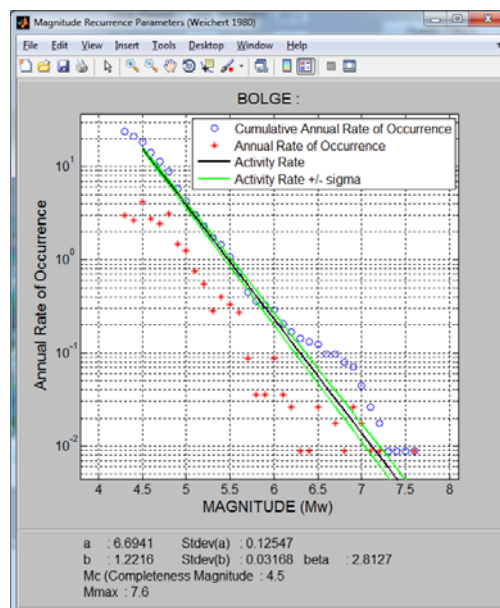


Figure 10. The fitted curve on earthquake recurrence data together with +/- σ

As the secondary method, users can utilize the method by Kijko and Smith (2012) to estimate magnitude recurrence parameters of the selected set of earthquakes. Similar to the previous method, maximum magnitude is

decided by the user. However, this method does not require any other input other than completeness data file. According to this method, selected set of earthquakes are divided into sub-catalogues so that each sub-catalogue established according to the completeness periods. Then, each sub-catalogue is treated as a complete catalogue and maximum likelihood estimates of recurrence parameters of each sub-catalogue are calculated on the basis of Richter's (1958) equation. The recurrence parameters of each sub-catalogue are then combined by a joint function and magnitude recurrence parameters are derived for the entire set of earthquake. The ECAT program does not provide a plot for the results if Kijko and Smith (2012) is utilized. The results are displayed on the command window.

As the final method, users can also select to proceed with truncated exponential fit option where selected earthquakes are considered as complete in each magnitude bin. Accordingly, the maximum likelihood estimates of magnitude recurrence parameters are calculated on the basis of Richter's (1958) relationship. A sample view of the fitted function is displayed in Figure 11 where circles red dots correspond to annual rate of occurrence and blue circles designate cumulative annual rate of occurrence.

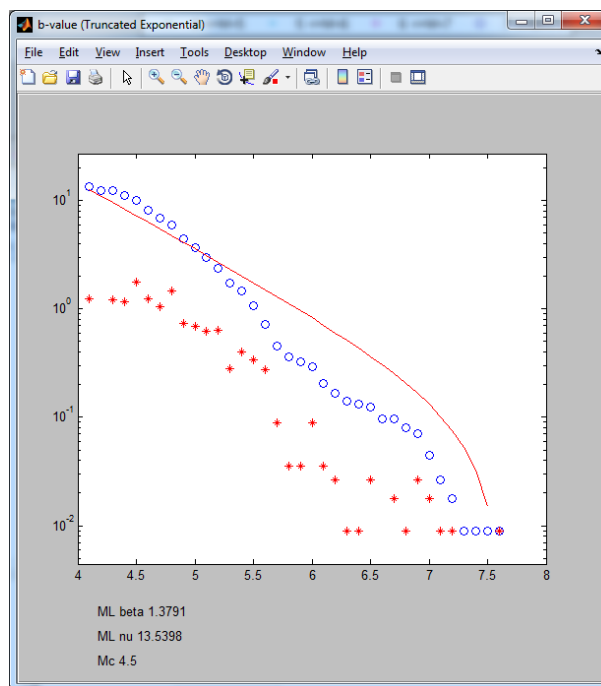


Figure 11. A sample view of fitted exponential curve in case truncated exponential fit option is selected

Concluding Remarks

This paper presents capabilities of the ECAT software that is developed to assess completeness of earthquake catalogues that have unequal completeness periods. In the recent version of the program, the completeness tool incorporates routines for Stepp (1972) and Mulargia et al. (1987) methods. The program also incorporates magnitude recurrence calculation tool that offers 3 methods to calculate maximum likelihood estimates of earthquake recurrence parameters. Among these methods, two of them are applicable to earthquake catalogues with unequal completeness periods. In the current version, the methods by Weichert (1980) and Kijko and Smith (2012) are integrated in the software. It is believed that the ECAT software will be a useful tool for researchers and engineers particularly for those who deal with earthquake catalogues that have unequal completeness periods.

References

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