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PRECURSORY SEISMIC QUIESCENCE BEFORE 1 MAY 2003 BINGÖL (TURKEY) EARTHQUAKE: A STATISTICAL EVALUATION

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ABSTRACT

The variations of seismicity rate changes prior to the occurrence of 1 May 2003 Bingöl earthquake has been analyzed by statistical method, with the observation of pointing up precursory seismic sequence. We investigated the significance of seismic quiescence for the region 39.6ºE-40.6ºE and 38.2ºN-39.6ºN. The analysis was carried out on the instrumental catalogue of the Boğaziçi University, Kandilli Observatory and Earthquake Research Institute (KOERI), covering the period from 1970 to 2005. The catalogue is homogeneous for duration magnitude, M_D, including 1926 crustal earthquakes of magnitude equal and greater than 1.8, with depths less than 70 km. For the calculations, we used the completeness magnitude as 3.2 and the number of events exceeding this magnitude is 915. In the first step, we declustered the catalogue using the Reasenberg algorithm. 43% of the events were removed and the number of these events was reduced to 522. The analysis was carried out making use of the *ZMAP* software package. The methodology we use involves the gridding method at the nodes of a 0.02º grid spacing. By *ZMAP*, the number of events associated with each grid point was selected as 50 after a few tests. The data are subdivided in bins of 28 days for each sample and we used a mowing time window T_W=5 years for the imaging of space and time rate changes. Finally, using the declustered catalogue spatial variability of *Z*-values is mapped for every one year between 1990 and 1998. It is not observed any significant seismic quiescence in time interval 1990 and 1993 around the 2003 main shock. After 1993, we observed a clear quiescence in and around the main shock epicenter of 1 May 2003 Bingöl earthquake with *Z* level between 2 and 3. This quiescence period is best revealed between 1995 and 1998. To identify the starting time and duration of precursory quiescence it is plotted cumulative number of events corresponding LTA(*t*) function for a circle of 7.79 km radius centered on Bingöl main shock. A decrease of the seismicity rate is found with Z_{max}=2.5 level at 1997.6. Thus, we found that Bingöl earthquake on May 1, 2003 (2003.33) followed an outstanding seismic quiescence starting 5.73 years before main shock. Based on this result, an estimate of future seismic hazard of these areas is made by the detection of seismic quiescence.

Keywords: *Bingöl, earthquake prediction, seismic quiescence, precursors, decluster.*

1. INTRODUCTION

The seismicity rate changes have been used in a great number of studies as a significant tool in order to explain the stress distribution in a specific area of the Earth's crust. Many authors have reported that precursory seismic quiescence occurred in and around focal areas several years before earthquakes: Tokachi-Oki [1,2], Tonga-Kermadec [3], Morgan Hill [4], San Andreas [5,6], Izu-Oshima [7], Kurile [8], Colfiorito [9] and Kefalonia [10]. Some studies on precursors of past earthquakes suggest that particular space-time seismicity patterns, including the phenomenon of precursory quiescence, can be related to the seismo-tectonic processes that lead to earthquakes [6,11,12,13]. The quiescence hypothesis, as formulated by Wyss and Habermann [11], postulates that the quiet volume overlaps the main shock source volume. The seismic quiescence hypothesis assumes that some main shocks are preceded by seismic quiescence, which is a significant decrease of the mean seismicity rate (number of events of magnitude exceeding a given threshold, per unit time), as compared to the preceding declustered background rate in the same crustal volume [9]. As requisite for the quiescence to be positively correlated with an eventual subsequent main shock, the decrease of seismicity rate must be defined by objective criteria [14] and be observed in all or a part of the source volume of the main shock. In some cases, it has been observed that the quiescence lasts until the time of the main shock, but in others the quiescence is separated from the main shock by a period of increased seismicity. The possibility of comparing the seismicity rate in a relatively small time and space volume, with the background seismicity level, is based on the assumption that the average seismicity rate in large crustal volumes and long time intervals, is constant [7].
To detect the significant seismic quiescence, it is necessary to decluster the earthquake catalogue. For this process, it has been made use of the algorithm introduced by Reasenberg [15]. The cluster analysis algorithm of Reasenberg [15] "declusters" or decomposes a regional earthquake catalogue into main and secondary events [16]. It removes all the dependent events from each cluster, and substitutes them with a unique event, equivalent in energy to that of whole series. The declustering process introduces some artificial manipulations. In fact, the declustering algorithm contains some arbitrary parameters that allow the user to remove aftershocks in a smaller or larger time or space interval with respect to the main shock location [9].
Seismic quiescence as originally proposed by Wyss and Habermann [11] is investigated for crustal events. It can be recognized by the methodology introduced by Wiemer and Wyss [17] and implemented in the *ZMAP* software package [18]. The *ZMAP* technique allows the user to analyze and to obtain graphic displays of seismicty rate changes in both space and time, in selected magnitude ranges. It allows also the quantitative evaluation of the statistical significance of any rate change (quiescence), the percentage of space-time volume interested by anomalies and the conditions by which a quiescence episode can be put in relation with a main shock [9].
The purpose of this study is to evaluate the seismicity rate changes (quiescence episodes) occurred before 1 May 2003 Bingöl (Turkey) main shock. If such features could be recognized as a constant and reliable character of the seismicity, they could eventually contribute to the forecast of impending main shocks in future circumstances. Thus, we aimed to provide additional information regarding the future seismic hazard of Bingöl.

2. METHOD

A continuous image of space and time rate changes in seismicity is produced by *ZMAP*, creating a grid of geographical co-ordinates, and associating to each grid node a selected number of nearest events. The subset of events belonging to each grid node is sampled in short time windows (usually a few weeks), so that the average number of events occurred in a time period of several consecutive samples (foreground) can be compared with that of all the remaining samples (background) [9]. We applied the *ZMAP* method [17] for imaging the areas exhibiting a seismic quiescence. Wiemer and Wyss [17] described details of the method. In order to rank the significance of quiescence, we used the standard deviate *Z*-test, generating the LTA(t) (Log Term Average) function [5,17,19,20] for the statistical evaluation of the confidence level in units of standard deviations:

$$Z(t) = \frac{R_{all} - R_{wl}}{\sqrt{\frac{\sigma^2_{all}}{n_{all}} + \frac{\sigma^2_{wl}}{n_{wl}}}} \tag{1}$$

where R_{all} is the mean rate in the overall period including T_W (from t_0 to t_e), R_{wl} the mean rate in the considered time window (from t to $t+T_W$). σ_{all} and σ_{wl} are the standard deviations in these periods, and n_{all} and n_{wl} the number of samples. t is the "current time" ($t_0<t<t_e$). The Z-value, calculated for all times t between t_0 and t_e-T_W

(Figure 1), by the equation is statistically appropriate for estimating seismicity rate change in a time window T_W in contrast with background seismicity. The *Z*-value computed as a function of time, letting the foreground window slide along the time duration of catalogue, is called LTA(*t*). The shape of the LTA(*t*) function strongly depends on the choice of the length of the foreground window (*wl*). While the statistical robustness of the LTA(*t*) function increases with the size of *wl*, its shape becomes more and more smooth, if the *w*l length exceeds the duration of the anomaly. Moreover, if one has to evaluate the statistical significance of an anomaly, it is not only necessary to decide the threshold level for the *Z*-value (in terms of standard deviations unit), but also the maximum time length allowed after the end of anomaly, before the occurrence of the main shock. The selection of the number of events at each point, and of the time bin, introduces two more free parameters in the procedure, and other three come from the choice of the geographical co-ordinates and the size of the sample. So, the geographical extension of the examined area must be sufficiently large in comparison with the presumable extension of the source area of an earthquake magnitude and the temporal extension of the catalog must be large enough [8].

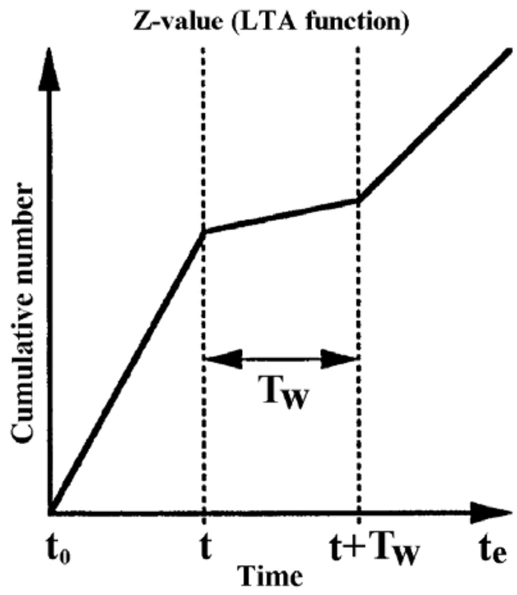


Figure 1. Schematic explanation of how to calculate *Z*-values. R_{all} is the average number of events in the whole background period, R_{wl} is the mean seismicity rate computed in the foreground window and T_W is the length of the time window in year. σ_{all} and σ_{wl} are the variances of the means, and n_{all} and n_{wl} the corresponding number of bins with a measured seismicity rate. *t* is the "current time" ($t_0<t<t_e$).

The duration of quiescence is the important parameter to be determined and its significance is maximized when T_W is equal to that value and for meaningful results we demand that they do not depend on the choice of T_W. Since it is not known how long quiescence may last it is varied the window length from 1.5 to 5.5 years, because this is in the range of reported seismic quiescence prior to crustal main shocks [21,22].

3. DATA USED

The database we analyzed in this study is taken from the instrumental catalogue of Boğaziçi University, Kandilli Observatory and Earthquake Research Institute (KOERI), starting from 1970 up to 2005. The catalogue is homogeneous for duration magnitude (M_D). We carried out our analysis in the rectangular area limited by the co-ordinates 38.2ºN and 39.6ºN in latitude and by the co-ordinates 39.6ºE and 40.6ºE in longitude. Figure 2 shows the epicenter distribution of shallow earthquakes (depth<70 km) in and around Bingöl occurred in time between 1970 and 2005 together with principal main shocks ($M_D \geq 5.0$). The catalogue includes 1926 events of magnitude $M \geq 1.8$. The completeness magnitude for Bingöl area is 3.2 and the number of earthquakes exceeding this magnitude range is 915. In this study, we proceed to decluster the appropriate catalogue using Reasenberg's [15] algorithm in order to remove aftershock sequences which can induce artificial quiescence. 43% of the events were removed and the number of events for *Z*-value analysis was reduced to 522. The cumulative number of earthquakes versus time for events with $M_D \geq 3.2$ (original catalog) and for declustered events (excluding aftershocks from original catalog) is shown in Figure 3.

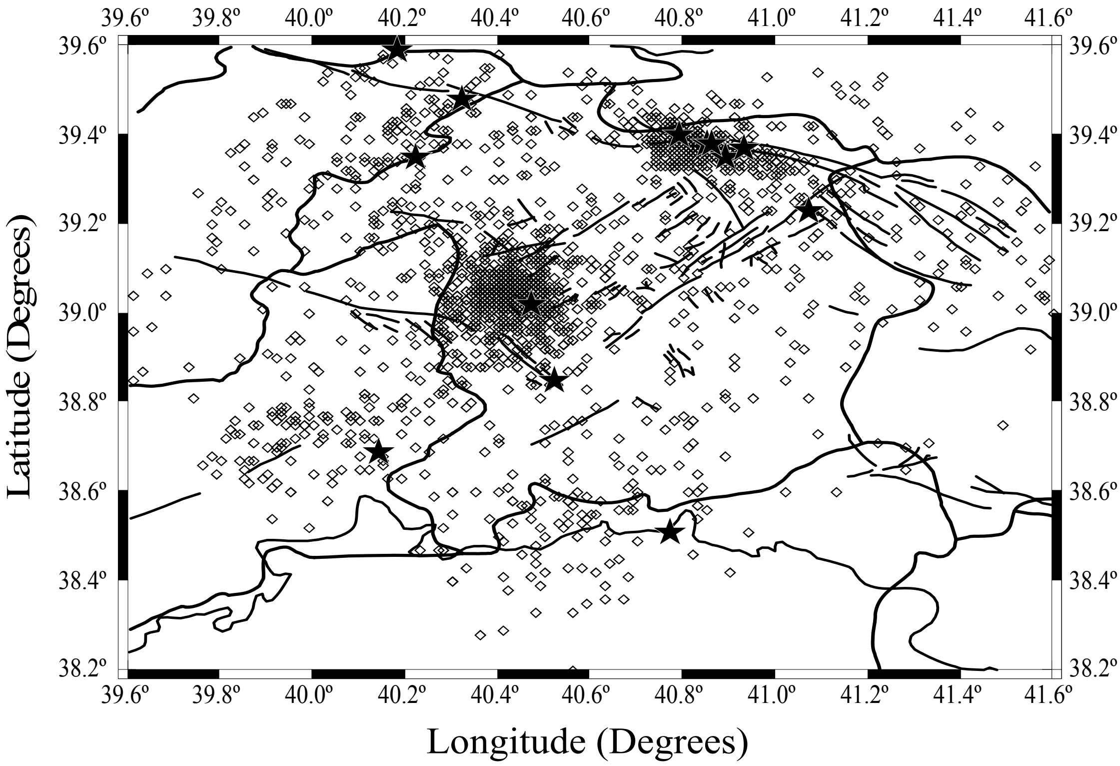


Figure 2. Epicentral map of the shallow seismicity (M_D≥3.2) between 1970 and 2005 in and around Bingöl. Stars show the principal main shocks with M≥5.0.

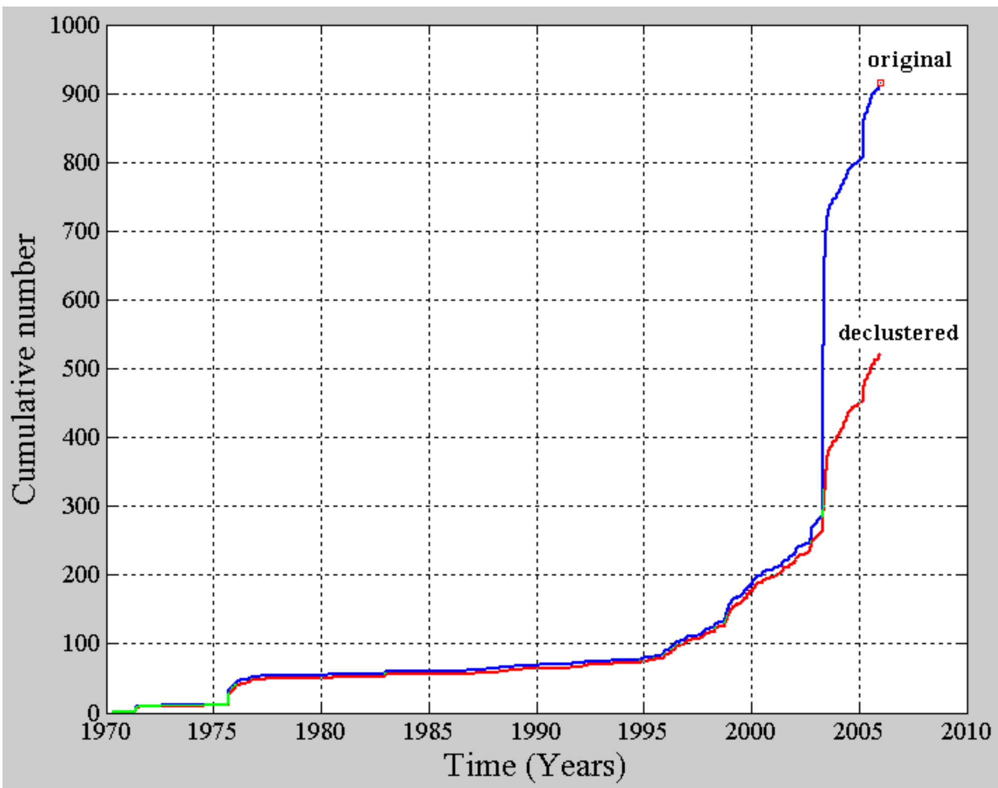


Figure 3. Cumulative number of earthquakes versus time for the original earthquake catalogue of KOERI containing 915 events and for the declustered catalogue containing 522 events, with M_D≥3.2 and depths less than 70 kilometers from 1970 until 2005.

4. ANALYSIS

Using *ZMAP*, we measured the significance of seismicity rate changes with a grid of points spacing 0.02º in longitude by 0.02º in latitude because this is related to the accuracy of epicentral determinations of the catalogue and it also provides a dense coverage in space. After some preliminary tests, we took the nearest earthquakes N=50 at each node and searched for rate changes by a moving time window T_W, stepping forward through the time series by a sampling interval as described by Wiemer and Wyss [17]. The sampling interval is selected as a time step of 28 days in order to have a continuous and dense coverage in time and N and T_W values are usually selected accordingly in order to enhance the quiescence signal and this choice does not influence the results in anyway. The total duration of the catalogue is 35.67 years.

The geographical distributions of Z-value for Bingöl and surrounding area are shown in Figure 4. The Z-maps of Figure 4 represents a choice obtained after numerous tests, carried out trying different values of T_W (indicated as *iwl* in the respective figure; 1.5, 2, 2.5, 3, 3.5, 4, 4.5 and 5 years) and different starting times for the foreground windows. Spatial variability of Z-values is presented for every one year between 1990 and 1998 based on the declustered catalogue. Each value of Z is represented by a different color: the scale spans from the lowest Z-values, indicating no significant changes in seismicity rate, shown in blue, and the highest ones (decrease in seismicty rate), shown in red. It should be recalled that in this representation each Z-value, computed in correspondence of a different grid point, comes from circular areas, the size of which is inversely proportional to the density of the spatial distribution of earthquakes. The time window, T_W, in which the mean rate is compared to the mean background rate, is 5 years. As shown in Z-value maps, there is no significant seismicity change in time interval 1990 and 1993. These maps show a clear area of quiescence after 1993, nearly overlapping the epicenter of the Bingöl, 2003 main shock with Z level between 2 and 3 (red areas). This quiescence is best revealed at the epicenteral areas of the main shock of Bingöl earthquake between 1995 and 1998.

As stated before, in this study we are aiming to the recognition of a quiescence episode before the Bingöl 2003 earthquake. We want also to identify the beginning and duration of quiescence. For this purpose, we plotted cumulative number of events in a circular area including the epicenter of the 2003 Bingöl earthquake. Figure 5 shows the cumulative number curve versus time and the correspondent LTA(t) function for a circle of 7.79 km radius centered on Bingöl main shock. The Z-value peaked with Z_{max}=2.5 at 1997.6. Thus, we observed that the duration of quiescence is 5.73 years before the 2003.33 (1 May 2003) Bingöl earthquake.

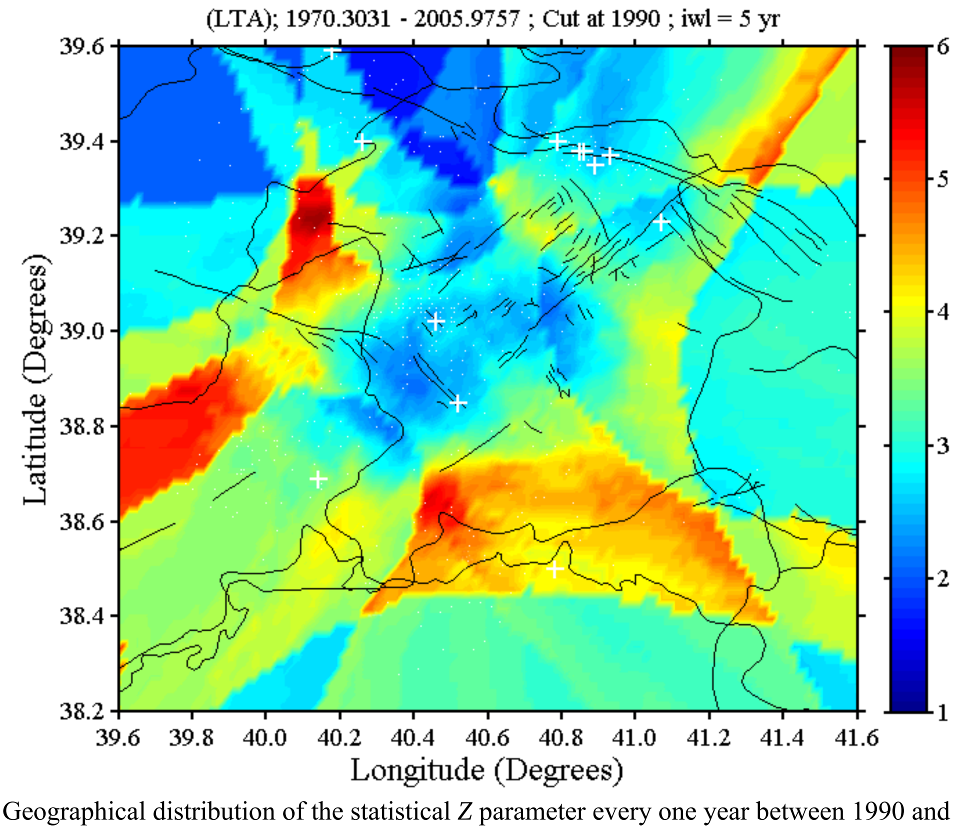
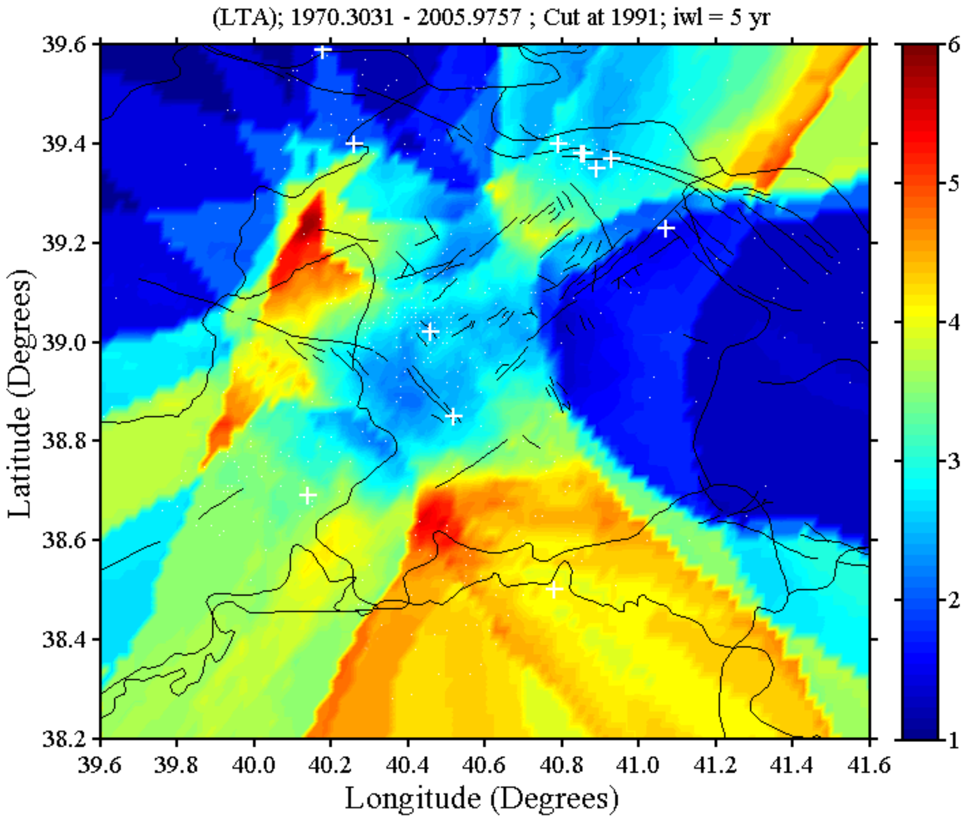
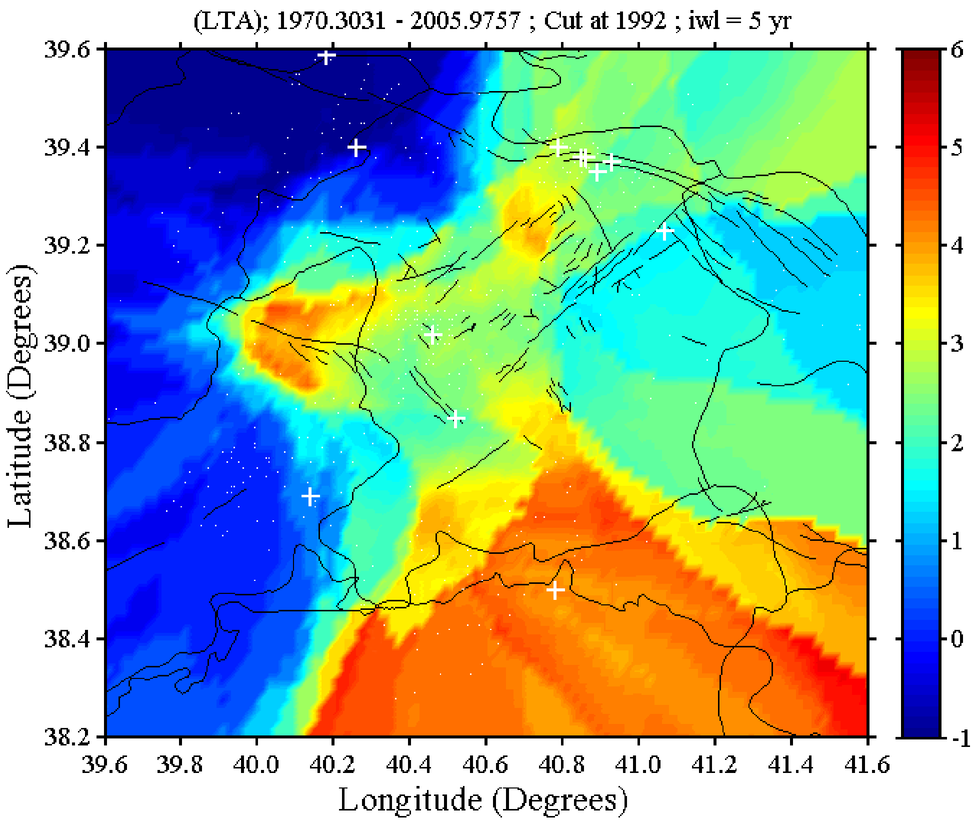


Figure 4. Geographical distribution of the statistical Z parameter every one year between 1990 and 1998 using declustered catalogue. The length of time window T_W is 5 years. The epicenter of main shocks with M_D≥5.0 is indicated by "+" symbol. Red color represents a decrease in seismicity rate.





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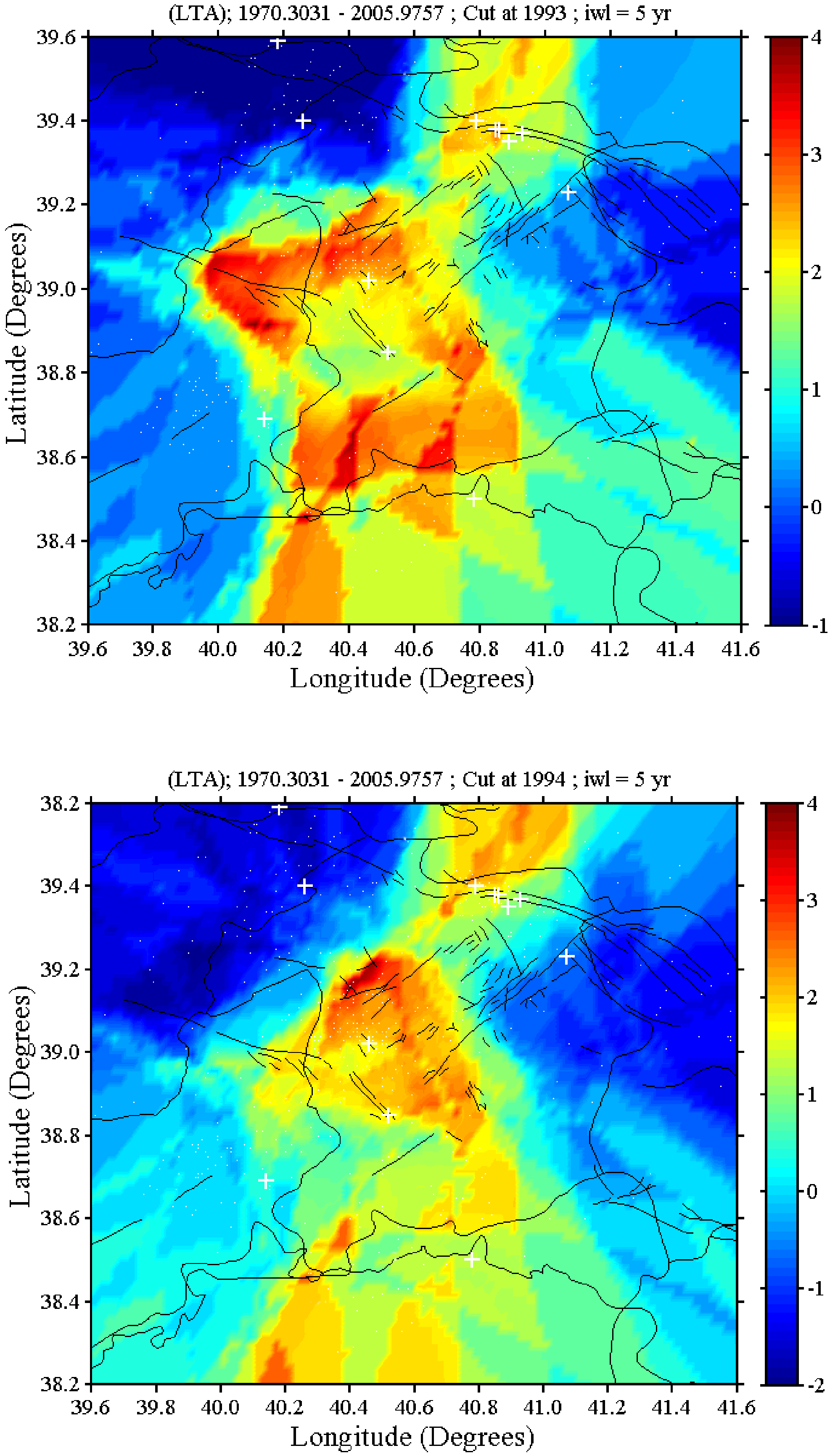

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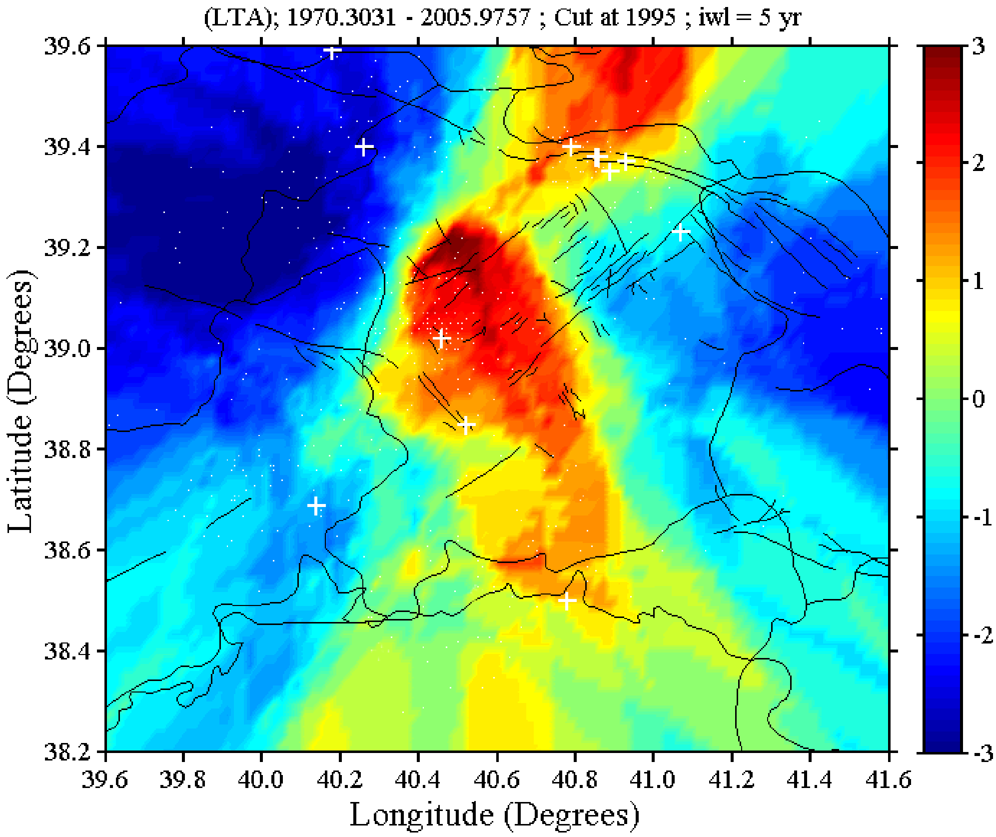

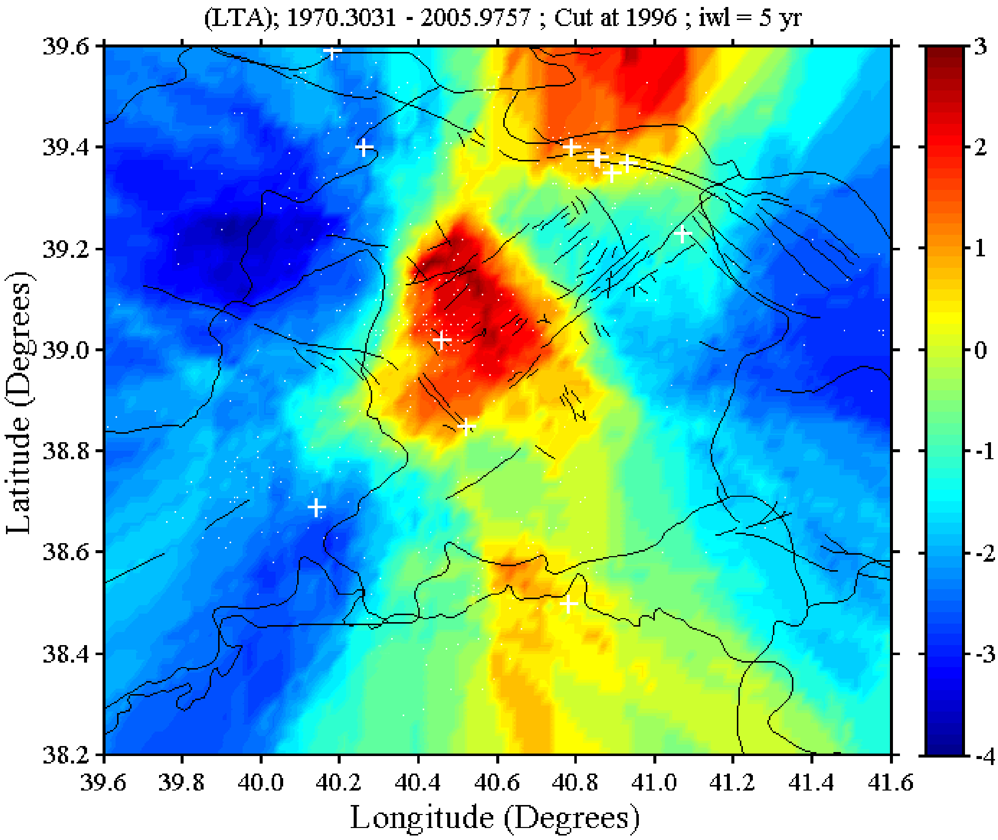

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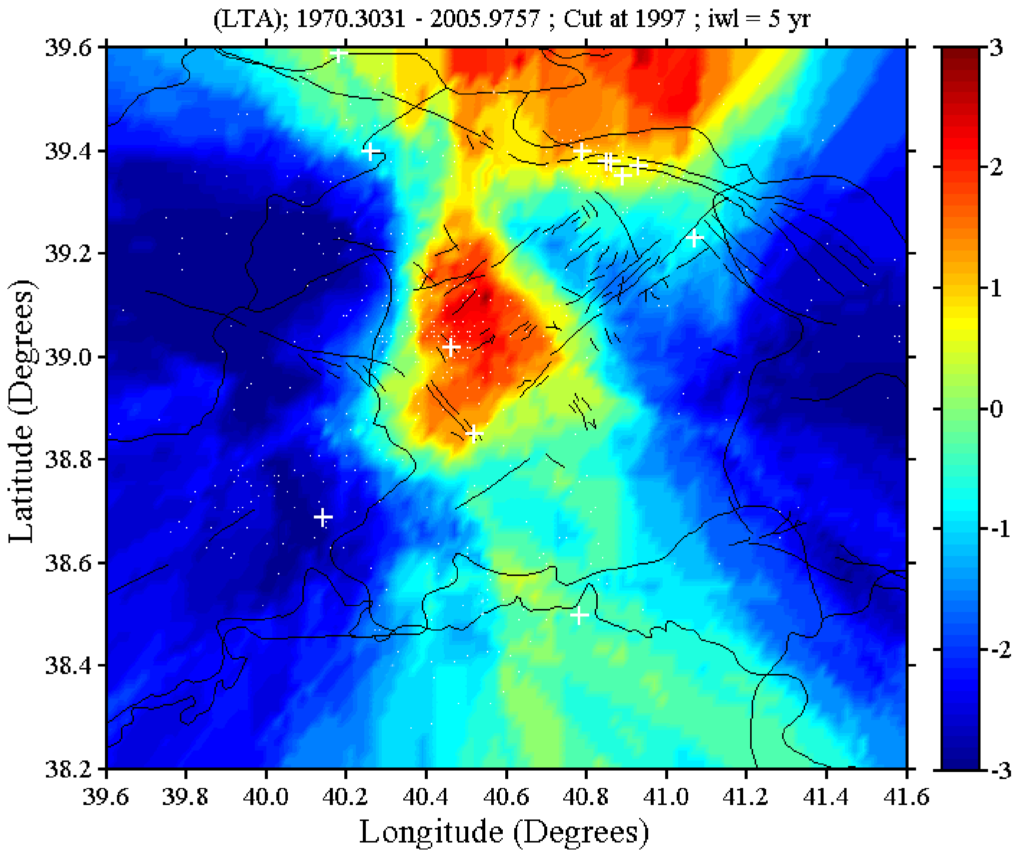

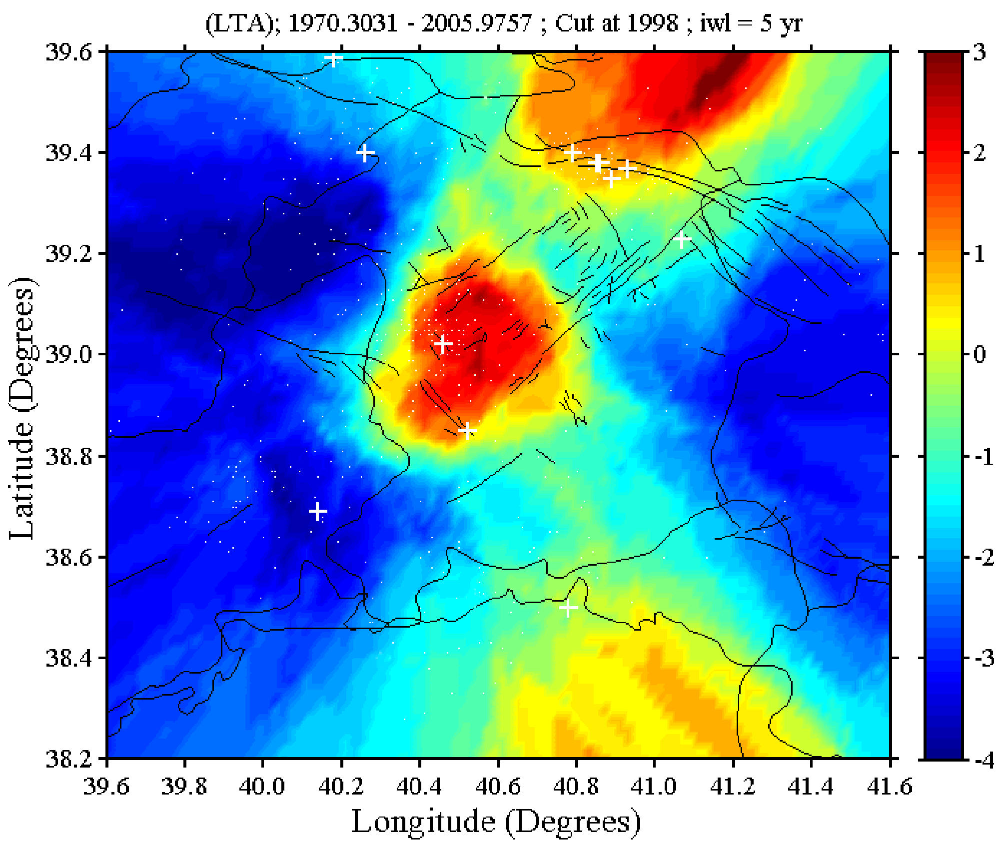

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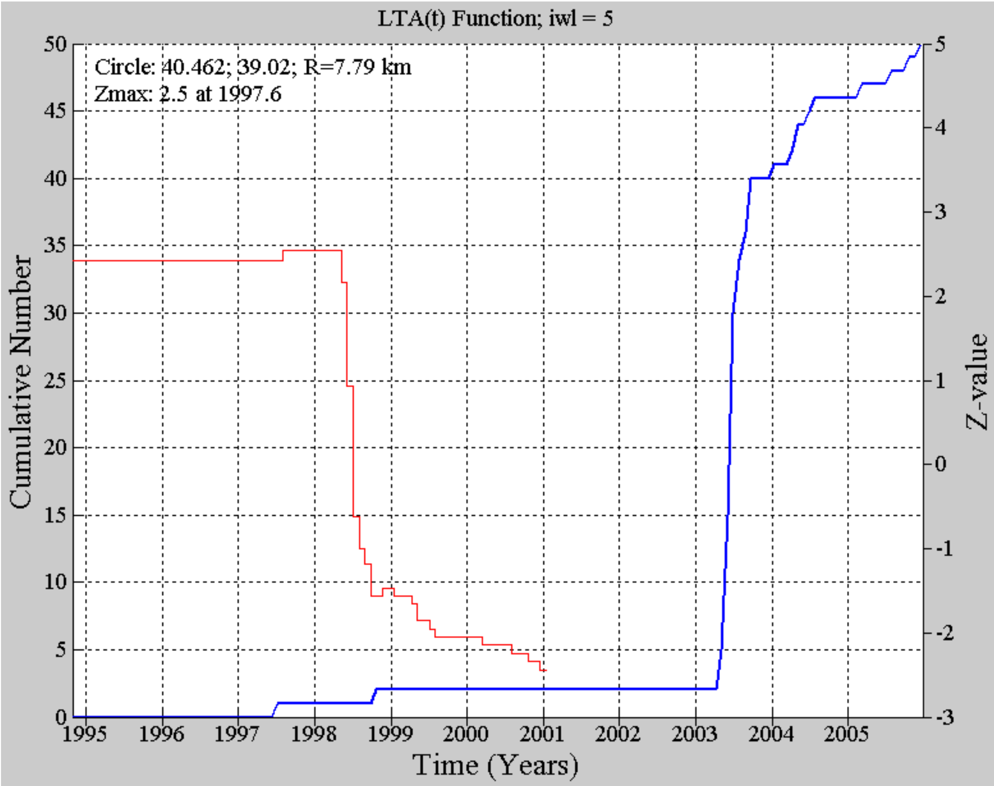

Figure 5. Cumulative number plots for the anomalous areas detected in Figure 4. Blue lines in cumulative number plots shows cumulative number and red lines Z-value as a function of time. Also, the center and radius of circle, Z_{max} value and the beginning time of the quiescence are given.

5. CONCLUSIONS

In this study we mapped the seismicity rate changes for future seismic hazard before May 1, 2003 Bingöl earthquake. The comparison is made by means of the standard deviate Z-test generating the LTA(t) function for the statistical evaluation of the confidence level in units of standard deviations. For this purpose, we used the instrumental earthquake catalog of the Boğaziçi University, Kandilli Observatory and Earthquake Research Institute (KOERI) from 1970 until 2005, for 1926 crustal earthquakes of magnitude equal and greater than 1.8, with depths less than 70 km. The catalogue is homogeneous for duration magnitude, M_D, and the completeness magnitude is 3.2. The number of events exceeding this magnitude is 915. We used the declustering algorithm in order to remove aftershock sequences from the catalogue. The process of declustering reduced the number of these events to 522 and 43% of the events were removed. We used the gridding method and the *ZMAP* software at each node of a grid spacing of 0.02º in order to investigate the significance of seismic quiescence pattern prior to the occurrence of 1 May 2003 Bingöl earthquake. We carried out our analysis in the rectangular area limited by the co-ordinates 38.2ºN and 39.6ºN in latitude and by the co-ordinates 39.6ºE and 40.6ºE in longitude. Using *ZMAP* software package, the number of events associated with each grid point was chosen, after several preliminary tests, equal to 50. For each sample, the data are subdivided in bins of 28 days. The total duration of the catalogue is 35.67 years. For the rate changes, it is used a moving time window T_W=5 years after a few different values from 1.5 to 5 years, and different starting times for the foreground windows. Finally, regional distribution of Z-values is mapped for every one year between 1990 and 1998 using the declustered catalogue. We could not observe any significant seismicity rate change in time interval 1990 and 1993. There is a clear area of quiescence after 1993, near the main shock epicenter of 1 May 2003 Bingöl earthquake with Z level between 2 and 3. This quiescence is best revealed at the epicenteral areas of the main shock of Bingöl earthquake between 1995 and 1998. Also, we plotted cumulative number curve versus time in a circular area including the epicenter of the 2003 Bingöl earthquake in order to define the beginning and duration of quiescence. Corresponding LTA(t) function for a circle of 7.79 km radius centered on Bingöl main shock, a decrease of the seismicity rate is found at 1997.6 with Z_{max}=2.5 level. Thus, 5.73 years of seismic quiescence was clearly observed before 1 May 2003 Bingöl main shock. In conclusion, the detection of seismic quiescence is the key to the success of intermediate term earthquake prediction.

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