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Precursory seismicity changes associated with the $M_w = 7.4$ 1999 August 17 Izmit (Turkey) earthquake

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SUMMARY

We investigated precursory seismicity in and around the epicentral zone of the $M_w = 7.4$ 1999 August 17 Izmit (Turkey) earthquake, by applying a statistical method—the RTL (Region–Time–Length) algorithm—to earthquake catalogues derived from that for the period 1981–1999 of Kandilli Observatory and Earthquake Research Institute (KOERI). The derived catalogues are complete for events $M_D \geq 3$ in most of western Turkey. After declustering aftershocks, we investigated the seismicity patterns preceding the Izmit event at local (Izmit tectonic zone) and national (Turkey) scales. The RTL parameter indicates that a period of seismic quiescence started at the end of 1995 and reached a minimum in December 1996. An activation phase lasting about three months followed. The main shock in Izmit and vicinity did not occur when the seismicity returned to its background level, but occurred with a delay of nearly 2.5 yr. We present a new parameter to quantify the spatial distribution of seismic quiescence. The results from both catalogues indicate that a significant quiescence anomaly appeared in 1996 around the epicenter of the Izmit earthquake. The primary characteristics of the seismicity patterns prior to the Izmit earthquake are similar to those obtained for large events in Russia and Japan. The variations of seismicity patterns revealed by the RTL algorithm may offer better understanding of the physical nature of seismo-tectonics and provide useful information for seismic hazard estimation. The varying characteristics of the Izmit and other events may reflect the difference between seismo-tectonics in Turkey and in other regions such as Russia and Japan.

Key words: Izmit earthquake, quiescence, seismicity, seismo-tectonics, statistical method.

1 INTRODUCTION

In August 1999, a strong earthquake with $M_w = 7.4$ struck Izmit, an industrial city 100 km east of Istanbul, the biggest city of Turkey. More than 15 000 people died and 24 000 people were injured during this event, which has been named the 'Izmit earthquake' (sometimes the 'Kocaeli earthquake'). The epicenter was located on the western part of the North Anatolian fault, an east–west trending strike-slip fault with a length of nearly 1,200 km.

The seismo-tectonics of Turkey are determined by the configuration of the Arabian and the Anatolian plates in eastern Turkey as shown in Fig. 1 (McKenzie 1972; Alptekin 1973; Sengör 1979; Sengör *et al.* 1985; Taymaz *et al.* 1990, 1991; Jackson 1994; Jackson & McKenzie 1988; Papazachos 1990; Öncel *et al.* 1998). The ongoing collision between these plates forces the Anatolian block to move toward the west, causing a tensional stress regime and the formation of horsts in southwestern Turkey, although some authors regard that backarc tension mechanisms associated with the Cretan arc are a principal driver of the tectonic regime of the Aegean and western Turkey. The northern boundary of Anatolian plate is known as the North Anatolian Fault Zone (NAFZ).

The NAFZ is well defined morphologically from about 31°E to 41°E, where a sequence of migrating major earthquakes occurred on the NAFZ since 1939 (Allen 1969). Dextral strike-slip faulting along the NAFZ appears to continue eastward, beyond the triple junction (41°E, labelled by K in Fig. 1) along the East Anatolian Fault Zone (EAFZ), but is not as continuous as it is along the NAFZ (Jackson 1992). Öncel *et al.* (1995, 1996a,b) have examined seismicity rate changes in time and space along the NAFZ and have interpreted these results as a potential precursor of the Izmit earthquake (Öncel & Wilson 2002).

West of 31°E, the NAFZ breaks into two strands extending towards the northern Aegean Sea region (Fig. 2). Based on long-term historical data (Ambraseys & Jackson 2000), GPS data (McClusky *et al.* 2000), and variation of frequency-magnitude parameters (see Fig. 4 of Öncel & Wyss 2000), the northern strand is a more active

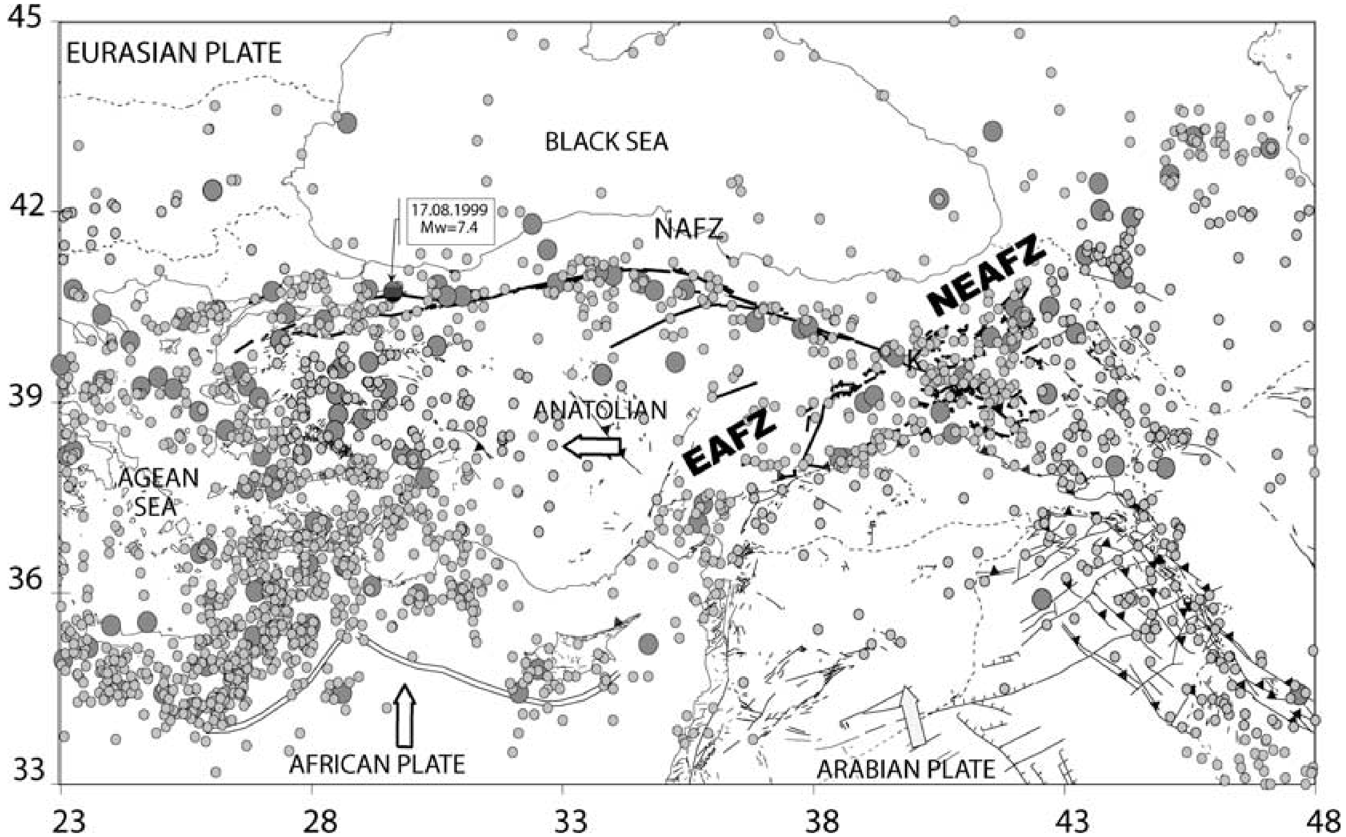

Figure 1. Tectonic setting and main shocks for Turkey. Modified after Öncel & Alptekin (1999). Main shocks ($M > 4.5$) cover the period between 1900 and 1999. Arrows indicate the direction of plate motions.

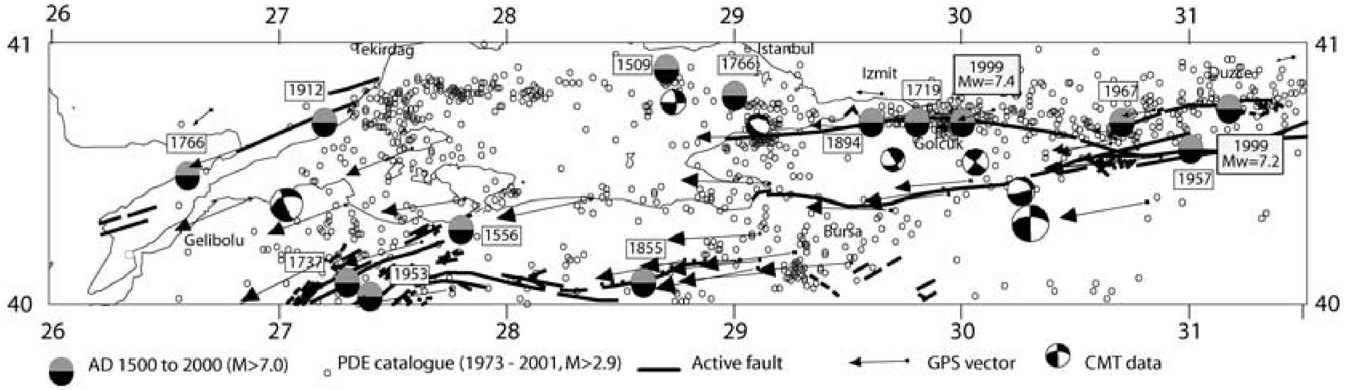

Figure 2. Seismo-tectonic setting of the Marmara Sea Region based on GPS (McClusky *et al.* 2000) and focal mechanisms of CMT (Modified after Öncel & Wyss 2000). Historical earthquakes are taken from Ambraseys & Jackson (2000).

region with higher seismic hazard than the southern. The Izmit event filled in a 100–150 km gap between the 1967 event and the 1963 and 1964 events, which was first noted by Toksöz *et al.* (1979) and later identified as an asperity of Izmit earthquake on the basis of microseismicity before the Izmit earthquake (see Fig. 4c of Öncel & Wyss 2000, also see Fig. 2 of this paper).

Thus, a close investigation of the seismicity patterns associated with the Izmit earthquake is important for understanding the physical nature of seismic cycles and hazards along the NAFZ. Several methods for identification of precursory seismic quiescence from earthquake catalogues have been examined during studies on earthquake prediction and hazard estimation (Wyss & Habermann 1988; Keilis-Borok & Kossobokov 1990; Kossobokov & Keilis-Borok 1990; Wiemer & Wyss 1994).

The recently developed RTL (Region-Time-Length) algorithm (Sobolev & Tyupkin 1997) can be used to investigate characteristics of seismicity changes, including both quiescence and activation patterns. In contrast to previous approaches, all three parameters (time, place and magnitude) of earthquakes are taken into account in this algorithm. This technique was initially tested using the earthquake catalogue for Kamchatka, Russia (Sobolev & Tyupkin 1997, 1999). The results indicated that seismic quiescence and activation had preceded strong earthquakes in Kamchatka. The seismic quiescence phases started a few years before the main shock and lasted 1 to 2.5 yr. The duration of the subsequent phases of seismic activation lasted from several months to 1.5 yr. The dimension of the quiescence zone reached a few hundred kilometres, while the activation zone was generally in order of several tens of kilometres. Similar variations of seismicity patterns of the 1995 $M = 7.2$ Kobe earthquake, the 2000 $M = 6.8$ Nemuro Peninsula earthquake, and the 2000 $M = 7.3$ Tottori earthquake were obtained recently using the earthquake catalogue of the Japan Meteorological Agency (JMA) (Huang & Sobolev 2001, 2002; Huang & Nagao 2002; Huang *et al.* 2001).

In this study, we apply the RTL algorithm to investigate the seismicity patterns associated with the $M_w = 7.4$ 1999 August 17 Izmit (Turkey) earthquake, based on local (Izmit tectonic zone) and national (Turkey) earthquake catalogues. These two catalogues were compiled from the raw catalogue (1981–1999) of the Kandilli Observatory and Earthquake Research Institute, Bosphorus University (KOERI) by declustering aftershocks. First, we discuss the temporal variation of seismicity patterns at the epicenter of the Izmit earthquake. Second, we present a new parameter, which is different from our previous approach (e.g. Huang *et al.* 2001), to quantify the spatial distribution of the seismic quiescence of this event. Finally, we investigate the possible correlation between the seismicity changes revealed by this study and the Izmit earthquake.

2 METHODS

The principle of the RTL algorithm introduced previously (e.g. Sobolev & Tyupkin 1997; Huang *et al.* 2001) is as follows:

The basic assumption of the RTL algorithm is that the influence weight of each prior event on the main event under investigation may be quantified in the form of a weight. The weight of an event is greater when it is closer to the eventual epicenter (x, y, z) and/or the occurrence time (t) of the earthquake in question. The parameter RTL can be calculated by the following three functions: epicentral distance, $R(x, y, z, t)$, time, $T(x, y, z, t)$ and rupture length, $L(x, y, z, t)$, where t is time.

In the RTL algorithm, the above three functions are defined as,

$$
\begin{aligned}
R(x,y,z,t) &= \left[\sum_{i=1}^{n} \exp\left(-\frac{r_i}{r_o}\right)\right] - R_{bk}(x,y,z,t)\\
T(x,y,z,t) &= \left[\sum_{i=1}^{n} \exp\left(-\frac{t-t_i}{t_o}\right)\right] - T_{bk}(x,y,z,t) \qquad (1)\\
L(x,y,z,t) &= \left[\sum_{i=1}^{n} \left(\frac{l_i}{r_i}\right)\right] - L_{bk}(x,y,z,t)
\end{aligned}
$$

where l_i is the rupture dimension (a function of magnitude, see eq. 2), t_i the occurrence time of the ith earthquake, r_i the distance from the position (x, y, z) to the epicenter of the ith event; r_0 and t_0 are a characteristic distance and time-span, respectively; n is the number of events satisfying some criteria (such as $M_i \geq M_{\min}$, where M_i is the magnitude of the ith earthquake and $M_{\min}$ is the cut-off magnitude ensuring the completeness of the earthquake catalogue, $r_i \leq R_{\max} = 2r_0$ and $(t - t_i) \leq T_{\max} = 2t_0$, where $R_{\max}$ and $T_{\max}$ are cut-off distance and time interval, and $d_i \leq d_0$ (d_i is the focal depth of the ith earthquake, d_0 is the cut-off depth)); $R_{\mathrm{bk}}(x, y, z, t)$, $T_{\mathrm{bk}}(x, y, z, t)$ and $L_{\mathrm{bk}}(x, y, z, t)$ are the trends (background values) of $R(x, y, z, t)$, $T(x, y, z, t)$ and $L(x, y, z, t)$, respectively.

$R(x, y, z, t)$, $T(x, y, z, t)$ and $L(x, y, z, t)$ are dimensionless functions, describing the influence weights of location, occurrence time and magnitude of earthquakes. They are further normalized by their standard deviations, after removing their trends (background values). The product of the above three functions is calculated as the RTL parameter, which describes the deviation from the background level of seismicity. A decrease of negative RTL parameter means a decrease of seismicity compared to the background level around the study place and time, i.e. seismic quiescence can be quantified using the RTL parameter. A recovery stage from quiescence to background level is described as an activation stage of seismicity.

In this study, we calculate RTL at a time step of 10 days. Because the RTL value at time t is calculated based on the earthquakes in the time window $[(t - T_{\max}), t]$, it is not possible to calculate the RTL value for times before $t_{\mathrm{cs}} + T_{\max}$, where t_{cs} is the start time of the catalogue in use.

The rupture dimension, l for earthquakes in Turkey was given by an empirical relation with magnitude, M (Toksöz *et al.* 1979),

$$\log l\ (\mathrm{km}) = 0.78M - 3.62 \qquad (2)$$

and this relation is used to determine l_i for earthquakes in the present study.

Taking into account reports of seismic quiescence around the rupture zone and our previous experiences in Kamchatka, Kobe, and Hokkaido (Sobolev & Tyupkin 1997, 1999; Sobolev *et al.* 2002; Huang & Sobolev 2001; Huang *et al.* 2001), we adopted a characteristic distance $r_0 = 50$ km that is a threshold distance $R_{\max} = 2r_0 = 100$ km. We also adopted a characteristic time-span $t_0 = 1$ yr that is a threshold time-span $T_{\max} = 2t_0 = 2$ yr, based on our previous experiences and the observation that duration of seismic quiescence is generally of the order of one year. We chose a limit of focal depth $d_i \leq d_0 = 100$ km as another criterion. Although the selection of the focal depth criterion is somewhat arbitrary, it has little influence on the results of this study, as will be discussed later.

In this study, we employ a new parameter $Q(x, y, z, t_1, t_2)$, an average of the RTL values over some time window $[t_1, t_2]$, to quantify the seismic quiescence at position (x, y, z). The parameter $Q(x, y, z, t_1, t_2)$ is defined as,

$$Q(x,y,z,t_1,t_2) = \frac{1}{m}\sum_{i=1}^{m} \mathrm{RTL}(x,y,z,t_i), \qquad (3)$$

where t_i is the time in the window $[t_1, t_2]$, $\mathrm{RTL}(x, y, z, t_i)$ is the RTL parameter calculated as the product of the three functions in eq. (1) using the earthquakes in a cylindrical volume, and m is the number of data points available in $[t_1, t_2]$. In this way, we can obtain the spatial distribution of seismic quiescence as a function of position. In this study, we calculate the averaged value of RTL on an 0.1° grid of longitude and latitude. We also fixed the cylindrical volume ($r_i \leq R_{\max} = 2r_0 = 100$ km and $d_i \leq d_0 = 100$ km) for the RTL calculation at each site. A sketch of the above approach is given in Fig. 3.

Because we are concerned with the intermediate-term variation of seismicity, we choose an averaging interval of six months with a background from 1981 January 1 to any investigated time. We found that the length of the averaging interval has little influence on the results of spatial distribution of RTL.

3 RESULTS

Earthquakes may not be reported homogeneously due to the inhomogeneous distribution of seismological observatories, so before applying the RTL algorithm we estimated the completeness of the earthquake catalogue based on the frequency-magnitude power-law. To avoid possible disturbance to the background seismicity, we also

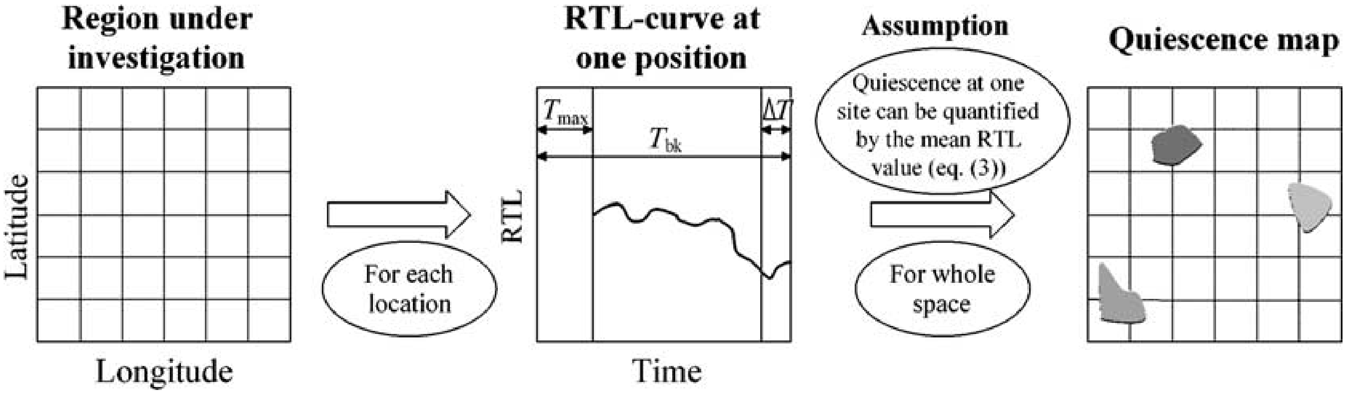

Figure 3. A sketch map quantifying the spatial distribution of seismic quiescence. The middle-panel shows the RTL-curve at one site investigated, where T_{bk} is the total background time for the RTL calculation, T_{max} is the threshold time window, and ΔT is the time window investigated for seismic quiescence.

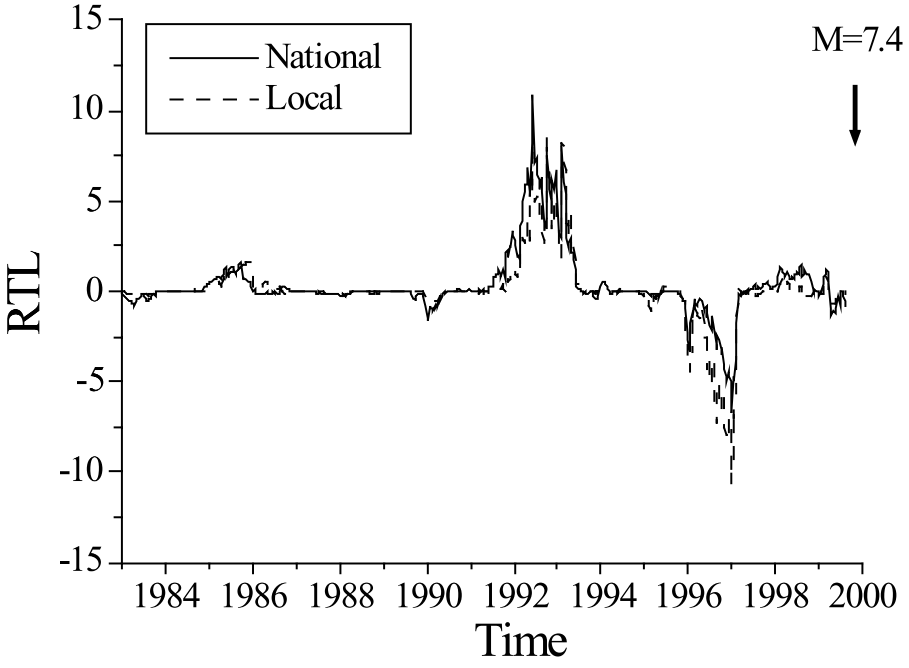

Figure 4. Temporal variation of the RTL parameter at the epicenter of the $M_w = 7.4$ Izmit earthquake, calculated from the national (Turkey) and the local (the total rupture zone of the Izmit earthquake and the $M_w = 7.2$ Duzce event) earthquake catalogues. The arrow indicates the occurrence time of the mainshock.

excluded aftershocks from the catalogue using Gardner–Knopoff's method (Gardner & Knopoff 1974; Öncel & Alptekin 1999).

Our work is based on the KOERI catalogue 1981 to 1999. Completeness analysis showed that it is complete for $M \geq 3$ for most of western Turkey. However, due to lack of station coverage, a threshold of $M \geq 4.5$ is observed in eastern Turkey. Therefore, a cut-off magnitude $M_{min} = 3$ was used for both the 'national' catalogue covering western Turkey, compiled after declustering aftershocks from the raw KOERI catalogue and the 'local' catalogue extracted from the KOERI catalogue to cover the total rupture zone of the Izmit earthquake and the Duzce event ($M_w = 7.2$, 1999 November 12). Because the completeness of the earthquake catalogue in the eastern Turkey and some western regions can not be satisfied for $M_{min} = 3$, for better reliability, we take use in our calculations only events in the region of completeness (i.e. the zone in Fig. 5). The actual region for which results are available is indicated by the solid rectangle in Fig. 5, after taking into account that earthquakes within R_{max} (e.g. $R_{max} = 2r_0 = 100$ km) are used in calculating RTL parameter.

3.1 National catalogue

The solid curve in Fig. 4 gives the temporal variation of the RTL parameter at the epicenter of the 1999 Izmit earthquake, which was calculated from the national catalogue. The quiescence, revealed by the RTL parameter, started at the end of 1995 and reached its minimum in December 1996. The greatest deviation from the background exceeds 6 standard deviations. An activation phase with duration of about three months followed.

The spatial distribution of the seismic quiescence is given in Fig. 5. Using the approach described in Fig. 3 and the section 'Methods', We calculated, the quiescence distribution during 1996 July 1–1996 December 31, the RTL parameter revealed in this period by an obvious quiescence phase (Fig. 4). A clear quiescence anomaly

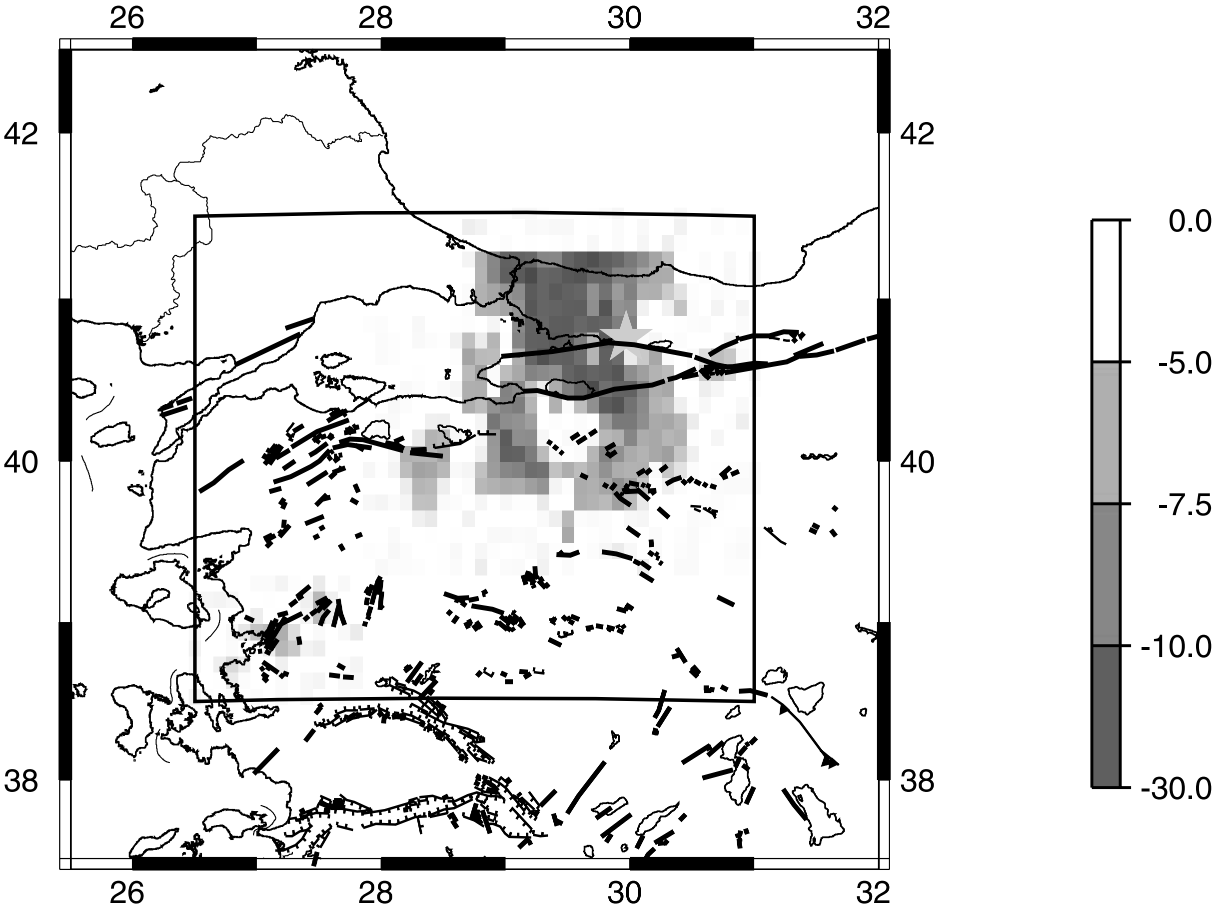

Figure 5. A clear seismic quiescence was obtained during July 1, 1996–December 31, 1996 from the national (Turkey) catalogue. The scale on the right corresponds to the RTL value in units of the standard deviation. The grey star represents the epicenter of the Izmit earthquake (29.97°E, 40.76°N). The solid rectangle indicates the calculated region.

appeared around the epicenter of the Izmit earthquake. The maximum linear dimension of this anomalous zone exceeds 150 km.

3.2 Local Izmit catalogue

The dashed curve in Fig. 4 shows the temporal variation of the RTL parameter at the epicenter of the Izmit earthquake calculated from the local Izmit catalogue. The RTL parameter indicates that a quiescence stage started at the end of 1995 and a minimum (with a maximum deviation over 10σ) appeared in December 1996. An activation phase with a duration of about three months followed.

An anomalous zone of seismic quiescence was detected around the epicenter during 1996 July 1–1996 December 31 (Fig. 6). The maximum linear dimension of this anomalous zone was about 150 km. For comparison, the dashed rectangle indicates the displayed region, the same as was used in calculating Fig. 5.

4 DISCUSSION

Because we introduced some 'free' parameters (for example, threshold focal depth d_0, characteristic distance r_0 and characteristic time t_0) to the RTL algorithm, it is appropriate to investigate whether or not the results are artefacts due to the selection of the above model parameters. For this purpose, we repeated our calculations changing these parameters for both the national and the local catalogues. We also calculated the correlation coefficient between the results obtained from different model parameters. These investigations indicated that the variations of the model parameters do not have much influence on our results at a statistical significance level of 0.05. Generally, the lower cut-off magnitude $M_{\min}$ should not be a 'free' parameter, because it is determined by the completeness of the earthquake catalogue. Nevertheless, we repeated our calculations changing $M_{\min}$. We found that the changing $M_{\min}$ gives similar results, as long as the number of events for each $M_{\min}$ is sufficient for valid statistical analysis. Because different magnitude-frequency relations may hold for small and large earthquakes (for instance, Ikeya & Huang 1997), in our previous study on the 2000 January 28 Nemuro Peninsula earthquake(Huang & Sobolev 2001), we introduced the upper cut-off magnitude $M_{\max}$. Detailed investigation indicated that introducing $M_{\max}$ has little influence on our results (Huang & Sobolev 2002). Therefore, we conclude that our results are not artifacts due to the selection of model parameters.

To investigate the significance of the quiescence anomaly revealed by the RTL parameter in 1996 (Fig. 4), we make following stochastic test.

First, we generate random earthquake catalogues by randomizing the time and space (longitude and latitude) of the real national/local catalogue. Then, for each random catalogue, we calculate the RTL parameter at the epicenter of the Izmit earthquake. We choose the same criteria as were used in the calculations for the real catalogue. To estimate the probability of occurrence of an RTL anomaly, we

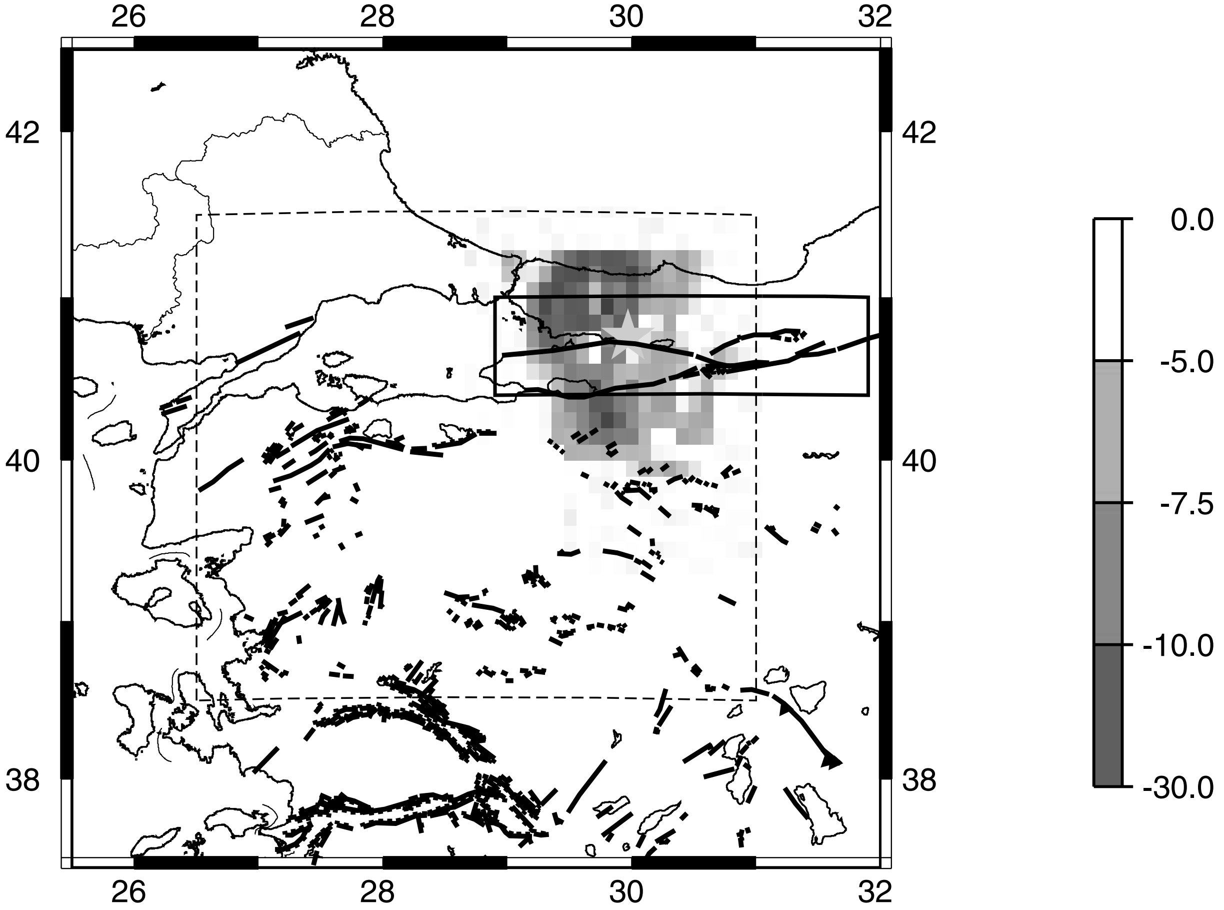

Figure 6. Spatial distribution of the seismic quiescence during 1996 July 1–1996 December 31 from the local catalogue (the solid rectangle is the total rupture zone of the Izmit earthquake and the $M_w = 7.2$ Duzce event). For comparison, the dashed rectangle indicates the calculated region, the same as that used in Fig. 5. The scale on the right corresponds to the RTL value in units of the standard deviation. The grey star represents the epicenter of the Izmit earthquake (29.97°E, 40.76°N).

make the following assumptions to quantify the negative anomaly of the RTL parameter: (1) minimum RTL value $\leq \mathrm{RTL}_{\mathrm{minc}}$ (for example, $\mathrm{RTL}_{\mathrm{minc}} = -5\sigma$), (2) duration t_{d}, defined as the interval with RTL parameter $\leq \mathrm{RTL}_{\mathrm{c}}$ (e.g. $\mathrm{RTL}_{\mathrm{c}} = -2\sigma$), is greater than some time interval t_{c}. Finally, we calculate the RTL parameters at the epicenter for 1000 random catalogues and estimate the probability of occurrence of an RTL anomaly for different values of $\mathrm{RTL}_{\mathrm{minc}}$ and t_{c}. The results indicated that the chance probabilities of the observed RTL anomalies before the main shock for the national and the local catalogues are less than 0.039 and 0.012, respectively. We conclude that the RTL anomalies obtained before the Izmit earthquake (Fig. 4), are unlikely to be chance anomalies, so are significant.

Large positive anomalies of RTL parameter were also observed at the epicenter of the Izmit earthquake during 1992–1993 for both the national and the local catalogues (Fig. 4). Unfortunately, we have not yet defined a technique to use positive anomalies of the RTL parameter even though positive anomalies were found before some Kamchatka earthquakes. In our limited experience, positive anomalies of the RTL parameter are most probably due to clustering of events (Huang & Nagao 2002) or increased seismicity. We investigated the spatio-temporal distribution of the earthquakes used in the RTL calculation at the epicenter of the Izmit earthquake in detail and found that the number of events during 1992–1993 ($N_{92/93}$) is much larger than the average number (N_{mean}) for the whole background time interval ($N_{92/93}/N_{\mathrm{mean}} = 1.8$). We also investigated temporal changes of earthquake rate after extracting the events in the rupture region (local catalogue) from the national catalogue and obtained a similar result (for example, the seismicity in 1992 is about twice the mean level). Thus the large positive anomaly during 1992–1993 is most probably related to increased seismicity. Such increased seismicity would reflect the feature of regional seismicity, rather than the local effect in the rupture zone. For the above reasons, we find it is hard to claim that the positive anomaly around 1992 is related to preparation for the 1999 Izmit earthquake.

Also, about three months after the Izmit earthquake, another large earthquake, the $M_w = 7.2$ Duzce earthquake occurred more than 100 km east of the epicenter of the Izmit event. It would be interesting to calculate the RTL parameter at the epicenter of the Duzce event. However, because the occurrence of a strong earthquake leads to a large disturbance in the stress distribution around the epicenter, using the current RTL algorithm, it is difficult to study the seismicity changes of one large earthquake immediately followed by another, nearby, large event. Nevertheless, we calculated the RTL parameter at the epicenter of the Duzce earthquake. We do obtain an anomalous quiescence (although it is somewhat weaker than that of the Izmit earthquake) 2–3 yr before the Duzce event. We also observed large variations in RTL around August 1999, associated with the Izmit earthquake, as we might have expected. But unfortunately, the number of events in the stacking time window before 1990 is too small to ensure the reliability of statistical analysis in RTL algorithm. Thus, we are unable to discuss the Duzce earthquake in detail, because we cannot ensure the reliability of the RTL result for the Duzce earthquake.

Clear quiescence anomalies were detected around the epicenter of the 1999 Izmit earthquake for both the national and the local catalogues during 1996 July 1–1996 December 31 (Figs 5 and 6). We also calculated the spatial distribution for other time windows and found that no quiescence anomaly was observed around the epicenter either before late 1995 or after early 1997. Taking into account the previous analyses of parametrization artifacts and chance analysis of RTL anomaly, and the temporal and spatial characteristics of the quiescence anomaly, we can reasonably assort that the quiescence anomaly that occurred a few years before the main shock around the epicenter is related to the preparation stage of the Izmit earthquake.

The temporal variation of the seismicity patterns of the 1999 Izmit earthquake revealed by the RTL algorithm showed similar characteristics to those obtained before strong earthquakes in Kamchatka (Sobolev & Tyupkin 1997, 1999) and Japan (Huang & Sobolev 2001, 2002; Huang & Nagao 2002; Huang *et al.* 2001). The similarity in these variations of seismicity patterns prior to strong earthquakes in different tectonic regions may reflect the natural evolution of the seismogenic process. As has been discussed, tests in Russia, Japan and Turkey have indicated that the RTL algorithm is an effective tool for revealing seismic quiescence and activation phases before strong earthquakes.

The seismic quiescence associated with the Izmit earthquake started at the end of 1995 and lasted until the end of 1996, about 2.5 yr before the main shock (Figs 3 and 5). It lasted about one year. The activation phase appeared early in 1997 with a duration of about three months. However, the Izmit event did not occur immediately after the activation stage, but with a delay of about two years. A similar time delay after the activation phase was also reported for the $M = 7.7$ 1997 December 5 Kamchatka earthquake and the $M = 6.8$ 2000, January 28 Nemuro earthquake (Sobolev & Tyupkin 1999; Huang & Sobolev 2001).

It seems reasonable to suppose that an earthquake is most likely to occur once the relevant source region has passed through the quiescence and activation phases. Variations of seismicity patterns may provide information useful for earthquake alert. Detailed investigation of spatial changes of seismic quiescence anomalies after combining the temporal variations of seismicity patterns at different position would be useful for seismic hazard assessment. However, the existence of the time delay reported in this and the previous studies makes it difficult to determine the occurrence time of a future event with the accuracy required for short-term prediction. It seems reasonable to suppose that a candidate zone under investigation has reached a critical state, after it has passed through quiescence and activation phases. So macrofracture around this zone may be triggered by changes in any number of local, regional or global factors (for instance, meteorological, occurrence of neighbouring or remote earthquakes, etc.).

Similar temporal variations of the RTL parameter (Fig. 4) and similar spatial distributions of quiescence (Figs 5 and 6) were obtained for both the national and the Izmit catalogues. However, a more significant anomaly was detected in the case of the Izmit catalogue. It seems that the ratio of signal-to-noise would be improved, if the analysis were restricted to earthquakes from the same tectonic zone as the event under investigation. Seismicity patterns in the same tectonic zone are likely to exhibit similar characteristics and a different background seismicity might be expected for different tectonic zones.

The similarities between the seismicity patterns obtained from the national and the local Izmit catalogues indicates the reliability of seismicity changes associated with the Izmit event. Differences between the results obtained from the two catalogues seems to support the hypothesis that the seismicity patterns revealed by the RTL algorithm are correlated with the seismo-tectonics in the zone investigated. Therefore, seismo-tectonics may provide information useful for the RTL algorithm, for example, applying the RTL algorithm to a zone with known seismo-tectonics may produce a better signal-to-noise ratio, as revealed in this study.

5 CONCLUSIONS

A significant precursory seismic quiescence, quantified by the RTL parameter and tested by the stochastic analysis, has been detected at the epicenter of the $M_w = 7.4$, 1999 August 17 Izmit (Turkey) earthquake. It was followed by an activation phase with a duration of about three months. The main shock occurred with a time delay of about two years after the completion of the quiescence and activation phases. The spatial distribution of quiescence indicates that a clear quiescence anomaly appeared around the epicenter. The maximum linear size of the anomalous zone exceeded 150 km. We obtained similar results from both local (Izmit tectonic zone) and national (Turkey) earthquake catalogues, indicating the reliability of seismicity changes associated with the preparation stage of the Izmit event.

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