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Estimation of characteristic parameters in region-time-length algorithm and its application*

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Abstract

On the basis of gap's temporal-spatial characteristics in and around source area before an earthquake, we propose a method to estimate characteristic parameters (characteristic distance and time) in the region-time-length (RTL) algorithm and introduce the method of correlation coefficient developed by some authors in 2006 to determine the characteristic parameters. The anomalous seismic activities before four moderately strong earthquakes occurred in the northwestern and southwestern China in recent years are studied by the two methods. The results show that the method to estimate characteristic parameters advanced in this paper is a simple one, which possesses a physical meaning and is well applicable to the four moderately strong earthquakes studied.

Key words: **RTL algorithm**; **characteristic distance**; **characteristic time**

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Introduction

The region-time-length (RTL) algorithm brought forward by Sobolev *et al* (1997) has been widely used in studying precursory characteristics of seismic activities (activation and quiescence) before moderate, especially strong earthquakes (Giovambattista and Tyupkin, 2000; Huang *et al*, 2001, 2002; JIANG *et al*, 2004; LIU and SU, 2006). These studies have revealed that seismic anomalous activities including activation and quiescence are detected to different extends before main earthquakes for all the studied examples.

There are two important parameters, *i.e.*, characteristic distance and characteristic time in the RTL algorithm. In the previous studies, the two parameters are determined experientially, as a result, the authors' subjectivity might be included to a certain extent. In this paper, we attempt to propose a method for estimating the two characteristic parameters in the RTL algorithm and then apply it to the study on precursory characteristics of seismic activities before four moderately strong earthquakes occurred in the northwestern and southwestern China in recent years.

1 RTL algorithm

The so-called RTL algorithm is to construct R, T and L functions at temporal-spatial point (x,

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y, z, t) as follows.

$$R(x, y, z, t) = \left[\sum_{i=1}^{n} \exp\left(-\frac{r_i}{r_0}\right)\right] - R_{\rm bg}(x, y, z, t) \tag{1}$$

$$T(x, y, z, t) = \left[\sum_{i=1}^{n} \exp\left(-\frac{t-t_i}{t_0}\right)\right] - T_{\rm bg}(x, y, z, t) \tag{2}$$

$$L(x, y, z, t) = \left[\sum_{i=1}^{n} \left(-\frac{l_i}{r_i}\right)\right] - L_{\rm bg}(x, y, z, t) \tag{3}$$

$$V_{\rm RTL}(x, y, z, t) = R(x, y, z, t)T(x, y, z, t)L(x, y, z, t) \tag{4}$$

In the above equations, $R(x, y, z, t)$, $T(x, y, z, t)$ and $L(x, y, z, t)$ represent respectively the epicentral distance, time and rupture length functions, and $R_{\rm bg}(x, y, z, t)$, $T_{\rm bg}(x, y, z, t)$ and $L_{\rm bg}(x, y, z, t)$ are their background values, *i.e.*, the linear trend after linear regression of R, T, L in the selected time period. l_i and t_i denote the rupture dimension and occurrence time of the ith earthquake. r_i indicates the distance from the point (x, y, z) to the epicenter of the ith event. And $V_{\rm RTL}(x, y, z, t)$ is the RTL function. It is apparent from equations (1), (2) and (3) that the weight of rupture length is smaller than those of epicenter distance and time. Considering the notable variations of earthquake strength or energy before the main shock, JIANG *et al* (2004) changed equation (3) into an exponent form to strengthen the effect of rupture length

$$L(x, y, z, t) = \left[\sum_{i=1}^{n} \exp\left(-\frac{l_i}{r_i}\right)\right] - L_{\rm bg}(x, y, z, t) \tag{5}$$

and normalized equation (4) to

$$V_{\rm RTL}(x, y, z, t) = \frac{R(x, y, z, t)}{R(x, y, z, t)_{\max}} \cdot \frac{T(x, y, z, t)}{T(x, y, z, t)_{\max}} \cdot \frac{L(x, y, z, t)}{L(x, y, z, t)_{\max}} \tag{6}$$

It makes the $V_{\rm RTL}$ function changing within [−1, 1] and the expectation value is zero. $V_{\rm RTL}>0$ or $V_{\rm RTL}<0$ imply respectively seismic activation or quiescence upon background values.

In the actual calculation, the following constraint conditions are introduced.

$$M_i \geq M_{\min} \tag{7}$$

$$r_i \leq R_{\max} = 2r_0 \tag{8}$$

$$t_i \leq T_{\max} = 2t_0 \tag{9}$$

$$d_i \leq d_0 \tag{10}$$

Where $M_{\min}$ is the cut-off magnitude, which is related to the completeness of the earthquake catalogue and is determined by the Gutenberg formula. M_i is the magnitude of the ith event. d_i is the focal depth of the ith event and d_0 is the cut-off depth. Generally, earthquakes with all depths in the catalogue are selected. r_0 and t_0 are the characteristic distance and time, respectively.

It is evident from equations (1~3) and equations (8) and (9) that the two characteristic parameters r_0 and t_0 not only affect directly the values of R, T and L, but also determine the range and duration of the events calculated, so as to affect the final value of $V_{\rm RTL}(x, y, z, t)$. It shows the importance of these two parameters in the RTL algorithm. For selecting r_0 and t_0, the previous authors generally gave a synthetical consideration for rupture length and location precision, and then tried artificially from their experiences to determine by test calculation in a certain range of distance and time. This method has subjectivity to a certain extent.

2 A method for determining characteristic parameters

Considering the importance of characteristic parameters in the RTL algorithm, CHEN and WU (2006) proposed a method to determine the two characteristic parameters by calculating the correlation coefficient of a set of r_0 and t_0 and applied it to the 1999 Chi-Chi earthquake, Taiwan. This method can acquire mathematically a relatively steady pattern of RTL function by using the obtained r_0 and t_0.

In fact, the anomalous seismic activities including activation and quiescence in and around source areas before moderate and strong earthquakes have already drawn more attentions. It is well known that a gap of seismic activity would occur before a moderate or a strong earthquake. The gap is actually the region with anomalous seismic quiescence before main shock. Mogi (1997) brought forward two kinds of concept for seismic gap. This paper refers to the gap formed by small earthquakes before a moderate or a strong earthquake.

Many researchers have discovered that the size (dimension) and duration of gap are related to a certain extent to the magnitude of the coming main shock. HAN and XI (1984) studied the gap's characteristics using a method of *R*-*t* figure on the basis of synthetical consideration of spatial and temporal factors. The so-called *R*-*t* figure involves setting the epicenter of the largest earthquake in the studied region as the origin and the time as the *x*-coordinate and calculating the distance *R* between the small events and the origin from the time as earlier as possible to obtain the *R*-*t* figure. If earthquake absence appears near the *x*-coordinate, it implies seismic quiescence of small earthquakes appearing in the corresponding duration around the epicenter. From the obtained *R*-*t* figure, the duration and the maximum spatial dimension of gap can be estimated.

HAN and XI (1984) obtained the empirical relations between the spatial dimension, the appearing duration of gap and the magnitude of main shock from 10 earthquake examples as follows.

$$M = 5.50\lg R_{\max} - 2.33 \pm 1.32 \tag{11}$$

$$M = 2.98\lg T + 2.94 \pm 1.06 \tag{12}$$

Where $R_{\max}$ is the maximum dimension of gap in the unit of kilometer, T is the appearing duration in the unit of month. Equations (11) and (12) are linearly correlated with the significance level of 0.10 and 0.01, respectively.

Since the gap and seismic quiescence in the RTL algorithm are the phenomena based on the same physical mechanism, it clews us taking the gap's dimension and appearing duration as the characteristic distance and time in the RTL algorithm as follows.

$$M_S = 5.50\lg r_0 - 2.33 \tag{13}$$

$$M_S = 2.98\lg t_0 + 2.94 \tag{14}$$

It should be pointed out that at first we take the gap's temporal-spatial dimension expressing the quiescence of seismic activity as the characteristic time and distance to detect the seismic quiescence before a great earthquake. The so-called "seismic quiescence" refers to the lower level of seismic activity under the background level before a great earthquake, which is due to larger energy concentration than release in the duration. The longer the quiescence time, the larger the quiescence range, and the higher the energy concentration is, the greater the coming earthquake will be. On the basis of the one-dimensional gliding-block model for earthquake preparation and occurrence, Hainzl *et al* (1999) improved it to a two-dimensional gliding-block model, which is capable to simulate not only the more realistic fault system, but also the seismic phenomena like seismic quiescence, foreshock, aftershock, *etc*. Moreover, Hainzl *et al* (2000) approved that the seismic quiescence can be taken as a precursory index for a coming great earthquake. Therefore, the seismic quiescence relative to the background level is a kind of very important precursor before a moderate or a strong earthquake. The abnormity of higher seismic activity level than the background (if it exists) can also be detected by the RTL algorithm, since the seismic quiescence and activation are relative to the background. Secondly, the equations above are obtained experientially by studying a number of earthquake examples and the experiential relations in different regions are different to a certain extent, so the obtained characteristic distance and time are changeable in a certain range, which should be approved in the studied area.

3 Precursory characteristics of seismic activities before four earthquakes

For comparison, the anomalous seismic activities before four moderately strong earthquakes occurred in the northwestern and southwestern China in recent years are studied by the characteristic distance and time calculated from equations (13) and (14) and the method of correlation coefficient, respectively. The two results are shown as follows.

3.1 Data

The four earthquakes in Table 1 are studied in detail.

Table 1 Seismic parameters of earthquakes studied

Date a-mo-d	Origin time h:min:s	Epicenter $\varphi_N/°$	Epicenter $\lambda_E/°$	M_S	Location
2000-09-12	08:27:31	35.56	99.64	6.4	Xinghai, Qinghai
2003-07-21	23:16:30	25.95	101.24	6.2	Dayao, Yunnan
2002-12-14	21:27:29	39.82	97.33	5.9	Yumen, Gansu
2003-10-25	20:41:36	38.35	100.93	6.1	Shandan, Gansu

On the basis of the earthquake catalogue publicized by Institute of Earthquake Science, Chinese Earthquake Administration (CEA), we select a square region with the side length of 4° centering at the epicenter of the studied earthquake and the data of five years prior to the event for a detailed study. And we estimate the completeness of earthquake catalogue by the frequency-magnitude power law (Gutenberg formula)

$$\lg N = a - bM \tag{15}$$

to determine the minimum magnitude (Figure 1). It is apparent from Figure 1 that the minimum magnitude selected is 2.0 for Xinghai M_S6.4, Dayao M_S6.2 and Yumen M_S5.9 earthquakes, and 1.5 for Shandan M_S6.1 earthquake.

If a large event occurs before the studied earthquake in the selected temporal-spatial range, its aftershocks will inevitably affect the background seismicity and bring about disturbance to the anomalous characteristics (see next text). However, it is very complex to delete aftershocks. REN

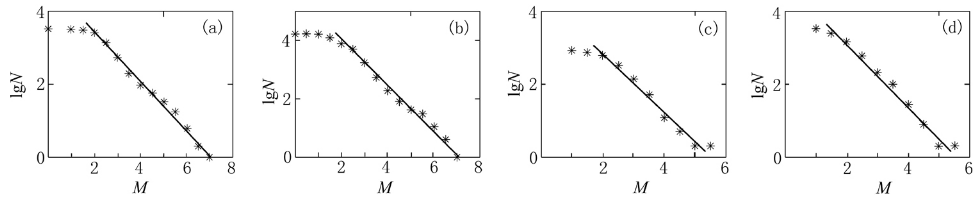

Figure 1 Magnitude-frequency curves for earthquakes in the selected temporal-spatial range
(a) Xinghai M_S6.4; (b) Dayao M_S6.2; (c) Yumen M_S5.9; (d) Shandan M_S6.1

(2005) created a method to quantitatively delete aftershocks on the basis of many methods. In this paper, we use her method to delete the aftershocks of $M_S \geq 5.0$ earthquakes in the seismic catalogue in the selected temporal-spatial range.

3.2 About rupture length

The rupture length of an earthquake is related to its magnitude, we use GUO and QIN's formula (1991)

$$M = 3.3 + 2.1\lg L \tag{16}$$

to calculate the rupture length

$$L = 10^{0.48M-1.57} \tag{17}$$

Where the unit of rupture length is kilometer.

3.3 RTL's calculation and results

CHEN and WU (2006) derived the two characteristic parameters by the method of correlation coefficients. The method is that for a given characteristic distance r_0, by changing the characteristic time t_0 with a certain step length in a possible range, the RTL functions of each combination of r_0 and t_0 are calculated, and then the correlation coefficients are computed. Their average value is just the correlation coefficient of the given characteristic distance. Then by making the characteristic distance changing with a certain step length in a certain range, the correlation coefficients of each characteristic distance are computed using the same method mentioned above. Finally the characteristic distance with the maximum correlation coefficient can be selected as the one to calculate the RTL functions. The characteristic time with the maximum correlation coefficient can also be obtained by the same method.

The correlation coefficients of characteristic distance and time obtained by the above-mentioned method for four earthquakes are shown in Figure 2. The characteristic distance and time can be obtained from the corresponding maximum correlation coefficients. For the earthquake with the correlation coefficients in the rough in a certain range, the characteristic distance and time can be determined by test in this range. The characteristic parameters obtained from correlation coefficients and equations (13) and (14) are shown together in Table 2.

The RTL functions are calculated from the characteristic parameters obtained by the above-mentioned two methods, which are shown respectively in Figure 3.

Table 2 Characteristic parameters obtained by two methods

Events	M_S	r_0 and t_0 at maximum correlation coefficients		r_0 and t_0 obtained by equations (13) and (14)	
		r_0/km	t_0/day	r_0/km	t_0/day
Xinghai	6.4	62	840	42	507
Dayao	6.2	77	630	36	372
Yumen	5.9	30	330~1000	31.4	295
Shandan	6.1	20, 50~80	450, 630	34.1	345

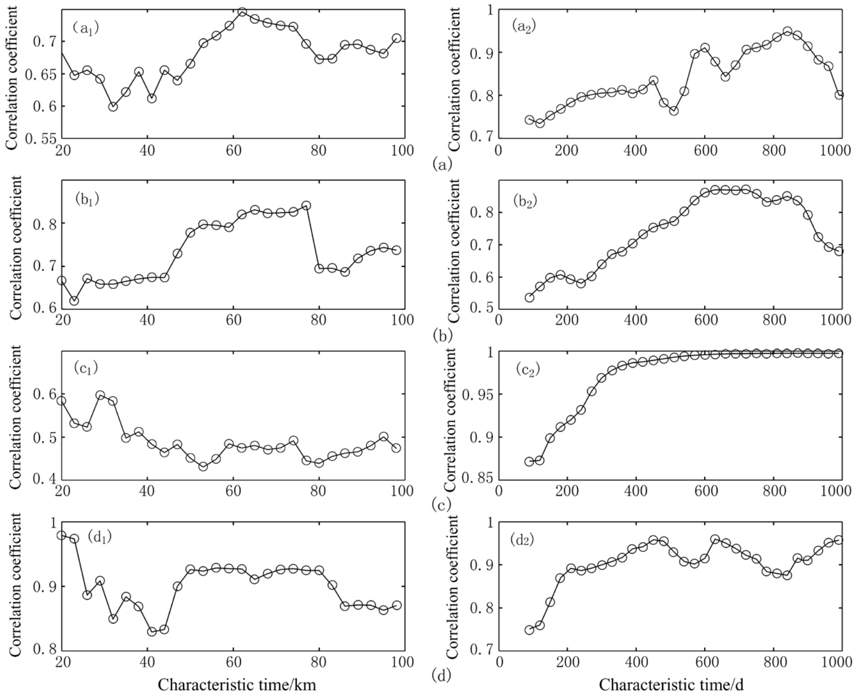

Figure 2 Characteristic parameters calculated by correlation coefficient method

(a_1) Xinghai M_S6.4 characteristic distance; (b_1) Dayao M_S6.2 characteristic distance; (c_1) Yumen M_S5.9 characteristic distance; (d_1) Shandan M_S6.1 characteristic distance; (a_2) Xinghai M_S6.4 characteristic time; (b_2) Dayao M_S6.2 characteristic time; (c_2) Yumen M_S5.9 characteristic time; (d_2) Shandan M_S6.1 characteristic time

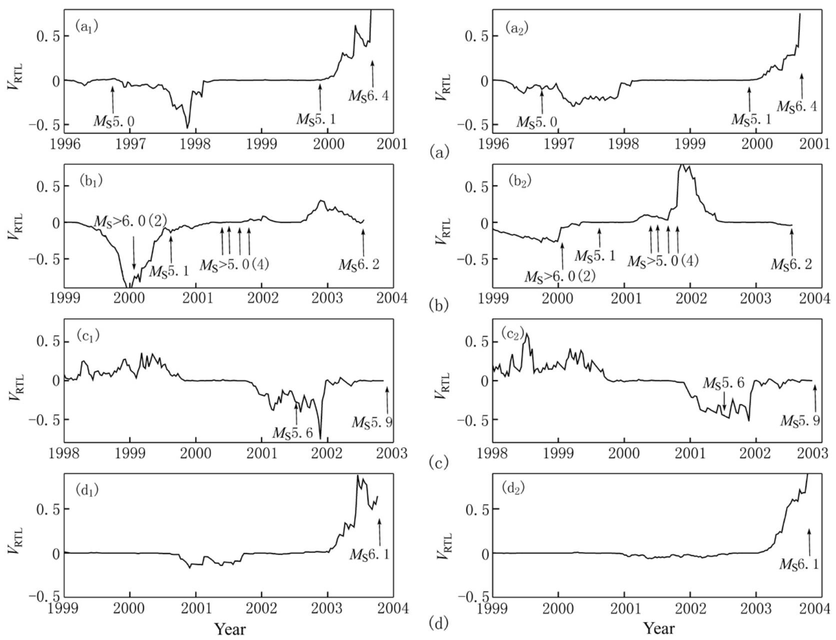

Figure 3 V_{RTL} functions for four studied earthquakes

(a) Xinghai M_S6.4; (b) Dayao M_S6.2; (c) Yumen M_S5.9; (d) Shandan M_S6.1

In Figure 3, the left figures show the results using characteristic parameters obtained by equations (13) and (14); the right figures show the results using characteristic parameters obtained by correlation analysis. The vertical lines and corresponding values indicate the moderately strong earthquakes occurred before the main shock in the region studied, and the digits within the bracket after magnitude are the numbers of the earthquake

5 Discussion and conclusions

1) In this paper, two methods are used for estimating the characteristic parameters in the RTL algorithm. One is the method to calculate correlation coefficients proposed by CHEN and WU (2006), the other is to calculate characteristic distance and time by using equations (13) and (14) proposed by us on the basis of gap's temporal-spatial characteristics. It should be noticed that CHEN and WU's method for calculating correlation coefficients was only used for one event, *i.e.*, the Chi-Chi earthquake in Taiwan and good results are obtained. As to the four earthquakes studied in this paper, good result is obtained for one earthquake (Xinghai M_S6.4); the only position with the maximum correlation coefficient is not obtained for some earthquakes (*e.g.*, Yumen M_S5.9 and Shandan M_S6.1); and obviously unreasonable characteristic parameters are obtained for some earthquakes (*e.g.*, the characteristic distance of 20 km for Shandan M_S6.1). The calculation of RTL functions in these conditions still needs determining characteristic parameters by test, which brings a certain difficulty for using the method of correlation coefficients in practice.

2) It is apparent from the comparison of results in Figure 3 that the curves of RTL functions with approximately the same change can be obtained from both methods, but we can see that the results of characteristic parameters calculated by equations (13) and (14) based on gap's temporal-spatial characteristics are better than that by CHEN and WU's method and the amplitudes showing seismic quiescence and activation are relatively large. For Dayao earthquake, the seismic activity shows a higher level near the year 2000, because a larger characteristic distance (77 km) is obtained by the method of correlation coefficient and more events are calculated in this range. As a kind of seismic precursor, seismic quiescence is more reliable than high activation as mentioned above. This is because that the minus values of RTL function (lower seismic activity) are induced only by possible absence of seismic catalogue rather than other factors in the calculation. While the high values of RTL are easily caused by seismic background, aftershocks, swarm earthquakes, or even larger moderately strong earthquakes.

3) Deleting aftershocks is more effective on the results, especially for the area with frequent moderately strong earthquakes like Yunnan. The RTL functions of Dayao earthquake before and after the deletion of aftershocks are shown in Figure 4 as an example.

It is evident from the comparison between (a) and (b) in Figure 4 that the $M_S \geq 5.0$ earthquakes occurred frequently in 2001 lead to a higher level of seismic activity, which is restrained in the curve of RTL function after aftershocks are deleted.

4) Our purpose to study the characteristics of anomalous seismic activity by the RTL algorithm is to apply the method to the prediction of great earthquake in an area, *i.e.*, to do scanning and searching for the area concerned. If we use the method of correlation coefficient to estimate characteristic parameters, a large number of calculations will be needed for each area. Moreover, on the basis of CHEN and WU's results (2006), it is possible to obtain unreasonable characteristic parameters with the maximum correlation coefficient, which needs artificial determination of characteristic parameters in this case. Therefore, it is difficult to apply this method to realistic pre-

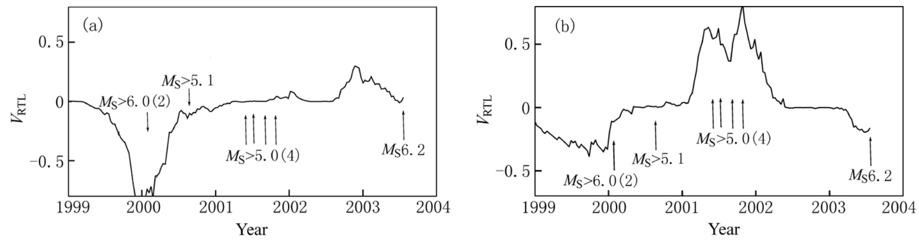

Figure 4 V_{RTL} function before and after the deletion of aftershocks for Dayao M_S6.2 earthquake
(a) Aftershocks are deleted; (b) Aftershocks are not deleted. In the figure, the vertical lines and corresponding values indicate the moderate-strong earthquakes occurred before the main shock in the region studied, and the digits within the bracket after magnitude are the numbers of the earthquake

diction. However, the method to estimate characteristic parameters in the RTL algorithm proposed in this paper has not only a physical basis but also a simple and easy application to realistic earthquake prediction. In practice, we should at first set a starting magnitude (*e.g.*, M=5.0) for the area needed for detection, calculate characteristic parameters from equations (13) and (14), scan the region concerned by using the RTL algorithm, and find out the risk area where an earthquake with the selected magnitude (*e.g.*, M=5.0) might occur. Then the same detection for larger earthquakes (*e.g.*, M=6.0, 7.0) can be made so as to find out seismic risk areas with different magnitudes for reference in earthquake prediction.

5) The study on the four $M\approx6$ earthquakes occurred in the northwestern and southwestern China shows that typical abnormal precursors of seismic quiescence-activation-occurrence appear before all earthquakes studied, which provides examples of earthquake for using the method in earthquake prediction.

6) It should be pointed out that the method proposed here to estimate characteristic parameters in the RTL algorithm is on the basis of the studies on gap's temporal-spatial characteristics, so the method needs verification by more examples of earthquake and further improvement because of the uncertainty of relations between the temporal-spatial dimension and the magnitude of main shock and the difference of different regions.

References

CHEN Chienchih and WU Yixuan. 2006. An improved region-time-length algorithm applied to the 1999 Chi-Chi, Taiwan earthquake [J]. *Geophys J Int*, **166**: 1 144-1 147.

Di Giovambattista R, Tyupkin Yu S. 2000. Spatial and temporal distribution of seismicity before the Umbria-Marche September 26, 1997 earthquakes [J]. *J Seismology*, **4**: 589-598.

GUO Zeng-jian and QIN Bao-yan. 1991. *Seismogenesis and Earthquake Prediction* [M]. Beijing: Seismological Press, 177-178 (in Chinese).

Hainzl S, Zoller G, Kurths J. 1999. Similar power laws for foreshock and aftershock sequences in a spring-block model for earthquakes [J]. *J Geophys Res*, **104**: 7 243-7 254.

Hainzl S, Zoller G, Kurths J. 2000. Seismic quiescence as an indicator for large earthquakes in a system of self-organized criticality [J]. *Geophys Res Lett*, **27**: 597-600.

HAN Wei-bin and XI Dun-li. 1984. Temporal and spatial characteristics of seismic gaps formed by weak earthquakes before strong earthquakes in Sichuan Province [J]. *Acta Seismologica Sinica,* **6**(1): 8-21 (in Chinese).

Huang Q, Oncel A O, Sobolev G A. 2002. Precursory seismicity changes associated with the M_w=7.4 1999 August 17 Izmit (Turkey) earthquake [J]. *Geophys J Int*, **151**: 235-242.

Huang Q, Sobolev G A, Nagao T. 2001. Characteristics of the seismic quiescence and activation patterns before the M=7.2 Kobe earthquake, January 17, 1995 [J]. *Tectonophysics*, **337**: 99-116.

JIANG Hai-kun, HOU Hai-feng, ZHOU Huan-peng, *et al*. 2004. Region-time-length algorithm and its application to the study of intermediate-short term earthquake precursor in North China [J]. *Acta Seismologica Sinica*, **17**(2): 164-176.

LIU Hong and SU You-jin. 2006. Application of region-time-length algorithm to Yunnan area [J]. *Journal of Seismological Research*, **29**(1): 25-29 (in Chinese).

Mogi K. 1979. Two kinds of seismic gap [J]. *Pure Appl Geophys*, **117** (6): 1176-1186.

REN Xue-mei. 2005. Study on aftershock deletion of $M\geq5.0$ earthquakes occurred in the eastern part of the northwest China [D] [MS Dissertation]. Lanzhou: Earthquake Institute of Lanzhou, China Earthquake Administration: 17-21 (in Chinese).

Sobolev G A and Tyupkin Y S. 1997. Low-seismicity precursors of large earthquakes in Kamchatka [J]. *Volc Seis*, **18**: 433-446.