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The peak point of LURR and its significance

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SUMMARY

The Load/Unload Response Ratio (LURR) value fluctuates around one during the early stage of the seismogenic process and then rises and reaches its peak point before the occurrence of a strong earthquake; the strong earthquake however does not onset at that time, but after the peak point LURR decreases sharply at the eve of the main shock before the final event outbreak. Thus, the peak point of LURR is ahead of the occurrence of an earthquake. We denote the lead time as T_2. The discovery of peak point for LURR and the relationship between T_2 and magnitude M is of great significance as the peak point is usually easy to determine and then we can predict the occurrence time for the coming event according to Equation (3) so that we can enhance the precision of time for earthquake prediction in terms of LURR from 'year' scale to 'month' scale. The variation of LURR around the Wenchuan earthquake and its lesson to us are depicted in the paper. Copyright © 2009 John Wiley & Sons, Ltd.

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KEY WORDS: Load/Unload Response Ratio (LURR); earthquake prediction; peak point of LURR; Wenchuan earthquake

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INTRODUCTION

Load/Unload Response Ratio (LURR) is a new approach to earthquake prediction. Till date we have made tremendous achievement in real earthquake prediction practice using LURR, especially for medium term earthquake prediction (e.g. one-year time scale) [1–12].

Every year, in November, our team submits an annual report [13–16] on LURR spatial scanning for the mainland of China to the relevant authorities, in which the LURR anomaly regions are represented. These reports have been published in the book series. The Research on Seismic Tendency of China in xxxx year, edited by the Center for the Analysis and Prediction (now it is changed as Institute of Earthquake Science), CSB and published at the end of the same year. It is predicted that there will be strong earthquakes occurring in the future (especially in the next year) in the seismogenic regions based on the LURR anomaly regions, but larger than them [12].

Since the year of 2004, we have made a major breakthrough in annual earthquake prediction in terms of LURR. In 2004, 33 strong earthquakes ($M \geq 5$) occurred in the Chinese mainland. Among them 16 events occurred in the data scarcity regions from where the data were unavailable for calculating LURR and should be neglected during the evaluation prediction effect. Among the other 17 strong earthquakes, 15 events fell into the seismogenic regions predicted at the end of year 2003 using LURR. The percentage is $\frac{15}{17} = 88\%$. For 2005, 2006 and 2007 these percentages are

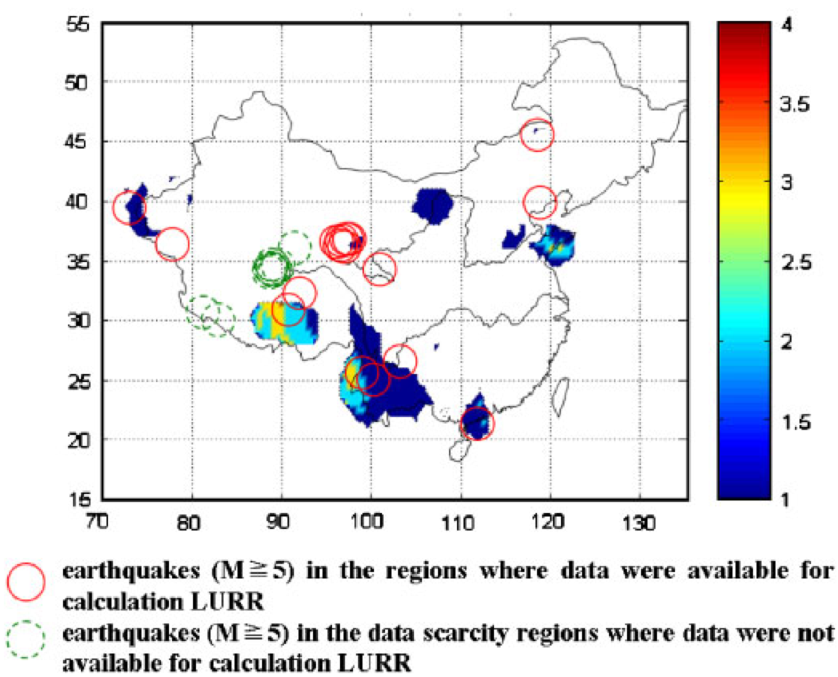

Figure 1. The LURR anomaly regions according to the results calculated in November 2003 and the epicenter distribution map of the earthquakes with magnitude $M \geq 5$ that occurred in 2004 in the mainland of China.

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$\frac{12}{13} = 92\%$, $\frac{8}{9} = 89\%$ and $\frac{12}{12} = 100\%$, respectively. The average percentage in the four years from 2004 to 2007 is 92%.

The details of the prediction for 2004 in terms of LURR have been depicted in [11–13]. Owing to space limitations, here we only depict the LURR anomaly regions according to the result calculated in November 2003 and the epicenters distribution map of the earthquakes with magnitude $M \geq 5$ occurred in the next year (2004) in the Chinese mainland (Figure 1).

THE PEAK POINT OF LURR AND ITS SIGNIFICANCE

As introduced above the annual earthquake prediction using LURR has been progressing steadily in the recent years. Our most important goal is to enhance the preciseness of the prediction time in terms of LURR.

According to the comprehensive research in the variation of LURR (experimental, numerical, analytical researches, real seismic data and analysis with damage mechanics), the evolution law of LURR is that the LURR value fluctuates around 1 during the early stage of the seismogenic process and then rises and reaches its maximum (significantly larger than 1), called *peak point* before the occurrence of a strong earthquake or catastrophic failure of the specimen; however, the strong earthquake does not onset at that time, but after the peak point LURR decreases sharply at the eve of the main shock and finally the outbreak of the event.

The entire process is shown in Figure 2. The picture on the left is the result of seismic data (Loma Preita earthquake) [12], the middle one is an experimental result of rock specimen [8,17] and the one on the right is an analytical result in terms of damage mechanics [18].

In other words, the earthquake lags behind the peak point of LURR or the peak point of LURR will be ahead of the occurrence of earthquake. We denoted the lead time (the duration between the

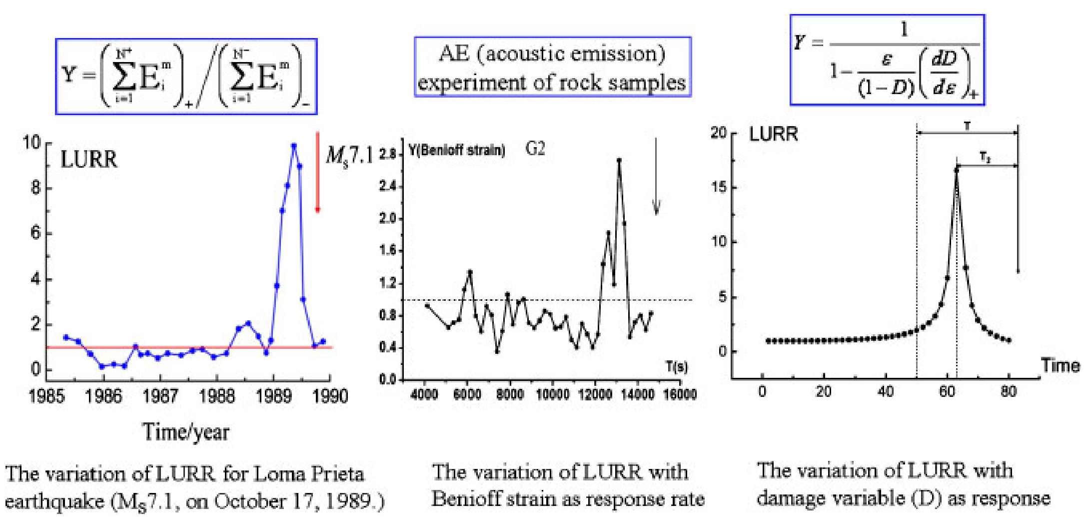

Figure 2. THE LURR evolution curves with different measures: left—seismic data; middle–rock acoustic emission experiment and right—damage mechanics analysis.

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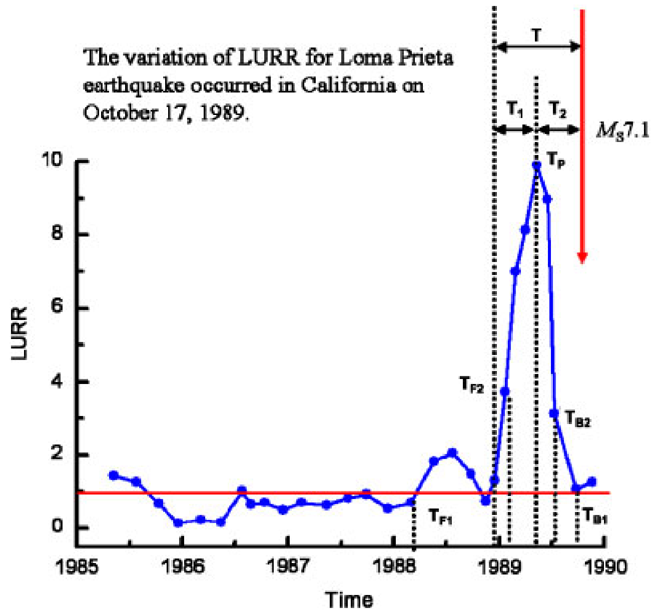

Figure 3. The definitions of T, T_1 and T_2.

Table I. $T2$ as the function of magnitude M.

Magnitude	R (km)	T_w (mon)	T_2 (mon)
5	100	15	5 ± 2
6	200	18	14 ± 4
7	300	24	22 ± 5
8	300	24	28 ± 8

Note: R is the radius of space window and T_w is the time window in LURR special scanning.

time of LURR peak point and the occurrence of the quake) as T_2 and the total anomaly duration of LURR as T (Figure 3)

$$T = T_1 + T_2 \tag{1}$$

T, T_1 and T_2 depend on the magnitude M of the incoming event as follows [12,19]:

$$T_2 = 60(1 - 2.3 \times 10^{-0.08M}) \tag{2}$$

and

$$T = 80(1 - 2.5 \times 10^{-0.09M}) \tag{3}$$

For the sake of clarity, we calculate T_2 for $M = 5, 6, 7$ and 8 and list the results in Table I.

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The discovery of peak point for LURR and the relationship between T_2 and magnitude M is of great significance since the peak point is usually easy to determine and then we can predict the occurrence time for the coming event according to Equation (3). In this way we can enhance the precision of prediction time in terms of LURR from ‘year’ scale to ‘month’ scale.

THE VARIATION OF LURR AROUND THE WENCHUAN EARTHQUAKE

On 12 May 2008, a great earthquake with magnitude $M_s 8$ ($M_w 7.9$) occurred at Wenchuan city, Sichuan Province, south-western China. Its epicenter was located at (103.50°E, 30.95°N) and the rupture occurred over a length of ~ 270 km along Longmen Shan faults.

The LURR evolution before the Wenchuan earthquake is shown in Figure 4. Figure 4 is the LURR special scanning for the Chinese mainland, which was calculated before Wenchuan earthquake. The time window is two years and the special window is a circle region with radius 300 km. There are 48 maps of the LURR anomaly regions in different time arranged in temporal order from top to bottom and from left to right. The first map at the top left corner is the time window from 2002.05.01 to 2004.04.30, and the last map is the time window from 2006.02.01 to 2008.03.31 (from now on we just note the end time of the time window).

According to Equations (1)–(3), for an earthquake with $M8$, its T_1 should be 20 ± 8 months and T_2 should be 28 ± 8 months. This implies that its LURR anomaly duration should last about 4 years and T_2 would be about 2–3 years.

In fact the LURR anomaly along Longmen Shan appeared in 2005.01 (Figure 4)—41 months ahead of the great earthquake and the peak point of LURR was in 2006.06, 23 months before the earthquake. This means that the LURR evolution along Longmen Shan has described the seismogenic progress of the Wenchuan earthquake very well.

In fact, in our annual report [15] written at the end of 2005, we had indicated that there was a LURR anomaly region in the Sichuan Province. Furthermore, in our annual report [16] written at the end of 2006, we pointed out clearly that ‘along the belt (Longmen Shan) the LURR anomaly had lasted for a long time’ and predicted that ‘a strong earthquake will occurred there within 18 months starting from August 2006’. ‘Within 18 months starting from August 2006’ means a period with its end of March 2008 which was just 2 months ahead of the occurrence time of the Wenchuan earthquake.

Unfortunately at the end of 2007 when we wrote the annual report for 2008, we made a terrible mistake by not insisting on this earthquake prediction for the Longmen Shan region once more, but gave it up, since at that time the LURR peak point had passed a long time ago (more than one year), but the predicted had not occurred and the LURR anomaly degree in that region was getting more and more less. Such a mistake misled us to not having successfully predicted the Wenchuan earthquake.

It is a little more gratifying that we had predicted the type of the aftershock sequence of the Wenchuan earthquake and some strong aftershocks successfully in terms of LURR. We divided the whole aftershock area of the Wenchuan earthquake into two portions: SW and NE (see in Figure 5), as ‘reverse and right-slip components are of comparable magnitude along the southwestern portion of the rupture, but right-slip dominates the northeastern portion of the rupture’ [20,21].

The LURR evolutions of SW and NE portions are shown in Figure 6, respectively, which indicate that the values of LURR for both portions SW and NE were less than the unity obviously just after the main shock. This implies that the main shock had released most of the accumulated energy in

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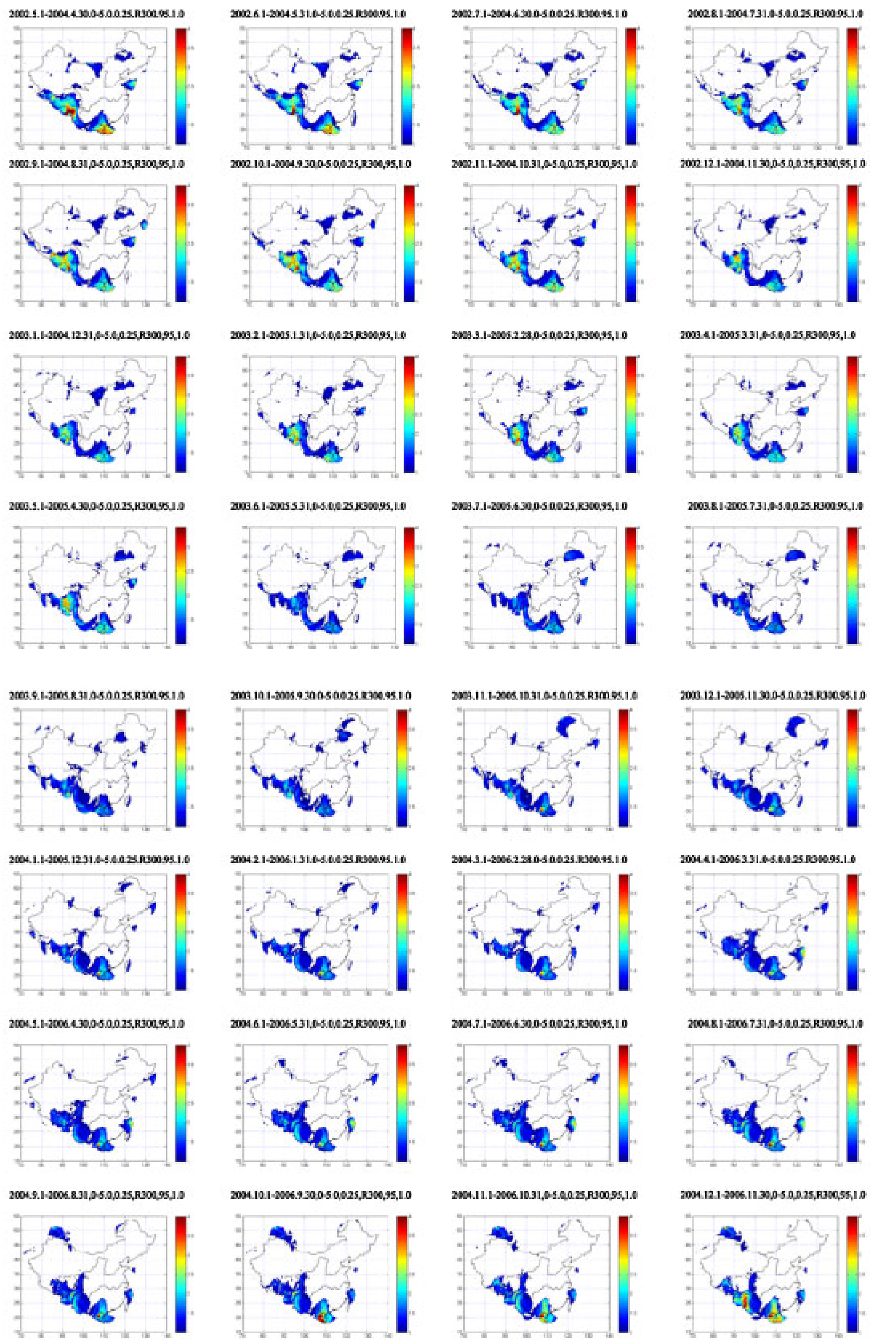

Figure 4. The results of LURR spatial scanning in different periods.

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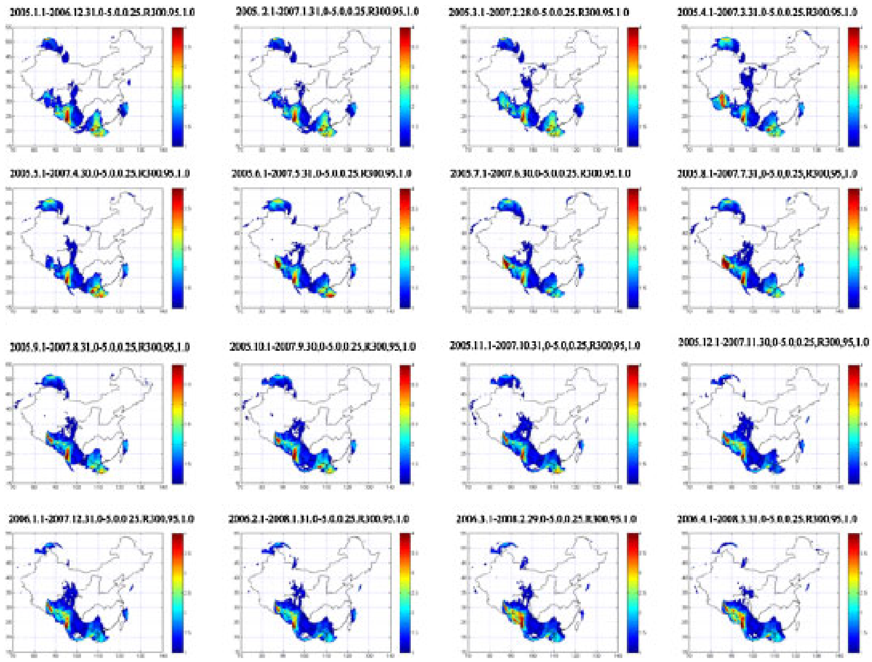

Figure 4. *Continued.*

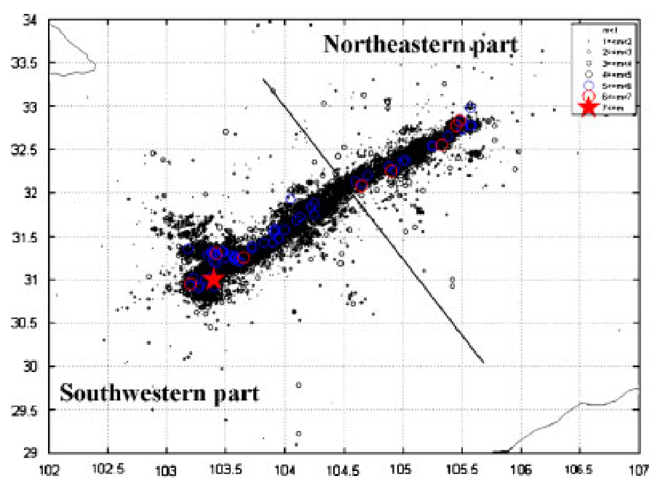

Figure 5. Dividing the rupture area of the Wenchuan earthquake into two portions: southwestern portion SW and northeastern portion NE. Two portions with different seismic mechanisms (SW: 229, 33, 141; NE: 229, 33, 180).

that region and led the crust of that region into a quite stable state. According to this result, it is predicted that its aftershock sequences could be the so-called 'main-shock-aftershock sequence', which means that the maximum magnitude in its aftershocks will be much smaller than that one

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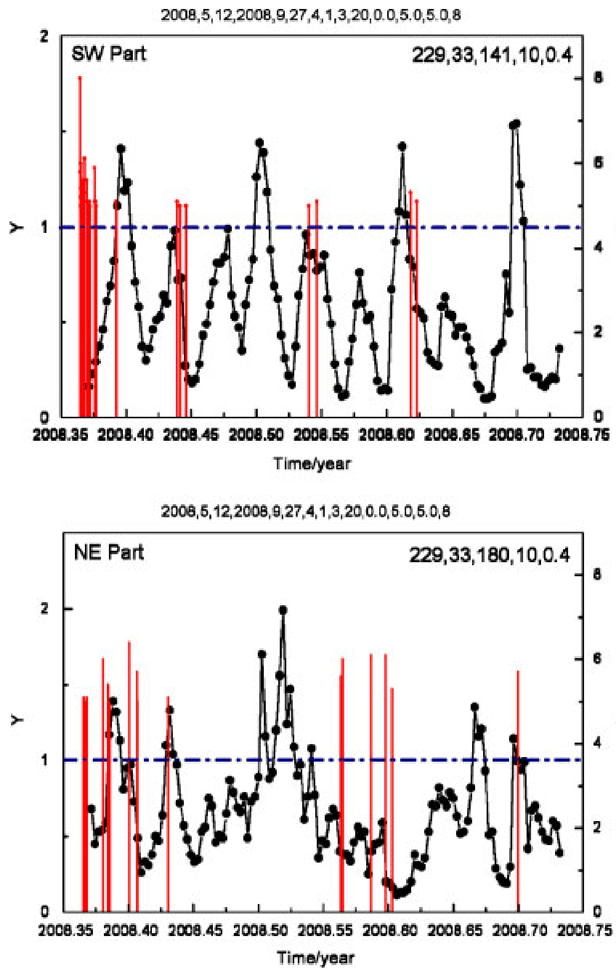

Figure 6. The evolution of LURR for the two portions of rupture area of the Wenchuan earthquake. The curve denotes LURR and the vertical lines denote earthquakes.

of the main shocks. Till now, more than 15 months after the main shock, the strongest aftershock was M 6.4 that is not comparable with the magnitude of the main shock.

Figure 6 manifests that the strong aftershocks ($M \geq 5$) usually occurred behind the peak points of LURR for both NE and SW portions. We have traced the LURR continuously since the main shock and successfully predicted most strong aftershocks in real time.

CONCLUDING REMARKS

As mentioned above for a large earthquake ($M \geq 7$), the whole LURR anomaly duration (T) and even T_2 would last several years. After the peak point of LURR, it usually decreases sharply and even disappears at the eve of the main shock, but the anticipated event does not happen at that time. It is easy to mislead us doubting our prediction and even give it up in such a complex situation. This is a profound lesson to us written in blood from the Wenchuan earthquake.

Relating to the temporal scaling, the spatial scaling is also of importance. We have investigated the spatial scaling of seismogenious progress also [10,22,23]. The radius R of LURR special scanning is also the function of magnitude of the predicted earthquake as follows:

$$\text{Log}\, R(\text{km}) = 0.087 + 0.34\, M \tag{4}$$

In order to predict earthquakes of different magnitudes, we have to conduct LURR tempo-spacial scanning using different scales of time windows and spacial ones hence the computing work is tremendous. It is well known that earthquake predictions need treating the seismic data in real time; consequently, HPC is indispensable.

It is emphasized that seismogenious process of a large earthquake lasts a long time in a vast region. From this it is clear from Figure 4 that a super large earthquake with magnitude much larger than 8 could be preparing in southwestern China which includes Tibet, Yunnan, Guangxi and part of Qinghai and Sichuan. We will trace it out carefully in the future and narrow the ranges of time and space of the prediction as much as we can do.

POSTSCRIPT

On 12 May 2008, the day of the great Wenchuan earthquake, the first author of this paper was participating in the 6th ACES Workshop in Cairns, Australia and gave a presentation titled ‘The peak point of LURR and its significance’ (the same one as in this paper). After that we knew the bad news of this earthquake. The next day, the first author gave a short presentation on the Wenchuan earthquake and showed Figure 4 at the Workshop. However, it was no longer a successful prediction, but a deep feeling of grief for the souls of the deceased people in this earthquake.

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