The earthquake trend in Australia indicated by LURR method

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Australia seems to have less frequent large earthquakes than other countries around the Pacific rim. While this low frequency has benefited Australia in most aspects, it also lessens people's awareness against earthquake disaster. The 1989 Newcastle earthquake is just a reminder that Australia is not immune to disastrous earthquakes. In the future, if a much greater earthquake hits a dense populated area without warning, huge loss would be inevitable. Therefore it is not surprising that the public interest about earthquakes changed dramatically overnight in Australia after the great Sumatra Earthquake in 2004. To reduce public confusion and panic, the earthquake trend prediction in Australia has become important and necessary, even though the predictability of earthquakes is still a controversial topic and a perfect prediction method is yet to emerge. Because the LURR (Load/Unload Response Ratio) method has shown promise in the past, we try to identify earthquake trend in Australia using this method in this paper.

Brief introduction of the LURR theory

LURR is a method for earthquake prediction proposed on the basis of the constitutive relationship of rock deformation (Yin et al 1991, 1995, 2000).

It is recognized by most scientists that the physical essence of an earthquake is the failure or instability of the focal media accompanied by rapid release of energy. Therefore the preparation process of an earthquake is exactly the deformation and damage process of the focal media.

The damage process has been intensively studied for decades but many fundamental questions remain unsolved. The problem of damage and failure in solid mechanics is as difficult as turbulence in fluid mechanics; this is the inherent difficulty of earthquake prediction.

From the macroscopic viewpoint, a suite of effective phenomenological methods have been developed to probe the issue, to which the key is the constitutive relationship of materials that describes the mechanical property of the material, i.e. relation between stress and strain. If we could put the earth crust under a loading machine and observe its entire constitutive curve, we would be able to determine its stage of evolution towards failure, i.e. to ***predict*** its behavior at any moment. Certainly this idea is just a dream that may never come true. An alternative to observing the whole constitutive curve of focal media is monitoring a parameter that is easy to observe but also reflects the nature of constitutive relationship.

A typical constitutive curve of rock is shown in Figure 1. For generality, the ordinate denotes general load ***P*** instead of stress and the abscissa is the response ***R*** instead of strain. If the load exerted on the material increases monotonically, the material will experience elastic regime (OA), damage regime (AB) and failure or destabilization regime (BC) in order. The most essential characteristic of the elastic regime is its reversibility, i.e. the positive process and the contrary process are reversible. In other words, the loading modulus is equal to the unloading modulus. Contrary to the elastic regime, the damage regime is irreversible and the loading modulus is different from the unloading one. This difference indicates the deterioration of material due to damage.

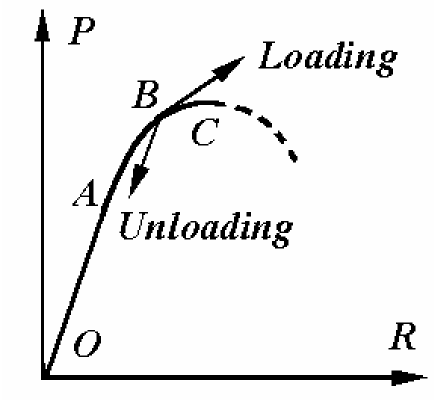

Figure 1, A conceptual constitutive curve. Section OA, AB and BC refers to elastic, damage and failure regime respectively. At the damage regime (AB), loading follows a path different from that of unloading.

In order to measure quantitatively the difference, two parameters are introduced as follows. The first one is the response rate X defined as

$$X = \lim_{\Delta P \to 0} \frac{\Delta R}{\Delta P} \qquad (1)$$

where ΔP and ΔR denote the increments of load *P* and response *R*, respectively. By this definition, X is the reciprocal of slope of constitutive curve P-R. It indicates the stage of damage process of rocks. But X is a dimensional parameter depending upon both response R and loading P. In order to get a universal indicator, we introduce a dimensionless parameter, the Load/Unload Response Ratio (LURR) *Y,* that is defined as

$$Y = \frac{X_+}{X_-} \qquad (2)$$

where X_+ and X_- refer to the response rate under loading and unloading condition respectively at the same point in P-R space.

It is clear that Y=1 corresponds to elastic regime since X_+=X_- and Y>1 refers to damage regime due to $X_+ > X_-$. The more seriously damaged is the material, the greater the Y value will be. As the media approach failure, the Y value becomes larger and larger. So, Y value is a parameter that could measure the proximity to failure.

Formula (2) is the basic definition of response ratio. In practice, we use the seismic energy release as response and the duration of loading as general loading and define LURR as follow:

$$Y = \frac{\sum_{t \in T_+} E(t)/T_+}{\sum_{t \in T_-} E(t)/T_-} = \frac{T_-}{T_+} \cdot \frac{\left(\sum_{i=1}^{N^+} E_i^m \right)_+}{\left(\sum_{i=1}^{N^-} E_i^m \right)_-}, \qquad (3)$$

where the sign "+" means loading and "–" unloading. The sum of energy E denotes total energy release can be calculated according to Gutenberg-Richter formula $\log E = a + bM$ (b=1.5 in general) while N_+ and N_- denote the number of earthquake occurred during the loading and unloading period respectively. The exponential factor m=0, 1/3, 1/2, 2/3 or 1 and usually takes ½ to denote the Benioff strain.

The near periodical deformation of the earth caused by gravitational forces of celestial bodies (Sun, Moon etc.) serves as loading and unloading after special processing. The stress due to both solid earth tides and ocean loading effect can be calculated with relatively high precision. The Coulomb failure hypothesis is adopted to judge loading/unloading according to the sign of the increment of tidal Coulomb Failure Stress(CFS), which is defined according to the following formula:

$$CFS = \tau_n + f\sigma_n, \qquad (4)$$

where f, τ_n and σ_n refer to intrinsic frictional coefficient, shear stress and normal stress (positive in tension) respectively, **n** the normal of a specific plane that used to be the mainshock fault plane. Because the mainshock fault plane is usually unknown for prediction purpose, an optimum plane is used instead. The optimum plane is the plane by which the maximum LURR over a long time span (say 5 or 10 years) is generated and has proved to be better than the mainshock fault plane (Yin & Mora, 2004).

Retrospective examinations

Before the analysis of earthquake trend in Australia, some retrospective examinations of past earthquakes important to Australia are reviewed here.

2004 M9.0 Sumatra-Andaman Islands Earthquake

The earthquake occurred offshore Sumatra, Indonesia on December 26, 2004. It generated one of the most disastrous tsunami waves in recorded history and took over a quarter million lives in many countries around the Indian Ocean (http://earthquake.usgs.gov/eqinthenews/2004/usslav/eqsummary.html).

Because of insufficient data, we have to use a large window radius of 500km around the epicentre of the mainshock(E95.85, N3.32). The time window is 10 years with a step of 2 months. M<=7. There is no obvious LURR anomaly using the two nodal planes given by Harvard CMT solution. However, LURR anomaly is very prominent when using the optimum plane (60°, 60°, 60°), where the three angles mean strike, dip and rake respectively, as the plane to define tidal CFS (Fig. 2).

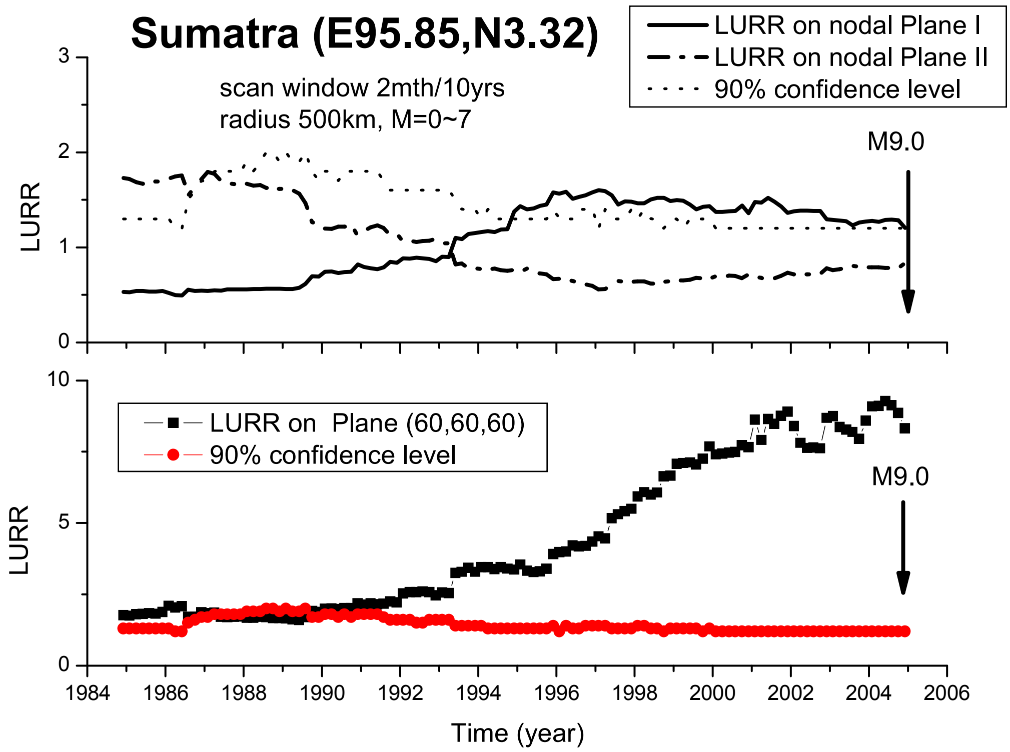

Figure 2, LURR vs. time curves for the 2004 M9.0 Sumatra-Andaman Islands earthquake. Time window is 10yrs with step of 2mths, radius 500km, magnitude ranges 0.0~7.0. (**Top**) result from using the focal mechanisms obtained by Harvard CMT. LURR show no obvious anomaly on either of the two nodal planes: Plane I (329, 8, 110) and Plane II (129, 83, 87); (**Bottom**) result from using the optimum plane (60,60,60). LURR continually rises above the 90% confidence level for over a decade before the mainshock.

It is of interest to note that the N60E striking optimum plane is very different from the actual focal mechanism of the mainshock. According to the optimum plane, a nearly N-S orientated compression in over ten years is favoured for the formation of this great earthquake, while according to the actual focal mechanism, the mainshock was the result of NE-SW orientated compression. Compared with the stress map in this region (website: www.world-stress-map.org), the optimum plane is in agreement with the stress regime of the west Sumatra part of the Indian and Australian plate (west of the epicentre), but different from the stress regime of the tectonic plate in the east.

1989 Newcastle, Australia, Earthquake

This only deadly earthquake in Australia so far cost about $4 billion of property damage and took 13 lives. The data used here was provided by Dr. C. Sinadinovski at Geoscience Australia. The earthquake occurred on a thrust fault plane with north-west strike and 75° dip (McCue et al, 1990; Sinadinovski et al, www.ga.gov.au/pdf/GA1769.pdf). A window with radius of 250 km and time span of 2 years is used. Time step is one month and magnitude M>=0 (no upper threshold).

Figure 3 clearly shows a LURR anomaly prior to the disastrous mainshock both on the actual fault plane and the optimum plane. The result suggests that the Newcastle earthquake might have been able to be forecast.

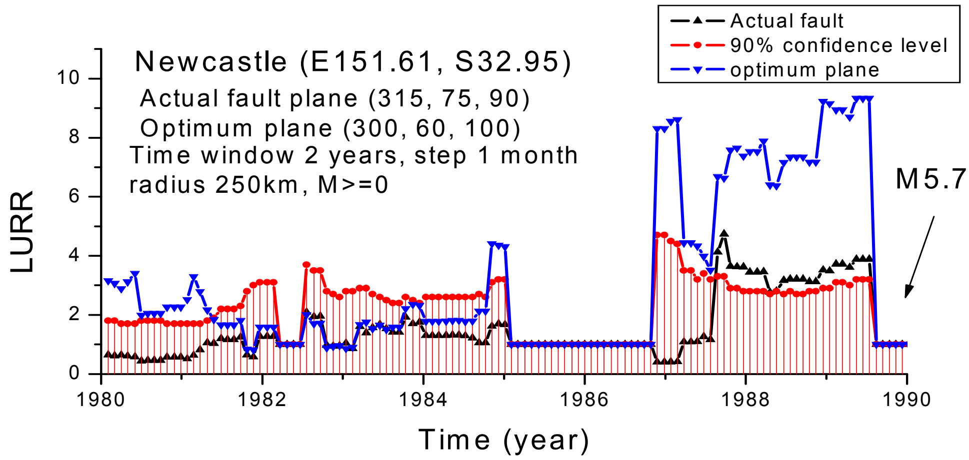

Figure 3. LURR vs. time curve for 1989 Newcastle earthquake. The optimum plane used here is the plane by which LURR over a 5 year period prior to the mainshock reaches its maximum. It differs from the actual fault plane a little but basically agrees with the tectonic stress.

Earthquake trend in Australia

Since the great Sumatra Earthquake, many people started to worry about the possibility of a large earthquake hitting Australia. It is a good opportunity for LURR method to be examined. The earthquake catalogue necessary to conduct this examination was downloaded from Geoscience Australia's website. Because of limited data (Fig. 4), only three regions are selected to conduct LURR calculation, namely the vicinity of Canberra, ACT, Tennant Creek, NT and Burakin, WA. The latest event is up to May 1, 2005.

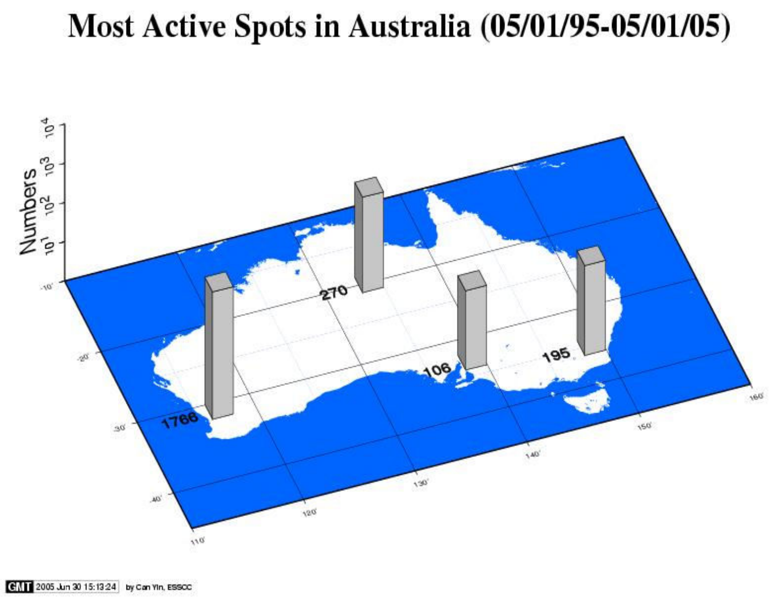

Figure 4. Four regions where the number of events exceeds 100 within a 200km radius in the past 10 year prior to May 1, 2005. The bar represents the positions where the earthquake density is the highest in the region. Because the number of events occurred in South Australia is far less than the other source the author found, LURR calculation is not conducted there.

The LURR value at a certain time is calculated according to the following procedure: First we select the earthquakes within 2-year time period prior to the indicated time within 200km radius around the location of interest, then calculate the tidal stress at the time when each event occurred, then calculate the optimum fault plane, then calculate the tidal CFS on the optimum fault plane, and finally obtain the LURR value at the indicated time. Proceed forward with a time step of 50 days and a LURR vs. time curve is obtained. The magnitude range is set as 0<=M<=4.0.

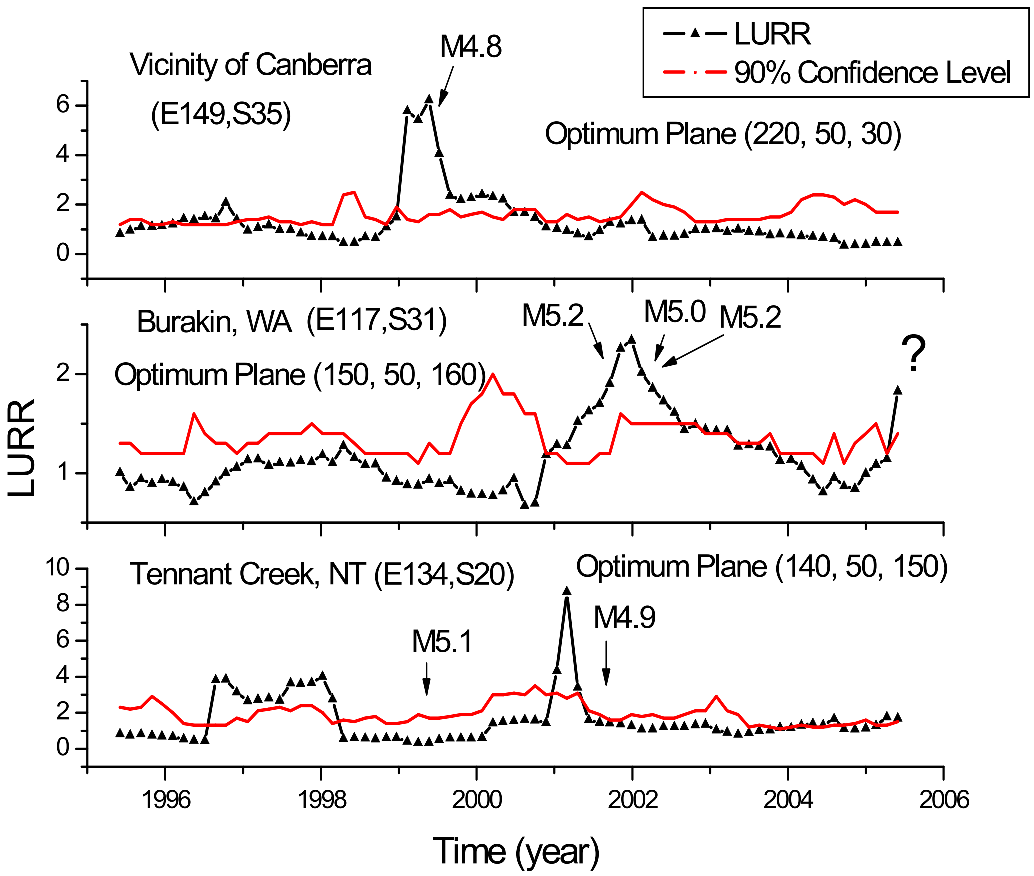

Figure 5. LURR evolution with time for the three computable regions in the time span from 05/1995 to 05/2005. Time window 2 years, step 50 days, radius 200km, 0<=M<=4.0. : (**Top**)A place near Canberra, ACT; (**Middle**) Burakin, WA and; (**Bottom**) Tennant Creek, NT.

In retrospective view, the LURR anomaly was immediately followed by relatively large earthquake(s) in all 3 cases (Fig. 5). In the case of Canberra vicinity, a magnitude M=4.8 earthquake occurred on 1999/3/17 at Appin, NSW (E1150.77°, S34.234°). In Burakin, three M5+ earthquakes occurred on 2001/9/28/, 2002/3/5 and 2002/3/30 around (E117, S30.5) respectively. In Tennant Creek, two significant earthquakes occurred on 1999/4/15 at (E134,S19.8) and 2001/9/14 at (E133.9,S19.7). These examples proved that LURR is an effective precursor for major earthquakes in Australia.

Up to 2005/5/1, only in Burakin region the LURR value is increasing over the 90% confidence level recently. We have to keep an eye on this region. However, the LURR value hasn't exceeded its height in 2002 when a series of 3 magnitude 5 earthquakes occurred. Therefore there might be a middle strength earthquake around M5 upcoming by the end of 2005.

For the other two regions, Y values are very low in the past 4 years, therefore the likelihood of a significant earthquake (M>=4.0) occurring in the next 2 years is also low.

Note: Because of the limited source, a more complete dataset may reveal some different scenarios. The conclusion presented here is preliminary and subject to such change.

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