Two improved version of the Load/Unload Load /Unload Response Ratio method for forecasting large earthquakes and strong aftershocks

Speaker: Shao Yi-Lien

References

Yu Huai-zhong, Z. Shen, et al (2006). Increasing critical sensitivity of the Load/Unload Response Ratio before large earthquakes with identified stress accumulation pattern. Tectonophysics 428, 87-94.

Yin Xiang-chu, H.Z. Yu, et al (2004). Load-Unload Response Ratio (LURR), Accelerating Moment/Energy Release (AM/ER) and State Vector Saltation as precursors to failure of rock specimens. Pure and Applied Geophysics 161, 2405-2416.

Zhang Lang-ping and J. Zhuang (2011). An improved version of the Load/Unload Response Ratio method for forecasting strong aftershocks. Tectonophysics 509, 191-197.

Outline

- Introduction
- Load/Unload Response Ratio (LURR)
  - Increasing critical sensitivity of the LURR
  - Combination of the LURR method and the ETAS
- Conclusions

Introduction

- The Critical Point Hypothesis (CPH) considers earthquake rupture as a critical point (Vere-Jones, 1977; Bowman et al., 1998).
- During the establishment of criticality the crust must be characterized by susceptibility to external factor.
- The factor will lead to triggering of earthquakes by tidal stress (Grasso and Sornette, 1998) and consequently anomalously high values of LURR (Yin, 2000) are observed prior to large earthquakes.

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The LURR values that measure the degree of closeness to instability for a nonlinear system can be defined as

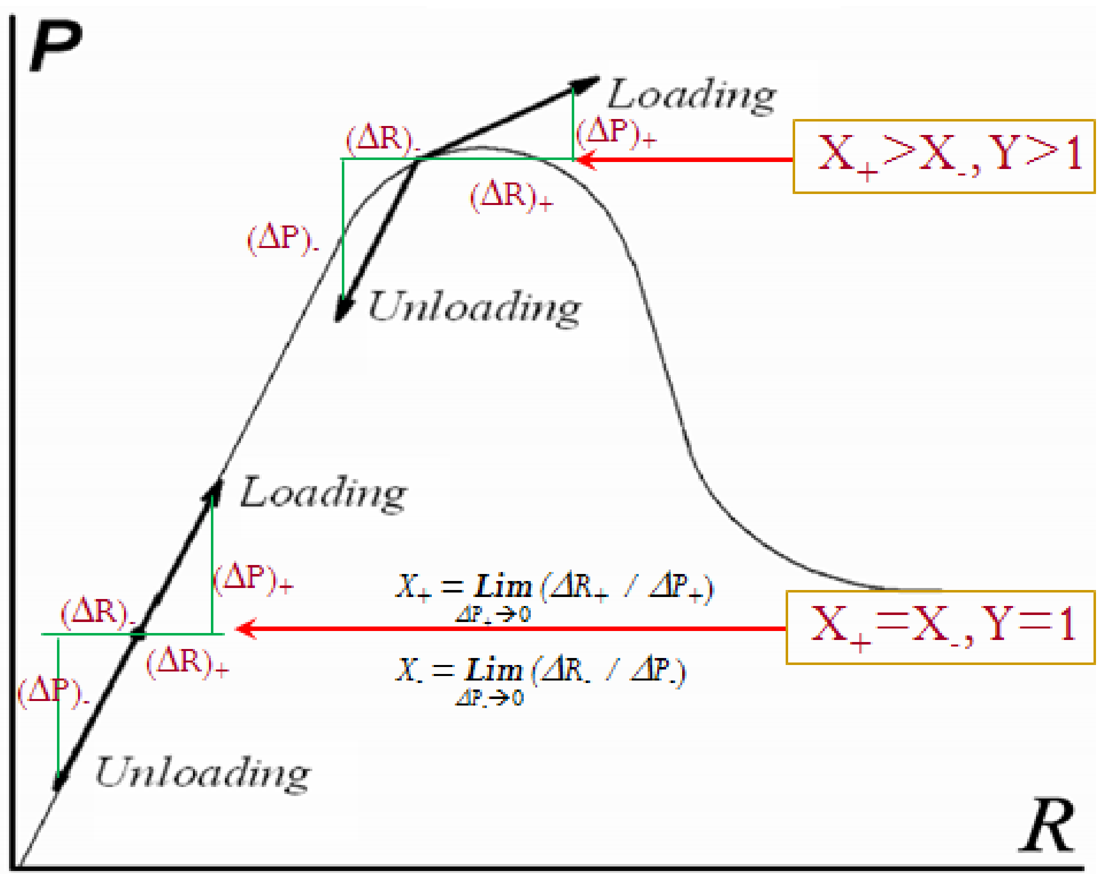
$$Y_{1/2} = \frac{\left(\sum_{i=1}^{N+} E_i\right)_+}{\left(\sum_{i=1}^{N-} E_i\right)_-}$$

$$Y = \frac{X_+}{X_-}$$

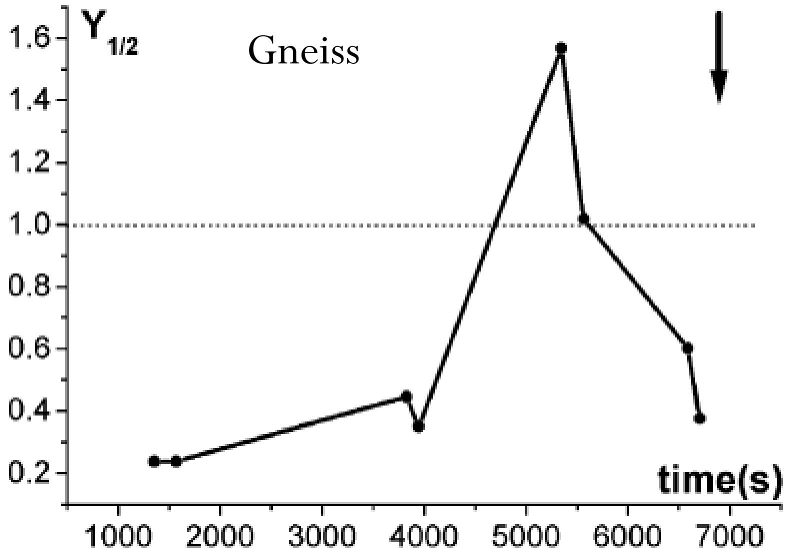
X is the response rate

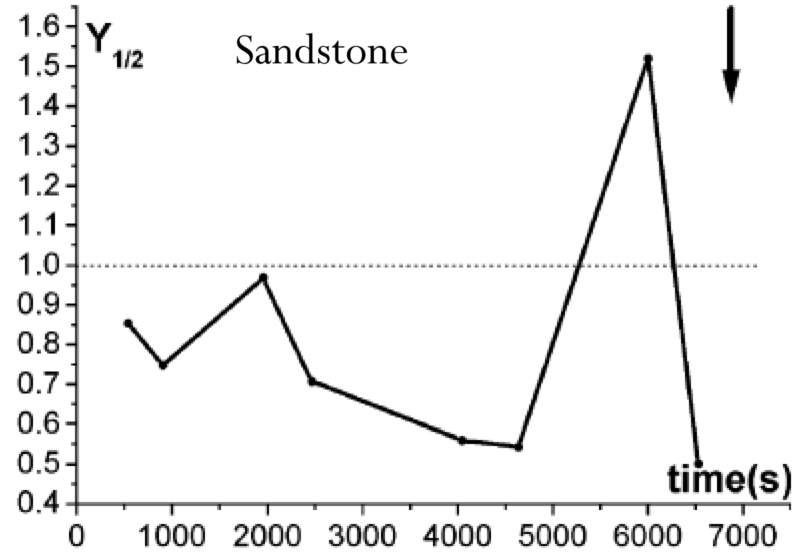
$$X = \lim_{\Delta P \to 0} \frac{\Delta R}{\Delta P},$$

ΔR denotes the small increment of R, resulted from a small change of ΔP on P.

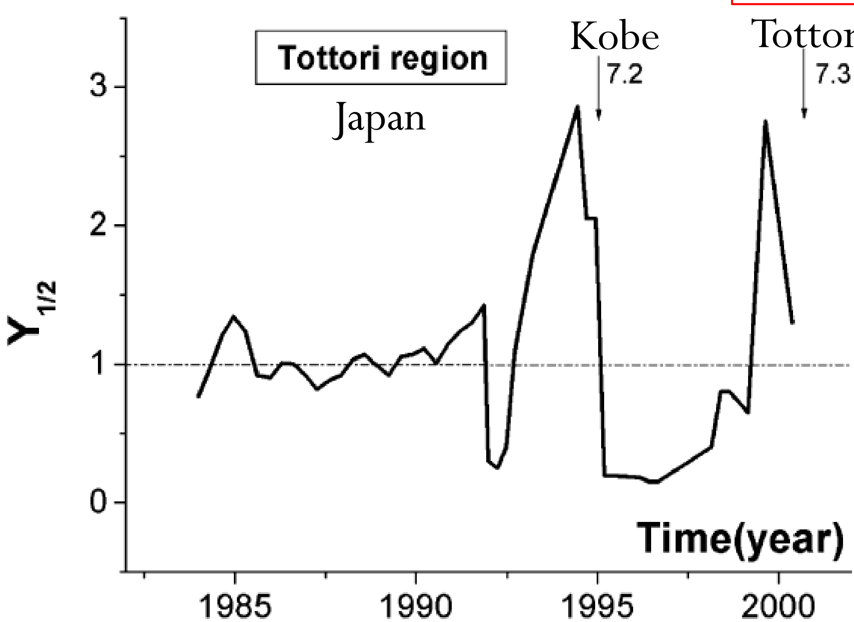


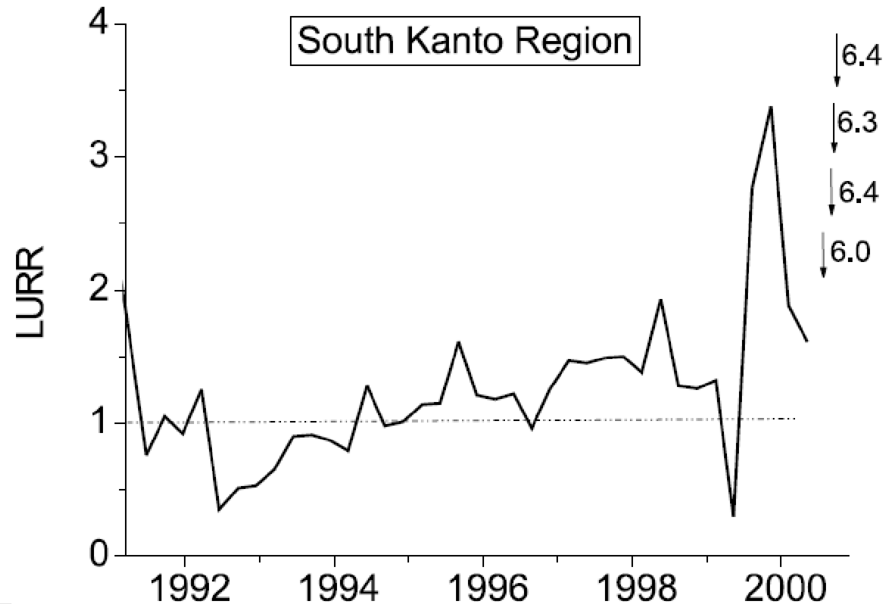
Rock fracture experiments





Real cases





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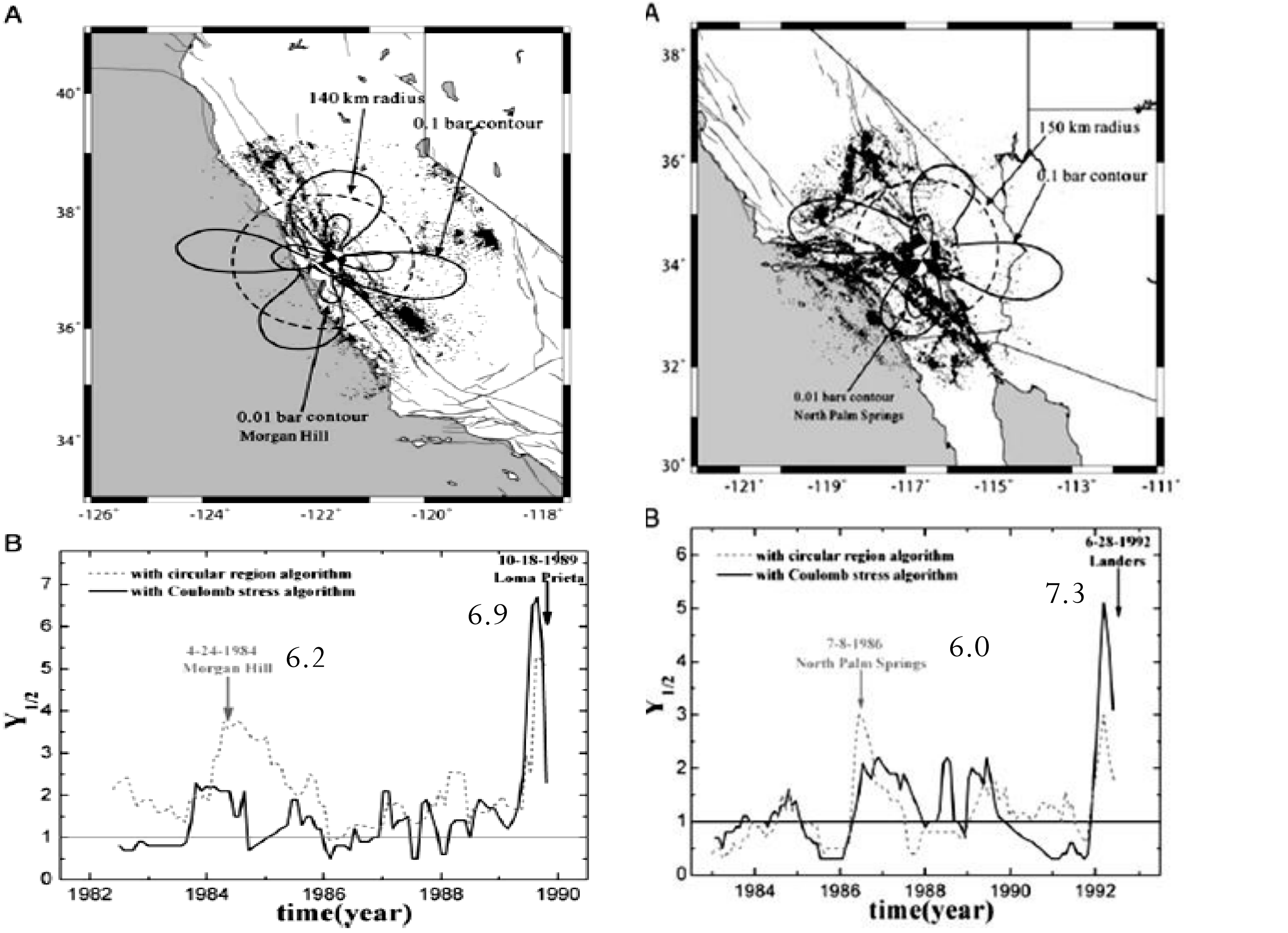
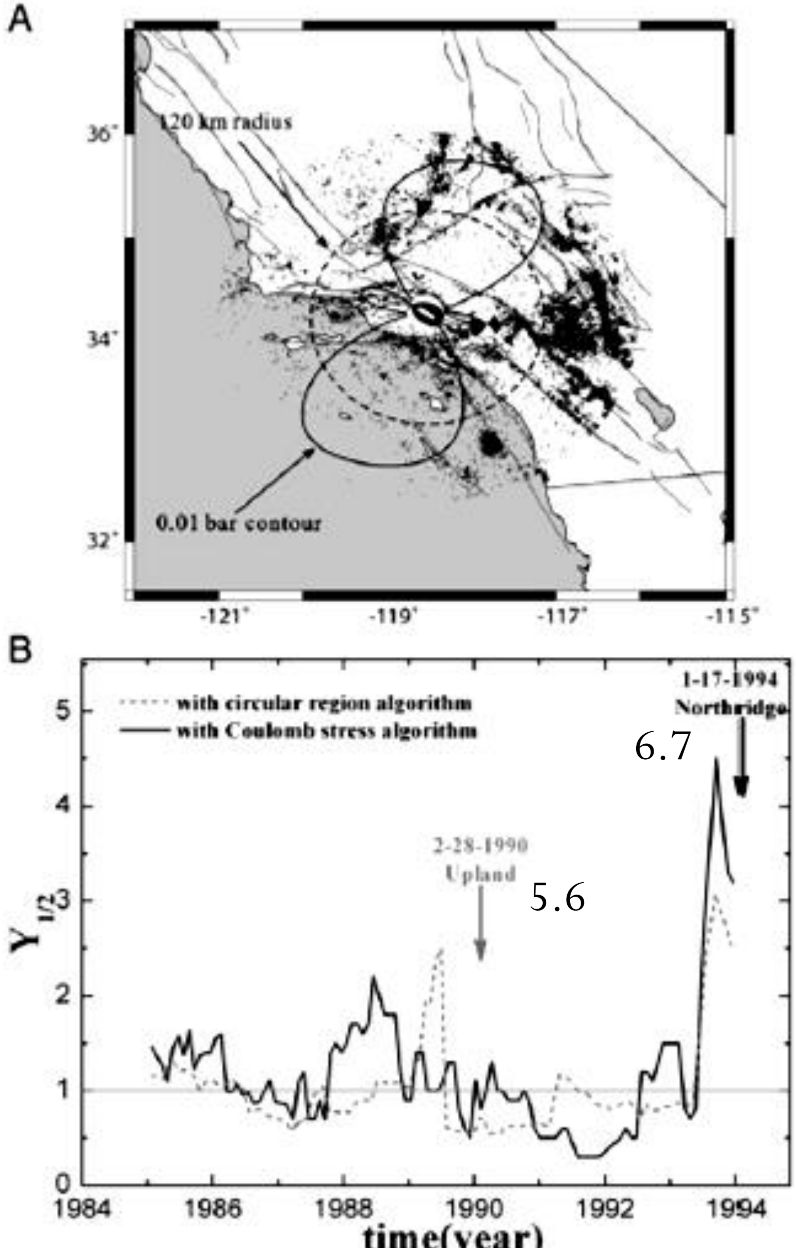
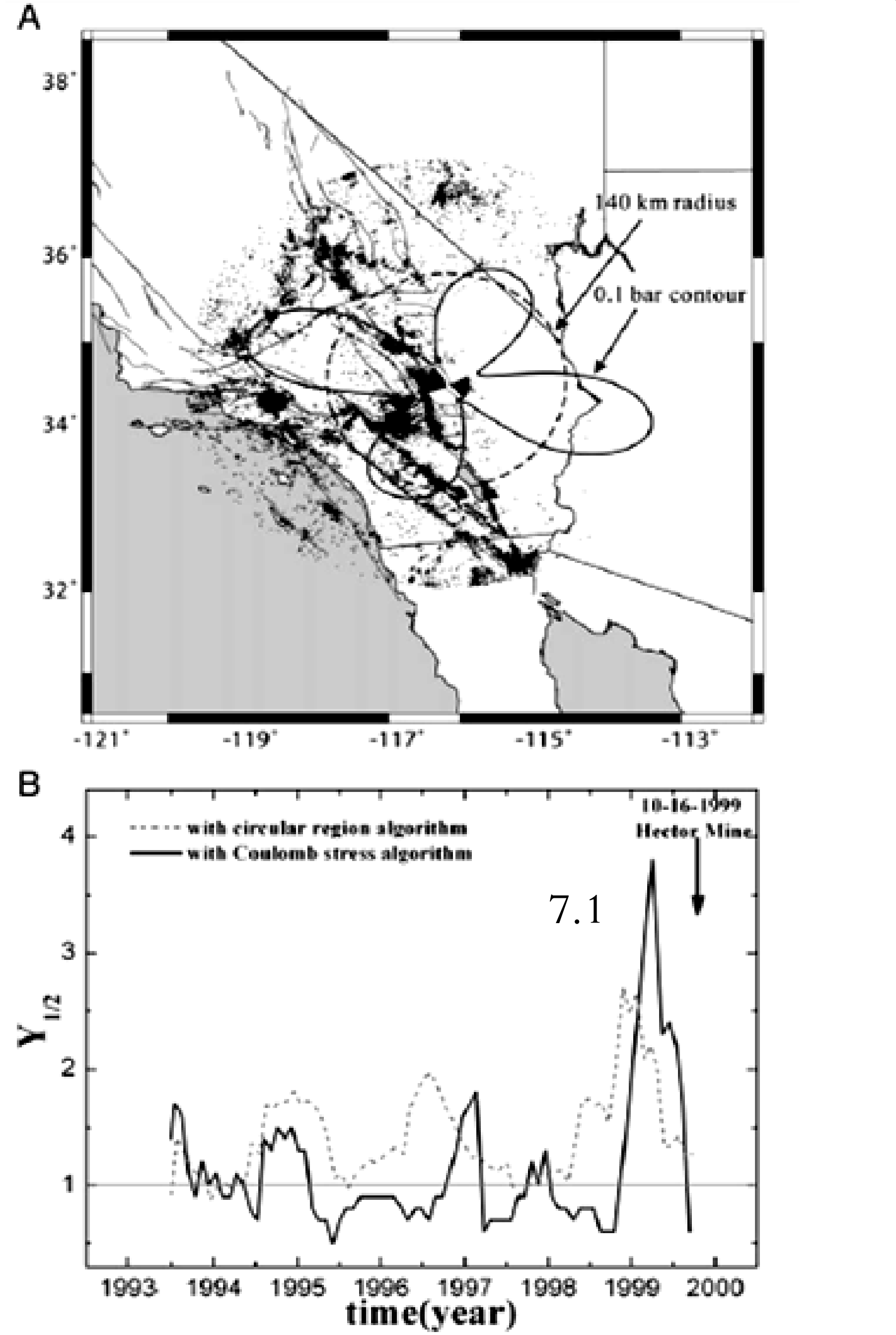
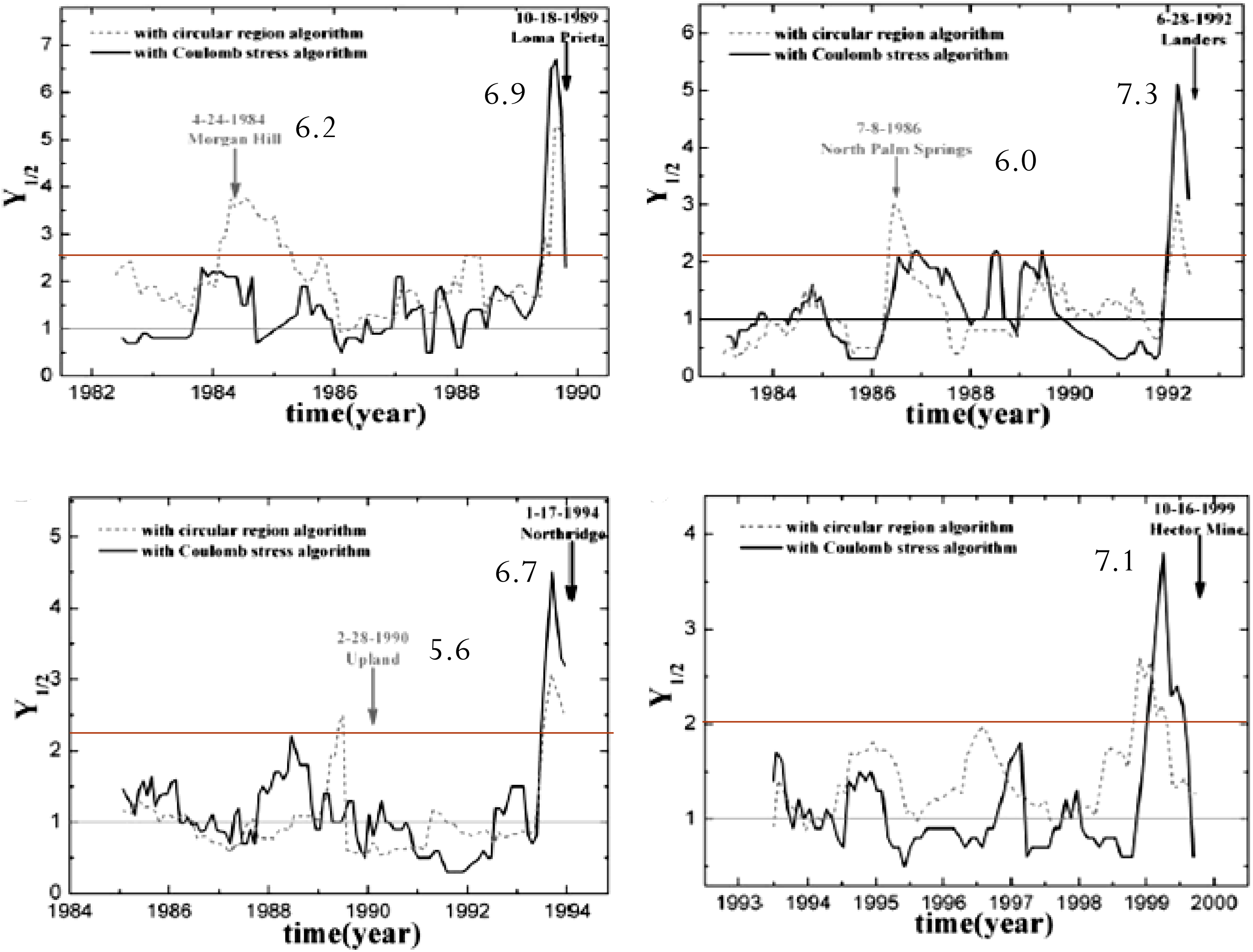
- Usually, larger earthquakes occur when Coulomb stress increases.
- But in previous studies, researchers selected the spatial data based on the relation between region size and the magnitude.
- Therefore, Yu et al. proposed a new method that they select data only when Coulomb stress is positive in a region.



A
140 km radius
0.1 bar contour
0.01 bar contour
Morgan Hill
A
150 km radius
0.1 bar contour
0.01 bars contour
North Palm Springs
B
with circular region algorithm
with Coulomb stress algorithm
10-18-1989
Loma Prieta
6.9
4-24-1984
Morgan Hill
6.2
$Y_{1/2}$
time(year)
B
with circular region algorithm
with Coulomb stress algorithm
6-28-1992
Landers
7.3
7-8-1986
North Palm Springs
6.0
$Y_{1/2}$
time(year)


A
120 km radius
0.01 bar contour
36°
34°
32°
-121°
-119°
-117°
-115°
B
with circular region algorithm
with Coulomb stress algorithm
1-17-1994
Northridge
6.7
2-28-1990
Upland
5.6
$Y_{1/2}$
time(year)
1984
1986
1988
1990
1992
1994
0
1
2
3
4
5


A
140 km radius
0.1 bar contour
38°
36°
34°
32°
-121°
-119°
-117°
-115°
-113°
B
with circular region algorithm
with Coulomb stress algorithm
10-16-1999
Hector Mine.
7.1
$Y_{1/2}$
time(year)
1993
1994
1995
1996
1997
1998
1999
2000
1
2
3
4



with circular region algorithm
with Coulomb stress algorithm
10-18-1989
Loma Prieta
6.9
4-24-1984
Morgan Hill
6.2
Y1/2
time(year)
with circular region algorithm
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Landers
7.3
7-8-1986
North Palm Springs
6.0
Y1/2
time(year)
with circular region algorithm
with Coulomb stress algorithm
1-17-1994
Northridge
6.7
2-28-1990
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5.6
Y1/2
time(year)
with circular region algorithm
with Coulomb stress algorithm
10-16-1999
Hector Mine
7.1
Y1/2
time(year)

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- The LURR can also be used to predict the occurrence of strong aftershocks.
- However, clustering effects and the rapid decay of aftershocks can lead to large variations in the number of aftershocks occurring in the loading and unloading periods, giving rise to strong variations in the LURR values.
- In order to eliminate such clustering effects, Zhang use the ETAS model as the baseline model for evaluation of the LURR.

ETAS

- In this model, every event, irrespective of whether it represents background seismicity or is triggered by a previous earthquake, can trigger its own aftershocks.
- The time-varying seismicity rate is given by

$$\lambda_0(t) = \lim_{\Delta t \to 0^+} \frac{\Pr\{\text{at least 1 event occurs in } [t, t+\Delta t] \mid \text{obeservations before } t\}}{\Delta t}$$

$$= \mu + K \sum_{i:t_i<t} \frac{e^{\alpha(m_i - m_0)}}{(t - t_i + c)^p}$$

- Gutenberg-Richter law

$$\lambda_0(t,m) = \lim_{\Delta t \to 0^+} \lim_{\Delta m \to 0} \frac{\Pr\{\text{at least 1 event occurs in } [(t, t+\Delta t) \times (m, m+\Delta m)] \mid \text{obeservations before } t\}}{\Delta t \Delta m}$$

$$= \lambda_0(t) s(m)$$

$s(m) = \beta e^{-\beta(m - m_0)}$: probability density form of the Gutenberg-Richter law

- Introducing the loading and unloading responses to changes in the tidally induced forces into earthquake clustering

$$\lambda(t,m) = X(t)\lambda_0(t,m) = X(t)\lambda_0(t)s(m)$$

- h(t, m) is a predictable process

$$E\left[\sum_{i:t_i \in S} h(t_i, m_i)\right] = E\left[\int_M \int_S h(t,m)\lambda(t,m)\,\mathrm{d}m\,\mathrm{d}t\right]$$

- $h(t,m)=f(m)/\lambda_0(t_i)$, $|S_+|$ the length of the loading period

$$E\left[\sum_{i:t_i \in S_+} h(m_i)/\lambda_0(t_i)\right] = E\left[\int_M \int_{S_+} \frac{h(m)\lambda(t,m)}{\lambda_0(t)}\mathrm{d}m\,\mathrm{d}t\right]$$

$$= E\left[\int_M \int_{S_+} h(m)s(m)X(t)\,\mathrm{d}m\,\mathrm{d}t\right]$$

$$= \mathrm{X}_+|\mathrm{S}_+|\mathrm{E}[f(m)]$$

- S_- the length of the loading period

$$E\left[\sum_{i:t_i\in S_-} h(m_i)/\lambda_0(t_i)\right] = X_- |S_-| E[f(m)]$$

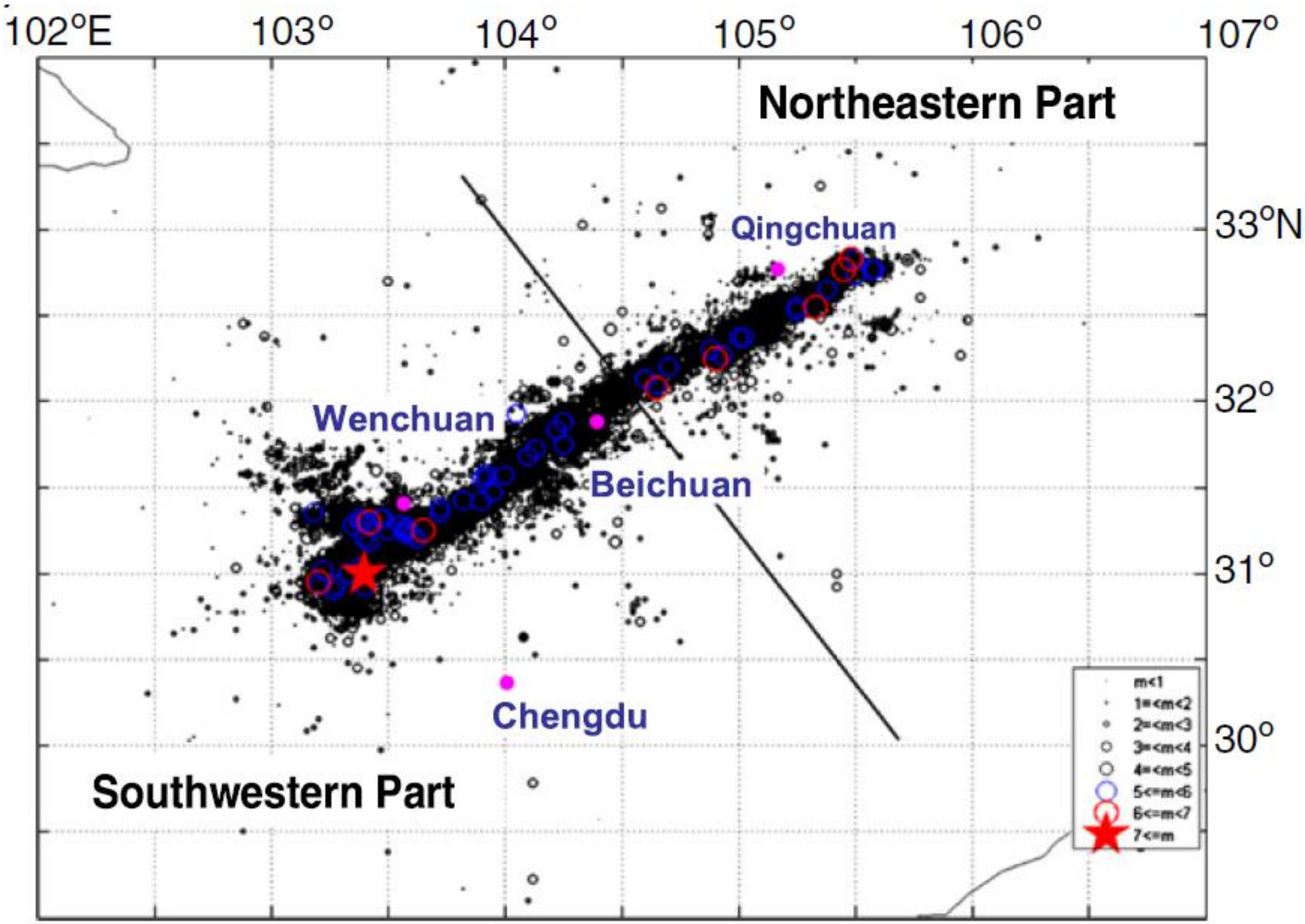
- Y can be obtained as

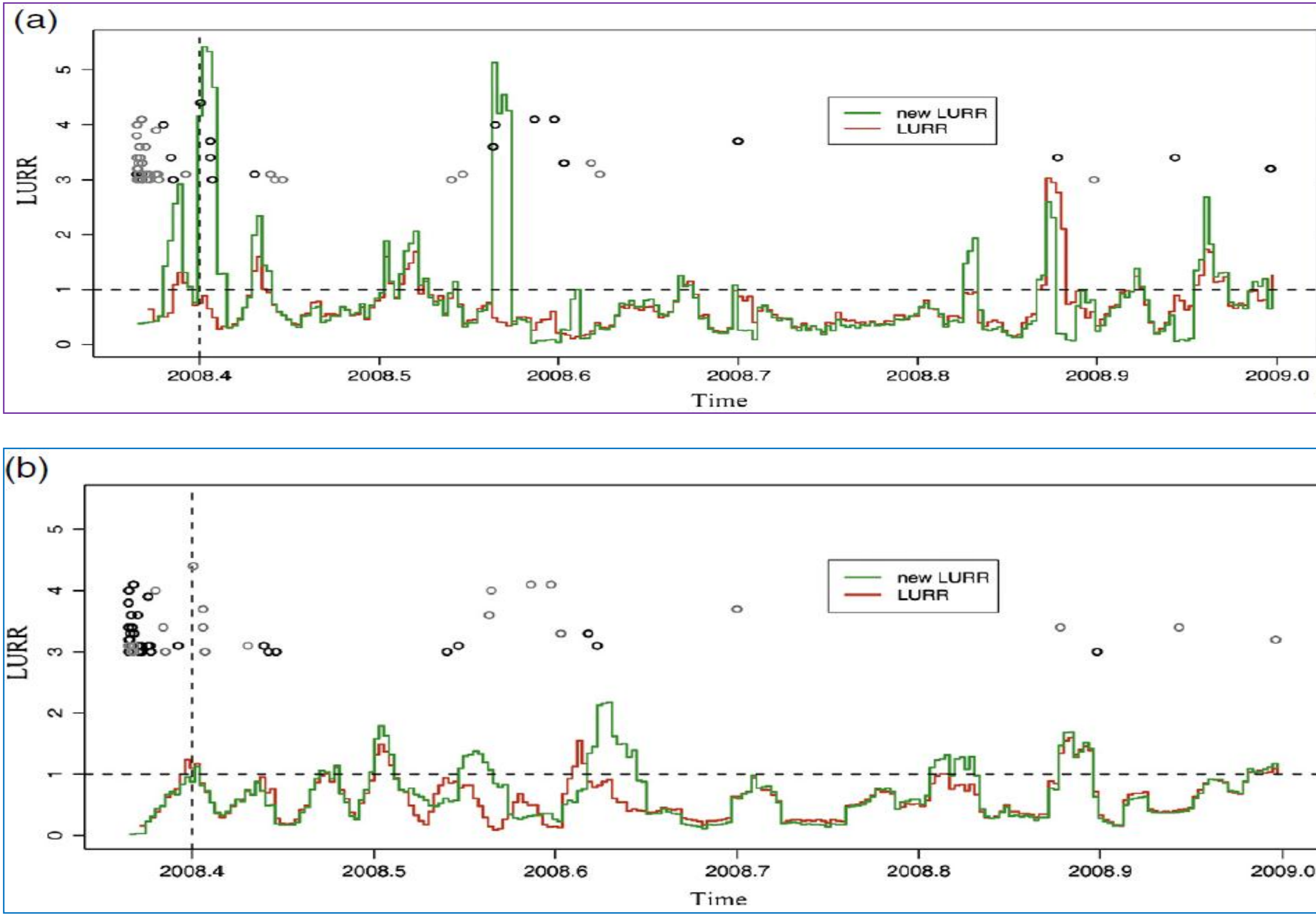
$$Y = \frac{X_+}{X_-} = \frac{|S_-| E\left[\sum_{i:t_i\in S_+} f(m)/\lambda_0(t_i)\right]}{|S_+| E\left[\sum_{i:t_i\in S_-} f(m)/\lambda_0(t_i)\right]} \approx \frac{|S_-| \sum_{i:t_i\in S_+} f(m_i)/\lambda_0(t_i)}{|S_+| \sum_{i:t_i\in S_-} f(m_i)/\lambda_0(t_i)}$$

- New LURR formula becomes

$$Y_2 \approx \frac{|S_-| \sum_{i:t_i\in S_+} E_i^{1/2} / \lambda_0(t_i)}{|S_+| \sum_{i:t_i\in S_-} E_i^{1/2} / \lambda_0(t_i)}$$

Wenchuan earthquake and its aftershocks





(a)
LURR
new LURR
LURR
Time
2008.4
2008.5
2008.6
2008.7
2008.8
2008.9
2009.0
(b)
LURR
new LURR
LURR
Time

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  - The epidemic-type aftershock sequence (ETAS) model
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Conclusions

- For the circular region algorithm, because of its uniform selection of the region for LURR testing, it is less sensitive to a scenario earthquake. Instead, it could be used for detecting the potential of a wider range of earthquakes, with less sensitivity.
- Rather than the circular seismogenic regions. The Coulomb stress increase with anomalously increased LURR values before a large earthquake cold provide a relatively more precise estimation of the criticality of the ensuing event.
- By combining the LURR method with the evaluation of Coulomb stress increase before an earthquake, the predictive power of current LURR technique can be improved.

- Temporal clustering in aftershock sequences affects the calculation of the original LURR. And this effect can be eliminated by using the ETAS model as the baseline model in the calculations.
- This new LURR curves are likely to be in better agreement with actual aftershock occurrence than the original ones, and exhibit much higher peaks. This result suggest that this combined method could be used as a prediction index for strong aftershocks.

Thanks for your attention.