A Dimensional Analysis Method for Improved Load–Unload Response Ratio

Yue Liu[1], Xiangchu Yin[1,2]

1. Institute of Earthquake Forecasting, China Earthquake Administration. Email: liuyue@cea-ies.ac.cn

2. State Key Laboratory of Nonlinear Mechanics, Institute of Mechanics, Chinese Academy of Sciences

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Introduction: The load–unload response ratio (LURR) method is proposed to measure the damage extent of source media and the criticality of earthquake. Before the occurrence of a large earthquake, anomalous increase in the time series of LURR within the certain temporal and spatial windows has often been observed. In this paper, a dimensional analysis technique is devised to evaluate quantitatively the magnitude and time of the ensuing large earthquake within the anomalous areas derived from the LURR method. Based on the π-theorem, two dimensionless quantities associated with the earthquake time and magnitude are derived from five parameters (i.e. the seismic energy (E_S), the average seismic energy (E_W), the maximum value of LURR's seismogenic integral (I_{PP}), the thickness of seismogenic zone (h), the time interval from I_{PP} to earthquake (T_2), and the shear strain rate ($\dot{\gamma}$). As study examples, we applied this approach to study four large events, namely the 2012 M_S5.3 Hami, 2015 MS5.8 Alashan, 2015 MS 8.1 Nepal earthquakes, and the 2013 Songyuan earthquake swam. Results show that the predicted location, time, and magnitude correlate well with the actual events. This provides evidence that the dimensional analysis technique may be a useful tool to augment current predictive power of the traditional LURR approach.

New method to assess earthquake hazard

- **Dimensionless quantities**

$$[E_s]=[E_w]^{\alpha_1}\cdot[I_{pp}]^{\alpha_2}\cdot[h]^{\alpha_3}\cdot[\dot{\gamma}]^{\alpha_4}$$

$$[\mathrm{F}\cdot\mathrm{L}]=[\mathrm{F}\cdot\mathrm{L}^{-1}\cdot\mathrm{T}^{-1}]^{\alpha_1}\cdot[\mathrm{L}^2]^{\alpha_2}\cdot[\mathrm{L}]^{\alpha_3}\cdot[\mathrm{T}^{-1}]^{\alpha_4}$$

$$\pi_1=\frac{E_s\cdot\dot{\gamma}}{E_w\cdot I_{pp}}\qquad \pi_2=T_2\times\dot{\gamma}\qquad \pi_3=\pi_1\times\pi_2$$

- **Quantifying magnitude and time of future event**

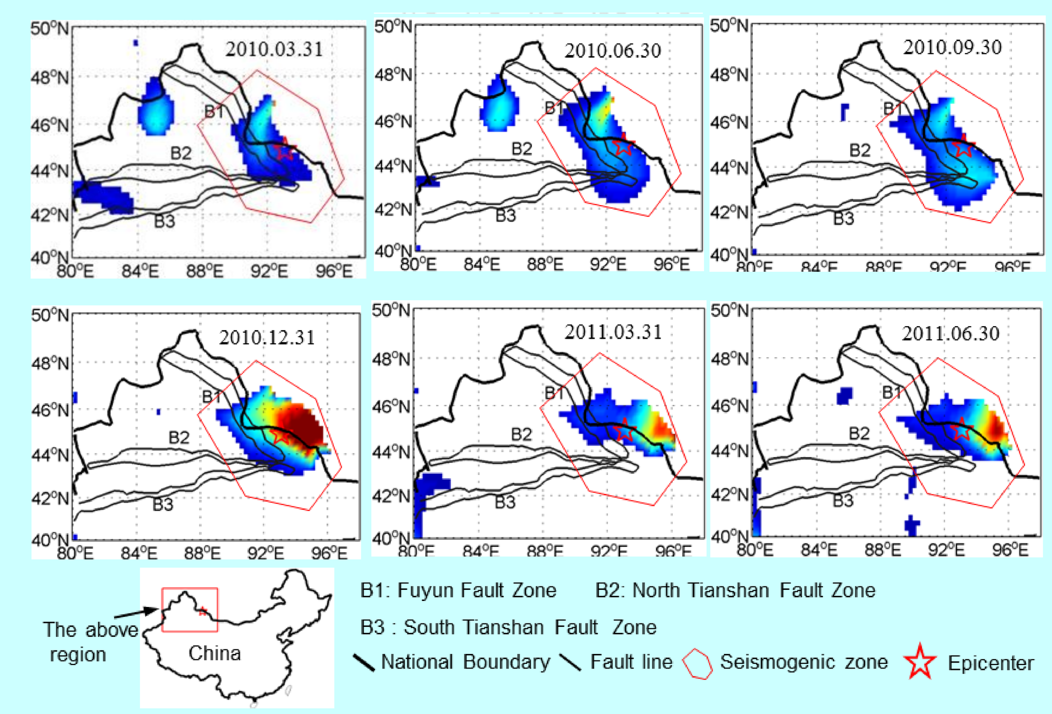
$$M_{sp}=5.14\lg E_d-112.08\qquad E_d=\frac{E_W\cdot I_{pp}}{\dot{\gamma}}$$

$$T_{2p}=\frac{8.5\times E_d\times10^{0.03M_s}\times10^{-30.8}}{\dot{\gamma}}$$

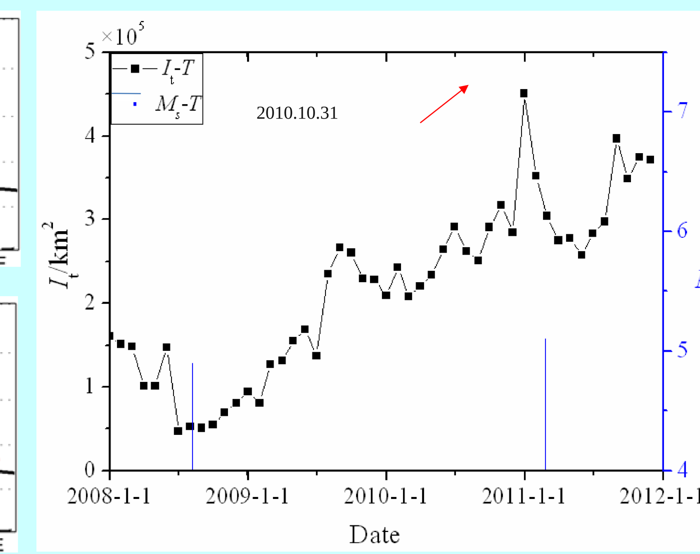
In earthquake forecasting, the first is to detect the anomalous region of LURR. When the seismogenic integral of the anomalous area is peaked, that is the maximum value of I_{pp} is derived, the average seismic energy E_W and shear strain rate $\dot{\gamma}$ of the area should be fixed then. The magnitude and time of a coming event in the anomalous area could be evaluated by the above formulas, and the critical region is optimized.

Forecasting examples:

- The 2012.2.10 M_S 5.3 Hami Earthquake



Sketch of the tempo-spatial evolution of LURR prior to the Hami M_S5.3



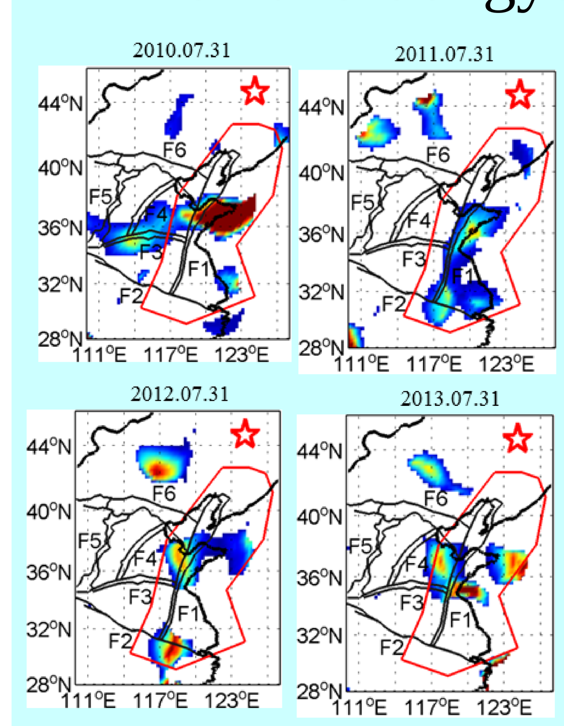
The temporal variation of I_t prior to the Hami M_S5.3 and earthquake sequence

$I_{PP}=4.52\times10^5\mathrm{km}^2$, $\dot{\gamma}=7\sim12\times10^{-9}\,/\,\mathrm{a}$

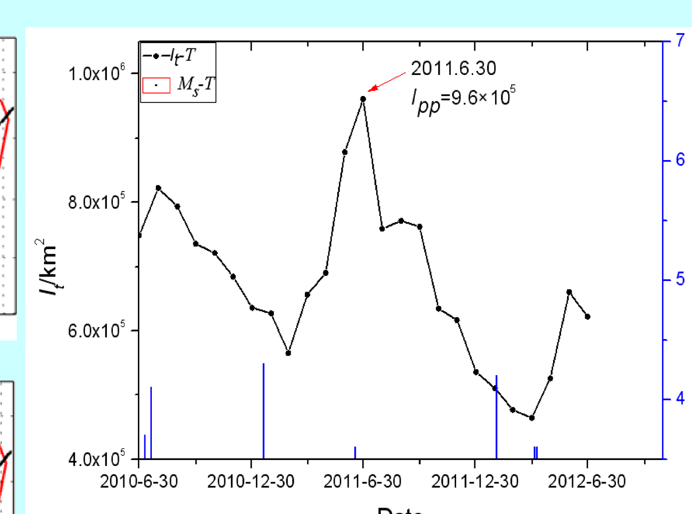
$\mathrm{E_W}=(1.0\sim1.2)\times10^9\,\mathrm{J}/(\mathrm{km}^2.\mathrm{a})$

Prediction result: M_{SP} = 5.5 ± 0.5, T_P=2012.3.1-2012.7.31

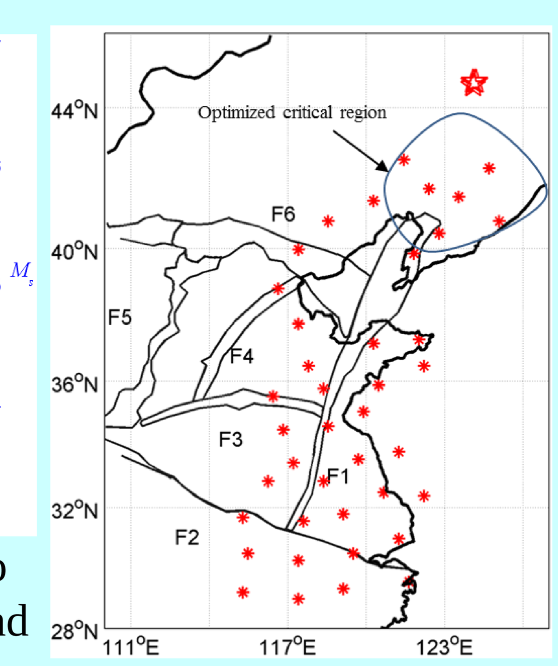
- The 2013 Songyuan Earthquake Swarm



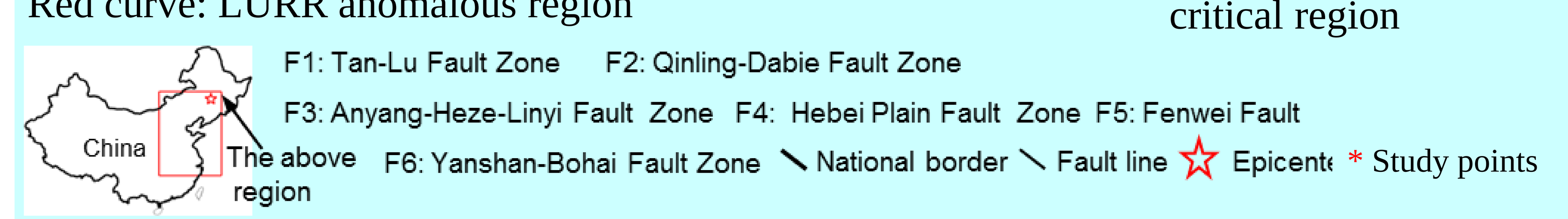
Red curve: LURR anomalous region



The temporal variation of I_t prior to the Songyuan earthquake swarm and earthquake sequence



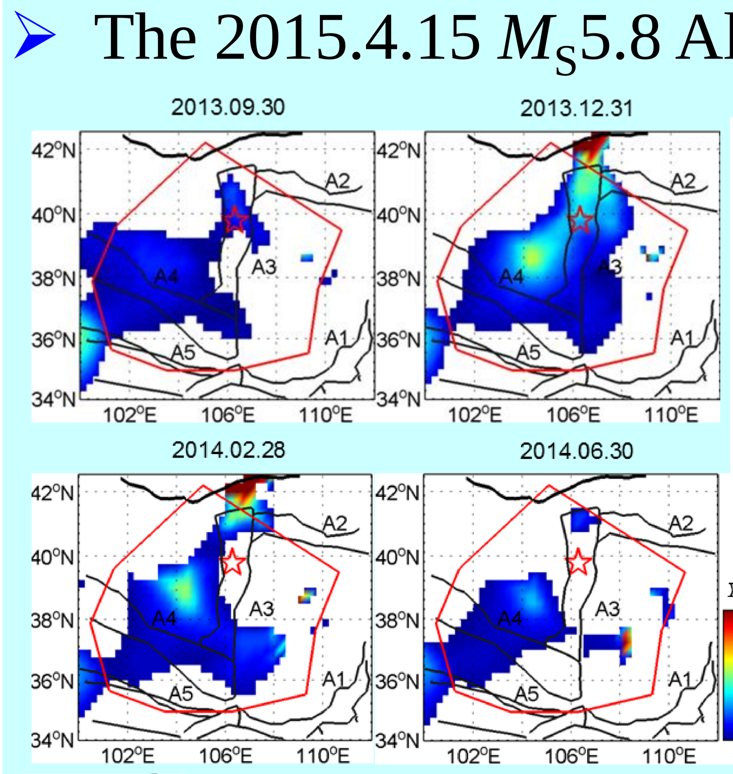
Blue curve: optimized critical region

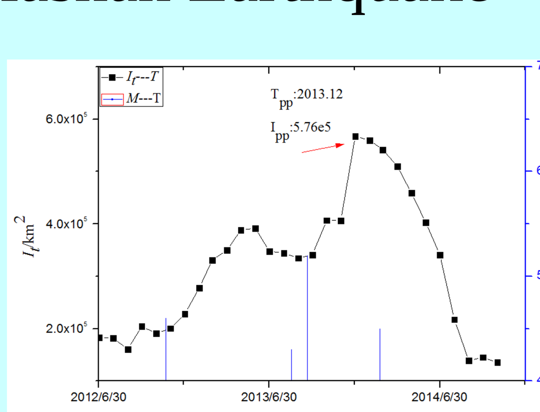


Prediction result: M_{SP} = 6.0 ± 0.6, T_P=2012.9.1-2014.2.28

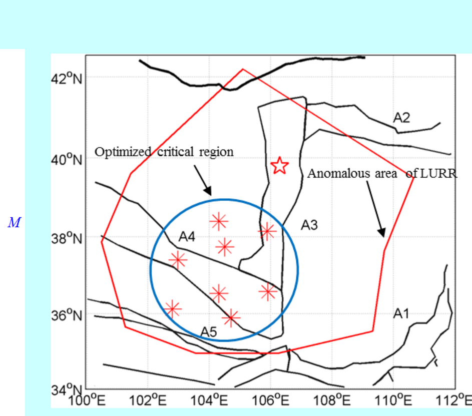
The critical region is optimized from a relatively large one (red curve) to a small region (blue curve).

- The 2015.4.15 M_S5.8 Alashan Earthquake



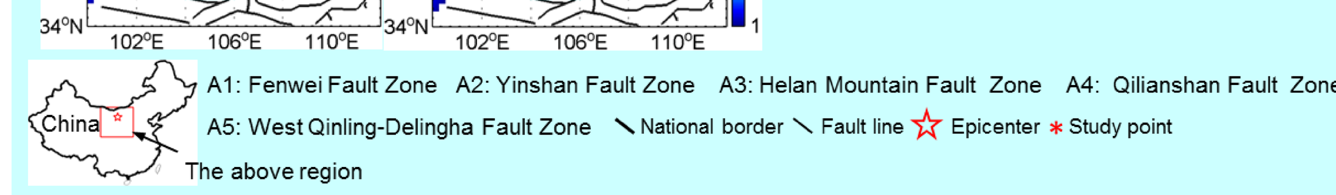


The temporal variation of I_t prior to the Alashan earthquake and earthquake sequence



Blue curve: optimized critical region

Red curve: LURR anomalies



Prediction result: M_{SP} = 6.4 ± 0.5, T_P=2014.11.1-2015.12.31

Discussion: the value of average seismic energy and shear strain rate plays a key role for the prediction, so it's very important to set the parameters.

芦山M_S7.0地震前地震活动性分析及区域地震活动水平参数I_{RTL}的应用

刘 月，吕晓健，田勤俭

中国地震局地震预测研究所 中国地震局地震预测重点实验室

刘月，吕晓健，田勤俭. 芦山 M_S 7.0 地震前地震活动性分析及区域地震活动水平参数 I_{RTL} 的应用. *地学前缘*, *24*(2), 220-226.

摘要： 本文采用Region-Time-Length (RTL)方法分析在汶川M_s8.0地震引起的地震活动增强背景下芦山M_s7.0地震前地震活动性变化，并提出了综合反映区域地震活动水平的参数I_{RTL}。芦山地震前1年在震中和周边地区检测到地震活动平静异常，主要分布在龙门山断裂带南段30°N～31.5°N，101.5°E～103.5°E的范围内，持续了近8个月，异常范围和异常程度呈现由小→大→小的特征。新提出的地震活动水平参数I_{RTL}，早期在0值附近波动，于震前一年开始不断下降，降至波谷后回升至0值附近，波谷后9个月发震。I_{RTL}在一定程度上为“识别”芦山地震发生危险性提供了参考。以上研究对了解芦山地震孕育过程提供了新的认识。

方法介绍：

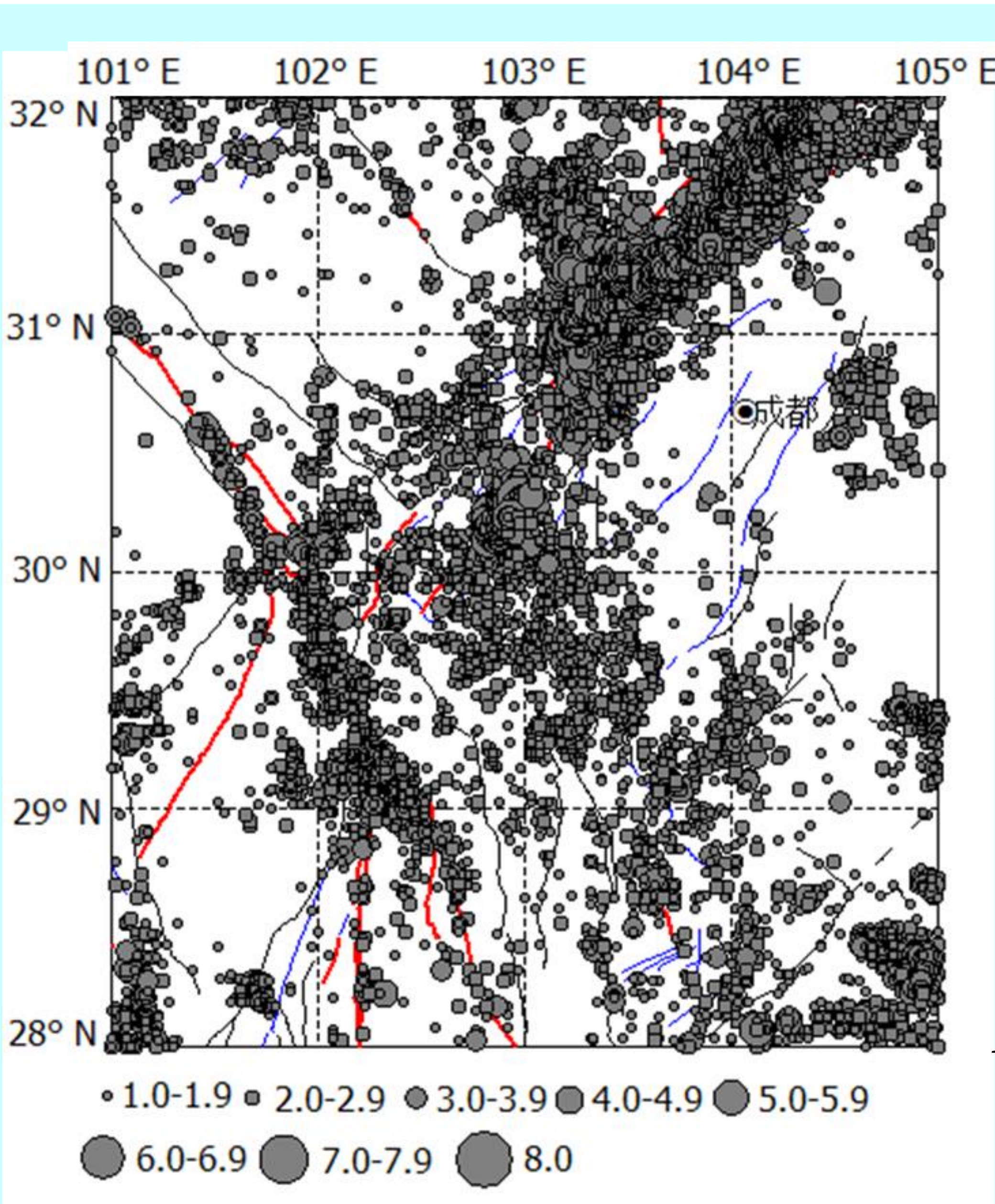
- Region-Time-Length (RTL)

Region-Time-Length (RTL) 方法以地震目录为研究资料，通过统计方法得到无量纲的RTL值，来地震活动水平的相对平静或增强。RTL(x, y, t)<0代表t时刻的地震活动水平低于时间t之前的背景水平，为地震活动平静；RTL(x, y, t)>0 意味着t时刻的地震活动水平高于t之前的背景水平，为地震活动增强。

- 孕震积分—— I_{RTL}

$$I_{RTL}=\iint \mathrm{RTL}dxdy \quad \begin{cases}\mathrm{RTL}\le a:\text{地震活动平静异常}(a<0)\\ \mathrm{RTL}\ge b:\text{地震活动增强异常}(b>0)\end{cases}$$

资料选取：



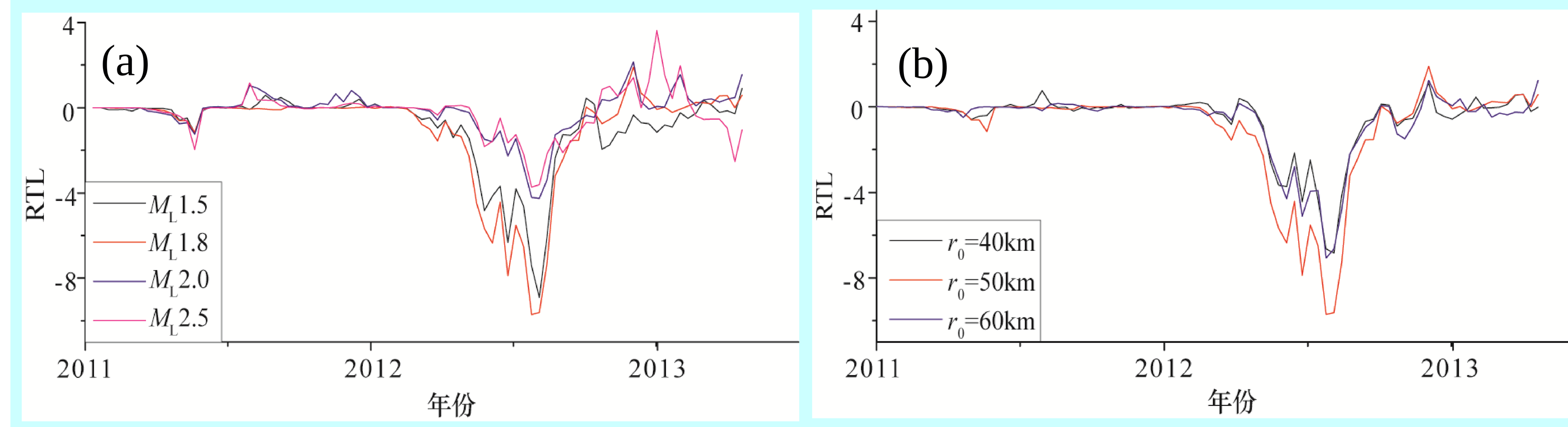
2009.1.1-2013.4.19龙门山断裂带及周边M_L≥1.0的震中分布图

余震剔除：
扩散链法

震级完整性分析：
震级-序号图像法
最大曲率法
拟合度检测法
M_C=1.5

芦山地震前地震活动性分析

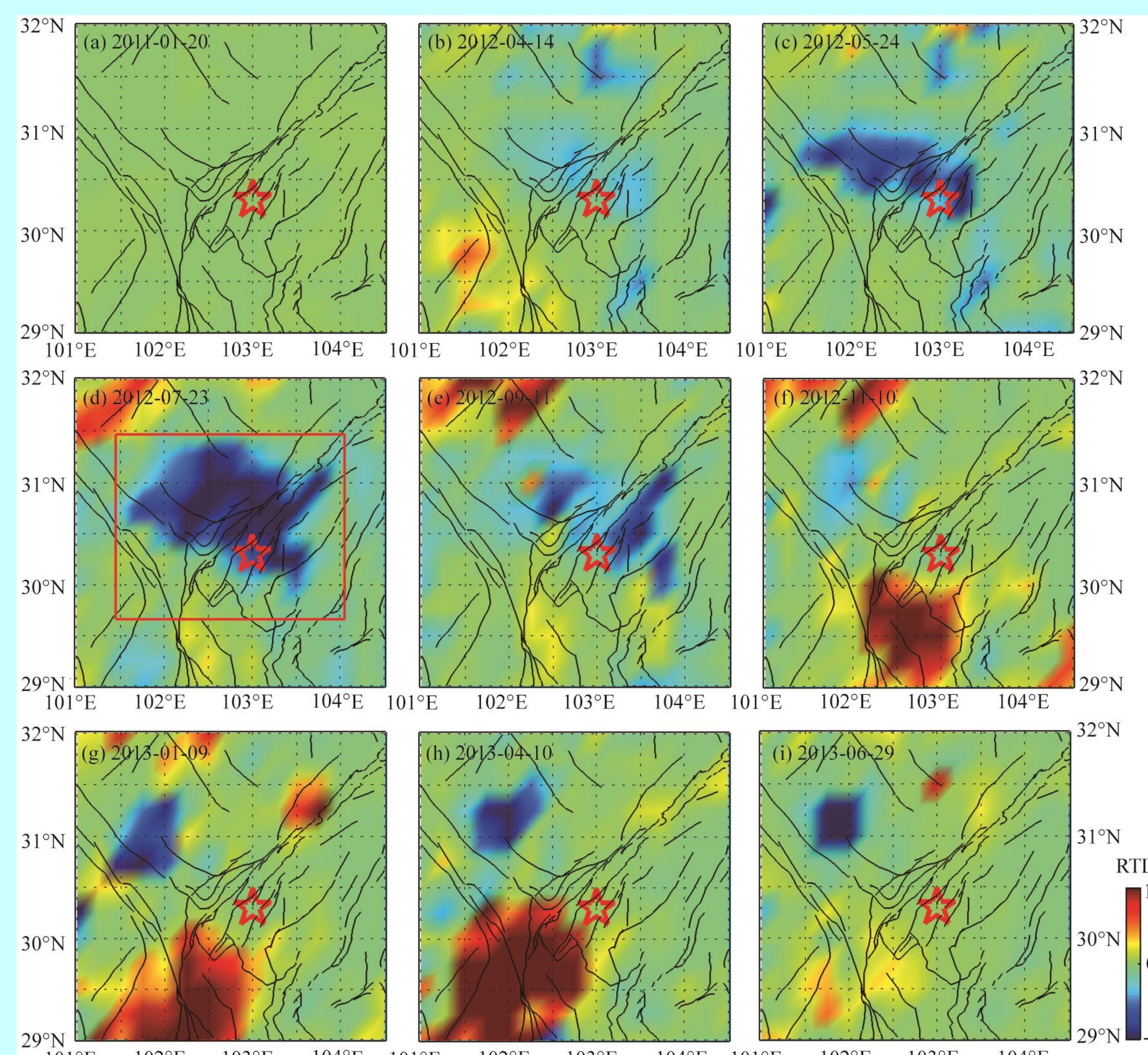
- 时间异常分析



芦山地震发震前，震中附近地震活动随时间的变化: (a) 选取不同的震级下限，分别为M_L1.5\1.8\2.0\2.5；(b)不同扫描半径，分别为R=80\100\120km

检测到：2012年4月至9月底表现为平静异常，即震前一年开始出现平静异常，持续6个月。

- 空间异常分析



2011年1月-2013年6月，即芦山地震前后，RTL空间分布随时间的变化

冷色为地震活动平静，暖色为地震活动增强。至2012年4月，以芦山地震震中为中心，在龙门山断裂带南段检测到大范围地震活动平静异常，异常区域不断扩大，异常程度增强，于2012年7月达到峰值水平，之后减弱。至2013年1月，震中附近的地震活动平静异常消失并持续至发震。在地震活动平静异常程度由强减弱的过程中，于2012年11月在鲜水河断裂带南端的康定-石棉之间检测到地震活动增强，至发震前增强程度不断增加。震后，地震活动较发震前无显著变化。

- 区域地震活动水平定量分析

上图RTL异常区孕震积分I_{RTL}随时间的变化

结果显示：2012年3月至7月，区域地震活动平静水平不断增强，之后开始减弱。I_{RTL}曲线波谷至地震发生的时间为9个月。

讨论： 参数I_{RTL}显示地震活动水平异常峰值至芦山地震发生为数月，I_{RTL}或许可用来探索地震活动异常与发震时间的定量关系，进而用于地震预测研究。