基于“解剖地震”研究中物理模型的强震预测展望

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介绍内容

1、研究背景及意义

2、国内外研究进展

3、关键科学问题及及技术路线

4、展望与讨论

1、研究背景及意义

1 研究背景及意义

The validation of model-based predictions against data is a key SCEC activity

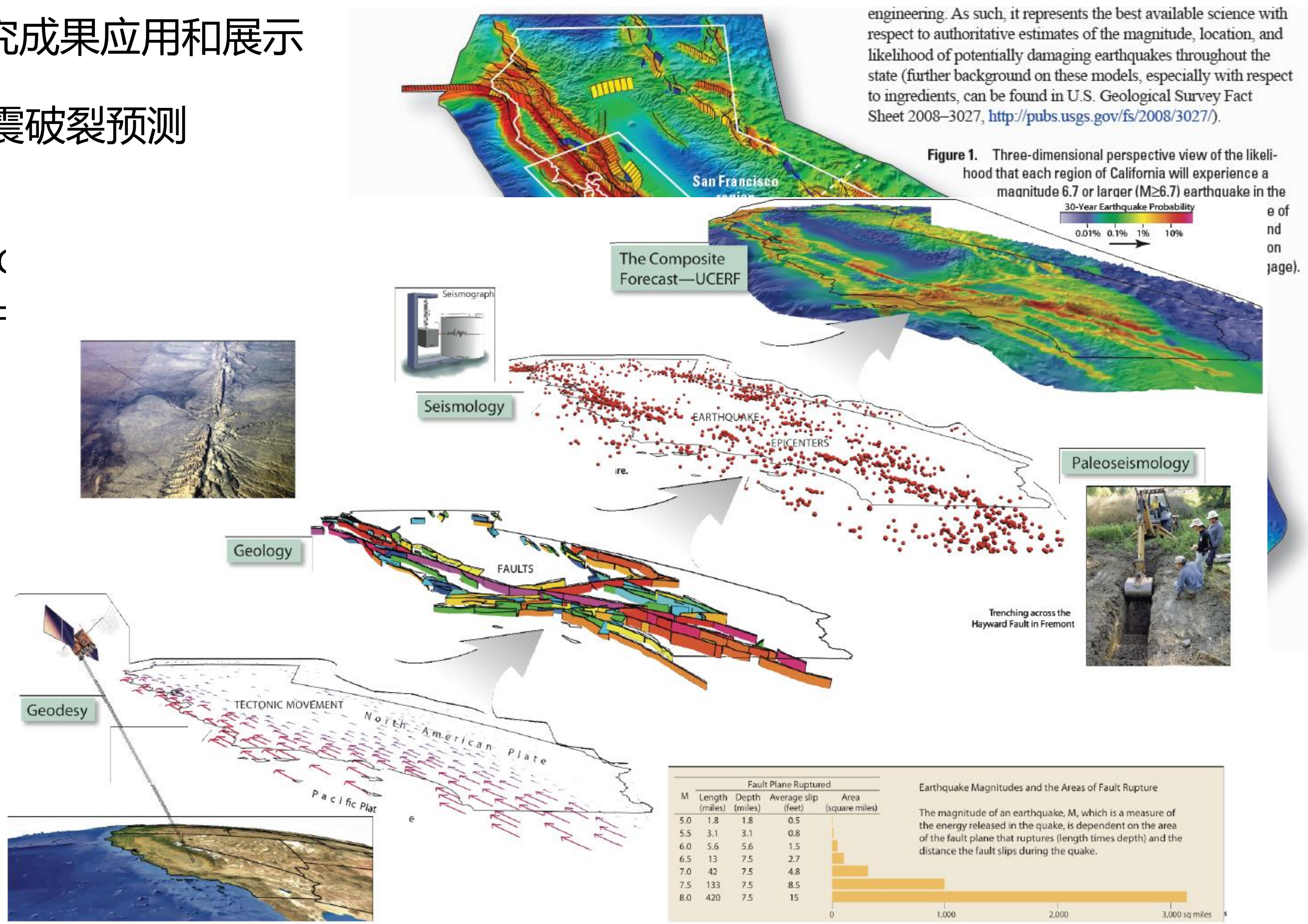
基础研究成果应用和展示

加州地震破裂预测

UCERF

Uniform C

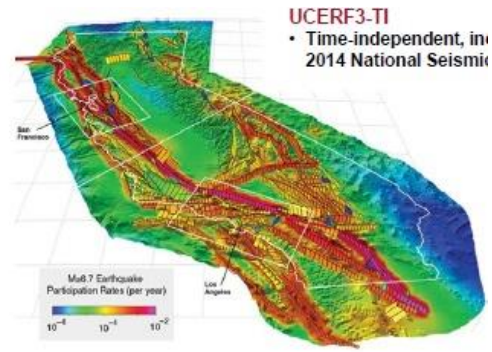
Rupture F

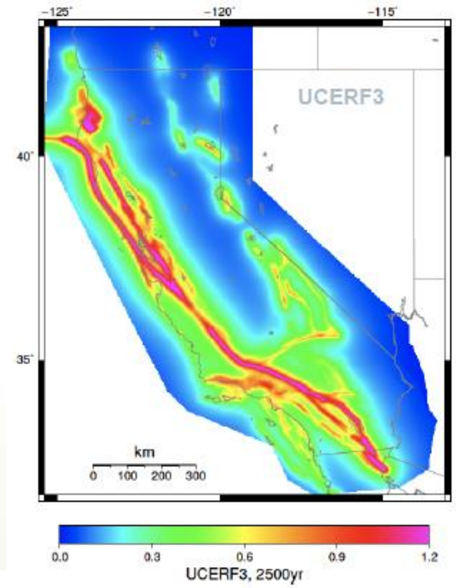


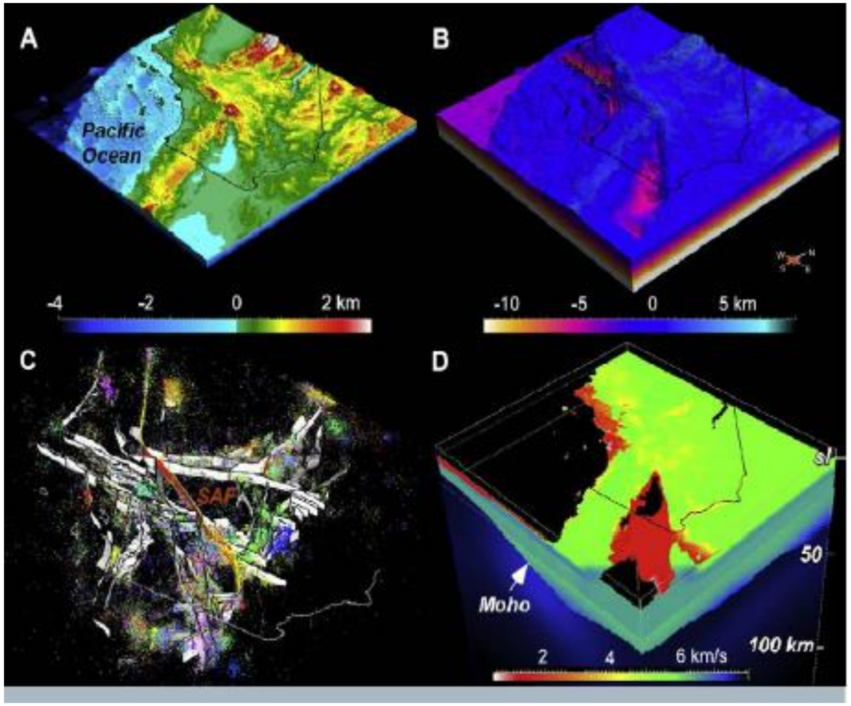
M	Fault Plane Ruptured: Length (miles)	Depth (miles)	Average slip (feet)	Area (square miles)
5.0	1.8	1.8	0.5	
5.5	3.1	3.1	0.8	
6.0	5.6	5.6	1.5	
6.5	13	7.5	2.7	
7.0	42	7.5	4.8	
7.5	133	7.5	8.5	
8.0	420	7.5	15	

1 研究背景及意义

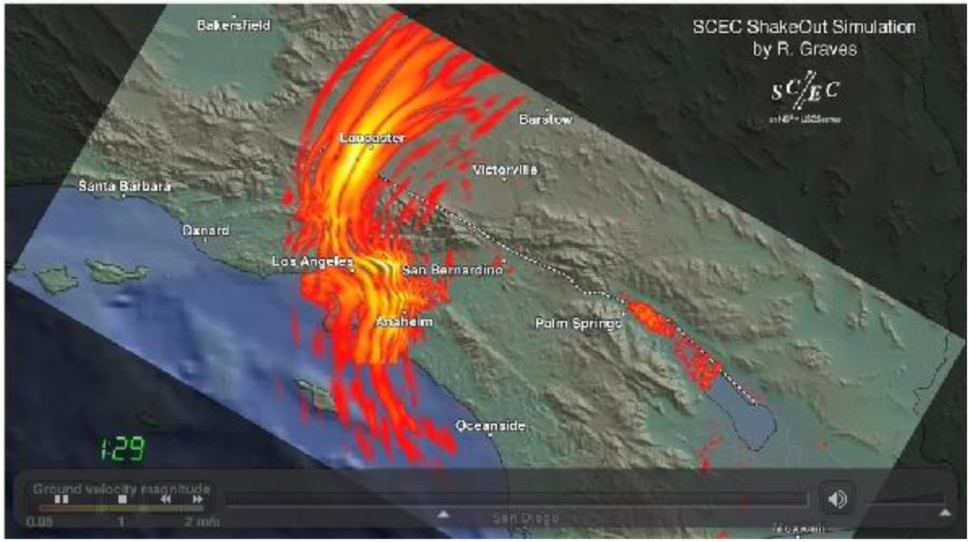
Basic science of earthquakes
Earthquake forecasting
Hazard estimation
Public education







John E. VIDALE,2018



1 研究背景及意义

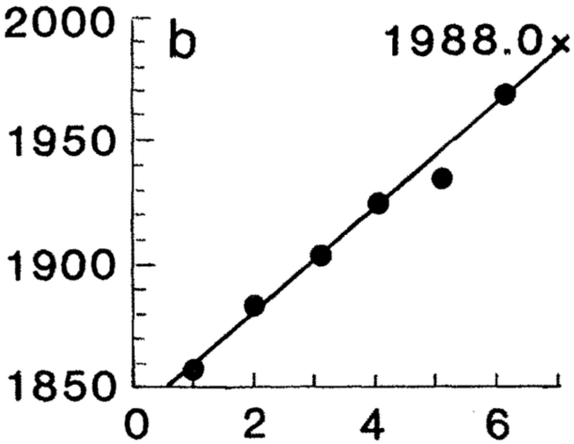
SCEC AN NSF+USGS CENTER

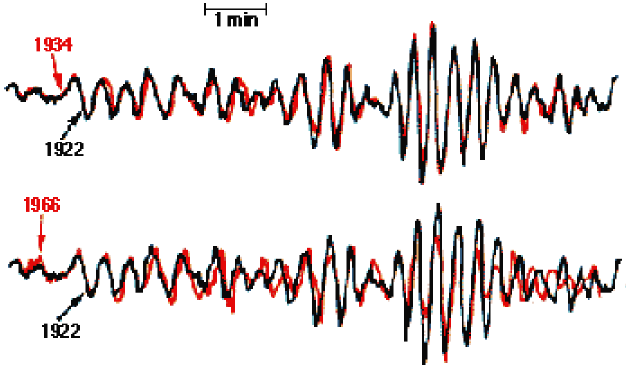
Southern California Earthquake Center

Studying earthquakes and their effects in California and beyond

一方面，经过30多年的发展，板块构造演化深入研究、断层模型已被广泛接受、计算技术的快速发展，地震科学取得跨越式发展；另一方面，社会对减轻地震灾害的需求逐渐增加。

建立一个有效的框架来**整合（integrate）**某个区域内所有地震相关的科学信息以达成科技界**共识**，然后在这个区域内推向公众。





1 研究背景及意义

- **His original Master Model goal remains inspiring:** “to develop a model of the Earth's lithosphere in which we predict the occurrence of earthquakes on the basis of the space-time distribution of tectonic stress calculated using various geophysical observables, as the atmospheric scientists forecast weather by computer on the basis of observed pressure, temperature, wind speed.”

Effect of local site conditions on ground motion

seismologists ⇄ engineers

Transportability of the Master Model Concept to Other Regions

Balance Synthesis Consensus

——Aki, 2002, Synthesis of Earthquake Science Information and Its Public Transfer: Synthesis of Earthquake Science Information and Its Public Transfer: A history of the Southern California Earthquake Center

1 研究背景及意义

From Master Model to the Physics of Earthquakes

Earthquake System Science:

(a) the dynamics of fault systems

(b) the dynamics of fault rupture

(c) the dynamics of ground motions

断裂系统的动力学过程：在小时到世纪的时间尺度，断裂系统内如何演化出一系列地震活动?

断层破裂的动力学过程：在秒到分钟的时间尺度，断层是如何破裂最终导致一次地震事件?

地面运动的动力学过程：从断层破裂到地表晃动的过程中，地震波是如何传播的?

Two Approaches to Earthquake Prediction

Probabilistic Earthquake Forecasting

"Silver-Bullet Approach" X

Deterministic Earthquake Prediction

"Brick-by-Brick Approach" √

Collaboratory for the Study of Earthquake Predictability

Earthquakes: Separating Fact from Fiction

John Vidale

Director of the Southern California...

SCEC's long-range science vision

Earthquake System Science:

(a) the dynamics of fault systems

(b) the dynamics of fault rupture

(c) the dynamics of ground motions

SCEC5's core program is to provide new concepts that can improve

(a) the predictability of the earthquake system models

(b)new data for testing the models

(c)a better understanding of model uncertainties

1 研究背景及意义

我有一个梦想

实现这个梦想要靠科学

科学应该去伪存真

1 研究背景及意义

公共结构模型
公共速度模型
公共断层模型
公共块体模型
大地测量模型
构造块体模型
变形模型
区域概率模型
衰减模型
。。。

主体模型
(Master Model)

SCEC1
探索

地震系统科学：
断层系统动力学
断层破裂动力学
地表响应动力学

大地测量
地震学
地震地质

基于物理
观测的概
率预测
场地效应

SCEC2
起步

M_W7.1 Landers 1992
M_W6.7 Northridge 1994
M_W7.1 Hector Mine 1999

M_W6.0 Parkfiled 2004
“传统前兆”
UCERF
无震滑移、震颤
CyberShake

基于CVM实现真实震源物理的强地面运动数值模拟

SCEC3
发展

基础模型完善
UCERF推广
UCERF3

基于物理模型的强震概率预测
基于破裂模型和强地面运动算法验证

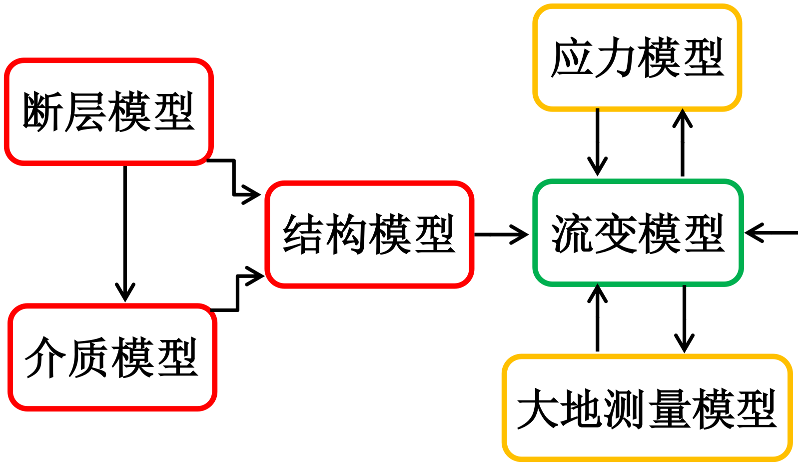
SCEC4
完善

研究基于震源物理模型的强地面高频运动

1991 2002 2007 2012 2018

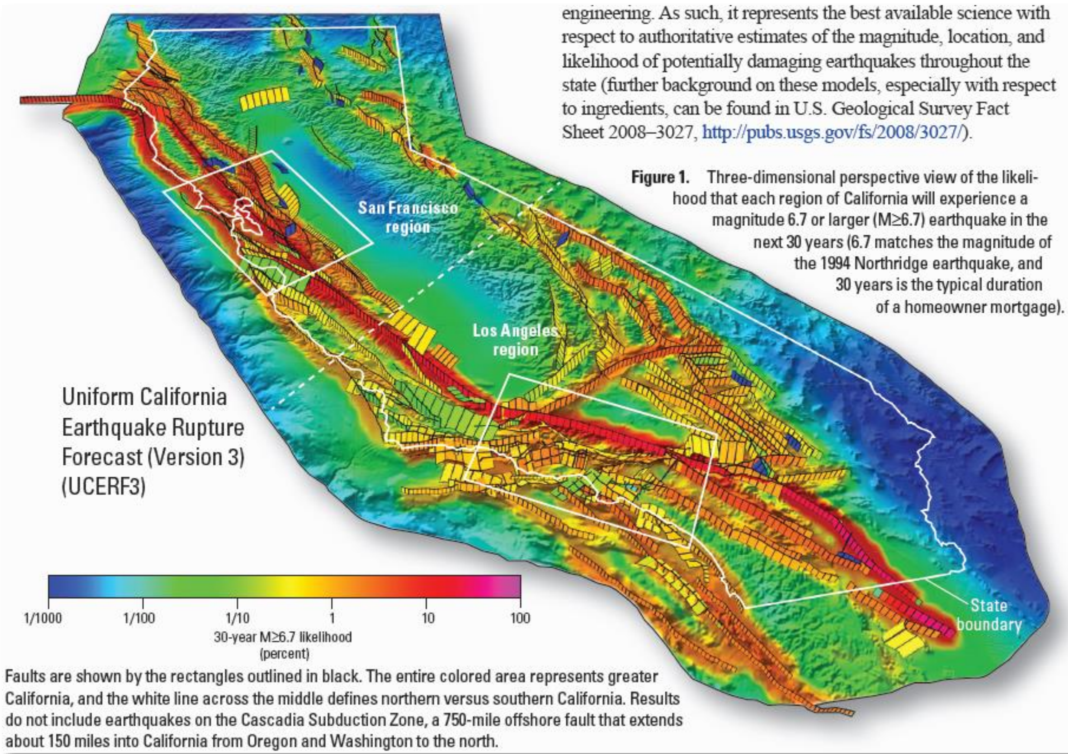
2、国内外研究进展

板块边缘的美国加州震源物理模型



美国地质调查局
美国南加州地震中心（2017）

美国加州地震预测



engineering. As such, it represents the best available science with respect to authoritative estimates of the magnitude, location, and likelihood of potentially damaging earthquakes throughout the state (further background on these models, especially with respect to ingredients, can be found in U.S. Geological Survey Fact Sheet 2008–3027, http://pubs.usgs.gov/fs/2008/3027/).

Figure 1. Three-dimensional perspective view of the likelihood that each region of California will experience a magnitude 6.7 or larger (M≥6.7) earthquake in the next 30 years (6.7 matches the magnitude of the 1994 Northridge earthquake, and 30 years is the typical duration of a homeowner mortgage).

Faults are shown by the rectangles outlined in black. The entire colored area represents greater California, and the white line across the middle defines northern versus southern California. Results do not include earthquakes on the Cascadia Subduction Zone, a 750-mile offshore fault that extends about 150 miles into California from Oregon and Washington to the north.

地震预报的难点

同时预测地震“时、空、强”三要素

地震预报的“亚”问题

仅同时预测“三要素”中的两个；

难度大大降低；

有助于防震减灾

据陈晓非, ppt，2017

2 国内外研究进展

近年来显著地震事件震前相关研究进展调研

智利中部终于发生大地震

早在10多年前就知道智利中部会发生地震，终于在2010年2月27日在强闭锁断层段发生了预期地震

Madariaga R et al., Science, 2010

Central Chile Finally Breaks

Raul Madariaga[1], Marianne Métois[1], Christophe Vigny[1], Jaime Campos[2]

It has been known for 10 years that the site of the Maule mega-earthquake of 27 February 2010 was fully locked and ready to break.

最大限度地利用地震研究

更好地利用已有的技术手段来改进地震预报研究

Kanamori H., Nature, 2012

Putting seismic research to most effective use

"Forecasters could improve warnings simply by using existing technology better."

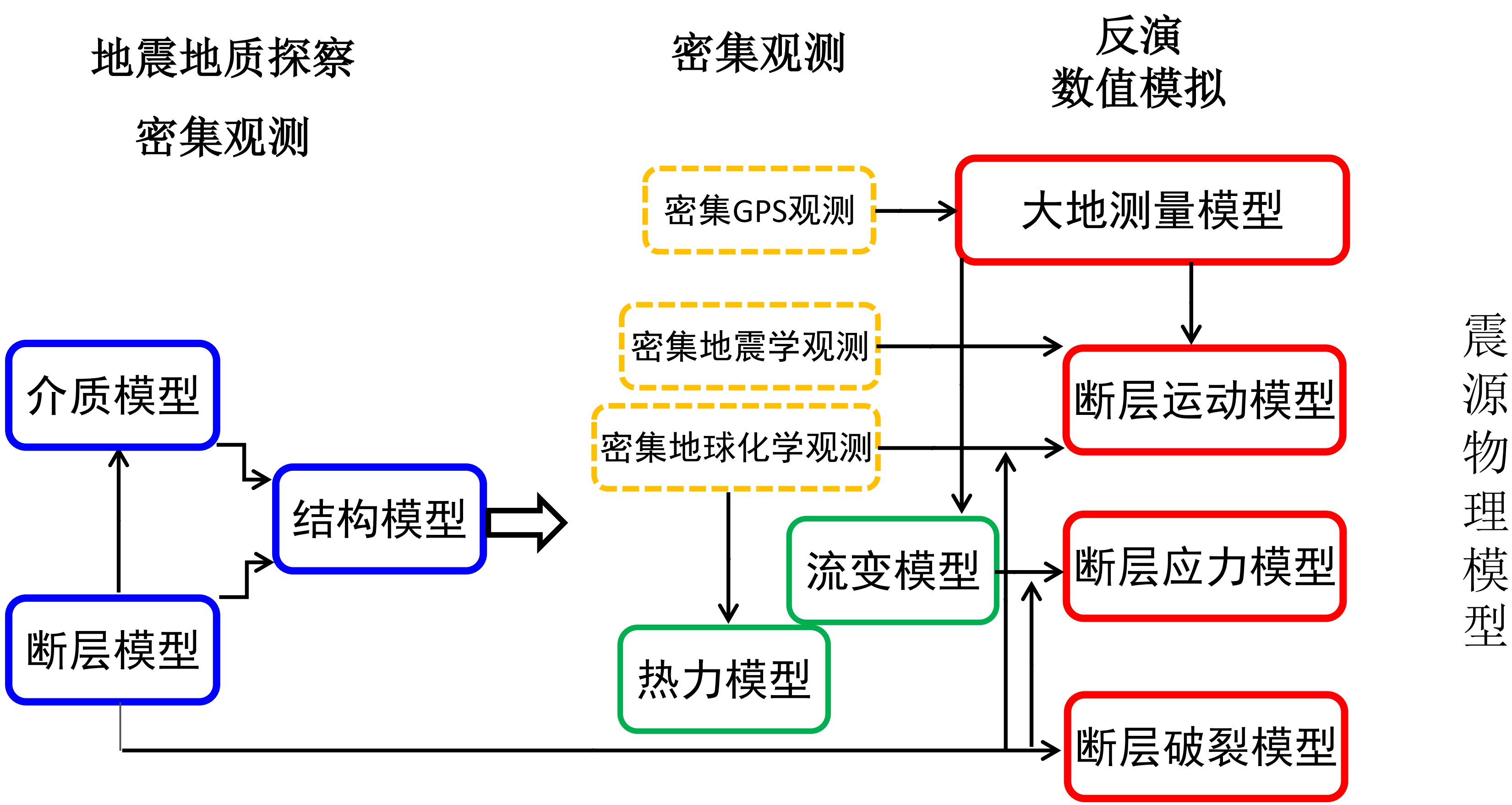
2 国内外研究进展

近年来几次显著地震事件震前相关物理现象统计表

	地震地质	断层运动	断层应力	震源异常
2015年尼泊尔8.1级地震	历史地震-强震破裂空段	GPS-断层闭锁	b值-应力累积水平较高	地震围空
2014年智利8.1级地震	历史地震-强震破裂空段	GPS-断层闭锁	b值-应力显著增强	前震
2011年日本9.0级地震	历史地震-强震破裂空段 历史地震-发震概率	GPS-断层闭锁，扰动	b值、p值-应力显著增强	前震，无震滑移，低频地震
2010年智利8.8级地震	历史地震-强震破裂空段	GPS-断层闭锁		波速异常-流体活动?
2010年海地7.3级地震	历史地震-强震破裂空段	GPS-断层闭锁	库仑应力-累积水平较高	
2004年苏门答腊9级地震	历史地震-强震破裂空段		库仑应力-累积水平较高	
1999年土耳其7.8级地震	历史地震-强震破裂空段		库仑应力-累积水平较高	
……	……			

蓝色-震前无效
红色-震前有效
黑色-震后研究

2 国内外研究进展

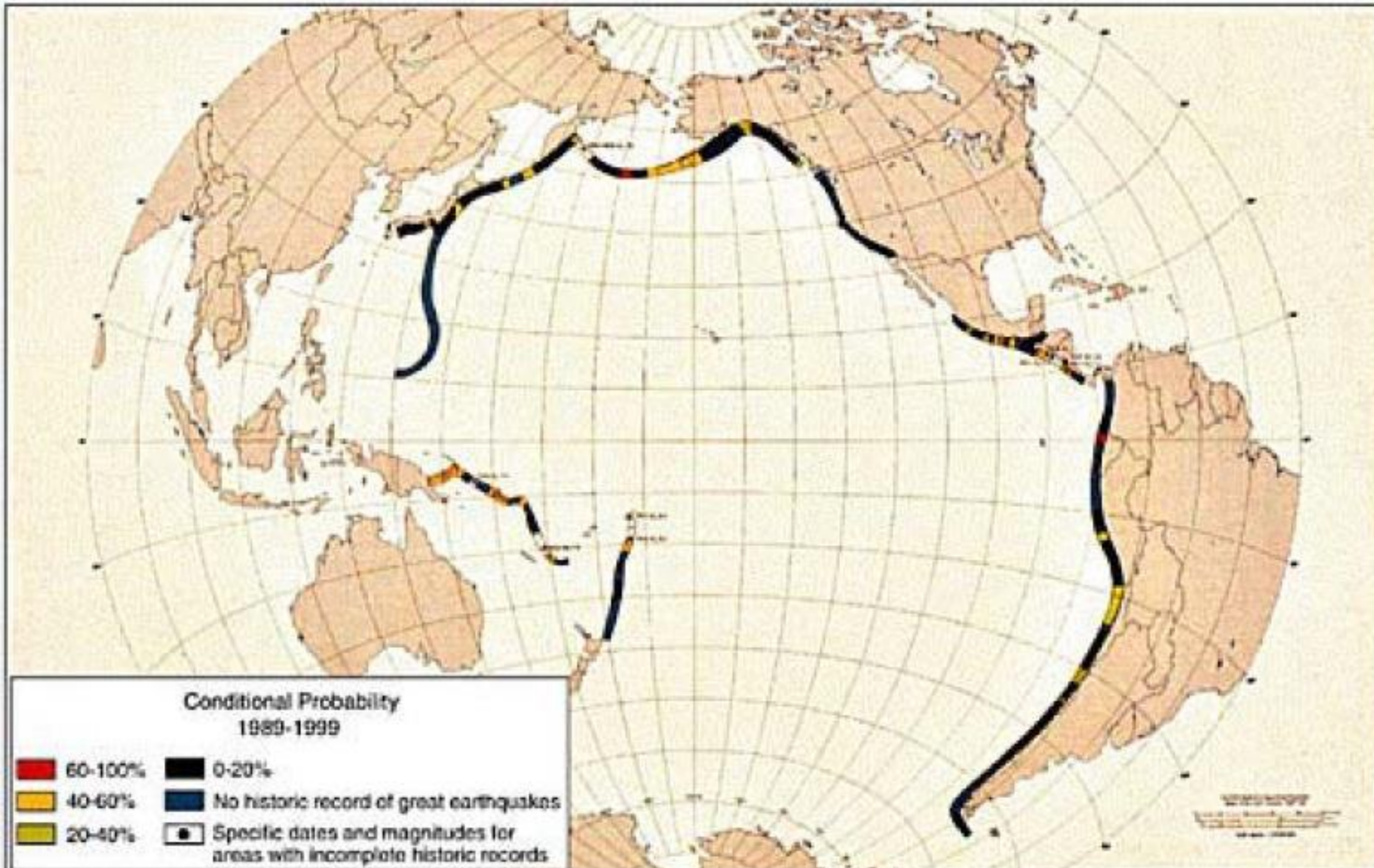

地震地质探察
密集观测
密集观测
反演
数值模拟
密集GPS观测
大地测量模型
密集地震学观测
密集地球化学观测
断层运动模型
介质模型
结构模型
断层模型
流变模型
热力模型
断层应力模型
断层破裂模型
震源物理模型

2 国内外研究进展

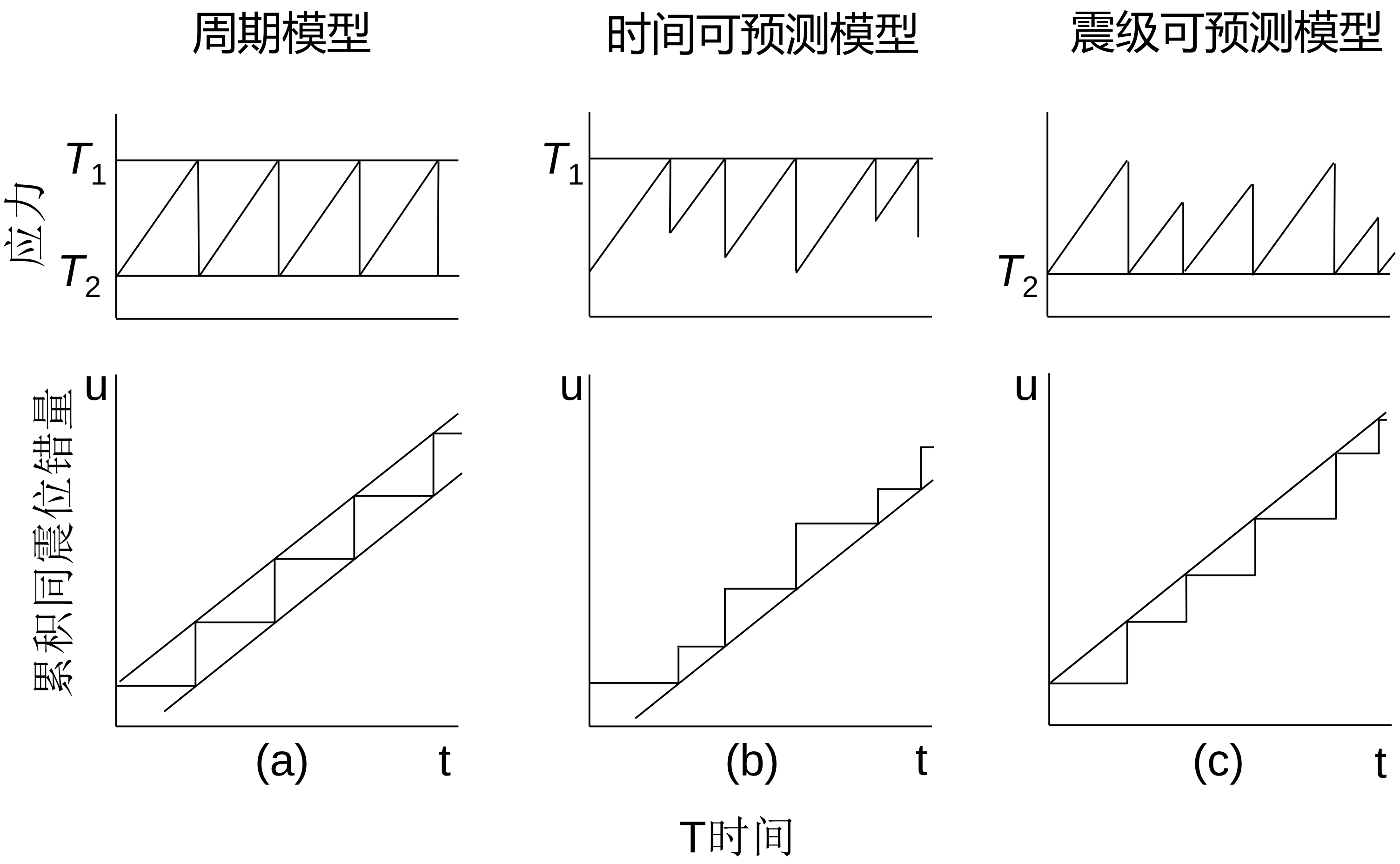
强震破裂空段

Nishenko's Circum-Pacific Seismic Gap Model, 1991

Tables included characteristic magnitudes and probability estimates.

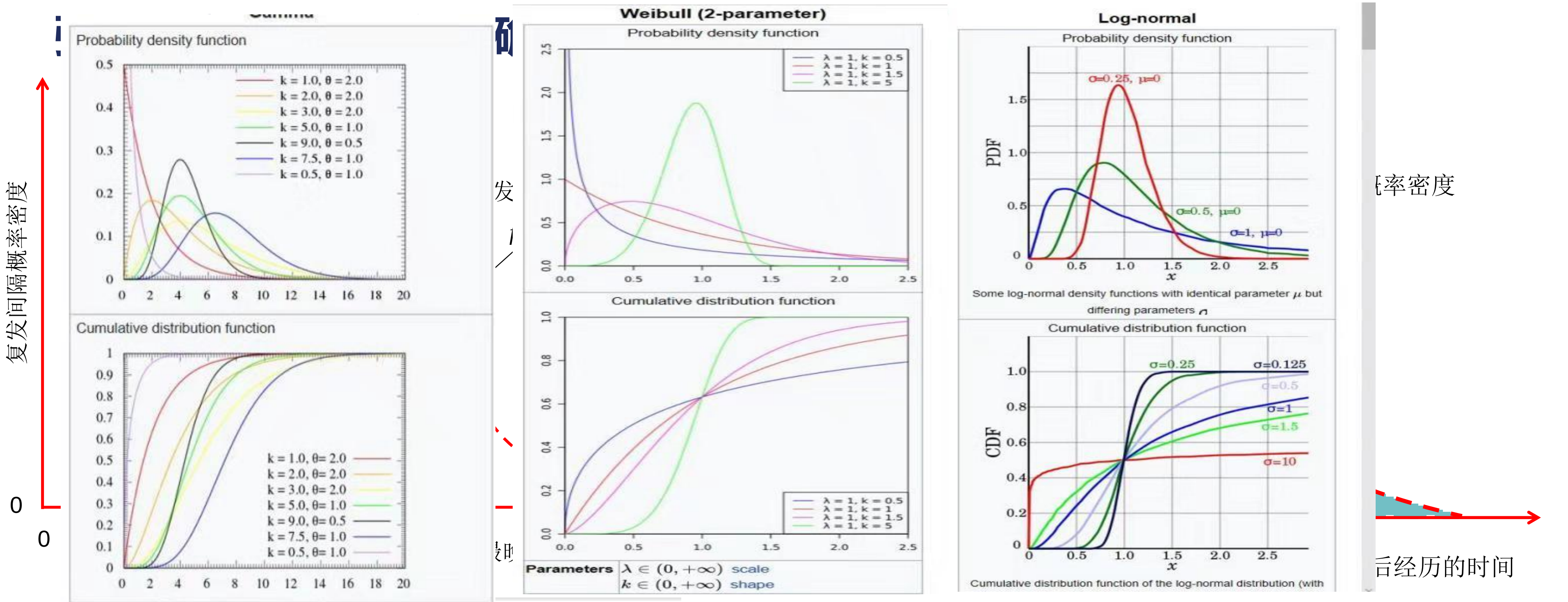


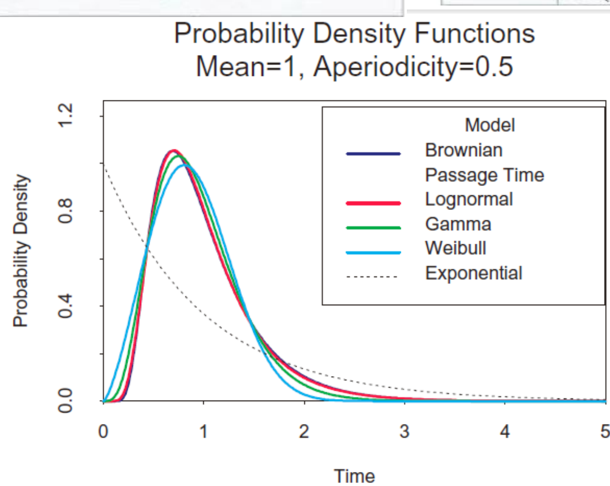
地震预测模型

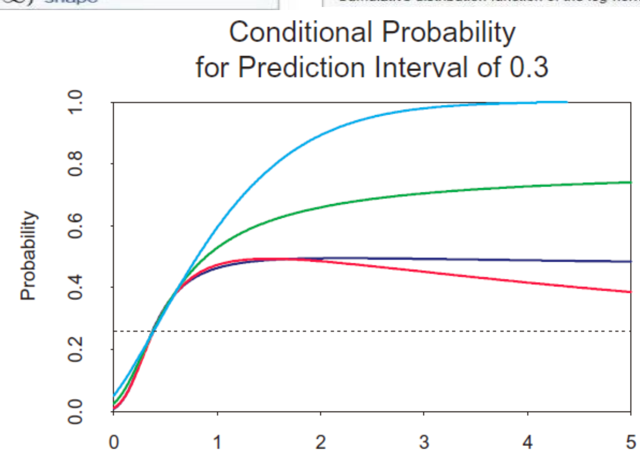


Shimazaki and Nakata, 1980

2 国内外研究进展

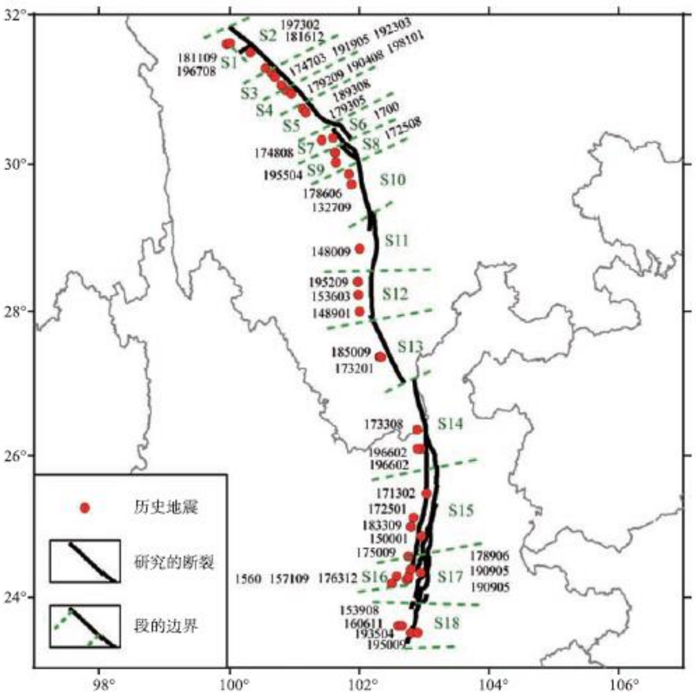

复发间隔概率密度
Gamma
Probability density function
Cumulative distribution function
Weibull (2-parameter)
Probability density function
Cumulative distribution function
Parameters $\lambda \in (0, +\infty)$ scale
$k \in (0, +\infty)$ shape
Log-normal
Probability density function
Some log-normal density functions with identical parameter μ but differing parameters σ
Cumulative distribution function
Cumulative distribution function of the log-normal distribution (with
概率密度
后经历的时间

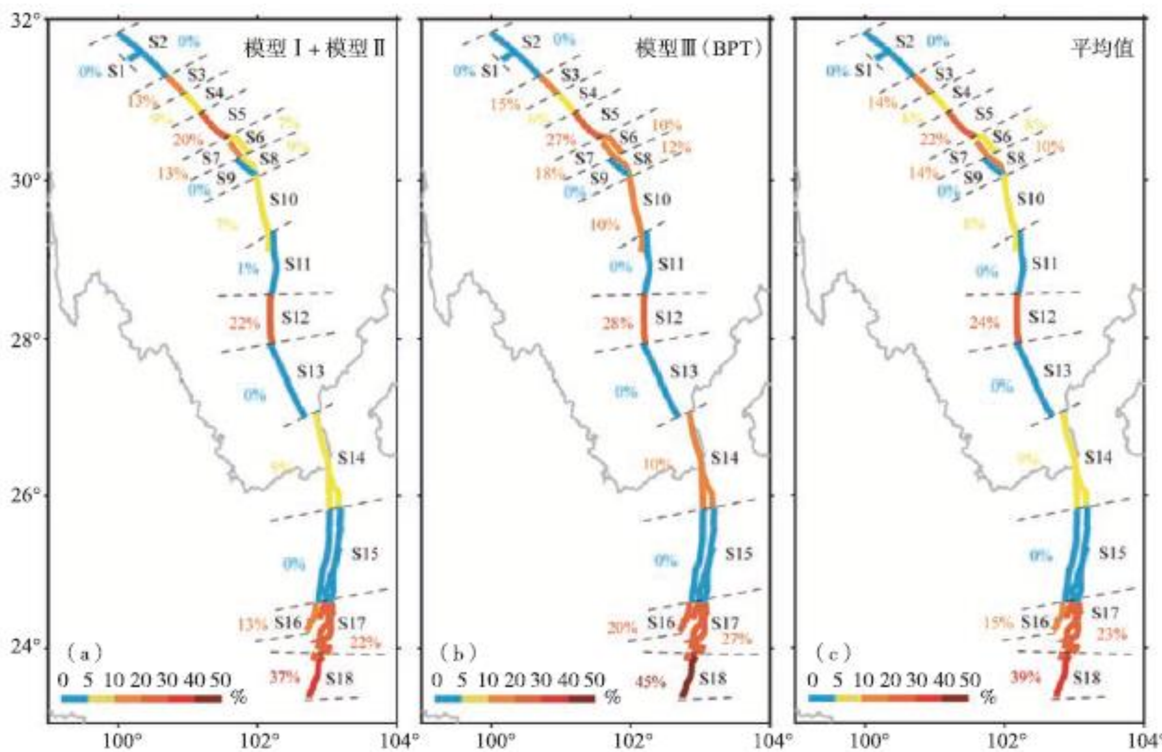

Probability Density Functions
Mean=1, Aperiodicity=0.5
Model
Brownian Passage Time
Lognormal
Gamma
Weibull
Exponential
Probability Density
Time


Conditional Probability
for Prediction Interval of 0.3
Probability

2 国内外研究进展

强震概率预测（时间不确定性）





闻学泽等，2017

地震破裂模型（震级不确定性）

相邻断层段级联破裂理论分析

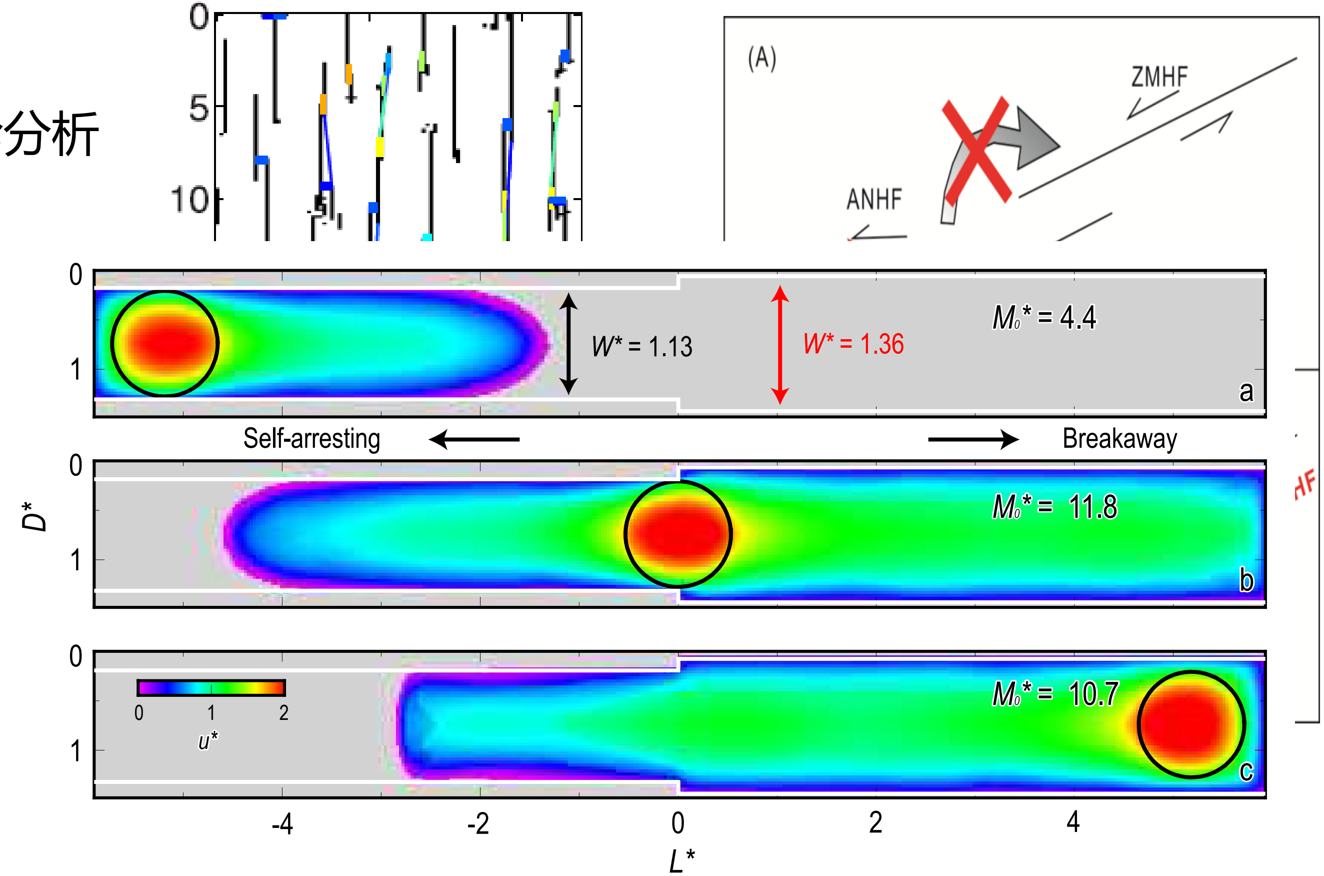
断层几何性质：

走向变化

倾角变化

阶跃距离

孕震层深度变化

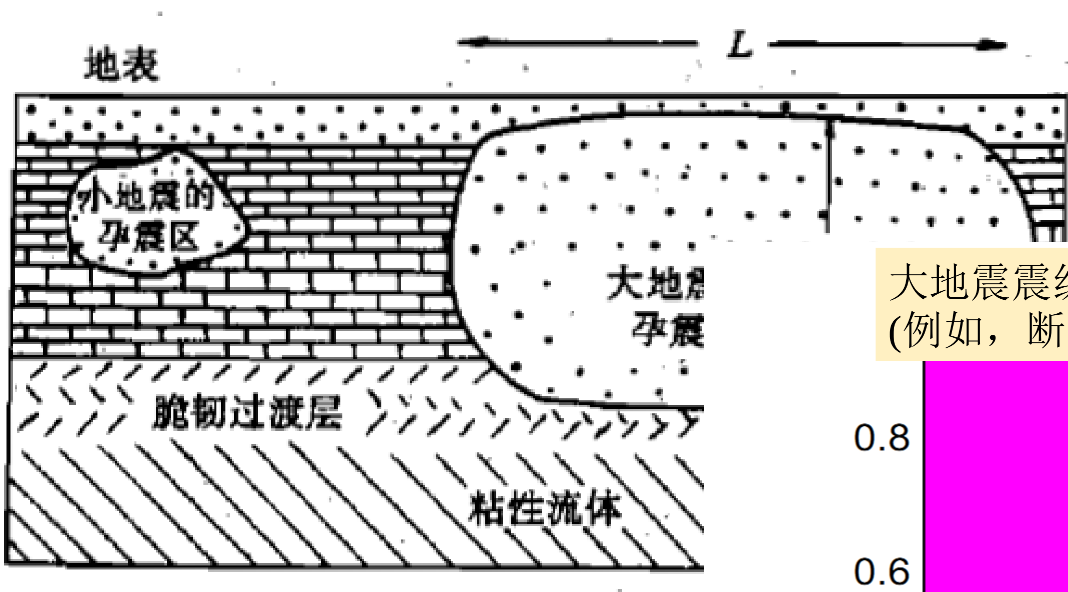


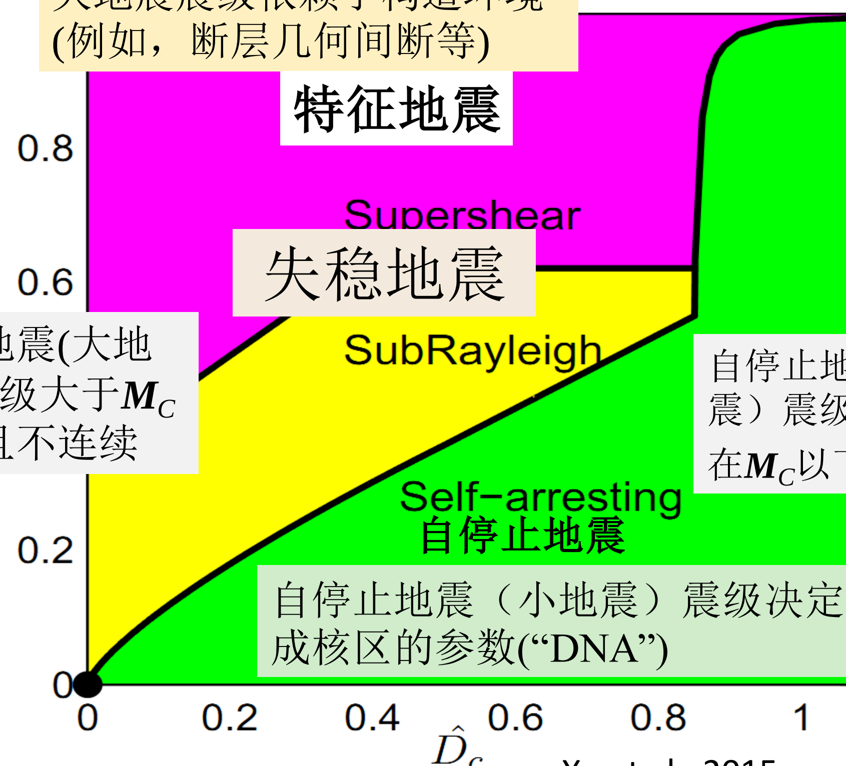
相邻不同宽度凹凸体的震中与破裂尺度间关系

Weng and Yang, 2017, GRL

2 国内外研究进展

特征地震？发震能力？（震级不确定性）





大地震震级依赖于构造环境(例如，断层几何间断等)

失稳地震

失稳地震(大地震) 震级大于M_C，并且不连续

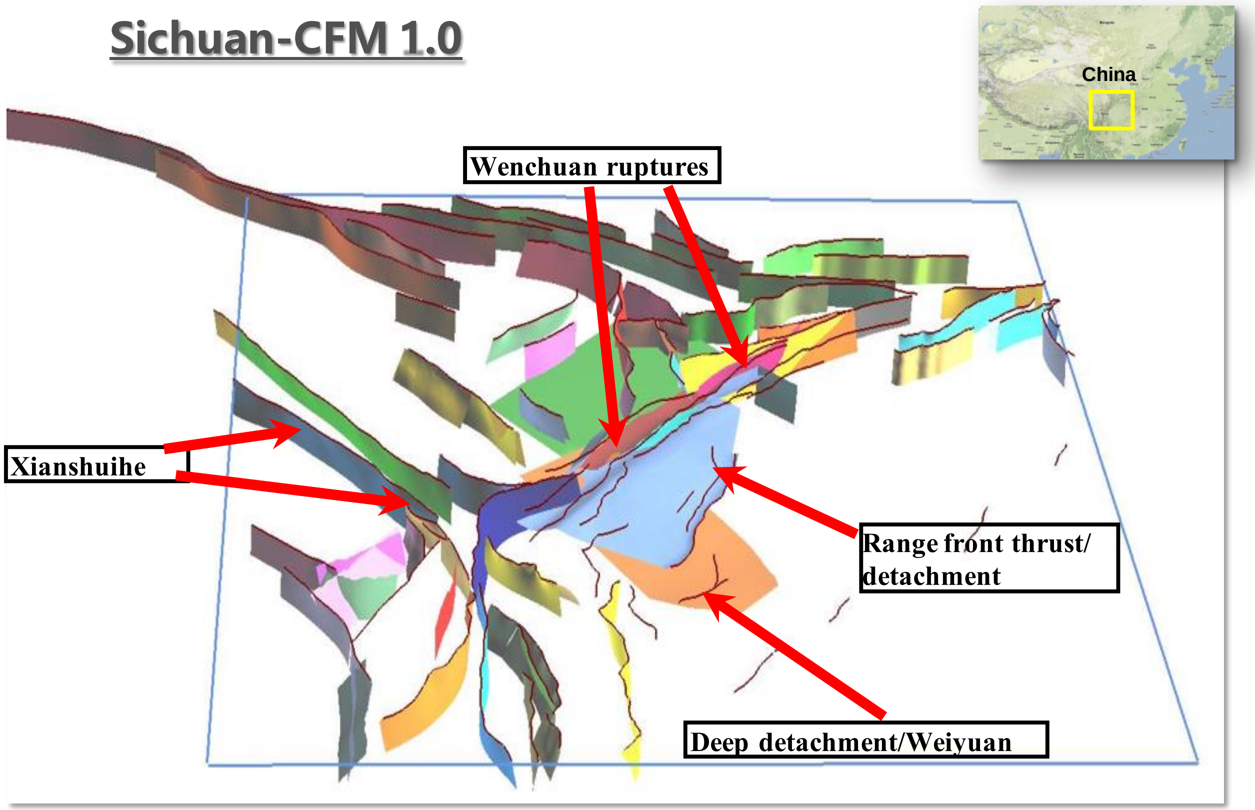
自停止地震（小地震）震级范围：在M_C以下连续变化

自停止地震（小地震）震级决定于成核区的参数(“DNA”)

Xu et al., 2015

2 国内外研究进展

地震地质研究结果在地震预测中的应用展望

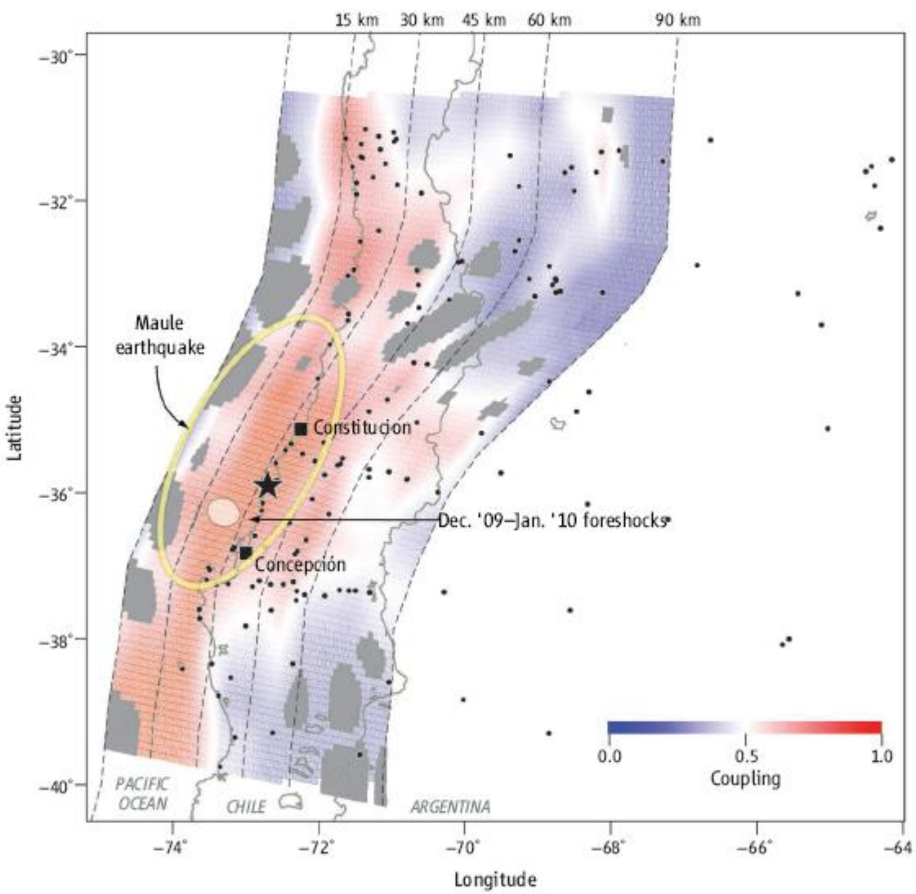


河海大学，王毛毛教授

几何模型	破裂空段	级联破裂分析	离逝率
基础	地点	震级	长期

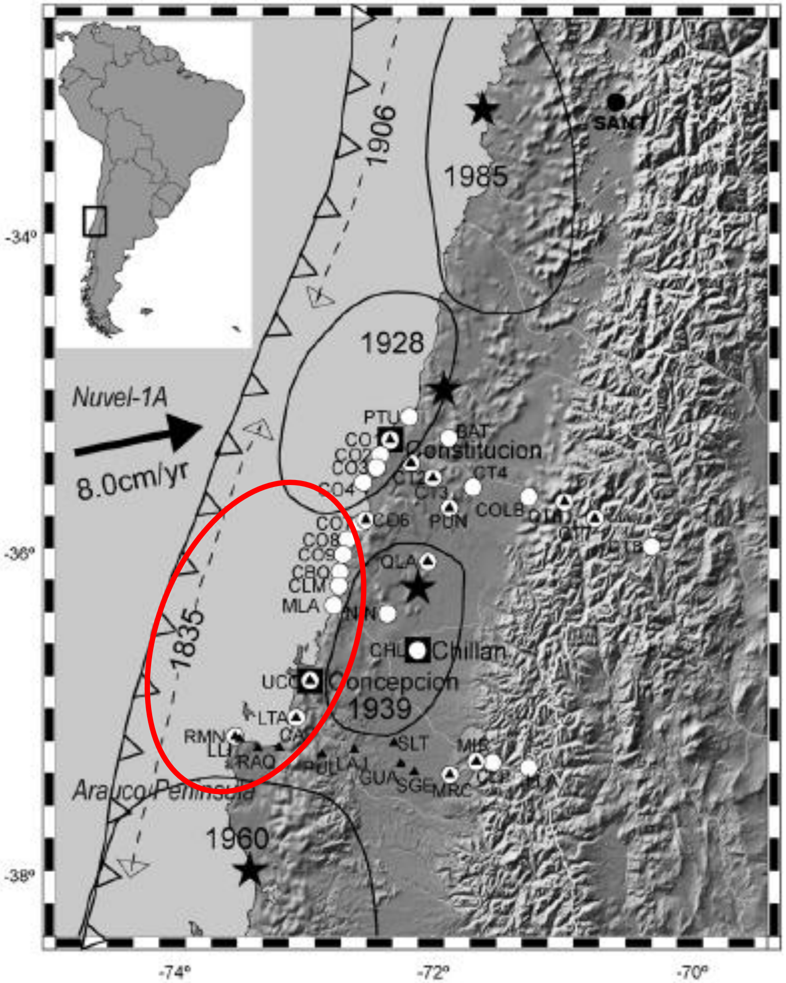
2 国内外研究进展

震间位移反演断层闭锁程度——大地测量



强闭锁区域

Madariaga R et al., Science, 2010



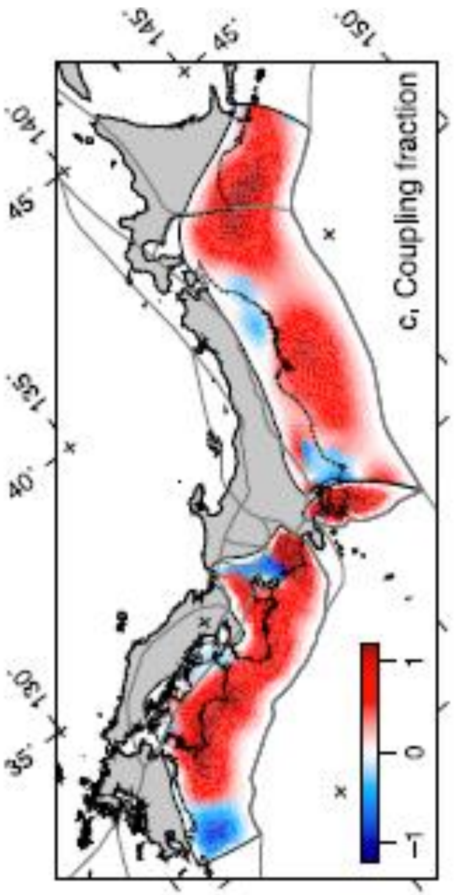
强震破裂空段

Ruegg J C et al., 2009

2 国内外研究进展

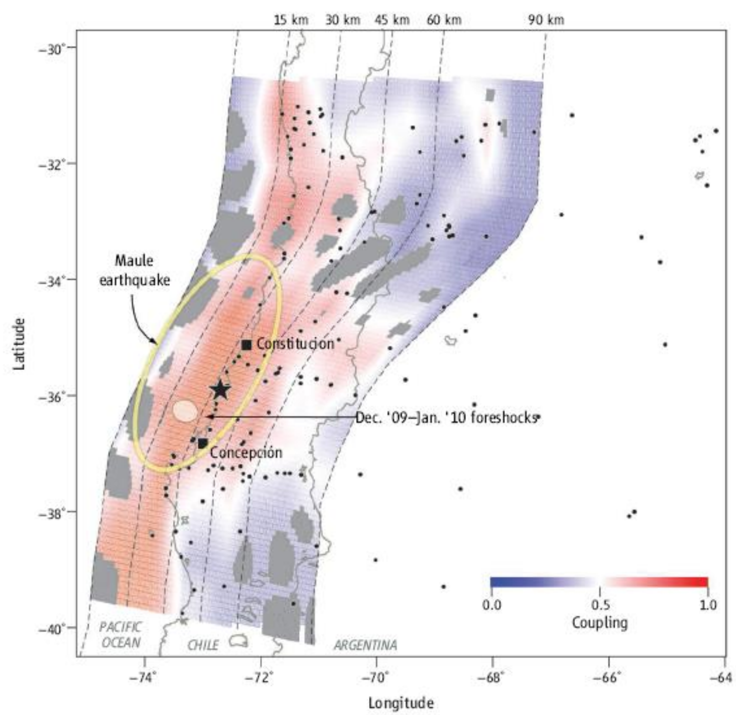
震源区断层运动闭锁是强震前较为普遍的现象

2011年日本9级地震前



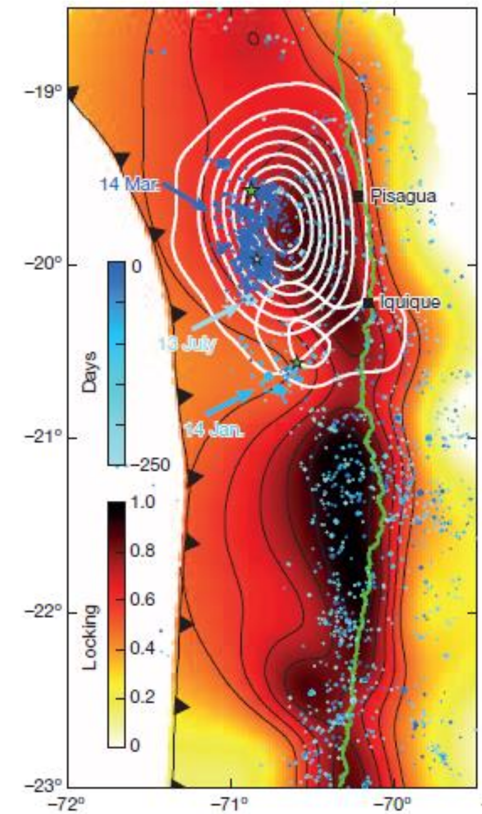
Hashimoto C, et al., Nature Geosci., 2009
Loveless J P, et al., JGR, 2010

2010年智利8.8级地震前



Madariaga R et al., Science, 2010

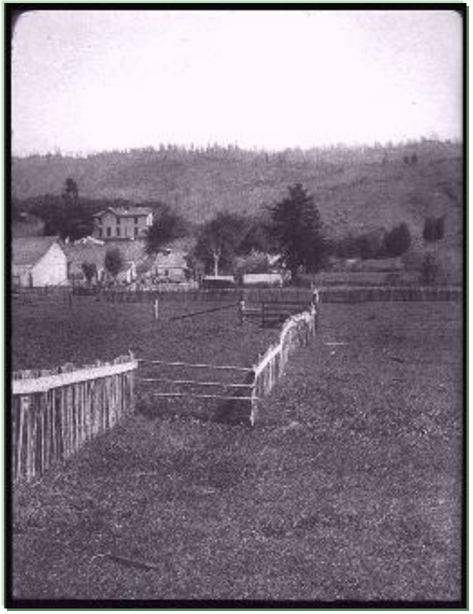
2014年智利8.1级地震前

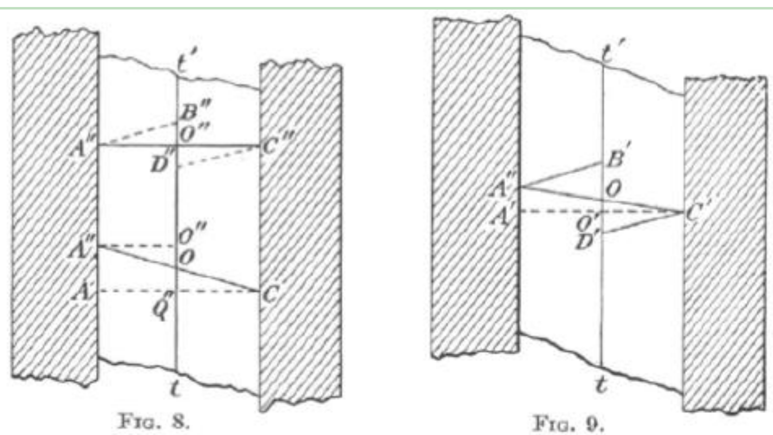


Bernd S, et al. Nature, 2014

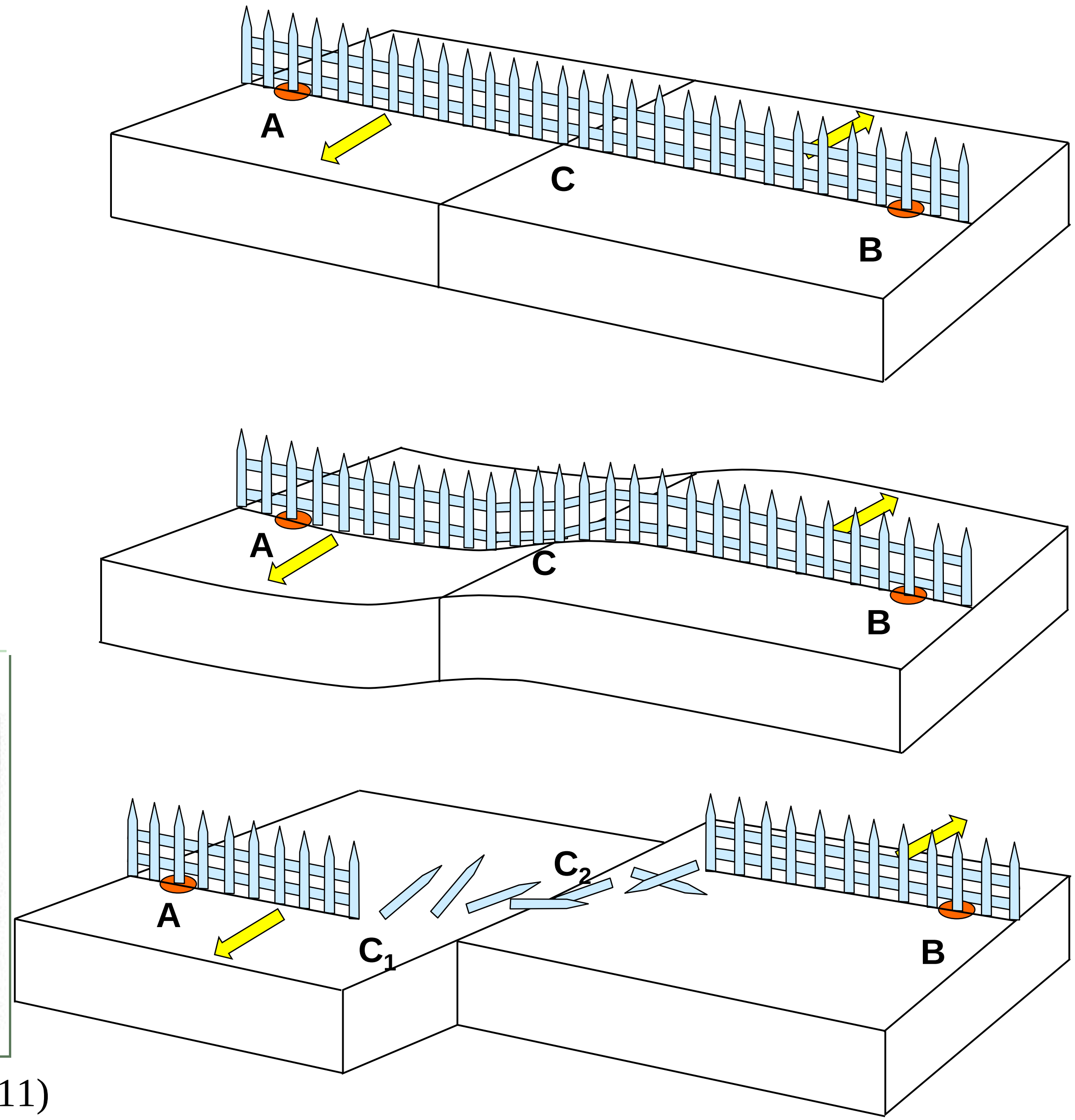
2 国内外研究进展

弹性回跳模型与断层运动



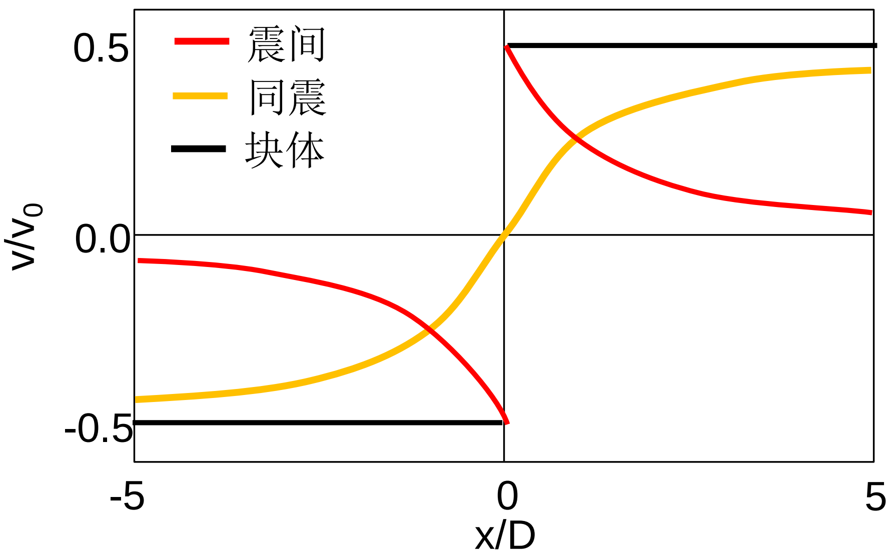


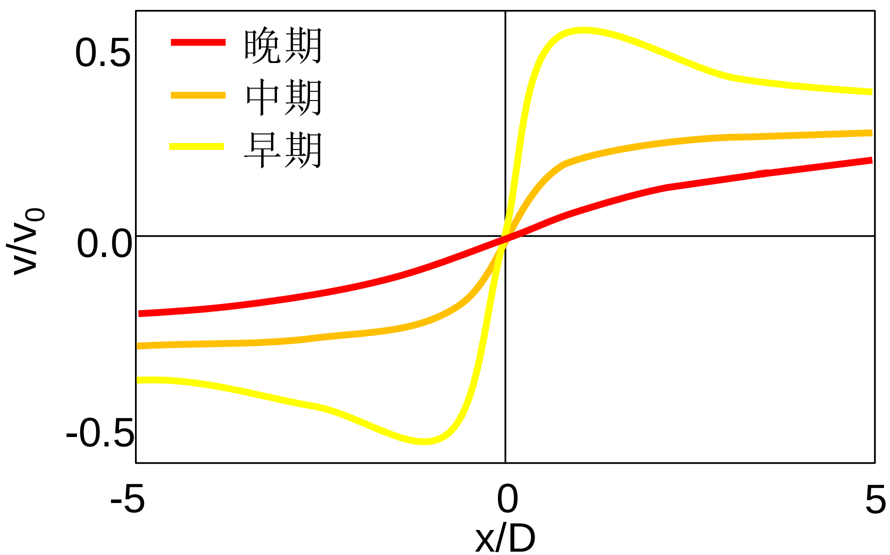
经典的弹性回跳理论 (Reid, 1910，1911)



2 国内外研究进展

弹性回跳模型与断层运动

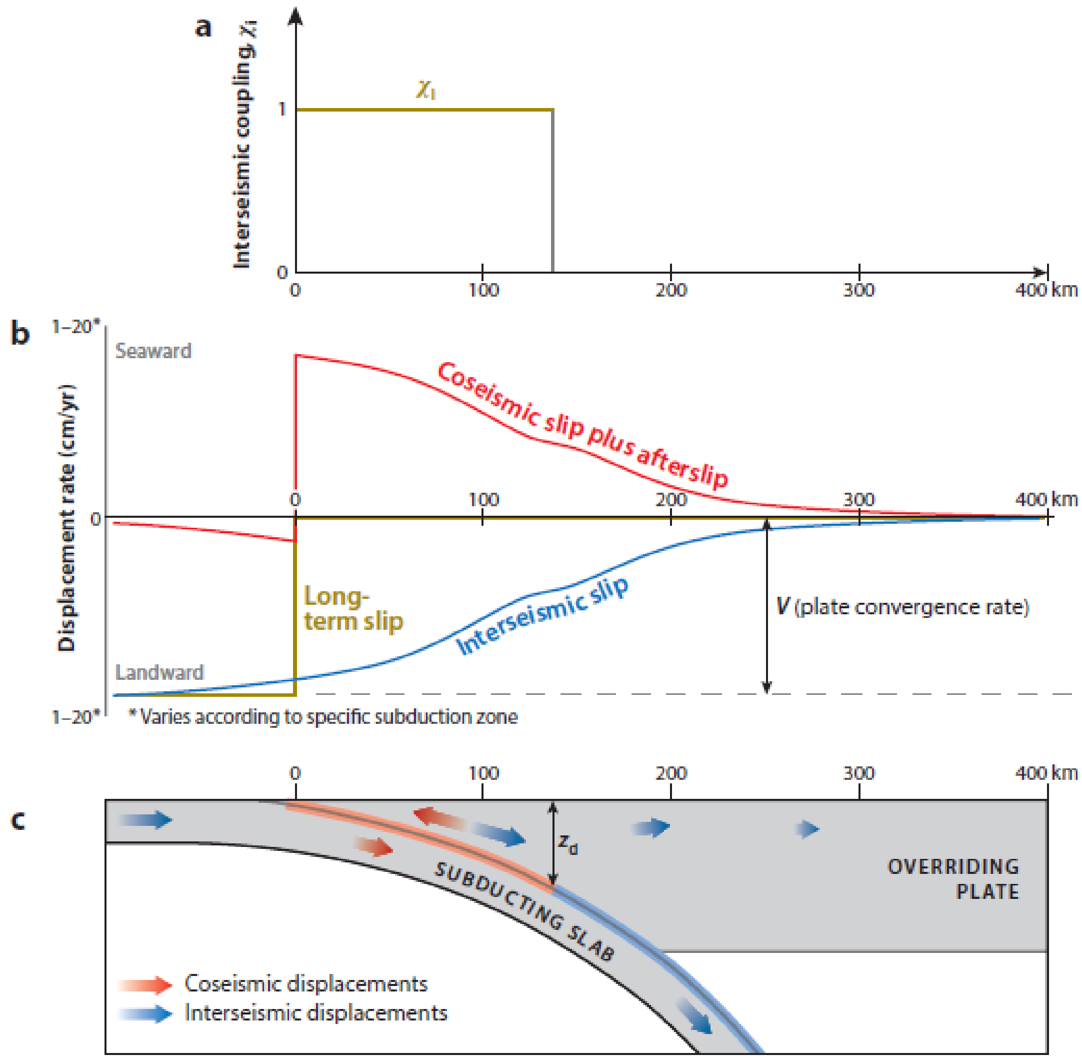




(Meade et al., 2005,JGR)

2 国内外研究进展

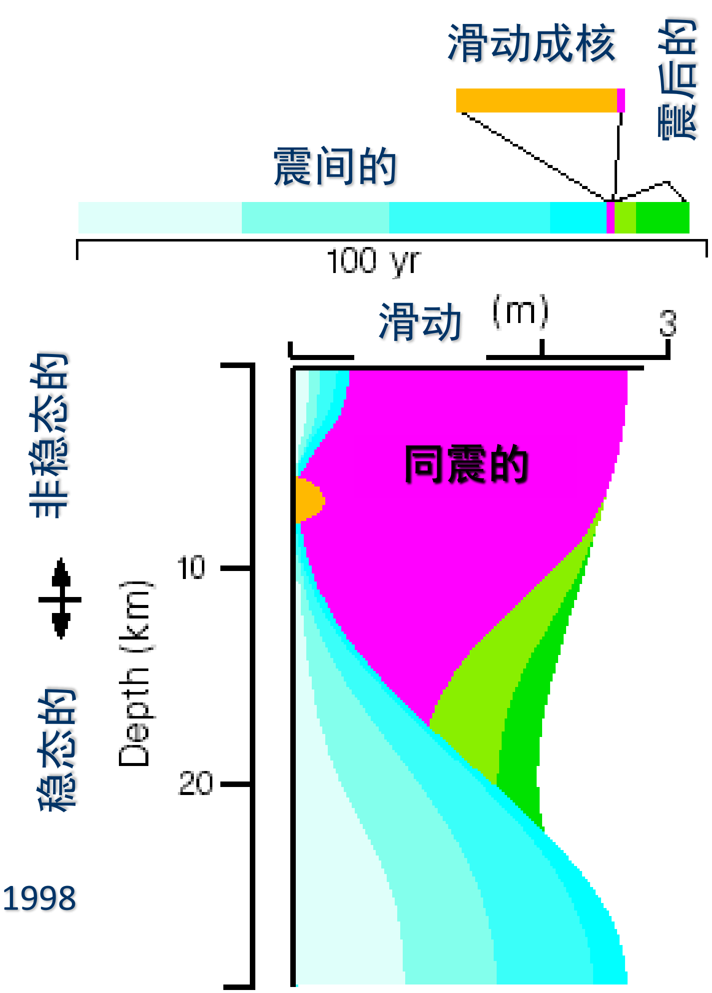
弹性回跳模型与断层运动



(Avouac et al., 2015)

2 国内外研究进展

地震断层运动随时间和深度变化理论模式



Scholz, 1998

震间阶段：

—脆-延转换带以下深度发生持续性稳定滑动，滑动量随深度增加

—地壳浅部可能发生小量级的稳定滑动（蠕动）

—脆-延转换带以上深度的断层面大部分闭锁（无滑动），积累来自下方稳定滑动所产生的应变

震前阶段：

—脆-延转换带以下深度和地壳浅部的断层面的续性稳定滑动可会有所加速

—闭锁的断层面在主震前不久可能发生预位移

震时阶段：

—闭锁的断层面突然滑动成核

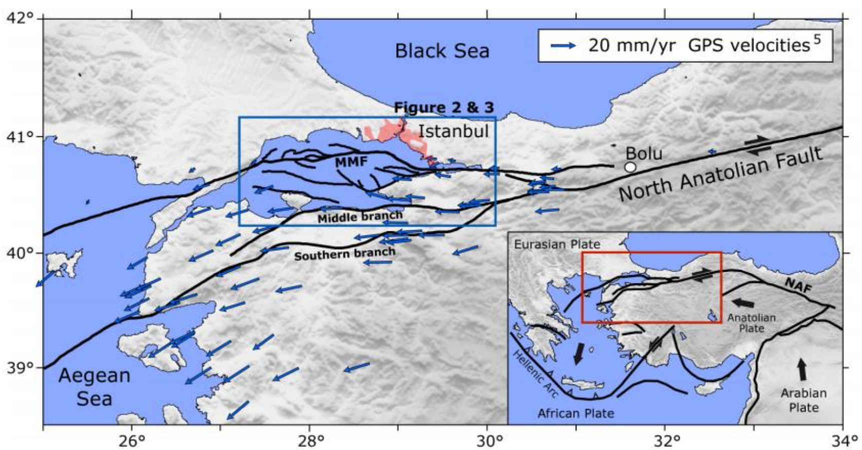
震后接段：

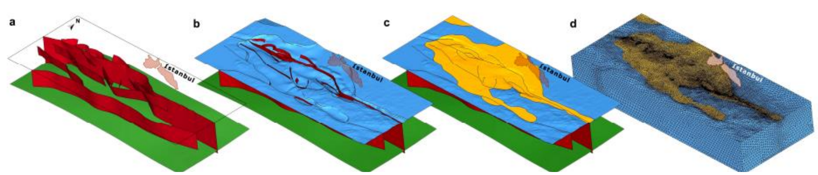
—断层面作震后调整滑动，以脆-延转换带附近调整幅度最大

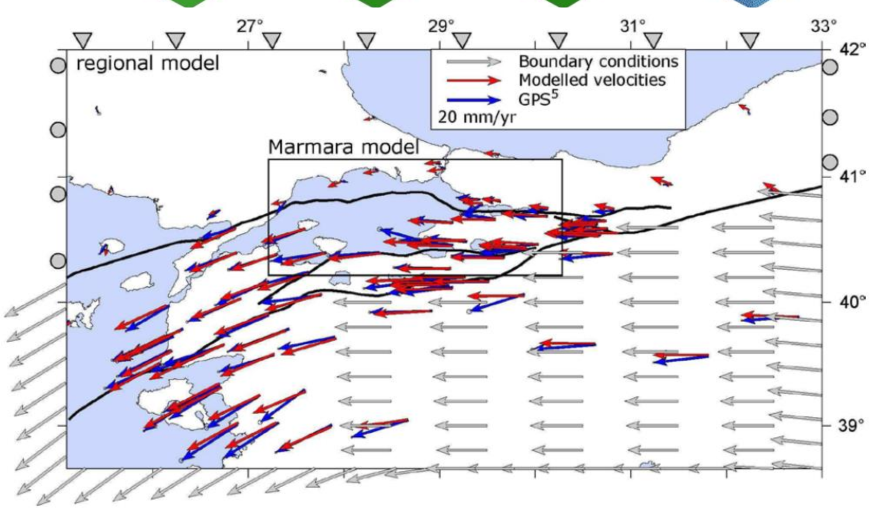
引自闻学泽老师讲义

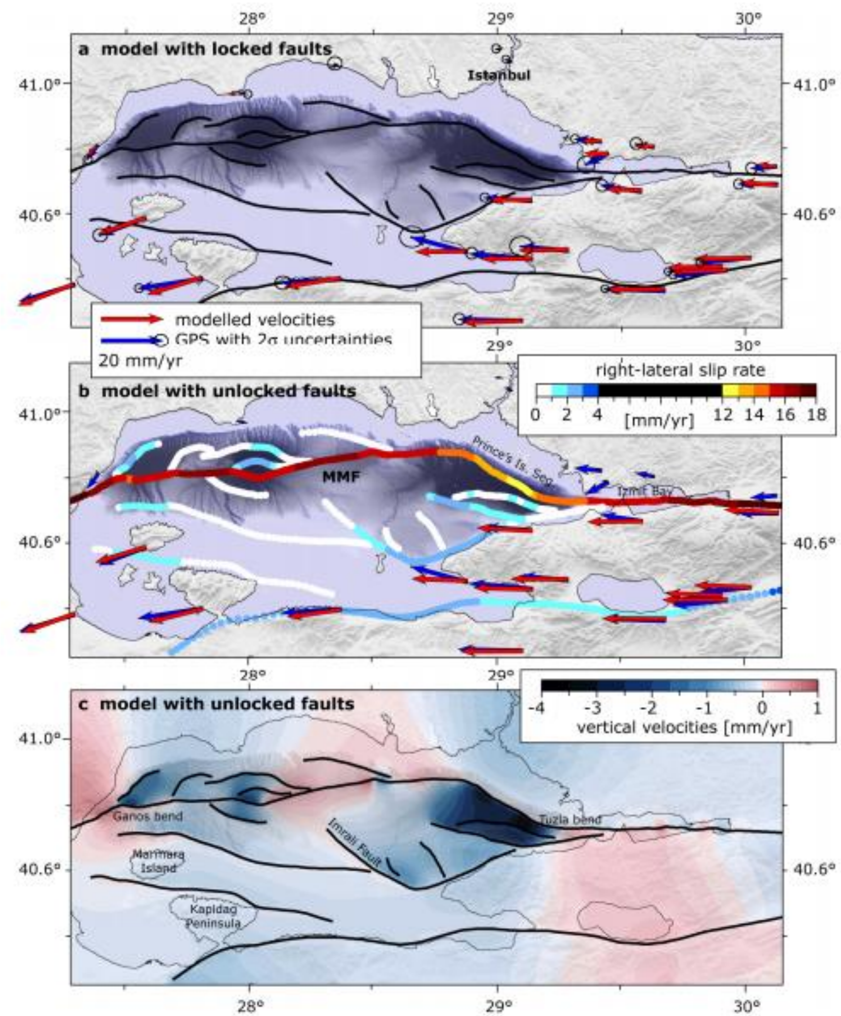
2 国内外研究进展

有限元数值模拟区域地壳运动



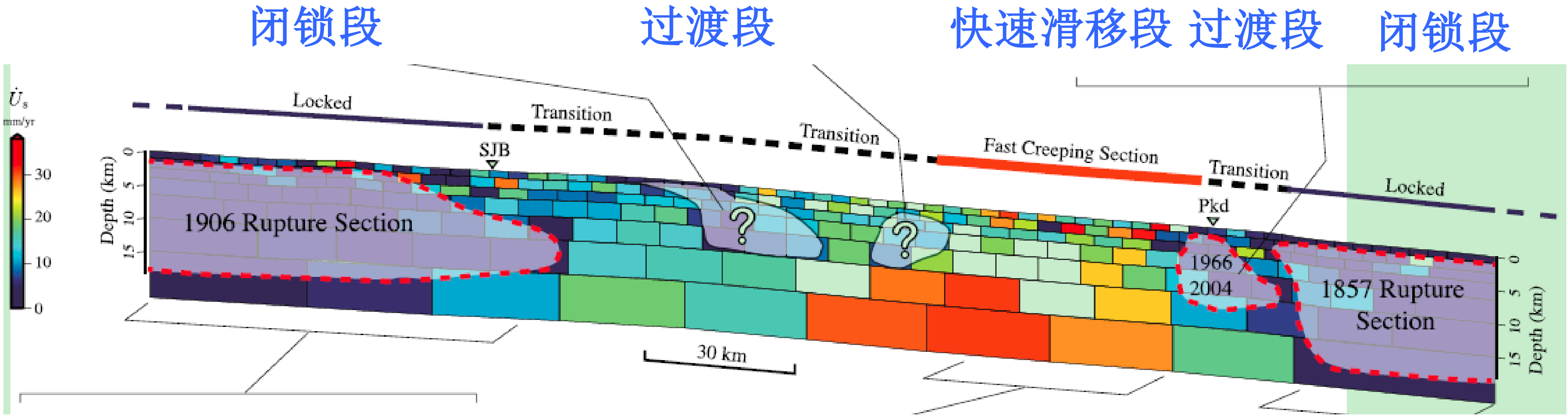






Hergert et al., Nature Geosci, 2010

断层面二维断层运动速率反演



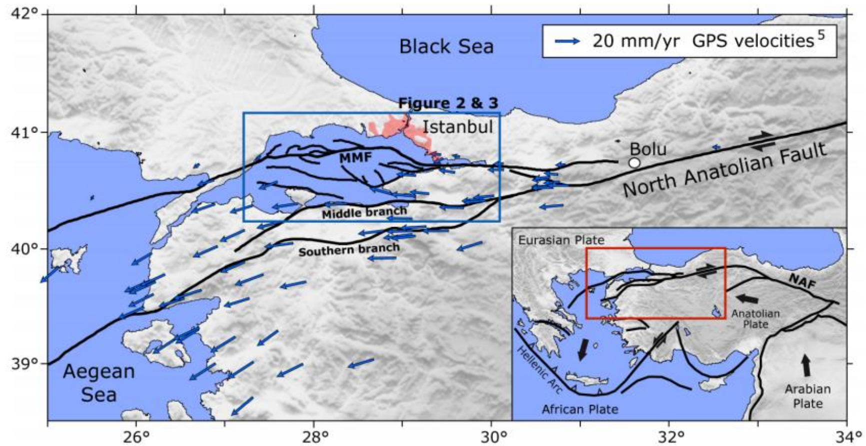
圣安德烈斯断裂带中段断层运动分段特征

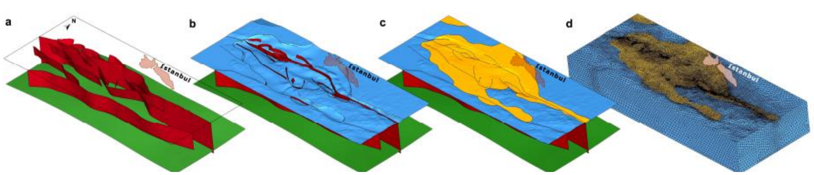
Jolivet, et al., 2015

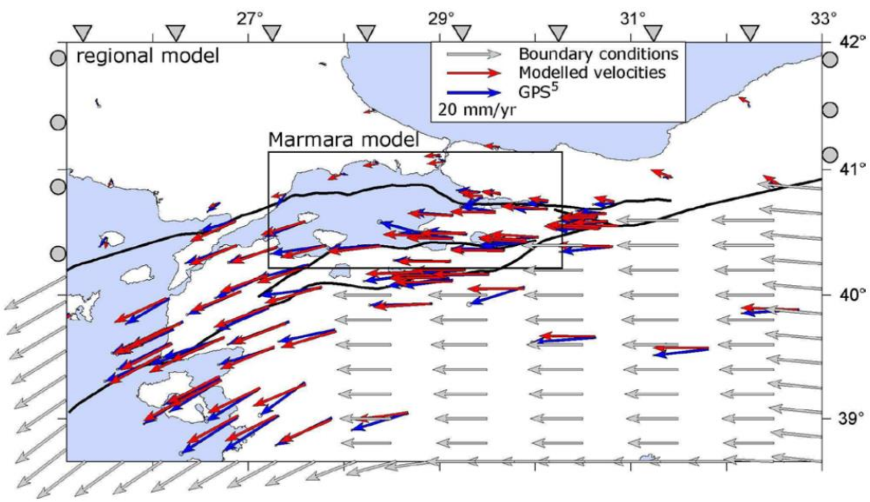
2 国内外研究进展

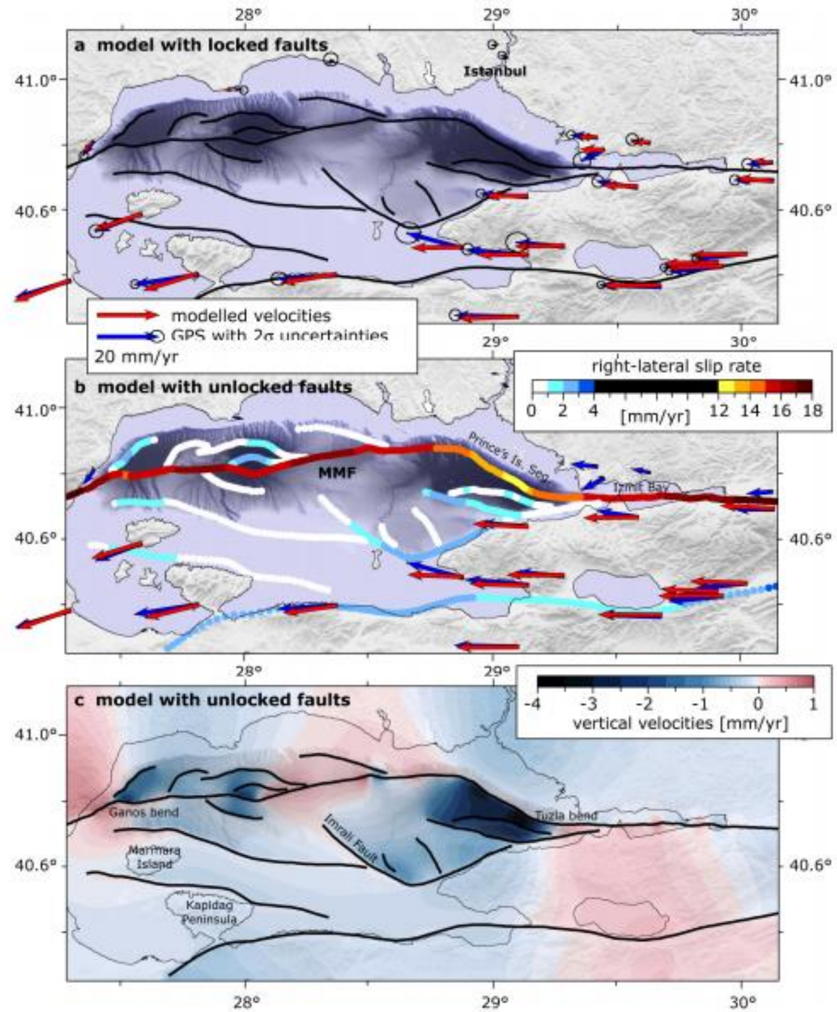
INSTITUTE OF EARTHQUAKE FORECASTING, CEA

有限元数值模拟区域地壳运动



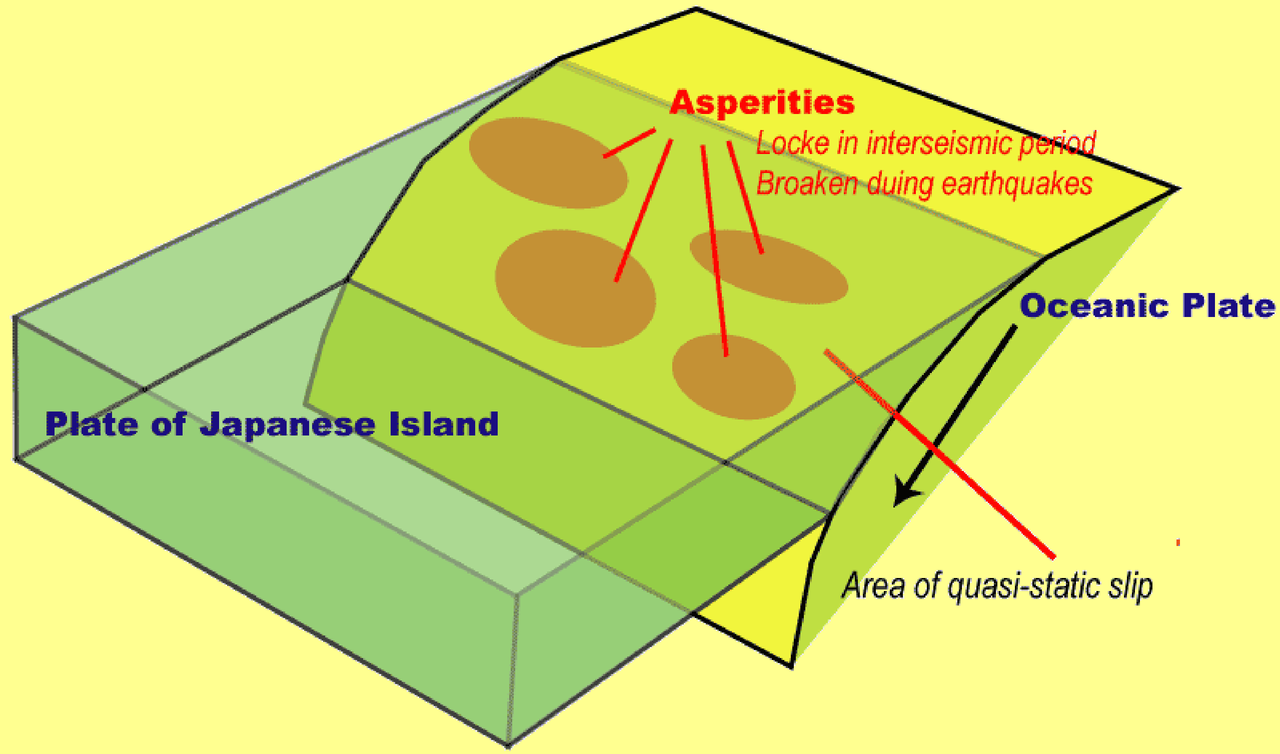






Hergert et al., Nature Geosci, 2010

凹凸体模型

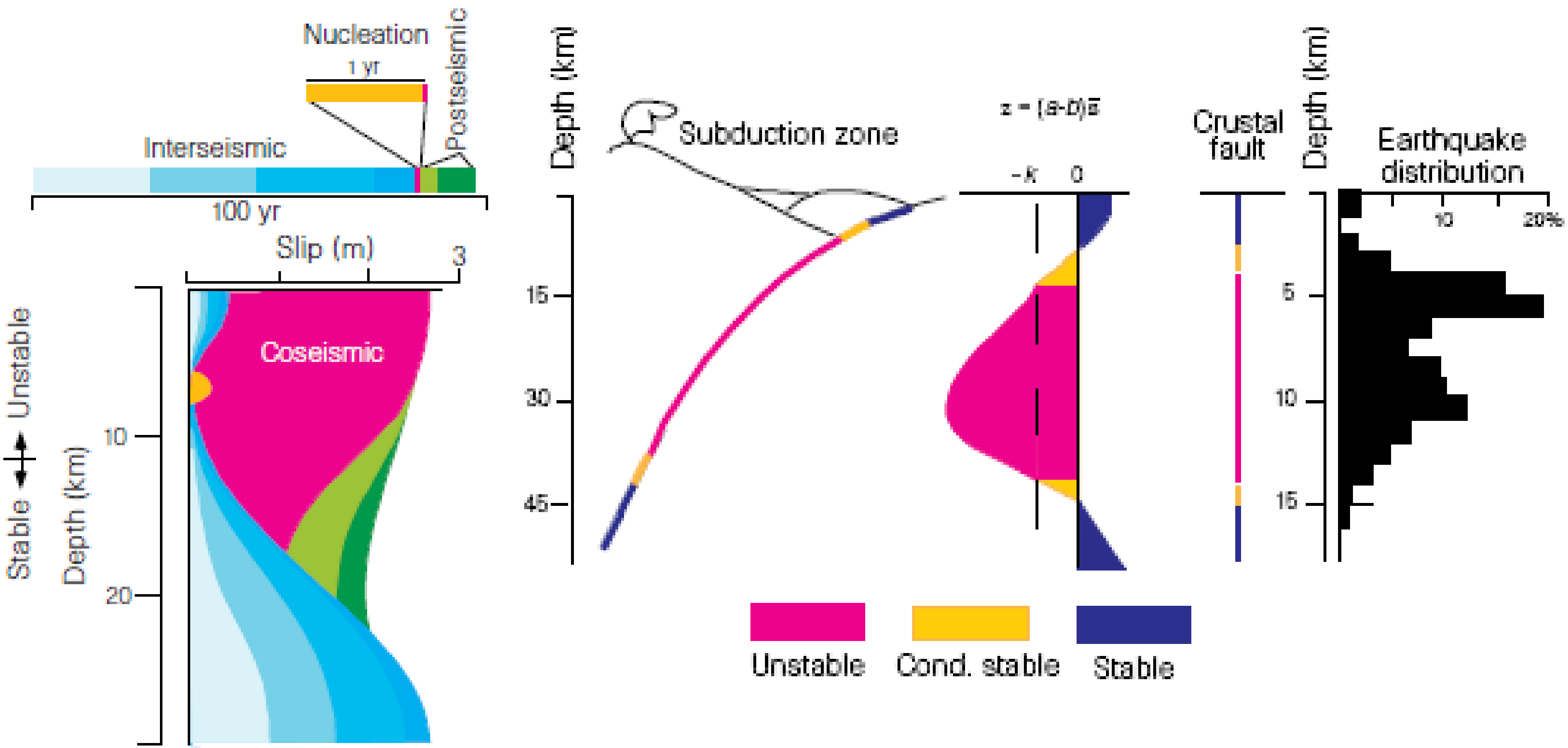


Rate-and-state friction law are applied on the plate boundary

Yamaoka,2005

2 国内外研究进展

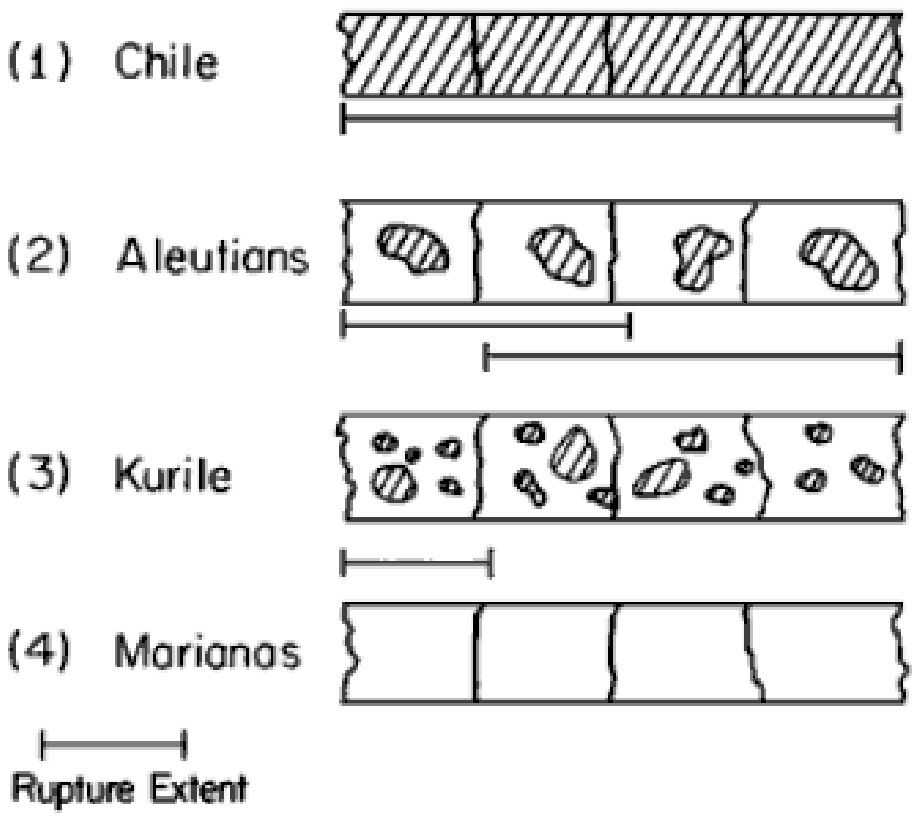
凹凸体与断层摩擦

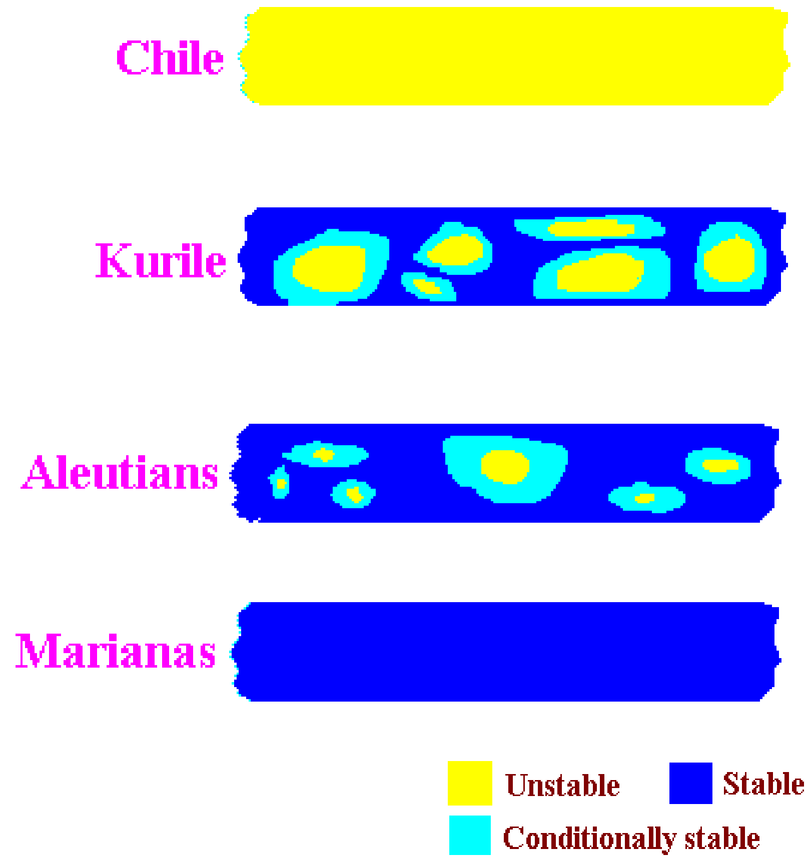


Scholz,1998

2 国内外研究进展

凹凸体与断层摩擦



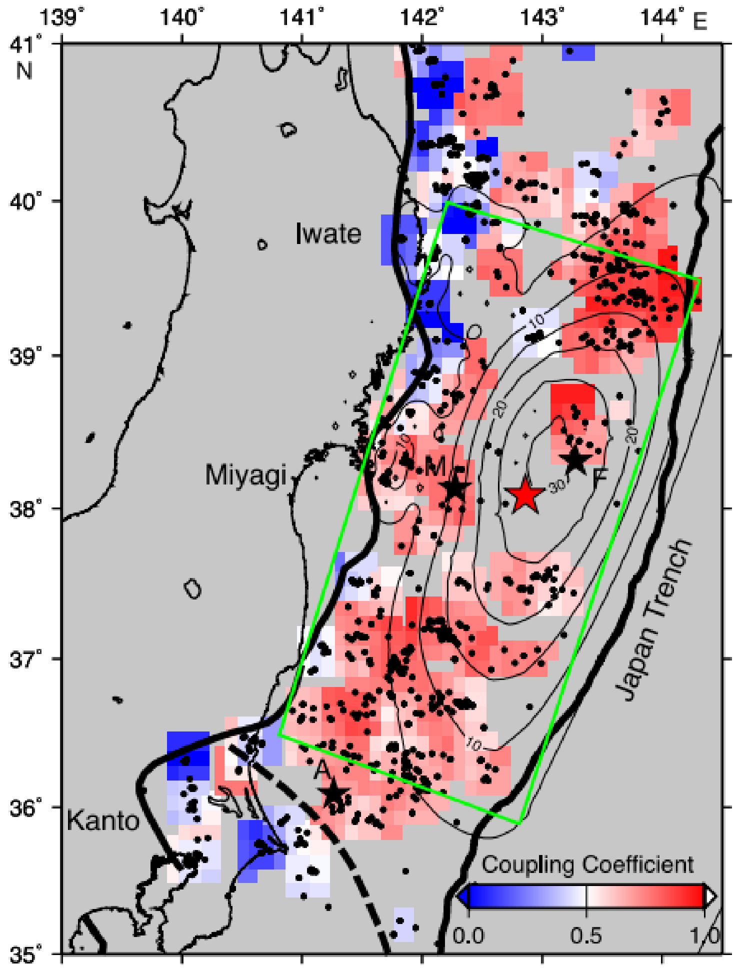


Lay T and Kanamori H,1981

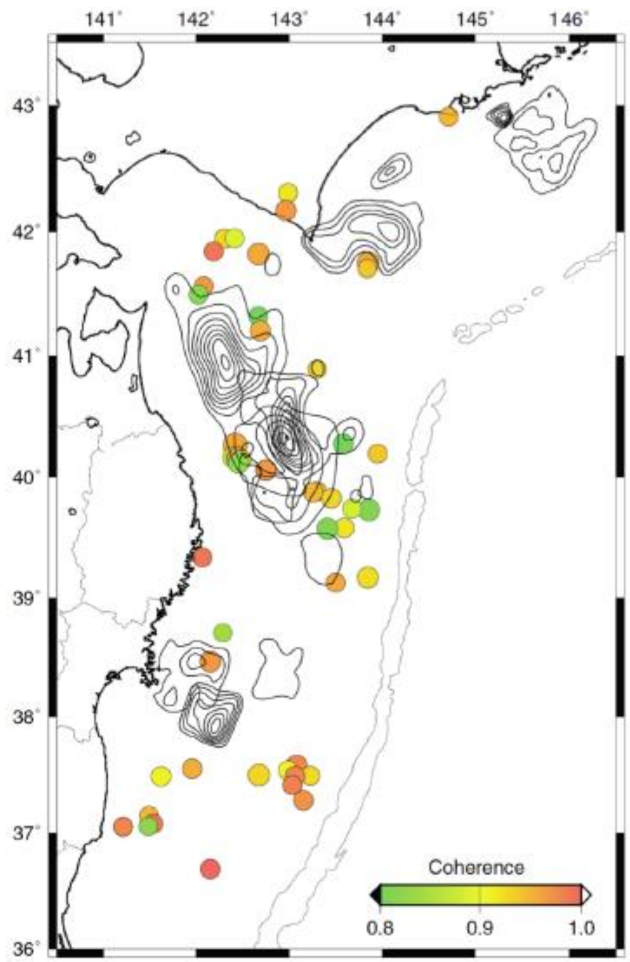
R. McCaffrey,2006

2 国内外研究进展

重复地震与凹凸体



1993-2007年重复地震

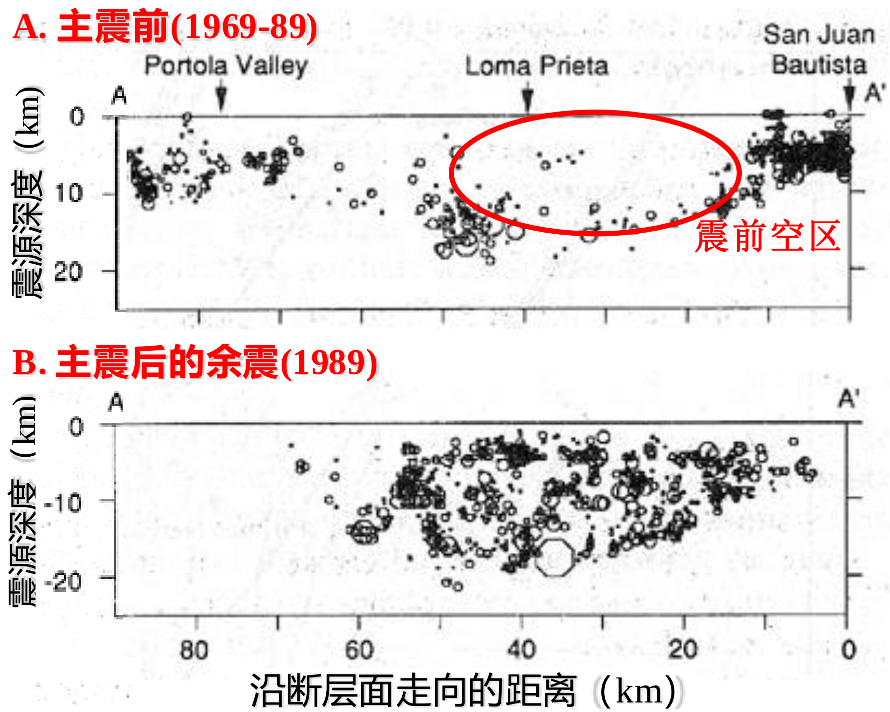


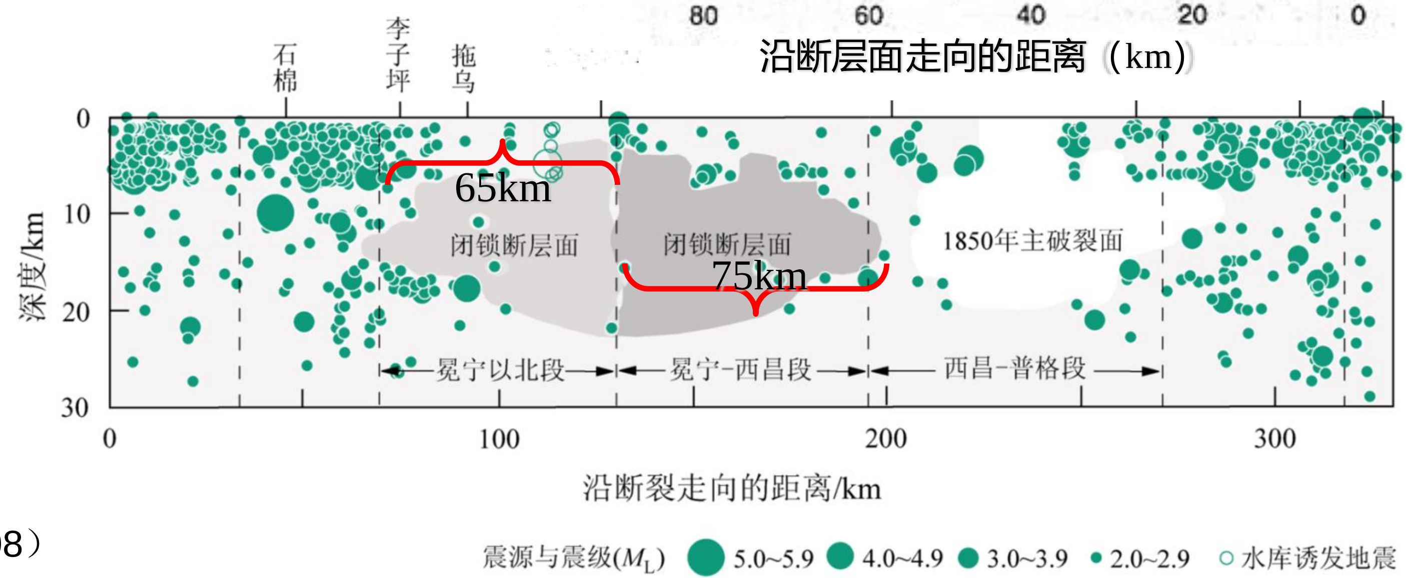
1984 – 2009年 M 4.5 – 6.2

Uchida et al., 2011

地震重新定位结果

1989年加州M7.1地震前后
沿圣安德烈斯断裂带的震源深度剖面

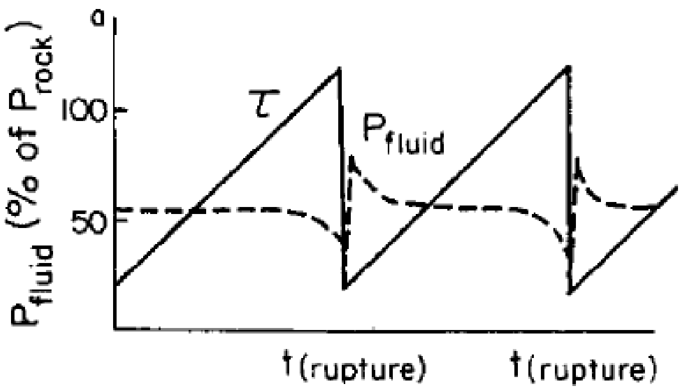


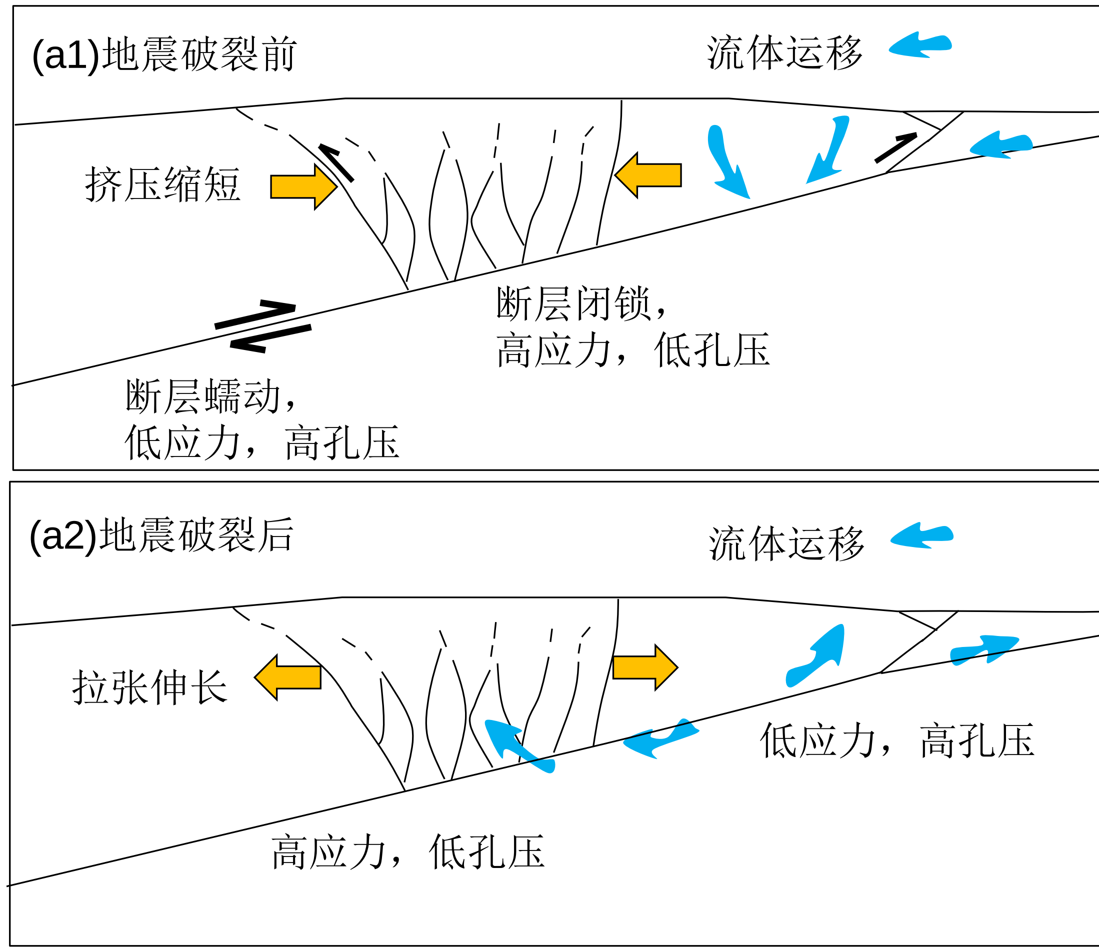


（闻学泽等，2008）

2 国内外研究进展

断层孕震阶段状态的判定

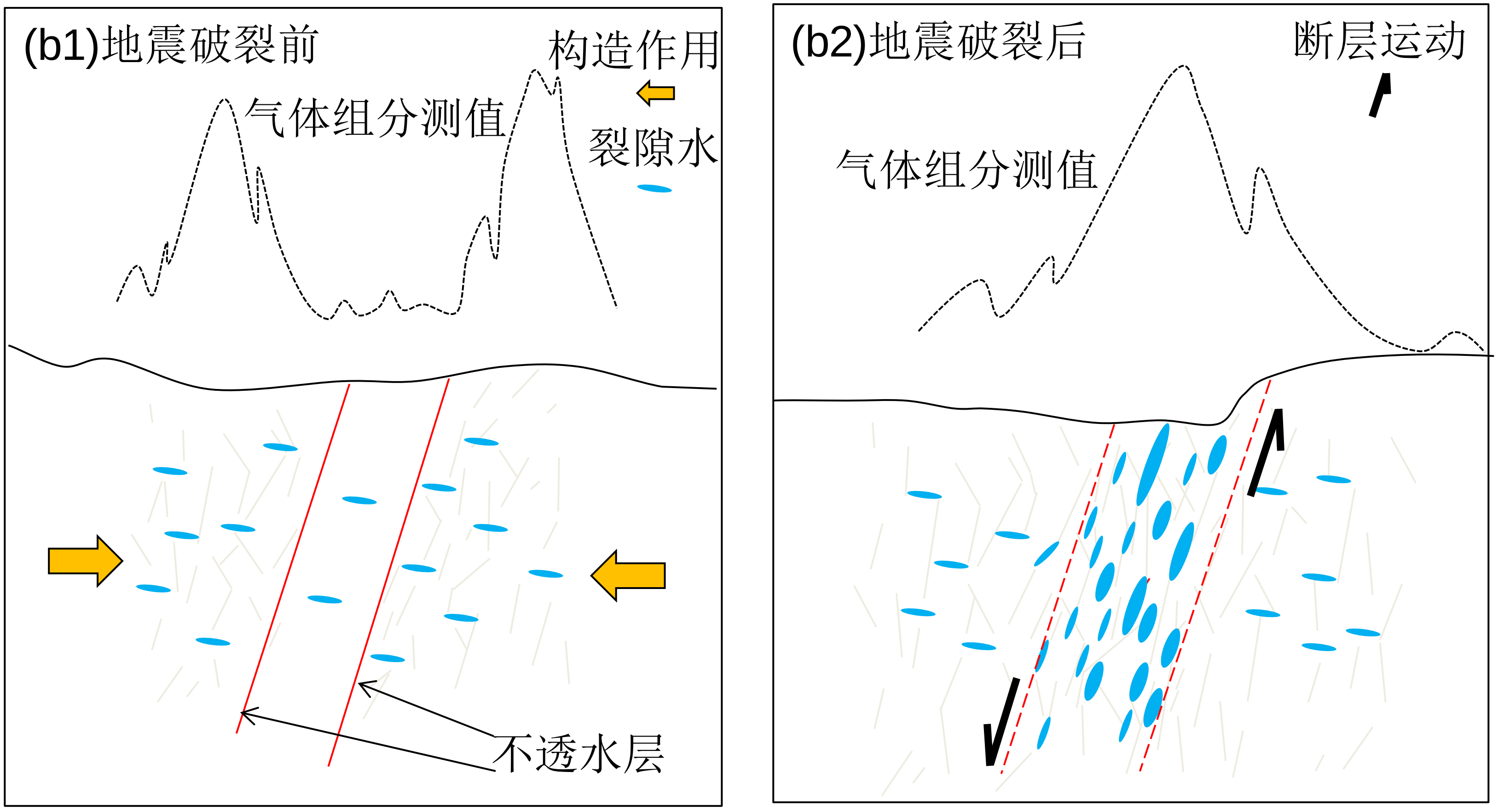




McCaig，1988; Carter et al., 1990

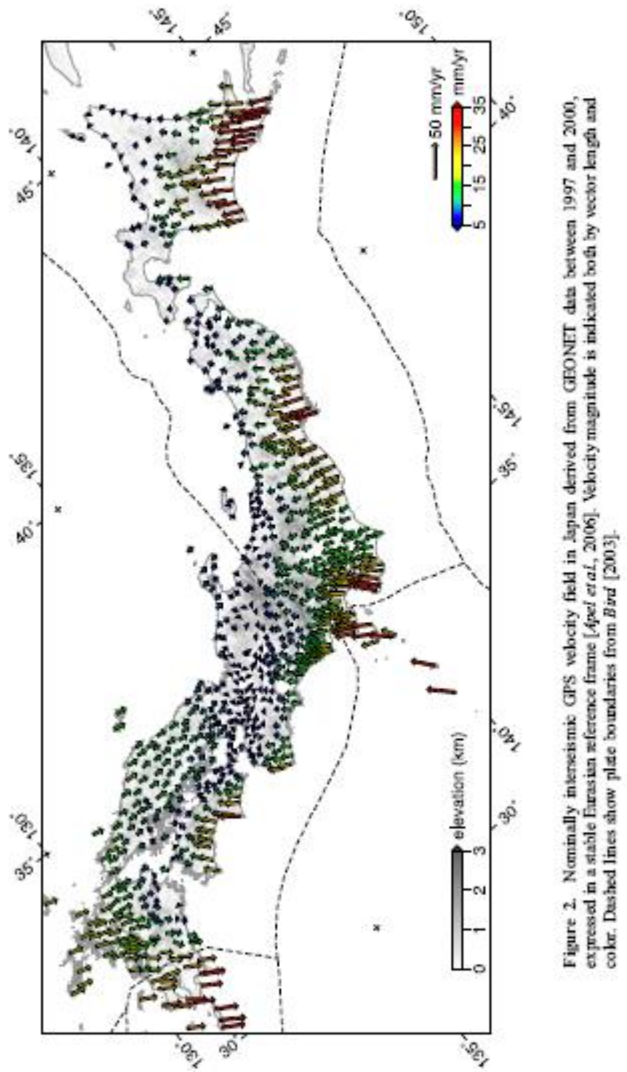
2 国内外研究进展

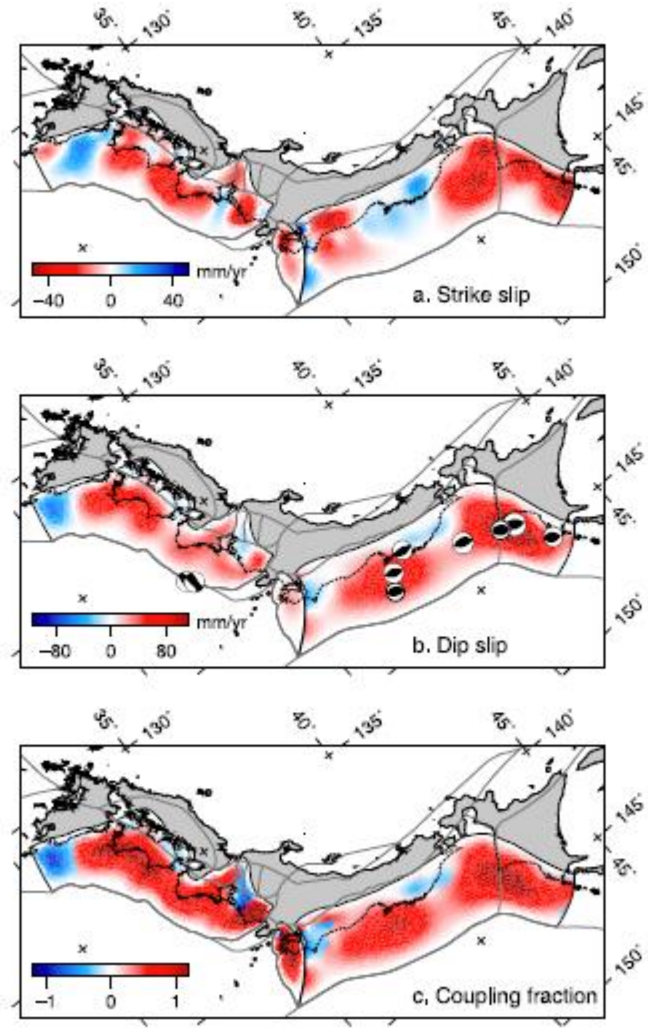
断层孕震阶段状态的判定



Annunziatellis et al., 2008
Tadokoro and Ando（2002）

2 国内外研究进展

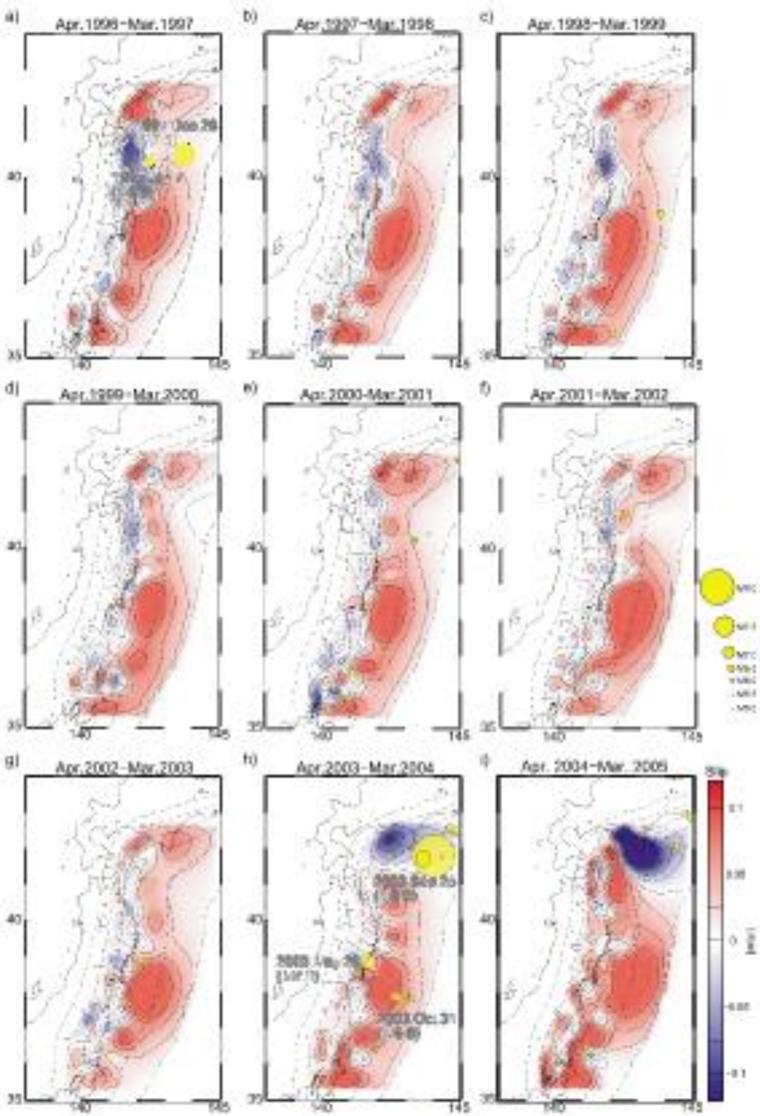


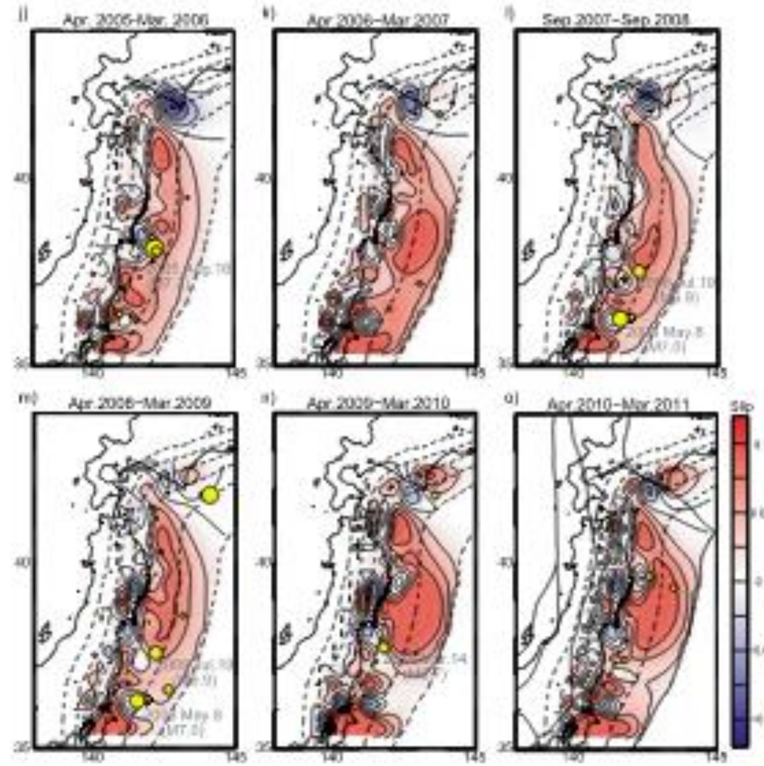


GEONET观测所得日本地壳运动速率（1997-2000，欧亚参考基准）与断层闭锁率

Loveless J P and Meade B J, 2010

2 国内外研究进展

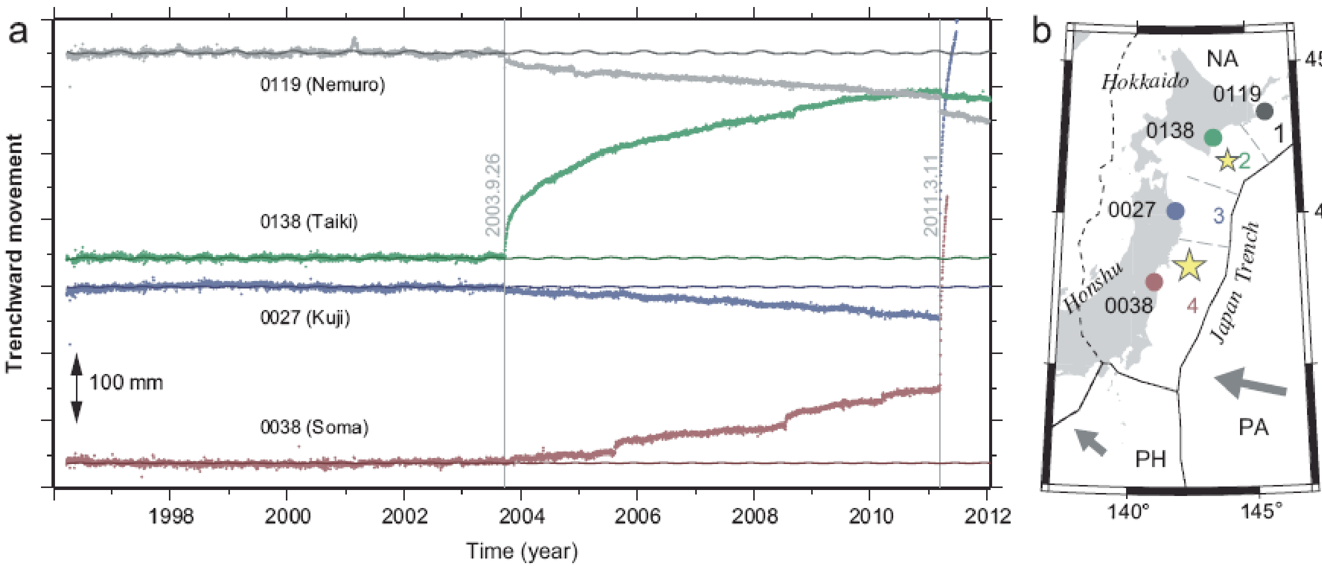


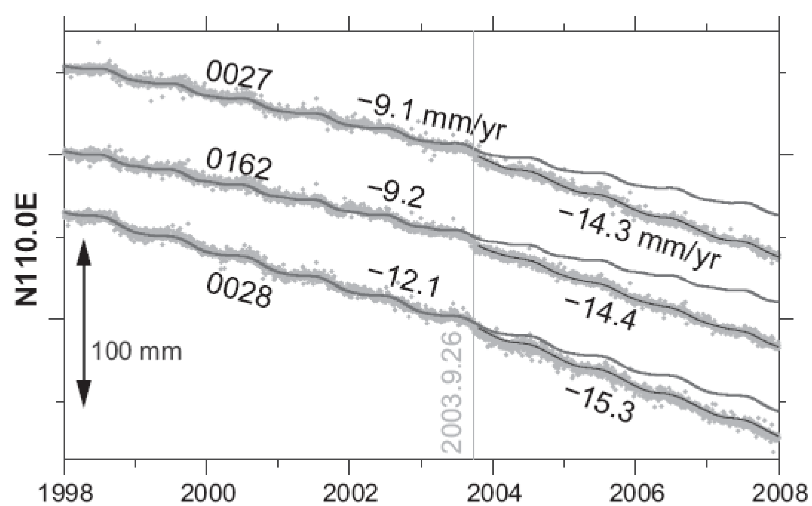


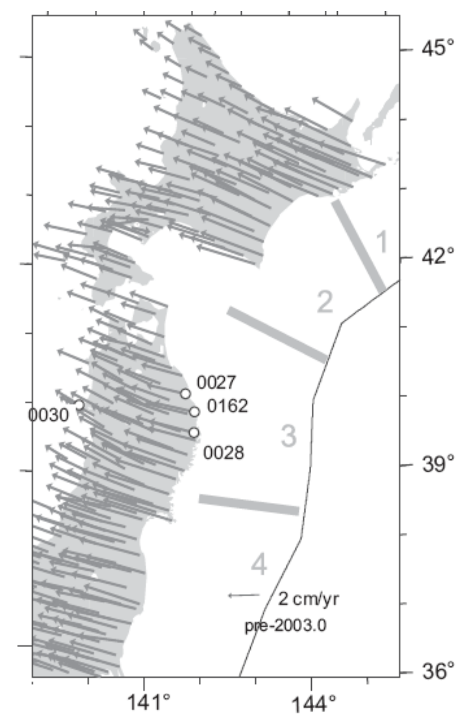
2003年之前是比较稳定的，最大特点是在北纬36-40之间位移亏损较大，其峰值位于北纬38附近（Ikuta et al., 2012）。而2003年之后由于一系列的7级左右地震的同震和震后位移导致日本海沟俯冲断层闭锁程度存在较大时空变化。

2 国内外研究进展

GEONET连续GPS观测典型时间序列

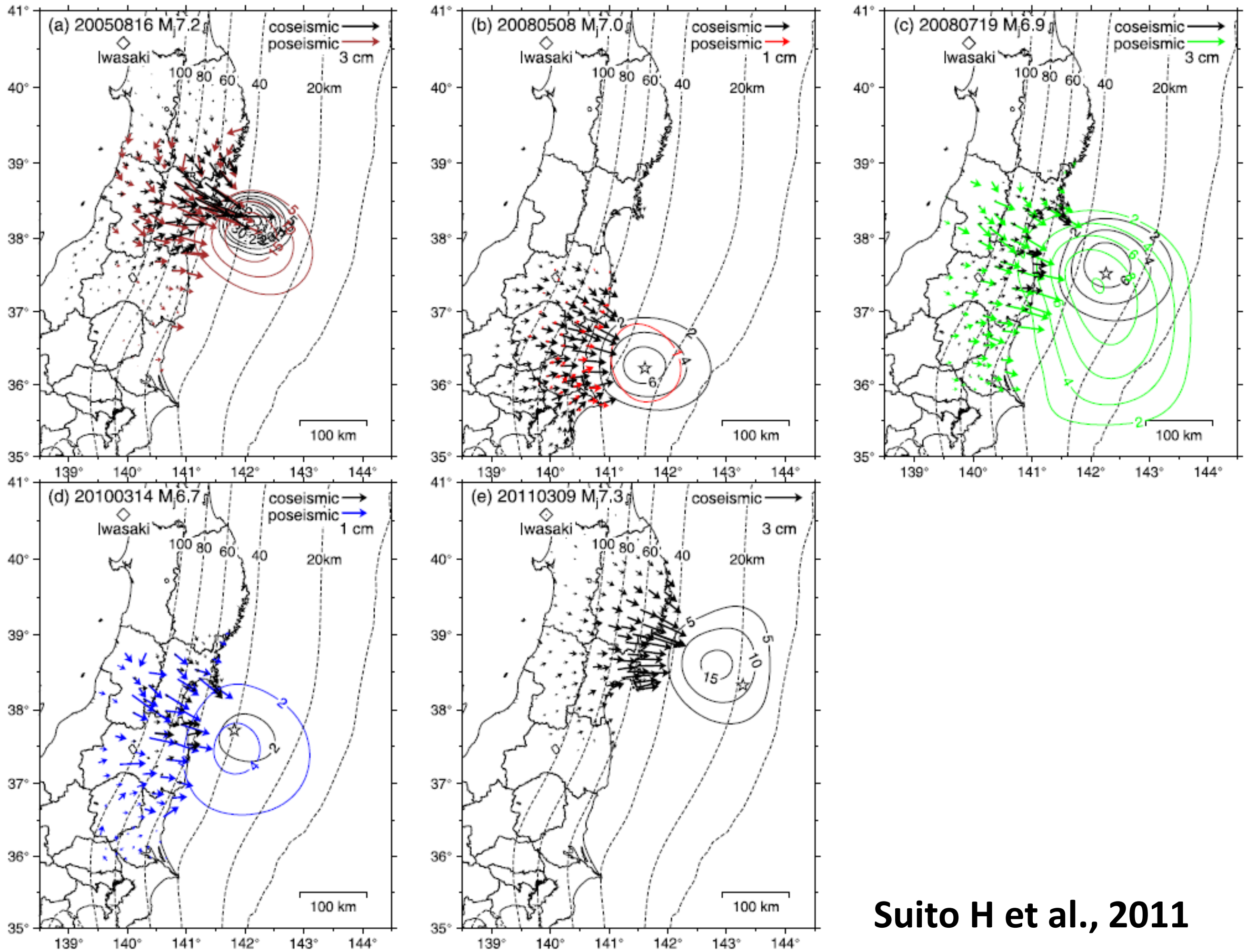


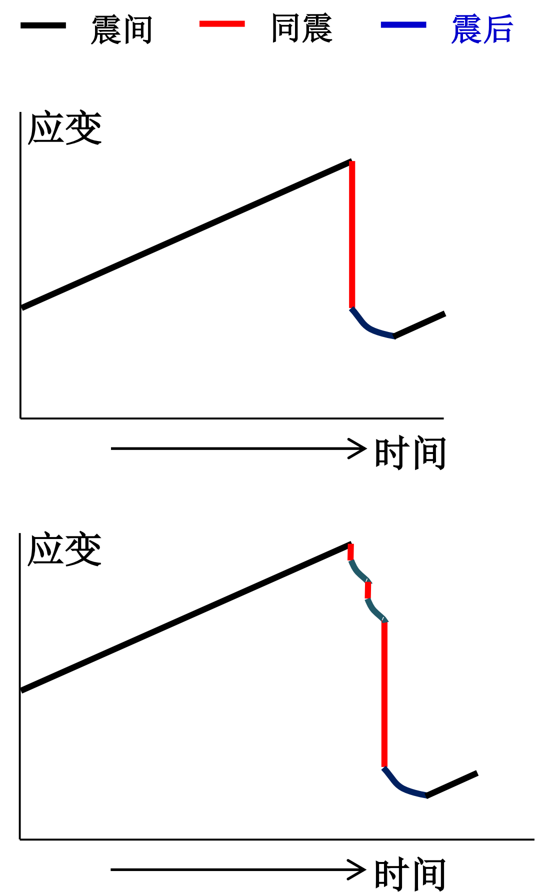




Heki and Mitsui, 2013

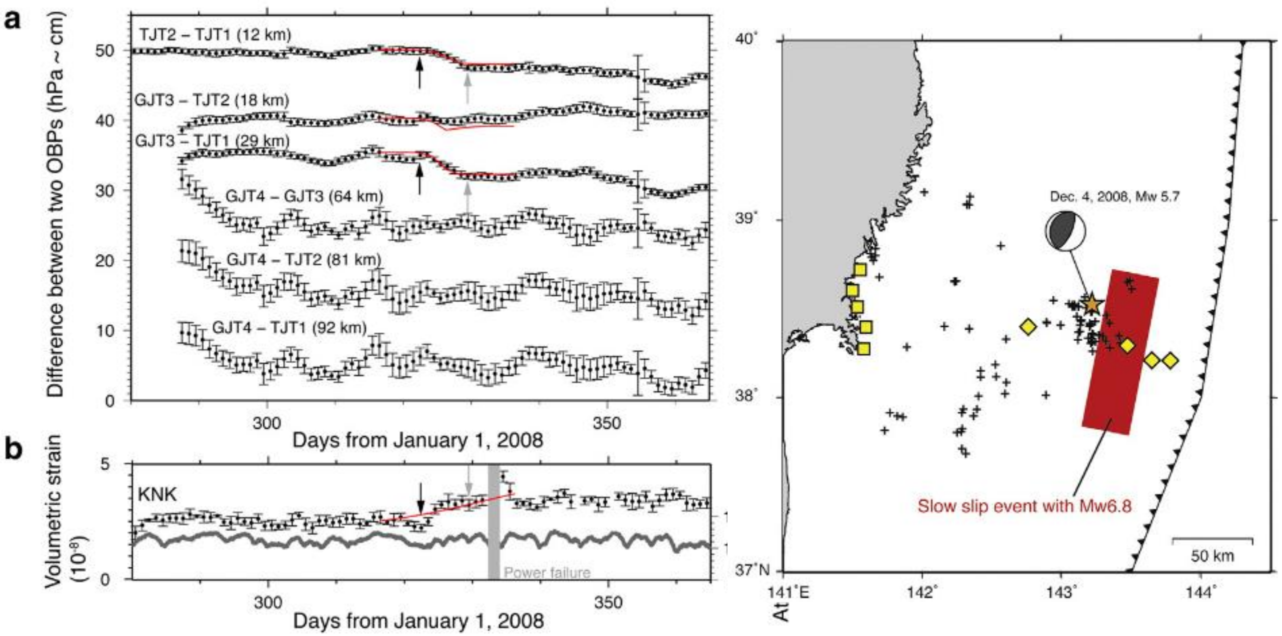
2005-2011年期间日本海沟地区显著地震事件同震和震后断层运动特征

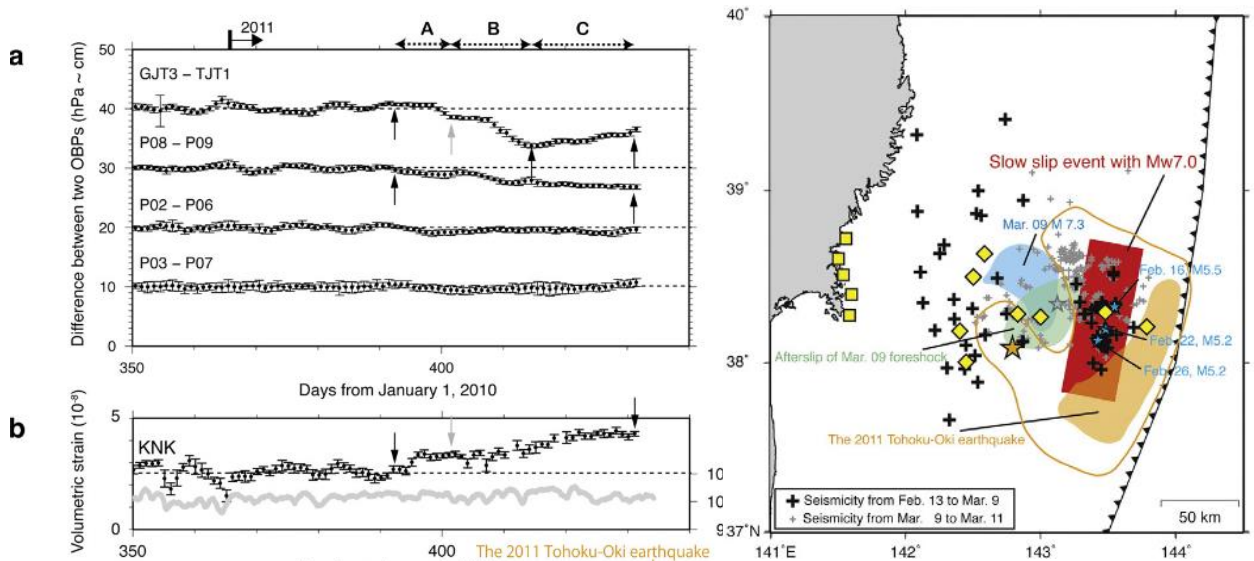




Suito H et al., 2011

2 国内外研究进展

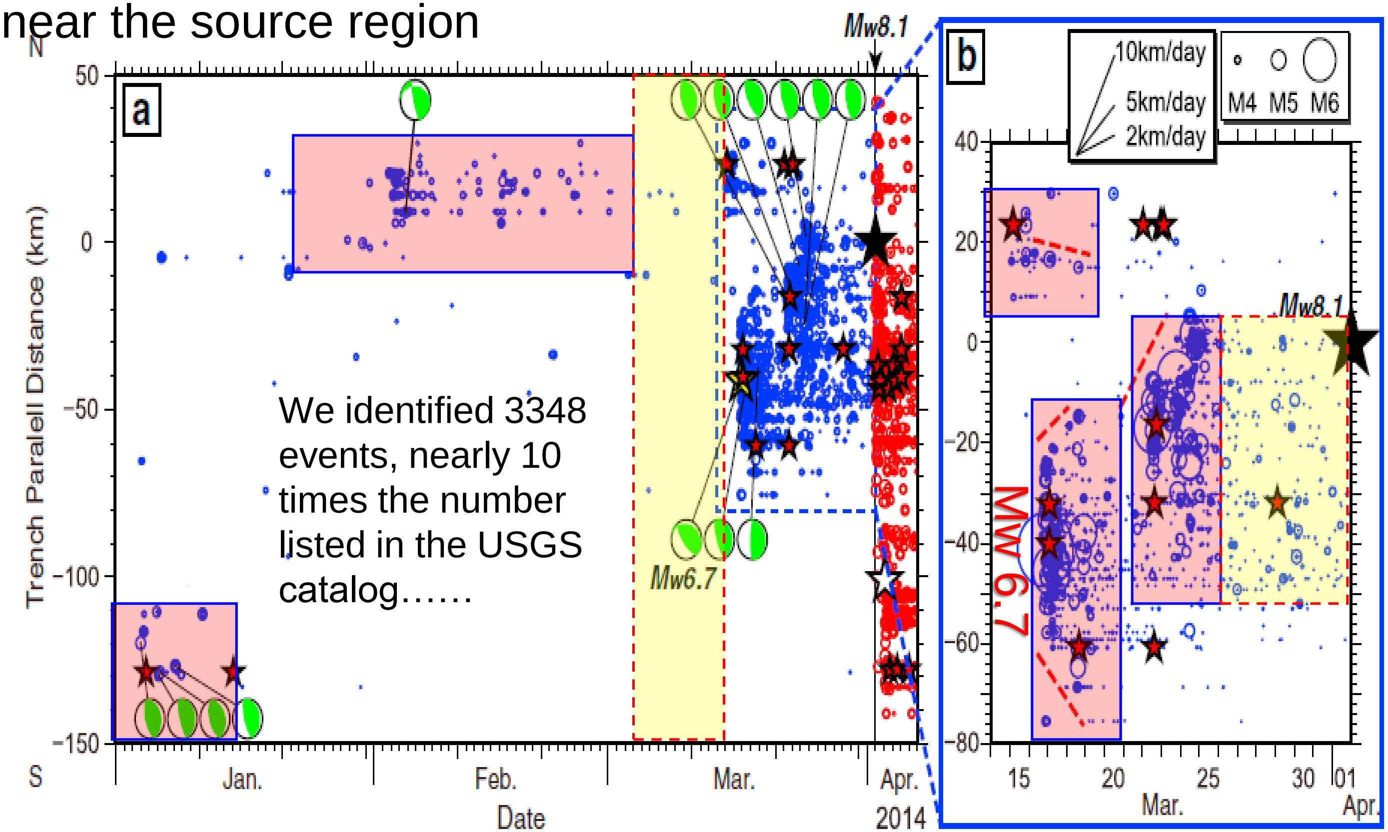




利用海底压力计和海岸体应变观测仪确认2008年持续1周和2011年持续1个月，在震中附近分别发生相当于*M*6.8和*M*7.0慢滑移事件，为同震最大位错集中区，而且2011年慢滑移事件可能触发了一组5级地震活动（Ito et al., 2013）。

➢ Pre-shock Phenomenon

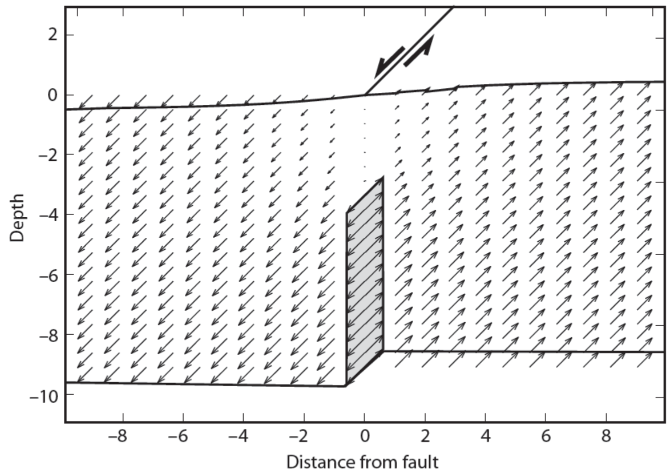
a matched filter technique to continuous seismograms recorded near the source region

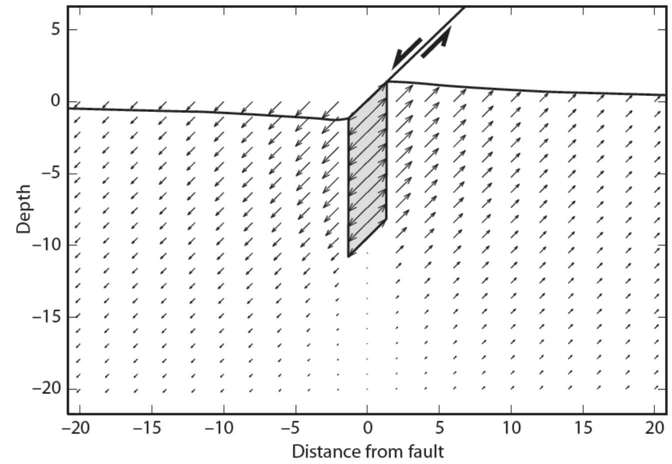


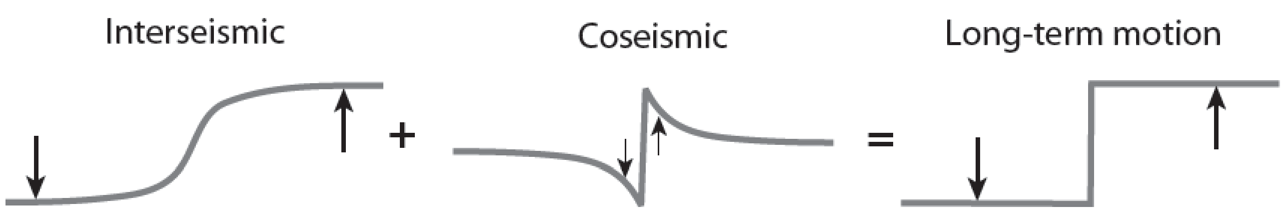
Aitaro Kato and Shigeki Nakagawa，2014

2 国内外研究进展

断层运动在地震预测中的应用展望



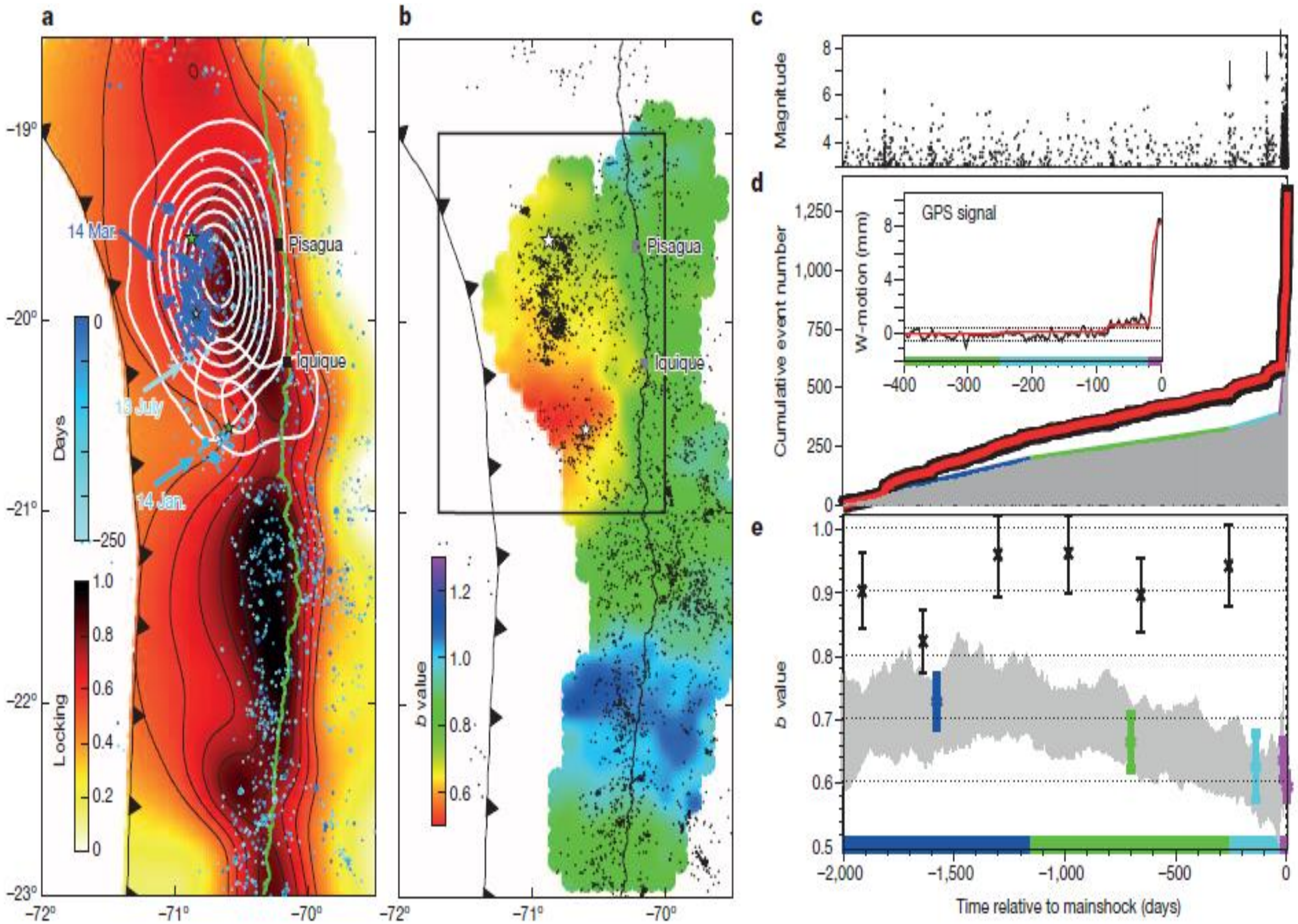




凹凸体确定　　级联破裂分析　　闭锁程度　　依据形变观测分析孕震阶段

地点　　震级　　长期　　中长期

断层闭锁到一定程度，应力状态可能是发震紧迫程度的判定方法

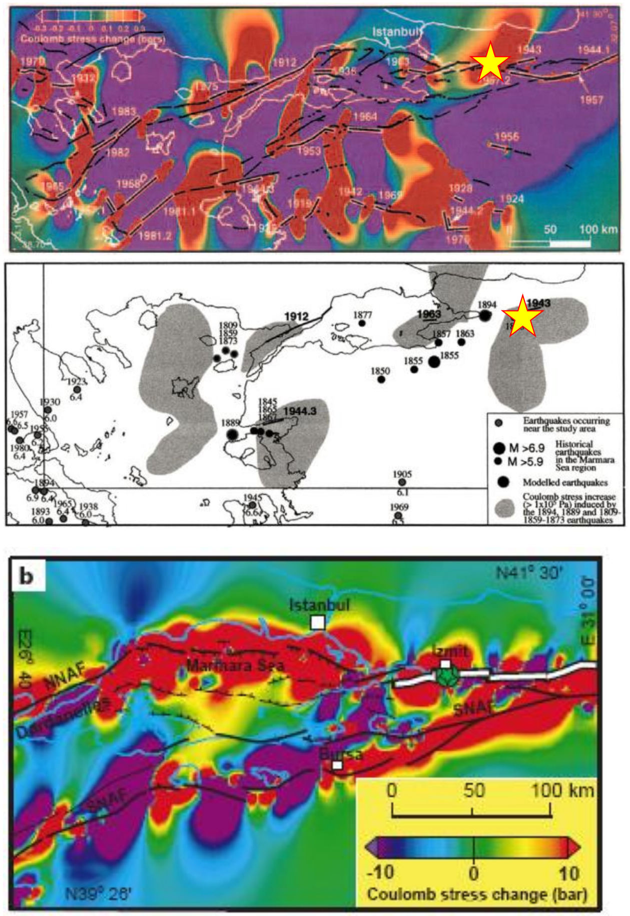


Bernd Schurr, et al. 2014

2 国内外研究进展

震源区震前断层应力累积水平在区域内相对较高

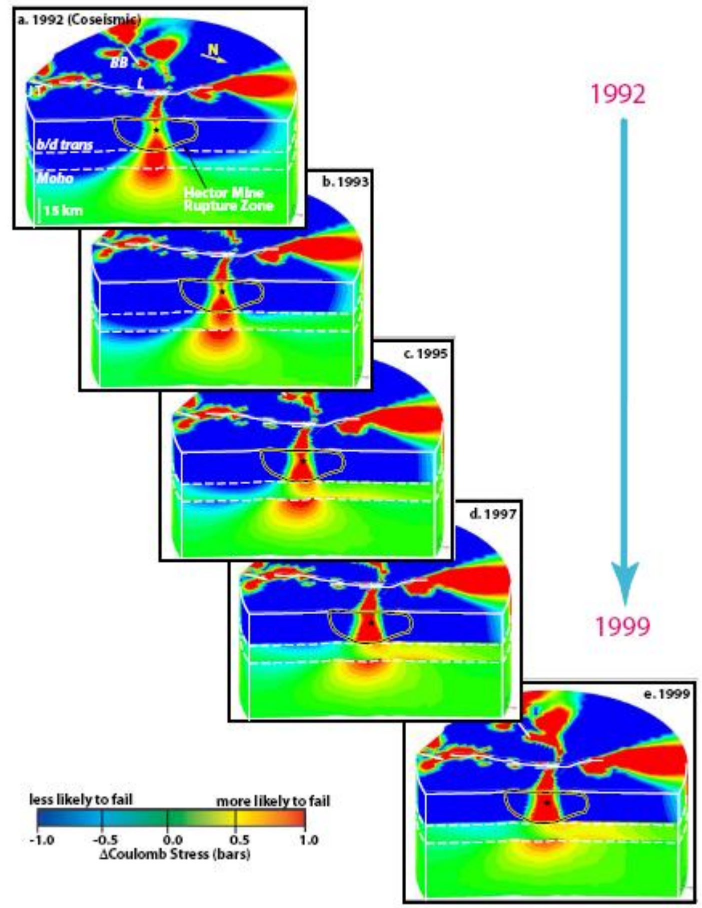
1999年土耳其伊兹米特7.8级地震前



Nalbant et al., JGR, 1998

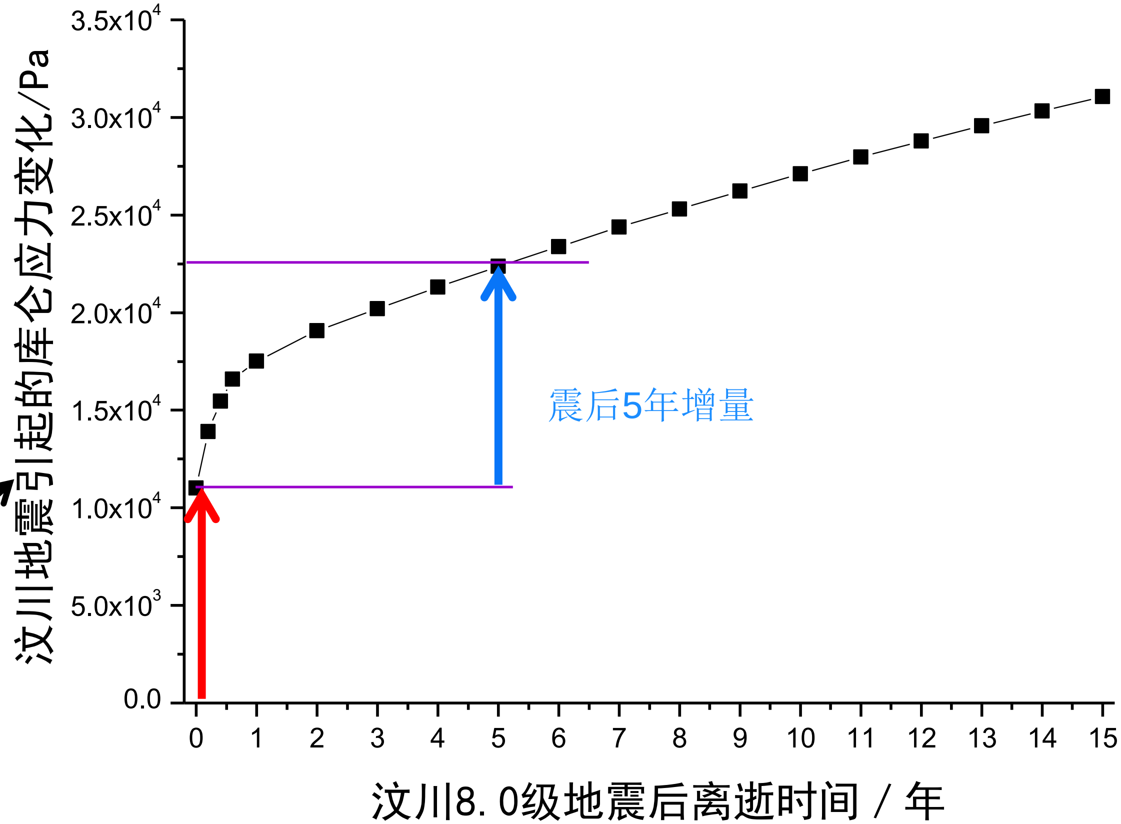
Hubert-Ferrarl et al., Nature , 2000

1999年美国南加州7.4级地震前

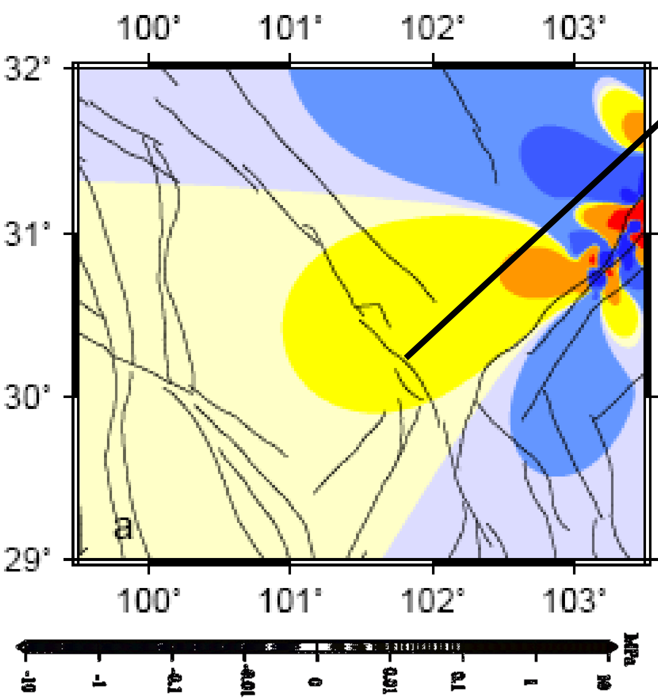


Lin & Freed,. Nature , 2004

2 国内外研究进展

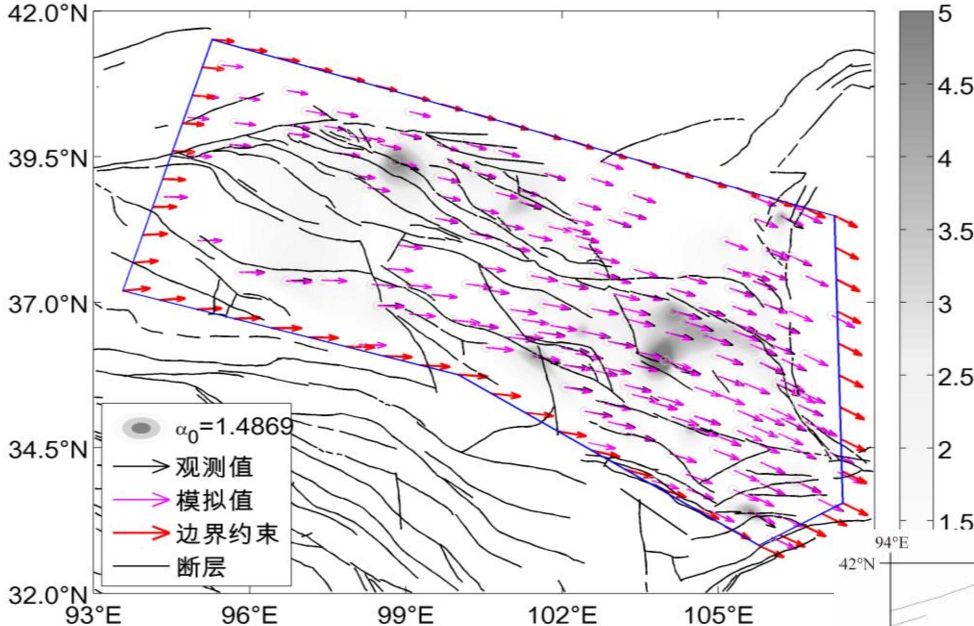


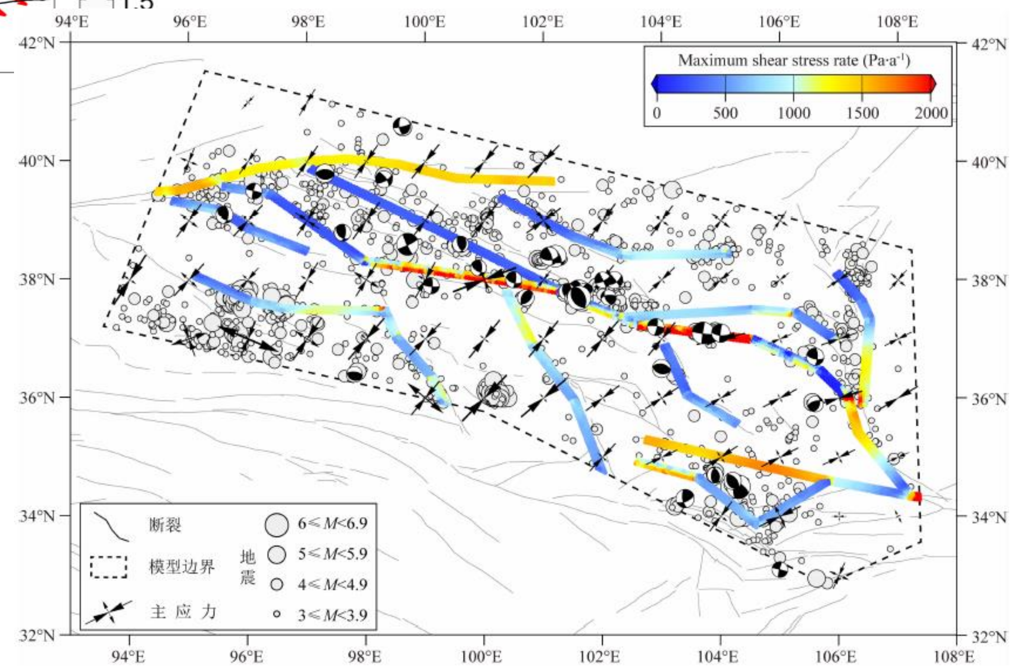
同震＋震后粘滞松弛



汶川地震引起的库仑应力变化

2 国内外研究进展



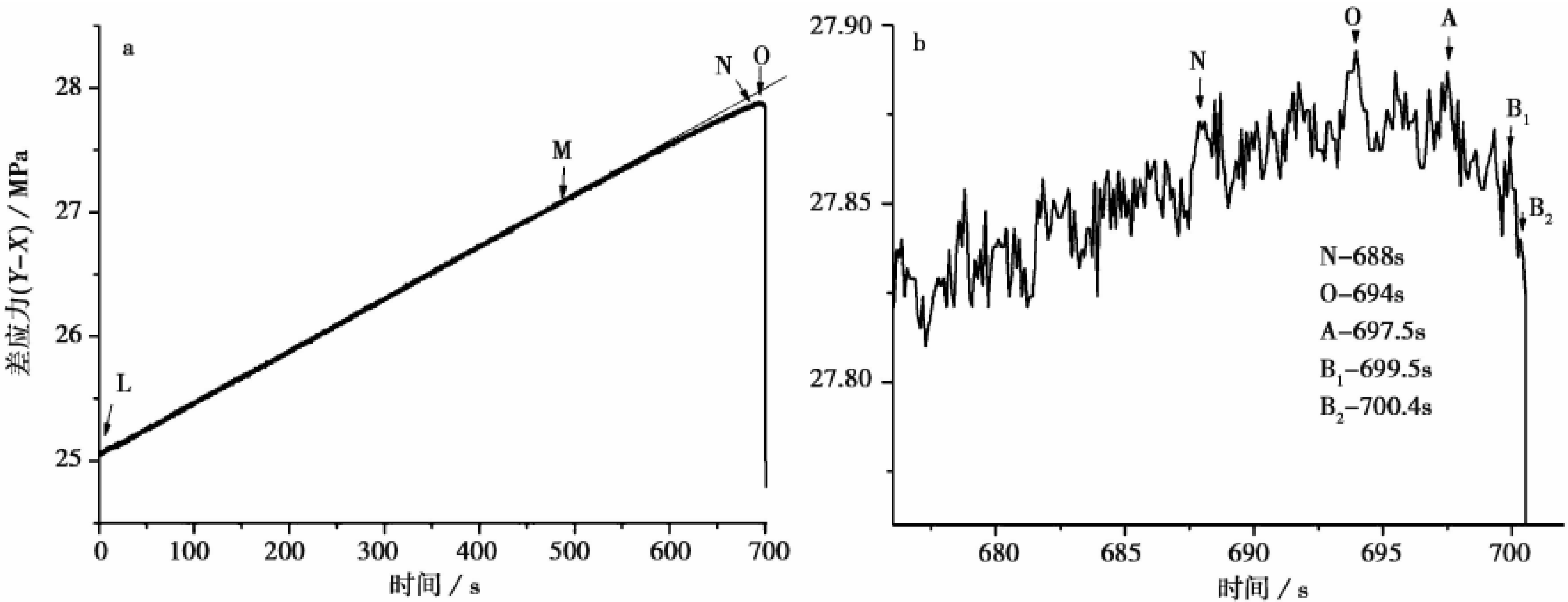


青藏高原东北缘地壳运动速率与剪切应力率

石富强等，2018

2 国内外研究进展

震源区应力状态的判定



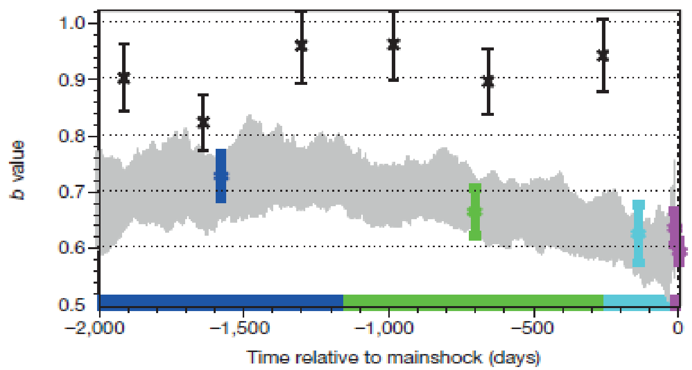
差应力-时间过程（a）与变形后期阶段的放大图（b）

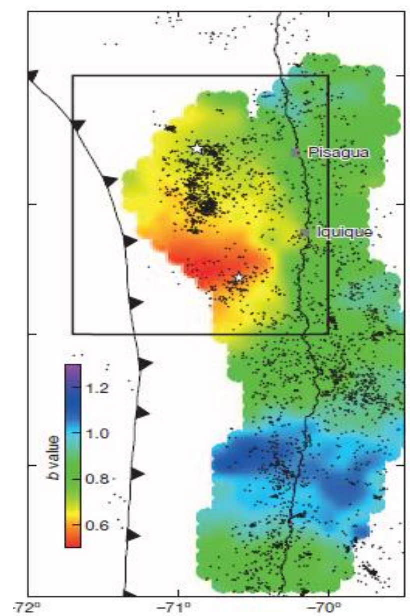
马瑾和郭彦双，2014

2 国内外研究进展

震源区震前区域应力显著增强可能表明发震紧迫程度增强

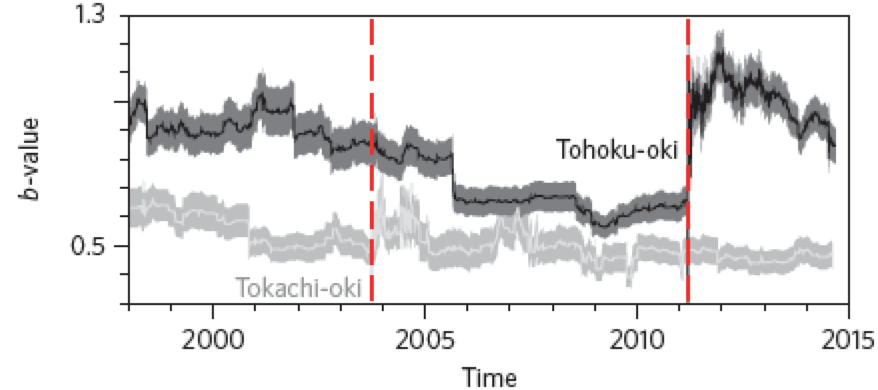
2014年智利8.1级地震前

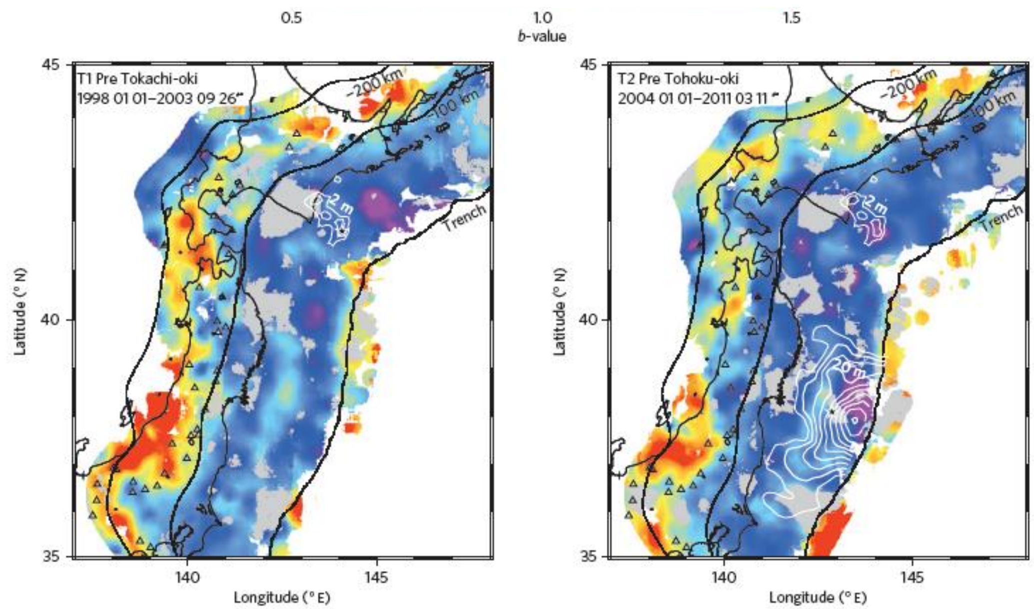




Bernd S, et al. Nature, 2014

2003年日本8级地震前、2011年日本9级地震前

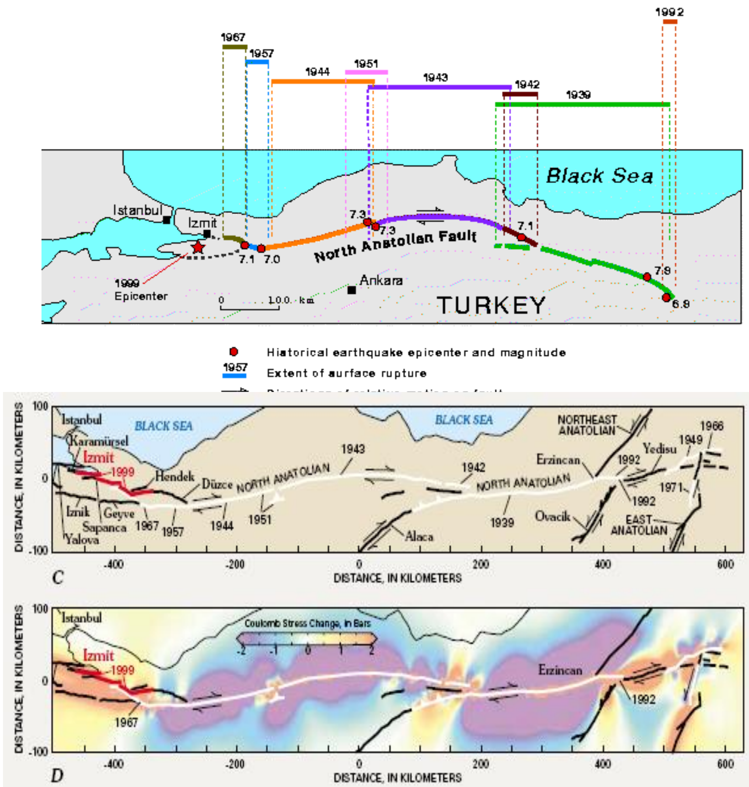


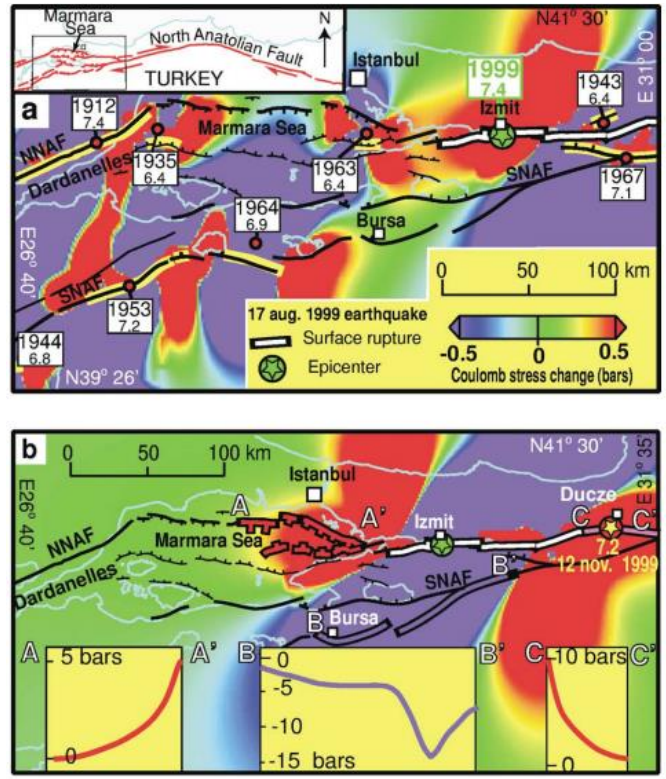


Tormann T, et al., Nature Geosci., 2015

2 国内外研究进展

断层应力在地震预测中的应用展望





King et al., 2001

累积水平	累积速率	应力状态
地点	震级	长期-中期

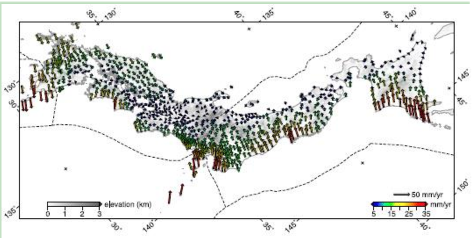
2 Master Model-UCERF

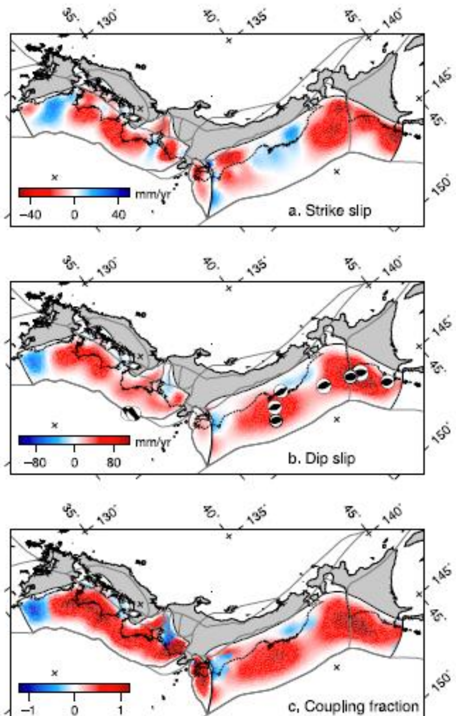
大地测量

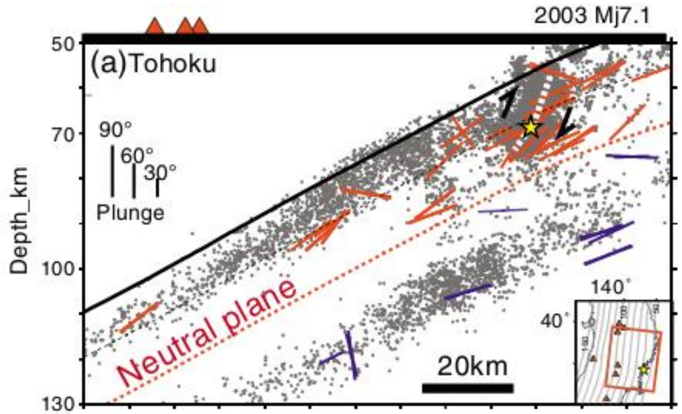
数字地震学

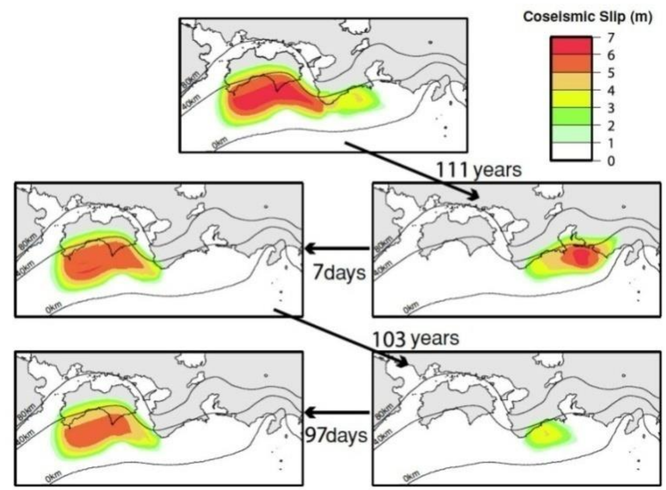
地球动力学

Earth Simulator









GEOPHYSICS

Central Chile Finally Breaks

Raul Madariaga[1], Marianne Métois[1], Christophe Vigny[1], Jaime Campos[2]

Chile is the site of some of the largest earthquakes in the world: On average, a magnitude 8 earthquake occurs there every 10 years or so. These earthquakes take place in the subduction zone, either as interplate ruptures at the interface between the South American and Nazca plates or as intraplate events within the subducted Nazca plate. A few times in every century, massive plate-interface earthquakes break several hundred kilometers in a single shock. This is what happened on 27 February 2010, when a major earthquake (magnitude 8.8) occurred in the Maule and Biobío regions in central Chile (see the first figure). This region had last experienced a major subduction earthquake in 1835, when Darwin (1) visited the area as part of his voyage on the Beagle. His description of the earthquake inspired many seismologists and historians of Chilean earthquakes (2, 3).

In the early 1970s, Kelleher proposed that Chilean earthquakes occurred on "gaps" left from previous large events (4). At the time, the Maule region was not identified as a gap, because a very large e… 7.8) had occurred ther… (5); the deadliest ever… claimed some 20,000 lives (3). In the 1990s, seismologists found that the 1939 earthquake was not a subduction earthquake but the largest intraplate event ever recorded in Chile (6–9).

Once the region between Concepción and …

… to north but is largest in the most ancient gaps.

In the second figure, we show the plate coupling in the area of the Maule earthquake derived from all available GPS data. The red areas

It has been known for 10 years that the site of the Maule mega-earthquake of 27 February 2010 was fully locked and ready to break.

Tsunami damage. Shortly after the Maule mega-earthquake, a tsunami hit nearby coastal areas, such as the village of Penco (near Concepción), shown here.

CREDIT: JONNE RORIZ/AGENCIA ESTADO/AE (AGENCIA ESTADO VIA AP IMAGES)

[1]Laboratoire de Géologie et LIA Montessus de Ballore, CNRS and Ecole Normale Supérieure, 75231 Paris Cedex 05, France. [2]LIA Montessus de Ballore, Departamento de Geofísica, FCFM, Universidad de Chile, Santiago, Chile. E-mail: madariag@geologie.ens.fr

www.sciencemag.org SCIENCE VOL 328 9 APRIL 2010 181

It has been known for 10 years that the site of the Maule mega-earthquake of 27 February 2010 was fully locked and ready to break.

日本地震预报思路

- Long-term prediction
  - Statistical prediction using time history of earhtquake occurrence.
- Mid-term prediction
  - Computer simulation based on physical model using monitoring data.
- Short-term prediction
  - Prediction using precursory phenomena of earthquakes.

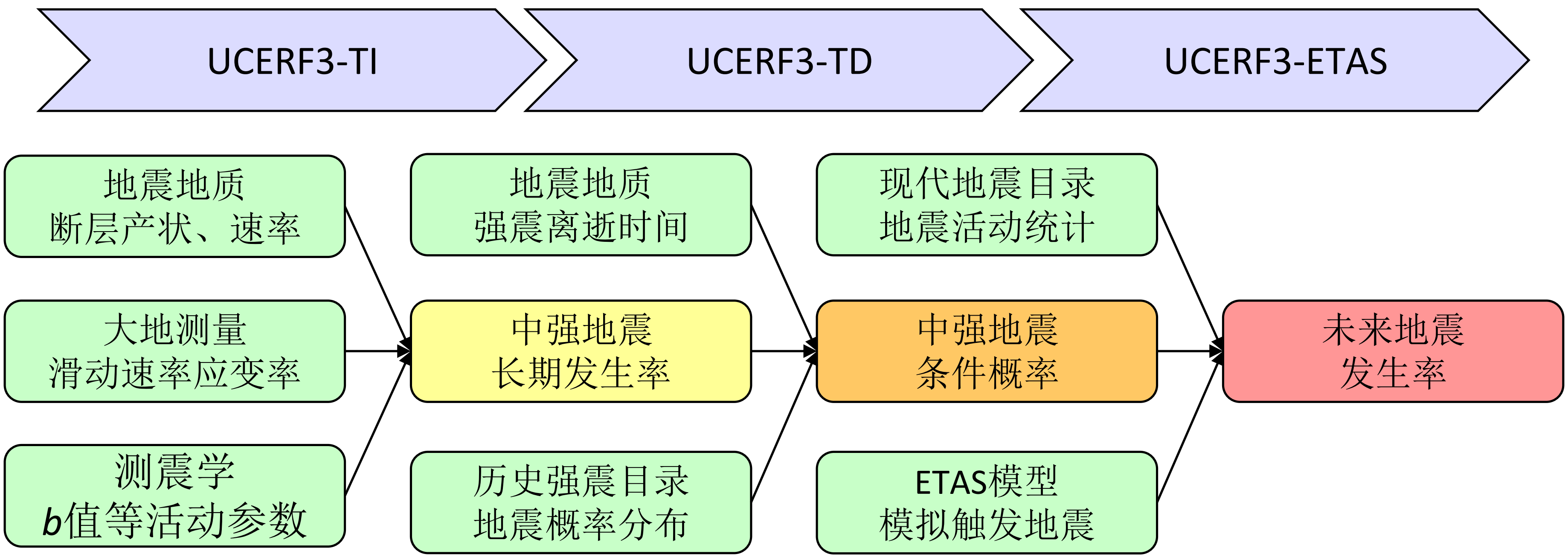
Earthquakes mechanism and prediction， Koshun Yamaoka，2006，报告

2 国内外研究进展

基于长期地震预测结果的中短期预报

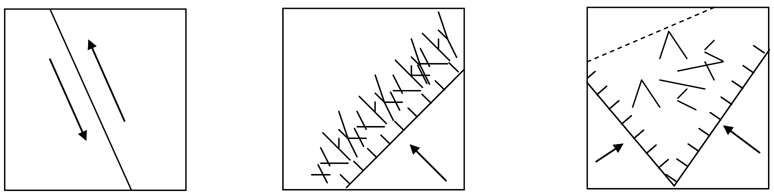
UCERF->UCERF+ETAS、 UCERF+TD
Uniform California Earthquake Rupture Forecast

Field et al., 2014, BSSA　　Field et al., 2015, BSSA　　Field et al., 2017, BSSA



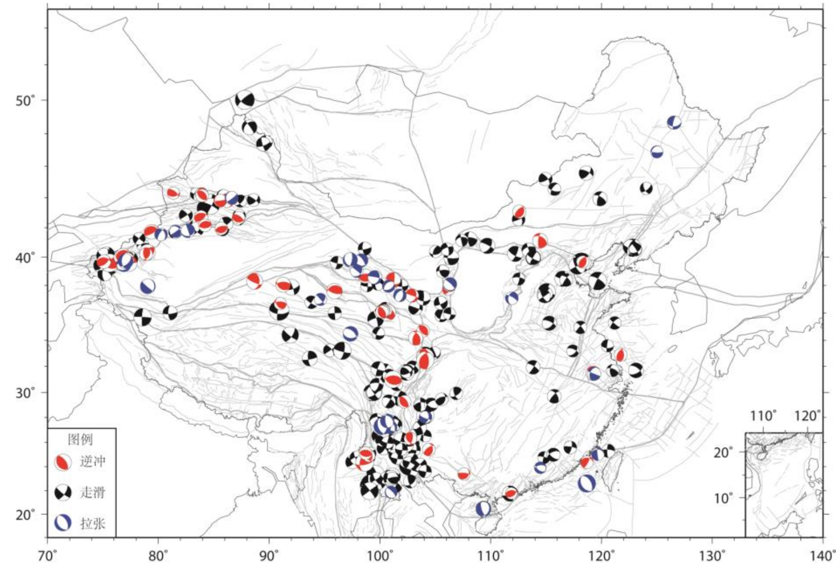
2 国内外研究进展

震源异常主要跟踪资料



	中加州	日本	中国(某些地区)
应力	剪	压	压
结构(断层)	直	复杂 小	复杂 大
前兆	没有或小	较显著 范围小	较显著 范围大

美国加州、日本、中国简化构造与前兆现象的本质
(Mogi,1984)



《中国震例》中1966-2012年的地震

地球物理场资料

区域地壳变形异常
区域重力观测异常
区域地磁观测异常
断层运动异常

地震活动异常

定点前兆异常

地震第二类空区
地震条带

区域异常时空演化

2 国内外研究进展

震源物理模型

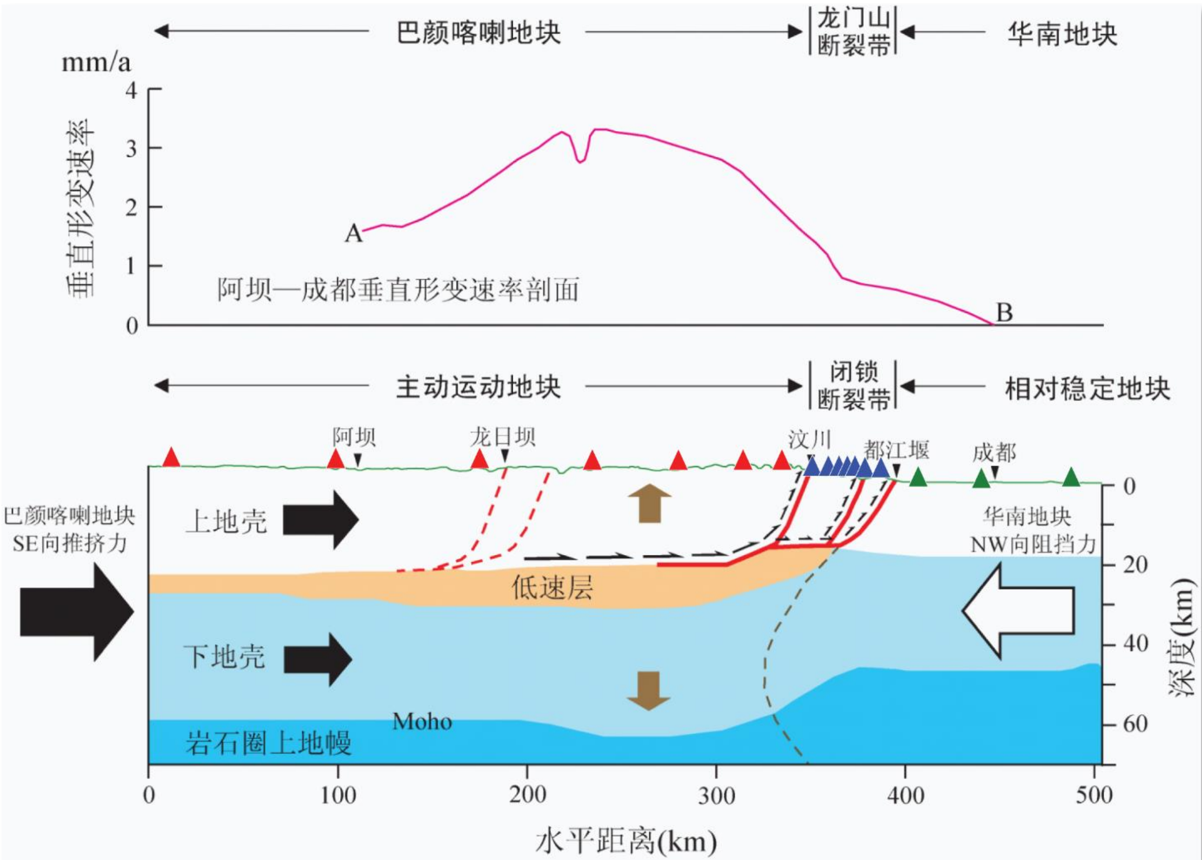
不同孕震阶段

不同构造部位

不同类型、不同现象的观测异常

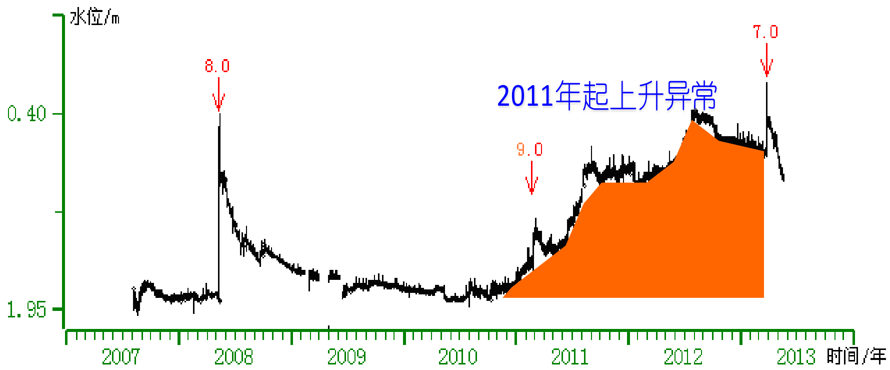
基于强震物理过程构建

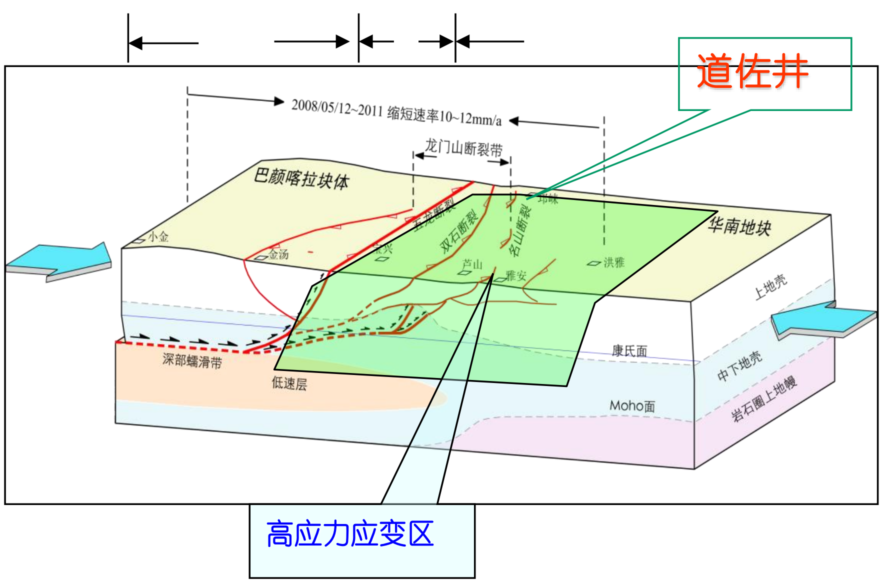
年度强震发震紧迫程度

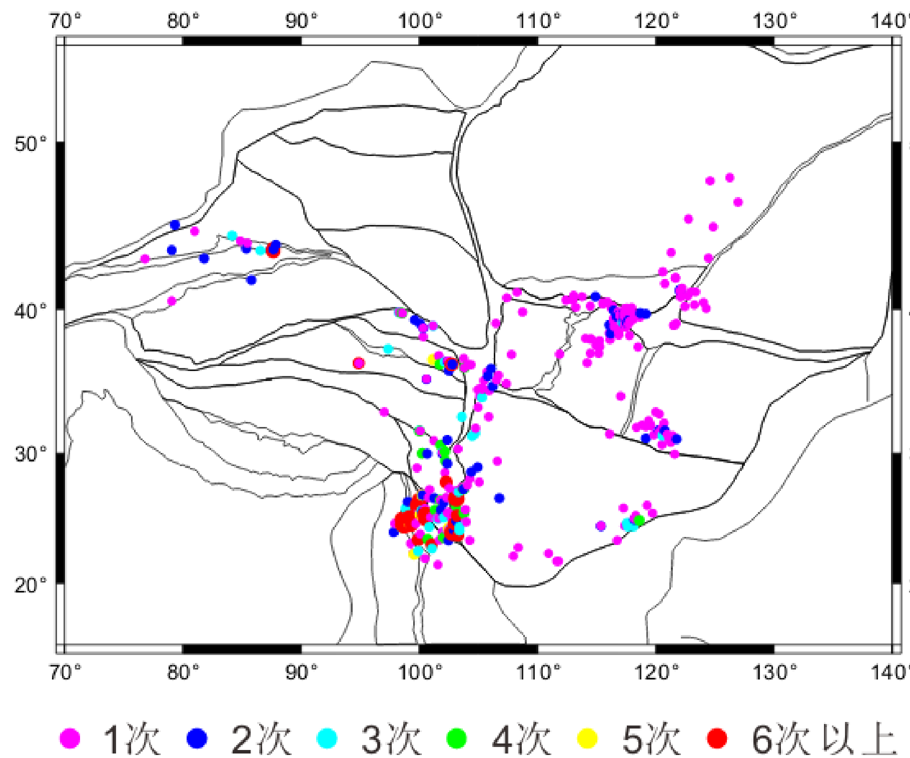


据张培震等（2009）
杜方等（2009）改绘

2 国内外研究进展







地下流体观测台站映震能力

2 国内外研究进展

中国震例

↓

震例回溯性研究

异常识别技术　异常特征研究

异常与未来强震关系研究

↓

预测方法有效性

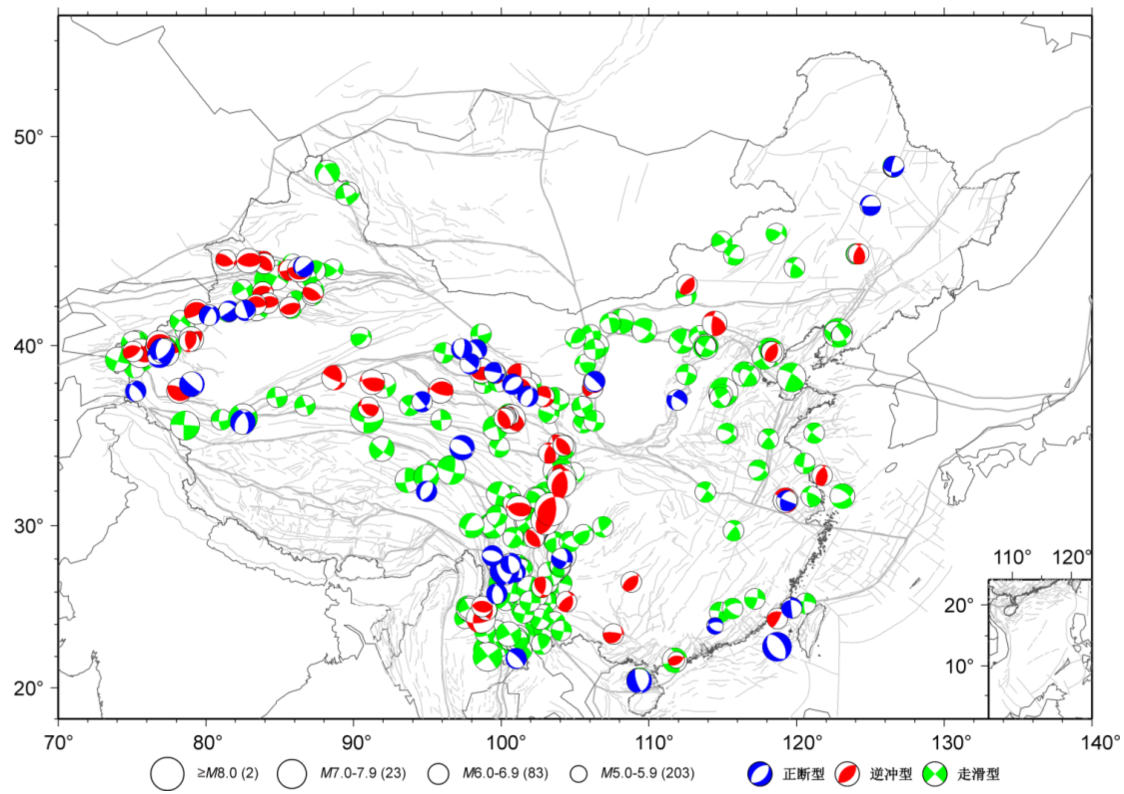
地点、时间、震级预测指标

指标体系与软件

↓

区域短临预测模式

中国大陆1966年以来积累了300多震例资料



$M_S \geqslant 8.0$ (2)

$M_S 7.0-7.9$ (23)

$M_S 6.0-6.9$ (83)

$M_S 5.0-5.9$ (203)

3、关键科学问题和技术路线

3 关键科学问题与技术路线

- 关键科学问题1：基于密集观测构建大陆型强震震源物理模型

基于大地测量、地震学、地球化学等密集观测资料，构建介质模型、断层几何模型、断层运动模型、断层应力模型、断层破裂模型等基础模型在内的大陆型强震震源物理模型。

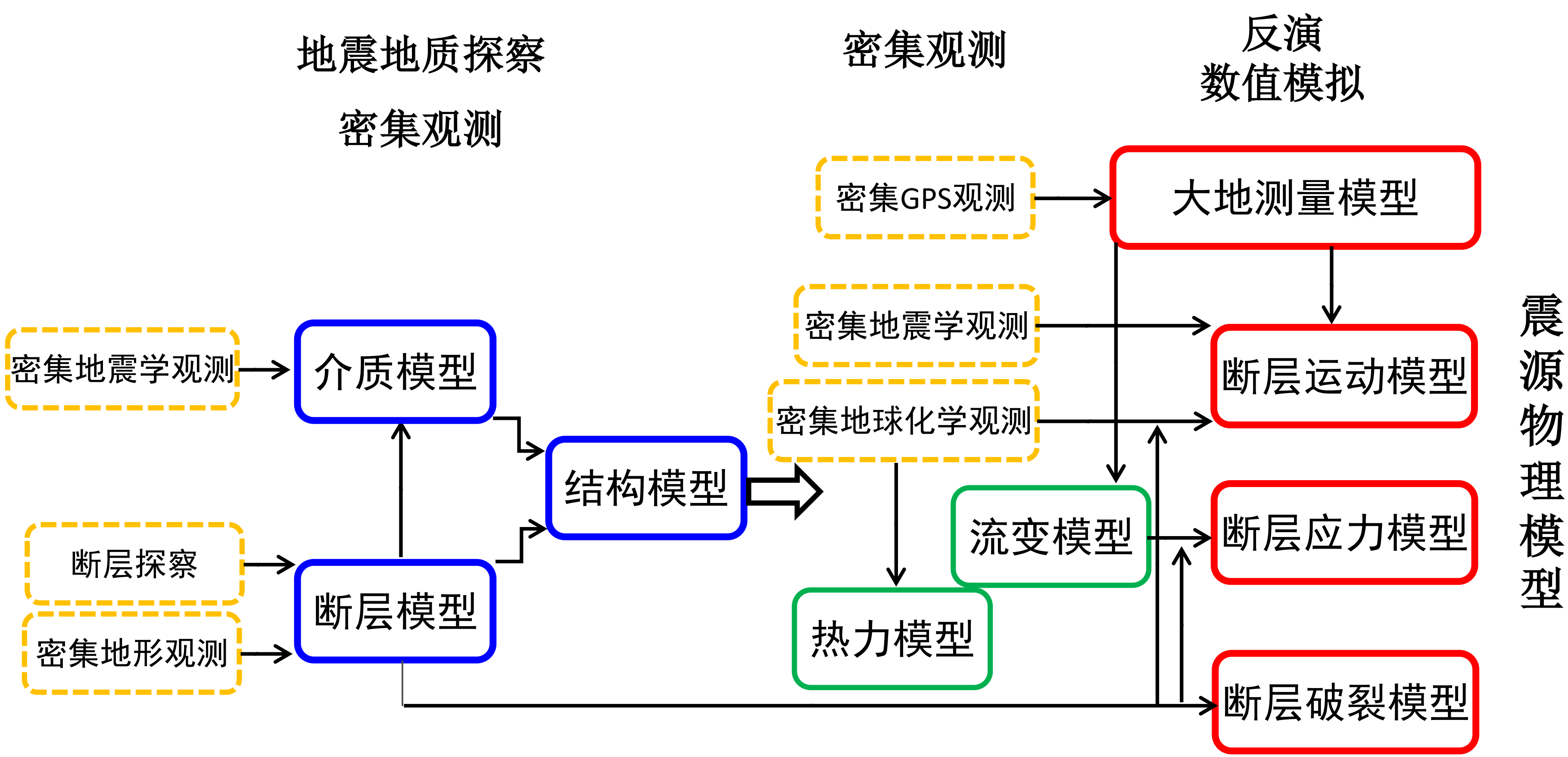
- 关键科学问题2：大陆型强震孕育动力学过程

针对中国大陆典型走滑、拉张、逆冲构造带，基于上述震源物理模型，利用“空间换时间”工作思路，构建中国大陆不同类型强震的孕育动力学过程。

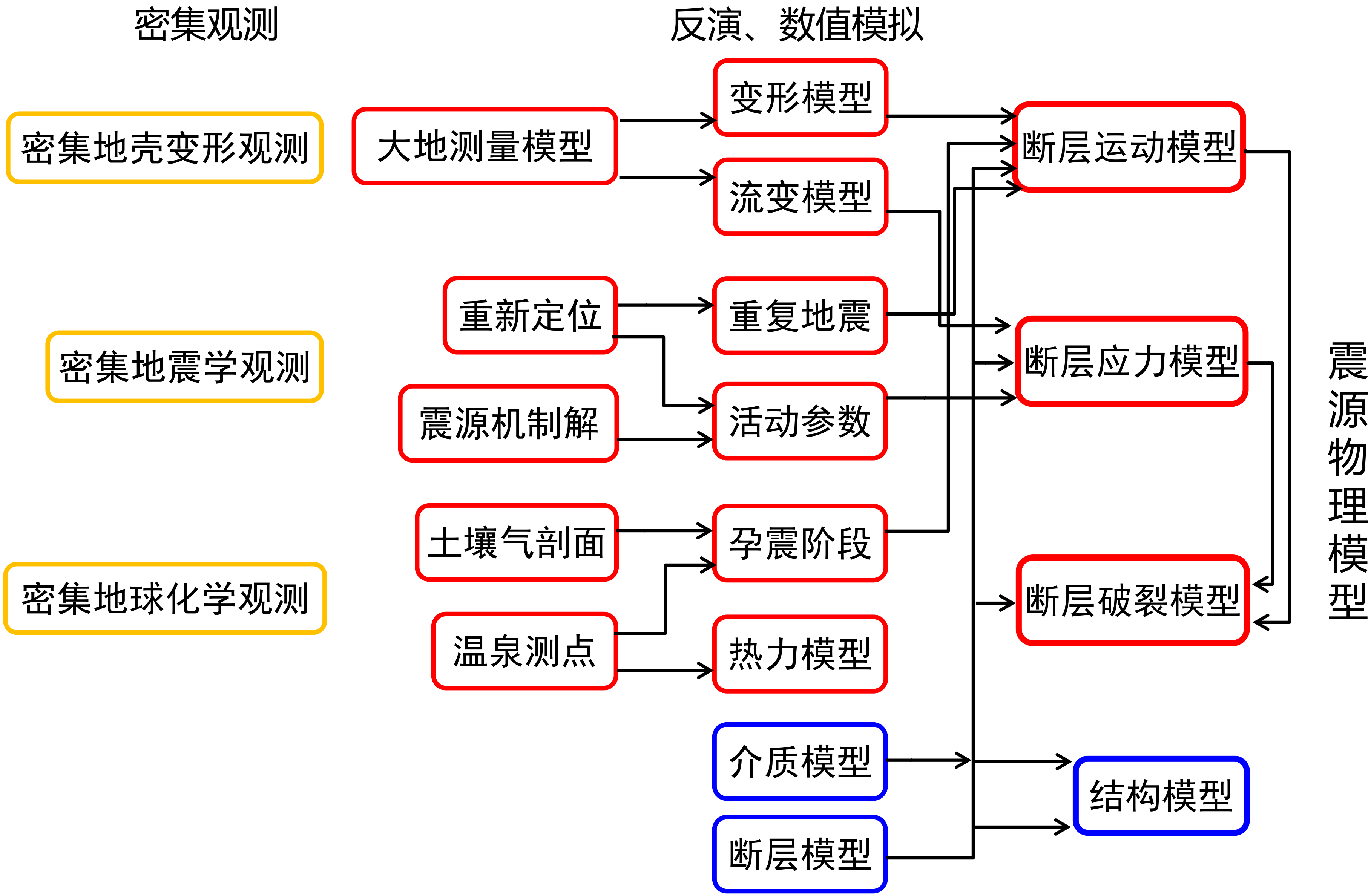
- 关键科学问题3：基于物理模型的强震综合概率预测

基于震源物理模型和强震孕育动力学过程，分别给出主断裂各断层段级联破裂概率、各断层段现今强震长期概率、各断层段强震长期概率应力修正结果、基于强震长期概率的中短期概率增益。。

3 关键科学问题与技术路线

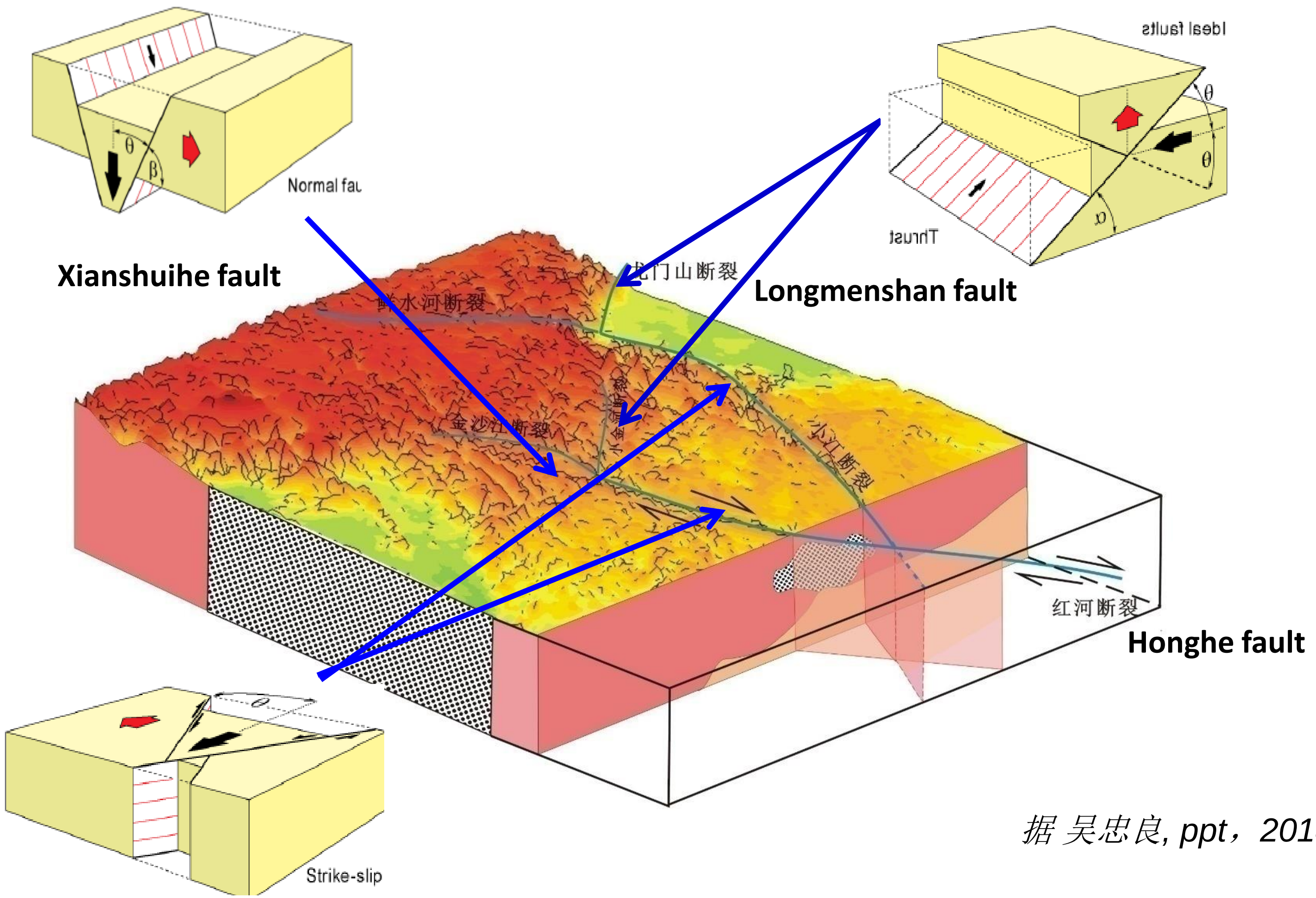


3 关键科学问题与技术路线



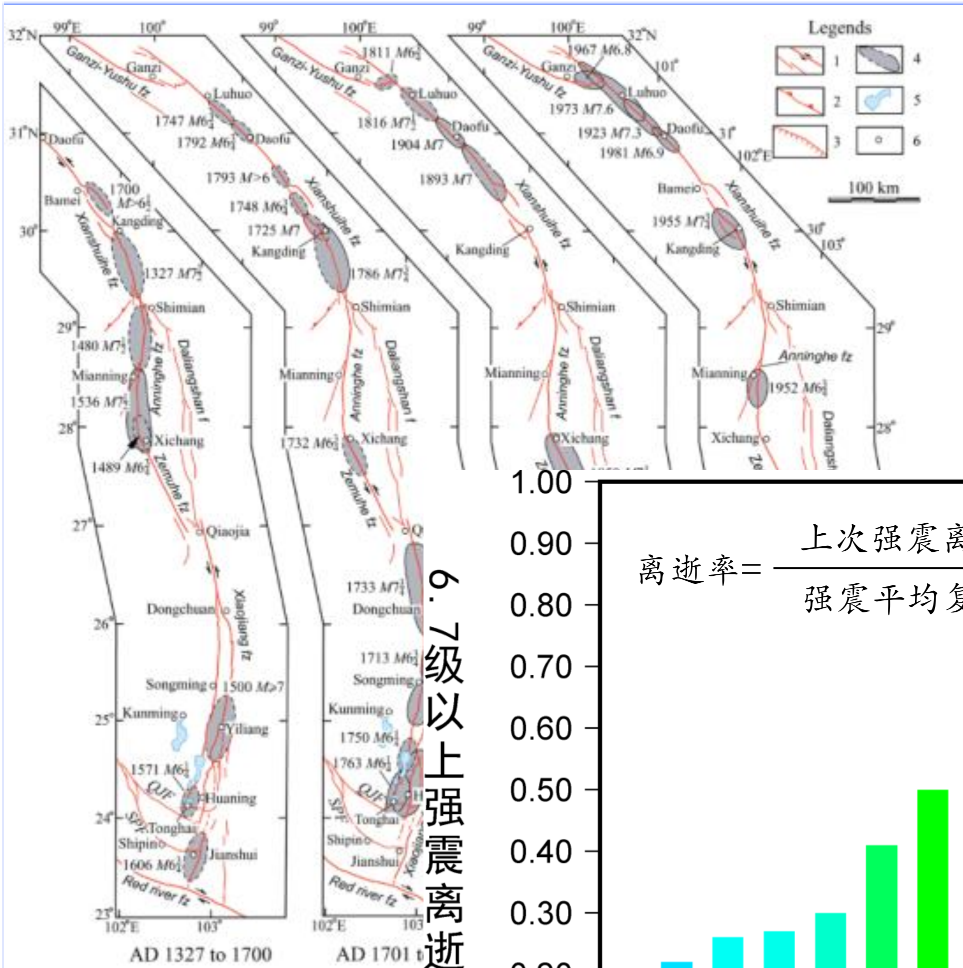
3 关键科学问题与技术路线

川滇菱形块体的活动地块与断层模型构建



据 吴忠良, ppt，2018

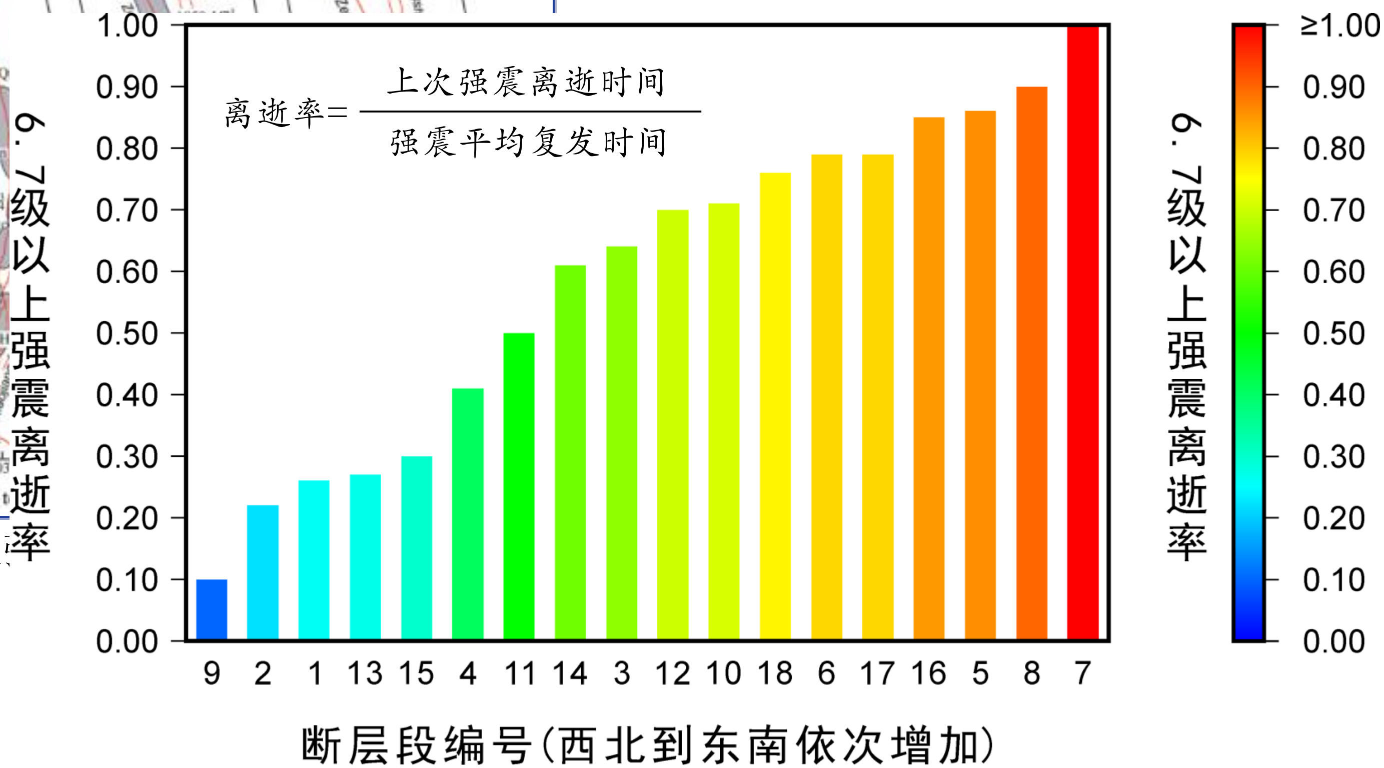
3 关键科学问题与技术路线



川滇菱形块体东边界历史

“以空间换时间”—震源物理模型

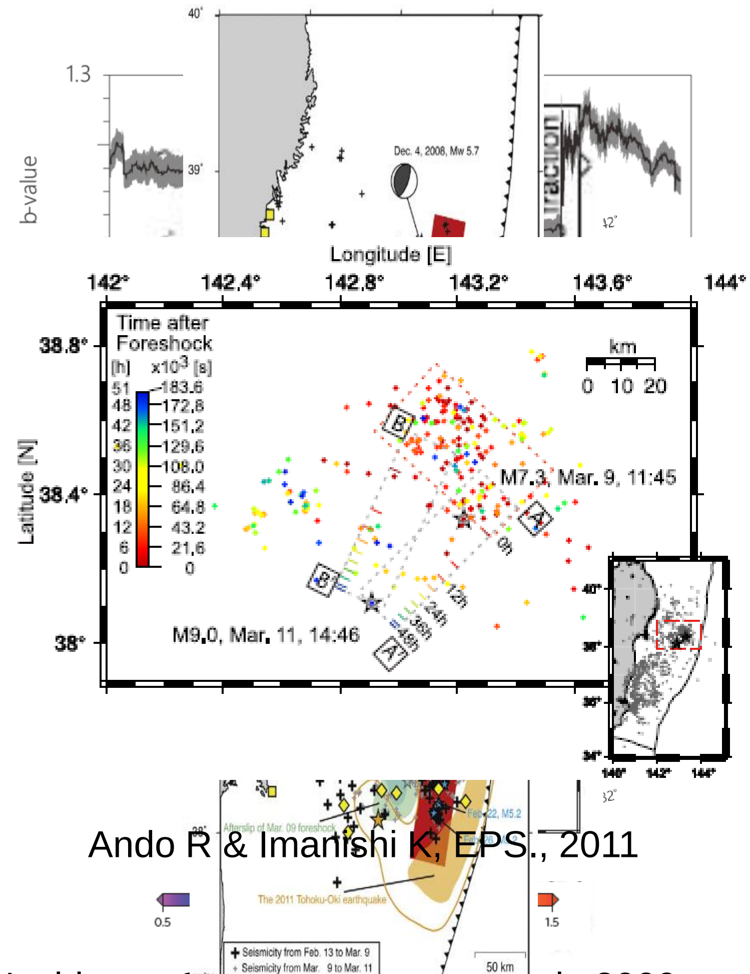
构建大陆走滑型强震动力学过程



断层强闭锁背景下，震源区应力明显升高，震源异常现象显著 “由静变动”

2011年日本9级地震前

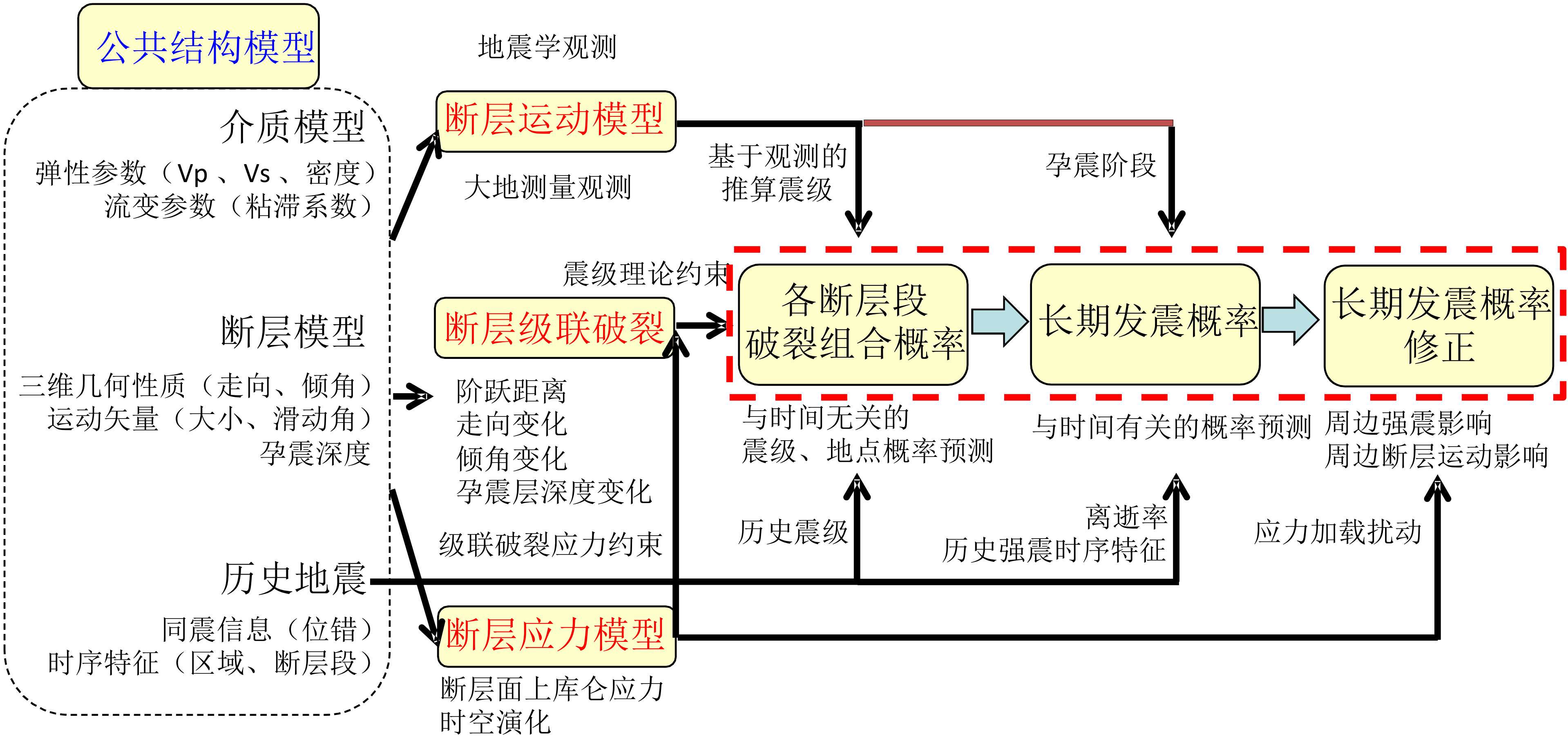
有记录以来7级强震	数十年尺度，强震破裂空段
1997-2000年地壳速度场	10年尺度，断层强闭锁
1998年以后b值时序曲线	5年尺度，应力显著升高
海底形变观测	3年尺度，震源异常活动
海底形变和地震观测	震前数月，震源异常活动 伴随中等地震活动
地震观测	震前2天，7级前震
	9级地震发生



Hashimoto C ... ci., 2009
Loveless J P, et al., JGR, 2010
Tormann T et al., Nature Geosci., 2015
Ando R & Imanishi K, EPS., 2011
Ito et al., Tectonophysics., 2013

3 关键科学问题与技术路线

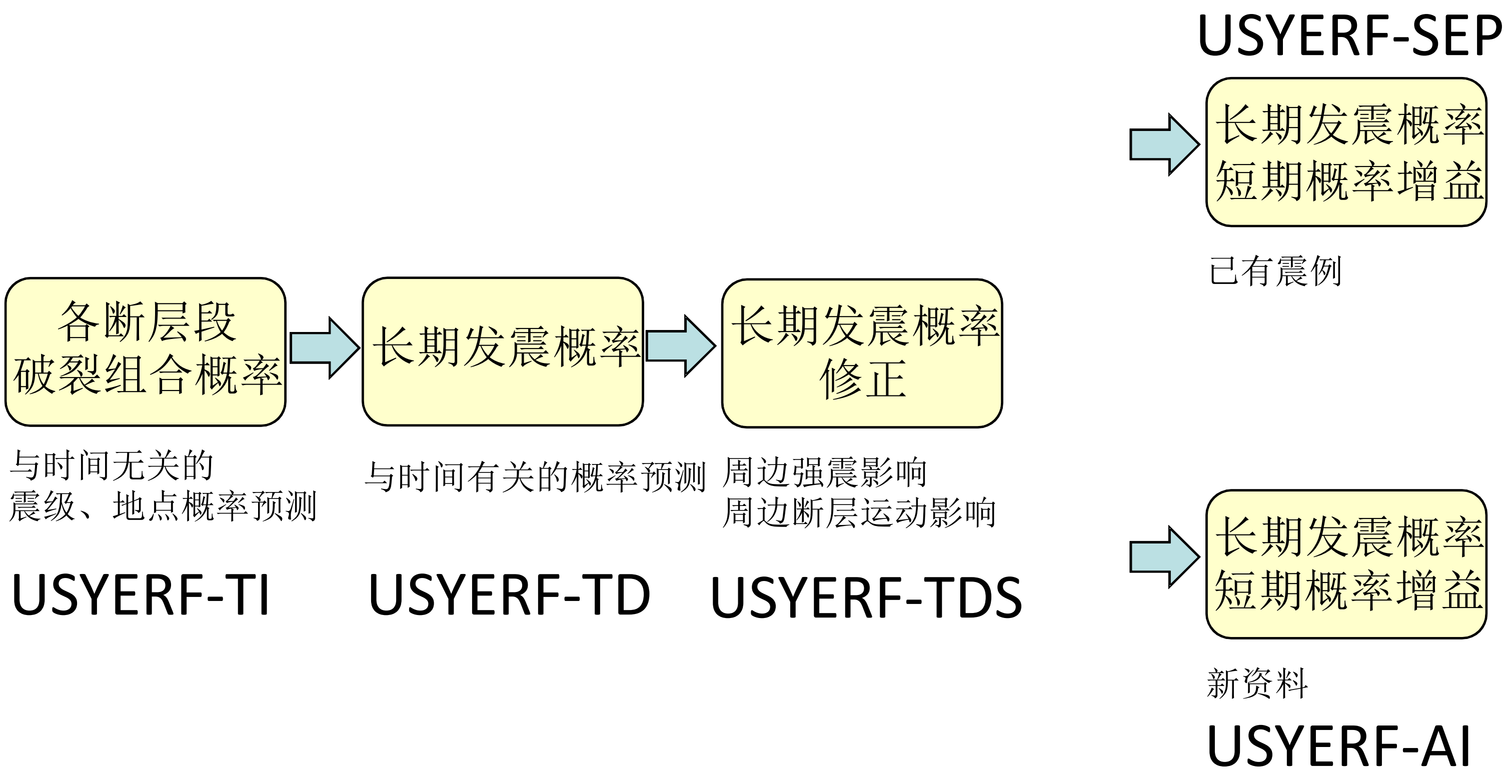
USYERF（统一川滇地震破裂预测）技术路线



3 关键科学问题与技术路线

基于长期地震预测结果的中短期预报

Uniform Sichuan-Yunnan Earthquake Rupture Forecast

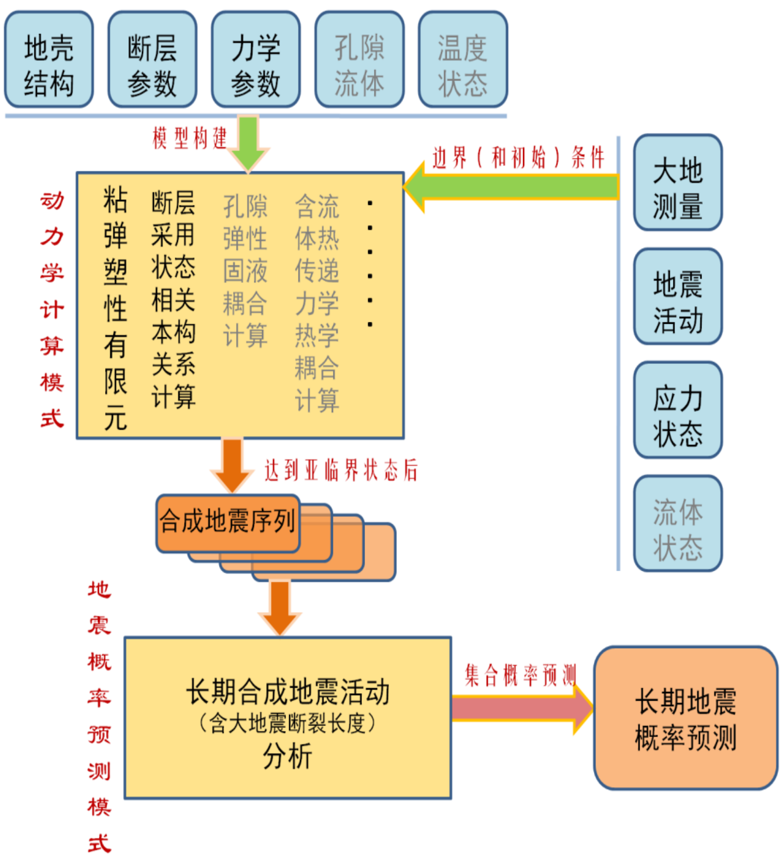


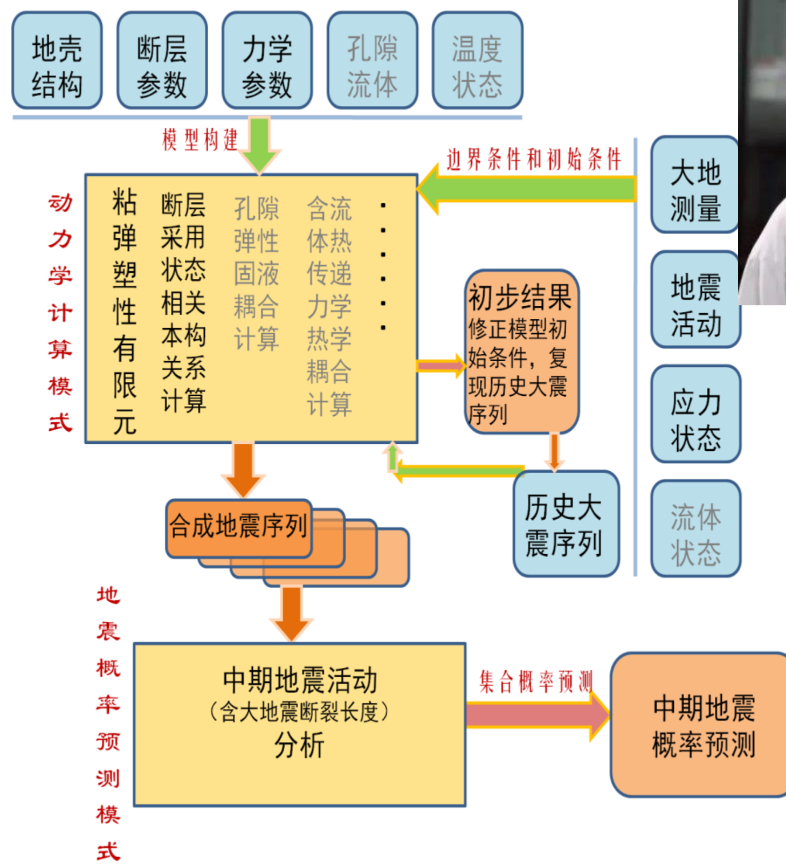
Uniform China Earthquake Rupture Forecast

3 关键科学问题与技术路线

地震数值预测联合实验室（筹建）

中国地震局地震预测研究所，中国科学院大学，南方科技大学





石耀霖，2018

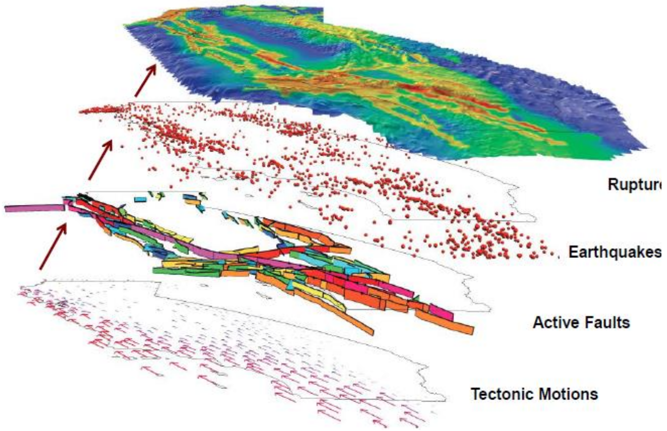
3 关键科学问题与技术路线

地震数值预测联合实验室（筹建）

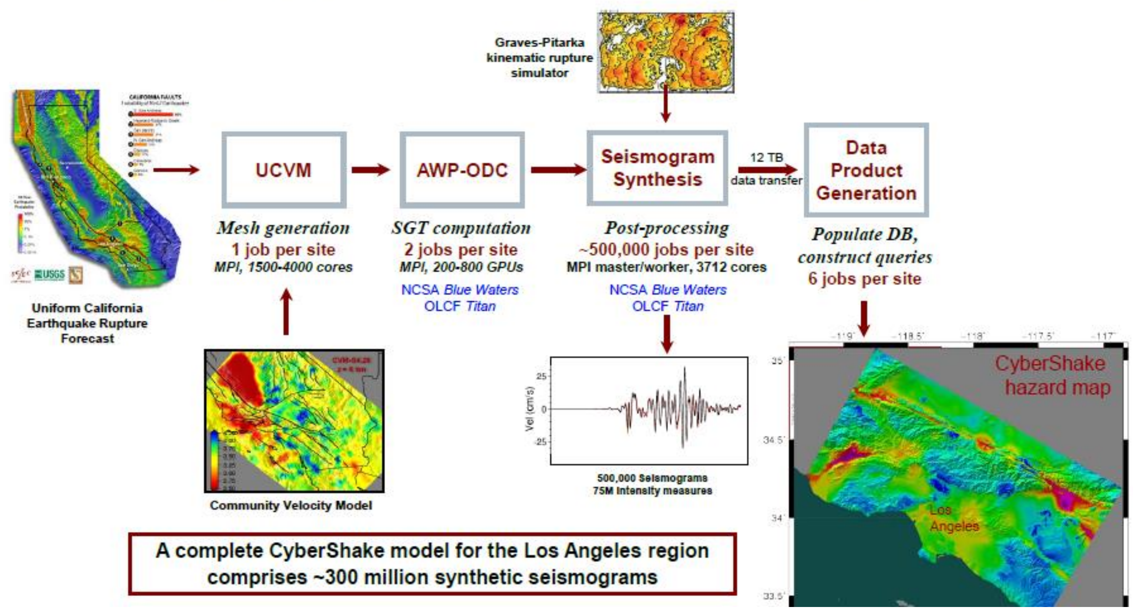
中国地震局地震预测研究所，中国科学院大学，南方科技大学

基于地震破裂预测模型的强地面运动数值模拟及强震风险预测

Uniform California Earthquake Rupture Forecast
UCERF



Coupling of Models in the CyberShake Workflow



John E. VIDALE,2018

4、展望与讨论

4 展望与讨论

物理主体模型

预测主体模型

统一结构模型

从板块到断层的动力加载过程

大陆型强震震源物理模型

基于强震动力学过程的物理预报方法探索

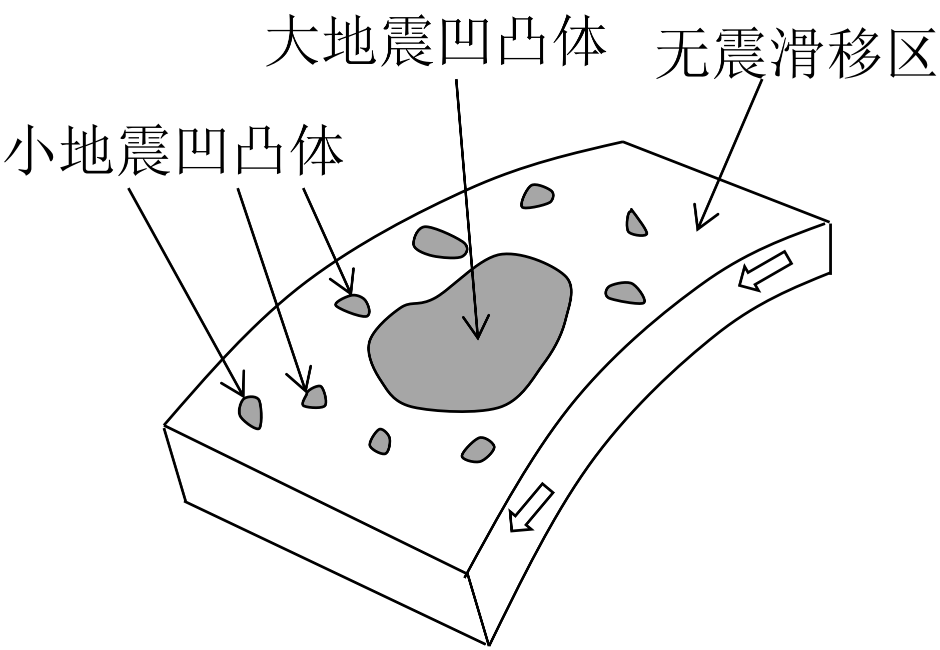
基于物理观测的概率预测综合模型

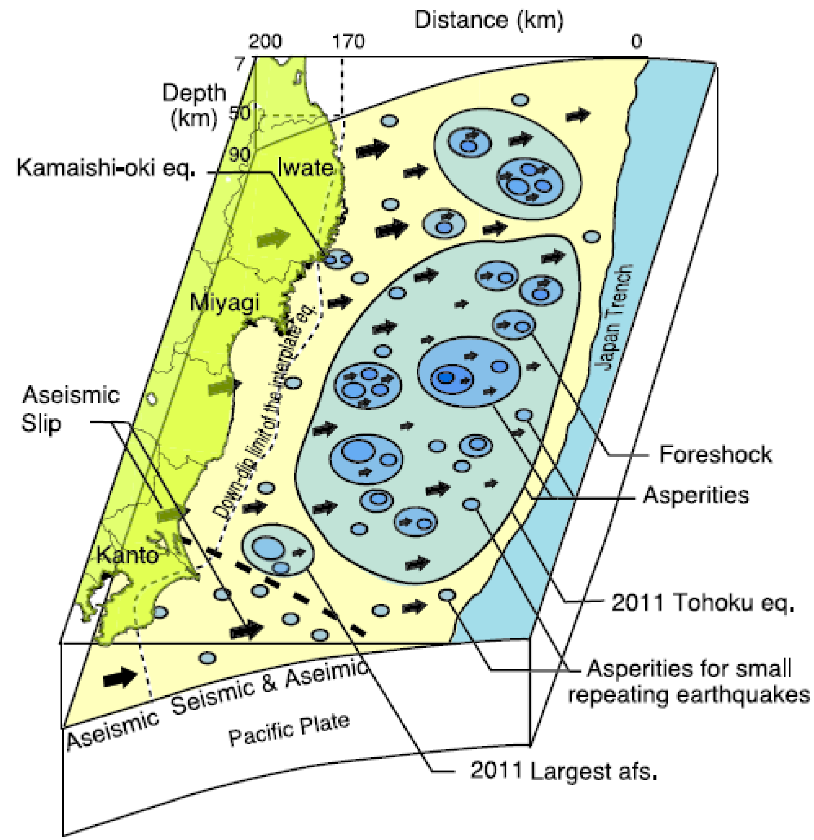
强震动力学概率预测

强震地表响应

4 展望与讨论

不同震级的凹凸体空间分布

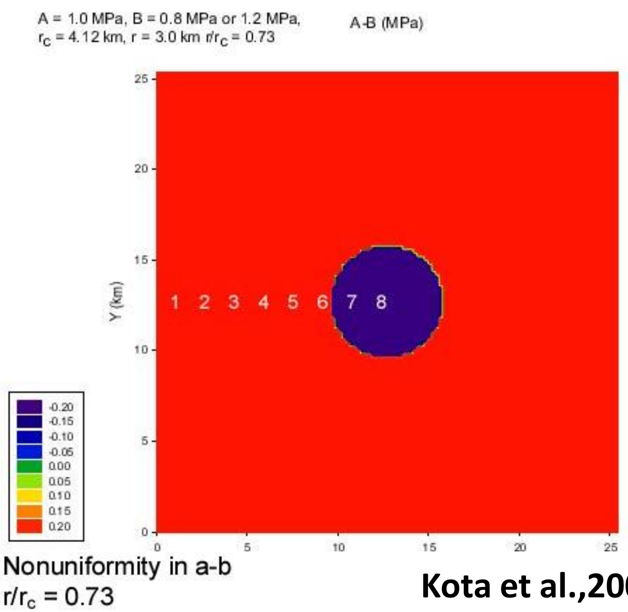


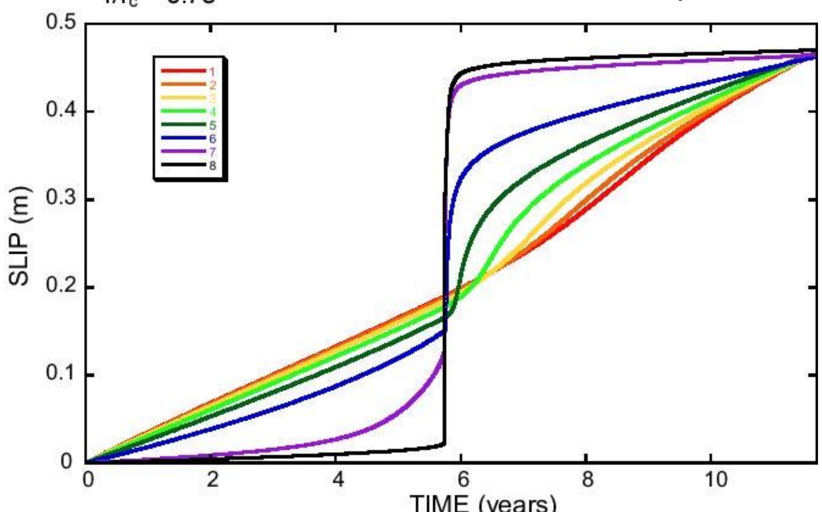


Uchida N and Matsuzawa T, 2011

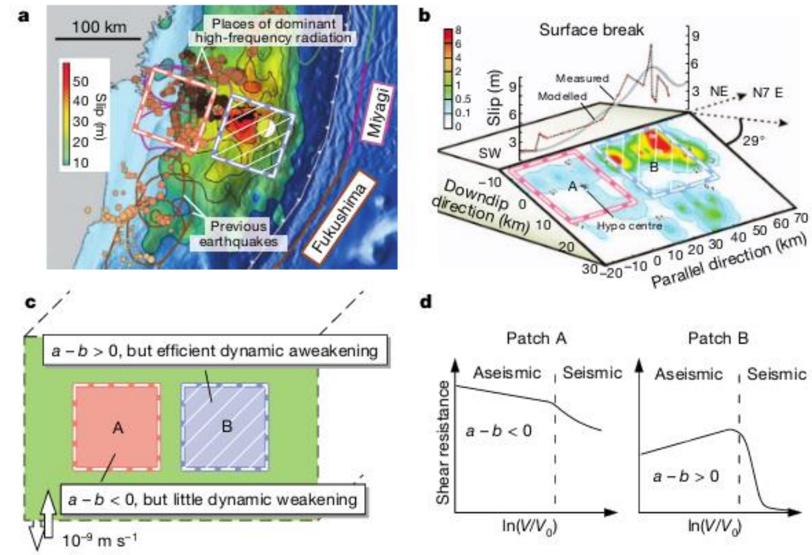
4 展望与讨论

断层摩擦性质的复杂性

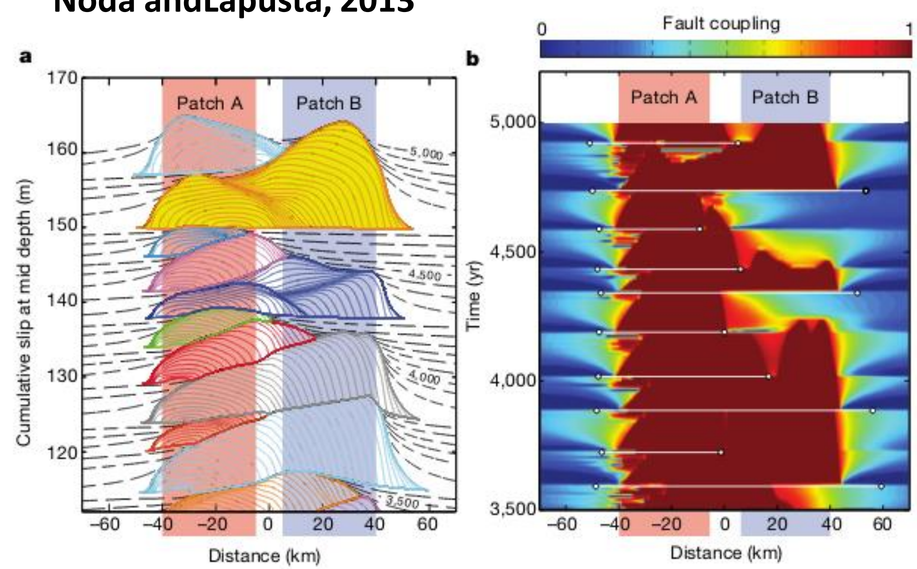




Kota et al.,2009



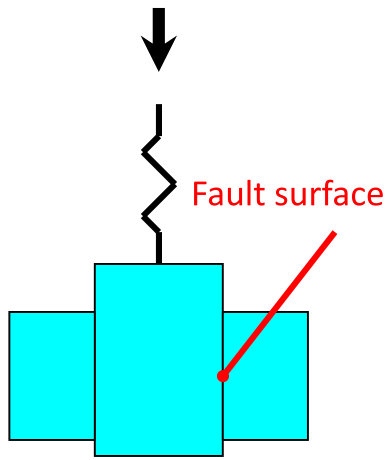
Noda andLapusta, 2013



4 展望与讨论

INSTITUTE OF EARTHQUAKE FORECASTING, CEA

断层摩擦等力学参数的确定

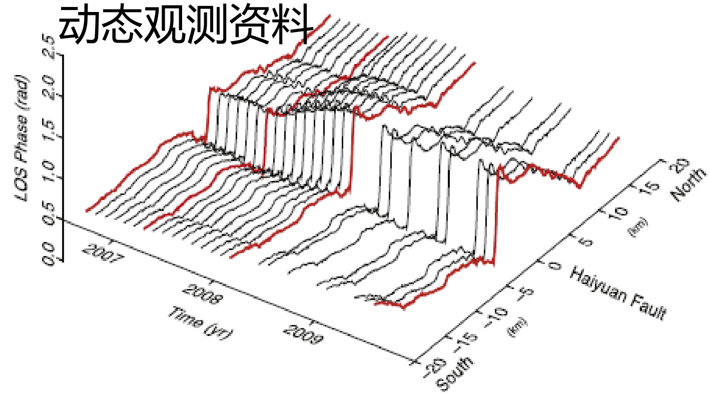


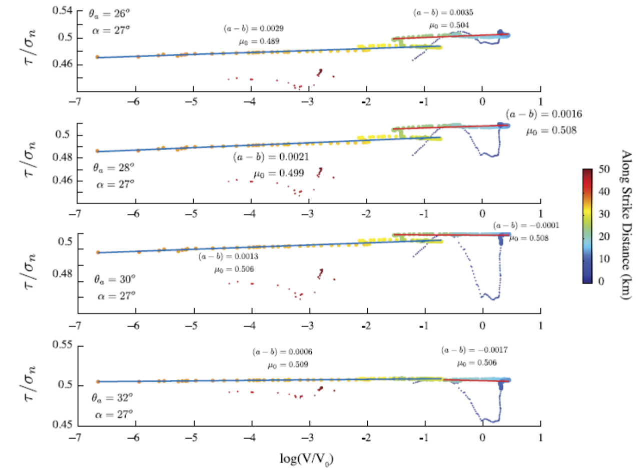
断层摩擦参数

几何尺寸等比缩小原则

岩石试验

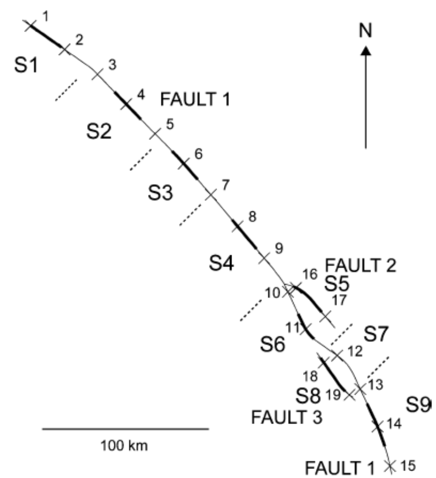
动态观测资料

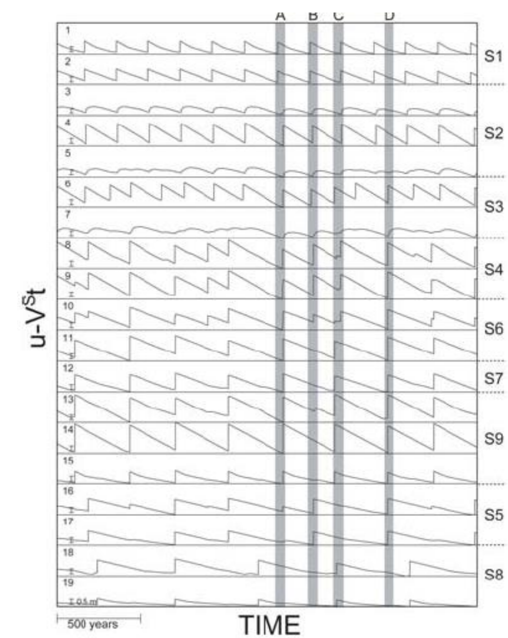




Jolivet et al.,2013

重复强震时空演化特征



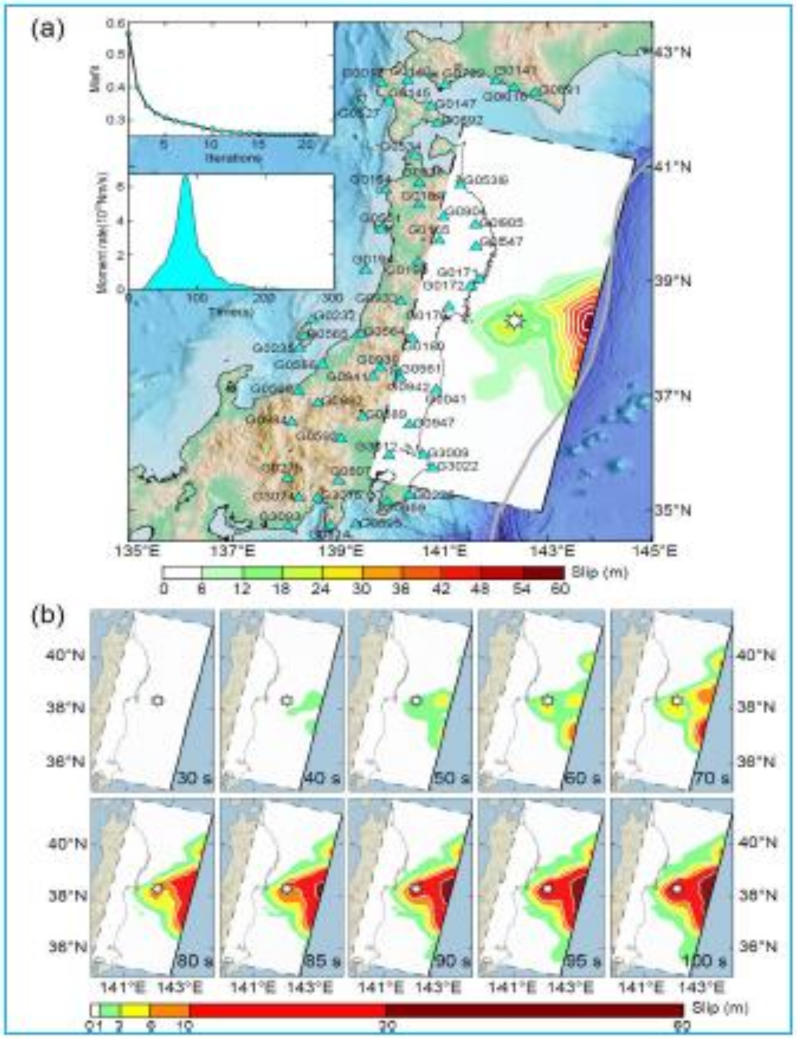


Kato et al.,2007

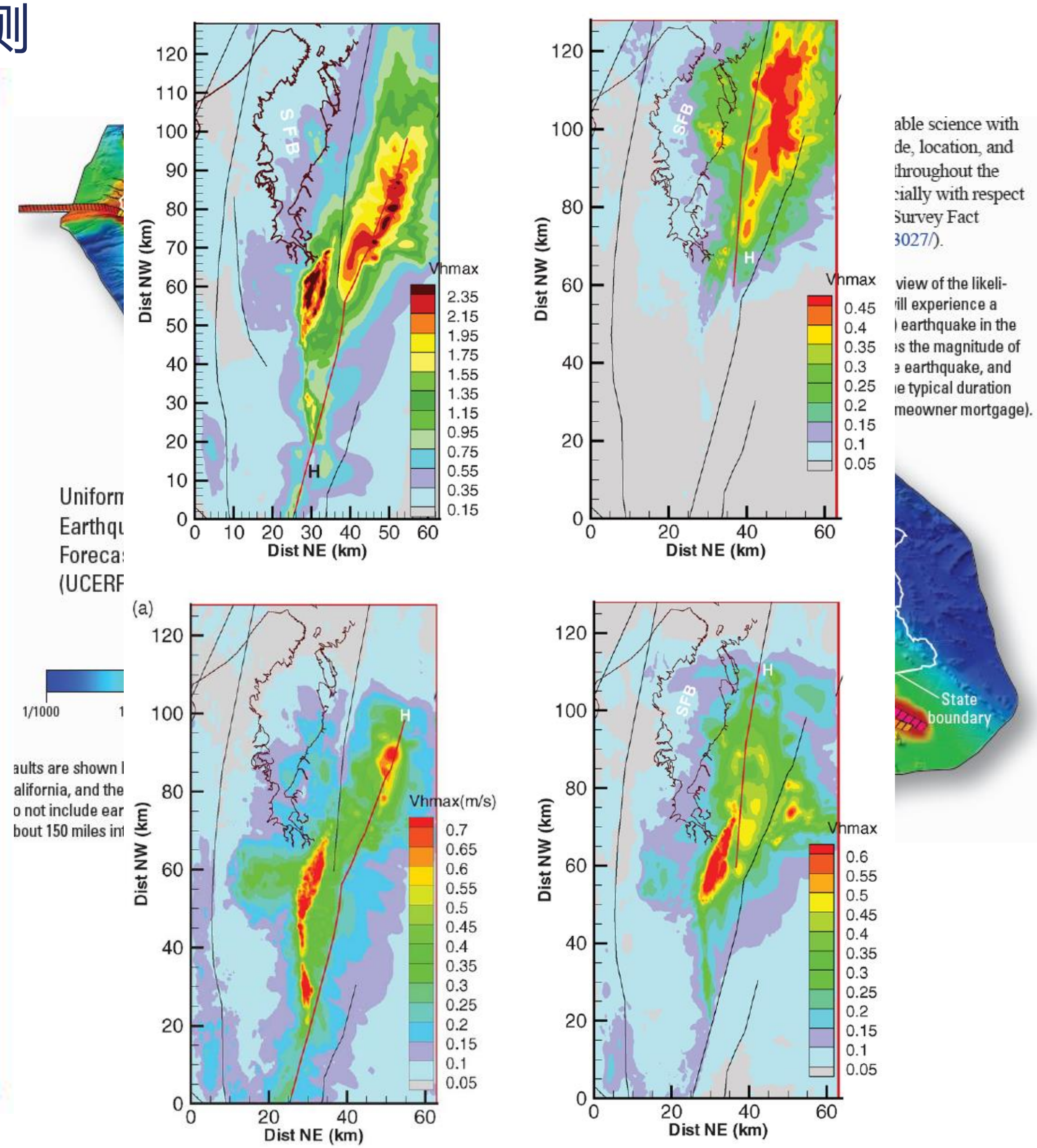
4 展望与讨论

INSTITUTE OF EARTHQUAKE FORECASTING, CEA

地震破裂预测实际中仍缺震中预测



Zhang et al., 2015

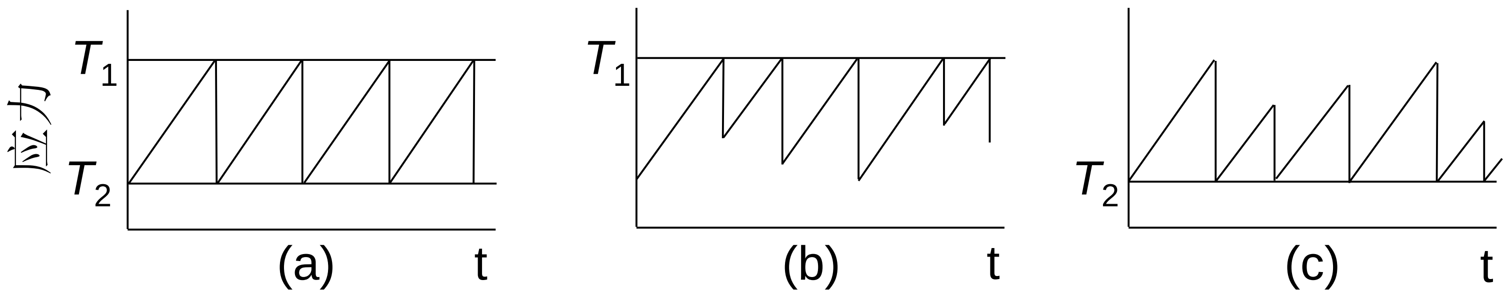


4 展望与讨论

壳幔与断层的绝对应力确定

地震预测模型

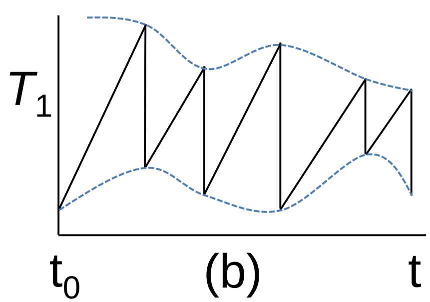
周期模型　　时间可预测模型　　震级可预测模型



T时间

Shimazaki and Nakata, 1980

实际情况



T时间

If techniques were developed to probe not only stress buildup (as with geodesy) but also the spatial distribution of **absolute stresses**, we would be one **small step** away from being able to **estimate a time-dependent probability** based on **dynamic modeling,** opening the possibility for a weather forecasting approach to seismic hazard.

Jean-Philippe Avouac

Thank you!

中国地震局地震预测研究所
INSTITUTE OF EARTHQUAKE FORECASTING, CEA