

2019/9/19, 十三陵



球形地球位错理论及其应用研究

付广裕

中国地震局地震预测研究所

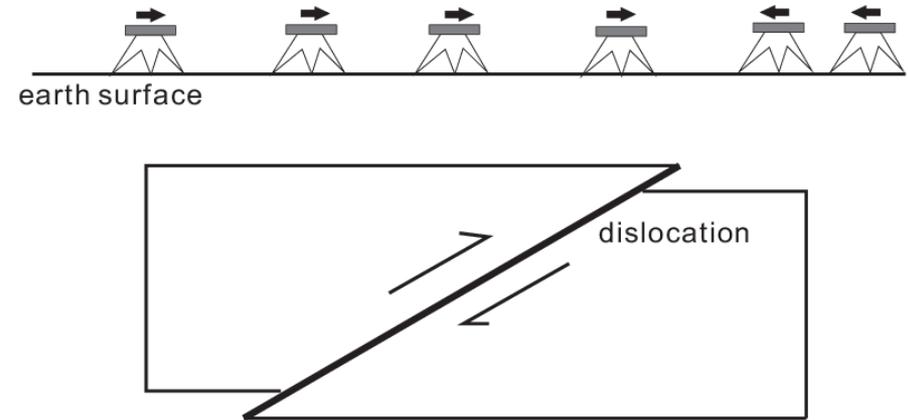
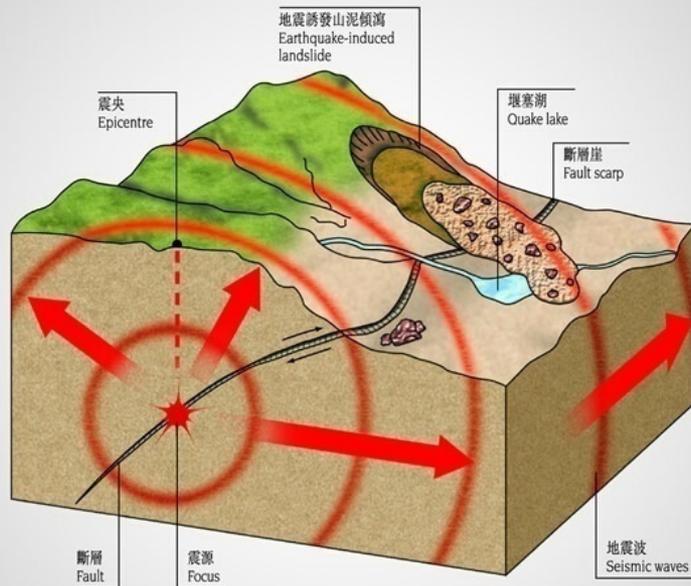
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地震位错理论



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- 位错理论是地震与地表形变之间的理论联系

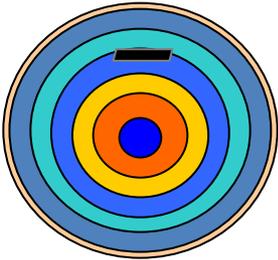
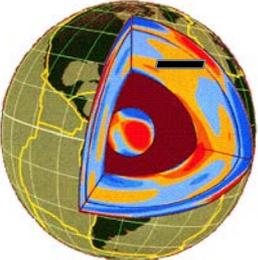


简化为断层两侧的相对运动

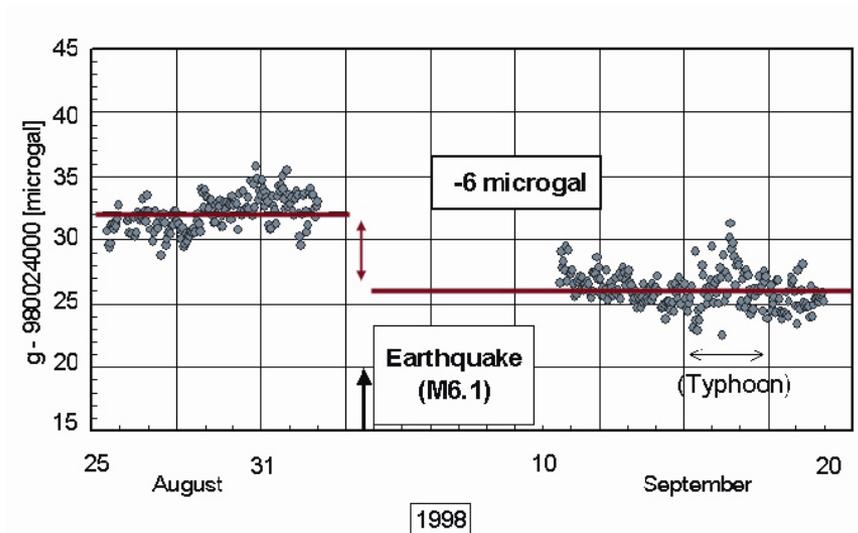
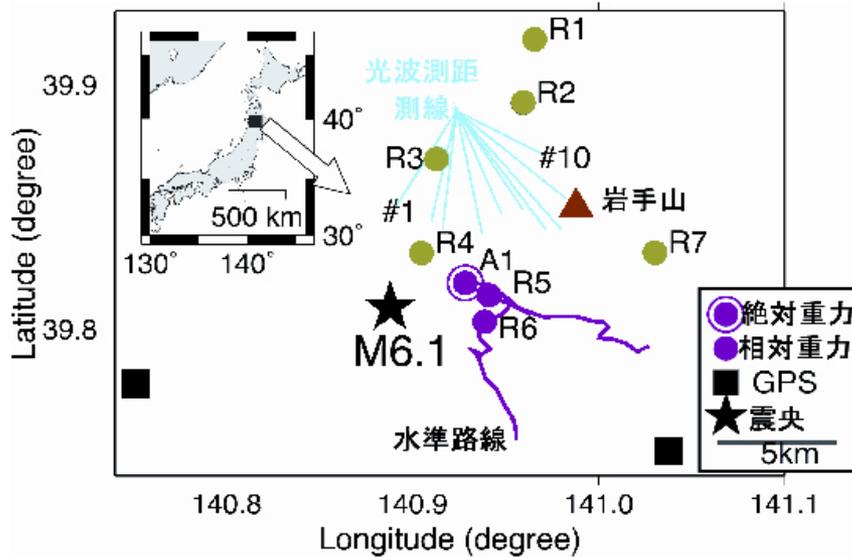
地震位错引起的位移与重力变化理论简介



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Earth model	Dislocation Theory	
	Gravity Changes	Displacements
	Okubo, 1991; 1992	Steketee, 1958; Maruyama, 1964; Okada, 1985; 1992 Wang et al., 2006
	Sun and Okubo, 1993; Tanaka et al., 2006	Sun et al., 1996; 2009 Tanaka, 2007 Pollitz, 1996; 1997
	Fu and Sun, 2008	Pollitz, 2003; Fu et al., 2010

地震引起的同震重力变化



1998/9/3 M6.1

星号表示震源

震中距: 约3公里

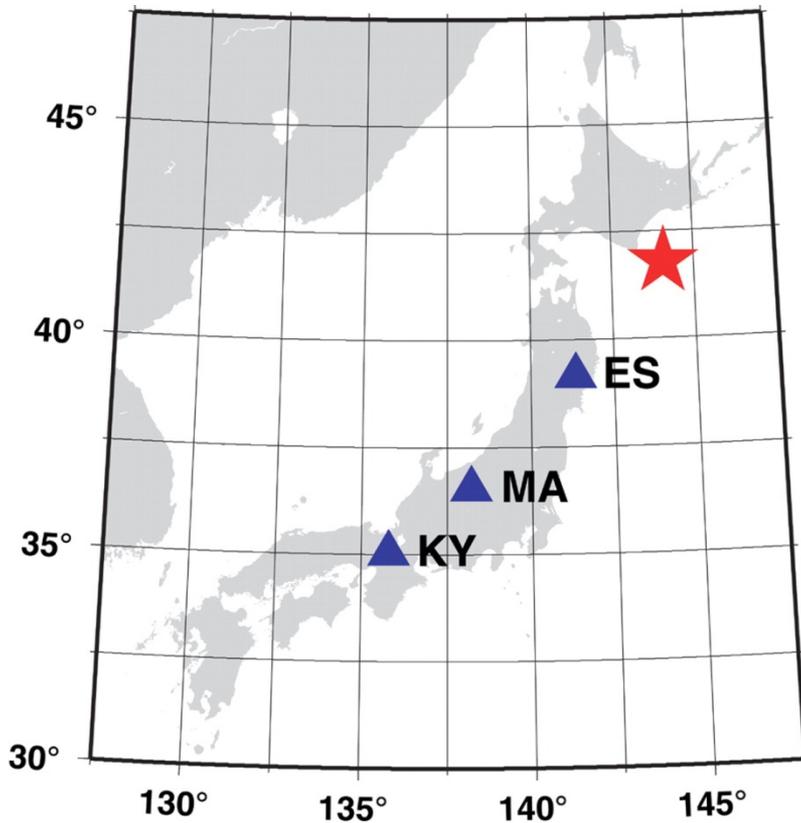
地震引起的重力变化
8天间隔, 6微伽的变化
观测误差为1微伽.

位错理论 (Okubo, 1992) ✓

地球模型的影响

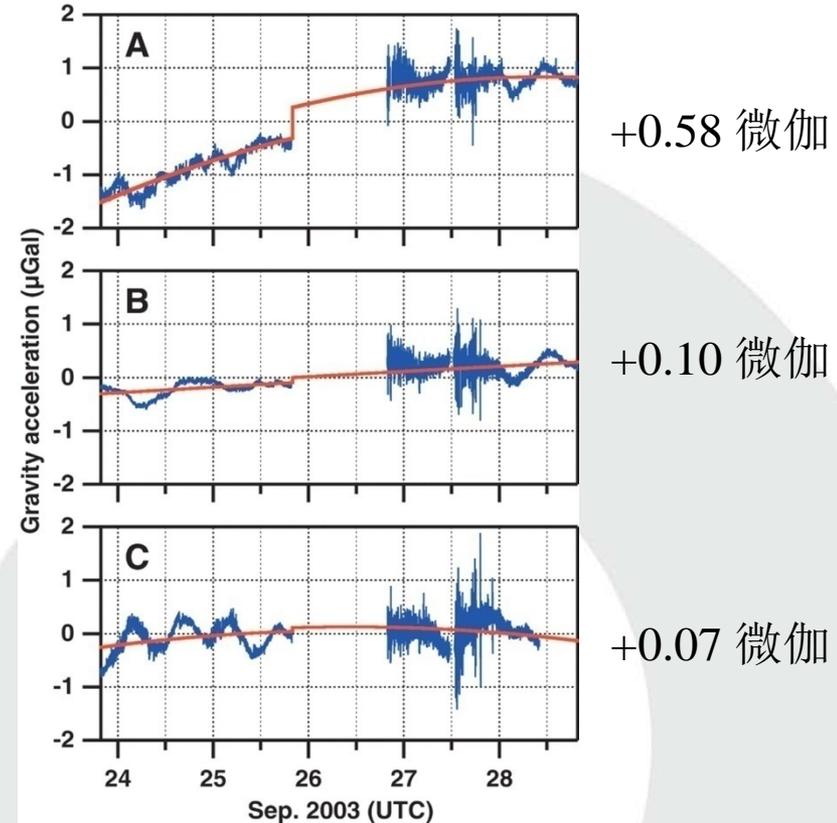


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绝对重力观测
2003/9/25，
北海道地震，M8.0

Imanishi et al., *Science*, 2004



球体位错理论 ✓

平面位错理论 ✗

地球模型的影响很重要

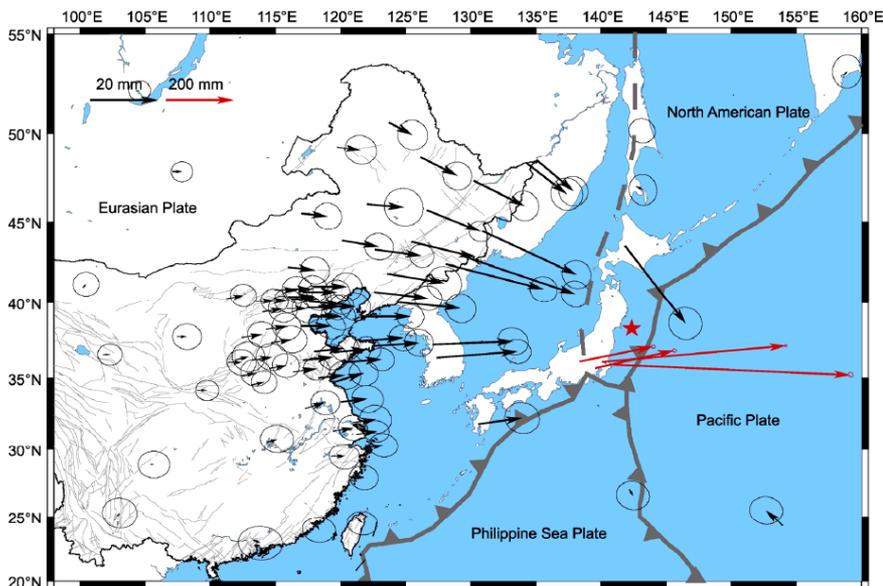
大地震引起的远场形变



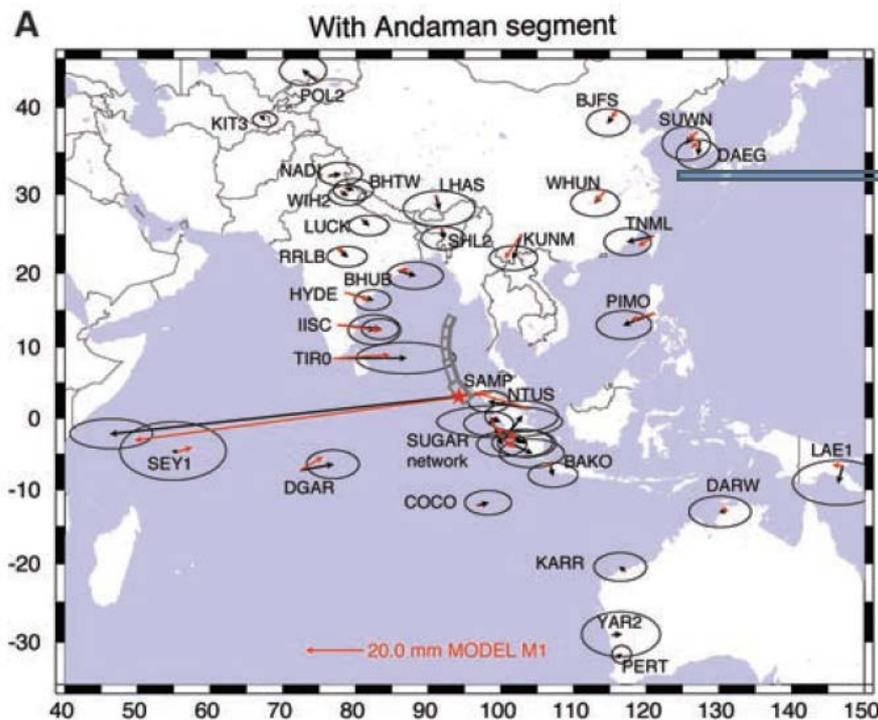
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日本Mw9.0地震

Wang et al., CSB, 2011

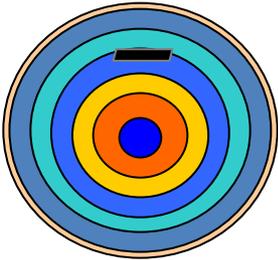
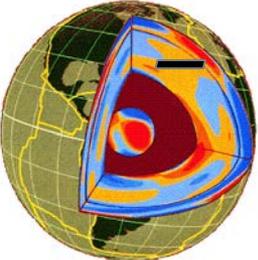


苏门答腊Mw9.1地震



远场形变数据需用球形地球位错理论进行解释!

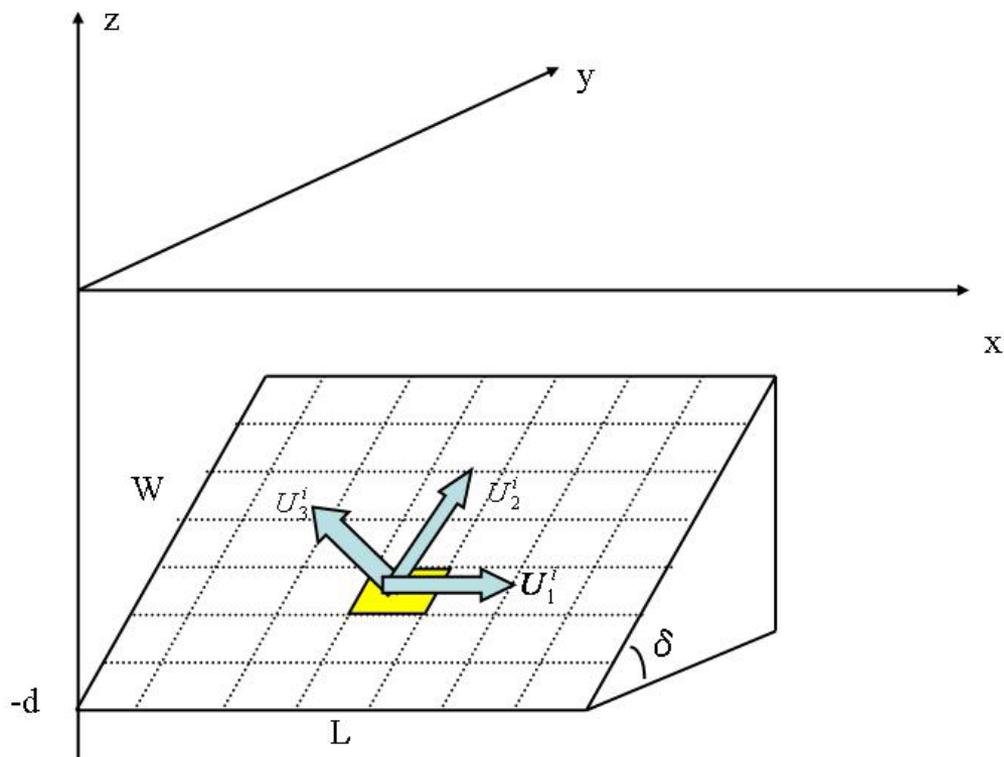
地震位错引起的位移与重力变化理论简介

Earth model	Dislocation Theory	
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	<p>Sun and Okubo, 1993; Tanaka et al., 2006</p>	<p>Sun et al., 1996; 2009 Tanaka, 2007 Pollitz, 1996; 1997</p>
	<p>Fu and Sun, 2008</p>	<p>Pollitz, 2003; Fu et al., 2010</p>

Tanaka程序基本设计思路及其缺陷



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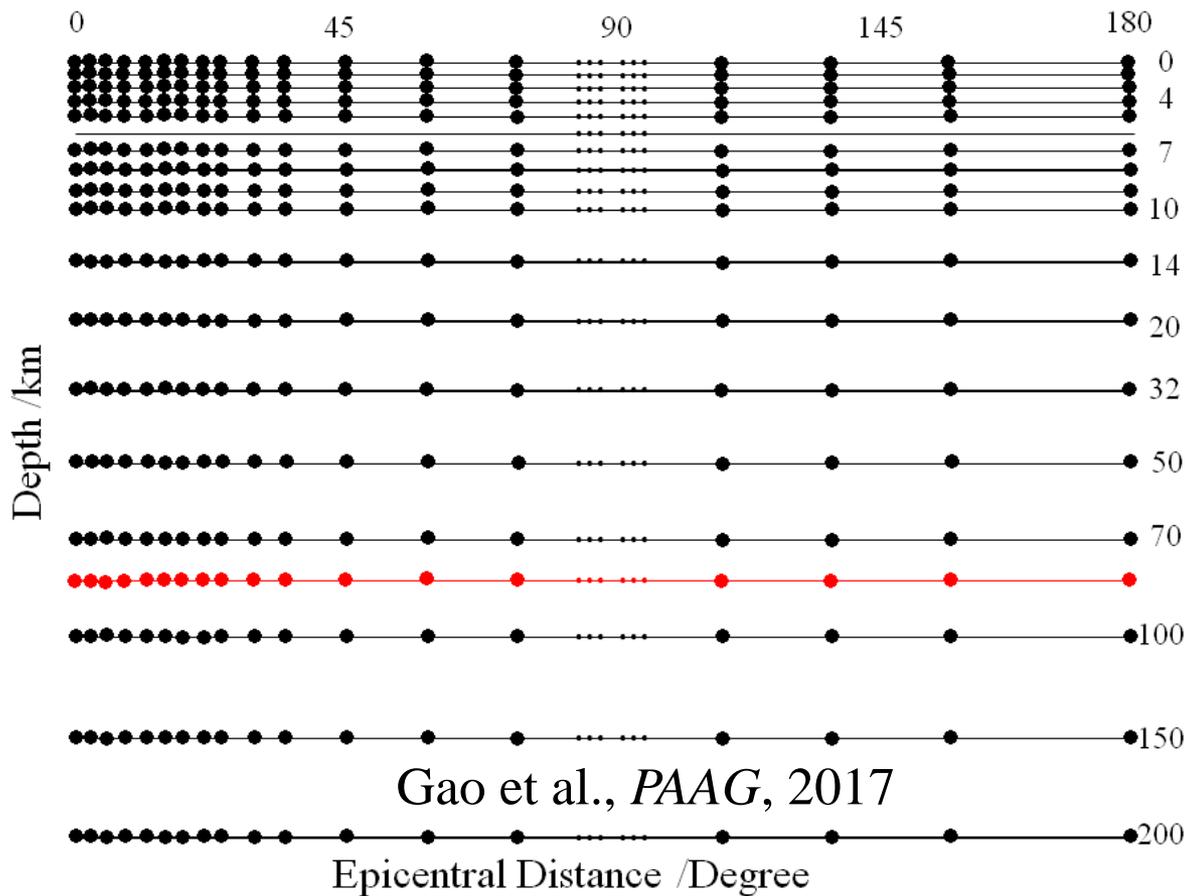


1. 不同地震，格林函数需分别计算，繁琐且易出错
2. 近场结果计算精度较低

新程序：位错格林函数数值框架+插值计算程序



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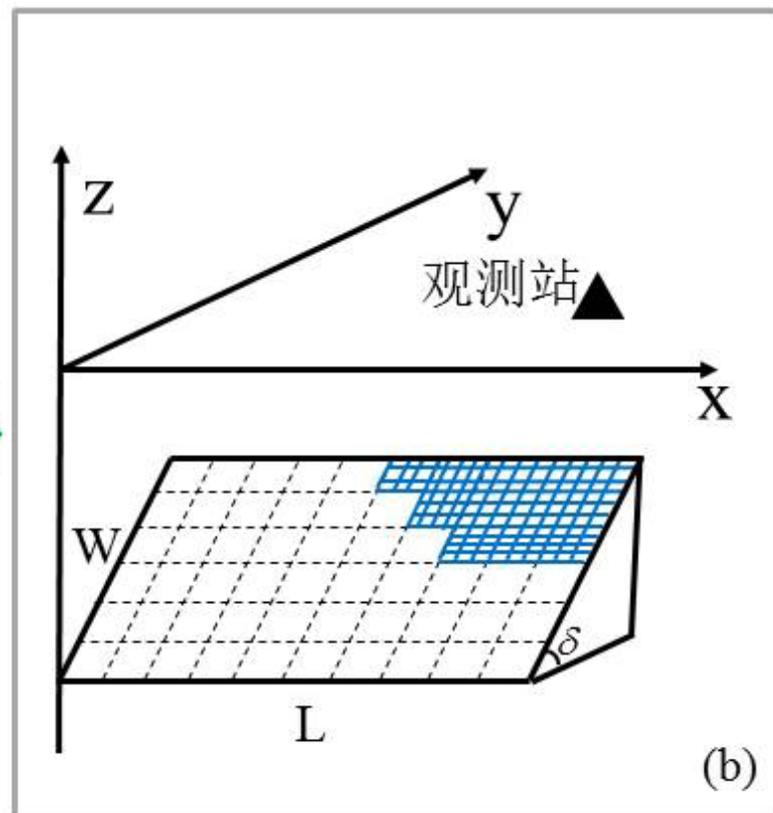
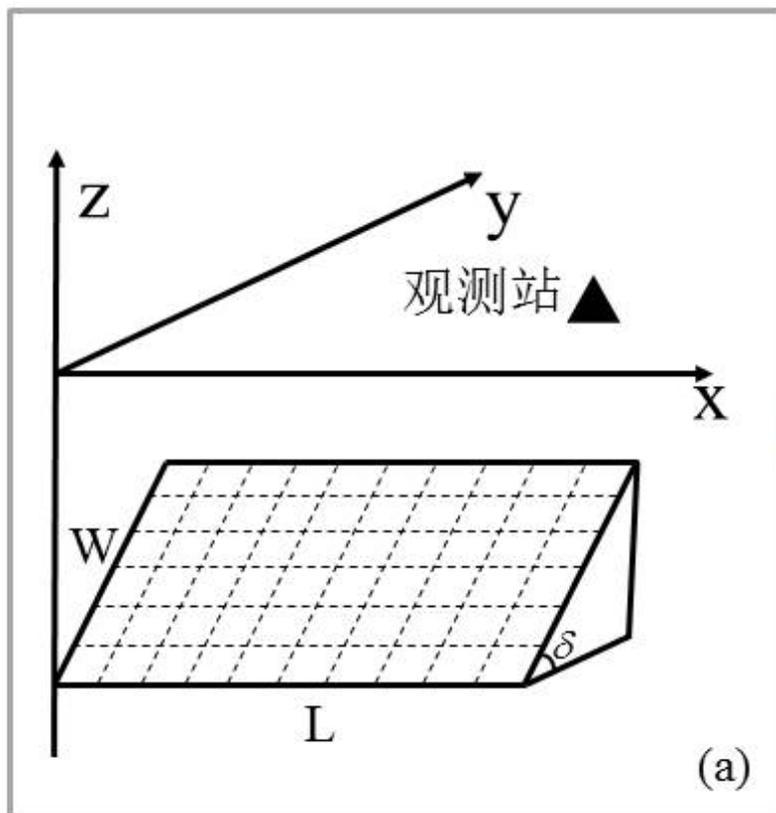


不同震例，皆可用这套算法计算出位错格林函数

子断层自动细分



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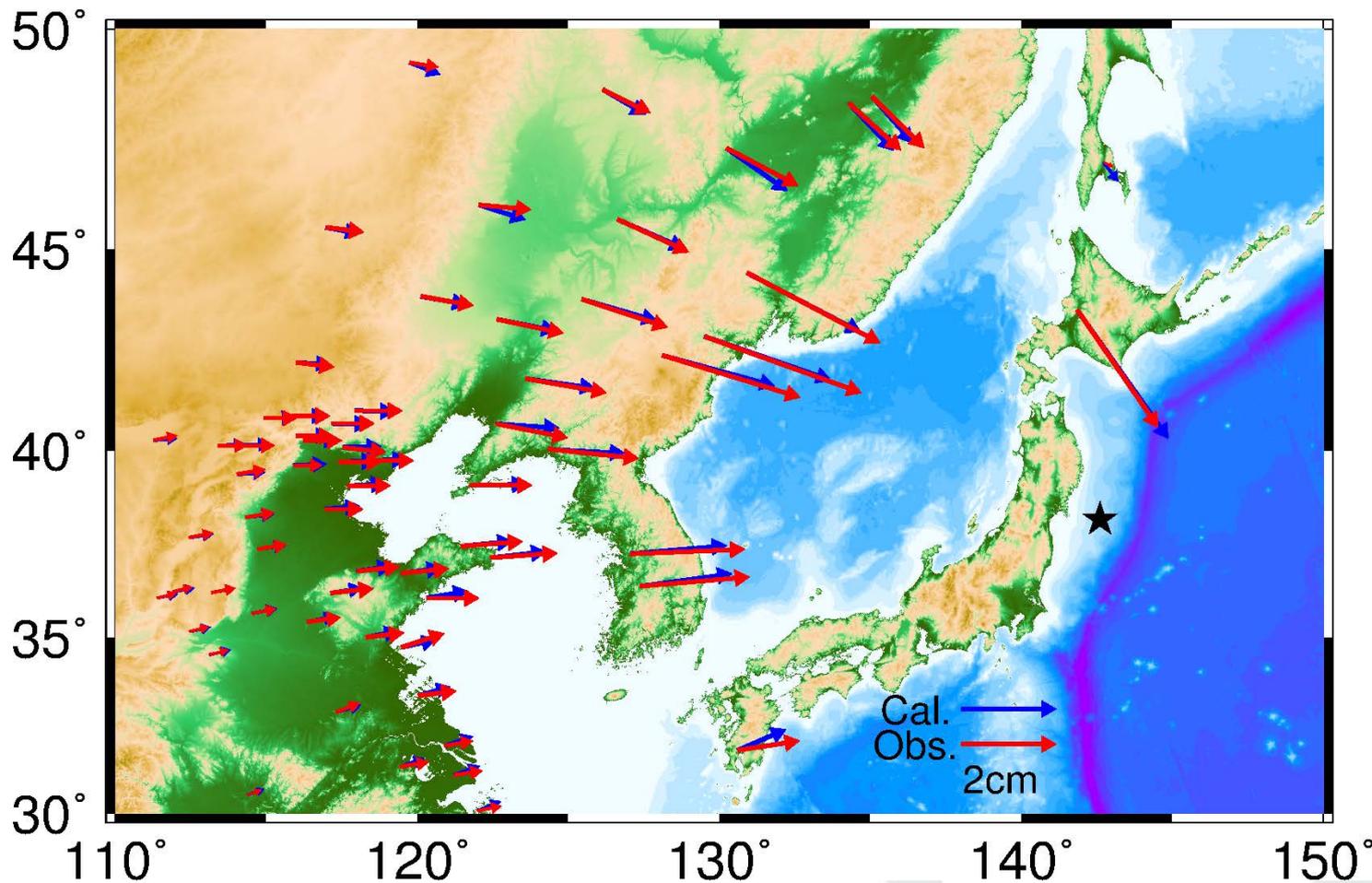


提高近场震后形变计算精度

计算结果与GPS观测结果的比较



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同震位移观测结果与模拟结合吻合

地震形变研究与应急响应平台



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位移变化 x

124.207.150.85:8085/opening/shExpandGRA

地震变形研究与应急响应平台
EARTHQUAKE DEFORMATION RESEARCH

2019年8月20日 星期二

平台首页 最新动态 位移变化 重力和大地水准面变化 应变变化 库仑应力变化

重力与大地水准面变化

输入参数 / 生产数据

地震参数:

地震纬度*	地震经度*	地震震级*	地震深度*
32	100	7	20

计算参数:

经纬度网格*	经纬度范围*	弹性层厚度*	粘度系数*
0.1	2	50	1 *10 ¹⁹

提交并开始计算绘图

震后年数*

1

提示: 计算完成后, 可快速切换年数数据。

建设中

当前数据编号: 20190820110804652 - 1

<http://124.207.150.85:8085/opening/index>



震后形变机理的分离：以日本Mw9.0地震为例

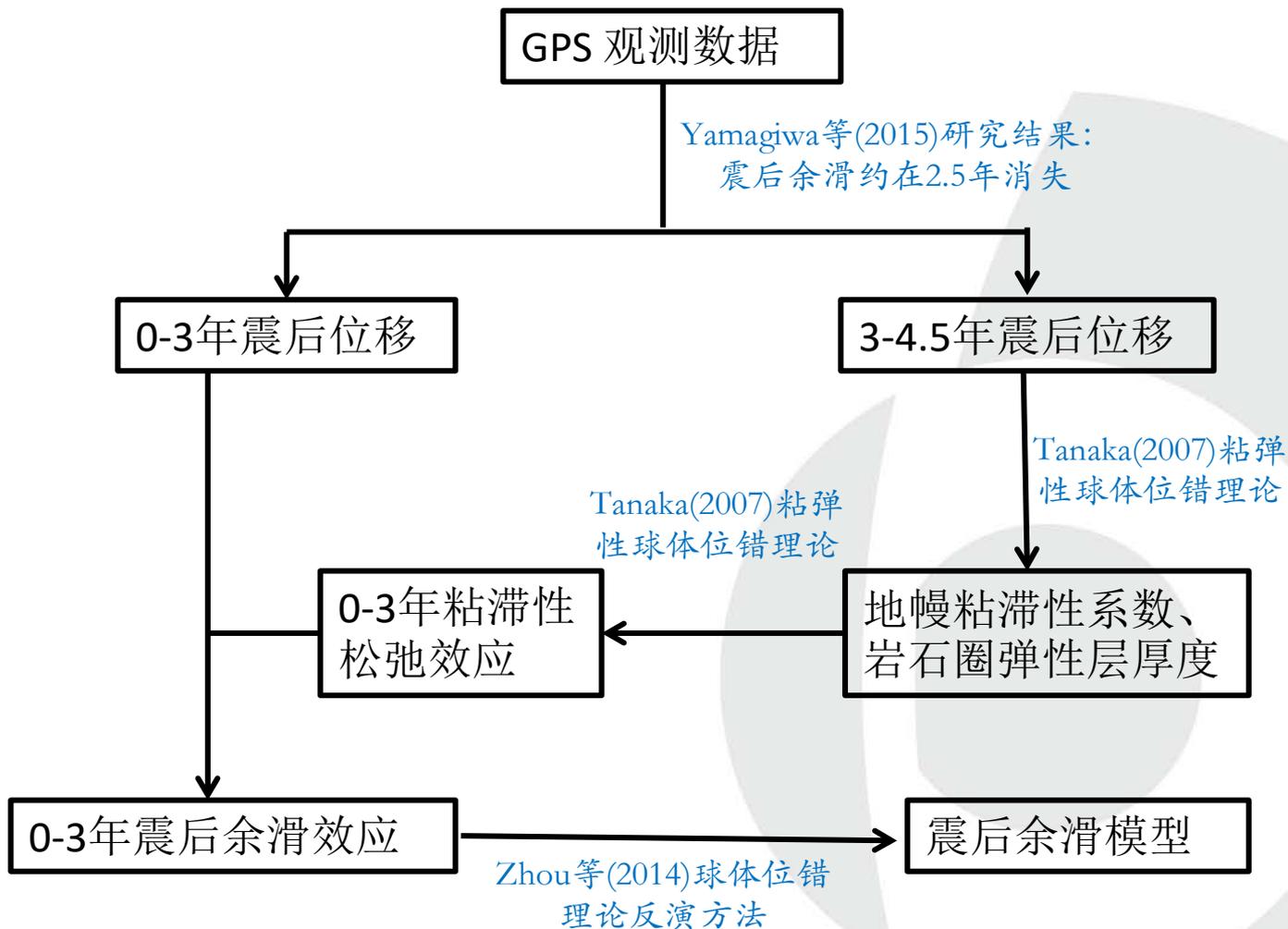
- 地幔粘滞性松弛效应：**长期效应**
 - ◆ 地震后地幔物质应力松弛引起的震后形变
- 震后余滑效应：**一般2年以内**
 - ◆ 断层余滑指断层同震破裂周边区域的继续破裂，一般在震后初期表现明显，并随时间迅速衰减
- 孔隙流体回弹效应：**一般数月以内**
 - ◆ 孔隙流体回弹是孔隙水流动重新平衡的现象，持续时间较短

从震后形变数据中分离各种因素对应的形变效应是一个重要课题

基本思路



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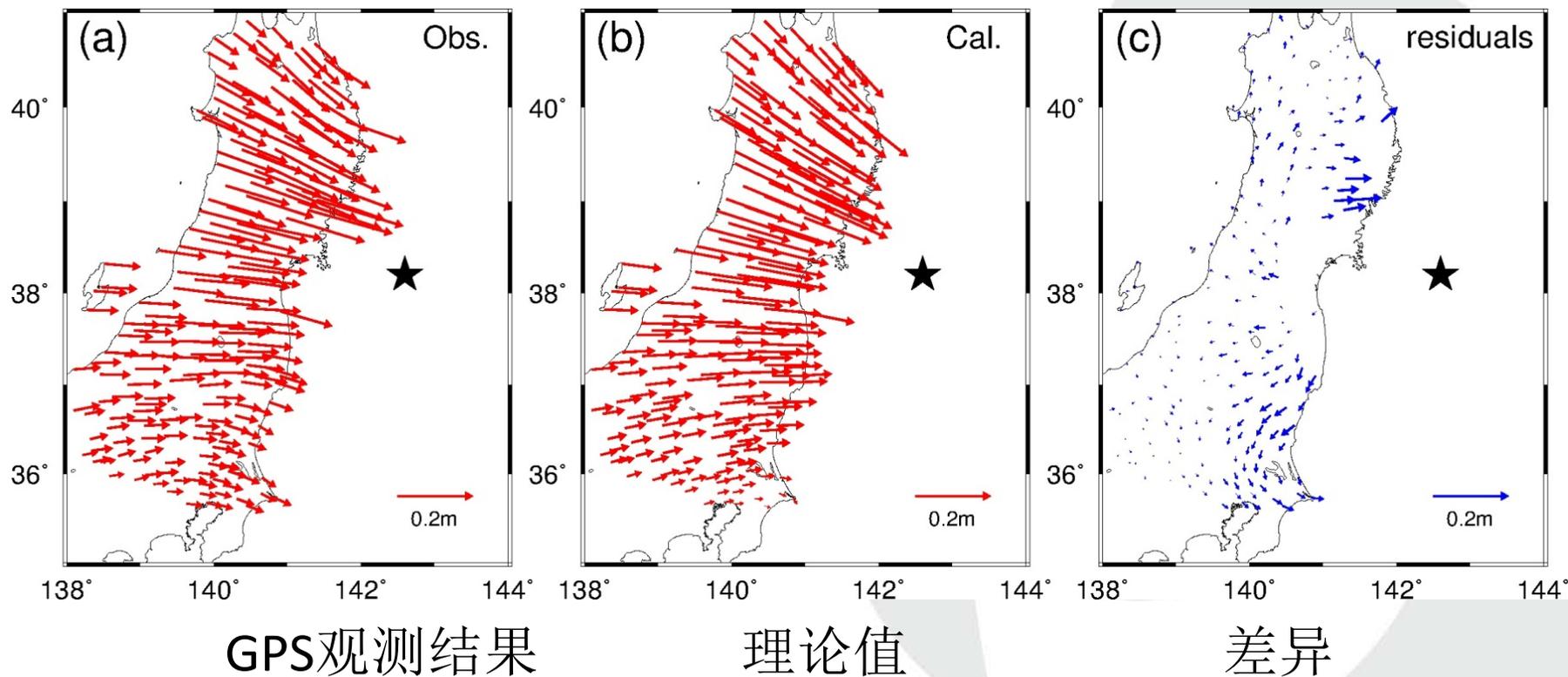


日本M_w 9.0地震震后3-4.5年内水平位移



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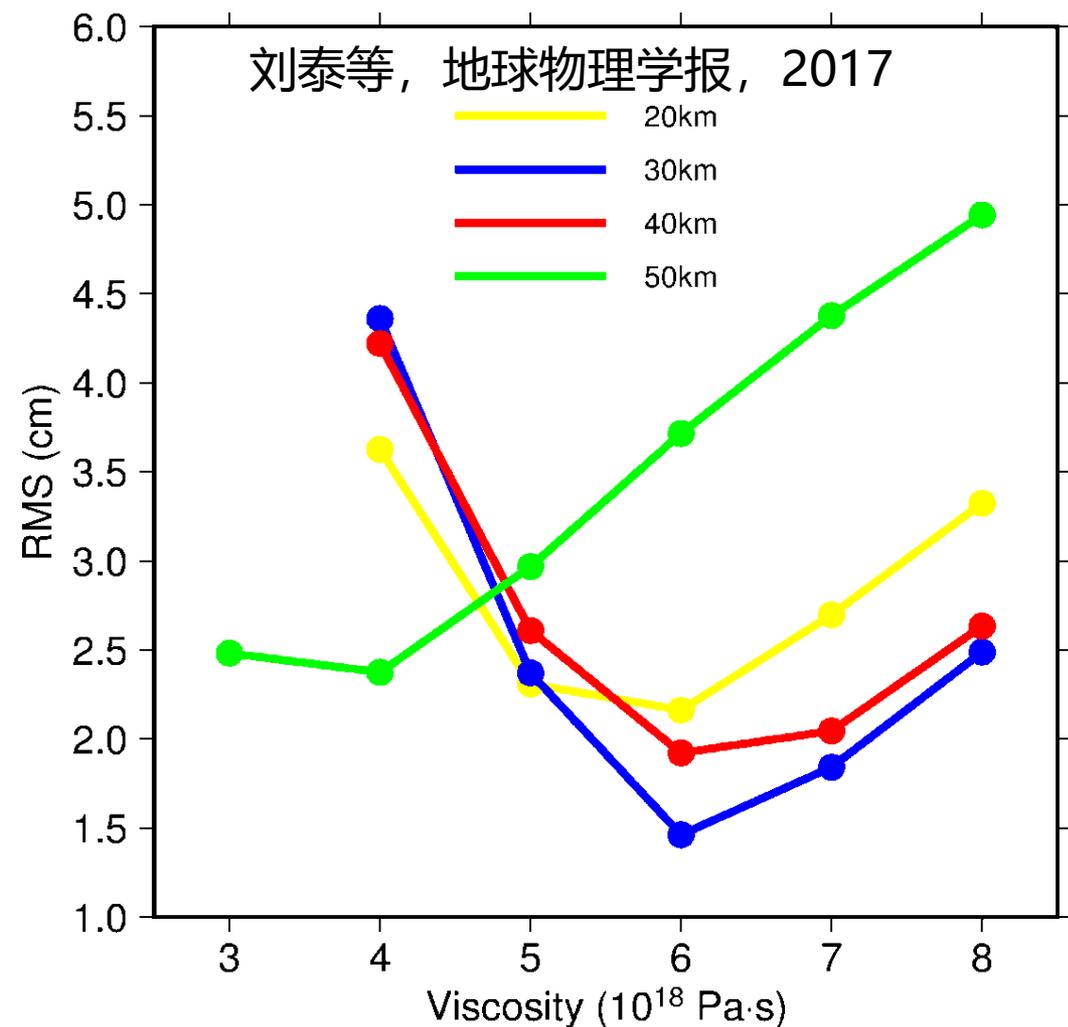
同震破裂模型 (Wei et al., 2012)



岩石圈弹性厚度与地幔粘滞性系数反演



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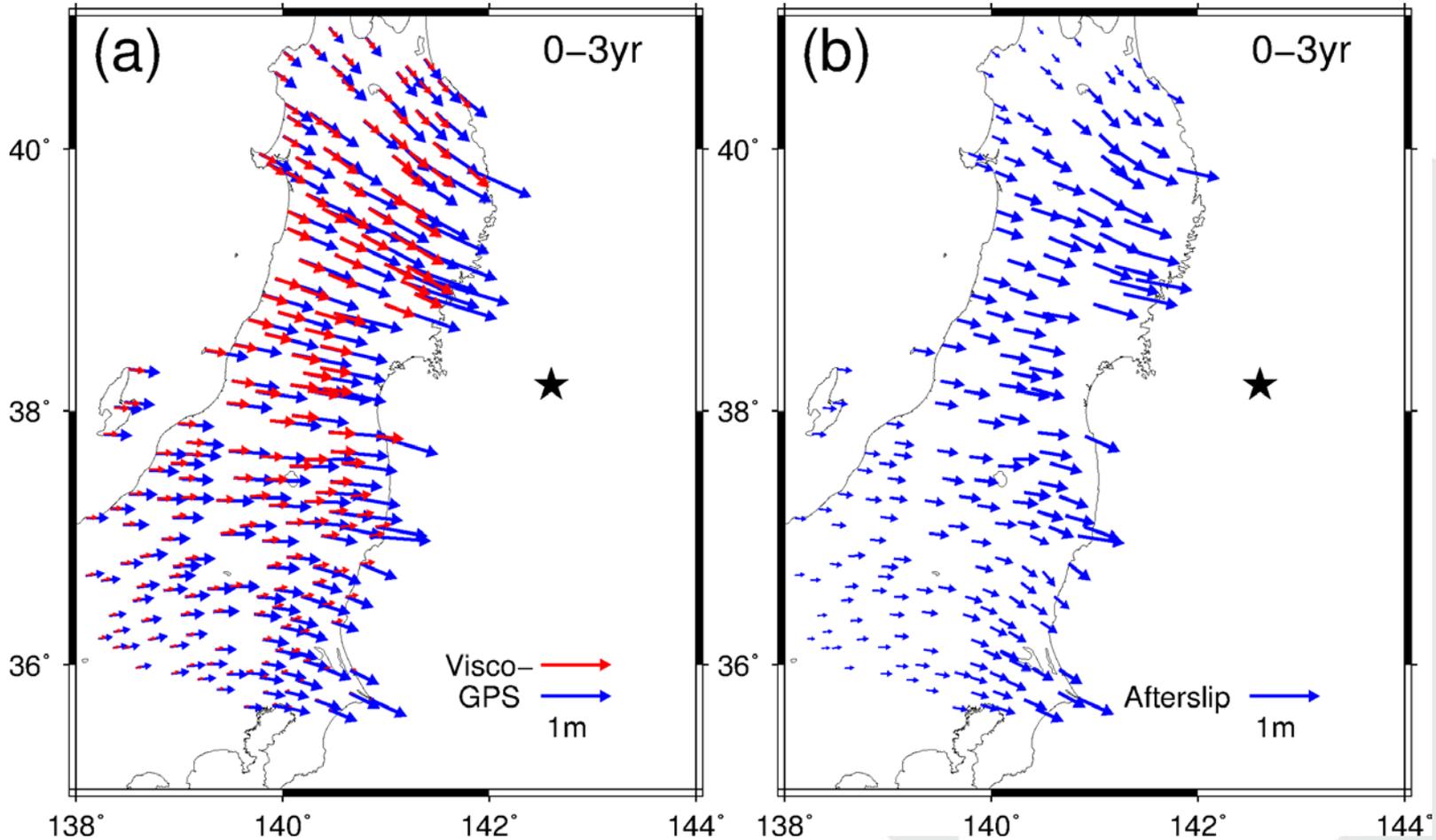
理论与观测残差曲线

最优解:

粘滞性系数: 6×10^{18} Pa.s

岩石圈弹性层厚度: 30 km

震后余滑和地幔粘滞性松弛效应



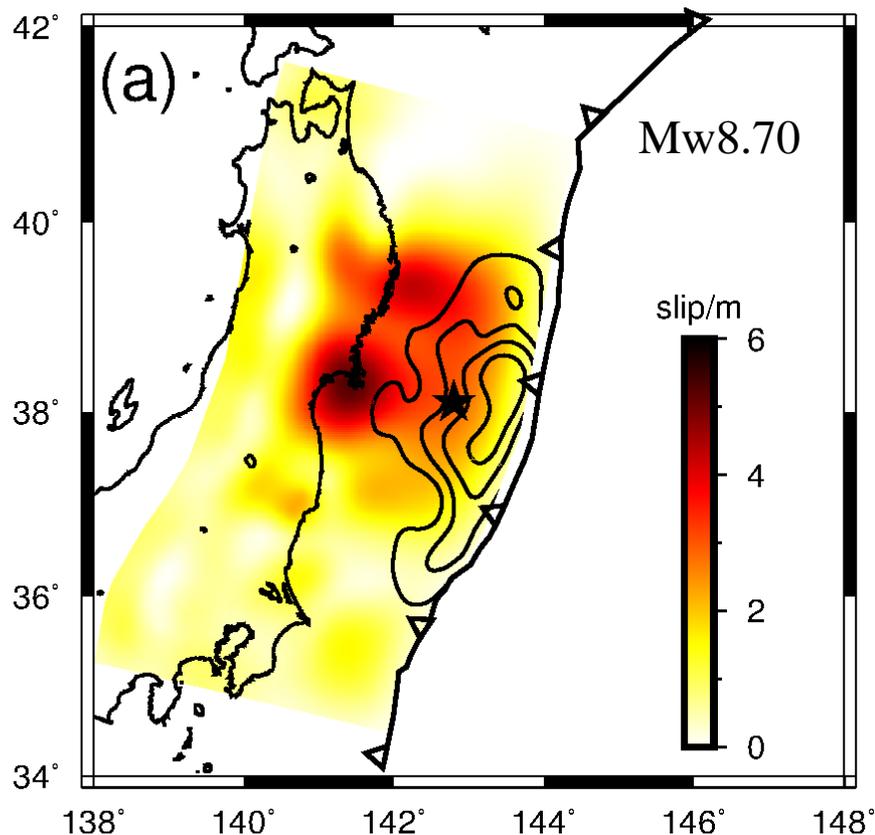
粘滞性松弛效应（红色）

震后余滑效应

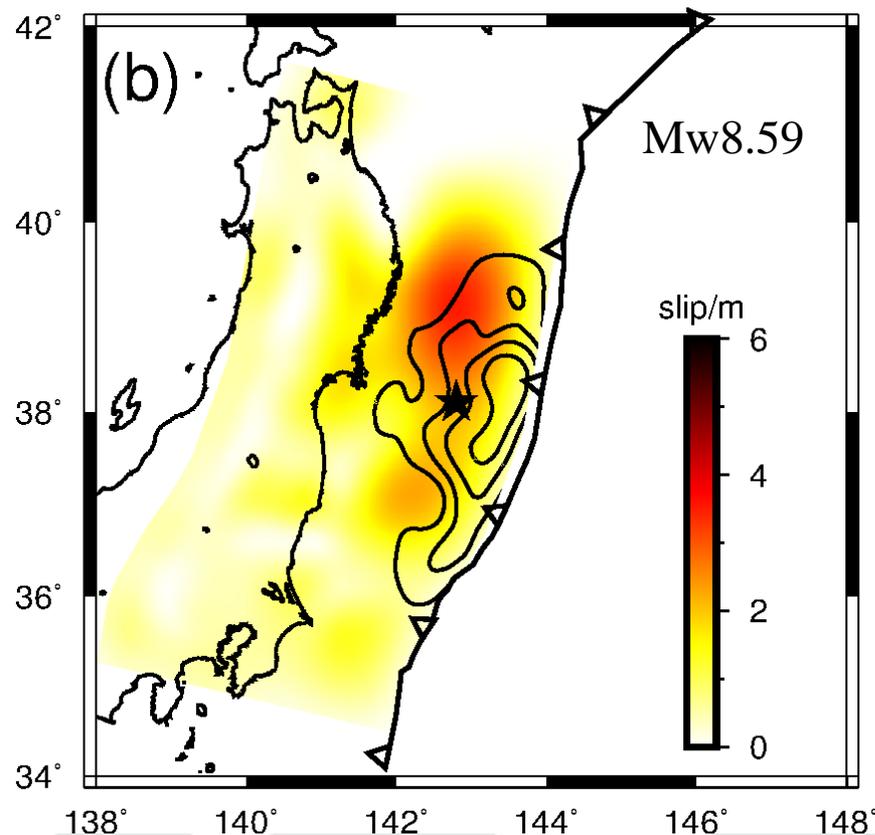
日本M_w 9.0地震震后3年累计震后余滑分布



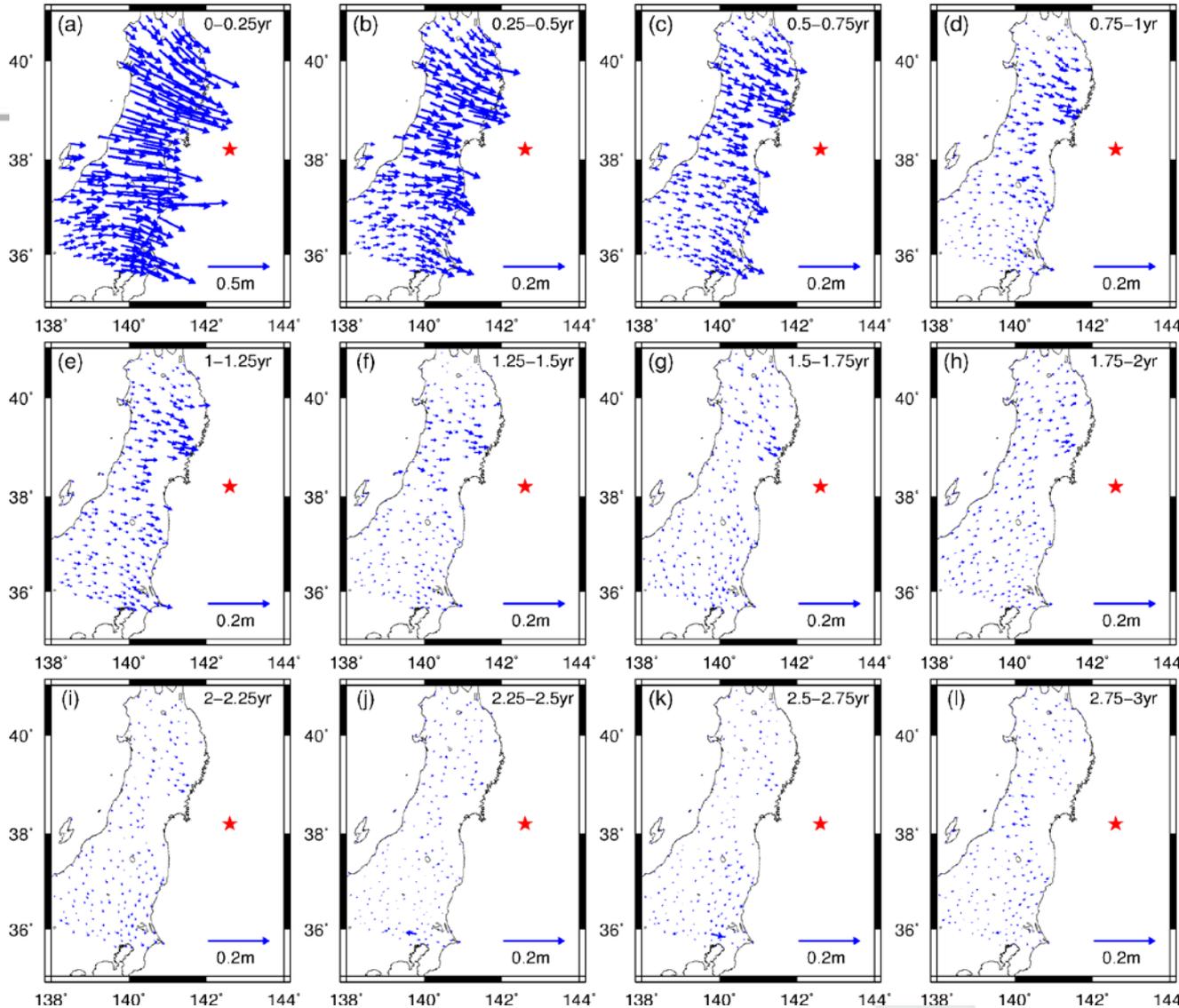
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不排除粘滞性松弛效应后
得到的震后余滑模型

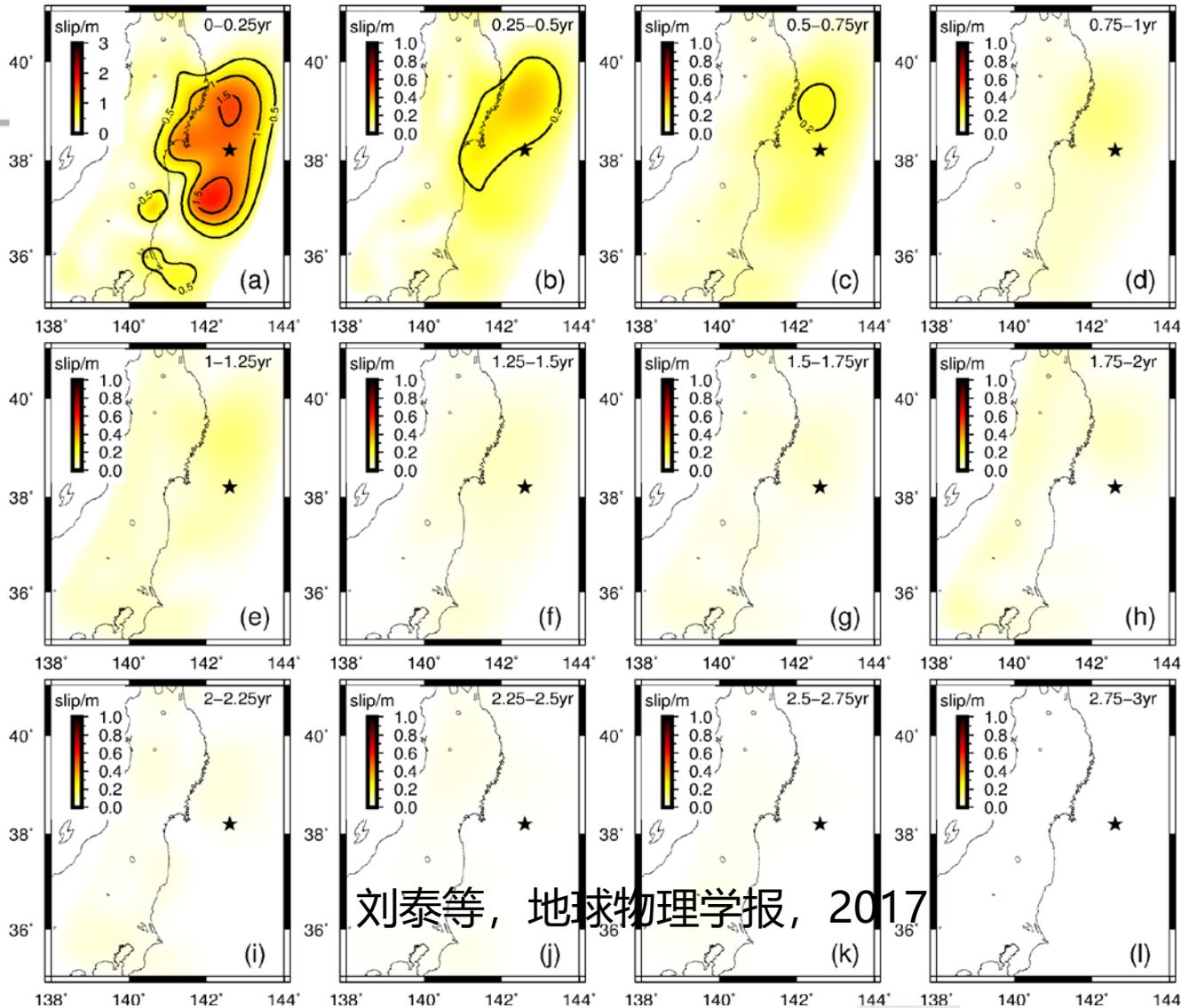


扣除粘滞性松弛效应后得
到的震后余滑模型



从GPS观测中 扣除地幔松 弛效应

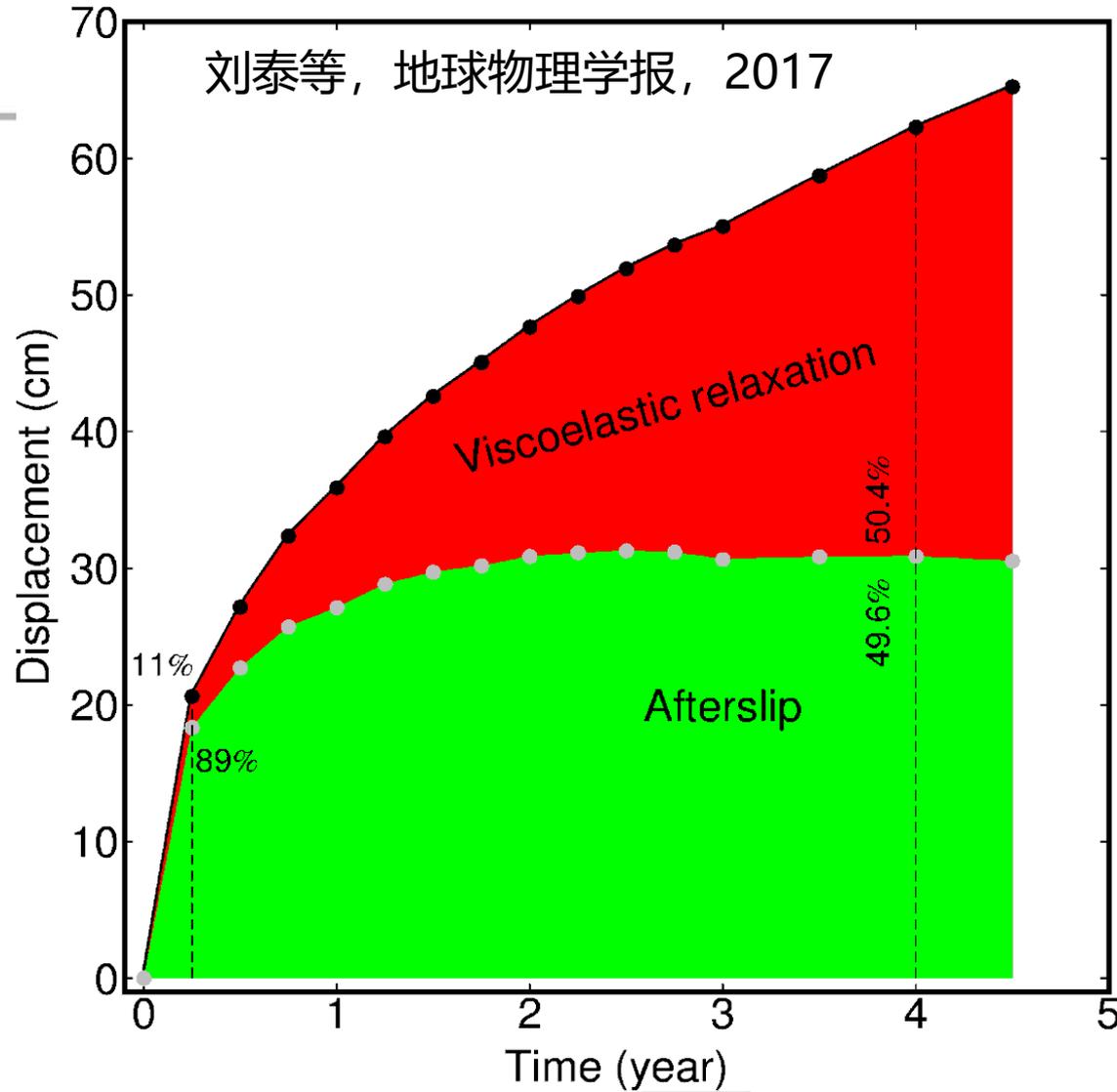
日本 M_w 9.0 地震震后余滑引起的震后位移
时间间隔为0.25年



Zhou et al.
(2014) 的
反演方法

刘泰等, 地球物理学报, 2017

日本 M_w 9.0地震震后余滑时空演化过程
时间间隔为0.25年

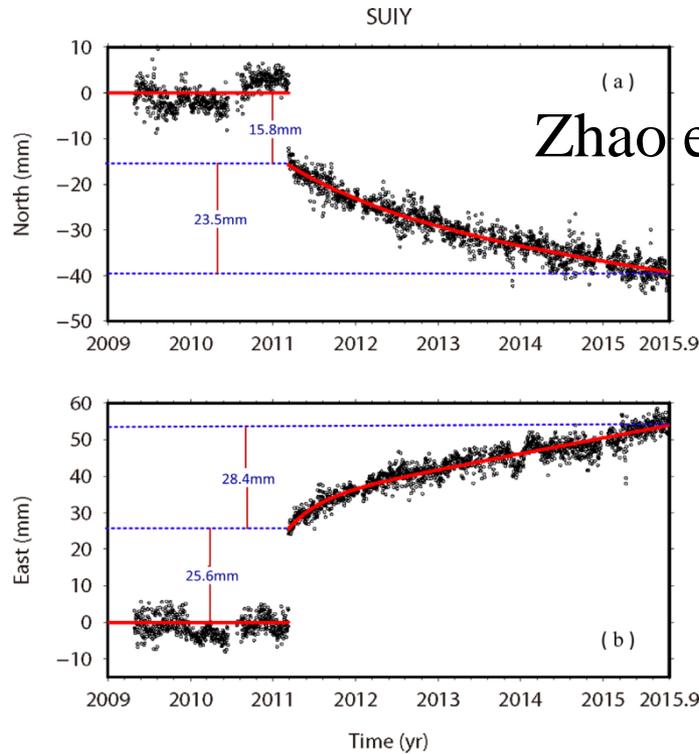


粘滞性松弛效应和余滑效应对应的震后位移均值

远场震后位移约束的地幔粘滞性因子



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Zhao et al., *GJI*, 2018

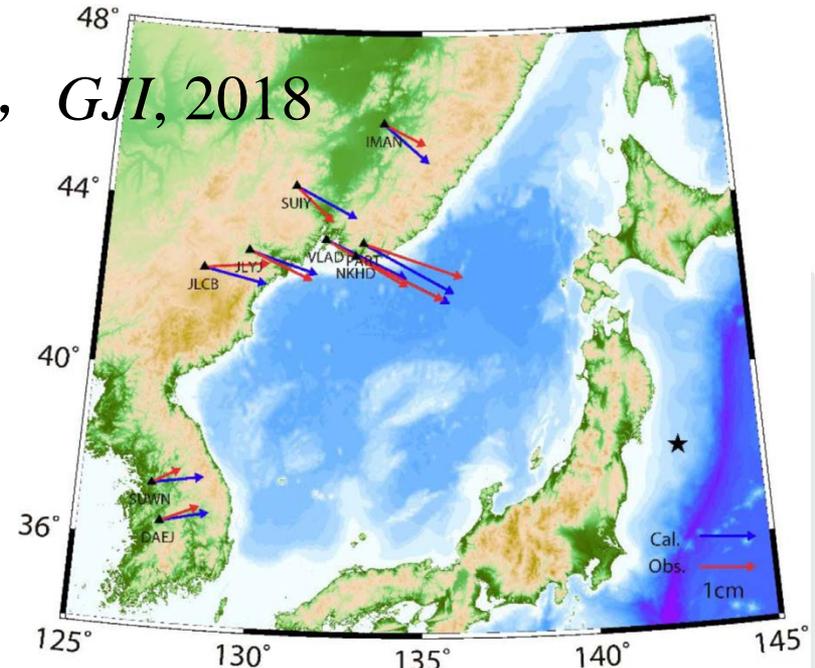


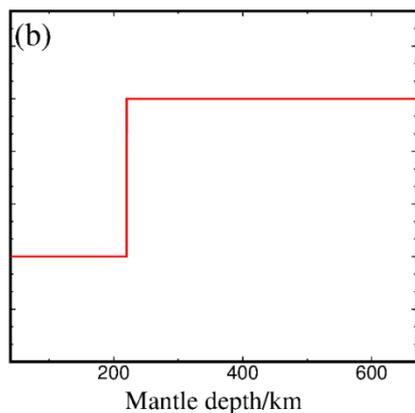
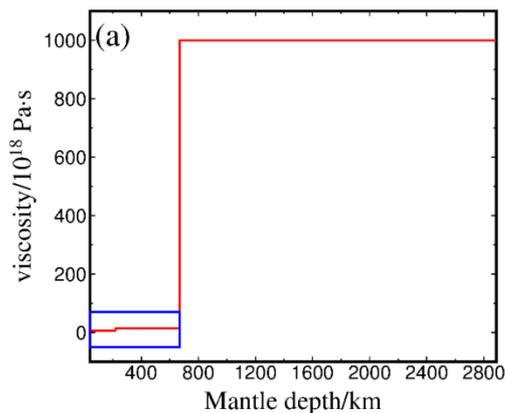
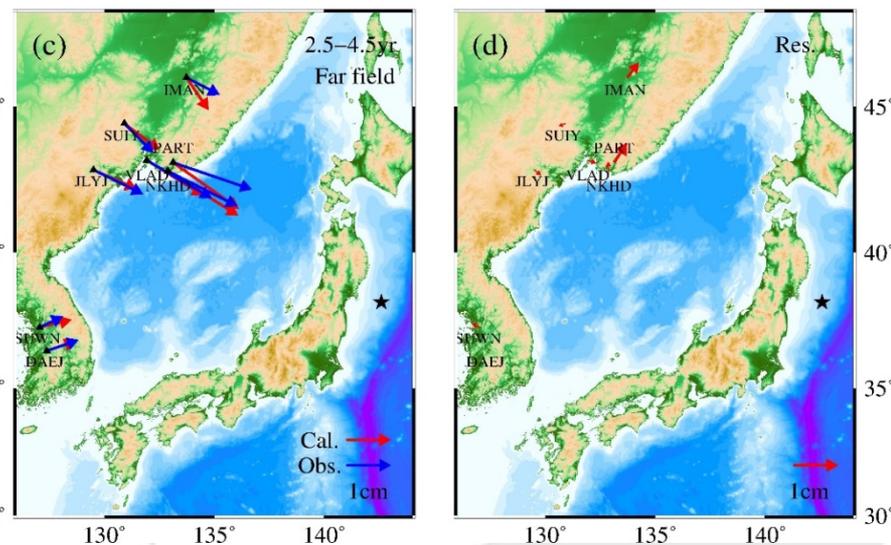
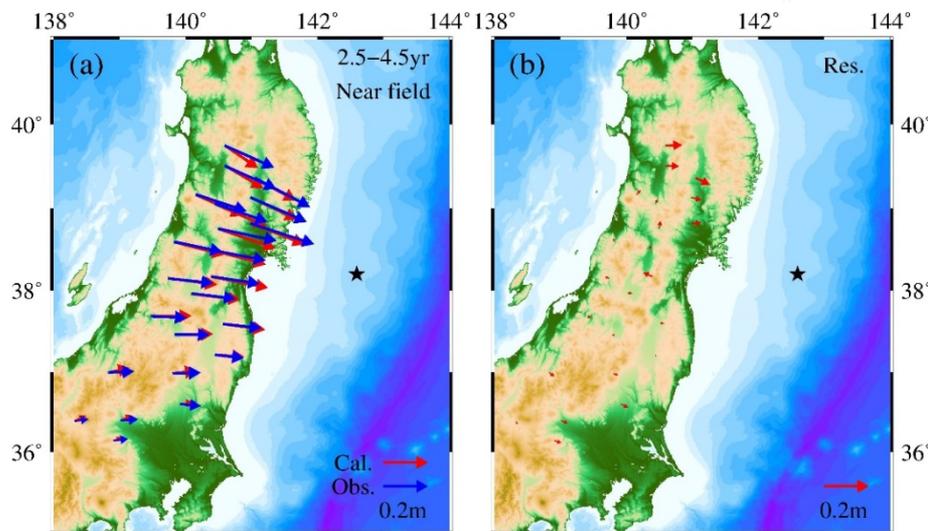
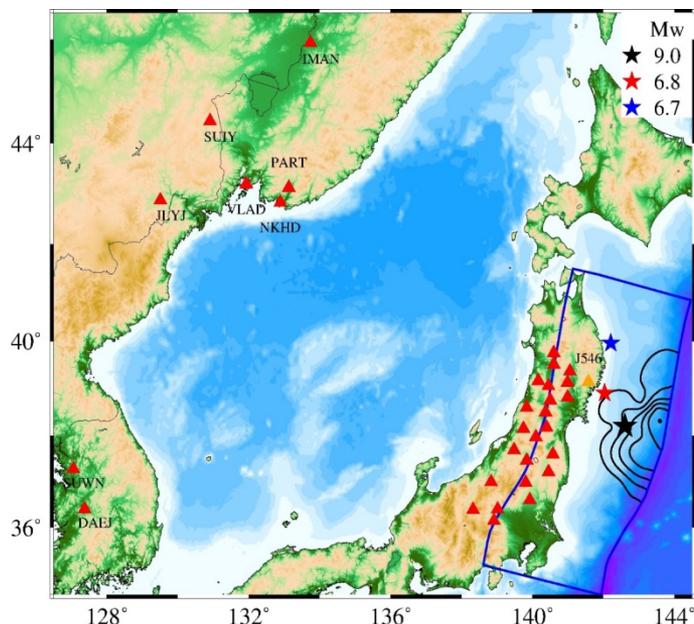
Table 3. Root-mean-square between observed and simulated results with different viscosity and lithosphere thickness.

	Residuals (cm)	Lithosphere thickness (km)			
		20	30	40	50
Viscosity (Pa s)	8×10^{18}	2.26	2.70	5.45	5.26
	1×10^{19}	2.87	1.89	3.98	3.87
	1.2×10^{19}	4.18	1.99	1.94	1.90
	1.4×10^{19}	5.22	3.19	1.92	1.91
	1.6×10^{19}	5.99	4.23	2.77	2.81
	1.8×10^{19}	6.65	5.10	3.70	3.76
	2×10^{19}	7.21	5.79	4.55	4.58

地幔粘滞性因子的垂向变化



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陈飞等, 地球物理学报, 待刊



主要参考文献

INSTITUTE OF EARTHQUAKE FORECASTING, CEA

- ◆ 陈飞, 刘泰, 付广裕, 余雅文 (2019), 震后GPS观测数据揭示的日本Mw 9.0地震周边地区地幔粘滞性结构垂向变化, *地球物理学报*, 已接收
- ◆ Zhao, Q., G. Fu., W. Wu, T. Liu, L. Su, X. Su, and N. V. Shestakov (2018), Spatial-temporal evolution and corresponding mechanism of the far-field post-seismic displacements following the 2011 Mw9.0 Tohoku earthquake, *Geophys. J. Int.*, 214:1774-1782.
- ◆ 付广裕, 刘泰 (2017), 基于粘弹性球体地球模型的震后位移与重力变化计算软件, *大地测量与地球动力学*, 37(7): 661-667.
- ◆ 刘泰, 付广裕, 周新, 苏小宁 (2017), 2011年日本Mw9.0地震震后形变机制与震源区总体构造特征, *地球物理学报*, 60(9): 3406-3417.
- ◆ Gao, S., G. Fu, T. Liu and G. Zhang (2017), A new code for calculating post-seismic displacements as well as Geoid and gravity changes on a layered visco-elastic spherical earth, *Pure and Applied Geophysics*, 174: 1167-1180.



Thank you!

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