基于密集地震台网的大震震源研究及其在地震防灾中的应用

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(王墩)

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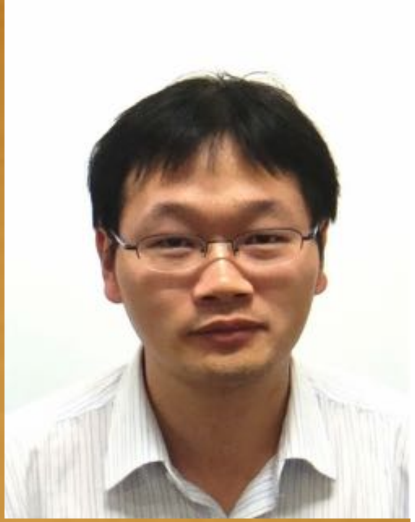
三楼阶梯教室，中国地质大学（武汉）秭归基地，秭归，宜昌，2018年9月3日

自我介绍

http://dxy.cug.edu.cn/info/1182/2321.htm



- 2000-2004年 中国地质大学地球科学学院地质学基地班专业;
- 2004-2007年 中国地震局地震研究所防灾减灾工程专业;
- 2010-2013年 京都大学地球物理专业，获理学博士学位;
- 2013-2016年 东京大学地震研究所工作 (JSPS Fellowship));
- 2016-至今，中国地质大学@武汉 地球科学学院（学科骨干人才（百人计划））。

研究兴趣

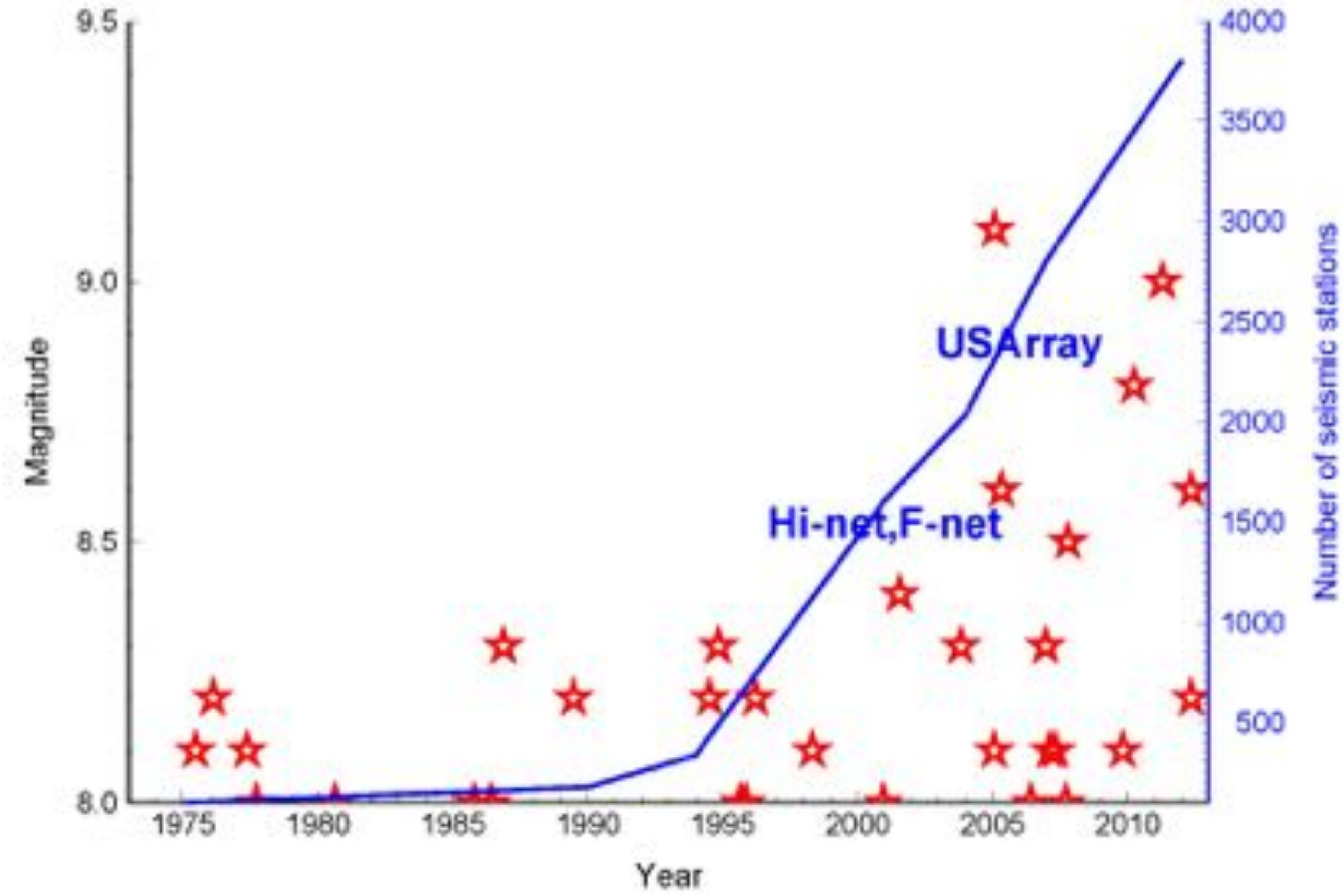
实时地震学及其在防灾减灾中的应用；
大震震源破裂过程分析及震源参数确定；
诱发地震机理研究；
构造应力场及深源地震。

以第一作者或通讯作者发表论文20余篇，合作发表学术论文共计30余篇。其中以第一作者在国际重要地学期刊（JCR top journals: Earth and Planet Science Letters (2篇), JGR-solid earth (1篇)，Geophysical Research Letters (4篇)； Bulletin of the Seismological Society of America，Earth Planets Space，Tectonophysics）发表论文11篇,被国际主流杂志引用两百余次。常年参与EPSL、GRL、BSSA等国际主流地学期刊论文的评审工作。

本报告中涉及的论文

1. **<u>Wang, D.</u>**, and A., Hutko, Relative relocations of the North Korean nuclear tests from 2006 to 2017 using the Hi-net array in Japan. ***Geophysical Research Letters*** (in press).
2. **<u>Wang, D.</u>**Kawakatsu, H., Zhuang, J., Mori, J., Maeda, T., Tsuruoka, H., & Zhao, X., Automated determination of magnitude and source length of large earthquakes using backprojection and P wave amplitudes. ***Geophysical Research Letters***, 44(11), 5447-5456, 2017.
3. **<u>Wang, D.</u>**,H., Kawakatsu, J., Mori,B. Ali, Z.K., Ren, and X.L., Shen, Back-Projection Analyses from Four Regional Arrays for Rupture Over a Curved Dipping Fault: The Mw 7.7 September 24, 2013 Pakistan Earthquake***, J. Geophys. Res. Solid Earth***,121,1948–1961, 2016.
4. **<u>Wang, D.</u>**,J., Mori, and T., Uchide, Supershear Rupture on Conjugate Faults for the Mw8.6 Off Northern Sumatra, Indonesia Earthquake of April 11, 2012,***Geophys. Res. Lett.,*** Vol. 39, L21307, pp.1-5, November, 2012.
5. **<u>Wang, D.</u>**,J., Mori, and K., Koketsu, Fast Rupture Propagation for Large Strike-slip Earthquakes, ***Earth and Planetary Science Letters***, Volume 440, Pages 115–126, 15 April, 2016.
6. **<u>Wang, D.</u>**, Takeuchi, N., Kawakatsu, H., and Mori, J., Estimating high frequency energy radiation of large earthquakes by image deconvolution back-projection. ***Earth and Planetary Science Letters***,449, 155-163, 2016.
7. **<u>Wang, D.</u>** and J., Mori, The 2010 Qinghai, China Earthquake: A Moderate Earthquake with Supershear Rupture, ***Bull. Seismol. Soc. Am***., Vol. 102, No.1, pp. 301-308, February, 2012.
8. **<u>Wang, D.</u>** and J., Mori, Frequency-dependent energy radiation and fault coupling for the 2010 Mw8.8 Maule, Chile and 2011 Mw9.0 Tohoku, Japan earthquakes, ***Geophys. Res. Lett***., Vol. 38, L22308, pp.1-6, November, 2011.

近年来大震发生频率与地震台站数



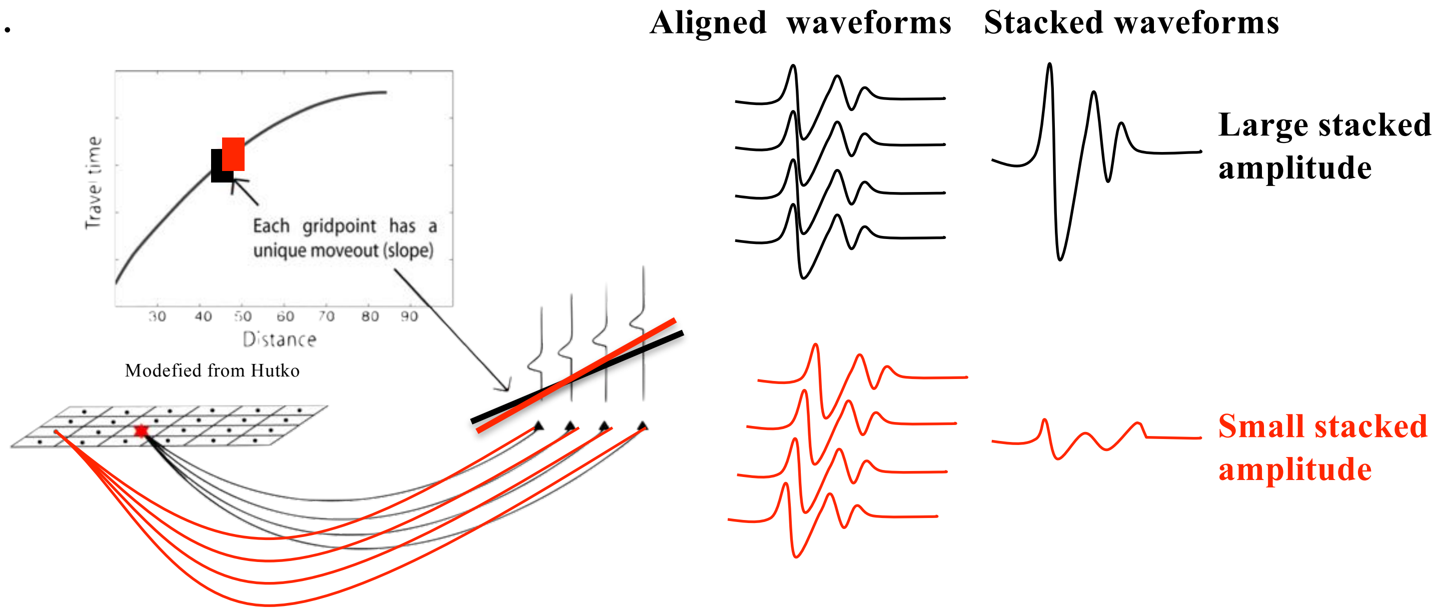
M > 8 earthquakes since 1973 (USGS)

(Ishii et al., 2005, Nature)

Methods

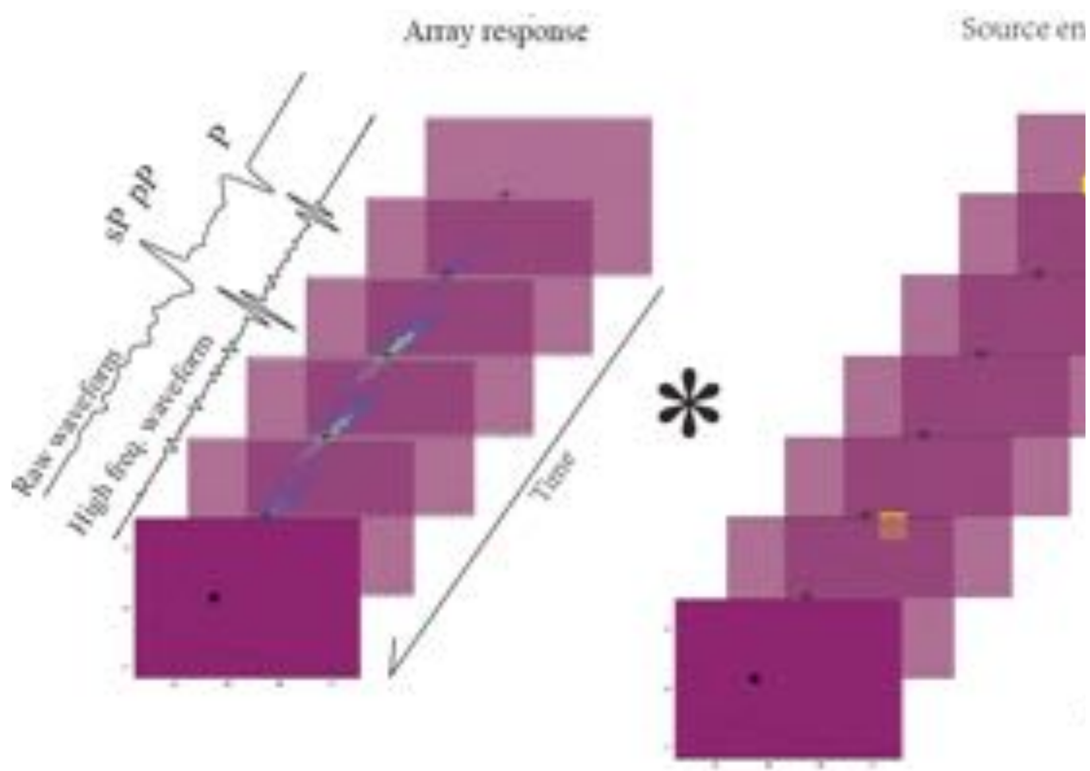
Back Projection

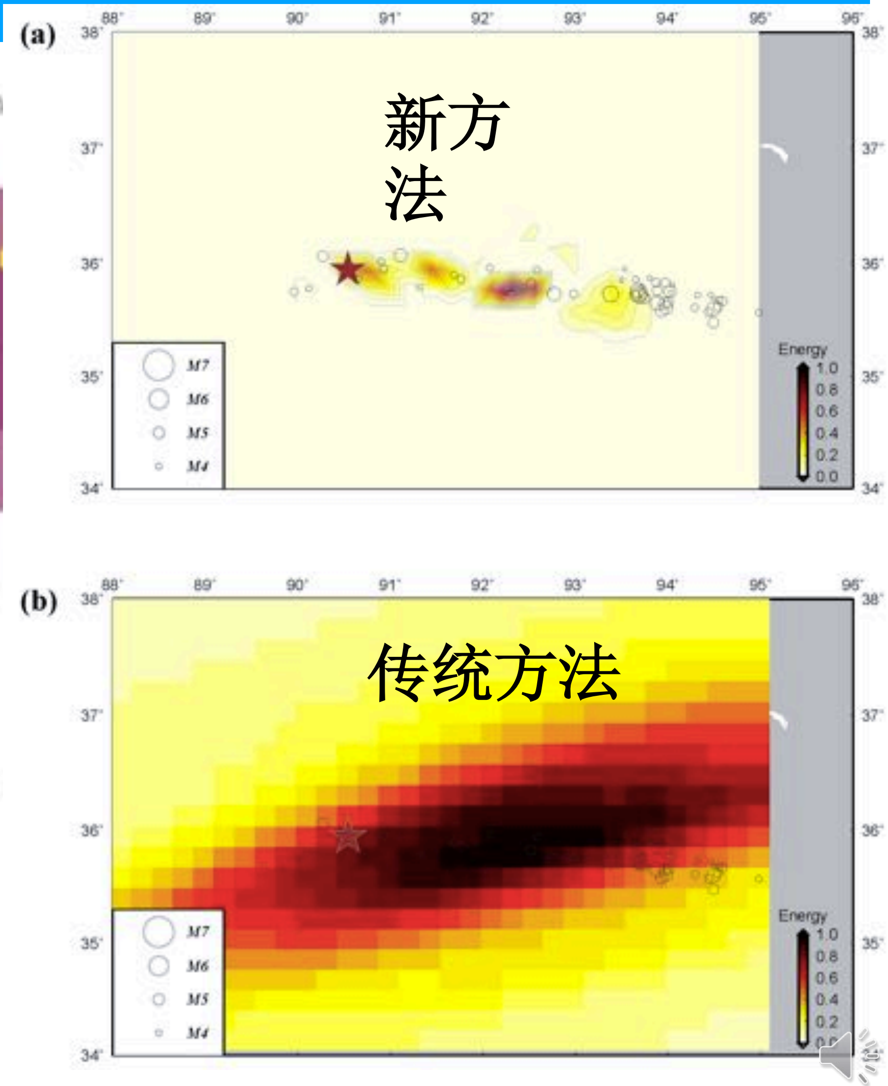
Search a grid of points to determine the best location for the source of seismic radiation in each designated time window of interested waves.



一种新的震源过程成像方法

Image Deconvolution Back-Projection (IDBP)





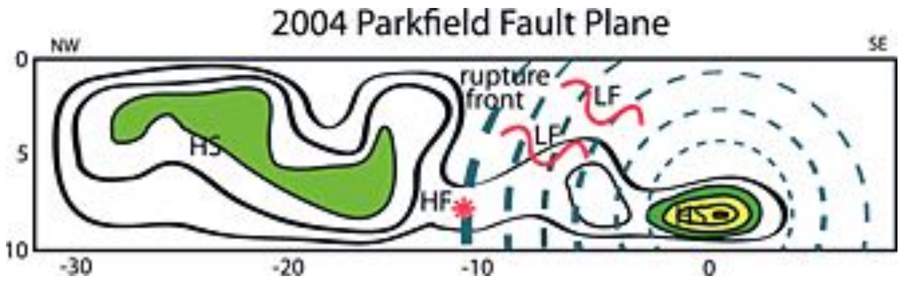
(Wang et al., 2016b, EPSL)

大震破裂过程研究

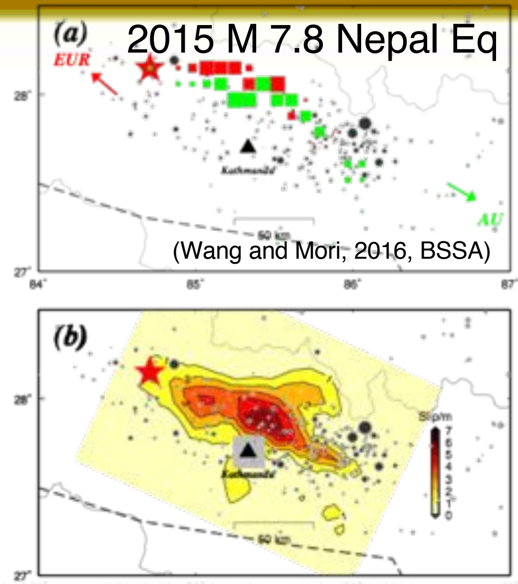
Frequency-dependent Energy Radiation

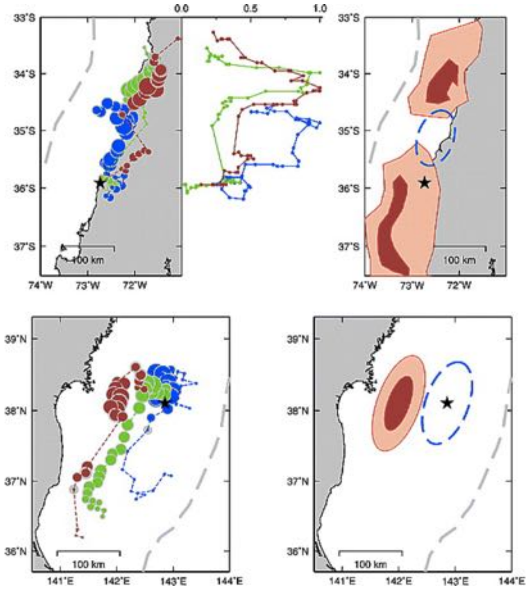
Rupture Speed

Frequency-dependent Energy Radiation

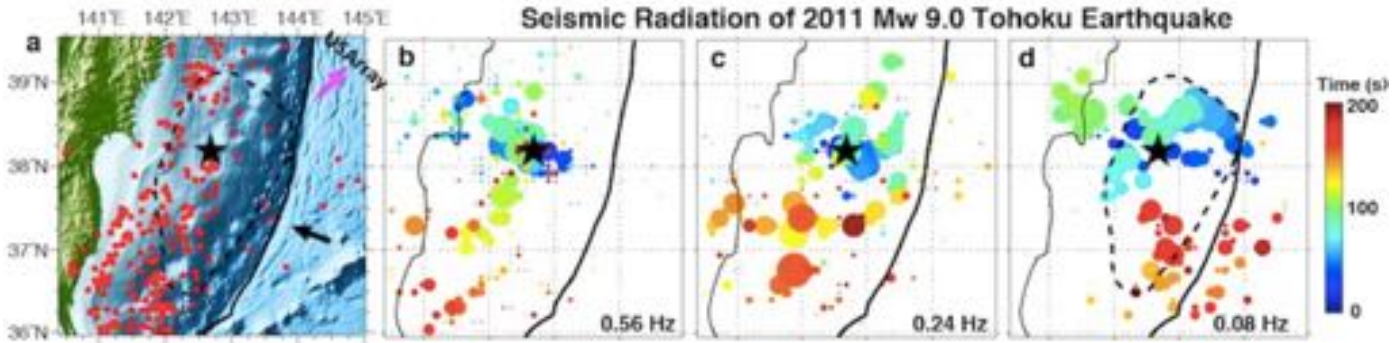


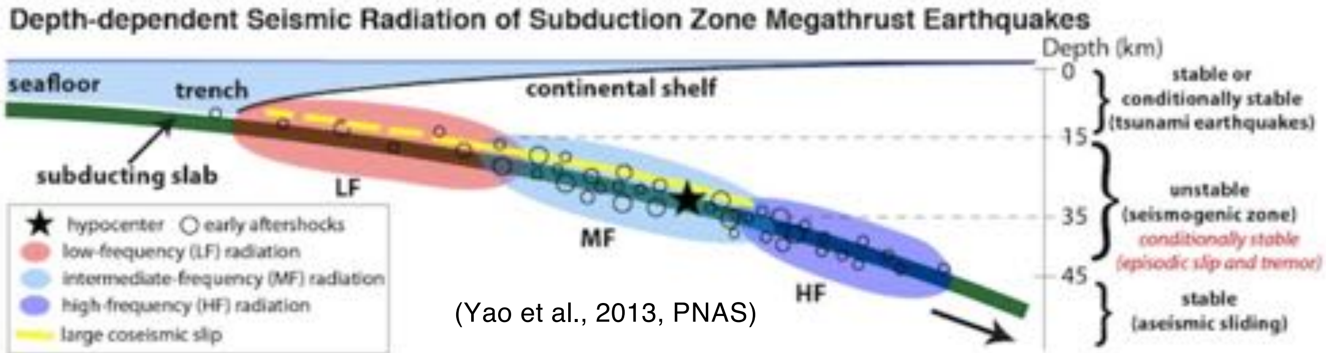
(Fletcher et al., 2014, JGR)





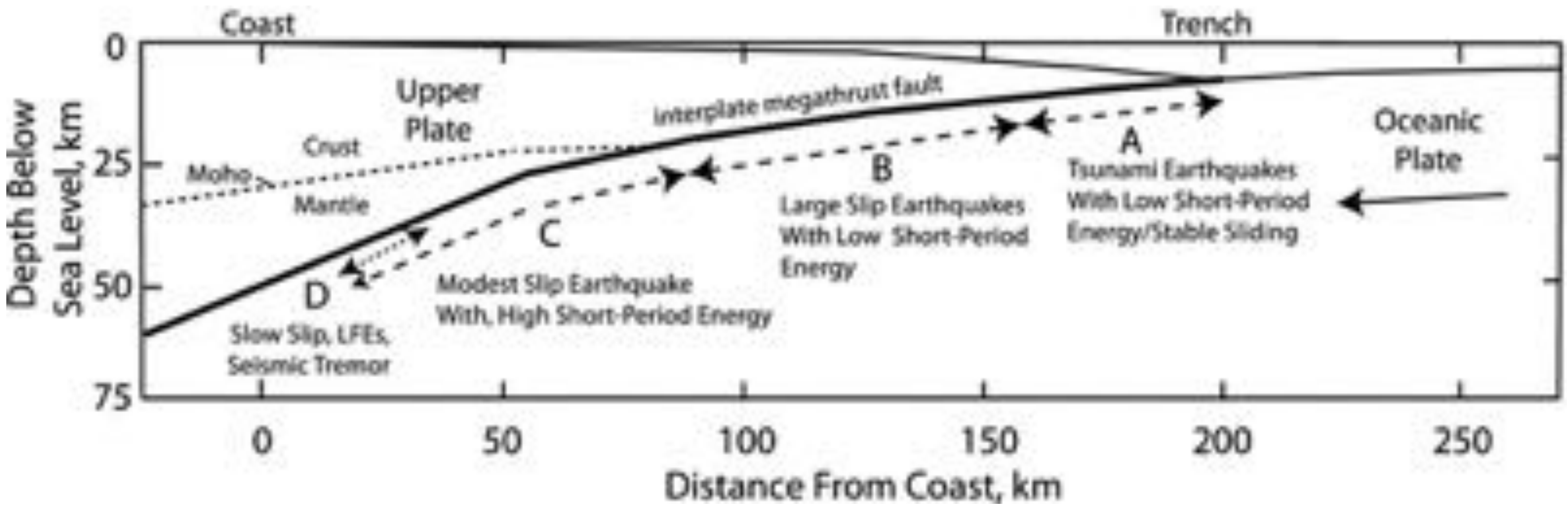
2010 M 8.8 Chile and 2011 M 9.0 Tohoku earthquakes





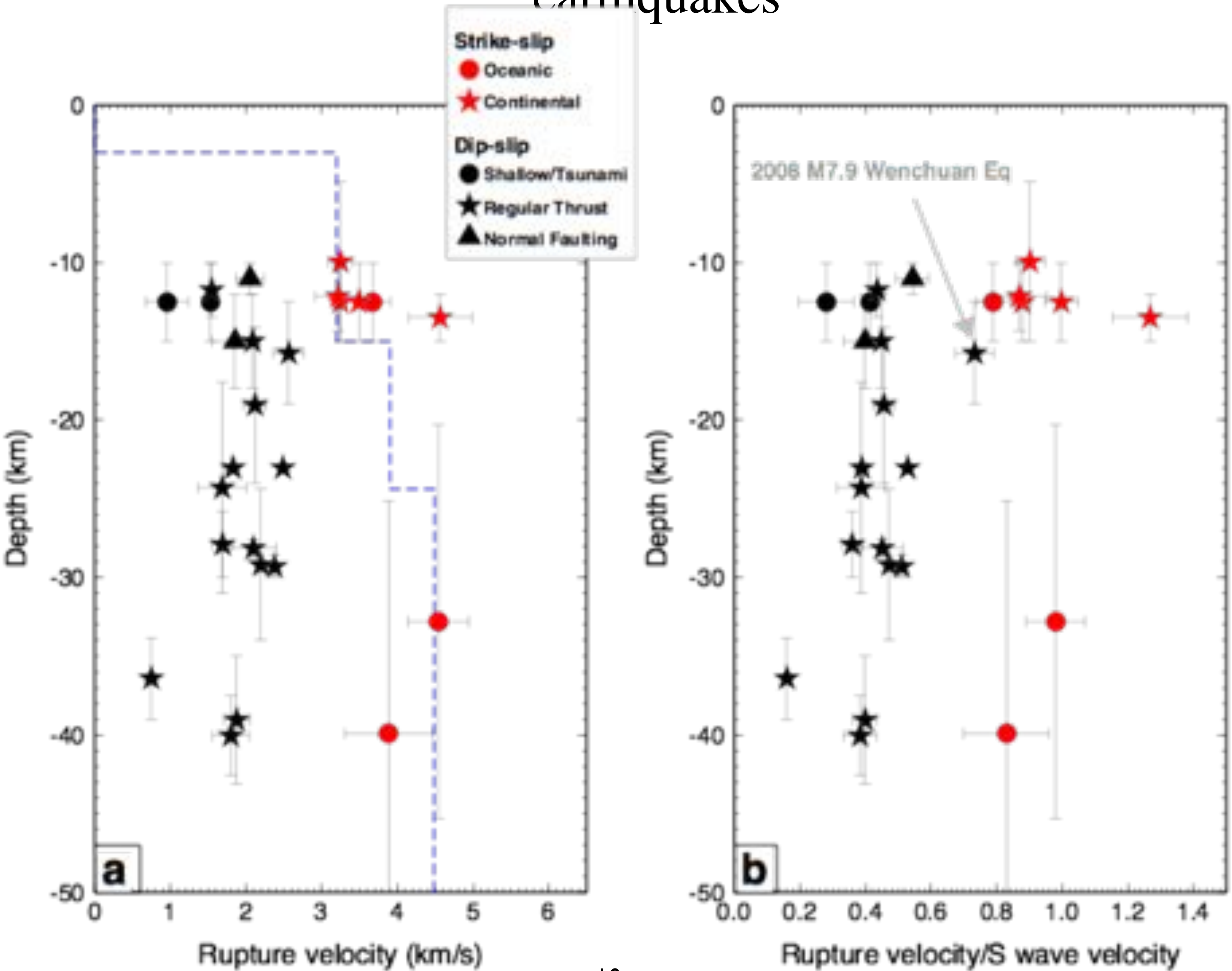
(Yao et al., 2013, PNAS)

Frequency-dependent Energy Radiation



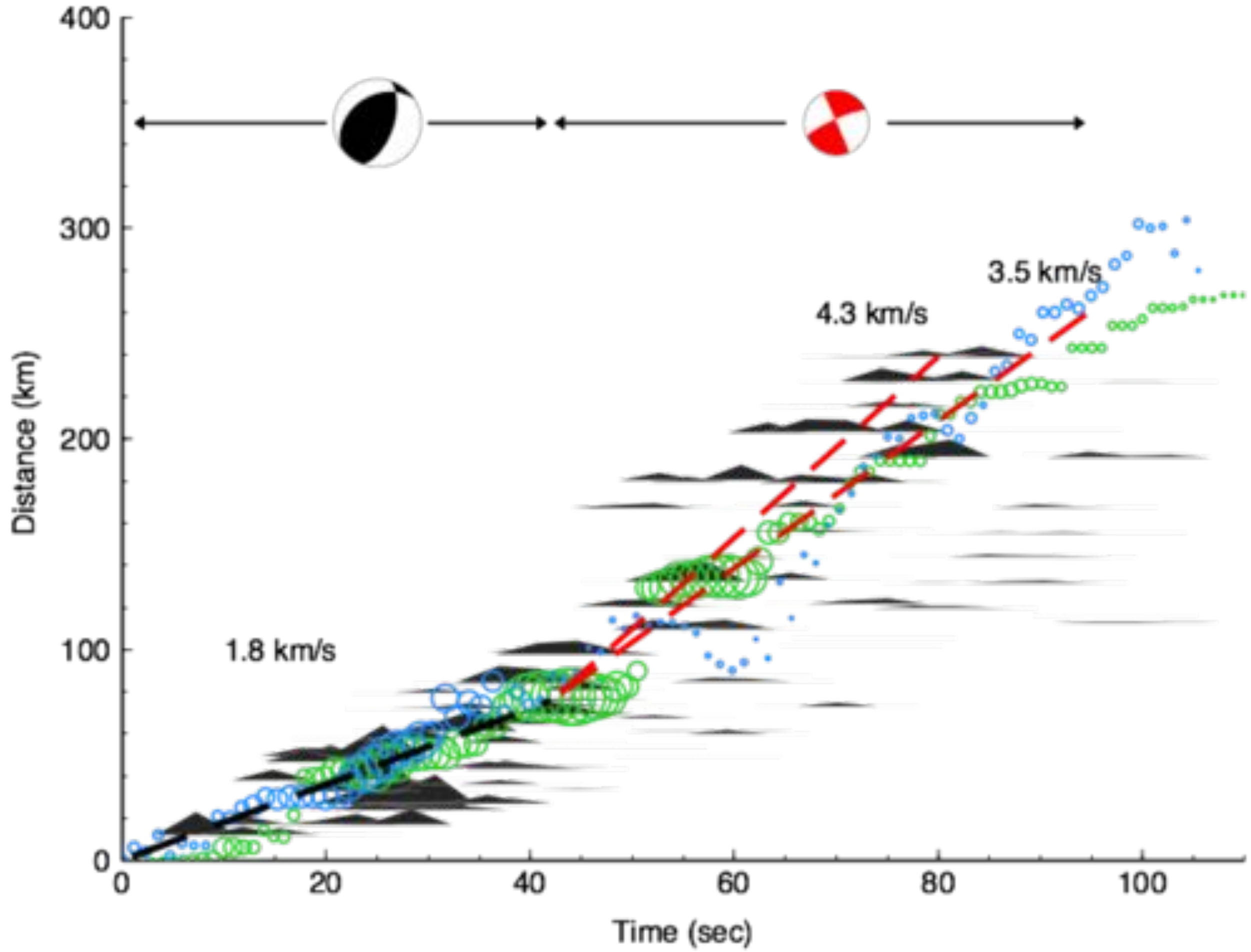
(Lay et al., 2012, JGR)

Average rupture speeds of recent large earthquakes



(Wang et al., EPSL, 2016a)

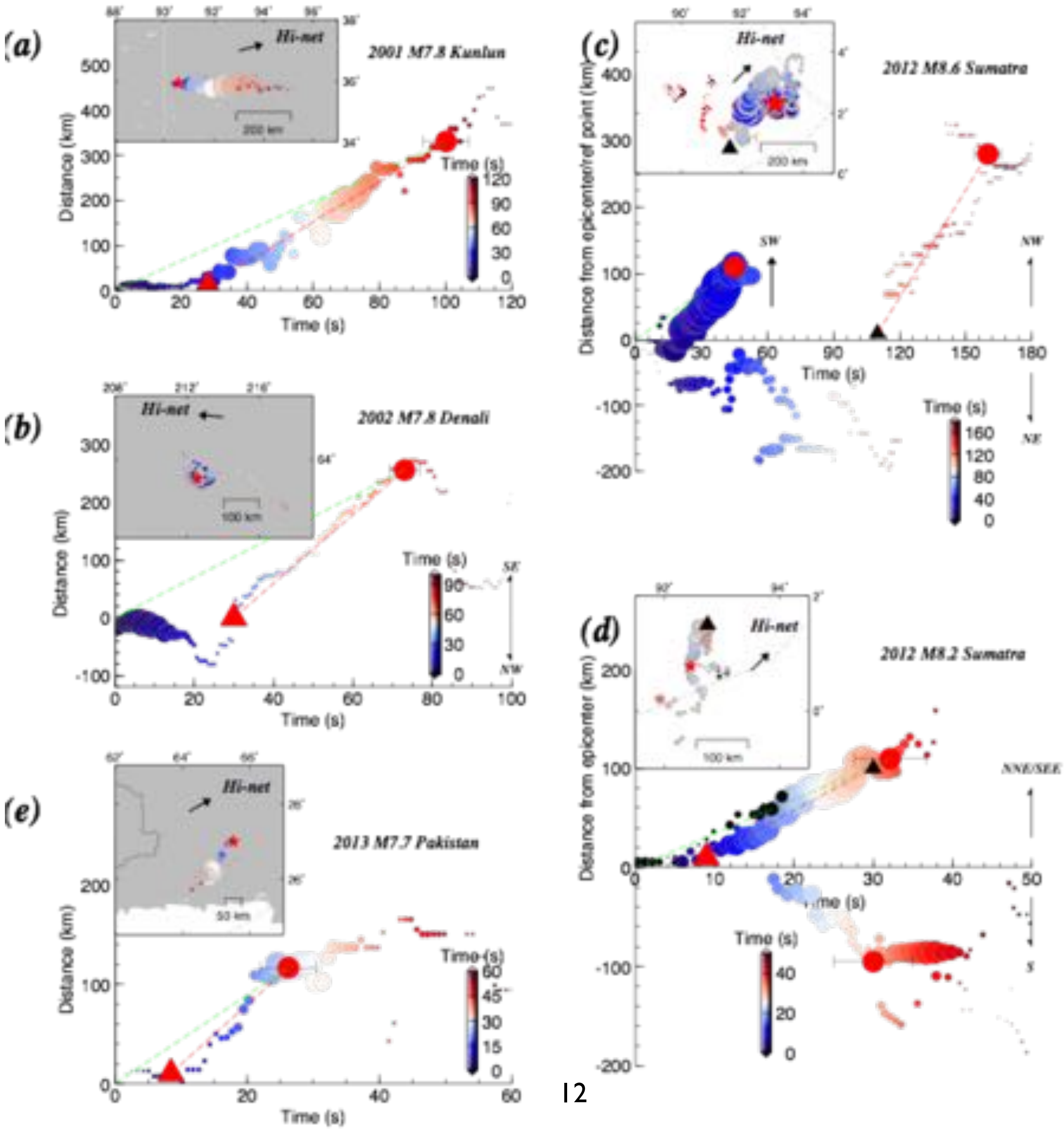
2008 M 7.9 Wenchuan earthquake



Rupture speeds derived from back-projection using EUR data and Alaska regional array (blue, by Du et al., 2009) and strong motion inversion (black triangles, by Zhang et al., 2012) for the 2008 M 7.9 Wenchuan earthquake.

(Wang et al., EPSL, 2016a)

Rupture propagation for five large strike-slip earthquakes



(Wang et al., EPSL, 2016a)

全球破坏性大震震级快速自动测定

Automated Determination of Magnitude (M_{dt}) of Large Shallow Earthquakes in Japan using Real Time Seismic data recorded in China and across the Globe (GSN)

央视网消息（新闻联播）：中共中央总书记、国家主席、中央军委主席习近平2日下午在中南海同团中央新一届领导班子成员集体谈话并发表重要讲话，他强调，青年一代有理想、有本领、有担当，国家就有前途、民族就有希望。代表广大青年、赢得广大青年、依靠广大青年是我们党不断从胜利走向胜利的重要保证。中华民族伟大复兴的中国梦终将在一代代青年的接

Motivation

Expected Earthquake Sources
50 to 150 km segments
M6.7 to 8.2
(Headquarters for Earthquake Research Promotion, Japan)

30 year Probabilities

North Sanriku-oki ~M8
0.2 to 10%

South Sanriku-oki ~M7.7
80 to 90%

Off Miyagi ~M7.5
> 90%

Off Fukushima ~M7.4
7%

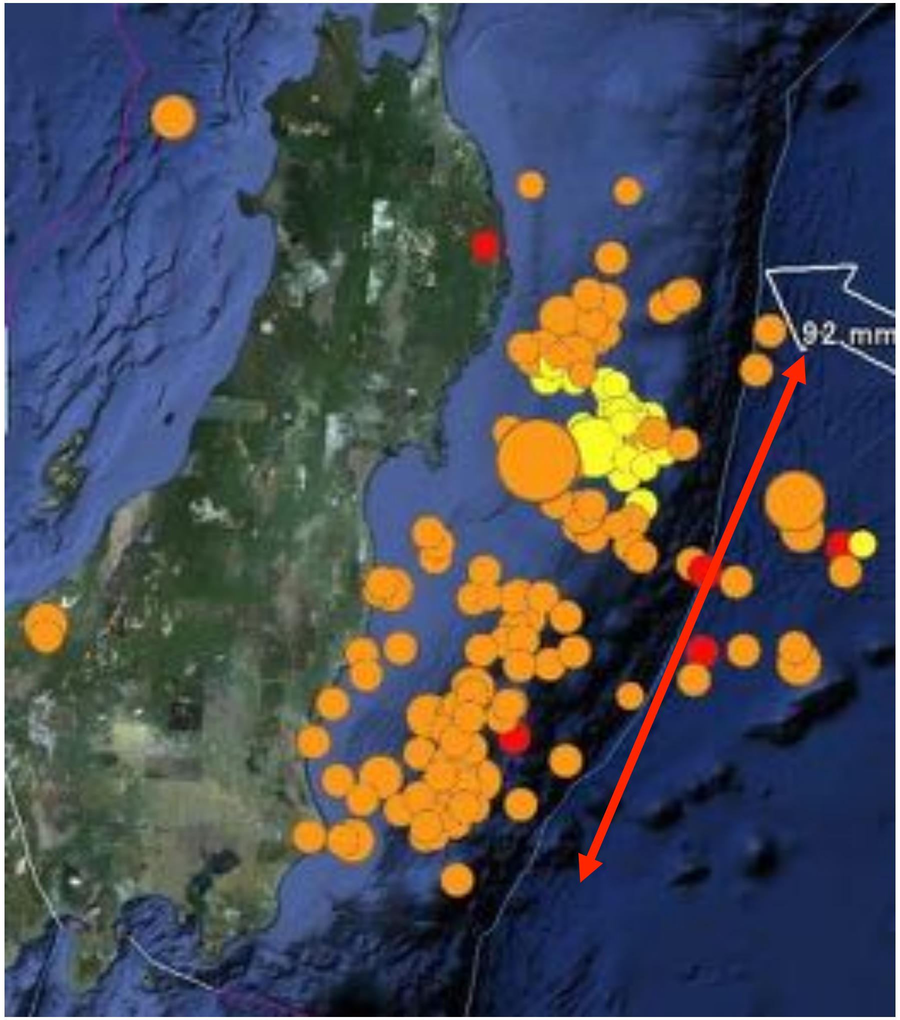
Off Ibaraki ~M6.7 – M7.2
90%

Sanriku to Boso M8.2 (plate boundary)
20%
Sanriku to Boso M8.2 (Intraplate)
4-7%

(Concluded by Jim Mori)

Earthquake much bigger than expected !

Expected Earthquake Sources
50 to 150 km segments
M6.7 to 8.2
(Headquarters for Earthquake Research Promotion)

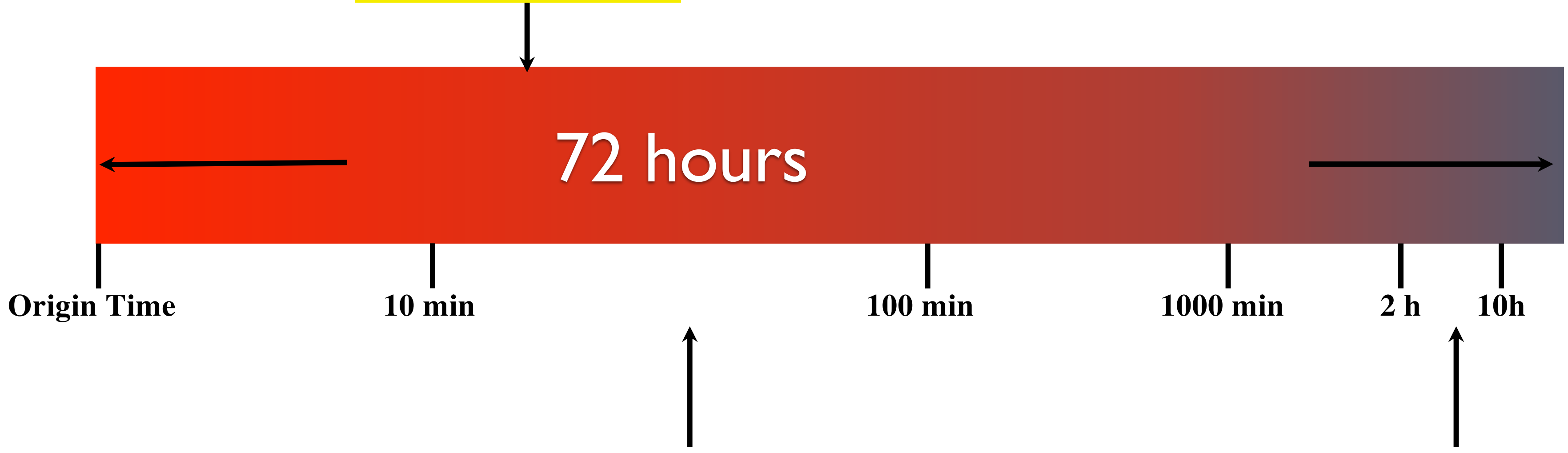


2011 Tohoku Earthquake
500 km long fault, M 9.0
(Aftershock map from USGS)

The 2011M 9.0 Tohoku, Japan earthquake

The 2011 M 9.0 Tohoku earthquake

M*w*
Source extent
source duration
asperity locations



Magnitude

5-13 min after O.T.
Mwp 7.9
USGS

32 min after O.T.
Mw 8.9
USGS W phase

7 h after O.T.
Mw 9.1
GCMT

Tsunami warning

4 -24 min after O.T. warning based on Mjma 7.9 (JMA)

Tsunami hit the nearest coast (JMA), and Tsunami Warning extended

Source extent

?

Slip models

研究背景——常用震级

➢M_L，里氏震级；m_b，体波震级；M_s，面波震级；

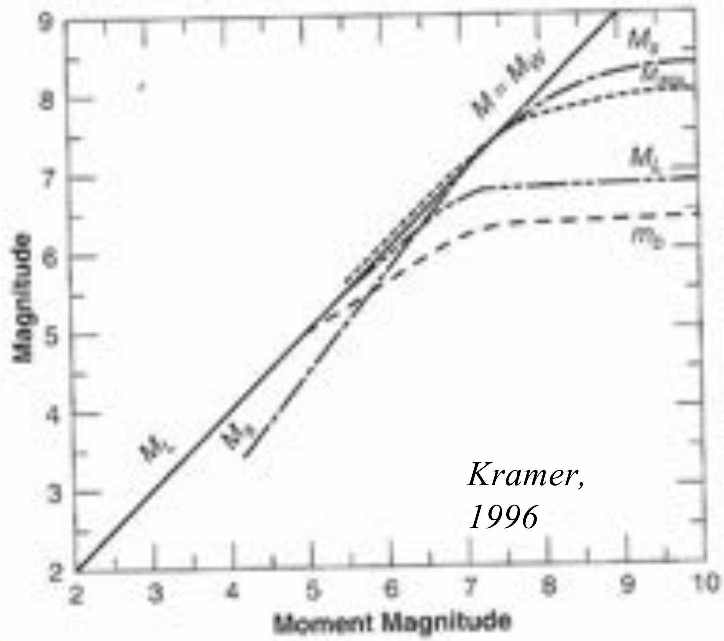
$$M = \log\left[\frac{A}{T}\right] + F(h,\Delta) + C$$

振幅　周期　震源深度　震中距

$$M_W = \frac{\log M_0}{1.5} - 10.73$$

$$M_0 = \mu \bar{D} S$$

破裂面积　剪切模量　平均位移



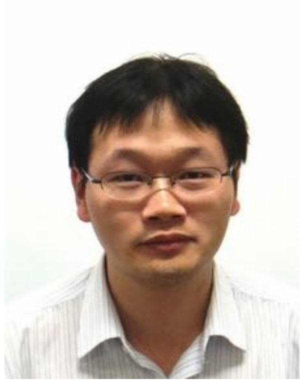
➢M_w，矩震级，有物理意义，不存在饱和现象；M_{ww}（W-phase）应用广泛；但是涉及全波形反演，时效性不高，其次对长持续时间的地震测定有误差；

➢M_{dt}: P maximum displacement **(D)** + source duration **(T)**.

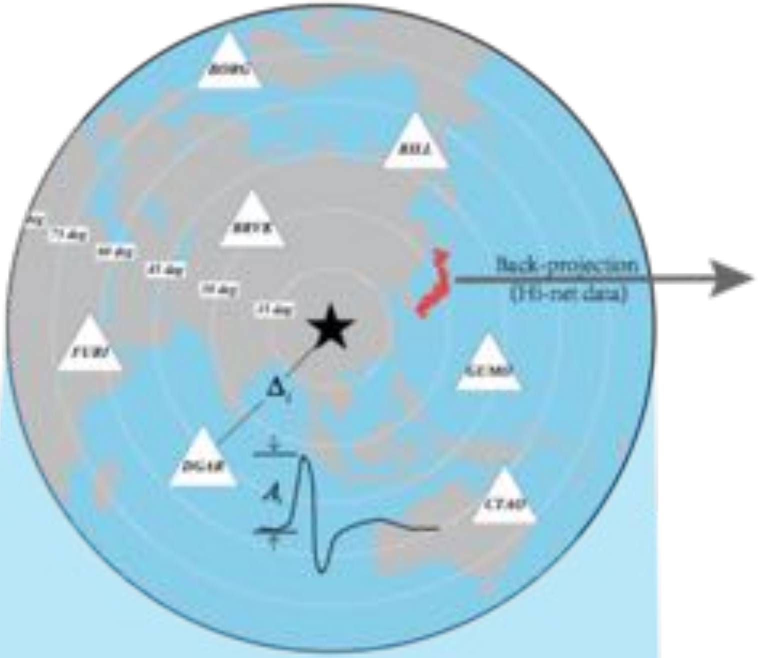
(Qiang Yao, 2018)

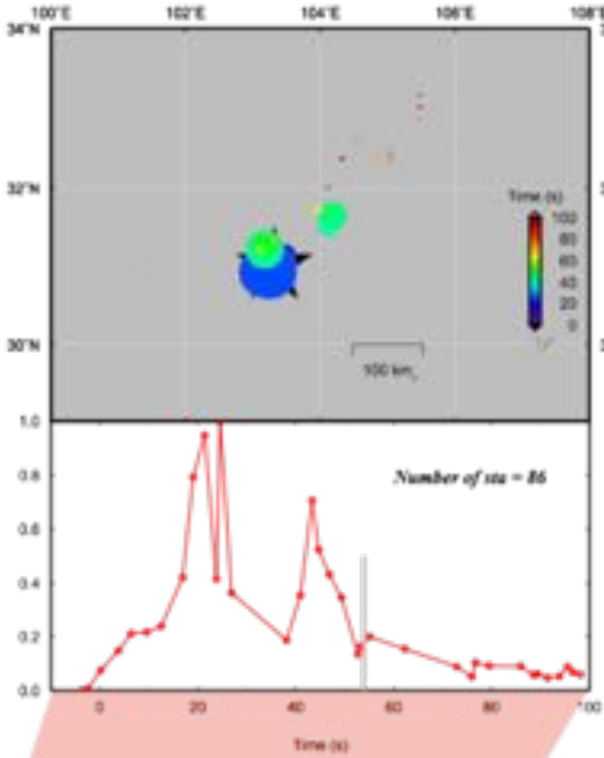
A new magnitude *scale*

M_{dt} (Displacement & Time)




Dun Wang & Tatsuhiko Hara

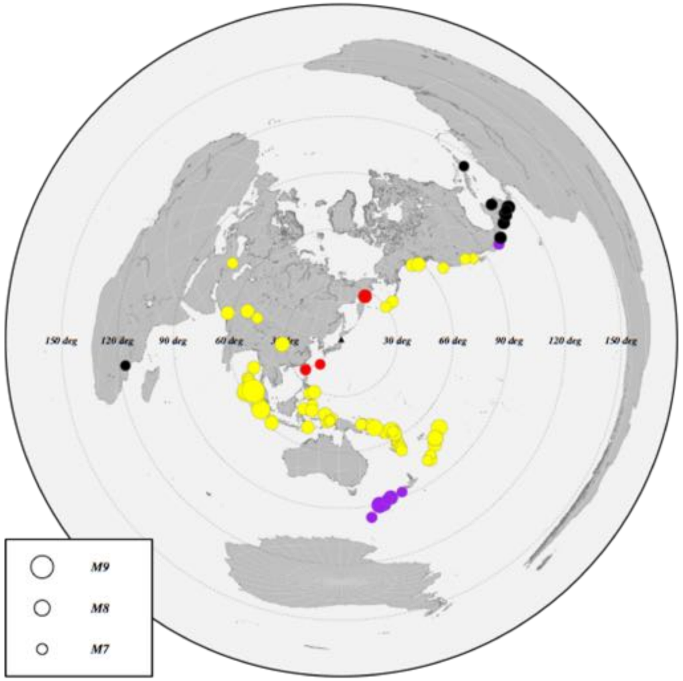




Maximum displacement of global P wave

Source duration

$$M = \frac{?}{N}\sum_{i=1}^{N}\log A_i + \frac{?}{N}\sum_{i=1}^{N}\log\Delta_i + ?\log(duration) + ?$$



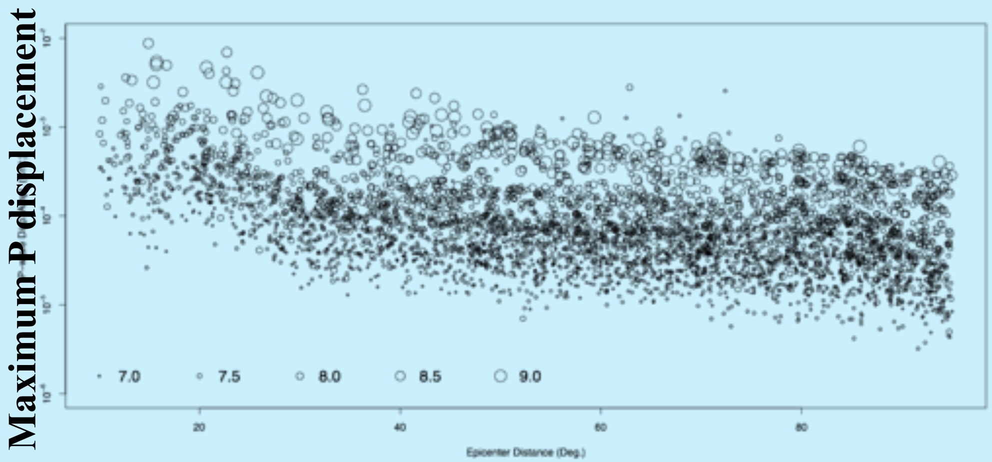
Locations of earthquakes analysed in this study (Depth <= 60 km; Magnitude （**Mww**） >= 7.0; Distance (to station HMNH) = 15 - 120 deg.; 2004-2014**).**

Dashed lines represent the distances to the Hi-net center (black triangle).

Color indicates the distance to Hi-net (red, 10-30°; yellow, 30-85°; purple, 85-100°; black, 100-120°)

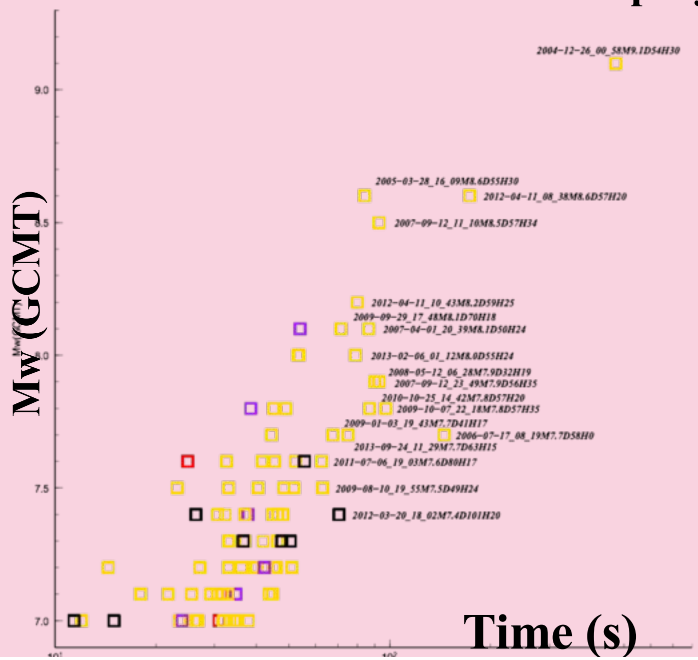
From global stations

Maximum displacement of P wave



From Hi-net

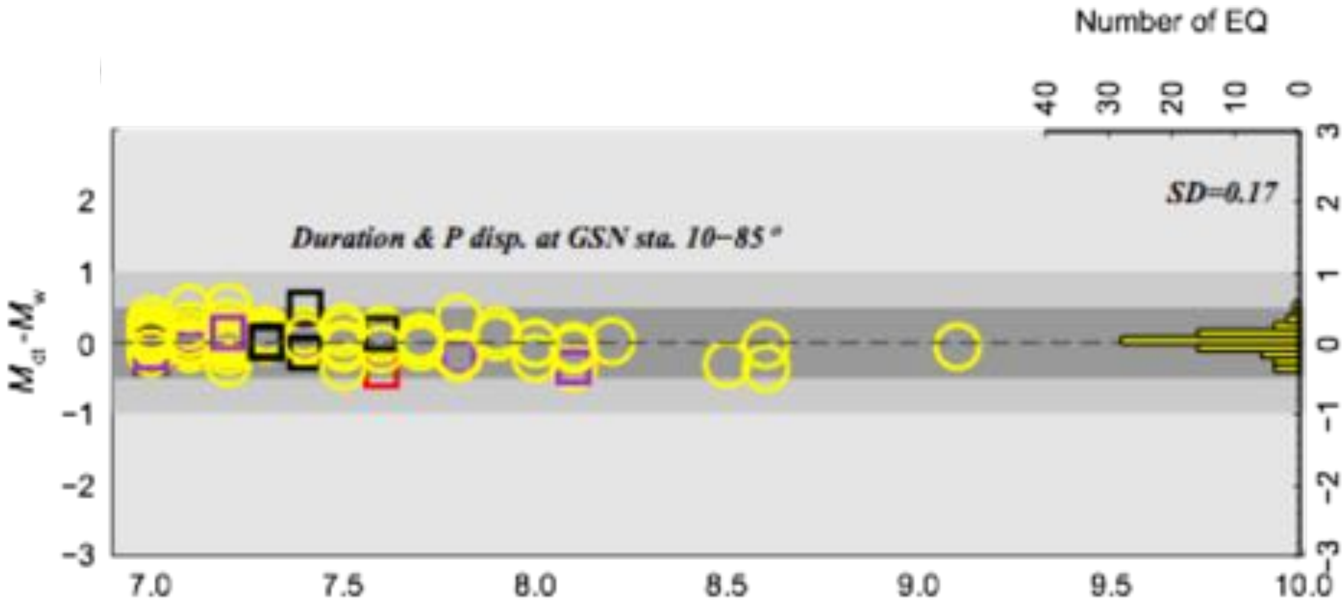
Source duration derived from back-projection

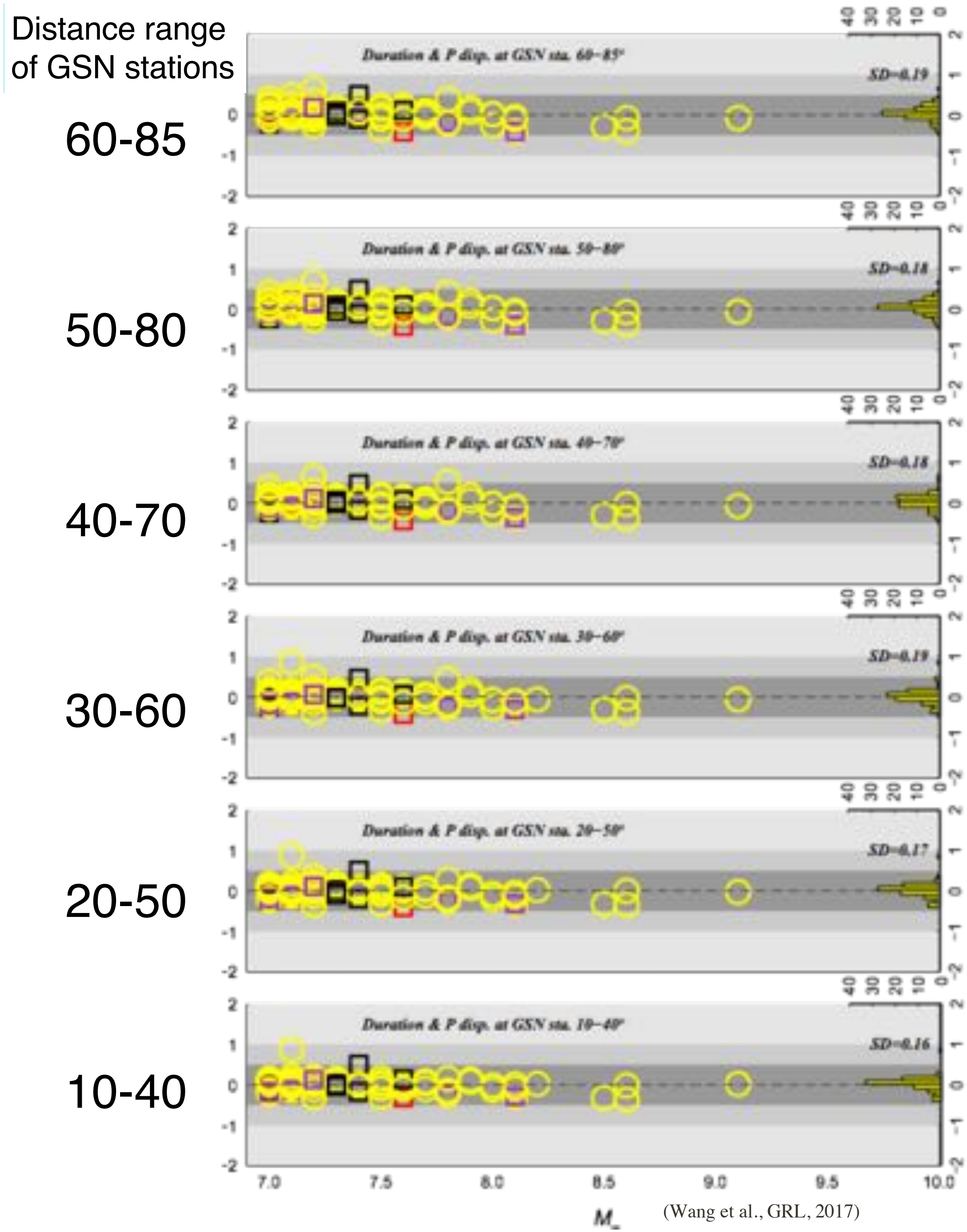


Maximum displacement of global P wave

Source duration

$$M = \frac{0.55}{N}\sum_{i=1}^{N}\log A_i + \frac{0.67}{N}\sum_{i=1}^{N}\log \Delta_i + 1.01\log(duration) + 5.55$$





(Wang et al., GRL, 2017)

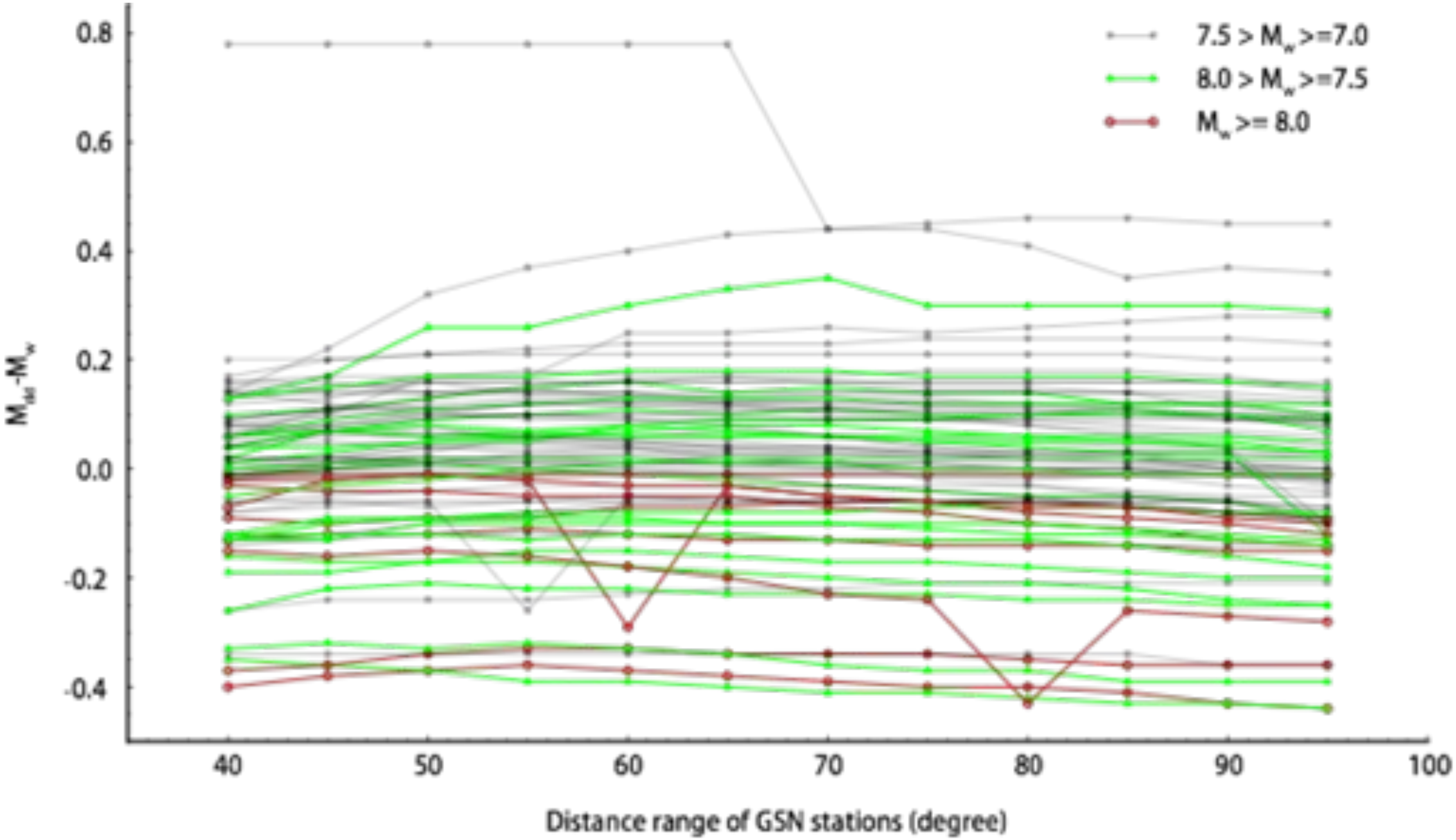
Robust with a few global stations

Duration & GSN stations in a series of distance ranges with respect to the epicenters.

Color indicates distance ranges to the Hi-net center.

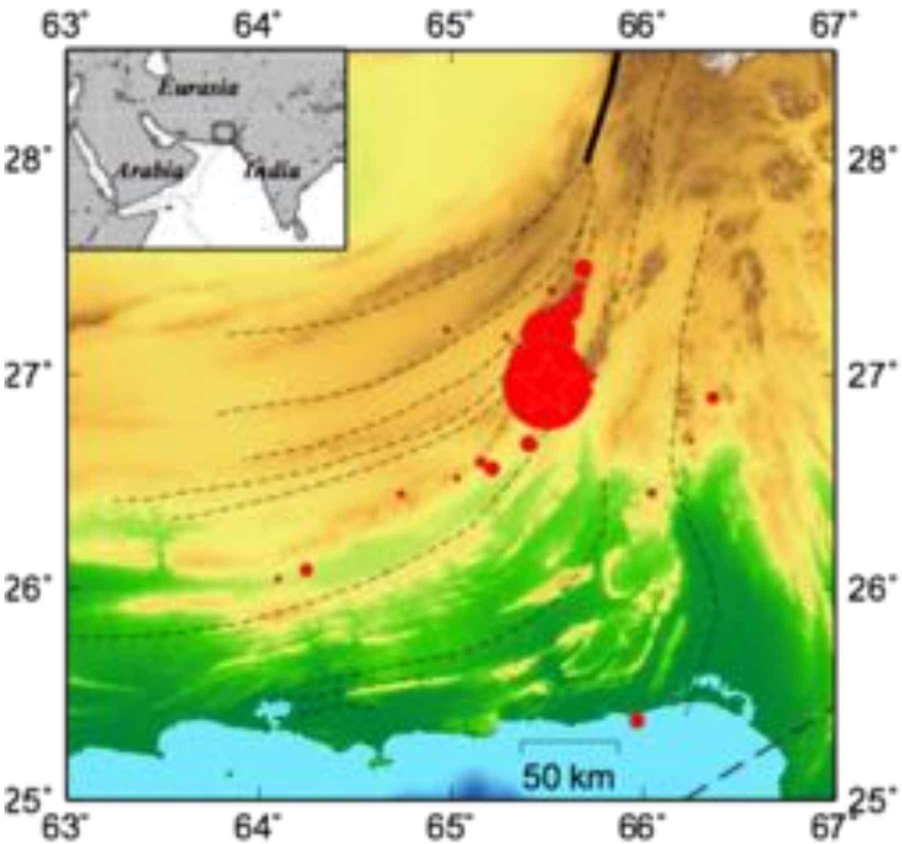
Inset panel shows the frequency content of the difference between magnitudes estimated from GCMT and our system for earthquakes that were located 30-85° to Hi-net.

Magnitude Variation with elapsed time



Source extent and energy radiation

The September 24, 2013, Mw 7.7 Pakistan earthquake



(a)

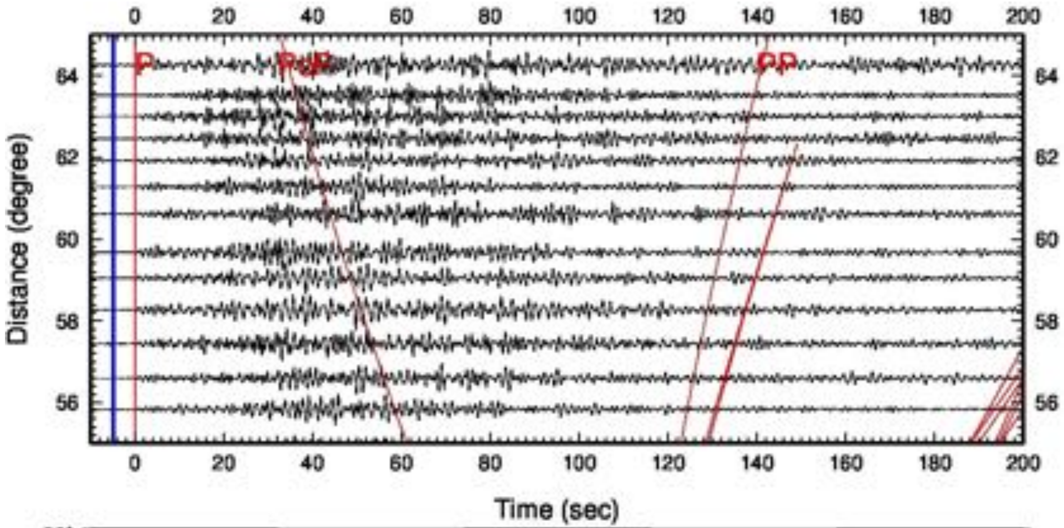
(a) Locations of aftershocks that occurred one week following the September 24, 2013, Mw 7.7 earthquake. The red star indicates the epicentre (USGS).

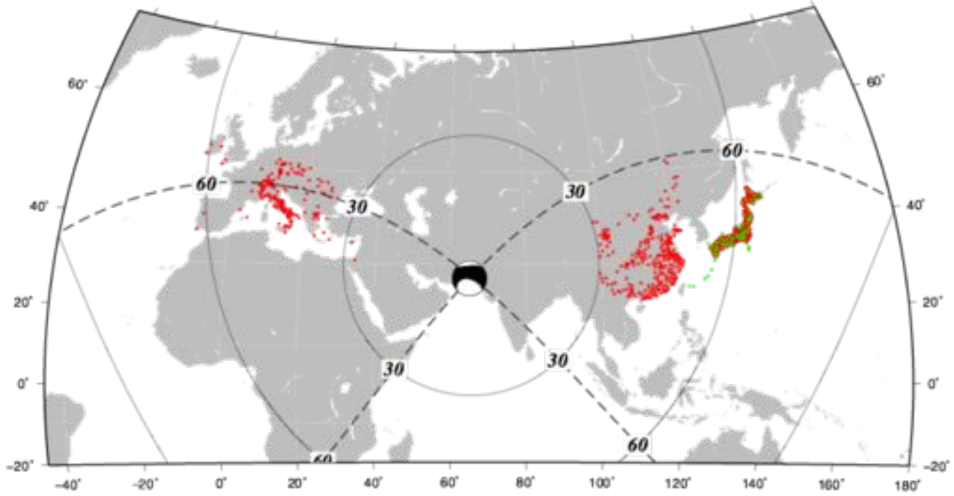
(b) White and red shaded squares indicate health facilities which were undamaged and damaged, respectively (http://www.ndma.gov.pk).

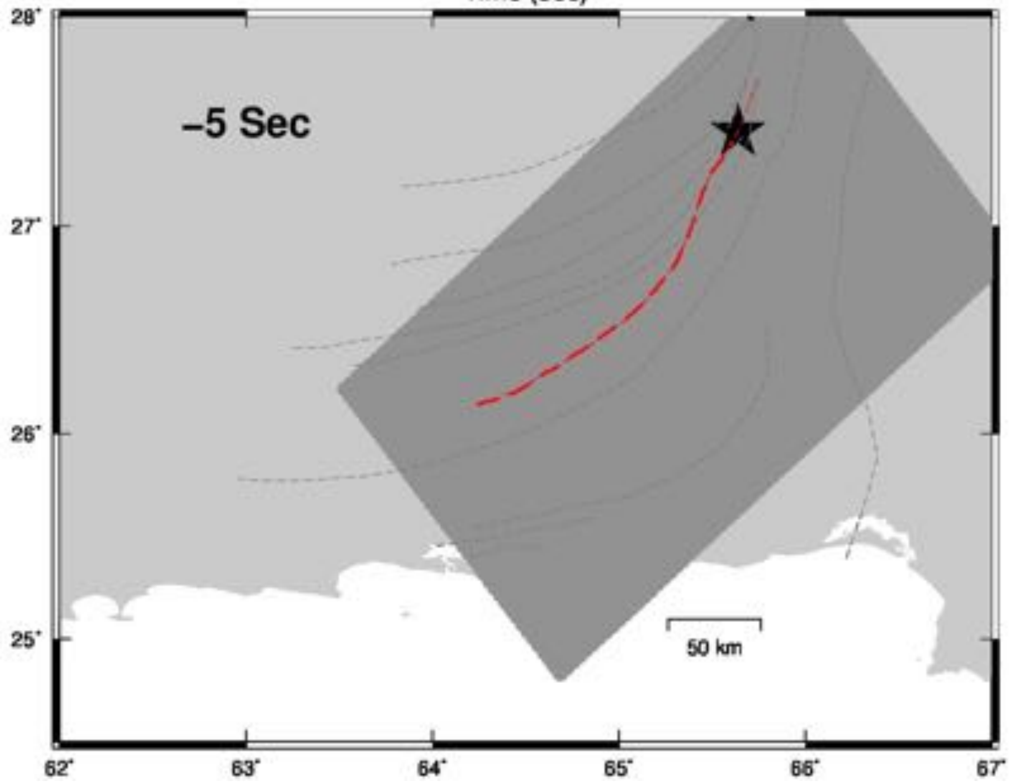
(Wang et al., JGR, 2016)

The September 24, 2013, Mw 7.7 earthquake

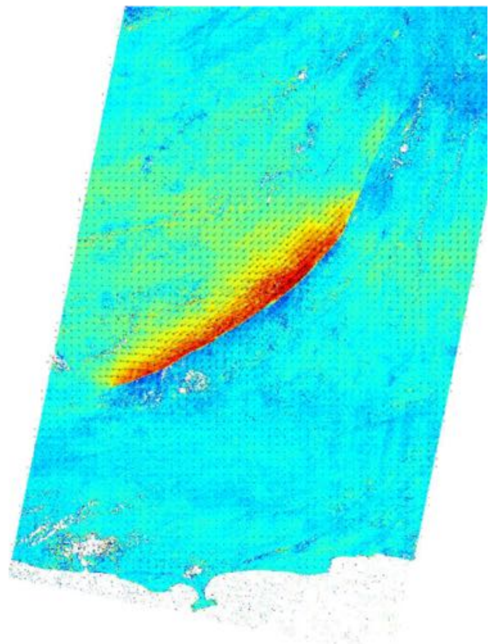
Data: Hi-net, band-pass filtered 1.0-10.0 Hz







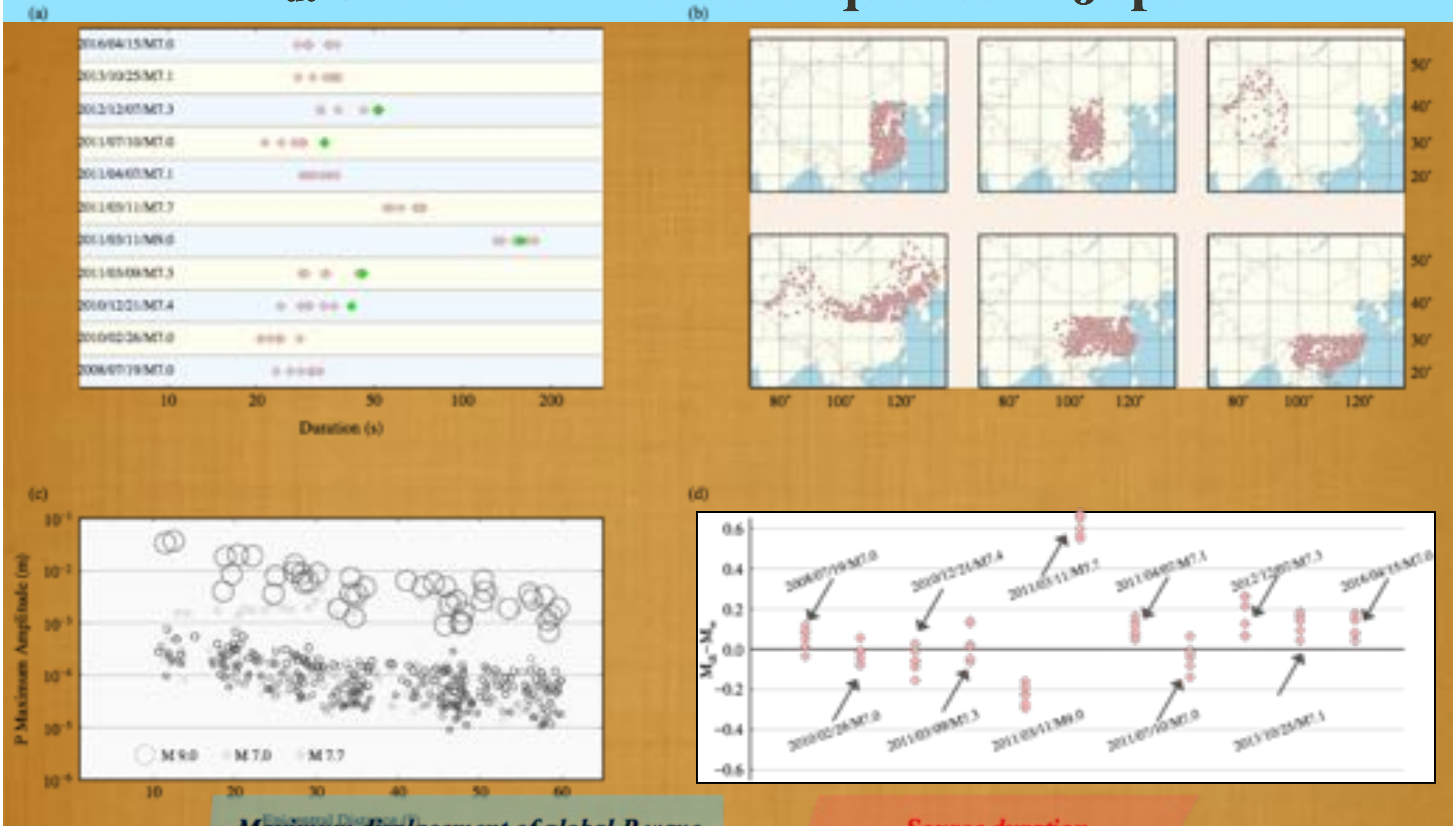
（Wang et al., JGR, 2016 ）



基于光学卫星影像的地震地表位移 （Avouac et al., 2014, EPSL ）

M>= 7.0 earthquakes in Japan from 2008 to 2016

M_{dt} of the M>= 7.0 earthquakes in Japan

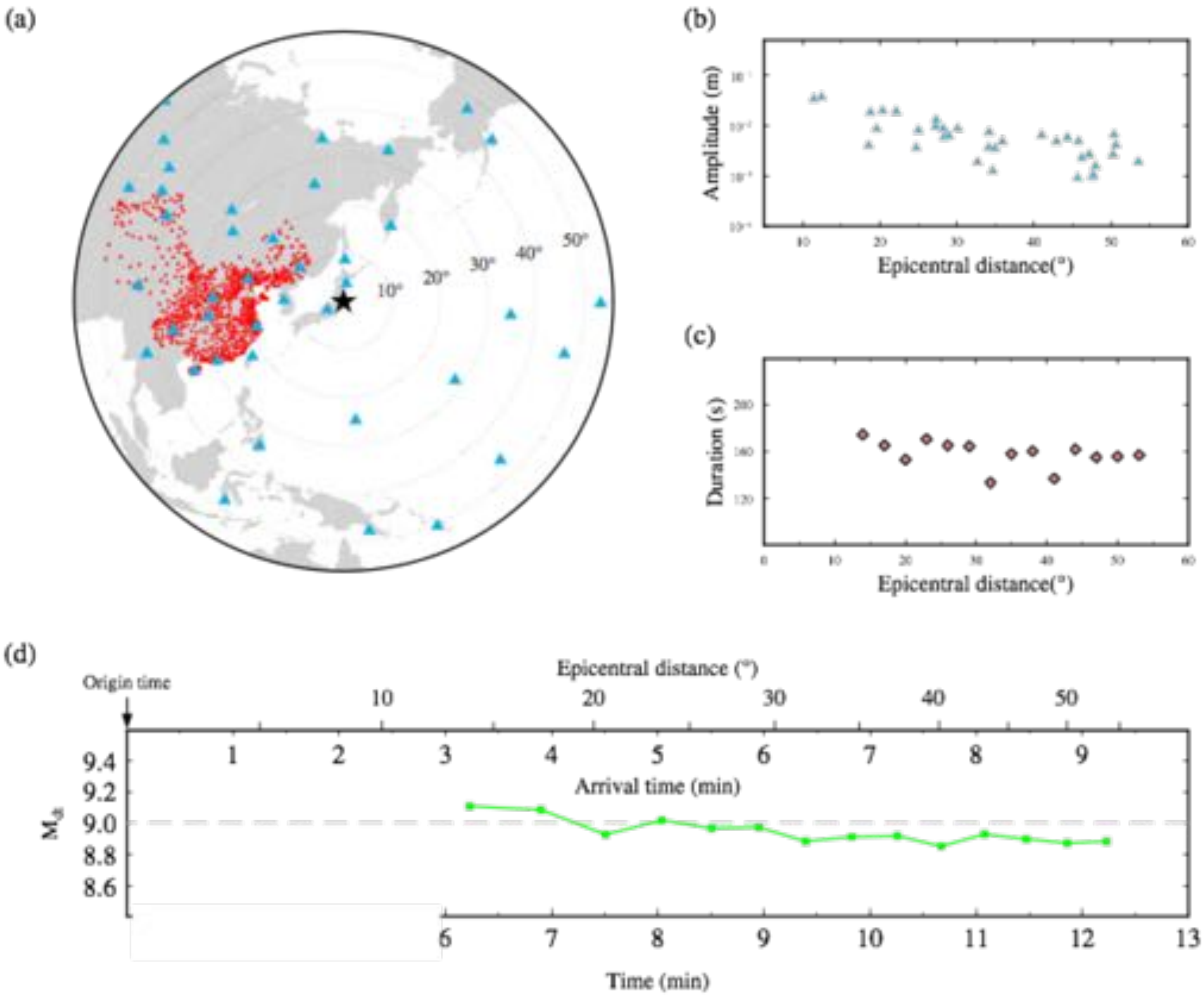


Maximum displacement of global P wave

Source duration

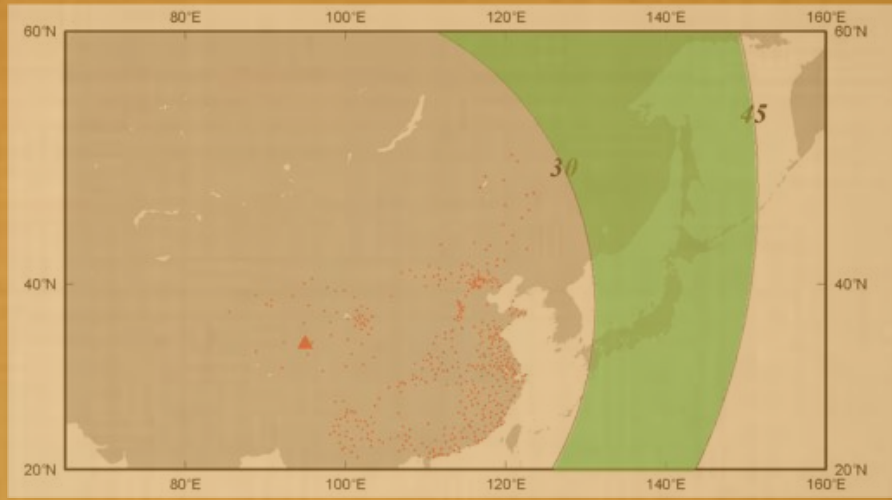
$$M = \frac{0.55}{N}\sum_{i=1}^{N}\log A_i + \frac{0.67}{N}\sum_{i=1}^{N}\log \Delta_i + 1.01\log(duration) + 5.55$$

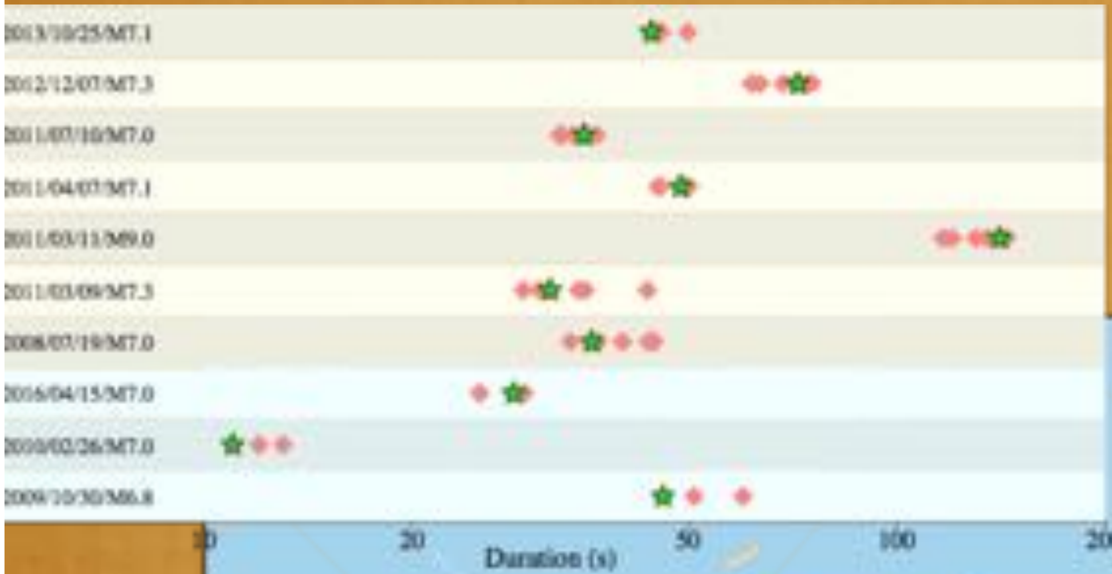
The 11 March 2011 Tohoku, Japan earthquake

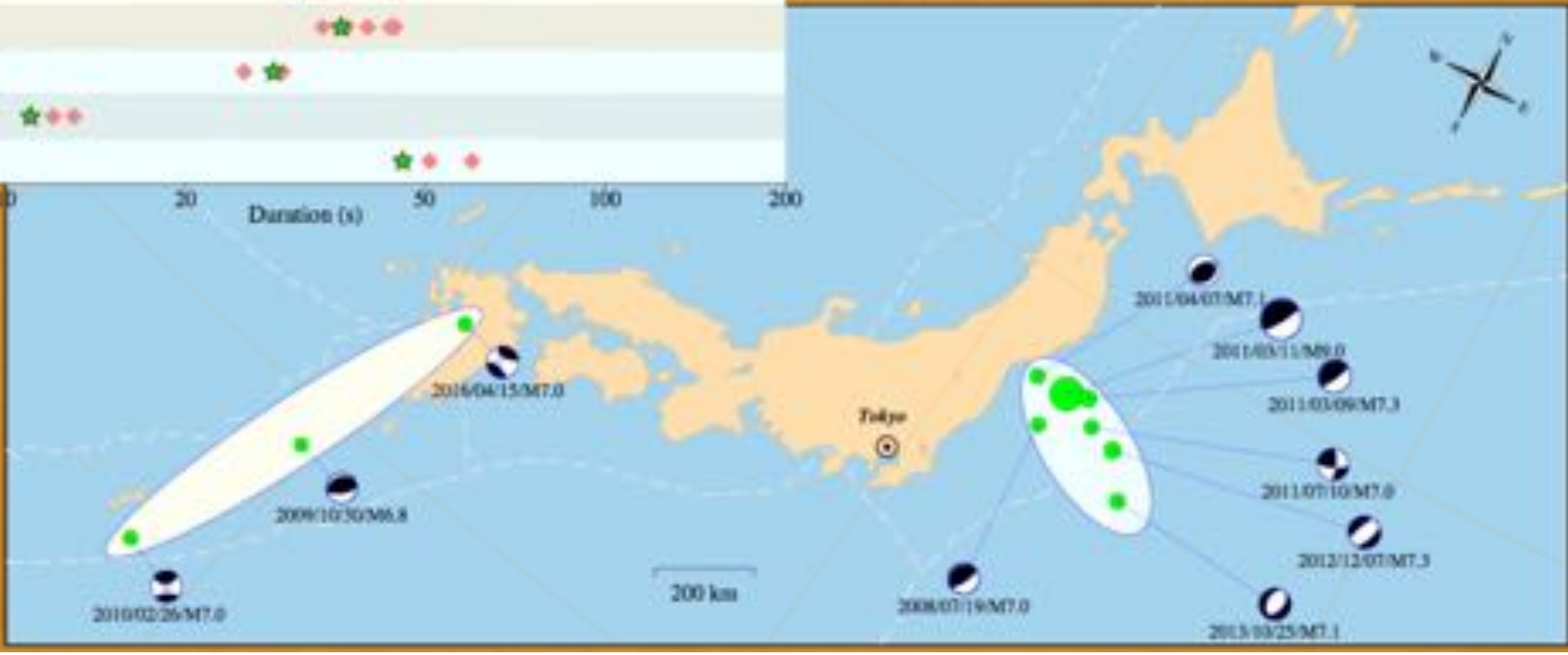


Station correction database

Automated back-projection in real time doesn't need the earthquake catalog







Timing

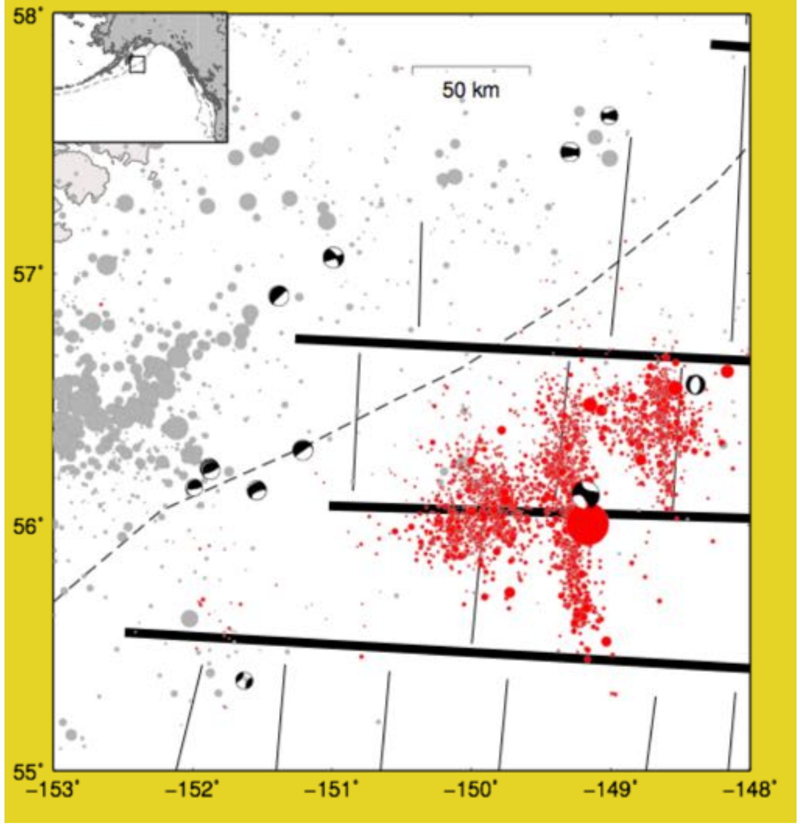
- How fast can this method offer information for the *M*w, source extent, asperity locations now?

Epicenter distance (degree)	10	30	50	90
Travel Time (minute)	2-3	6	9	13
Epicenter distance (km)	1111.2	3335.7	5556	10000.8

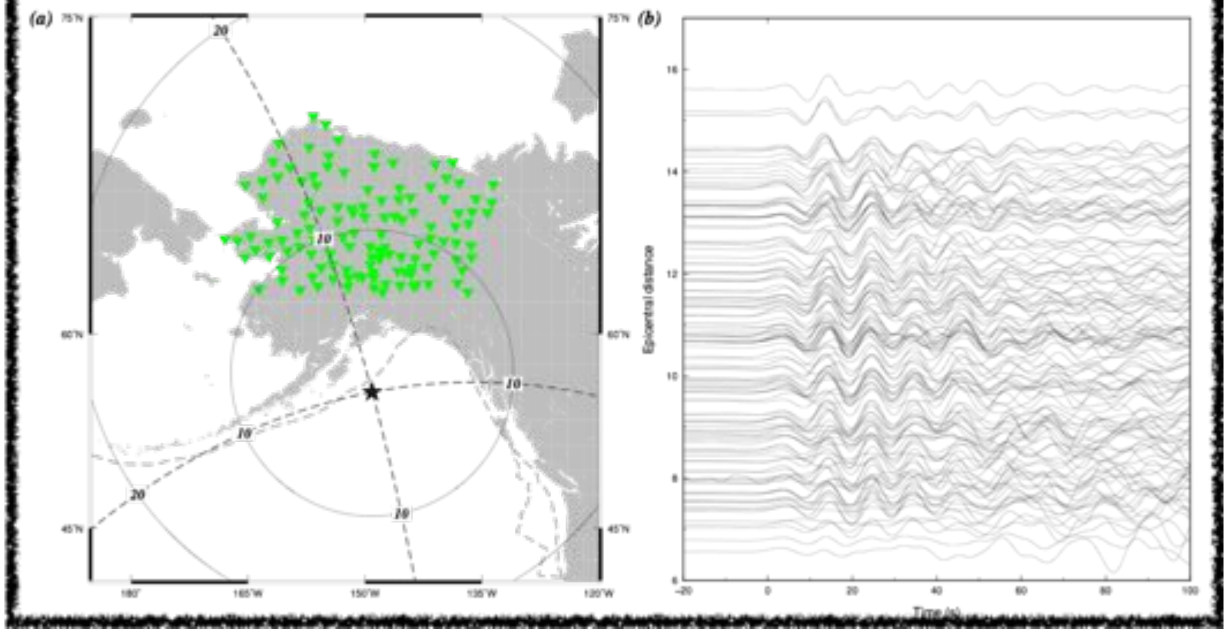
- Source extent, IRIS, 60 min after O. T. of earthquakes
- W-phase inversion, ~30 min, Moment magnitude

Magnitude of the 23 January 2018 M7.9 Alaska Eq

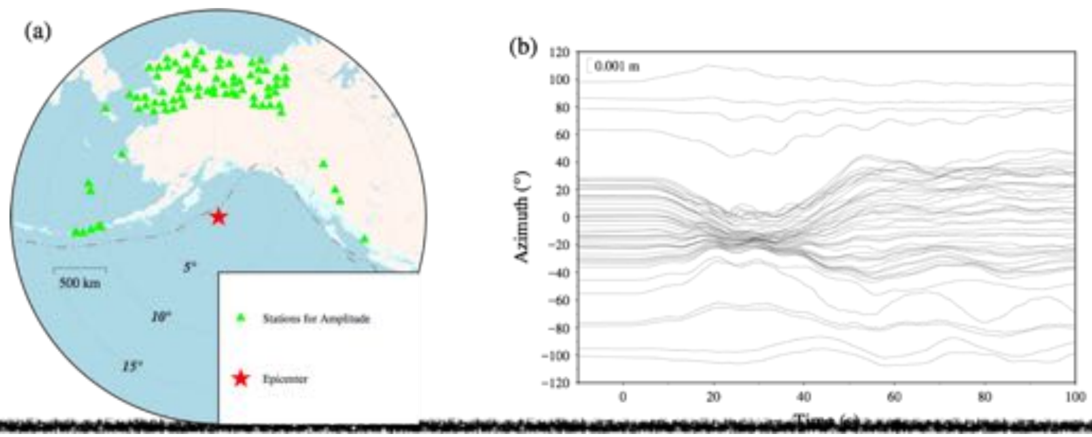
The earthquake sequence



Stations used in back-projection



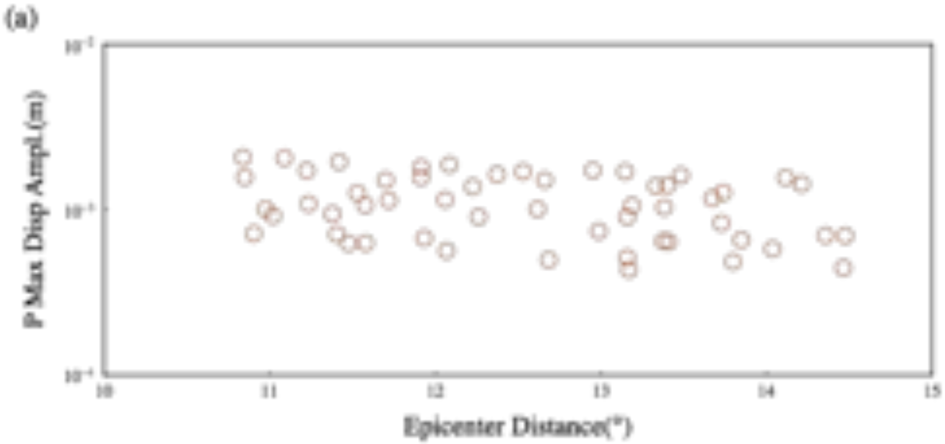
Global stations used for P displacements

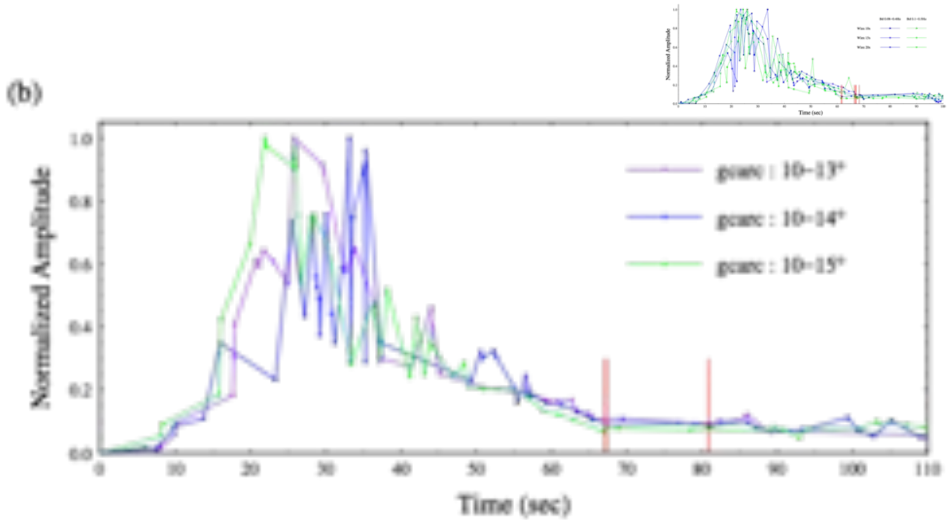


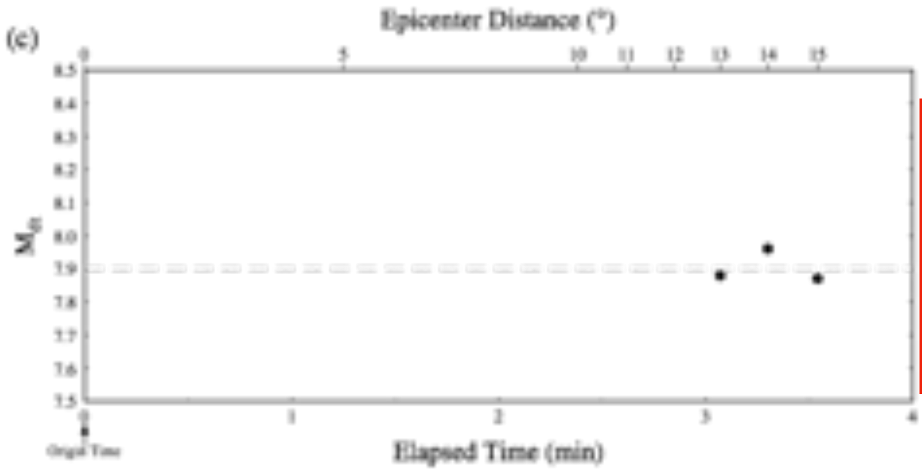
Magnitude of the 23 January 2018 M7.9 Alaska Eq

Maximum displacements of P waves

Source duration



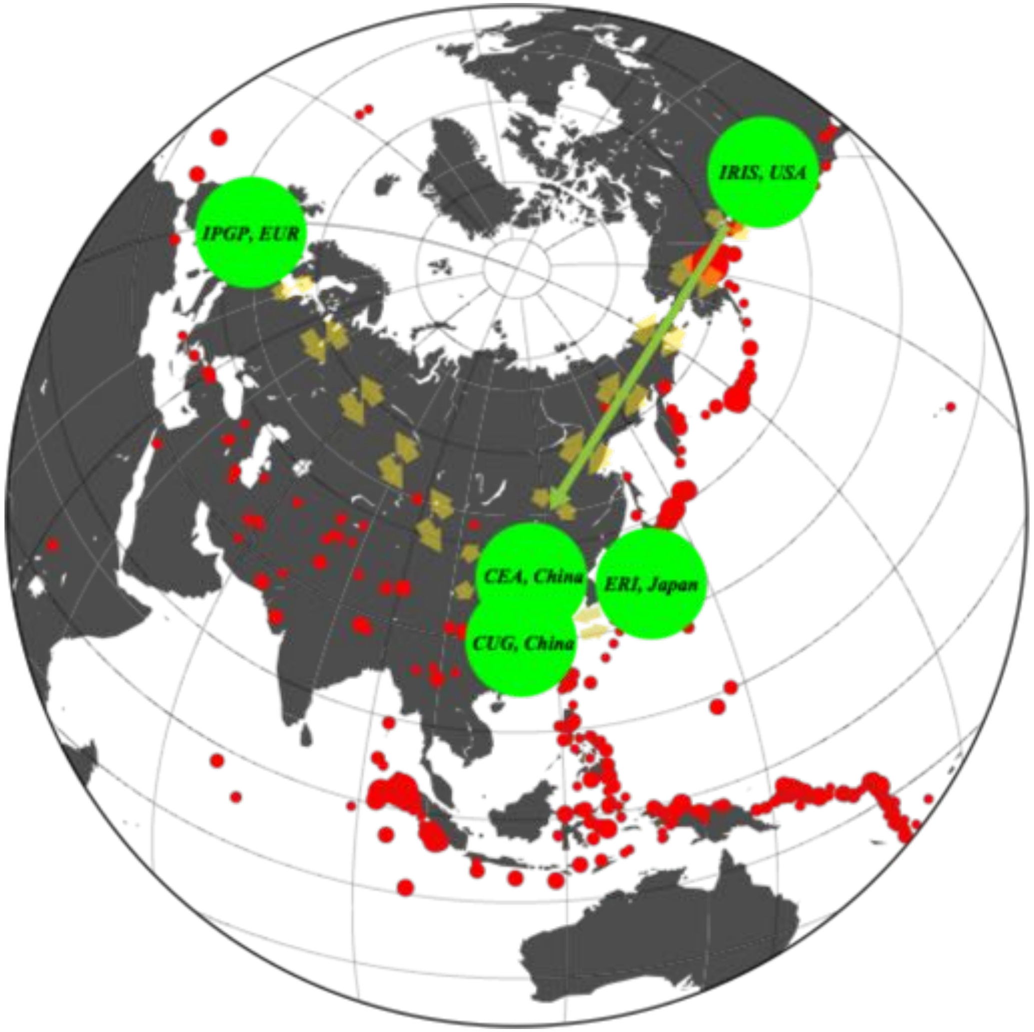




PTWC,NOAA/NEIC

M 8.0-8.2 in the first hour, became M7.9 around 2 hours after the origin time.

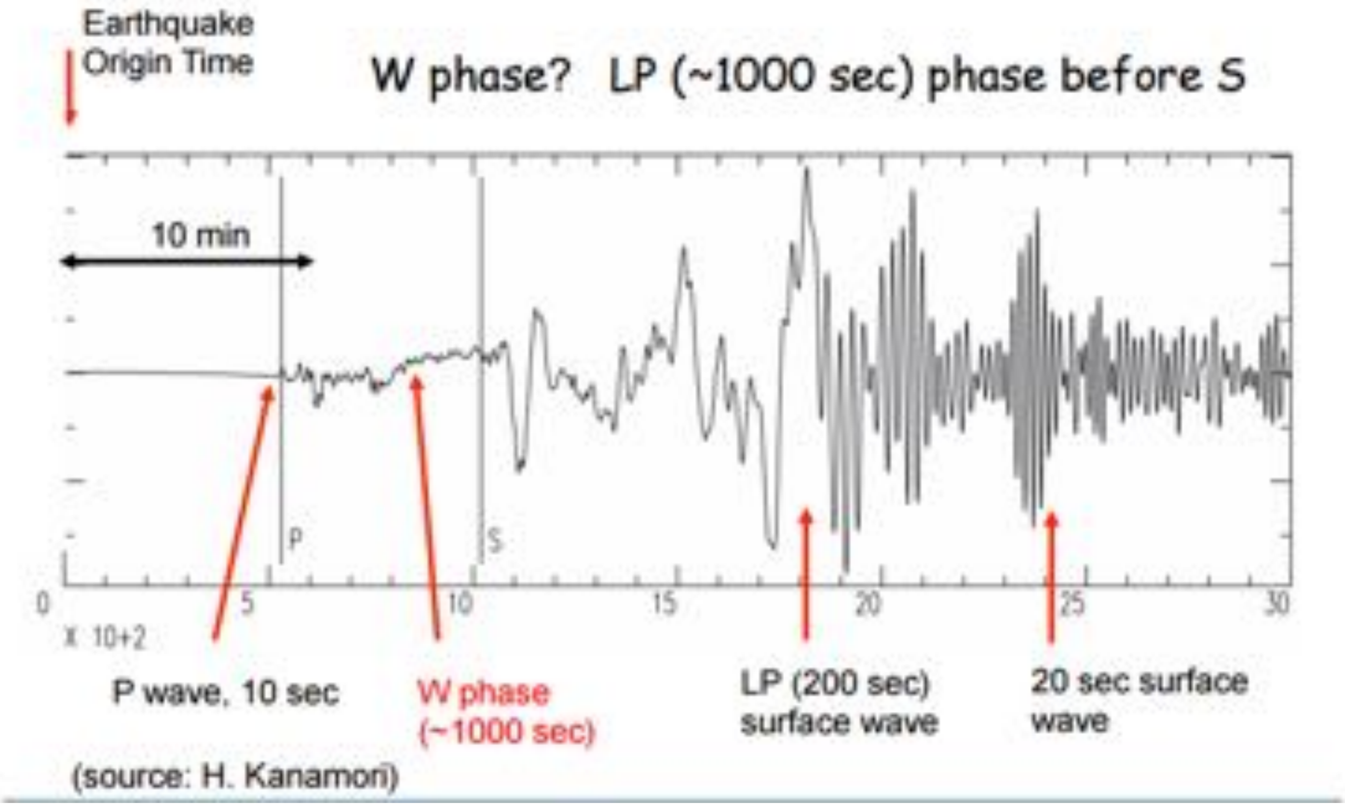
Future Work: For global earthquakes



M >= 7.5, Depth < 60 km, USGS catalog (1970-2014)

谢谢聆听！

W-phase 反演



- W-phase is well-suited to real-time determination of magnitudes & focal mechanisms for large earthquakes
- Real-time, point-source inversion soon to be operational (?) at ATWS
- Extensions of the w-phase technique, for finite faulting and compound events, may be possible in the near future.