地震轮回全过程的构造变形特征及其对地震预测的含义

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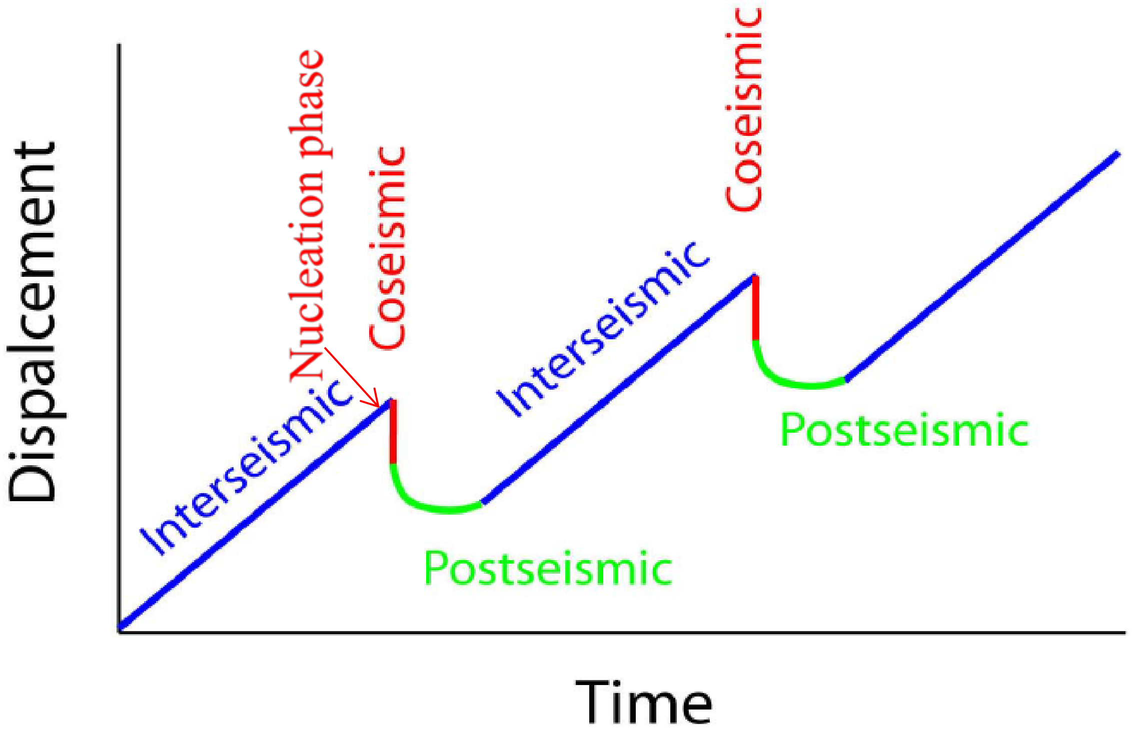
提纲

- Earthquake deformation cycle models
- GPS applications to earthquake deformation cycle
  - Inter-seismic deformation
  - Co-seismic deformation
  - Post-seismic deformation
- Summary

Seismic deformation cycle model

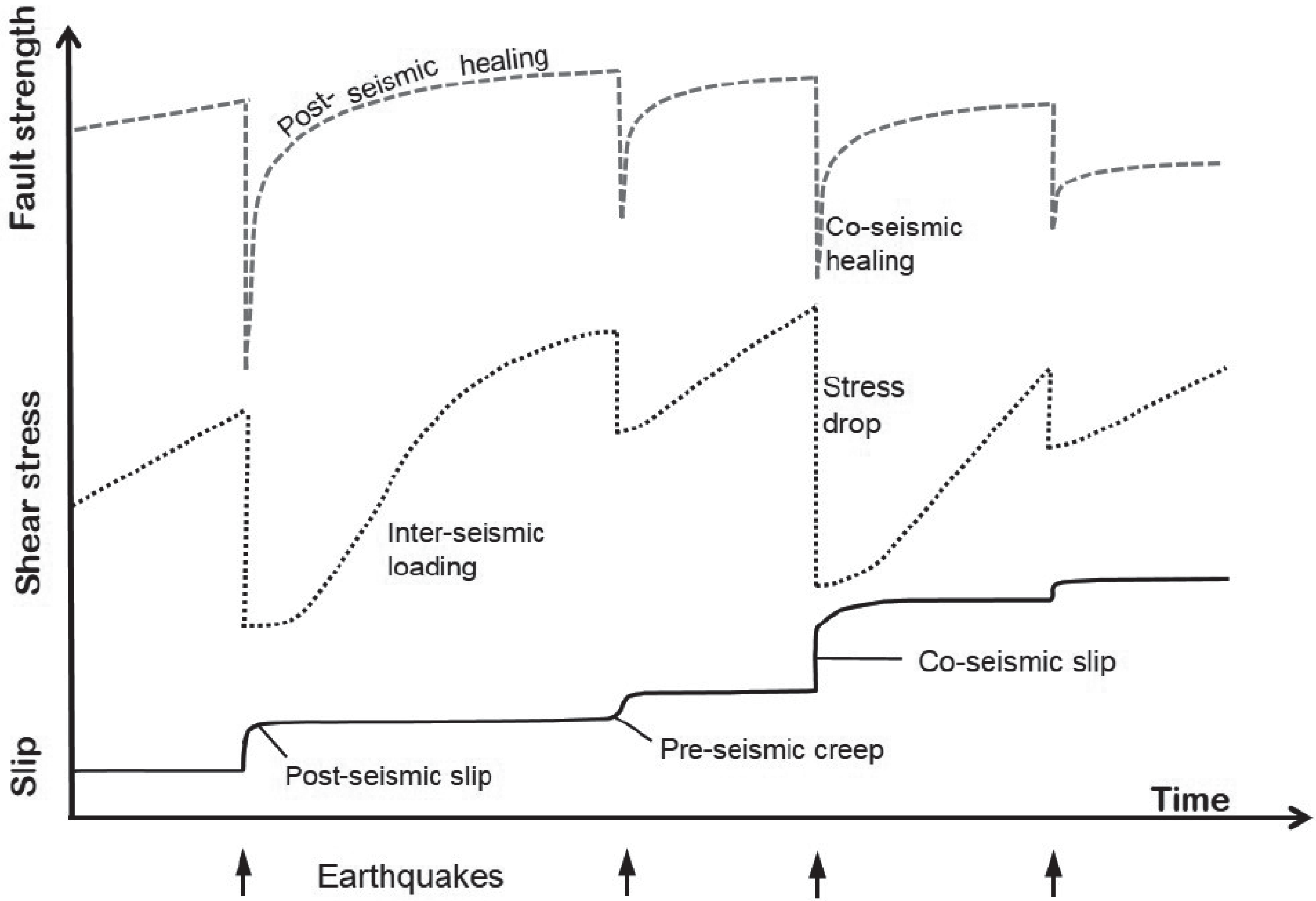
Deformation changes steadily and jumps in an earthquake with characteristic period:

- Theoretical geodetic time series
- **Interseismic**: displacement at a given site is linear as a function of time ⇒ constant velocity
- **Coseismic**: jump in the time series, related to the magnitude, location, and depth of the seismic rupture
- **Postseismic**: strain readjustments (afterslip, viscoelastic relaxation, poroelasticity), decay related to the mechanism and the lithospheric rheology

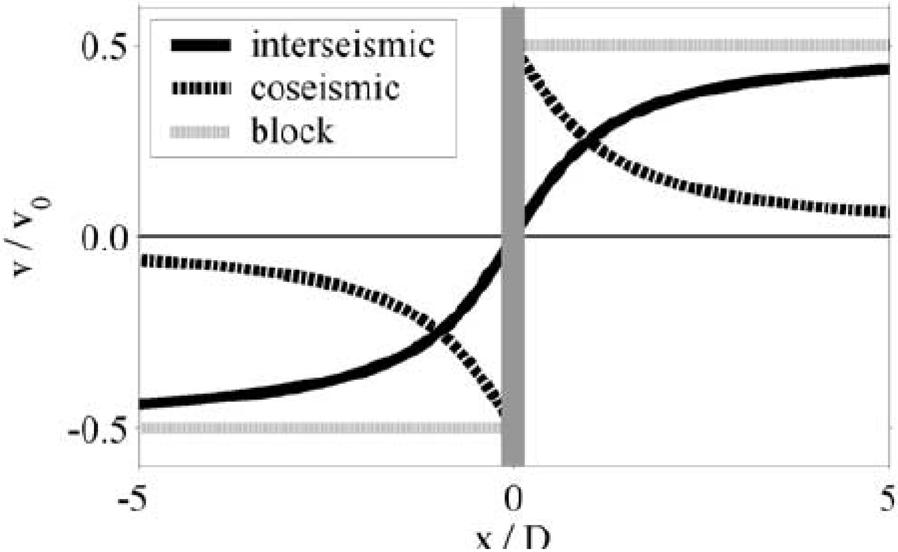


The duration of one cycle varies strongly; that is, seismic cycle is not necessarily periodic.

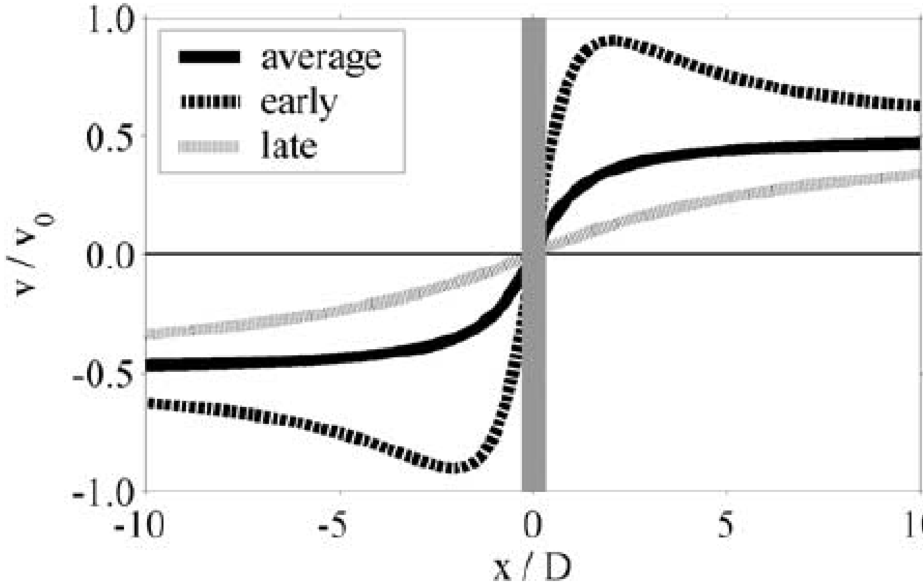
地震轮回过程中断层物理特征变化



Relationship of deformation in various phases for strike fault

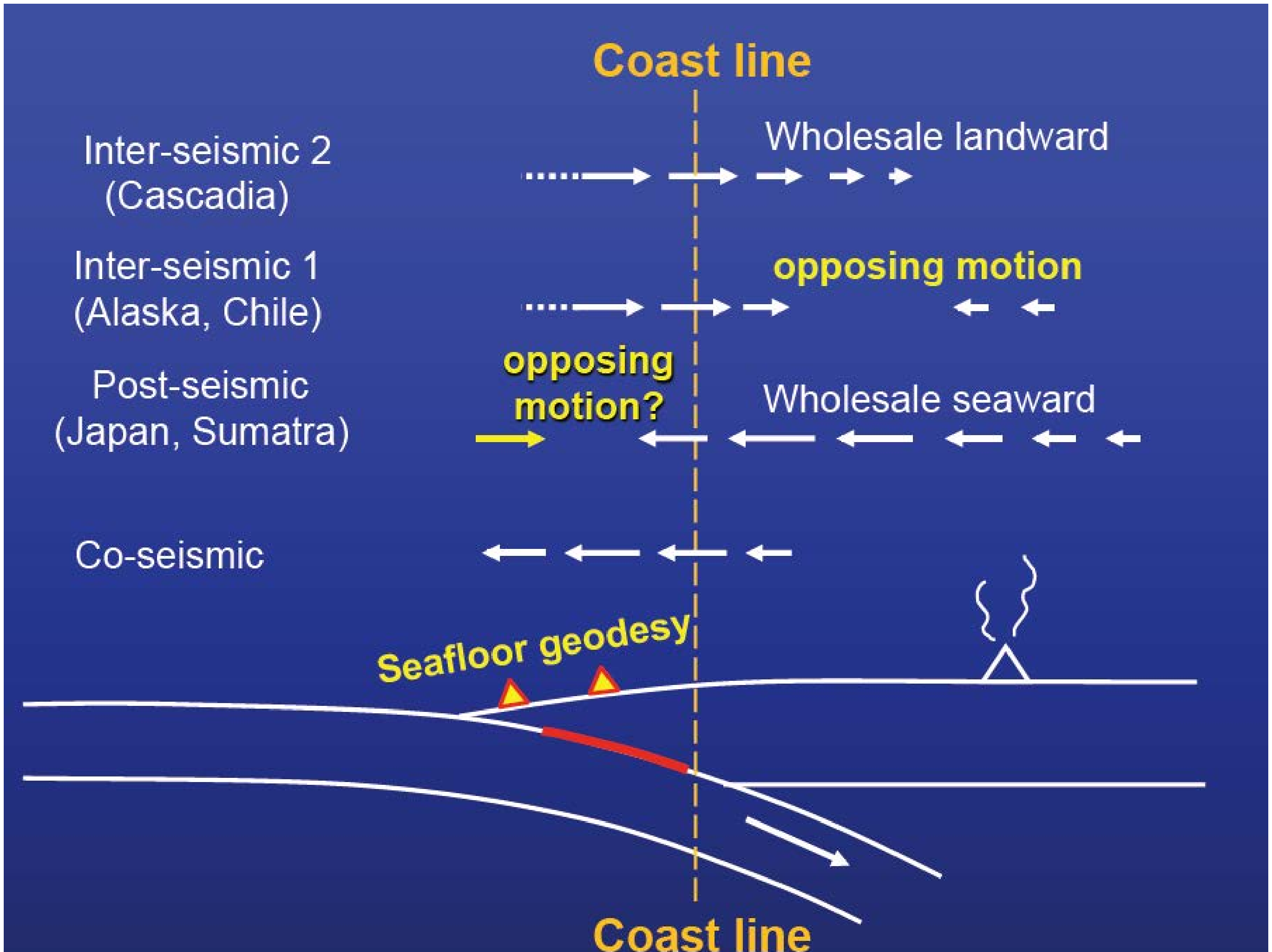


Savage & Burford, 1973



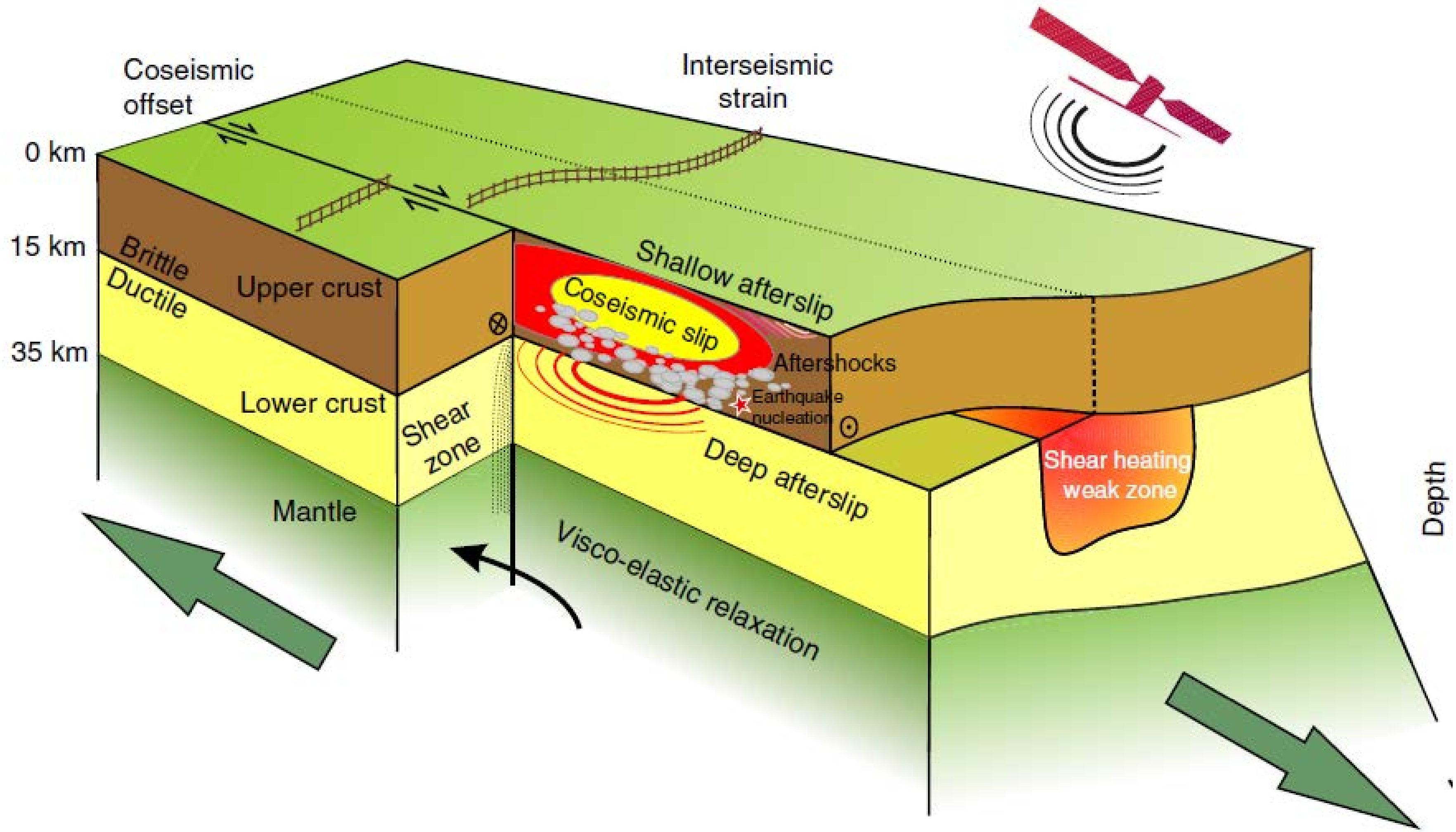
Savage & Prescott, 1978

Earthquake deformation cycle for megathrust earthquake



Wang , ICTP, 2013

Deformation in the crust and uppermost mantle



Elliott et al., 2016

GPS data application to seismic deformation cycle

- Inter-seismic deformation (Liupan Shan fault area)
- Co-seismic deformation (2011 Tohoku Mw9.0 Eq.)
- Post-seismic deformation (2010 Ms7.1 Yushu Eq.)

Ten CGPS sites constructed in 2013

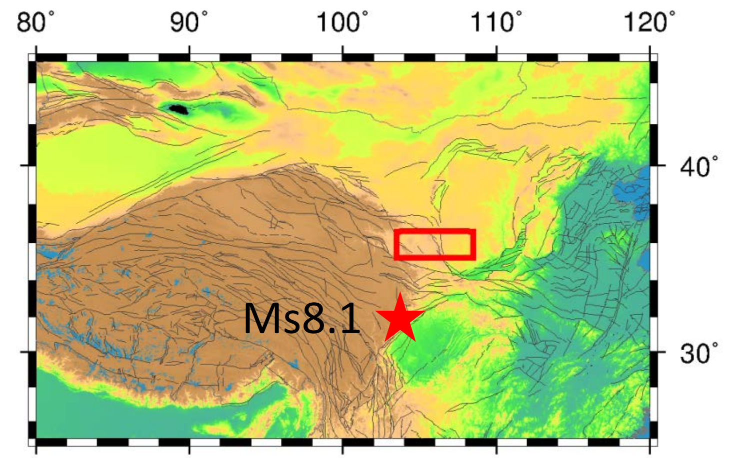
Length of profile:165km

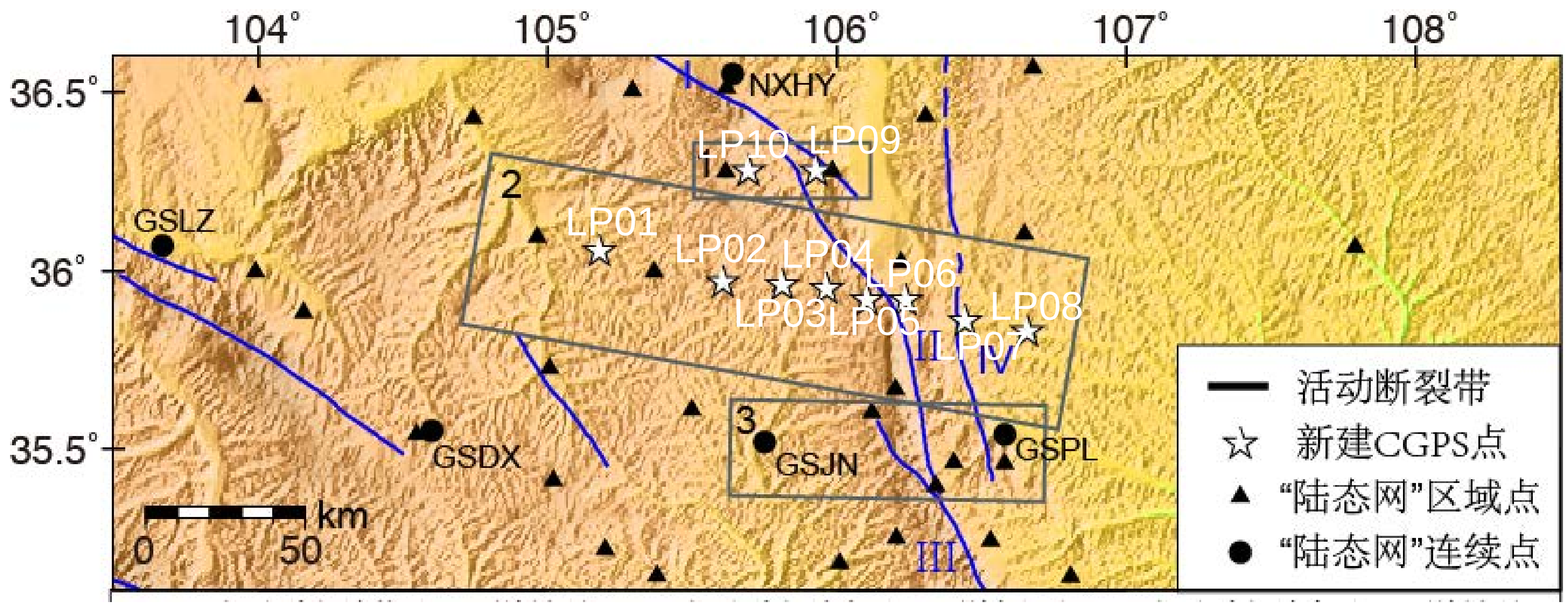
Baseline length(km):

LP01--LP02--LP03--LP04--LP05--LP06--LP07--LP08

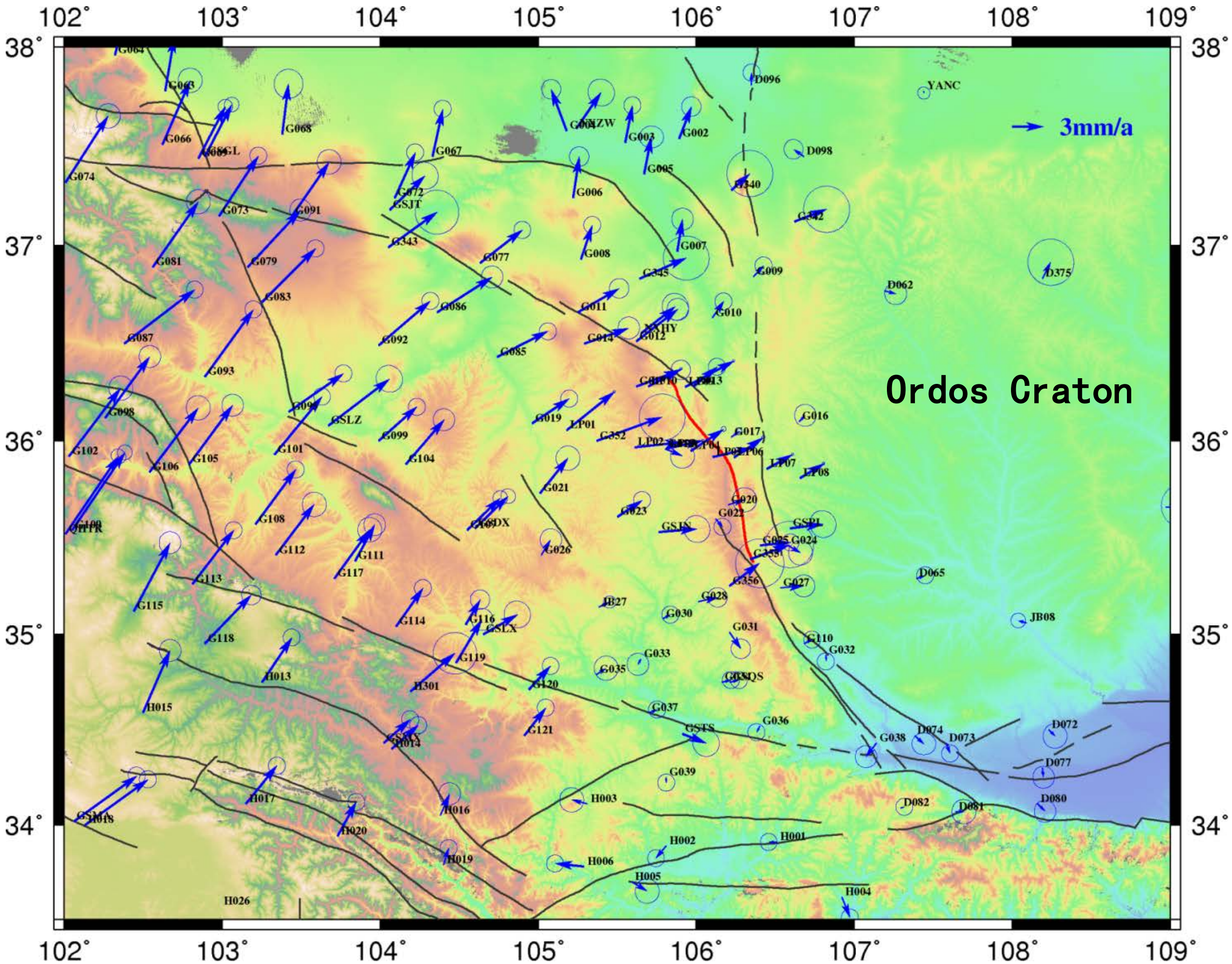
50.3 19.5 14.6 16.8 12.5 26.9 25.0

LP09—LP10: 21.3





GPS horizontal velocities WRT Ordos Craton

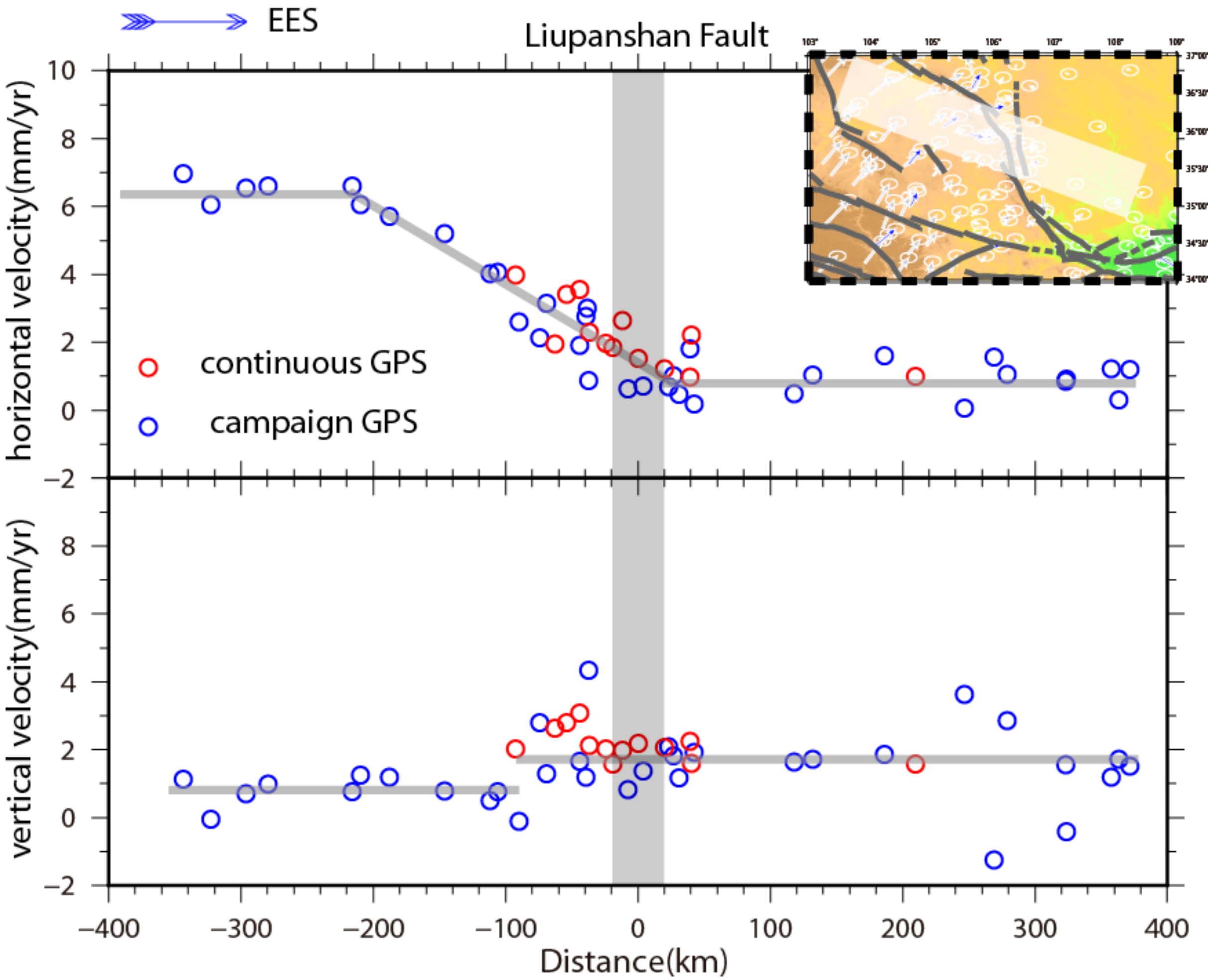


Campaign occupation s:
2009 to 2015

Velocities decrease eastward

GPS velocities at 0 - 6 mm/yr. Sites move northeastward

GPS velocity profile across Liupan Shan Fault zone

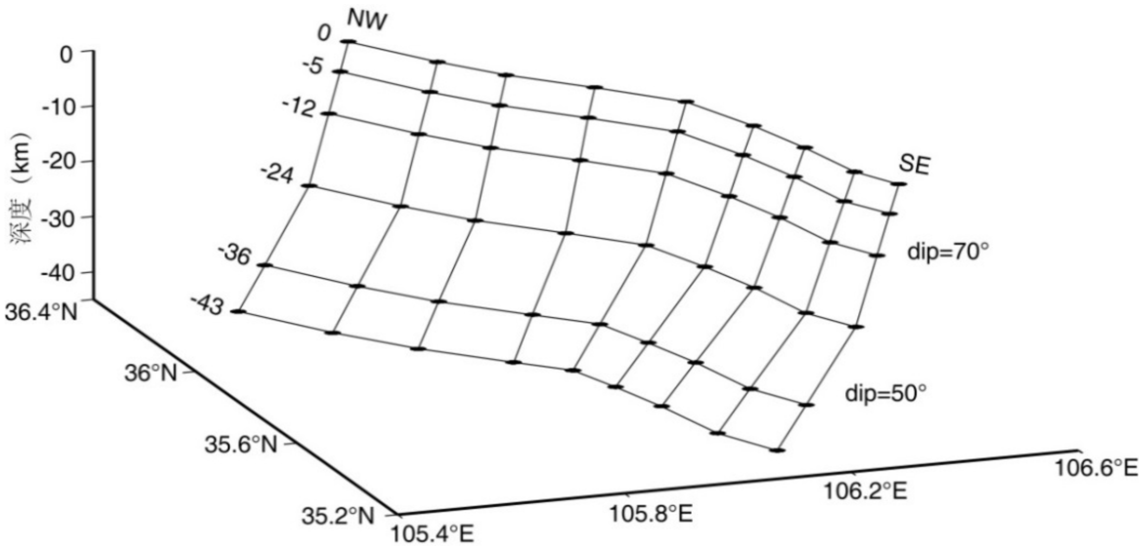


Striking decrease of GPS velocity eastward; the width of deformation zone is about 250km; the compressional rate is 5.3mm/yr.

Uplift rate west of Liupan Shan fault is smaller than the around and east;

The largest uplift rate is 3.6 mm/yr, and distributed at the 50 km west of Liupan Shan fault.

Fault model implementation



Three-dimensional fault model

Strike direction:
330-350° based on geological study

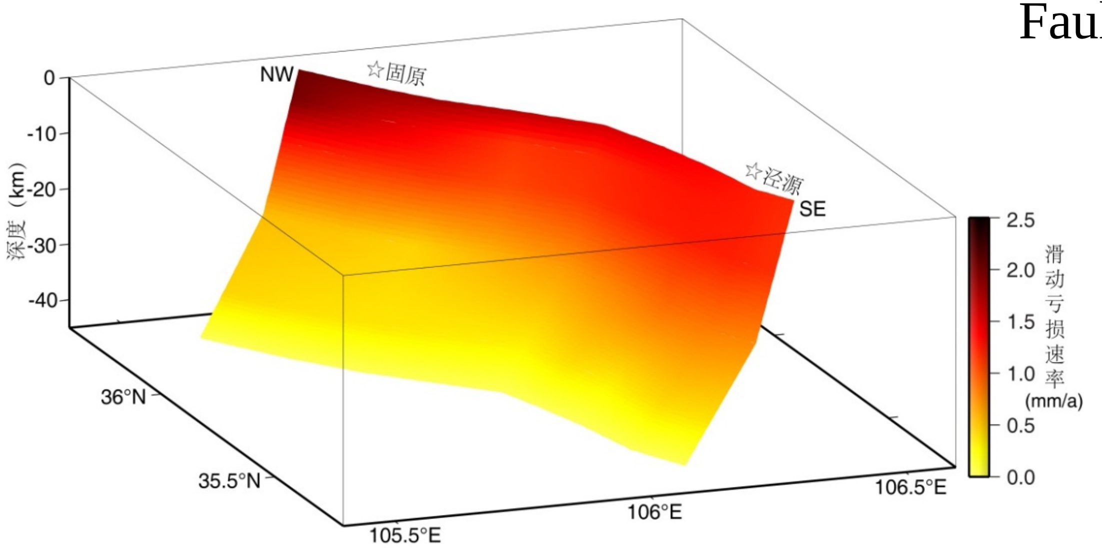
Dip angle:
Different angle: from 50-70 degree

Nodes in six layers：
0km、5km、12km、24km、36km、43km

Decay pattern of locking coefficient：
decays monotonously downwards : $\phi(z+1) \leq \phi(z)$

Slip deficit distribution

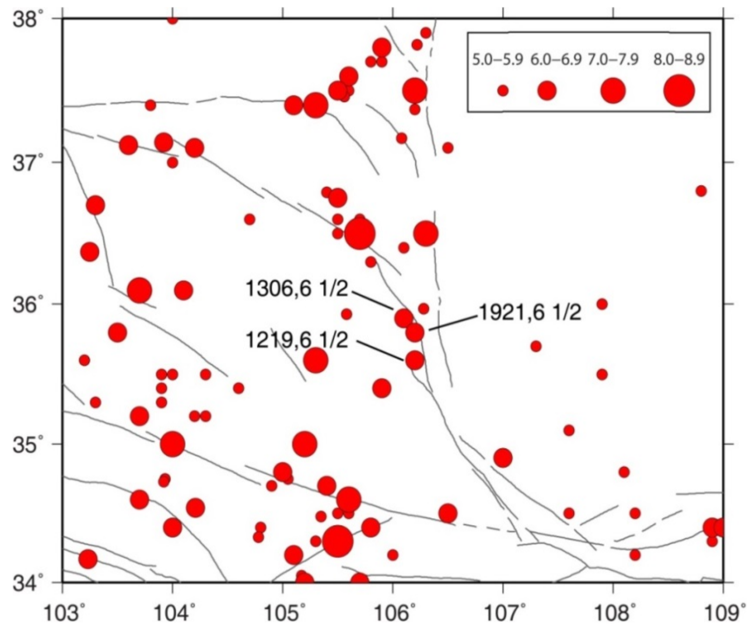
Fault slip deficit: 0～2.5 mm/yr.



depth（km）	north（mm/yr）	middle（mm/yr）	south（mm/yr）
0-24	1.57	1.25	1.45
24-40	0.75	0.45	1.05
40-43	0	0	0
0-43	1.16	0.85	1.25

Maximum magnitude of potential earthquake

Average slip deficit =0.60mm/a



$$\dot{M}_0 = \mu \times S \times A$$

$$M_0 = \dot{M}_0 \times T$$

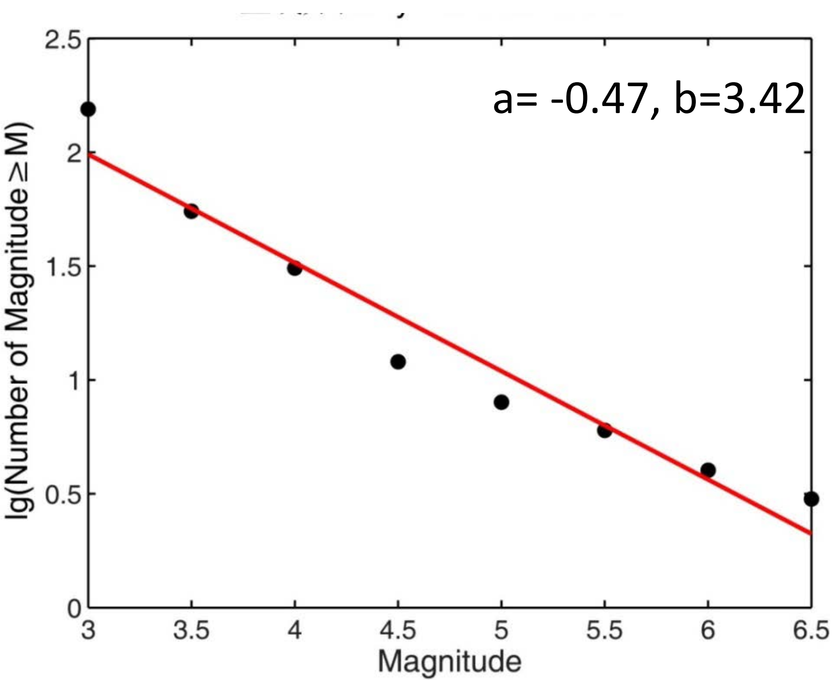
$$M_w = \frac{2}{3} lg M_0 - 6.07$$

Accrued energy has been equivalent to an Mw6.2 earthquake since last M6.5 Eq. in 1921

Recurrence interval of Maximum earthquake

$$T(M_{max}) = \frac{1}{(1-2b/3)\alpha}\frac{M_{max}}{\dot{M}_0}$$ （Avouac，2014）

Gutenberg-Richter earthquake relationship



Average slip deficit =0.60mm/a，

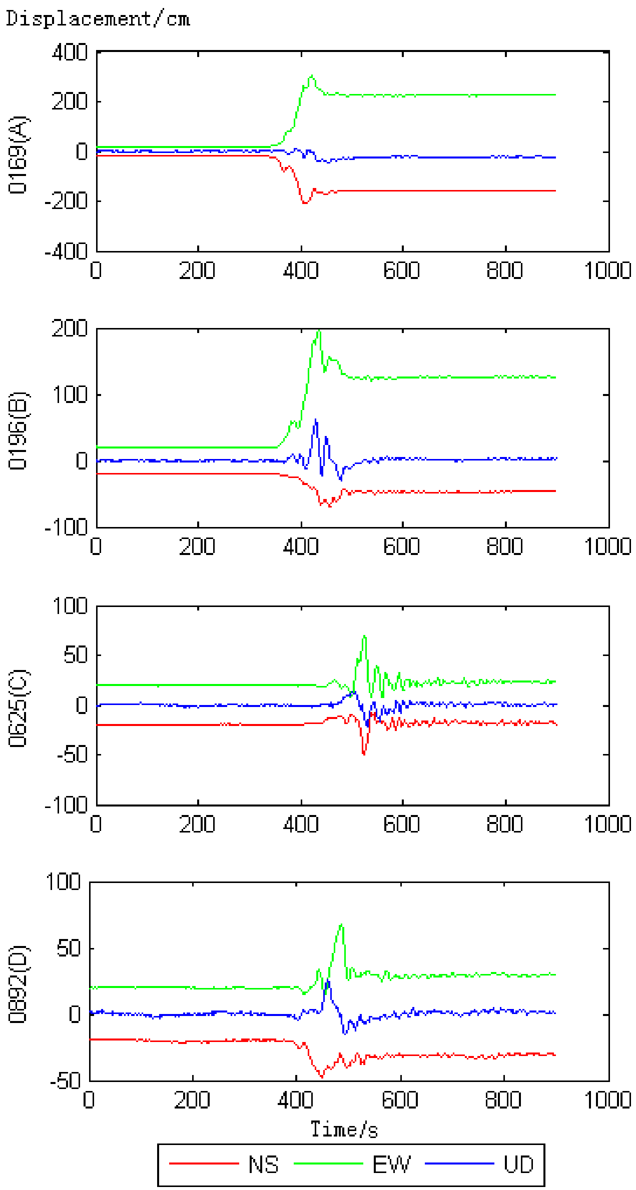
$\dot{M}_0$=5.30×10^{16}N m

Estimated recurrence interval is 126 years for an Ms6.5 earthquake

GPS data application to seismic deformation cycle

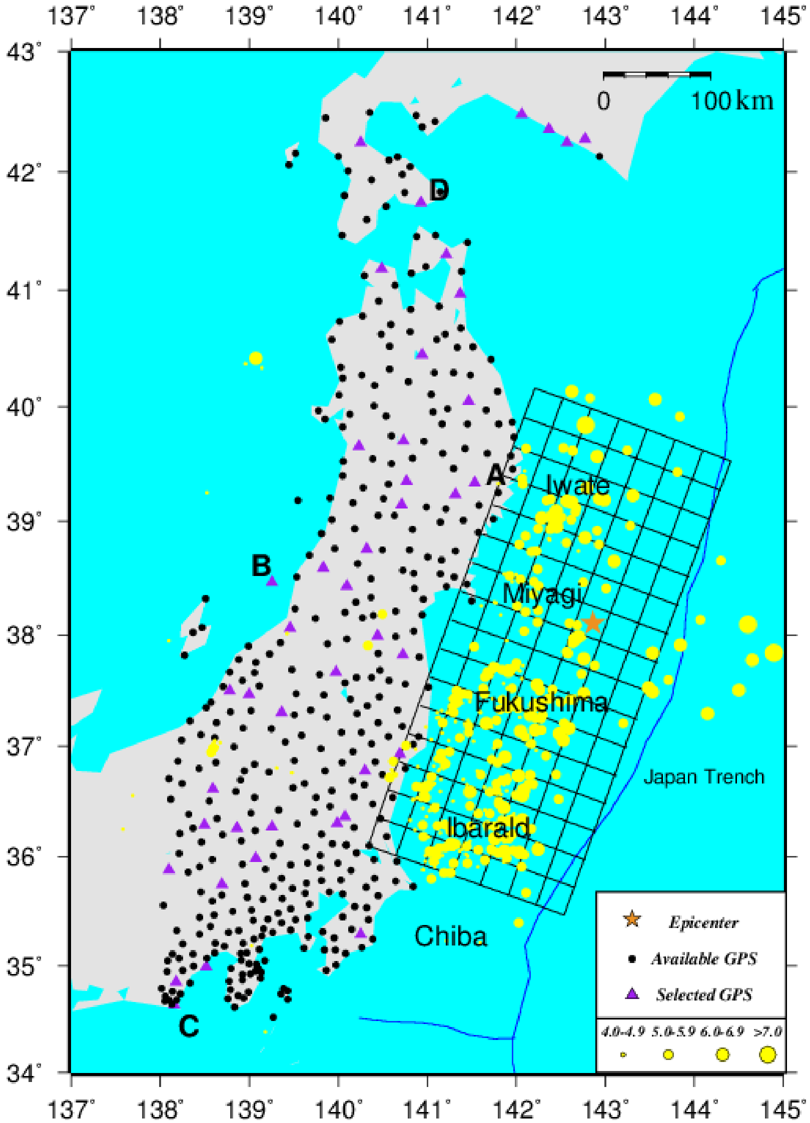
- Inter-seismic deformation, taking Liupan Shan fault as an example
- Co-seismic deformation (2011 Tohoku Mw9.0 Eq.)
- Post-seismic deformation (2010 Ms7.1 Yushu Eq.)

1-Hz GPS waveform



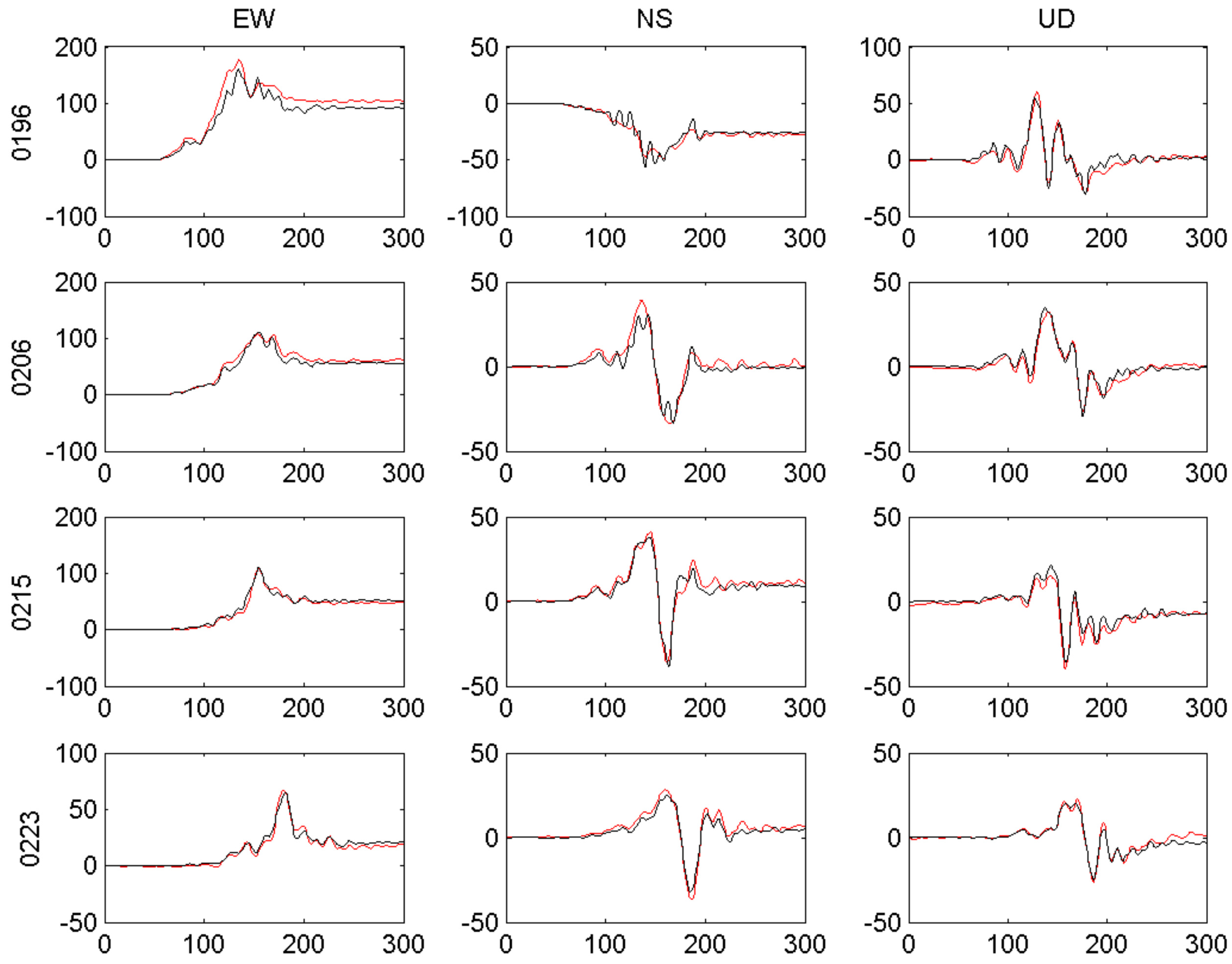
- Time window：300s before and 600s after the occurrence time
- 0.1Hz low pass Butterworth filter

Fault model

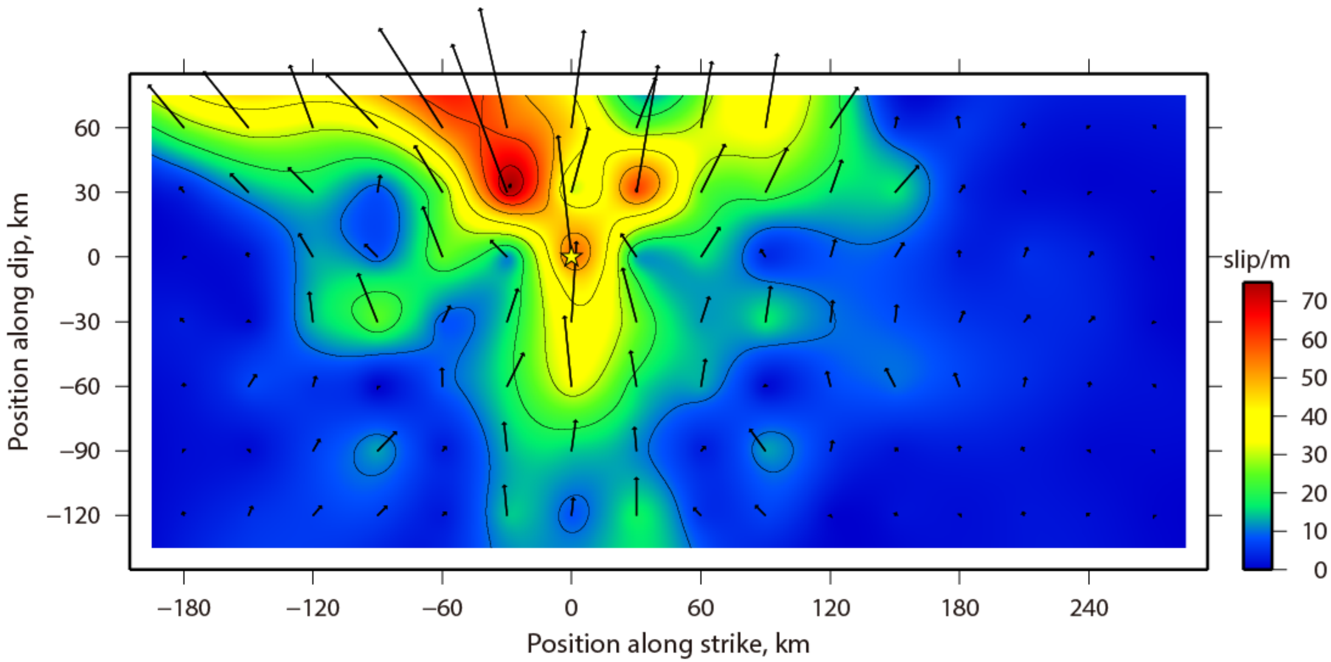


- ◆ strike: 200° dip: 12°
- ◆ fault area: 480×210 km²
- ◆ subfault: 30×30 km²
- ◆Hypocenter depth: 17 km
- ◆Starting rupture: 05:46:18 (UTC)

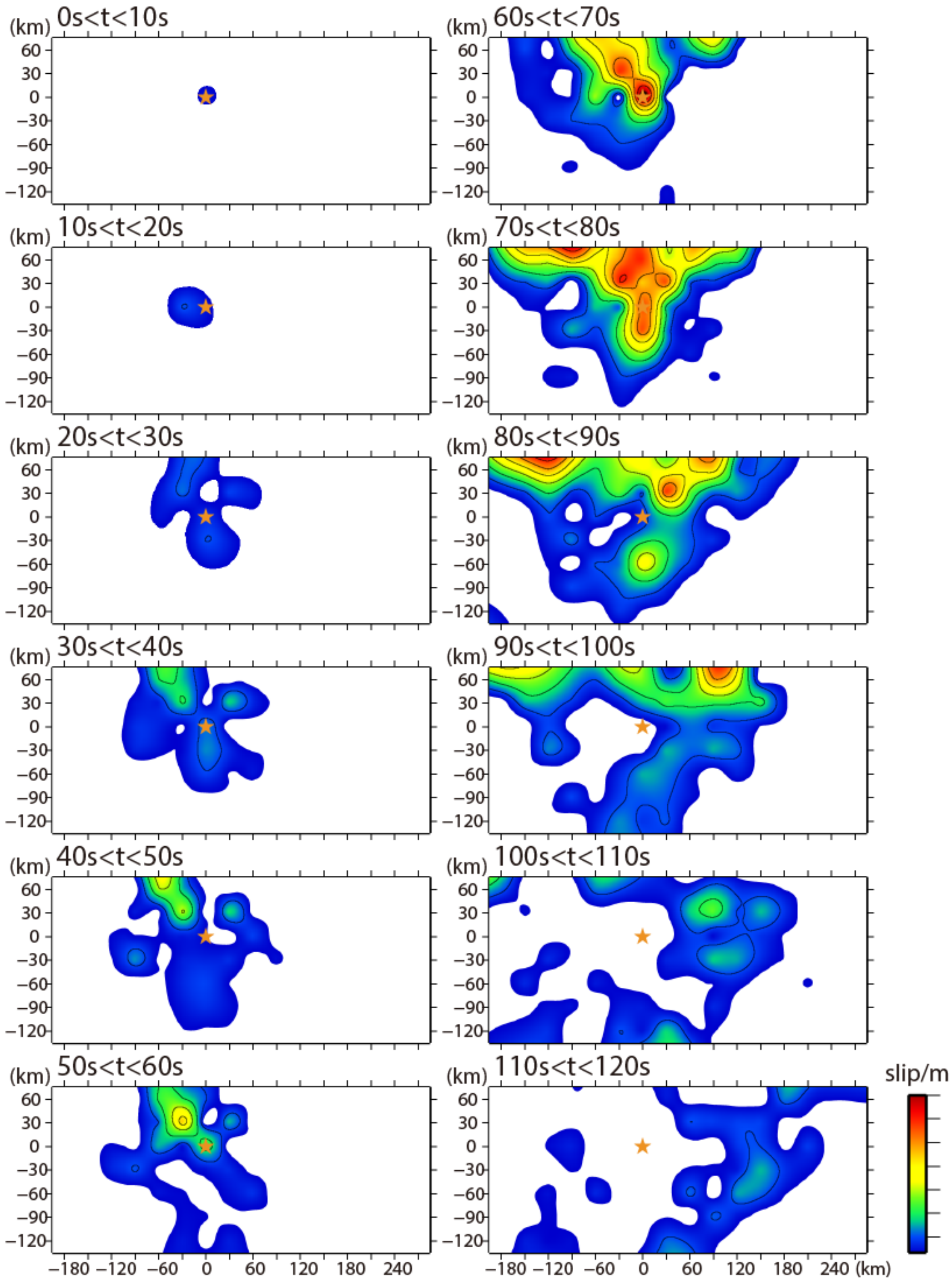
Observed and modeled 1-Hz GPS waveforms



Total slip distribution



- Maximum slip: 70 m 30 km above hypocenter
- Rupture concentrates between hypocenter and sea trench
- dominant reverse slip, with minor sinistral and dextral slip at 2 flanks
- Moment: 3.8×10^{22}Nm（*Mw* 9.0）



Slip snapshot

- ◆ 0-60s是破裂开始阶段，发震后断层从震源向周围缓慢破裂，呈现较大北西向破裂的趋势，在50-60s破裂延伸至地表（海沟）

- ◆ 60-100s是主要破裂阶段，破裂集中在震中附近及以上区域，并在震中周围和海沟处形成了最大的位错区

- ◆ 100-120s破裂急剧减小，破裂主要发生在断层的南半段，即余震最集中区域

Slip distribution by various data

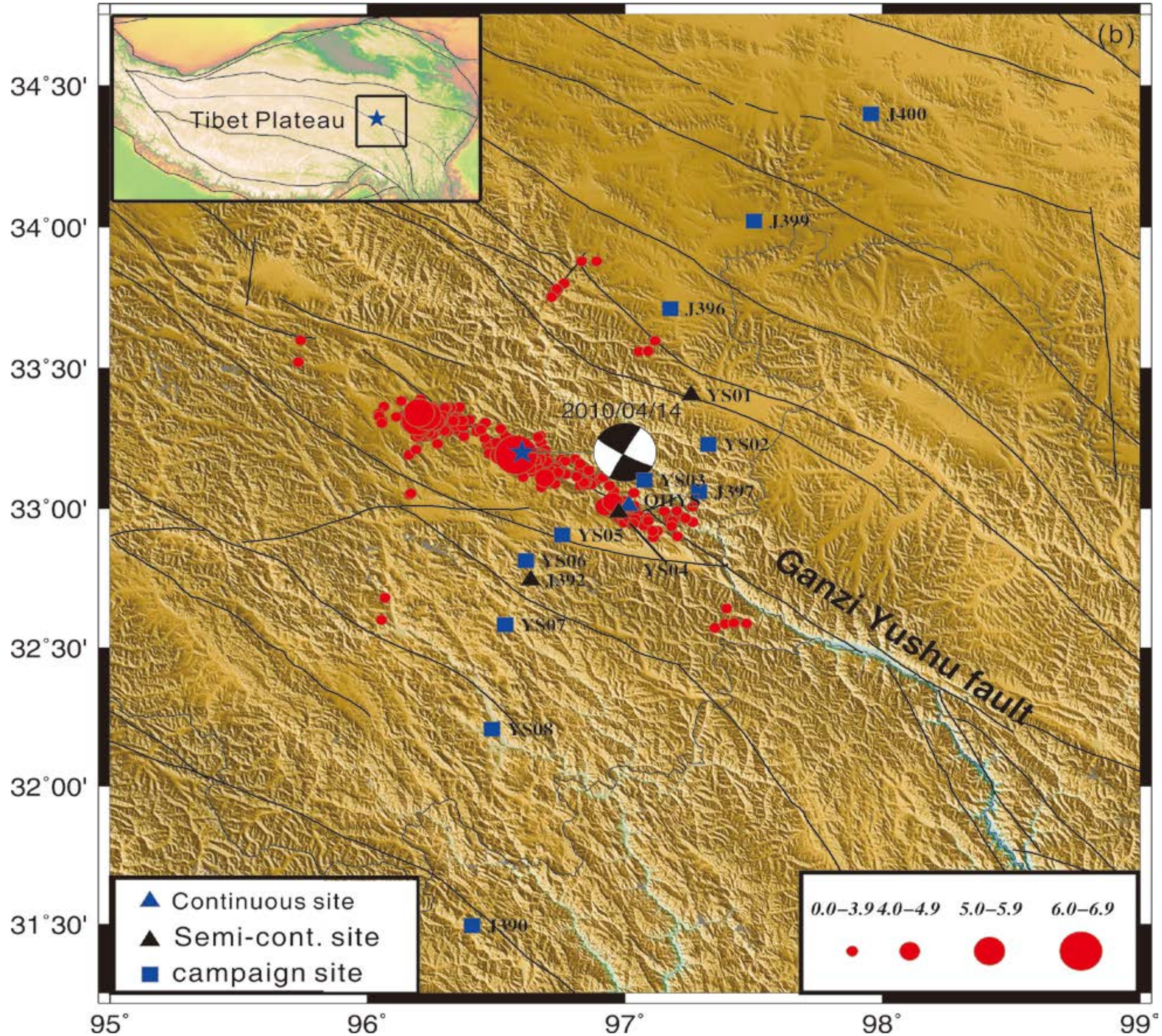
<table>
<tr><td>Fujiii et al., 2011</td><td>海嘯數據</td><td rowspan="3">淺源的集中破裂，延伸至海溝</td></tr>
<tr><td>Yoshida et al., 2011</td><td>長週期強震記錄</td></tr>
<tr><td>Yue and Lay, 2011</td><td>高頻GPS、靜態GPS</td></tr>
<tr><td>Koketsu et al., 2011</td><td>遠震、強震、靜態GPS</td><td rowspan="3">集中於震源附近，較為深源的破裂特徵</td></tr>
<tr><td>Suzuki et al., 2011</td><td>遠震、低頻強震</td></tr>
<tr><td>Ozawa et al., 2011</td><td>靜態GPS</td></tr>
</table>

- Shallow asperity generated tsunami
- With Sea floor GPS data included, slip migrates to sea trench

GPS data application to seismic deformation cycle

- Inter-seismic deformation, taking Liupan Shan fault as an example
- Co-seismic deformation (2011 Tohoku Mw9.0 Eq.)
- Post-seismic deformation (2010 Ms7.1 Yushu Eq.)

2010 Ms 7.1 Yushu, Tibet Plateau earthquake



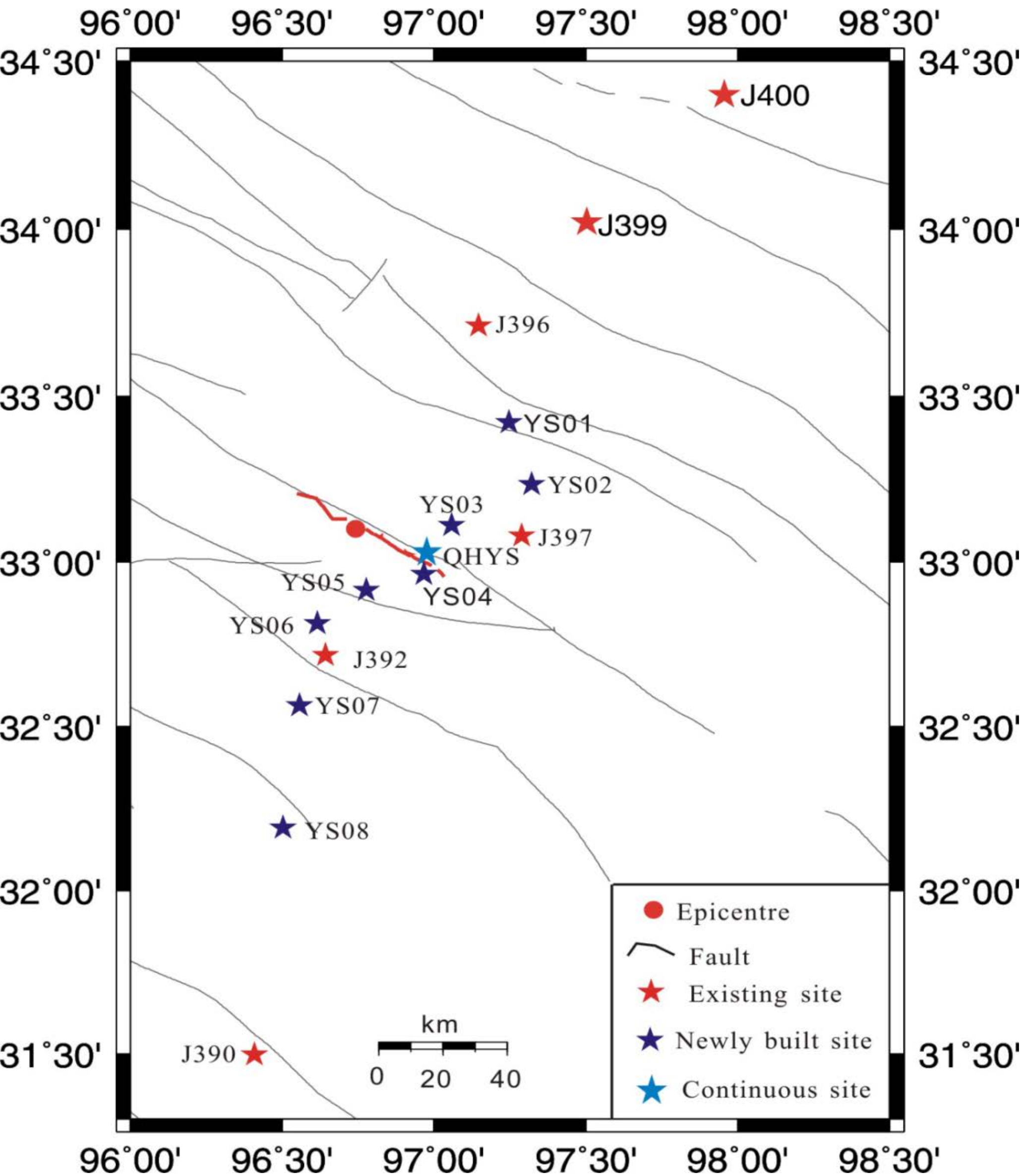
Magnitude: Ms7.1

Depth: 14km

Focal mechanism:

Dominant strike-slip with minor normal slip

GPS sites across the Yushu faulting trace

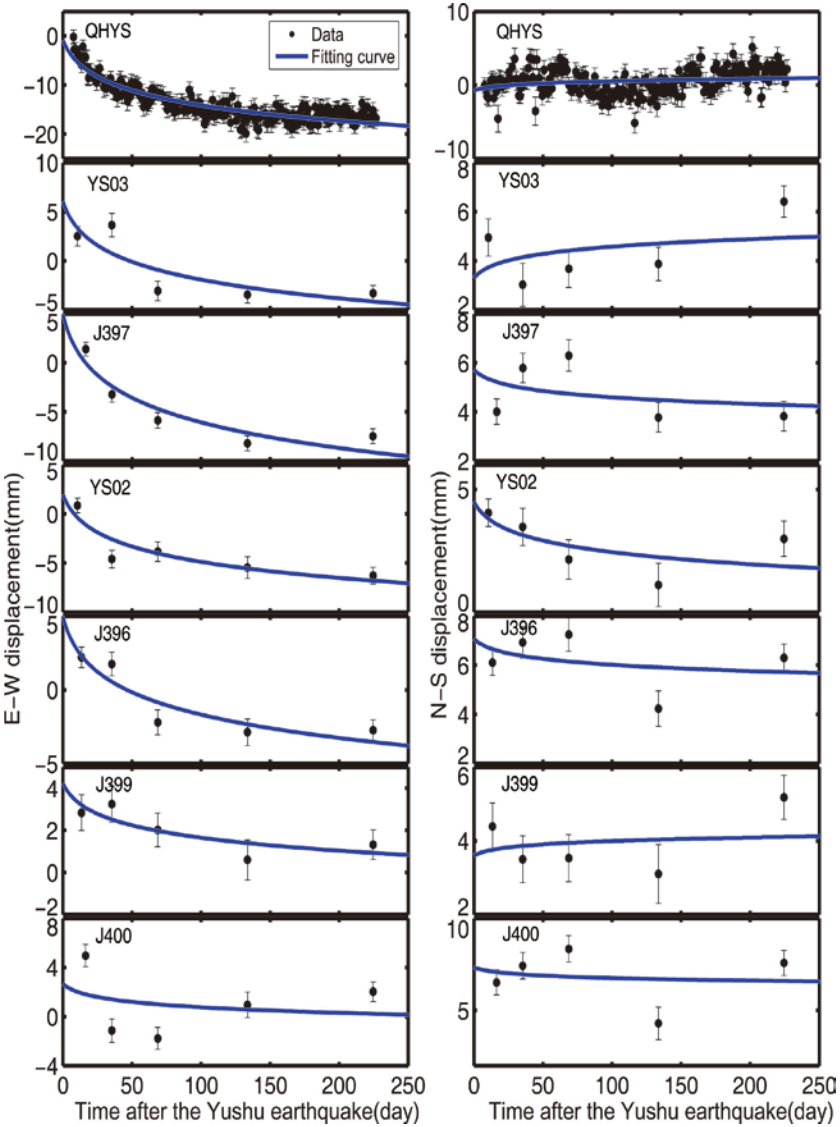


- **6 pre-existing sites**
- **8 newly built sites**
  - **1 continuous station(QHYS)**
  - **3 semi-continuous stations (YS01, YS04, J392)**
  - **4 campaign stations**
- **cross-section length: 360 km**

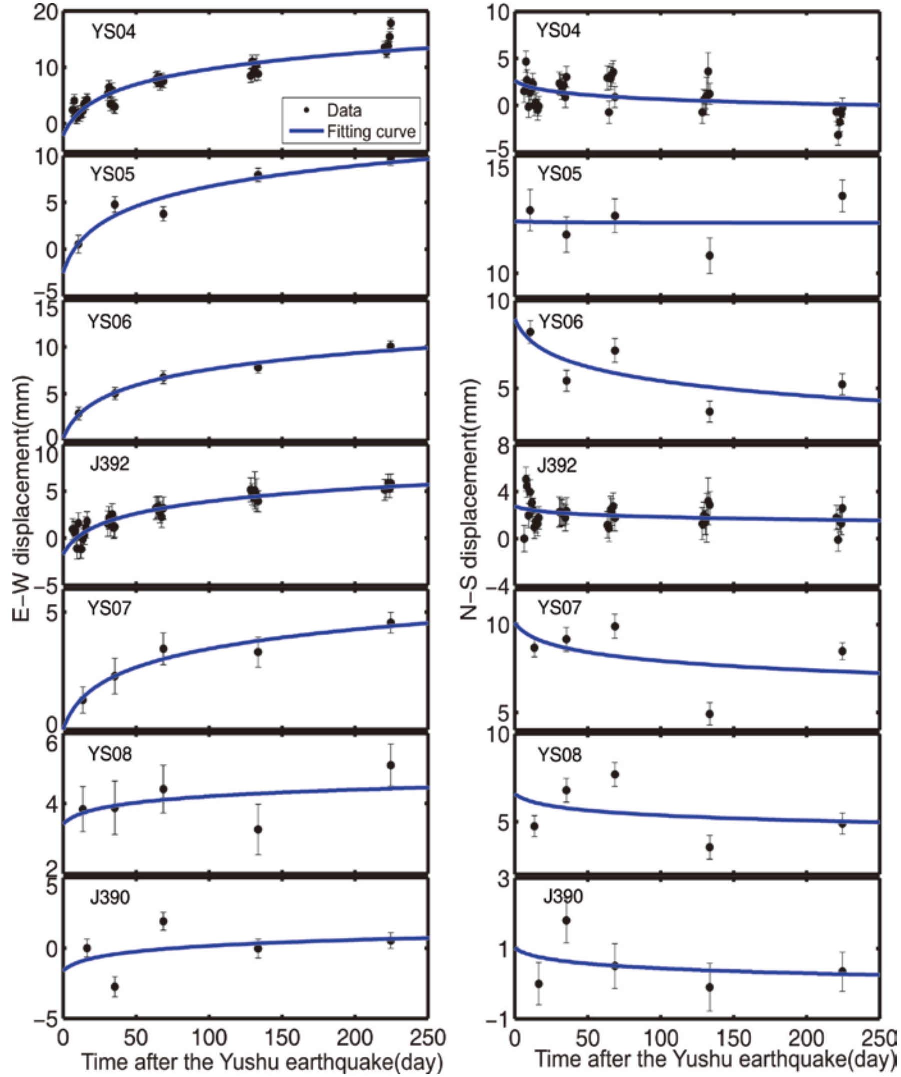
采集到连续站第一批数据

Postseismic deformation fitting with logarithmic functions

Northern sites

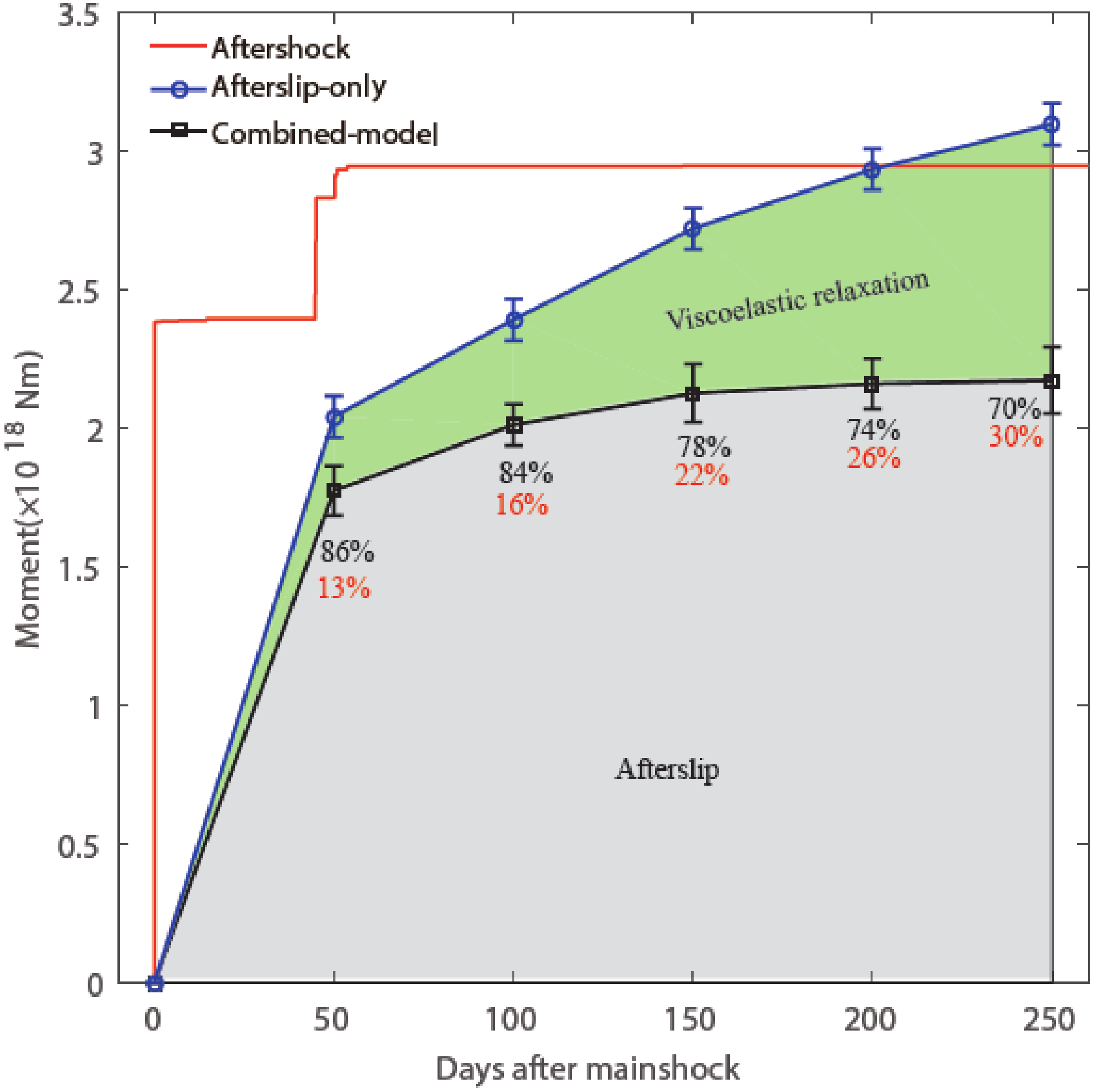


Southern sites



Dominant deformation appear during the early 50 days

Moments of aftershocks, afterslip and viscoelastic relaxation



Recurrence interval for an M 7 class earthquake

$$Trec = \frac{M0_{\cos} + M0_{post}}{dM0_{\text{int}\,er} / \mathrm{dt}}$$

Co-seismic moment only: ~130 yr.

Co-seismic and afterslip included: ~147 yr.

Co-seismic, afterslip and aftershocks included: ~167 yr.

Summary

- Inter-seismic deformation can be characterized with ever-growing geodetic techniques, to understanding locking area, strain accumulation, maximum magnitude of potential earthquake, and recurrence interval.
- Co-seismic static and dynamic displacements recorded by GPS receivers benefit the study of focal mechanism, slip rupture process.
- Post-seismic signals by GPS contribute to refining recurrence interval of identical earthquakes.

Thank you for your attention.

precision of the GNSS data processing results

Daily solutions
1mm in horizontal component and
3mm in vertical component as shown in statistics of the.

Epoch by epoch GPS positioning
10mm in horizontal component
30mm in vertical component.