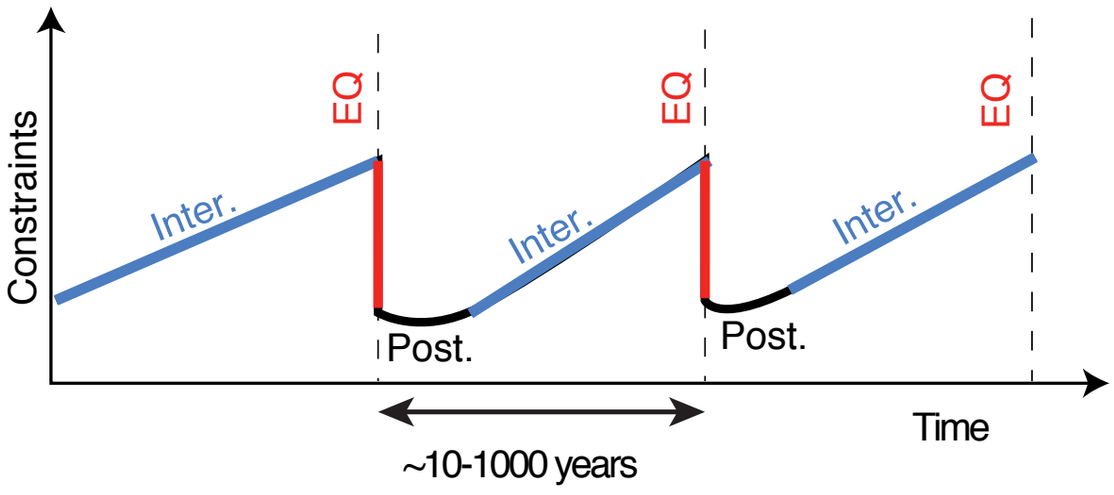
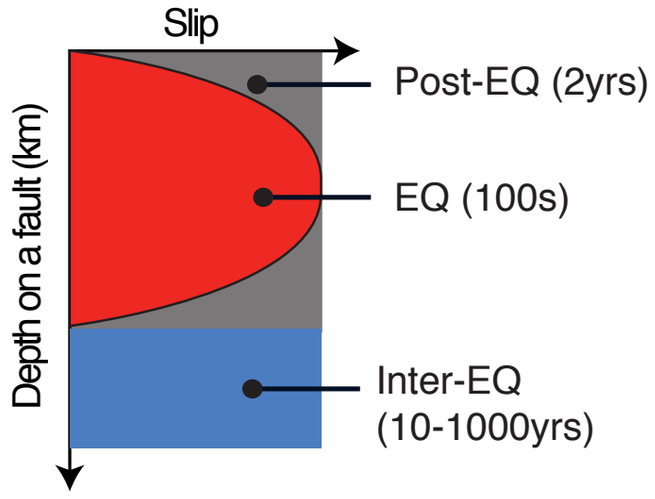
ILLUMINATING WITH AN INSAR TIME SERIES THE SHALLOW ASEISMIC RISING OF A THRUST-FOLD STRUCTURE

Simon Daout, A. Steinberg, T. Kausch,
H. Sudhaus, M. Isken, S. Heiman

BridGeS

Classical model of the earthquake cycle:





Implication:
Topography created during earthquakes

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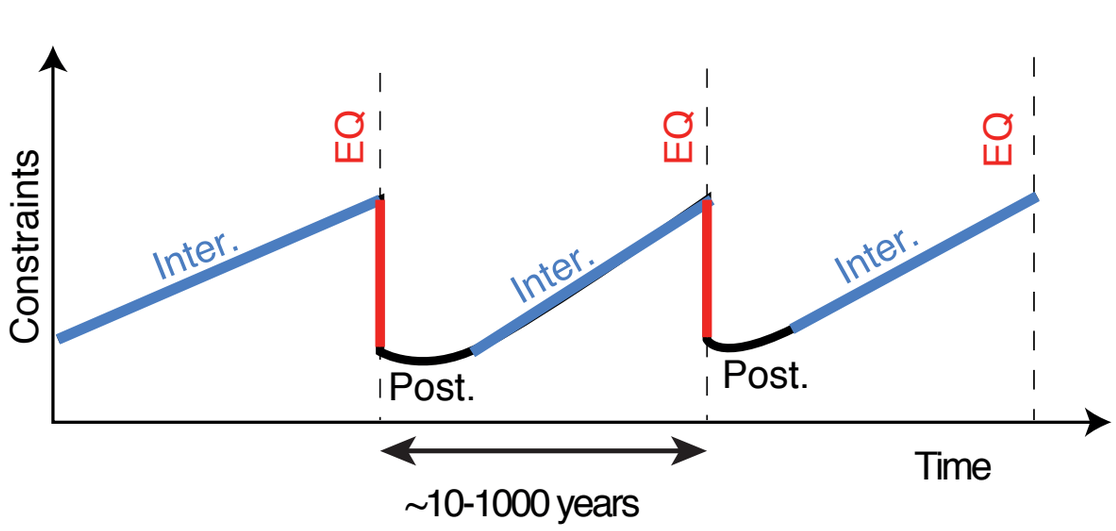
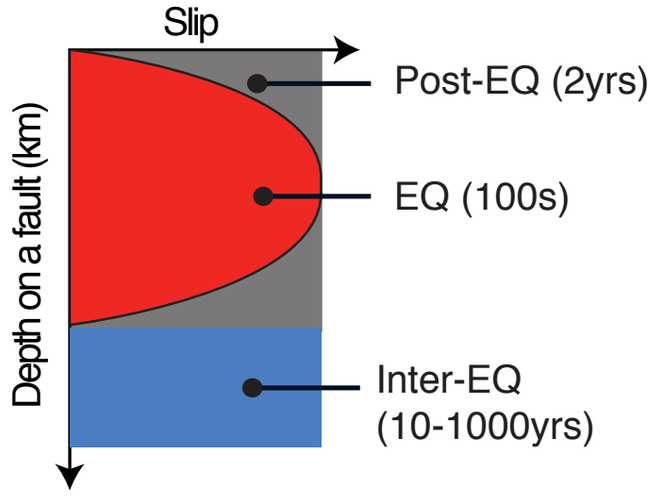
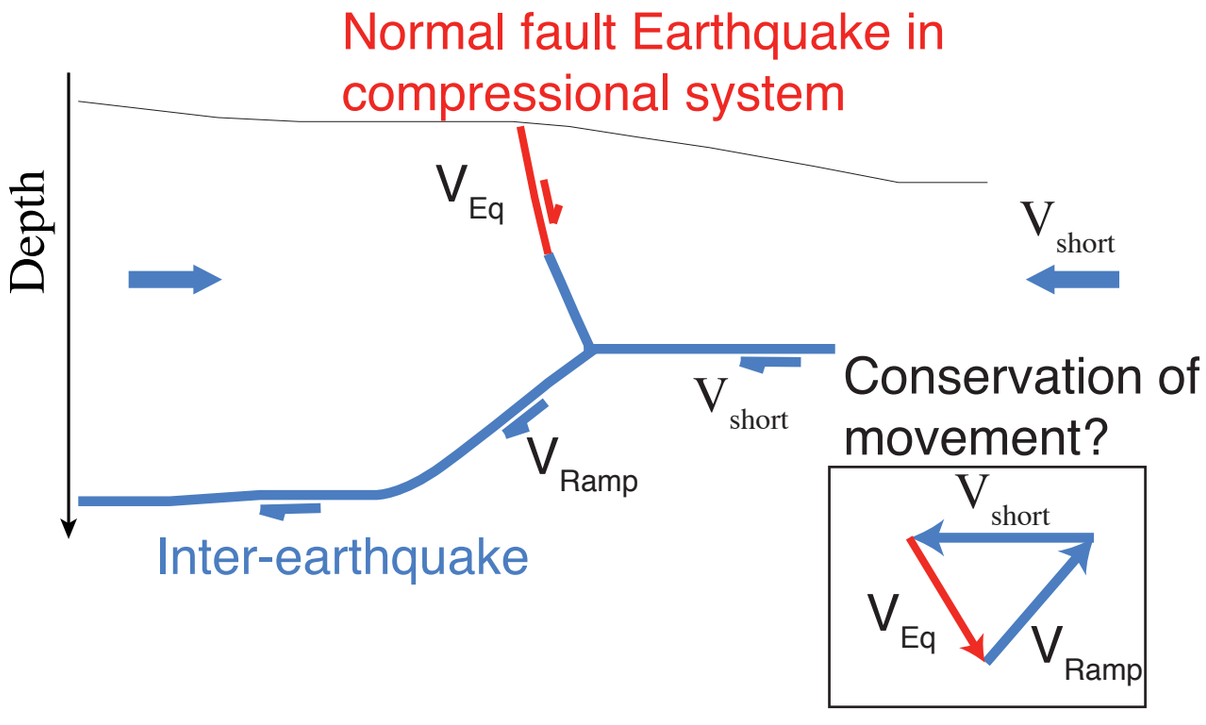




Implication:
Topography created during earthquakes

However… a fault-system is not a simple rectangular patch:

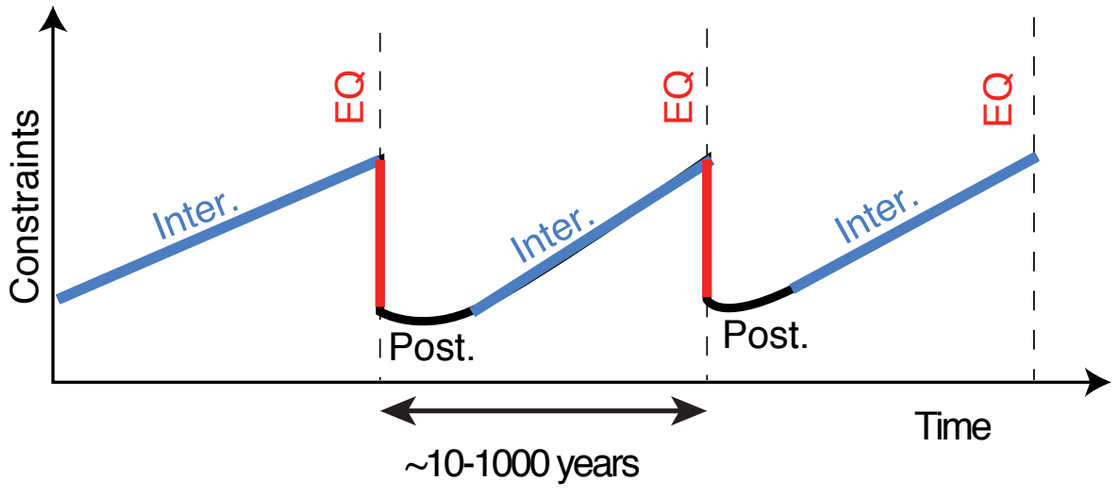


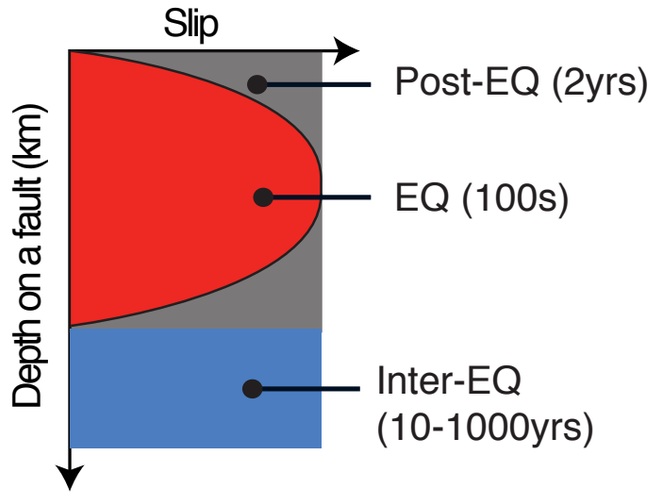
- Fault-segmentation/interaction
- Slip-partitioning

(Daout et al., 2016, GJI; Daout et al., 2016, GRL)

Topography only created by Vramp?

Classical model of the earthquake cycle:





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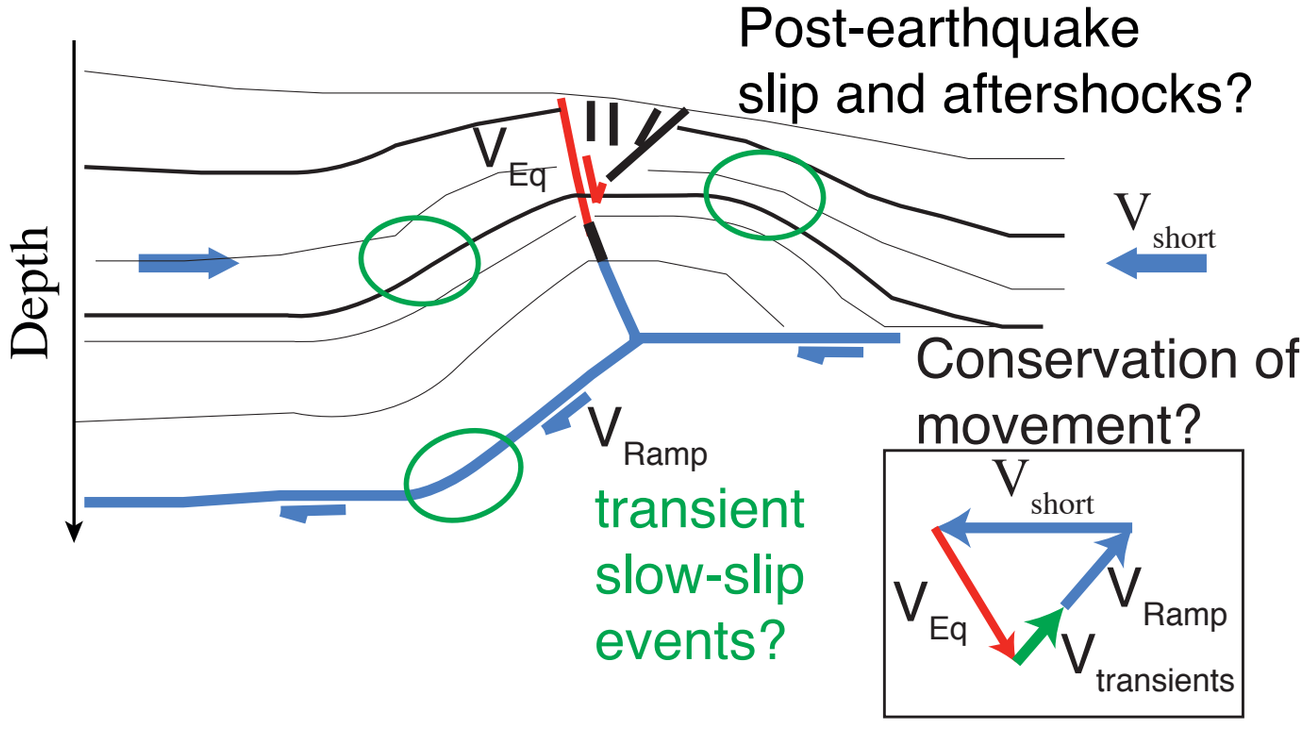
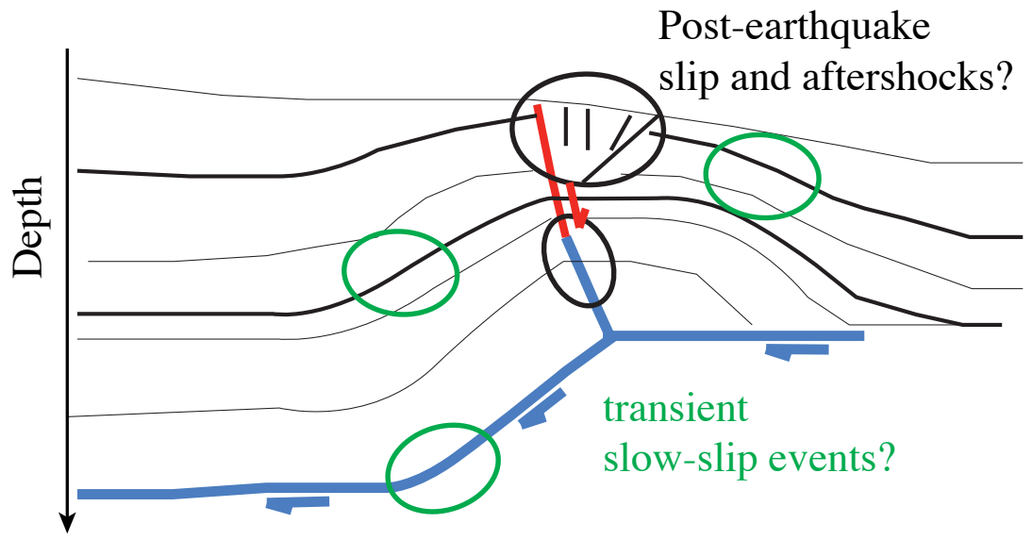
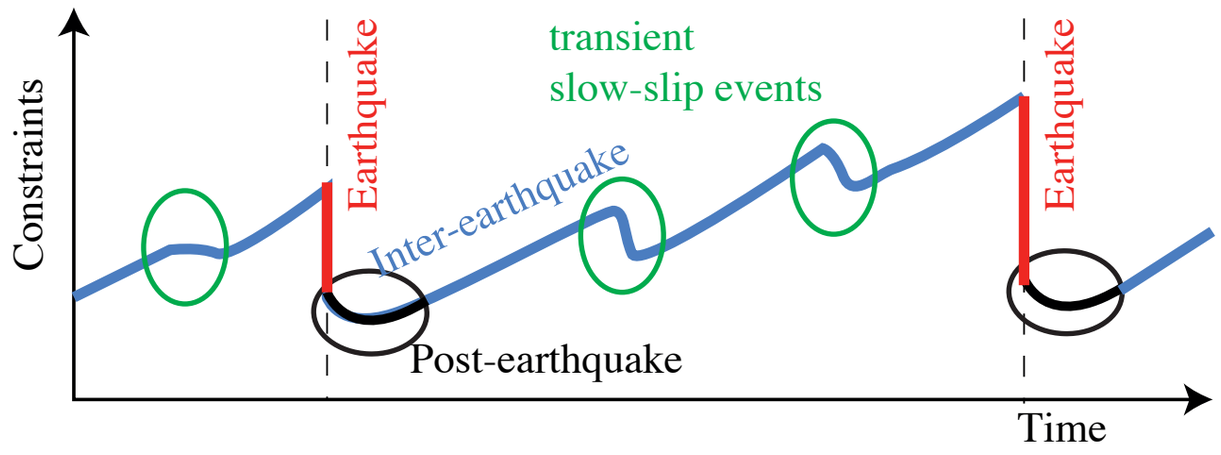


- Slip on secondary structures
- Intra-block deformation along folds

Role of aseismic processes?



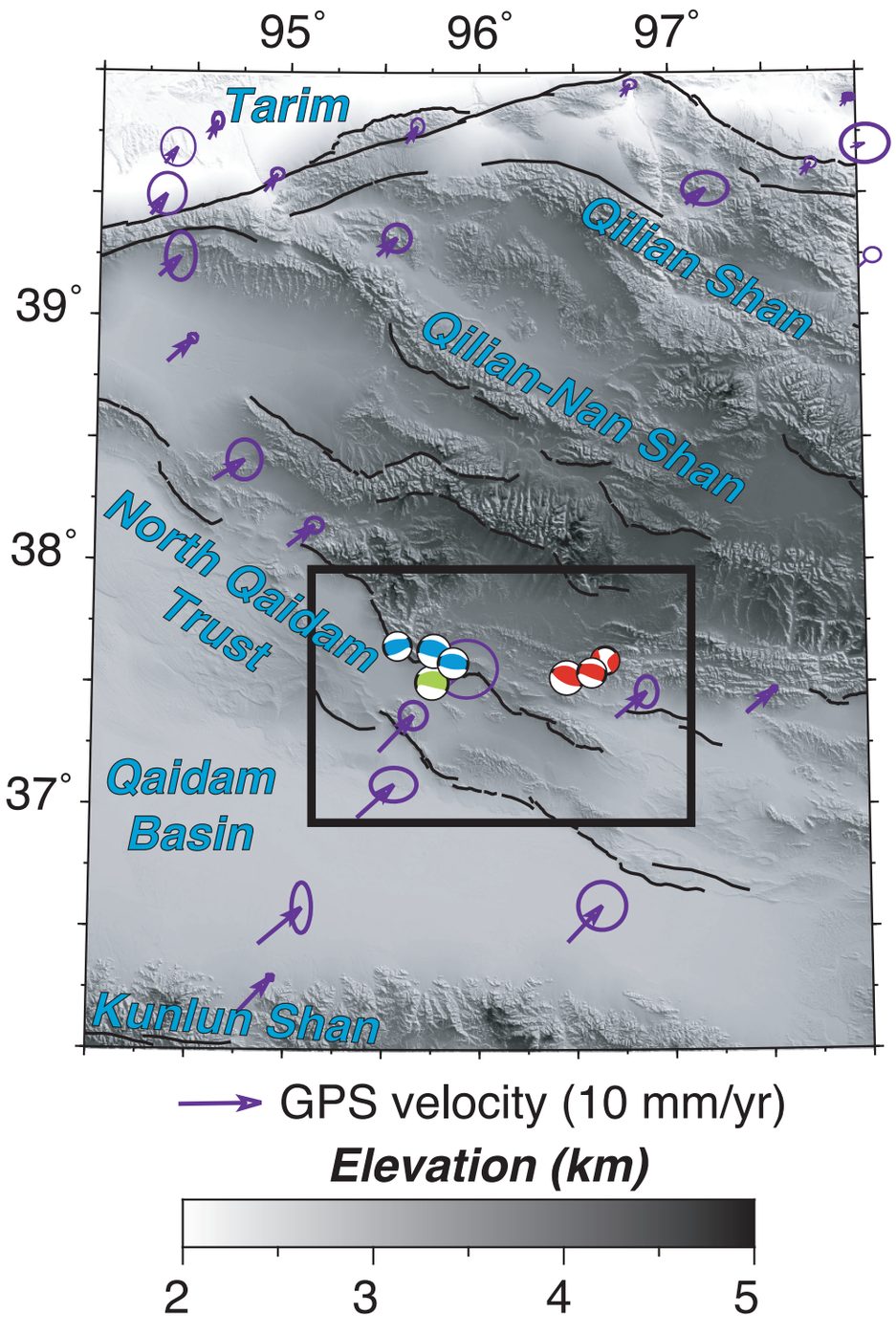


How is topography built during several seismic cycles?

When are folds or secondary faults deforming during the seismic cycle?

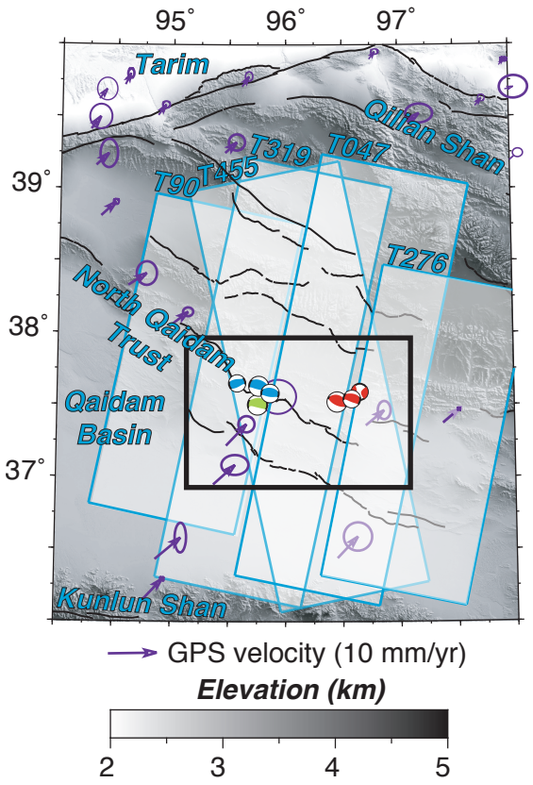
Interaction between basement faults and shortening in the sedimentary cover?

The North Qaidam Shan thrust-fold, Tibet :



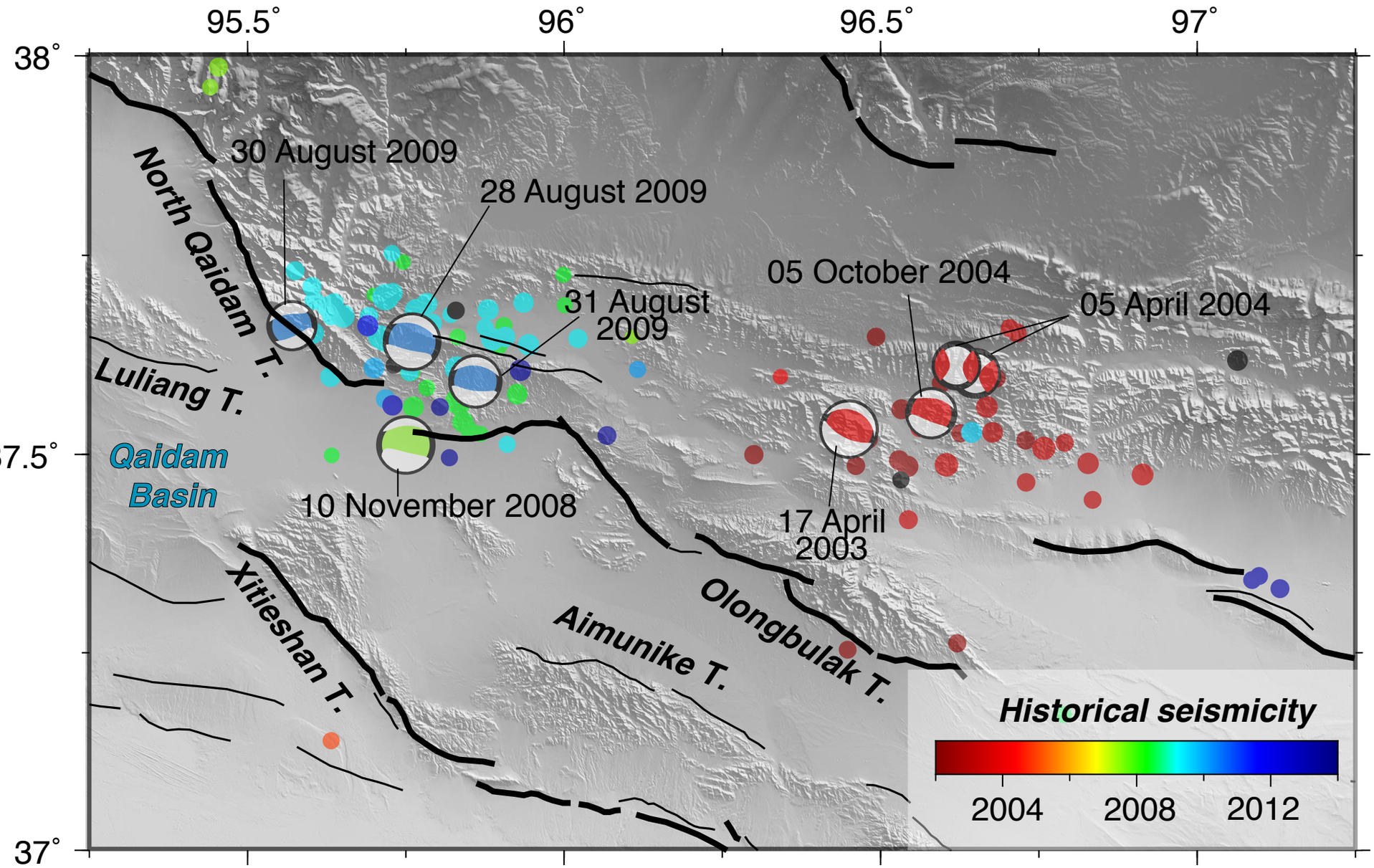
- 5-6 mm/yr of convergence, thrusts & folds

The North Qaidam Shan thrust-fold , Tibet :



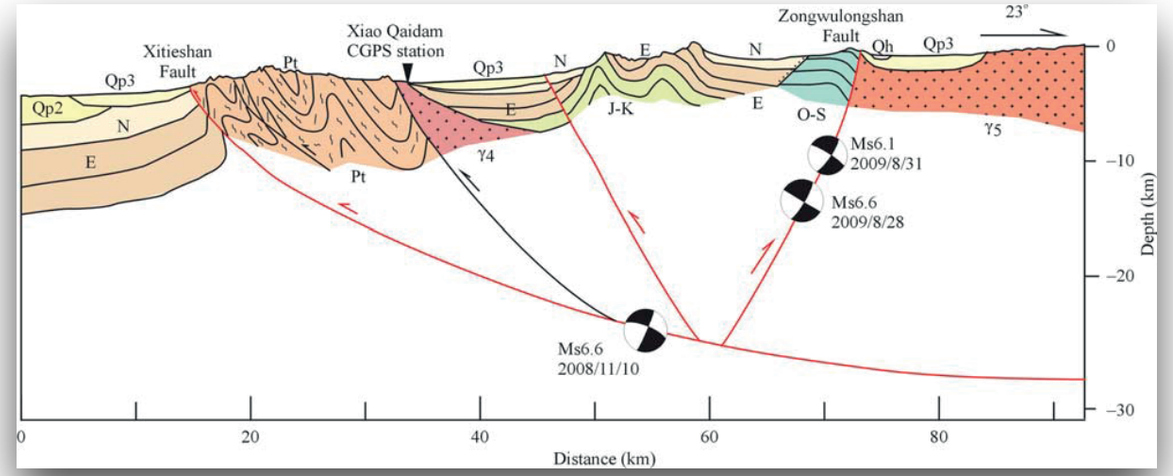
- 4 descending tracks
- 1 ascending

- 3 Mw 6.3 EQs in 2003, 2008 and 2009



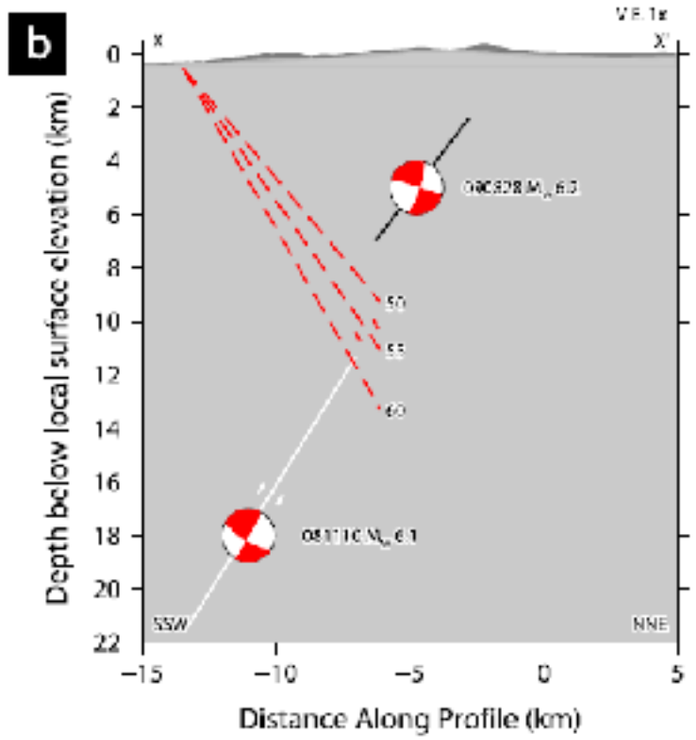
Main Objectives:

- Ambiguity of fault plane for the 2008 event



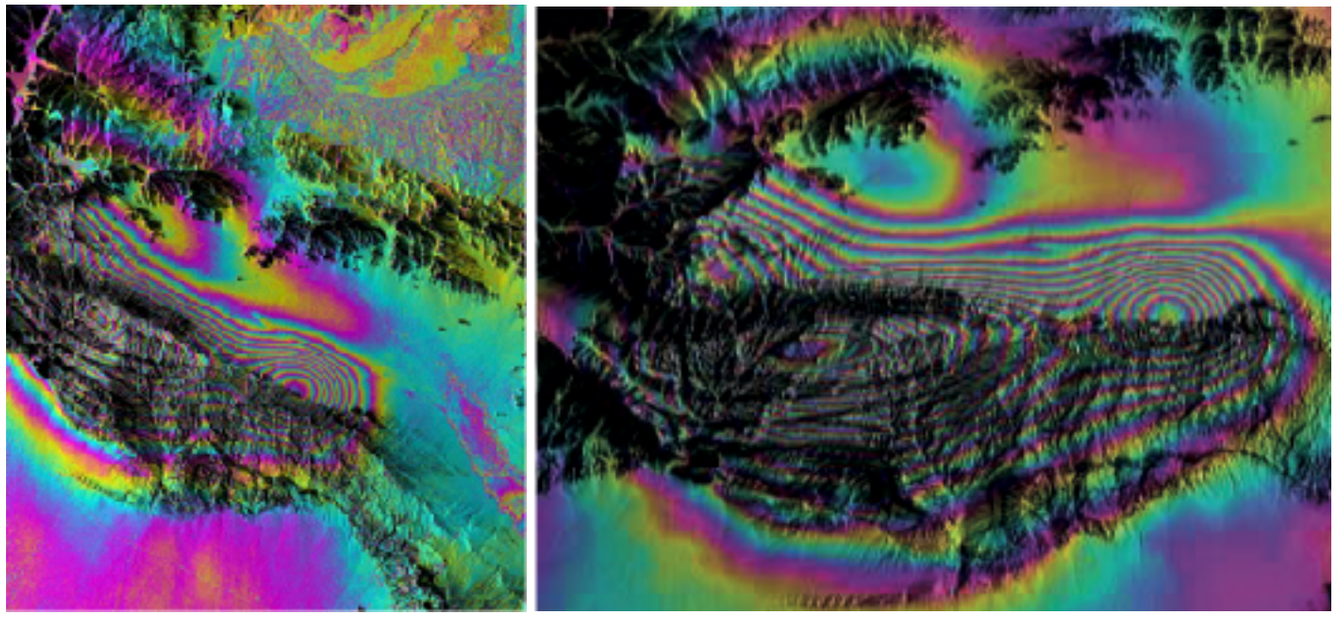
(Chen et al., 2013)

(Elliott et al., 2011)



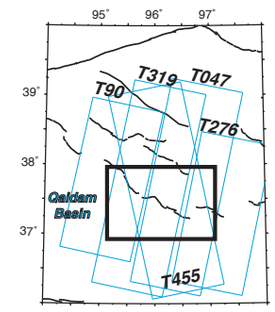
- Capture the slow inter-earthquake surface displacements with an InSAR time series analysis approach

Ground motion of the 2009 Earthquake:



(Ascending) (Descending)

Time Series of cumulative surface displacements:



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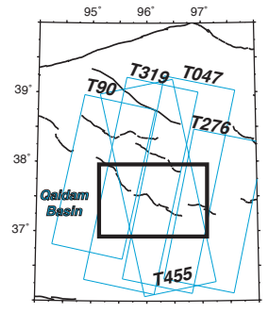
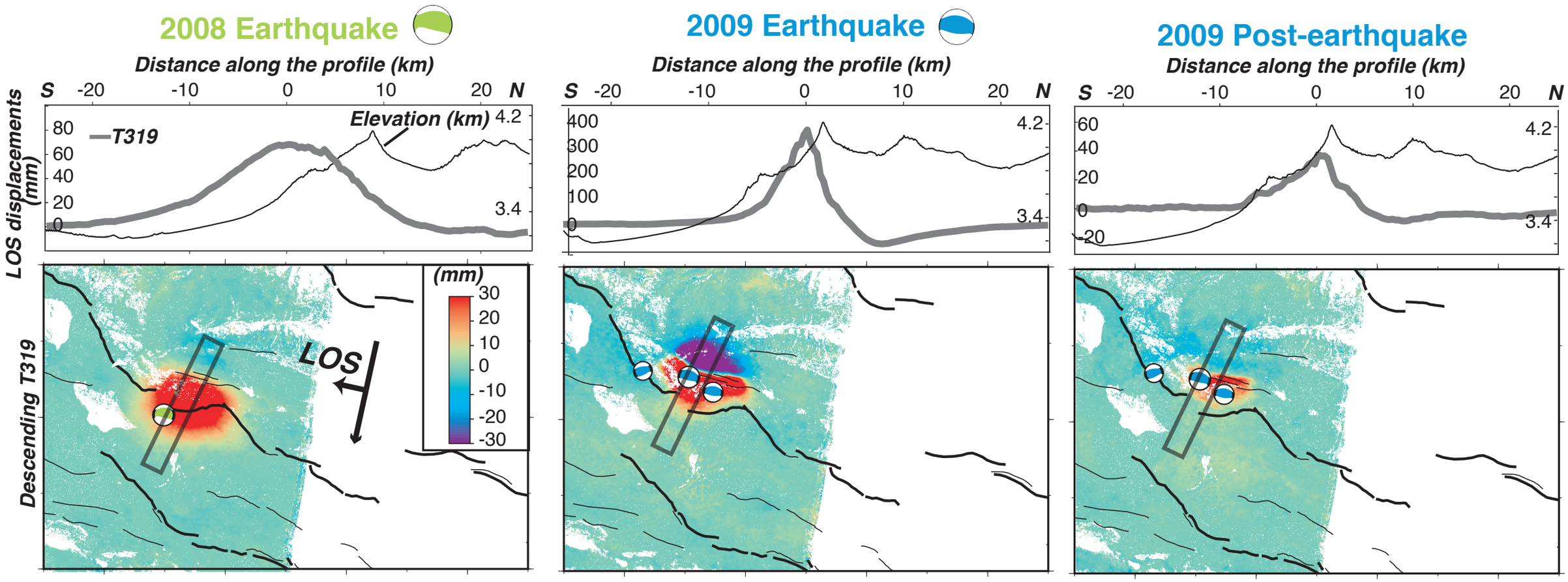
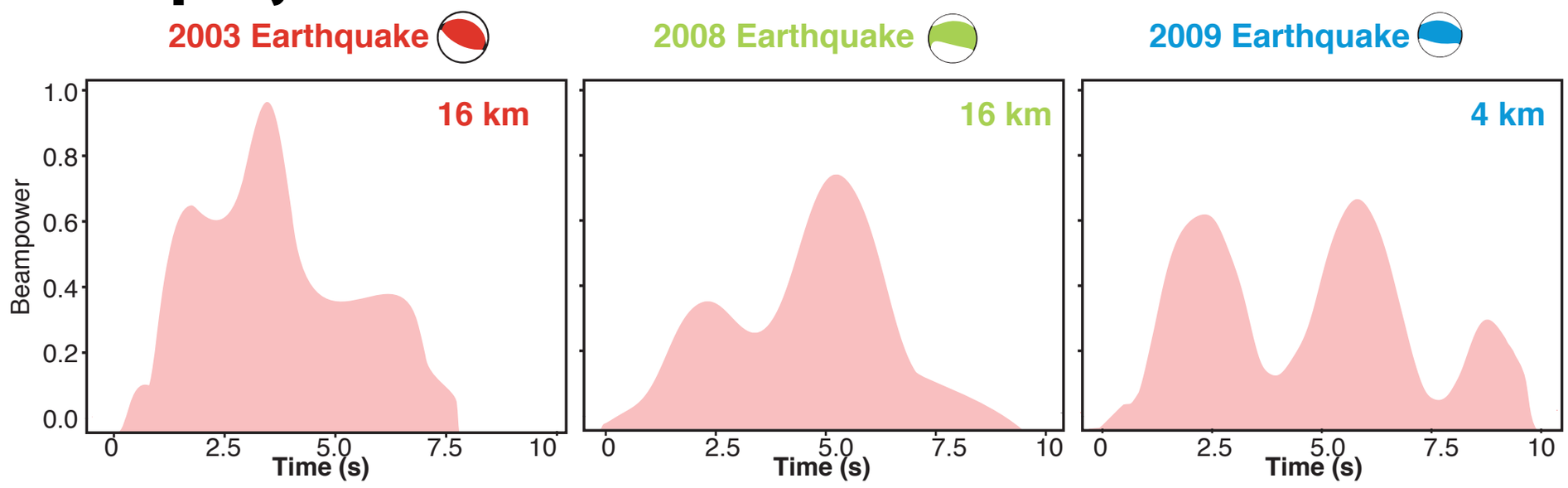




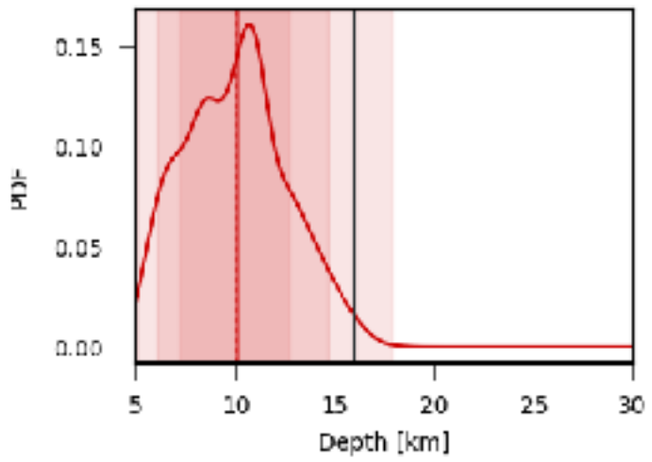
Seismic back-projection:

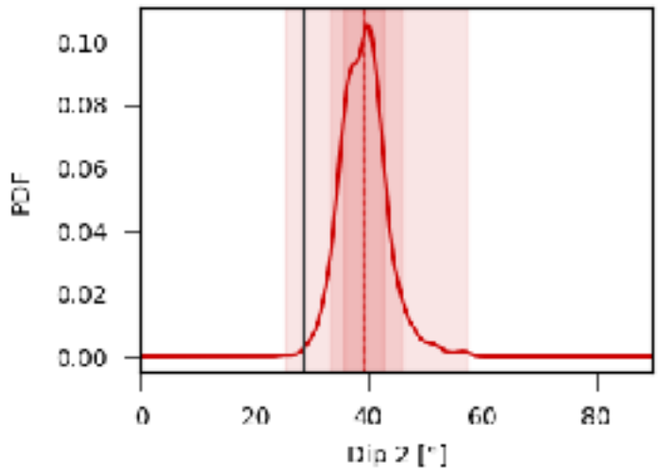


(back-projection method from Steinberg et al., in prep)

*More about the **Pyrocko** software:*
Presentations of Henriette Sudhaus and Marius Isken on Thursday morning

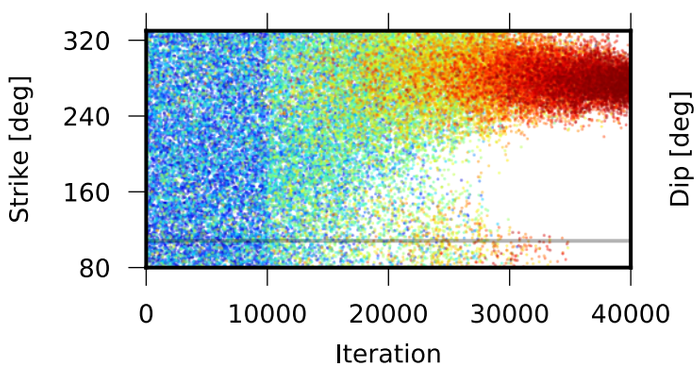
2003 Double-Couple modelling:

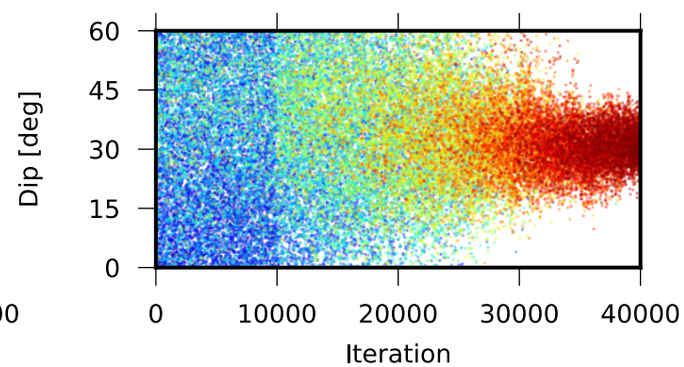




- 8-14 km depth
- 38-46°dip

2008 Rectangular fault modelling:

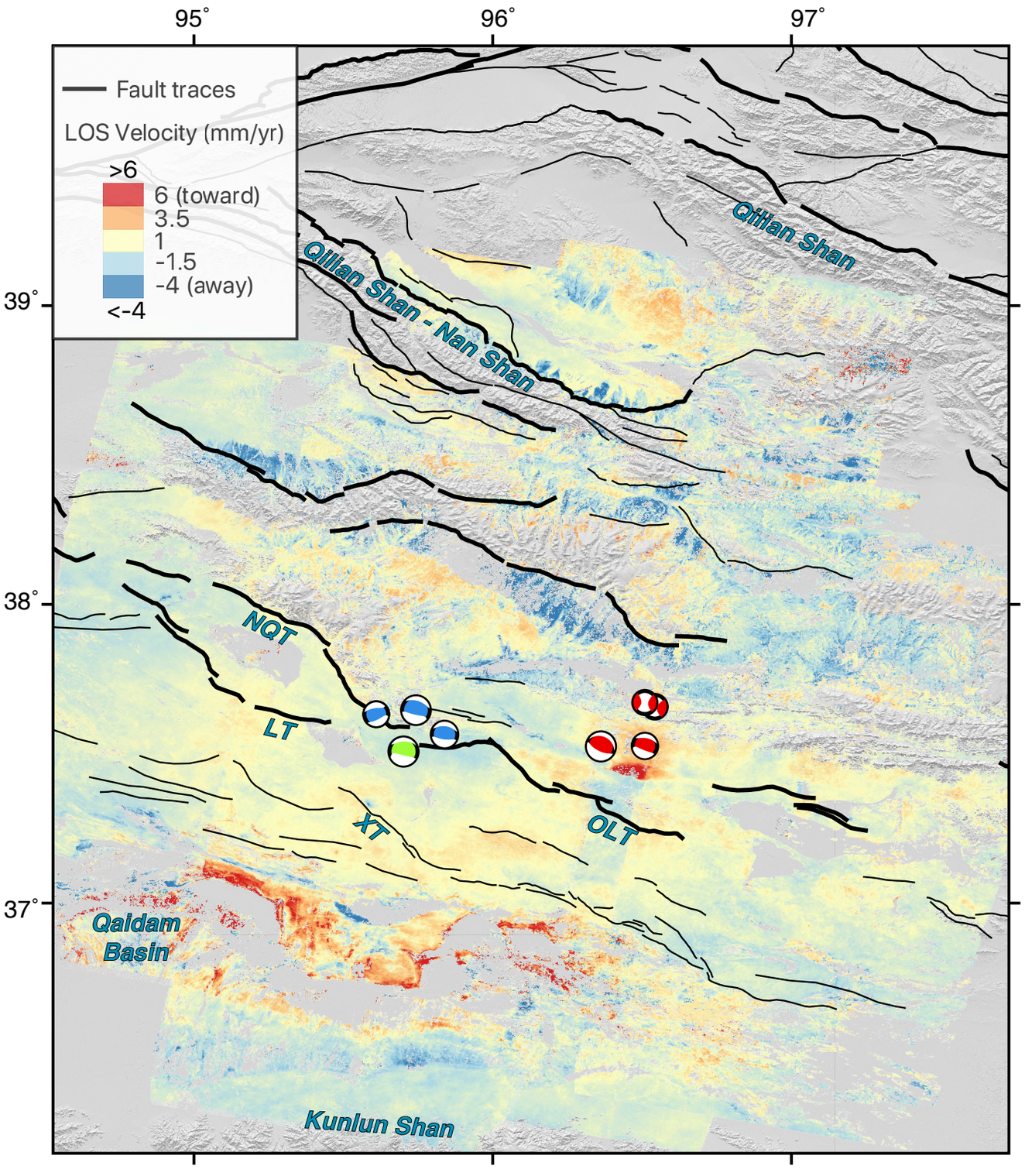




- 9-11 km-depth
- 27-33°north-dipping

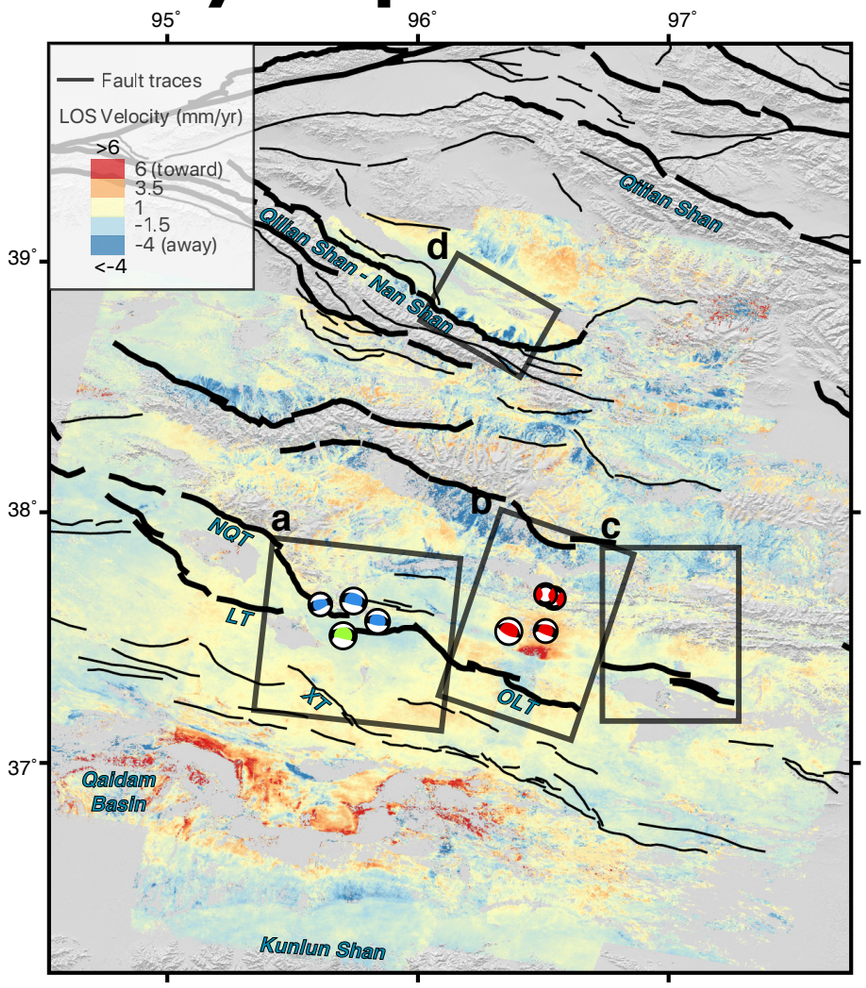
- Both north-dipping and south-dipping bimodal solutions are explored simultaneously

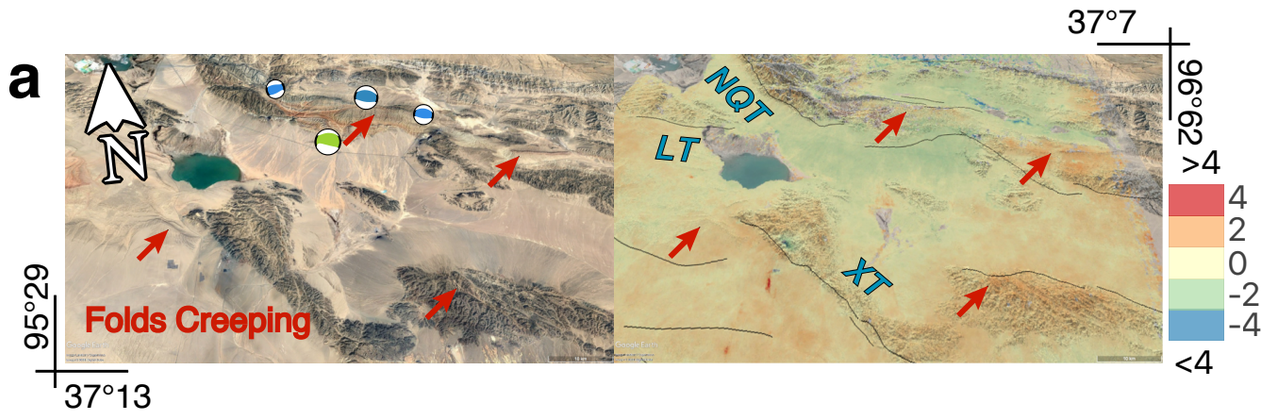
Velocity Map:



- Continuous view of the inter-earthquake decadal linear ground motion from 2003 to 2011

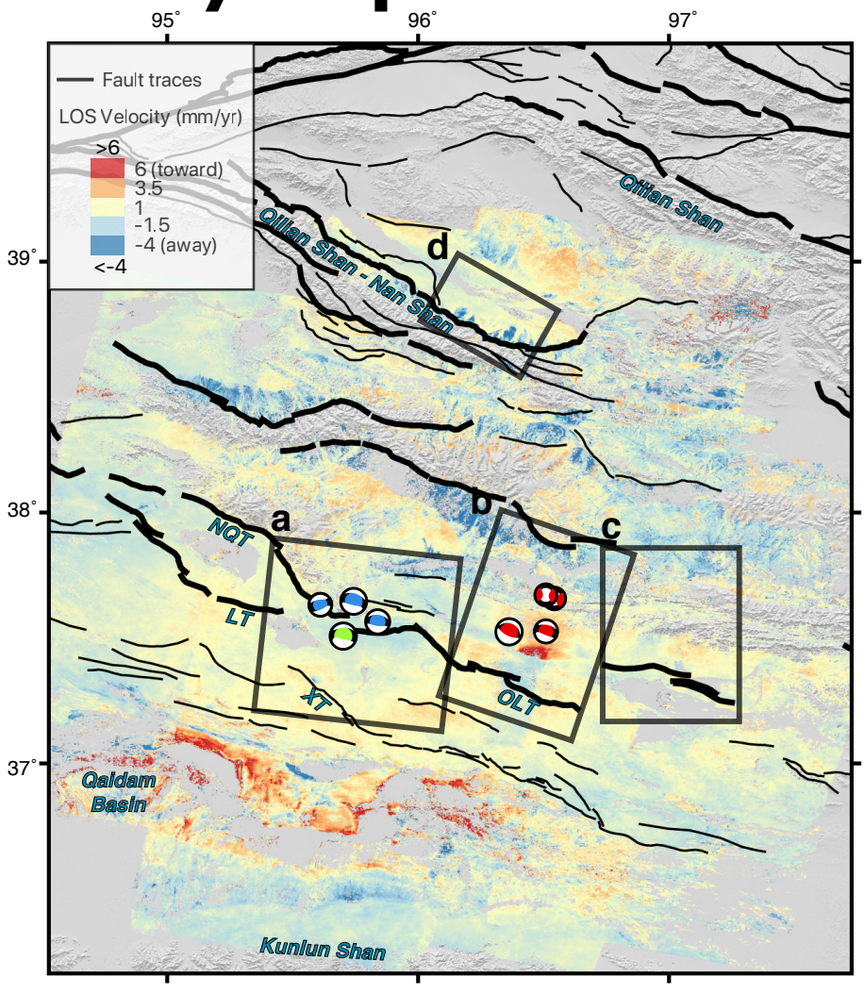
Velocity Map:

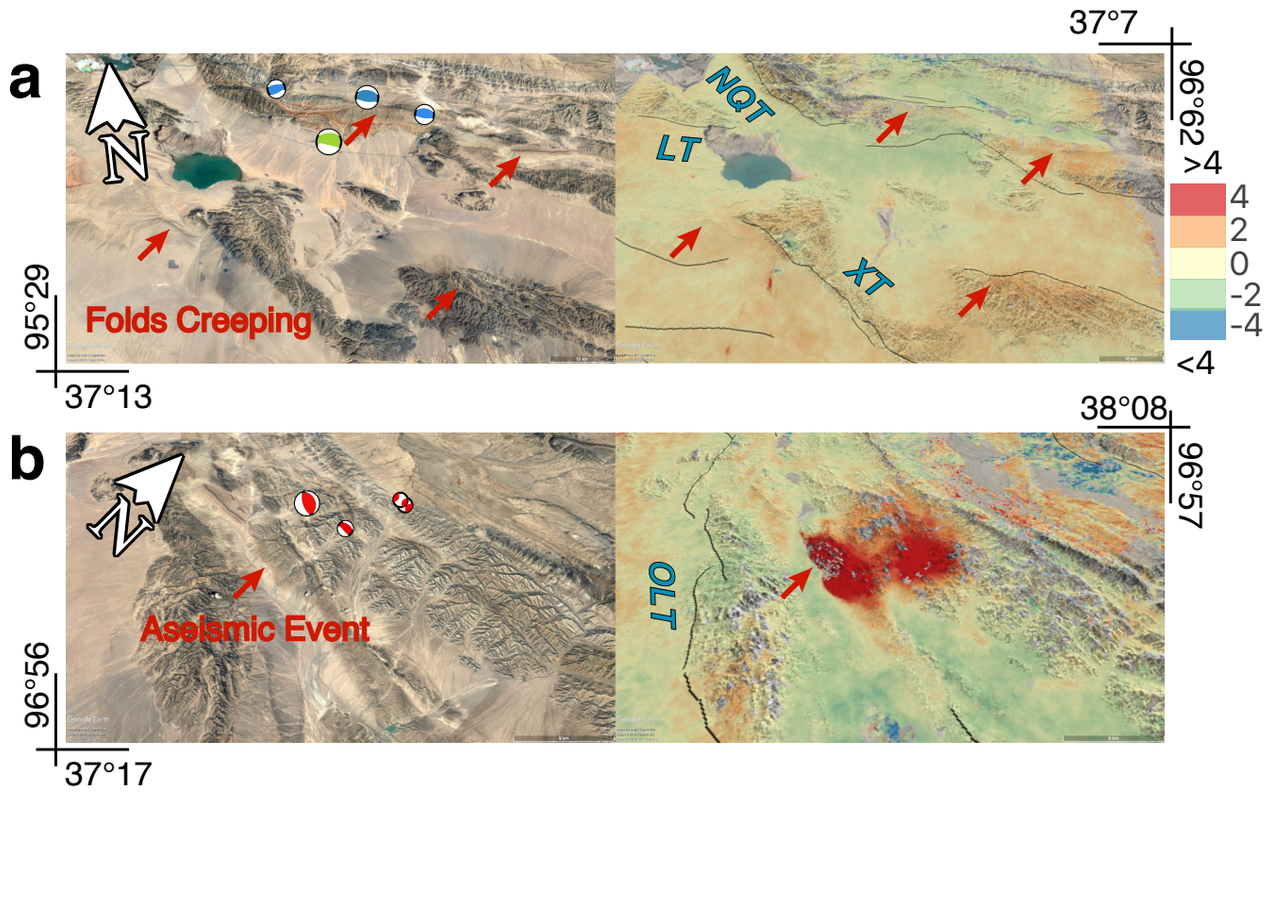




- Creep across thrust-folds

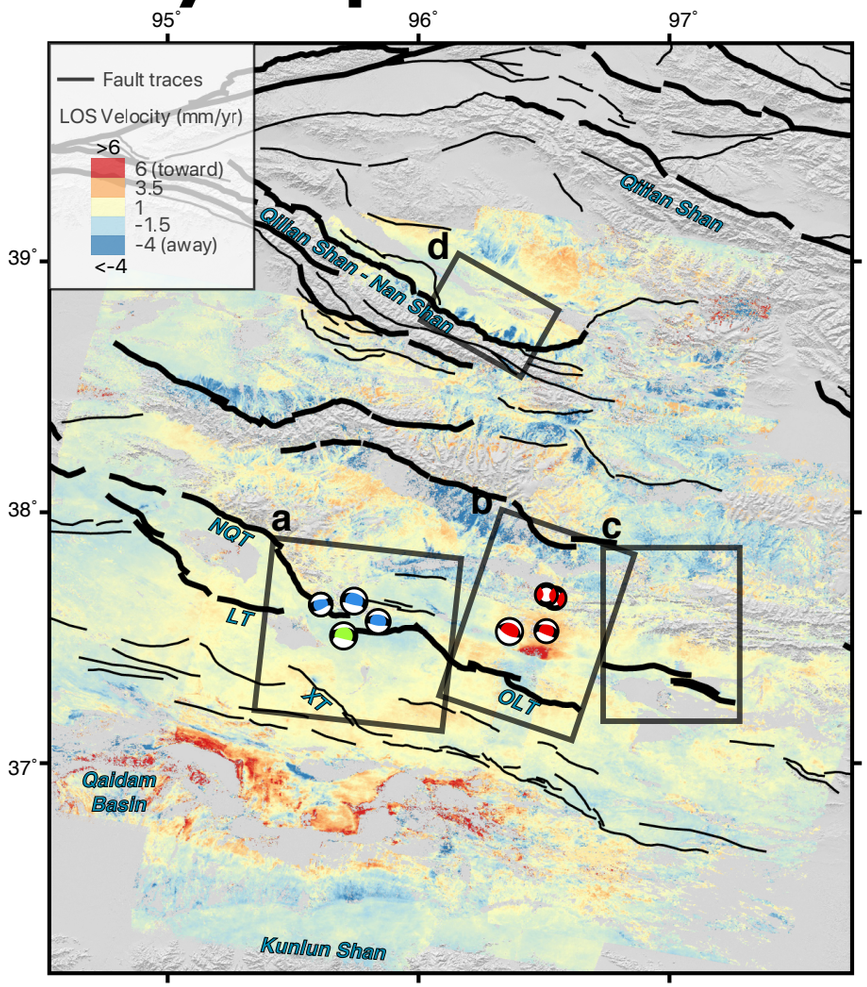
Velocity Map:

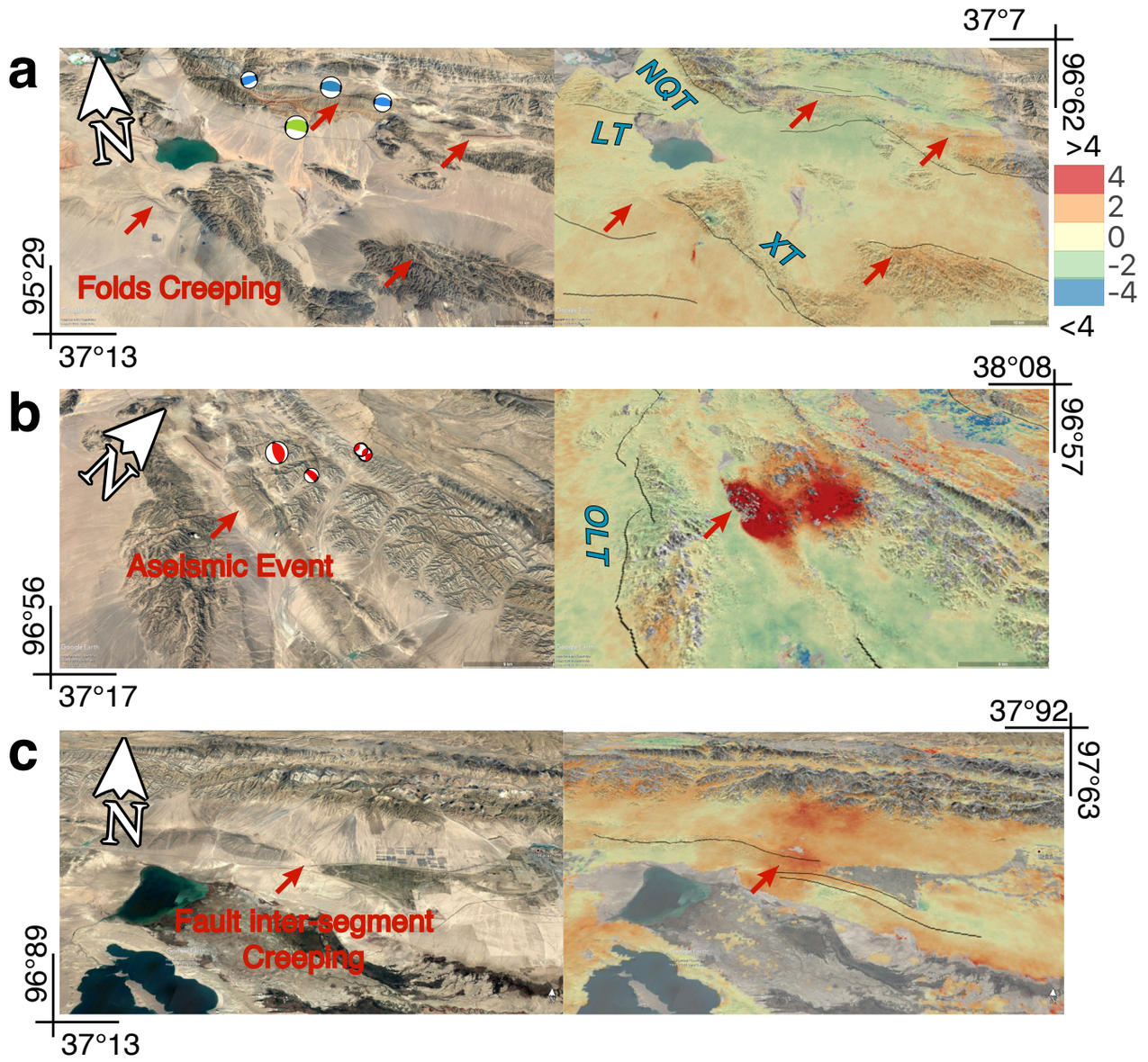




- Creep across thrust-folds
- Aseismic slip

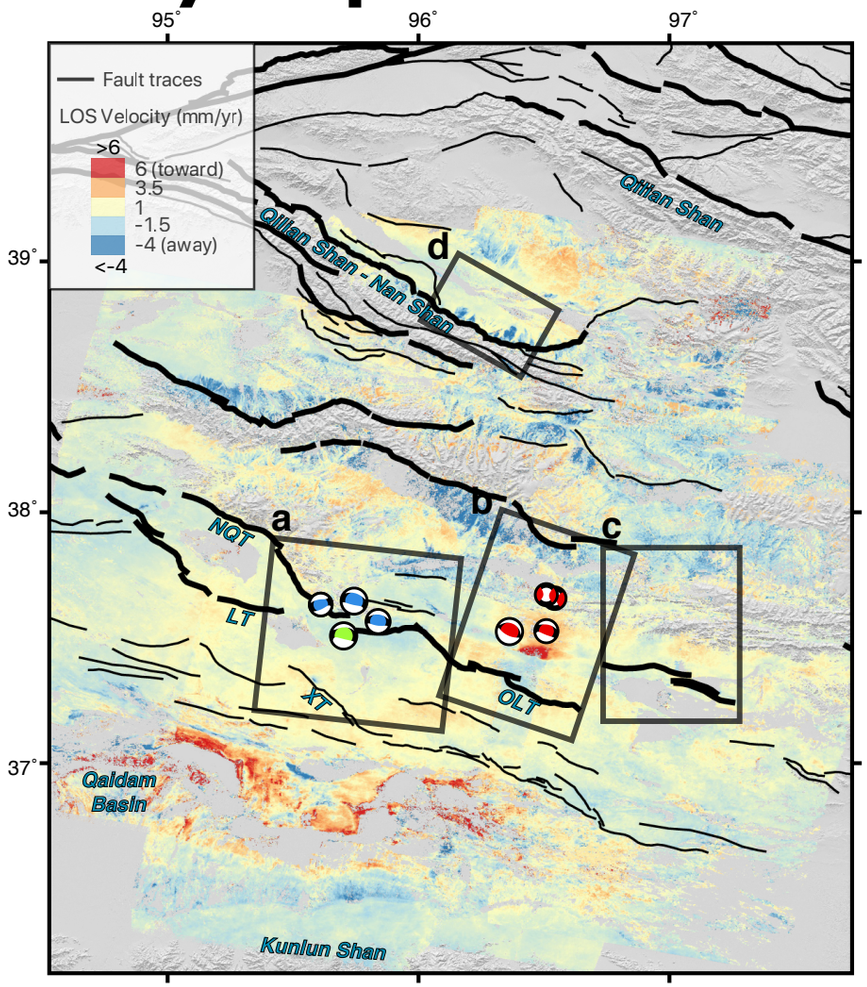
Velocity Map:

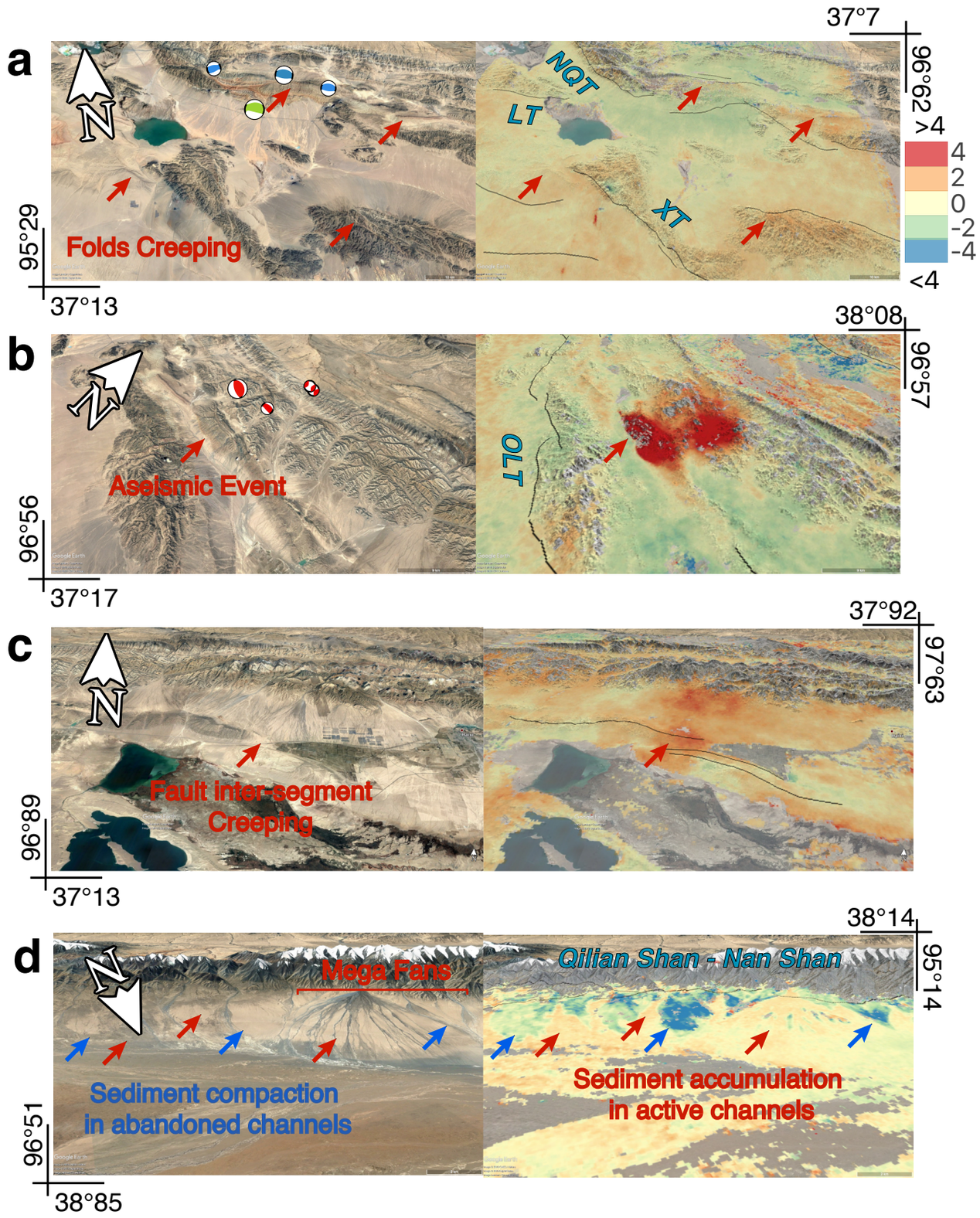




- Creep across thrust-folds
- Aseismic slip
- Fault inter-segments creep

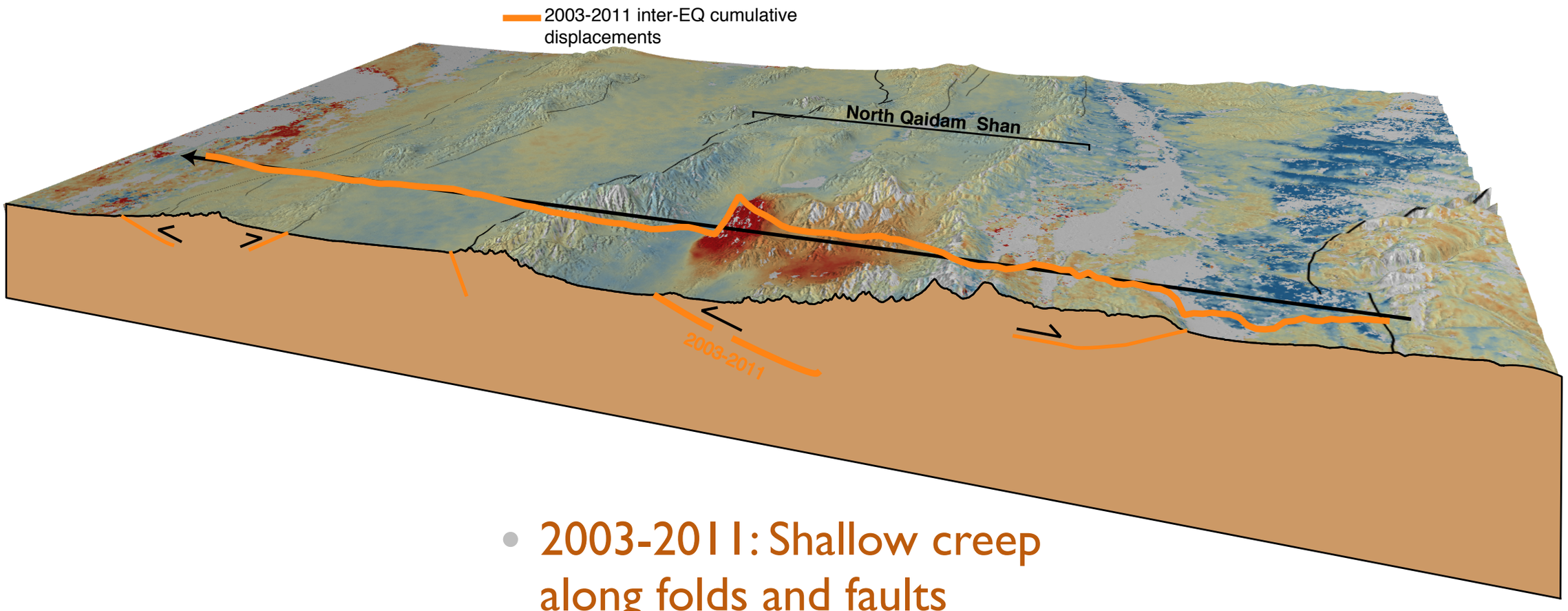
Velocity Map:





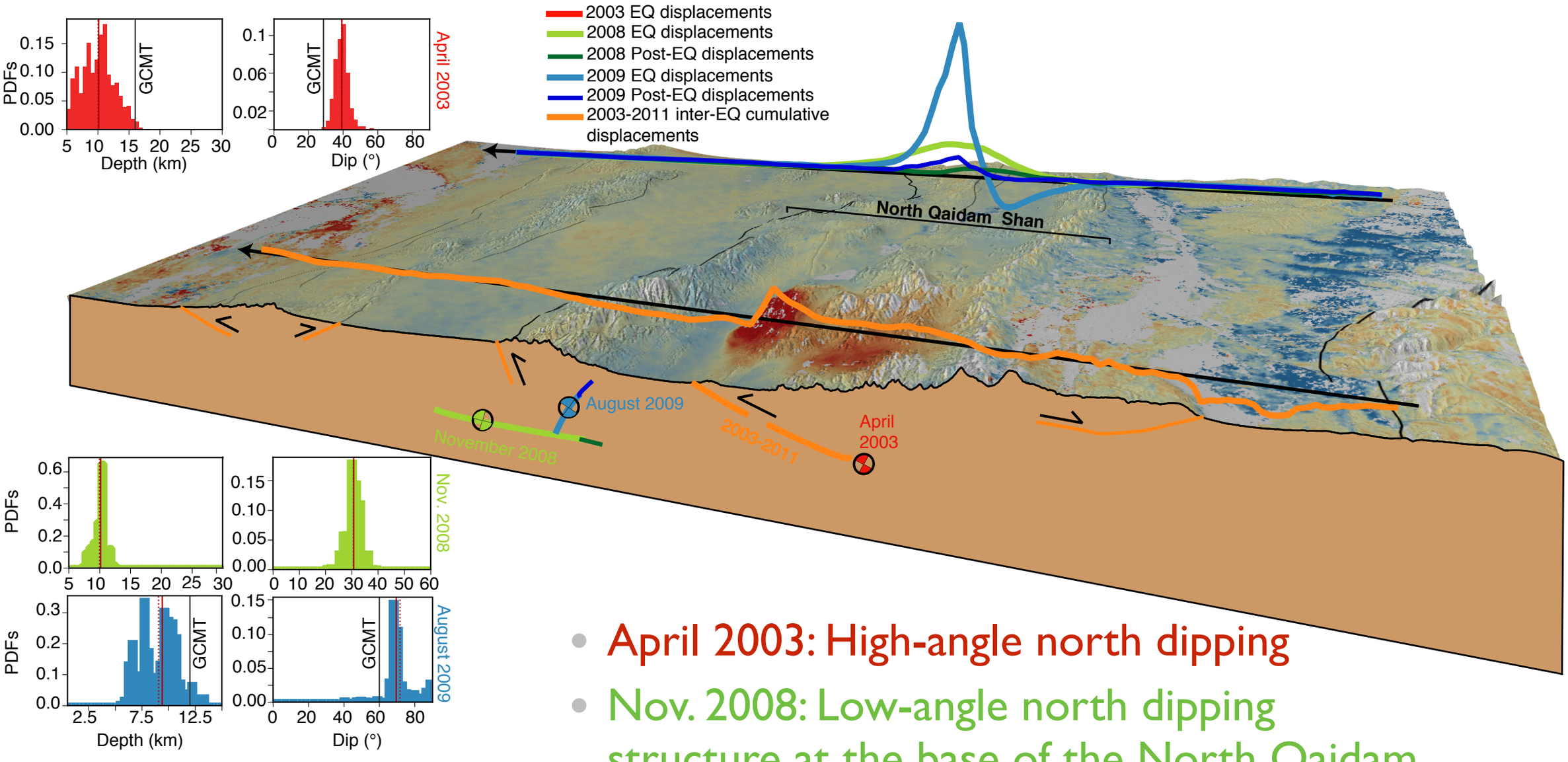
- Creep across thrust-folds
- Aseismic slip
- Fault inter-segments creep
- Sediment compaction

Schematic block model:



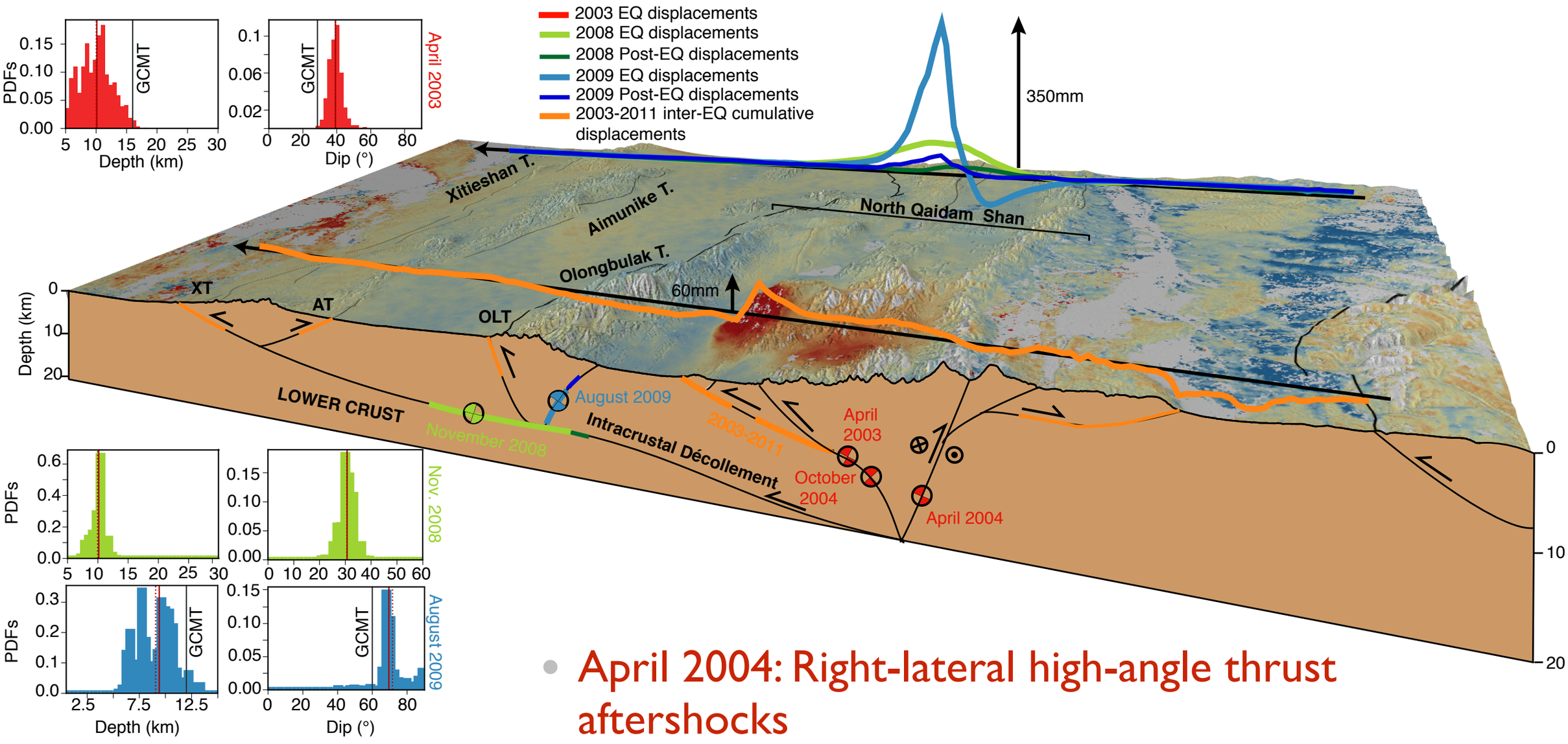
- 2003-2011: Shallow creep along folds and faults

Schematic block model:



- April 2003: High-angle north dipping
- Nov. 2008: Low-angle north dipping structure at the base of the North Qaidam Thrusts
- Aug. 2009: High-angle 5km shallow south-dipping thrust, shallow post-seismic slip

Schematic block model:



- April 2004: Right-lateral high-angle thrust aftershocks

Conclusions

How is topography built during several seismic cycles?

- Fundamental role of shallow aseismic processes

When are folds or secondary faults deforming during the seismic cycle?

- During episodic post-earthquake slip or steady-state creep

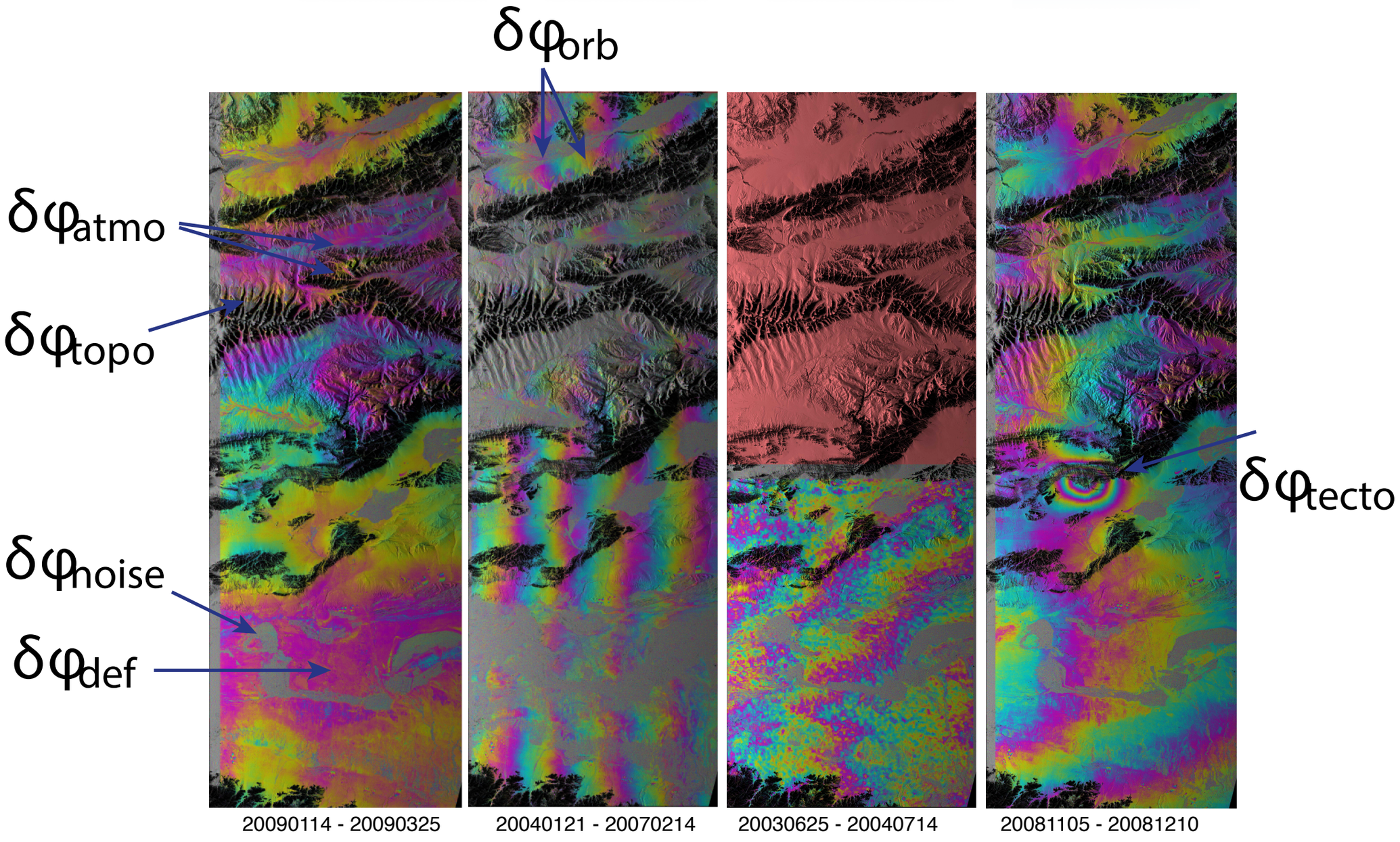
Interaction between basement faults and shortening in the sedimentary cover?

- High-angle thrusts connect to low-angle faults, which partition vertically the shortening rate producing short-wavelength topography

I hope convince you today that bringing together different expertises, it is possible to advance some fundamental scientific knowledge and that this kind of study could serve as basis for further analysis with the new generation of SAR satellites.

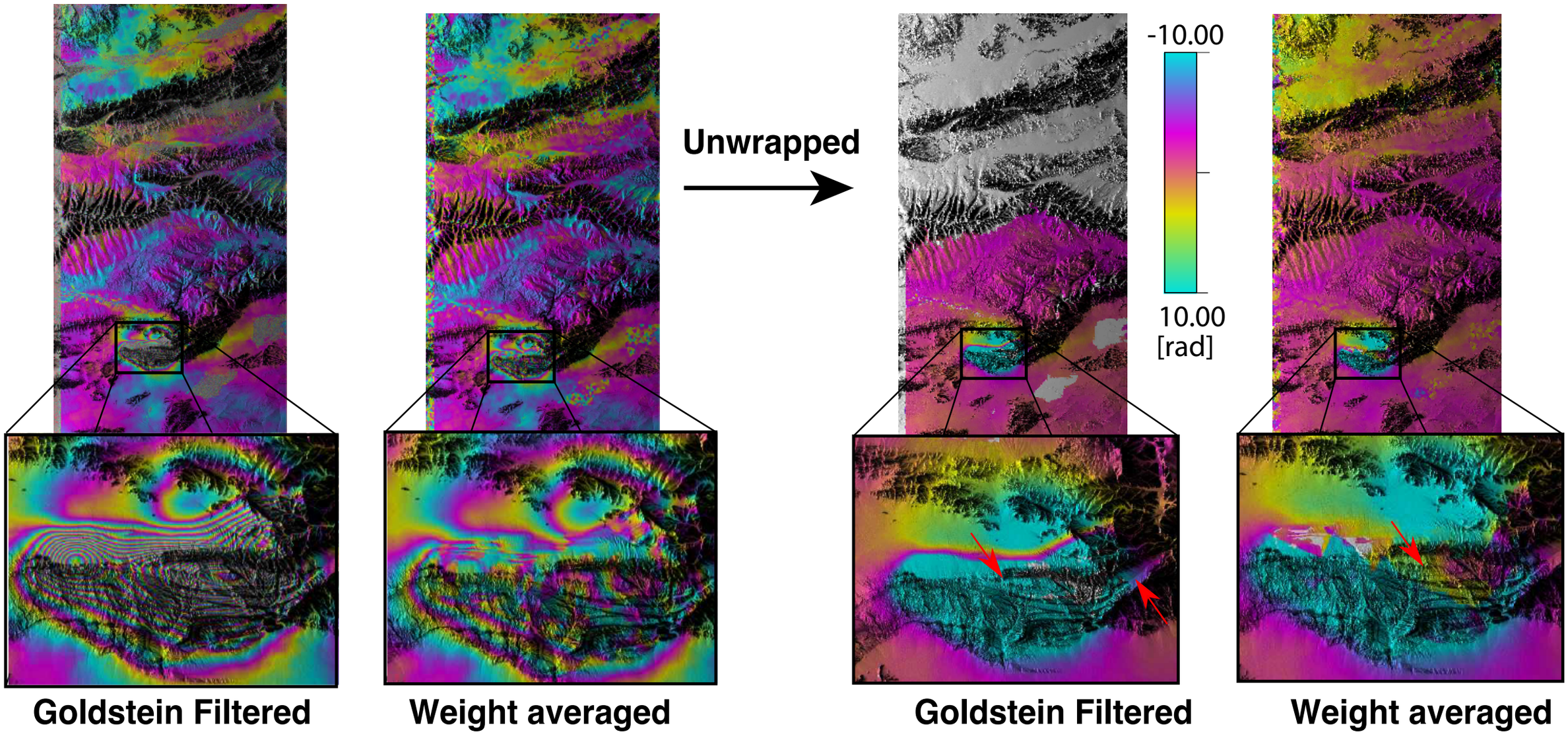
Parasite signals:

$$\delta\phi = \delta\phi_{\text{tecto}} + \delta\phi_{\text{atmo}} + \delta\phi_{\text{orb}} + \delta\phi_{\text{topo}} + \delta\phi_{\text{noise}} + \delta\phi_{\text{def}}[2\pi]$$

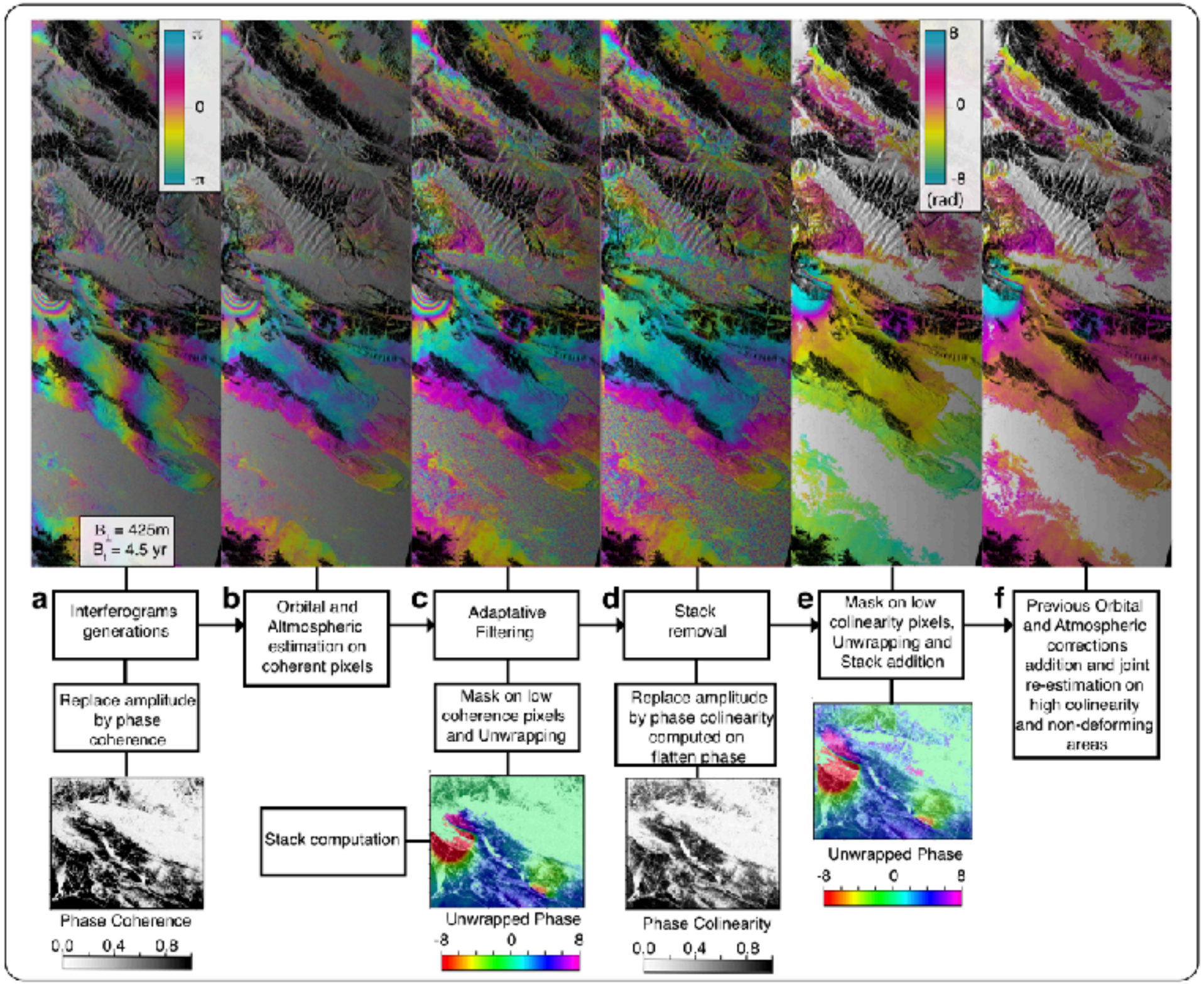


Unwrapping challenge

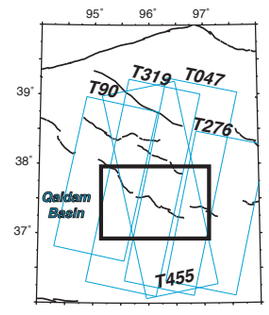
$$\delta\phi = \delta\phi_{\text{tecto}} + \delta\phi_{\text{atmo}} + \delta\phi_{\text{orb}} + \delta\phi_{\text{topo}} + \delta\phi_{\text{noise}} + \delta\phi_{\text{def}}[2\pi]$$



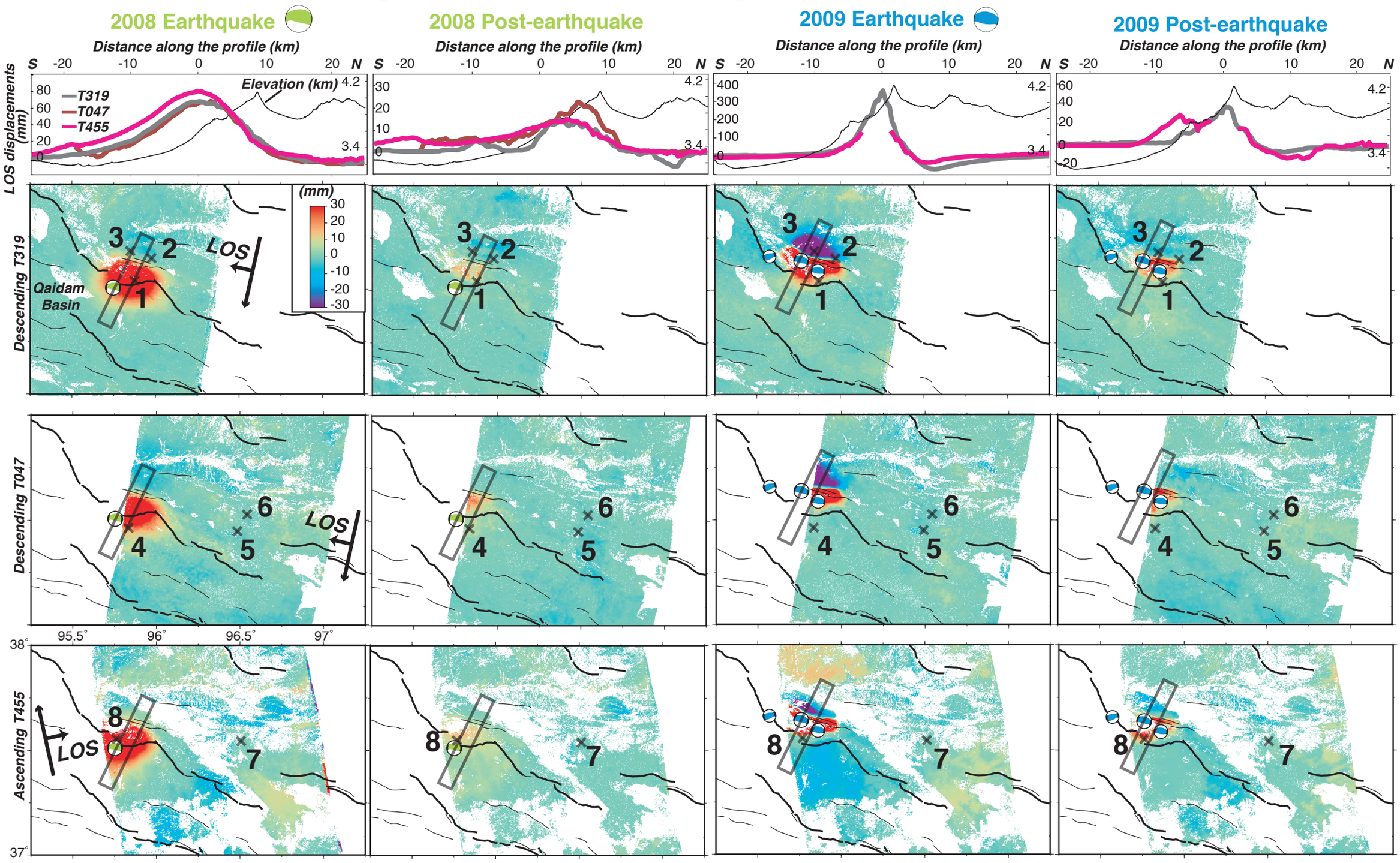
Processing flow:



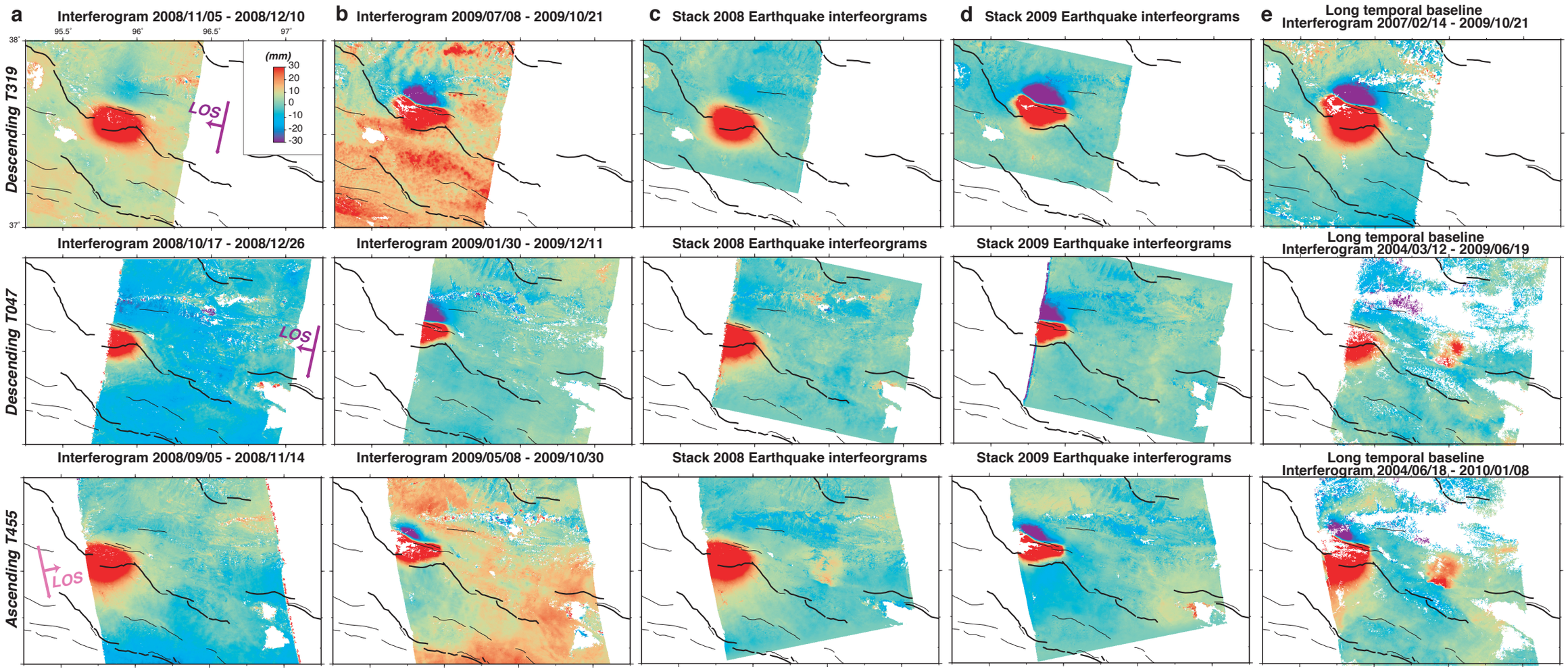
Time Series of cumulative surface displacements:



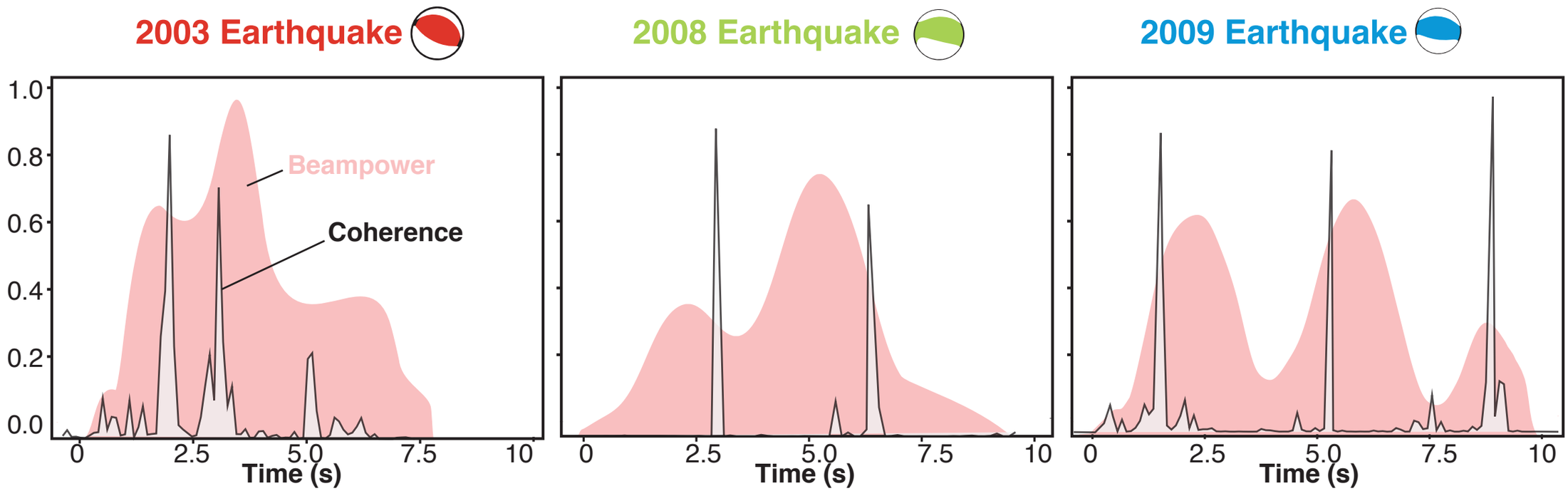
Co- and Post-earthquake surface displacements:



- Decrease of the noise in comparison to single interferograms

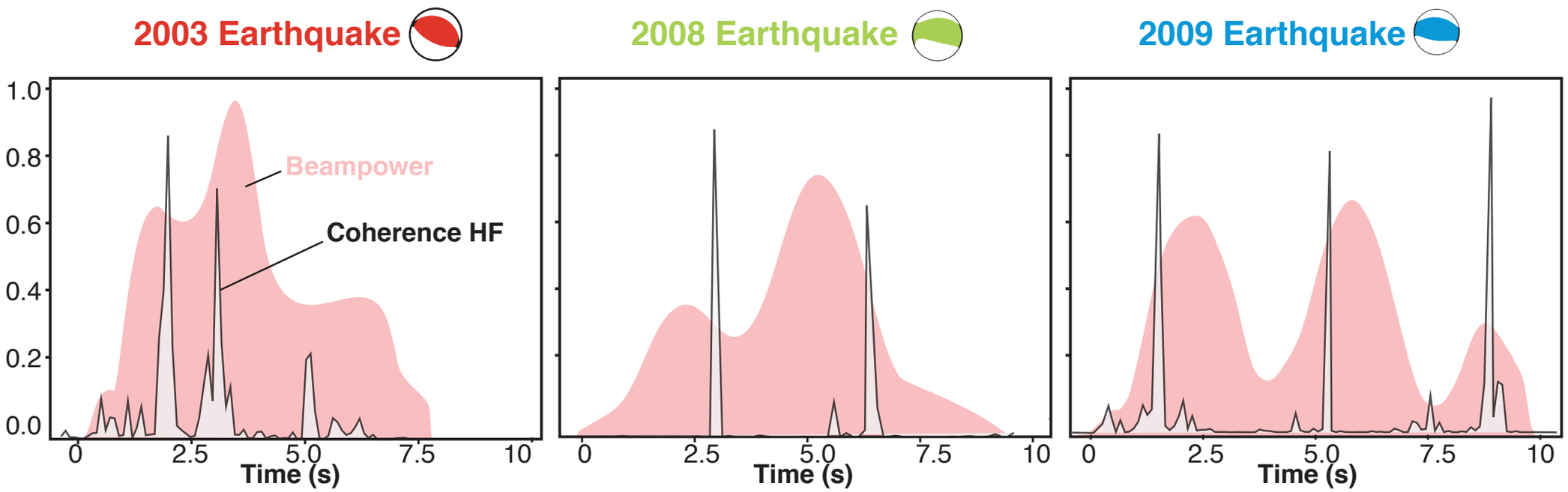

a
Interferogram 2008/11/05 - 2008/12/10
b
Interferogram 2009/07/08 - 2009/10/21
c
Stack 2008 Earthquake interfeorgrams
d
Stack 2009 Earthquake interfeorgrams
e
Long temporal baseline
Interferogram 2007/02/14 - 2009/10/21
95.5°
96°
96.5°
97°
38°
37°
(mm)
30
20
10
0
-10
-20
-30
LOS
Descending T319
Interferogram 2008/10/17 - 2008/12/26
Interferogram 2009/01/30 - 2009/12/11
Stack 2008 Earthquake interfeorgrams
Stack 2009 Earthquake interfeorgrams
Long temporal baseline
Interferogram 2004/03/12 - 2009/06/19
LOS
Descending T047
Interferogram 2008/09/05 - 2008/11/14
Interferogram 2009/05/08 - 2009/10/30
Stack 2008 Earthquake interfeorgrams
Stack 2009 Earthquake interferograms
Long temporal baseline
Interferogram 2004/06/18 - 2010/01/08
LOS
Ascending T455

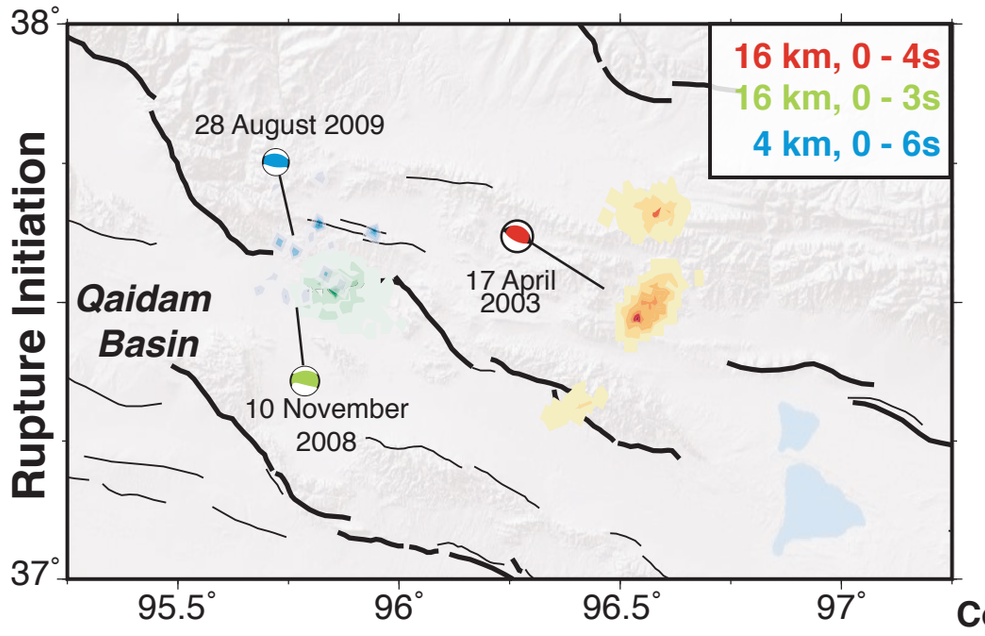
Seismic back-projection:

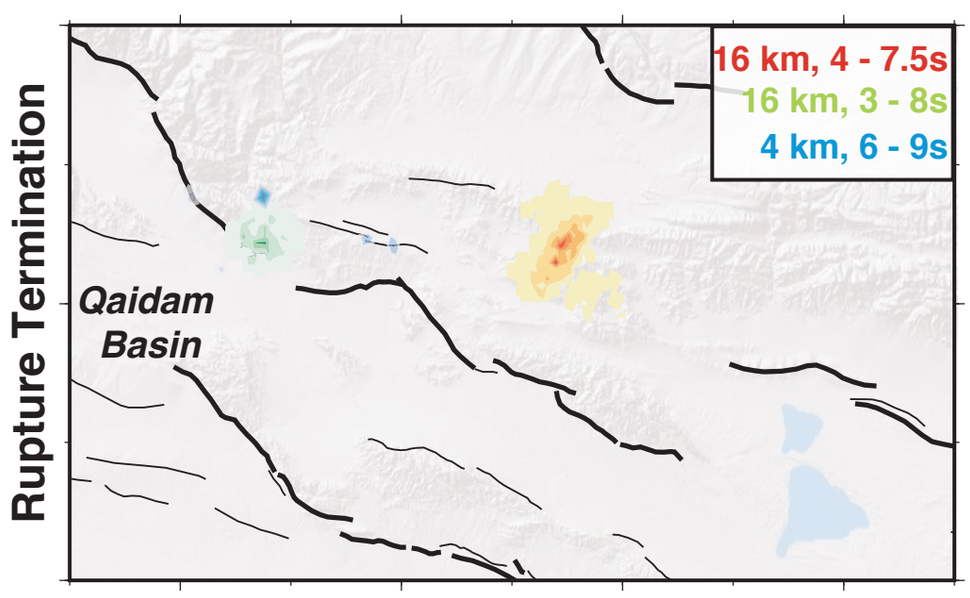


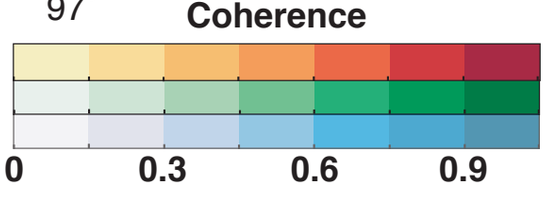
- April 2003: fast emission of the energy during the first 4s
- Nov. 2008: initiates and terminates slowly
- Aug. 2009: rupture segmentation with 3 peaks at 2.5, 5.5 and 8.5s

Seismic back-projection:

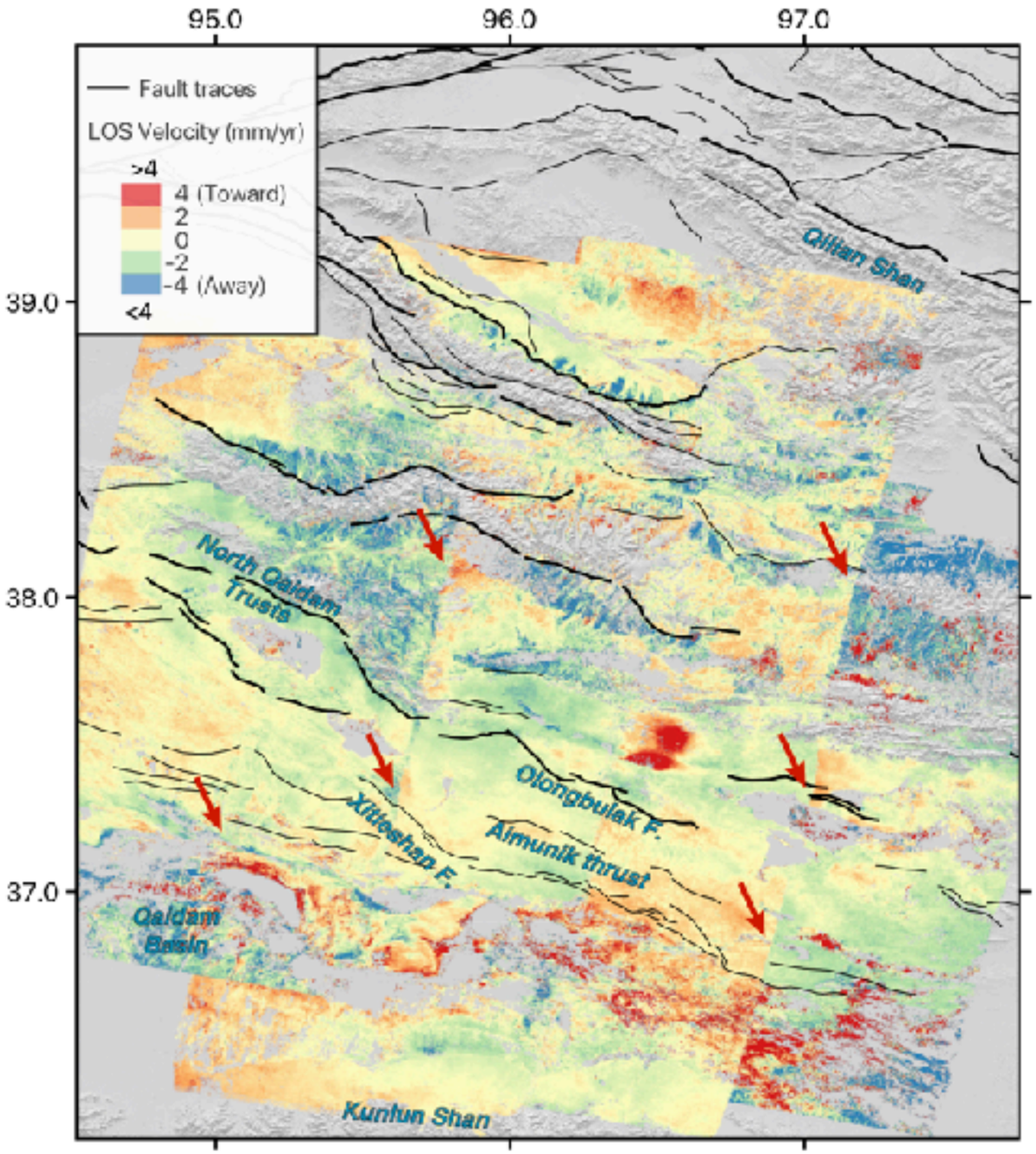


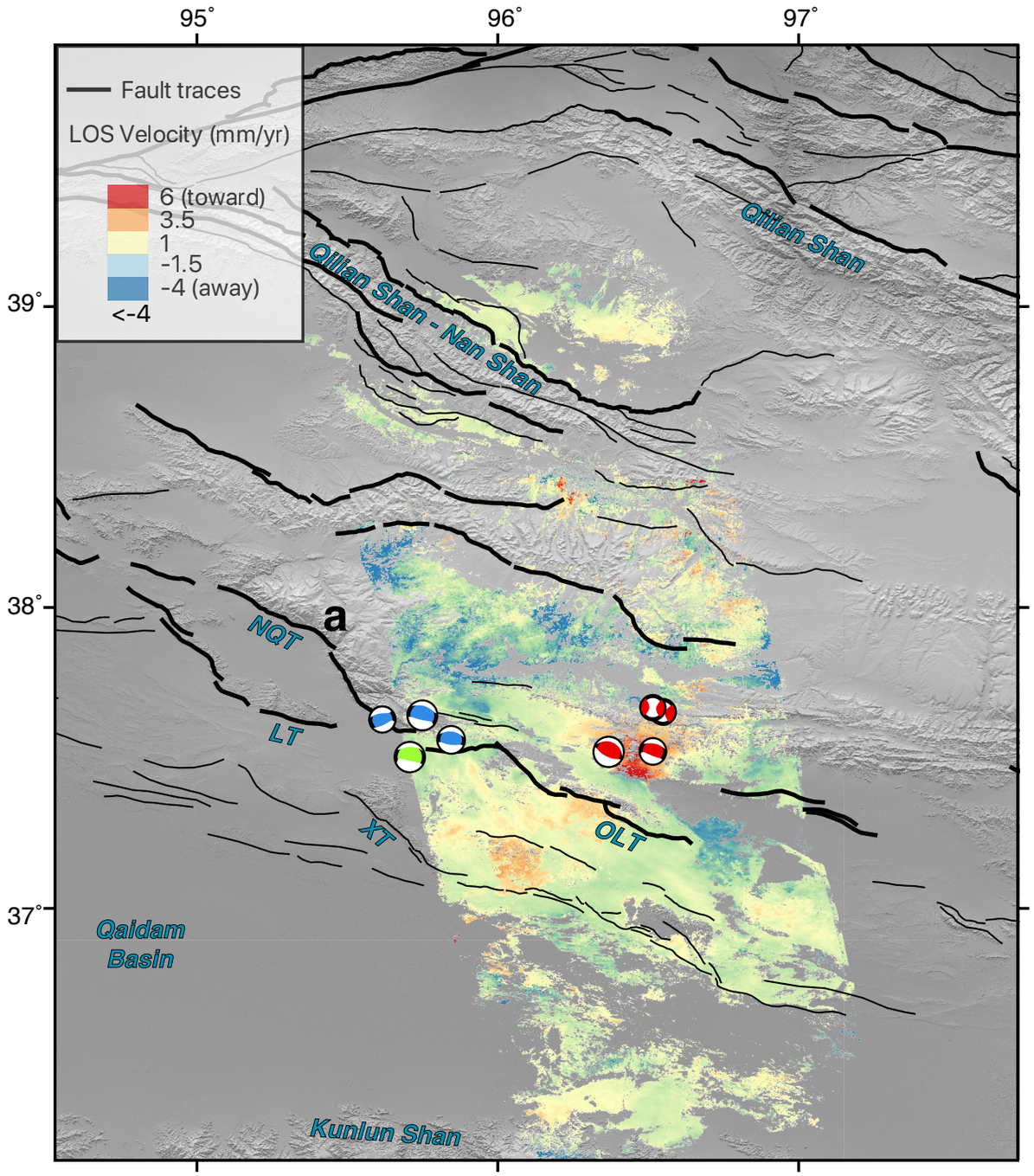






- Westward propagation
- Westward propagation
- Fault-segments jump


95.0
96.0
97.0
39.0
38.0
37.0
Fault traces
LOS Velocity (mm/yr)
>4
4 (Toward)
2
0
-2
-4 (Away)
<4
Qilian Shan
North Qaidam Thrusts
Oiongbulak F.
Xitieshan F.
Almunik thrust
Qaidam Basin
Kunlun Shan


95°
96°
97°
39°
38°
37°
Fault traces
LOS Velocity (mm/yr)
6 (toward)
3.5
1
-1.5
-4 (away)
<-4
Qilian Shan
Qilian Shan - Nan Shan
a
NQT
LT
XT
OLT
Qaidam Basin
Kunlun Shan

(Chen et al., 2013)