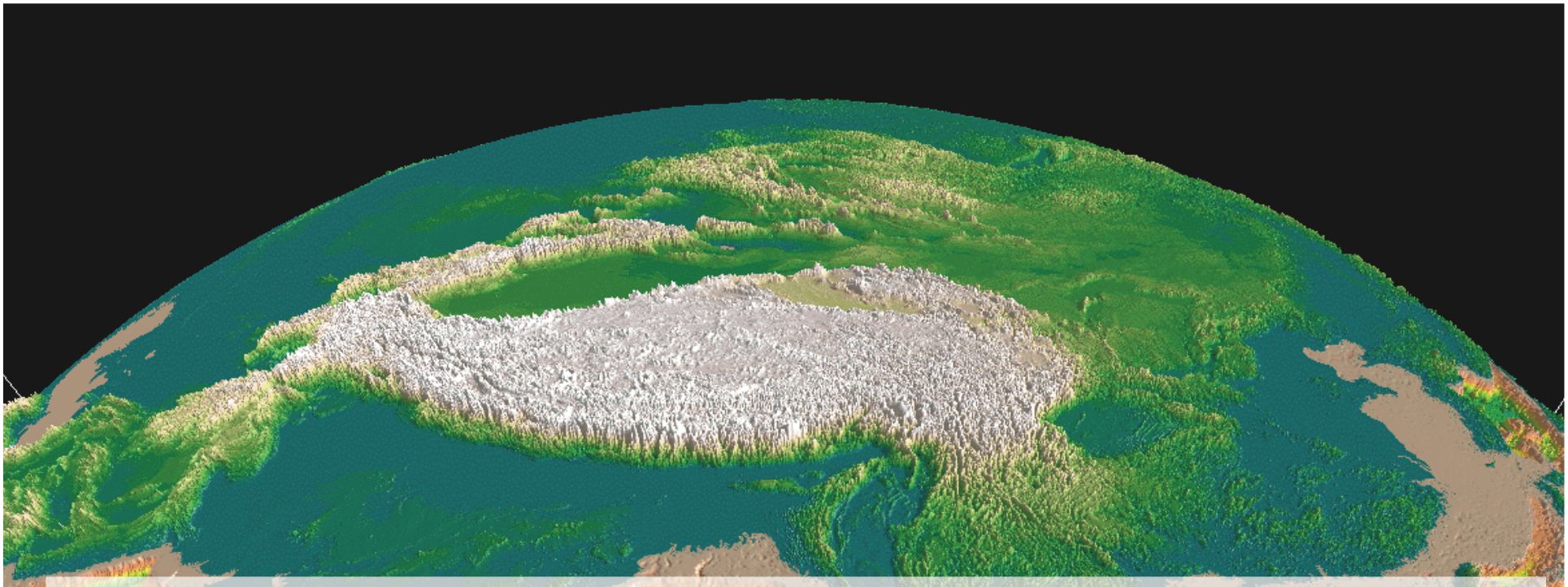


Mapping Regional Deformation with InSAR

Tim J Wright[1], Hua Wang[1,2], Matt Garthwaite[1], Carolina Pagli[1,3]

(1) School of Earth and Environment, University of Leeds, UK
(2) Dept of Surveying Engineering, Guangdong University of Technology, China
(3) School of Geography, Earth and Environmental Sciences, University of Plymouth, UK

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

THE ROYAL SOCIETY

esa

COMET+
Centre for the Observation and Modelling of Earthquakes, Volcanoes & Tectonics

The Leverhulme Trust

UNIVERSITY OF LEEDS

Outline

- Introduction
- Measuring slow deformation with InSAR
  - Deformation in central Tibet
- Using InSAR to constrain large scale velocity fields
  - Method
  - Results from western Tibet
- Conclusions and Outlook

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

THE ROYAL SOCIETY

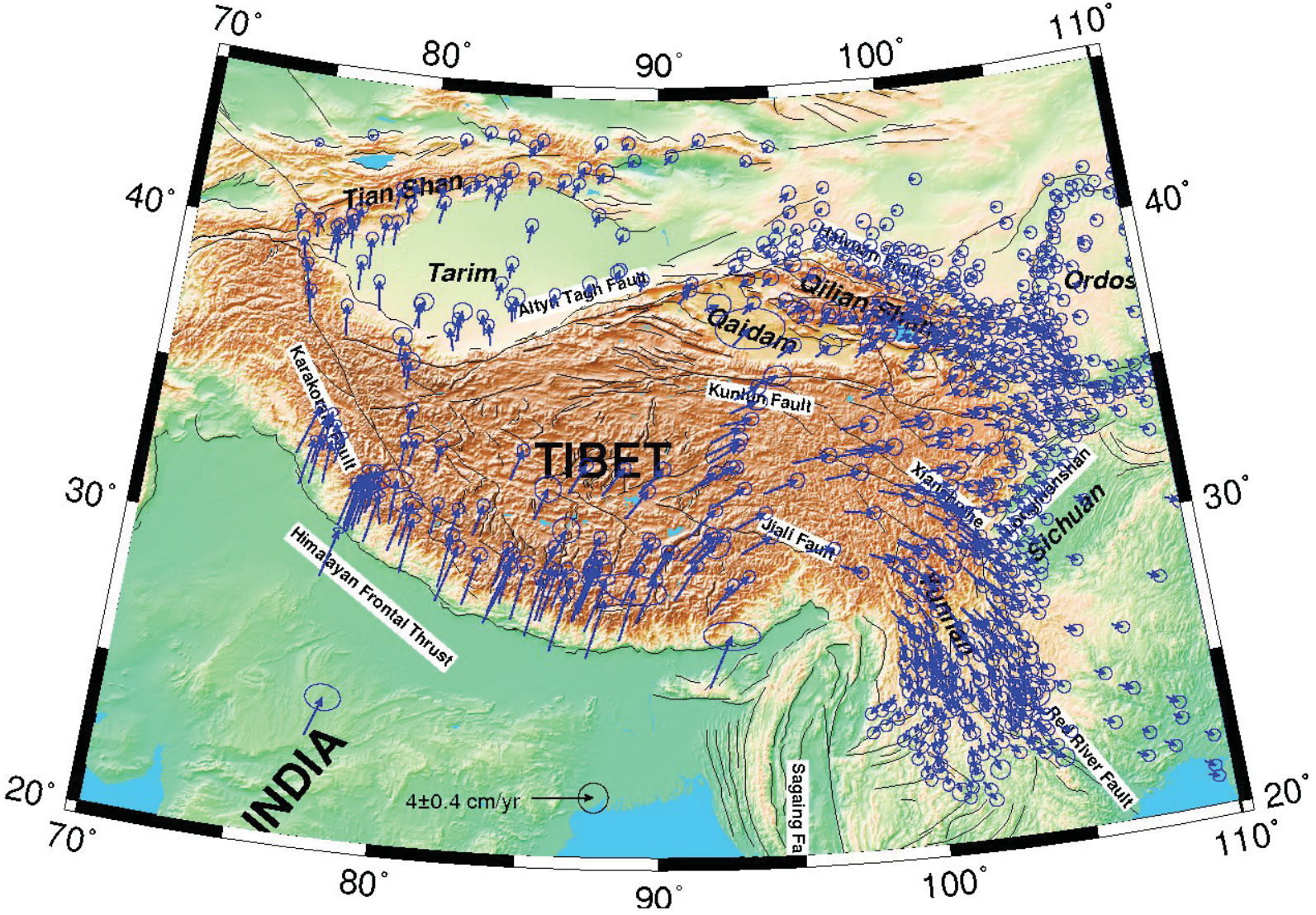
esa

COMET+
Centre for the Observation and Modelling of Earthquakes, Volcanoes & Tectonics

The Leverhulme Trust

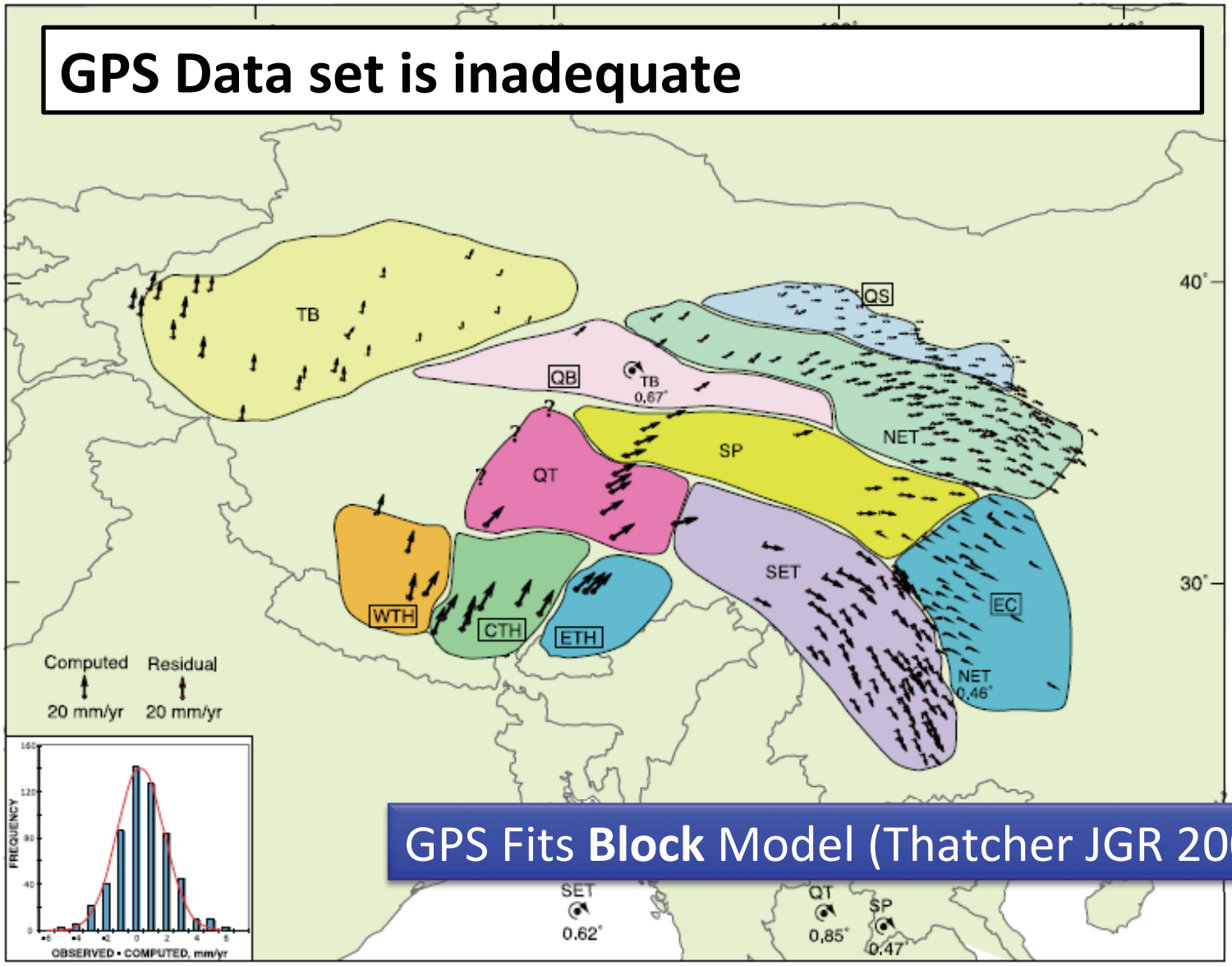
UNIVERSITY OF LEEDS

Key Questions:
- Is continental tectonics best described by blocks or a continuum?
- How much strain is focused on major faults?



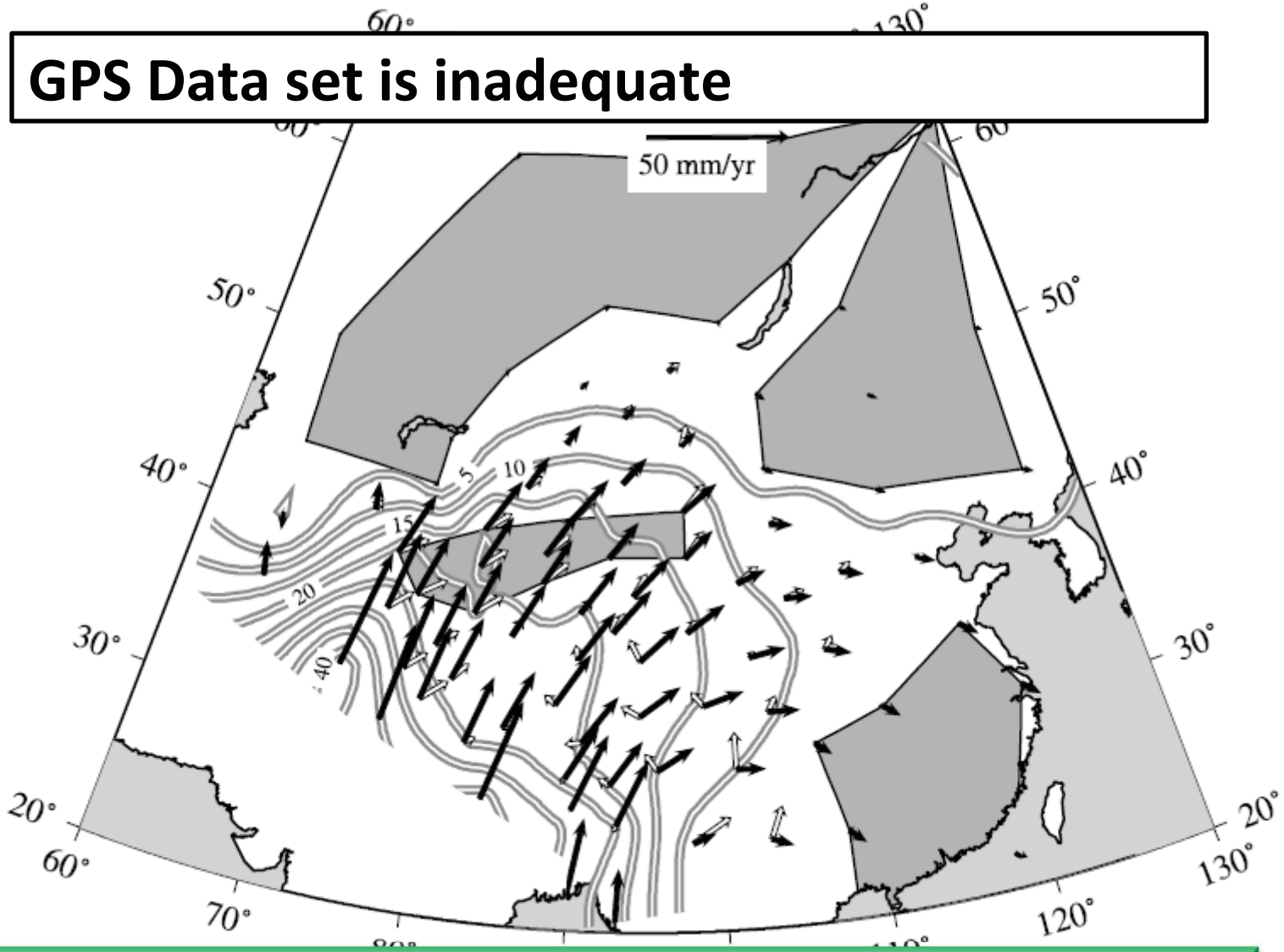
GPS data from Gan et al., 2007

GPS Data set is inadequate



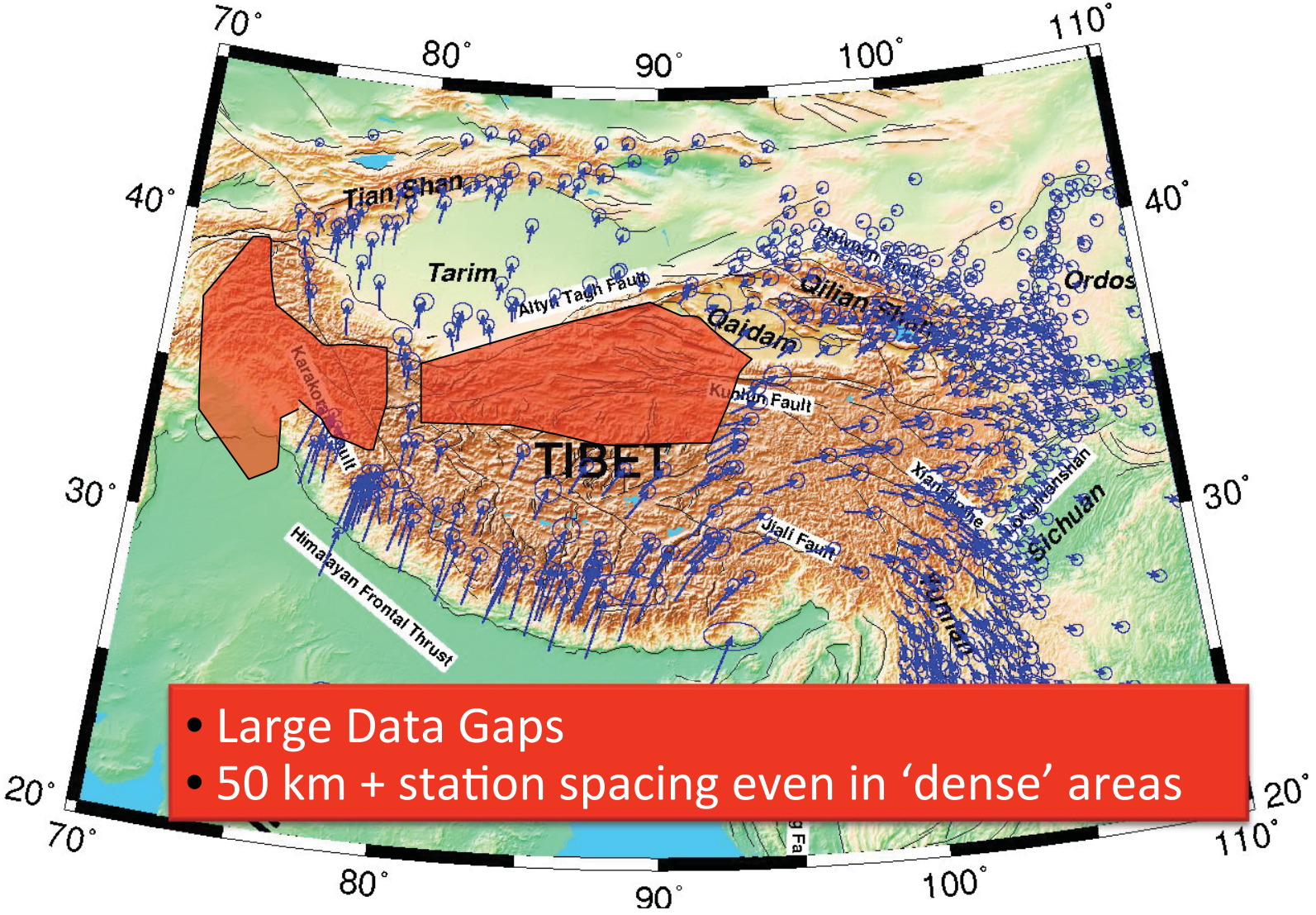
GPS Fits **Block** Model (Thatcher JGR 2007)

GPS Data set is inadequate



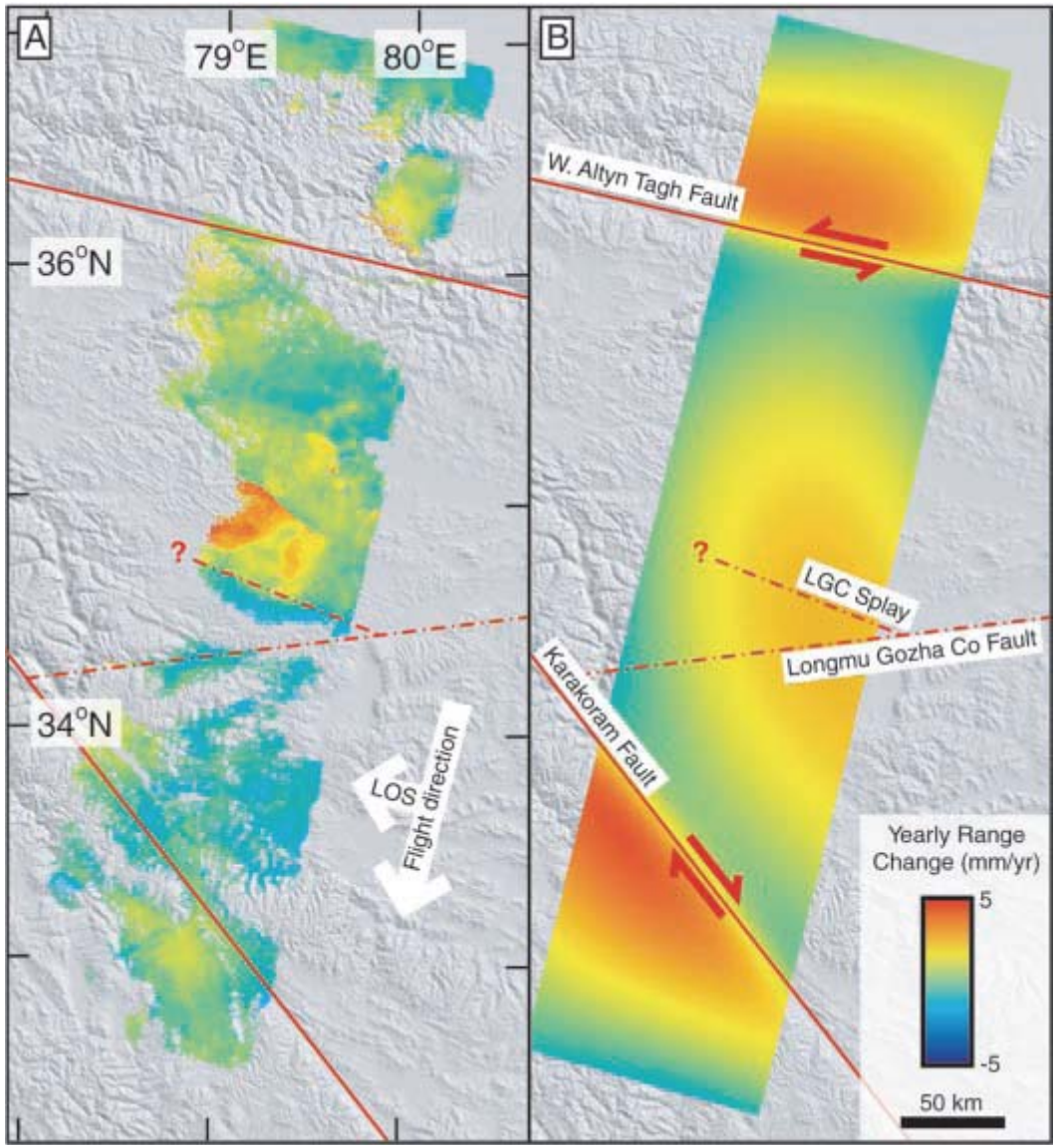
GPS Fits **Continuum** Model (England and Molnar, JGR 2005)

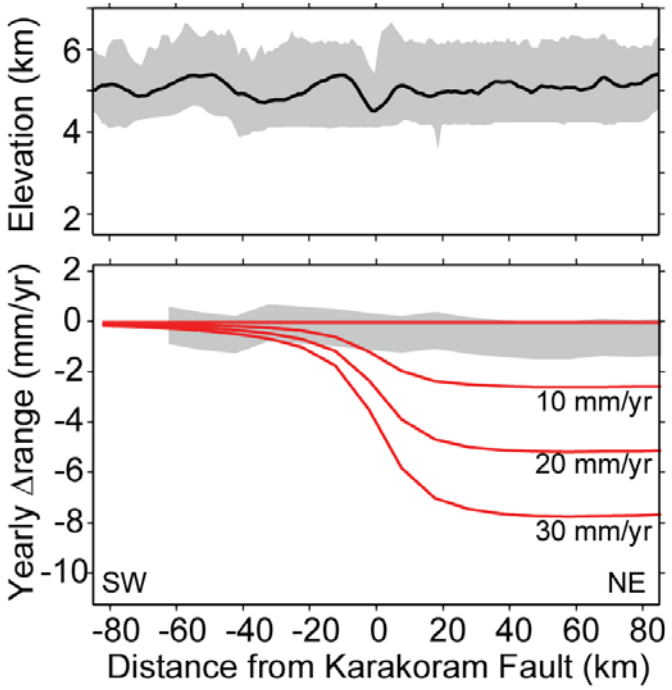
GPS Data set is inadequate



GPS data from Gan et al., 2007

Interseismic strain from InSAR



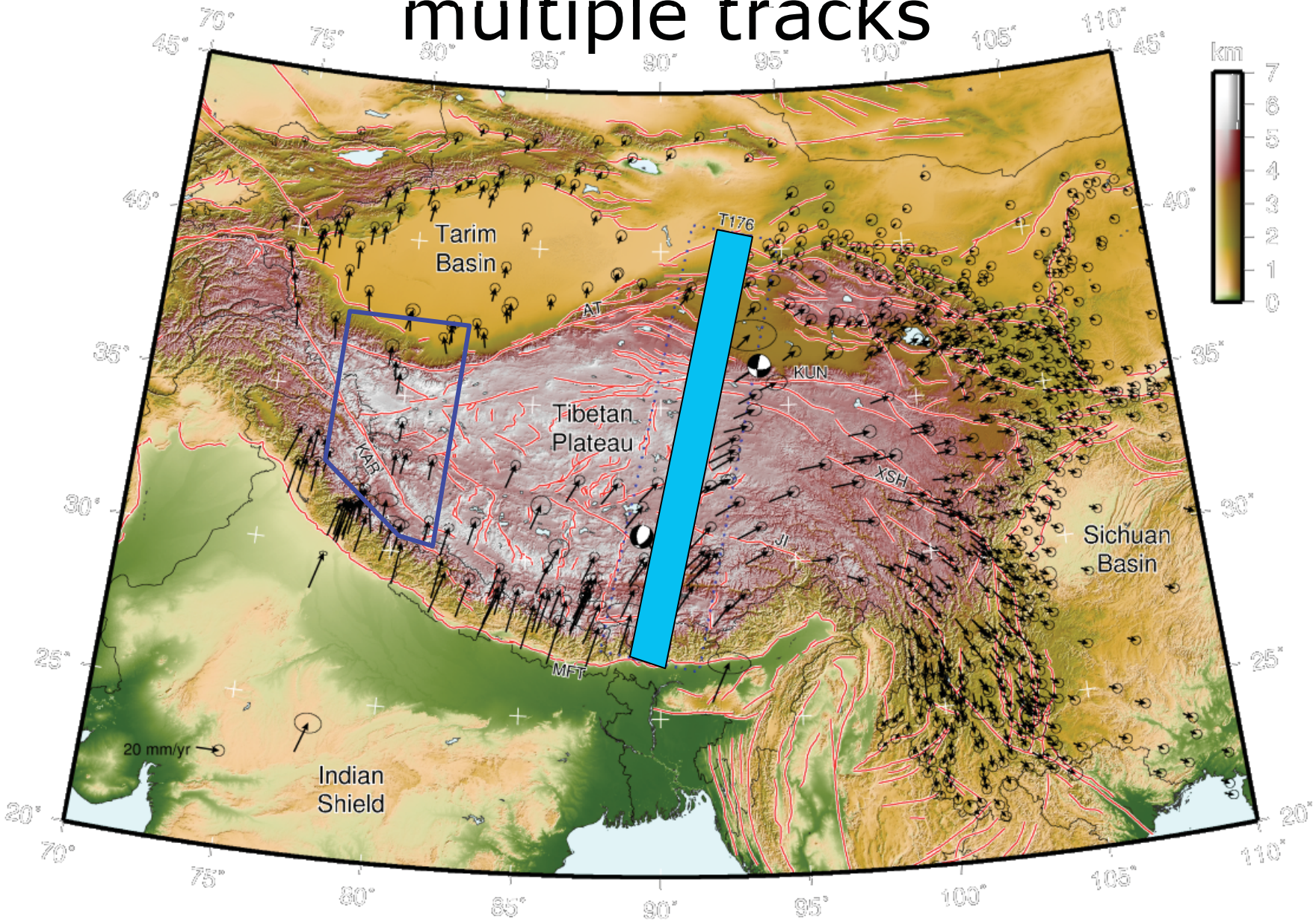


Altyn Tagh Fault: 5±5 mm/yr

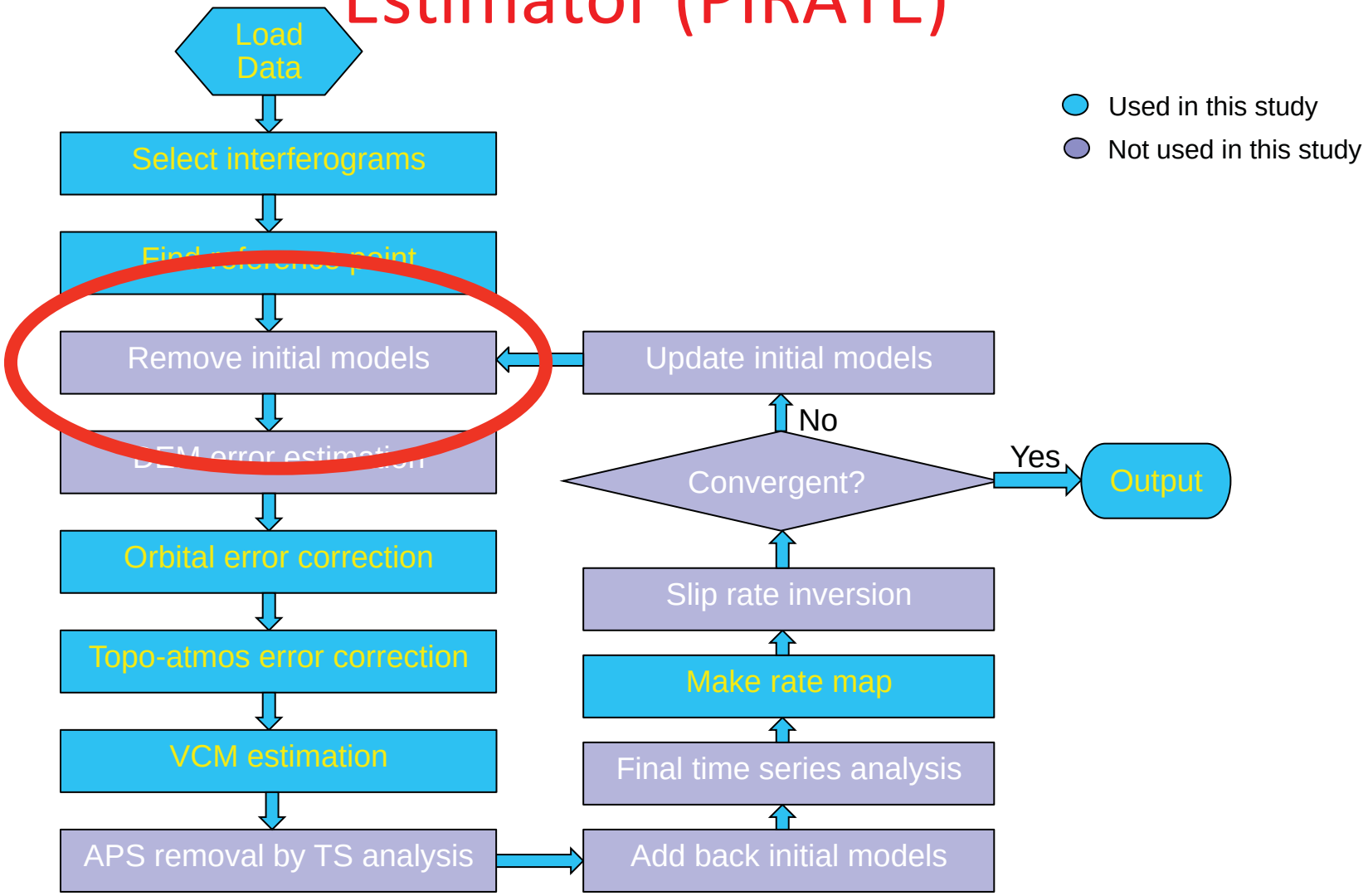
Karakoram Fault: 1±3 mm/yr

Wright et al., 2004, Science

Large areas – long swaths or multiple tracks

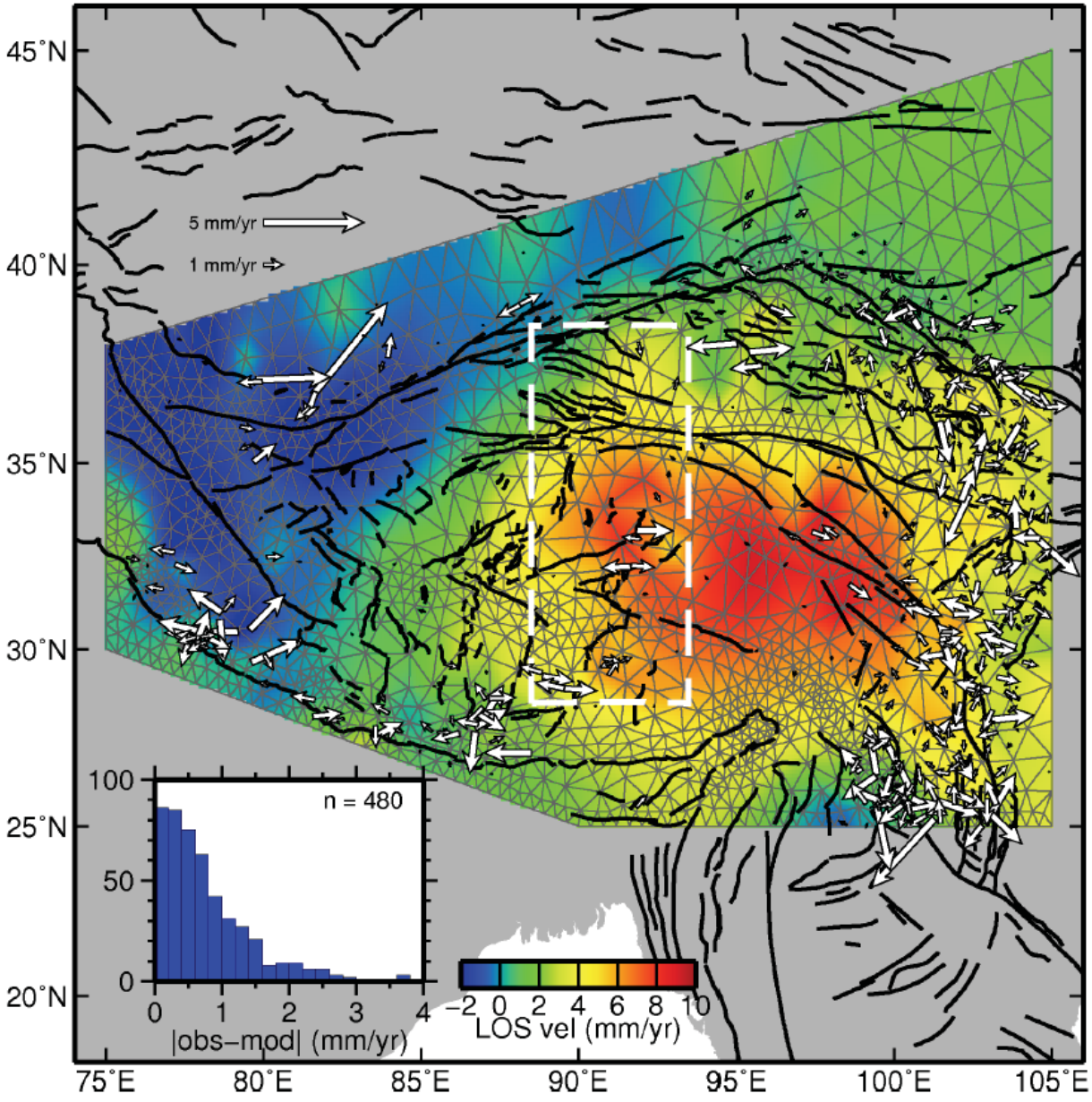


Poly-Interferogram Rate and Timeseries Estimator (PIRATE)

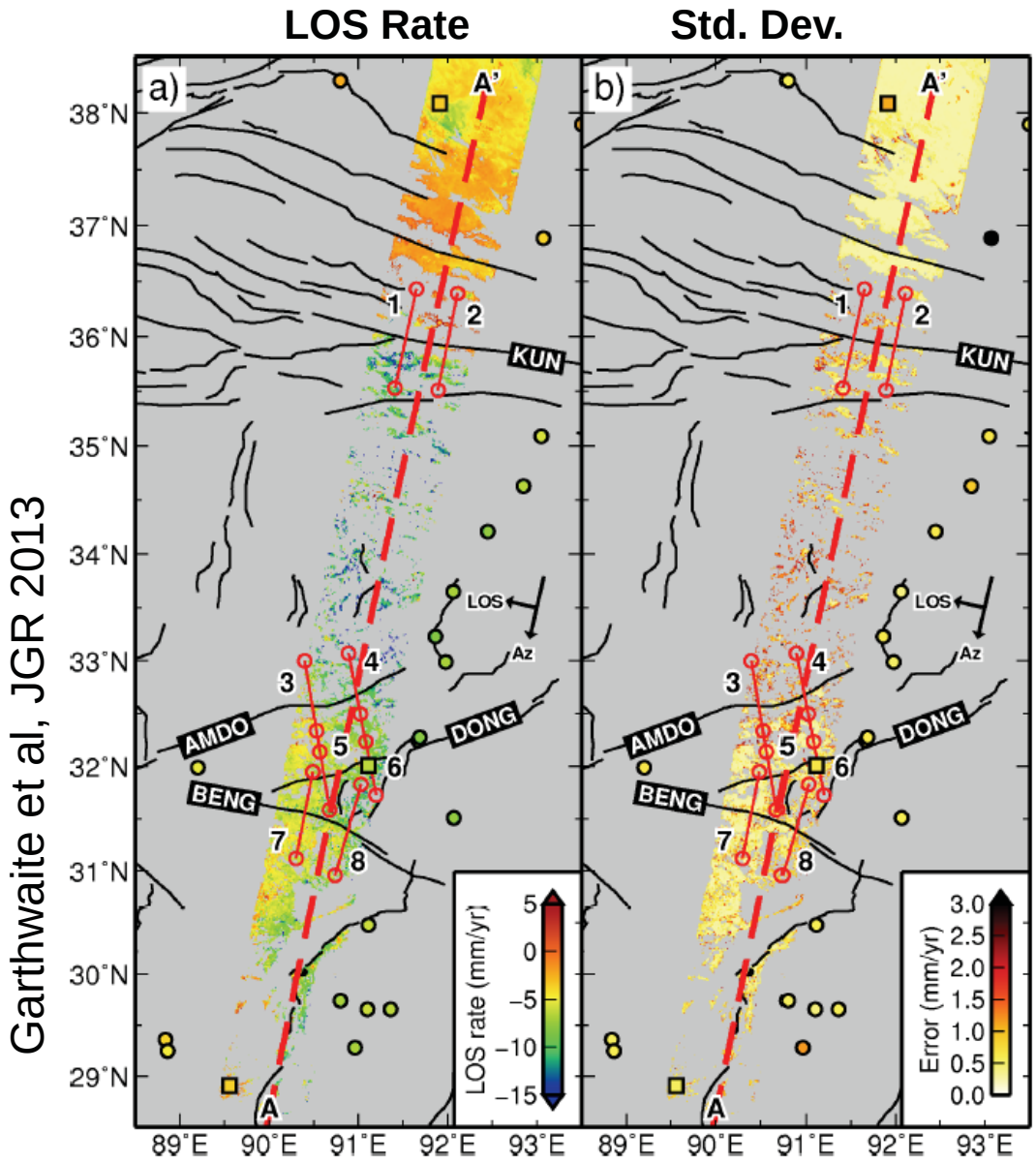


Biggs et al., 2007; Elliott et al., 2008; Wang et al., 2009,2012.

Initial Model based on GPS velocity field

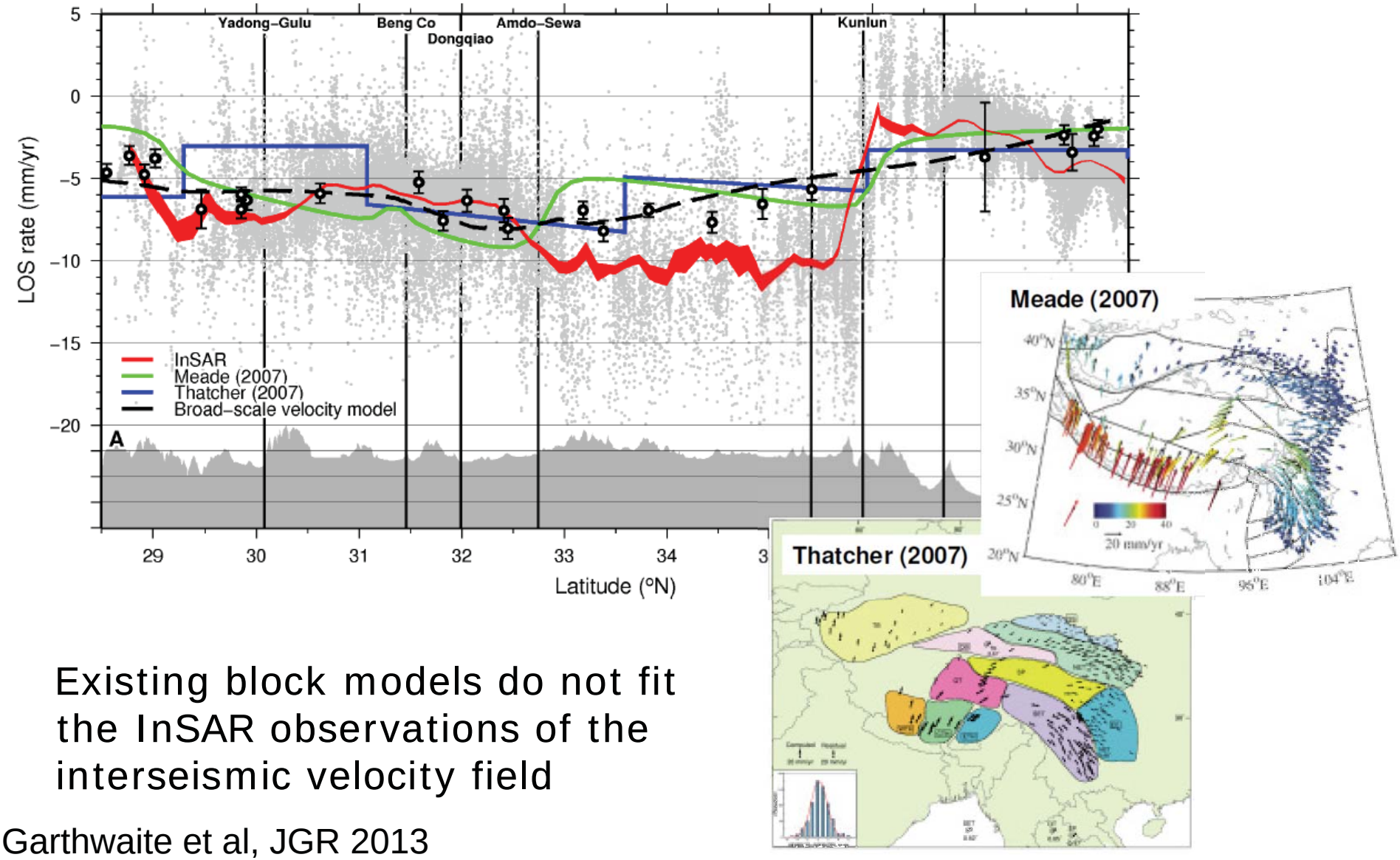


Deformation across Central Tibet



Garthwaite et al, JGR 2013

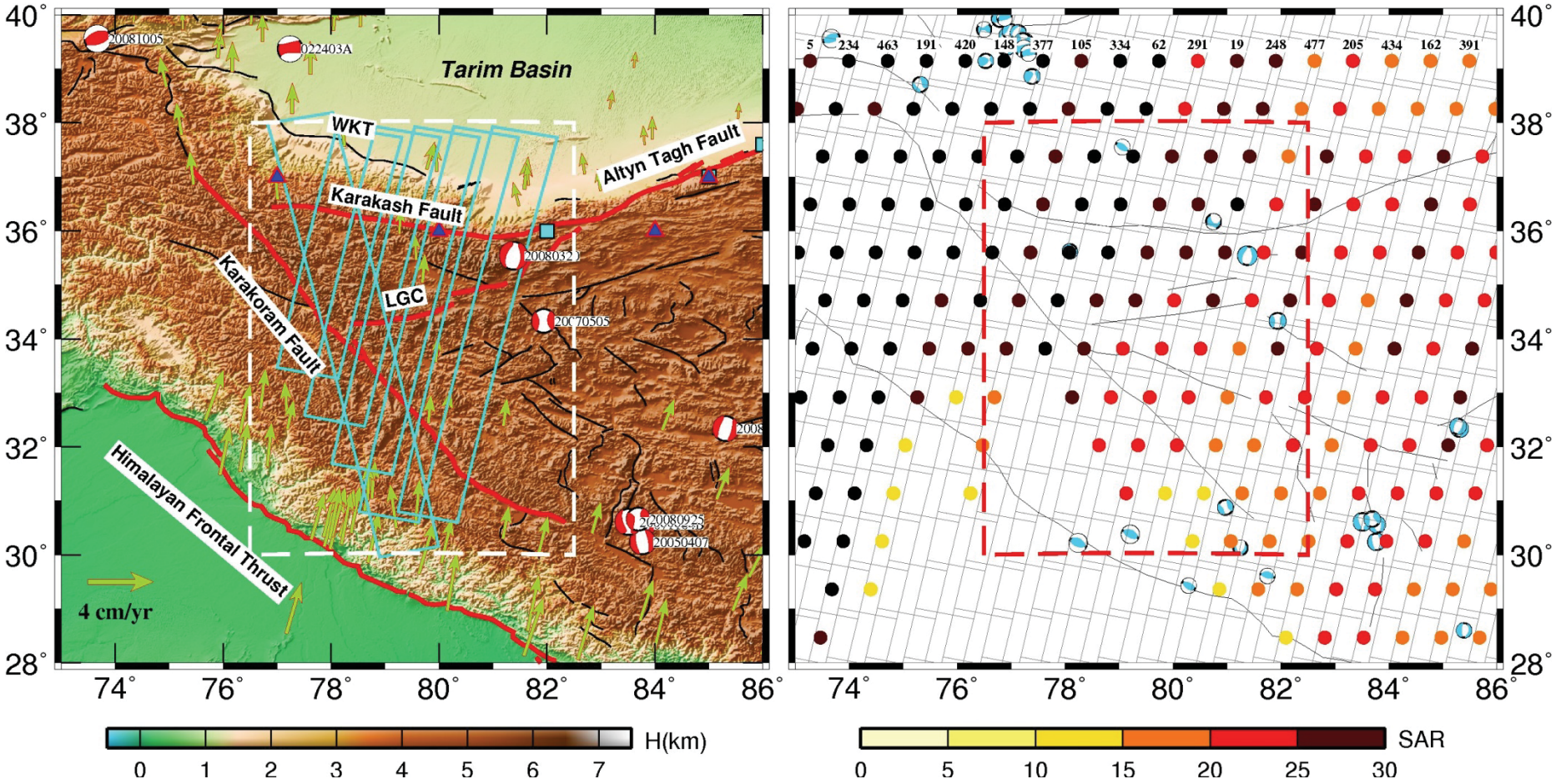
Comparison with block models



Existing block models do not fit the InSAR observations of the interseismic velocity field

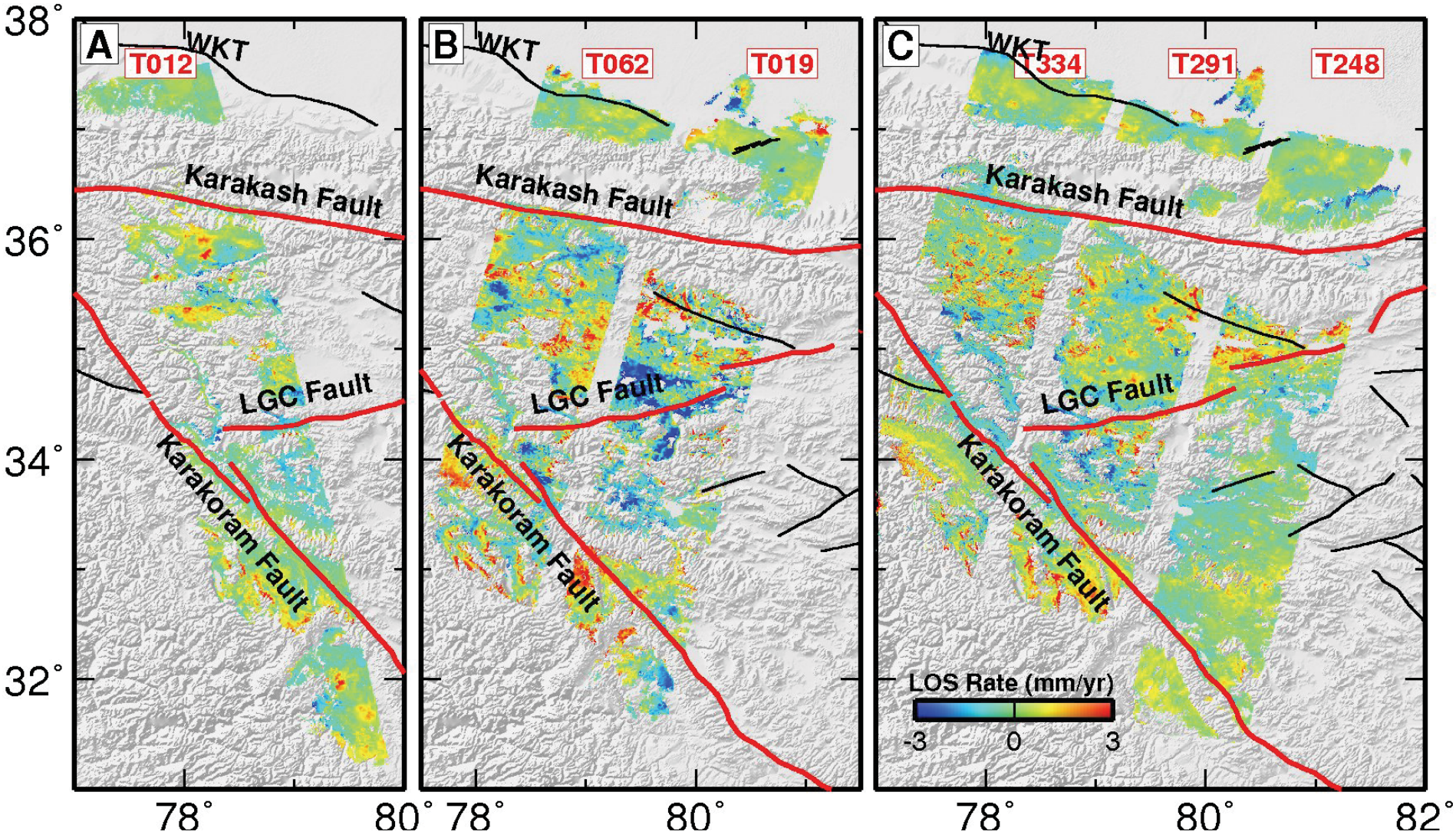
Garthwaite et al, JGR 2013

Western Tibet

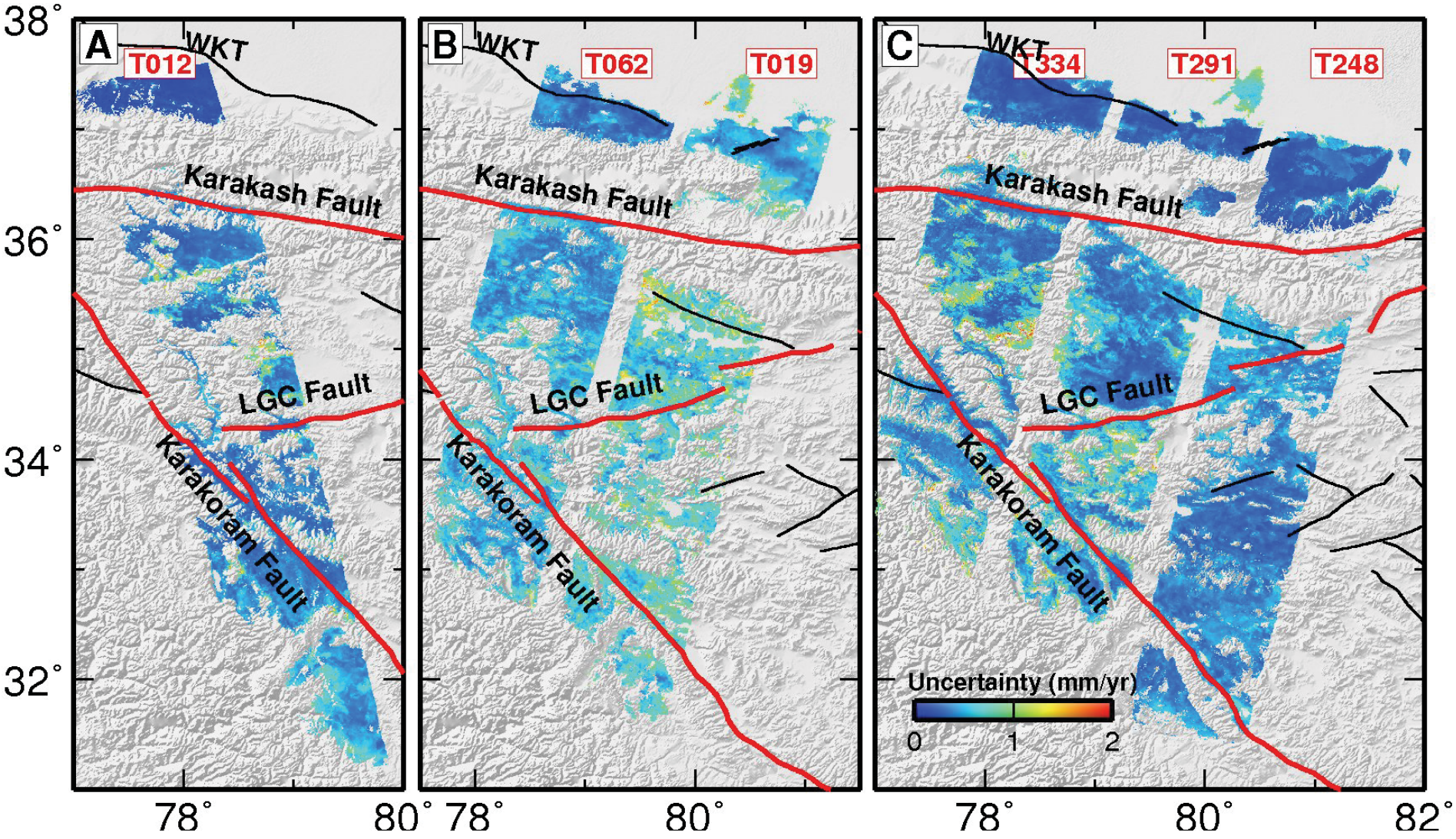


- Large archive (dragon project ; background mission)
- Fairly good coherence, low atmosphere (on plateau)

InSAR Rate Maps



InSAR Error Maps

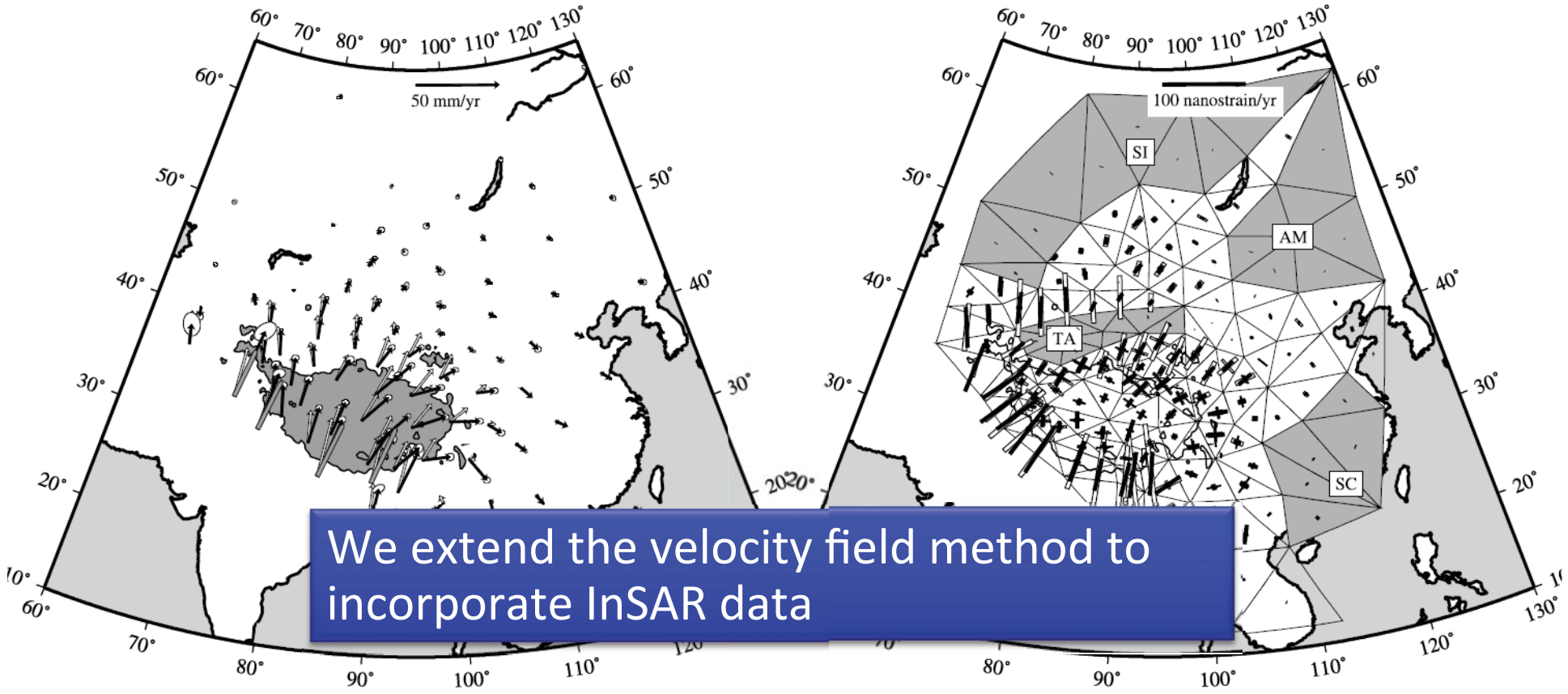


InSAR Rate Maps

- How can we combine information from multiple tracks, incidences, (satellites... etc) with GPS to form best representation of surface velocities?

GPS Velocity Fields

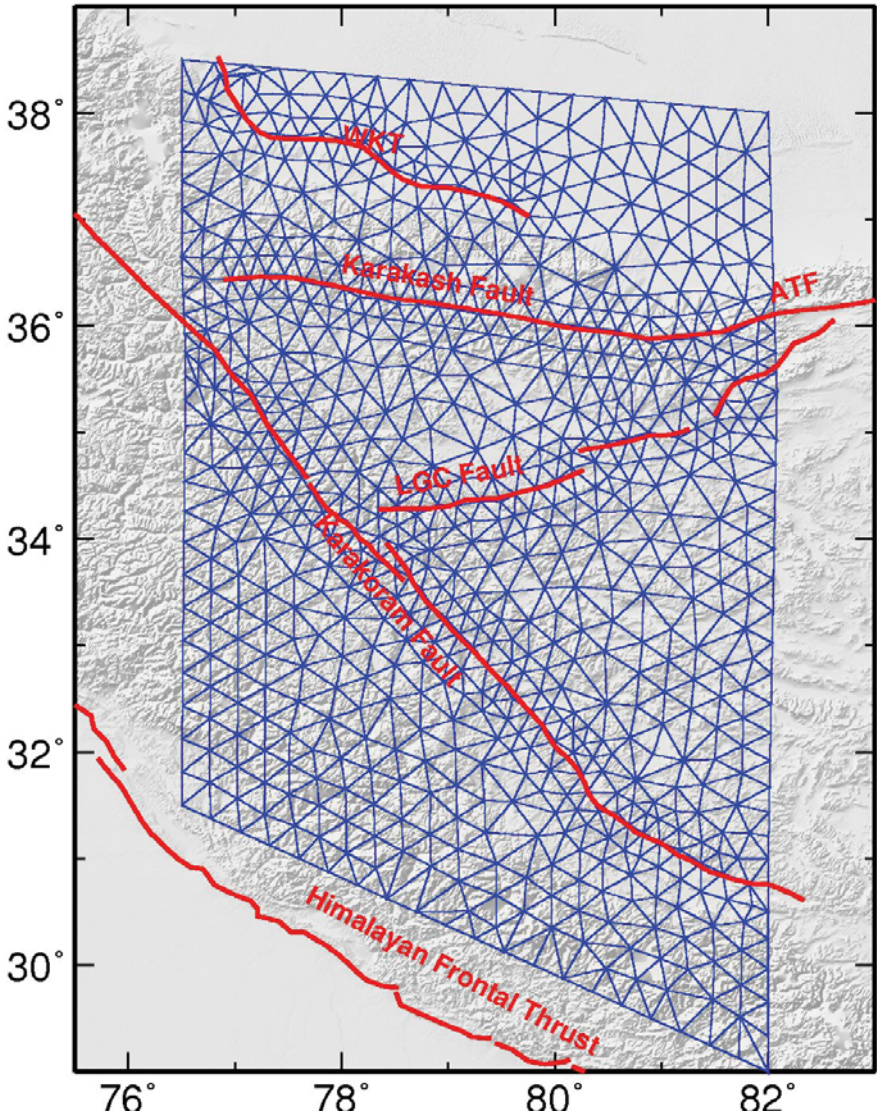
e.g. England and Molnar, JGR 2005

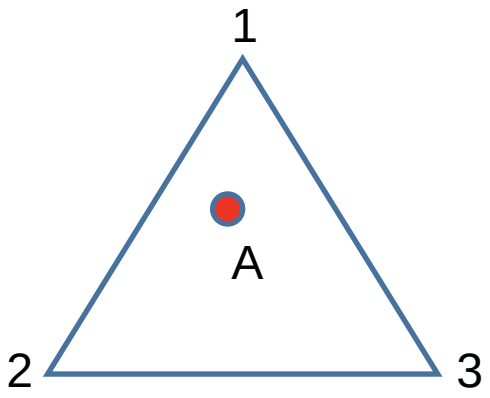


We extend the velocity field method to incorporate InSAR data

Velocities (left) and strain (right) from GPS, quaternary fault data and earthquake focal mechanisms

Triangular Mesh and Interpolation



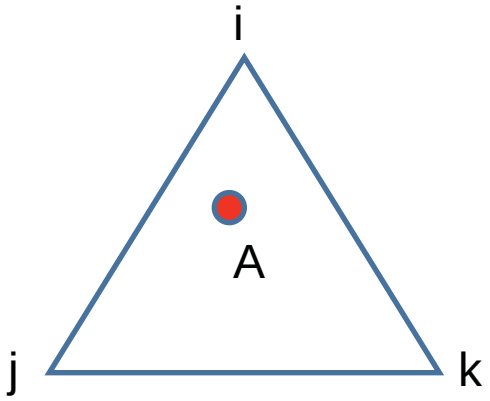


England & Molnar, 2005, JGR

Combination of InSAR rate maps and GPS velocities

$$\begin{bmatrix} G_{insar} & G_{orb} & G_{atm} \\ G_{gps} & 0 & 0 \\ \kappa^2 G_{sm} & 0 & 0 \end{bmatrix} \begin{bmatrix} M_{vel} \\ M_{orb} \\ M_{atm} \end{bmatrix} = \begin{bmatrix} V_{insar} \\ V_{gps} \\ 0 \end{bmatrix}$$

Design matrix for GPS and InSAR



$$G_{ve} = \begin{bmatrix} \cdots & N_i \cdots & N_j \cdots & N_k \end{bmatrix}$$

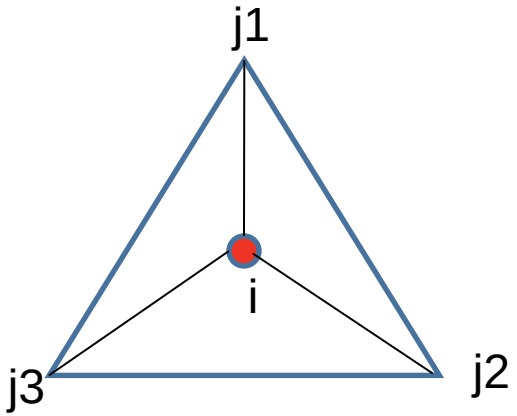
$$G_{vn} = G_{vu} = G_{ve}$$

$$G_{gps} = \begin{bmatrix} G_{ve} & 0 \\ 0 & G_{vn} \end{bmatrix}$$

$$G_{insar} = \begin{bmatrix} diag(U_e) & diag(U_n) \end{bmatrix} \begin{bmatrix} G_{ve} & 0 \\ 0 & G_{vn} \end{bmatrix}$$

Simplify by assuming $v_u = 0$

Laplacian smoothing operator



$$G_{sm}^{i} = \frac{2}{E} \sum_{j \in N_1(i)} \frac{x_j - x_i}{\left| e_{ij} \right|}, \quad E = \sum_{j \in N_1(i)} \left| e_{ij} \right|$$

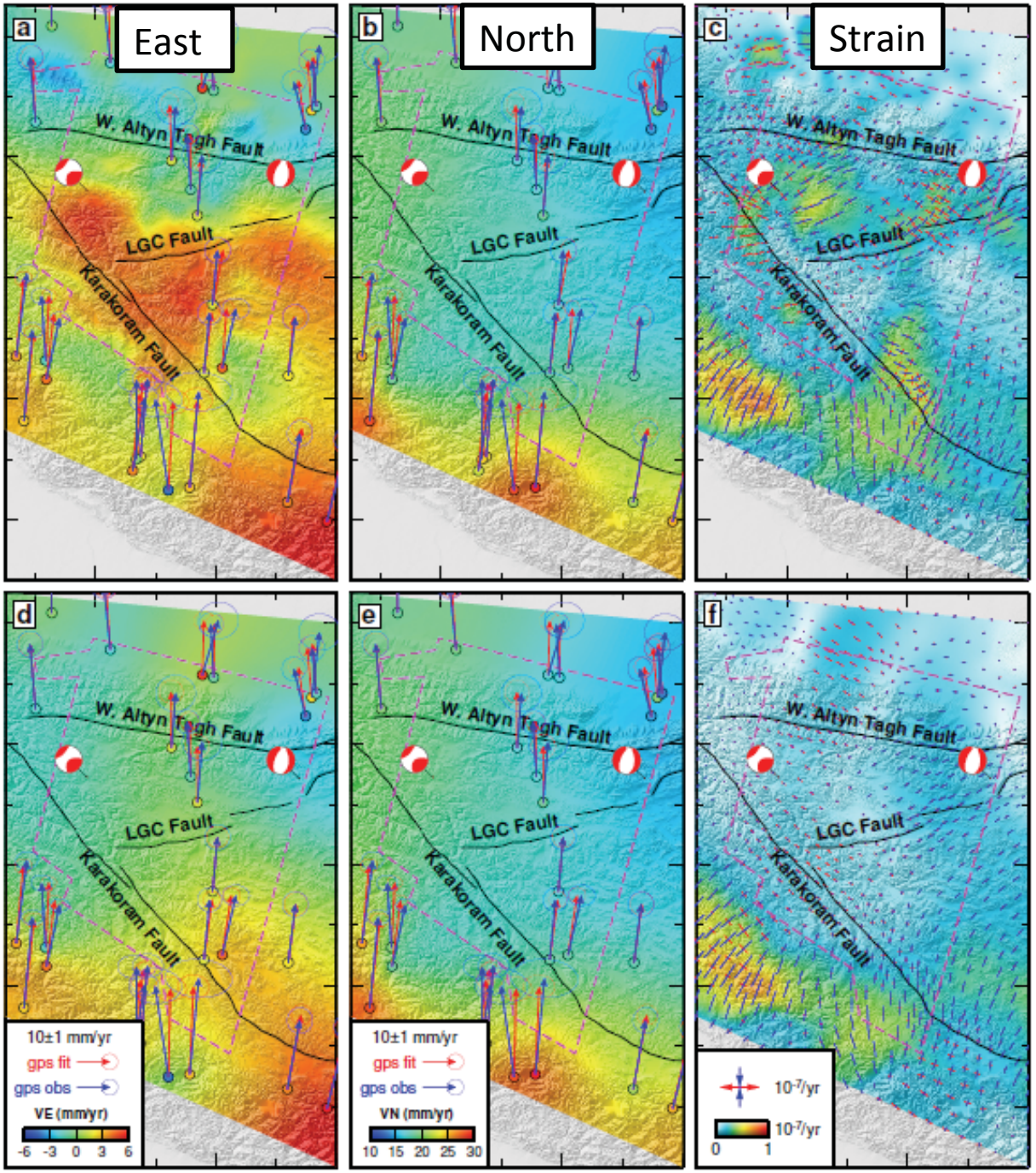
Combination of InSAR rate maps and GPS velocities

$$\begin{bmatrix} G_{insar} & G_{orb} & G_{atm} \\ G_{gps} & 0 & 0 \\ \kappa^2 G_{sm} & 0 & 0 \end{bmatrix} \begin{bmatrix} M_{vel} \\ M_{orb} \\ M_{atm} \end{bmatrix} = \begin{bmatrix} V_{insar} \\ V_{gps} \\ 0 \end{bmatrix}$$

Weighted LS solution:

$$\hat{M} = (G^T W G)^{-1} G^T W V$$

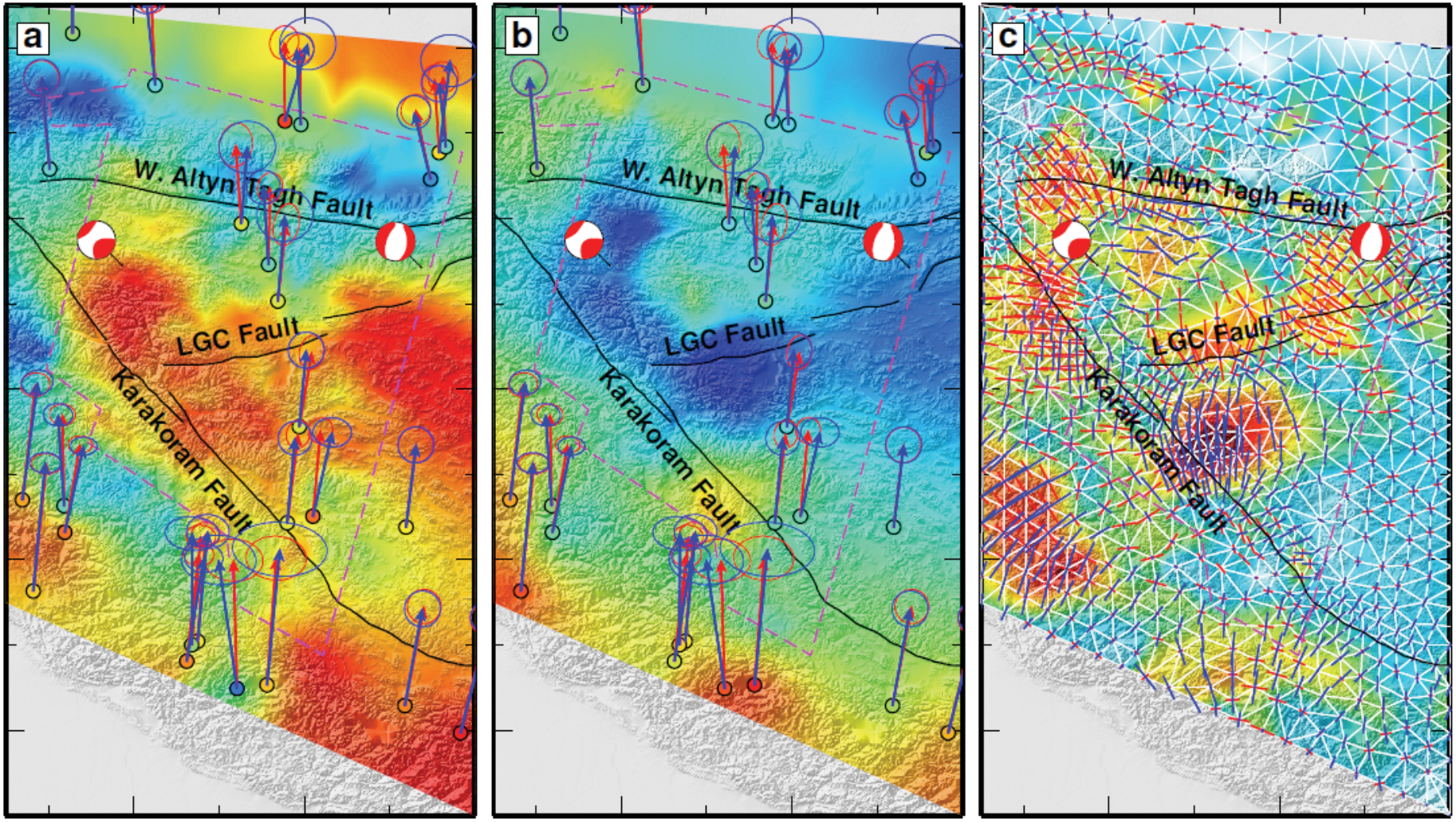
Weighting using full data covariances



GPS + InSAR

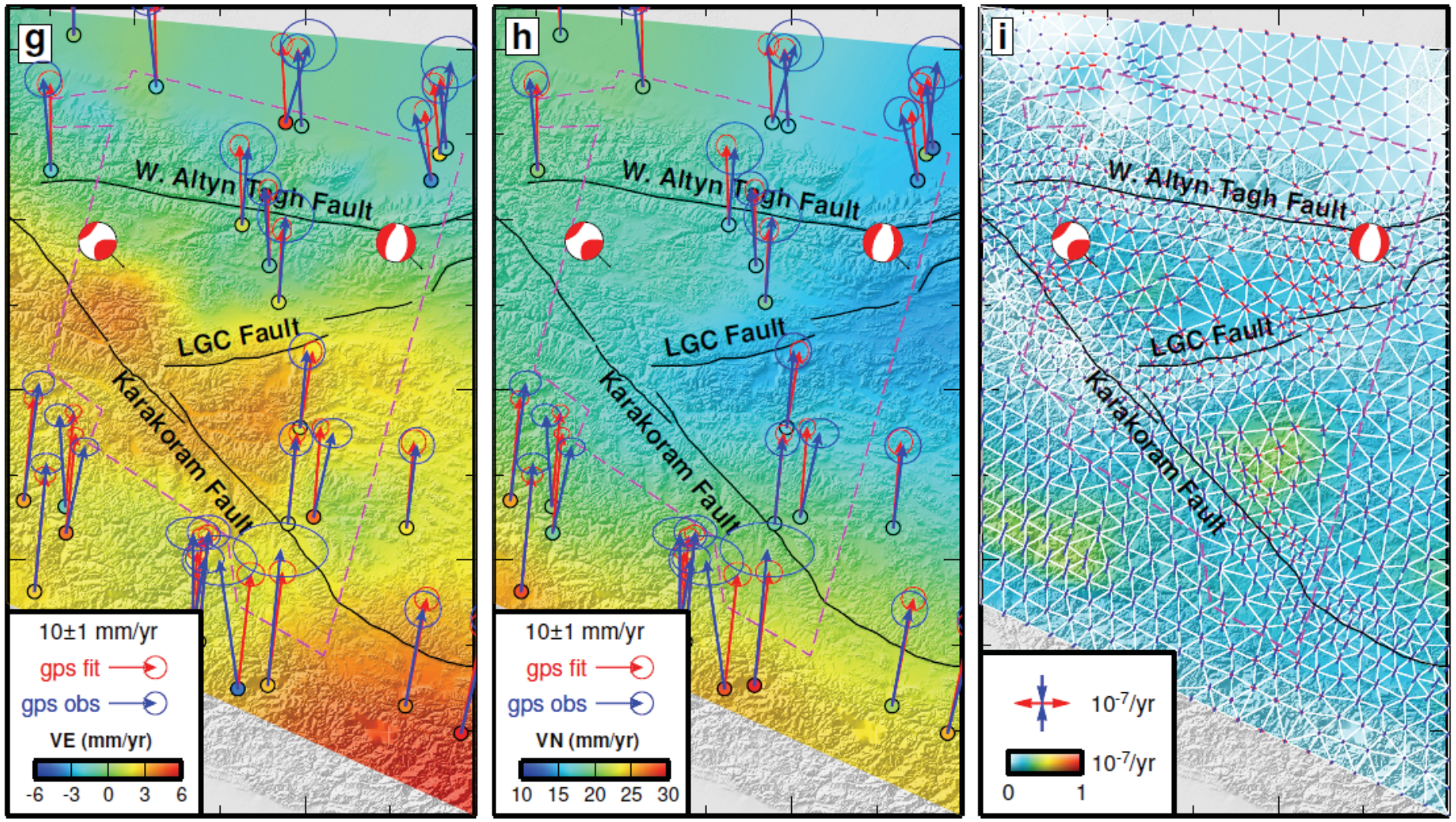
GPS only

Choice of smoothing



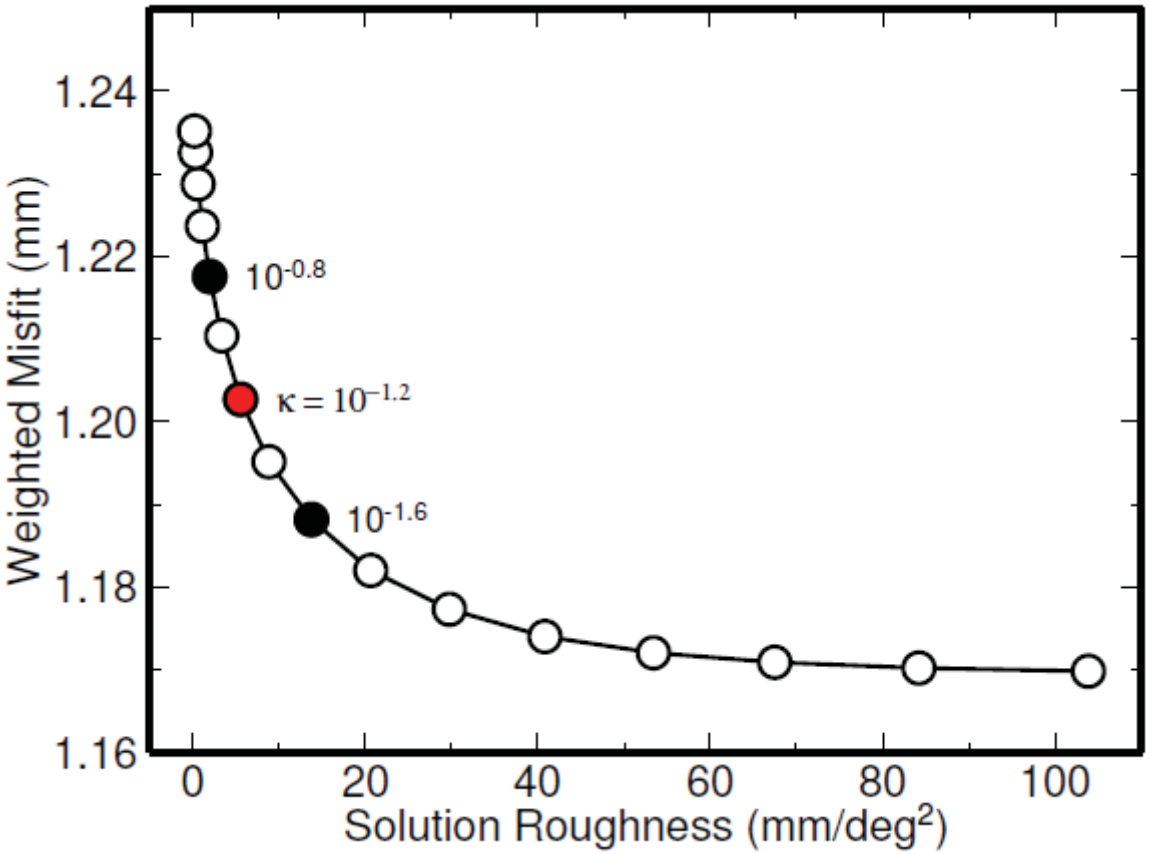
"Too rough"

Choice of smoothing

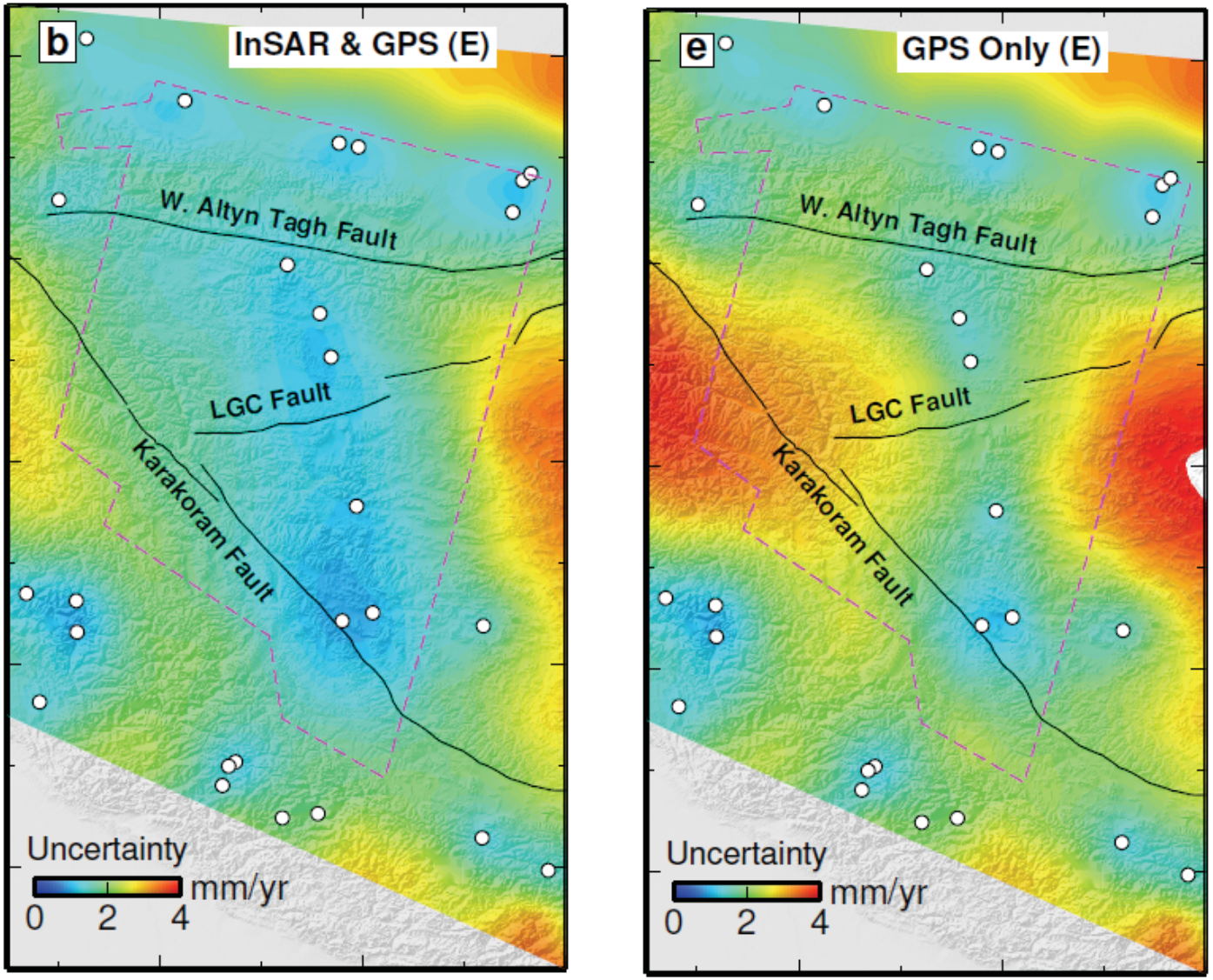


"Too smooth"

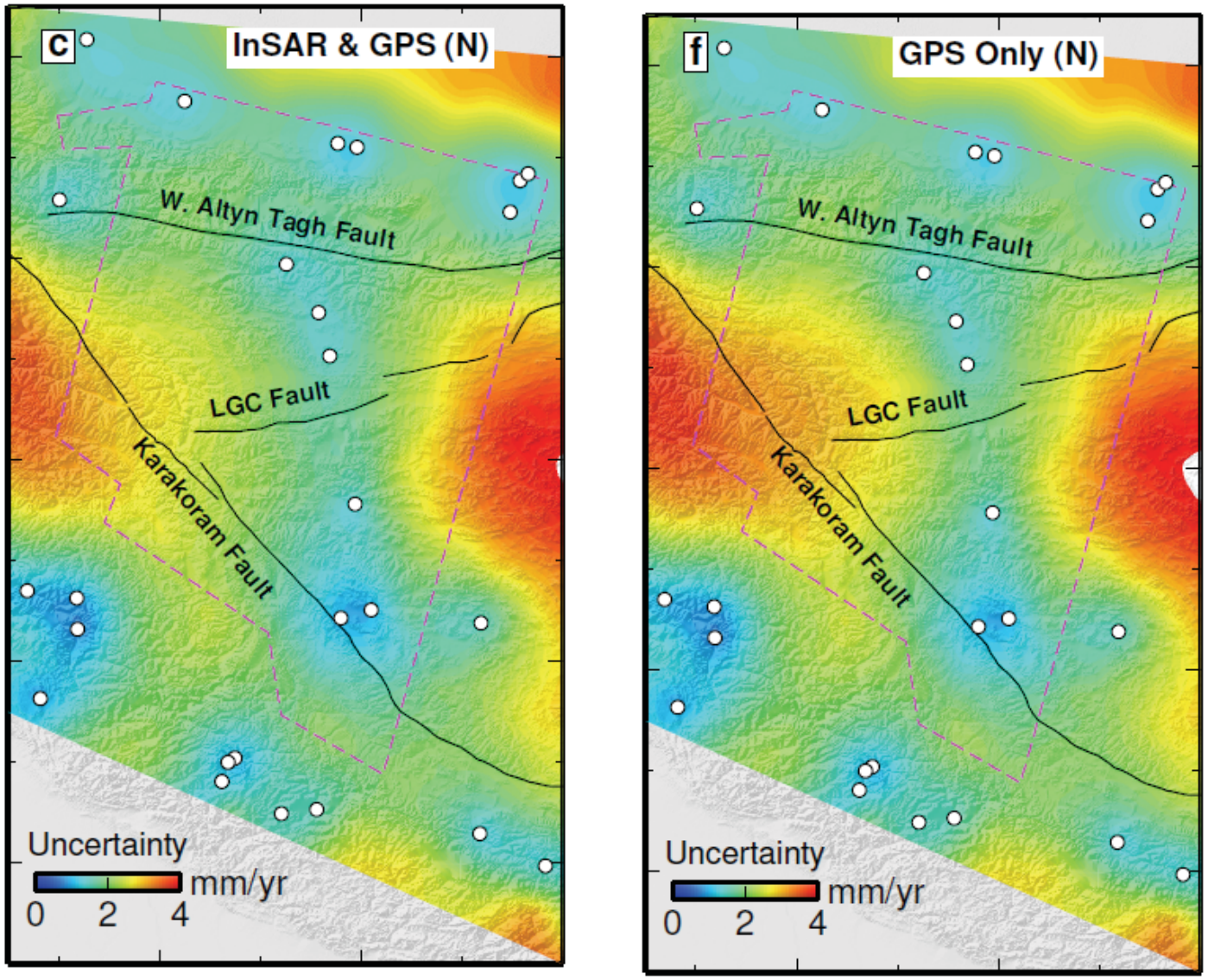
Choice of smoothing



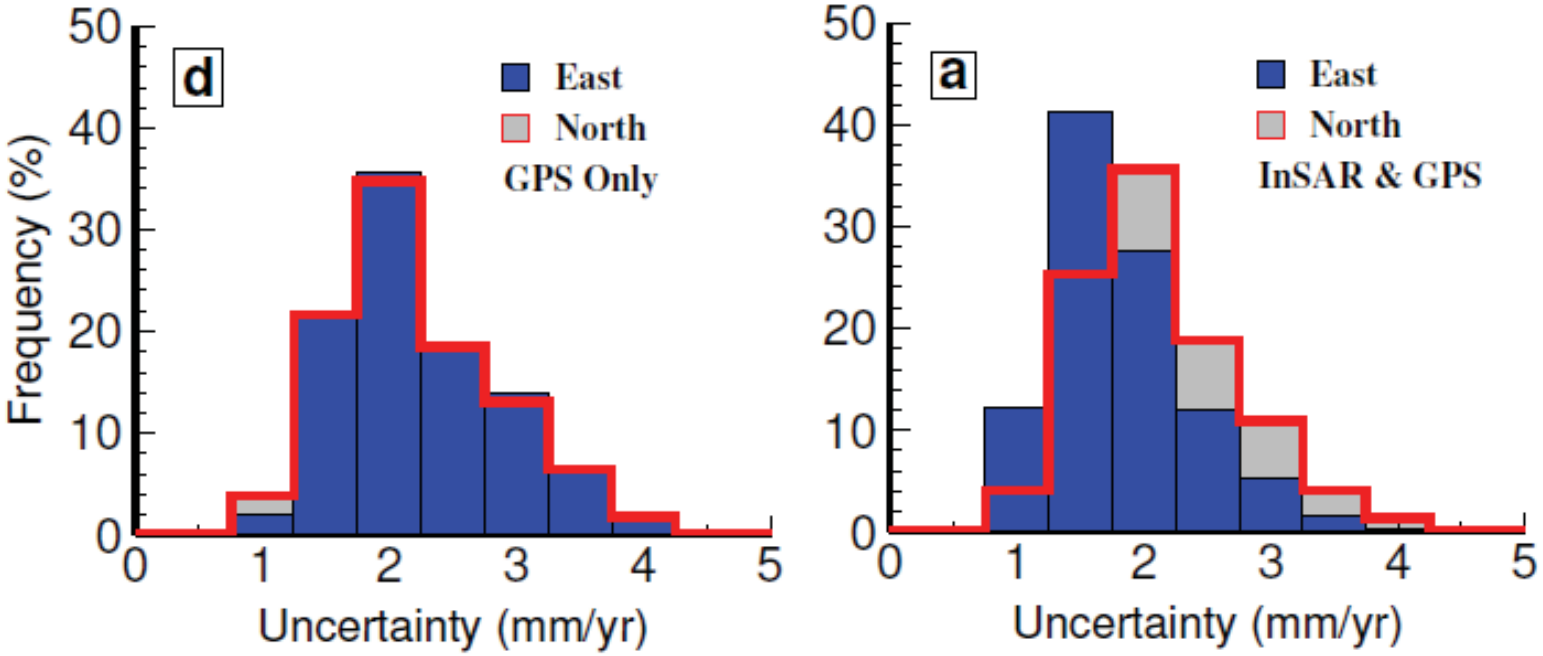
Uncertainty in estimate of V_east



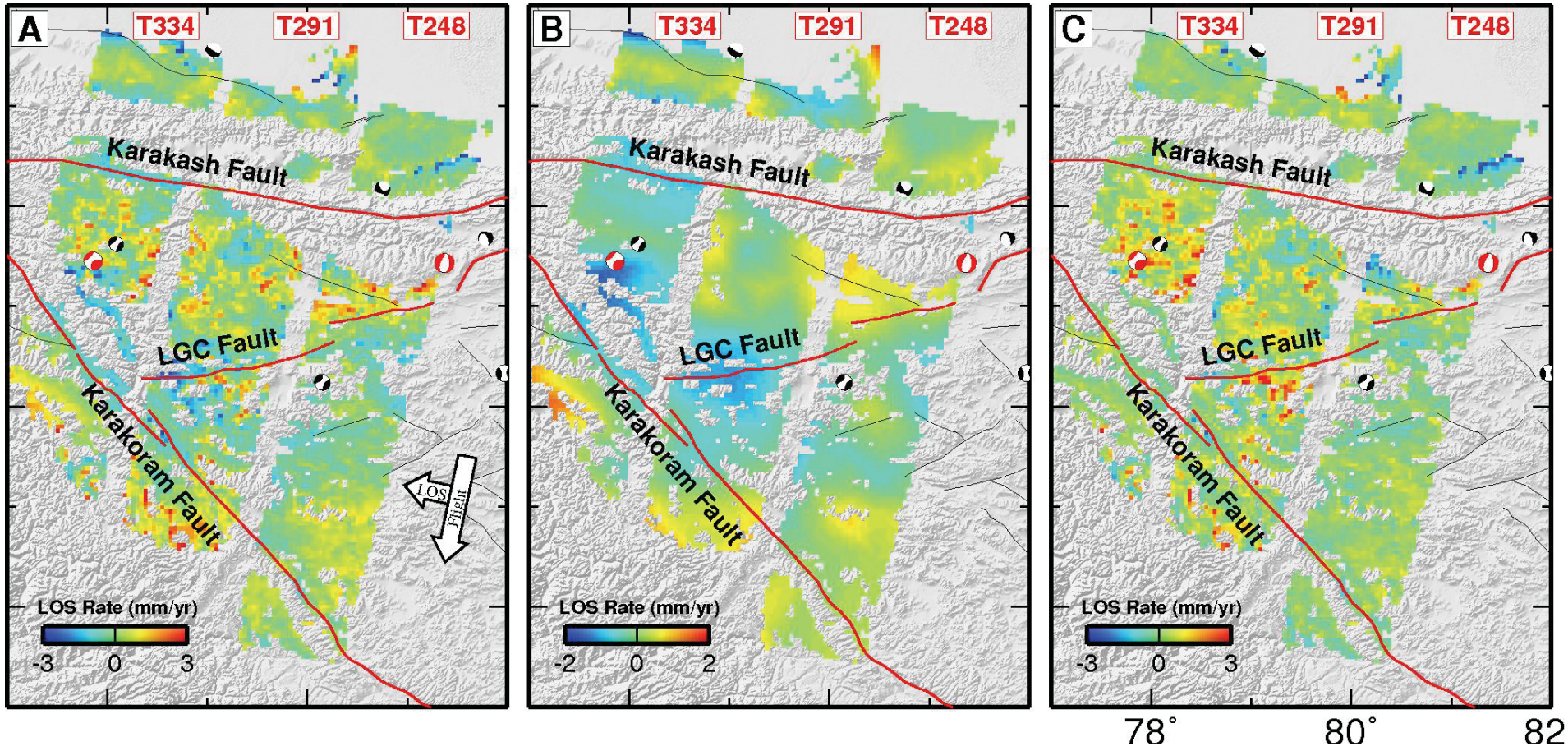
Uncertainty in estimate of V_north



InSAR improves estimates of east-west velocities.



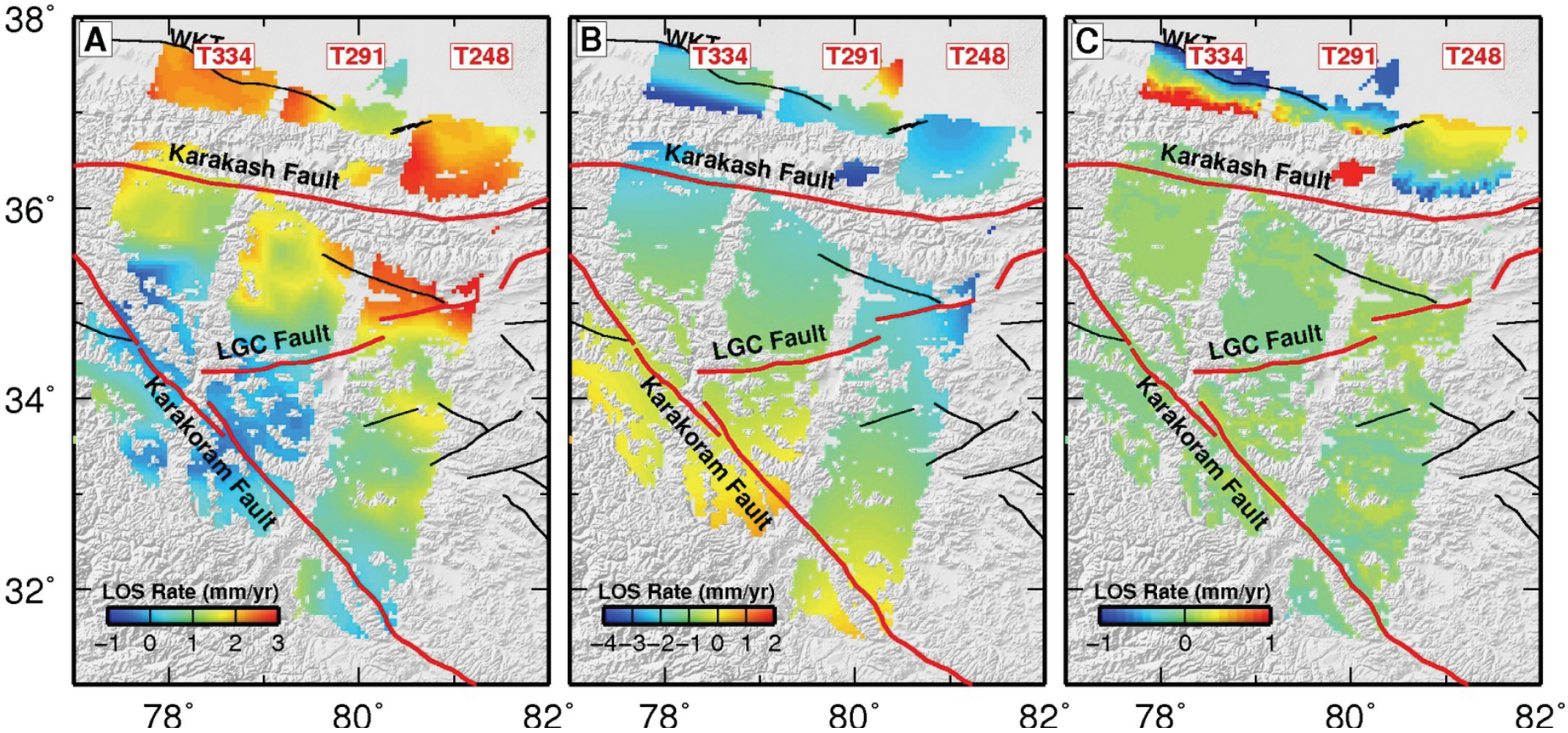
Fit to InSAR Data (track 334/291/248)



observed model residuals

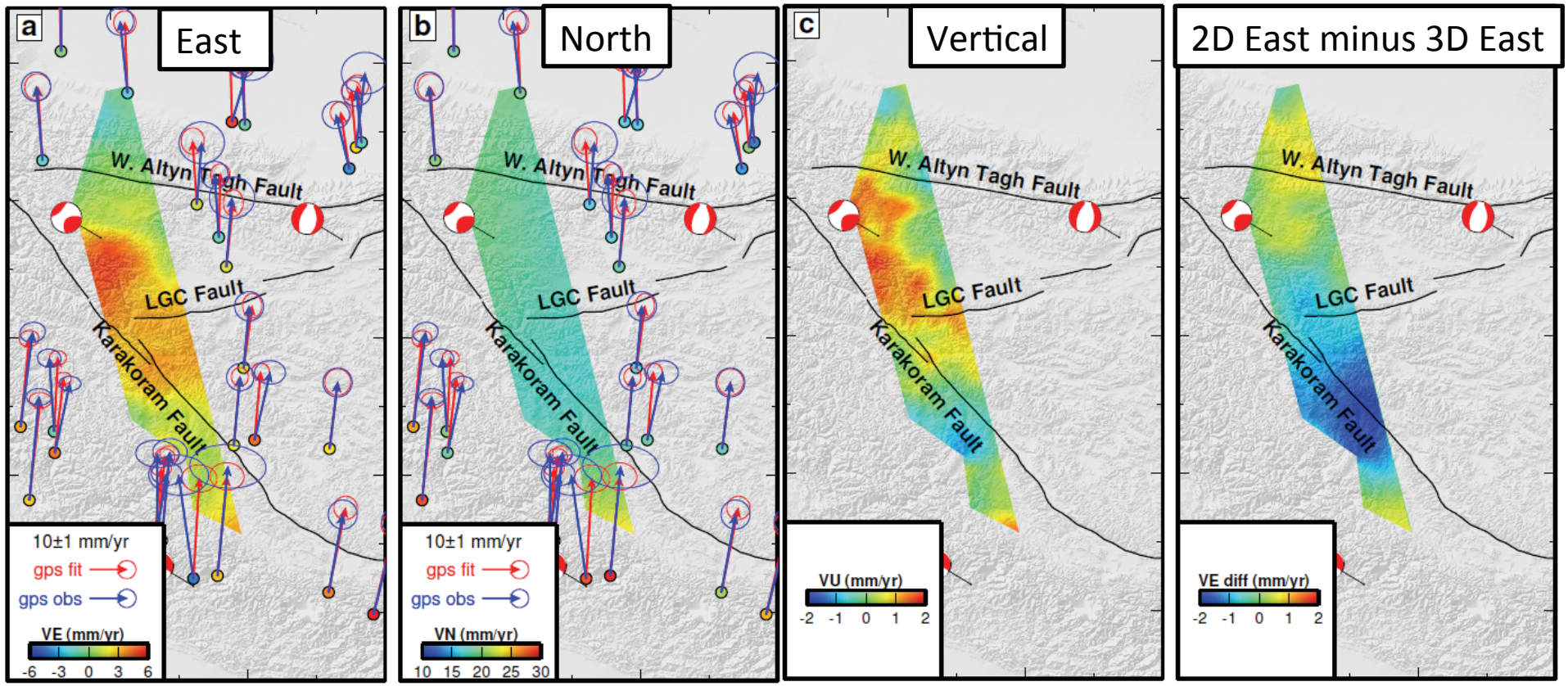
Fit to InSAR Data (track 334/291/248)

InSAR model components



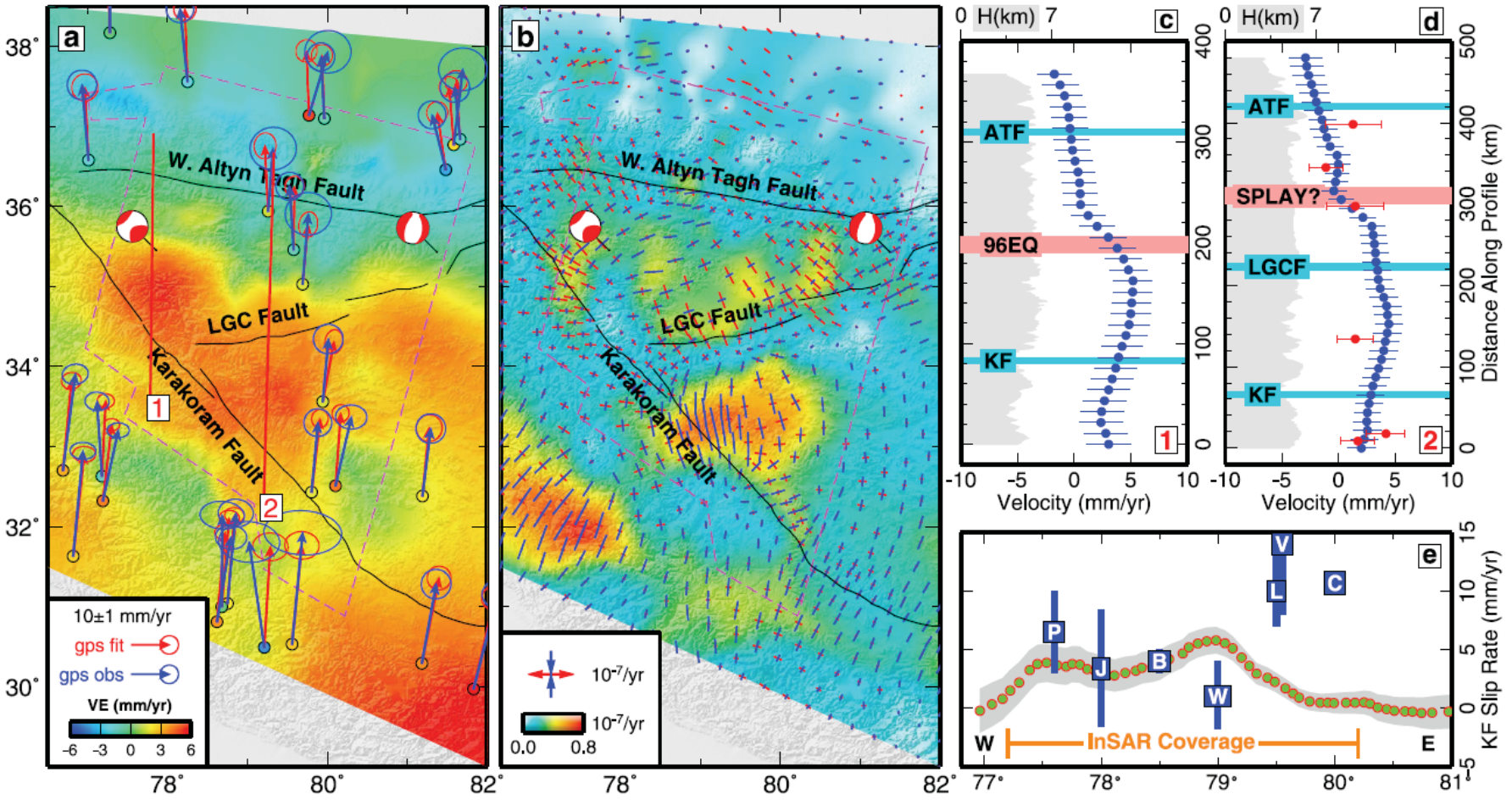
velocity orbit atmosphere

What about vertical motions?



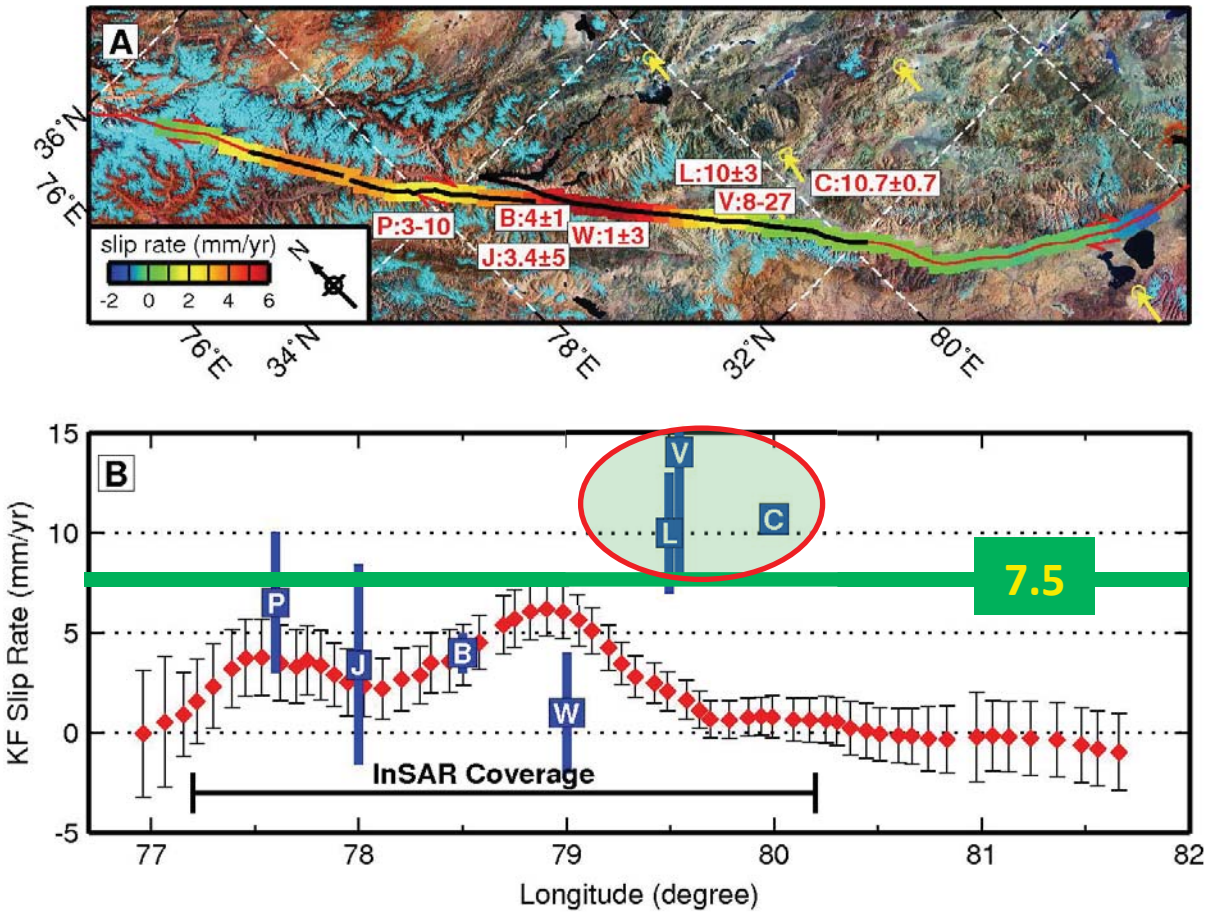
With ascending and Descending data, can calculate vertical motions by prescribing North-South motion from GPS data alone

Velocity Field from GPS & InSAR

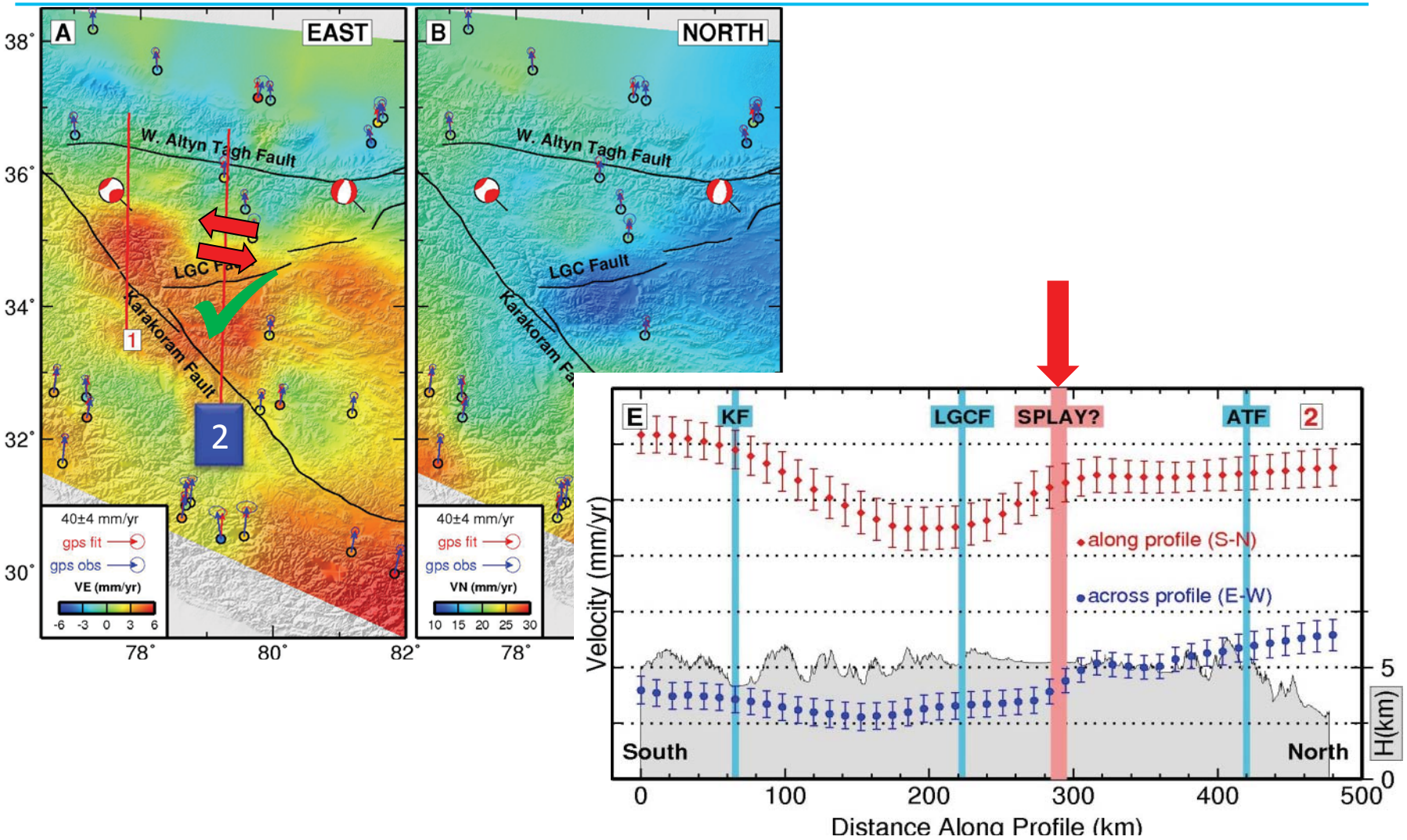


Slip Rates Along the Karakoram Fault

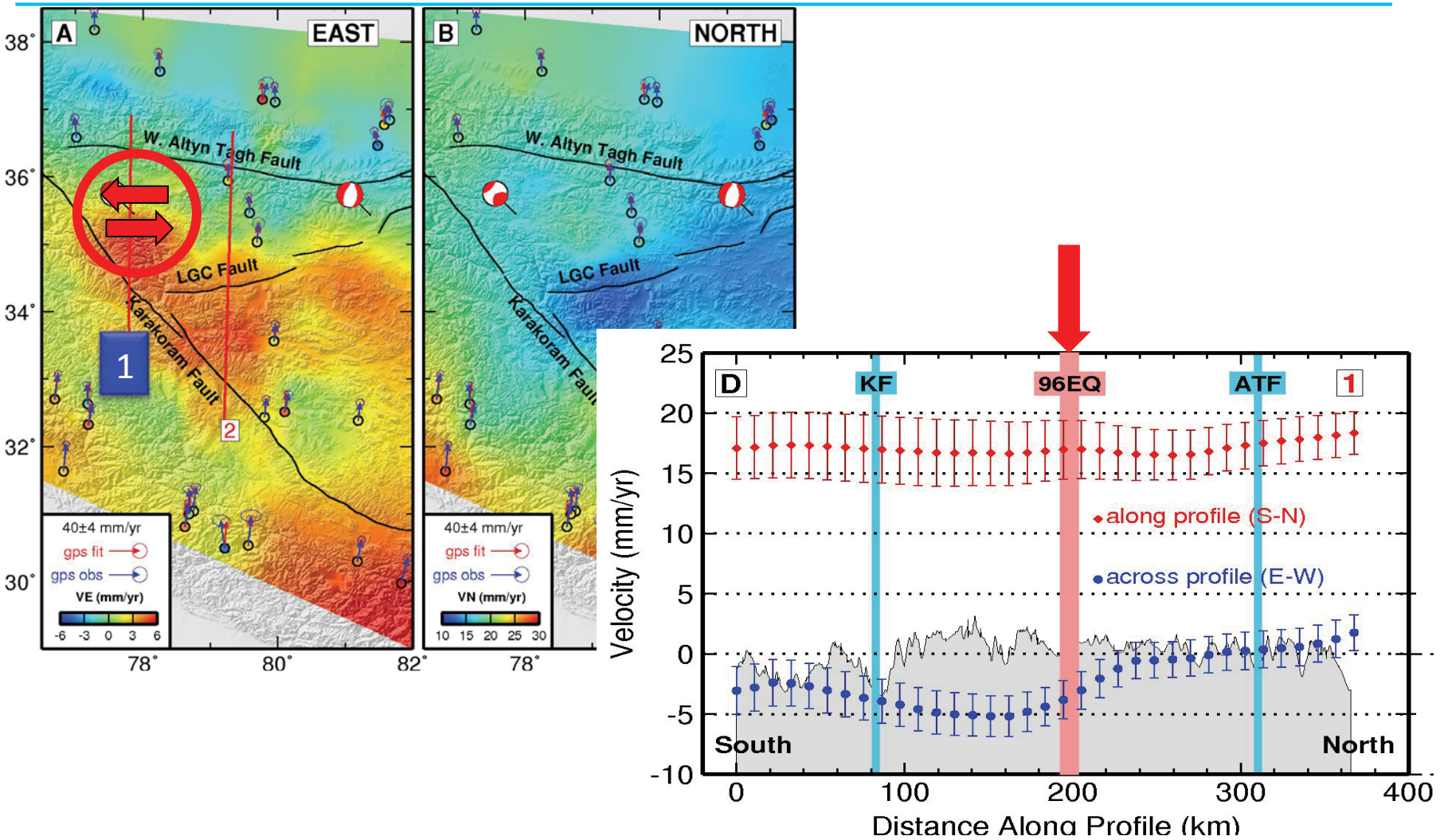
- Right-lateral slip along the entire fault
- Variable slip rate along the fault (0-6 mm/yr)
- Rule out present-day slip rates of >10 mm/yr
- No significant focused strain



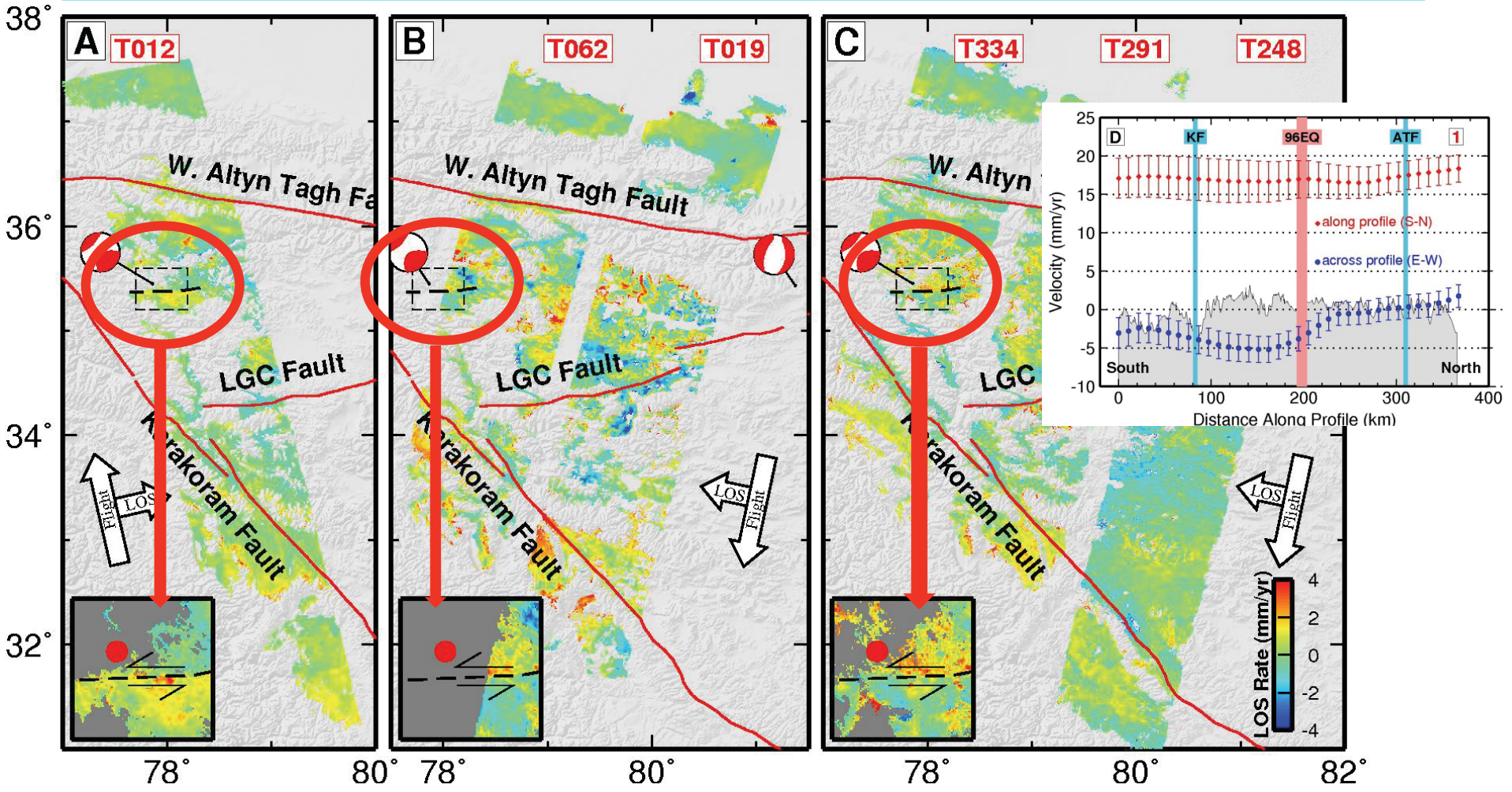
Velocity Profiles across Western Tibet



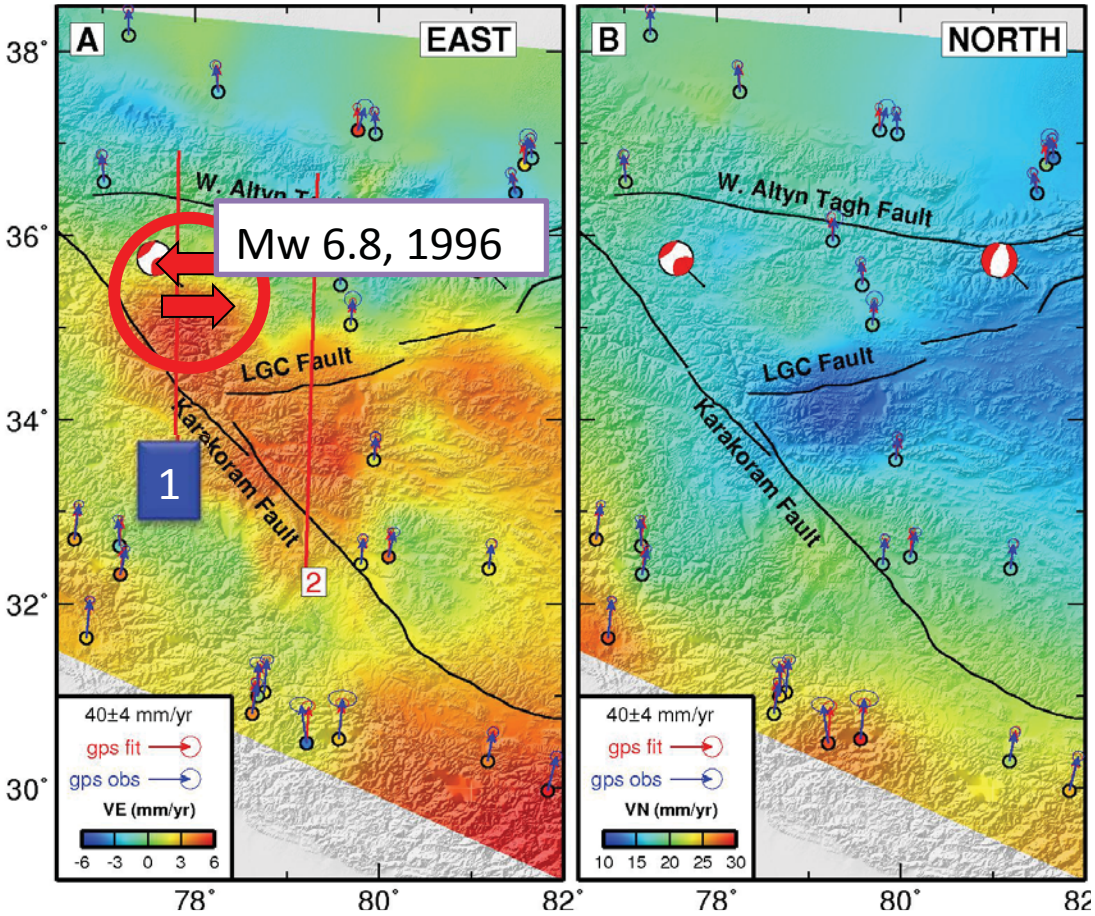
Velocity Profiles across Western Tibet



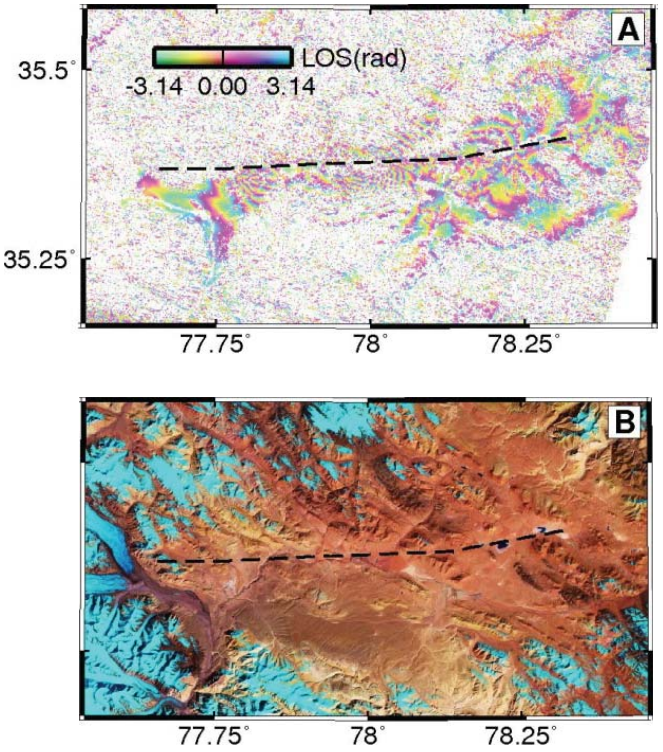
Left-Lateral Shear in A-/Descending Data Sets



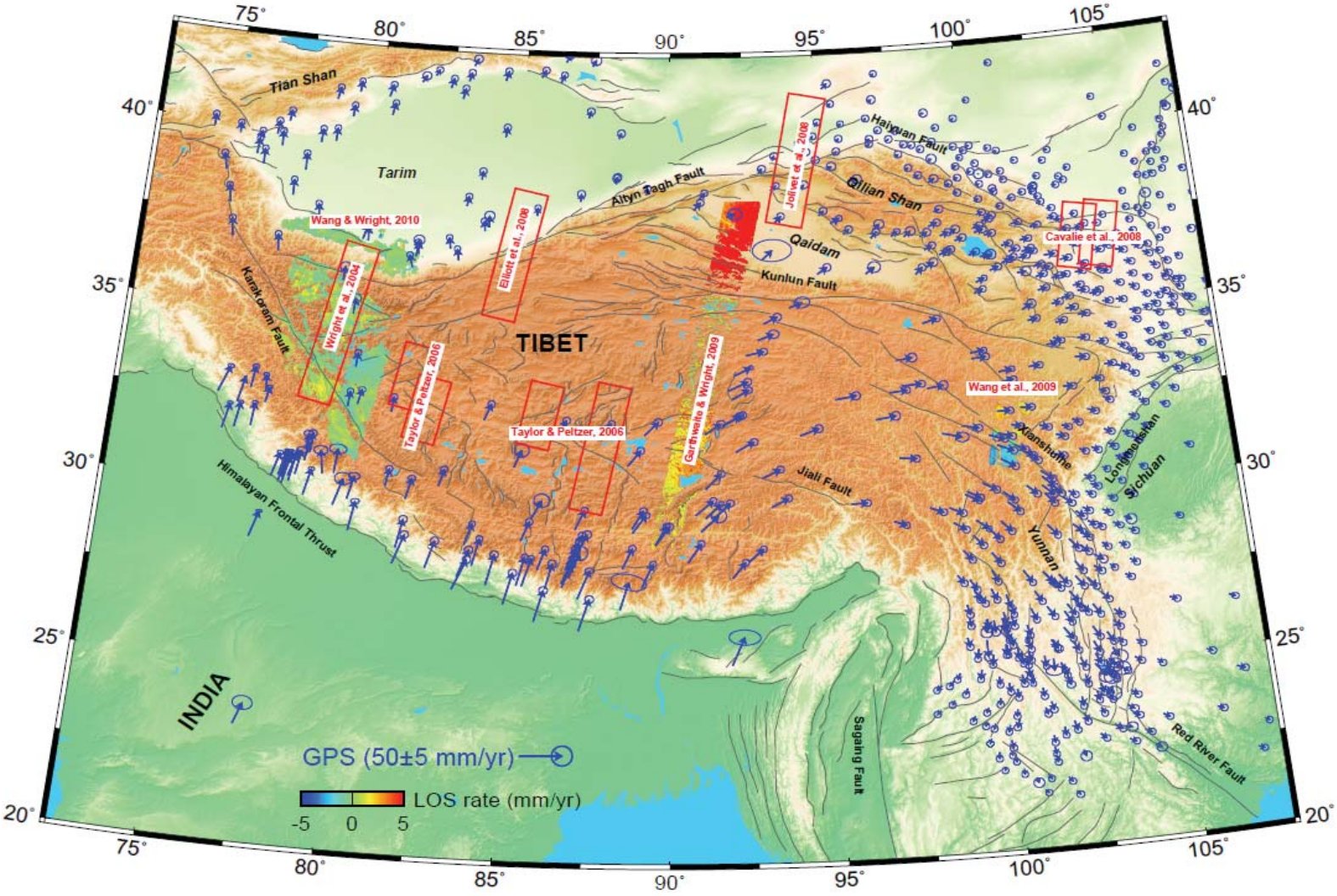
Cause: Postseismic transient



Coseismic interferogram shows consistent fault trace and the sense of slip

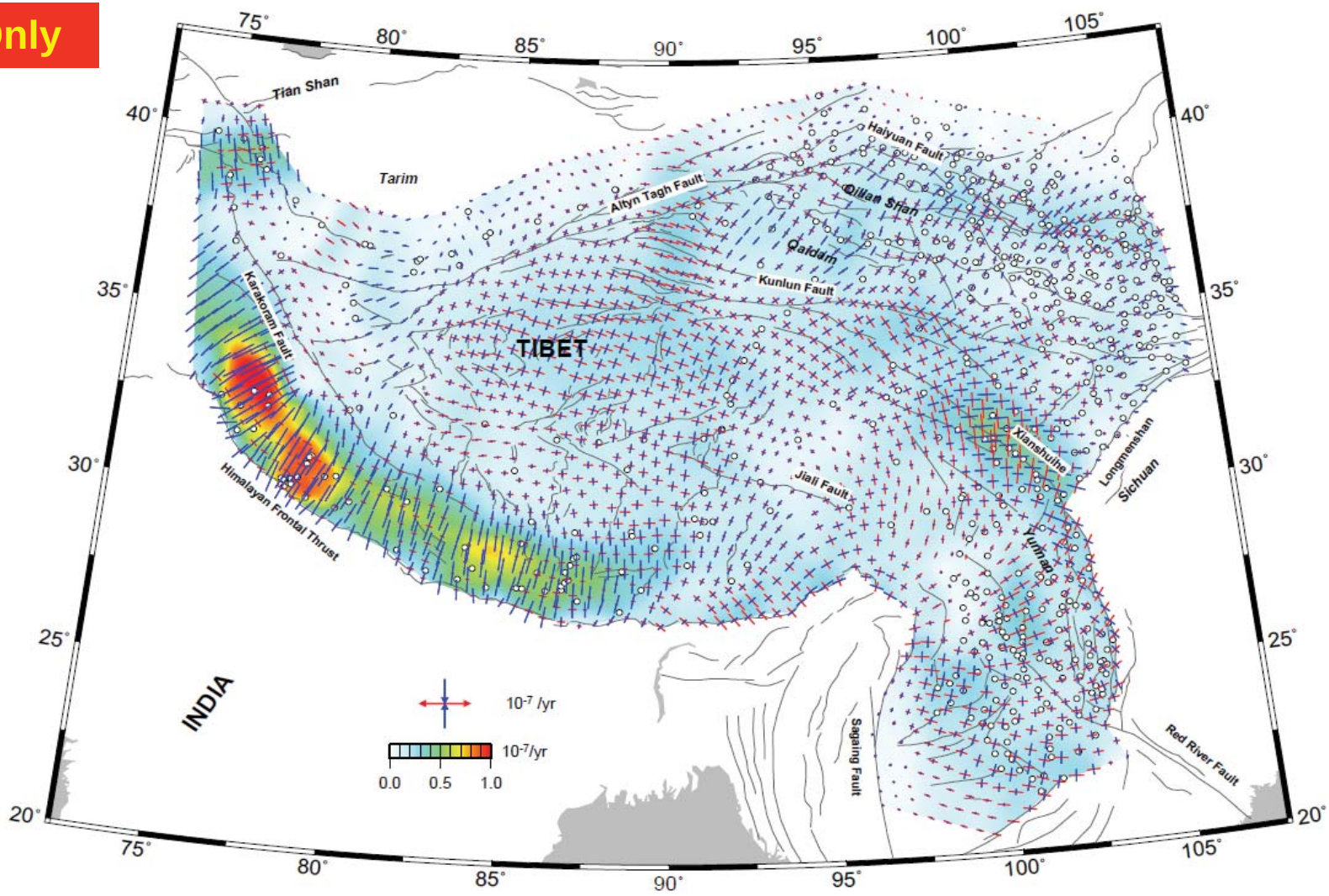


Towards Continental Scale Velocity Fields



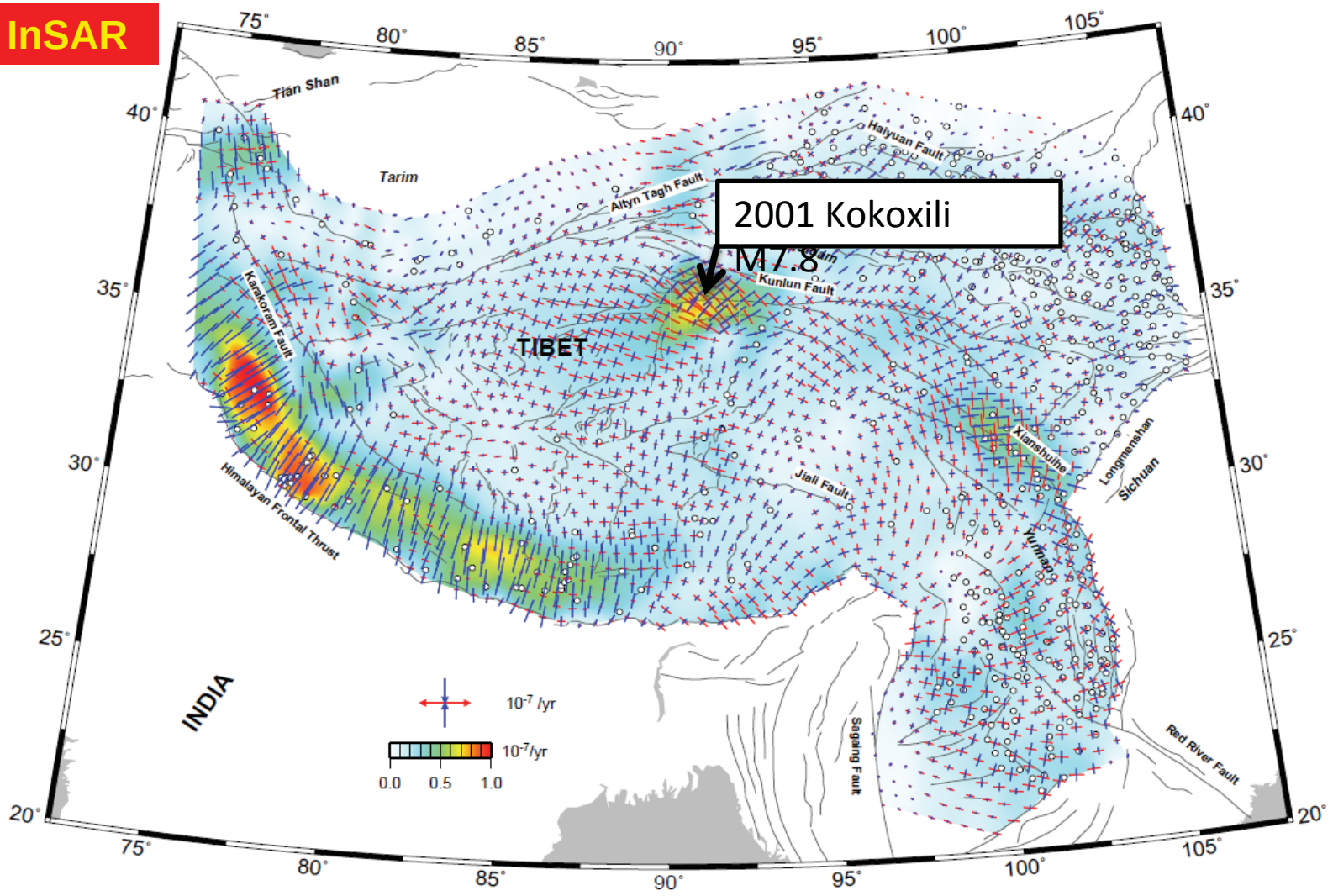
Towards Continental Scale Velocity Fields

GPS Only

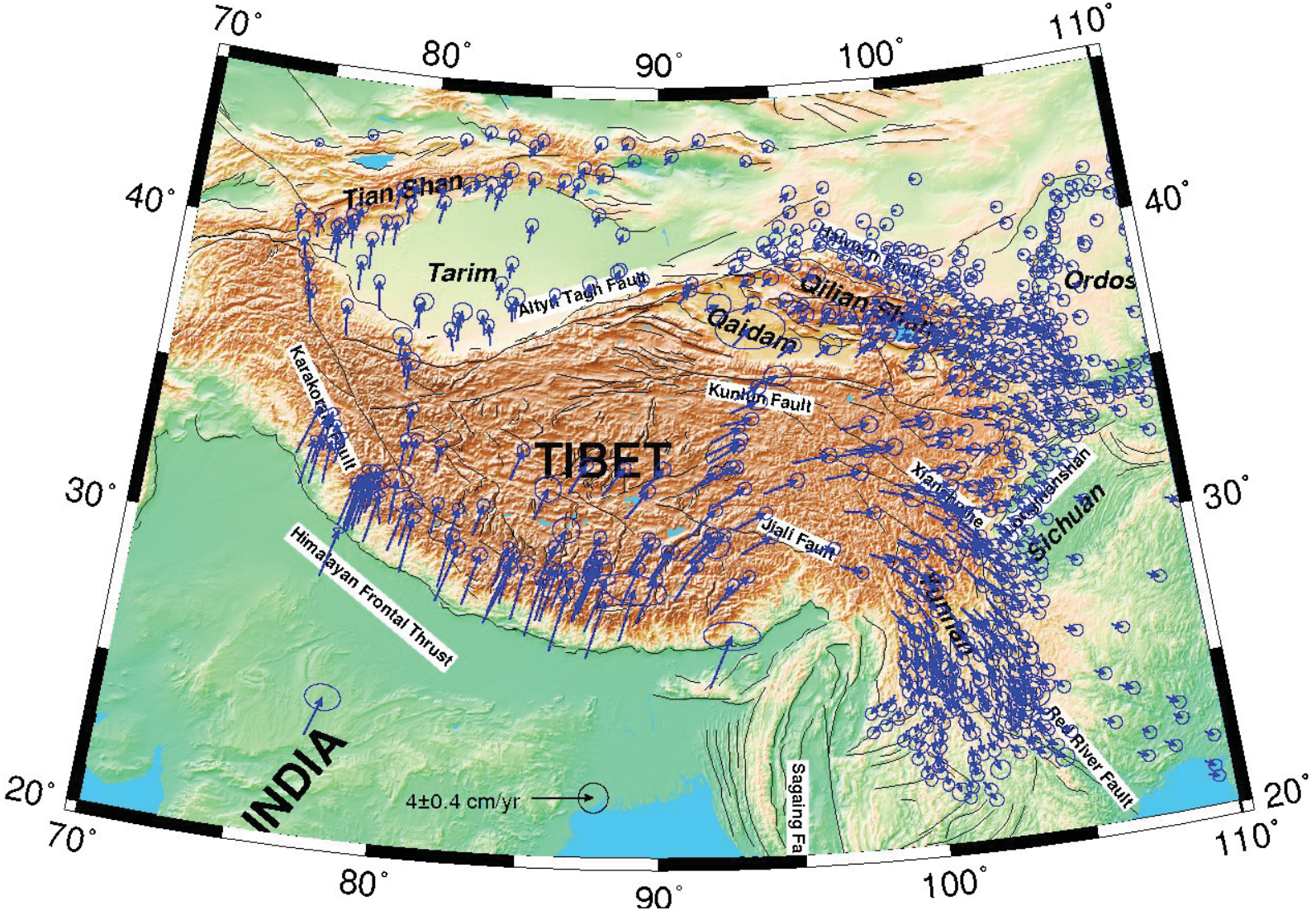


Towards Continental Scale Velocity Fields

GPS + InSAR



Key Questions:
- Is continental tectonics best described by blocks or a continuum?
- How much strain is focused on major faults?

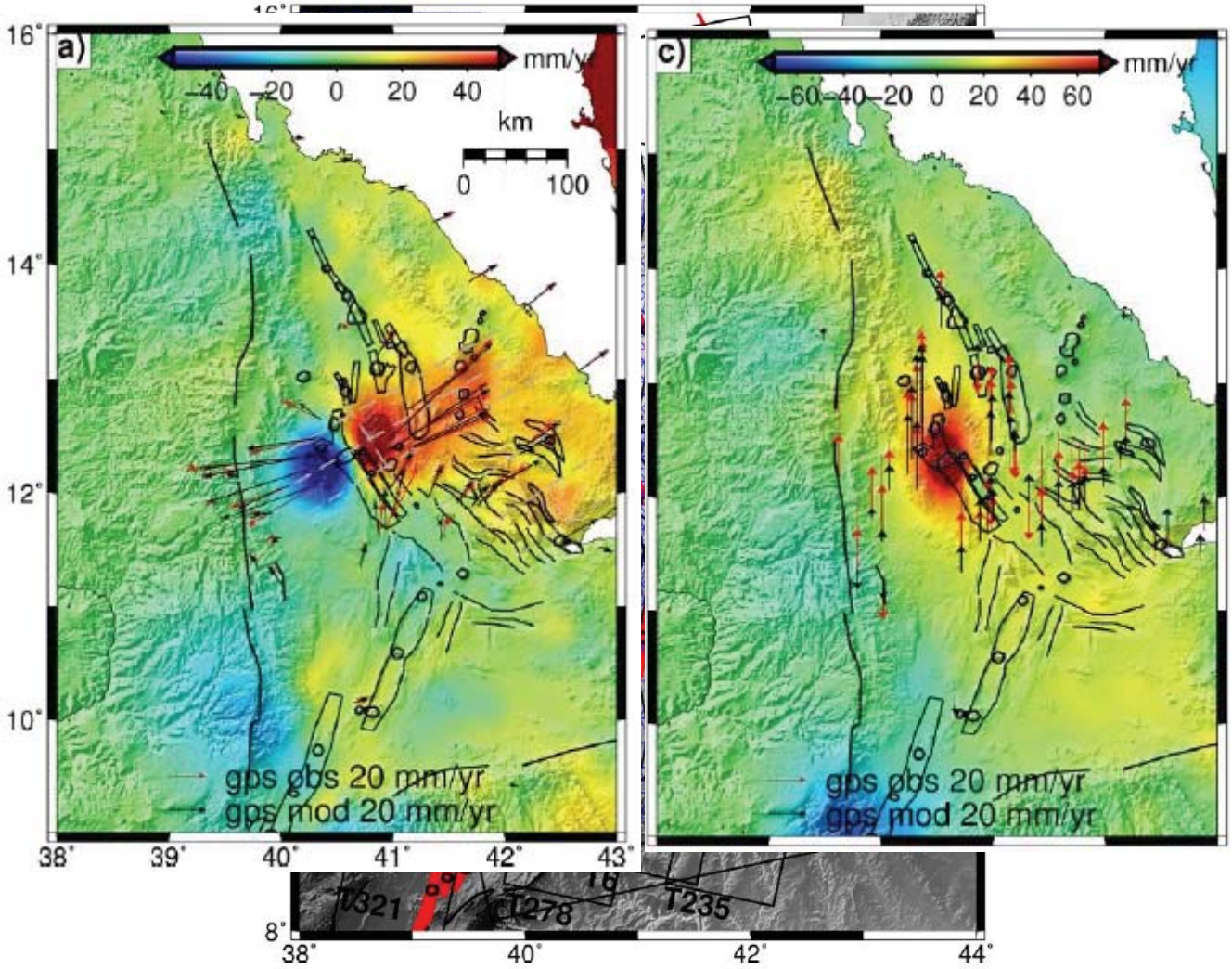


GPS data from Gan et al., 2007

Conclusions

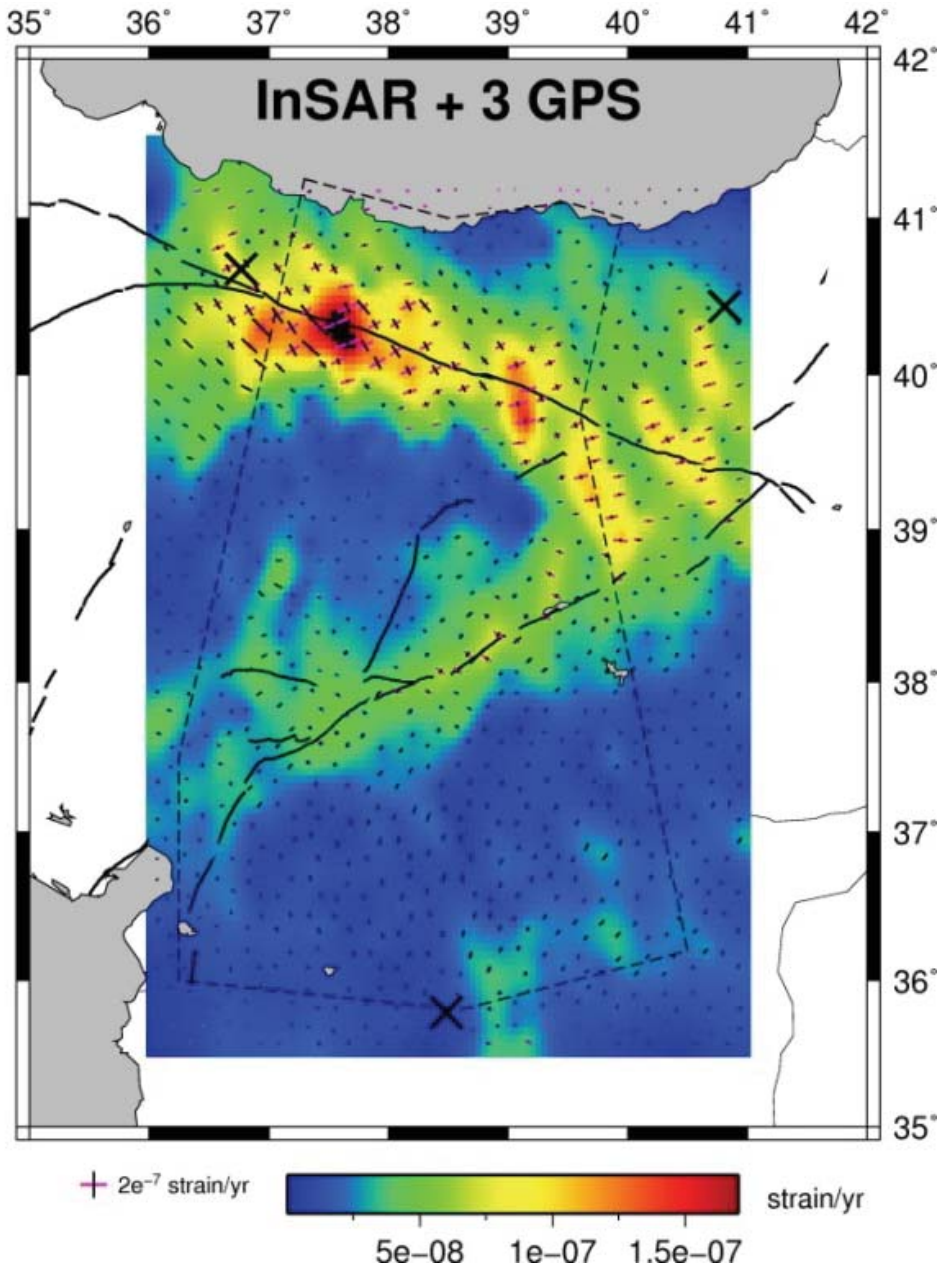
- Data sets from Western and Central Tibet are incompatible with block models.
- Presence of high strain zones is not predicted by Thin Viscous Sheet Models.
- Velocity field shows long-lived post-seismic strain transients.
- Is it possible to decouple earthquake cycle effects from secular strain?

Deformation in Afar Triple Junction



Pagli et al., in prep 2013

Strain Rates in Eastern Turkey from InSAR + 3 GPS

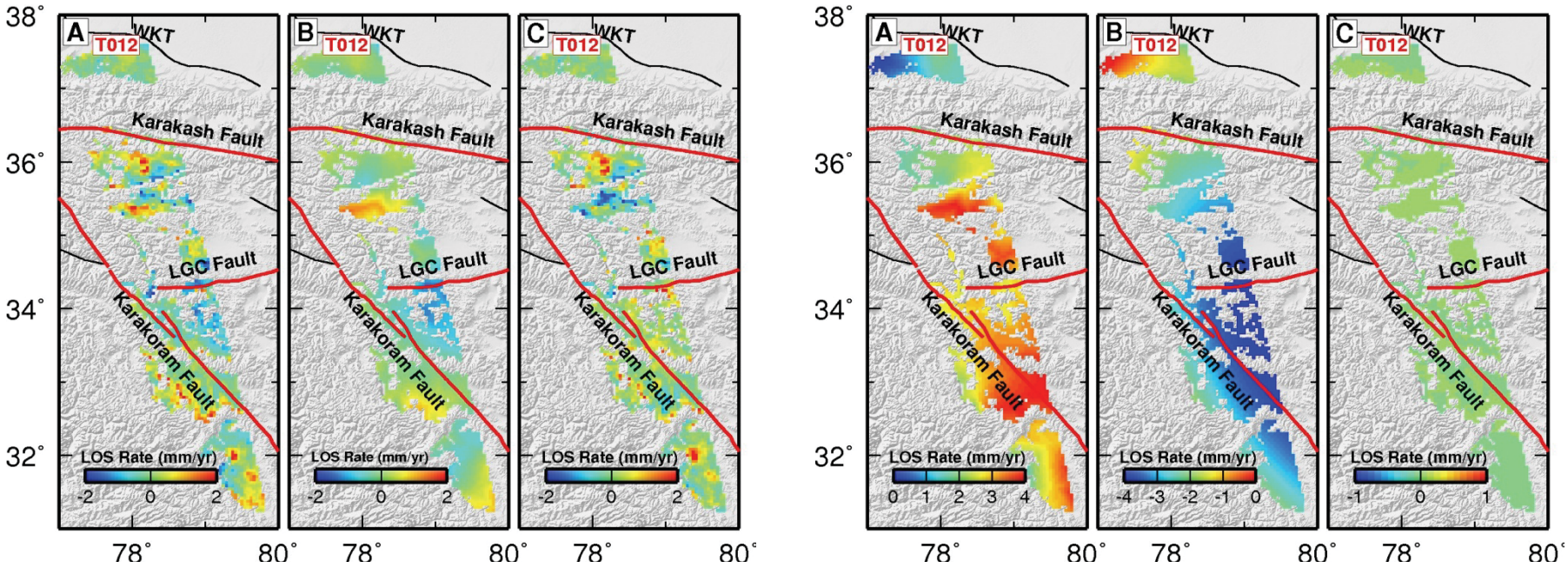


See Richard Walters' talk on Wednesday

Outlook

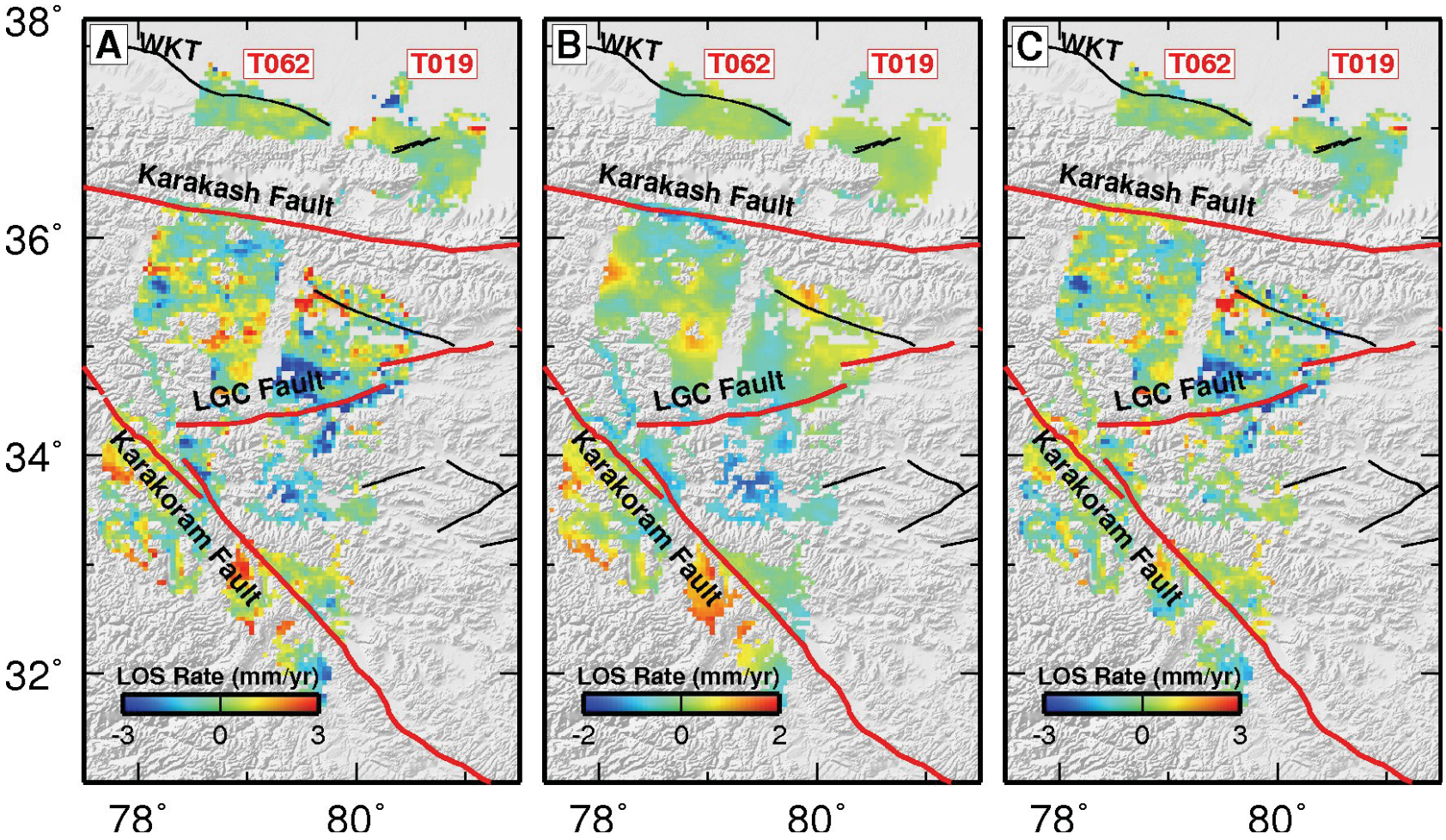
- Regular acquisitions from Sentinel-1 will allow us to measure line of sight deformation for all deforming zones.
- Velocity field methods are one way of combining these data into a global, easy-to-understand product.
- Additional information from InSAR is most valuable where there is limited GPS data.
- We are funded to build a processing system for Sentinel-1 for the Alpine-Himalayan Belt and East African Rift. Results will be made available to the community.

Fitted InSAR Data (Track 12)

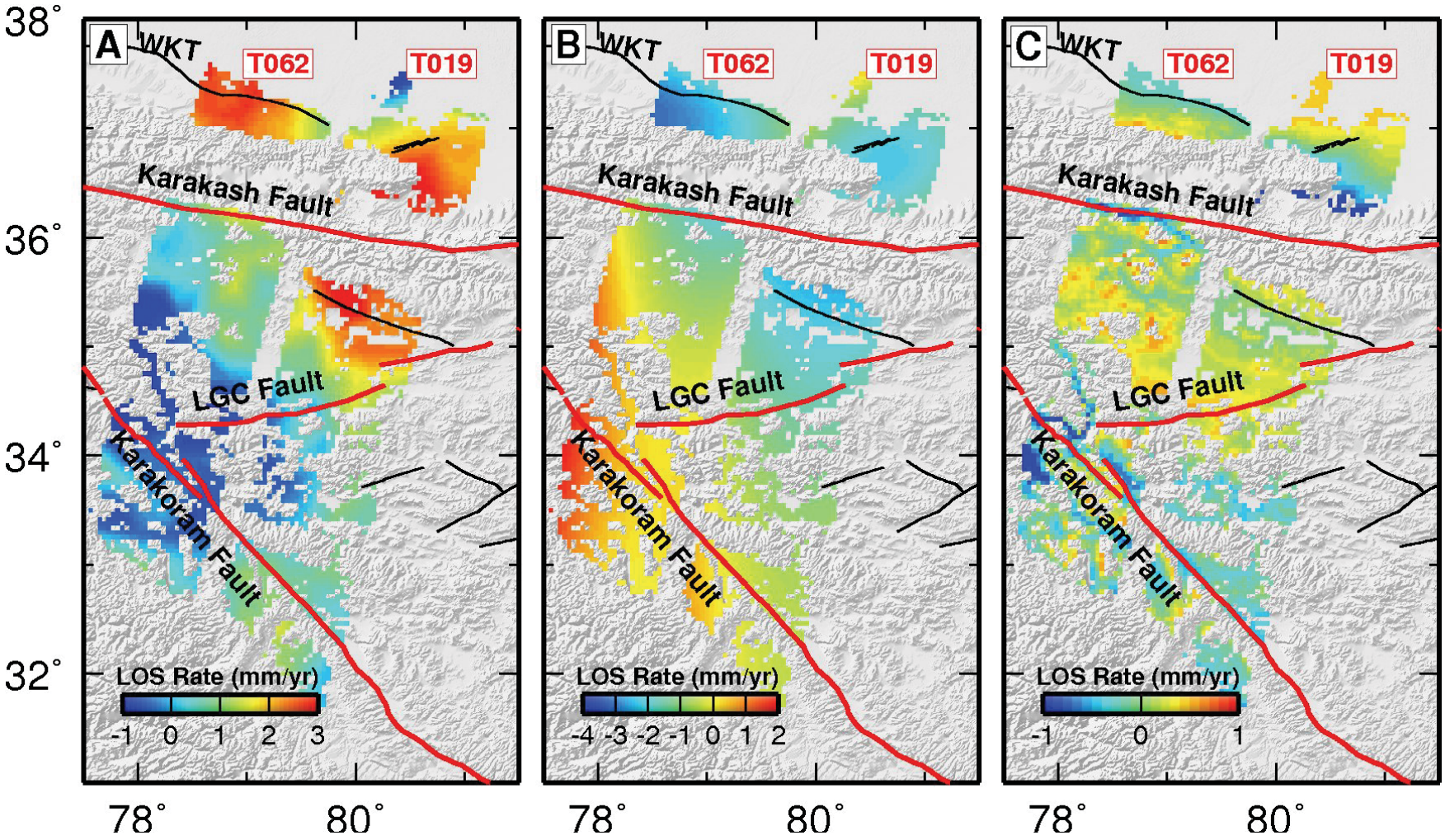


obs fitted residuals velocity orb atm

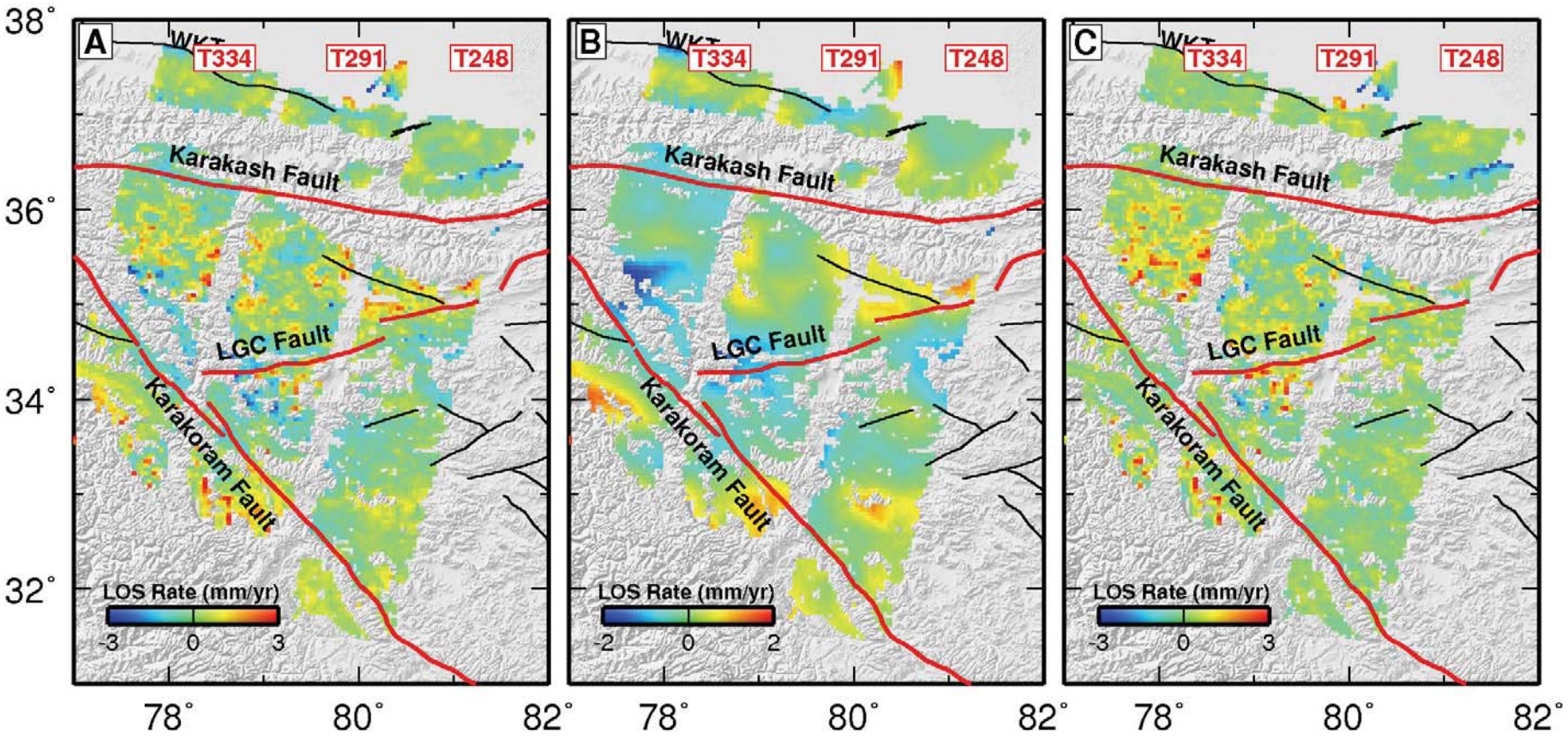
Fitted InSAR Data (Track 19/62)



Fitted InSAR Data (Track 19/62)



Fitted InSAR Data (track 334/291/248)

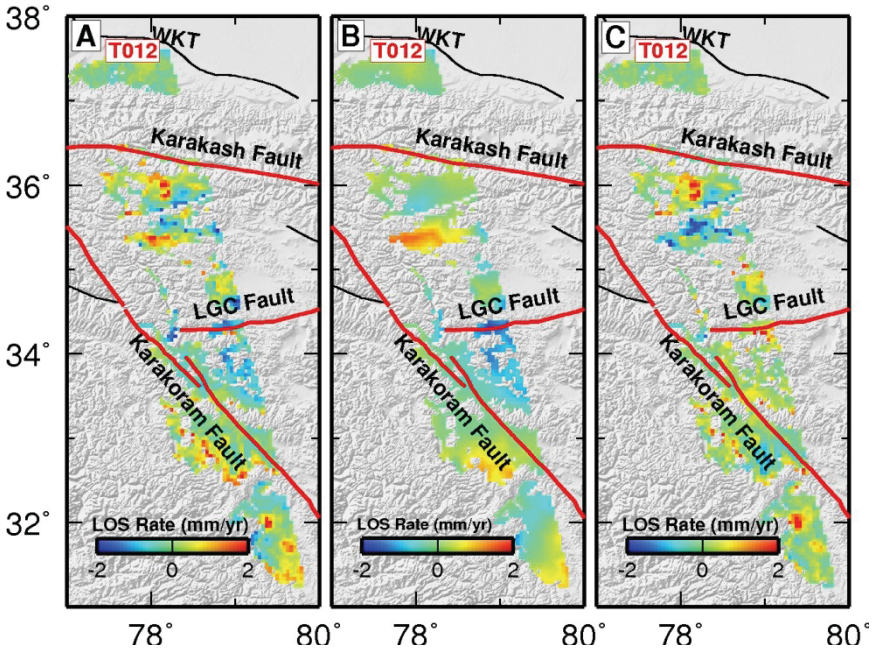


obs

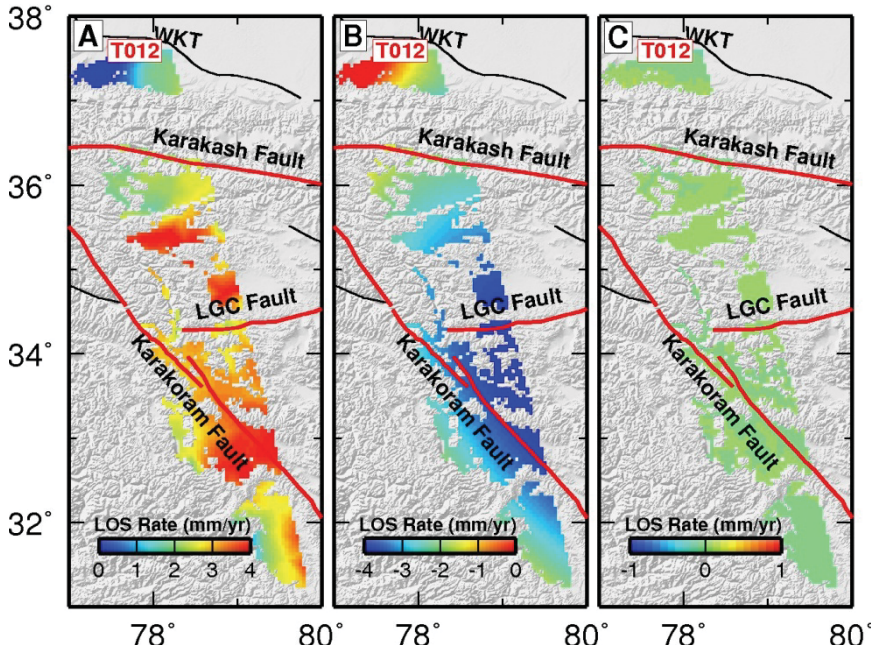
fitted

residuals

Fitted InSAR Data (Track 12)

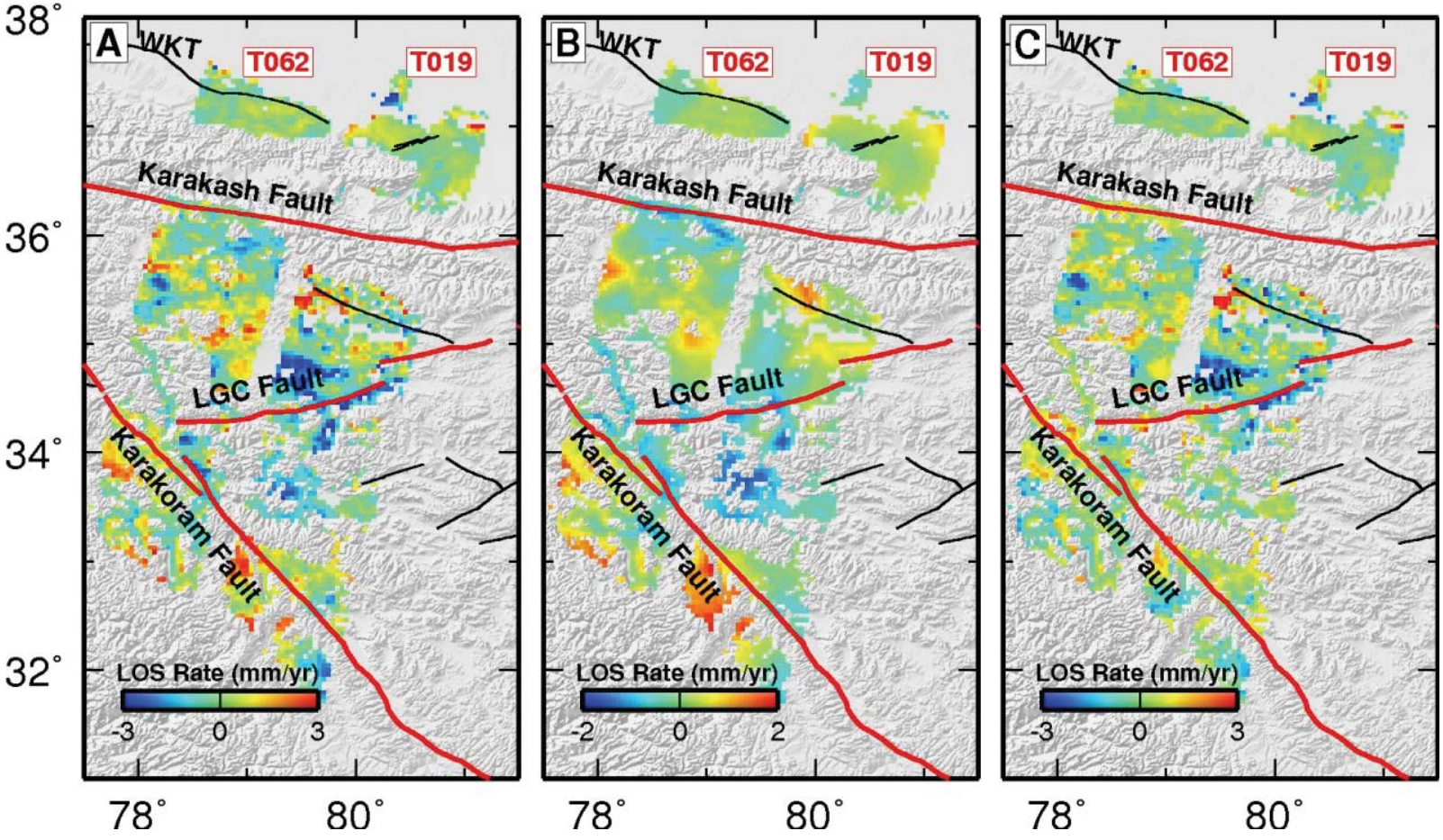


obs fitted residuals



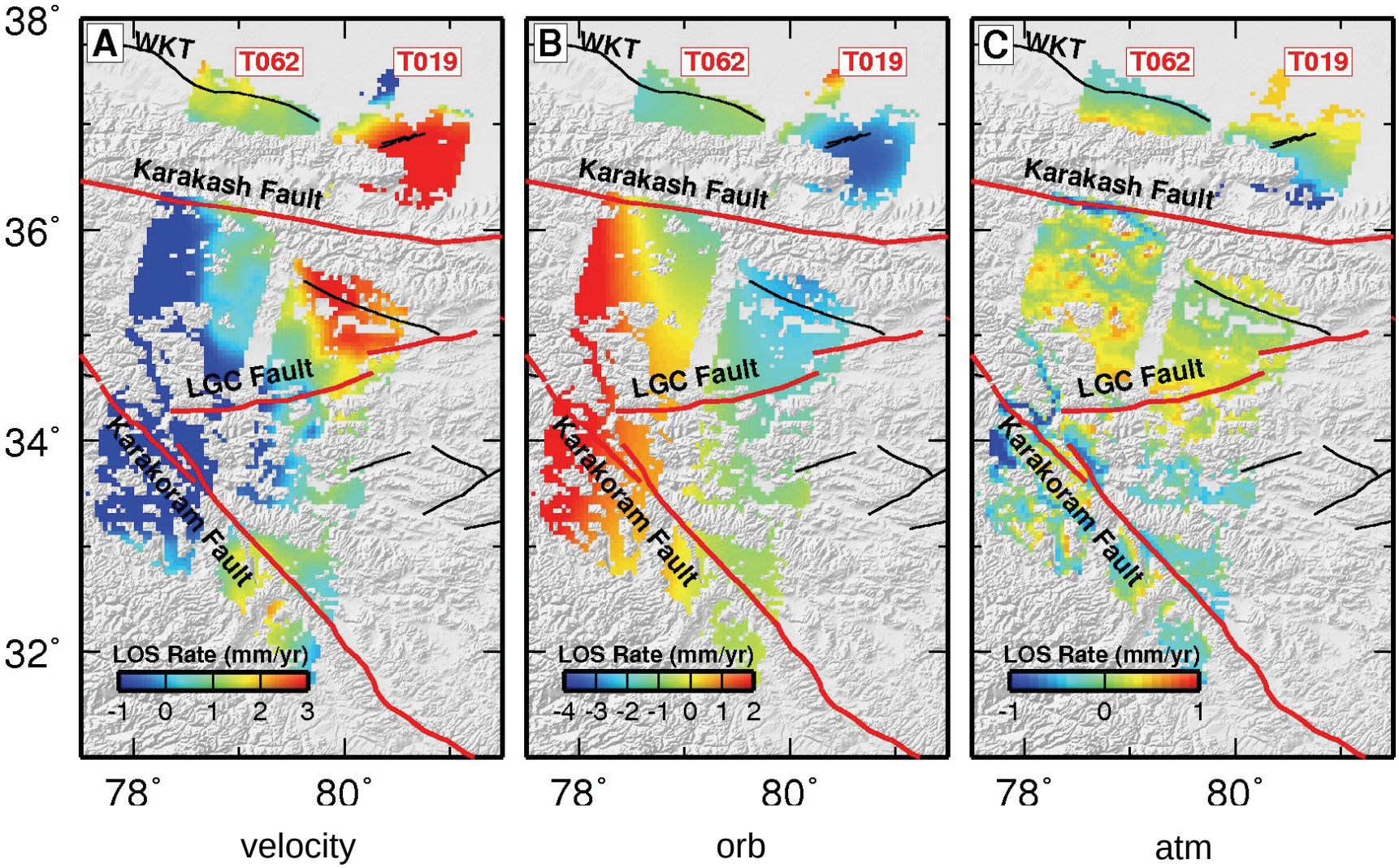
velocity orb atm

Fitted InSAR Data (Track 19/62)

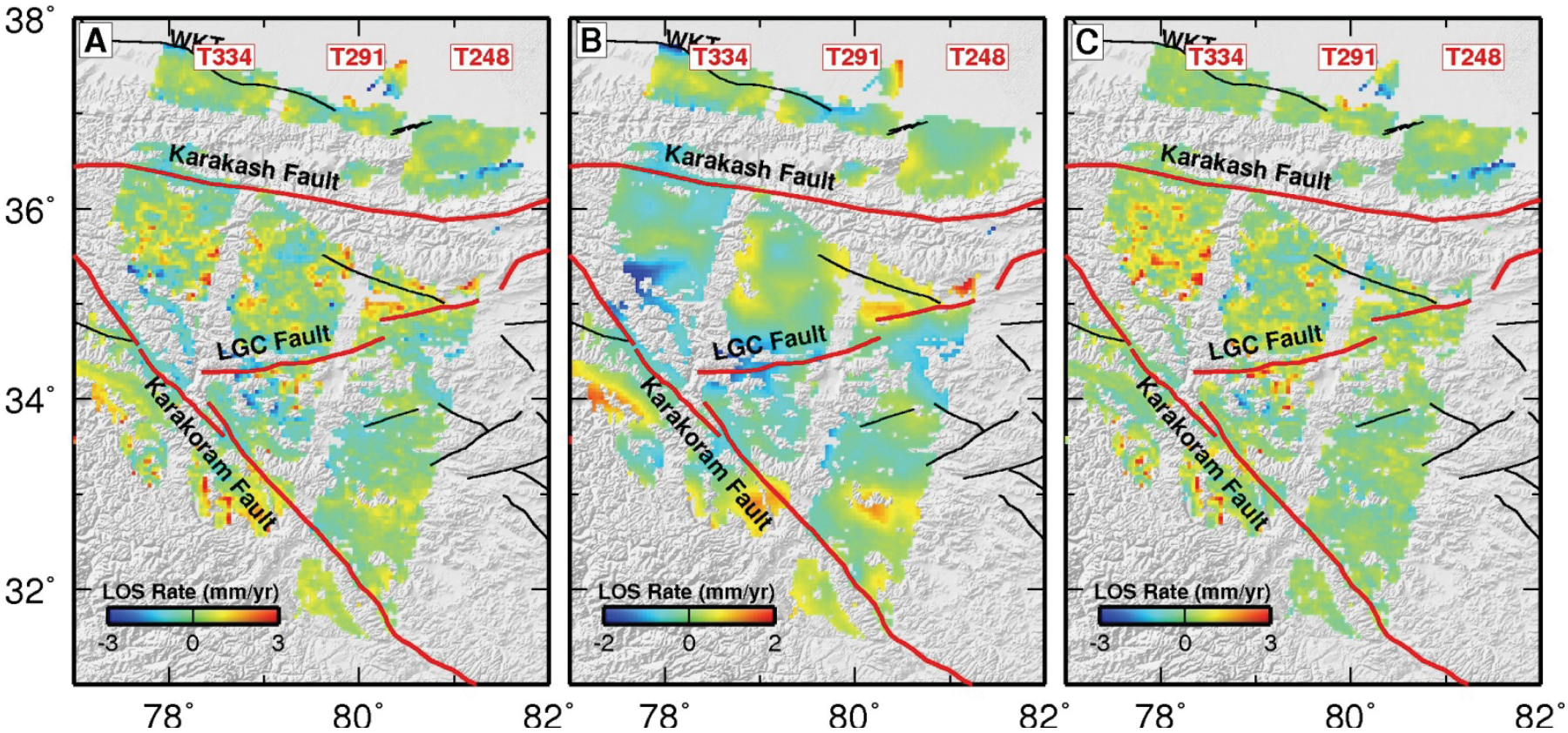


obs fitted residuals

Fitted InSAR Data (Track 19/62)



Fitted InSAR Data (track 334/291/248)

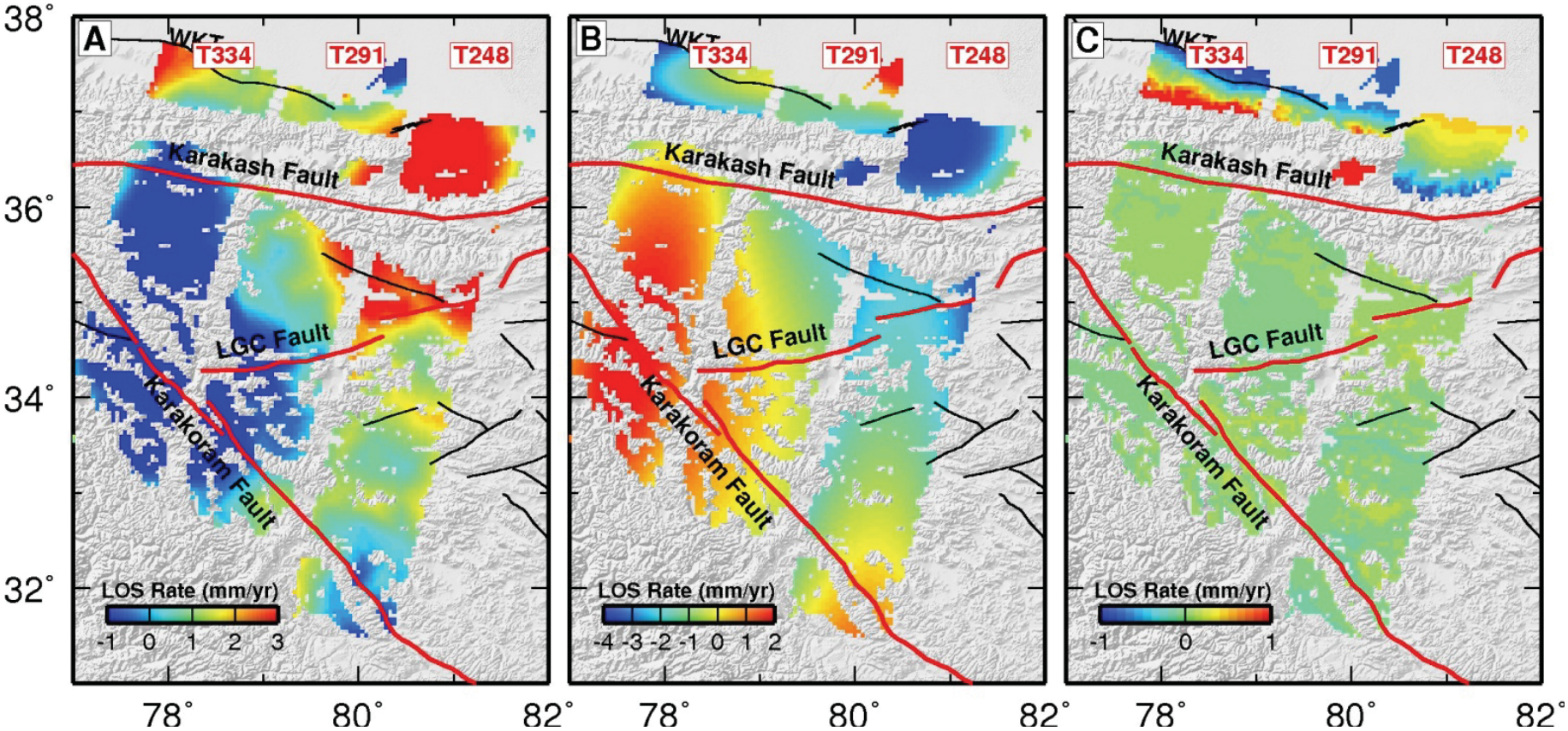


obs

fitted

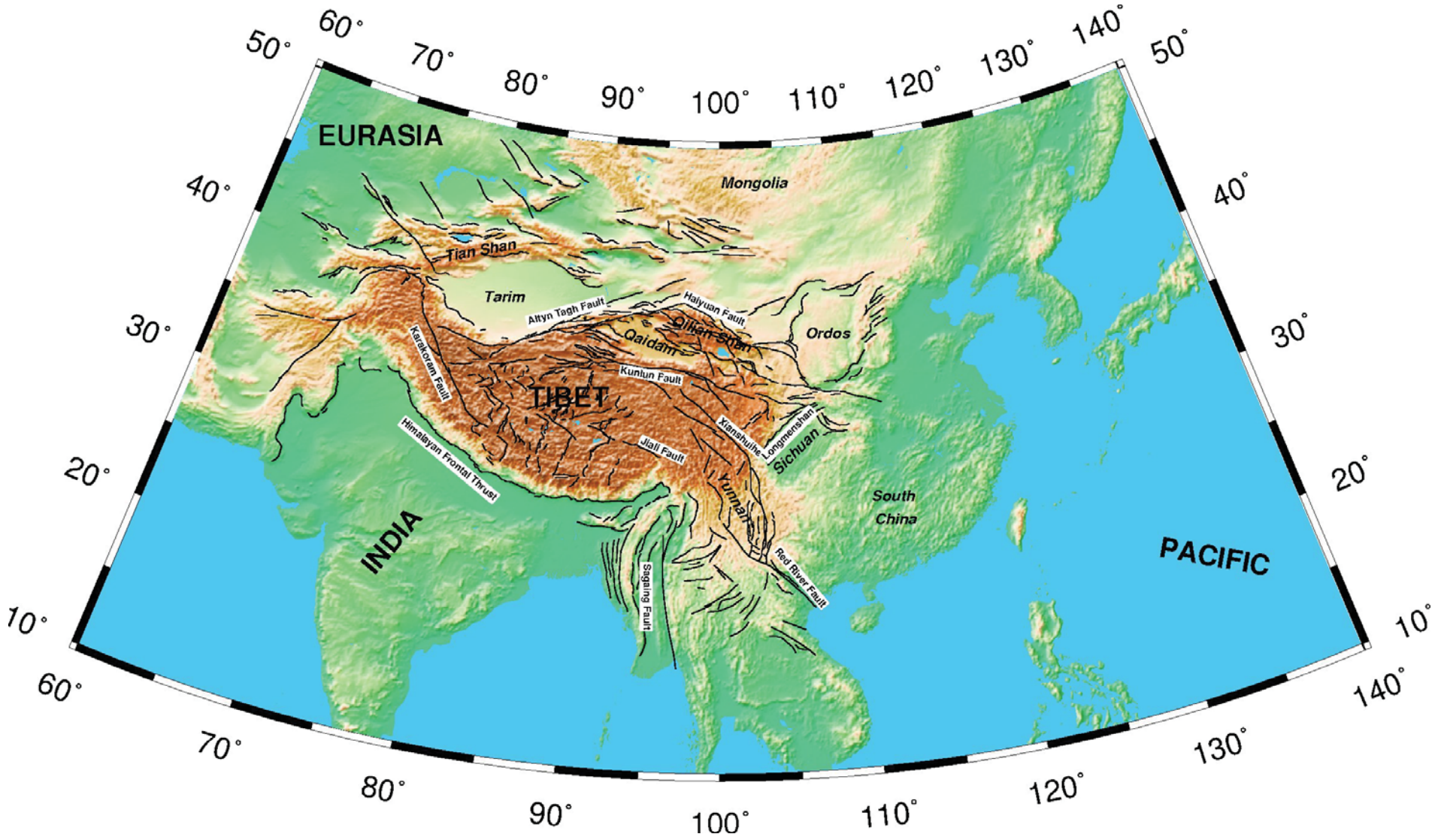
residuals

Fitted InSAR Data (track 334/291/248)



velocity orb atm

Tibet: Supersite for continental tectonics



Fault map from Taylor & Yin, 2009

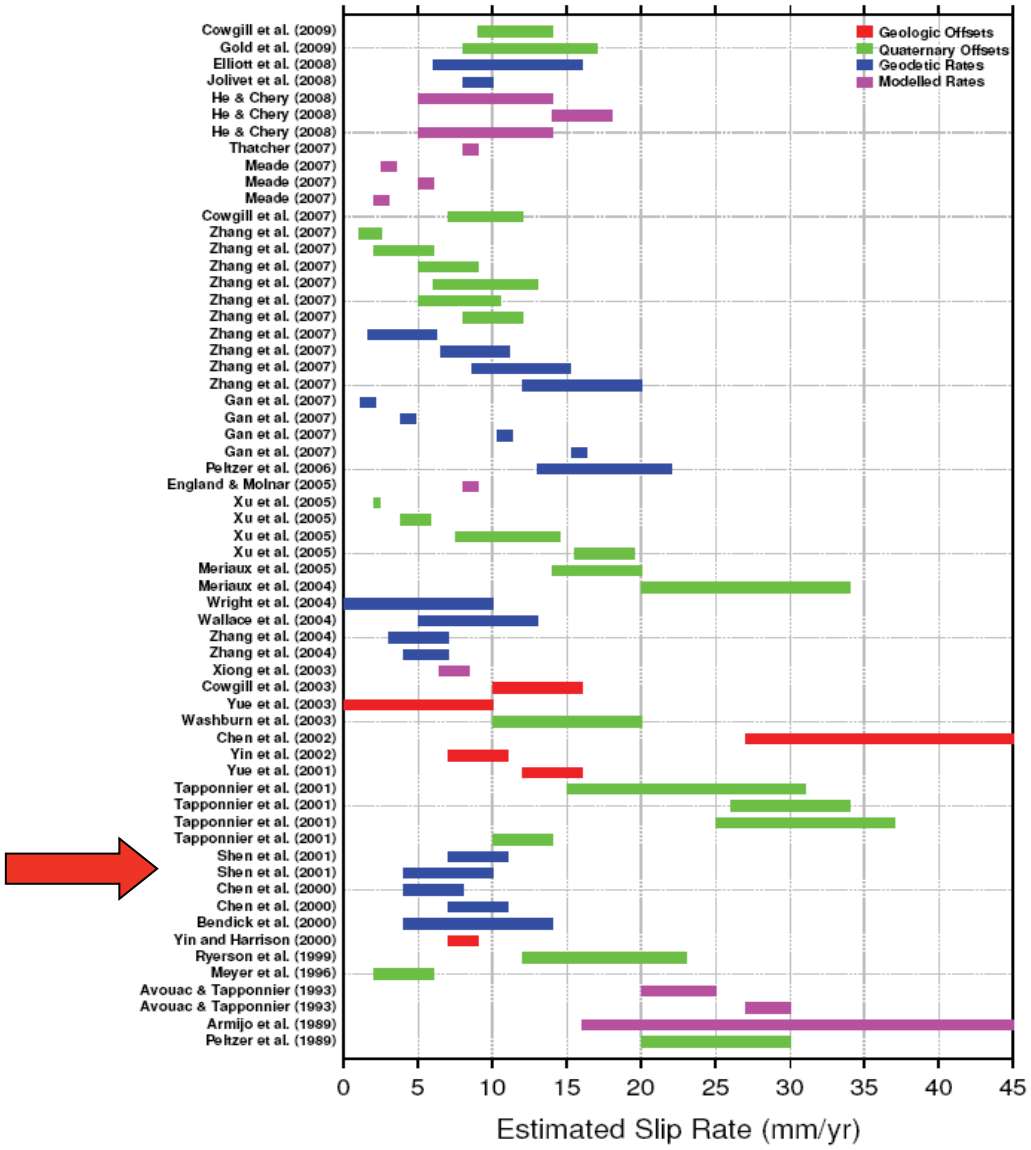
Tibet deformation models

1. Microplate or block models

2. Continuum models

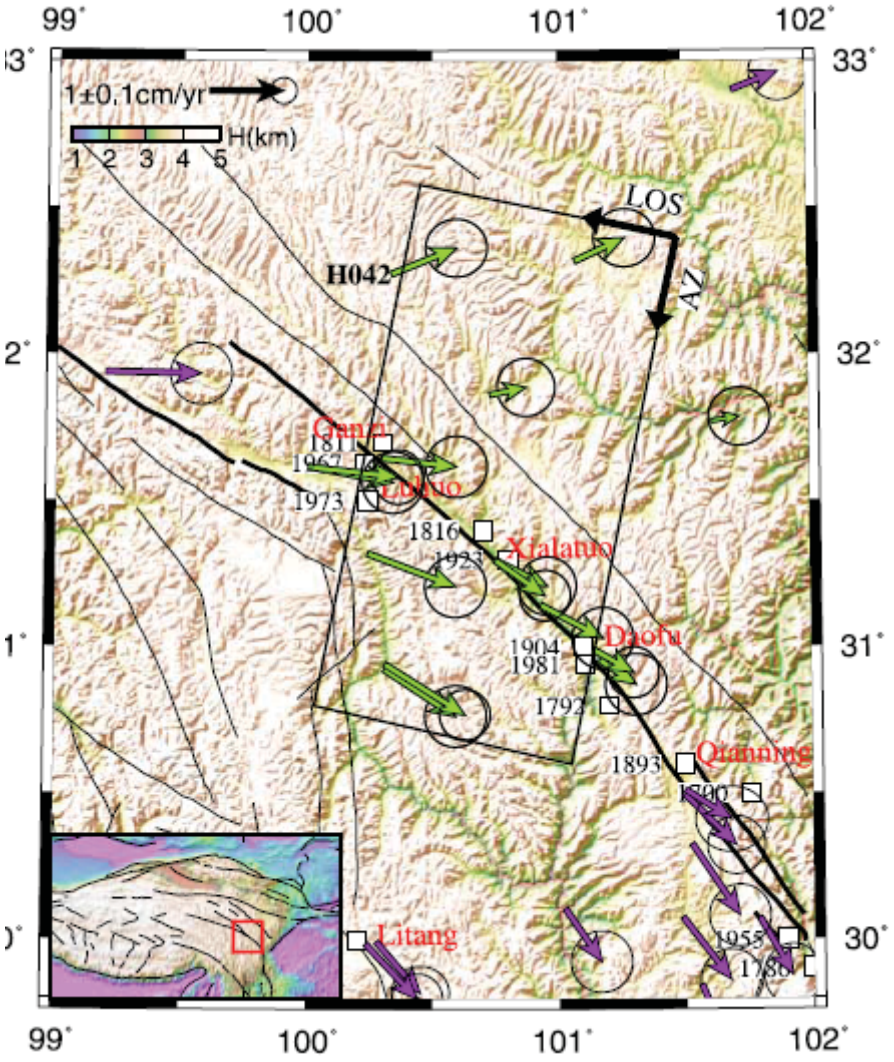
Fault slip rate: key evidence to distinguish these models

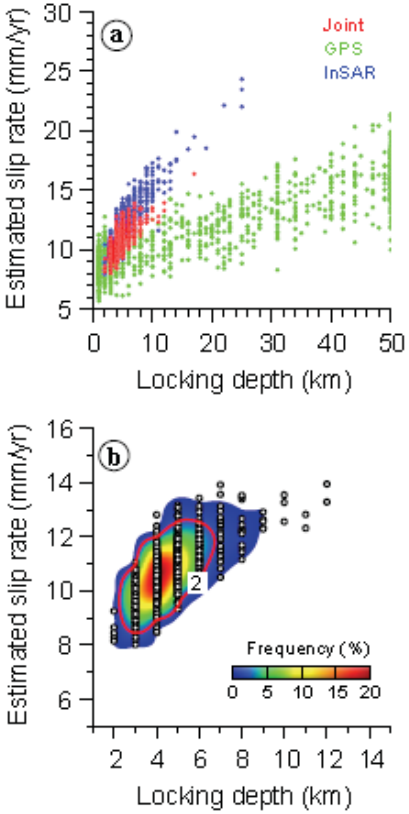
Slip rate along the full length of the ATF ordered by publication date (from Elliott, 2009)



Interseismic strain from InSAR

Interseismic Slip Rate of the Xianshuihe Fault (SE Tibet) from InSAR

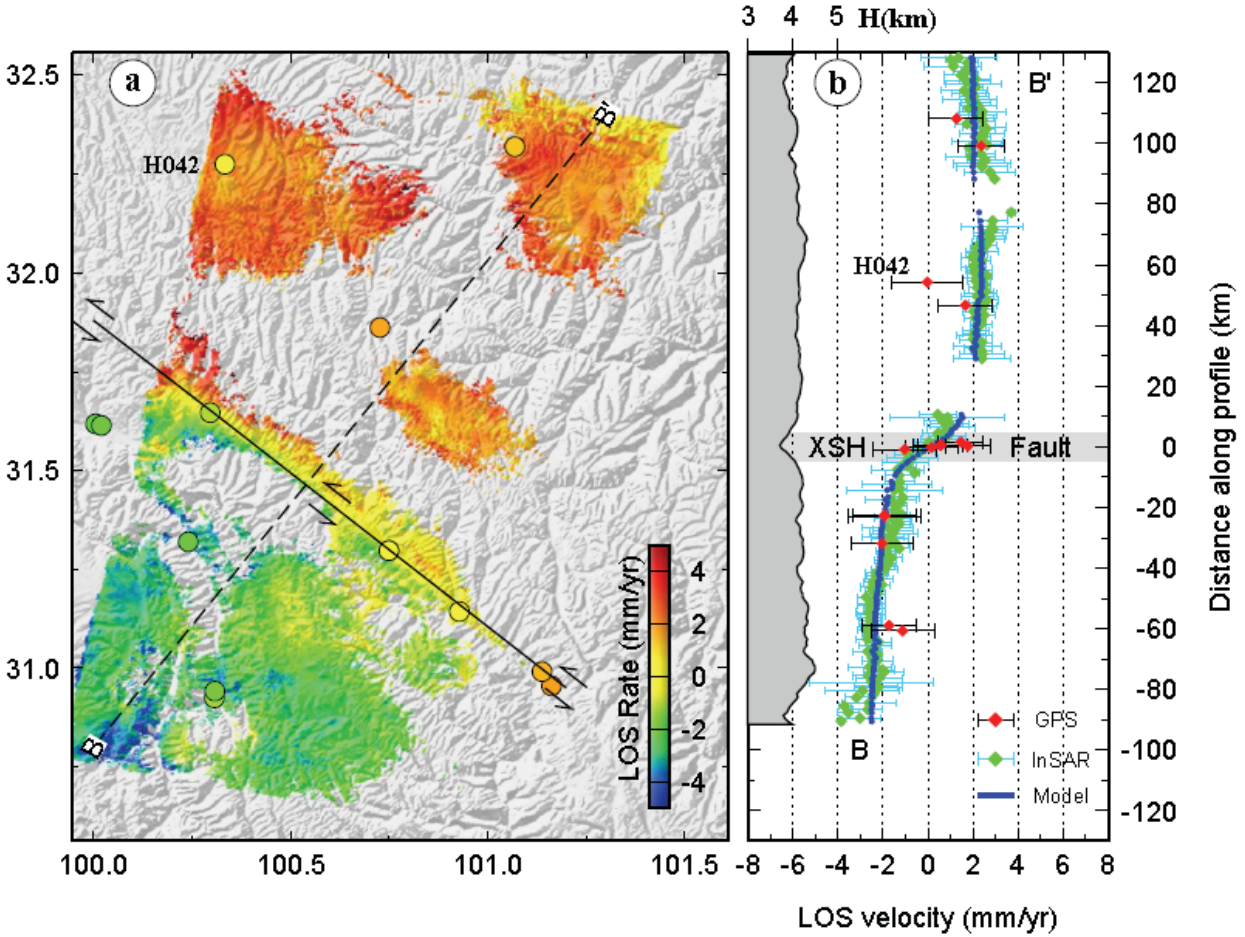




Wang, Wright and Biggs, GRL 2009

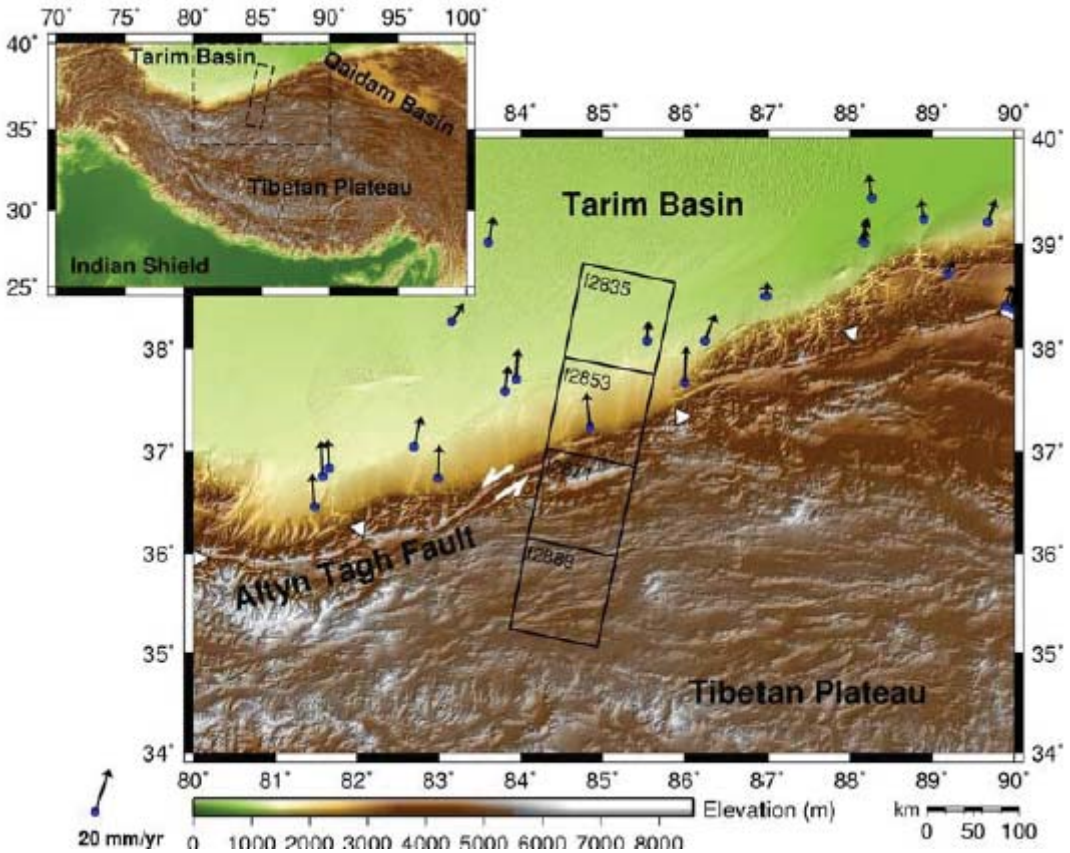
Interseismic strain from InSAR

Interseismic Slip Rate of the Xianshuihe Fault (SE Tibet) from InSAR



Interseismic strain from InSAR

Interseismic Slip Rate of the Altyn Tagh Fault (Elliott et al, GRL 2008)

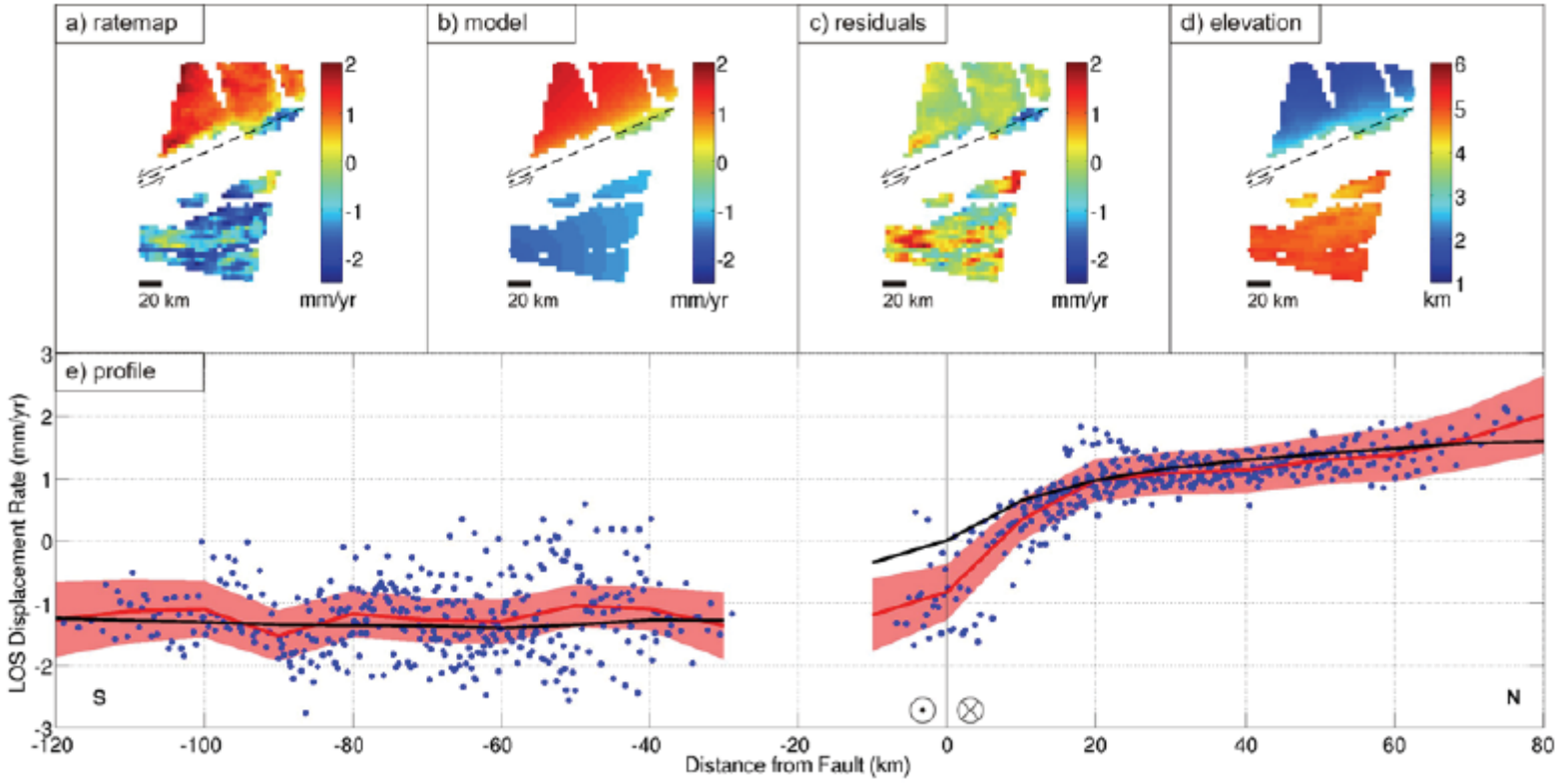


Most studies to date have looked at one fault

Interseismic strain from InSAR

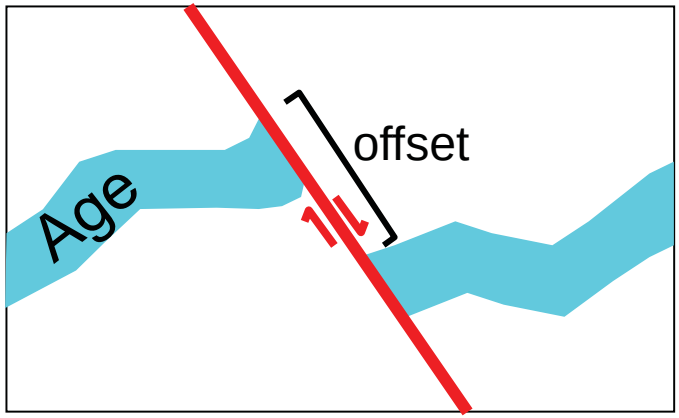
Interseismic Slip Rate of the Altyn Tagh Fault (Elliott et al, GRL 2008)

Slip rate = 11 ± 5 mm/yr



Most studies to date have looked at one fault

Tibet deformation observations: Geology



$$slip\ rate = \frac{offset}{age}$$??

Geological slip rate at Cherchen He (figure from Zhang et al., 2007)