Crustal deformation in the Pamir, Alai valley, Hindu-Kush and Tajik basin

Observed by GNSS and InSAR

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Z. Ilyasova, A. H. Panjsheri, J. R. Rahmani, M. Borisov,
S. R. Saaid, Sh. Murodkulov, M. Y. Zayrab, M. Bartsch
A. Ahmedov, T. Schöne, and many more...

CATENA
CLIMATIC AND TECTONIC NATURAL HAZARDS IN CENTRAL ASIA

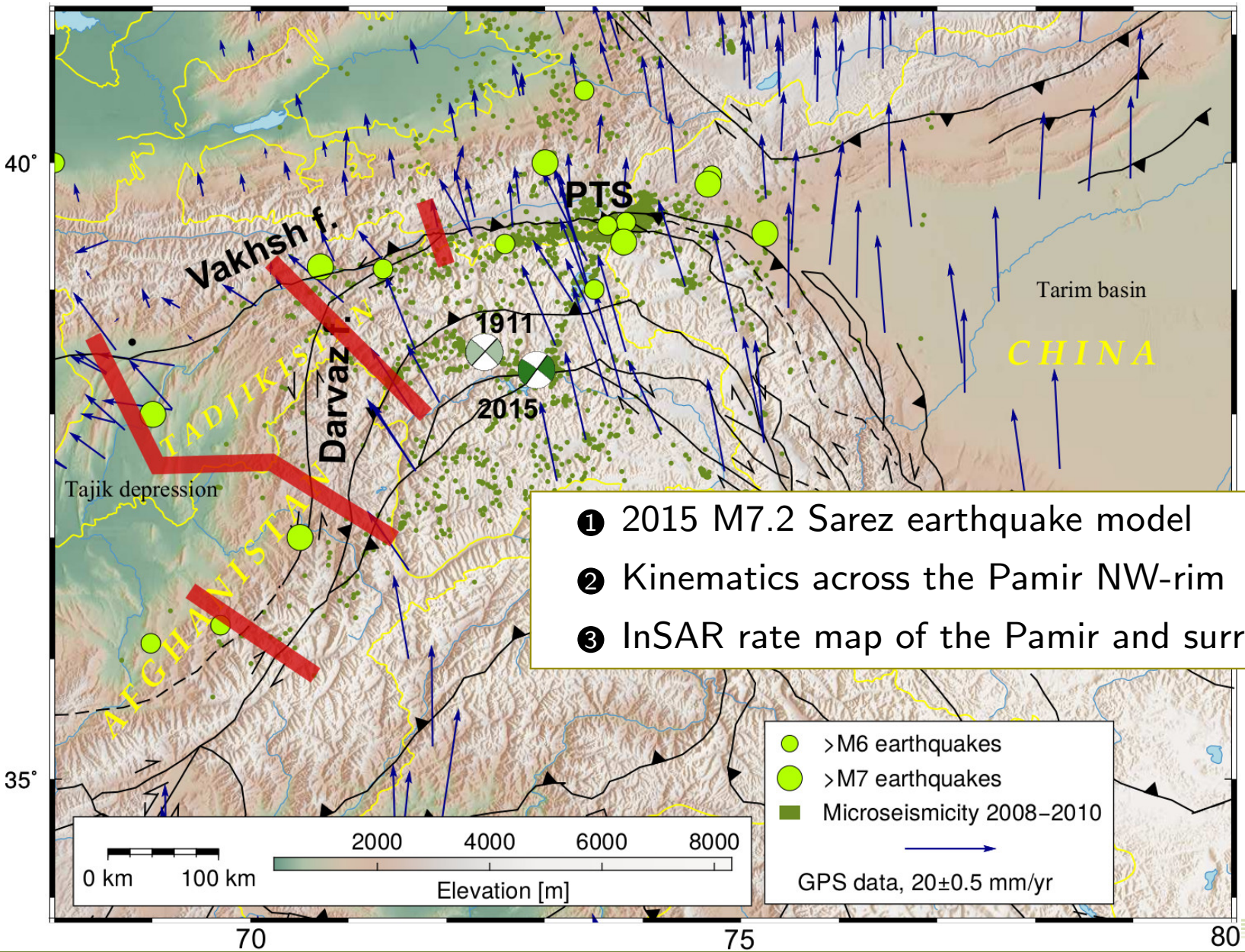
Federal Ministry of Education and Research
CLIENT II
International Partnerships for Sustainable Innovations

GFZ
Helmholtz-Zentrum
POTSDAM

Thank you! – Field work impressions Hindu Kush/Badakhshan

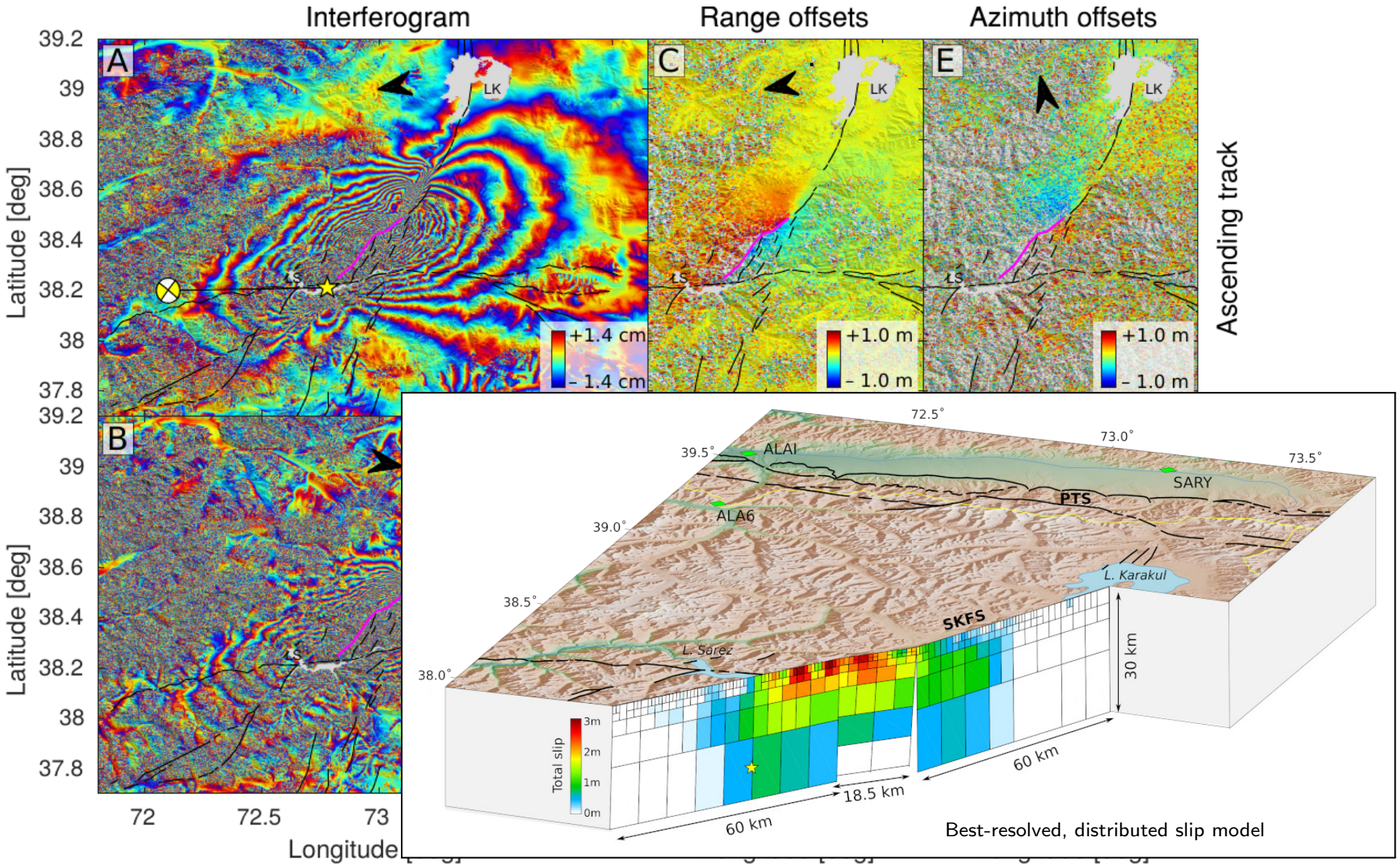
Thank you! – Field work impressions Pamir

Pamir kinematics



1. 2015 M7.2 Sarez earthquake model
2. Kinematics across the Pamir NW-rim
3. InSAR rate map of the Pamir and surroundings

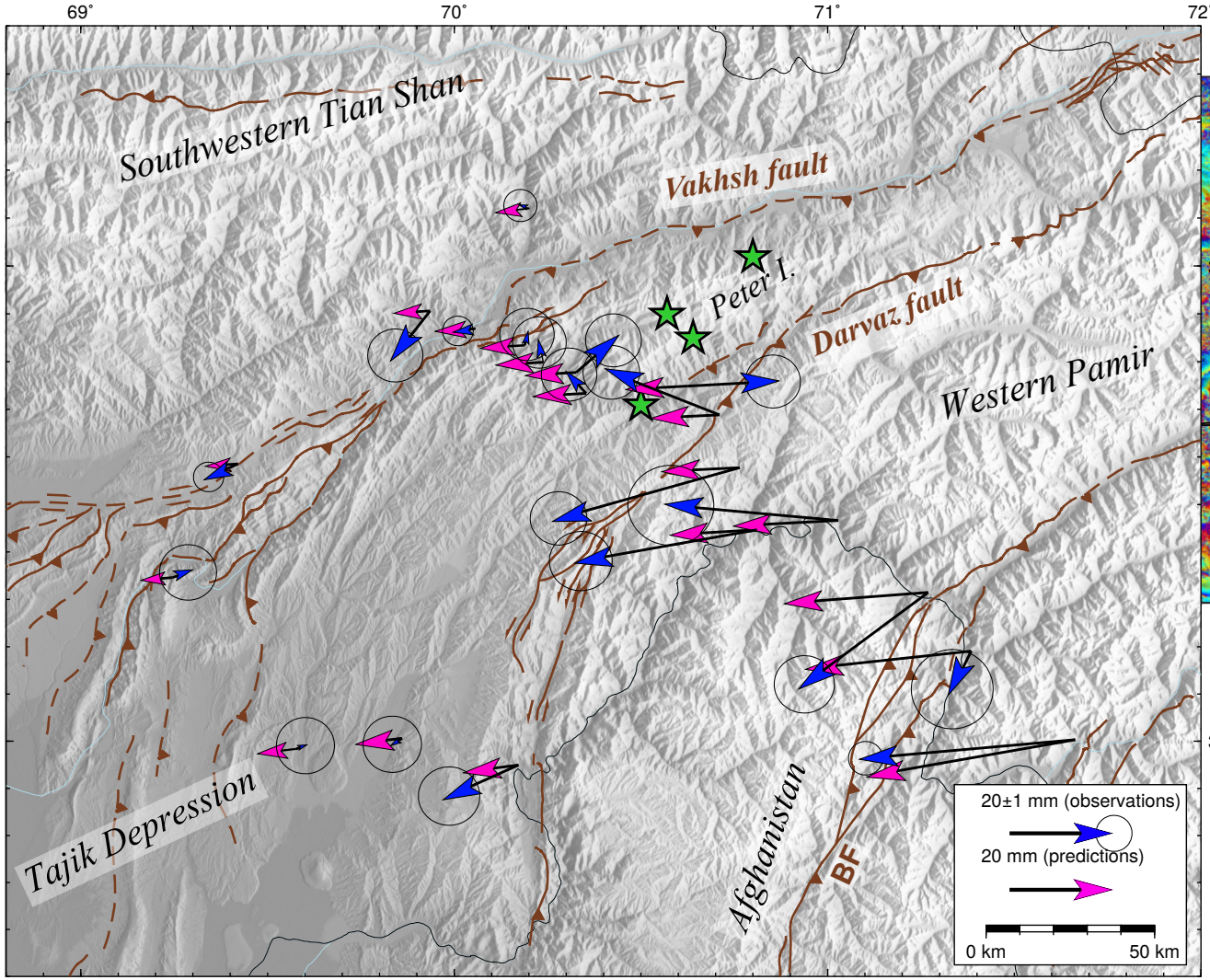
Analysis of the 2015 M7.2 Sarez, Central Pamir, earthquake

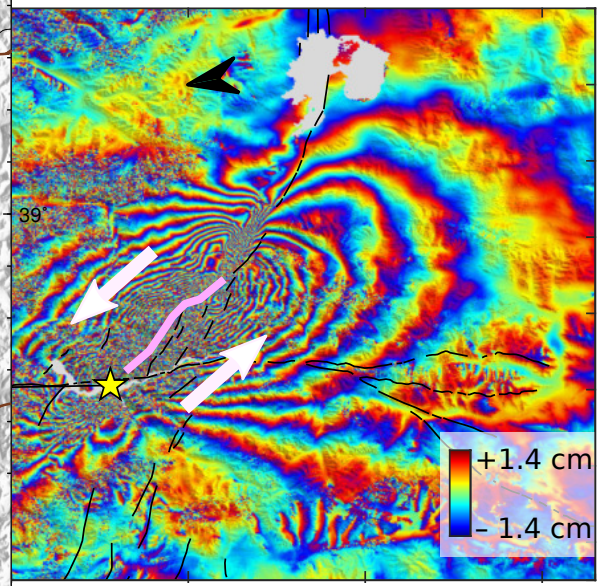


Metzger et al. (2017)

Slip triggered by the M7.2 2015 earthquake

cm-slip on the Darvaz fault



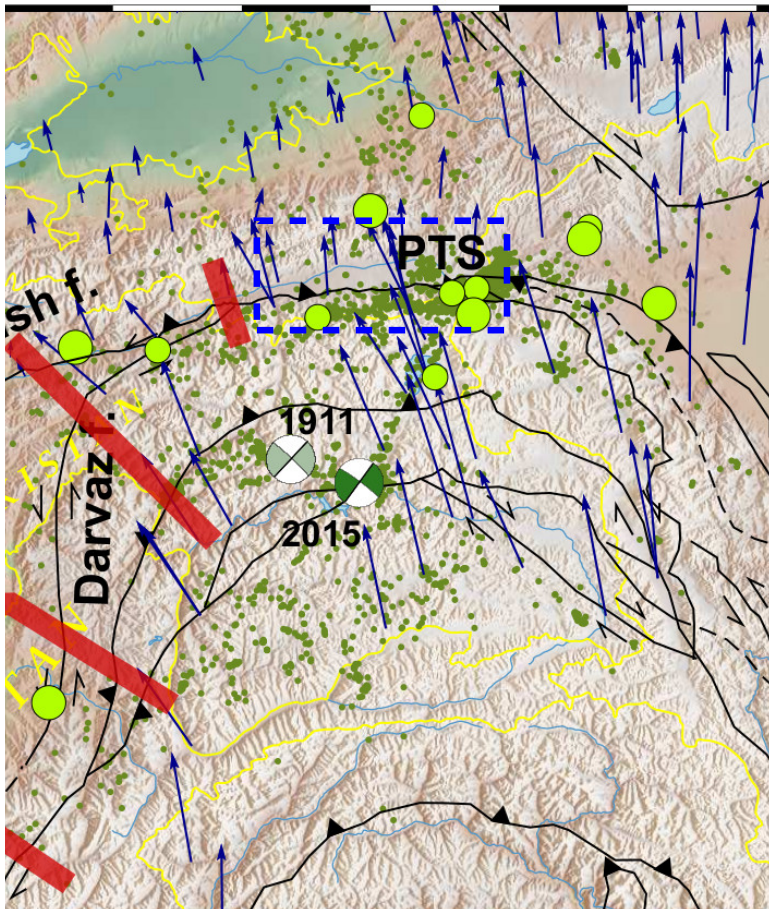


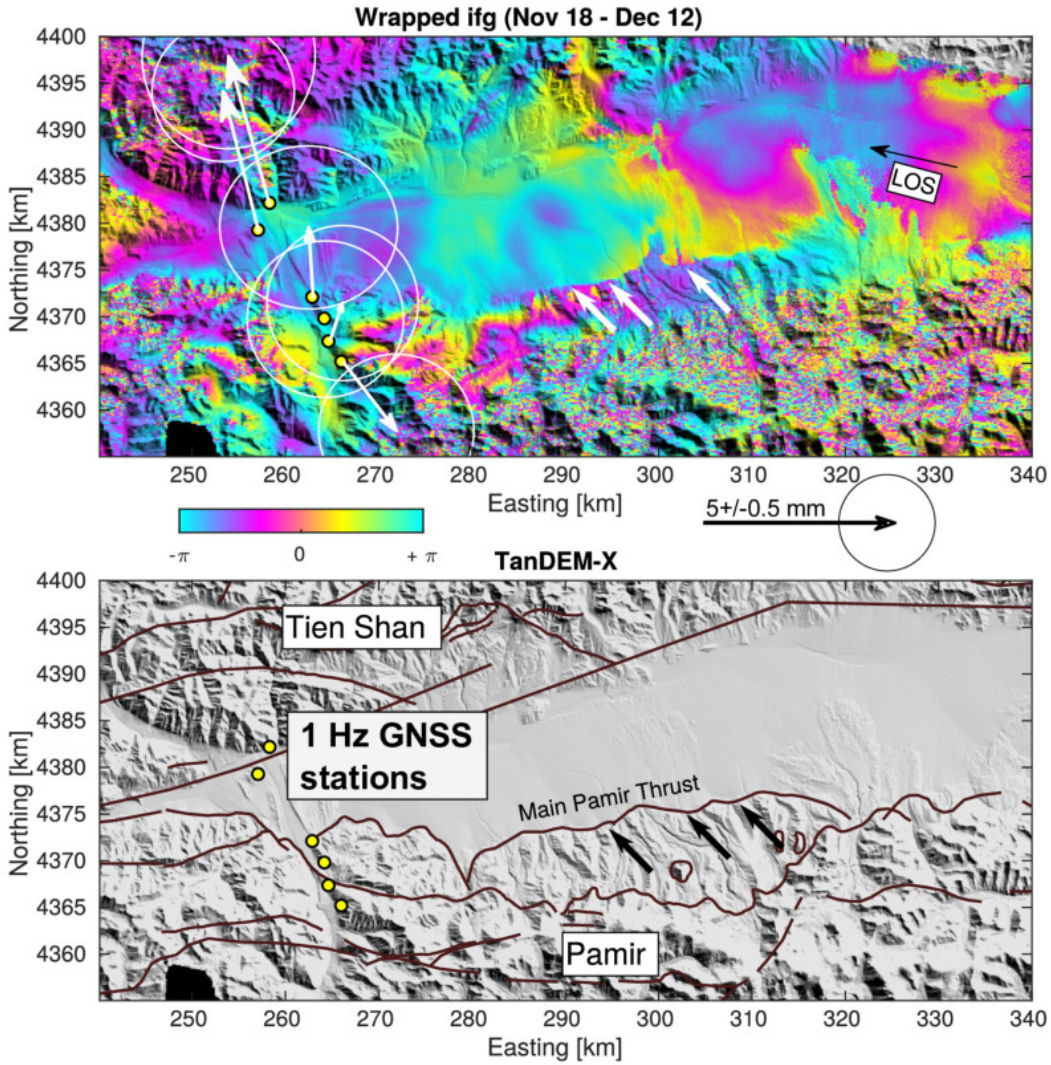
InSAR signal of Sarez EQ (Metzger et al., 2015)

Blue arrows show co-seismic offset of Sarez earthquake. The sign flips when crossing the Darvaz fault. The model (pink) does not account for slip on the Darvaz and does a poor job (Metzger et al. 2017)

Slip triggered by the M7.2 2015 earthquake

cm-slip on the Pamir main thrust

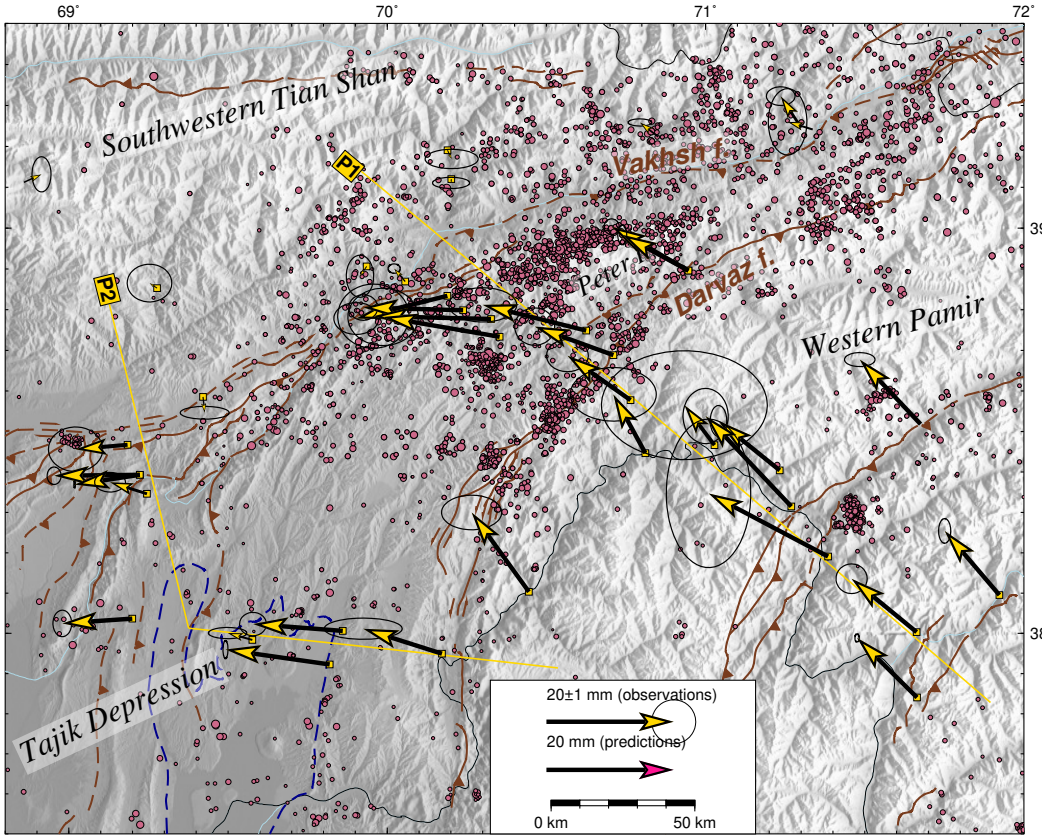




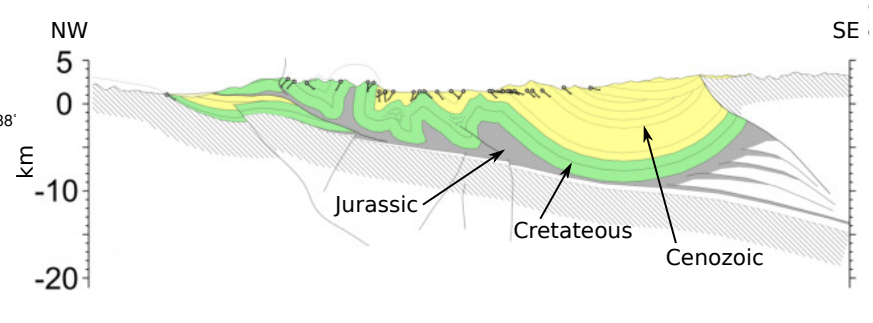
Upper figure: InSAR offsets due to Sarez earthquake collocate with Main Pamir Thrust. 1Hz-GNSS arrows (relative to third station from the bottom) show ∼5 mm extension.

Interseismic GNSS rates

Westward outflux of Pamir crust into Tajik basin



Metzger et al. (2018)



Geologic cross section (Gagala et al., 2020)

Model results

- Vakhsh: 15^{+4}_{-2} mm/yr shortening and 16 ± 3 mm/yr shear below $\sim$3 km
- Darvaz: ~ 10 mm/yr extension and ~ 15 mm/yr shear below $\sim$9 km

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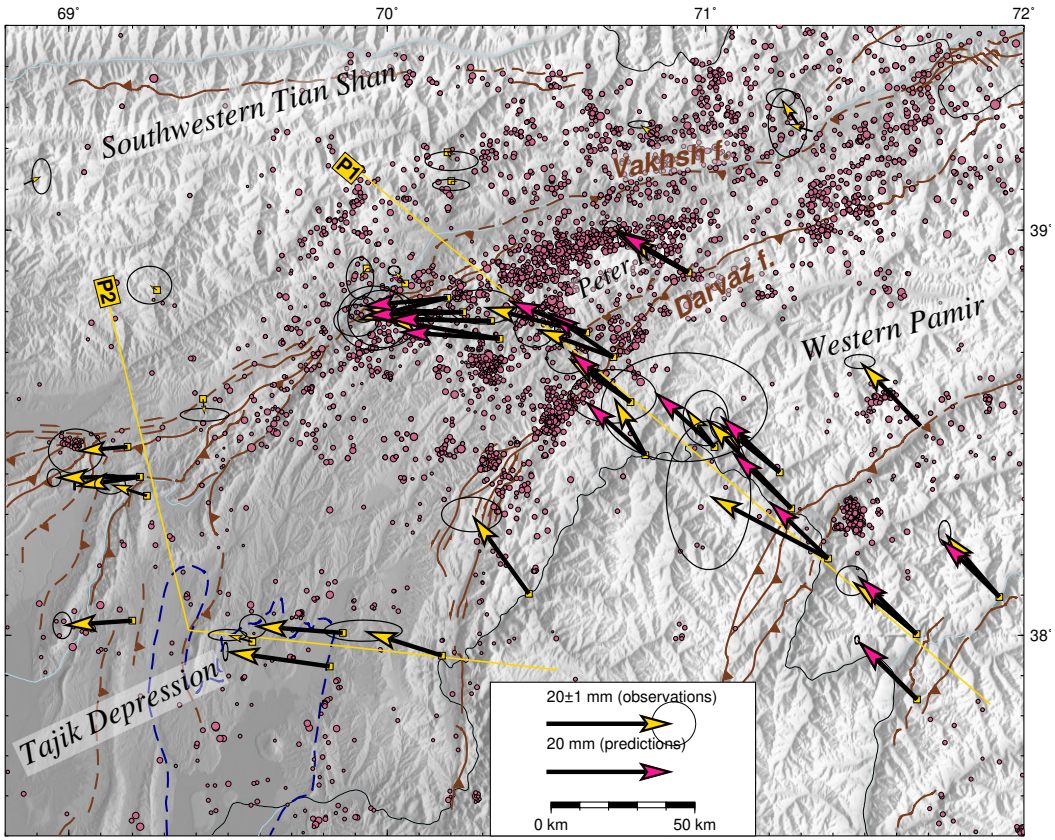
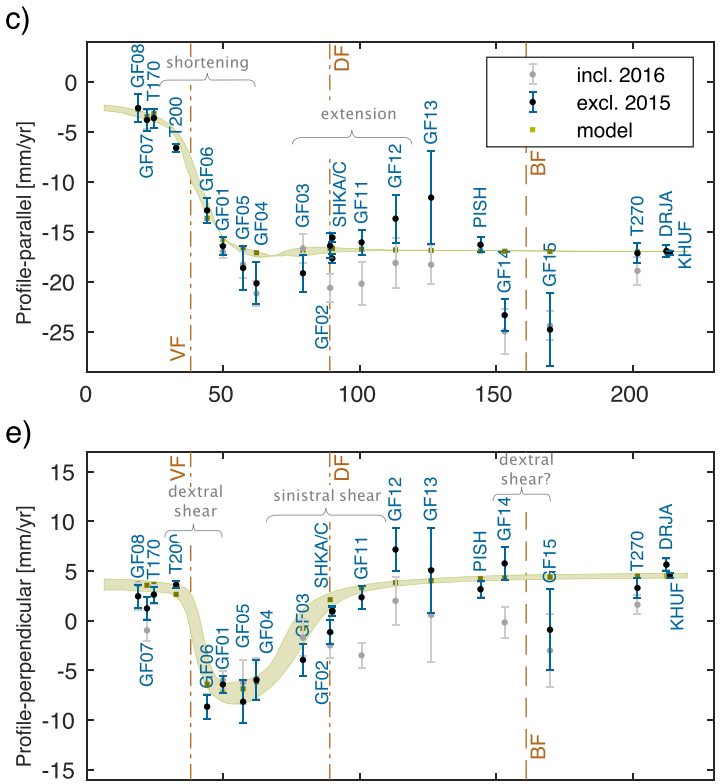


Metzger et al. (2018)

Profile P1



Model results

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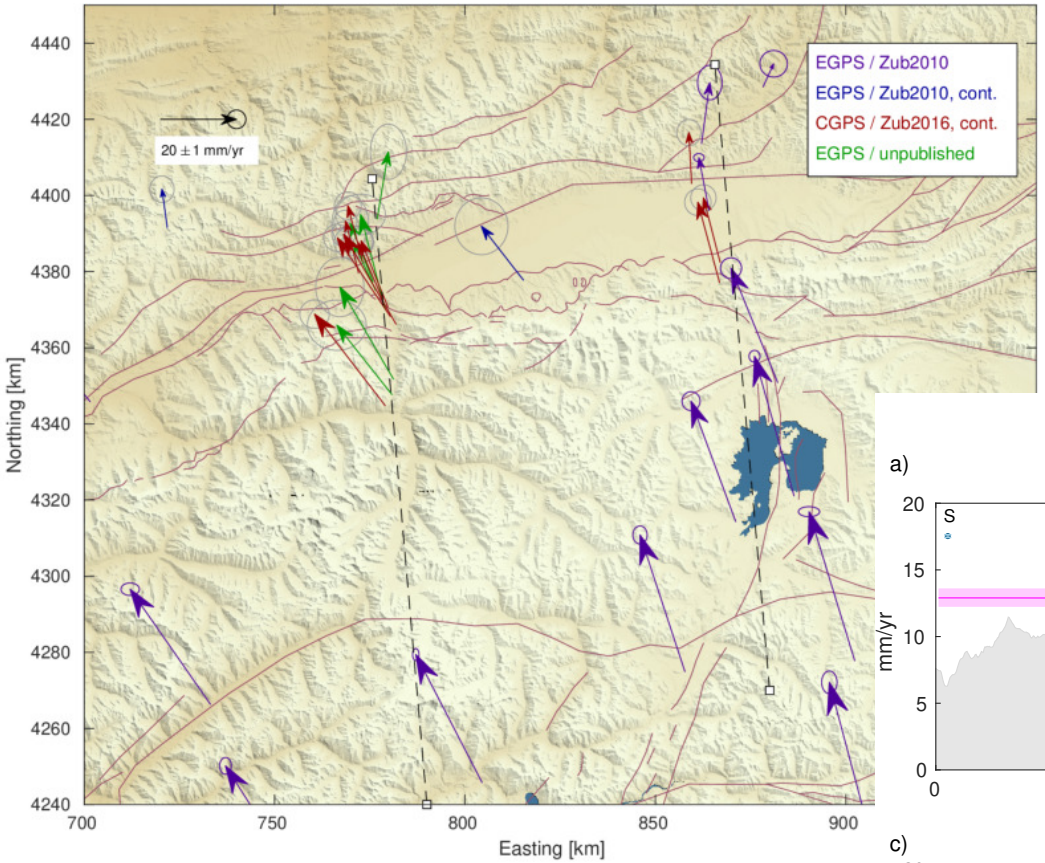
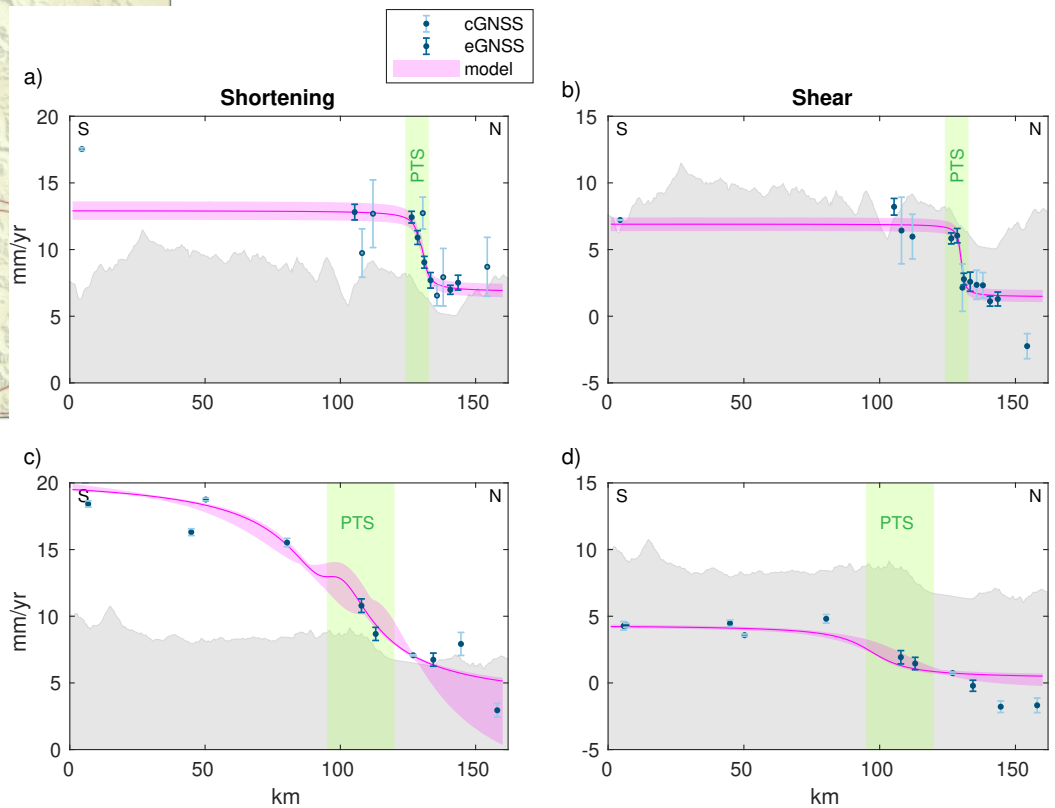
Shortening across the Pamir Thrust System



- 2-dimensionsal elastic half-space
- semi-infinite fault plane, dip fixed to 10°S

⇒ slip-partitioning in East Alai?

⇒ increased shear, decreased thrust towards West Alai



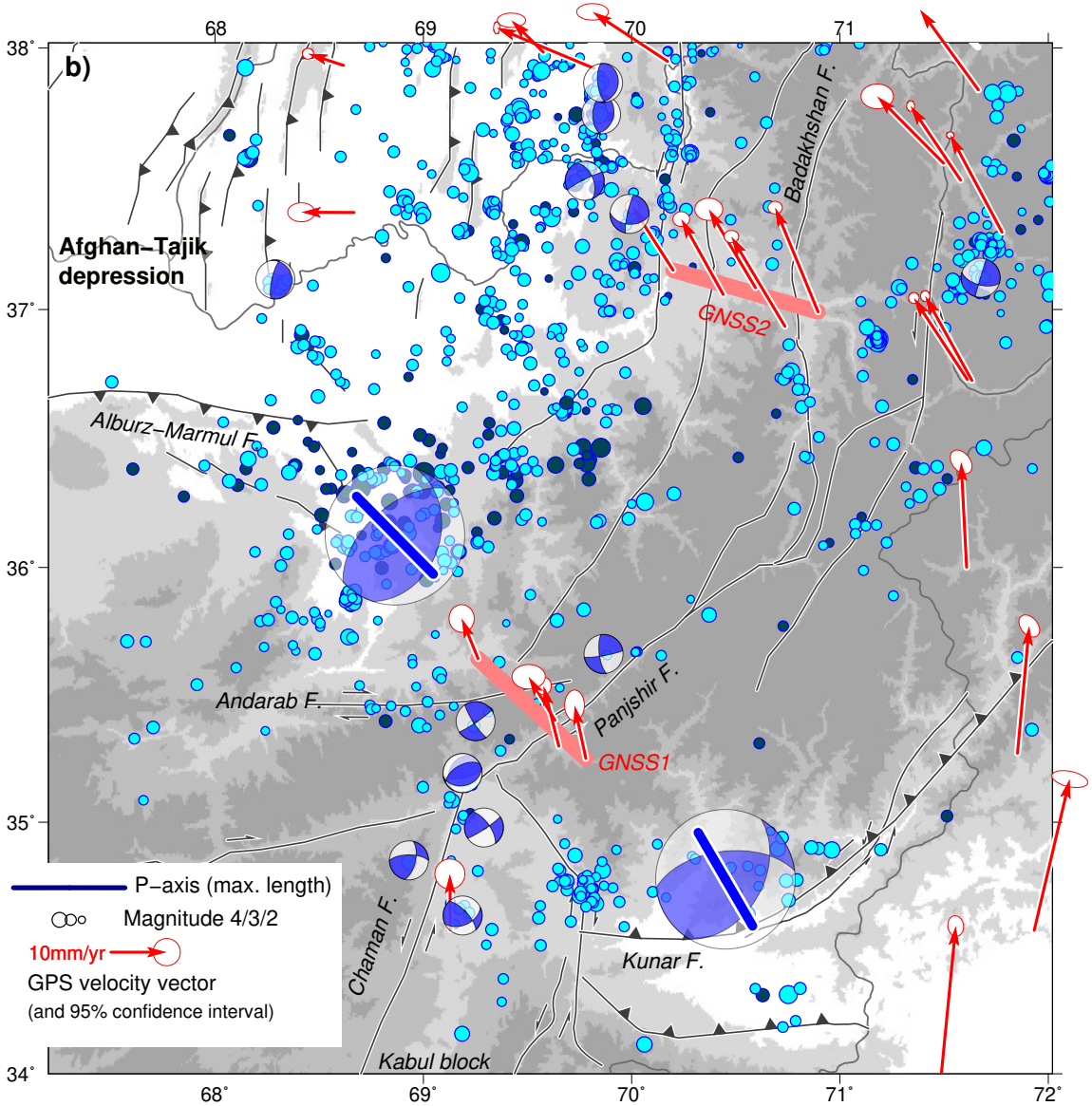
Model results West Alai:

- $6.2^{+0.7}_{-0.5}$ mm/yr shortening,
  5.5 ± 0.3 mm/yr shear below ∼0.9 km

Model results East Alai:

- $17.8^{+9.2}_{-0.7}$ mm/yr shortening,
  $4.1^{+1.0}_{-0.1}$ mm/yr shear below ∼ 11 km

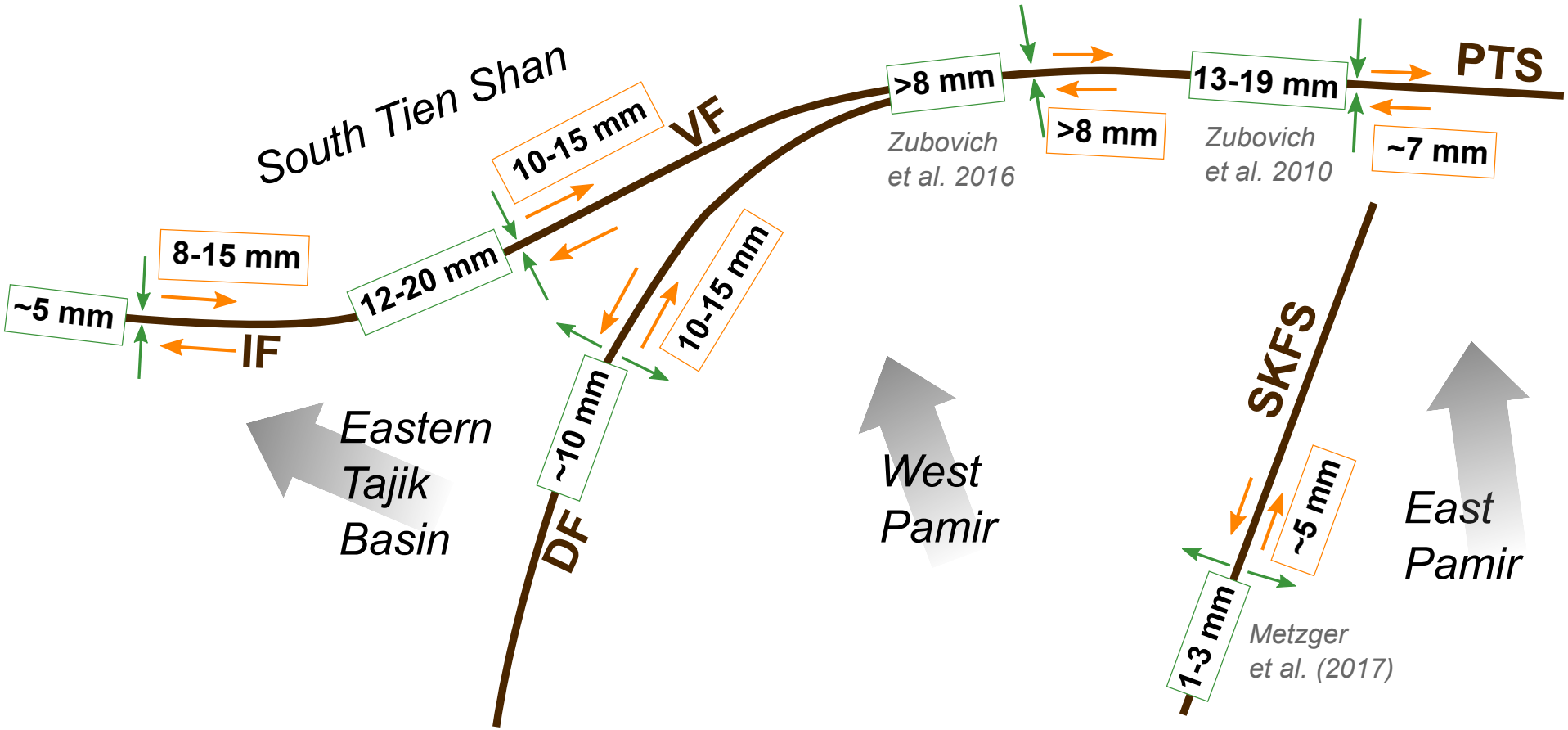
Hindu Kush



Crustal seismicity (above 40km) and GNSS rates, Kufner et al. (subm.)

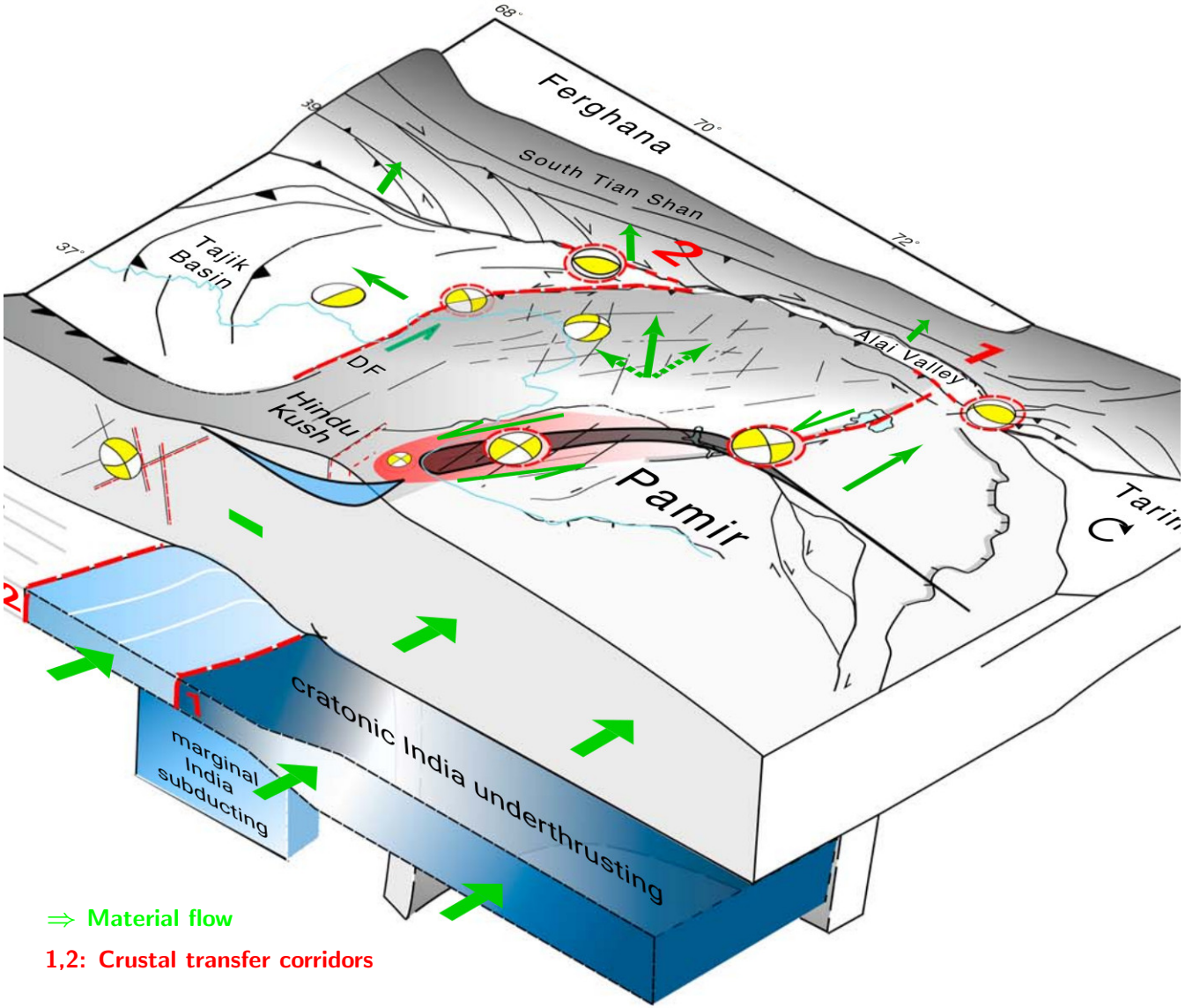
- Little seismicity *within* Hindu Kush, mostly along foot hills
- Rates across Badakhshan fault: 0.4±0.4 mm/yr West, 7.1±0.3 mm/yr North (sinistral-transtensive)
- Rates across Panjsheer fault: 0.9±1.0 mm/yr West, 2.2±1.6 mm/yr South (sinistral-transpressive:)

Kinematic synthesis



Metzger et al. (2020)

Comprehensive dynamic model



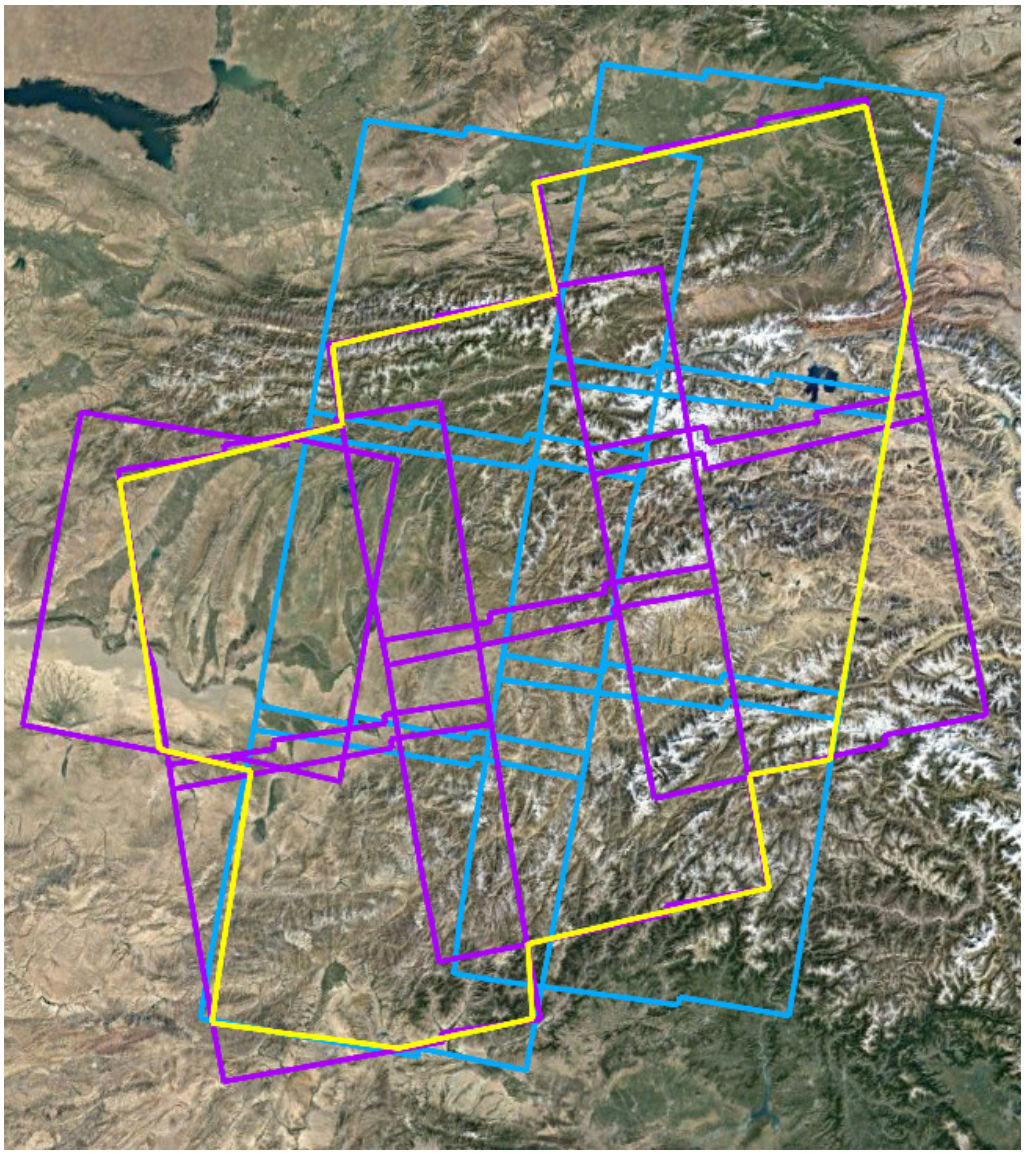
Kufner et al. (2018)

Interpretation, based on mantle tomography

- Cratonic India bulldozes into the Pamir and piles up Pamir
- Gravitational collapse/mass outflux towards west
- Active faults mark transfer corridor above weak, marginal India
- Highest strain found along Northern Pamir front, Vakhsh and Iliac fault

LiCSBAS time-series analysis

Data base

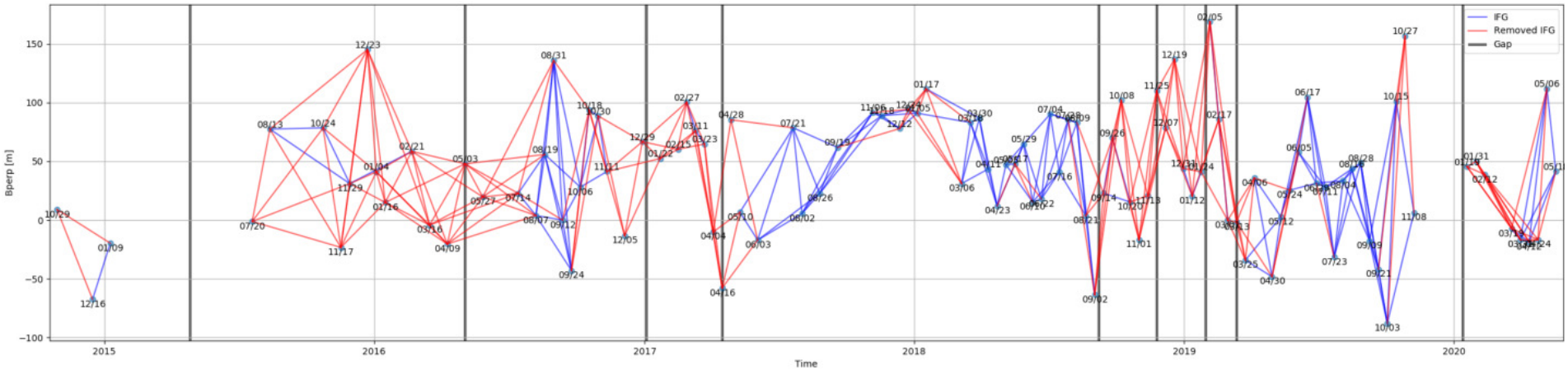


- acquisition period: 2015-2020
- 13 tiles, 100 radar images per tile
- ∼10 TB raw data, resulted in
- ∼350 ifgs per tile
- automatically processed ifgs (LiCSAR [Lazecký et al. (2020)])
- small-baseline time-series analysis using LiCSBAS
- atmospheric correction using ECMWF, provided by [GACOS]
- Sentinel-1 data: λ=5.6 cm
- decorrelation due to snow
- unwrapping errors due to topography/decorrelation
- more details on LiCSBAS: [Morishita et al., 2020]

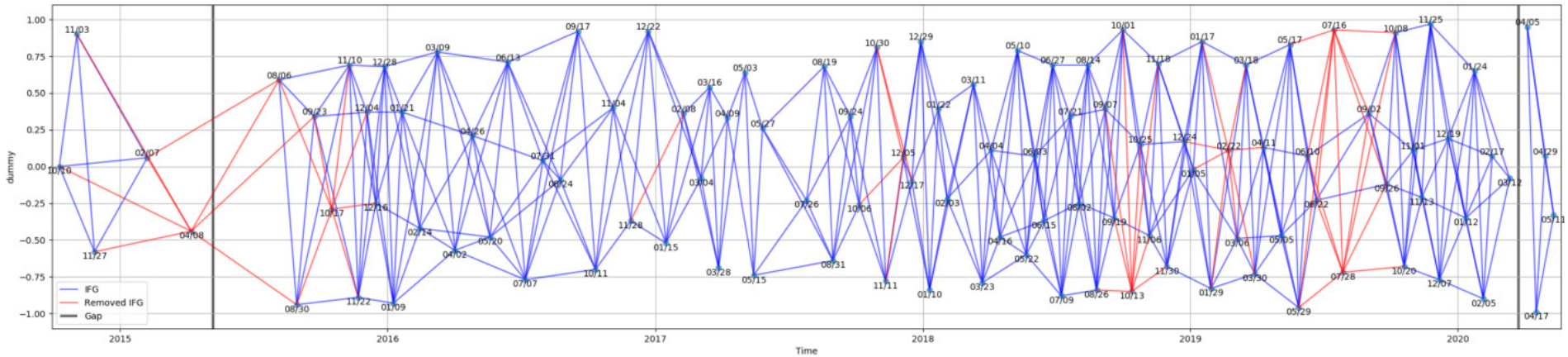
LiCSBAS time-series analysis

Example networks for different tiles

Poor data set: Coherent time-series



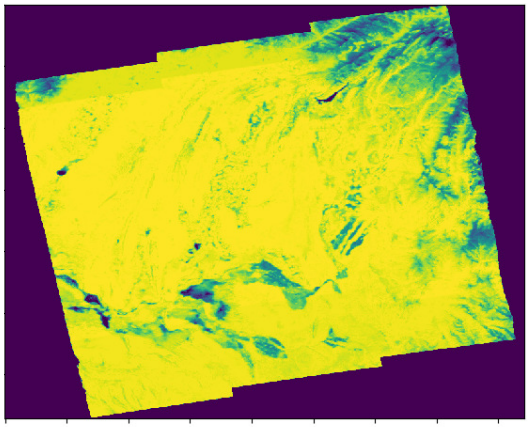
Good data set: Incoherent time-series, many ifg were removed from processing



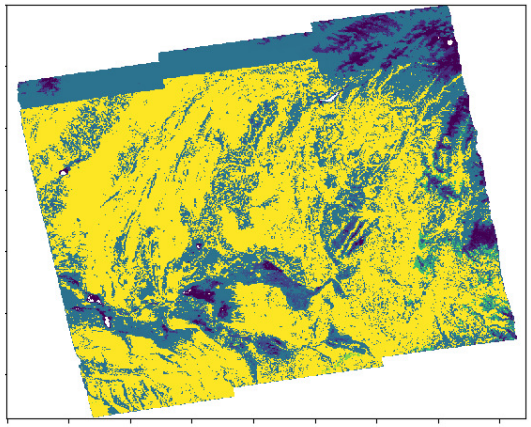
LiCSBAS time-series analysis

Quality measures used for mask out bad data

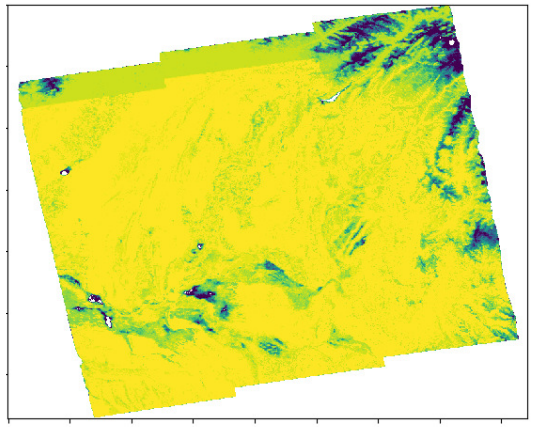
Number of input ifg



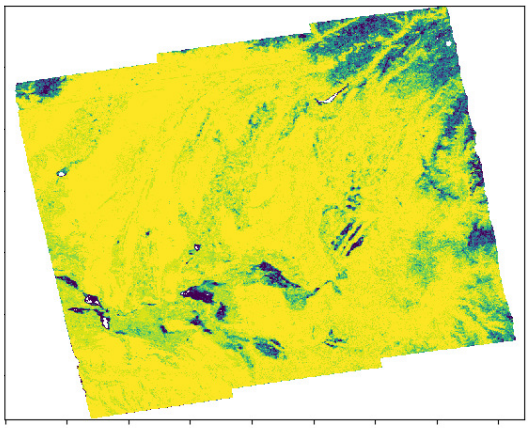
Max. length (ΔT, yr)



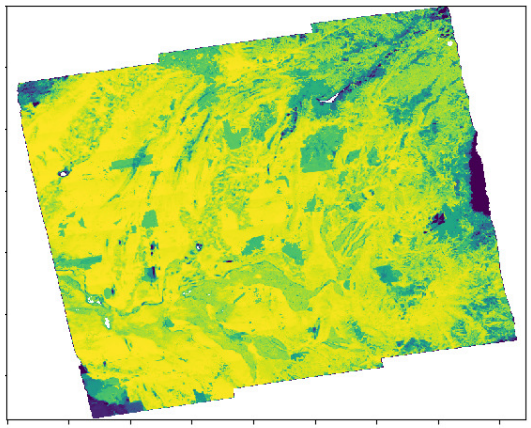
Number of data gaps



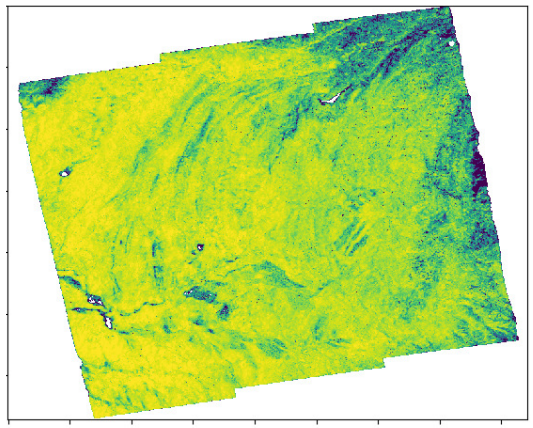
Number of prob. bad ifgs



RMS



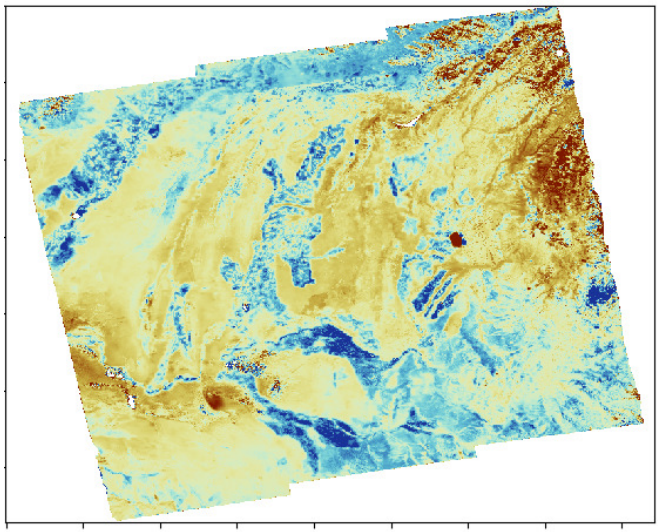
Spatio-temporal consistency [mm]



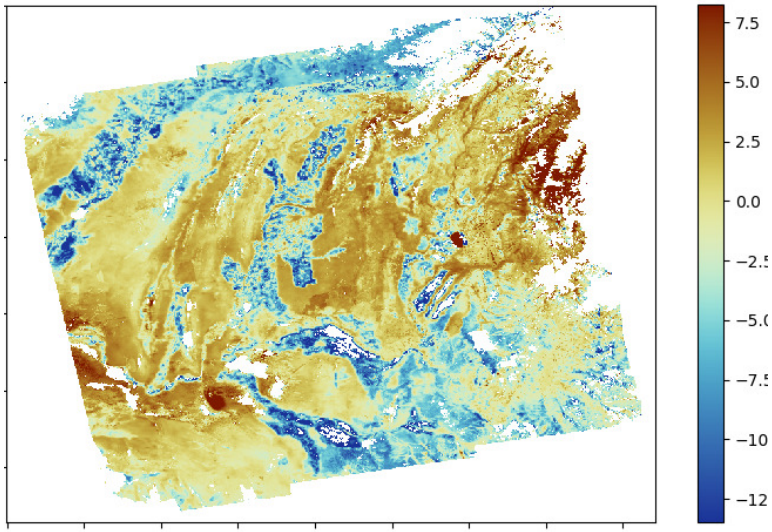
LiCSBAS time-series analysis

Resulting rate map for one tile

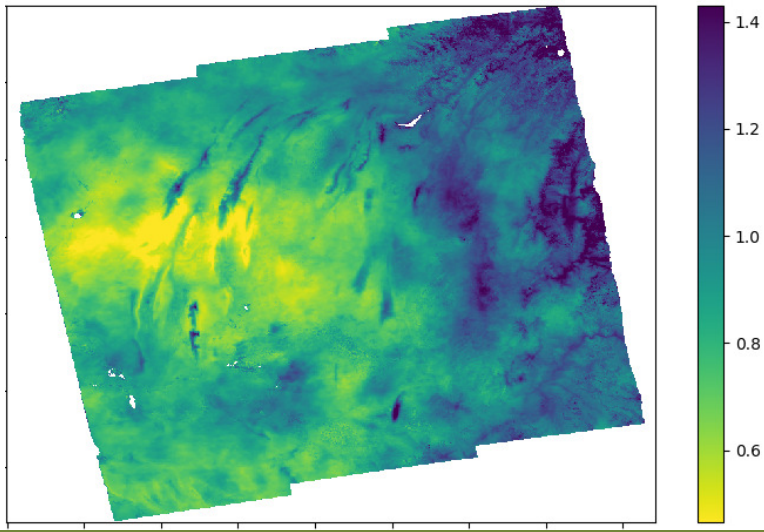
Velocity [mm/yr]



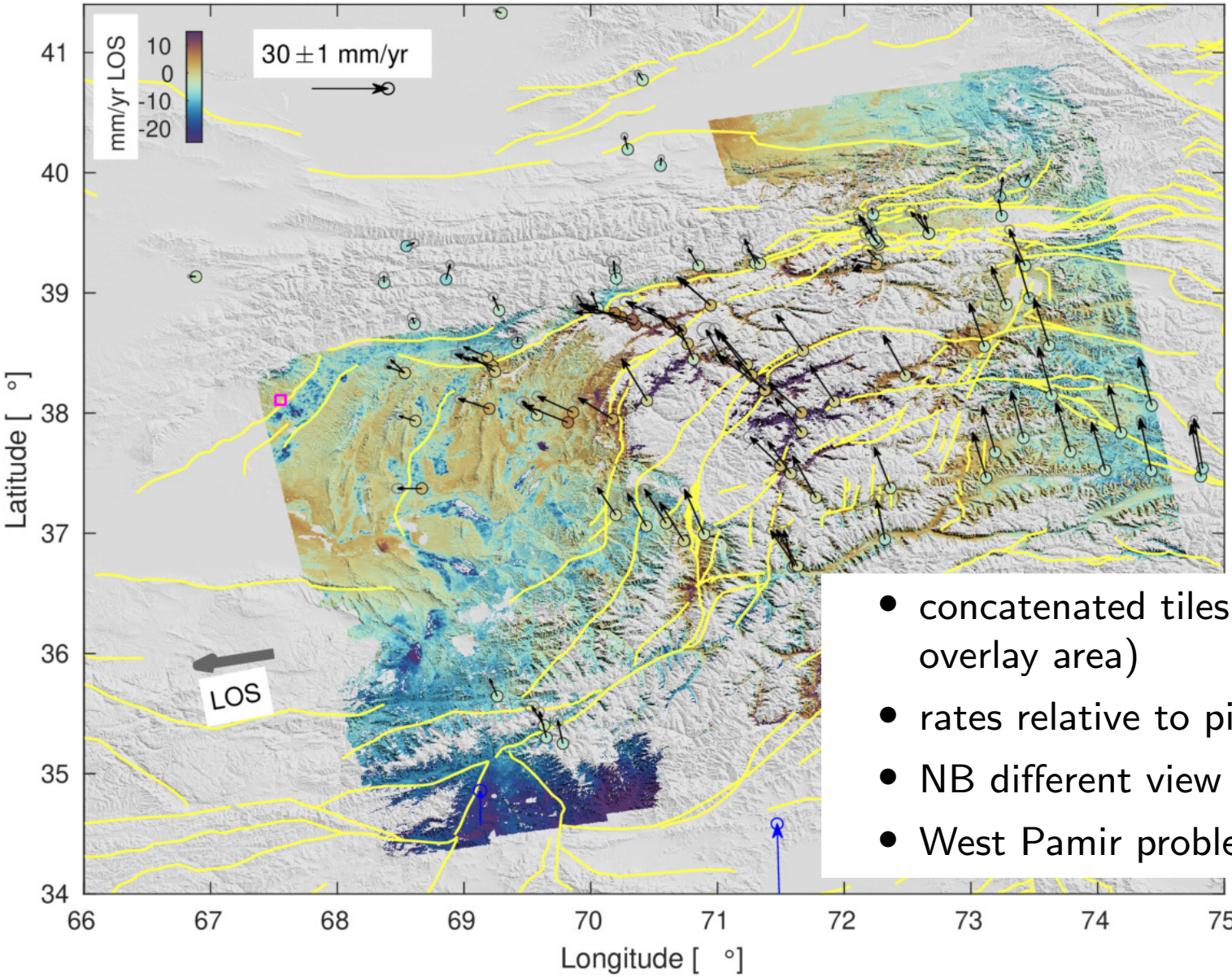
Masked velocity [mm/yr]



Standard deviation [mm/yr]



Rate maps in line-of-sight (LOS)



- concatenated tiles (synchronizing overlay area)
- rates relative to pink square
- NB different view angle (LOS)
- West Pamir problematic

(NB: work in progress! Be cautious with interpretation!)

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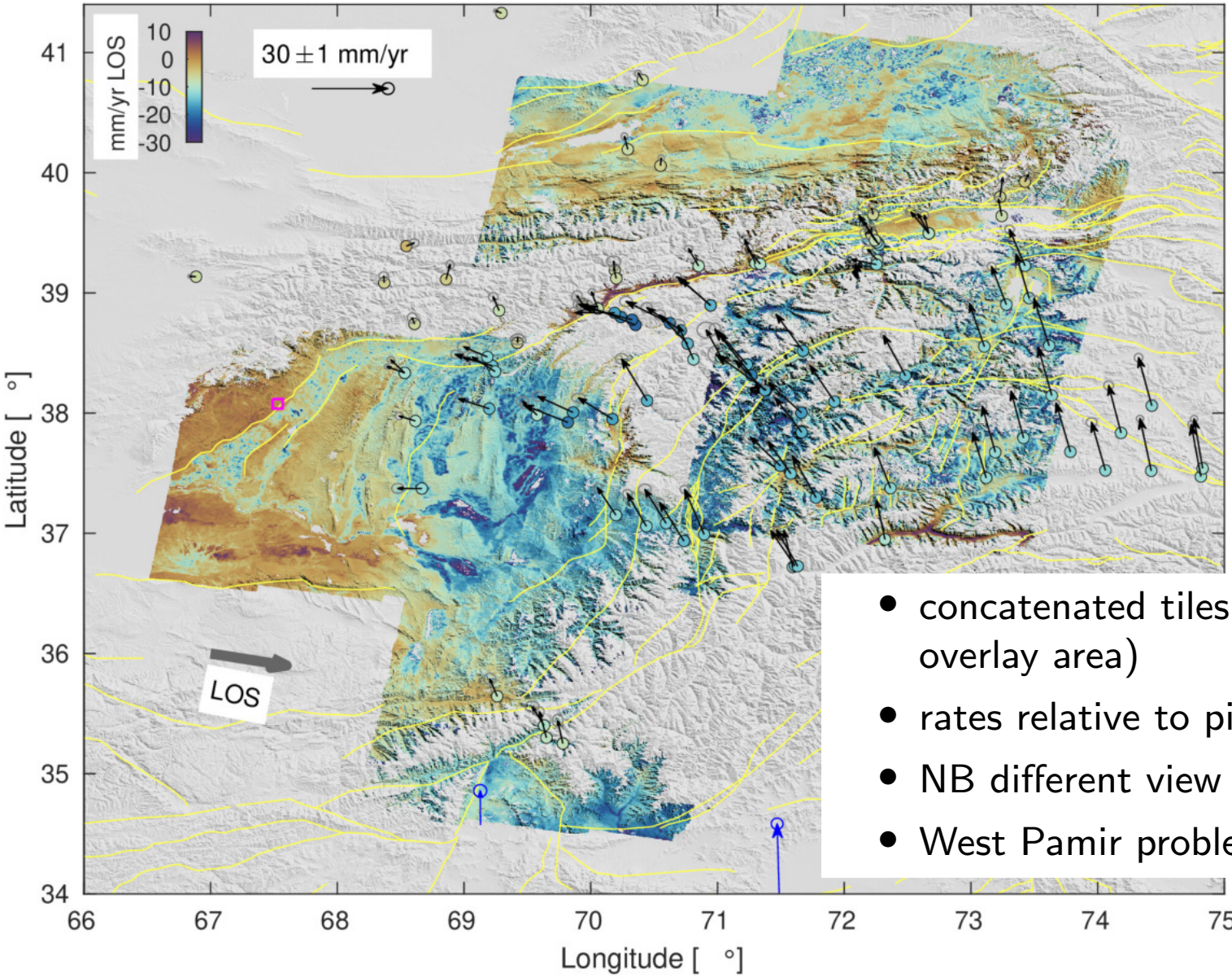

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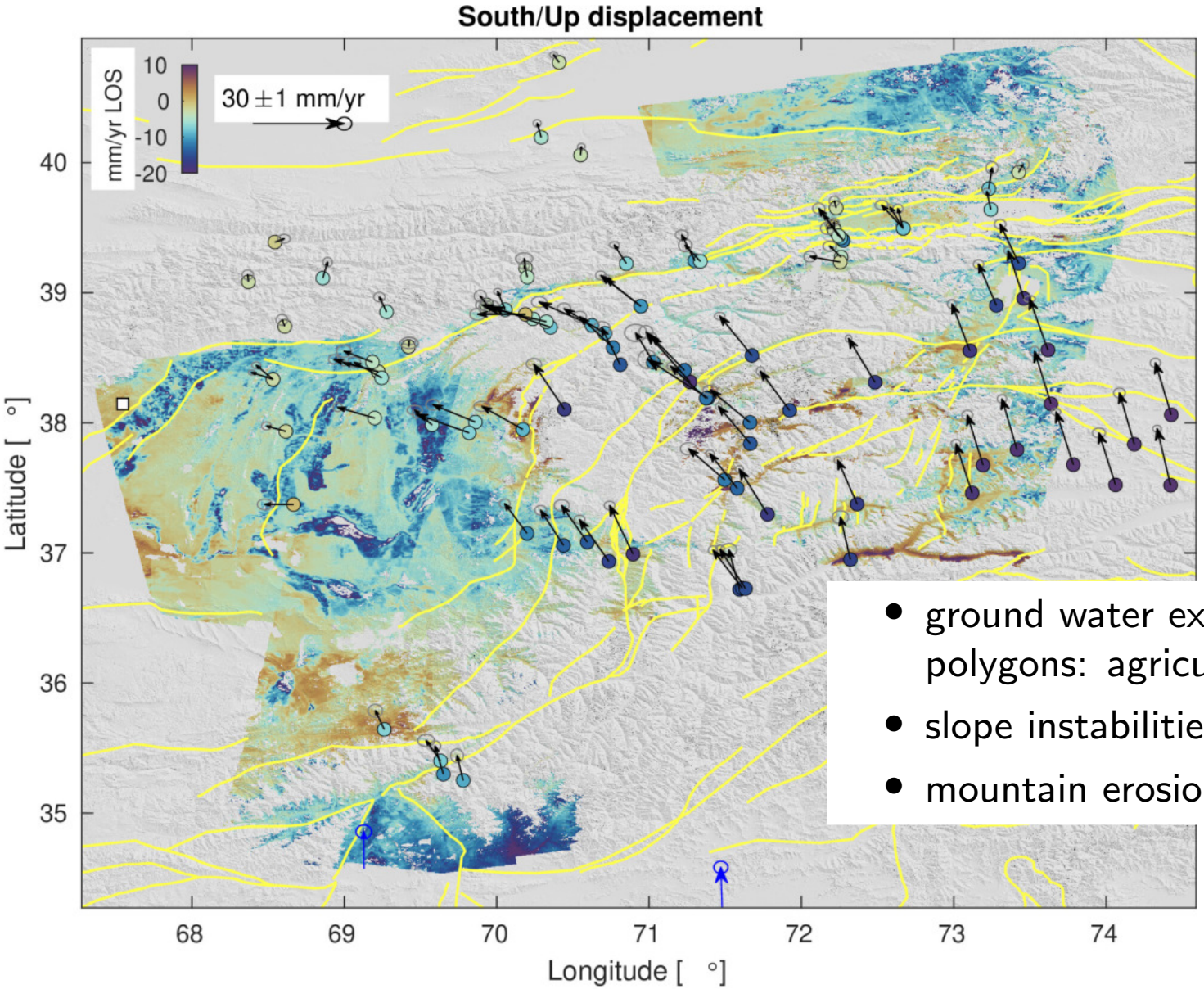
Decomposed rate maps



- ground water extraction (shaded polygons: agricultural land)
- slope instabilities
- mountain erosion, sagging slopes?

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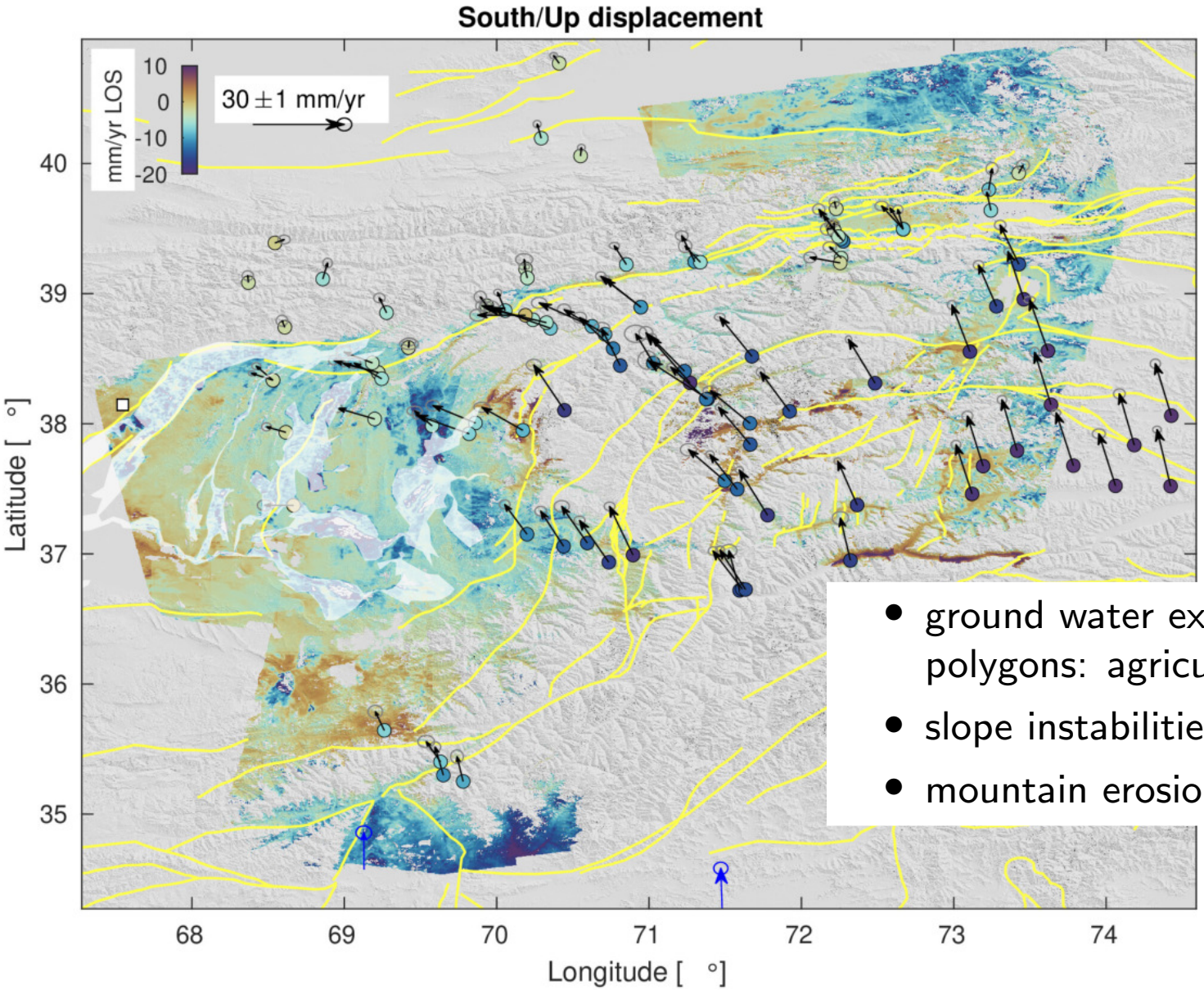

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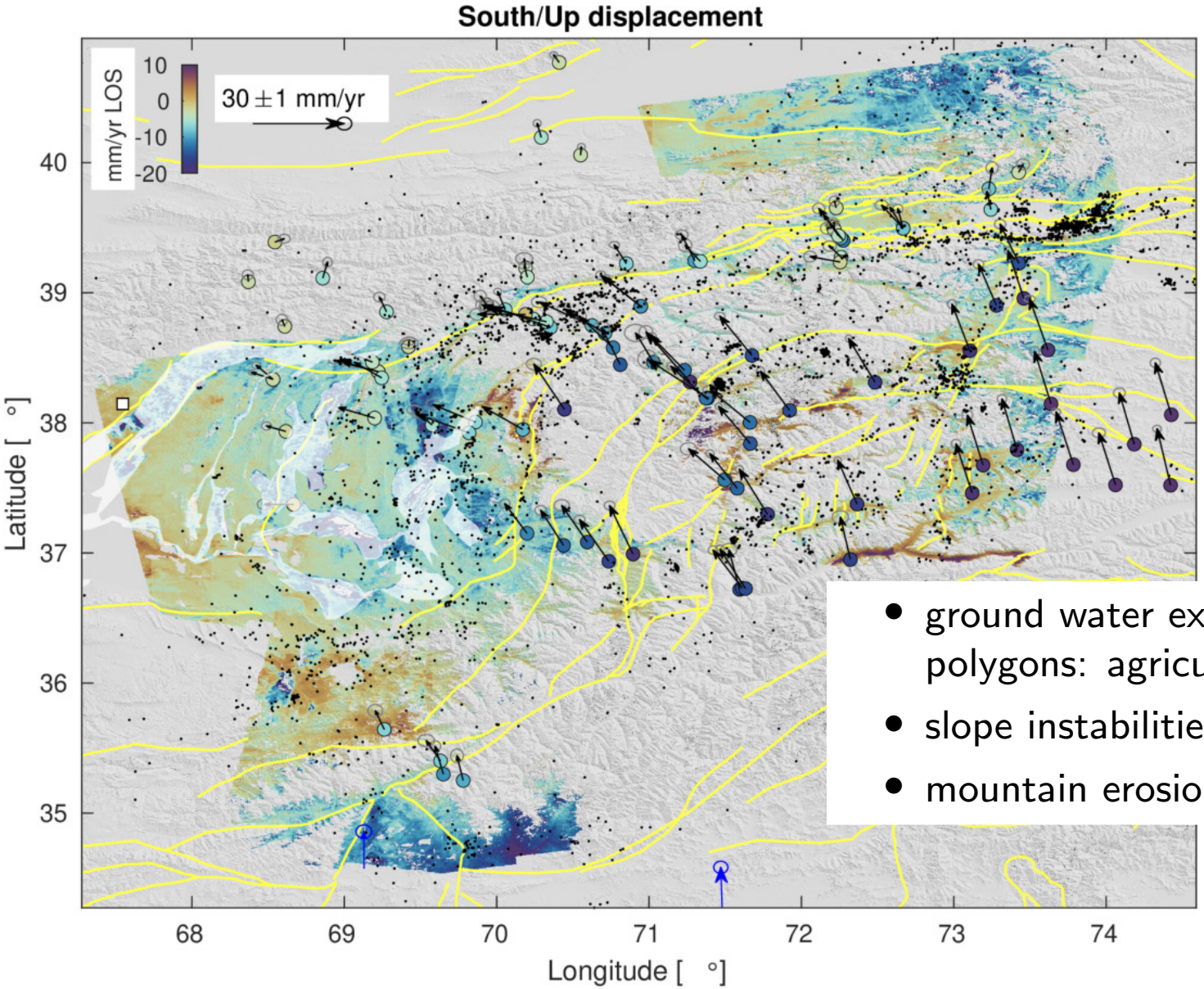

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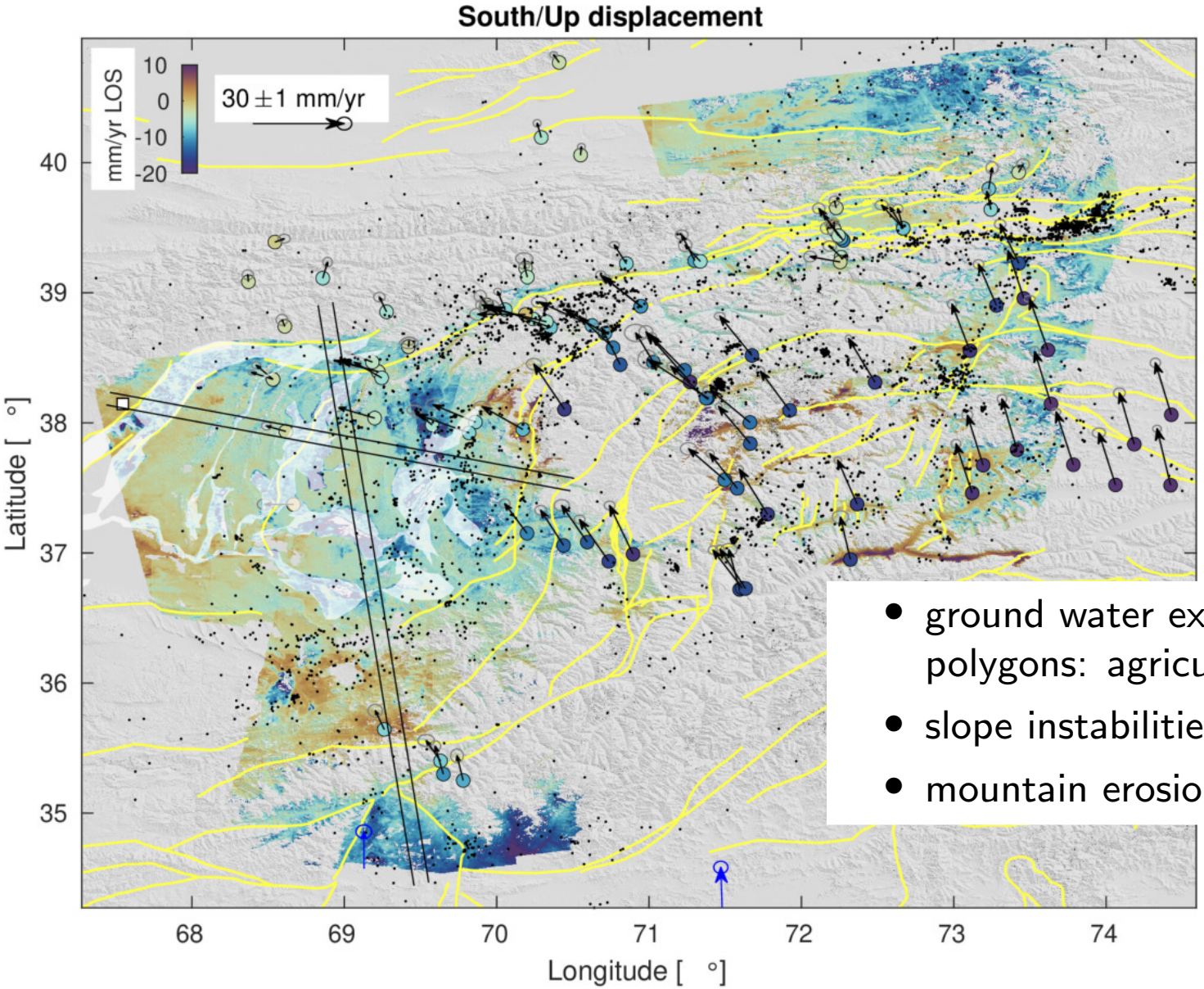

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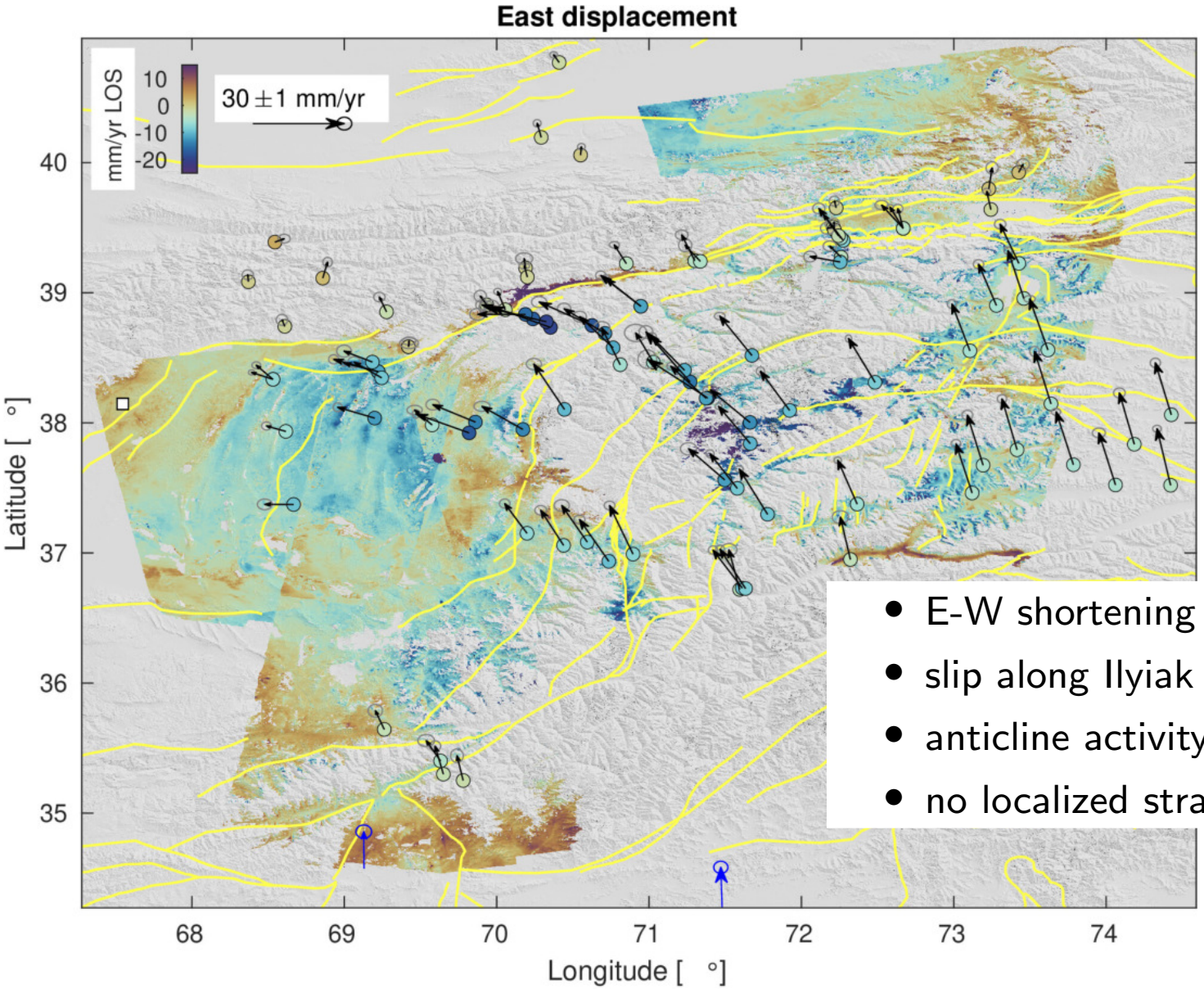

- E-W shortening in Tajik basin
- slip along Ilyiak fault
- anticline activity in Tajik basin
- no localized strain in Hindu Kush

(NB: work in progress! Be cautious with interpretation!)

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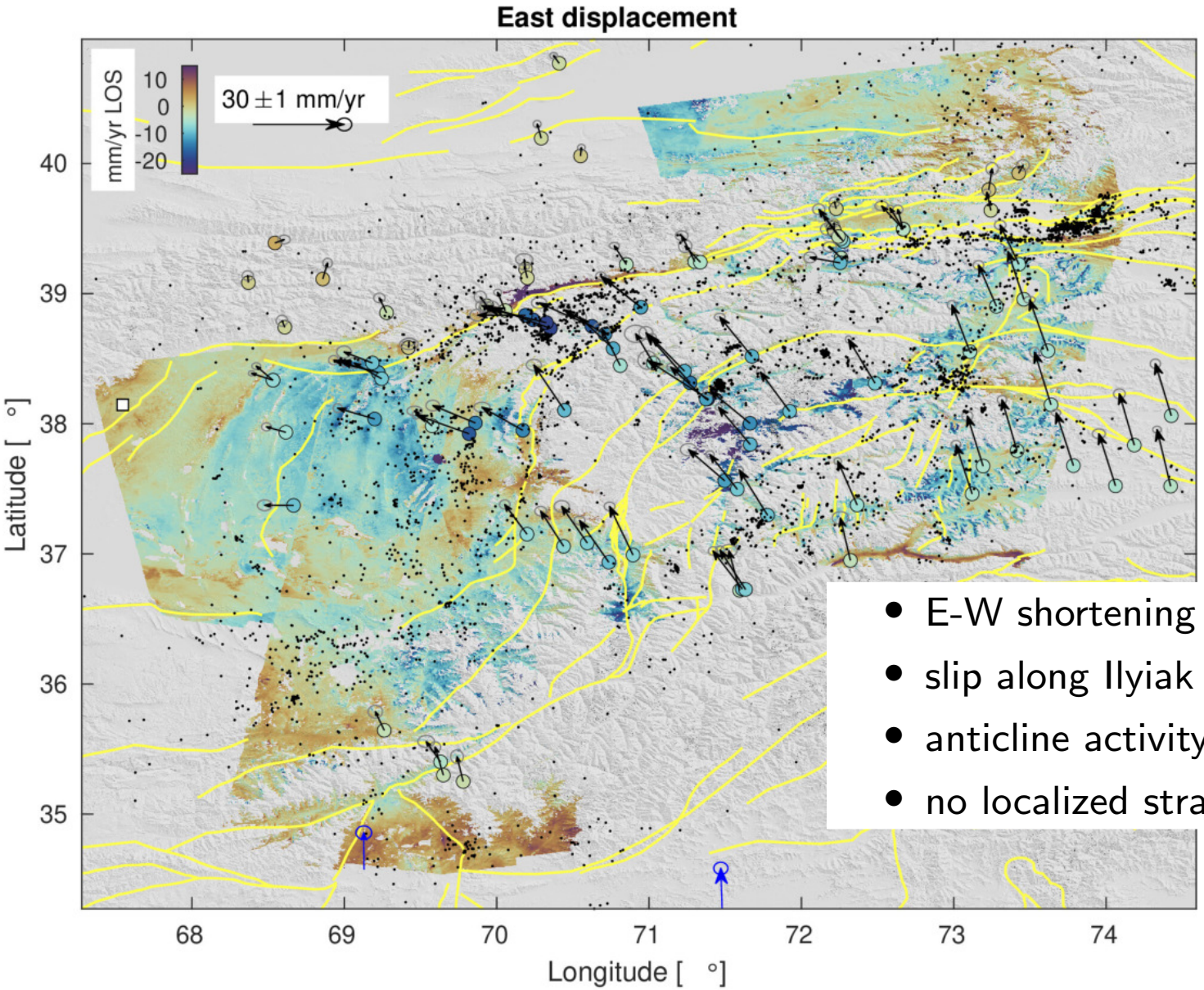

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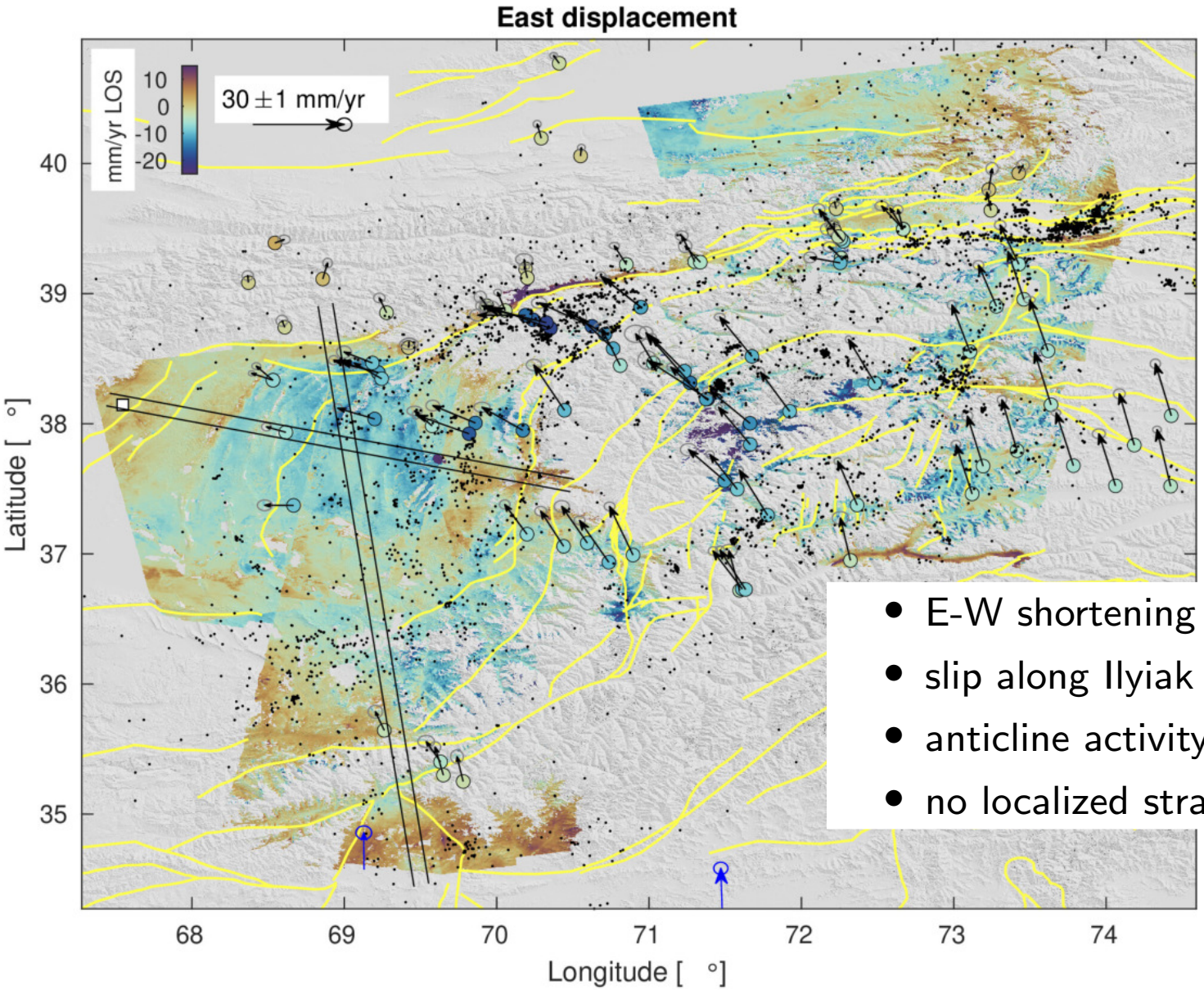

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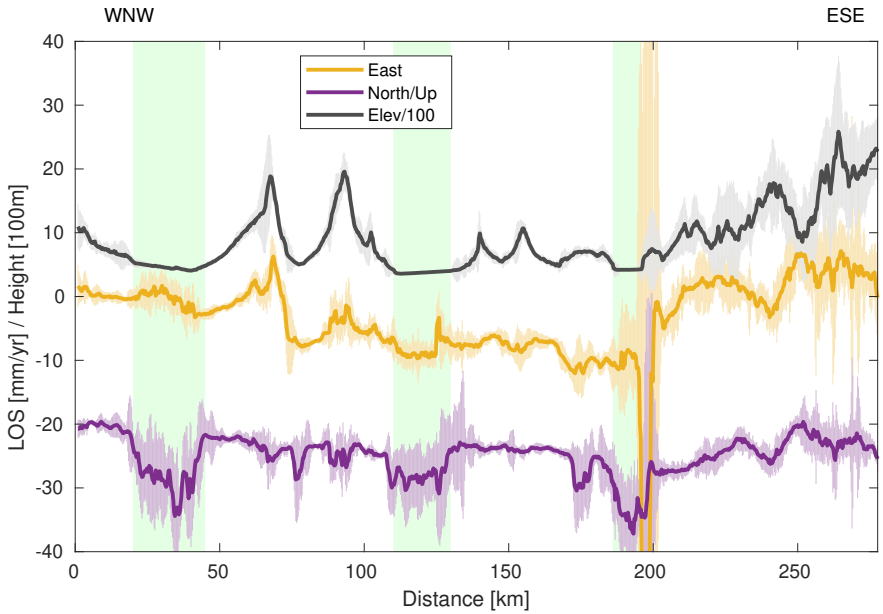
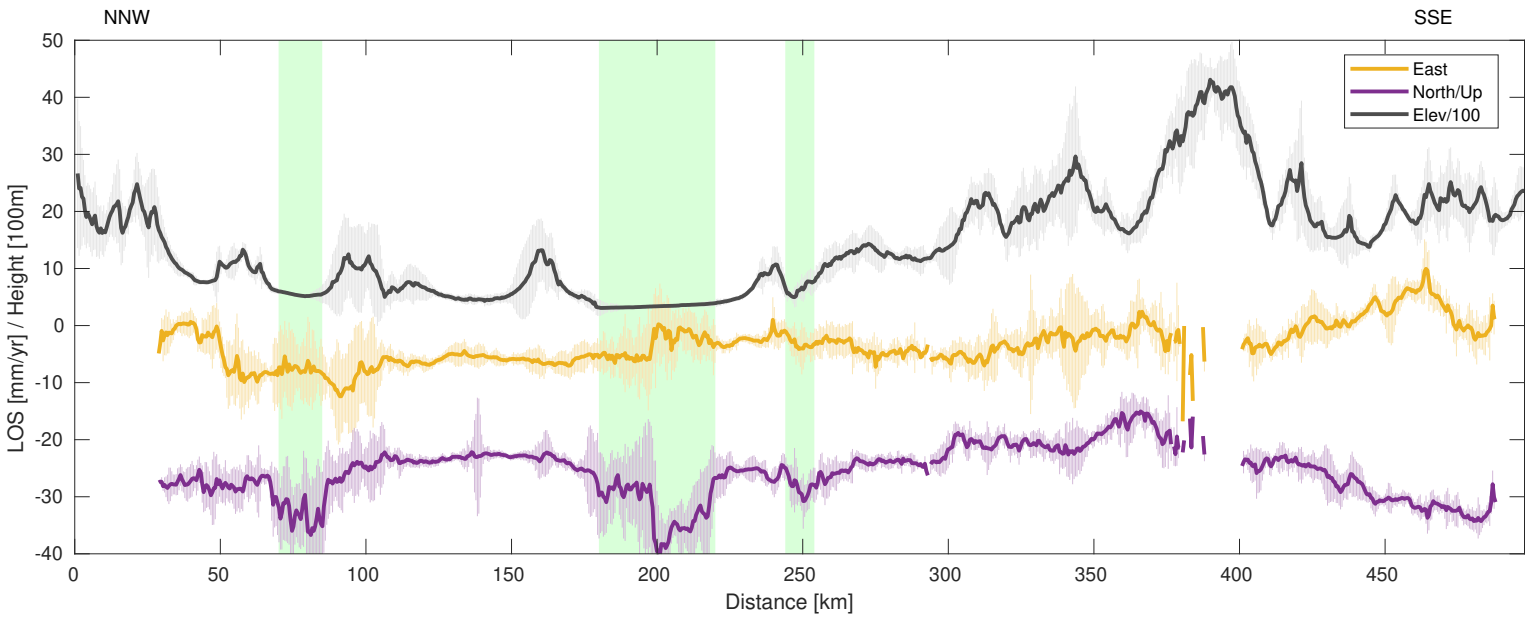
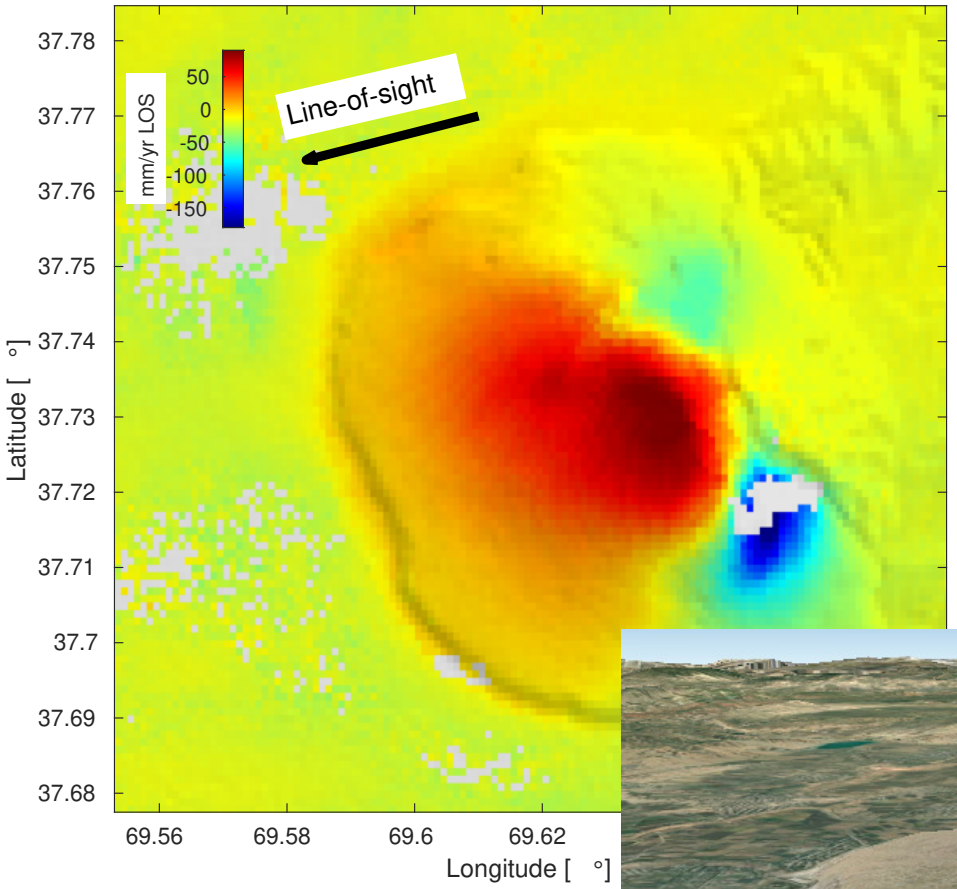
Profiles



- ground water exploitation, marked with bright blue bands (North/Up)
- anticline activity (upper profile, East, 75km)
- slip at Ilyak fault (lower profile, East, 50km)
- salt tectonics: Hoja Mumin diapir (upper profile, 200km)



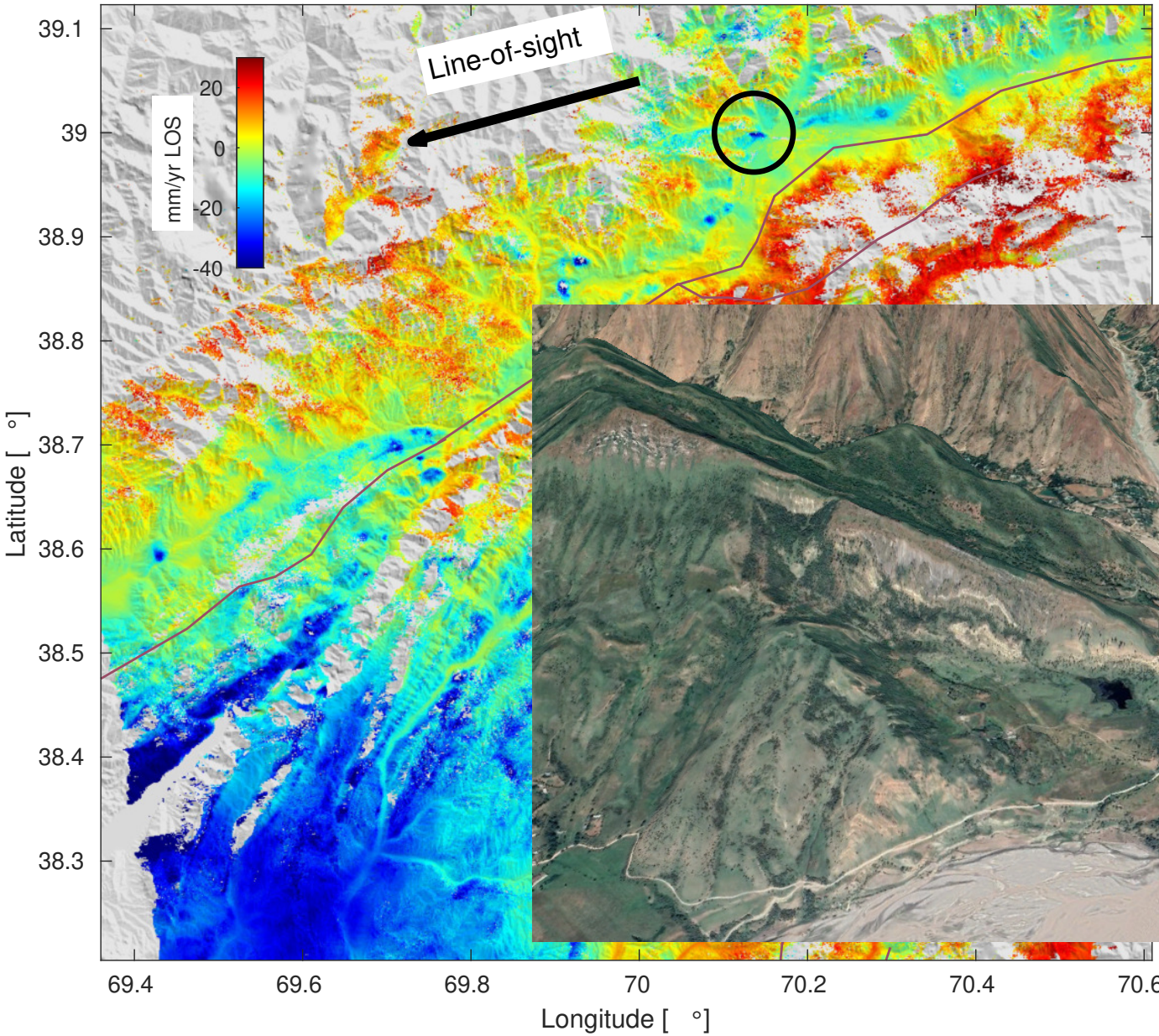
Hoja Mumin diapir near Kulyab



- ∼7 km diameter
- 850 m elevation above alluvial plain
- Observed LOS uplift: ∼110 mm/yr
- Estimated extrusion rate: ∼170 mm/yr (Leith & Simpson, 1986)

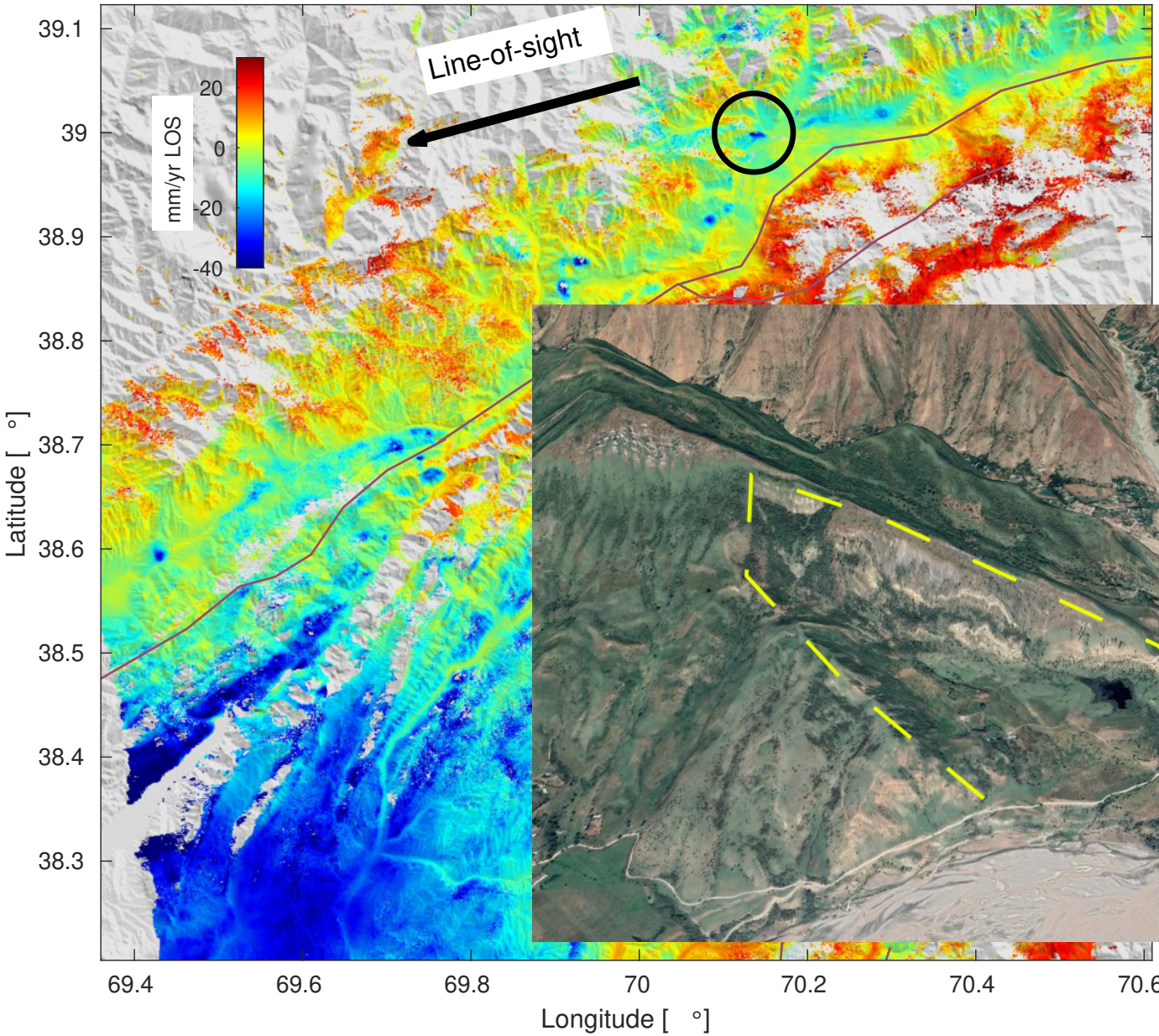
Google Earth

Instable slopes



Instable slope near Navobod (Google Earth)

Instable slopes



Instable slope near Navobod (Google Earth)

Take-home messages

- While the Eastern Pamir remains relatively stable, the western Pamir collapses into the Tajik basin. The left-lateral **Sarez Karakul fault** ($\sim$5 mm/yr of shear) separates these two domains.
- In the Alai valley, the **Pamir thrust system** exhibits a decrease in shortening (from E to W) and an increase in dextral shear.
- The north-advancing west Pamir squeezes Peter I. towards the Tajik basin. Active boundaries are the fast-slipping dextral **Vakhsh thrust**, and the sinistral-normal *Darvaz fault*.
- In the Hindu Kush the sinistral-transtensive **Badakhshan fault** and the sinistral-transpressive **Panjsheer fault** seem to be fully locked (i.e. sparse seismicity, no creep).
- InSAR rate maps exhibit:
  1. E-W shortening of the Tajik basin
  2. activity on the **Iliac fault** (5-10 mm/yr) and a NE-SW oriented **anticline**
  3. subsidence in the Tajik basin due to irrigation
  4. slope instabilities

$\Rightarrow$ Coming soon: reviewed geotiff/kml of InSAR rate map