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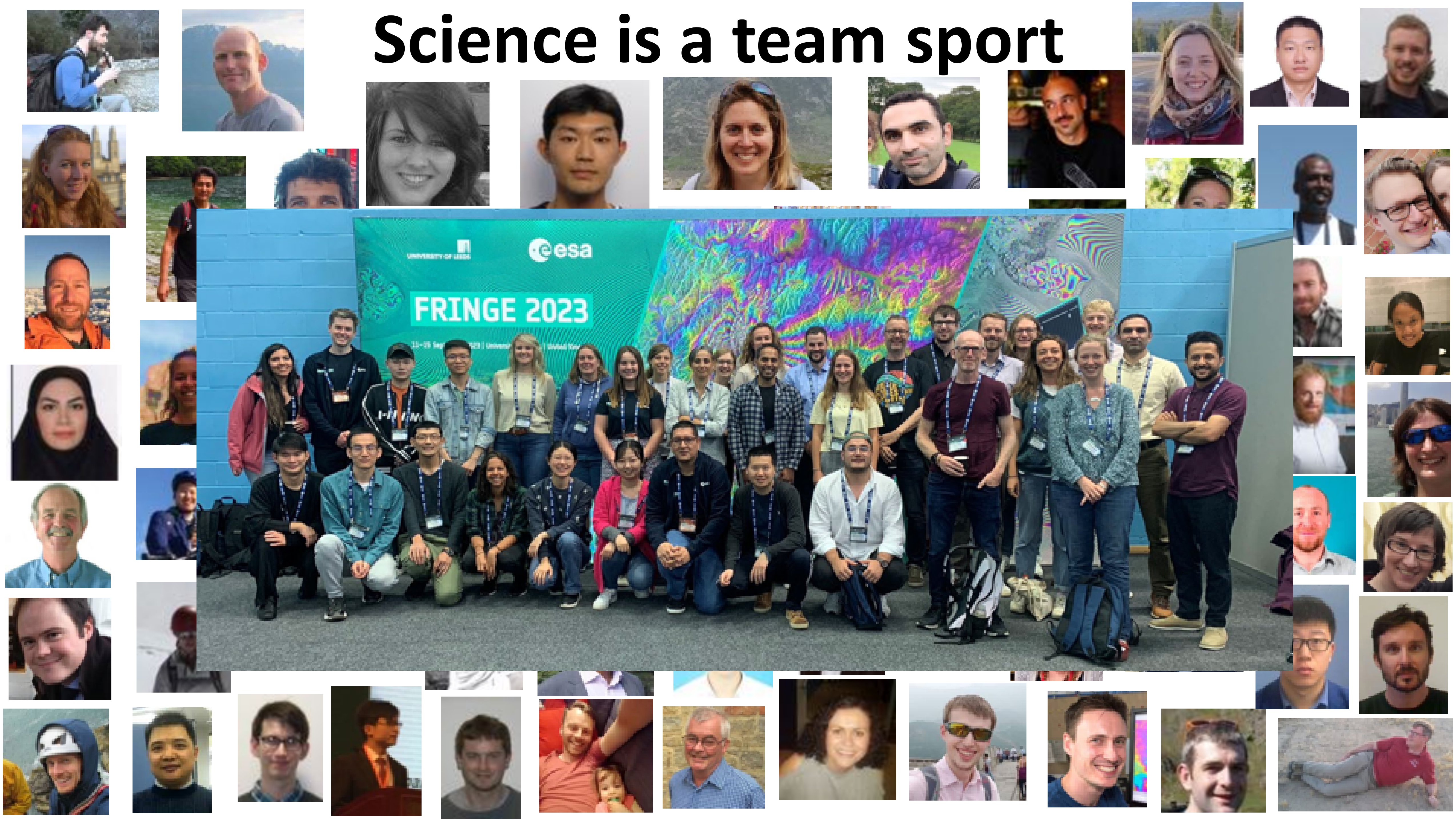
@timwright_leeds

From Türkiye to China: tectonic strains and velocities in the Alpine-Himalayan Belt from Sentinel-1 InSAR and GNSS

Tim J Wright[1], Yasser Maghsoudi[1], Milan Lazecky[1], Andrew J Hooper[1], John R Elliott[1], Qi Ou[1], Andrew Watson[1], Chris Rollins[2], Lin Shen[1], Jin Fang[1], Dehua Wang[1] Scott Watson[1], Barry Parsons[3], Gang Zheng[1], Jonathan Weiss[4]

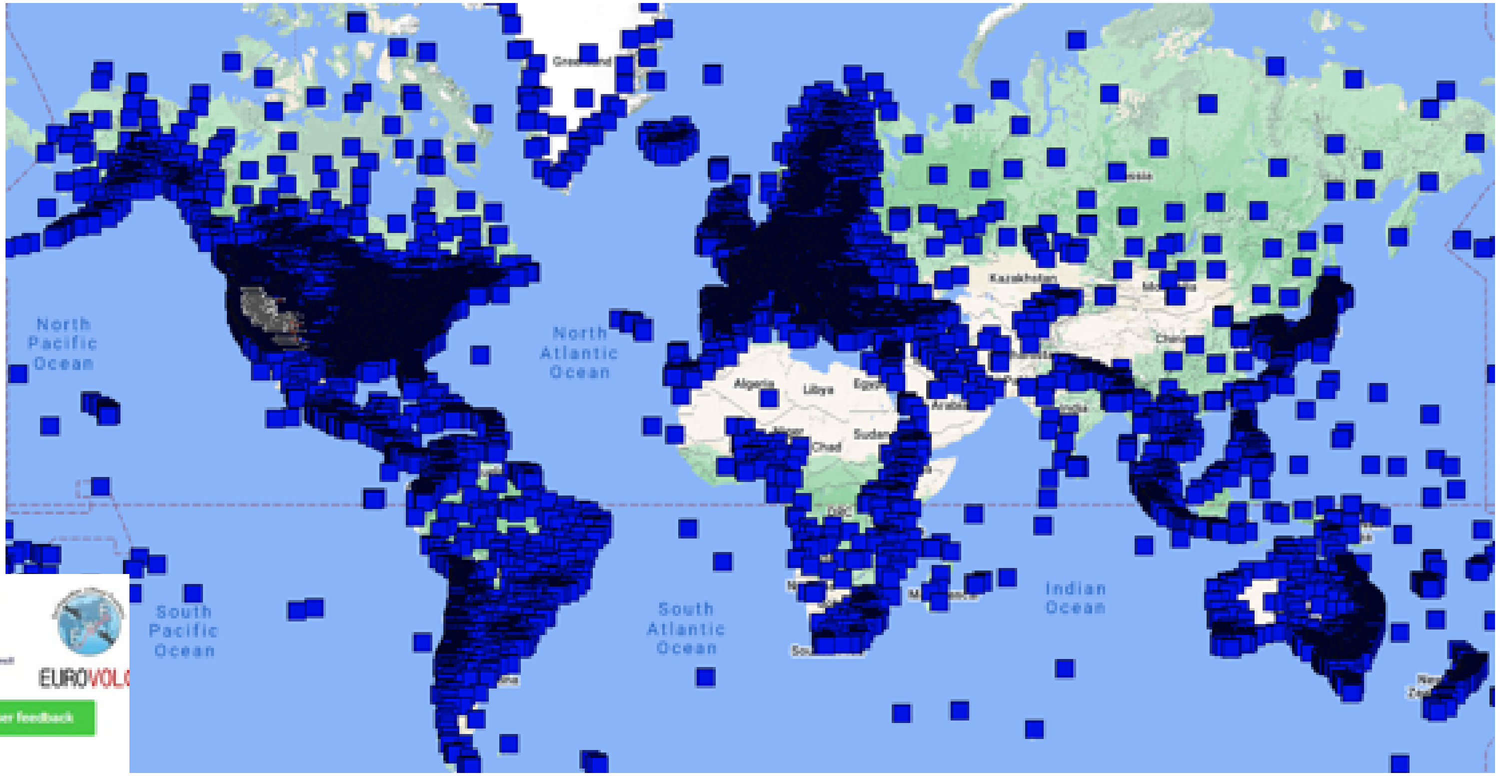
(1) COMET, University of Leeds, UK; (2) GNS Science, New Zealand;
(3) COMET, University of Oxford, UK; (4) NOAA/NWS/Pacific Tsunami Warning Center, USA

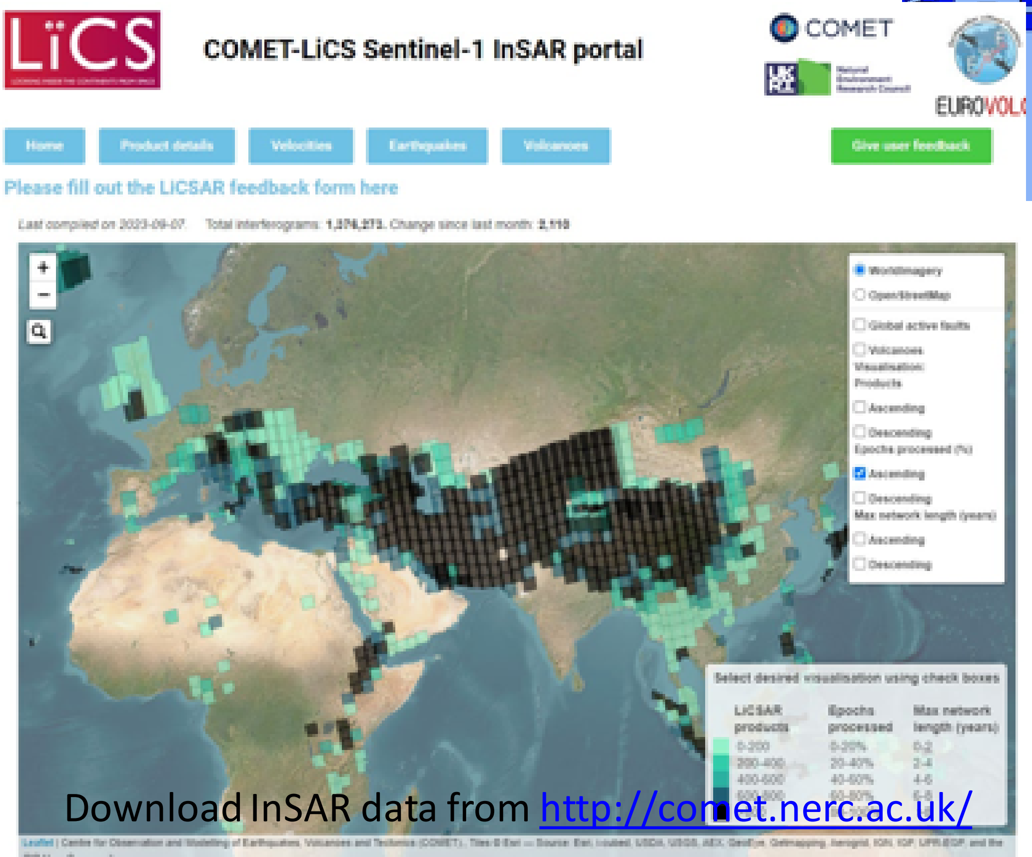
Science is a team sport



We have entered an era of geodetic big data

GNSS data: e.g. 20,843 points processed by Nevada Geodetic Lab (Blewitt et al., 2018)





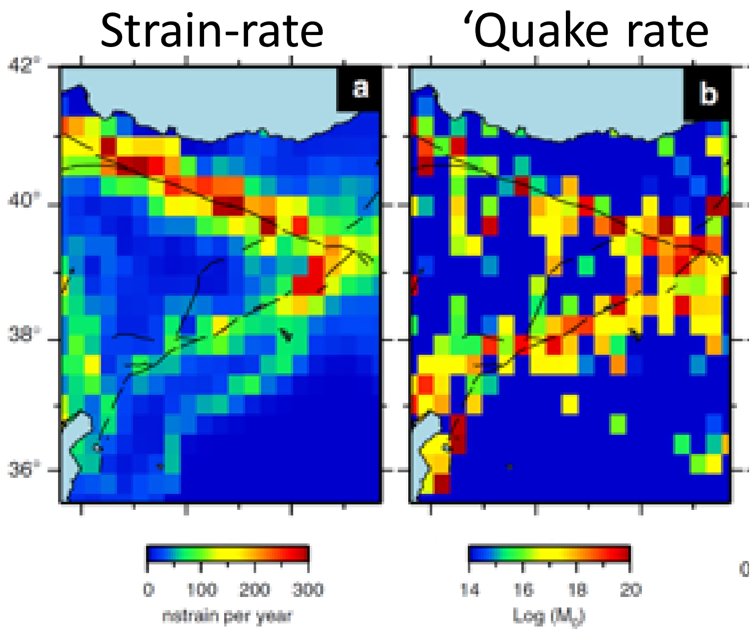
InSAR: Sentinel-1 has acquired a vast collection of SAR data over Earth's tectonic areas (e.g. COMET-LiCSAR system, has >1.3M interferograms)

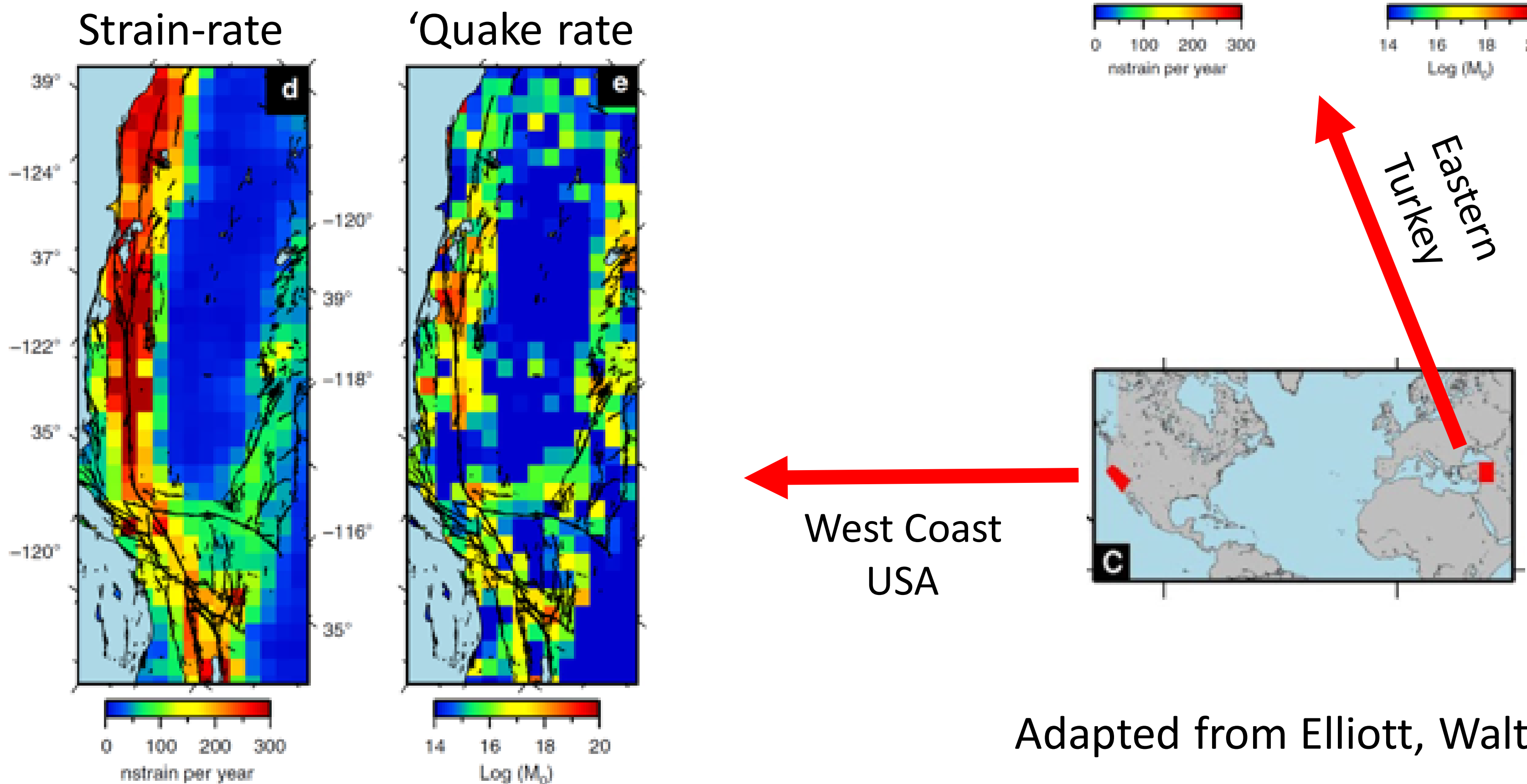
We would like to combine these to produce high-resolution maps of tectonic velocities and strains on a continental scale

Download InSAR data from http://comet.nerc.ac.uk/

Why measure tectonic strain?

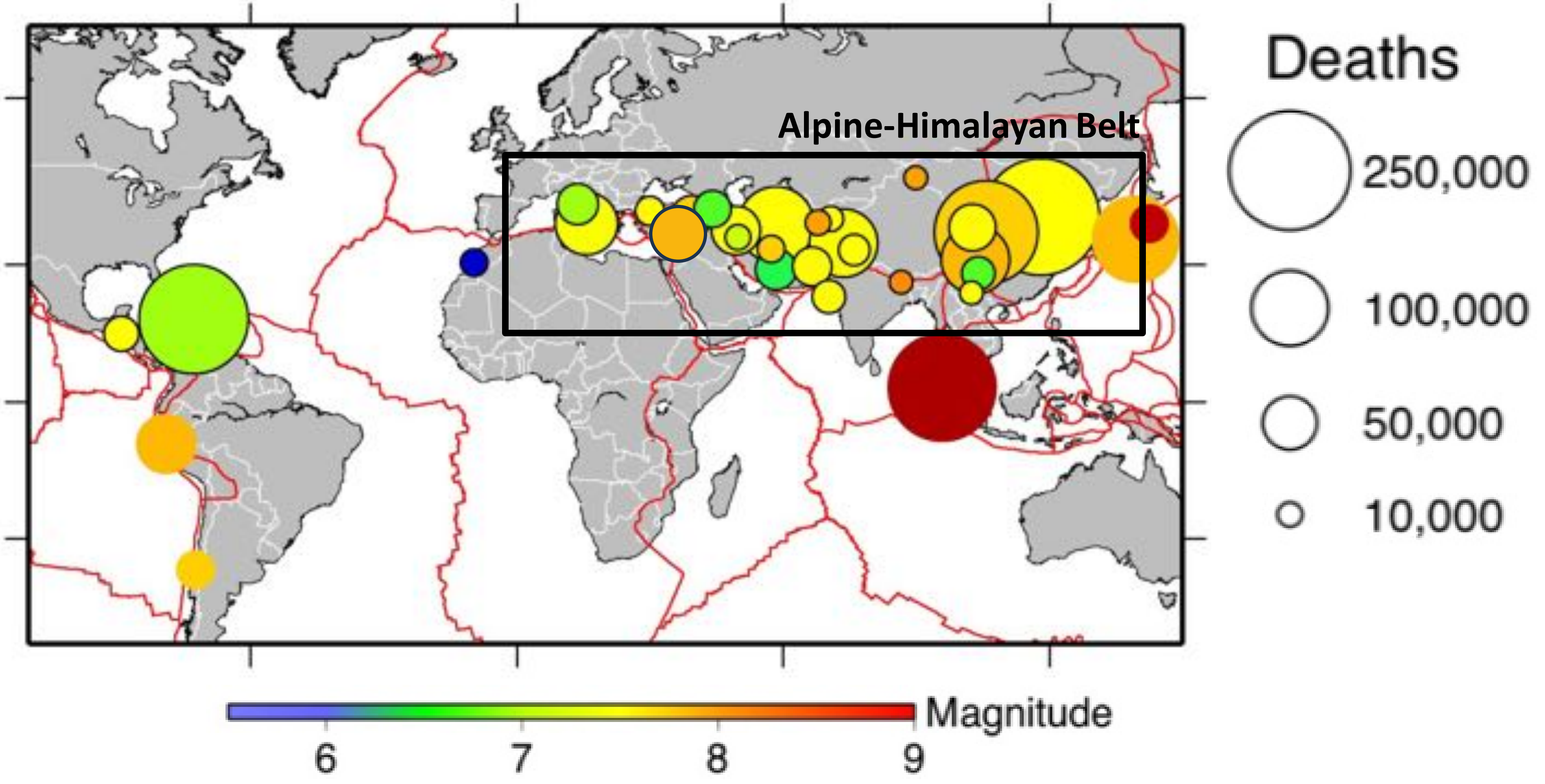
- Seismic hazard models primarily based on PAST seismicity.
- If we can measure strain, it should be causally linked to FUTURE seismic hazard





Adapted from Elliott, Walters & Wright, 2016

Focus on the Alpine-Himalayan Belt due to high-vulnerability to earthquakes



Original figure from John Elliott

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Outline

- Method and Tibet case study
- Results from across the Alpine-Himalayan Belt
- Outlook
- Conclusions

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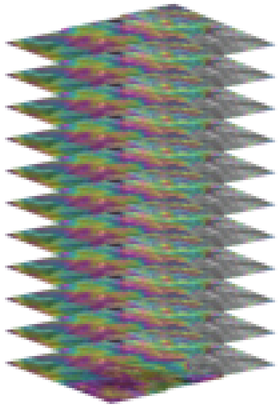
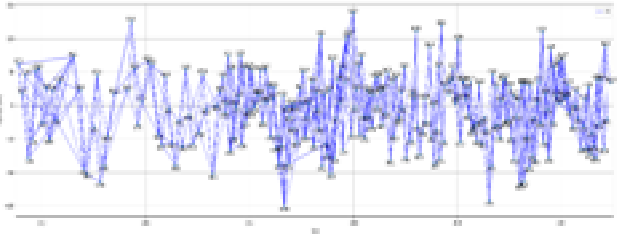
Methodology: Measuring velocities and strain with InSAR and GNSS

1. Make Interferograms (COMET-LiCSAR)

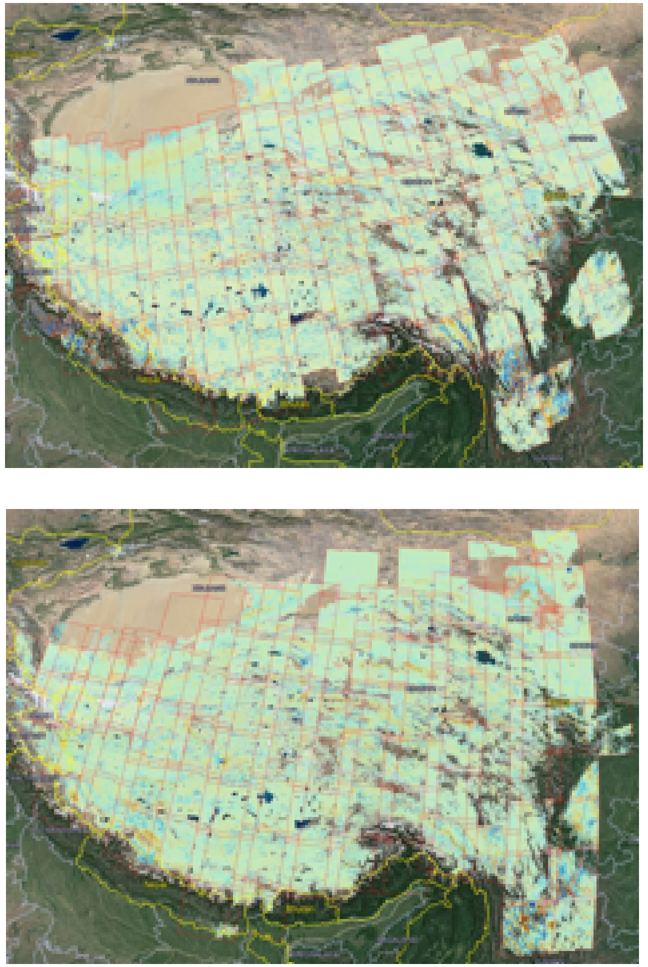


Sentinel-1 SLC data

Interferogram Network

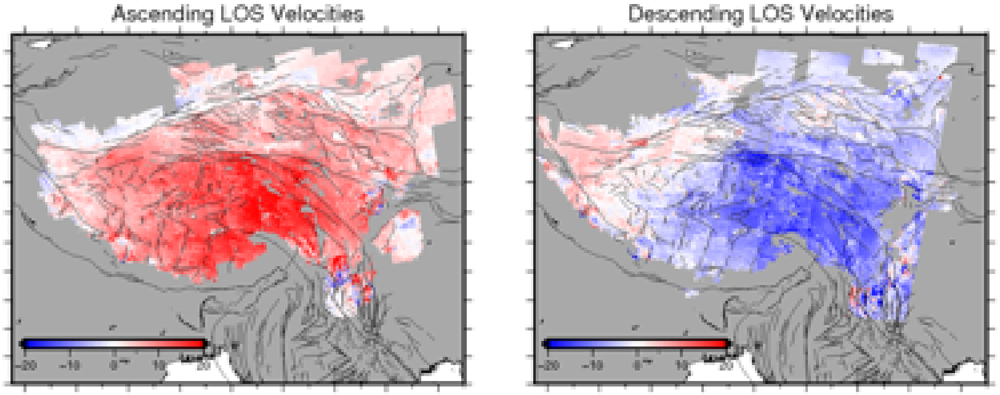


2. Invert for LOS Velocities for each frame (LiCSBAS)

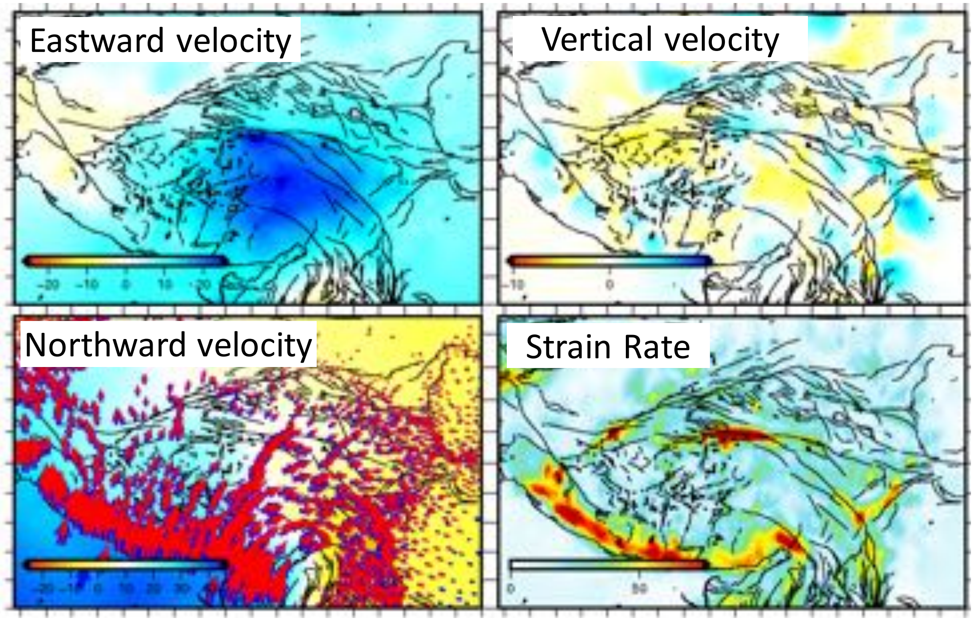


3. Invert InSAR and GNSS to find (simultaneously):

(i) reference frame adjustments



(ii) 3D velocity and strain rate fields



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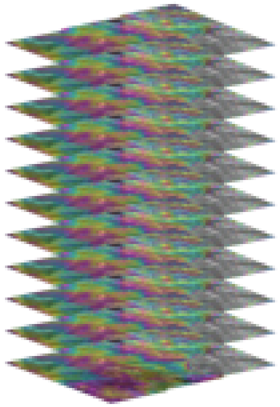

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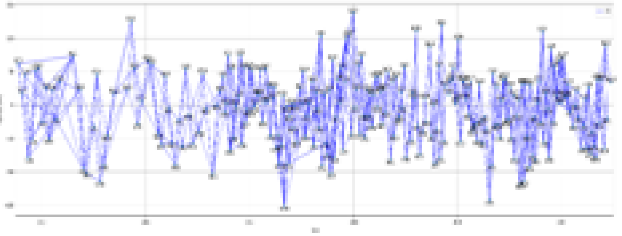

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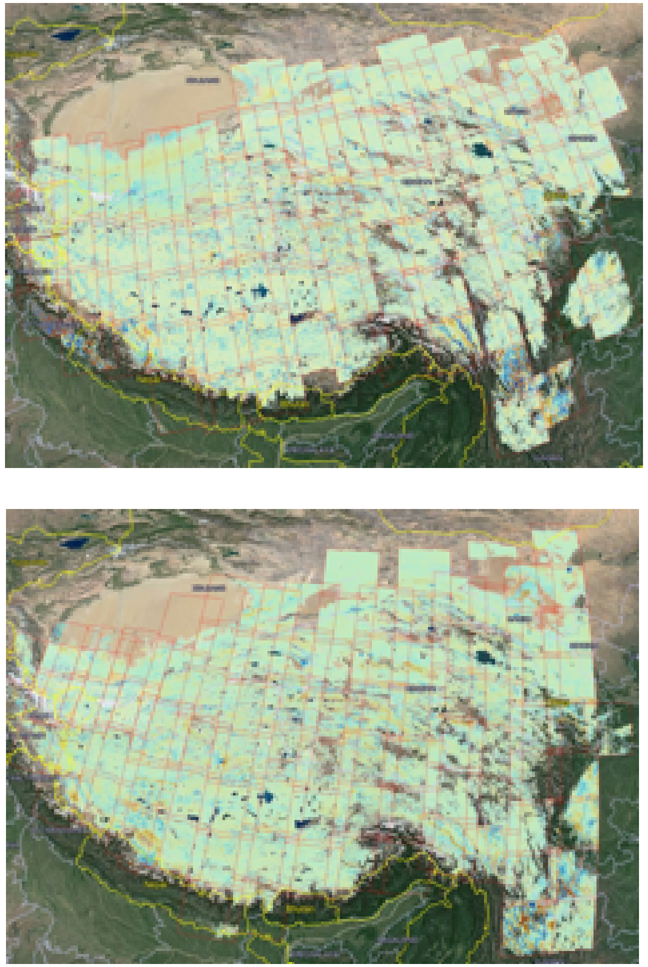

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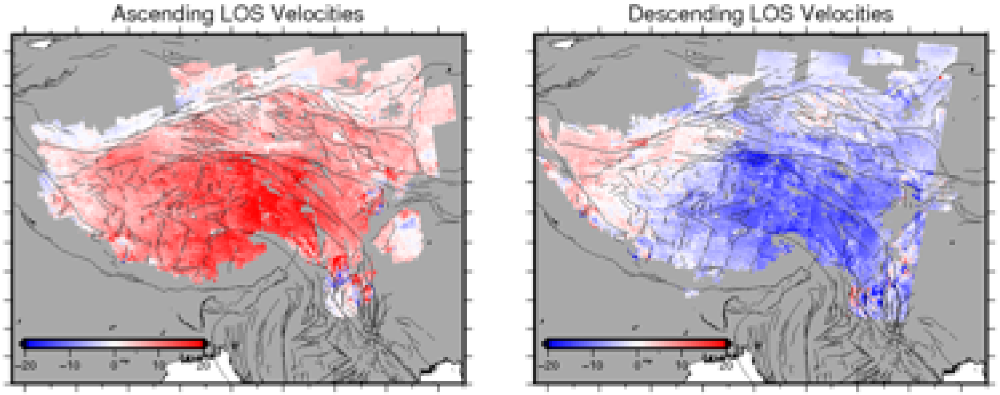

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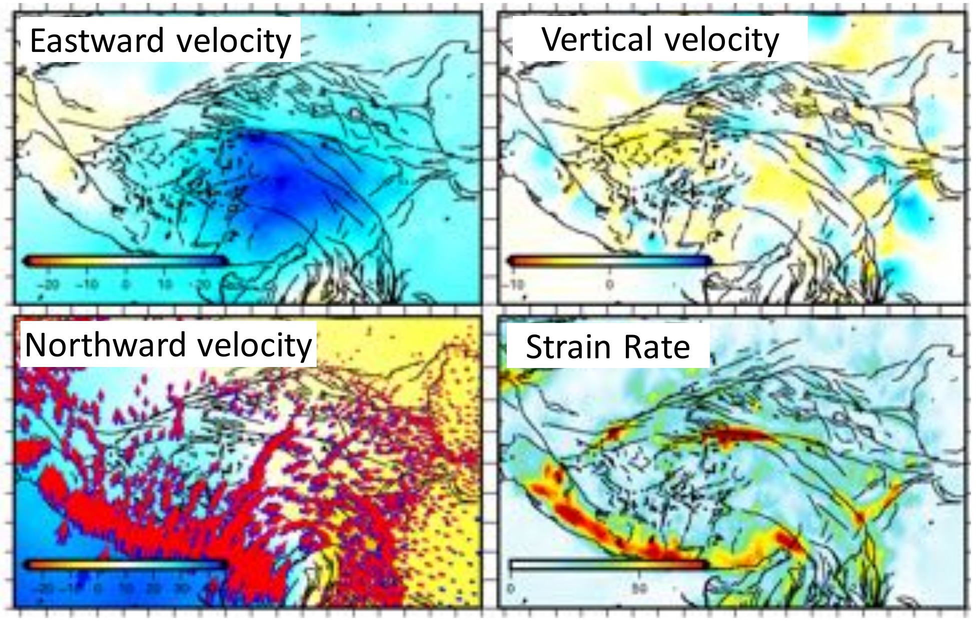

- We make interferograms automatically for 250 x 250 km frames, using LiCSAR (**Processed and archived at UK JASMIN/CEDA facility)**
- For details of approach see
  - *Lazecky et al.* **Remote Sensing 2020**, doi:10.3390/rs12152430
  - *Lazecky et al.* Poster - this meeting
- 1.3M+ interferograms are available for download from COMET-LICSAR portal (*Greater than 3 x increase since Fringe 2021*).

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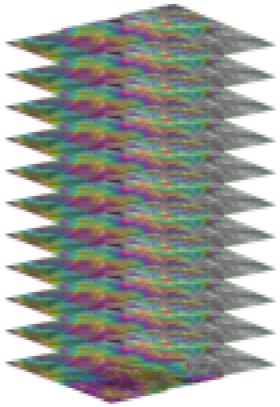

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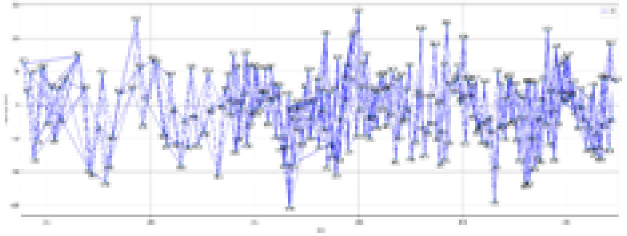
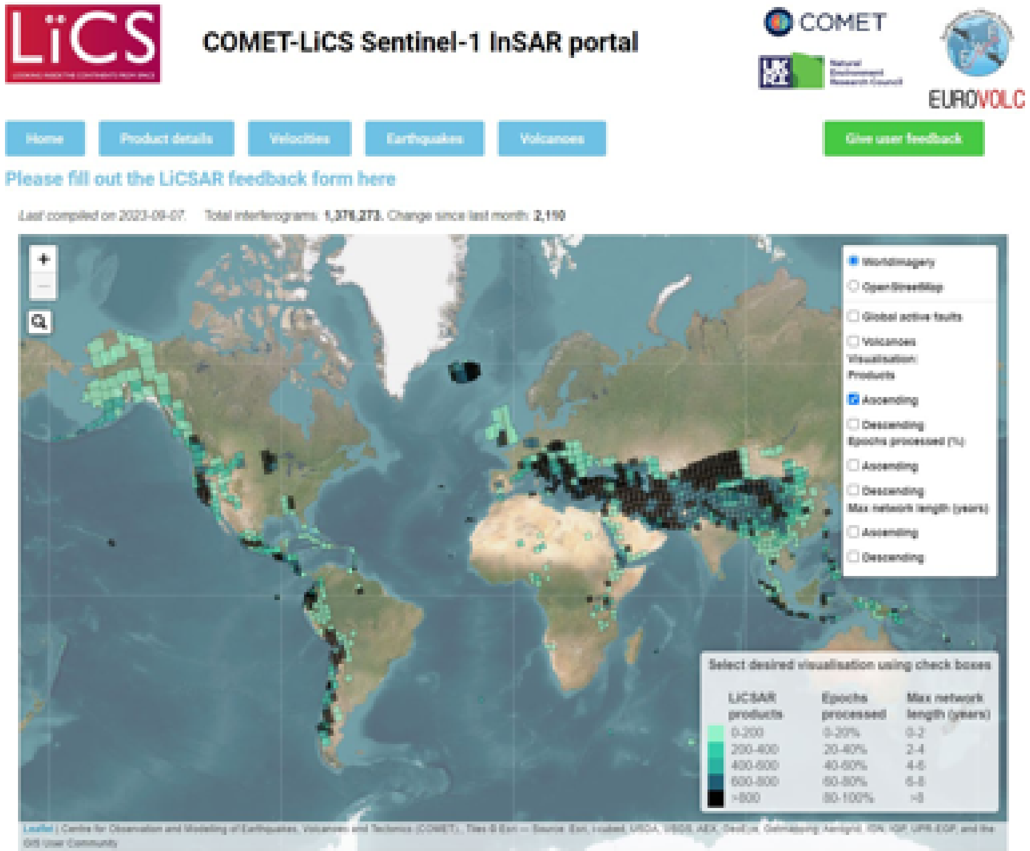
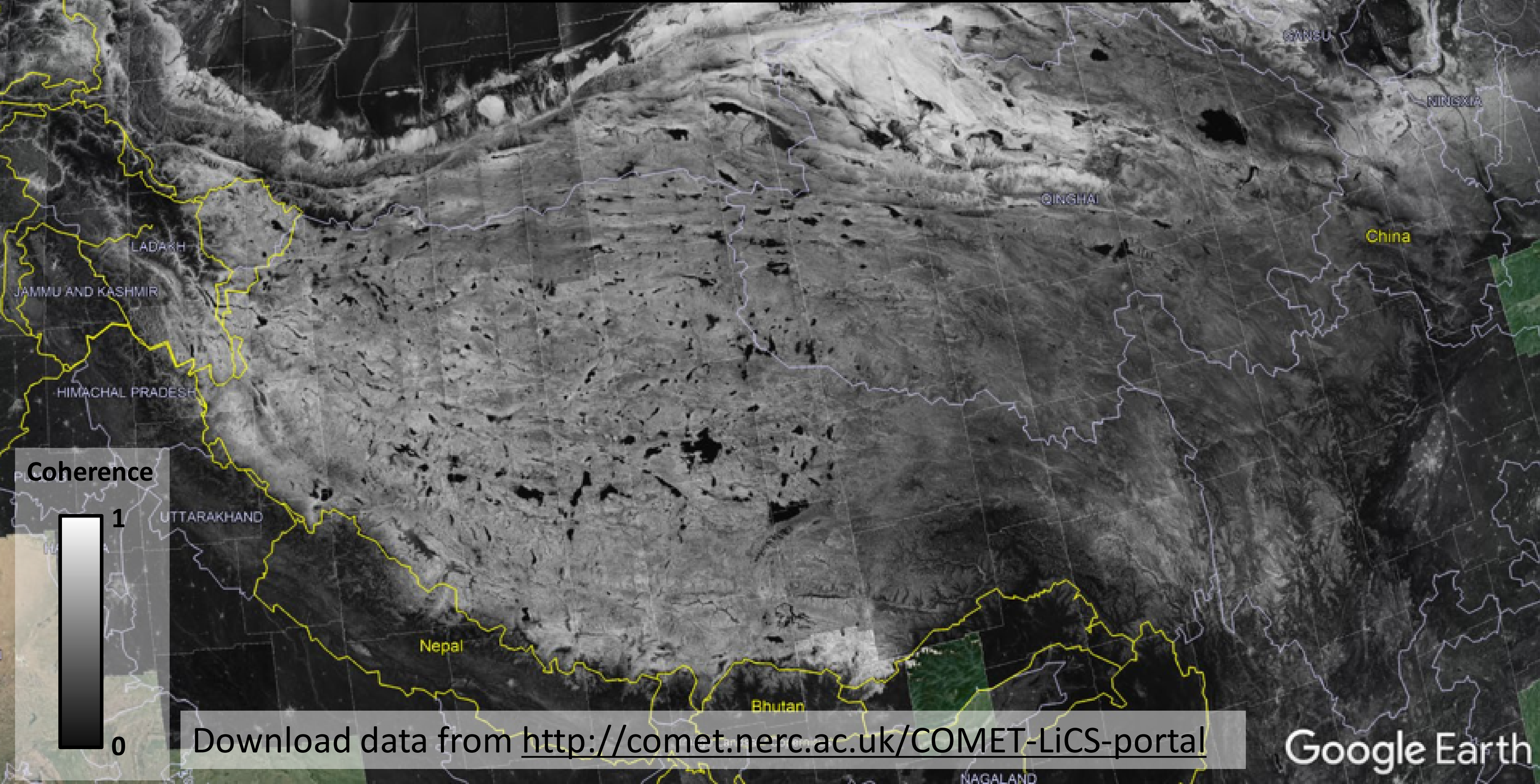




Download from http://comet.nerc.ac.uk/COMET-LiCS-portal and

EPOS
EUROPEAN PLATE OBSERVING SYSTEM

Average Coherence for Sentinel-1 data (ascending)



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Methodology: Measuring velocities and strain with InSAR and GNSS

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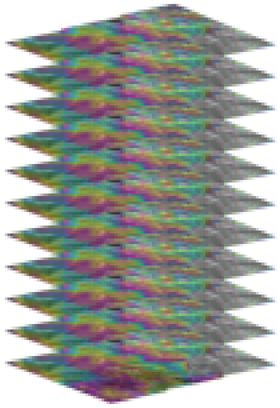

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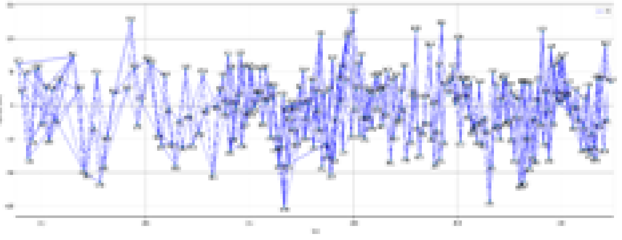

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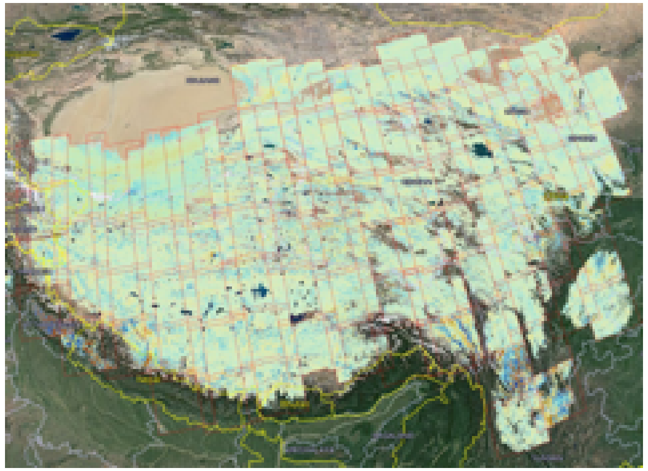

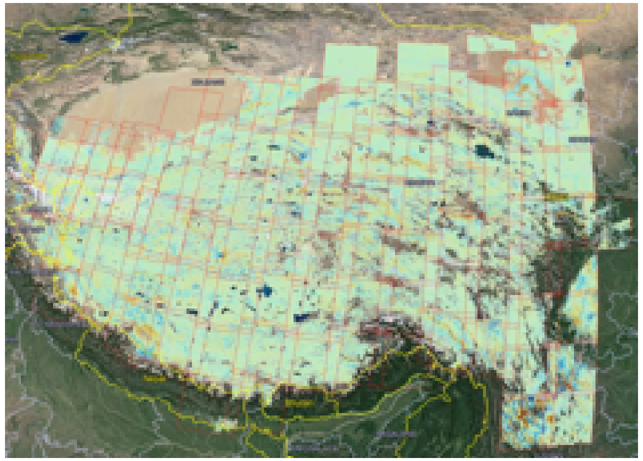

3. Invert InSAR and GNSS to find (simultaneously):

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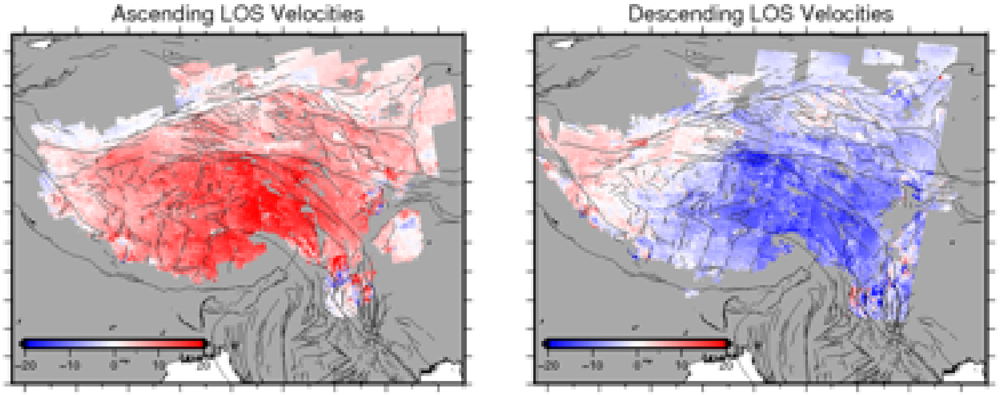

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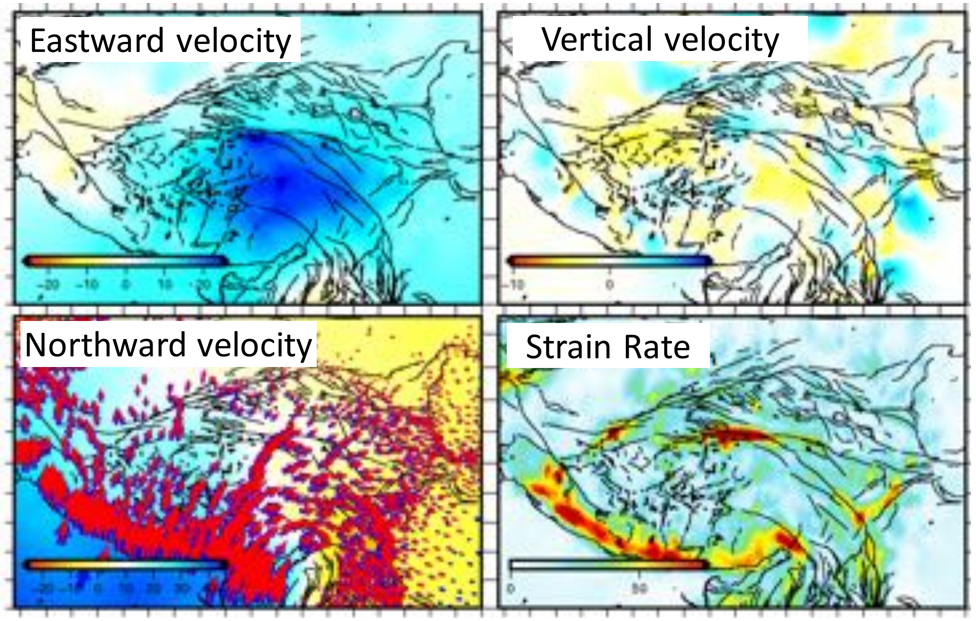

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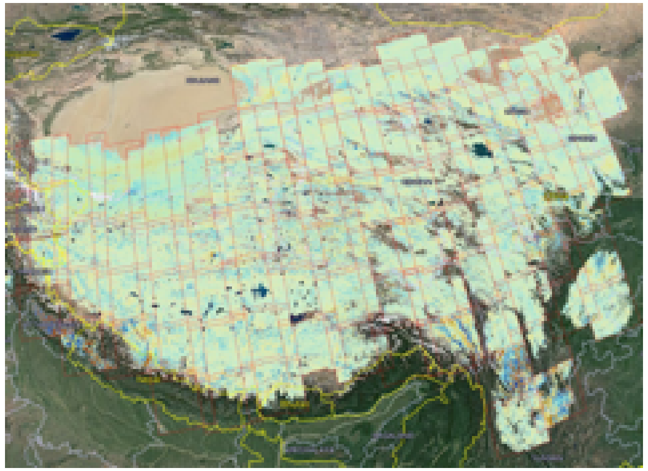
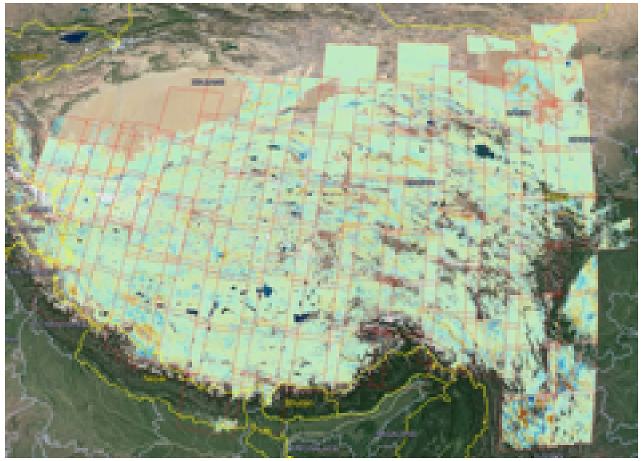
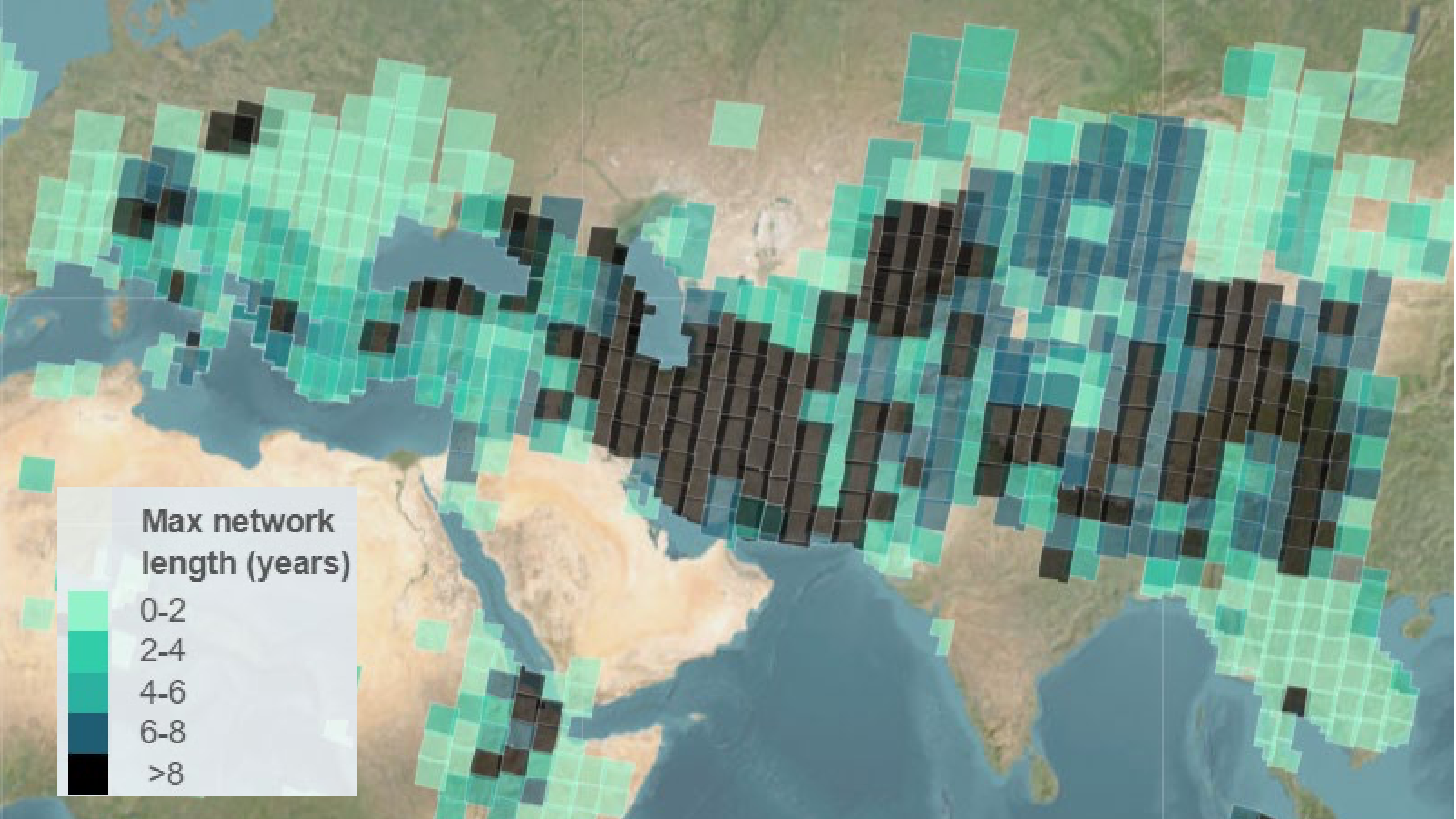


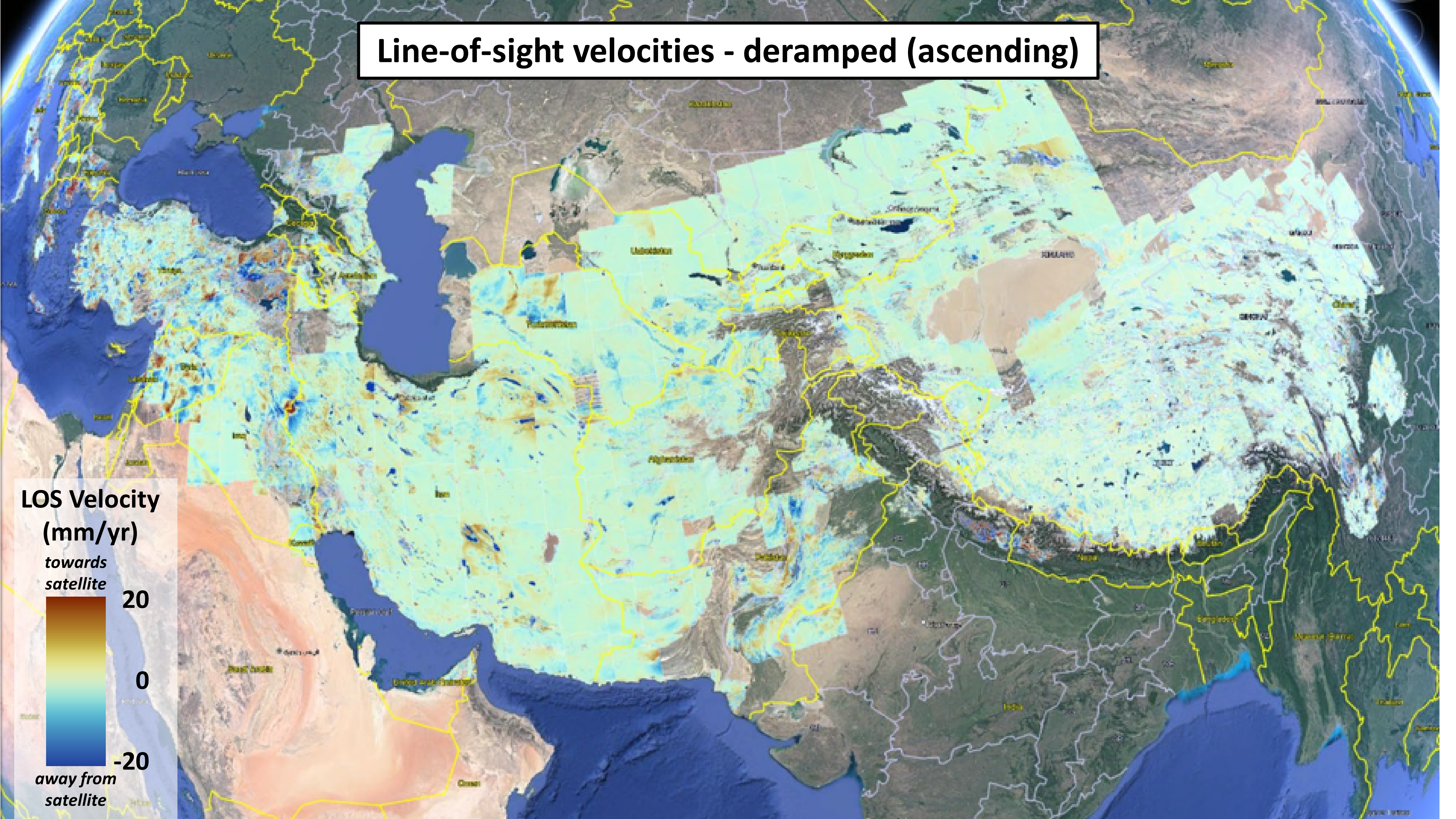


- We create average line-of-sight velocities using LiCSBAS (Morishita et al, 2020)
- We calculate LOS velocities over entire Alpine Himalayan Belt (AHB) at 1 km resolution
- ~651 frames; 155,000 acquisitions; 670,000 interferograms
- We remove long-wavelength quadratic ramps from each frame.

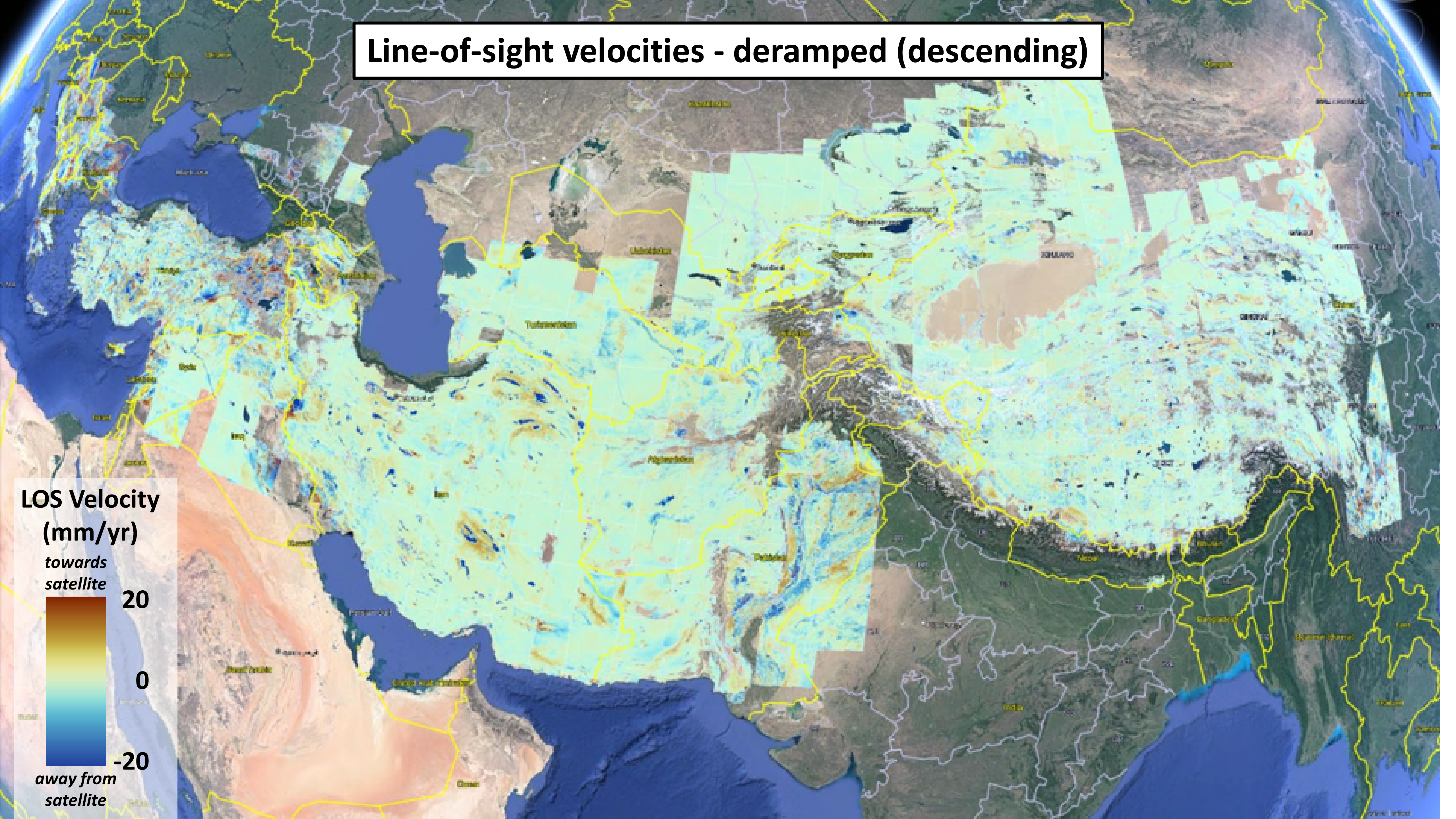
LiCSBAS: Morishita et al. **Remote Sensing 2020**, doi:10.3390/rs12030424


Max network
length (years)
0-2
2-4
4-6
6-8
>8

Line-of-sight velocities - deramped (ascending)



Line-of-sight velocities - deramped (descending)



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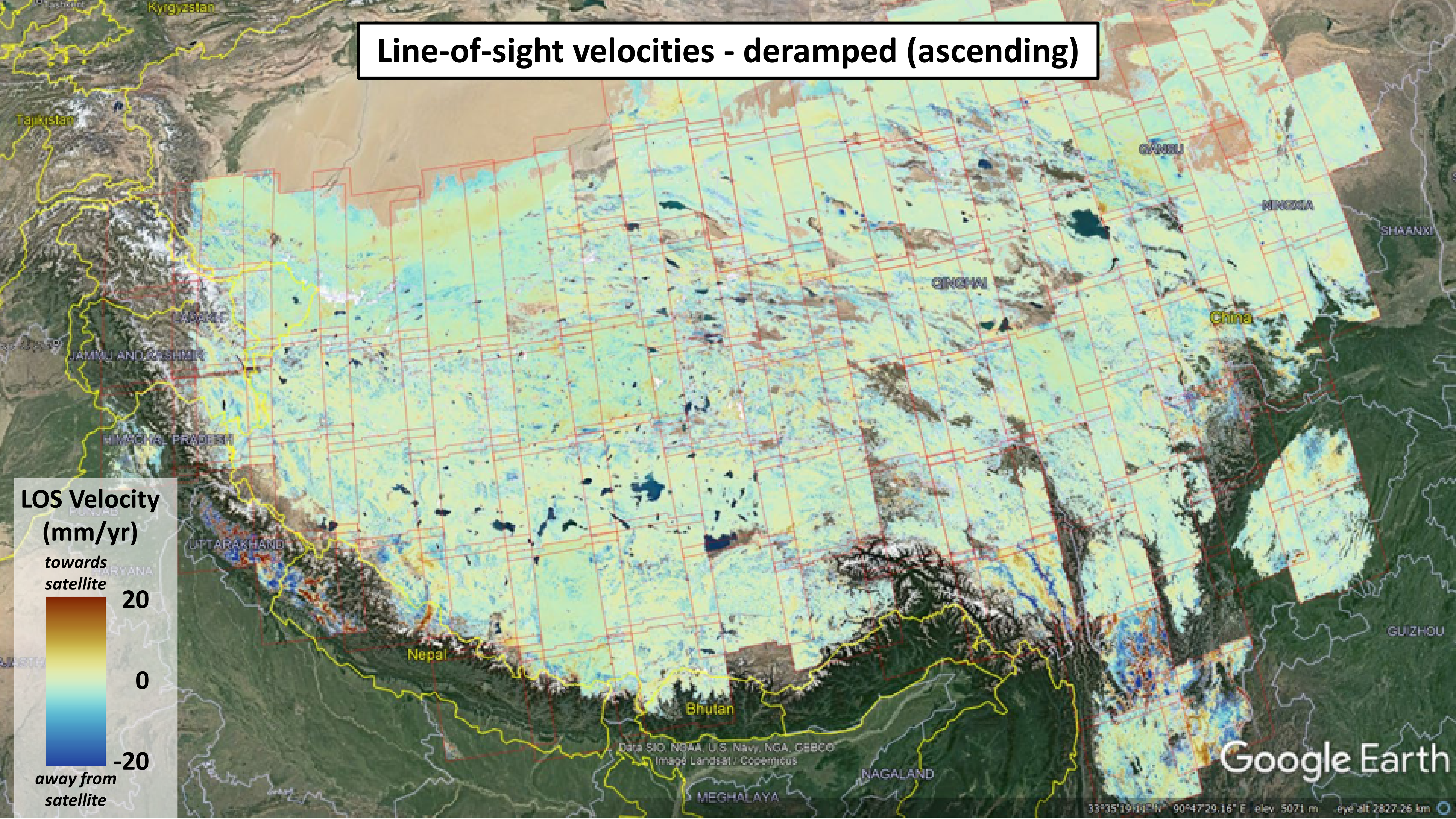

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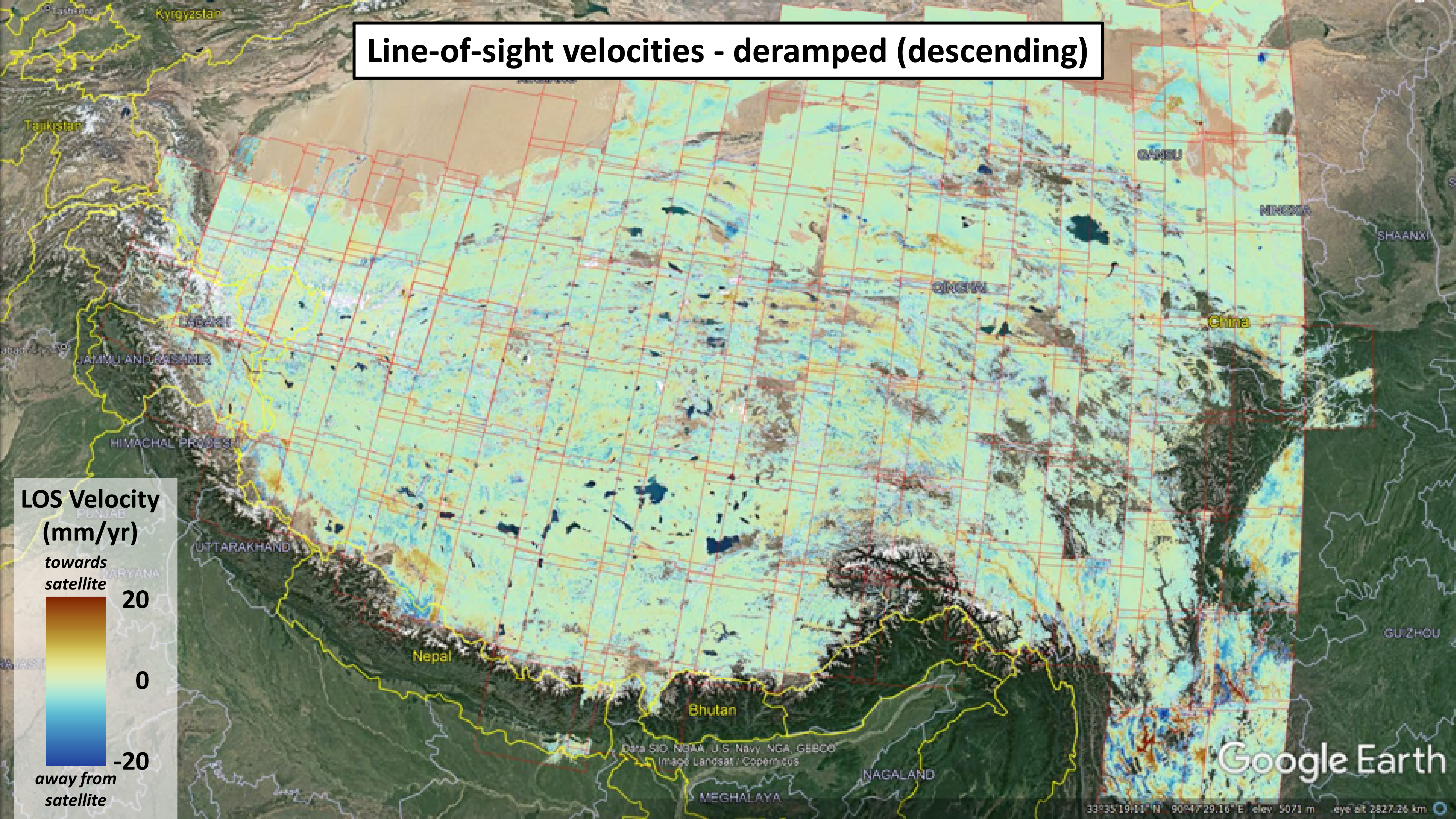

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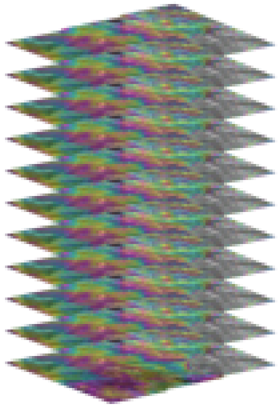
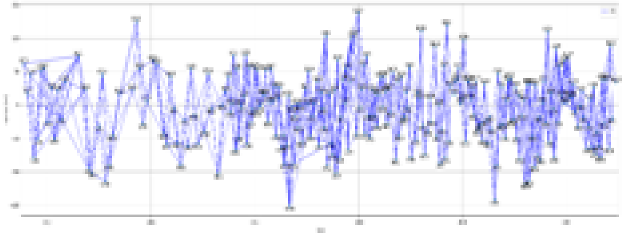
Sentinel-1
SLC data



Interferogram
Network



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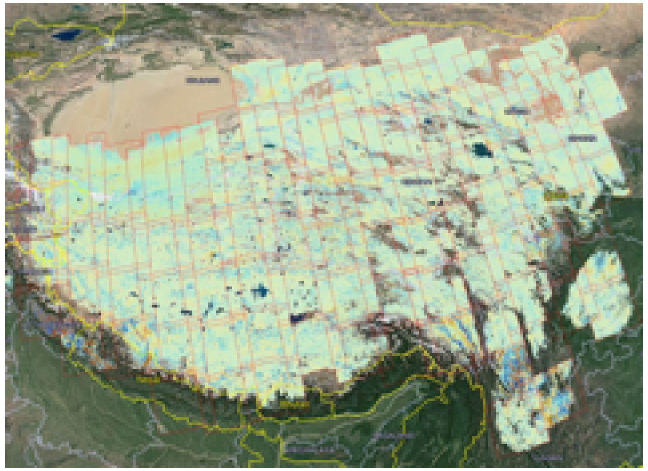

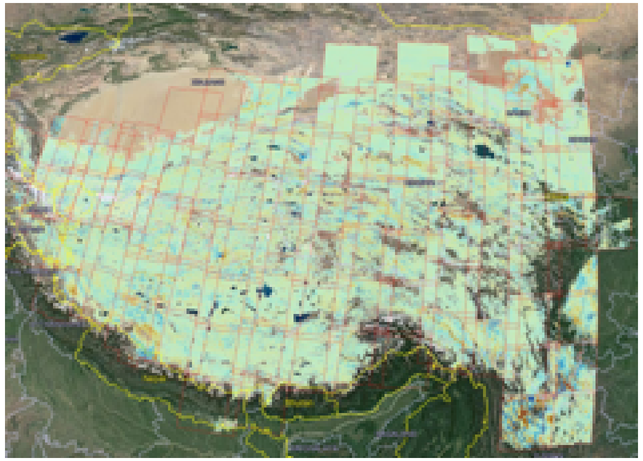

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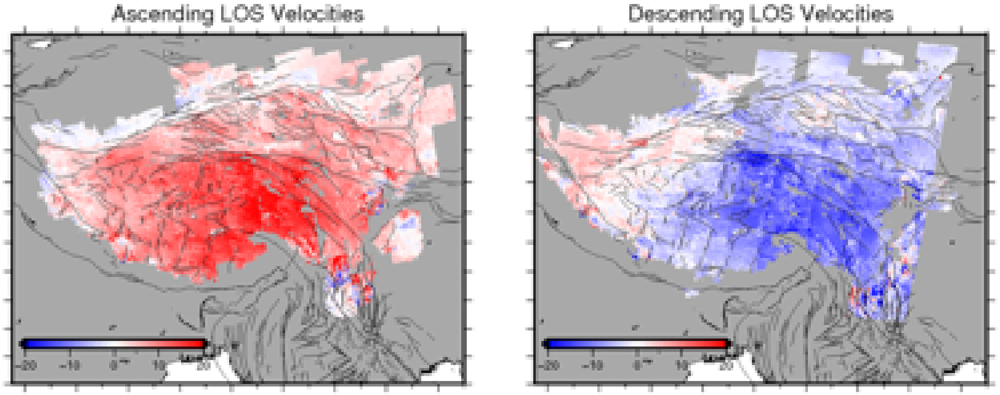

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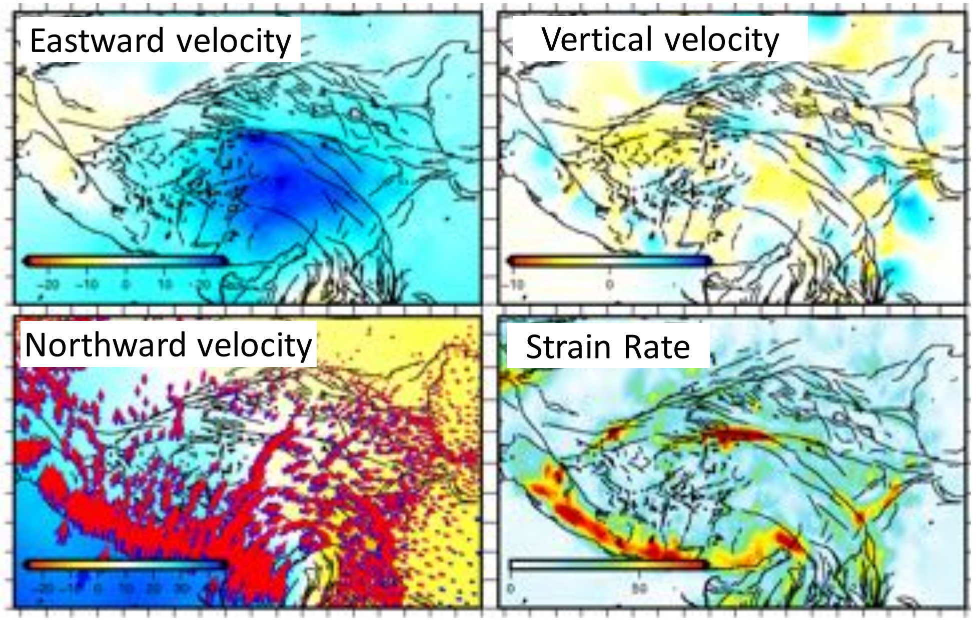
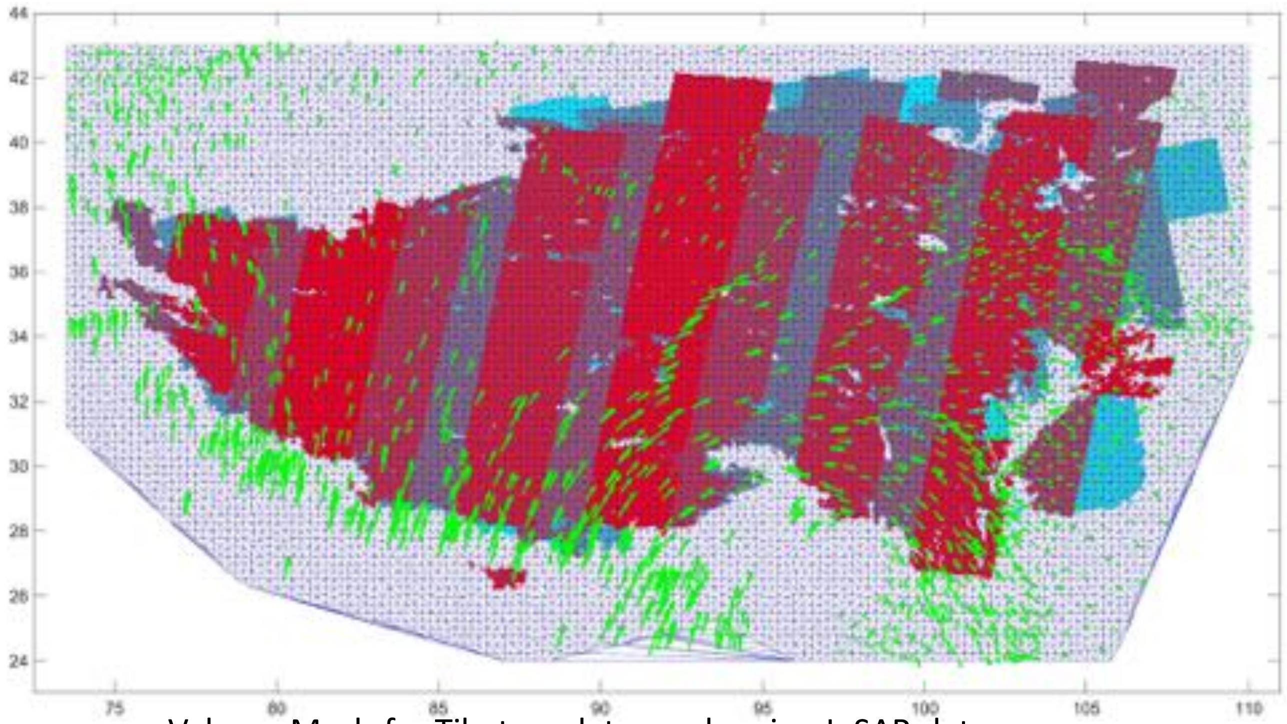


Creating Velocity Feld: Workflow

- We **jointly** invert GNSS and InSAR LOS velocities using the Velmap approach (Wang and Wright, GRL 2012).
- This solves for **velocities of the nodes** in a mesh of spherical triangles (0.2° spacing) AND **reference frame adjustment parameters**



Velmap Mesh for Tibetan plateau, showing InSAR data coverage
(GNSS from complication by Chris Rollins, including Wang and Shen 2020 for China)

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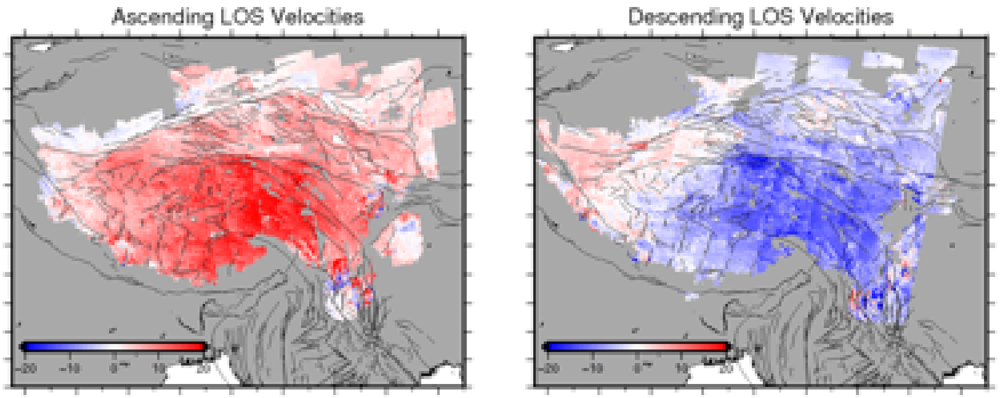

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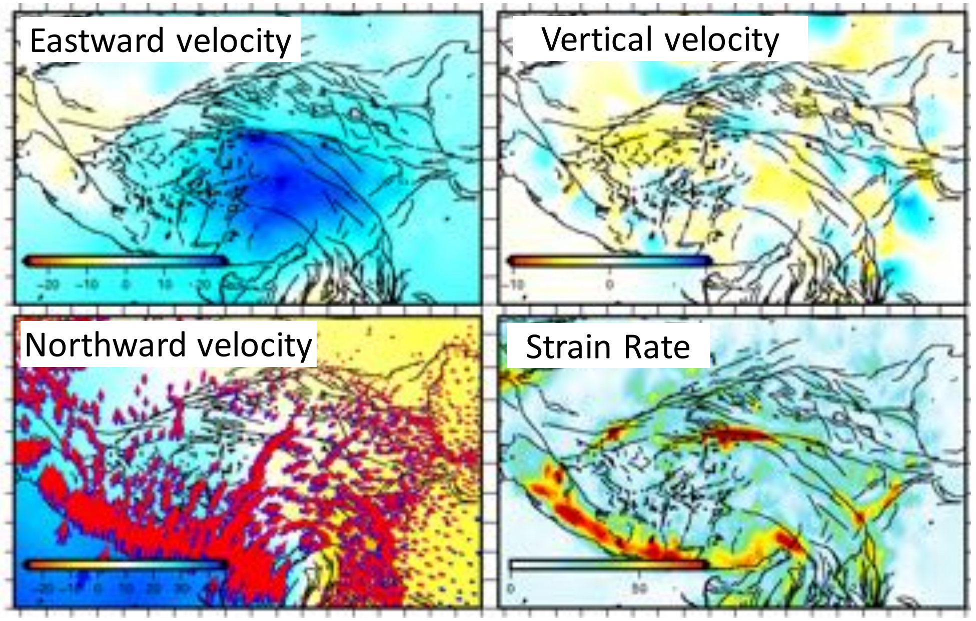
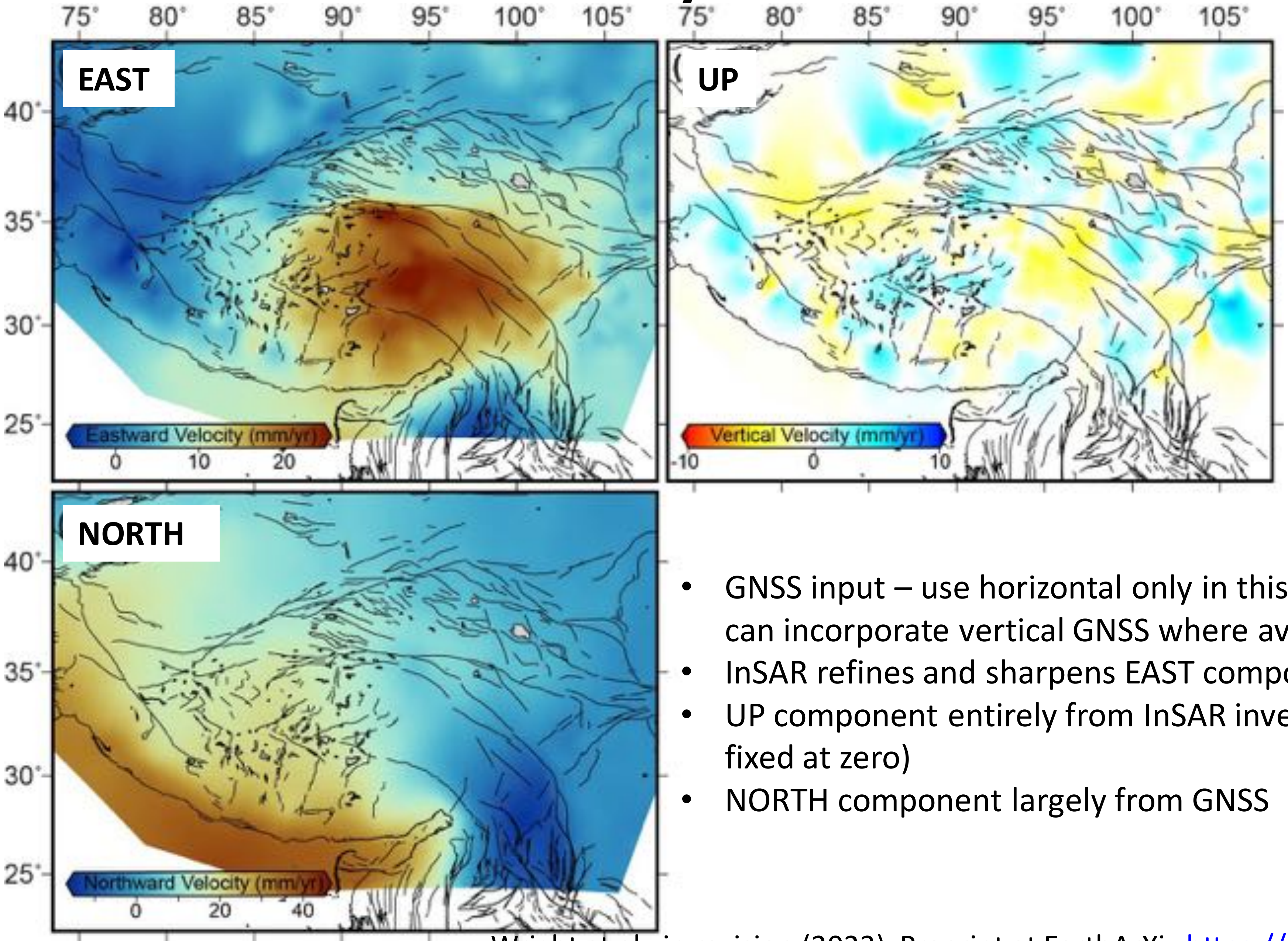


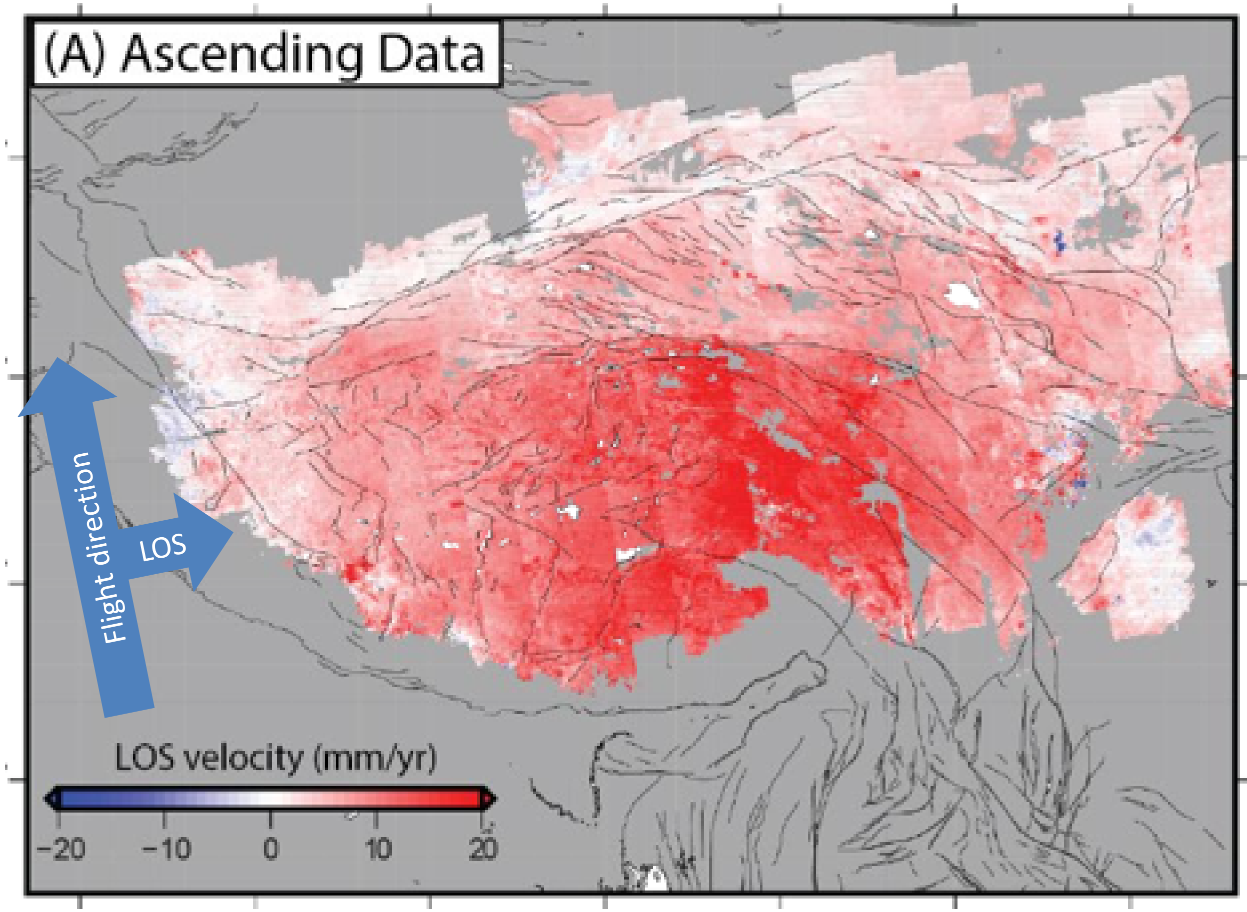
Velocity Field model

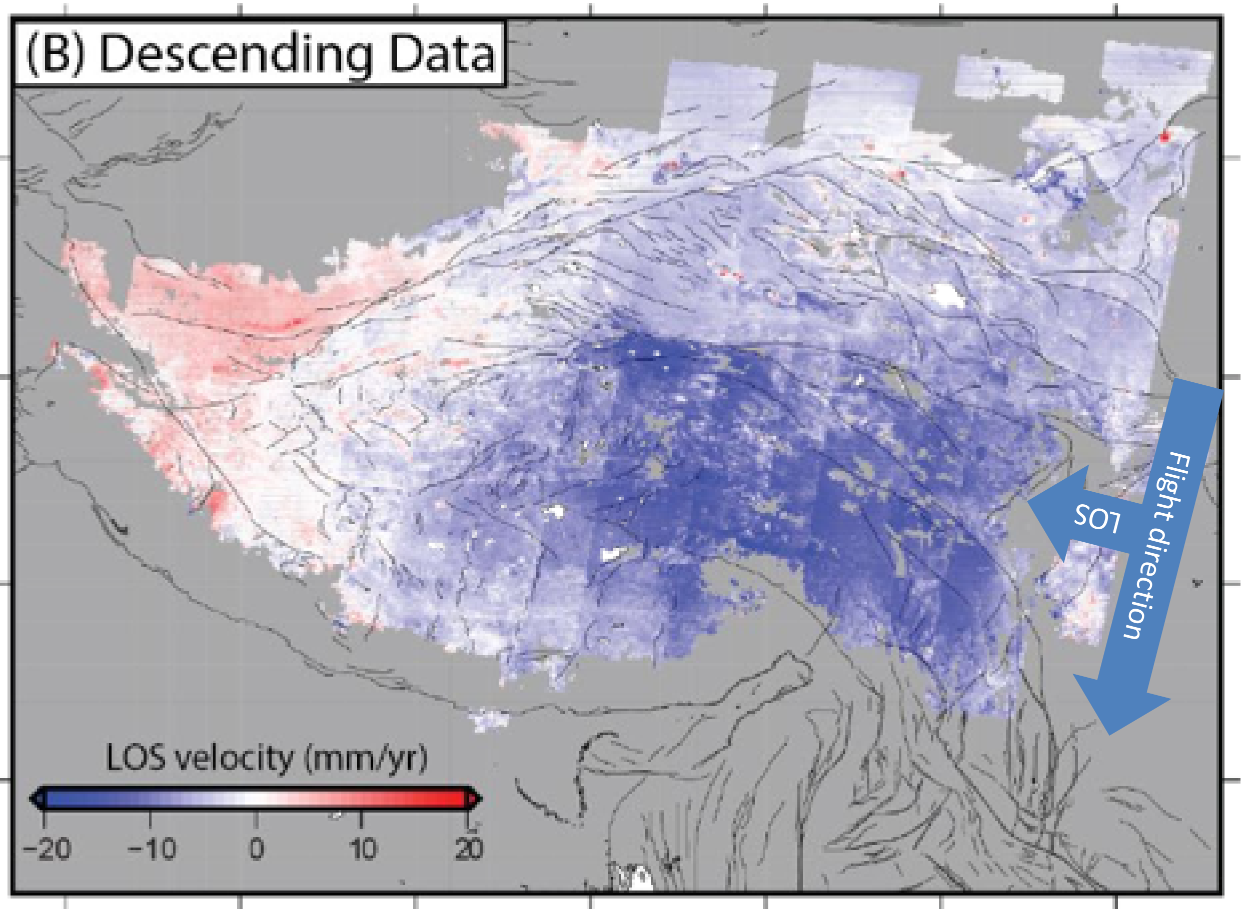


- GNSS input – use horizontal only in this inversion, but can incorporate vertical GNSS where available
- InSAR refines and sharpens EAST component
- UP component entirely from InSAR inversion (average fixed at zero)
- NORTH component largely from GNSS

Wright et al., in revision (2023); Preprint at EarthArXiv https://doi.org/10.31223/X5G95R

InSAR line-of-sight velocities in a Eurasia Reference Frame: **Data**





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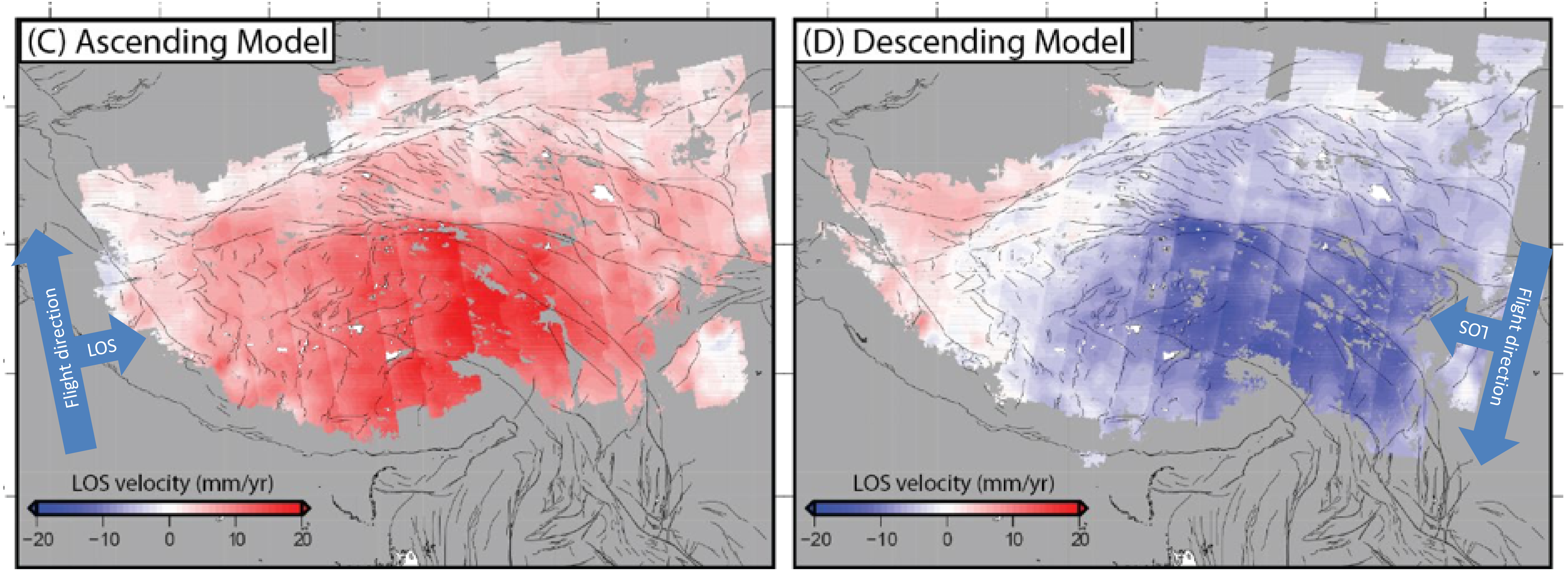
InSAR line-of-sight velocities in a Eurasia Reference Frame: **Model**



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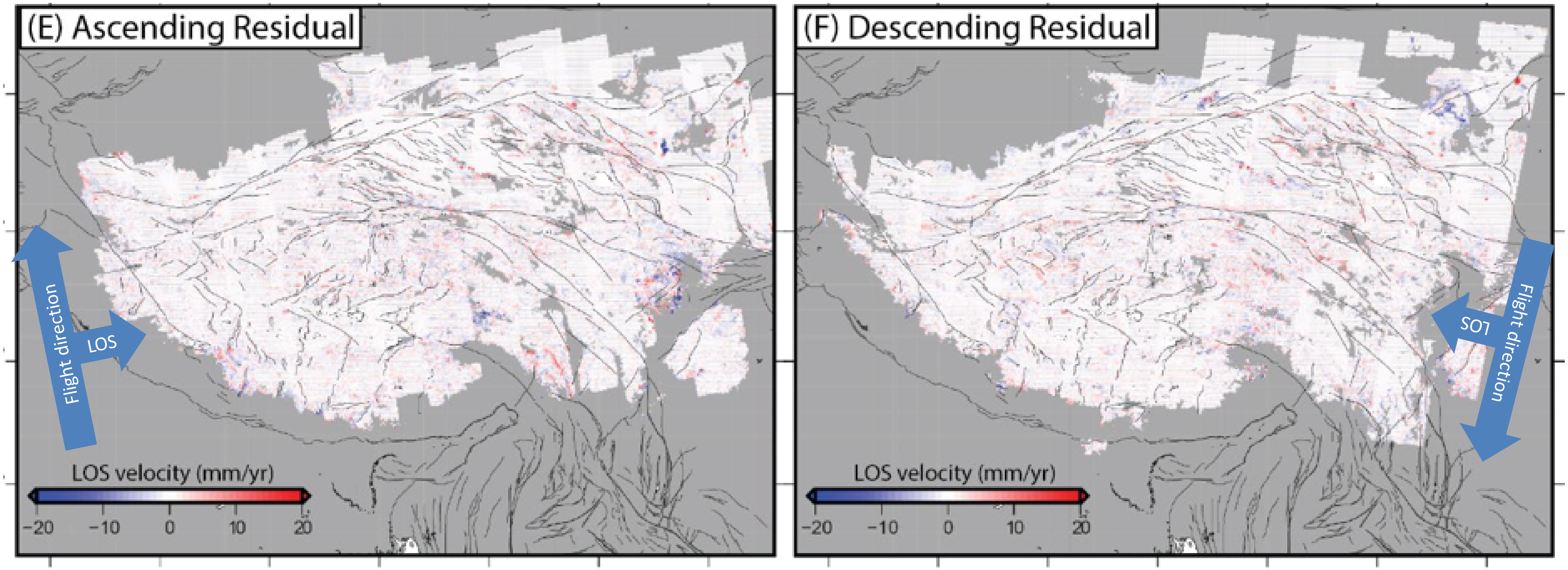
InSAR line-of-sight velocities in a Eurasia Reference Frame: **Residual**



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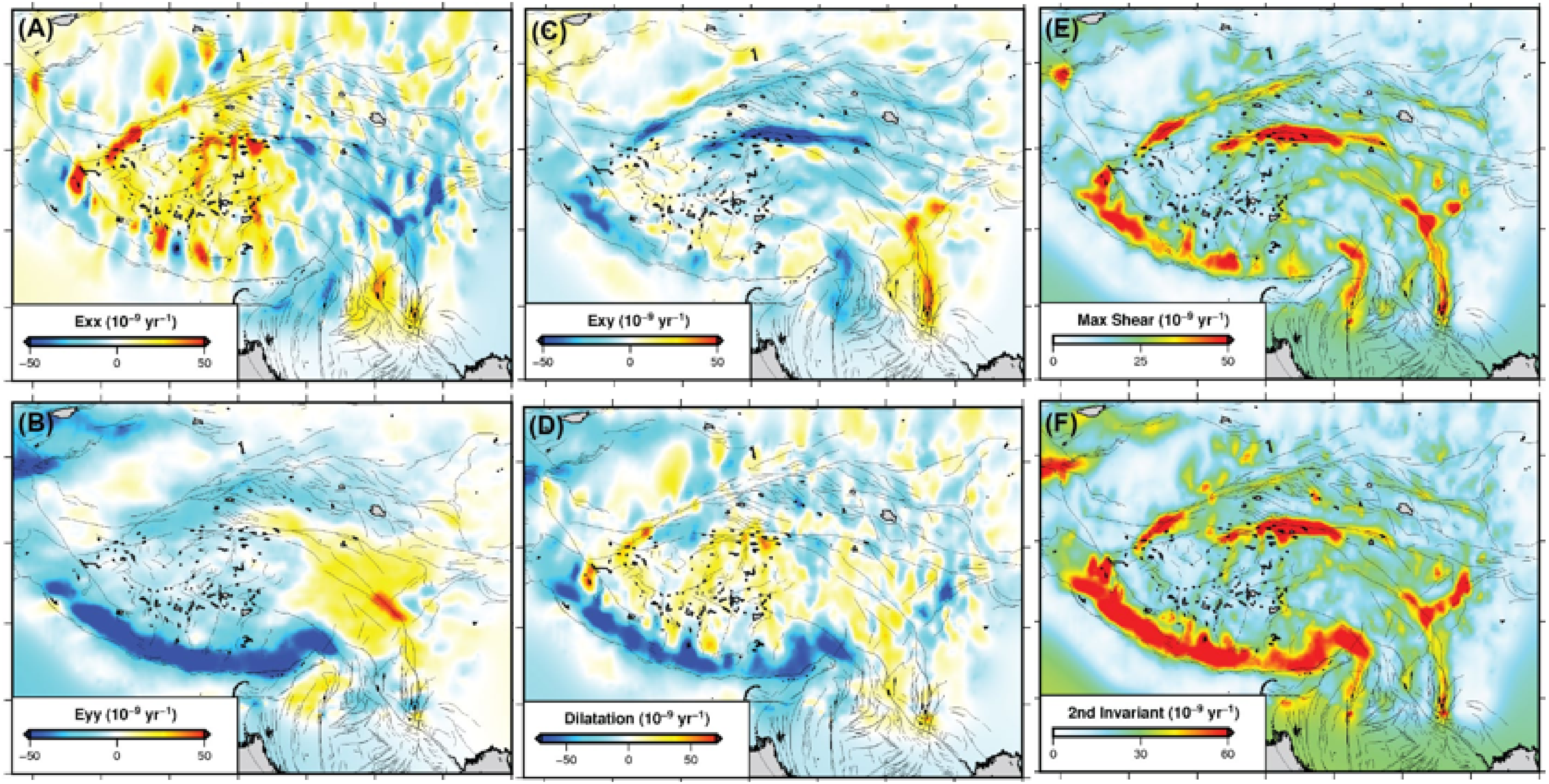
Strain Rate Fields (derived from Velocity Field Model)



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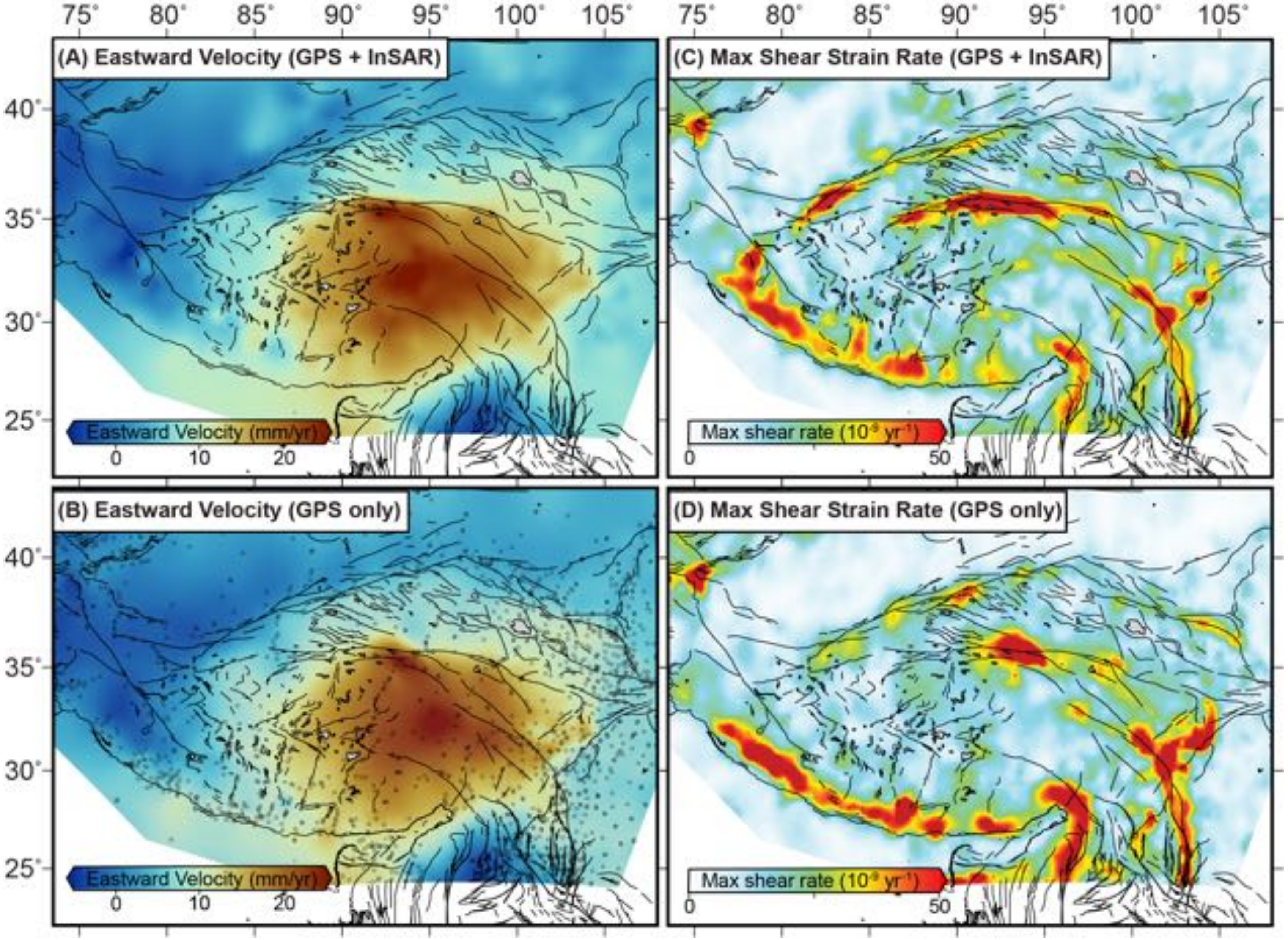
How much impact does the InSAR have?



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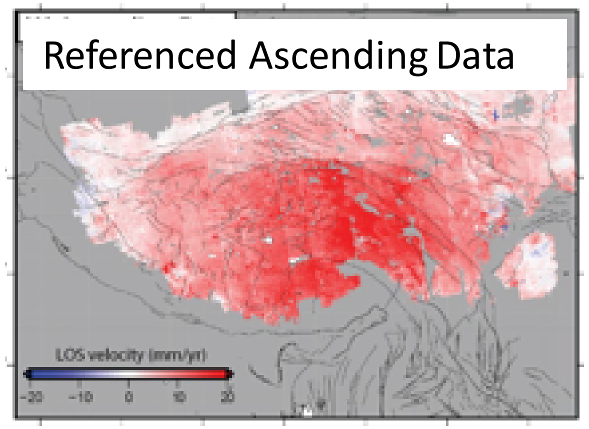
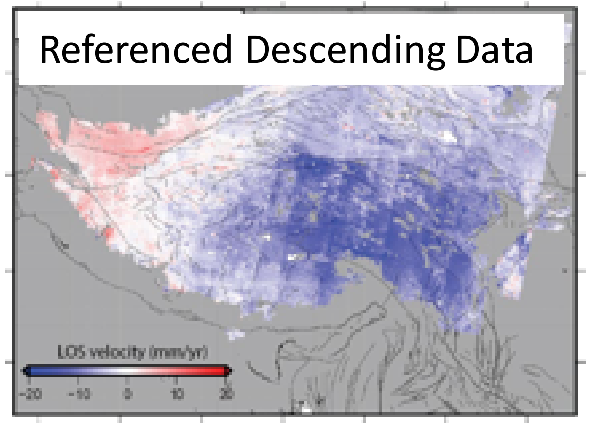
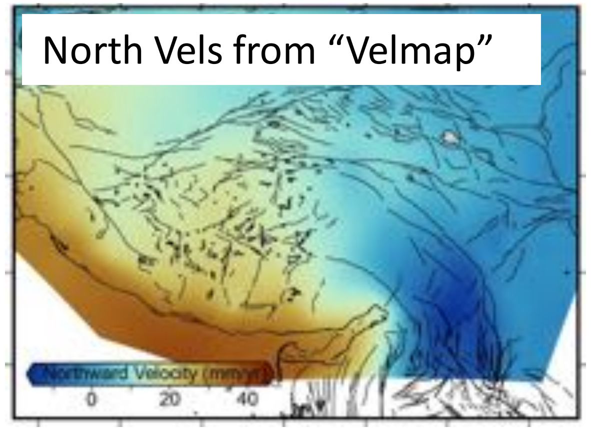
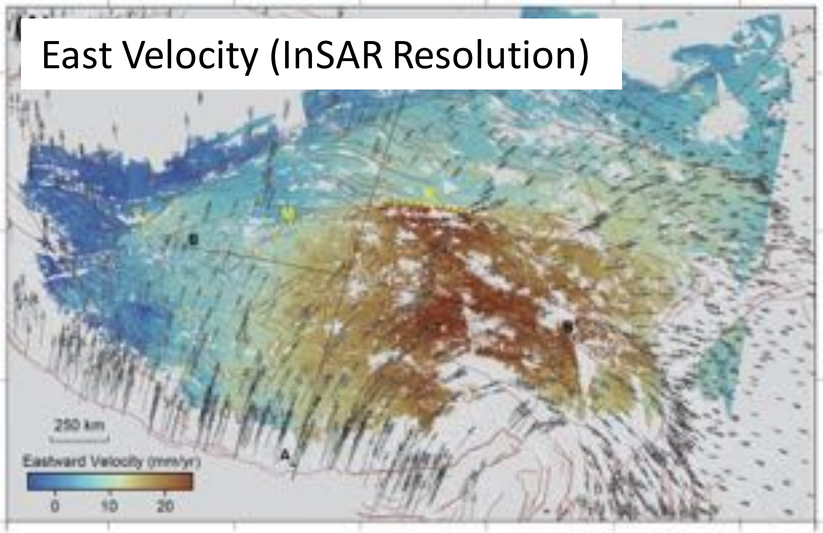
Invert for East and Up velocity grids at InSAR resolution

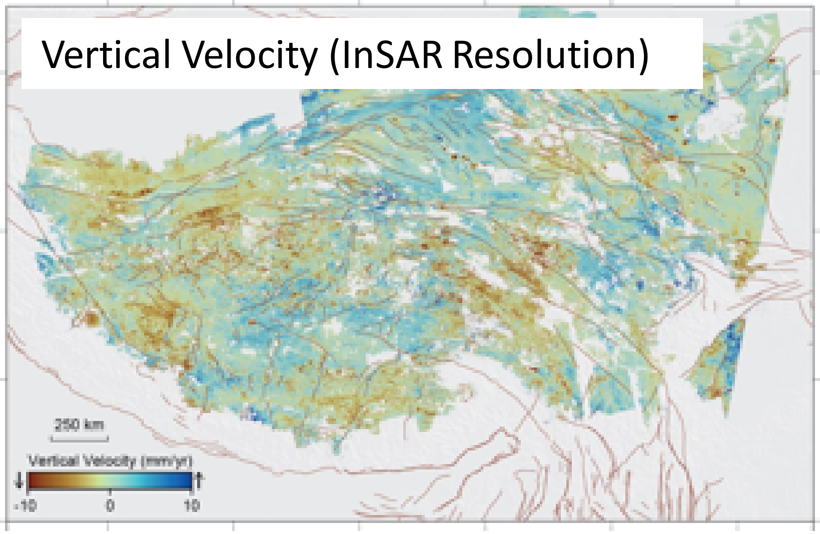






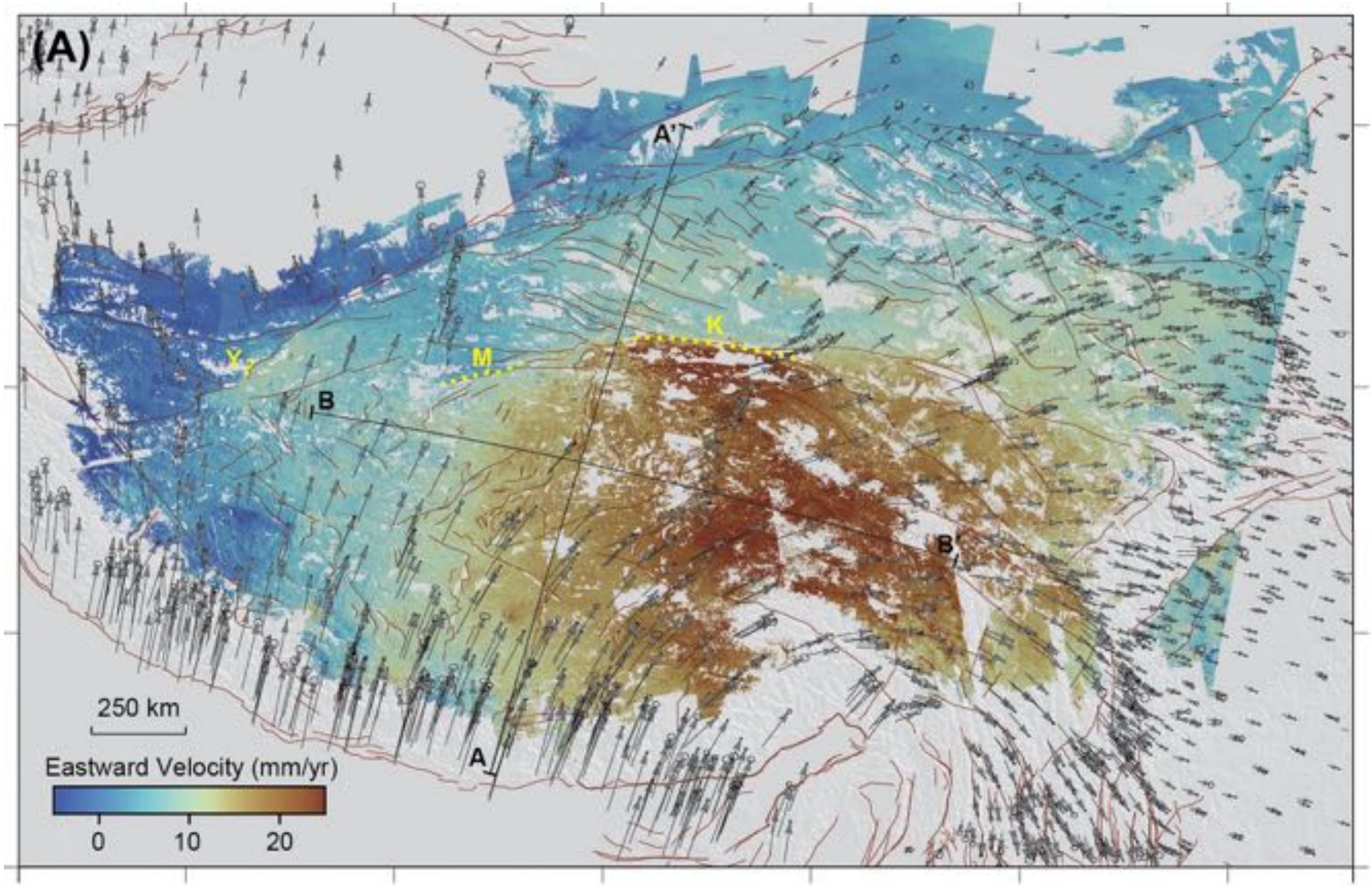
Pixel wise inversion using all available data at each pixel





Method: e.g. Wright et al., 2004; Weiss et al., 2020

Eastward Velocity of Tibet



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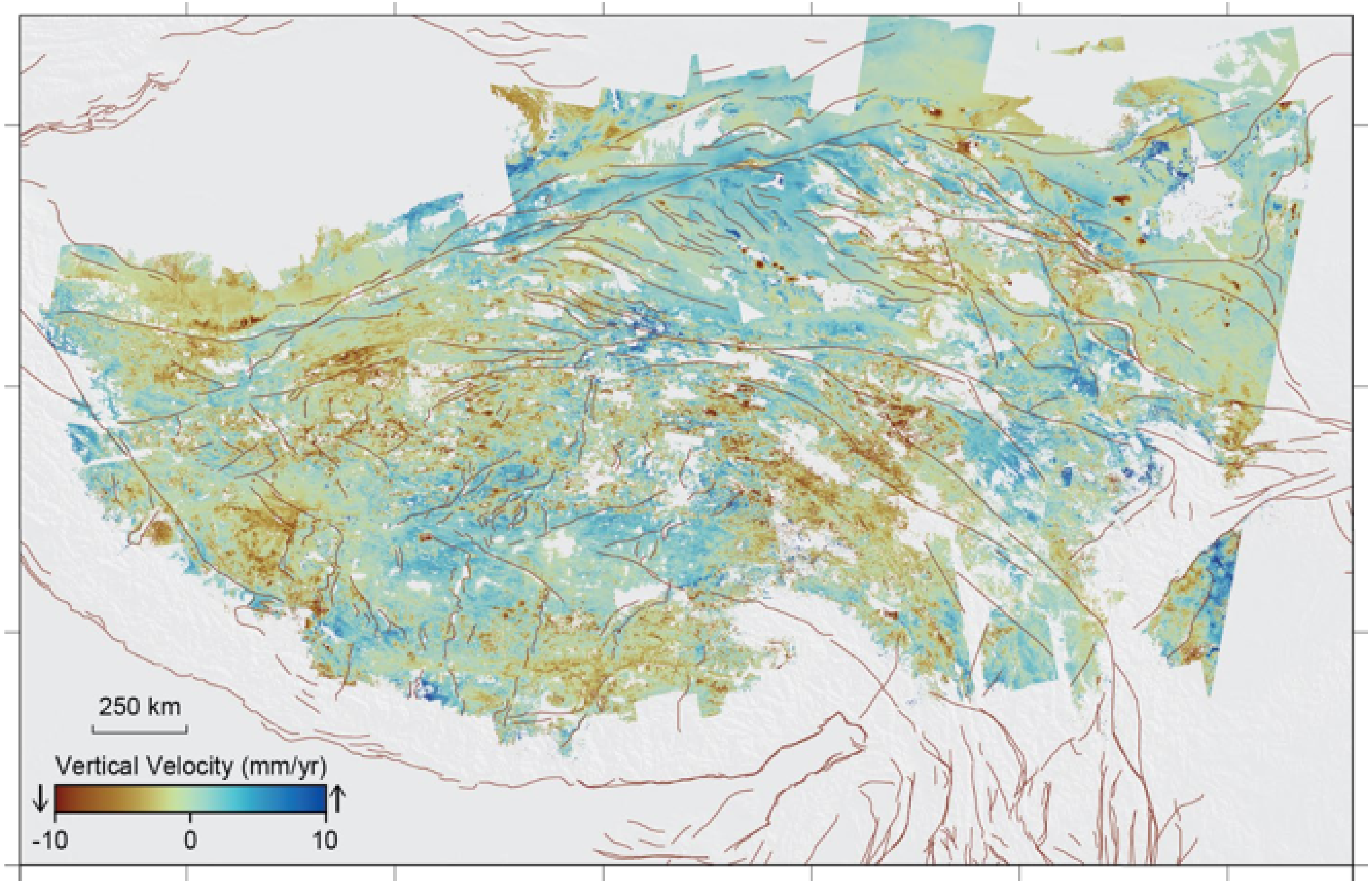
Vertical Velocity of Tibet



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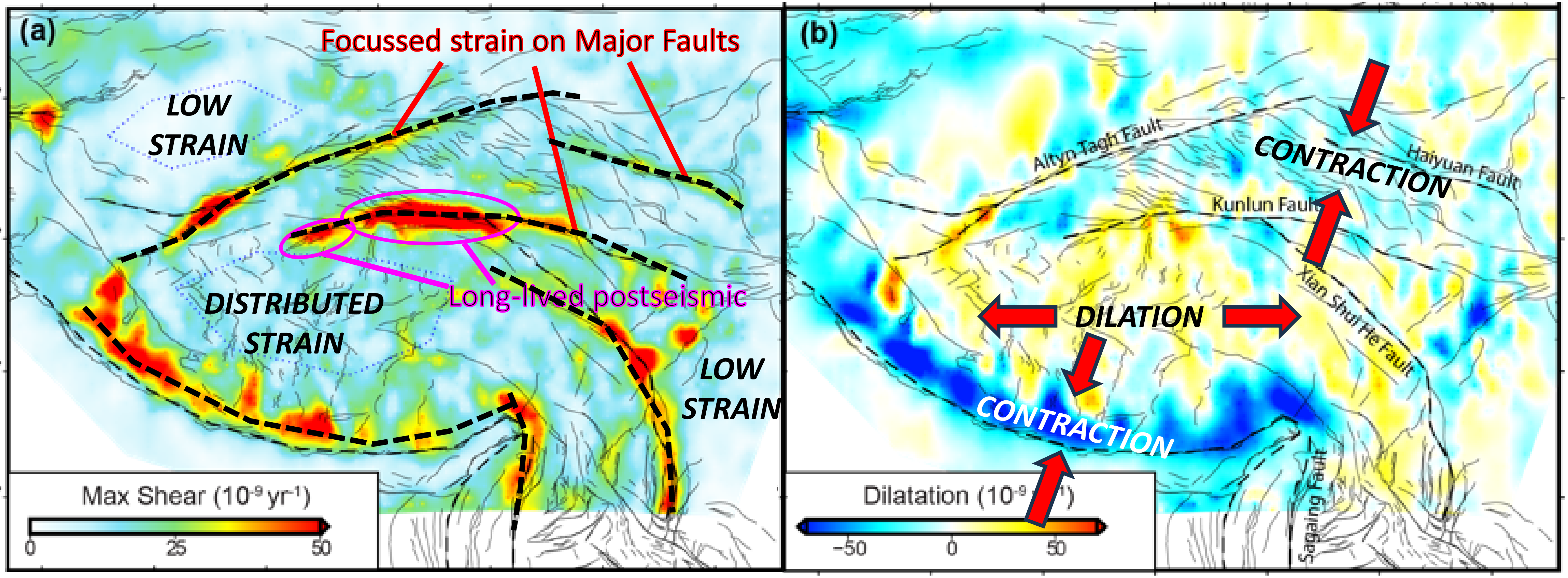
Key features of Deformation Field



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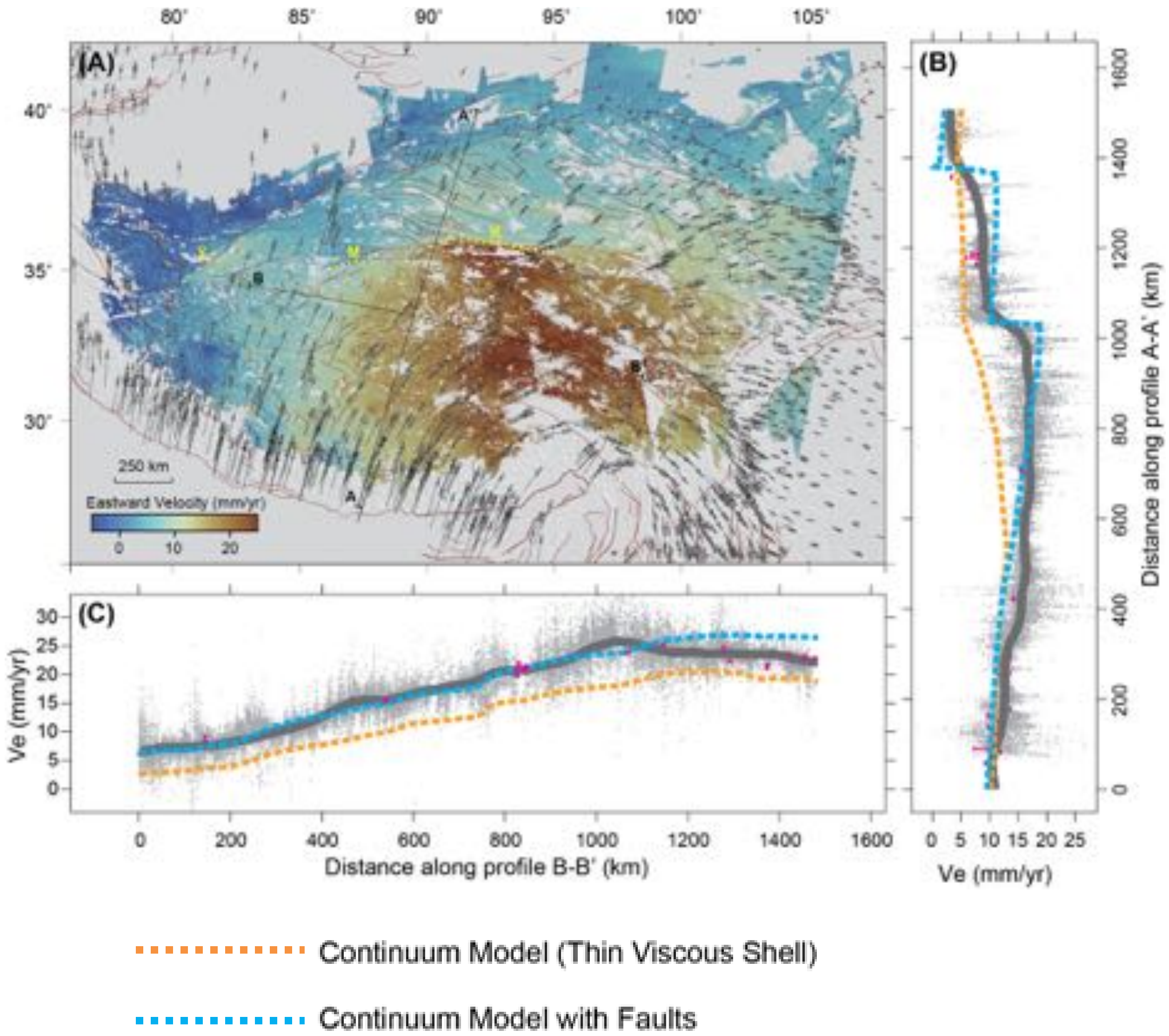
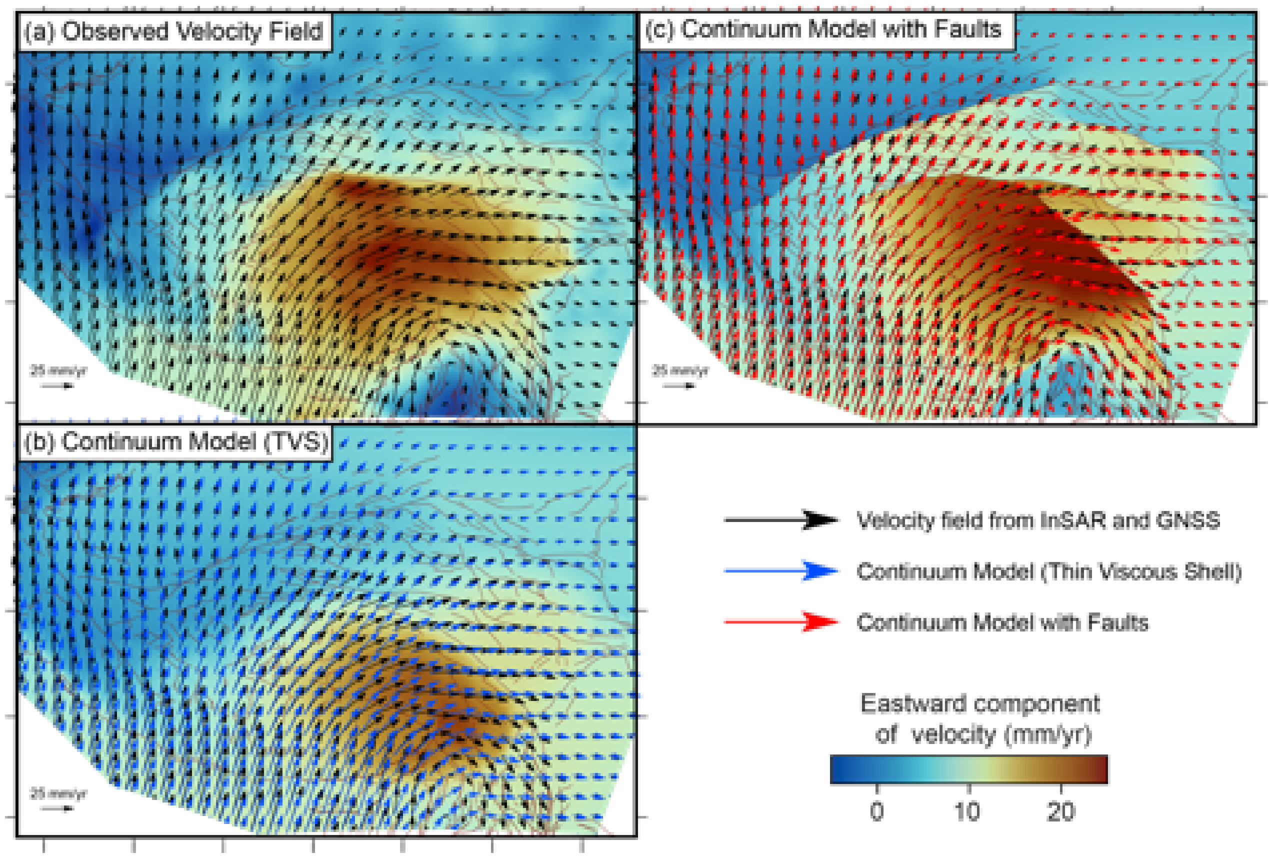
Deformation of Tibet – Continuum modulated by major faults?





Wright et al., in revision (2023); Preprint at EarthArXiv https://doi.org/10.31223/X5G95R

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Outline

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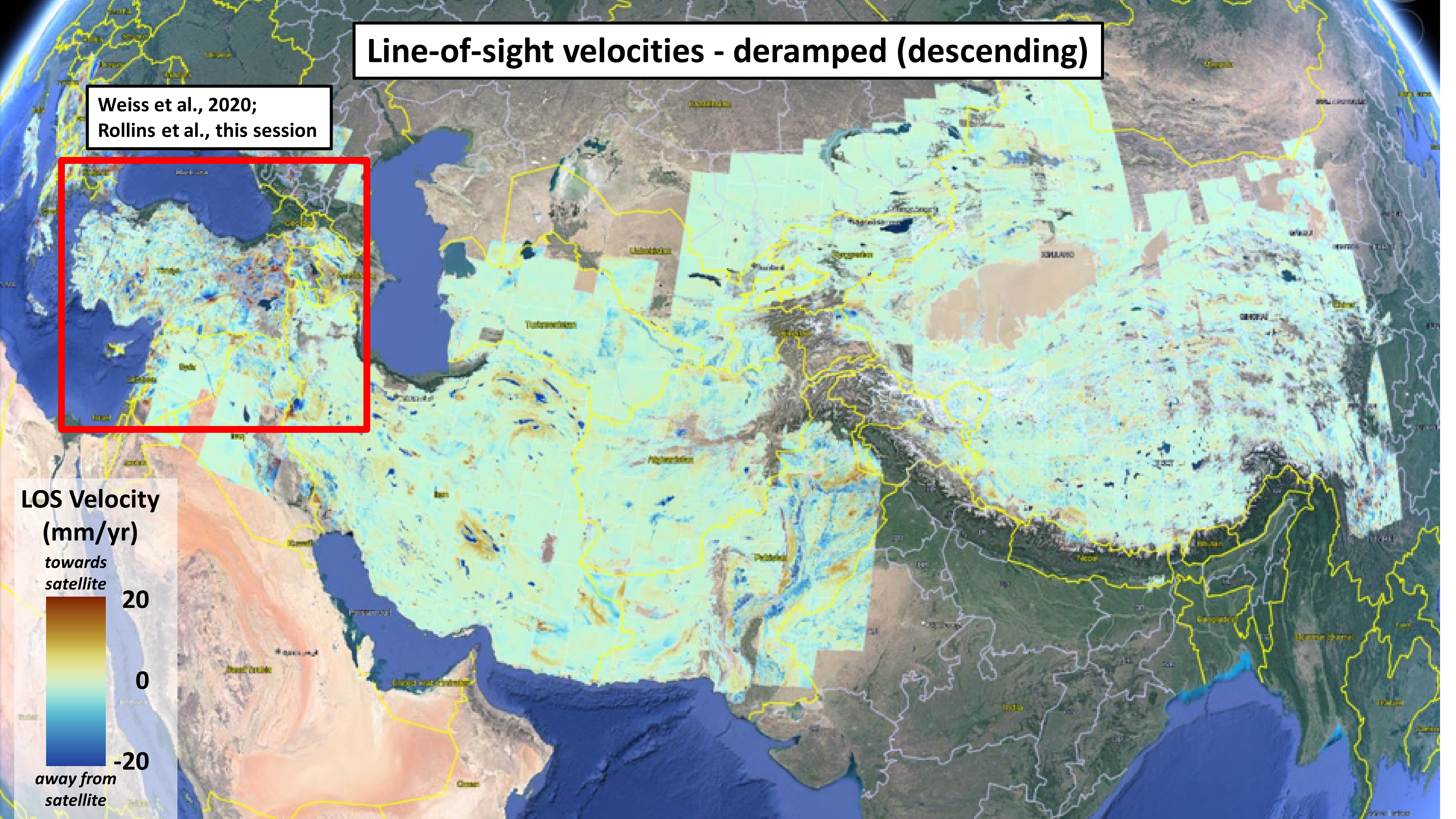
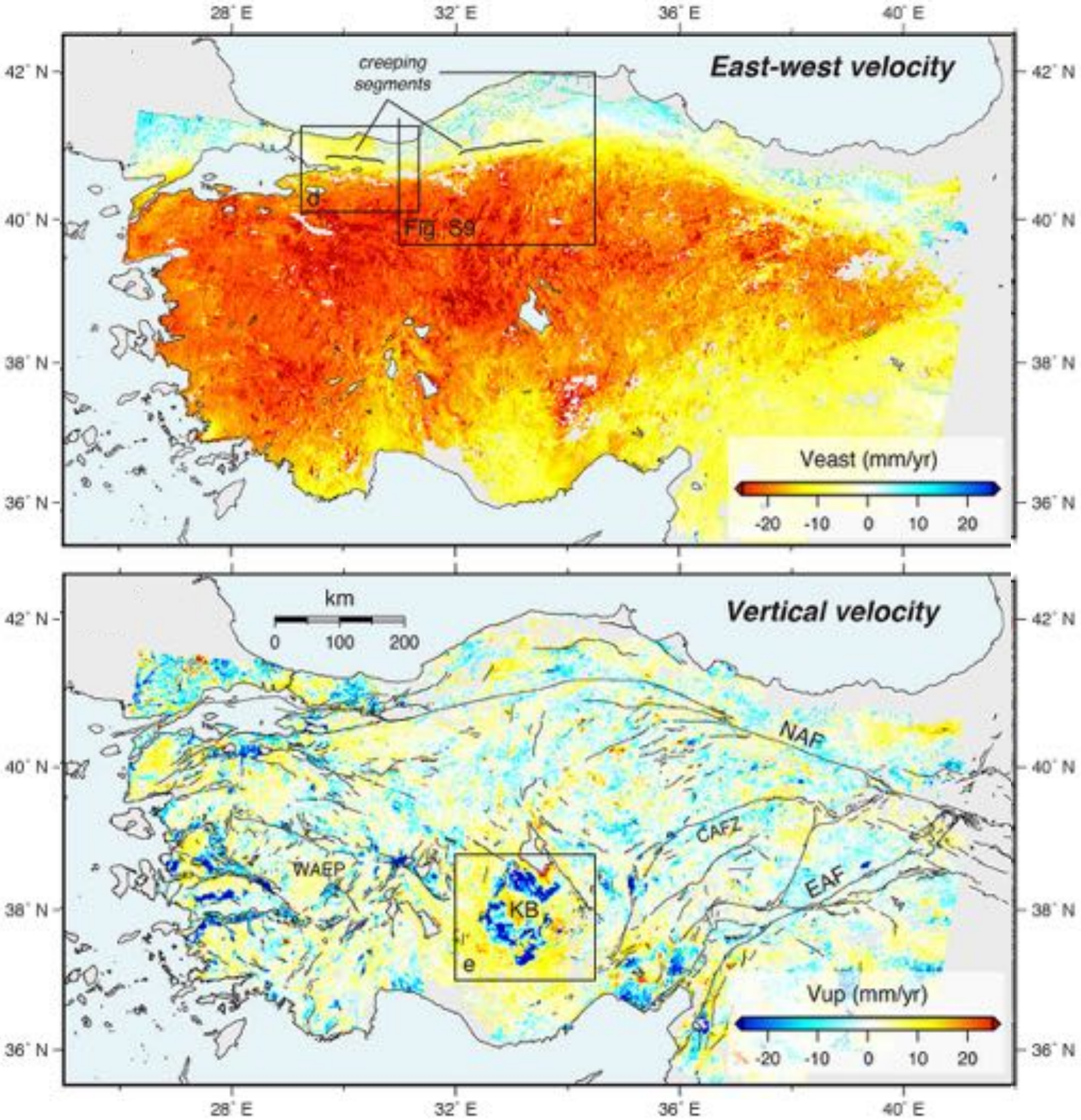
- Outlook
- Conclusions


Line-of-sight velocities - deramped (descending)
Weiss et al., 2020;
Rollins et al., this session
LOS Velocity
(mm/yr)
towards satellite
20
0
-20
away from satellite

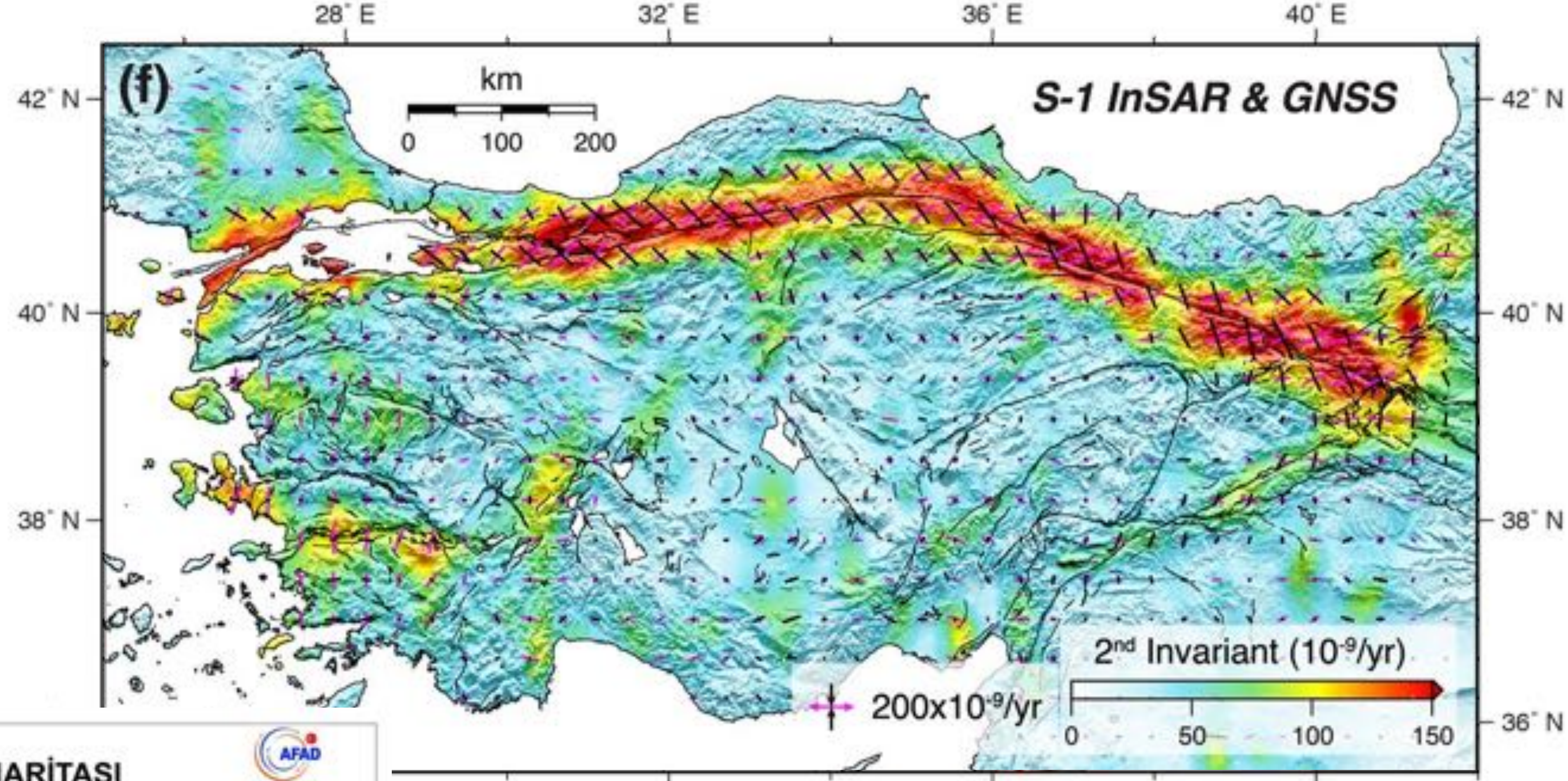
Velocity Field for Türkiye from Sentinel-1

(Weiss et al., GRL 2020)



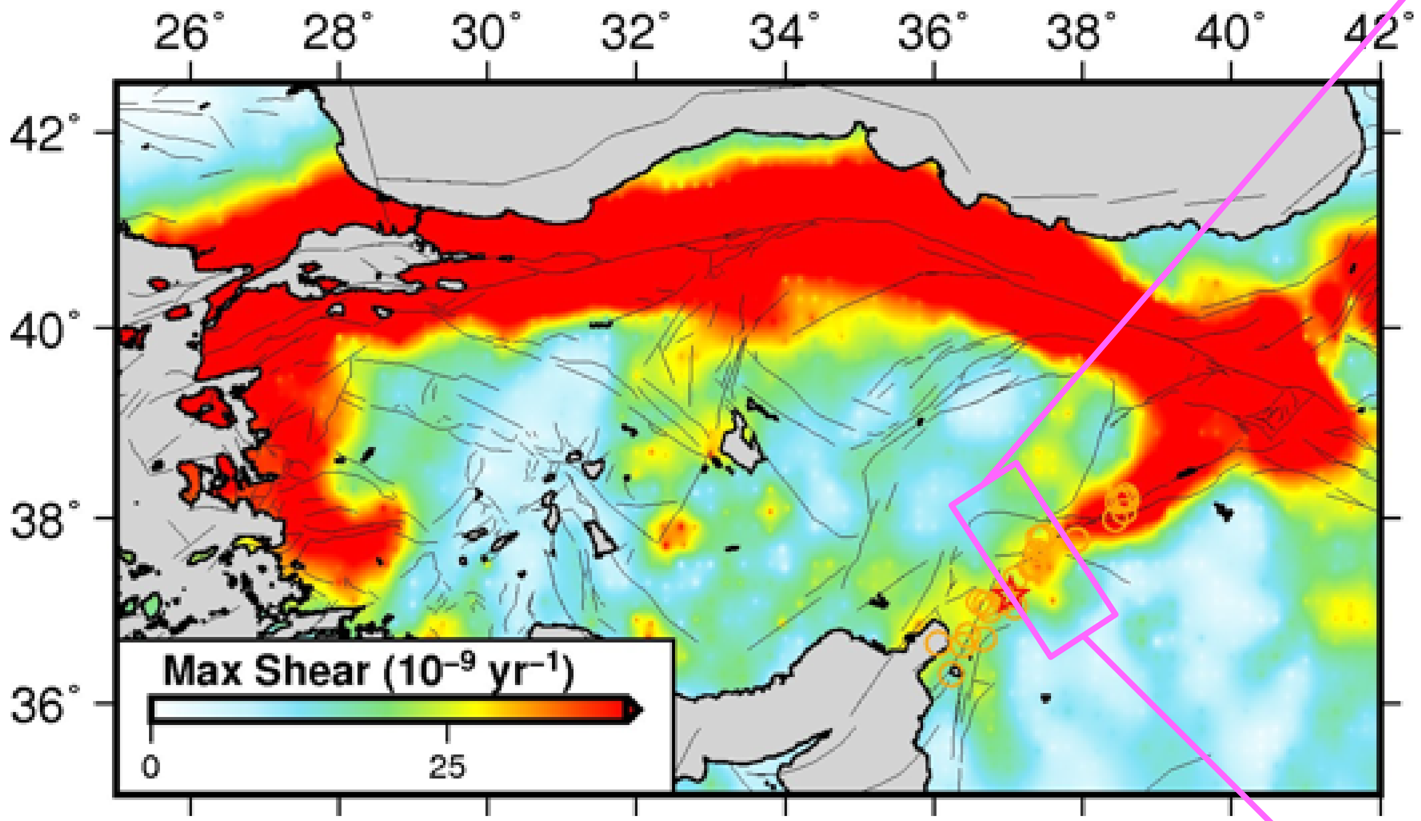
Velocity Field for Türkiye from Sentinel-1

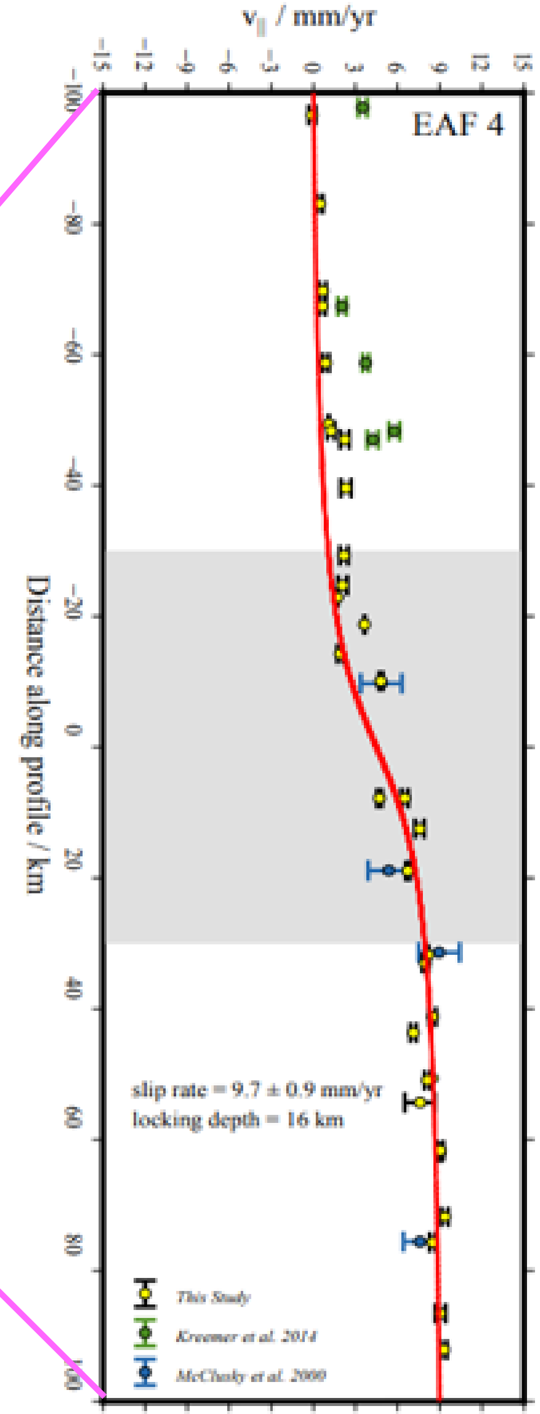
(Weiss et al., GRL 2020)



Strains in Türkiye are similar to most recent seismic hazard model

Strain accumulation in location of 2023 Türkiye-Syria earthquakes

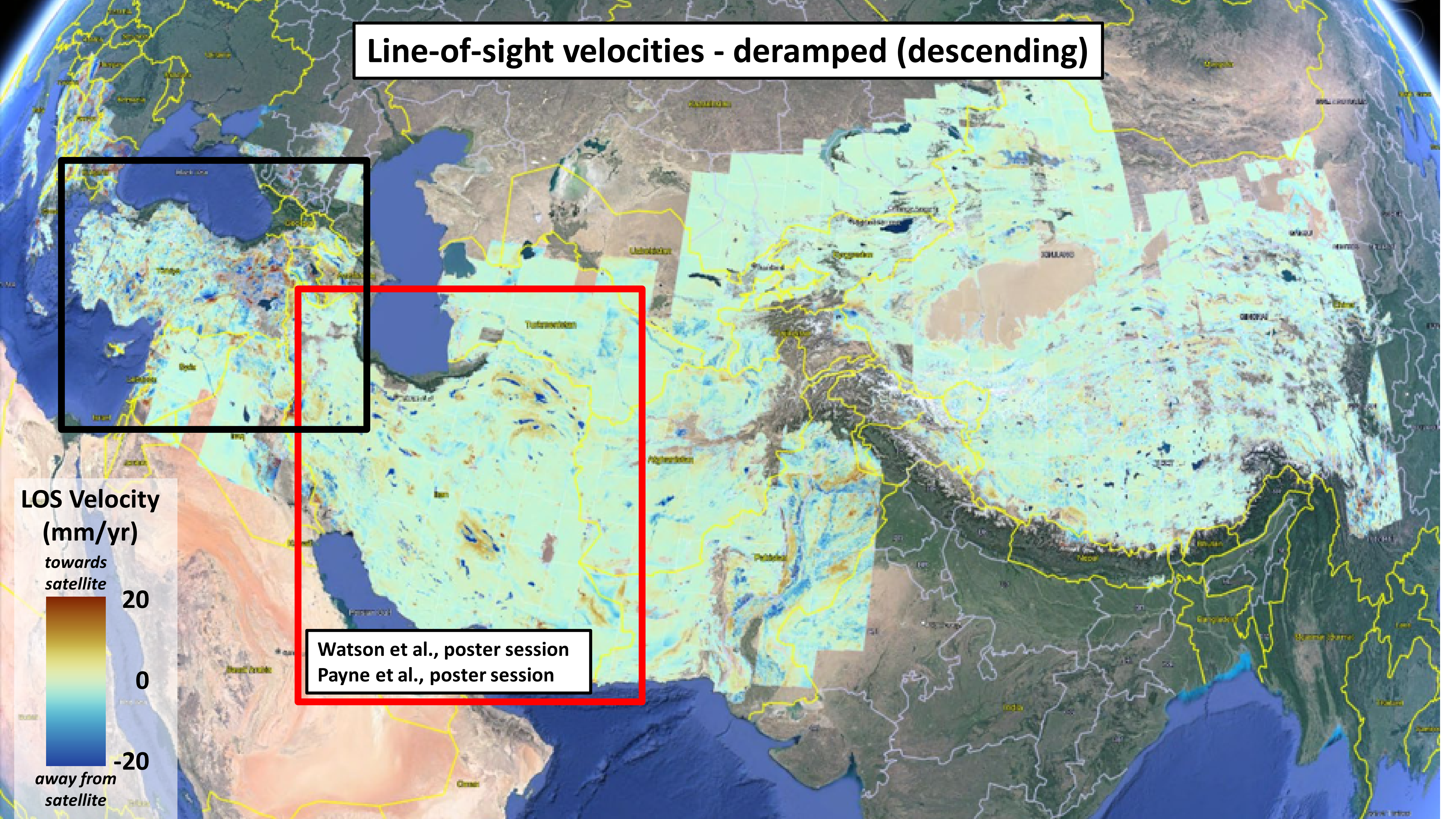




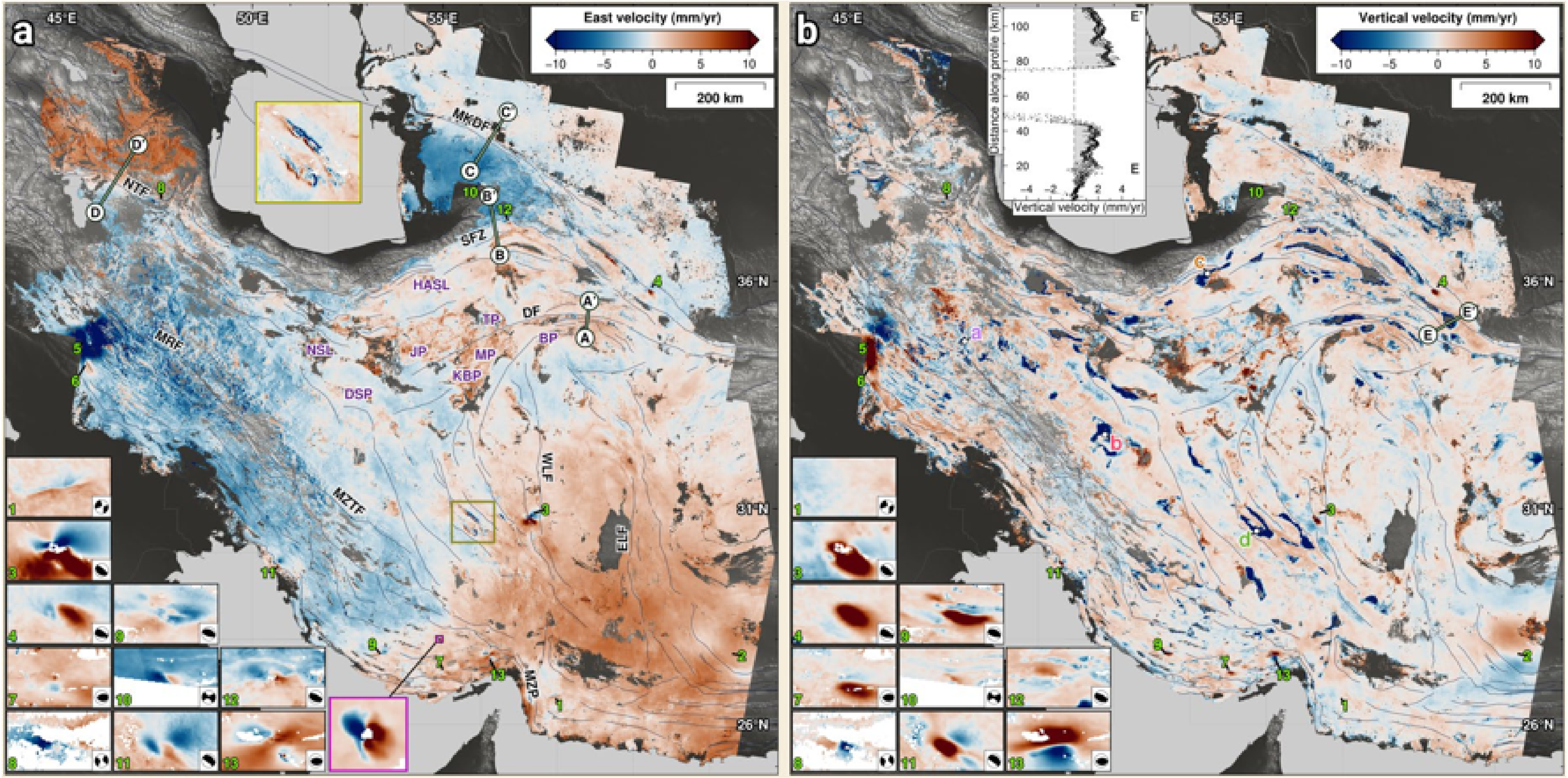
Kurt et al., 2023

Also see Chris Rollins talk later in this session

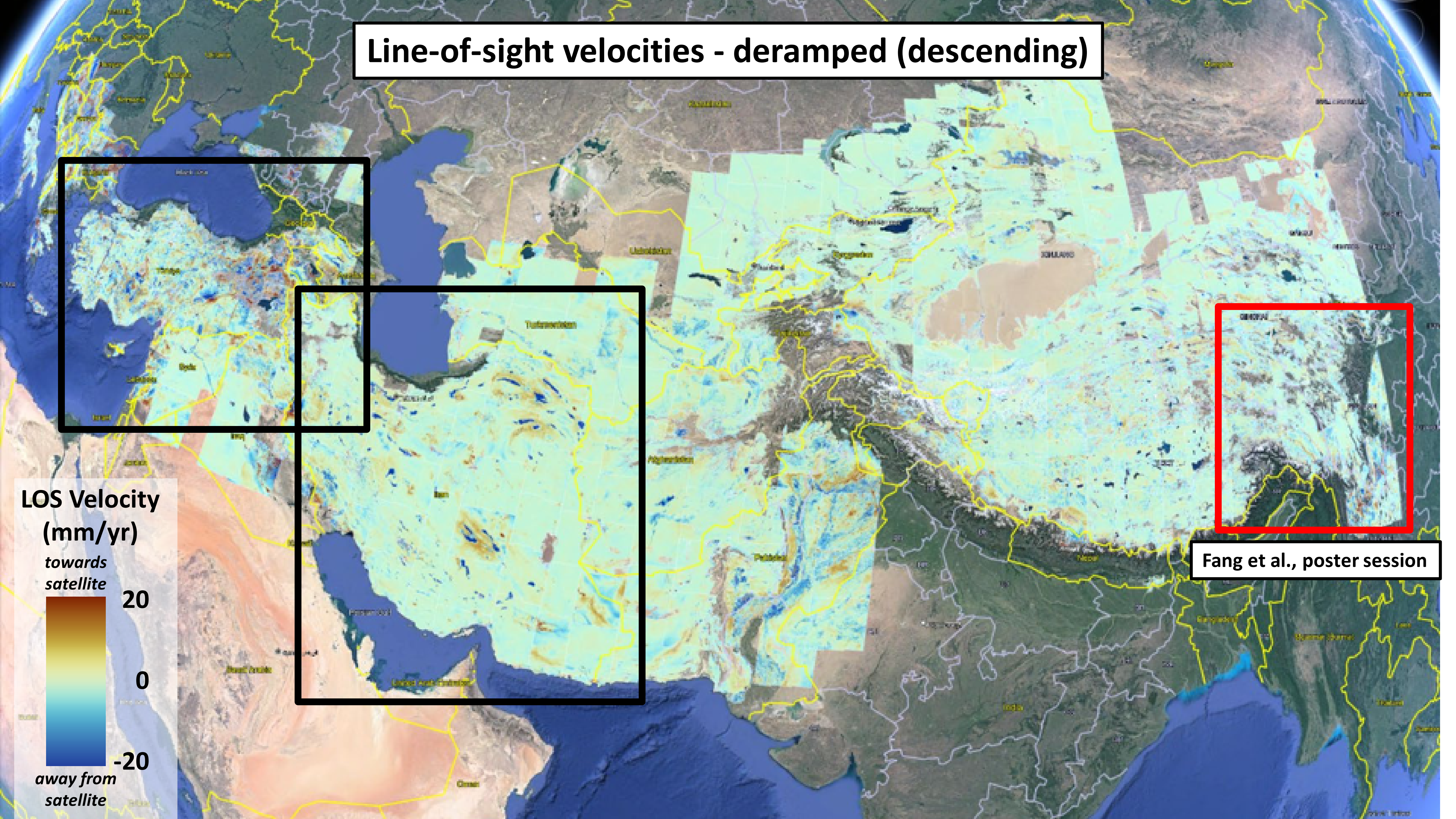
Line-of-sight velocities - deramped (descending)



Velocity Field for Iran

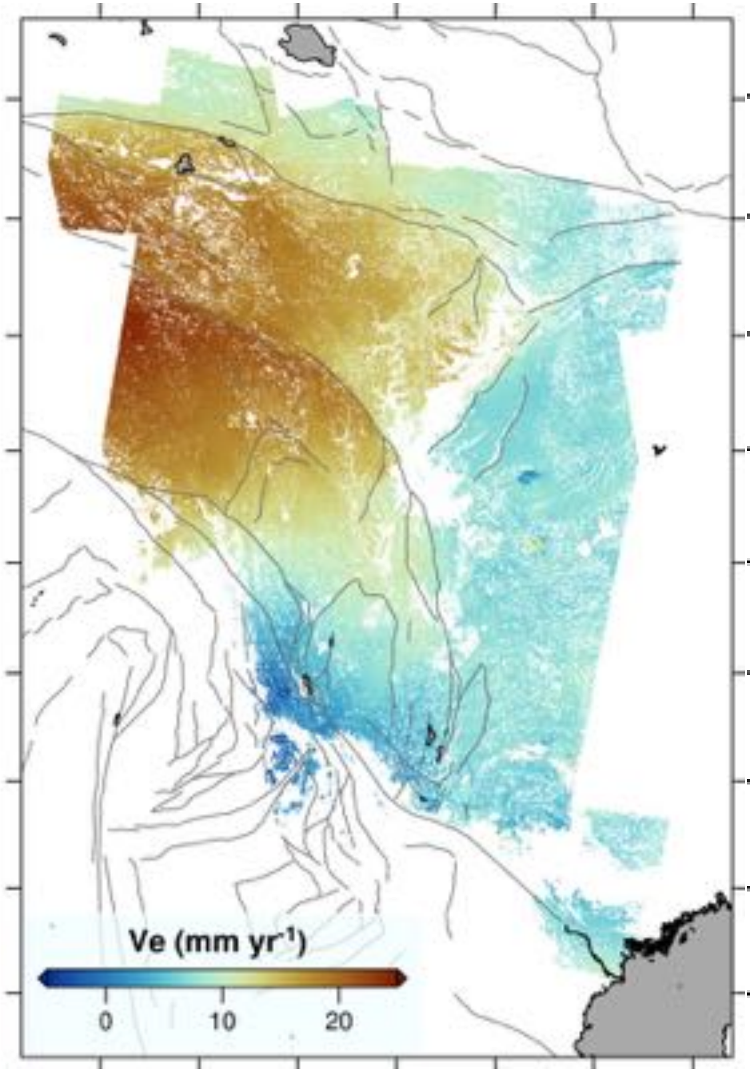


See Andrew Watson and Jessica Payne posters at this meeting

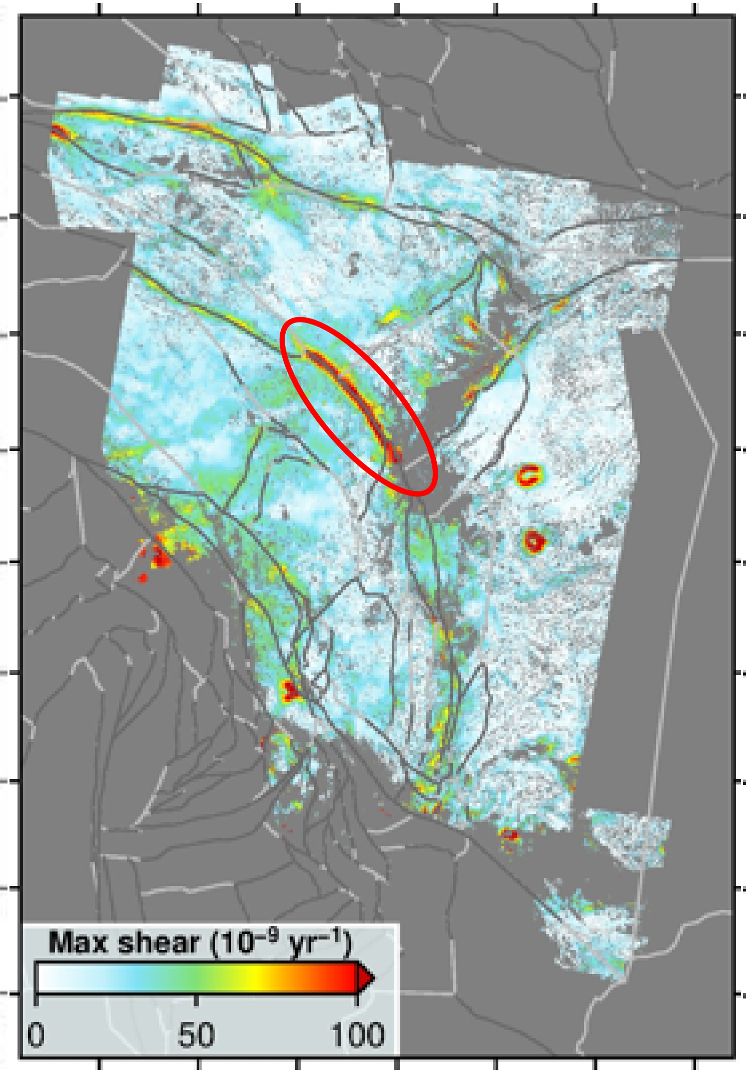


Line-of-sight velocities - deramped (descending)
LOS Velocity (mm/yr)
towards satellite
20
0
-20
away from satellite
Fang et al., poster session

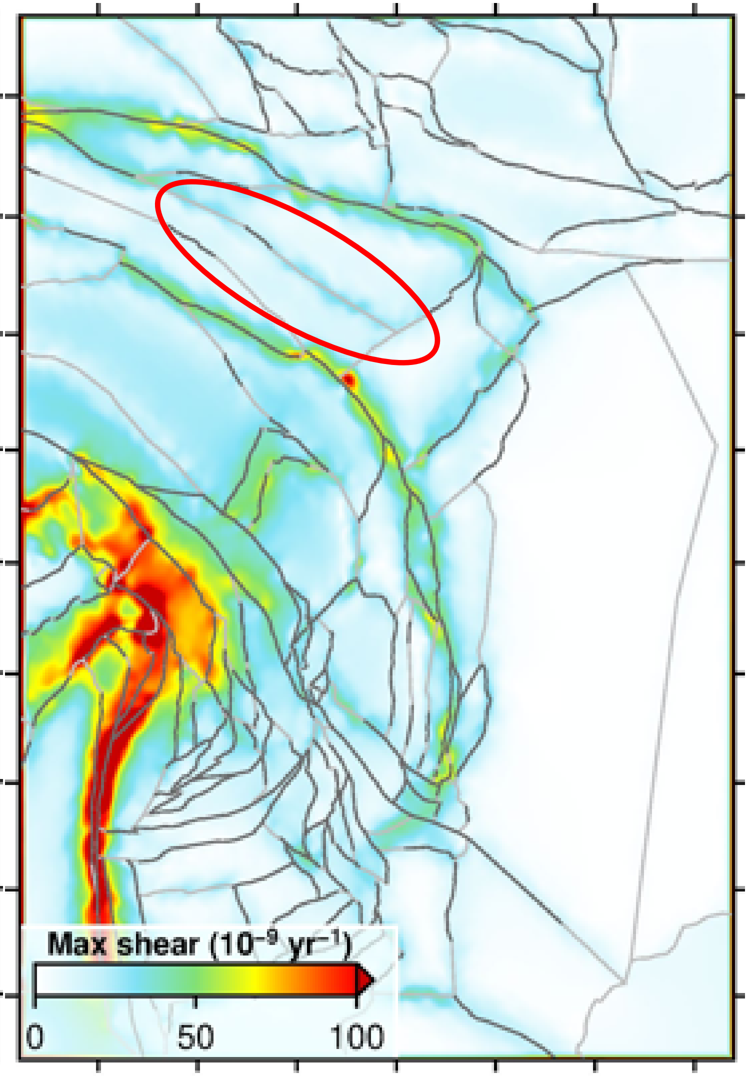
Velocity Field for SE Tibetan Plateau (See Jin Fang Poster)



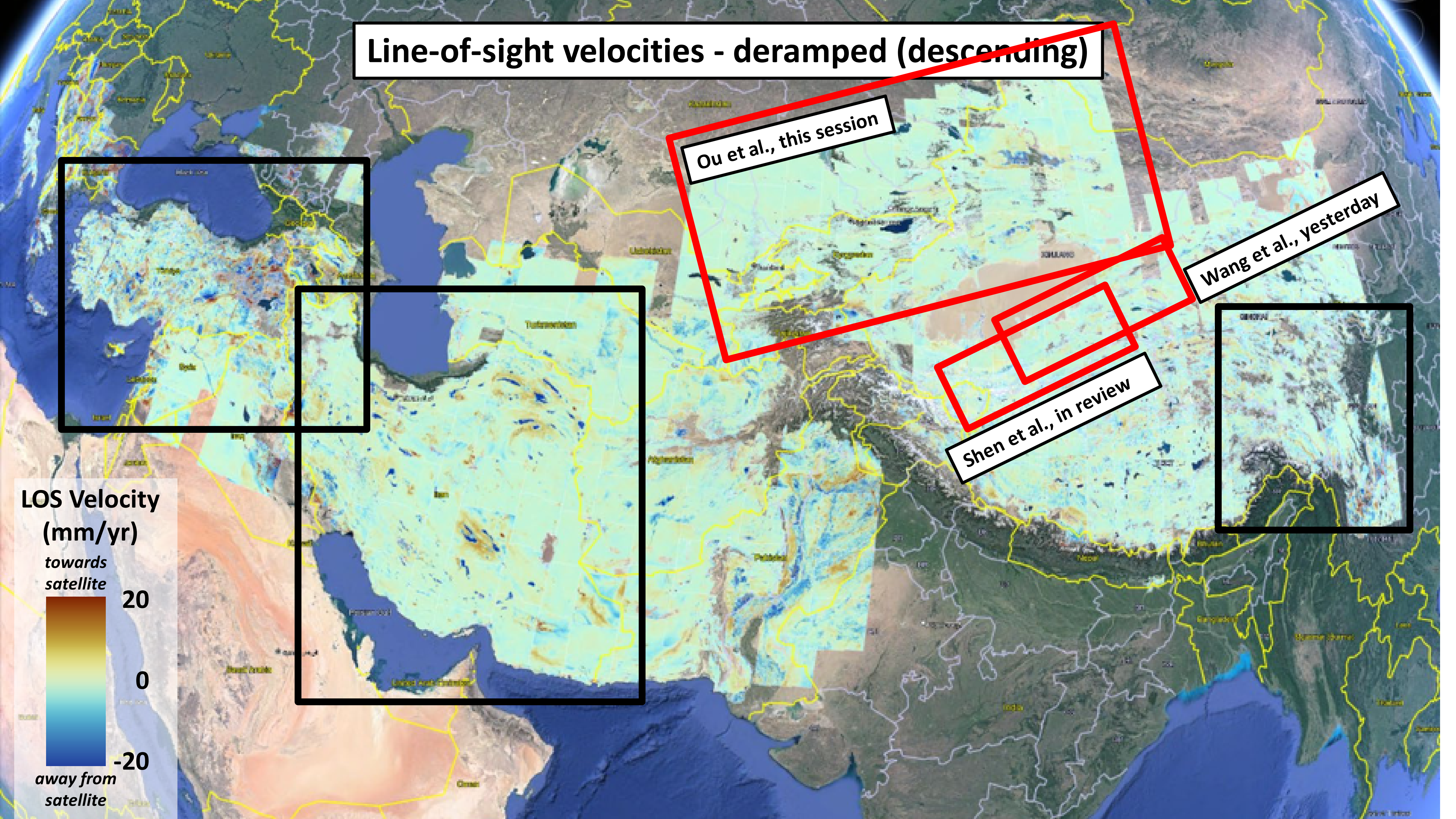
East velocity



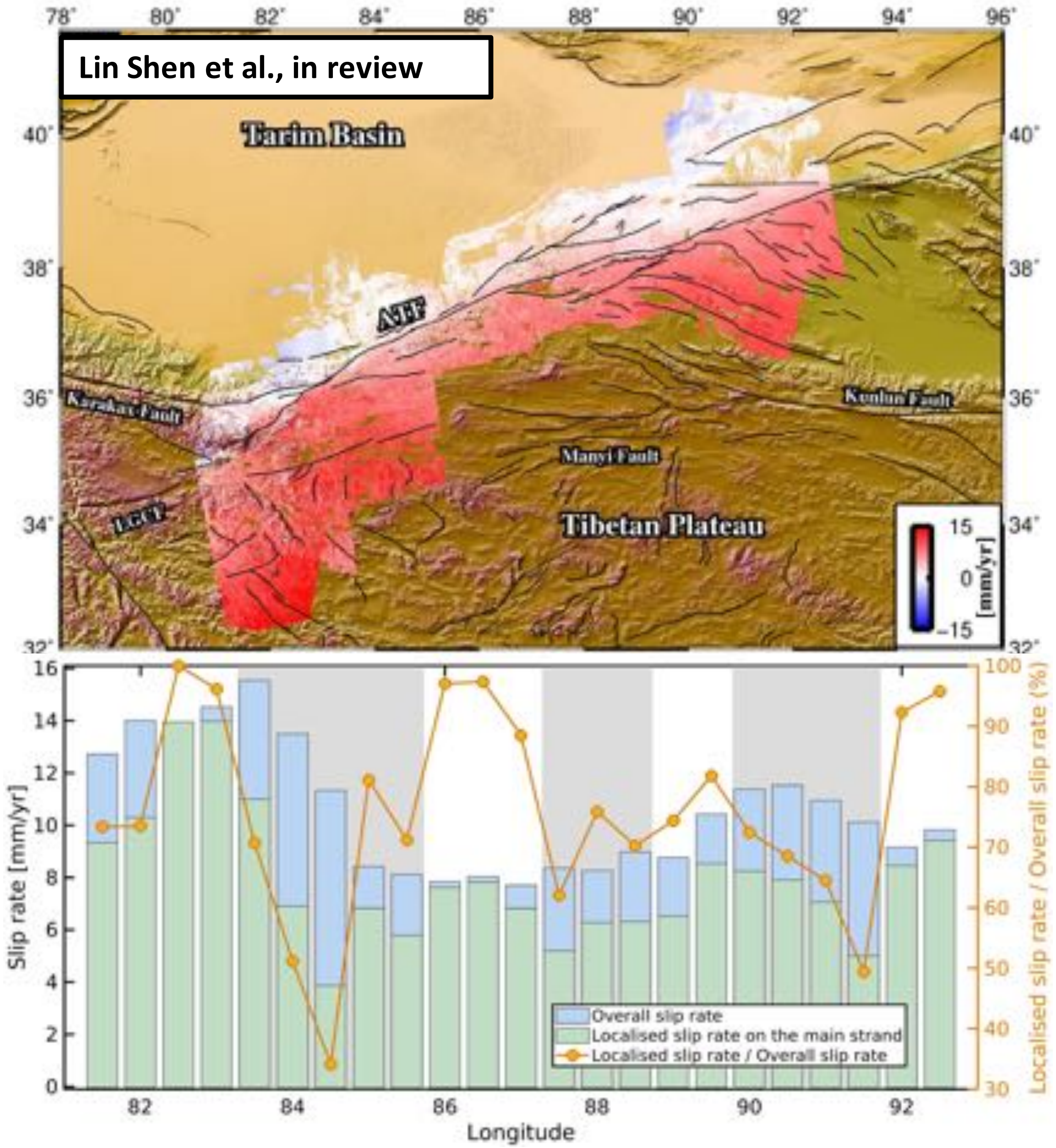
Maximum Shear Strain (deried from East Velocity at InSAR resolution)

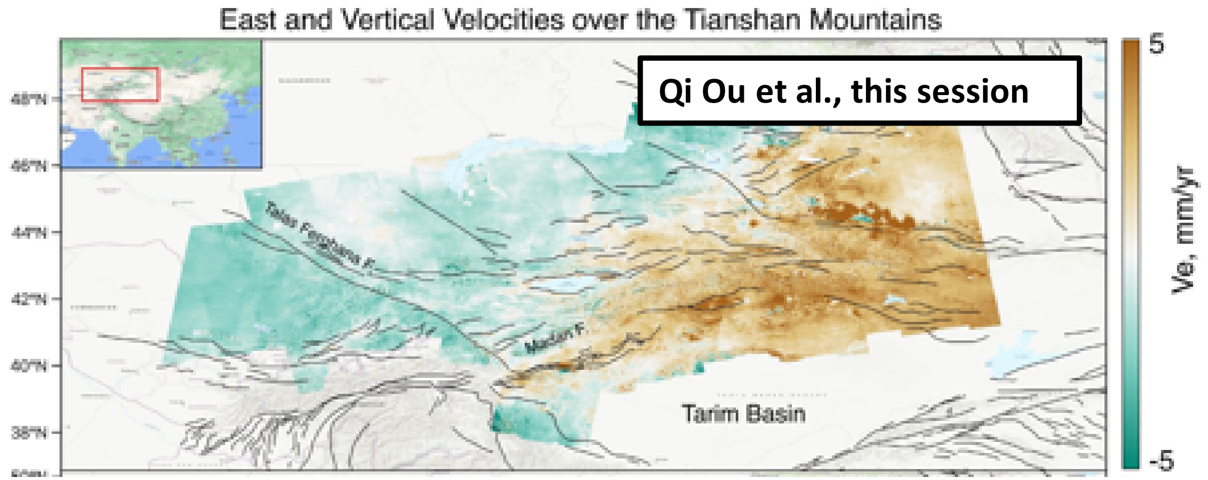


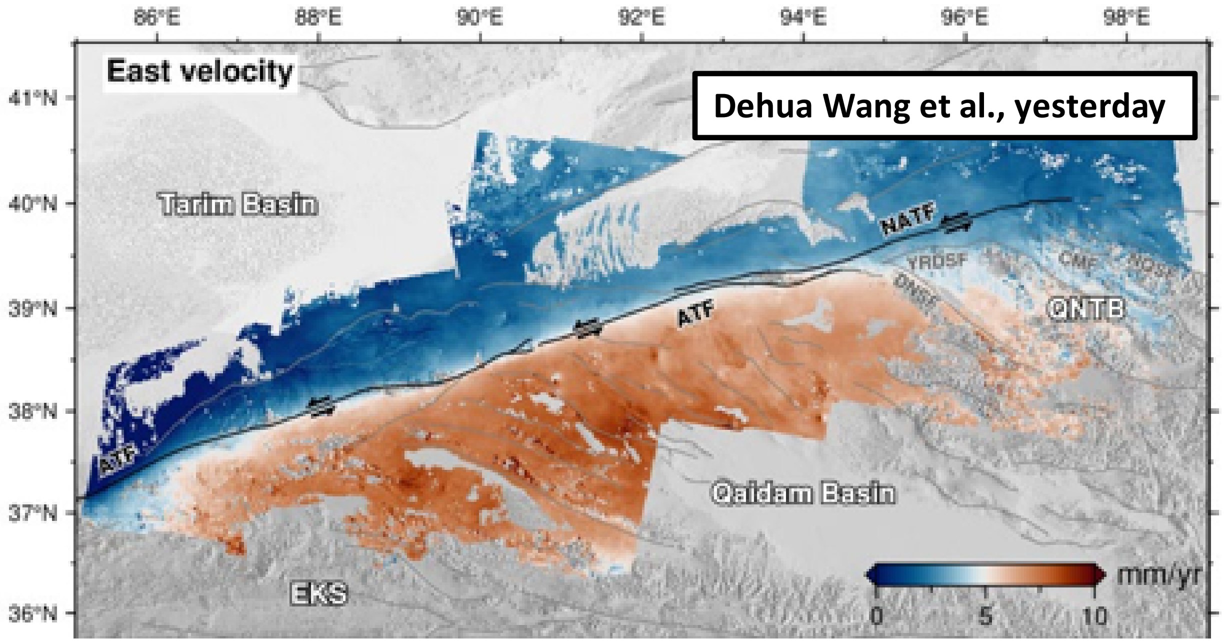
Maximum Shear Strain (derved from Styron et al (2023) block model.)


Line-of-sight velocities - deramped (descending)
Ou et al., this session
Wang et al., yesterday
Shen et al., in review
LOS Velocity (mm/yr)
towards satellite
20
0
-20
away from satellite

Regional studies in the India-Eurasia collision zone







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Key SAR missions for tectonic InSAR

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Conclusions

- We can combine InSAR and GNSS to map tectonic movement across very large regions
- Large, open archive from Sentinel-1 has made this possible.
- Automatic processing gives good results – can be improved with bespoke local area processing
- We are using the results to help understand geodynamics and seismic hazard
- Future missions make this an exciting time for tectonic geodesy