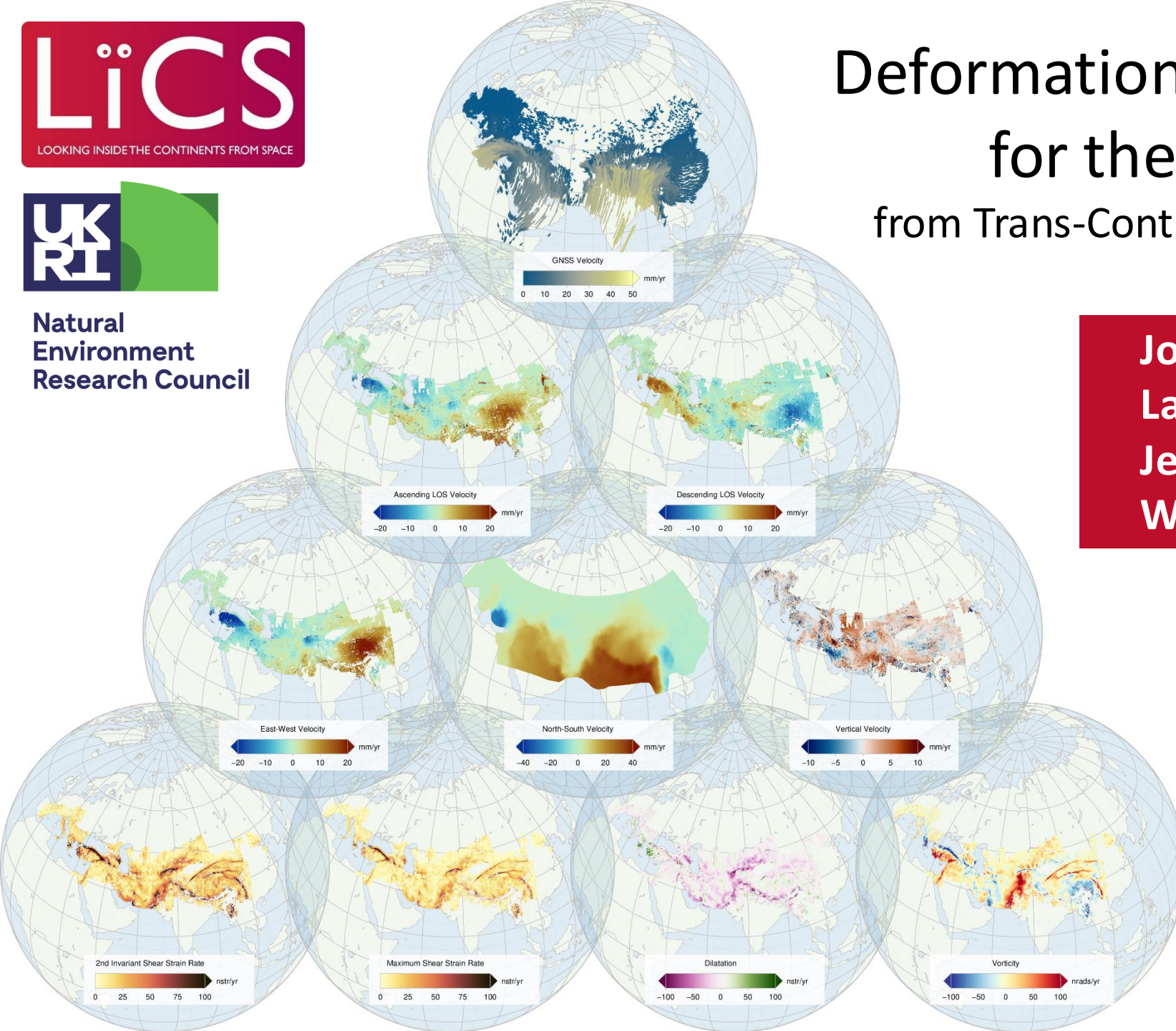
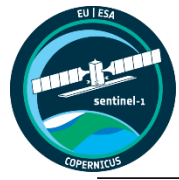


Deformation, Strains and Velocities for the Alpine-Himalayan Belt from Trans-Continental Sentinel-1 InSAR and GNSS

John Elliott, Jin Fang, Milan Lazecký, Yasser Maghsoudi, Qi Ou, Jess Payne, Chris Rollins, Dehua Wang, Andy Hooper & Tim Wright

THE
ROYAL
SOCIETY





Remote Sensing of Environment 338 (2026) 115320



Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse



Jin Fang



Milan Lazecký



Yasser Maghsoudi

Deformation, strains and velocities for the Alpine Himalayan Belt from trans-continental Sentinel-1 InSAR & GNSS

J.R. Elliott^{a,*}, J. Fang^{a,*}, M. Lazecký^a, Y. Maghsoudi^b, Q. Ou^c, J.A. Payne^a, C. Rollins^d, D. Wang^a, A. Hooper^a, T. J. Wright^a

^a COMET, School of Earth & Environment, University of Leeds, Woodhouse Lane, Leeds, LS2 9JT, West Yorkshire, UK

^b Centre for Environmental Mathematics, University of Exeter, Penryn Campus, Nr Falmouth, TR10 9FE, Cornwall, UK

^c School of GeoSciences, University of Edinburgh, Drummond Street, Edinburgh, EH8 9XP, West Lothian, UK

^d Earthquake Physics and Statistics, GNS Science, 1 Fairway Drive, Avalon, 5011, Lower Hutt, New Zealand



Qi Ou



Jess Payne



Chris Rollins

HIGHLIGHTS

- First 3D velocity field of Alpine-Himalayan Belt derived from Sentinel-1 InSAR & GNSS.
- Strain localised on major faults with diffuse deformation extensive across continents.
- Horizontal motion is dominated by tectonics; vertical from aquifer-driven subsidence.

<https://doi.org/10.1016/j.rse.2026.115320>



Dehua Wang



Andy Hooper



Tim Wright



THE UNIVERSITY
of EDINBURGH



Active Tectonics & Crustal Deformation

Linking
geodetic rates
to long term
tectonics

- Growth of Mountains
- Geological Structures

Time-varying
deformation

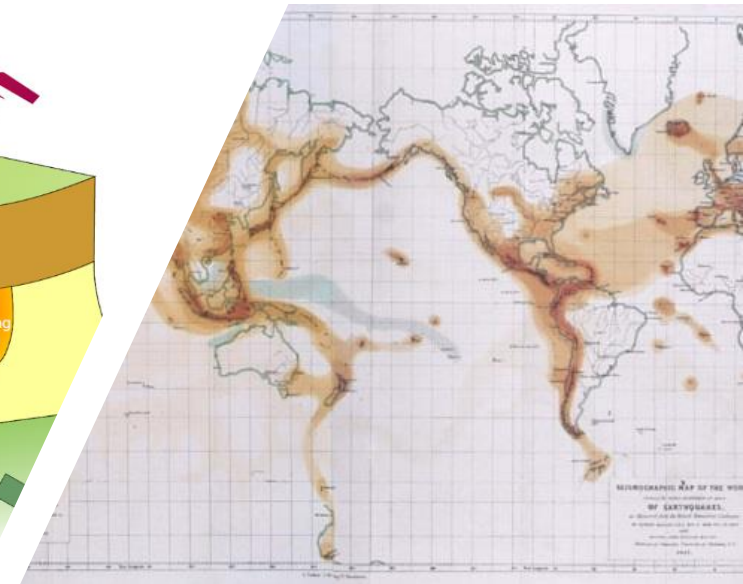
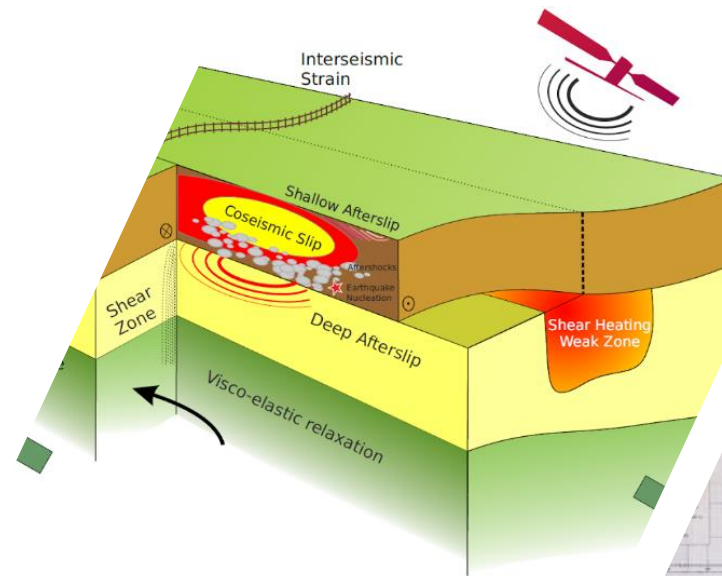
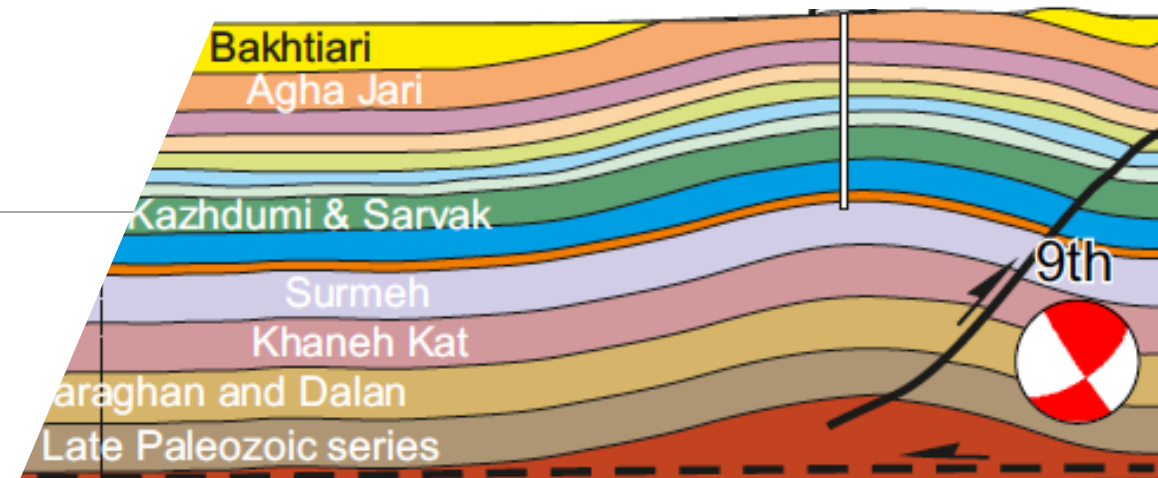
- The Earthquake Cycle
- Fault Slip Rates through Time

Continental-
scale
kinematics

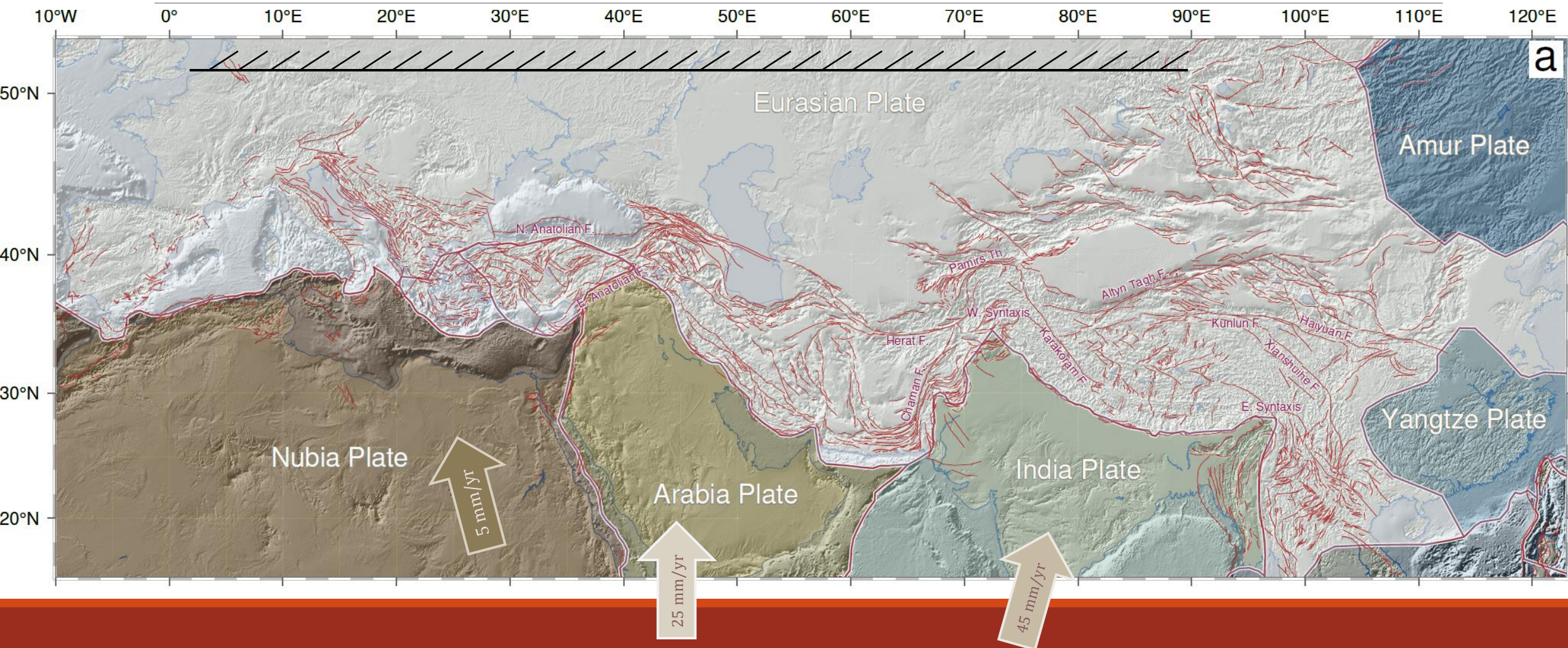
- Distribution of Crustal Deformation
- Nature of Faulting at Depth

How to use
strain rates in
seismic hazard

- Link of strain to earthquake rate
- Challenge of slowly deforming regions



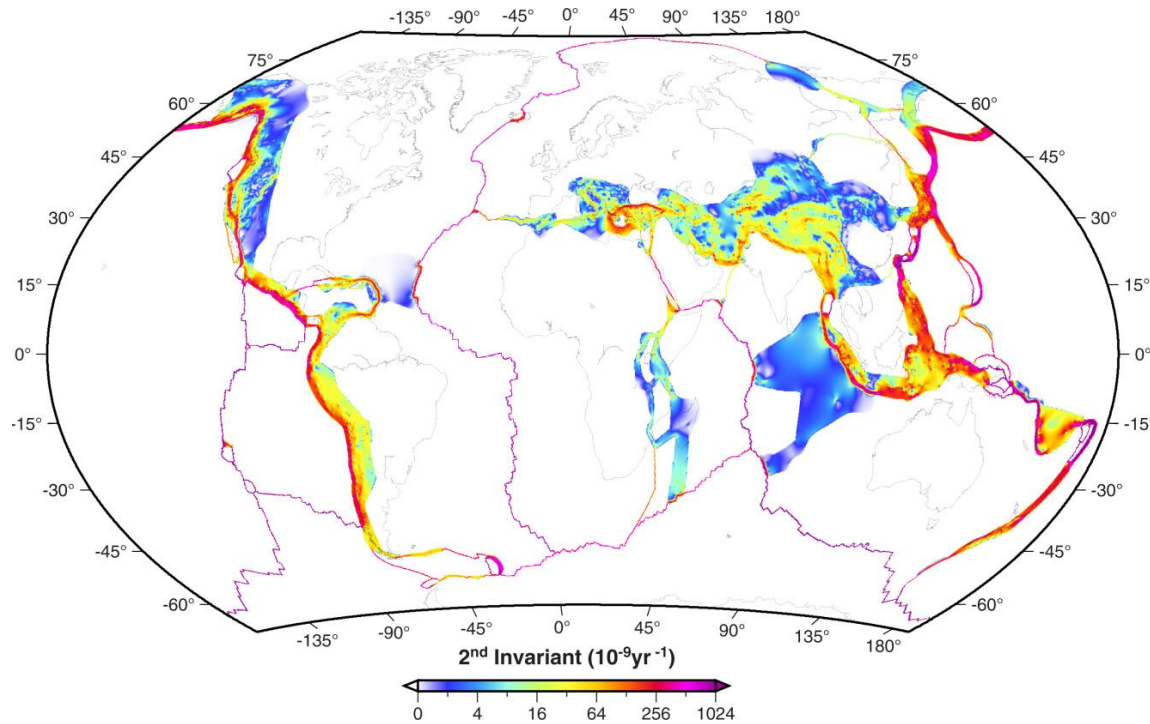
Alpine-Himalayan Belt - Plate Tectonics





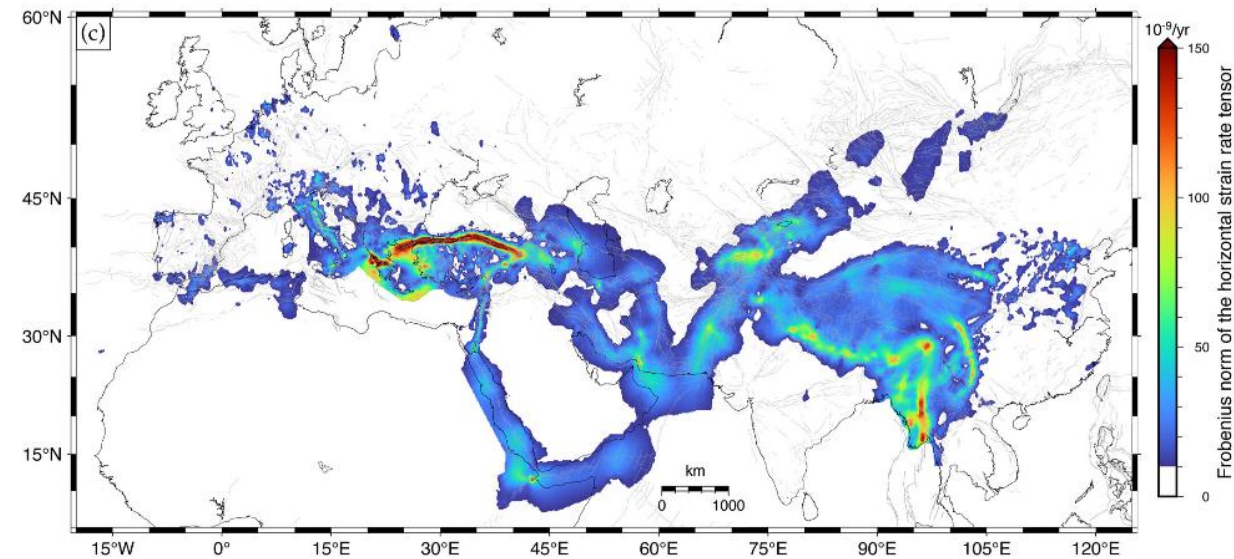
Previous Strain Rate Fields

KREEMER ET AL., (2014) – GSRM



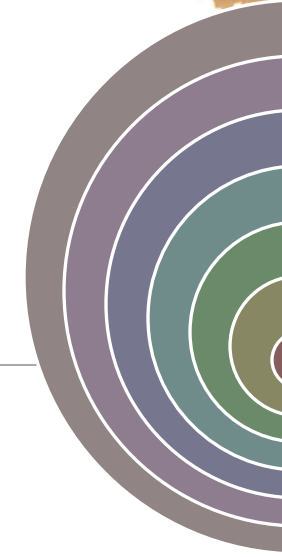
22,415 velocities at 18,356 sites from 233 studies (0.25x0.2 degree)

CASTRO-PERDOMO ET AL., (2025)



11,177 horizontal and 3,940 vertical velocities from 42 studies

Türkiye - Anatolia



Sentinel-1 for Anatolia

2014 → 2019, 40 frames

~200 images/frame

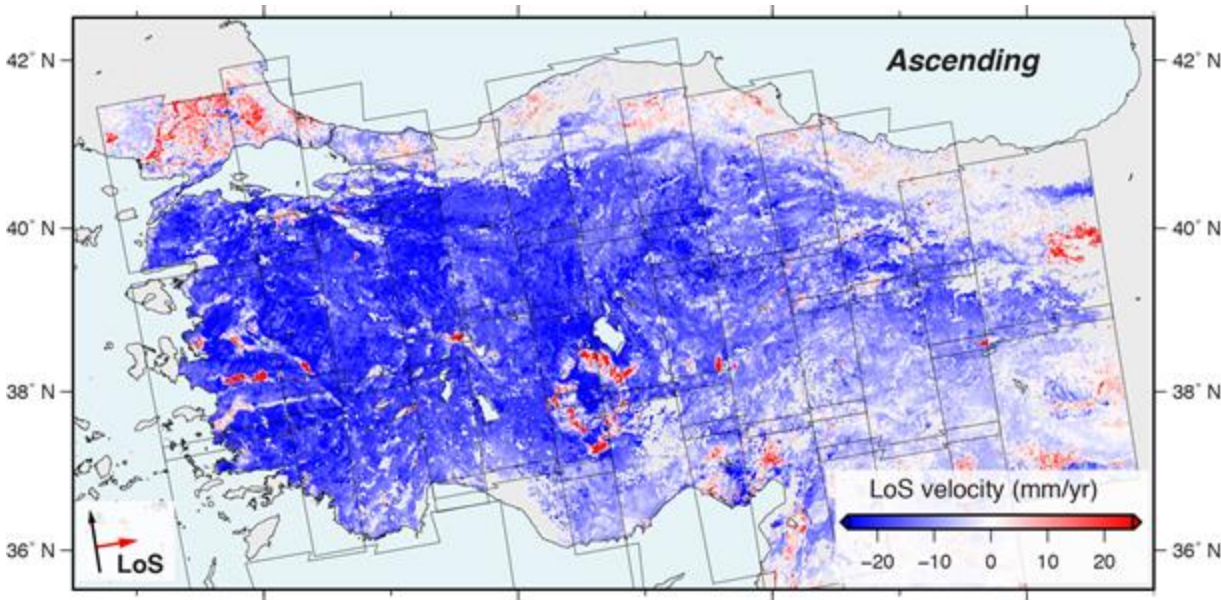
~8,000 images

~800 ifgs/frame

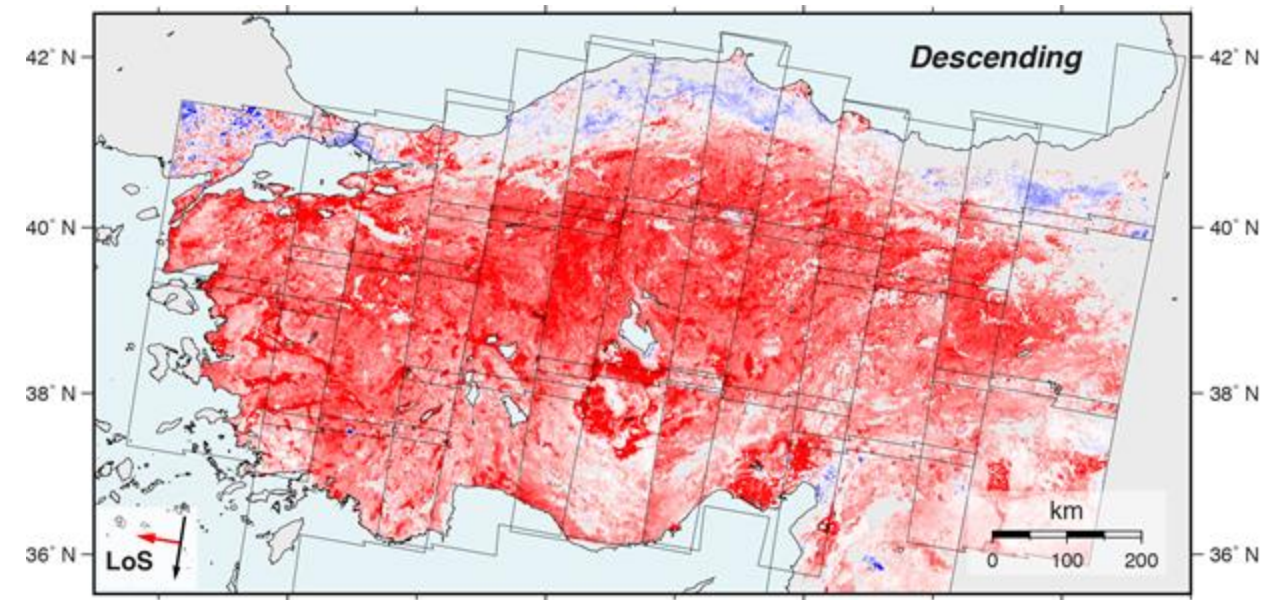
~30,000 ifgs

~ 800,000 km²

ASCENDING



DESCENDING



Iran

Sentinel-1 for Iran

Late 2014 → mid 2022, 7 yr

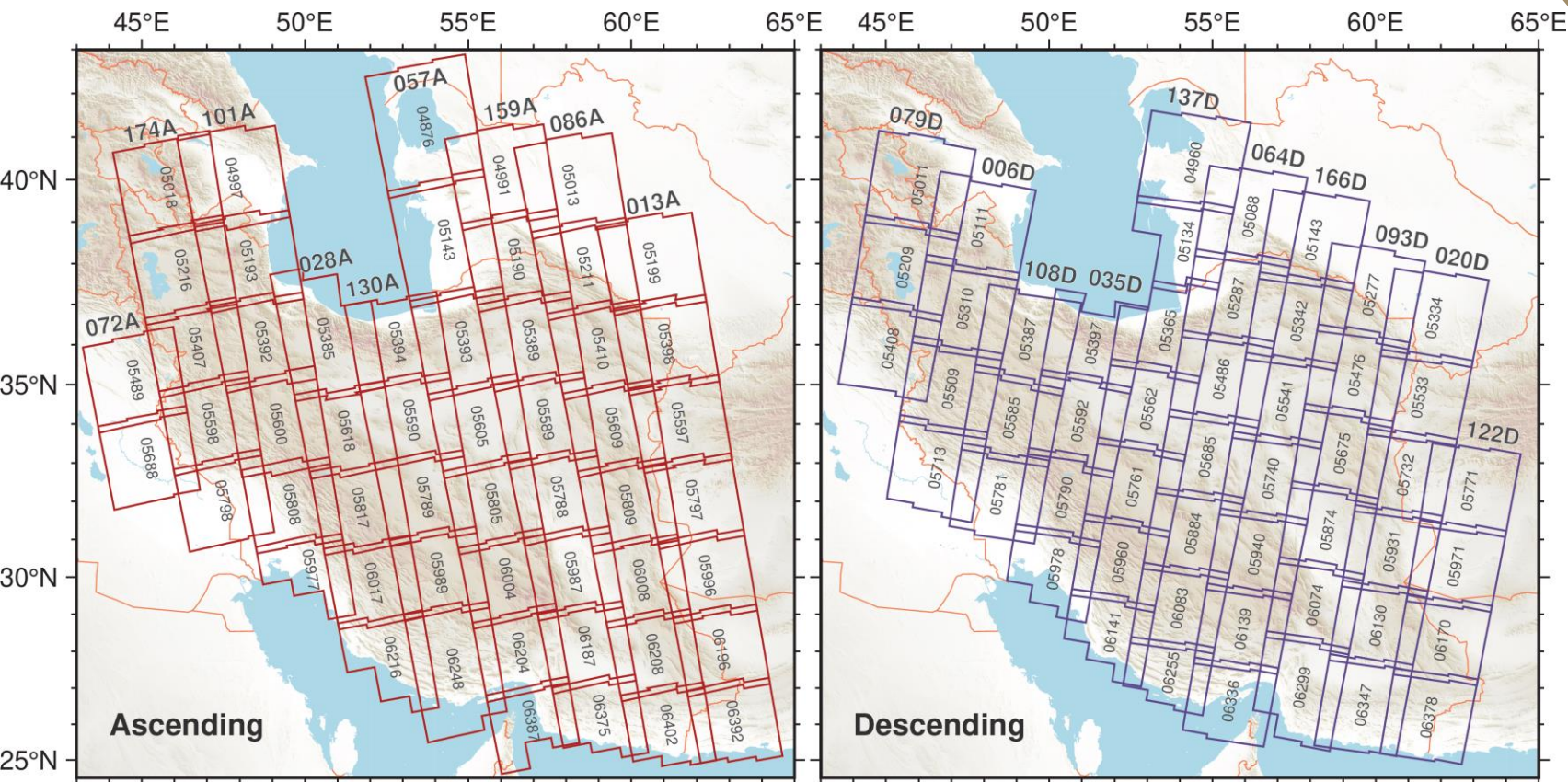
55/52 frames asc/dsc, ~ 2,300,000 km²

~197/179 images/frame

~20,000 images

~875/766 ifgs/frame

~85,000 ifgs



- Regional deformation is diffuse, with interseismic strain localized onto the Doruneh, Main Kopet Dagh, North Tabriz, and Sharoud faults.

- Iran contains a wealth of time-varying, short-wavelength signals associated with groundwater extraction, salt diapirism, and sediment motion

Tibetan Plateau

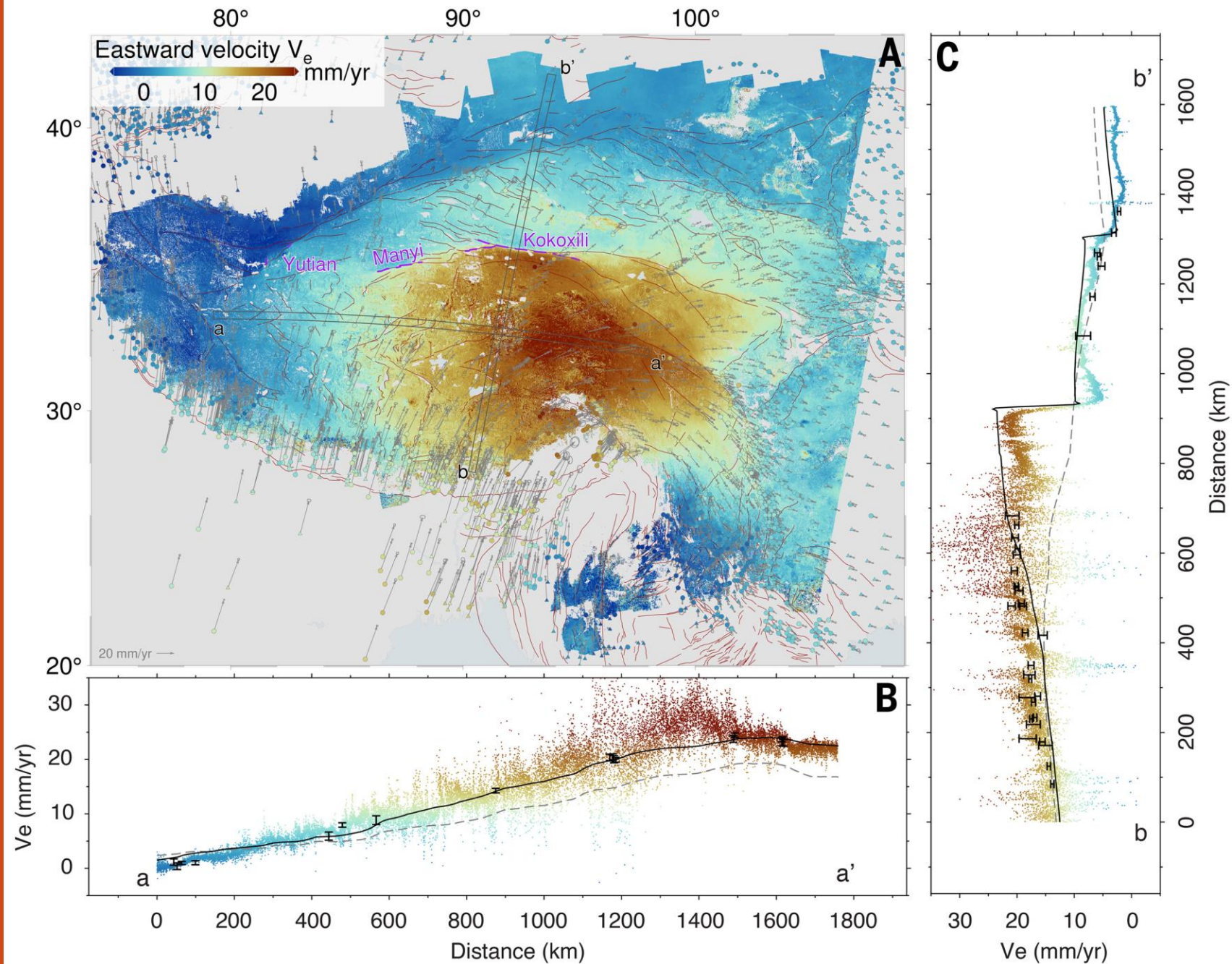
4 million sq km

A few major strike-slip fault systems separate regions of more uniformly distributed deformation.

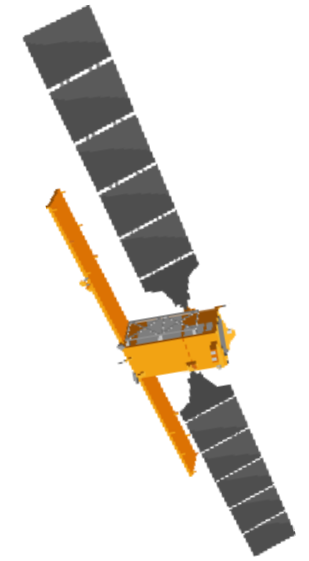
Focused strain on major fault systems is enabled by relatively low-viscosity ductile shear zones extending through the lithosphere beneath the seismically active fault planes

Wright et al., Science 2026

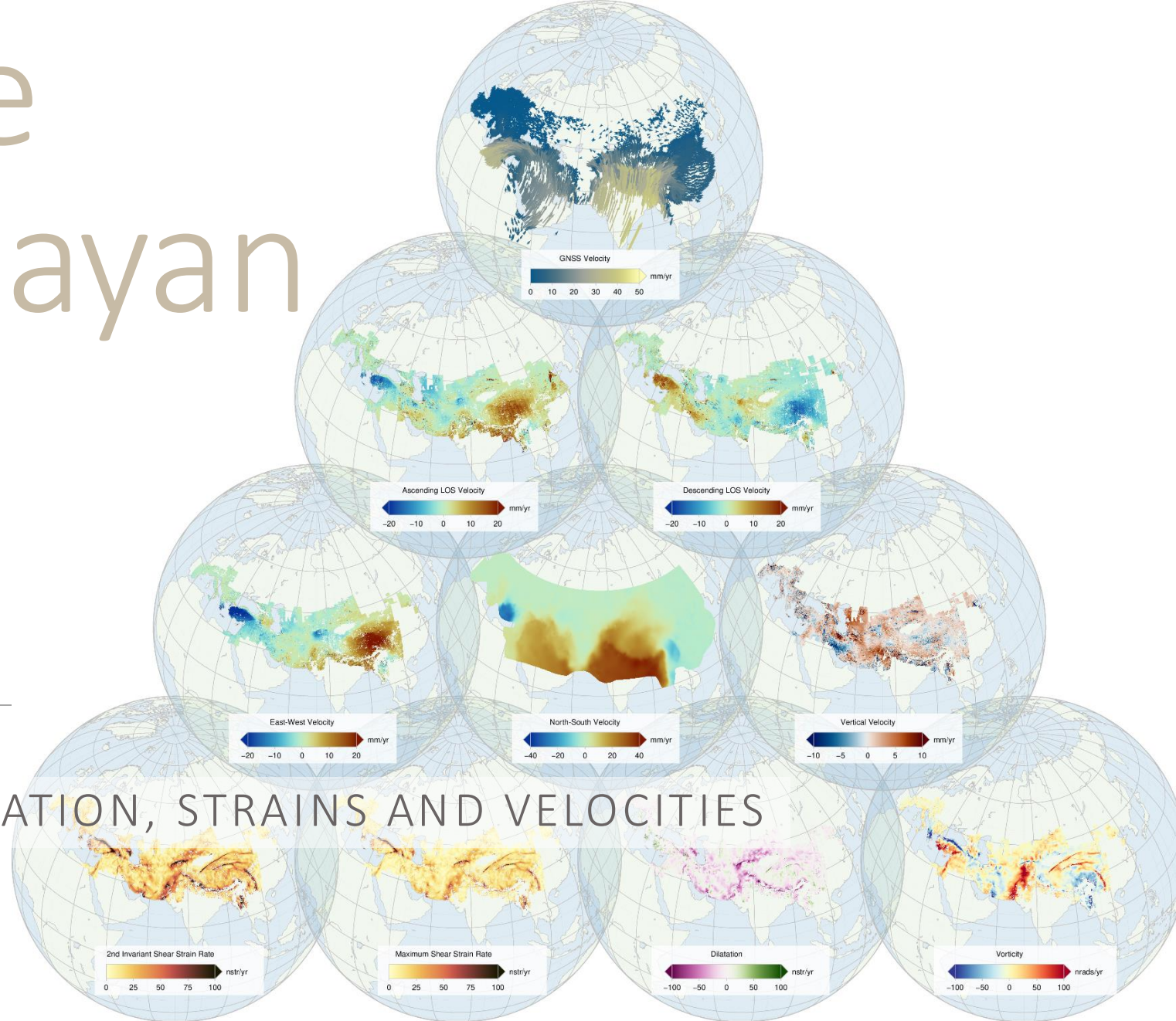
<https://doi.org/10.1126/science.adi3552>



Alpine Himalayan Belt



DEFORMATION, STRAINS AND VELOCITIES



GNSS & Levelling

Compiled 73,335 point velocities of surface motion across the Alpine-Himalayan Belt

- From 171 studies and datasets
- 27,401 are 3D, 31,576 are horizontal-only & 4143 are vertical-only
- 10,074 levelling rates

Reference	Number of Sites	Sites Used	Region Covered	Region Covered
Abbasi et al. (2023)	20	19	57.3–62.3°E	25.2–28.3°N
Ader et al. (2012)	37	6	79.9–86.9°E	6.9–32.0°N
Aktug et al. (2016)	142	128	26.7–56.2°E	26.2–39.4°N
Alothman et al. (2016)	19	18	36.1–56.1°E	16.7–33.3°N
Ashurkov et al. (2016)	12	6	103.1–127.5°E	50.3–54.0°N
Atanasova-Zlatareva (2014)	30	4	22.7–28.4°E	41.6–44.2°N
Aung et al. (2016)	8	0	–°E	–°N
Barman et al. (2017)	42	41	66.9–102.8°E	13.0–43.7°N
Bishti et al. (2021)	6	1	77.2–77.7°E	31.8–31.8°N
Bitharis et al. (2024)	212	21	20.5–27.9°E	35.2–41.3°N
Blewitt et al. (2018)	5032	438	–8.4–128.1°E	5.0–54.7°N
Bock et al. (2021)	307	72	34.6–125.4°E	6.9–54.8°N
Briole et al. (2021)	327	98	19.9–29.6°E	35.1–41.5°N
Brockmann et al. (2019)	3174	116	–4.5–27.9°E	36.0–53.3°N
Castro-Perdomo et al. (2022)	110	101	–4.0–91.1°E	9.0–52.9°N
Cheloni et al. (2014)	147	1	12.5–12.5°E	46.0–46.0°N
Choudhury et al. (2018)	1	1	72.7–72.7°E	23.2–23.2°N
Chousiantis et al. (2015)	99	98	19.8–25.4°E	36.3–41.1°N
d'Agostino et al. (2020)	343	332	1.0–31.3°E	35.1–53.9°N
Dai et al. (2023)	28	24	99.4–100.4°E	25.6–26.5°N
DeMets et al. (2020)	81	19	42.0–83.0°E	8.4–26.9°N
Devachandra et al. (2014)	19	7	66.9–114.4°E	13.0–43.8°N
Diao et al. (2019)	27	25	97.5–101.1°E	34.0–36.7°N
Dimitrov and Nakov (2022)	28	26	22.7–24.1°E	41.6–43.1°N
Duong et al. (2013)	22	22	103.0–105.3°E	20.6–22.3°N
Ergeshov et al. (2020)	6	6	60.7–71.8°E	37.5–41.5°N
Ergintay et al. (2014)	112	1	29.1–29.1°E	40.9–40.9°N
Ergintay et al. (2023)	796	720	19.5–44.0°E	33.7–43.0°N
Fang et al. (2022b)	96	91	74.1–94.4°E	13.0–34.6°N
Fazilova et al. (2018)	5	5	66.9–70.6°E	38.7–42.0°N
Fazilova et al. (2025b)	16	11	68.7–69.8°E	40.2–41.6°N
Fazilova et al. (2025a)	9	2	65.9–65.9°E	38.5–38.5°N
Floyd et al. (2023)	360	136	19.5–30.9°E	35.0–42.0°N
Frohling and Szeliga (2016)	19	4	64.4–66.6°E	26.2–29.1°N
Fu and Freymueller (2012)	25	1	85.0–85.0°E	27.2–27.2°N
Fu et al. (2020)	15	14	102.6–103.3°E	26.1–27.1°N
Gahleitner et al. (2019)	22	22	69.0–72.8°E	21.0–24.7°N
Gan et al. (2022)	501	488	95.5–107.1°E	20.6–34.0°N
Gautam et al. (2017)	6	0	–°E	–°N
Gharbia et al. (2025)	11	11	34.4–34.7°E	25.2–25.5°N
Gorshkov et al. (2023) (LSS)	330	201	19.9–61.0°E	41.6–55.0°N
Gorshkov et al. (2023) (MED)	331	191	19.9–61.0°E	41.6–55.0°N
Gupta et al. (2015)	39	0	–°E	–°N
Hamiel and Platiatratova (2021)	291	274	15.0–51.3°E	19.2–44.4°N
Hao et al. (2016)	38	2	101.5–102.2°E	25.1–28.3°N
Hao et al. (2019)	1000	969	74.3–134.3°E	18.2–53.5°N
Hao et al. (2021)	990	968	101.0–117.0°E	31.0–43.9°N
Hao et al. (2024)	177	176	99.0–112.2°E	33.6–42.3°N
Huang et al. (2023)	26	26	100.5–102.7°E	23.0–25.3°N
Jade et al. (2011)	20	0	–°E	–°N
Jade et al. (2014)	70	63	66.9–102.8°E	10.2–43.2°N
Jade et al. (2017)	80	2	78.5–93.8°E	10.7–27.6°N
Jade et al. (2020)	45	41	66.9–114.4°E	6.9–43.2°N
Jolivet et al. (2023)	39	14	32.1–33.4°E	40.7–41.0°N
Jouanne et al. (2017)	78	71	80.1–87.7°E	26.5–30.0°N
Jouanne et al. (2020)	65	64	71.6–77.5°E	31.8–36.8°N
Kadirov et al. (2014)	86	85	43.8–49.8°E	37.8–43.0°N
Kannaujia et al. (2022)	15	9	77.6–79.6°E	29.0–30.5°N
Ghasemi Khalkhali et al. (2021)	25	18	44.2–47.7°E	37.6–39.4°N
Ghasemi Khalkhali et al. (2023a)	31	22	55.1–61.1°E	31.5–37.8°N
Ghasemi Khalkhali et al. (2023b)	10	10	55.1–62.3°E	25.3–31.3°N
Khorrami et al. (2019)	398	391	39.8–67.1°E	14.5–44.9°N
Kresmer et al. (2014)	7999	1268	–9.6–154.9°E	5.5–54.1°N
Kufner et al. (2021)	20	20	68.6–71.8°E	35.3–38.0°N
Kumar et al. (2023)	9	9	75.4–77.4°E	30.7–32.5°N
Kundu et al. (2014)	10	10	74.1–76.2°E	33.4–34.6°N
Kurt et al. (2023)	836	832	25.9–44.6°E	36.0–42.0°N
Li et al. (2017)	212	198	100.1–107.4°E	33.9–39.4°N
Li et al. (2018)	994	942	66.9–108.0°E	32.0–45.9°N
Li et al. (2021)	200	193	100.1–107.4°E	33.9–39.4°N
Li et al. (2022)	73	69	75.7–79.4°E	39.5–40.9°N
Lindsey et al. (2023)	111	74	89.5–97.7°E	16.1–25.1°N
Lukhnev et al. (2025)	95	76	89.9–114.6°E	43.1–54.9°N
Maddahi et al. (2025)	8	8	50.7–52.1°E	35.6–36.1°N
Mallick et al. (2019)	24	24	88.7–97.1°E	17.4–27.3°N
Mantovani et al. (2015)	488	20	9.8–15.1°E	37.5–45.8°N
Marchal et al. (2016)	35	15	89.4–91.5°E	26.8–28.1°N
Masson et al. (2015)	26	26	34.6–36.2°E	29.1–31.4°N
Metzger et al. (2020)	74	57	68.4–74.8°E	36.7–40.8°N
Meyer et al. (2024)	28	26	71.6–73.9°E	31.8–34.0°N
Milyukov et al. (2015)	7	2	42.5–44.7°E	43.0–43.3°N
Milyukov et al. (2022)	13	10	38.1–42.0°E	43.6–47.9°N
Mironov et al. (2021)	10	10	41.6–44.7°E	42.4–43.8°N
Mohanty et al. (2024)	32	30	76.2–80.4°E	32.5–36.0°N
Mondal et al. (2016)	14	2	78.1–80.2°E	30.1–30.3°N

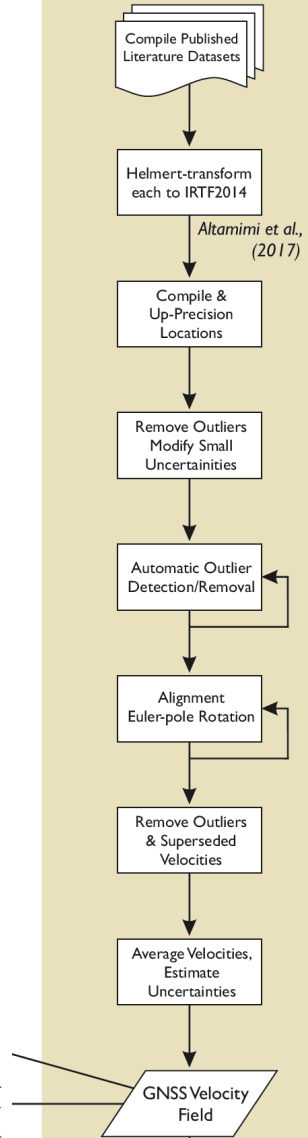
Continued in the next Table...

Table SA1: GNSS datasets used in the point-velocity field, with the number of velocities initially contributed by each study and the number retained in the final combination. The latitudinal and longitudinal ranges are the regions covered by the velocities retained here. Continued in next Table SA2.

Reference	Number of Sites	Sites Used	Region Covered
Continued from previous Table...			
Mukul et al. (2018)	24	23	87.2–89.2°E 23.5–29.4°N
Mullick and Mukhopadhyay (2020)	51	48	86.4–92.9°E 22.1–26.5°N
Nocquet et al. (2016)	76	76	3.9–9.9°E 43.0–47.0°N
Oryan et al. (2023)	68	66	88.6–97.4°E 21.8–25.2°N
Osman Pour (in prep.)	57	3	51.2–51.6°E 35.9–36.1°N
Özarpacı et al. (2021)	49	26	29.4–30.4°E 40.1–40.8°N
Özbey et al. (2024)	98	91	31.1–41.4°E 29.5–40.2°N
Özdemir and Karşioğlu (2019)	211	199	–4.0–74.7°E 30.6–52.9°N
Özkan et al. (2023)	61	21	35.5–37.0°E 35.9–37.2°N
Palano et al. (2013)	328	309	30.9–58.6°E 12.8–43.8°N
Palano et al. (2018)	835	63	35.1–62.2°E 11.5–39.8°N
Pan et al. (2019)	278	274	66.9–94.9°E 35.1–48.7°N
Pan et al. (2020)	272	265	93.0–107.0°E 34.0–40.7°N
Pan et al. (2021)	264	35	91.0–134.3°E 18.2–50.6°N
Pan et al. (2023)	52	47	66.9–89.5°E 36.4–49.8°N
Pappachen et al. (2021)	34	33	44.4–115.9°E 13.0–54.8°N
Perry et al. (2019)	79	3	70.4–71.6°E 36.7–38.7°N
Piña-Valdés et al. (2022)	3678	3524	–9.4–44.5°E 30.6–55.0°N
Pintori et al. (2022)	545	535	–0.5–20.3°E 42.4–49.8°N
Pirooznia et al. (2020)	4	3	49.6–51.3°E 36.7–37.3°N
Ponraj et al. (2019)	20	1	79.7–79.7°E 29.6–29.6°N
Porkolab et al. (2023)	909	851	10.1–29.9°E 42.0–52.0°N
Qiao et al. (2017)	150	7	74.8–79.5°E 39.4–41.3°N
Rashwan et al. (2021)	163	151	–4.0–57.8°E 19.2–52.1°N
Ray et al. (2019)	23	23	80.5–94.5°E 23.7–30.0°N
Rudenko et al. (2013)	60	2	30.6–34.9°E 32.5–36.8°N
Rui and Stamps (2019)	1719	1098	65.8–134.3°E 10.2–53.5°N
Rui et al. (2024)	31	29	100.9–103.6°E 28.0–28.3°N
Rui et al. (2025)	276	155	101.0–104.9°E 26.1–30.0°N
Saji et al. (2020)	50	47	74.4–93.6°E 13.0–34.1°N
Saji et al. (2025)	40	39	76.9–80.6°E 28.6–31.4°E
Santamaría-Gómez et al. (2012)	69	66	–9.4–121.2°E 13.0–54.8°N
Santamaría-Gómez et al. (2024)	3686	250	–7.9–125.4°E 5.3–54.8°N
Serpelloni et al. (2013)	794	51	–6.6–35.8°E 29.5–47.2°N
Serpelloni et al. (2016)	497	464	–4.4–25.3°E 42.2–54.7°N
Serpelloni et al. (2022)	2865	264	–9.2–125.4°E 6.1–54.8°N
Sharma et al. (2020)	41	38	75.7–80.2°E 26.5–32.4°N
Sharma et al. (2021)	15	4	79.2–79.6°E 30.3–30.5°N
Shirazinejad (in prep.)	25	24	44.2–47.4°E 36.9–39.4°N
Shevchenko et al. (2021)	40	0	–°E –°N
Shringeshwara et al. (2023)	13	13	74.3–76.2°E 33.6–34.6°N
Shukurov (2020)	13	0	–°E –°N
Singh et al. (2022)	18	18	73.9–76.2°E 32.7–34.6°N
Socquet and Janex (2019)	978	1	2.4–2.4°E 44.7–44.7°N
Sokhadze et al. (2018)	70	52	40.3–104.3°E 22.2–52.2°N
Steckler et al. (2016)	53	52	66.9–114.4°E 13.0–52.2°N
Steffen et al. (2025)	2061	1960	–9.4–44.0°E 30.6–55.0°N
Su et al. (2018)	58	47	100.1–109.3°E 33.3–38.6°N
Suribabu et al. (2022b)	8	7	69.2–70.1°E 23.1–23.2°N
Suribabu et al. (2022a)	4	4	69.0–72.0°E 21.0–22.3°N
Timofeev et al. (2024)	15	14	81.2–91.1°E 29.7–54.8°N
Vardić et al. (2022)	154	17	36.1–125.4°E 6.9–52.2°N
Verma et al. (2024)	22	13	78.9–79.8°E 29.1–29.7°N
Vila (2020)	70	24	73.8–94.8°E 13.0–28.2°N
Vilayev et al. (2017)	10	9	76.0–78.4°E 43.0–43.9°N
Viltres et al. (2020)	33	33	38.1–45.0°E 11.6–19.2°N
Viltres et al. (2022)	189	173	34.7–58.2°E 9.0–36.2°N
Wang et al. (2022b)	618	610	97.5–106.4°E 21.1–34.0°N
Wang et al. (2017a)	29	5	115.8–118.3°E 38.5–41.0°N
Wang et al. (2017b)	1846	1744	65.8–120.8°E 10.2–49.9°N
Wang and Shen (2020)	2489	2450	–4.0–134.3°E 13.0–54.8°N
Wang et al. (2020)	524	521	73.5–98.9°E 34.4–44.0°N
Wang et al. (2022a)	881	431	107.3–124.0°E 28.1–41.9°N
Wang et al. (2024b)	547	527	67.0–121.9°E 24.7–48.8°N
Wang et al. (2018)	2	2	51.3–51.3°E 35.7–35.7°N
Wang et al. (2024a)	95	77	85.5–99.1°E 35.4–41.9°N
Wani et al. (2025)	13	13	74.0–76.2°E 33.0–34.6°N
Wu et al. (2024a)	316	290	99.0–110.1°E 32.2–40.5°N
Xiong et al. (2021)	1985	1945	74.3–134.3°E 18.2–53.5°N
Yadav et al. (2019)	34	33	78.0–82.2°E 28.7–31.0°N
Yadav et al. (2021)	7	0	–°E –°N
Yavasoglu et al. (2021)	51	2	28.2–29.3°E 41.0–41.1°N
Younes (2023)	48	21	31.1–34.3°E 23.3–31.3°N
Zhang et al. (2021)	151	139	75.4–98.7°E 20.8–34.8°N
Zhao et al. (2017)	723	663	103.1–117.0°E 32.0–43.9°N
Zhao et al. (2023)	857	331	74.3–110.3°E 18.2–48.7°N
Zheng et al. (2017)	1623	1562	66.9–134.3°E 18.2–54.8°N
Zhou et al. (2016)	152	144	56.1–121.2°E 13.0–52.2°N
Zhou et al. (2023)	25	25	102.6–103.5°E 25.5–27.1°N
Zubovich et al. (2016)	4	4	72.2–72.3°E 39.4–39.6°N

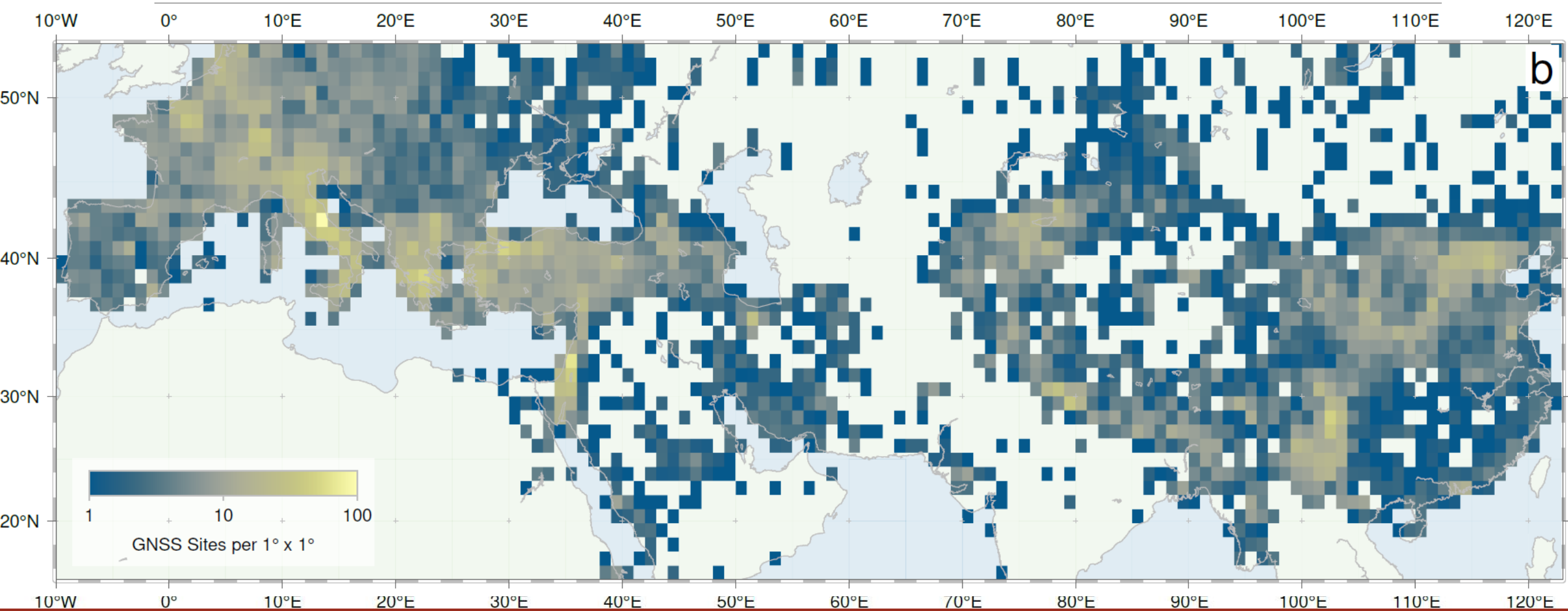
Table SA2: Continued from Table SA1. GNSS datasets used in the point-velocity field, with the number of velocities initially contributed by each study and the number retained in the final combination. The latitudinal and longitudinal ranges are the regions covered by the velocities retained here.

c. GNSS

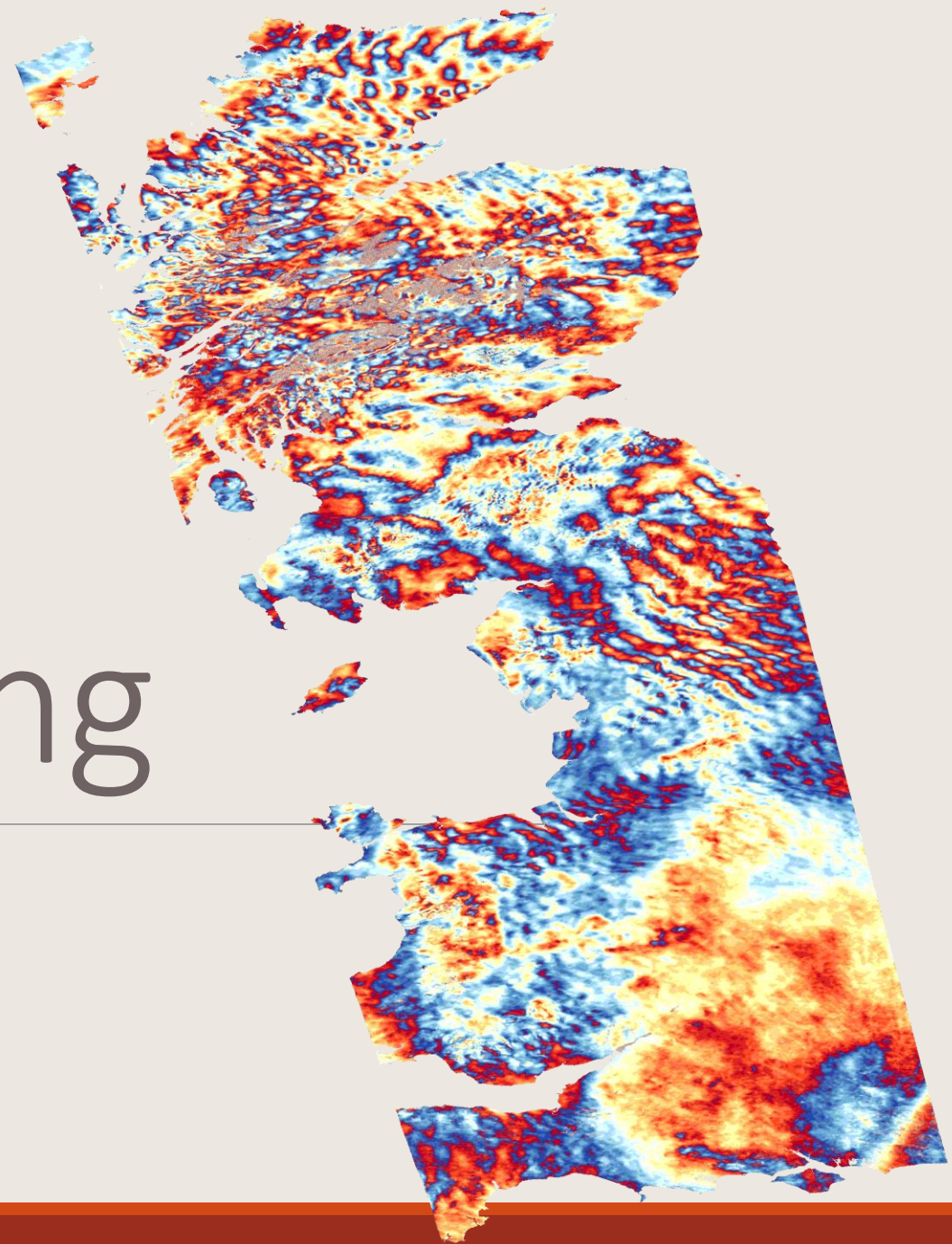




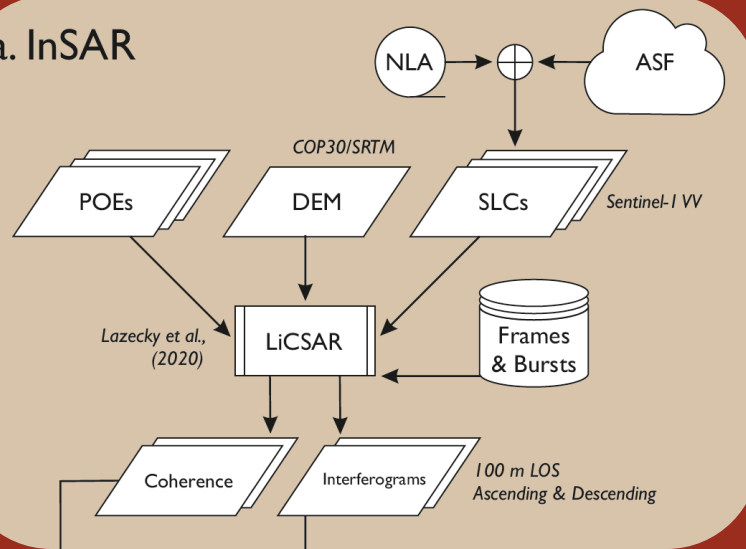
GNSS



InSAR Processing

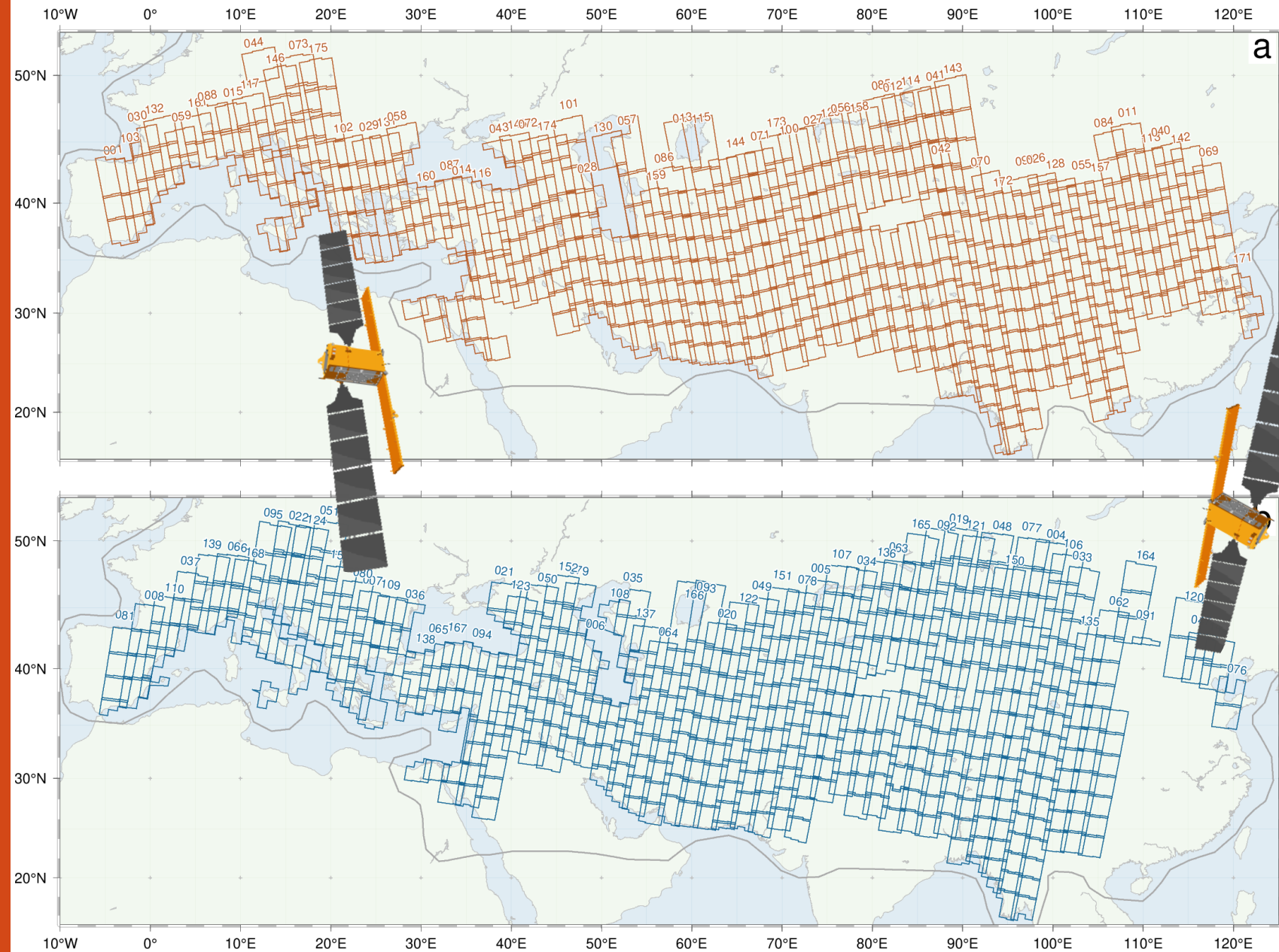


a. InSAR



Sentinel-1 SAR

- Defined 469 ascending & 459 descending frames (comprising 3 subswaths and about 13 bursts each)
- Processed 221,319 Sentinel-1A/B epochs from 2016-2024, typically acquired every 12 days (6-24 days).

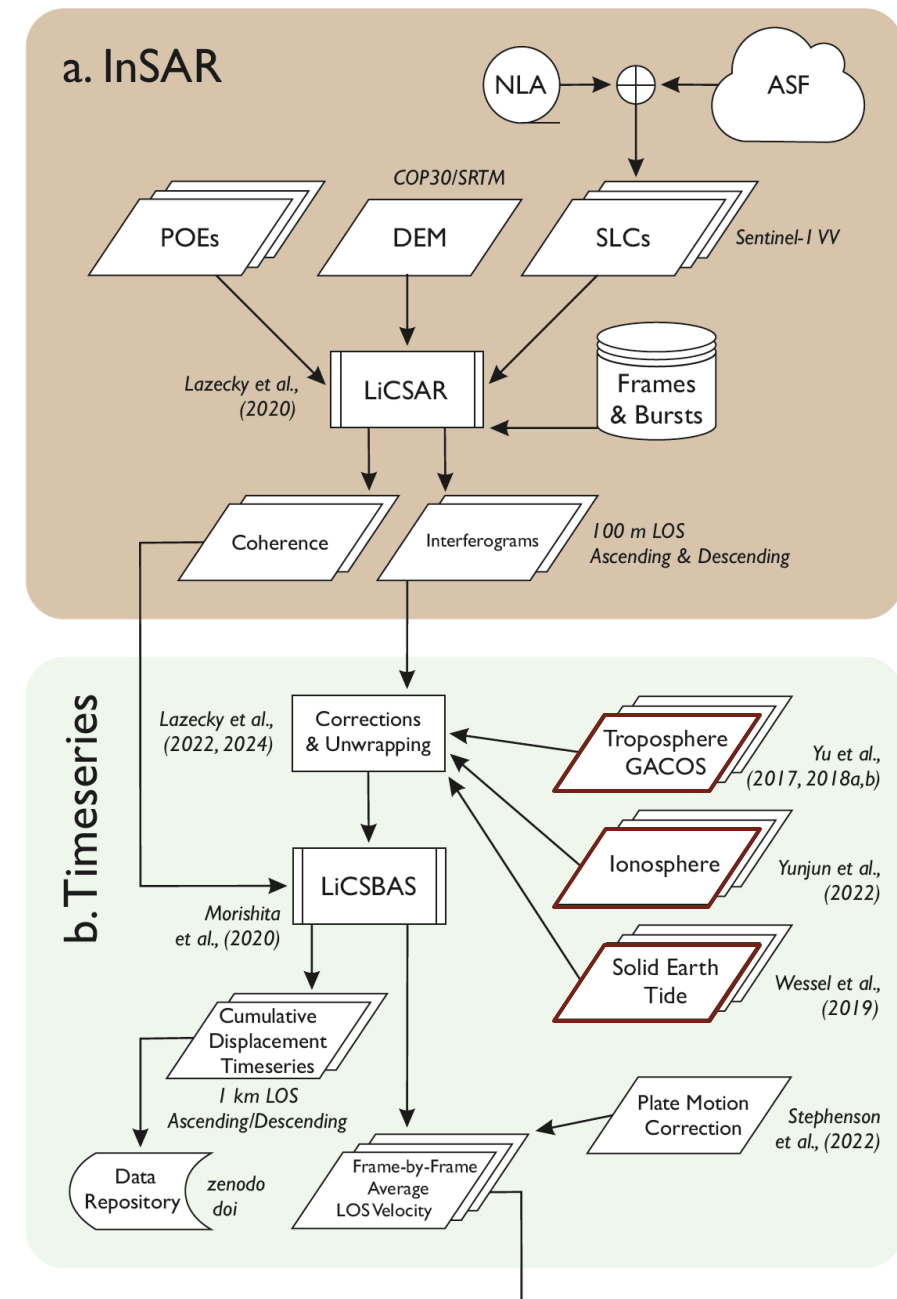


Atmospheric Corrections

TROPOSPHERIC WATER VAPOUR & HYDROSTATIC DELAY

IONOSPHERE

PLUS SOLID EARTH TIDE (SET)

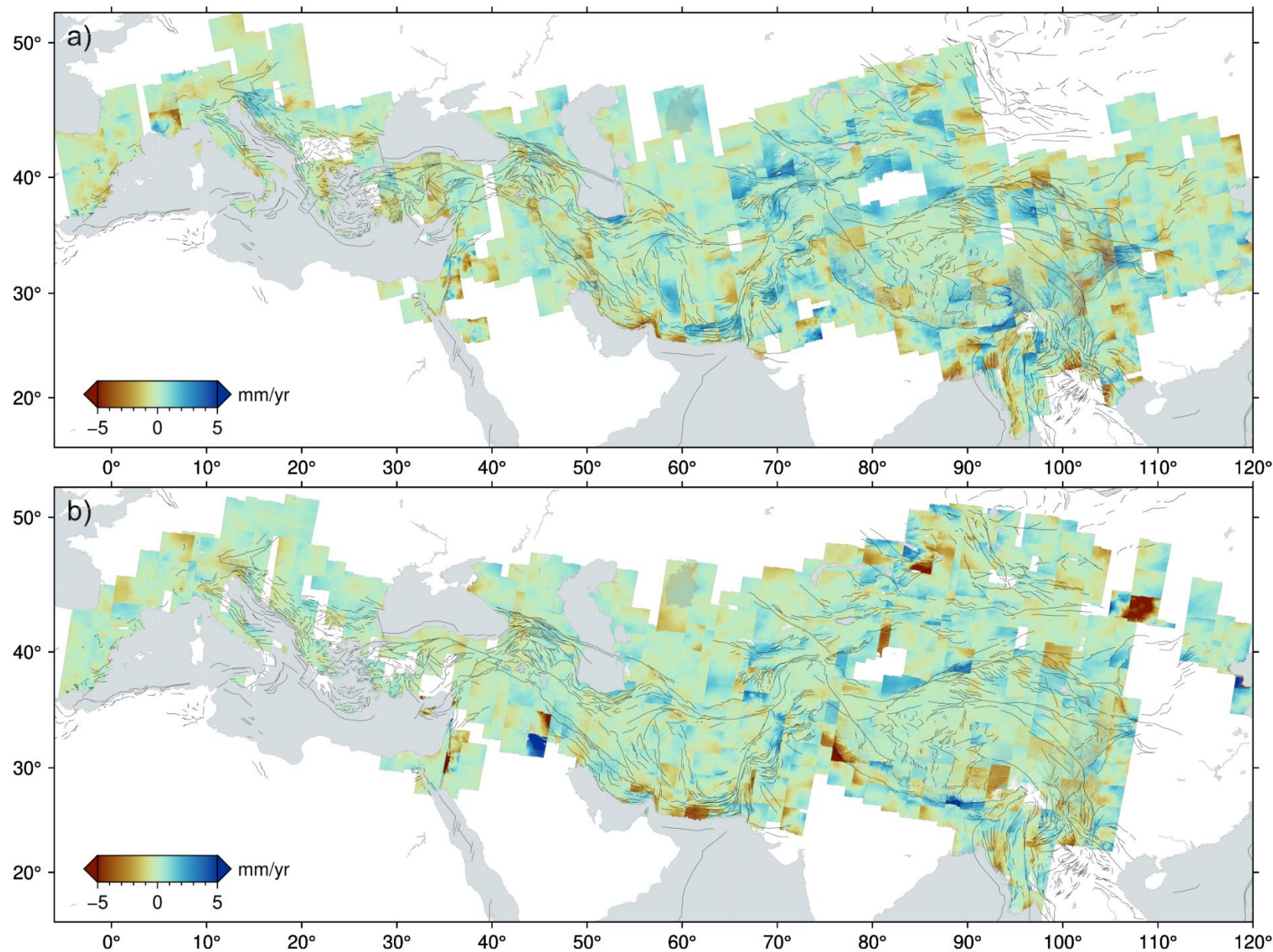


GACOS Corrections

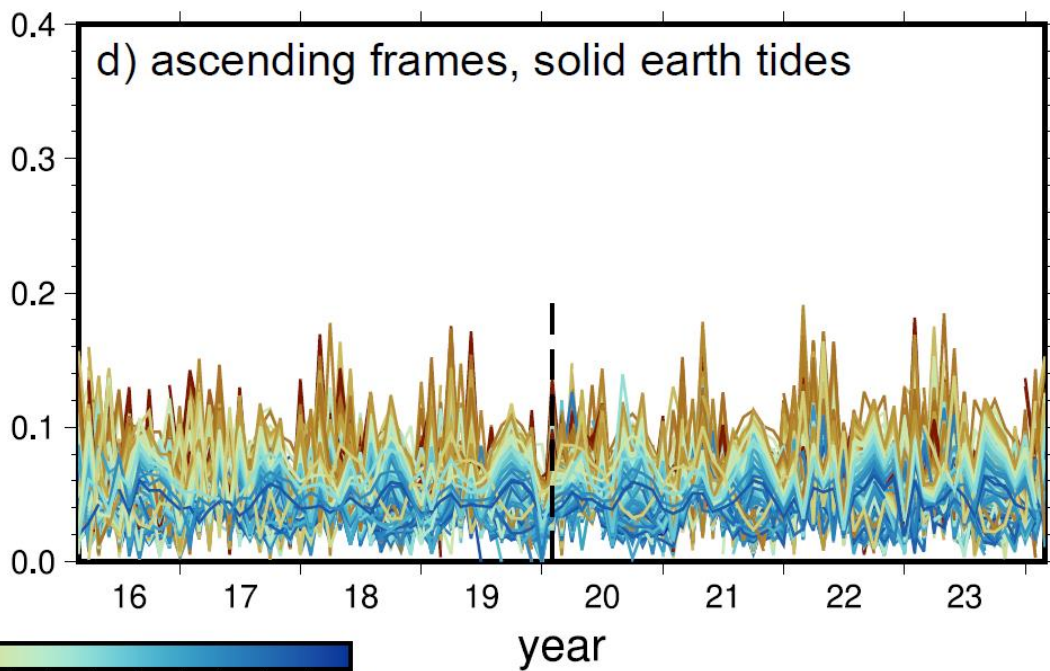
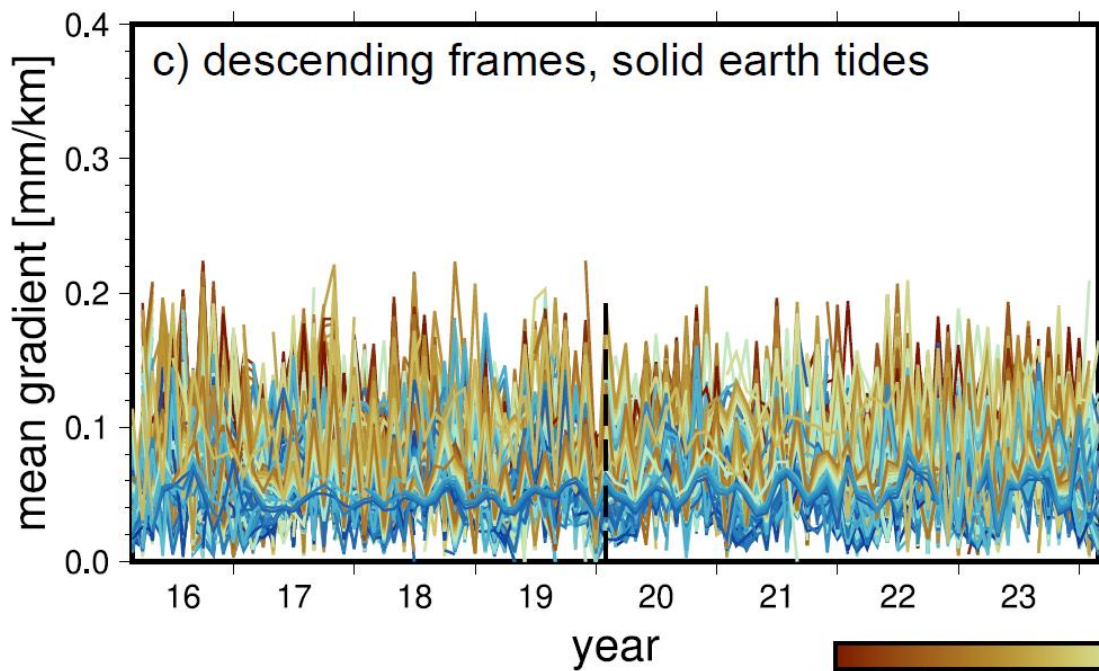
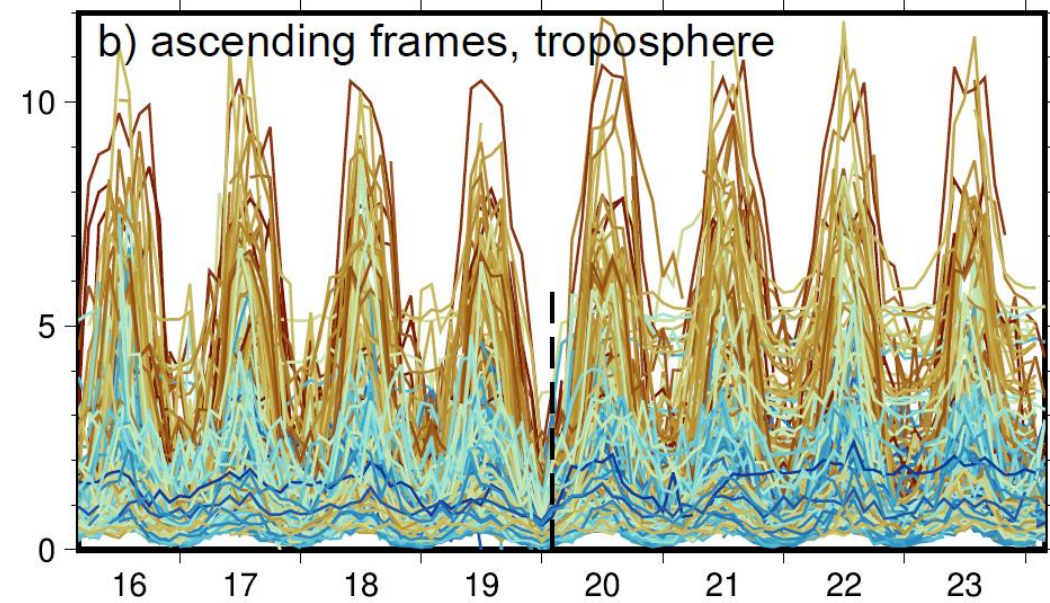
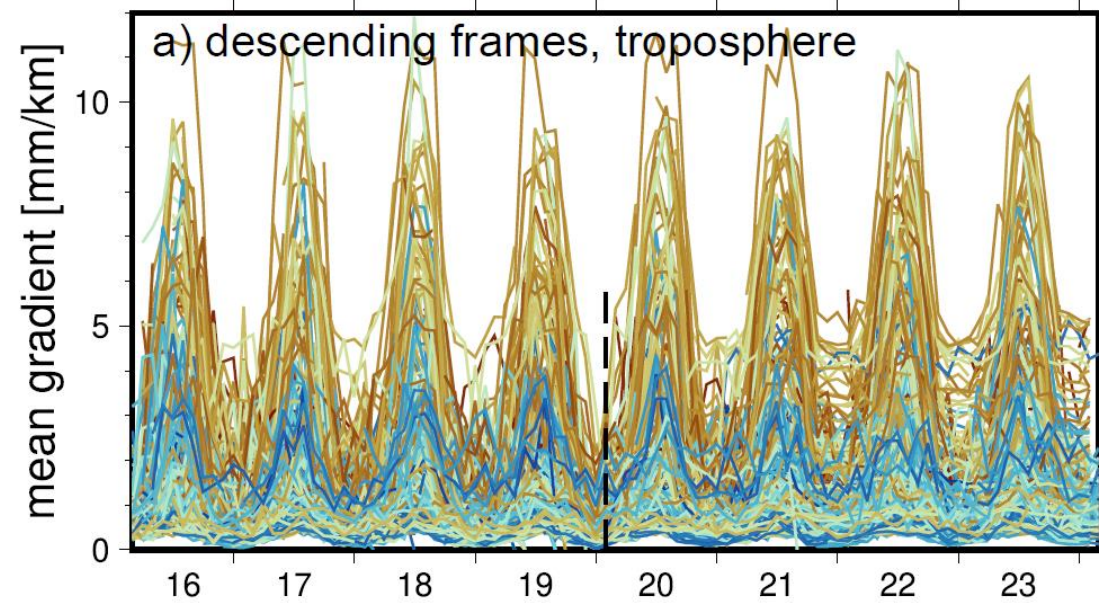
Generic Atmospheric Correction
Online Service for InSAR

Yu et al (2018a,b)

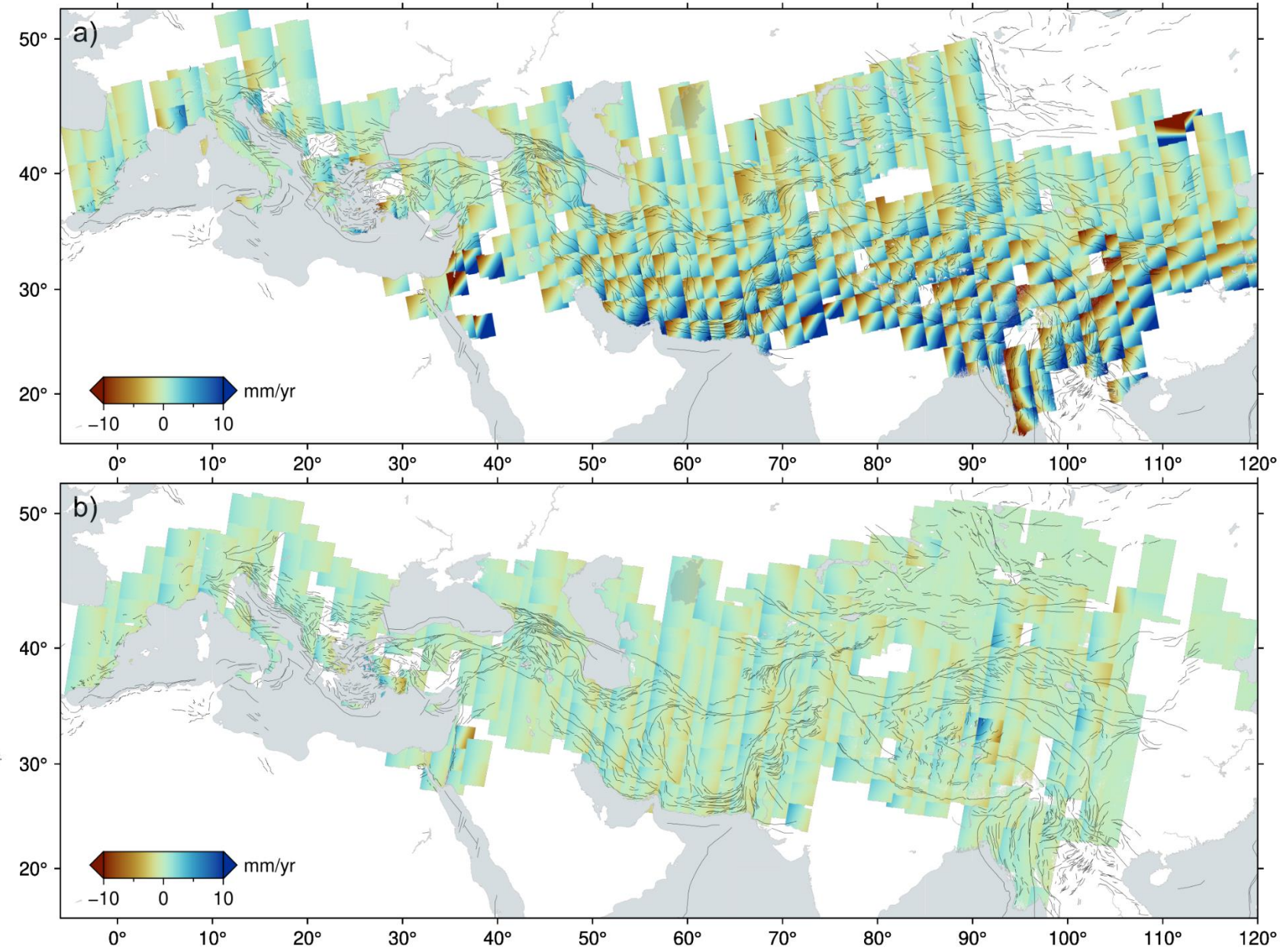
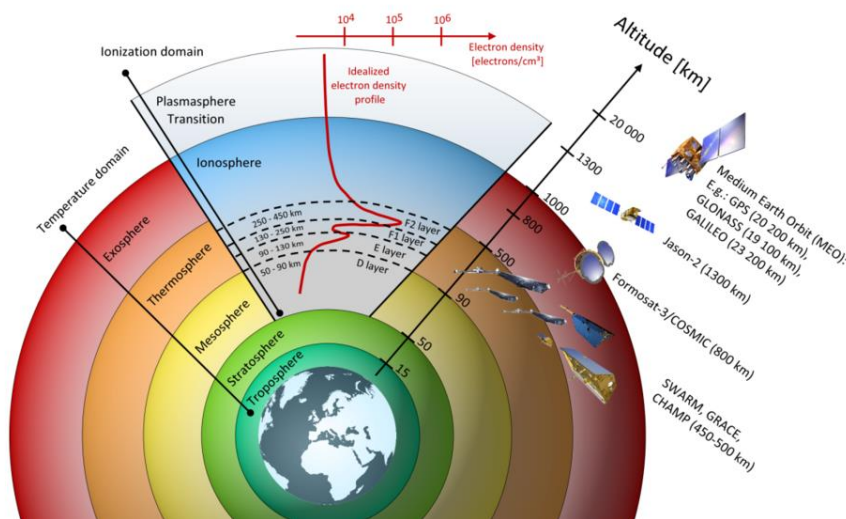
<http://www.gacos.net/>



Troposphere & SET gradients



Corrections - Ionosphere



Corrections - Ionosphere

SOLAR MINIMUM

SOLAR MAXIMUM

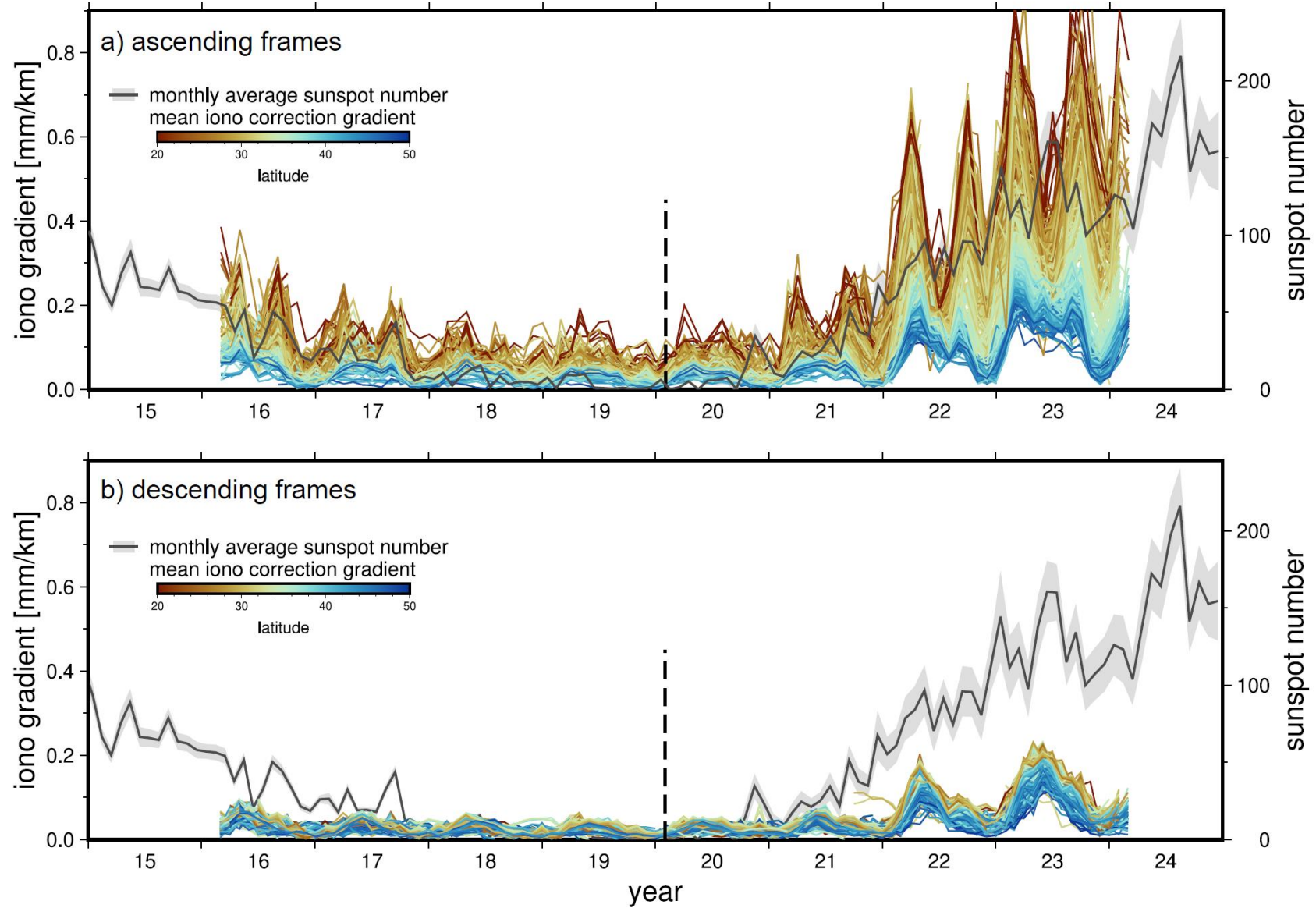
Visible

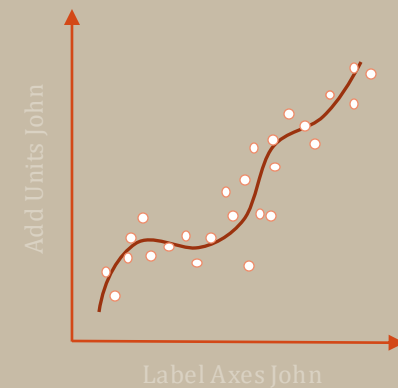
UV

Dec 2019

May 2024

NASA – Solar Dynamics Observatory





Time Series Analysis

LiCSBAS

Platform Solutions Resources Open Source Enterprise Pricing Search or jump to... Sign in Sign up

yumorishita / LiCSBAS2 Public Notifications Fork 10 Star 65

< Code Issues 7 Pull requests Projects Wiki Security and quality Insights

master 11 Branches 16 Tags Go to file Code

About
LiCSBAS2: InSAR time series analysis software
doi.org/10.3390/RS12030424
insar time-series-analysis
deformation displacement
Readme
GPL-3.0 license
Activity
65 stars
3 watching
10 forks
Report repository

Releases 4
v1.9.2 Latest on Sep 10, 2025
+ 3 releases

Packages
No packages published

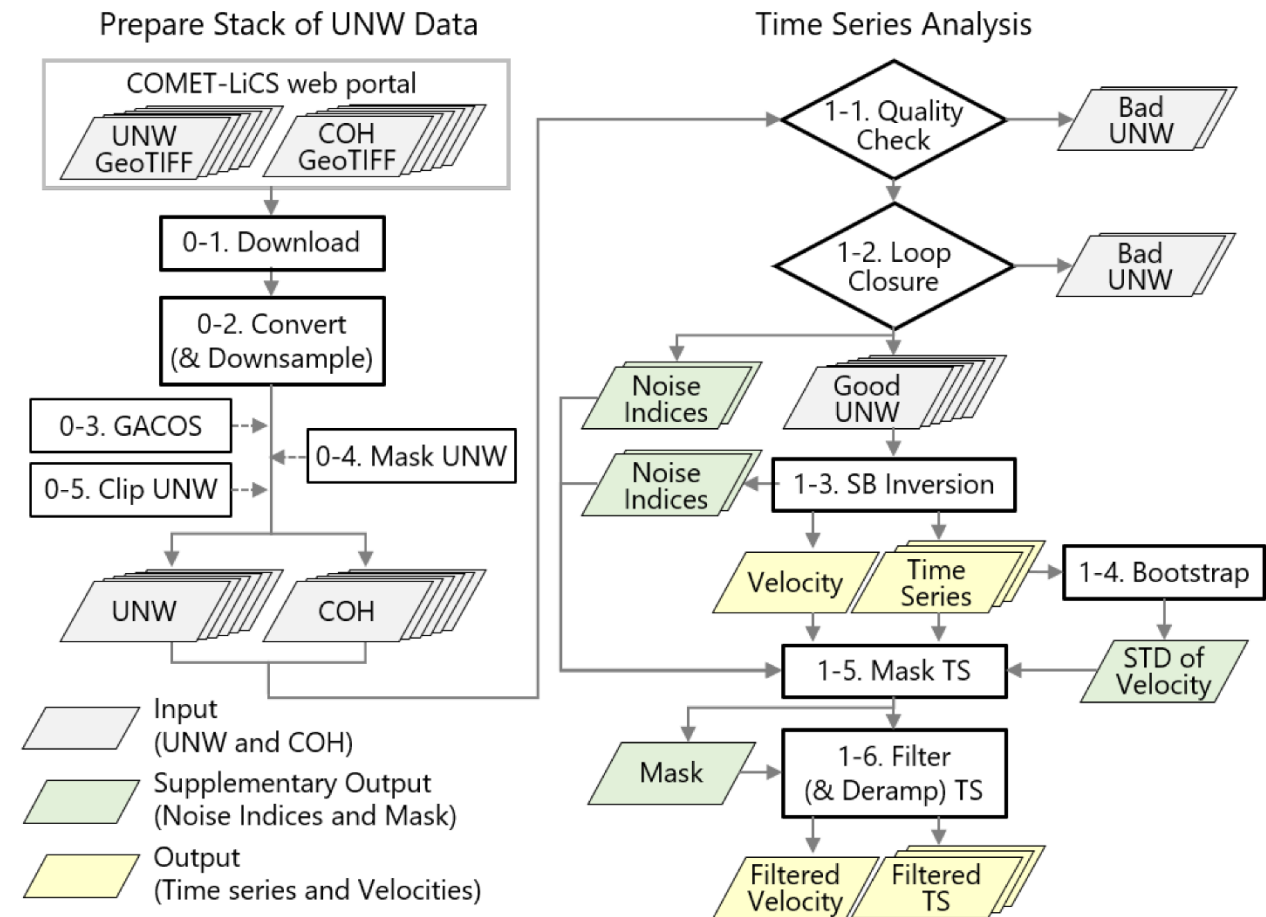
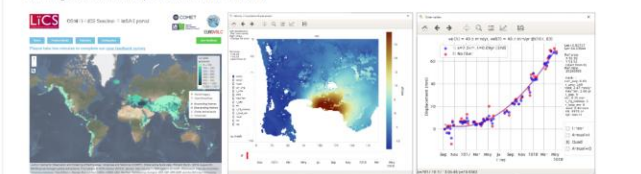
Contributors 1
yumorishita Yu Morishita

Languages
Python 95.7% Shell 4.3%

LiCSBAS2

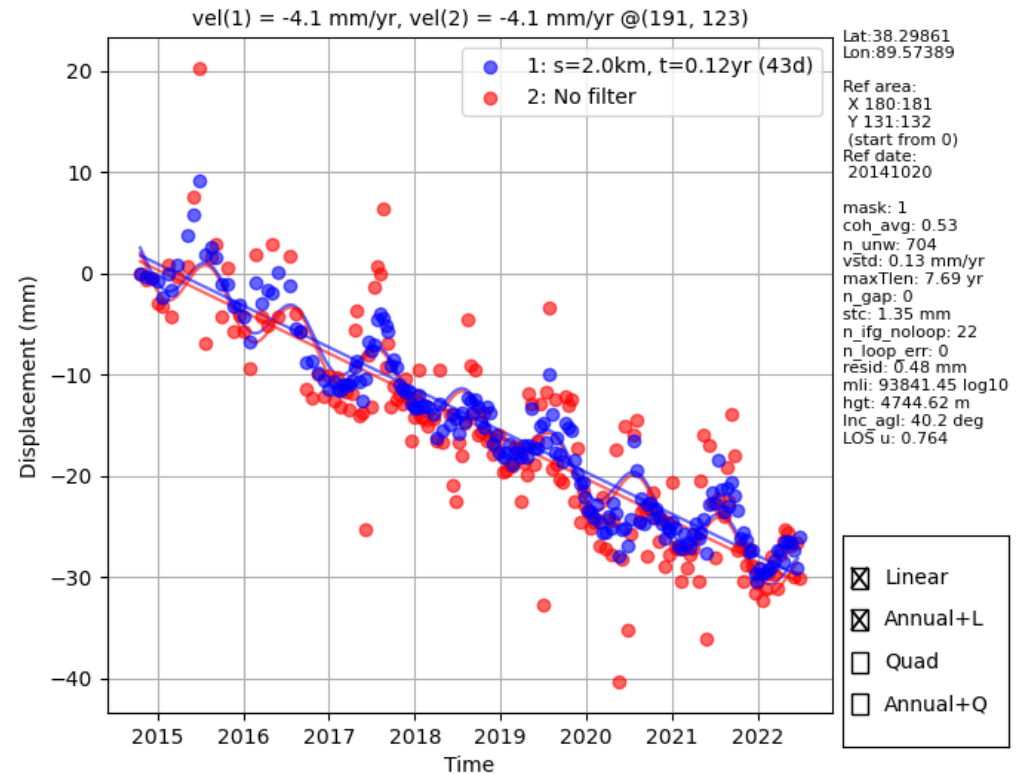
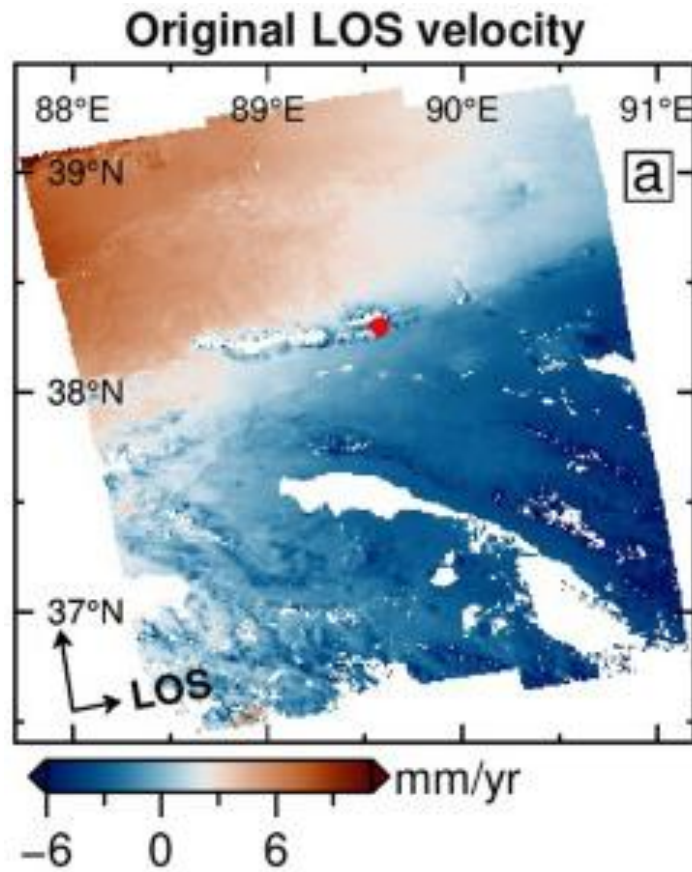
LiCSBAS is an open-source package in Python and bash to carry out InSAR time series analysis using LiCSAR products (i.e., unwrapped interferograms and coherence) which are freely available on the [COMET-LiCS web portal](https://doi.org/10.3390/RS12030424). LiCSBAS2 is the successor of LiCSBAS.

Users can easily derive the time series and velocity of the displacement if sufficient LiCSAR products are available in the area of interest. LiCSBAS also contains visualization tools to interactively display the time series of displacement to help investigation and interpretation of the results.

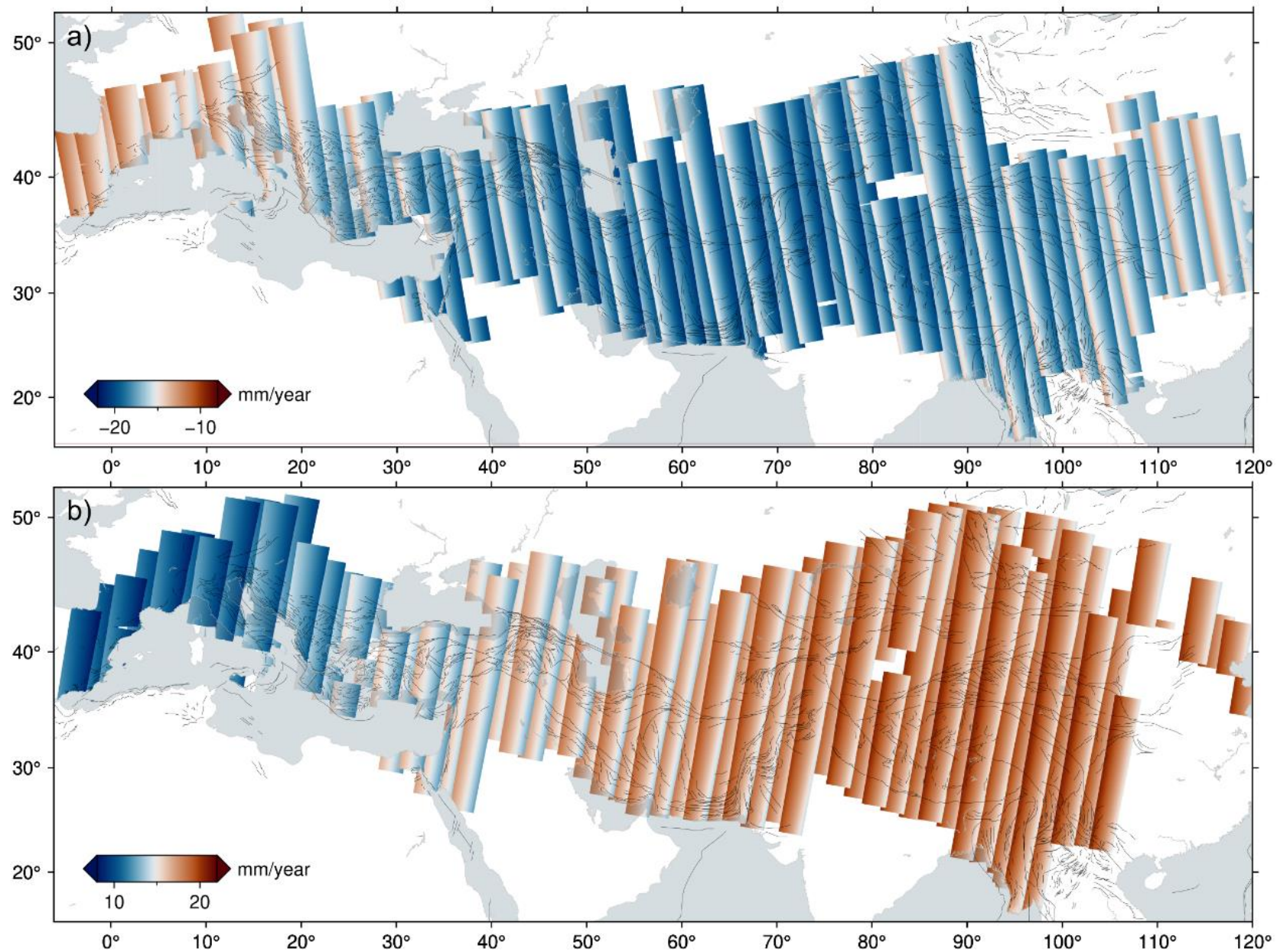




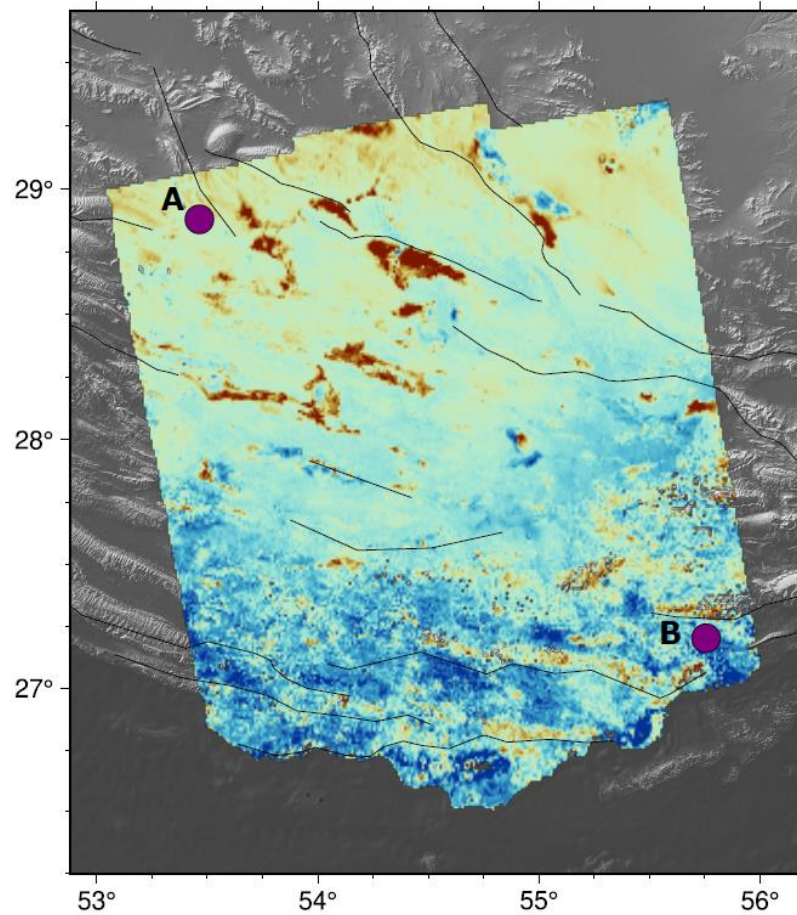
Time Series Analysis - LiCSBAS



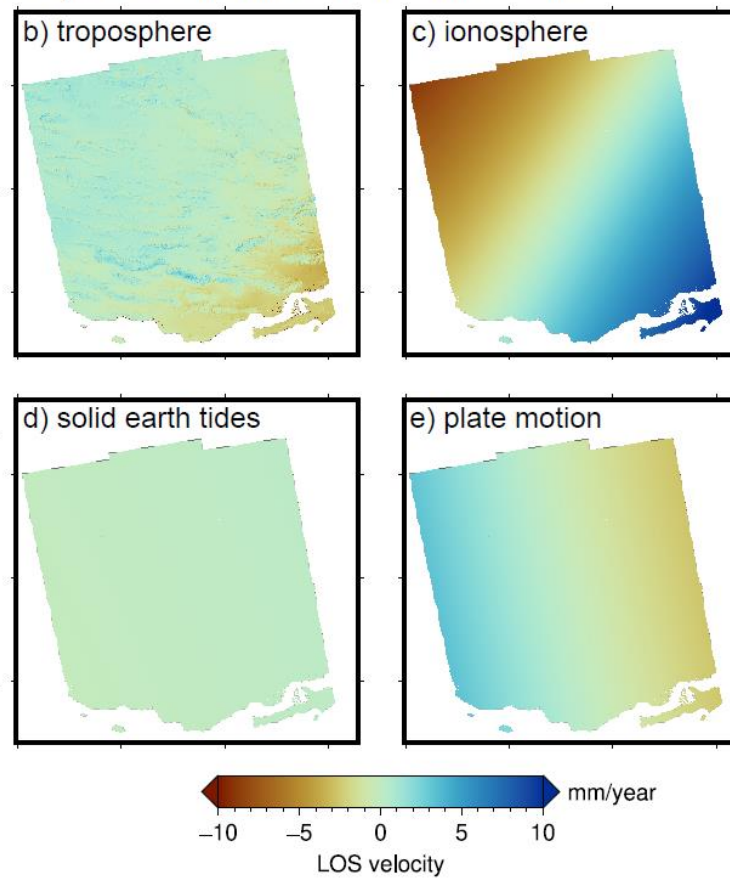
Corrections – Plate Motion



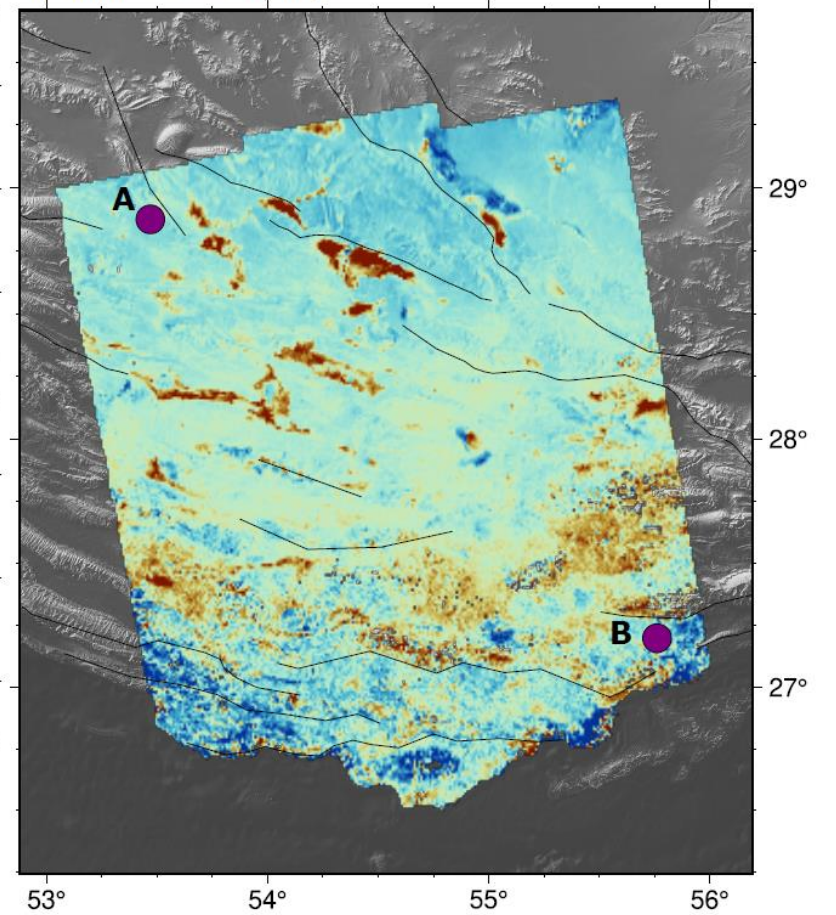
a) LOS velocity without corrections



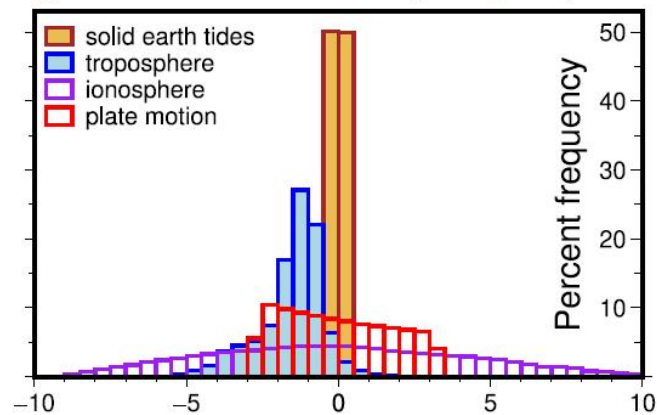
b-e) LOS velocities from corrections



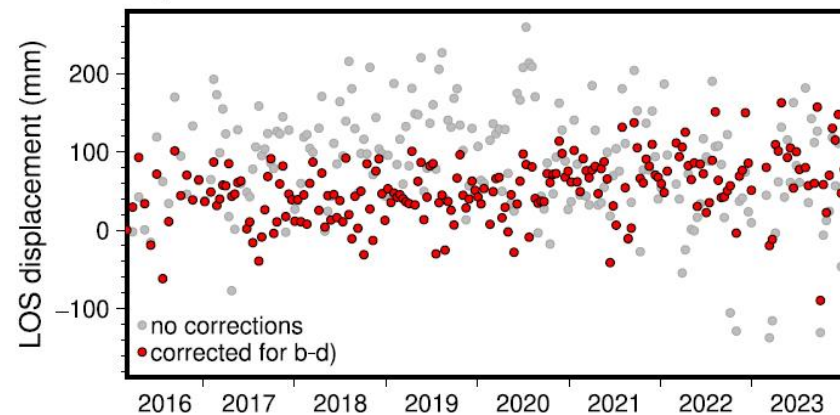
f) final LOS velocity



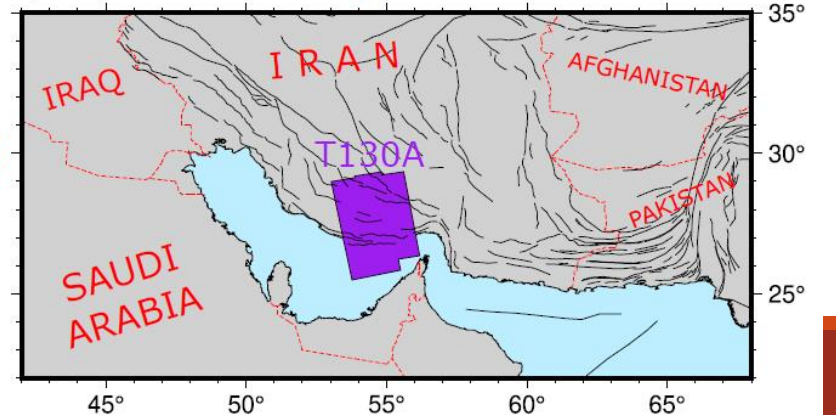
g) Correction velocities (mm/year)



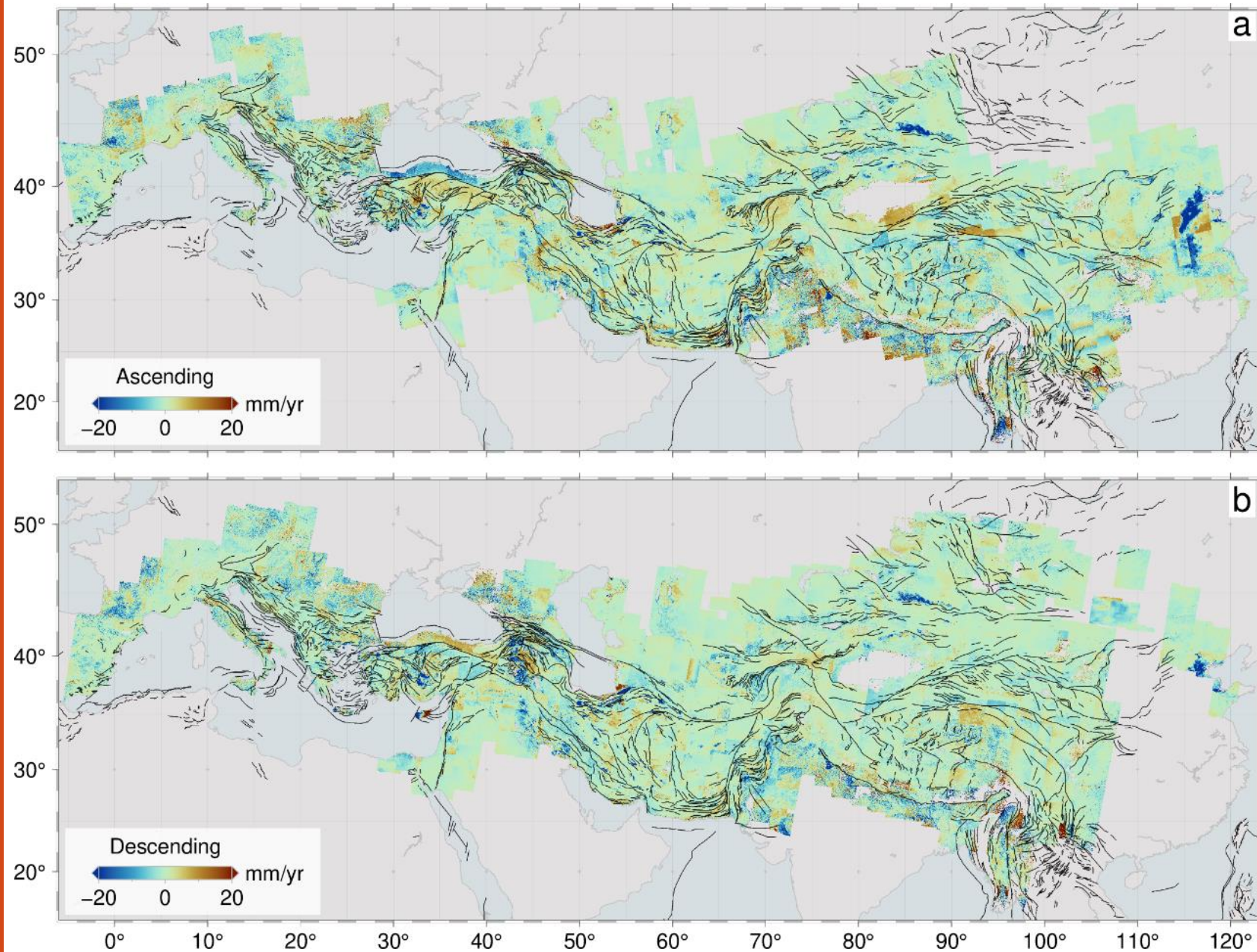
h) Time series of area A w.r.t. B

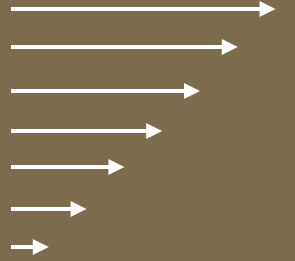


i) Localisation of the processed frame



Line-of-Sight Velocities





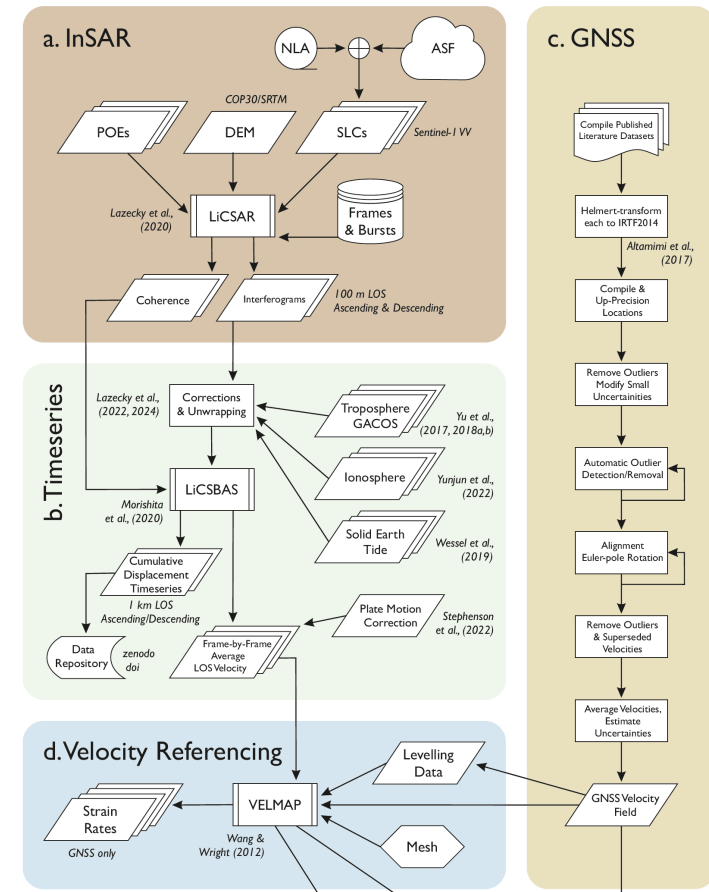
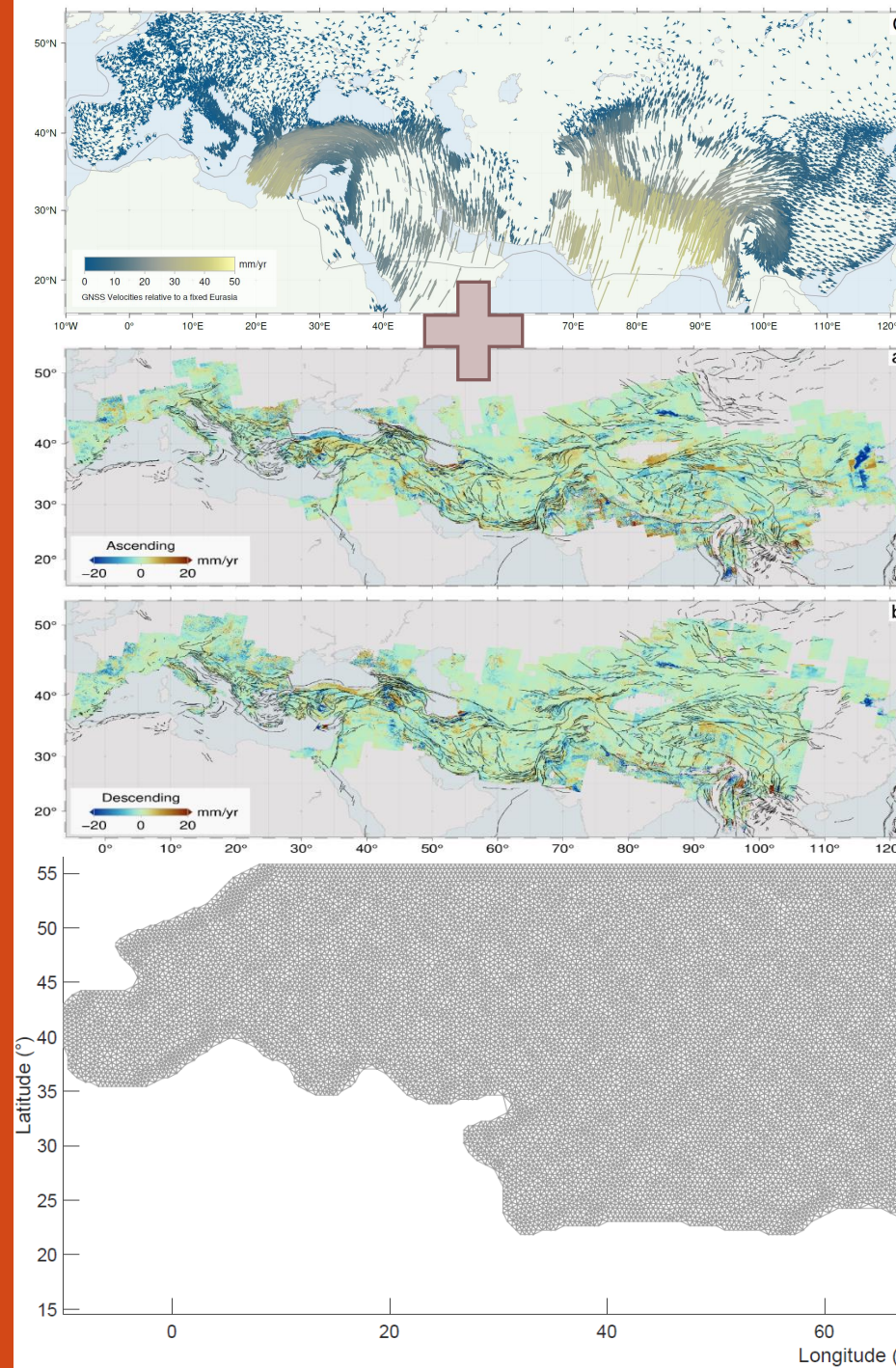
Velocity Field Generation

VELMAP

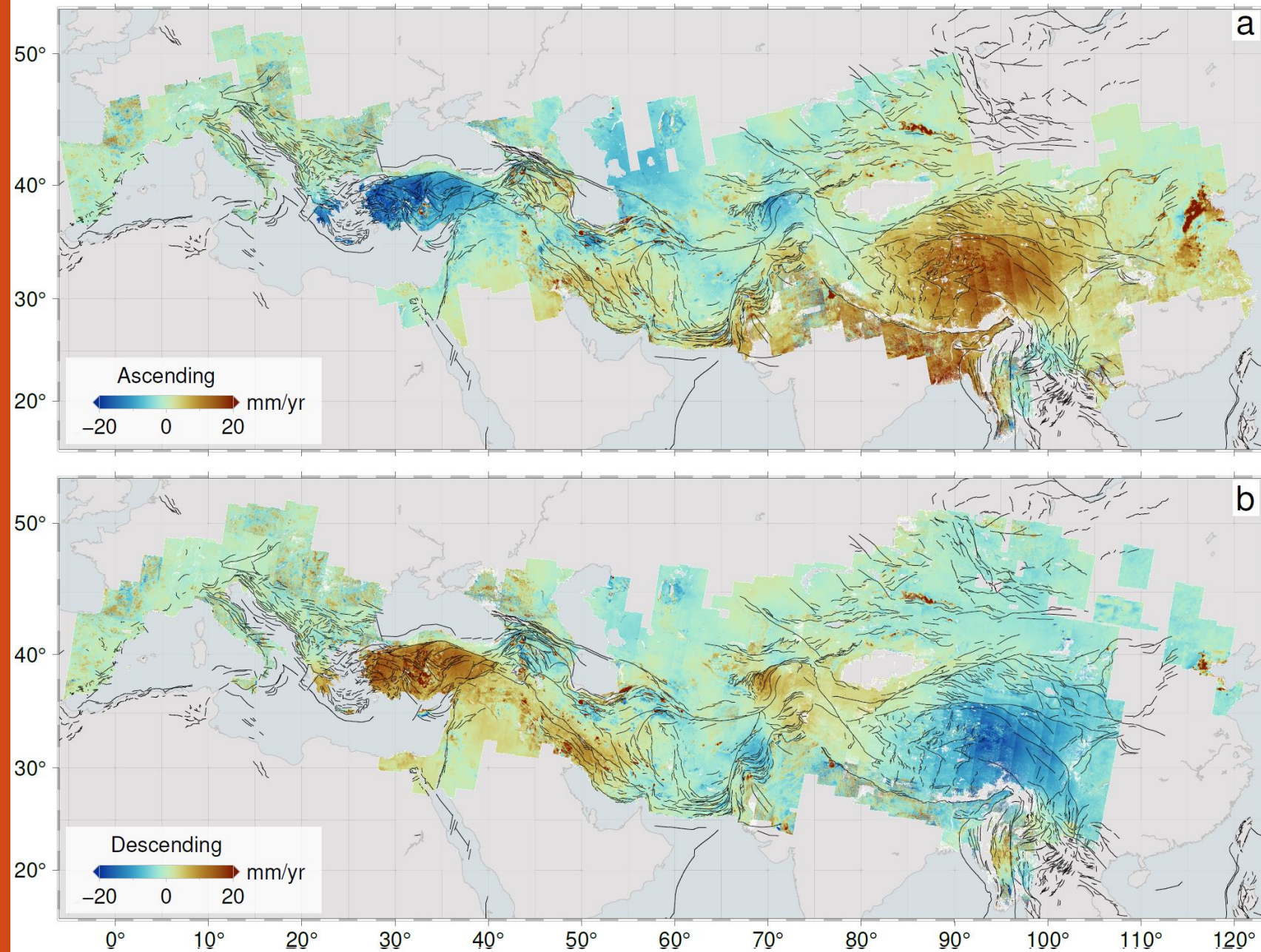
each frame is independently
referenced for line-of-sight (LOS)
velocity estimation

Triangular mesh covering AOI with
vertices space ~ 40 km

Inversion solves for velocities at each
triangular mesh node, reference frame
adjustment parameters - a long-
wavelength quadratic ramp for each
frame and a linear atmospheric
correction term based on elevation

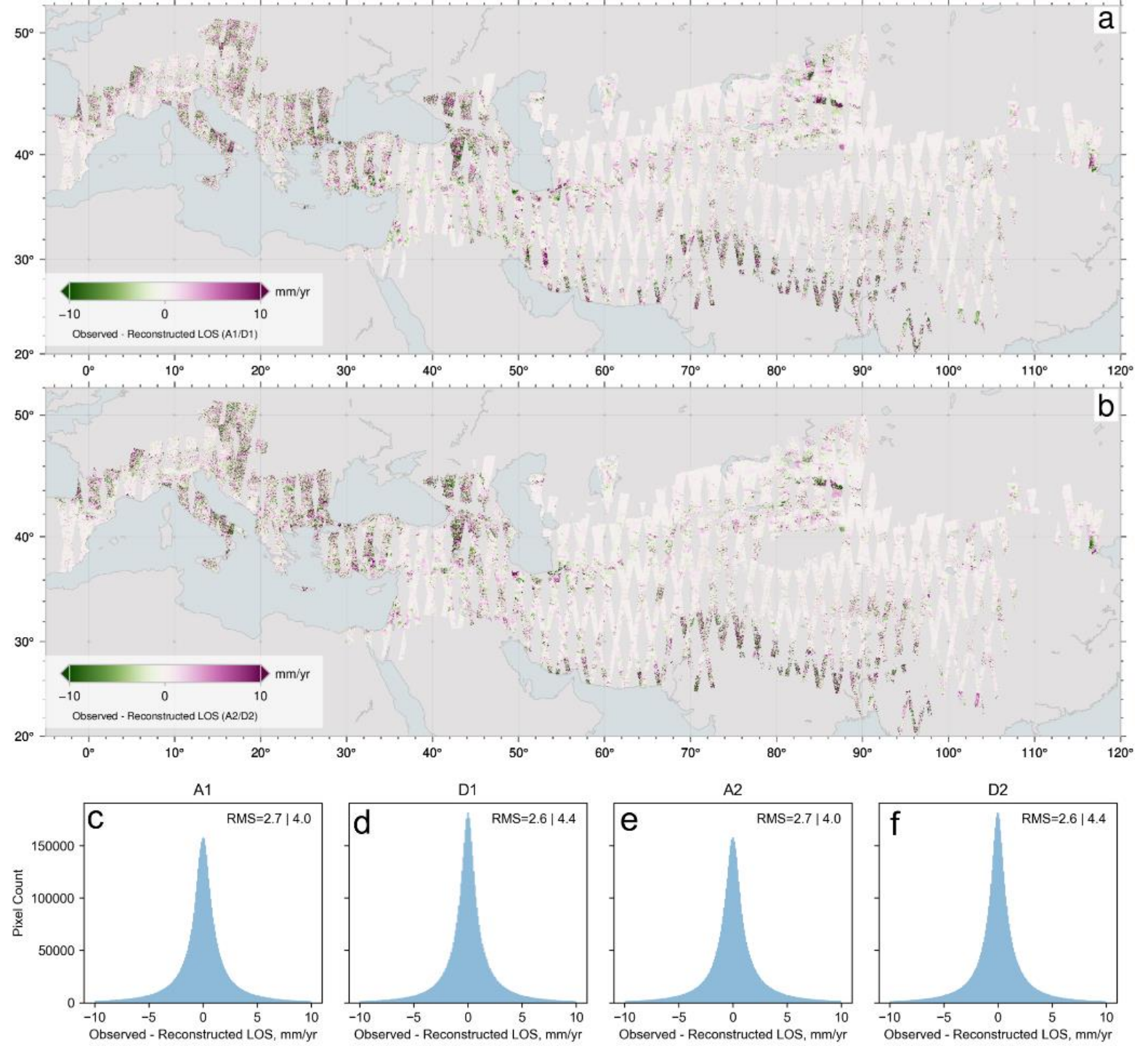


Line-of-Sight Velocities

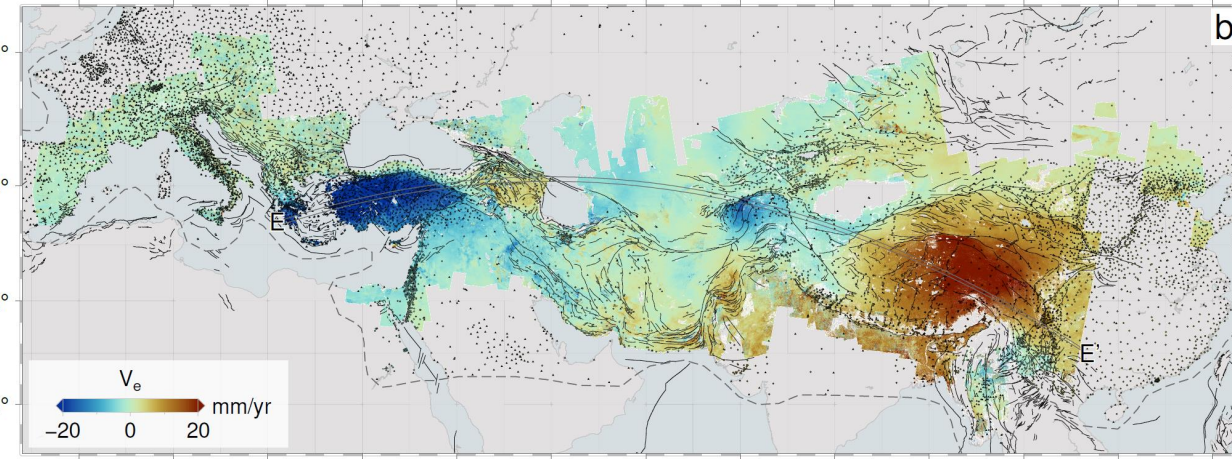
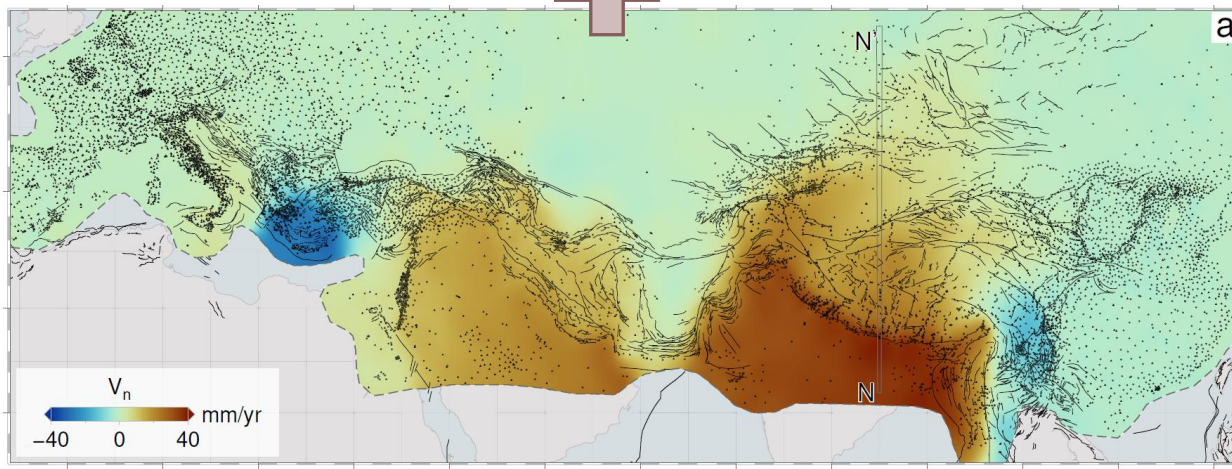
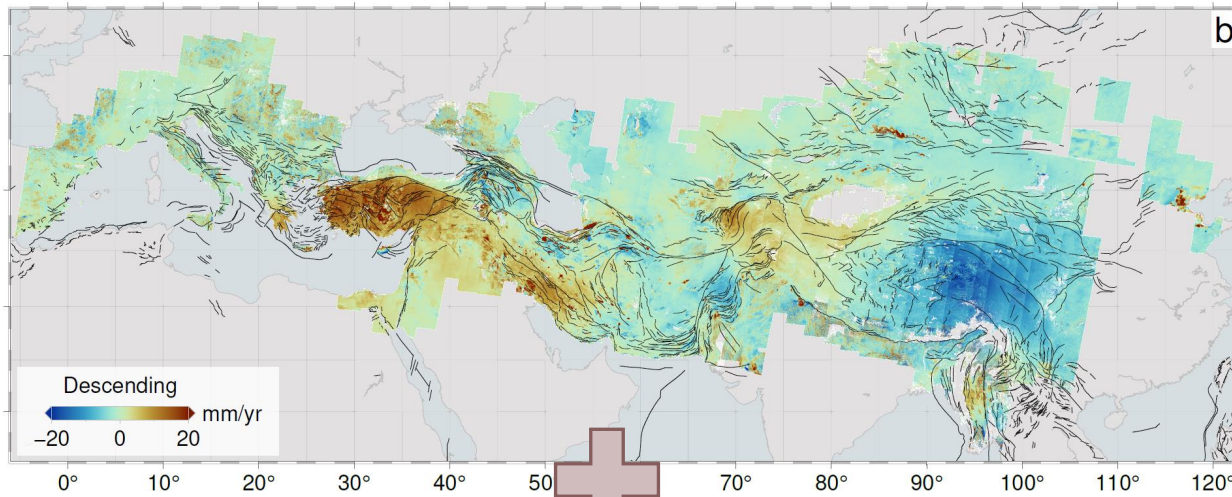
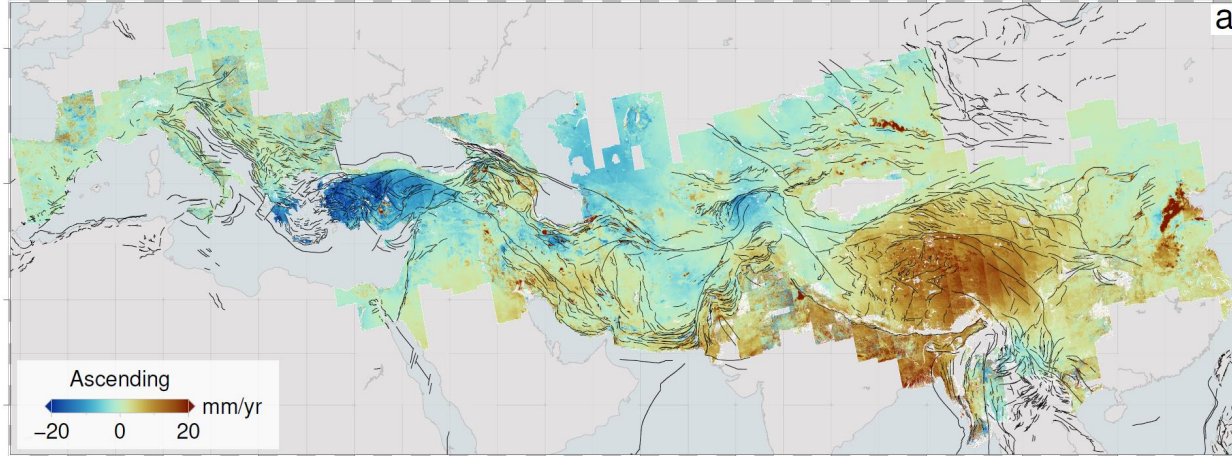


More Realistic Uncertainties

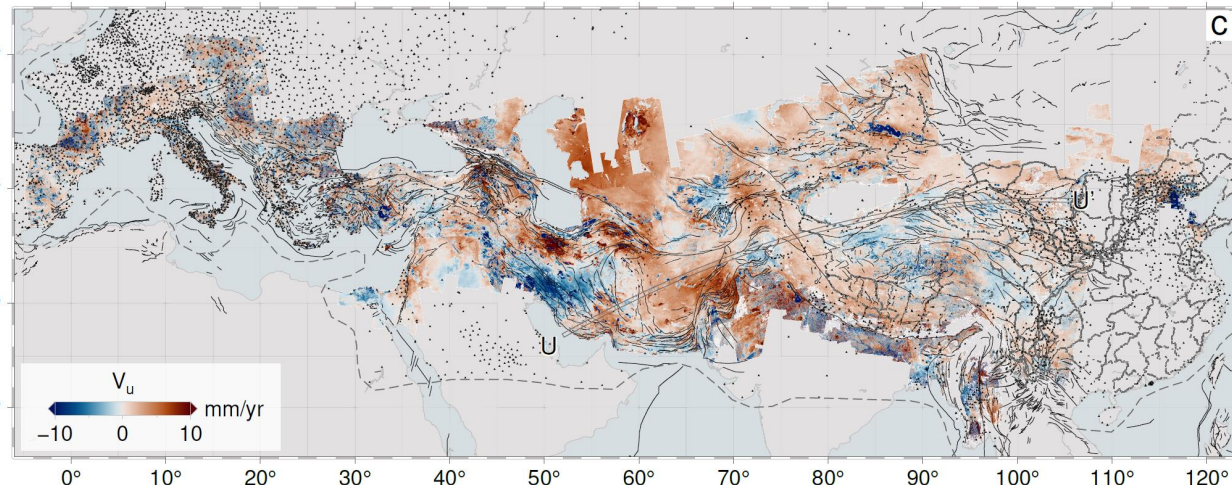
The mosaics of the two InSAR line-of-sight (LOS) velocities in a common reference frame, as well as the VELMAP north velocities from GNSS, allow us to evaluate the uncertainties of our LOS velocities at track overlaps, where we have a redundancy of one LOS velocity measurement in ascending or descending



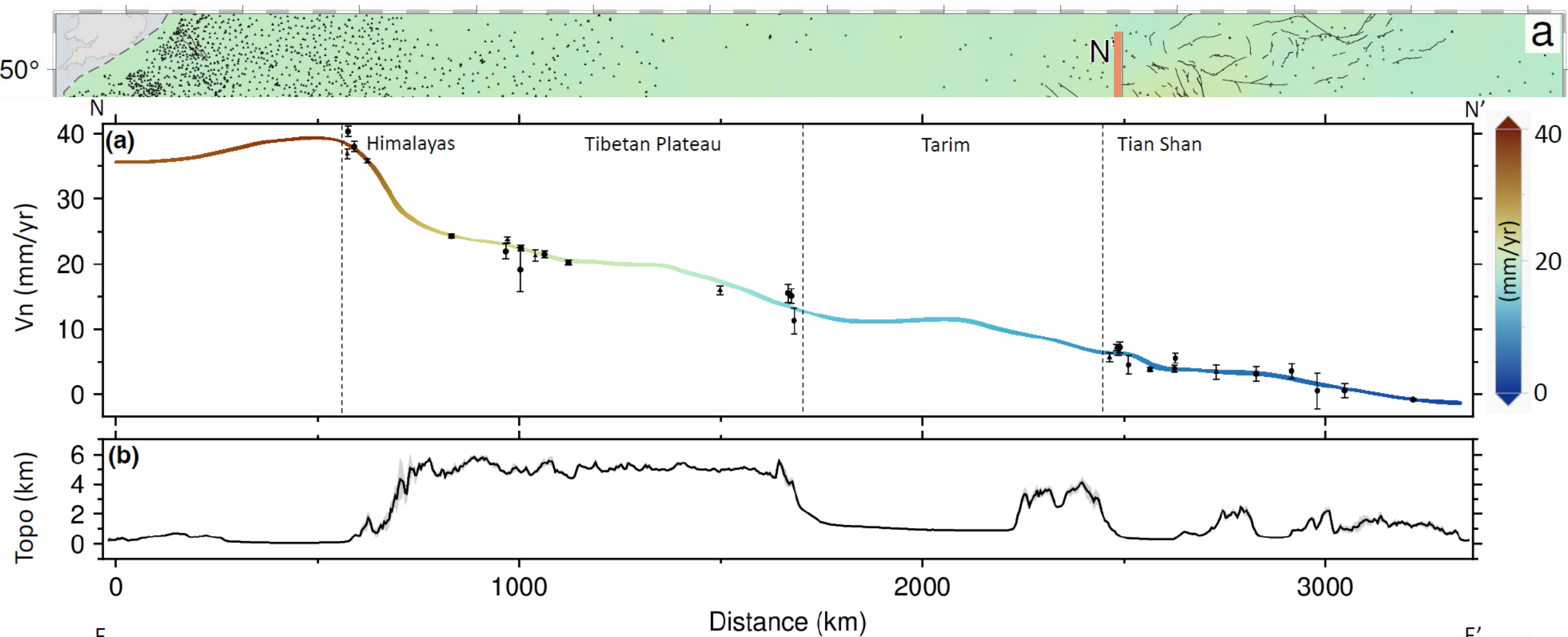
Velocity Decomposition



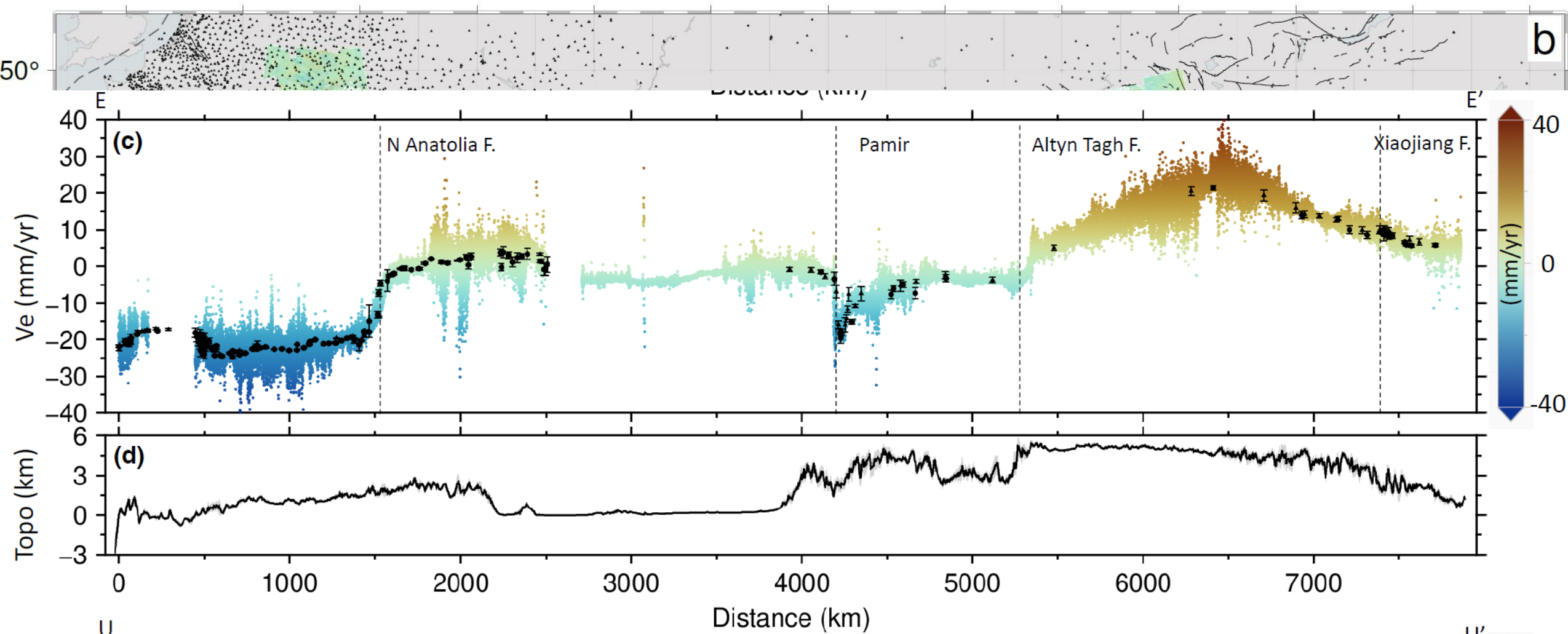
➡ Weighted Pixel-wise inversion of all InSAR los data 1km resolution



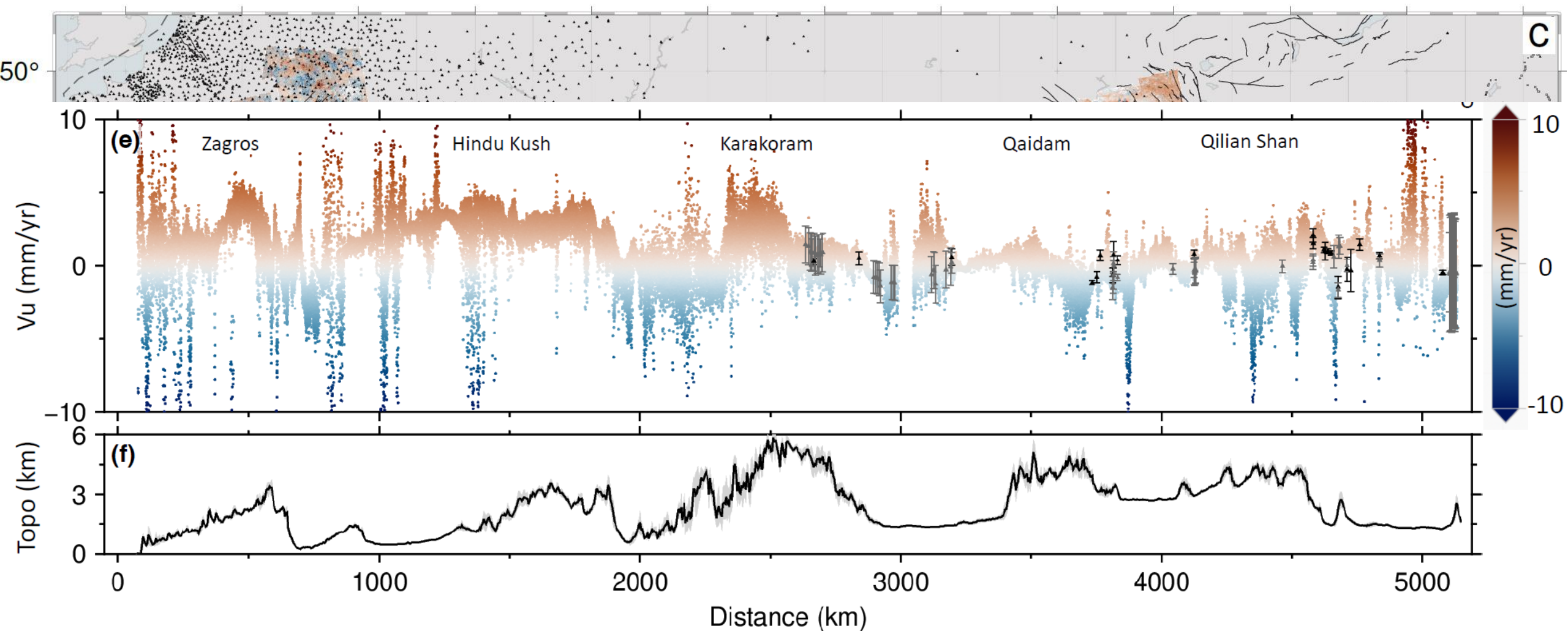
3 component velocity field



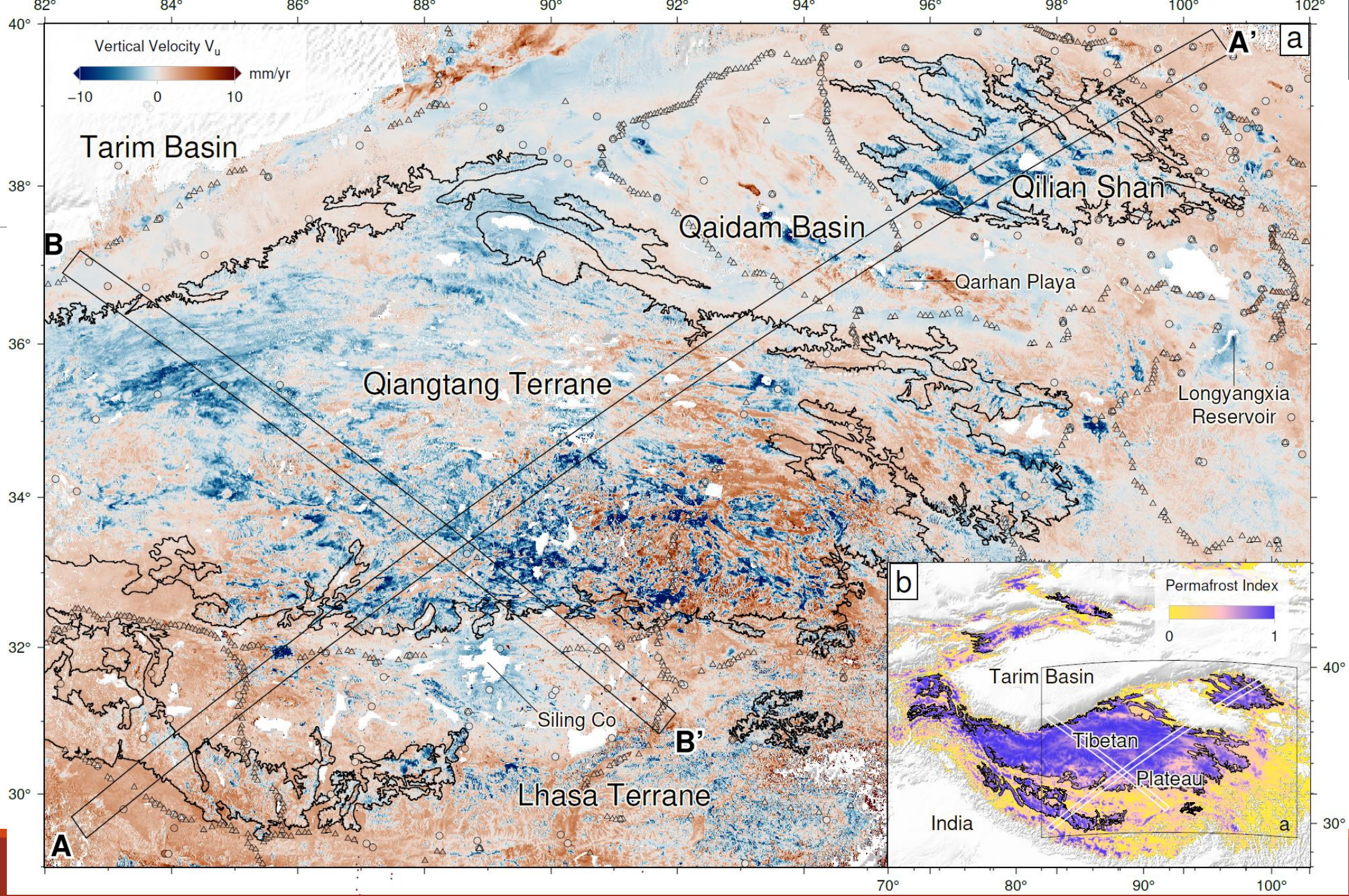
3 component velocity field



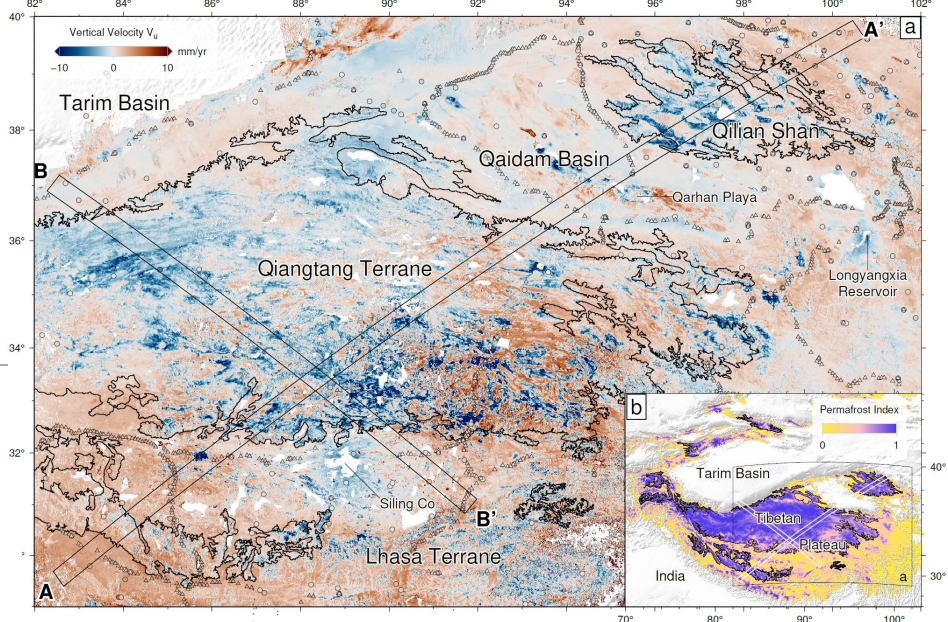
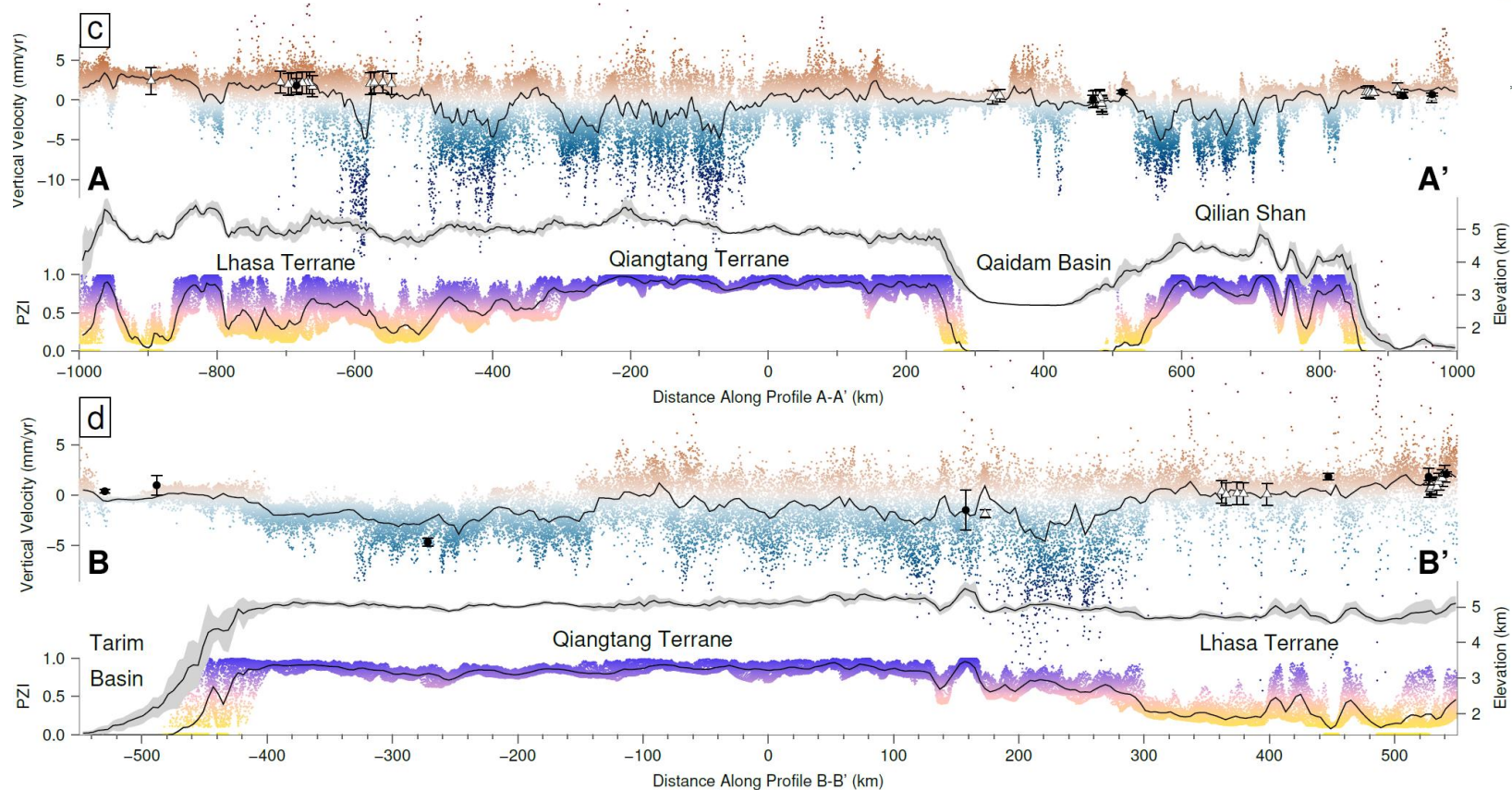
3 component velocity field



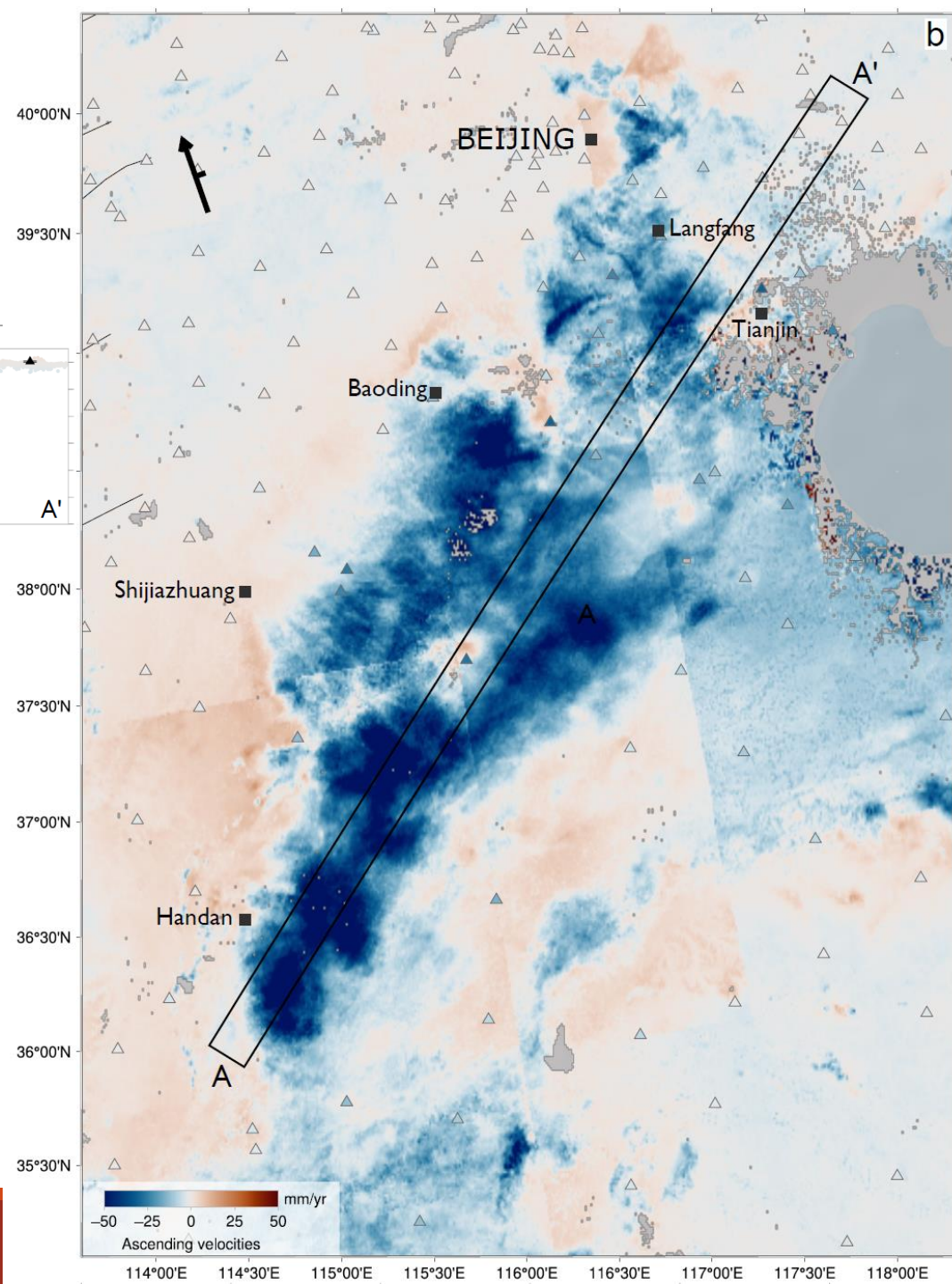
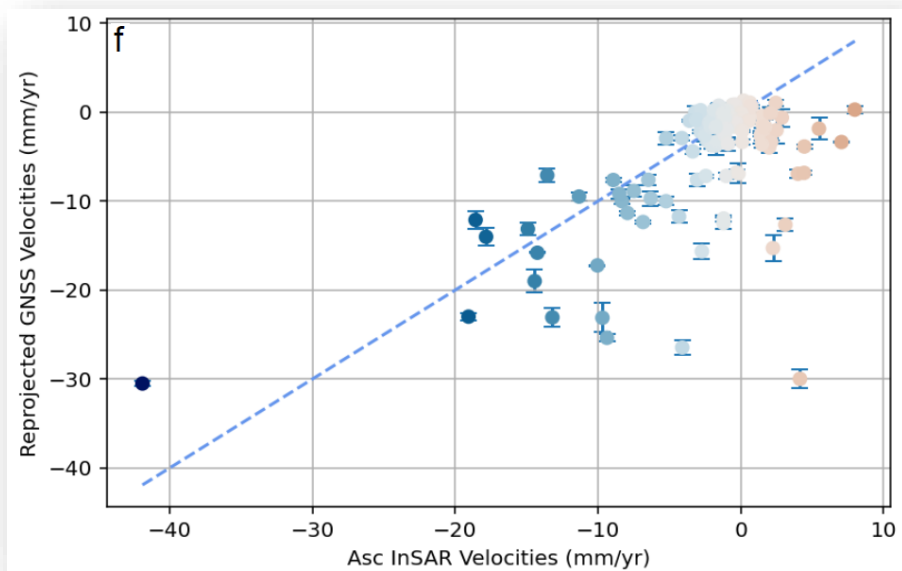
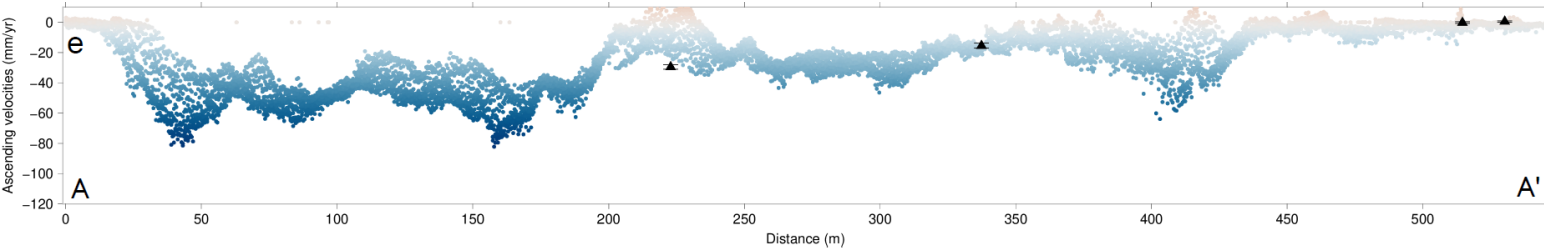
Permafrost Related Deformation



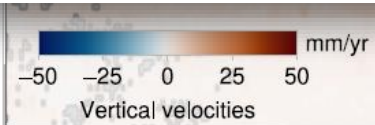
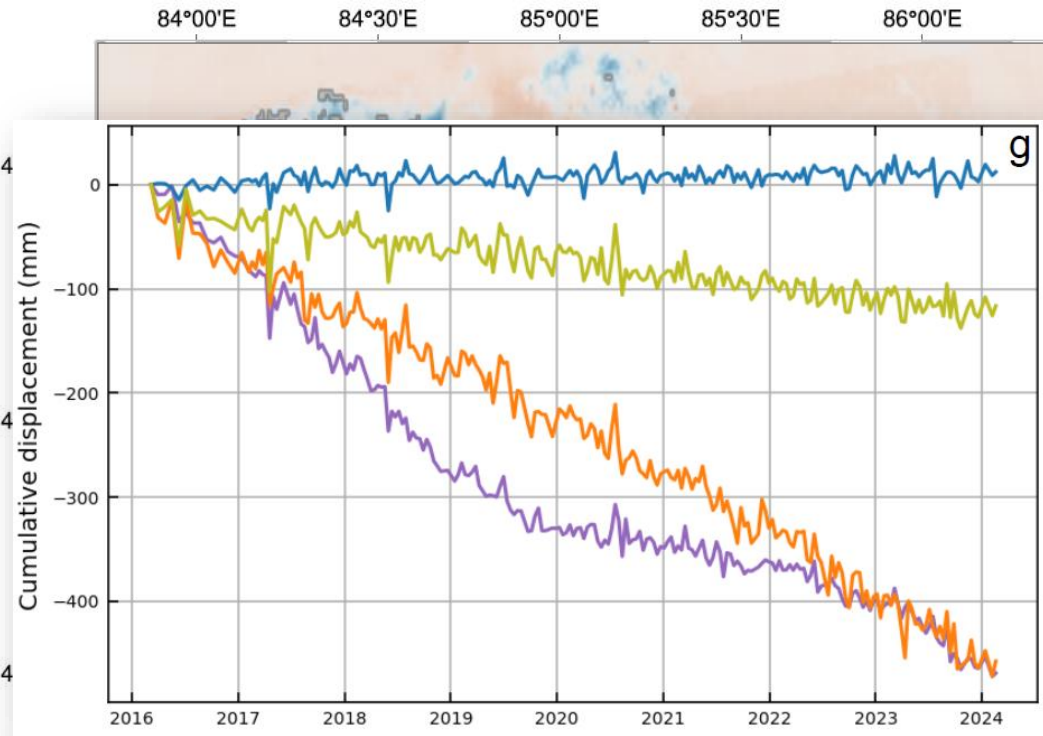
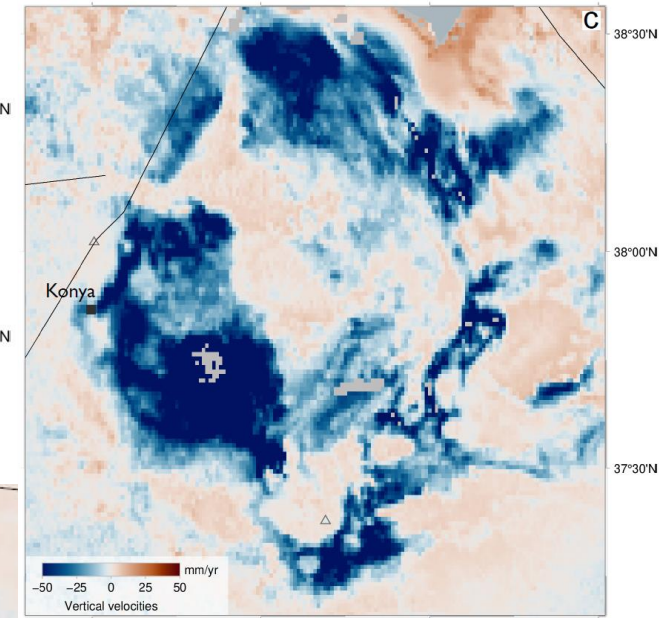
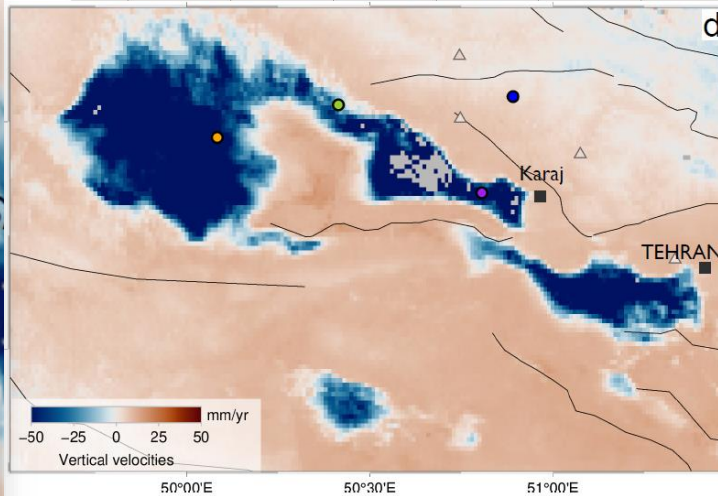
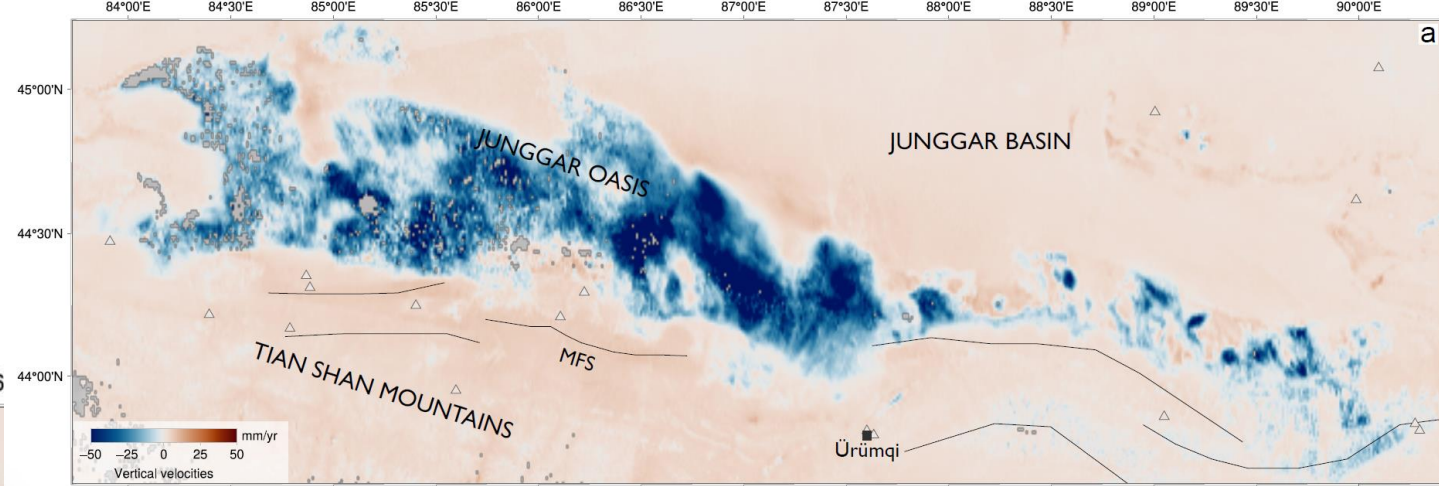
Permafrost Related Deformation

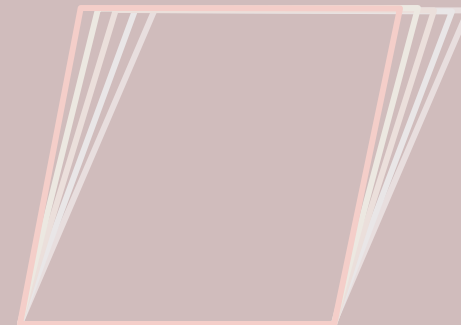


Water-Related Land Subsidence



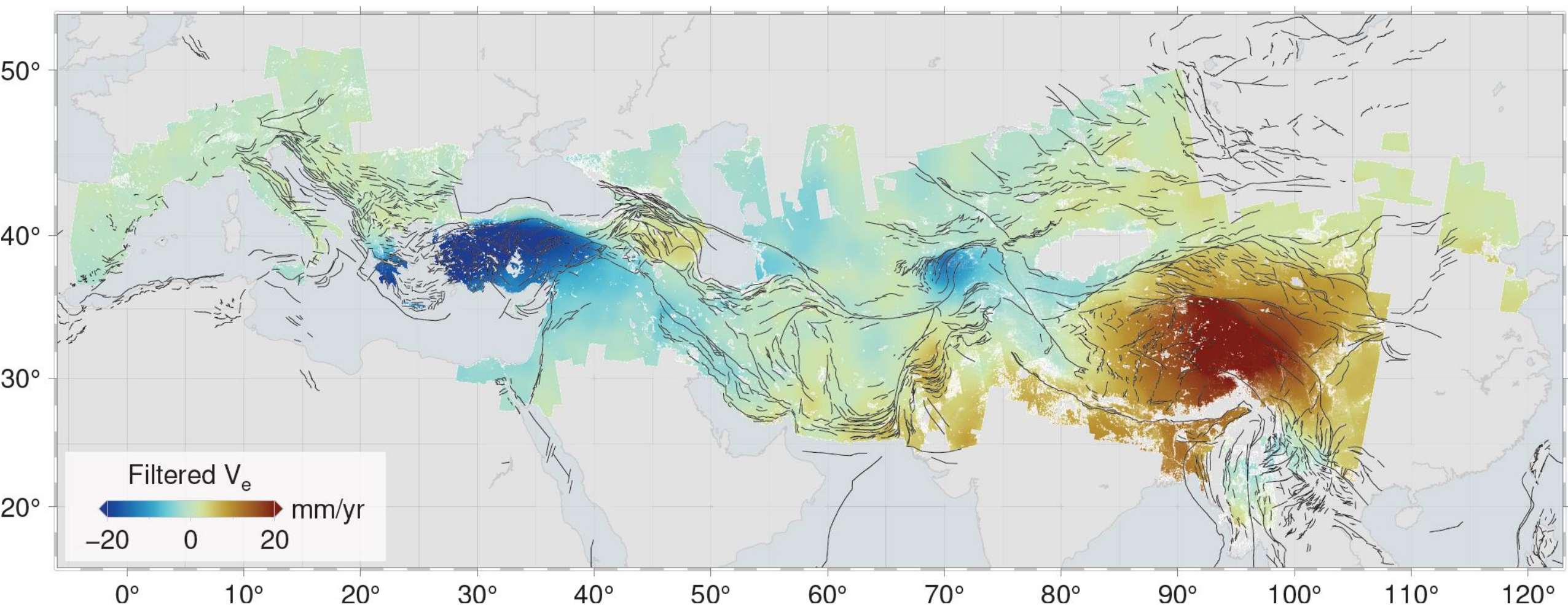
Water-Related Land Subsidence





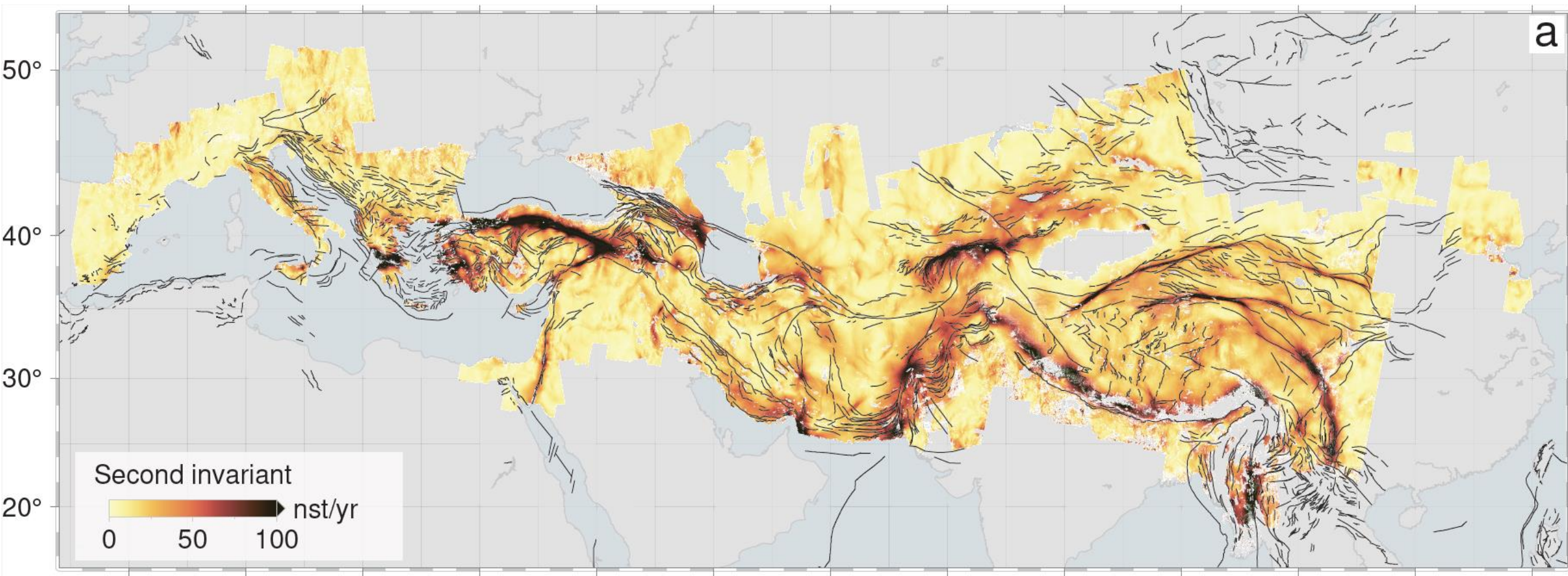
Strain Rates

Filtered Velocities



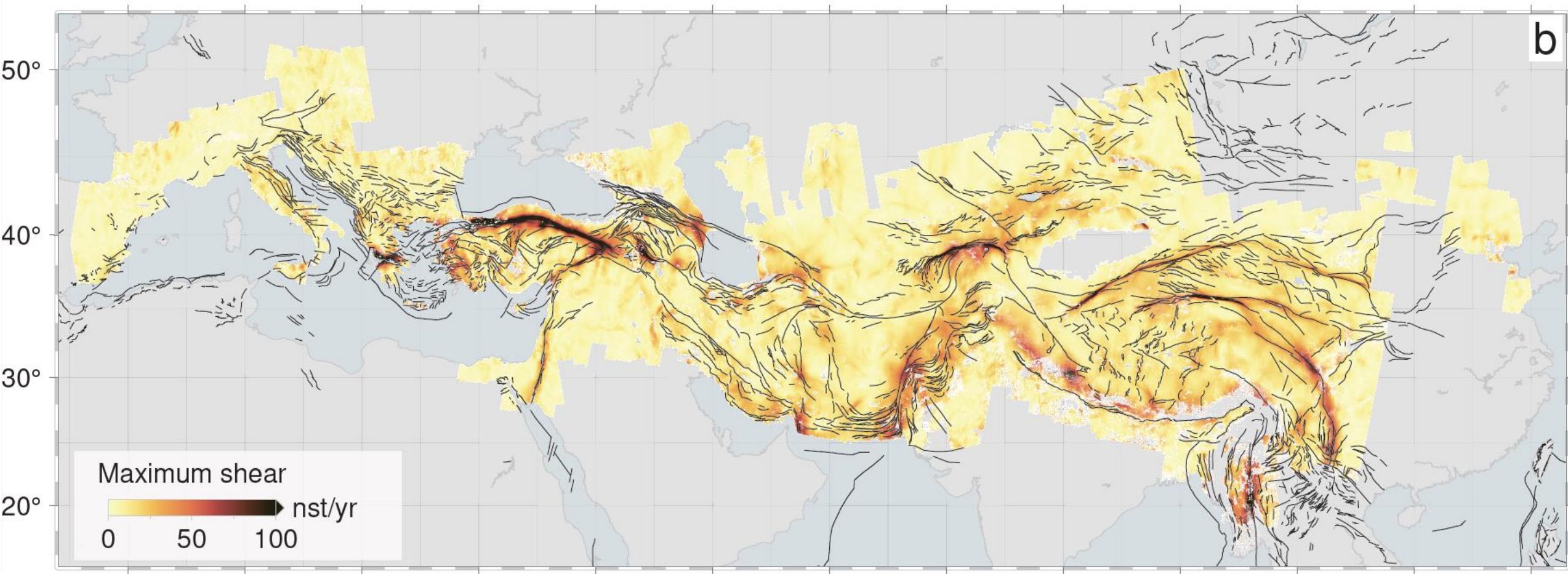
150 km Median Filtered

Strain Rates



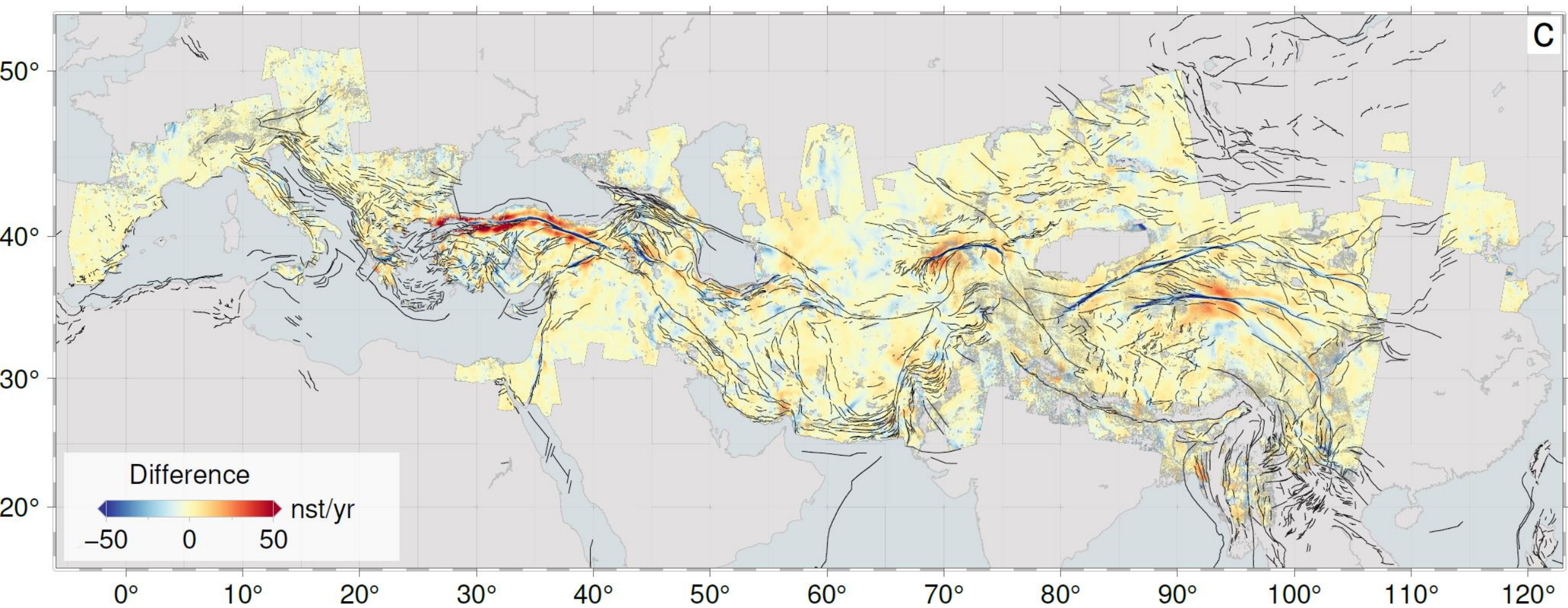
$$\dot{\epsilon}_{II_h} = \sqrt{\dot{\epsilon}_{EE}^2 + 2\dot{\epsilon}_{EN}^2 + \dot{\epsilon}_{NN}^2}$$

Strain Rates

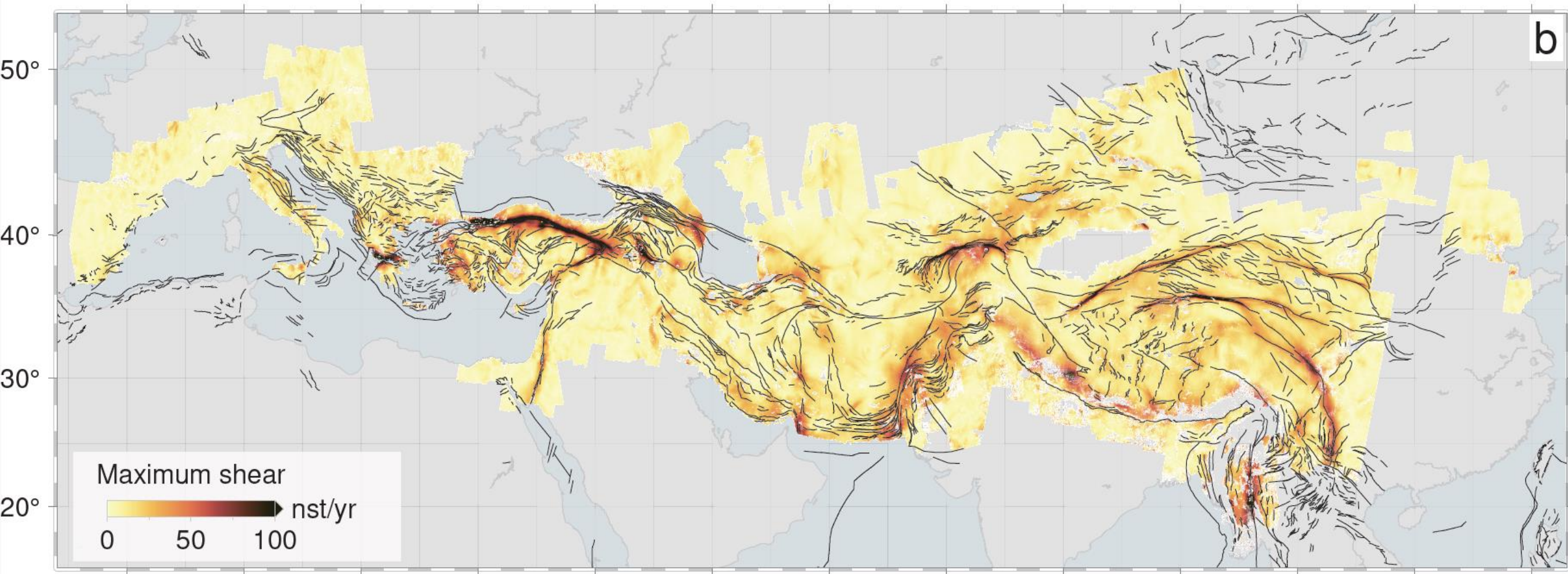


$$\dot{\epsilon}_{shear} = \sqrt{\dot{\epsilon}_{EN}^2 + \frac{(\dot{\epsilon}_{EE} - \dot{\epsilon}_{NN})^2}{4}}$$

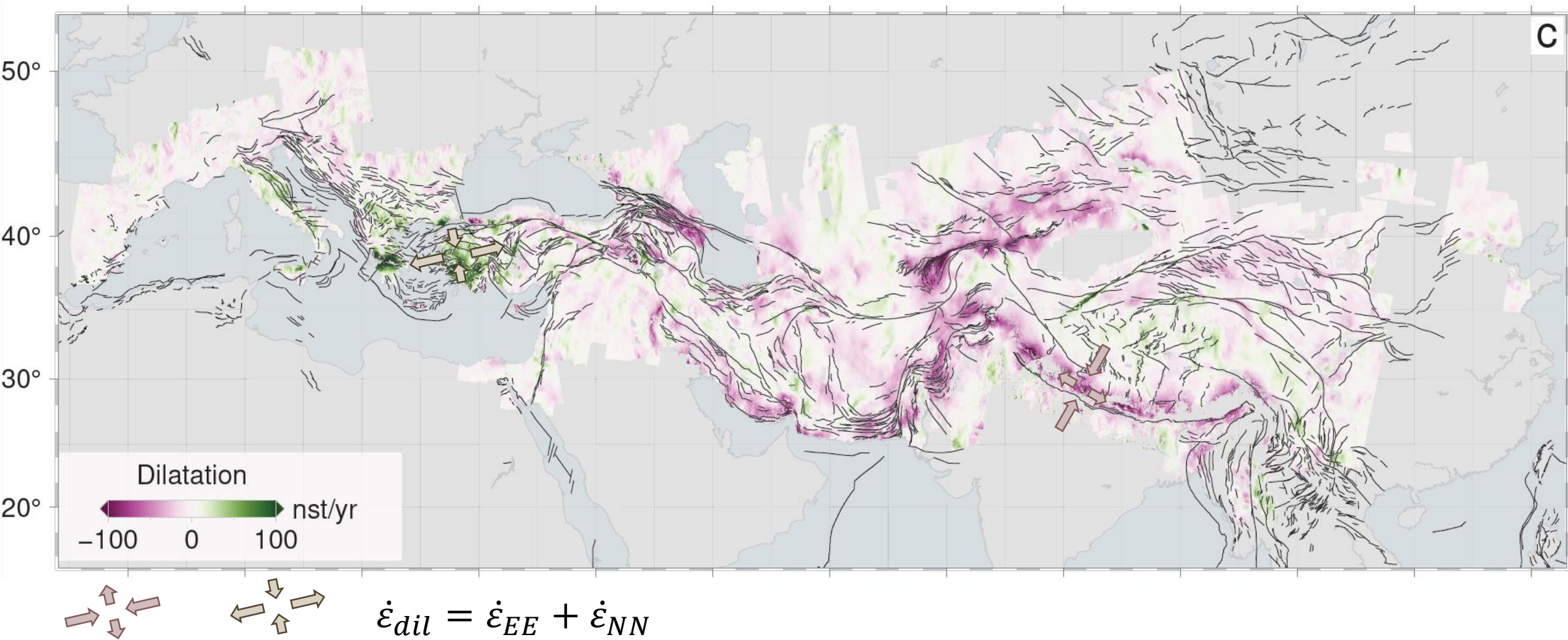
Comparison – GNSS vs GNSS+InSAR



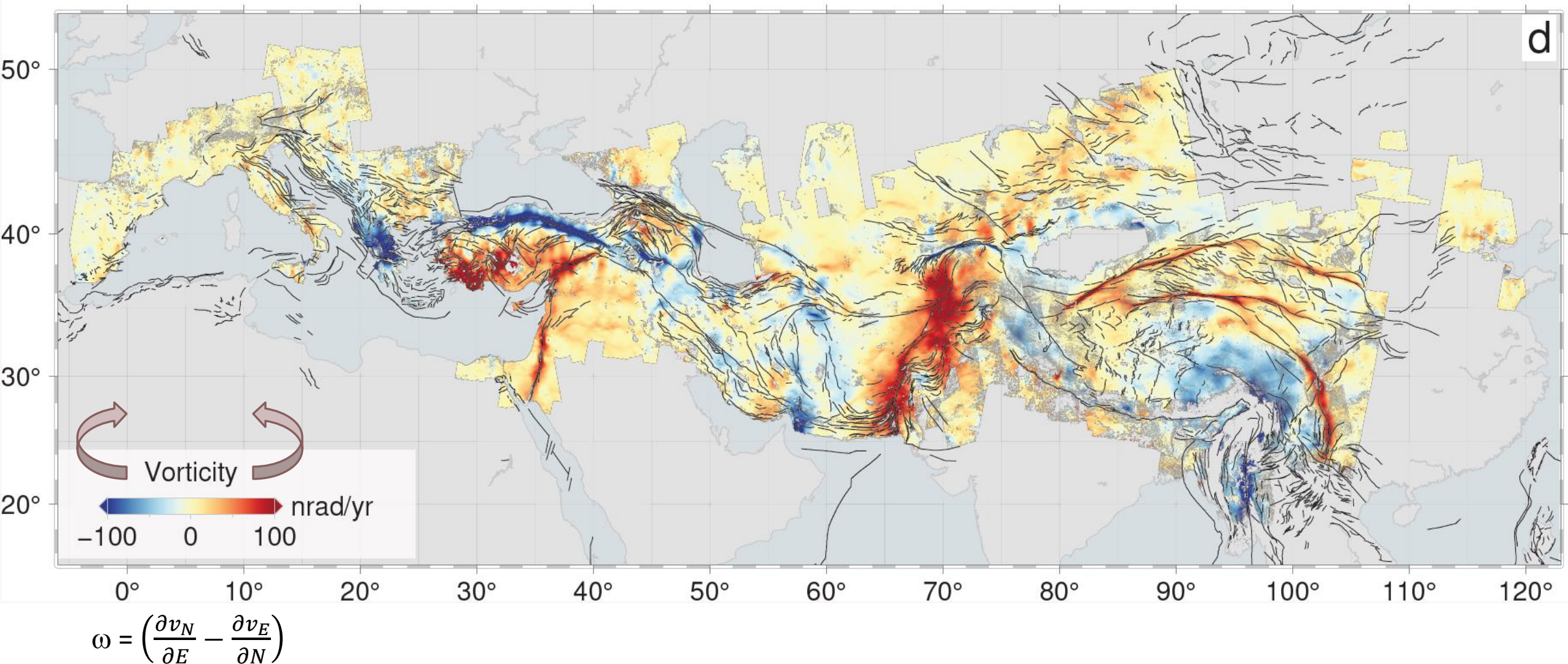
Comparison - GSRM



Strain Rates



Strain Rates



Open Datasets

DATA REPOSITORY

The screenshot shows the Zenodo dataset page for the record 18924920. The title is "Deformation, Strains and Velocities for the Alpine Himalayan Belt from trans-continental Sentinel-1 InSAR & GNSS". The authors listed are Elliott, John; Fang, Jin; Lazceky, Milan; Maghsoudi, Yasser; Ou, Qi; Payne, Jess; Rollins, Chris; Wang, Dehua; Hooper, Andy; and Wright, Tim. The page indicates it was published in 2026 and is version v2. It shows 259 views and 113 downloads. A sidebar on the right contains sections for Versions (v2 and v1), External resources (Indexed in OpenAIRE), Details (DOI, Resource type, Publisher), Rights (License: CC BY-NC 4.0), and Files (Strain_rates_v2.zip). The main content area includes an update notice from March 2026, a contact email, and a reference to the dataset.

<https://zenodo.org/records/18924920>

TIMESERIES ARCHIVE

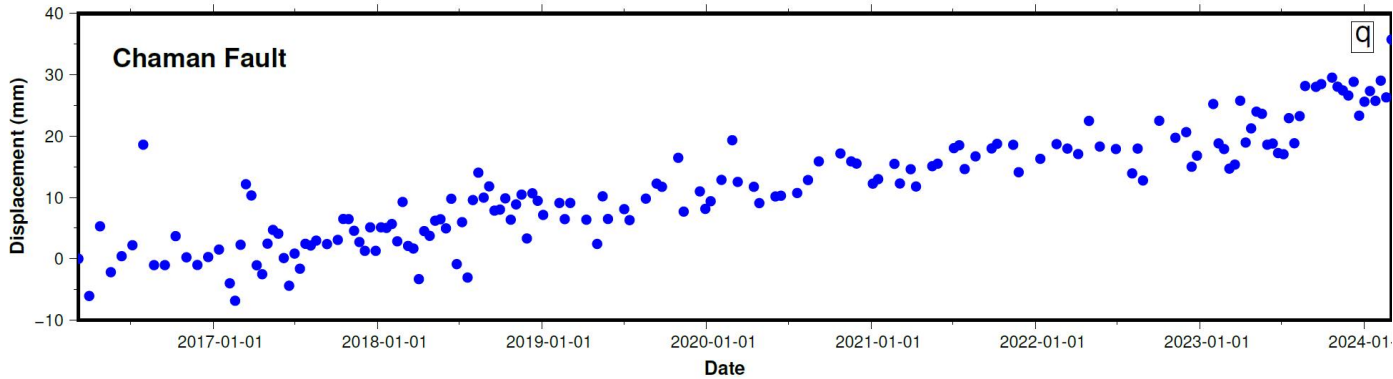
The screenshot shows the CEDA Archive dataset page for the same record. The title is "Deformation, Strains and Velocities for the Alpine Himalayan Belt from trans-continental Sentinel-1 InSAR & GNSS". The page indicates it was published in 2026 and is version v2. It shows 259 views and 113 downloads. A sidebar on the right contains sections for Versions (v2 and v1), External resources (Indexed in OpenAIRE), Details (DOI, Resource type, Publisher), Rights (License: CC BY-NC 4.0), and Files (Strain_rates_v2.zip). The main content area includes an update notice from March 2026, a contact email, and a reference to the dataset.

<https://catalogue.ceda.ac.uk/uuid/5c8a8297aed24118b23440f6742b860e/>

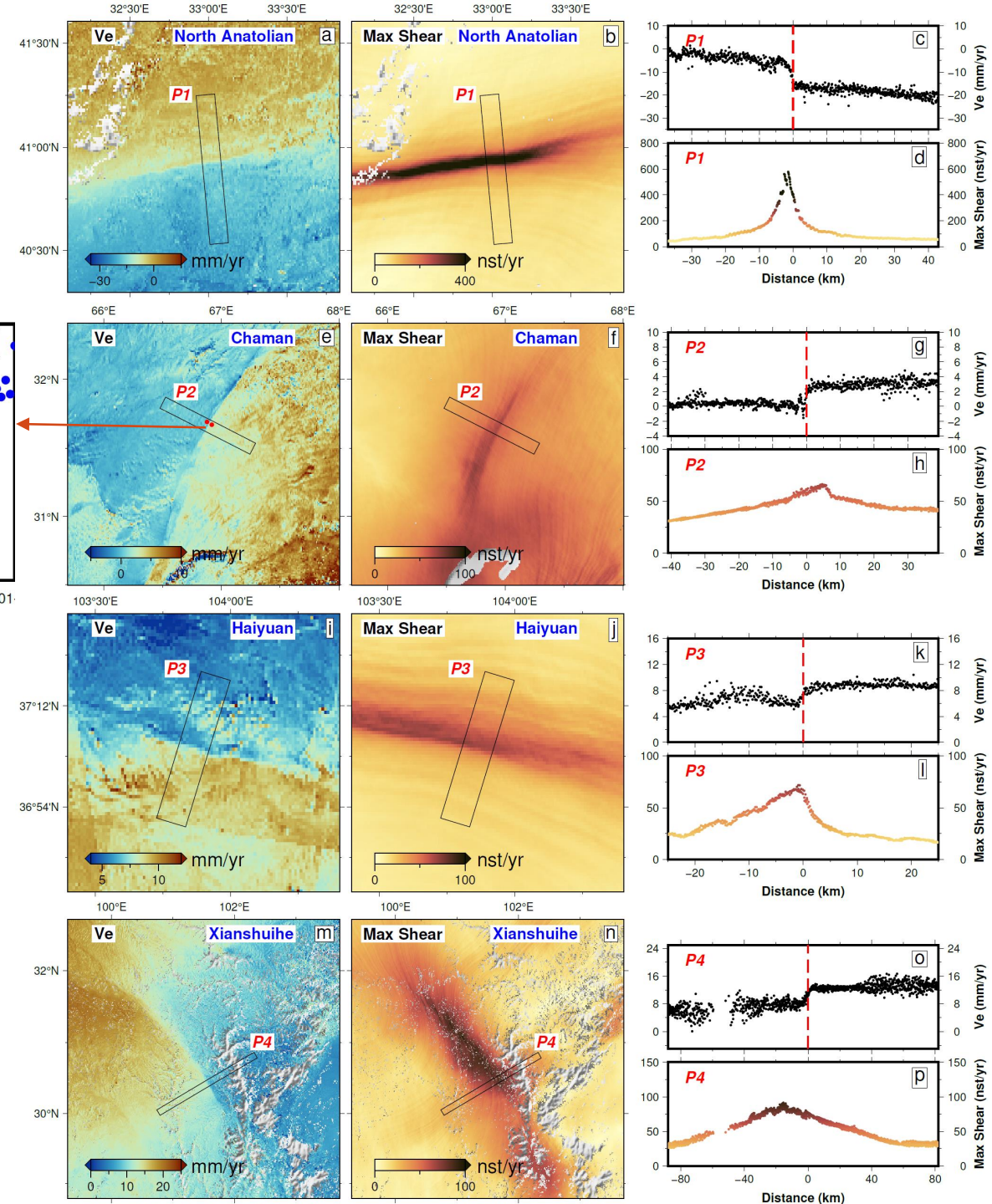


Active Tectonics

Creeping Faults

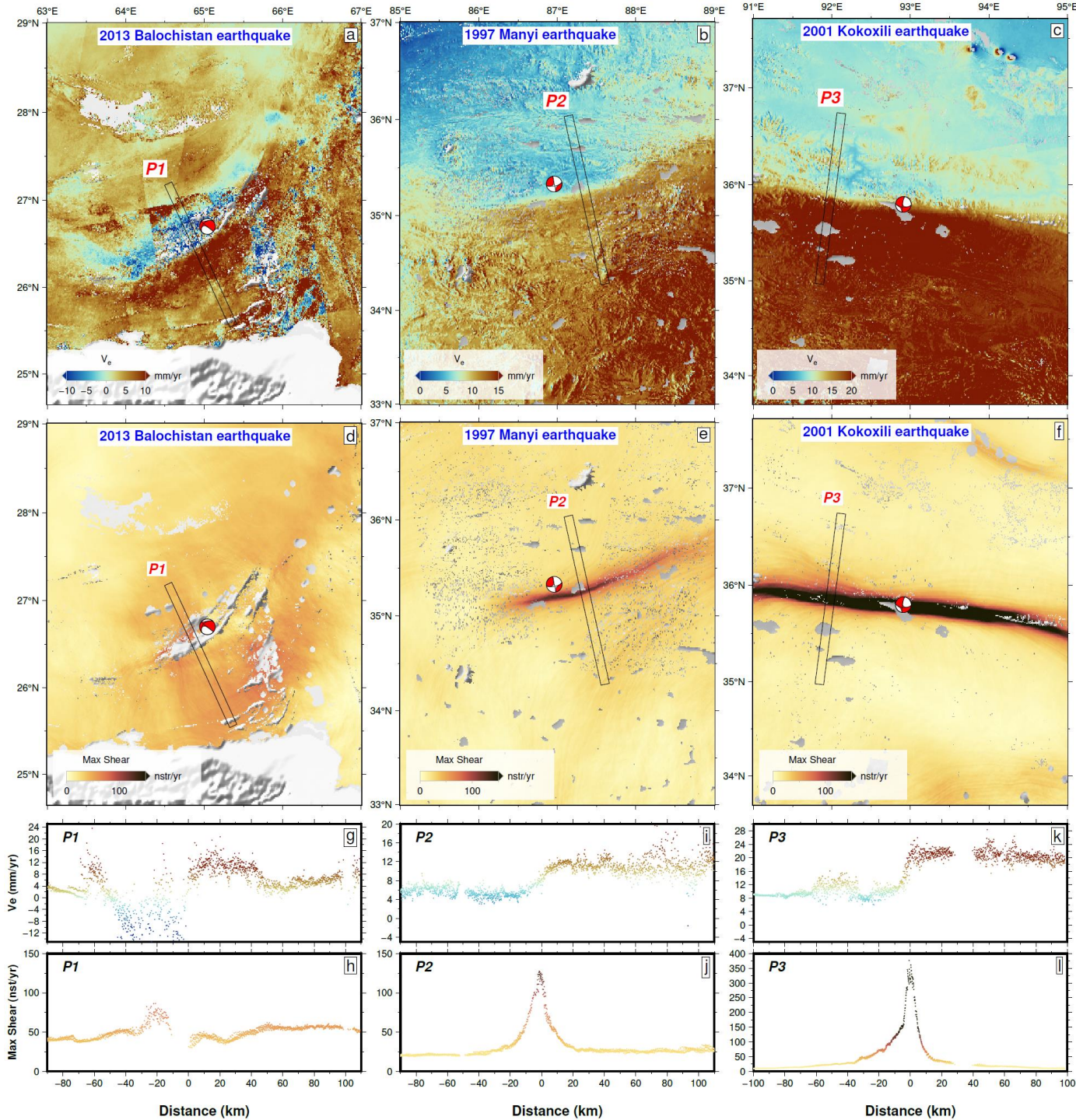
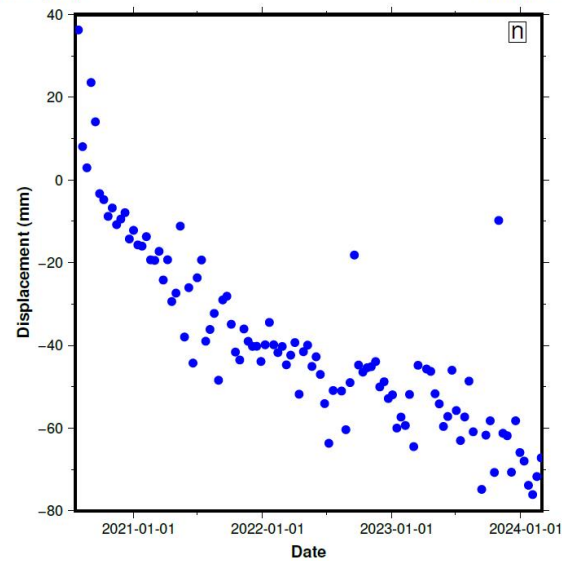
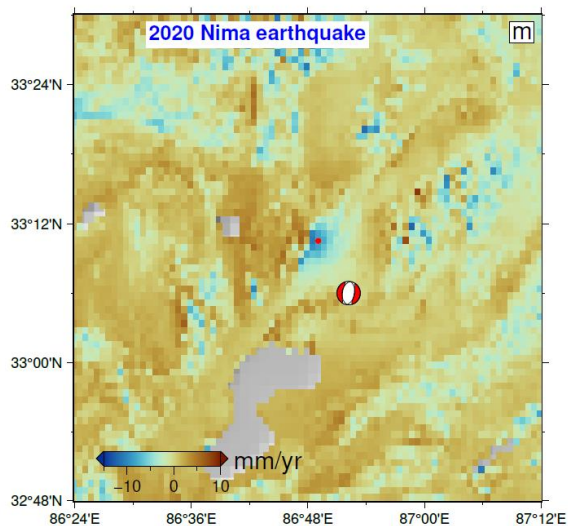


Sharp velocity gradients associated with aseismic slip on major strike-slip faults

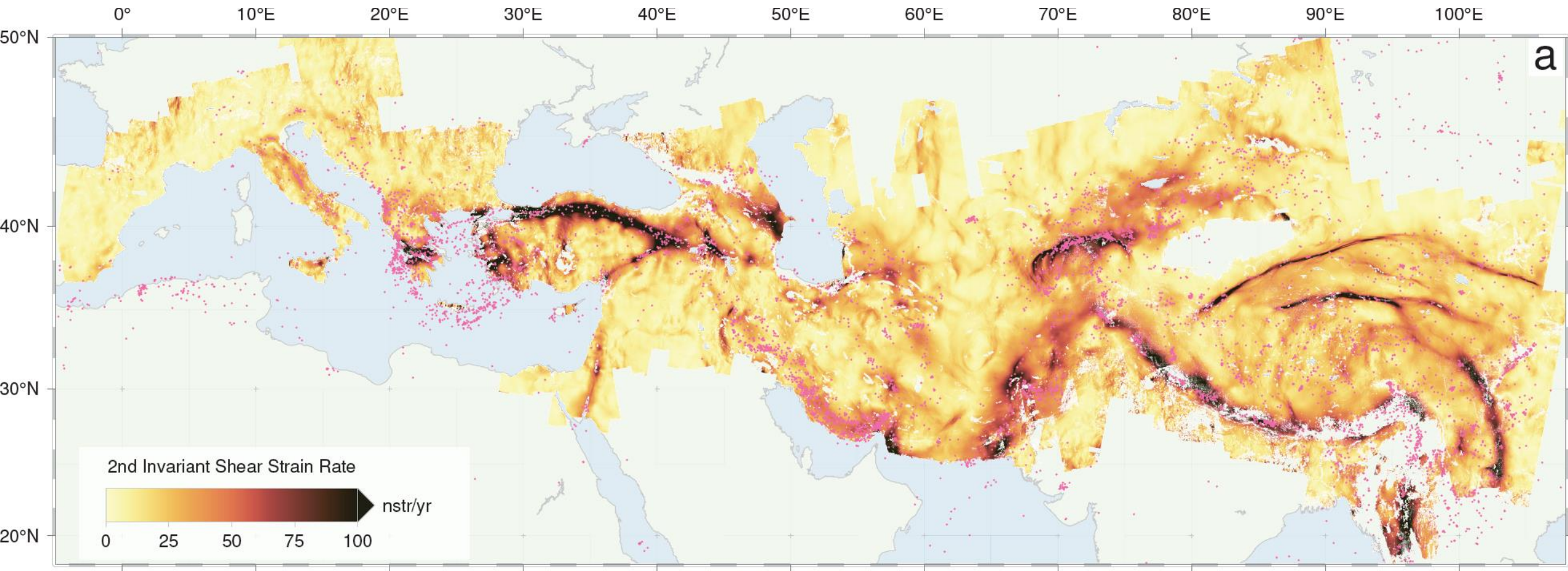


Postseismic Deformation

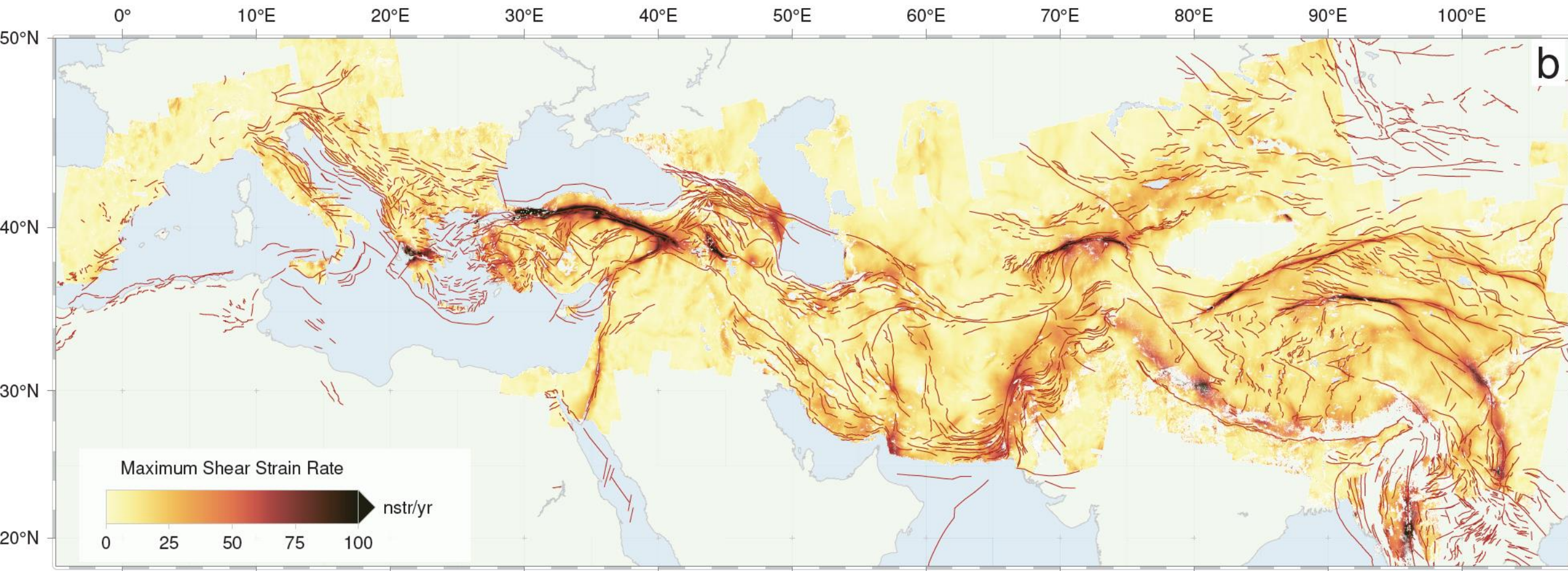
We removed the impact of the coseismic signals that occurred during the acquisition timeframe by adding gaps or truncating the data. However, we did not attempt to correct for postseismic deformation resulting from earthquakes that occurred before the Sentinel-1 observation period nor which occurred within the observation window (although we did truncate time series before some earthquakes that occurred late in the observation window)

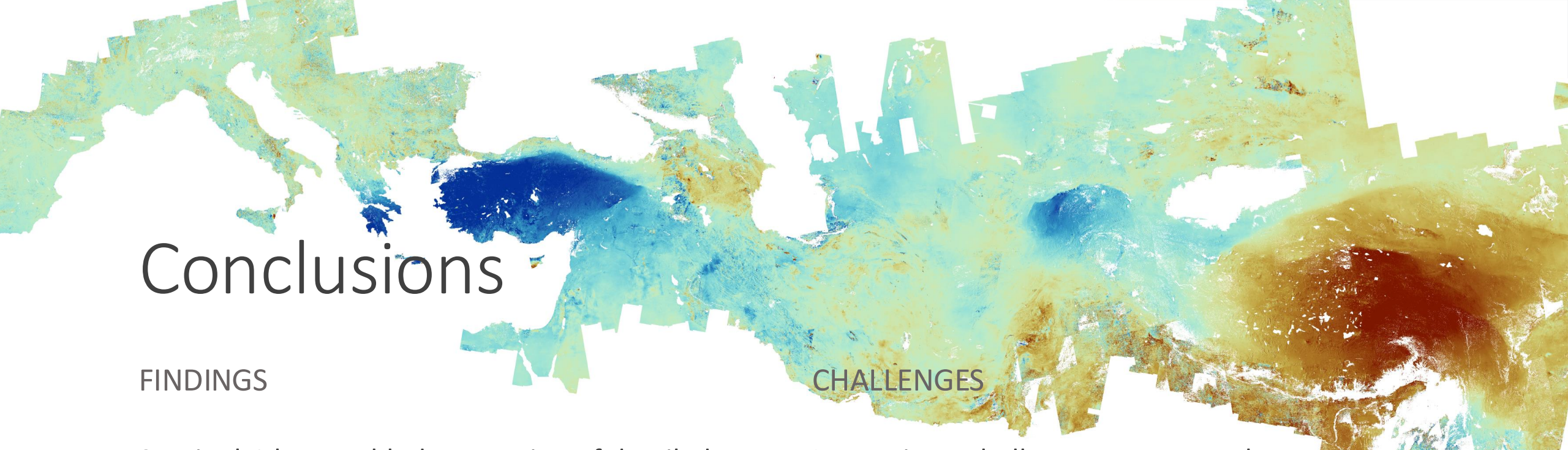


Seismicity & Strain Rates



Faulting & Strain Rates





Conclusions

FINDINGS

Sentinel-1 has enabled generation of detailed velocity and strain rate fields at continental scales

Horizontal motion is dominated by tectonics; vertical from aquifer-driven subsidence.

Strain localised on major faults with diffuse deformation extensive across continents.

Many loci of current strain are scars of old earthquakes

CHALLENGES

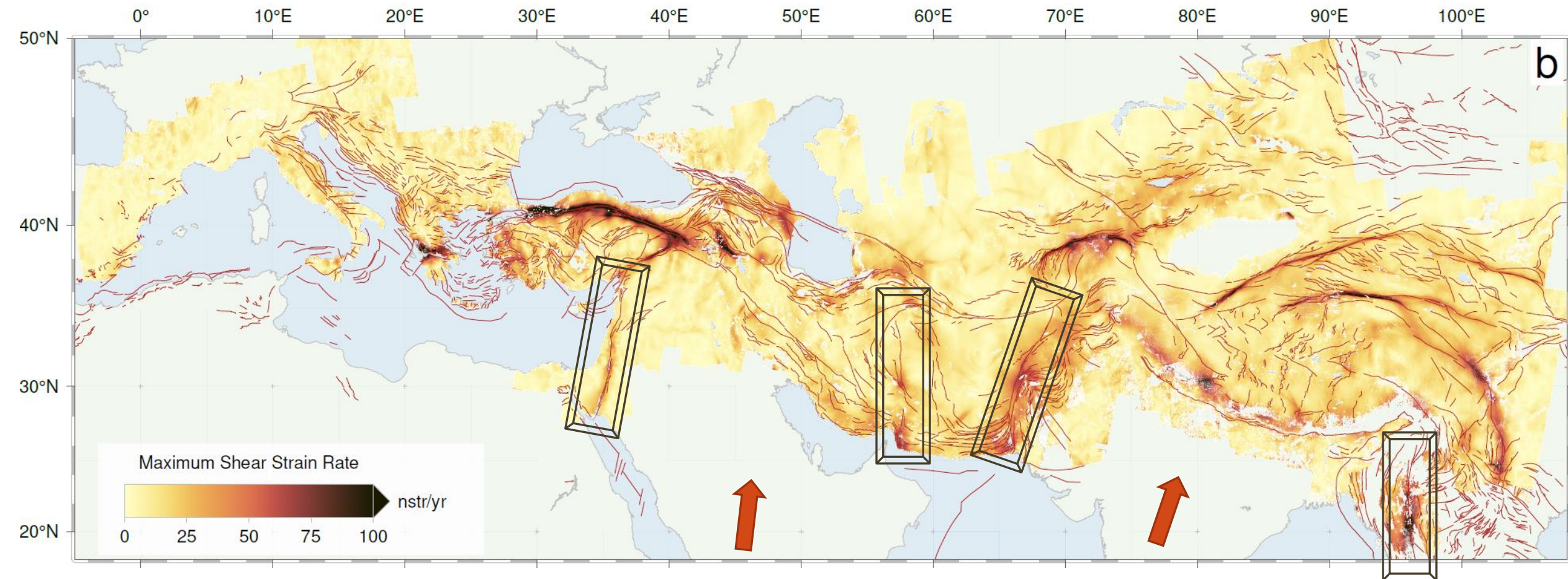
It remains a challenge to measure long-wavelength deformation & slow strain rates

North-south entirely dependent on GNSS distribution

Vertical rates of tectonic deformation still unreliable

Systematic coverage in areas of dense vegetation (SE Asia) unlikely to be possible with this approach

Resolving strain and seismic hazard at continental shear zones



Resolving strain and seismic hazard at continental shear zones

