Large-scale velocity mapping over the Tianshan mountains

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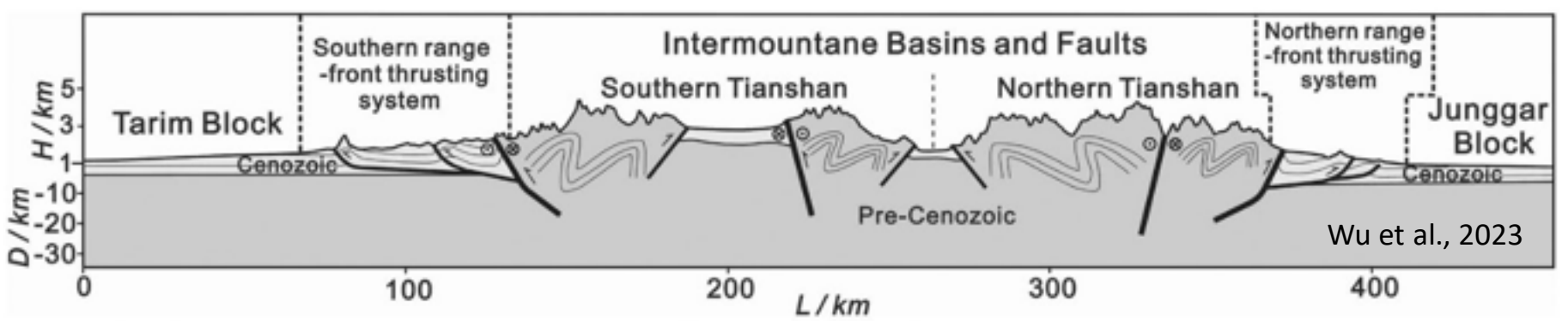
[1] COMET, University of Leeds; [2] GNS Science

Reactivated Orogenic Belt



Wu et al., 2023

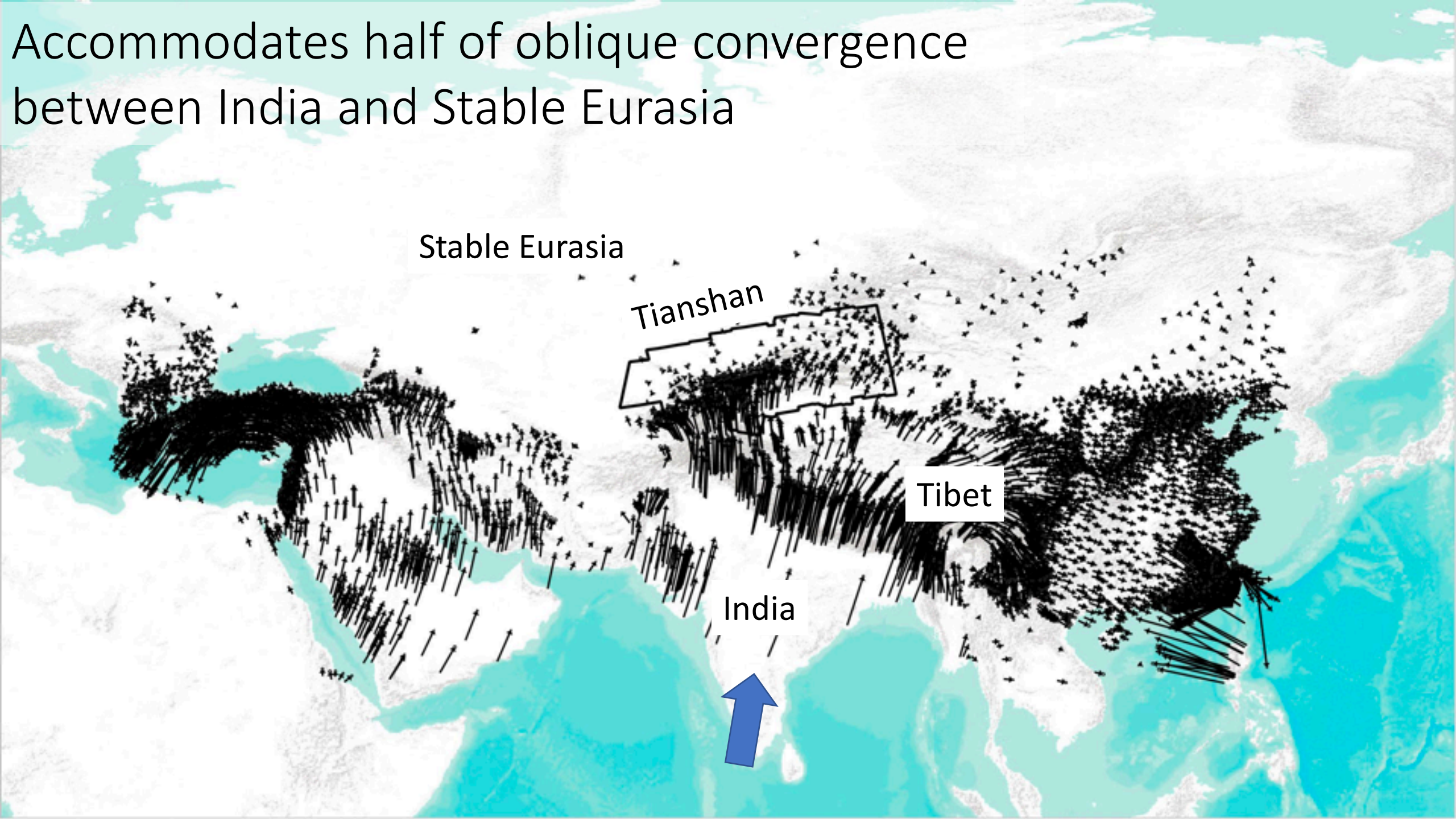
Stable Eurasia

Tianshan

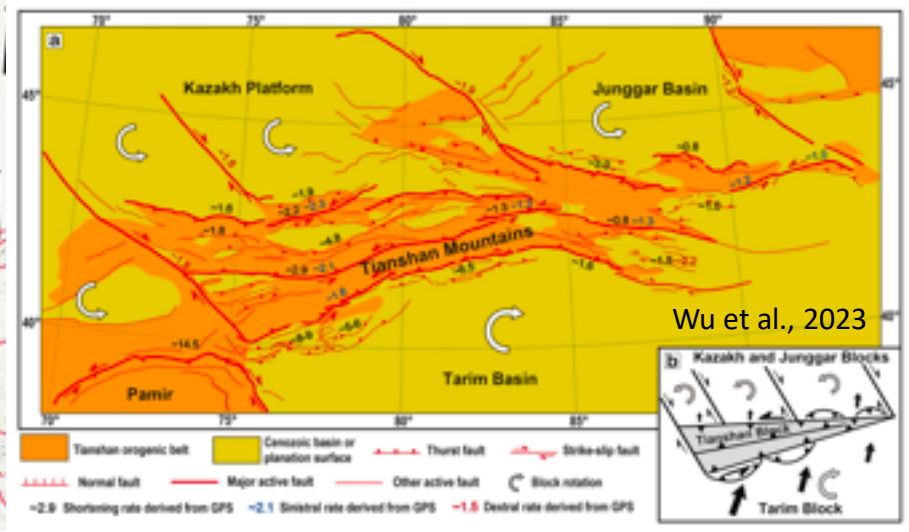
Tibet

India

Accommodates half of oblique convergence between India and Stable Eurasia



How is deformation accommodated?

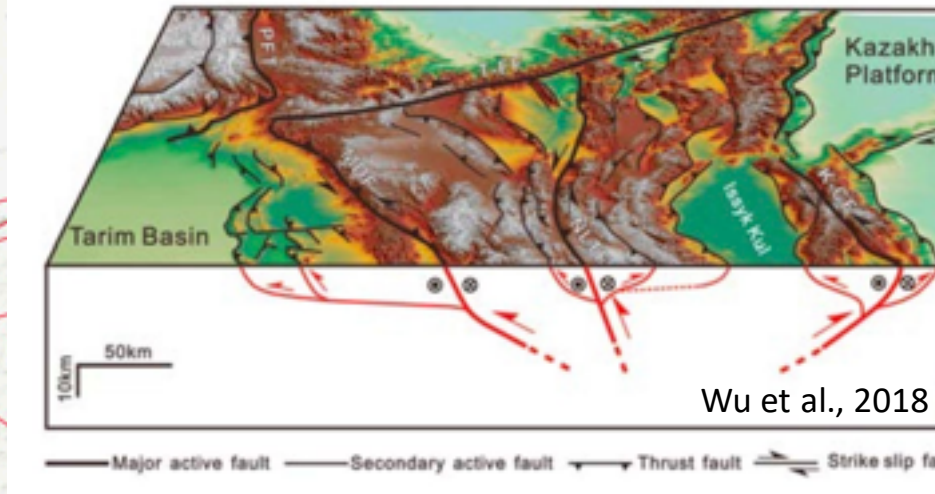


Wu et al., 2023

How fast is Tianshan rising? Or is it?

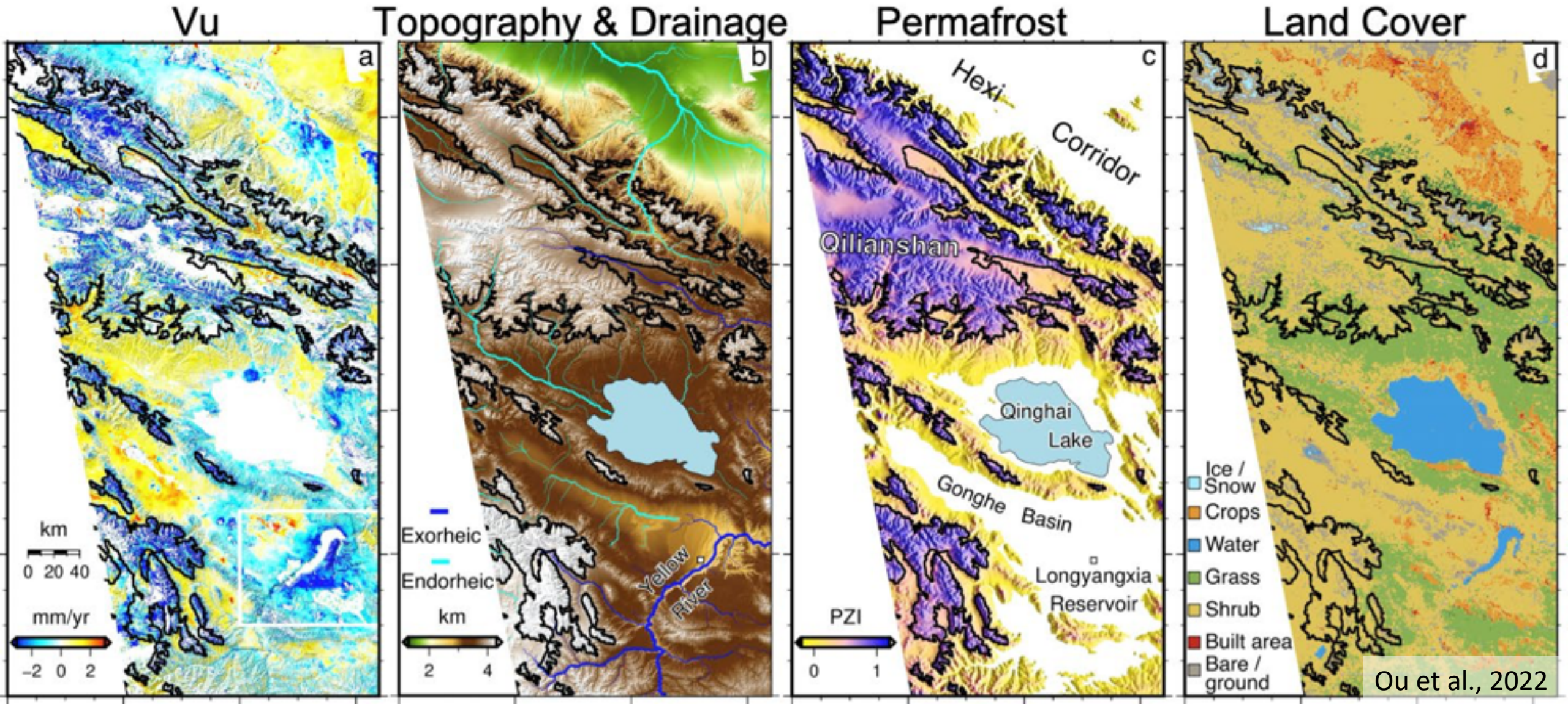
- -44.24 - -2
- -2 - -0.5
- -0.5 - 0.5
- 0.5 - 2
- 2 - 25.07

GNSS Vu mm/yr



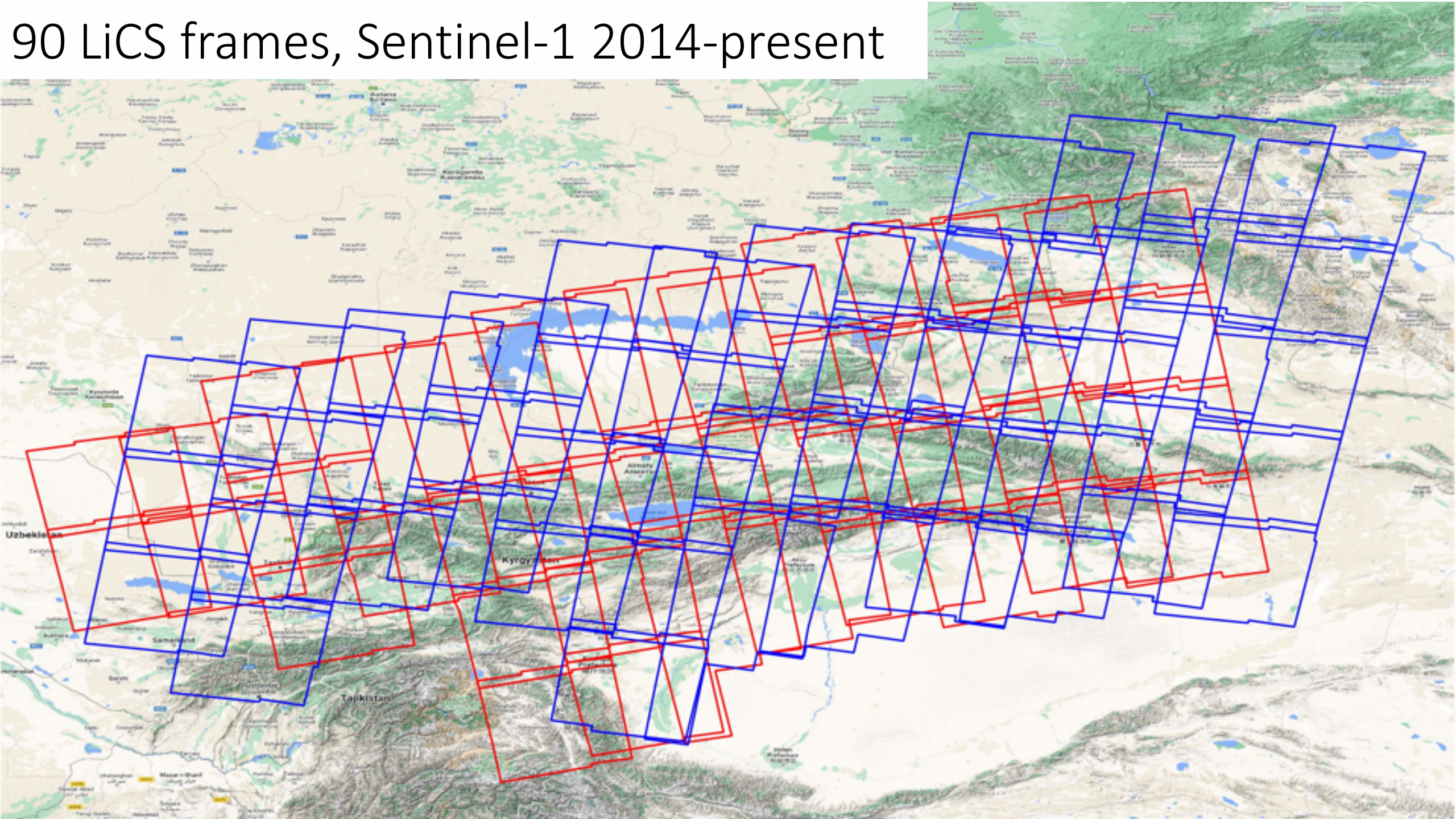
Wu et al., 2018

InSAR helps identify sources of vertical motion

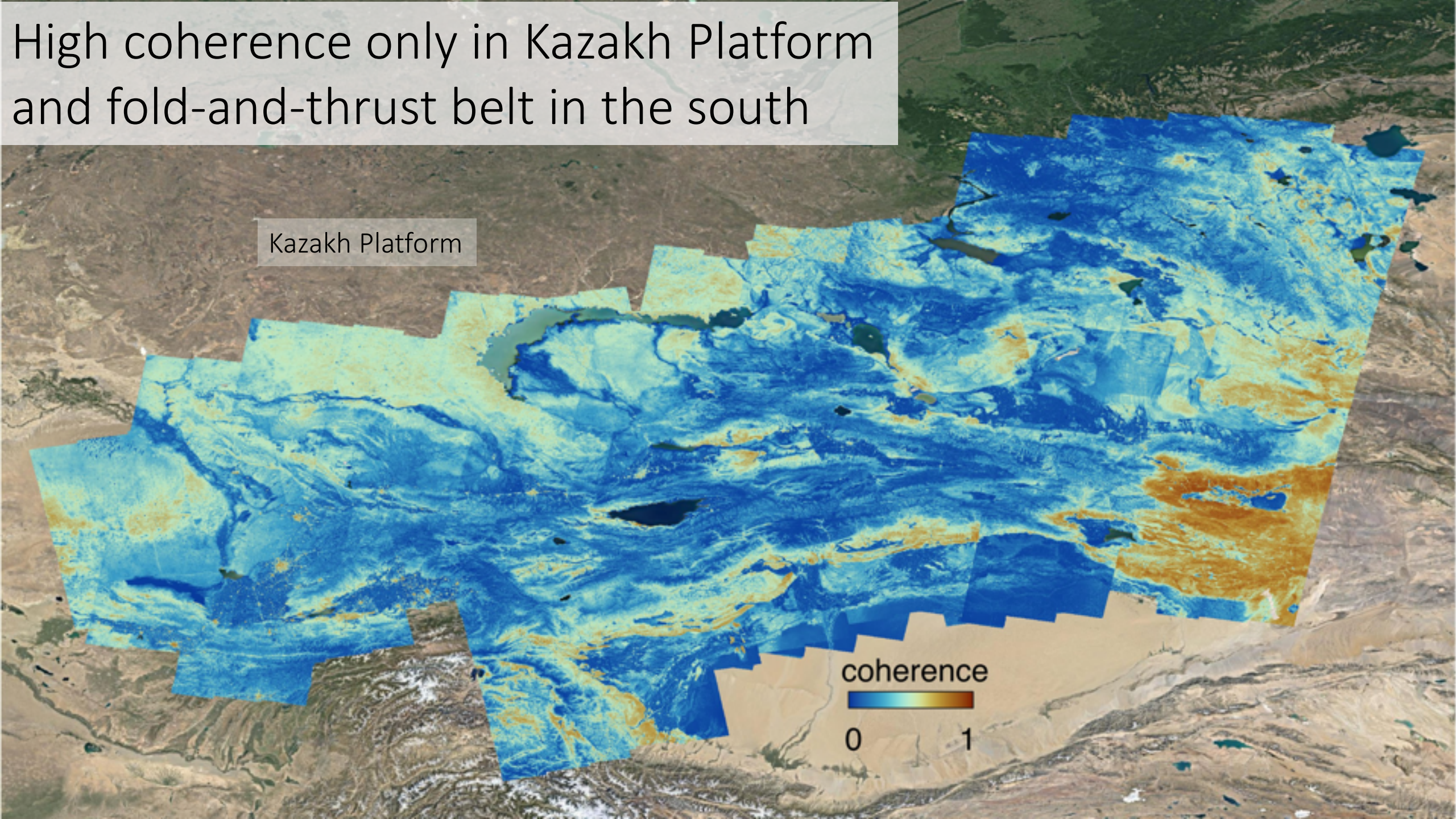


Ou et al., 2022

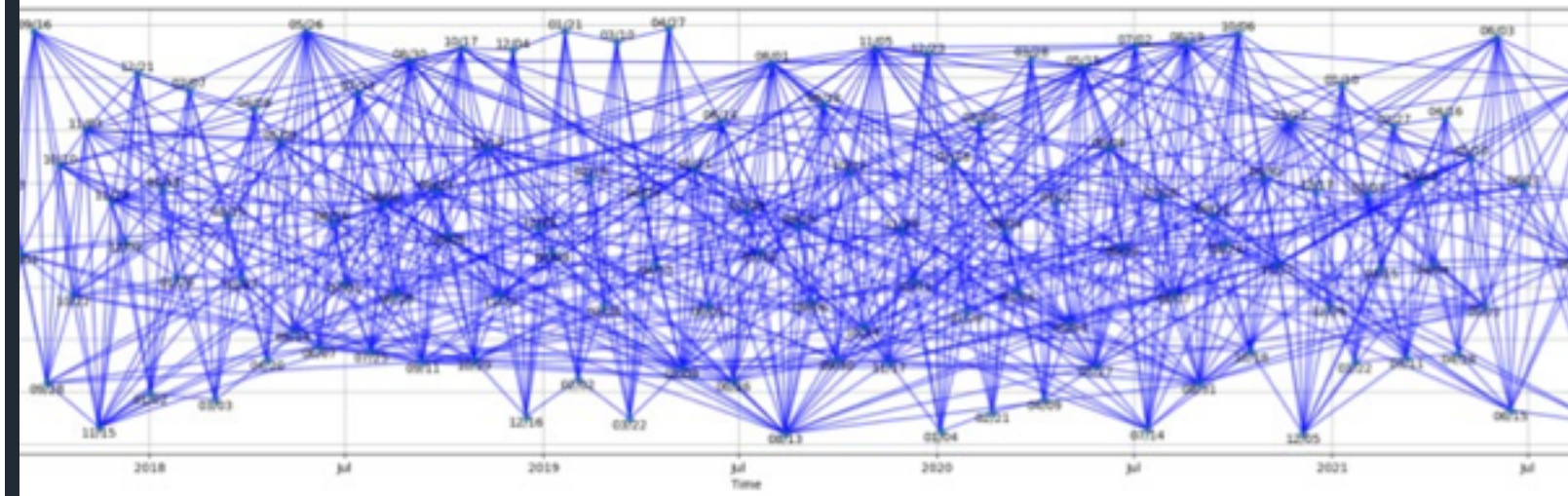
90 LiCS frames, Sentinel-1 2014-present



High coherence only in Kazakh Platform and fold-and-thrust belt in the south



“Tianshan Strategy”
LiCSAR with a twist

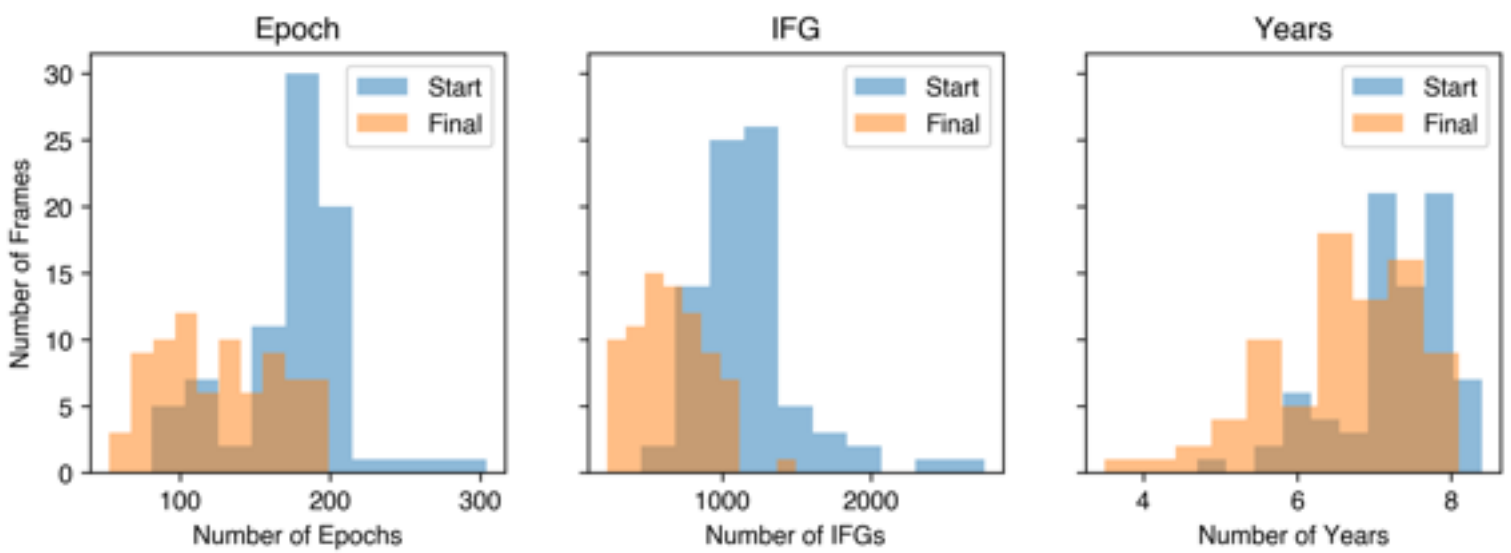


- Copernicus 30 m DEM
- Primary epoch in Aug. 2020
- 50 m-resolution IFGs
- Network
  - 5 forward nearest epoch +
  - 3, 6, 9, 12-month IFGs

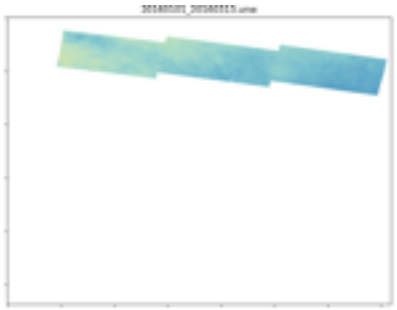
		End Year											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Jan												
S	Feb												
t	Mar												
a	Apr												
r	May					12			3			6	
t	Jun						12			3			
	Jul							12			3		
Y	Aug					9			12			3	
e	Sep						9			12			
a	Oct							9			12		
r	Nov					6			9			12	
	Dec												

Time Series Analysis

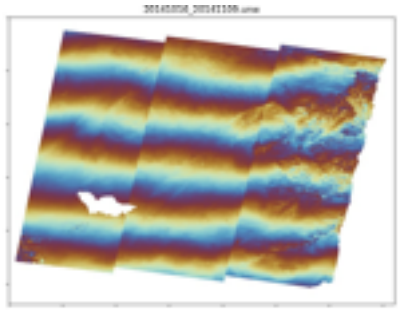
LiCSBAS with a twist

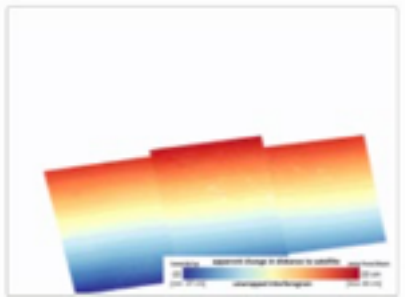


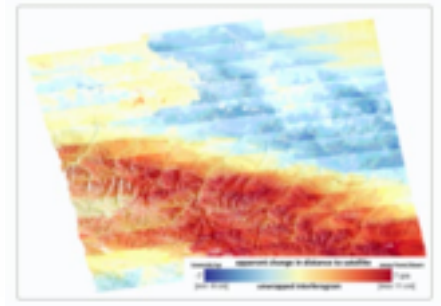
Missing bursts



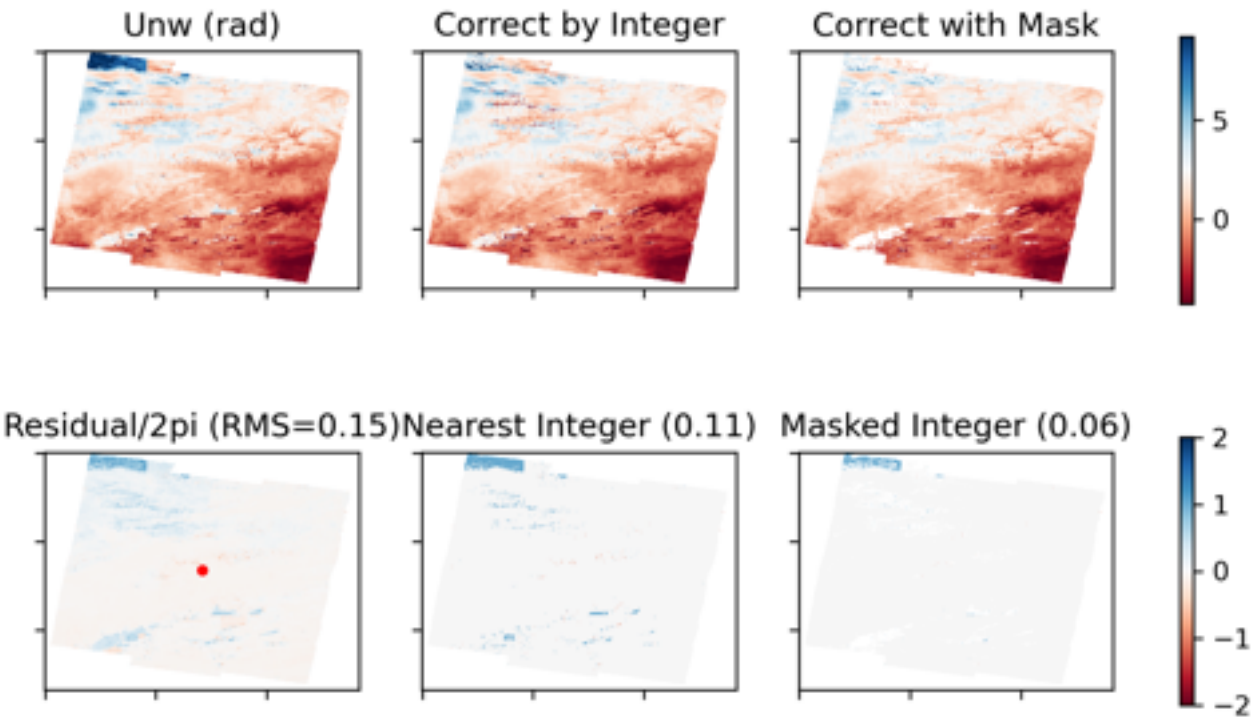
Coregistration Error



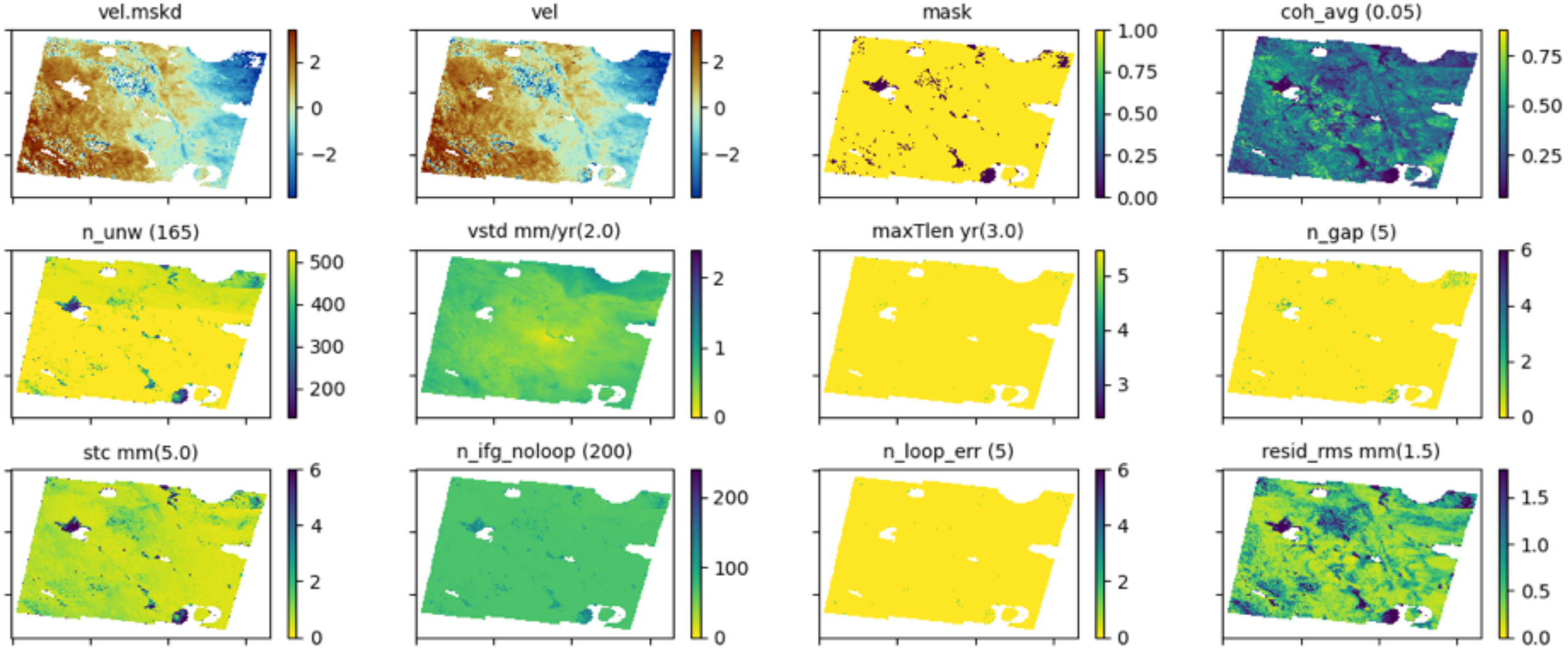


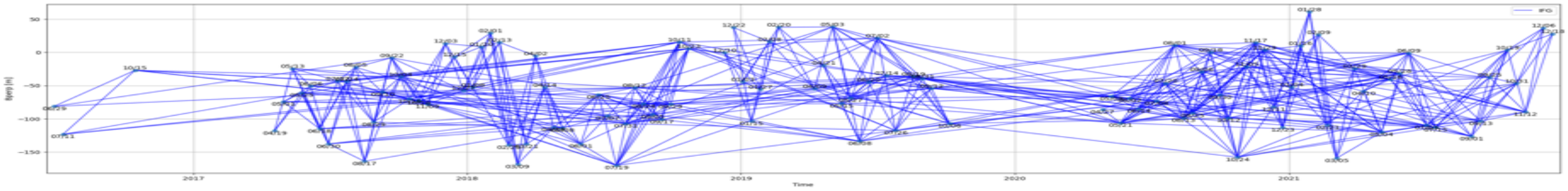


Automatic correction for unwrapping mistakes

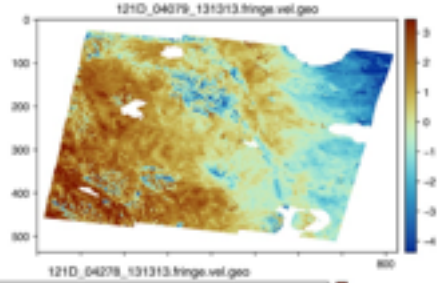


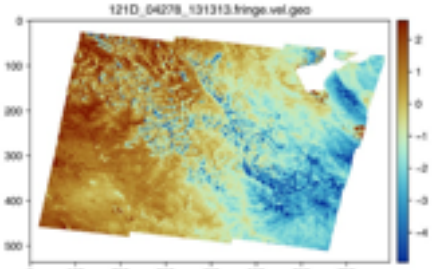
Quality of final dataset

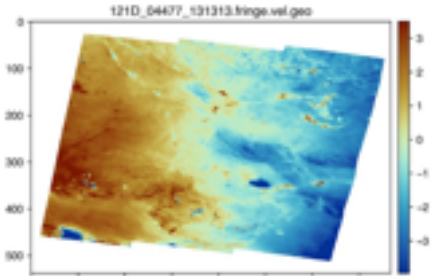


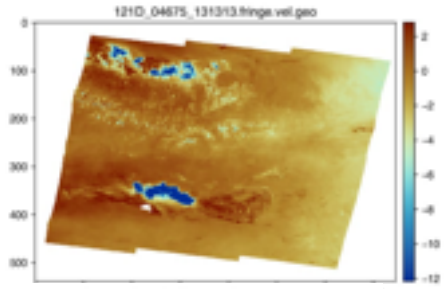


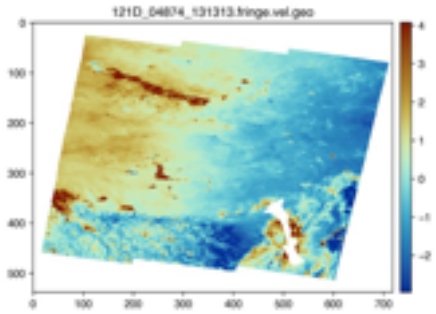
Mosaic by a constant

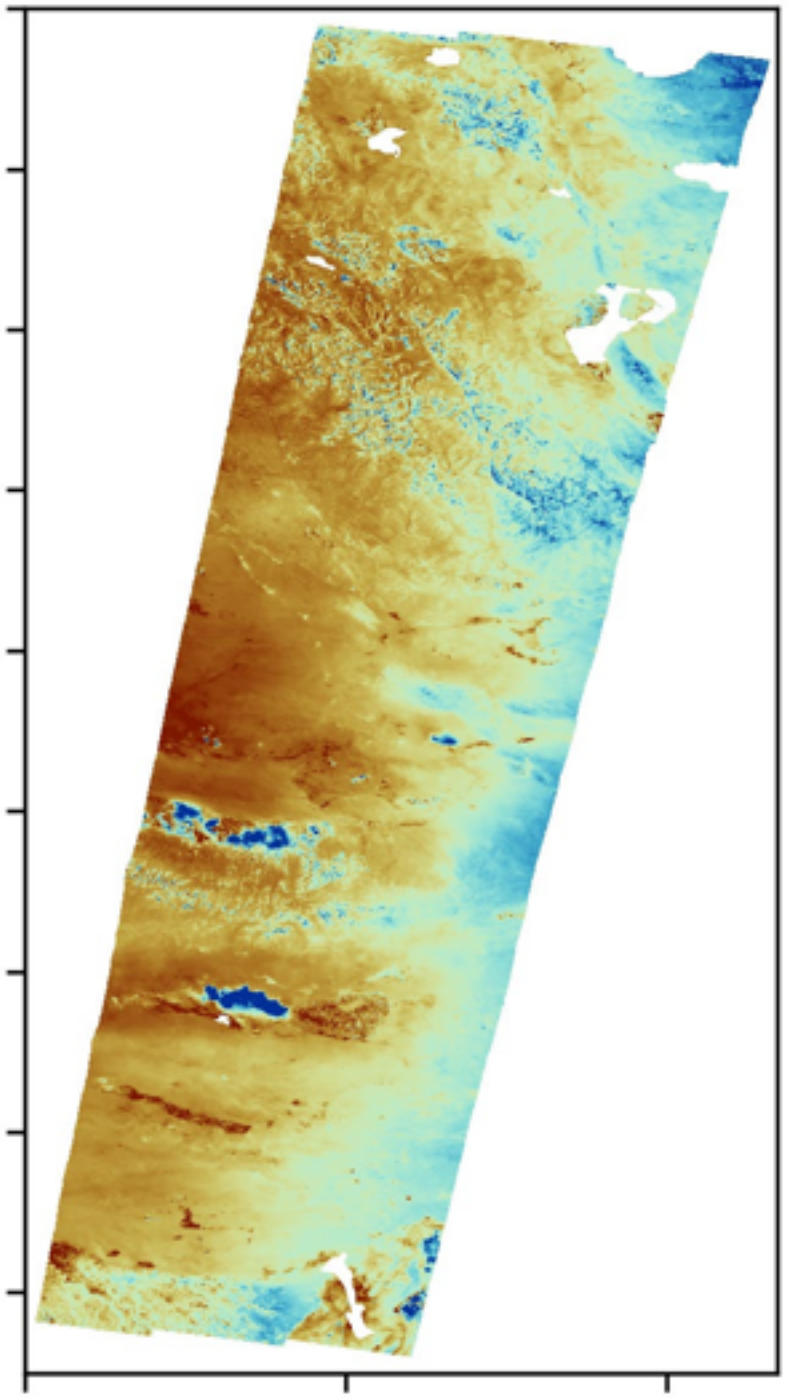


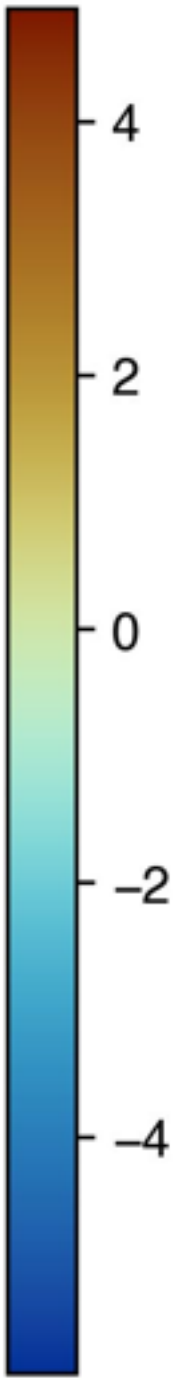


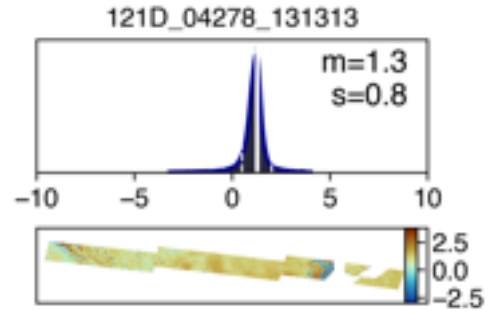


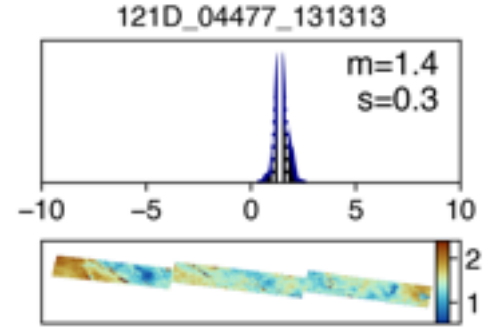


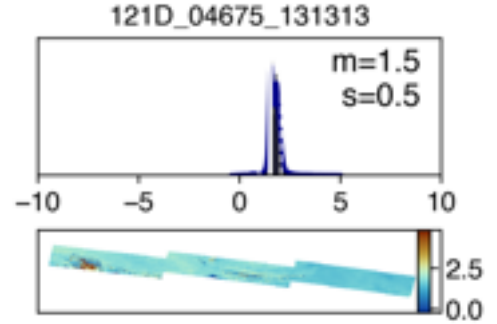


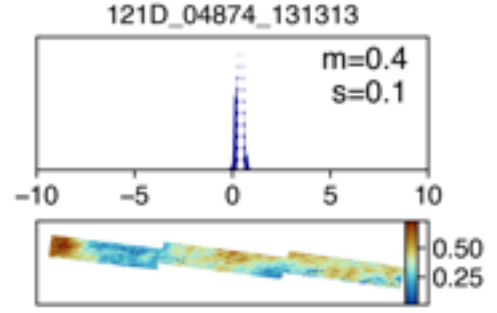


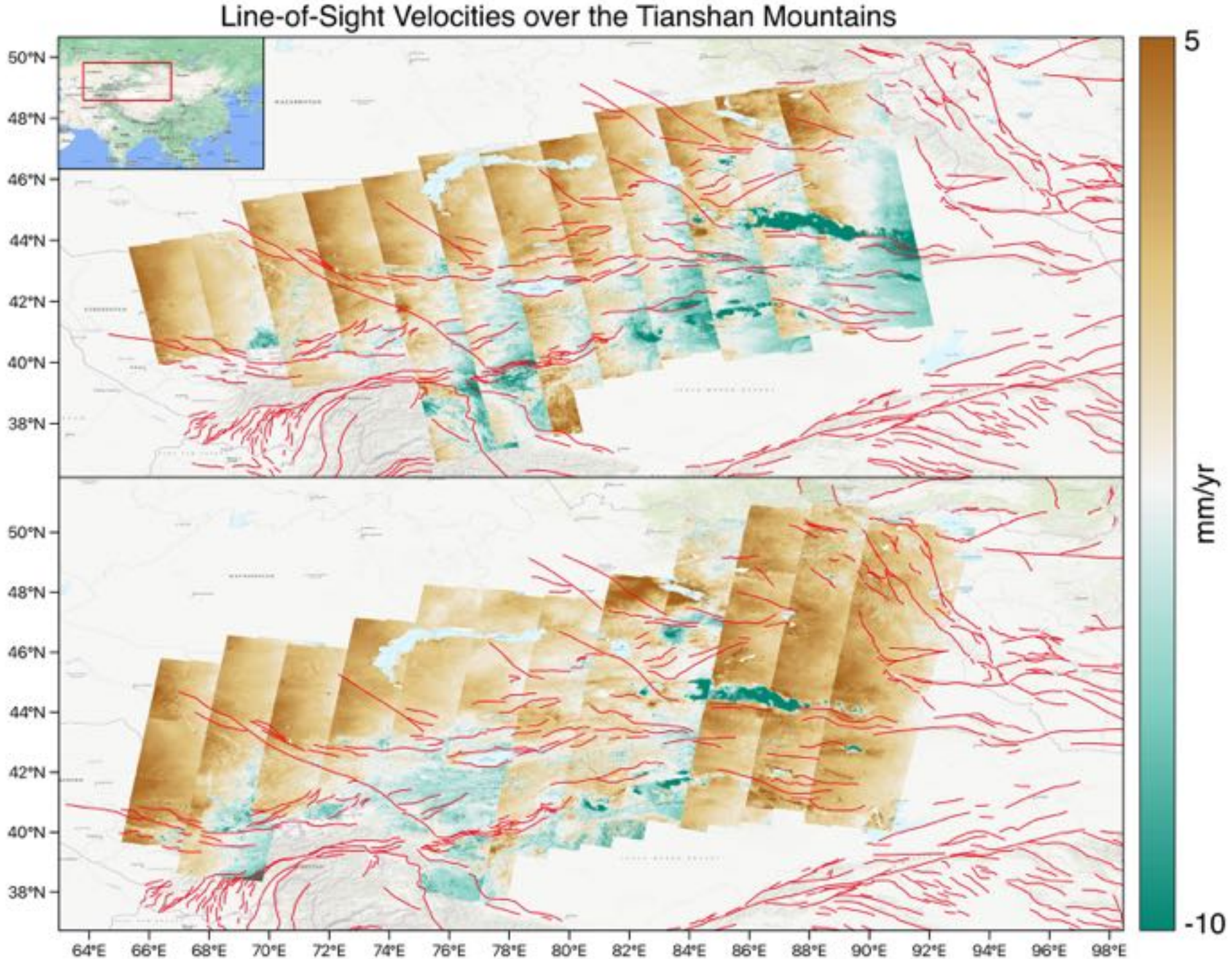




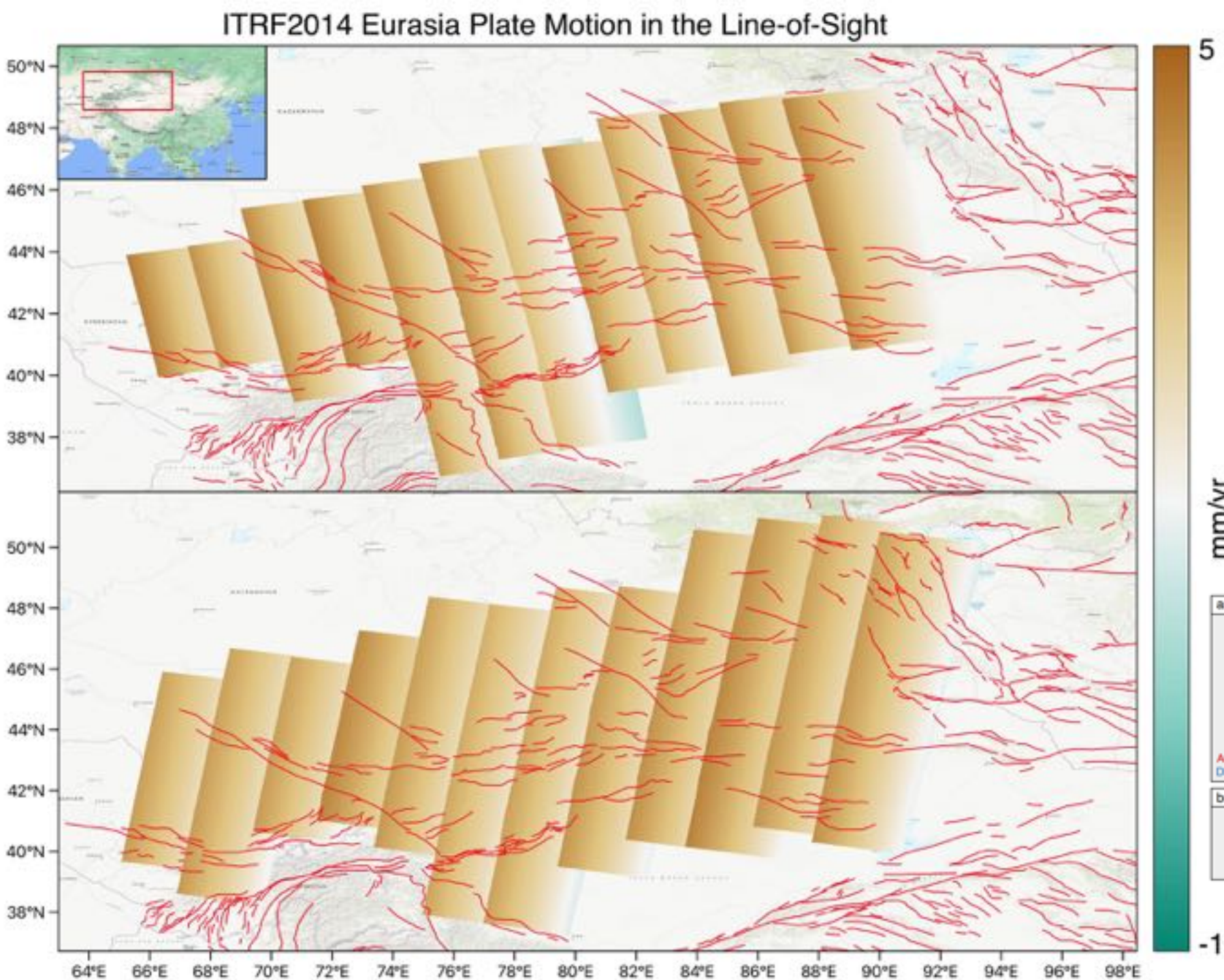




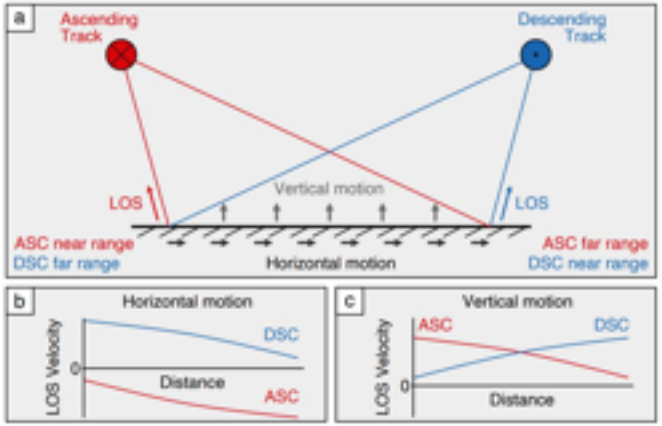




Mosaic by constants



Remove Plate Motion



Stephenson et al., 2022

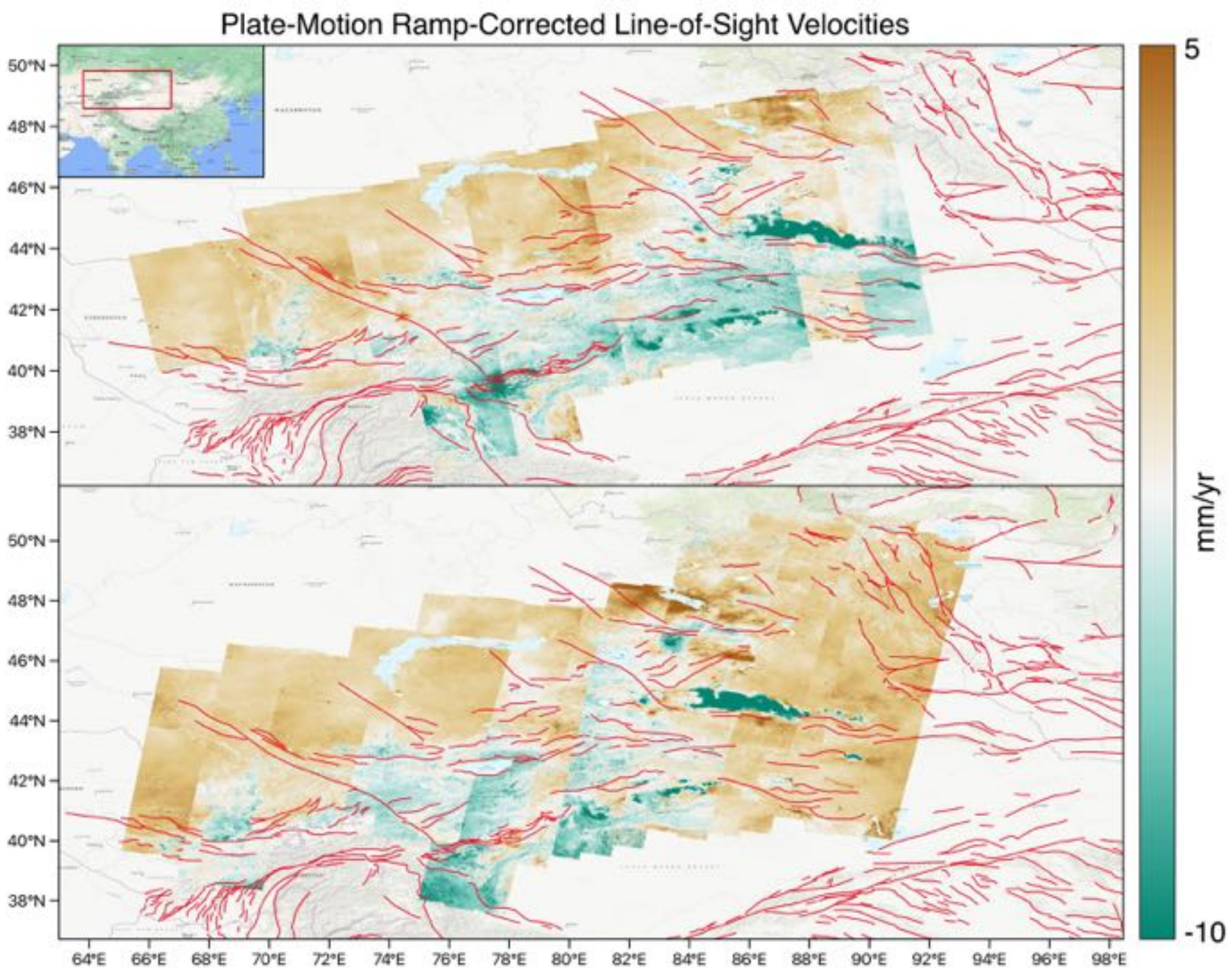
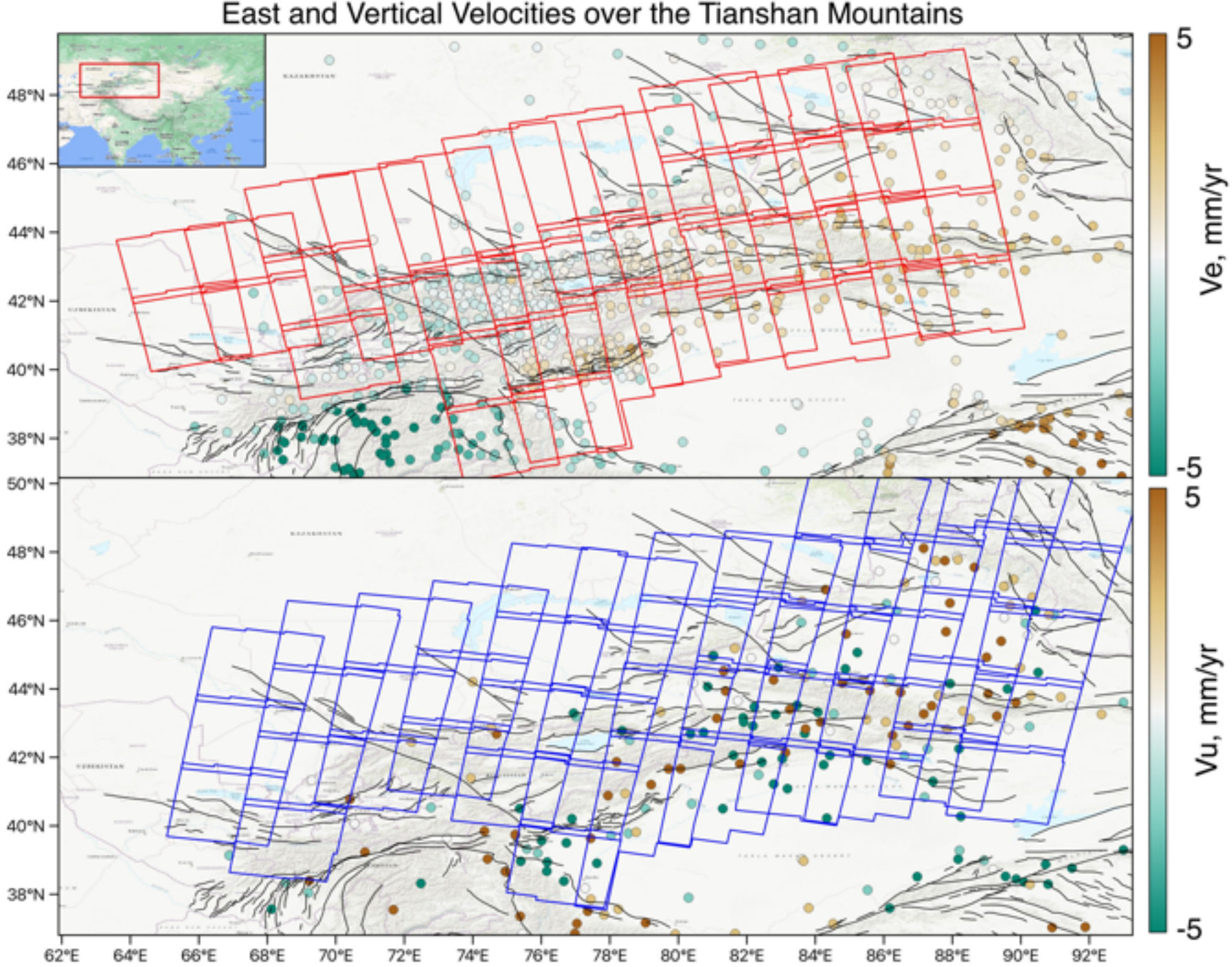


Plate-motion corrected LOS

Independent from GNSS

Uncertainties accumulate down track

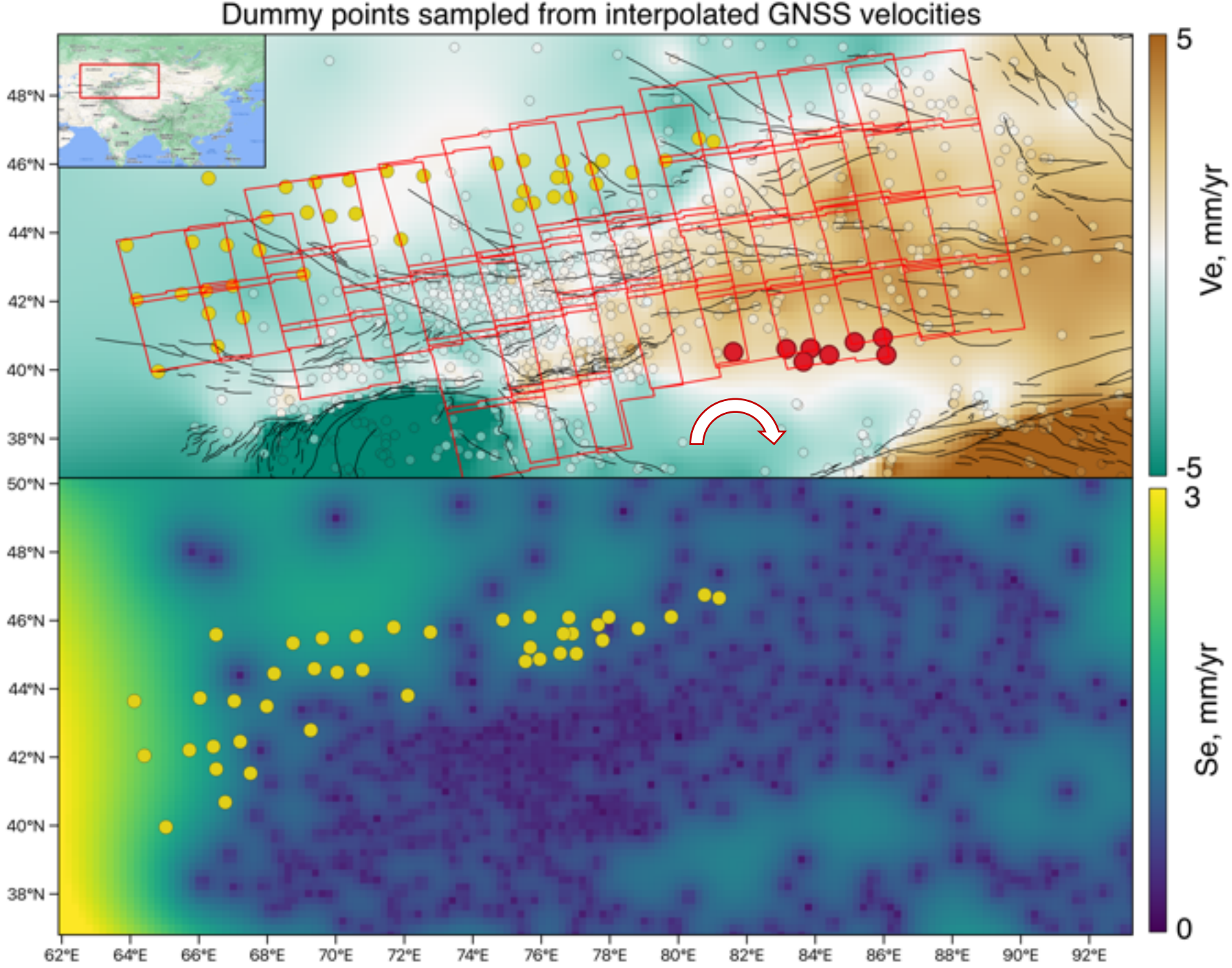
ETAD?



673 GNSS velocities

From 24 studies
ITRF2014 Fixed Eurasia

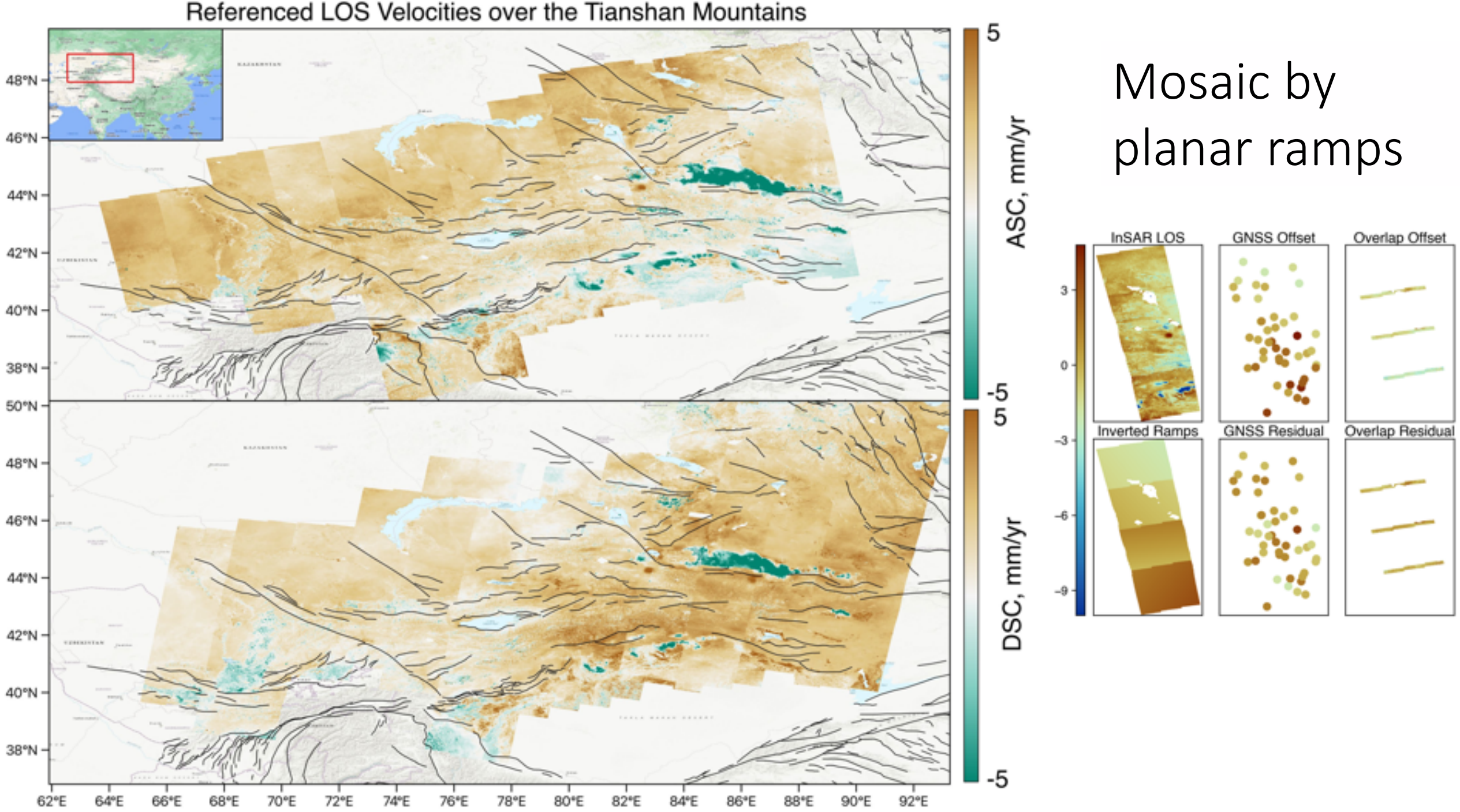
Cleaned by uncertainty
Grouped by station
Averaged by location



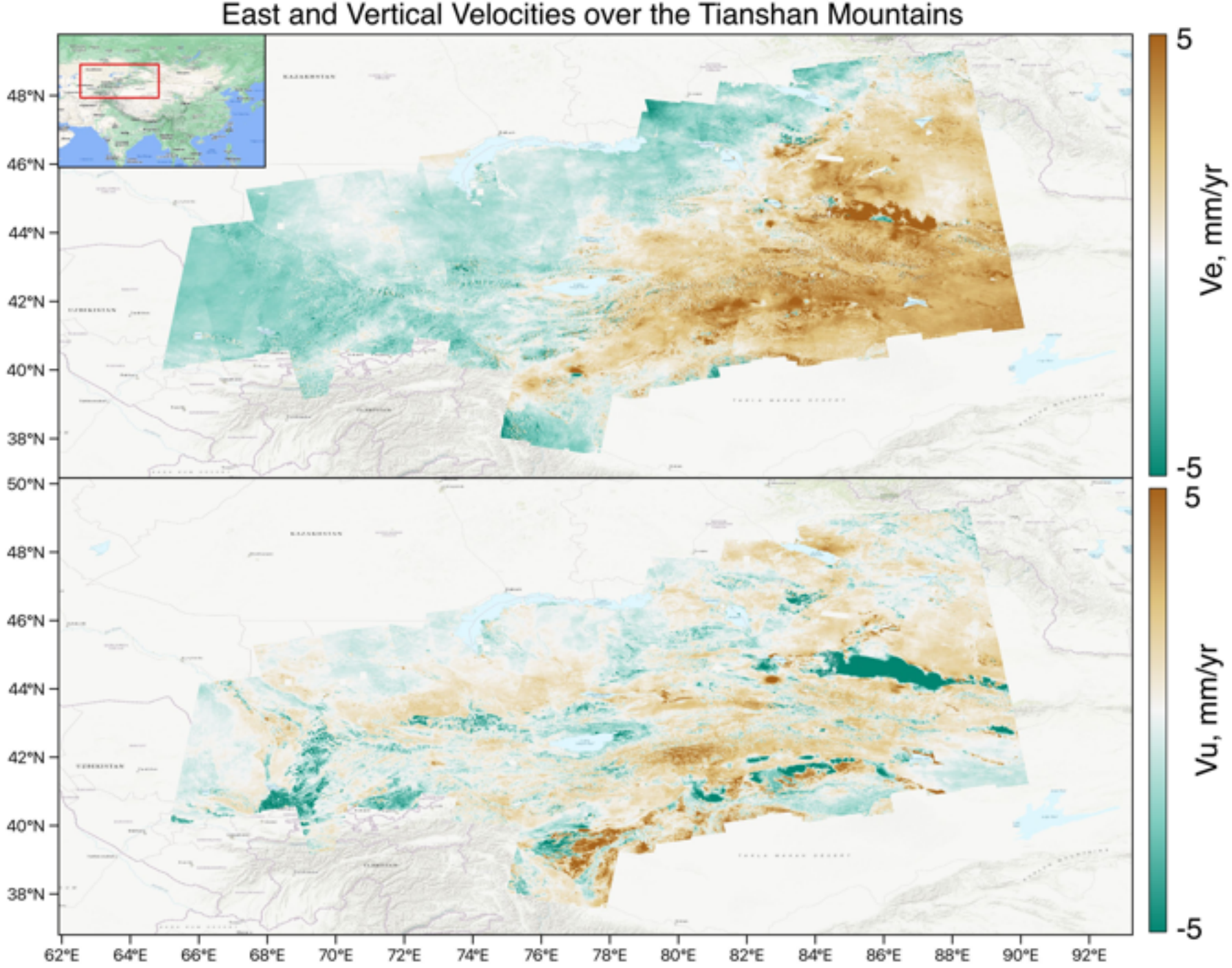
Dummy GNSS

Sampled from interpolated GNSS and uncertainties

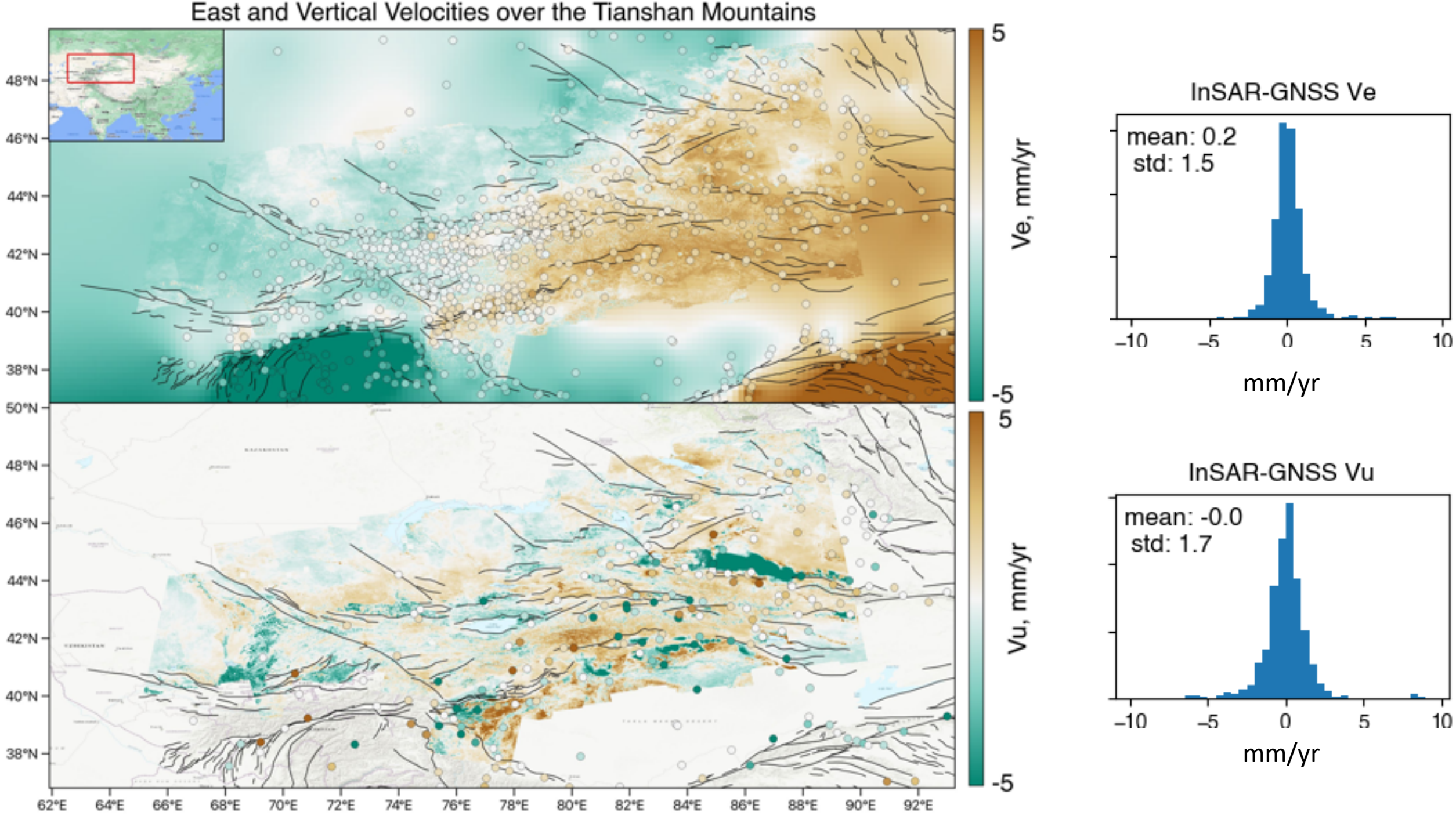
Calculated from Tarim rotation



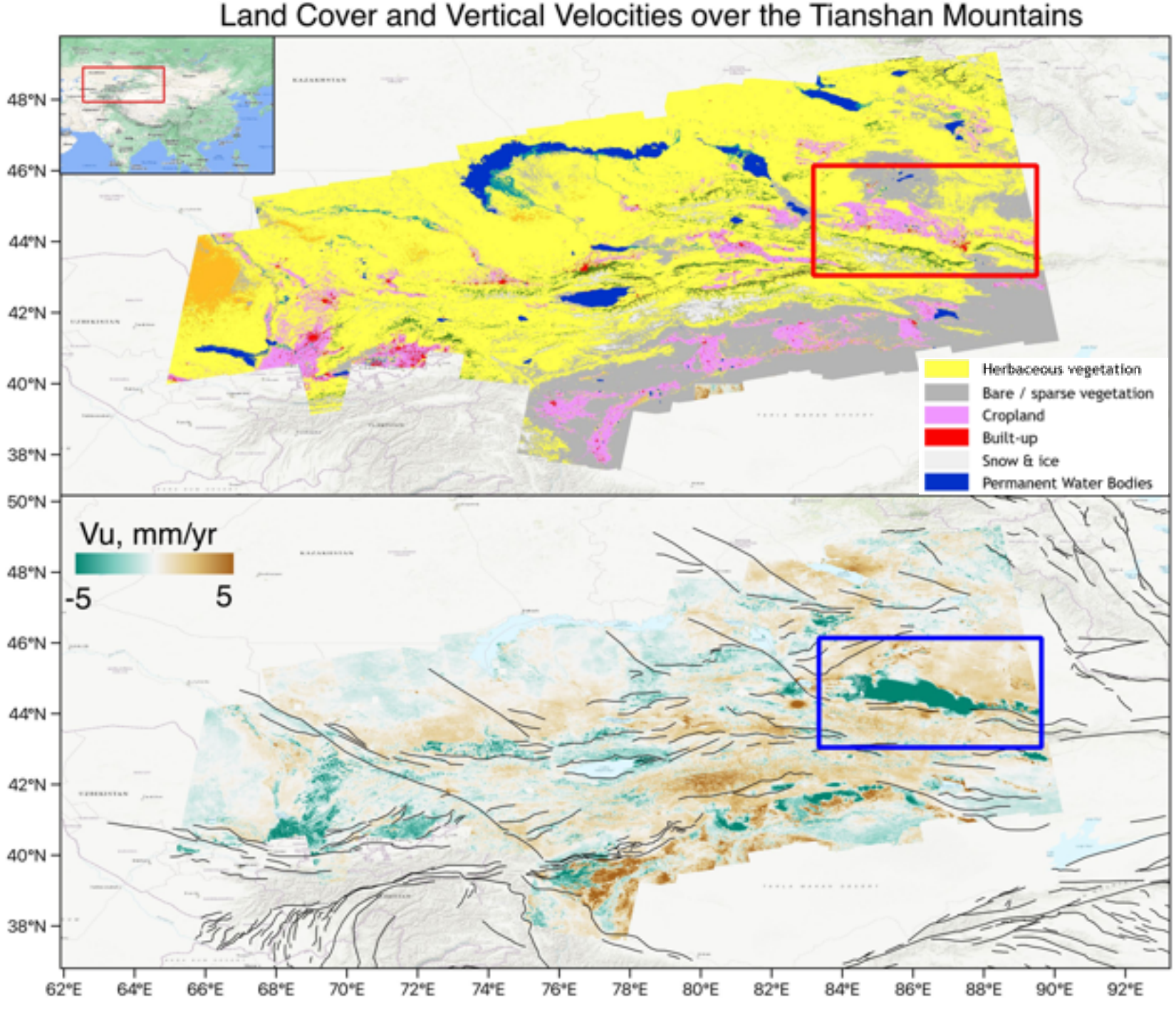
Mosaic by planar ramps

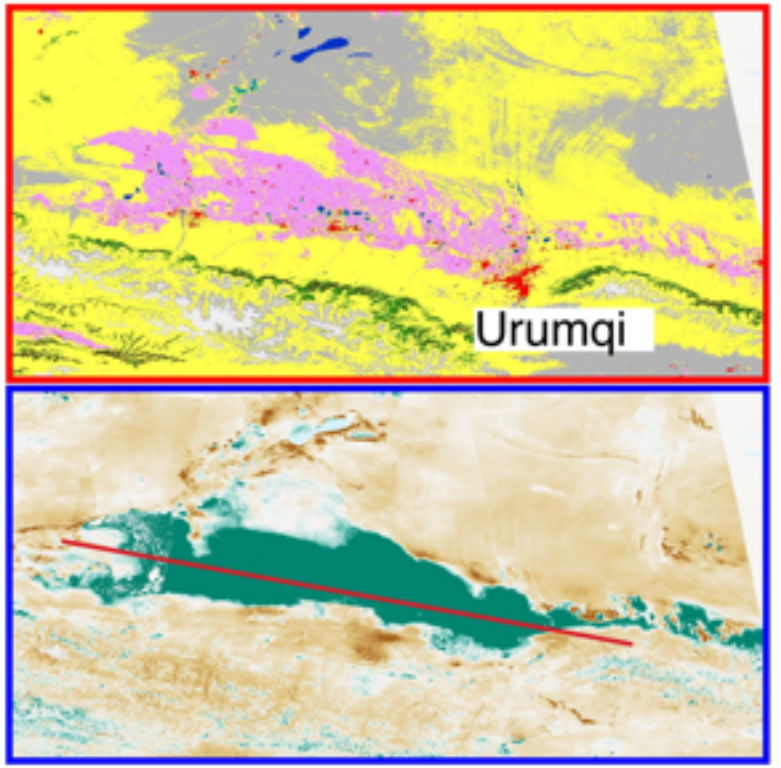


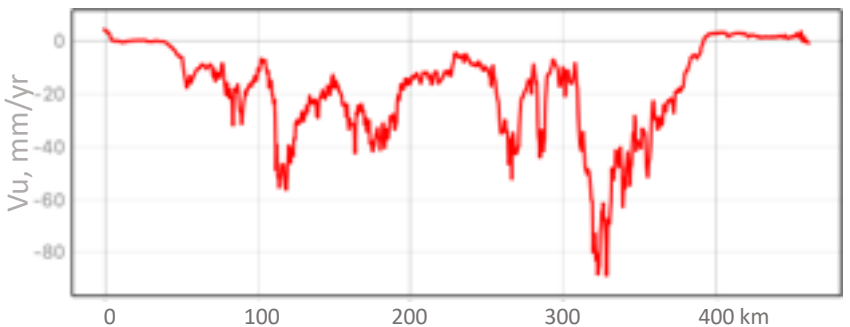
Ve and Vu in ITRF2014 Fixed Eurasia


East and Vertical Velocities over the Tianshan Mountains
48°N
46°N
44°N
42°N
40°N
38°N
50°N
62°E
64°E
66°E
68°E
70°E
72°E
74°E
76°E
78°E
80°E
82°E
84°E
86°E
88°E
90°E
92°E
5
-5
Ve, mm/yr
Vu, mm/yr
InSAR-GNSS Ve
mean: 0.2
std: 1.5
−10
−5
0
5
10
mm/yr
InSAR-GNSS Vu
mean: -0.0
std: 1.7
−10
−5
0
5
10
mm/yr

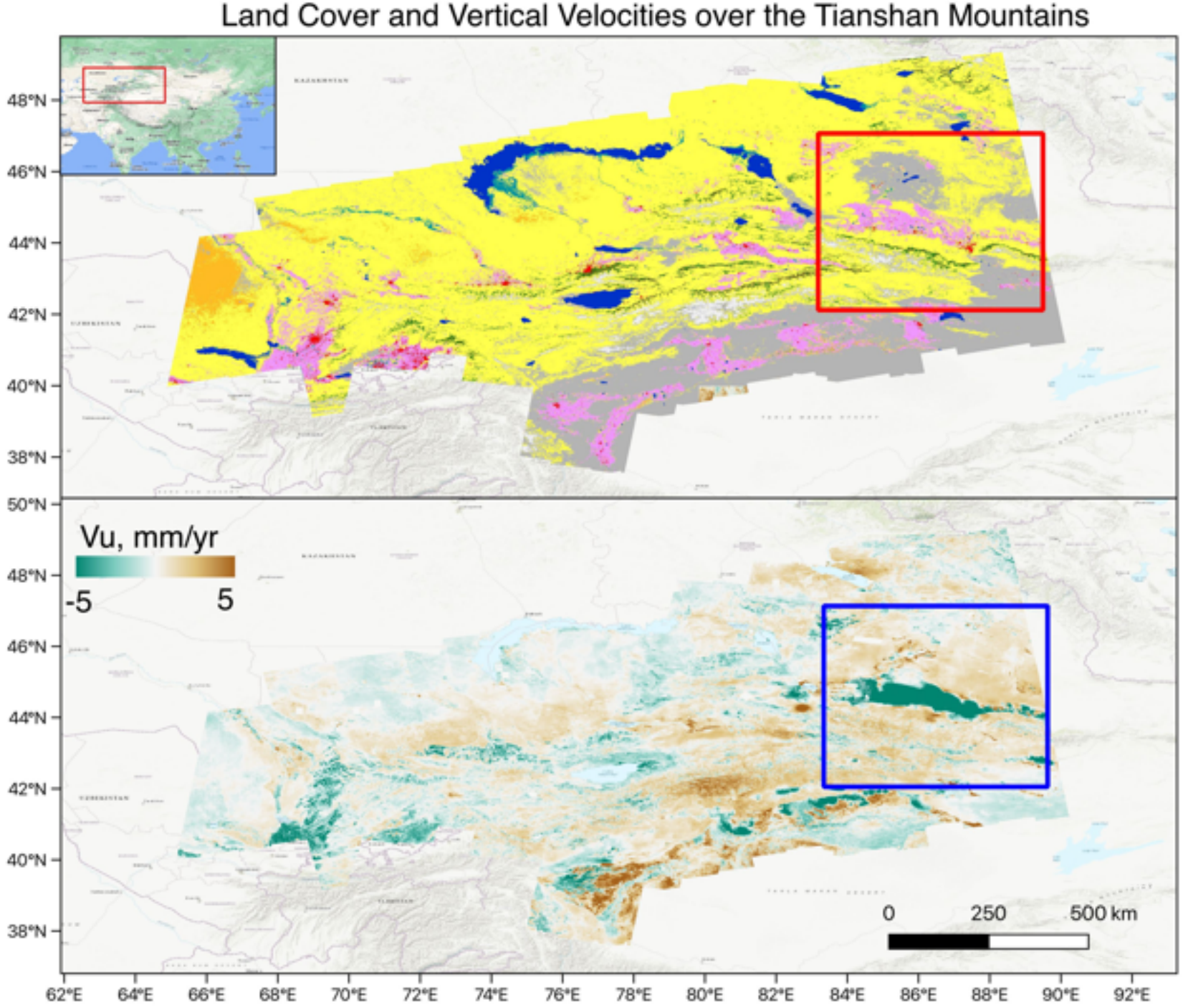
Groundwater Extraction

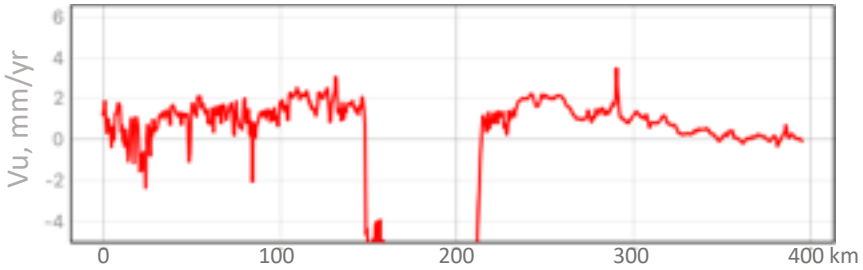


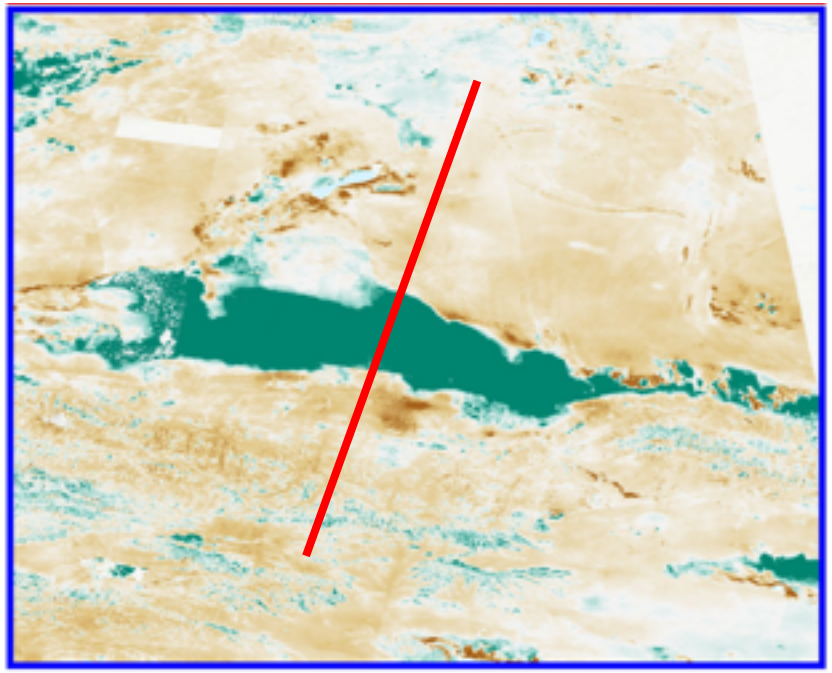




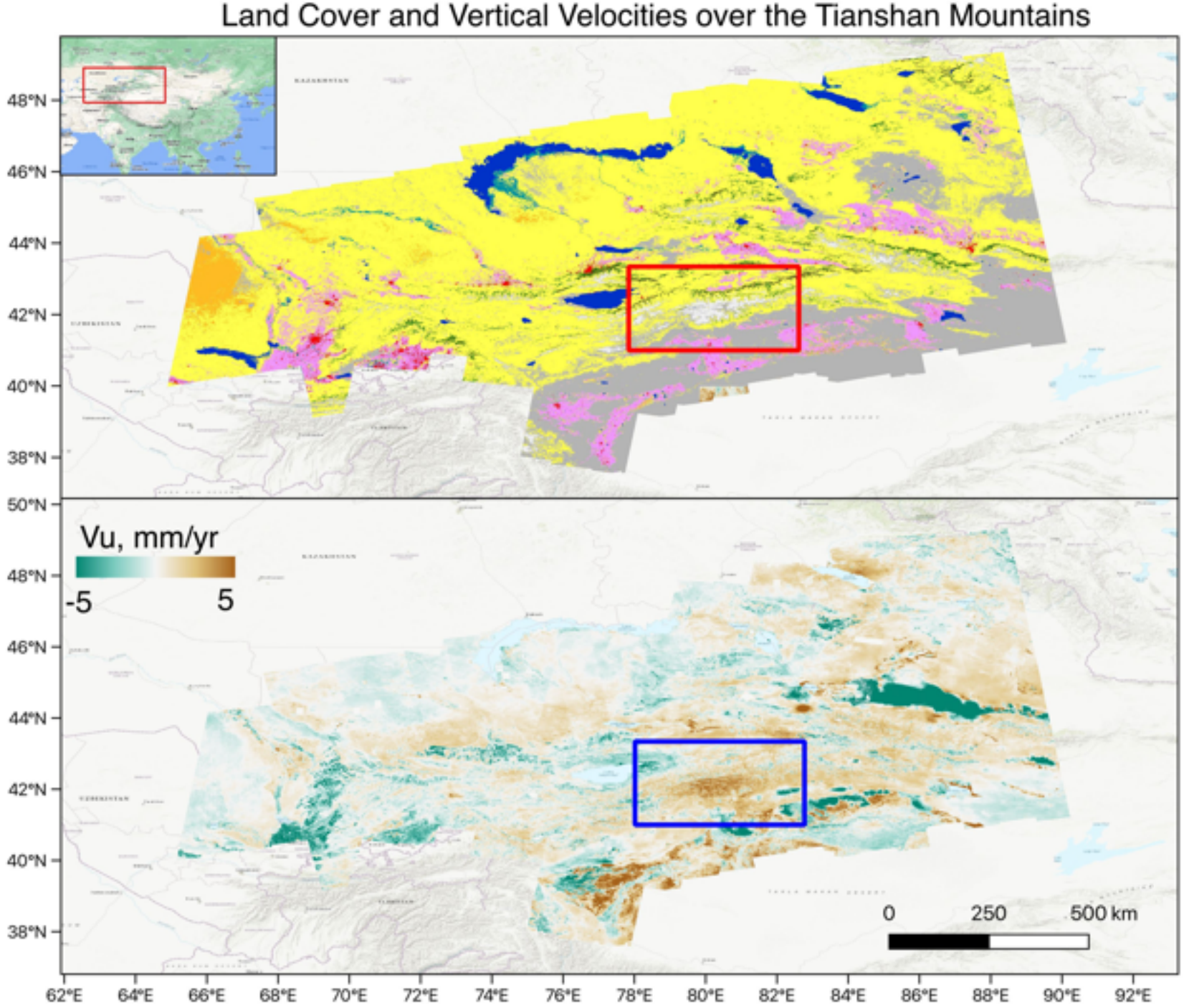
Elastic Bending

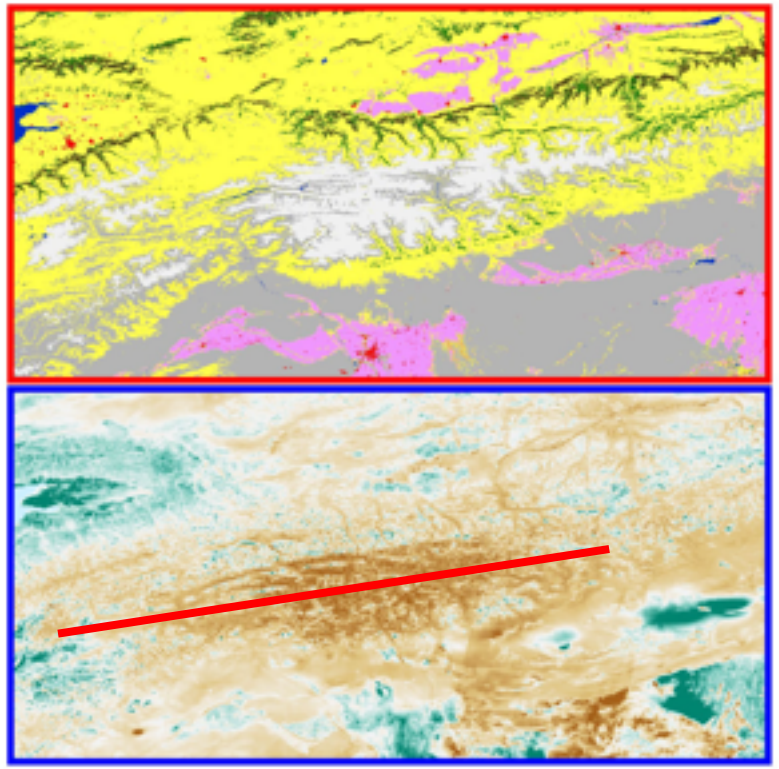


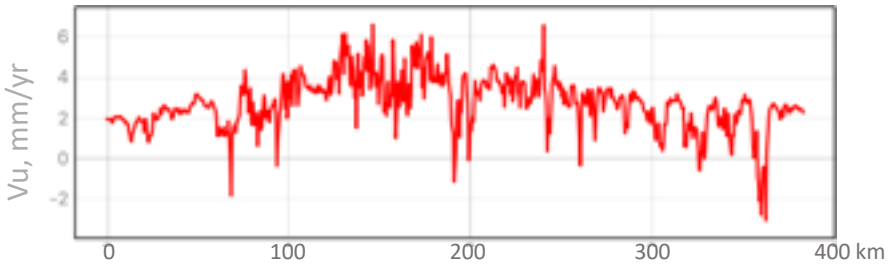




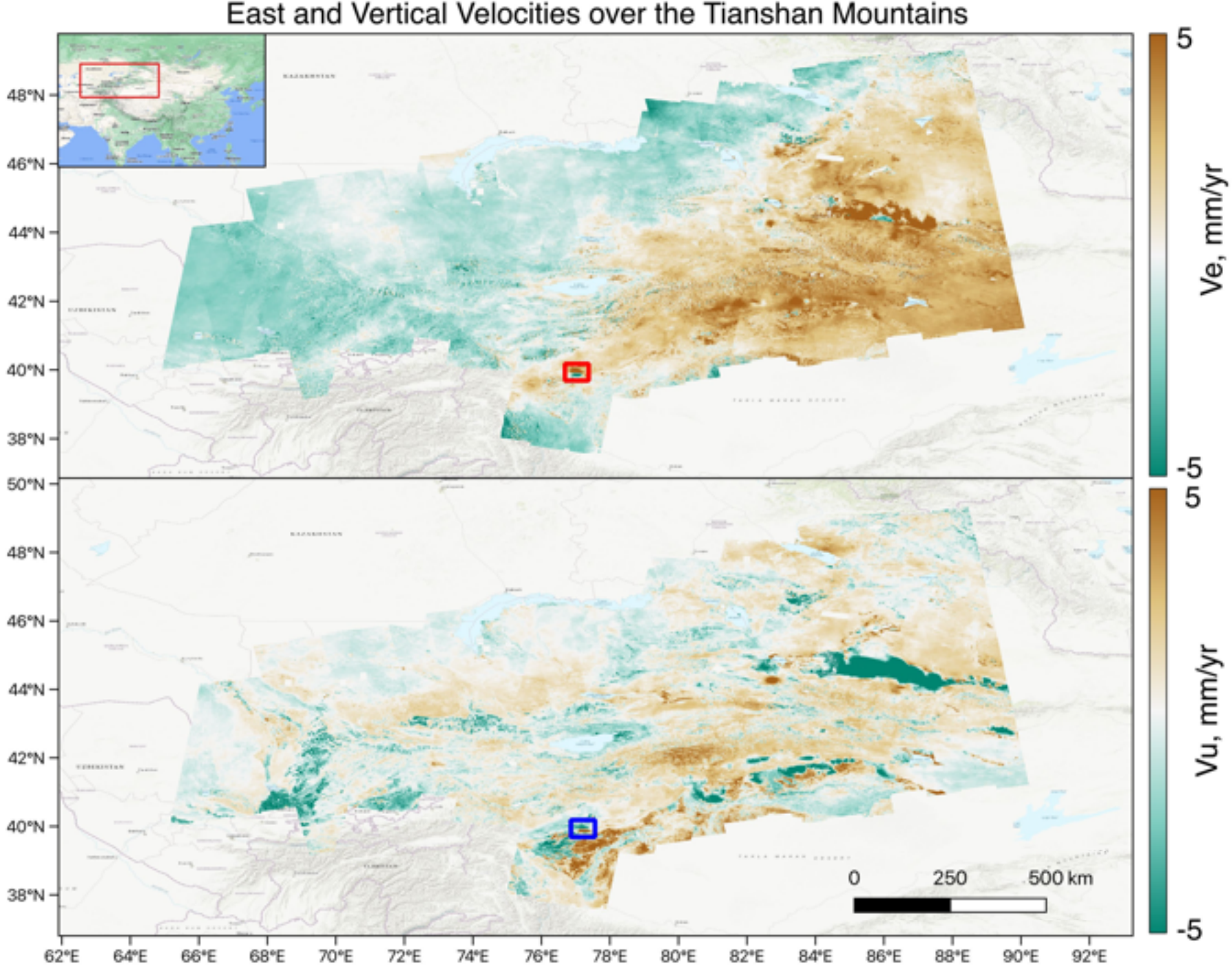
Glacial Isostatic Adjustment



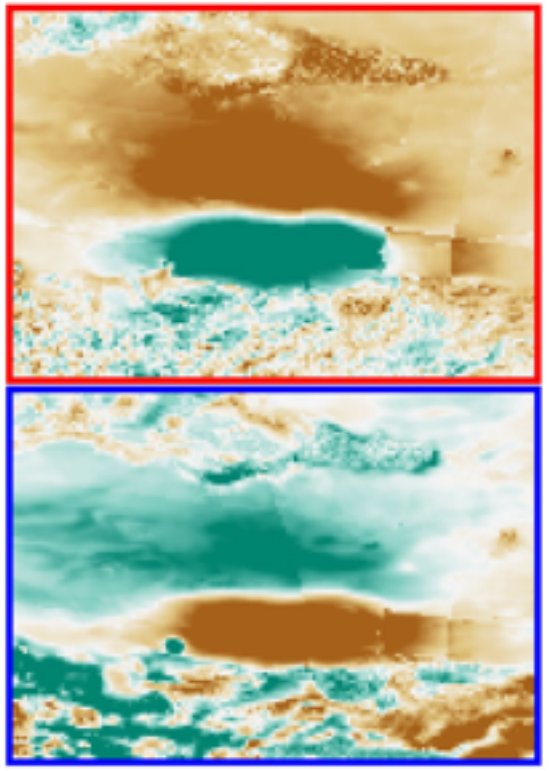


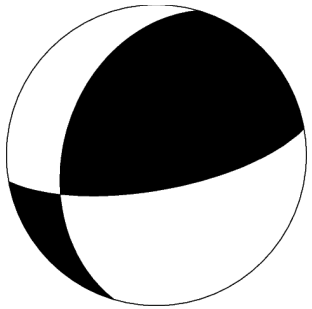


East and Vertical Velocities over the Tianshan Mountains



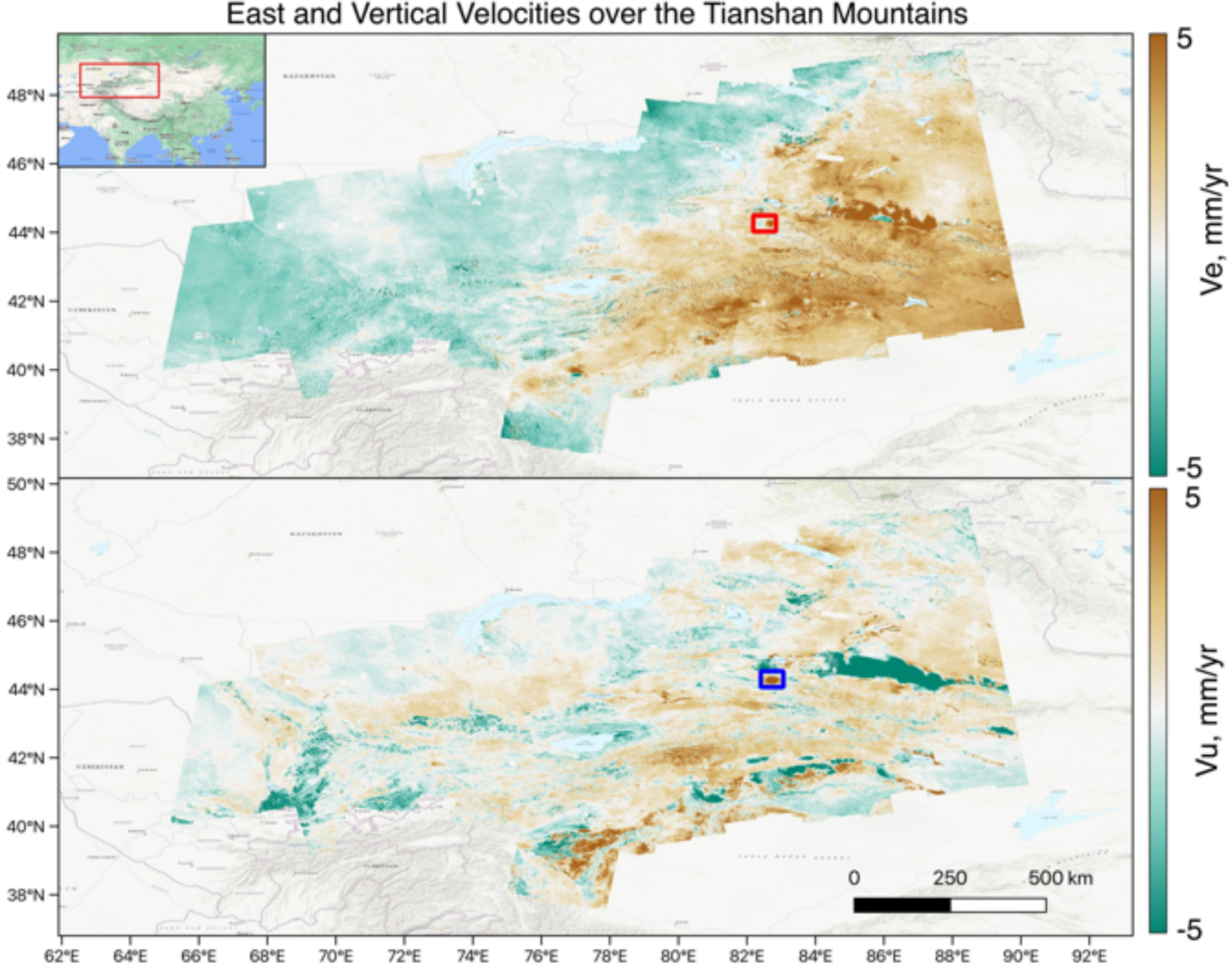
2020 Mw 6.0
Jiashi Eqk



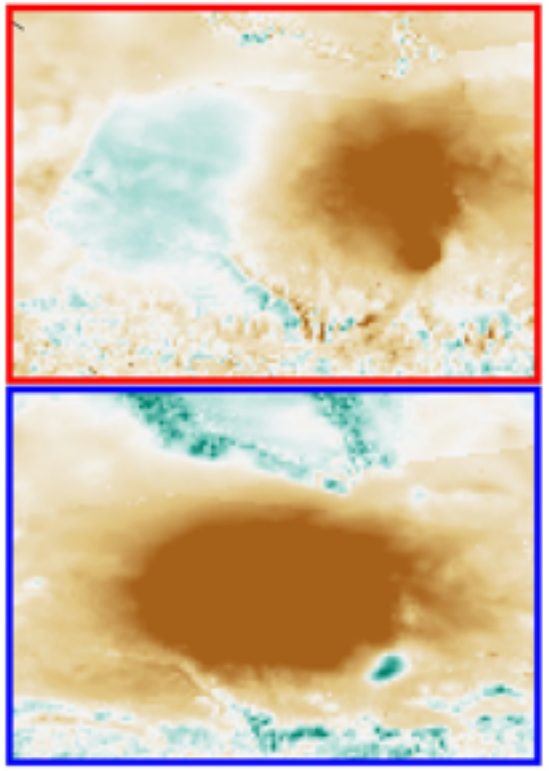


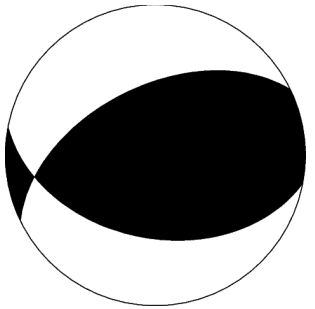
12 km
depth

East and Vertical Velocities over the Tianshan Mountains



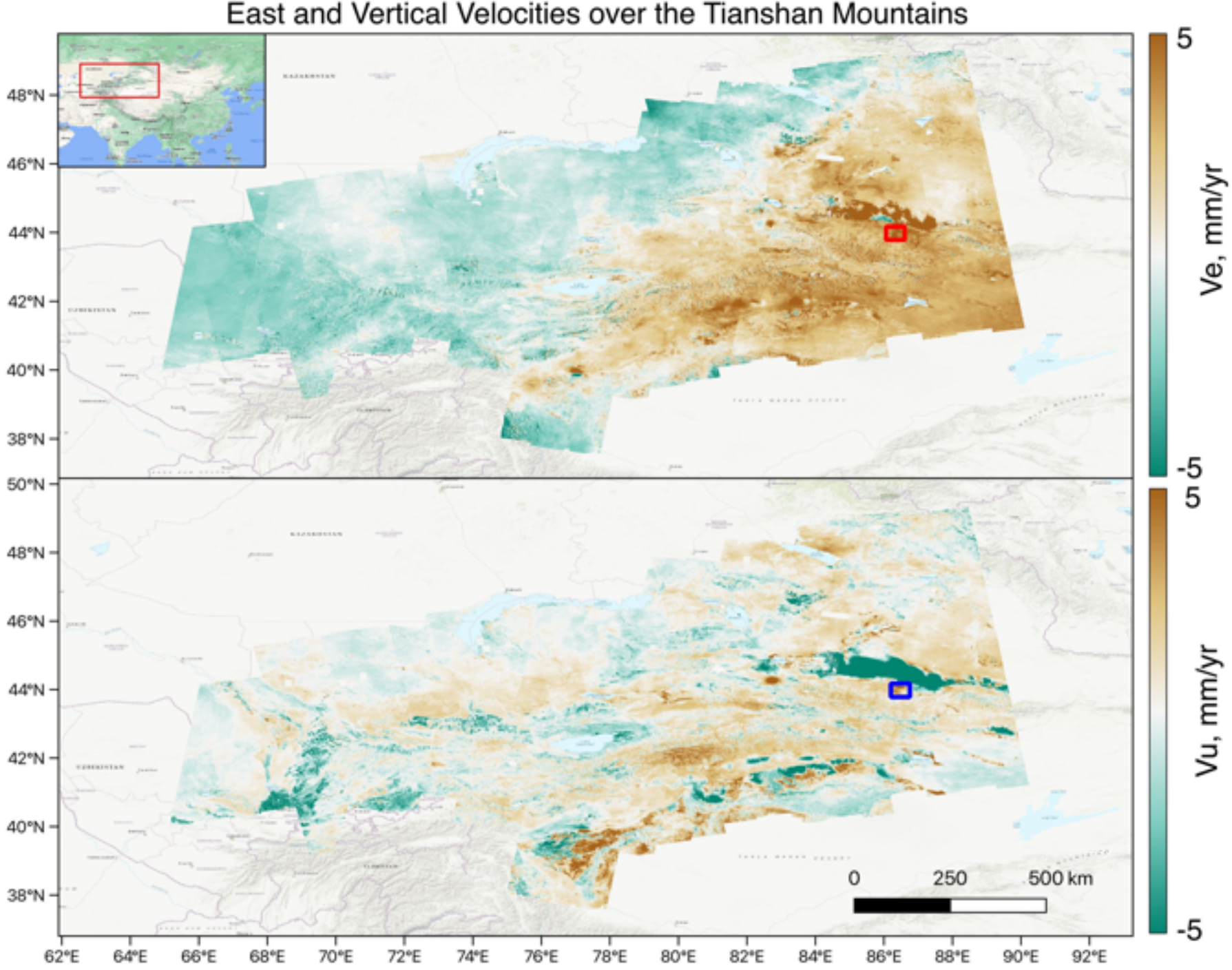
2017 Mw 6.3
Jinghe Eqk



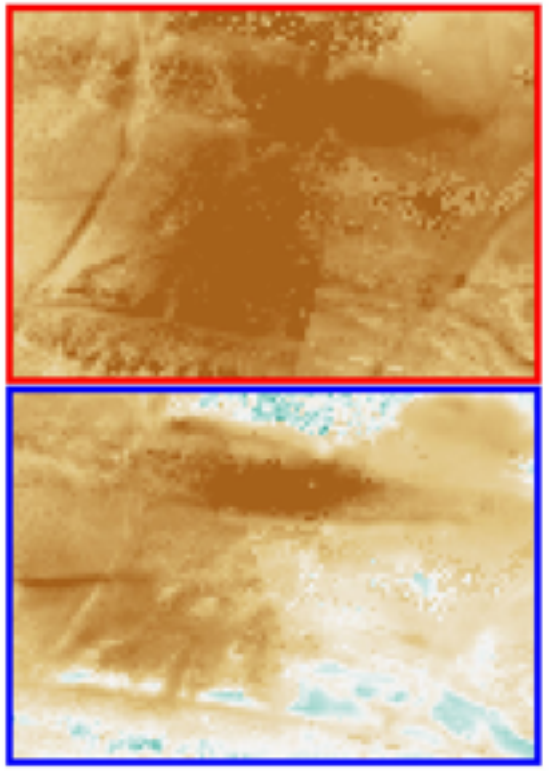


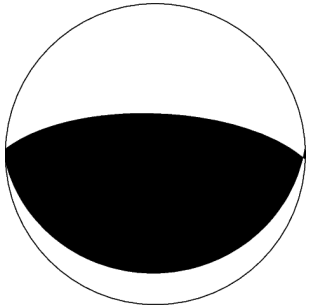
28 km
depth

East and Vertical Velocities over the Tianshan Mountains



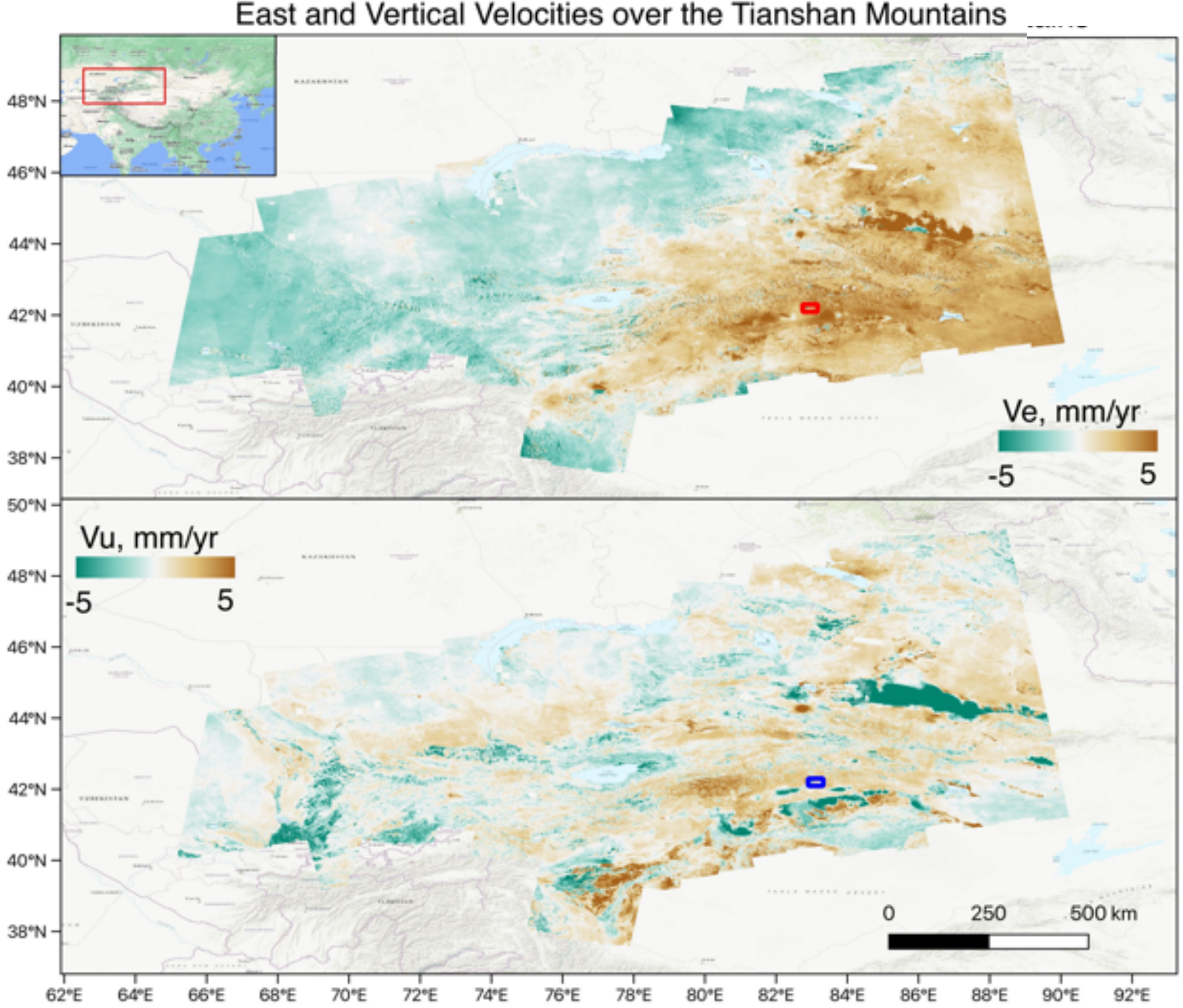
2016 Mw 6.0
Hutubi Eqk

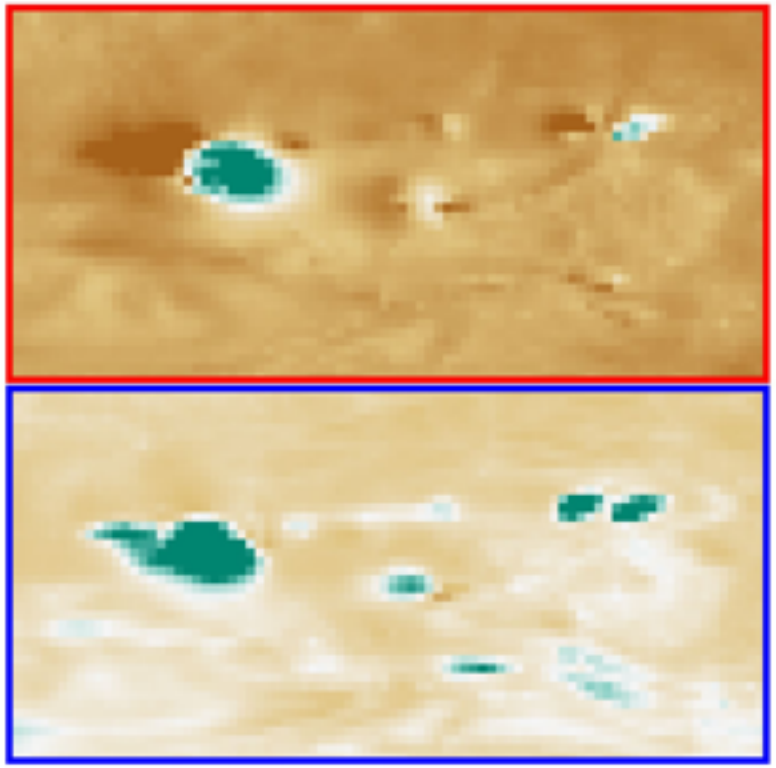


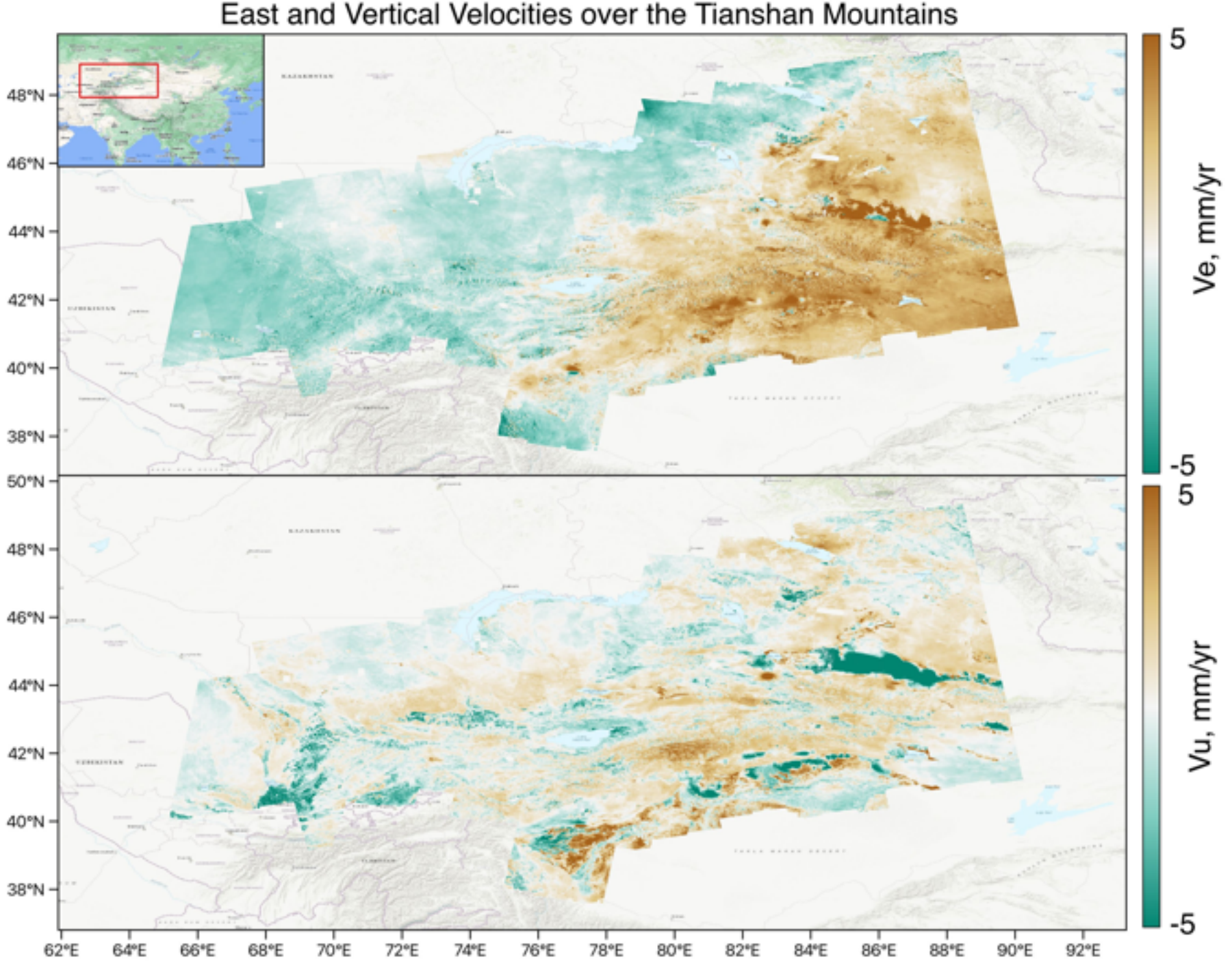


20 km
depth

Mine & Slow landslide

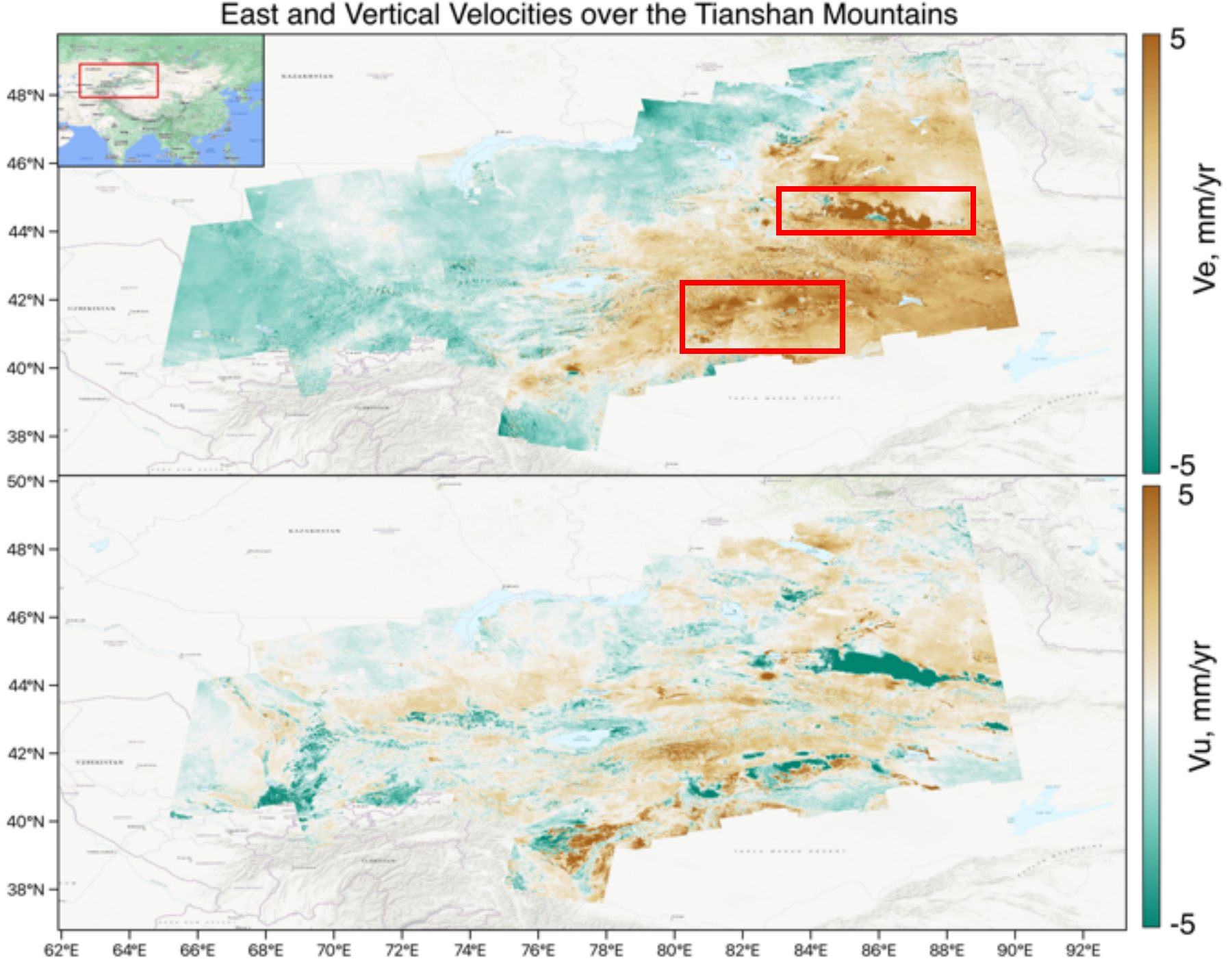






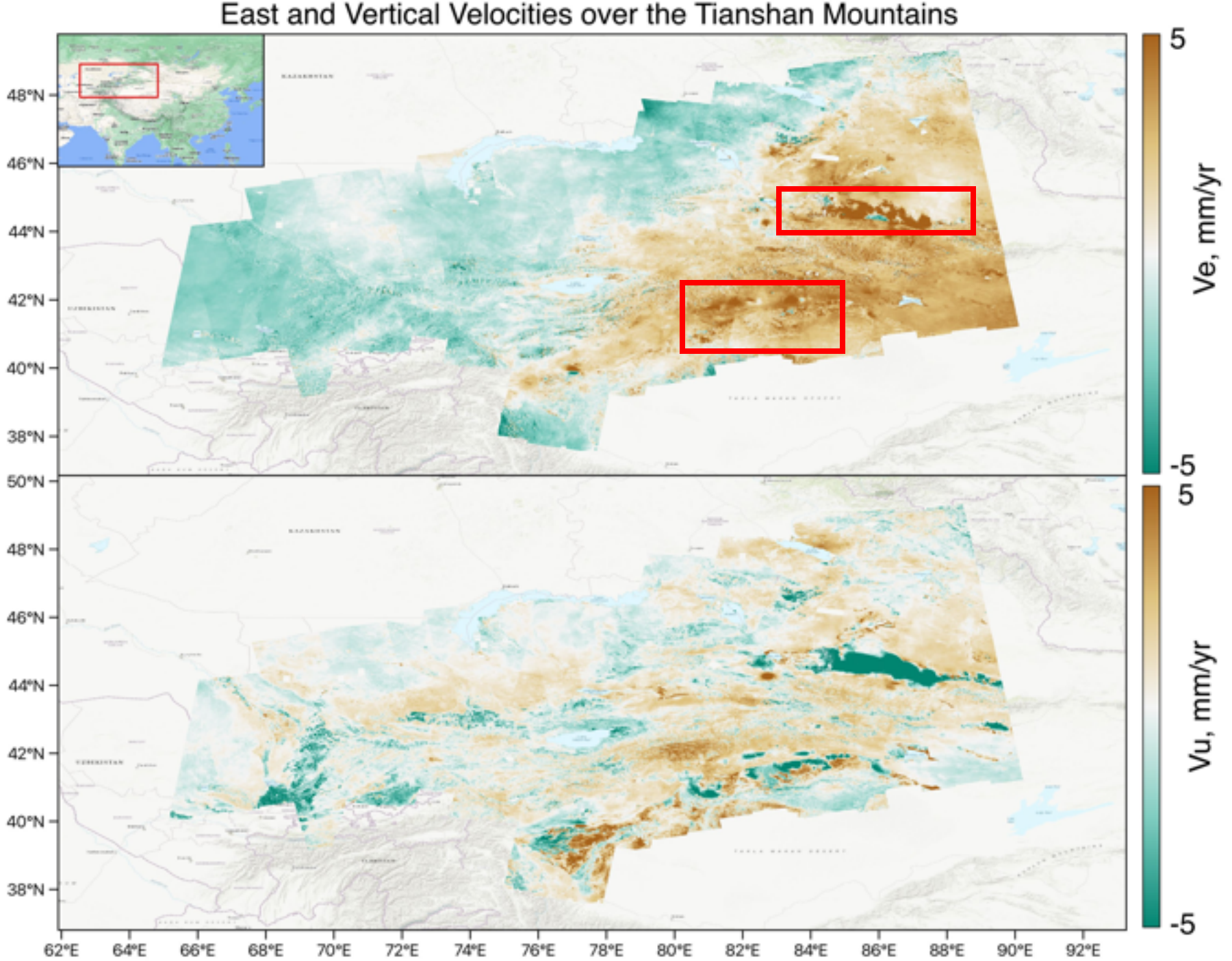
Tectonics?

Yes in Ve



Tectonics?

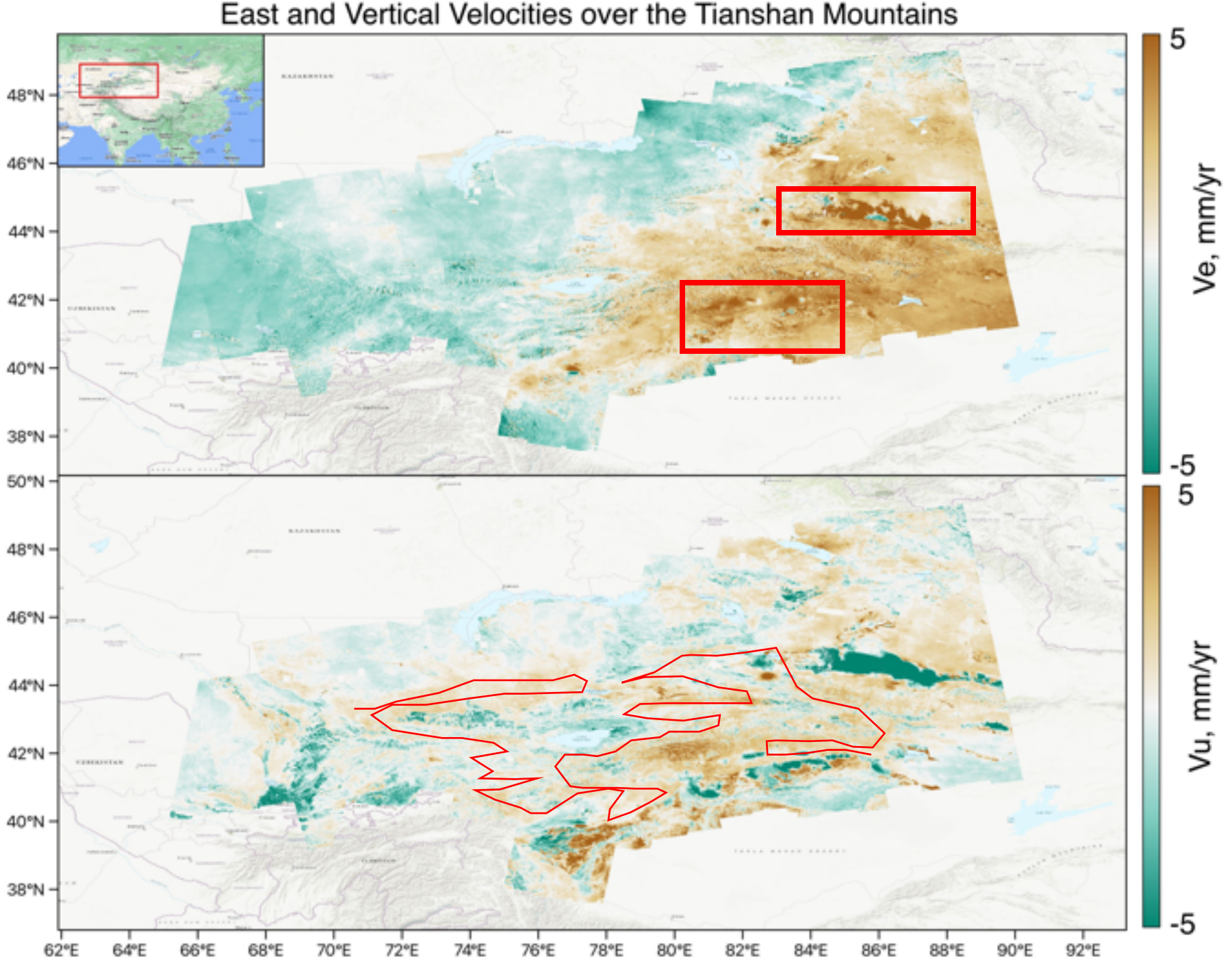
Yes in Ve except..



Tectonics?

Yes in Ve except..

Yes in Vu if we avoid all that's not…



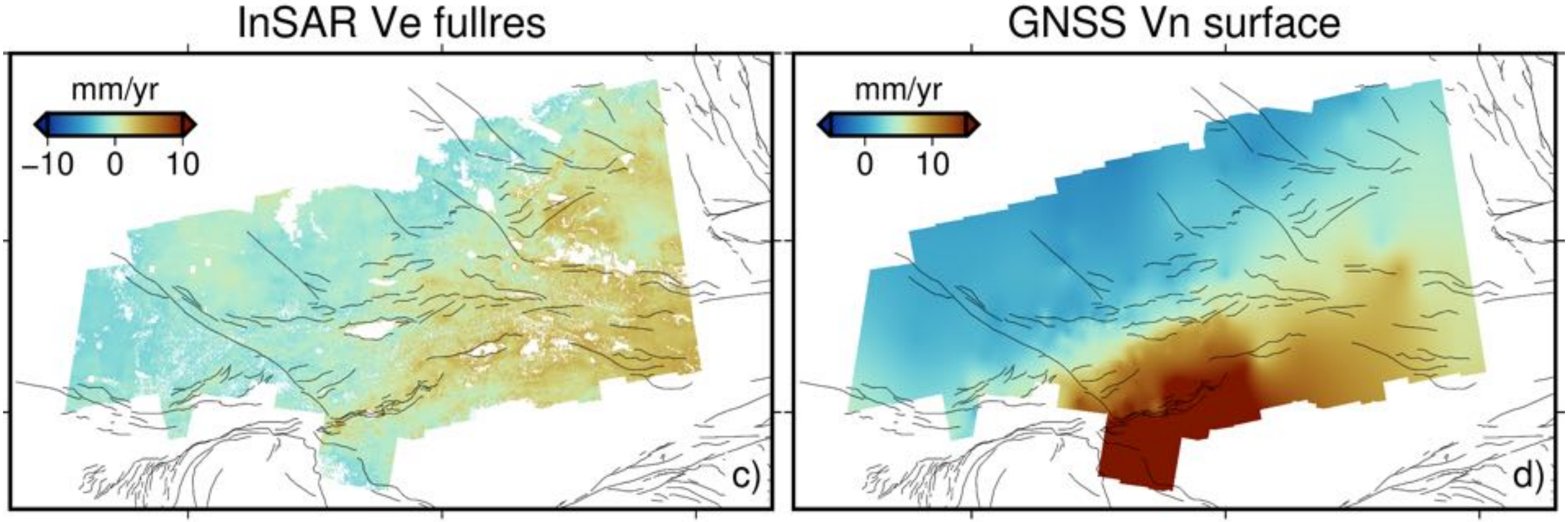
Tectonics?

Yes in Ve except..

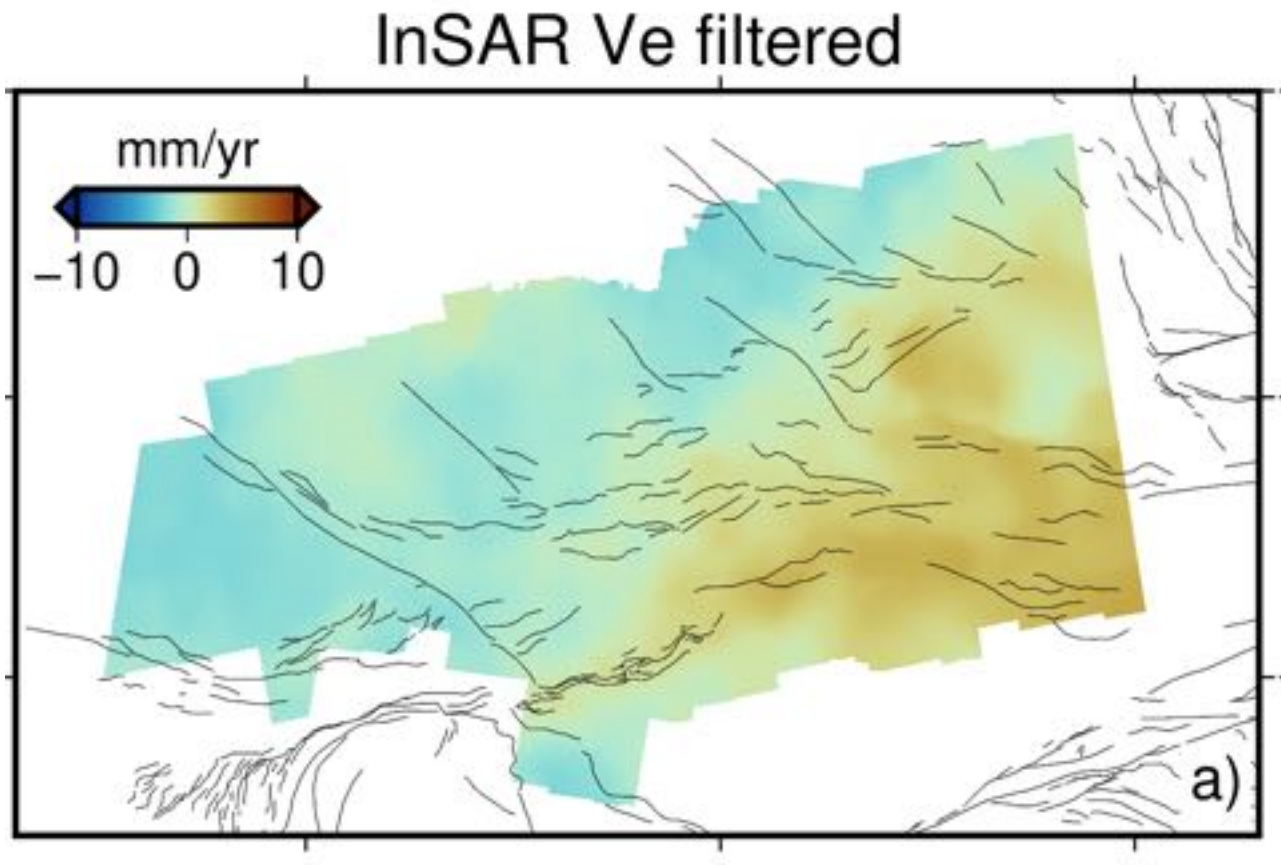
Yes in Vu, if we avoid all that's not...

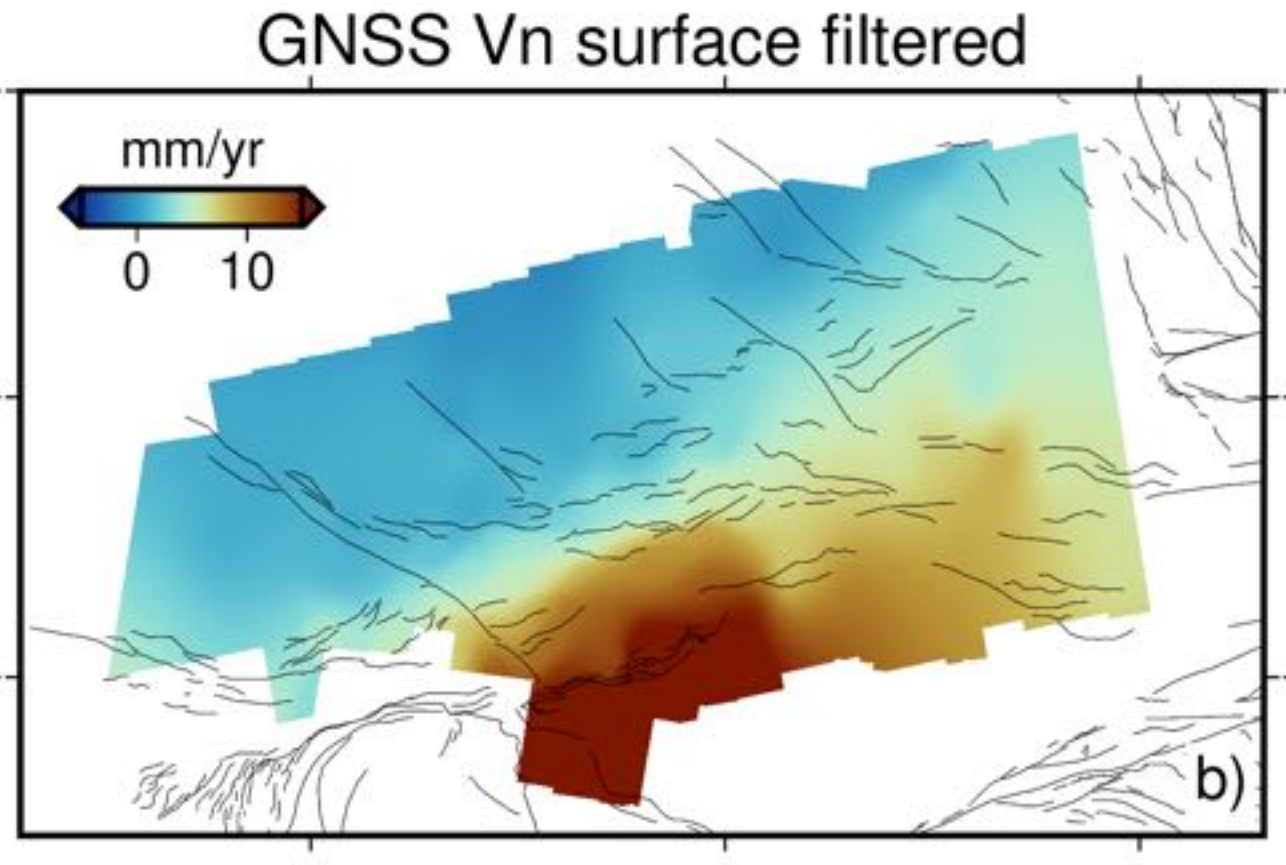
0.96±0.89 mm/yr !

Horizontal Strain from InSAR Ve and GNSS Vn

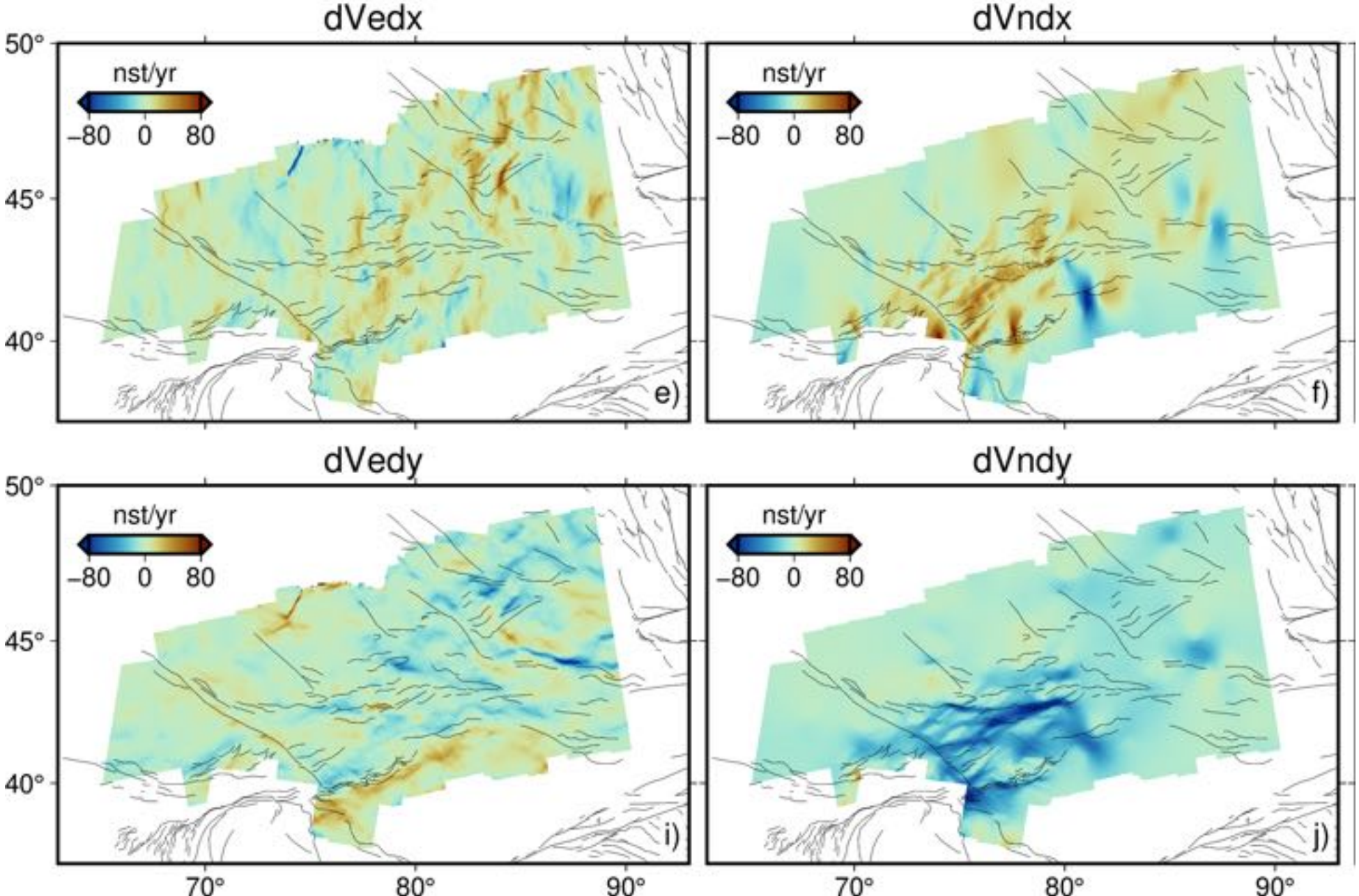


Median filtered with 100 km window

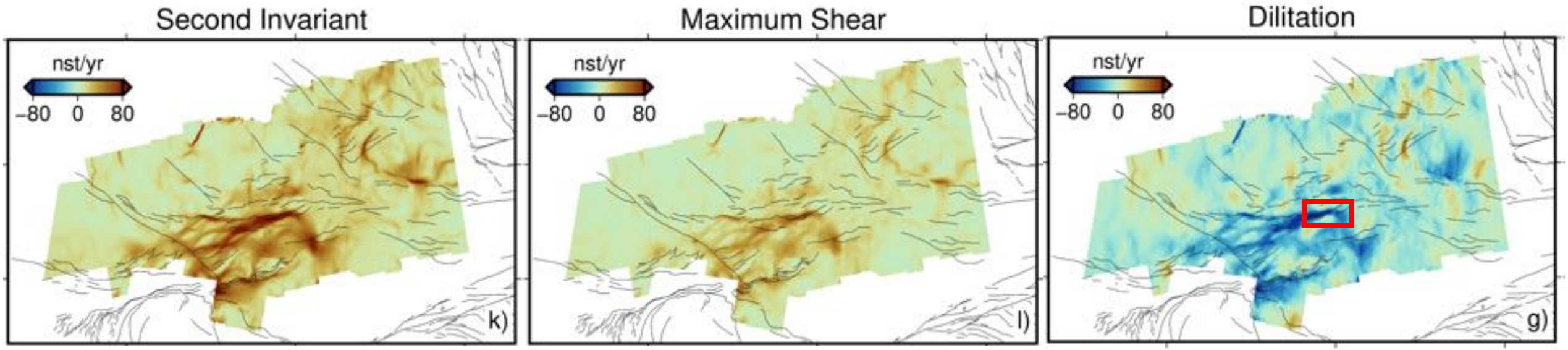




Horizontal velocity gradients

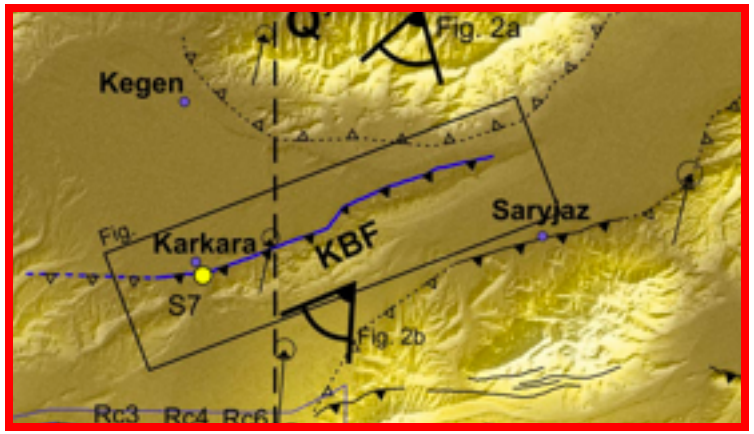


Strain rates (100 km)

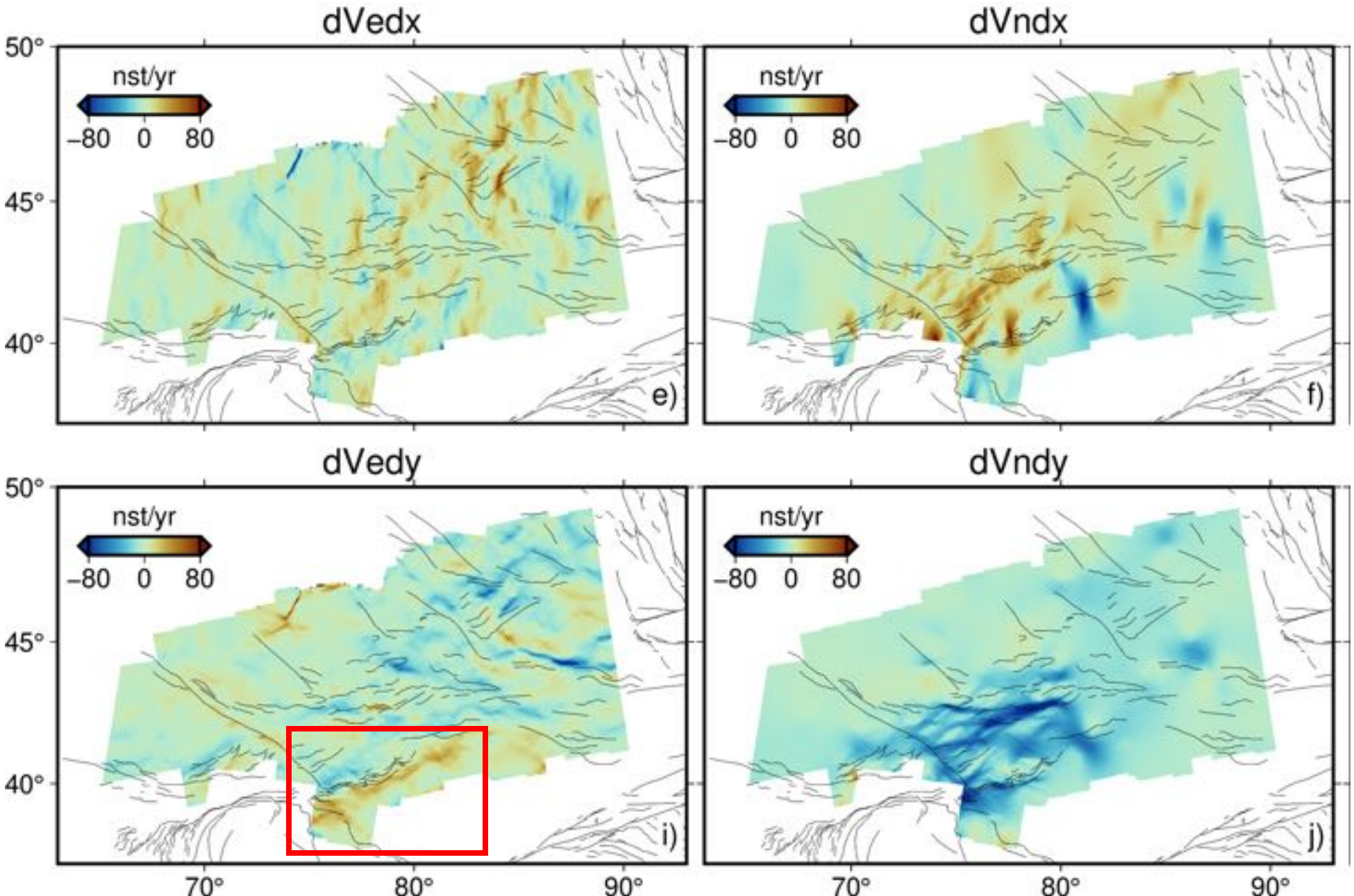


Creeping Karkara Thrust

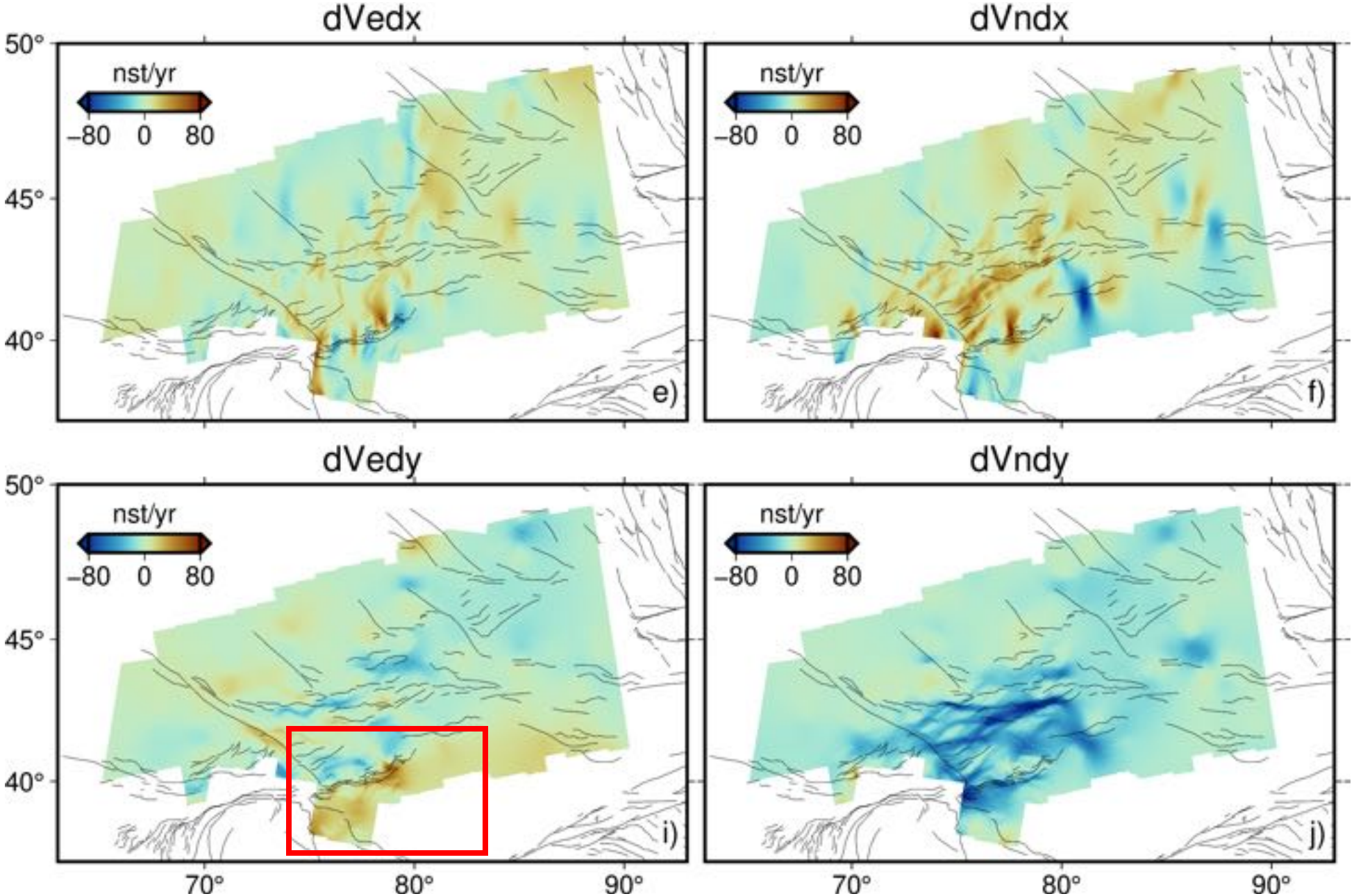
Mackenzie et al, 2018



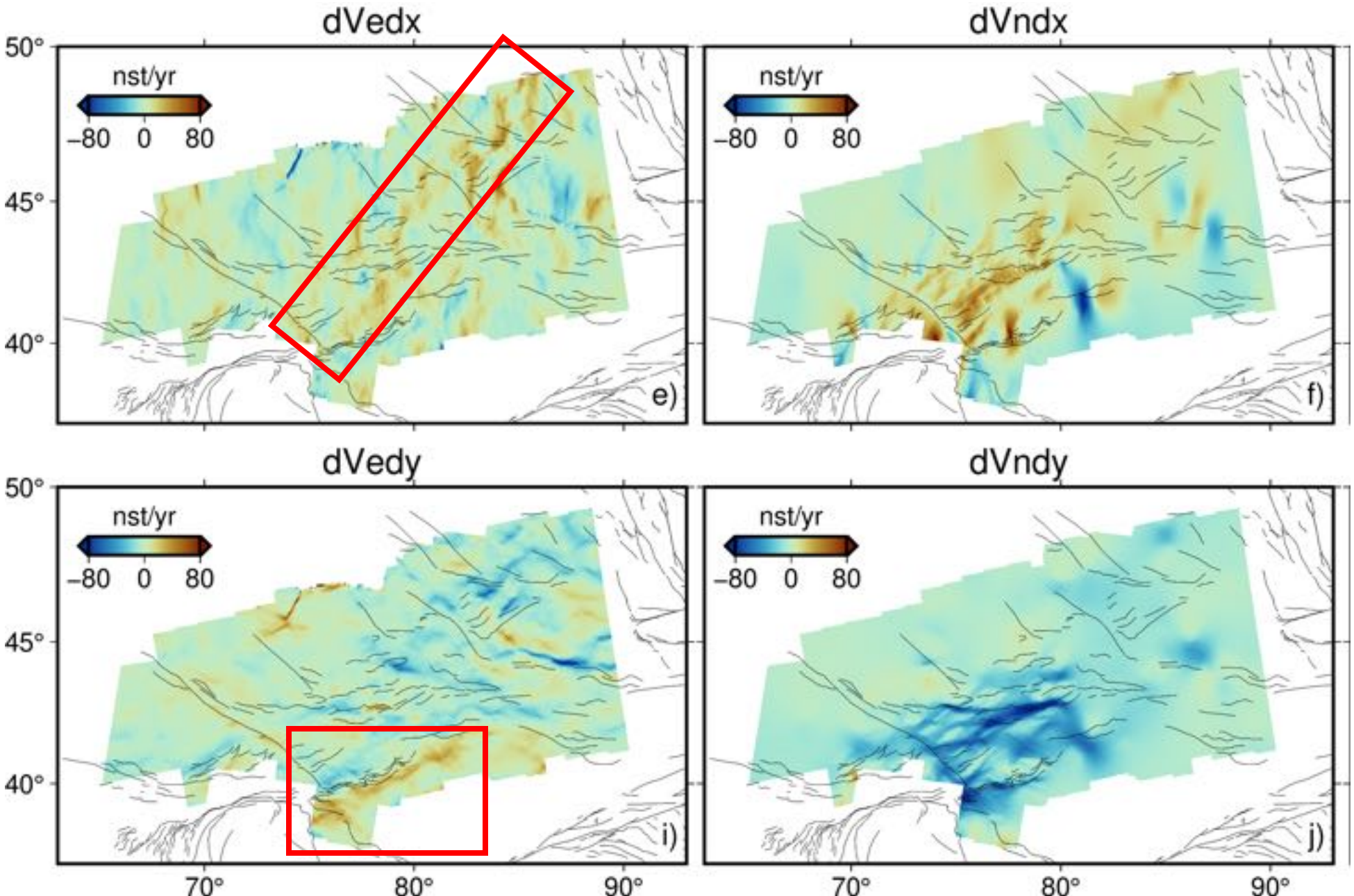
Gradients of InSAR Ve and GNSS Vn



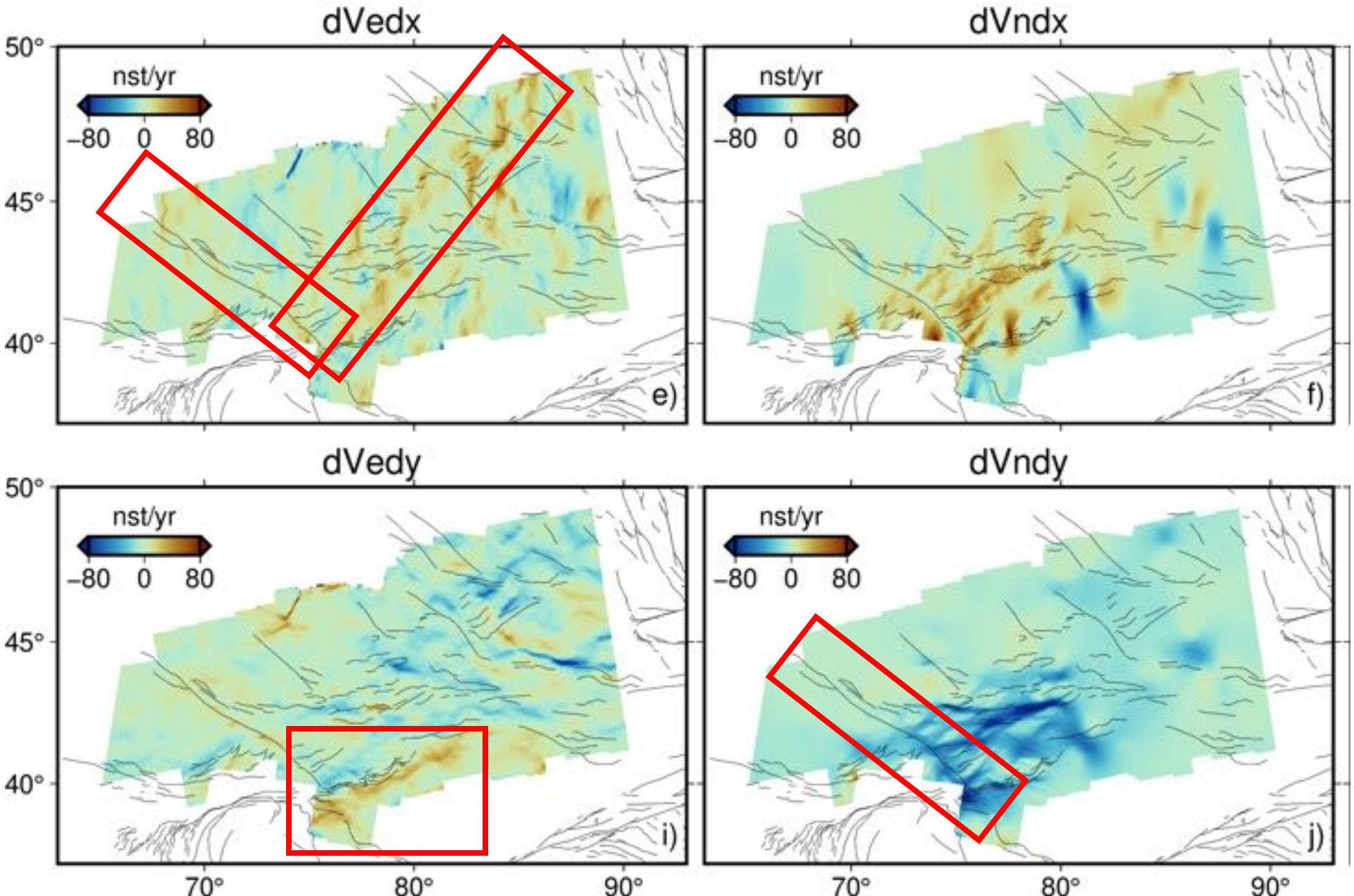
Gradients of GNSS Ve and GNSS Vn



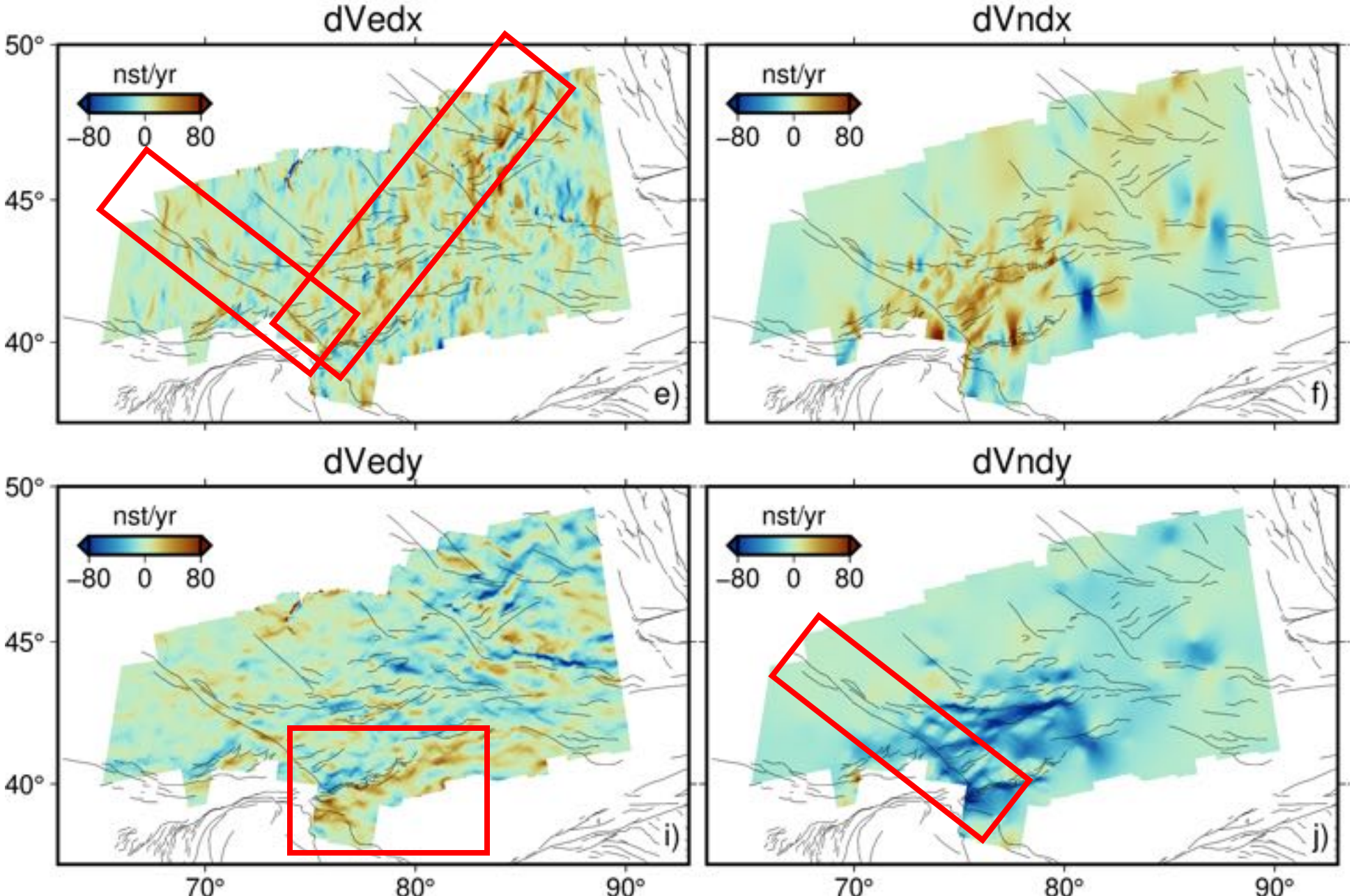
Gradients of InSAR Ve and GNSS Vn



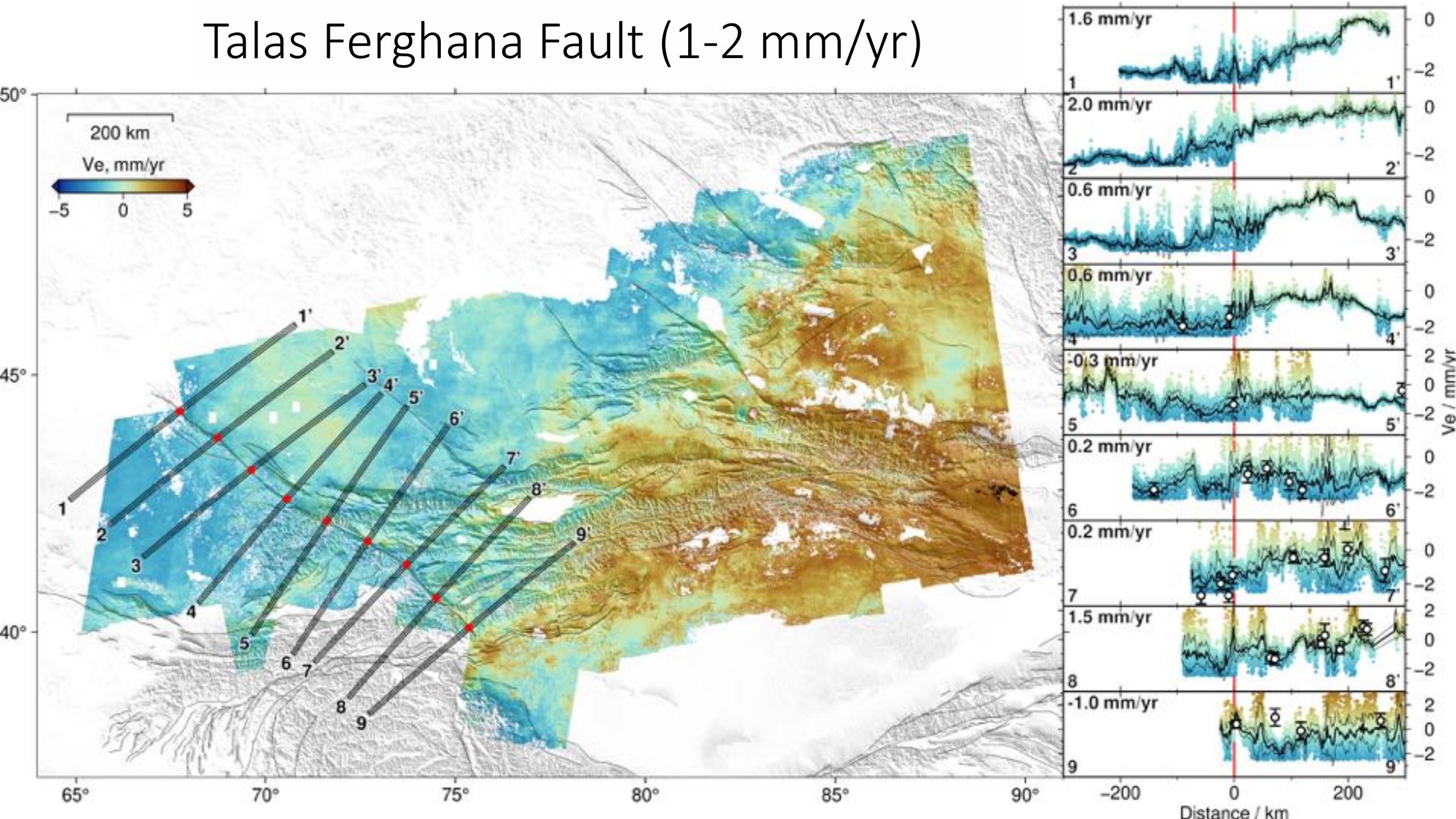
Gradients of InSAR Ve and GNSS Vn



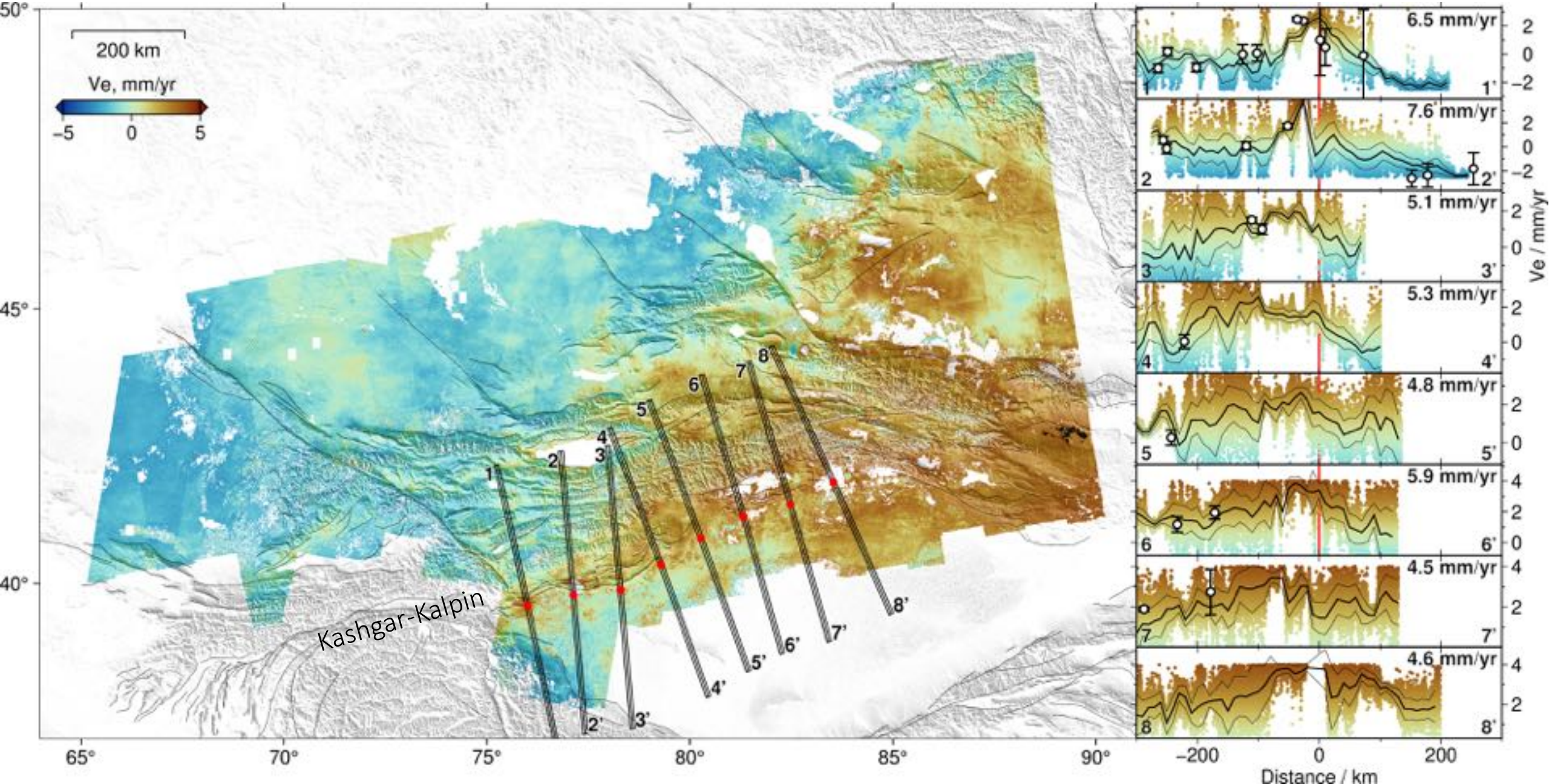
Gradients of InSAR Ve and GNSS Vn 60 km filter



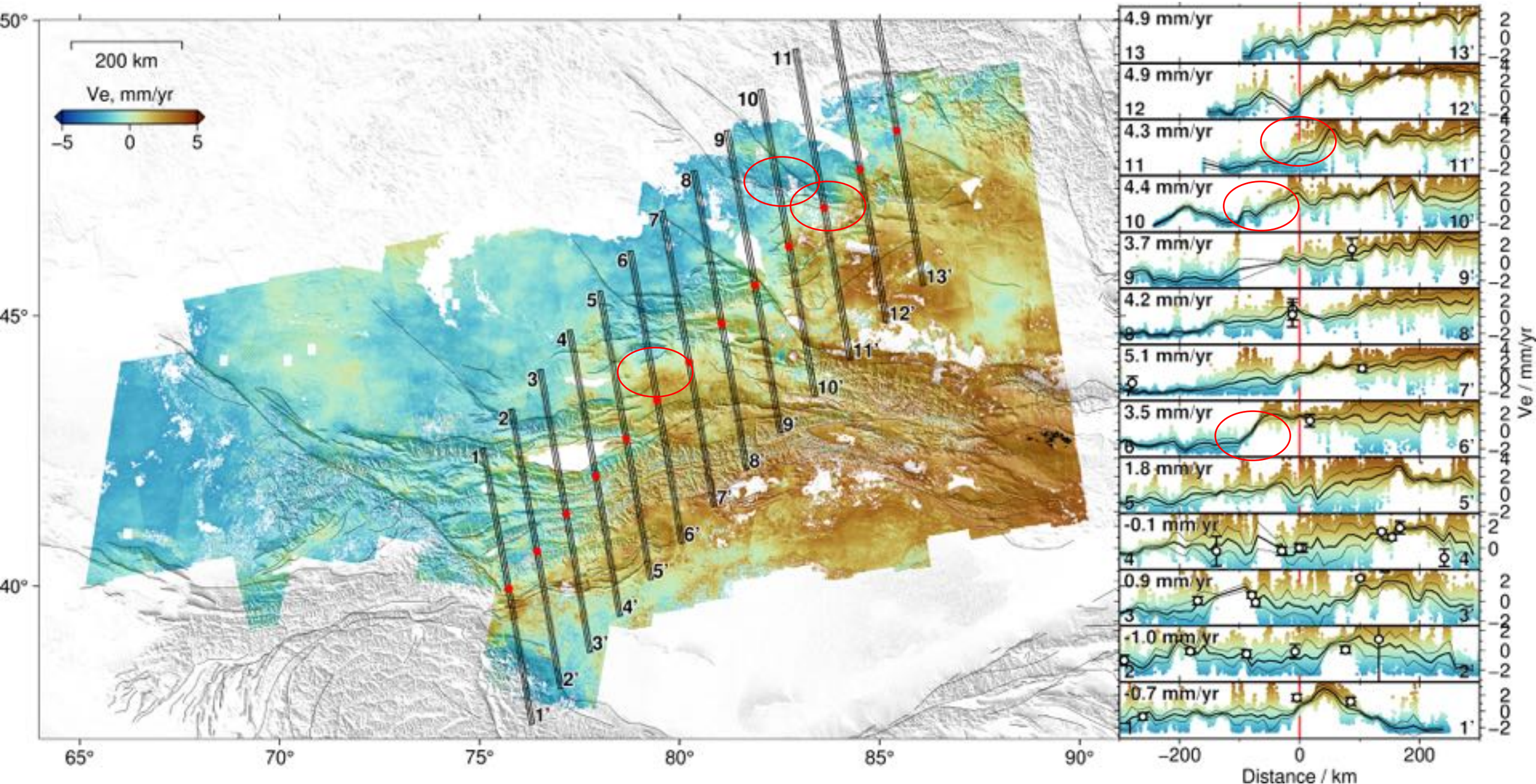
Talas Ferghana Fault (1-2 mm/yr)



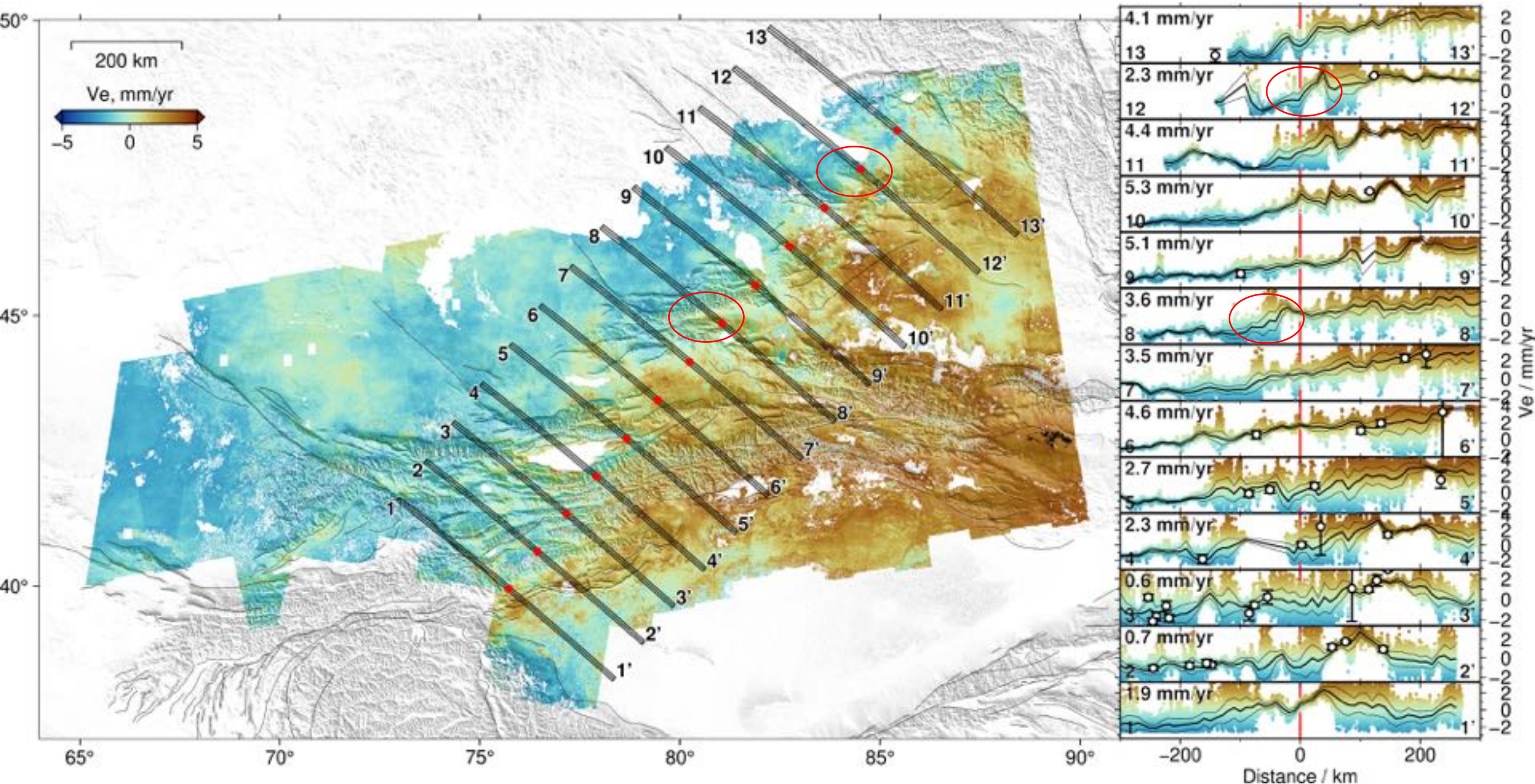
Kashgar-Kalpin Thrusting System Moving East (5-7 mm/yr)



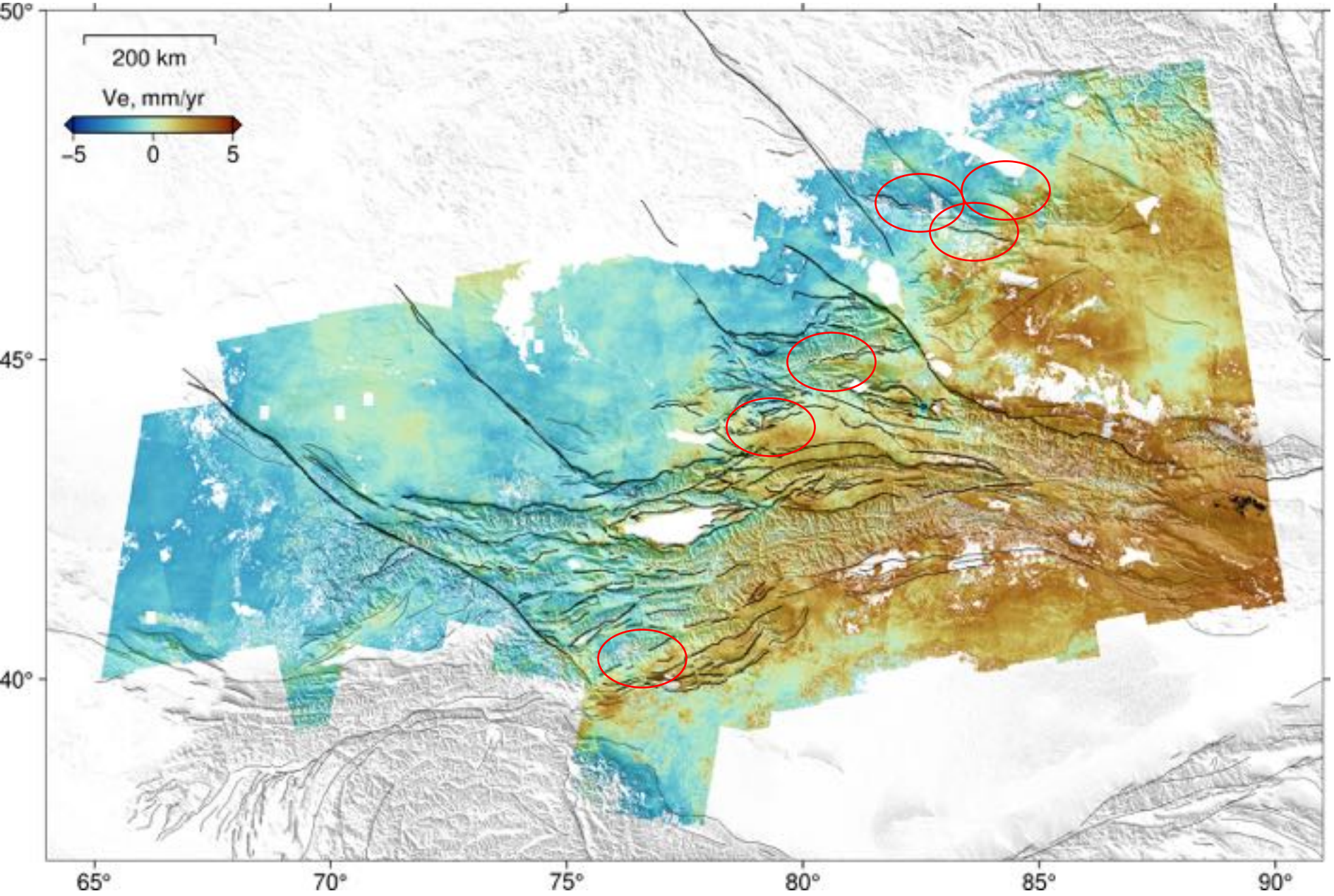
Distributed shear with some localisation



Distributed shear with some localisations

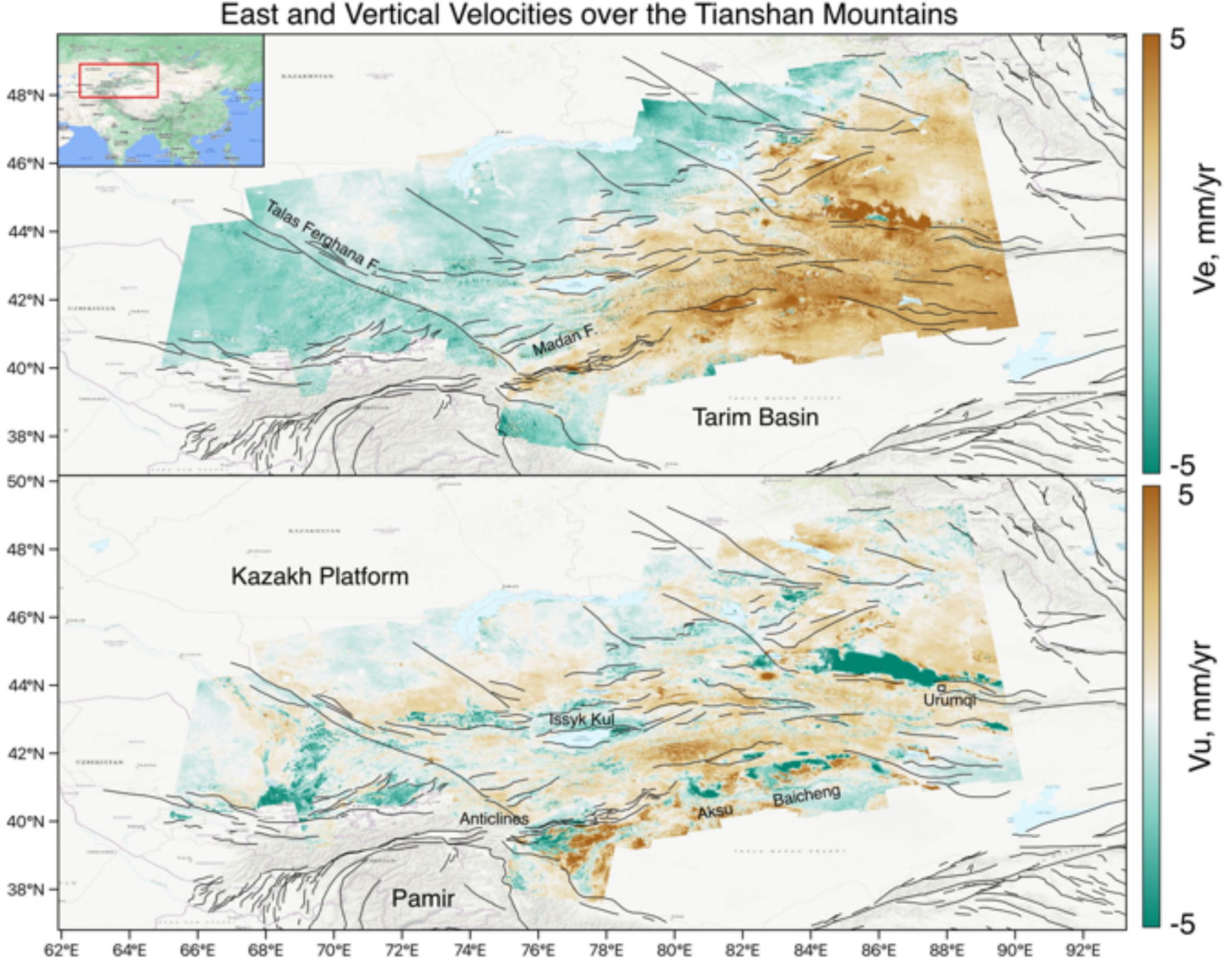


COMET Tien Shan Active Fault Database



Level 1: Scarp
Level 2: Geomorphic
Level 3: Seismic

King et al., coming soon!

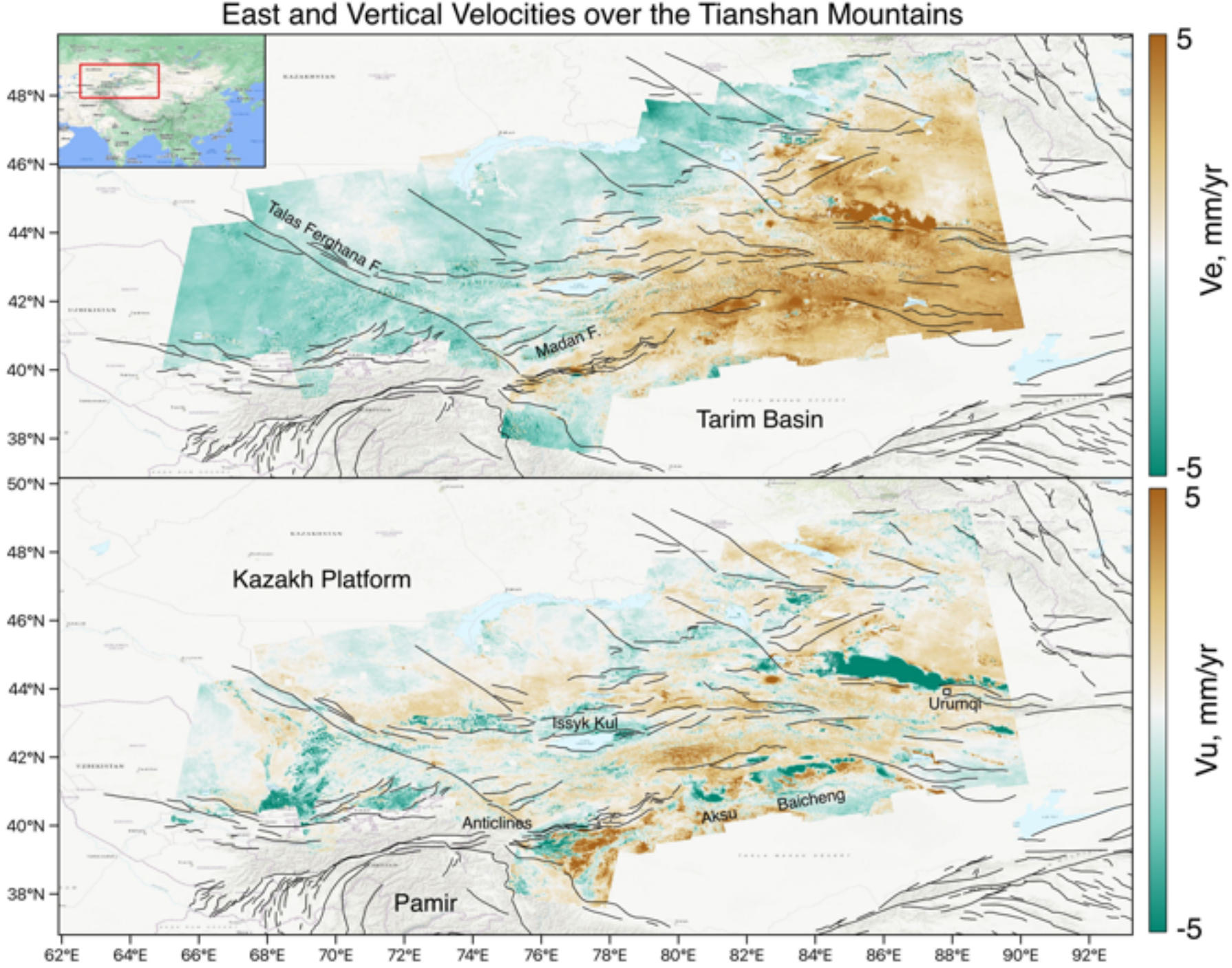


Summary

Ve and Vu

1.6 million km²

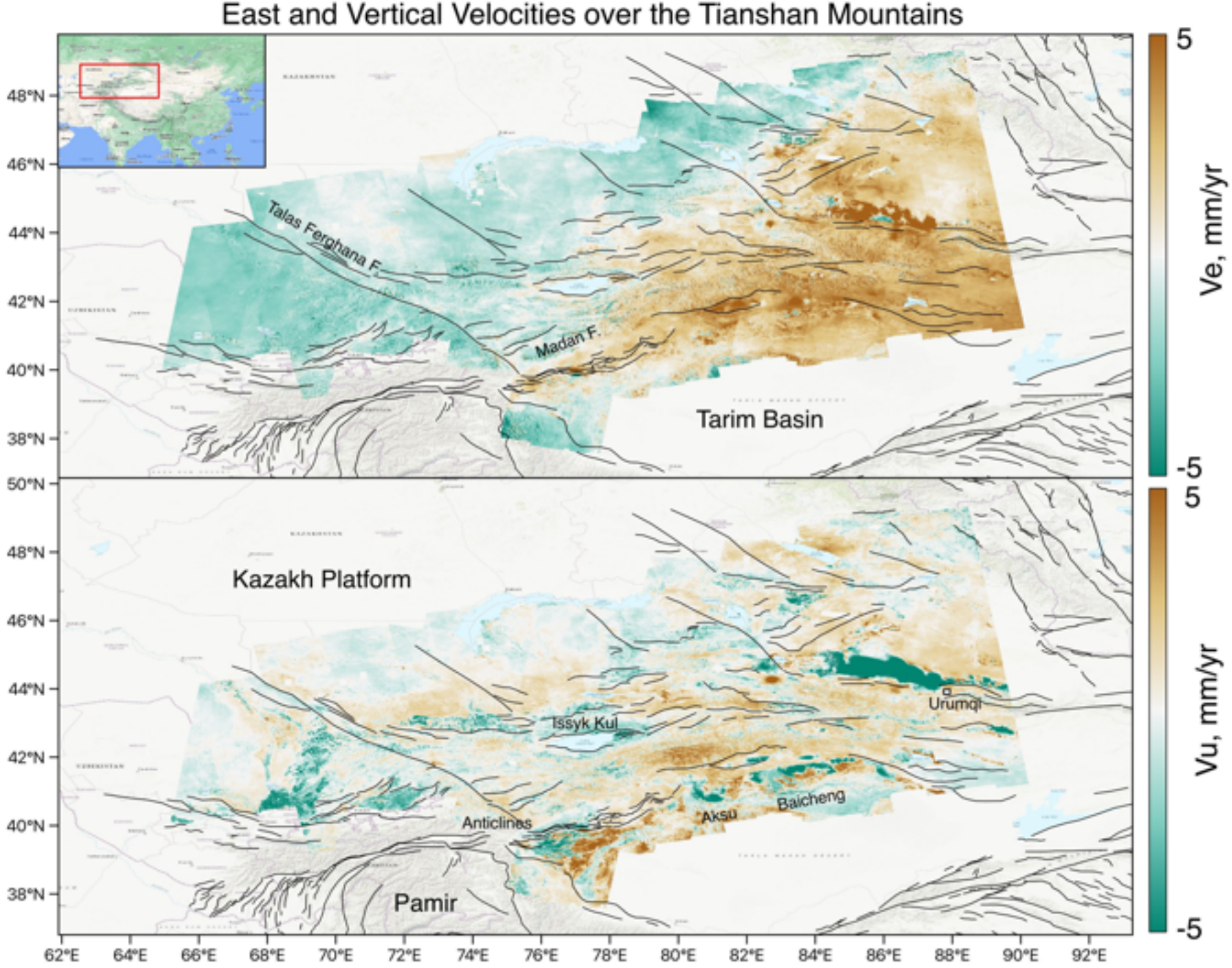
500 m resolution



Summary

Ve and Vu
1.6 million km²
500 m resolution

Distributed EW extension with some localized shear on faults missing from GEM Fault Database



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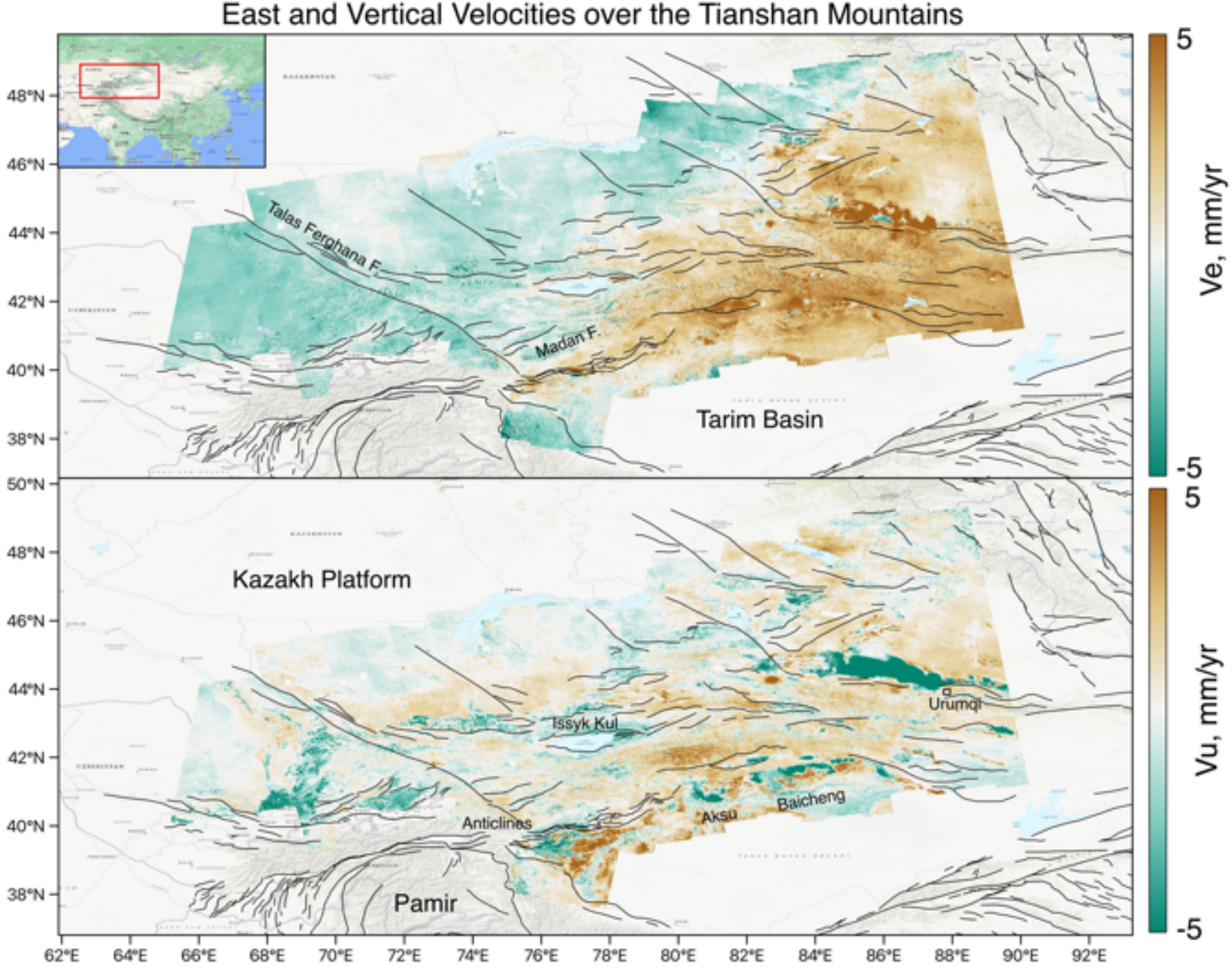
1 mm/yr tectonic uplift and much more!



Summary

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1.6 million km²
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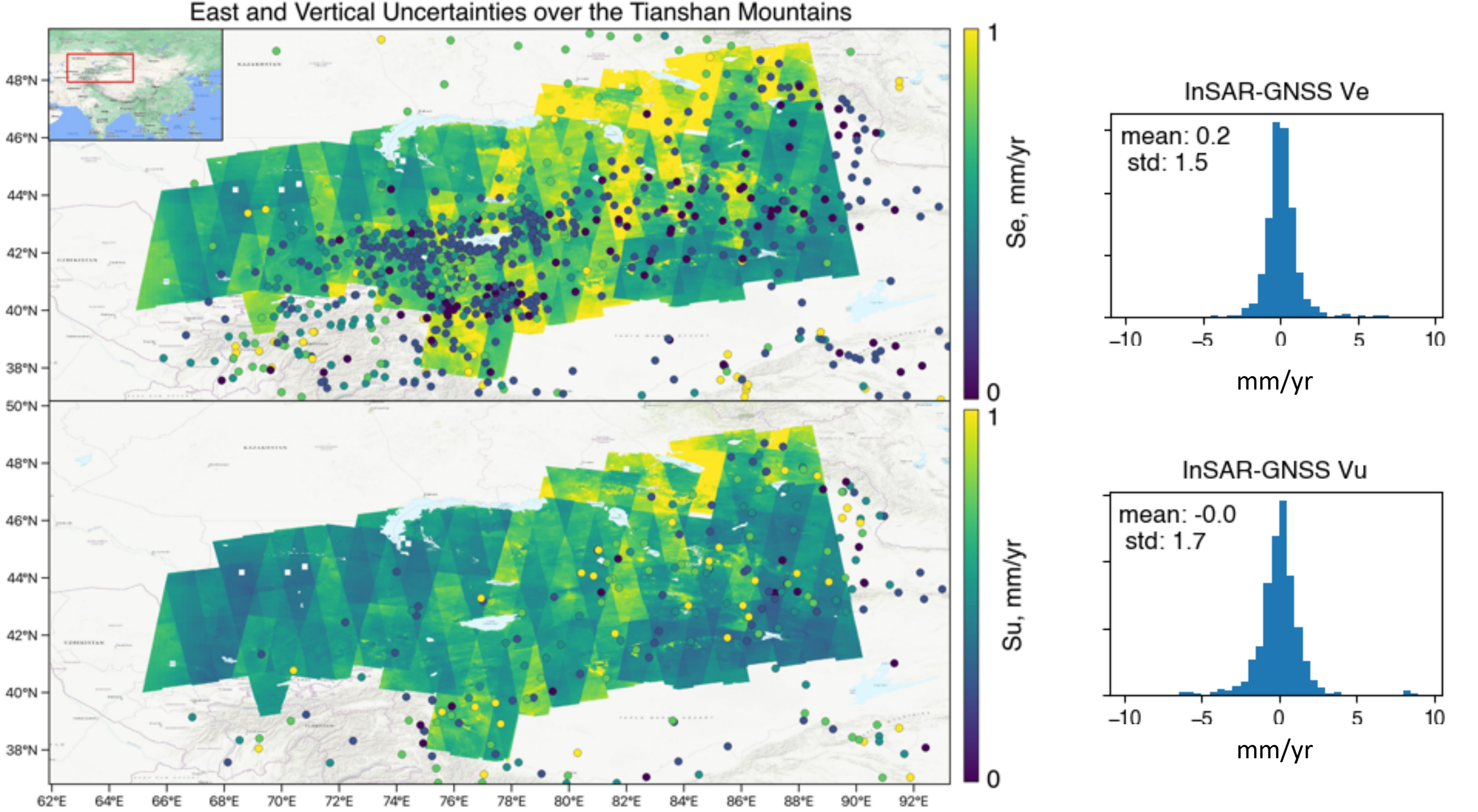
Distributed EW extension with some localized shear on faults missing from GEM Fault Database

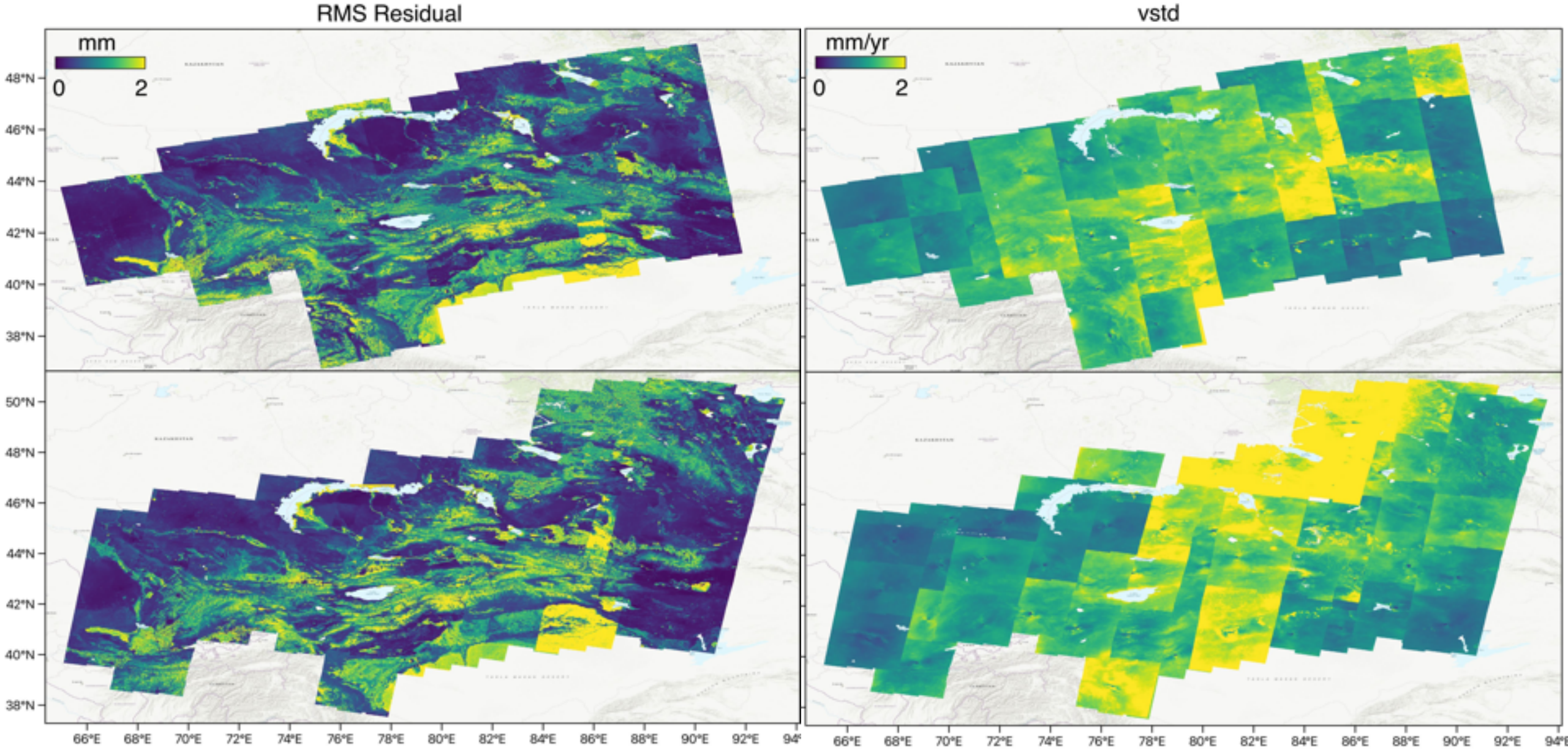
1 mm/yr tectonic uplift and much more!

Feeding into Global Earthquake Model.

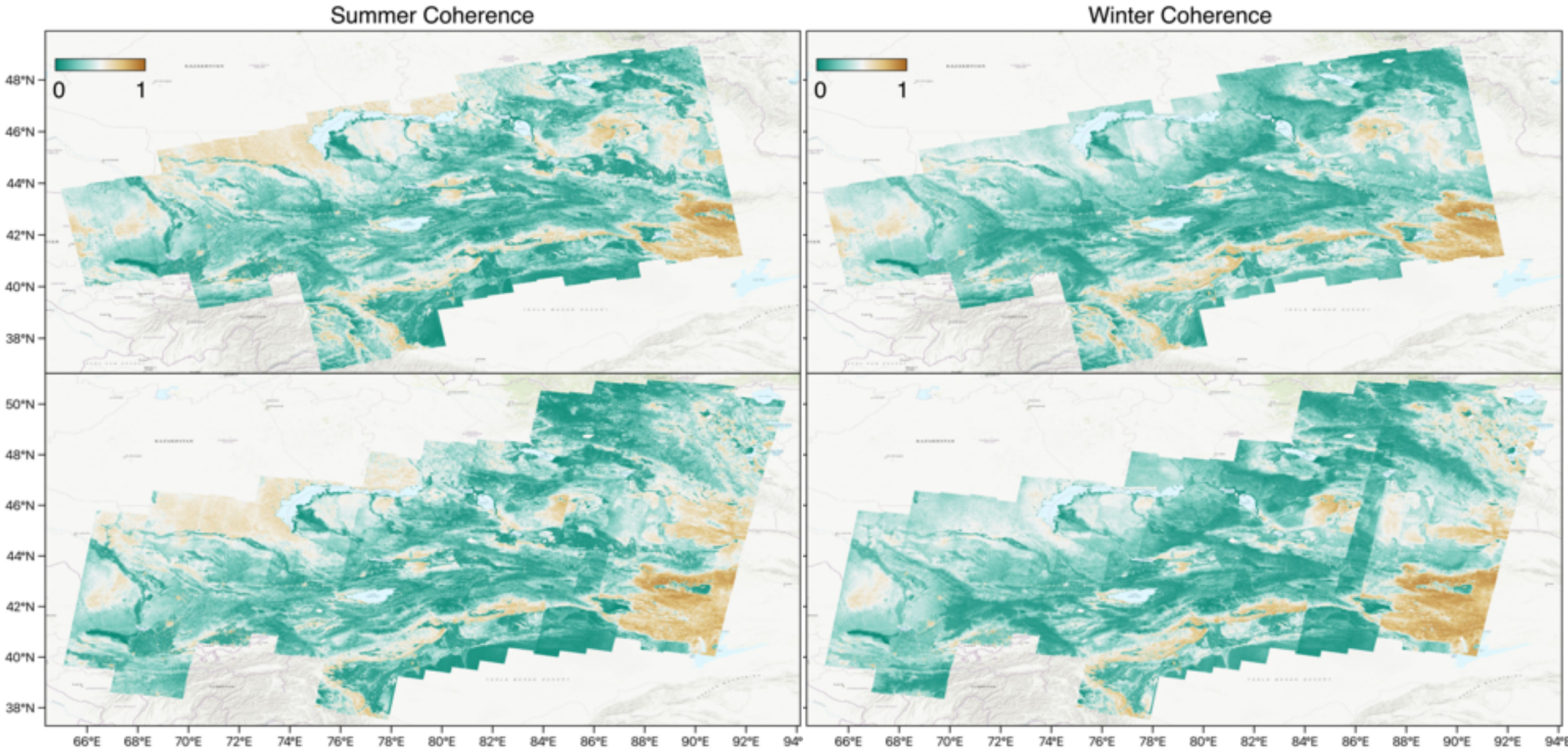
q.ou@leeds.ac.uk

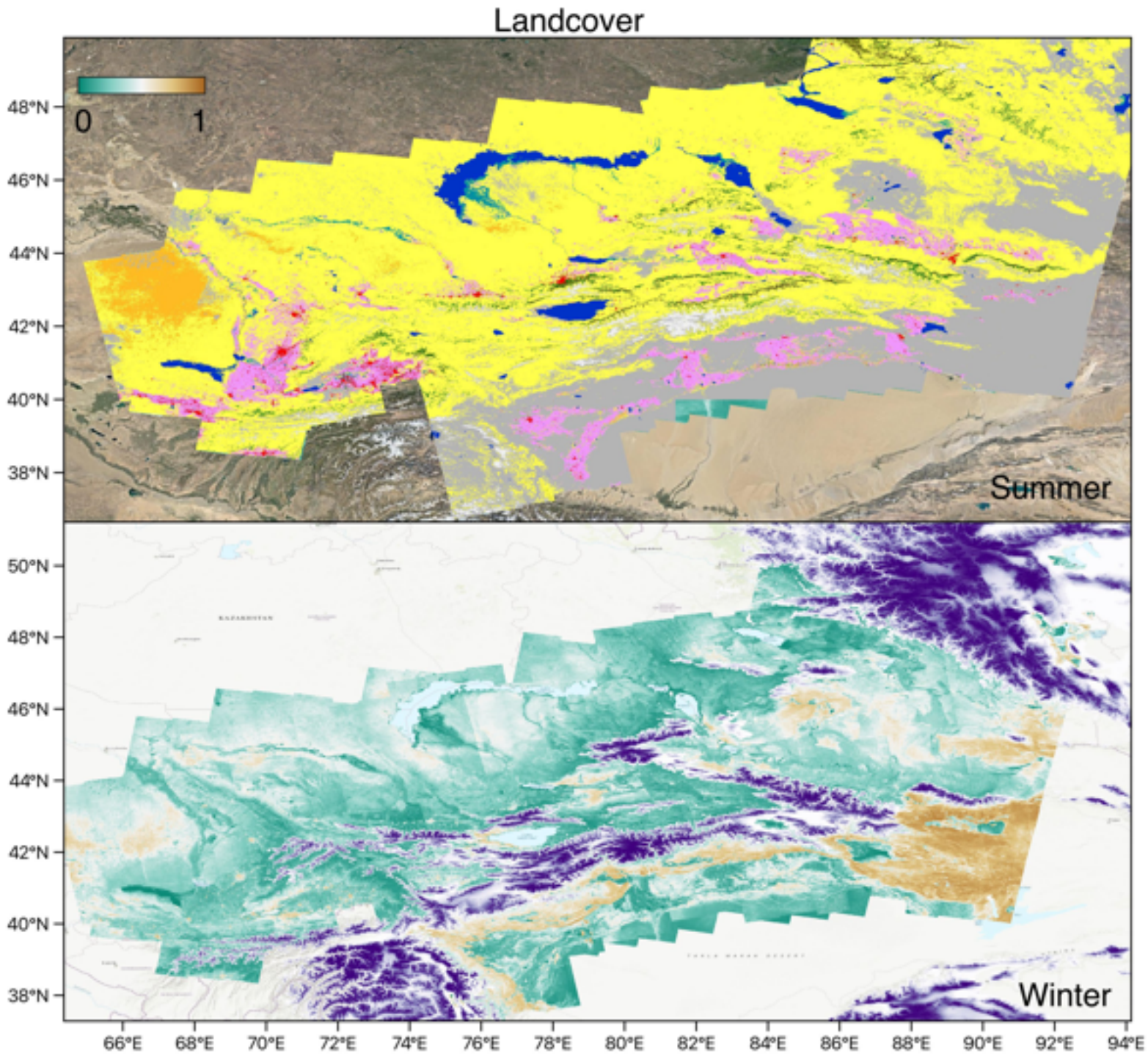

East and Vertical Uncertainties over the Tianshan Mountains
48°N
46°N
44°N
42°N
40°N
38°N
50°N
62°E
64°E
66°E
68°E
70°E
72°E
74°E
76°E
78°E
80°E
82°E
84°E
86°E
88°E
90°E
92°E
1
0
Se, mm/yr
Su, mm/yr
InSAR-GNSS Ve
mean: 0.2
std: 1.5
InSAR-GNSS Vu
mean: -0.0
std: 1.7
−10
−5
0
5
10
mm/yr

Quality Statistics



Coherence


Summer Coherence
Winter Coherence
0
1
0
1
48°N
46°N
44°N
42°N
40°N
38°N
50°N
48°N
46°N
44°N
42°N
40°N
38°N
66°E
68°E
70°E
72°E
74°E
76°E
78°E
80°E
82°E
84°E
86°E
88°E
90°E
92°E
94°

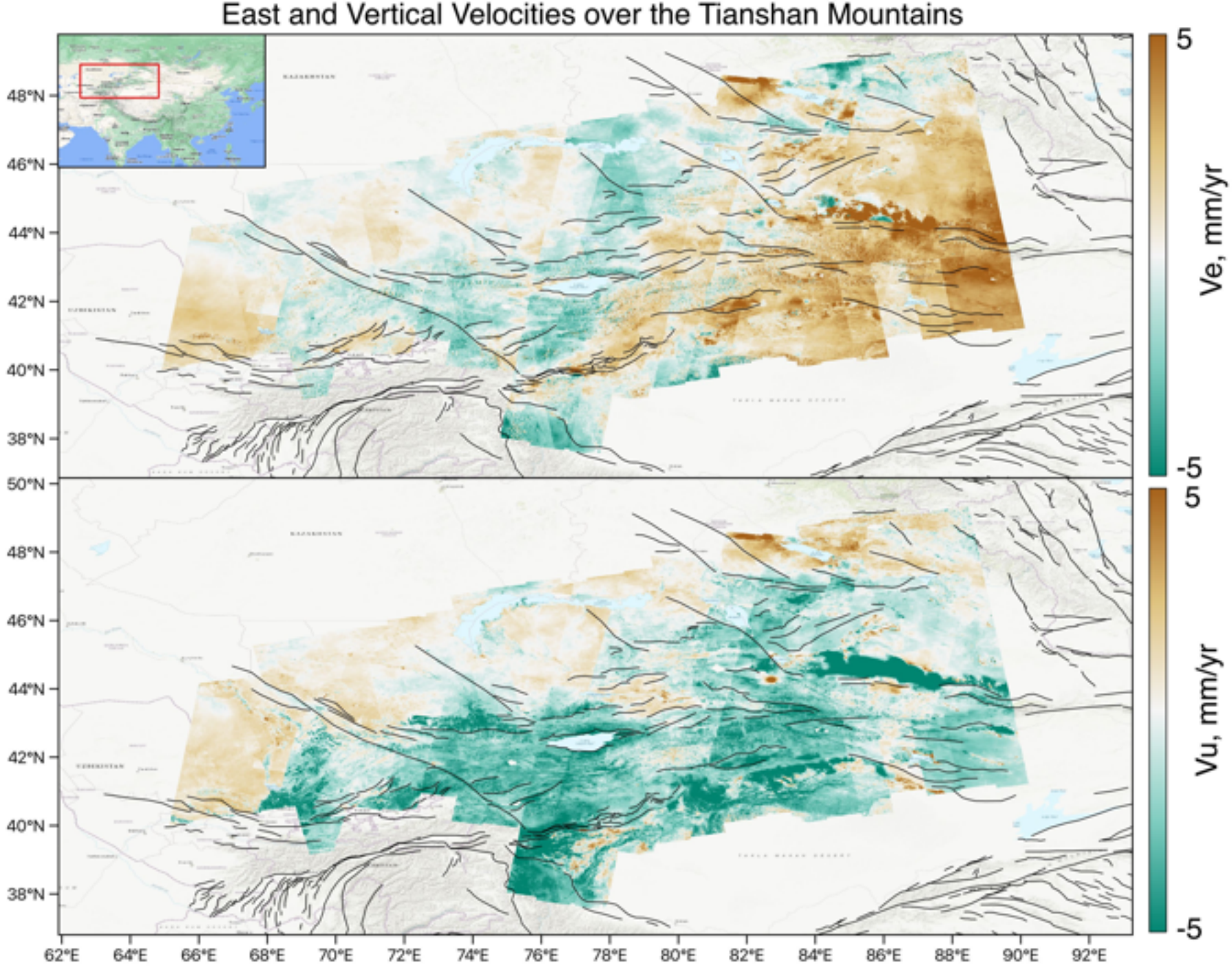


- Shrubland
- Herbaceous vegetation
- Herbaceous Wetland
- Moss & lichen
- Bare / sparse vegetation
- Cropland
- Built-up
- Snow & ice
- Permanent Water Bodies
- Ocean
- No input data available
- Mixed closed forest type

1

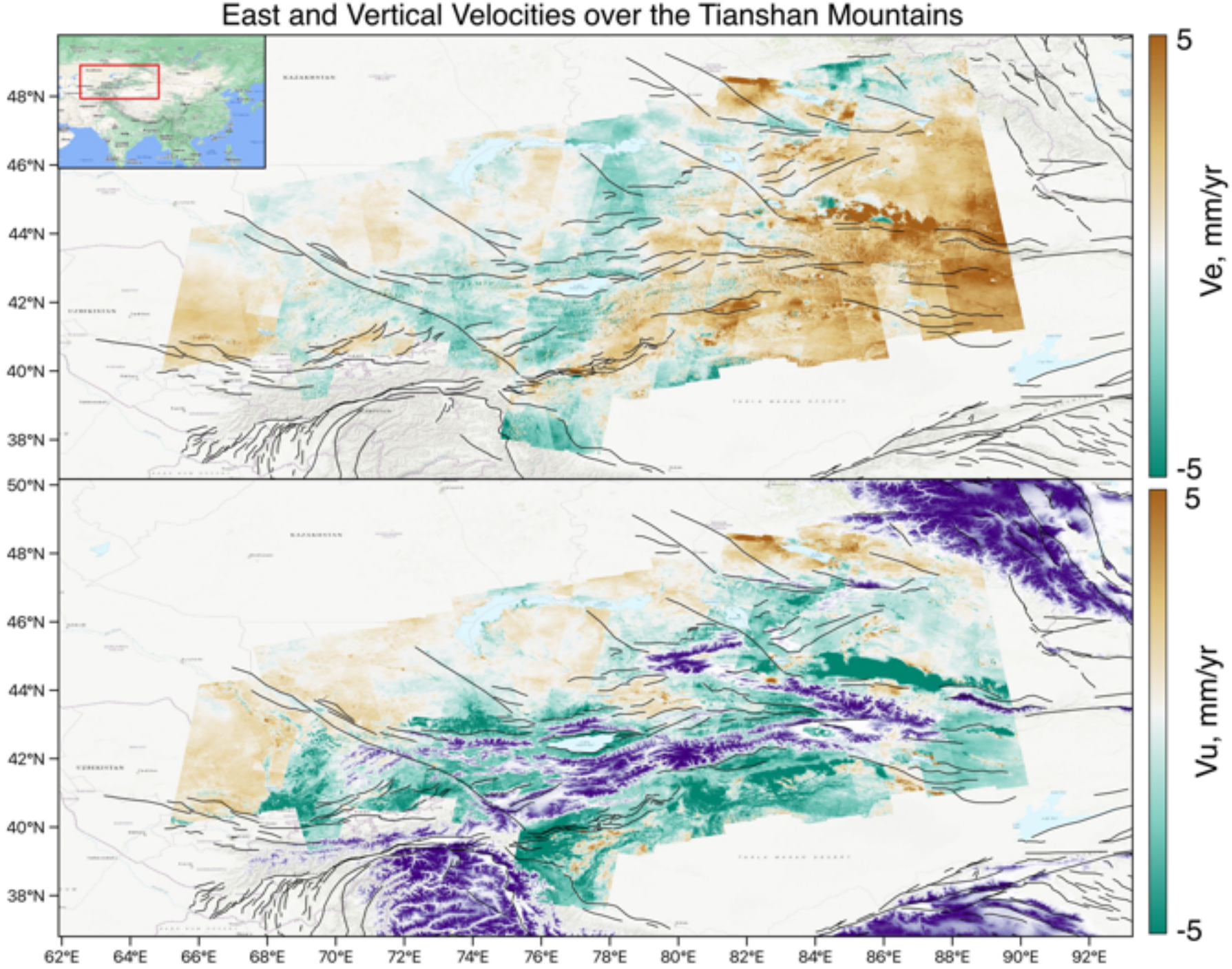
Permafrost Zonation Index

0

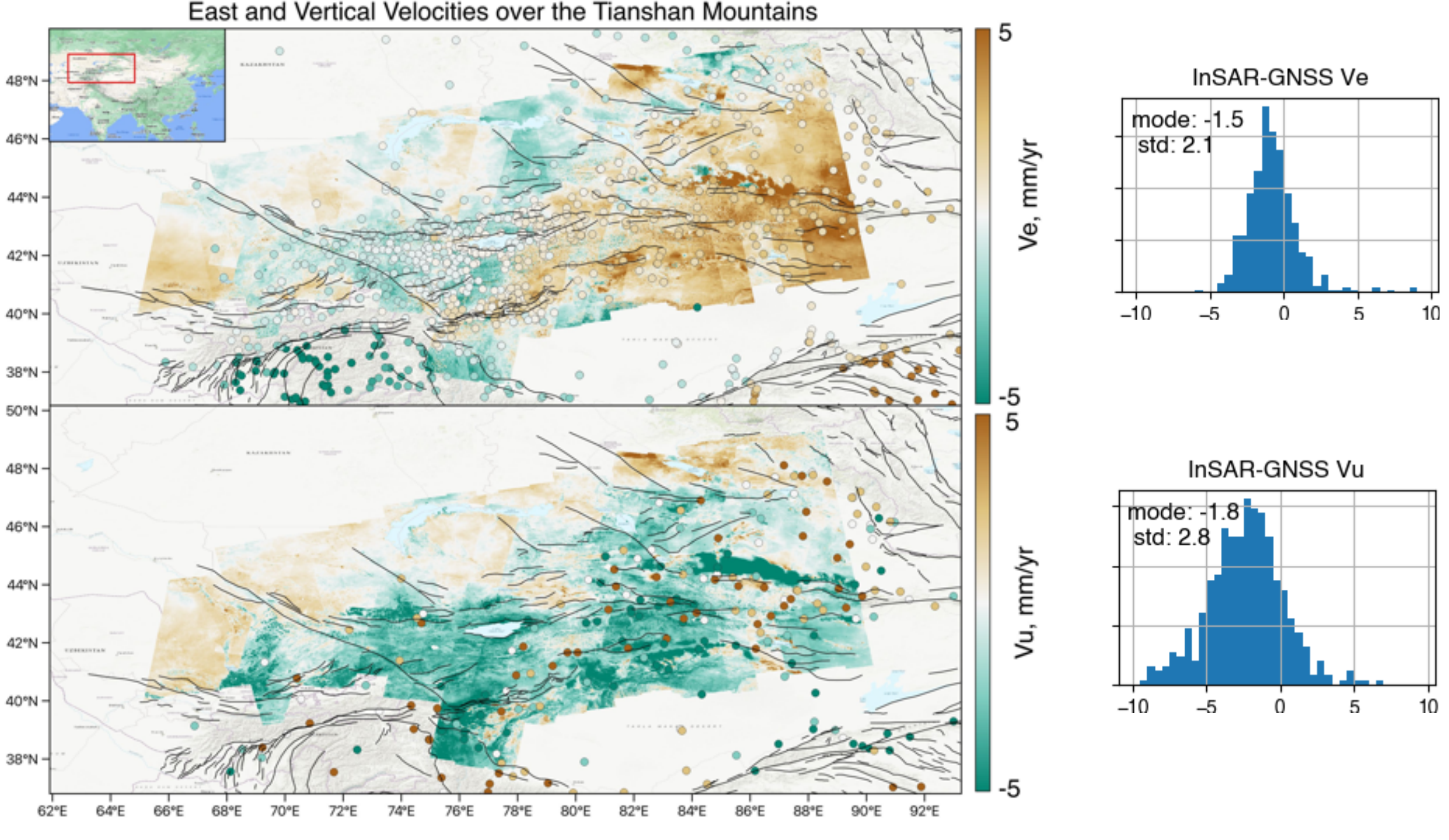


Decompose to Ve and Vu

Large-scale subsidence



Large-scale subsidence cannot be explained by permafrost


East and Vertical Velocities over the Tianshan Mountains
48°N
46°N
44°N
42°N
40°N
38°N
50°N
62°E
64°E
66°E
68°E
70°E
72°E
74°E
76°E
78°E
80°E
82°E
84°E
86°E
88°E
90°E
92°E
5
-5
Ve, mm/yr
Vu, mm/yr
InSAR-GNSS Ve
mode: -1.5
std: 2.1
InSAR-GNSS Vu
mode: -1.8
std: 2.8
−10
−5
0
5
10

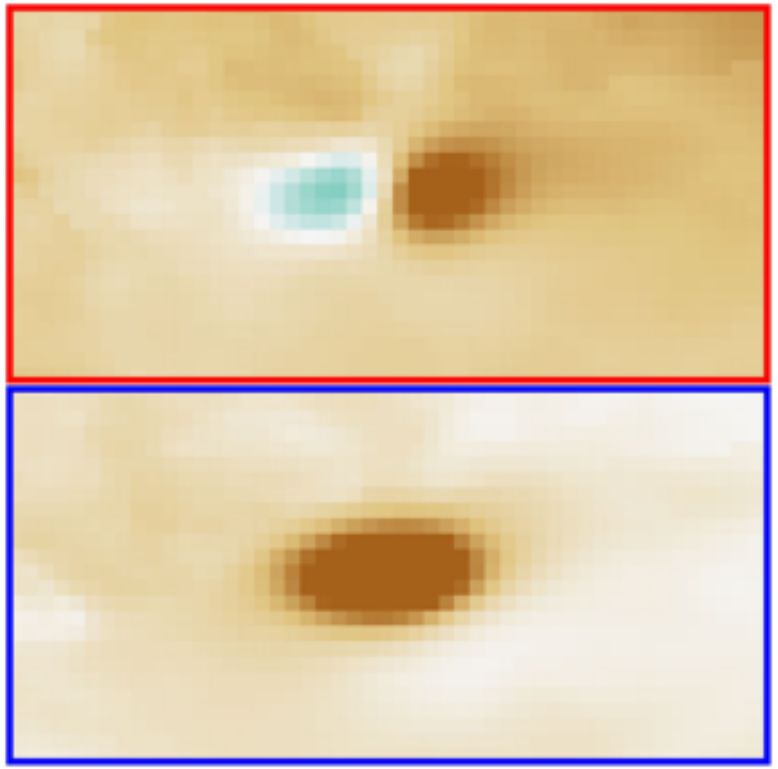
East and Vertical Velocities over the Tianshan Mountains

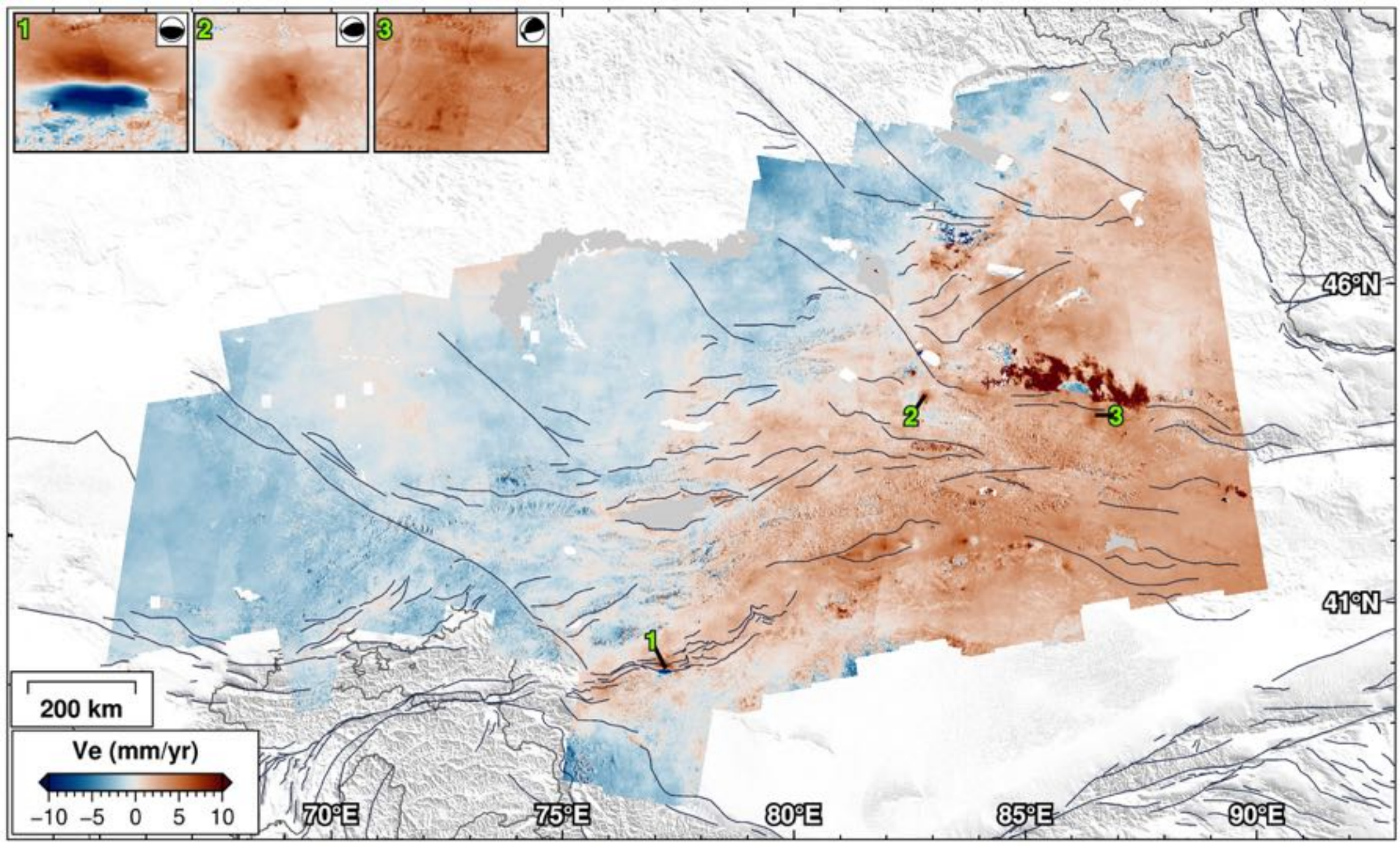
Ve, mm/yr
-5
5

Vu, mm/yr
-5
5

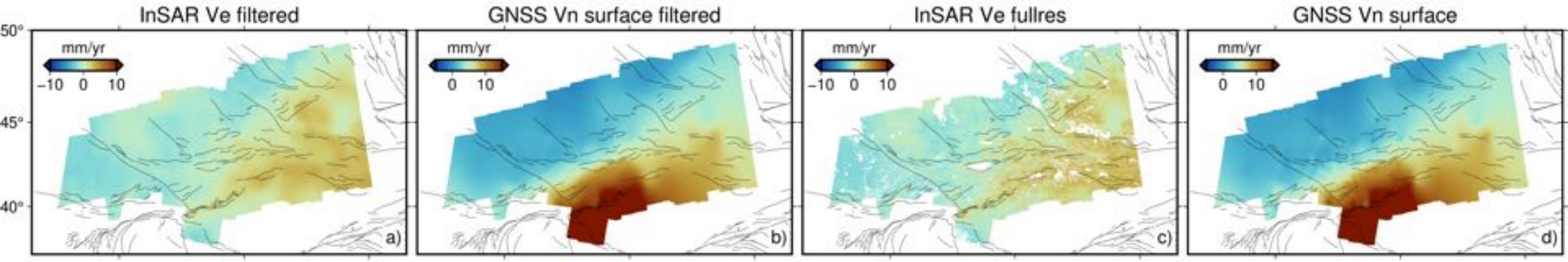
48°N
46°N
44°N
42°N
40°N
38°N
50°N
48°N
46°N
44°N
42°N
40°N
38°N
62°E
64°E
66°E
68°E
70°E
72°E
74°E
76°E
78°E
80°E
82°E
84°E
86°E
88°E
90°E
92°E

Eqk / salt?

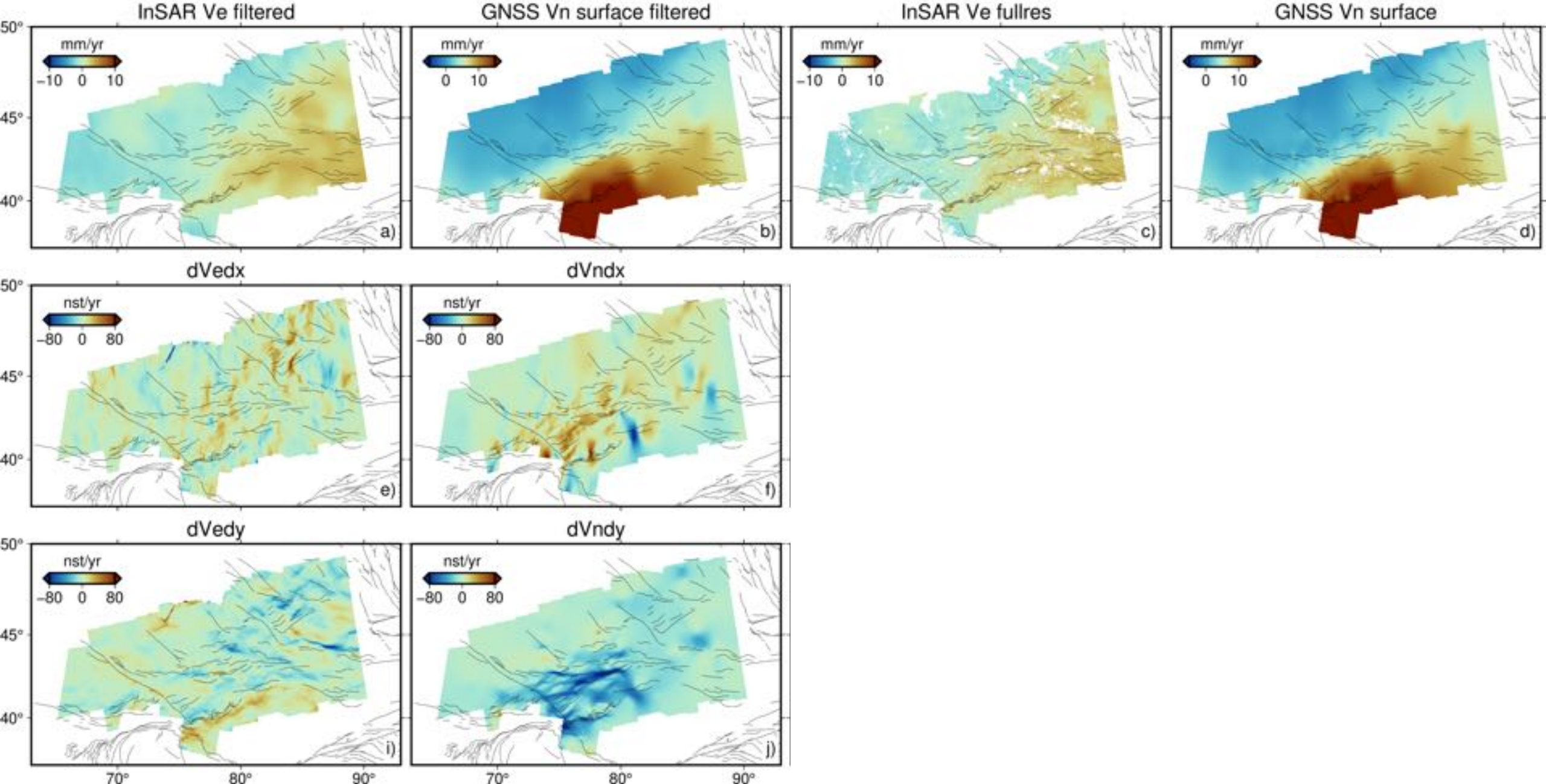



1
2
3
46°N
41°N
70°E
75°E
80°E
85°E
90°E
200 km
Ve (mm/yr)
−10 −5 0 5 10

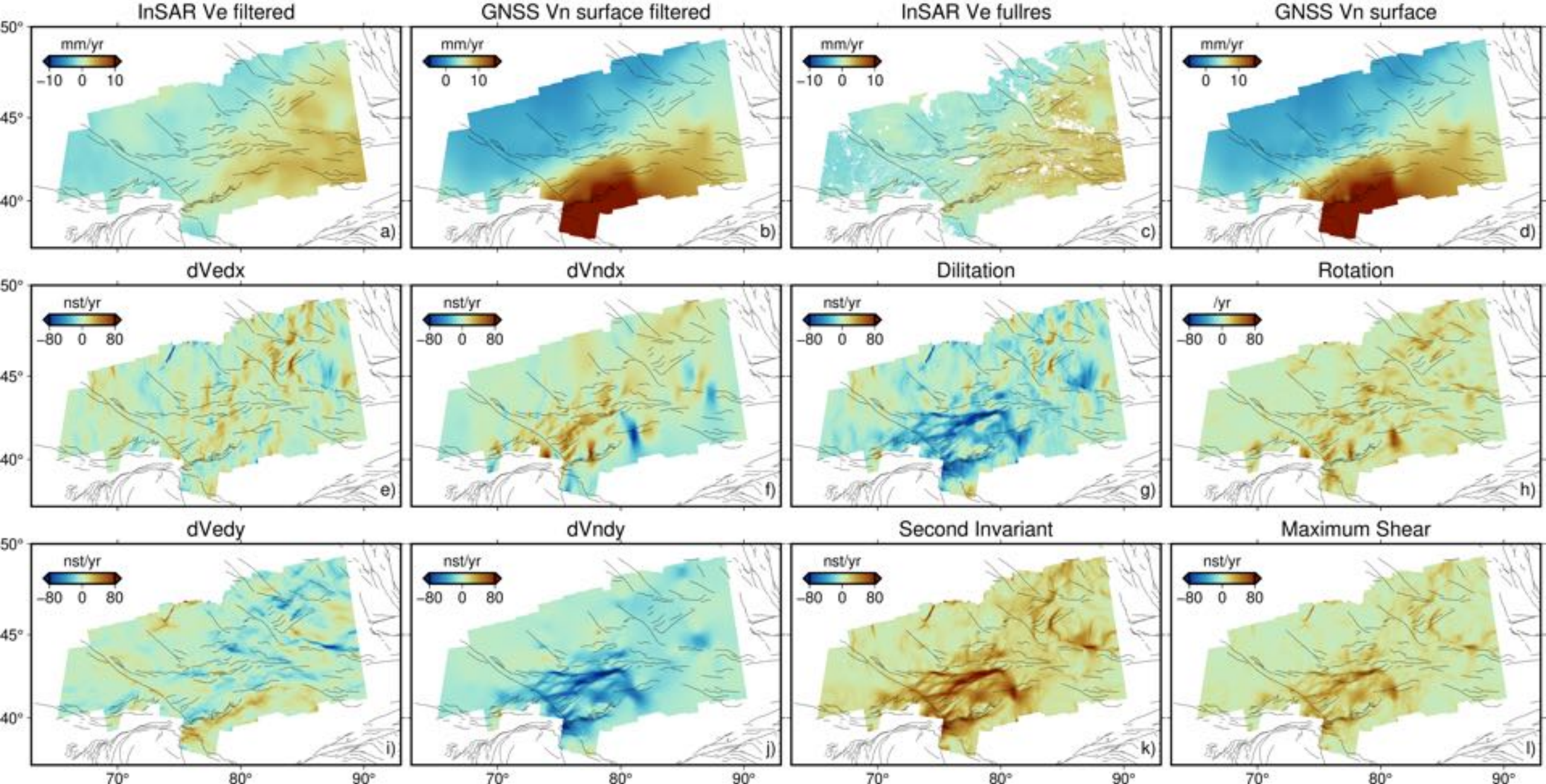
Median filtered with 100 km window



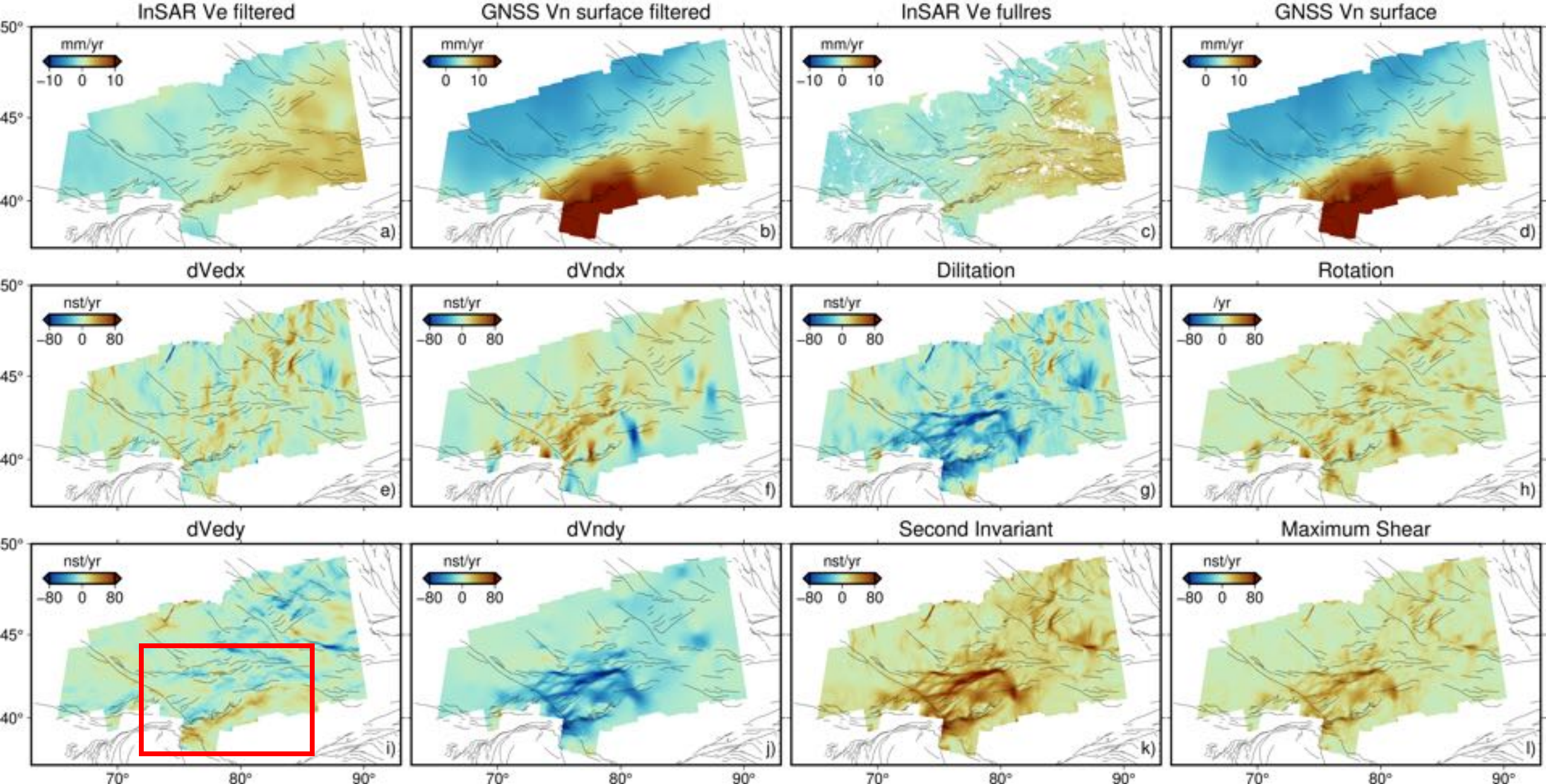
Horizontal velocity gradients



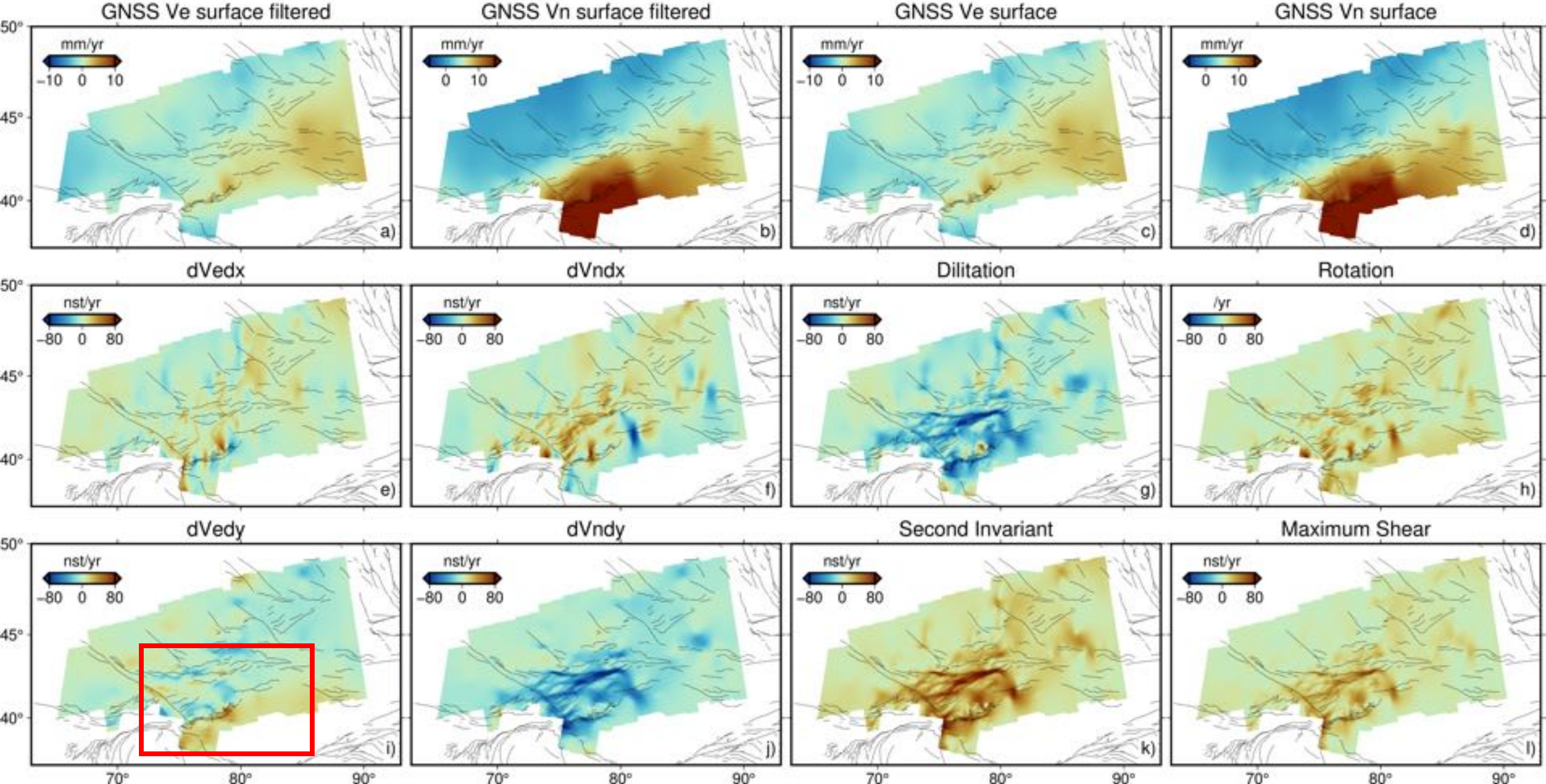
Strain rates (100 km)



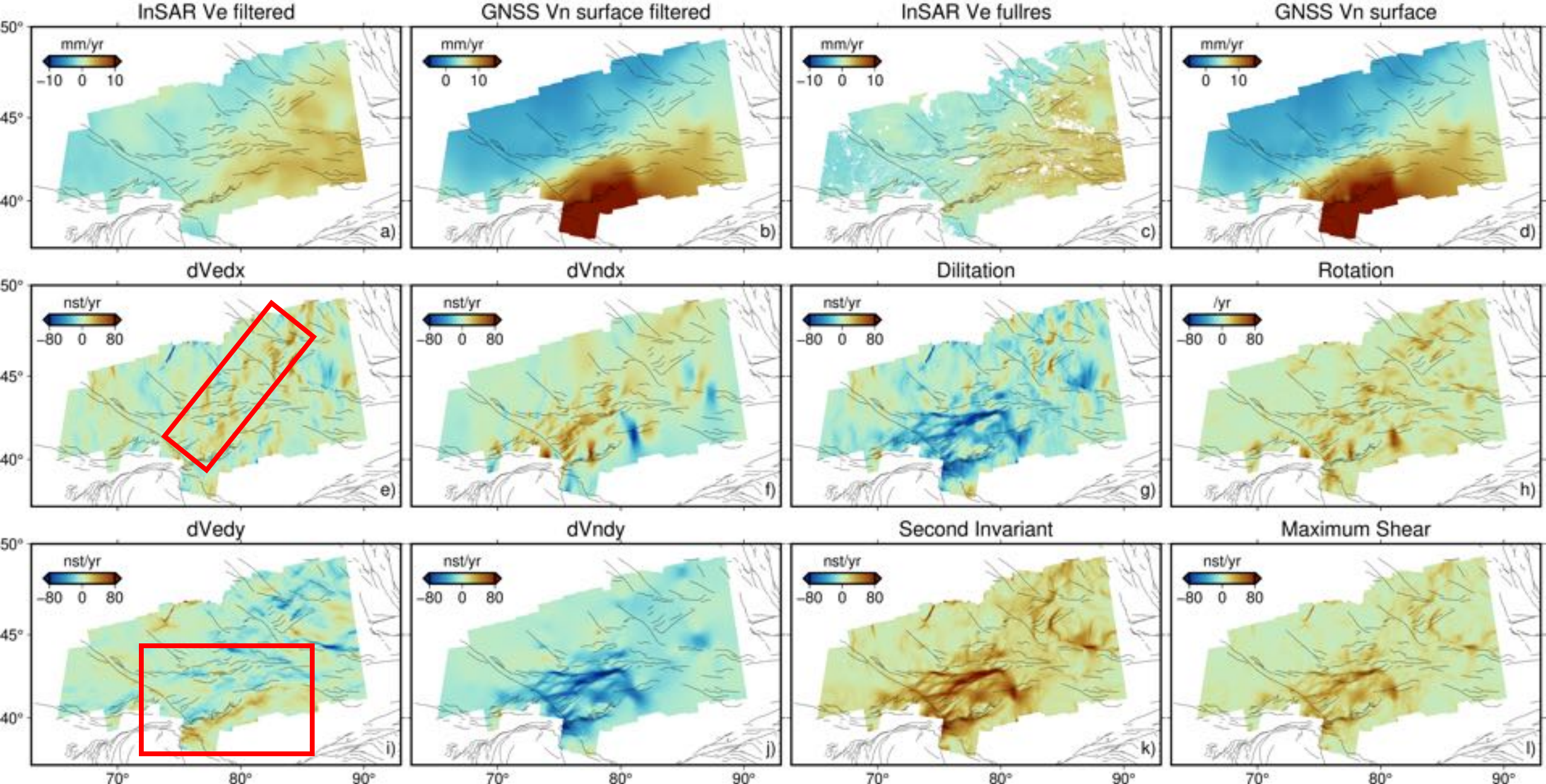
Strain rates (100 km)



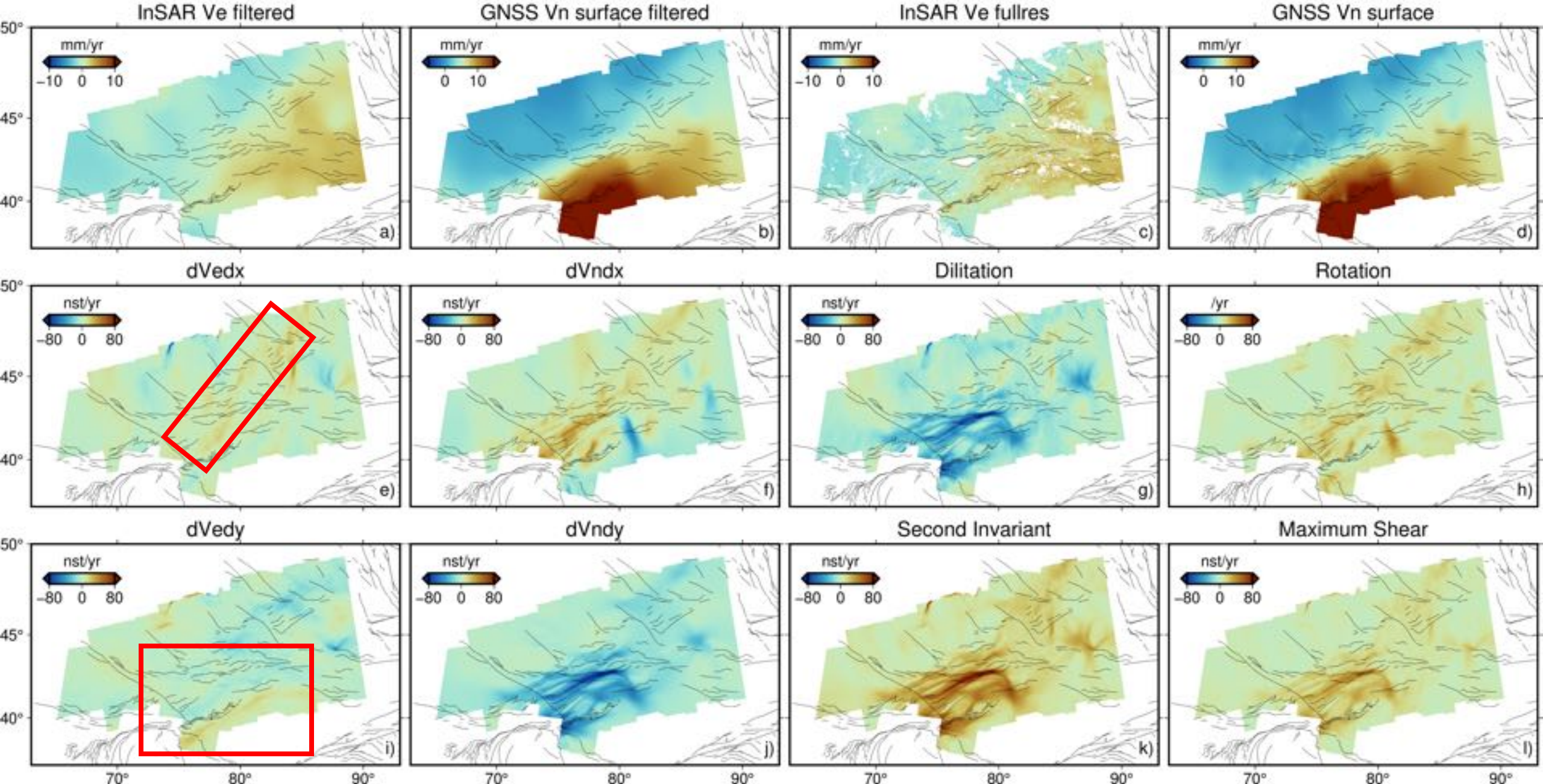
Strain rates from GNSS



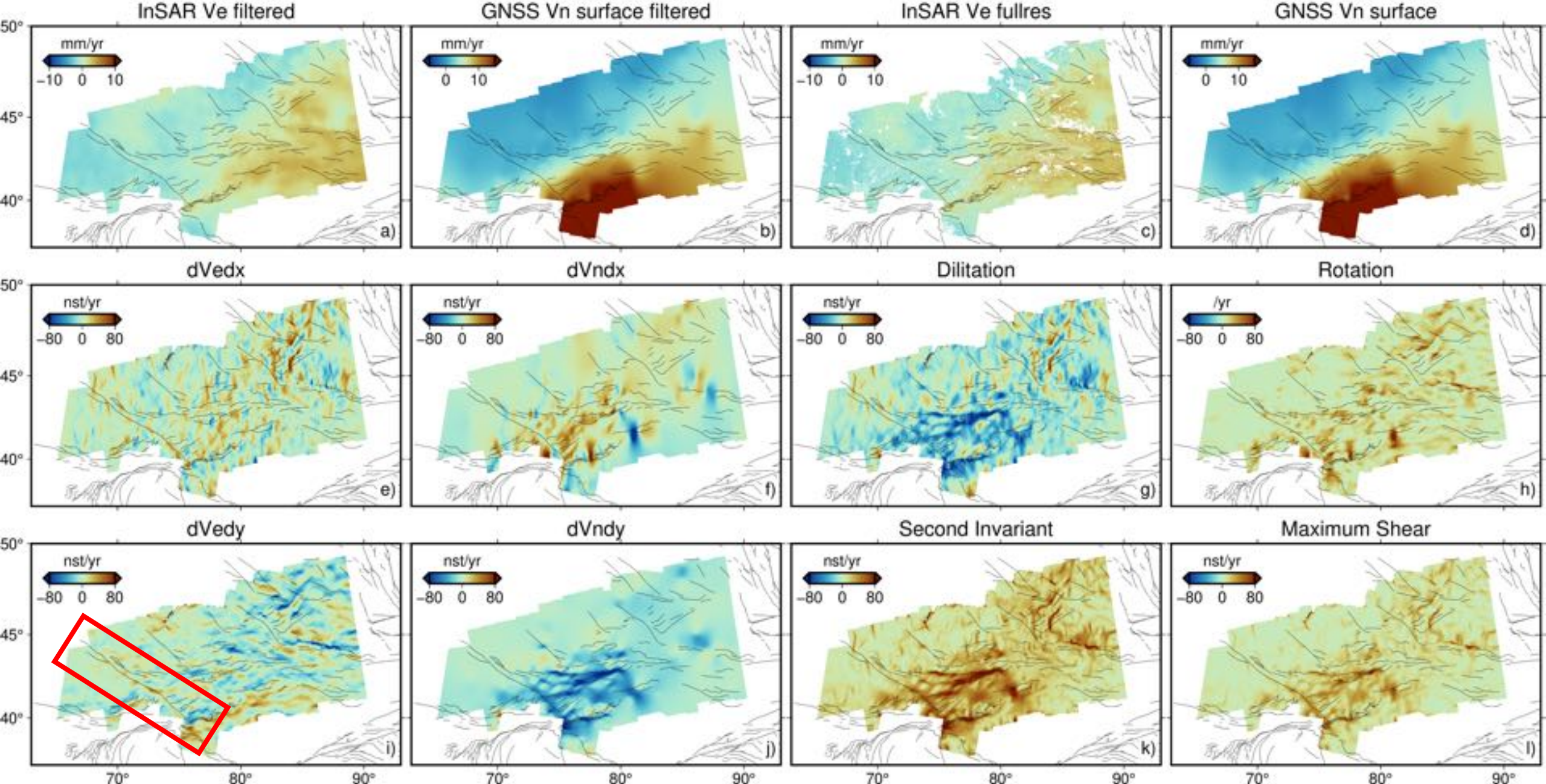
Strain rates (100 km)



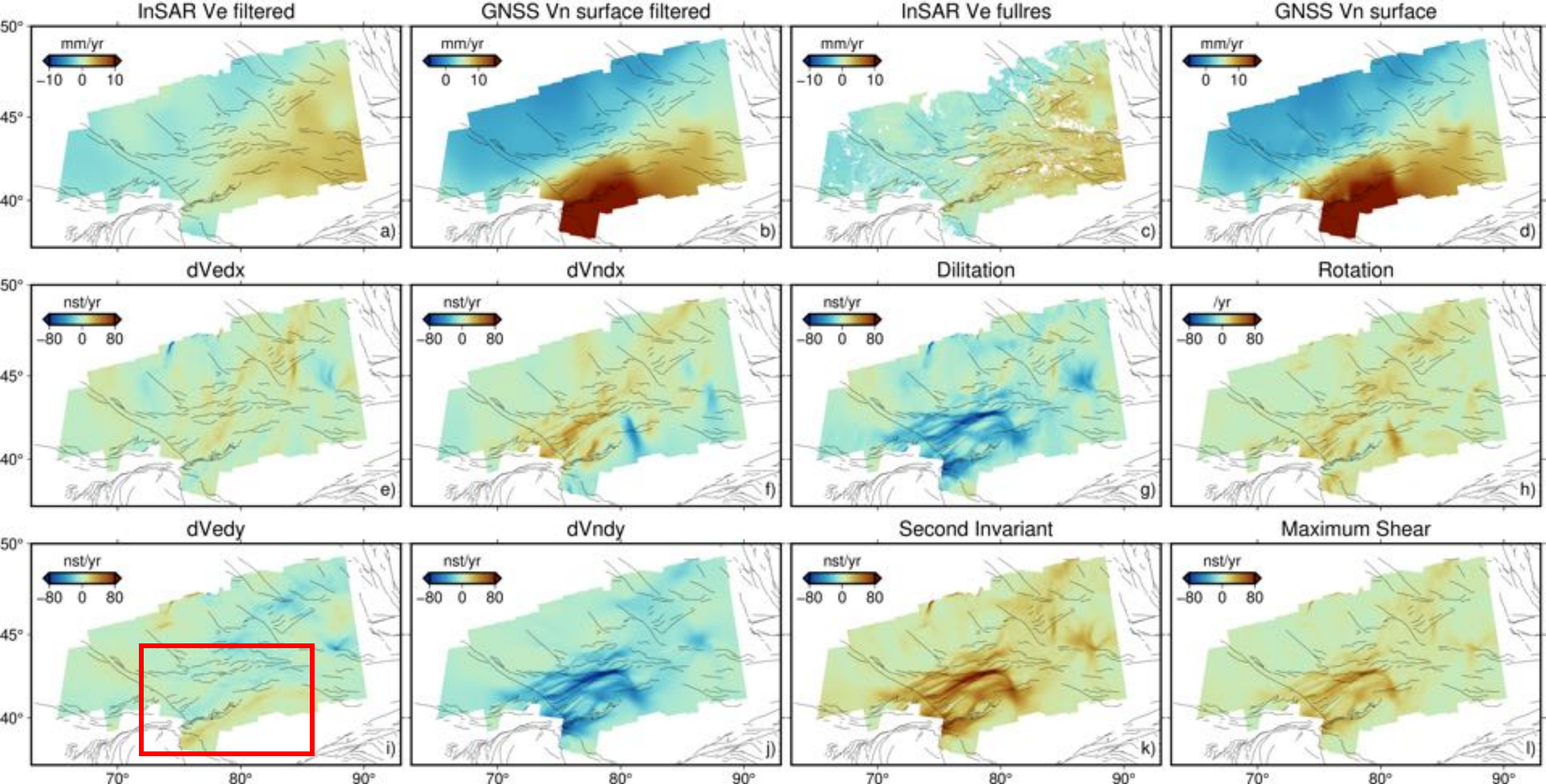
Strain rates (200 km)



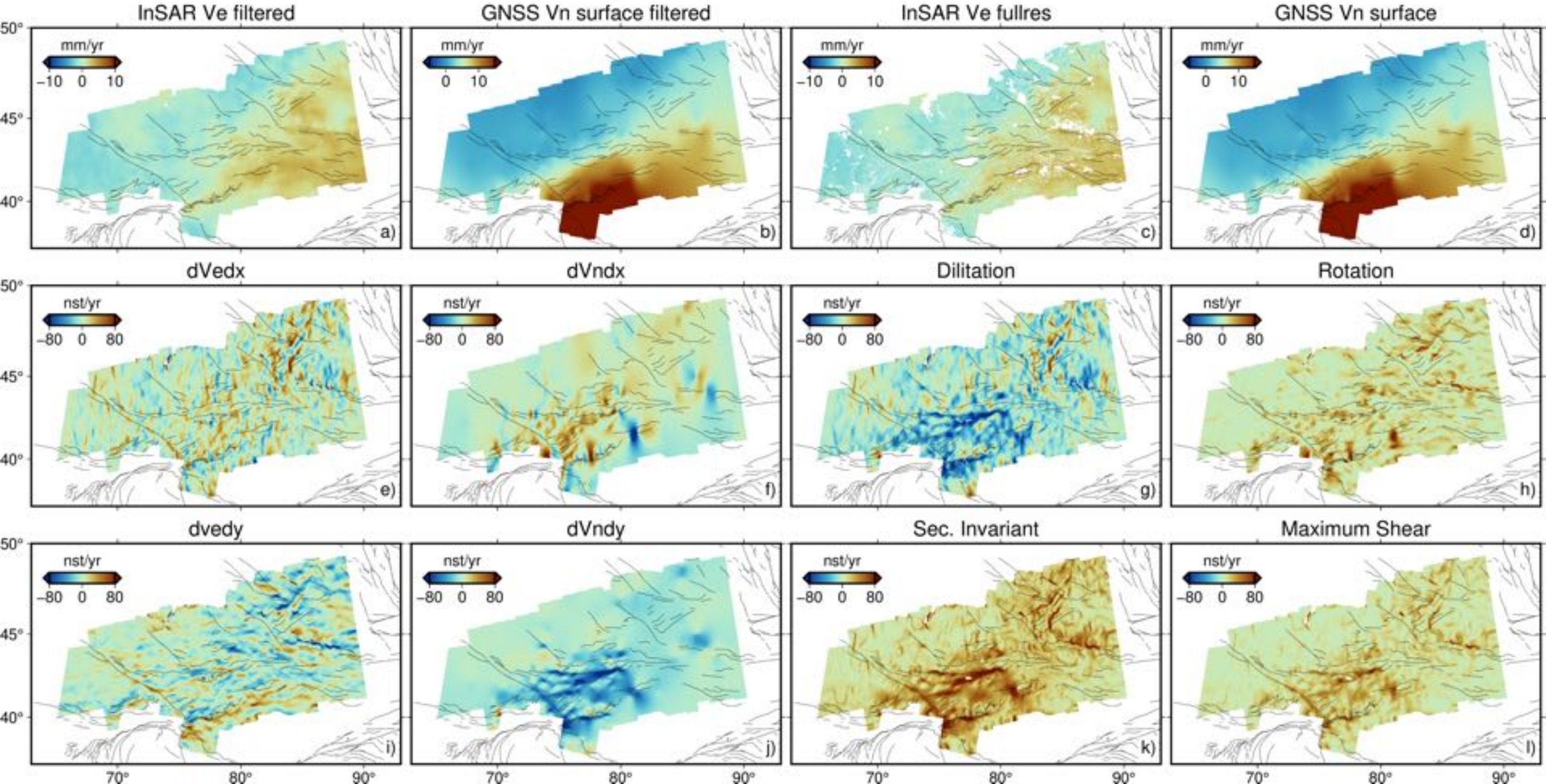
Strain rates (60 km)



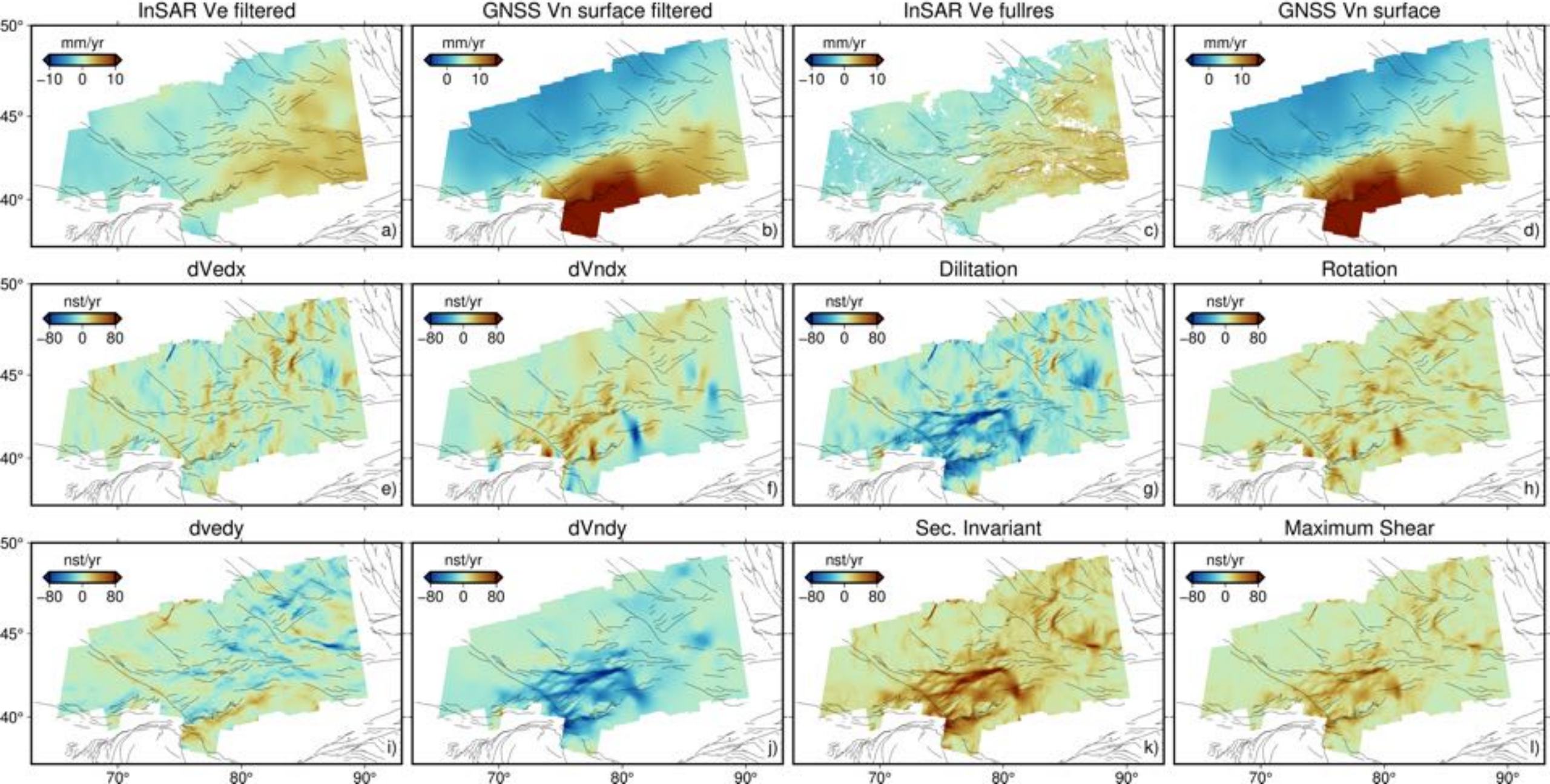
Strain rates (200 km)



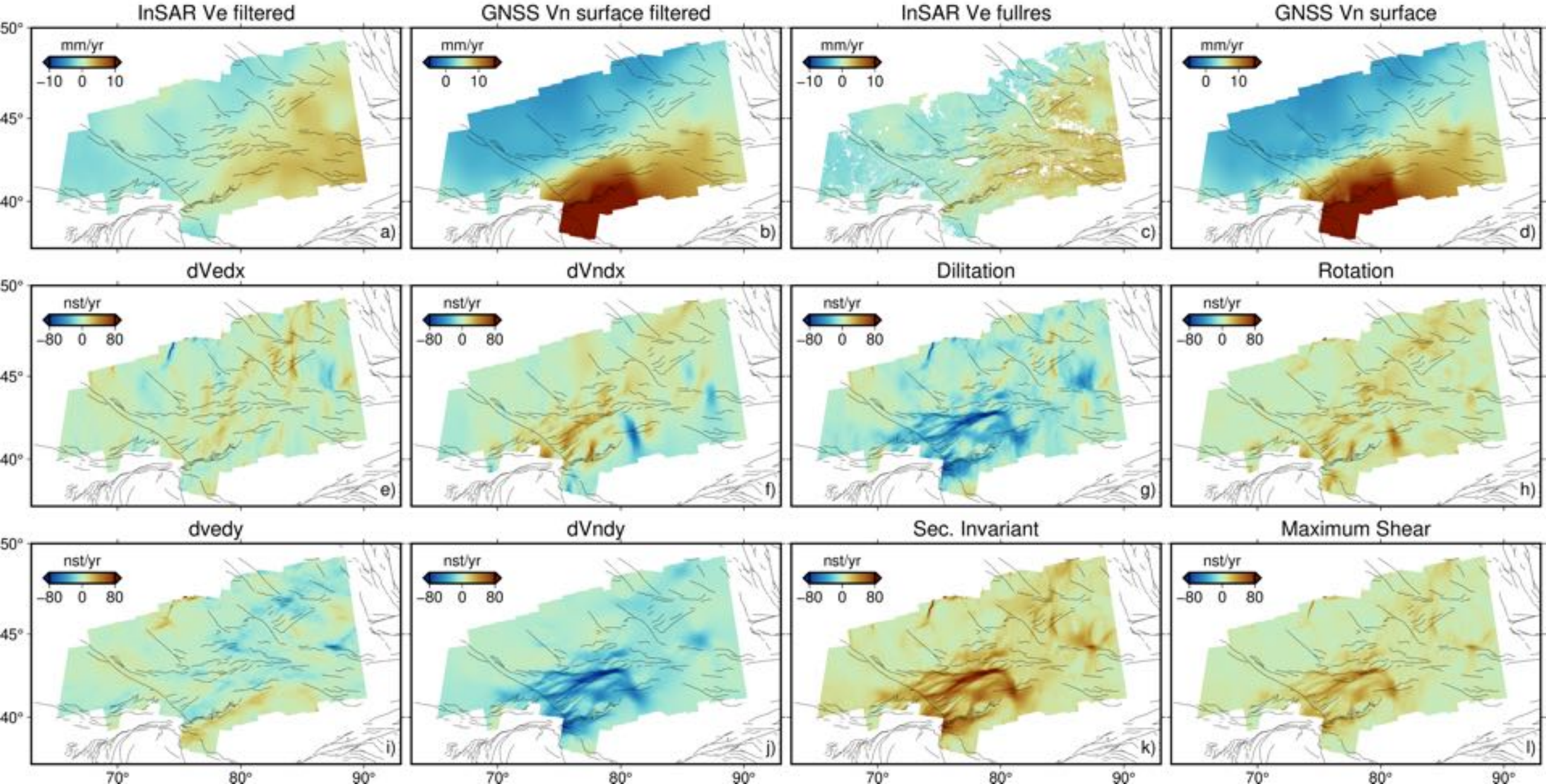
unmasked_clipped_filter_50km



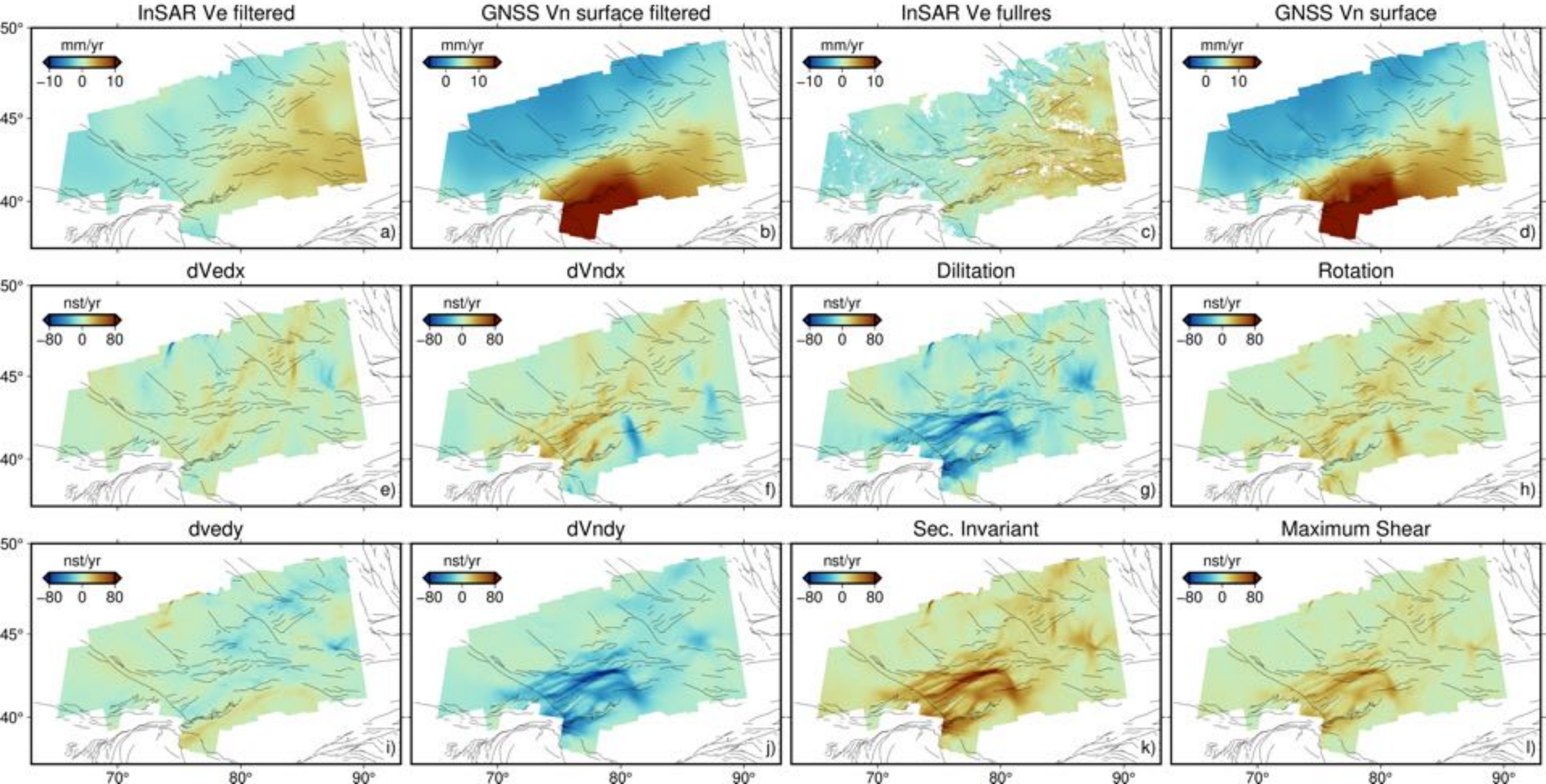
unmasked_clipped_filter_100km



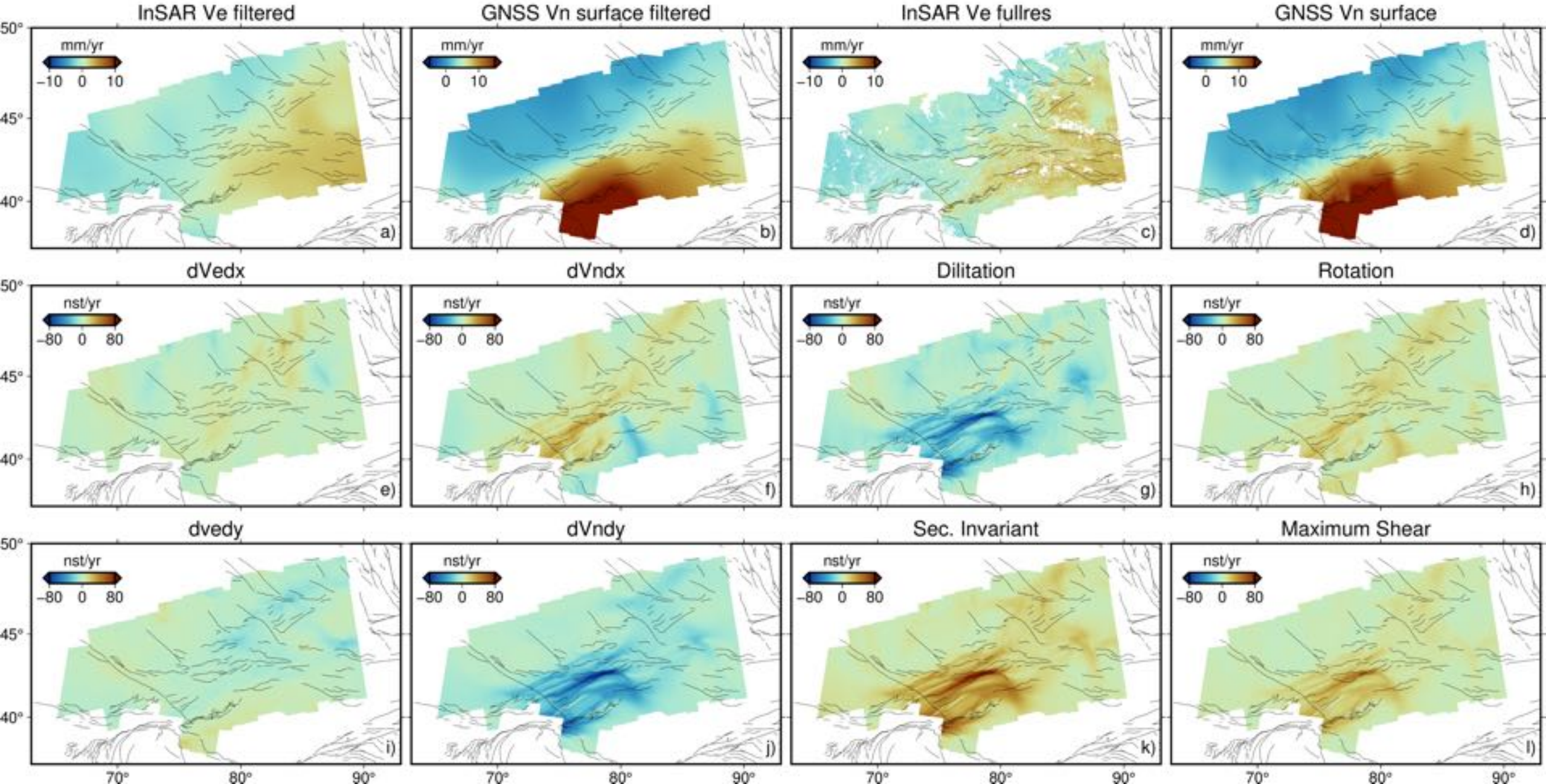
unmasked_clipped_filter_150km

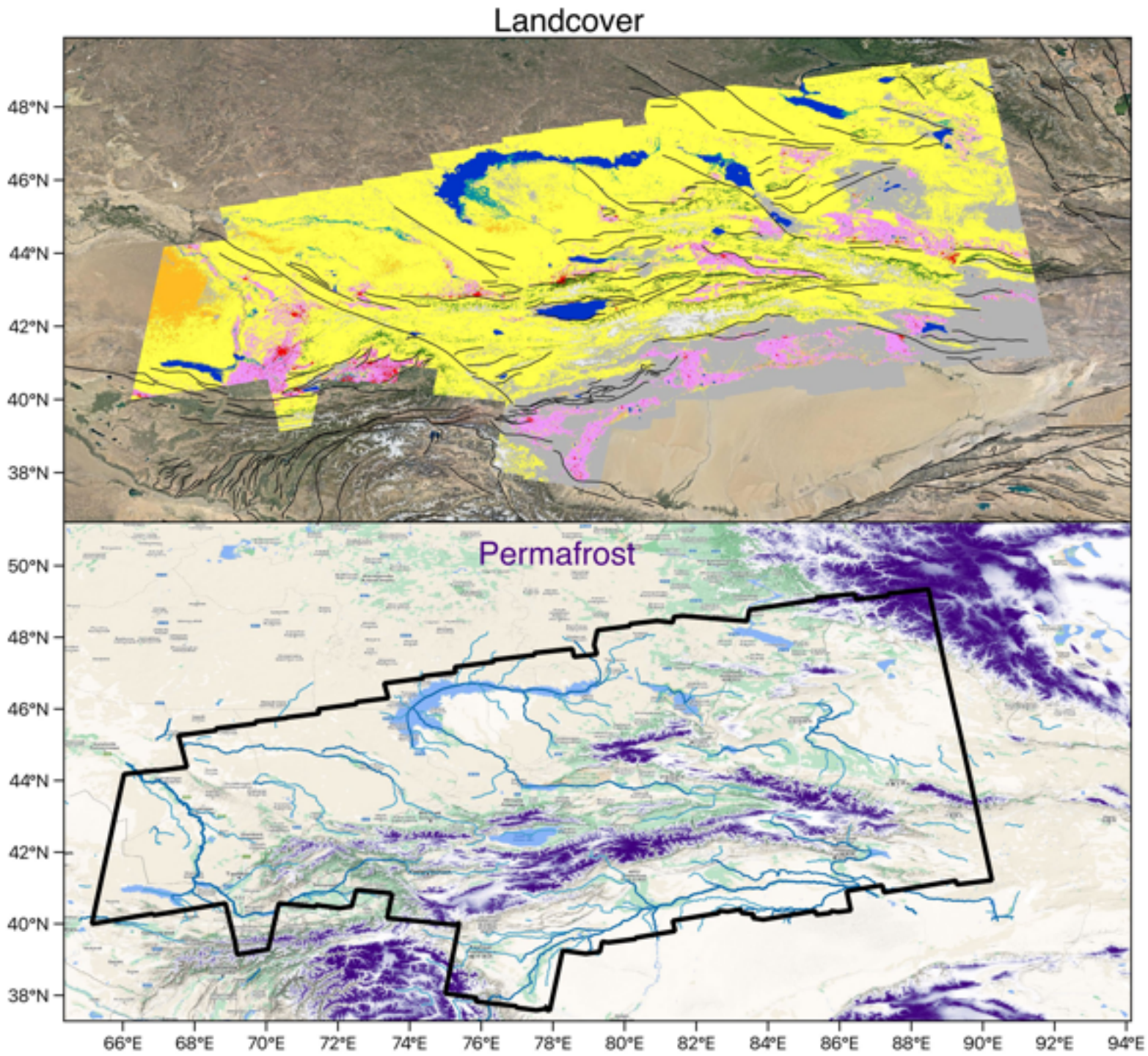


unmasked_clipped_filter_200km



unmasked_clipped_filter_300km





Shrubland

Herbaceous vegetation

Herbaceous Wetland

Moss & lichen

Bare / sparse vegetation

Cropland

Built-up

Snow & ice

Permanent Water Bodies

Mixed closed forest type

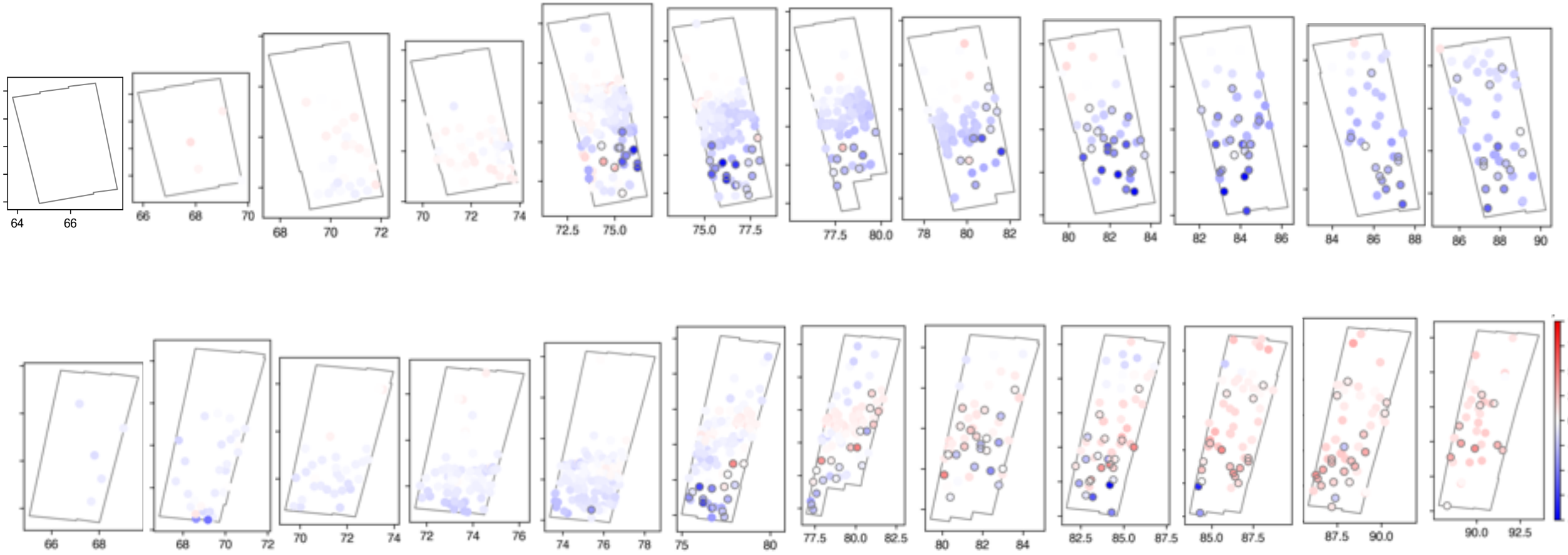
1

Permafrost Zonation Index

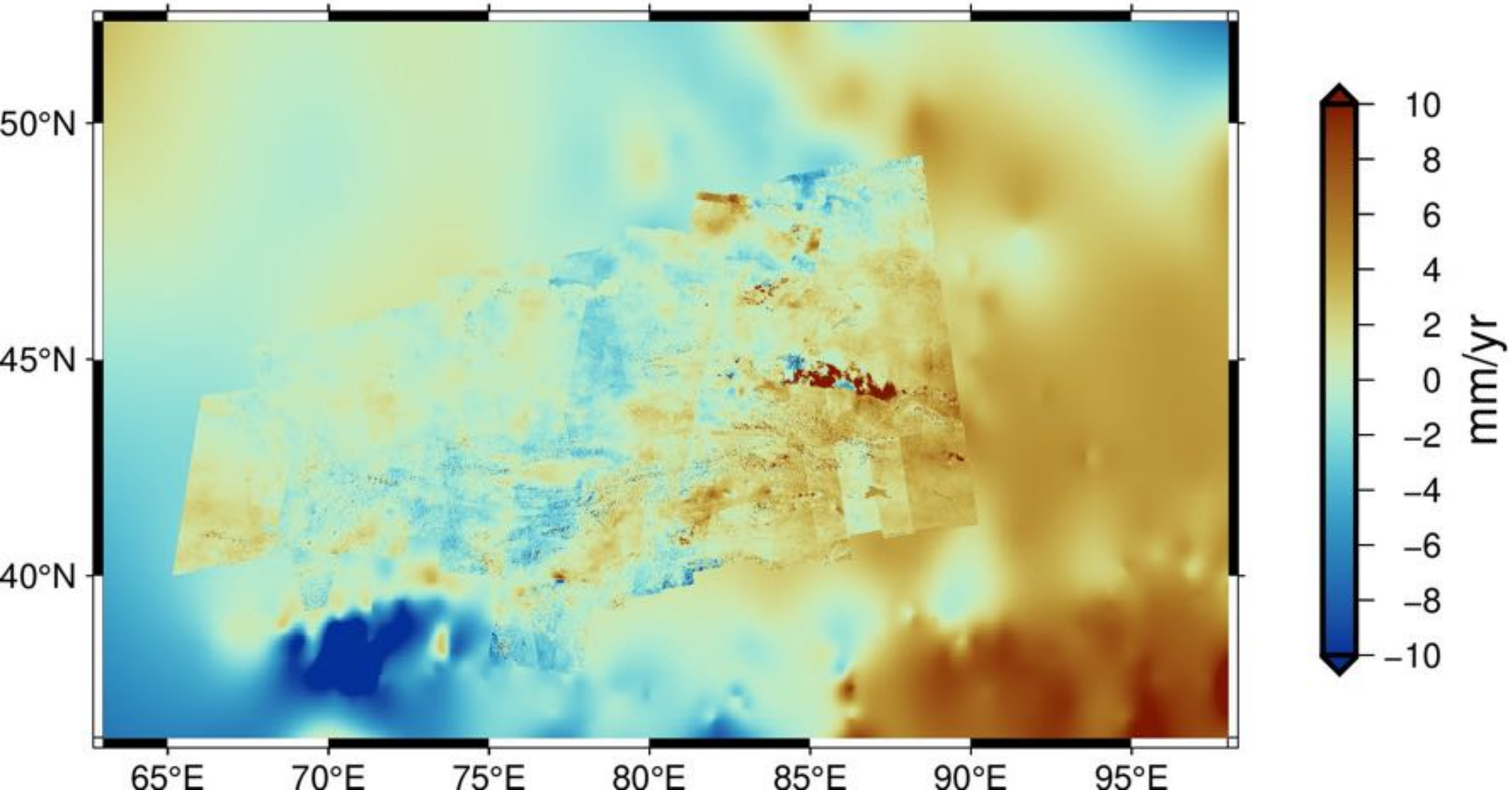
0


Evergreen needleleaf closed forest
Deciduous needleleaf closed forest
Evergreen broadleaf closed forest
Deciduous broadleaf closed forest
Mixed closed forest type
Unknown closed forest type
Evergreen needleleaf open forest
Deciduous needleleaf open forest
Evergreen broadleaf open forest
Deciduous broadleaf open forest
Mixed open forest type
Unknown open forest type
Shrubland
Herbaceous vegetation
Herbaceous Wetland
Moss & lichen
Bare / sparse vegetation
Cropland
Built-up
Snow & ice
Permanent Water Bodies
Ocean
No input data available

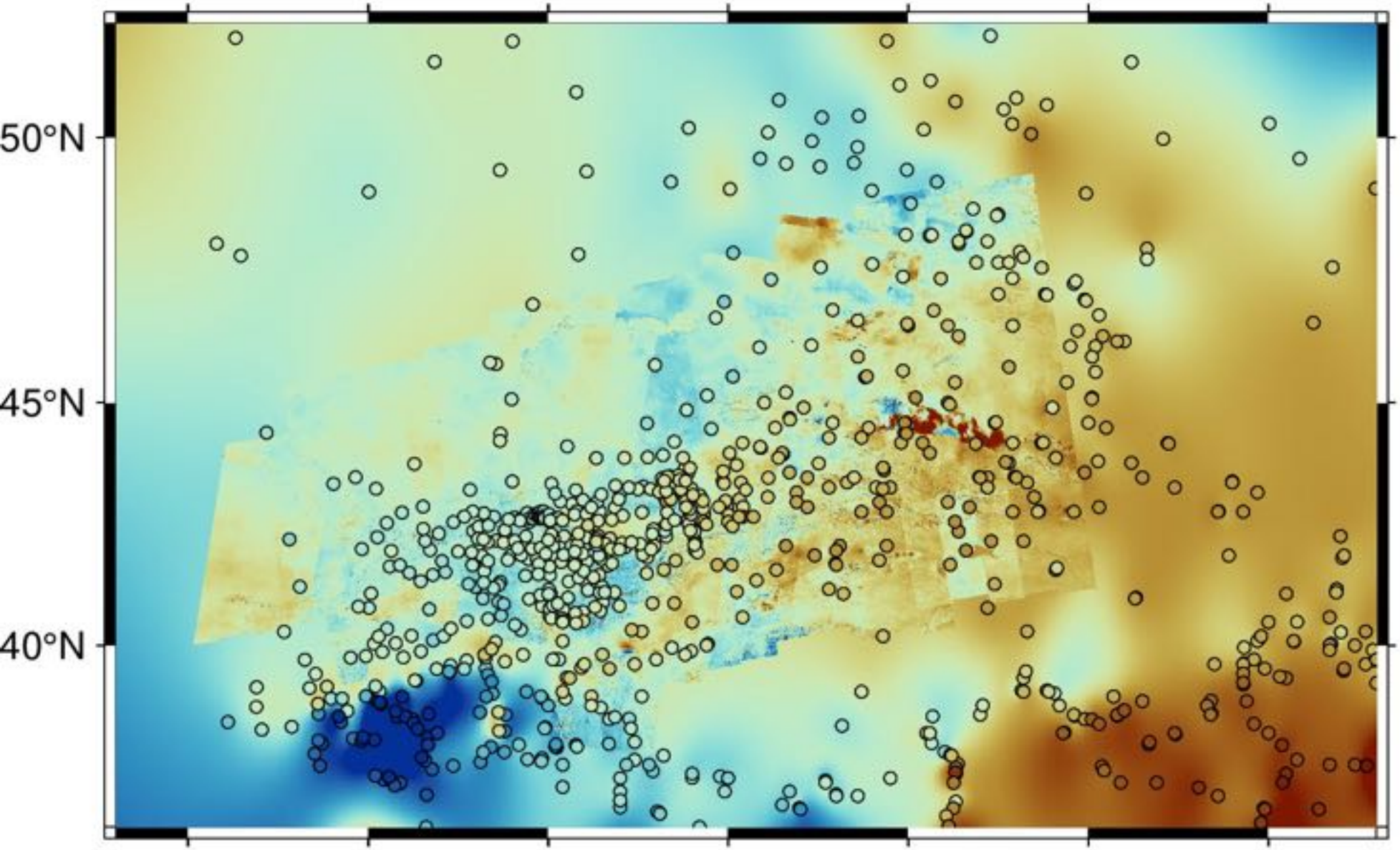
Fit InSAR LOS to GNSS LOS by a constant per track, assuming 2D GNSS has Vu=0, outlined circles are 3D GNSS

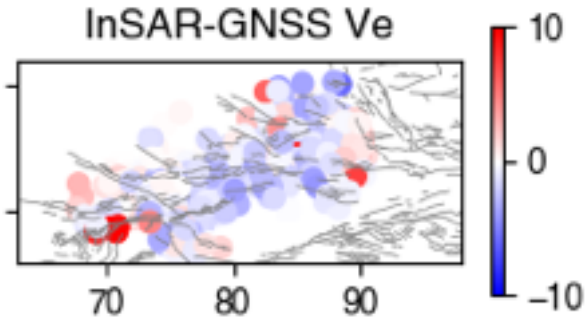


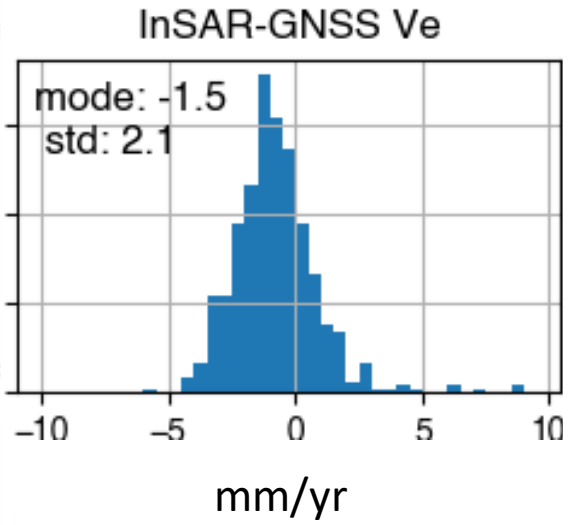
Independent InSAR Ve and interpolated GNSS Ve



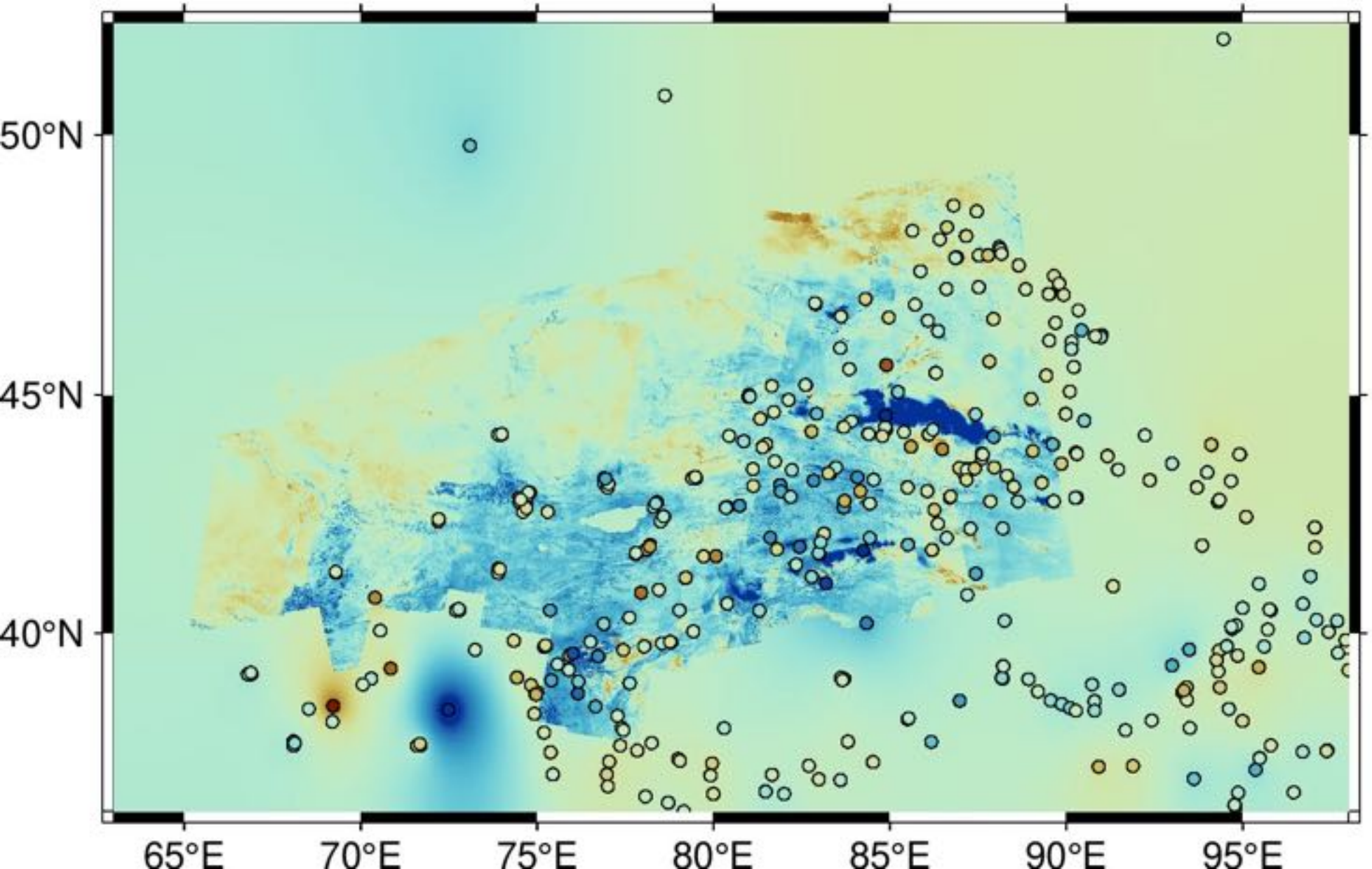
Independent InSAR Ve and GNSS Ve

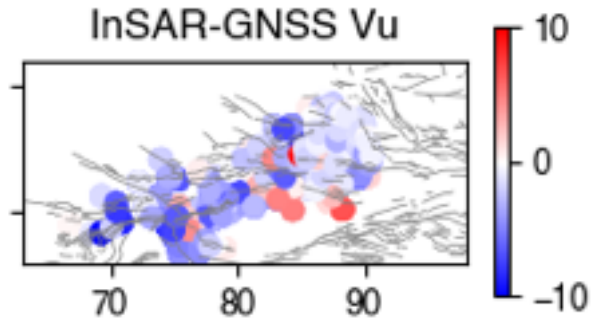


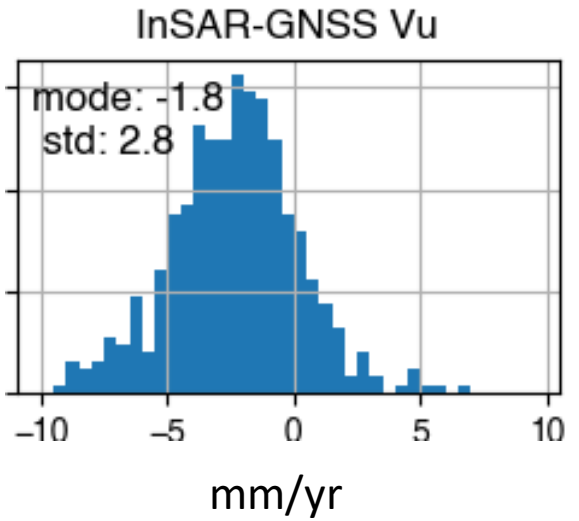




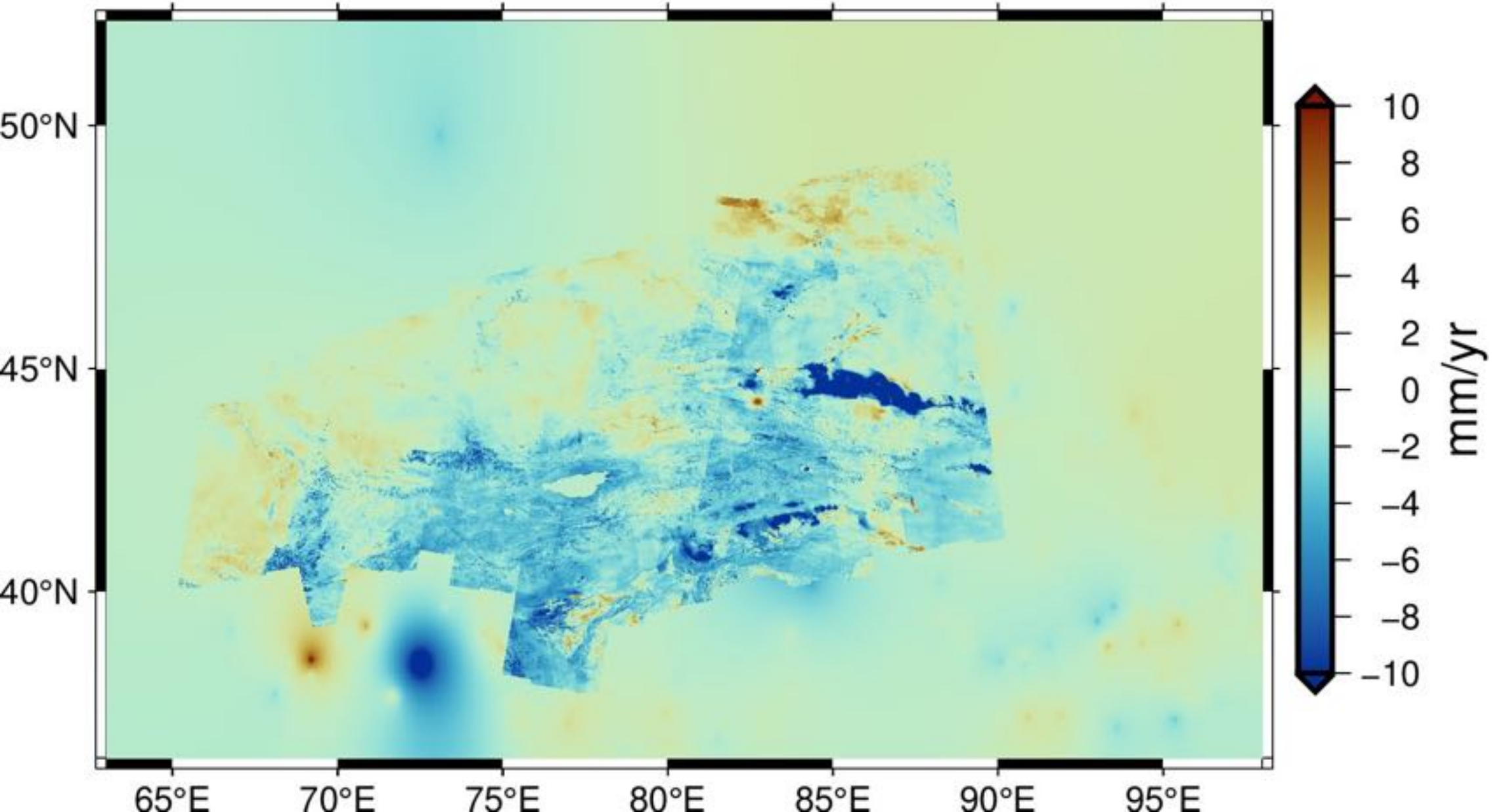
Independent InSAR Vu and GNSS Vu



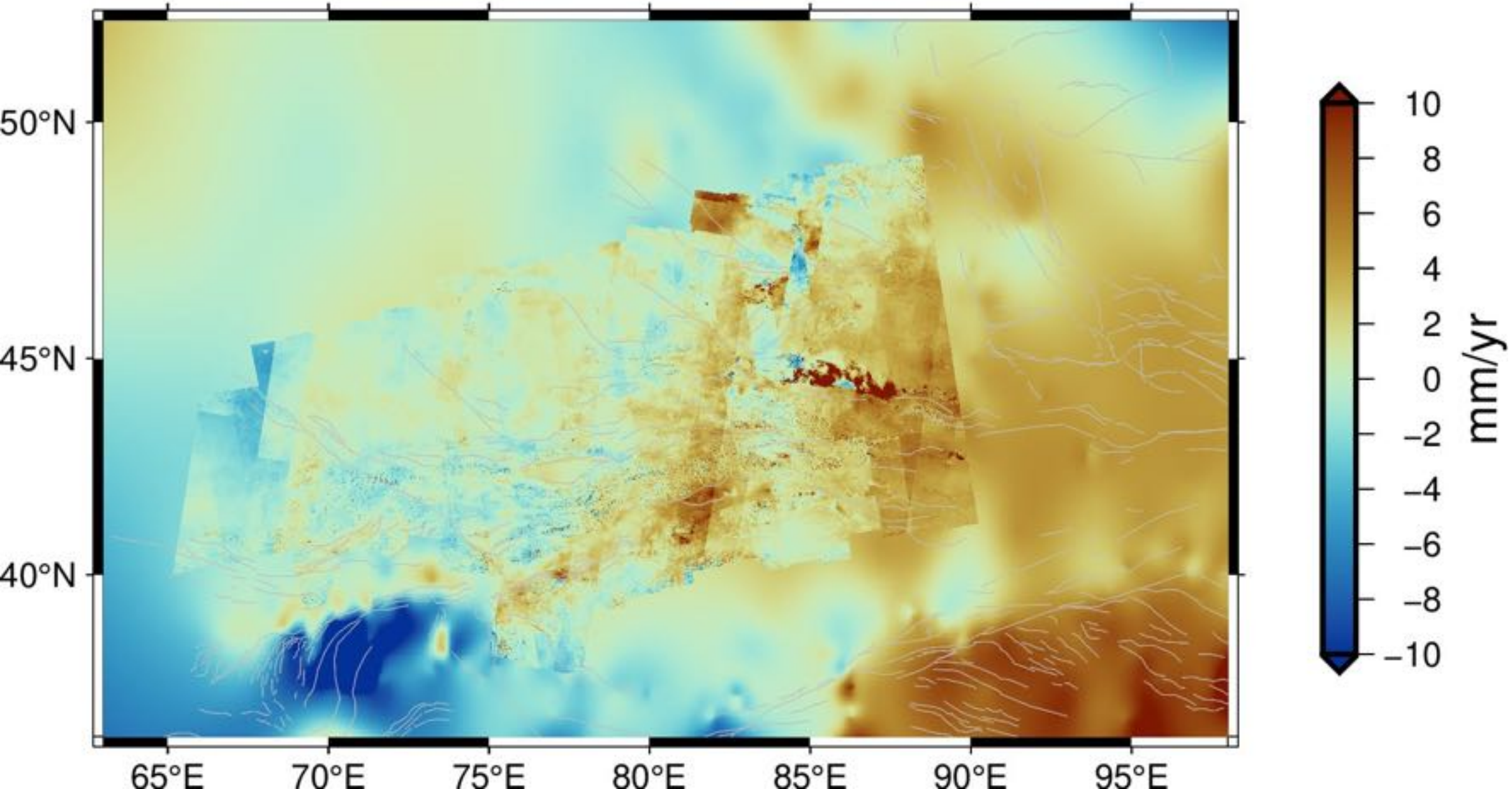




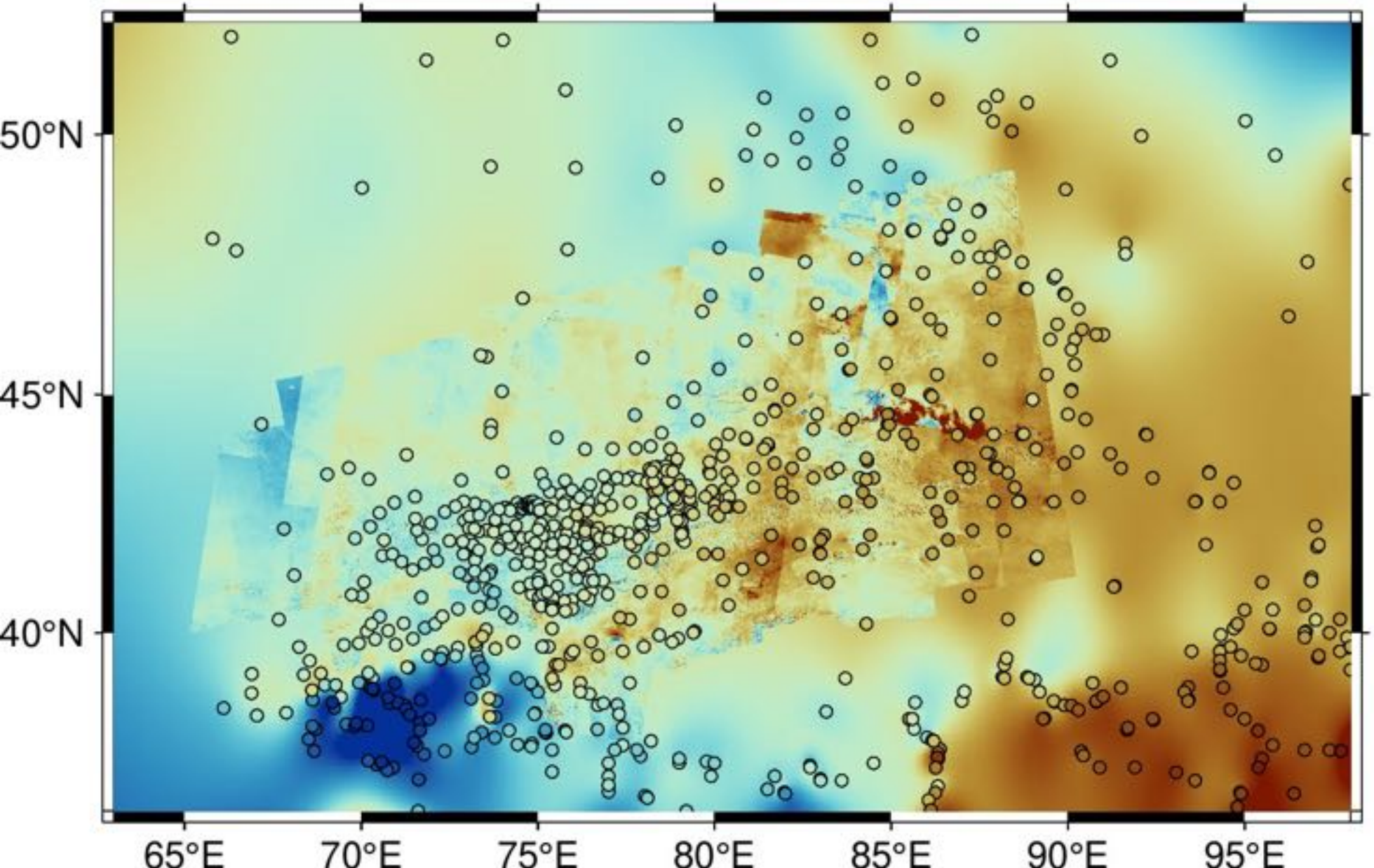
Independent InSAR Vu and interpolated GNSS Vu

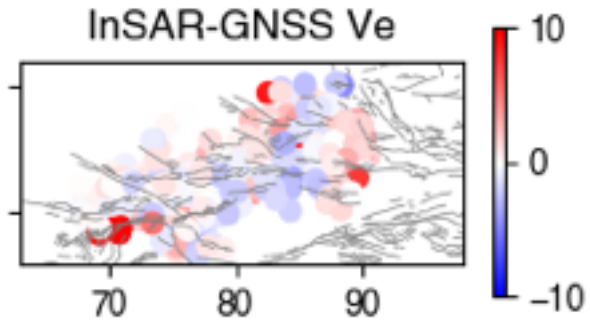


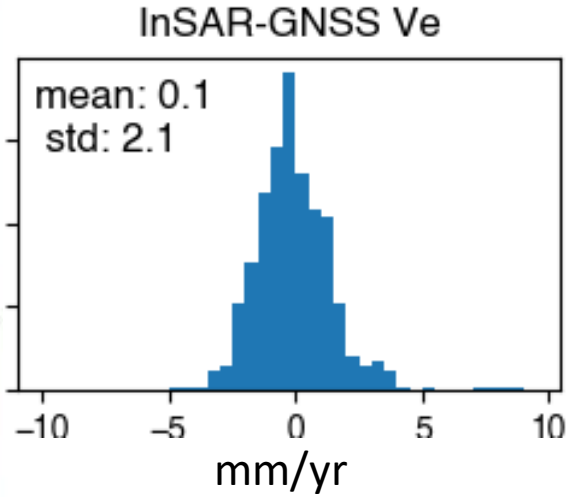
InSAR Ve after referenced to GNSS LOS by constant



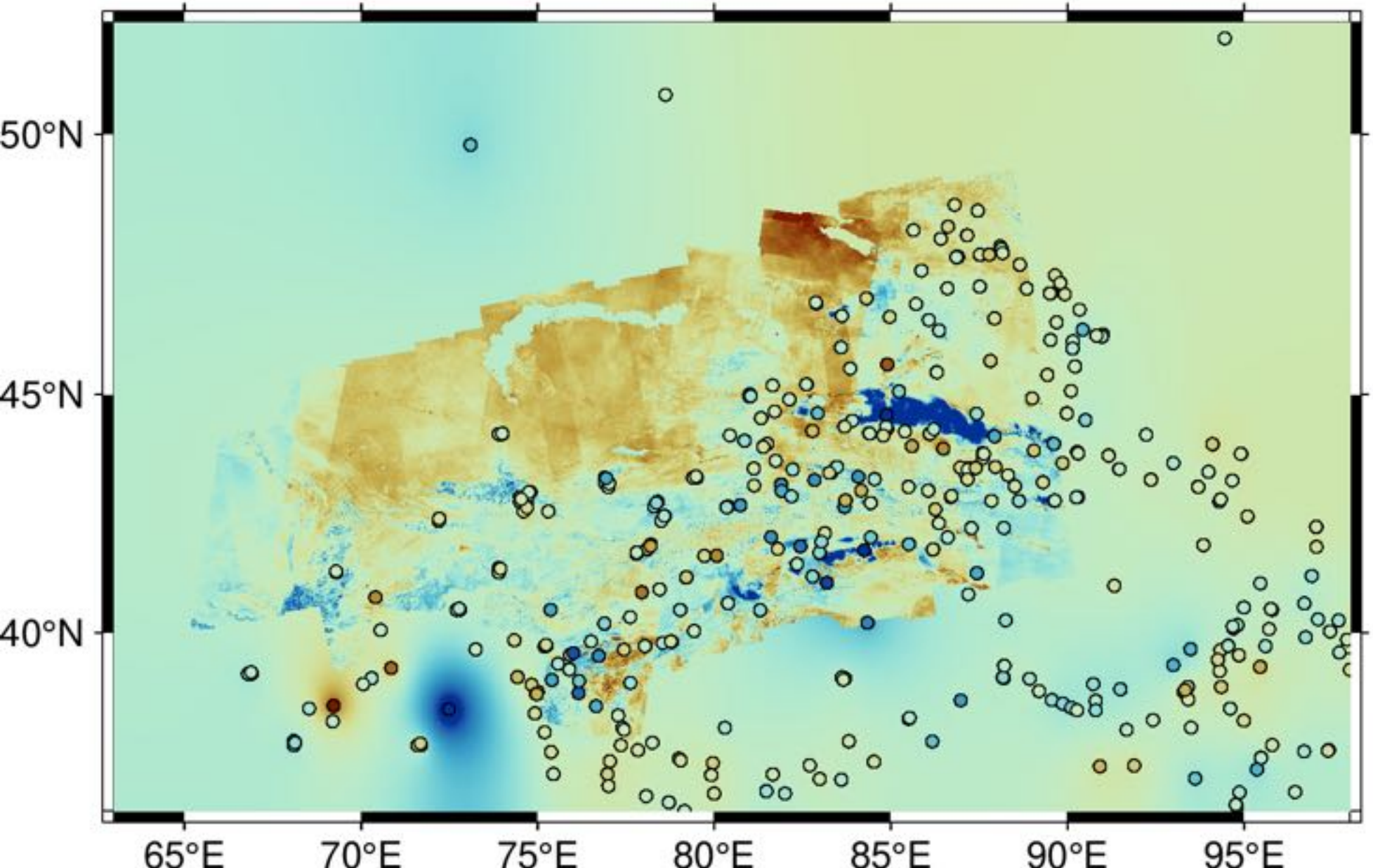
InSAR Ve after referenced to GNSS LOS by constant

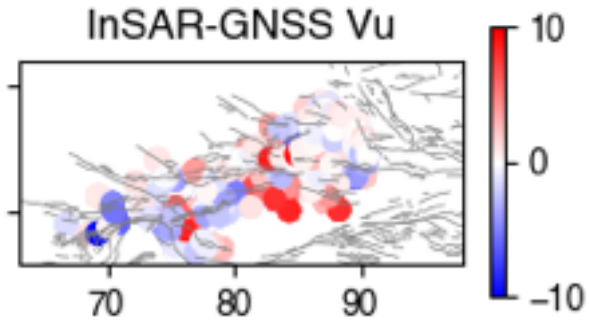


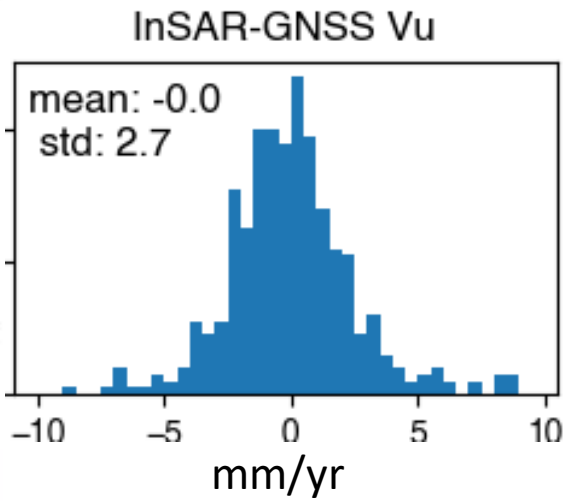




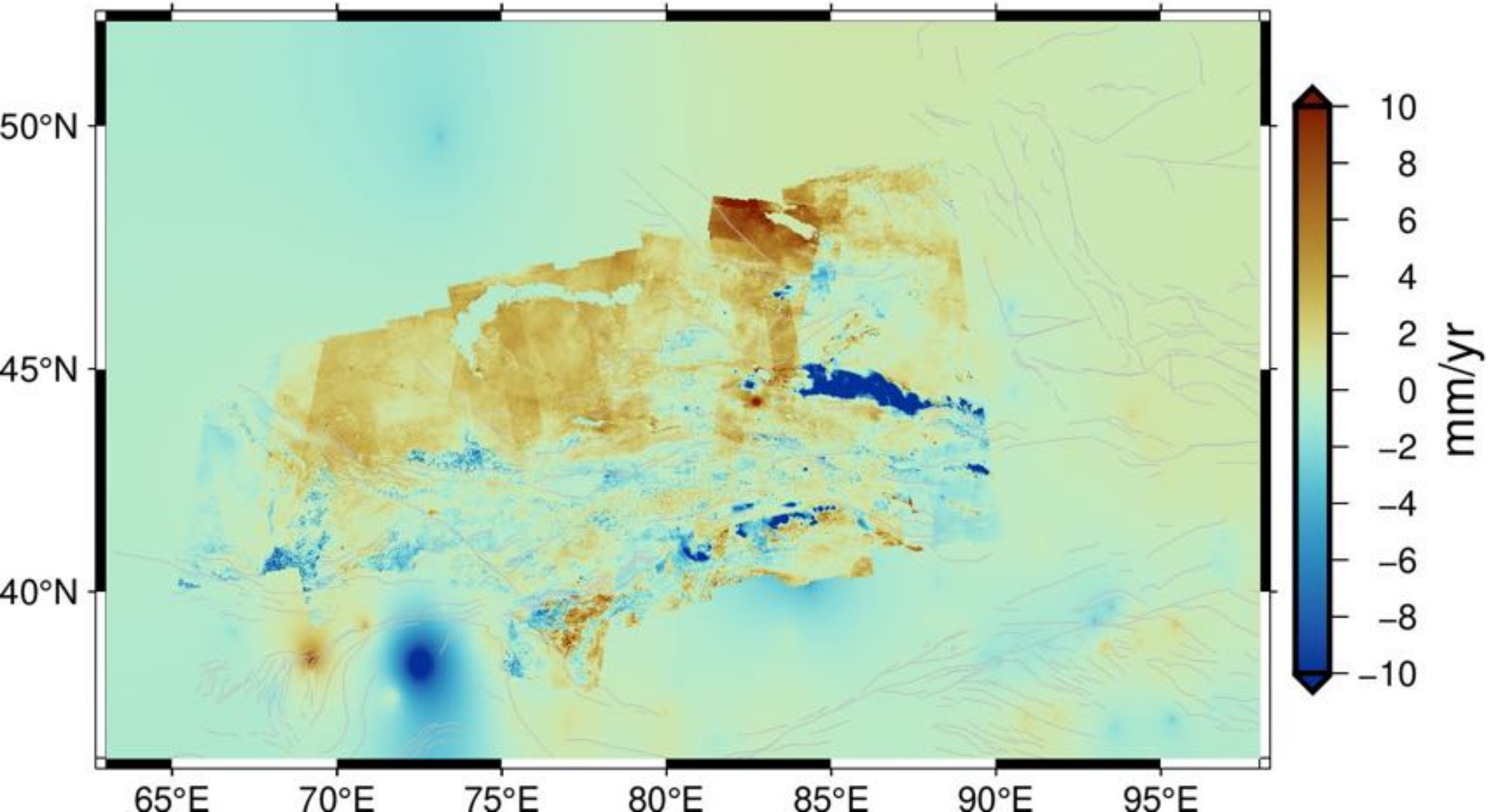
InSAR Vu after referenced to GNSS LOS by constant

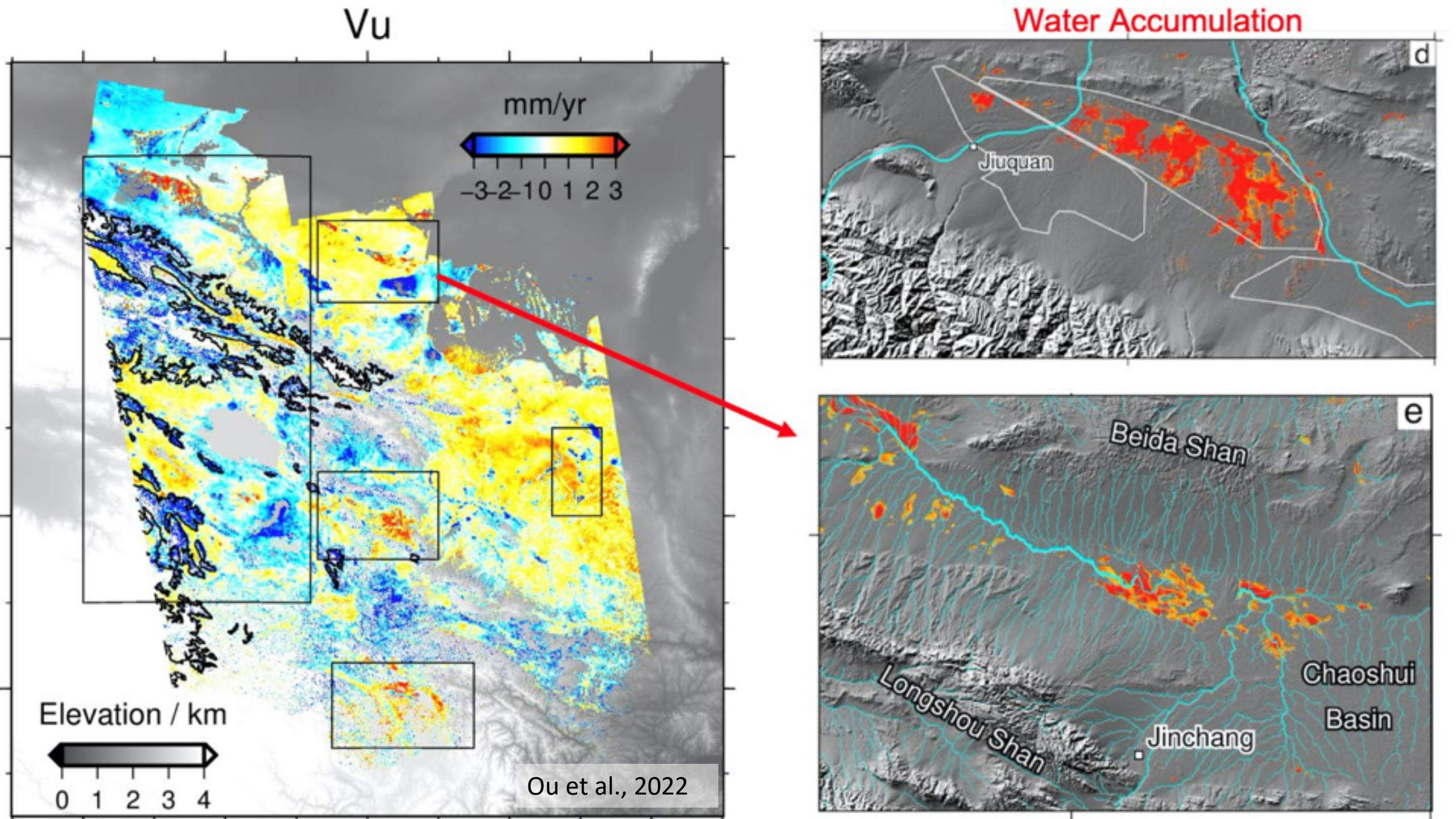




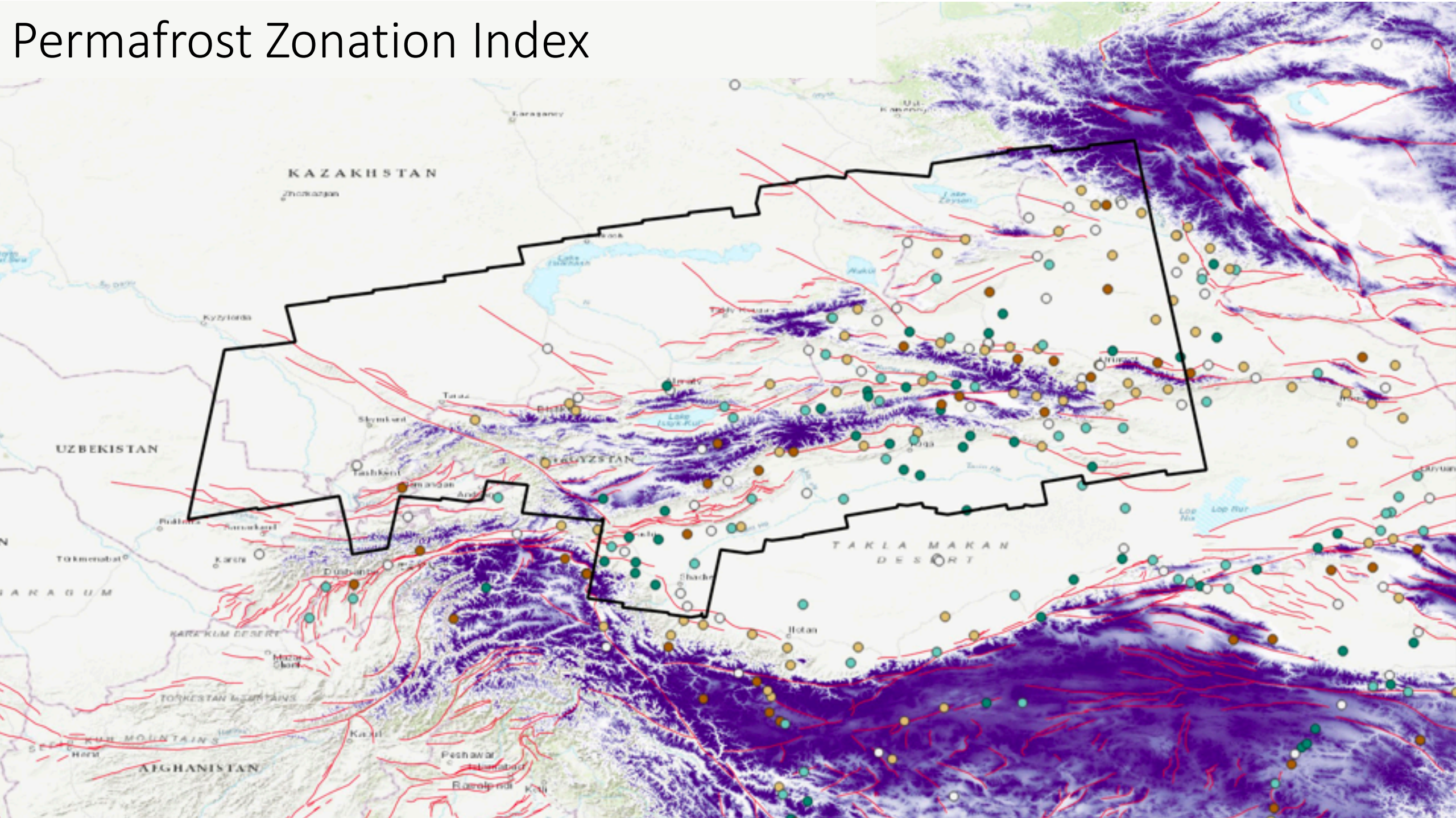


InSAR Vu after referenced to GNSS LOS by constant

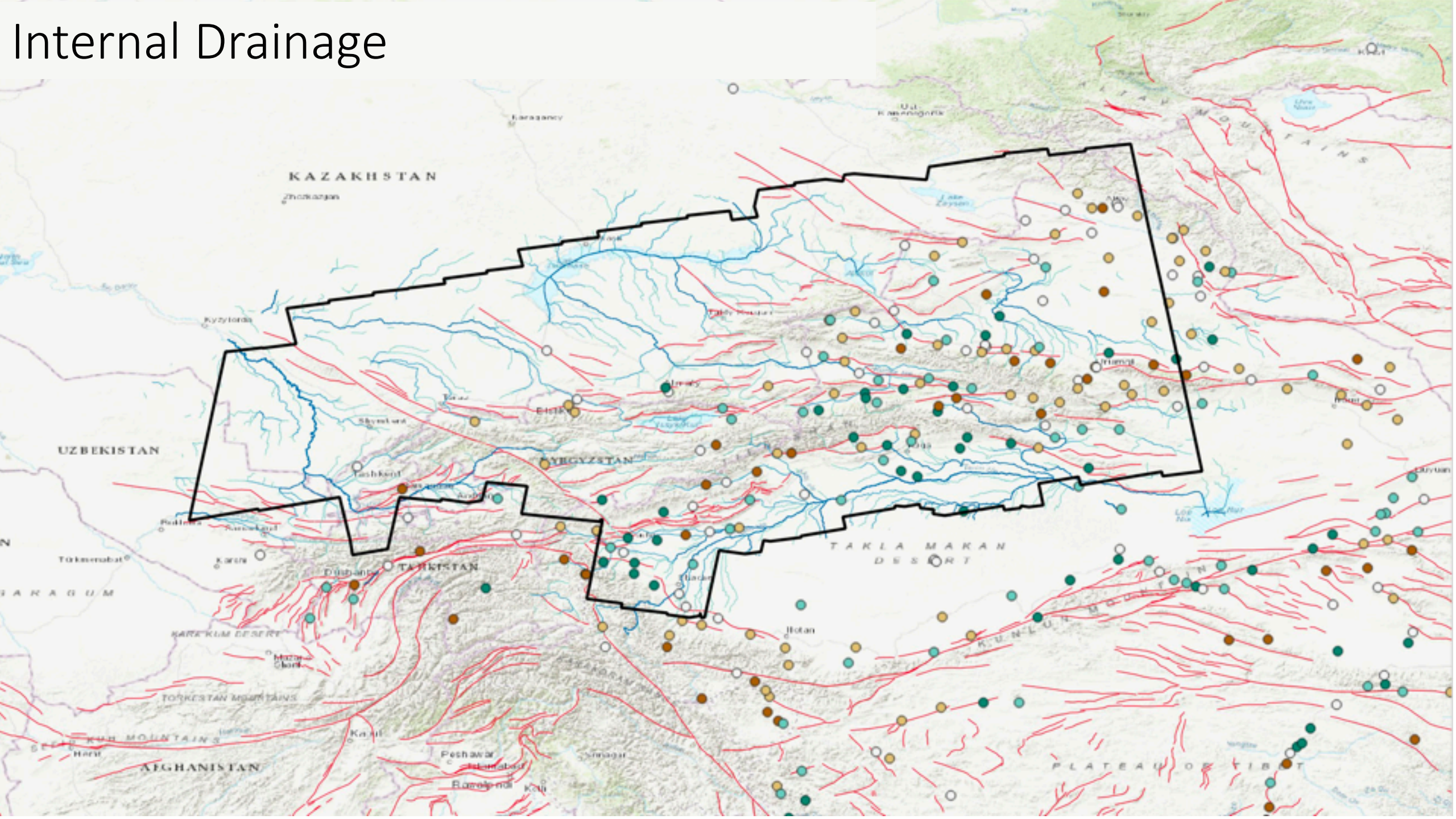



Vu
mm/yr
−3 −2 −1 0 1 2 3
Elevation / km
0 1 2 3 4
Ou et al., 2022
Water Accumulation
d
Jiuquan
e
Beida Shan
Longshou Shan
Jinchang
Chaoshui
Basin

Permafrost Zonation Index



Internal Drainage



Mascon Visualization Tool

Colorado Center for Astrodynamics Research | CU Boulder

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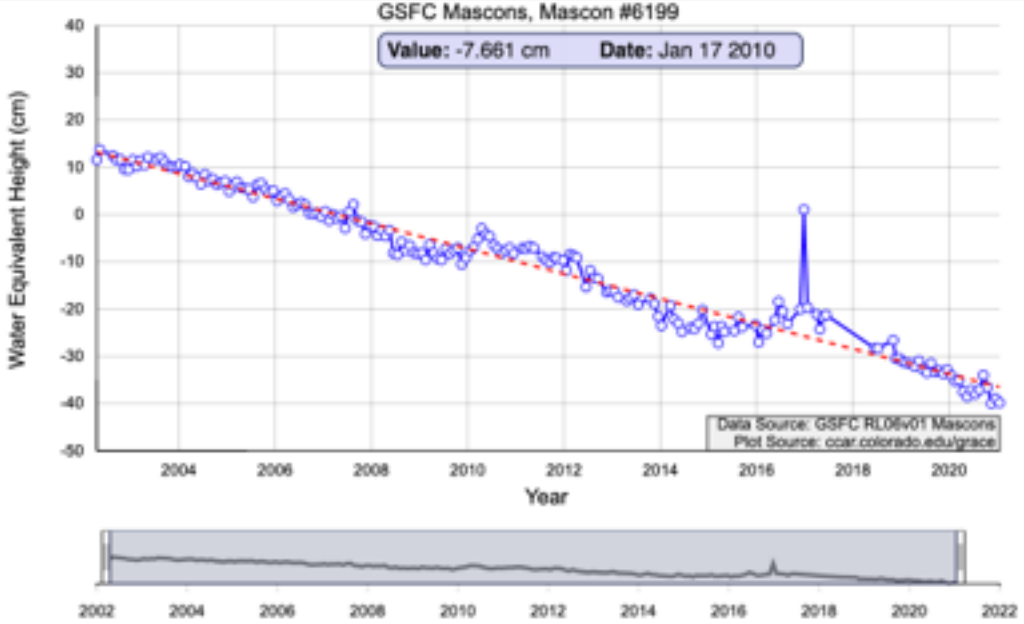
GSFC Mascons

Trend: -2.65 cm/yr
Annual Amplitude: 1.04 cm
Semi-Annual Amp.: 0.60 cm

GSFC Mascons, Mascon #6199

Value: -7.661 cm **Date:** Jan 17 2010



Plot Settings

Units:
cm Gt

Deseason: (?)
On Off

Show Trend:
On Off

Save Image

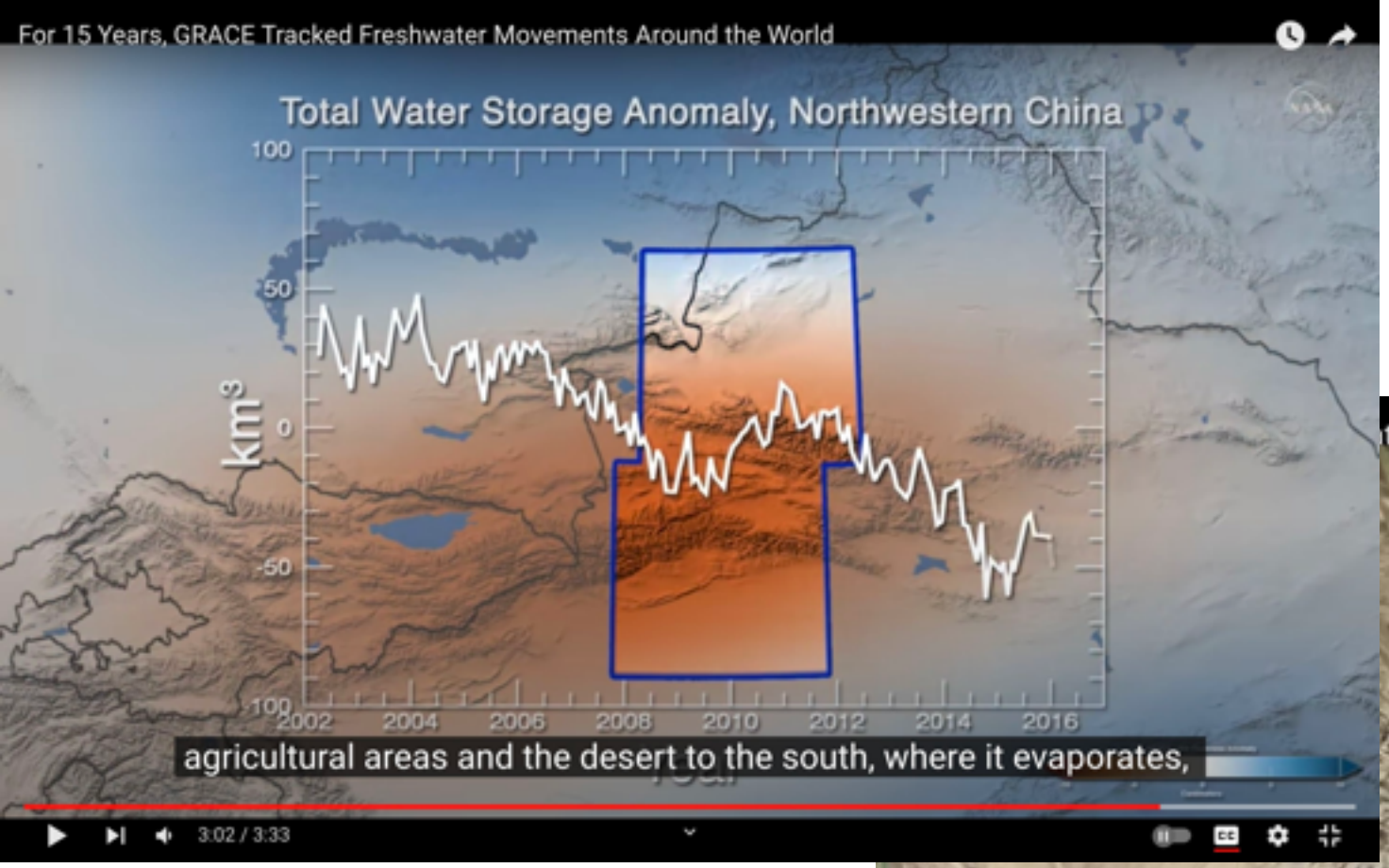
Get Data

Mascon #: 6199
Lat: 43.69
Lon: 84.51

-2.0
-4.0
-6.0
-8.0
-10.0
cm/year

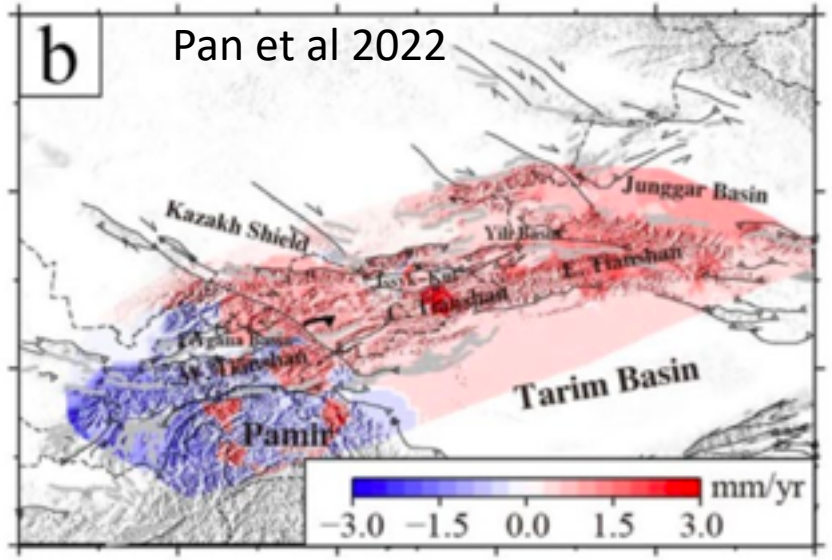
Colorbar Max: 10

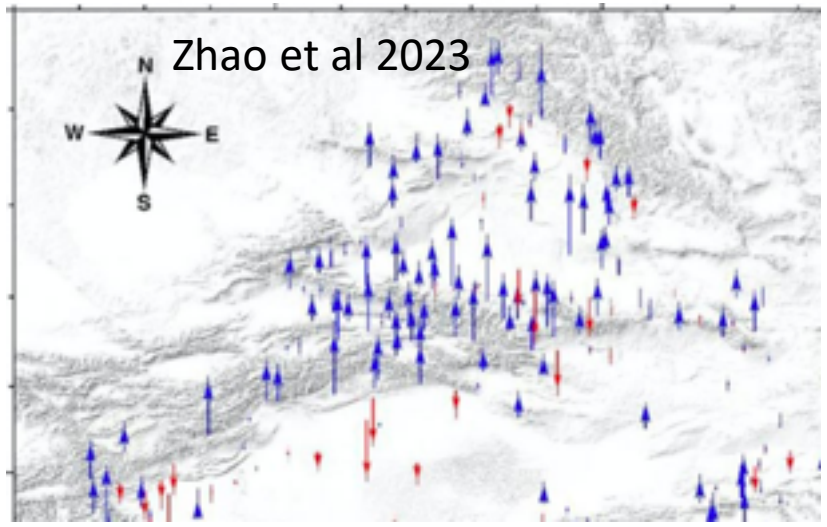
Total water loss over two decades

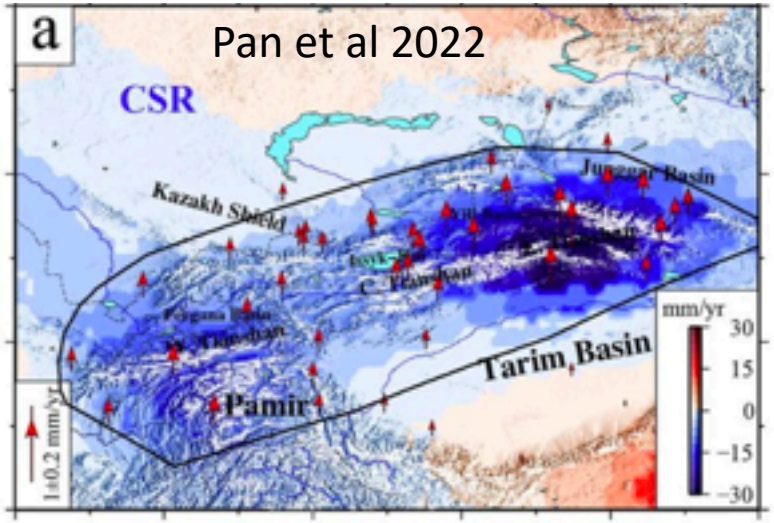


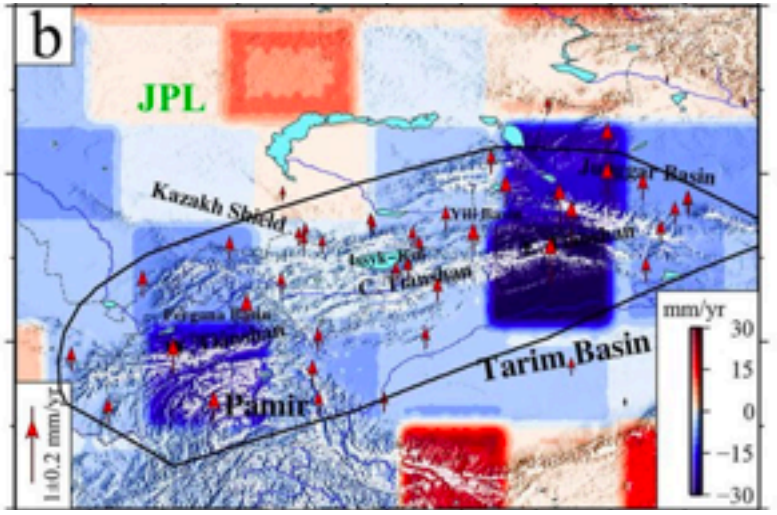
At odds with the GNSS studies

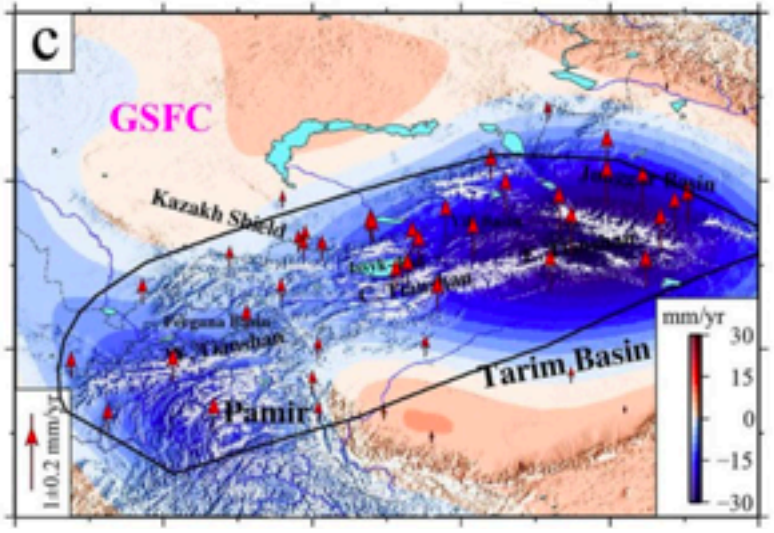
Tianshan is uplifting at 0.72 ± 0.12 mm/yr =
0.39 mm/yr from unloading due to glacier melting, +
0.33 mm/yr from crustal thickening.
Data from 2010-2016

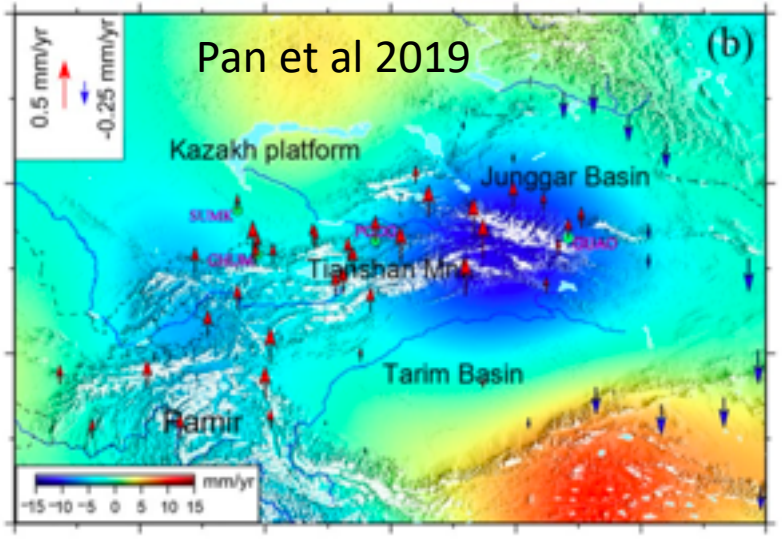




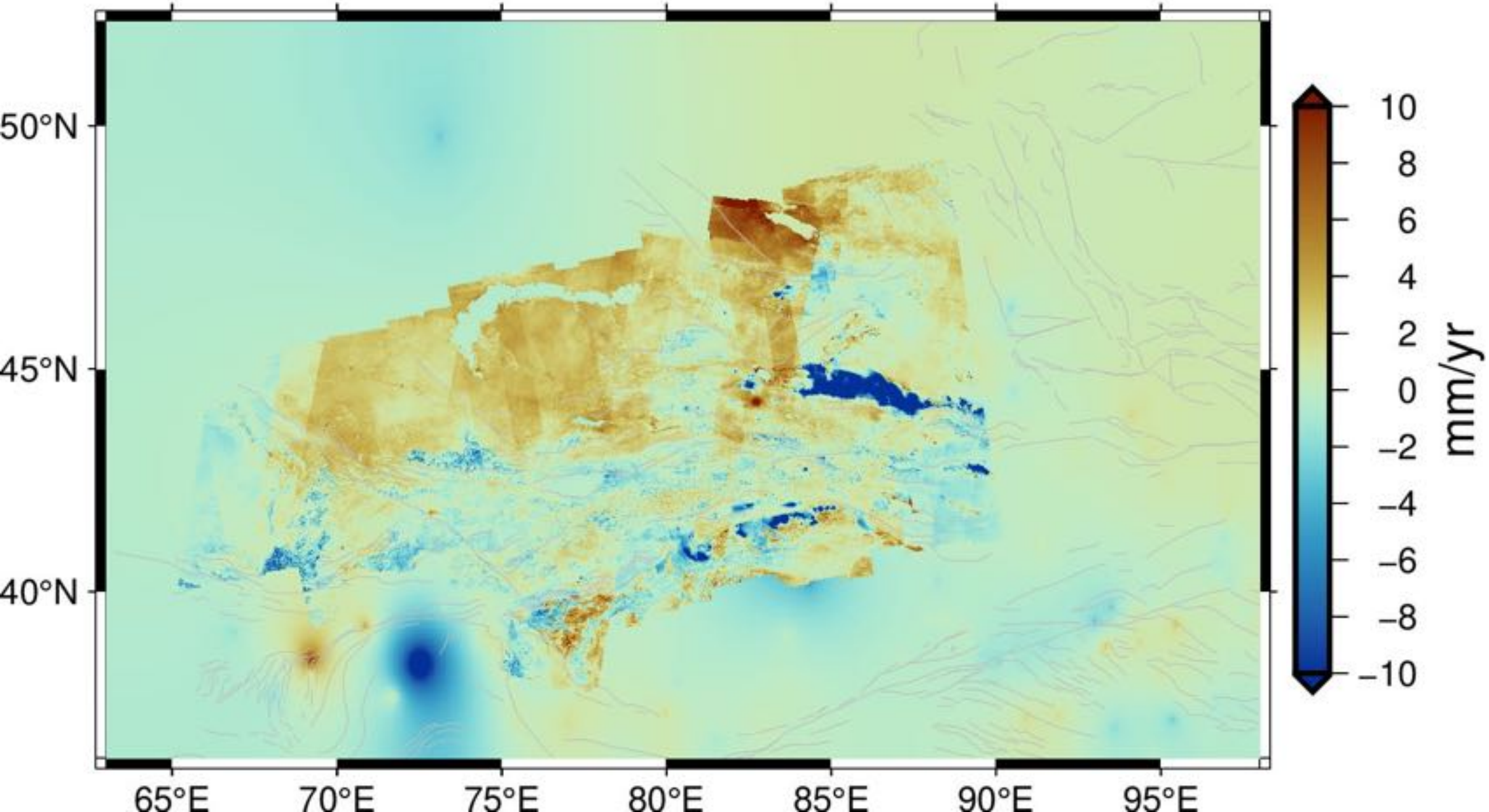




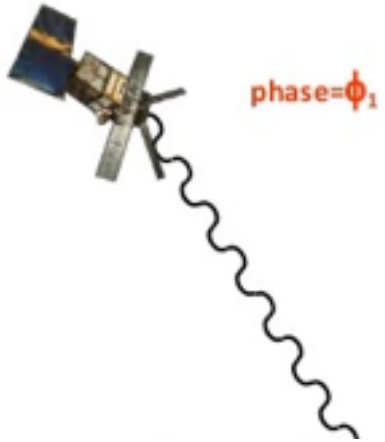




InSAR Vu after referenced to GNSS LOS by constant



What does it mean?



GPS

Unconsolidated sediments = supported by ice, collapse after ice melts

Bedrock = purely elastic

Poor GPS Vu?

How to calc rebound?

Phase bias?

Ionosphere?

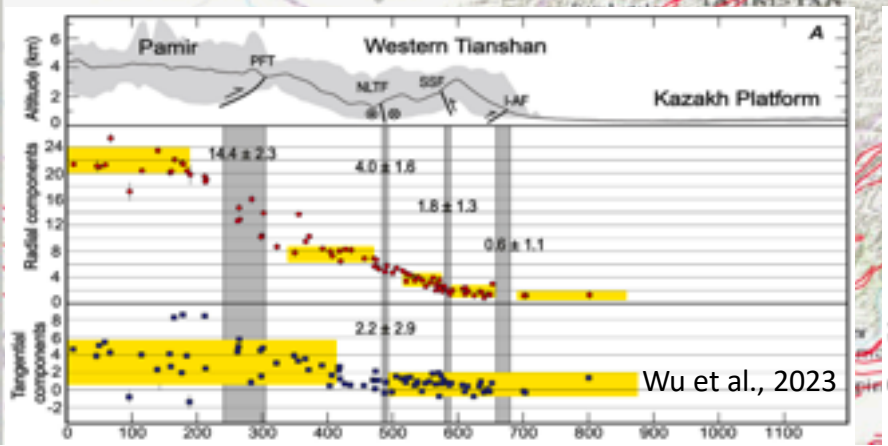
Residual Atmosphere?

Which faults are more active?

Kazakh Platform

Bishkek

Almaty



Wu et al., 2023