Present-Day Kinematics of Continental Greece and the Balkans Revealed by Sentinel-1 InSAR Data

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Session Earthquakes & Tectonics 3
18 June 2026 – 3:20-3:40PM

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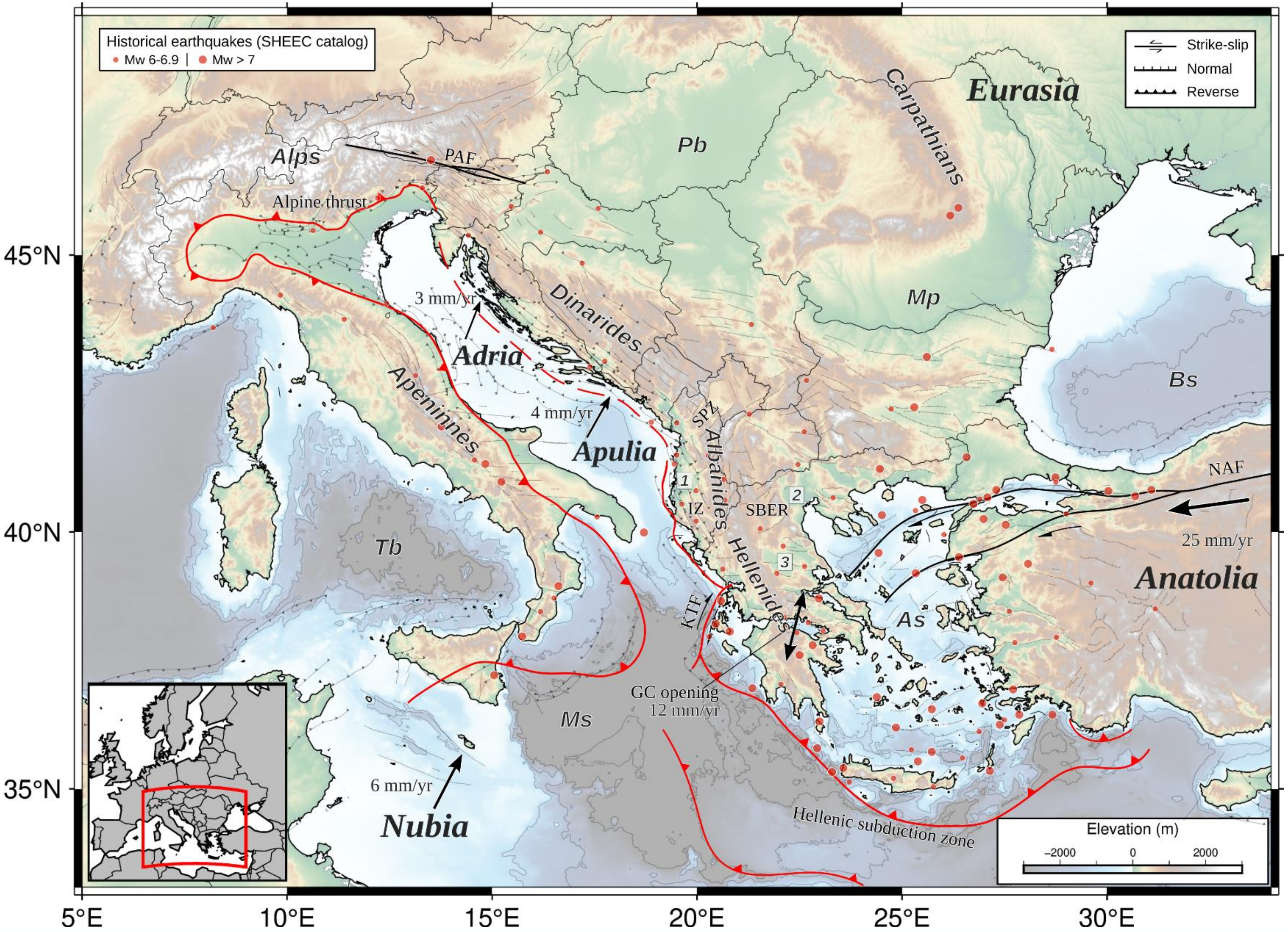
Major tectonic structures and interactions



Major active tectonic structures:

- Hellenic subduction zone
- North Anatolian Fault
- Alpine collision front

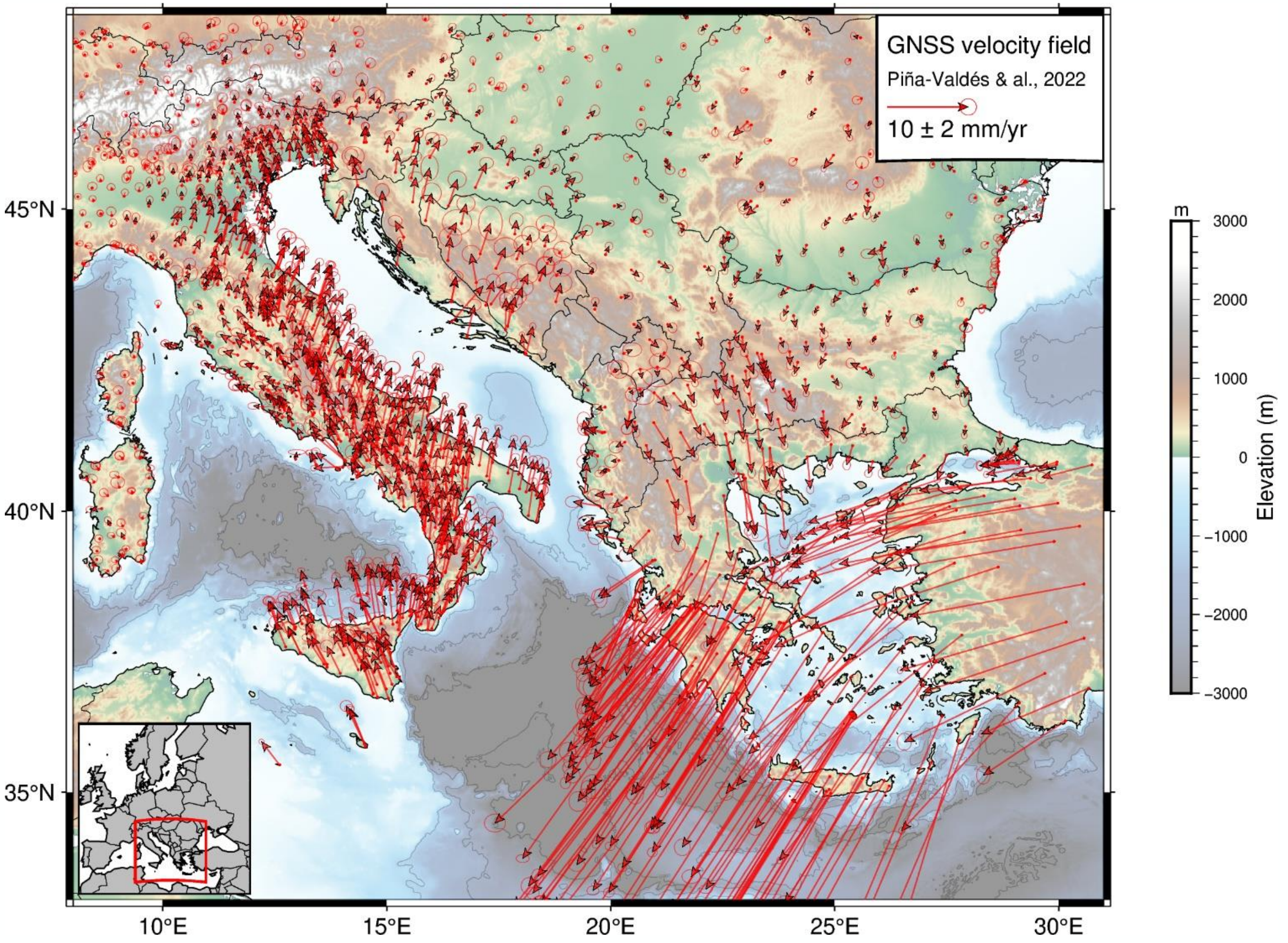
Plate motions (w.r.t. Eurasia):

- Nubia: ~6 mm/yr
- Adria: ~3 mm/yr
- Apulia: ~4 mm/yr
- Anatolia: ~25–30 mm/yr

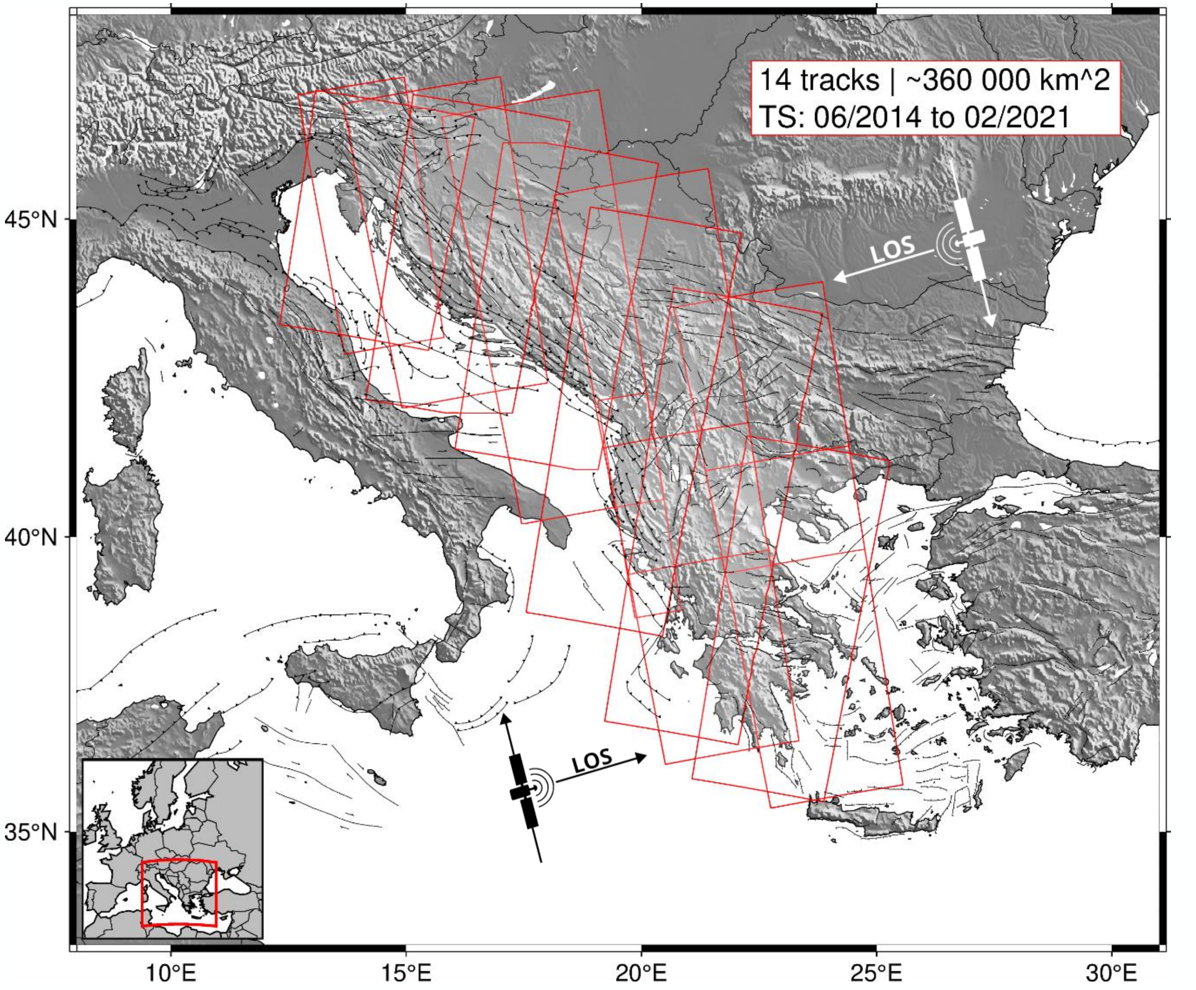
- **High seismicity**
- **&**
- **Complex geodynamic framework**

GNSS and InSAR FLATSIM datasets

GNSS velocity solution (Piña-Valdés et al., 2022)



New Sentinel-1 InSAR time series (FLATSIM service)



Can InSAR provide new information in a low straining area (#mm/yr) ?

FLATSIM overview : Balkans Dataset

ForM@ter Large-scale Multi-temporal Sentinel-1 InterferoMetry service

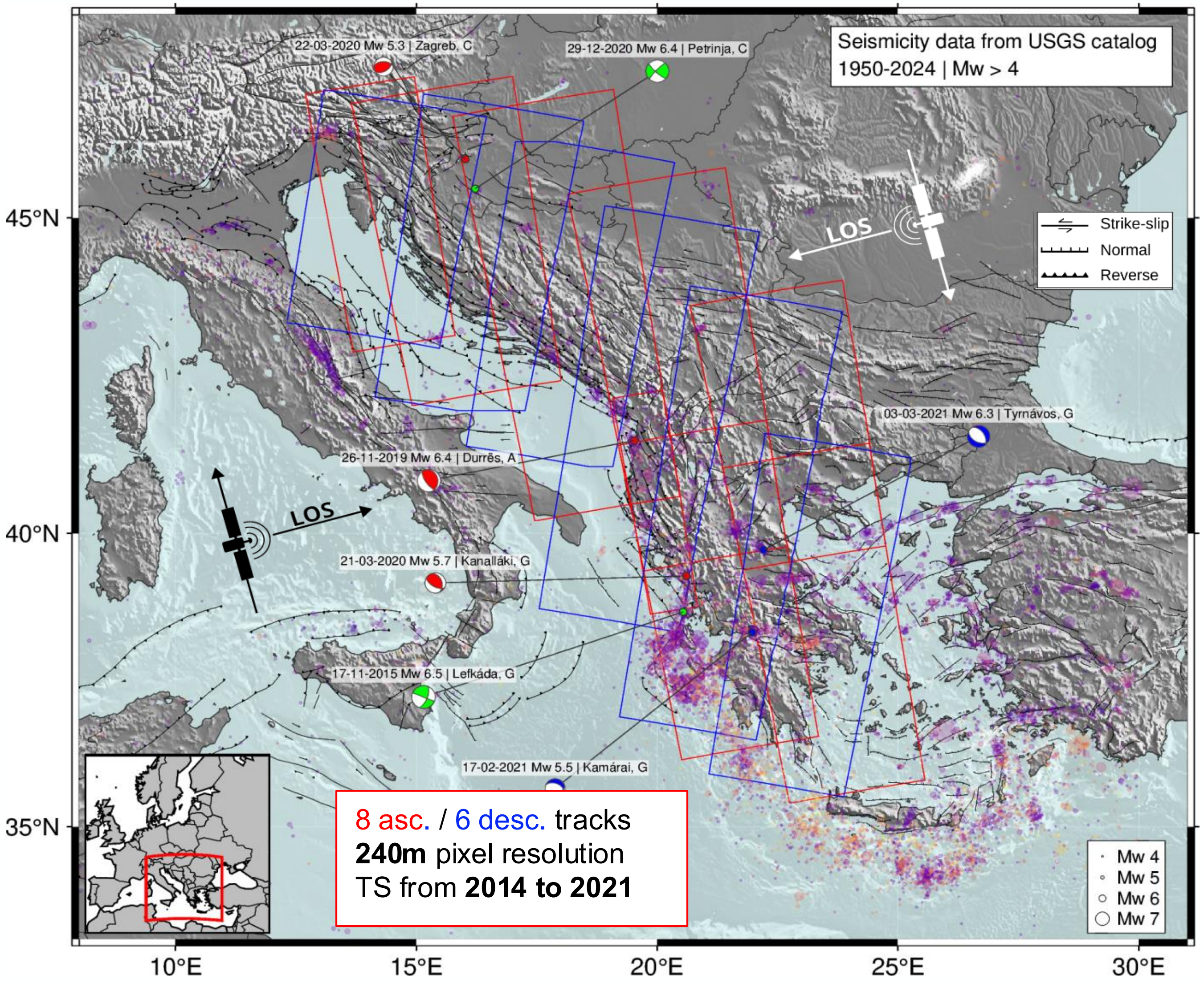
InSAR automated processing for S-1 data over large areas, using NSBAS processing chain (Doin et al., 2011; Grandin et al., 2015)

Main products :

- Wrp and Uwrp Interferograms
- LOS linear velocity maps
- **Phase displacement time series (TS)**
- Quality indicators and coherence-based metrics

Why using FLATSIM ?

- Consistent processing along long tracks (600–700 km)
- Atmospheric corrections using ERA5 (Jolivet et al., 2011)
- Multiple temporal baselines to reduce phase biases (Ansari et al., 2020; Marconato et al., 2025)



Referencing InSAR velocity : InSAR vs $GNSS_{LOS}$

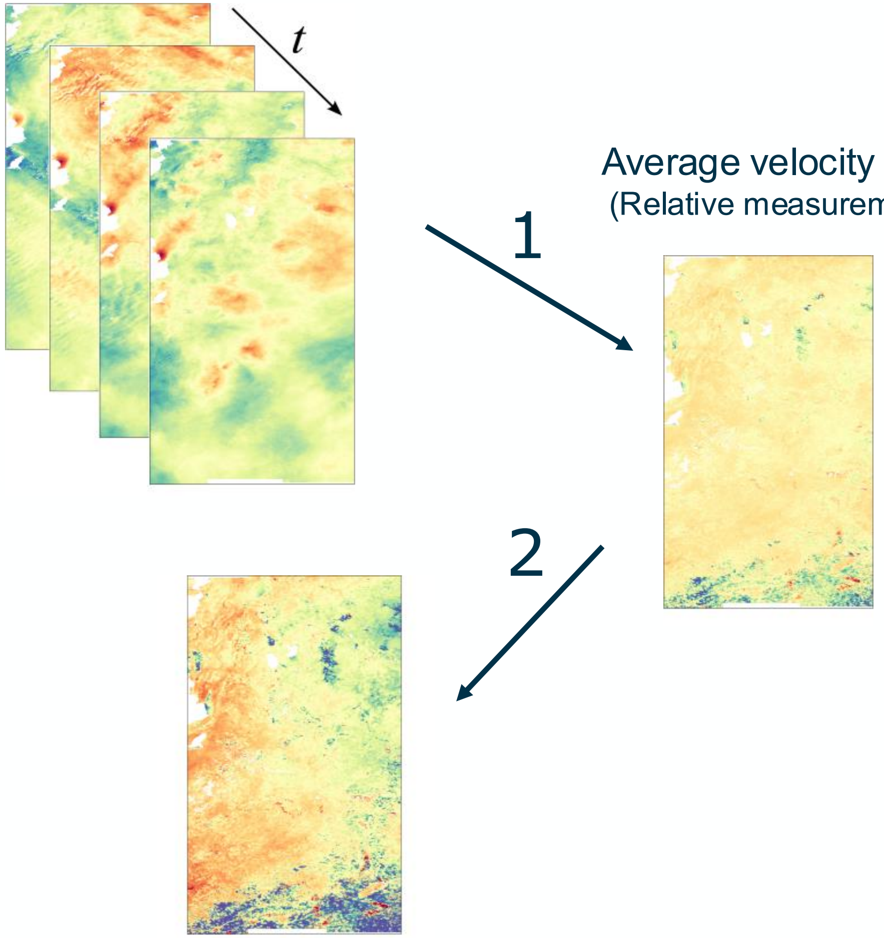
1st step : Parametric decomposition

$$\phi_{\text{model}}(t) = \overbrace{V}^{\textbf{interseismic vel.}} \cdot t + \underbrace{\sum_{i=1}^{N} c_i \cdot H(t - t_i)}_{\text{coseismic}} + \overbrace{A \cdot \cos\left(\frac{2\pi \cdot t}{T}\right) + B \cdot \sin\left(\frac{2\pi \cdot t}{T}\right)}^{\text{seasonnal}} + d$$

2nd step : Absolute referencing with minimal azimuthal adjustment to GNSS

adapted from Lemrabet et al., 2023

RAW FLATSIM DISPLACEMENT TS



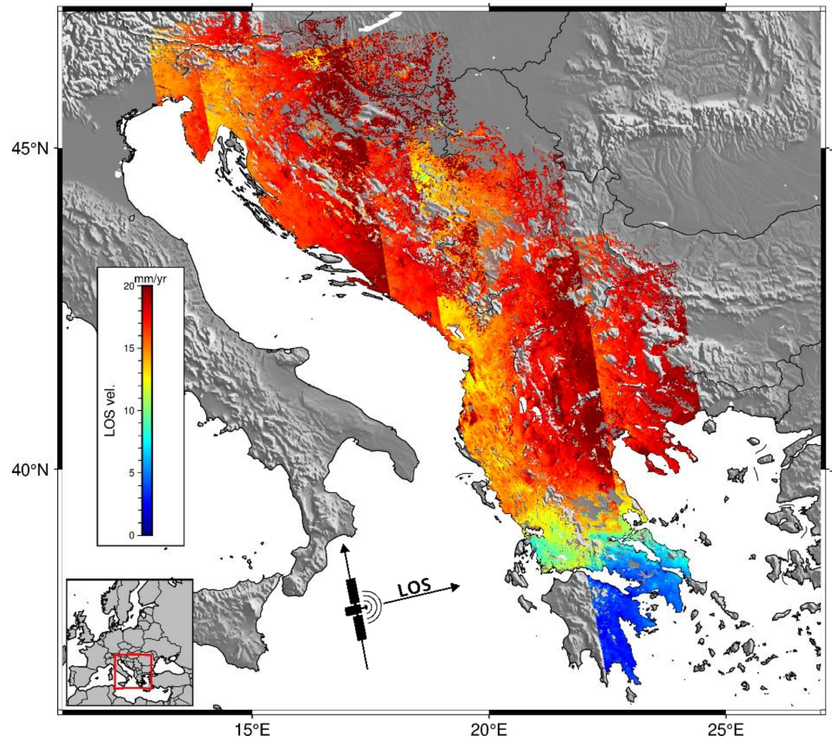
Average velocity map
(Relative measurement)

Average velocity map in ITRF14

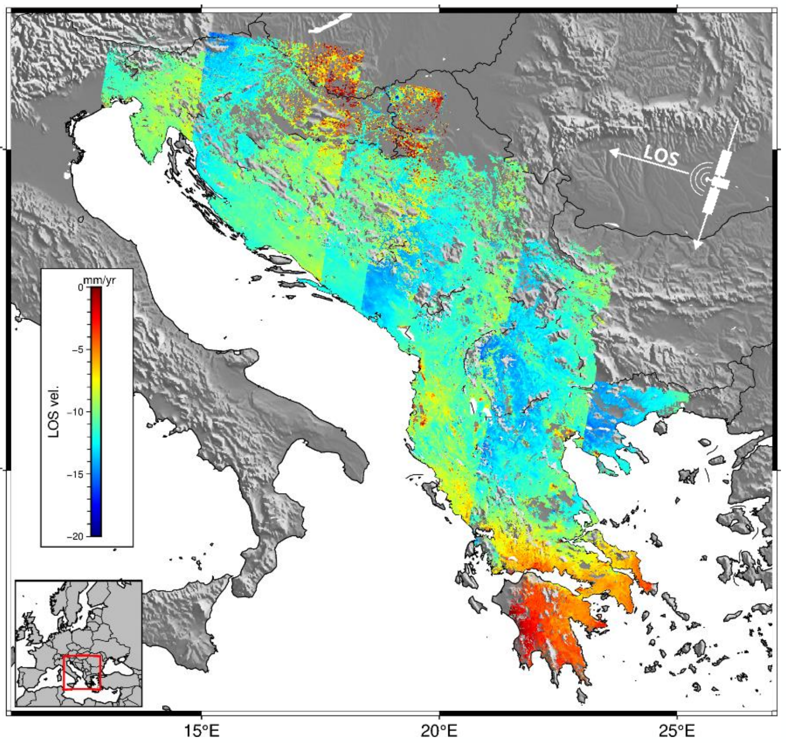
(Altamimi et al., 2016)

Regional InSAR velocity maps over Balkans Peninsula

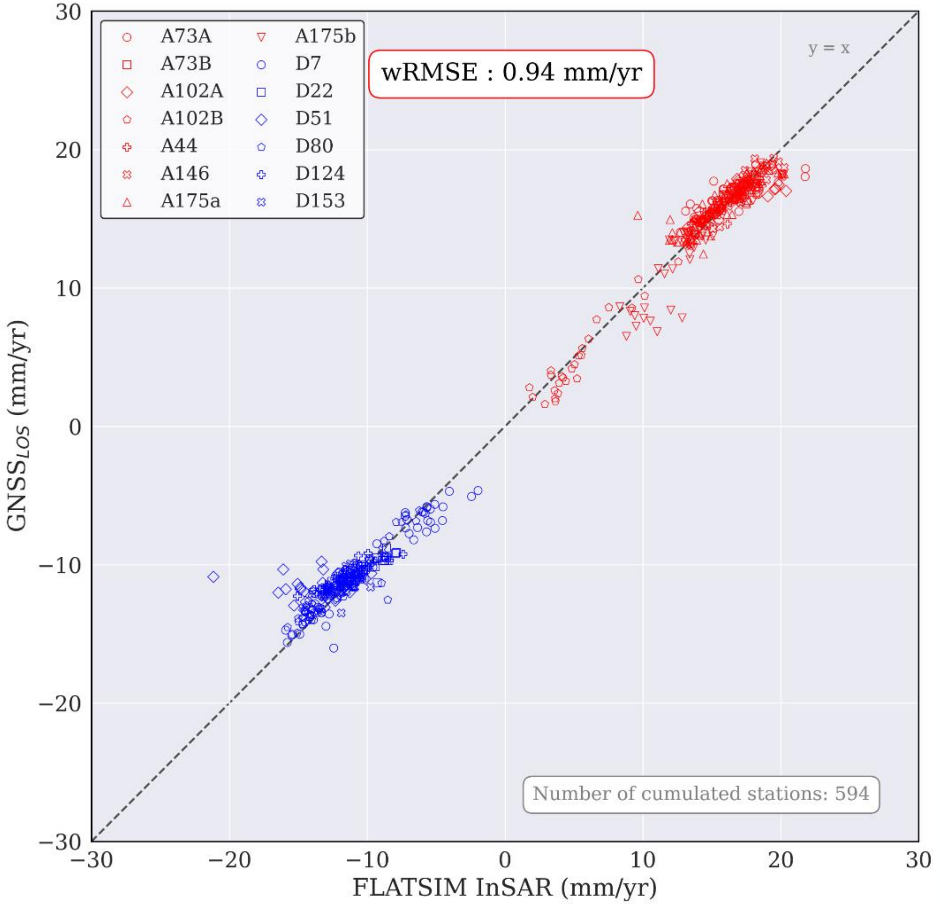
Ascending tracks



Descending tracks



InSAR vs GNSS$_{LOS}$



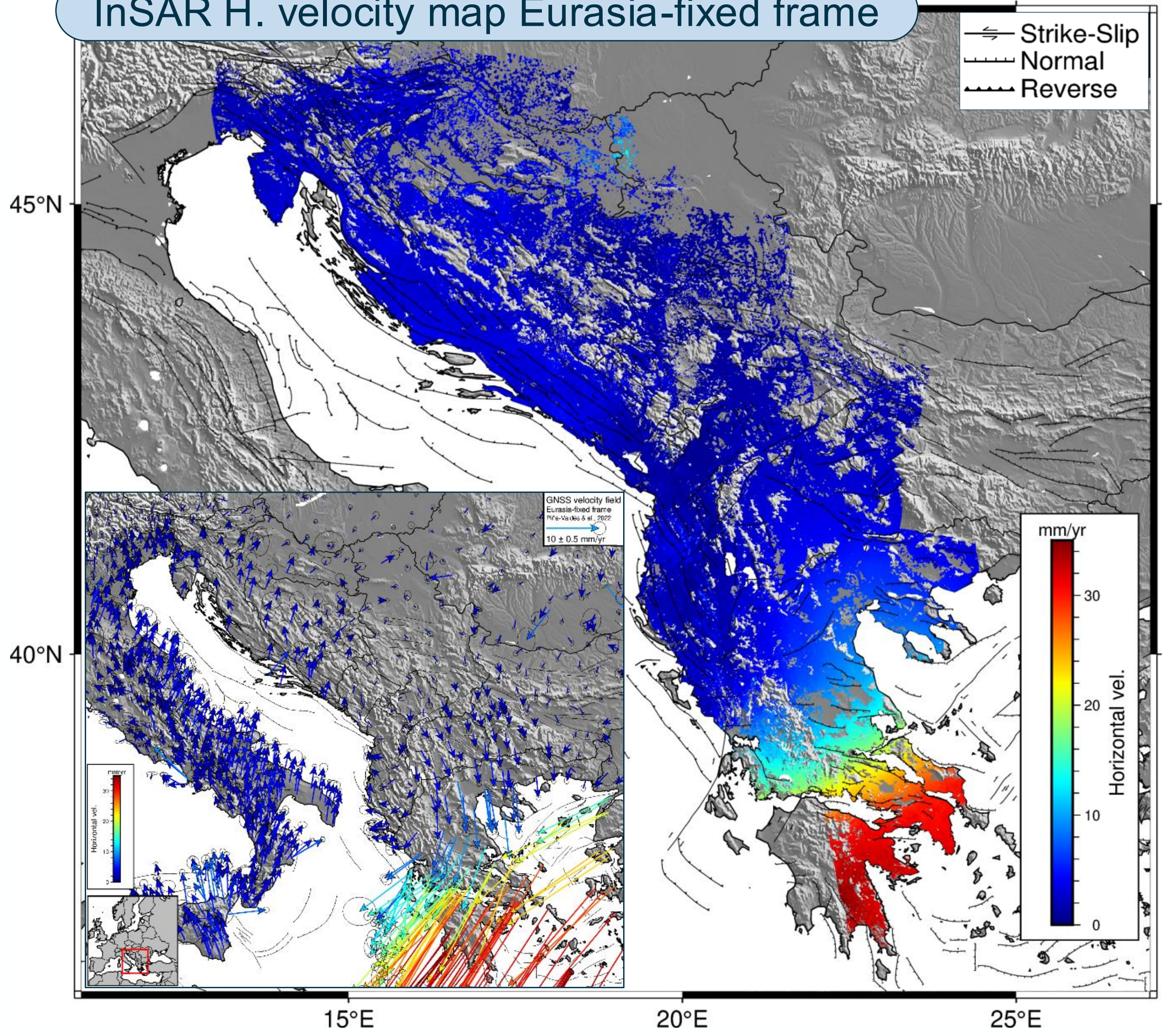
- Very good agreement with 2D GNSS velocities projected in LOS

Unprecedented spatial resolution (240m) to explore surface deformation

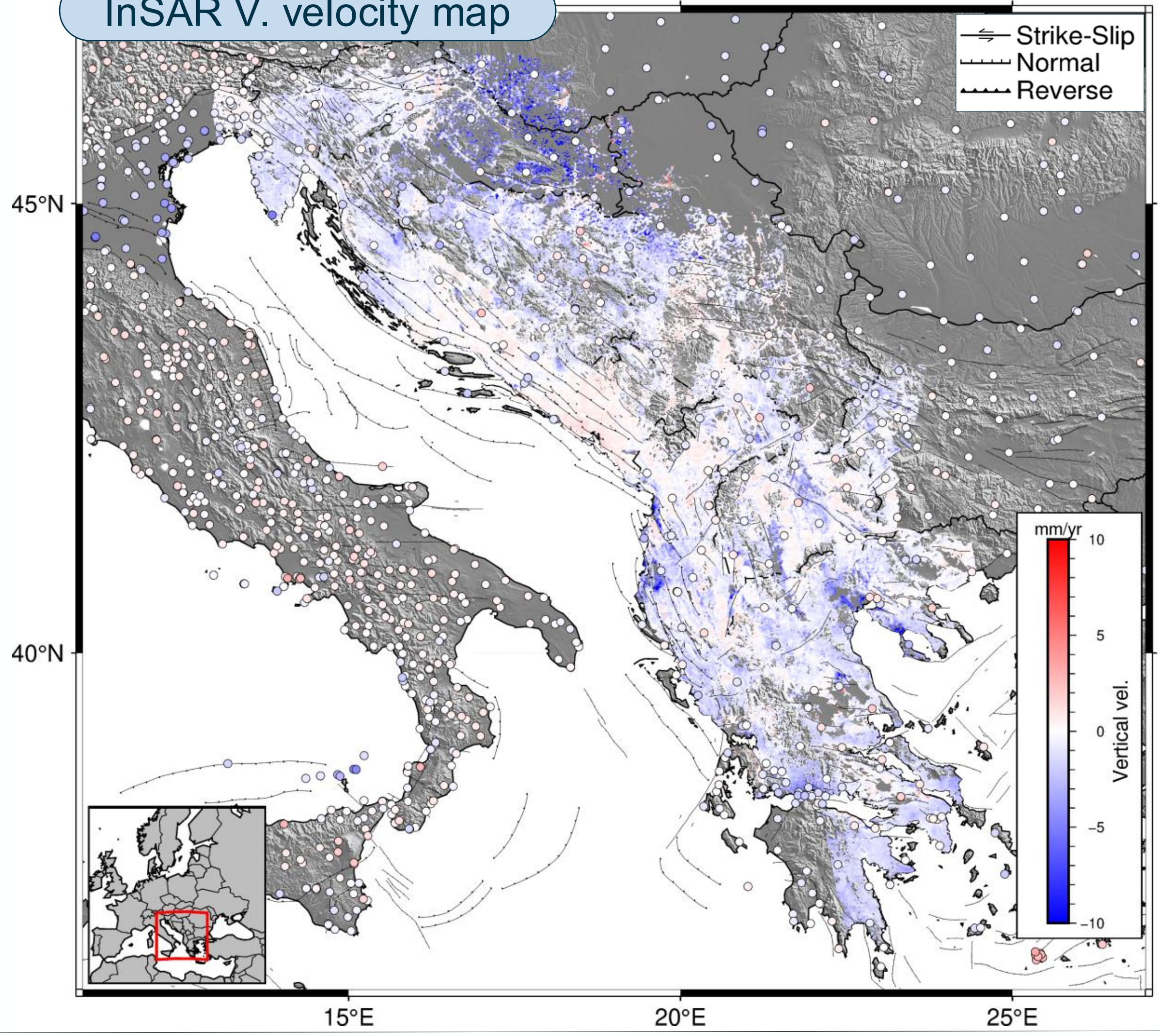
Tectonic and non-tectonic signals !

- **Hypothesis :** horizontal motion parallel to the direction given by the interpolated 2D GNSS velocity field (Métois et al., 2025)

InSAR H. velocity map Eurasia-fixed frame

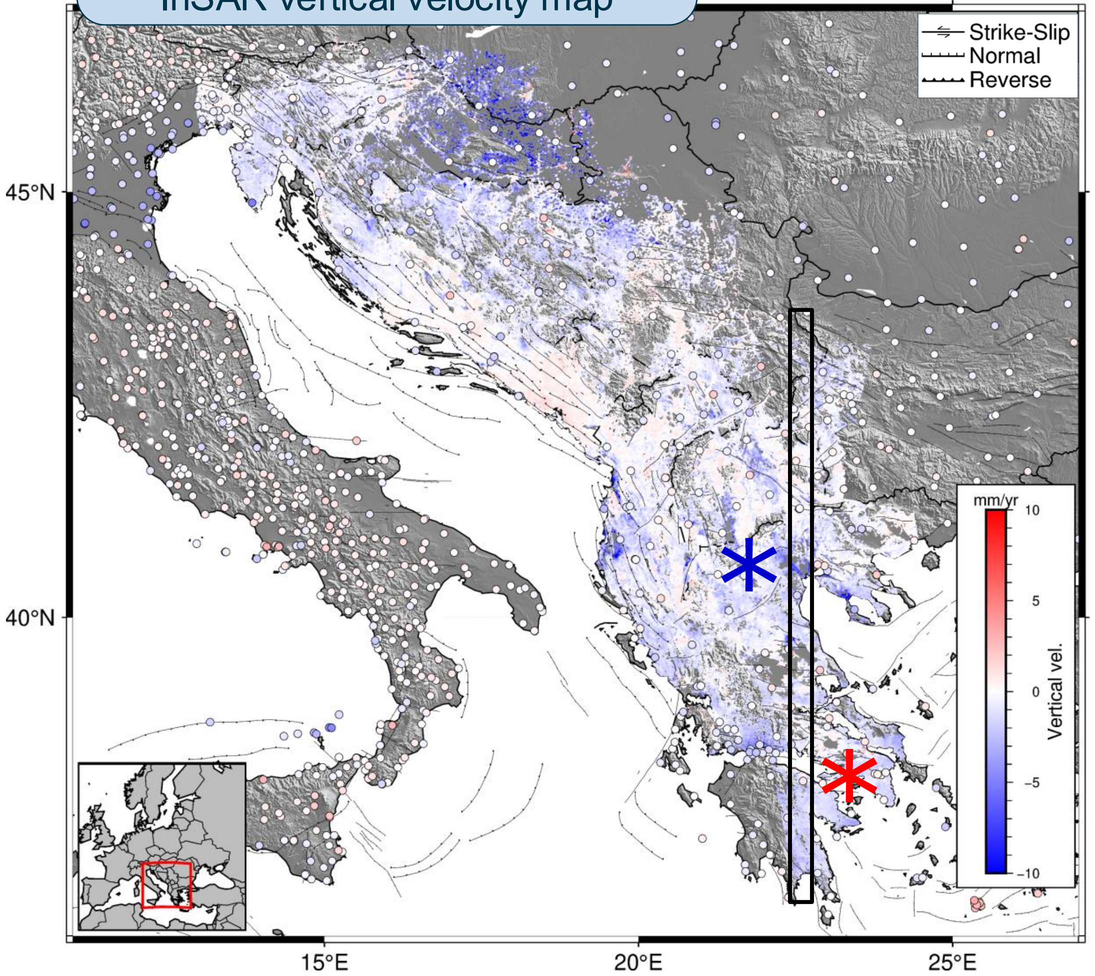


InSAR V. velocity map



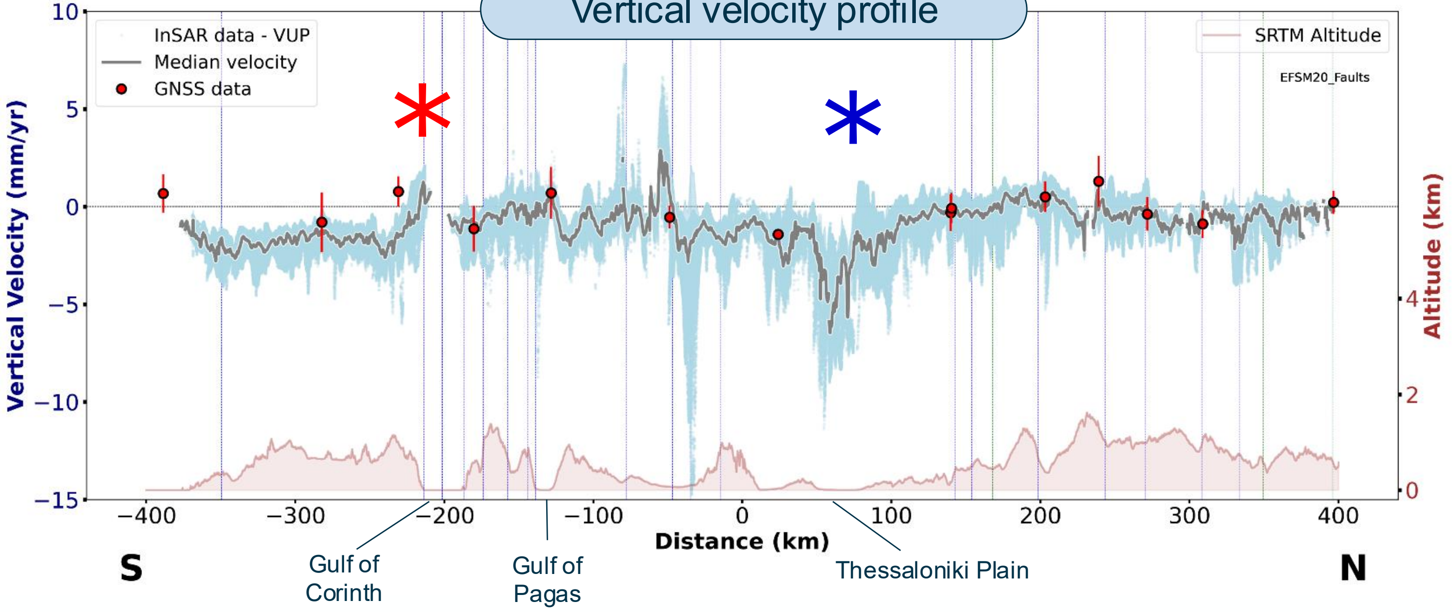
Tectonic and non-tectonic signals !

InSAR vertical velocity map



- **Tectonic** uplift of the southern side of the Gulf of Corinth | **3 mm/yr** *
- **Anthropogenic** subsidence in basins | **5 mm/yr** *

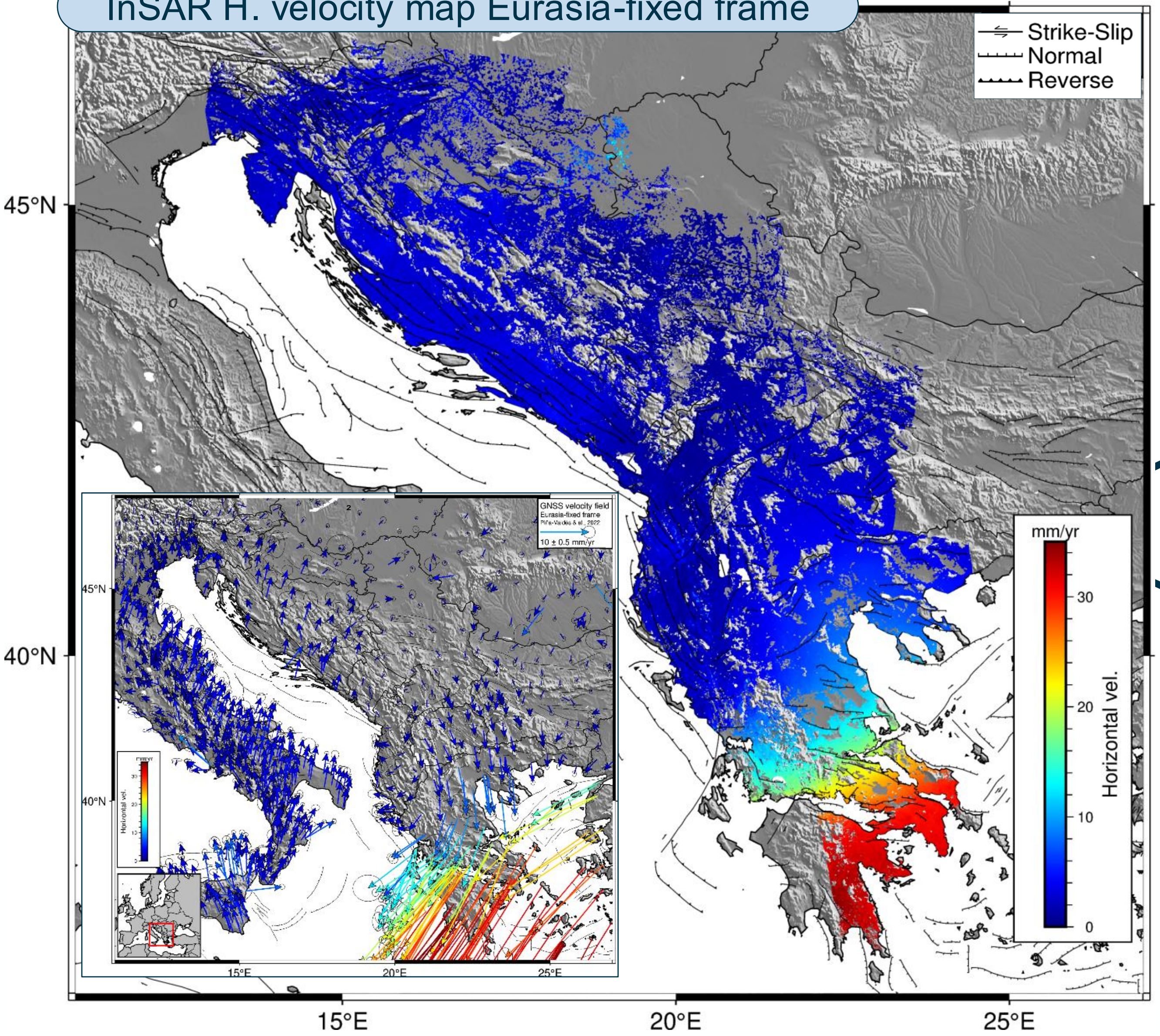
Vertical velocity profile



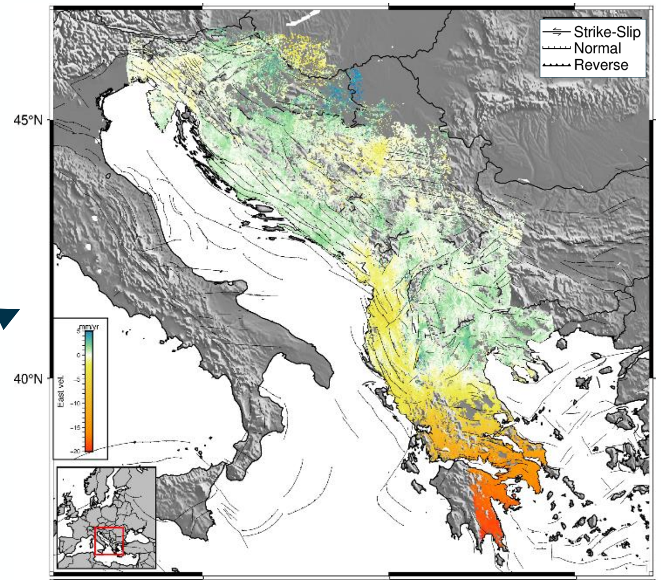
Vertical InSAR maps highlight non-tectonic and tectonic signals

H vel. = E + N vel. components

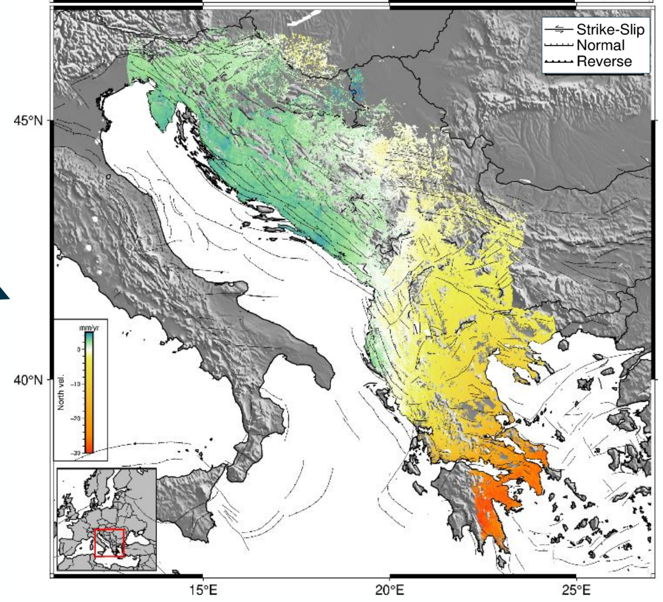
InSAR H. velocity map Eurasia-fixed frame



East velocity

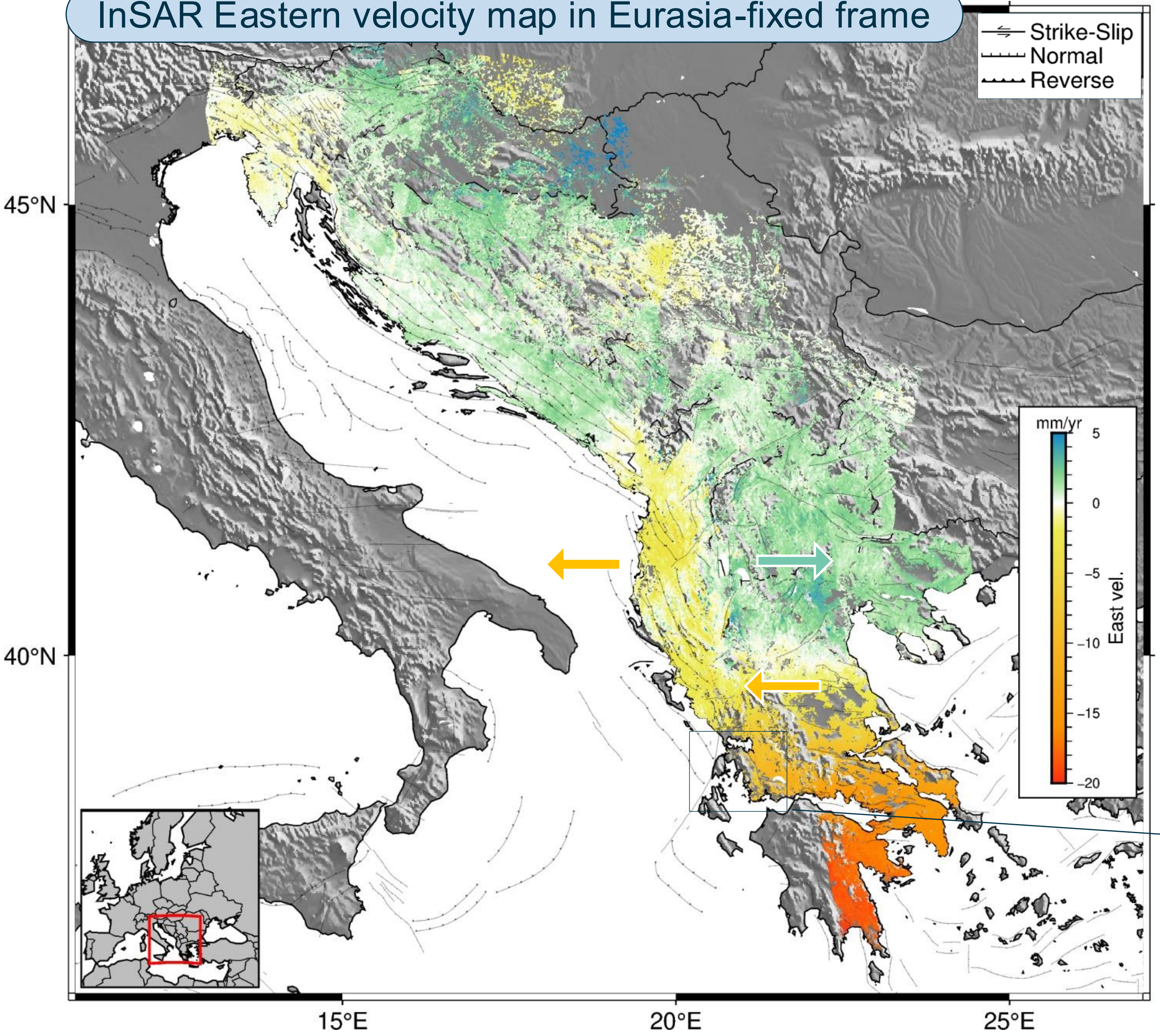


North velocity

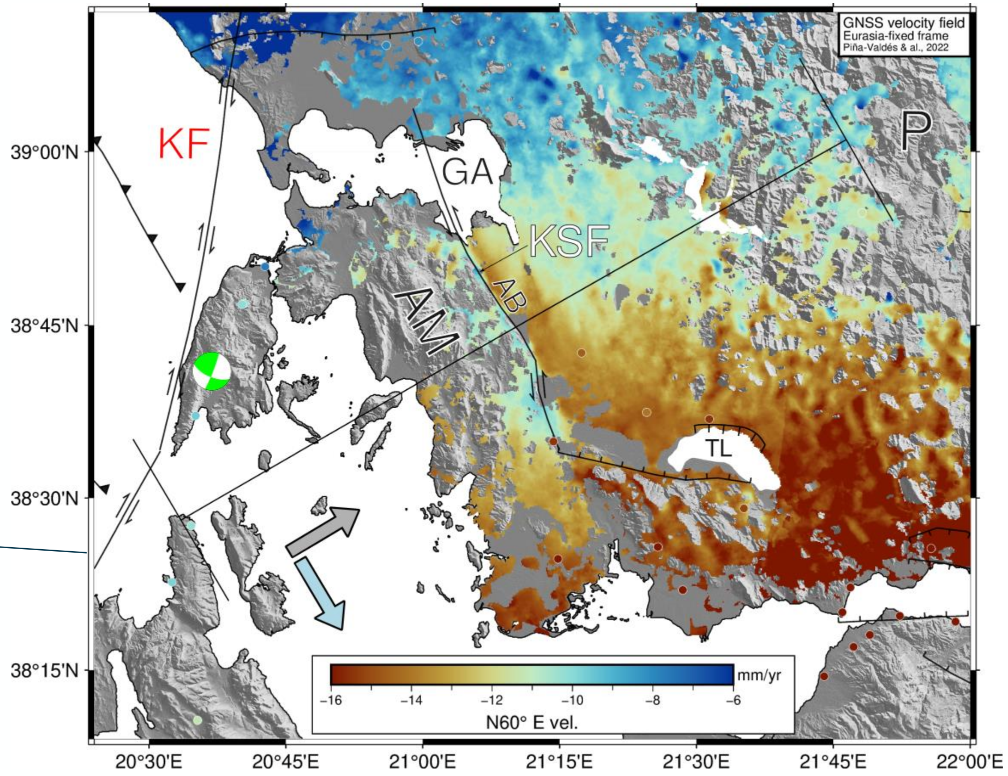


Tectonic deformation is dominant on H !

InSAR Eastern velocity map in Eurasia-fixed frame

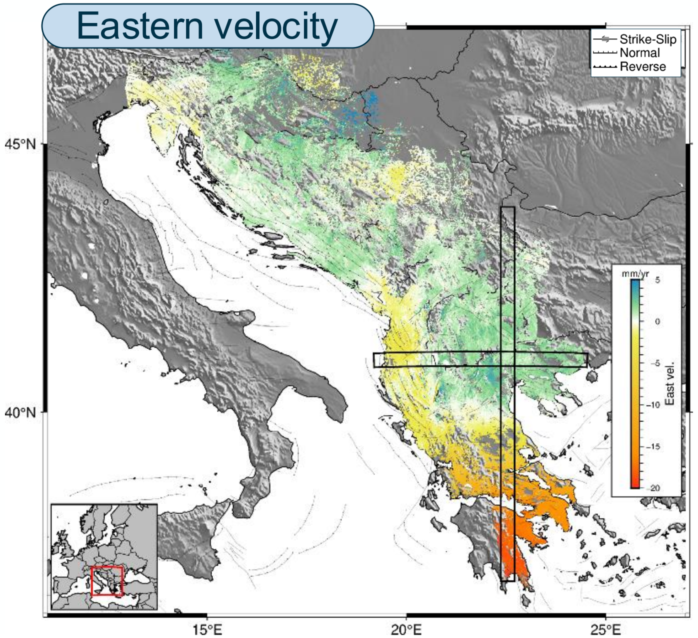


- Localization of transtension refined in inner Albanides
- Large shear zone in Continental Greece
- Fault-related deformation (ex. of Katouna-Stamna fault, Greece)

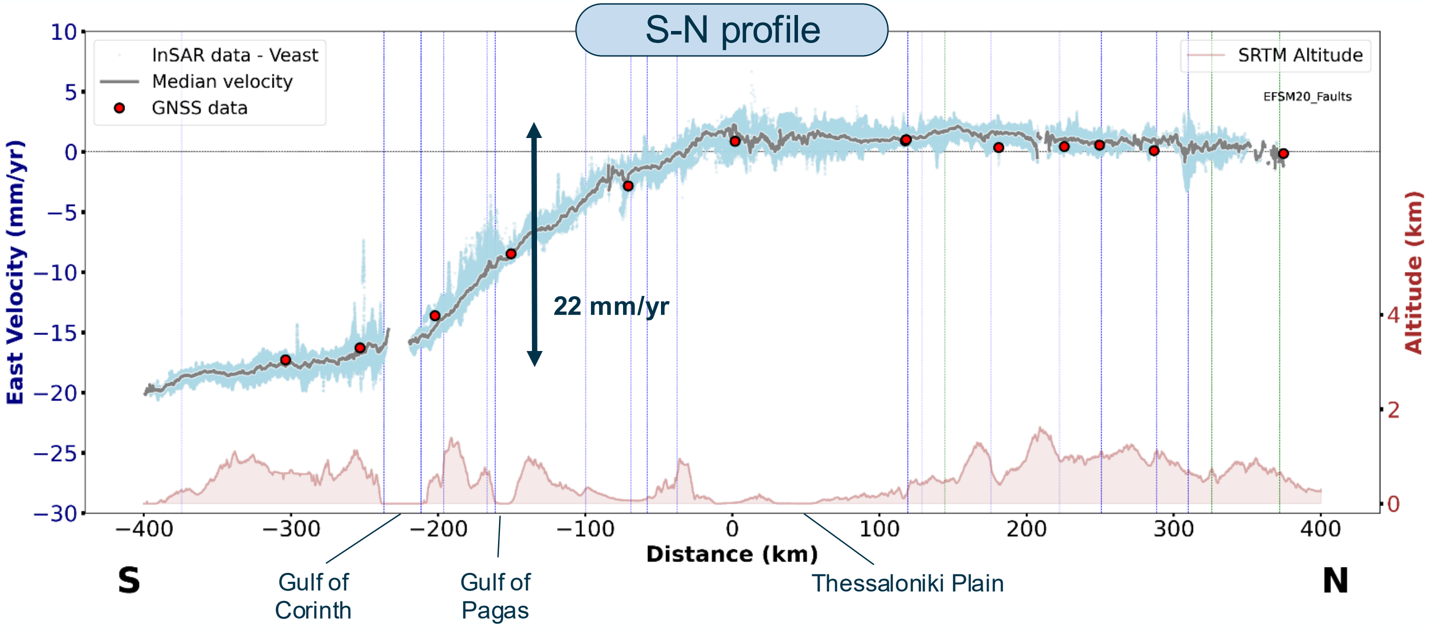


Shear and extension: Greece and Albania

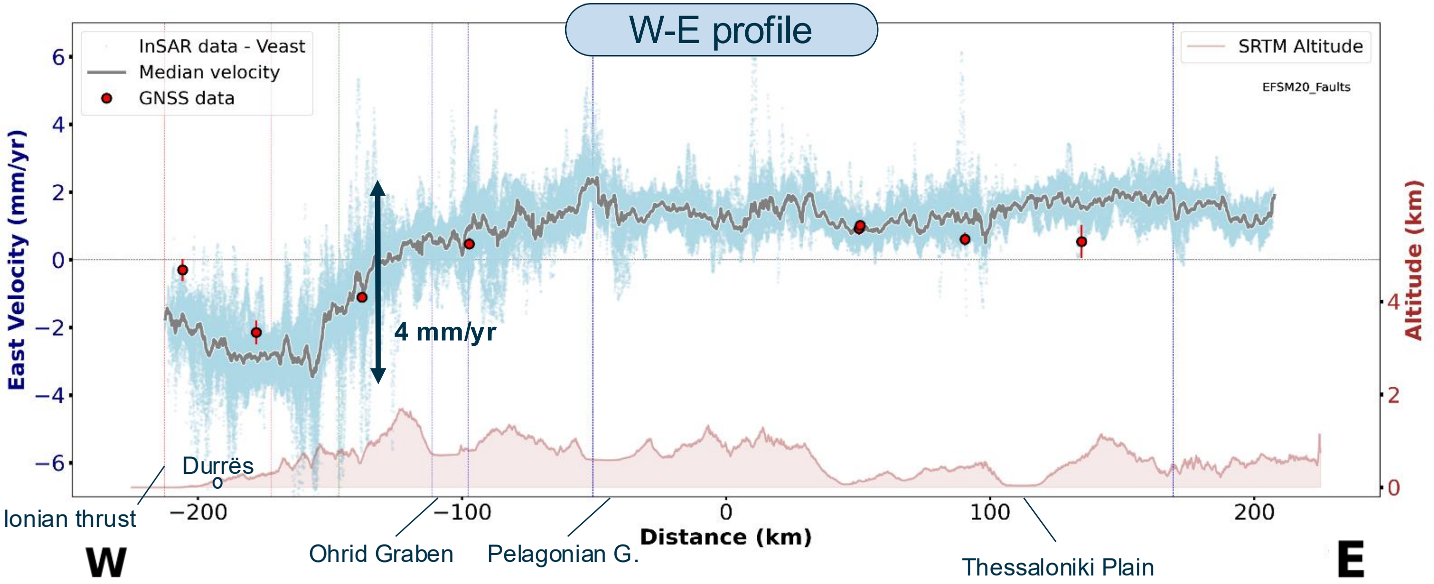
Eastern velocity



S-N profile



W-E profile



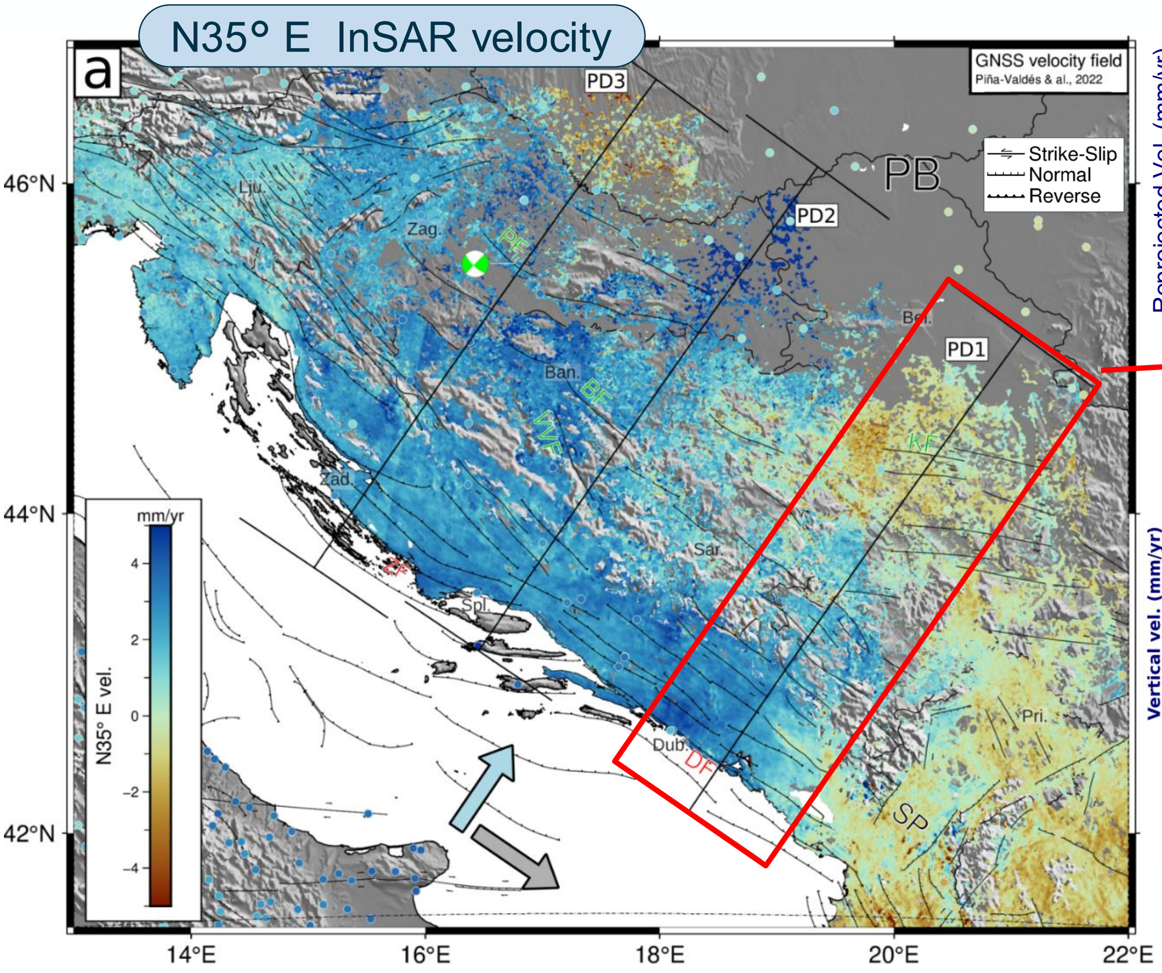
- **250 km-**long wavelength gradient of **2 cm/yr** in Greece

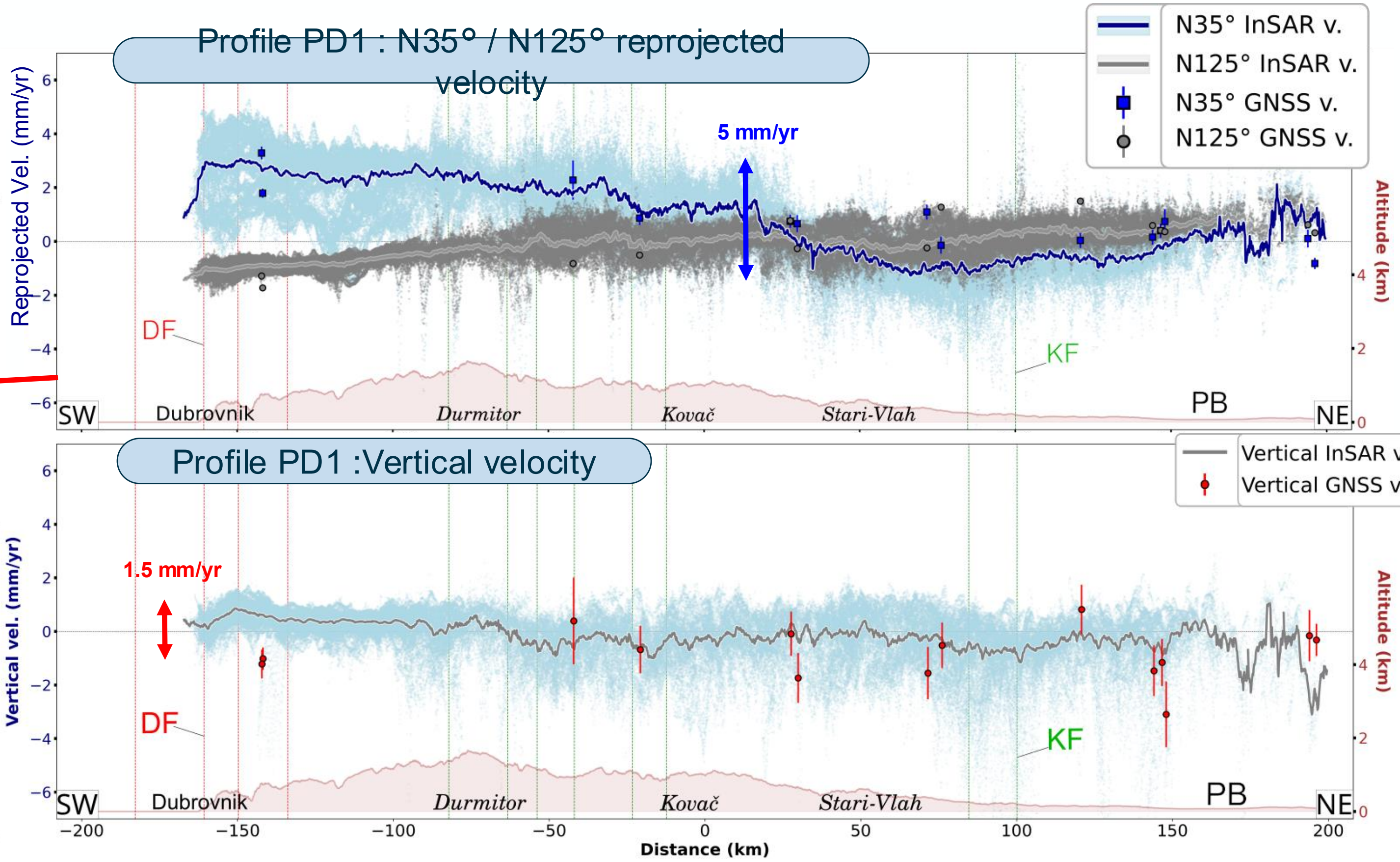
  Lithospheric-scale processes ?

- **~80 km-**long wavelength gradient of **~4 mm/yr** in Albanides

InSAR can catch a wide range of velocity gradients at various wavelengths

Low-strain area : The Dinarides

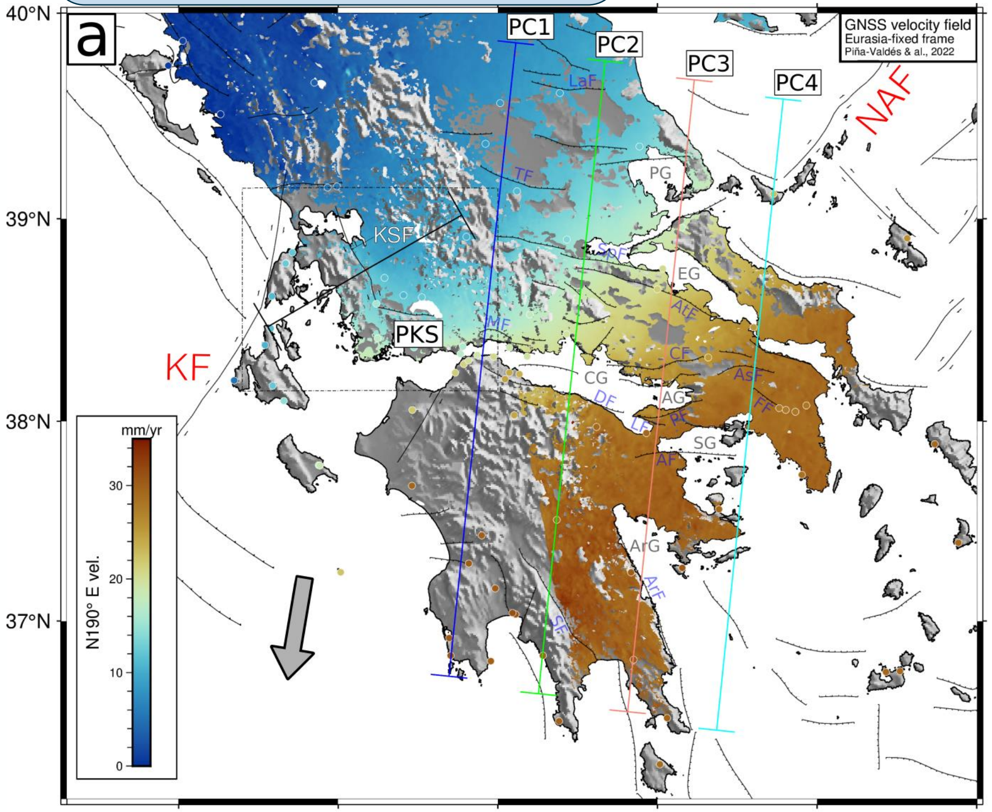




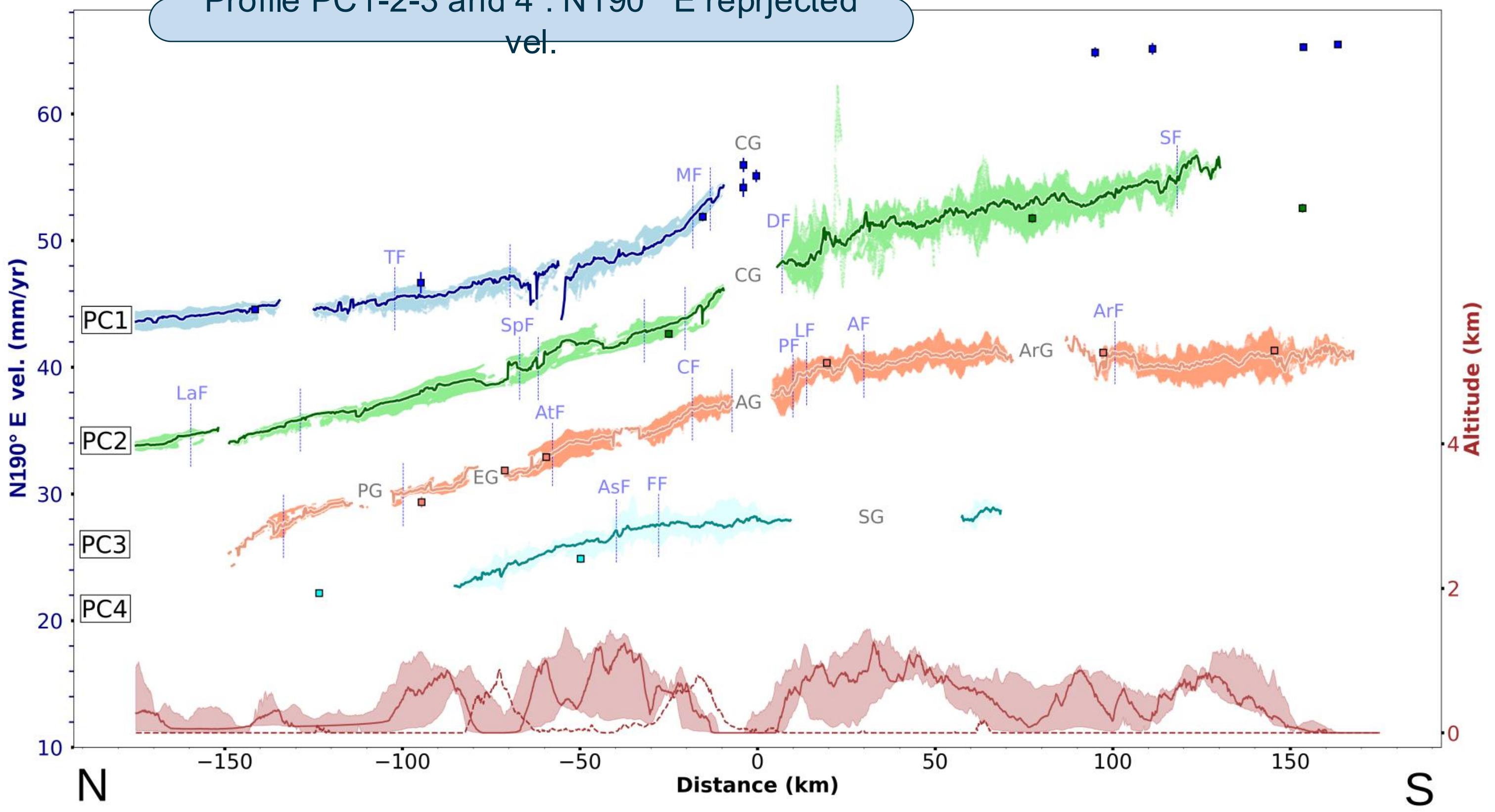
- **150 km-**long wavelength gradient of **5 mm/yr** on range-perpendicular component
- Potential uplift of **1–1.5 mm/yr** along the **southern Dinarides coast**

Really insensitive to NS-like deformation ?

N190° E InSAR velocity



Profile PC1-2-3 and 4 : N190° E reprjected vel.

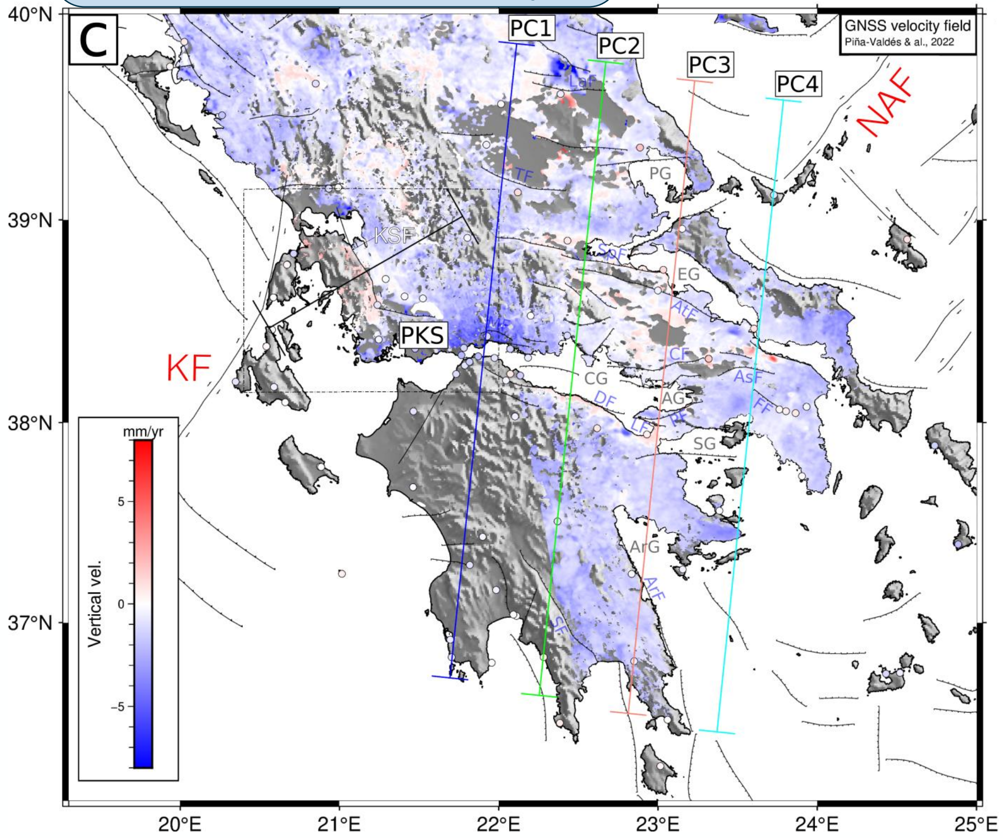


- PC1-2: rift-like deformation pattern, semi-arc tan shape north of Gulf of Corinth
- Good consistency with GNSS, coherent large-scale deformation trend

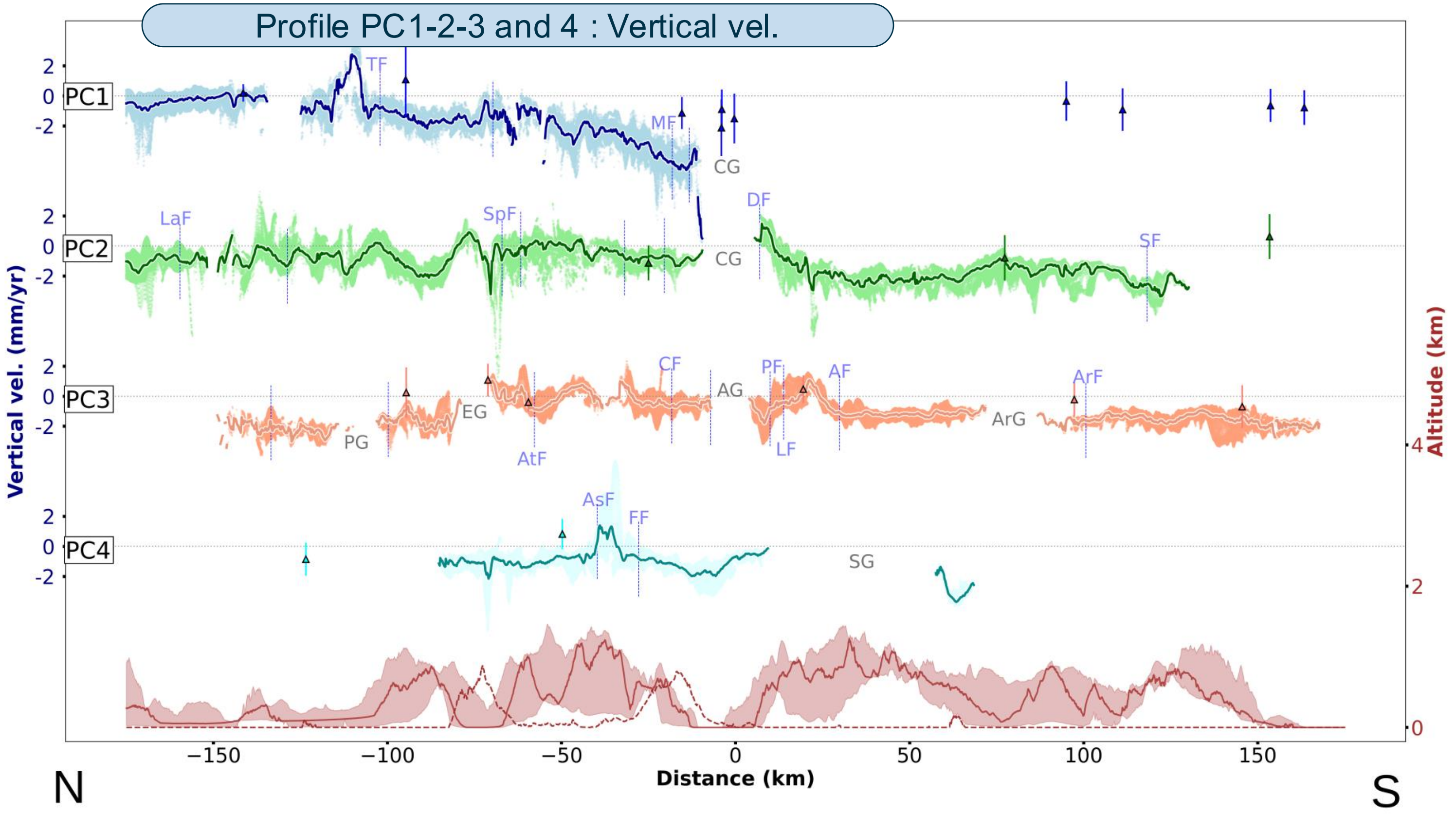
InSAR capability to capture along-track deformation, at mid-long wavelengths

Vertical deformation near Gulf of Corinth

Vertical InSAR velocity



Profile PC1-2-3 and 4 : Vertical vel.

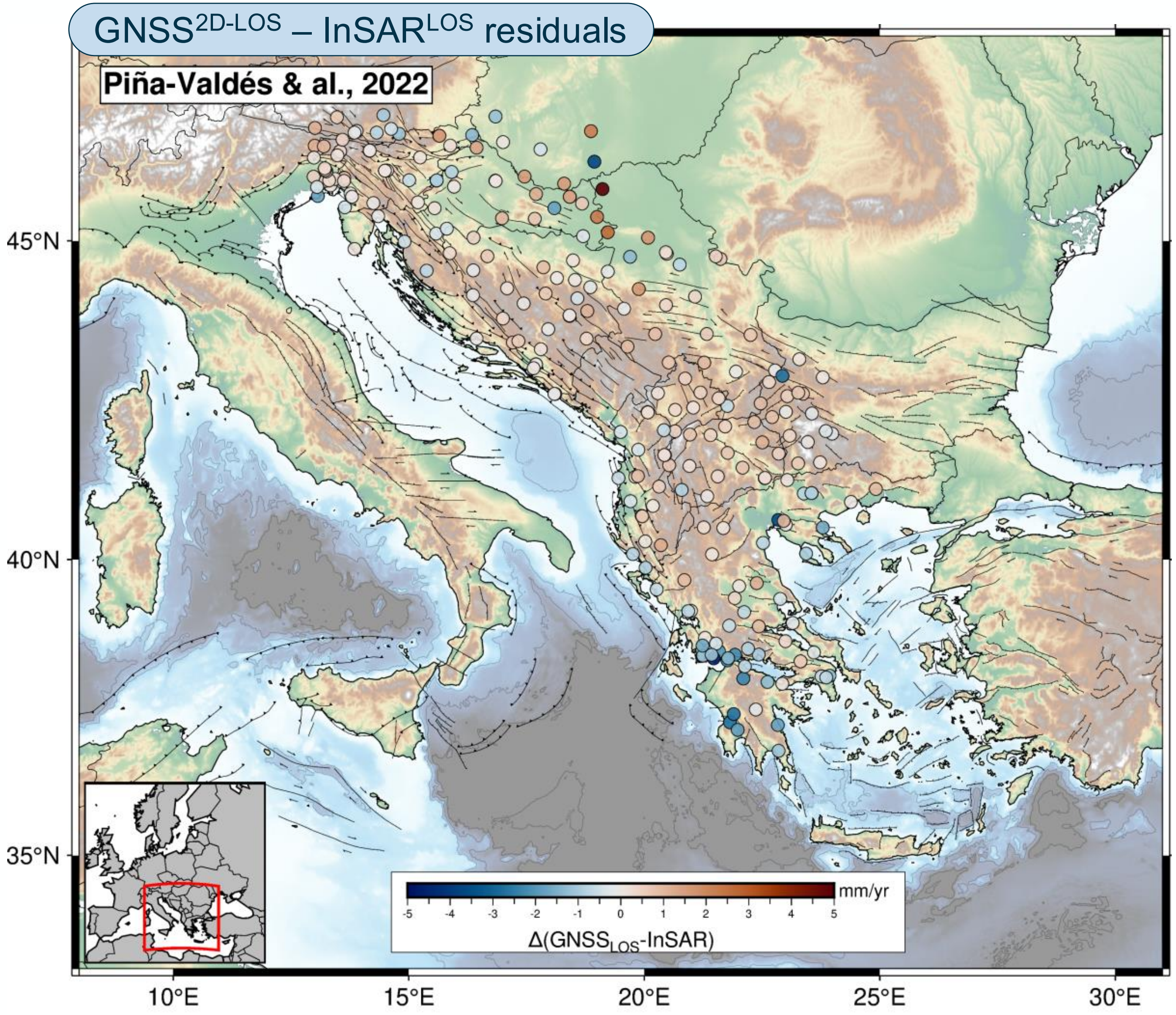


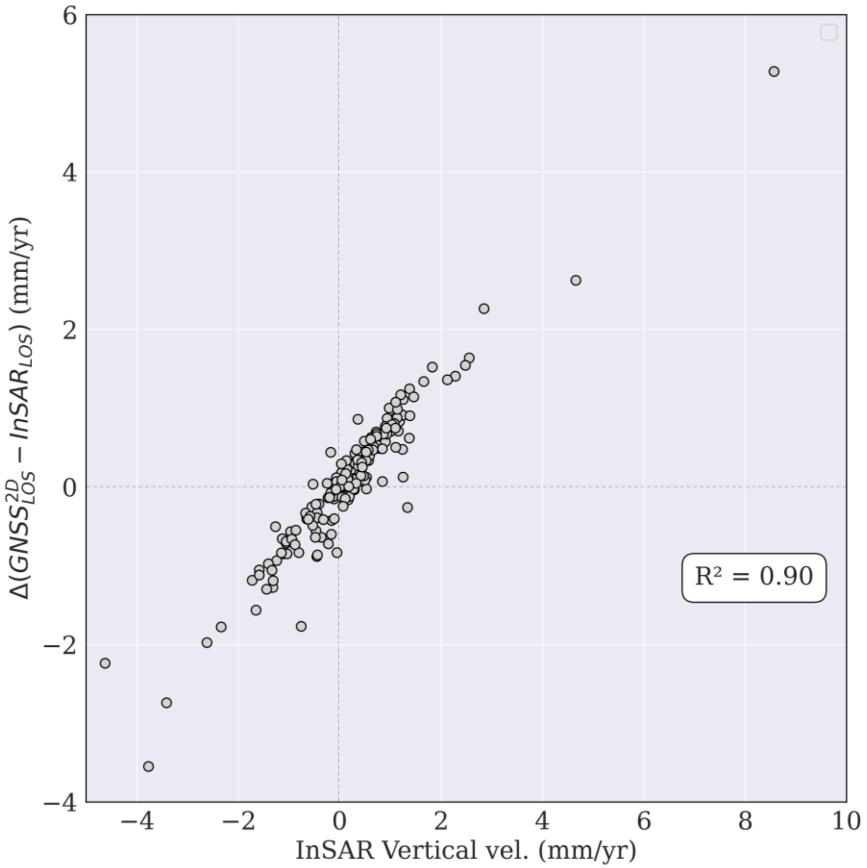
- Lateral variation of vertical velocities → High subsidence vel. (PC1 - PC2)
- Some discrepancies with GNSS vertical vel. near Gulf of Corinth

Does the discrepancies between GNSS and InSAR vel. are random ?

InSAR Vertical added-value

GNSS$^{2D\text{-}LOS}$ – InSAR^{LOS} residuals





Systematic GNSS–InSAR discrepancy where InSAR vertical deformation dominates

Take-home messages

LGL TPE

✓ **High-resolution referenced interseismic InSAR velocity field for Balkans Peninsula**

✓ **Remarkable GNSS-InSAR agreement** in challenging area (**low deformation rate**, low SNR, seasonal noise, co-seismic signals…)

✓ **NEW insights from InSAR :**

Wide range of **velocity gradients** (**few mm/yr** to #cm/yr) highlighted, of **tectonic** and **non-tectonic** origin

Added value in areas of high vertical motion (tectonic and anthropogenic deformation)

➢ **Perspectives :** Integration of InSAR velocity into **new strain rate calculation**

➢ **Meridi et al., 2026** (final review) / Open-access **ITRF LOS & ENU velocity maps on EaSyData** very soon

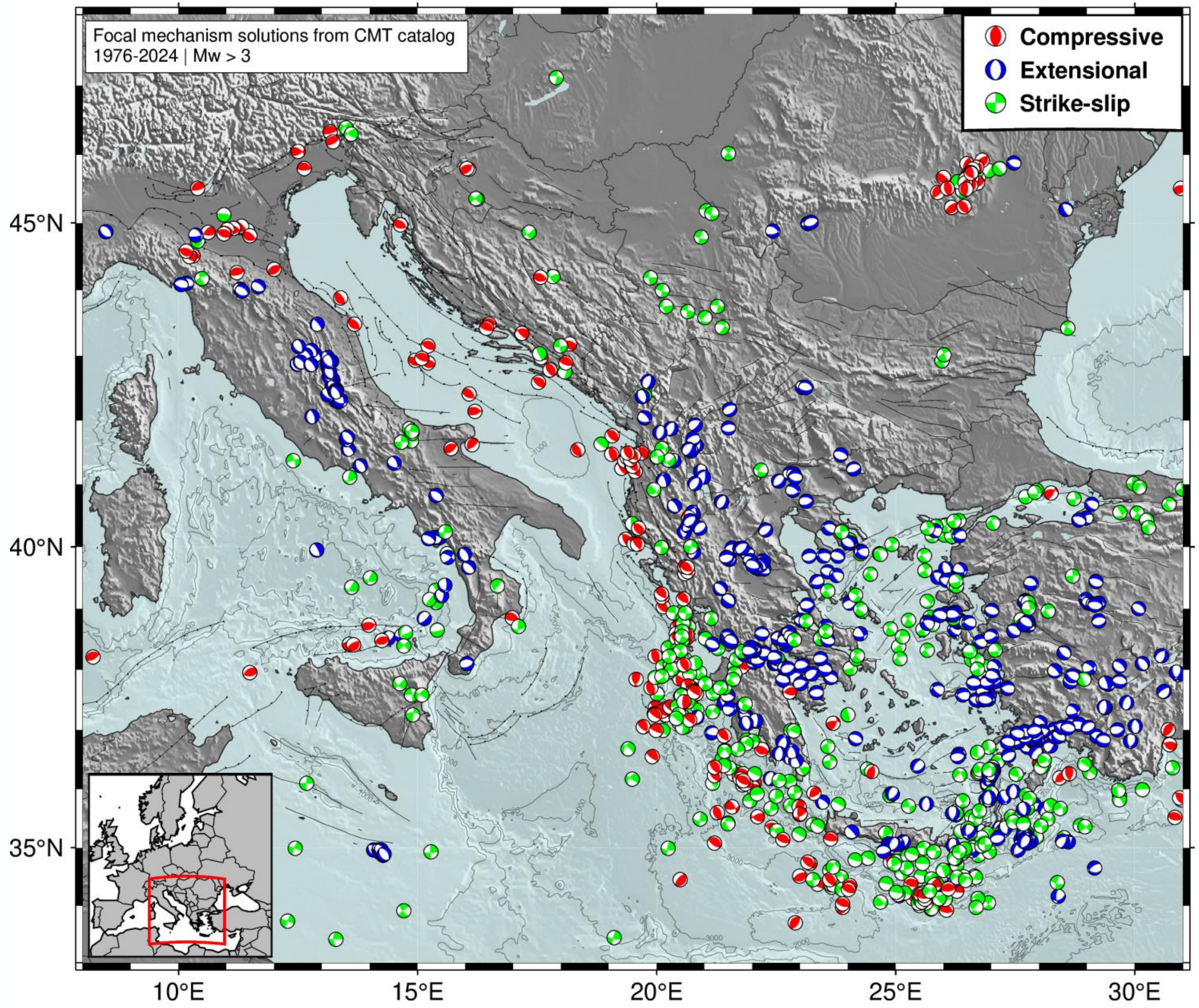
EaSy Data
Earth System Data Repository

Resolving Coseismic and Potential Postseismic Deformation of the 2019 Mw 6.4 Durrës Earthquake in Albania

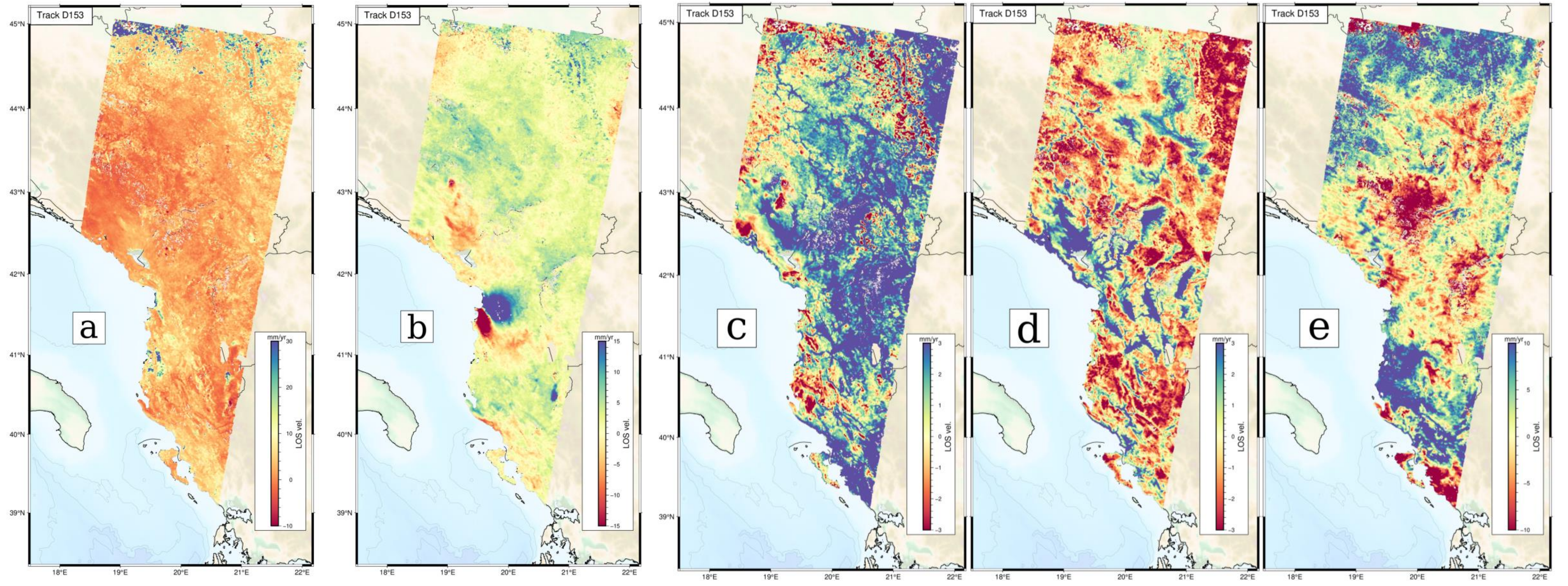
A. Meridi, C. Twardzik, M. Métois, C. Lasserre, M. Henriquet, Z. Dubois, R. Grandin

Session Poster 2
Board N°25

Thank you for your attention !



Focal mechanism solutions from CMT catalog
1976-2024 | Mw > 3
Compressive
Extensional
Strike-slip
45°N
40°N
35°N
10°E
15°E
20°E
25°E
30°E



Track D153
a
b
c
d
e
45°N
44°N
43°N
42°N
41°N
40°N
39°N
18°E
19°E
20°E
21°E
22°E
mm/yr
LOS vel.

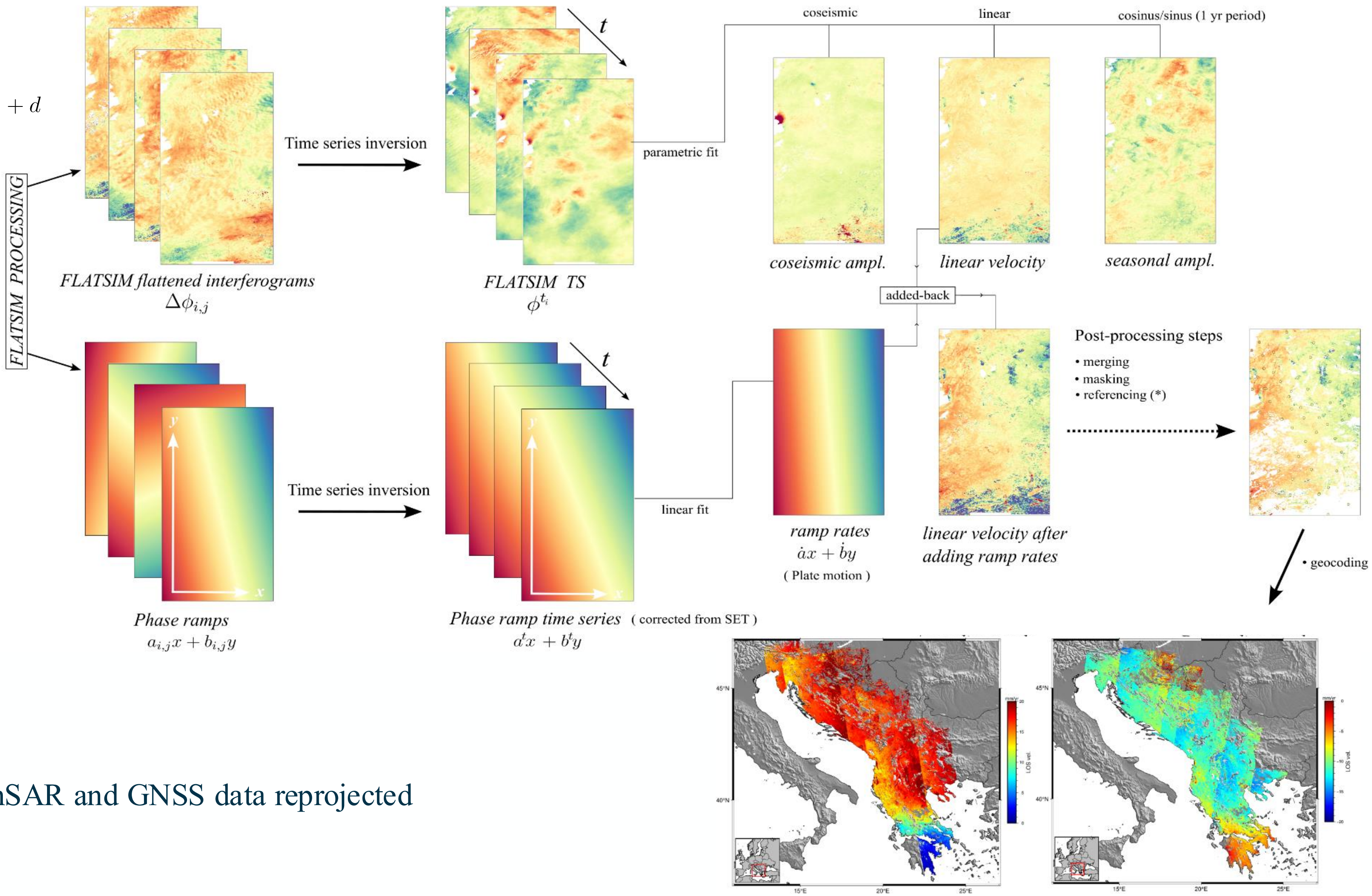
Referencing workflow derived from Lemrabet et al. (2023)

- Interseismic velocity estimated from parametric decomposition

$$\phi_{\text{model}}(t) = V \cdot t + \sum_{i=1}^{N} c_i \cdot H(t - t_i) + A \cdot \cos\left(\frac{2\pi \cdot t}{T}\right) + B \cdot \sin\left(\frac{2\pi \cdot t}{T}\right) + d$$

- InSAR data priori relative in time and space measurements

- **referenced to ITRF 2014** (Altimimi et al., 2016)



Aim : demonstrate that phase gradients derived from InSAR and GNSS data reprojected in ITRF14 have consistent magnitudes. (6)

- Interseismic velocity estimated from parametric decomposition

$$\phi_{\text{model}}(t) = V \cdot t + \sum_{i=1}^{N} c_i \cdot H(t-t_i) + A \cdot \cos\left(\frac{2\pi \cdot t}{T}\right) + B \cdot \sin\left(\frac{2\pi \cdot t}{T}\right) + d$$

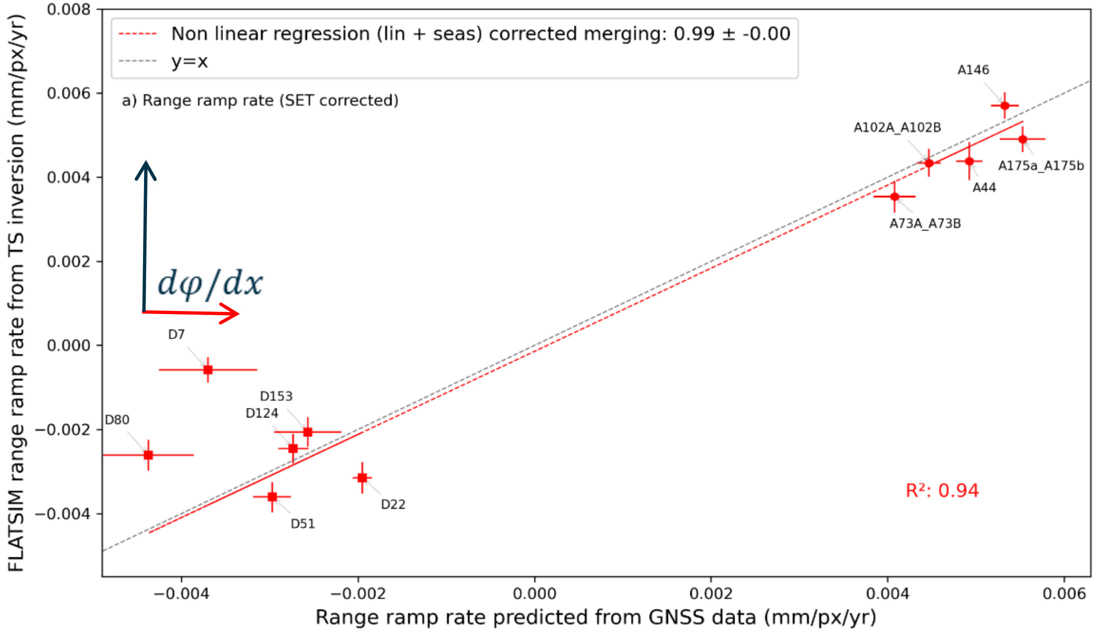
- InSAR data priori relative in time and space measurements

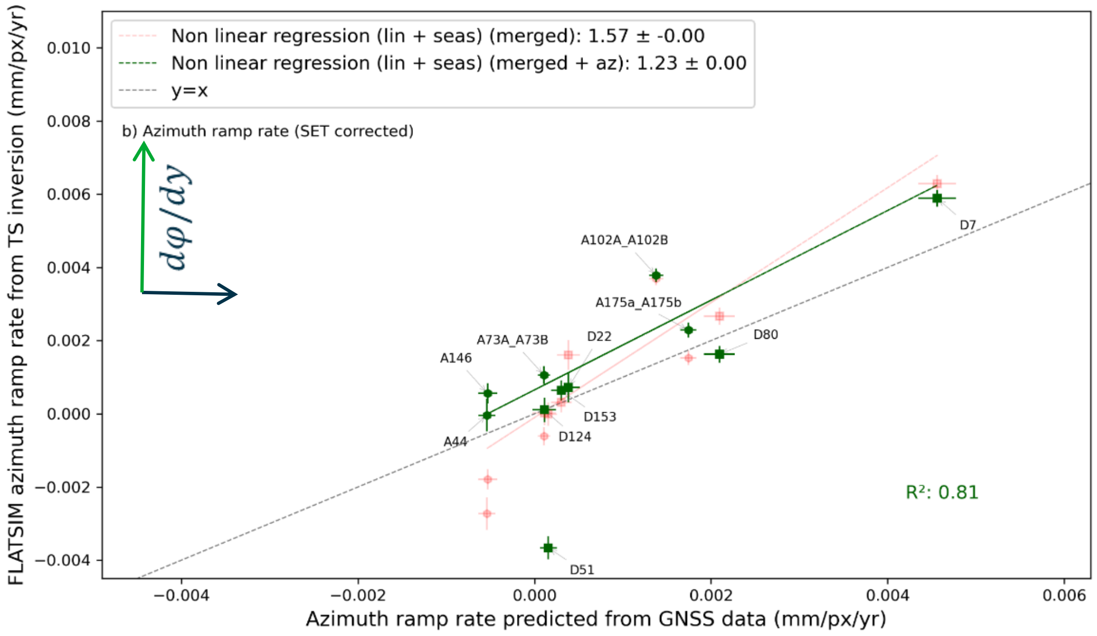
Aim : demonstrate that phase gradients derived from InSAR and GNSS data reprojected **in ITRF14** (Altimimi et al., 2016) have consistent magnitudes.

- Ramp rates significantly correlated in range direction

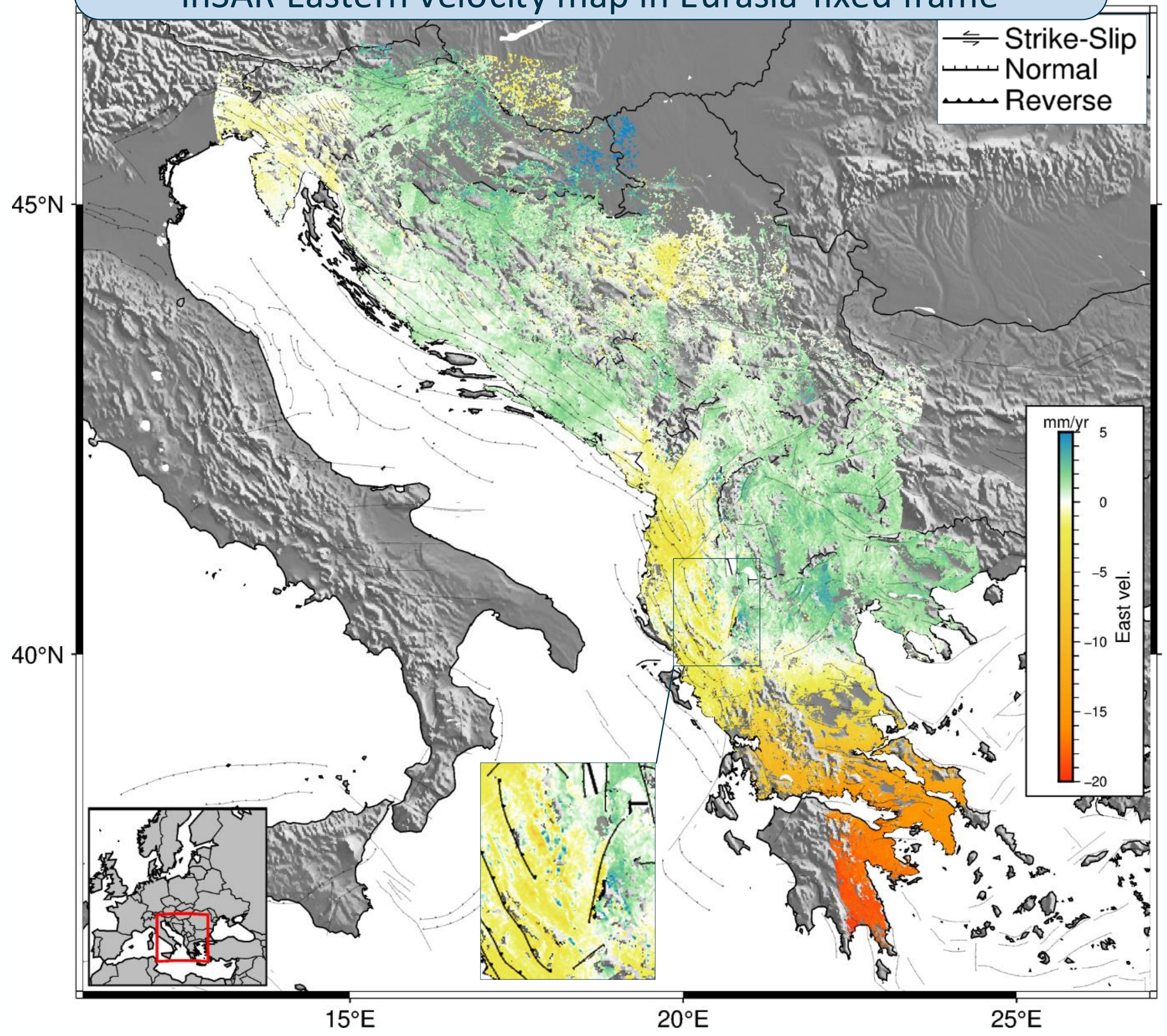
- Less constrained in azimuth direction

Reinjection of FLATSIM ramp rates, containing the plate motion signal at large-scale



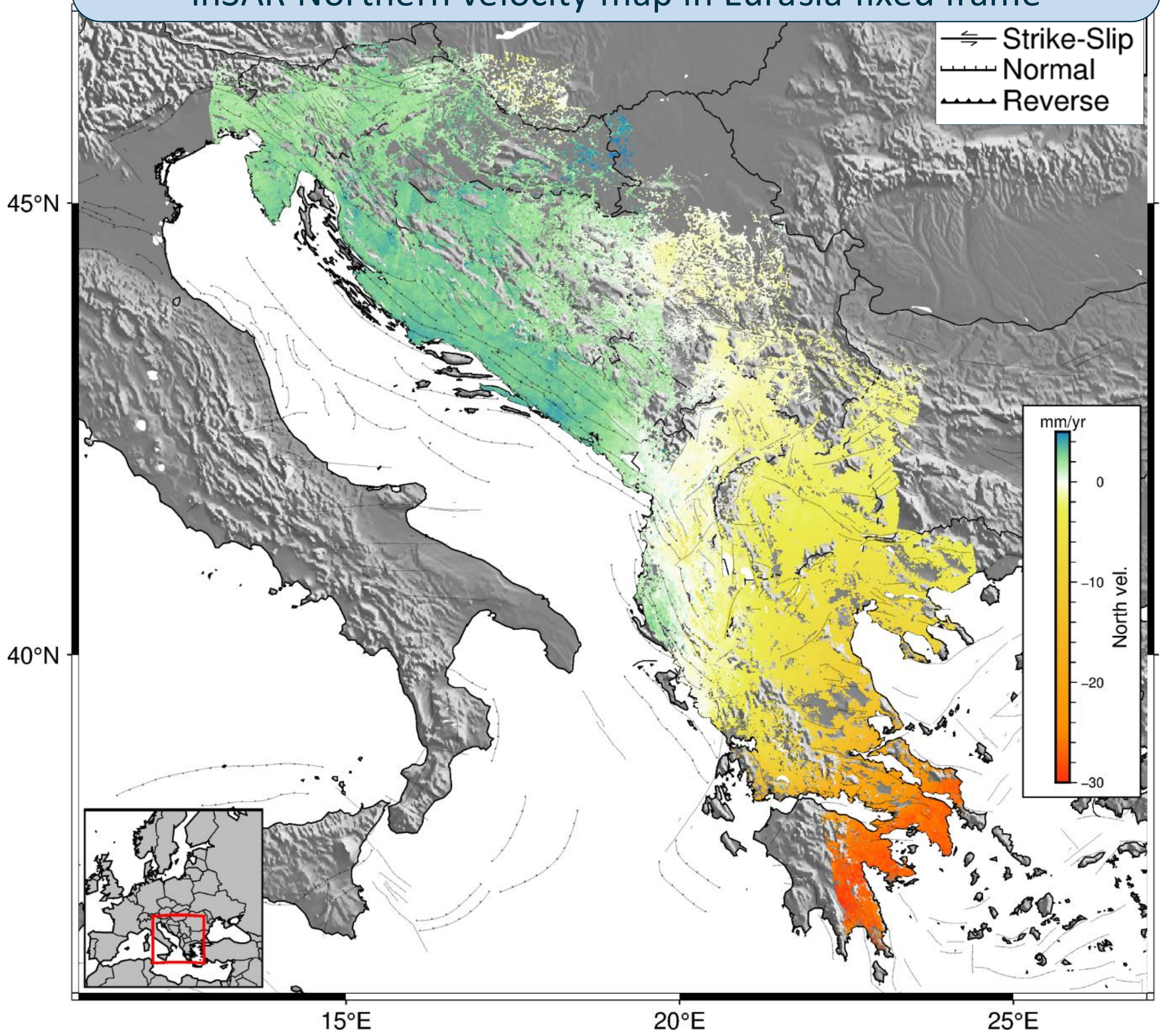


InSAR Eastern velocity map in Eurasia-fixed frame

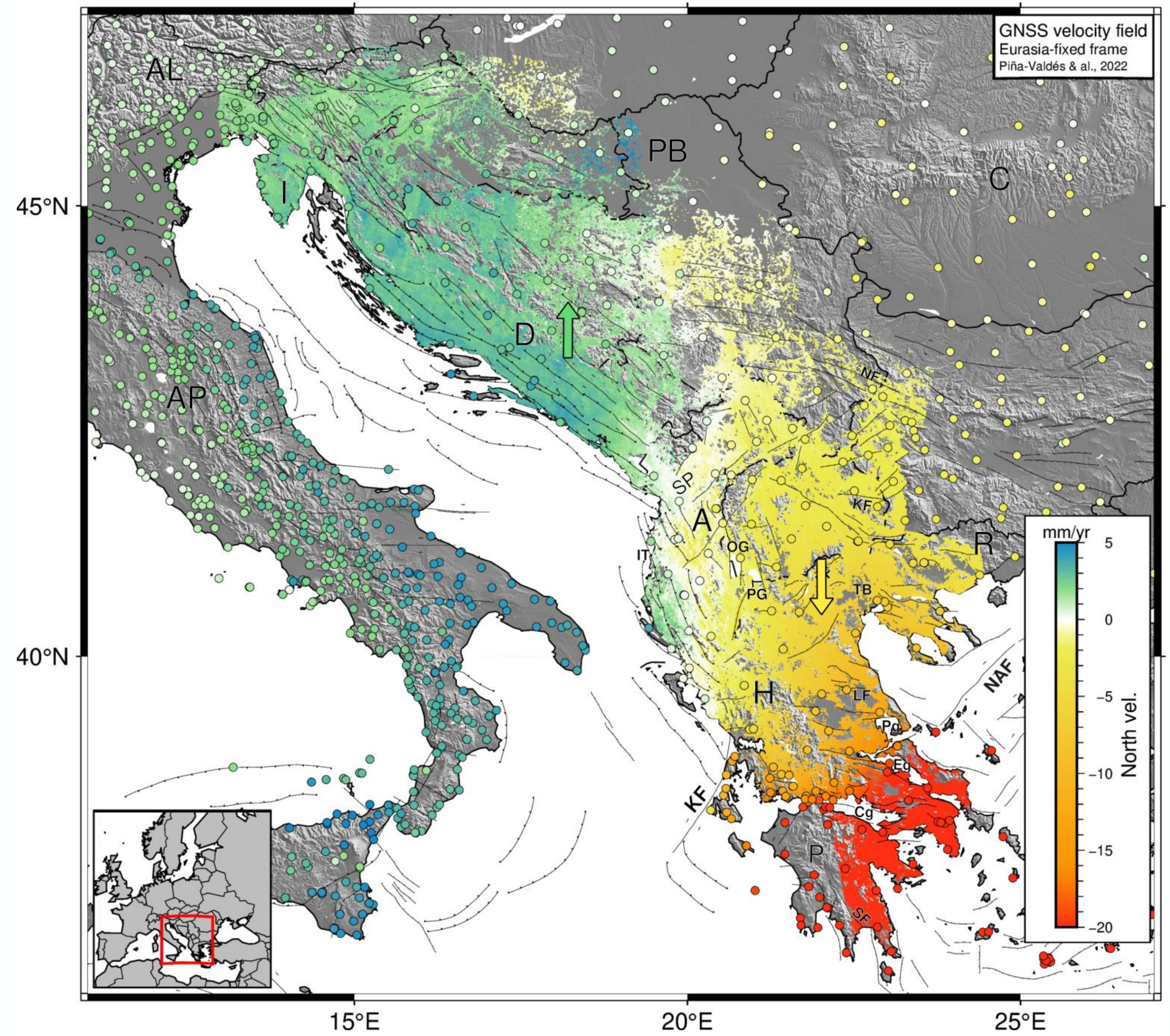


- Localization of transtension refined in inner Albanides
- Localized gravitational patterns / Sharp signals

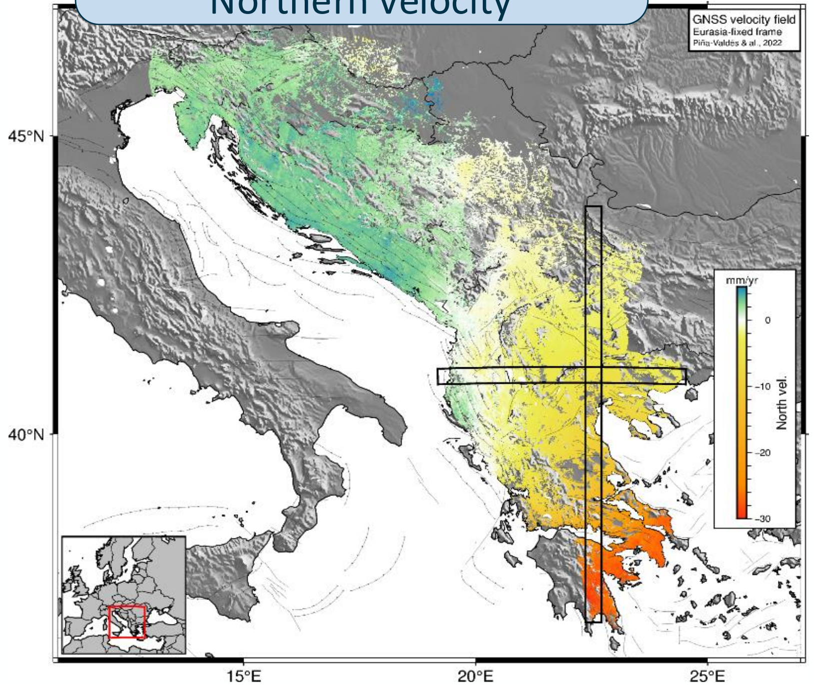
InSAR Northern velocity map in Eurasia-fixed frame



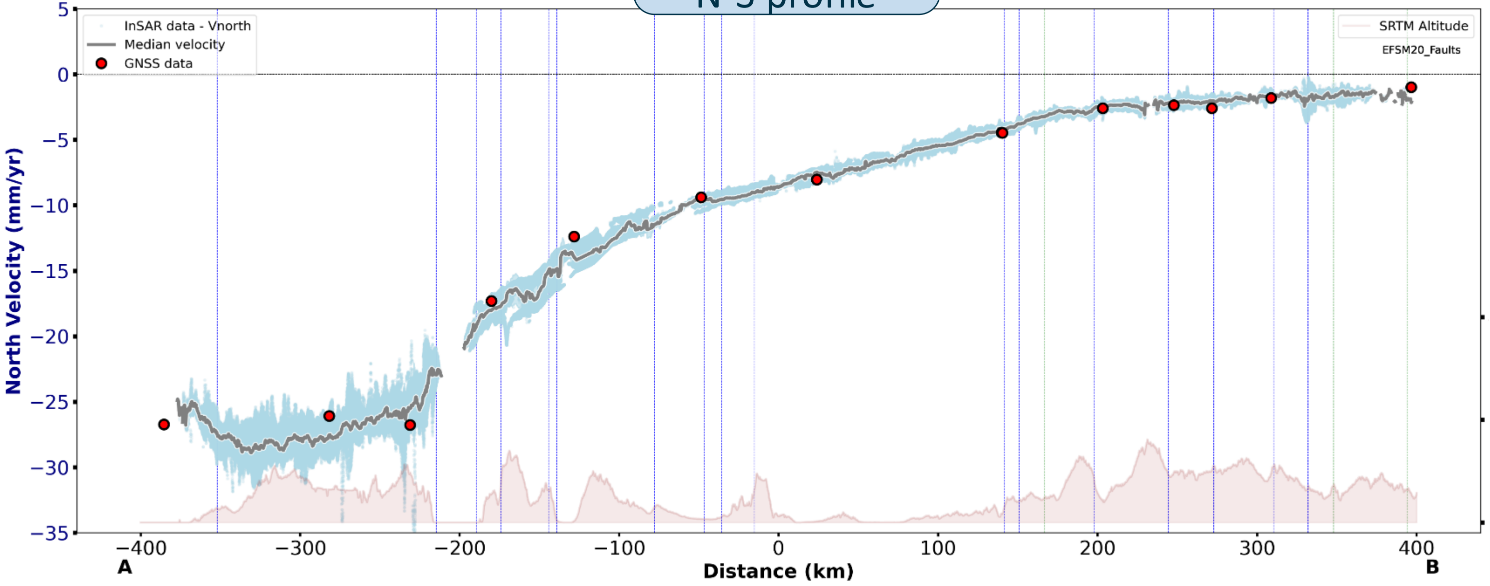
- Large area accommodates the shear deformation
- Bulges of higher NE + slight uplift vel. in South Dinarides


GNSS velocity field
Eurasia-fixed frame
Piña-Valdés & al., 2022
AL
PB
C
I
45°N
D
AP
NF
SP
KF
A
OG
IT
R
PG
TB
40°N
NAF
H
LF
Pg
Eg
KF
Cg
P
SF
mm/yr
5
0
−5
−10
−15
−20
North vel.
15°E
20°E
25°E

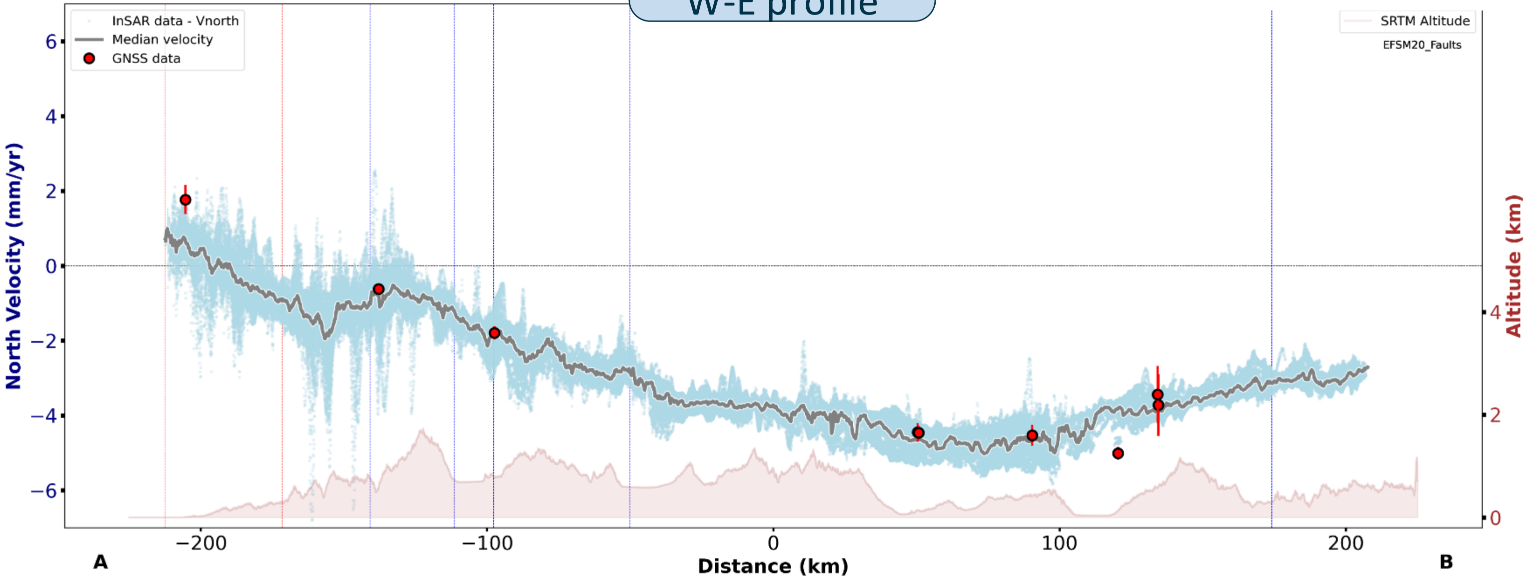
Northern velocity



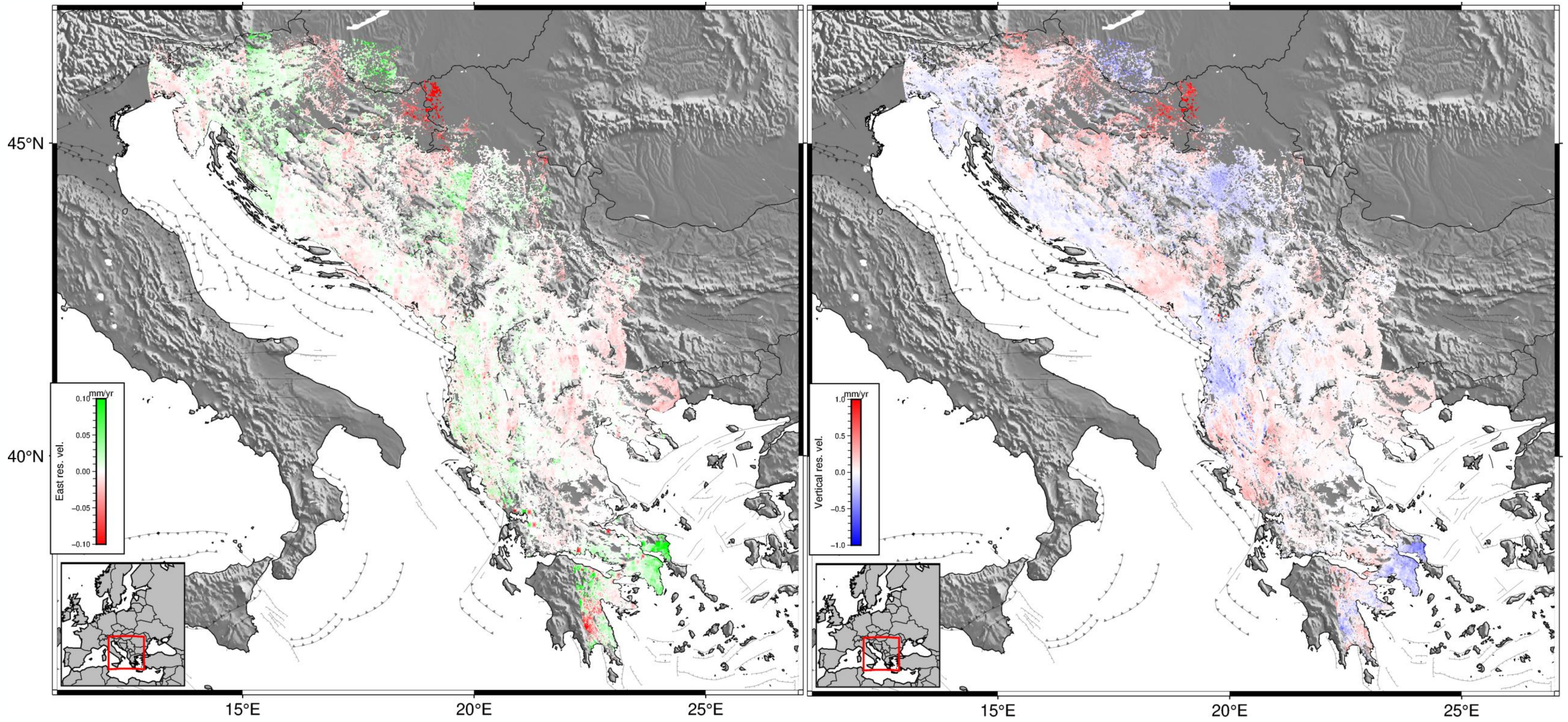
N-S profile



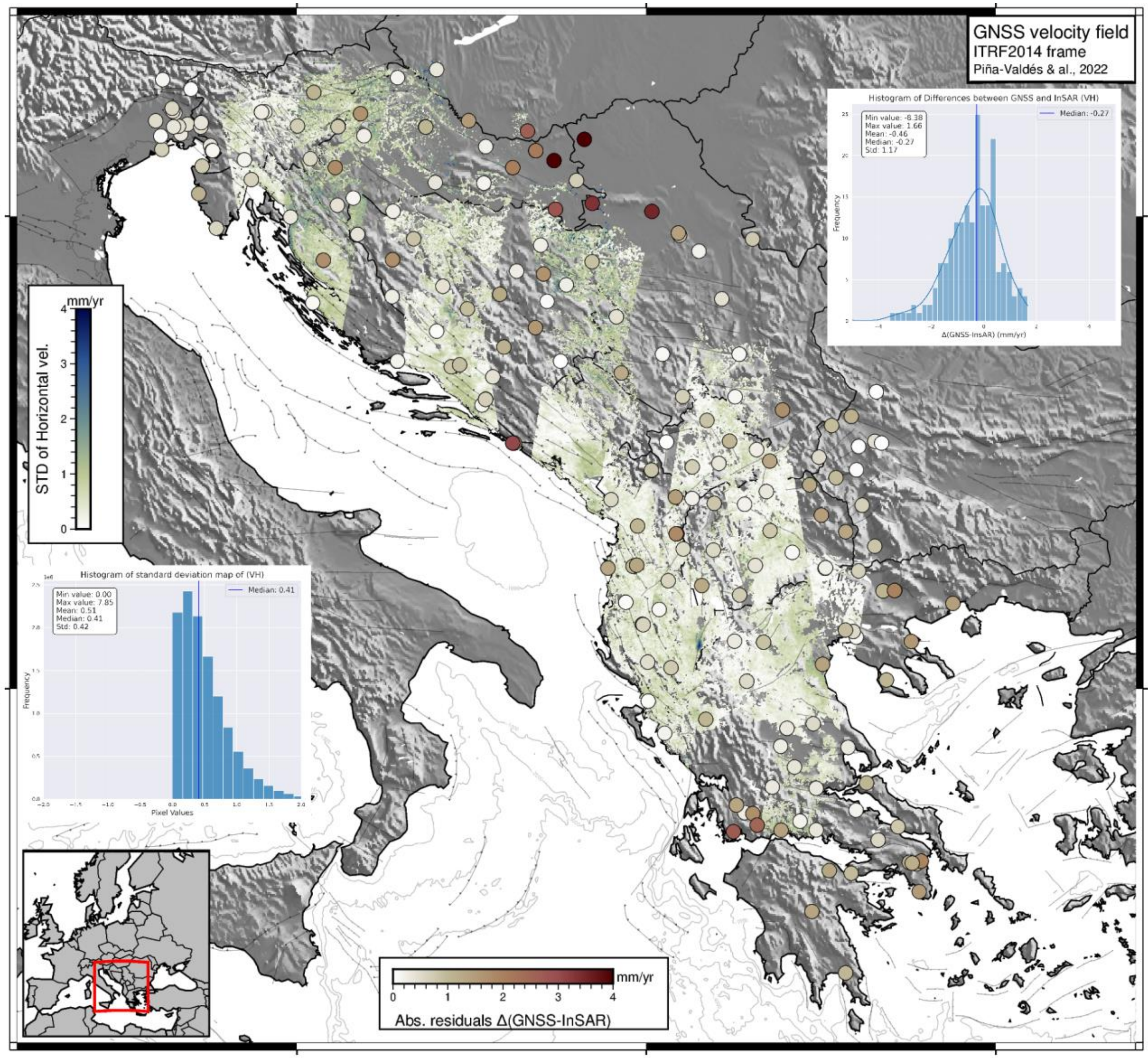
W-E profile

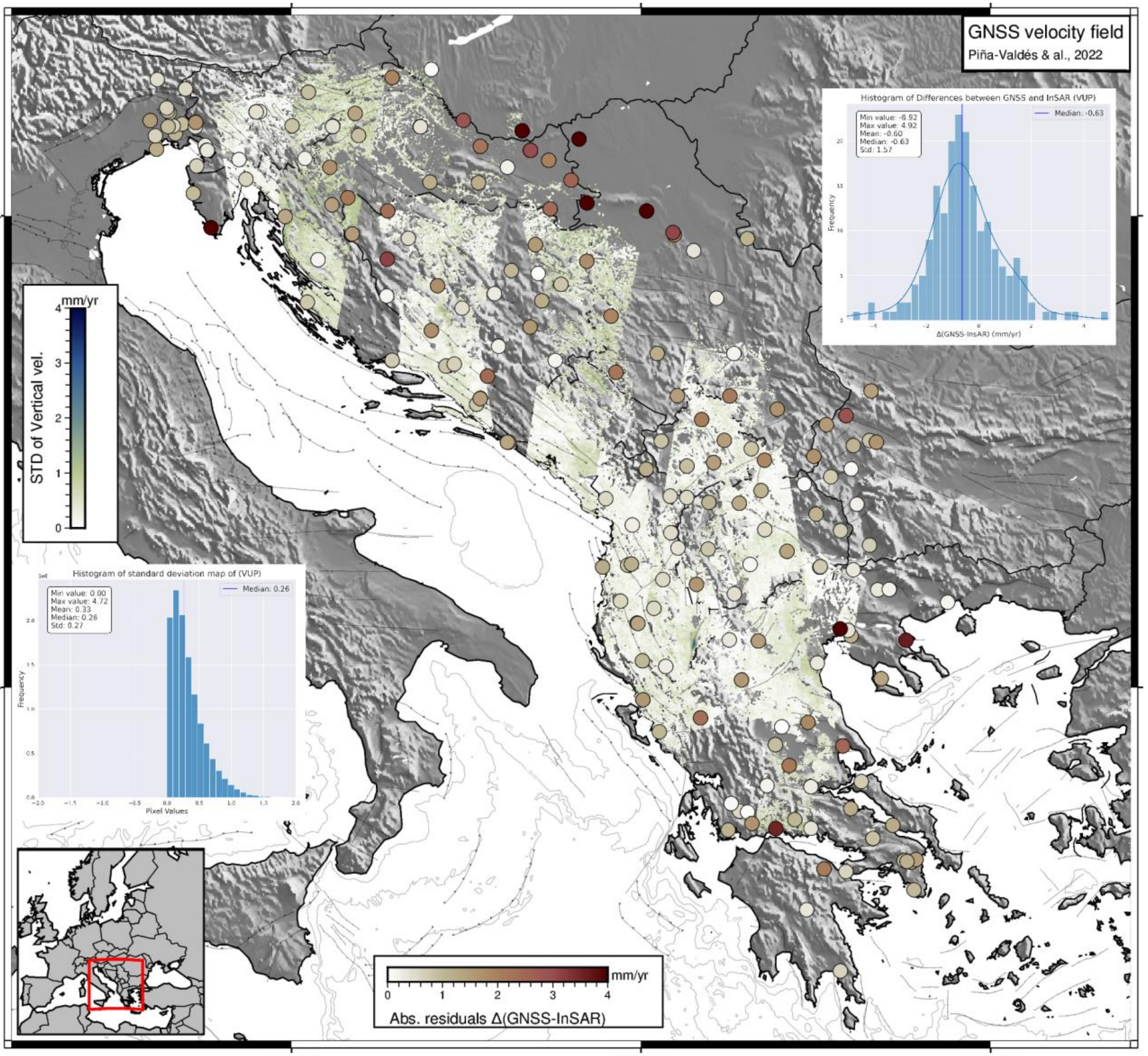


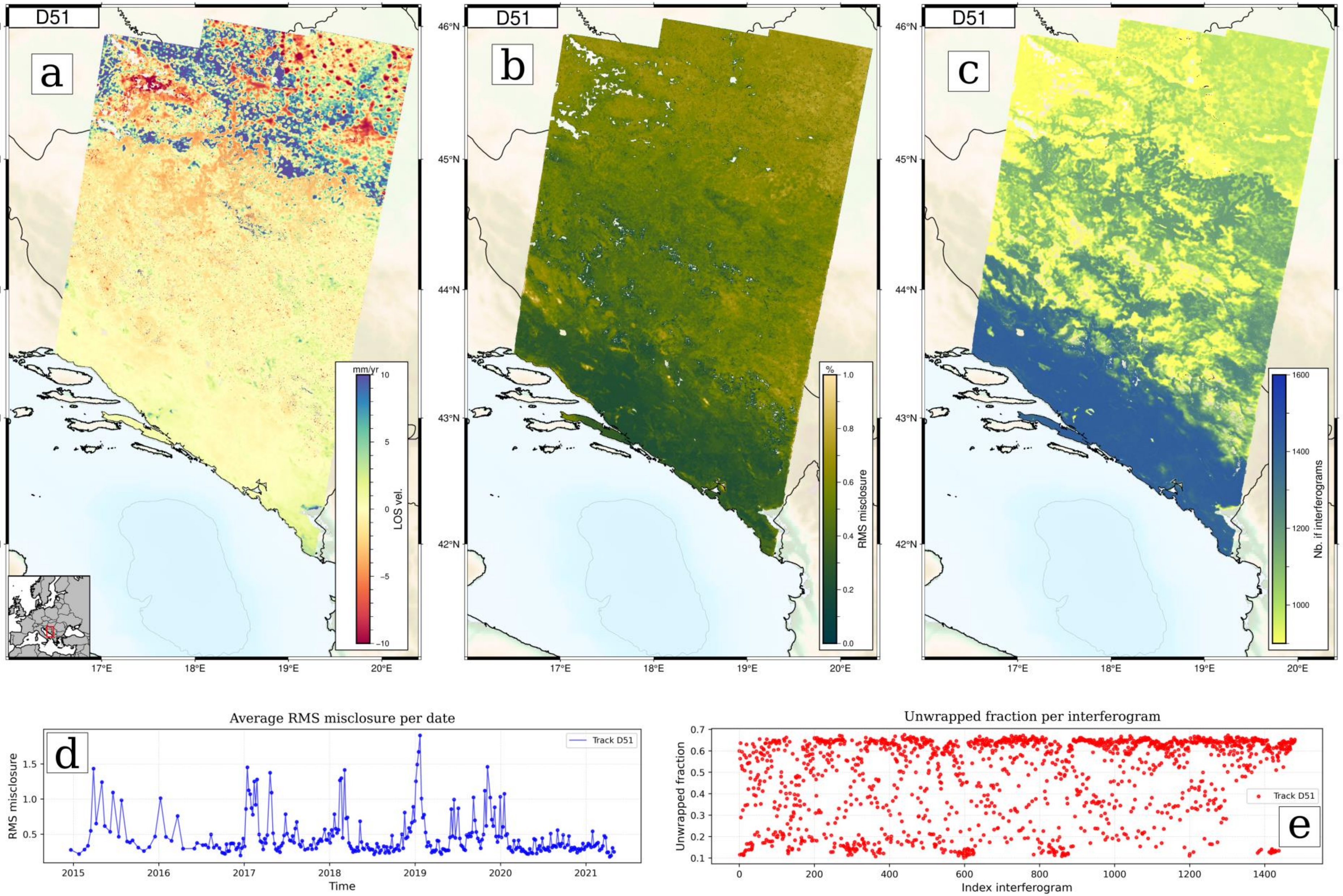
- North velocity consistent with GNSS
- InSAR ability to catch NS component at long wave-length



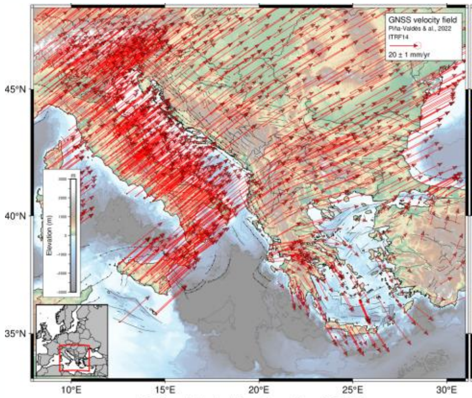
Present-Day Kinematics of Western Greece and the Balkans Revealed by Sentinel-1 InSAR Data


GNSS velocity field
ITRF2014 frame
Piña-Valdés & al., 2022
Histogram of Differences between GNSS and InSAR (VH)
Median: -0.27
Min value: -8.38
Max value: 1.66
Mean: -0.46
Median: -0.27
Std: 1.17
Frequency
Δ(GNSS-InSAR) (mm/yr)
mm/yr
STD of Horizontal vel.
Histogram of standard deviation map of (VH)
Median: 0.41
Min value: 0.00
Max value: 7.85
Mean: 0.51
Median: 0.41
Std: 0.42
Frequency
Pixel Values
45°N
40°N
15°E
20°E
25°E
mm/yr
Abs. residuals Δ(GNSS-InSAR)

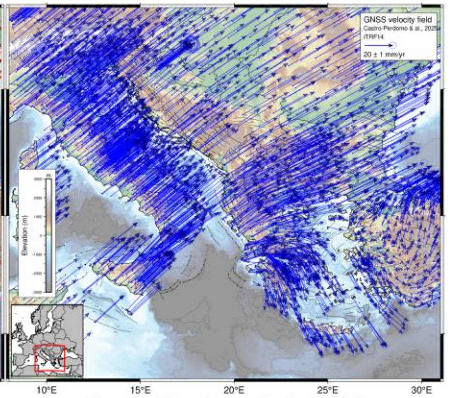

GNSS velocity field
Piña-Valdés & al., 2022
Histogram of Differences between GNSS and InSAR (VUP)
Median: -0.63
Min value: -8.92
Max value: 4.92
Mean: -0.60
Median: -0.63
Std: 1.57
Frequency
Δ(GNSS-InSAR) (mm/yr)
mm/yr
STD of Vertical vel.
Histogram of standard deviation map of (VUP)
Median: 0.26
Min value: 0.00
Max value: 4.72
Mean: 0.33
Median: 0.26
Std: 0.27
Frequency
Pixel Values
15°E
20°E
25°E
mm/yr
Abs. residuals Δ(GNSS-InSAR)



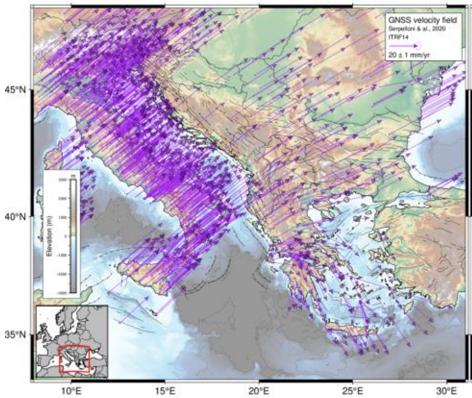
Present-Day Kinematics of Western Greece and the Balkans Revealed by Sentinel-1 InSAR Data



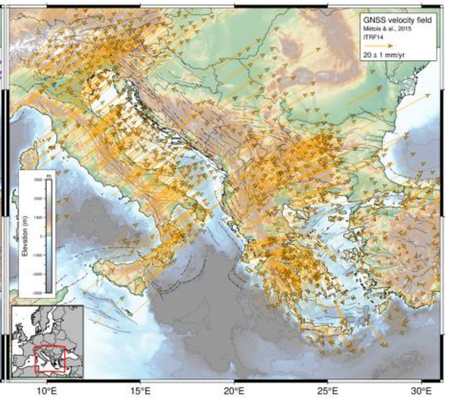
Piña-Valdés & al., 2022



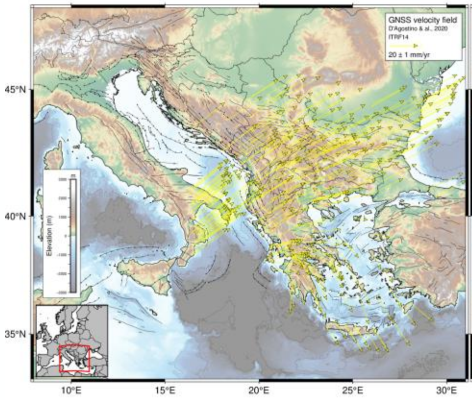
Castro-Perdomo & al., 2025



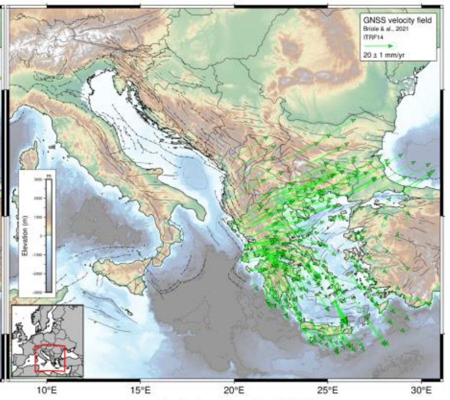
Serpelloni & al., 2022



Métois & al., 2015



D'Agostino & al., 2020



Briole & al., 2021