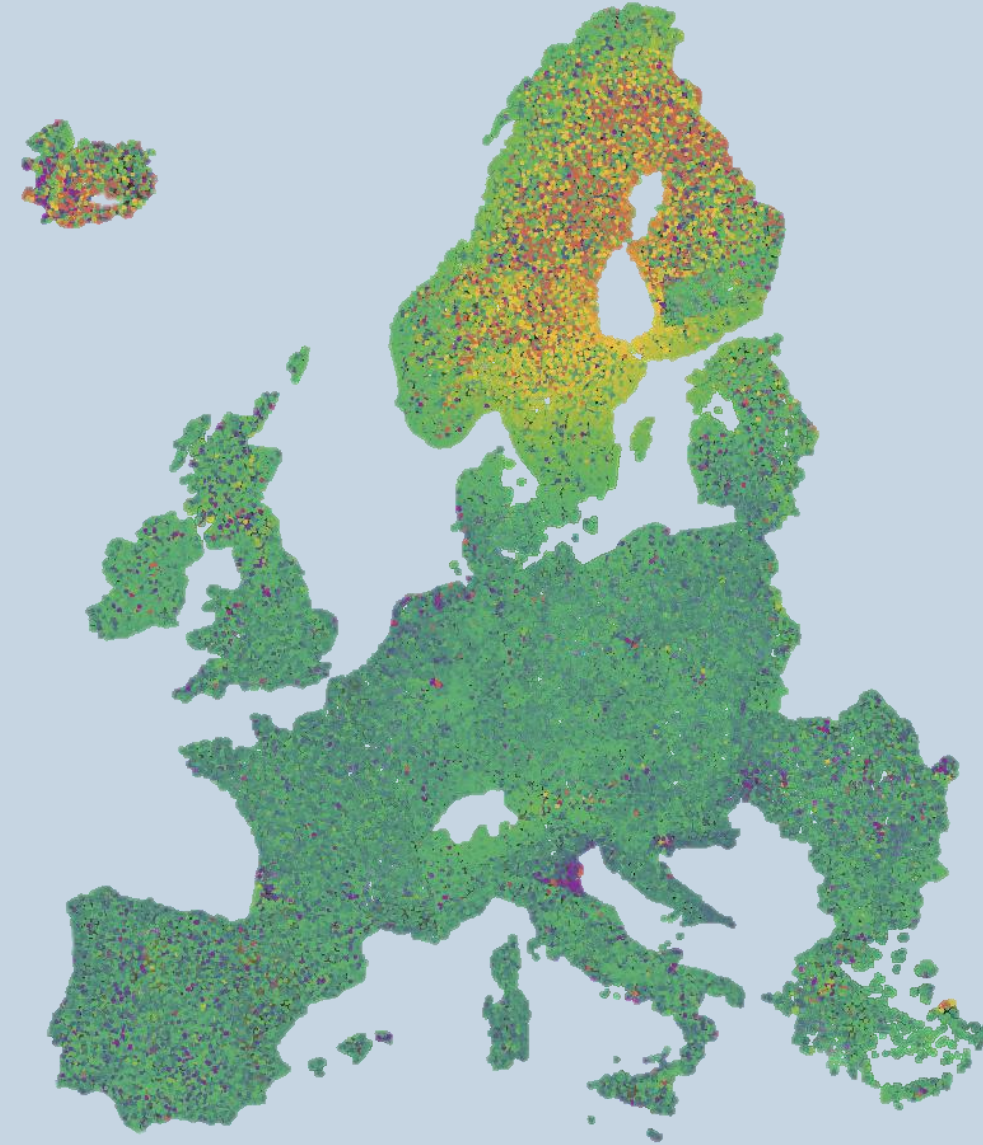


Exploiting Sentinel-1 burst overlaps for the reference frame connection of InSAR time series

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DI RIPRESA E RESILIENZA

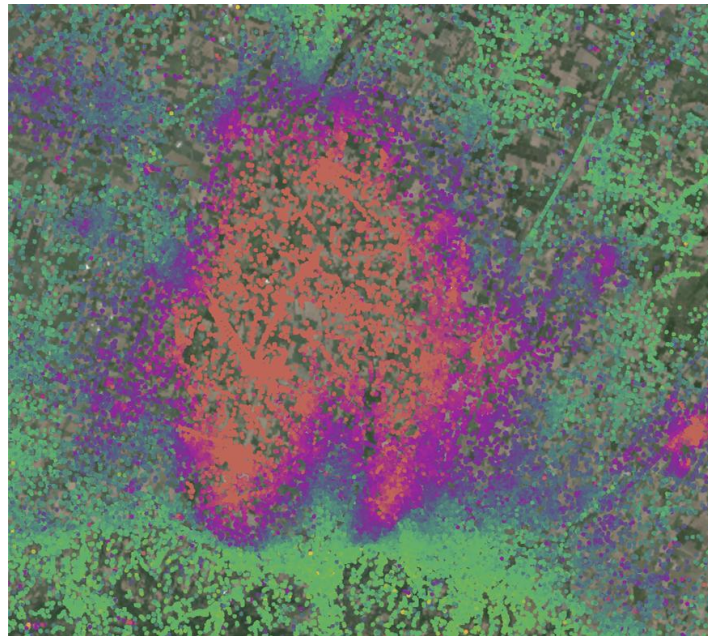


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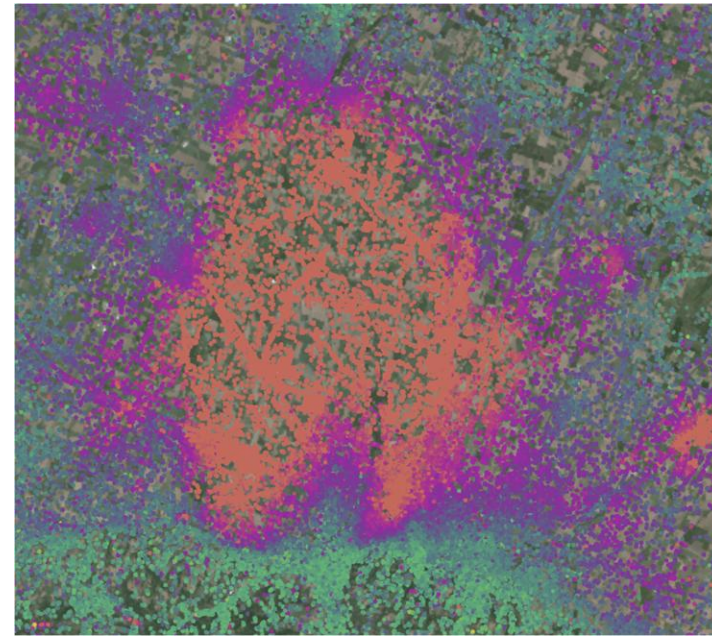
Reference frame connection of InSAR time series

InSAR displacement measurements are inherently **double-differenced**:

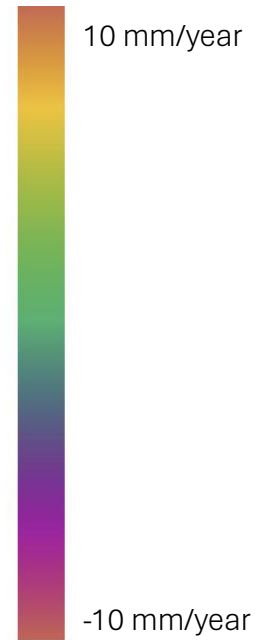
- **In time**: with respect to a **reference epoch**
- **In space**: with respect to a chosen **reference pixel/area**



Subsidence near Bologna, EGMS Basic product



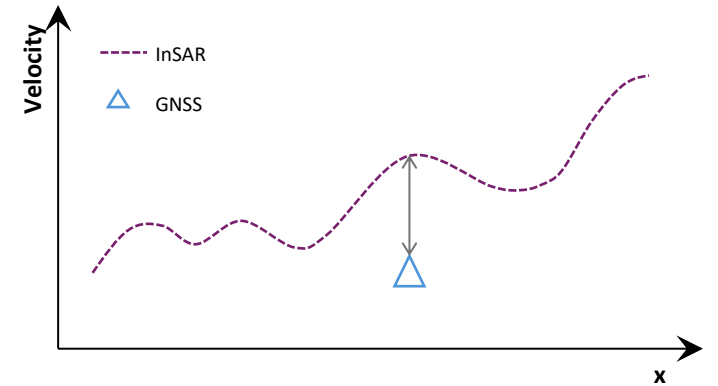
Subsidence near Bologna, EGMS Calibrated product



Reference frame connection of InSAR time series

To estimate **line of sight** (LOS) displacements in an **absolute reference frame** using InSAR measurements, complementary geodetic techniques (e.g., **GNSS** and **levelling**) are commonly used. Main strategies include (Johnston et al., 2021):

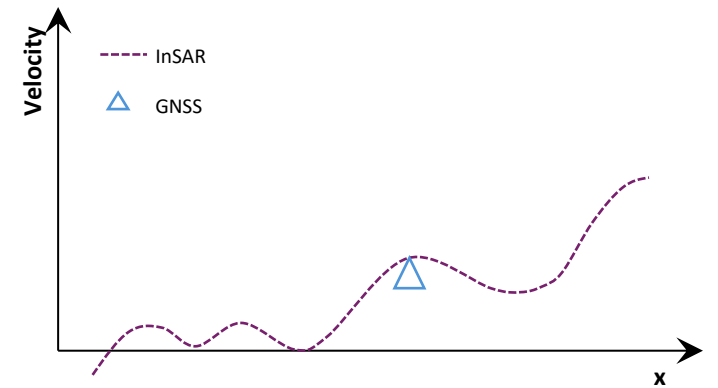
1. Assigning a **unique velocity value**/displacement time series to the reference pixel using one or multiple GNSS stations



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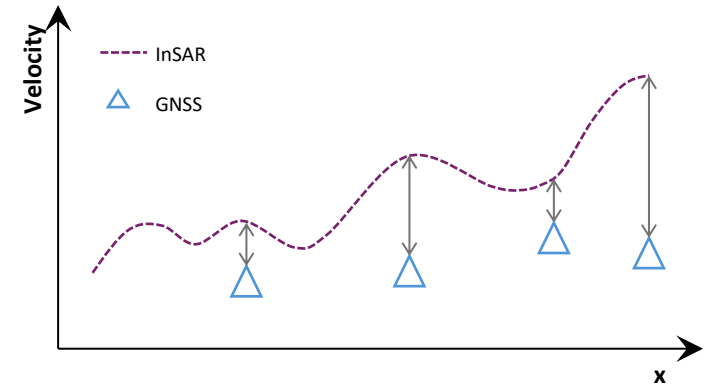
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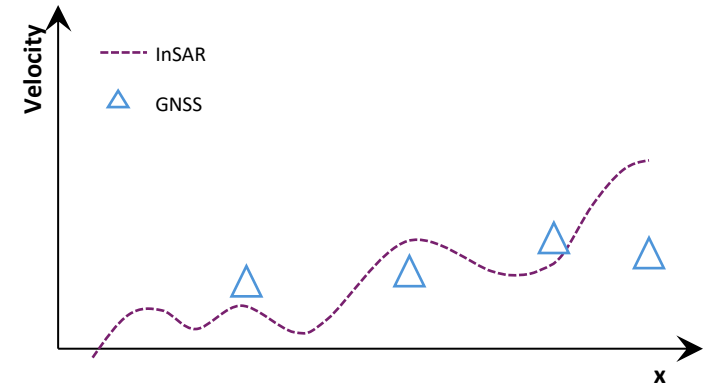
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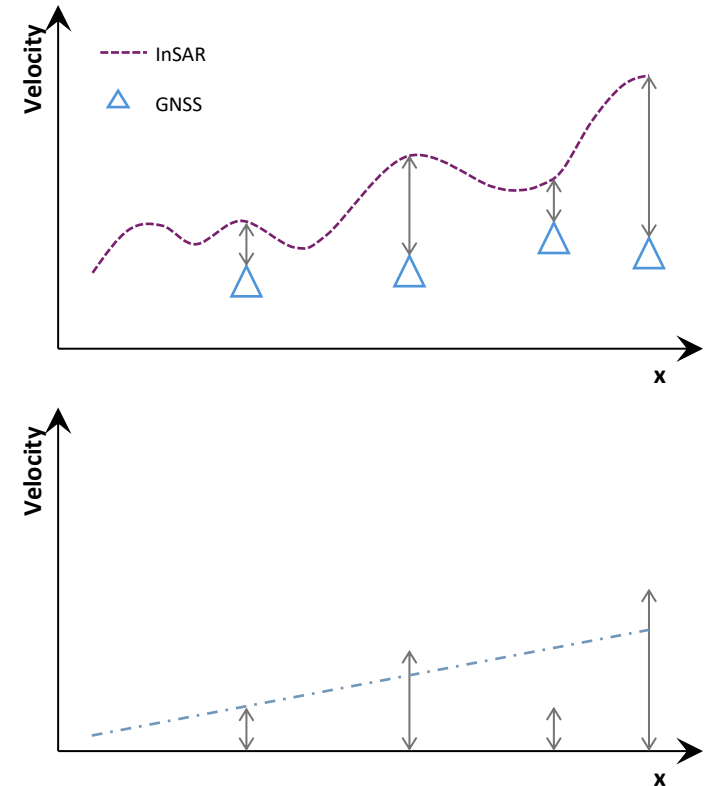
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Reference frame connection of InSAR time series

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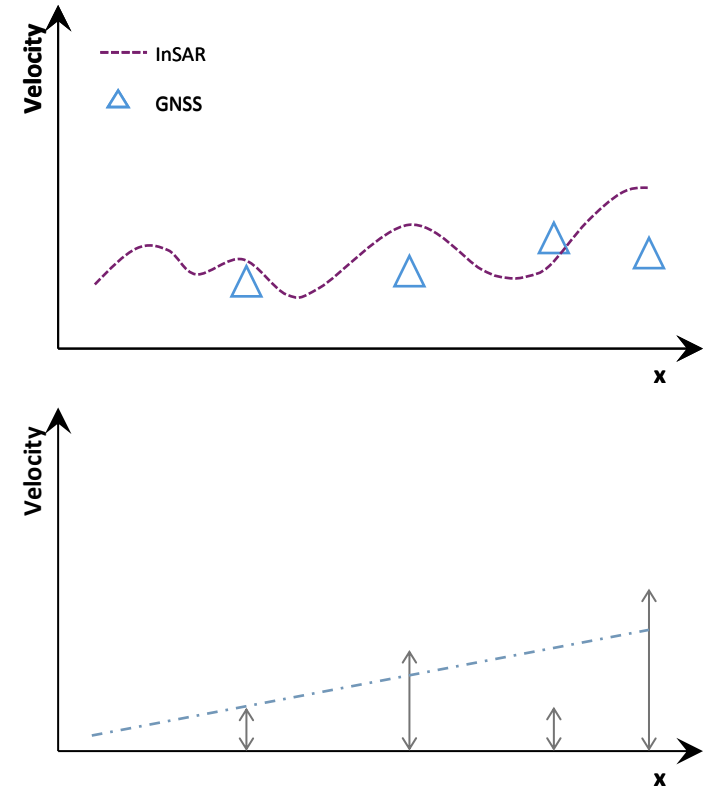
1. Assigning a **unique velocity value**/displacement time series to the reference pixel using one or multiple GNSS stations
2. Estimating a **reference surface** across the image area based on multiple stations



Reference frame connection of InSAR time series

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1. Assigning a **unique velocity value**/displacement time series to the reference pixel using one or multiple GNSS stations
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Connection and deramping leveraging burst overlaps

Between epochs t_0 and t_1 , point P undergoes a displacement:

$$d_p = (e_p, n_p, u_p)$$

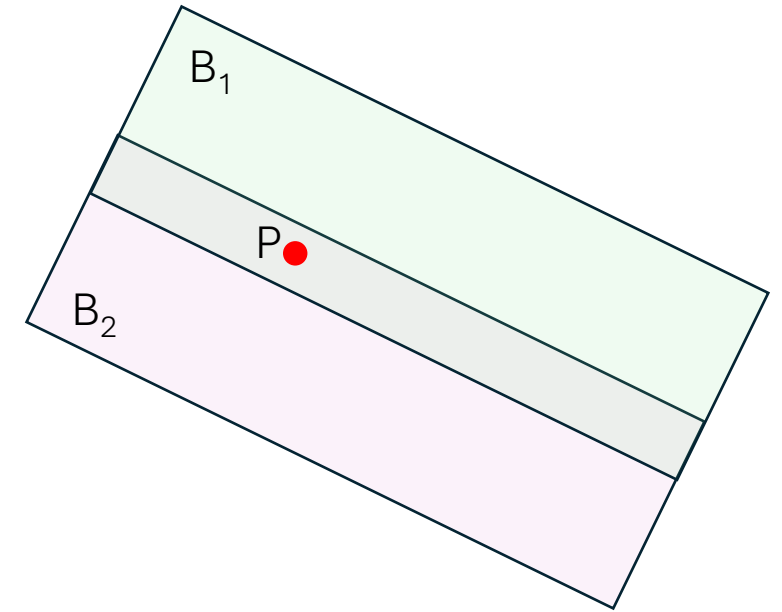
The displacement observed for point P in bursts 1 and 2 is:

$$d_{p,b1} = \vec{d}_p \cdot \vec{v}_{p,B1} - \vec{d}_{rp1} \cdot \vec{v}_{rp1}$$

$$d_{p,b2} = \vec{d}_p \cdot \vec{v}_{p,B2} - \vec{d}_{rp2} \cdot \vec{v}_{rp2}$$

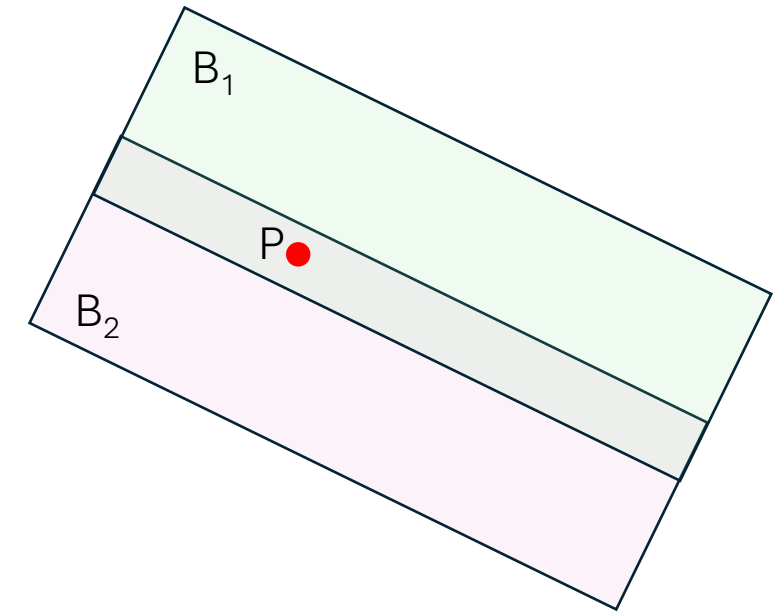
Assuming $\vec{v}_{p,B1} \approx \vec{v}_{p,B2}$ (valid when the bursts are in the same relative orbit):

$$d_{p,b1} - d_{p,b2} = \vec{d}_{rp2} \cdot \vec{v}_{rp2} - \vec{d}_{rp1} \cdot \vec{v}_{rp1}$$



Connection and deramping leveraging burst overlaps

- Shen, L., Hooper, A., Elliott, J. R., & Wright, T. J. (2024). Variability in interseismic strain accumulation rate and style along the Altyn Tagh Fault. *Nature Communications*, 15(1), 6876. An InSAR-GNSS Velocity Field for Iran
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- Kalia, A. C., Frei, M., & Lege, T. (2017). A Copernicus downstream-service for the nationwide monitoring of surface displacements in Germany. *Remote Sensing of Environment*, 202, 234-249.



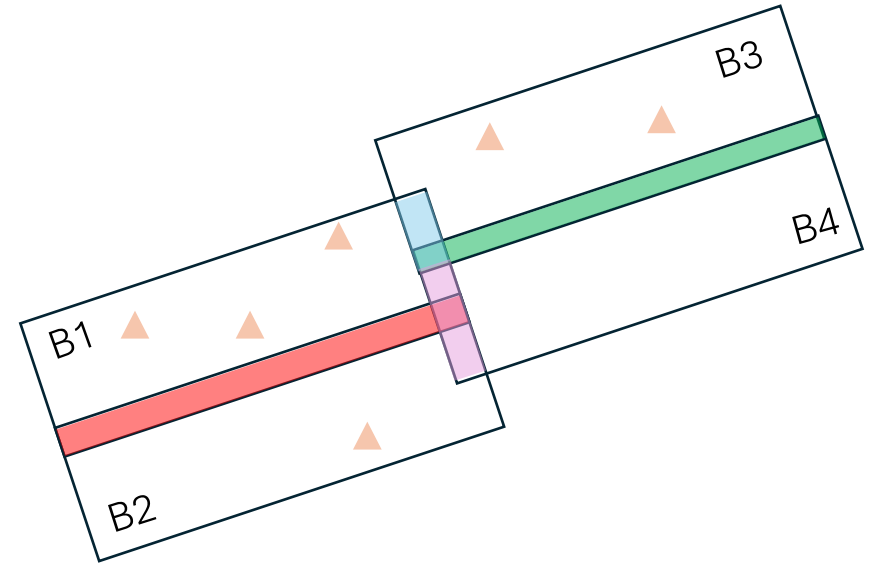
About this work

- We propose a **general formulation** for the deramping and reference frame connection of InSAR time series, that allows us to leverage and **weight** the information in the **overlapping areas**
- The connection is performed epoch by epoch, in the **displacement domain**, modeling the residual between GNSS and InSAR with a smoothing function
- We test the procedure over data belonging to the same **Sentinel-1 track** to limit the influence of changes in the **viewing geometry**

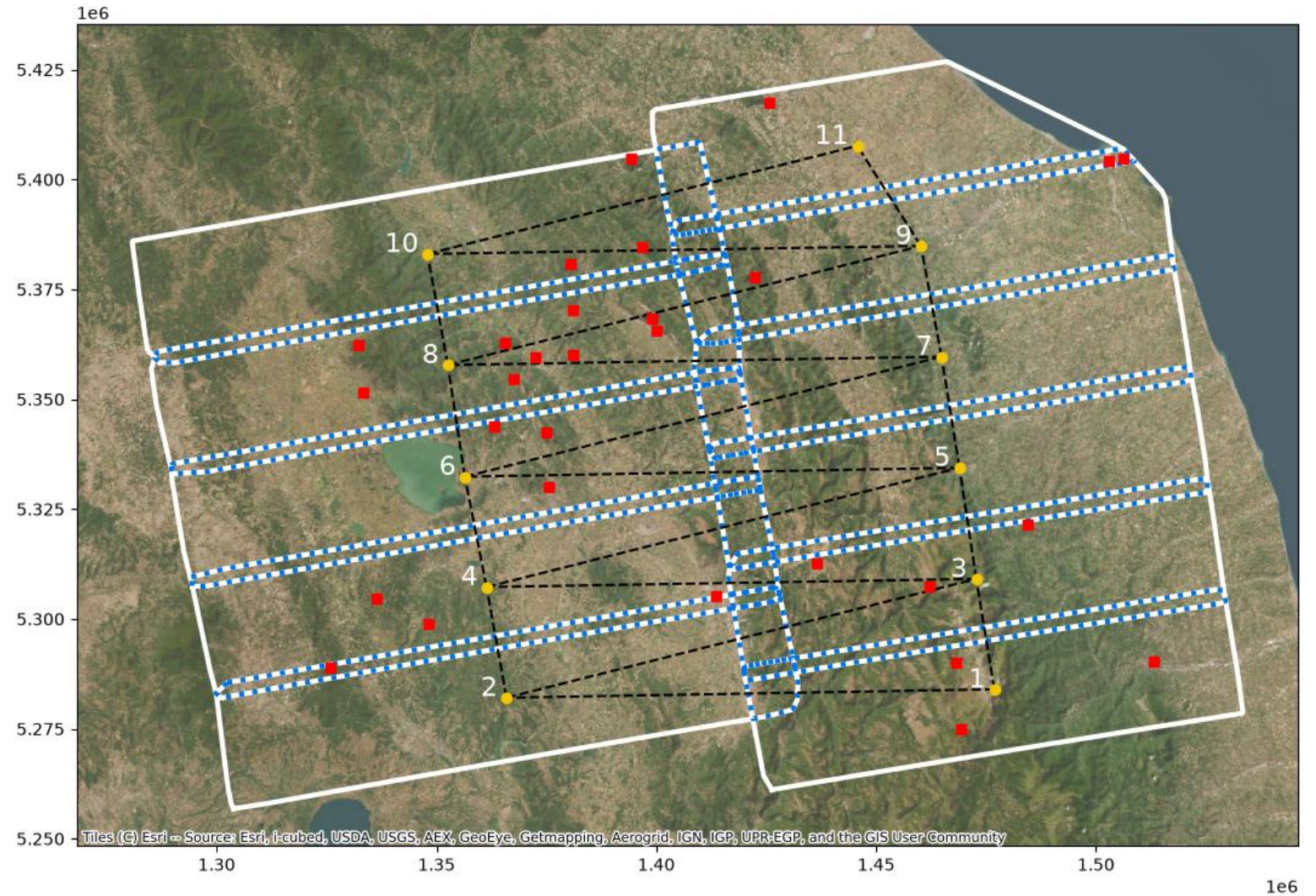
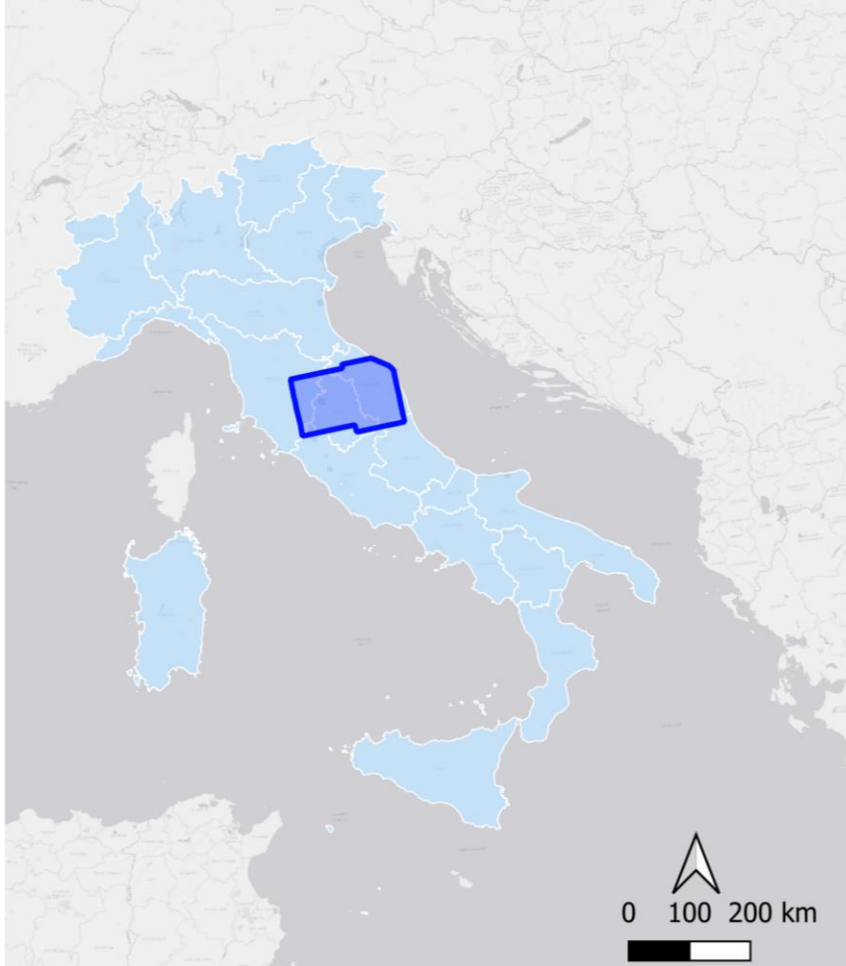
Proposed approach

$$\text{o. f.} = \min \left\{ \sum_{i=1}^N \sum_{l=1}^{S_i} [\mathbf{a}_i \beta x_{il} + \mathbf{b}_i \beta y_{il} + \mathbf{c}_i + \Delta d_{il}]^2 \right. \\ \left. + \alpha \frac{1}{2} \sum_{i=1}^N \sum_{j=1}^N \delta_{ij} \sum_{k=1}^{P_{ij}} [\mathbf{a}_i \beta x_{ijk} + \mathbf{b}_i \beta y_{ijk} + \mathbf{c}_i - \mathbf{a}_j \beta x_{jik} - \mathbf{b}_j \beta y_{jik} - \mathbf{c}_j + \Delta d_{ijk}]^2 \right\}$$

- When $\beta = 0$ we estimate a unique offset for each burst
- When $\alpha = 0$ we don't consider the overlapping areas
- By setting α we impose the relative weight between the two terms of the function



Study area



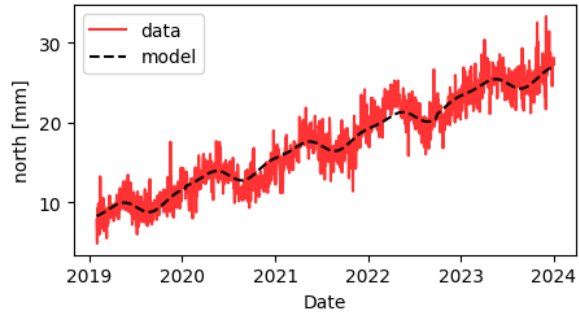
Input Data

- 29 stations with at least five years of data between 2014 and 2023 exhibiting strong linear behavior
- The daily time series of displacement of each station in IGS20 were downloaded from the Nevada Geodetic Laboratory website

- 11 files from the Basic product of the European Ground Motion Service, all belonging to ascending track 117
- The files relative to the same bursts and track of the Calibrated product (in ETRF2000) were also downloaded.

GNSS and InSAR modeling

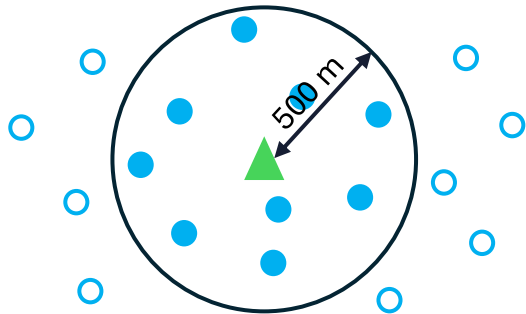
GNSS modeling



LOS projection
of the linear
component

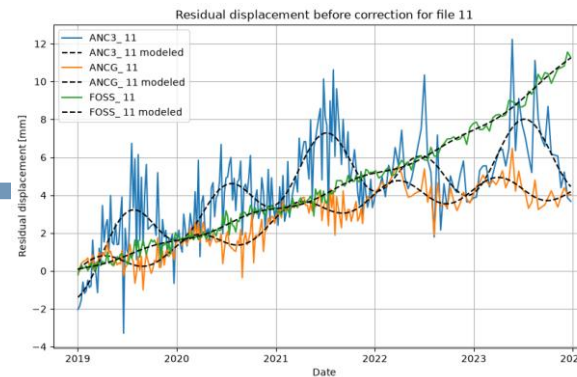
$$\hat{d}_{GNSS}(t) = \underset{trend}{linear} + \underset{Harmonics}{(T = 365, + steps \\ T = 182.5)}$$

PS selection

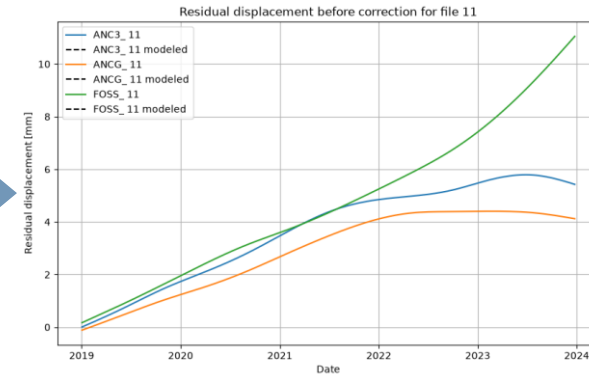


Median per
epoch

Difference and modeling



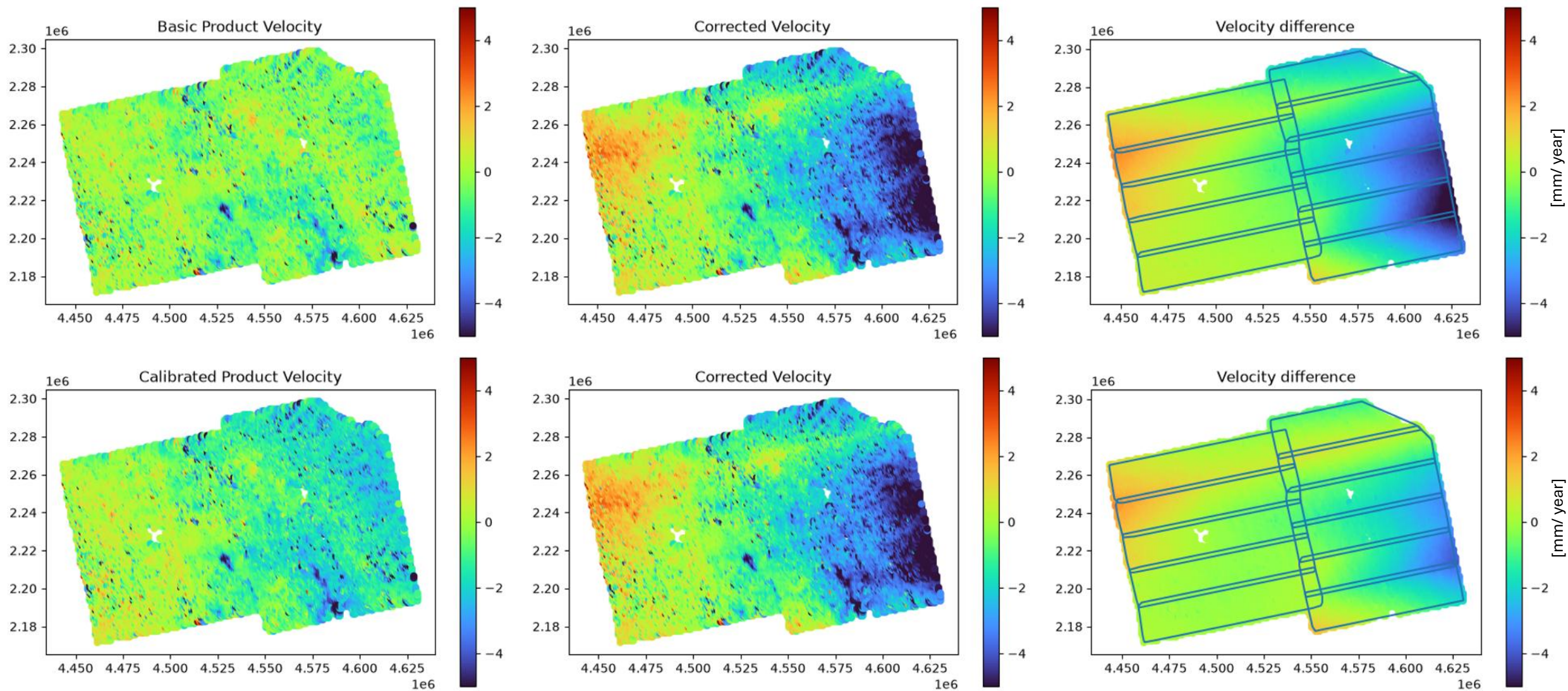
Seasonality removal



$$\Delta \hat{d}_{InSAR,GNSS}(t) = \text{splines} + \text{seasonality}$$

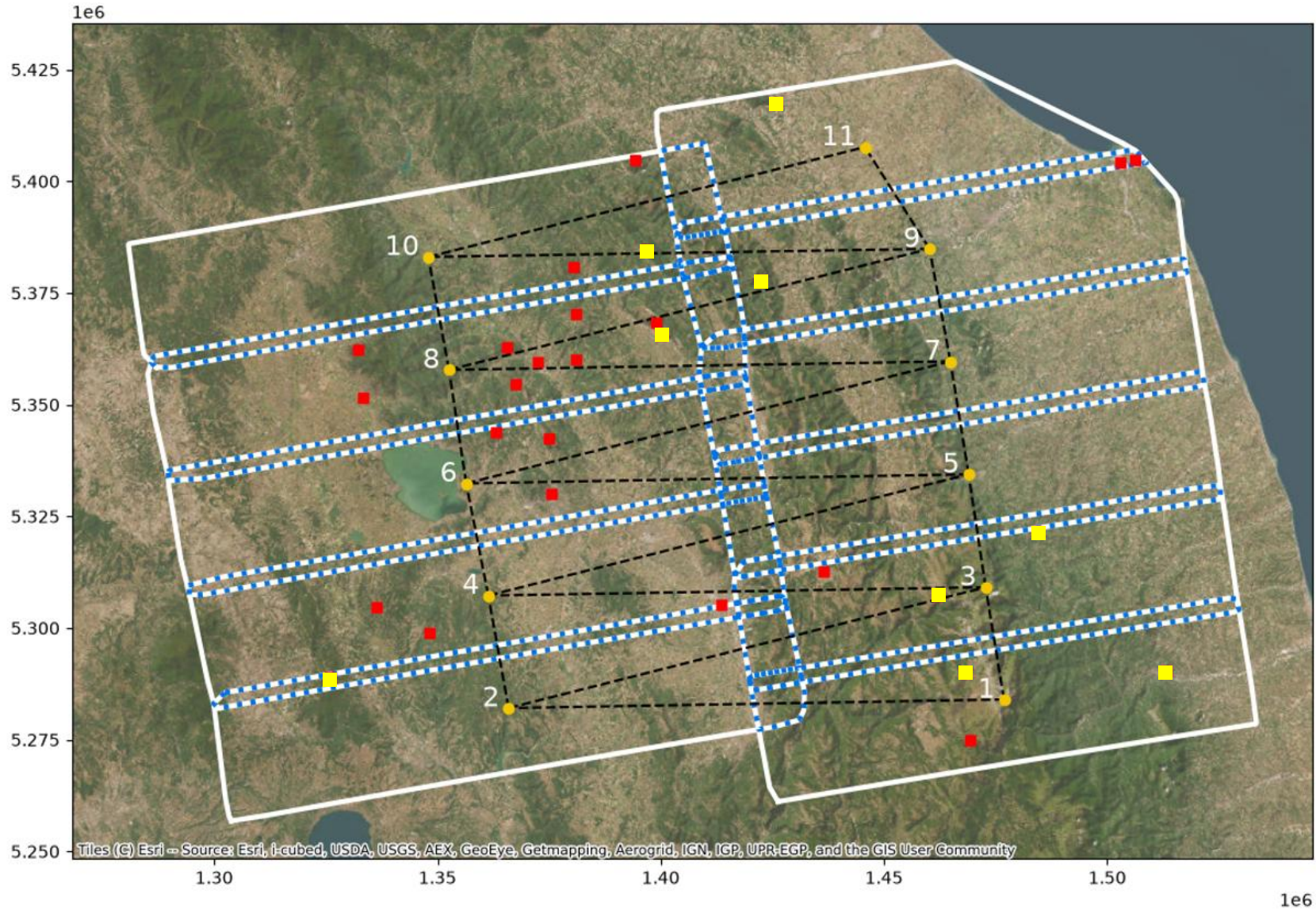
Results – Test 1

- All stations, $\beta \neq 0$



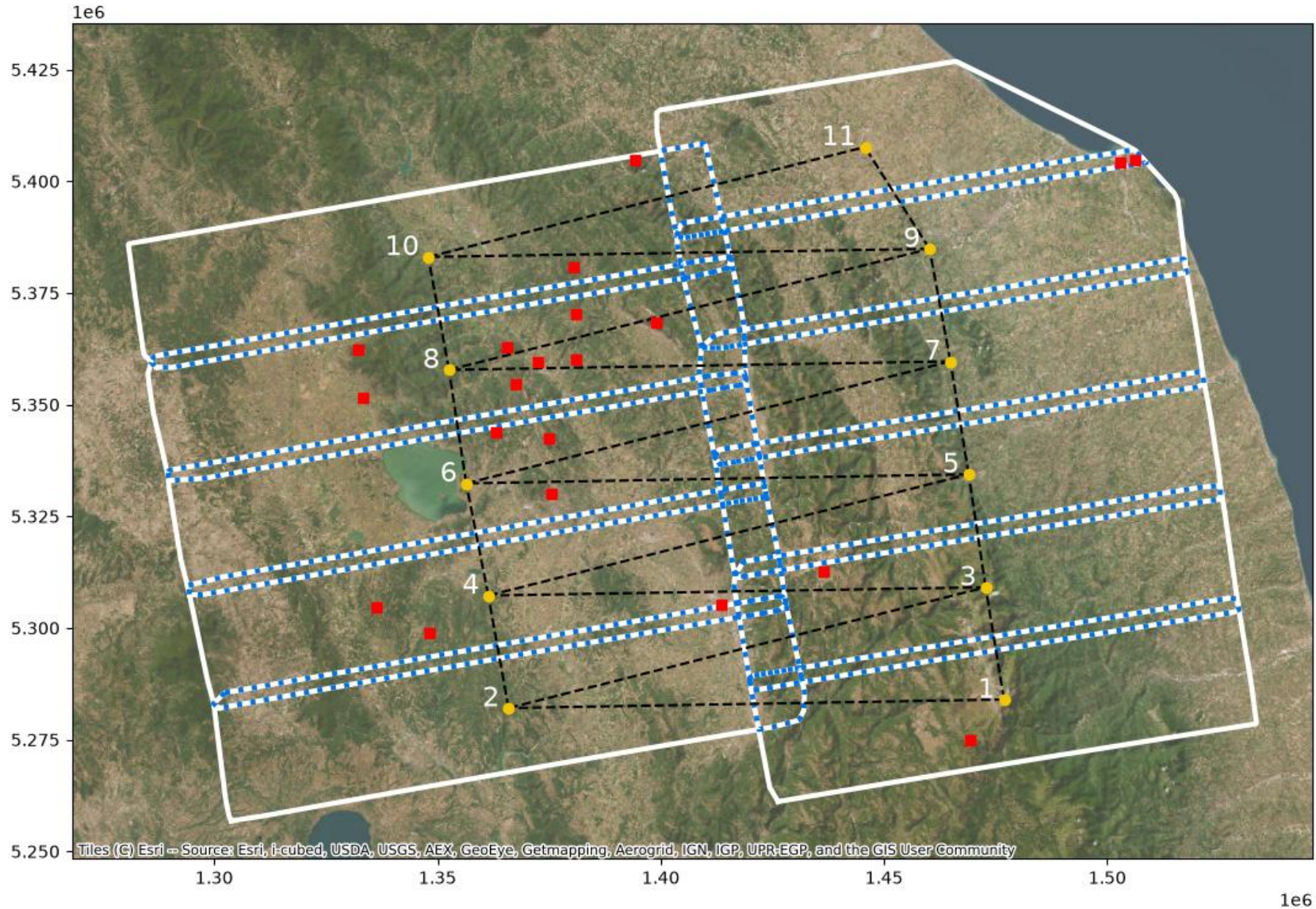
Results – Test 2

- Selected stations, $\beta \neq 0$



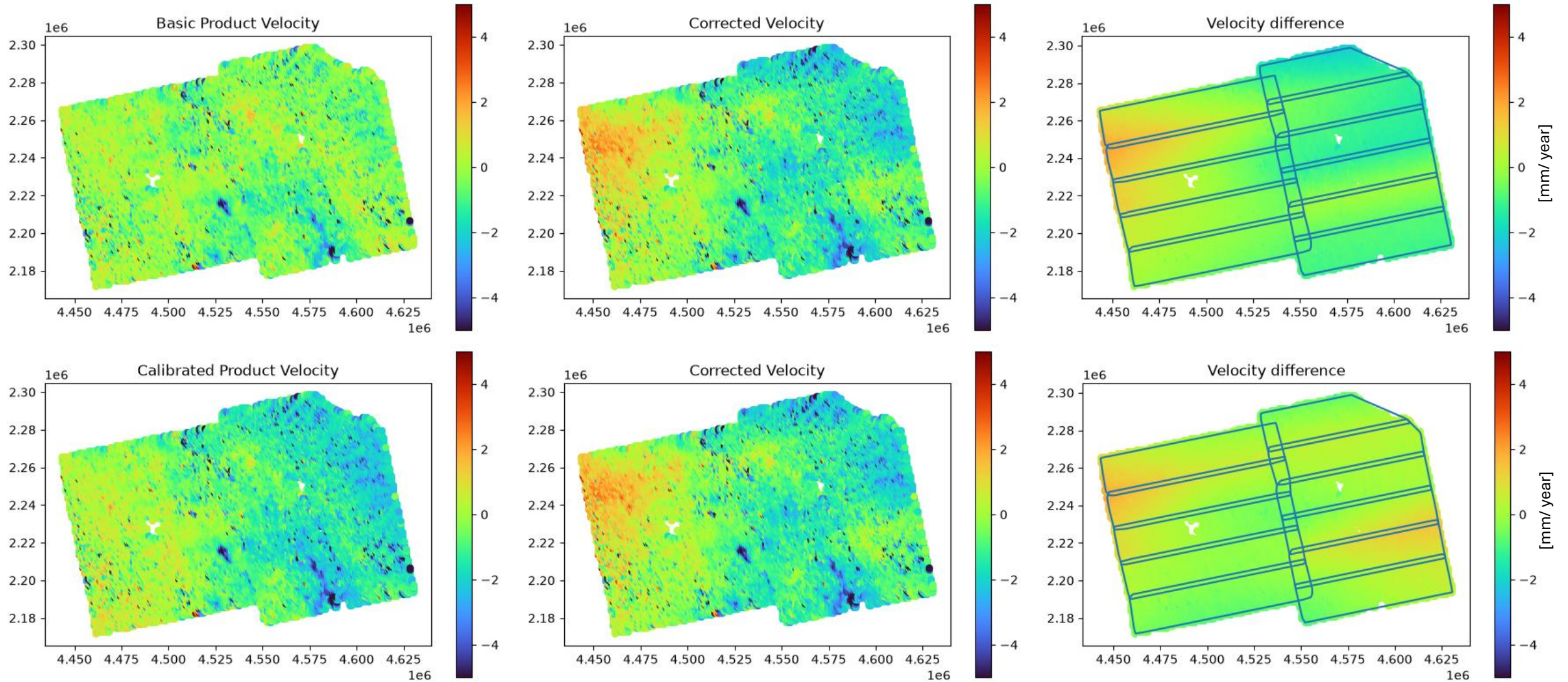
Results – Test 2

- Selected stations, $\beta \neq 0$



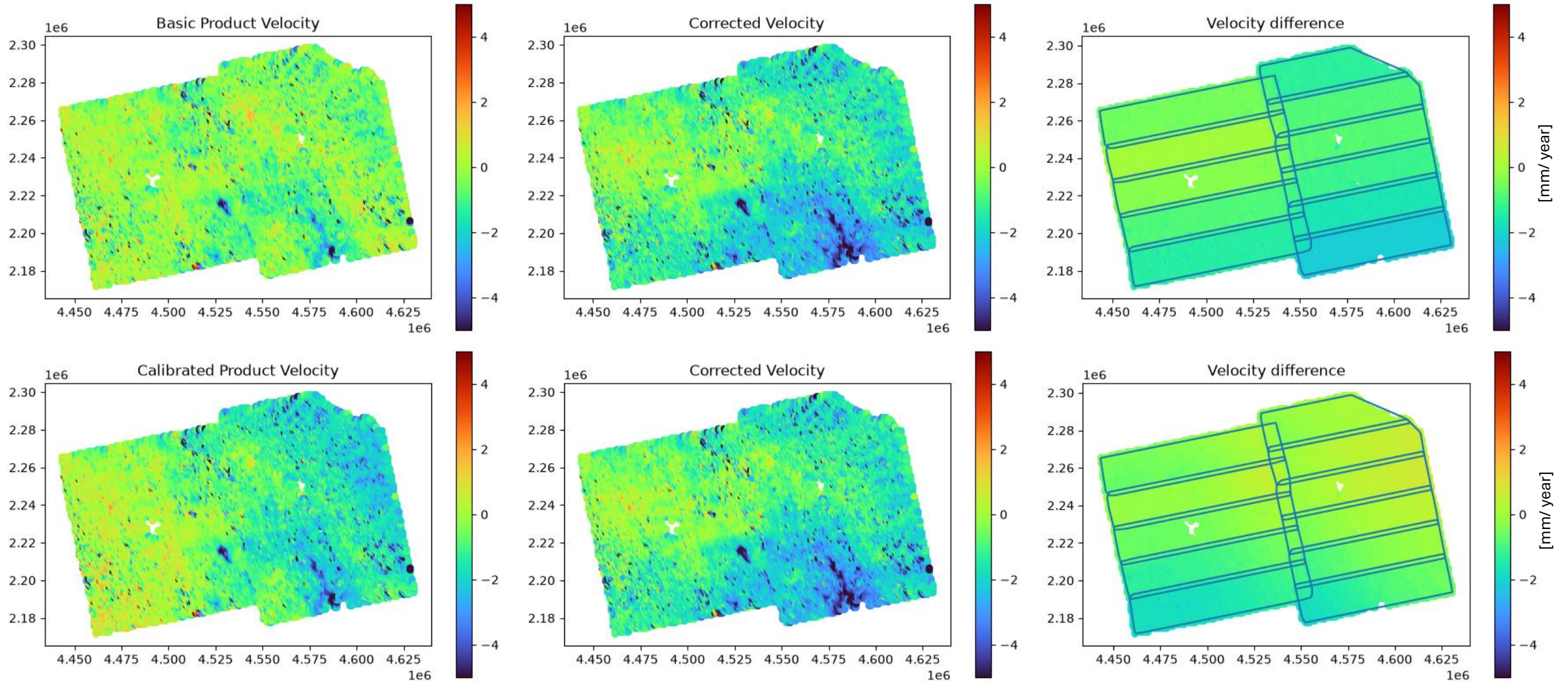
Results – Test 2

- Selected stations, $\beta \neq 0$



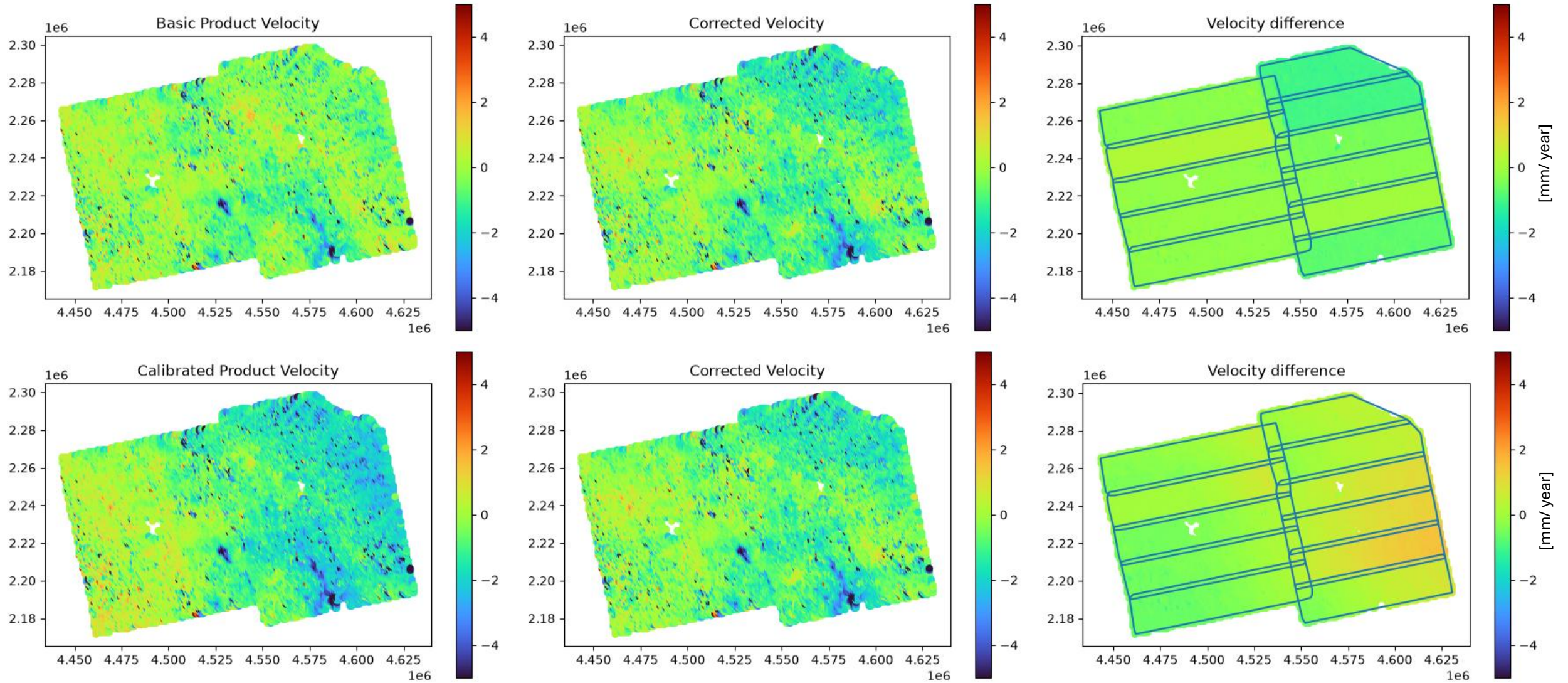
Results – Test 3

- All stations, $\beta = 0$



Results – Test 4

- Selected stations, $\beta = 0$



Conclusions and Outlook

1. The **solution** to the minimization problem **varies significantly** depending on the **selected stations**
2. In this case, a large number of stations yields worse results compared to a smaller **selected subset**
3. The proposed method (and, in general, deramping using GNSS data) requires carefully evaluating whether the time series of the chosen stations and nearby scatterers represent the **same deformation phenomenon**
4. As expected, the estimation of a **constant offset** is more **robust** against outliers compared to the plane estimation
5. Using **co-located corner reflectors** and **GNSS stations**, as in Integrated Geodetic Reference Stations (IGRS) (Zouros, 2021, Hanssen & Bazzocchi, 2024), would remove the issue described in point three, making the residuals dependent only on the reference pixel time series and the GNSS and InSAR noise
6. We plan to implement statistical testing to evaluate the **significance of the estimated parameters**

Acknowledgements

This study received funding from the European Union Next-GenerationEU (National Recovery and Resilience Plan – NRRP, Mission 4, Component 2, Investment 1.3 – D.D. 1243 2/8/2022, PE0000005) and has been prepared using European Union's Copernicus Land Monitoring Service information.

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5. “Calibrated. European Union's Copernicus Land Monitoring Service information, <<https://egms.land.copernicus.eu>> <DOI: <https://doi.org/10.2909/8889e0a7-a6df-47a8-b4e7-a9cb32cbbf6b>>”
6. Hanssen, R. and Bazzocchi, P.: Geolocation accuracy and precision for InSAR point positioning; validation using the Dutch IGRS network, EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-21827, <https://doi.org/10.5194/egusphere-egu24-21827>, 2024.
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