

INTERFEROMETRIC PHASE CORRECTIONS BASED ON ESA'S EXTENDED TIMING ANNOTATION DATASET (ETAD) FOR SENTINEL-1

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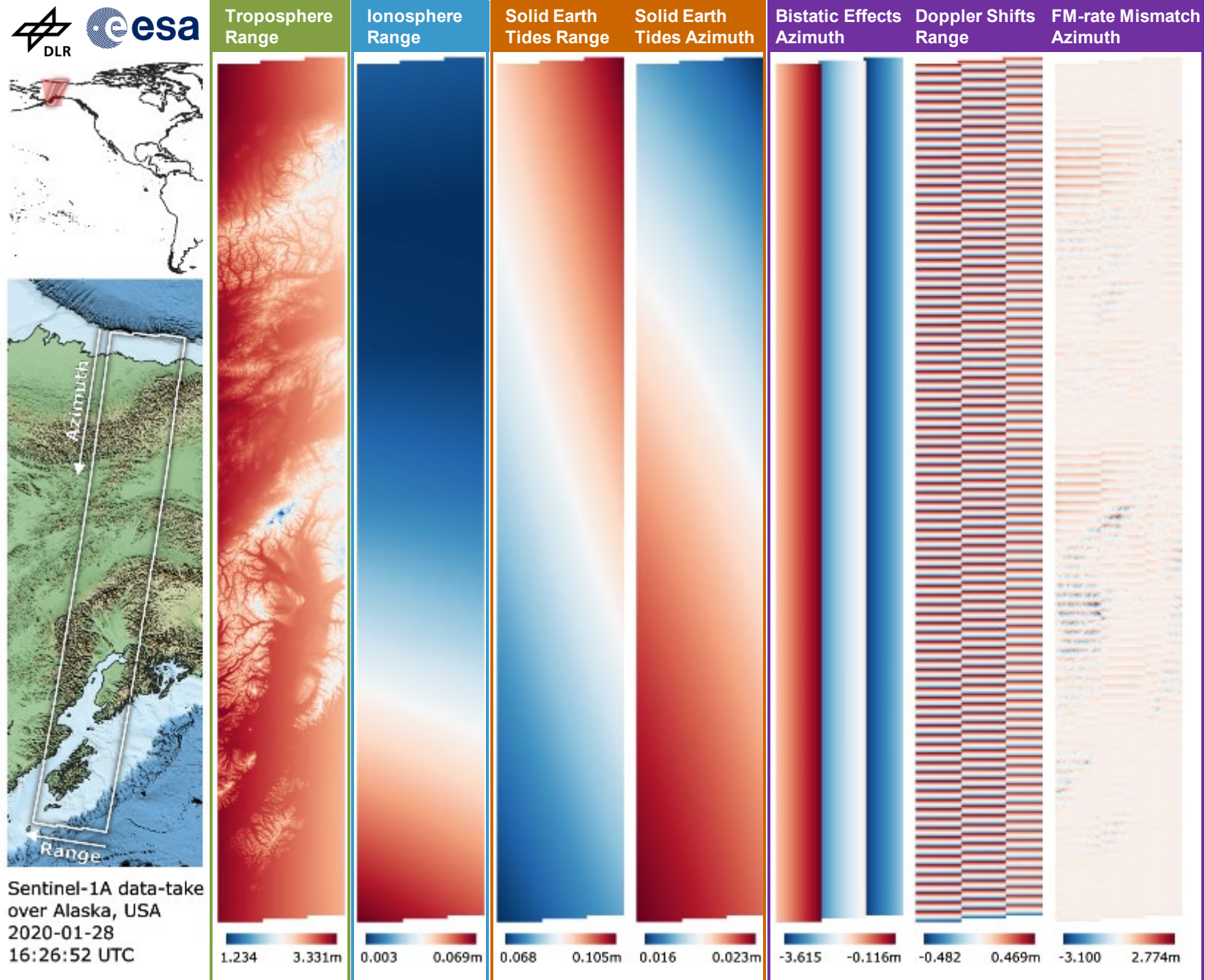
Outline



1. Sentinel-1 ETAD
2. InSAR corrections based on ETAD
3. Tropospheric phase screen corrections
4. Interferometric processing results: Alps study case
5. Conclusions and outlook

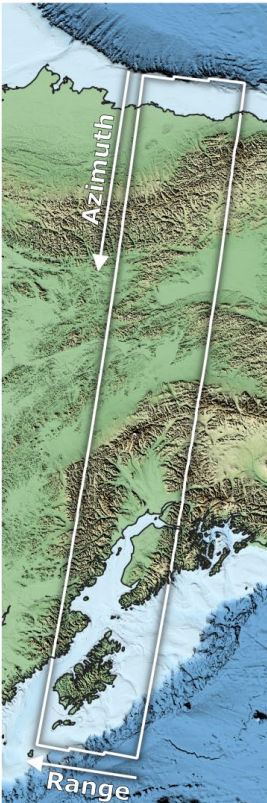
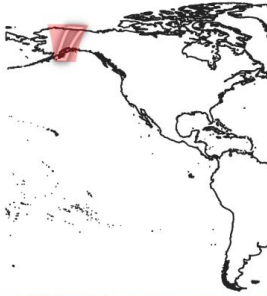
Sentinel-1 ETAD

- **E**xtended **T**iming **A**nnotation **D**ataset for S-1 SAR data
- Gridded corrections (~200m) in SAR slant range and azimuth
 - **Tropospheric path delay**
 - **Ionospheric path delay**
 - **Solid Earth tides**
 - **S-1 system corrections**
- ETAD routine generation started for IW and SM products
- Public dissemination foreseen Q3/Q4 2023

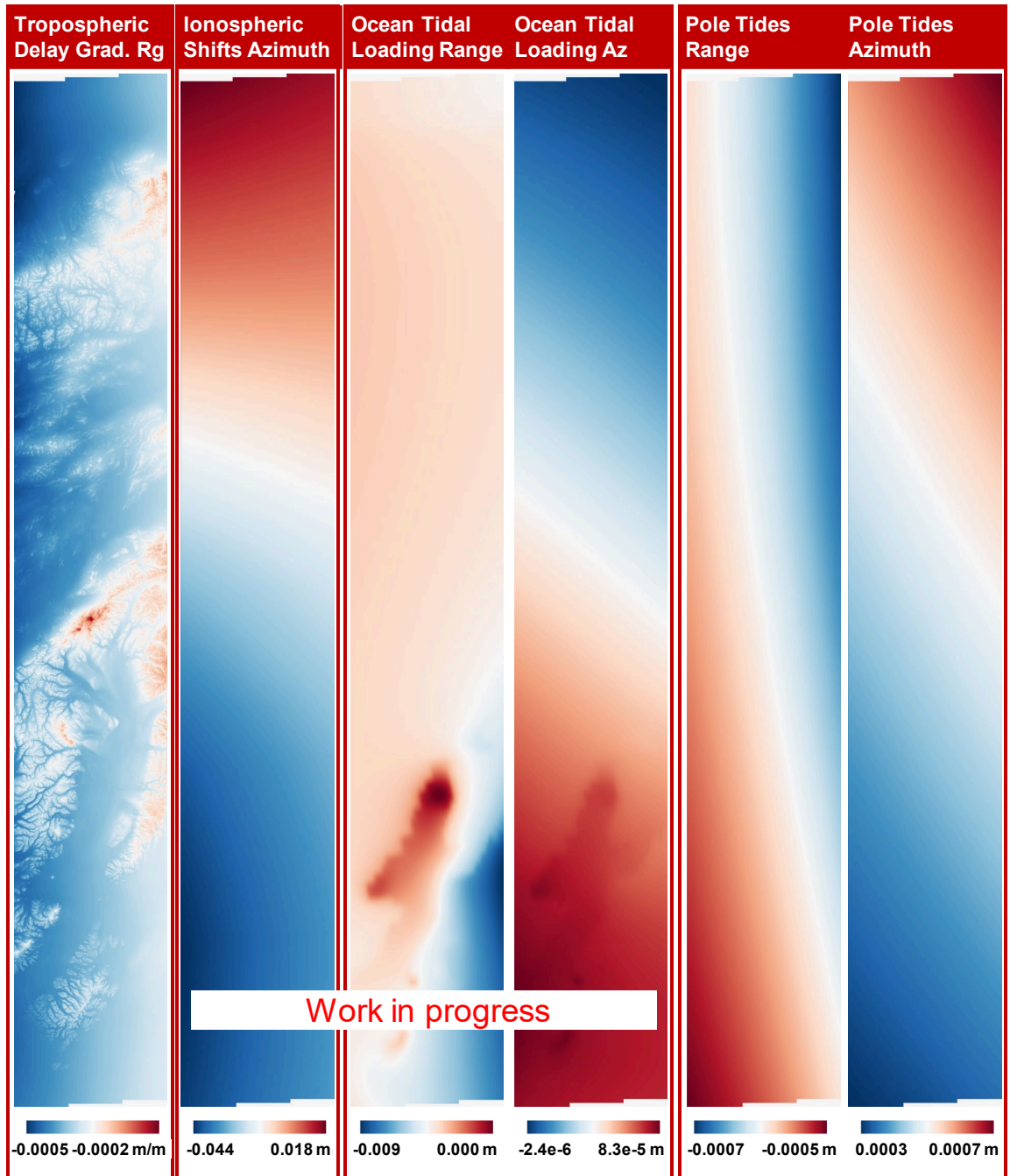


Sentinel-1 ETAD Scientific Evolution

- Extended Timing Annotation Dataset for S-1 SAR data
- Gridded corrections (~200m) in SAR slant range and azimuth
 - Tropospheric path delay
 - Ionospheric path delay
 - Solid Earth tides
 - S-1 system corrections
- Additional experimental layers
 - Ocean tidal loading
 - Pole tides
 - Ionospheric azimuth shifts
 - Tropospheric delay gradient



Sentinel-1A data-take over Alaska, USA
2020-01-28
16:26:52 UTC



InSAR corrections based on ETAD

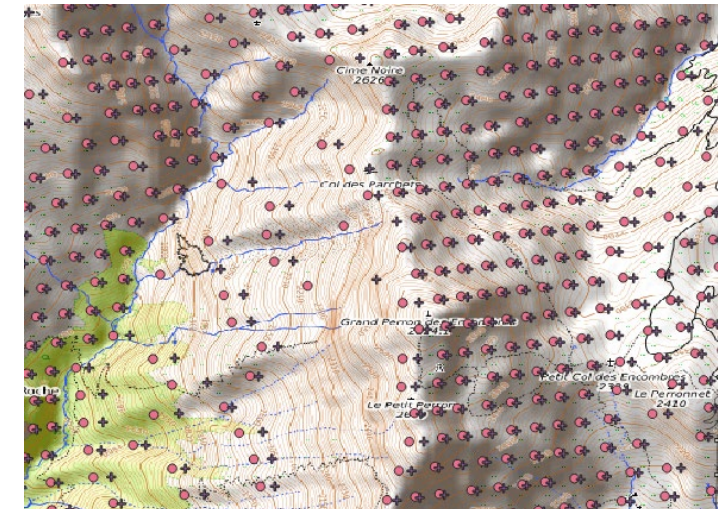
- Timing corrections enable enhanced geolocation (single image)
- Differential timing corrections can be converted to interferometric phase corrections (image pair)

$\Delta_{\text{delay}} =$

$$\begin{aligned} & (\text{troposphericCorrectionRg} + \text{geodeticCorrectionRg} - \text{ionosphericCorrectionRg} + \text{TimingCalibrationRg})_{\text{reference}} \\ & - (\text{troposphericCorrectionRg} + \text{geodeticCorrectionRg} - \text{ionosphericCorrectionRg} + \text{TimingCalibrationRg})_{\text{secondary}} \end{aligned}$$

$$\phi_{\text{ETAD}} = -\Delta_{\text{delay}} \cdot 2\pi c / \lambda_{s1}$$

- For InSAR, resampling image pairs to a common grid is required (coregistration)
- ETAD correction grid varies from datatake to datatake:
 - different timing reference (e.g. start/stop times)
 - different resampling of DEM in radar coordinates (range, azimuth)



InSAR corrections based on ETAD



- **ETAD pilot study**¹ → feedback received on ETAD for various applications, including InSAR
- Direct application of ETAD-derived phase corrections to interferometric phase results in visible artefacts (IREA-CNR, TRE ALTAMIRA)
- Tropospheric corrections depend heavily on topography (stratification):

Resampling to different grid must consider local dependency of tropospheric range delay with vertical height (derivative) and the height at the target position

- Adaptation to target height, prior to lateral interpolation:

$$\Delta\tau_{tropo}(h_{POI}) = \Delta\tau_{tropo}(h_{GP}) + \frac{\Delta\tau_{tropo}}{\Delta h} \cdot (h_{POI} - h_{GP})$$

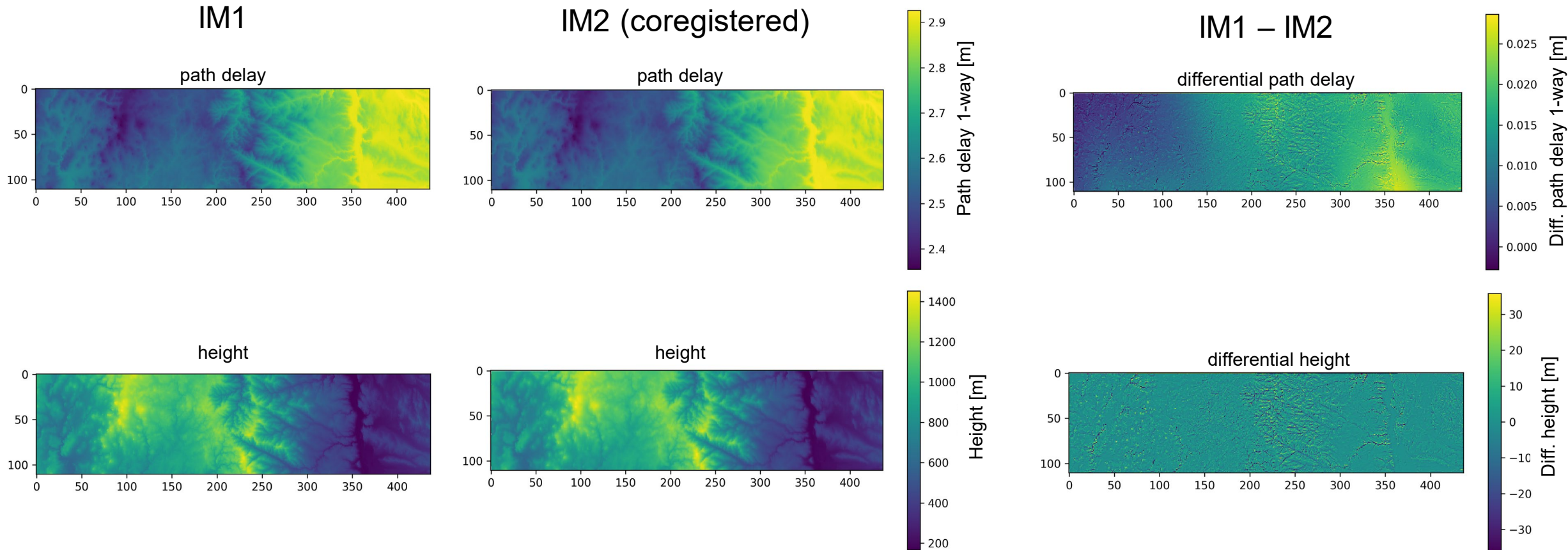
Diagram annotations for the equation above:

- tropospheric delay to height derivative (points to the fraction $\frac{\Delta\tau_{tropo}}{\Delta h}$)
- tropospheric delay at grid point (points to $\Delta\tau_{tropo}(h_{GP})$)
- height at the point of interest (points to h_{POI})
- height of close-by correction grid point (points to h_{GP})

¹ Participating groups in alphabetical order: Caltech, DIAN srl, DLR, ENVEO, IREA-CNR, JPL, Joanneum Research, NORCE, PPO.labs, TRE ALTAMIRA, University of Jena, University of Leeds, University of Strasbourg.

Tropospheric phase screen corrections

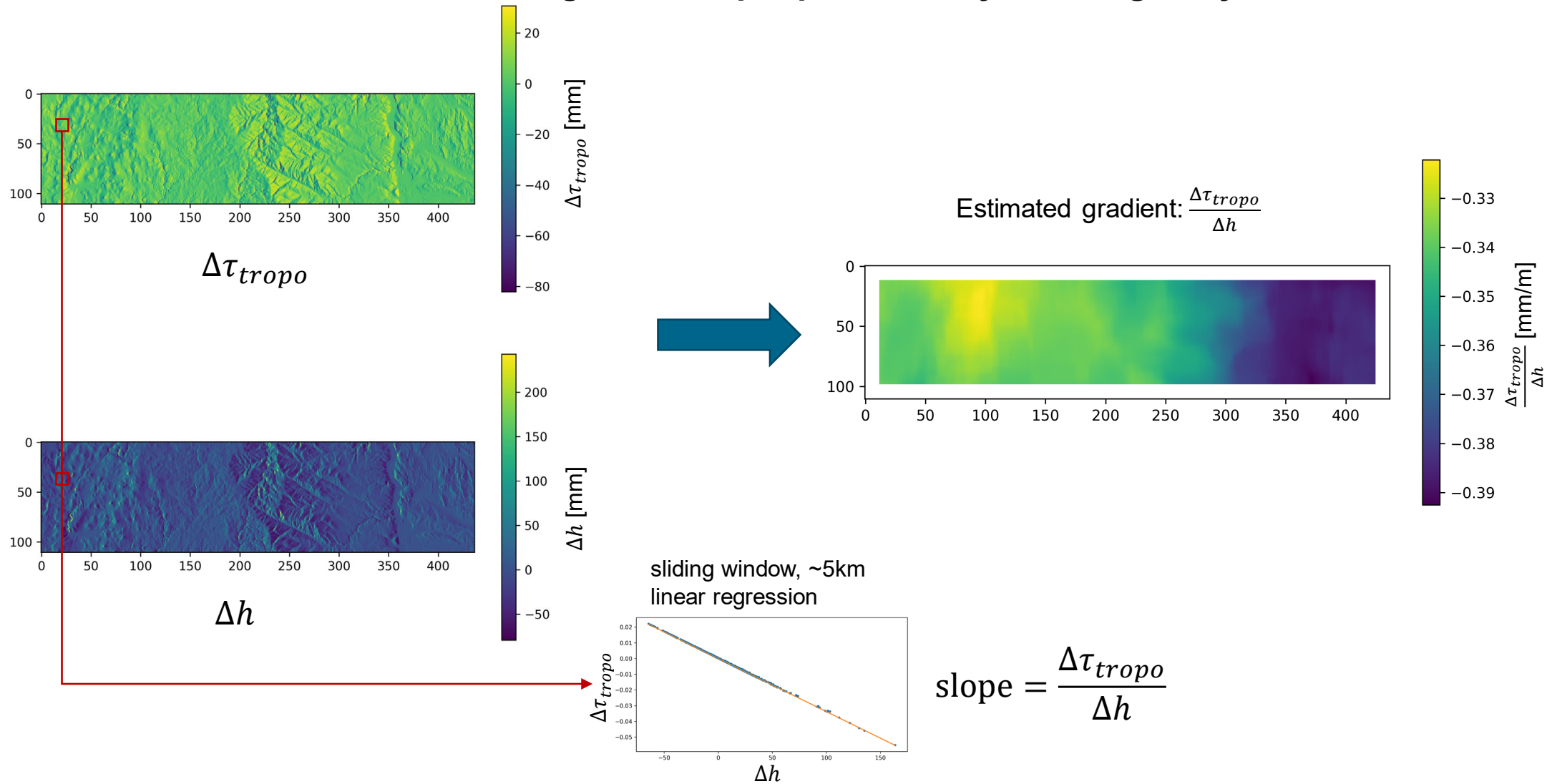
Case study: Western Alps, arbitrary ETAD IW burst, tropospheric path delay



Differential path delay artifacts and extreme values related to height difference

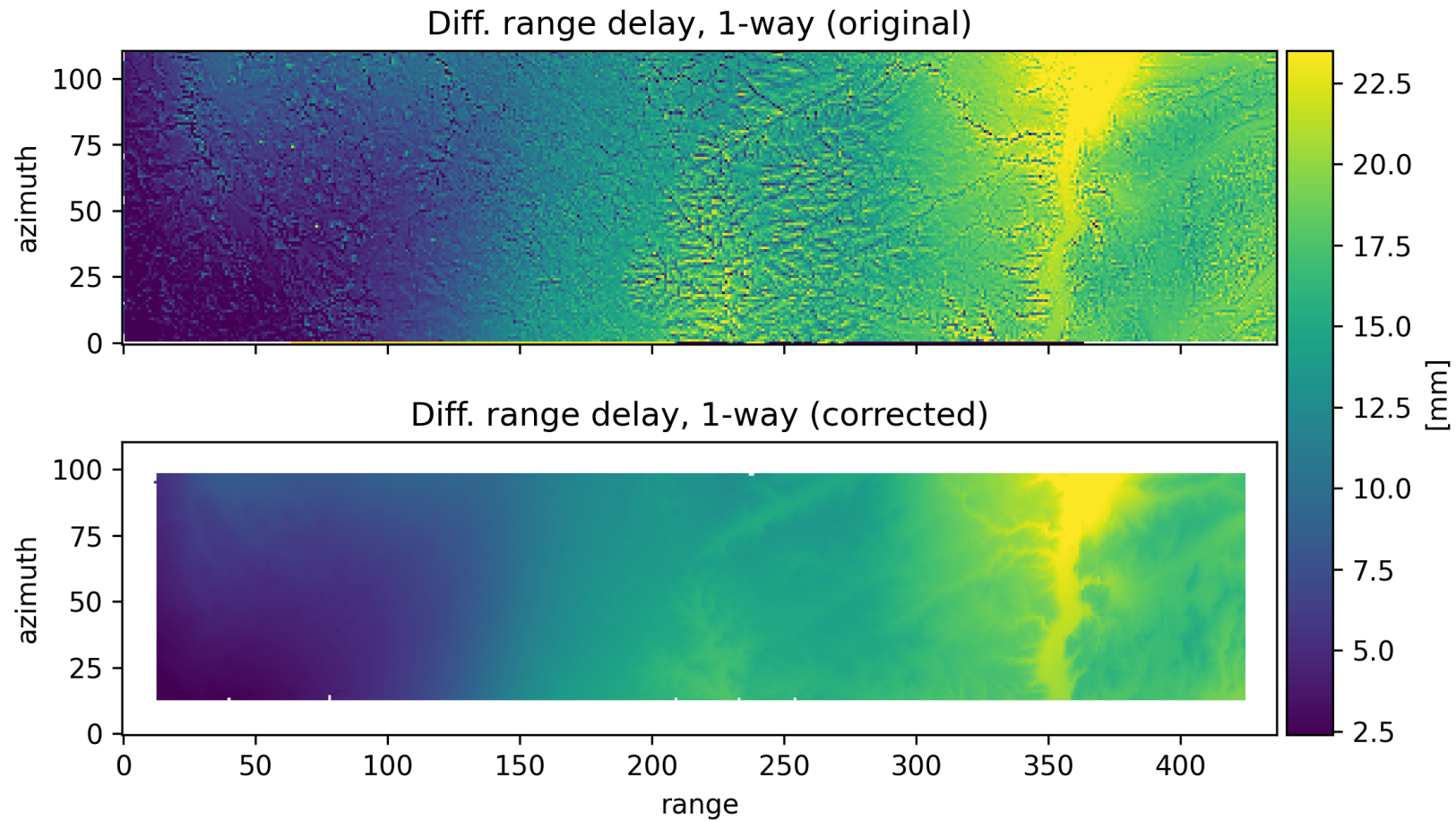
Tropospheric phase screen corrections

Gradient estimation from existing ETAD tropospheric delay and height layers



Tropospheric phase screen corrections

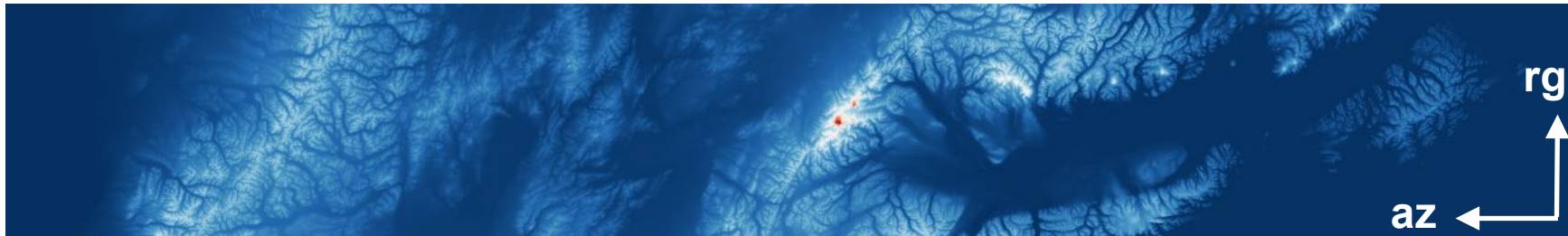
Differential range delay, single ETAD burst, $\Delta\tau_{tro_1} - \Delta\tau'_{tro_2}$



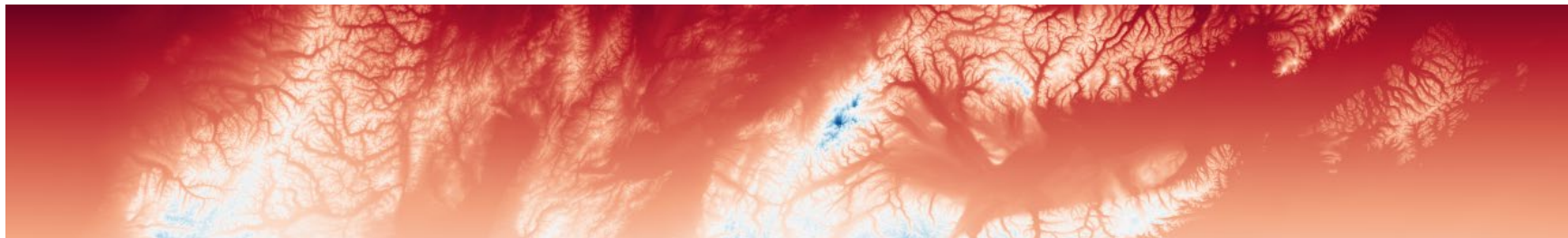
Tropospheric phase screen corrections



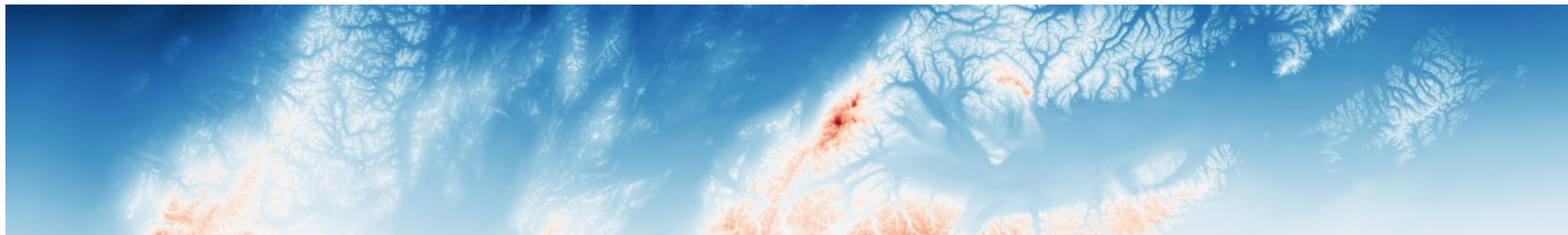
- **ETAD-SE product, new gradient layer (Alaska test case, full S-1 datatake)**



DEM Height
-20...+6178 m



Tropospheric Delay
8.24e-09...2.22e-08 s
(1.23...3.33 m)



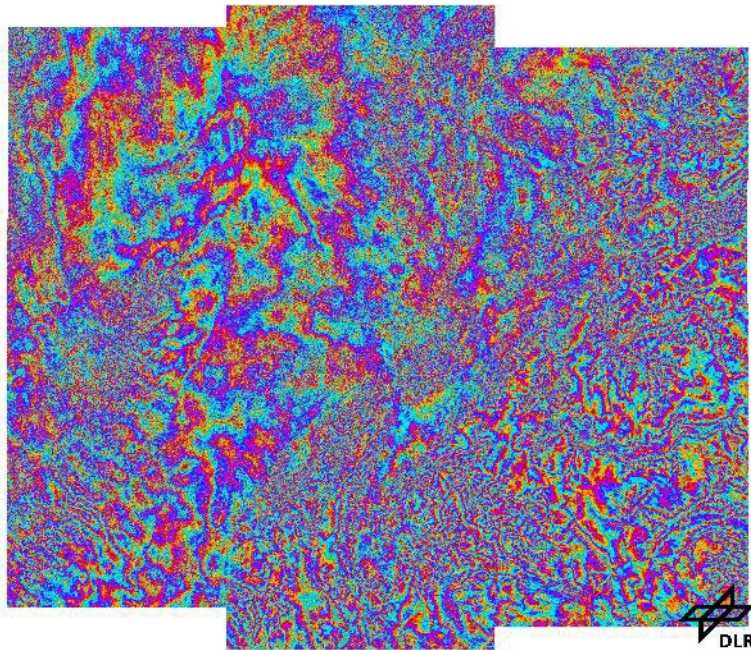
Tropospheric Gradient
-3.33e-12...-1.31e-12 s/m
(-0.50...-0.20 mm/m)

Given for every correction grid point. Obtained from support points along the slant range path.

Interferometric processing results: Alps study case

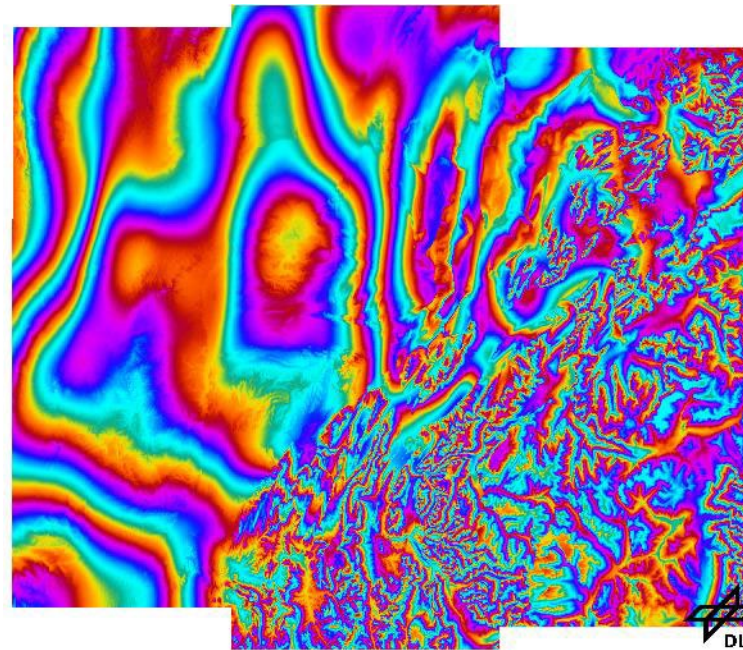


Example: Alps interferogram, summer, short temporal baseline

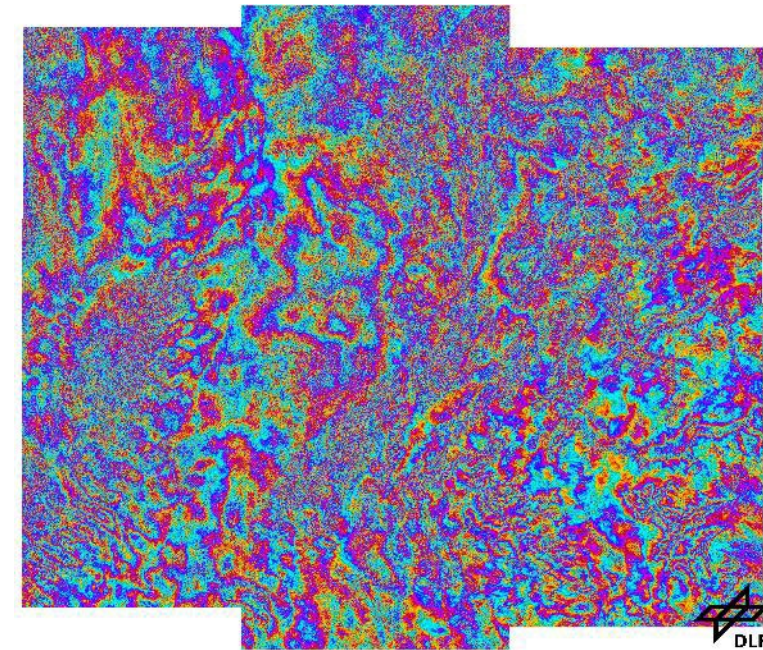
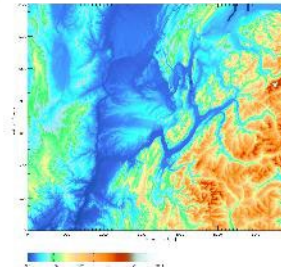


Diff. interferogram, no corrections

Acquisition date primary 2021-07-23T17:31:37 (SEN-1A)
Acquisition date secondary 2021-07-29T17:30:55 (SEN-1B, resliced)
Temporal baseline -6 days
Eff. baseline -95.9 m
Height of amb. 162.2 m



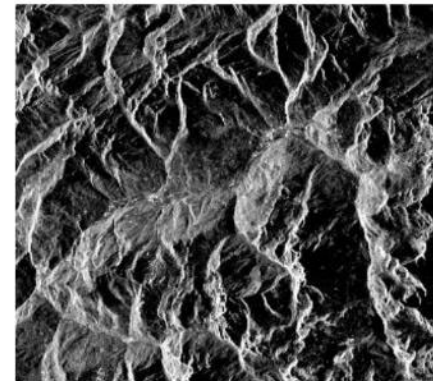
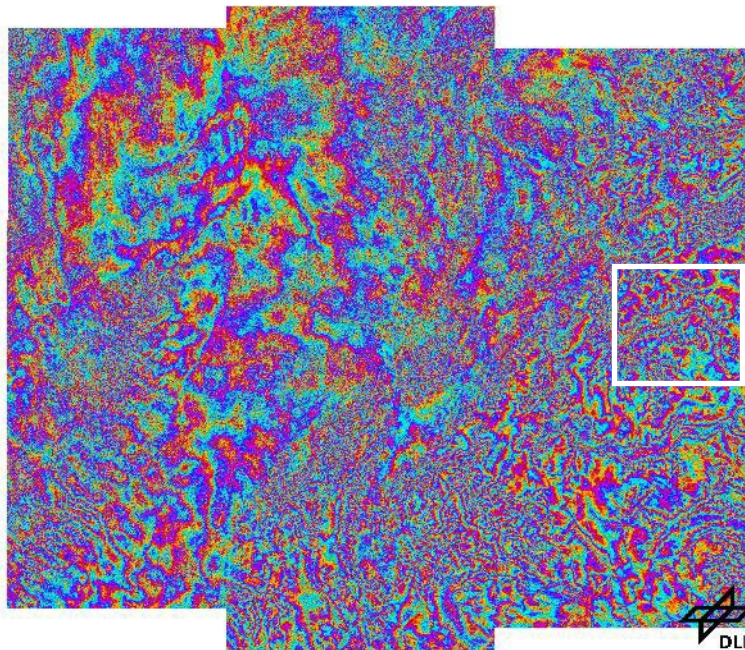
Correction screen
(tropo+iono+SET)



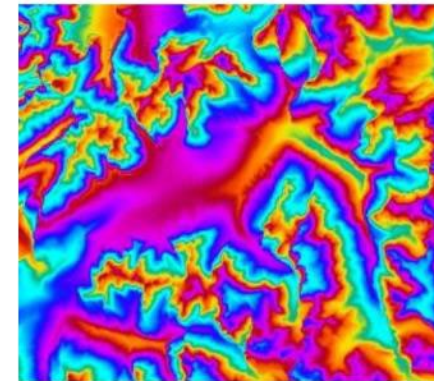
Corrected interferogram

Interferometric processing results: Alps study case

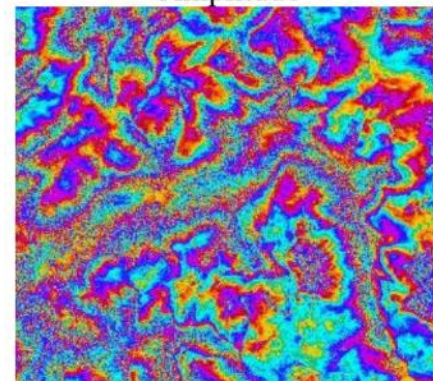
Example: Alps interferogram, summer, short temporal baseline



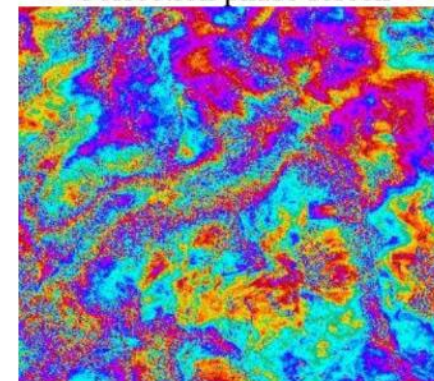
Amplitude



Correction phase screen



Non-corrected phase



Corrected phase

Diff. interferogram, no corrections

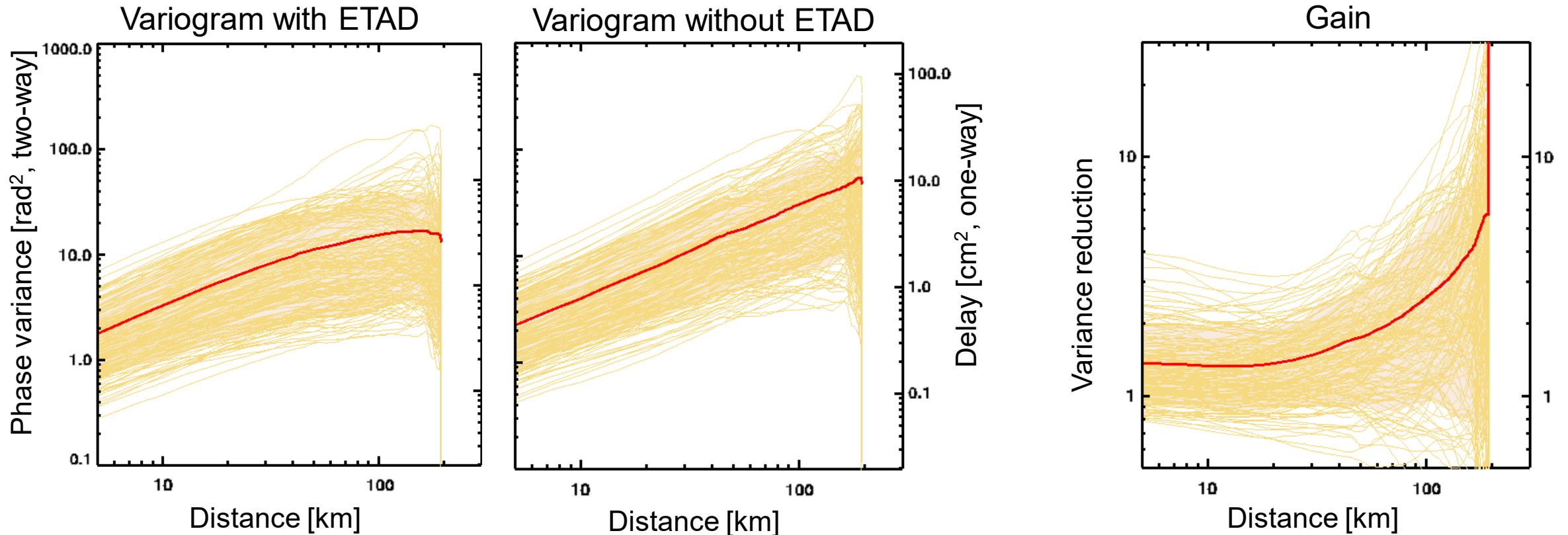
Acquisition date primary 2021-07-23T17:31:37 (SEN-1A)
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Temporal baseline -6 days
Eff. baseline -95.9 m
Height of amb. 162.2 m

Interferometric processing results: Alps stack processing



3 years 2019-2021, 176 re-sliced Sen-1A and Sen-1B acquisitions, with and without ETAD corrections

Phase variograms from short temporal baseline interferograms

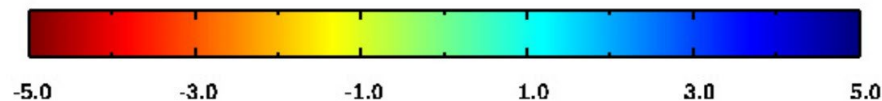
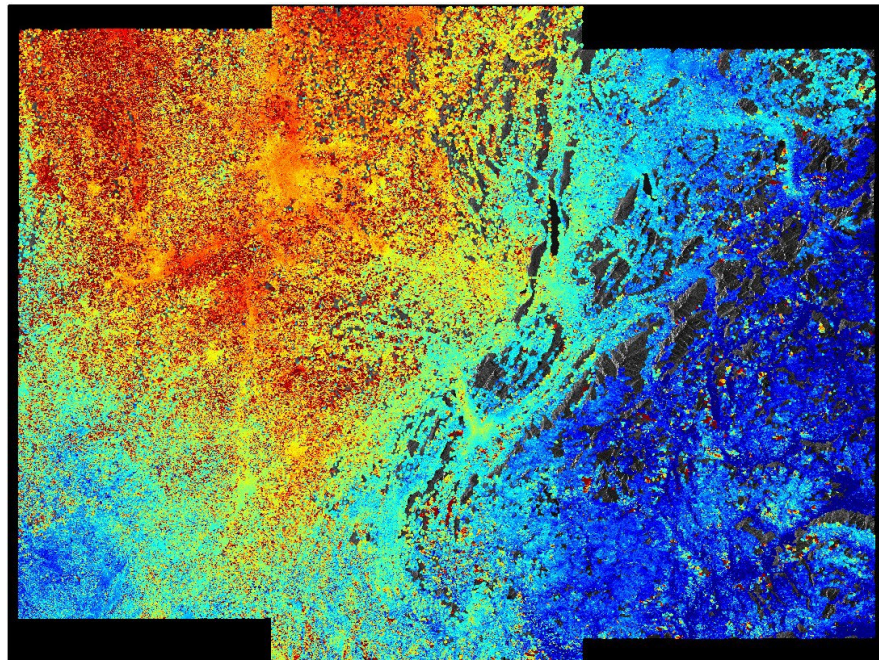


Interferometric processing results: Alps stack processing



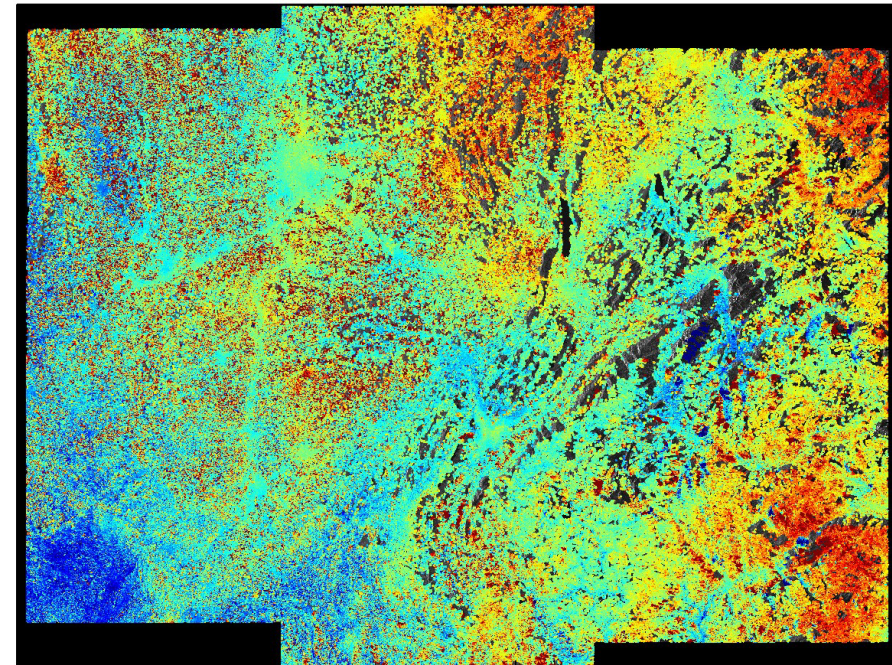
Joint PS+DS analysis, linear+seasonal deformation model

No ETAD corrections



linear deformation [mm/year]

With ETAD corrections



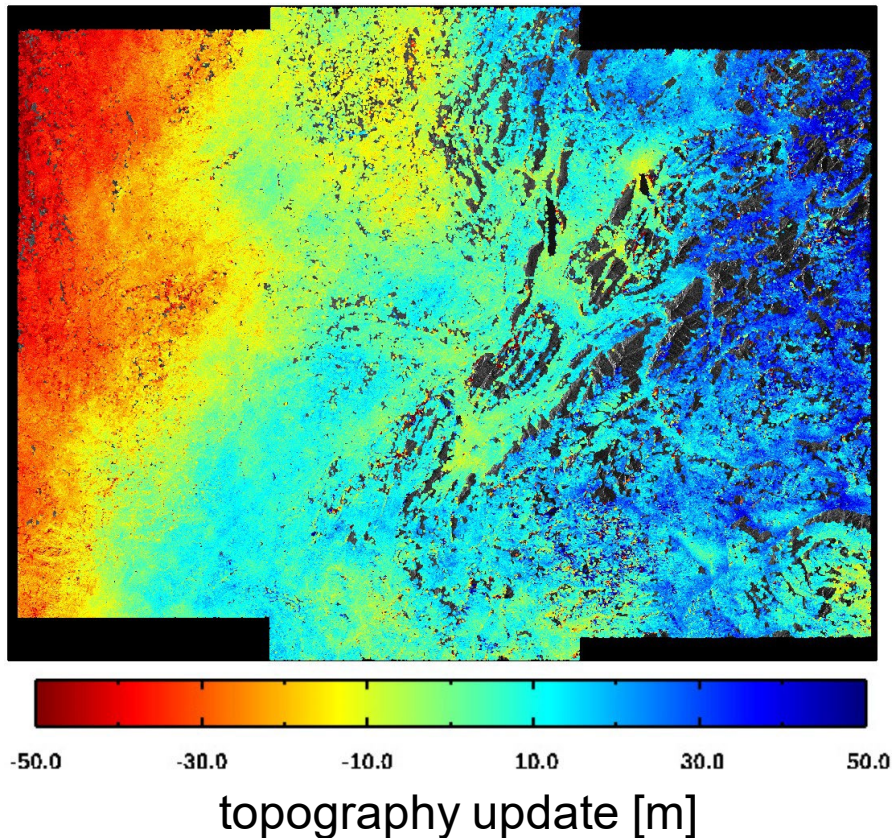
linear deformation [mm/year]

Interferometric processing results: Alps stack processing

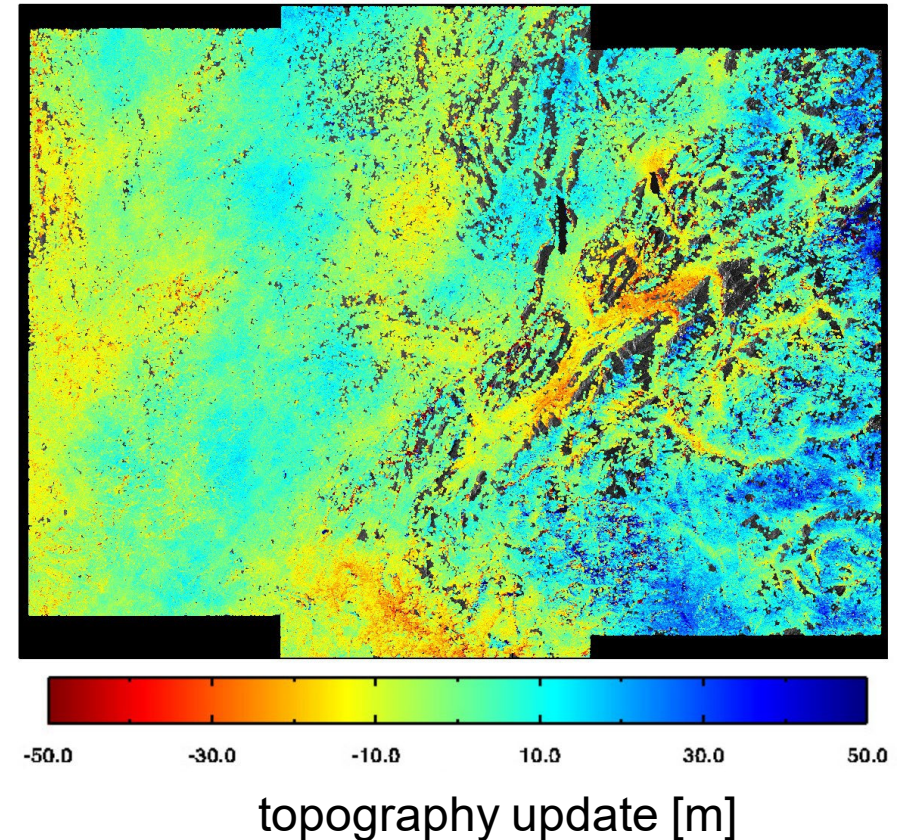


Joint PS+DS analysis, linear+seasonal deformation model

No ETAD corrections



With ETAD corrections



Conclusions and outlook



- ETAD base product available from autumn 2023.

Docs and python API: <https://sentinel.esa.int/web/sentinel/missions/sentinel-1/data-products/etad-dataset>

- ETAD SE currently under development, preliminary results obtained.
- Overall reduction of stratification artifacts, fringes in strong topography areas.
- PS + DS analysis performed on 3 years stack:
 - Variograms show significant reduction of interferometric phase variance as a function of distance between points.
 - Deformation and DEM error spatial trends related to uncorrected medium/large scale effects do not show in the ETAD-corrected stack
- Next: validation and integration of new correction layers (OTL, pole tides)

Acknowledgement



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