2022 DRAGON 5 SYMPOSIUM

MID-TERM RESULTS REPORTING

17-21 OCTOBER 2022

PROJECT ID. 59332

GEOPHYSICAL AND ATMOSPHERIC RETRIEVAL FROM SAR DATA STACKS OVER NATURAL SCENARIOS

OCTOBER 18, 2022

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PROJECT TITLE: GEOPHYSICAL AND ATMOSPHERIC RETRIEVAL FROM SAR DATA STACKS OVER NATURAL SCENARIOS

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Objectives

Overarching goal: development and application of processing methodologies for future stack-based spaceborne applications.

Two specific sub-topics:

- ***Subsurface target detection and imaging***

⇒ internal structure of natural media

- ***Monitoring atmospheric phase field and surface deformations***

⇒ joint estimation of deformation and water vapour maps

The activities are intended to support use of multi-pass data stacks from:

- the upcoming P-Band mission BIOMASS
- future L-Band missions, such as the SAOCOM constellation, the upcoming Chinese L-Band bistatic Mission Lu-Tan1, and potentially Tandem-L and Rose-L
- C-Band Sentinel Missions and X-Band Cosmo-Skymed Missions

EO Data Delivery

Data access (list all missions and issues if any). NB. in the tables please insert cumulative figures (since July 2020) for no. of scenes of high bit rate data (e.g. S1 100 scenes). If data delivery is low bit rate by ftp, insert "ftp"

ESA, Explorers & Sentinels data	No. Scenes
1.Sentinel-1	700
2. ASAR (04/2007- 02/2009)	19

ESA Third Party Missions	No. Scenes
1.TerraSAR-X/TanDEM-X and PAZ constellation	60

Other data sources	No. Scenes
1. ALOS-2 PALSAR-2	60
Total:	
Issues:	

ESA Campaigns	No. Scenes
1.TomoSense P	40
1.TomoSense L	40x2
1.TomoSense C	40x2
4. AlpTomoSAR	32
5. AfriSAR	10
Total:	≈ 242

European Young scientists contributions in Dragon 5

Name	Institution	Poster title	Contribution
Marco Manzoni	Politecnico di Milano	Large scale SAR Atmospheric Phase Screens estimation with GNSS cross-calibration	Main author, data procurement, signal processing
Naomi Petrushevsky	Politecnico di Milano	Large scale SAR Atmospheric Phase Screens estimation with GNSS cross-calibration	Co-author, data procurement, signal processing

Chinese Young scientists

Chinese YS	Institution	Current position
Chuanjun Wu	Wuhan University, *Academic exchange at PoliMi for a period of two years(since Jun.,,2022)*	**Ph.D. student**
Ru Wang	Wuhan University, *Academic exchange at University of Leeds for a period of two years(since Sep.,2021)*	**Ph.D. student**
Yi'an Wang	Wuhan University, *Academic exchange at Polytechnic University of Catalonia for a period of a year and a half (since Oct.,2022)*	**Ph.D. student**

Project schedule

2020-2021:

- Procurement of satellite stacks.
- Acquisition of campaign data.
- Data pre-processing, preliminary analysis.
- Presentation at Dragon symposium 2021.

2021-2022:

- Advanced analysis of satellite data.
- Advanced analysis of campaign data.
- Presentation at Dragon symposium 2022.
- Preparation of one or more journal papers

2022-2023:

- Advanced data analysis.
- Presentation at Dragon symposium 2023.

2023-2024:

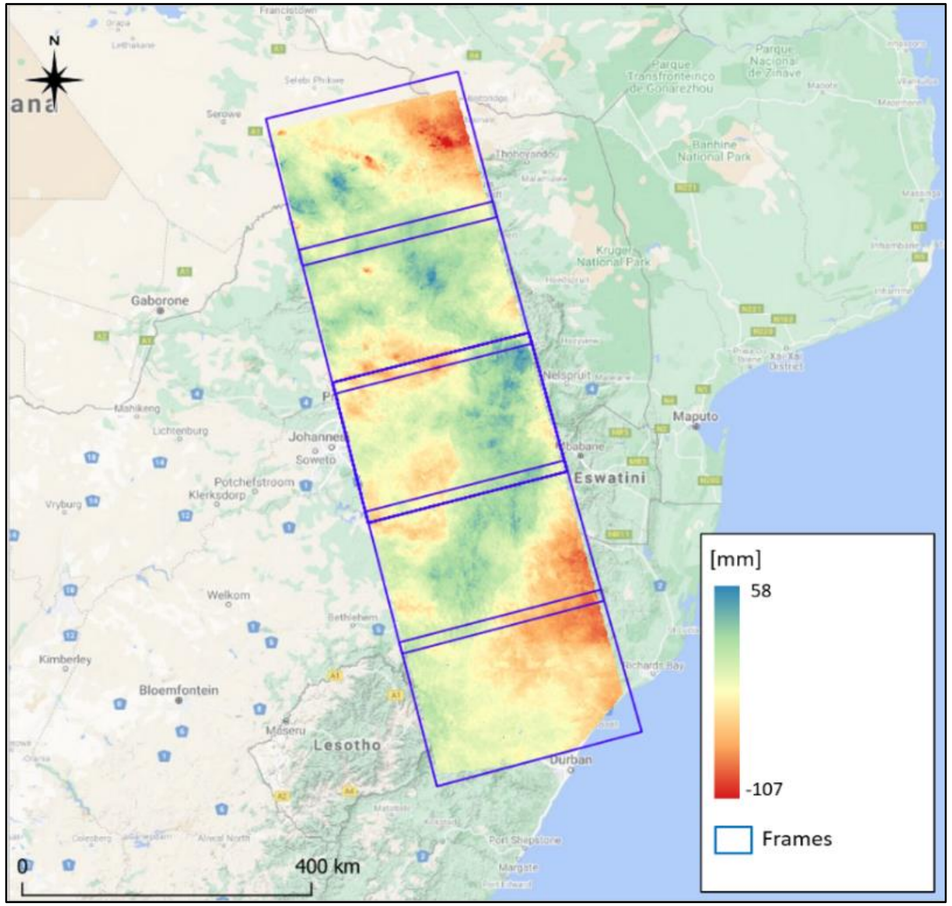
- Presentation of final results
- Preliminary analysis of BIOMASS data.
- Presentation at Dragon symposium 2024.
- Preparation of one or more journal papers

Expected results

- Development and testing of methodologies for the characterization of the internal structure of forested areas.
- Development and testing of methodologies for estimation and compensation of ionospheric and tropospheric phase screens.
- Validation against reference data from airborne campaigns.
- Validation on simulated P- and L-band spaceborne bistatic data.
- Development of an efficient method to estimate and remove ionospheric phase from C band Sentinel-1 stacks already coregistered and DEM compensated (i.e. output from SNAP tool)
- Develop of a method to generate (1) absolute water-vapor maps at fine resolution by integrating GNSS, SAR (long term PS and short term DS) and meteorological mode – over very wide area and aiming to near real time, (2) deformation series, local and high resolution
- Validation of developed methods
- Analysis of data from BIOMASS after launch.

Preliminary results from Year 2

Monitoring atmospheric phase field and surface deformations



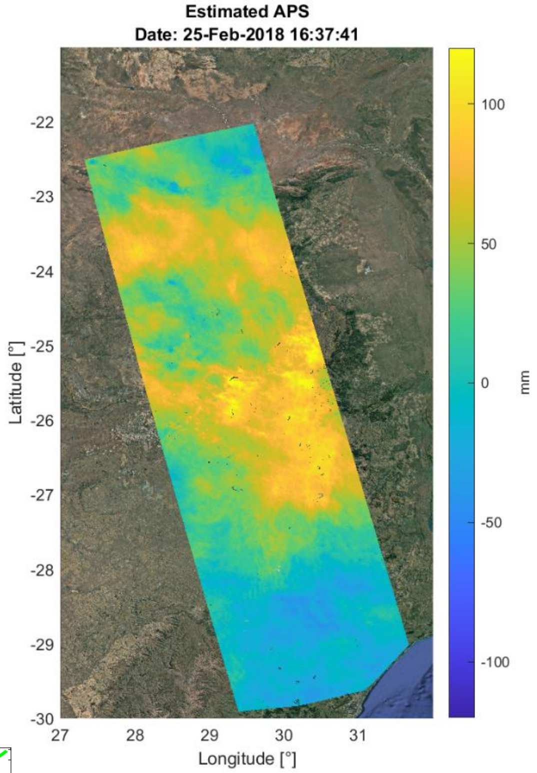
Generation of GNSS calibrated differential ZWD maps from Sentinel-1,
in synergy with TWIGA-EU project.

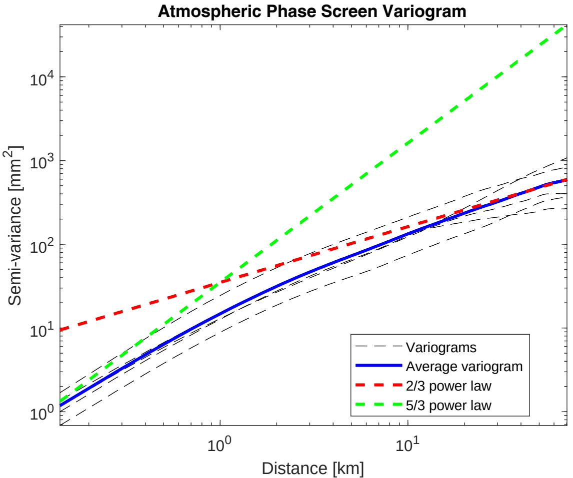
The objective now is a comparison with Gacos, and the generation of an absolute product that can be assimilated into water-vapor map.

Preliminary results from Year 2

South Africa

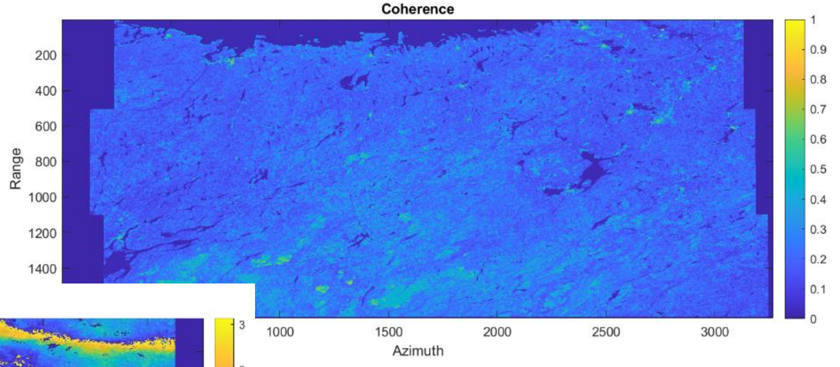
- $250 \times 850\ km^2$
- Very good accordance with theoretical models



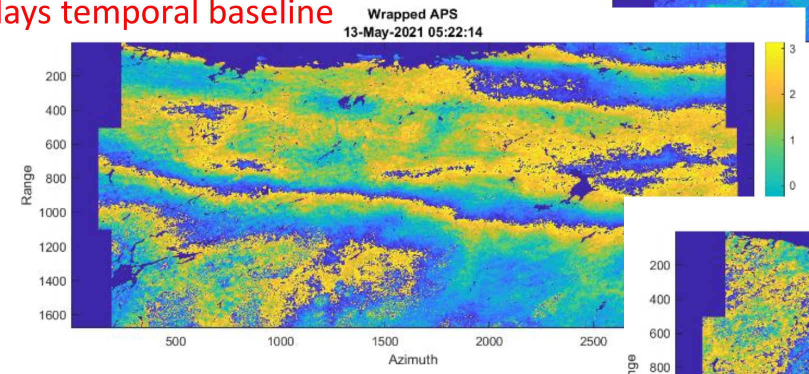


Sweden

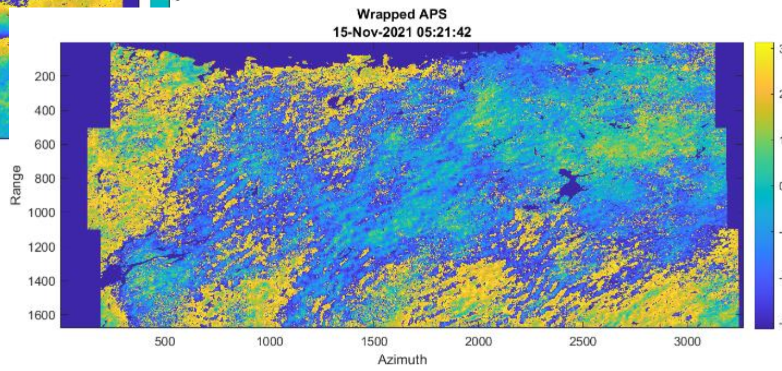
- Poor coherence, but still the phase is smooth

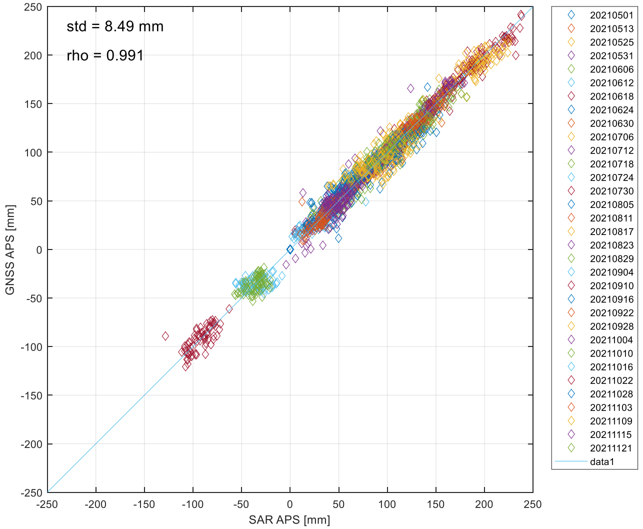


6 days temporal baseline



6 months temporal baseline

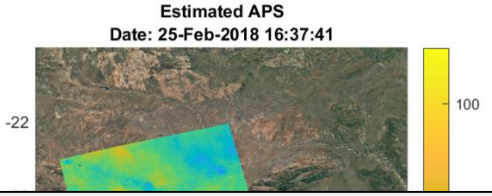




Preliminary results from Year 2

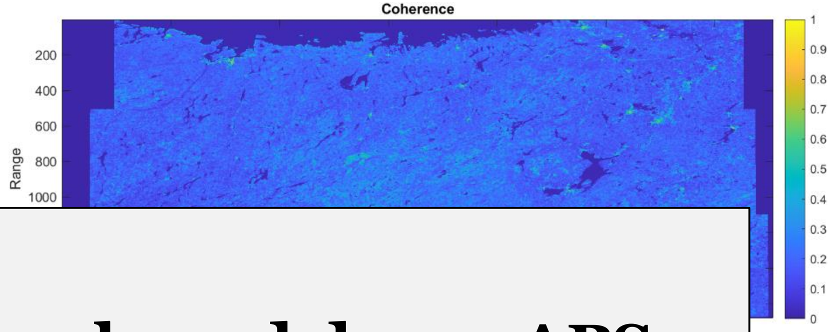
South Africa

- $250 \times 850\ km^2$
- Very good accordance

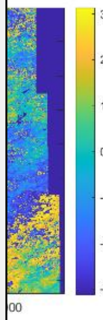


Sweden

- Poor coherence, but still the phase is smooth

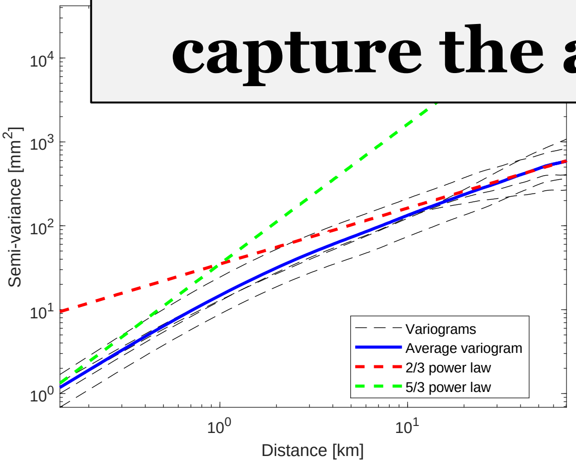


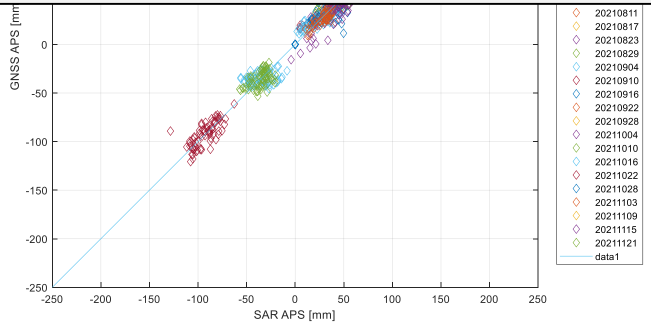
line



Conclusions

- **The proposed method is able to generate large scale and dense APS maps.**
- **The calibration procedure removes low frequency trends in the APS maps.**
- **Validation using theoretical models and an independent set of GNSS has been carried out confirming the capability of the method to capture the atmosphere dynamic.**





Preliminary results from Year 2

Subsurface target detection and imaging

Test site 1:

- The Kermeter forested area at the Eifel Park in North-West Germany, investigated in the context of the ESA campaign TomoSense in 2019-2022

Campaign data include:

- Tomographic P-Band data
- Bistatic airborne SAR surveys at L- and C-Band collected by flying two aircrafts in close formation, with one following the other at a distance of approximately 30 m.
- In-situ collection of relevant forest parameters at approximately 80 plots.
- Collection of TLS data at a scale of 1 ha at three to five plots.
- Installation of 5 m trihedral reflectors for P-Band calibration

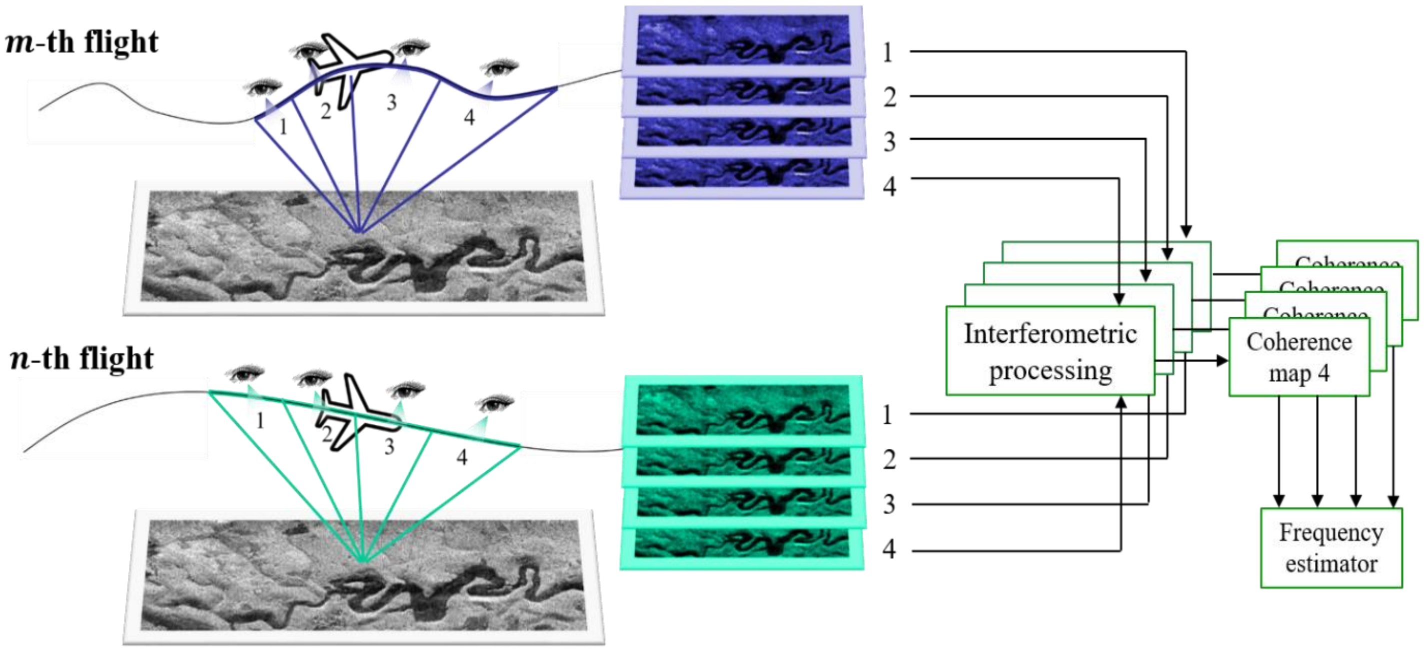
Preliminary results from Year 2

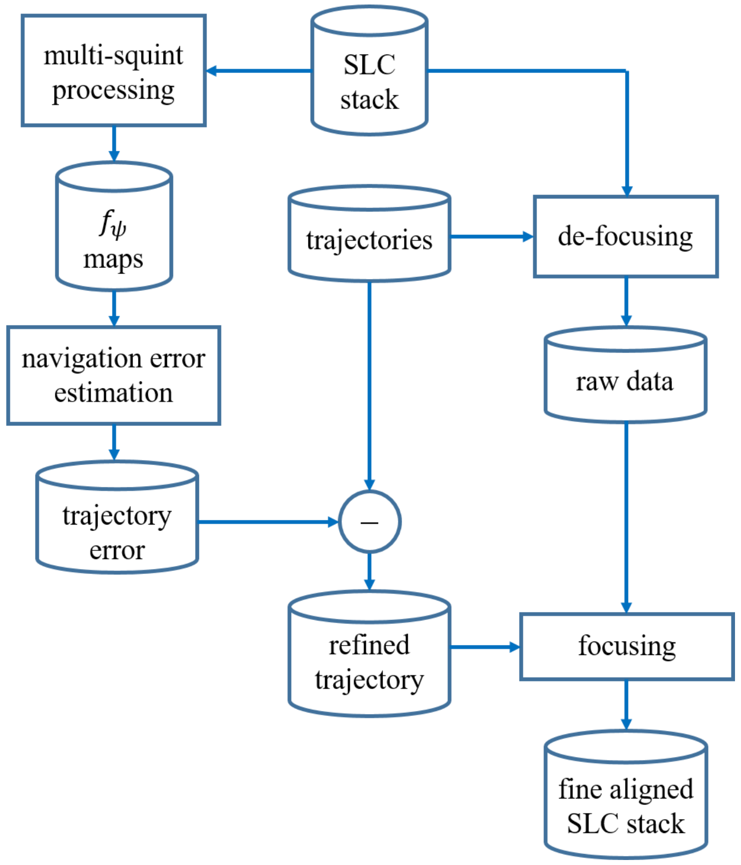
The acquired data stack turned out to be affected by space-varying azimuth co-registration errors at large ranges due to residual baseline variations unpredicted by navigational data

⇒ ***Massive processing required***

Trajectory correction was carried out by Multi-Squint Interferometry

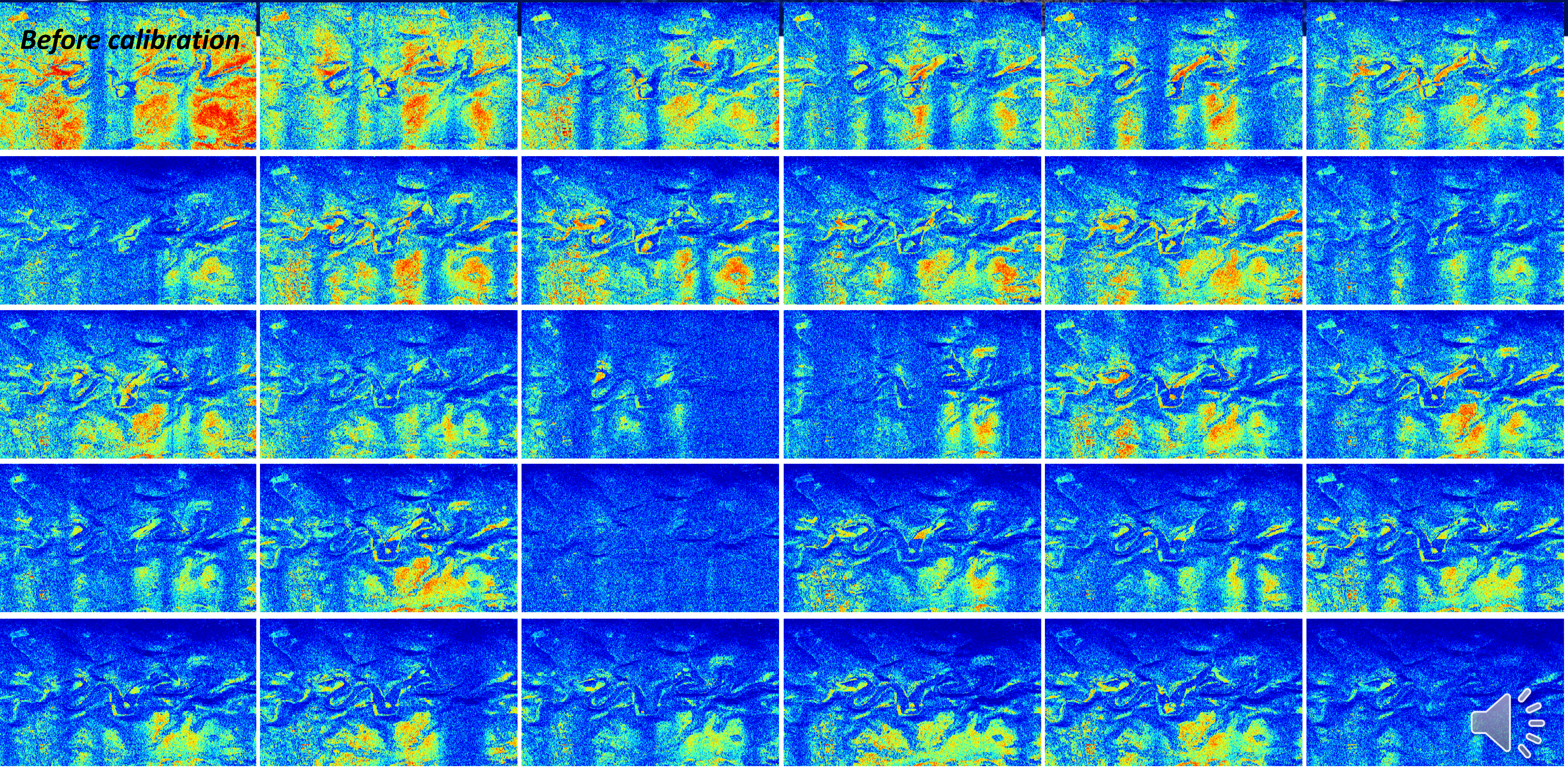
- Defocusing to raw data using trajectories from navigational data
- Formation of sub-images at different squint angles
- Trajectory estimation by multi-squint InSAR
- 2D Refocusing using corrected trajectories



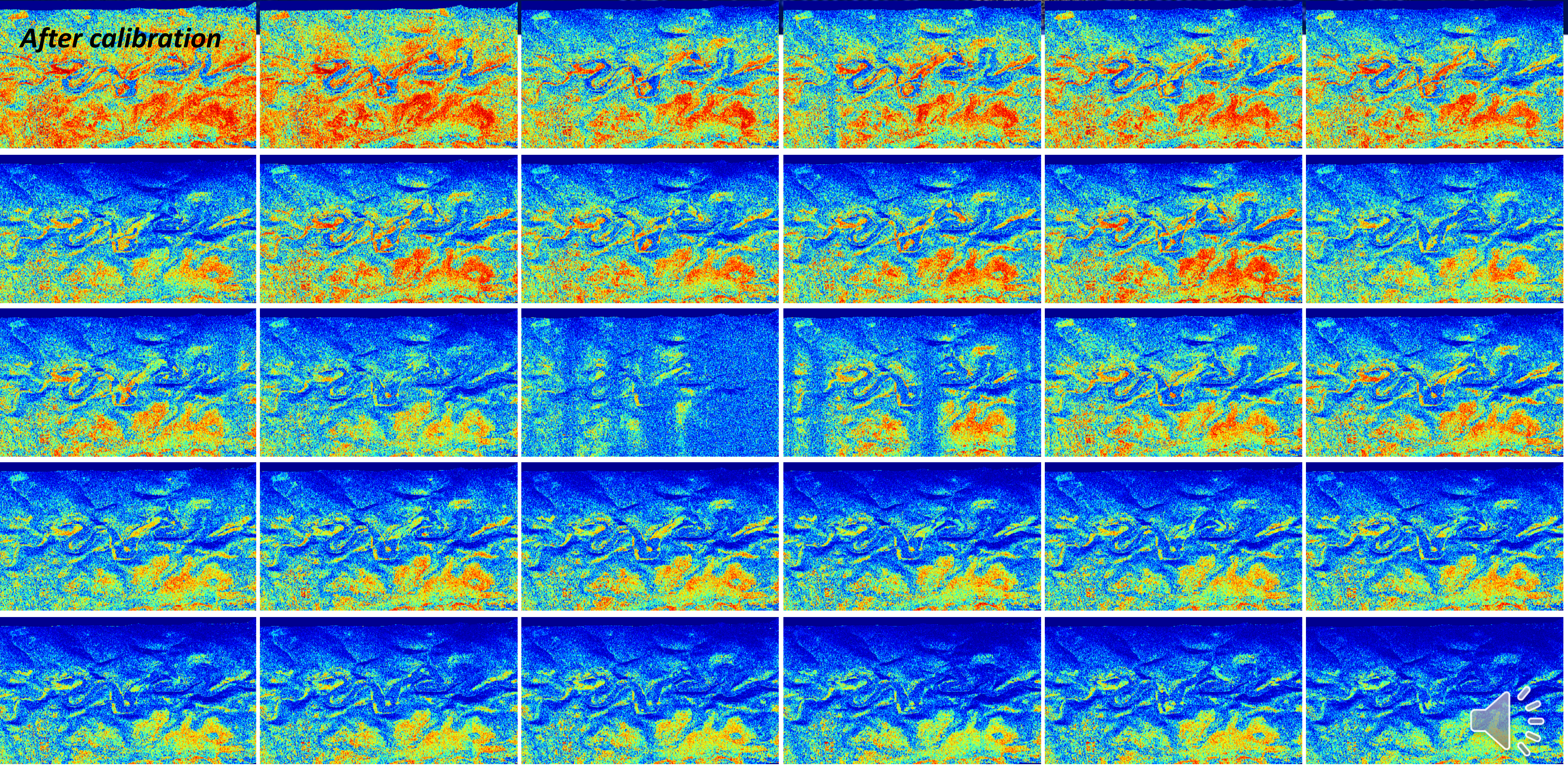


Thousands of interferograms processed

Preliminary results from Year 2



Preliminary results from Year 2



Preliminary results from Year 2

Tomographic calibration

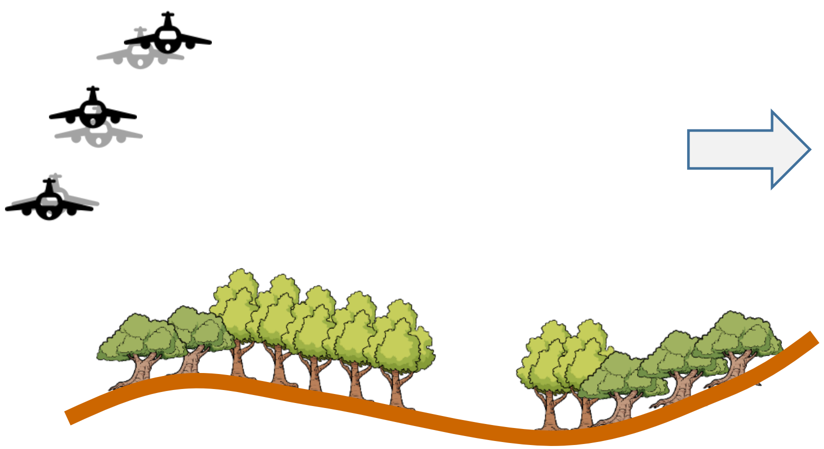
- Multi-squint InSAR recovers large part of the trajectory errors, but it is prone to neglecting slowly varying terms that cause blurring in tomographic imaging

⇒ Need for a further calibration step

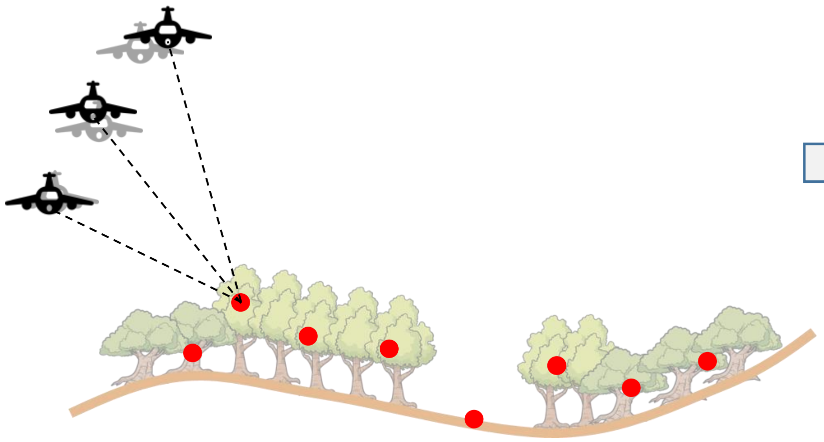
Bistatic Phase Center Double Localization

- Represent a forest as a collection of point targets by (again) a joint analysis of all available interferograms
- Find the position of all sensors and all targets given the set of all *Tx> target > Rx* distances

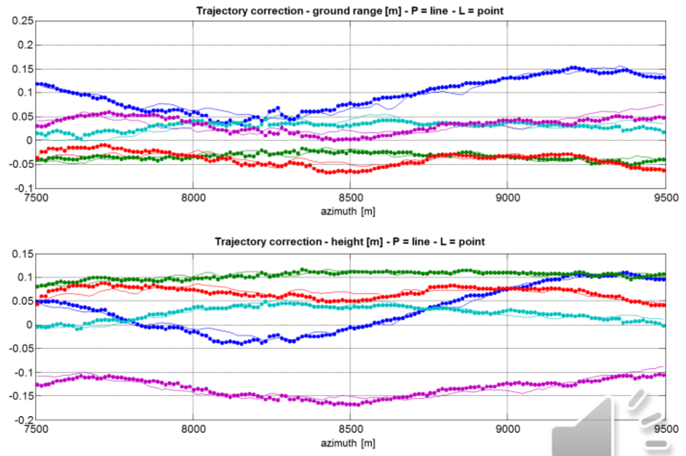
Forest scenario



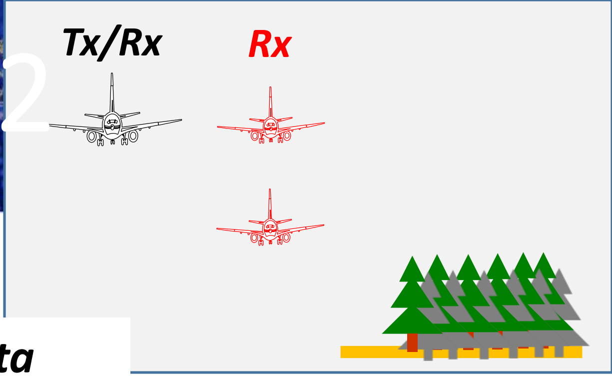
Virtual point targets



Trajectory correction

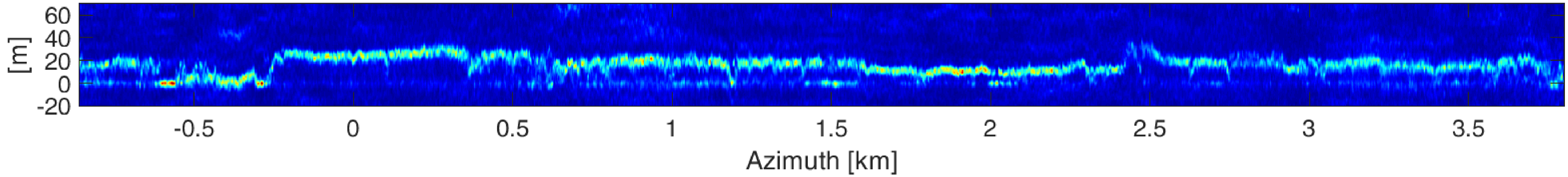


Preliminary results from Year 2

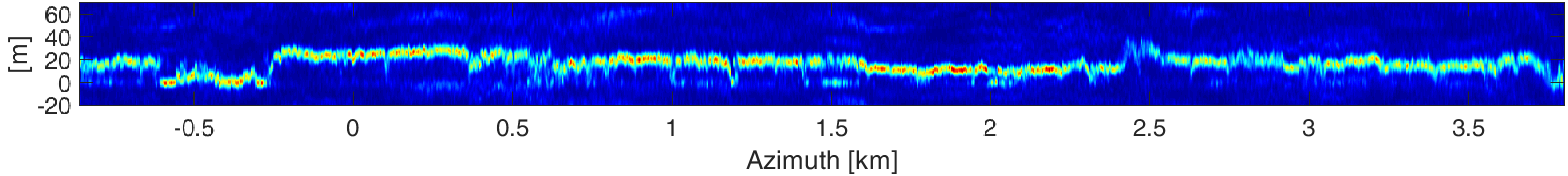


Ground-steered L-Band vertical sections

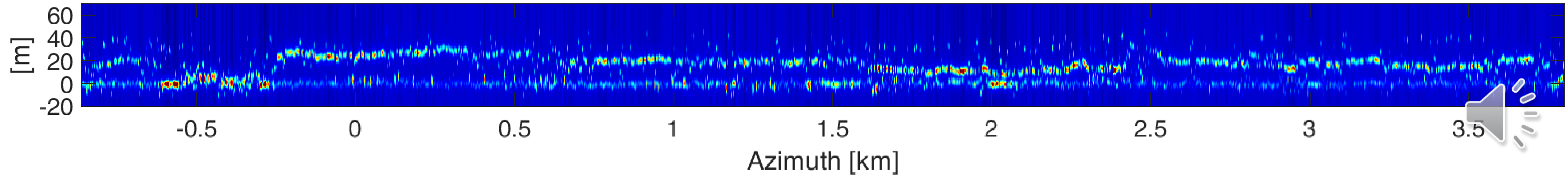
L-Band – HH – Vertical section from repeat pass mono-static data



L-Band – HH – Vertical section from repeat pass bi-static data



L-Band – HH – Vertical section from simultaneous Tx/Rx interferograms



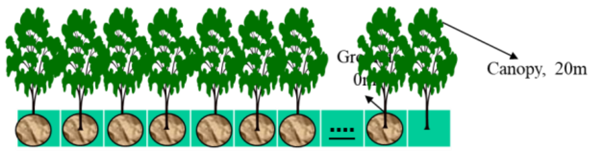
Preliminary results from Year 2

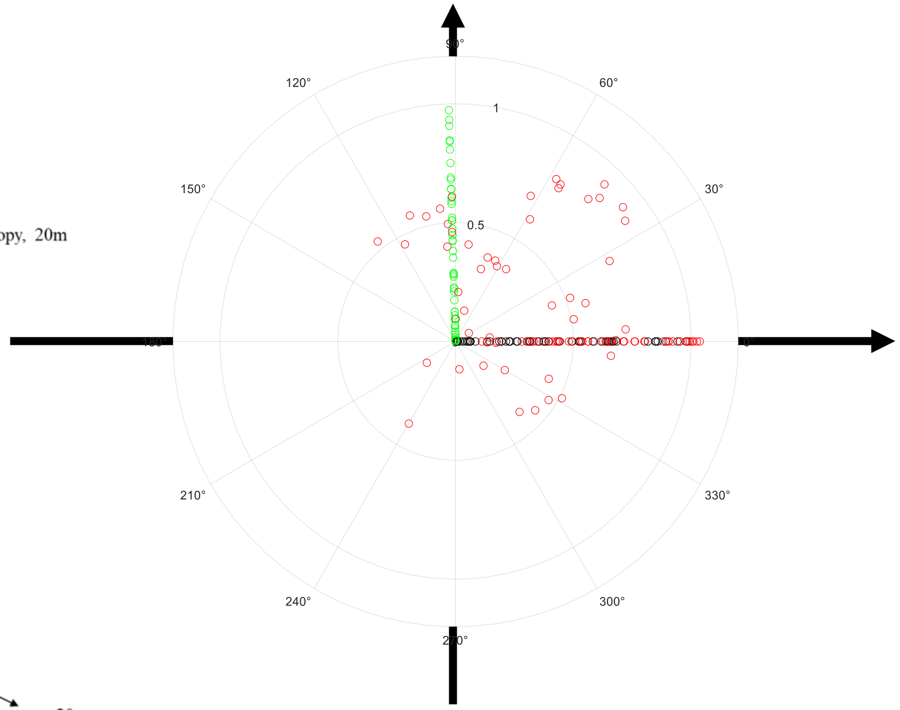
Investigation of the **Phase Histogram technique**

- Dominant scatterer model
- Distributed scatterer model

$$g(z_n) = \sum_{i=1}^{M} \omega_i f(s_1, s_2) \chi_i(z_n, \varphi_i)$$

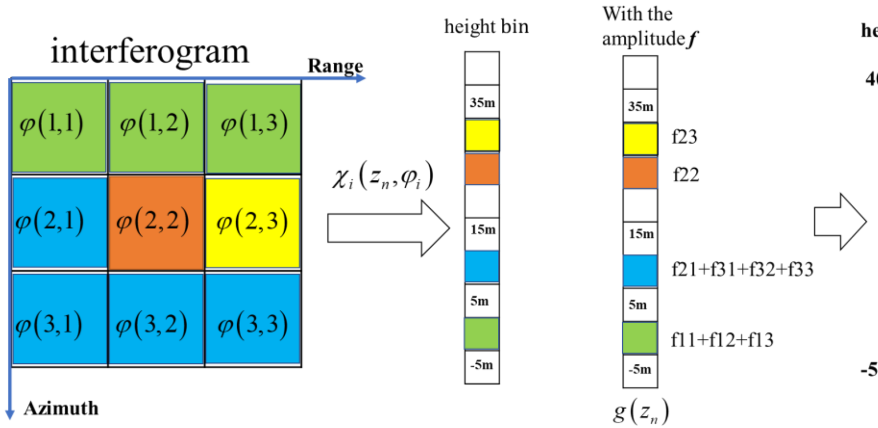
Simple case of simulation with distributed scatterer

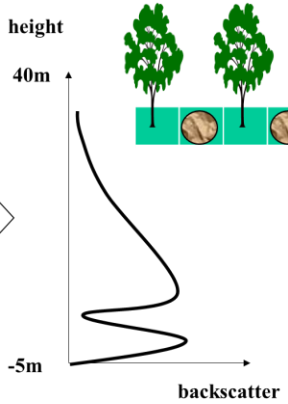




Representation of Interferograms in Polar Coordinates

Simple case of simulation with dominant scatterer

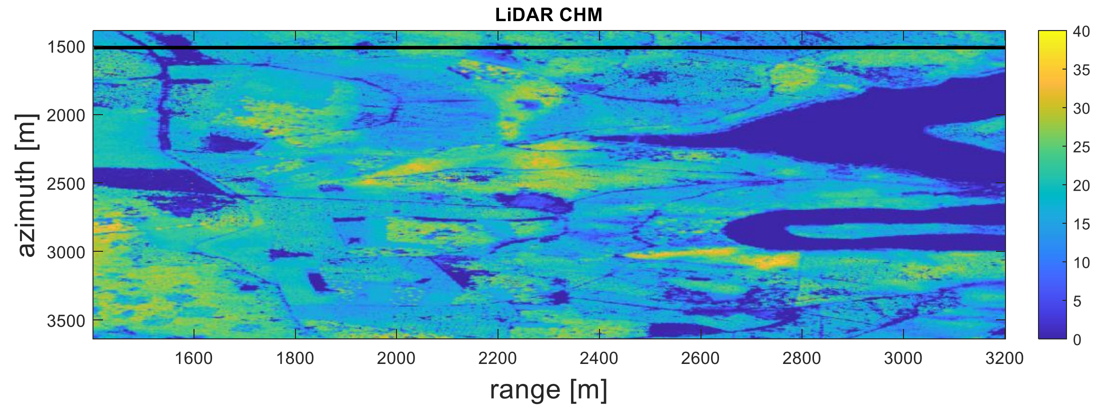


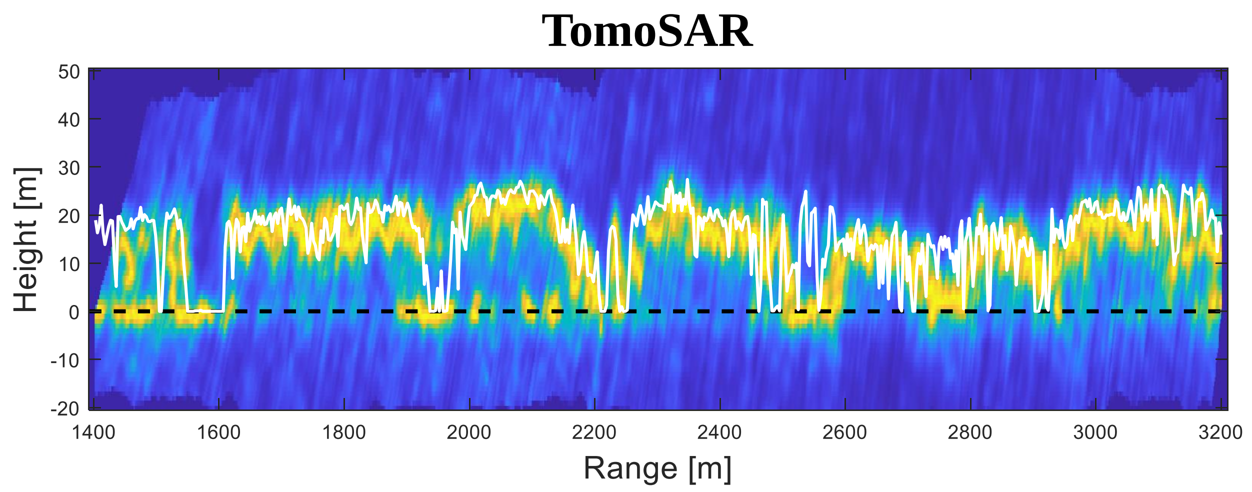


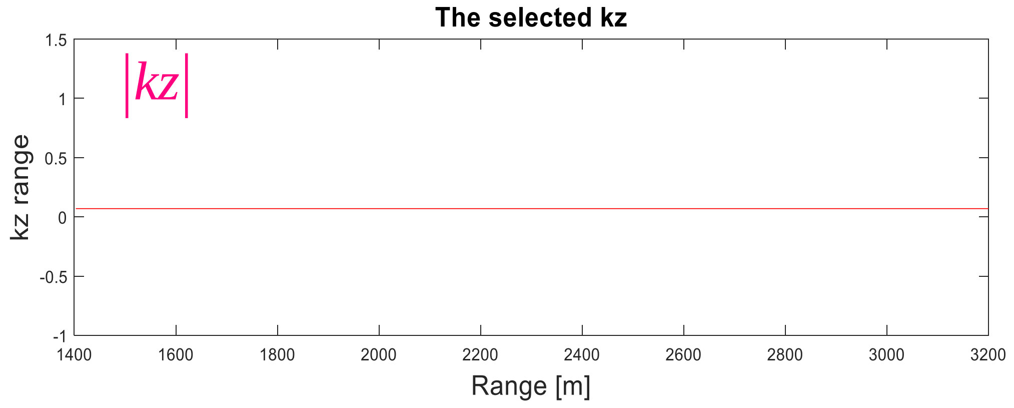
The profile of central pixel

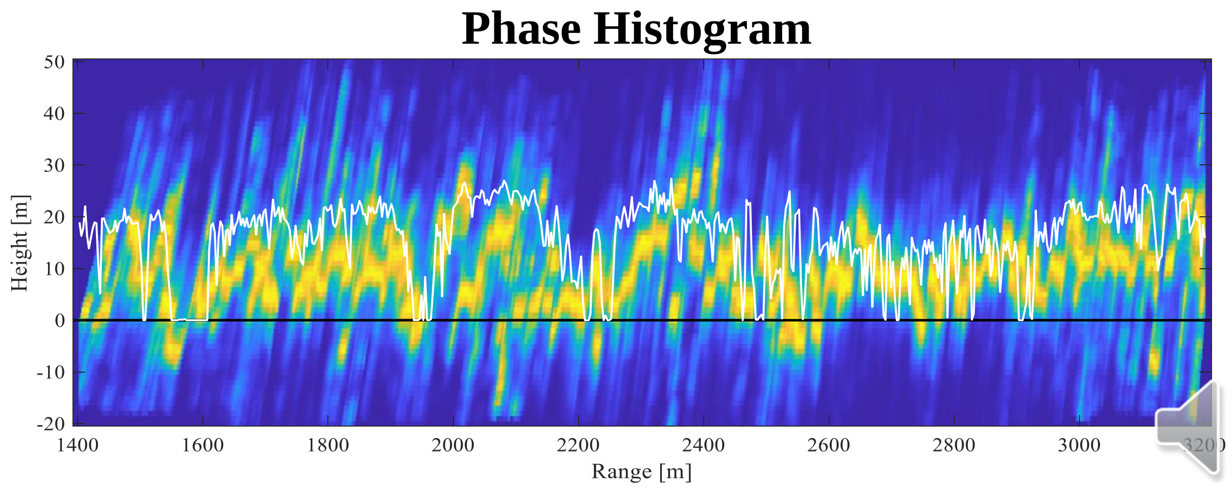
Preliminary results from Year 2

Generation of a super interferogram at constant *kz* based on joint analysis of all available (435) interferograms









Preliminary results from Year 2

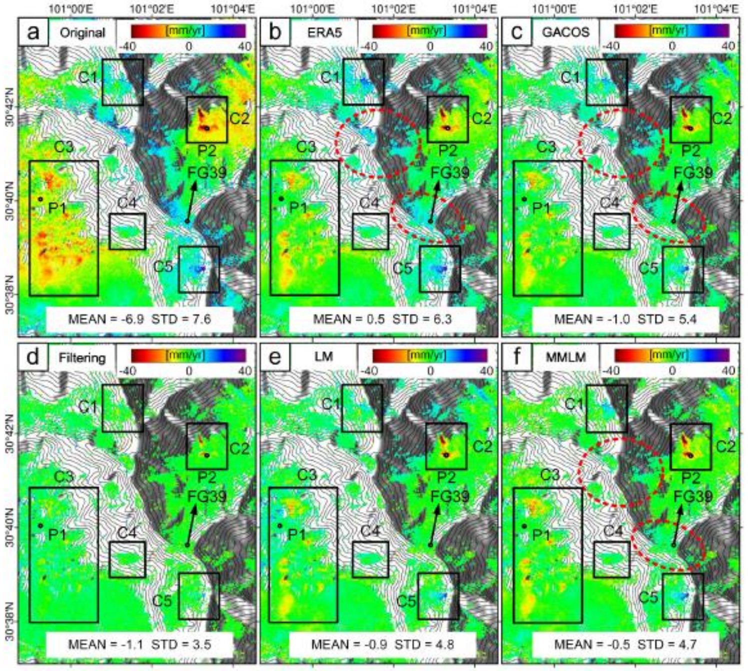
InSAR tropospheric delay correction for wide-area landslides investigation

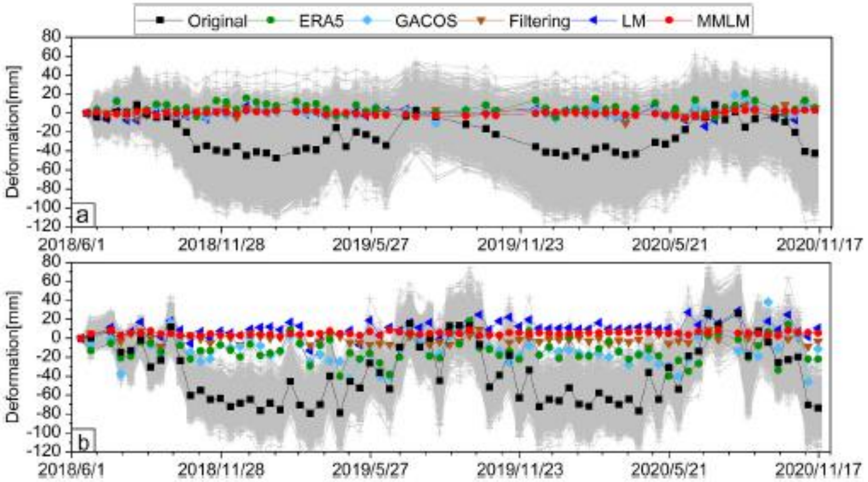
Test-site: Lianghekou hydropower station, China, 2018-2020

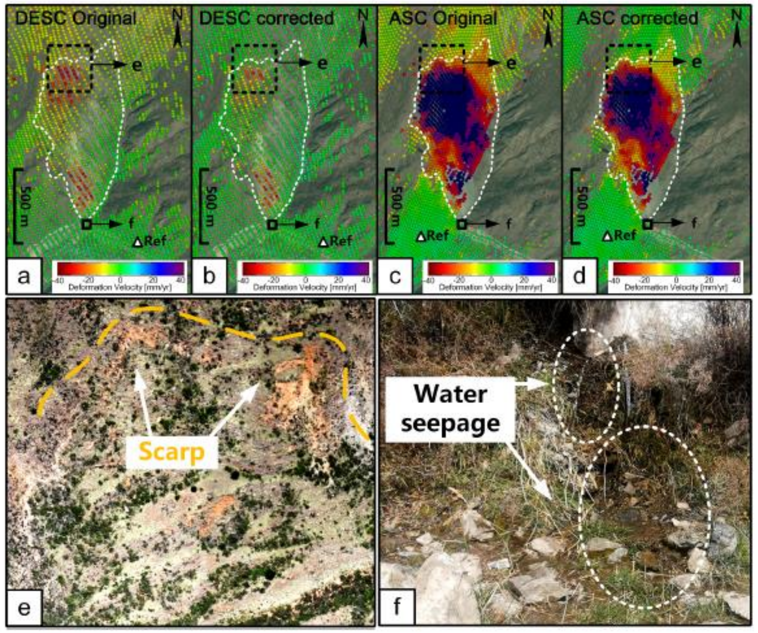
Proposing a multi-temporal moving-window linear model (MMLM)

Mitigating the influence of local turbulent phase, local landslide deformation, and phase unwrapping error on parameter estimation

Providing precise heterogeneous atmospheric corrections







Wang Y, Dong J, Zhang L, et al. Refined InSAR tropospheric delay correction for wide-area landslide identification and monitoring[J]. Remote Sensing of Environment, 2022, 275: 113013.

Preliminary results from Year 2

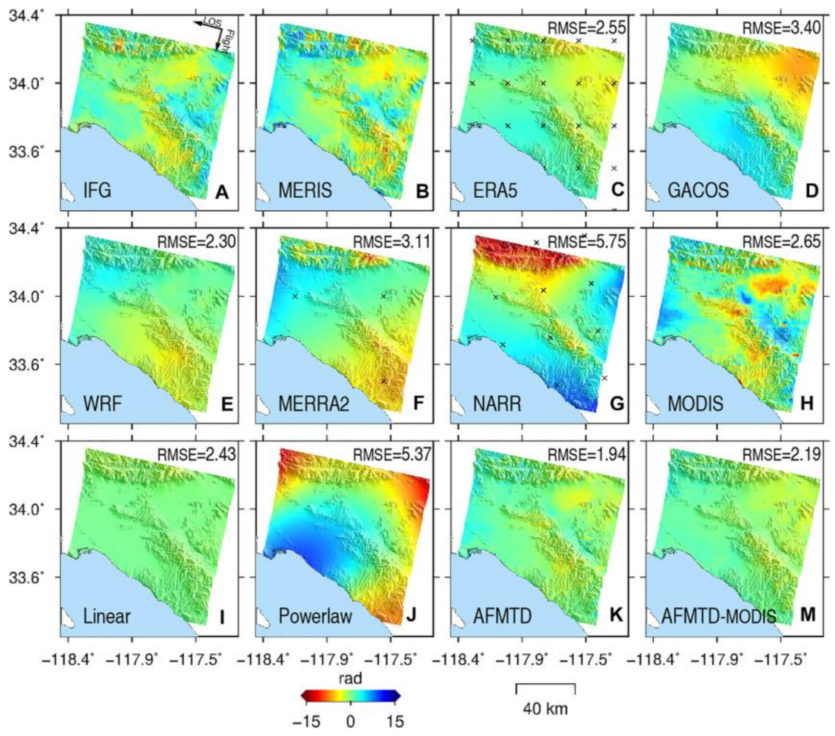
InSAR tropospheric delay Estimates for InSAR Deformation Measurements

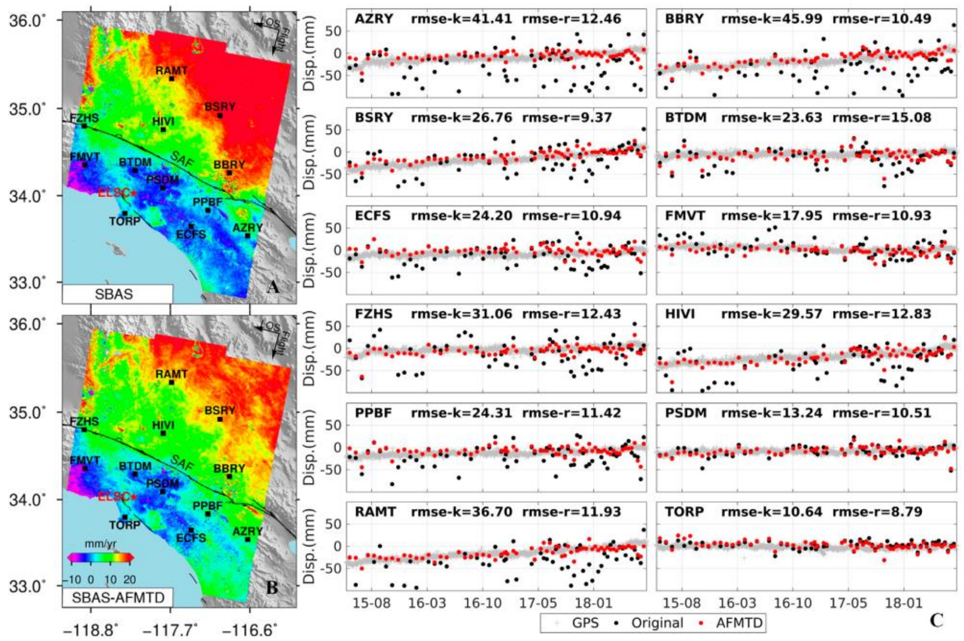
Test-site: Los Angeles of Southern California

Proposing an adaptive fusion of multi-source tropospheric delay (AFMTD) method

Improving the spatial heterogeneity of tropospheric delay and estimating delays more reliably

Validating with ENVISAT ASAR and Sentinel-1 datasets





Zhang L, Dong J, Zhang L, et al. Adaptive Fusion of Multi-Source Tropospheric Delay Estimates for InSAR Deformation Measurements[J]. Frontiers in Environmental Science, 2022: 213.

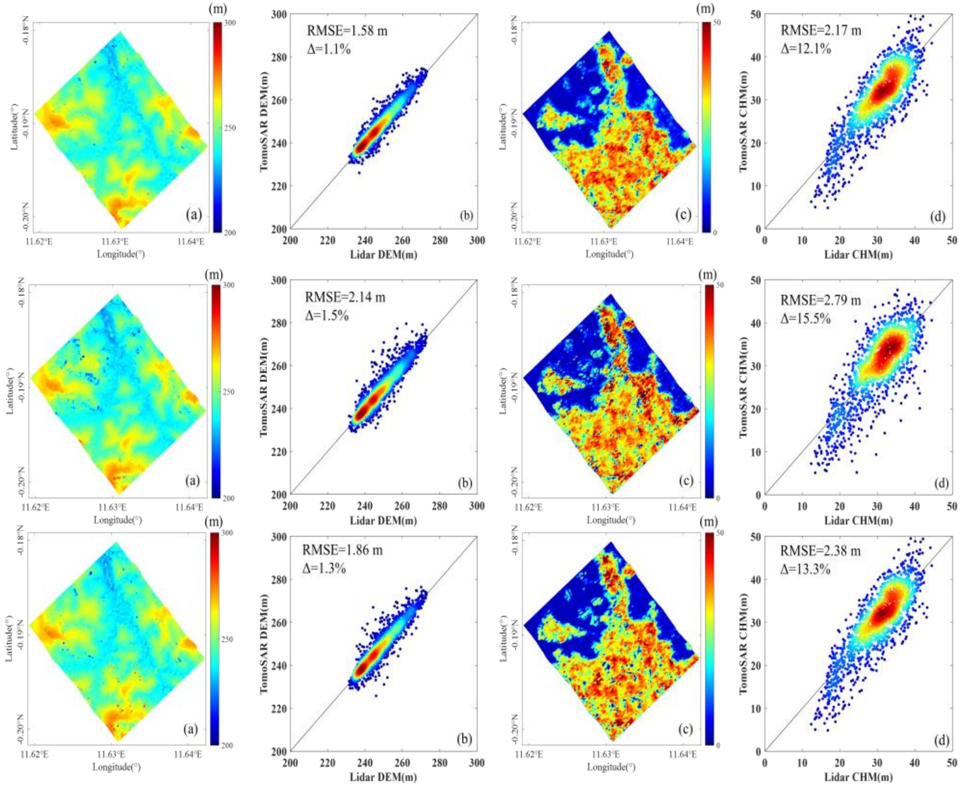
Preliminary results from Year 2

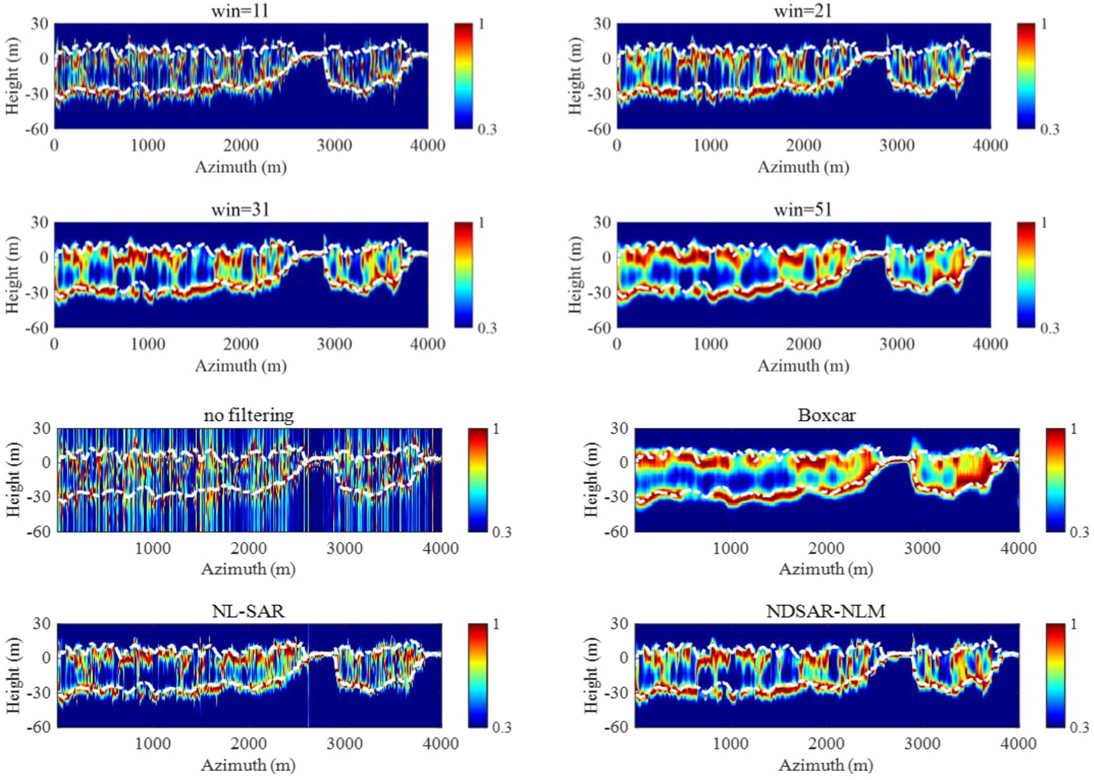
Forest Vertical Structure Parameter Extraction by TomoSAR

Test-site: Lopè National Park, Gabon, 2016

Evaluating different TomoSAR algorithms for forest height and underlying topography extraction

Exploring the effects of different baseline designs and filter methods on the reconstruction of the tomographic profile

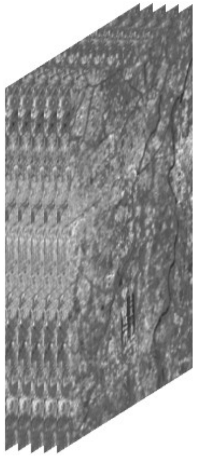


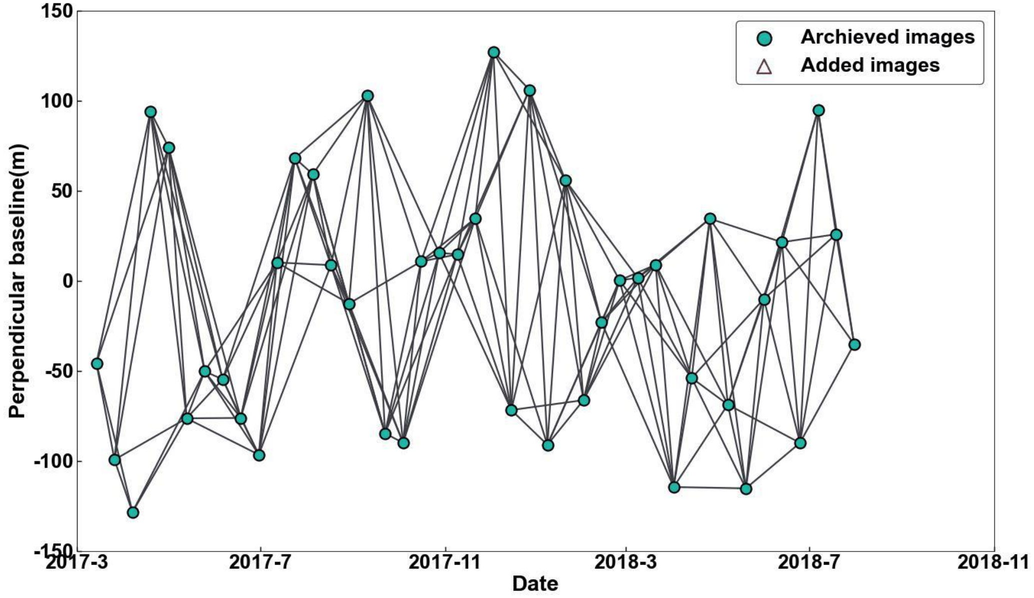


Wu C, Yang X, Yu Y, et al. Assessment of underlying topography and forest height inversion based on TomoSAR methods[J]. Geo-spatial Information Science, 2022: 1-16.

Preliminary results from Year 2

Time-series InSAR Dynamic Analysis with Robust Sequential Adjustment





Ⅰ: Robust initialization of parameters

- Generation of SBAS interferograms
- Selection of coherent pixels
- **Robust time series estimation of archived data**

Ⅱ: Generate new observations

- Interferograms generation corresponding to new SAR images
- phase unwrapping of new interferograms

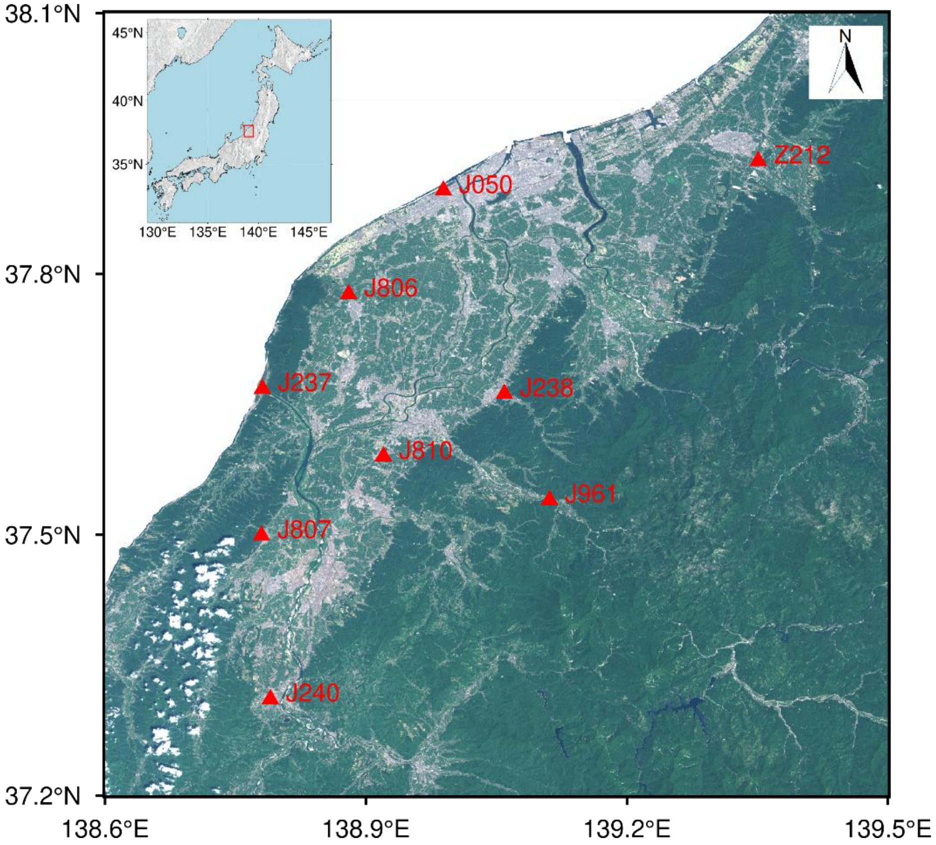
Ⅲ: Robust sequential adjustment

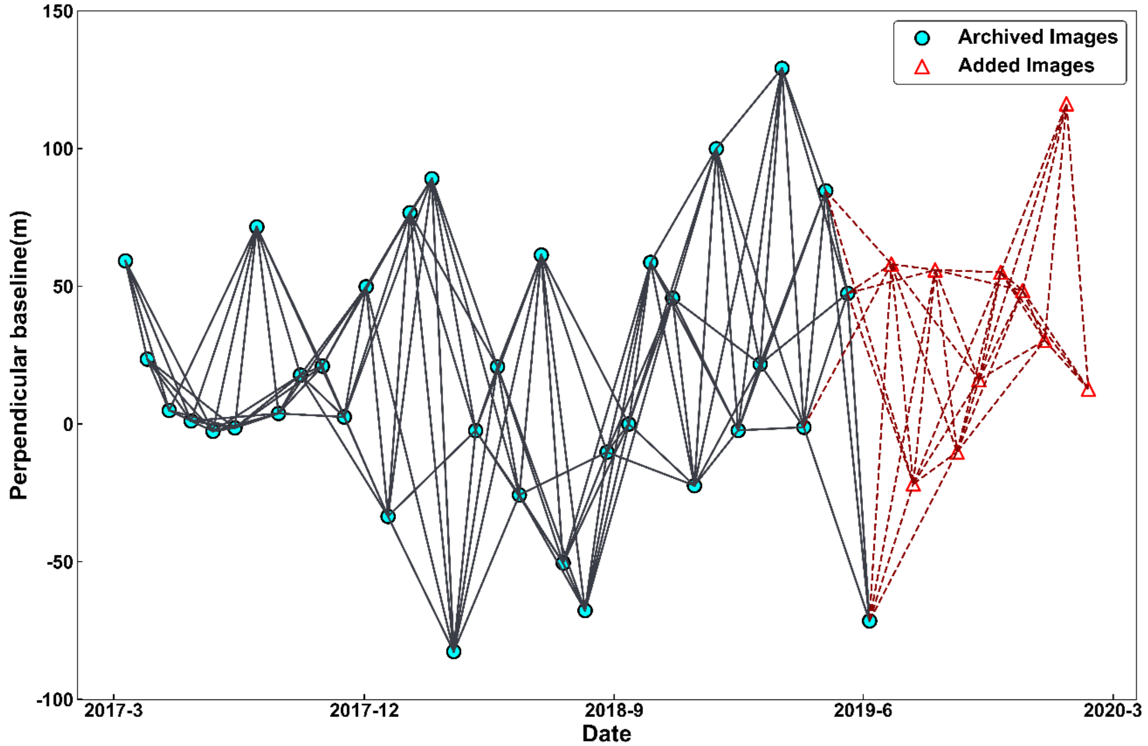
- Updating deformation time series corresponding to the new SAR acquisition date with robust sequential adjustment

Preliminary results from Year 2

- **Study Area and Data**

- Echigo plain, the largest rice-growing area in Japan, is an alluvial plain formed by the Shinano and Agano Rivers, surrounded by sea to the north
- Triangles in red are the location of GPS stations.



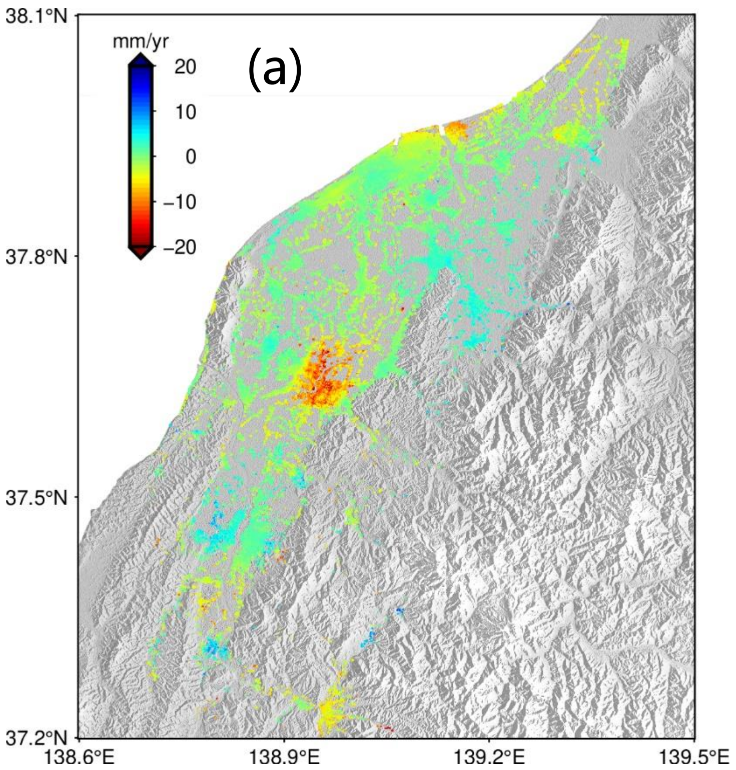


- **45 Sentinel-1 SAR images** from 14 March 2017 to 3 February 2020 were employed to generate 169 differential interferograms by setting the spatial and temporal baseline thresholds.
- For the sequential InSAR processing, we prepared 129 and 40 unwrapping phases for historical 35 SAR and 10 newly added observations respectively.

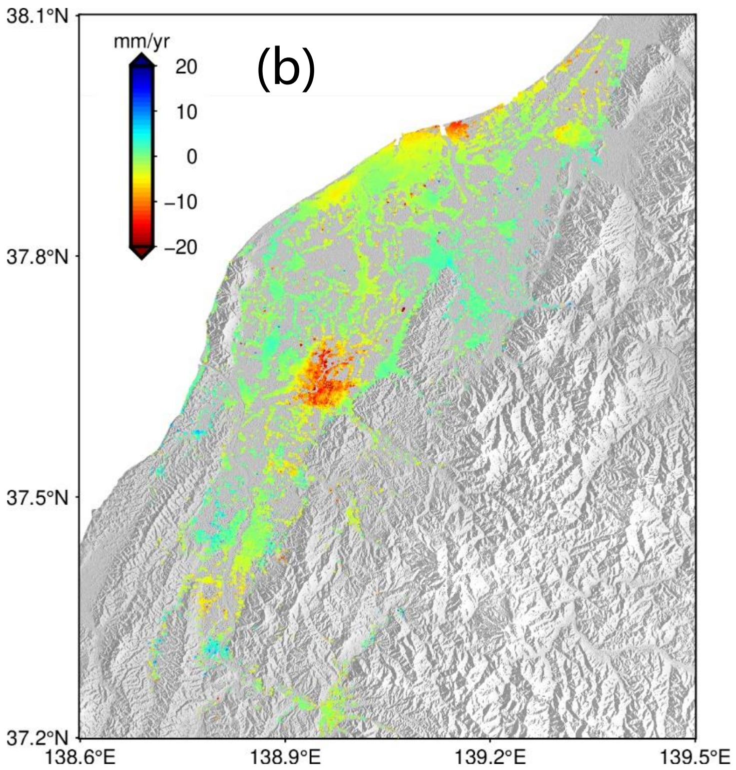
Preliminary results from Year 2

- **Results and Analysis**

□ Comparison of the Deformation Rate Maps



Sequential least squares



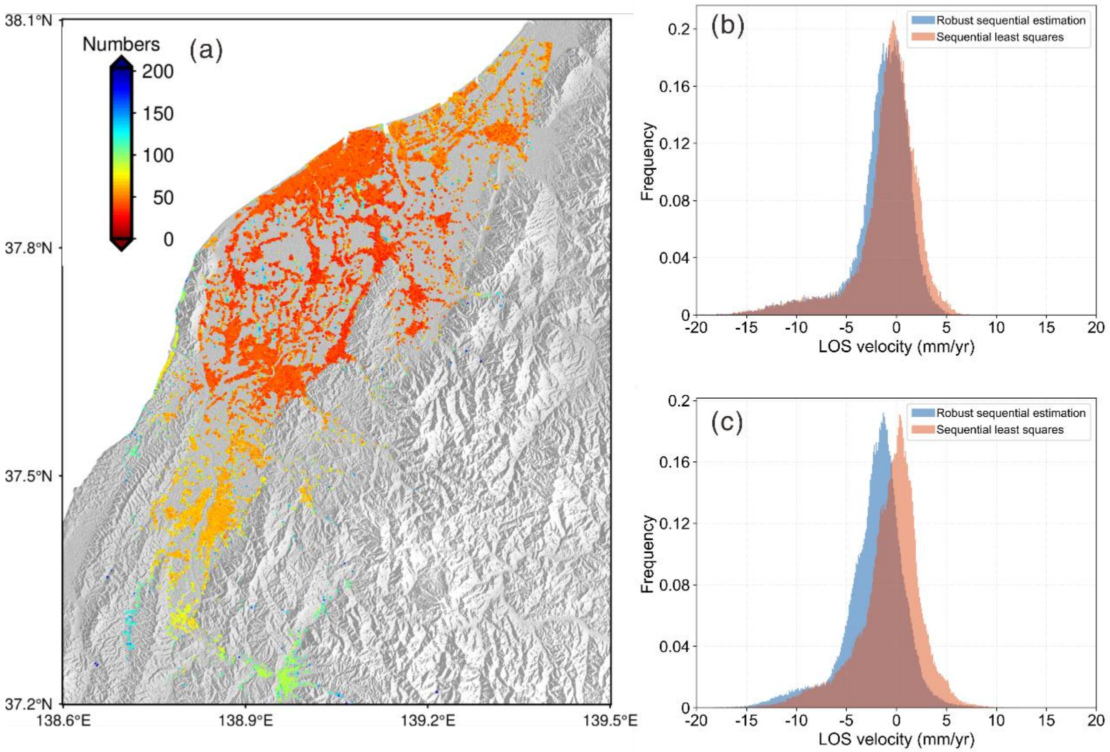
Robust sequential adjustment

- Sparse measurement points density implies **low-coherence scenarios**
- Compared with Fig(b), **the left and bottom areas** in Fig(a) seem to be **overestimated**

Time-series InSAR Dynamic Analysis with Robust Sequential Adjustment

- **Results and Analysis**

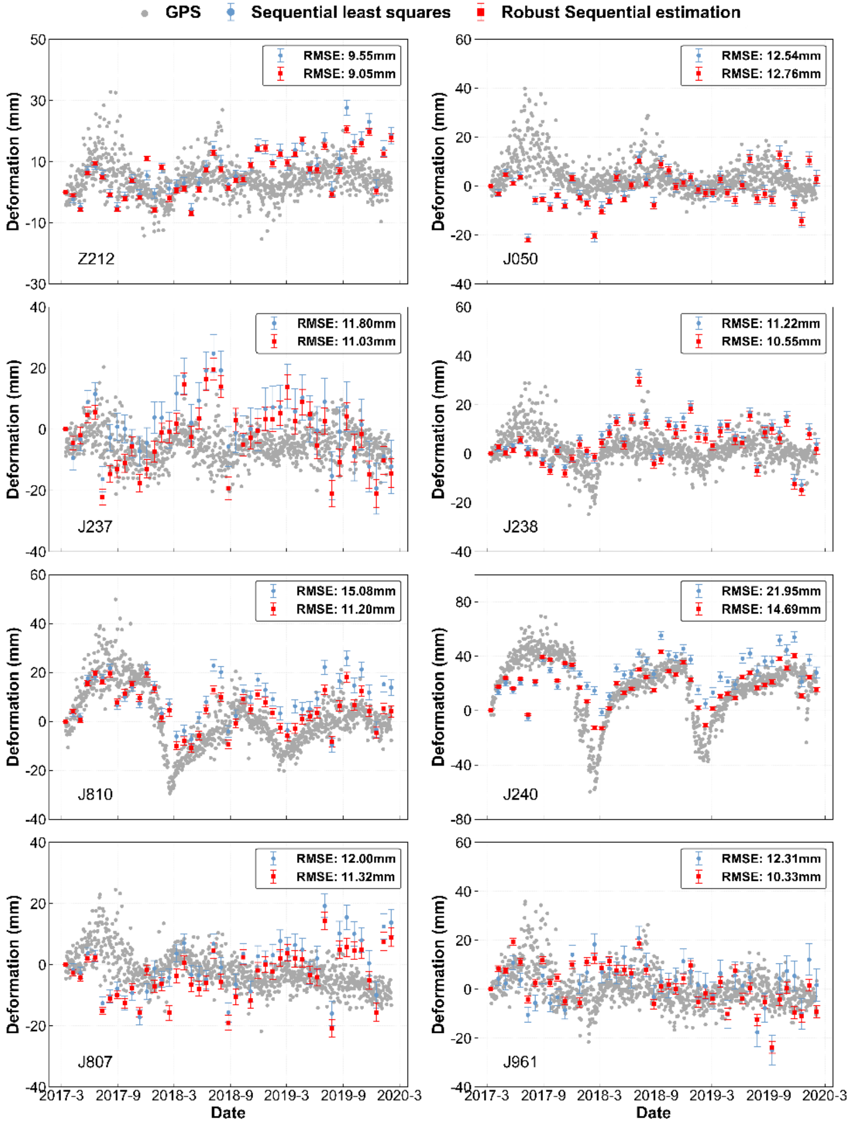
☐ Performance versus Number of Ambiguities



➢ Number of **non-closing loops** for each point (169 interferograms and 247 loops)

➢ Velocity histogram for points with non-closing loops by thresholding **15%**

☐ Accuracy evaluation with GPS datasets



Preliminary results from Year 2

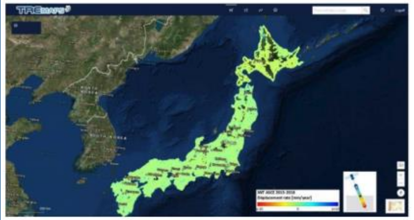
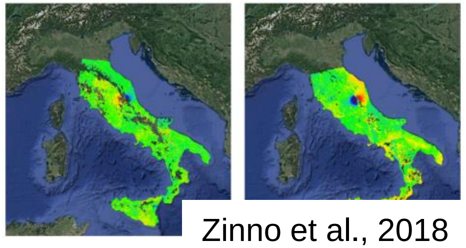


Figure 1: Map of the average displacement rate measured along ascending satellite tracks.



Zinno et al., 2018

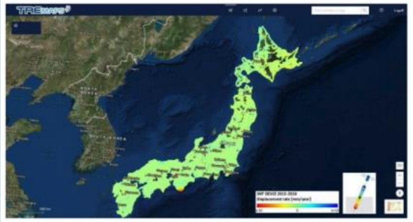
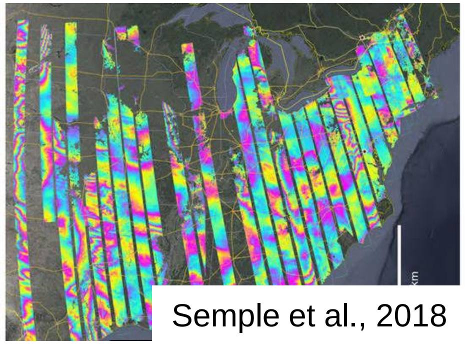
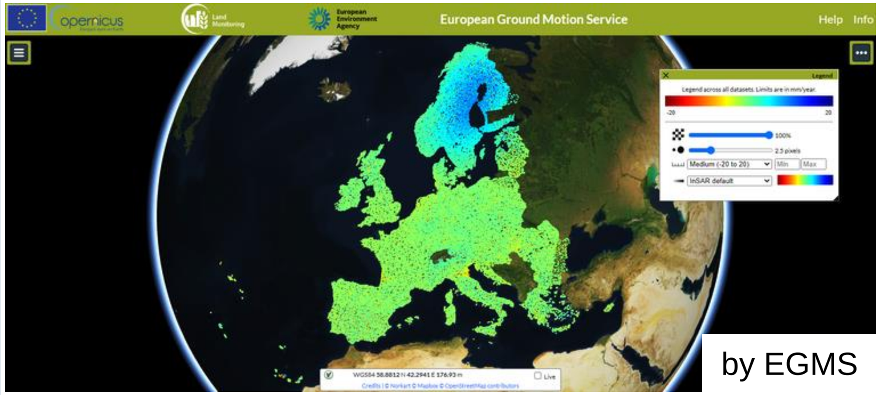


Figure 2: Map of the average displacement rate measured along descending satellite tracks.

Ferretti et al., 2019



Semple et al., 2018



by EGMS

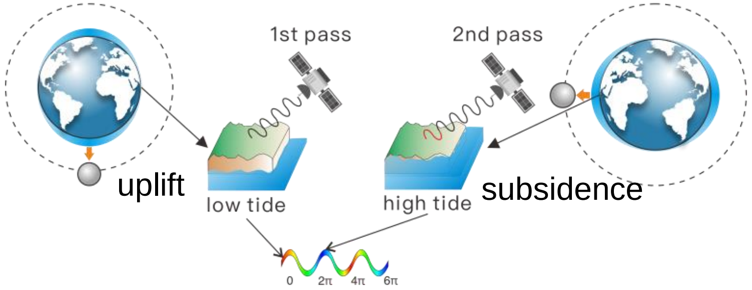
InSAR applications:
local, regional → large, nationwide

Ocean tide loading effects on Large-scale InSAR Observations

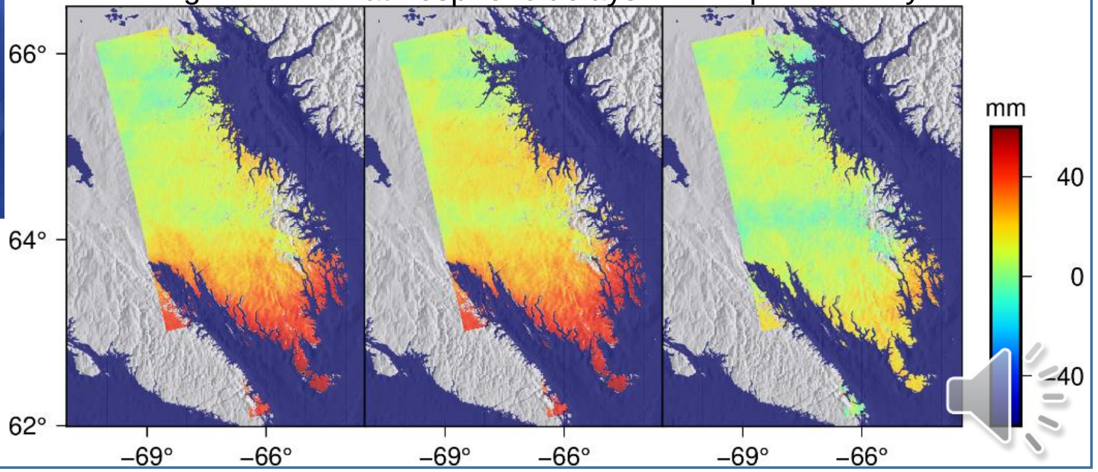
Common long wavelength errors at large scale (mitigation methods):

- ✓ Orbital uncertainties (precise orbit control, etc.)
- ✓ Ionospheric delays (split-spectral technique, etc.)
- ✓ Atmospheric delays (numerical weather model, etc.)
- ➢ Ocean tide loading (OTL) displacement

Periodic redistribution of ocean mass deforms the solid Earth.

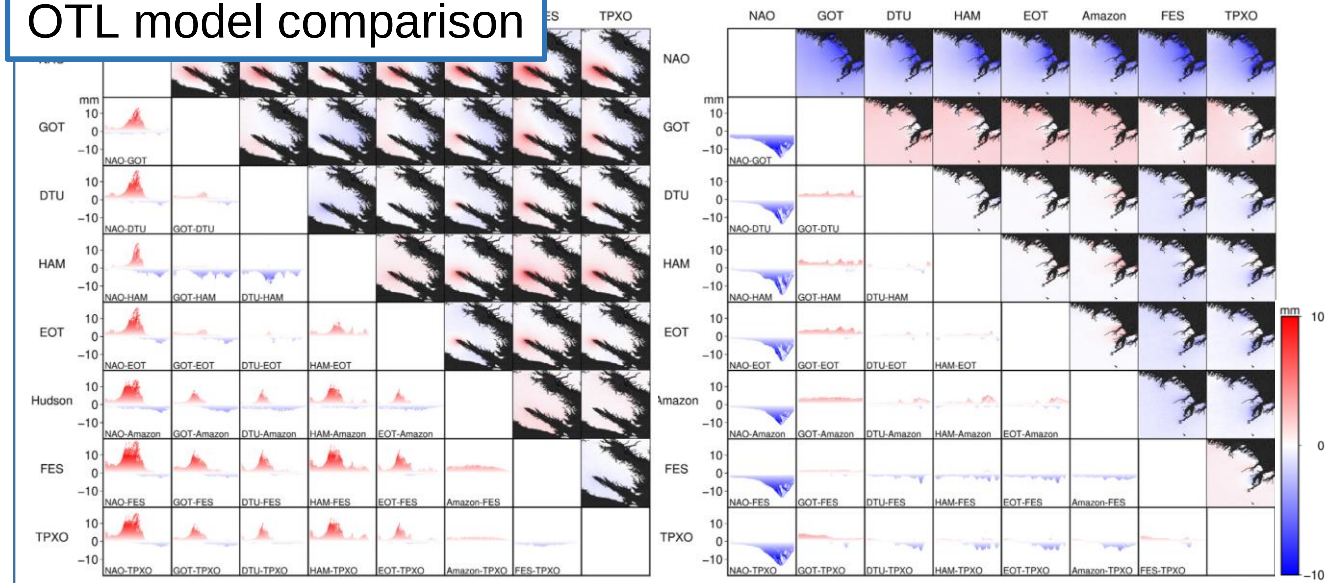


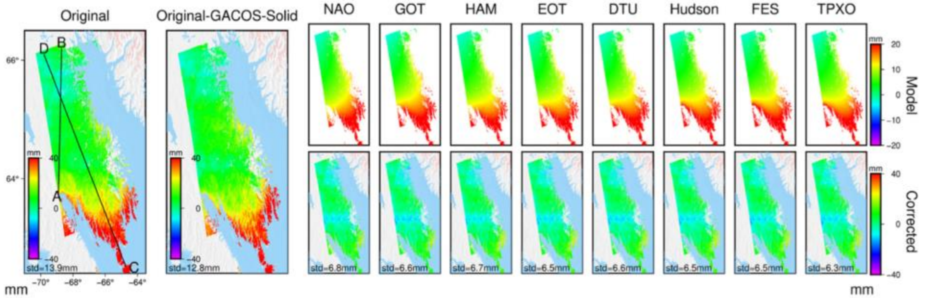
OTL introduces long wavelength errors in interferograms

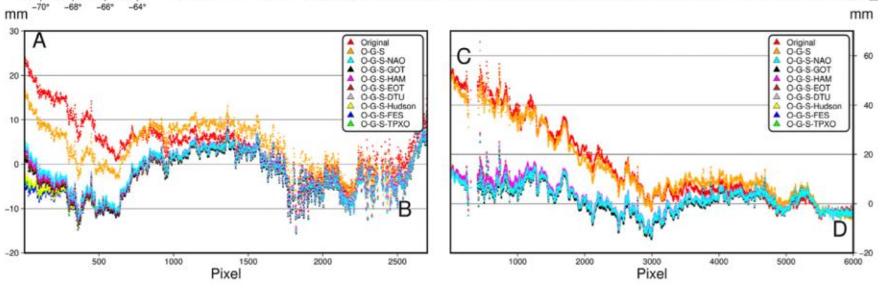


Preliminary results from Year 2

OTL model comparison



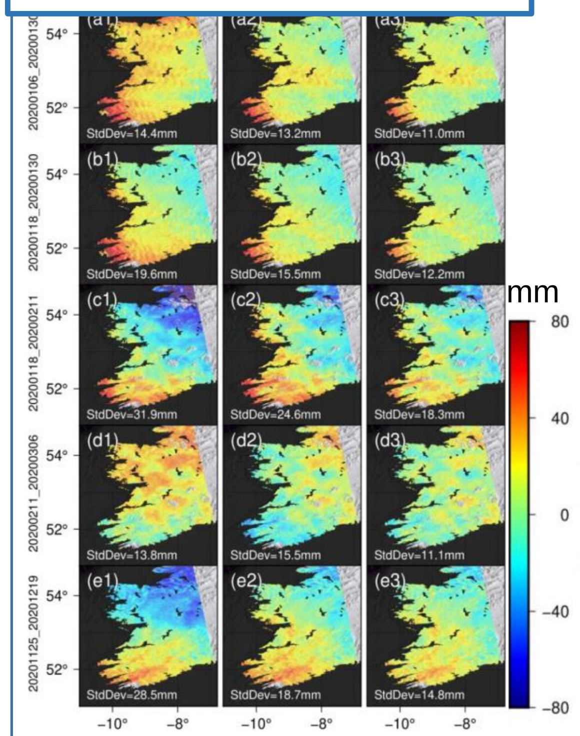


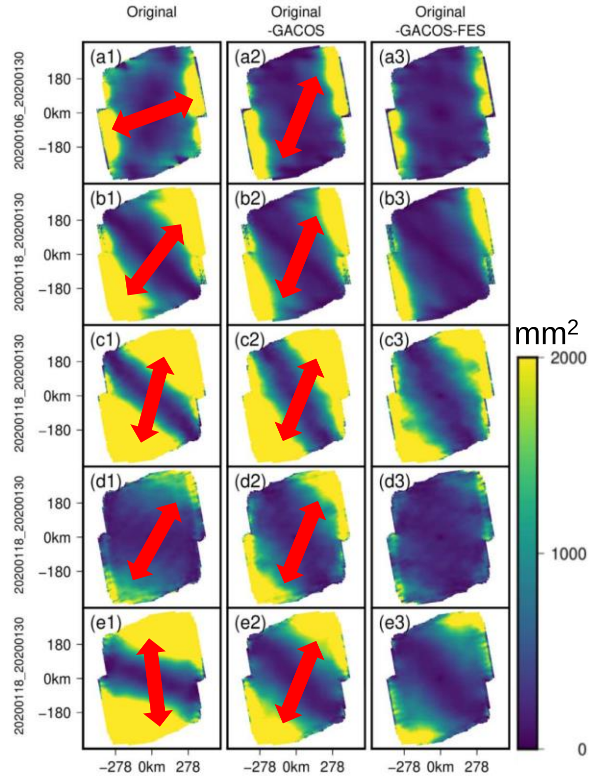


Assessment based on ground GNSS data distributed over three sites in Canada, Brazil and France for the year 2019.

Best models:
FES2014
TPXO9
Local model

OTL effects in DInSAR





OTL characteristics in DInSAR:

- ☐ OTL has **larger magnitude** than atmospheric delays in some cases
- ☐ OTL distributes in a **fixed direction**

Summary

ID. 59332

PROJECT TITLE: GEOPHYSICAL AND ATMOSPHERIC RETRIEVAL FROM SAR DATA STACKS OVER NATURAL SCENARIOS

4 Universities: PoliMi, Wuhan, Sun Yat-Sen, Pisa

2 European and 3 Chinese Young scientists

Topics reported:

- Development of airborne and spaceborne signal processing methods for SAR data stacks
- Vertical structure of forested areas
- Tropospheric estimation and correction
- Landslides
- Updating deformation time series
- Ocean Tide Loading

感谢您的关注

Grazie per l’attenzione!

Thanks for your attention!