

Bistatic and tomographic SAR imaging: current status and latest experiments with the compact Gamma L-band SAR systems

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selected SAR campaigns in collaboration with:

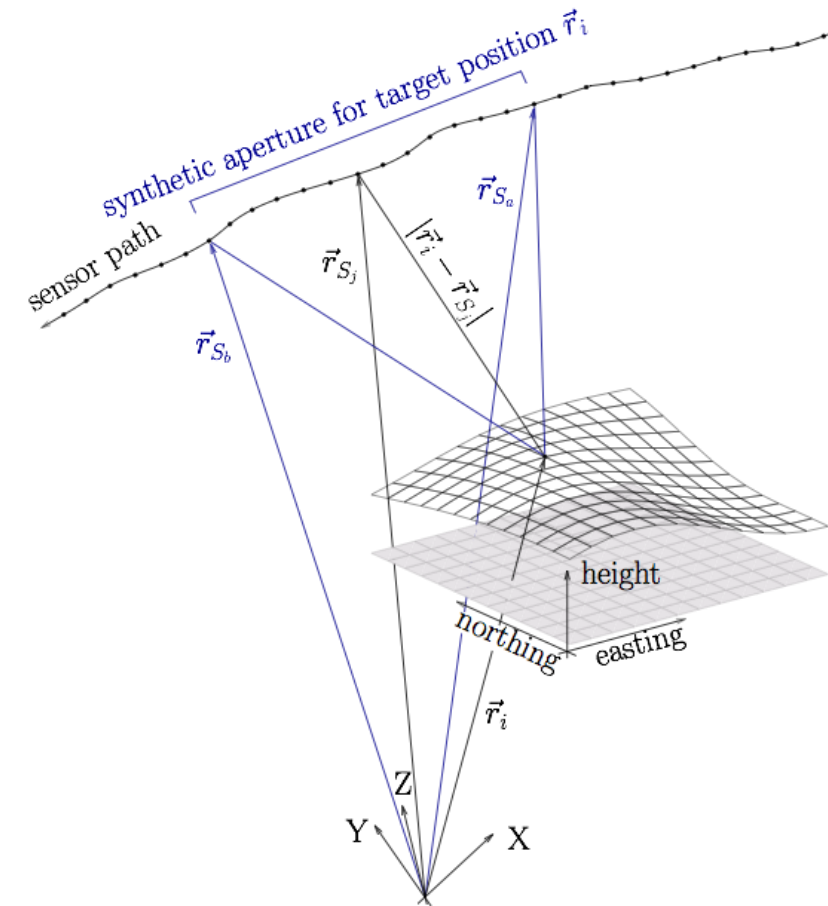
T. Sadeghi Chorsi ³, R. Van Alphen ³, T. Dixon ³,
A. LeWinter ⁴, D. L. Filiano ⁴, C. J. Wagner ⁴, E. Deeb ⁴

³ University of South Florida, USA,

⁴ Cold Regions Research and Engineering Laboratory (CRREL), Hanover NH, USA

Our history towards demonstration of UAV-borne SAR imaging with the Gamma SAR Systems at L-band (and S-band)

- 1. step: SAR imaging from agile platforms / UAV
→ time-domain back-projection focusing (C/CUDA → GPU)
using a digital elevation model
- 2. step: repeat-pass D-InSAR from car / UAV
- 3. step: repeat-pass SAR tomography from quad-copter UAV at L-band
- 4. step: work in progress: bistatic imaging (and eventually bistatic interferometry/tomography)



Frey, O., Magnard, C., Rüegg, M., Meier, E.:
“Focusing of Airborne Synthetic Aperture Radar Data
from Highly Nonlinear Flight Tracks”.
IEEE Trans. Geosci. Remote Sens., 47(6):1844-1858, June 2009.

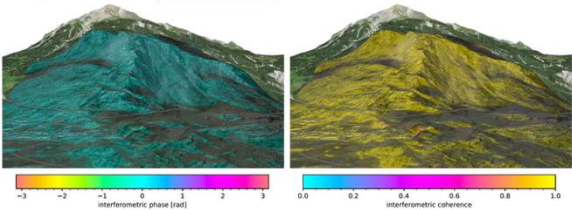
Step 1&2: First demonstrations of UAV-borne DInSAR at L-band and car-borne DInSAR at L-/S-/Ku-band using Gamma SAR systems

2023

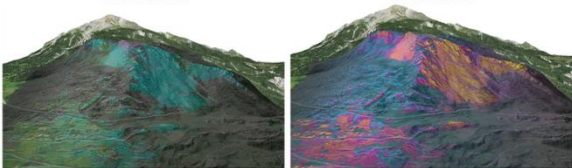
Short-term (2.5min, 2023-10-16) interferom. phase & coherence

Car-borne SAR

• L-band



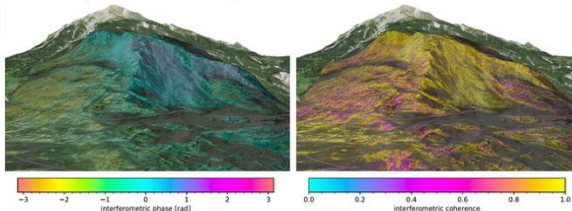
• Ku-band



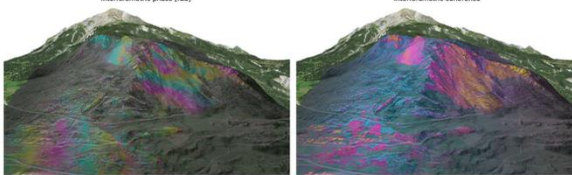
1-day (2023-10-16 to 17) interferometric phase & coherence

Car-borne SAR

• L-band

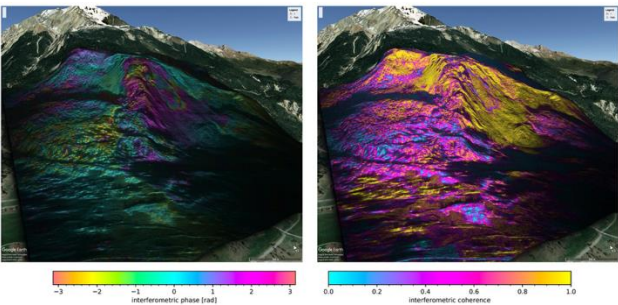


• Ku-band

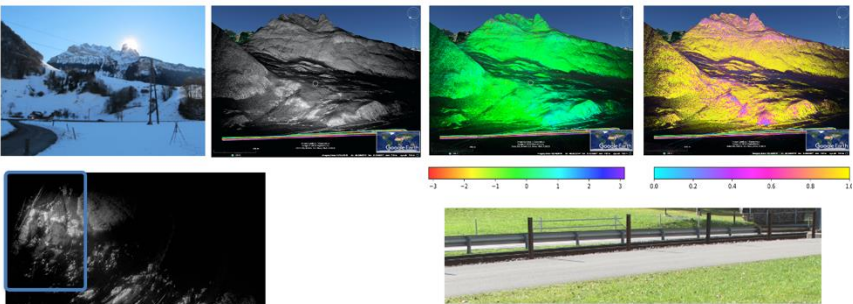
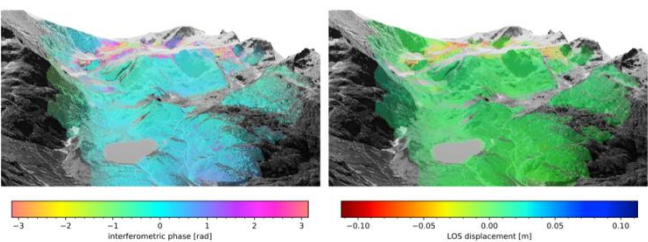
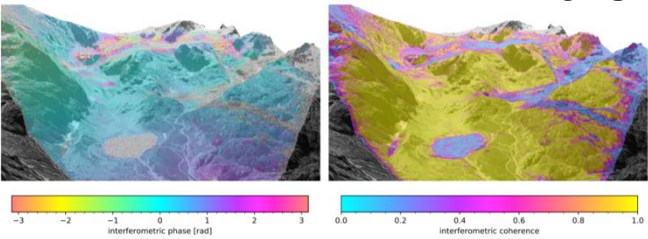


S-Band ~ 1d 16h : 20240820T164209_20240822T082704

2024



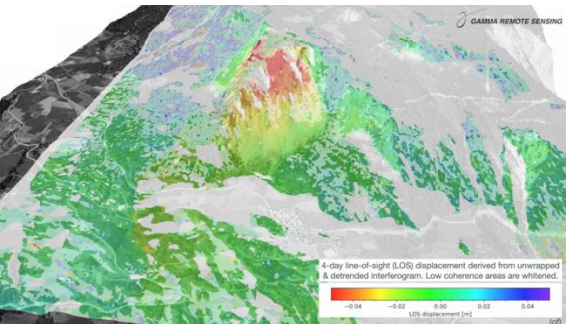
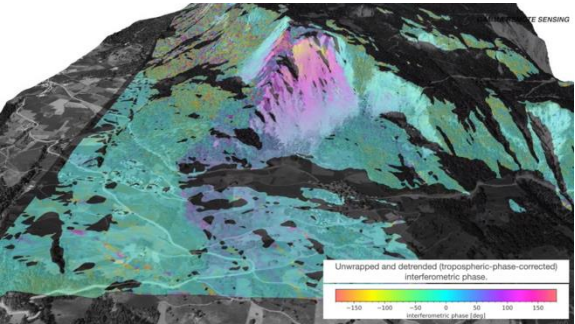
2018



2019



2020



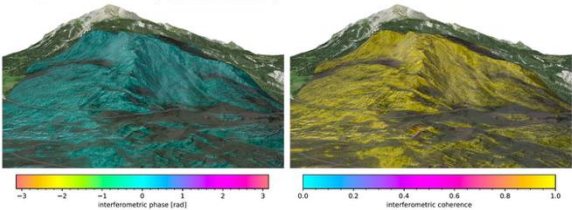
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2023

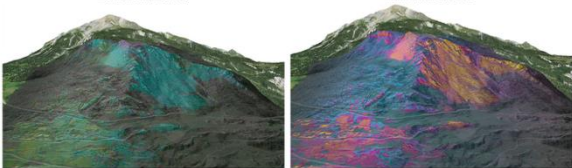
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Car-borne SAR

• L-band



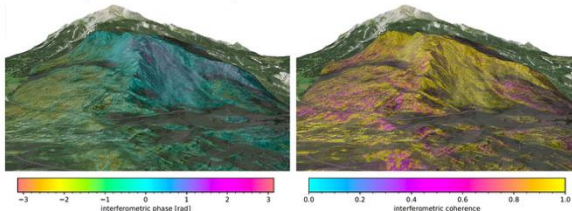
• Ku-band



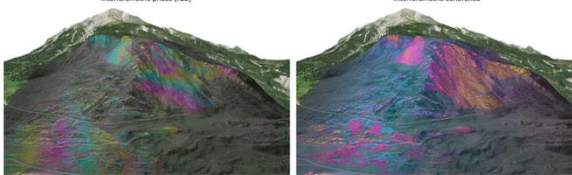
1-day (2023-10-16 to 17) interferometric phase & coherence

Car-borne SAR

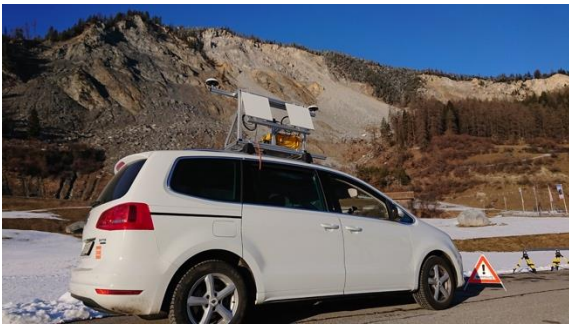
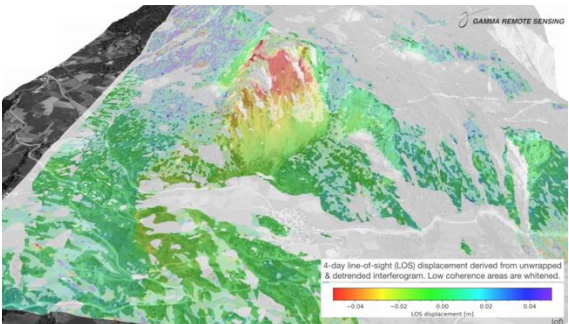
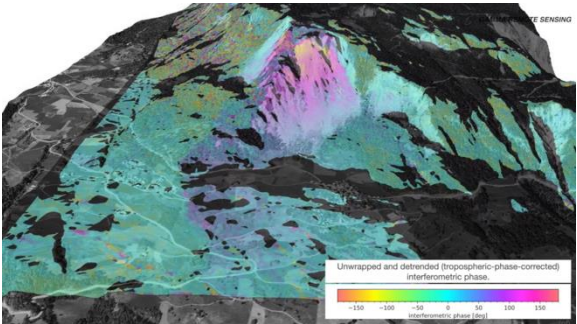
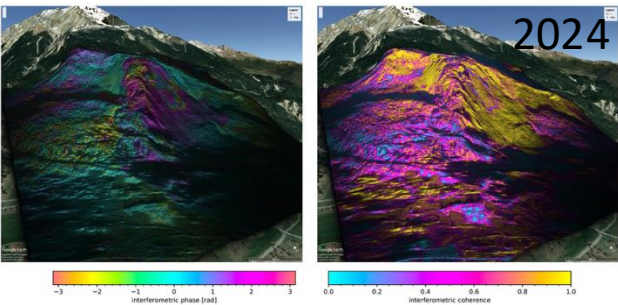
• L-band



• Ku-band



S-Band ~ 1d 16h : 20240820T164209_20240822T082704

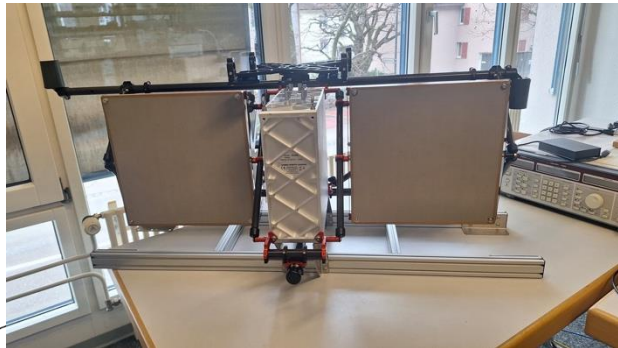
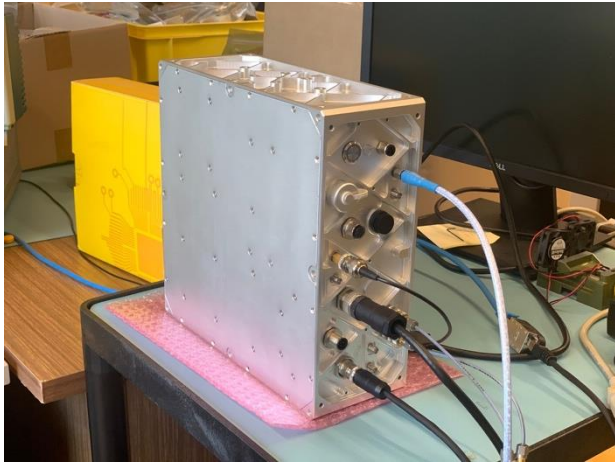


2020



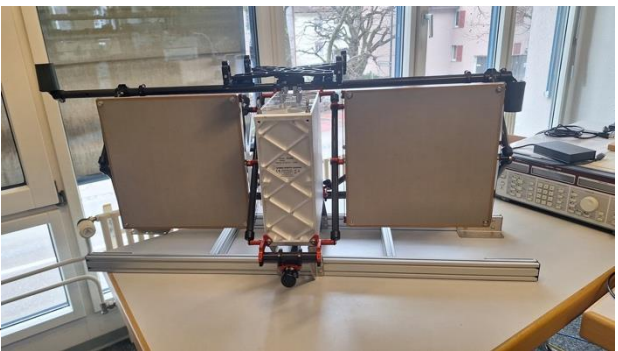
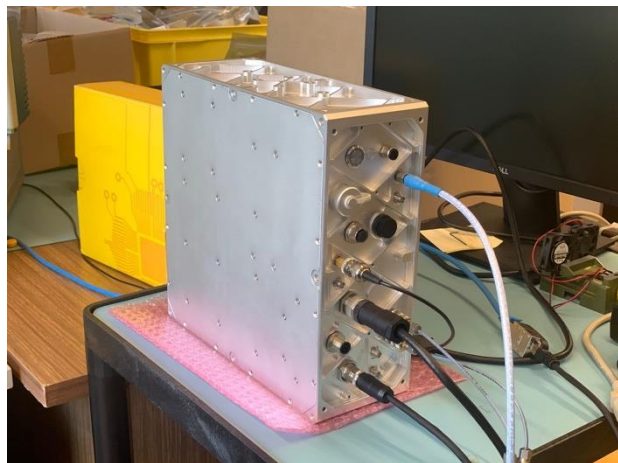
Quad-copter UAV-borne repeat-pass SAR interferometry at L-band:

- **Gamma L-band SAR (GLSAR) with re-designed, more compact and light-weight form factor**
- Down-sized L-band SAR with:
 - total payload : < 7 kg
 - for quadcopter drones
 - and other platforms (airborne, HAPS w/ modification...)



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HGUIDE n580 NAVIGATION PERFORMANCE			
POSITION ACCURACY		HEADING ACCURACY ¹	PITCH/ROLL ACCURACY
Horizontal (m, 1 σ)	Vertical (m, 1 σ)	($^{\circ}$, 1 σ)	($^{\circ}$, 1 σ)
0.01 RTK 0.6 SBAS	0.025 RTK 0.6 SBAS	0.05	0.015

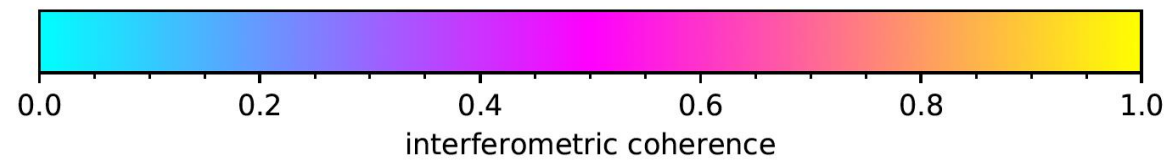
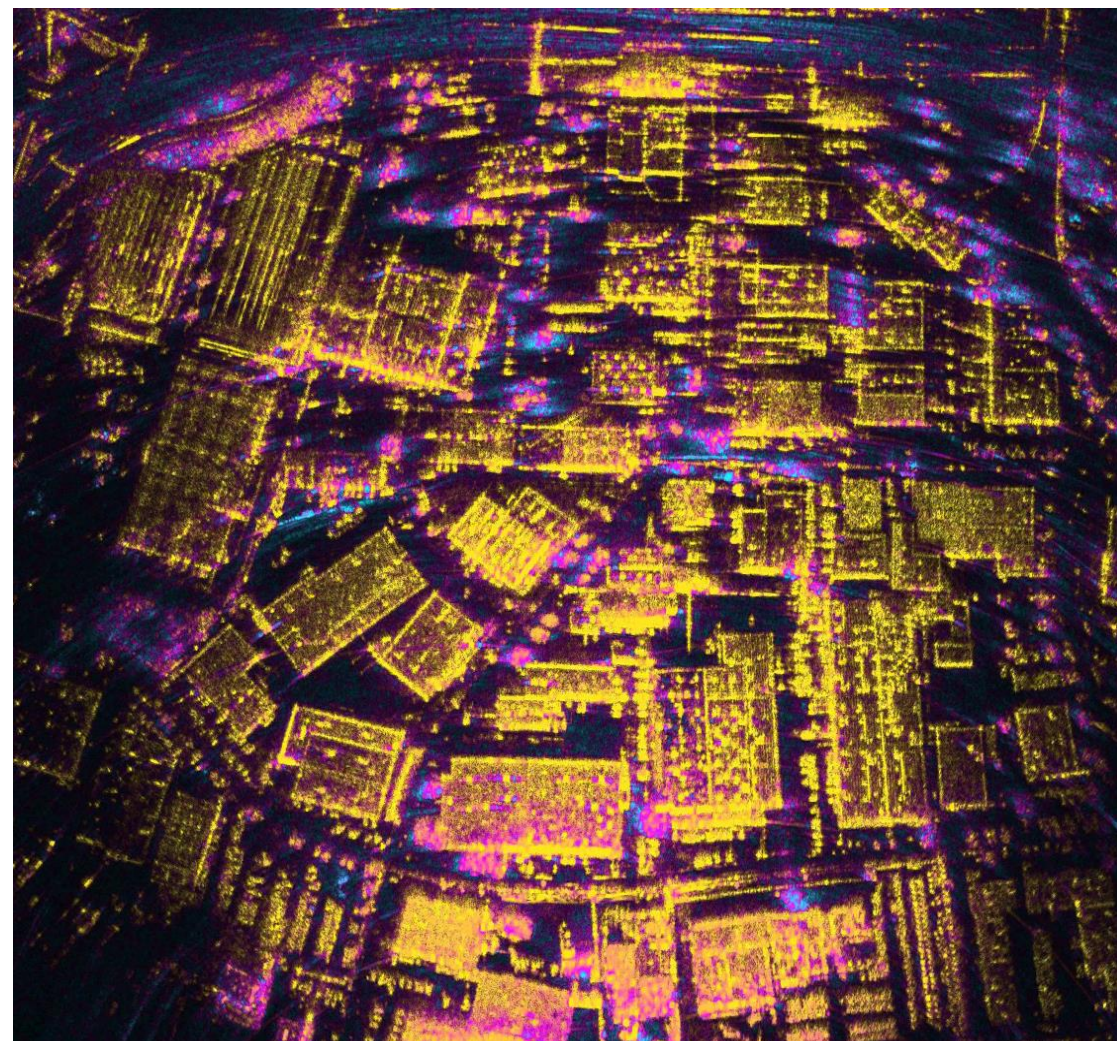
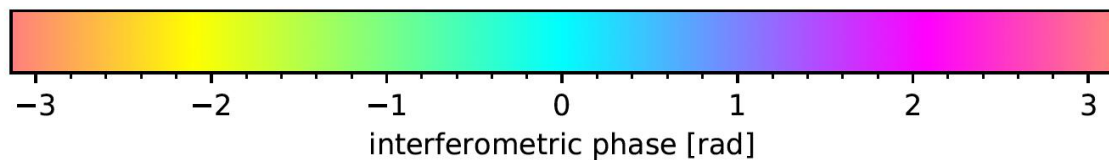
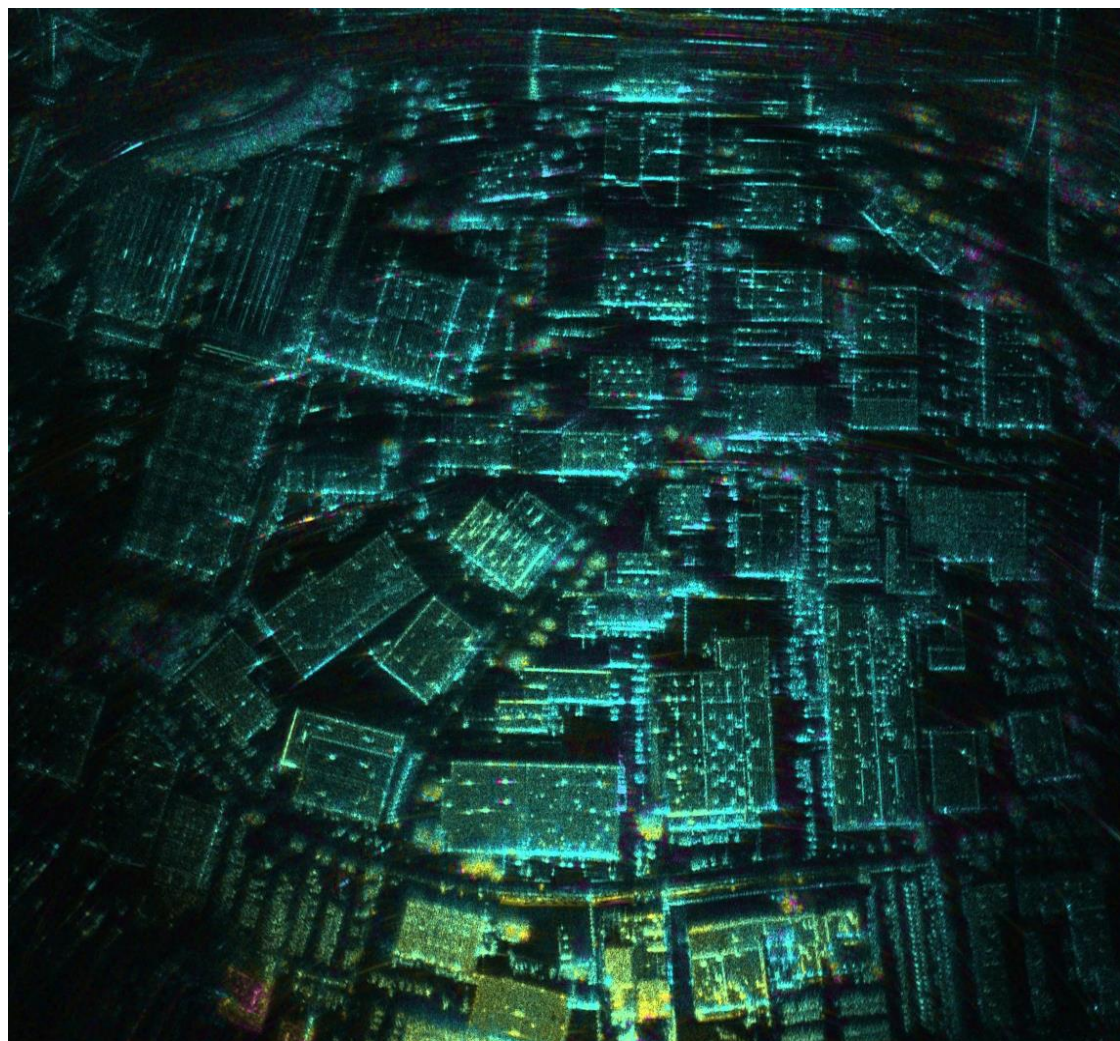


Quad-copter UAV-borne repeat-pass SAR interferometry at L-band: Gamma L-band SAR on Freely Alta-X quad-copter UAV

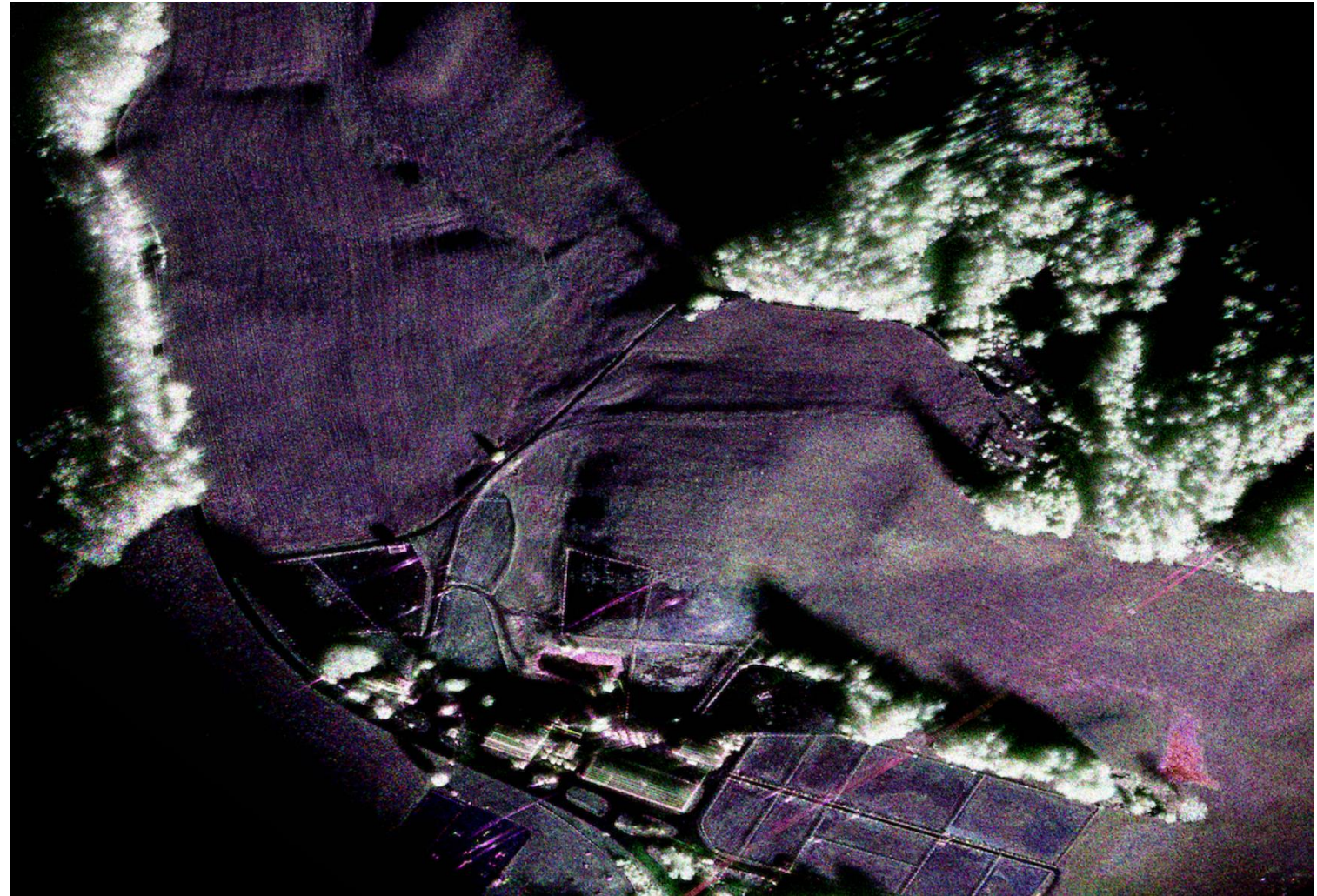
L-band SAR image: 200MHz bandwidth, res. < 1m



Quad-copter UAV-borne repeat-pass SAR interferometry at L-band, zero-baseline (nominally):
Gamma L-band SAR on Freely Alta X, 200Mhz BW, max SA: $\sim 200\text{m}$



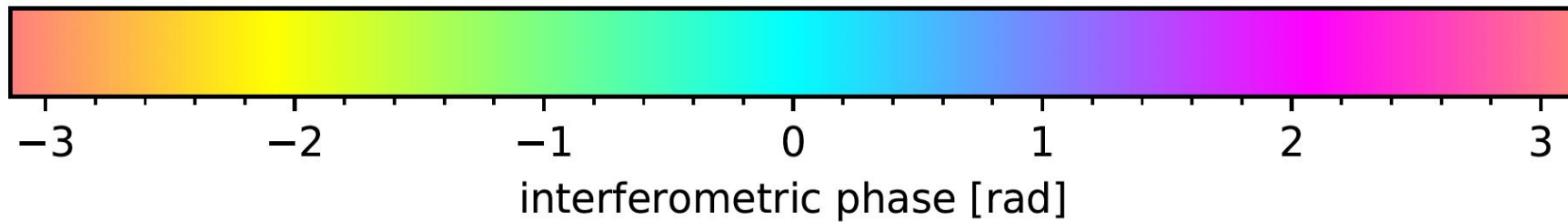
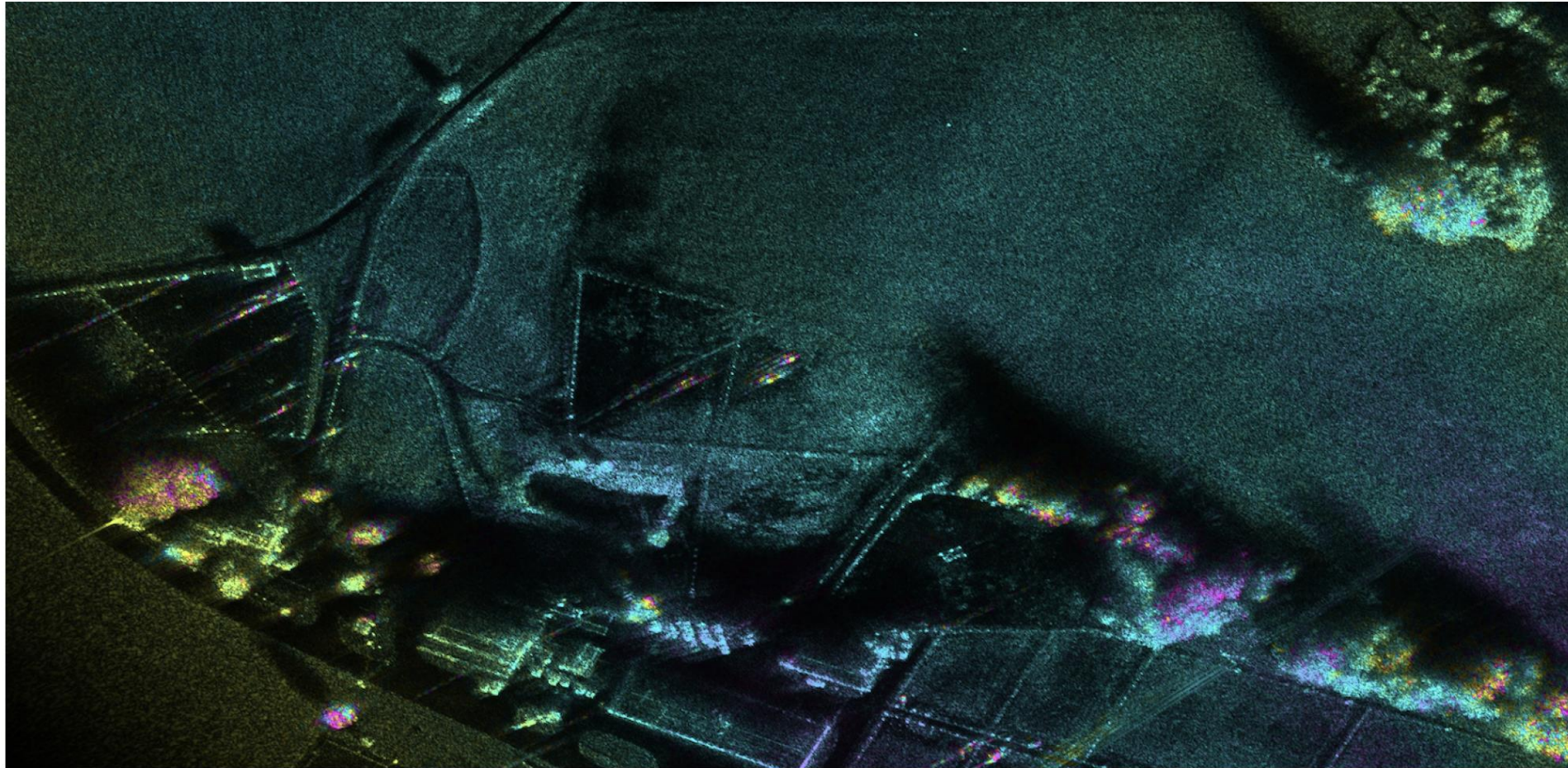
UAV-borne S-Band SAR imaging and interferometry



Gamma S-band SAR Quad-Pol Pauli-Image

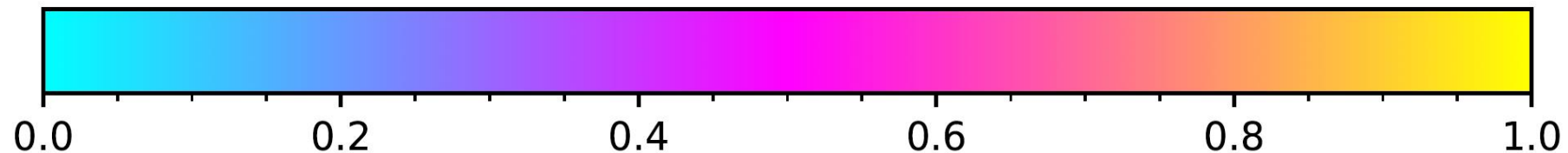
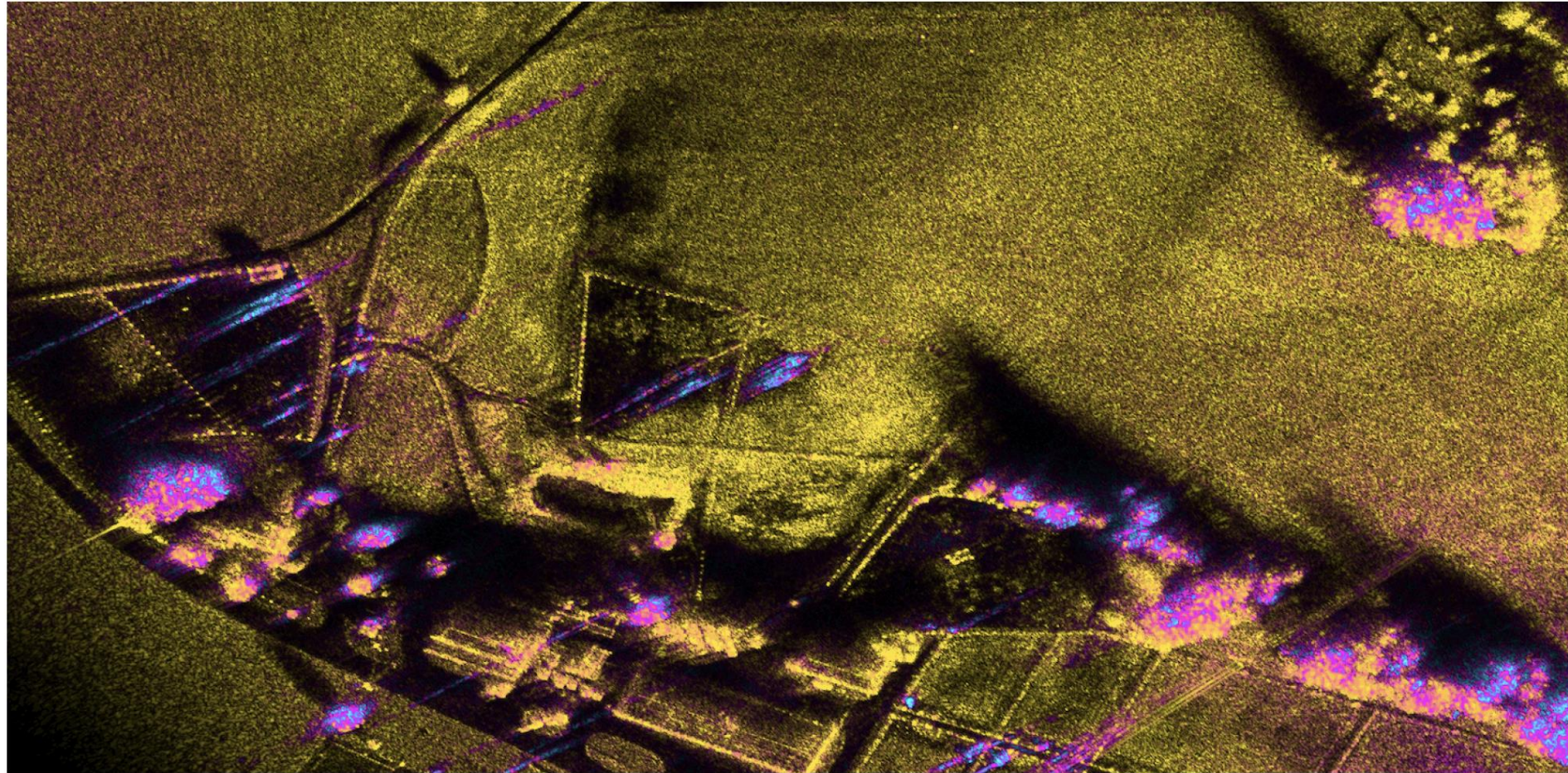
UAV-borne SAR imaging and interferometry

Zoomed view: phase (5-min repeat-pass)



UAV-borne SAR imaging and interferometry

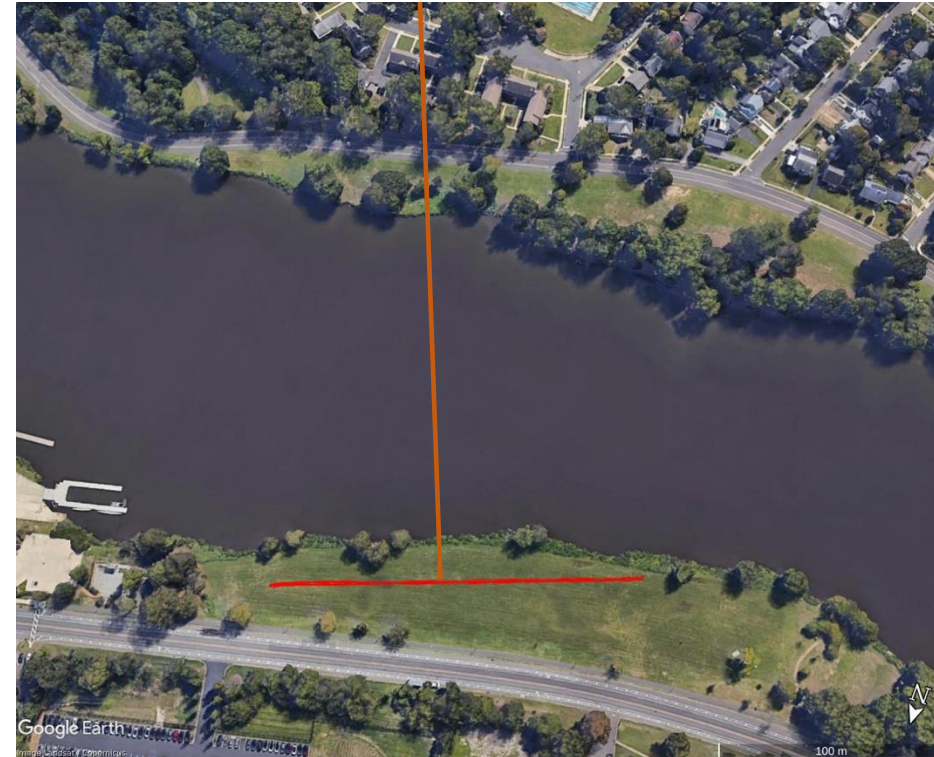
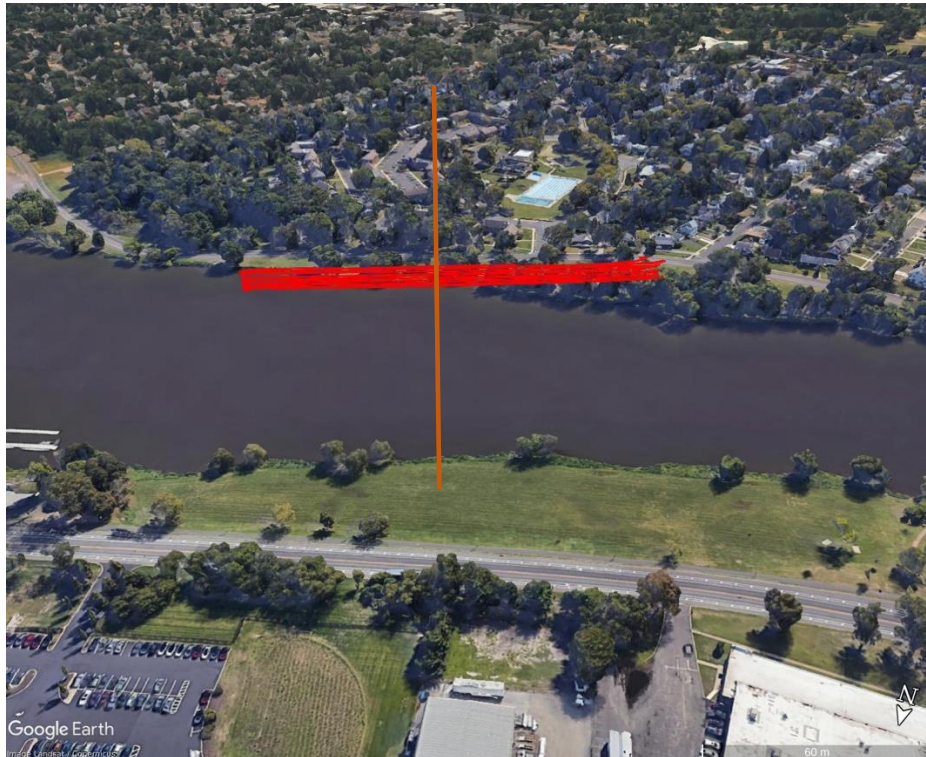
Zoomed view: coherence (5-min repeat-pass)



interferometric coherence

Quad-copter UAV-borne repeat-pass SAR tomography at L-band

- “Opportunity” SAR tomography data set acquired on the next day after very first repeat-pass test flights.
- Opposite side across the river includes trees in a park area + buildings
- Originally more than 30 tracks acquired.
- Only 17 tracks with valid navigation data due to a power outage when hot-swapping UAV batteries.

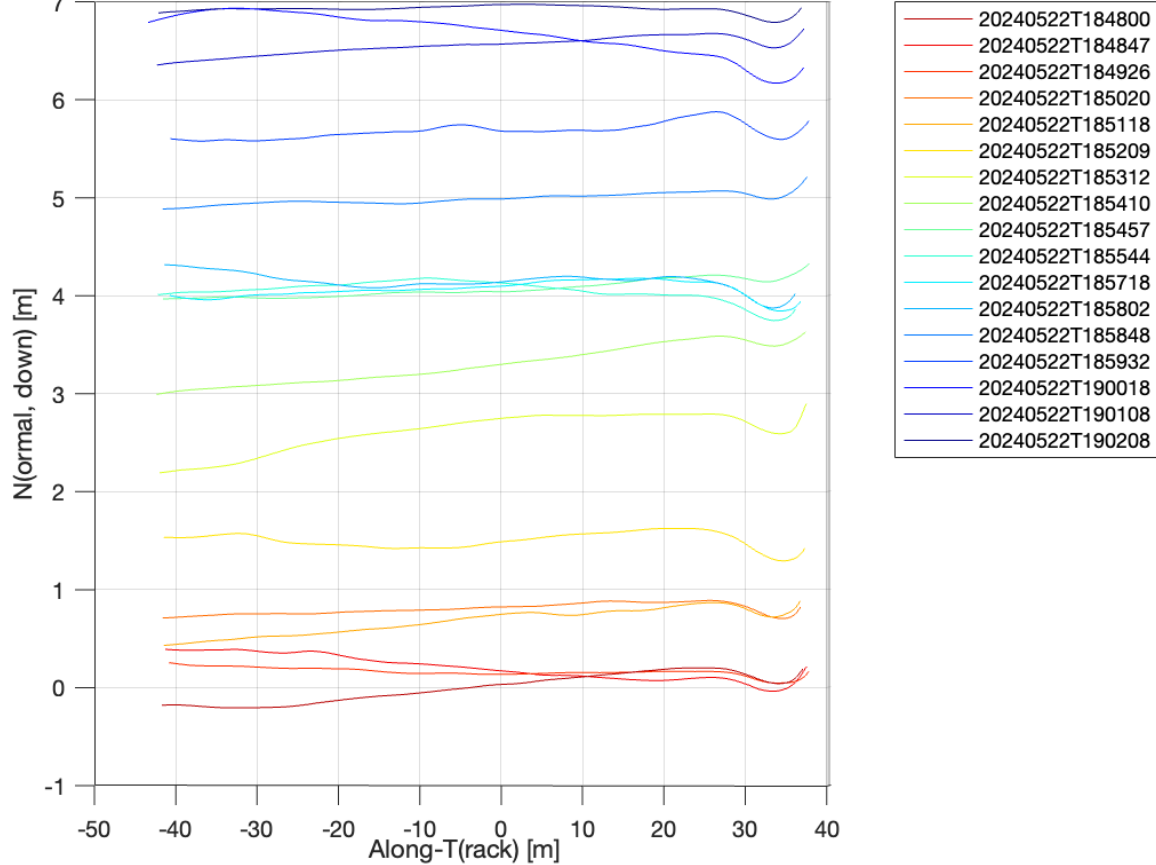


Quad-copter UAV-borne repeat-pass SAR tomography at L-band

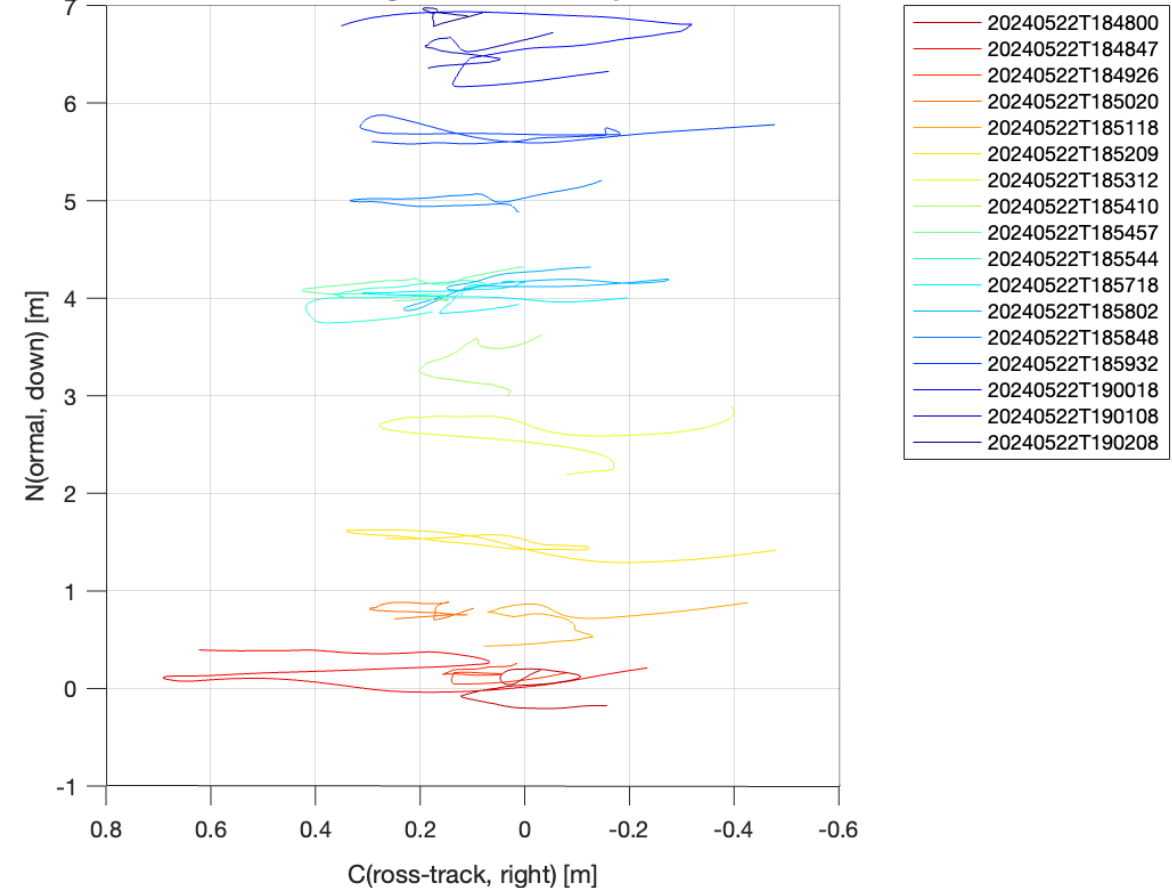
- Some of the 17 tracks are redundant.
- Potential reason: drone pilot manually adjusted height in flight planning software.



flight tracks relative to average reference track pos. in TCN coordinates



flight tracks relative to average reference track pos. in TCN coordinates

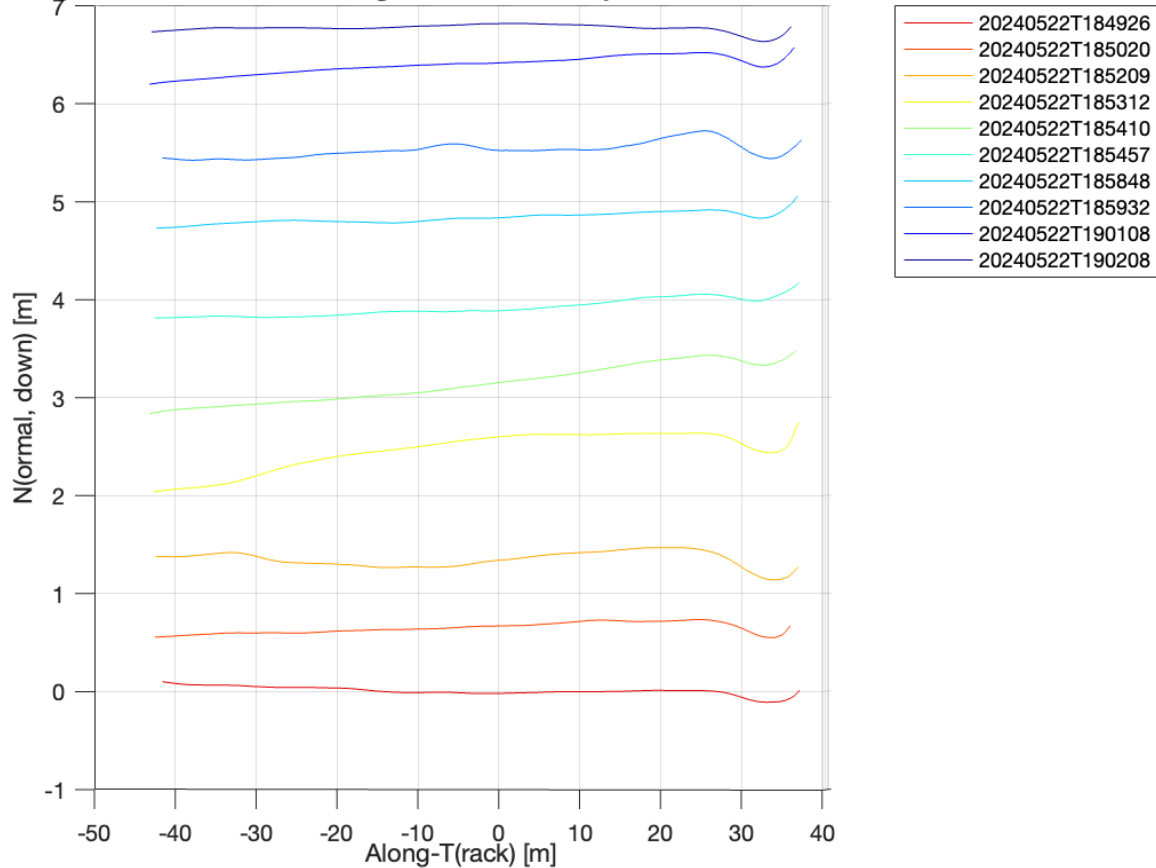


Quad-copter UAV-borne repeat-pass SAR tomography at L-band

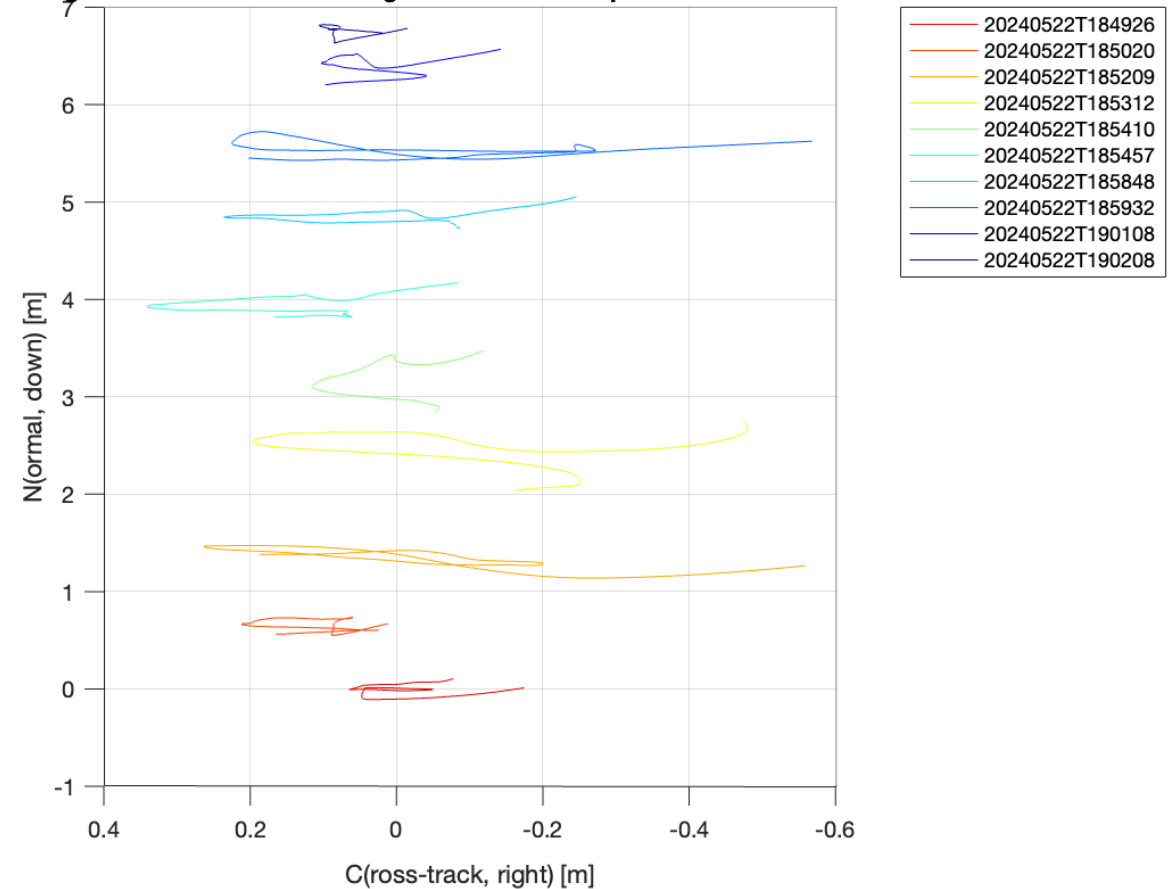
- 10 tracks after removing redundant tracks.
- Fairly regular baselines.
- But: only 7m of total baseline.



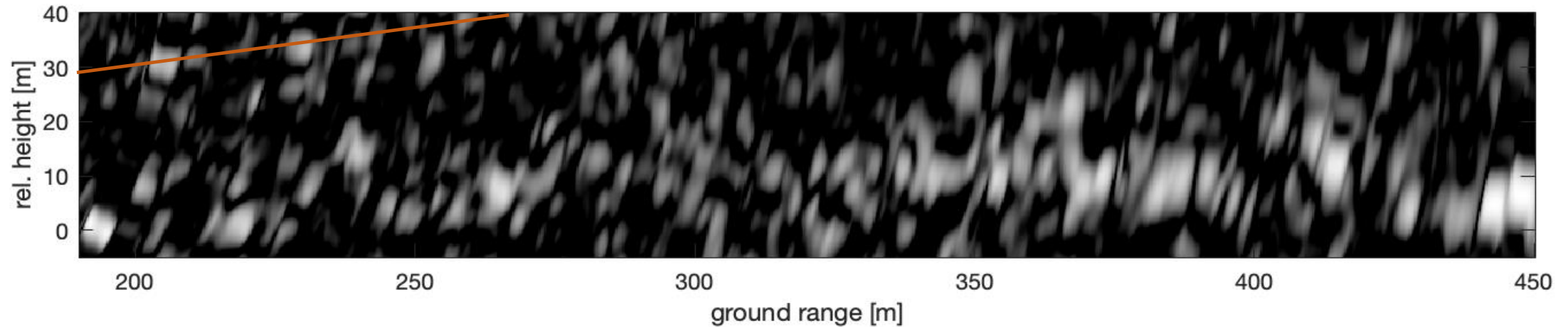
flight tracks relative to average reference track pos. in TCN coordinates



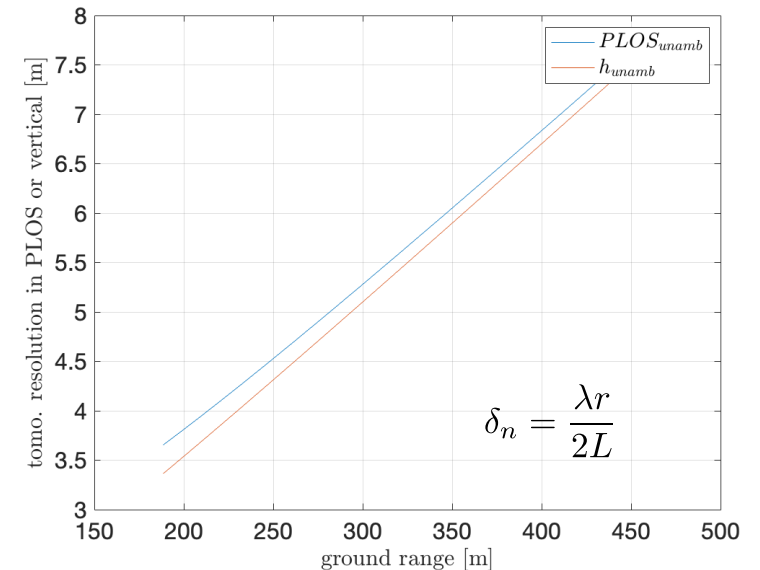
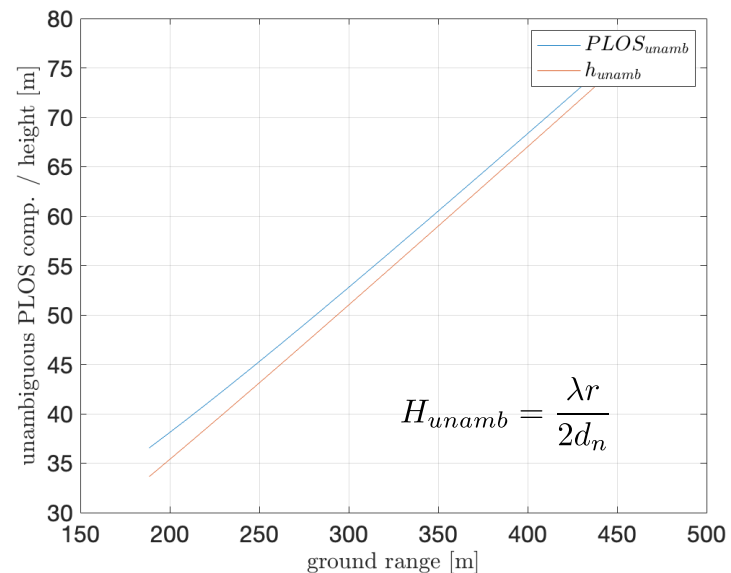
flight tracks relative to average reference track pos. in TCN coordinates



Vertical profile image obtained from SAR tomography (10 tracks, 7m total baseline)



- Profile of 3-D structures is reconstructed in vertical transect.
- Imaging is not optimal due to given acquisition geometry:
 - Sidelobes due to
 - limited number of tracks
 - + non-uniform tomographic sampling (tracks).
 - Limited tomographic resolution particularly towards far range.



First UAV-borne bistatic campaign w/ Gamma L-band SARs in May 2025



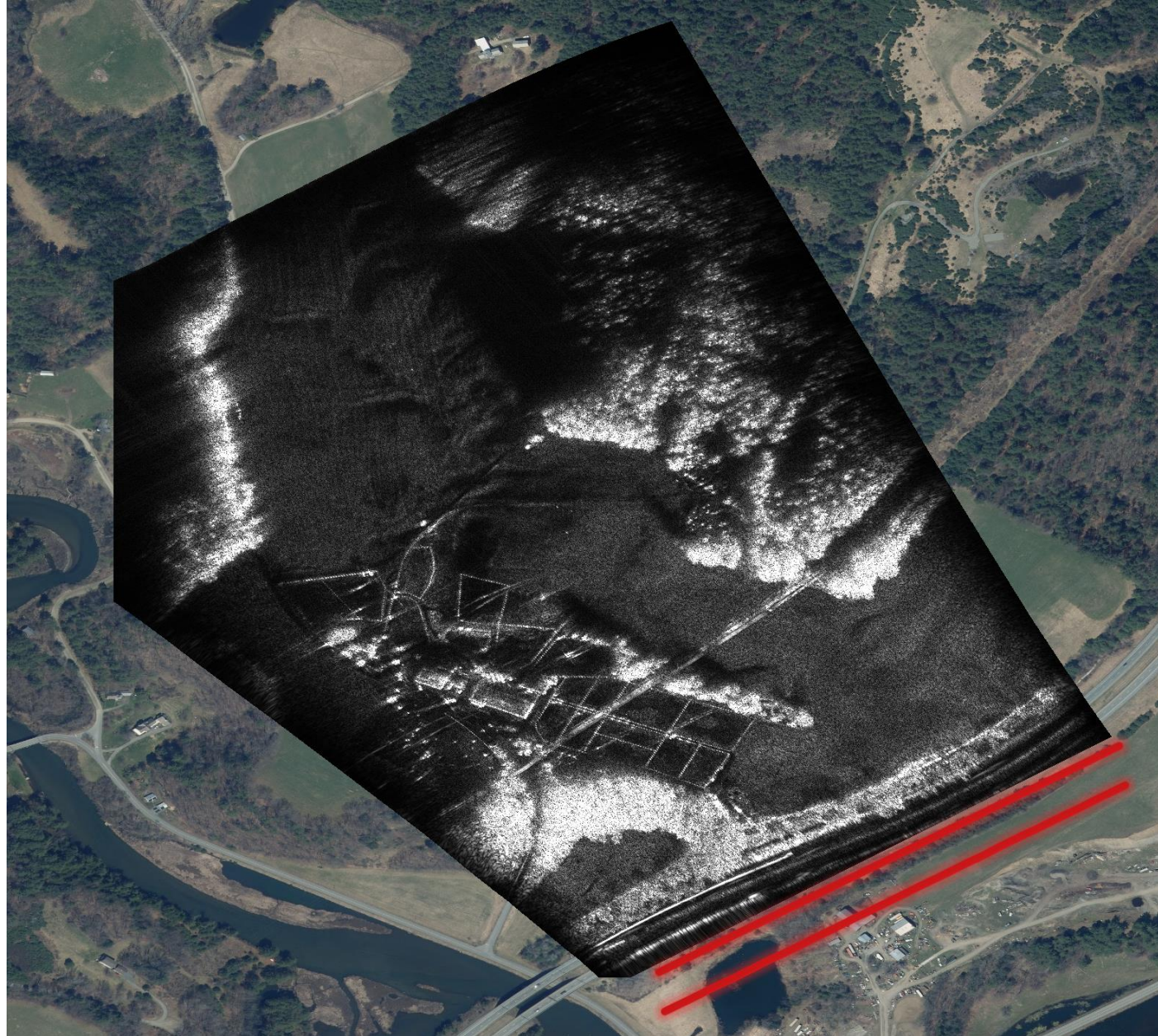
First UAV-borne bistatic campaign w/ Gamma L-band SARs in May 2025



UPDATED

First UAV-borne bistatic campaign w/ Gamma L-band SARs in May 2025

Monostatic image
of transmitter



UPDATED

First UAV-borne bistatic campaign w/ Gamma L-band SARs in May 2025

(Preliminary) bistatic SAR image,

- no synchronization & phase calibration, yet
- just GNSS/PPS-disciplined oscillators

→ image is

- shifted
- defocused



UPDATED

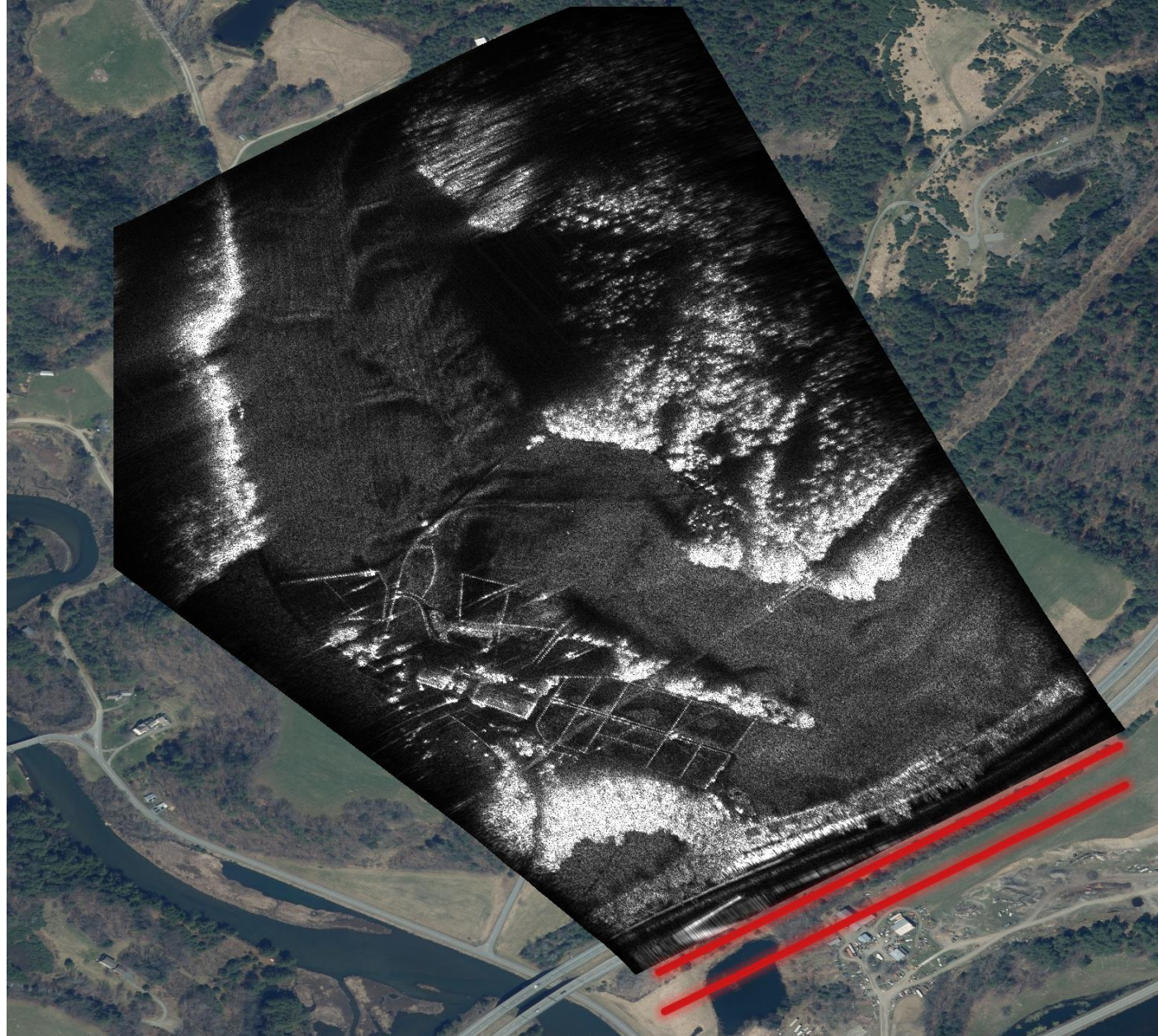
First UAV-borne bistatic campaign w/ Gamma L-band SARs in May 2025

Bistatic image
after compensation
of a timing offset
between the 2 GPSDO:

➔ Compensated time
shift: ca. 35m
equiv. range

No compensation
of phase drifts along
Azimuth (, yet).

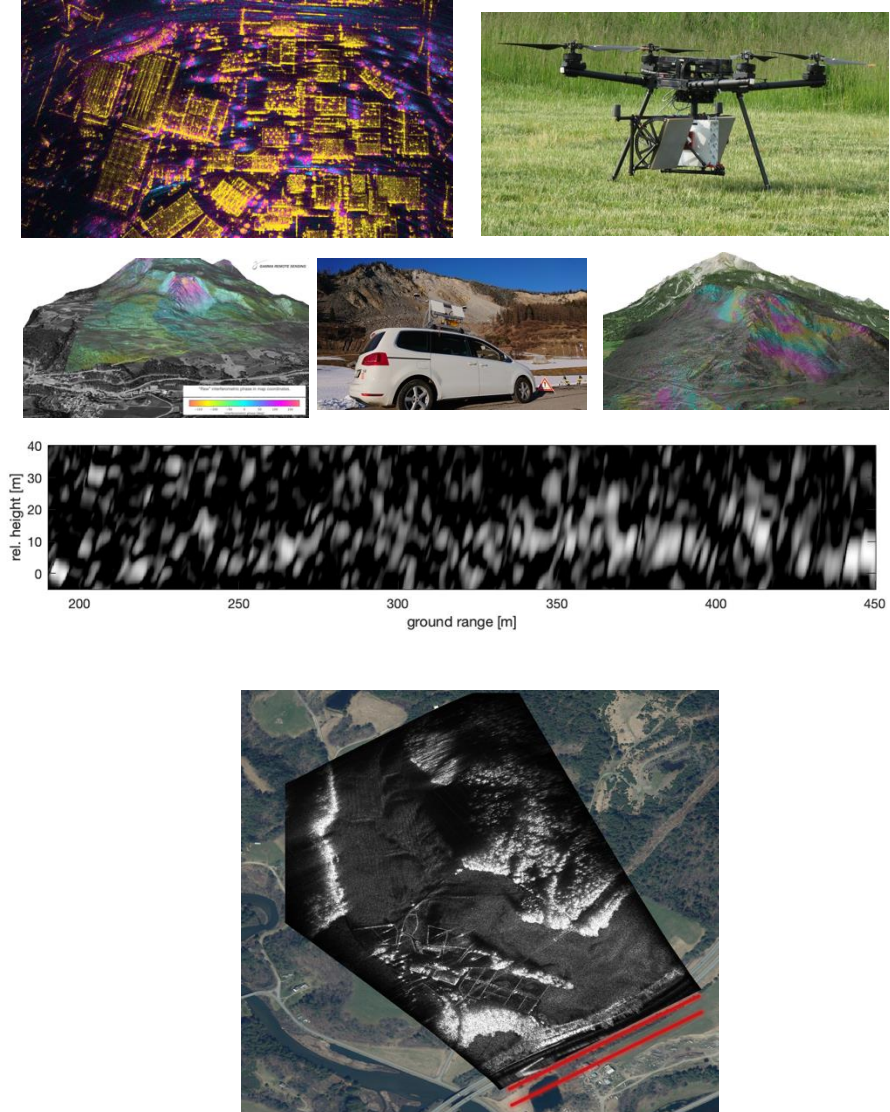
Work in progress...



UPDATED

Summary / Status

1. UAV-based **SAR imaging** demonstrated for L-band
(and car-based SAR imaging for L-/S-/Ku-band) ✓
2. UAV-based **repeat-pass SAR interferometry** demonstrated for L-band
(and car-based DInSAR for L-/S-/Ku-band) ✓
3. UAV-based **repeat-pass SAR tomography** works ...
... but still *needs work*
+ *new experimental data* set with improved
 - **spatial sampling** (calm weather conditions)
 - **tomo. resolution** (more tracks/baselines)to demonstrate the desired imaging capability for forest tomography. ✓
4. UAV-based **bistatic imaging**:
work in progress: first campaign data available since
a few weeks,
synchronization, further analysis & refined processing are on the way ✓



Thank you!

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<https://www.gamma-rs.ch>

