Multistatic Radar Workshop 2025, Laboratory Multistatic SAR

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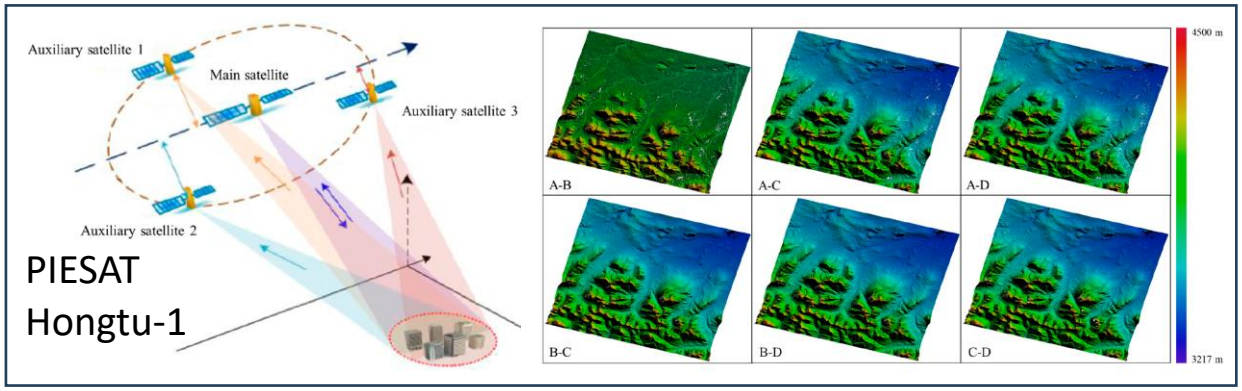
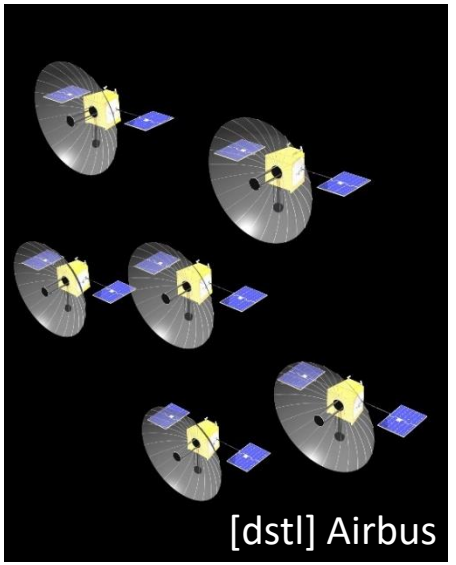
Introduction

- Multistatic SAR UAV swarms and SAR satellite constellations are increasingly attractive options:
  - Including high proportion of receiver-only elements in swarm, could lead to a cost-effective way of obtaining additional SAR collections for different SAR modes.
- Planned multistatic constellations include Dstl/Airbus **Oberon,** ESA **Harmony**
- Existing systems include: **Hongtu-1,** 4-nodes:



- A multistatic SAR laboratory provides a cost-effective approach for test and development of multistatic SAR concepts.

Bright Carbon 6 node multistatic UAV system



Oberon SAR satellite constellation concept

Cranfield GBSAR Research strands

- Under the Dstl Oberon project, three research strands have been pursued through PhD projects:

    1. Multistatic polarimetric interferometry, Dr Alex Hagelberg

    2. Multistatic polarimetric 3D image formation, Richard Welsh

    3. Multistatic polarimetric ISAR, Anmol Rattan

- Current MSc projects are investigating:

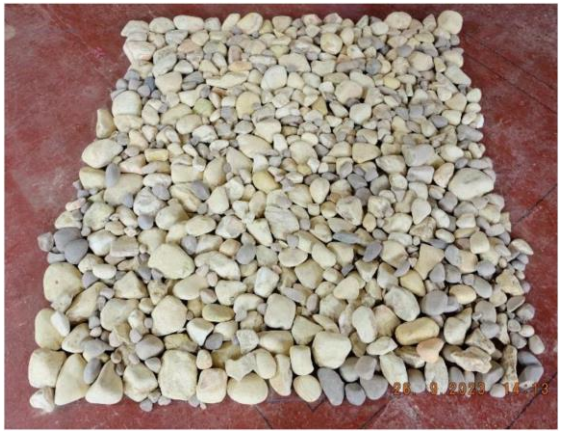
    - Frequency Division Multiplexing (FDM) MIMO 3D SAR, Salman Albogami

    - SAR signature stability under bistatic SAR geometry variation, Dan Heath

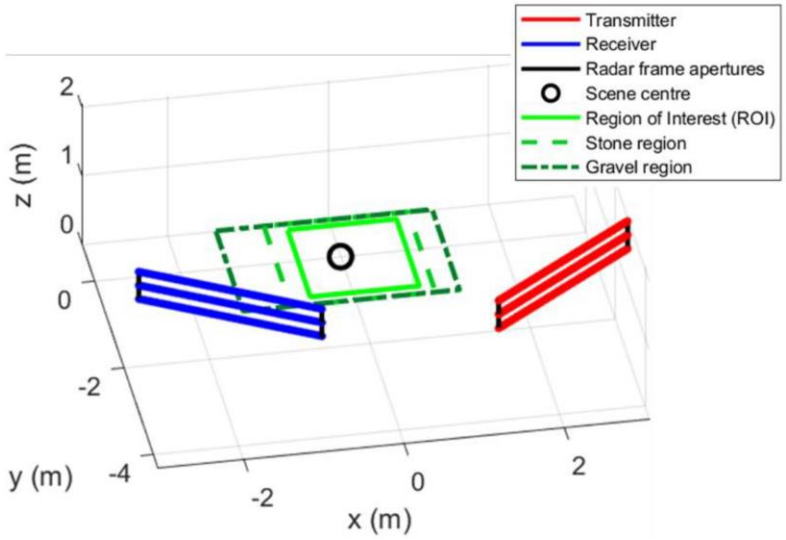
Ground-Based SAR Laboratory

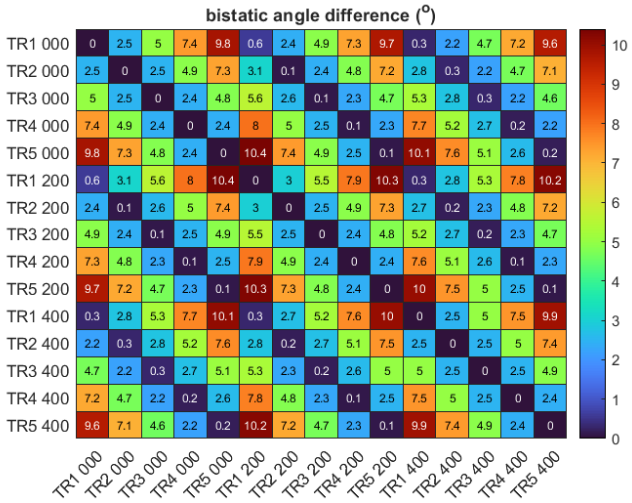
- **SAR Imaging modes**: Monostatic, Bistatic, Multistatic (repeat scans), Interferogram, CCD, curved / arbitrary trajectories, 3D-SAR, emulated ISAR, moving targets.
- **Two vertical SAR Aperture Windows:** 3.5m x 1.46m and 2.4m x 1.46m
- **Frequency**: 1GHz to 50GHz
- **Polarisation**: Full Quad
- **Scene**: 8m x 8m

Bistatic SAR Coherence



- 5 collections at each of 3 heights with SAR Bistatic angle varying from 46º to 63.4º.
- Two terrain types investigated at x-band: gravel and stones.





bistatic angle **difference** between SAR geometries.

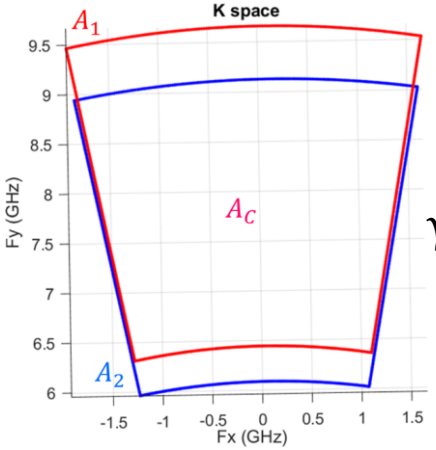
Bistatic SAR Coherence

- We measure SAR coherence, and investigate component coherence factors:

$$\gamma_{true} = \gamma_{temp} \cdot \gamma_{SNR} \cdot \gamma_{alg} \cdot \underbrace{\gamma_{geom}}_{\gamma_{misreg}\gamma_{baseline}\gamma_{Scat}}$$

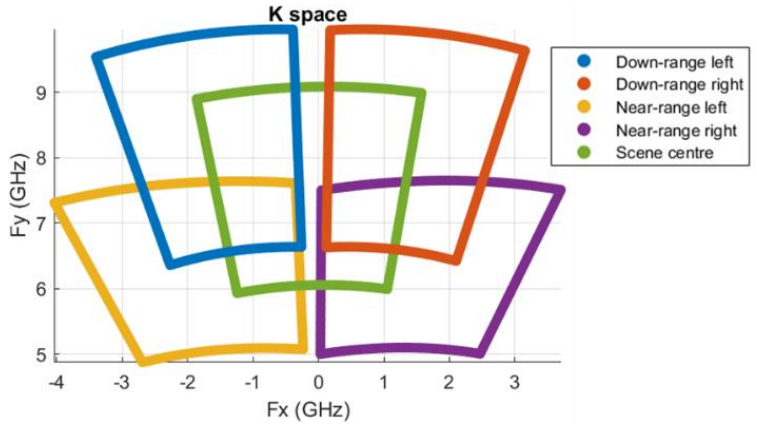
- We wish to estimate the RCS term γ_{Scat} so need to understand the others, in particular $\gamma_{baseline}$ i.e. K-space overlap term.

- However, in SAR near-field, or alternatively for non-flat terrain, baseline should be calculated in a spatially variant manner (per pixel).



$$\gamma_{\text{baseline}} = \frac{\mathrm{A_c}}{\sqrt{\mathrm{A_1 A_2}}}$$

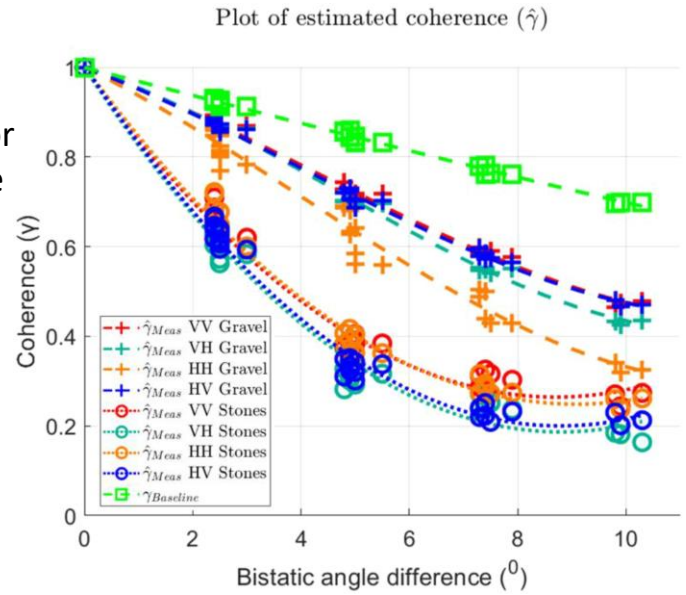
- The alternative approach of forming images with only the overlap radar data (per pixel) was also implemented.

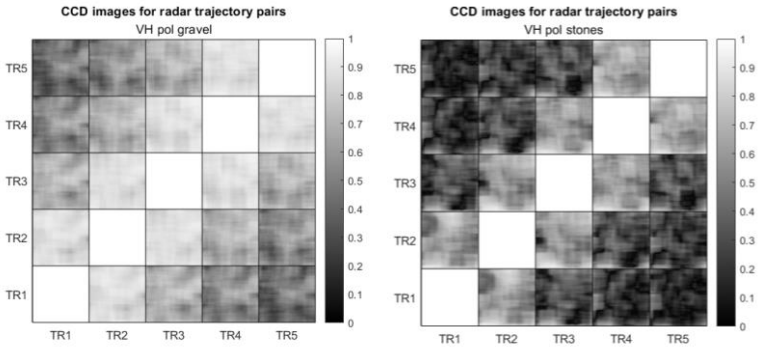


Ground plane projection spatial frequency plots showing the outline of five spatial frequency domain segments in the SAR near-field regime, corresponding to the four corners and centre of the measured scene.

Bistatic SAR Coherence

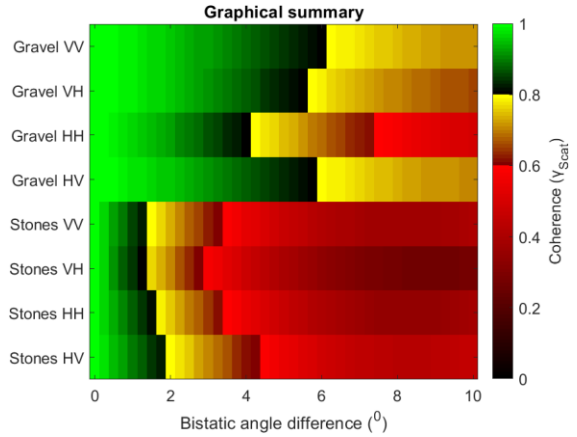
Coherence plotted against bistatic angle difference for the gravel and stone scene datasets, with $\gamma_{baseline}$:





Gravel CCD, VH

Stones CCD, VH



- The measurements provided $\hat{\gamma}_{scat}$.
- Also, parameter values for a bistatic coherence prediction model for the two terrains were found (see references).

Summary of results showing the bistatic angular difference extents of coherence ($\hat{\gamma}_{scat}$) performance bands for the gravel and stone scenes. “Good” CCD performance is represented by green, “Moderate” by yellow and “Poor” by red.

Hagelberg A, Andre D & Finnis M. (2024). Bistatic multi-polarimetric synthetic aperture radar coherence investigation using spatially variant incoherence trimming. IET Radar, Sonar & Navigation, 18(12)

Hagelberg A, Andre D & Finnis M. (2024). Combined intensity and coherent change detection with four classes for laboratory multistatic polarimetric synthetic aperture radar. IET Radar, Sonar & Navigation, 18(11)

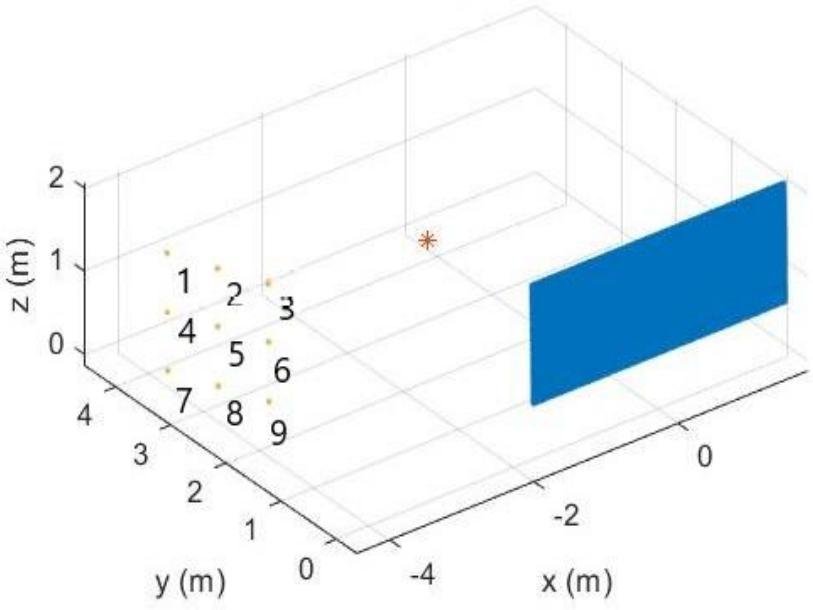
Hagelberg A, Andre D & Finnis M. (2024). Bistatic multi-polarimetric synthetic aperture radar coherence investigation using spatially variant incoherence trimming. IET Radar, Sonar & Navigation, 18(12)

Hagelberg A, Andre D & Finnis M. (2023). Laboratory bistatic synthetic aperture radar coherent change detection investigation. Electronics Letters, 59(15)

Multistatic 3D SAR

- For each of 9 receiver positions, the transmitter swept a finely sampled 2D SAR aperture (blue), at x-band.
- This is equivalent to **9 simultaneous receptions for a single transmitter aperture.**

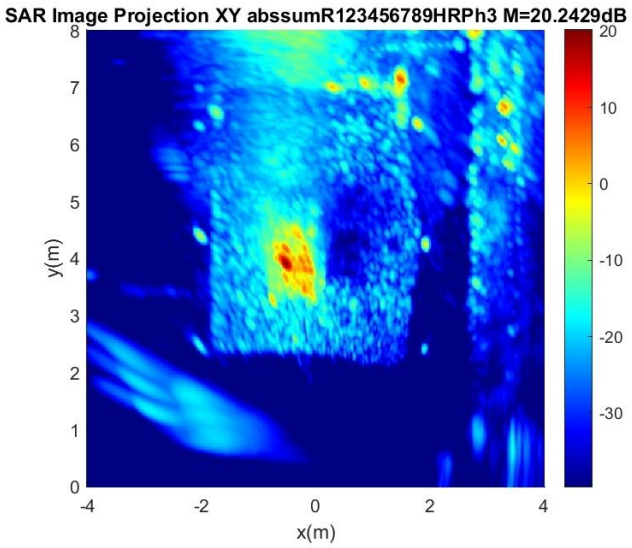
- Each receiver gives rise to a 3D SAR image.
- If the 9 images are summed incoherently, then SAR resolution will not increase, though interpretability may.
- However, if summation is coherent, then SAR resolution may improve.

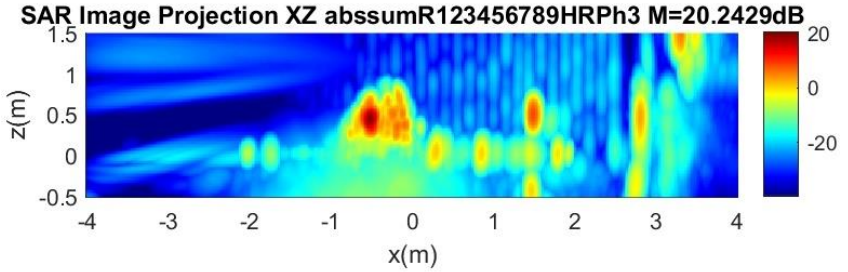


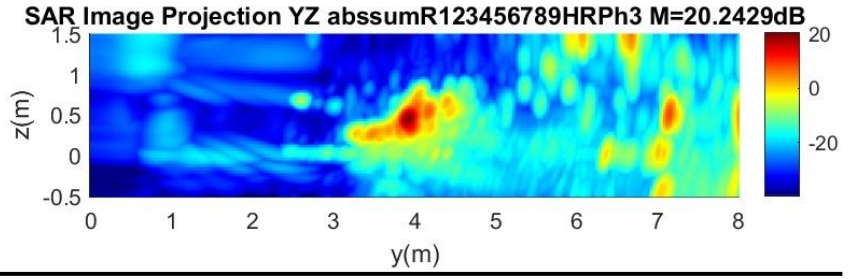
Multistatic 3D SAR geometry, with 2D SAR transmitter aperture in blue, and nine fixed receiver positions to the left.

Multistatic 3D SAR image sum Maximum Intensity Projections (MIPs)

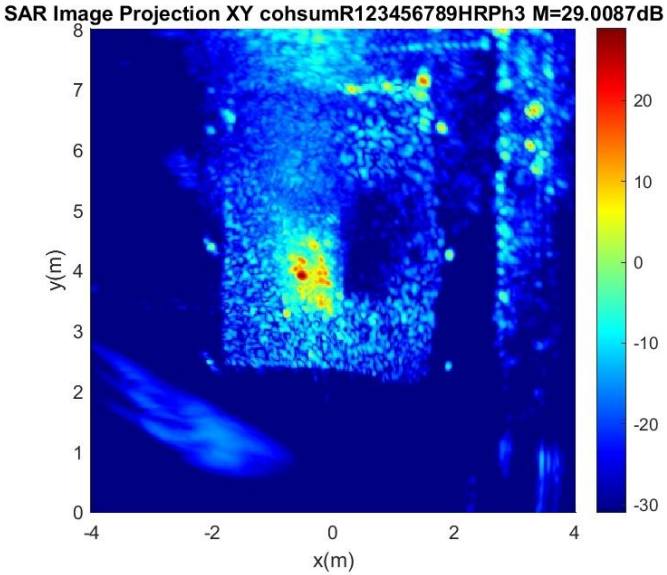
Incoherent sum:

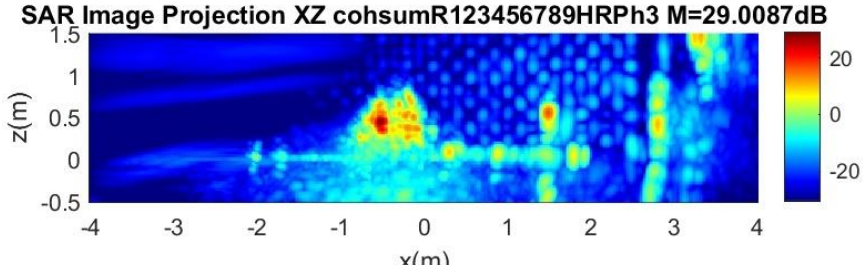


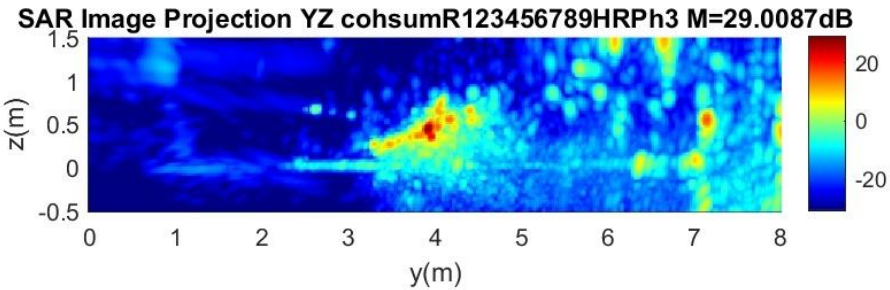




Coherent sum:





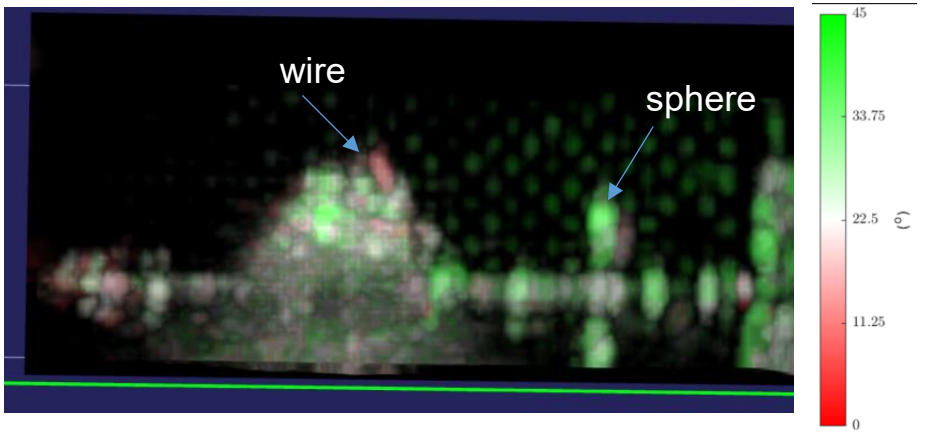


Bistatic 3D SAR image polarimetric decompositions

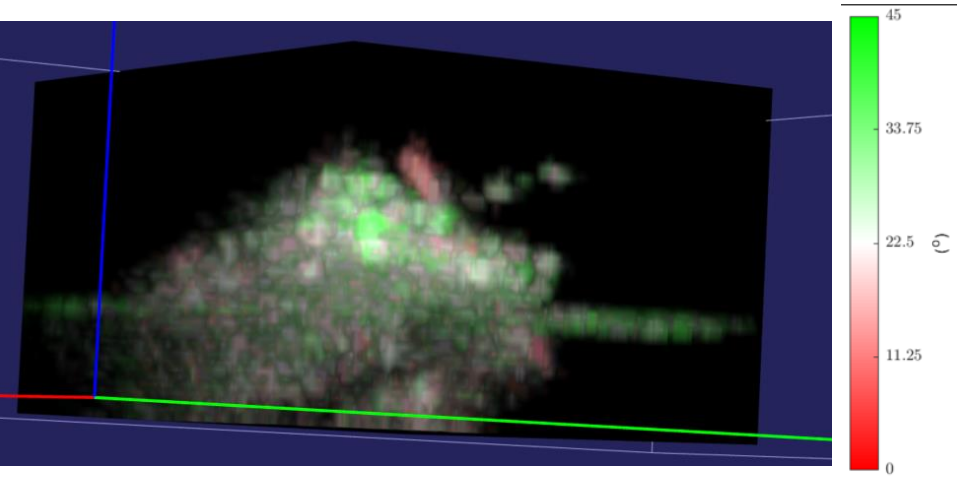
- Bistatic generalization of Huynen fork parameter decomposition investigated.

- Coherent sum of the nine Bistatic 3D SAR collections gave higher resolution result with **similar polarimetric decomposition results** as for individual bistatic images.

- Particular features and their properties could be identified, e.g. wire and sphere.



Coherent sum **Huynen 1: Polarizability**



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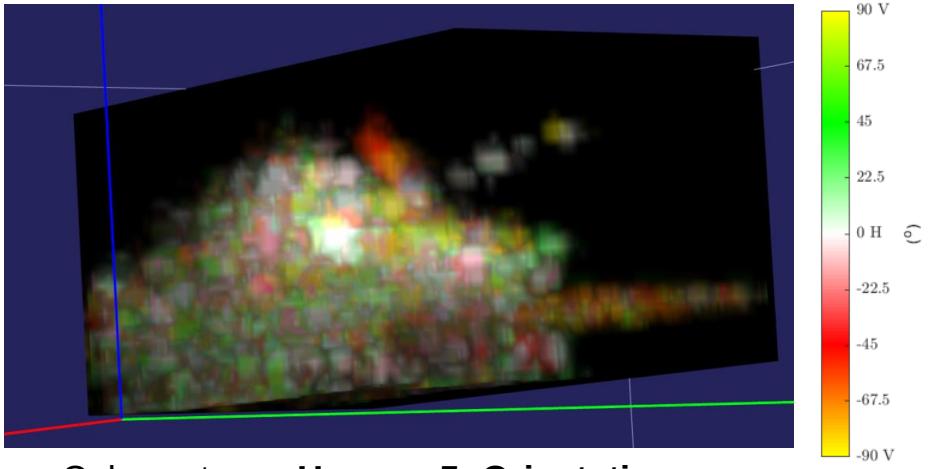
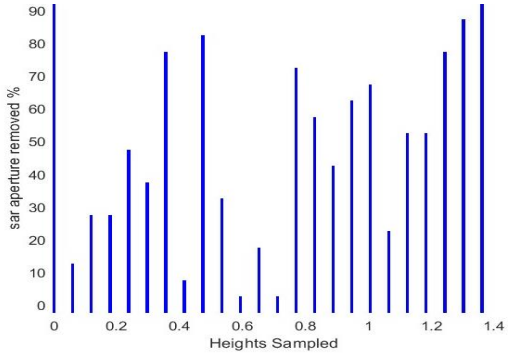


Coherent sum **Huynen 5: Orientation**

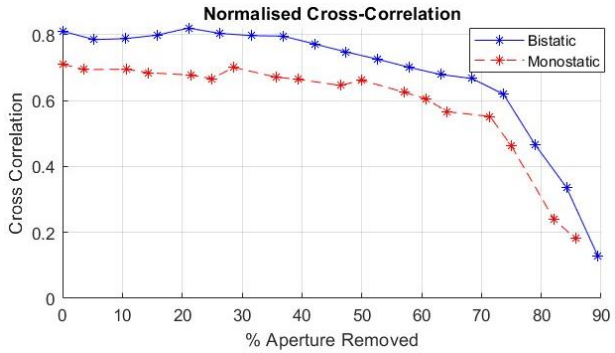
Sparse Multistatic 3D SAR

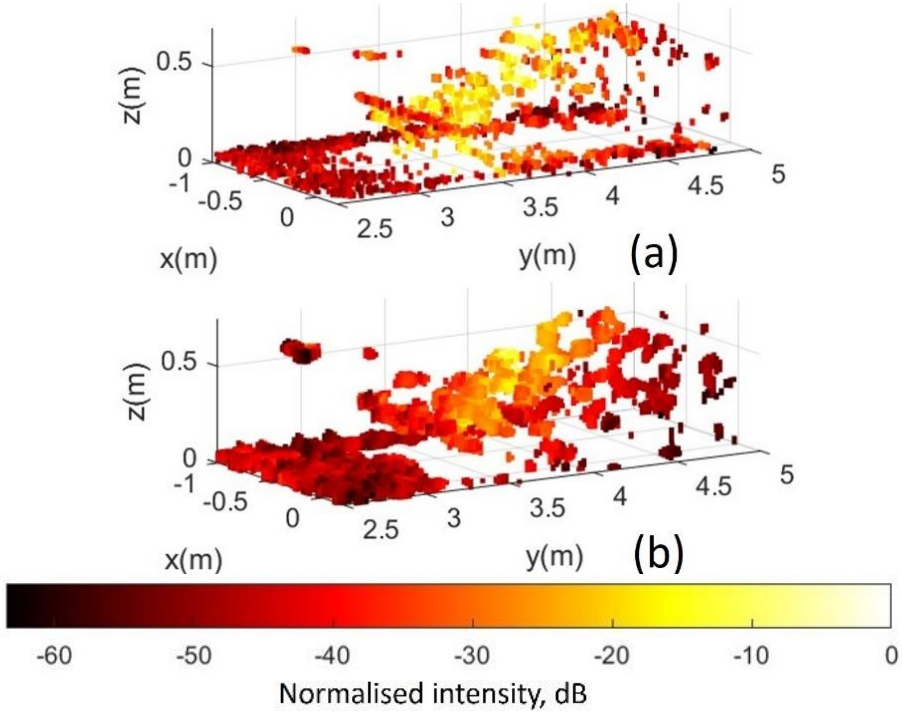
- Sparse aperture 3D point clouds, through combination of volumetric interferograms.

Sequence of sparse apertures:



Normalised cross-correlation of sparse aperture point clouds with full aperture BPA volumetric SAR images:





Sparse aperture point clouds, 50% and 37% SAR aperture removed for monostatic (a) and bistatic (b) SAR

- Algorithm demonstrated for monostatic, single bistatic, multistatic combinations.
- Generalized to joint polarimetric channel approach.
- Algorithm naturally accepts combinations of non-parallel and non-linear trajectories.

Welsh R, Andre D & Finnis M. (2025). Polarimetry for sparse multistatic 3D SAR. IET Radar, Sonar & Navigation, 19(1)
Welsh R, Andre D & Finnis M. (2024). Laboratory multistatic 3D SAR with polarimetry and sparse aperture sampling. IET Radar, Sonar & Navigation, 18(1)
Welsh R, Andre D & Finnis M. (2023). Volumetric interferometry for sparse 3D synthetic aperture radar with bistatic geometries. Electronics Letters, 59(12)

Burning questions?!

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