InSAR analysis and Corner Reflector Experiments for Infrastructure Stability Monitoring Using Sentinel-1 Imagery

Zahra Sadeghi[1], Stephan Hobbs[2], Mushfiqul Alam[2], Michael Seller[2], James Deas[3], Sean Coleman[3] and Lucy Kennedy[1]

1 Spottitt Ltd.,
2 School of Aerospace, Transport & Manufacturing, Cranfield University
3 National Grid Electricity Transmission

FRINGE 2023
University of Leeds, UK | 11 - 15 September 2023.

→ THE EUROPEAN SPACE AGENCY

Introduction

With regards to asset motion National Grid Energy Transmission (NGET) spends over £6 million per year to monitor 1% of their assets most at risk from asset motion issues.

Research questions

- Q1:Could a synthetic Corner Reflector (CR) be sized, designed, and installed on assets such as towers such that the asset itself becomes a radar reflector?
- Q2:Could the team find the NGET assets that can be selected as natural radar reflectors in the selected NGET sites?
- Q3:Could more than one synthetic radar reflector be installed on a single asset to get multiple asset motion readings from a single asset? For example, to measure the asset motion of each tower leg or each corner of a substation.

Q1→CR design for NGET assets

Assuming:

- sub-cm uncertainty in displacement
- SCR (Signal to Clutter Ratio) equals to 10 dB for a typical UK rural landscape away from woodland

The CR’s were sized to 70 cm inner leg.

Special adaptations for installation on an electricity tower included:

- Mounting for ease of installation to tower and alignment to Sentinel 1 descending tracks
- Debris net
- Drainage holes
- Chain between CR and tower to prevent falling

Reflector fitted to mount using the Doughty Half Couplers

Front View

Water Drain Hole

Left Side View

Rear View

Right Side View

6mm Butterfly Netting to stop debris collecting

Tie wrap & brazing rod used to secure the netting to reflector

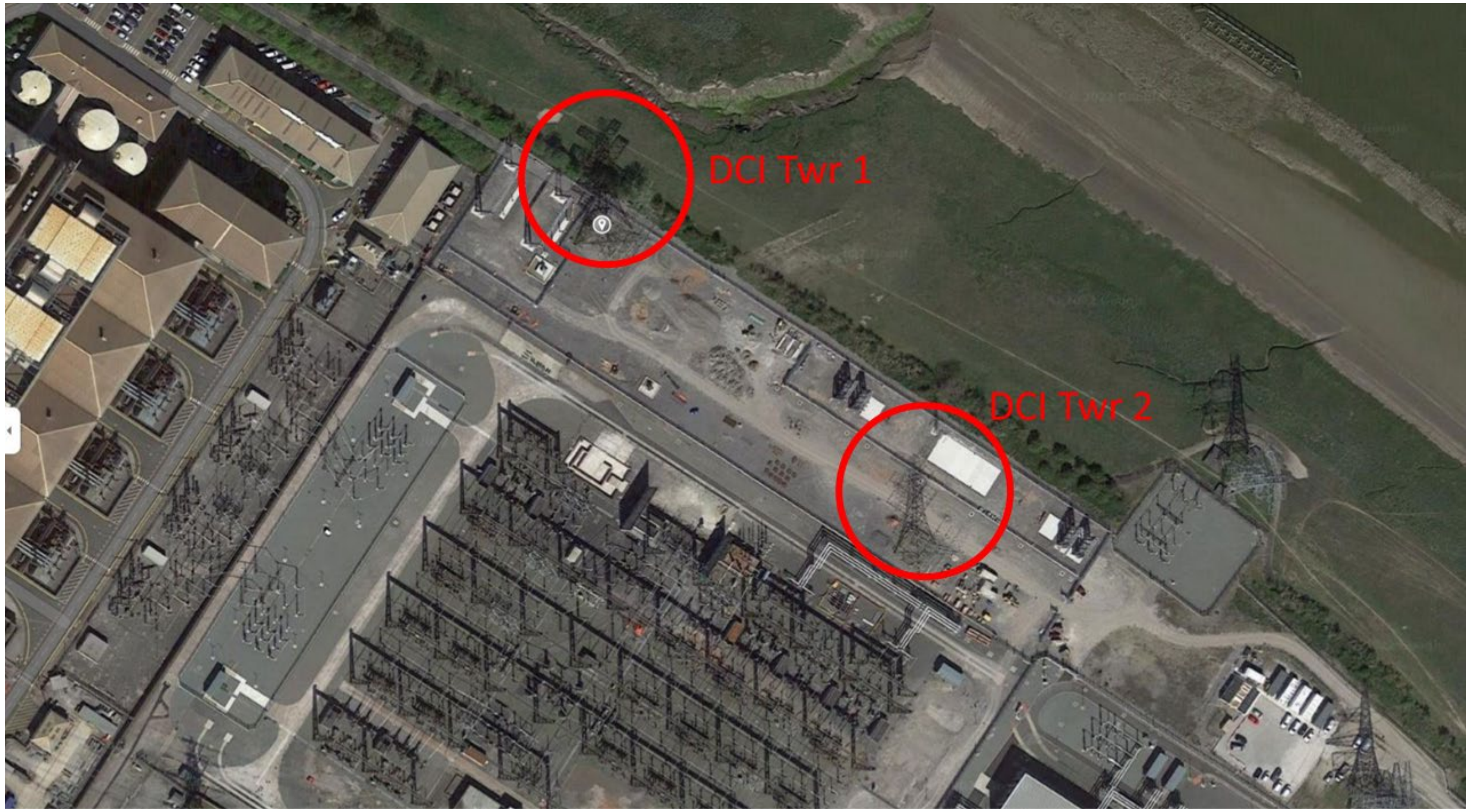
Safety chain fixing points

Q1→CR installation on NGET assets

NGET Deeside test site

First test CR installed on tower 1 on 2nd Nov 2022 with a 100% clear view to descending Sentinel 1 track (154).

Second test CR installed on tower 2 on 7th Dec 2022 with a 0% clear (fully obstructed by the body and arms of the tower) view to descending Sentinel 1 track (154).



Q1→CR installation on NGET assets

Q1→ SAR Processing

Sentinel-1 images track 154, 3 images before installation and 6 images after the installation, 1 image after CR removal

All co-registered w.r.t the first image after the CR installation

Georeferenced the images using a high-resolution LiDAR DEM and finally manually corrected using a visible feature in the SAR image

Q1→ Experimental results

CR on tower 1 showed a more than 1.5 times jump in the amplitude time series after installation

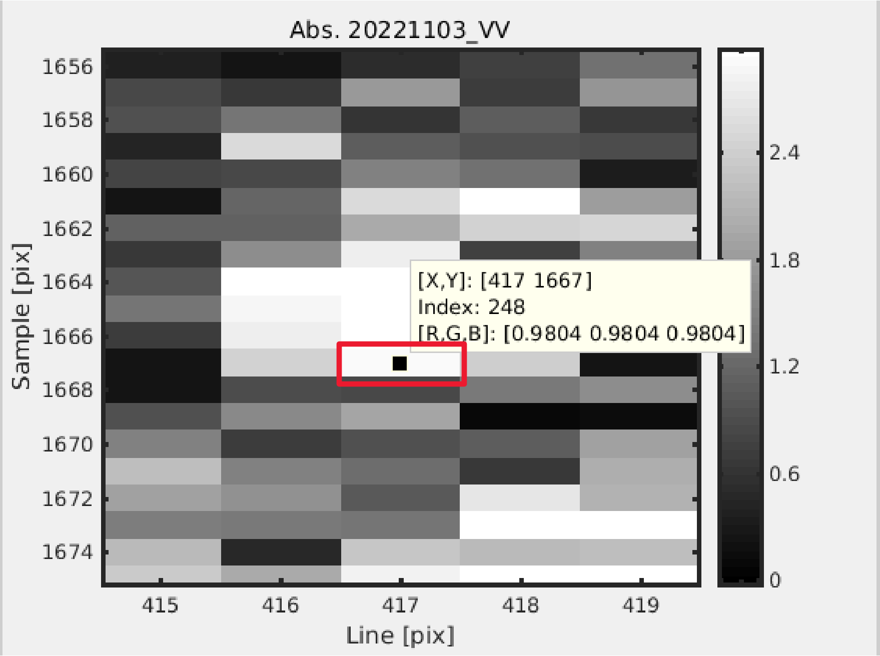


Image after installation

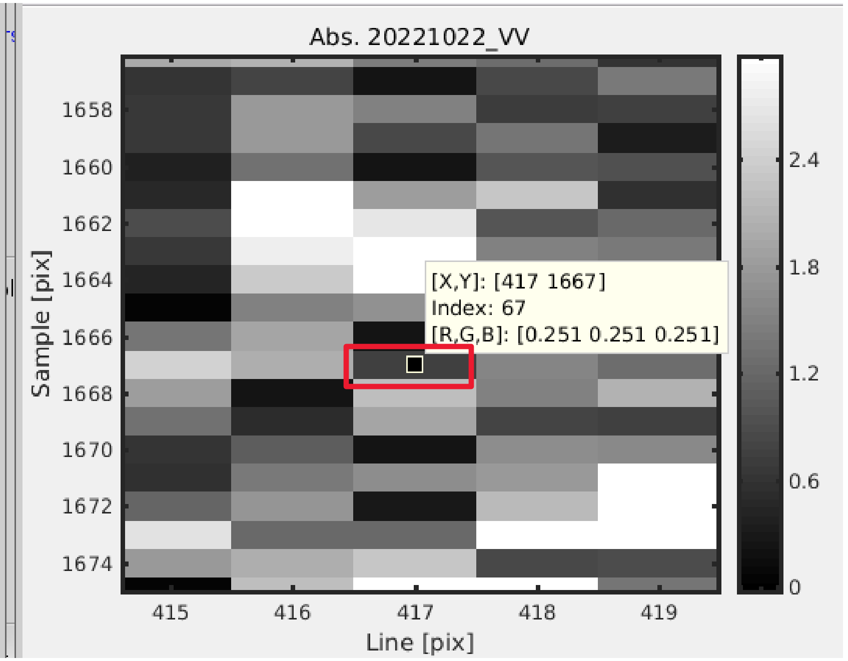
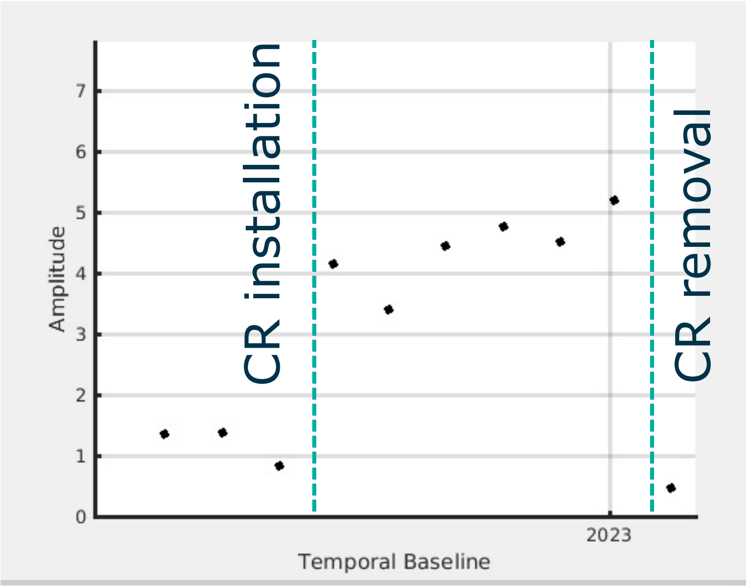


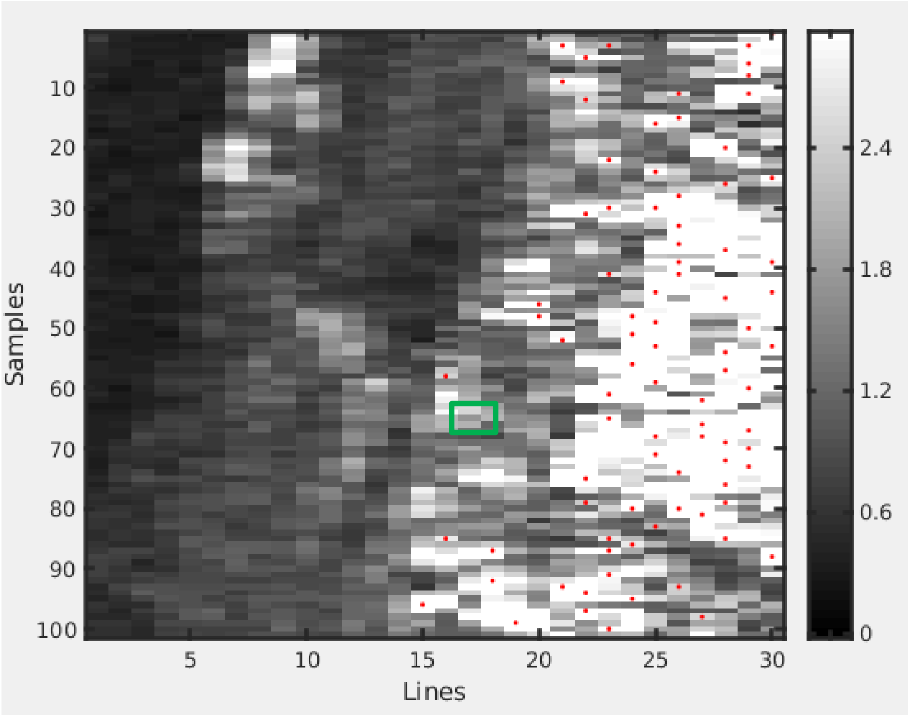
Image before installation



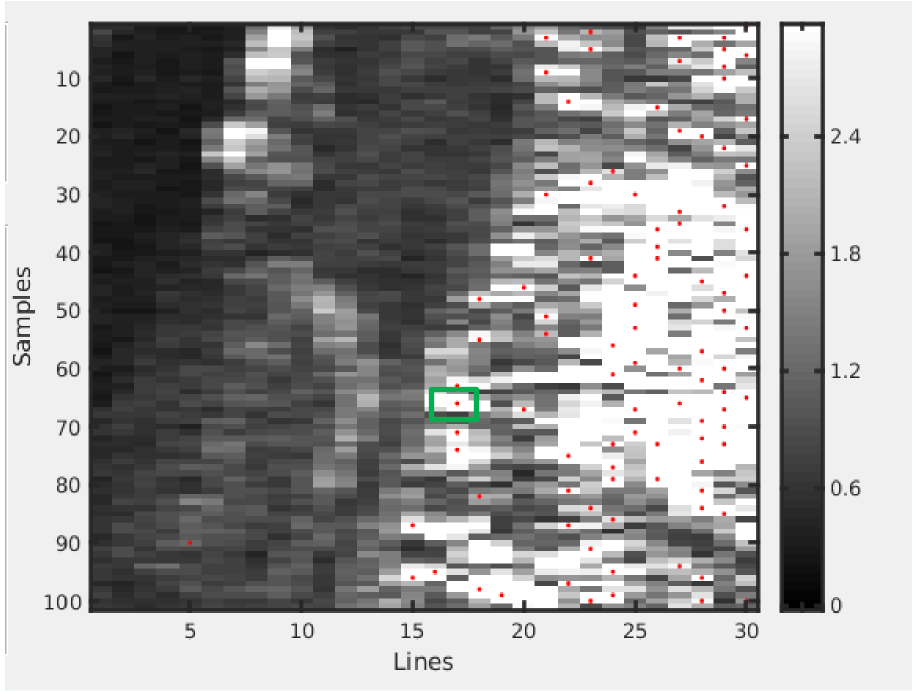
As anticipated due to the obstruction caused by the tower body, there was no amplitude increase post installation for CR on the tower 2

Q1→ InSAR processing

Conventional PSInSAR analysis using SARPROZ [*] and 13 Sentinel-1 images between 20230303 and 20230725 from track 154 descending (after CR1 installation) and 15 Sentinel-1 images between 20220507 and 20221022 from track 154 descending (before CR1 installation)



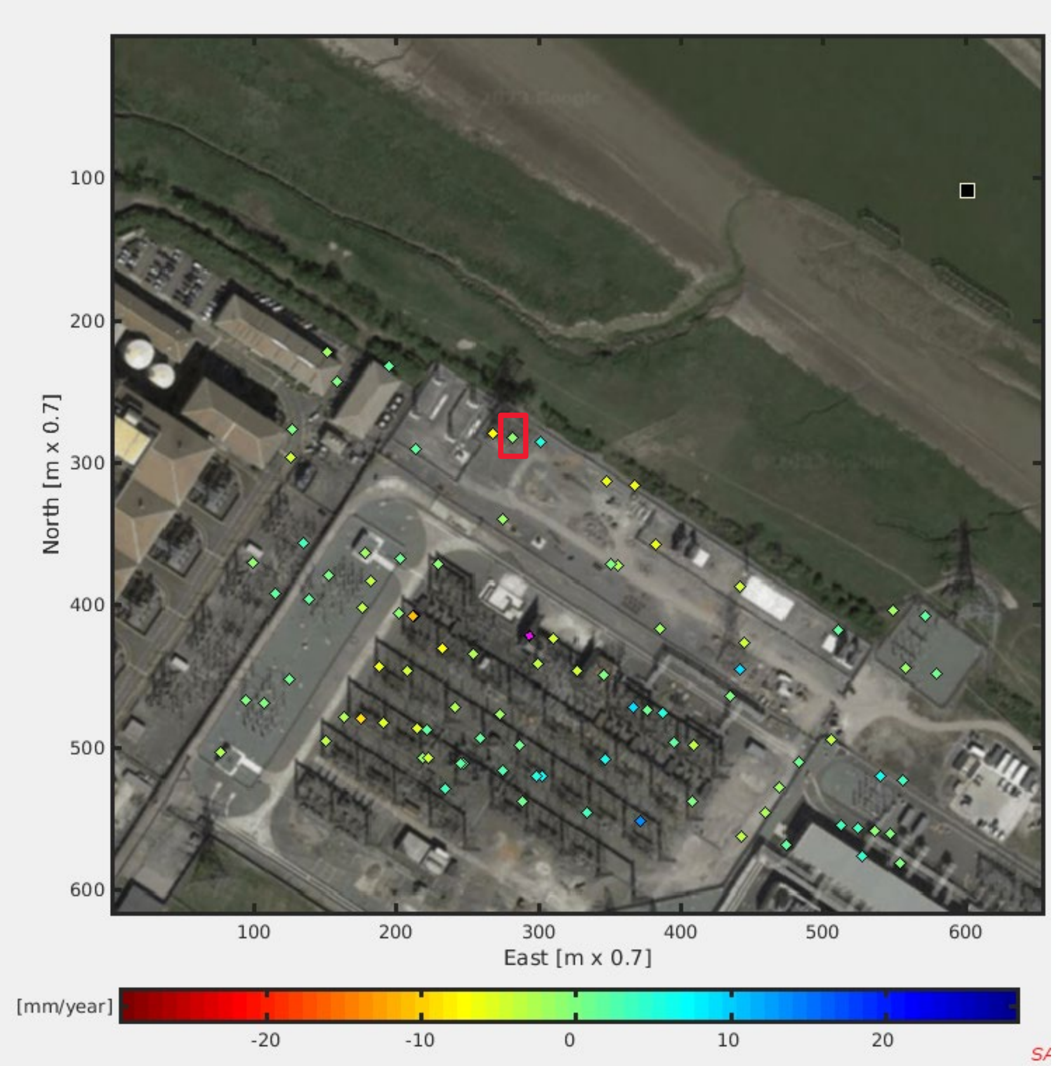
Before CR installation

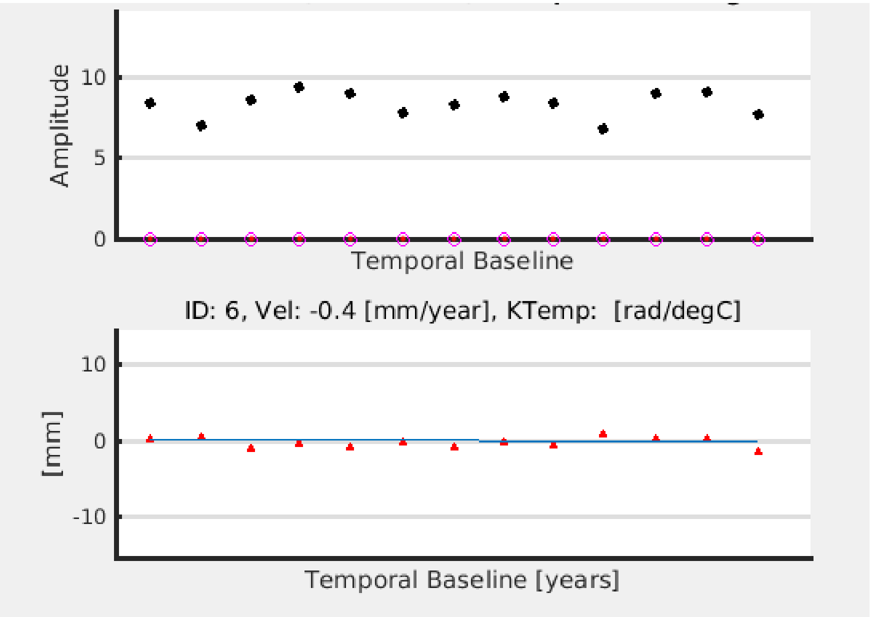


After CR installation

[*] Perissin, D., Wang, Z., Wang, T., "The SARPROZ InSAR tool for urban subsidence/manmade structure stability monitoring in China", Proc. of ISRSE 2011, Sidney, Australia, 10-15 April 2011.

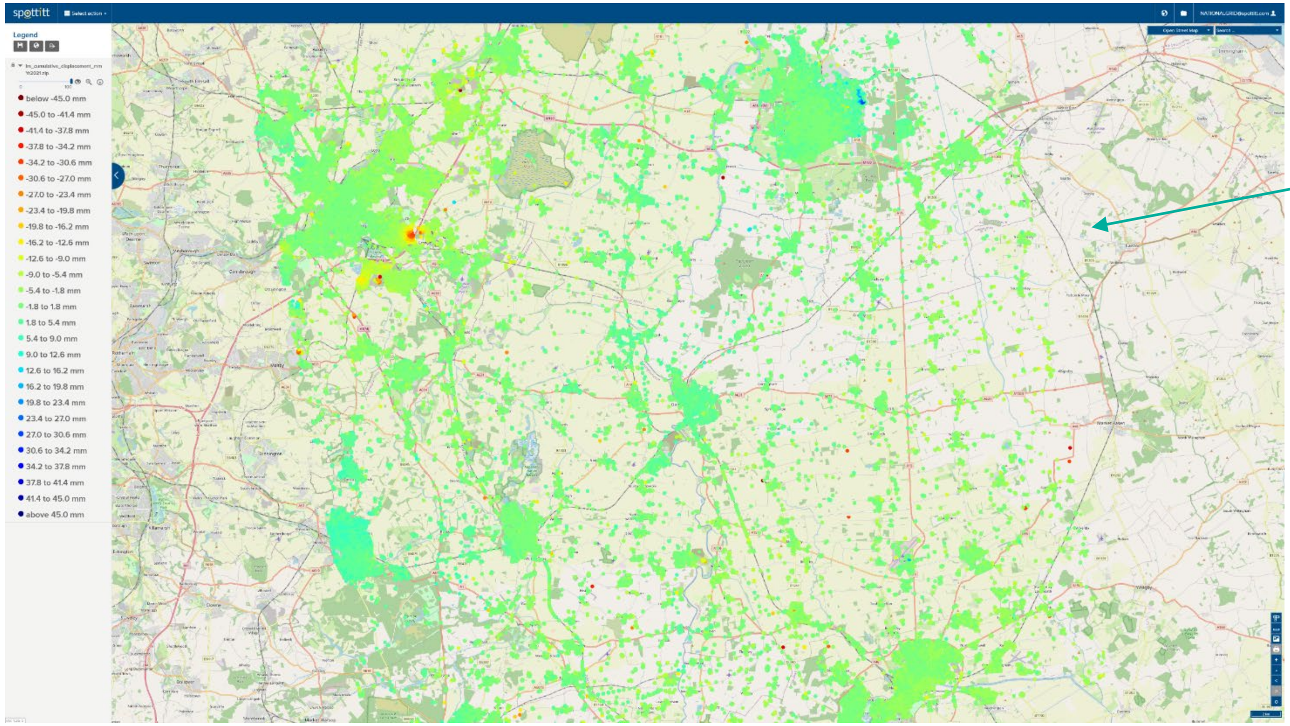
Q1→ Experimental results





Q2→InSAR analysis outcome across NGET assets

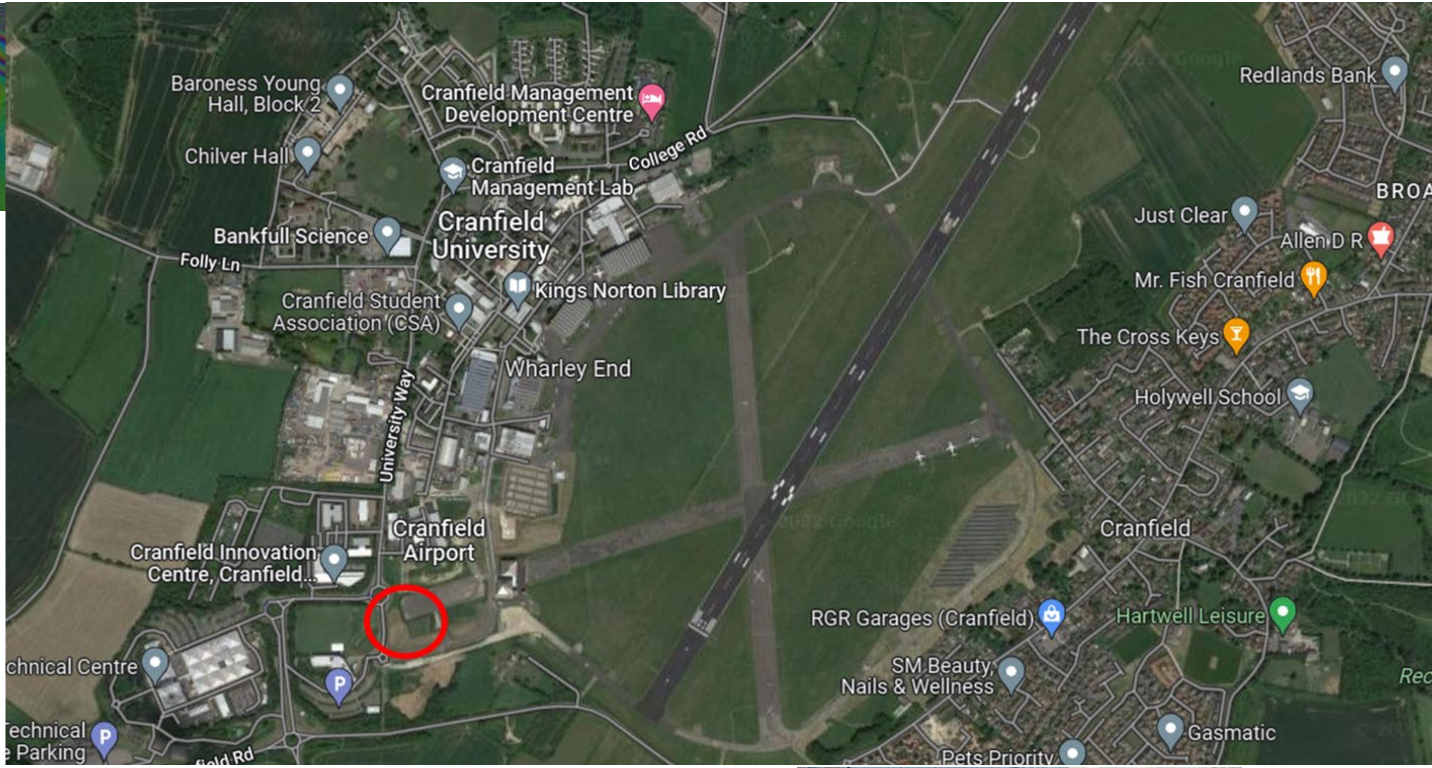
We used SARPROZ to apply PSInSAR analysis using Sentinle-1 images in three NGET test sites.



Q2→ InSAR analysis outcome across NGET assets

Some towers can be natural radar reflectors because of their orientation relative to the Sentinel-1 satellites.

Q3→ CR Installation



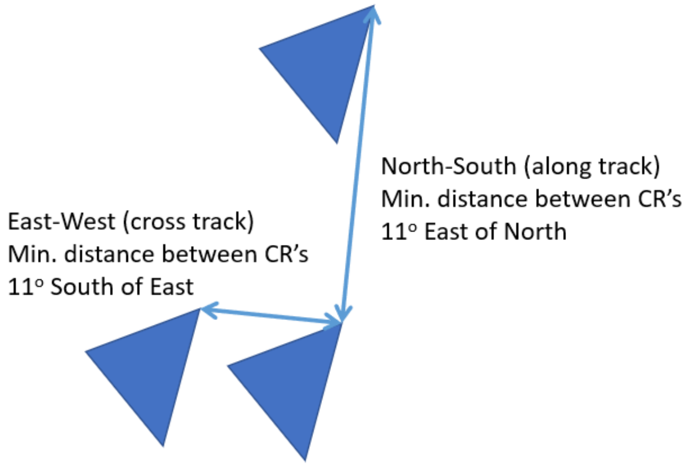
Objective

To define the minimum distance required between two CR's in both the along track and across track directions and still get two resolvable CR signals.

Cranfield test site

3 CRs installed on the Cranfield University site in an open grassy area SW of the runway.

The 3 CRs were mounted in an L shaped formation each with a 100% clear view to the Sentinel 1 satellite, descending track (81).



Q3→ SAR processing

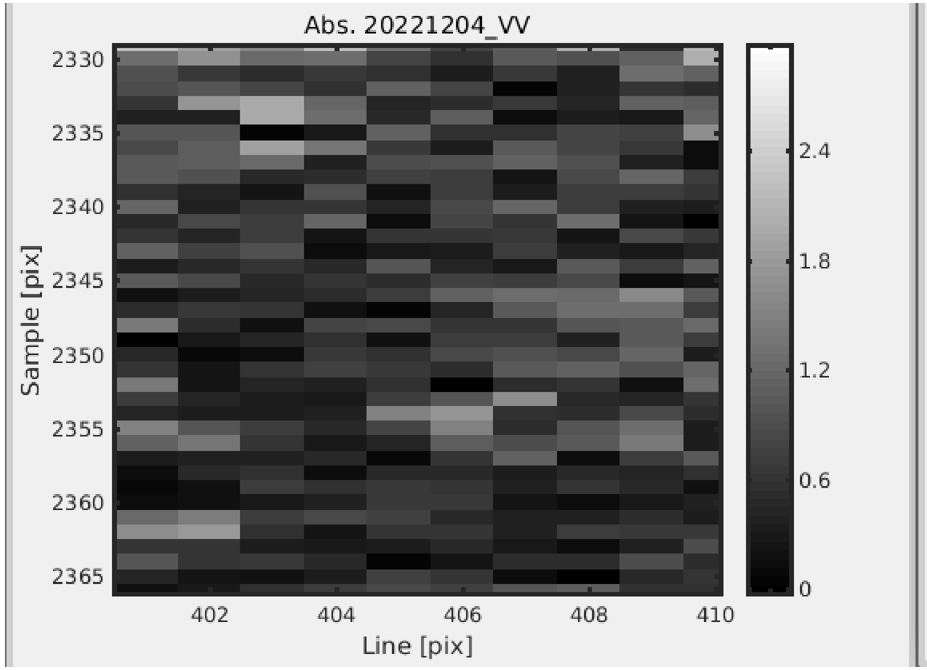
Sentinel-1 images descending track (81), 3 images before installation and), 1 image after each layout installation

All co-registered w.r.t the first image after the first layout installation

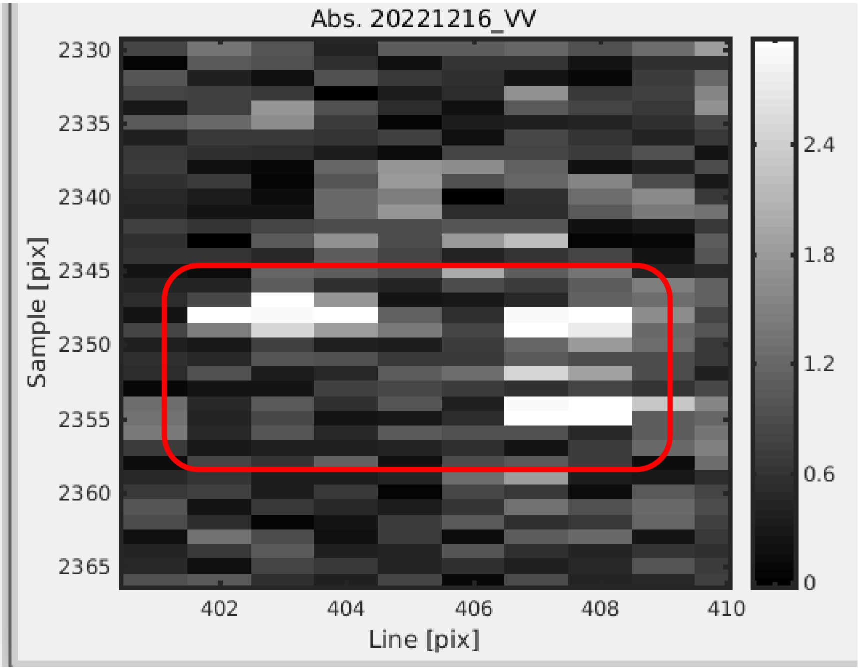
Georeferenced the images using a high-resolution LiDAR DEM and finally manually corrected using a visible feature in the SAR image

First layout

Date	Along-track (N-S)	Across-track (E-W)	Comment
16 Dec 2022(I1)	60 m	20 m	3 distinct signals
28 Dec 2022(I2)			
9 Jan 2023	30 m	10 m	
21 Jan 2023 (I3)		5 m, 10 m	



Cranfield CR's captured before first layout



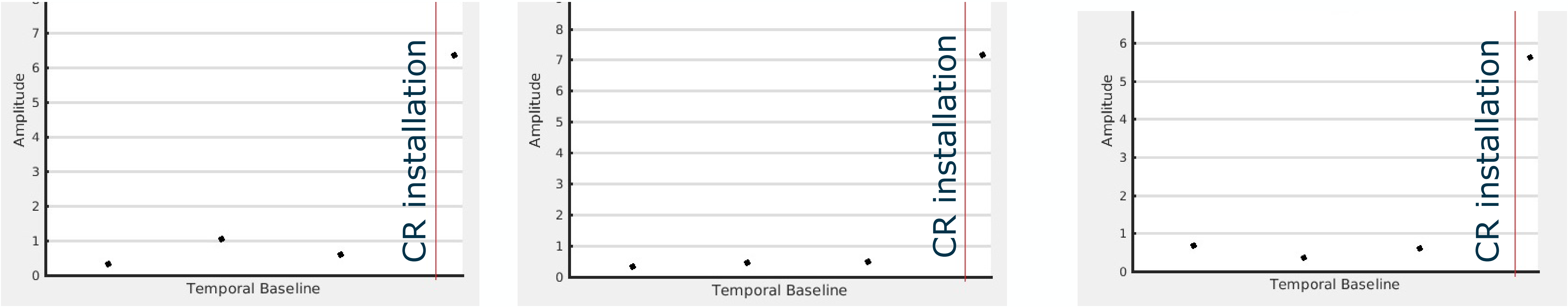
*Cranfield CR's captured 16th Dec 2022 (**I1**)*

Q3→ Experimental results

First layout

Date	Along-track (N-S)	Across-track (E-W)	Comment
16 Dec 2022(I1)	60 m	20 m	3 distinct signals
28 Dec 2022			
9 Jan 2023(I2)	30 m	10 m	
21 Jan 2023 (I3)		5 m, 10 m	

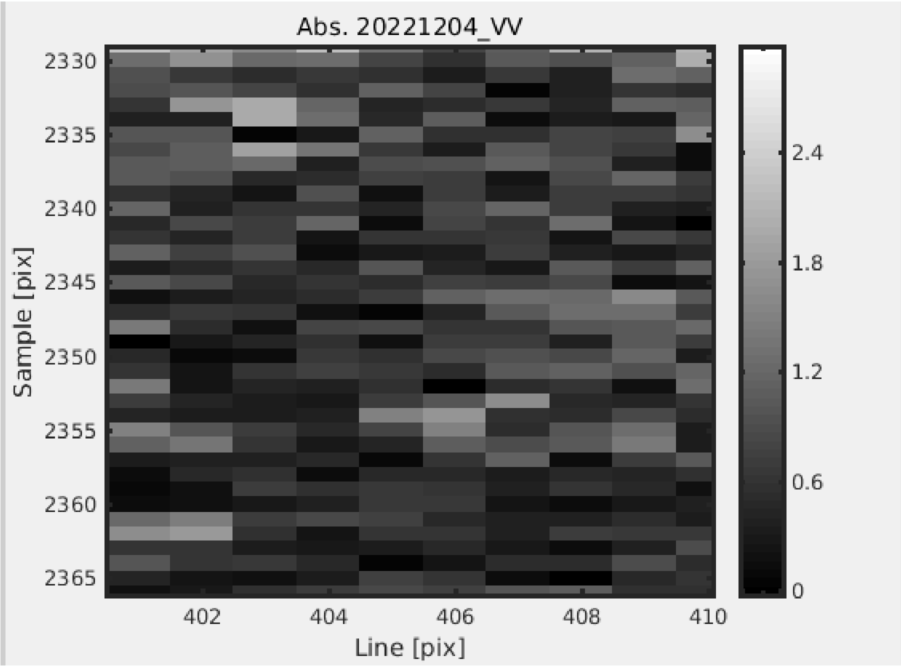
Amplitude time series of the three distinct signal



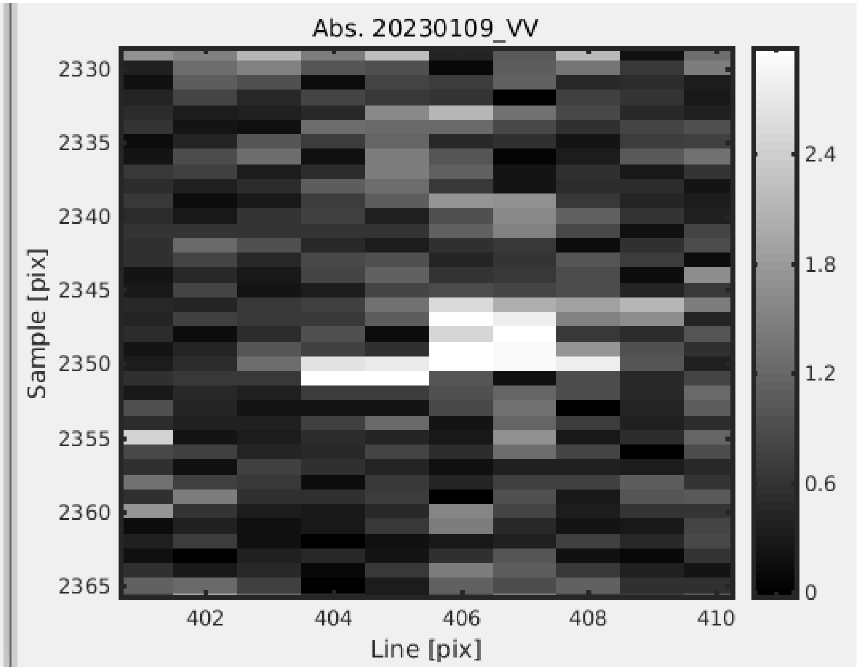
Q3→ Experimental results

Second layout

Date3	Along-track (N-S)	Across-track (E-W)	Comment
16 Dec 2022(I1)	60 m	20 m	3 distinct signals
28 Dec 2022			
9 Jan 2023(I2)	30 m	10 m	2 distinct signals in along-track, signals in across-track starts overlapping
21 Jan 2023 (I3)		5 m, 10 m	



Cranfield CR's captured before first layout



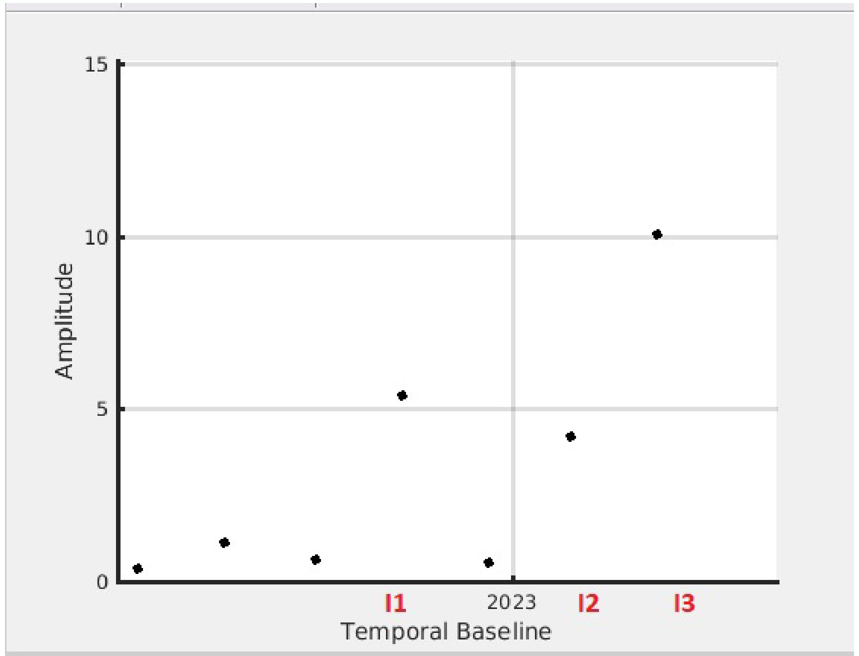
*Cranfield CR's captured 9h Jan 2023 (**I2**)*

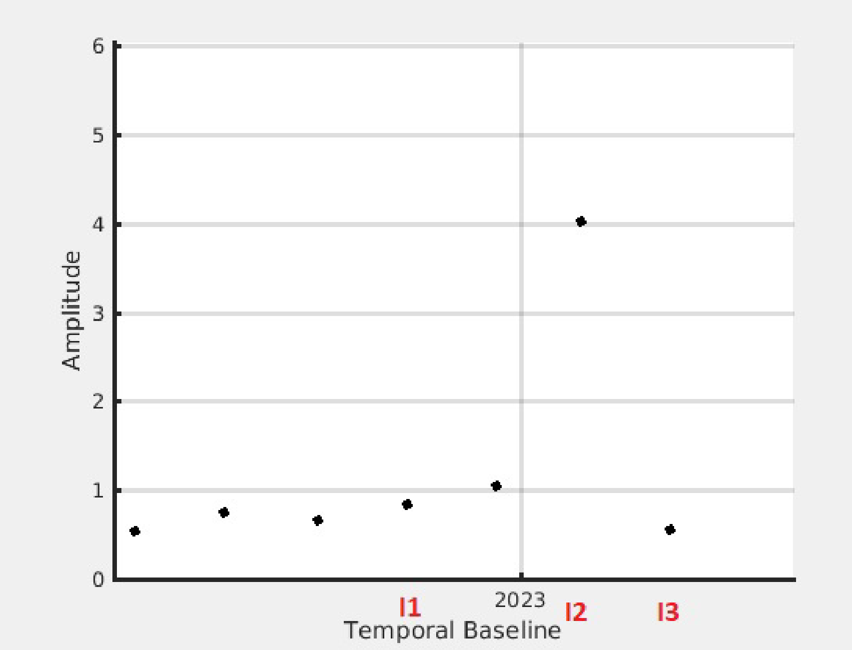
Q3→ Experimental results

Second layout

Date3	Along-track (N-S)	Across-track (E-W)	Comment
16 Dec 2022(I1)	60 m	20 m	3 distinct signals
28 Dec 2022(I2)			
9 Jan 2023	30 m	10 m	2 distinct signals in along-track, signals in across-track starts overlapping
21 Jan 2023 (I3)		5 m, 10 m	

Amplitude time series of the two distinct signals in along-track direction

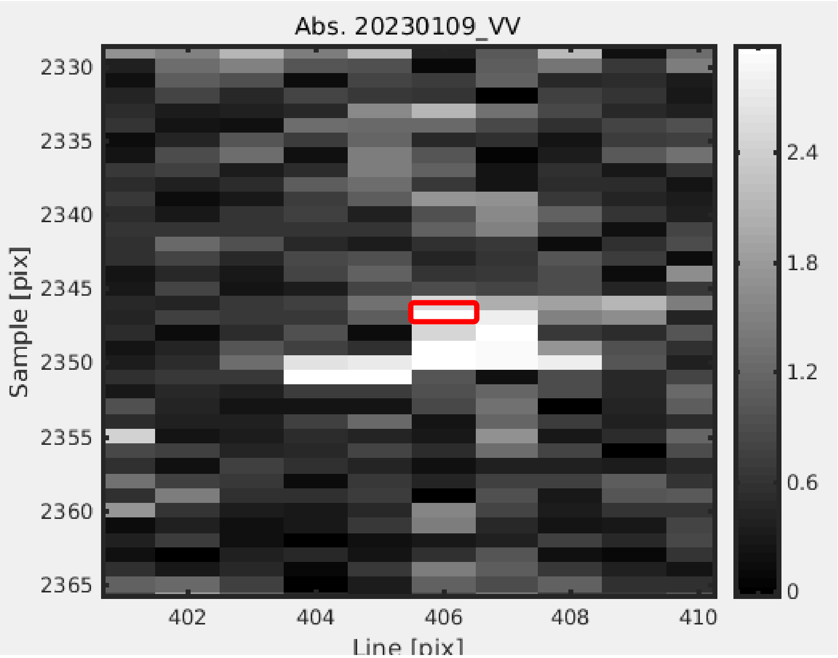




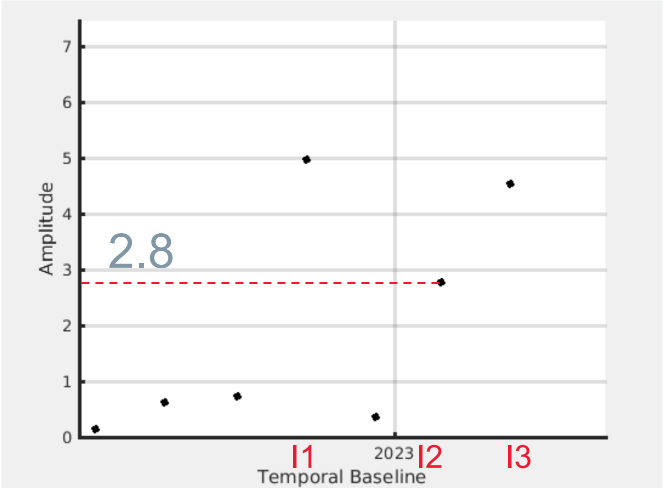
Central CR in three layouts

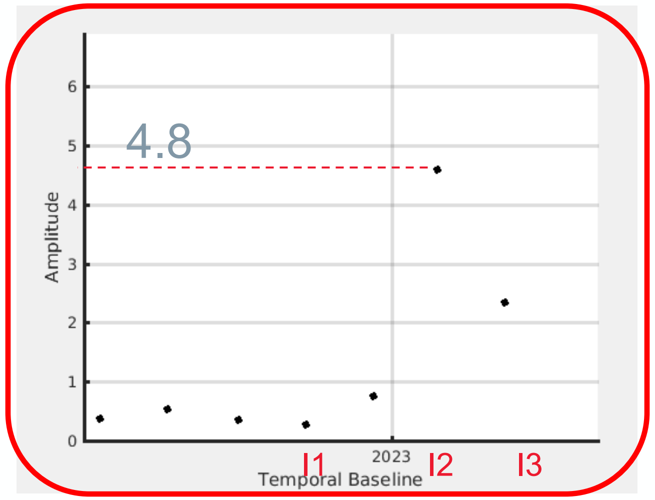
Q3→ Experimental results

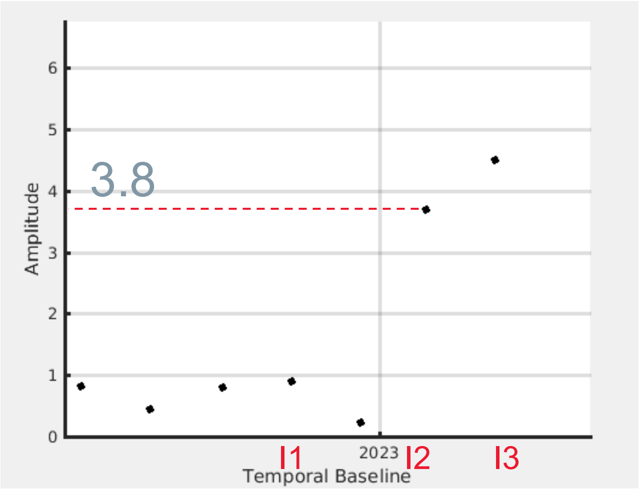
Second layout

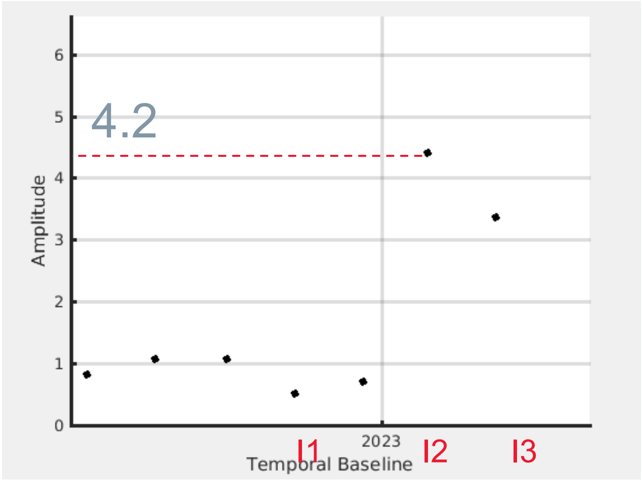


Amplitude time series of the bright pixels in the overlapping area





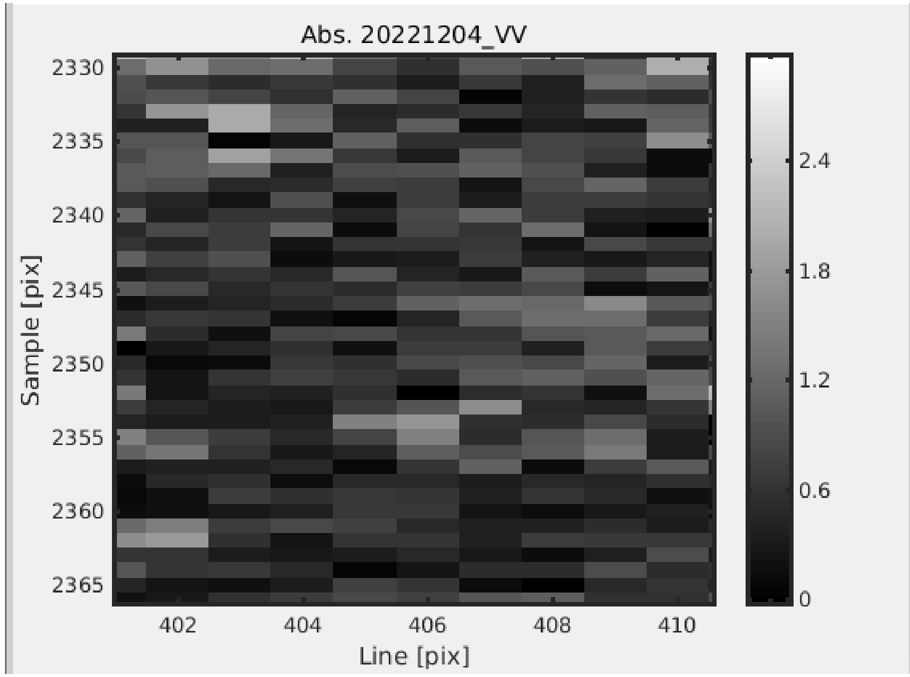




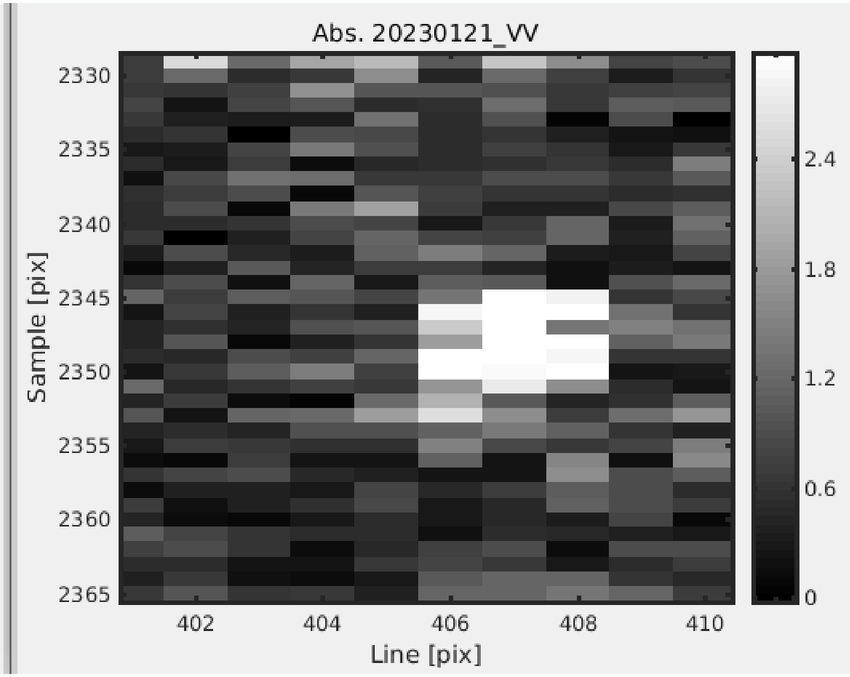
Q3→ Experimental results

Third layout – all 3 in across track

Date	Along-track (N-S)	Across-track (E-W)	Comment
16 Dec 2022(I1)	60 m	20 m	3 distinct signals
28 Dec 2022(I2)			
9 Jan 2023	30 m	10 m	2 distinct signals in along-track , signals in across-track starts overlapping
21 Jan 2023(I3)		5 m, 10 m	2 signals start to overlap, and 2 signals are overlapping



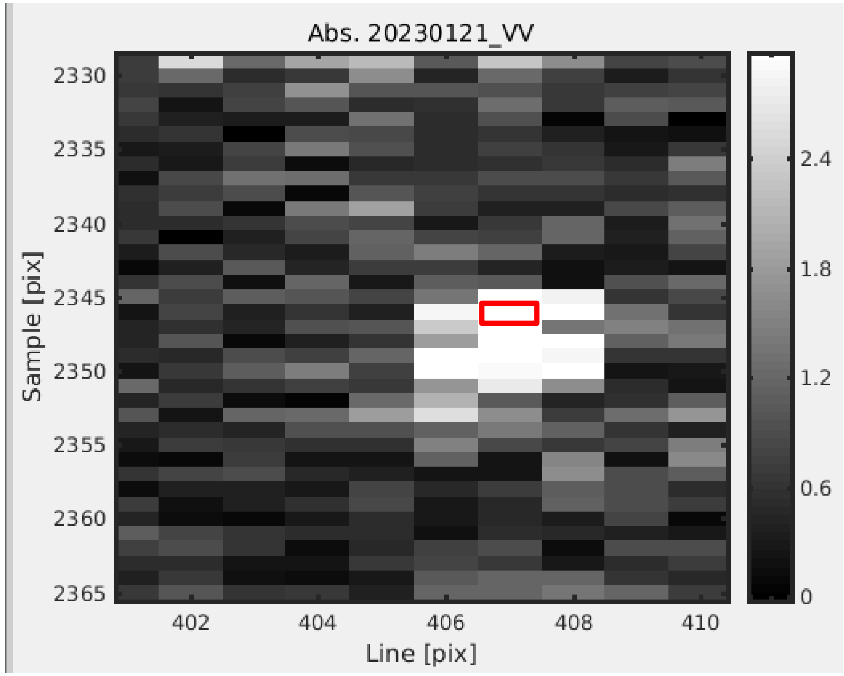
Cranfield CR's captured before first layout



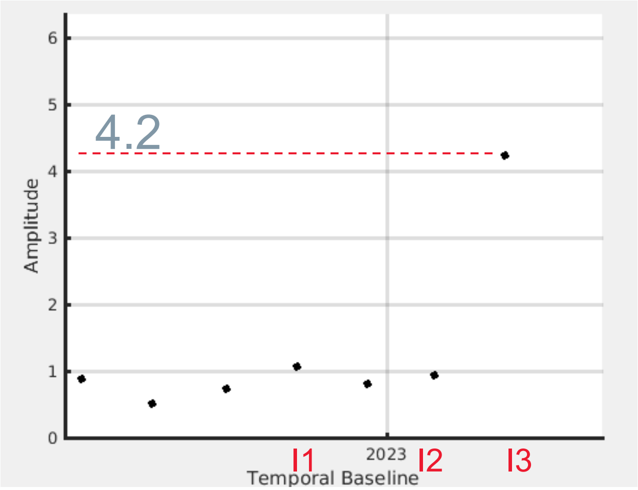
Cranfield CR's captured 21th Jan 2023 (I3)

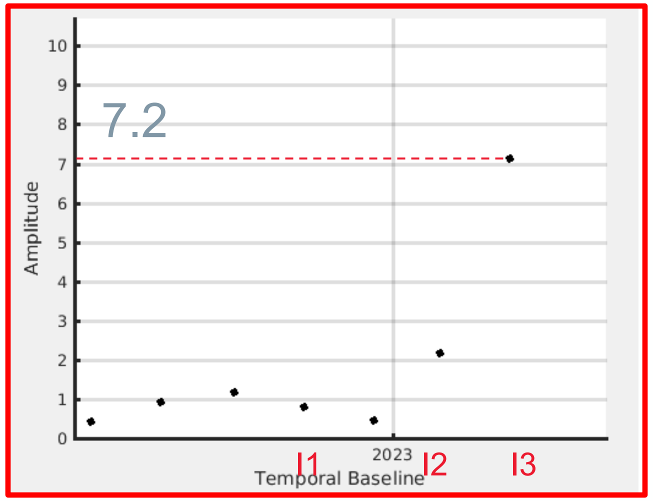
Q3→ Experimental results

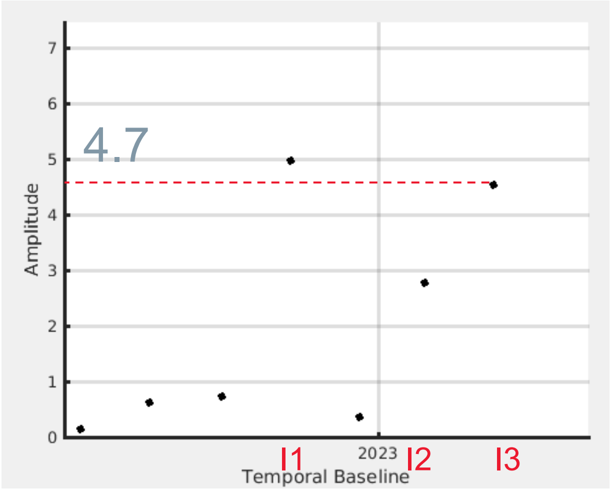
Third layout – all 3 in across track

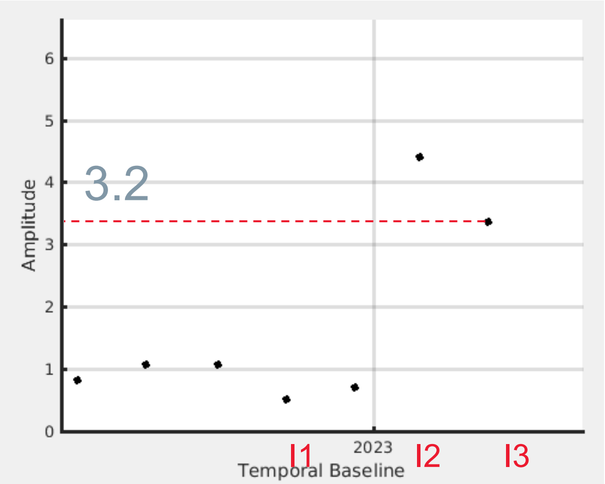


Amplitude time series of the bright pixels in the area starts to overlap



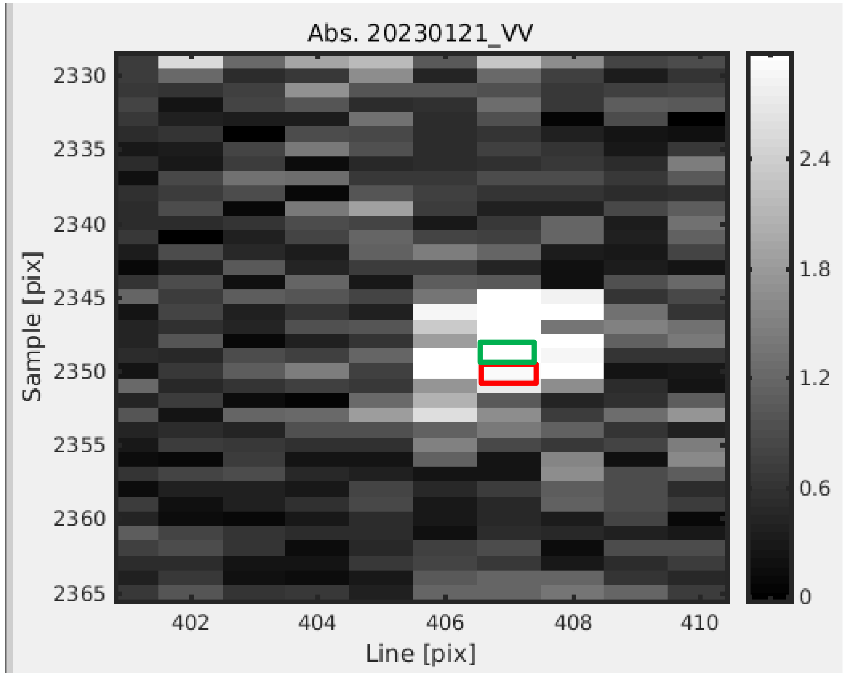




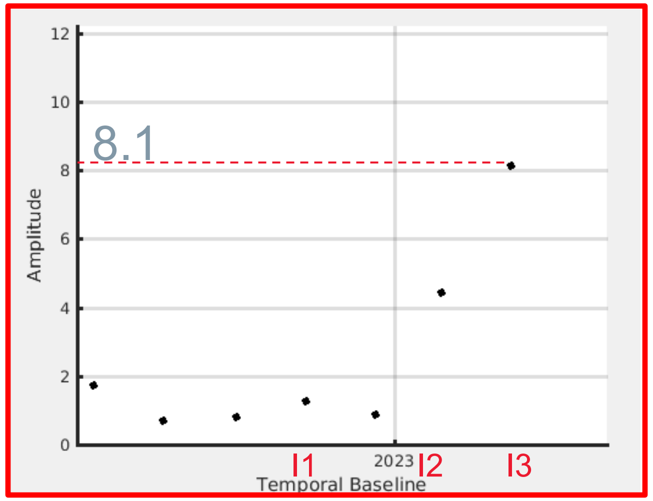


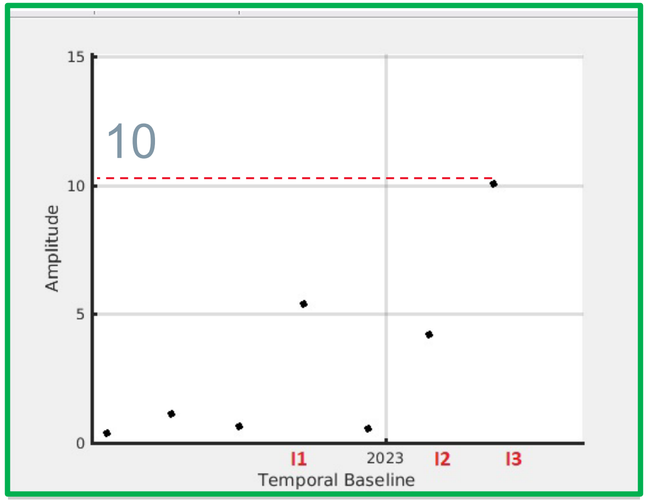
Q3→ Experimental results

Third layout – all 3 in across track



Amplitude time series of the bright pixels in the overlapping area

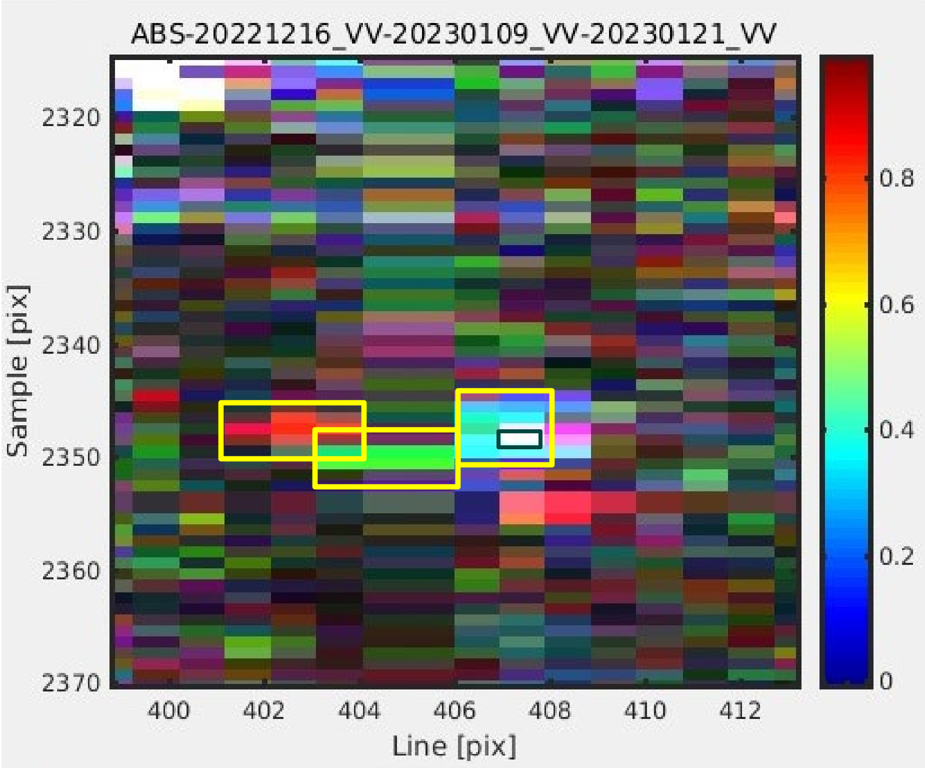


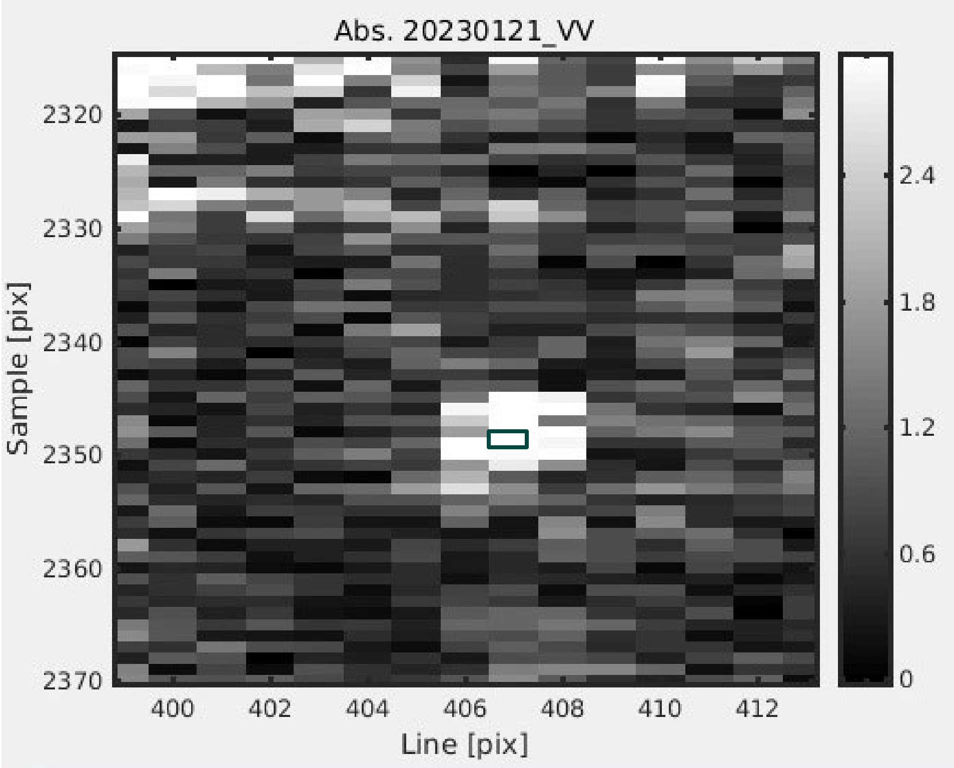


Central CR in three layouts

Q3→ Experimental results

A RGB colour composite analysis using I1, 20221216 as red, I2, 20230109 as green, and I3, 20230121 as blue.

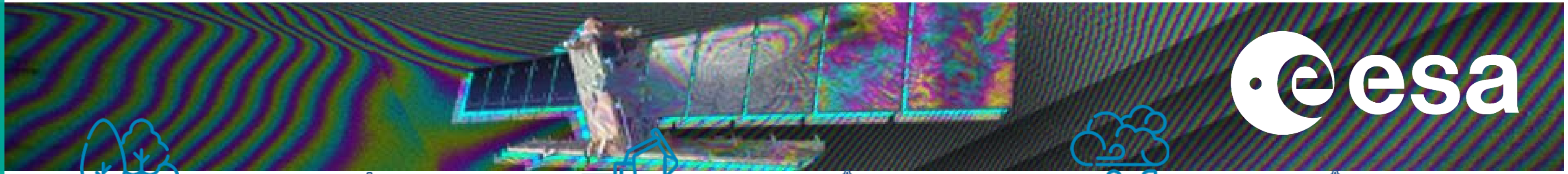




Conclusions:

- Synthetic corner reflectors can be designed, installed and used for monitoring the displacement of NGET assets.
- Some NGET assets e.g. towers can be natural radar reflectors because of their orientation relative to the Sentinel-1 satellites.
- Design of a larger corner reflector (1-meter inner leg) or an array of small corner reflectors and installation on the NGET towers would improve signal strength.
- As long as the spacing is more than approximately 30 m (along-track) or 10 m (across-track) then the coroner reflectors should be visible as distinct targets.
- This translates to 1-2 corner reflectors per tower but multiple corner reflectors per sub-station.
- It is recommended to investigate how practical could be installation of 2 corner reflectors on an electricity tower with regards to the size of the towers to still have two distinct signals for future study.

Thanks



We protect infrastructure assets Worldwide

Spottitt helps companies anywhere in the world get the geospatial information they need to increase the reliability, safety and performance of their assets

SCAN ME

Vegetation monitoring
Better plan VM activities and validate tree-cutting works done by third parties

3rd party work & change detection
Monitor human activities and changes around your assets

Climate conditions monitoring
Trends related to climate conditions around the assets

Biodiversity monitoring
Divide your land into 17 habitats and understand their evolution over time

Gas leak monitoring
Methane emissions monitoring and risk detection of gas leaks

Land and asset motion monitoring
Tracking land and asset movements at mm / year resolution

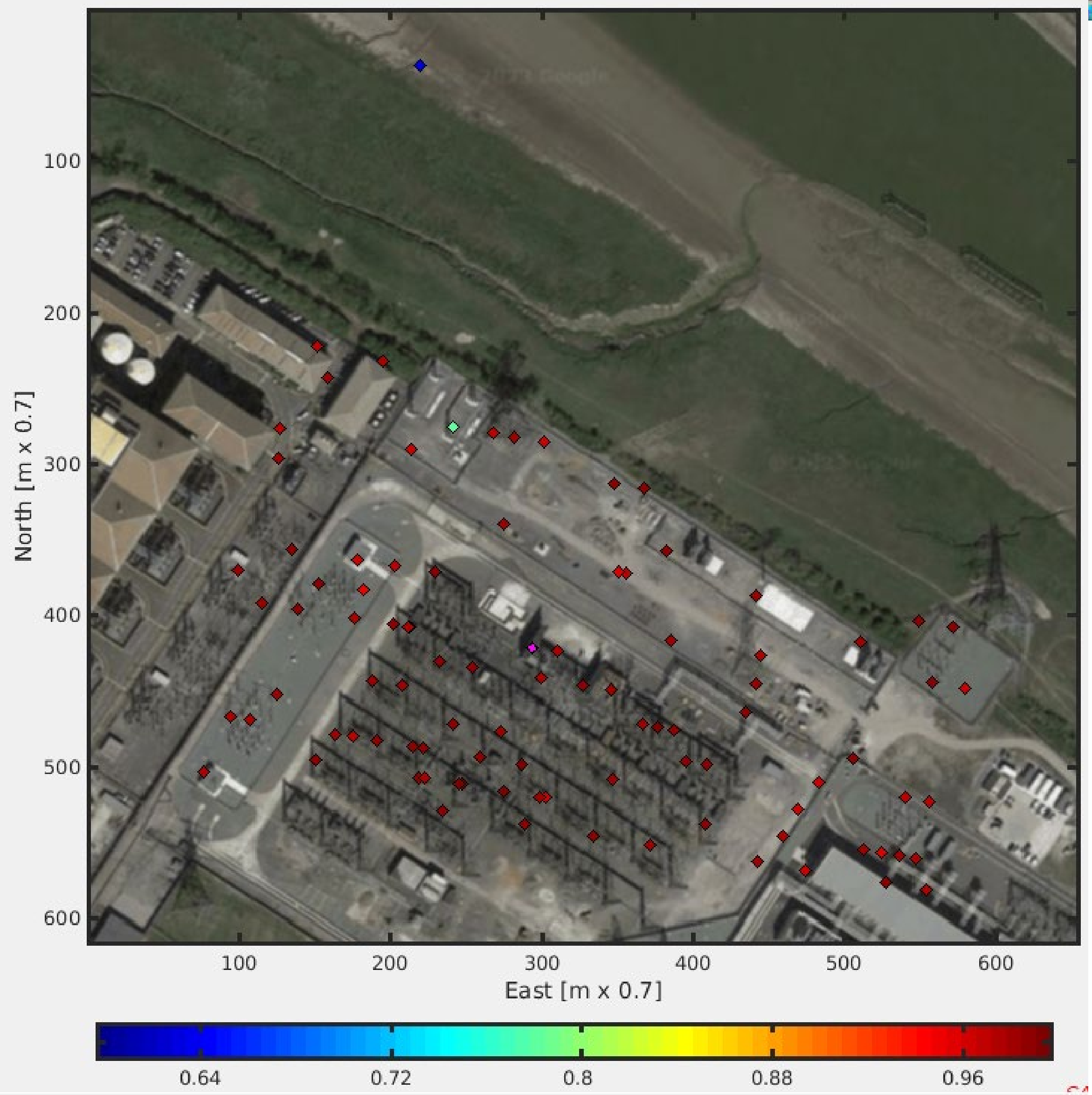
PV site selection
Select anywhere the perfect sites for rooftop or ground solar installations

Wind site selection
Select anywhere the perfect sites for onshore wind farm installations

Flood monitoring
Near real time flood footprint and depth mapping for your assets

spottitt

→ THE EUROPEAN SPACE AGENCY


North [m x 0.7]
100
200
300
400
500
600
East [m x 0.7]
100
200
300
400
500
600
0.64
0.72
0.8
0.88
0.96