Polarimetrically augmented Coherent Change Detection three stage detector for multistatic laboratory Synthetic Aperture Radar

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November 2023

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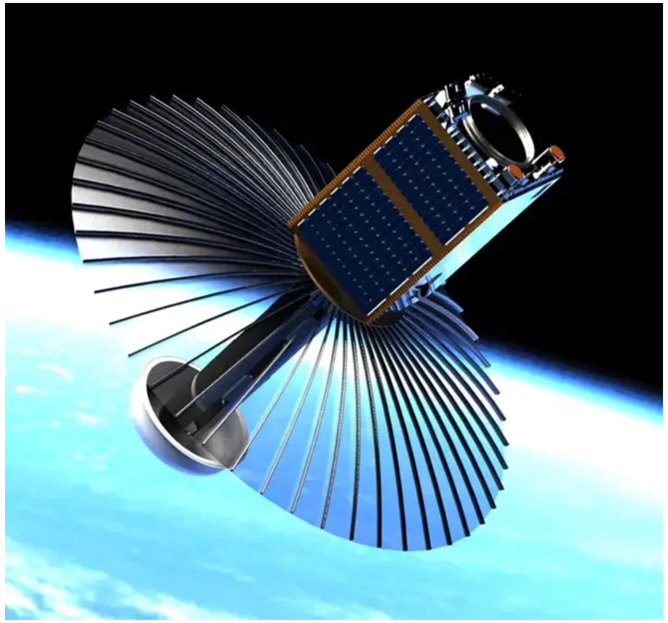
Introduction

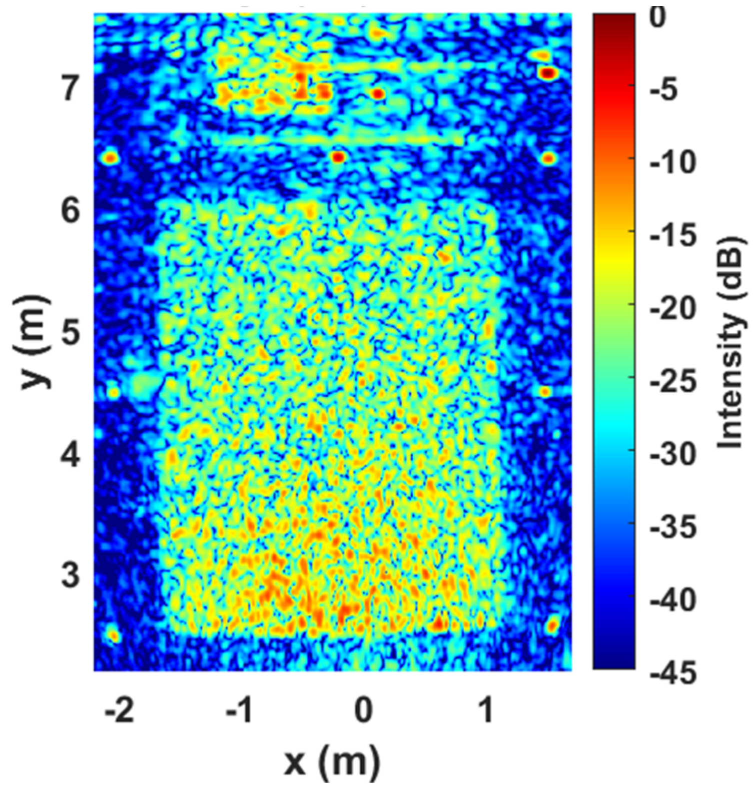
- Multistatic SAR satellite constellation being considered by DSTL (Oberon concept). We are supporting the de-risking stage.
  - A multistatic constellation may provide improved resolution, information and imaging capability.
- Coherent Change Detection (CCD) images can allow for the detection of very small changes such as vehicle tracks.
- This work investigated the performance of bistatic and multistatic polarimetric SAR change detection.
- This work is part of a PhD sponsored by DSTL.



[dstl]
The Science Inside

SAR images and change detection

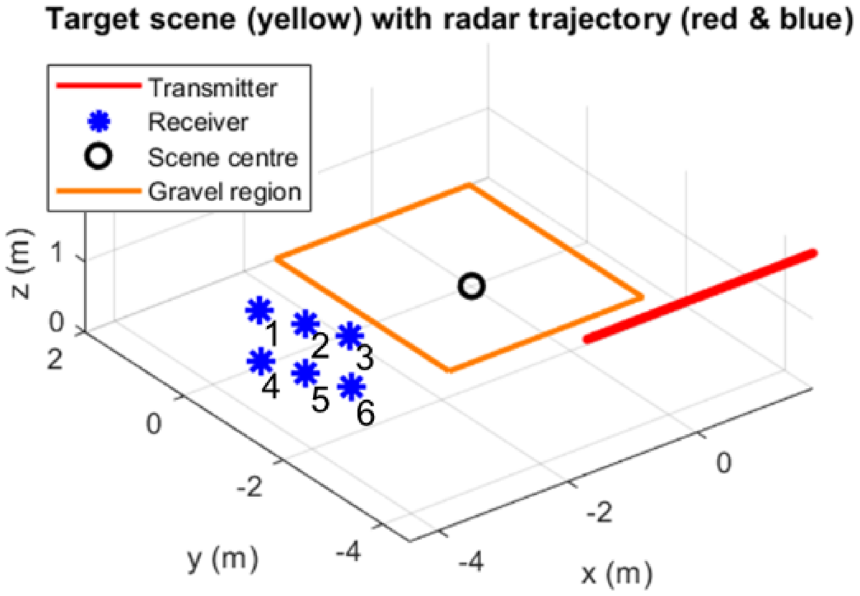
- Remote sensing technique that uses microwave EM waves.
- Active sensor which allow s all weather, day night imaging.
- Reliant on a moving transmitter or receiver to synthesise a larger antenna and thus provide high resolution.



Example high resolution monostatic SAR image

Methodology

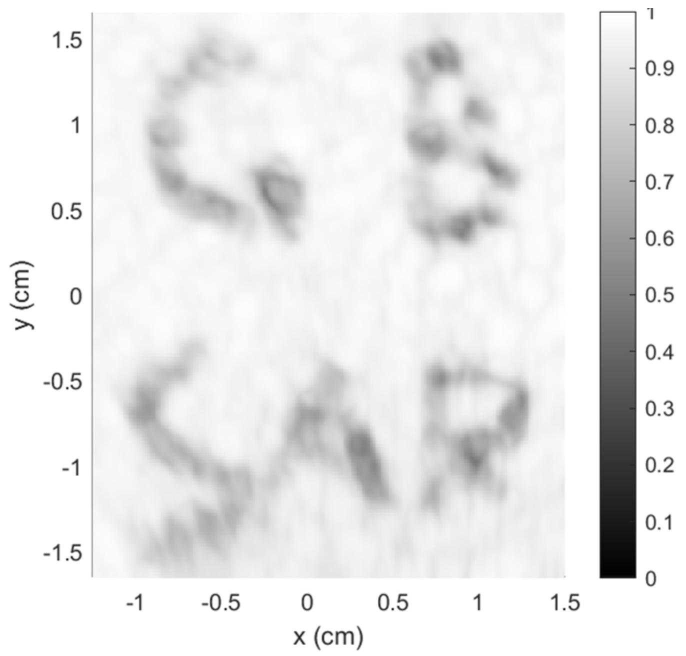
- Measurements were undertaken at the Ground Based Synthetic Aperture Radar (GSAR) laboratory in Shrivenham UK.
- The Antenna horns moved within two two-dimensional apertures. A disturbance was written in the gravel for use in CCD images.
- 6.6-10 GHz was used. Images were background subtracted. Quad polarization VV, VH, HH & HV.



CCD and NCCD

- CCD coherence is calculated between two SAR images.
- CCD is carried out over a sliding window across the SAR images.
- For each window a normalized complex cross-correlation is calculated. The magnitude (γ) is called coherence.

$$\gamma = \frac{\left|\sum_{k=1}^{N} S_1(k) S_2^*(k)\right|}{\sqrt{\sum_{k=1}^{N} |S_1(k)|^2 \sum_{k=1}^{N} |S_2(k)|^2}}$$



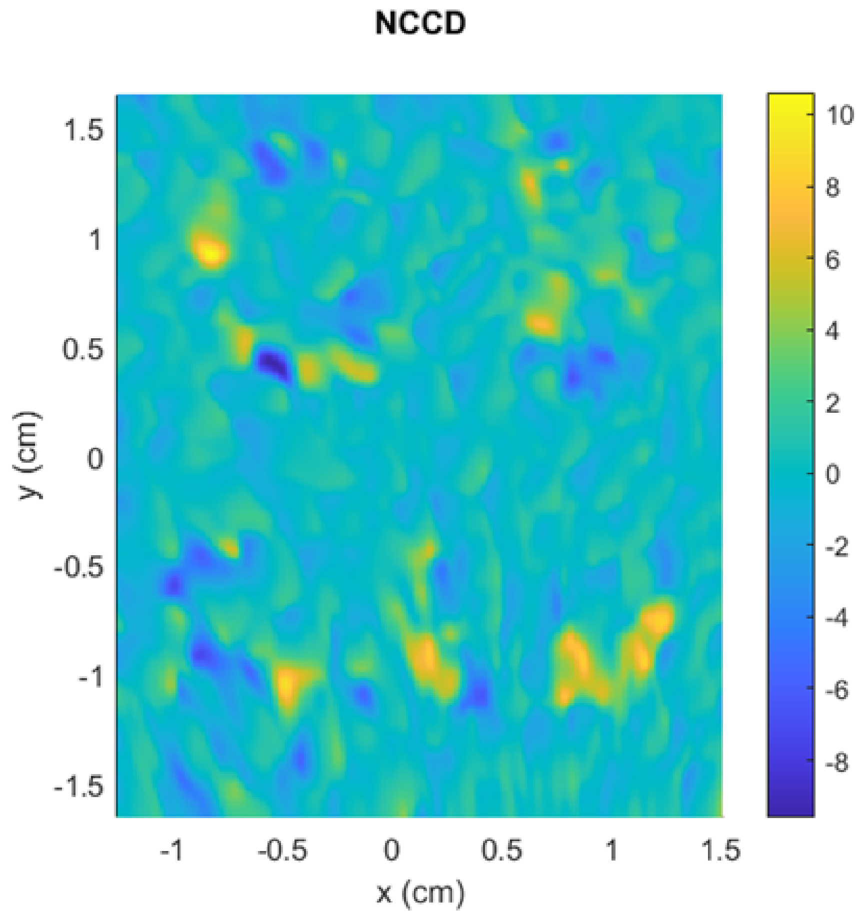
Example CCD image

CCD and NCCD

- Non-Coherent Change Detection (NCCD) uses a comparison of the backscatter power (amplitude squared).

$$NCCD = Power_1 - Power_2$$

$$NCCD = 10log_{10}\left(\frac{1}{N}\sum_{k=1}^{N}|f_k|^2\right) - 10log_{10}\left(\frac{1}{N}\sum_{k=1}^{N}|g_k|^2\right)$$



Example NCCD image

Polarimetry

- EM waves have an orientation. Vertically, V or horizontally, H.
- Using the four polarisations we can form a polarimetric *decomposition*. This allows us to characterise different scattering mechanisms, such as odd or even bounce.
- Using the Pauli decomposition we get four parameters: a, b, c & d.
- Finding the difference between these parameters in the reference and mission image can indicate changes.

$$\boldsymbol{S} = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} = \begin{bmatrix} a+b & c-jd \\ c-jd & a-b \end{bmatrix}$$

$$\boldsymbol{S} = a\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} + b\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} + c\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} + d\begin{bmatrix} 0 & -j \\ j & 0 \end{bmatrix}$$

$$a = \frac{S_{hh} + S_{vv}}{2} \qquad b = \frac{S_{hh} - S_{vv}}{2}$$

$$c = \frac{S_{hv} + S_{vh}}{2} \qquad d = \frac{S_{vh} - S_{hv}}{2j}$$

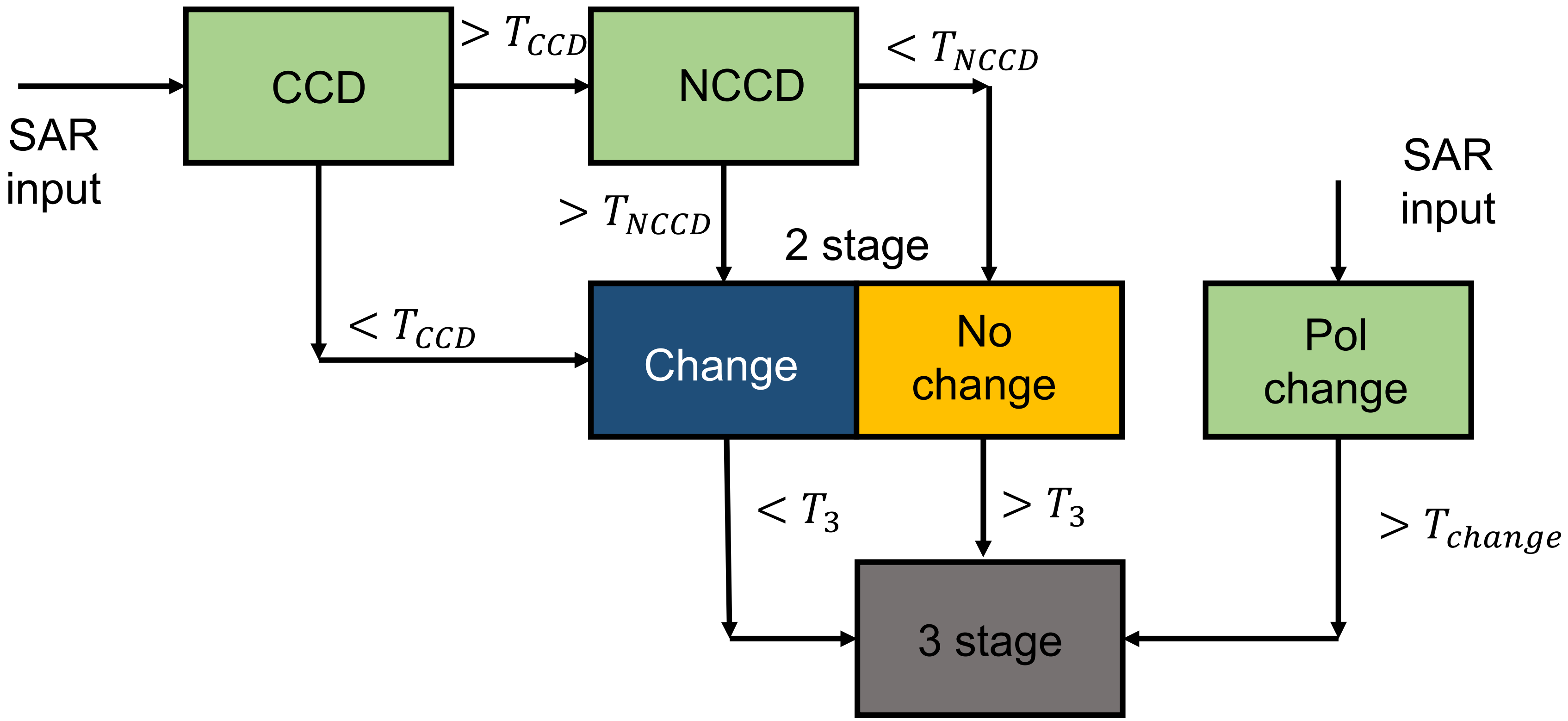
Methodology – Performance metrics

Confusion Matrix		Event Observed	
		Yes	No
Event Forecast	Yes	TP	FP
	No	FN	TN

Name	Formula	Value range
Probability of Detection	$POD = \frac{TP}{TP + FN}$	[0,1]
Critical success Index	$CSI = \frac{TP}{TP + FP + FN}$	[0,1]
False Alarm Rate	$FAR = \frac{FP}{TP + FP}$	[0,1]
Proportion Correct	$PC = \frac{TP + TN}{TP + TN + FP + FN}$	[0,1]
Heidke Skill Score	$HSS = \frac{2 * (TP \cdot TN - FP \cdot FN)}{(TP + FN)(FT + TN) + (TP + FP)(FP + TN)}$	$[-\infty, 1]$
Matthews's Correlation Coefficient	$MCC = \frac{TP \cdot TN - FP \cdot FN}{\sqrt{(TP + FP) \cdot (TP + FN) \cdot (TN + FP) \cdot (TN + FN)}}$	[−1,1]
Root Mean Squared Error	$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Predicted_i - Actual_i)^2}$	$[0, \infty]$

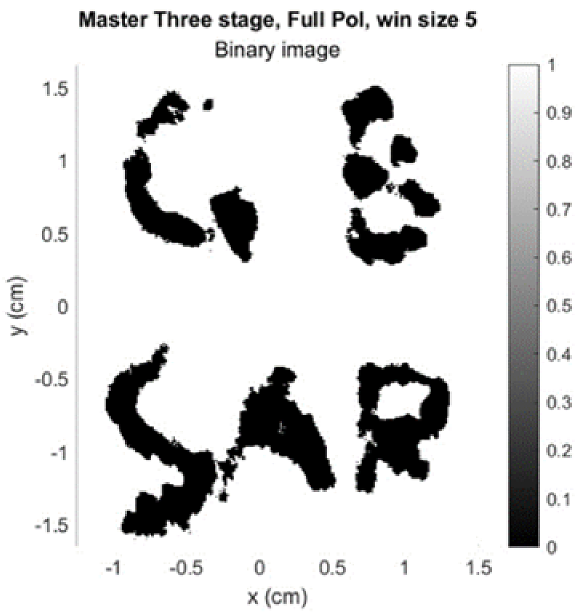
Methodology – Block diagram

- Simplified block diagram of the three-stage change detection process.

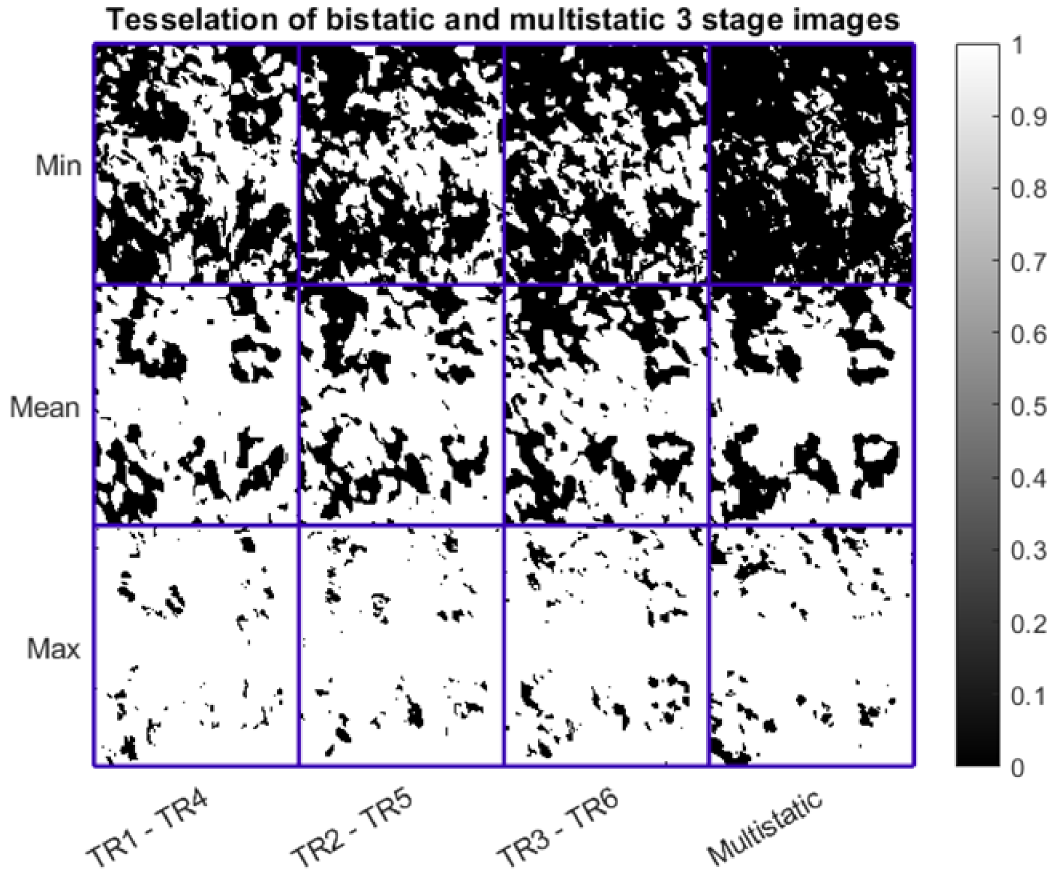


Results - Qualitative

- The bistatic and multistatic results can be qualitatively analysed against the master image.



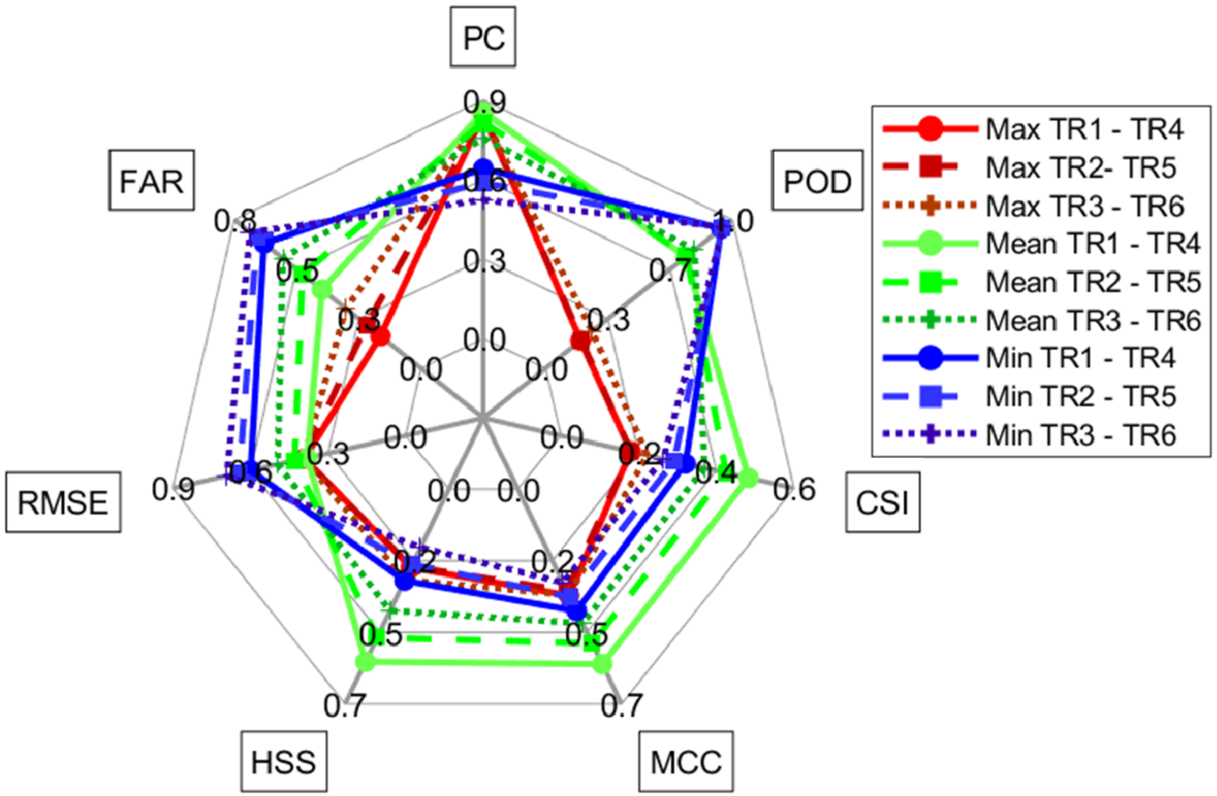
Master three-stage image



Tessellation of three-stage images

Results - Bistatic

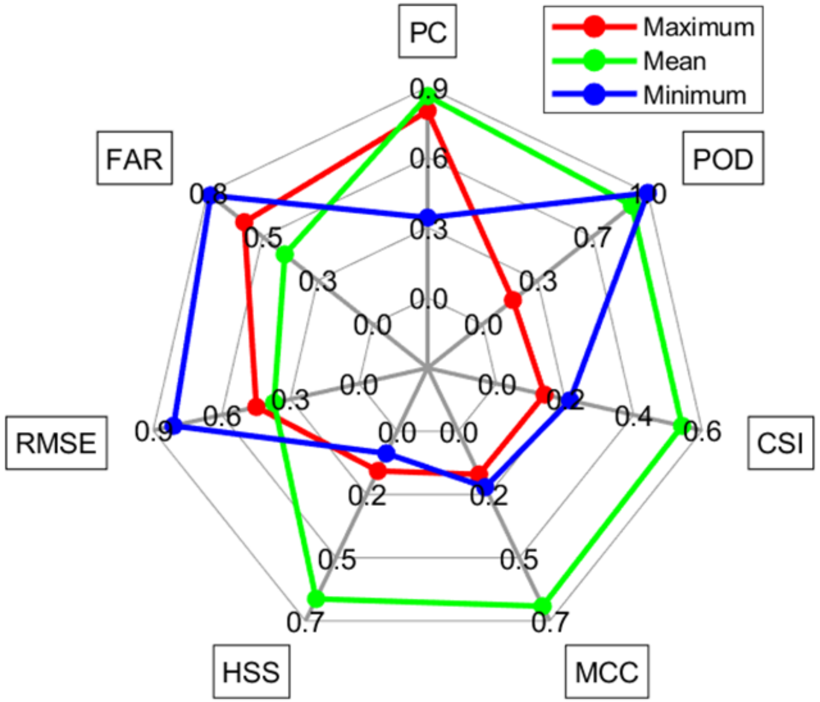
- Looking at just PC, FAR and RMSE the maximum appears to perform best.
- Maximum maximises coherence so this makes sense when we inspect the master image.
- Mean generally performs best
- Min performs poorly except for POD.



- Shows the importance of multiple metrics, as well as understanding the data.

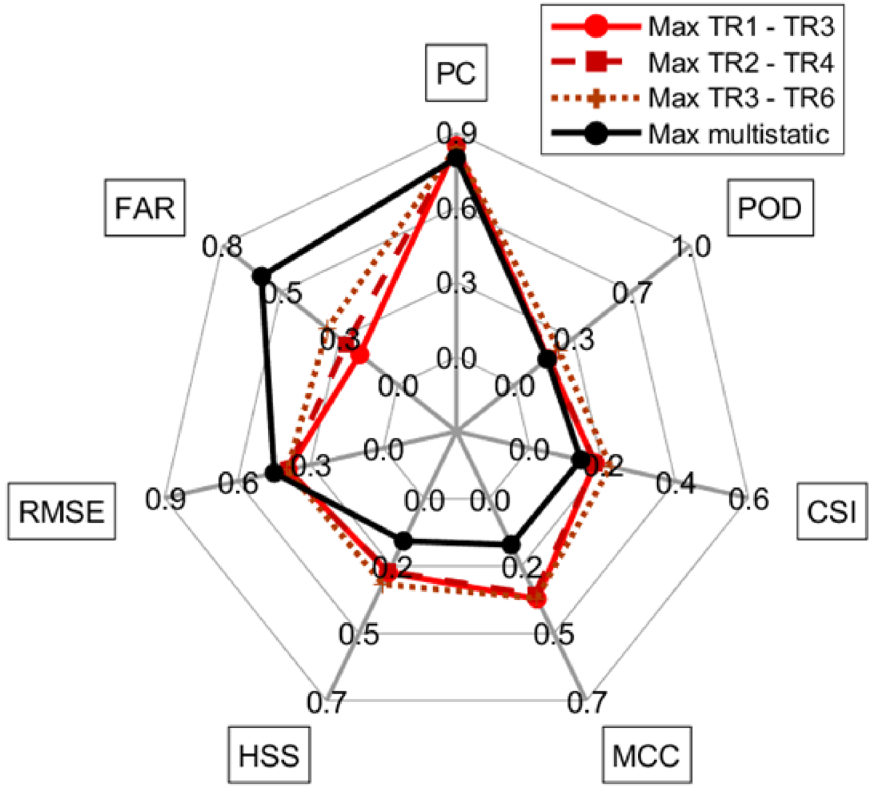
Results - Multistatic

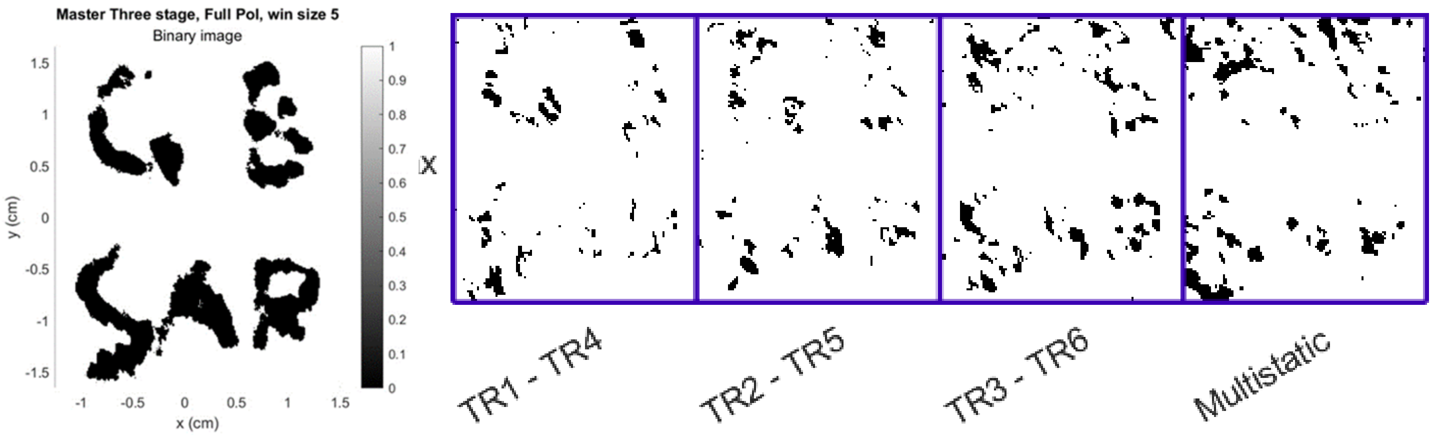
- Here the Mean clearly performs better.
  - It outperforms the max and min in all categories except POD.
- The maximum and minimum images perform poorly.
  - Minimum shows particularly poor RMSE, FAR and PC performance.
  - Both max and min have poor HSS and CSI performance.



Results - Maximum

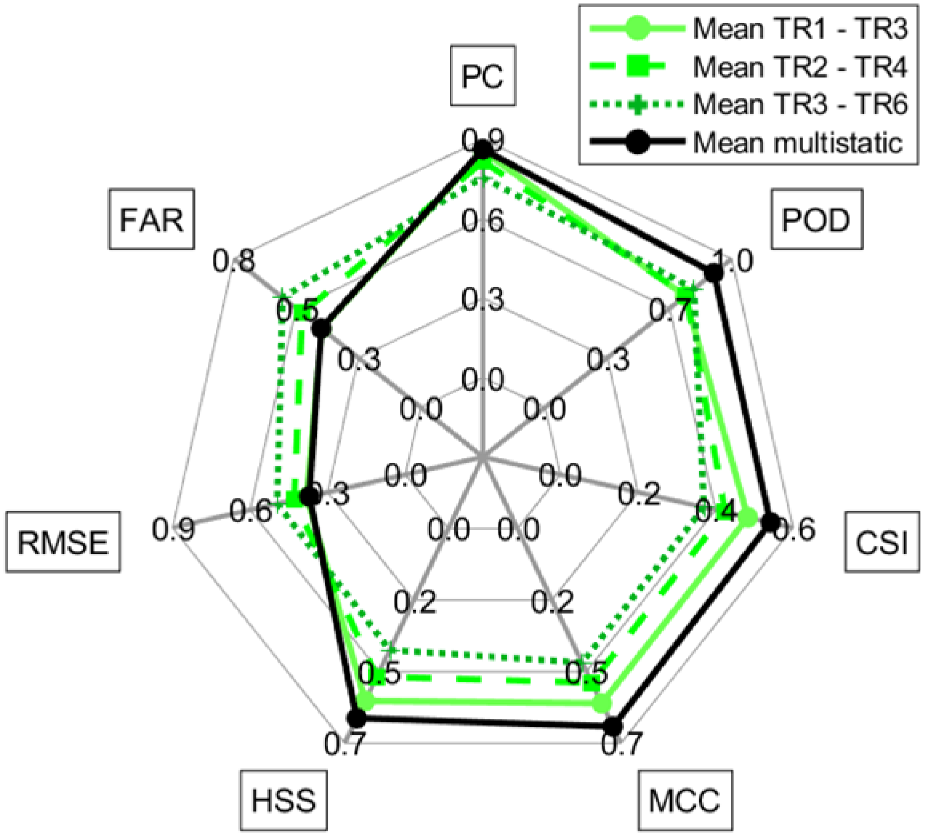
- The performance of the multistatic is actually worse than the bistatic.
- The low POD reflects the low number of changes detected, as coherence is maximised.

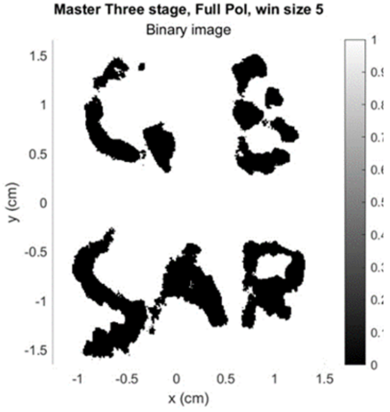


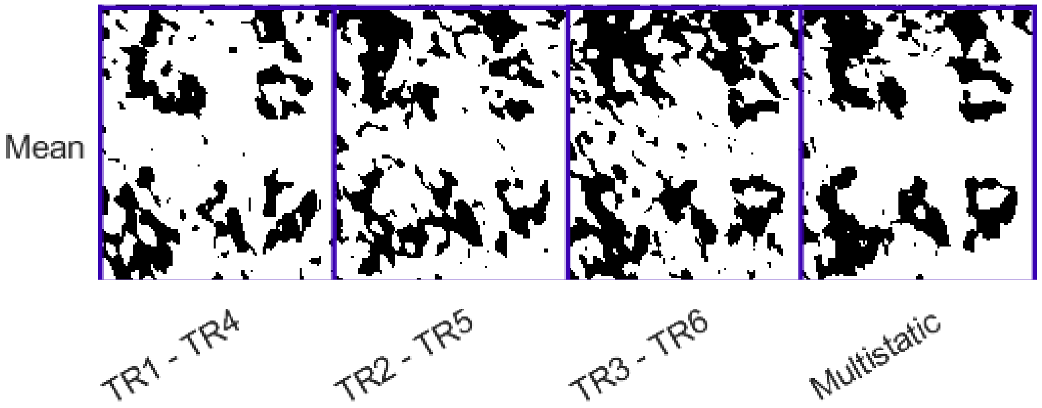


Results - Mean

- For the mean images, the multistatic performs better than the bistatic.
- Clearly seen in the performance metrics.
- Also shown in the final change detection image, which is visually more similar to the master.

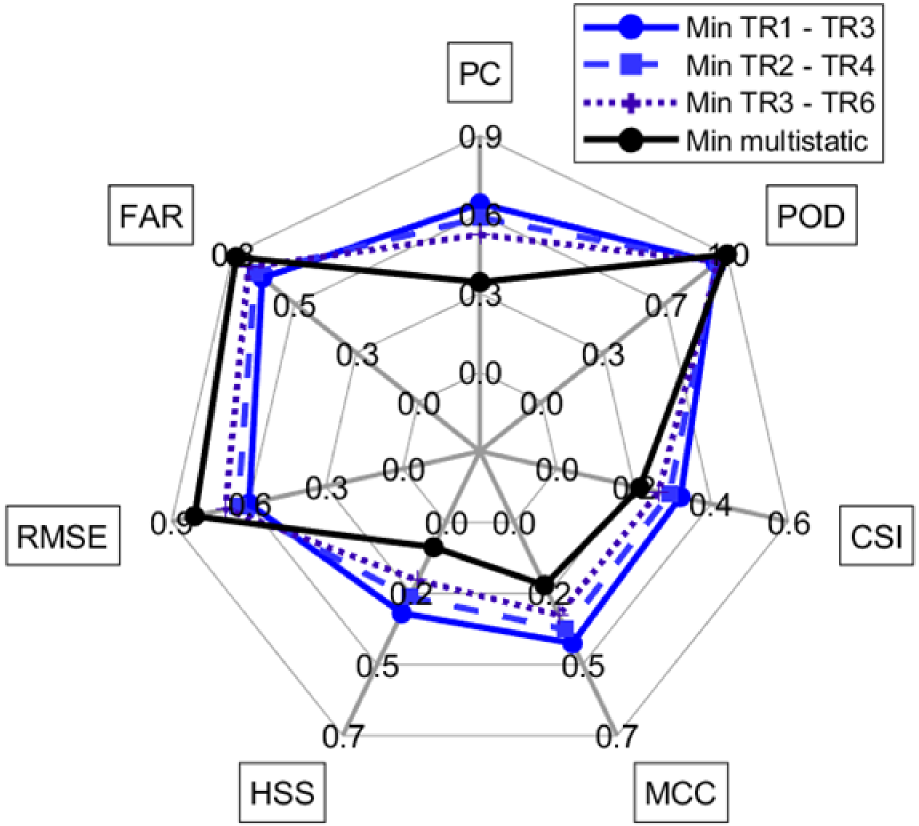


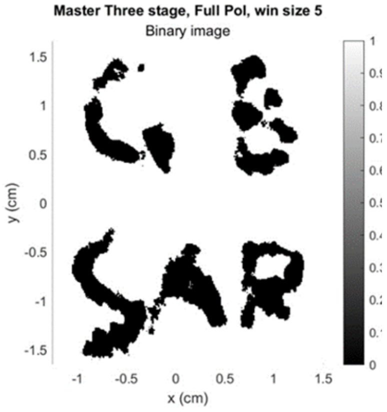


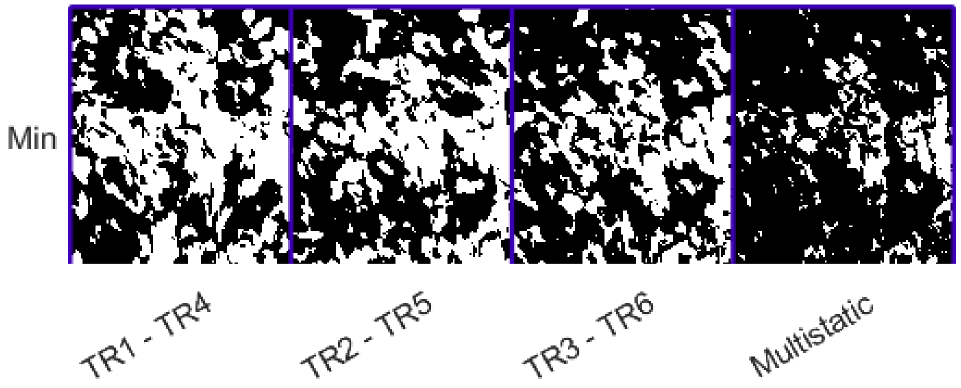


Results - Minimum

- Similar to the maximum, the minimum also performs poorer for the multistatic case. The increased FAR and low PC as well as POD are clearly shown in the images below.







Conclusions

- Shown the feasibility of a three-stage change detector using CCD, NCCD and polarimetric decompositions.
- Investigated the performance of this change detector. Utilizing multiple performance metrics is advisable. Additionally inspecting the detector or model output also aid in the analysis of performance.
- For this dataset, the mean multistatic performed best. This attempting to maximize the detections in multistatic data does not always lead to the best results.
- The polarimetric decomposition used was not roll-invariant, and future work could investigate the use of roll-invariant decompositions or parameters such as the Huynen fork.