

Long-Wavelength SAR for Foliage-Penetrating Detection of Illegal Logging and Deforestation

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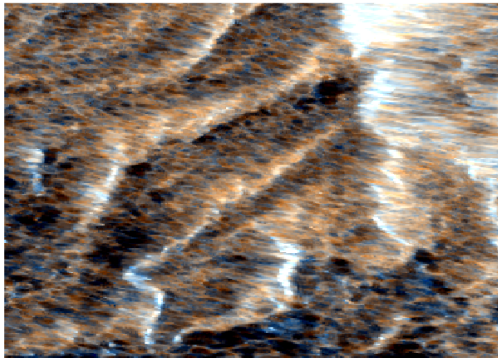
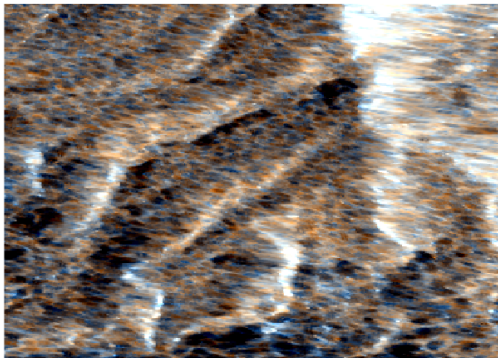
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Why L-band change detection is hard

- Long-wavelength SAR **penetrates foliage**: it can reveal underlying changes in vegetation, farming vehicles, metallic objects, new structures and clearings invisible to optical sensors (FOPEN).
- But the return mixes ground, trunk, branch and volume scattering:
 - speckle and coarse resolution,
 - temporal decorrelation, aspect/season effects $\Rightarrow$ irrelevant “changes”,
 - changes are **small and sparse**.
- Existing detectors:
 - *statistical*: CCD, CFAR, Bayesian rules, low-rank + sparse (RPCA);
 - *learned*: Siamese FCNs, contrastive / metric learning, SAR foundation models.
- L-band is temporally stable over unchanged natural scenes $\Rightarrow$ room to fully exploit **polarimetric** information, not only power.

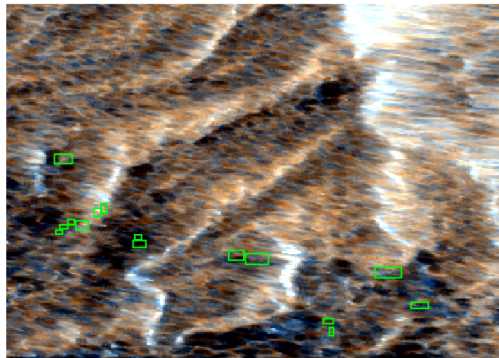
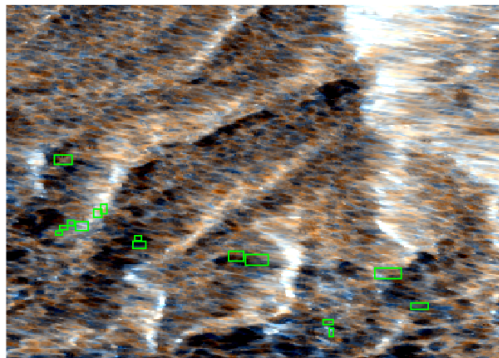
Challenge: spot the changes in RGB false colors



SAOCOM L-band pair over a forested area in Ukraine: *before* (left) and *after* (right).

Can you spot the **genuine changes** by eye?

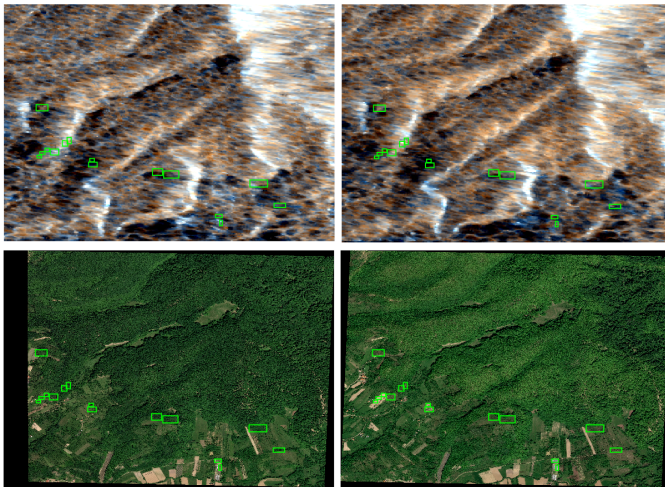
Challenge: the answer



Genuine changes are marked in **green**: small, sparse and buried in speckle.

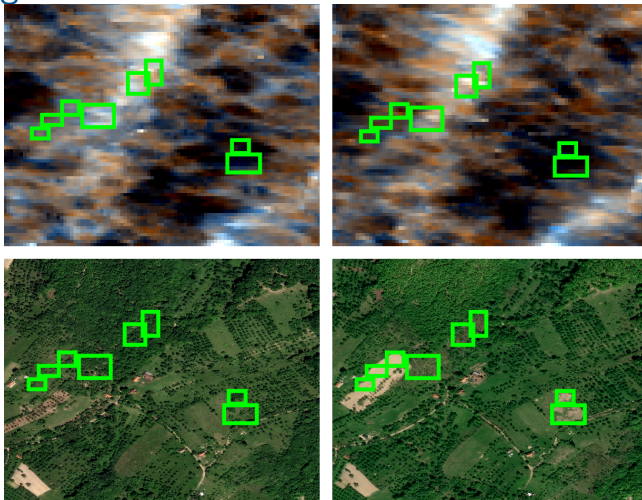
But how do we **know** these are real changes?

Confirming visible changes with optical imagery



In the absence of ground truth, changes **visible in optical imagery** (bottom) can serve as reference labels for the SAR pair (top).

Confirming changes: closer look



Zoom on the bottom-left cluster, where most changes occur: SAR (top) and optical (bottom), before (left) and after (right).

The missing cue: inter-channel covariance

- Almost all learning based methods consume **intensities**: amplitude, VV/VH power, or a pseudo-RGB of them.
- Natural media are near reflection-symmetric $\Rightarrow$ VV–VH correlation ≈ 0 .
- Oriented man-made scatterers (vehicle–ground dihedral), forest edges **break the symmetry**: correlation changes, power may not.
- Principled polarimetric test exists (complex Wishart LRT) but is rarely combined with, or compared against, learned features.
- **Question**: can a learned detector operate directly on the **dual-pol covariance** C_2 , and what does that offer over intensity inputs?

Contributions

1. **Covariance-domain Siamese detector**: each acquisition represented by its 2×2 covariance $\mathbf{C}_2$, encoded by a $\mathbf{C}_2$ -adapted DINOv3 ViT-L/16, compared via a symmetric difference head.
2. **Analysis under the complex Wishart model**:
 - an intensity-only *blind spot* for coherence changes,
 - Wishart LRT $\equiv$ Bhattacharyya distance,
 - a *time-swap symmetry* result that motivates the fusion head.
3. **Evaluation** on SAOCOM L-band change scenarios with Pléiades Neo reference, against model-based and learned intensity baselines.

Model-based reference: the Wishart LRT

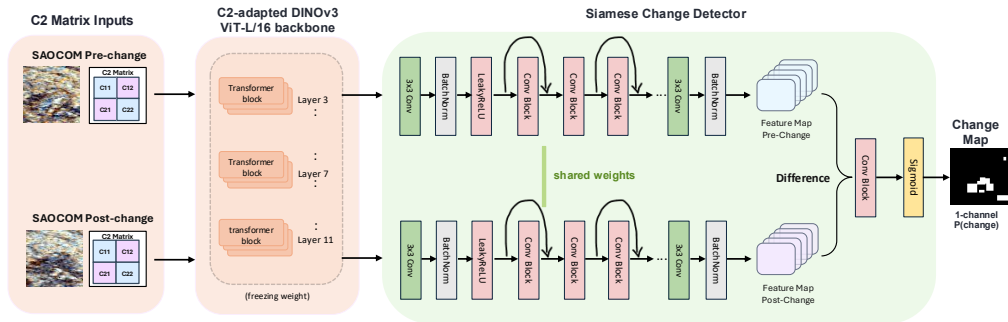
Proposition (LRT as Bhattacharyya distance)

For $H_0 : \Sigma^{(1)} = \Sigma^{(2)}$ vs. $H_1 : \Sigma^{(1)} \neq \Sigma^{(2)}$ with L looks at both times, the likelihood-ratio statistic Q (Conradsen *et al.*, 2003) satisfies

$$-\ln Q = 2L D_B(\mathbf{C}_2^{(1)}, \mathbf{C}_2^{(2)}), \quad D_B(\mathbf{A}, \mathbf{B}) = \ln \det \frac{1}{2}(\mathbf{A} + \mathbf{B}) - \frac{1}{2} \ln \det \mathbf{A} - \frac{1}{2} \ln \det \mathbf{B}.$$

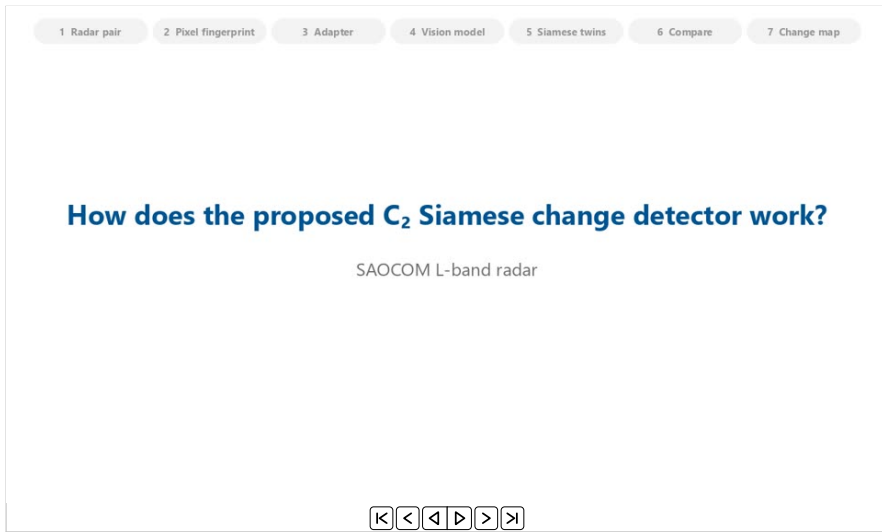
- $-\ln Q \geq 0$, with equality iff $\mathbf{C}_2^{(1)} = \mathbf{C}_2^{(2)}$.
- **Symmetric** under time exchange.
- **Invariant** to a common channel transform $\mathbf{C}_2^{(t)} \mapsto \mathbf{A} \mathbf{C}_2^{(t)} \mathbf{A}^H$, $\mathbf{A} \in GL(2, \mathbb{C})$: gain, VV/VH imbalance, phase rotation, cross-talk.
- $-2 \ln Q \xrightarrow{d} \chi_4^2$ under $H_0 \Rightarrow$ CFAR-type threshold.
- Used as the full- $\mathbf{C}_2$ **model-based baseline**: same information as the learned detector.

C_2 covariance-domain Siamese change detector



- Frozen, C_2 -adapted DINOv3 ViT-L/16; features from blocks 3, 7, 11.
- Shared-weight Siamese encoder, **absolute-difference** fusion, conv head, sigmoid.

How the detector works: step by step



Click the image to play/pause · [open as video](#)

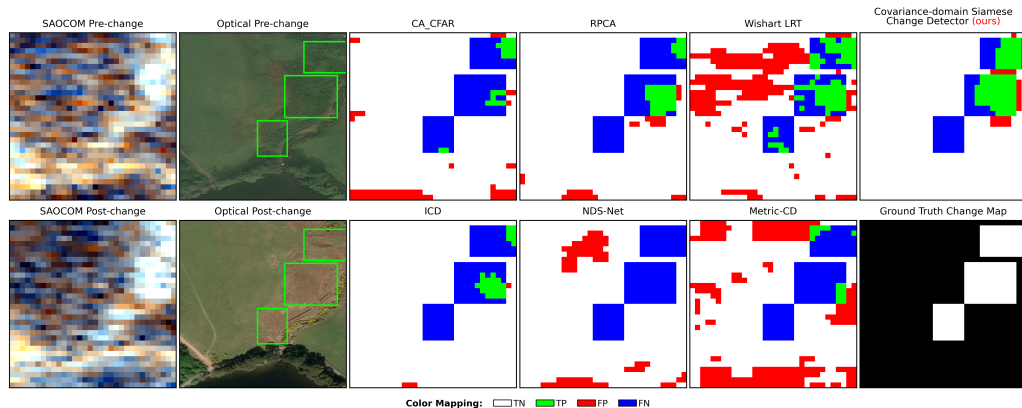
Data and evaluation protocol

- **SAOCOM** L-band VV/VH pairs, calibrated and co-registered; C_2 from SNAP, speckle-filtered, terrain-corrected.
- Reference masks from **Pléiades Neo** high-resolution optical imagery.
- Five test cases:

Code	Scenario	Patch	Setting
GMO	ground metallic objects	64×64	forest-adjacent, FOPEN
NC	new constructions	64×64	general L-band CD
HCO	half-concealed objects	64×64	FOPEN
VSA	vehicle staging areas	64×64	general L-band CD
DEF	deforestation	32×32	FOPEN

- Metrics: **F1** and **AUC** (sparse change: overall accuracy is uninformative).
- Baselines: CA-CFAR, RPCA, NDS-Net, Metric-CD (intensity); Wishart LRT (C_2 , χ_4^2 threshold at $P_{FA} = 10^{-2}$).

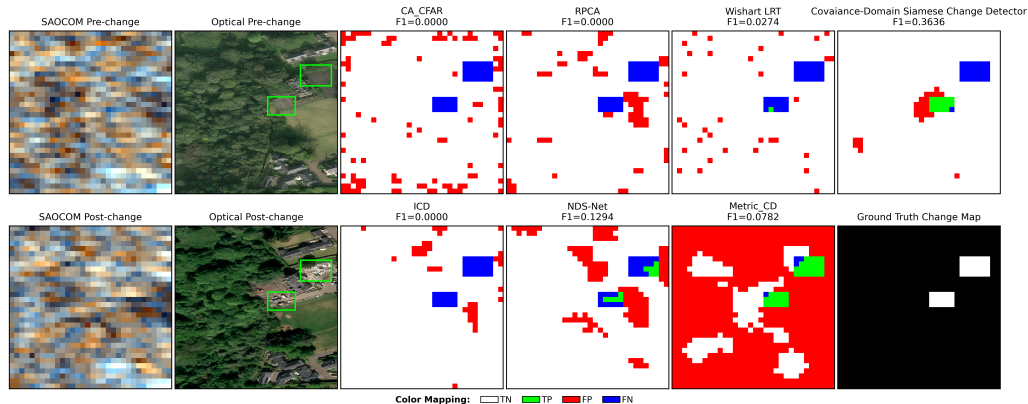
Qualitative results: deforestation (DEF)



Deforestation, 10 instances: C_2 Siamese F1 = **0.429** vs. best baseline 0.351 (Metric-CD).

Prediction maps: TN white, TP green, FP red, FN blue.

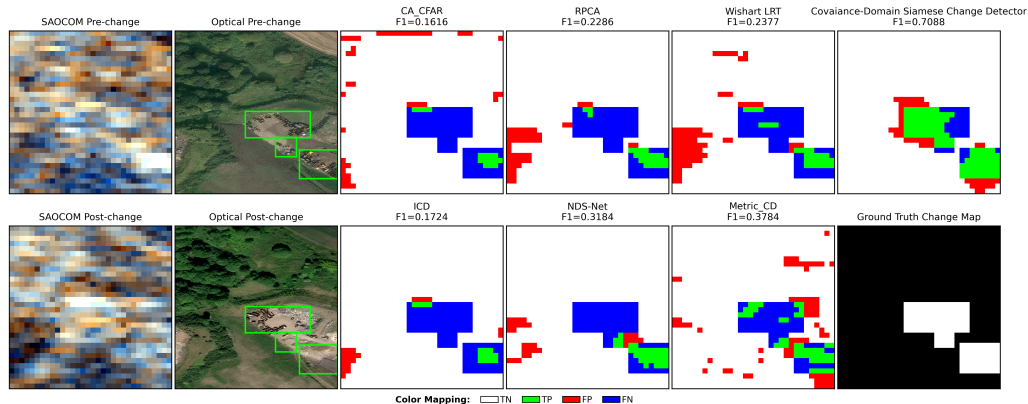
Qualitative results: trucks, vans, construction materials in forest



Ukraine border example 9: C_2 Siamese F1 = **0.364** vs. best baseline 0.129 (NDS-Net).

Prediction maps: TN white, TP green, FP red, FN blue.

Qualitative results: metallic loading facilities



Ukraine border example 4: C_2 Siamese F1 = **0.709** vs. best baseline 0.378 (Metric-CD).

Prediction maps: TN white, TP green, FP red, FN blue.

Conclusions

- L-band radar sees **day and night, through cloud and partly through the canopy**.
- Using **how the two polarisations relate**, not just brightness, exposes hidden man-made objects and clearings.
- **No labelled change examples** needed; best F1 in all five SAOCOM test scenarios.
- **Applications:**
 - monitoring illegal logging and deforestation;
 - tracking vehicles and heavy equipment in forests and border areas;
 - flagging new depots and loading sites for optical follow-up.
- **Next:** larger benchmark; operational pipeline for SAOCOM and future L-band missions (ROSE-L, NISAR).

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Thank you — questions?

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