

Intra-Year detection of tropical forest disturbances using multimodal foundation model embeddings

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Tropical forest disturbance

Climate regulation

Biodiversity
preservation

Sustaining local
livelihoods

Ecosystem resilience

Beyond deforestation, forests face subtle and **heterogeneous disturbances**



Tropical forest disturbances \neq just deforestation

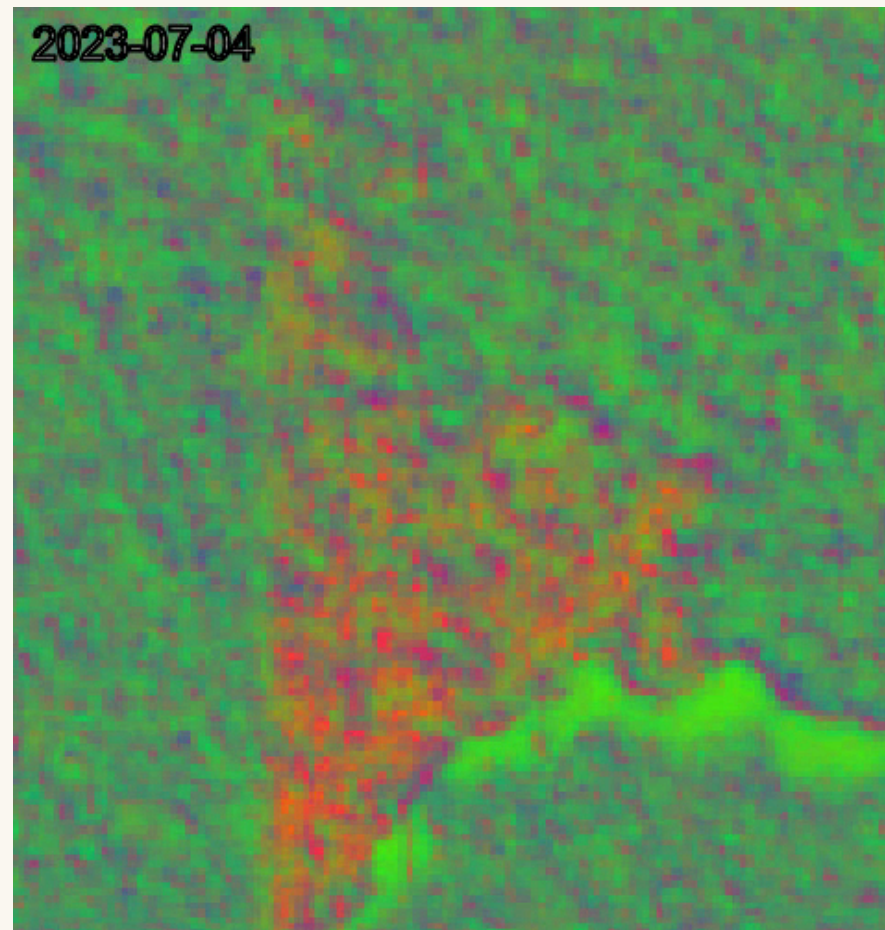


Fig 1. Clear cutting bare soil

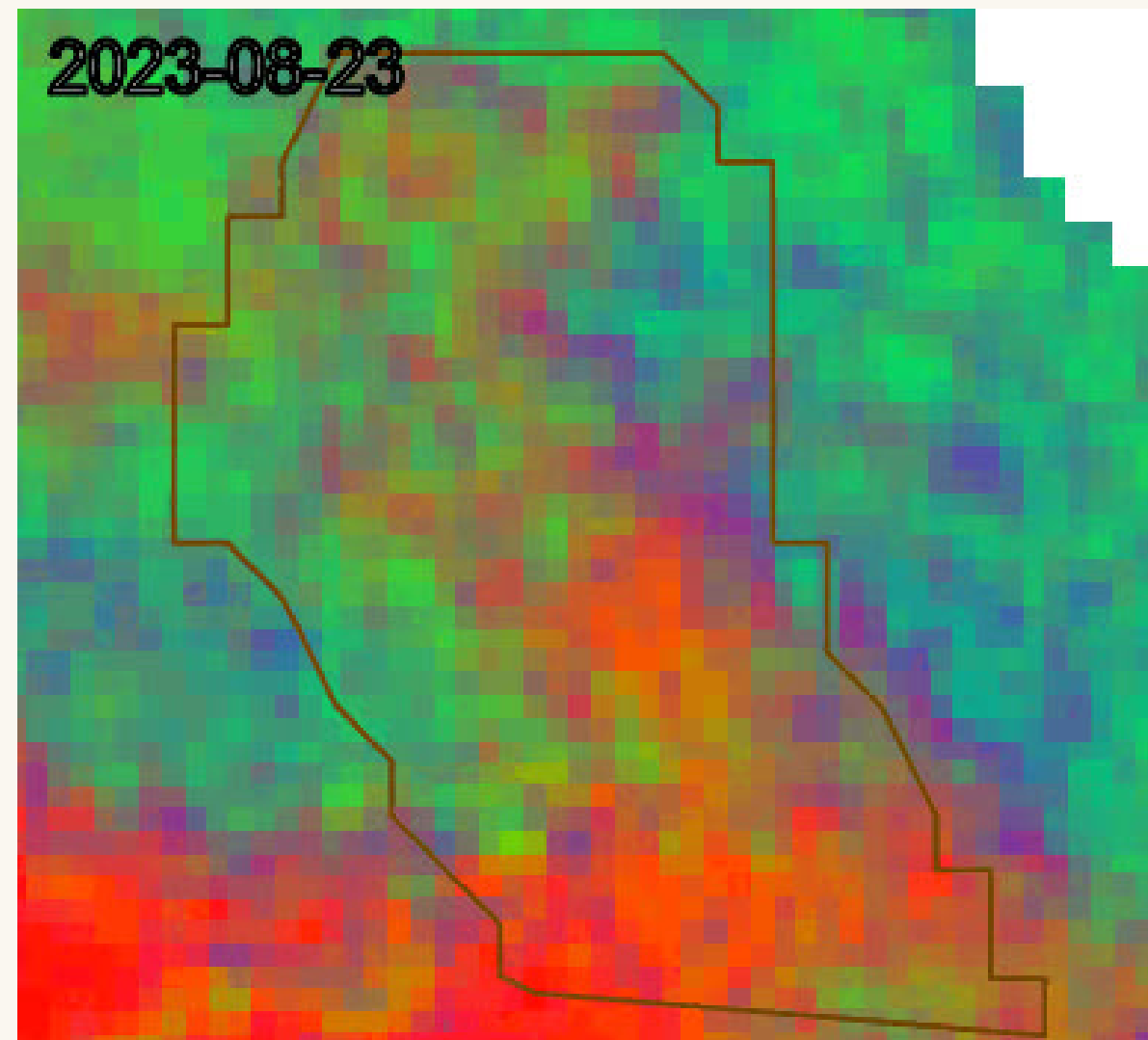


Fig 2. Fire scar

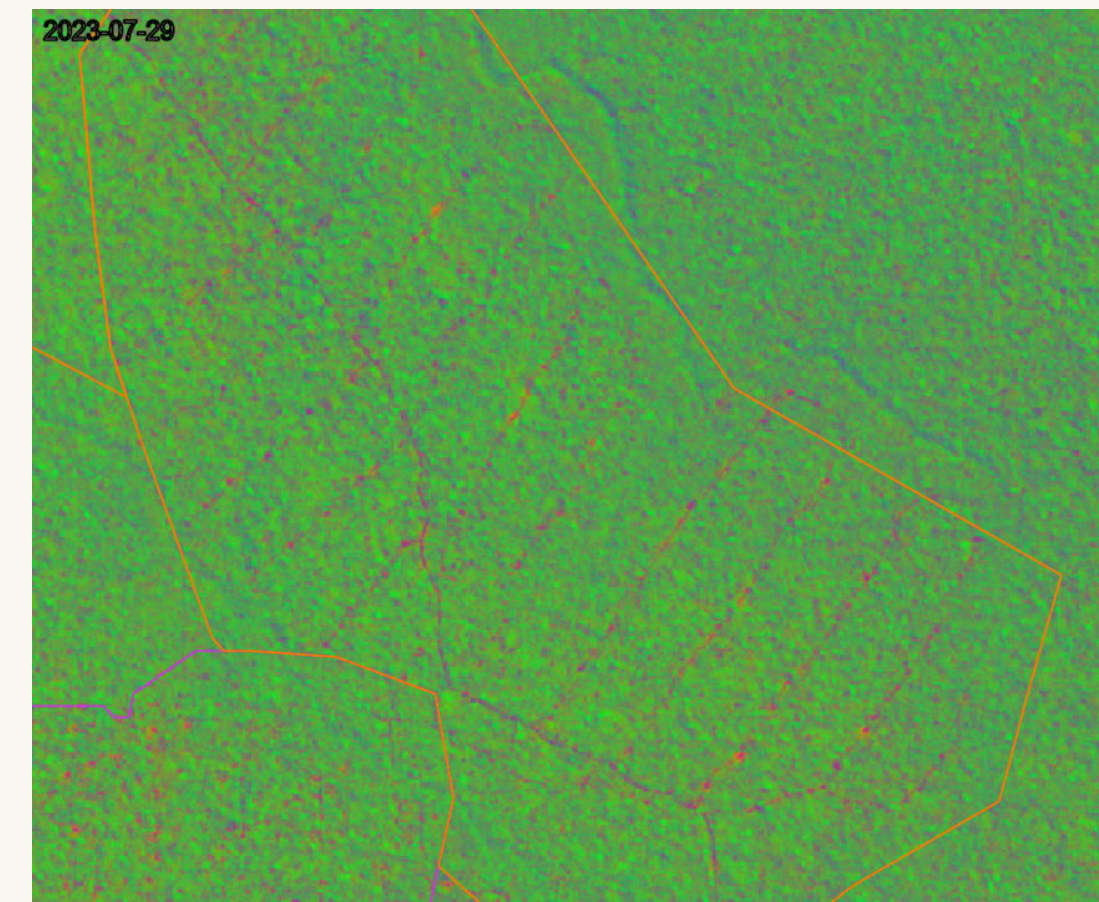


Fig 3. Geometric logging



Monitoring

Detecting these disturbances is challenging, especially at **short temporal** scales and over **large areas**

Remote sensing data

- Monitor vast and remote areas where field observations are infeasible
- **Optical** sensors: spectral info on vegetation condition
- **SAR**: forest structure + moisture, works through cloud cover
- Mixing both improves monitoring precision [Reiche et al., 2018] → **Multimodal foundation models**



Limitations of current change detection methods

- Focus on binary detection (forest/not forest)
- Single-sensor, require sensitive calibration
- Struggle with early-stage degradation
- Work at pixel level, losing the spatial context → **Multimodal foundation models**



Objective

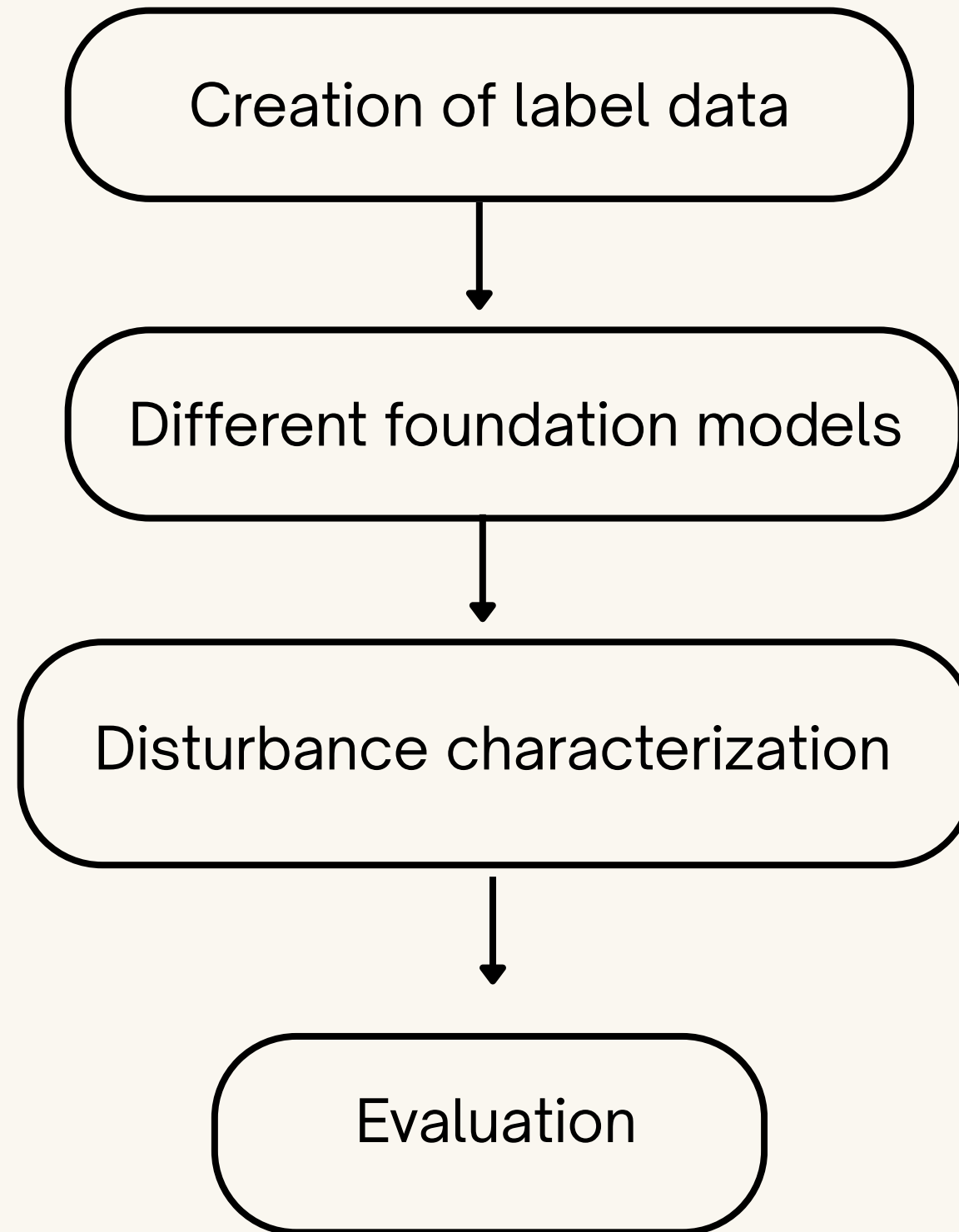
Develop an embedding-based framework combining optical and SAR time series for scalable, near-real-time detection of tropical forest disturbances, improving timeliness and sensitivity to degradation.

Research questions

- How do embeddings from different foundation models differ in their ability to characterize and distinguish tropical forest disturbance?
- How do cloud filtering strategies on optical time series affect the quality and temporal consistency of the resulting embeddings for change detection?
- Can foundation model embeddings enable near-real-time disturbance detection with shorter detection delays than conventional Bayesian approaches?



Methodology



Data

389 DETER polygons 2025

Rondonia region in the Brazilian Amazon

Before - Event - After images with GEE

Histogram to decided the window of time

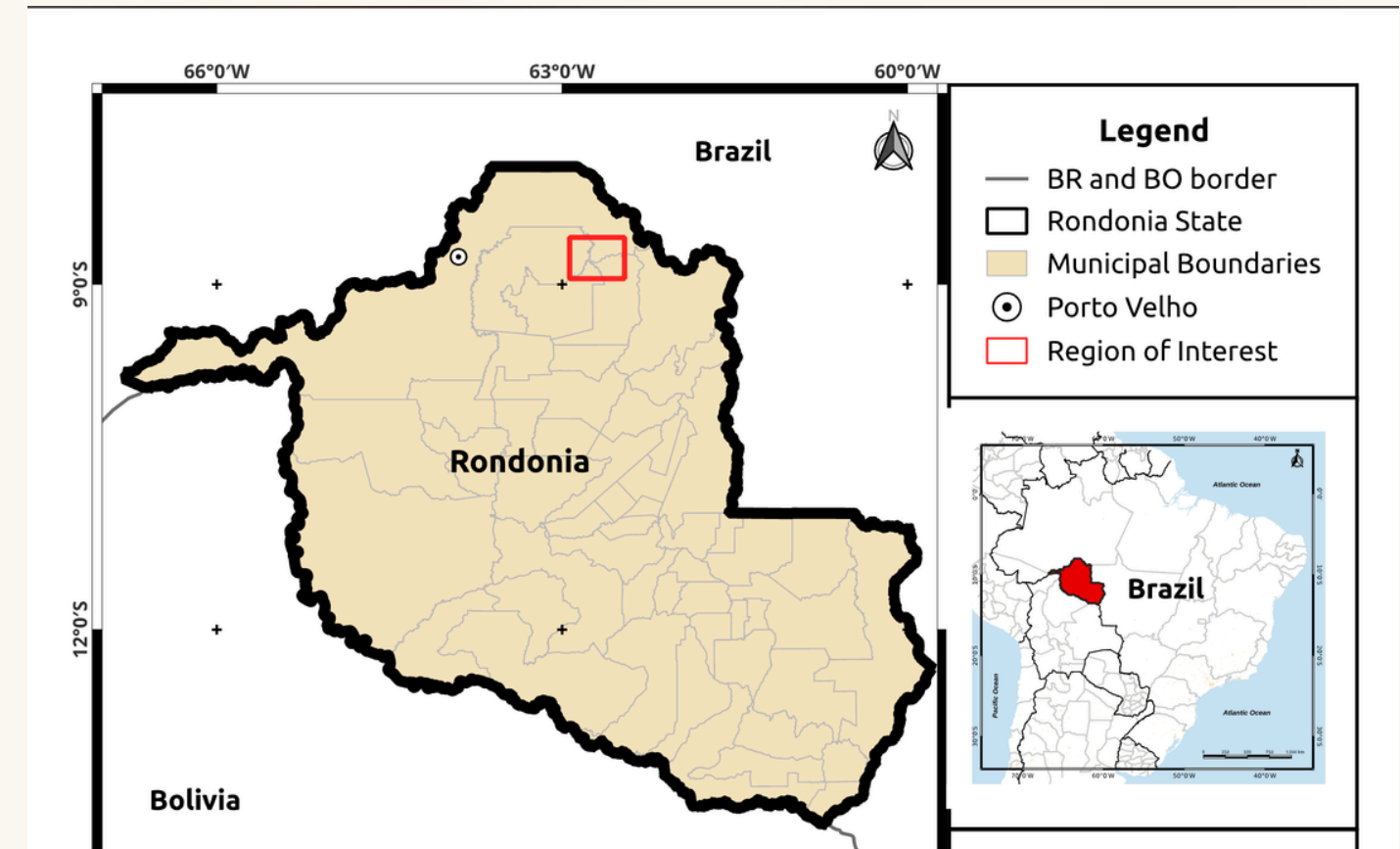


Fig 4. Rondonia area

Filtering cases

Case 1. QA60 + SCL

Case 2. Cloud score

Case 3. Cloud score + dilatation



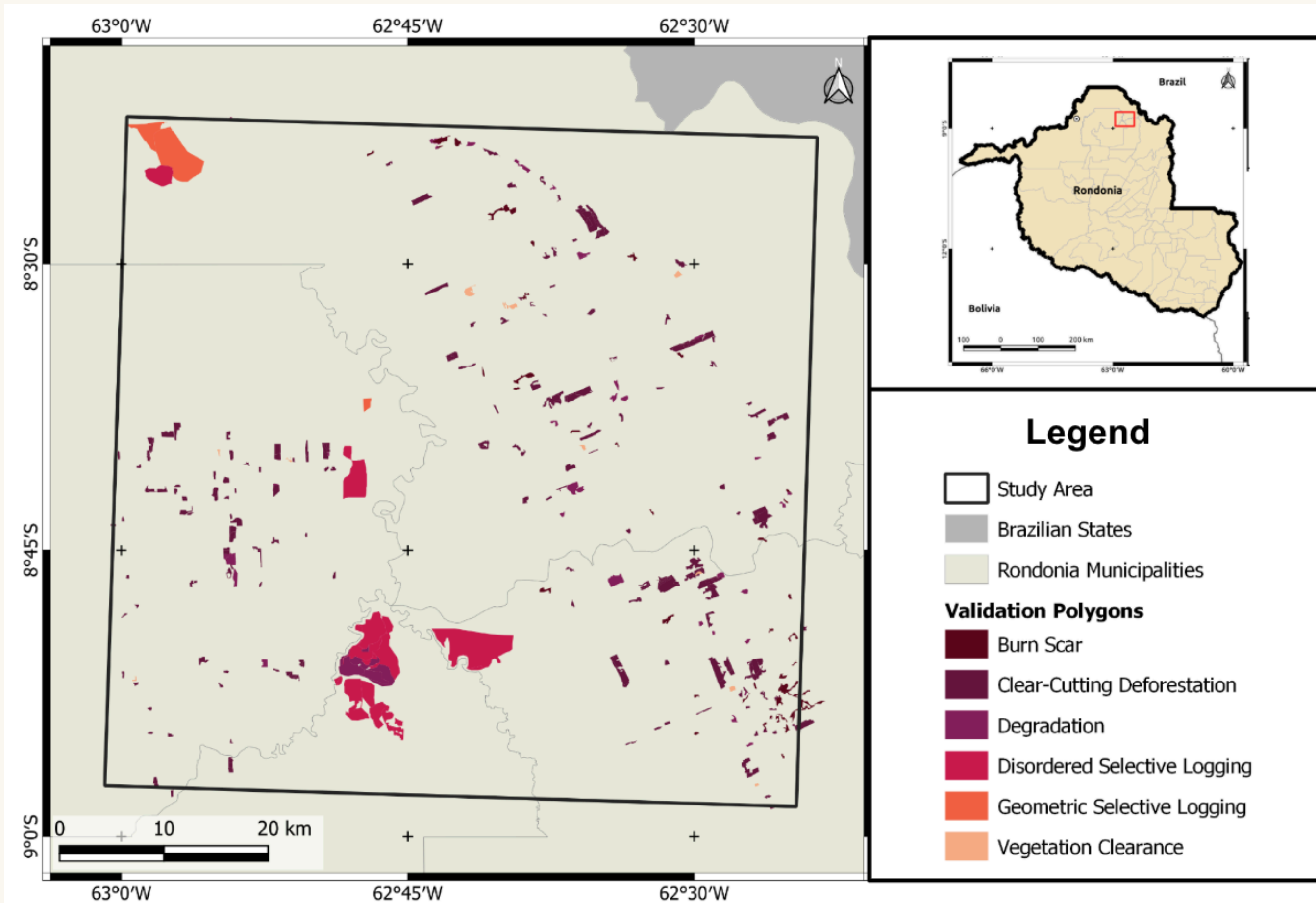


Fig 5. Rondonia label polygons

Data

Fig 6. Sentinel 2 visualization

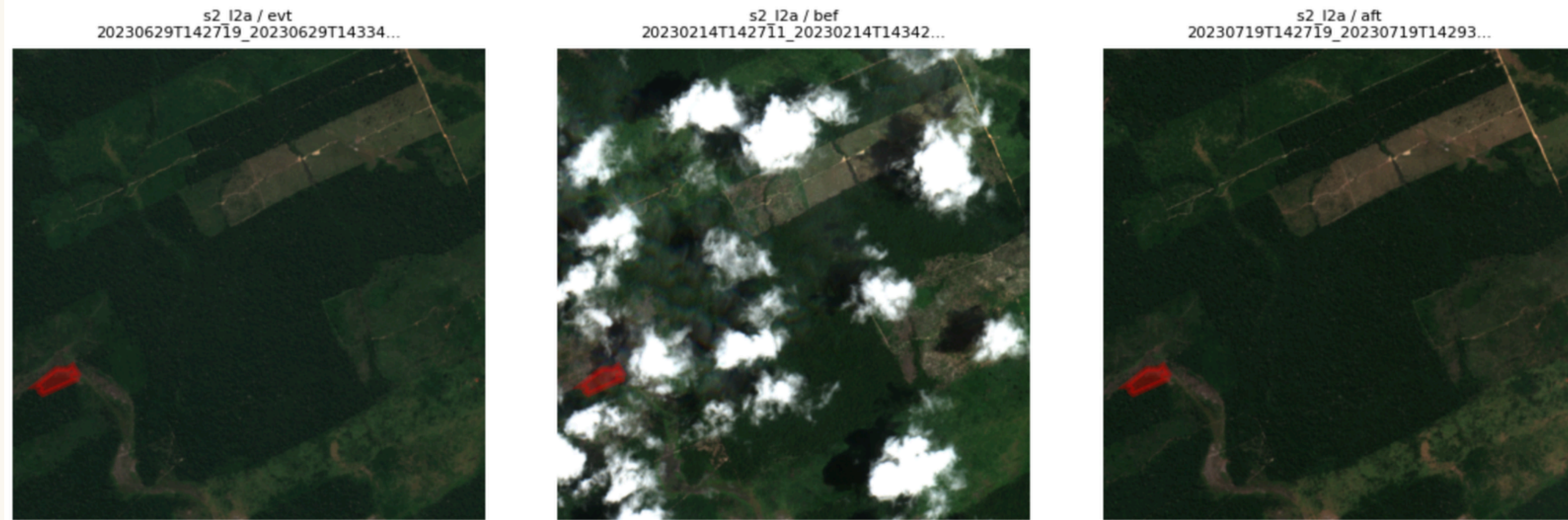
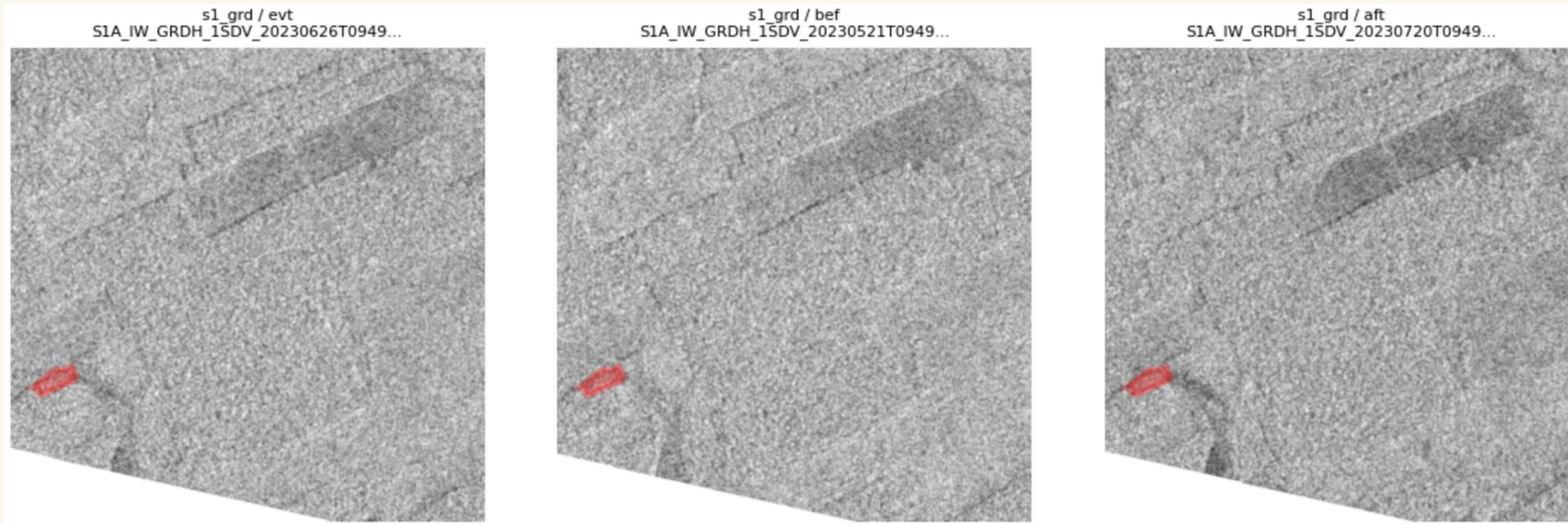


Fig 7. Sentinel 1 visualization



Different foundation models

Feature	CROMA	TerraFM	Clay v1.5	SkySense
Default input size	120 x 120 pixels	534 x 534 pixels	256 x 256 pixels	64 x 64 (S1, S2). 2048 x 2048 (RGB VHR).
Base architecture	ViT (CoCa-inspired, 3 encoders)	ViT (DINO-style teacher-student)	ViT-based MAE	Factorized multi-modal spatiotemporal encoder (DINO-style teacher-student)

5. Sentinel-1 Handling

Feature	CROMA	TerraFM	Clay v1.5	SkySense
S1 product	GRD (backscatter)	RTC (Radiometrically Terrain Corrected)	RTC	Standard-calibrated SAR (TSARI) - GRD (supposion)

6. Sentinel-2 Handling

Feature	CROMA	TerraFM	Clay v1.5	SkySense
S2 product	L2A (surface reflectance)	Both L1C and L2A (treated as separate modalities)	L2A	L2A (atmospherically corrected surface reflectance), cloud-filtered
S2 bands used	12 surface reflectance bands (cirrus removed)	Up to 13 bands (L1C/L2A)	10 bands	10 bands: B2-B8, B8A, B11, B12 (visible + NIR resampled to 10m; VRE + SWIR at 20m)

CROMA embeddings

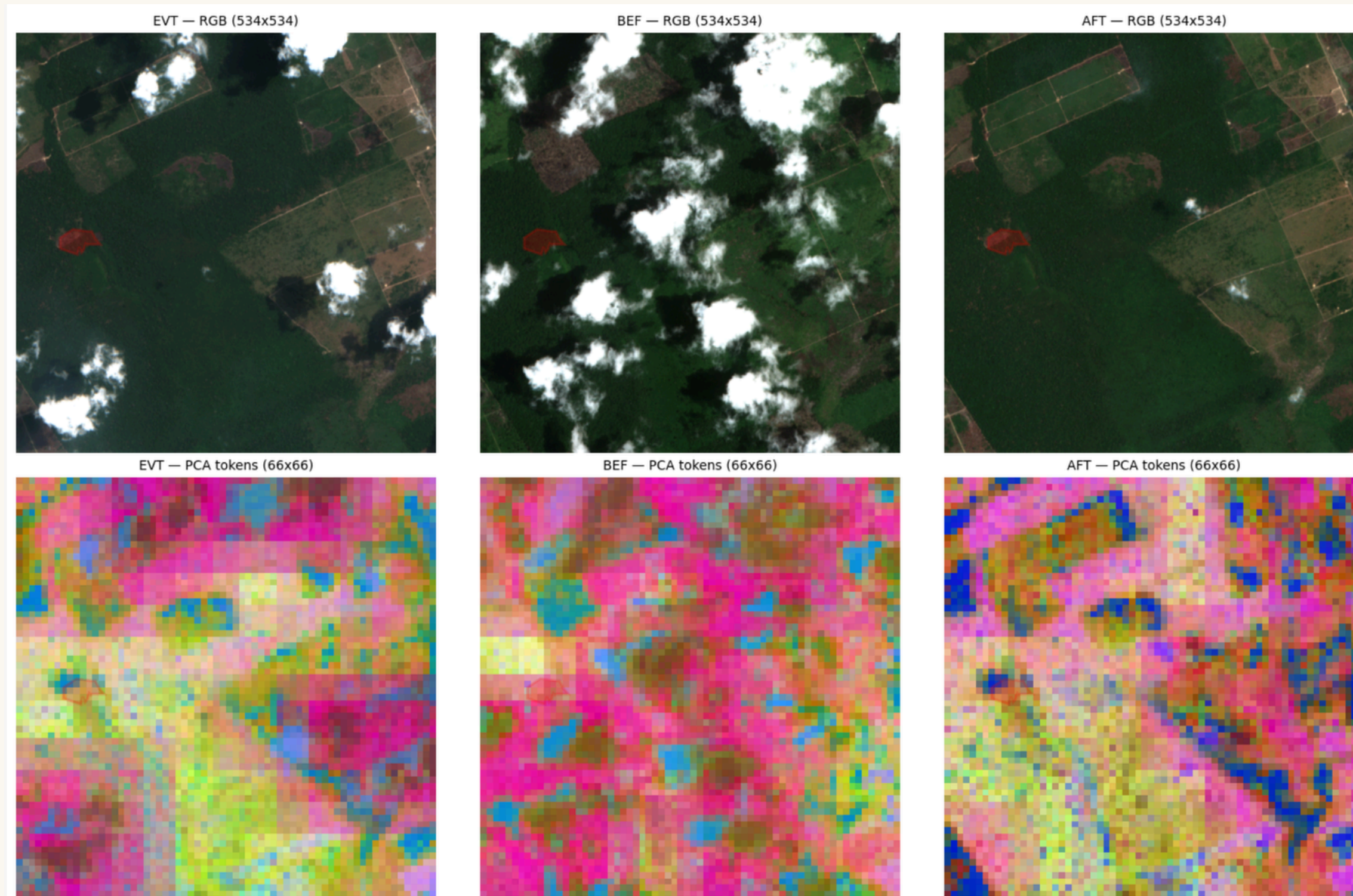


Fig 8. Optical embeddings for one polygon

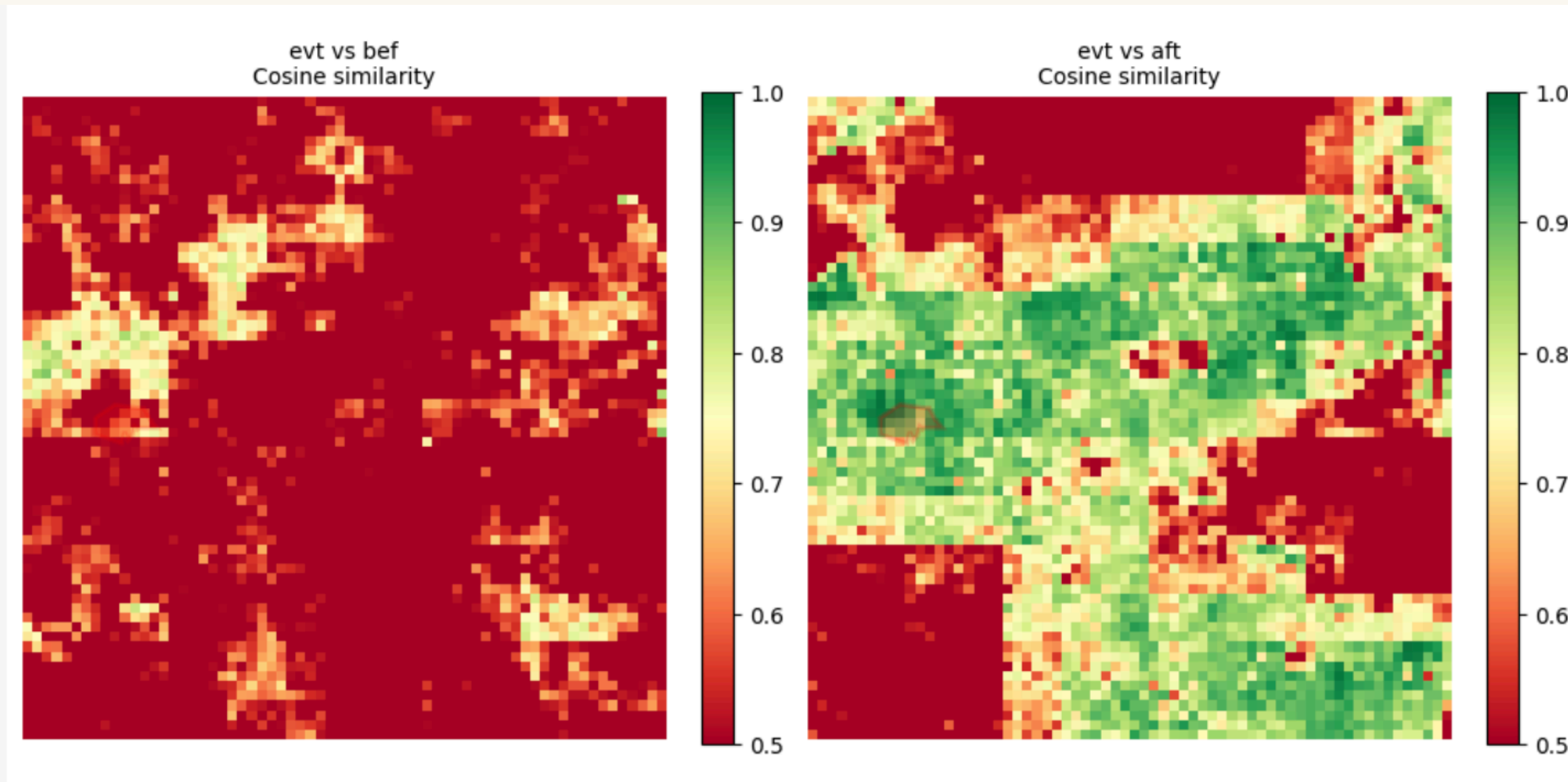


Fig 9. Cosine similarity between optical embedding of the same area. Green is similar, Red is different.

References

- [Fuller et al., 2023] Fuller, A., Millard, K., and Green, J. (2023). CROMA: Remote sensing representations with contrastive radar-optical masked autoencoders. *Advances in Neural Information Processing Systems*, 36:5506–5538.
- [Reiche et al., 2018] Reiche, J., Hamunyela, E., Verbesselt, J., Hoekman, D., and Herold, M. (2018). Improving near-real time deforestation monitoring in tropical dry forests by combining dense Sentinel-1 time series with Landsat and ALOS-2 PALSAR-2. *Remote Sensing of Environment*, 204:147–161.



Annexes

