23rd June 2026

Bridging the Gap Between Deep Learning and End-Users: Application to Instability Segmentation on SAR Interferograms

by Antoine BRALET

Atelier Télédec@USMB 2026

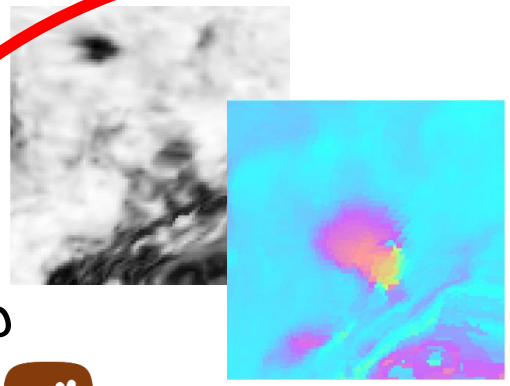
Introduction

AI for end-users

Dédé

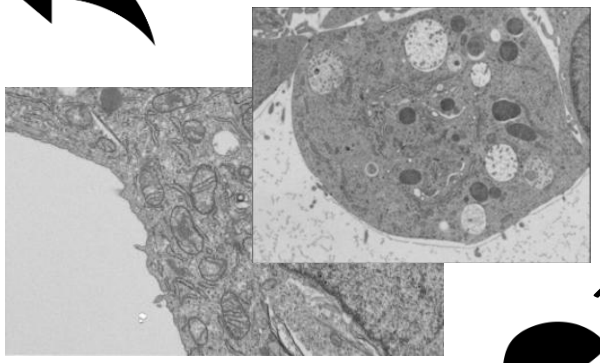
Corn ?
Wheat ?

Deep Network



Bob

Landslide ?
Rock Glacier ?



Mitochondrion ?
Reticulum ?

Anne

Detecting Slope Instabilities

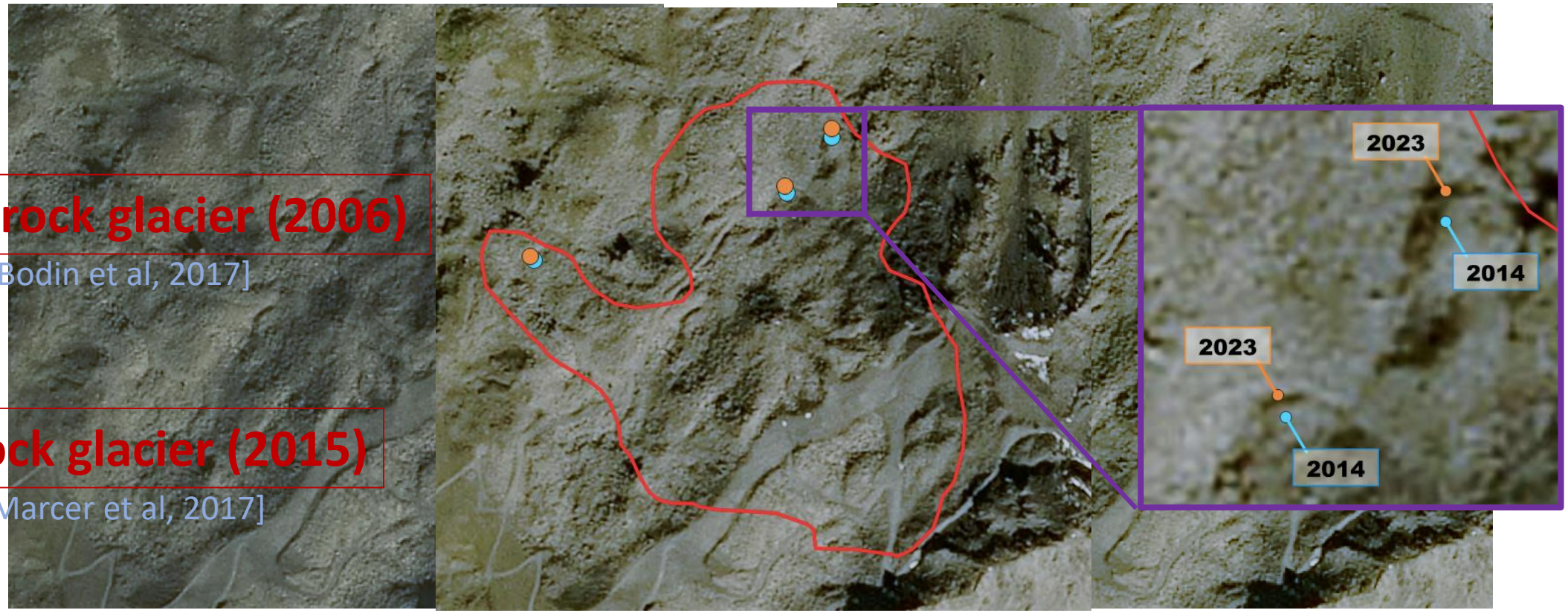
Slow Moving Slope Instabilities

Bérard rock glacier (2006)

[Bodin et al, 2017]

Lou rock glacier (2015)

[Marcer et al, 2017]



Optical SPOT6/7 - 2014

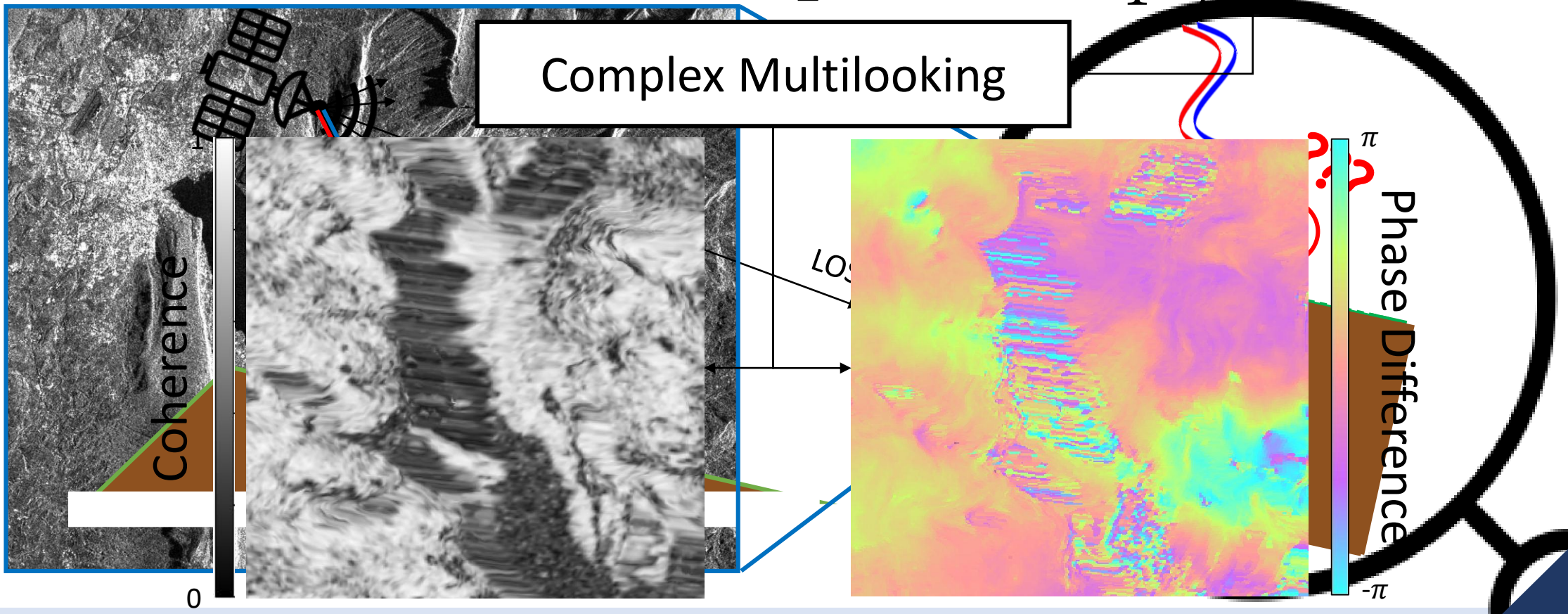
Optical SPOT6/7 - 2023

[Bodin et al, 2017] Bodin, X., Krysiecki, J.-M., Schoeneich, P., Le Roux, O., Lorier, L., Echelard, T., Peyron, M., and Walpersdorf, A. (2017). The 2006 Collapse of the Bérard Rock Glacier (Southern French Alps). Permafr. Periglac. Process., 28(1):209–223. eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/ppp.1887

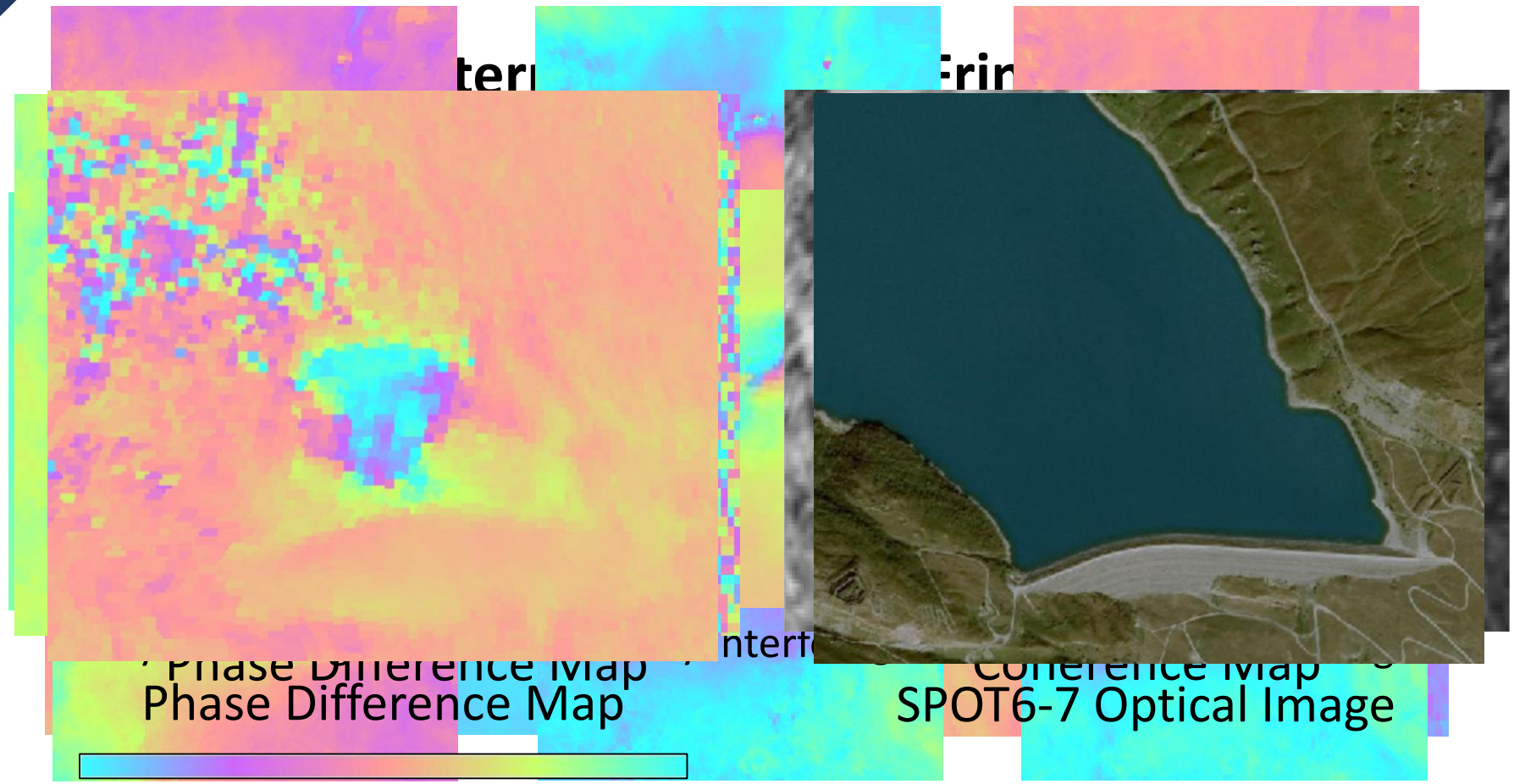
[Marcer et al, 2020] Marcer, M., Ringsø Nielsen, S., Ribeyre, C., Kummert, M., Duvillard, P.-A., Schoeneich, P., Bodin, X., and Genuite, K. (2020). Investigating the Slope Failures at the Lou Rock Glacier Front, French Alps. Permafr. Periglac. Process., 31(1):15–30.

Interferometric SAR

$$* \overline{A_2\, e^{i\varphi_2}} = A_1 A_2\, e^{i(\varphi_1 - \varphi_2)}$$



Annotation Routine *[Bralet et al, 2024]*



1. Bubbles or Fri
2. Temporal Con
3. Baseline Cons
4. High Coheren
5. Optical Clues

BOB APPROVED !

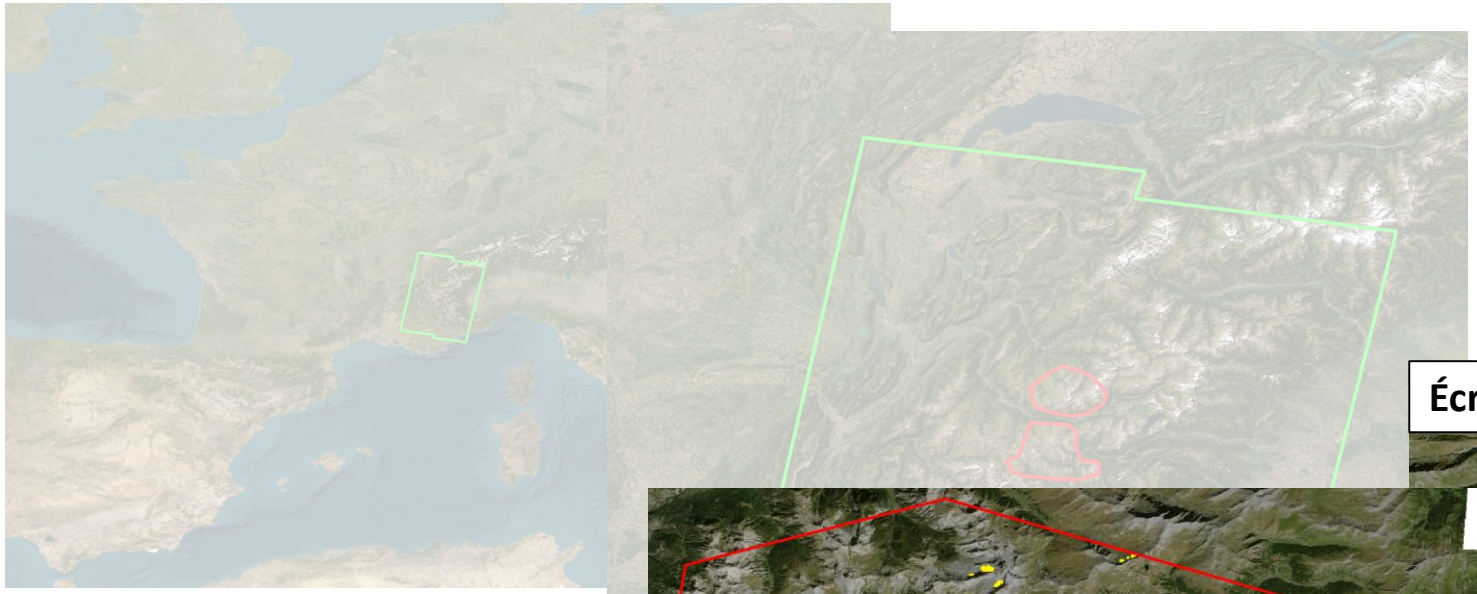
[Bralet et al, 2024] Bralet, A., Trouvé, E., Chanussot, J., & Atto, A. M. (2024). ISSLIDE: A new InSAR dataset for Slow SLIding area DEtection with machine learning. *IEEE Geoscience and Remote Sensing Letters*, *21*, 1-5.

ISSLIDE Dataset

[Bralet et al, 2024]

[Bralet et al, 2024] Bralet, A., Trouvé, E., Chanussot, J., & Atto, A. M. (2024). ISSLIDE: A new InSAR dataset for Slow SLIding area DEtection with machine learning. *IEEE Geoscience and Remote Sensing Letters*, *21*, 1-5.

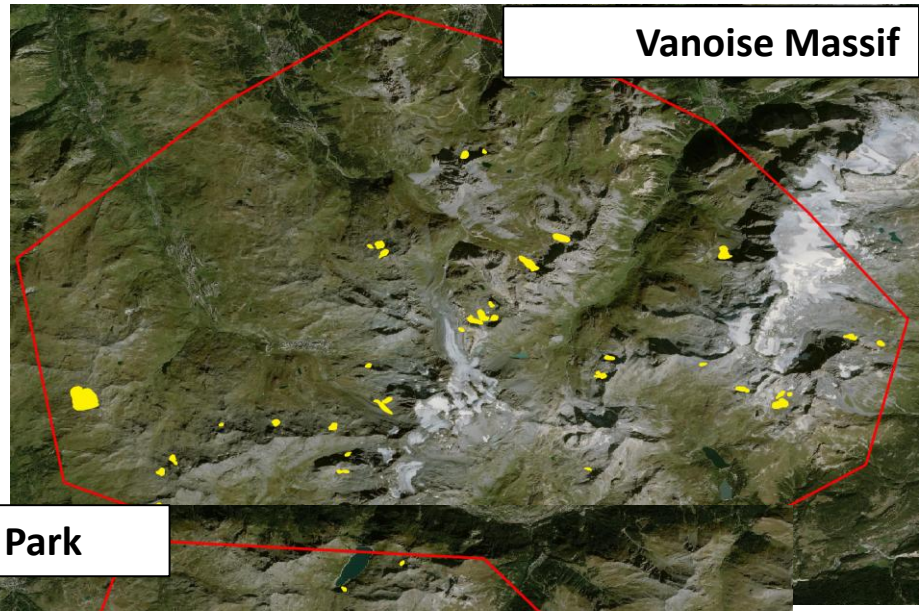
Region of Interest

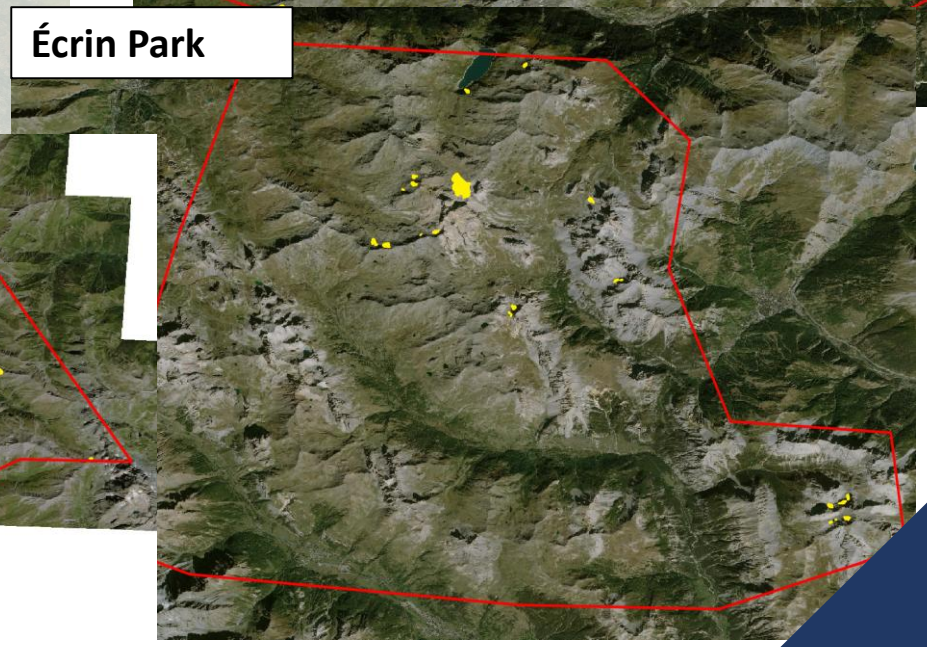


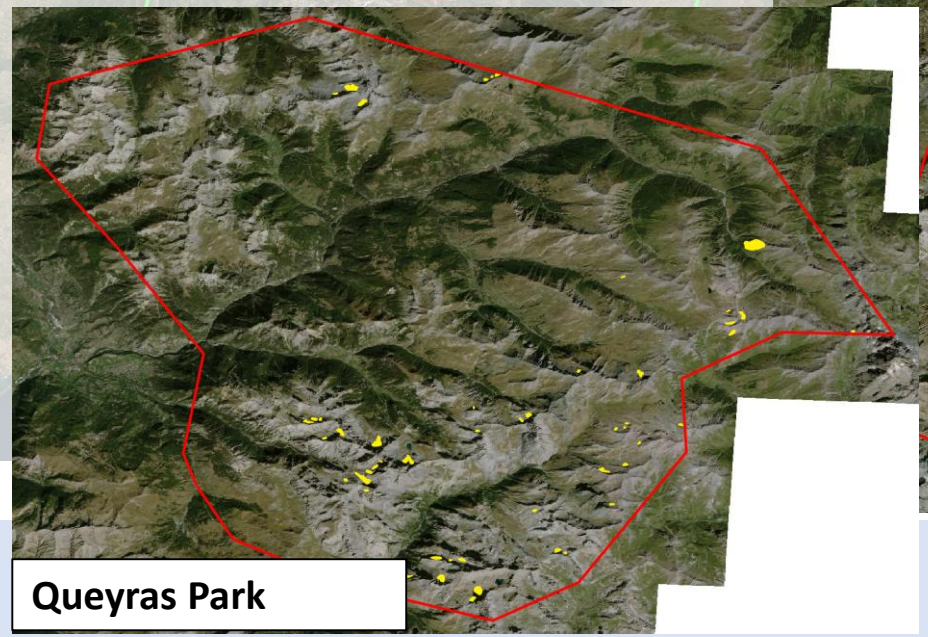
Interferogram extent

Regions of interest

Annotations with a
6-days temporal baseline







ACTUALISATION EN COURS !

Stage Aurore Benoit

- Données de 2025
- Vérification de la persistance des mouvements
- Future disponibilité sur Data Terra

[Bralet et al, 2024] Bralet, A., Trouvé, E., Chanussot, J., & Atto, A. M. (2024). ISSLIDE: A new InSAR dataset for Slow SLIding area DEtection with machine learning. *IEEE Geoscience and Remote Sensing Letters*, *21*, 1-5.

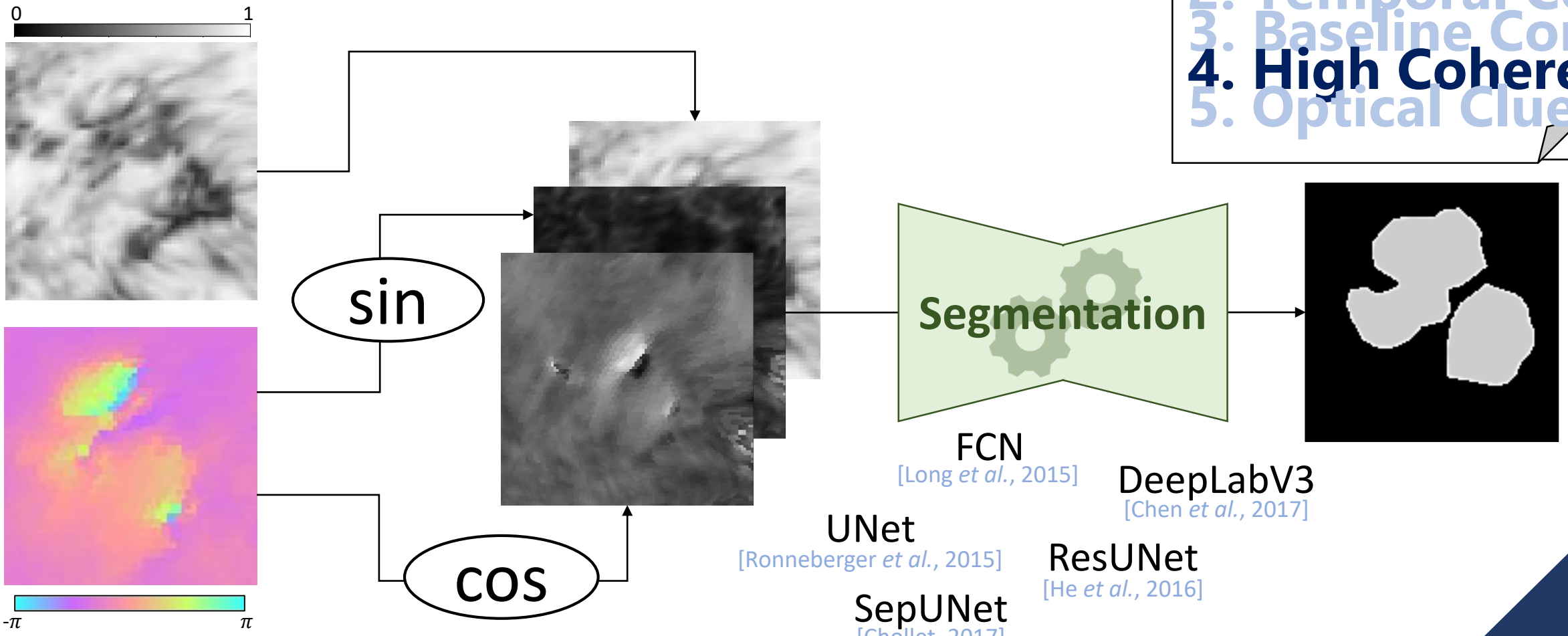
Interferogram Segmentation

[Bralet et al, 2024]

[Bralet et al, 2024] Bralet, A., Trouvé, E., Chanussot, J., & Atto, A. M. (2024). ISSLIDE: A new InSAR dataset for Slow SLIding area DEtection with machine learning. *IEEE Geoscience and Remote Sensing Letters*, *21*, 1-5.

Training on ISSLIDE

1. Bubbles or Fri
2. Temporal Cont
3. Baseline Consi
4. High Coherenc
5. Optical Clues



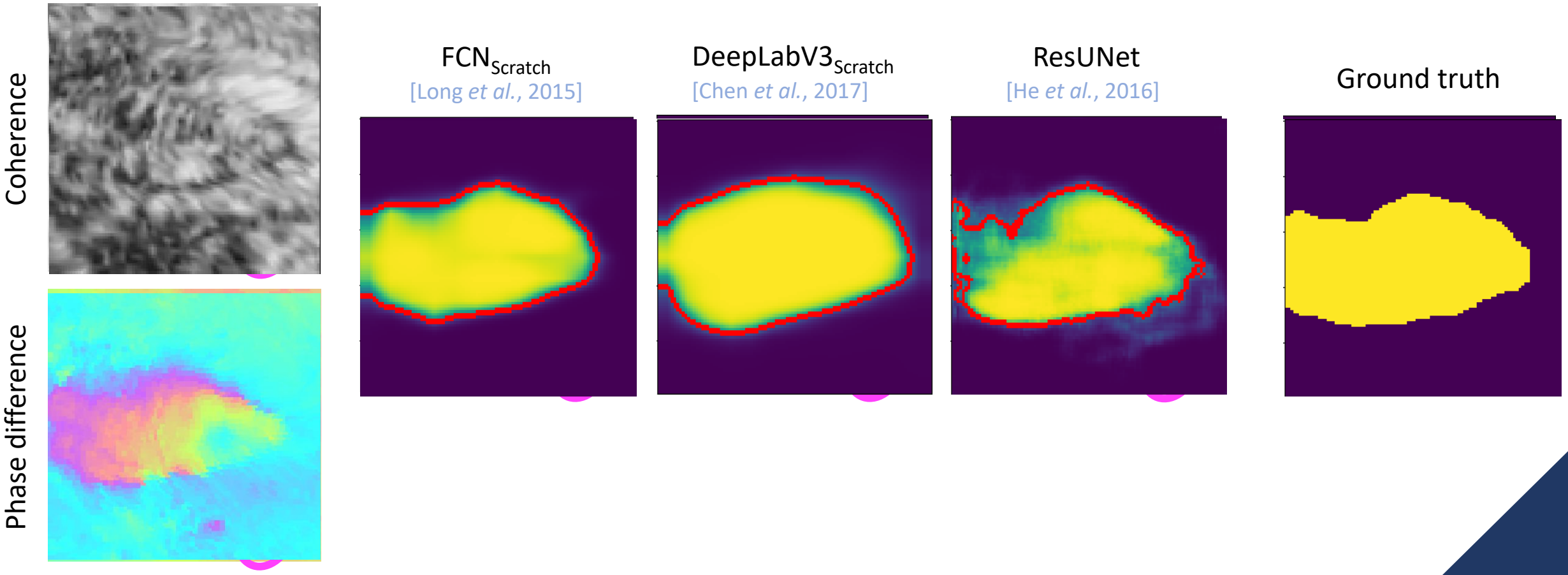
[Ronneberger et al., 2015] Ronneberger, O., Fischer, P., and Brox, T. (2015). U-Net: Convolutional Networks for Biomedical Image Segmentation. In Navab, N., Hornegger, J., Wells, W. M., and Frangi, A. F., editors, Medical Image Computing and Computer-Assisted Intervention – MICCAI 2015, Lecture Notes in Computer Science, pages 234–241, Munich, Germany. Springer International Publishing.

Quantitative Performance

Optimal Threshold

	F1-S ↑	AUC ↑	Dice ↑	IoU ↑	HD ↓
$FCN_{Scratch}$ [Long *et al.*, 2015]	**0.690**	**0.980**	**0.645**	**0.503**	**21.695**
$FCN_{Pre\text{-}trained}$ [Long *et al.*, 2015]	0.677	0.976	0.628	0.486	22.951
$DeepLabV3_{Scratch}$ [Chen *et al.*, 2017]	0.673	0.978	0.630	0.486	<u>22.352</u>
$DeepLabV3_{Pre\text{-}trained}$ [Chen *et al.*, 2017]	0.666	0.976	0.620	0.480	22.887
UNet [Ronneberger *et al.*, 2015]	0.675	0.977	0.636	0.497	25.912
ResUNet [He *et al.*, 2016]	<u>0.681</u>	<u>0.979</u>	<u>0.639</u>	<u>0.500</u>	25.921
SepUNet [Chollet, 2017]	0.651	0.972	0.606	0.466	28.026

Qualitative Performance



Key Takeaways

Outcomes:

- Standard networks succeed to process interferograms and identify slow moving instabilities
- Coherence map **seems** to be correctly interpreted… is it ?

Remaining issues:

- Great margin for improvements
- Does not follow all geomorphological guidelines

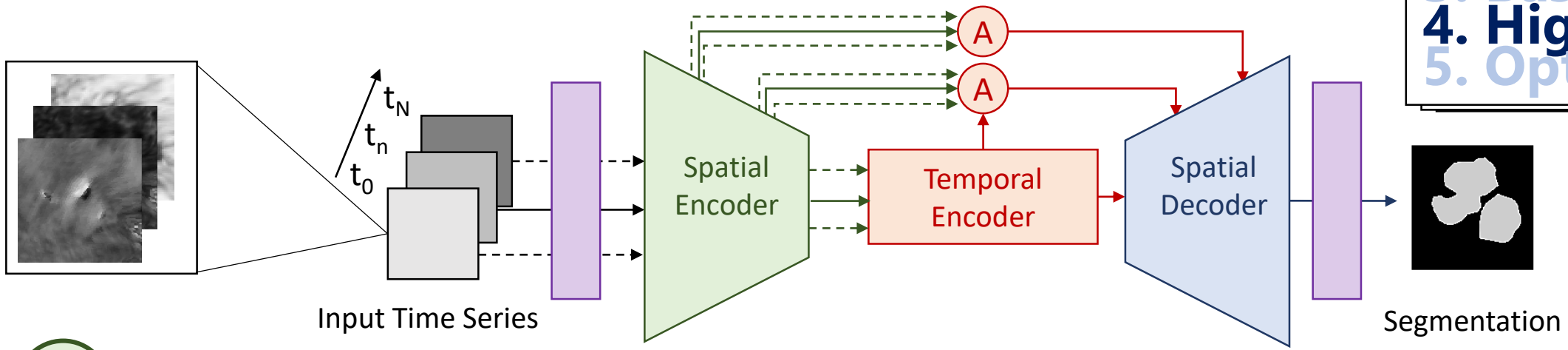
Interferogram Time Series Segmentation

[Bralet et al, 2025]

[Bralet et al, 2025] Bralet, A, Trouvé, E, & Atto, A.M. (2025). Spatio-Temporal Encoding for Deep Slope Instability Detection from Time Series of SAR Interferograms. *2025 International Conference on Machine Intelligence for GeoAnalytics and Remote Sensing (MIGARS)*. IEEE. 1-4.

Standard UTAE *[Garnot et al, 2021]*

1. Bubbles or Frin
2. Temporal Conti
3. Baseline Consis
4. High Coherence
5. Optical Clues



1 Spatial encoding of each time step **independently** with convolutional blocks

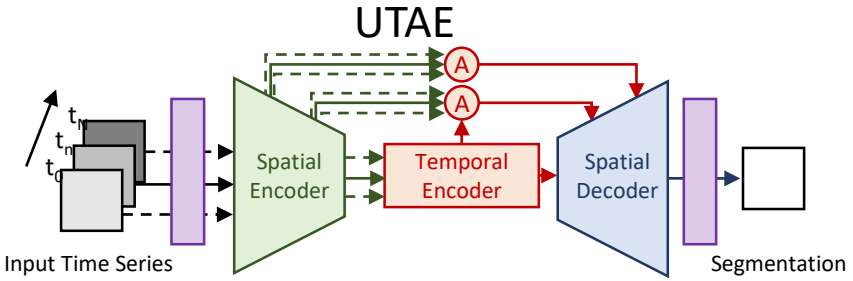
2 Temporal encoding with a **L-TAE** *[Garnot et al., 2020]* and use attention maps to fuse intermediate features

3 Decode the latent features to generate a **segmentation** map

[Garnot et al, 2021] GARNOT, Vivien Sainte Fare and LANDRIEU, Loic. Panoptic segmentation of satellite image time series with convolutional temporal attention networks. In : *Proceedings of the IEEE/CVF International Conference on Computer Vision*. 2021. p. 4872-4881.

[Garnot et al, 2020] GARNOT, Vivien Sainte Fare et LANDRIEU, Loic. Lightweight temporal self-attention for classifying satellite images time series. In : *International Workshop on Advanced Analytics and Learning on Temporal Data*. Cham : Springer International Publishing, 2020. p. 171-181.

Exploiting Temporality



UTAE$_{pre}$

Temporal Encoding prior to Spatial Encoding

→ Extract suspicious temporal patterns

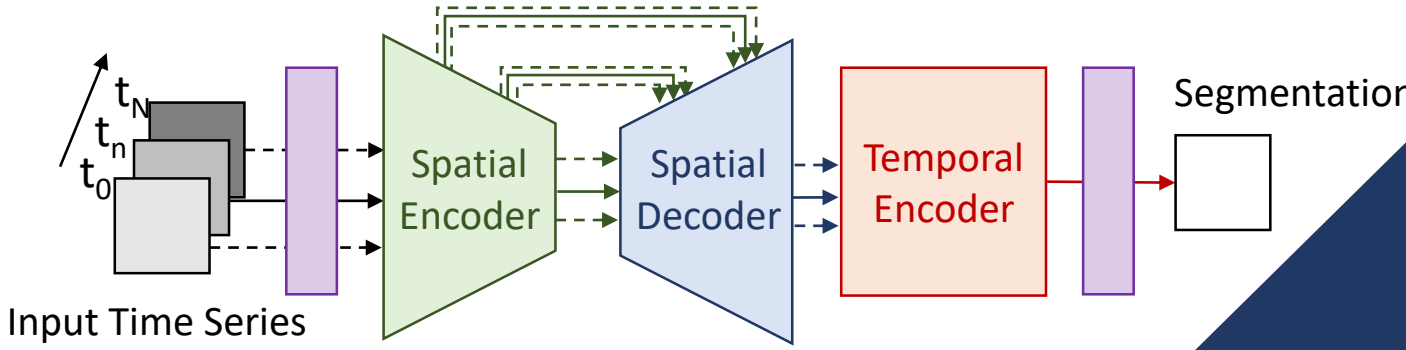
→ Verify spatial consistency

Spatial Encoding prior to Temporal Encoding

→ Extract suspicious spatial patterns (independent)

→ Verify temporal consistency

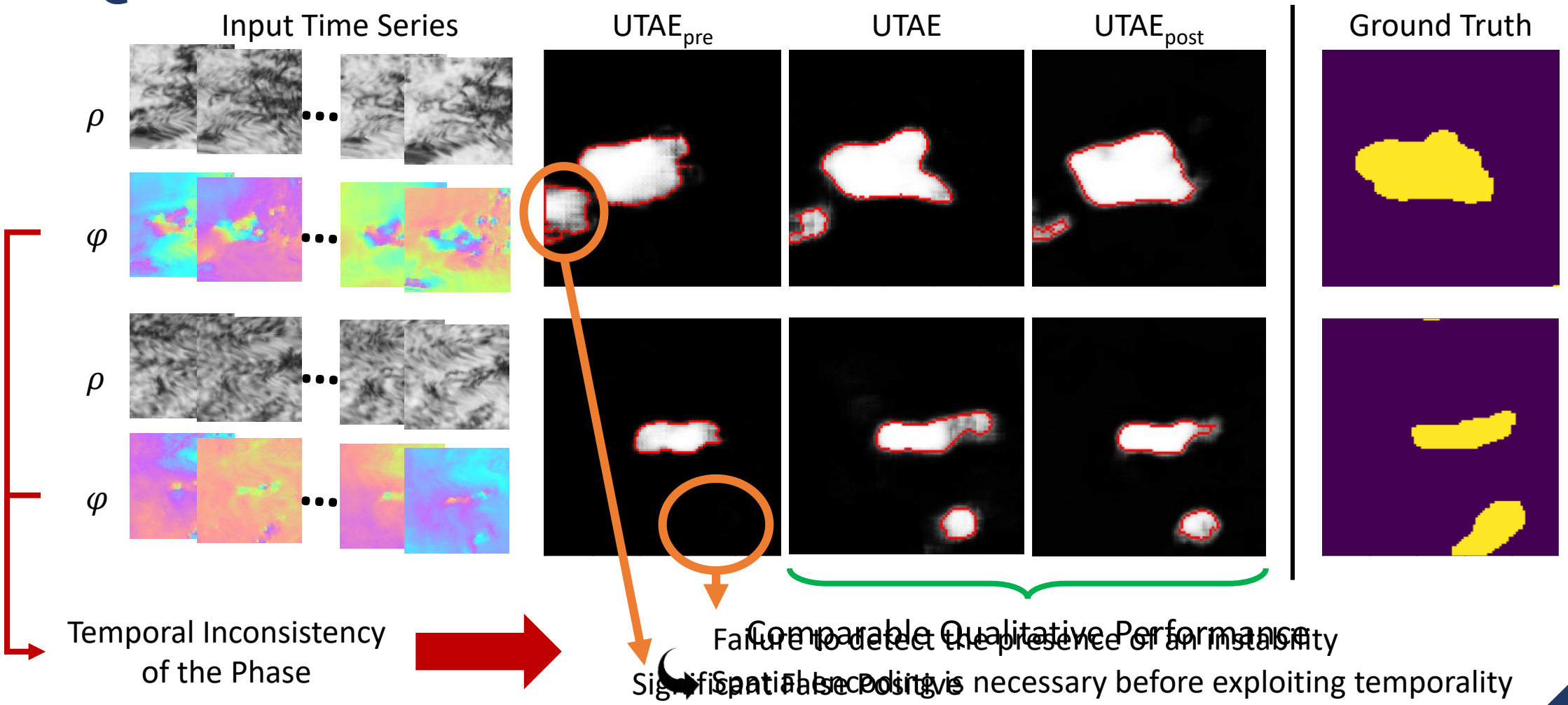
UTAE$_{post}$



Quantitative Results

	F1-Score	Dice	IoU	HD
Mono-Interferogram Networks				
FCN	0.690	0.645	0.503	<u>21.70</u>
DeepLabv3	0.673	0.630	0.486	22.35
ResUNet	0.681	0.639	0.500	25.92
Interferogram Time Series Networks				
U-TAE	<u>0.738</u>	<u>0.702</u>	<u>0.562</u>	21.94
U-TAE$_{pre}$	0.693	0.652	0.506	24.58
U-TAE$_{post}$	**0.747**	**0.713**	**0.575**	**20.85**

Qualitative Results



Key Takeaways

Outcomes:

- Including the temporality significantly improves performance
- Processing spatial first better follow geomorphological routine

Remaining issues:

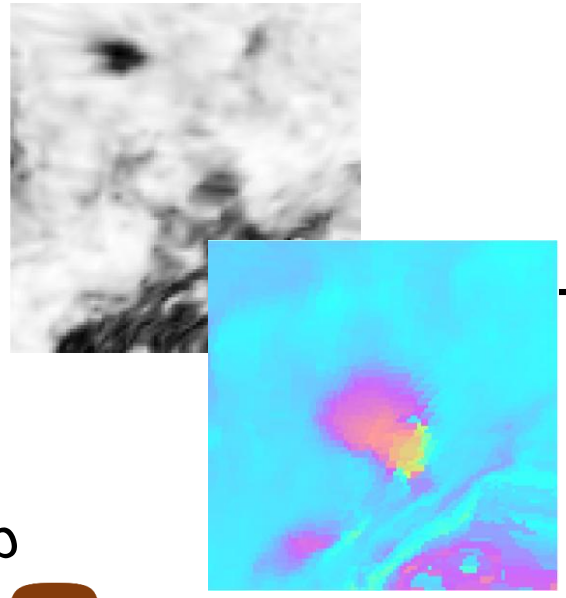
- Still a margin of improvement and possibility to reduce false detection
- Closer to geomorphological routine but still missing optical clues
- What helped the network to take the decision? Which time step is the most relevant? Why ?

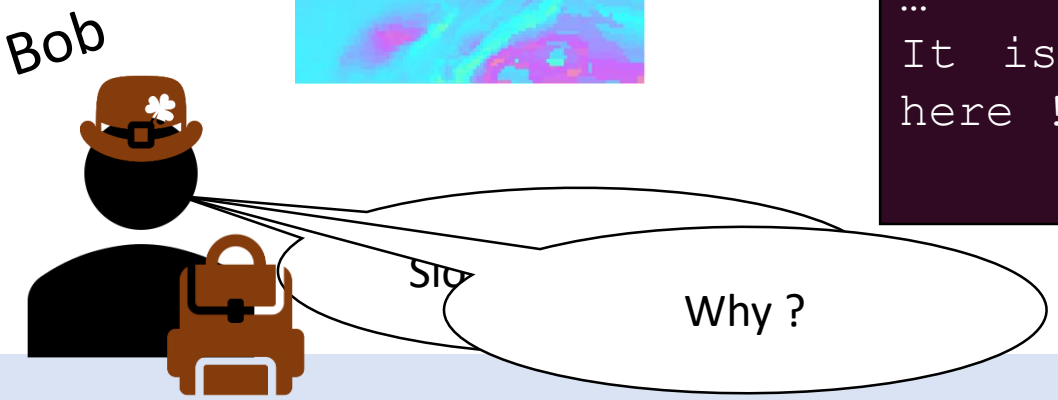
Explainable Detections

[Bralet et al, 2025]

[Bralet et al, 2025] Bralet, A., Atto, A. M., Chanussot, J., & Trouvé, E. (2025). ECSPLAIN: Explainability Constrained-claSsifier for Pairing the detection and the Localization of moving Areas from SAR INterferograms. *IEEE Transactions on Geoscience and Remote Sensing*.

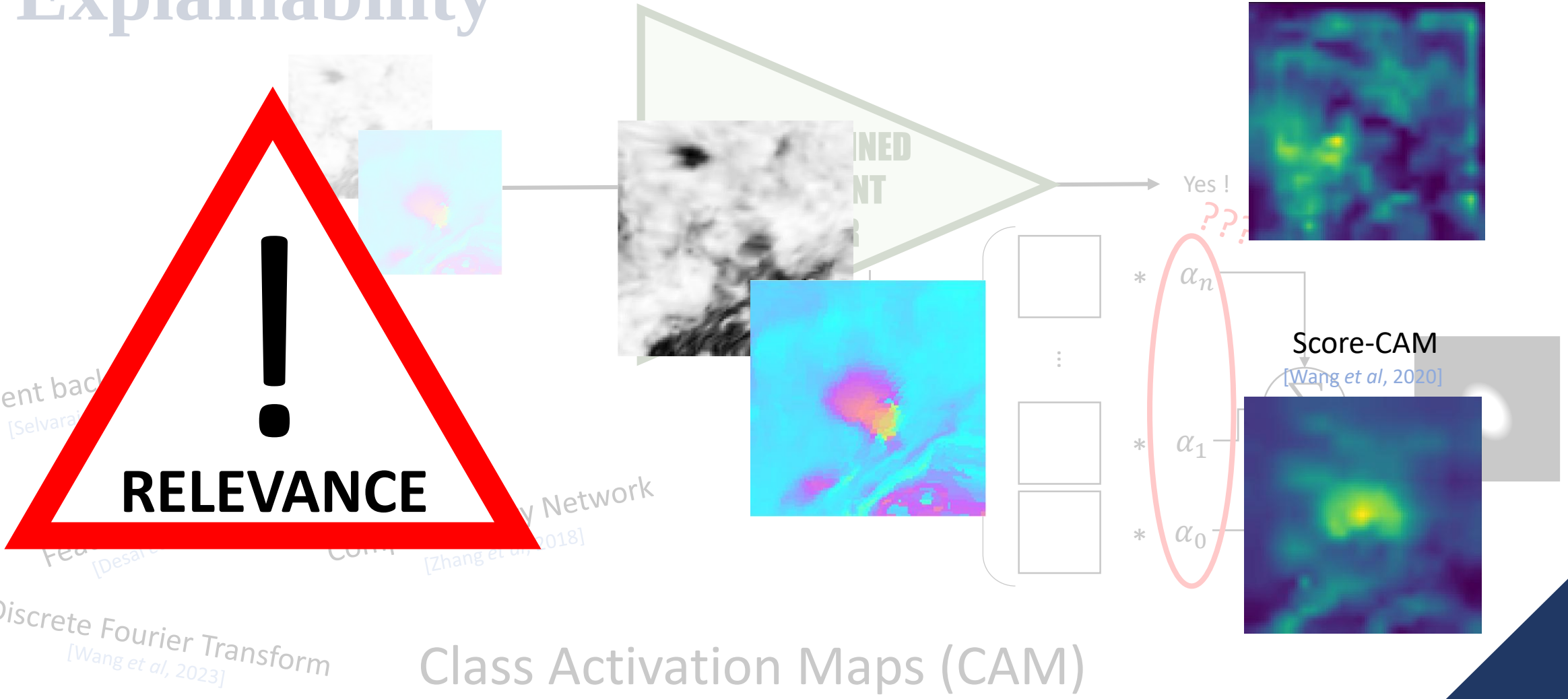
Explainability





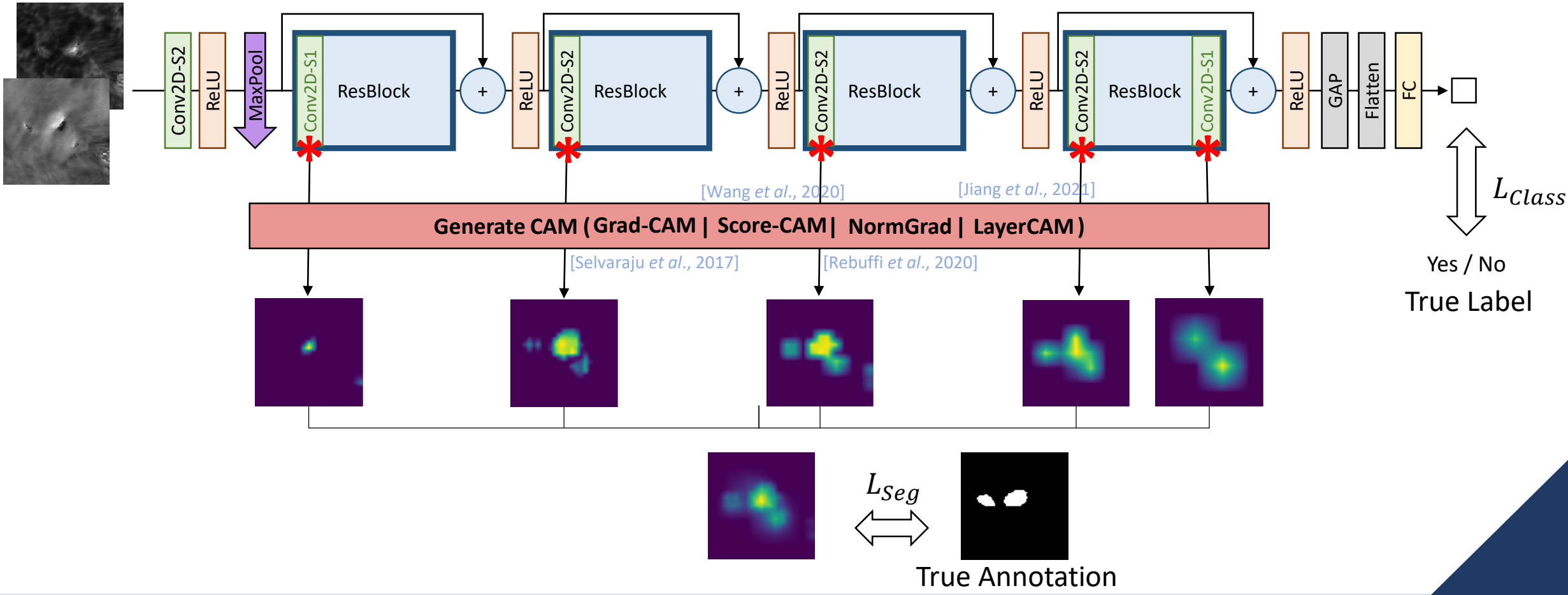

```
bob@bobnet:~/BobNet/$
bob@bobnet:~/BobNet/$ vim BobNetExplain.txt

The third kernel of the second layer gets an activation of 1.705,
The second kernel of the fifth layer of the second branch gets an activation of 2.803,
Combined with the fact that the first pixel of the twentieth row of the image is colored in blue but less than the eighth pixel of the fifty-third row,
…
…
…
It is obvious that there is an instability right here !
```

Explainability



Class Activation Maps (CAM)

ECSPLAIN *[Bralet et al, 2025]*



[Bralet et al, 2025] Bralet, A., Atto, A. M., Chanussot, J., & Trouvé, E. (2025). ECSPLAIN: Explainability Constrained-claSsifier for Pairing the detection and the Localization of moving Areas from SAR INterferograms. *IEEE Transactions on Geoscience and Remote Sensing*.

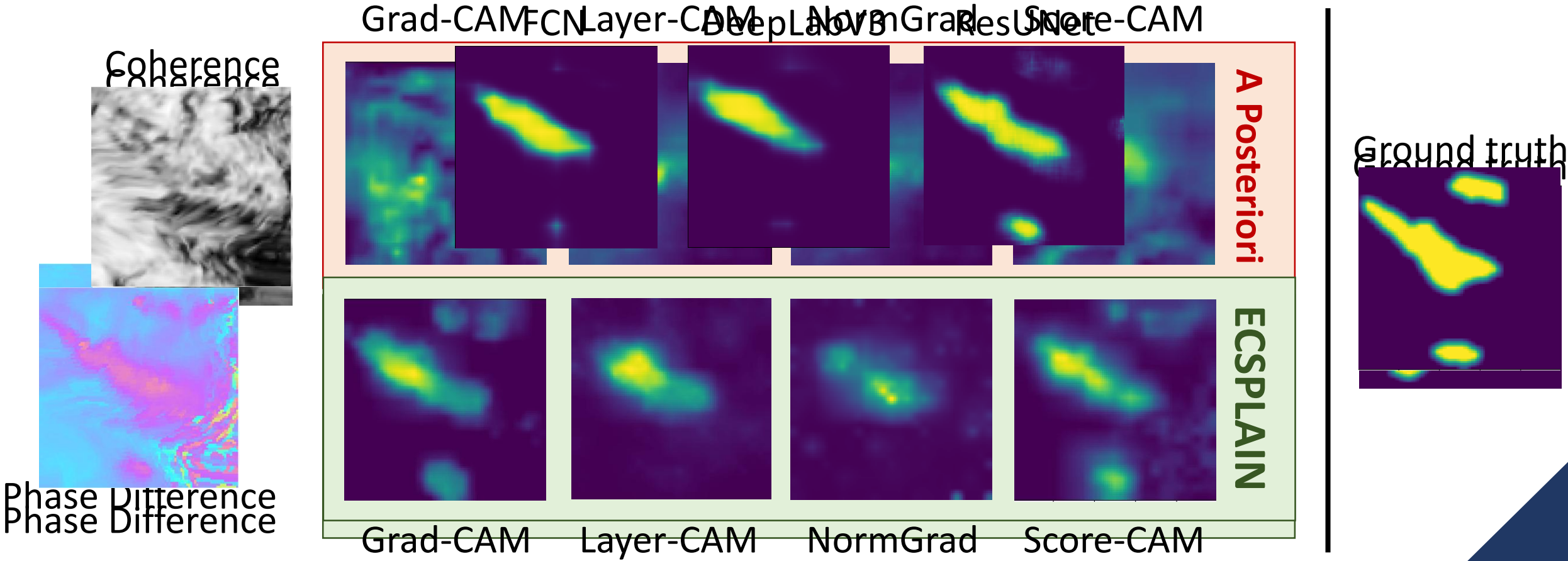
Quantitative Classification Performance

	Accuracy	Precision	Recall	F1-Score
Trained without the ECSPLAIN framework				
	94,67%	92,43%	92,27%	0,923
Trained with the ECSPLAIN framework				
Grad-CAM *[Selvaraju et al., 2017]*	95,04%	92,66%	93,15%	0,929
Layer-CAM *[Jiang et al., 2021]*	94,00%	94,02%	88,40%	0,911
NormGrad *[Rebuffi et al., 2020]*	95,89%	95,63%	92,44%	0,940
ScoreCAM *[Wang et al., 2020]*	95,71%	94,47%	93,16%	0,938

Quantitative Segmentation Performance

	MAE	Dice	mIoU	HD	AUC
	MAE	*A Posteriori* Evaluation	mIoU	HD	AUC
Grad-CAM *[Selvaraju et al., 2017]*	13,74E-02	Segmentation Network	0,093	58,01	0,524
Layer-CAM *[Jiang et al., 2021]*	01,36E-02	0,661	0,523	25,52	0,953
NormGrad *[Rebuffi et al., 2020]*	01,64E-02	0,622	0,480	36,62	0,955
ScoreCAM *[Wang et al., 2020]*	01,43E-02	0,684	0,547	25,69	0,964
Trained with the ECSPLAIN framework					
Grad-CAM *[Selvaraju et al., 2017]*	03,35E-02	0,637	0,504	25,54	0,949
Layer-CAM *[Jiang et al., 2021]*	04,72E-02	0,570	0,435	26,45	0,920
NormGrad *[Rebuffi et al., 2020]*	04,73E-02	0,575	0,439	25,98	0,923
ScoreCAM *[Wang et al., 2020]*	05,92E-02	0,643	0,500	24,08	0,959

Qualitative Performance



Key Takeaways

Outcomes:

- Constraining network's explainability improves classification performance
- Segmenting from classification is feasible, lighter, faster and as accurate as standard segmentation networks
- The ECSPLAIN framework detected >800 susceptible instabilities

Remaining issues:

- Are we sure to capture the most accurate features?
- Can we partially guide the network?

What's more?

Future Works

PIPAM

Knowledge Preserving for SAR-Optical Modality Alignment

Baptiste Lafabrègue

APPALOOSA

Representation Learning Guided by Statistical A Priori for SAR Image Analysis

Matthieu Gallet, Yassine Mhri

ANR DECOL

Domain Adaptation for Crop Type Classification from Satellite Image Time Series

Charlotte Pelletier

Thank you for your attention

Antoine BRALET (abralet@unistra.fr)

Atelier Télédec@USMB 2026 – 23/06/2026

References

[Bodin et al, 2017] Bodin, X., Krysiecki, J.-M., Schoeneich, P., Le Roux, O., Lorier, L., Echelard, T., Peyron, M., and Walpersdorf, A. (2017). The 2006 Collapse of the Bérard Rock Glacier (Southern French Alps). Permafr. Periglac. Process., 28(1):209–223. eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/ppp.1887

[Bralet et al, 2024] Bralet, A., Trouvé, E., Chanussot, J., & Atto, A. M. (2024). ISSLIDE: A new InSAR dataset for Slow SLIding area DEtection with machine learning. *IEEE Geoscience and Remote Sensing Letters*, *21*, 1-5.

[Bralet et al, 2025] Bralet, A., Atto, A. M., Chanussot, J., & Trouvé, E. (2025). ECSPLAIN: Explainability Constrained-claSsifier for Pairing the detection and the Localization of moving Areas from SAR INterferograms. *IEEE Transactions on Geoscience and Remote Sensing*.

[Bralet et al, 2025] Bralet, A, Trouvé, E, & Atto, A.M. (2025). Spatio-Temporal Encoding for Deep Slope Instability Detection from Time Series of SAR Interferograms. *2025 International Conference on Machine Intelligence for GeoAnalytics and Remote Sensing (MIGARS)*. IEEE. 1-4.

[Chen *et al.*, 2017] Chen, L.-C., Papandreou, G., Schroff, F., and Adam, H. (2017). Rethinking Atrous Convolution for Semantic Image Segmentation. arXiv:1706.05587 [cs].

[Chollet, 2017] Chollet, F. (2017). Xception: Deep Learning With Depthwise Separable Convolutions. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, pages 1251–1258, Honolulu, HI, USA.

[Desai *et al*, 2020] Desai, S. and Ramaswamy, H. G. (2020). Ablation-CAM: Visual Explanations for Deep Convolutional Network via Gradient-free Localization. In 2020 IEEE Winter Conference on Applications of Computer Vision (WACV), pages 983–991, Snowmass Village, CO, USA.

[Garnot et al, 2021] Garnot, V. S. F. and Landrieu, L.. Panoptic segmentation of satellite image time series with convolutional temporal attention networks. In : *Proceedings of the IEEE/CVF International Conference on Computer Vision*. 2021. p. 4872-4881.

[Garnot et al, 2020] Garnot, V. S. F. et Landrieu, L. Lightweight temporal self-attention for classifying satellite images time series. In : *International Workshop on Advanced Analytics and Learning on Temporal Data*. Cham : Springer International Publishing, 2020. p. 171-181.

[He *et al.*, 2016] He, K., Zhang, X., Ren, S., and Sun, J. (2016). Deep Residual Learning for Image Recognition. In 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), pages 770–778, Las Vegas, NV, USA.

[Jiang *et al.*, 2021] Jiang, P.-T., Zhang, C.-B., Hou, Q., Cheng, M.-M., and Wei, Y. (2021). LayerCAM: Exploring Hierarchical Class Activation Maps for Localization. IEEE Trans. Image Process., 30:58755888.

[Long *et al.*, 2015] Long, J., Shelhamer, E., and Darrell, T. (2015). Fully Convolutional Networks for Semantic Segmentation. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, pages 3431–3440, Boston, MA, USA.

[Marcer et al, 2020] Marcer, M., Ringsø Nielsen, S., Ribeyre, C., Kummert, M., Duvillard, P.-A., Schoeneich, P., Bodin, X., and Genuite, K. (2020). Investigating the Slope Failures at the Lou Rock Glacier Front, French Alps. Permafr. Periglac. Process., 31(1):15–30.

[Rebuffi *et al.*, 2020] Rebuffi, S.-A., Fong, R., Ji, X., and Vedaldi, A. (2020). There and Back Again: Revisiting Backpropagation Saliency Methods. In 2020 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), pages 8836–8845, Seattle, WA, USA.

[Selvaraju *et al*, 2017] Selvaraju, R. R., Cogswell, M., Das, A., Vedantam, R., Parikh, D., and Batra, D. (2017). Grad-CAM: Visual Explanations From Deep Networks via Gradient-Based Localization. In Proceedings of the IEEE International Conference on Computer Vision, pages 618–626, Honolulu, HI, USA.

[Wang *et al*, 2020] Wang, H., Wang, Z., Du, M., Yang, F., Zhang, Z., Ding, S., Mardziel, P., and Hu, X. (2020). Score-CAM: Score-Weighted Visual Explanations for Convolutional Neural Networks. In Proceedings of the IEEE/CVF conference on computer vision and pattern recognition workshops, pages 24–25, Seattle, WA, USA.

[Wang *et al*, 2023] Wang, Y. Y. and Bunyak, F. (2023). DFT-CAM: Discrete Fourier Transform Driven Class Activation Map. In 2023 IEEE International Conference on Image Processing (ICIP), pages 500–504, Kuala Lumpur, Malaysia.

[Zhang *et al*, 2018] Zhang, X., Wei, Y., Feng, J., Yang, Y., and Huang, T. (2018b). Adversarial Complementary Learning for Weakly Supervised Object Localization. In 2018 IEEE/CVF Conference on Computer Vision and Pattern Recognition, pages , 1325–1334, Salt Lake City, UT, USA.

Introduction

How to Detect?

ISSLIDE

Raw Segmentation

Temporal Segmentation

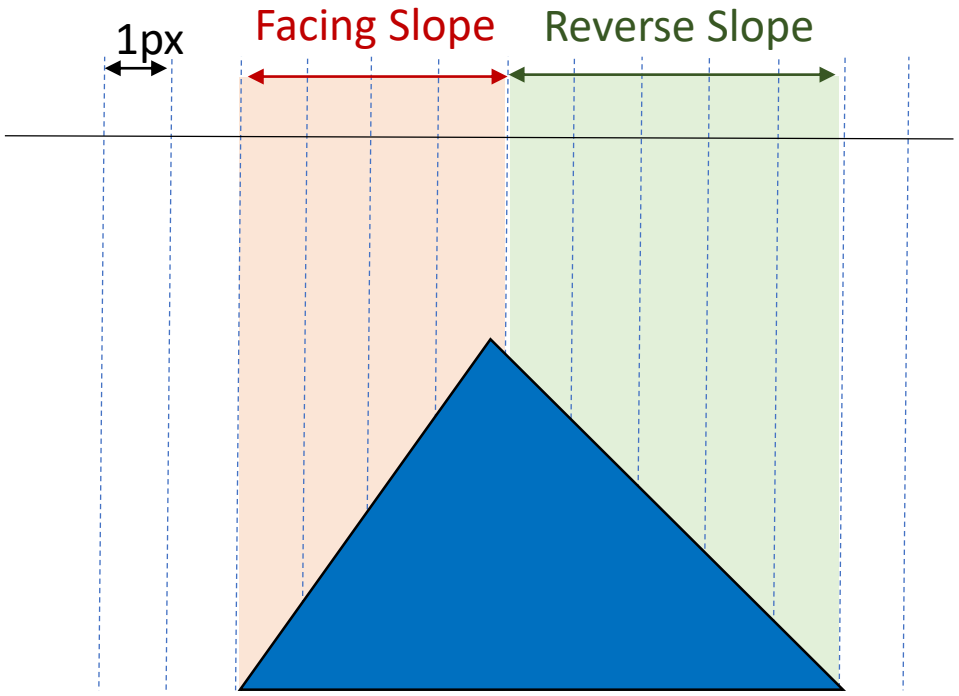
ECSPLAIN

Perspectives

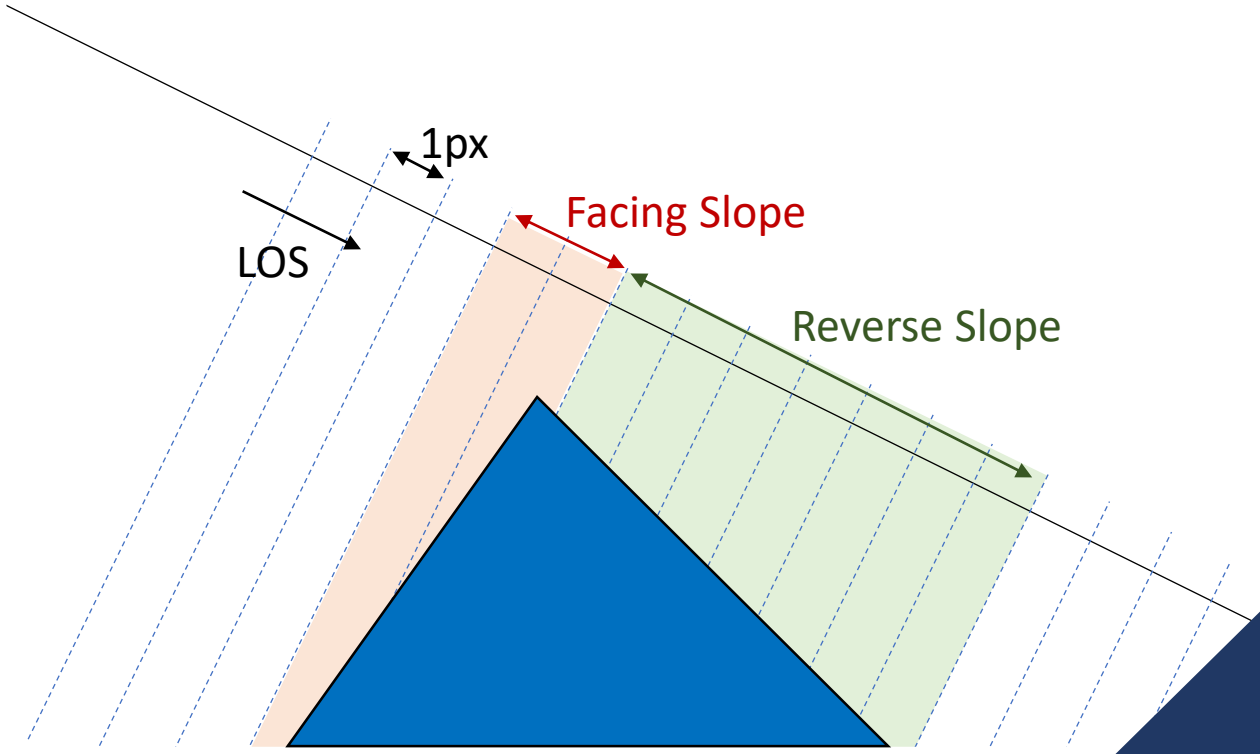
Backslides

Geometrical Distortions

Ground geometry

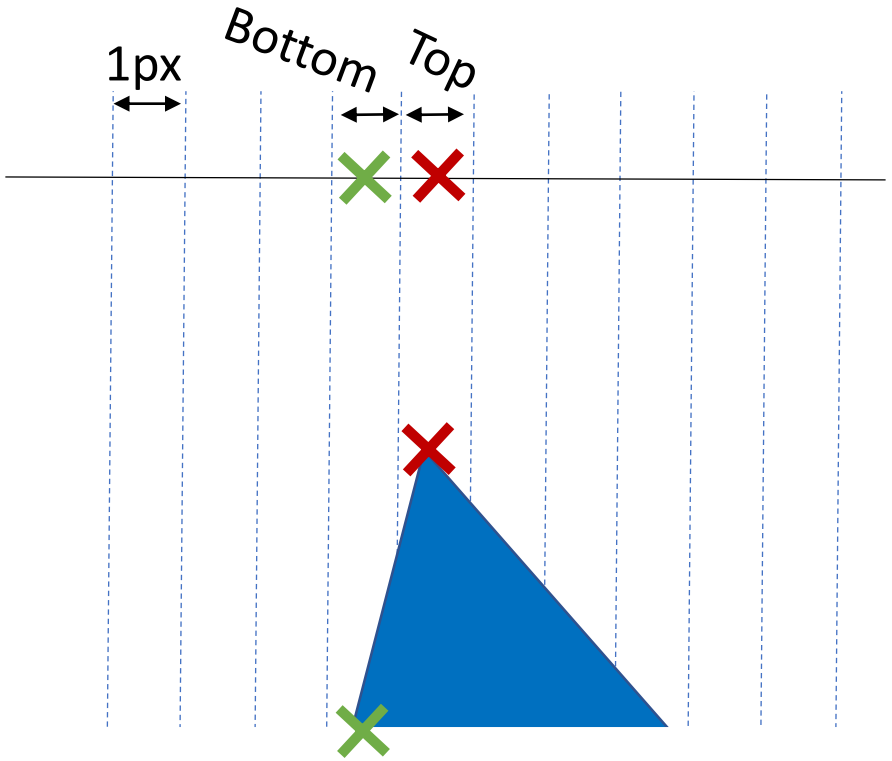


Radar geometry

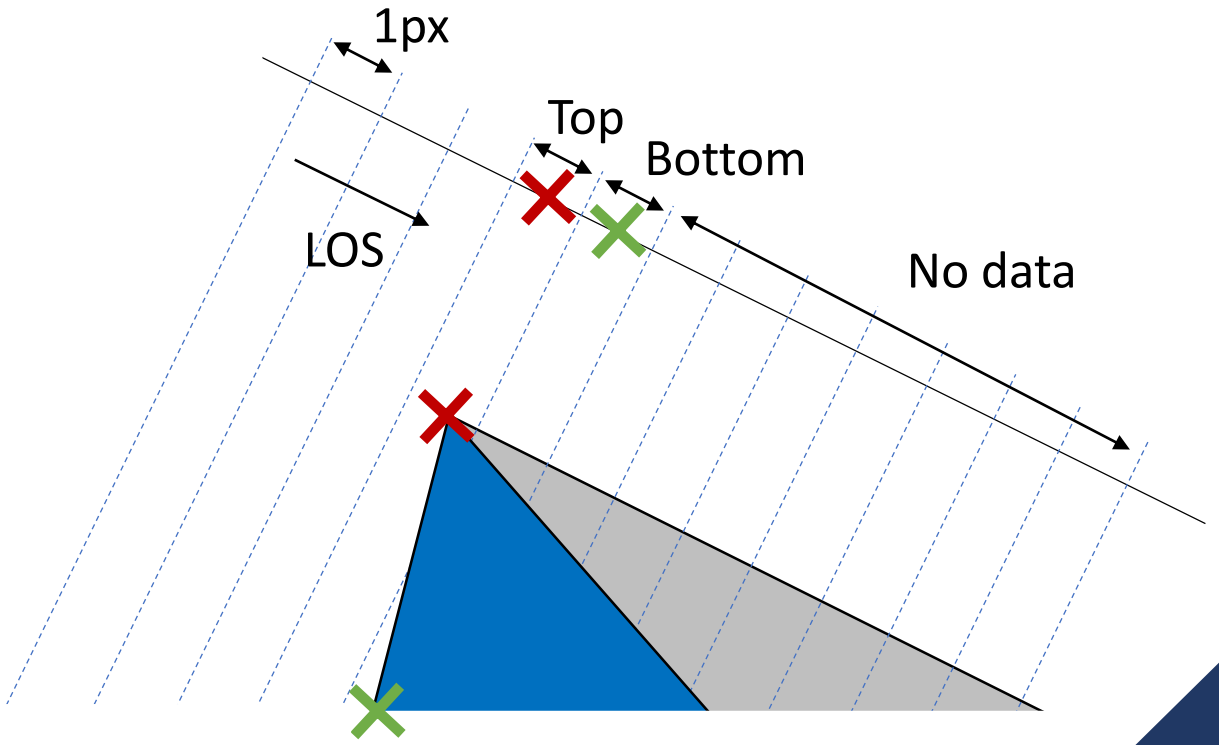


Geometrical Distortions

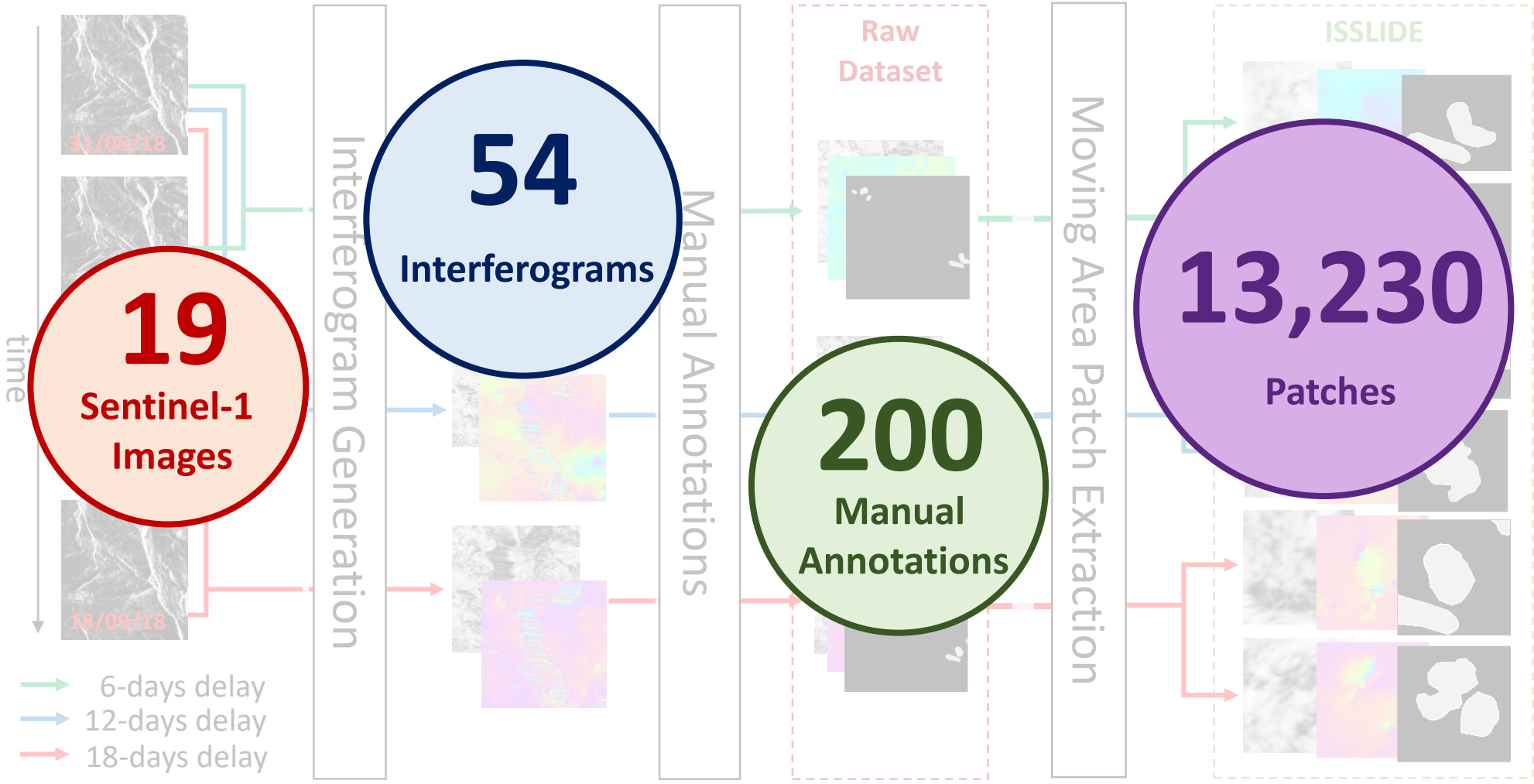
Ground geometry



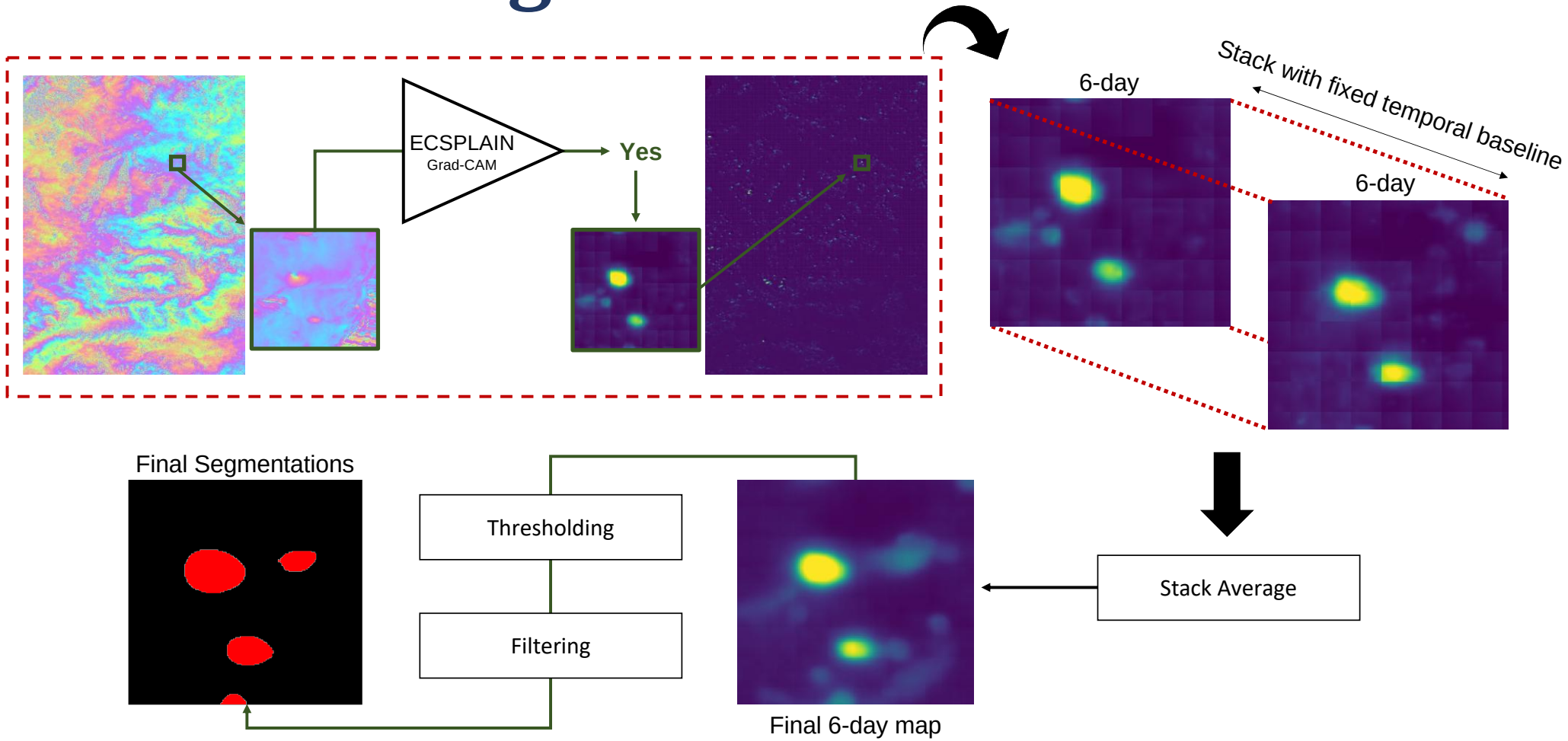
Radar geometry



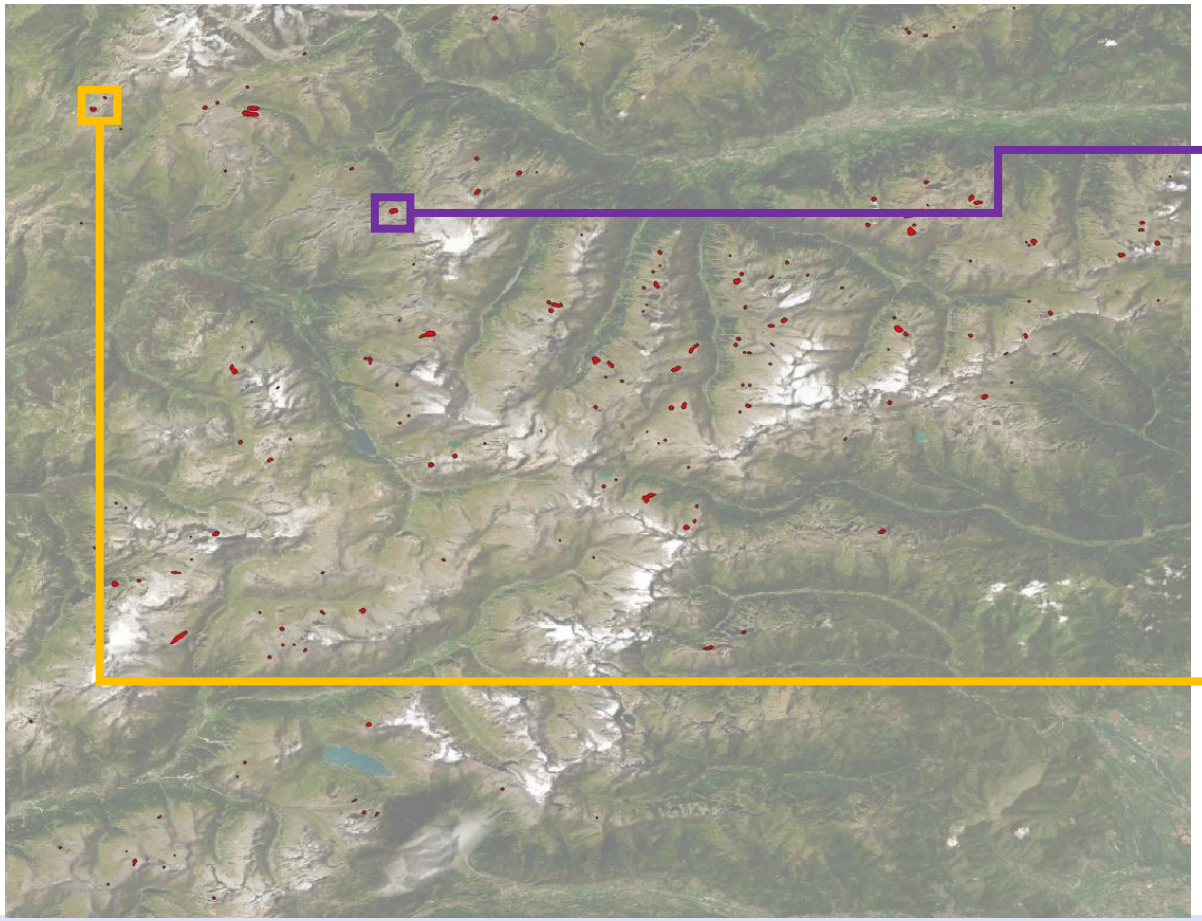
ISSLIDE Dataset

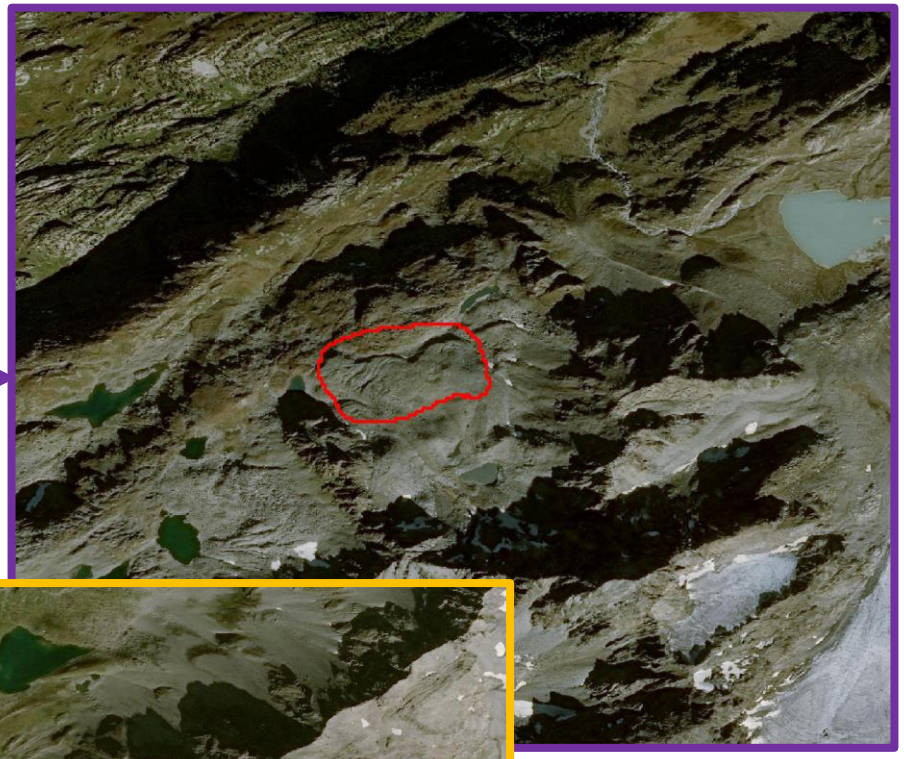


ECSPLAINing ISSLIDE

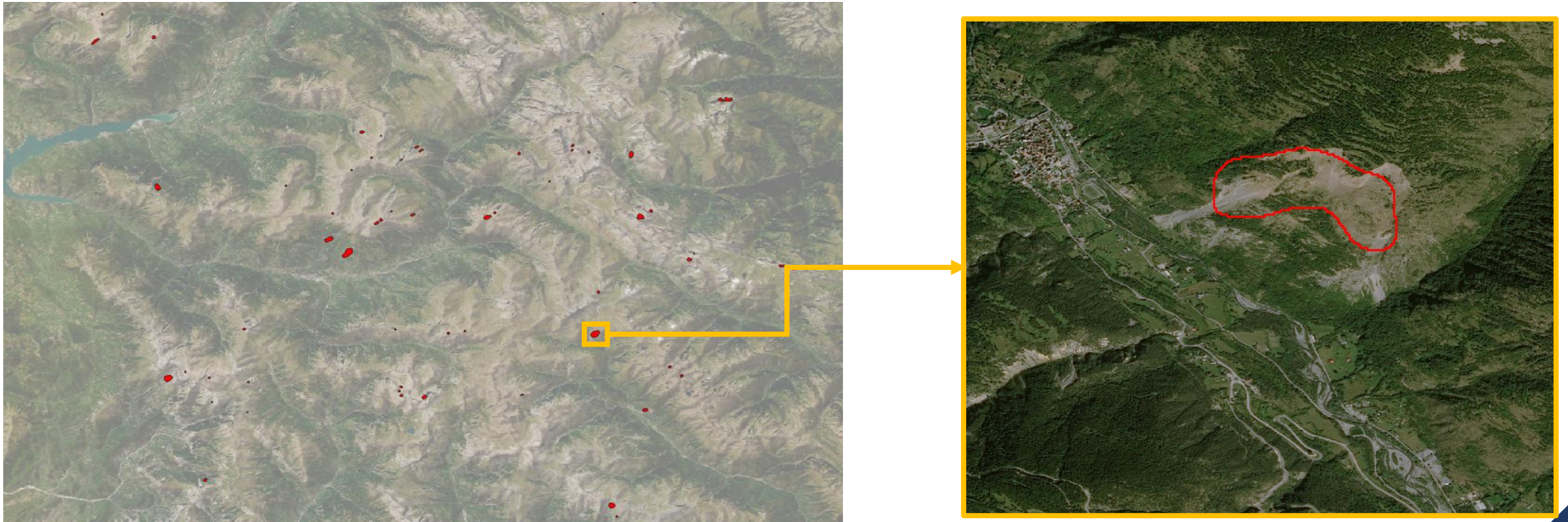


ECSPLAINing ISSLIDE





ECSPLAINing ISSLIDE



ECSPLAINing ISSLIDE Data

	Number of Detections			
Area ($\times$ 1,000m^2)	[10,50]	[50,100]	100 <	Total
6 days	308	118	89	515
12 days	282	121	92	495
18 days	252	96	82	430

178

Common polygons

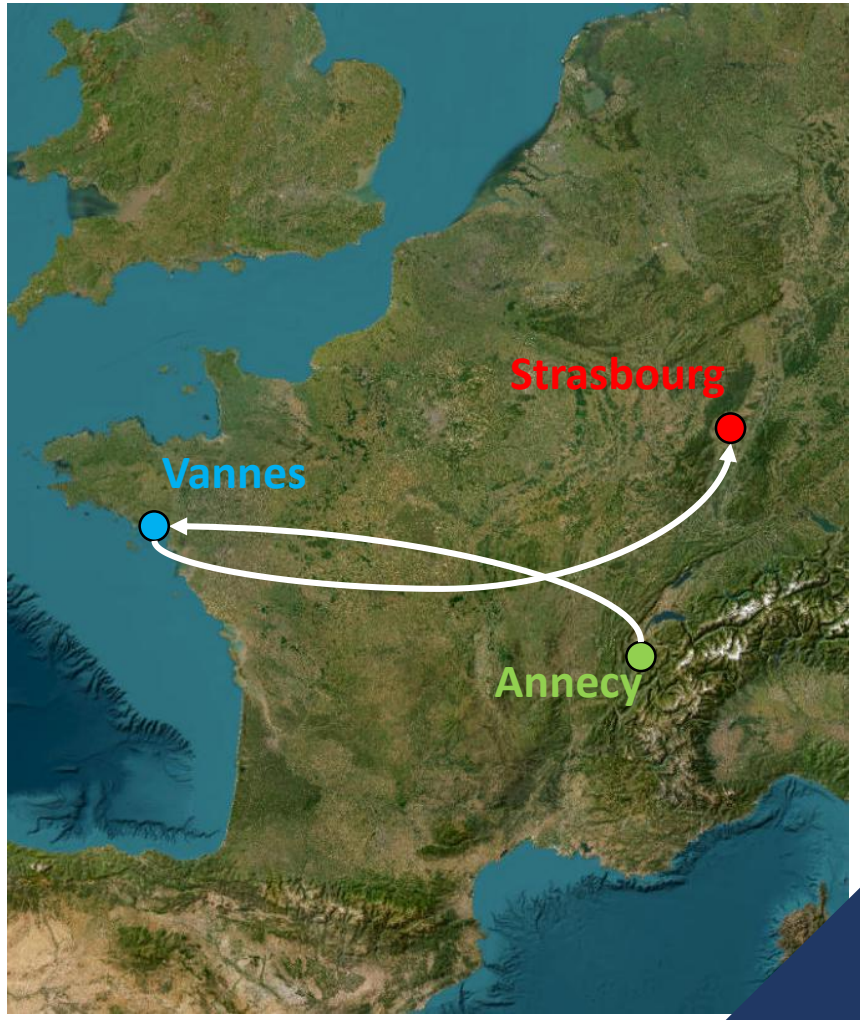
Hi everyone

- **PhD Thesis** *(oct 2021- oct 2024)*
  Université Savoie Mont-Blanc, LISTIC
  Spécialité STIC, Traitement de l'Information
  - ↪ Multimodality
  - ↪ Bi-temporality
  - ↪ Explainability
  - ↪ Remote Sensing

  Abdourrahmane Atto, Emmanuel Trouvé
  Jocelyn Chanussot

- **Post-Doc** *(dec 2024 - aug 2025)*
  Université Bretagne Sud, IRISA, Vannes
  - ↪ Time Series
  - ↪ Domain Adaptation
  - ↪ Remote Sensing

  Charlotte Pelletier

- **Associate Professor CNU 27 (intern)** *(sept 2025 - now)*
  Université de Strasbourg, ICube, Strasbourg
  - ↪ Representation Learning
  - ↪ Domain Adaptation
  - ↪ Modality Alignment
  - ↪ Biomedical
  - ↪ Remote Sensing

  Étienne Baudrier, Hassen Drira