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Detecting Methane Plumes using PRISMA : Deep Learning Model and Data Augmentation

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Remote sensing detection of methane plumes

Methane is the 2nd largest contributor to climate change after CO_2, considered 84 more potent than CO_2 (over 20Y) [1]

Global concentrations have **tripled** in the post-industrial era, and **60-70%** of the emissions are **anthropogenic**

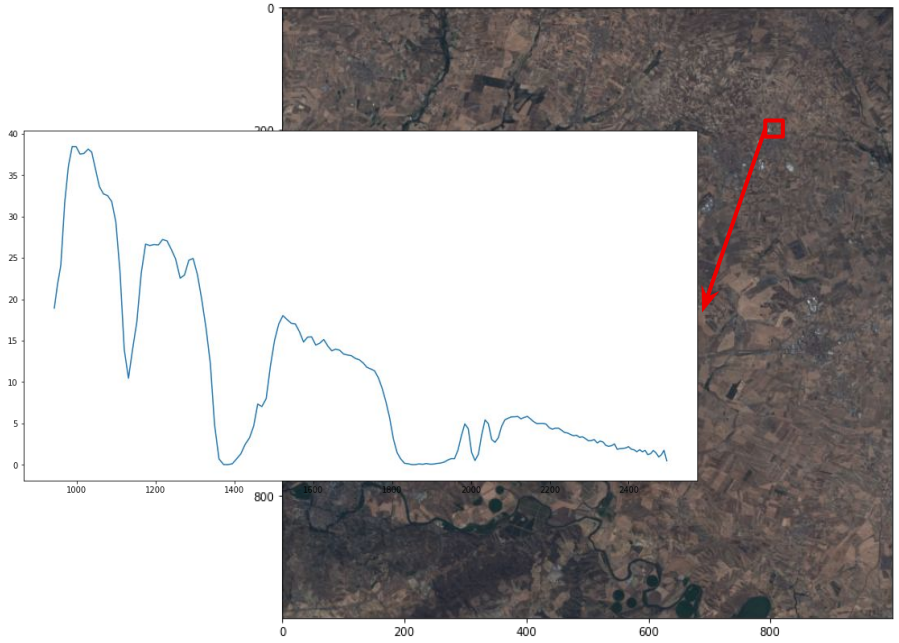
Emissions from the **Oil & Gas** industry account for **20%** of the global emissions and are probably the **easiest target** for mitigation efforts

A lack of data on the sources and volume of leaks allows emissions to grow unchecked

Satellite imagery constitutes a continuous large-scale source of data to identify super-emitters

PRISMA

- New generation of hyperspectral satellites → improved detection thresholds
- Spatial resolution = 30 m
- the sensors measure a radiance spectrum over 171 wavelengths in the SWIR (1000 nm - 2500 nm)



Methane retrieval pipeline

- Spectral recalibration to increase precision in measures
- Matched-filter algorithm to extract excess methane from a high spectral resolution absorption spectrum

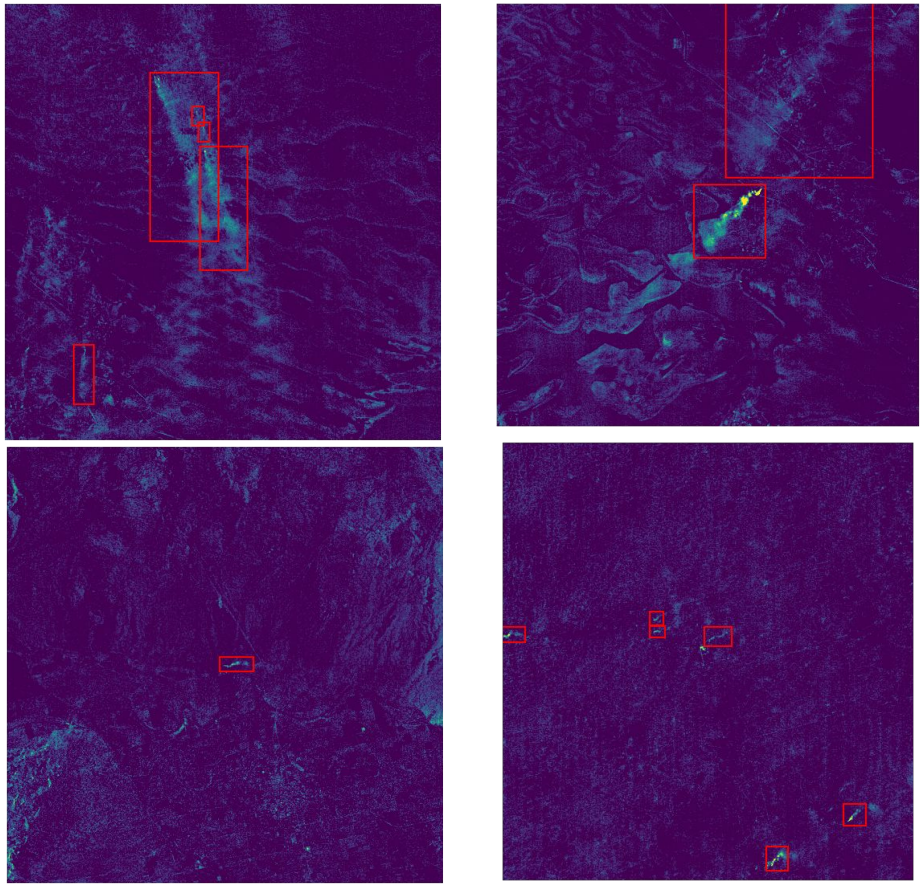


Figure : Methane maps from PRISMA images. The bounding boxes correspond to visually identified plumes.

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Plume Detection on methane map

- Visual detection is laborious and prone to errors

- Automatic methods are required but are challenging in a context of data scarcity
  - Only 40 PRISMA images with plumes available (75 plumes)
  - A large diversity in the content of the scene : size, density, level of noise, intensity, presence of False Positive

- Solved by data augmentation or domain adaptation :
  - Artificial plume generation : Gaussian plume, Large Eddy Simulation
  - Transfer learning from a larger dataset of methane maps from Sentinel-2 images (obtained following the method of [2] by a band ratio and a temporal regression)

Plume transfer from Sentinel-2 to PRISMA

- We observed that a gamma distribution fitted well the distribution of concentrations within a given plume mask from a PRISMA image
- Estimation of the underlying distribution of the parameters of the gamma distributions
- Use masks from true plumes in Sentinel-2 images

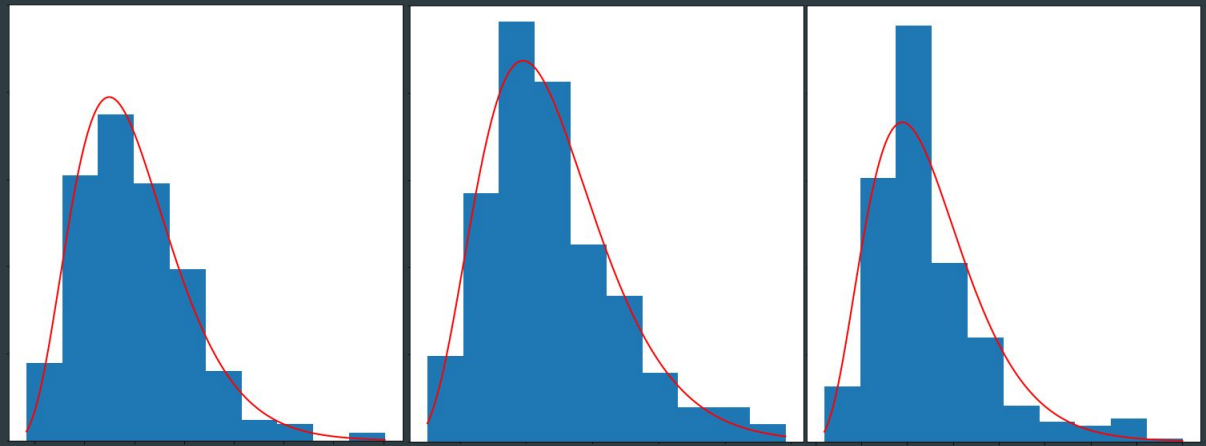
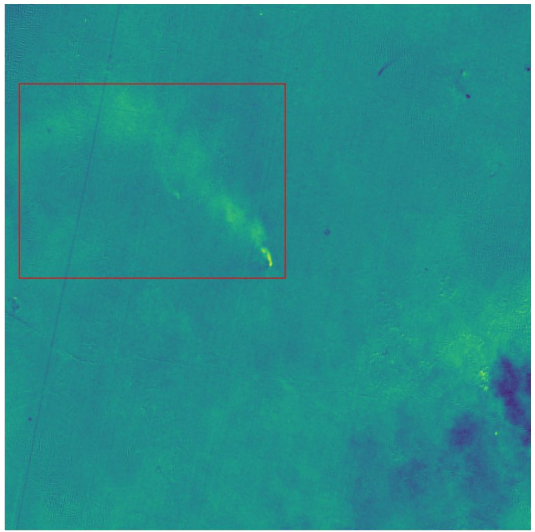


Figure : gamma distribution fit to distribution of methane concentrations within a PRISMA plume

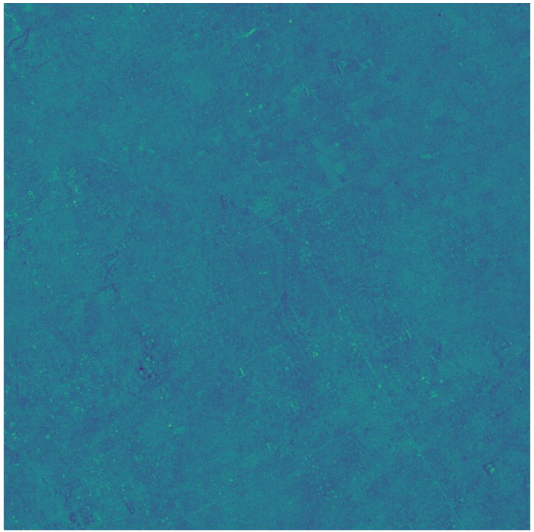
Plumes transfer

1. Randomly select a Sentinel-2 and a PRISMA image

Sentinel-2 image



PRISMA image (no plume)



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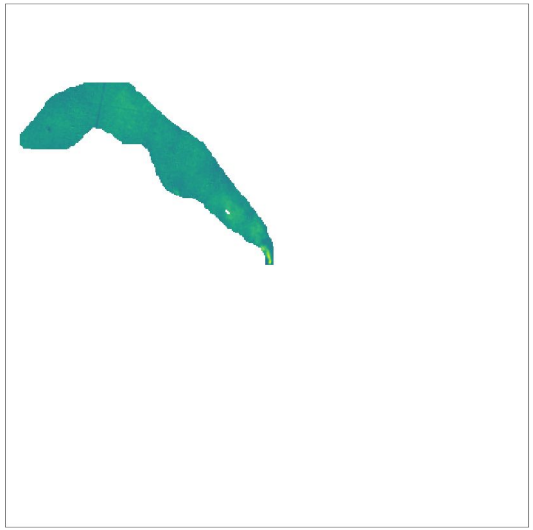
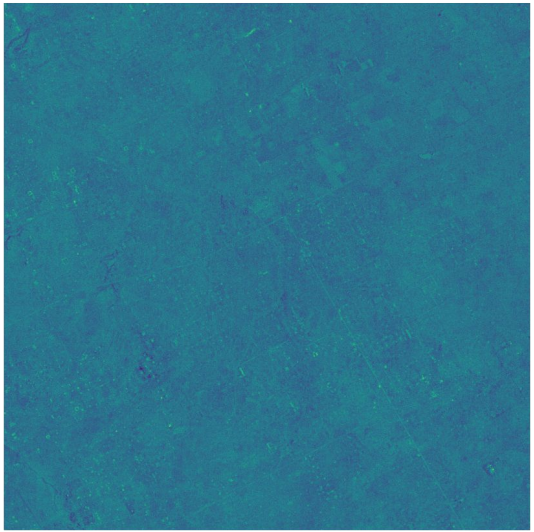
Plumes transfer

1. Randomly select a Sentinel-2 and a PRISMA image
2. Isolate the plume

Sentinel-2 plume (N pixels)



PRISMA image (no plume)



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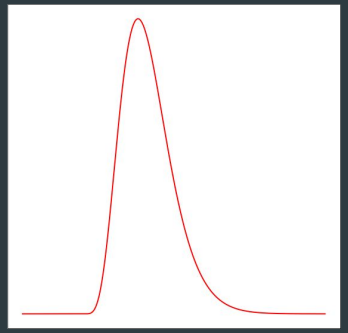
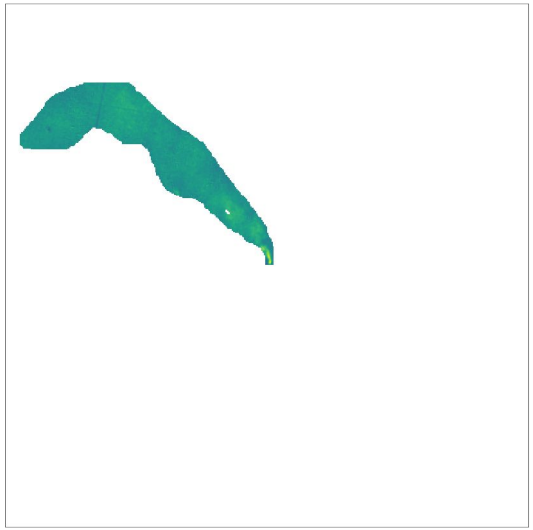
Plumes transfer

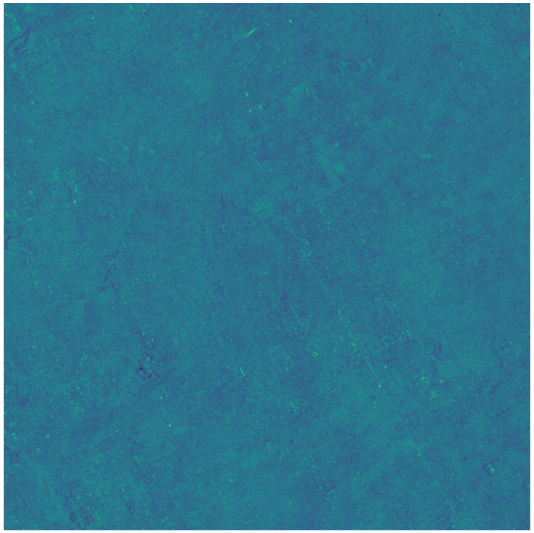
1. Randomly select a Sentinel-2 and a PRISMA image
2. Isolate the plume
3. Randomly sample gamma distribution parameters from the estimated distributions



Sentinel-2 plume (N pixels)



PRISMA image (no plume)



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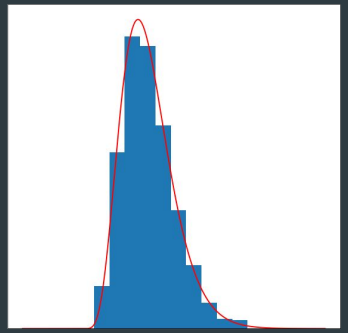
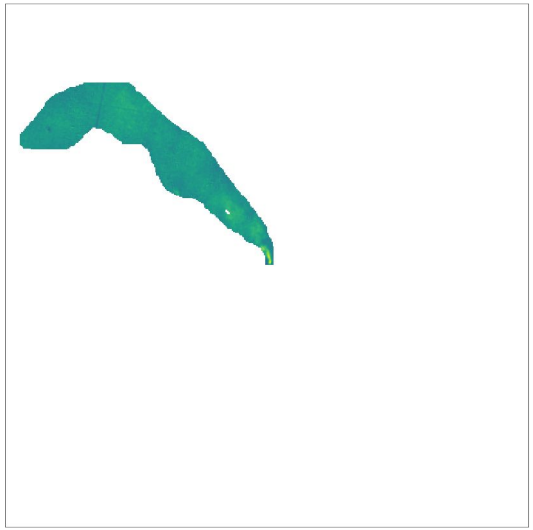
Plumes transfer

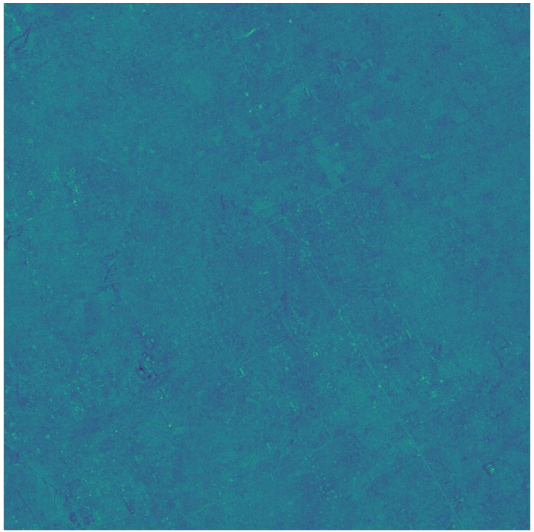
1. Randomly select a Sentinel-2 and a PRISMA image
2. Isolate the plume
3. Randomly sample gamma distribution parameters from the estimated distributions
4. Randomly sample N values from this distribution



Sentinel-2 plume (N pixels)



PRISMA image (no plume)



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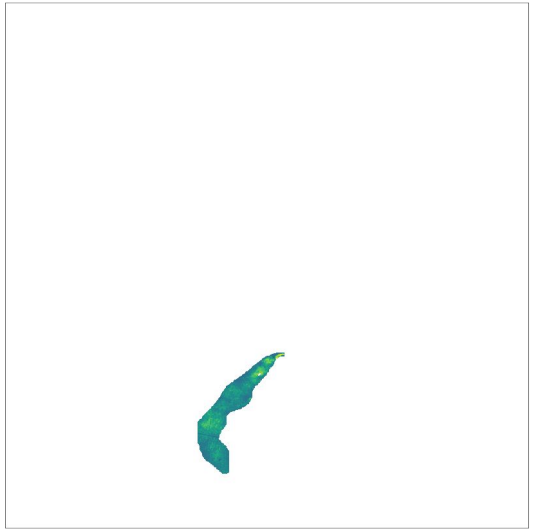
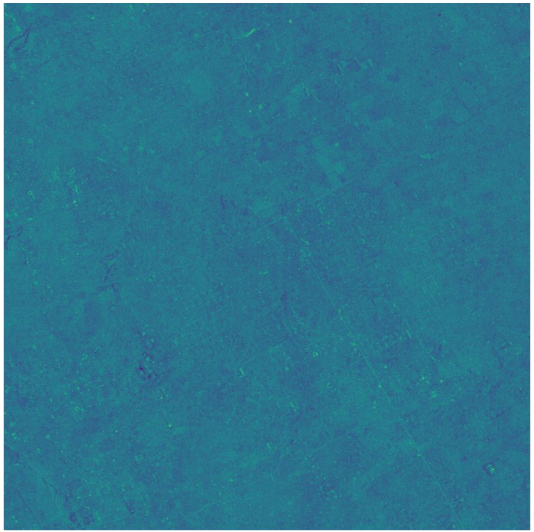
Plumes transfer

1. Randomly select a Sentinel-2 and a PRISMA image
2. Isolate the plume
3. Randomly sample gamma distribution parameters from the estimated distributions
4. Randomly sample N values from this distribution
5. Replace the values in the plume and random rotation / translation

Forged Sentinel-2 plume (N pixels)



PRISMA image (no plume)



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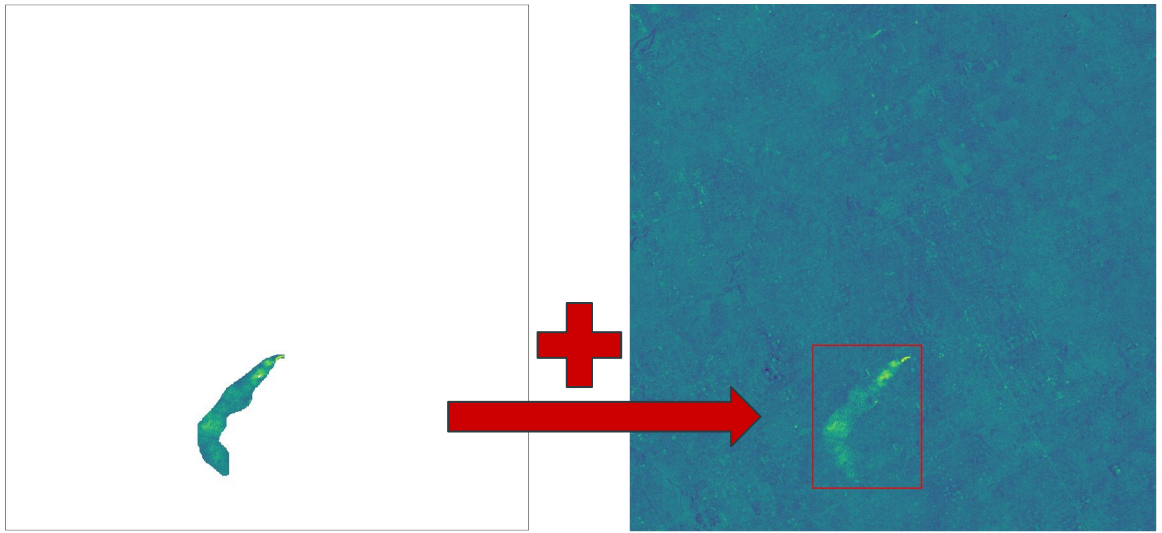
Plumes transfer

1. Randomly select a Sentinel-2 and a PRISMA image
2. Isolate the plume
3. Randomly sample gamma distribution parameters from estimated distributions
4. Randomly sample N values from this distribution
5. Replace the values in the plume and random rotation / translation
6. Sum the plume with the PRISMA image

Forged Sentinel-2 plume
(N pixels)

Forged PRISMA image
(with plume)



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Model performance

- UNet architecture trained for the segmentation task
- Compare two models
  - Model trained solely on artificial images and tested on true PRISMA images
  - Model trained by transfer learning from the weights for the task on S2
- the model trained using the proposed data augmentation largely outperforms the baseline

	detection metrics			segmentation metrics	
	precision	recall	f1-score	IoU	mIoU
Transfer Learning	0.28	0.53	0.37	0.21	0.13
Plumes Transfer	0.88	0.42	0.57	0.61	0.19

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Thank you !

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References

[1] Forster, P.; Storelvmo, T.; Armour, K.; Collins, W.; Dufresne, J.-L.; Frame, D.; Lunt, D.; Mauritsen, T.; Palmer, M.; Watanabe, M.; Wild, M.; Zhang, H. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Intergovernmental Panel on Climate Change, Ed.; Cambridge University Press, 2021.

[2] T. Ehret, A. Truchis, M. Mazzolini, J.-M. Morel, A. d'Aspremont, T. Lauvaux, R. Duren, D. Cusworth, and G. Facciolo, "Global tracking and quantification of oil and gas methane emissions from recurrent sentinel-2 imagery," Environmental Science Technology, vol. 56, 07 2022.