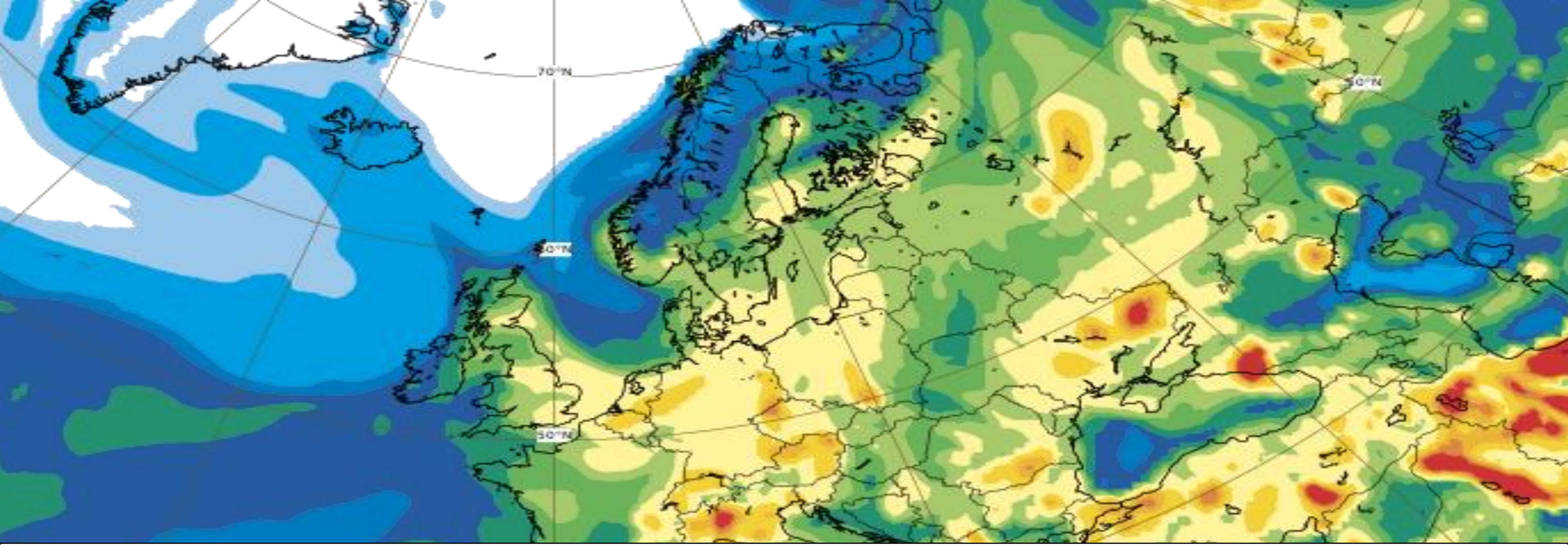
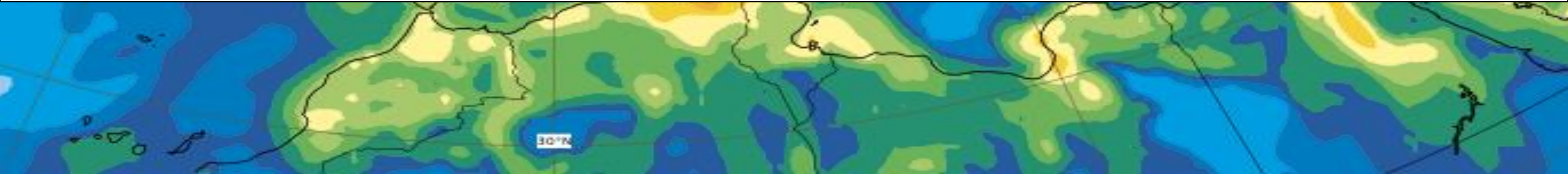


Artificial Intelligence for atmospheric composition

Maximilien Houël
16 / 03 / 2022



Introduction

- Software developer at SISTEMA GmbH / M.E.E.O srl (since 2019)
- Remote sensing and environmental geography background
- Application of Artificial Intelligence solutions in earth observation

Content

1) Machine learning and computer vision : (Everyday images)

- Image resolution enhancement

2) Machine learning and earth observation : (Optical Satellite Imagery)

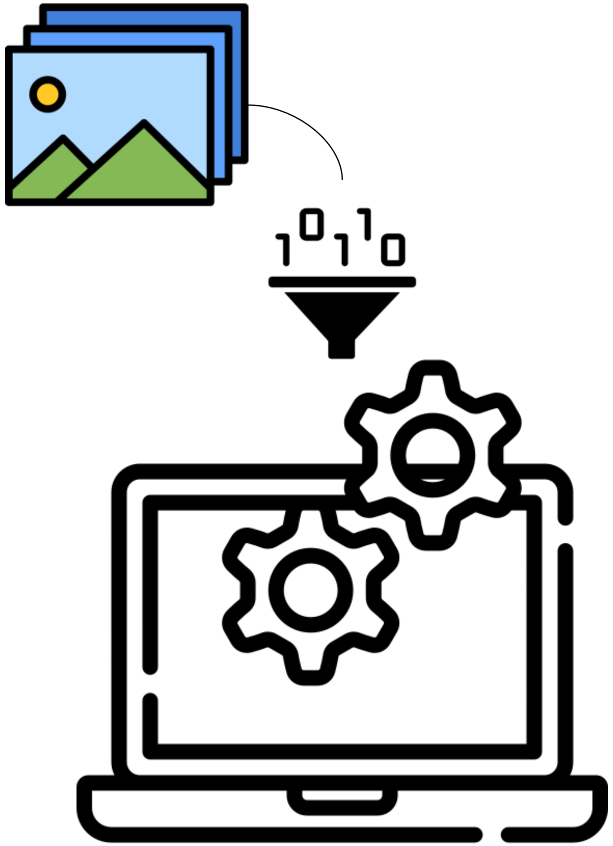
- Spatial resolution enhancement

3) Machine learning and atmospheric monitoring : (CAMS / Sentinel-5p NO_2 analysis)

- Pre - processing remote sensing data for machine learning
- FastAI introduction
- Building a SISR (Single Image Super Resolution)

Machine learning

Computer Vision



- Image classification
- Image segmentation
- Object detection
- Super-resolution

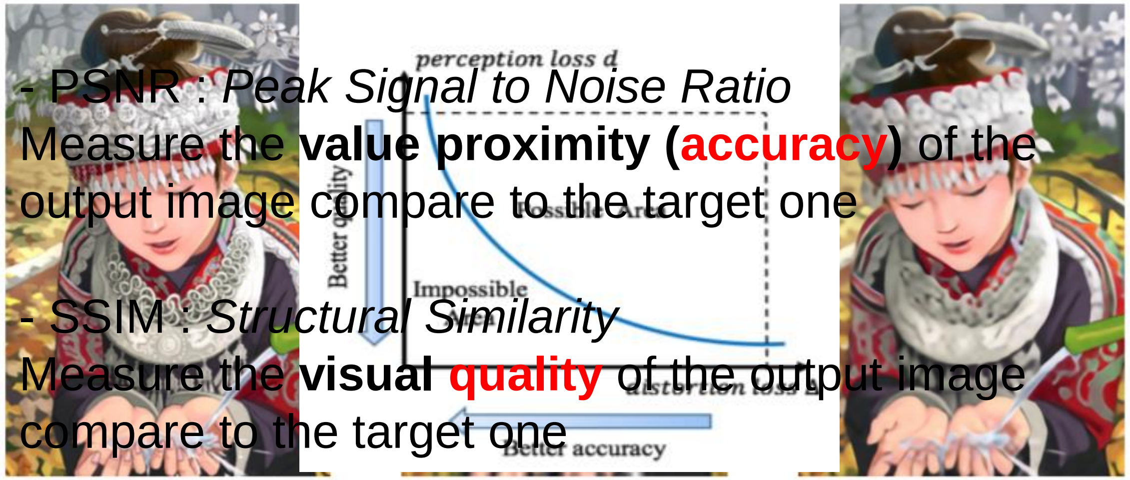
...

How to enhance image resolution

Single Image Super Resolution

Models	PSNR/SSIM(×4)	Train data	Parameters	Mult&Adds
SRCNN_EX [48]	30.49/0.8628	ImageNet subset	57K	52.5G
ESPCN [49]	30.90/-	ImageNet subset	20K	1.43G
VDSR [61]	31.35/0.8838	G200+Yang91	665K	612.6G
DRCN [63]	31.53/0.8838	Yang91	1.77M(recursive)	17974.3G
DRRN [70]	31.68/0.8888	G200+Yang91	297K(recursive)	6796.9G
LapSRN [84]	31.54/0.8855	G200+Yang91	812K	29.9G
SRResNet [68]	32.05/0.9019	ImageNet subset	1.5M	127.8G
MemNet [76]	31.74/0.8893	G200+Yang91	677K(recursive)	2265.0G
RDN [78]	32.61/0.9003	DIV2K	22.6M	1300.7G
EDSR [71]	32.62/0.8984	DIV2K	43M	2890.0G
MDSR [71]	32.60/0.8982	DIV2K	8M	407.5G
DBPN [90]	32.47/0.898	DIV2K+Flickr+ ImageNet subset	10M	

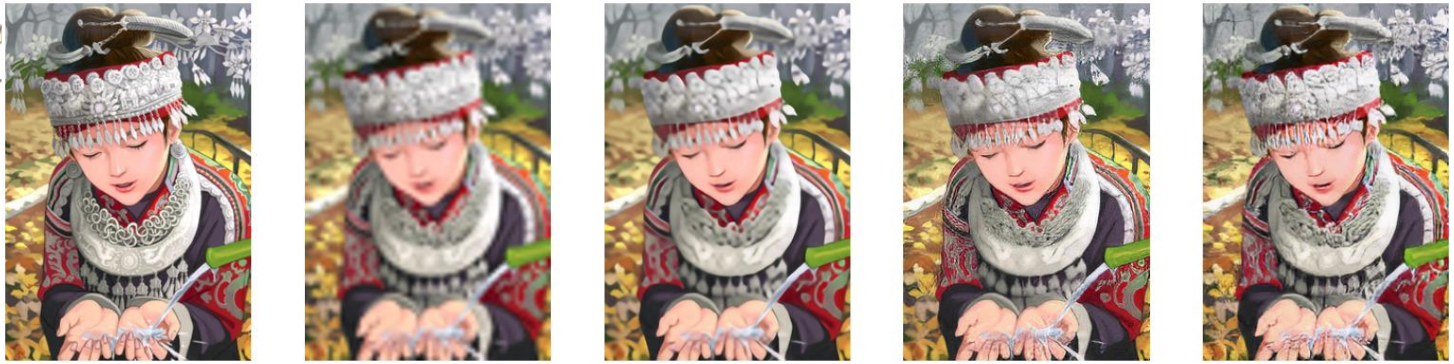
Yang, Wenming, Xuechen Zhang, Yapeng Tian, Wei Wang, et Jing-Hao Xue. « Deep Learning for Single Image Super-Resolution: A Brief Review ». IEEE Transactions on Multimedia 21, nº 12 (décembre 2019): 3106-21. https://doi.org/10.1109/TMM.2019.2919431.



- PSNR : *Peak Signal to Noise Ratio*
Measure the **value proximity (accuracy)** of the output image compare to the target one

- SSIM : *Structural Similarity*
Measure the **visual** quality of the output image compare to the target one

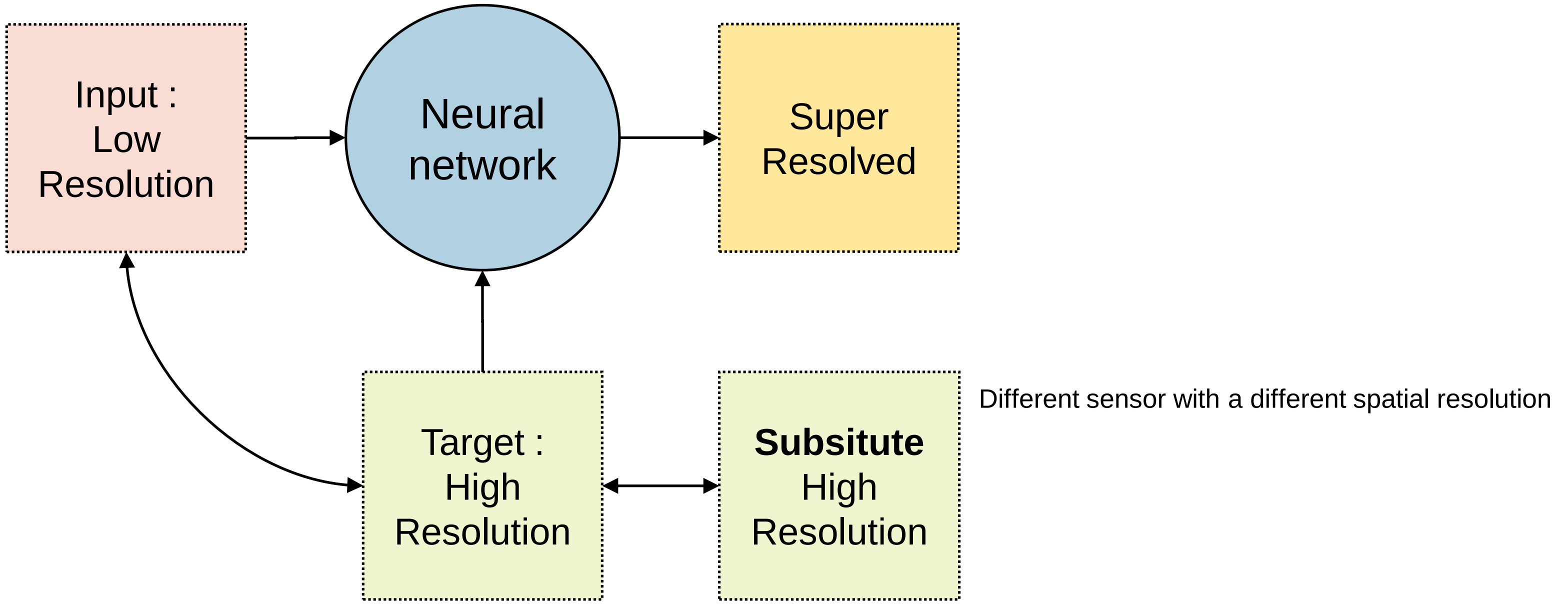
(a) HR
(b) bicubic(21.59dB/0.6423)
(c) SRResNet(23.53dB/0.7832)



(a) HR
(b) bicubic(21.59dB/0.6423)
(c) SRResNet(23.53dB/0.7832)
(d) SRGAN(21.15dB/0.6868)
(e) SRCX(20.88dB/0.6002)

How to enhance spatial resolution

Earth observation application

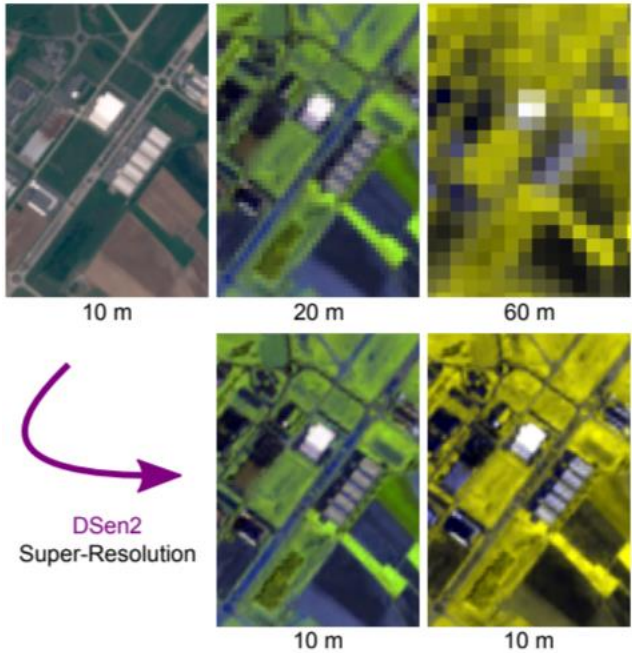


<u>Need of a high resolution reference</u>

How to enhance spatial resolution

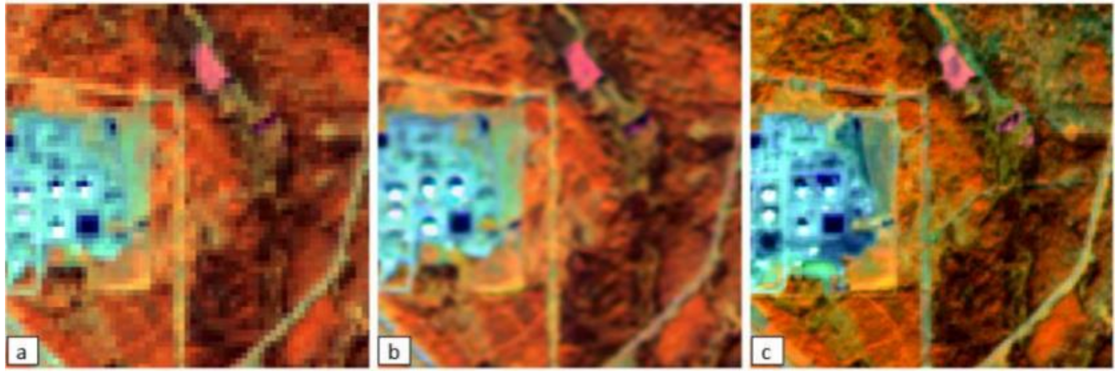
Earth observation application

Use same sensor with different spatial resolution :



Lanaras, Charis, José Bioucas-Dias, Silvano Galliani, Emmanuel Baltsavias, et Konrad Schindler. « Super-Resolution of Sentinel-2 Images: Learning a Globally Applicable Deep Neural Network ». ISPRS Journal of Photogrammetry and Remote Sensing 146 (décembre 2018): 305-19. https://doi.org/10.1016/j.isprsjprs.2018.09.018.

Use another sensor as proxy for high resolution :

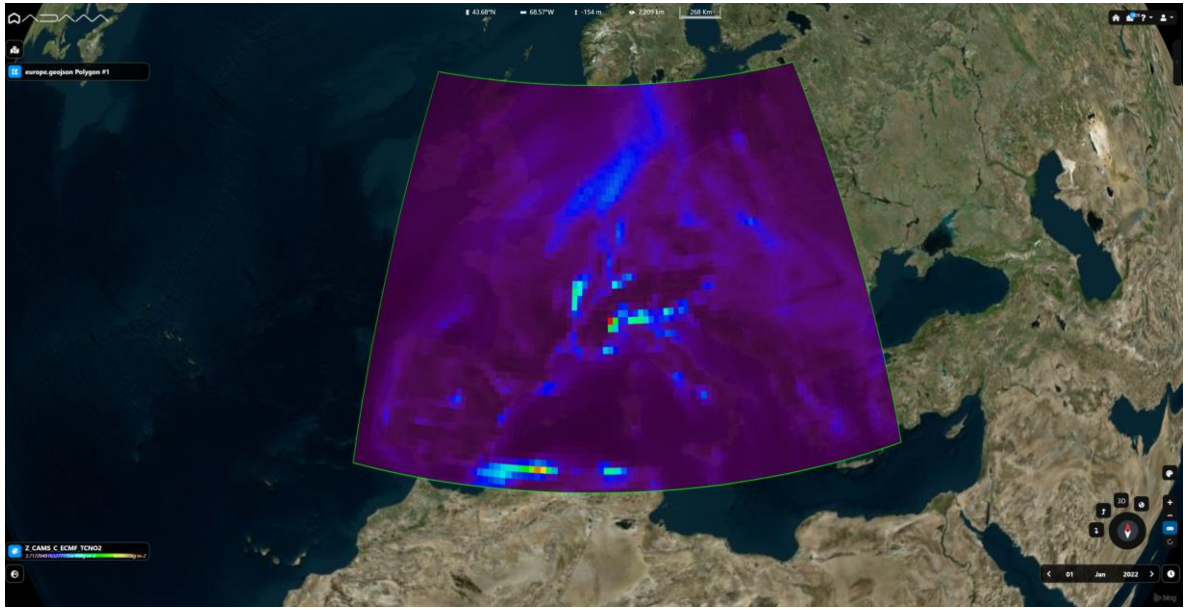


Landsat (30m) SR result (10m) Sentinel-2 (10m)

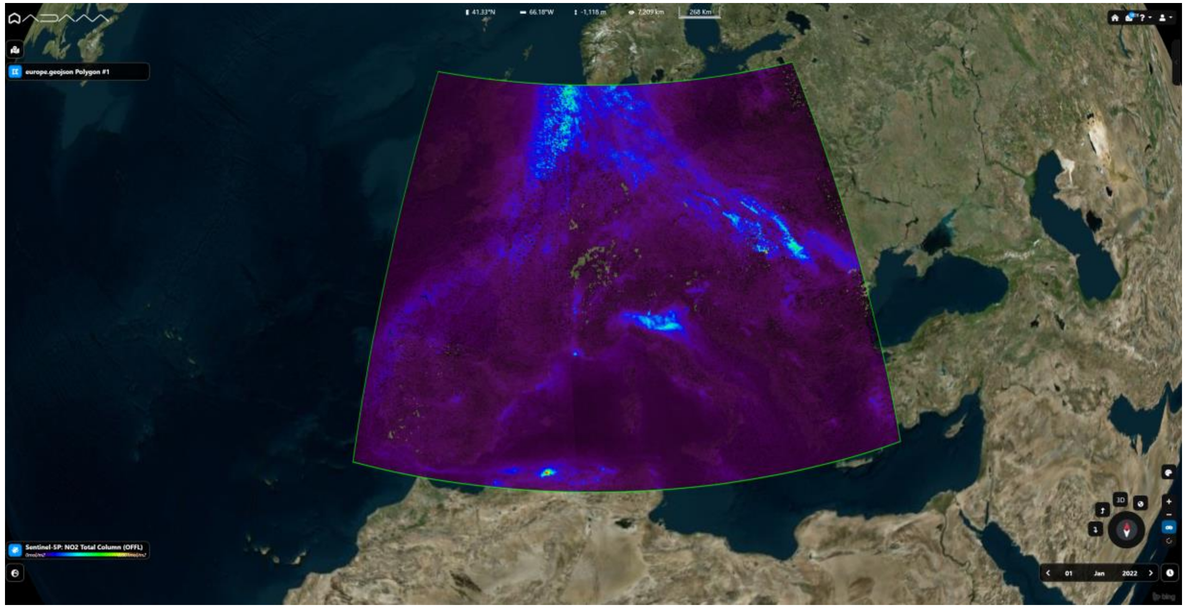
Pouliot, Darren, Rasim Latifovic, Jon Pasher, et Jason Duffe. « Landsat Super-Resolution Enhancement Using Convolution Neural Networks and Sentinel-2 for Training ». Remote Sensing 10, nº 3 (3 mars 2018): 394. https://doi.org/10.3390/rs10030394.

How to enhance spatial resolution

Atmospheric monitoring



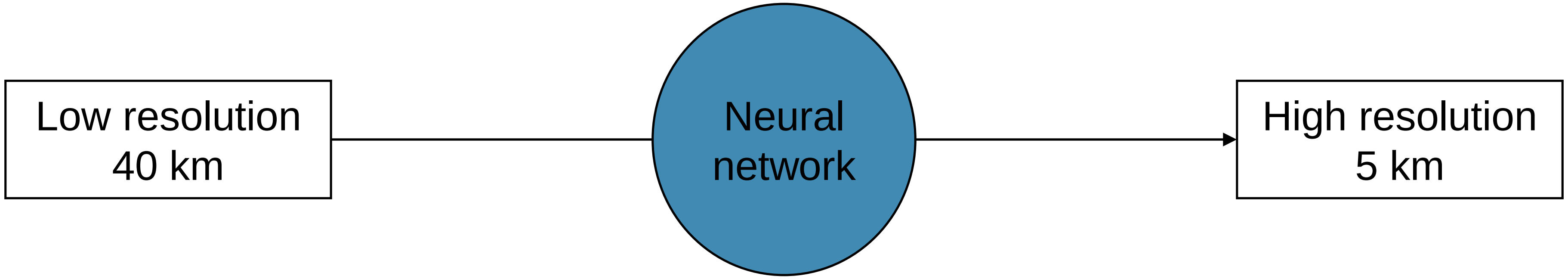
Global scale CAMS : Europe
Total Column NO_2 analysis *(kg/m²)*
40 km spatial resolution
Hourly temporal resolution



Global scale Sentinel-5p : Europe
Total Column NO_2 measurement *(mol/m²)*
5.5 x 3.5 km spatial resolution
Daily temporal resolution

How to enhance spatial resolution

Objective



High upscaling factor

Non exact temporality

Presence of artefact (NaN values)

Several models for different upscaling

Matching the data at the closest

Image selection

Working on remote sensing data

Geographical Referencement

Input

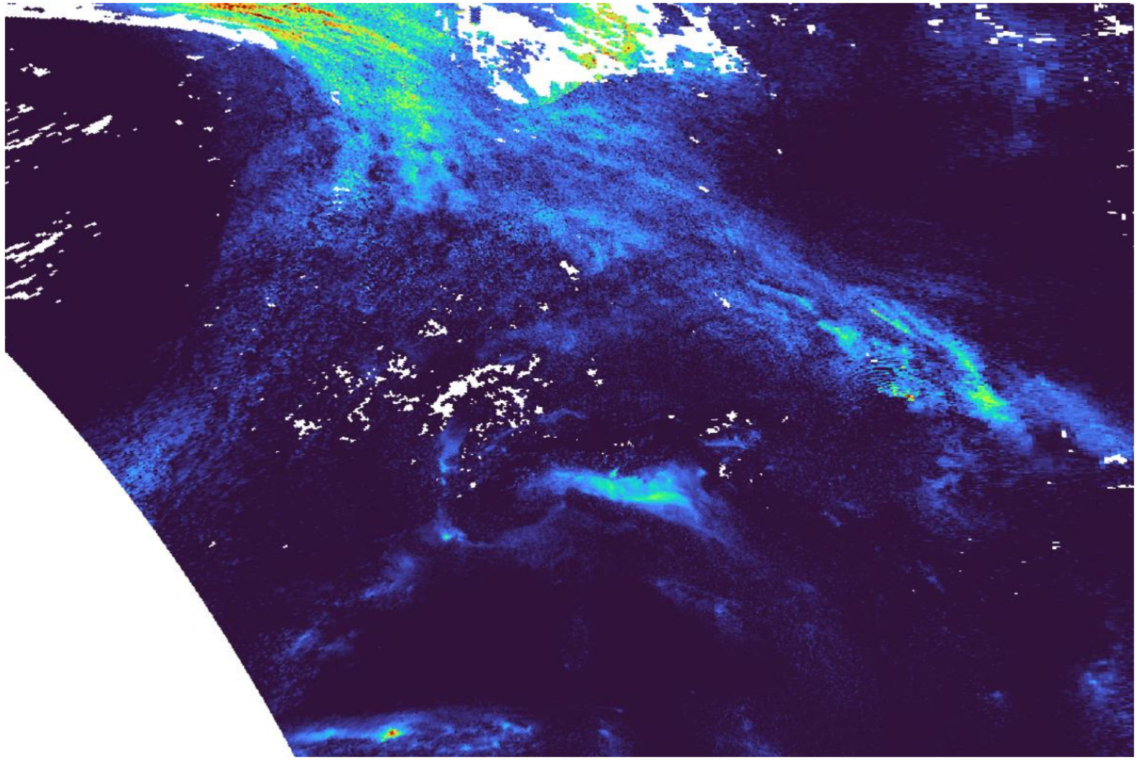
Target

Preprocessing

CAMS

Sentinel-5p

Geo Referencement



CAMS NO_2 TC analysis
2022-01-01 T12:30

S5P NO_2 TC measurement
2022-01-01 T13:07

Extracting the closest image in terms of spatial and temporal location.

Working on remote sensing data

Patch creation

Input

CAMS

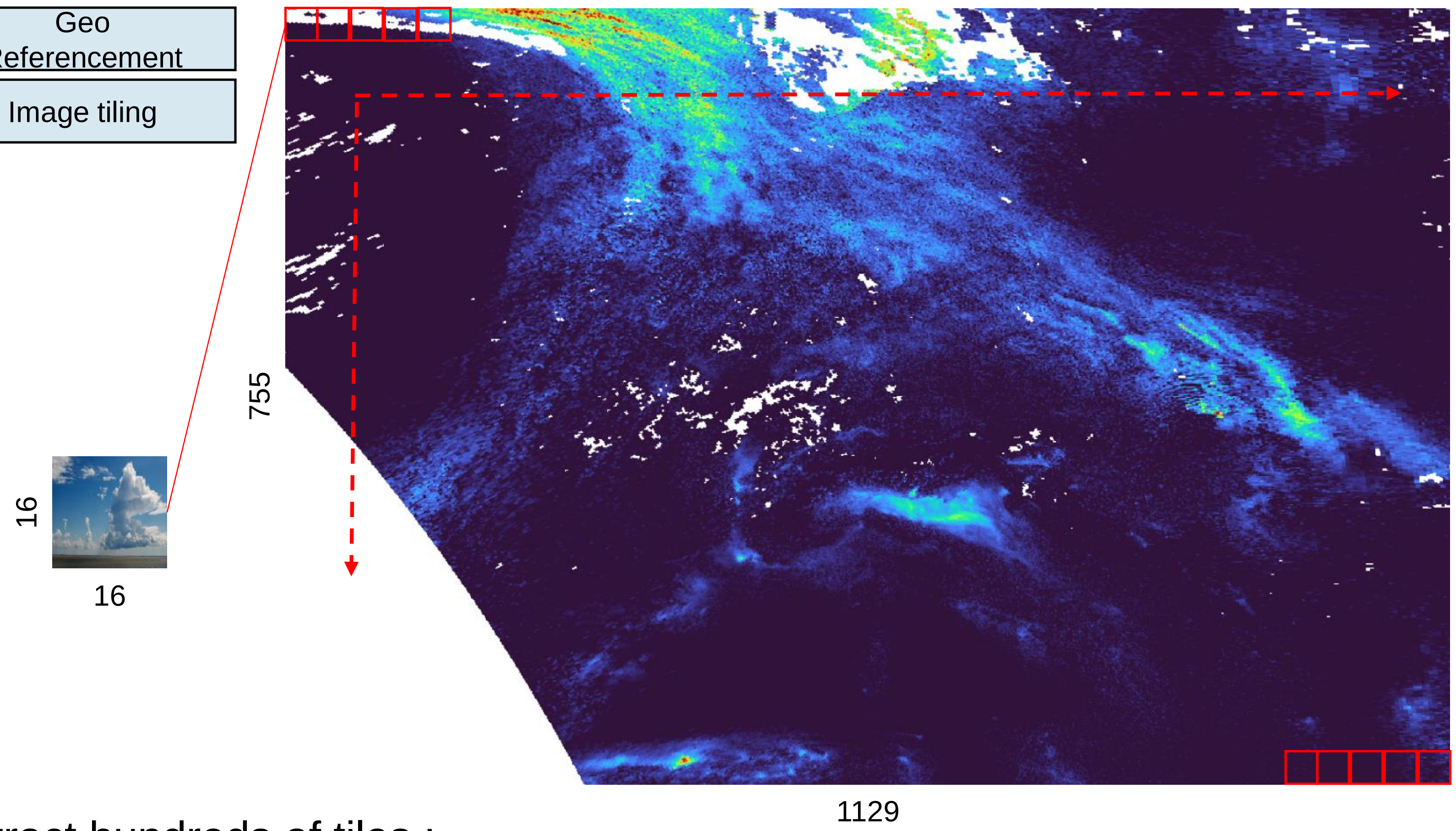
Target

Sentinel-5p

Preprocessing

Geo Referencement

Image tiling



Building a dataset on a global scale

From one single global image we extract hundreds of tiles :

We can then repeat for all the images collected.

Working on remote sensing data

Value optimization

Input

Target

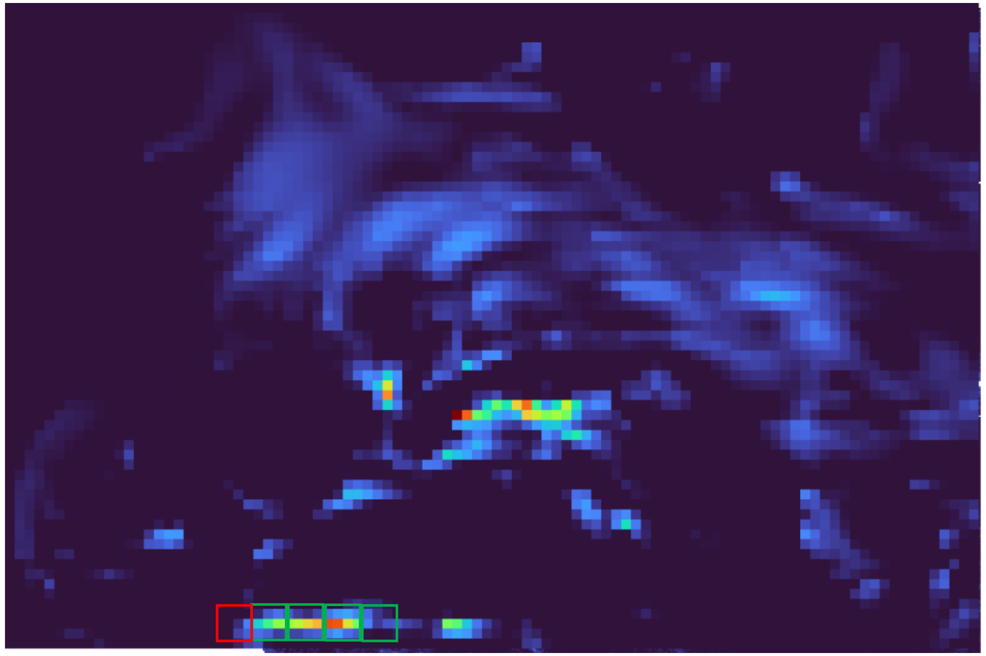
CAMS

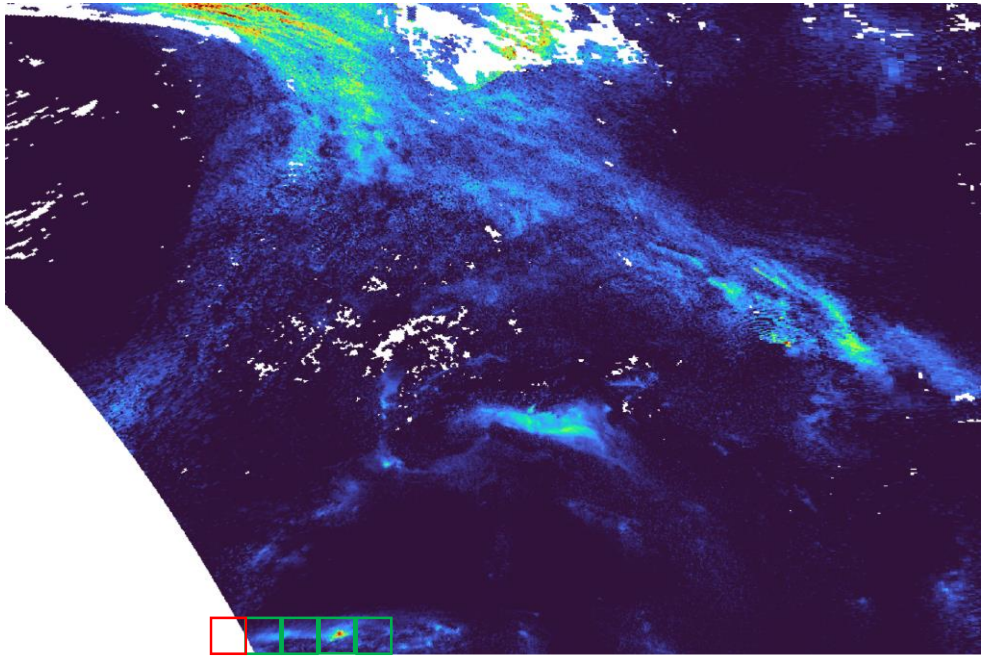
Sentinel-5p

Preprocessing

- Geo Referencement
- Image tiling
- Value verification
  - Conversion
  - NaN values

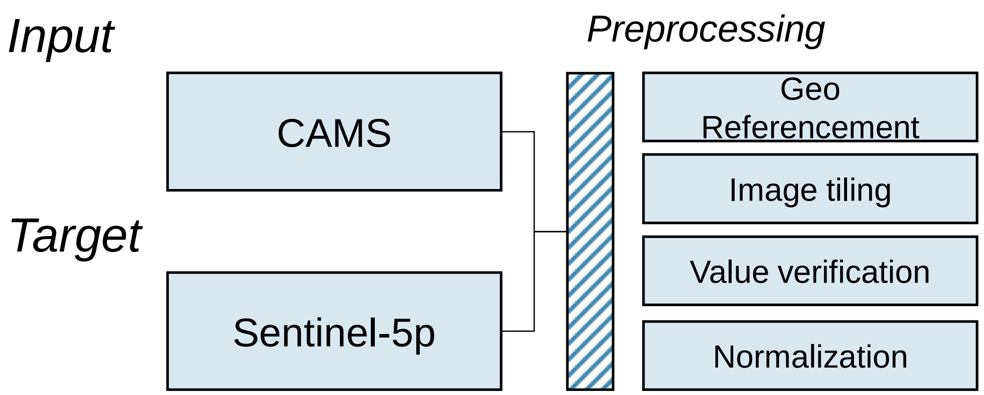
Sentinel-5p expressed in mol/m² ---> kg/m²



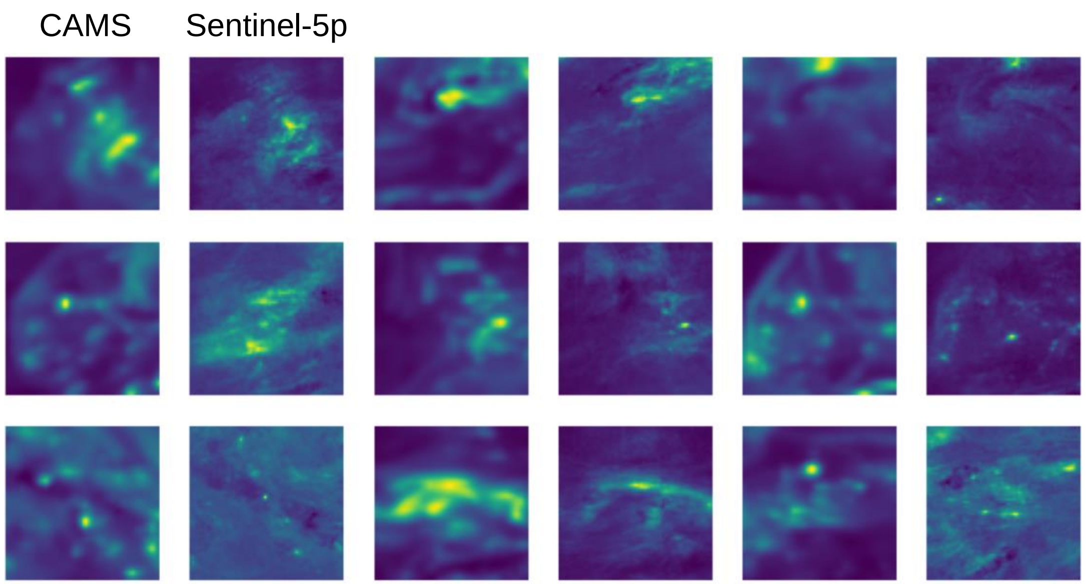


Working on remote sensing data

Normalization

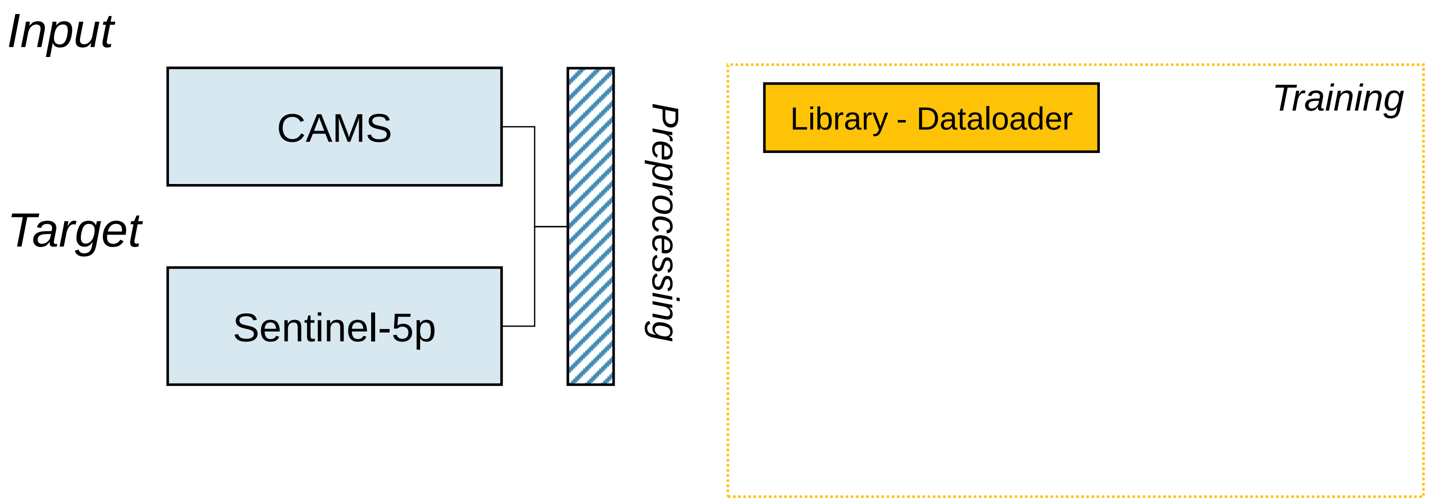


Scaling the values based on a specific range



Machine learning journey

Library



DataLoader :

Opening function of each patches to be analyzed during the training

Machine learning journey

FastAI Solution

Python solution on top of PyTorch developed by Jeremy Howard and Rachel Thomas :

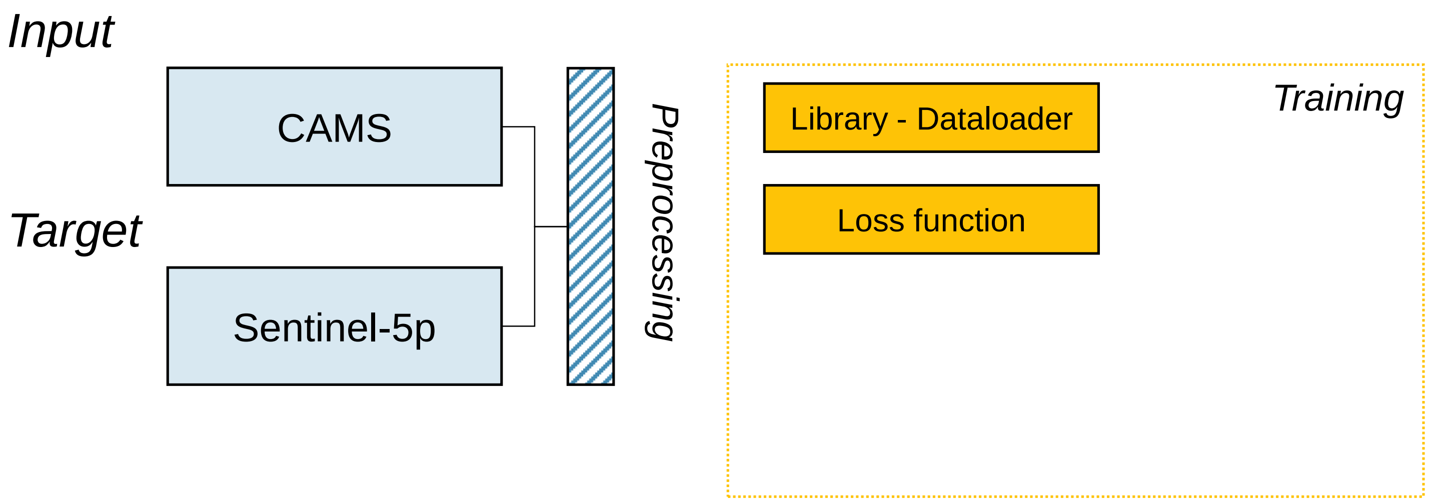
*«fastai is organized around two main design goals: to be **approachable** and rapidly **productive**, while also being deeply **hackable** and **configurable**.»*

- Fast access to Deep Learning architecture
- State of the art exploitation
- Adjustable with different datasets / libraries

https://docs.fast.ai

Machine learning journey

Loss function



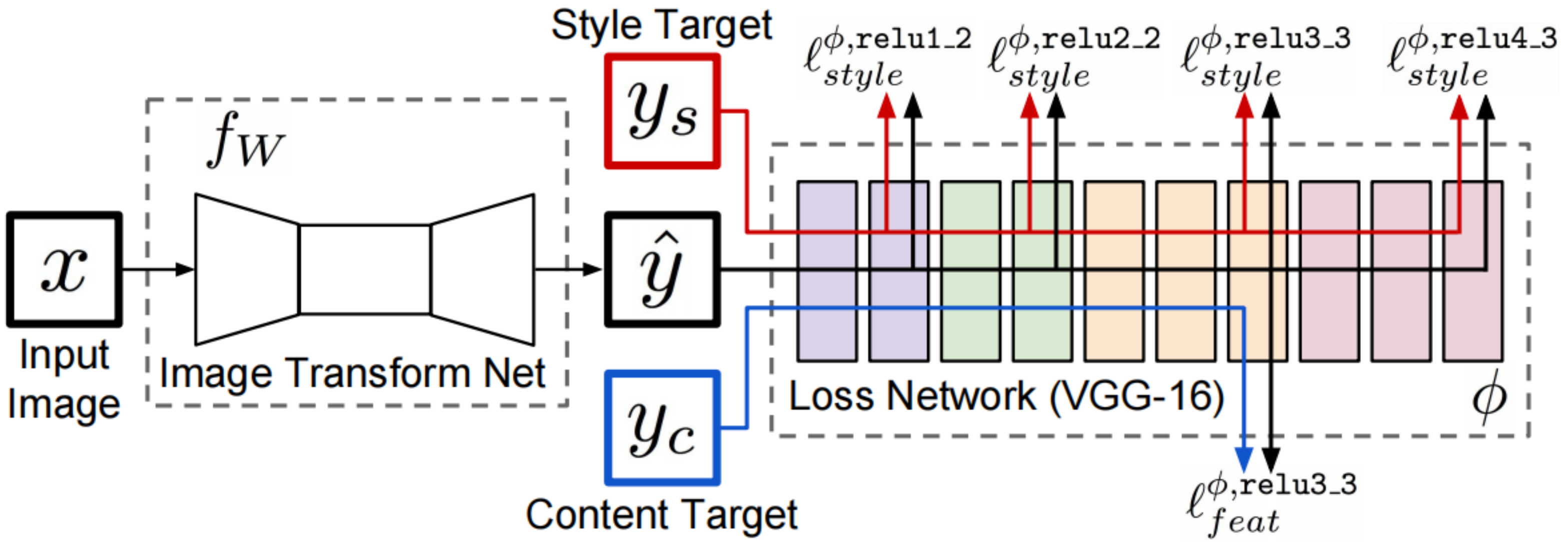
Also «error» function :

- Determine the loss / error between our output (Super resolved CAMS) and our target (Sentinel-5p).

- Lower is the loss more efficient the model is supposed to be.

Machine learning journey

Loss function

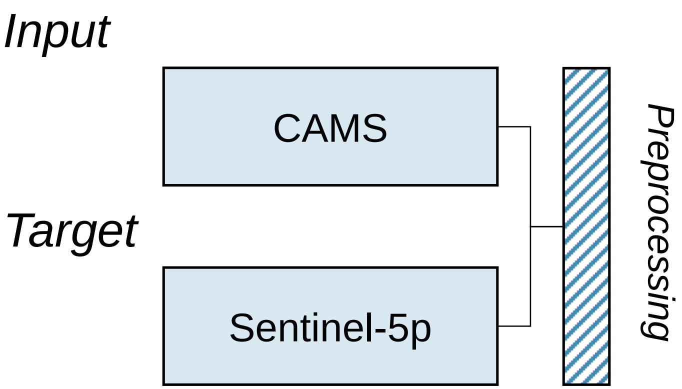


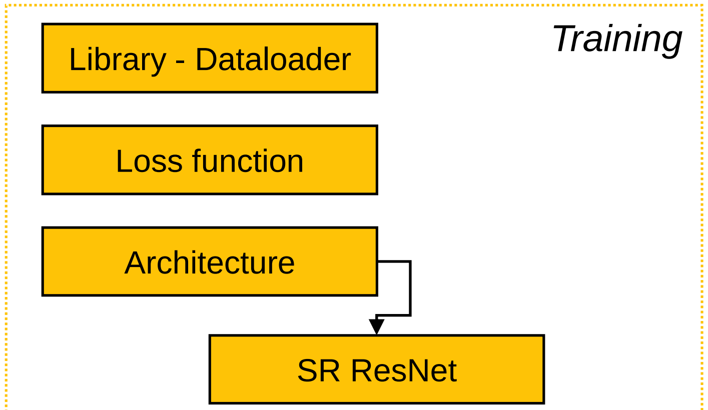
Johnson, Justin, Alexandre Alahi, et Li Fei-Fei. « Perceptual Losses for Real-Time Style Transfer and Super-Resolution ». ArXiv:1603.08155 [Cs], 26 mars 2016. http://arxiv.org/abs/1603.08155.

Feature loss :
- Style : visual structure of the image
- Content : pixel values of the image

Machine learning journey

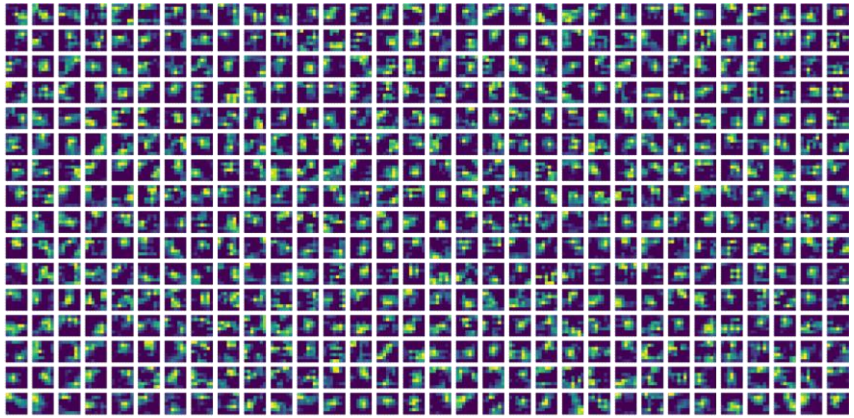
Architecture



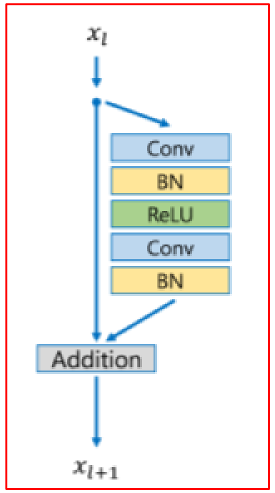


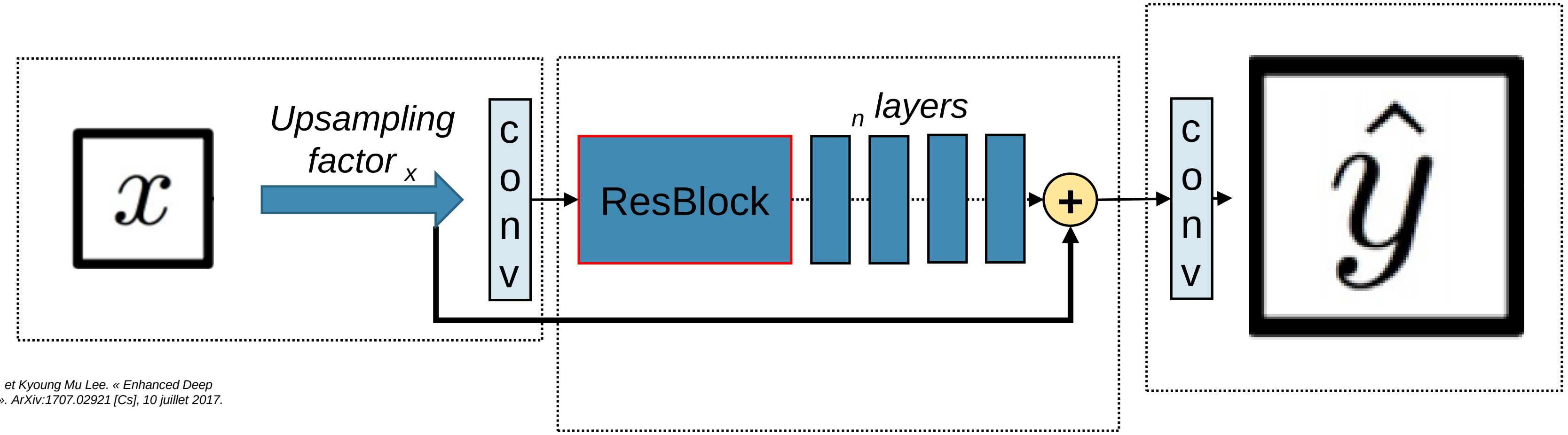
Ledig, Christian, Lucas Theis, Ferenc Huszar, Jose Caballero, Andrew Cunningham, Alejandro Acosta, Andrew Aitken, et al. « Photo-Realistic Single Image Super-Resolution Using a Generative Adversarial Network ». In 2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 105-14. Honolulu, HI: IEEE, 2017. https://doi.org/10.1109/CVPR.2017.19.

Feature extraction



https://medium.com/the-owl/extracting-features-from-an-intermediate-layer-of-a-pretrained-model-in-pytorch-c00589bda32b

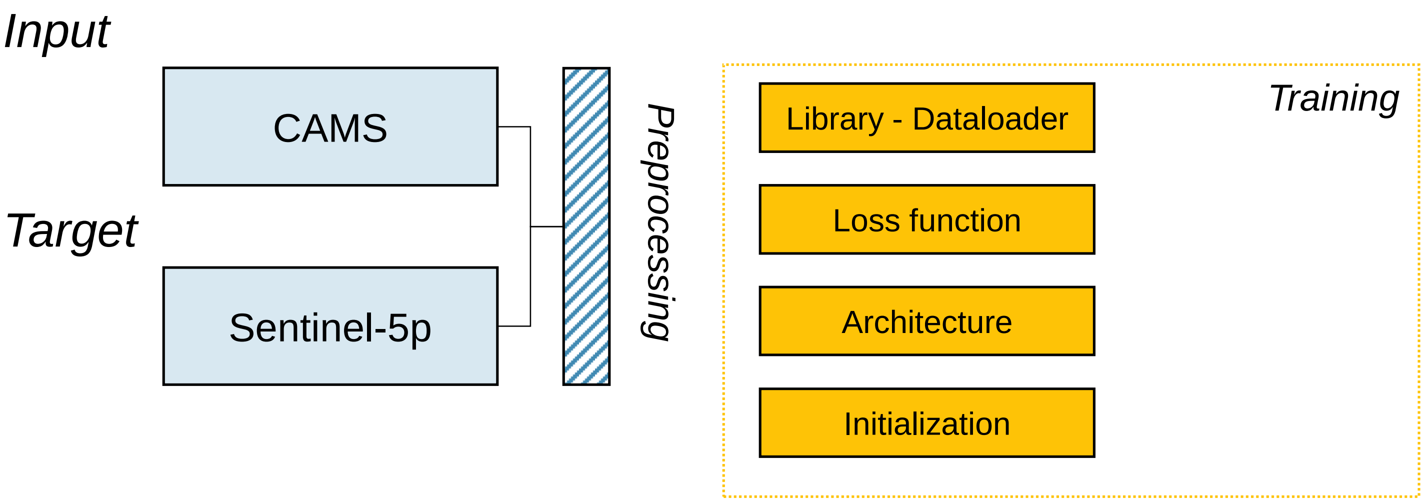




Lim, Bee, Sanghyun Son, Heewon Kim, Seungjun Nah, et Kyoung Mu Lee. « Enhanced Deep Residual Networks for Single Image Super-Resolution ». ArXiv:1707.02921 [Cs], 10 juillet 2017. http://arxiv.org/abs/1707.02921.

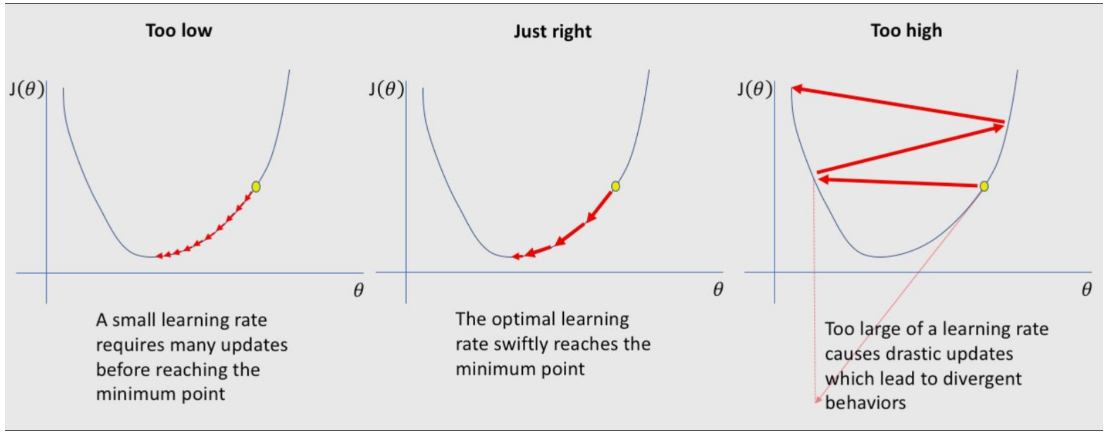
Machine learning journey

Initialization



Batch Size :
Number of sample to work through before update of the model parameters

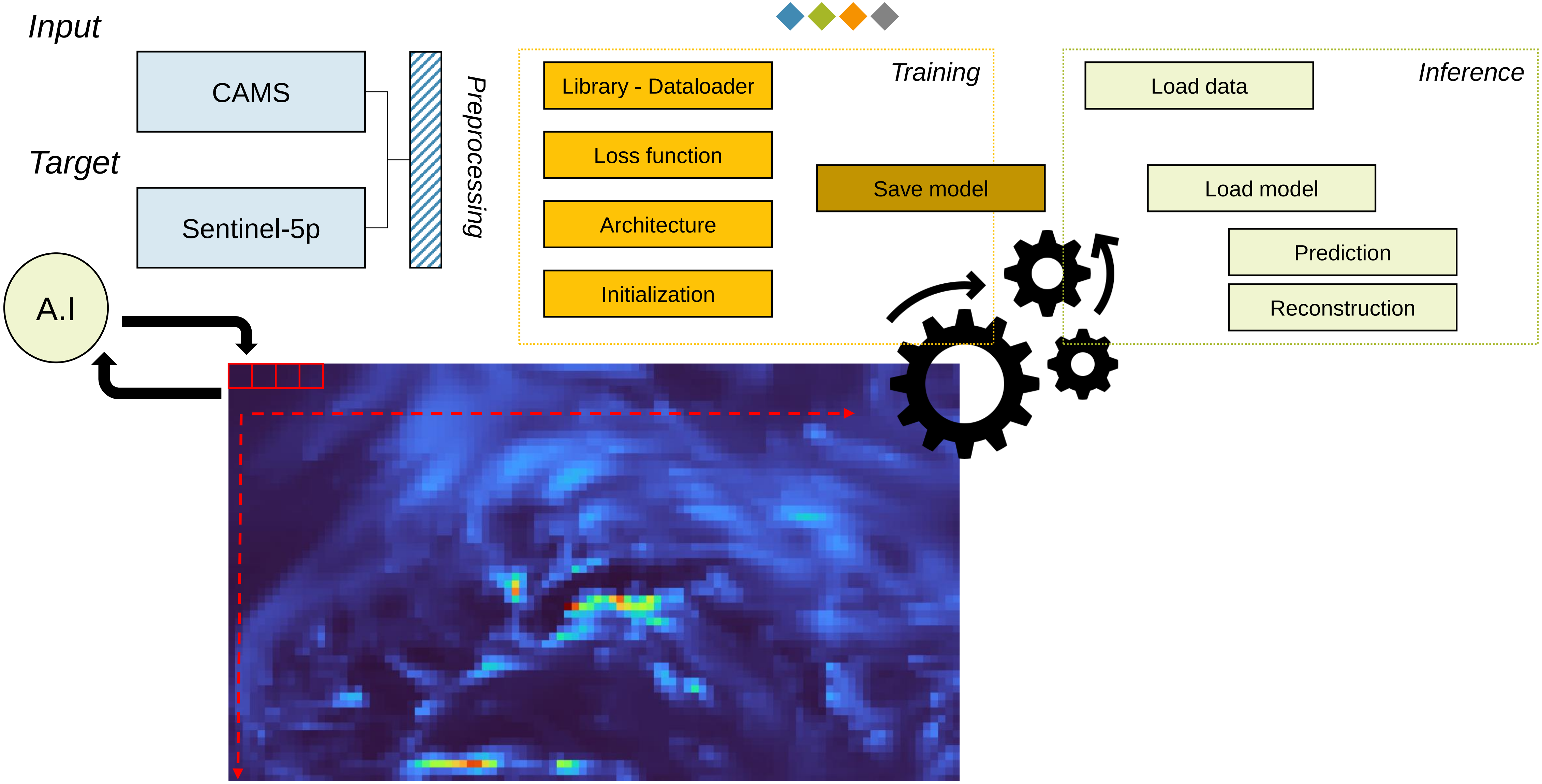
Learning rate



Epochs :
Loops for training

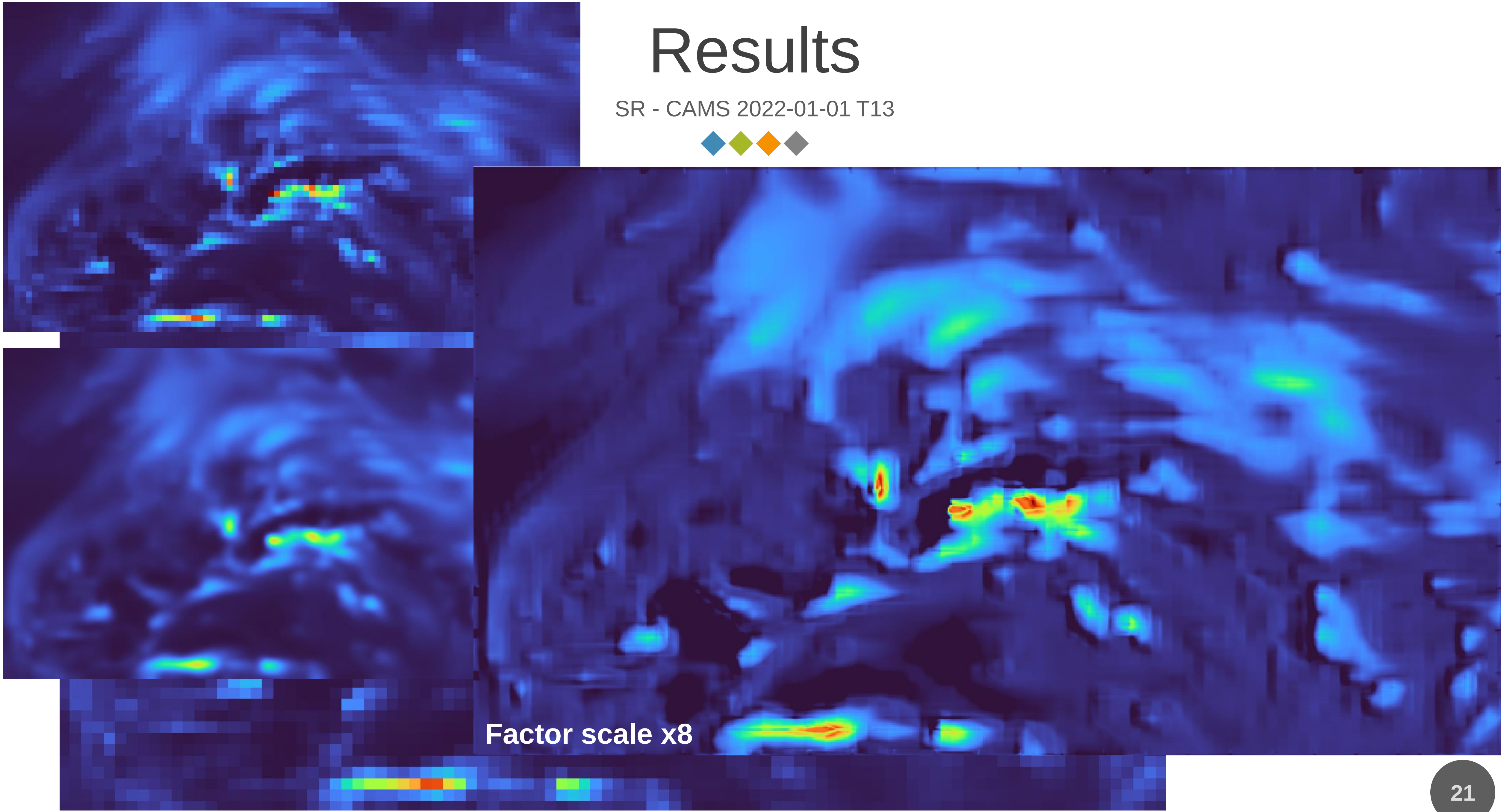
Machine learning journey

Inference



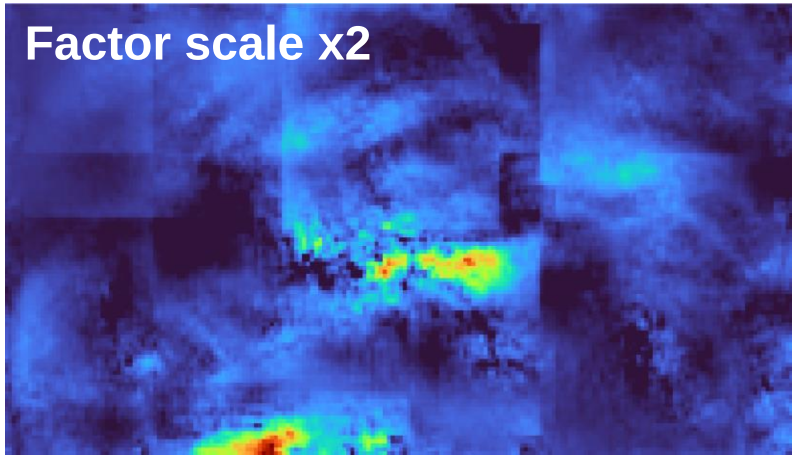
Results

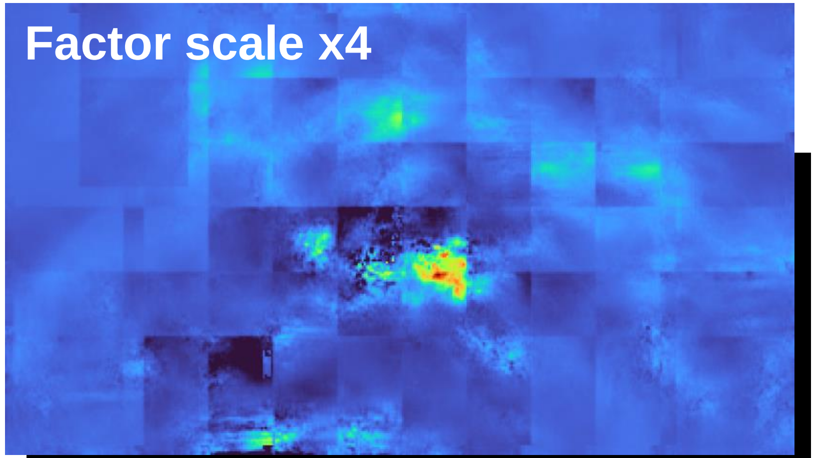
SR - CAMS 2022-01-01 T13



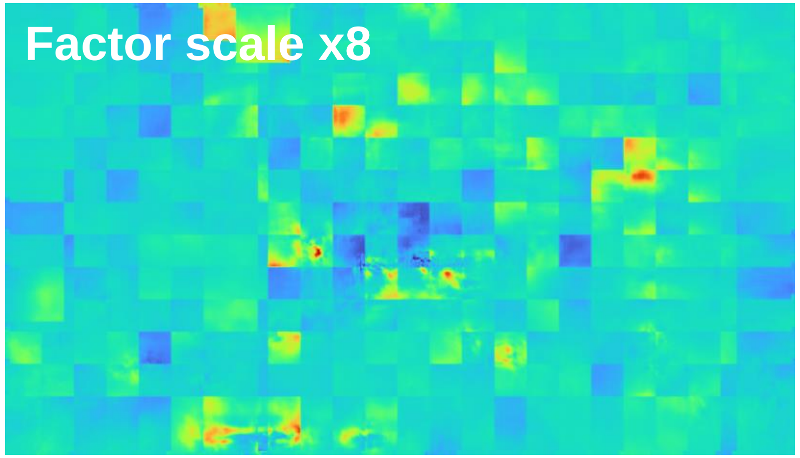
Results

Sometimes it doesn't go well





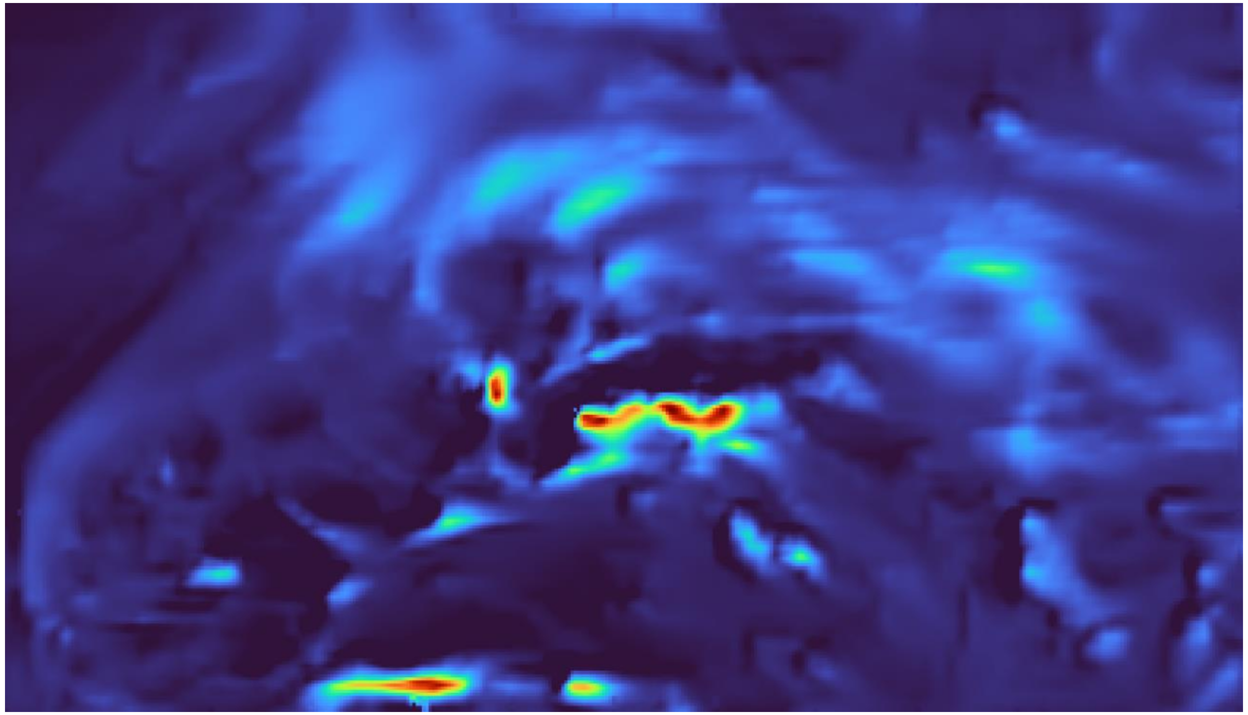
Convergence but still gridding effects th[redacted]

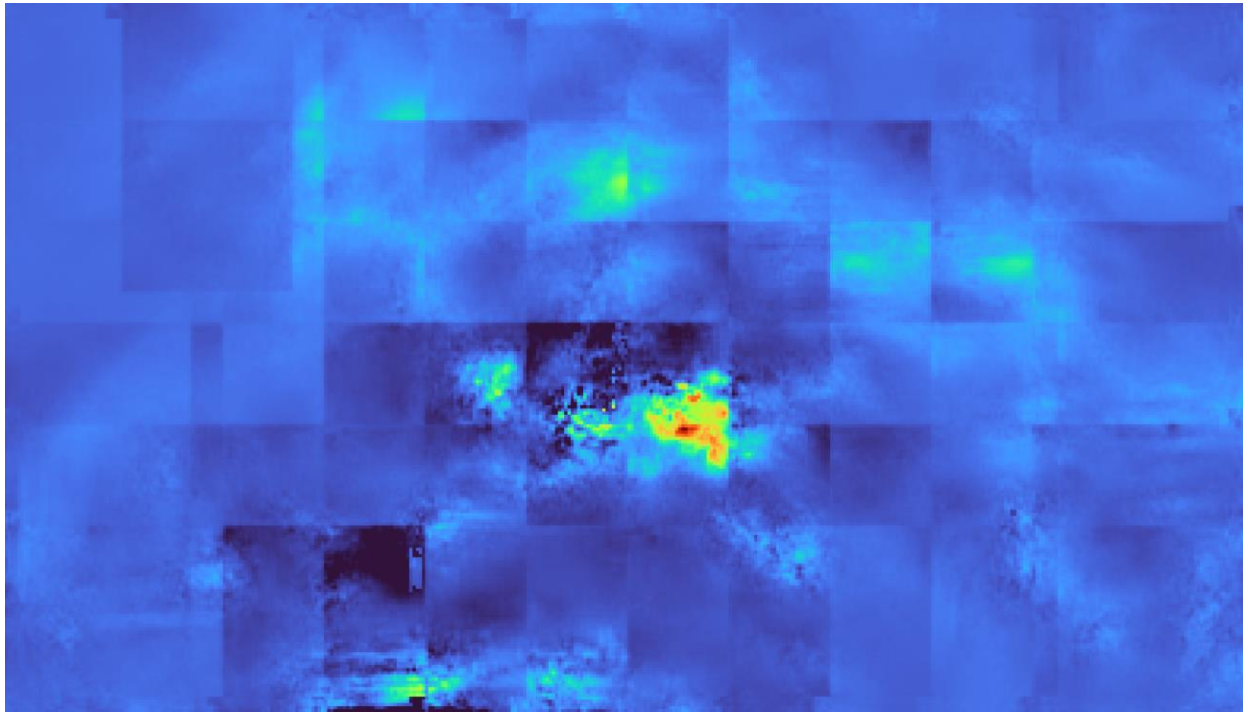


No convergence --> no consistency

Results

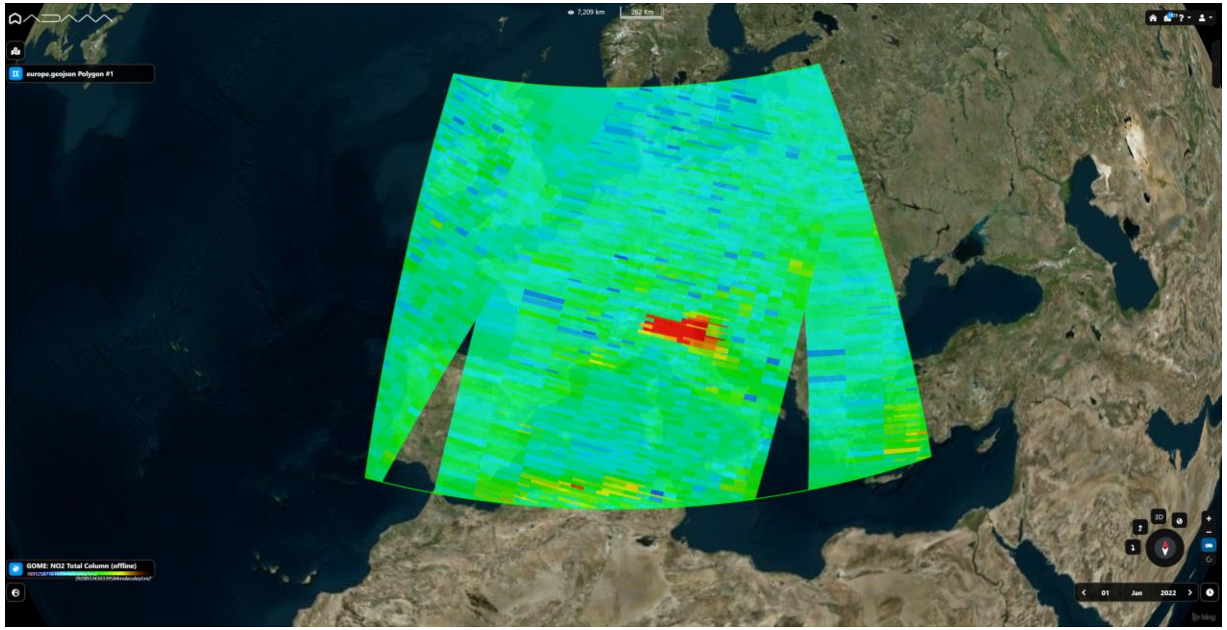
What is expected ?



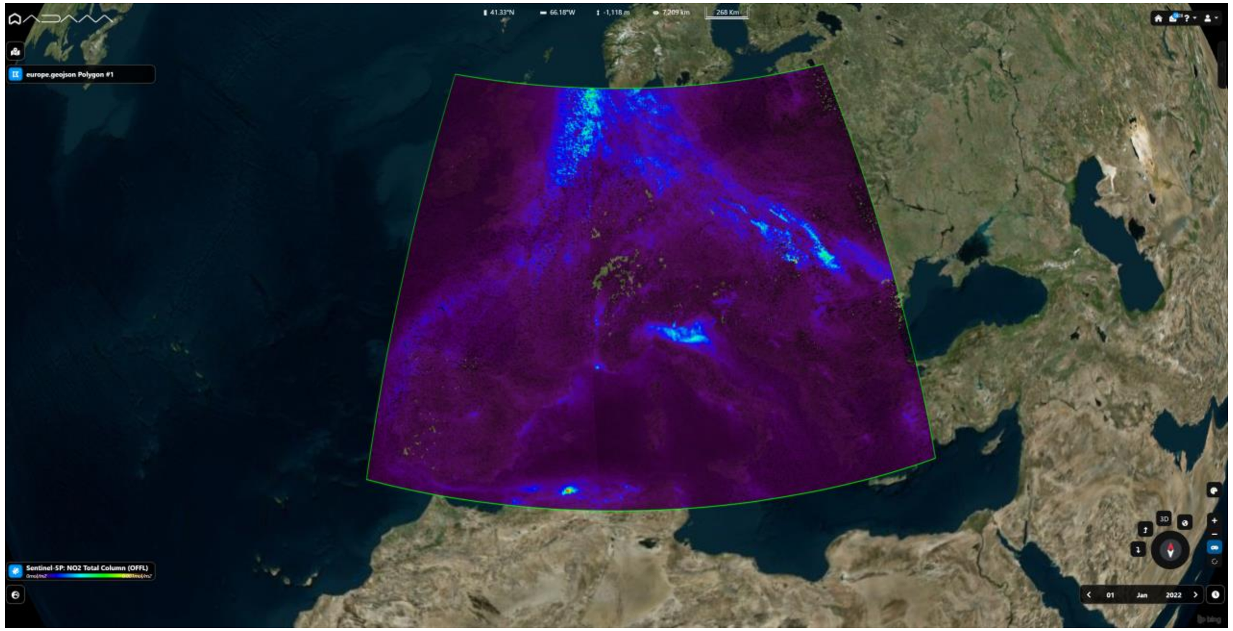


Next steps

Other sensors



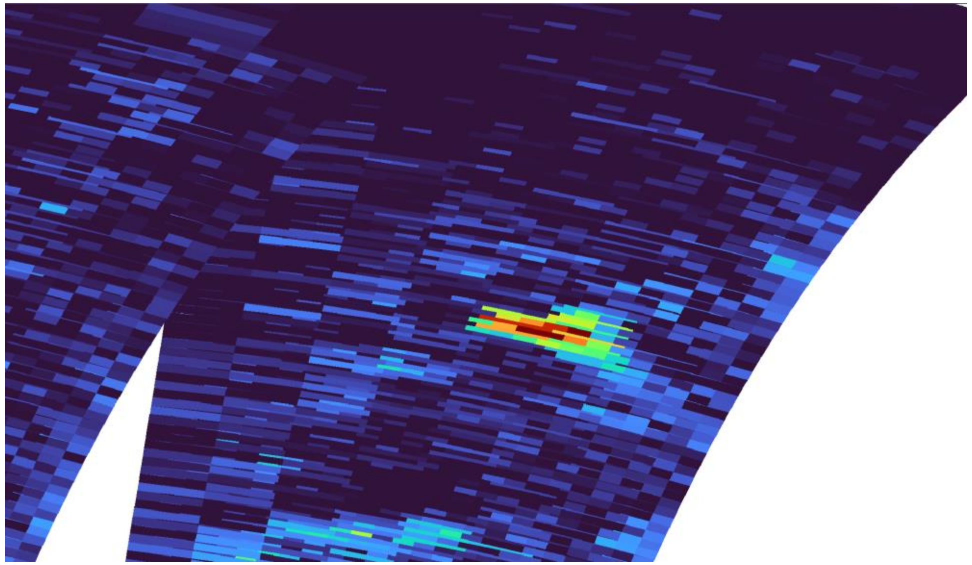
Global scale GOME (Metop-B) : Europe
Total Column NO_2 measurement *(molecule/cm²)*
80 x 40 km spatial resolution
Daily temporal resolution

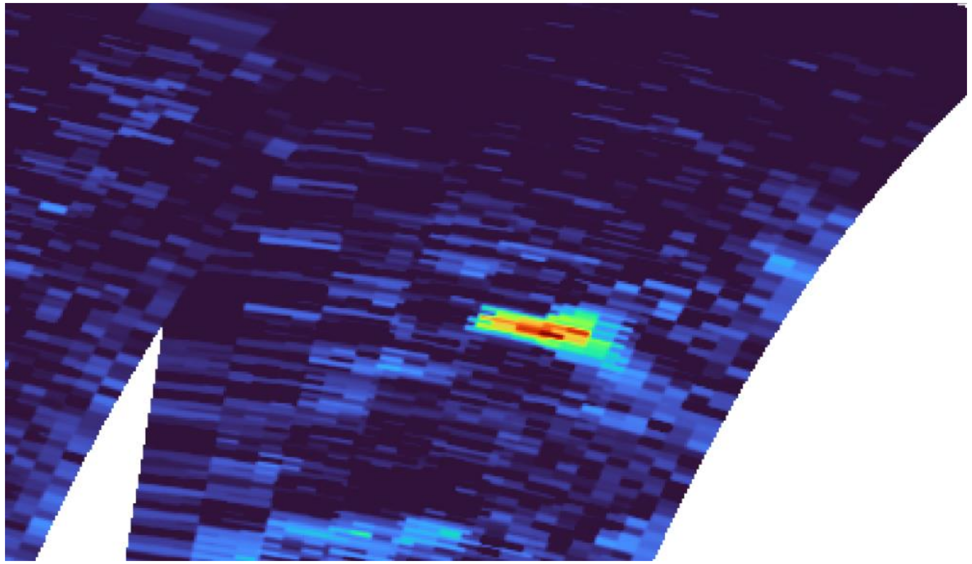


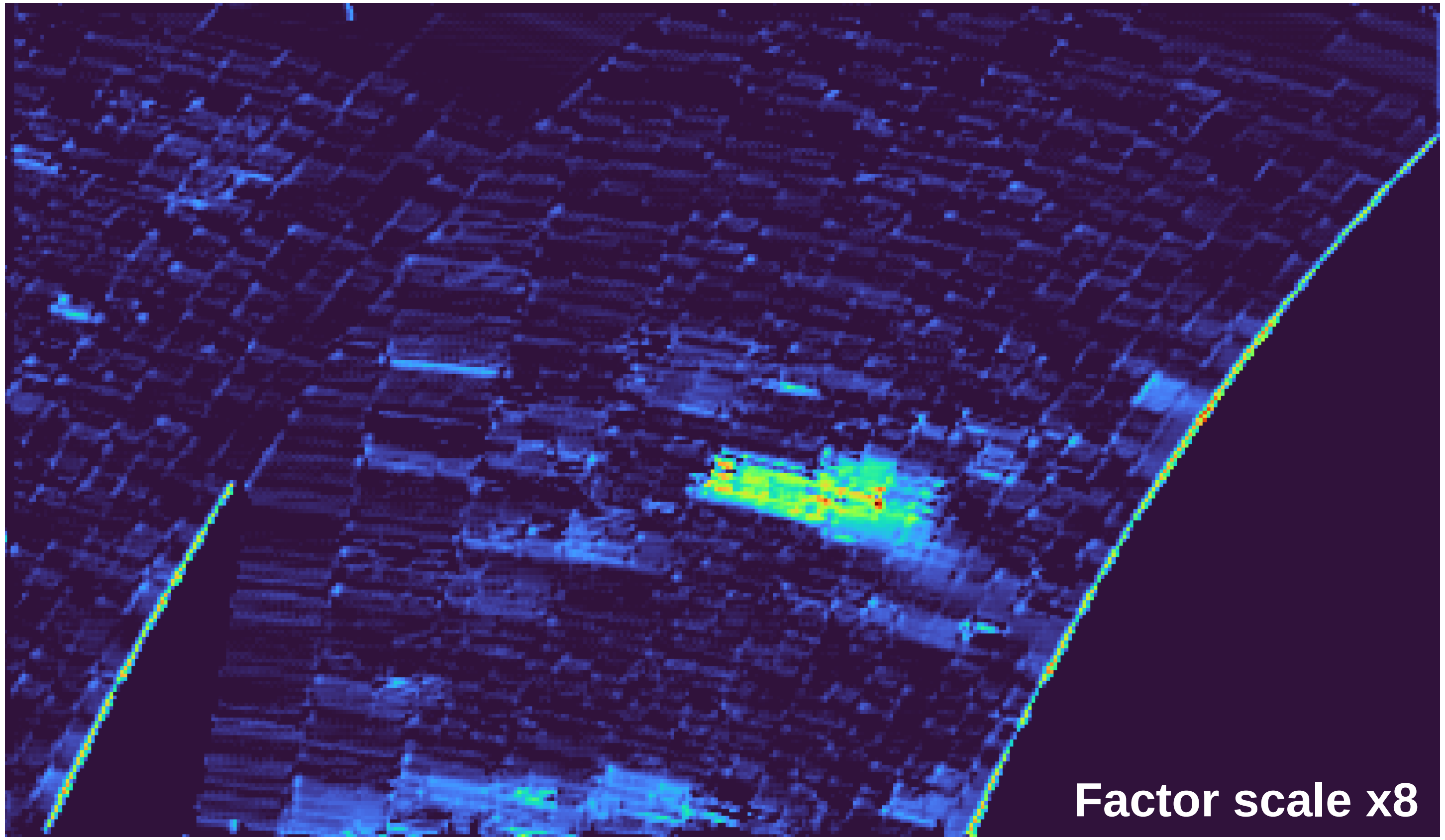
Global scale Sentinel-5p : Europe
Total Column NO_2 measurement *(mol/m²)*
5.5 x 3.5 km spatial resolution
Daily temporal resolution

Results

SR - GOME 2022-01-01

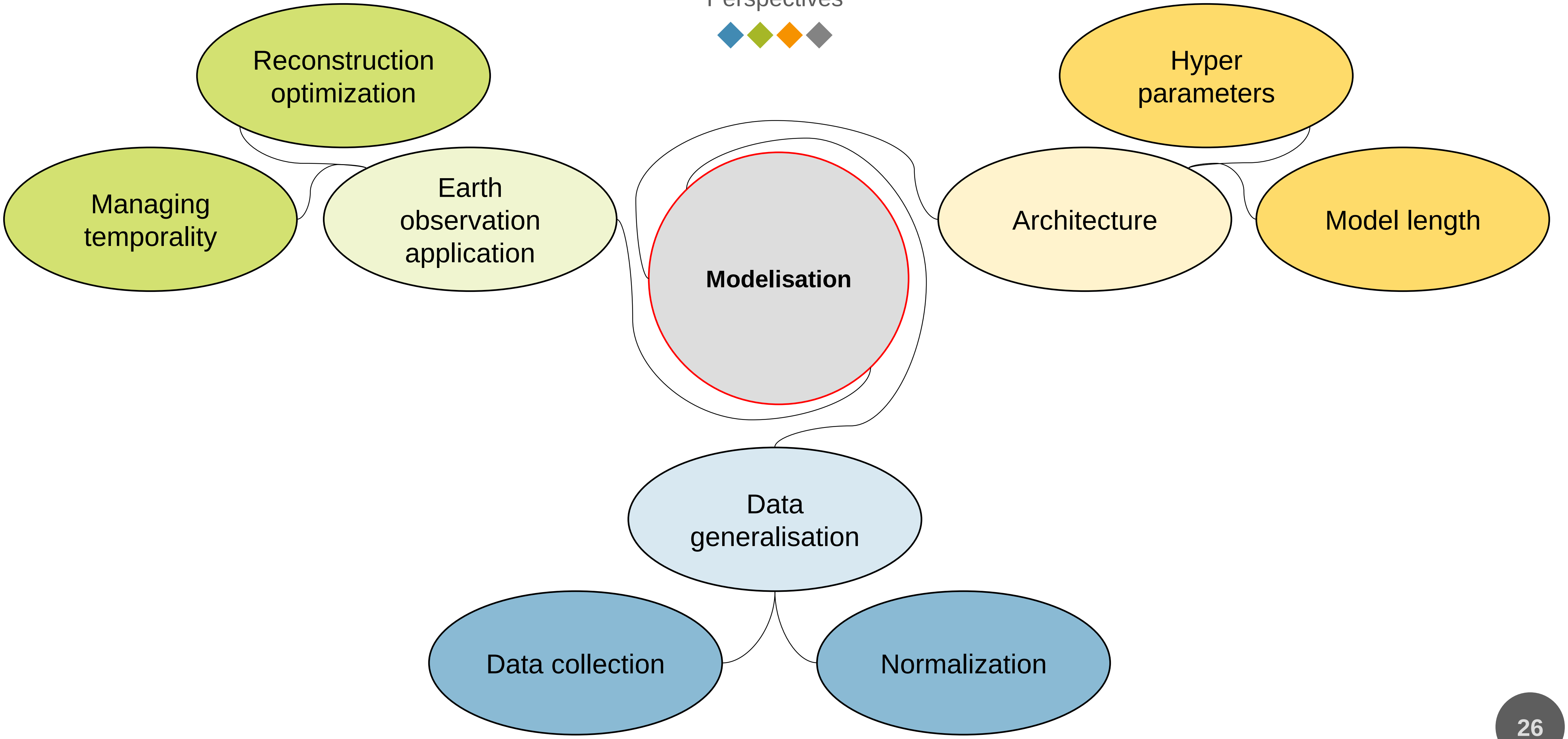






What’s next ?

Perspectives



Thank you for your attention

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