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In collaboration with

MEOSS
MAPS EARTH OBSERVATION SATELLITE SERVICES

CESBIO

Super-Resolution Applied To Sentinel-2 for EO Applications and Services

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Project ambition

Single Image Super Resolution :

Sentinel-2 :
10m : B2, B3, B4, B8
20m : B5, B6, B7, B8a

→

Venµs :
5m : B2, B3, B4, B8, B5, B6, B7, B8a

Pan Sharpening :

Sentinel-2 :
10m : B2, B3, B4, B8
20m : B5, B6, B7, B8a, B11, B12

→

Sentinel-2 SR :
5m : B11, B12

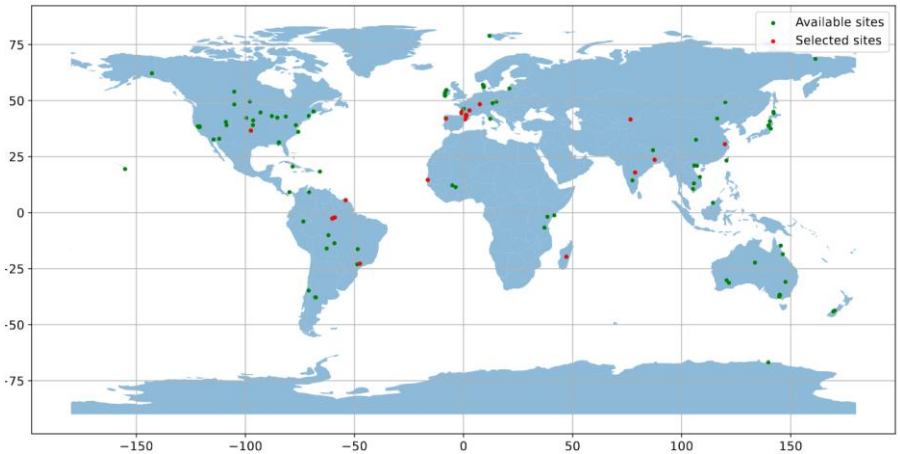
No high resolution reference!

Validation on actual EO applications

Our method for Super resolution applied to Sentinel-2

SEN2VENµS Dataset

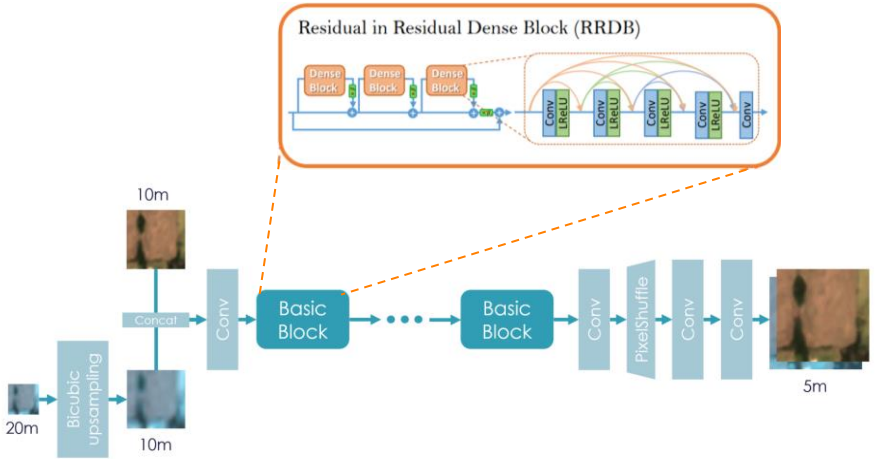
- SISR dataset Sentinel-2 → VENµS, by CESBIO
  - 132 955 patches
  - 29 locations
  - 8 Sentinel-2 bands, from 10m/20m to 5m (VENµS resolution)
  - Open Dataset made available on Zenodo : https://zenodo.org/record/6514159



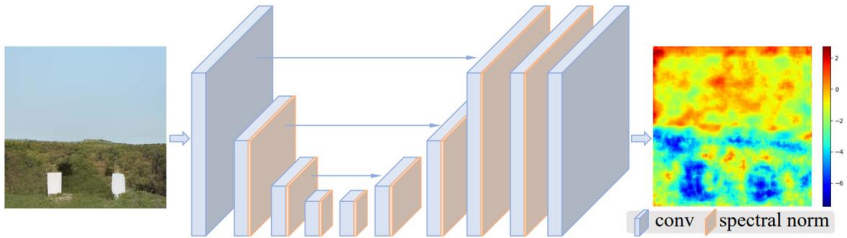
Our method for Super resolution applied to Sentinel-2

Use of the **ESRGAN** architecture for the Generator and **Real-ESRGAN** Discriminator :

Adaptation of ESRGAN Generator architecture



Real-ESRGAN U-Net Discriminator architecture



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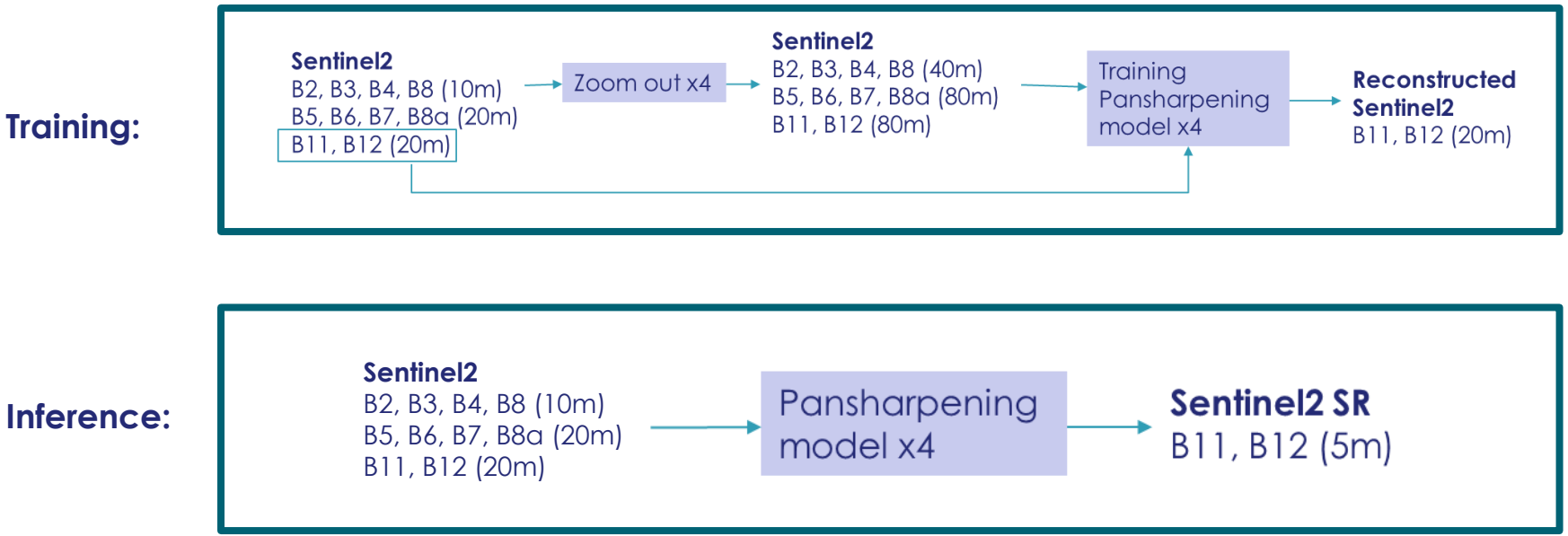
Our method for Super resolution applied to Sentinel-2

Use of the WALD protocol for Pan sharpening of B11 and B12 bands



Our method for Super resolution applied to Sentinel-2

VENµS images

Problem : small geometric and radiometric distortion appears in the dataset.

Our method for Super resolution applied to Sentinel-2

Sentinel-2 images

Problem : small geometric and radiometric distortion appears in the dataset.

Our method for Super resolution applied to Sentinel-2

A naively trained network learns the geometric and radiometric bias

Sentinel-2 image
Bicubic up sample

Our method for Super resolution applied to Sentinel-2

A naively trained network learns the geometric and radiometric bias

ESRGAN output
RGB 5m

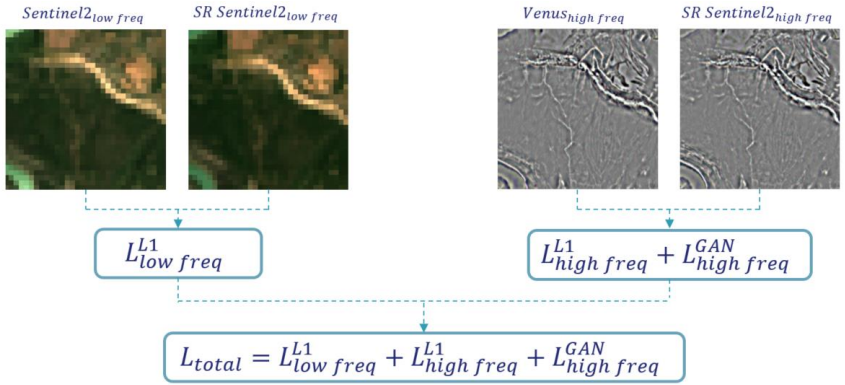
Our method for Super resolution applied to Sentinel-2

A naively trained network learns the geometric and radiometric bias

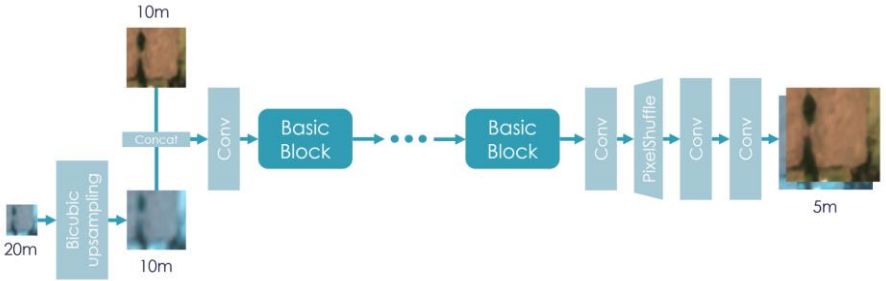
VENµS image
RGB 5m

Our method for Super resolution applied to Sentinel-2

2 main solutions were used



1: Separation of High and Low frequencies in the training loss



2: Carefully chosen network depth

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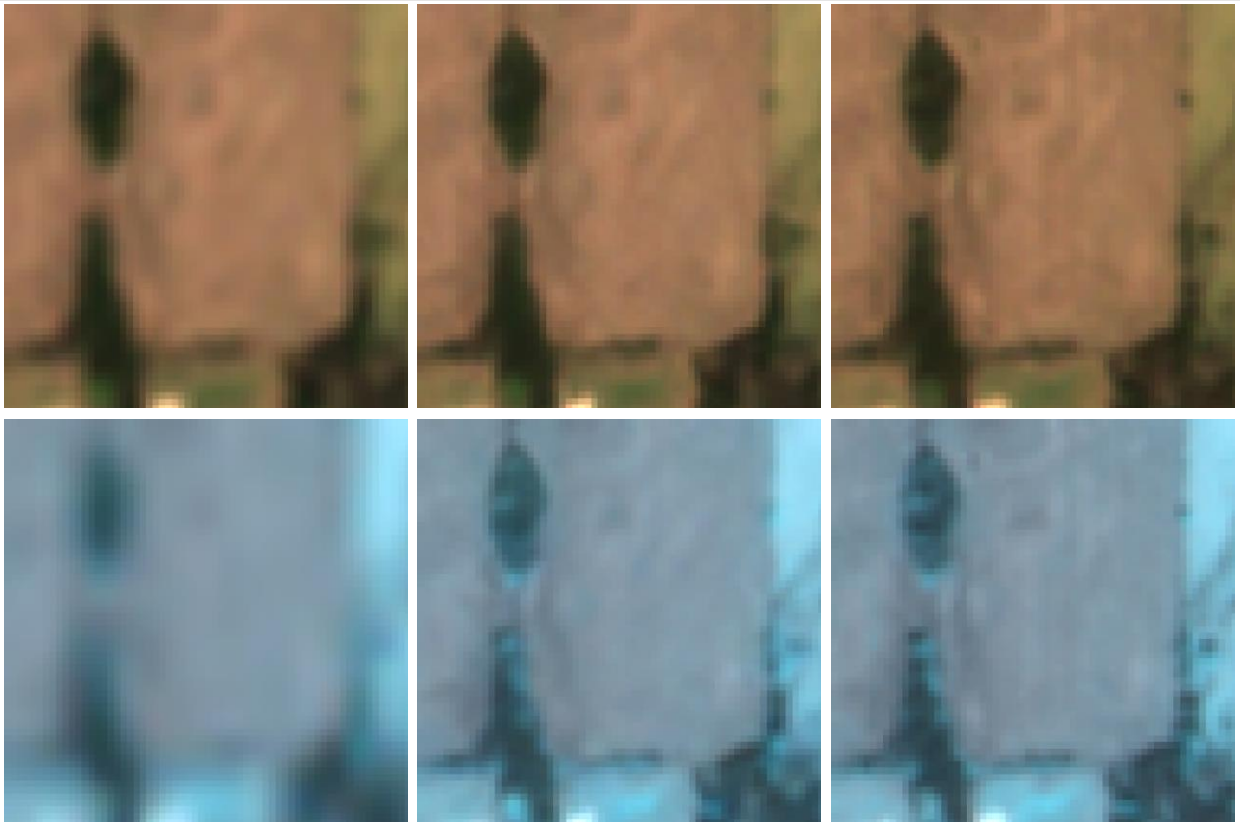
Validation independent of EO applications

Bands B2 B3 B4
10m -> 5m

Bands B5 B6 B7
20m -> 5m



Sentinel-2
Bicubic up sample

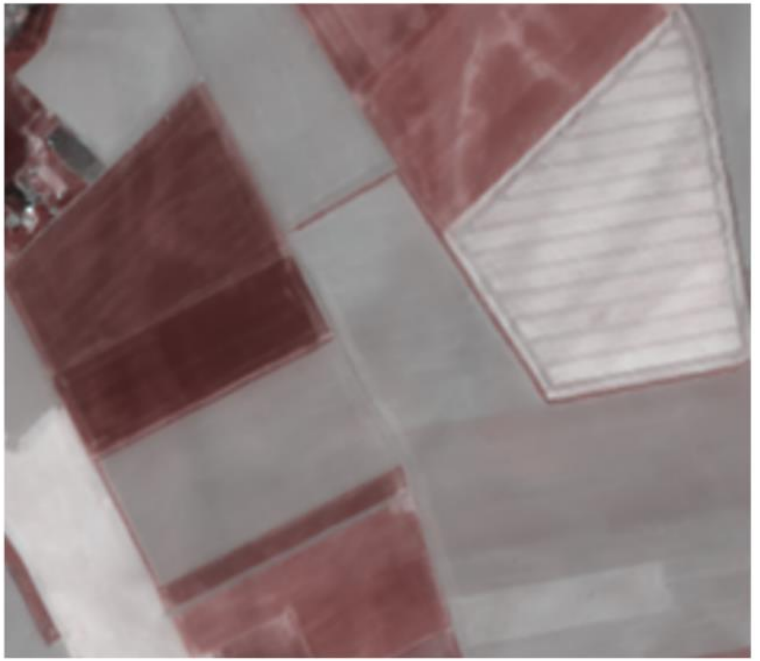
Sentinel-2 SR with our method

Venμs

Validation independent of EO applications

Bands B11 B12
20m -> 5m

Sentinel-2
Bicubic up sample



Sentinel-2 SR with Wald
protocol

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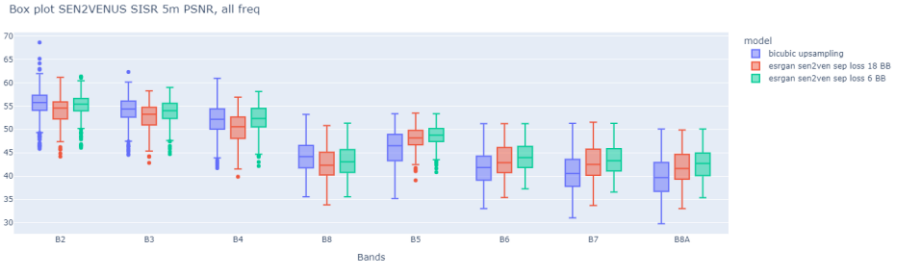
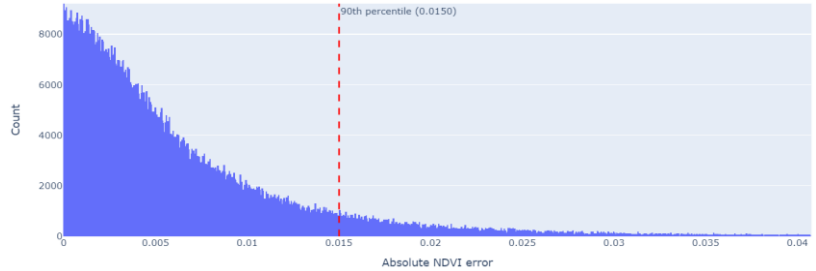
Validation independent of EO applications

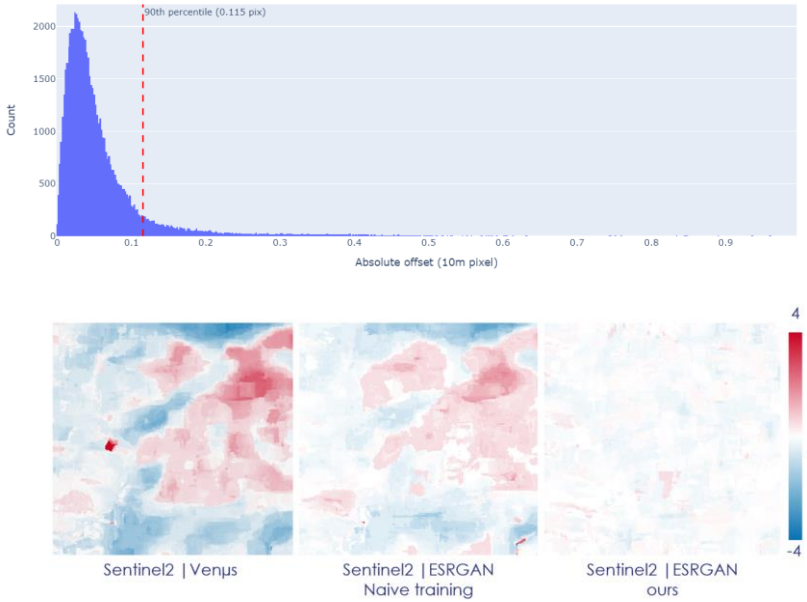
Careful validation of low frequencies conservation, and geometric distortions



Per band analysis



Biophysical indices analysis



Geometric distortion analysis

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Validation dependent of EO applications

Validation with application-related performance metrics

Quantitative assessment of extracted information from images

- On multiple scales :
  - **Pixel**-by-pixel based statistics
  - **Object**-oriented classification
- Using several reference databases :
  - Local and thematic **databases available** in open source or provided by end-users
  - **Classified data from the original images** from MEOSS **current tools**

→ Difference of performance between the two data sources to be evaluated to provide a **quantitative estimation of the gains/losses** in quality and performance

Use case studied by MEOSS: Water Resources Estimation

Additional use case studied by Thales: Land cover maps

3 sites selected for the validation :
- Cannes
- Pays basque
- Gers

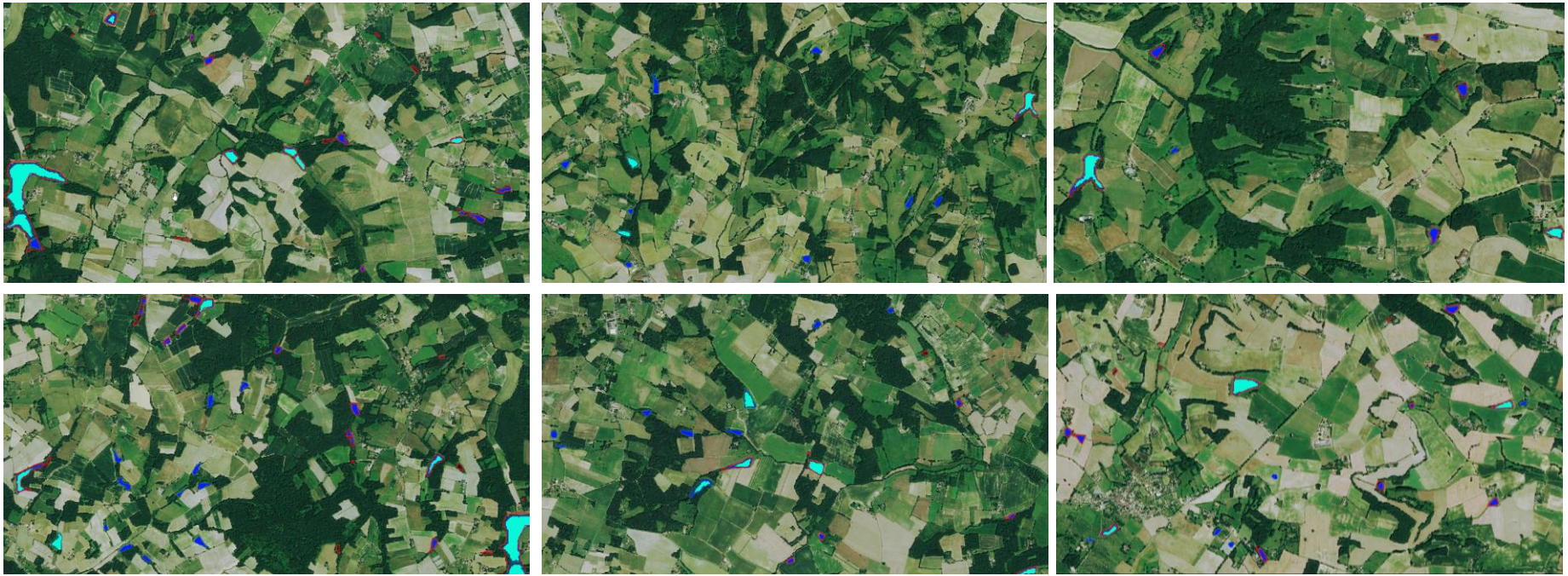
Use-case assessment: Water Resource

Category	Sentinel-2 L2A (10m) VNIR Bands + SWIR (20m)	Super-Resolution (5m) VNIR Bands + SWIR	Gain/loss
Total number of objects detected	1035	3099	About 200 %
Total areas detected	2880 ha	3933,04 ha	+ 23 % of areas detected in addition
Cumulative areas of water bodies smaller than 0.5 ha	16 ha	260 ha	16 times more surface areas

- **+23%** areas detected
- **3 times more** objects detected
- **16 times more** surface areas for water bodies smaller than 0,5 ha
- **No augmentation of false positive**

Use-case assessment: Water Resource

Illustration of improved detections on small water bodies



Water bodies detected from Sentinel-2 data at 10 m

Water bodies detected from Super resolution data at 5 m

Water bodies from local reference data (DB- Gers)

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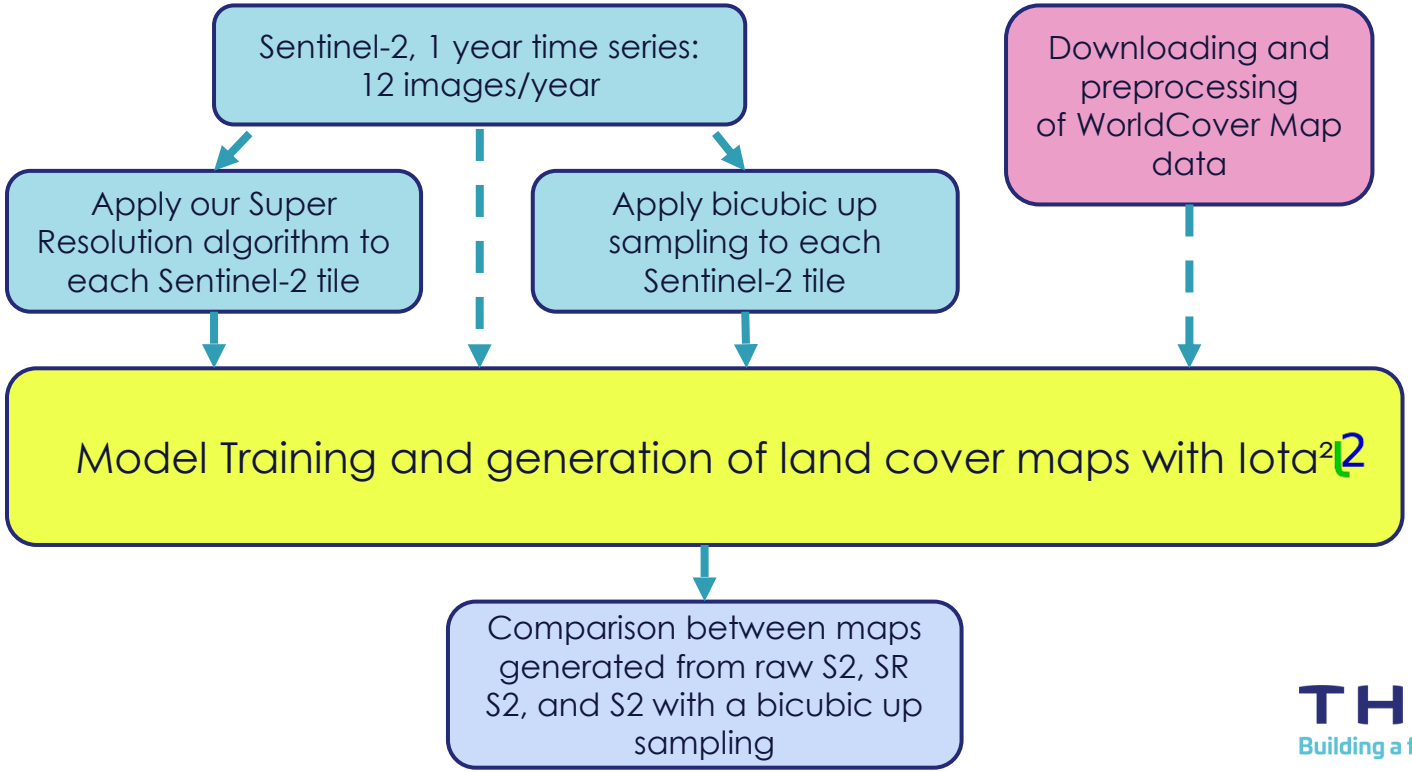
Use-case assessment: Water Resource

Water bodies from local reference data (DB-Gers)
Water bodies detected from SR data at 5m
Water bodies detected from S2 data at 10m and 20m

Additional use-case: Land cover maps

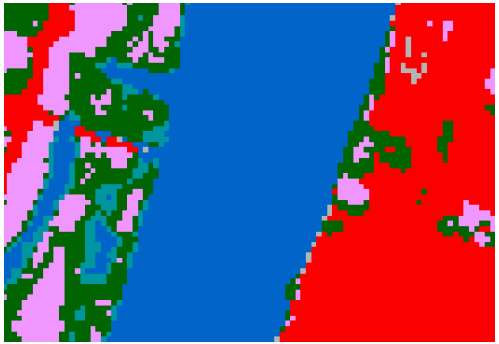
Use of Iota² L2 tools for land cover map generation, and WorldCover Map 2021 as ground truth

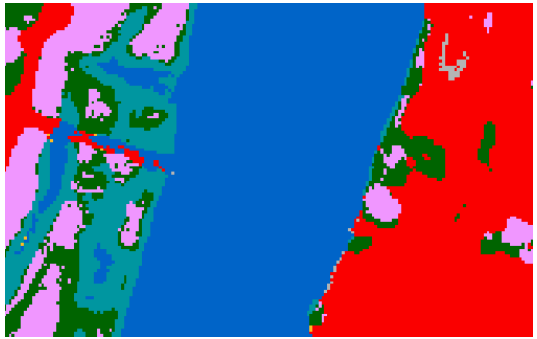


Additional use-case: Land cover maps

Case 1: Study of land cover in the Nile region of Egypt

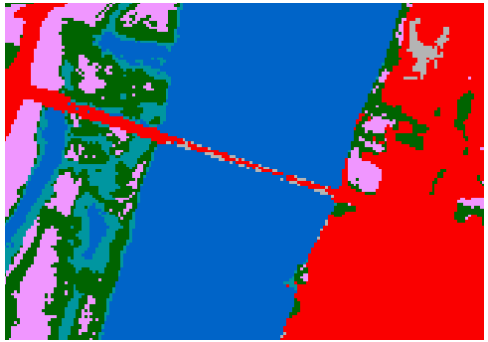
Map generated from original S2 images





Map generated from S2 images with a bicubic up sampling

Map generated from S2 images with our SR algorithm



Sentinel-2 image

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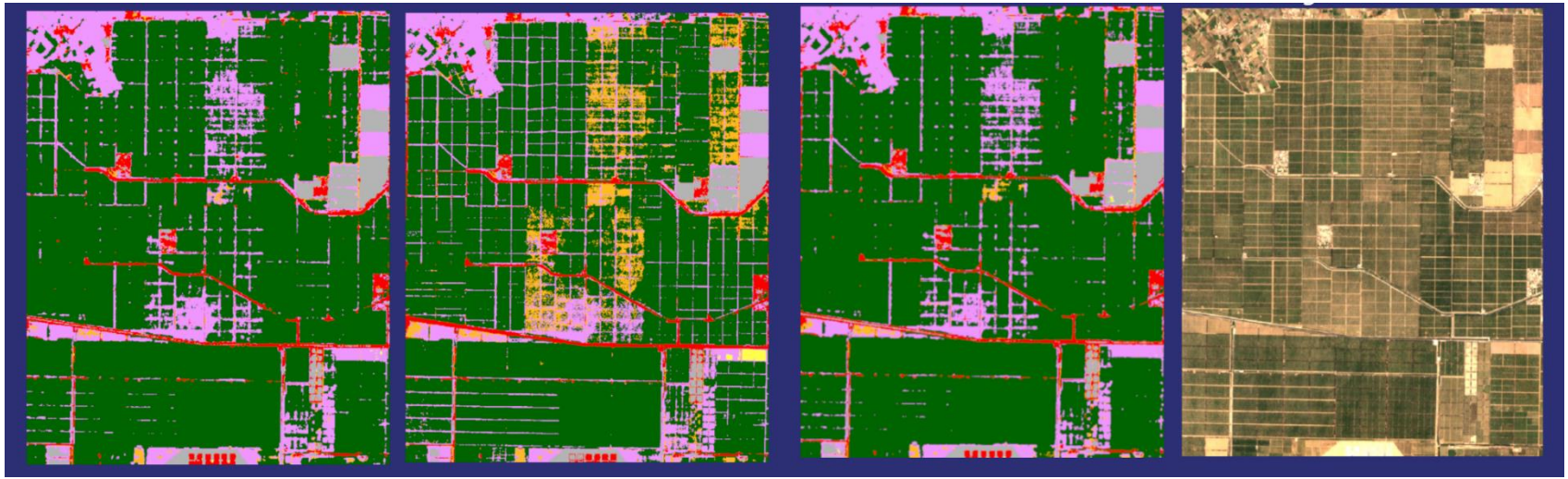
Additional use-case: Land cover maps

Case 1: Study of land cover in the Nile region of Egypt

Original | SR | Bicubic | Sentinel-2



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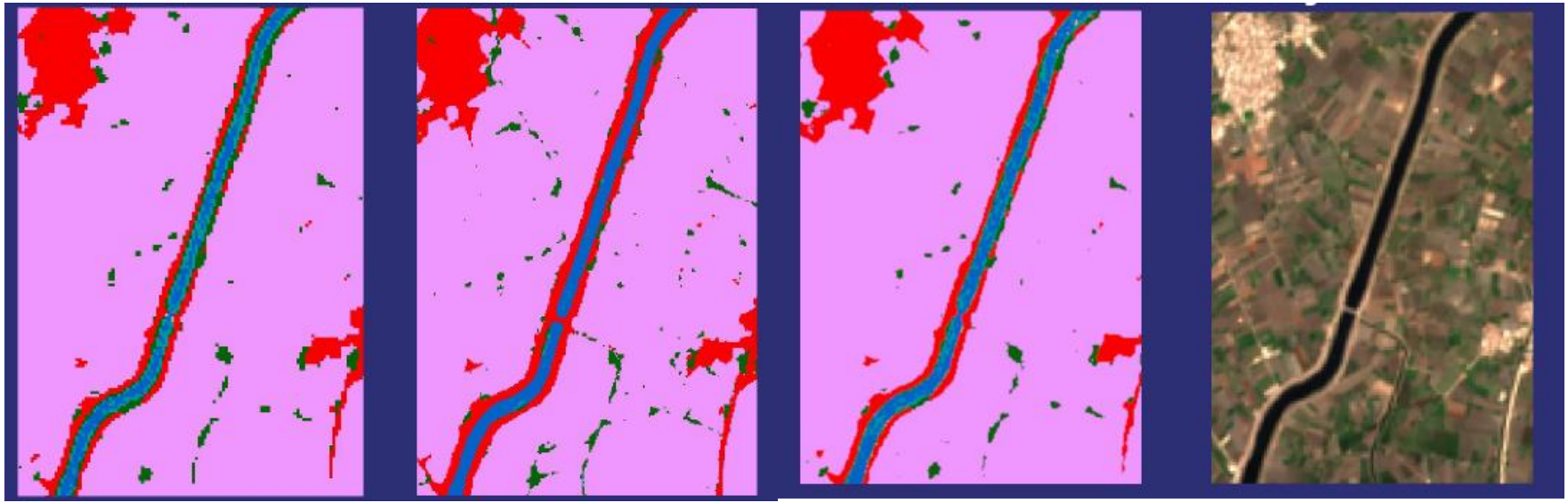
Additional use-case: Land cover maps

Case 1: Study of land cover in the Nile region of Egypt

Original | SR | Bicubic | Sentinel-2



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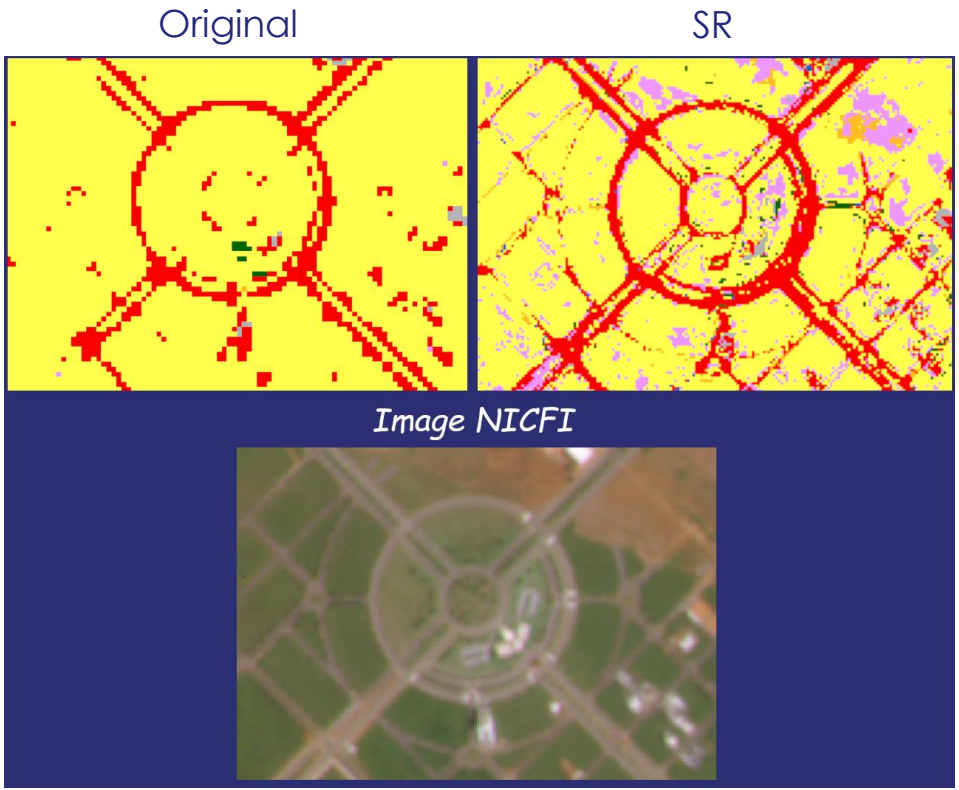
Additional use-case: Land cover maps

Case 2: Study of land cover in the Amazon rainforest of Brazil



Conclusion

Contributions

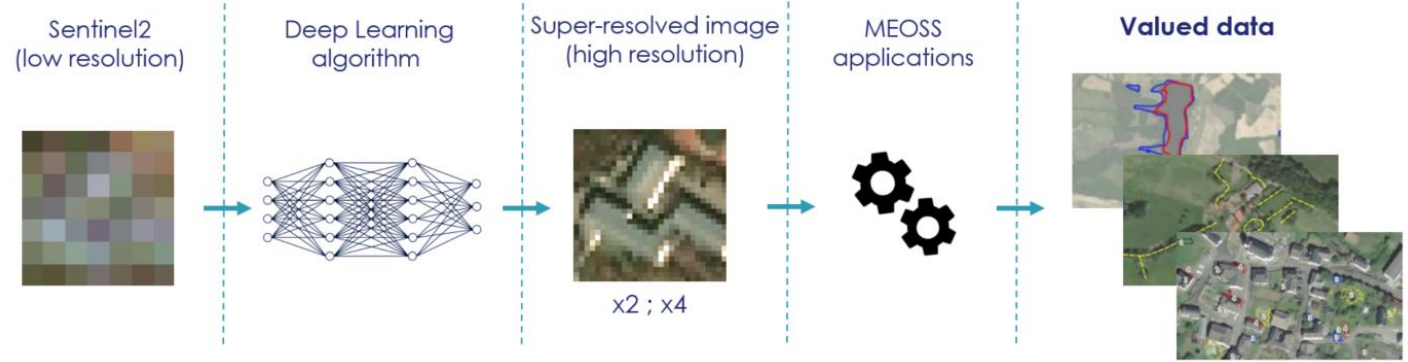
Realization of a complete super resolution pipeline of all Sentinel-2 bands:

- **5m resolution** for all Sentinel-2 bands
- Reference dataset **representative worldwide**
- A rigorous **validation of signal preservation**
- A detailed **validation of the benefits of SR through specific applications** regarding earth observation

Downstream application following the ESA project

Implementation of an operational service to monitor water surfaces and volumes stored in reservoirs.

- provide **up to date information** on:
  - **Water surface area** for all water bodies larger than 1ha
  - **Volumes of water** stored and filling rates for dam reservoirs and hillside reservoirs over 1ha
  - **Variations in the volumes** of water bodies larger than 3ha
- **Processing on a Thales aerospace platform**
- **End user:** French Ministry of Ecological Transition (monthly report)



Contact : vincent.poulain@thalesgroup.com

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