Self-Supervised Super-Resolution of Sentinel-2 L1B products, Thanks to Inter-Band Shift, Alias and Detectors Overlap

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Introduction

Researcher at:

- Kayrros: start-up in Environmental Intelligence, leveraging most satellite sources

  many products: Methane detection, wildfire detection, power-plant monitoring, biomass estimation, …

- Centre Borelli, ENS Paris-Saclay: mathematics research lab, image processing & remote sensing team

Previous work on satellite images restoration, including multi-frame super-resolution with Planet Skysat L1A.

This talk is less about cal/val and more about demonstrating our user experience with the S2 imagery.

Context

Goal: super-resolve Sentinel-2 imagery (10m -> 5m GSD)

- “Only” x2 super-resolution: scientific image restoration, not beautification
- Forbid the use of perceptual-oriented methods (no GAN, no perceptual loss)

Our work:

- Nguyen, N. L., Anger, J., Raad, L., Galerne, B. and Facciolo, G., 2023. On the Role of Alias and Band-shift for Sentinel-2 Super-Resolution. In 2023 International Geoscience and Remote Sensing Symposium.
- Nguyen, N.L., Anger, J., Davy, A., Arias, P. and Facciolo, G., 2023. L1BSR: Exploiting Detector Overlap for Self-Supervised Single-Image Super-Resolution of Sentinel-2 L1B Imagery. In 2023 Conference on Computer Vision and Pattern Recognition.

Two main takeaways:

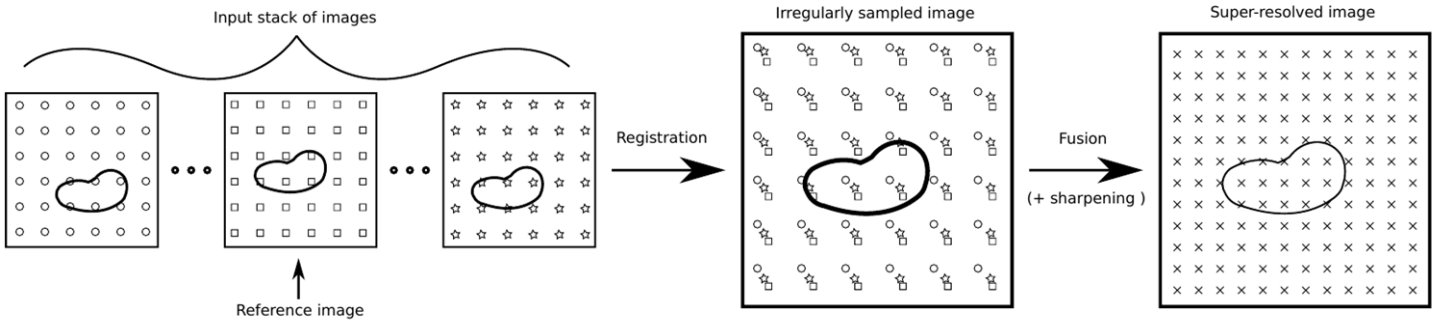
1. Alias and band-shift are providing essential information for super-resolution
2. Overlap between detectors allows to train a network without high-resolution supervision

(3. self-supervised cross-spectral registration)

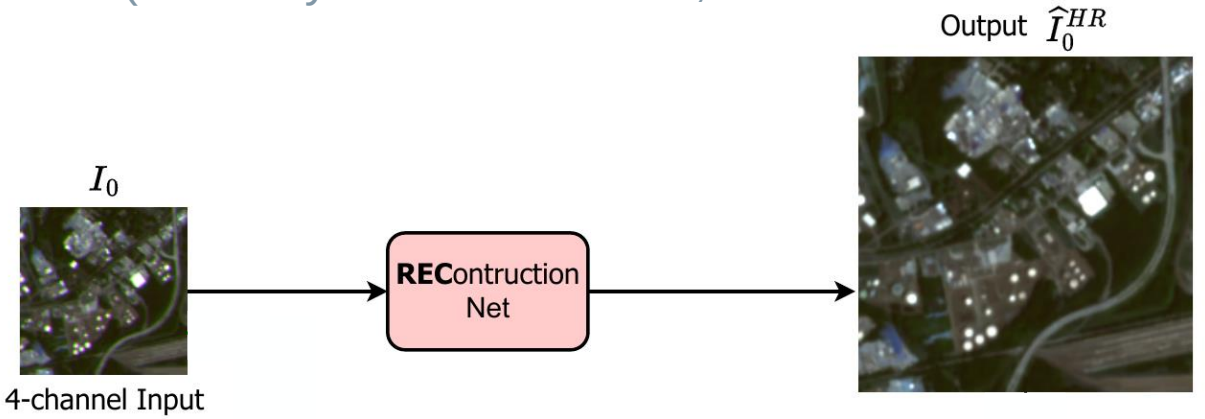
Introduction to super-resolution

Two types:

1. Multi-frame super-resolution (mostly well-posed, based on sampling theory)



1. Single-frame super-resolution (nowaday: neural networks, sometimes with GAN and up-to x10 SR…)



Alias and Band-shift

Sentinel-2 imagery shows two related “artifacts”: alias and band-shift

“Band-shift” / temporal offset causes the signal to be sampled at irregular positions on the ground

Combined with the high MTF of S2, we observe aliasing patterns different in each band

-> basis for a super-resolution method (multiple aliased observations at different positions)

PlanetScope
(well-sampled)

Sentinel-2
(aliased, band shift)

Exploiting Alias and Band-shift

ground-truth

1. Simulation of datasets

LR input

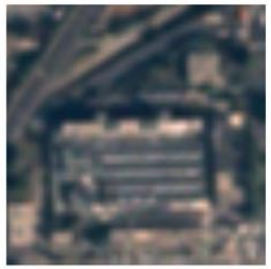
Aliased: No
Band-shift: No

Aliased: Yes
Band-shift: No

Aliased: Yes
Band-shift: Yes

Looks like Sentinel-2

Exploiting Alias and Band-shift



ground-truth

1. Simulation of datasets

Aliased: No
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LR input

2. training

SR result

Looks like Sentinel-2

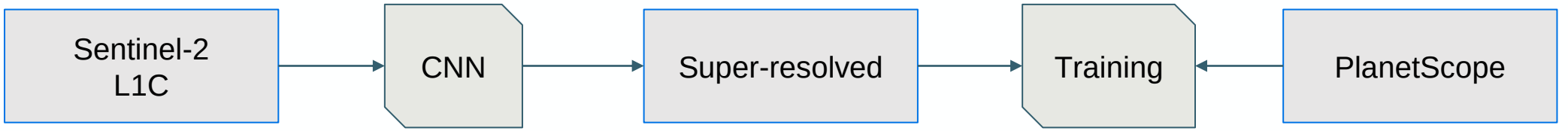
Best restoration are obtained when the input contains alias and band-shift.

-> **Sentinel-2 MSI has a specific configuration that enables super-resolution!**

(not studied: SNR, sampling patterns, …)

L1C Super-Resolution

Train a x2 super-resolution network using PlanetScope (5m) as ground-truth for the training step



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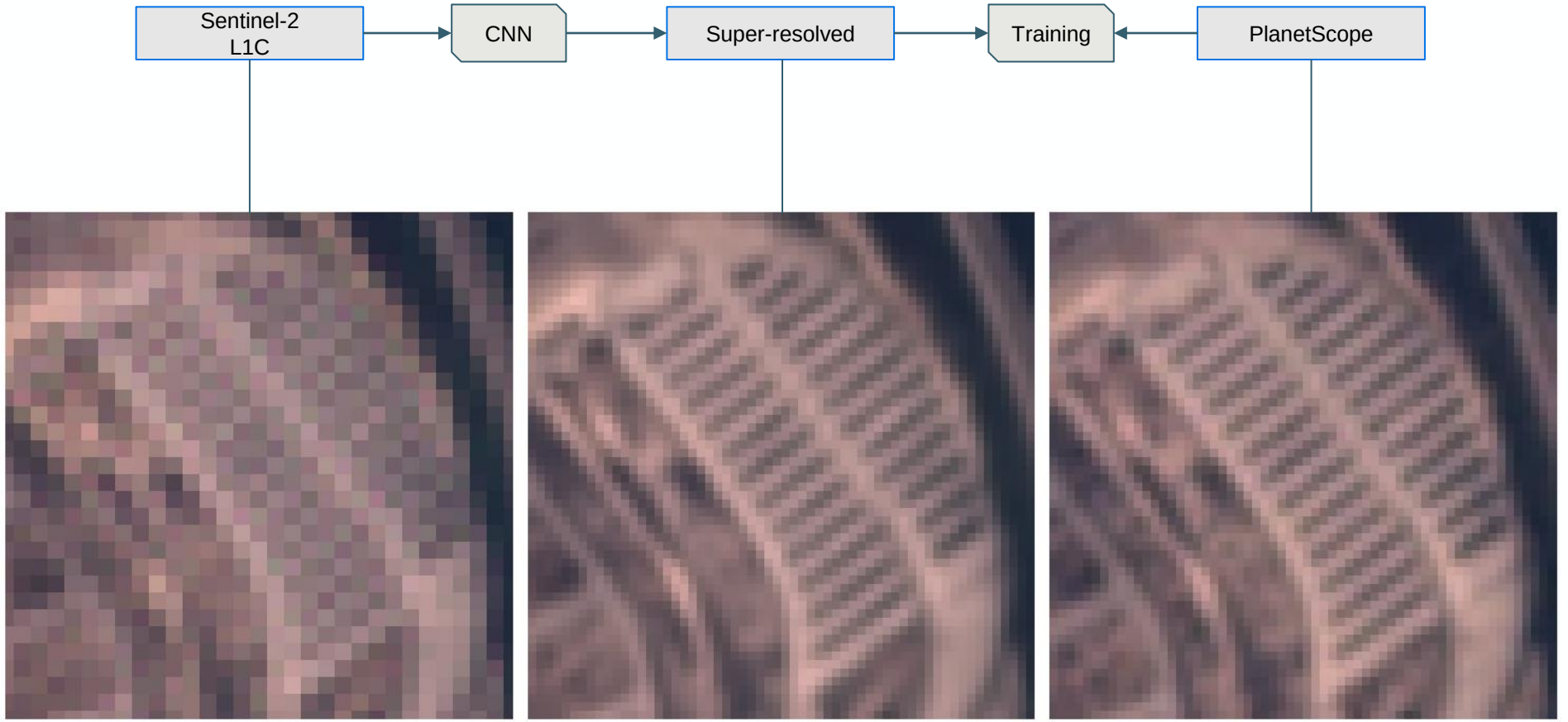

Results:

→ THE EUROPEAN SPACE AGENCY

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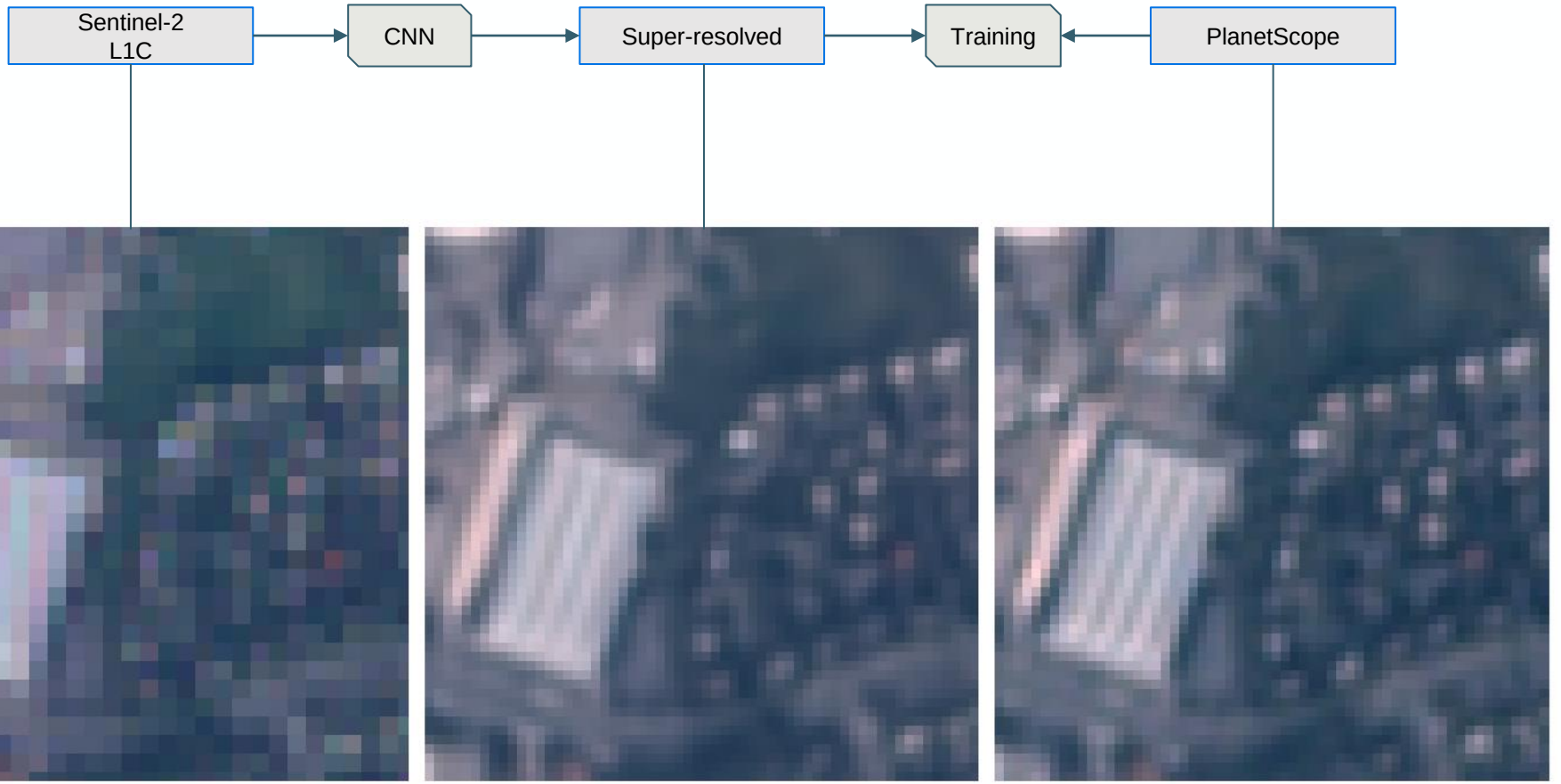

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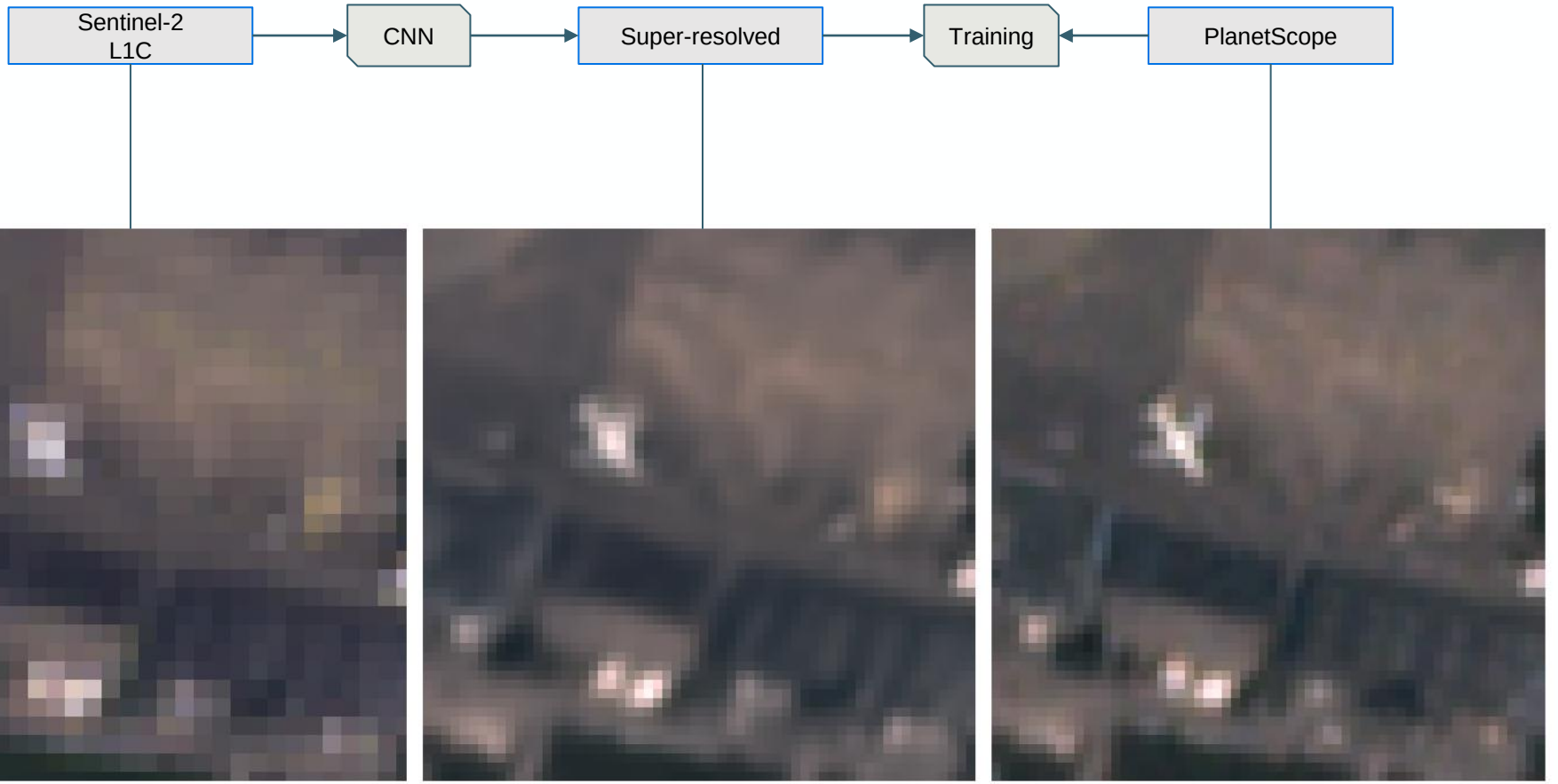

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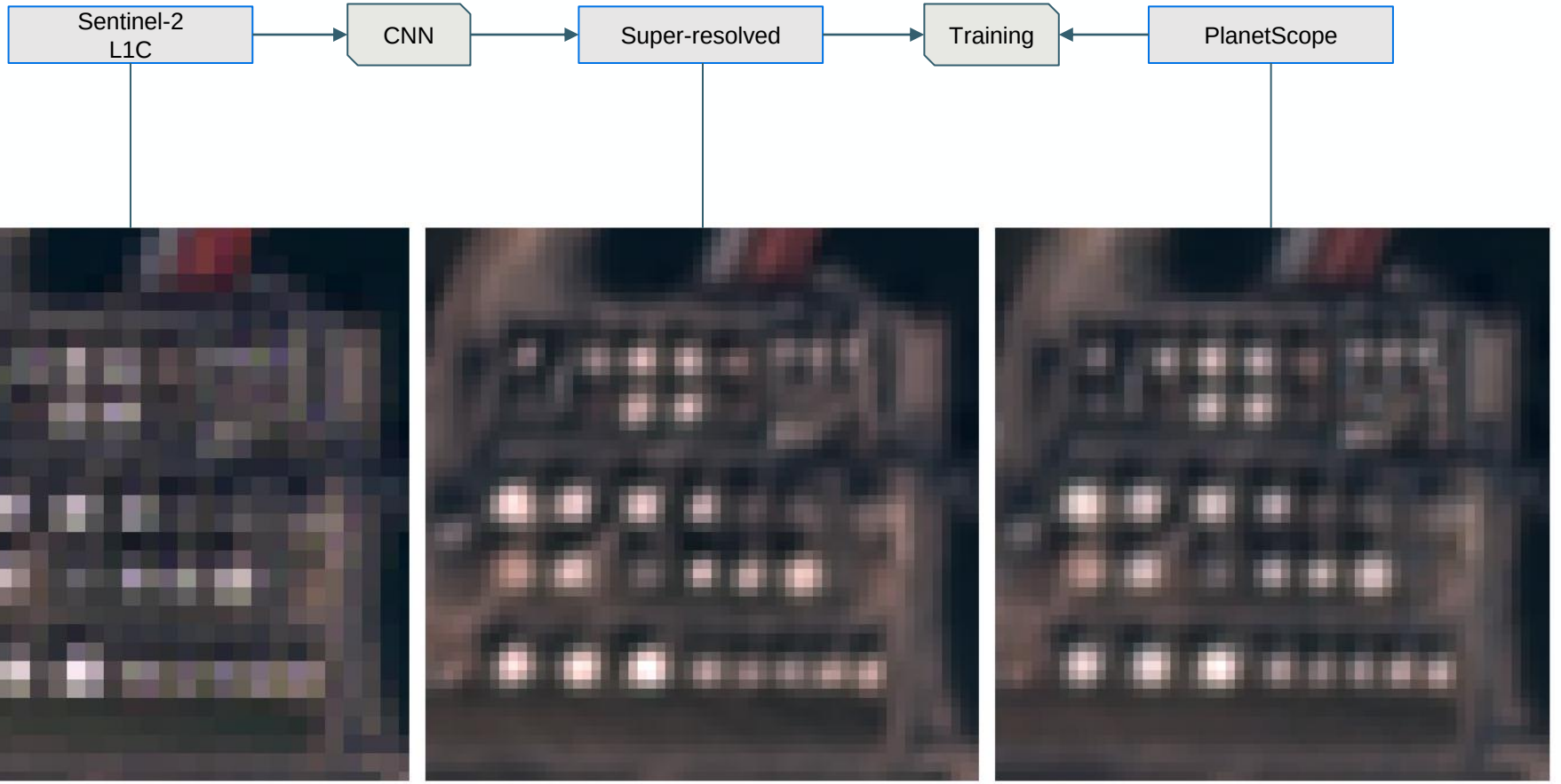

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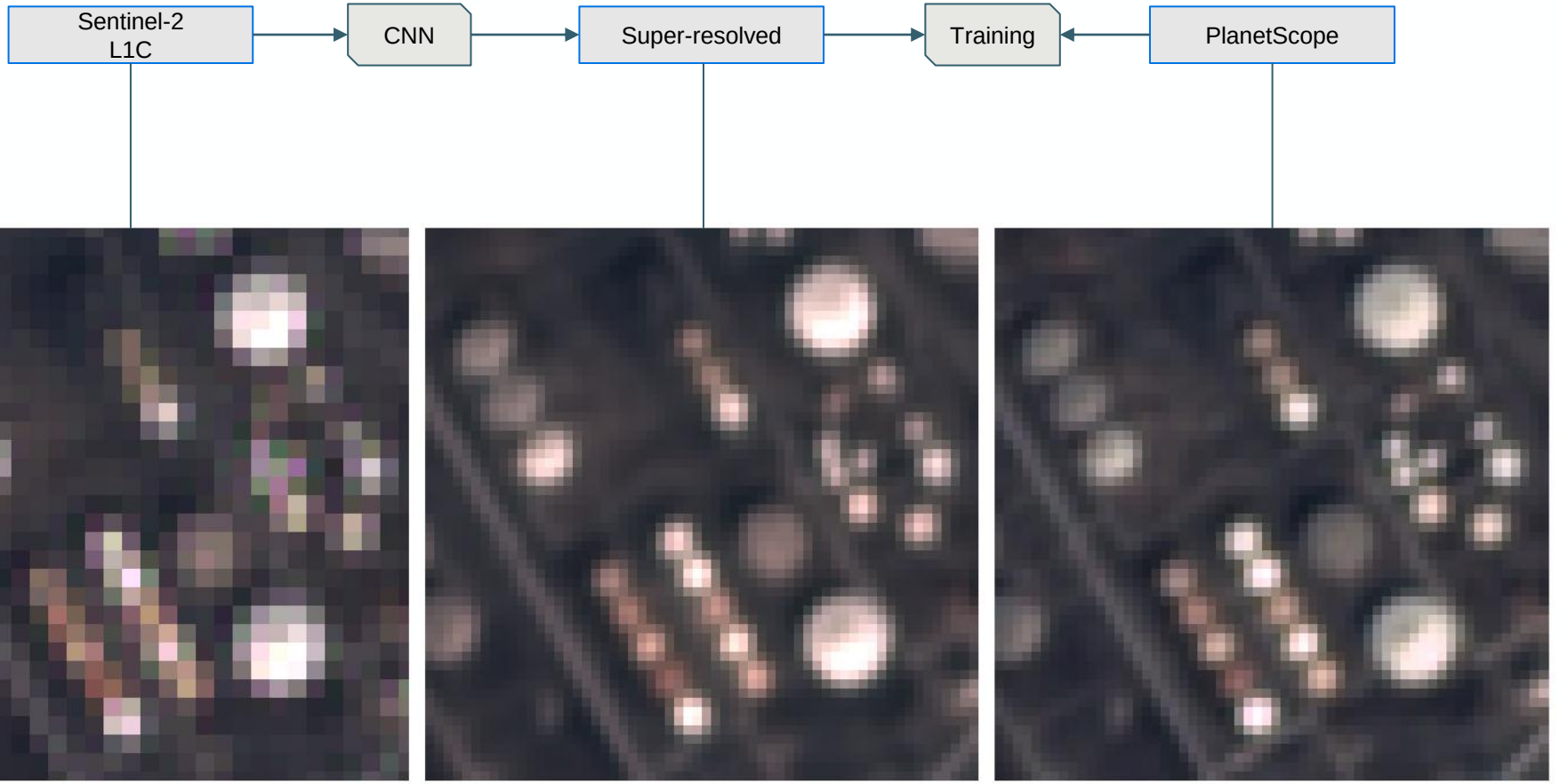
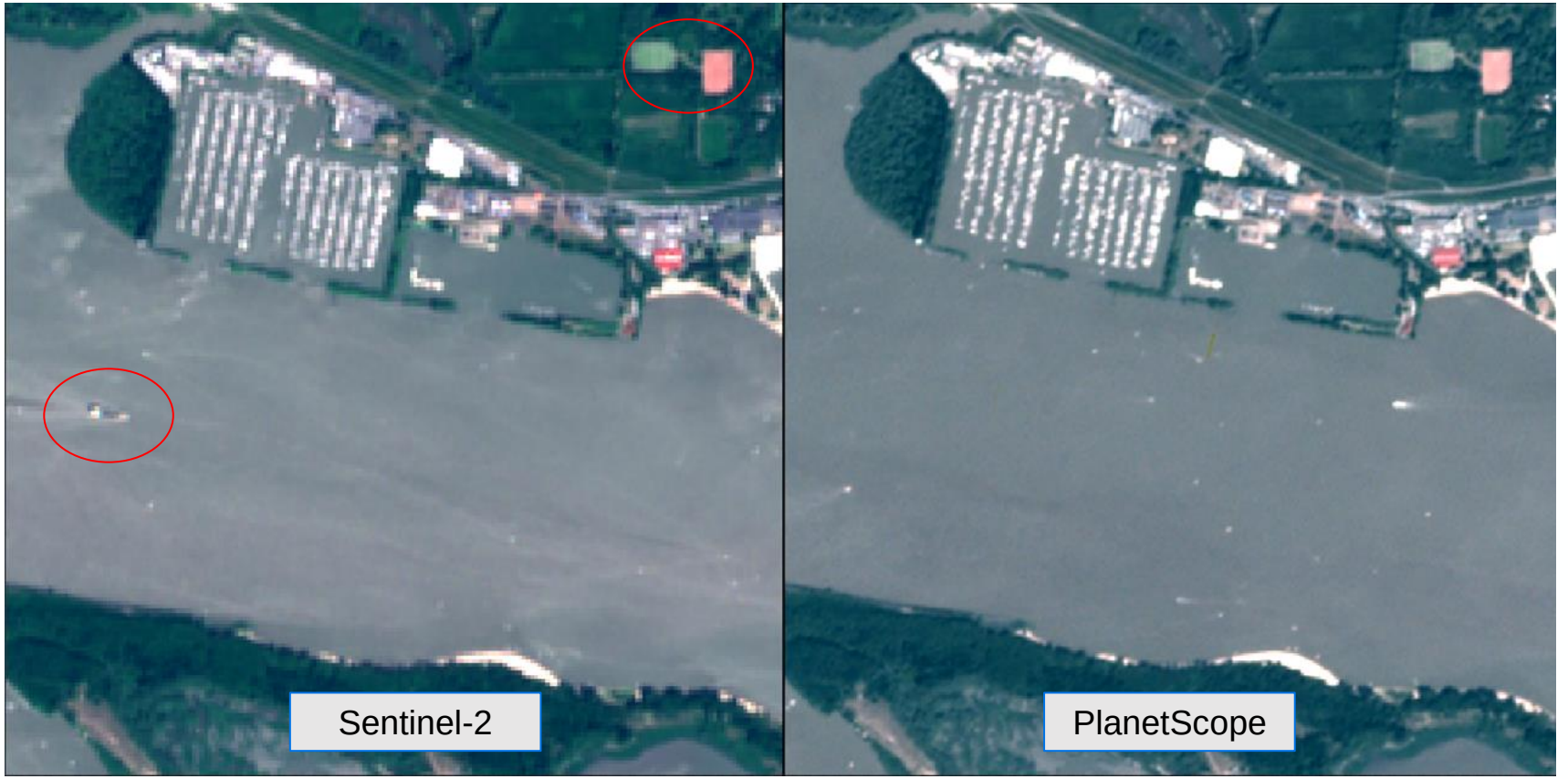


Results:

L1C Super-Resolution – Limitations

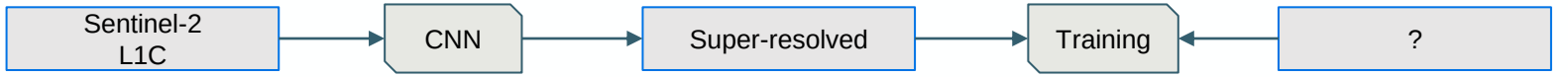
Limitations: using PlanetScope as supervision is not ideal:

- Different spectral characteristics
- Different view angle
- Different time (up-to 1 hours in our dataset, but it is too long for shadows or transient objects)



Looking for supervision

We don’t need PlanetScope!



We need imagery taken
at the **same time**,
from the **same angle**,
with the **same sensor**…

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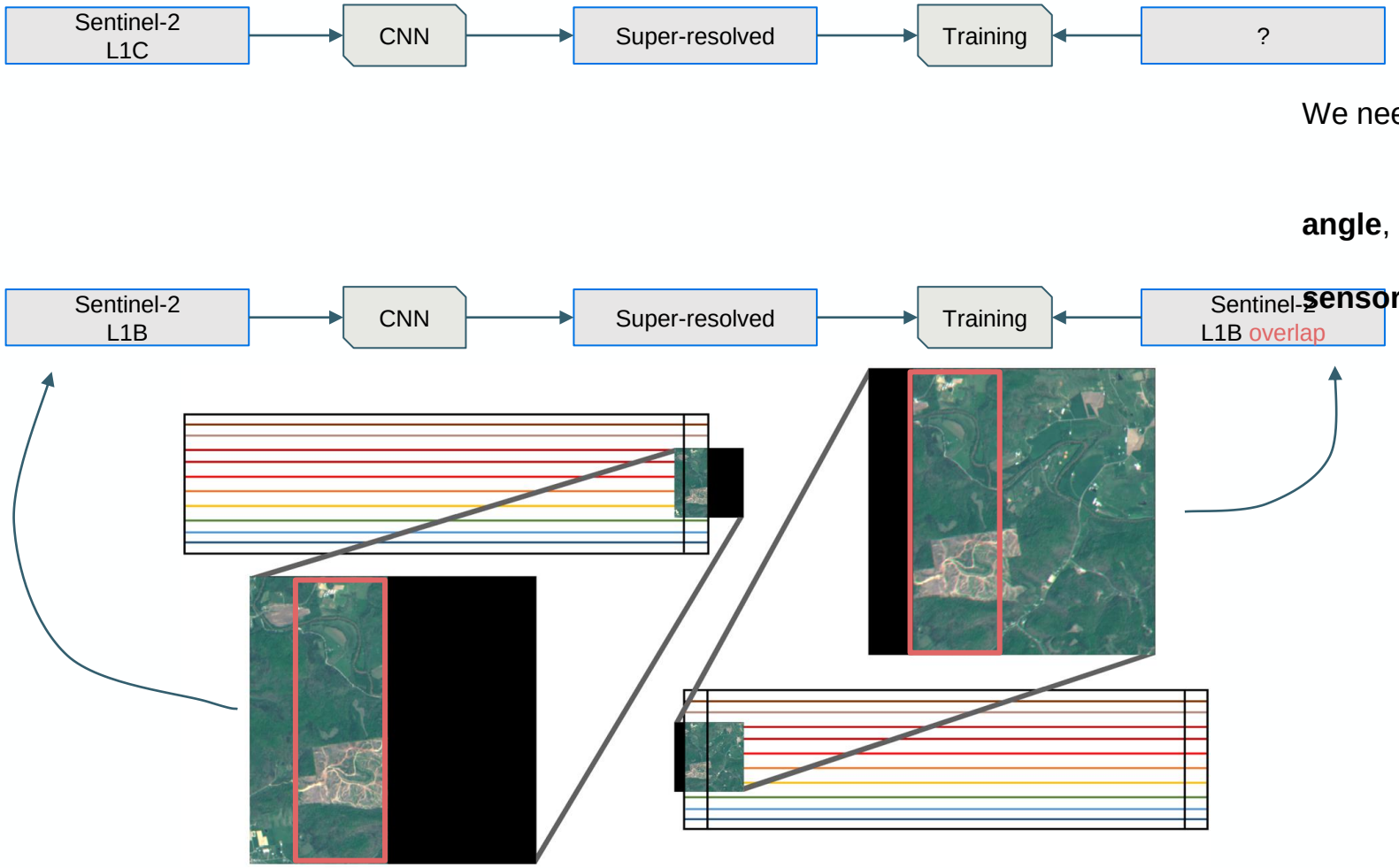

We need imagery taken at the **same time**, from the **same angle**, with the **same sensor**…

Sentinel-2 L1B overlaps dataset

Crop within the overlap region of consecutive detectors.

Approximate registration between bands and between detectors (only integer translation, to avoid resampling)

The network will register the bands during restoration.

The loss will register the bands and detectors during training.





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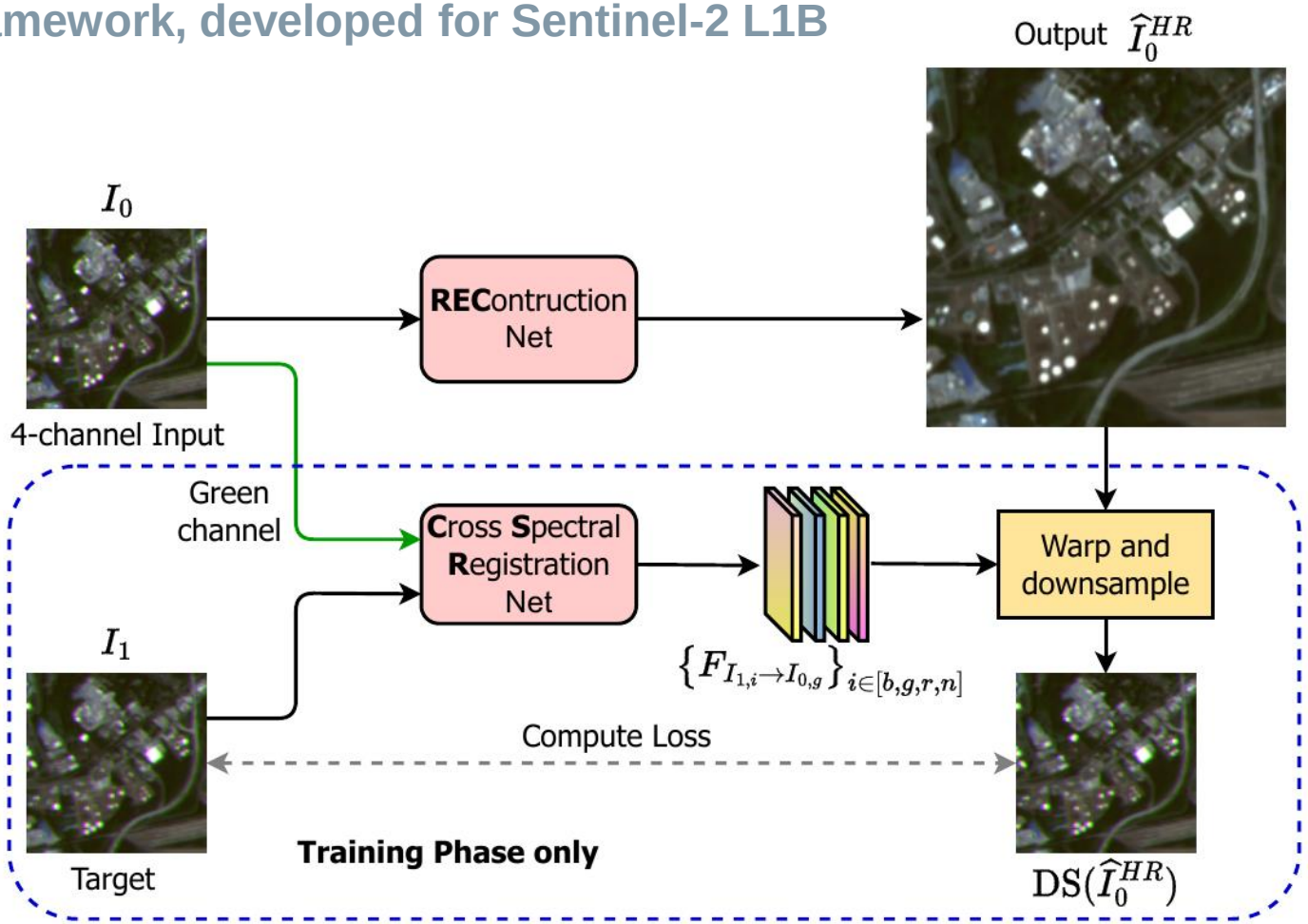
Self-Supervised Super-Resolution of S2 L1B

Same resolution, how to train a super-resolution network?

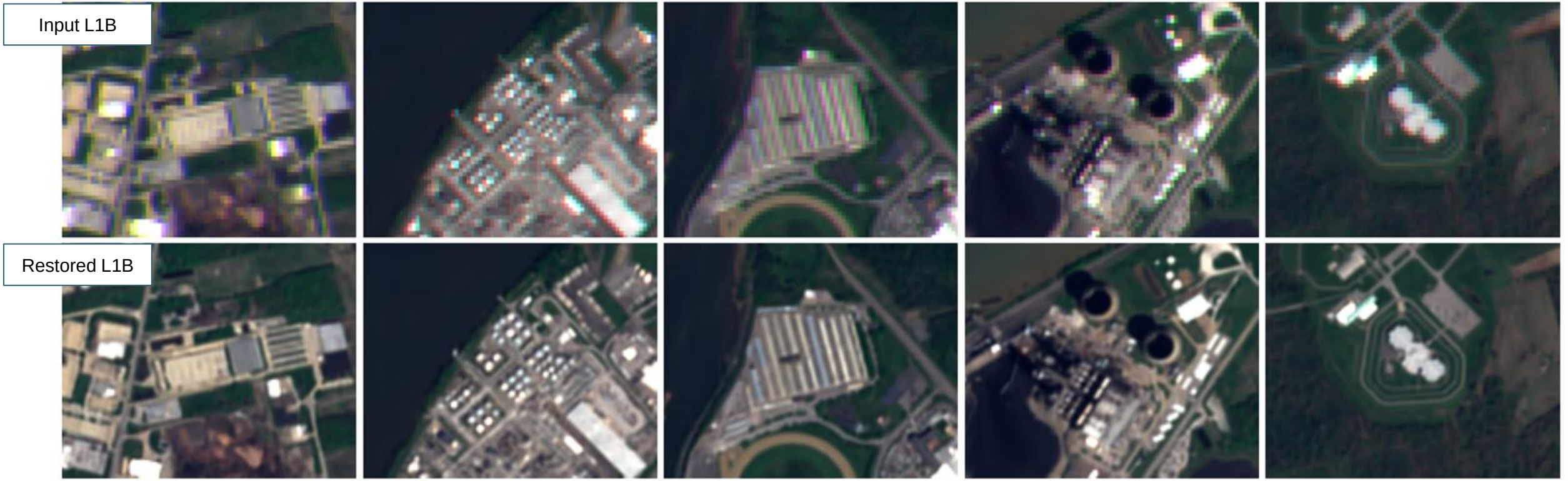
-> **Self-supervised framework, developed for Sentinel-2 L1B**



Super-Resolution of S2 L1B

The network:

- Spatially registers the bands
- Super-resolves (de-aliasing, restore fine details)
- Denoises, sharpens…



Conclusion

The L1B dataset and pretrained weights for cross-spectral registration and super-resolution are available:

https://github.com/centreborelli/L1BSR/

Online demo: https://ipolcore.ipol.im/demo/clientApp/demo.html?id=77777000471

We found that:

- Alias and band-shift -> **enable super-resolution for Sentinel-2**
- Supervision with PlanetScope works, but has issues (radiometric and geometric mismatch)
- Detector overlap -> **enable self-supervised training**.
- At Kayrros, we found that the super-resolution helps for small target classification, human labeling…

Work in progress:

- Super-resolve all bands and not just B02, B03, B04, B08.
- Train with L1B but apply on L1C.
- More in-depth validation of the imagery after super-resolution (GSD is 5m): resolution, SNR, etc

Thanks to the CNES and ESA for providing the L1B samples! And looking forwards the L1Bs on CDSE!