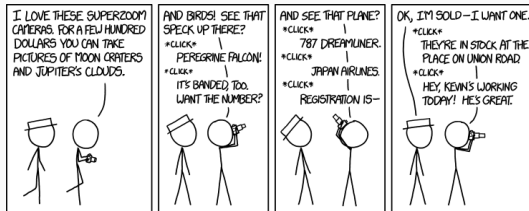


# Sentinel-2 data at 2m every 2 days: Assessment of spatio-temporal fusion algorithms between the Sentinel-1R and Sentinel-2 (NG) missions

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<https://xkcd.com/1719>

## What is Sentinel-HR ? A phase-0 mission study

Sentinel-HR would be a VHR and 3D Sentinel mission complementary to Sentinel-2 (NG)

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Coverage	All land and coasts (similar to S2)
Ground Sampling Distance	$\leq 2.5$ meters
Revisit time	20 days
Spectral bands	Blue, Green, Red, Near Infra Red (similar to S2 10m bands)
Viewing angles	Constant Nadir (at center of swath)
Stereoscopic capability	Systematic with height accuracy better than 4m CE90
Orbit	Sun-synchronous
Tasking	no tasking, instrument always on over lands
Mission lifetime	7 years or more
Proposed launch date	2028
Products	Analysis Ready, free and open data

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Aim : gather multi-temporal, high resolution observations for land surface change detection



# Hybridation : Problem statement

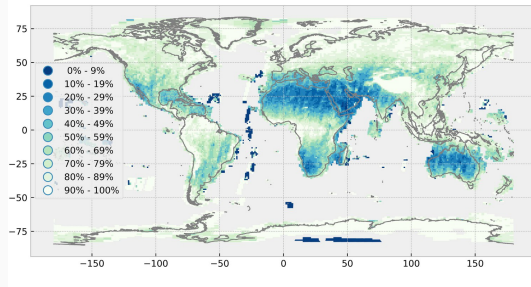
## Problem

- Some use-cases require both 2m resolution and revisit better than 20 days
- Cloud cover will impair the 20 days revisit in most locations

## Idea

- Combine Sentinel-HR images (2m, 20 days) with :
  - Sentinel-2 (10m, 5 days)
  - Sentinel-2 NG (5m, 2 days)
- To make 2 meters prediction with revisit < 20 days

## Percentage of S2 cloud contaminated scenes in 2017



## Phase 0 Objective

Demonstrate feasibility of hybrid products and assess expected performances

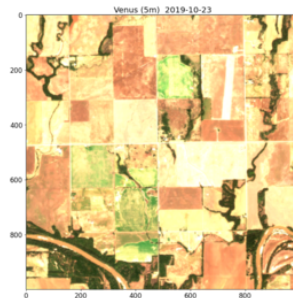
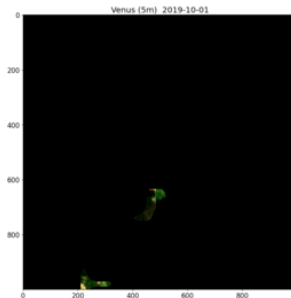
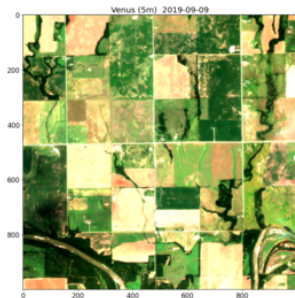
## Hybridation : Dataset

- Use Venµs and Sentinel-2 L2A products from Theia archives
- Search for Venµs 5m "guide" series with  $\approx 20$  days revisit (will act as Sentinel-HR)
- Cross-search "target" series of Sentinel-2 and Venµs less than 1 day apart (will act as S2 with its high resolution reference)
- Downsample Sentinel-2 to 25m (ratio of 5 SHR+S2) or 12.5m (ratio of 2.5 for SHR+S2NG)
- Spatial registration and radiometric harmonization by linear regression

Site Name	Location	Landscape	Guide	Target	Time range
SUDOE-4	France	Montains	10	14	2019.07 - 2020.01
MAD-AMBO	Madagascar	Desert	17	39	2018.11 - 2020.01
FR-LQ1	France	Mixed	9	27	2020.04 - 2020.10
FR-BIL	France	Agricultural, urban	12	16	2020.03 - 2020.11
ARM	USA	Agricultural	16	23	2019.03 - 2020.01
ESGISB-2	France	Agricultural, urban	10	14	2018.11 - 2019.05

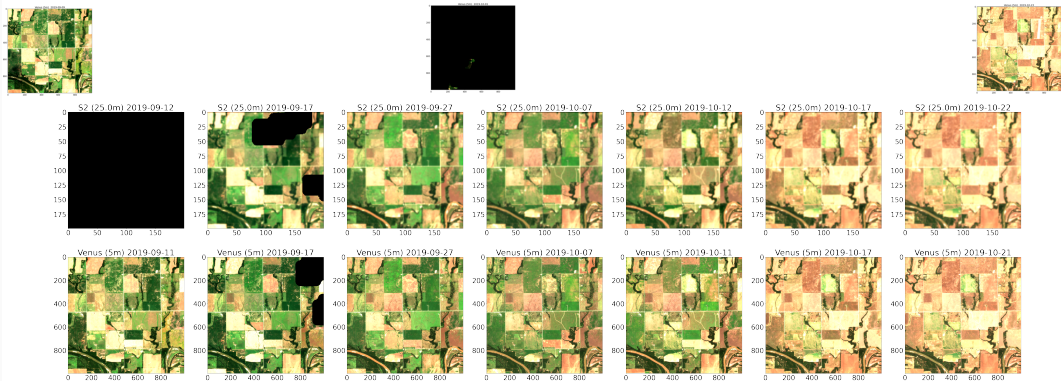
# Hybridation : Dataset

Guides : Venus 5m time series with revisit  $\approx 20$  days (our Sentinel-HR series)



# Hybridation : Dataset

Targets : in-between Sentinel-2 25m time series (our Sentinel-2 series) + corresponding Venus 5m reference



# Hybridation : Benchmark

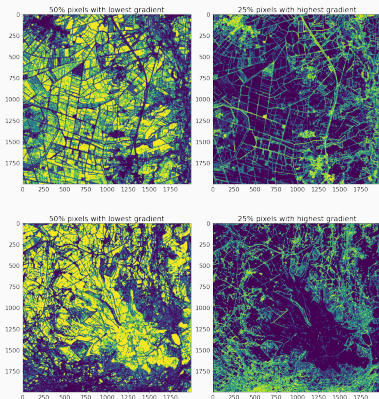
## Principle

- Predict all target dates at 5m using 5m guide dates and 25m or 12.5m target dates
- Derive different metrics (RMSE, MAE, PSNR, UIQI, CE90, CE99, SAM, Structural, ERGAS ...)
- Computed on bands + NDVI, for whole image, 50% of lowest gradient pixels, 25% of highest gradient pixels

## Methods overview

Method	Use HR images	Use LR images
Temporal interpolation	yes	no
Spatial interpolation	no	yes
SISR (CARN) [AKS18]	training	inference
Data Driven Interpolation (ours)	inference	training*
STARFM / ESTARFM [GMSH06]	yes	yes

## Low / High gradient magnitude stratas

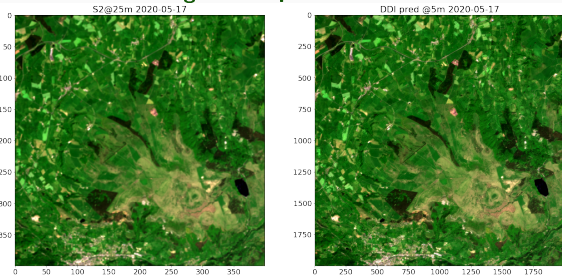


# Data Driven Interpolation

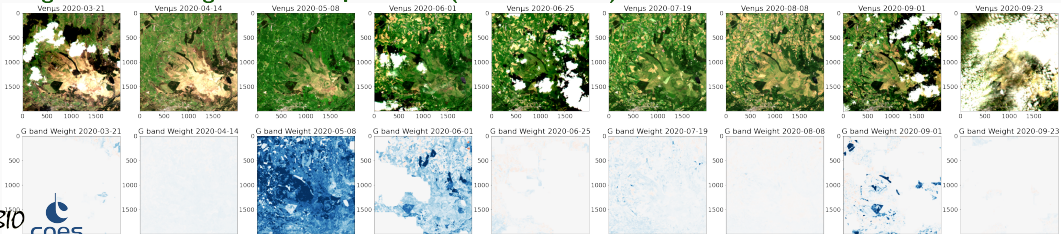
## Main ideas

- Each target pixel is a linear combination of the same pixel at guide dates
- Weights are estimated per pixel by a Multi-Layer Perceptron
- Learning is done at low resolution, and then model is applied at high resolution with residual correction
- New training for each date to predict

## Left : 25m S2 date, right : 5m prediction



## Weight of each 5m guide date in prediction (for Green band)

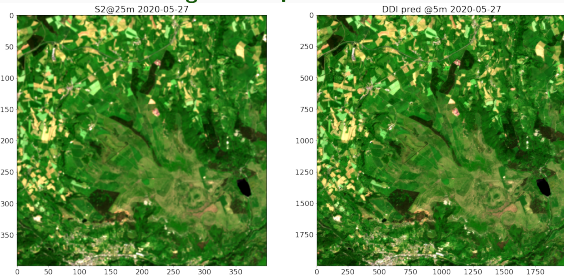


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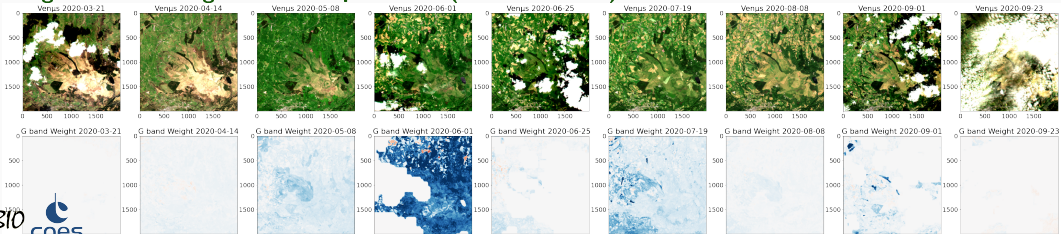
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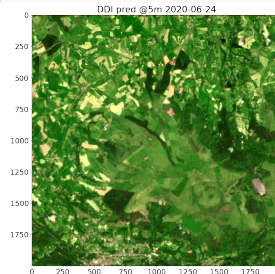
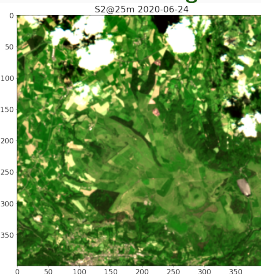


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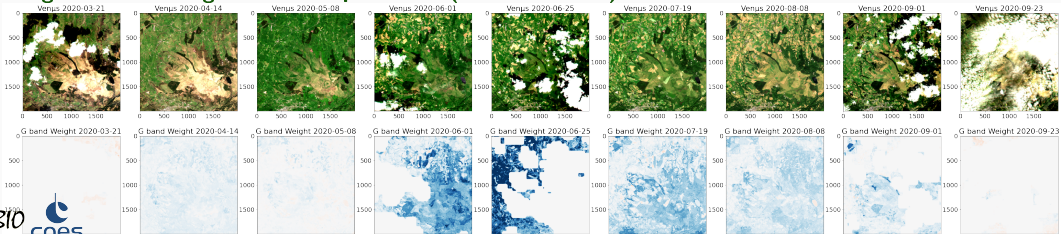
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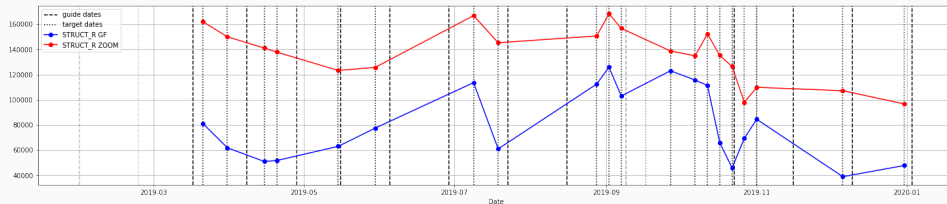
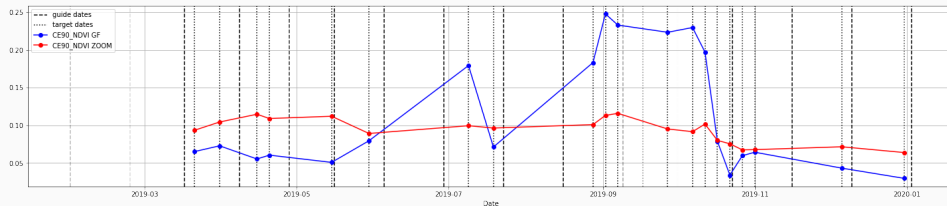
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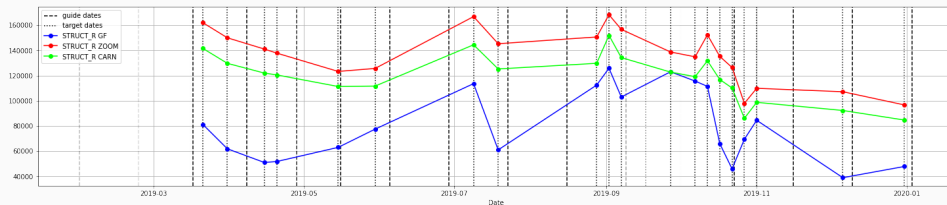
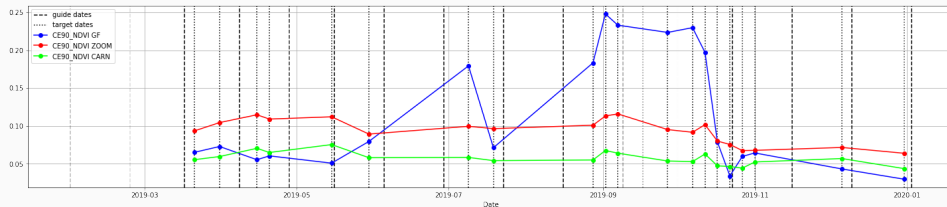
# CE90 NDVI metric ( $\approx$ radiometry) and STRUCT R metric ( $\approx$ edges) on ARM site, res $\times 5$

Trivial methods : SHR dates temporal interpolation, S2 dates spatial interpolation



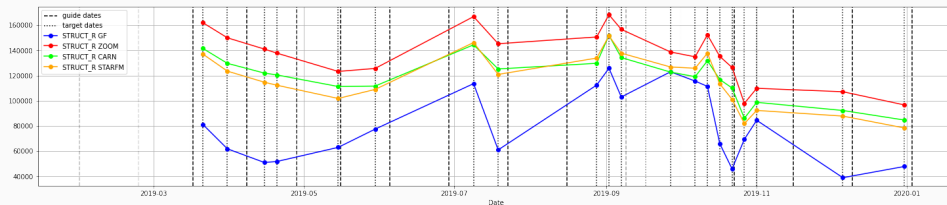
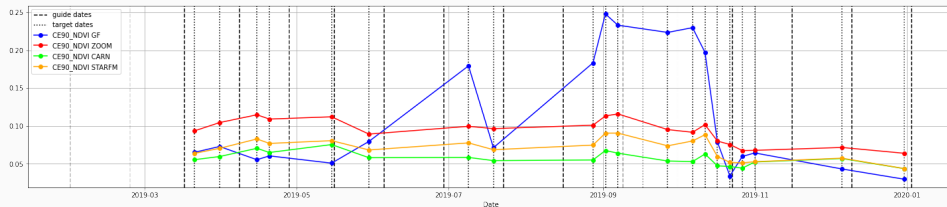
# CE90 NDVI metric ( $\approx$ radiometry) and STRUCT R metric ( $\approx$ edges) on ARM site, res $\times 5$

Adding CARN (Deep Learning based Single Image Super-Resolution)



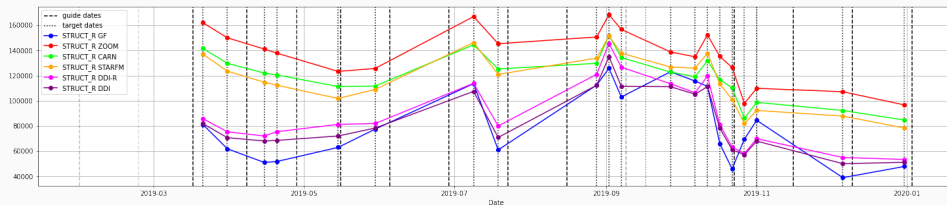
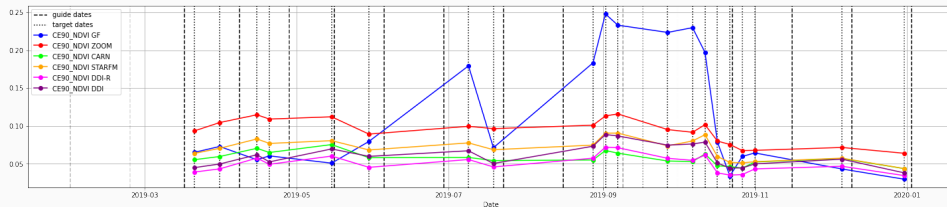
# CE90 NDVI metric ( $\approx$ radiometry) and STRUCT R metric ( $\approx$ edges) on ARM site, res $\times 5$

## Adding STARFM (Seminal Spatio-Temporal Fusion Method)



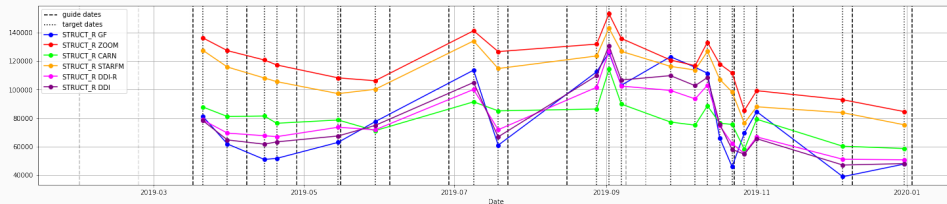
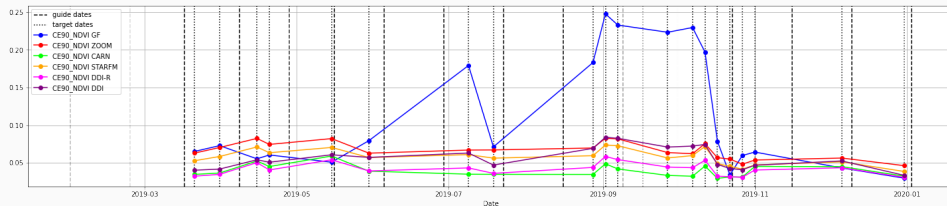
# CE90 NDVI metric ( $\approx$ radiometry) and STRUCT R metric ( $\approx$ edges) on ARM site, res $\times 5$

## Adding Data Driven Interpolation (ours)

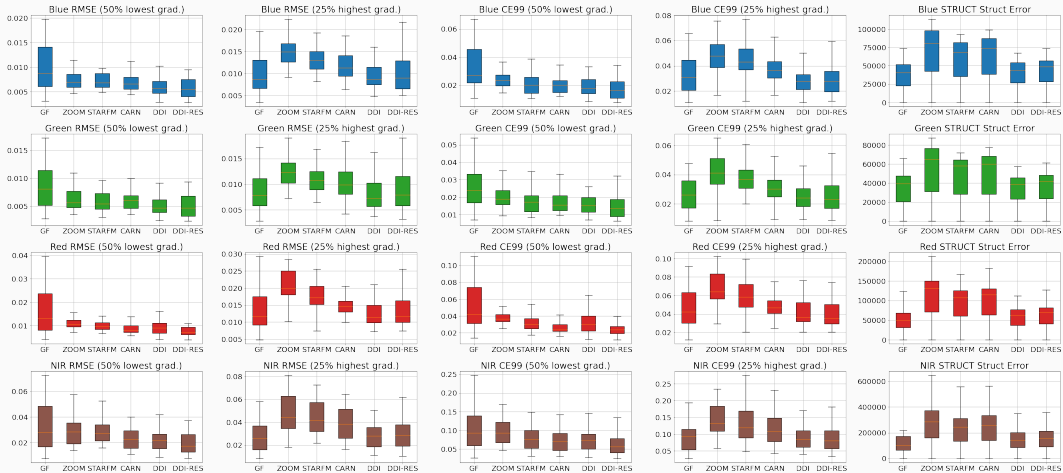


# CE90 NDVI metric ( $\approx$ radiometry) and STRUCT R metric ( $\approx$ edges) on ARM site, res $\times 2.5$

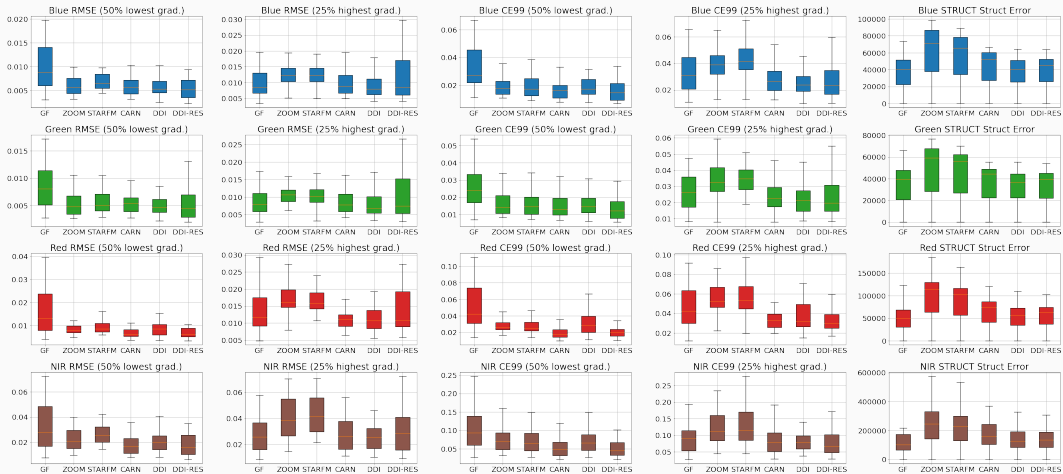
Same graphs but with resolution  $\times 2.5$  : 12.5 meters  $\Rightarrow$  5 meters



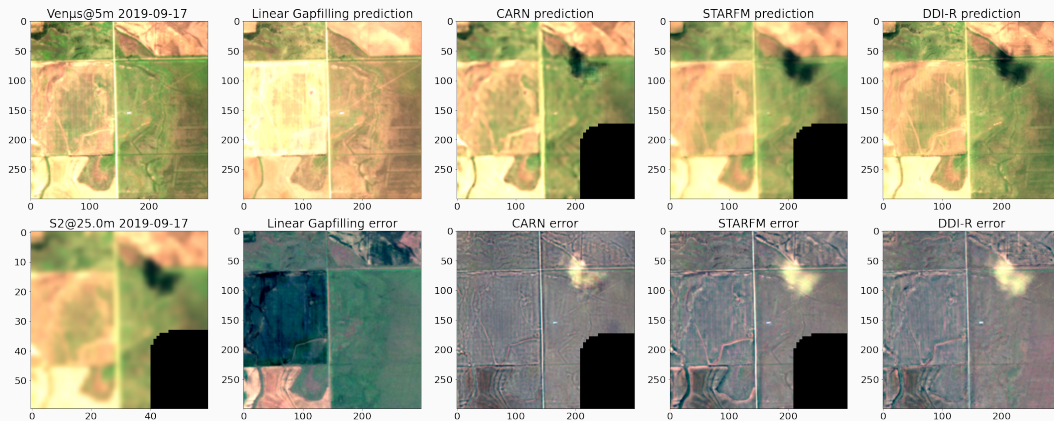
# Res $\times 5.0$ , metrics on all sites, reference and prediction on same day (54 images)



# Res $\times 2.5$ , metrics on all sites, reference and prediction on same day (54 images)

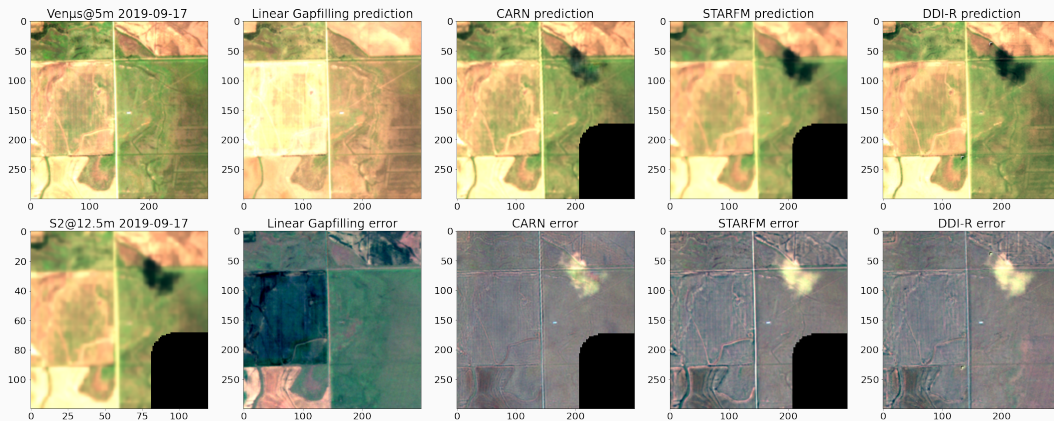


# Predictions for ARM site, resolution $\times 5$





# Predictions for ARM site, resolution $\times 2.5$



# Conclusion

## Main outcomes from the benchmark

- 99% of pixels have abs. error  $< 0.01$  TOC (RGB) and  $< 0.15$  TOC (NIR) for more than 75% of scenes
- Super Resolution seems competitive for a ratio of 2.5 (provided that training data are available). Also very simple to use after offline training (only requires the low resolution S2 date)
- DDI more interesting for higher ratios, and provides gap-filling as well, but requires (fast) training for each date and SHR dates buffering
- Clear interest on mixing SHR with S2(NG) with any method (instead of temporal interpolation)
- Intra and inter series spatial registration is mandatory, as well as spectral bands consistency

## Limitations

- Generalisation to 2m target resolution? (non linear effects of landscape scales)
- Quantitative spec. on spatial registration not investigated
- Other revisit have not been explored. 20 days is an educated guess of the best revisit trade-off
- Increase ground segment complexity (buffering dates, GPUs for computation)

### Full report of Sentinel-HR phase-0 available on HAL



- Covers hybridation study but also user requirements and mission design

Julien Michel, Olivier Hagolle, Anne Puissant, Pierre-Alexis Herrault, Thomas Corpetti, et al.. Sentinel-HR Phase 0 Report. [Research Report] CNES - Centre national d'études spatiales; CESBIO. 2022. ⟨hal-03643411⟩



### SEN2VEN $\mu$ S, a dataset for the training of Sentinel-2 super-resolution algorithms



- Open Dataset on Zenodo : <https://zenodo.org/record/6514159>
- 132 955 patches, 29 locations, 8 Sentinel-2 bands, from 10m/20m to 5m (VEN $\mu$ S resolution)

Michel, J. ; Vinasco-Salinas, J. ; Inglada, J. ; Hagolle, O. SEN2VEN $\mu$ S, a Dataset for the Training of Sentinel-2 Super-Resolution Algorithms. Preprints 2022, 2022050230 (doi : 10.20944/preprints202205.0230.v1). *Submitted to MDPI Data.*

# Bibliography

-  Namhyuk Ahn, Byungkon Kang, and Kyung-Ah Sohn.  
**Fast, accurate, and lightweight super-resolution with cascading residual network.**  
In *Proceedings of the European Conference on Computer Vision (ECCV)*, pages 252–268, 2018.
-  Feng Gao, Jeff Masek, Matt Schwaller, and Forrest Hall.  
**On the blending of the landsat and modis surface reflectance : Predicting daily landsat surface reflectance.**  
*IEEE Transactions on Geoscience and Remote sensing*, 44(8) :2207–2218, 2006.