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PERSEO Project: Enhancing archaeological prospection with Hyperspectral Imaging and Machine Learning

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The PERSEO project

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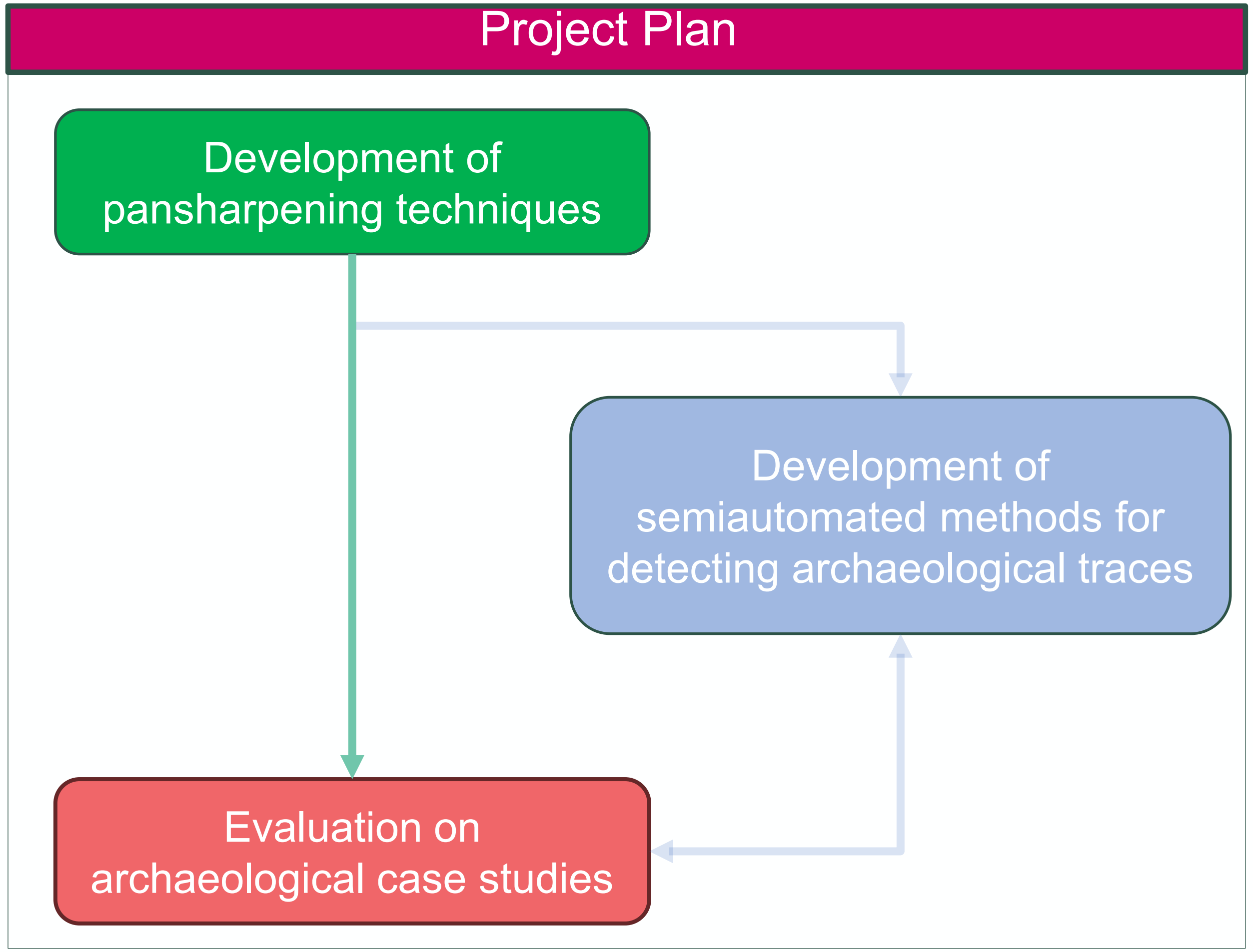
PRISMA Hyperspectral Image **E**nhancement for **R**evealing Cultural Heritage **S**ites from **E**arth **O**bservation



Objective:

- Assess the **suitability of** PRISMA satellite **hyperspectral data** in the identification of archaeological sites

A partnership between the **Center for Cultural Heritage Technology (CCHT)** and **Agenzia Spaziale Italiana (ASI)** as part of the co-funded research programme "PRISMA SCIENZA"

ASI Agenzia Spaziale Italiana

The PERSEO project

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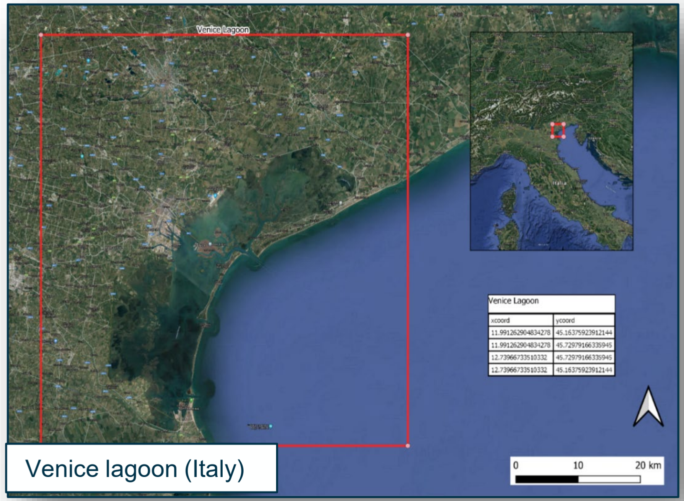
Case studies: selected on diverse characteristics

- Geographical
- Environmental
- Geological
- Archaeological

Targets: traces of subsoil / shallow geo-archaeological features

- Road network
- Sites and structures
- Palaeochannels

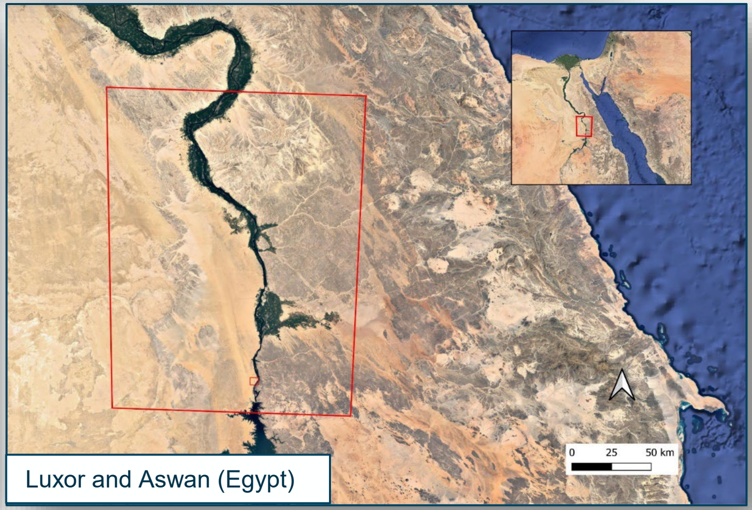
Ground-truth accessibility



Venice lagoon (Italy)

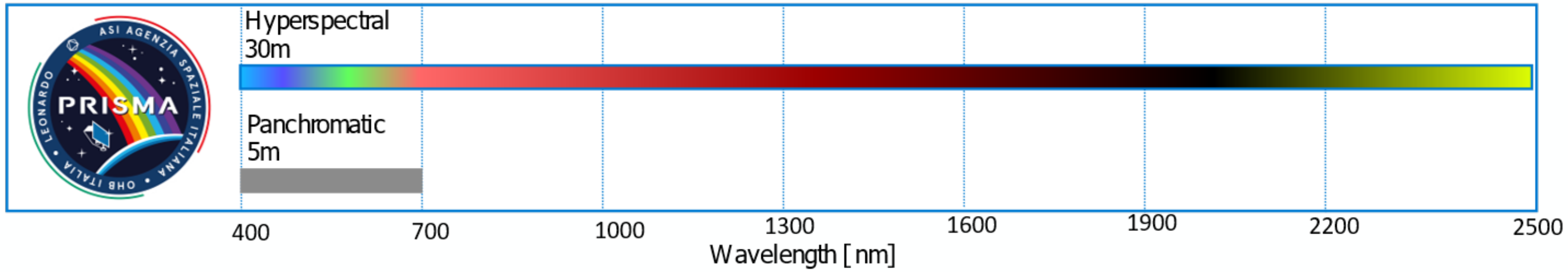
Aquileia (Italy)

Beja (Tunisia)



Luxor and Aswan (Egypt)

PRISMA satellite characteristics



Hyperspectral sensor:

- ***30m GSD***,
- 239 bands with **<12nm** spectral sampling interval in the range **400nm to 2500nm**

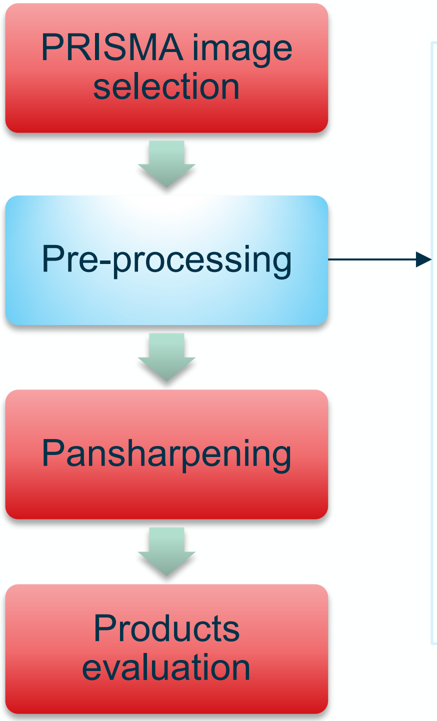
Panchromatic camera:

- ***5m GSD***
- single waveband from **400nm to 700nm**

Hyperspectral image. RGB (b30-b20-b10)

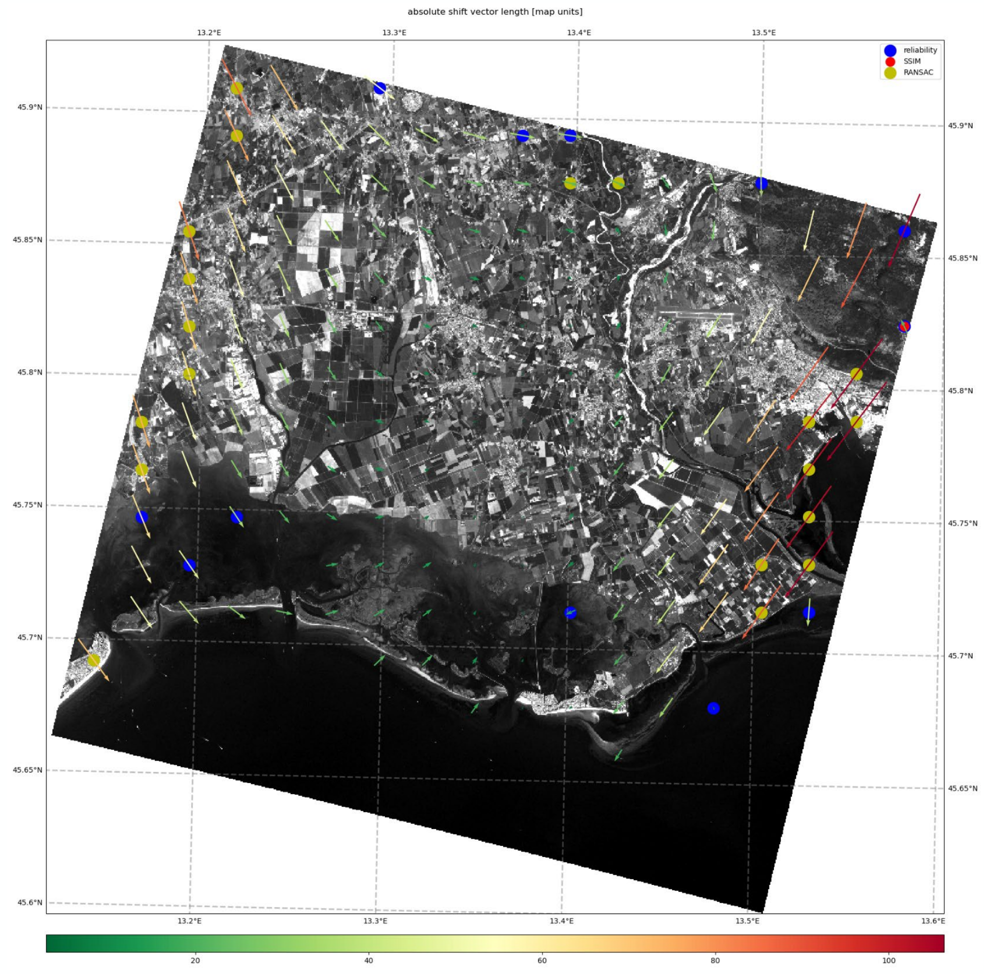
PAN image

Pre-processing



Python pipeline:

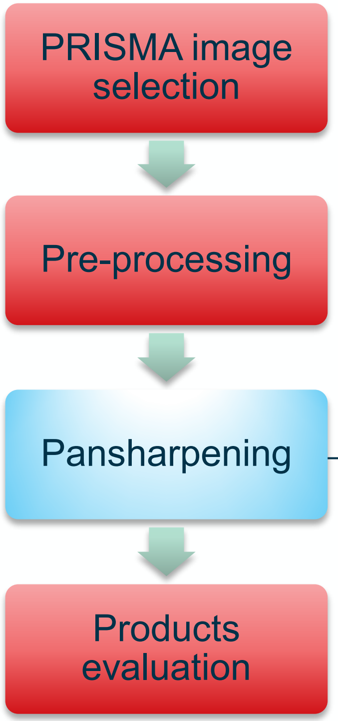
- Read L2D datacube and save to GeoTiff rasters [HS (VNIR+SWIR) + PAN]
- Remove faulty bands, atmospheric absorption bands and low SNR bands
- Co-registration to a Sentinel-2 image in AROSICS[1] (both HS and PAN images)



Output of the displacement and deformation adjusted in AROSICS

[1] https://github.com/GFZ/arosics

Pansharpening



Implementation of pansharpening methods:

- Modulation Transfer Function – Generalised Laplacian Pyramid (MTF-GLP) [1]
- Gram-Schmidt Adaptive (GSA) [1]
- HySure
- HySure + BM3D

[1] G. Vivone, A. Garzelli, Y. Xu, W. Liao and J. Chanussot, "Panchromatic and Hyperspectral Image Fusion: Outcome of the 2022 WHISPERS Hyperspectral Pansharpening Challenge," in *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 16, pp. 166-179, 2023.

Products evaluation

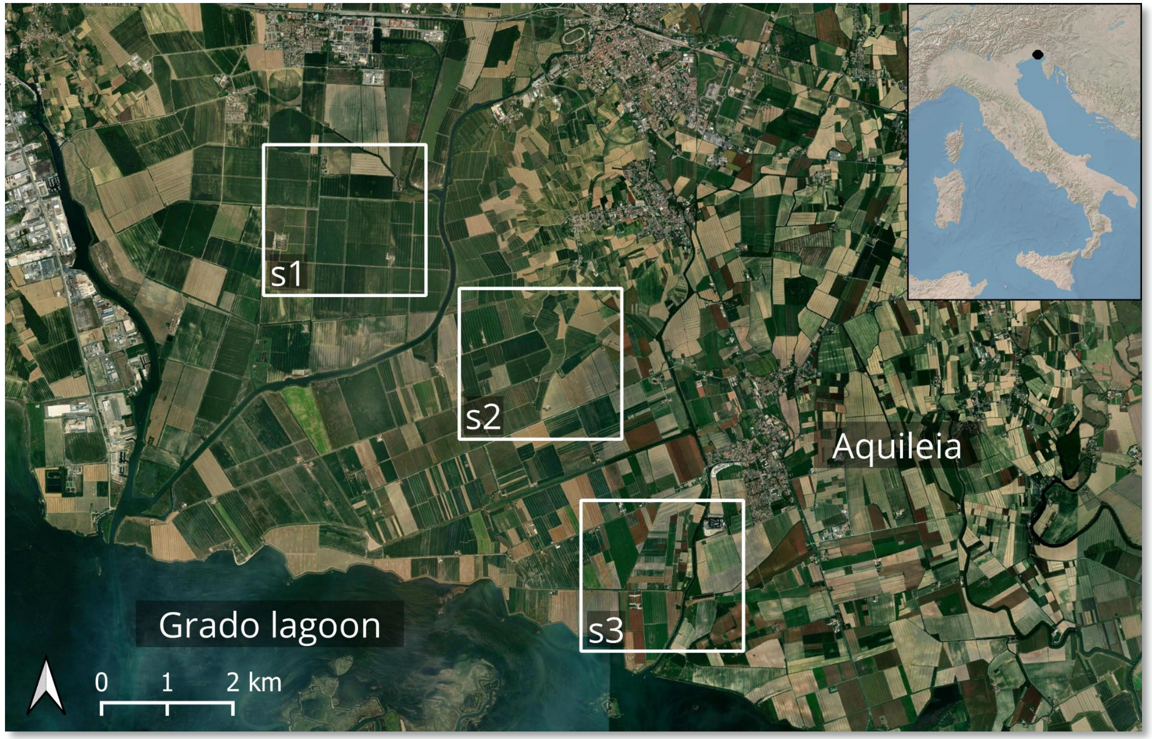
PRISMA image selection → Pre-processing → Pansharpening → Products evaluation

Qualitative assessment:

- 3 sectors of 2 km by side
- selected on relevant geo-archaeological traces

Quantitative assessment:

- *Wald's protocol*
- *Full-resolution evaluation*

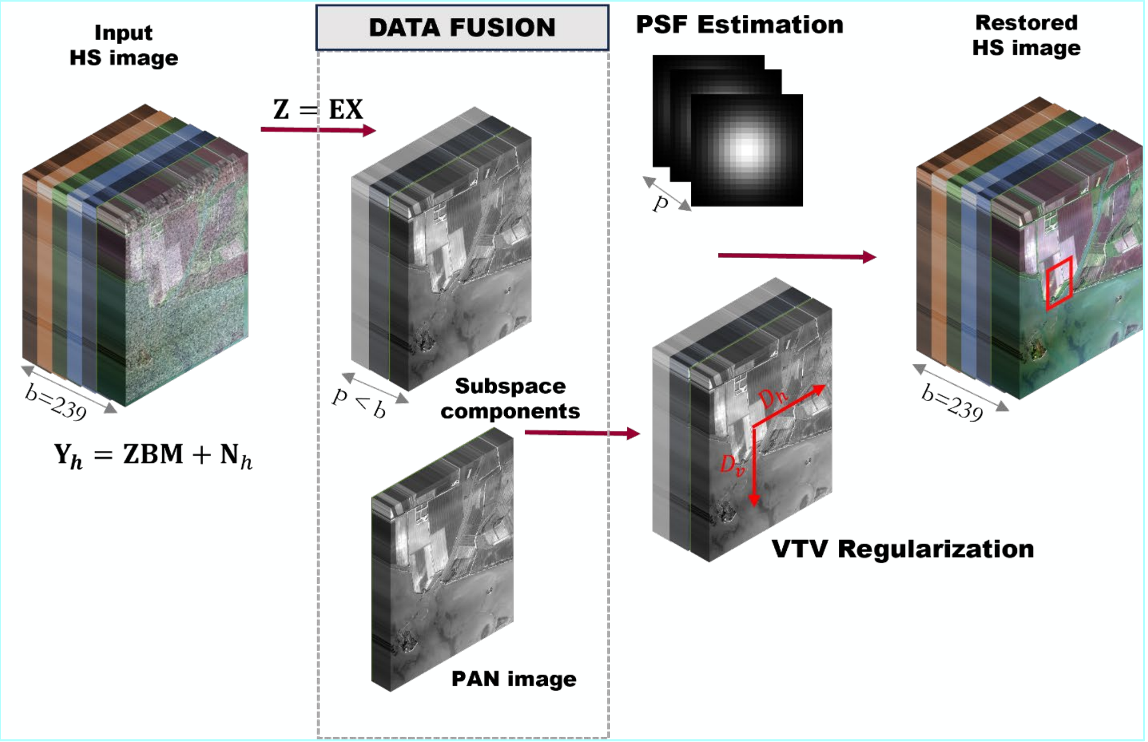


Qualitative assessment area (s1, s2, s3) and entire quantitative assessment area

HySure pansharpening

HySure [1]

$$\min_{X} \frac{1}{2}\|\boldsymbol{Y}_h - \boldsymbol{EXBM}\|_F^2 + \frac{\alpha}{2}\|\boldsymbol{Y}_m - \boldsymbol{REX}\|_F^2 + \beta\, VTV(\boldsymbol{X})$$



Hyperspectral cube reconstruction

$\boldsymbol{B}$: Point spread function

$\boldsymbol{M}$: Uniform down-sampling matrix

Panchromatic image reconstruction

$\boldsymbol{R}$: Spectral response of the panchromatic band

Vector Total Variation

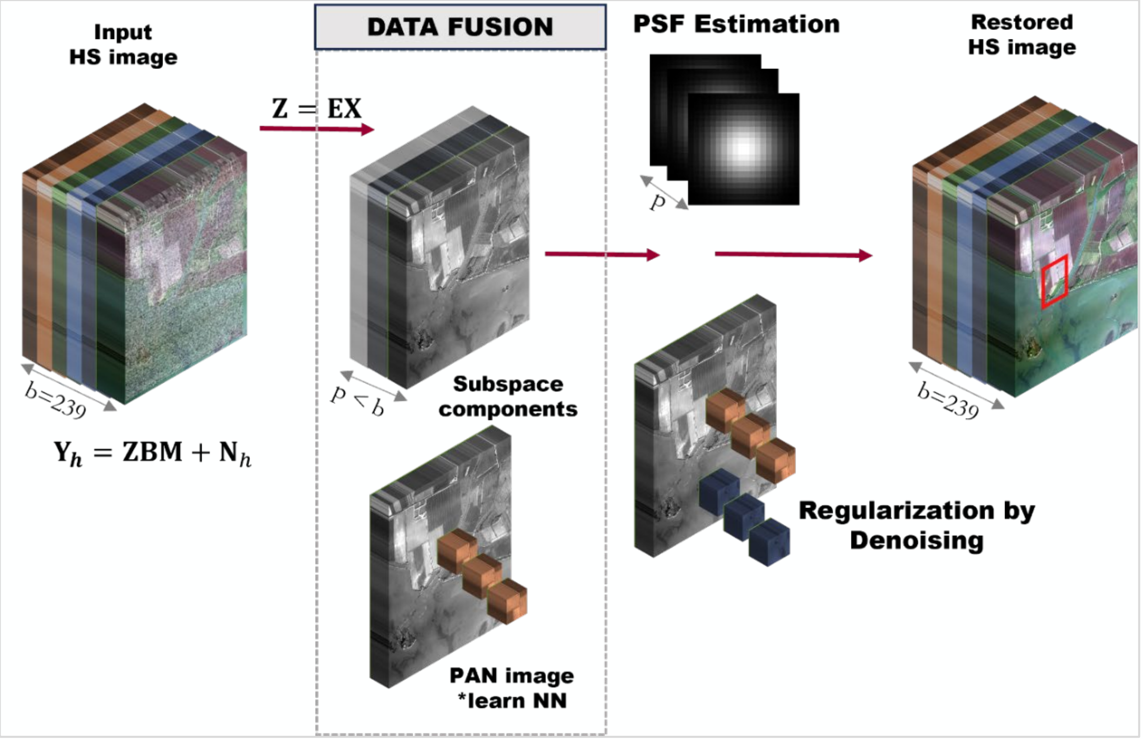
Promote sparse image gradient (smoother image, harder edges)

[1] M. Simões, J. Bioucas-Dias, L. B. Almeida and J. Chanussot, "A Convex Formulation for Hyperspectral Image Superresolution via Subspace-Based Regularization," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 53, no. 6, pp. 3373-3388, June 2015.

HySure + BM3D pansharpening

HySure + BM3D

$$\min_{X} \frac{1}{2}\|Y_h - EXBM\|_F^2 + \frac{\alpha}{2}\|Y_m - REX\|_F^2 + \beta\, \Phi(X)$$



Moreau proximity operator of the denoiser

Selected denoiser: Block Matching 3D filter (BM3D)

Any denoiser can be plugged-in

Convexity depends on the denoiser properties

Quantitative results

s1

HS

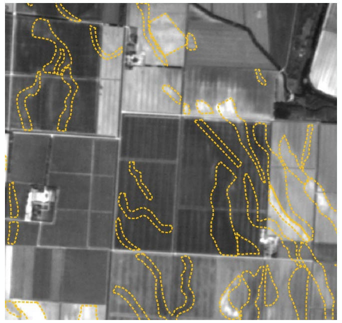
GSA

MTF-GLP

HySure

HySure + BM3D

PAN + Ground Truth



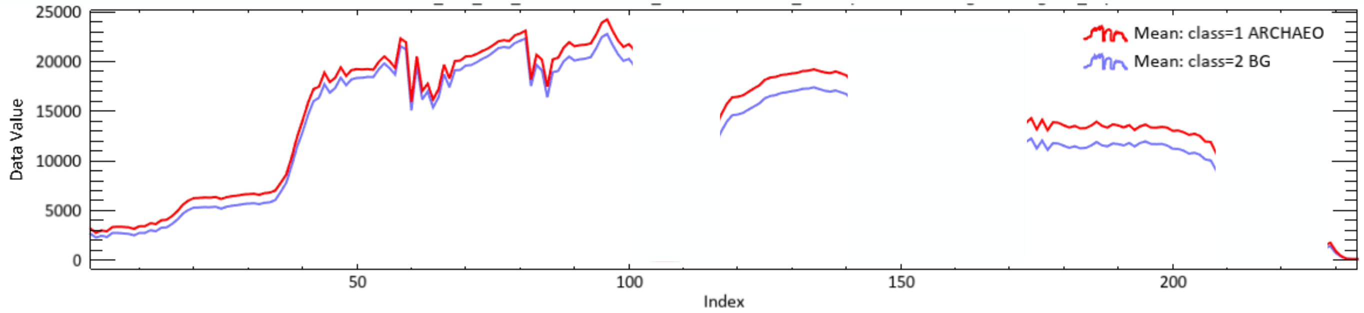
	UIQI	*SAM*	*ERGAS*
GSA	**0.9809**	**6.7952**	**3.0607**
MTF-GLP	0.9806	6.8578	3.1245
HySure	0.9764	7.0071	3.1051
HySure-BM3D	0.9627	8.3917	3.6670

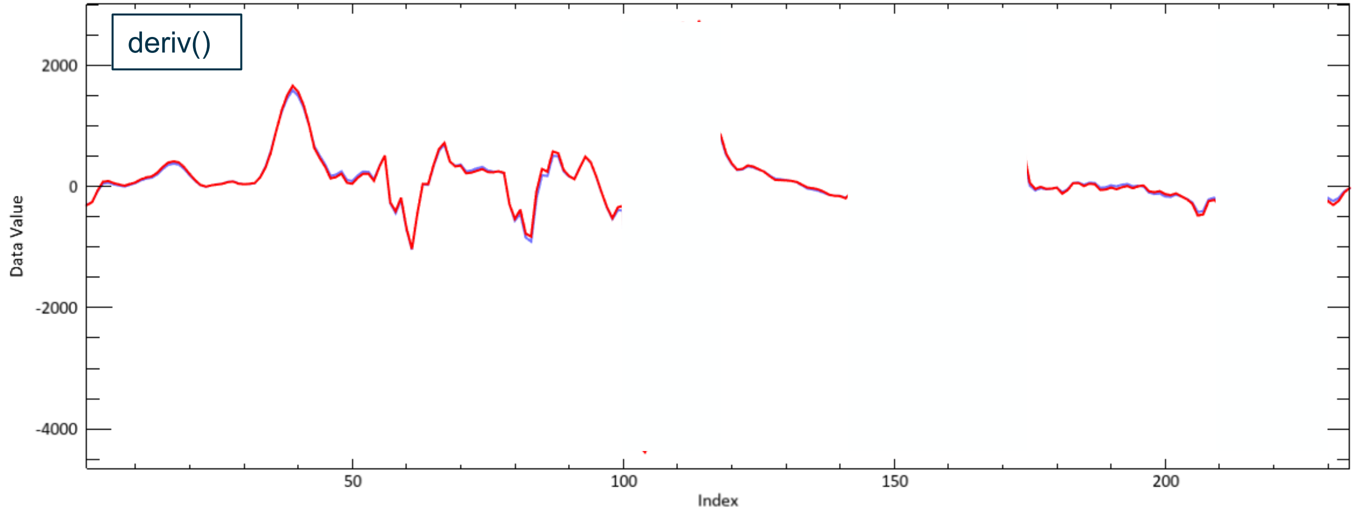
	D_S^*	D_λ^k	Q^*
GSA	0.55155	0.00844	0.44466
MTF-GLP	0.55137	0.00850	**0.44482**
HySure	0.55199	**0.00811**	0.44437
HySure-BM3D	**0.55054**	0.01062	0.44467

- GSA is the overall best method by Wald’s protocol.
- HySure achieves lower spectral distortion.
- HySure – BM3D achieves the lower spatial distortion.
- MTF-GLP achieves the best overall quality index.

Dimensionality reduction

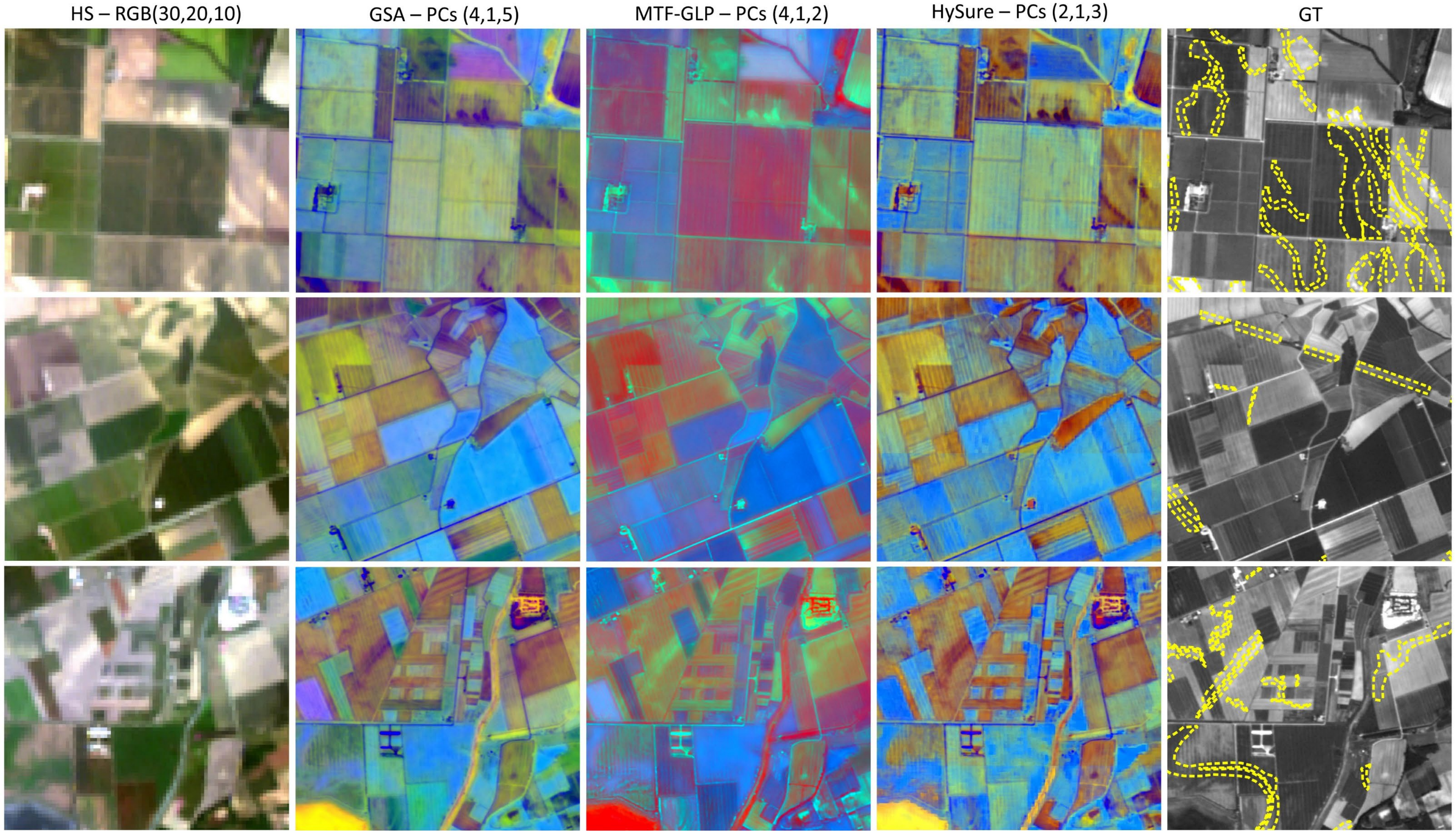
- Band math (spectral indexes): noise enhancement ⚠
- Visual analysis of ROIs spectral profile (“archaeological class” vs “neighbour BG pixels”)





Dimensionality reduction

- Principal Component Analysis
- Components manually selected to create FCC combinations
- Contrast between archaeological traces and the background is better in GSA and Hysure
- Hysure has more micro-contrast

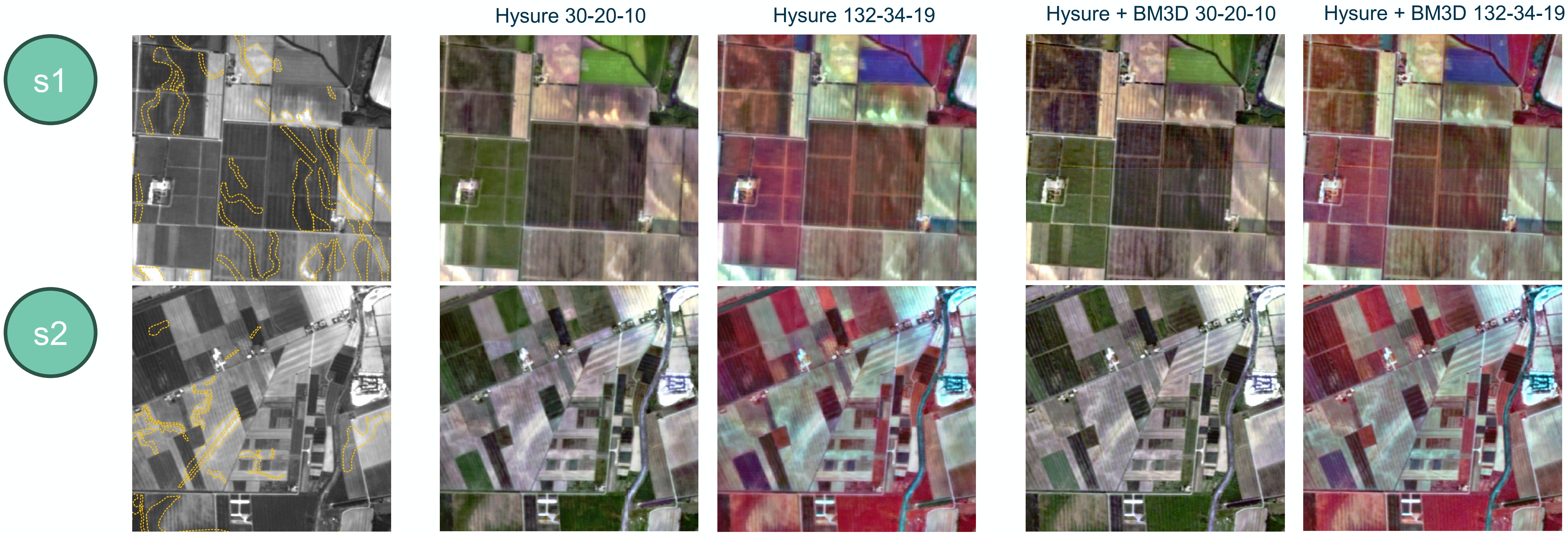


Dimensionality reduction

- Inter-Band Redundancy Analysis and Greedy Spectral Selection [1]
  - Recursive collinearity analysis + ranking based on information entropy in image classification performance

    \+ A good way to test relevant parts of the spectrum

    \- Not always selecting bands with good spatial details



[1] Morales, G.; Sheppard, J.W.; Logan, R.D.; Shaw, J.A. Hyperspectral Dimensionality Reduction Based on Inter-Band Redundancy Analysis and Greedy Spectral Selection, Remote Sens. 2021, 13, 3649.

Conclusions

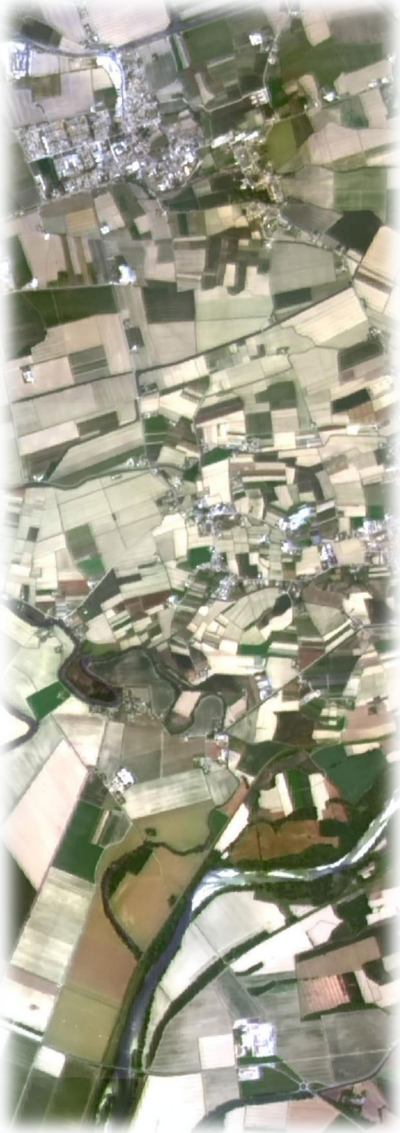
- Pansharpening effectively improves the visibility of small-scale geo-archaeological subsoil elements through enhanced spatial resolution

- The PyTorch implementation significantly reduces pansharpening processing time (7x) and enables a smoother integration of neural-network-based denoisers (Plug-and-Play)

- There is a discrepancy between the best **quantitative results** and the effectiveness in aiding **the identification of small-scale archaeological elements.**

- **Results in:**

Sech, G., Poggi, G., Ljubenovic, M., Fiorucci M., and Traviglia, A. *Pansharpening of PRISMA products for archaeological prospection,* 2024 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), https://doi.org/10.1109/IGARSS53475.2024.10642261



Thank you for your attention!

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