LPVE23 - WORKSHOP ON LAND PRODUCT VALIDATION AND EVOLUTION

Data fusion of PRISMA hyperspectral imagery with Sentinel-2 multispectral imagery for spatial resolution improvement

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ABSTRACT

The PRISMA (*PRecursore IperSpettrale della Missione Applicativa*) hyperspectral (HS) satellite platform, by the Italian Space Agency (ASI), is a promising precursor system for finer monitoring of the chemical-physical characteristics of Earth's natural resources and atmosphere, whose calibration/validation is still in progress. Although it operates a HS sensor at high spectral resolution, improving its medium spatial resolution (30 m) would ensure Earth observation in greater spatial detail. In a general context, the fusion of HS data with the higher spatial resolution multispectral (MS) images has given good results in literature, providing high spatial resolution HS imagery, and minimizing spectral degradation.

In the present study, the results of a HS-MS fusion approach, aimed at the enhancement of PRISMA spatial resolution by employing the spatial and spectral information of the Sentinel-2 MS data, were illustrated. As first step, the proposed workflow involved the correct sub-pixel alignment of the two datasets. For this purpose, the displacements between the two datasets were detected adopting the AROSICS (Automated and Robust Open-Source Image Co-Registration Software) free-available library, built on a phase correlation criterion. Subsequently, the HySure (HS Super Resolution) fusion method, in which the fusion process between PRISMA and Sentinel-2 bands is formulated as the resolution of convex quadratic optimization exploiting subspace-based regularization, was employed to obtain a high spectral and spatial resolution HS dataset. Finally, the obtained high resolution PRISMA fused images were compared to very high resolution hyperspectral airborne images, and some accuracy metrics were computed in order to validate the results of the proposed fusion approach.

STUDY AREAS

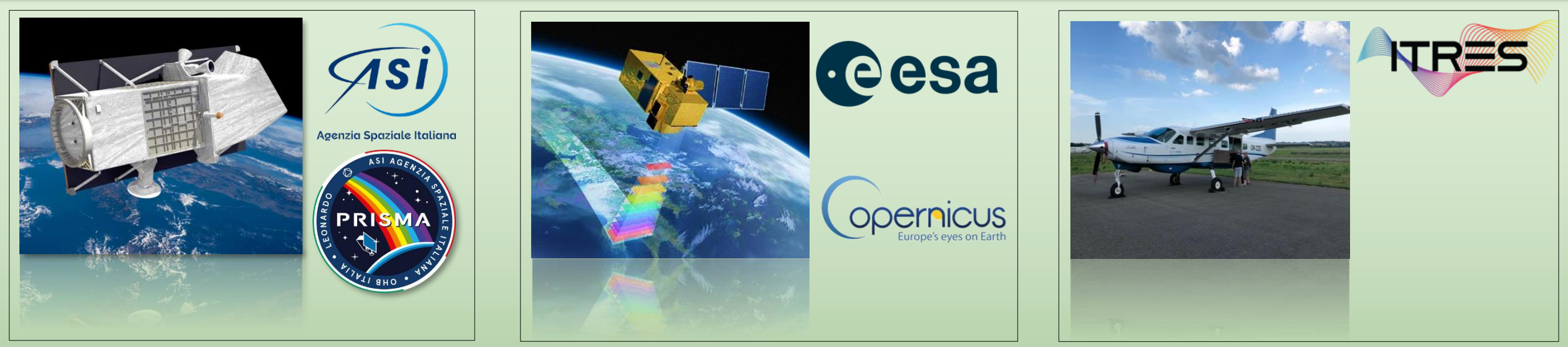
The HS-MS fusion approach was tested on three different study areas located in the territories of Grosseto (N42°82'94'', E11°06'96''), Prato (N42°87'99'', E11°08'93'') and Arborea (N39°80'15'', E8°60'44''), representing heterogeneous anthropic and natural landscapes (agriculture, urban, forest, etc). In the present poster, only the results retrieved on the Grosseto study area are presented.

DATASET

The HS part of the data was composed by the PRISMA Level 2D (atmospherically corrected, geocoded), while the 20m (resampled to 10m pixel size) and 10m native pixel-size bands of Sentinel-2 Level 2A (atmospherically corrected, geocoded) were employed as MS information.

A dataset of high resolution images, acquired using the airborne HS sensors CASI (for visible and near infrared) and SASI (short-wave infrared), was obtained on the same scene to validate the fusion product. The airborne image, natively at very high spatial resolution (CASI: 1.5 m; SASI: 3.75 m), had been previously resampled to 10m pixel size in order to match the spatial resolution of satellite HS and MS images.

Both the satellite HS and MS imagery and the airborne HS image were simultaneously acquired on the same date (August 1th 2020).



	PRISMA HS	Sentinel-2	CASI/SASI
Spectral Resolution	VNIR 400 – 1010 nm (66 bands) SWIR 920 – 2500 nm (173 bands)	VNIR 490–864 nm (8 bands) SWIR 1610 & 2202 nm (2 bands)	VNIR 380 – 1060 nm (96 bands) SWIR 950 – 2450 nm (100 bands)
Spectral Width	≤ 12 nm	15-185 nm	≤ 12 nm
Spatial Resolution	30m	10m (VNIR); 20m (RedEdge/NIR; SWIR)	1.5m (VNIR); 3.75m (SWIR)

METHODS

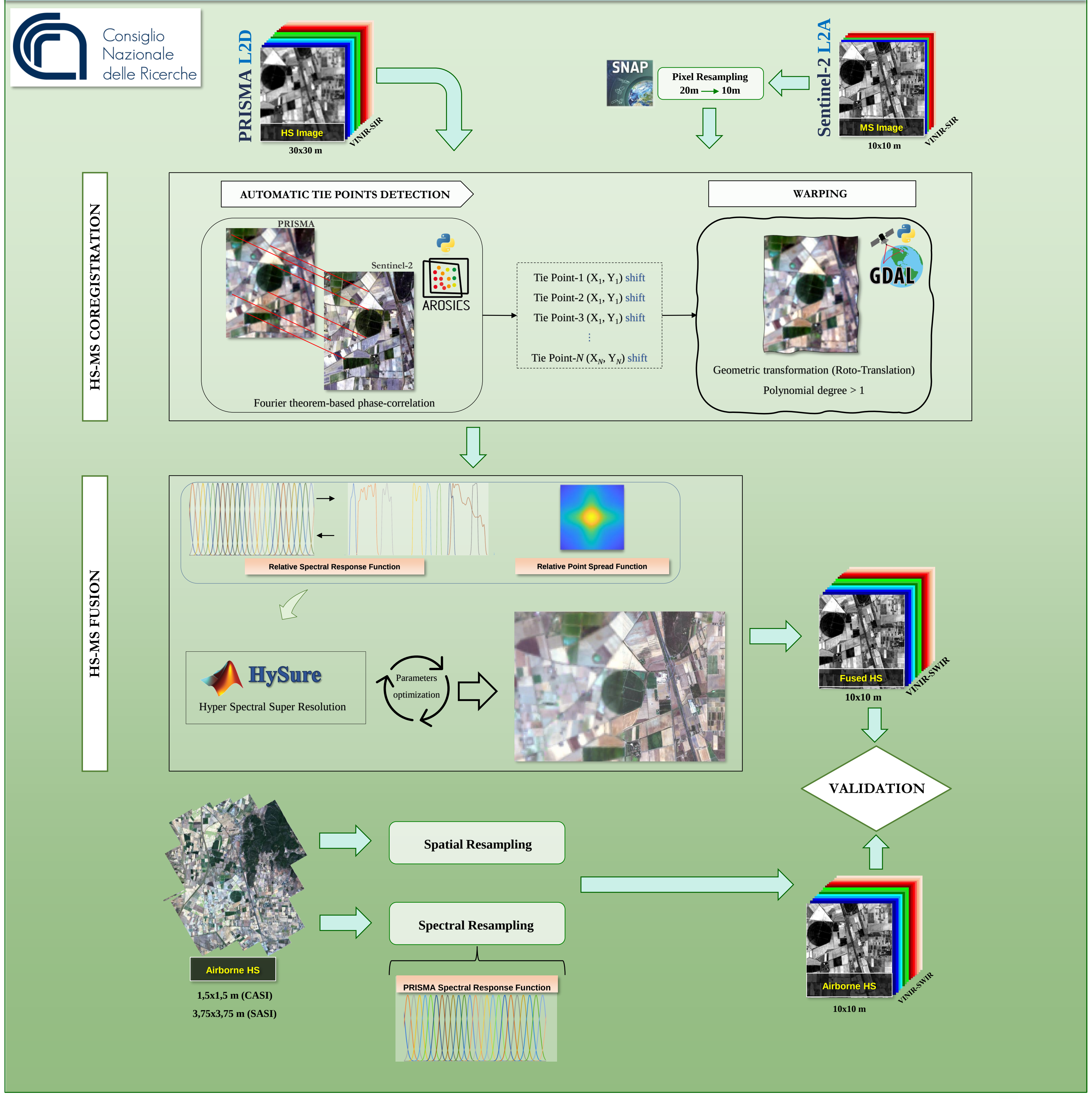
The proposed workflow consisted of three main processing steps:

A. HS-MS Coregistration. Image fusion processing requires images to be accurately aligned at the pixel and sub-pixel level, in order to mitigate the presence of geometric artifacts in the fused results. The AROSICS algorithm (Scheffler et al. 2017), implementing a Fourier's theorem-based phase-correlation approach, was employed to estimate the common tie points on PRISMA and Sentine-2 scenes. The estimated tie points were then used for the geometric (roto-translation) transformation (warping) of the PRISMA image, in order to accurately fit it on the Sentinel-2 geospatial placement.

B. HS-MS fusion. The hyperspectral super resolution (HySure) (Simoes et al., 2015) model was implemented to fuse HS and MS images. The algorithm addresses the fusion problem as a minimization of a convex objective function in a subspace configuration, retrieved from the low-resolution HS image by adopting the vertex component analysis (VCA) endmember extraction technique. It automatically calculates the relative spectral response function and the point spread function of the two sensors. The best combination of model parameters values was set by adopting the one that gave the best accuracy result among the various combinations tested (parameters optimization.

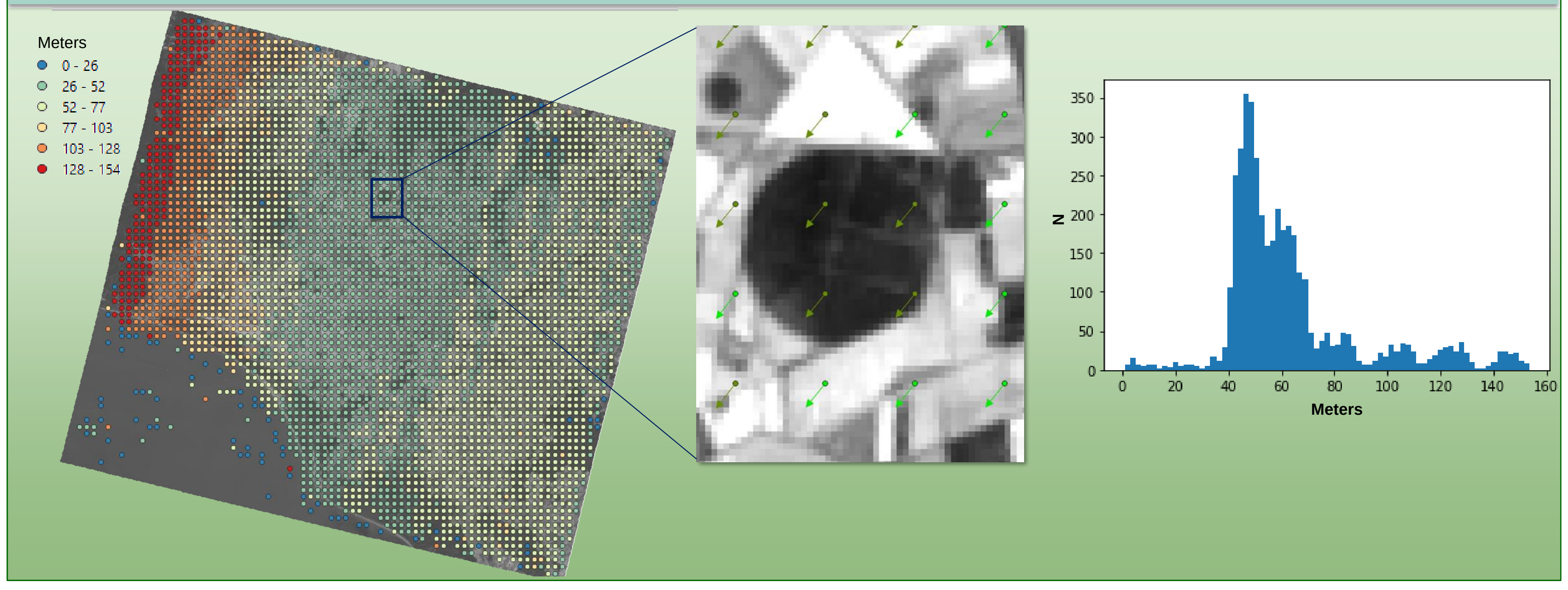
C. Validation of the results by comparing them with HS aerial data. The resulted fused image (high spectral and spatial resolution HS image) was finally compared and validated with the respective airborne HS image (reference). The root mean square error (RMSE), the spectra angle mapper (SAM) and the peak signal-to-noise ratio (PSNR) metrics were computed to account the accuracy/error. The spectral signatures of some representative pixels of the fused and reference images were also compared.

Most of the procedures were carried out implementing open-source and free-available software, libraries and/or codes.



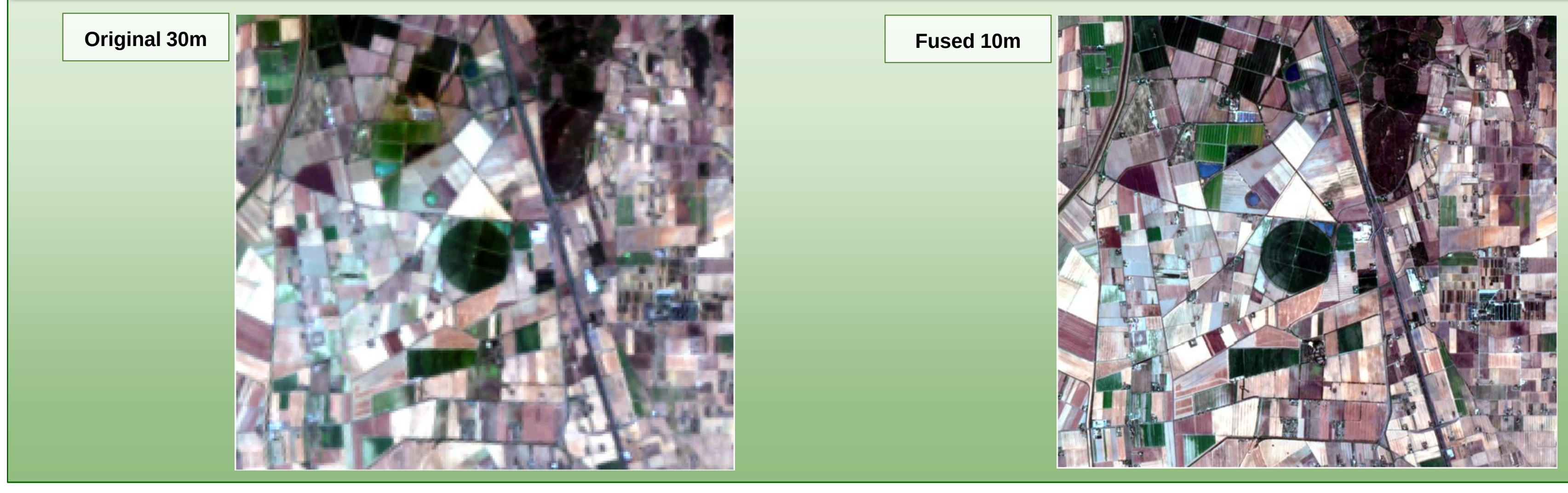
RESULTS: HS-MS COREGISTRATION

Below, the tie points grid, retrieved from the coregistration step, is shown (on the left) vested by a colour palette representing the magnitude of the shifting (in meters). It is noticeable the non-linear spatial patterns of the pixels shift (lowest in the center image, highest towards the edges) . The histogram (on the middle) describes the frequency of the shift magnitude across all the tie points on the scene, reporting that the most frequent shift extension is between 40 and 70 meters. On the right, a fine-detail scene overview shows the direction (vectors) of the shift for each tie point; the length of the vector is proportionate to the respective shift magnitude.



RESULTS: HS-MS FUSION

The figure below displays an overview of the PRISMA image with original spatial resolution at 30 m (RGB) of the Grosseto study area (on the left). On the right, the result of the HS-MS fusion between PRISMA and Senitnel-2 imagery, carried out by implementing the HySure model, is shown (RGB) on the same scene.



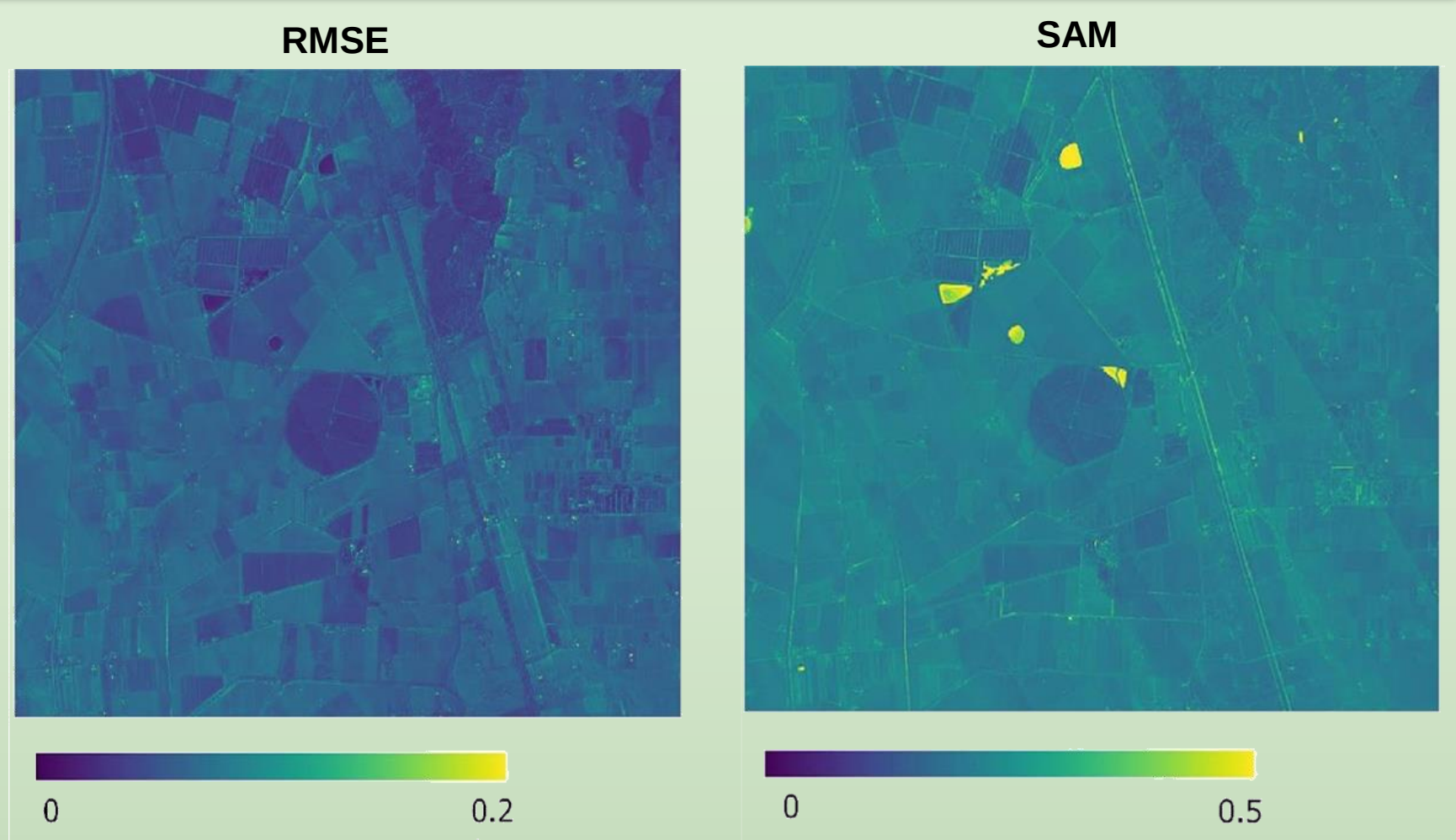
RESULTS: VALIDATION

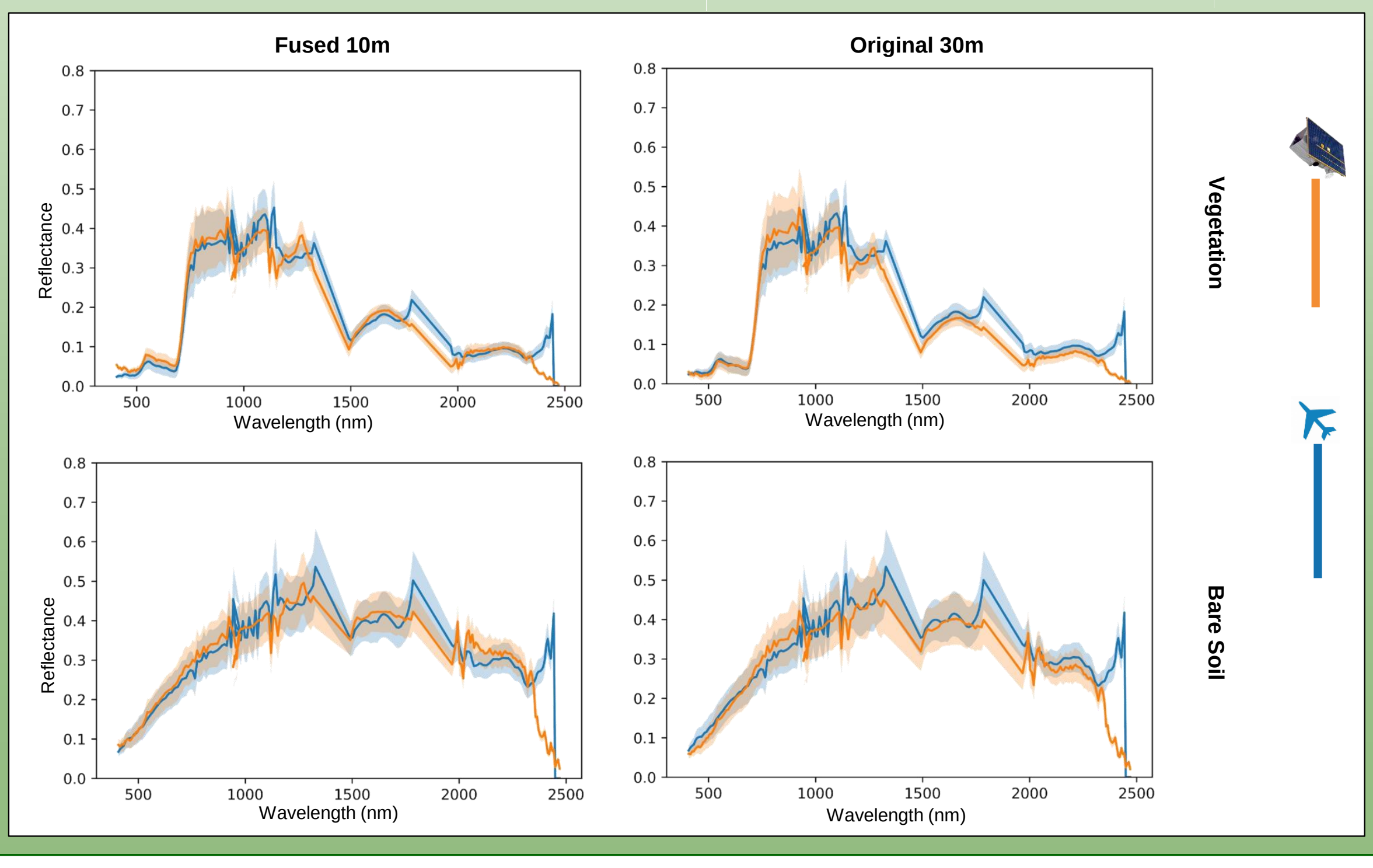
The table below shows the mean values, and relative standard deviations, of the accuracy metrics (RMSE, SAM, PSNR) obtained by comparing the results of the HS-MS fusion and the HS airborne images. The values express good level of accuracy if compared with those reported in the literature.

The spatial distribution of the error, represented in this case by the RMSE and SAM indices, was also calculated and shown in the figures on the right of the table. The results show a high dependence of the error on the land cover, with lower values of error for the vegetated surfaces.

At the bottom, the average spectral signatures of some pixels, representative of the vegetation and bare soil that cover the scene, are compared. In vegetation it is noticeable as the greatest variability occurs at the level of the NIR bands, while this variability is widespread across the entire spectrum for bare soil. This corroborated what has already been observed in the spatial distribution of RMSE and SAM. Next, the spectral signatures are reported for the same pixels at the original spatial resolution (not fused) of PRISMA (30 m), compared with the airborne HS resampled at 30m. This demonstrates how the slight discrepancies between the spectra were already present between the original images, and are not caused by the HS-MS fusion model. This highlights the effectiveness of the presented approach.

Index	Formula	μ ±σ
RMSE	$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\mathbf{x}_i - \hat{\mathbf{x}}_i)^2}{n}}$	0.088 ±0.015
SAM	$\mathrm{SAM}(\mathbf{x}_j, \hat{\mathbf{x}}_j) = \arccos\left(\frac{\mathbf{x}_j^T \hat{\mathbf{x}}_j}{\lVert \mathbf{x}_j \rVert_2 \lVert \hat{\mathbf{x}}_j \rVert_2}\right)$	0.26 ±0.033
PSNR	$\mathrm{PSNR}(\mathbf{x}_i, \hat{\mathbf{x}}_i) = 10 \cdot \log_{10}\left(\frac{\max(\mathbf{x}_i)^2}{\lVert \mathbf{x}_i - \hat{\mathbf{x}}_i \rVert_2^2 / P}\right)$	81.90 ±7.98





Conclusions

Results proved the effectivity of the proposed approach. The coregistration phase assured an accurate alignment of the target and reference pixels, thus reducing geometric errors during the fusion phase. Furthermore, the HySure fusion algorithm renstitued appreciable results, with very low error value. In particular, the strong point of this application was the availability of real high-resolution HS airborne images for the validation of the results.

Future developments will concern the more in-depth analysis of the errors, the comparison with the use of the panchromatic band for HS image pansharpening and, eventually, the development of a semi-automatic co-registration-fusion tool.

12 14 June 2023 | ESA-ESRIN | Frascati (Rome), Italy