ITINERIS

Cross-RI dataset provision of UAV multi platform hyperspectral data and site level measurements over different RI ecosystem sites (eLTER, ICOS, ANAEE) and comparison with satellite products.

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1. INTRODUCTION

This deliverable presents the development of a comprehensive framework aimed at enhancing the accuracy of vegetation monitoring at RI sites through the integration of airborne and satellite remote sensing imagery. The proposed methodology encompasses preprocessing steps to mitigate external factors, the harmonization of diverse remote sensing products, and the implementation of physical and machine learning based modeling techniques and spectral mixture analysis to ensure precise interpretation of optical remote sensing data. This document outlines the methodologies employed, details the research activities undertaken, and presents the results and outcomes achieved.

Near-real-time vegetation data is crucial for informed management decisions. It provides essential information to evaluate ecosystem health and sustainability while on crops it supports farmers to optimize management. Remote sensing techniques are increasingly valued for their ability to deliver fast and georeferenced information over field crops and large scales, with repetitive coverage. These techniques mainly rely on the spectral absorption features of different canopy components to characterize vegetation. However, traditional methods of spectral data interpretation often involve empirical, non-physical image processing, which limits the direct estimation and quantification of pure surface components. Remote sensing acquisitions are influenced by various external factors that impact data accuracy, such as the geometric characteristics of the acquisitions and atmospheric constituents, which require corrective preprocessing. This correction is particularly crucial when harmonizing remote sensing products obtained from different sensors, times, or locations. Sensor-specific characteristics, such as spatial resolution, also play a crucial role in data quality. The spatial resolution determines the surface area from which information is collected, making data from heterogeneous landscapes prone to mixed spectral signatures—especially in coarser spatial resolution satellite imagery. Also, most traditional approaches rely on empirical techniques like vegetation indices (VIs), which use only a limited number of spectral bands. These techniques often lack the physical basis needed for directly estimating plant traits and quantifying surface components.

Validation of remote sensing products can be achieved through ground-truth data or by leveraging data from other sensors that offer lower radiometric disturbances and higher spectral and spatial resolution, such as high-resolution aerial imagery both from UAV and manned aircraft platform. Utilizing these aerial images as a benchmark for validating satellite products significantly enhances the accuracy and reliability of satellite data. Therefore, the objectives of this work are (i) to develop a robust preprocessing pipeline aimed at removing external disturbances in aerial images, that allows harmonizing them with satellite products for improved validation and correction; (ii) to validate the use of an unmixing model in satellite products with coarse spatial resolution, using high-resolution aerial imagery as a reference; and (iii) to deploy the proposed spectral modeling technique for monitoring plant traits and health at RI sites, and validate with ground-truth data.

2. FRAMEWORK DEVELOPMENT

2.1 Aerial imagery preprocessing

The present work proposes a comprehensive pipeline for removing radiometric disturbances from airborne acquisitions, enabling the validation of satellite data through image harmonization (Figure 1). The process begins with radiometric corrections to generate radiance values ($\mu W\ cm^{-2}\ sr^{-1}\ nm^{-1}$) using RadCorr (Itres Ltd). These corrections are performed with pixel-specific calibration parameters obtained in a controlled laboratory environment. To further refine and validate the atmospheric correction, ground truth spectral data is collected at the surface level using a handheld spectroradiometer (Spectral Evolution RS-5400). The conversion of ground-level radiance measurements to reflectance values is achieved using a white reference Spectralon panel (Labsphere Inc., North Sutton, NH, USA).

Subsequently, atmospheric correction of the at-sensor radiance is conducted using the ATCOR-4 software, which employs MODTRAN-based radiative transfer calculations to remove atmospheric and adjacency effects, thereby retrieving accurate surface reflectance values. To mitigate spectral noise, absorption bands related to water vapor and those at the spectral range boundaries are excluded. Additionally, the first and last sensor bands, known for their lower sensitivity, are filtered out to ensure data integrity.

Further preprocessing steps, including geometric corrections, orthorectification, and georeferencing, are executed using GeoCor (Itres Ltd.), incorporating data from the GNSS/IMU unit and the digital terrain model. Spatial resampling and coregistration of images acquired by various airborne sensors are performed to ensure consistent spatial resolution across all products.

Harmonization with satellite imagery involves a multi-step process. First, spectral resampling is carried out using the Spectral Resampling tool in ENVI 5.6 to match the satellite's spectral response function (SRF), after filtering out noisy wavelengths. The images are then converted to a 32-bit floating-point format [0, 1] for uniformity. Finally, the airborne and satellite datasets are precisely co-registered using the AROSICS open-source software, ensuring spatial alignment between datasets for reliable cross-comparison and validation.

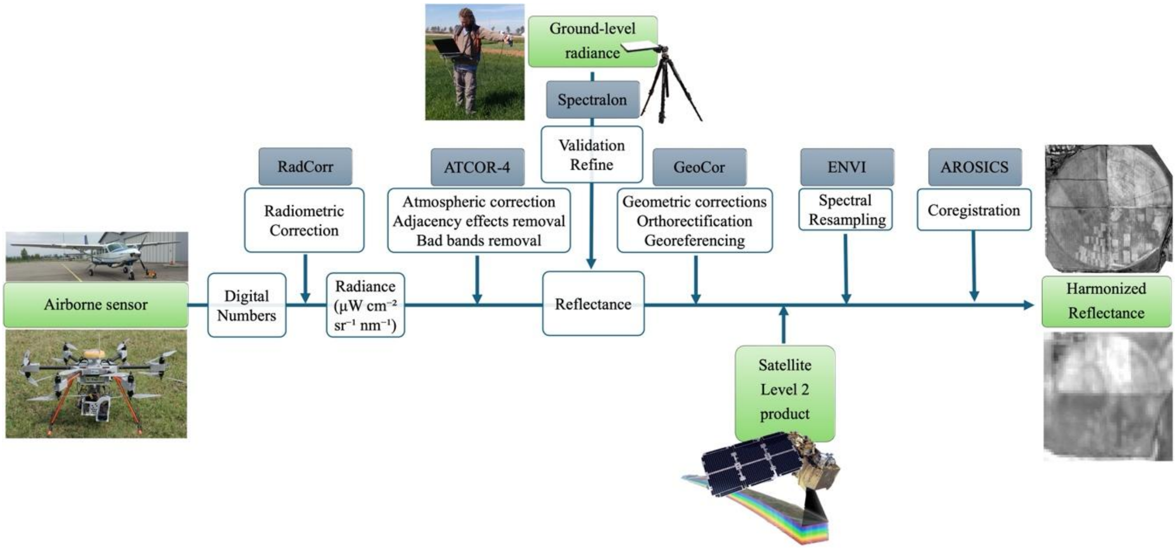

Figure 1 - Pipeline followed for preprocessing aerial optical images and harmonize with satellite images.

2.2 Hybrid Machine Learning-Radiative Transfer Model

This work proposes and validates a hybrid machine learning (ML) and radiative transfer model (RTM) approach for retrieving vegetation parameters in agricultural and forest ecosystems using both aerial and spaceborne sensors (Figure 2). The hybrid model leverages the entire optical spectrum to provide a physically-based retrieval of plant traits corresponding to the observed spectra. This technique relies on simulated spectra generated by the RTM, which are spectrally resampled to match satellite bands and then used to train a ML model for accurate traits estimation of the target spectrum.

Several biophysical RTMs have been developed for this purpose. Among them, the PROSAIL-PRO model stands out for its ability to provide quantitative information on key plant traits, such as leaf area index (LAI), chlorophyll content (Cab; μg cm²), and equivalent water thickness (EWT; g cm²). Additionally, PROSAIL-PRO considers external factors influencing the spectral signal, including viewing and illumination geometry, as well as soil background spectra, making it particularly useful for agriculture and forest monitoring applications.

Given the growing potential of satellite missions to provide global plant trait retrievals, the hybrid method was tested on various spaceborne imagers. The accuracy and transferability of the retrievals were validated across different ecosystems, using ground-truth measurements and high-resolution aerial acquisitions, which offer superior radiometric quality and both high spectral and spatial resolution.

The hybrid ML-RTM framework was implemented using the R package ToolsRTM, following these steps:

i) A Look-up-Table (LUT) is generated using the RTM to simulate a wide range of reflectance spectra and their associated plant traits. For this study, PROSAIL-PRO was employed due to its reliability in providing crucial plant trait information and its proven accuracy.

ii) The 1 nm-resolution reflectance spectra from the LUT are convolved to match the bands of the target optical sensors. In this work, spectra were convolved to align with Sentinel-2 bands using its SRF, and PRISMA bands were modeled using a Gaussian distribution function based on the Full Width at Half Maximum (FWHM). This step ensures the model's applicability to various sensor data.

iii) The LUT is used to train a machine learning model to estimate plant traits based on the convolved reflectance bands. In this study, an artificial neural network (ANN) algorithm was chosen for its robust predictive capabilities.

iv) The trained ML model is applied to the observed spectral bands to retrieve the plant traits corresponding to the observed area, allowing for efficient large-scale vegetation monitoring.

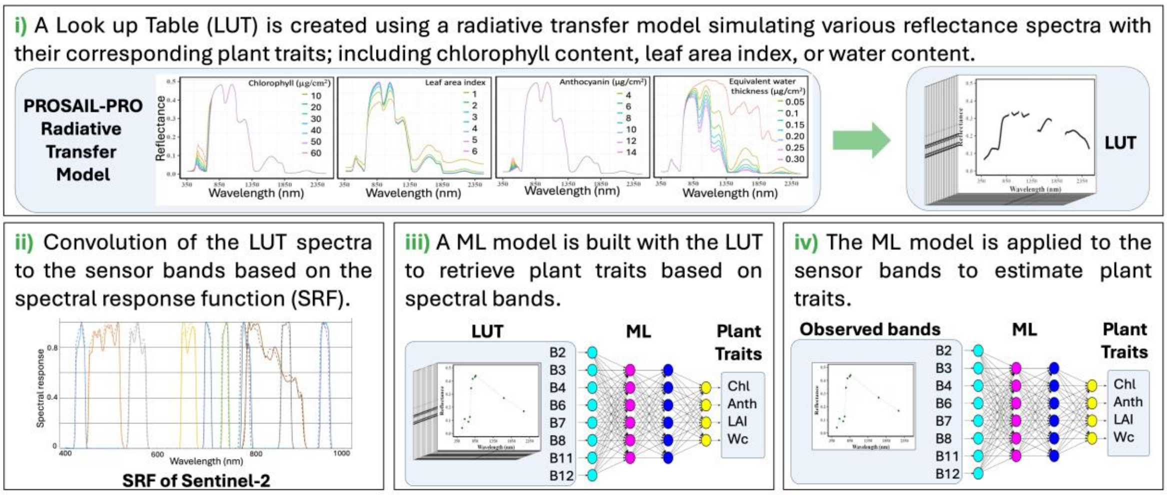

Figure 2 - Workflow of the hybrid Machine-Learning-PROSAIL model application in satellite acquisitions.

2.3 Multiple Endmember Spectral Mixture Analysis (MESMA)

To address the mixed pixel problem and quantify pure surface components at a sub-pixel level, spectral mixture analysis (SMA) techniques, especially the optimized Multiple Endmember SMA (MESMA) approach, have been widely and effectively adopted in literature. MESMA addresses the mixed pixel problem by accounting for sub-pixel spectral features, estimating the proportion of each physical component within a pixel (Figure 3). It assumes each pixel's spectrum is a mixture of signals from different components, offering a physical description of the surface rather than just classification. MESMA allows for the testing and selection of different endmembers (spectral signature representing a pure surface/material) composing each pixel, using a threshold criterion based on root mean square error (RMSE), therefore accounting for endmember variability and spectral heterogeneity.

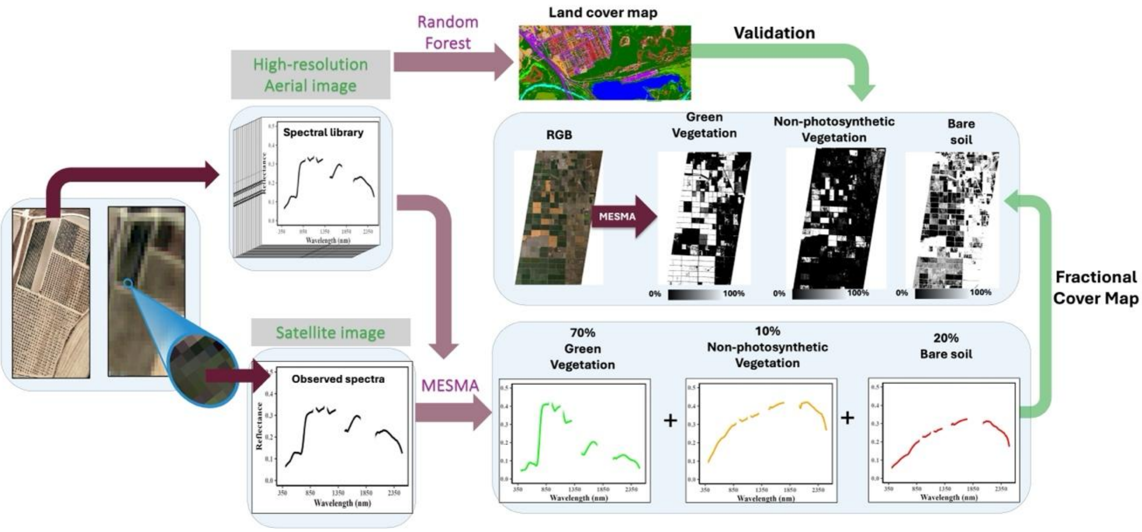

Figure 3 - Workflow of the validation with high-resolution aerial image of Multiple Endmember Spectral Mixture Analysis (MESMA) applied to medium resolution satellite images.

3. APPLICATIONS

3.1 Aerial image preprocessing

The described preprocesing steps of the aerial products (Figure 1) have been applied on existing aerial surveys with hyperspectral payloads, specifically on two areas in Italy surveyed with two different airborne hyperspectral systems: the area of Prato (Italy) surveyed with an HySpex payload on June 22nd 2020 and the area of Lucca (Italy) surveyed on July 15th 2023 with a CASI/SASI payload (Figure 4). The HySpex system (Norsk Elektro Optikk, Norway) carries two separate push-broom sensors: the VNIR-1800, ranging between 400 and 1000 nm over 186 bands with a spectral sampling interval of 3.3 nm, and the SWIR-384, spanning 960 to 2500 nm over 288 bands with a spectral sampling interval of 5.5 nm.

This pipeline allowed the characterization of the different land covers found in the two study areas thanks to the radiometric quality and the spatial resolution of the images. This work allowed retrieving the albedo of the different land covers for analyzing the environmental impact of different scenarios created by simulating albedo changes. The results provided insights to landscape planners to reduce environmental impact, and any strategy aiming at decarbonization can make use of this information in its planning.

Additionally, these preprocessed aerial products were harmonized to the coincident PRISMA satellite images to validate the outputs when applying the modeling techniques to the coarse spatial resolution of the PRISMA images. The spectral distance between the PRISMA central wavelengths and the HySpex sensors was ≤ ±2 nm, while the spectral distance with CASI/SASI sensors did not exceed 3 nm for CASI and 7 nm for SASI across the entire spectral range. The Ground Sampling Distance (GSD) for CASI was 1 m and for SASI was 3.75 m.

This pipeline developed and validated with the aircraft images serve as the preliminary steps for its application in the hyperspectral 400-2500 nm images that will be collected with an upcoming UAV. The deployable UAV will collect high-resolution images in agricultural and forest study sites from ITINERIS selected according to FOR2N meta database. This process will provide a powerful tool for validating the satellite outcomes and for providing high-quality maps.

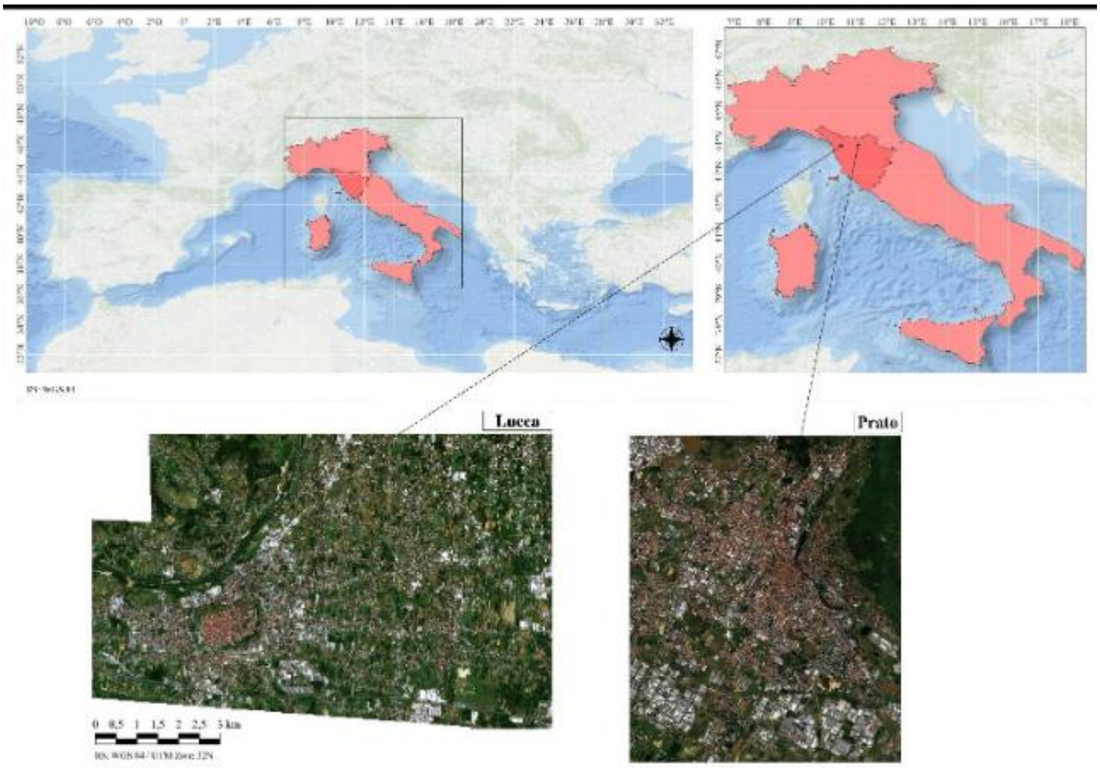

Figure 4 - Location of study collected with the SASI and CASI airborne sensors. Images show the true-color frames including the city center, the peri-urban belt and the rural area of Lucca and Prato.

3.2 Hybrid Machine Learning-Radiative Transfer Model

This work aims to tune-up and validate the hybrid model for its application in aerial and satellite images for agriculture and forest monitoring. For this purpose, the model has been applied and validated in an agricultural experimental field using sentinel-2 imagery and in ICOS forest sites using Sentinel-2 and PRISMA. Future work will validate the hybrid model on high resolution UAV images collected in agricultural AnaEE sites and in forest ICOS sites.

3.2.1 Agriculture

- Precision agriculture

The model has been applied to a time series of Sentinel-2 images collected on an experimental winter wheat field (Figure 5). The objective of this study is to validate the application of the hybrid model to the multi-spectral acquisition for retrieving plant traits and estimating the nitrogen (N) status in a precision agriculture context. The experimental design was based on 16 plots, established during two consecutive years with 4 N levels and two levels of water. The validation was performed by comparing the retrieved Cab and LAI with ground-truth data collected at three key growth stages: mid stem elongation, final stem elongation and flowering. The chlorophyll content was measured with a Dualex leaf-clip sensor and LAI was obtained with a ceptometer. Additionally, the time series of the retrieved plant traits was analyzed to identify its capacity to monitor crop growth.

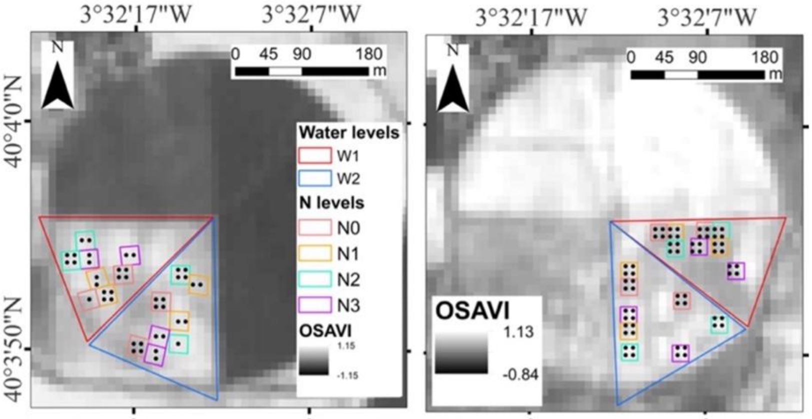

Figure 5 - Winter wheat experimental field showing the nitrogen (N) and water (W) levels of both experimental years. Points indicate the Sentinel-2 pixel selected.

The Cab and LAI values estimated with the hybrid ML-RTM applied to Sentinel-2 displayed an $R^2 = 0.39$ and a RMSE = 7.6 ($\mu g\ cm^{-2}$) with the Cab measured with the Dualex leaf-clip sensor and an $R^2 = 0.5$ and a RMSE = 1.03 LAI calculated with a ceptometer when using measurements of the three key growth stages. The results allowed the identification of the N levels from early growth stages (Figure 6; Figure 7), while outperformed the accuracy of the traditional VIs. In addition, the temporal dynamics of the retrieved crop traits matched the physiological development of the crop by correctly describing the growing and senescence seasons. The retrieved values showed differences between N levels from early growth stages, even earlier than the traditional VIs. These results validate the capacity of the hybrid model of accurately retrieving specific plant traits and its application in precision agriculture by identifying the N deficiencies for adjusting N fertilizer rates.

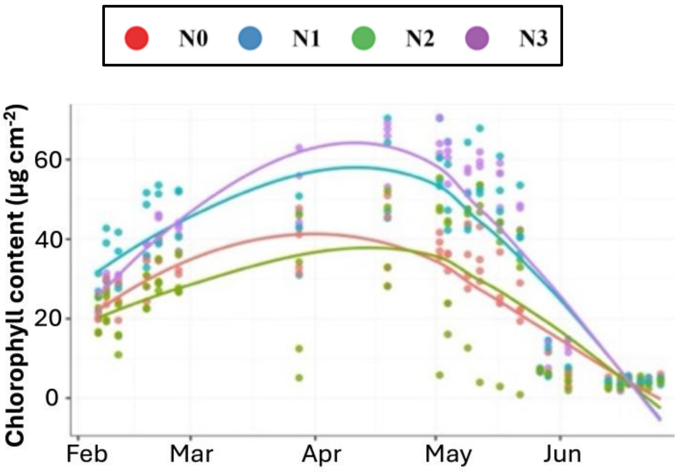

Figure 6 - Time series of Chlorophyll content (Cab) retrieved with the hybrid artificial neural network-PROSAIL model applied to Sentinel-2. Each dot represents the mean value of a winter wheat plot, with colors indicating the N level. Mean values of each N level. Mean values of each N level are connected through a smoothed line.

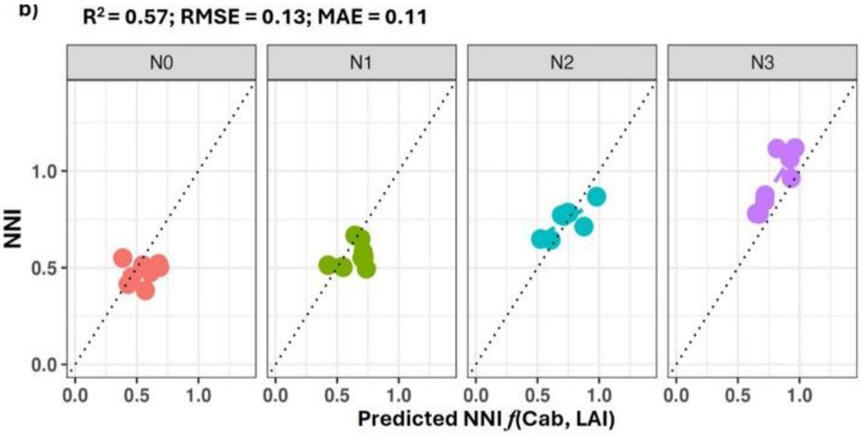

Figure 7 - Linear correlation between the nitrogen nutrition index (NNI) calculated with crop samples and NNI based on the Sentinel-2 retrieved Cab and LAI. The dotted line indicates 1:1.

- Identification of agricultural management practices

Monitoring time series of key plant traits, such as leaf chlorophyll content (Cab) allows understanding olive orchards response to climate conditions and management practices. We monitored monthly variations of Cab in two differently managed olive orchards (i.e., extensive vs intensive) in the Tuscany region, Italy for the period 2017-2024 coupling two Sentinel-2 datasets and the hybrid model using the ToolsRTM R package.

The results showed that time-series of Cab were consistent with olive tree phenological stages, achieving the highest value of Cab during winter and the lowest during summer period (Figure 8). This variability was especially evident in the extensive orchard, where the mean Cab varied from 52.3 (µg cm^{-2}) in winter to 12.4 (µg cm^{-2}) in summer, while in the intensive orchards it only varied from 40.3 to 30.7 (µg cm−2). These results validate the suitability of the hybrid ANN-PROSAIL model for Cab retrievals in olive orchards across seasons, as well as its capability for identifying management strategies.

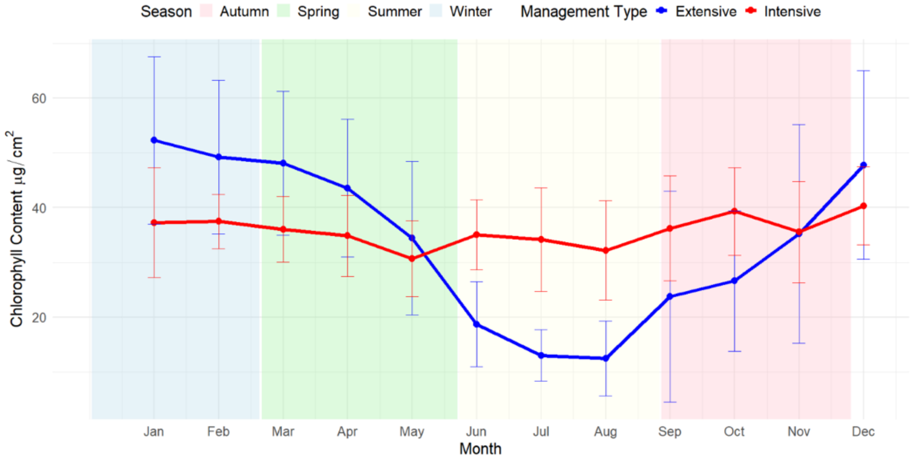

Figure 8 - Monthly mean and standard deviation of chlorophyll content (Cab) intensive and extensive olive orchards during 8 years estimated with Sentinel-2 and the hybrid model.

3.2.2 Forest

A diverse set of ICOS ecosystem sites across Europe, representing various forest formations, was carefully selected to test the accuracy and transferability of the hybrid model. The selection process was based on several key criteria, including the type of vegetation, the availability of high-quality ground-truth data, and the existence of PRISMA satellite acquisitions for those areas. These criteria ensured a comprehensive assessment of the model's performance across different forest ecosystems and environmental conditions.

After a thorough evaluation, a total of 13 ICOS sites were chosen for this study (Figure 9). These sites encompass a range of forest types, providing a robust dataset to validate the model's accuracy when applied to the available Sentinel-2 and PRISMA satellite imagery.

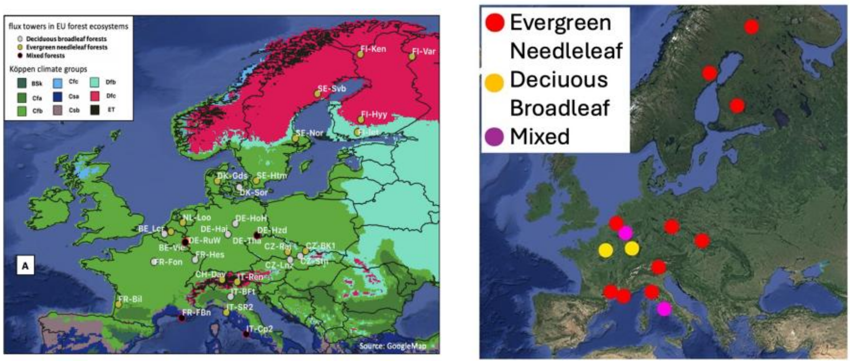

Figure 9 - ICOS ecosystem sites selected for the application of the hybrid ANN-PROSAIL-PRO model in the a) Sentinel-2 and b) PRISMA images.

- ### *Plant traits retrieval*

This work aims to validate the application of the hybrid model to Sentinel-2 and PRISMA satellite imagery using ground data collected by the ICOS network. The extensive LAI measurements collected under varying time and locations provides a robust ground-truth dataset to validate the retrieved plant traits in different forest formation, allowing testing and confirming its transferability and adaptability across various ecosystems.

- ### *Gross Primary Production*

The eddy covariance ICOS towers provide measurements that allow determining plant health, such as the gross primary production (GPP). Validating the use of remote sensing data to calculate the GPP in different ecosystems is crucial for assessing ecosystem productivity and health. Comparing data from ICOS towers with satellite imagery, such as Sentinel-2 and PRISMA, allows developing models to estimate GPP at large-scale to monitor vegetation dynamics and forest health, enabling better understanding and response to environmental changes.

Since GPP is influenced by a variety of plant traits, this work focuses on developing a ML model that utilizes these retrieved plant traits as explanatory variables for GPP estimation. By incorporating various plant traits, such as LAI, Cab or EWT, together with structural and chlorophyll-related vegetation indices, retrieved from Sentinel-2, the predicted GPP correctly matched the temporal variations of the GPP measured with the flux tower (Figure 10), displaying an $R^2 = 0.86$ and a RMSE 2.25 (μmol CO_2 m^{-2} s^{-1}) when analyzing the 31 studied ICOS sites across diverse European ecosystems.

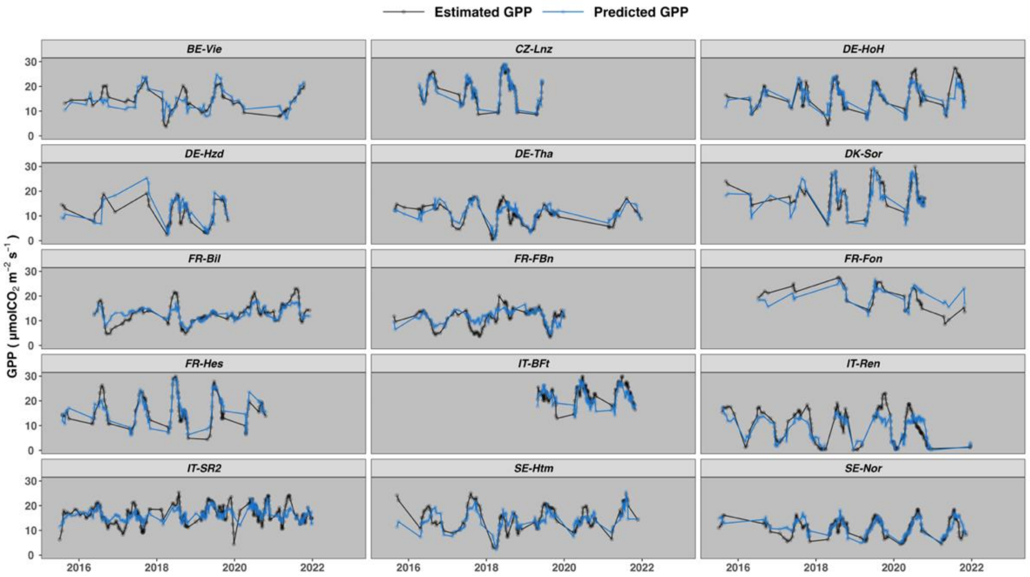

Figure 10 - Gross Primary Production (GPP) estimated with the eddy covariance ICOS flux towers and predicted based on the plant traits retrieved with Sentinel-2.

- *Disease Detection*

Various fungal infections have been detected at multiple Italian ICOS sites, including San Rossore and Castel Porziano. Satellite imagery can be a powerful tool for monitoring biotic infections and their spread, primarily due to its ability to capture repeated, large-scale images over time. The increasing availability and frequency of satellite data offer a unique opportunity to identify infections at their early stages, thereby providing crucial information that can inform timely and effective management decisions to minimize environmental impacts.

Fungal infections can significantly affect various plant traits, such as reducing Cab, LAI or EWT. Therefore, this study aims to validate the use of the hybrid method for monitoring these infections by analyzing the different of plant trait obtained from Sentinel-2 and PRISMA satellite imagery. By analyzing time series of the retrieved plant traits in both healthy and infected areas, this research seeks to quantify the impact of fungal infections and assess the potential of remote sensing for their early detection. Ultimately, this approach could lead to more effective monitoring strategies and management interventions, helping to mitigate the damage caused by fungal pathogens in forest ecosystems.

The hybrid model was applied to 348 Sentinel-2 and 20 PRISMA images collected on San Rossore ICOS site after filtering for clouds and radiometric quality. Another set of PRISMA was created by compensating for the off-nadir view angle effect based on the relationship with the Sentinel-2 bands. Three areas were marked in the pine forest of IT-SR2 to extract the spectra: i) healthy area around the ICOS flux tower, ii) area affected by *Fomes fomentarius* up to late 2020 (only Sentinel-2), and iii) area affected from 2021 (Figure 11).

The retrievals accuracy was assessed by comparing the retrieved LAI with on-ground LAI measurements (n=23 for Sentinel-2 and n=7 for PRISMA). The hourly GPP (μmol CO_2 m^{-2} s^{-1}) was calculated with the ICOS eddy covariance tower following the variable Ustar (u*) threshold (VUT) method and averaged to a daily basis. The plant traits retrieved with the Sentinel-2 images were used as explanatory variables in an artificial neural network model to estimate the average GPP of the corresponding acquisition day.

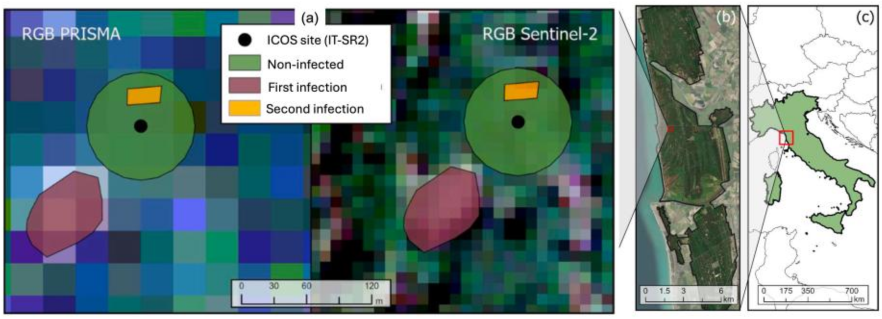

Figure 11 - RGB map of PRISMA and Sentinel-2 over the San Rossore ICOS site (IT-SR2), b) location of the site in San Rossore and c) location within Italy.

The infection detection was analysed by comparing the temporal dynamics of the plant traits retrieved in the three areas. For each trait, an ANOVA test was conducted to find significant differences between areas.

The LAI calculated with the hybrid model and at ground-level obtained an RMSE=0.47 with Sentinel-2 and 0.8 with the original PRISMA. The RMSE of PRISMA was reduced to 0.41 when the reflectance was corrected with the Sentinel-2 bands. The GPP estimated by combining the S2 retrievals matched the temporal trends of GPP from the ICOS tower (Fig. 2), obtaining an R^2=0.82 and an RMSE=1.27 (µmol CO2 m^{-2} s^{-1}). The EWT retrieved by applying the hybrid model to Sentinel-2 showed a decrease in the infected area in July 2019, while the infection wad detected at ground level in July 2020 (Figure 12). This result supports the capacity of the model applied to Sentinel-2 time series for early identification of fungus infection, allowing effective management interventions for minimizing the impact.

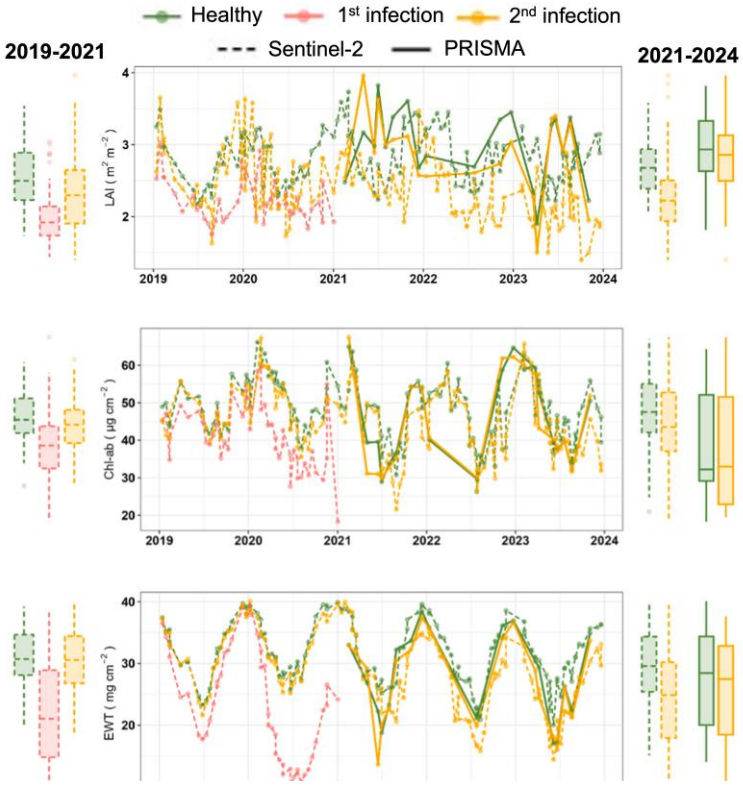

Figure 12 - Time series of leaf area index (LAI), Chlorophyll content (Chl-ab) and Equivalent water content (EWT) calculated with the hybrid model applied to Sentinel-2 and PRISMA of the healthy area, the area infected in 2019, and the area infected in 2021. Box plots describe the values retrieved during the first (left) and second (right) infection.

3.3 Multiple Endmember Spectral Mixture Analysis (MESMA)

In this work the MESMA was exploited to overcome the low spatial resolution and spectral mixture of the hyperspectral satellite PRISMA to carry out a multi-level detail large-scale mapping of a complex landscape. The high-resolution airborne data enabled the collection of pure endmembers and also served as a reference for assessing the accuracy of the PRISMA retrieved sub-pixel fractional covers at the pixel scale (Figure 13). The good match between aerial and PRISMA maps validated the use of MESMA for quantifying complex landscapes composition at sub-pixel level from PRISMA data. These results demonstrate that the proposed framework integrating MESMA and PRISMA is a valuable tool to provide detailed land composition to support landscape planning and enhance environmental sustainability with satellite data.

The results of this work leaded to the publication of a scientific manuscript titled “PRISMA imaging for land covers and surface materials composition in urban and rural areas adopting multiple endmember spectral mixture analysis (MESMA)”.

Future work will be conducted by following the same methodology in the future high-resolution UAV images, as it will provide high-resolution products allowing accurate quantification of the fractional covers of each canopy components. This process will be performed in the images collected on different sites within ITINERIS RI.

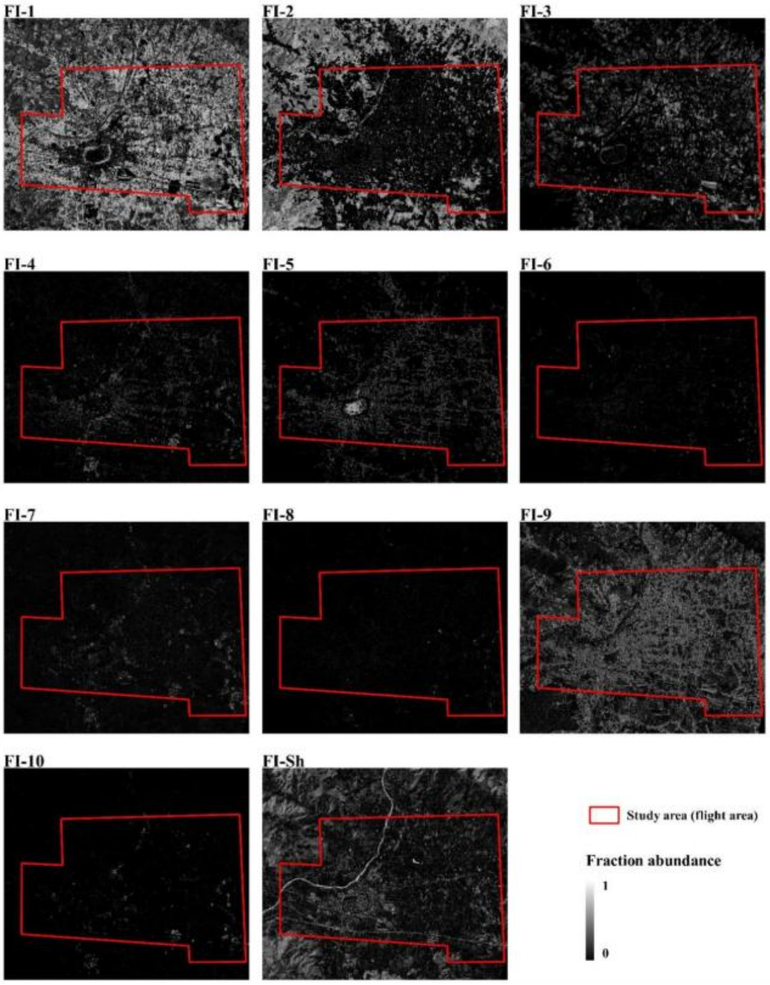

Figure 13 - Fractional abundance images (FIs) of the Lucca study area calculated with MESMA model applied to PRISMA: FI-1: Green Vegetation; FI-2: Nono-photosynthetic vegetation; FI-3: Bare soil; FI-4: Red Surface; FI-5: Bright white surfaces; FI-6: Dark surfaces.

3.4 Landscape planning

The validation of MESMA application in medium resolution PRISMA images extended this methodology for urban and rural planning. In this context, the high-resolution aerial images were also used to study the effect of vegetation and other surfaces in urban heat islands (UHI) and CO_2-equivalent emissions to support public policies for landscape planning through the combined use of land use maps, high-resolution thermal images and albedo maps (Figure 14). The aerial image collected in Prato, used simulated albedo manipulation scenarios to conclude that green vegetation, white roofs and bright pavements can offset up to 10.3% of the city's CO_2 equivalent emissions for decarbonization strategies. The image in Lucca area was used to analyze the thermal and spectral properties of various land cover types to evaluate the impact on UHI, with special focus on photovoltaic solar panels. Results highlighted the importance of green vegetation for mitigating UHI and revealed that the effectiveness of solar panels depends on the underlying material. Together, these studies demonstrate the value of remote sensing in landscape planning.

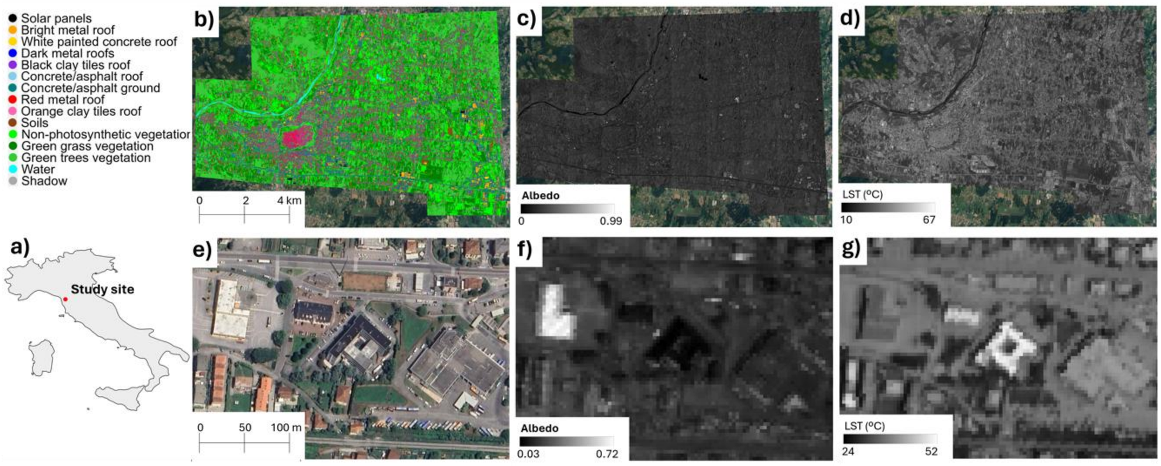

Figure 14 - a) Location of the Lucca study site within Italy where the b) land cover, c) albedo and d) land surface temperature (LST) maps were developed using the CASI-1500, SASI-600 and TASI-600 airborne products. Zoom to a region of the study area containing roofs with different colors (white, black, grey and orange) showing the e) RGB, f) albedo and g) LST maps.

4. OUTCOMES

4.1 Related scientific publications:

The described work has led to the development of different scientific papers. Some of them are currently under review and other are in stage of preparation:

Published:

- Jose Luis Pancorbo; Miguel Quemada; Maria Dolores Raya-Sereno; Beniamino Gioli; Pieter S.A. Beck, Carlos Camino. Integrating Artificial Neural Network-PROSAIL with Sentinel-2 to monitor crop traits dynamics and nitrogen status. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 2025.
  DOI: 10.1109/JSTARS.2025.3585080

- Quemada, M., Pancorbo, J.L., Raya-Sereno, M.D., Camino, C. and Zarco-Tejada, P.J., 2025. Airborne and satellite imagery for optimizing nitrogen management in bread wheat (Triticum aestivum L.). In Precision agriculture'25 (pp. 431-438). Wageningen Academic.
  DOI: 10.3920/9789004725232

- Giandomenico De Luca; Jose Luis Pancorbo; Federico Carotenuto; Beniamino Gioli; Giuseppe Modica; Lorenzo Genesio. PRISMA imaging for land covers and surface materials composition in urban and rural areas adopting multiple endmember spectral mixture analysis (MESMA). ISPRS Journal of Photogrammetry and Remote Sensing. 07/2025.
  DOI: 10.1016/j.isprsjprs.2025.04.038

- Federico Carotenuto; Lorenzo Brilli; Giandomenico De Luca; Marianna Nardino; L. Cremonini; Lorenzo Genesio; Jose Luis Pancorbo; Beniamino Gioli. Emission offsets by albedo manipulations strategies based on bright materials and greening in urban areas assessed by hyperspectral remote sensing. Urban Climate. 03/2025.
  DOI: 10.1016/j.uclim.2025.102357

- Jose Luis Pancorbo; Federico Carotenuto; Giandomenico De Luca; Lorenzo Genesio; Beniamino Gioli. Thermal and Radiative Properties of Photovoltaic, Artificial and Natural Land Covers to Support Urban Planning. IGARSS 2024 IEEE International Geoscience and Remote Sensing Symposium.
  DOI: 10.1109/IGARSS53475.2024.10642148

To be published:

- Monitoring physiological plant traits linked to GPP by combining Sentinel-2 imagery with a biophysical model for forest disturbance detection. C. Camino; J.L. Pancorbo, K. Araño; L. Dutrieux; N. Arriga; U. Gomarasca, L. Šigut; M. Pavelka; N. Kowalska; P. Lukeš4; G. Caudullo; J.B. Féret ; J. Peñuelas; B. Gioli; M. Migliavacca; P.S.A. Beck.

- Thermal and spectral aerial survey of solar panels on urban and natural areas to minimize Urban Heat Island and CO2 equivalence emissions. Jose Luis Pancorbo, Federico Carotenuto, Giandomenico De Luca, Lorenzo Genesio, Beniamino Gioli.

4.2 Conference presentations

The results described have been presented in different international scientific congress with the objective of sharing ITINERIS findings with the scientific community, obtaining feedback to improve the study, and fostering collaborations. The research findings have been shared at the following conferences, including those already completed as well as one upcoming presentation:

Congress and workshops presentations:

- Jose Luis Pancorbo, Paul Mille, Giandomenico De Luca, Beniamino Gioli, Nicola Arriga, Flor Álvarez-Taboada, Pieter S.A. Beck, Lorenzo Genesio, Carlos Camino. Combining PRISMA and Sentinel-2 imagery with biophysical models for plant traits retrievals and fungus infection detection. ESA Living Planet Symposium - June 2025

- Giacomo Panza, Jose Luis Pancorbo, Lorenzo Brilli, Carlos Camino, Simona Maccherini2, Beniamino Gioli. Detection of olive tree chlorophyll content under different management practices integrating Sentinel-2 and a hybrid ANN-PROSAIL model. VI Convegno AISSA#under40 . Le Scienze Agrarie per Coltivare il Domani: Sostenibilità e Innovazione in Agricoltura

- Jose Luis Pancorbo, Miguel Quemada, Maria Dolores Raya-Sereno, Beniamino Gioli, Pieter S.A. Beck, Carlos Camino. Optimizing Crop Wheat Nitrogen Fertilization Through a Neural Network Algorithm Coupling PROSAIL with Sentinel-2 Imagers. 1st Mediterranean Agroecology Congress 2025.

- Jose Luis Pancorbo, Vegetation monitoring with remote sensing and radiative tranfer models. AnaEE's hybrid Data, Modelling and Technology Workshop - May 13- 15th 2025, Conegliano, Italy

- Jose Luis Pancorbo, Giandomenico De Luca, Lorenzo Brilli, Sergi Costafreda-Aumedes, Alessandro Zaldei, Federico Carotenuto, Beniamino Gioli. Remote sensing retrieval of plant traits and sub-pixel constituents in agriculture. AnaEE conference #1 Paris, 8-9-10 October 2024

- Jose Luis Pancorbo, Paul Mille, Giandomenico De Luca, Beniamino Gioli, Nicola Arriga, Flor Álvarez-Taboada, Pieter S.A. Beck, Lorenzo Genesio, Carlos Camino. Fusion of PRISMA and Sentinel-2 imagery with biophysical models for plant functional retrievals in ICOS sites across Europe. Integrated Carbon Observation Systems (ICOS) Science Conference 10th-12th September 2024.

- Jose Luis Pancorbo, Federico Carotenuto, Giandomenico De Luca, Lorenzo Genesio, Beniamino Gioli. Thermal and radiative properties of photovoltaic, artificial and natural land covers to support urban planning. IEEE International Geoscience and Remote Sensing Symposium. 7 - 12 July, 2024, Athens, Greece

4.3 Web application and integration in ITINERIS HUB

A web-based tool is under development to establish an automated process for retrieving key plant traits and detecting the spread of biotic stressors using near real-time Sentinel-2 and PRISMA imagery. This tool aims to provide a rapid and efficient means of monitoring vegetation health by leveraging high-frequency satellite data. As a preliminary step, the hybrid model is being validated using Sentinel-2 and PRISMA data collected on 31 and 13 ICOS sites across Europe. In particular, the tool's capacity to detect biotic infection is being tested at the San Rossore ICOS site. This validation process is crucial as it serves to fine-tune the model's accuracy and reliability. Once validated, the same methodology will be automatically applied for near real-time monitoring of fungal spread, allowing for early detection and more effective management responses. The implementation of this tool has the potential to significantly enhance the ability to monitor and mitigate the impact of biotic infections on ecosystems. The code and data currently used for this work are available on GitLab (https://gitlab.com/caminoccg/icos-prisma). The tool will be linked to the ITINERIS HUB in the final version.

4.4 Datasets

Remote sensing Level 2 and Level 3 products obtained from the modeling techniques described will be released. These products will include data derived from high-resolution UAV and airborne imagery as well as Sentinel-2 and PRISMA satellite images. The Level 2 products will consist of processed radiometric and geophysical data, such as reflectance values corrected for atmospheric effects and LST. The Level 3 products will provide a range of biophysical parameters, including Leaf Area Index (LAI), chlorophyll content (Cab), and equivalent water thickness (EWT) and land cover maps. By offering detailed spatial and temporal insights into vegetation health, forest structure, and the spread of biotic stressors, these datasets will enable comprehensive ecosystem monitoring. The datasets be linked to the ITINERIS HUB in the final version.