2025 *Activity Report*

RESEARCH CENTRE: **Inria Branch at the University of Montpellier**

IN PARTNERSHIP WITH: **INRAE, CIRAD**

Project-Team

EVERGREEN

Earth obserVation and machine lEarning foR aGRo-Environmental challENges

In collaboration with Territoires, Environnement, Télédétection et Information Spatiale

Project-Team EVERGREEN

Creation of the Project-Team: 2024 January 01

Each year, Inria research teams publish an Activity Report presenting their work and results over the reporting period. These reports follow a common structure, with some optional sections depending on the specific team. They typically begin by outlining the overall objectives and research programme, including the main research themes, goals, and methodological approaches. They also describe the application domains targeted by the team, highlighting the scientific or societal contexts in which their work is situated. The reports then present the highlights of the year, covering major scientific achievements, software developments, or teaching contributions. When relevant, they include sections on software, platforms, and open data, detailing the tools developed and how they are shared. A substantial part is dedicated to new results, where scientific contributions are described in detail, often with subsections specifying participants and associated keywords. Finally, the Activity Report addresses funding, contracts, partnerships, and collaborations at various levels, from industrial agreements to international cooperations. It also covers dissemination and teaching activities, such as participation in scientific events, outreach, and supervision. The document concludes with a presentation of scientific production, including major publications and those produced during the year.

Keywords

Computer sciences and digital sciences

A3.1.10. – Heterogeneous data

A5.3.2. – Sparse modeling and image representation

A5.3.3. – Pattern recognition

A9.2. – Machine learning

A9.2.1. – Supervised learning

A9.2.2. – Unsupervised learning

A9.2.6. – Neural networks

A9.2.8. – Deep learning

A9.3. – Signal processing

A9.12.1. – Object recognition

Other research topics and application domains

B3.1. – Sustainable development

B3.1.1. – Resource management

B3.4.1. – Natural risks

B3.5. – Agronomy

B3.6. – Ecology

B3.6.1. – Biodiversity

Contents

1 Team members, visitors, external collaborators

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- Raffaele Gaetano [CIRAD, Researcher]
- Roberto Interdonato [CIRAD, Researcher, HDR]
- Diego Marcos Gonzalez [INRIA, Advanced Research Position]

Post-Doctoral Fellow

- Pallavi Jain [CIHEAM, Post-Doctoral Fellow]

PhD Students

- Ananthu Aniraj [INRIA]
- Bruno Bio Nikki Sare [CIRAD]
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- Juan Li [INRAE, until Nov 2025]
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- Pablo Ubilla Pavez [INRIA, from Oct 2025]
- Quentin Yeche [ATOS, CIFRE, until Oct 2025]
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- Adam Menoud [INRIA, Intern, from Oct 2025]
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- Valérie Zermatten [EPFL, until Feb 2025]

2 Overall objectives

Nowadays, modern space missions continuously collect information about the earth surface, generating massive amounts of data. The multitude of Earth Observation (EO) systems allows to acquire data via different sensors (e.g., optical, radar, LiDAR - Light Detection And Ranging) at different spatial and temporal resolutions with diverse spectral characteristics. On the one hand, this huge volume of collected information opens up new opportunities to better understand and monitor natural, agricultural and other anthropized spaces at different scales. On the other hand, the quantity and diversity of the collected information sets up new challenges to the remote sensing community. As a matter of fact, in order to take the most out of the digital revolution that is impacting the domain, recent and future analysis tasks require a paradigm shift towards data-intensive methodologies. **The main objectives of the EVERGREEN project-team is to develop machine learning models and tools for the exploitation and analysis of Earth Observation (EO) data in accordance with the constraints of the operational settings and in constant interaction with potential users and targeted stakeholders.** Examples of possible applications range from land use/land cover mapping to natural resources monitoring, including territorial planning as well as biodiversity mapping. More broadly, that may include all possible EO-based applications that support the modern agro-environmental transition.

3 Research program

EVERGREEN is an interdisciplinary team working on the design and application of machine learning techniques to deal with the analysis of Earth observation data to support modern agro-environmental challenges. Our research is organized along the three following research axes:

- Tailored Machine Learning methods for EO data (Section 3.1) is the first fundamental research axis. It focuses on advancing the methodologies related to Satellite Image Time Series (SITS) management and on tackling the multi-source exploitation of EO data.

- Adoption and development of advanced learning paradigms to support Earth Observation data analysis (Section 3.2) is the second fundamental research axis of the team. The research objectives related to this axis are devoted to make a step further with the exploitation of multiple EO data sources, dealing with ground truth paucity leveraging semi-supervised and self-supervised learning settings and advancing the spatio/temporal transferability of machine learning models for EO data.

- Interaction between Domain expert and Machine Learning models (Section 3.3) is the last research axis. Here the goals are to introduce a priori knowledge to guide the learning process and design explainabilty/interpretability neural network models.

3.1 Tailored Machine Learning methods for EO data analysis

The research objectives about this topic are devoted to: i) advance the methodologies related to Satellite Image Time Series (SITS) management and ii) tackle the multi-source exploitation of EO data. Improving the management of SITS data requires to directly cope with signals that are *non-stationary* (the spectral and temporal responses over land elements sharing the same spatio-temporal dynamics may vary across space and time), *temporally discontinuous* (sudden events - e.g. human intervention - generally alter the signal responses), and/or affected by missing observations (e.g. due to cloud coverage), but that can exhibit a strong spatial correlation (“close” observations of a same land element are likely to be similar). To tackle such points, we aim to develop new approaches capable of coping with missing values in SITS data, and to integrate external or background knowledge to guide the learning process and explicitly consider the dependency of a SITS signal with its spatial context. Concerning the multi-source exploitation of Earth Observation data, ad hoc solutions exist but there is still a lack of a general methodological framework to leverage the complementarity of different sources according to the considered downstream task. This is especially the case when one of the involved sources is represented by SITS data. Our goal is to provide multi-source EO data fusion paradigms related to a specific downstream task. For instance, if the downstream task is classification or regression, our framework should reduce as much as possible the intermediate steps existing between the raw data and their use for the particular task at hand (i.e. avoid resampling the data source at the same spatial and/or temporal scale or avoid separating feature extraction and model calibration). The reduction of such intermediate steps is directly related to possible bias affecting intermediate products as well as the volume of data to manage.

3.2 Advanced learning paradigms to support EO data analysis

The research objectives related to this topic are devoted to: i) going further with the complementary exploitation of multiple EO data sources, ii) dealing with ground truth paucity leveraging semi-supervised machine learning settings and iii) advancing the spatio/temporal transferability of machine learning models for EO data. Ameliorating the analysis of EO data, regarding particular applications, requires to intelligently manage heterogeneous and complementary information taking the most out of the combination of the different sensors. To this end, we aim to conceive and design new methodological frameworks for multi-source and cross-modal EO data analysis. In this direction, we will investigate settings related to the general domain of Knowledge Distillation and Adversarial Training to tackle the scenario in which some modalities are missing at inference time. While such methodological settings are largely investigated in the context of standard computer vision applications, they are still unexplored in the remote sensing field. Despite the huge amount of sensor data we can dispose of on a study area, the time and costly acquisition of ground truth to calibrate machine and deep learning models can negatively influence the deployment of such strategies in an operational context. Here, we will provide research studies contributing to the general domain of self-supervised learning, partially labeled and semi-supervised scenarios (i.e. positive unlabeled learning), spatial active learning strategies and, weakly supervised setting. Last but not least, this axes also targets the investigation of spatio/temporal transferability of machine learning models for EO data analysis with a particular focus on how to adapt a classification model learnt on a study area to generalize over another study area characterized by different climate/environmental conditions as well as transfer a model learnt on data coming from a time period to data coming from the same, or similar, study area acquired at a different period of time.

3.3 Interaction between Domain expert and Machine Learning models

The research objectives associated with this topic are devoted to: i) integrate a priori knowledge (expert or biophysical) in the learning process of the machine learning models, ii) design learning models that explicitly allow to interpret the decision process under different dimensions (i.e. temporal, spatial, ...) and iii) move towards multi-modal exploitation of EO data. Concerning the first point, related to the integration of a priori knowledge, both domain expert and physical modeling can be exploited to guide the exploration of model parameters, with the aim to reduce the possible search space avoiding implausible solutions supplied by the model. The second point involves the design of learning models that explicitly permit the interpretation and the explaination of the decision process. This research direction is related to the current necessity to get insights on how machine learning models make their decisions with the aim to supply additional information to the end user and raising up the level of transparency and trustworthiness associated to the decision process. The third direction, related to the multi-modal exploitation of EO data, cover aspects related to the integration of EO data with non-EO data such as, for instance, text or audio modalities. Such a multi-modal analysis raises new challenges related to how to integrate data coming from a remote sensing modality with non spatially explicit information going further with the analysis of heterogeneous data sources and opening novel research questions about multi-modal data integration and mining.

4 Application domains

The application scope of the team is mainly guided by the application domains of the INRAE et CIRAD partners with applications related to agricultural and environmental monitoring and assessment. In addition, the application domains of the team is constantly growing and changing with the aim to answer to societal questions related to the modern agro-environmental transition and the challenges it is raising up.

4.1 Food Security

The role of remote sensing in the assessment of food security indicators, especially those concerning food supply (one of the four pillars for food security along with accessibility, quality and stability) through the monitoring of agricultural activities, has been long proven in the last decades. Products typically targeted by these activities go, across scales, from cropland and crop type mapping, to the detection of anomalies in vegetation growth as well as crop yield estimation and forecast. Leveraging remote sensing for the design of novel spatio-temporal indicators related to agricultural production and food security is of paramount importance to support policy makers and social actors in their decision processes. Additionally, remote sensing derived information can provide up-to-date information in order to assess the underlying sustainability of the agricultural production. This is even more important in the context of tropical agricultural systems.

This domain application is at the core of the EVERGREEN activity with multiple research efforts devoted to the analysis of land use and land cover mapping that are of fundamental importance in order to subsequently extract spatio-temporal indicators to characterize agricultural production. For instance, actions related to this application domain are conducted in the context of the CIFRE PhD thesis of Quentin Yeche (INRAE/ATTOS) on the topic of parcel identification/extraction and characterization, the PhD thesis of Azza Abidi (University of Montpellier, University of Manouba/Tunisie) and Bruno Bio Nikki (CIRAD) related to the analysis of multi-temporal/multi-source remote sensing data for land cover mapping in conventional and tropical agricultural systems.

4.2 Forest monitoring

New challenges are arising about the quantity and quality of the information about forest cover which can effectively support decision making processes at global, national and local scales. The need for a deeper description of the forest cover seems to emerge, by means of a larger set of biophysical or structural indicators carrying information about its diversity in terms of species and their "role" in the landscape. Notable examples are i) the possibility of discriminating between proper forests and tree cover related to agricultural exploitation, which do not provide the same carbon sequestration potential, and ii) to precisely identify the spatial extent of a forest cover, also with respect to changes in its density and "greenness", especially in transition areas between different ecosystems and/or climatic zones. Among these indicators, many have been proven to be derived from EO data. The EVERGREEN team is increasing its activities related to the analysis and monitoring of forest areas due to the paramount importance of this natural resource. For instance, members of the EVERGREEN team are involved in both European (HORIZON Eco2Adapt) and National projects (ANR PREDISPOSE) related to the analysis of forest disturbances (i.e. forest fires) or they are collaborating with international partners (i.e. DLR/Germany, Wageningen University/Netherlands) on the analysis of forest covers and its properties in Southern Countries (i.e. Africa).

4.3 Biodiversity mapping and monitoring

Biodiversity loss is now considered to be an existential threat to humankind on par with climate change. In order to advance the understanding of the underlying phenomena behind this phenomena, we first need to have a clear picture of the current ranges and population densities of species globally. This is a crucial challenge that will require vast amounts of data in the form of species observations coupled with Earth observation-based habitat suitability. To this end, our objective is to link ground-level data to remote sensing imagery in order to map fundamental niches of species and monitor their spatial shifts under climate change and other anthropogenic pressure. Actions related to this application domain cover the collaboration with the Iroko team, via the co-superivision of a post-doc researcher on species distribution modeling and spatial biases, international collaborations covering the development of visual-language model for ecology mapping with the EPFL University (Switzerland) through the visiting research stay of Valerie Zermatten and the national project IMPACT, funded by the OFB (Office français de la biodiversité) on the detection of possible plant disease outbreaks via remote sensing multi-temporal data.

5 Social and environmental responsibility

5.1 Footprint of research activities

- **Work trips**. While the sanitary crisis had drastically cut the number of work trips of the team, recent years have seen an increase in the physical participation in conferences and various committees. However compared to the pre-covid period, one can note that the majority of movements are national or at best European, with very few trips outside of Europe and, when it is possible, trains are preferred to planes.

- **Utilization of computing resources.** Being a team specialized in computer vision and machine learning for remote sensing data, a recurrent task in EVERGREEN is to run CPU/GPU-intensive algorithms on large data collections. To this end, our strategy towards computing resources is driving us to increase the use of regional, national and institutional infrastructures (i.e. Jean Zay, ABACA) in order to leverage sustainable computing platforms instead of local server/workstation with a general positive effect on energy consumption.

5.2 Impact of research results

We estimate that our research work can have several impacts on the society due to the fact that EVERGREEN is working on challenges related to modern agro-environmental analysis. We give below two examples of impact of our research results:

- Most of the research work is conducted in collaboration with scientists from environmental and agricultural sciences considering both applied research and operational scenarios. Such interdisciplinary work paves the way to the deployment of our research contributions in projects related to a more sustainable and reasoned management of natural (i.e. forest, water, ...) and agricultural resources.

- A part of our research work is conducted in partnership with companies, through CIFRE PhDs and collaboration actions. Hence, the addressed research problems concern an important challenge for the companies, and the solutions proposed are evaluated on their relevance to tackle this challenge.

6 Highlights of the year

- Article at the Thirty-Ninth *AAAI Conference on Artificial Intelligence* (AAAI-25) on hybrid phenology modeling for predicting temperature effects on tree dormancy [24].

- Article in the *Nature Communications* journal on the effective integration of drone technology for mapping and managing palm species in the Peruvian Amazon.

- Organization of the 7th edition of the MACLEAN (Machine Learning of Earth Observation) workshop co-located with the ECML/PKDD 2025 conference (see link) and the co-organization of the MVEO (Machine Vision for Earth Observation and Environment Monitoring) workshop co-located with BMVC 2025 conference (see link).

6.1 Awards

- Best presentation award at the British Machine Vision Conference (BMVC) 2025.

7 Latest software developments, platforms, open data

7.1 New platforms

7.1.1 MORINGA: an open-source platform for automatic land cover classification from multi-sensor imagery

Participants: Raffaele Gaetano.

Started in 2015 in the framework of the activities of the Land Cover Scientific Expertise Center as part of the French Land Surface Data and Services Hub - THEIA, the developement of the MORINGA [1] processing chain was initially aimed at providing a "turn key" solution, addressed to thematic specialists with relatively low programming skills, for the automatic land cover classification from multi-sensor, multi-resolution and multi-temporal satellite imagery. It particularly targets the needs for accurate land cover mapping in the context of tropical agricultural systems, where several specificities (landscape heterogeneity and fragmentation, small field sizes, high cloud coverage during cropping seasons) call for the combination of different resolutions and acquisition modes to both capture spatial details and temporal profiles. Leveraging an object-based approach and a suitable supervised classification framework based on legacy machine learning techniques, the MORINGA processing chain takes in charge imagery provided by different satellite missions, both at high (Sentinel-1 and -2, Landsat 8/9, etc.) and very high (Pléiades, SPOT6/7) spatial resolution, and automatically manages their pre-processing and ingestion in the object based machine learning framework, with limited user interaction. Reference data are also automatically processed to provide the best possible validation also in cases of data paucity, which are rather common in the targeted application. To date, MORINGA has become a feature-rich, modular platform for remote sensing image analysis, which can also be used as a lower-level API to ease common image processing tasks. Thanks to the support of thematic experts and cartography specialists, it has since been used for the production of high quality land cover maps in many different scientific and dissemination contexts (see [33] for a notable example in 2024). The software package is currently bound to evolve to a larger remote sensing based land cover workbench, including novel deep learning techniques for both image pre-processing/enhancement and multi-sensor classification.

8 New results

In this section, we briefly summarize and reference the major research results published in 2025. The research works are organized into three subsections: i) Tailored Machine Learning Methods for EO Data Analysis; ii) Advanced Learning Paradigms to Support EO Data Analysis; and iii) Interaction Between Domain Experts and Machine Learning Models.

8.1 Tailored Machine Learning methods for EO data analysis

8.1.1 Geographical Context Matters: Bridging Fine and Coarse Spatial Information to Enhance Continental Land Cover Mapping

Participants: Cássio Fraga Dantas, Raffaele Gaetano, Dino Ienco.

Collaborators: Babak Ghassemi (BOKU - University of Natural Resources and Life Sciences, Vienna, Austria), Omid Ghorbanzadeh (BOKU - University of Natural Resources and Life Sciences, Vienna, Austria), Emma Izquierdo-Verdiguier (BOKU - University of Natural Resources and Life Sciences, Vienna, Austria), Francesco Vuolo (BOKU - University of Natural Resources and Life Sciences, Vienna, Austria).

Keywords: Geospatial Analysis, Deep Learning, Large-Scale Analysis, Land Cover Mapping.

Land use and land cover mapping from Earth Observation (EO) data is a critical tool for sustainable land and resource management as, for instance, in domains like biodiversity and agricultural food production. While advanced machine learning and deep learning algorithms excel at analyzing EO imagery data, they often overlook crucial geospatial metadata information that could enhance scalability and accuracy across regional, continental, and global scales. To address this limitation, we propose BRIDGE-LC (Bi-level Representation

[1] MORINGA

Integration for Disentangled GEospatial Land Cover), a novel deep learning framework that explicitly integrates multi-scale geospatial information into the land cover classification process. By simultaneously leveraging fine-grained (latitude/longitude) and coarse-grained (biogeographical region) spatial information, our lightweight multi-layer perceptron architecture learns from both multi-scale information during training but only requires fine-grained information for inference, allowing it to disentangle region-specific from region-agnostic land cover features while maintaining computational efficiency comparable with standard machine learning approaches. To assess the quality of our framework, we use an open-access in-situ dataset spanning the 27 countries of the European Union and we adopt several competing classification approaches commonly considered for large-scale land cover mapping. A visual sketch of the proposed framework is depicted in Figure 1. We evaluated all the approaches through two scenarios: an extrapolation scenario in which training data encompasses samples coming from all the biogeographical regions and a leave-one-region-out scenario where samples from all the regions, except one, are employed for the training stage. Additionally, we also explore the spatial representation learned by the proposed deep learning model, highlighting a connection between its internal manifold and the geographical information used during the training stage. Our results demonstrate that integrating geospatial information improves land cover mapping performances, with the most substantial gains achieved by jointly leveraging both fine-grained and coarse-grained spatial information.

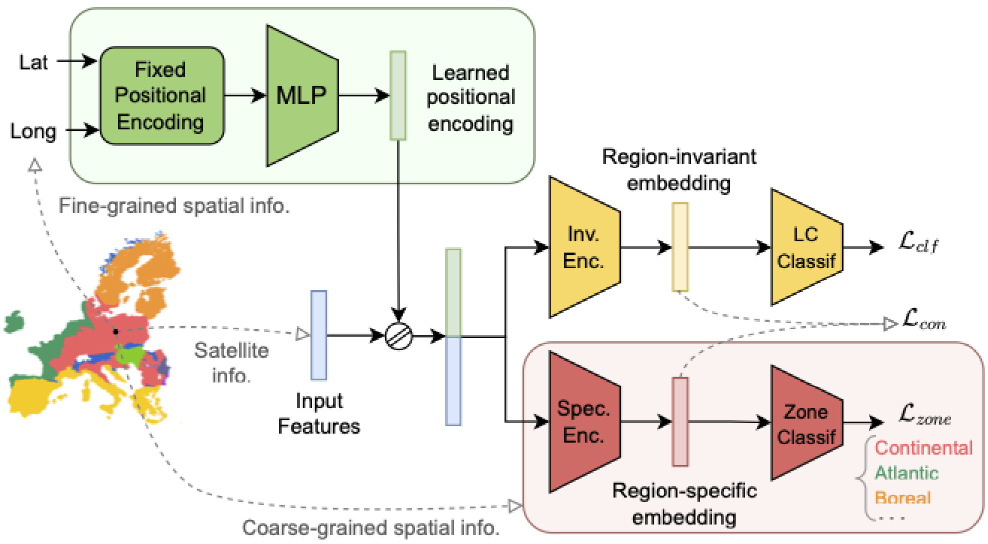

Figure 1: Our framework, in addition to the standard land cover classification branch (yellow), which processes reflectance-based input features, we introduce two complementary components: (1) a fine-grained spatial information branch (green) utilizing latitude-longitude coordinates, and (2) a coarse-grained spatial information branch (red) based on biogeographical region labels. During training, the red branch guides the model to learn region-invariant embeddings that are more robust and generalizable for land cover classification. This branch is used only during training and is successively discarded at inference time.

This work has been published at the Science of Remote Sensing journal (Elsevier) [14].

8.1.2 Environmental and bioclimatic data for epidemiological analysis over French Mediterranean areas

Participants: Dino Ienco.

Collaborators: Camille Portes (UR BioSP, INRAE, France), Eric Verdin (UMR Pathologie Végétale, INRAE, France), Edith Gabriel (UR BioSP, INRAE, France)

Keywords: climate, epidemiology, land type, machine learning.

Risk-based surveillance is now a well-established paradigm in epidemiology, involving the distribution of sampling efforts differentially in time, space, and within populations, based on multiple risk factors. To assess and map the risk of the presence of the bacterium Xylella fastidiosa, we have compiled a dataset that includes factors influencing plant development and thus the spread of such harmful organism. To this end, we have collected, preprocessed, and gathered information and data related to land types, soil compositions, and climatic conditions to predict and assess the probability of risk associated with X. fastidiosa in relation to environmental features. This resource can be of interest to researchers conducting analyses on X. fastidiosa and, more generally, to researchers working on geospatial modeling of risk related to plant infectious diseases.

This work has been published at the Environmental Data Science journal (Cambridge Press) [21].

8.1.3 Assessing habitat suitability for black grouse broods at the bioregional scale

Participants: Dino Ienco.

Collaborators: Alexandre Defossez (UMR TETIS, INRAE, France), Samuel Alleaume (UMR TETIS, INRAE, France), Marc Montadert (OFB - Office français de la biodiversité, France), Josselin Giffard-Carlet (UMR TETIS, INRAE, France), Nadia Guiffant (UMR TETIS, INRAE, France), Sandra Luque (UMR TETIS, INRAE, France)

Keywords: Lyrurus tetrix, brood habitat suitability, species distribution models, remote sensing, wildlife monitoring.

The black grouse Lyrurus tetrix, a galliform species emblematic of the European Alps, is currently threatened by habitat change, particularly given the closure of heathland linked to the rising tree line at higher altitudes. The presence of heathlands in good ecological condition is, however, imperative for the species' reproduction. In this study, we attempted to map black grouse brood habitat suitability at a bioregional scale in the French Alps, coupling a species distribution model with multi-source remote sensing data. To predict brood habitat suitability, we used a random forest ensemble model. Altitude, ericaceous heathland, and the annual maximum normalized difference vegetation index (NDVI) emerged as the three most important variables, consistent with the ecological needs of black grouse. The proportion of ericaceous heathland was especially representative of the foraging and vegetation cover needs of black grouse hens. The resulting map was evaluated by black grouse experts and found to be consistent with their local knowledge in the context of the French Alps.

This work has been published at the Wildlife Biology journal (Nordic Council for Wildlife Research) [13].

8.1.4 Rapeseed mapping using machine learning methods and Sentinel-1 time series coupled with growing degree-days information

Participants: Cássio Fraga Dantas, Dino Ienco.

Collaborators: Saeideh Maleki (UMR TETIS, INRAE, France), Nicolas Baghdadi (UMR TETIS, INRAE, France), Sami Najem (UMR TETIS, INRAE, France), Ya Gao (NSSC - National Space Science Center [Beijing], China), Hassan Bazzi (UMR TETIS, AgroParisTech, France)

Keywords: InceptionTime, Random Forest, Sentinel-1 SAR image time series, Growing degree days.

In light of recent escalations of geopolitical conflicts around the world, mapping rapeseed areas has garnered great interest given its importance to food security. Sentinel-1 (S1) SAR data was used for timely and regular rapeseed mapping. By coupling S1 data with GDD (Growing Degree Days) information, S1

GDD series were also created and assessed. Rapeseed classification was realized using random forest (RF) and inception time (IT). An alignment method based on detected flowering dates was proposed with the aim of alleviating the possible shifts in the growth cycle between the different sites and years. The spatial (cross-regional) transferability of the models was tested accordingly, before and after alignment. The results showed that using the S1 time series before alignment, the overall F1-score achieved by RF was 81.3%, and the overall F1-score of IT was 89.2%. After alignment, RF achieved an overall F1-score of 90.3%, while the overall F1-score of IT was 91.7%. Using the S1 GDD series, before alignment, the overall score of RF was 58.2%, while the overall F1-score achieved by IT was 86.6%. After the alignment of the S1 GDD series, the F1-score achieved by RF was 73.9%, and the F1-score of IT was 86.8%. The best configuration for rapeseed mapping was using IT with S1 time series after alignment, as it gave the highest overall F1-score and the best consistency with the lowest standard deviation. Overall, the S1 time series provided better results than the S1 GDD series, meaning that employing thermal time does not enhance the classification performance. The results indicate that the proposed method enables reliable, timely and continuous rapeseed monitoring, Paving the way for more effective food stock management and planning by policymakers and stakeholders.

This work has been published at the Science of Remote Sensing journal (Elsevier) [20].

8.1.5 Sentinel-1 (S1) time series alignment method for rapeseed fields mapping

Participants: Cássio Fraga Dantas, Dino Ienco.

Collaborators: Saeideh Maleki (UMR TETIS, INRAE, France), Nicolas Baghdadi (UMR TETIS, INRAE, France), Sami Najem (UMR TETIS, INRAE, France), Hassan Bazzi (UMR TETIS, AgroParisTech, France)

Keywords: InceptionTime, Random Forest, classification algorithm, Synthetic Aperture Radar, machine learning algorithms.

Mapping rapeseed fields plays a crucial role in agricultural management as rapeseed being a major source for oilseed, protein meal, livestock feed, and industrial liquid biofuels. Accurately monitoring the distribution and characteristics of rapeseed fields enables farmers and decision-makers to make informed decisions regarding fertilizer application, optimize harvest dates, and estimate yield. The conducted research presents a comprehensive analysis of rapeseed fields mapping using Sentinel-1 (S1) time series data. We applied a time series alignment method to enhance the accuracy of rapeseed fields detection, even in scenarios where reference label data are limited or not available.

This work has been published at the Frontiers in Remote Sensing journal (Frontiers) [16].

8.1.6 Effective integration of drone technology for mapping and managing palm species in the Peruvian Amazon

Participants: Diego Marcos.

Collaborators: Ximena Tagle (Wageningen University, The Netherlands), Rodolfo Cardenas-Vigo (IIAP, Perú), Martin Herold (GFZ Potsdam, Germany), Timothy R. Baker (University of Leeds, UK) and others

Keywords: Tree species mapping, UAV imagery, instance segmentation, Peruvian Amazonia.

Remote sensing data could increase the value of tropical forest resources by helping to map economically important species. However, current tools lack precision over large areas, and remain inaccessible to stakeholders. Here, we work with the Protected Areas Authority of Peru to develop and implement precise, landscape-scale, species-level methods to assess the distribution and abundance of economically important arborescent Amazonian palms using field data, visible-spectrum drone imagery and deep learning. We compare the costs and time needed to inventory and develop sustainable fruit harvesting plans in two communities using traditional plot-based and our drone-based methods. Our approach detects individual palms of three species, even when densely clustered (average overall score, 74%), with high accuracy and completeness for Mauritia flexuosa (precision; 99% and recall; 81%). Compared to plot-based methods, our drone-based approach reduces costs per hectare of an inventory of Mauritia flexuosa for a management plan by 99% (USD 5/ha versus USD 411/ha), and reduces total operational costs and personnel time to develop a management plan by 23% and 36%, respectively. These findings demonstrate how tailoring technology to the scale and precision required for management, and involvement of stakeholders at all stages, can help expand sustainable management in the tropics.

This work has been published in Nature Communications [22].

8.1.7 Fully automatic extraction of morphological traits from the web: Utopia or reality?

Participants: Diego Marcos.

Collaborators: Robert van de Vlasakker (Wageningen University, The Netherlands), Ioannis N. Athanasiadis (Wageningen University, The Netherlands), Pierre Bonnet (UMR AMAP, Cirad, France), Hervé Goëau (UMR AMAP, Cirad, France), Alexis Joly (IROKO, Inria, France), W. Daniel Kissling (University of Amsterdam, The Netherlands), César Leblanc (IROKO, Inria, France), André S. J. van Proosdij (Wageningen University, The Netherlands)

Keywords: Tree species mapping, UAV imagery, instance segmentation, Peruvian Amazonia.

Plant morphological traits, their observable characteristics, are fundamental to understanding the role played by each species within its ecosystem; however, compiling trait information for even a moderate number of species is a demanding task that may take experts years to accomplish. At the same time, online species descriptions contain massive amounts of information about morphological traits, but the lack of structure makes this source of data impossible to use at scale. To overcome this, we propose to leverage recent advances in large language models and devise a mechanism for gathering and processing plant trait information in the form of unstructured textual descriptions, without manual curation. We evaluate our approach by automatically replicating three manually created species–trait matrices. Our method found values for over half of all species–trait pairs, with an F1 score of over 75%. Our results suggest that large-scale creation of structured trait databases from unstructured online text is now feasible due to the information extraction capabilities of large language models. However, the process is currently limited by the availability of textual descriptions that cover all traits of interest.

This work has been published in Applications in Plant Sciences [17].

8.2 Advanced learning paradigms to support EO data analysis

8.2.1 Deep learning interpretability for understanding forest disturbance driver classification from Sentinel-1 and -2 data

Participants: Diego Marcos.

Collaborators: Laura Elena Cué La Rosa (Wageningen University, The Netherlands), Jonas van Duijvenbode (WWF), Zillah Calle (Wageningen University, The Netherlands), Jorn Dallinga (WWF) and Johannes Reiche (Wageningen University, The Netherlands)

Keywords: Explainable AI, Sentinel-1, Sentinel-2, Forest Disturbance driver, Feature-level fusion.

Monitoring the drivers of tropical forest disturbances using remote-sensing data has become increasingly critical to supporting actionable law enforcement and sustainable land management. Using information captured by multi-source Earth Observation data, deep learning-based fusion models are state-of-the-art in many remote sensing applications. Despite their efficacy, the inherent black-box nature of these deep neural networks poses challenges to our understanding of their decision-making processes. To enhance their interpretability, we applied eXplainable Artificial Intelligence (XAI) methods for several deep learning-based models including single and multi-modal approaches. We evaluated six XAI methods: Integrated Gradients, GradientShap, Saliency, Deconvolution, Guided Grad-CAM, and Guided Backpropagation. Using both quantitative and qualitative assessments, we conducted extensive experiments to evaluate the capability of each XAI method to interpret the proposed models. Our analysis included variable importance, single- and multi-class explanations, cloud cover analysis, and instances of misclassification. We identified Guided Grad-CAM as the most reliable of these methods. In addition, we gained deeper insight into how positive and negative attribution scores influence the interpretation of model output, highlighting the need for more research on the significance of negative values. Our study improves the understanding of deep learning model decisions in the context of forest disturbance driver classification, shedding light on the interpretability of fusion models and dataset characteristics. It establishes a connection between remote sensing applications and XAI methodologies. This work was supported by the Open Domain Science project Forest Carbon Crime under Grant OCENW.M.21.203; Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO); Norway's Climate and Forest Initiative (NICFI) and World Wide Fund for Nature (WWF) the Netherlands.

This work has been published at the International Journal of Remote Sensing (Taylor & Francis) [11].

8.2.2 SAHARA: Heterogeneous Semi-Supervised Transfer Learning with Adversarial Adaptation and Dynamic Pseudo-Labeling

Participants: Cássio Fraga Dantas, Raffaele Gaetano, Dino Ienco.

Collaborators: Giuseppe Guarino (University of Naples Parthenope), Gemine Vivone (CNR - National Research Council of Italy), Matteo Ciotola (University of Naples Parthenope), Giuseppe Scarpa (University of Naples Parthenope)

Keywords: Domain Adaptation, Heterogeneous data, Pseudo-labeling, Feature Disentanglement, Adversarial Learning.

Semi-supervised domain adaptation aims to transfer knowledge from a labeled source domain to a scarcely labeled target domain, despite distribution shifts. The challenge becomes greater when source and target data differ in acquisition modality, as in remote sensing where variations in sensor type (e.g., optical vs. radar), spectral properties (e.g., RGB vs. multispectral), or spatial resolution are common. This challenging scenario, known as Semi-Supervised Heterogeneous Domain Adaptation (SSHDA), requires learning across modalities with limited target labels. In this work, we have proposed SAHARA (Semi-supervised Adaptation in Heterogeneous domains via conditional Adversarial Representation disentanglement and Adaptive pseudo-labeling), a new method for SSHDA that combines conditional adversarial feature adaptation with dynamic pseudo-labeling to learn domain-invariant features and handle extremely scarce target annotations. Experiments on two heterogeneous remote sensing benchmarks for scene classification, conducted with both convolutional and transformer-based backbones, demonstrate that SAHARA consistently outperforms existing SSHDA and semi-supervised methods.

This work has been published at the IEEE Geoscience and Remote Sensing Letter journal (IEEE) [15].

8.2.3 Multi-Modal Co-Learning for Earth Observation: Enhancing single-modality models via modality collaboration

Participants: Cássio Fraga Dantas, Roberto Interdonato, Dino Ienco.

Collaborators: Francisco Mena Toro (DFKI - Deutsches Forschungsinstitut für Künstliche Intelligenz), Andreas Dengel (DFKI - Deutsches Forschungsinstitut für Künstliche Intelligenz)

Keywords: Multi-sensor model, Missing sensor data, Deep Learning.

Multi-modal co-learning is emerging as an effective paradigm in machine learning, enabling models to collaboratively learn from different modalities to enhance single-modality predictions. Earth Observation (EO) represents a quintessential domain for multi-modal data analysis, wherein diverse remote sensors collect data to sense our planet. This unprecedented volume of data introduces novel challenges. Specifically, the access to the same sensor modalities at both training and inference stages becomes increasingly complex based on real-world constraints affecting remote sensing platforms. In this context, multi-modal co-learning presents a promising strategy to leverage the vast amount of sensor-derived data available at the training stage to improve single-modality models for inference-time deployment. Most current research efforts focus on designing customized solutions for either particular downstream tasks or specific modalities available at the inference stage. To address this, we have proposed a novel multi-modal co-learning framework capable of generalizing across various tasks without targeting a specific modality for inference. A visual sketch of the proposed framework is depicted in Figure 2. Our approach combines contrastive and modality discriminative learning together to guide single-modality models to structure the internal model manifold into modality-shared and modality-specific information. We evaluate our framework on four EO benchmarks spanning classification and regression tasks across different sensor modalities, where only one of the modalities available during training is accessible at inference time. Our results demonstrate consistent predictive improvements over state-of-the-art approaches from the recent machine learning and computer vision literature, as well as EO-specific methods. The obtained findings validate our framework in the single-modality inference scenarios across a diverse range of EO applications.

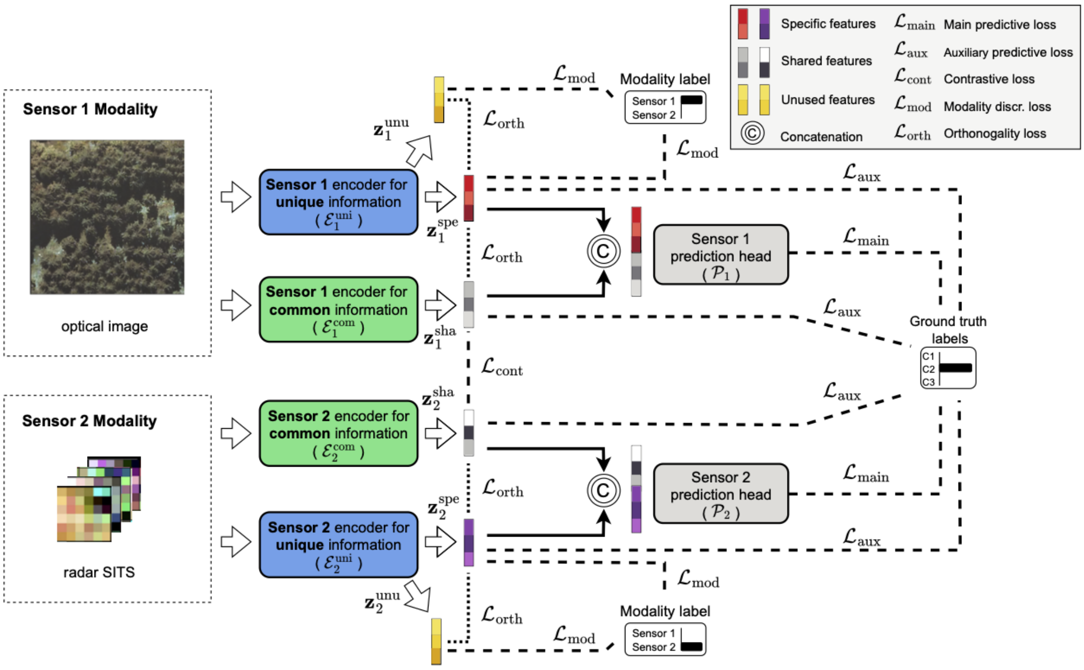

Figure 2: Illustration of MDiCo framework with shared, specific, and unused features. The main prediction per modality is shown in regular arrows, while the multiple losses are shown with dashed lines. Two sensor modalities are shown: an optical image and a radar Satellite Image Time Series (SITS).

This work has been published at the Machine Learning journal (Springer) [19].

8.2.4 Revisiting Cross-Modal Knowledge Distillation: A Disentanglement Approach for RGBD Semantic Segmentation

Participants: Cássio Fraga Dantas, Dino Ienco.

Collaborators: Roger Ferrod (UNITO - Università degli studi di Torino = University of Turin), Luigi di Caro (UNITO - Università degli studi di Torino = University of Turin)

Keywords: Knowledge Distillation, Cross-modal learning, RGBD data, Semantic Segmentation.

Multi-modal RGB and Depth (RGBD) data are predominant in many domains such as robotics, autonomous driving and remote sensing. The combination of these multi-modal data enhances environmental perception by providing 3D spatial context, which is absent in standard RGB images. Although RGBD multi-modal data can be available to train computer vision models, accessing all sensor modalities during the inference stage may be infeasible due to sensor failures or resource constraints, leading to a mismatch between data modalities available during training and inference. Traditional Cross-Modal Knowledge Distillation (CMKD) frameworks, developed to address this task, are typically based on a teacher/student paradigm, where a multi-modal teacher distills knowledge into a single-modality student model. However, these approaches face challenges in teacher architecture choices and distillation process selection, thus limiting their adoption in real-world scenarios. To overcome these issues, we introduce CroDiNo-KD (Cross-Modal Disentanglement: a New Outlook on Knowledge Distillation), a novel cross-modal knowledge distillation framework for RGBD semantic segmentation (Figure 3). Our approach simultaneously learns single modality RGB and Depth models by exploiting disentanglement representation, contrastive learning and decoupled data augmentation with the aim to structure the internal manifolds of neural network models through interaction and collaboration. We evaluated CroDiNo-KD on three RGBD datasets across diverse domains, considering recent CMKD frameworks as competitors. Our findings illustrate the quality of CroDiNo-KD, and they suggest reconsidering the conventional teacher/student paradigm to distill information from multi-modal data to single modality neural networks. Source code is available here.

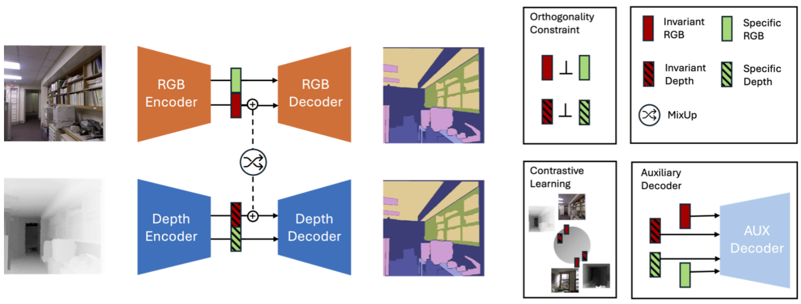

Figure 3: Overview of the CroDiNo-KD architecture, composed by two encoder-decoder models, for both RGB and Depth modalities. In addition an auxiliary decoder and a set of loss functions are adopted to enforce the desired disentanglement properties between modalities, i.e., modality-invariant and modality-specific features for both RGB and Depth information.

This work has been published at the European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases (ECML/PKDD) 2025 [26].

8.2.5 Multi-sensor Model for Earth Observation Robust to Missing Data via Sensor Dropout and Mutual Distillation

Participants: Cássio Fraga Dantas, Roberto Interdonato, Dino Ienco.

Collaborators: Francisco Mena Toro (DFKI - Deutsches Forschungsinstitut für Künstliche Intelligenz), Andreas Dengel (DFKI - Deutsches Forschungsinstitut für Künstliche Intelligenz)

Keywords: Multi-sensor model, Missing sensor data, Deep Learning.

Multi-sensor data has become a foundation of Earth Observation (EO) research, offering models with enhanced accuracy via optimal fusion strategies. However, the unavailability of sensor data at the regional or country scale during inference can significantly undermine model performance. The literature explores diverse approaches to increasing model robustness to missing sensor scenarios, i.e., to reducing the decline in accuracy caused by missing data at inference time. Nevertheless, most of them have suboptimal behavior when a single-sensor is available for prediction. To address this challenge, we propose a novel method for multi-sensor modeling, Decision-level Sensor Dropout with mutual distillation, named DSensD+ (Figure 4). This employs a decision-level fusion, ignoring predictions from missing sensors and incorporating the Sensor Dropout (SensD) technique. Unlike works that use the SensD at the input or feature level, we use it at the decision level. Moreover, we include a mutual distillation strategy to improve the robustness. From a practical viewpoint, the additional components in the DSensD+ method are incorporated only for the training phase. During inference, it operates as a standard decision-level fusion model that ignores missing sensors.We validate our method on three EO datasets, spanning binary, multi-class, and multi-label classification tasks for crop- and tree-mapping related applications. Notably, DSensD+ outperforms several state-of-the-art methods, achieving consistent improvements across moderate (single-sensor missing) and extreme (single-sensor available) conditions, as well as with full-sensor data. These results demonstrate the robustness of DSensD+ and highlight the effectiveness of our method for the missing sensor problem, advancing the field of multi-sensor modeling in EO.

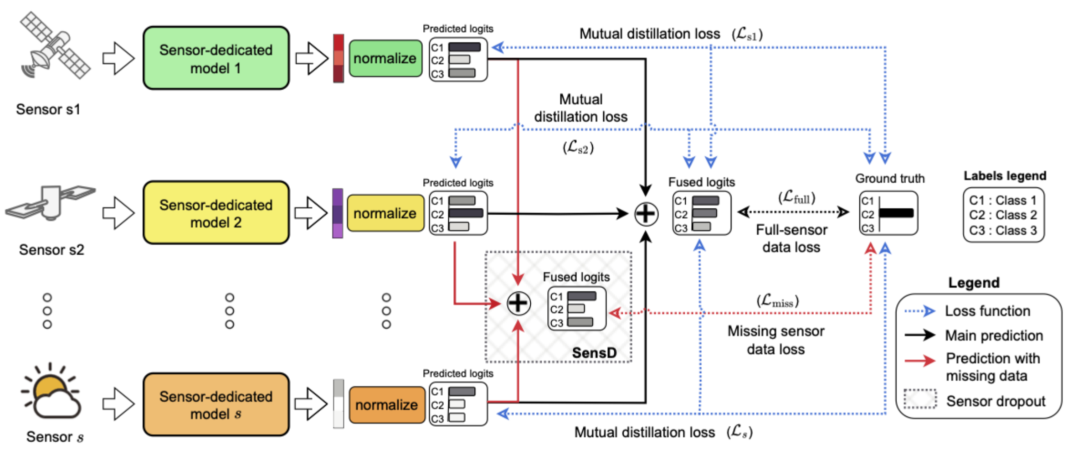

Figure 4: Illustration of the DSensD+ model during training, where the fusion, sensor dropout, and mutual distillation occur at the decision-level. During inference, the forward pass of the model corresponds to only the dark arrows.

This work has been published at the IEEE ACCESS journal (IEEE) [18].

8.2.6 Transfer Land Cover Maps Across Years: A Time Series-based Semantic Segmentation Approach

Participants: Cássio Fraga Dantas, Roberto Interdonato, Dino Ienco.

Collaborators: Christopher Jabea (UMR TETIS, INRAE, France), Flavie Cernasson (UMR TETIS, AgroParisTech, France), Eric Barbe (UMR TETIS, INRAE, France), Nadia Guiffant (UMR TETIS, INRAE, France), Christiane Weber (UMR TETIS, CNRS, France)

Keywords: Transfer learning, Satellite image time series, Semantic Segmentation.

The widespread availability of satellite imagery data has enabled advancements in Land Use/Land Cover (LULC) and Urban Fabric (UF) mapping through deep learning. However, maintaining up-to-date urban land cover maps is challenged by the high cost and operational constraints of continuous field data collection. This study explores the feasibility of updating urban LULC maps using SITS-based semantic segmentation models trained on historical data, specifically examining a transfer scenario where a model trained on 2015 data is applied to 2020 imagery. We benchmark the performance of two convolution-based architectures (Unet and Unet3D), plus a recent spatiotemporal transformer-based approach (TSViT) and a proposed variant, named TSViT+SW, which incorporates a shifted window attention scheme. Experimental evaluations covering the urban area of Lyon, France, reveal that the proposed TSViT+SW model achieves the best results among transferred models, minimizing performance degradation compared to the ideal in-year training scenario. This work offers insights into the potential and limitations of using historical data to update urban land cover in the absence of fresh labeled data.

This work has been published at the Joint Urban Remote Sensing Event (JURSE) 2025 [27].

8.2.7 SenCLIP: Enhancing zero-shot land-use mapping for Sentinel-2 with ground-level prompting

Participants: Diego Marcos, Roberto Interdonato, Dino Ienco.

Collaborators: Pallavi Jain (CIHEAM-IAMM - Centre International de Hautes Etudes Agronomiques Méditerranéennes - Institut Agronomique Méditerranéen de Montpellier), Tristan Berchoux (CIHEAM-IAMM - Centre International de Hautes Etudes Agronomiques Méditerranéennes - Institut Agronomique Méditerranéen de Montpellier)

Keywords: Visual Language Model, Remote Sensing Analysis, Zero shot prompting.

Pre-trained vision language models (VLMs) like CLIP have demonstrated impressive zero-shot classification capabilities based on free-form prompts, showing some generalization capabilities even in specialized domains. However, these models face limitations when applied to satellite imagery due to the relatively low prevalence of such data in their training datasets, compared to ground level and natural images. Furthermore, due to the nature of image-text associations found in these datasets, current prompting techniques are limited to simplistic overhead view prompts like *"a satellite image of..."*, limiting their applicability for zero-shot land-use/land-cover mapping. To address these challenges, we create a large dataset of satellite (Sentinel-2) and geotagged ground-level images across the whole European Union to transfer the richer ground level representation in the CLIP representation to satellite imagery. This dataset enables a representation of satellite images that captures ground level concepts and allows using rich, ground level perspective prompts (Figure 5). We explore prompt style variations from both satellite and ground level views. Our approach results in a substantial improvement on zero-shot land use/land cover classification on two Sentinel-2 benchmarks, EuroSAT and BigEarthNet, compared to directly using CLIP or specialized remote sensing VLMs, opening the doors to zero-shot land-use/land-cover mapping by using free-form textual descriptions.

This work has been published at the IEEE/CVF Winter Conference on Applications of Computer Vision (WACV) 2025 [28].

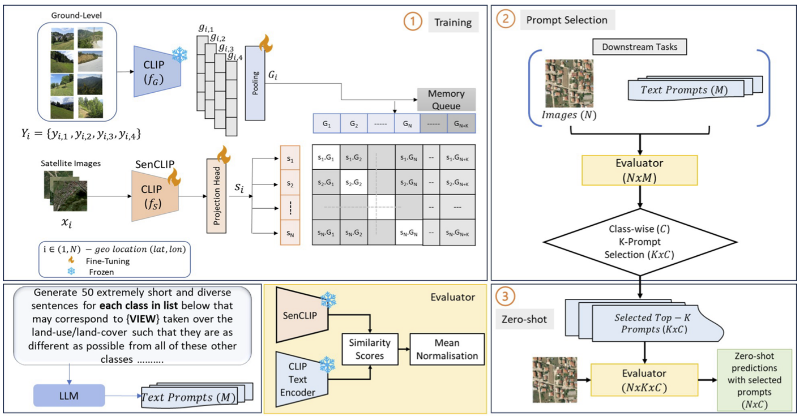

Figure 5: Architecture: The figure illustrates the three-step pipeline consisting of Pre-Training, Prompt Selection, and Zero-shot Predictions. It also demonstrates the prompt generation process from LLMs, which is utilized for prompt selection and then selected prompts for zero-shot prediction.

8.2.8 MARA: a deep learning based framework for multilayer graph simplification

Participants: Roberto Interdonato, Dino Ienco.

Collaborators: Cheick Tidiane Ba (Queen Mary University of London, London, United Kingdom), Sabrina Gaito (Department of Computer Science, University of Milan, Milan, Italy)

Keywords: Graph Neural Network, Graph Simplification, Multilayer Graph.

In many scientific fields, complex systems are characterized by a multitude of heterogeneous interactions/relationships that are challenging to model. Multilayer graphs constitute valuable tools that can represent such complex systems, thus making possible their analysis for downstream decision-making processes. Nevertheless, modeling such complex information still remains challenging in real-world scenarios. On the one hand, holistically including all relationships may lead to noisy or computationally intensive graphs. On the other hand, limiting the amount of information to model through the selection of a portion of the available relationships can introduce boundary specification biases. However, the current research studies are demonstrating that it is more beneficial to retain as much information as possible and at a later stage perform graph simplification i.e., removing uninformative or redundant parts of the graph to facilitate the final analysis. While simplification strategies, based on deep learning methods, have been already extensively explored in the context of single-layer graphs, only a limited amount of efforts have been devoted to simplification strategies for multilayer graphs. In this work, we have proposed the MultilAyer gRaph simplificAtion (MARA) framework, a Graph Neural Network (GNN) based approach designed to simplify multilayer graphs based on the downstream task. MARA generates node embeddings for a specific task by training jointly two main components: i) an edge simplification module and ii) a (multilayer) graph neural network. We tested MARA on different real-world multilayer graphs for node classification tasks (Figure 6). Experimental results show the effectiveness of the proposed approach: MARA reduces the dimension of the input graph while keeping and even improving the performance of node classification tasks in different domains and across graphs characterized by different structures. Moreover, deep learning-based simplification allows MARA to preserve and enhance important graph properties for the downstream task. To our knowledge, MARA represents the first simplification framework especially tailored for multilayer graphs analysis .

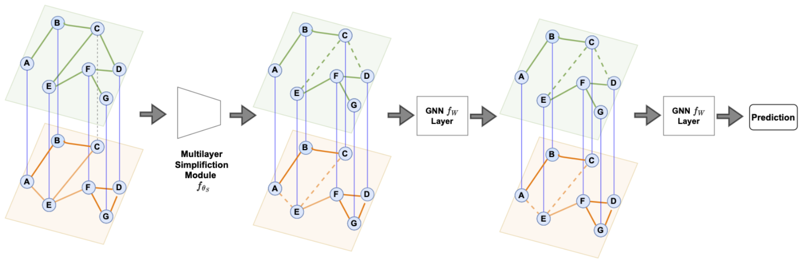

Figure 6: Multilayer graph simplification with multilayer GNN. A multilayer simplification module detects the links to remove by taking into account the whole input multilayer graph, while a GNN is used to generate node embeddings for a downstream task.

This work has been published at the Neurocomputing journal (Elsevier) [9].

8.2.9 Hybrid phenology modeling for predicting temperature effects on tree dormancy

Participants: Diego Marcos.

Collaborators: Ron van Bree (Wageningen University, The Netherlands), Ioannis Athanasiadis (Wageningen University, The Netherlands)
Keywords: Plant phenology, hybrid models.

Biophysical models offer valuable insights into climate-phenology relationships in both natural and agricultural settings. However, there are substantial structural discrepancies across models which require site-specific recalibration, often yielding inconsistent predictions under similar climate scenarios. Machine learning methods offer data-driven solutions, but often lack interpretability and alignment with existing knowledge. We present a phenology model describing dormancy in fruit trees, integrating conventional biophysical models with a neural network to address their structural disparities. We evaluate our hybrid model in an extensive case study predicting cherry tree phenology in Japan, South Korea and Switzerland. Our approach consistently outperforms both traditional biophysical and machine learning models in predicting blooming dates across years. Additionally, the neural network's adaptability facilitates parameter learning for specific tree varieties, enabling robust generalization to new sites without site-specific recalibration. This hybrid model leverages both biophysical constraints and data-driven flexibility, offering a promising avenue for accurate and interpretable phenology modeling.
This work has been presented in the AAAI conference [24].

8.2.10 EcoWikiRS: Learning Ecological Representation of Satellite Images from Weak Supervision with Species Observations and Wikipedia

Participants: Diego Marcos.

Collaborators: Valerie Zermatten (EPFL, Switzerland), Javiera Castillo-Navarro (EPFL, Switzerland), Devis Tuia (EPFL, Switzerland)
Keywords: Biodiversity, vision-language models, aerial imagery, Wikipedia.

The presence of species provides key insights into the ecological properties of a location such as land cover, climatic conditions or even soil properties. We propose a method to predict such ecological properties directly from remote sensing (RS) images by aligning them with species habitat descriptions. We introduce the EcoWikiRS dataset, consisting of high-resolution aerial images, the corresponding geolocated species observations, and, for each species, the textual descriptions of their habitat from Wikipedia. EcoWikiRS offers a scalable way of supervision for RS vision language models (RS-VLMs) for ecology. This is a setting with weak and noisy supervision, where, for instance, some text may describe properties that are specific only to part of the species' niche or is irrelevant to a specific image. We tackle this by proposing WINCEL, a weighted version of the InfoNCE loss. We evaluate our model on the task of ecosystem zero-shot classification by following the habitat definitions from the European Nature Information System (EUNIS). Our results show that our approach helps in understanding RS images in a more ecologically meaningful manner.

This work has been presented in the CVPR EarthVision workshop [30].

8.2.11 Atomizer: Generalizing to unseen modalities by breaking images down to a set of scalars

Participants: Roberto Interdonato, Diego Marcos.

Collaborators: Sylvain Lobry (Université de Paris Cité, France)

Keywords: Multi-modal remote sensing, transformers, foundation models.

The growing number of Earth observation satellites has led to increasingly diverse remote sensing data, with varying spatial, spectral, and temporal configurations. Most existing models rely on fixed input formats and modality-specific encoders, which require retraining when new configurations are introduced, limiting their ability to generalize across modalities. We introduce Atomizer, a flexible architecture that represents remote sensing images as sets of scalars, each corresponding to a spectral band value of a pixel. Each scalar is enriched with contextual metadata (acquisition time, spatial resolution, wavelength, and bandwidth), producing an atomic representation that allows a single encoder to process arbitrary modalities without interpolation or resampling. Atomizer uses structured tokenization with Fourier features and non-uniform radial basis functions to encode content and context, and maps tokens into a latent space via cross-attention. Under modality-disjoint evaluations, Atomizer outperforms standard models and demonstrates robust performance across varying resolutions and spatial sizes.

This work has been presented in the British Machine Vision Conference [29], where it was awarded the Best Presentation Award.

8.2.12 Predicting Near-future Deforestation Across the Tropics Using Deep Learning: Insights from the Forest Foresight Project

Participants: Diego Marcos.

Collaborators: Laura Elena Cué La Rosa (Wageningen University, The Netherlands), Jonas van Duijvenbode (WWF), Zillah Calle (Wageningen University, The Netherlands), Jorn Dallinga (WWF) and Johannes Reiche (Wageningen University, The Netherlands)

Keywords: Deforestation forecasting, tropical forests

Tropical deforestation continues to threaten biodiversity, carbon storage, and climate regulation. While satellite-based near-real-time monitoring systems track deforestation across local to global scales, they only detect forest loss after it occurs. Proactively identifying areas at risk can help support timely mitigation efforts. As part of the Forest Foresight initiative led by the World Wide Fund for Nature (Netherlands), we developed a deep learning model to predict near-future deforestation risk. The model produces monthly risk maps at a 400-meter spatial resolution with a six-month prediction horizon, based on near real-time deforestation alerts and various open-access geospatial datasets used as predictors. It was tested in 17 countries across humid tropical forests in South America, Africa, and Southeast Asia, and achieved an average F0.5 score of 64.8%. It demonstrates a modest performance gain over both a rule-based baseline model (4% global improvement) and an XGBoost decision forest model (1.4% improvement globally), as well as greater temporal and cross-country prediction stability. Prediction performance was highest in areas near recent deforestation and declined with increasing distance from these areas, highlighting the model's dependence on past deforestation patterns as the main limitation. The model is less effective in predicting new deforestation events in previously undisturbed forests, such as regions where new logging roads are being developed after the prediction date. To substantially improve prediction performance, it is essential to integrate frequently updated, region-specific, and novel data sources, particularly real-time indicators of human activity, such as mobile phone movements or economic signals.

This work has been accepted at Environmental Research Communications [10].

8.2.13 Learning transferable land cover semantics for open vocabulary interactions with remote sensing images

Participants: Diego Marcos.

Collaborators: Valerie Zermatten (EPFL, Switzerland), Javiera Castillo-Navarro (EPFL, Switzerland), Devis Tuia (EPFL, Switzerland)
Keywords: Biodiversity, vision-language models, aerial imagery, Semantic Segmentation.

Why should we confine land cover classes to rigid and arbitrary definitions? Land cover mapping is a central task in remote sensing image processing, but the rigorous class definitions can sometimes restrict the transferability of annotations between datasets. Open vocabulary recognition, i.e. using natural language to define a specific object or pattern in an image, breaks free from predefined nomenclature and offers flexible recognition of diverse categories with a more general image understanding across datasets and labels. The open vocabulary framework opens doors to search for concepts of interest, beyond individual class boundaries. In this work, we propose to use Text As supervision for COntrastive Semantic Segmentation (TACOSS), and we design an open vocabulary semantic segmentation model that extends its capacities beyond that of a traditional model for land cover mapping: In addition to visual pattern recognition, TACOSS leverages the common sense knowledge captured by language models and is capable of interpreting the image at the pixel level, attributing semantics to each pixel and removing the constraints of a fixed set of land cover labels. By learning to match visual representations with text embeddings, TACOSS can transition smoothly from one set of labels to another and enables the interaction with remote sensing images in natural language. Our approach combines a pretrained text encoder with a visual encoder and adopts supervised contrastive learning to align the visual and textual modalities. We explore several text encoders and label representation methods and compare their abilities to encode transferable land cover semantics. The model's capacity to predict a set of different land cover labels on an unseen dataset is also explored to illustrate the generalization capacities across domains of our approach. Overall, TACOSS is a general method and permits adapting between different sets of land cover labels with minimal computational overhead.

This work has been presented in the ISPRS Journal of Photogrammetry and Remote Sensing [23].

8.3 Interaction between Domain expert and Machine Learning models

8.3.1 Evaluation of geographical distortions in language models

Participants: Roberto Interdonato.

Collaborators: Rémy Decoupes (UMR TETIS, INRAE, France), Mathieu Roche (UMR TETIS, CIRAD, France), Maguelonne Teisseire (UMR TETIS, INRAE, France), Sarah Valentin (UMR TETIS, CIRAD, France)

Keywords: NLP, LLM, Spatial information, Bias.

Geographic bias in language models (LMs) is an underexplored dimension of model fairness, despite growing attention being given to other social biases. We investigate whether LMs provide equally accurate representations across all global regions and propose a benchmark of four indicators to detect undertrained and underperforming areas: (i) indirect assessment of geographic training data coverage via tokenizer analysis, (ii) evaluation of basic geographic knowledge, (iii) detection of geographic distortions, and (iv) visualization of performance disparities through maps. Applying this framework to ten widely used encoder- and decoder-based models, we find systematic overrepresentation of Western countries and consistent underrepresentation of several African, Eastern European, and Middle Eastern regions, leading to measurable performance gaps. We further analyze the impact of these biases on downstream tasks, particularly in crisis response, and show that regions most vulnerable to natural disasters are often those with poorer LM coverage. Our findings underscore the need for geographically balanced LMs to ensure equitable and effective global applications.

This work has been published in the Discovery Science conference [25] and succcessively extended in a publication on the Machine Learning journal (Springer Nature) [12].

9 Bilateral contracts and grants with industry

9.1 Bilateral contracts with industry

- **ATOS - Cifre thesis**

  Participants: Raffaele Gaetano, Diego Marcos, Dino Ienco.

  This Cifre Ph.D. thesis project, entitled “Multi-source satellite image segmentation for the extraction of geometric landscape objects with an application to the extraction of agricultural land parcels”, started in September 2023, for a total duration of 3 years.

  Context: Delineating agricultural field plot accurately and efficiently is important not only for the declaration-based subsidy systems such as the European Common Agricultural Policy, but also for monitoring agricultural activities on several scales (environmental impact, territorial development, crop monitoring and precision farming, etc.) and get useful information regarding the status of agricultural production. To this end, the necessity of precise and timely spatialized products, such as land use and land cover maps and the estimation of agricultural yields at field level, are essential. These tools are part of a process of developing value-added services linked to digital agriculture. The accuracy and freshness of these products could prove to be a key factor in supporting decision-making by a wide range of stakeholders, including farmers, land managers and political decision-makers.

  Objectives: Initial work on the extraction of agricultural land parcels from satellite imagery using deep learning techniques has recently been proposed but these are mainly studies that directly deploy techniques from the state of the art in computer vision in this field of application, and therefore with a limited adaptation to the field of satellite imagery, particularly with regard to taking into account the multi-source, multi-temporal and multi-scale information that is accessible via modern Earth observation missions. It is in this context that this CIFRE thesis aims to tackle the problem of the automatic extraction of agricultural fields from remotely sensed data on a territory and its characterization in terms of land use and land cover. To this end, the thesis project plans to leverage deep learning techniques such as semantic segmentation and instance segmentation to propose new approaches tailored to the analysis of satellite data for the task of extracting geometric contours for the delineation of agricultural fields, as well as for characterizing the corresponding land use (in terms of cropping practices).

10 Partnerships and cooperations

10.1 International initiatives

- **OBSYDYA**

  Participants: Raffaele Gaetano, Roberto Interdonato.

  Official website of the OBSYDYA project

  Title : Observatoire Pilote des Paysages et des Dynamiques Agricoles du Bénin (Pilot Observatory of Landscapes and Agricultural Dynamics in Benin).
  Duration: From January 1, 2022 to December 31, 2026.
  Summary: The OBSYDYA project, Observatoire Pilote des Paysages et Dynamiques Agricoles (*Pilot Observatory of Landscapes and Agricultural Dynamics in Benin*), is a DeSIRA (Development Smart Innovation through Research in Agriculture) project funded by the European Union. The project aims at taking advantage of the possibilities offered by recent satellite images to monitor changes in the landscape and provide information on the agricultural practices that induce them, in order to finally have more reliable and frequent agricultural statistics to guide agricultural advisory services and infrastructure planning. The overall aim of the project is to set up a pilot observatory of agrarian systems and landscapes, in the form of a platform of services dedicated to the capitalization of spatialized information (maps, satellite images, surveys), the production of indicators (regular and inexpensive) and the mapping of the dynamics of agrarian systems and landscapes in Central and Northern Benin.

  This project funds the PhD of Bruno Bio Nikki.

- **Land Matrix Initiative**

  Participants: Roberto Interdonato.

  Official website of the Land Matrix Initiative

  Title : Land Matrix Phase IV - Increased Transparency and Accountability on Land Acquisitions: Indigenous peoples and local communities, biodiversity hotspots and new pressures on land in the context of climate change and sustainable supply chains.
  Duration: From January 1, 2024 to December 31, 2027
  Summary: The Land Matrix Initiative (LMI) is an independent global land monitoring initiative, consisting of several global and regional partners, including CIRAD. The LMI was created in 2009 to address the lack of robust data on Large Scale Land Acquisitions (LSLAs). The first version of the Land Matrix database was launched in April 2012, providing a systematic overview of large-scale agricultural investments. Today, in addition to a large collection of global data illustrating the magnitude of LSLAs at an international scale, the collection of country-specific data is carried on by the four regional focal points in Africa, Asia, Eastern Europe and Latin America, as well as the national land observatories in Argentina, Cameroon, the Philippines, Senegal and Uganda. The project, funded by IFAD - International Land Coalition (ILC), has recently completed its Phase III (*Open data for transparency and accountability on land and investment*, 2019-2023) and entered its Phase IV in January 2024, under the theme *Increased Transparency and Accountability on Land Acquisitions: Indigenous peoples and local communities, biodiversity hotspots and new pressures on land in the context of climate change and sustainable supply chains*.

  EVERGREEN participates in this project concerning the modeling and analysis of complex network models issued by data about the global land trade market.

- **CNPq/MCTI/FNDCT (Brazil) Collaboration Network**

Participants: Cássio Fraga Dantas.

Title: Collaboration Network for the Development of Methods in Responsible Artificial Intelligence.

Duration: From September 1, 2025 to August 31, 2027

Summary: A major challenge in artificial intelligence (AI) is to reconcile all the benefits of its applications with a responsible use of the algorithms. For example, it is well known that, when dealing with historical data, machine learning algorithms can learn (and replicate) biased decisions toward different segments of society, such as race and gender. Furthermore, an important challenge when working with nonlinear models, such as neural networks, is understanding the relationships between the attributes used as model inputs and the predicted outputs. These challenges motivate the problems addressed in this project, in which the central topic is the development of ethical (or responsible) AI solutions. In the first research topic, we shall develop and analyze new machine learning methods for bias mitigation and identification, especially considering the unsupervised paradigm. The second line addresses the development of explainability algorithms capable of providing insights into the functioning of the so-called black-box models. As a major objective, we aim to jointly develop new solutions in these two areas, exploring the synergies between the teams based in Brazil and in the partner institutions abroad. Additionally, aiming to establish a long-term cooperation network, the project also has as an important objective to establish graduate projects to be jointly supervised by a researcher based in Brazil and a researcher based abroad. The project is funded by a CNPq/MCTI/FNDCT call for project Brazil Knowledge Program aimed at fostering and supporting collaborative research networks involving Brazilian researchers abroad. The funded project establishes partnerships with research groups in the state of São Paulo, such as the University of Campinas (with the project lead, Leonardo Tomazeli Duarte) and the Federal University of ABC.

10.2 European initiatives

10.2.1 Horizon Europe

- **Eco2Adapt**

Participants: Dino Ienco, Cássio Fraga Dantas.

Eco2Adapt project on cordis.europa.eu

Title : Ecosystem-based Adaptation and Changemaking to Shape, Protect and Maintain the Resilience of Tomorrow's Forests

Duration: From September 1, 2022 to August 31, 2027

Summary: Forests can be destroyed through climatic events such as storms or drought, or attacked by pests and pathogens, leaving a devastated landscape and despairing local populations. The EU-funded eco2adapt project will develop the ecosystem-based adaptation framework derived from nature-based solutions and work in Living Labs located in climate hotspots in Europe and China. It will use an advanced Decision Theatre approach to investigate how to integrate disturbance and vulnerability into forest management by developing changemaking scenarios. Furthermore, it will create innovative technical, economic and governance mechanisms at a regional level, apply semantic technology to establish a knowledge base for hosting FAIR data, create a smartphone application (OneForest ToolBox) to enable users to add data on climate-resilient forests, and provide cutting-edge tools to monitor vulnerability and resilience.

EVERGREEN is involved in Task 3.3 "Defining and estimating forest ecosystem services" that D. Ienco co-leads. The interest for the team is to advance spatio-temporal analysis for the analysis of forest disturbances at large scale with the exploitation of satellite derived products. We have a post-doctoral researcher for 18 months funded by this project.

10.3 National initiatives

- **#DigitAg: Digital Agriculture**

  Participants: Cássio Fraga Dantas, Raffaele Gaetano, Roberto Interdonato, Diego Marcos, Dino Ienco.

  Duration: From September 2017 to August 2026
  Summary: #DigitAg is a “Convergence Institute” dedicated to the increasing importance of digital techniques in agriculture. Its goal is twofold: First, making innovative research on the use of digital techniques in agriculture in order to improve competitiveness, preserve the environment, and offer correct living conditions to farmers. Second, preparing future farmers and agricultural policy makers to successfully exploit such technologies. While #DigitAg is based in Montpellier, Rennes is a satellite of the institute focused on cattle farming.

  EVERGREEN is involved in the “agricultural territoy management” challenge of the institute, which D. Ienco leads. The interest for the team is to design novel methods and frameworks to analyze and manage heterogeneous remote sensing data for agricultural applications. In 2024, we had an internship funded by this initiative.

- **PEPR IRiMa**

  Participants: Cássio Fraga Dantas, Diego Marcos, Dino Ienco.

  Duration: From September 2023 to August, 2031
  Summary: The exploratory IRiMa PEPR aims to formalize a "science of risk" to contribute to the development of a new strategy for the management of risks and disasters and their impacts in a context of global change. To achieve this, it implements a series of research projects and expert assessments (involving observation, analysis or decision support) to accelerate the transition to a society capable of facing a range of threats (hydro-climatic, telluric, technological, health-related, coupled), by adapting and becoming more resilient and sustainable. In order to face this challenge, which is increased by climate change, it is necessary to consolidate, stimulate and coordinate the national research effort.

  EVERGREEN is involved in the project Intelligent Mapping, funded by the PEPR IRIMA, for the analysis and management of multi-source remote sensing data for the monitoring of coastal areas. To this end, a post-doctoral researcher, for a duration of 3 years, is scheduled in the framework of the Intelligent Mapping project.

- **REUSTIS - TOSCA - CNES**

  Participants: Cássio Fraga Dantas, Raffaele Gaetano, Dino Ienco.

  Title: Re-Use of historical ground truth data to improve land cover mapping based on satellite imagery time series

Duration: From January 2024 to December 2026
Summary: This proposal explores the possibility of reusing historical ground truth data to improve the land cover mapping process based on single and multi-source satellite imagery time series. To this end, the objectives of this project are: i) to develop and implement a deep learning methodology that can reuse historical ground truth data to improve land cover mapping results by explicitly taking into account differences and/or shifts in the distribution of remote sensing data associated with each field campaign; ii) propose this new methodology both in a single-sensor context (exploiting only Sentinel-2 optical imagery time series) and, in a second phase, extend the proposed approach to the multi-sensor radar/optical context, in particular by targeting the simultaneous exploitation of Sentinel-1 and Sentinel-2 time series.

EVERGREEN is leading this project that is devoted to the reuse of historical ground truth data for the current analysis of remote sensing information for the downstream task of land use and land cover mapping. This project funds several master/engineering internships and publications fees.

10.3.1 ANR

- **ANR GLOURB**

  Participants: Cássio Fraga Dantas, Roberto Interdonato, Dino Ienco.

  Title: Floodplain urbanization at global scale
  Duration: From December 2022 to November, 2026
  Summary: GloUrb addresses the issue of floodplain urbanization at global scale since the 1980s based on an interdisciplinary and integrated approach. Floodplains are amongst the most threatened and vulnerable ecosystems, but vital for human society. GloUrb builds on the need for global references to support understanding of floodplain urbanization processes and their socio-ecosystem consequences (biodiversity, flood risk, urban resilience, environmental justice); explain such trends and distinguish between local and global scale drivers; inform and increase the public awareness; monitor to prevent threats and manage future changes. GloUrb will use existing local and global information, web data mining, remote sensing and innovative signal analysis techniques. We will inform people on urbanization processes to support sustainable, integrated and adaptive management, developing a global online information system with a monitoring interface showing urbanization trends and targeting potential threats.

  EVERGREEN is involved in the project for the analysis of remote sensing time series data with the aim to conceive, design and develop techniques for the downstream task of land use land cover mapping with a focus on how the process can be transferred temporally from one period of time to another period of time.

- **ANR GeoReSeT**

  Participants: Roberto Interdonato, Diego Marcos, Dino Ienco.

  Title: Generalized Earth Observation with Remote Sensing and Text
  Duration: From September 2023 to August, 2027
  Summary: This research proposal aims to develop a versatile foundation model for geo-spatial data that can be used for any task and with any data modality. By using location on the Earth's surface as the common link between different modalities, the model will be able to incorporate a variety of data sources, including remote sensing imagery, textual descriptions of places, and features in maps. Through self-supervised learning methods such as contrastive learning or multi-modal masked autoencoders, the model will leverage the large amounts of unlabeled geo-spatial data from these different sources to learn a better representation of any geo-spatial location and convey a semantic representation of the information.

EVERGREEN is co-leading the project with D. Marcos as co-PI (principal investigator) of the project. The project objectives are at the core of the research activities of the team.

- **ANR PREDISPOSE**

  Participants: Dino Ienco.

  Title: Fire prevention: preparing the French regions
  Duration: From March 2025 to Februray, 2029
  Summary: This research project aims to address the escalating risk of wildfires in France, as highlighted by the 6th IPCC report and corroborated by studies predicting an increase in fire occurrence, particularly in the north and west at an accelerated rate. We aim to develop a comprehensive methodology based on scientific research and tools, some new and some adapted, with the overall objective of improving the prevention of forest fires in forested and semi-natural ecosystems.

  EVERGREEN contributes to the project by analyzing remote sensing data to extract large-scale information about vegetation strata. This analysis supports landscape-level assessments and enables the extraction of essential landscape variables that are crucial for wildfire forest monitoring.

10.4 Public policy support

- **IMPACT - OFB (Office Français pour la Biodivérsité)**

  Participants: Dino Ienco.

  Title: Integrating the mosaic of landscapes mapped by remote sensing, and the associated epidemic risk, for more agro-ecological management of regulated diseases of perennial crops
  Duration: From September 2023 to August, 2031
  Summary: This project focuses on regulated vector-borne diseases of perennial plants. Epidemiosurveillance of these diseases, centered on a crop of interest, will be extended to the diversity of landscape mosaics in order to reduce compulsory treatments and promote preventive management of reservoirs. Remote sensing and modeling will be used to map the risk of 3 diseases: HLB, sharka and flavescence dorée (FD). More detailed characterization of the FD pathosystem (experiments on the vector, sequencing to distinguish between epidemic and non-epidemic variants) will also improve its management.

  EVERGREEN is in charge of conducting analysis and exploration, through the analysis of multi-temporal remote sensing data, to detect the current status of vineyard plantations. To this end, a research engineer, for a duration of 18 months, is scheduled in the framework of the project.

11 Dissemination

11.1 Promoting scientific activities

11.1.1 Scientific events: organization

Local

- Cássio Fraga Dantas and Diego Marcos are part of the organization committee of Machine Learning in Montpellier (ML-MTP) seminars.

National

- Dino Ienco has co-organized the IA+Remote Sensing event in the frame of the AI Prospects (half a day of workshop and discussion) of the INEE institute of CNRS.

International

- Cássio Fraga Dantas, Roberto Interdonato, and Dino Ienco have organized the seventh edition of the MACLEAN (Machine Learning for Earth Obervation Data) workshop co-located with the European conference on Machine Learning and Data Mining (ECML/PKDD).
- Roberto Interdonato organized the special session "Network Science Meets AI" as part of the ESANN 2025 conference, European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning, Bruges (Belgium), April 23-25, 2025. The session was co-organized with Matteo Zignani, University of Milan (Italy), Fragkiskos D. Malliaros, Paris-Saclay University (France), Ingo Scholtes, Julius-Maximilians-Universitat Wuurzburg (Germany) and Manuel Dileo, University of Milan (Italy) .
- Roberto Interdonato co-organized the SAI4OID worksop, 1st International Workshop on Sustainable Artificial Intelligence for addressing Online Information Disorder, co-located with the 24th International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT 2025, 17 November, 2025, London, United Kingdom). Workshop is co-organized with Francesco Scala (ICAR-CNR, Italy), Liliana Martirano (ICAR-CNR, Italy), Marco Minici (ICAR-CNR, Italy), Luca Luceri (USC Information Sciences Institute, USA), Sergio Flesca (Università della Calabria, Italy).

11.1.2 Scientific events: selection

Chair of conference program committees

- Roberto Interdonato is Short Paper Program Chair of WSDM 2026, The 19th ACM International Conference on Web Search and Data Mining (Boise, Idaho, USA, February 22 – 26, 2026).

Member of the conference program committees

- Dino Ienco: DS25 (Discovery Science), ECML/PKDD25 - Journal Track (European Conference on Machine Learning and Principle and Practice of Knowledge Discovery), PAKDD25 (Pacific Asian Conference on Knoweldge Discovery from Data), IJCAI25 (International Joint Conference on Artificial Intelligence), Senior PC AAAI25 (AAAI Conference on Artificial Intelligence), EGC25 (Extraction et Gestion des Connaissances), APIA25 (Conférence Nationale sur les Applications Pratiques de l'Intelligence Artificielle).
- Roberto Interdonato: BMVC25 (British Machine Vision Conference 2025), ECML/PKDD25 (European Conference on Machine Learning and Principle and Practice of Knowledge Discovery), AAAI25 - Special Track on AI for Social Impact (AAAI Conference on Artificial Intelligence), DS25 (Discovery Science), CCS25 (Conference on Complex Systems 2024), Complex Networks 2025 (International Conference on Complex Networks and their Applications), IC2S2'24 (International Conference for Computational Social Science), CARI'2025 (African Conference on Research in Computer Science), FRCCS 2025 (French Regional Conference on Complex Systems 2025), IGARSS 2025 (International Geoscience and Remote Sensing Symposium 2025).
- Cássio Fraga Dantas: International Geoscience and Remote Sensing Symposium (IGARSS), IEEE International Conference on Multimedia (ICME), International Conference on Computer Vision (ICCV), IEEE/CVF Winter Conference on Applications of Computer Vision (WACV), Workshop MVEO (Machine Vision for Earth Observation and Environment Monitoring, in conjunction with BMVC'25), Workshop TerraBytes (Towards global datasets and models for Earth Observation, in conjunction with ICML'25).
- Diego Marcos: Conference on Computer Vision and Pattern Recognition (CVPR), International Conference on Learning Representations (ICLR), NeurIPS, International Conference on Computer Vision (ICCV), IEEE/CVF Winter Conference on Applications of Computer Vision (WACV), Workshop MVEO (Machine Vision for Earth Observation and Environment Monitoring, in conjunction with BMVC'25).

11.1.3 Journal

Member of the editorial boards

- Dino Ienco: Associate Editor for the Scientific Report journal (Springer Nature), Associate Editor for the Remote Sensing journal (MDPI), member of the Editorial Board of the ISPRS Journal of Photogrammetry and Remote Sensing, Action Editor for the Machine Learning journal (Springer Nature).

- Roberto Interdonato: Associate Editor for the Applied Network Science journal (Springer Nature), member of the Editorial Board of the Frontiers in Big Data journal.

Reviewer - reviewing activities

- Dino Ienco: IEEE Geoscience and Remote Sensing Magazine, IEEE Geoscience and Remote Sensing Letters, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Transactions on Geoscience and Remote Sensing, ISPRS Journal of Photogrammetry and Remote Sensing (Elsevier), Data Mining and Knowledge Discovery (Springer), Machine Learning Journal (Springer), Remote Sensing of Environment (Elsevier), Multimedia Tools and Applications (Elsevier), Applied Intelligence (Elsevier), International Journal of Remote Sensing (Taylor and Francis), Computers and Electronics in Agriculture (Elsevier), Neural networks (Elsevier).

- Roberto Interdonato : IEEE Transactions on Geoscience and Remote Sensing, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, PLOS One, Expert Systems with Applications (Elsevier), ISPRS Journal of Photogrammetry and Remote Sensing (Elsevier), International Journal of Applied Earth Observation and Geoinformation (Elsevier), ACM Computing Surveys, Artificial Intelligence (Springer), World Development (Elsevier), Data Mining and Knowledge Discovery (Springer), Neurocomputing (Elsevier), Geo-spatial Information Science (Taylor & Francis), Artificial Intelligence in Geosciences (Elsevier).

- Cássio Fraga Dantas: IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (JSTARS), IEEE Transactions on Multimedia (TMM), IEEE Transactions on Artificial Intelligence (TAI).

11.1.4 Invited talks

National

- *Diego Marcos*: *Adapting Maxent species distribution models to deep learning and remote sensing* at Prospective Biodiversité & IA, CNRS, Paris.

International

- *Dino Ienco*: *Collaborative Cross-Modal Knowledge Distillation via Disentanglement Representation for imagery data* at the Jožef Stefan Institute, Ljubjana, Slovenia.

11.1.5 Scientific expertise

- Dino Ienco: Remote Reviewer for the Research Foundation Flanders - FWO post-doctoral project.

- Dino Ienco: Member of an ANR committee for project evaluations.

- Roberto Interdonato: Reviewer for “Starting Grant” for Young Researchers, University of Cagliari (UniCA), Italy.

11.1.6 Research administration

- Dino Ienco is participating to the activities of the Doctoral School I2S (Information Structures Systèmes) as a sub referee of the Computer Science speciality. Among the other tasks related to this activity, this involves the participation to several Doctoral advisory committee per year (around 20/25).
- Dino Ienco is member of the CEP (Committee of the Project Team) of the Inria Center at Université Côte d'Azur.
- Dino Ienco is member of the BCEP (Bureau of the the Project Team Committee) of the Inria Center at Université Côte d'Azur.
- Dino Ienco is Member of the Scientific Direction Council (Conseil de Direction Scientifique) at the UMR TETIS.
- Roberto Interdonato is head of the MISCA team (Modélisation de l'Information Spatiale, extraction de Connaissances et Analyse) at UMR TETIS.
- Roberto Interdonato is Research Scientists' representative at the UMR TETIS Council (Conseil d'Unité).
- Roberto Interdonato is Member of the Scientific Direction Council (Conseil de Direction Scientifique) at the UMR TETIS.

11.2 Teaching - Supervision - Juries - Educational and pedagogical outreach

11.2.1 Teaching

- Cássio Fraga Dantas: *Introduction to Machine Learning* module (12h of practical sessions) for M1 students from the Energy and Environment masters at EPF engineering school, Montpellier. *Introduction to Machine Learning* module (9h courses, 12h practical sessions) for M1 students from the Data Engineering masters at EPF engineering school.
- Raffaele Gaetano: at MSc level, responsible for the teaching unit "Spatial imagery for the management of environmental resources", *M2 Géomatique*, jointly organized by Université de Montpellier, Université Paul Valéry and AgroParistech (7h courses, 15h practical sessions). For professional training, participation to the teaching unit "Information extraction from remote sensing imagery", *Mastère SILAT*, AgroParistech (2h courses, 5h practical session). R. Gaetano also delivered a tutorial on the use of the MORINGA processing chain to partners in the OBSYDYA project (24h practical sessions) in February 2025.
- Diego Marcos: *Advanced Data Science* (4.5h of courses and 15h of practical sessions) and *Artificial Intelligence* at Université de Montpellier.

11.2.2 Supervision

- PhD in progress: Ananthu Aniraj, Explainable image classification through supervised and unsupervised part detection, co-advised by Diego Marcos, Cássio Fraga Dantas and Dino Ienco, funded by the CPJ OBTEA, since April 2023.
- PhD in progress: Camille Portes, Increased risk-based epidemio-surveillance for Xylella fastidiosa, advised by Dino Ienco, in collaboration with Edith Gabriel (BioSP - Biostatistique et Processus Spatiaux Unit), funded by École Universitaire de Recherche (EUR) Implanteus, since October 2021.
- PhD in progress: Bruno Bio Nikki, Deep learning and multi-sensor remote sensing imagery for land use and land cover mapping of agricultural systems in Northern Benin, co-advised by Raffaele Gaetano, Roberto Interdonato (co-supervised by Prof. Yvon C. Hountoundji, Univeristy of Parakou - Benin), funded by the EU OBSYDYA project, since October 2023.

- PhD in progress: Ron van Bree, Hybrid AI for Food Security, co-advised by Ioanis Athanasiadis (Wageningen University) and Diego Marcos, since April 2024.
- PhD in progress: Valerie Zermatten, co-advised by Devis Tuia (EPFL) and Diego Marcos, since 2023
- PhD in progress: Christopher Jabea, AI approaches for the identification of morphological patterns in coastal areas from Earth observation data, co-advised by Cássio Fraga Dantas and Dino Ienco, in collaboration with Isabelle Manighetti (University Côté D'Azur), Bruno Castelle (CNRS).
- PhD in progress: Anas Zakroum, Analysis of complex networks for landscape dynamics analysis, co-advised by Roberto Interdonato, Pascal Degenne, Danny Loseen and Mathieu Roche (UMR TETIS, CIRAD, France).
- PhD in progress: Hugo Riffaud de Turckheim, Fundamental geospatial models for Earth observation: integration of textual and remote sensing data, co-advised by Diego Marcos, Roberto Interdonato and Sylvain Lobry (Université Paris Cité, France).
- PhD in progress: Pablo Ubilla, Deep learning-based species distribution models for integrating different data sources, co-advised by Diego Marcos, Roberto Interdonato and Christophe Botella (Inria Montpellier, IROKO team).

11.2.3 Juries

HDR

- Dino Ienco was a member of the following HDR Jury in 2025 (2): Nicolas Audebert, University Paris-Est, Paris, France (examiner); Lionel Bombrun, University of Bordeaux, Bordeaux, France (reviewer).

PhD

- Dino Ienco was a member of the following PhD Juries in 2025 (8): George Killick, University of Glasgow, Glasgow, UK (opponent); Ataollah Kamal, University of Lyon, Lyon, France (reviewer); Colin Prieur, University of Montpellier, Montpellier, France (president); Matteo Contini, University of Montpellier, Montpellier, France (president); Marion Boyer, Inria Center of the University Côte d'Azur, Sophia-Antipolis, France (reviewer); Mahdi Djama Rayaleh, University of Montpellier, Montpellier, France (president); Sarah Mauny, University Paris-Saclay, Paris, France (examiner); Marjan Stoimchev, University of Ljubjana, Ljubjana, Slovenia (reviewer).
- Roberto Interdonato was a member of the following PhD juries in 2025 (3): Florian Teste, AgroParisTech, France (examiner); Corentin Dufourg, Université de Bretagne Sud, France (reviewer); Asma Mesdour, CIRAD, France (examiner).

Doctoral advisory commitee

- Dino Ienco was a member of the following PhD mid-term evaluation committees (21): Axel Dubar (Univ. Montpellier), Guillaume Fouret (Univ. Montpellier), Elliot Butz (Univ. Montpellier), Charlotte Fabre (Univ. Montpellier), Khelian Larvet (Univ. Montpellier), Erwan Reinders (Univ. Montpellier), Guillaume Picaud (Univ. Montpellier), Florian Lecourt (Univ. Montpellier), Théo Larcher (Univ. Montpellier), Loai Gandeel (Univ. Montpellier), Guillaume Coulaud (Univ. Montpellier), Charles Berger (Univ. Montpellier), Kawtar Zaher (Univ. Montpellier), Sebastien Gigot (Univ. Montpellier), Imran Meghazi (Univ. Montpellier), Eugenio Dias Riberto Neto (Univ. Montpellier), Anas Zakroum (Univ. Montpellier), Nathan Guilhot (Univ. Montpellier), Charles Ngom (Univ. Montpellier), Tiziano Maisonhaute (Univ. Montpellier), Remy Decoupes (Univ. Montpellier).
- Roberto Interdonato was a member of the following PhD mid-term evaluation committees (4): Camille Portes (Univ. Avignon), Hussam Ghanem (Université Bourgogne Europe), Théo Morel (Univ. Normandie Le Havre), Nicolas Houdré (Université Paris Cité).

Recruitment

- Dino Ienco: Member of the recruitment jury for an INRIA Junior Research - Chargé de Recherche - (INRIA).

11.3 Popularization

- *Dino Ienco*: Participation as speaker on a roundtable on Artificial Intelligence and Agriculture, organized by Agri-Sud Ouest Innovation, an innovation and competitive pole

12 Scientific production

12.1 Major publications

[1] A. Aniraj, C. F. Dantas, D. Ienco and D. Marcos. 'PDiscoFormer: Relaxing Part Discovery Constraints with Vision Transformers'. In: *Proceedings of the European Conference on Computer Vision (ECCV)*. ECCV 2024 - 18th European Conference on Computer Vision. Vol. 15143. Lecture Notes in Computer Science. Milano, Italy: Springer Nature Switzerland, 27th Nov. 2025, pp. 256–272. DOI: 10.1007/978-3-031-73013-9_15. URL: https://hal.science/hal-04659631.

[2] R. van Bree, D. Marcos and I. Athanasiadis. 'Hybrid Phenology Modeling for Predicting Temperature Effects on Tree Dormancy'. In: AIAA 2025 - 39. Annual AAAI Conference on Artificial Intelligence. Vol. 39. AAAI-25 Special Track on AI for Social Impact, Senior Member Presentations, New Faculty Highlights, Journal Track 27. Philadelphia, United States, 11th Apr. 2025, pp. 28458–28466. DOI: 10.1609/aaai.v39i27.35068. URL: https://hal.science/hal-05196296.

[3] D. Carcereri, P. Rizzoli, L. Dell'amore, J.-L. Bueso-Bello, D. Ienco and L. Bruzzone. 'Generation of country-scale canopy height maps over Gabon using deep learning and TanDEM-X InSAR data'. In: *Remote Sensing of Environment* 311 (Sept. 2024), p. 114270. DOI: 10.1016/j.rse.2024.114270. URL: https://hal.science/hal-04629344.

[4] R. van der Klis, S. Alaniz, M. Mancini, C. F. Dantas, D. Ienco, Z. Akata and D. Marcos. 'PDiscoNet: Semantically consistent part discovery for fine-grained recognition'. In: ICCV 2023 - International Conference on Computer Vision. 2023 IEEE/CVF International Conference on Computer Vision (ICCV). Paris, France, Oct. 2023, pp. 1866–1876. DOI: 10.1109/ICCV51070.2023.00179. URL: https://hal.inrae.fr/hal-04183747.

[5] K. Panousis, D. Ienco and D. Marcos. 'Coarse-to-Fine Concept Bottleneck Models'. In: NeurIPS 2024 - 38th Annual Conference on Neural Information Processing Systems. Vancouver (BC), Canada, 9th Dec. 2024. URL: https://hal.science/hal-04709806.

[6] E. Pelous, N. Méger, A. Benoit, A. Atto, D. Ienco, H. Courteille and C. Lin-Kwong-Chon. 'Explaining the decisions and the functioning of a convolutional spatiotemporal land cover classifier with channel attention and redescription mining'. In: *ISPRS Journal of Photogrammetry and Remote Sensing* 215 (Sept. 2024), pp. 256–270. DOI: 10.1016/j.isprsjprs.2024.06.021. URL: https://hal.science/hal-04650672.

[7] X. Tagle Casapia, R. Cardenas-Vigo, D. Marcos, E. Fernández Gamarra, H. Bartholomeus, E. N. Honorio Coronado, S. Di Liberto Porles, L. Falen, S. Palacios, N.-E. Tsenbazar, G. Mitchell, A. Dávila Díaz, F. C. Draper, G. Flores Llampazo, P. Pérez-Peña, G. Chipana, D. del Castillo Torres, M. Herold and T. R. Baker. 'Effective integration of drone technology for mapping and managing palm species in the Peruvian Amazon'. In: *Nature Communications* 16.1 (22nd Apr. 2025), p. 3764. DOI: 10.1038/s41467-025-58358-5. URL: https://hal.science/hal-05210646.

[8] V. Zermatten, J. Castillo-Navarro, D. Marcos and D. Tuia. 'Learning transferable land cover semantics for open vocabulary interactions with remote sensing images'. In: *ISPRS Journal of Photogrammetry and Remote Sensing* 220 (Feb. 2025), pp. 621–636. DOI: 10.1016/j.isprsjprs.2025.01.006. URL: https://hal.science/hal-05167931.

12.2 Publications of the year

International journals

[9] C. T. Ba, R. Interdonato, D. Ienco and S. Gaito. 'MARA : a deep learning based framework for multilayer graph simplification'. In: *Neurocomputing* 612 (31st Jan. 2025), p. 128712. DOI: 10.1016/j.neucom.2024.128712. URL: https://hal.science/hal-04740726 (cit. on p. 21).

[10] L. E. Cue, J. van Duijvenbode, Z. Calle, D. Marcos, J. Dallinga and J. Reiche. 'Predicting Near-future Deforestation Across the Tropics Using Deep Learning: Insights from the Forest Foresight Project'. In: *Environmental Research Communications* (2025). DOI: 10.1088/2515-7620/ae1f69. URL: https://hal.science/hal-05382102 (cit. on p. 23).

[11] L. E. Cué La Rosa, D. Marcos, B. Slagter and J. Reiche. 'Deep learning interpretability for understanding forest disturbance driver classification from Sentinel-1 and -2 data'. In: *International Journal of Remote Sensing* (11th Dec. 2025), pp. 1–35. DOI: 10.1080/01431161.2025.2598147. URL: https://hal.science/hal-05455933 (cit. on p. 15).

[12] R. Decoupes, R. Interdonato, M. Roche, M. Teisseire and S. Valentin. 'Evaluation of geographical distortions in language models'. In: *Machine Learning* 114.12 (27th Oct. 2025), p. 263. DOI: 10.1007/s10994-025-06916-9. URL: https://hal.science/hal-05334410 (cit. on p. 24).

[13] A. T. Defossez, S. Alleaume, M. Montadert, J. Giffard-Carlet, D. Ienco, N. Guiffant and S. Luque. 'Assessing habitat suitability for black grouse broods at the bioregional scale'. In: *Wildlife Biology* (2025). DOI: 10.1002/wlb3.01425. URL: https://hal.science/hal-05168858. In press (cit. on p. 12).

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