Activity Report 2023

Team OBELIX

Environment Observation through Complex Imagery

Machine Learning for Earth Observation

D6 – Signal, Image, Langage

1 Team composition

Head of the team
Nicolas Courty, Professor, Université Bretagne Sud

Université Bretagne Sud staff
Laetitia Chapel, Assistant Professor → Professor (September 2023)
Luc Courtrai, Assistant Professor
Chloé Friguet, Assistant Professor
Sébastien Lefèvre, Professor
François Merciol, Assistant Professor
Minh-Tan Pham, Assistant Professor
Charlotte Pelletier, Assistant Professor
Frédéric Raimbault, Assistant Professor

Associate/external members
Thomas Corpetti, Senior researcher (DR), CNRS
Romain Tavenard, Professor, Université Rennes 2

Post-docs
Abdelbadie Belmouhcine, Game of Trawls project → ATER (September 2023)
Hoàng-Ân Lê, since Jan 2021, OWFSOMM then ROMMEO+OTTOPIA projects
Shivam Pande, since December 2023, 6P project

PhD students
Paul Berg, ANR grant, since November 2021
Corentin Dufourg, CNES/RB grant, since October 2022
Iris de Gelis, CNES/Magellium grant, defended in April 2023
Manal Hamzaoui, ANR grant, defended in May 2023
Clément Bonet, LABEX grant, with LMBA and IMTA, defended in November 2023
Renan Bernard, ARED grant, oct 2021-jan2023
Jean-Christophe Burnel, RB/FEAMP grant, since September 2020
Matthieu Le Lain, fully-qualified teacher, since September 2023
Guillaume Mahey, ANR grant, since November 2021
Bjoern Michele, CIFRE with Valeo.AI, since October 2022
Huy Tran, ANR grant + chaire Polytechnique, since March 2021

Visiting student
Matteo Ciotola, Università degli Studi di Napoli Federico II (Unina), November 2022 - January 2023

Lynn Miller, Monash University, Australie, January-February 2023
Ana Paola Toro, University of Campinas (UNICAMP), Brazil, January-March 2023
Zoé Bessin, European Institute For Marine Studies (Brest), multiple visits in 2023

Visiting researchers

Tais Grippa, research fellow at Université Libre de Bruxelles, January-June 2023

Research engineers, technical staff

Quentin Hamard, research engineer at the France Energy Marines (FEM), co-supervision with Karine Heerah (FEM) and Dorian Cazau (ENSTA Bretagne)

Master and DUT students

Angelina Djamgaryan, L3 student in mathematics, 2 months.
Baki Uzun, BUT2 student in computer science, 2 months.
Edgar Joao Manrique Valverde (Master thesis, Univ. Bretagne Sud), co-supervision with Dino Ienco and Rafaelle Gaetano (INRAE, CIRAD, TETIS, France) and Dirk Tiede (University of Salzburg), 6 months.
Arioluwa Adedayo Aribisala (Master thesis, Univ. Bretagne Sud), co-supervision with Silvia Valero (CESBIO, France) and Dirk Tiede (University of Salzburg), 6 months.
Kennedy Adriko (Master thesis, Univ. Bretagne Sud), co-supervision with Gilberto Camara (INPE, Brazil) and Stefan Lang (University of Salzburg), 6 months.
Oscar Narvaez Luces (Master thesis, Univ. Bretagne Sud), co-supervision with Rémi Braun (SERTIT, Strasbourg) and Martin Sudmanns (University of Salzburg), 6 months.
Aimi Obayakashi (ENSTA), co-supervision with Nicolas Audebert (Cnam, France), 6 months.
Felix Kröber (Master thesis, Univ. Bretagne Sud), co-supervision with Dirk Tiede (University of Salzburg), 6 months.
Sarah Poch (Master thesis, Univ. Bretagne Sud), co-supervision with Zahra Dabiri (Department of Geoinformatics, University of Salzburg), 6 months.

2 Overall objectives

2.1 Overview

The overall objective of the Obelix team is the analysis of remote sensing data. In such a context, available data form a massive amount of complex, multidimensional and structured observations. Our objectives are to design and exploit **new artificial intelligence techniques** to leverage on this type of data and develop tools that help in **providing a digital twin of the Earth and understanding critical aspects of the impact of human activities on Earth planet**, such as climate change, biodiversity decline, urban growth, disaster prevention/recovery or monitoring of human living conditions or activities. Expected scientific outputs cover both theoretical and computational aspects of machine learning and computer vision dedicated to those problems, as well as applied and thematic contributions in the field of remote sensing.

2.2 Scientific foundations

2.2.1 Handling the specific nature of Remote Sensing data.

The remote sensing data have a specific nature: they are usually available in large quantities, but generally with only few labels. Some parts of the data may be missing (*e.g.* because of cloud covering) or corrupted by noises. Associated labels can furthermore be inexact or inaccurate because labelling strategies are generally inaccurate; their inherent nature change between captors. Also, large discrepancies can be observed between learning datasets and testing sets for a large number of reasons (time of acquisition, atmospheric conditions, etc.). We plan to devote a significant part of our research to the fundamental learning problems involved in those specific learning settings. This include for instance domain adaptation, data imputation, robust learning with label noise, few-shot or multi-task learning. Learning architectures will be primarily deep neural networks but not restricted to, as they might not always be the best solution to tackle those problems.

Example: *In a context of semantic segmentation of remote sensing data, one option to build a learning set is to derive labels from existing cadastral vector plans, that may suffer from registration issues with the observed image. This induces noise in the learning set labels, which negative effect on the final accuracy can be mitigated provided that the learning loss is robust to such noise. Finding computationally tractable robust optimization schemes in deep architectures, together with theoretical conditions of success, is still an open-subject in the machine learning community, and calls for further developments.*

2.2.2 Structured data

Most of the data usually inherits from structured components, that highlight pre-existing links or correlations/causality mechanisms. Those can be found in the intrinsic nature of the data (such as time series, graphs or trees). Taking the structure into account in learning or prediction scenarii, by defining proper metrics (e.g. based on sound mathematical theories such as optimal transport), embedding schemes or deep architectures (such as graph convolutional neural networks) will be considered;

Example: *A popular way to analyse remote sensing images is to rely on the object-based image analysis (OBIA) framework, where at each spatial scale specific objects of interest are extracted through segmentation, before being classified usually with some rule-based approach. However, such a methodology requires to set a high number of parameters (thus preventing its transfer to another dataset) and does not lead to a pure multiscale framework. In this context, an appealing alternative is to represent an image through a tree-based structure embedding its nested segmentations, before applying a unique classification procedure able to cope with regions from multiple scales, possibly inferring multiple labels corresponding to the land use classes that can be observed at various spatial scales. However, classification of structured data such as trees remains an open problem, especially when the processed tree is very large and contains numeric attributes; furthermore, there is not yet any robust method able to build a relevant tree structure from any kind of image.*

2.2.3 Generative modeling (GANs and beyond)

Generative modeling with neural networks has received a lot of attention in the machine learning community over the last years, through models like Variational Auto-encoders, Generative Adversarial Networks or Normalizing flows. While the use of generative modeling is mainly focused toward the generation of samples of high-dimensional objects such as images, their practical use in real applications is still in its infancy. In the context of remote sensing, we plan to use those models to tackle problems such as transfer across modalities (heterogeneous domain adaptation, or multi-modal image fusion), super-resolution, or inverse reconstruction problem with deep priors (for cloud removal applications for instance). We also consider to use those architectures for modeling physical processes. In this last case, the generation process not only relies on statistical constraints, but also on physical ones (which can be the case in super-resolution for instance, where one makes physical assumptions between the observation scales);

Example: *In a context of learning from a dataset which was acquired from a different modality (e.g. spatial and spectral resolution) than the image over which the inference is conducted, one needs some ways to adapt the learning information to tackle the observed data. This problem, known as heterogeneous domain adaptation, can benefit from generative models such as cycleGANs or normalizing flows, provided that they can operate between different modalities (i.e. different metric spaces). This is a challenging task, for which barely no solution exist at the moment, from both theoretical and algorithmic standpoints.*

2.2.4 Physics-driven Machine learning

As far as the underlying observed phenomena are physical by nature, learning tasks can leverage on existing physical models (usually in the form of PDEs) to better conduct the analysis. Coupling physical models and deep architectures (either by construction, such as neural ODEs, or by regularization schemes) will be considered. Also, in a reverse direction, recent parallels between how information is flowing in deep neural networks and statistical physics/PDEs have been made. We plan to get a better understanding of machine learning models by modeling them as interacting physical systems;

Example: *We consider here the improvement of the spatial resolution (i.e. super-resolution) of satellite images of temperatures (in the ocean or in urban/rural areas). Though some approaches have enriched neural networks with "physical layers" able to ensure some basis of physics, they are not designed to properly handle physical quantities, which can be critical for real applications. In this super-resolution context, we plan to constrain the generation process by the introduction of basic differentiable blocks of physical laws.*

2.2.5 Computational aspects

Last but not least, we will focus on efficient computational schemes for processing and analyzing large scale remote sensing data, towards a goal of green AI. Expected outputs will include novel algorithmic tools for efficient and scalable processing of big earth data, energetic efficiency of the machine learning models (by quantizing or compressing neural nets for instance), and also initiating new research axes such as combining quantum computing and machine learning for remote sensing applications.

Example: *The success of deep networks is due, among other factors, to the complexity of their underlying models (millions of learnt parameters). Training such models requires the availability of high-performance GPUs, usually far more powerful than the more conventional or embedded hardware that can be used for their inference. Since generic models usually fail to achieve perfect results in real-life scenarios due to the domain shift between the training and testing data, being able of lightly retraining the model in the deployment environment is sought. Designing very lightweight networks and networks updating schemes running on conventional/embedded hardware are challenging tasks, still largely unexplored in the community.*

2.3 Application domains

OBELIX activities contribute to Digital Twin Earth and as such aim to visualize, monitor and forecast natural and human activity on the planet in support of sustainable development.

AI tools for Copernicus The EU's EO *Copernicus* Program aims to deliver massive amounts of open remote sensing data (Petabyte scale), that can be exploited especially in its six thematic services, namely atmosphere, marine environment, land monitoring, climate change, emergency management, and security. Copernicus offers new opportunities for EO analytics, but also raises challenges related to high spatial resolution, dense time series, multiple modalities, etc. In this context, the Obelix team will design and scale-up its AI tools to make them usable by Copernicus services, e.g. land and human-settlement monitoring and climate change study at large-scale.

Climate change monitoring AI can help the monitoring and forecasting of the impacts of climate change locally (inside cities for example) and can be an appealing solution to generate reliable simulations, diagnostics and forecasts of critical situations (heat waves, pollution events for example). The anticipation of such sudden climatic events is crucial for the protection of population (UN indeed expects that more than 70% of world population will live in cities by 2050). At the moment to understand the local climate, climatologists rely on *Local Climate Zones* (LCZ) introduced in 2012 by Steward and Oke. LCZ consist of a categorization of local morphology into 17 different classes (depending on imperviousness, density of housings, vegetation etc), each of them being specific in term of local climate. Though largely used, there is no consensus about the existing classification that has been defined on the basis of US landscapes. AI will help both in the definition of more consistent LCZ and in their cartography at global scale to help the prevention of local sudden events.

Coastal and Ocean monitoring Given its geographical location on the seaside, UBS has a long experience in research activities related to the sea and the coast, now structured in its centre of excellence “Sea & Coast”. OBELIX plays an active role in these activities through collaborative projects focused on maritime megafauna monitoring from aerial, underwater, and in-situ observations with partners such as OFB (French Biodiversity Agency), IFREMER (French Research Institute for Exploitation of the Sea), and FEM (Institute for Energy Transition dedicated to Marine Renewable Energies); or coastal dynamics analysis in the context of global warming.

AI for social good Obelix team will actively seek and engage in projects which goals are focused toward using artificial intelligence to address societal issues and improve the well-being of the world (also known as AI for social good), through remote sensing. Such applications generally consider the challenges for developing countries to maintain sustainable development, food and water security, and disaster relief, as well as supporting humanitarian action. As a good example, mapping large-scale socioeconomic indicators, such as poverty or education level, from high-resolution satellite imagery, is challenging because the information is not directly observable from the image, and one need to consider more complicated inference schemes, involving structural or causal dependence, to perform such tasks.

3 Scientific achievements

3.1 Optimal Transport for machine learning and remote sensing

Participants: Nicolas Courty, Chloé Friguet, Laetitia Chapel, Minh-Tan Pham, Romain Tavenard, Paul Berg, Clément Bonet, Guillaume Mahey, Huy Tran.

Following our works on optimal transport for domain adaptation initiated in 2014, we developed an activity centered around the theme of optimal transport for machine learning. This research axis is mainly supported through ANR AI Chair OTTOPIA led by Nicolas Courty, and Labex COMINLABS project DynaLearn.

Sliced Optimal Transport for data on manifolds This line of work explores how the sliced optimal transport distance can be used in the case where the distributions are defined over manifolds. This line of work was mainly conducted within Clément Bonet PhD thesis, within the Labex DynaLearn Project.

- **Spherical Sliced-Wasserstein**. Many variants of the Wasserstein distance have been introduced to reduce its original computational burden. In particular the Sliced-Wasserstein distance (SW), which leverages one-dimensional projections for which a closed-form solution of the Wasserstein distance is available, has received a lot of interest. Yet, it is restricted to data living in Euclidean spaces, while the Wasserstein distance has been studied and used recently on manifolds. We focus more specifically on the sphere, for which we define a novel SW discrepancy, which we call spherical Sliced-Wasserstein, making a first step towards defining SW discrepancies on manifolds. Our construction is notably based on closed-form solutions of the Wasserstein distance on the circle, together with a new spherical Radon transform. Along with efficient algorithms and the corresponding implementations, we illustrate its properties in several machine learning use cases where spherical representations of data are at stake: sampling on the sphere, density estimation on real earth data or hyperspherical auto-encoders. Published as an ICLR paper [24]

- **Hyperbolic Sliced-Wasserstein via Geodesic and Horospherical Projections**. It has been shown beneficial for many types of data which present an underlying hierarchical structure to be embedded in hyperbolic spaces. Consequently, many tools of machine learning were extended to such spaces, but only few discrepancies to compare probability distributions defined over those spaces exist. Among the possible candidates, optimal transport distances are well defined on such Riemannian manifolds and enjoy strong theoretical properties, but suffer from high computational cost. On Euclidean spaces, sliced-Wasserstein distances, which leverage a closed-form of the Wasserstein distance in one dimension, are more computationally efficient, but are not readily available on hyperbolic spaces. In this work, we propose to derive novel hyperbolic sliced-Wasserstein discrepancies. These constructions use projections on the underlying geodesics either along horospheres or geodesics. We study and compare them on different tasks where hyperbolic representations are relevant, such as sampling or image classification. Published as in the ICML/TAG-ML Workshop [23]

- **Sliced-Wasserstein on Symmetric Positive Definite Matrices for M/EEG Signals**. When dealing with electro or magnetoencephalography records, many supervised prediction tasks are solved by working with covariance matrices to summarize the signals. Learning with these matrices requires using Riemanian geometry to account for their structure. In this paper, we propose a new method to deal with distributions of covariance matrices and demonstrate its computational efficiency on M/EEG multivariate time series. More specifically, we define a Sliced-Wasserstein distance between measures of symmetric positive definite matrices that comes with strong theoretical guarantees. Then, we take advantage of its properties and kernel methods to apply this distance to brain-age prediction from MEG data and compare it to state-of-the-art algorithms based on Riemannian geometry. Finally, we show that it is an efficient surrogate to the

Wasserstein distance in domain adaptation for Brain Computer Interface applications. Published as an ICML paper [22]

Turning Normalizing Flows into Monge Maps with Geodesic Gaussian Preserving Flows Normalizing Flows (NF) are powerful likelihood-based generative models that are able to trade off between expressivity and tractability to model complex densities. A now well established research avenue leverages optimal transport (OT) and looks for Monge maps, i.e. models with minimal effort between the source and target distributions. This paper introduces a method based on Brenier's polar factorization theorem to transform any trained NF into a more OT-efficient version without changing the final density. We do so by learning a rearrangement of the source (Gaussian) distribution that minimizes the OT cost between the source and the final density. We further constrain the path leading to the estimated Monge map to lie on a geodesic in the space of volume-preserving diffeomorphisms thanks to Euler's equations. The proposed method leads to smooth flows with reduced OT cost for several existing models without affecting the model performance. Work realised in the context of the DynaLearn project, and published in the TMLR journal [13].

Unbalanced CO-Optimal Transport Optimal transport (OT) compares probability distributions by computing a meaningful alignment between their samples. CO-optimal transport (COOT) takes this comparison further by inferring an alignment between features as well. While this approach leads to better alignments and generalizes both OT and Gromov-Wasserstein distances, we provide a theoretical result showing that it is sensitive to outliers that are omnipresent in real-world data. This prompts us to propose unbalanced COOT for which we provably show its robustness to noise in the compared datasets. To the best of our knowledge, this is the first such result for OT methods in incomparable spaces. With this result in hand, we provide empirical evidence of this robustness for the challenging tasks of heterogeneous domain adaptation with and without varying proportions of classes and simultaneous alignment of samples and features across single-cell measurements. Published as an AAAI paper [43]

SNEkhorn: Dimension Reduction with Symmetric Entropic Affinities Many approaches in machine learning rely on a weighted graph to encode the similarities between samples in a dataset. Entropic affinities (EAs), which are notably used in the popular Dimensionality Reduction (DR) algorithm t-SNE, are particular instances of such graphs. To ensure robustness to heterogeneous sampling densities, EAs assign a kernel bandwidth parameter to every sample in such a way that the entropy of each row in the affinity matrix is kept constant at a specific value, whose exponential is known as perplexity. EAs are inherently asymmetric and row-wise stochastic, but they are used in DR approaches after undergoing heuristic symmetrization methods that violate both the row-wise constant entropy and stochasticity properties. In this work, we uncover a novel characterization of EA as an optimal transport problem, allowing a natural symmetrization that can be computed efficiently using dual ascent. The corresponding novel affinity matrix derives advantages from symmetric doubly stochastic normalization in terms of clustering performance, while also effectively controlling the entropy of each row thus making it particularly robust to varying noise levels. Following, we present a new DR algorithm, SNEkhorn, that leverages this new affinity matrix. We show its clear superiority to state-of-the-art approaches with several indicators on both synthetic and real-world datasets. Published as a NeurIPS paper [45].

Fast Optimal Transport through Sliced Wasserstein Generalized Geodesics Wasserstein distance (WD) and the associated optimal transport plan have been proven useful in many applications where probability measures are at stake. In this paper, we propose a new proxy of the squared WD, coined min-SWGG, that is based on the transport map induced by an optimal one-dimensional projection of the two input distributions. We draw connections between min-SWGG and Wasserstein generalized geodesics in which the pivot measure is supported on a line. We notably provide a new closed form for the exact Wasserstein distance in the particular case of one of the distributions supported on a line allowing us to derive a fast computational scheme that is amenable to gradient descent optimization. We show that min-SWGG is an upper bound of WD and that it has a complexity similar to as Sliced-Wasserstein, with the additional feature of providing an associated transport plan. We also investigate some theoretical properties such as metricity, weak convergence, computational and topological properties. Empirical evidences support the benefits of min-SWGG in various contexts, from gradient flows, shape matching and image colorization, among others. Published as a NeurIPS (Spotlight) paper [39].

3.2 Time series analysis and change detection

Participants: Laetitia Chapel, Nicolas Courty, Chloé Friguet, Romain Tavenard, Charlotte Pelletier, Sébastien Lefèvre.

As mentioned above, an important research topic in the group is to take into account the specific structure of our data. Temporal structure is one example of this, with important applications in the Remote Sensing context. This research axis is, among others, mainly supported through ANR JCJC MATS led by Romain Tavenard.

Match-And-Deform: Time Series Domain Adaptation through Optimal Transport and Temporal Alignment While large volumes of unlabeled data are usually available, associated labels are often scarce. The unsupervised domain adaptation problem aims at exploiting labels from a source domain to classify data from a related, yet different, target domain. When time series are at stake, new difficulties arise as temporal shifts may appear in addition to the standard feature distribution shift. In this paper, we introduce the Match-And-Deform (MAD) approach that aims at finding correspondences between the source and target time series while allowing temporal distortions. The associated optimization problem simultaneously aligns the series thanks to an optimal transport loss and the time stamps through dynamic time warping. When embedded into a deep neural network, MAD helps learning new representations of time series that both align the domains and maximize the discriminative power of the network. Empirical studies on benchmark datasets and remote sensing data demonstrate that MAD makes meaningful sample-to-sample pairing and time shift estimation, reaching similar or better classification performance than state-of-the-art deep time series domain adaptation strategies. Published in ECML/PKDD [40].

Multivariate time series Elastic measures have been widely used to compare univariate time-series data. However, multivariate time series are more commonly used in practice. To extend state-of-the-art multivariate time series classification, we extended eleven elastic measures to the multivariate case and we proposed a new ensemble of nearest neighbors with this metrics [16].

End-to-end early classification of time series for in-season crop type mapping. Remote sensing satellites capture the cyclic dynamics of our Planet in regular time intervals recorded in satellite time series data. End-to-end trained deep learning models use this time series data to make predictions at a large scale, for instance, to produce up-to-date crop cover maps. Most time series classification approaches focus on the accuracy of predictions. However, the earliness of the prediction is also of great importance since coming to an early decision can make a crucial difference in time-sensitive applications. For such applications, we have introduced ELECTS, an end-to-end learned model that jointly decides on the the adequate time at which the prediction should be triggered and the class to be predicted at that point. Published in ISPRS Journal of Photogrammetry and Remote Sensing [15].

Change detection over 3D points clouds Point clouds have received a specific attention through the PhD thesis of Iris de Gélis. The change detection problem was tackled in the supervised settings, leading to the first supervised model (SiameseKPConv) able to perform change detection at the point level over pairs of points cloud (published in ISPRS Journal of Photogrammetry and Remote Sensing [3]). This model was further improved with specific attention given to the change information, either through inputting some handcrafted features to the network or learning them thanks to novel architectures (to be published in IEEE Transactions on Geoscience and Remote Sensing [1]). Despite their efficiency, the previous models are limited by their fully-supervised nature. The problem of change detection over 3D points clouds was thus also tackled under in unsupervised context, leading to a couple of developments, respectively relying on self-supervised learning (published in ISPRS Open Journal of Photogrammetry and Remote Sensing [4]) and, more interesting, on deep clustering (published in ISPRS Journal of Photogrammetry and Remote Sensing [2]). The latter is particularly appealing as it also led to efficient, user-guided analysis compliant with a low-label regime.

Change detection from satellite image time series Although deep learning has demonstrated promise for SITS analysis, the scarcity of annotations hinders the development of efficient deep learning change detection algorithms. In response, self-supervised learning has emerged as one of the most promising solutions over the last five years. The core idea is to use unlabeled data to train a network that will provide a latent representation of the data in a low-dimensional space, which can be used for many downstream tasks such as land cover classification or change detection. In this work, we propose exploring self-supervised representation learning to construct representations from a pair of SITS when semantic annotations are available only for one year. The main novelty is to leverage SITS acquired over two years. Experimental evaluation conducted on a study area in southwestern France demonstrates the effectiveness of the approach, with varying quantities of labeled training data. The results highlight the potential of self-supervised learning in producing accurate change detection maps for land cover analysis. Published at IEEE International Geoscience and Remote Sensing Symposium (IGARSS) [27].

3.3 Computer Vision for Earth Observation

Participants: Minh-Tan Pham, Charlotte Pelletier, Sébastien Lefèvre, Abdelbadie Belmouhcine, Jean-Christophe Burnel, Hoang-An Le.

Object detection and instance segmentation are two main computer vision problems in Earth Observation, for which the group has proposed several contributions. Besides, some novel regression models have been introduced for biomass estimation.

Multimodal object detection Object detection in remote sensing is a crucial computer vision task that has seen significant advancements with deep learning techniques. However, most existing works in this area focus on the use of generic object detection and do not leverage the potential of multimodal data fusion. We have conducted a comparison of methods for multimodal object detection in remote sensing, surveyed available multimodal datasets suitable for evaluation, and identified future directions. Published as an IGARSS paper in an invited session [20].

Multi-task learning of object detection and semantic segmentation We tackled the problem of multi-task learning from partially annotated data where each data point is annotated for only a single task. Such an approach is potentially helpful for data scarcity if a network can leverage the inter-task relationship. In our papers accepted at BMVC [33] and ICCV Workshop [35], we study the joint learning of object detection and semantic segmentation, the two most popular vision problems, from multi-task data with partial annotations. Extensive experiments are performed to evaluate each task performance and explore their complementarity when a multi-task network cannot optimize both tasks simultaneously. We propose employing knowledge distillation to leverage joint-task optimization. The experimental results show favorable results for multi-task learning and knowledge distillation over single-task learning and even full supervision scenario.

Unsupervised anomaly detection We propose a new model of Variational Autoencoder (VAE) for Anomaly Detection (AD) with improved modeling power. More precisely, we introduce a VAE model with a Gaussian Random Field (GRF) prior, namely VAE-GRF, which generalizes the classical VAE model. We show that, under some assumptions, the VAE-GRF largely outperforms the traditional VAE and some other probabilistic models developed for AD. Our experimental results suggest that the VAE-GRF could be used as a relevant VAE baseline in place of the traditional VAE with very limited additional computational cost. We provide competitive results on the public MVTec benchmark dataset for visual inspection, as well as on the public Livestock dataset dedicated to the task of unsupervised animal detection from aerial images. More details can be found in our publications in ICIP [28] and IGARSS [41].

Contour detection The task of glacier calving front modeling has often been approached as a semantic segmentation task. Recent studies have shown that combining segmentation with edge detection can improve the accuracy of calving front detectors. Building on this observation, we completely rephrase the task as a contour tracing problem and propose a model for explicit contour detection that does not incorporate any dense predictions as intermediate steps. The proposed approach, called 'Charting Outlines by Recurrent Adaptation' (COBRA), combines CNNs for feature extraction and active contour models for the delineation. By training and evaluating on several large-scale datasets of Greenland's outlet glaciers, we show that this approach indeed outperforms the aforementioned methods based on segmentation and edge detection. Finally, we demonstrate that explicit contour detection has benefits over pixel-wise methods when quantifying the models' prediction uncertainties. Published in TGRS journal [10].

Dwelling mapping through unsupervised domain adaptation instance segmentation Dwelling information is essential for humanitarian emergency response during or in the aftermath of disasters, especially in temporary settlement areas hosting forcibly displaced people. To map dwellings, the integration of very high-resolution remotely sensed imagery in computer vision models plays a key role. However, state-of-the-art deep learning models have two known downsides: (1) lack of generalization across space and time under changing scenes and object characteristics, and (2) extensive demand for annotated samples for training and validation. Both could pose a critical challenge during an emergency. To bypass this problem, we proposed the use of unsupervised domain adaptation for instance segmentation using a single-stage instance segmentation model, namely segmenting objects by location (SOLO). The goal is to adapt a SOLO model trained on a labelled source domain to detect dwellings in an unlabelled target domain. In this context, we study three domain adaptation techniques based on adversarial learning, domain discrepancy, and domain alignment mapping. We also propose domain similarity at different levels to understand its implication on domain adaptation. Analysis results show that in most source-target combinations unsupervised domain adaptation improves the performance by a large margin even surpassing a model trained with supervised learning. From the in-depth analysis of domain similarity at the image, object, and deep feature space levels, the former is more correlated with unsupervised domain adaptation performance. Published in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (JSTARS) [7].

Regression with limited training samples This study aims at recovering aboveground biomass information from ultra-high resolution UAV RGB-NIR orthophotos. We focus on a realistic scenario where a limited number of training samples for a landscape with heterogeneous herbaceous vegetation is given. Consequently, we explore different machine learning methods explicitly addressing the limitations of small training samples and compare their predictions quantitatively and qualitatively. Our results show that random forest models perform similarly well to deep learning models. While simpler machine learning models may, therefore, still be preferable, our study also points the way to promising architectures and regularisation techniques for deep learning approaches. Beyond vegetation cover, accurate regression of other variables, including vegetation height, volume and biomass remains a difficult task regardless of the model choice. Published as an IGARSS paper [32]. Beyond the previous regression task, we have pursued our more general study on the challenges raised by UAV ultra-high resolution imagery (millimetric scale) when designing novel deep learning models for ecology. A multi-team paper has been presented at VGC [25].

3.4 Hierarchical Models for Efficient Analysis of EO Data

Participants: Laetitia Chapel, Manal Hamzaoui, Sébastien Lefèvre, Minh-Tan Pham, Charlotte Pelletier, Corentin Dufourg, Thomas Corpetti.

The group has brought numerous contributions in mathematical morphology, especially on tree-based representations from which efficient algorithms can be derived. More recently, the research has focused on learning from these representations. This research axis is mainly supported through ANR MULTISCALE.

Learning with hierarchies Recently, in the computer vision and machine learning (ML) communities, a growing interest has been directed to similarity measures operating in hyperbolic spaces due to the geometric properties of these spaces which make them very suitable for embedding data with an underlying hierarchy. These hyperbolic spaces, although increasingly adopted, have received limited attention in the remote sensing community despite the hierarchical nature of RS data. The objective is therefore to examine the relevance of hyperbolic embeddings of remote sensing data, in particular when addressing the few-shot remote sensing scene classification problem. We adopt hyperbolic prototypical networks as a meta-learning approach to embed scene images along with a feature clipping technique to ensure a more numerically steady model. We then examine whether hyperbolic embeddings provide a better representation than Euclidean representations and better reflect the underlying structure of scene classes. We also studied the relevance of the hyperbolic spaces in the context of Variational Auto-Encoders for efficient remote sensing embeddings. Published in Pattern Recognition Letters [9] and in the IGARSS conference [31].

Learning with spatio-temporal graphs New satellite constellations allow the acquisition of high temporal and spatial resolution images at any point on the Earth. These data, assembled in the form of satellite image time series (SITS), are an important source of information for monitoring the evolution of the Earth's surface. Deep learning is one of the most promising solutions for the automatic analysis of large volumes of data acquired by new generations of satellites. However, these techniques often only exploit temporal or spatial structures. To take advantage of the temporal and spatial complementarity of the data without computational burden, we use graph-based modeling in combination with deep learning. In particular, we compare five graph neural networks applied to SITS. The results confirm the efficiency of graph models in understanding the spatio-temporal context of regions, which might lead to a better classification compared to attribute-based methods. Published at ORASIS [26] and IEEE International Geoscience and Remote Sensing Symposium (IGARSS) [27].

Classification of 3D points clouds with multi-scale features Three-dimensional data have become increasingly present in earth observation over the last decades. However, many 3D surveys are still underexploited due to the lack of accessible and explainable automatic classification methods, for example, new topo-bathymetric lidar data. We have introduced explainable machine learning for 3D data classification using Multiple Attributes, Scales, and Clouds under 3DMASC, a new workflow. This workflow introduces multi-cloud classification through dual-cloud features, encrypting local spectral and geometrical ratios and differences. 3DMASC uses classical multi-scale descriptors adapted to all types of 3D point clouds and new ones based on their spatial variations. We presented the performances of 3DMASC for multi-class classification of topo-bathymetric lidar data in coastal and fluvial environments. We showed how multivariate and embedded feature selection allows the building of optimized predictor sets of reduced complexity, and we identified features particularly relevant for coastal and riverine scene descriptions. Our results showed the importance of dual-cloud features, lidar return-based attributes averaged over specific scales, and of statistics of dimensionality-based and spectral features. Additionally, they indicated that small to medium spherical neighbourhood diameters (<7 m) are sufficient to build effective classifiers, namely when combined with distance-to-ground or distance-to-water-surface features. Without using optional RGB information, and with a maximum of 37 descriptors, we obtain classification accuracies between 91% for complex multi-class tasks and 98 % for lower-level processing using models trained on less than 2000 samples per class. Comparisons with classical point cloud classification methods showed that 3DMASC features have a significantly improved descriptive power. Our contributions have been made available through a plugin in the CloudCompare software, allowing non-specialist users to create classifiers for any type of 3D data characterized by 1 or 2 point clouds (airborne or terrestrial lidar, structure from motion), and two publicly available labelled topo-bathymetric lidar datasets. This work [48] has been submitted to ISPRS Journal of Photogrammetry and Remote Sensing (and published in 2024).

4 Software development

4.1 Software development

In compliance with ACM requirements, most of our research code is being made available through `http://github.io/myrepository` for reproducibility purposes.

In addition, the team contributed to the following pieces of software.

4.1.1 POT

Participants: Nicolas Courty, Laetitia Chapel, Romain Tavenard, Kilian Fatras, Huy Tran.

POT *is an open source Python library that provides several solvers for optimization problems related to Optimal Transport for signal, image processing and machine learning. It has more than 1M downloads (as of January 2024) and 2100+ stars on github. In 2021, we have received a support from CNRS to develop this software in the context of the national AI plan, with two engineers working part time on the development of the toolbox. We have also published a paper on it in JMLR Software.*

Website and documentation: `https://PythonOT.github.io/`

Source Code (MIT): `https://github.com/PythonOT/POT`

4.1.2 tslearn

Participants: Romain Tavenard.

tslearn *is a general-purpose Python machine learning library for time series that offers tools for pre-processing and feature extraction as well as dedicated models for clustering, classification and regression. It follows* **scikit-learn***'s Application Programming Interface for transformers and estimators, allowing the use of standard pipelines and model selection tools on top of* **tslearn**

objects. It is distributed under the BSD-2-Clause license, and its source code is available at `https://github.com/tslearn-team/tslearn`*.*

4.1.3 Triskele

Participants: François Merciol, Charles Deltel, Luke Abougit.

TRISKELE *stands for Tree Representations of Images for Scalable Knowledge Extraction and Learning for Earth observation. Triskele is an open source C++ library that provides several algorithms for building hierarchical representation of remote sensing images. It also includes usefull fonctionnalities to produce sobel or NDVI layers and Pantex index as well. (CeCILL-B licence) Source Code (IRISA):* `https://gitlab.inria.fr/obelix/triskele/`

4.1.4 Broceliande

Participants: François Merciol, Charles Deltel.

Broceliande *is a software for classification of remote sensing images. It uses TRISKELE and Random Forests. This software is used in industrial environnements to produce land cover mapping drive by EU projects. (CeCILL-B licence). Source Code (IRISA):* `https://gitlab.inria.fr/obelix/broceliande/`

4.1.5 Korrigan

Participants: François Merciol, Charles Deltel.

`Korrigan` *is a software to search patches in remote sensing databases based on Pattern Spectra. The goal is to offer data mining on big remote sensing image data bases. (CeCILL-B licence)*

Source Code (IRISA): `https://gitlab.inria.fr/obelix/korrigan/`

5 Contracts and collaborations

5.1 International Initiatives

5.1.1 MULTISCALE - PCRI 2019-2023

Participants: Laetitia Chapel, Sébastien Lefèvre, Thomas Corpetti, Minh-Tan Pham, François Merciol.

- Project type: ANR PRCI Tubitak
- Dates: 2019–2023
- PI institution: UBS
- Other partners: Costel Rennes 2, Gebze technical Univ., Istanbul technical univ.

- Principal investigator: Laetitia Chapel

- web: https://people.irisa.fr/Laetitia.Chapel/multiscale/

MULTISCALE is a research project that aims at providing a complete and integrated framework for multiscale image analysis and learning with hierarchical representations of complex remote sensing images. While hierarchical representations of RS images has led to an effective and efficient scheme to deal with panchromatic or at most multiband data, their application to complex data is still to be explored. In addition, despite their ability to encode structural and multiscale information, their so far exploitation have not reached beyond a mere superposition of monoscale analysis. In this context, the MULTISCALE project defines new methods for the construction of hierarchical image representations from multivariate, multi-source, multi-resolution and multi-temporal data, and provides some dedicated image analysis and machine learning tools to perform multiscale analysis. The new methodology will be implemented in various toolboxes used by the community to favor the dissemination of the results. Success of the project will be assessed by benchmarking the proposed framework on two remote sensing applications. Substantial breakthroughs over classical methods are expected, both in terms of efficiency and effectiveness.

5.1.2 ASI - NSF 2023

Participants: Charlotte Pelletier, Sébastien Lefèvre.

- Project type: NSF Advanced Studies Institutes
- Dates: 2019–2023
- PI institution: Boston University
- Other partners: University of Alaska Fairbanks, Northern Arizona University, Laboratoire Geo-Océan at UBS

The Advanced Studies Institutes (ASI) program for U.S. graduate students is supported by National Science Foundation (NSF) and provides students with the opportunity to engage with global experts in coastal zone hazard research. Each year a cohort of 14 U.S. graduate students will participate in a two-week summer program to be held in one of the three participating research centers abroad, i.e., University of South Brittany in France (2023), Tohoku University in Japan (2024), and University of Diponegoro in Indonesia (2025). The program is jointly run with foreign site collaborators and U.S. collaborators at Boston University, Northern Arizona University, and University of Alaska Fairbanks. Selected graduate students will participate in pre-travel virtual orientation, on site orientation, two weeks of hands-on classroom, laboratory, and field training, and cultural enrichment activities in the respective ASI sites. The training program will culminate with post-program follow-up activities.

5.2 National Initiatives

5.2.1 SESURE - SEntinel time series SUper REsolution

Participants: Charlotte Pelletier (project coleader).

- Project type: CNRS GdR ISIS - Projet exploratoire
- Dates: 2021–2023
- PI institution: IRISA
- Other partners: Nicolas Audebert (Cnam)

The SEntinel time series SUper REsolution (SESURE) project is interested in developing super-resolution approaches for satellite image sequences that make the most of the temporal structure of the data. By exploiting deep learning on the mass of Sentinel-2 data acquired in France since 2015, SESURE will make it possible to infer a subpixel structure of pixels in different colours. Unlike methods of the current state of the art, which is often limited to evaluations on synthetic data, the project will rely on SPOT-6 and -7 open data as a reference for high-resolution images and Sentinel-2 for low-resolution image series. SESURE aims to quantify the informational gap between Sentinel-2 time series and very high-resolution RGB SPOT acquisitions. In particular, we will study the existence of transformations, reversible or not, allowing to pass from one modality to another, and thus to solve the frequency-resolution dilemma currently faced by the computer vision community in remote sensing.

5.2.2 ANR JCJC DeepChange

Participants: Charlotte Pelletier.

- Project type: ANR JCJC
- Dates: 2021–2025
- PI institution: CESBIO
- Other partners: Silvia Valero (CESBIO)

Accurate and up-to-date land cover information constitutes key environmental data for developing efficient policies in this era of resource scarcity and climate change. New Satellite Image Times Series offer new opportunities for detecting land cover class transitions. Nevertheless, the challenges of the "Big Data" have become imminent for the exploitation of this massive flow of data. Deep generative models are one of the most promising tools for big data analysis. The use of such models has just started to emerge in the remote sensing. In this project, Generative Adversarial Networks and Variational Autoencoders want to be explored to face common remote sensing challenges, which are the lack of reference data and the exploitation of complex and heterogeneous information. The originality of the project relies on the development of new online change detection methodologies by using generative models, which incorporate the temporal information within the model.

5.2.3 ANR JCJC MAGE

Participants: Charlotte Pelletier.

- Project type: ANR JCJC
- Dates: 2022–2026
- PI institution: Cnam
- Other partners: Nicolas Audebert (Cnam, IGN)

Mapping Aerial imagery with Game Engine data (MAGE) aims to leverage procedural generation and modern rendering engines to generate labeled synthetic data for deep Earth Observation models. It investigates the following questions: how can we generate synthetic data of cities, before and after a natural disaster? How can make the simulated images look more realistic? How to train deep models on a mix of real unlabeled data and simulated labeled images?

5.2.4 DynaLearn - Labex CominLabs 2020-2023

Participants: Nicolas Courty (project leader), Clément Bonet, Diego di Carlo, Thomas Corpetti.

- Project type: Labex CominLabs
- Dates: 2020–2023
- PI institution: UBS
- Other partners: IMT Bretagne, LMBA
- Principal investigator: Nicolas Courty, François Rousseau (IMT)
- web: https://project.inria.fr/dynalearn/

Neural networks are powerful objects used in machine learning, but poorly understood from a theoretical point of view. A recent line of research consist in studying the flow of information through or in these networks through the lens of dynamical systems and their associated Physics. The Dynalearn project aims at contributing on those aspects in a two-fold way:

- By exploring how dynamical formulation of learning process can help in understanding better learning deep neural architectures, as well as proposing new learning paradigms based on the regularization of the flows of information;
- By leveraging on novel neural architectures and available data to devise new data-driven dynamical simulation models, with applications in Earth Observation and Medical Imaging.

5.2.5 MATS - ANR/JCJC 2019-2023

Participants: Romain Tavenard (leader), Laetitia Chapel, Thomas Corpetti, Nicolas Courty, Chloé Friguet.

- Project type: ANR JCJC
- Dates: 2019–2024
- PI institution: Univ Rennes 2
- Principal investigator: Romain Tavenard
- web: http://rtavenar.github.io/research/projects/mats.html

A huge trend in recent earth observation missions is to target high temporal and spatial resolutions (e.g. SENTINEL-2 mission by ESA). Data resulting from these missions can then be used for fine-grained studies in many applications. In this project we will focus on three key environmental issues: agricultural practices and their impact, forest preservation and air quality monitoring. Based on identified key requirements for these application settings, MATS project will feature a complete rethinking of the literature in machine learning for time series, with a focus on large-scale methods that could operate even when little supervised information is available. In more details, MATS will introduce new paradigms in large-scale time series classification, spatio-temporal modeling and weakly supervised approaches for time series. Proposed methods will cover a wide range of machine learning problems including domain adaptation, clustering, metric learning and (semi-)supervised classification, for which dedicated methodology is lacking when time series data is at stake. Methods developed in the project will be made available to the scientific community as well as to practitioners through an open-source toolbox in order to help dissemination to a wide range of application areas. Moreover, the application settings considered in the project will be used to showcase benefits offered by methodologies developed in MATS in terms of time series analysis.

5.2.6 OTTOPIA - ANR Chair on AI 2021-2025

Participants: Nicolas Courty (project leader), Chloé Friguet, Minh-Tan Pham, Charlotte Pelletier, Huy Tran, Paul Berg, Renan Bernard.

- Project type: ANR Chair on AI
- Dates: 2021–2025
- PI institution: UBS
- Other partners: CNES, PicTerra, Wipsea, Ecole Polytechnique, EPFL
- Principal investigator: Nicolas Courty

Earth Observation, whether it be by satellites, airborne captors or drones, allows a better understanding of the dynamics of environmental systems or our human society. It is a decisive tool to measure the impact of mankind on earth. In the last 50 years, the fast development of spatial missions and of the technology of the associated captors yields an unprecedented amount of data, largely under-exploited. Artificial intelligence can become a major help toward exploiting this wealth of information, by automatizing tasks cantoned to human operators, or even combining them to produce novel knowledge. Yet, the earth observation data come with specific challenges not only related to their volume but also their complexity. The OTTOPIA Chair project proposes to tackle some of them through the prism of Optimal Transport theory applied to machine learning. This mathematical tool makes it possible to apprehend the data through their distributions, and no longer as a sum of distinct individuals. Following significant advances in computational aspects, it has recently emerged as a tool of choice for multiple learning problems. We propose to exploit its principles on four challenges: 1. multi-modality and considering the heterogeneity of the data at transfer of learning, 2. Learning with few data, possibly corrupted by label noise, 3. Security of AI algorithms in Earth observation; and 4. Visual Question Answering, i.e. interacting with remote sensing data through natural language questions. The contributions of the Chair will naturally aim at fundamental developments in AI but also new applied methodologies for which a strong industrial transfer potential is envisaged.

5.2.7 OWFSOMM - ANR/FEM 2020-2023

Participants: Sébastien Lefèvre (scientific cochair), Minh-Tan Pham.

- Project type: PIA (CORED MRE-ITE 2019)
- Dates: 2019–2023
- PI institution: UBS
- Other partners: FEM, OFB, CEFE, Pelagis, WIPSEA, EDF Renewables, ENGIE Green, EOLFI, RWE Renewables, Ifremer
- Principal investigators: Georges Safi (FEM), Sébastien Lefèvre, Aurélien Besnard (CEFE / CNRS)
- web: www.france-energies-marines.org/projets/owfsomm

The project OWFSOMM (Offshore Wind Farm Surveys Of Marine Megafauna: standardization of tools and methods for monitoring at OWF scales) aims to provide, (i) a method for conducting a robust inter-calibration of surveys at sea from mobile platforms using historical and novel technologies and, (ii) an AI suite to optimize the use of multiple sensors in order to improve their efficiency in detecting, identifying and characterizing marine megafauna.

5.2.8 SEMMACAPE - ADEME 2019-2023

Participants: Sébastien Lefèvre (project leader), Minh-Tan Pham, Hugo Gangloff (Postdoc).

- Project type: ADEME (Appel projet "Energies durables")
- Dates: 2019–2022 (extended to May 2023)
- PI institution: UBS
- Other partners: France Energies Marines (FEM, Brest), Office Francais de la Biodiversité (OFB, Brest), WIPSEA (Rennes), IFREMER (Sète)
- Principal investigator: Sébastien Lefèvre
- web: http://semmacape.irisa.fr/

The analysis of the development impacts of a Marine renewable energies project generally requires aerial observations of marine megafauna (marine mammals and birds) to better characterize the species that frequent these sites. The Semmacape project aims to demonstrate the relevance of software solutions for processing and analyzing aerial photographs to ensure the automated census of marine megafauna. The importance of such monitoring has been reinforced by the need for impact studies, which are required for any wind power project subject to environmental authorization. Computer vision has undergone a recent upheaval with "deep learning" in the form of deep convolutional networks. The application of these networks to aerial images for the automated observation of marine megafauna is promising, but adaptations of existing algorithms are to be expected. In particular, these animals evolve in a context (sea) characterized by a highly variable visual content, which is detrimental to the performance of these deep networks. The Semmacape project aims to respond to these scientific obstacles in order to provide a technological leap forward in the field of aerial census of marine megafauna and its application to the environmental monitoring of offshore wind farms. The main gain will lie in the completeness of the observations, while minimising the risk of identification errors and allowing a reduction in analysis time.

5.2.9 6P - ANR/PRCE 2019-2023

Participants: Sébastien Lefèvre (WP leader), Thomas Corpetti, Javiera Castillo-Navarro (postdoc).

- Project type: ANR PRCE
- Dates: 2019–2023 (extended to June 2024)
- PI institution: G&E (Bordeaux)
- Other partners: EPOC (Bordeaux), ISPA (Bordeaux), BRGM (Orléans), Avion Jaune (Montpellier)

- Principal investigator: Florian Delerue, G&E Lab., ENSEGID, Bordeaux

SixP aims: i) to characterize the variation of plant-plant interactions along gradients of metal phyto-availability, while explaining the specific role of metallicolous species in these interactions; ii) to better identify the effects of multiple stress factors on these interactions; iii) to specify the plant functional strategies at stake; and iv) to assess the effect of plant-plant interactions at the community scale. The project will be implemented in several mine tailings in the Pyrénées at different altitudes (in the montane zone, and at the subalpine-alpine zone). At each site, several areas will be specified from peripheral low-contaminated areas towards tailings centers corresponding to a gradient of metal phyto-availability. The first three research directions will then be addressed by experimentations manipulating species in interaction. As for the last direction, the combination of very high resolution airborne data (lidar, multispectral images) covering the studied areas with in situ observations in a deep learning framework will be used to map species distribution and their geomorphological position. Spatial patterns of the different interacting species (aggregation vs repulsion) will exhibit the effects of plant-plant interactions on the long-term.

5.2.10 ROMMEO - SAD 2022-2024

Participants: Minh-Tan Pham (PI), Hoang-An Le.

- Project type: SAD Région Bretagne 2021.
- Dates: 2022–2024
- PI institution: UBS
- Principal investigator: Minh-Tan Pham

The objective of the project ROMMEO (Robust multitask learning via mutual knowledge distillation for earth observation) is to perform and combine knowledge distillation with a multitask learning (MTL) framework applied to EO data. Our objective is to develop a robust and compact model which is able to simultaneously perform several tasks with high accuracy. First, such a model can be trained from different data sets without fully annotated labels for all task, which is relevant for remote sensing data with lack of data annotations. Then, knowledge distillation can be mutually performed in order to capture and share complementary features from each task-specific large model. The ROMMEO model is aimed to reach state of the art performance on certain EO tasks such as semantic segmentation, object detection and scene understanding. More importantly, it is expected to become a high-impact solution with low computational and environmental costs not only in remote sensing, but also in other research domains.

5.2.11 SargAlert - ANR 2023-2026

Participants: Luc Courtrai.

- Project type: ANR Conjoint SARGASSUM.
- Dates: 2023–2026
- Principal investigator: Audrey MINGHELLI, Université de Toulon
- Other partners: Laboratoire d'Informatique et Systèmes (LIS, Université de Toulon), Mediterranean Institute of Oceanology (MIO, Marseille),AERIS/ICARE Data and Service Center (Université de Lille), MARine Biodiversity, Exploitation and Conservation (Marbec, Montpellier), Meteo France, Université Fédérale (Rurale) du Pernanbouc (UFPE/UFRPE, Brésil)

Modeling and forecasting Sargassum strandings in the tropical Atlantic Ocean is essential for designing effective integrated risk management strategies in link with environmental, economic, health, regulatory and decision-making policies.The objectives of the SargAlert proposal are, first, to greatly enhance the performances of the detection, monitoring, and prediction of Sargassum strandings from satellite observations and second, to release operational alert bulletins of Sargassum strandings dedicated to end-users. For those purposes, methodologies based on modeling approaches (radiative transfer, ocean dynamics, artificial intelligence), in-situ measurements and remote sensing data analysis are proposed. A full data processing chain starting from satellite observations up to stranding modelling forecasts will be built.

5.3 Bilateral industry grants

- Nicolas Courty CIFRE PhD thesis of Bjöern Michele with Valeo.AI
- Sébastien Lefèvre, PhD thesis of Iris de Gélis cofunded by Magellium and CNES

5.4 Collaborations

- LITIS (Université de Rouen Normandie, Université du Havre Normandie and INSA Rouen Normandie), through a collaboration (supervision of the Phd of Guillaume Mahey) with Gilles Gasso.
- Z_GIS (Paris Lodron University of Salzburg), through numerous joint MSc supervisions (EMJM CDE), joint work with Gella Getachew (visiting PhD student)
- TU Munich / DLR, through a joint work between Sébastien Lefèvreand Konrad Heidler (PhD student) and his supervisors (including Prof. XiaoXiang Zhu)
- UiT (Artic University of Norway, Tromsø) through the adjunct professorship position of Sébastien Lefèvrein UiT and his involvement in the KnowEarth project (funded by the Research Council of Norway)
- LGO and LETG Brest through the involvement of Sébastien Lefèvrein the supervision of a visiting PhD student (Zoé Bessin)

- Monash University (Australia), Faculty of Information Technology, with Geoffrey I. Webb (Professor in computer science) through the visit of Lynn Miller and the preparation of a review paper around satellite image time series analysis.
- Université Libre de Bruxelles (Belgium), with the visit of Taïs Grippa
- University of Campinas (UNICAMP), Brazil, with Gleyce Figueiredo and the co-supervision of Ana Paola Toro
- Luxembourg Institute of Science and Technology (LIST), through research collaboration on the topic of ship detection using remote sensing.

6 Dissemination

6.1 Promoting scientific activities

6.1.1 Scientific Events Organisation

General Chair, Scientific Chair

- Chloé Friguet: Scientific chair / Statlearn'23 (SFdS, Montpellier, april 2023)

Member of the Organizing Committees

- Thomas Corpetti, Minh-Tan Pham: MACLEAN'23: ECML-PKDD Workshop on Machine Learning for Earth Observation (MACLEAN'23)
- Chloé Friguet: Jeunes Probabilistes et Statisticien-ne-s (JPS'23, SMAI, Oléron, october 2023), Rencontres de Statistique (Univ. Bretagne Sud, november 2023)
- Charlotte Pelletier: Workshop EarthVision: large scale computer vision for remote sensing imagery at CVPR 2023
- Charlotte Pelletier: International Workshop on Temporal Analytics at PAKDD 2023

6.1.2 Scientific Events Selection

Member of Conference Program Committees

- Chloé Friguet: artificIAl intelligence and applied MAthematics for History and Archaeology (IAMAHA'23, Nice, november 2023)
- Sébastien Lefèvre: Big Data from Space (BiDS'23, Vienna, Austria, November 2023)
- Sébastien Lefèvre: Northern Lights Deep Learning Conference (NLDL'23, Tromsø, Norway, January 2023)

- Sébastien Lefèvre: Journées francophones des jeunes chercheurs en vision par ordinateur (ORASIS'23, Carqueiranne, May 2023)
- Charlotte Pelletier: Rencontres des Jeunes Chercheurs en Intelligence Artificielle (RJCIA)

Reviewer

- Nicolas Courty: ICLR, ICML, AISTATS, CAp, Gretsi
- Laetitia Chapel: ICLR, ICML, AISTATS, SSVM, CAp
- Chloé Friguet: JdS'23, IAMAHA'23
- Minh-Tan Pham: ICIP, Earthvision, MACLEAN
- Sébastien Lefèvre: IGARSS (student contest)
- Charlotte Pelletier: IEEE International Geoscience and Remote Sensing Symposium (IGARSS), ICLR Workshop machine Learning for Remote Sensing, Content-Based Multimedia Indexing (CBMI)

6.1.3 Journal

Member of the Editorial Boards

- Chloé Friguet: Associate Editor of Statistique et Société (Société Francaise de Statistique)
- Minh-Tan Pham: Member of Editorial Board of Digital Signal Processing, Elsevier

Reviewer - Reviewing Activities

- Nicolas Courty: IEEE T. PAMI and TGRS, ISPRS, JMIV, VISI,
- Laetitia Chapel: IEEE Transactions on Neural Networks and Learning Systems, Transactions on Machine Learning Research
- Chloé Friguet: Statistique et société
- Minh-Tan Pham: IEEE Transactions on Geoscience and Remote Sensing; IEEE Geoscience and Remote Sensing Magazines; MDPI Remote Sensing
- François Merciol: IEEE signal process, MDPI Remote Sensing, MDPI Water, MDPI Sensor, MDPI Imaging
- Sébastien Lefèvre: International Journal of Applied Earth Observation and Geoinformation

- Charlotte Pelletier: Machine Learning, Springer; Data Mining and Knowledge Discovery, Springer; IEEE Transactions on Geoscience and Remote Sensing; IEEE Geoscience and Remote Sensing Letters; Remote Sensing of Environment, Elsevier; ISPRS Journal of Photogrammetry and Remote Sensing, Elsevier; International Journal of Applied Earth Observations and Geoinformation, Elsevier; IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing

6.1.4 Invited Talks

- Laetitia Chapel: Invited talk at the Mathematics and Image Analysis conference at Berlin.

- Laetitia Chapel: Introductory course on Optimal Transport (9h) at the CNRS summer school "Geometry and Data" in Strasbourg.

- Laetitia Chapel: Invited talk given at the master students in statistics at Univ. Orsay.

- Laetitia Chapel: Keynote talk at the "optimal transport and machine learning" workshop at NeurIPS.

- Minh-Tan Pham: Invited talk, Weakly-supervised deep learning for marine animal detection from aerial images, Institut Francophone International (IFI), Vietnam National University (VNU), Online (August 2023)

- Sébastien Lefèvre: Invited talk, All we need is not (only) U-Net and YOLO but EO-driven deep learning research, Universität des Bundeswehr, Munich, Germany (May 2023)

- Sébastien Lefèvre: Invited talk, Deep learning in Computer Vision: Are Numerous Labels the Holy Grail? Brno University of Technology, Brno, Czech Republic (June 2023)

- Sébastien Lefèvre: Invited talk, 3D change detection, PIGMA Webinar, Online (October 2023)

- Charlotte Pelletier: Keynote at Machine Vision for Earth Observation and Environmental Monitoring Workshop (@BMVC) on Domain Adaptation for Satellite Image Time Series. (November 2023).

- Charlotte Pelletier: Invited talk on plenary symposium at Brazilian Symposium on Remote Sensing on Crop-type mapping from optical and radar time series using attention-based deep learning. (April 2023).

- Charlotte Pelletier Invited talk at Bristol doctoral school on Unsupervised domain adaptation for satellite image time series. (March 2023).

6.1.5 Leadership within the Scientific Community

6.1.6 Scientific Expertise

- Nicolas Courty: expert panel for the program 'Clusters of Excellence' in the field of Geosciences and Machine Learning for DFG, Deutschland (September 2023)
- Nicolas Courty: member of the *comité d'évaluation HCERES* for ISIR - Institut des Systèmes Intelligents et de Robotique (November 2023).
- Laetitia Chapel: member of the *comité d'évaluation scientifique* 23 (Intelligence Artificielle) of Agence Nationale de la Recherche.
- Minh-Tan Pham: expert *CIFRE* for ANRT
- Sébastien Lefèvre: expert panel on ICT for FWO, Belgium
- Sébastien Lefèvre: expert for the HORIZON-MSCA-PF 2023, EU
- Sébastien Lefèvre: expert for various bodies: ANRT (CIFRE), MESR (CIR), CEVL region at the national level; Belspo (Belgium), FNRS (Belgium), DFG (Germany), QNRF (Qatar), RIF (Cyprus) at the international level
- Charlotte Pelletier: chair of the working group on temporal geospatial data understanding of the International Society for Photogrammetry and Remote Sensing (ISPRS) (TCII/WG5)
- Charlotte Pelletier: co-chair of the technical committee 7 on remote sensing and mapping for the International Association of Pattern Recognition (IAPR) (TC7)

6.1.7 Research Administration

Scientific organisations

- Sébastien Lefèvre: member of the scientific board of AFRIF (French chapter of IAPR)
- Sébastien Lefèvre: adjunct professor at UiT, The Arctic University of Norway, Tromsø

Recruitment Committees

- Laetitia Chapel: member of a Recruitment Committee in Computer Science (Univ. Bretagne-Sud).
- Laetitia Chapel: member of a Recruitment Committee in IA (IMT Atlantique).
- Nicolas Courty: president of a Recruitment Committee in Computer Science (Sorbonne Paris Nord, Paris).

- Chloé Friguet: president of a Recruitment Committee in Statistics (associate professor) (Univ. Bretagne-Sud).
- Chloé Friguet: member of a Recruitment Committee in Mathematics (contract teacher) (Univ. Bretagne-Sud).
- Sébastien Lefèvre: chair of a Recruitment Committee in Computer Science - Full Professor (Univ. Paris Cité, Paris)
- Sébastien Lefèvre: member of a Recruitment Committee in Computer Science - Full Professor (CNAM, Paris)
- Sébastien Lefèvre: member of a Recruitment Committee in Computer Science - Associate Professor (ENSAT, Toulouse)
- Sébastien Lefèvre: chair of a Recruitment Committee in Computer Science - Contract Teacher (Univ. Bretagne Sud)
- Sébastien Lefèvre: chair of a Recruitment Committee in Computer Science - Contract Teacher (Univ. Bretagne Sud)
- Sébastien Lefèvre: member of a Recruitment Committee in Computer Science - Temporary Assistant Professor (Univ. Bretagne Sud)
- Charlotte Pelletier: member of a Recruitment Committee in Applied Mathematics - Associate Professor (UBS, Vannes)

6.2 Teaching, supervision

6.2.1 Teaching

For researchers, all activities are given. For professors and assistant professors, only courses at the M. Sc. level are listed.

- Laetitia Chapel
  - Master data science (Institut Agro Rennes-Angers): big data (24h)
- Charlotte Pelletier
  - Master in computer science and statistics engineering (Univ. Bretagne Sud): algorithmique des données (21h)
  - Master Copernicus in Digital Earth - geodata science specialization (Univ. Bretagne Sud): math and computer science refresher (6h), machine learning (12h), deep learning (18h), practical workshop (30 h)
- Nicolas Courty
  - machine learning, Deep learning in Master in Computer science and Statistics engineering, Univ. Bretagne Sud, Vannes France
  - Deep Learning and High-Performance computing, Copernicus Master in Digital Earth, Univ. Bretagne Sud, Vannes France

- Sébastien Lefèvre
  - Copernicus Master in Digital Earth - GeoData Science track, Univ. Bretagne Sud, Vannes France: computer vision (33h), data mining (12h), practical workshop (15h)
- Minh-Tan Pham
  - Computer vision, Copernicus Master in Digital Earth, Univ. Bretagne Sud, Vannes France (21h)
- François Merciol
  - Computer vision, Copernicus Master in Digital Earth, Univ. Bretagne Sud, Vannes France (6h)
- Romain Tavenard
  - Python programming (24h, MSc in Data Science, Univ. Rennes 2), NoSQL databases (24h, MSc in Data Science, Univ. Rennes 2), deep learning (20h, MSc in Data Science, Univ. Rennes 2 and EDHEC Business school, Lille), Machine Learning for Time Series (15h, MSc in Smart Data, ENSAI, Rennes)

6.2.2 Supervision

- PhD in progress:
  - **Renan Bernard**, Optimal transport and causality, 2022-thesis stopped in 2023, Nicolas Courty, Chloé Friguet and Valérie Garès (INSA Rennes, IRMAR)
  - **Jean-Christophe Burnel**, Deep Learning for Remote Sensing in Resource-Constrained Environment, 2020-2023, Sébastien Lefèvre, Laetitia Chapel
  - **Corentin Dufourg**, Learning and analysing spatio-temporal objects from satellite image time series, 2022-2025, Charlotte Pelletier, Sébastien Lefèvre
  - **Guillaume Mahey**, Unbalanced Optimal transport for out-of-sample detection, 2021-2024, Laetitia Chapel, Gilles Gasso (INSA Rouen)
  - **Huy Tran**, Comparison of incomparable spaces, 2021–2024, Nicolas Courty with Karim Lounici and Rémi Flamary (Ecole Polytechnique/CMAP)
  - **Paul Berg**, Robust representation learning from self-supervised distillation and domain adaptation in remote sensing, 2021-2024, Nicolas Courty, Minh-Tan Pham
  - **Rémi Cornillet**, Optimal Transport for tensor factorization, 2021-thesis stopped in 2023, Nicolas Courty and Jérémy Cohen, in the context of ANR JCJC LoRaIA.
  - **Bjöern Michele**, Domain Adaptation for Semantic Segmentation of point clouds, 2022-2025, Nicolas Courty and Valeo.AI (CIFRE contract)
  - **Matthieu Le Lain**, towards an astronomical foundation model, 2023-2026, Sébastien Lefèvre (fully-qualified teacher)
- PhD / HDR defended during the year

- PhD defense of **Iris de Gélis**, Deep learning for change detection from 3D point clouds, 2020-2023, Sébastien Lefèvre, Thomas Corpetti
- PhD defense of **Manal Hamzaoui**, From Euclidean to Hyperbolic Spaces: Rethinking Hierarchical Classification of Remote Sensing Scene Images, 2019-2023, Sébastien Lefèvre, Laetitia Chapel, Minh-Tan Pham, in the context of ANR Multiscale
- PhD defense of **Clément Bonet** (November 2023), Leveraging Optimal Transport via Projections on Subspaces for Machine Learning Applications, in the context of Labex Cominlabs Dynalearn project, with Nicolas Courty, Lucas Drumetz (IMTA) and Francois Septier (LMBA) as supervisors.

6.2.3 Juries

- Nicolas Courty: HDR jury member (*rapporteur*) of Loic Landrieu: 'Structured Learning of Geospatial Data', University Gustave Eiffel / IGN, May 2023
- Nicolas Courty: PhD jury member (*rapporteur*) of Mihailo Obrenović: 'Learning Domain Invariant Representations of Heterogeneous Image Data', University of Strasbourg, September 2023
- Nicolas Courty: PhD jury member (*rapporteur*) of Florentin Coeurdoux: 'Monte-Carlo Sampling and deep generative models for Bayesian Inference', INP Toulouse, November 2023
- Nicolas Courty: PhD jury member (*rapporteur*) of Ariel Kwiatkowski: 'Simulating Crowds with Reinforcement Learning', Ecole Polytechnique (Paris), November 2023
- Nicolas Courty: PhD jury member (*rapporteur*) of Raphael Baena: 'Beyond the training task in classification: looking at extensions of the notion of generalization', IMT Atlantique, December 2023
- Laetitia Chapel: PhD jury member (*examinateure*) of Ceédric Vincent-Cuaz: 'Transport Optimal pour l'apprentissage de représentations de graphes', Université Côte d'Azur, March 2023
- Laetitia Chapel: PhD jury member (*rapporteure*) of Skander Karkar: 'Unveiling the Transport Dynamics of Neural Networks: A Least Action Principle for Deep Learning', Sorbonne Univ., September 2023
- Laetitia Chapel: PhD jury member (*rapporteure*) of Antoine Salmona: 'Transport of probability distributions across different Euclidean spaces', Univ. Paris Saclay, November 2023
- Laetitia Chapel: PhD jury member (*examinateure*) of Arthur Lecert: 'Restauration d'images à faible luminosité à l'aide de méthodes d'apprentissage profond.', Univ. Rennes, December 2023

- Laetitia Chapel: PhD jury member (*rapporteure*) of Raphael Sturgis: 'Towards vessel behavior learning: taking into account geographical biases', Aix-Marseille Univ., 2023
- Sébastien Lefèvre: HDR jury member (*rapporteur*) of Gilles Le Chenadec, 'Combinaison de modèles de connaissances et de machine learning pour l'exploration de l'environnement sous-marin', ENSTA Bretagne (Brest), 2023
- Sébastien Lefèvre: PhD jury member (*rapporteur, président*) of Edward Jorge Yuri Cayllahua Cahuina, 'Algorithms for hierarchical graph-based image segmentation', University Gustave Eiffel (Paris) and Federal University of Minas Gerais (Brazil), 2023
- Sébastien Lefèvre: PhD jury member (*rapporteur*) of Laith Anwer Hasan Al-Shimaysawee, 'Automated Detection of Objects in Low Contrast and High Clutter Environments', University of South Australia (Sydney), 2023
- Sébastien Lefèvre: PhD jury member (*rapporteur*) of Martina Pastorino, 'Probabilistic graphical models and deep learning methods for remote sensing image analysis', University Côte d'Azur (Nice) and University of Genoa (Italy), 2023
- Sébastien Lefèvre: PhD jury member (*rapporteur*) of Quentin Ferdinand, 'Mitigating catastrophic forgetting via feature transfer and knowledge consolidation for deep class-incremental learning', ENSTA Bretagne (Brest), 2023
- Sébastien Lefèvre: PhD jury member (*rapporteur*) of Rollin Gimenez, 'Exploitation de données optiques multimodales pour la cartographie des espèces végétales suivant leur sensibilité aux impacts anthropiques', ISAE (Toulouse), 2023
- Sébastien Lefèvre: PhD jury member (*rapporteur*) of Victor Pellegrain, 'Exploitation de la Puissance des Donnés Multimodales et Textuelles dans l'Industrie 4.0', CentraleSupelec - University Paris Saclay (Paris), 2023
- Charlotte Pelletier: PhD jury member (*examinatrice*) of Romain Wengner: ' Apport des images Sentinel-1&2 et des méthodes l'apprentissage profond pour la cartographie et le suivi des modes d'occupation des sols', Université de Strasbourg, March 2023
- Charlotte Pelletier: PhD jury member (*examinatrice*) of Iris de Gelis: 'Deep learning for change detection in 3D point clouds', Université Bretagne Sud, April 2023
- Charlotte Pelletier: PhD jury member (*examinatrice*) of Pierre Nodet: 'Biquality Learning: from Weakly Supervised Learning to Distribution Shifts', Université Paris-Saclay, April 2023
- Charlotte Pelletier: PhD jury member (*rapporteur, Suisse*) of Mehmet Ozgur Turkoglu: 'Deep learning for vegetation classification from optical satellite image time series: machine learning and deep neural networks for point clouds and waveforms', ETH Zurich, June 2023

- Charlotte Pelletier: PhD jury member (*examinatrice*) of Mihailo Obrenović: 'Learning Domain Invariant Representations of Heterogeneous Image Data', University of Strasbourg, September 2023
- Charlotte Pelletier: PhD jury member (*examinatrice*) of Ngoc Long Nguyen: 'High-Definition from Above: Advancing Satellite Imagery Super-Resolution via Self-Supervision', ENS Paris-Saclay, October 2023
- Charlotte Pelletier: PhD jury member (*examinatrice*) of Mathilde Letard: 'Environmental knowledge extraction from topo-bathymetric lidar: machine learning and deep neural networks for point clouds and waveforms', Université de Rennes, December 2023

6.3 Popularization

- Nicolas Courty: Conference on Artificial Intelligence "Le Meilleur et le Pire", at centre culturel 'Les Arcs'. Attendance: 350 persons. (Queven, Lorient, October 2023)

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