Phd proposal
Data-driven and AI-guided multi-platform observing systems for poorly-resolved ocean processes

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Associated isblue theme: Theme 5 “Observing systems”

Abstract. Artificial Intelligence (AI) technologies, models and strategies open new paradigms to address poorly-resolved or poorly-observed processes **in ocean-atmosphere science** from the in-depth exploration of available observation and simulation big data. **This proposal aims to investigate such data-driven and AI-guided strategies for future ocean observing systems with a focus on context-aware and adaptive multi-platform systems.** From a methodological point of view, bridging the physical model-driven paradigm underlying ocean science and AI paradigms will at the core of this PhD with a view to developing geophysically-sound learning-based and data-driven representations of geophysical flows accounting for their key features (e.g., chaos, extremes, high-dimensionality). Such representations will then exploited for design and optimization of adaptive multi-platform observing systems. Using OSSE (Observing System Simulation Experiments), case-studies representative of multi-platform systems (e.g., synergies between different satellite sensors as well as satellite systems and in situ networks (e.g., ARGO floats)) will be considered to implement and evaluate the proposed methods and strategies.
The PhD candidate will benefit from the multidisciplinary expertise of the supervision team with proven expertise in Ocean Science, Ocean Remote Sensing, Fluid Dynamics, Artificial Intelligence and Control.

Keywords: Observing systems, space oceanography, in situ systems, data-driven methods, machine learning, dynamical systems, Adaptive observation

Scientific context and objectives

Understanding, modeling, forecasting and reconstructing fine-scale and large-scale processes and their interactions are among the key scientific challenges in ocean-atmosphere science. State-of-the-art approaches strongly rely on joint research effort in observing systems (e.g., in situ monitoring, satellite observations) and numerical simulations, especially ensemble simulation schemes [e.g., 6-7]. The ability to relate models and observation data, though significant advances in data assimilation, remain open questions for numerous processes (e.g., small-scale parameterization, ocean-atmosphere interactions, biogeochemical ocean dynamics, climate-scale dynamics) [e.g., 1-4]. Artificial Intelligence (AI) technologies, models and strategies open new paradigms to address these questions from the in-depth exploration of the existing observation and simulation big data [4,7-11].

The general goal of this project is to explore and develop these AI paradigms and their interactions with model-based approaches [5] for the design of future multi-platform adaptive ocean observing systems. It is widely acknowledged that no single-platform system may provide direct observations of all ocean processes and scales of interest. Sea surface winds, currents and waves are typical examples, for which for instance no in situ or space observing system can alone provide the direct observation of their dynamics at a synoptic scale even for the mesoscale range (i.e., up to horizontal scales of ~ten kilometers).

Synergies between different satellite sensors (e.g., scatterometers, SAR sensors, multi-spectral sensors), in situ networks (e.g., ARGO floats, buoys,...), airborne sensors (e.g., lidar sensors embedded on drones),... are clearly of interest. The rapid development of new embedded communication and processing capacities of such sensors further push for the design of **context-aware systems for the adaptive and optimized deployment of multi-platform observing systems** (e.g., acquisition or streaming of high-resolution satellite data conditionally to pre-analysis steps based on other observation/simulation data, adaptive routing of drone-based acquisitions based on synoptic observation and simulation data). **This PhD will investigate the data-driven and AI-guided methods and strategies that we envision to be the processing core of these new systems.**

Proposed approach

To address the general objective of the PhD, two specific methodological objectives will be considered:

- **The learning of geophysically-sound neural network representations of geophysical flows**: we aim to bridge model-driven formulations and learning-based representations [5,12-15]. Among the variety of machine learning frameworks, the focus will be given to neural networks, and more specifically to ResNet architectures. These computationaly-efficient and highly-flexible models can be regarded as neural-network-based implementation of numerical schemes of ODE/PDE (Ordinary and Partial Differential Equations). From a methodological point of view, the focus will be given to (i) learning and reconstruction issues when dealing with partial and noisy observations [e.g., 14,16], (ii) accounting for specific geophysical features of interest (e.g., chaotic patterns, occurrence of extremes,..).
- **The exploitation of neural network representations for the design and optimization of adaptive multi-platform strategies:** Based on the previously mentioned neural network representations, new learning-based strategies will be developed for the deployment of context-aware multi-platform observing systems. Reinforcement learning strategies are expected to be interest in this context.

For evaluation and demonstration purposes, case-studies representative of multi-platform systems (e.g., synergies between different satellite sensors as well as satellite systems and in situ networks (e.g., ARGO floats)) will be implemented. Two case-studies are envisioned: one case-study on upper ocean currents combining ARGO floats and satellite sensors (SKIM, SWOT, nadir altimeter data) and one case-study on extreme winds combining XXXX.

These case-studies will be implemented as Observing System Simulation Experiments (OSSE), which will make possible the simulation of adaptive observation strategies. Depending on work progress, real case-studies might be considered in collaboration with operational oceanography centers. In this context, the ongoing international collaboration with IMEDEA/SOCIB (OSTST project MANATEE) might be of key interest to explore synergies between satellite sensors and gliders within the fast-sampling phase of SWOT mission.

Contribution to ISBlue themes and Bretel themes

This project contributes to Isblue theme "Observing Systems" through the development of novel data-driven and AI-guided strategies for the design and optimization of multi-platform ocean observing systems for poorly-resolved processes. The considered case-studies on upper ocean dynamics are also of interest for Isblue theme "Ocean and Climate regulation".

This project also contributes to the objectives of GIS Bretel for the development of new observing systems of the ocean.

Through its contribution to Isblue and GIS Bretel, this project contributes to the regional scientific objectives (especially DIS7).

Supervision

This PhD proposal is a joint proposal between Lab-STICC/TOMS (R. Fablet, Prof. IMT Atlantique) and LOPS/SIAM (B. Chapron, Senior Scientist Ifremer), who have a proven collaboration experience. It will also benefit from the co-supervision, through mutual short-term visits, of Prof. S. Brunton, Univ. of Washington, who co-authored a pioneering work on the data-driven identification of governing equations of geophysical flows [12].

At the regional and national level, this PhD will be part of newly-launched LEFE initiative on artificial intelligence for Ocean, Atmosphere and Climate coordinated by R. Fablet. This initiative currently involves 9 research teams (LOPS, Lab-STICC, INRIA Rennes, LOCEAN, LATMOS, LIP6, IGE, INRIA Grenoble, CERFACS). It will provide a relevant platform for the scientific exchange and dissemination of the contributions expected from the PhD.

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