Spring 2024

4- to 6-month M2 internship in AI for Climate Sciences @LPENSL (Lyon)

Emulation of subglacial lake/ocean dynamics with machine learning

Supervisors : Julián Tachella (Chargé de Recherche, CNRS, LPENSL) & Louis-Alexandre Couston (Enseignant-Chercheur, UCBL, LPENSL)

Context. Subglacial lakes and oceans are key components of the Earth system[1,2]. They host unique ecosystems and interact with the seaward discharge of continental grounded ice, which drives sea-level rise. The dynamics of subglacial lakes and oceans are not represented in current climate models. The primary bottleneck is the computational cost of the (traditional) grid-based dynamical solvers that are required to capture their evolution. Their evolution is significantly different from the evolution of open oceans and lakes indeed, and thus specially dedicated solvers with high temporal and spatial resolution are required. Recently, new machine learning approaches (including deep learning methods) have demonstrated a good potential to capture the dynamics of physical systems, often with a significantly smaller computational cost than traditional solvers, promising a scalable alternative for complex climate simulations.

Goal. The overarching goal of the project is to design a machine learning algorithm that can emulate the dynamics of subglacial lakes and oceans simulated by computationally costly traditional grid-based models. The long-term objective is to present the climate community with an algorithm that can take as input the system state of a global climate model and output the response of the subglacial components over a prescribed time horizon in a small computational time.

Research environment. The student will be part of the physics laboratory at ENS Lyon, France. The student will benefit from a stimulating environment of experts in machine learning, signal processing and physics, with weekly machine learning and signal processing seminars given by international experts.

Required skills. The applicant should have a background in applied mathematics or computer science, and be part of a master degree in topics around machine learning, signal processing and/or optimization. They should be proficient in python programming and have some experience with machine learning libraries (e.g., scikit-learn, pytorch, etc.). Some knowledge in Earth System Science is considered beneficial but not required.

Proposed work. This M2 internship will focus on the design of a machine learning algorithm that can capture the temporal dynamics of a simplified model of subglacial lakes, investigated in detail by LA Couston using traditional grid-based solvers[3]. The model subglacial lake exhibits two different chaotic regimes depending on the ratio of two controlling parameters (see figure). The emulator will have to extrapolate the dynamics and bifurcations between the two regimes beyond the training horizon (prediction) satisfactorily, from a deterministic or (if impossible) statistical point of view. Two different approaches will be considered to construct the emulator: one based on statistical learning (PCA + SINDy[4], or equivalent), one based on deep learning (Fourier Neural Operators[5], or equivalent). In collaboration with the supervisors, the intern will: (i) design the learning algorithm, (ii) train the algorithm, and (iii) evaluate its prediction performance. We will pay particular attention to embedding geometrical symmetries into the ML algorithm[6]. The minimum success outcome (successful internship) will be to perform all steps using both approaches (statistical learning and deep learning) on one dataset (one set of control parameters for the physical system). Full success will be achieved if in addition a transfer learning methodology is identified and implemented to successfully generalize the algorithm to a second (or more) set of control parameters.

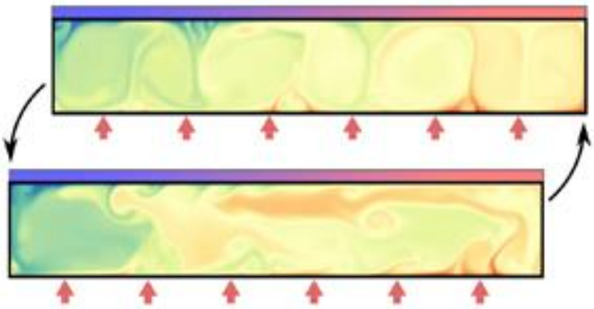

Figure 1: The dynamics of a subglacial lakes can change considerably over time, from a multiple roll state (top) to a single bursty anti-clockwise circulation (bottom). The goal of the internship is to build a machine learning algorithm that can capture these complex temporal and spatial dynamics.

How to apply. Applicants must provide a **short cover letter** describing their motivation for the internship and scientific interests (max 1 page), their **CV** and a **summary of grades** of their university studies. Potential applicants are invited to write Julián and Louis with any questions about the project at julian.tachella[…AT…]ens-lyon.fr and louis.couston[…AT…]ens-lyon.fr.

Fair and inclusive environment. We know diversity fosters creativity and innovation. We are committed to equality of opportunity, to being fair and inclusive, and to being a place where all belong. We therefore encourage applications from all candidates, including those who are likely to be underrepresented at LPENSL.

PhD thesis. This internship position provides a unique opportunity to acquire the knowledge and skills to continue—if the internship is successful—onto a PhD position that will be advertised in 2024 with a start date in fall 2024 or spring 2025. The PhD work will build on the internship results and address the same general questions. The PhD position will be funded by the IceAblation project, which is an ERC Starting Grant project led by Louis that will run from 2024 to 2029.

References.

1. Kennicutt, M. C. *et al.* Sustained Antarctic Research: A 21st Century Imperative. *One Earth* **1**, 95–113 (2019).
2. Livingstone, S. J. *et al.* Subglacial lakes and their changing role in a warming climate. *Nat. Rev. Earth \& Environ. 2022* 1–19 (2022) doi:10.1038/s43017-021-00246-9.
3. Couston, L.-A. Turbulent convection in subglacial lakes. *J. Fluid Mech.* **915**, 1–31 (2021).
4. Brunton, S. L., Proctor, J. L., Kutz, J. N. & Bialek, W. Discovering governing equations from data by sparse identification of nonlinear dynamical systems. *Proc. Natl. Acad. Sci. U. S. A.* **113**, 3932–3937 (2016).
5. Li, Z. *et al.* Fourier Neural Operator for Parametric Partial Differential Equations. *ICLR 2021 - 9th Int. Conf. Learn. Represent.* 1–16 (2021).
6. Chen, D. *et al.* Imaging With Equivariant Deep Learning: From unrolled network design to fully unsupervised learning. *IEEE Signal Process. Mag.* **40**, 134–147 (2023).

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