Master internship offer - year 2022

Simulation of the biogeochemical cycle in an urban lake: impact of external forcings on the ecosystem dynamics

Context

Lakes, both natural lakes and reservoirs, contain most of the freshwater available on Earth. Flows of nutrients and pollutants coming from human activities have a major impact on aquatic ecosystems. Water quality is deteriorating, biodiversity is declining and the ecosystem services provided by lakes (drinking water, fish resources, landscape, recreational activities ....) are affected. According to the European Environment Agency (EEA), only 40% of European surface water bodies had a good or high ecological status in 2018 (Kristensen et al. 2018). Thus the preservation of lake ecosystems, which is already a major challenge, will be even more crucial in the coming decades.

In France, the first water quality assessment system, set up in 1971, made it possible to define the intended use of a water body. In 2000, with the European Water Framework Directive (EU WFD), the objective is to reach a good ecological status for all European water bodies and to maintain it. To achieve this, regular measurement campaigns are carried out on all lakes with a surface area of more than 50 hectares: in France this represents about 500 water bodies which account for 65% of the total surface area of water bodies in Metropolitan France (see CarTHAge database http://www.sandre.eaufrance.fr).

In addition to anthropogenic pollution, lake ecosystems are subject to climate change. Several studies have highlighted the impact of global warming on lake thermal stratification and water temperature over the past few decades. Because the rate of change in water temperature is often greater than in air temperature, lakes can be considered as "sentinels" of climate change (Adrian et al. 2009).

The thermal regime of lakes is the most directly impacted, but it is not the only one. Strong modifications of the biogeochemical dynamics are also observed as highlighted by the increased occurrence and intensity of cyanobacterial blooms (potentially toxic). Although eutrophication, due to an excessive supply of nutrients, is partly responsible for these blooms, global warming is also involved. Cyanobacteria are favoured by warm water temperatures and low turbulence in the water column during more frequent or longer thermal stratification episodes. In addition, in certain hydro-climatic regions, climate change can induce more abundant rainfall, which can lead to an increase in the flow of nutrients from watersheds or groundwater.

In this context, it is therefore essential to understand and quantify the relative contributions of local anthropogenic activities and global changes in the inter-annual responses of lake ecosystems (water quality, biodiversity...). To do this, it is necessary to have a multi-year time-series of physico-chemical and biological in-situ measurements. However, the frequency of these measurements is often too low and the length of the time series too short to characterize the processes. Numerical modelling is therefore an interesting and even necessary tool when it comes to validating hypotheses of ecosystem functioning and making predictions based on this knowledge.

Objectives

The objective of this internship is to study the dynamics of a lake ecosystem by implementing a deterministic modelling approach describing the essential physico-bio-geochemical processes.

The proposed approach will be applied on the experimental lake of Champs-sur-Marne (Ile-de-France) where high-frequency measurements (meteorology, water temperature, water quality) are collected by the LEESU (Water, Environment and Urban Systems Laboratory, Ecole des Ponts ParisTech) since 2017. The modelling of the hydrodynamic and thermal regime of the water body will be done with the vertical one-dimensional model, GLM (General Lake Model), a reference model applied on many water bodies worldwide (e.g. Bruce et al., 2018). For the biogeochemical part, the model will be coupled to the open access AED (Aquatic Ecological Dynamics) library of biogeochemical processes.

The model will first be implemented, calibrated and compared with field data (from 2017 to 2021) before being used for a numerical exploration to determine the impact of some external forcings (meteorological in particular) on the ecosystem dynamics.

Work program

1. **Implementation of the GLM-AED model** on Lake Champs-sur-Marne with the configuration of the ecological part already set-up during previous works (Francesco Piccioni's Ph.D thesis, 2021) ;
2. **Calibration of model parameters** on the available data set from 2017 to 2021. One or more automatic calibration techniques will be tested and applied on the biological model to estimate the model parameters that will be identified as important by a sensitivity analysis. The targeted techniques are algorithms with meta-models such as the Efficient Global Optimization (EGO) method or other similar methods suitable for complex ecological models (Kandris et al., 2020).
3. **Numerical exploration to determine the impact of some external forcings on the dynamics of the ecosystem.** To do so, some climate variables (mean temperature, mean precipitation, or maximum temperature, etc.) will be varied and the system response will be analyzed. The methods used will be based on sensitivity analysis of model outputs; advanced methods combining sensitivity analysis and clustering (see for example (Roux et al 2021)) may also be considered.

References

Adrian, R., O'Reilly, C. M., Zagarese, H., Baines, S. B., Hessen, D. O., Keller, W., ... & Winder, M. (2009). Lakes as sentinels of climate change. Limnology and oceanography, 54(6part2), 2283-2297.

Bruce, L. C., Frassl, M. A., Arhonditsis, G. B., Gal, G., Hamilton, D. P., Hanson, P. C., ... & Hipsey, M. R. (2018). A multi-lake comparative analysis of the General Lake Model (GLM): Stress-testing across a global observatory network. Environmental Modelling & Software, 102, 274-291.

Kandris, K., Romas, E., & Tzimas, A. (2020). Benchmarking the efficiency of a metamodeling-enabled algorithm for the calibration of surface water quality models. Journal of Hydroinformatics, 22(6), 1718-1726.

Kristensen, P., Whalley, C., Zal, F. N. N., & Christiansen, T. (2018). European waters assessment of status and pressures 2018. EEA Report, (7/2018).

Piccioni, F., Casenave, C., Lemaire, B. J., Le Moigne, P., Dubois, P., & Vinçon-Leite, B. (2021). The thermal response of small and shallow lakes to climate change: new insights from 3D hindcast modelling. Earth System Dynamics, 12(2), 439-456.

Piccioni, F. (2021). Écosystèmes lacustres dans un contexte de changement climatique: stratégie de modélisation couplée hydrodynamique et biogéochimique. Thèse soutenue le 14 octobre 2021.

Piccioni, F., Casenave, C., Baragatti, M., Cloez, B., & Vinçon-Leite, B. Automated calibration of a complex aquatic ecological model through Approximate Bayesian Computation. Soumis à Environmental Modelling & Software 2021.

Roux, S., Buis, S., Lafolie, F., & Lamboni, M. (2021). Cluster-based GSA: Global sensitivity analysis of models with temporal or spatial outputs using clustering. Environmental Modelling & Software, 140, 105046.

Required skills

The applicant should be a master 2 student with skills and taste for modelling and numerical simulation. Knowledge in ecology-biogeochemistry would be a plus. A good level in programming is also required (R and/or python and/or matlab).

Terms of the internship

The student will be hosted at the UMR MISTEA (Mathematics, Informatics and Statistics for Environment and Agronomy), on the campus de la Gaillarde of Montpellier SupAgro - 2 place Pierre Viala, 34090 Montpellier. The internship will be supervised by Céline Casenave, INRAE researcher (National Institute for Agricultural, Food and Environmental Research) at the UMR MISTEA and by Brigitte Vinçon-Leite, researcher at LEESU-ENPC (Water, Environment and Urban Systems Laboratory, Ecole des Ponts ParisTech).
A visit to Lake Champs-sur-Marne will be organized during the internship.
The duration of the internship will be minimum 4 months up to 6 months and could start as early as February 2022 depending on the student's availability. The student will benefit from an internship grant as well as a reduced canteen rate.

Contact

Please send your application (curriculum vitae and motivation letter) to:

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