Modelling, Simulation and Prediction of lake ecosystem dynamics and Harmful Algal Blooms

CÉLINE CASENAVE[1,2]
MISTEA, Université de Montpellier, INRAE, Institut Agro, Montpellier, France
contact: celine.casenave@inrae.fr ; http://www.celinecasenave.fr

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).

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 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.

Objectives and Methods

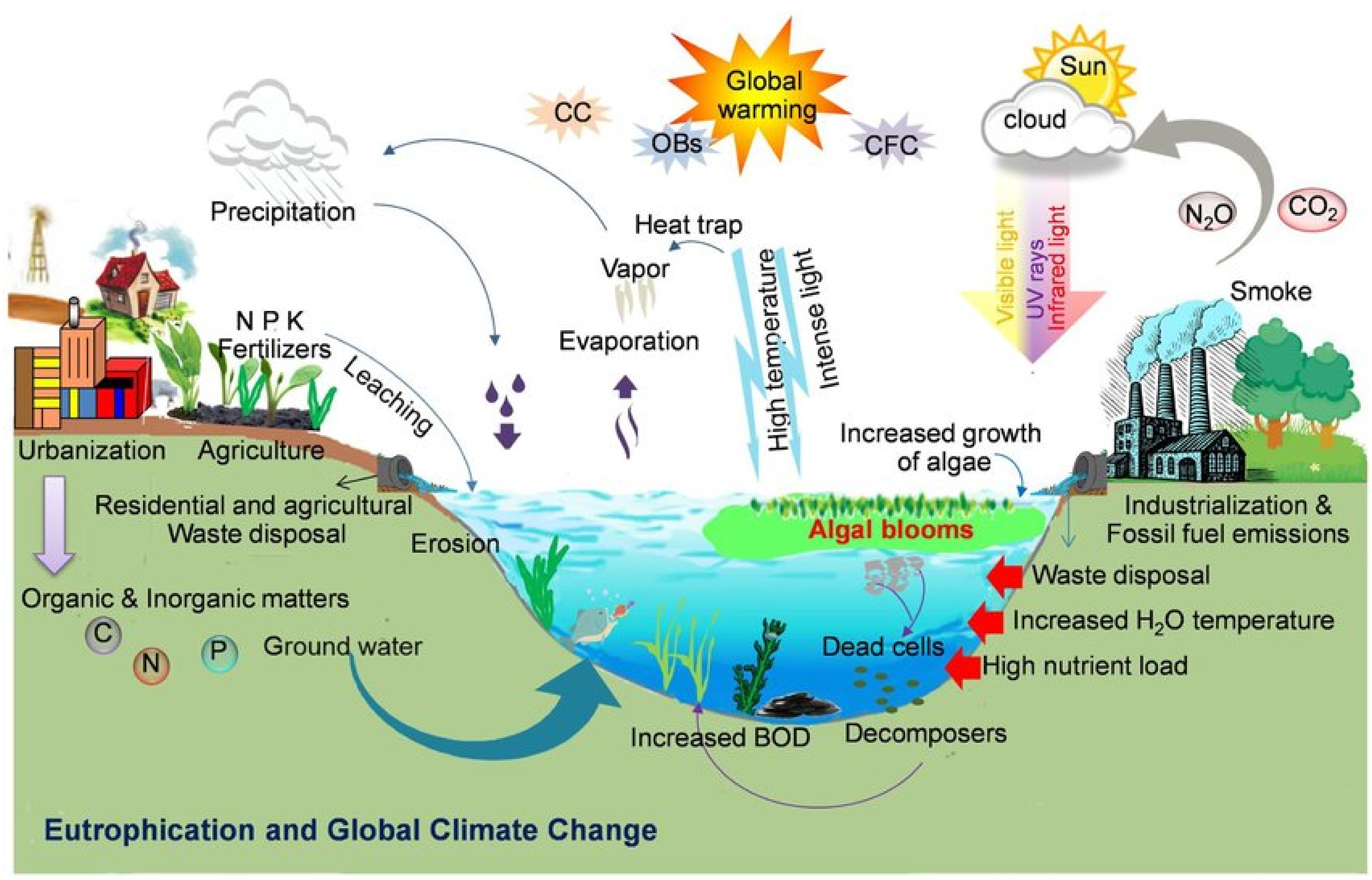
Objectives: develop tools for the management of lake ecosystems.
More precisely the objectives are:

- the **simulation of the lake ecosystem**, for a better understanding of the dynamics
- the **short-term prediction** (early warning system) of cyanobacterial blooms
- the **assesment of climate change impact** on the dynamics of lake ecosystem

Methods: use of **thermal-hydro-ecological models** (1D to 3D) which takes into account:

- the **hydrodynamics** of the Lake, that is the fluid dynamics;
- the **dynamics of the lake ecosystem**, especially of the cyanobacterial population.

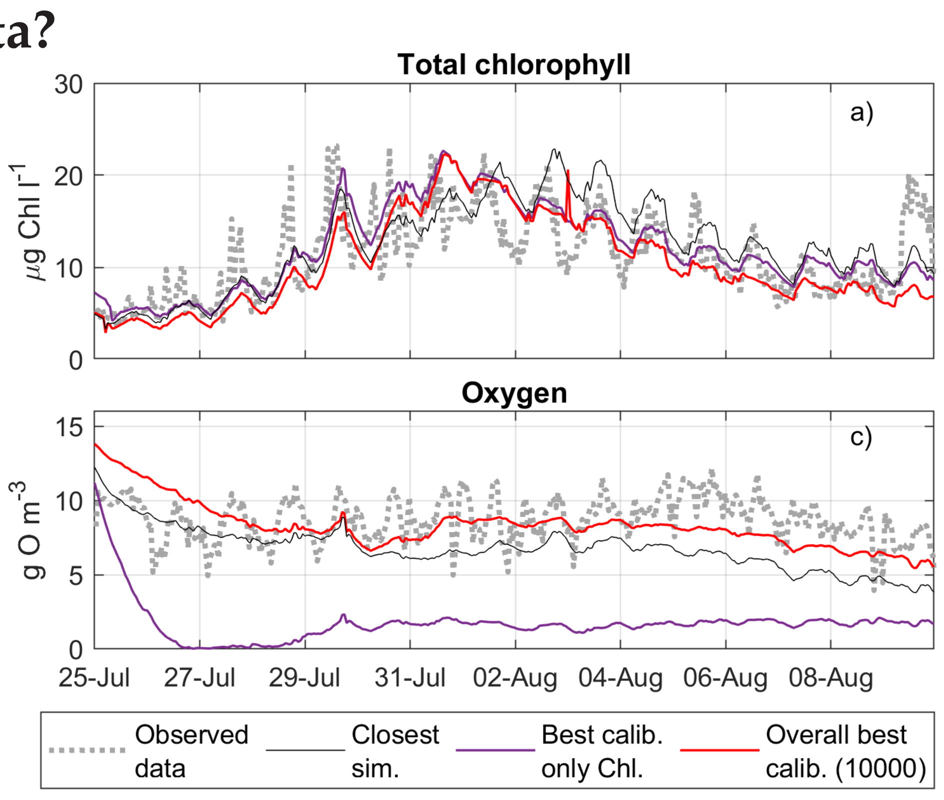
Key factors responsible for cyanobacterial blooms



(Illustration by R. P. Rastogi, taken from (Rastogi *et al* 2015)).

Model Calibration

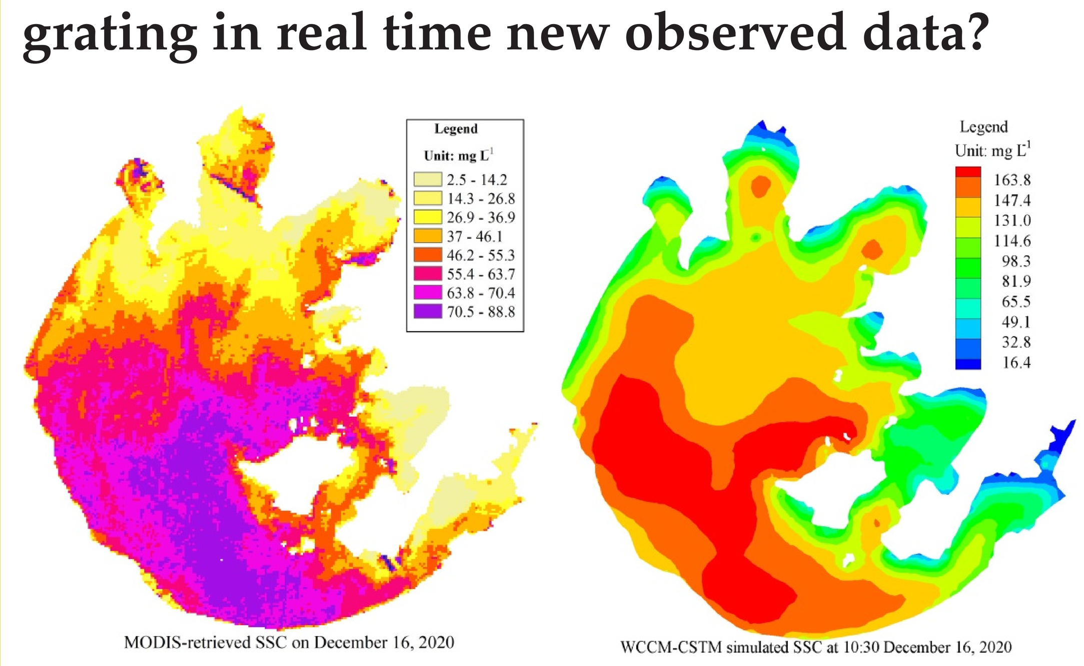
How can we determine the value of the model parameters that best reproduce the observed data?



Calibration with ABC-RF (Piccioni, et al. 2022)

Data assimilation

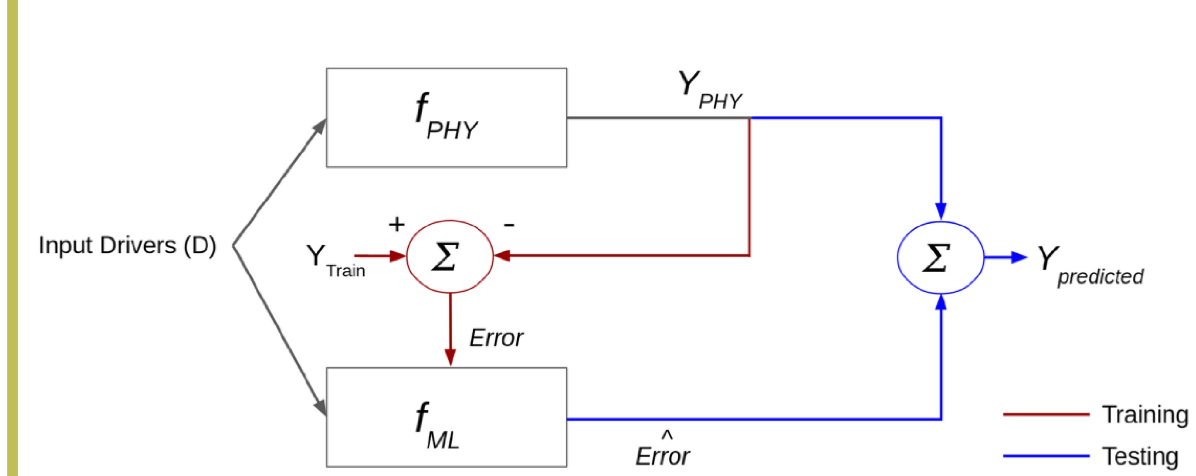
How can we improve model prediction by integrating in real time new observed data?



Satellite image (left) and model simulations (right). (Wu, et al. 2022)

Machine learning

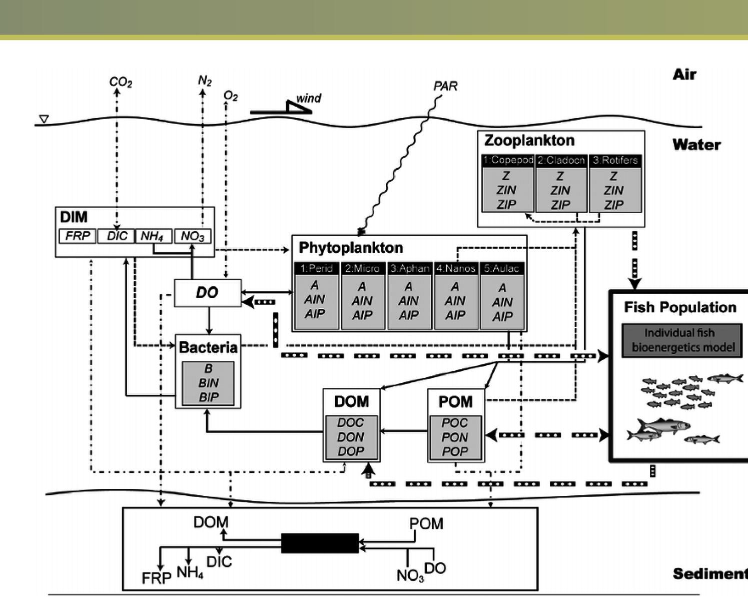
How can we combine knowledge based-model and machine learning to improve the quality of the predictions?

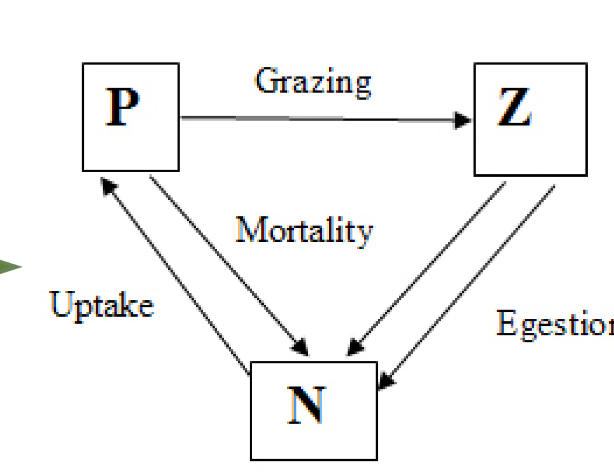


f_{ML}: machine learning model; f_{PHY}: physics-based model. (Willard*et al* 2022)

Model reduction

How can we reduce model complexity while preserving an interpretable model structure for climate-scale forecasting?





CAEDYM model (left); NPZ model (right).

References

[1] Piccioni, F. *et al.* (2022). *Calibration of a complex hydro-ecological model through Approximate Bayesian Computation and Random Forest combined with sensitivity analysis.*
[2] Willard, J. *et al.* (2022) *Integrating scientific knowledge with machine learning for engineering and environmental systems.*
[3] Baracchini, T. *et al.* (2020). *Data assimilation of in situ and satellite remote sensing data to 3D hydrodynamic lake models: a case study using Delft3D-FLOW v4. 03 and OpenDA v2. 4.*
[4] Snowden, T. J. *et al.* (2017). *Methods of model reduction for large-scale biological systems: a survey of current methods and trends.*