MODEL-DATA ASSIMILATION FRAMEWORK FOR HARMFUL ALGAL BLOOM (CYANOHAB) PREDICTION IN INLAND WATERS ON A CONTINENTAL SCALE

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Surface water quality in Australia is declining and recurring harmful algal blooms by toxic cyanobacteria species (CyanoHAB) are widespread. CyanoHABs impact ecosystem services, harming the health of water ecosystems and limiting recreational and cultural water uses. With current approaches, predicting and managing HABs require intensive local monitoring and data analysis for each waterbody. With thousands of reservoirs, wetlands and coastal lagoons scattered around Australia, only a few can be managed in this way. To address this, here we propose a model-data assimilation framework for algal bloom prediction at the continental scale, combining Earth Observation, in-lake monitoring, and coupled modelling frameworks to allow early detection and forecasting of CyanoHABs. The development of a national framework for prediction of harmful algal blooms will transform our ability to manage aquatic ecosystem health in data sparse environments. This project combines recent developments in inland water remote sensing of algal pigments, bio-optical (remote sensing) studies, and water quality models for algal blooms in lakes and reservoirs across Australia. Our initial study has focused on developing model components using Lake Burley Griffin, ACT, Australia as a case study.

1 INTRODUCTION

Harmful algal blooms in lakes and reservoirs caused by cyanobacteria (CyanoHABs) are an increasing thread in inland waters throughout the world. Cyanobacteria have the potential to produce different types of toxins impacting animal and also human health. While reports on death of cattle or dogs drinking from infested ponds are abundant, the short-term effect on humans is not that drastic. However, not much is known on long-term effects of constant exposure to cyanotoxins, e.g., there is a suspicion that neurotoxins produced by many cyanobacteria could support the development of motor neurone diseases. Drinking water reservoirs have to take into account such harmful algal blooms by changing routine water treatment to, e.g. reduce the concentration of dissolved cyanotoxins below safe levels. The most widespread effect of CyanoHABs is the direct exposure of humans to such water leading to skin irritation. Management of lakes and reservoirs usually restricts recreational activities during strong blooms of cyanobacteria.

Two major factors increasing the occurrence of CyanoHABs are rising temperature and nutrient levels. While a temperature increase is directly coupled to global climate change – blooms like it hot [1], an increase in nutrient levels is caused by, e.g., agricultural activities, changes in land-use, or storm water inflow. Other factors increasing cyanobacteria abundance are the mixing behavior of the lake waters due to the interplay of wind and heat flux, or increasing light exposure [2]. Furthermore, the underwater light field depends on the absorption characteristics of dissolved and particulate matter in the water column.

Continuous monitoring of cyanobacteria abundance by water sampling is the usual method to get information on the formation of blooms in a water body. Since the growth depends on a variety of factors, concentration can widely vary in different parts of a lake, e.g. due to wind shielding in bays, rapid daily warming of shallow regions, etc. A more general – in terms of local scale – measurement of light properties in a lake, chlorophyll and cyanobacteria pigment concentration as measures of abundance and type of cyanobacteria, or surface temperature, to name some variables, can be achieved using remote sensing.
The combination of Earth observation data, field sampling, and laboratory studies with coupled hydrodynamic, biogeochemical and bio-optical modelling is thus the way to get a detailed picture of past and future development of algal blooms, specifically CyanoHABs in inland waters. The long-term aim is to develop and install a framework for prediction of harmful algal blooms on a continental scale – here Australia, giving us the capability to predict their occurrence on a large scale based on satellite data, land-use information, streamflow, etc. allowing for land use and climate change impact studies. In the following, a brief description of a modelling framework for the prediction of harmful algal blooms is given.

2 MODEL FRAMEWORK

To predict cyanobacterial blooms one needs the combined knowledge of internal lake dynamics, catchment processes, regional climatic conditions and a spatial and temporal highly resolved set of data. Furthermore, the physiology of the different cyanobacteria species occurring in a lake needs to be known. Using hydrodynamic lake models driven by meteorological fields like wind, air temperature, irradiation, the physical processes in a lake can be described. Coupled with a biogeochemical model which describes nutrient cycling in the lake and the development of algal species, and a bio-optical model to determine the underwater light climate, this then gives a modelling suite to hindcast and predict CyanoHABS (Figure 1). To calibrate and validate simulation output from this model framework, large data sets on cyanobacteria, nutrients, physical variables, etc. in a lake are necessary. For some lakes such datasets exist. However, the majority of lakes and reservoirs are data-poor. This might be due to insufficient on-lake sampling strategies, or due to their remoteness. Remote sensing can be used for systematic water quality monitoring and supply data for such model calibration and validation [3].

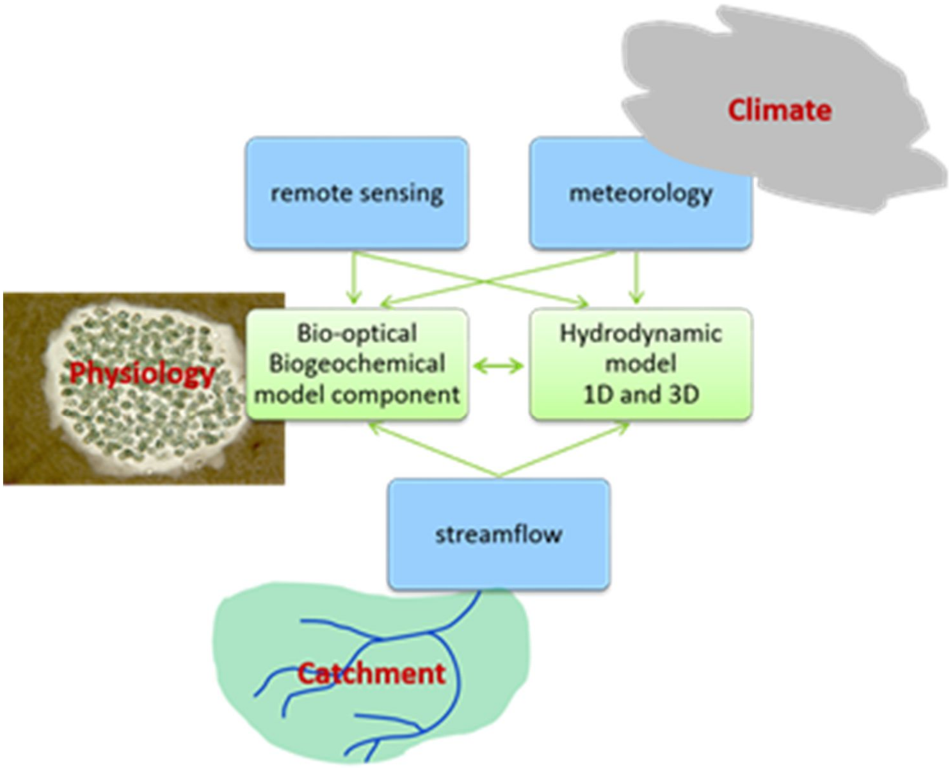

Figure 1: Conceptual layout of a model framework for harmful algal bloom modelling.

Depending on the satellite sensors this can give spatial resolutions in the range from 1000 m down to several meters. However, better spatial resolution currently comes with less frequent images and reduced numbers of spectral bands necessary to detect cyanobacteria. There is a demand for future advances in hyperspectral satellite missions to support water quality research [4]. The assimilation of such data into the simulation tools will further reduce the uncertainty of water quality predictions.

2.1 From local to regional model

The initial study is focusing on the modelling components using a specific, well researched lake, Lake Burley Griffin, ACT, Australia, as a case study. Lake Burley Griffin, the iconic lake of the Australian capital, is an outstanding example with recurring cyanobacteria (blue-green algae) blooms often leading to lake closure for recreational use. Model components – 1D/3D hydrodynamic, biogeochemical, bio-optical models – are currently combined and calibrated for this lake. We use both 1D as well as full 3D models to allow for fast analysis with the 1D model and in detailed analysis of spatial variability in specific lakes.

The validated model will then be applied to a set of lakes and reservoirs across Australia reaching from the tropical north (Queensland) to the temperate south (Tasmania). These lakes are chosen to reflect a) different dynamical regimes and b) different levels of data availability. For data-poor lakes proxy data for nutrient status need to be generated from land-use information. This results in a generalization of the used model parameterization and a validation of the model tools for data-poor environments.

2.2 Continental scale model

Applying this model framework for each and every lake (within a certain size limit reflecting the available resolution of remote sensing data) on a continental scale then needs further evaluation and input of data describing the larger environment such a lake is embedded in. Existing, continental hydrogeological, vegetation, and soil maps provide information on the nutrient status of a lake, land surface models deliver inflow and water balance. Earth observation gives information on geometry, vegetation cover, land-use changes etc. The 1D model can then be applied continental wide delivering information on potential harmful algal. This early warning system is meant for short-term predictions based on current conditions and weather predictions, i.e. over a range of several days up to a week. On a longer term climate scenarios can be used to forecast future lake status with respect to water quality and harmful algal blooms on a large scale.

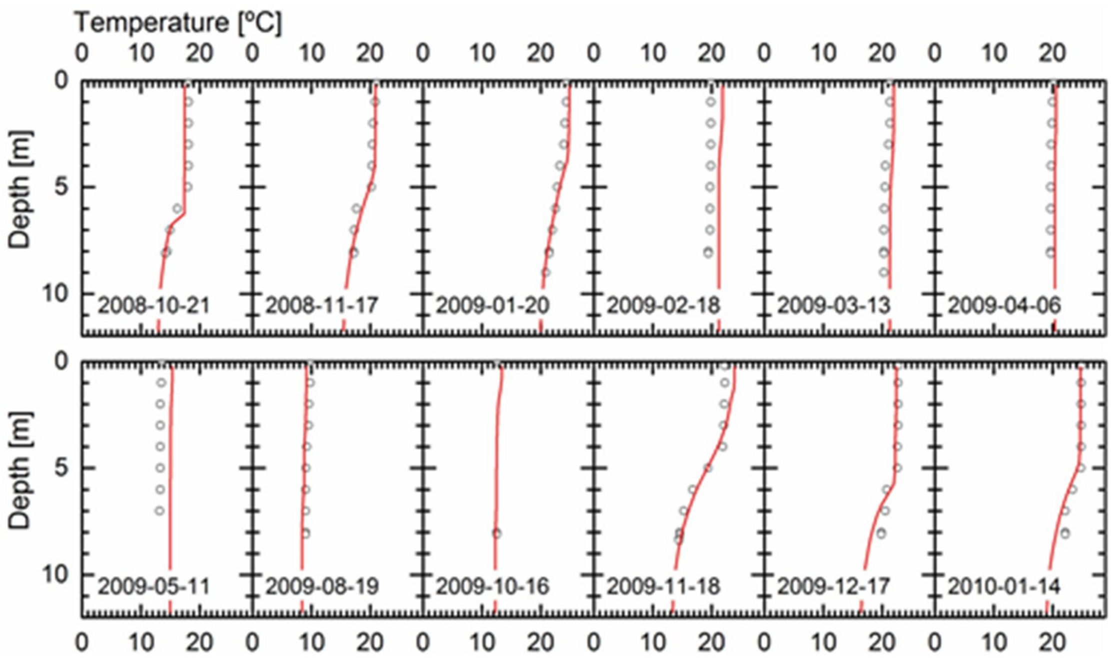

Figure 2: Thermal structure of Lake Burley Griffin (dots), and results from the 1D hydrodynamic simulation tool (red line).

2.3 Results

In a first step we have set up the hydrodynamic modules to simulate the thermal structure of Lake Burley Griffin driven by local meteorology from a nearby meteorological station. The calibration and validation was done against a dataset of monthly temperature profiles for this lake reaching from 1985 to 2015 (Figure 2).

3 CONCLUSION

Prediction tools for harmful algal blooms in lakes and reservoirs are currently not readily available on a large scale, they are usually lake specific. Here we present an attempt to set up a modelling framework which will operate on a continental scale drawing its input from a multitude of continental databases (vegetation, soil classification, meteorology, etc.). This will in future serve as an early warning system for CyanoHABs. Currently the model is implemented at a local study site, combining Earth observation with coupled hydrodynamic biogeochemical models. Upcoming satellite missions will further improve data availability and resolution to support water quality predictions on a large scale.

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