Monitoring extremes in aquatic systems with Earth Observation and Artificial Intelligence

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Lakes and rivers (referred collectively as inland waters) are a critical natural resource that supports important biodiversity and provide accessible freshwater for a wide range of human activities. However, inland waters are critically susceptible to the effects of climate change, in particular the occurrence of climatic extremes, such as heatwaves, storms, and droughts. Climatic extremes, such as these, can result in extreme conditions within aquatic systems, including the occurrence of thermal extremes, severe algal blooms and dangerously low water levels. These can have a dramatic influence on the functioning of aquatic systems as well as the benefits that they provide to society, such as the provision of water for drinking and irrigation, recreational use, and economic benefits such as fisheries and tourism. There is therefore a pressing need to monitor past changes and to predict the near-term future occurrence of extreme events in aquatic systems worldwide.

Due to the unpredictable and short-lived nature of extremes, frequent (e.g., daily) observations are needed. Traditional monitoring, which include in-situ observations at typically fortnightly to monthly intervals, are sufficient to record seasonal change but cannot adequately capture or resolve extreme events, which can be completely altered by short-term disturbances such as a sudden increase in air temperature. The temporal resolution of monitoring thus needs to be high enough to capture and define extremes but also long enough to ascertain the impacts of an event on a naturally varying ecosystem. Recent developments in satellite technology have made it now possible to monitor inland waters from space at high-temporal resolution, thus providing the potential to also monitor extremes. Such satellite data include those recently published by the European Space Agency's Climate Change Initiative Lakes project (https://climate.esa.int/en/projects/lakes/). However, these satellite data also have their limitations, including the presence of gaps (e.g., due to clouds), which could bias the identification of extremes. Gaps in satellite data can be filled with linear interpolation, but these can introduce unknown and unquantified errors, and are also likely to smooth and mask the occurrence of extreme events. To properly represent extreme events in satellite databases, novel techniques need to be developed and explored.

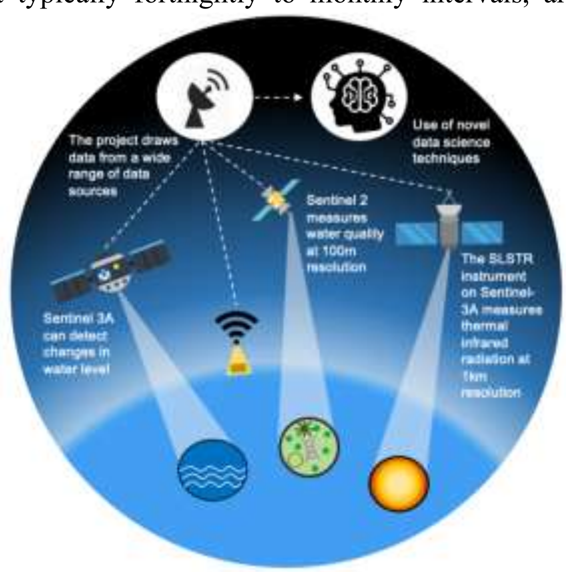

Fig 1. This project will combine novel observations of essential lake variables from space with new deep learning techniques to simulate lake dynamics at an unprecedented scale.

The overarching aim of this project is to investigate extreme events in inland waters by using new space observations and applying a unique combination of emerging and beyond state-of-the-art methodologies for global monitoring of aquatic systems (Fig. 1). Most notably, in this project, novel satellite observations from the European Space Agency will be investigated and combined with Machine Learning (ML; a subset of Artificial Intelligence) techniques to generate continuous data for a global distribution of aquatic ecosystems. Specifically, ML will be trained using past observations of inland waters and site-specific environmental conditions to gap-fill the satellite data, which will then be used for detecting extreme events, including anomalous conditions in water quality and water quantity. The PhD will also explore the use of ML to produce near-term forecasts of extreme events in inland waters, with the aim to predict when such extremes will next occur and, for example, to provide an early-warning indicator. When developing near-term forecasts, the PhD candidate will also explore the use of an emerging modelling paradigm known as "process-guided deep learning", which combines the strengths of process-based models (which simulates aquatic systems based on known physical and biogeochemical processes) with deep learning techniques to monitor extreme events more accurately. Ultimately, process-guided deep learning models will use advanced empirical methods to extract patterns from satellite data (via deep learning) while also imposing structure or rules based on scientific theory (via process-based models). As these hybrid models can be designed to remain true to physical laws while also learning very complex relationships when data are abundant, their predictions could result in a considerable advancement in our ability to monitor inland waters at a global scale.

Training opportunities:
The PhD candidate will receive training in data science and machine learning, in the utilization of satellite images of inland waters, and in numerical modelling. The European Space Agency Climate Office (ECSAT, UK) will host the PhD candidate for 3 months during the project. The successful candidate will also have the opportunity to work in cooperation with relevant scientific projects within ESA's Climate Change Initiative program. Additionally, the student will be encouraged to attend a wide range of learning and development activities, including presentational skills and paper writing.

Student profile:
This project would be suitable for students with a degree in physics, mathematics, computer science, earth sciences, or a closely related environmental or physical science. While knowledge of the climate and freshwater systems would be ideal, this knowledge can be taught to the right candidate. The candidate should be able to work independently and in groups as well as have an aptitude and enthusiasm for applying physical principles to solve real world problems.

Funding particulars:
This project is co-sponsored by the European Space Agency Climate Office.

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