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Replacing parametrisations of melt ponds on sea ice with machine learning emulators

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Sea ice plays an essential role in global ocean circulation and in regulating Earth's climate and weather, and melt ponds that form on the ice have a profound impact on the Arctic's climate by altering the ice albedo. Melt pond evolution is complex, sub grid scale and poorly understood - and melt ponds are represented in sea ice models as parametrisations. Parametrisations of these physical processes are based on a number of assumptions and can include many uncertain parameters that have a substantial effect on the simulated evolution of the melt ponds.

We have shown, using Sobol sensitivity analysis and through investigating perturbed parameter ensembles (PPEs), that a state-of-the-art sea ice column model, Icepack, demonstrates substantial sensitivity to its uncertain melt pond parameters. These PPEs demonstrate that perturbing melt pond parameters (within known ranges of uncertainty) cause predicted sea ice thickness over the Arctic Ocean to differ by many metres after only a decade of simulation. Understanding the sources of uncertainty, improving parametrisations and fine tuning the parameters is a paramount, but usually very complex and difficult task. Given this uncertainty, we propose to replace the sub grid scale melt pond parametrisation (MPP) in Icepack with a machine learning emulator.

Building and replacing the MPP with a machine learning emulator has been done in two broad steps that contain multiple computational challenges. The first is generating a melt pond emulator using 'perfect' or 'model' data. Here we demonstrate a proof of concept and show how we achieve numerically stable simulations of Icepack when embedding an emulator in place of the MPP - with Icepack running stably for the whole length of the simulations (over a decade) across the Arctic.

Secondly, we develop offline an emulator from observational data that faithfully predicts observed

sea ice albedo and melt pond fraction given climatological input variables. Embedding an observational emulator can require different challenges as compared to using model data, such as not all variables needed by the host model being observable/observed for an emulator to predict. We discuss how we achieve online simulations interfacing this emulator with the Icepack model.

Our focus on using column models ensures that our observational emulator of sea ice albedo and melt pond fraction can readily be used in sea ice models around the world, irrespective of grid resolutions and mesh specifications, and offers one approach for creating general emulators that can be used by many climate models.