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Network models for ponding on sea ice

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Arctic sea ice forms a thin but significant layer at the ocean surface, mediating key climate feedbacks. During summer, surface melting produces considerable volumes of water, which collect on the ice surface in ponds. These ponds have long been suggested as a contributing factor to the discrepancy between observed and predicted sea ice extent. When viewed at large scales ponds have a complicated, approximately fractal geometry and vary in area from tens to thousands of square meters. Increases in pond depth and area lead to further increases in heat absorption and overall melting, contributing to the ice-albedo feedback.

Previous modelling work has focussed either on the physics of individual ponds or on the statistical behaviour of systems of ponds. We present a physically-based network model for systems of ponds which accounts for both the individual and collective behaviour of ponds. Each pond initially occupies a distinct catchment basin and evolves according to a mass-conserving differential equation representing the melting dynamics for bare and water-covered ice. Ponds can later connect together to form a network with fluxes of water between catchment areas, constrained by the ice topography and pond water levels.

We use the model to explore how the evolution of pond area and hence melting depends on the governing parameters, and to explore how the connections between ponds develop over the melt season. Comparisons with observations are made to demonstrate the ways in which the model qualitatively replicates properties of pond systems, including fractal dimension of pond areas and two distinct regimes of pond complexity that are observed during their development cycle. Different perimeter-area relationships exist for ponds in the two regimes. The model replicates these relationships and exhibits a percolation transition around the transition between these regimes, a facet of pond behaviour suggested by previous studies. Our results reinforce the findings of these studies on percolation thresholds in pond systems and further allow us to constrain pond coverage at this threshold - an important quantity in measuring the scale and effects of the ice-albedo feedback.