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Critical percolation threshold is an upper bound on Arctic sea ice melt pond coverage

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During the summer, vast regions of Arctic sea ice are covered by meltwater ponds that significantly lower the ice reflectivity and accelerate melting. Despite their importance, melt ponds are still not well-understood. Ponds develop over the melt season through an initial stage of rapid growth followed by drainage through macroscopic holes. Recent analysis of melt pond photographs indicates that late-summer ponds resemble percolation clusters near a critical percolation threshold. Here, we identify the physical mechanism behind this previously-unrecognized constraint on pond evolution, thereby providing an unprecedented opportunity to improve representation of ponds in large-scale climate models. We show that the percolation threshold controls pond evolution due to pond drainage through macroscopic holes. The threshold, a tractable statistical property of ice topography, sets the upper limit and scales the pond coverage throughout its evolution after the beginning of drainage. Furthermore, we show that, after rescaling, the pond coverage fraction as a function of the number of open holes follows a universal curve. This curve governs pond evolution during and after pond drainage, which allows us to formulate an equation for pond coverage evolution that captures the dependence on physical properties of the ice and is supported by observations. Our work reveals some of the fundamental properties of melt pond physics. As such, it can be used in large-scale models to create a reliable albedo parameterization and improve predictions of Arctic sea ice's response to global warming.