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Radiative heating of ice-covered waterbodies of varying morphologies

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Millions of small, high-altitude lakes freeze their surface waters each winter season. Observations, however, reveal that their water temperature is increasing and the ice-on period is declining. Altering the thermal regime of ice-covered lakes have multiple impacts, including the loss of ecosystem services to increments in greenhouse gas emissions. These pervasive changes are affected by the heating rate of under-ice waters, which in turn regulates the water-to-ice heat flux, and therefore the rate of ice melting. In such aquatic systems, solar radiation warms the water beneath a diffusive boundary layer, thereby increasing its density and providing energy for convection in a diurnally-active mixing layer. Shallow regions are differentially heated to warmer temperatures, driving downslope buoyancy-driven currents that transport warm water to the interior basin. We characterize the energetics of these processes, focusing on the rate at which solar radiation supplies energy that is available to drive fluid motion. Using numerical simulations, we show that advective fluxes due to differential heating contribute to the evolution of the mixed-layer in waterbodies with significant shallow areas. We use a heat balance to assess the relative importance of differential heating to the one-dimensional effects of radiative heating and diffusive cooling at the ice-water interface in waterbodies of varying morphologies.