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Winter limnology: how do hydrodynamics and biogeochemistry shape ecosystems under ice?

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The ice-covered period in lakes is increasingly recognized for its unique hydrodynamic and biogeochemical phenomena and ecological relevance yet it remains poorly studied compared to the ice-free season. Knowledge gaps exist where research areas – hydrodynamics, biogeochemistry and biology – intersect. For example, density-driven circulation under ice coincides with an expansion of the anoxic zone, but abiotic and biotic controls on oxygen depletion have not been disentangled. While heterotrophic microorganisms and migrating phytoplankton often thrive at the oxycline, the extent to which physical processes induce fluxes of heat and substrates that further support under-ice food webs is uncertain. Similarly, radiatively-driven convection under ice in spring can promote growth of motile phytoplankton or diatoms depending on flow velocity, water clarity and mixing depth, but links between functional trait selection, trophic transfer to zooplankton and fish and the prevalence of microbial versus classical food webs in seasonally ice-covered lakes remain unclear. Under-ice processes cascade into and from the ice-free season, and are relevant to annual cycling of energy and carbon through aquatic food webs. Understanding the coupling between state transitions and the reorganization of trophic hierarchies is essential for predicting complex ecosystem responses to climate change. In this presentation, we briefly review existing knowledge regarding physical processes in lakes in winter and the parallel developments in under-ice biogeochemistry and ecology. We then illustrate interactions between these processes, identify extant knowledge gaps whose solution requires interdisciplinary approaches, and present (novel) methods to address outstanding questions.