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On the brine drainage and algal uptake controls of the nutrient supply to the sea ice interior

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Sea ice ecosystems are important components of the biogeochemical cycles (including carbon) and hence have a potential impact on climate. They are characterized by large stocks of micro-algae. Those algae (mostly diatoms) live in liquid inclusions of saline brine, which are encased within the solid ice matrix and require sustained nutrient supply to grow. In this study, we investigate the interactions between nutrients, brine motion and algal growth, using a one-dimensional (1D) sea ice model. The model includes (i) a classical formulation for snow and ice thermodynamics with explicit, reformulated brine physics and (ii) an idealized sea ice biological component, characterized by one single nutrient, namely dissolved silica (DSi), which stocks are reduced by a prescribed primary production. DSi is considered as a passive tracer dissolved within brine following fluid motion. The brine flow regime (advective, diffusive or turbulent) is computed as a function of environmental ice conditions. In winter, a Rayleigh number proposed by Notz and Worster (2008) is used to differentiate diffusion and convection. Ice salinity and DSi concentrations within the ice are solutions of 1D advection-diffusion equations over the variable volume brine network domain. The model is configured for a typical year of seasonal Weddell Sea ice. The simulated vertical salinity and tracer profiles as well as ice-ocean salt fluxes realistically agree with observations. Complex bio-physical interactions are simulated by the model. Analysis highlights the role of convection in the lowermost 5-10 cm of ice (gravity drainage), mixing highly saline, nutrient-depleted brine with comparatively fresh, nutrient-rich seawater. Hence, gravity drainage rejects salt to the ocean and provides nutrients to the ice interior. In turn, primary production and brine convection act synergetically to form a nutrient pump, which enhances the net ocean-to-ice DSi flux by 20-115%, compared to an abiotic situation. The other important simulated processes are winter and spring surface flooding of seawater which supplies nutrients near the ice surface, and melt water percolation which – if present in reality – would tend to flush nutrients back to the ocean in summer. The physical background for sea ice tracers developed here is general and could be used to simulate other sea ice tracers (e.g., dissolved organic matter, isotopes, gases, radio-nuclides, ...), constituting an improved modelling strategy for sea ice brine and ecosystem dynamics.