EGU2020-6039
https://doi.org/10.5194/egusphere-egu2020-6039
EGU General Assembly 2020

Microstructure and solutal boundary layer at the sea ice - ocean interface

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Sea ice growth into seawater proceeds by congelation of almost pure ice crystals, with most sea salts being rejected into a solute-enriched boundary layer. This solute enrichment does locally change the freezing point and thereby alter crystal growth due to a process termed "*Constitutional Supercooling*" (heat diffusing much faster than solute). It also sets up solute gradients that drive convection in a boundary layer of thickness *D/V*, where *D* is the coefficient of solute diffusion and *V* the ice growth velocity. The crystal pattern arising from such interaction of solute and temperature gradients, and respective solute and heat fluxes at the freezing interface, has been observed for other systems. It may be described by the theory of "*Morphological Instability*" formulated half a century ago by Mullins and Sekerka (1964). In principal this theory predicts the cell or dendrite spacing at a freezing interface of a saline solution. However, application of the theory to the case of sea ice growing from seawater has been incomplete so far due to three aspects: (i) detailed observations of the sea ice - ocean interface are difficult to obtain, as this high-porosity regime is rather fragile and often lost during sampling, and/or altered during cooling when the sample is removed from the water. However, from thin sections further up in the ice the interface is known to be lamellar, consisting of vertical oriented plates with a distance of 0.3 to 1 mm found for natural growth conditions; (ii) observations of the solutal boundary layer are even sparser and limited to a few laboratory studies, where this layer was heavily convecting; (iii) from a theoretical point it turns out that the classical Mullins-Sekerka theory needs to be modified due to such a convecting boundary layer. In the present talk I review the existing observations, and present novel 3-d observations of the microstructure near the interface of growing sea-ice. I propose an application of morphological stability theory to predict the plate spacing of sea ice and the salt fluxes through a convectively unstable solutal boundary layer. The predictions are consistent with observed plate spacings over a wide range of ice growth velocities, ranging from fast (100 cm/day) laboratory ice growth to slow (0.01 cm/day) accretion at the bottom of marine ice shelves. These predictions are not only of importance to predict ice properties near the interface, yet indicate the potential to trace sea ice and ice shelf growth rates through microstructure observations. Regarding the solutal boundary layer, the theory is found to be consistent with published observations of salt fluxes from growing sea ice.

W. W. Mullins and R. F. Sekerka, J. Appl. Phys., 1964, 35, 444.