Modeling of small scale processes in Antarctic sea ice and their impact on the biological pump in the future Southern Ocean

A coupled bi-scale approach

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Objectives of the work

This project aims to gain insight into the small-scale coupled physical processes of freezing and melting sea ice, the connection to the size and distribution of the enclosed brine channels and, furthermore, the coupling to algal growth and the unavoidable impact on the biological carbon pump.

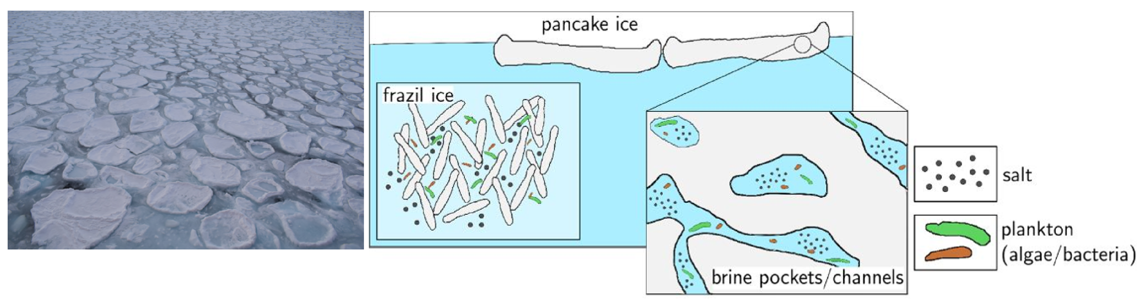


Figure 1: Sketch of pancake ice and brine pockets.

Climatic changes may influence the porous microstructure of sea ice. A coupled P-BGC model of an Antarctic sea ice floe will mathematically describe the complex coupled relationships between ice formation, nutrient transport, salinity and brine channel distribution, photosynthesis and carbonate chemistry. Different scenarios of sea ice formation, its effects on the growth of sea ice algae and their impact on vertical carbon export will be simulated.

Applied methods

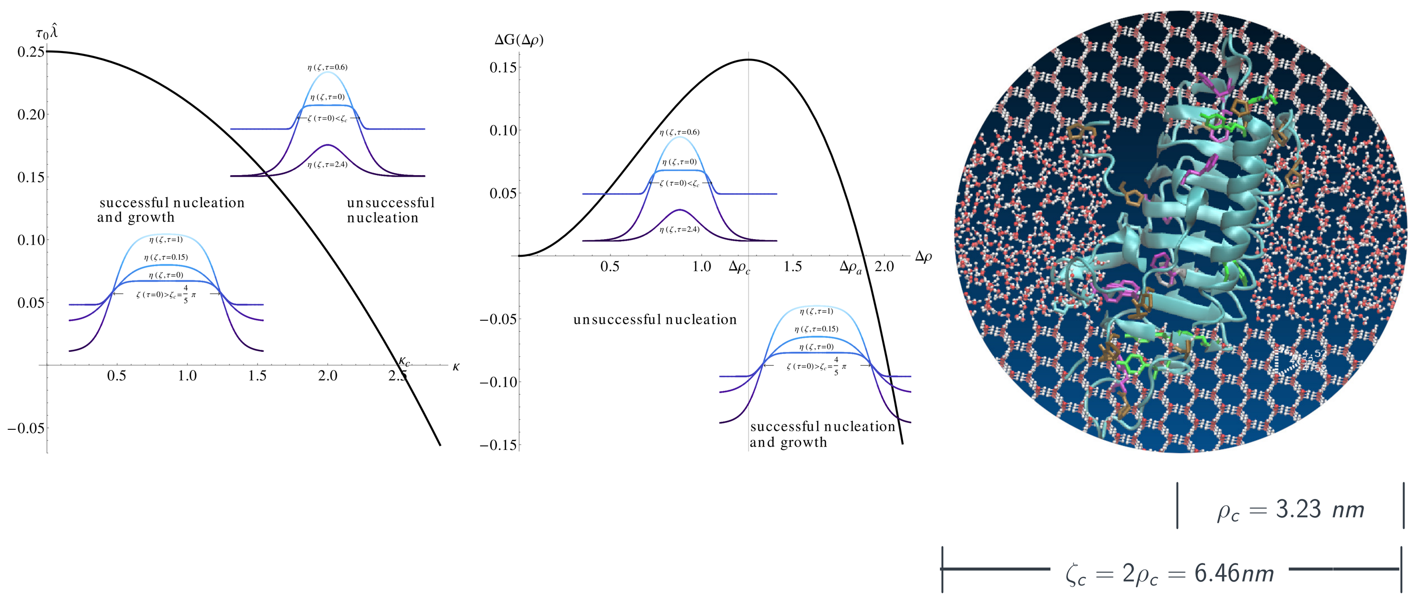
Depending on temperature distance $\Delta\Theta$ from freezing point and salinity σ, the formation of a graceful small-scale network of brine channels in sea ice is simulated using a modified thermohaline growth model based on an earlier approach [3]. The order parameter η describes the phase transition

$$
\begin{aligned}
\varepsilon^2\frac{\partial\eta}{\partial\tau} &= -\eta^3 + \left(\frac{3}{2} - m\right)\eta^2 - \left(\frac{1}{2} - m\right)\eta + \varepsilon^2\frac{\partial}{\partial\xi}\left(\gamma^2\frac{\partial\eta}{\partial\xi} - \gamma\frac{\partial\gamma}{\partial\theta}\frac{\partial\eta}{\partial\chi}\right) + \varepsilon^2\frac{\partial}{\partial\chi}\left(\gamma^2\frac{\partial\eta}{\partial\chi} + \gamma\frac{\partial\gamma}{\partial\theta}\frac{\partial\eta}{\partial\xi}\right)\\
\frac{\partial\Delta\Theta}{\partial\tau} &= \left(\frac{\partial^2\Delta\Theta}{\partial\xi{-}^2} + \frac{\partial^2\Delta\Theta}{\partial\chi^2}\right) + \Lambda\frac{\partial\eta}{\partial\tau}\\
\varepsilon^2\frac{\partial\sigma}{\partial\tau} &= -\sigma\left(1-\sigma\right)\left(\sigma - \frac{1}{2} + m - \alpha\eta\right) + \frac{\nu^2}{\varepsilon^2}\frac{\partial}{\partial\xi}\left(\sigma^2\frac{\partial\sigma}{\partial\xi} - \sigma\frac{\partial\sigma}{\partial\theta}\frac{\partial\eta}{\partial\chi}\right) + \frac{\nu^2}{\varepsilon^2}\frac{\partial}{\partial\chi}\left(\sigma^2\frac{\partial\sigma}{\partial\chi} + \sigma\frac{\partial\sigma}{\partial\theta}\frac{\partial\sigma}{\partial\xi}\right).
\end{aligned}
$$

The small-scale brine channels can be embedded in the larger-scale pancake ice using the Theory of Porous Media (TPM) [6].

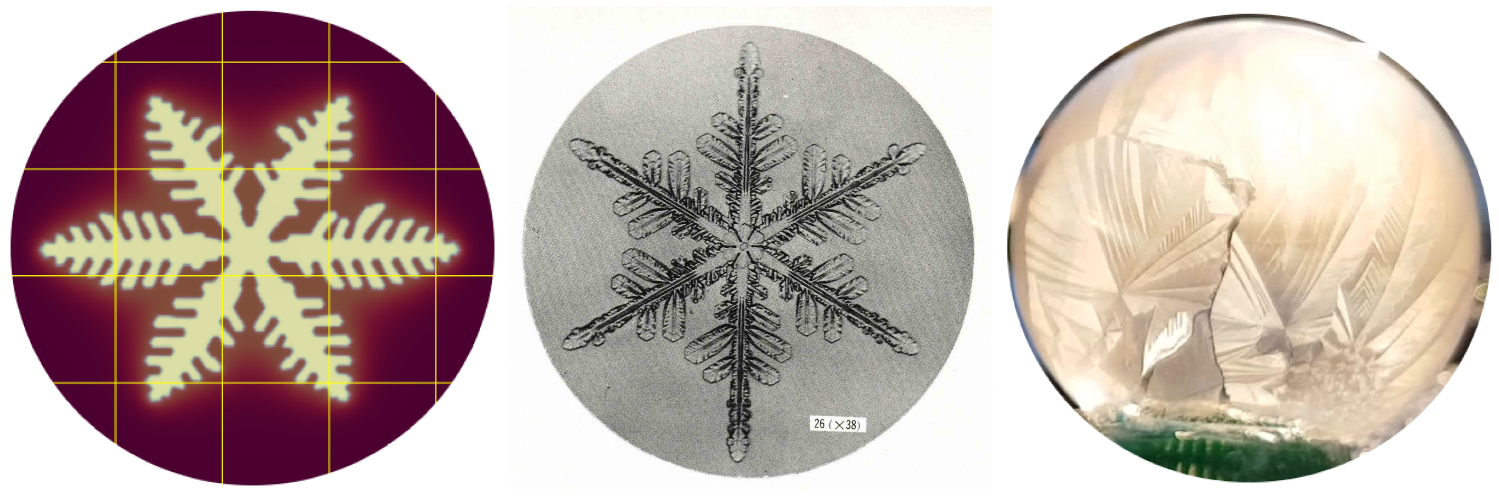
Initial results

- The critical nucleation radius can also be determined from the linear stability analysis of the time-dependent phase theory



The critical nucleation radius corresponds approximately to the length of an antifreeze protein of fragilariopsis cylindrus with the free energy $\Delta G_c = \frac{4\sqrt{2}}{81}\pi\varepsilon(\Delta\rho_a)^2$.

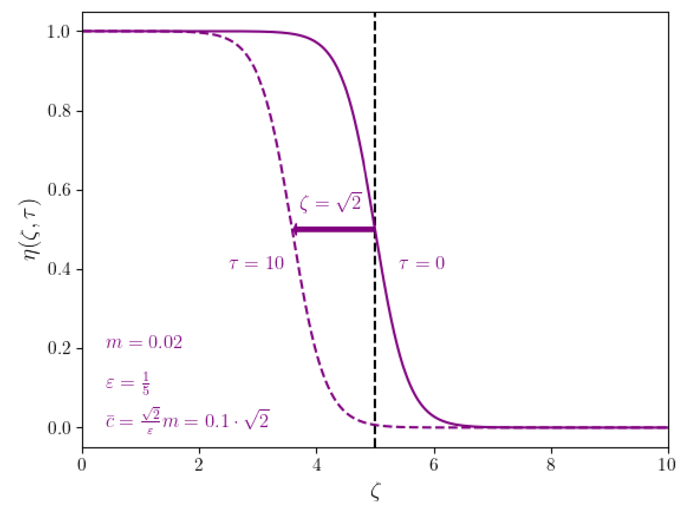
- The thermohaline approach allows for modeling of small scale pattern formation.



Simulation of order parameter and temperature field

2.6 mm
Artificial snow crystal [4]

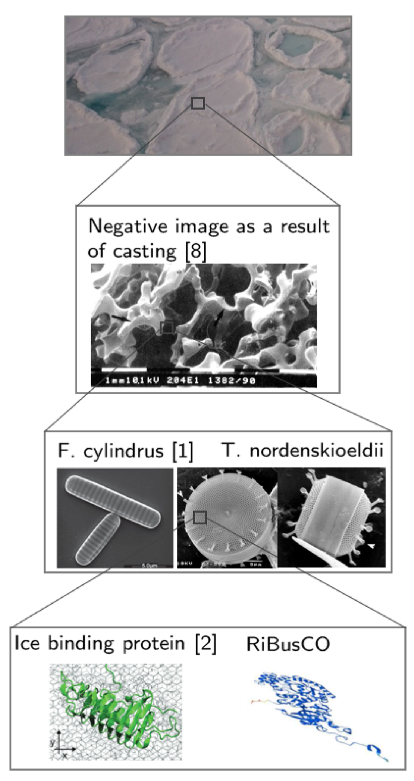
5.25 cm



- The freezing velocity for pure water as propagation of instanton solutions can be determined.
- Including freezing point depression, the pore volume of the brine channels can be estimated as a habitat for microorganisms

Outlook on future work

Physical-biogeochemical interactions



- The pore volume can be determined using the thermohaline approach. In order to estimate the CO_2-fixing capability [7] of phytoplankton (Fragilariopsis cylindrus, Thalassiosira nordenskioeldii, Thalassiosira antarctica, etc.) using the RecoM2 model [5], we obtain knowledge about the seasonally varying biomass in the brine channels.
- Combination of the three approaches, thermohaline model, Theory of Porous Media (TPM) and Recom2 by paramerization or coupling

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