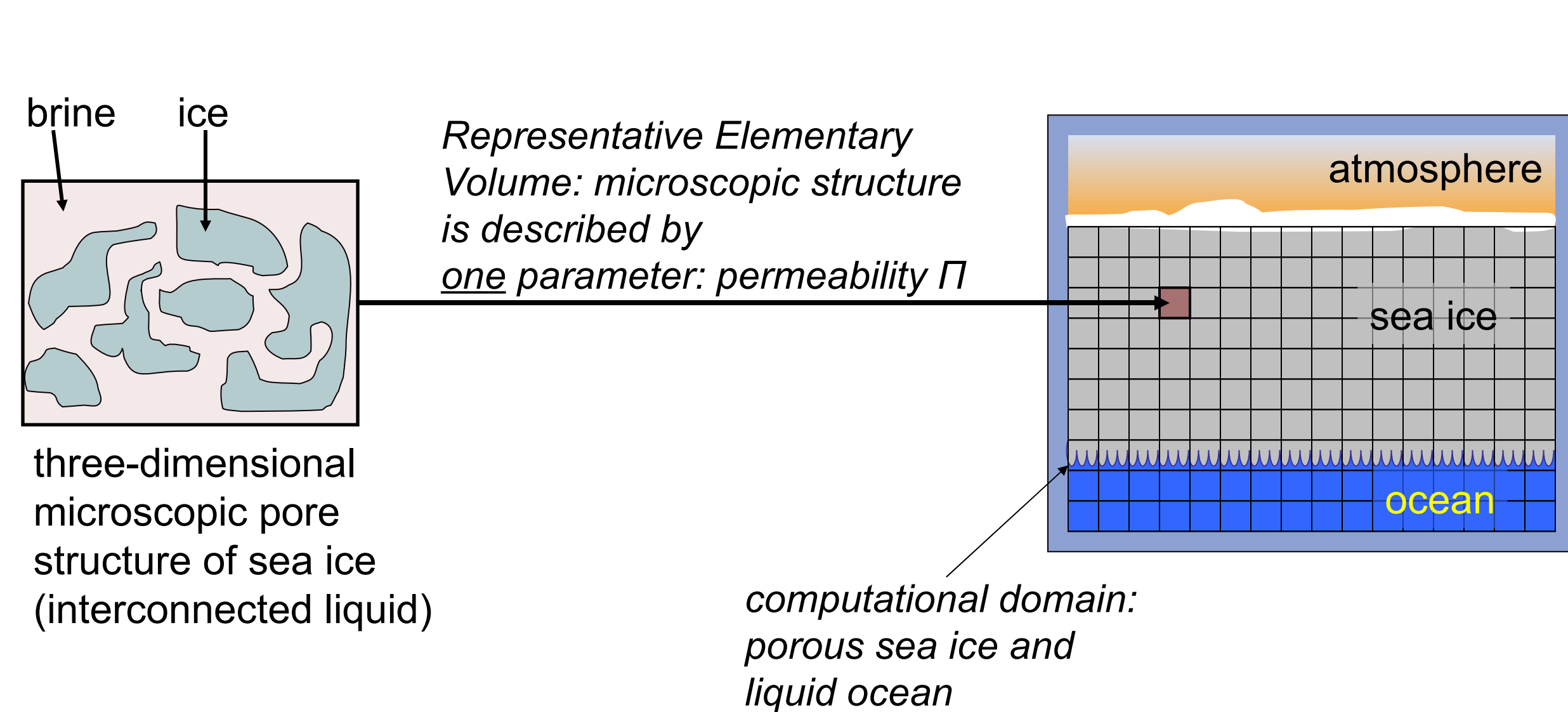


Introduction

Sea ice covers the polar oceans in winter and to a lesser extent in summer. Its presence affects the climate since it changes fluxes at the atmosphere—ocean transition: it reflects sunlight; it acts as a barrier to heat and vapor fluxes; it reduces agitation of the ocean mixed layer; and it is a source of dense brine into the ocean. Sea ice is an integral part of life in the Arctic: it serves as travel and hunting ground to coastal population, and it is a hazard to ship traffic and structures. Further, it is part of the habitat for mammals and microorganisms.

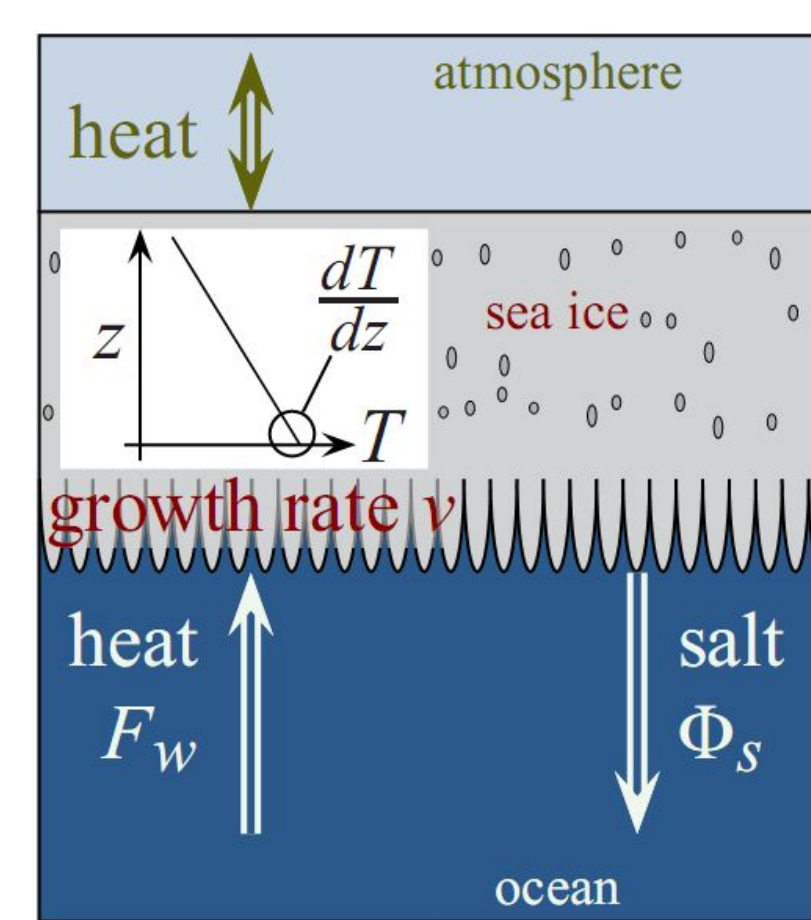
Although its importance is obvious, there are still a number of fundamental processes involving sea ice that we do not understand. Here, we investigate numerically the fluid dynamics of sea ice during the growth season. What salt fluxes can we expect from growing ice and what will be the salt content of the forming ice? What is the microscopic distribution of the brine inclusions? How large will be nutrient fluxes to microalgae thriving at the ice—ocean interface?

Method



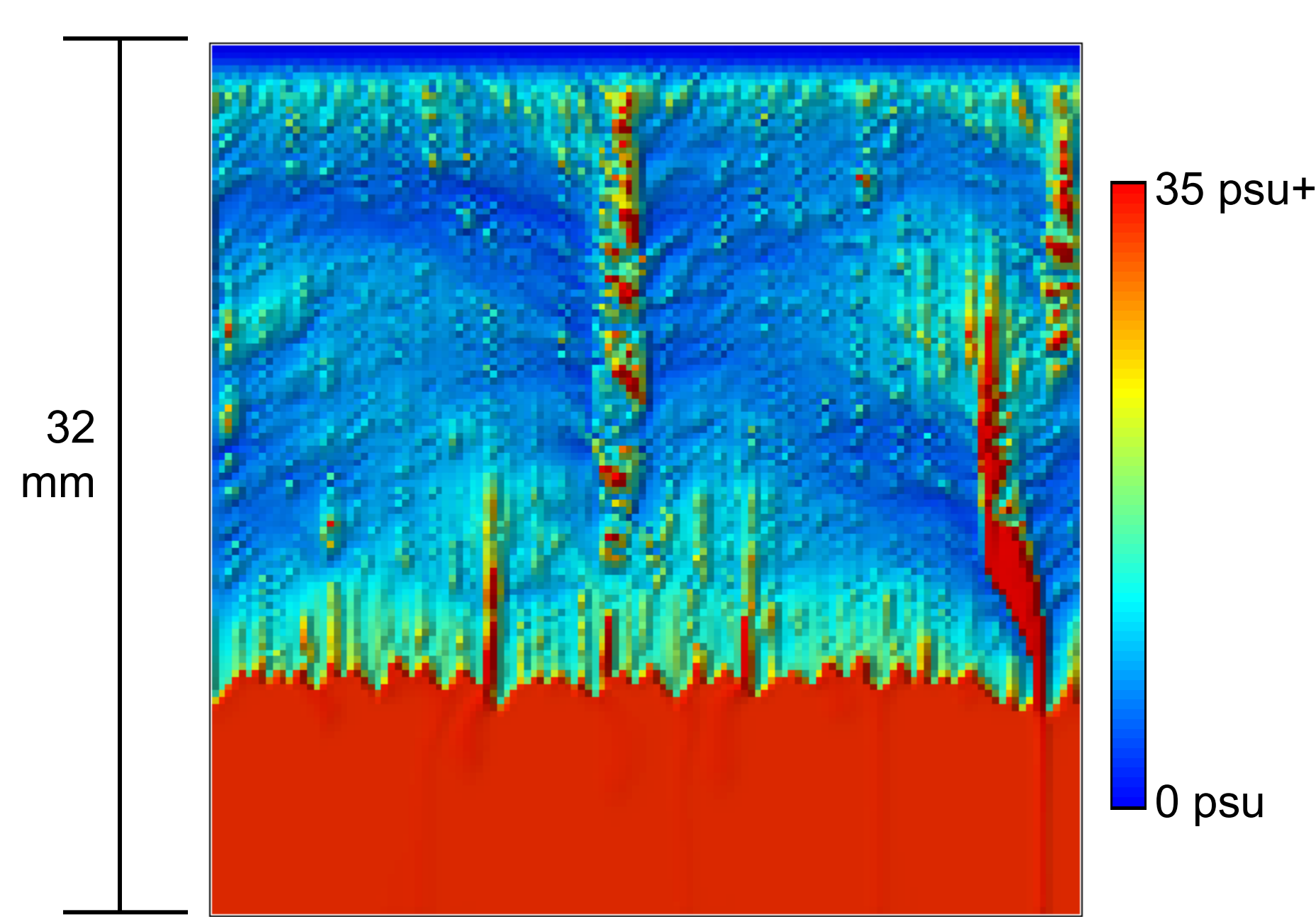
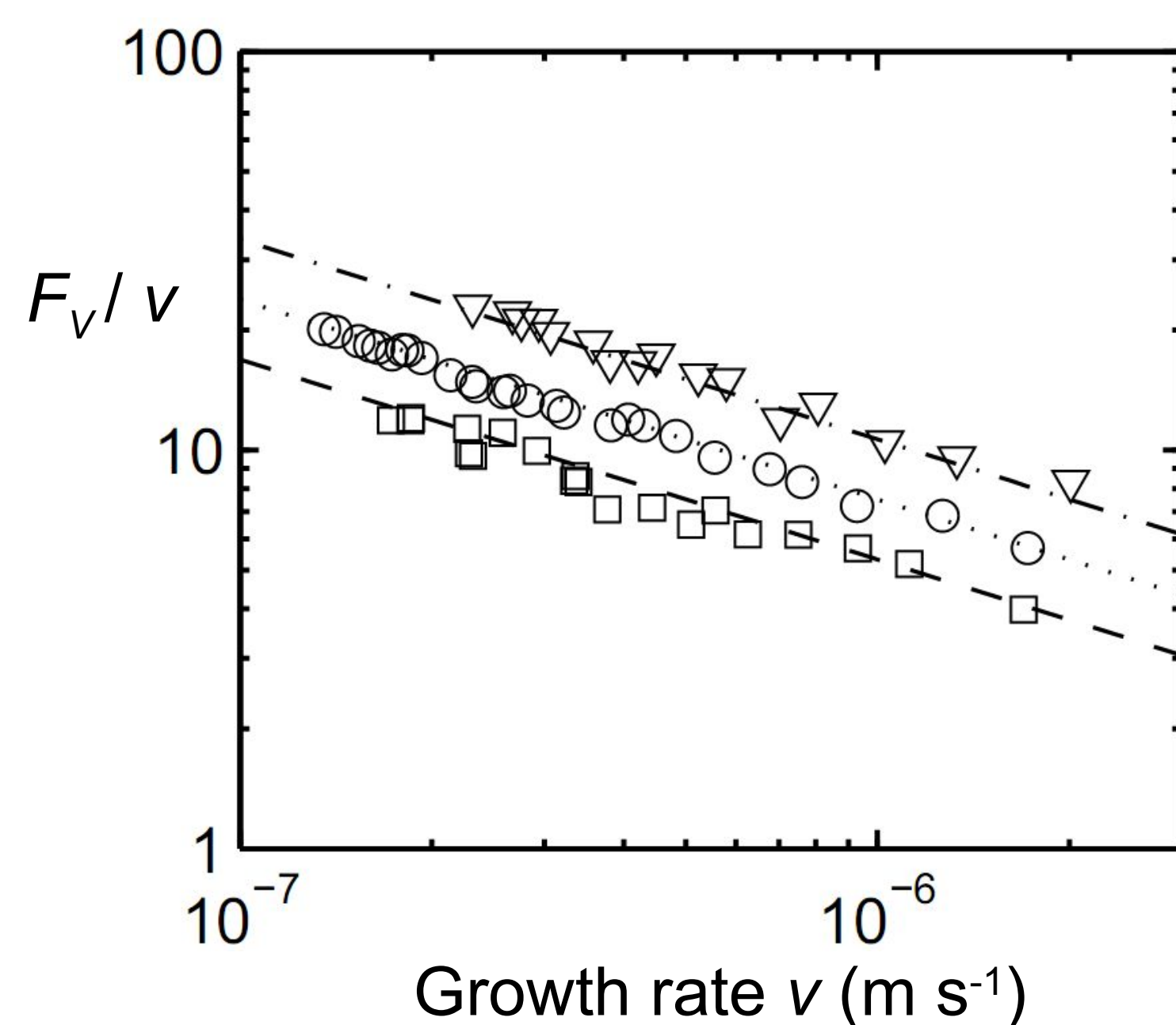
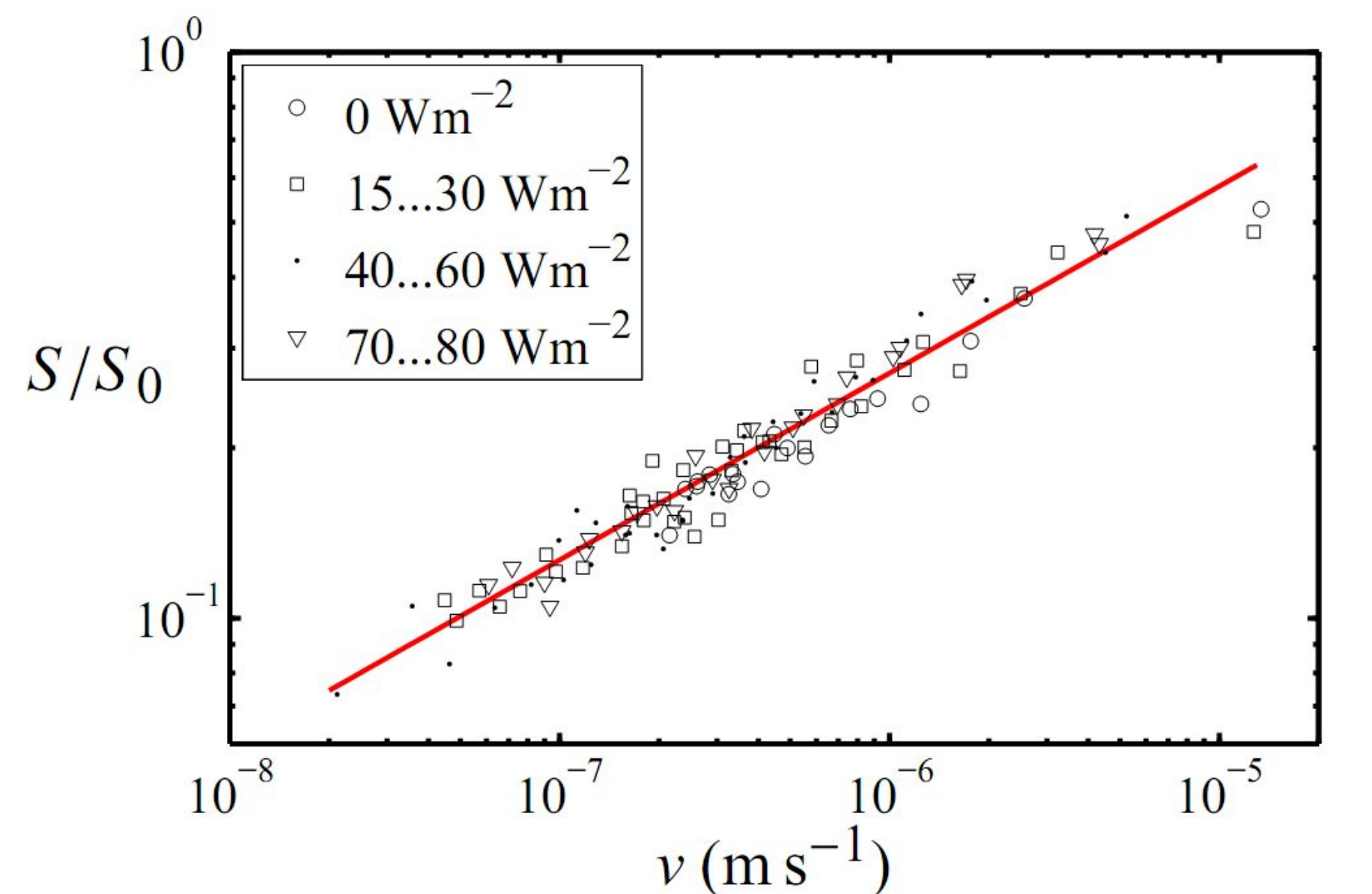
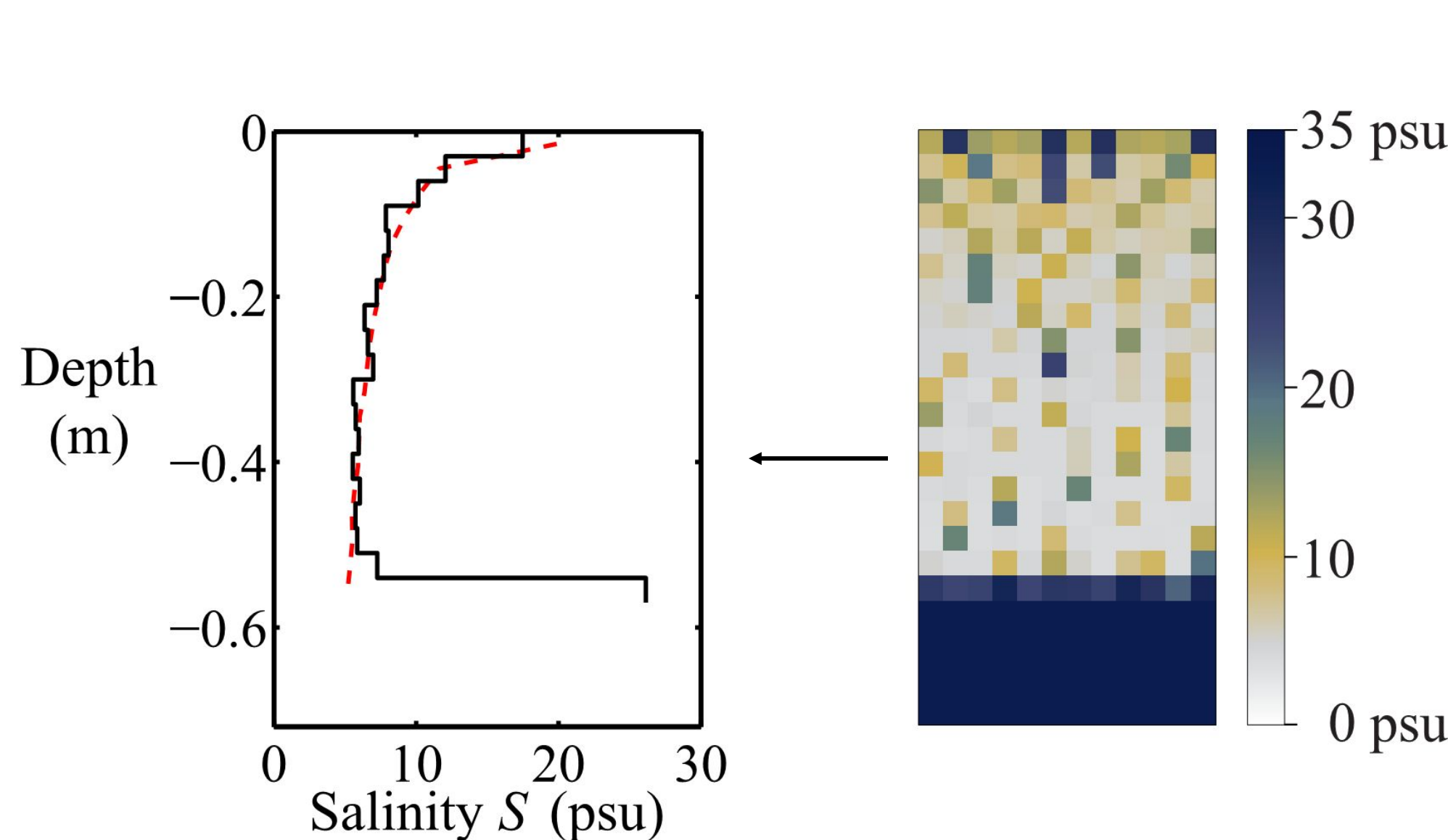
We developed a two-dimensional single-phase enthalpy-porosity computational fluid dynamics model to simulate convection in the presence of phase change with volume expansion. The Navier—Stokes equations with Boussinesq approximation were coupled to solute and energy conservation equations, and they were discretized with the Finite Volume Method (FVM) and solved on a staggered rectangular grid.

We applied this model to growing sea ice where we assessed the influence of oceanic and atmospheric heat flux on the development of the pore structure and corresponding salinity distribution in the ice. Further, we determined the volume flux at the ice—ocean interface.



result: temperature profile, growth rate v , salt flux, pore structure

Results



Conclusions

Our fluid dynamics simulations of growing sea ice reveal inclusion features similar to those observed in natural sea ice. This suggests that the pore structure of sea ice develops as a result of porous medium fluid dynamics. A quasi-steady salinity developed even in the presence of a completely interconnected pore space.

We were able to demonstrate that the ice growth rate is a proxy for the steady state bulk salinity of sea ice regardless of oceanic heat flux. Further, we find that microalgae at the growing interface may be exposed to large fluxes of nutrients as a result of convective transport through sea ice rather than turbulent ice—ocean interface fluxes.

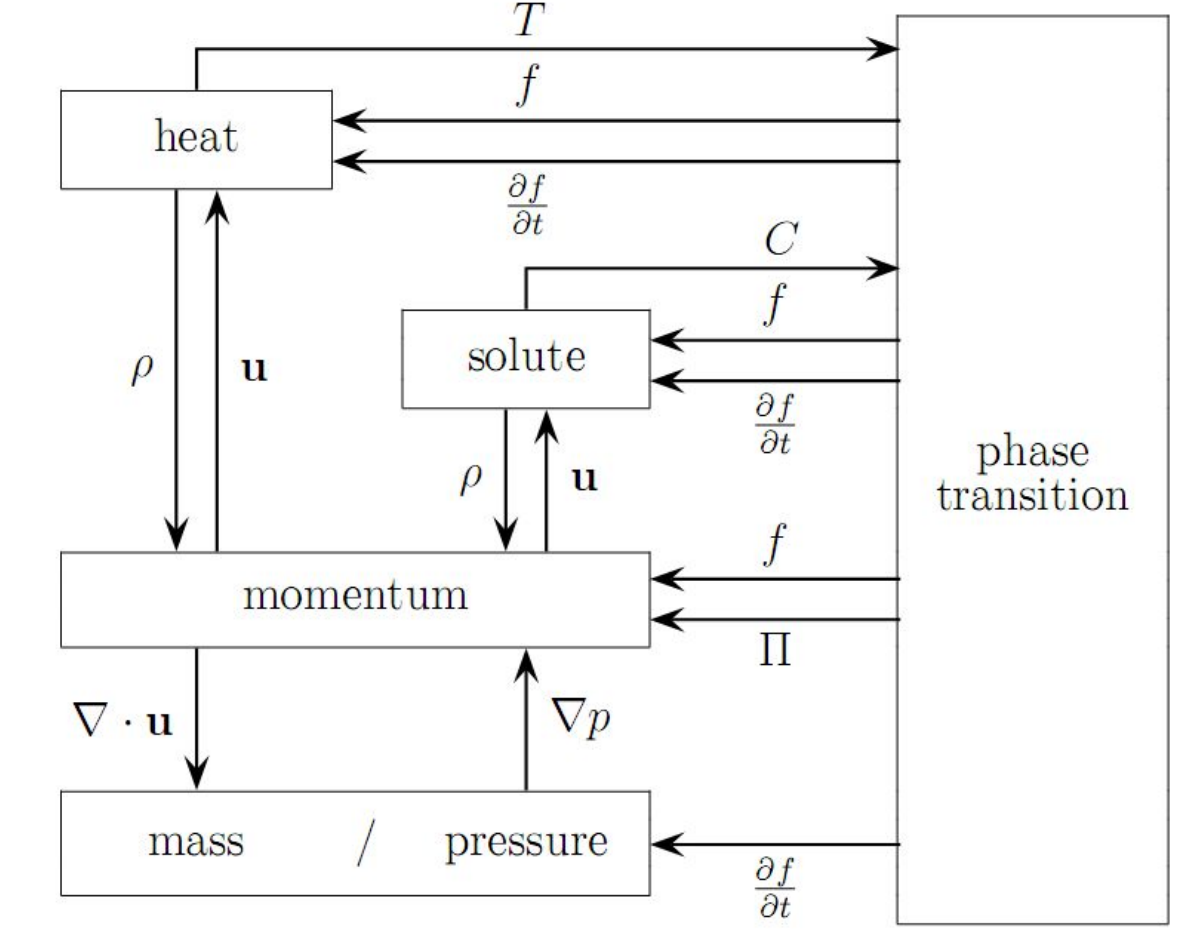
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Glossary

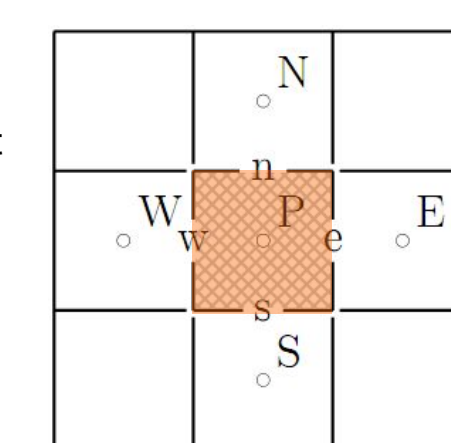
Coupled governing equations:

The governing equations (conservation equations for mass, momentum, solute, heat) and the constitutive relation (phase transition) form a system of mutually dependent differential equations. This interdependency is illustrated in the chart on the right for momentum u , pressure p , solute concentration C , temperature T , density ρ , porosity f , and permeability Π .



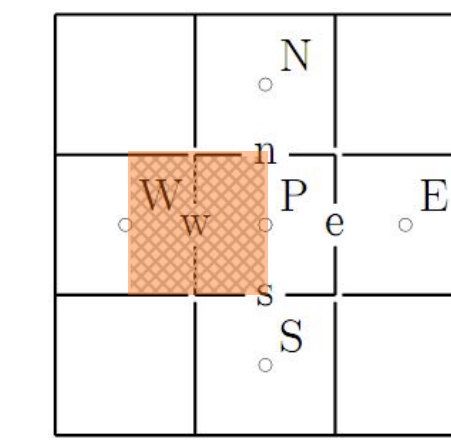
Finite Volume Method (FVM):

Method to discretize governing equations. Solutions are sought for the average properties of each cell (i.e. volume of finite size) of the domain.



Staggered grid:

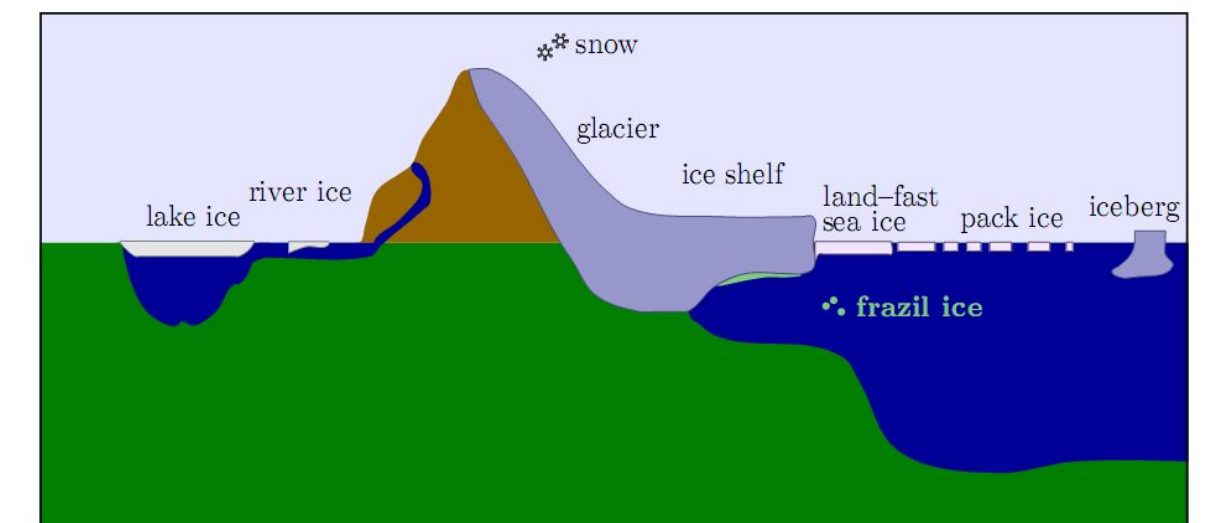
The governing equations for the velocity components are solved on a grid that is staggered by half a grid cell.



Lateral velocity components are solved at the lateral cell boundaries. Vertical velocity components are solved at the vertical cell boundaries.

Sea ice: ice that forms from freezing (salty) ocean water; typically 0.5 m to 3 m thick.

This distinguishes sea ice from snow, glaciers, and icebergs as those are frozen meteoric water.



Field work: seasonal opportunity to validate models, typically within 2000 km of either pole.

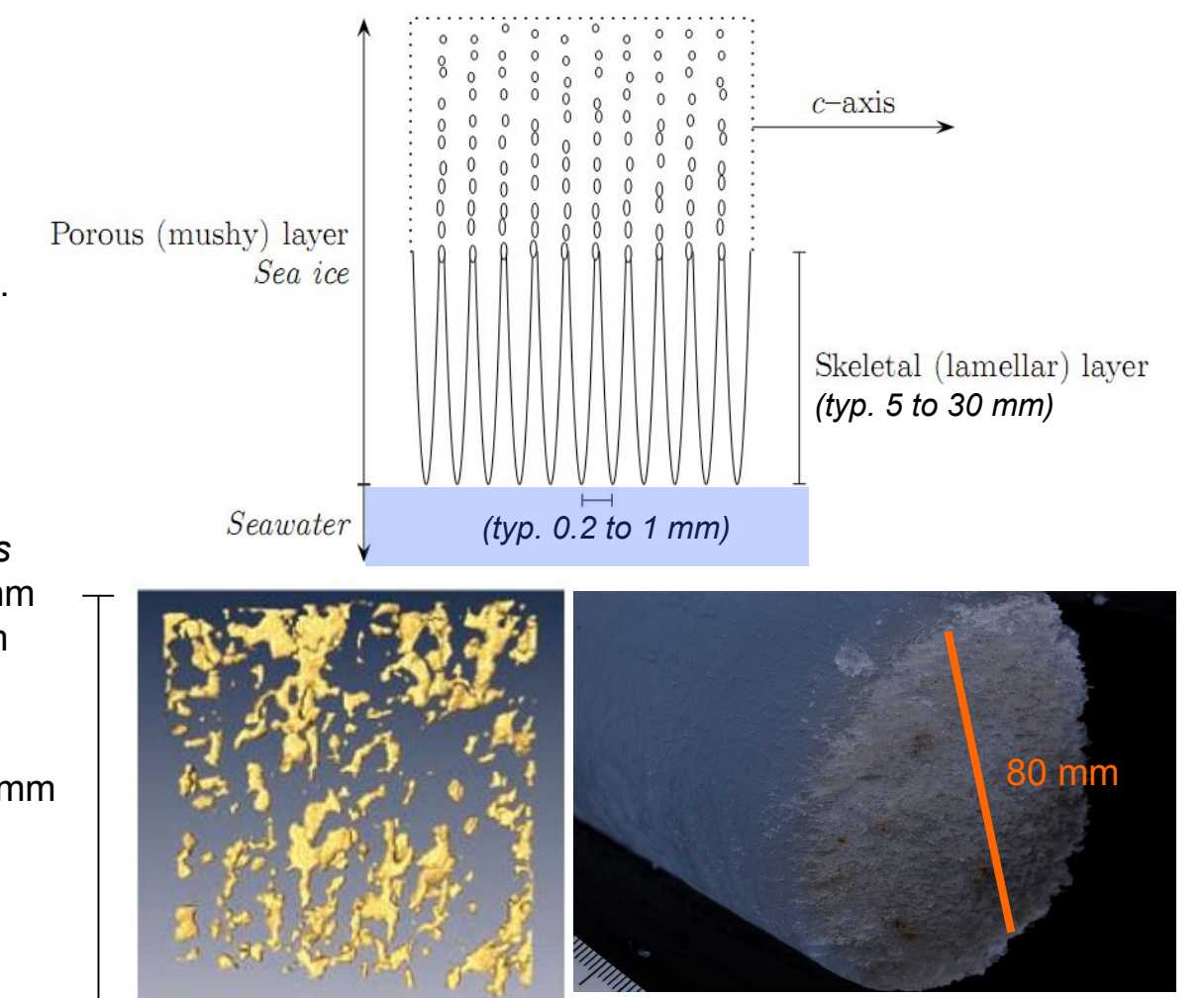


Sea ice pore structure:

more or less interconnected inclusions of very salty brine. Small brine inclusions are typically found layered in the basal plane of (hcp) ice crystals.

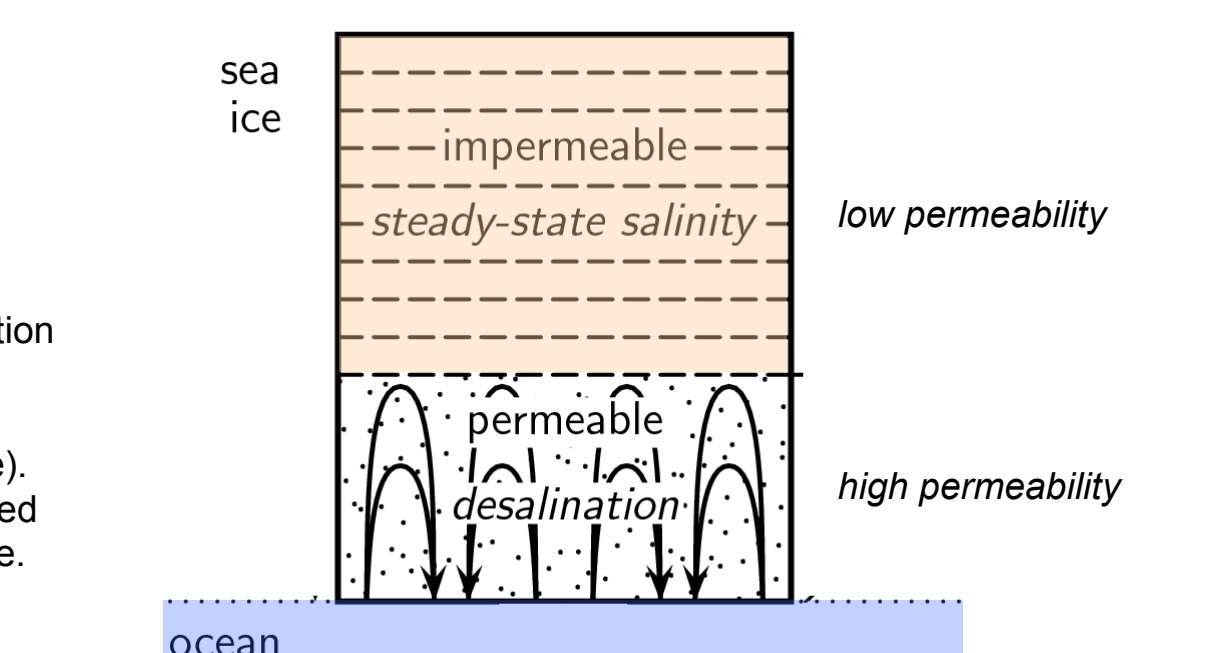
Individual brine pockets (called freckles in metallurgy) may be smaller than 10 μm .

Brine channels (called chimneys in metallurgy) may exceed 10 mm in diameter and several 100 mm in length.



Gravity drainage:

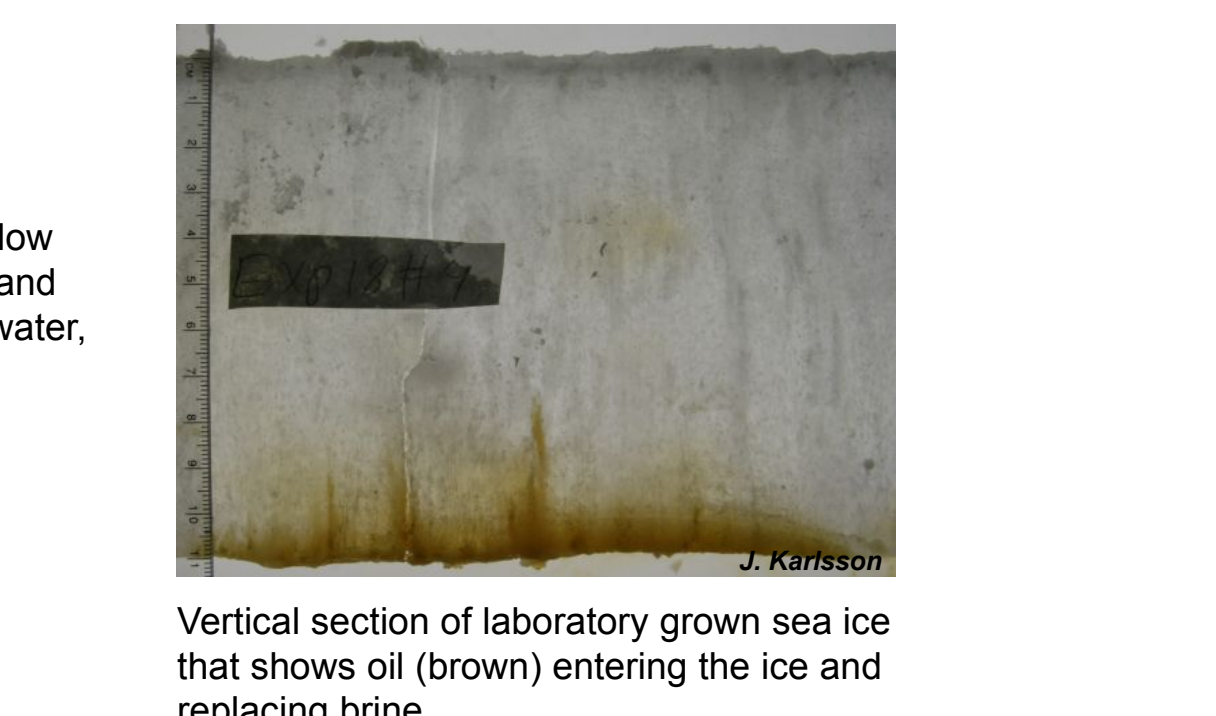
the process of sea ice desalination due to fluid exchange between brine in the sea ice pore structure (very saline) and the ocean (less saline). This process is generally due to natural convection of unstably stratified brine (very saline, dense brine above less saline and less dense brine). This process is generally confined to the bottom couple of cm of ice.



Single phase flow:

only one fluid moves in the domain (e.g. saltwater).

This contrasts with multiphase flow where two or more fluids move and interact in the domain (e.g. saltwater, oil, air).



Acknowledgements

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