Sea ice and the evolution of a brine channel

Russell Campbell

12/04/2022

Background

- Sea ice in the arctic

Decline

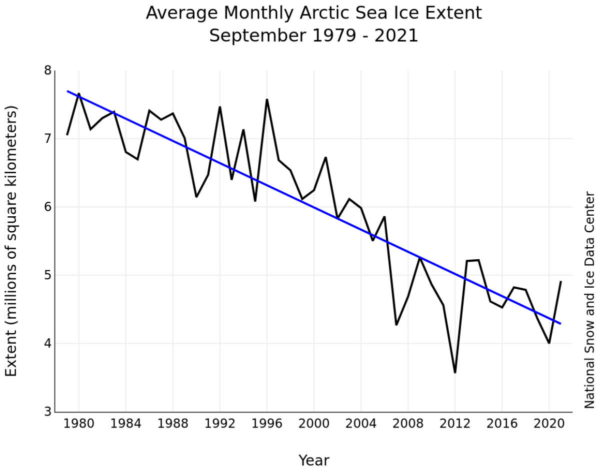


Figure 1: Source: National Snow and Ice Data Center

Decline

- Indicator of climate change...
- Loss also accelerates climate change

Environmental functions

Sea ice acts as an insulator

- Reduces heat fluxes from the ocean to atmosphere
- Reduces the amount of solar radiation absorbed by oceanic mixed layer (high albedo)

Various factors influence how effectively sea ice performs environmental roles

- Extent
- Thickness
- Albedo
- Duration of periods of low extent (summer)

Modelling the ice interior

- Sea ice: a mushy layer formed primarily of water and salt (Feltham 2006)
- Mushy layer: a multi-component porous medium which forms during phase transition

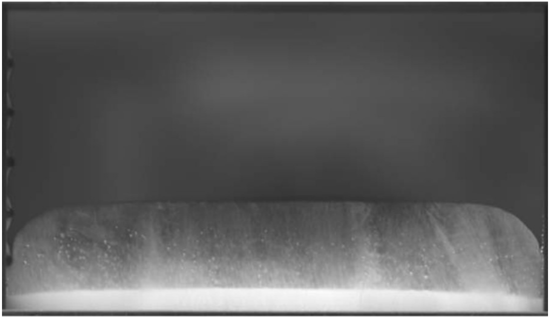


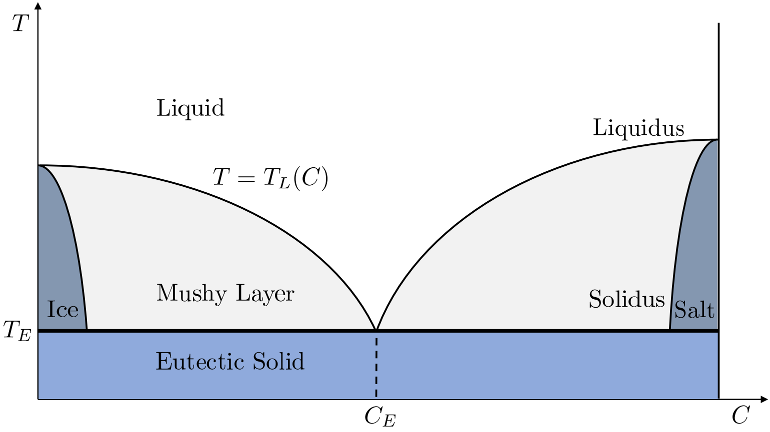
Figure 2: A mushy layer (Peppin 2007)

Modelling the ice interior

Four primary variables used to describe interior of ice:

- Temperature T (or enthalpy H)
- Concentration of salt C (liquid), $C_s \approx 0$ (solid)
- Solid fraction ϕ
- Darcy velocity $\mathbf{u}$

The liquidus relationship



- Temperature and concentration in local thermodynamic equilibrium in a mushy layer

Ideal mushy layer equations

- Evolution of ice interior described using the mushy layer equations
- Ideal M-L equations:

$$\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T = \kappa \nabla^2 T + \frac{L}{c_p} \frac{\partial \phi}{\partial t}$$

$$\frac{\partial}{\partial t} \left((1 - \phi) C + \phi C_s \right) = \mathbf{u} \cdot \nabla C$$

$$\mu \mathbf{u} = \Pi \left(-\nabla p - \rho \mathbf{g} \right)$$

$$\nabla \cdot \mathbf{u} = -\frac{\rho_s - \rho}{\rho} \frac{\partial \phi}{\partial t}$$

Brine channels

Critical feature controlling sea ice development and environmental properties

Stages of evolution:

- Formation
- Primary control of desalination during ice growth/warming - deepens oceanic mixed layer
- A control of melt pond balance - controls albedo

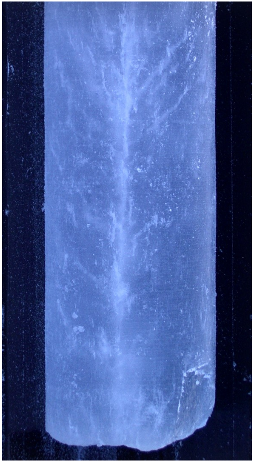


Figure 3: Brine channel in an ice core. Image courtesy of National Science Foundation

Formation and desalination control

- Once ice exceeds critical thickness, density gradient may cause brine channels to form

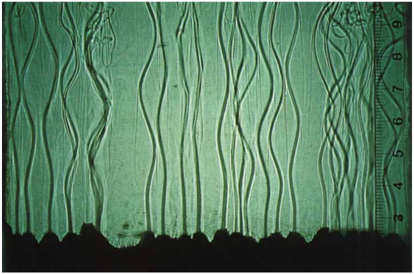


Figure 4: Solute-enriched plumes emanating from channels in a mushy layer (Huppert 1990)

- Nonlinear increase in permeability in channel formation results in focusing of flow
- Channels provide a means of desalination
- In spring, atmospheric warming results in further desalination
- Depth and salinity of oceanic mixed layer increase, bulk ice concentration decreases

A control of melt pond balance

- In summer, surface ice melts and meltwater flows through remnant brine channels
- Low salinity meltwater comes into contact with channel walls, freezing and blocking critical junctions
- Results in accumulation of ponds on ice surface, lowering albedo

Figure 5: An ice core with brine channels blocked by dyed meltwater (Polashenski 2017)

A control of melt pond balance

- As ice continues to warm, blockages melt and flow causes channels to widen and allow pond drainage

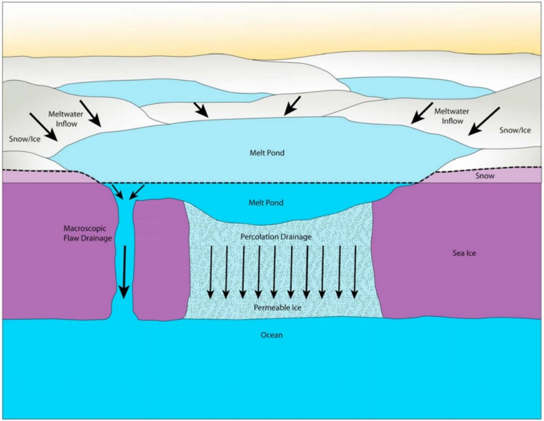


Figure 6: Illustration of melt pond drainage mechanisms (Polashenski 2012)

Closing remarks

- Brine channels: an important feature throughout ice development
- Directly affect the ice concentration and albedo as well as properties of the mixed layer
- Crucial to understanding the changing nature of ice properties which affect the environment