Sea ice salinity and salt flux from a growing ice sheet in the presence of an oceanic heat flux

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1. Summary

Known:
- Growing sea ice is a source of dense brine
- Physical properties of sea ice depend on salinity
- Salinity and salt flux depend on growth conditions

Aim:
- Determine the dependency of the stable sea ice salinity and salt flux on the growth velocity and temperature gradient in the ice in the presence of an oceanic heat flux.

Method:
- Treat sea ice as a porous medium, porosity f
- 2-dimensional finite volume fluid dynamics simulations
  - impose oceanic heat flux F_{ocean}
  - impose heat exchange with atmosphere
  - determine salt flux \Phi, sea ice salinity S
  - determine temperature gradient \partial T/\partial t; ice growth velocity \nu
- find empirical relationship \Phi = \Phi_f(F_o, \partial T/\partial t; \nu)

2. Governing equations

- Single set of governing equations for porous sea ice and ocean (Petrich et al., 2006)
- Volume averaged equations \rightarrow volume fraction of liquid, f
- Local physical properties: weighted averages of solid (\{\}) and liquid (\{\})
- Isotropic permeability B_f

Mass conservation:
\[ \frac{\partial (f \rho \Phi)}{\partial t} + \rho \Phi \cdot \nabla \Phi = \nabla \cdot \nabla \Phi \]

Momentum conservation:
\[ \frac{\partial (f \rho \Phi \nu)}{\partial t} + \rho \Phi \cdot \nabla \nu = \nabla \cdot \nabla \nu \]

Energy conservation:
\[ \frac{\partial (f \rho c_v \Phi T)}{\partial t} + \rho \Phi \cdot \nabla T = \nabla \cdot \nabla T \]

Solute conservation:
\[ \frac{\partial (f \rho \Phi C)}{\partial t} + \rho \Phi \cdot \nabla C = \nabla \cdot \nabla C \]

Local thermodynamic equilibrium:
\[ T = T_f(\Phi) \]

3. Background

Desalination occurs
- over a relatively short period of time (\Delta t) after initial freezing (Nakawo and Sinh, 1981)
- close to the ice-ocean interface

Energy balance at the ice-ocean interface:
\[ F_{ocean} = \nu \Phi(f + \Phi_f) + \frac{\partial T}{\partial t} \]

4. Computational domain

- Oceanic heat flux – imposed 0.1 to 0.2 m below the sea ice-ocean interface
- Enforced by adjusting the temperature of upwelling water
- Sea ice-atmosphere interface: constant T_s or constant \partial T/\partial t
- Domain is periodic horizontally

5. Sea ice permeability

Permeability–porosity relationship is based on laboratory work of Cox and Weeks (1975) (Petrich et al., 2006). The magnitude is calibrated to obtain salinities consistent with the model of Cox and Weeks (1988), assuming F_{ocean} = 0.

6. Salinity profile

- Oceanic heat flux F_{ocean} = 0 Wm^{-2}
- Oceanic heat flux F_{ocean} = 10 Wm^{-2}
- Oceanic heat flux F_{ocean} = 30 Wm^{-2}

Global salinity profile (solid line), and parameterisation (dashed line) from Equation (1).

7. Sea ice salinity

- Sea ice salinity S = S_0 \left( \frac{\Phi(t, \nu)}{\Phi_f(\nu)} \right)^{1/3} \]

8. Salt flux

- Comparison of the mean salt flux \Phi = \langle C_0 \rangle determined from the simulations with the parameterisation
\[ \Phi_{\text{param}} = C_0 \left( \frac{\nu}{\Phi_f(\nu)} \right) \]

9. Conclusion

- A fluid dynamics model has been used to determine parameterisations of the stable sea ice salinity and the salt flux of growing sea ice.
- In larger scale models, the stable salinity profile of a growing sea ice sheet can be parameterised based on the temperature gradient and oceanic heat flux. The relationship follows a power law.
- The salt flux depends on the growth velocity and the stable salinity of the ice.

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References

Cox, G. F. N., and W. F. Weeks (1975), Brine drainage and initial salt entrapment of growing, salty ice: Research Report 480, Cold Regions Research and Engineering Laboratory, Hanover, NH, USA.

