Modeling microphysics and salinity evolution of sea ice

Adrian Turner (LANL), Elizabeth Hunke (LANL), Cecilia Bitz (Univ. Washington) and Nicole Jeffery (LANL)

Los Alamos NATIONAL LABORATORY EST. 1943

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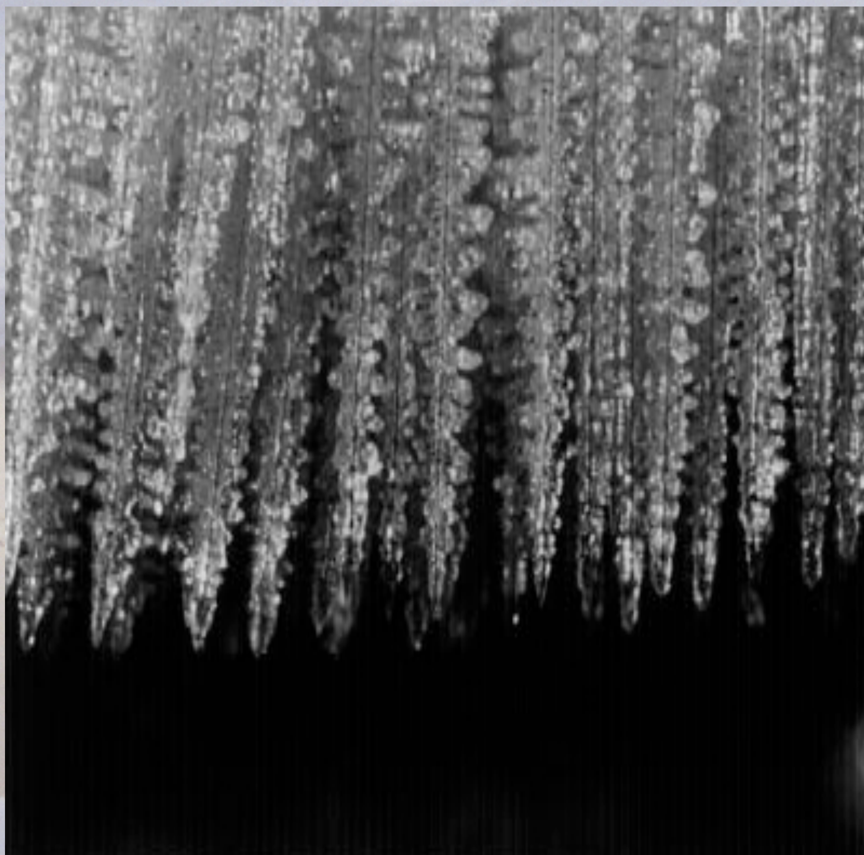
Project goal

- Currently Los Alamos sea ice model, CICE, has fixed salinity profile
- Aim to include salinity as a prognostic variable in the model
- Model processes that move brine around the ice and change salinity profile

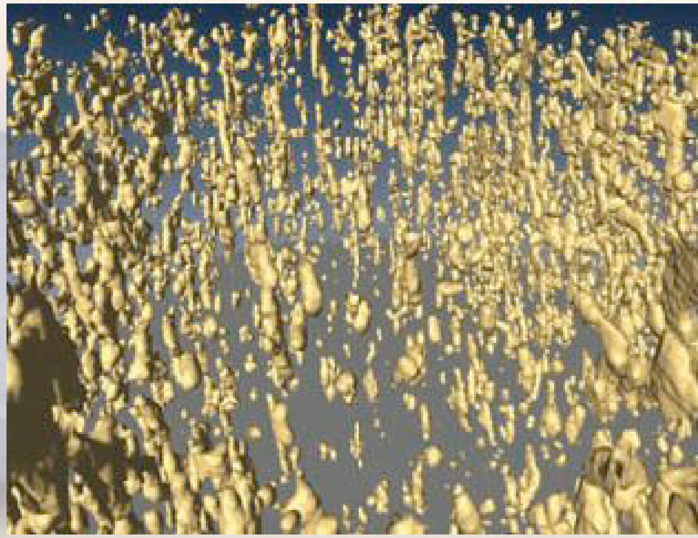
Sea ice formation

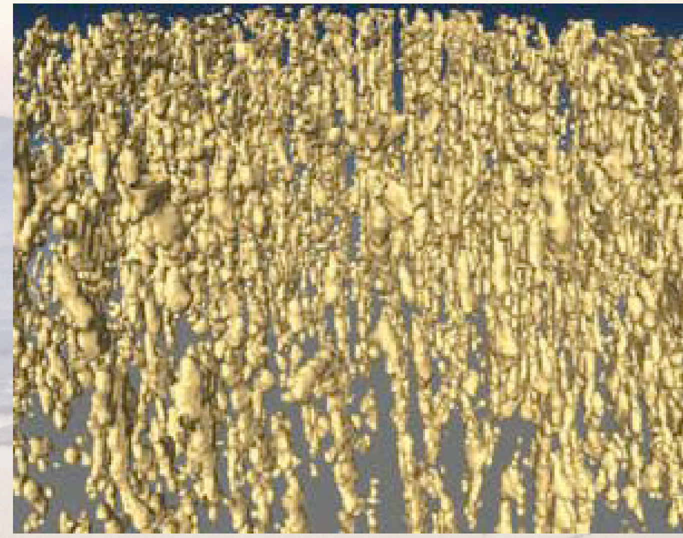


Worster (1999)

- Freezing interface becomes morphologically unstable during growth
- Brine is trapped between dendritic crystals
- Resulting structure is termed a "mushy layer"

Sea ice pore structure

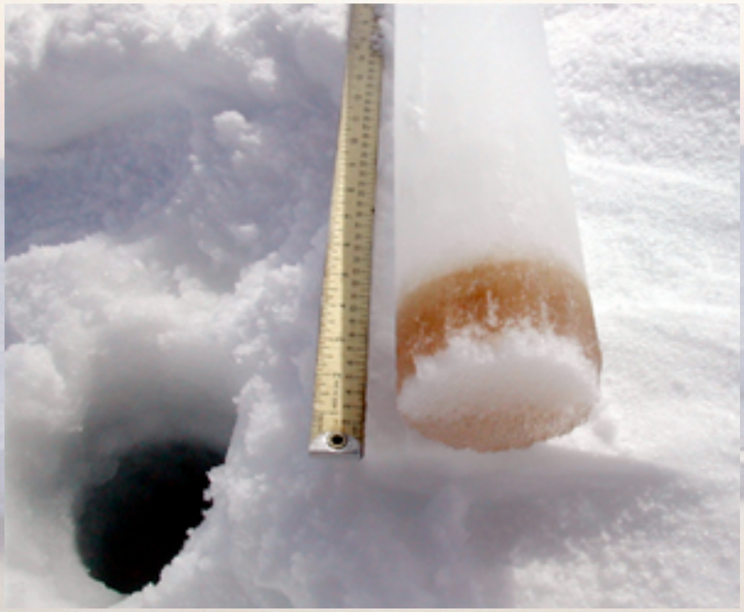




K. M. Golden et al. (2007)

- Pore structure changes dynamically according to changes in temperature and brine pocket salinity
- Temperature increase melts surrounding ice and increases liquid fraction
- Salinity increase dissolves surrounding ice and increases liquid fraction
- Brine actively flows through connected brine pockets

Effect of salinity structure



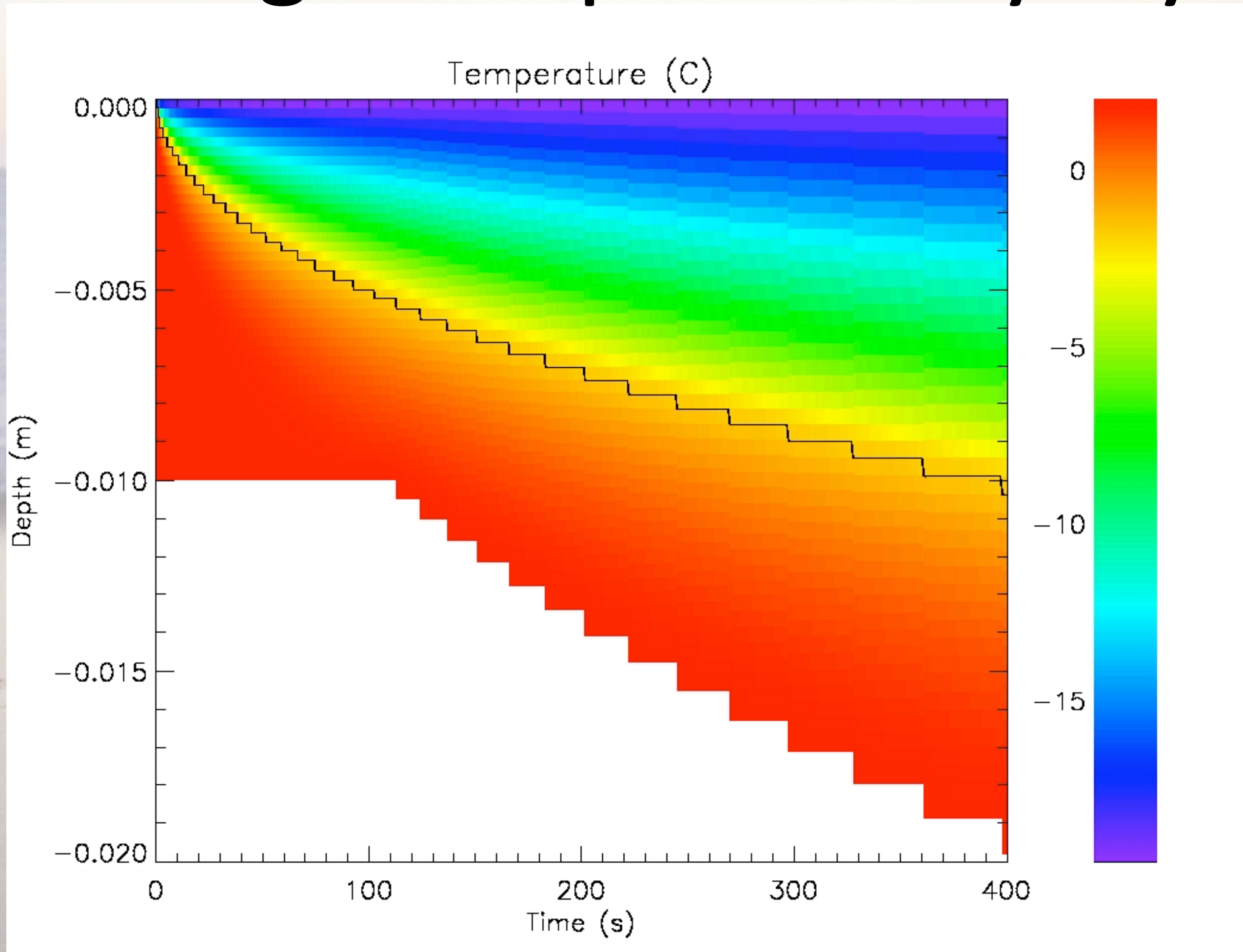
NOAA

- Sea ice is home to a wide variety of organisms – bacteria, diatoms
- Need to be able to simulate flow of brine around sea ice to model flow of nutrients that supports this life
- Biology affects radiation absorption through albedo
- Salinity profile also effects physical properties – ice strength, melt rate

The mushy layer

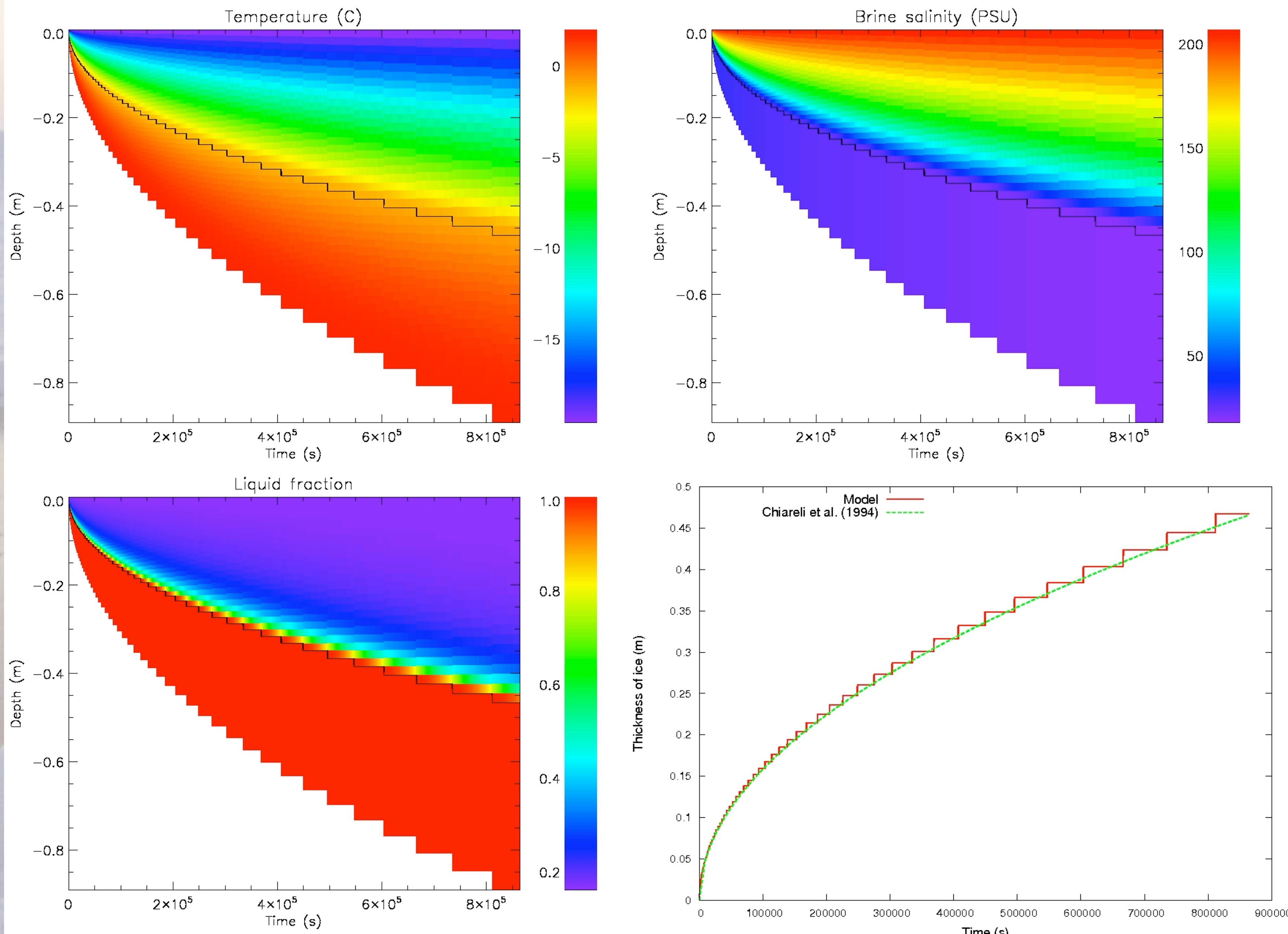
- Consider two dependent variables – Enthalpy, *q*, and Bulk Salinity, *S*
- Assume brine lies on the liquidus curve i.e. is in equilibrium with the ice – can infer brine salinity from the temperature
- Liquid fraction inferred from ratio of bulk salinity to brine salinity
- Governing equations are those of conservation of energy, salt, and mass
- Flow of brine in mushy layer governed by Darcy equation for flow in porous medium

Growing a simple mushy layer

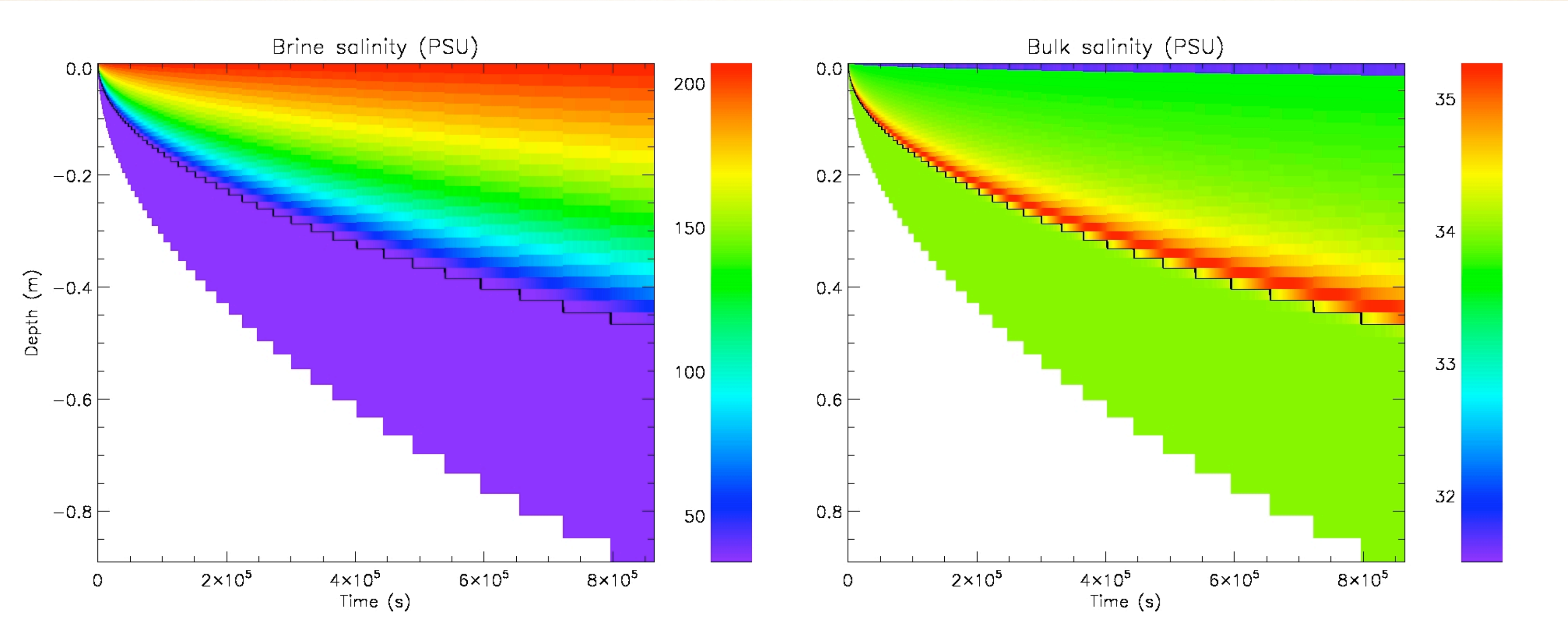


- 1cm of 2°C, 34 PSU salt water cooled from above at -20°C for 10 days
- Fixed domain including both pure liquid and mush which is periodically regrided to allow for growing ice interface
- No salt transport processes

Growing a simple mushy layer II



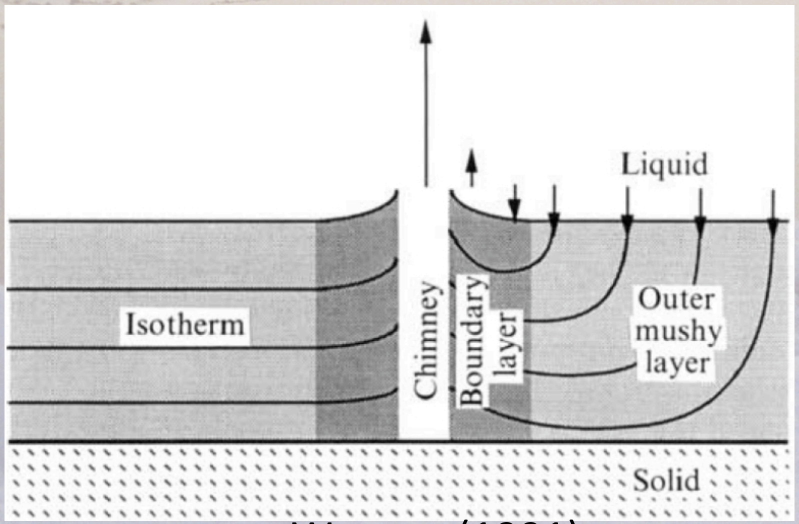
Molecular diffusion of salt



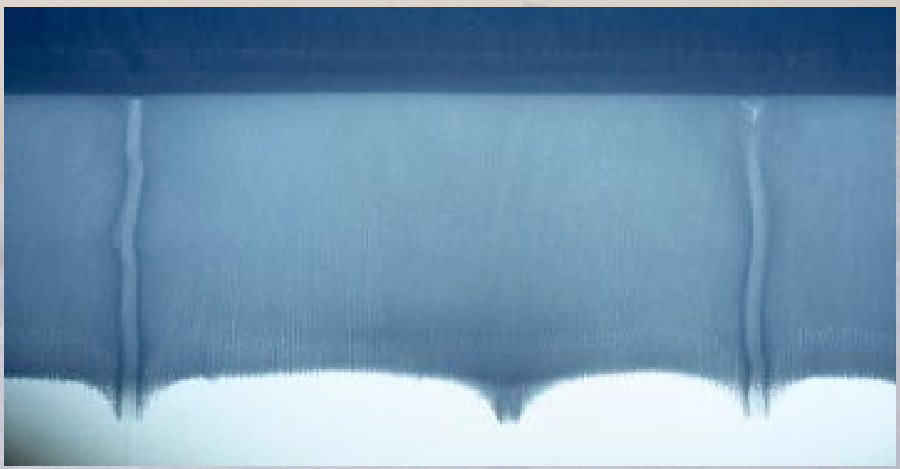
- Salt diffuses through pore structure down steep concentration gradient in brine
- Zero surface gradient in brine salinity for salt conservation
- Mild desalination of surface and increase in concentration at growing interface

Convection and Gravity Drainage

- Growing ice has high salinity brine overlaying low salinity brine – higher density brine over lower density brine
- Convection overturning of brine in ice matrix
- Brine motion results in change in ice matrix structure – development of chimneys
- Resulting brine loss from ice responsible for desalination of ice



Worster (1991)


Worster (2000)

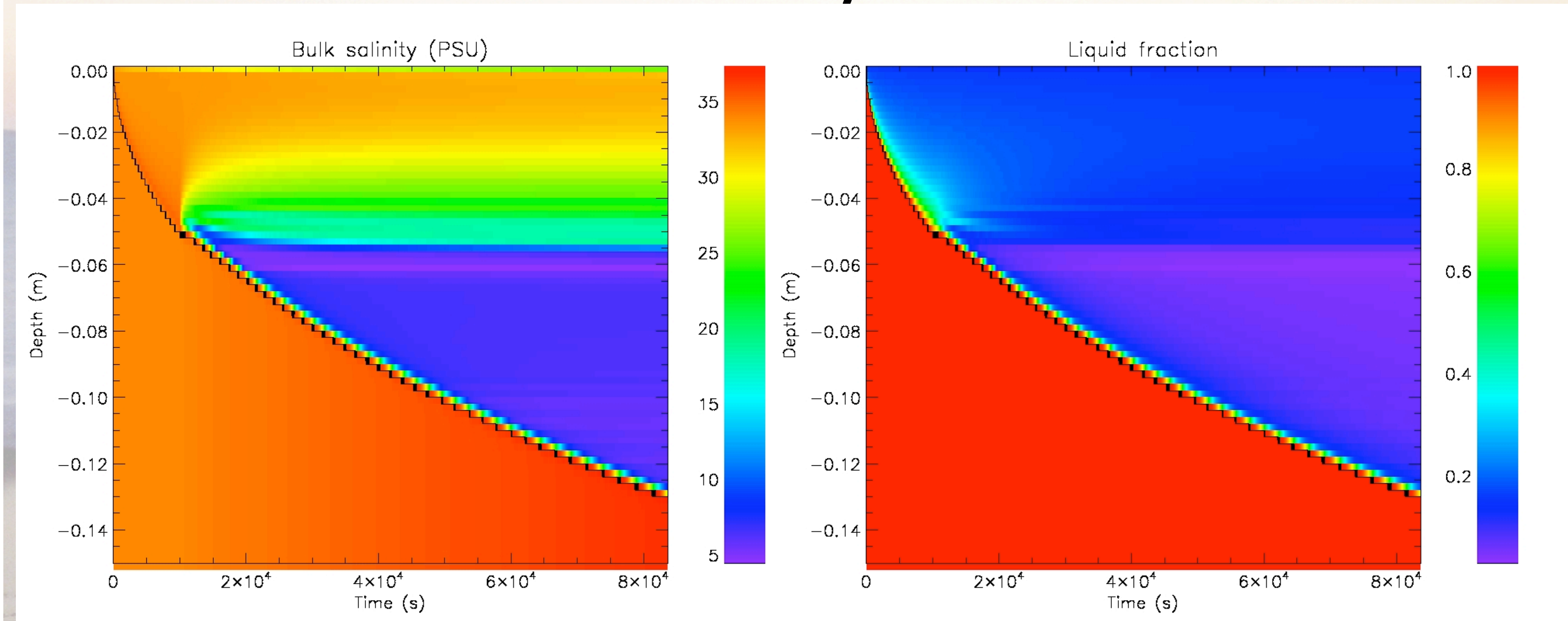
An Eddy diffusion parameterization

- Need to parameterize intrinsically multi-dimensional process of convection with one dimensional model
- Investigating a parameterization due to Nicole Jeffery (Jeffery et al. *in prep*)
  - Reynolds average three dimensional flow in ice
  - Propose Reynolds flux of salt given by diffusive parameterization

$$\mathrm{EddySaltFlux} = -D\frac{\partial S_{br}}{\partial z} = -wl\frac{\partial S_{br}}{\partial z}$$

  - Use mixing length theory to determine length scale *l*
  - Velocity scale *w* given by Darcy flow driven by density differences between ice and ocean
  - Various choices for length scale *l* and density difference that drives flow
  - Initially try constant mixing length, local permeability and density averaged over a surrounding region

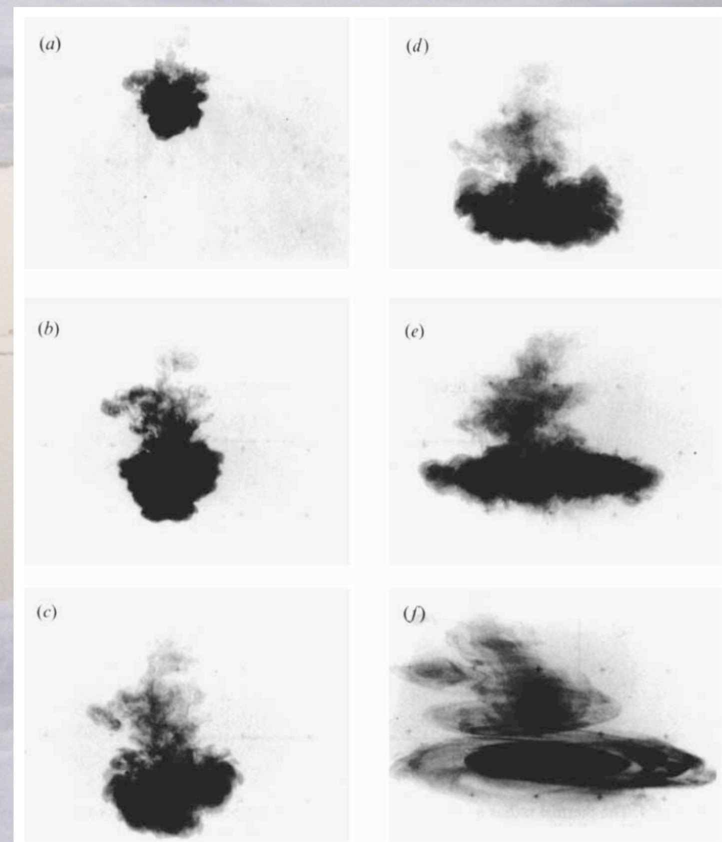
Preliminary results



- Fixed domain
- Switch on drainage when ice thickness reaches 5cm
- Get rapid desalination in lower regions and “C” shaped profile

Salt transport in the ocean

- Since are modelling part of ocean need to consider transport processes there
- Molecular diffusion is too small to transport salt away from interface sufficiently – drained brine should sink
- For comparisons with tank experiment will mix ice free region while conserving heat and salt
- For field comparisons with real ocean will have to decide parameterization – turbulent model (e.g. that of McPhee), salt plume model (e.g. Nguyen et al. 2009) or perfectly mixed layer

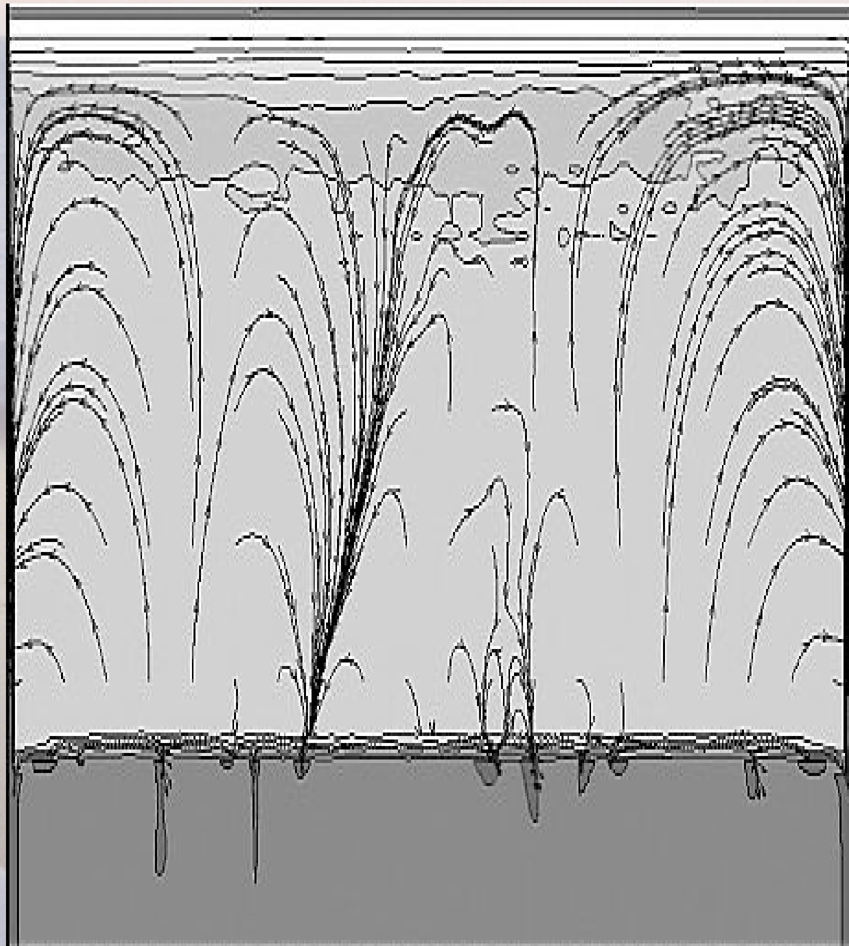


Helfrich (1994)

Numerics

- Need to solve system of non-linear coupled equations
- Currently developing two solvers:
  - Rosenbrock Runge-Kutta – explicit method with Jacobian calculated numerically and adaptive stepsize
  - Jacobian-free Newton Krylov – implicit method widely used for non-symmetric non-linear systems

High resolution 3D simulations



Oertling and Watts, 2004

- Use LANL cfdlib to directly simulate convective overturning in growing sea ice.
- Use results to guide simple 1D parameterizations.
- Work done in collaboration with Bucky Kashiwa (LANL)

Future processes

- Basal and surface melting
- Interface interchange processes
- Flushing by melt waters
- Non-equilibrium of brine
- Inclusion into GCM