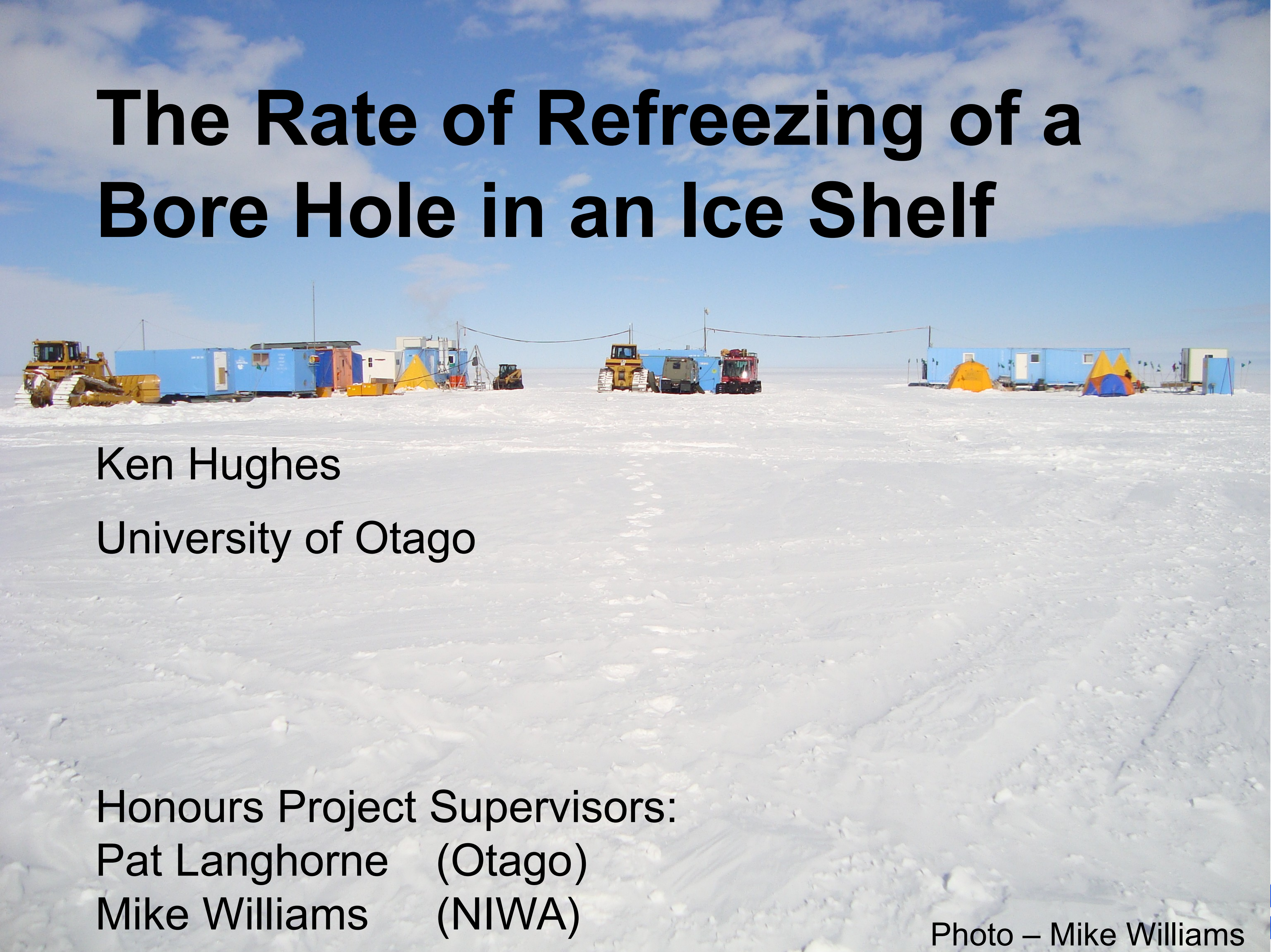
The Rate of Refreezing of a Bore Hole in an Ice Shelf



Ken Hughes

University of Otago

Honours Project Supervisors:
Pat Langhorne (Otago)
Mike Williams (NIWA)

Photo – Mike Williams

Hot Water Drilling

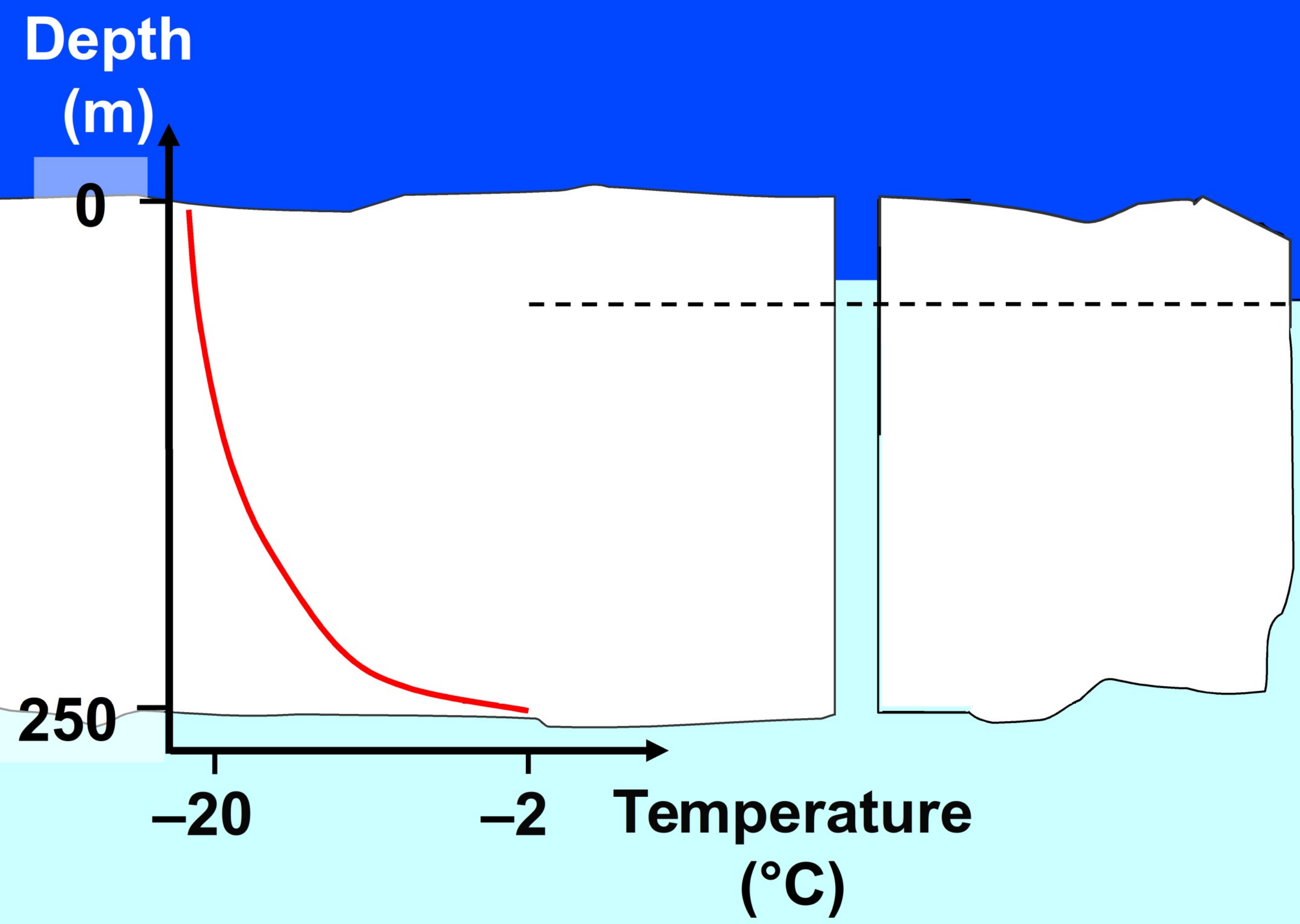
- Allows quick access to remote regions
- Creates holes for measurements in the ocean below the ice shelf
- Produces long, thin, cylindrical holes that refreeze quickly
- Why model this?

Field Study

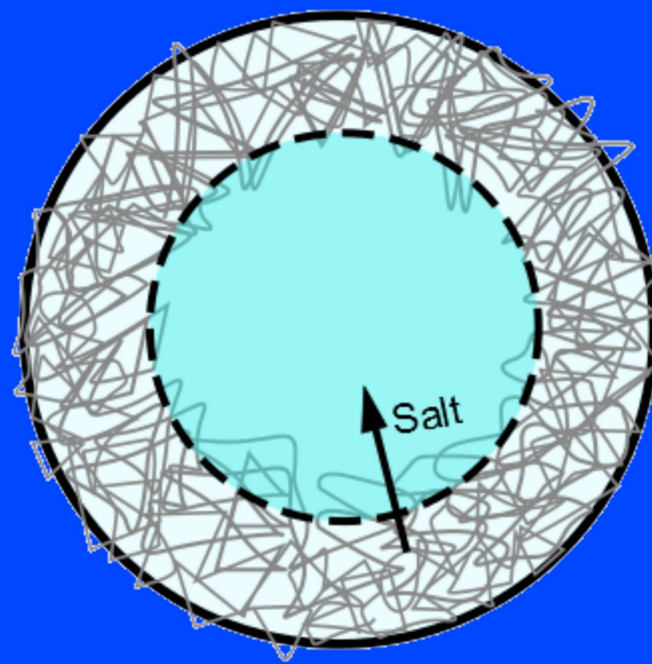
- Data taken from NIWA field study in December 2010
- Oceanographic casts
  - Temperature
  - Salinity
  - Depth
- 2 × 10 profiles

Photo: http://www.lib.utexas.edu/maps/polar.html

Bore Hole and Ice Shelf Dimensions



Refreezing Ice



- Rejects salt when freezing
  - Water becomes more salty

- Forms open structured ice on inside of hole
  - Best estimate of fraction solid of ice is 0.4

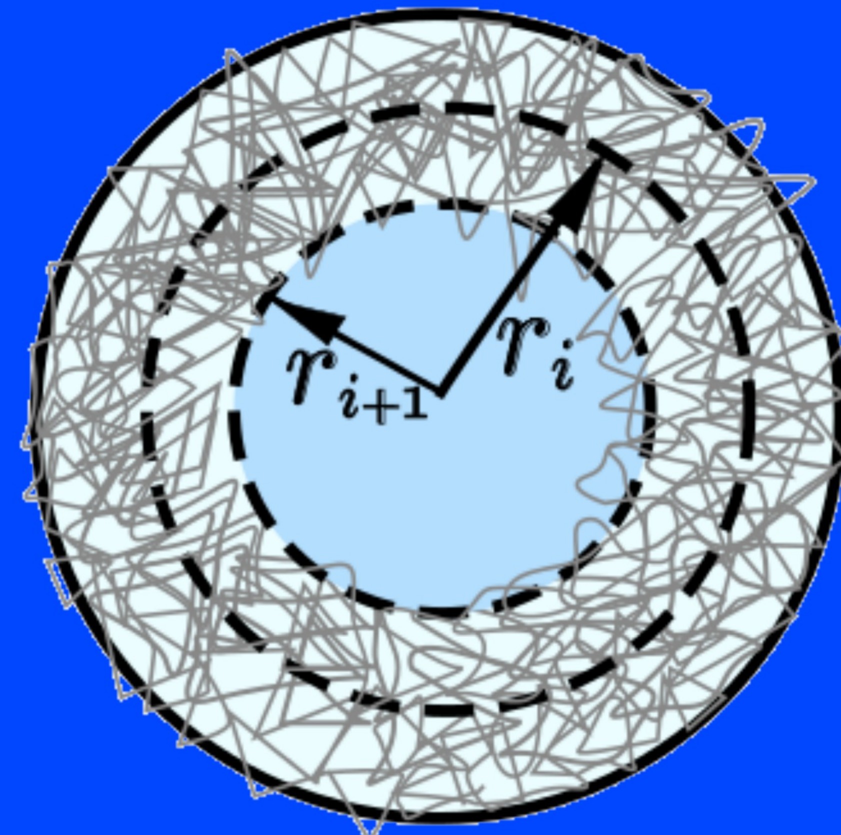
Photo: Craig Stevens (NIWA)

Calculations of Ice Growth

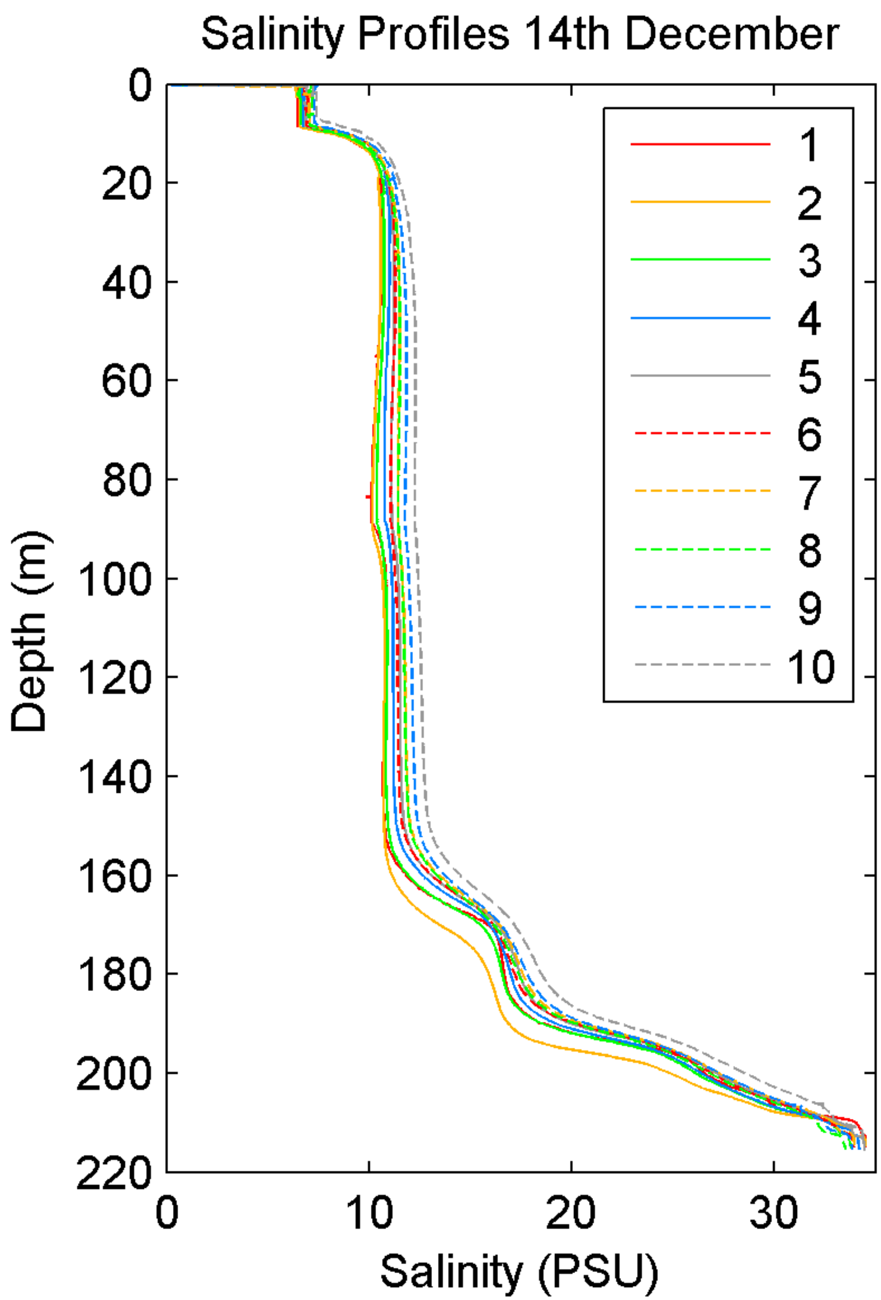
- Closure deduced from salinity
  - Salinity values used as a proxy for ice growth
- Equate conductive heat flux to latent heat from ice growth
- Distinct calculations other yet give similar results

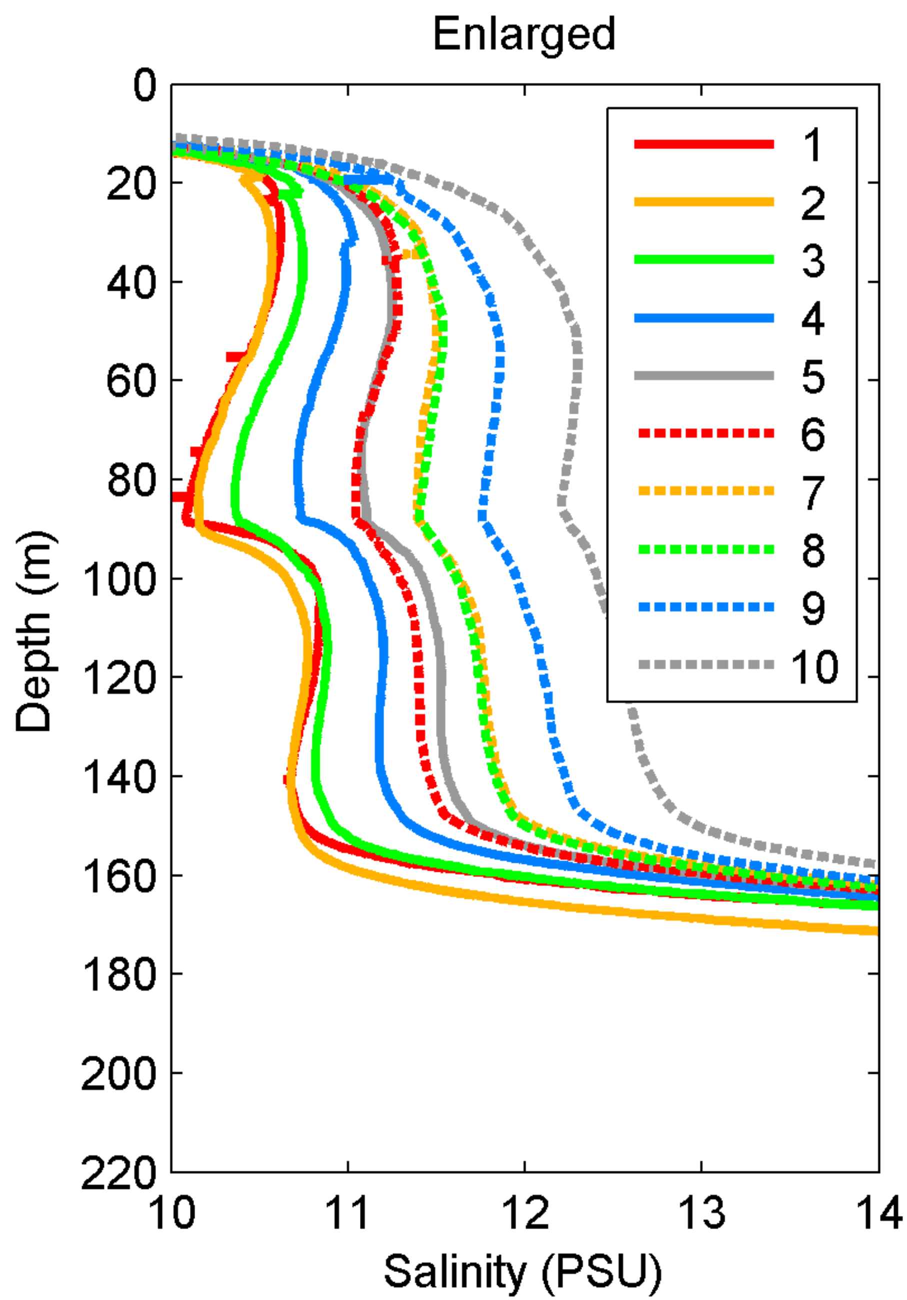
Ice Growth from Salinity

- Calculate closure rate from salinity measurements
- Conservation of mass of salt
- Model as number of independent 1D problems



Salinity Measurements



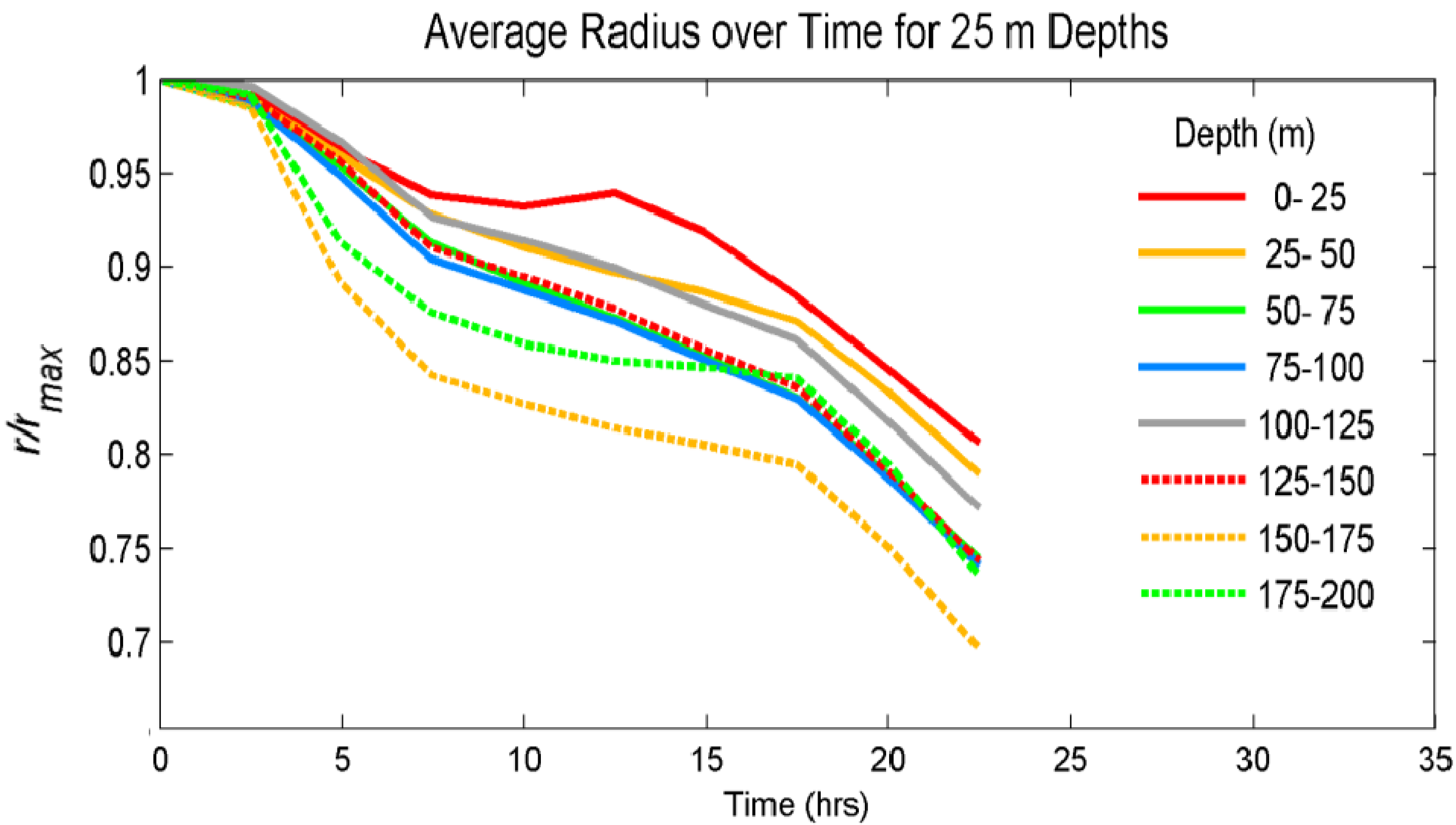


Casts 1-10 are sequential and 150 ± 5 minutes apart

Challenges with Salinity Calculation

- Awkward boundary condition
  - Assume closed system, ignoring connection to ocean
- Results sensitive solid ice fraction

Closure Deduced from Salinity



Growth from Heat Conduction

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} - \frac{1}{\kappa}\frac{\partial T}{\partial t} = 0 \qquad r > a$$

$$T(r,t) = T_{ice} \quad as \quad r \to \infty$$

$$T(r,0) = T_{ice}$$

$$T(r < a, t) = T_0$$

Use Matlab's 'pdepe' function

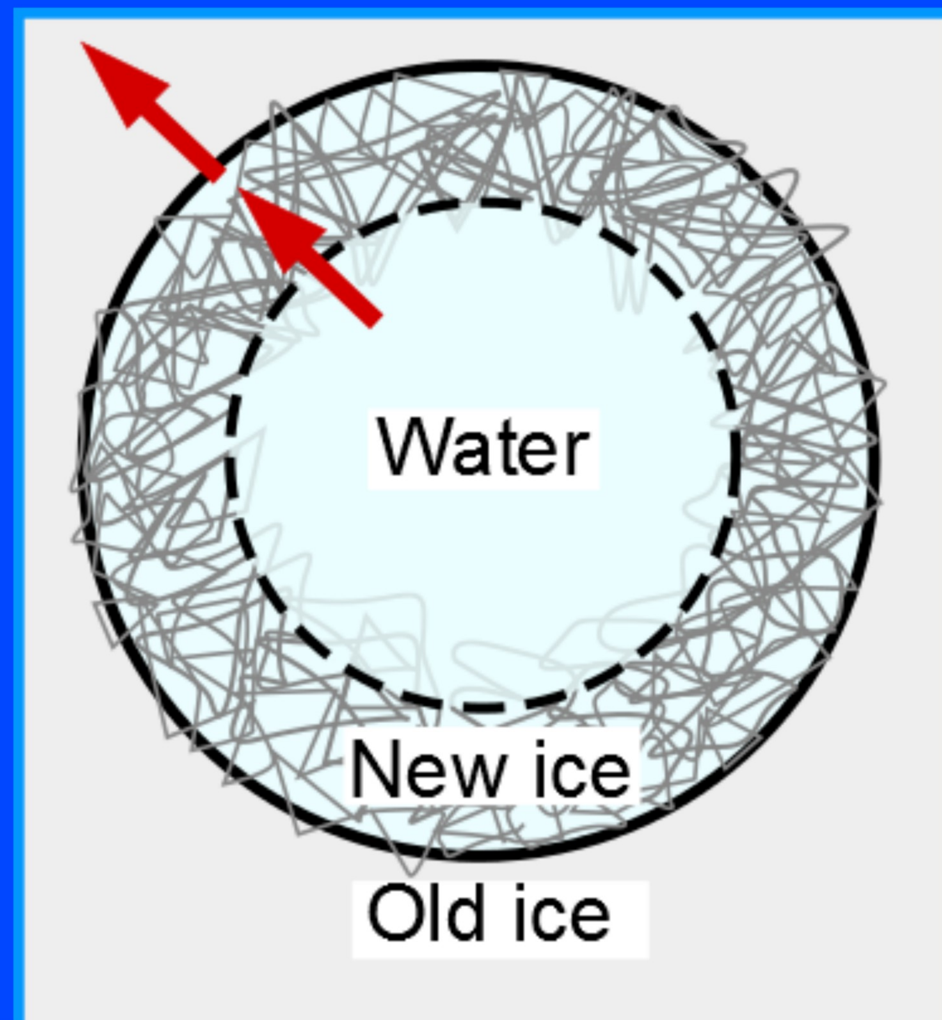
Carslaw and Jaeger 1959

Growth of Ice

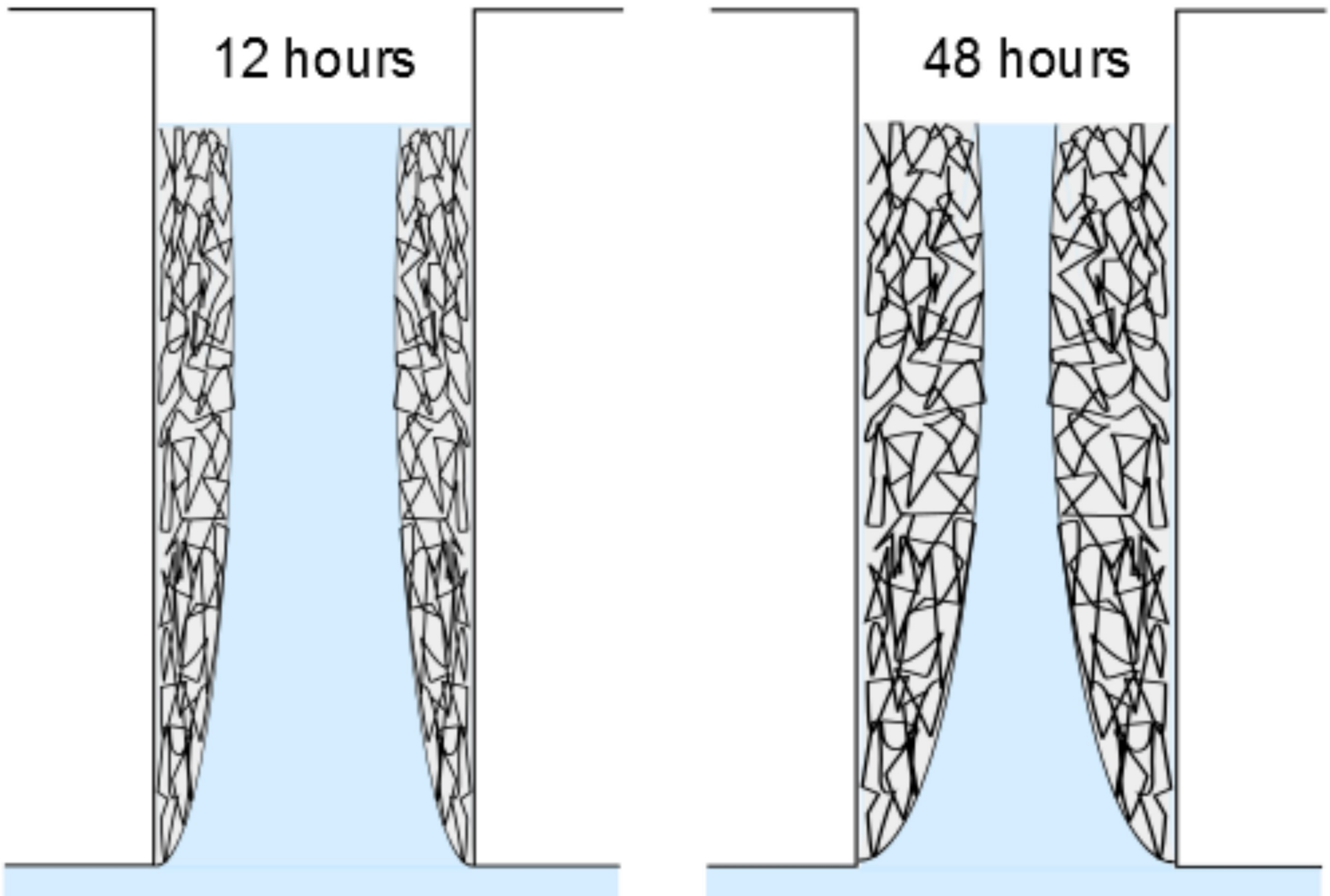
- Heat flux balance

  $Q_{ice} - Q_{water} = Q_{latent}$

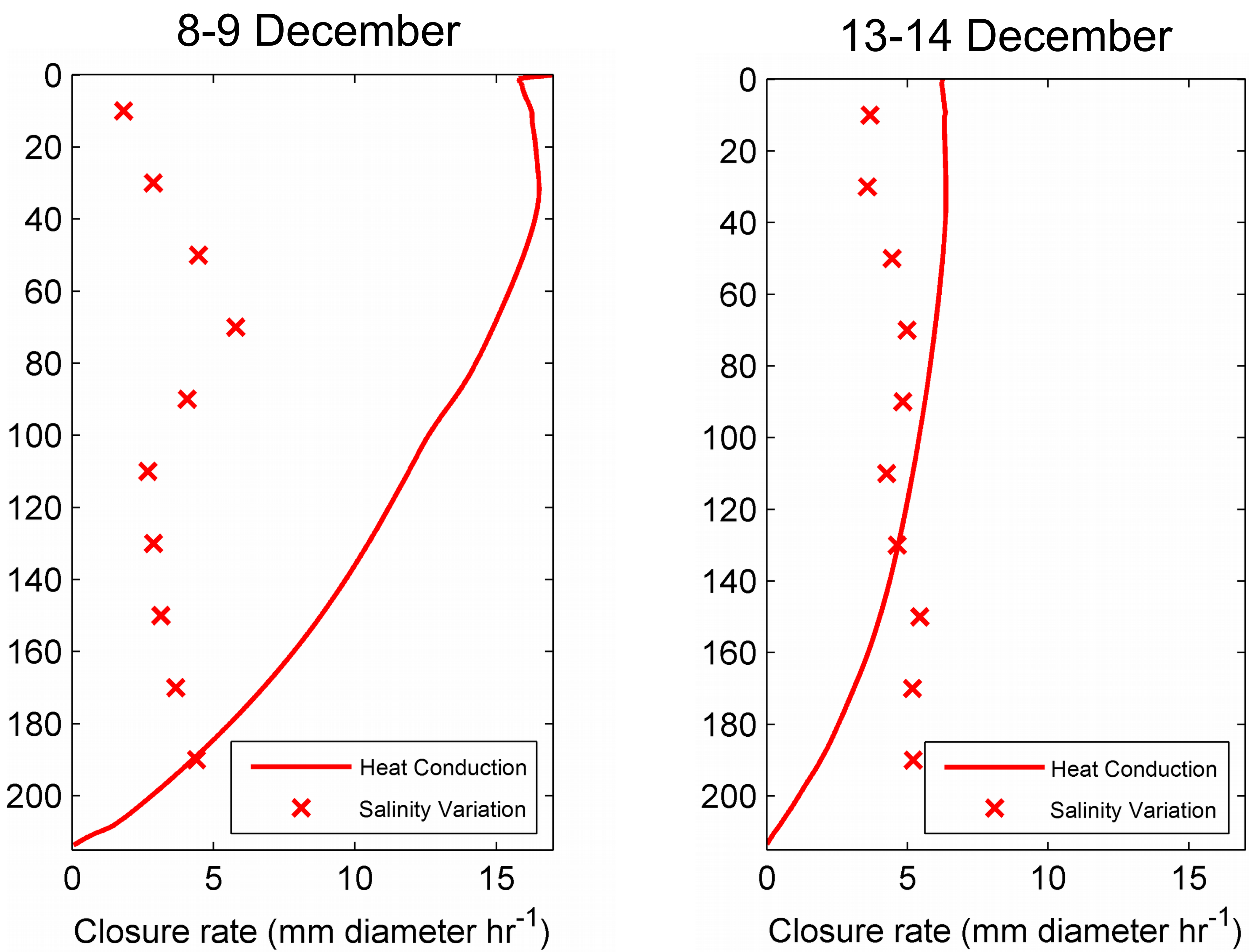
- Heat transfer in new ice



Result



Comparison



8-9 December
13-14 December
0
20
40
60
80
100
120
140
160
180
200
0
5
10
15
Closure rate (mm diameter hr^{-1})
Heat Conduction
Salinity Variation

Conclusions

- Heat flux model is verified by results from salt mass conservation equation
- Results sensitive to solid fraction value