Two modes of sea ice gravity drainage

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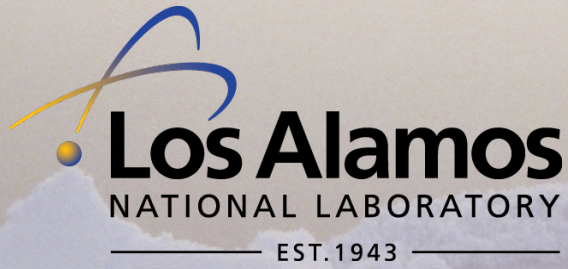

U.S. DEPARTMENT OF ENERGY

Office of Science

Project goal

- Previously Los Alamos sea ice model, CICE, had a 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
- Similar work done by Nicole Jeffery in different formulation

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Two modes of sea-ice gravity drainage: a parameterization for large-scale modeling

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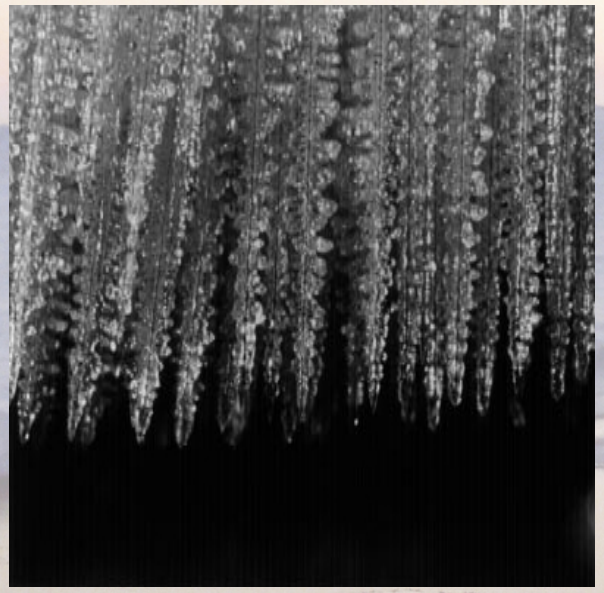
Abstract.

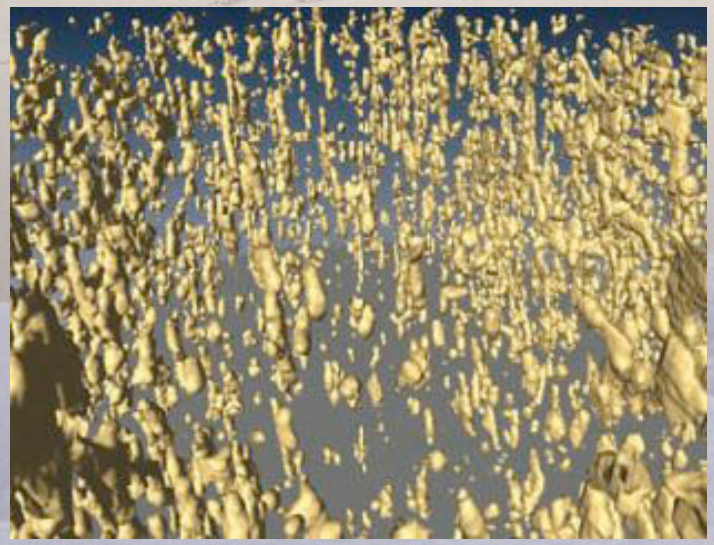
We present a new one-dimensional parameterization of gravity drainage implemented in an all-new thermodynamic component of the Los Alamos Sea Ice Model (CICE), based on mushy layer theory. We solve a set of coupled, nonlinear equations for sea-ice temperature (enthalpy) and salinity using an implicit Jacobian-free Newton-Krylov method. Time resolved observations of gravity drainage show two modes of desalination during growth. Rapid drainage occurs in a thin region just above the ice/ocean interface while slower drainage occurs throughout the ice. Parameterizations are designed to represent each of these modes and work simultaneously. Near the interface, desalination occurs primarily via the fast drainage, while slow drainage continues to desalinate ice above the interface. The rapid desalination is convectively driven and is parameterized based on a consideration of flow driven upward within the mush and downward in chimneys, modified by the Rayleigh number. The slow desalination is represented as a simple relaxation of bulk salinity to a value based on a critical porosity for sea-ice permeability. It is shown that these parameterizations can adequately reproduce observational data from laboratory experiments and field measurements.

Submitted to JGR

Sea ice formation



Worster (1999)

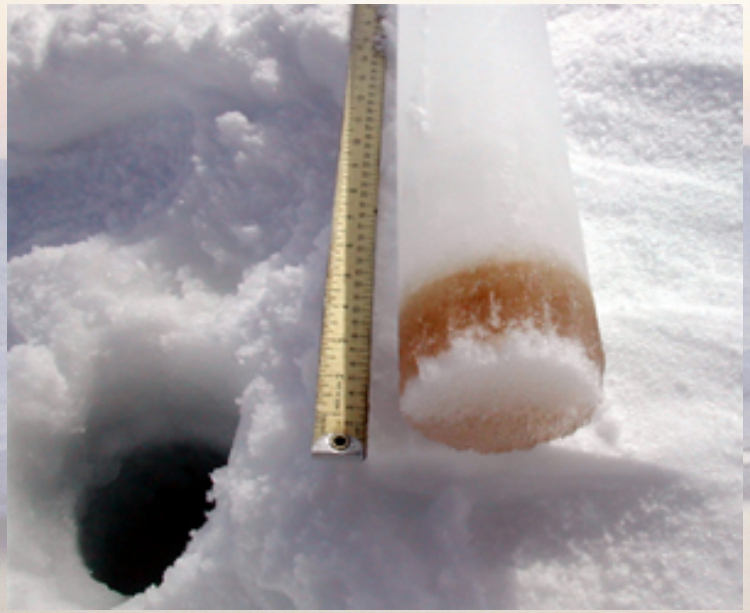


K. M. Golden et al. (2007)

- Freezing interface becomes morphologically unstable during growth
- Brine is trapped between dendritic crystals
- Resulting structure is termed a “mushy layer”
- Pore structure changes dynamically according to changes in temperature and brine pocket salinity
- Brine actively flows through connected brine pockets

Mushy Layer

Effect of salinity structure



NOAA

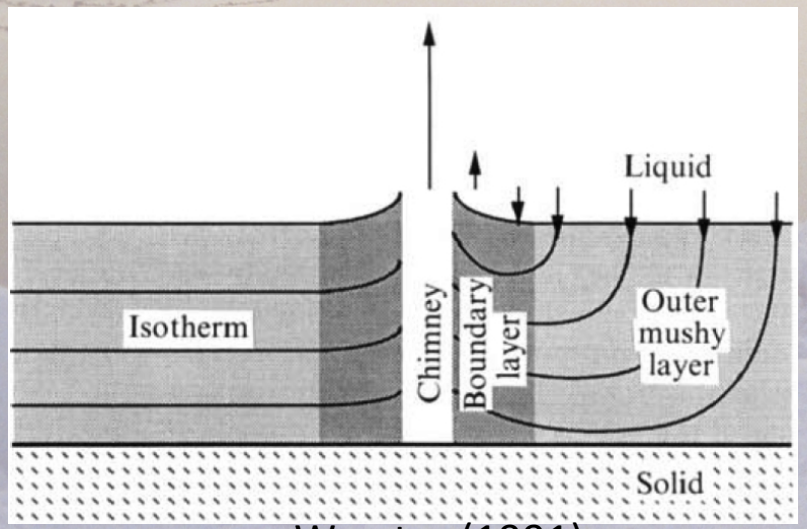
- Sea ice is home to a wide variety of organisms – bacteria, diatoms
- Need to be able to simulate flow of brine around sea ice to model flow of nutrients that supports this life
- Biology affects radiation absorption through albedo
- Salinity profile also effects physical properties – ice strength,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

New CICE vertical thermodynamics

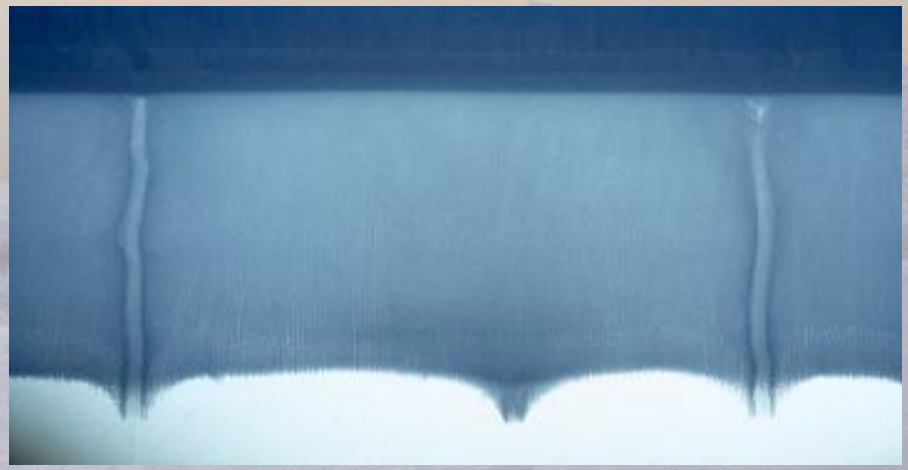
- Totally new heat diffusion routine
- Mostly same thickness change routines
- Solve mushy layer equations
  - Simultaneously solve for both enthalpy and bulk salinity – set of coupled non-linear equations
  - Temperature and brine salinity in equilibrium – on the liquidus curve
  - Solve implicitly with iterative Jacobian Free Newton Krylov method
  - Allows easy addition of additional physics
- Reasonable performance loss with addition of salt
  - About half the speed of current thermodynamics

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

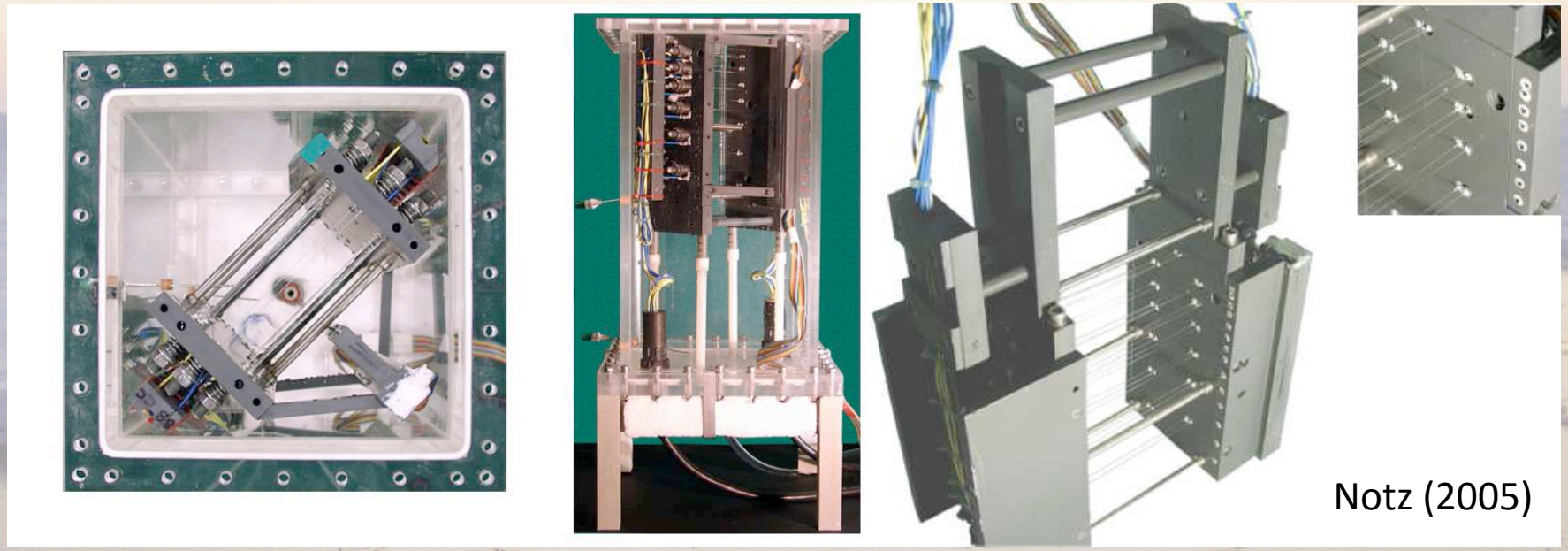


Worster (1991)



Worster (2000)

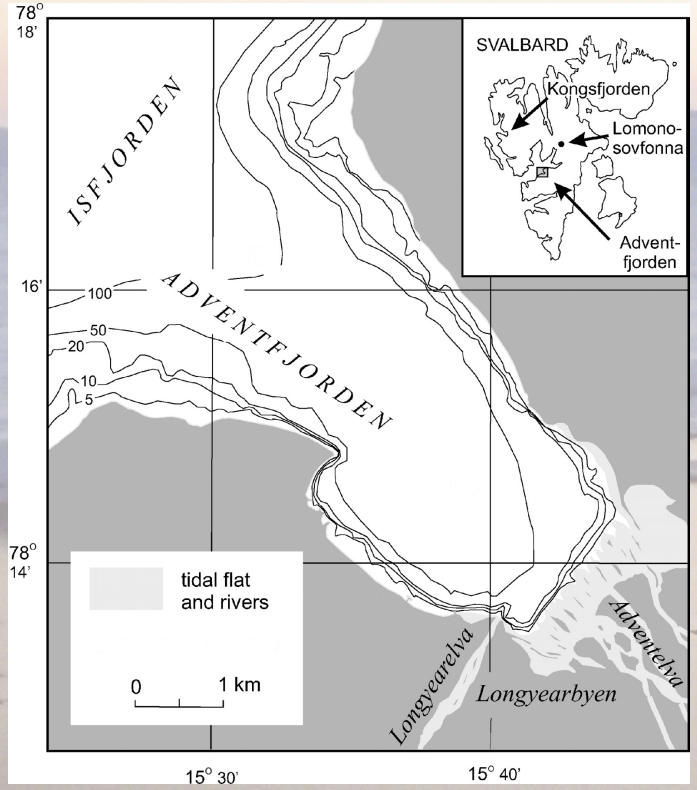
Experimental Results of Convection

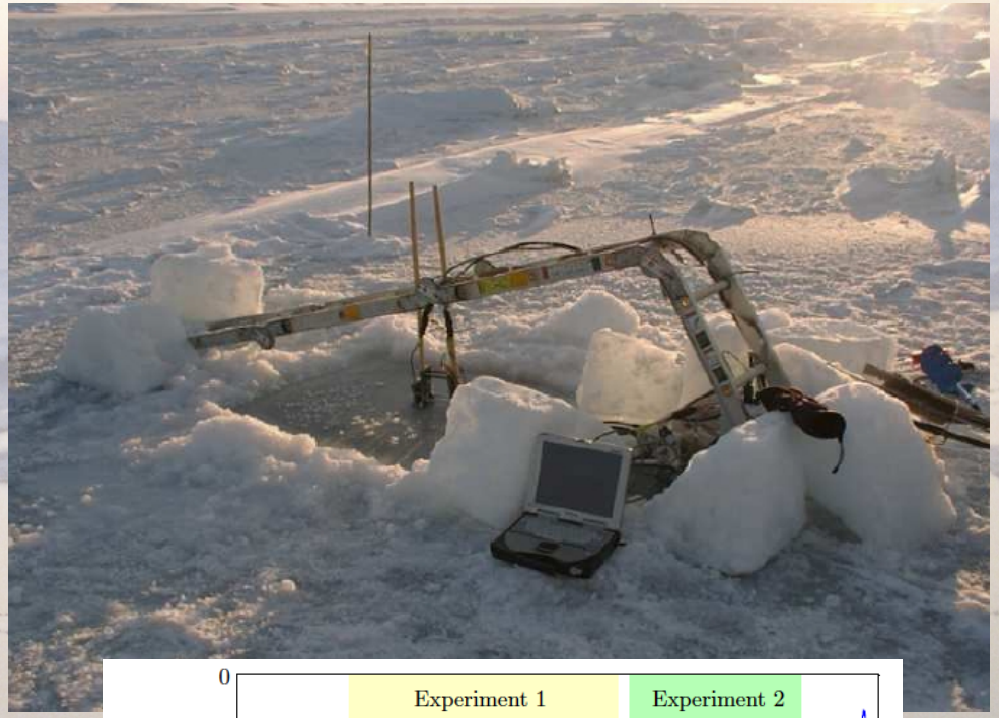


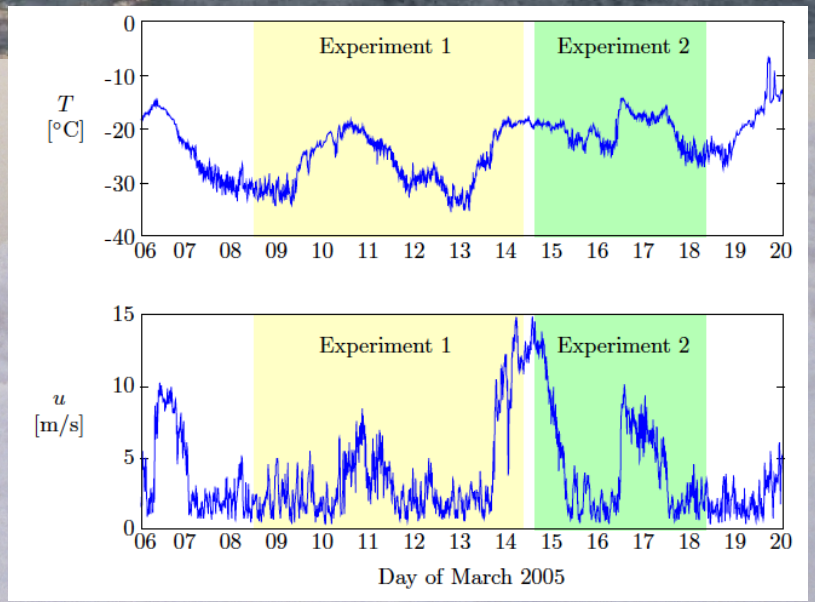
Notz (2005)

- Desalination experiments of Dirk Notz (2005) measured bulk salinity, temperature and solid fraction during ice growth
- 40×20×20cm Perspex tank with custom instrumentation
- Impedance measured between Platinum wires, temperature by thermisters.
- Solid fraction determined from wires. Bulk salinity inferred from temperature and solid fraction using Liquidus curve.

Fieldwork (Notz 2008)

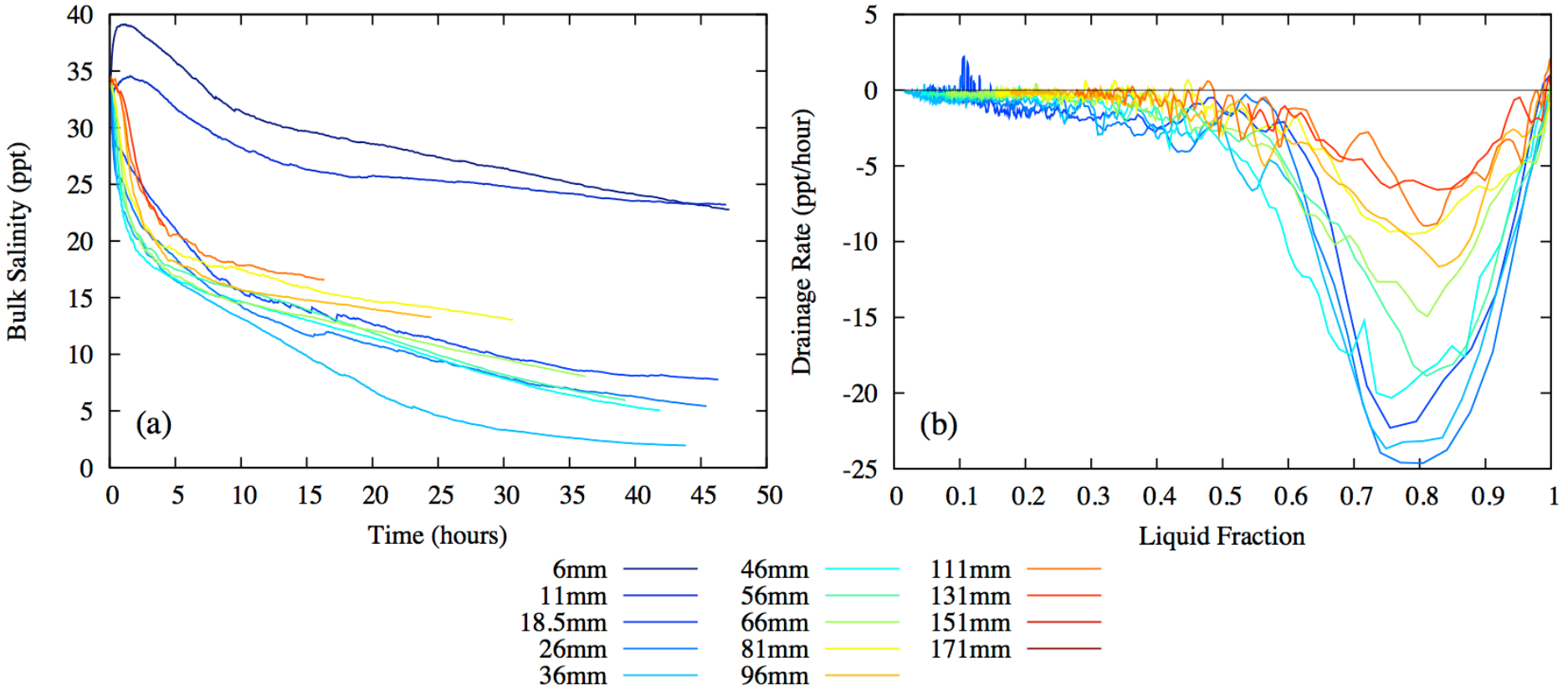






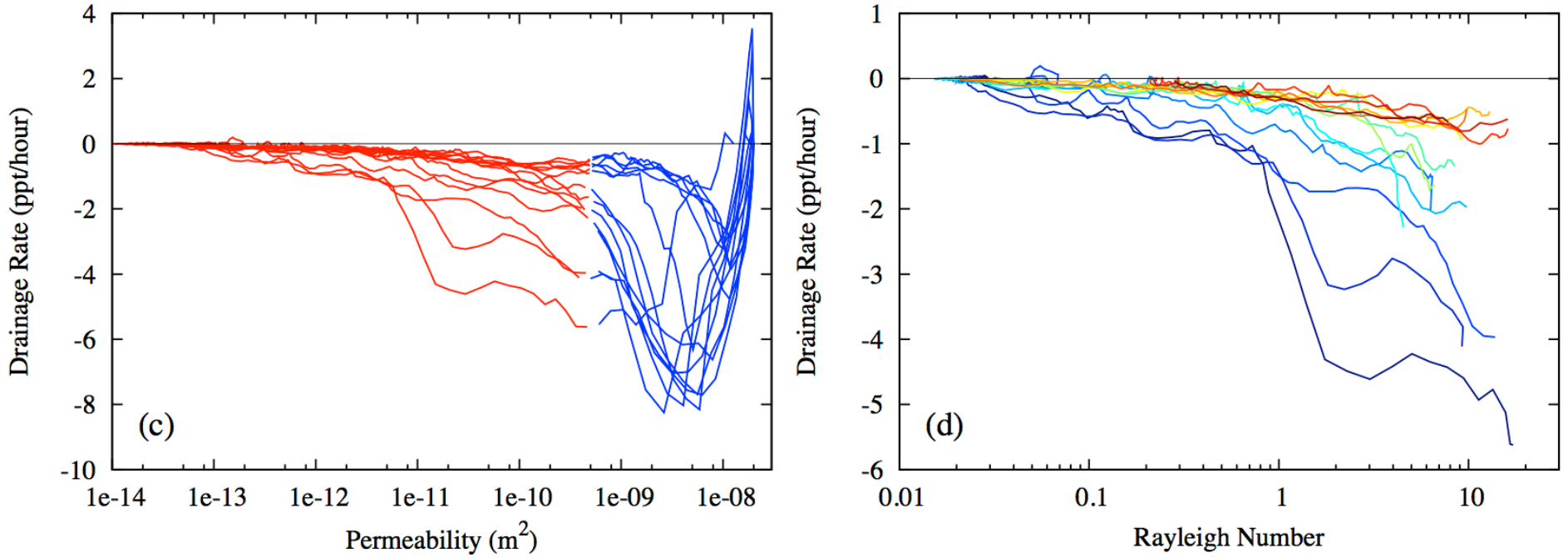
- Two sets of fieldwork experiments in Adventfjorden, Svalbard
- Ice grown from hole cut in ice

Experimental observation of drainage



- Gravity drainage shows two distinct phases
  - An initial rapid drainage to ~20 PSU that lasts a few hours
  - A slow drainage that is ongoing at ~0.25 PSU/hour

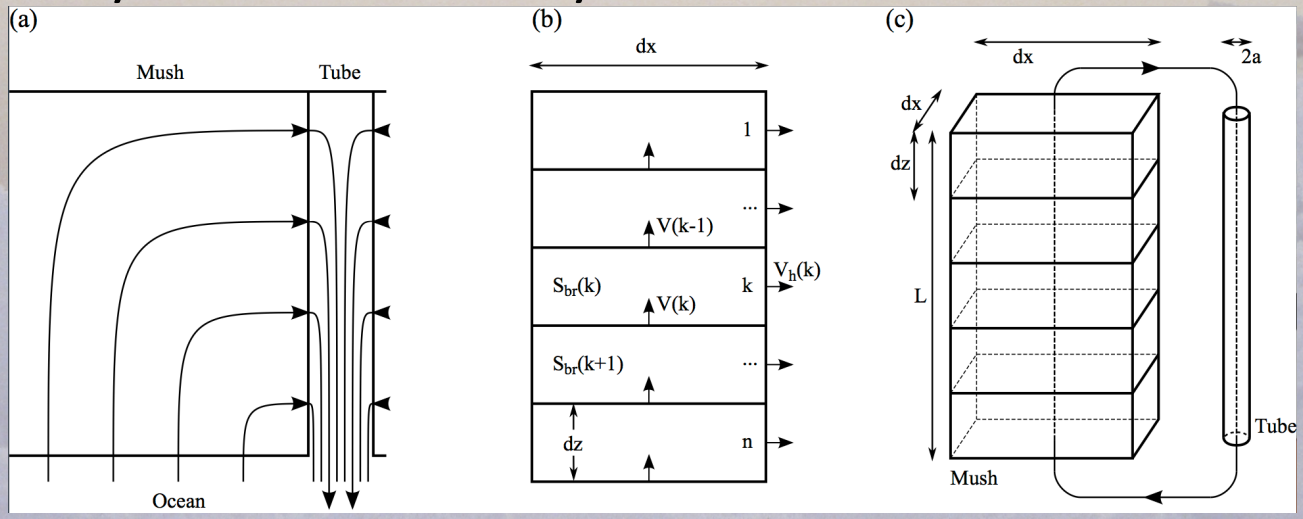
Fieldwork observation of drainage



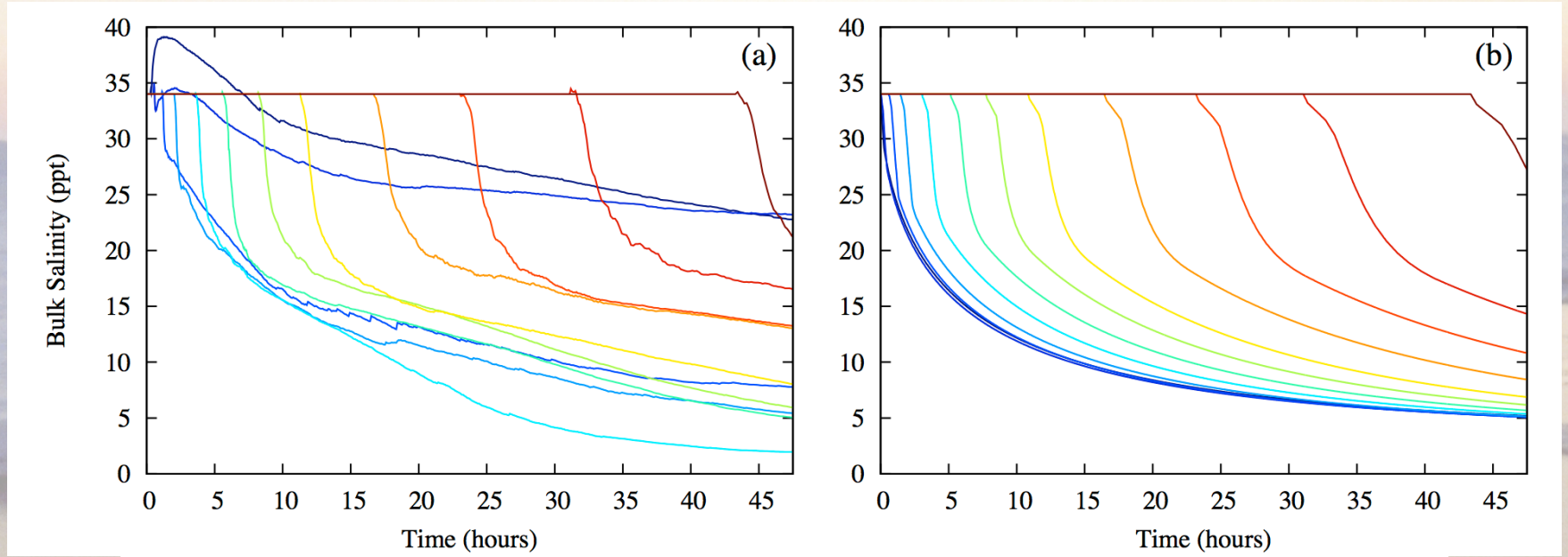
- Divide first fieldwork period data into initial and later drainage phase by permeability
- Examine desalination rate for later drainage versus mush Rayleigh number
- No evidence of cutoff in desalination with drainage rate
- No critical Rayleigh number

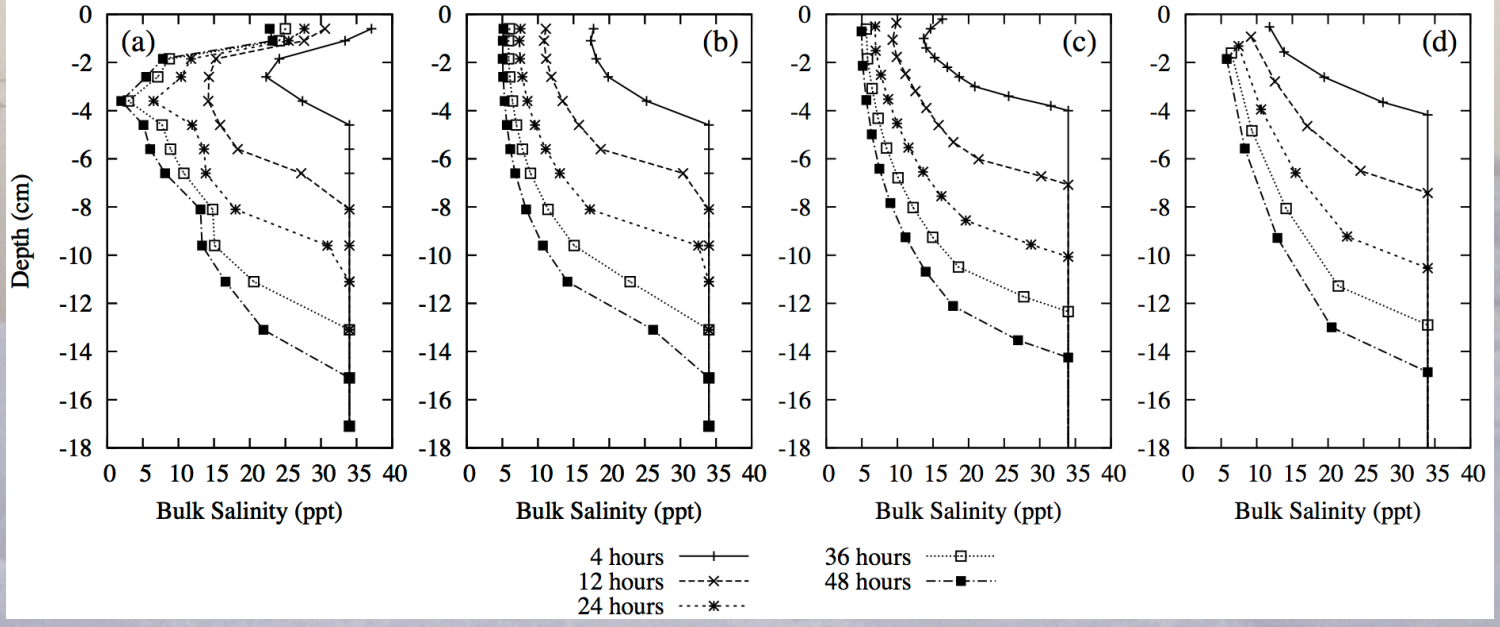
Drainage parameterizations

- Have two parameterizations – one for each phase
- Model initial rapid phase with explicit flow calculation assuming upflow in mush and downflow in narrow pipe
- Modify by critical Rayleigh number
- Use flow rate to advect brine upwards through the mush, resulting in desalination
- Model later desalination with source term proportional to porosity and brine density difference with the ocean

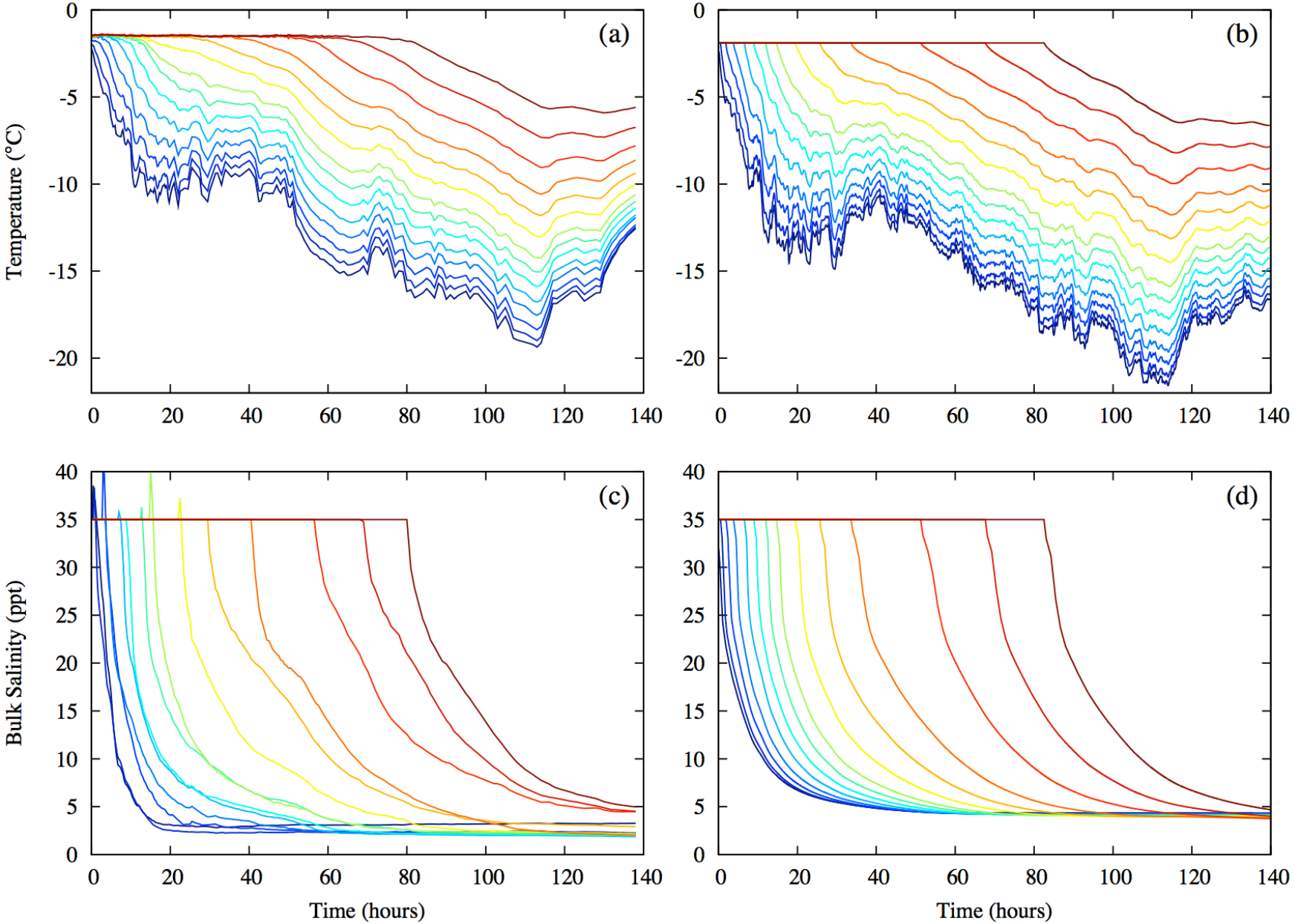


Results - experiment

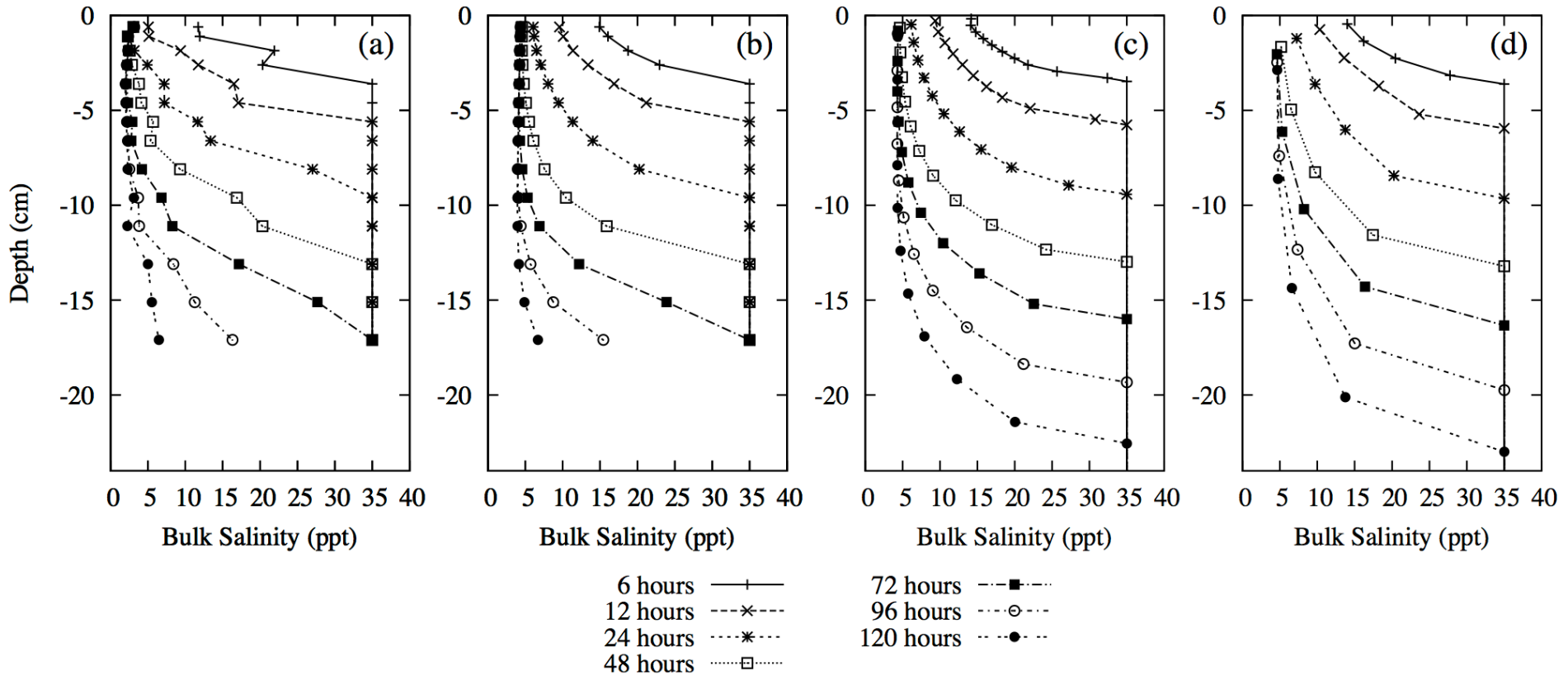




Results - fieldwork



Results - fieldwork



Other processes

- Snowice formation has been included but
  - Issue with how brine moves to the snow
  - Darcy, macro-channel, lateral?
- Flushing of meltponds included but
  - Need macro-channel to reproduce data? (Polashenski et al. 2012)

Future work

- Global simulations on the gx1
  - Comparison paper comparing to Nicole's work
- Cleaning the code for 2013 release
- Coupling/conservation issues

MPAS-CICE

- Development of MPAS-O requires sea-ice model to run on same grid
- Begun to plan how to perform work