Modeling Salinity of First-Year Sea Ice

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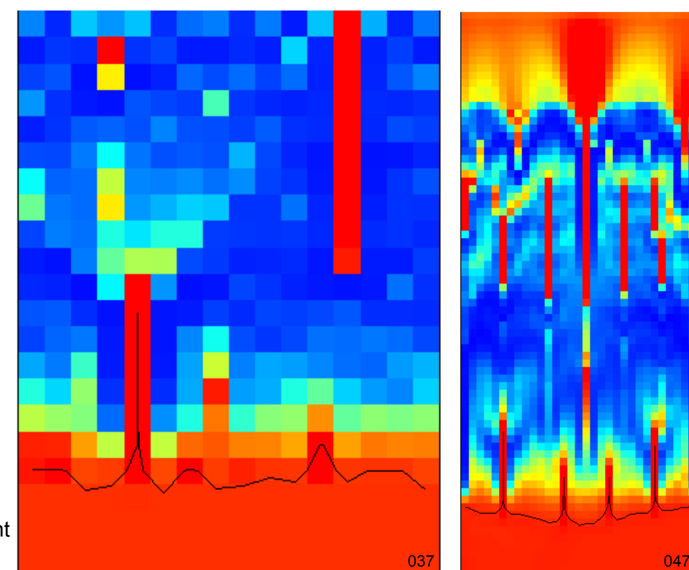
Near-Real Time Data:
Portal: http://www.SIZONet.org/
http://www.gi.alaska.edu/BRWICE/

google: Barrow Sea Ice


Barrow, AK, Jan 2009

GFDL, Ocean Climate Model Development Meeting, Oct 30, 2009



Sea ice in winter

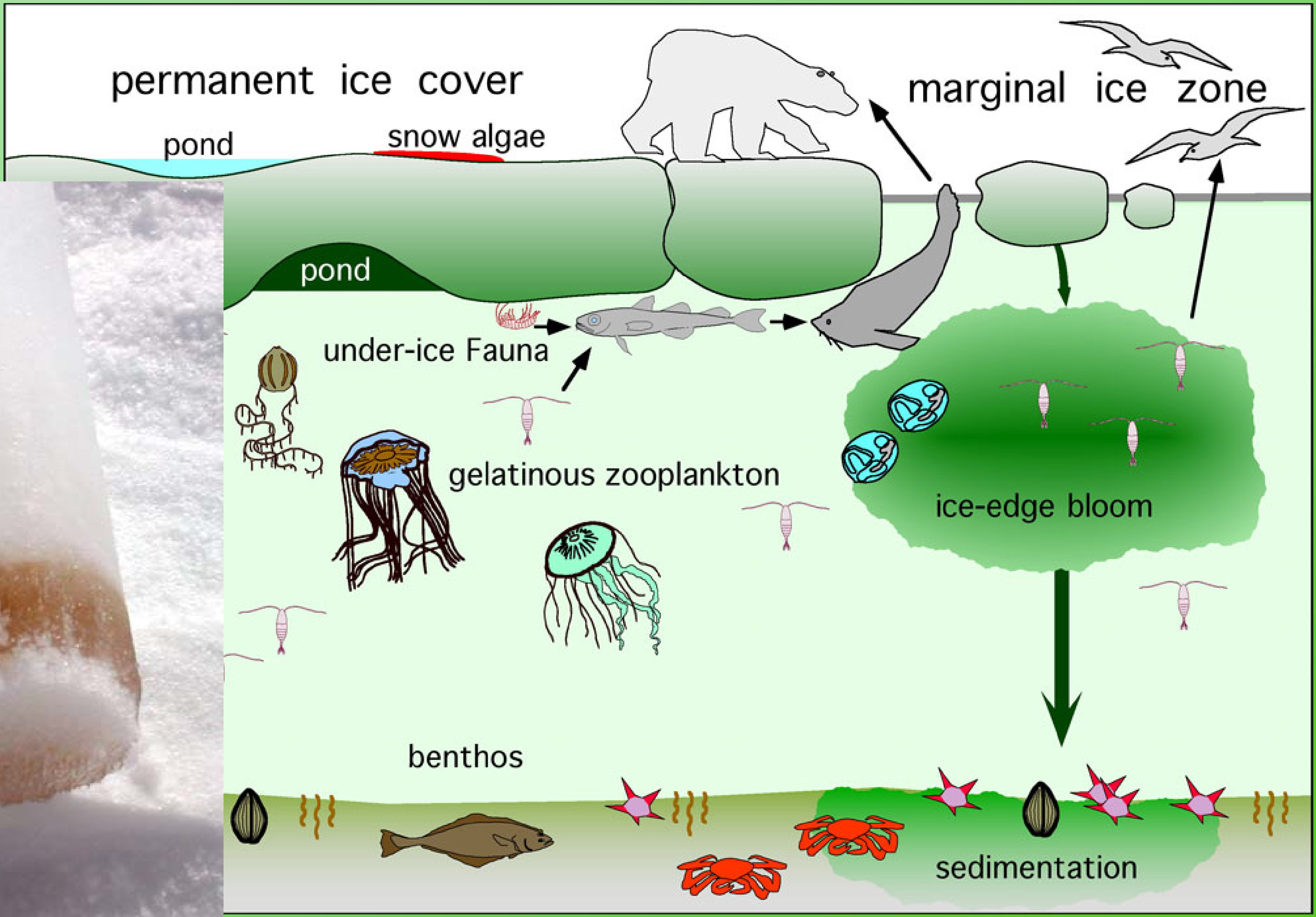
C. Petrich

Barrow AK, Feb 10, 2008

Oil movement in ice: oil spill recovery

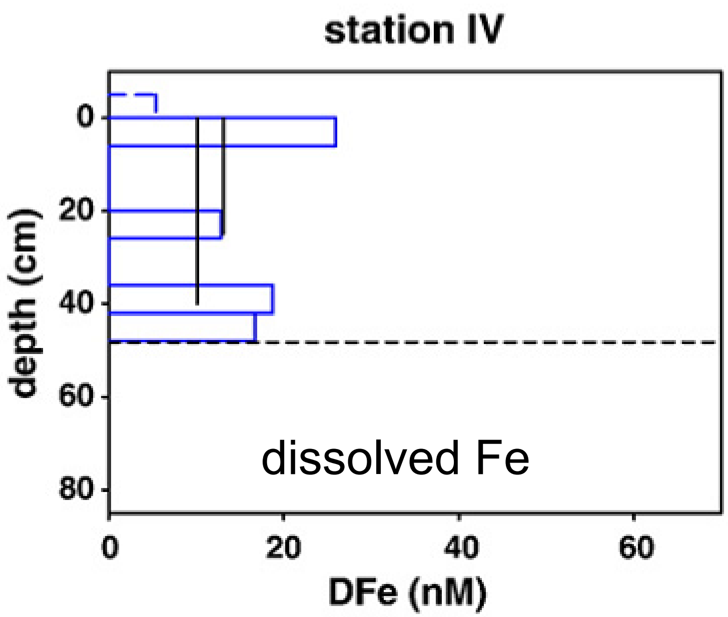
Example of oil encapsulation and upward migration

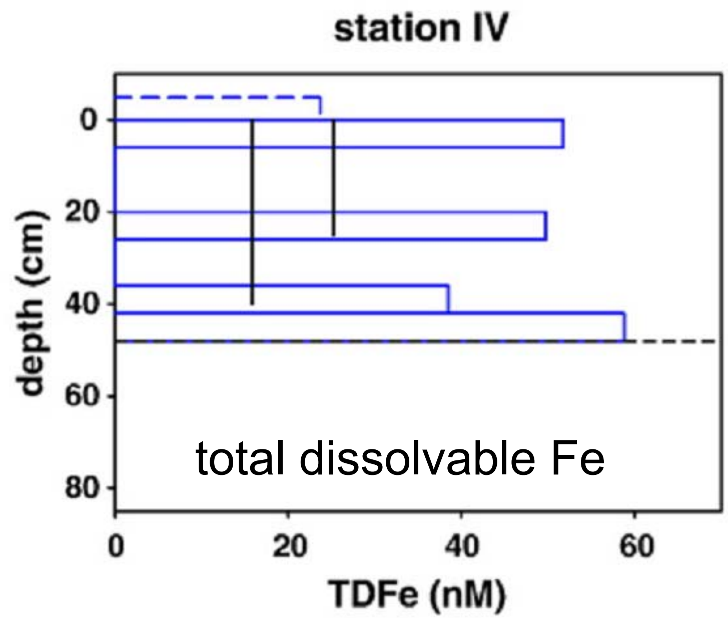
Sea ice nutrient flux



Enrichment of Fe in sea ice

10…30–fold enrichment of Fe in sea ice
with respect to ocean water



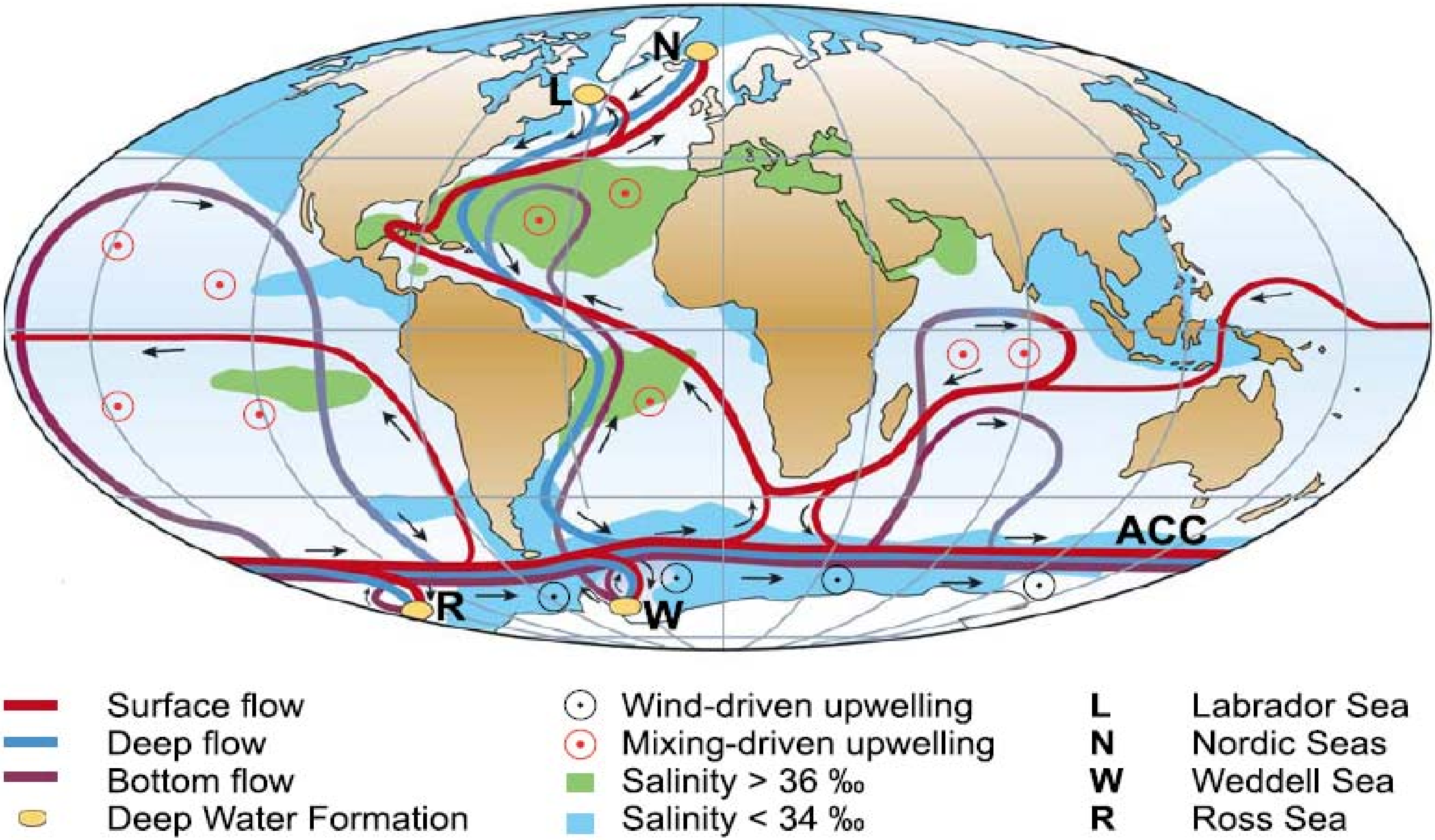


Seawater: 1..3 nM

Lannuzel et al. (2007), East Antarctica

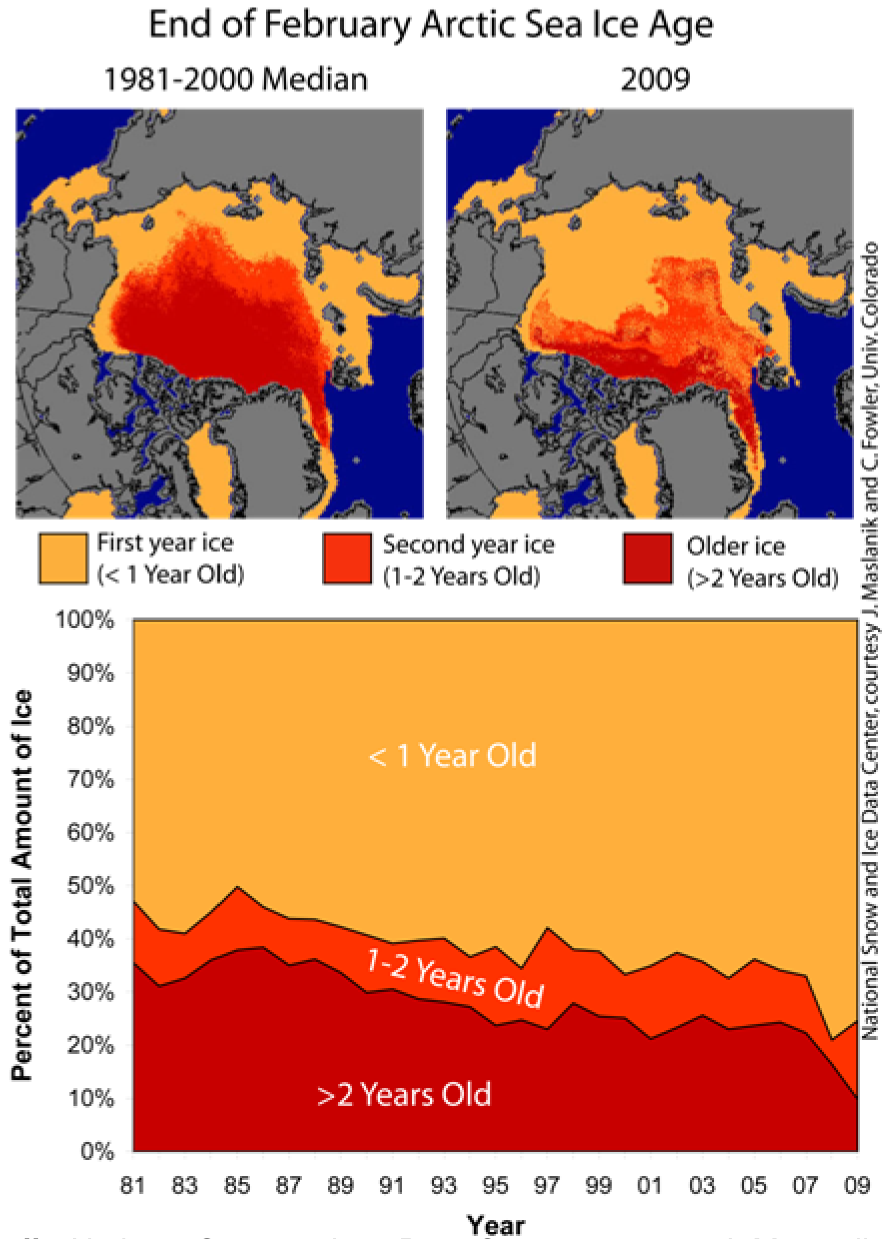
Fe sorptive to ice or
particulate matter?

Sea ice salt flux



Kulbrodt et al. (2007)

Arctic sea ice isn't what it used to be



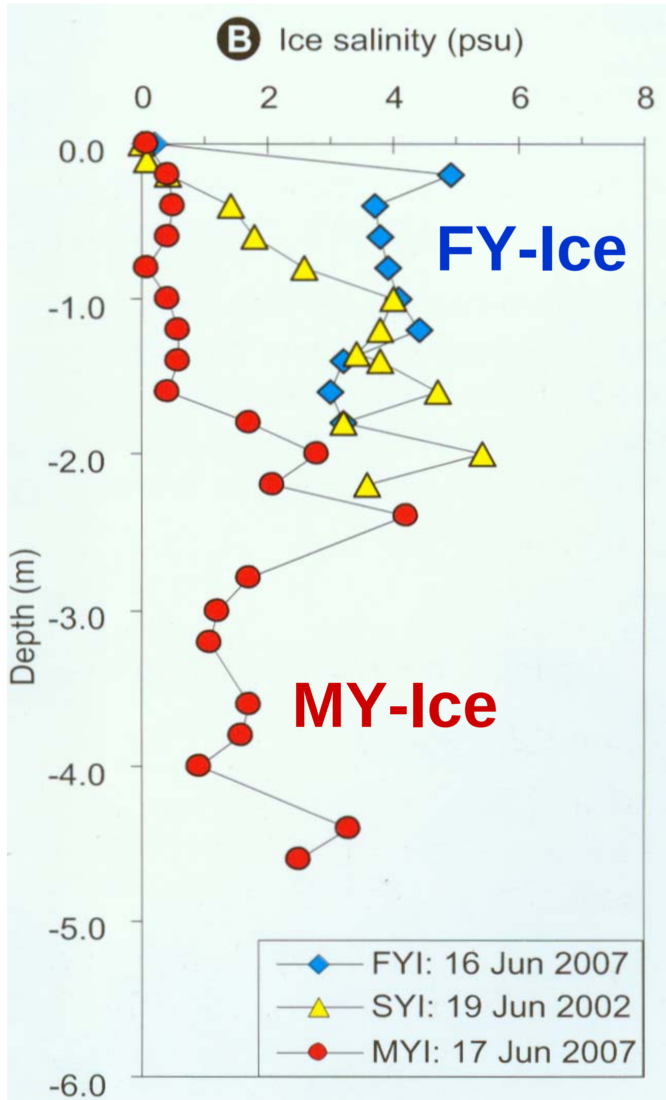
now:

- younger
- thinner
- saltier

Image Credit: National Snow and Ice Data Center, courtesy J. Maslanik and C. Fowler, University of Colorado http://nsidc.org/arcticseaicenews/2009/040609.html

Bulk Salinity
Multi-Year vs. First-Year Sea Ice

Johnston & Timco (2008)

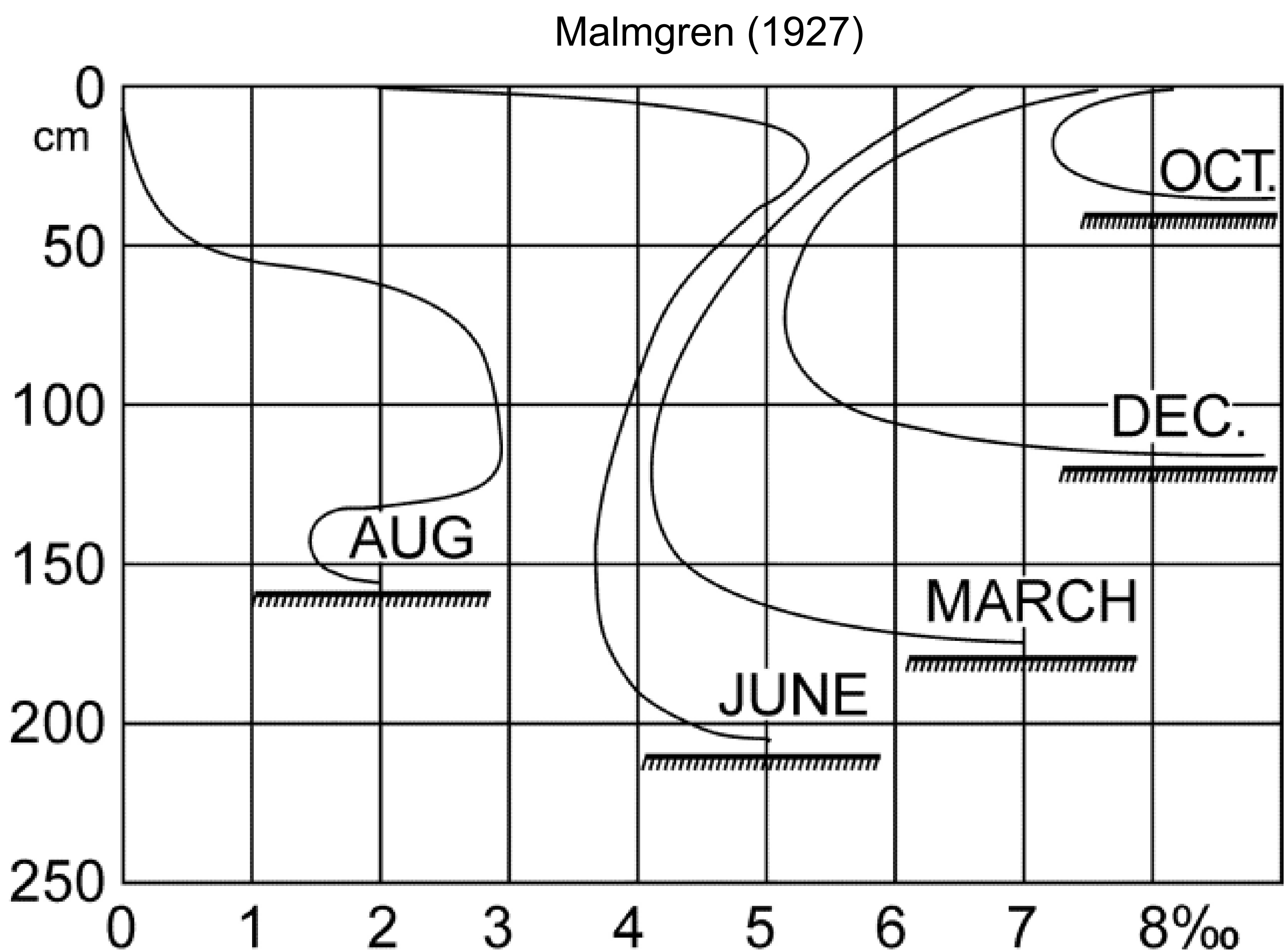


FY vs. MY Ice in mid June, 2007

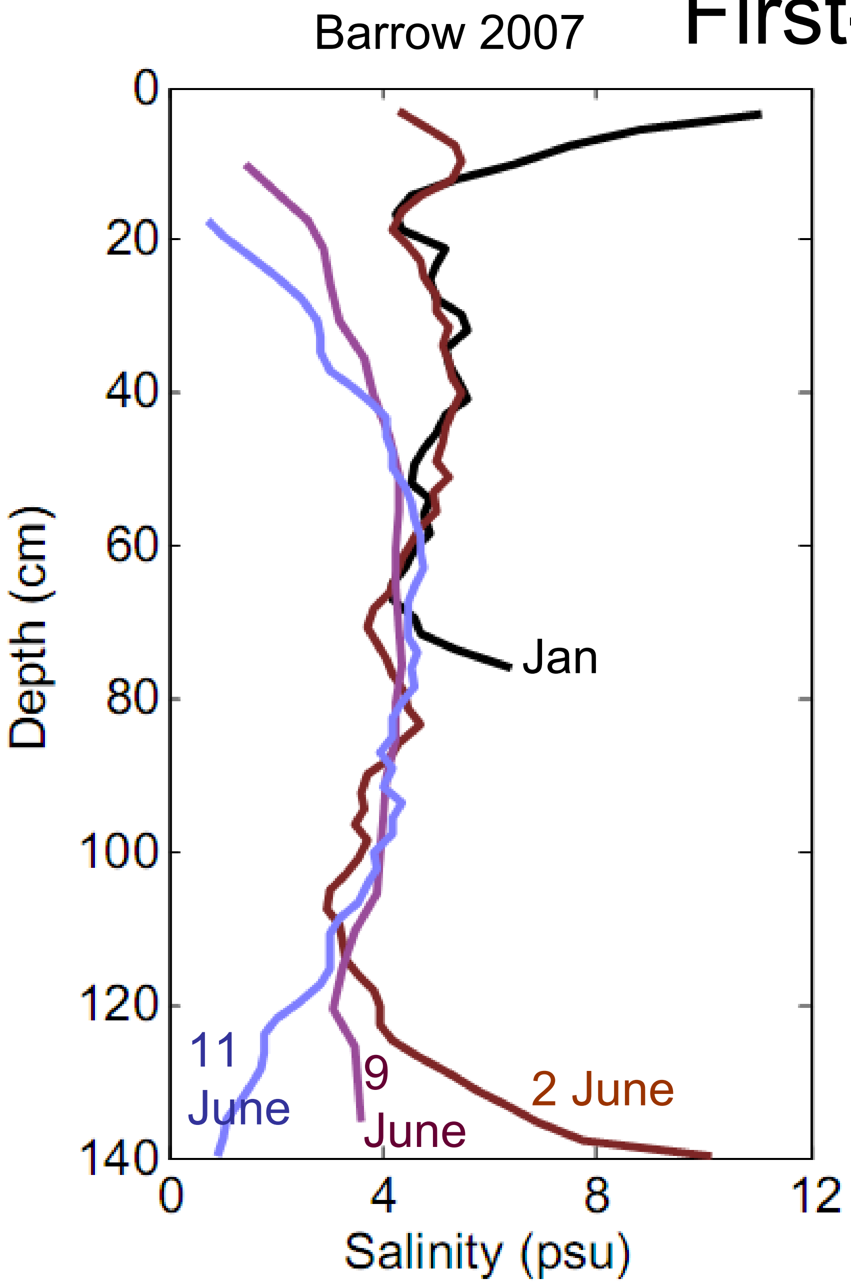
First-Year Ice:
- higher salinity
- thinner

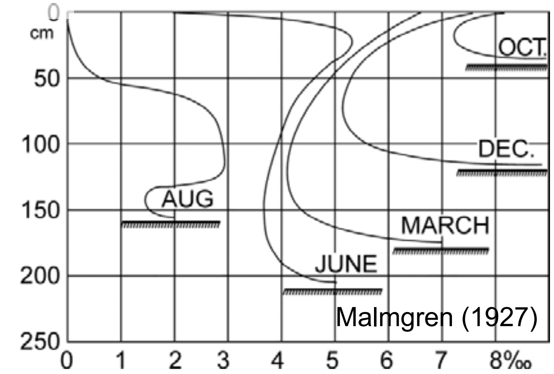
Johnston and Timco (2008), Understanding and Identifying Old Ice in Summer, CHC-TR-055

Bulk Salinity
First-Year Sea Ice



Bulk Salinity
First-Year Sea Ice





Bulk Salinity: 4…5

Significant changes during melt
– within a few days –

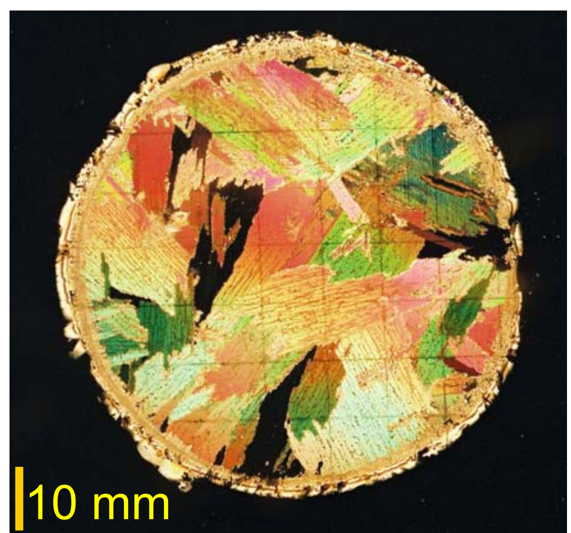
Sea Ice Microstructure resembles Porous Medium

Brine inclusions make sea ice porous
→ more so when ice is warm

100 mm

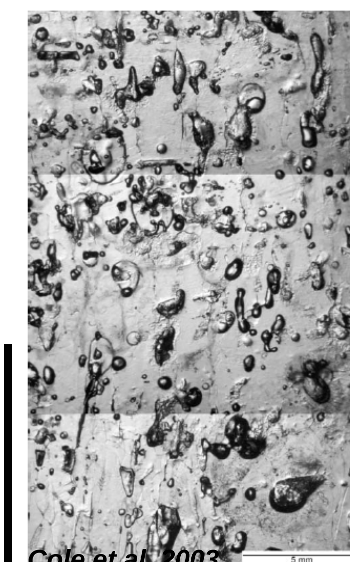
not transparent due to brine inclusions

horizontal section



vertical section

10 mm



Summer First-Year Sea Ice, Svalbard


photo: Sebastian Gerland, NPI

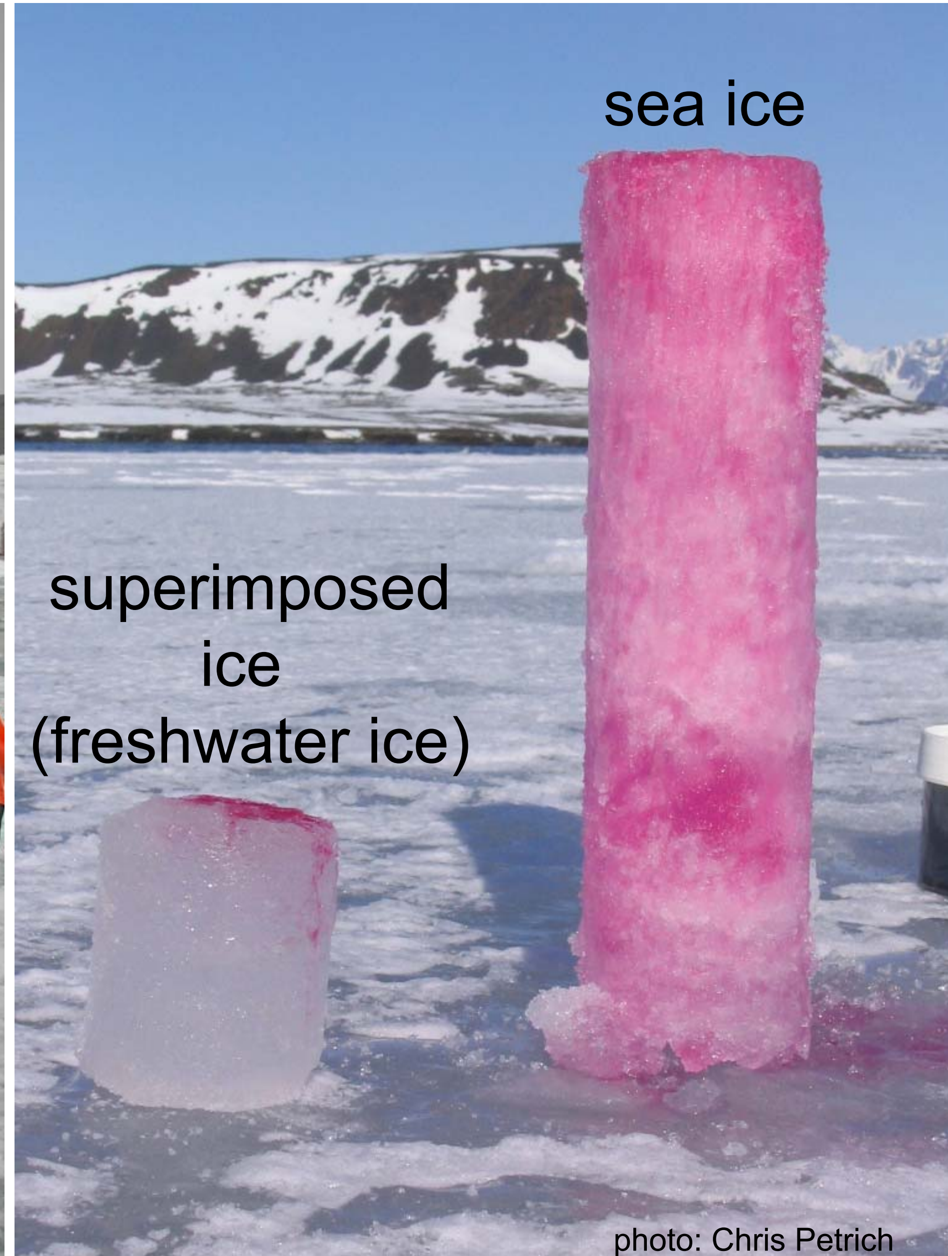
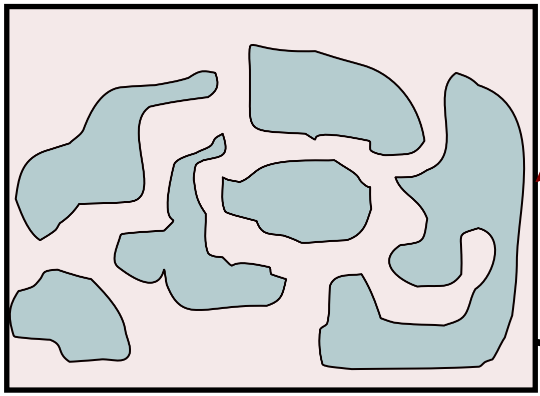


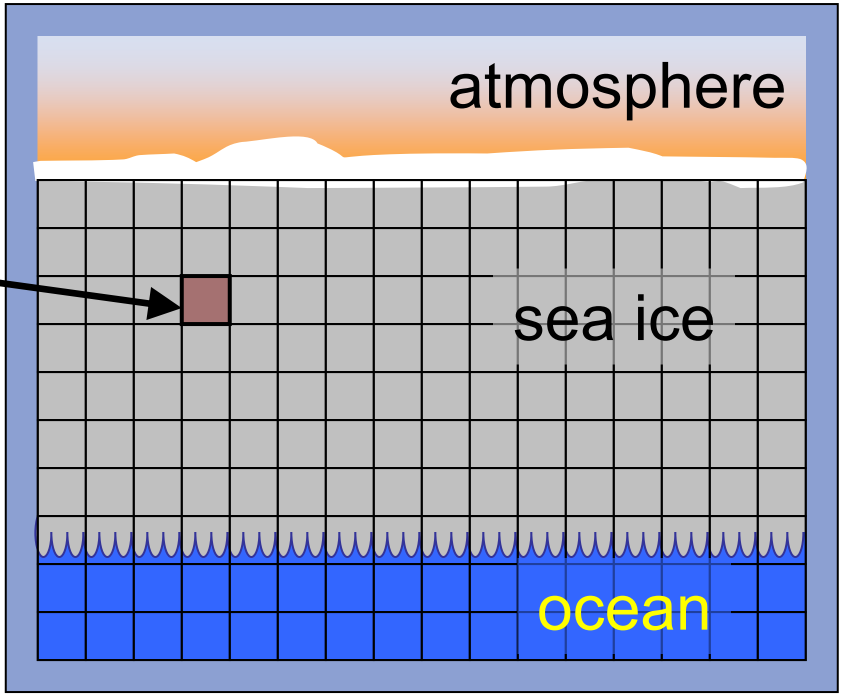
photo: Chris Petrich

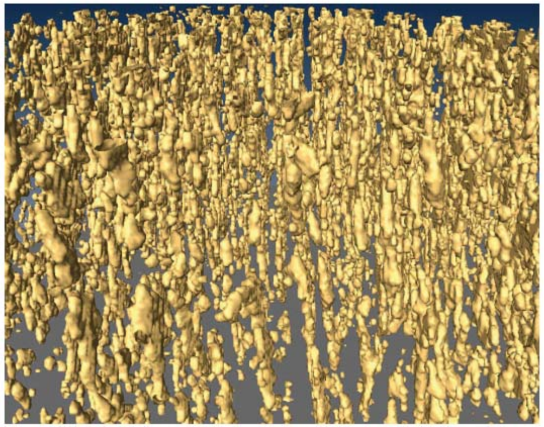
Scale in fluid dynamics model:

microscopic scale —*local average*→ effective medium/ continuum scale

microscopic structure described by <u>one</u> parameter: effective permeability Π







Golden et al. (2007)

Governing equations (2D)

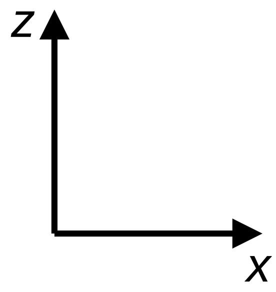
e.g. momentum conservation:
(porosity: *f*)

$$x: \quad \rho_l \left[\frac{\partial (f u)}{\partial t} + \frac{\partial (f u\, u)}{\partial x} + \frac{\partial (f u\, w)}{\partial z} \right] = \mu \left[\frac{\partial^2 (f u)}{\partial x^2} + \frac{\partial^2 (f u)}{\partial z^2} \right] - f \frac{\partial p}{\partial x} - f \frac{\mu}{\Pi} f u$$

$$z: \quad \rho_l \left[\frac{\partial (f w)}{\partial t} + \frac{\partial (f w\, u)}{\partial x} + \frac{\partial (f w\, w)}{\partial z} \right] = \mu \left[\frac{\partial^2 (f w)}{\partial x^2} + \frac{\partial^2 (f w)}{\partial z^2} \right] - f \frac{\partial p}{\partial z} + f \rho\, g - f \frac{\mu}{\Pi} f w$$

transient | advection | shear | pressure | friction

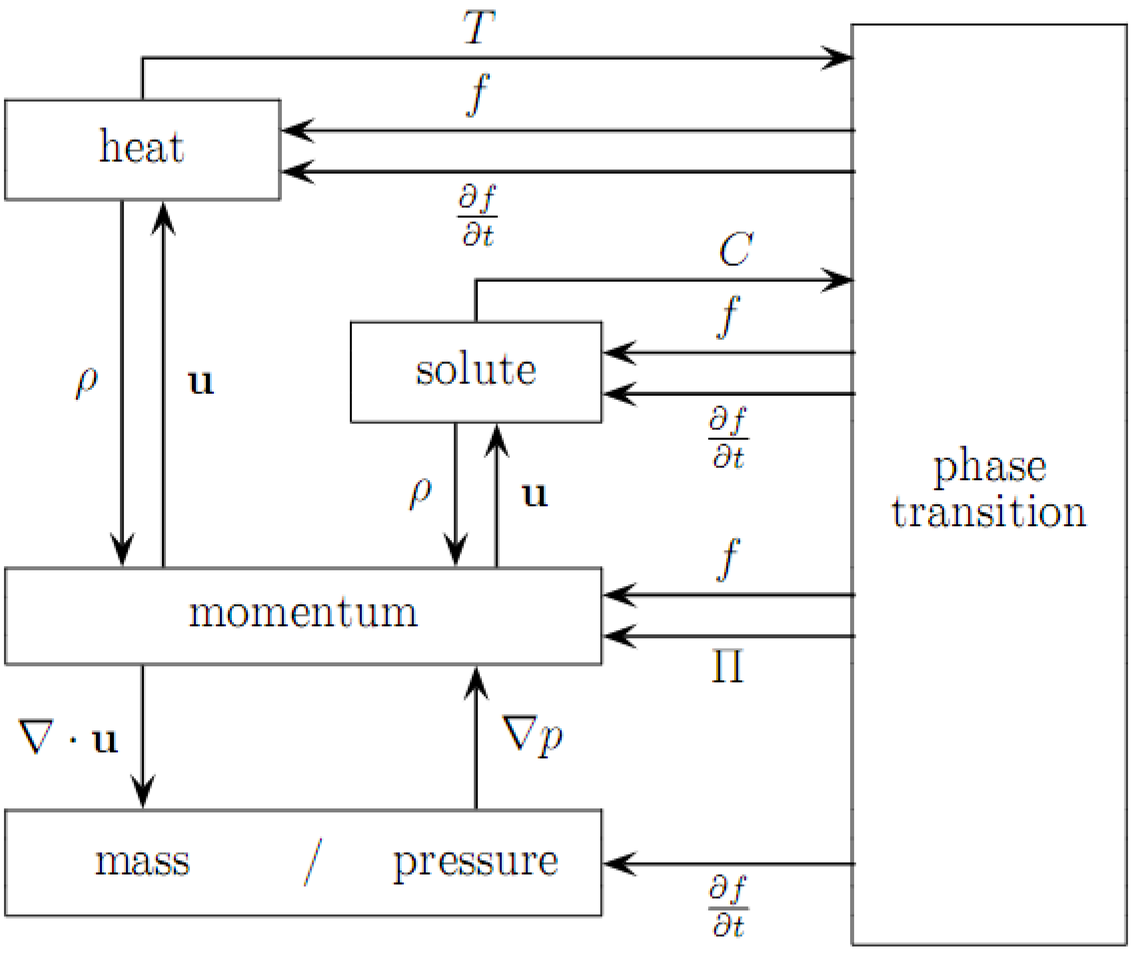
- similar for heat and solute conservation
- mass conservation
- local thermodynamic equilibrium
- volume expansion during freezing



reduce to
- Navier–Stokes equations in liquid
- Darcy's law in porous medium

Petrich et al. (2006)

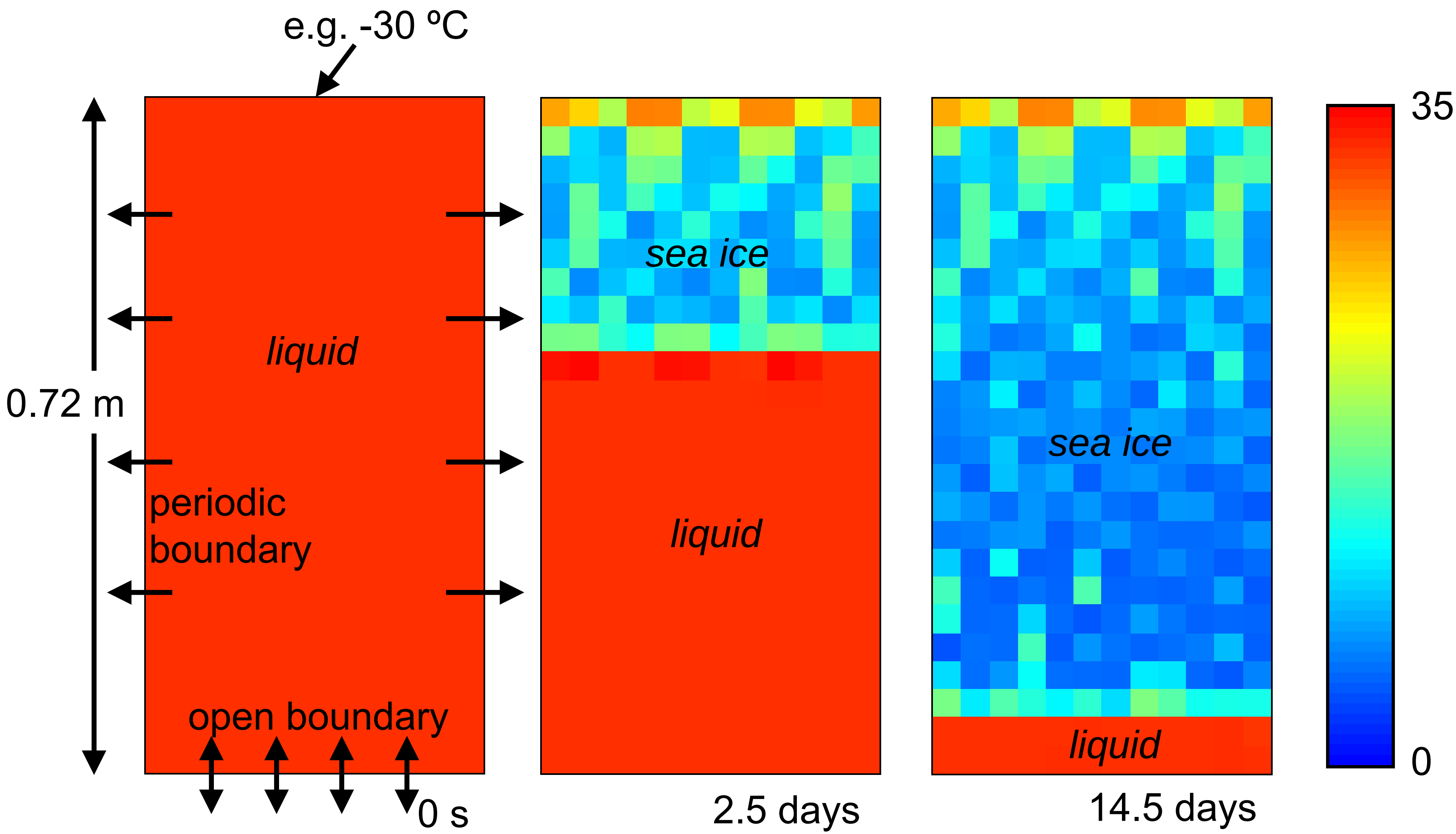
Coupled governing equations



Solved on staggered, rectangular grid w/ multigrid solver

Example:

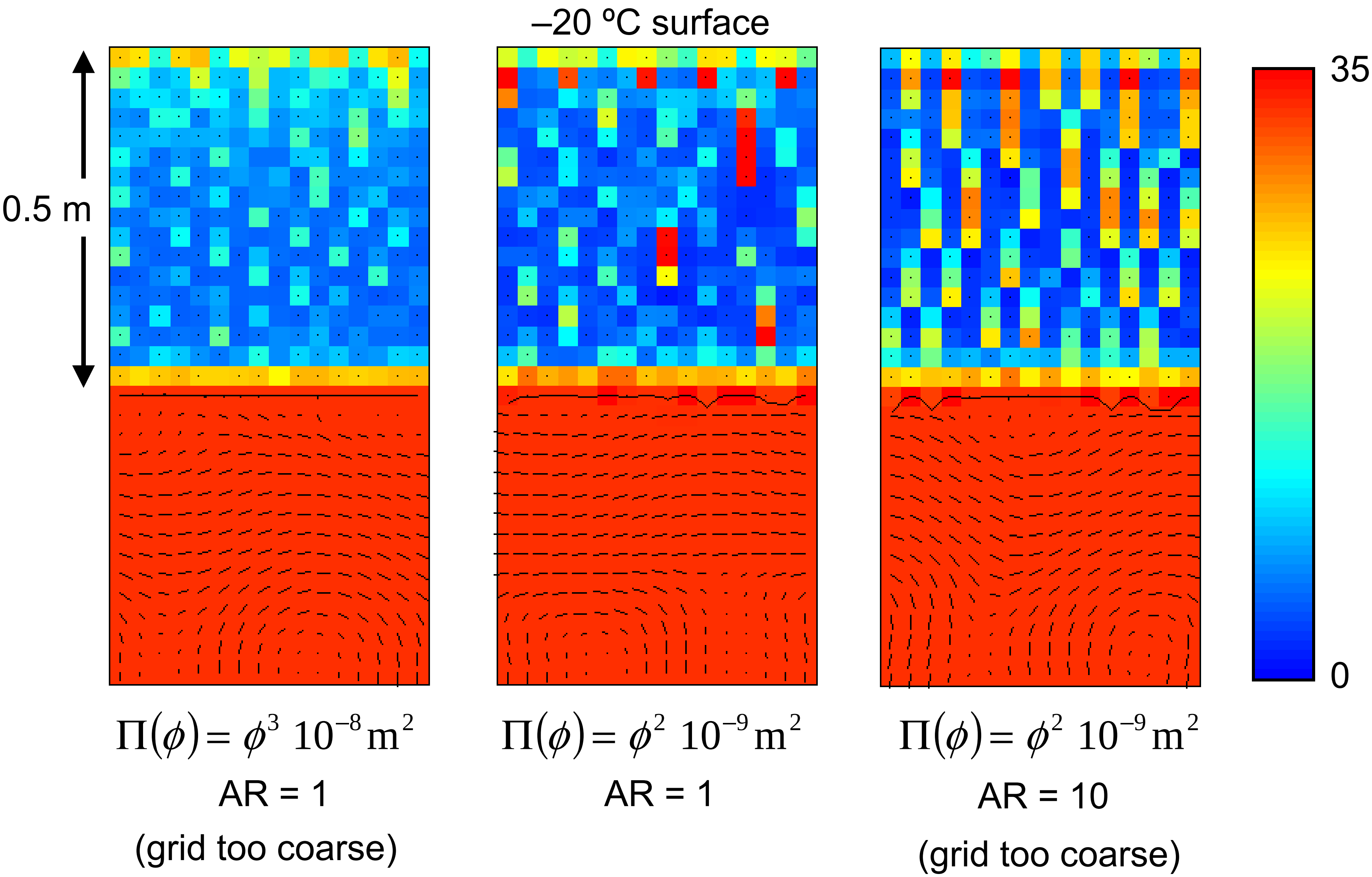
Development of the bulk salinity (salinity of the melt)



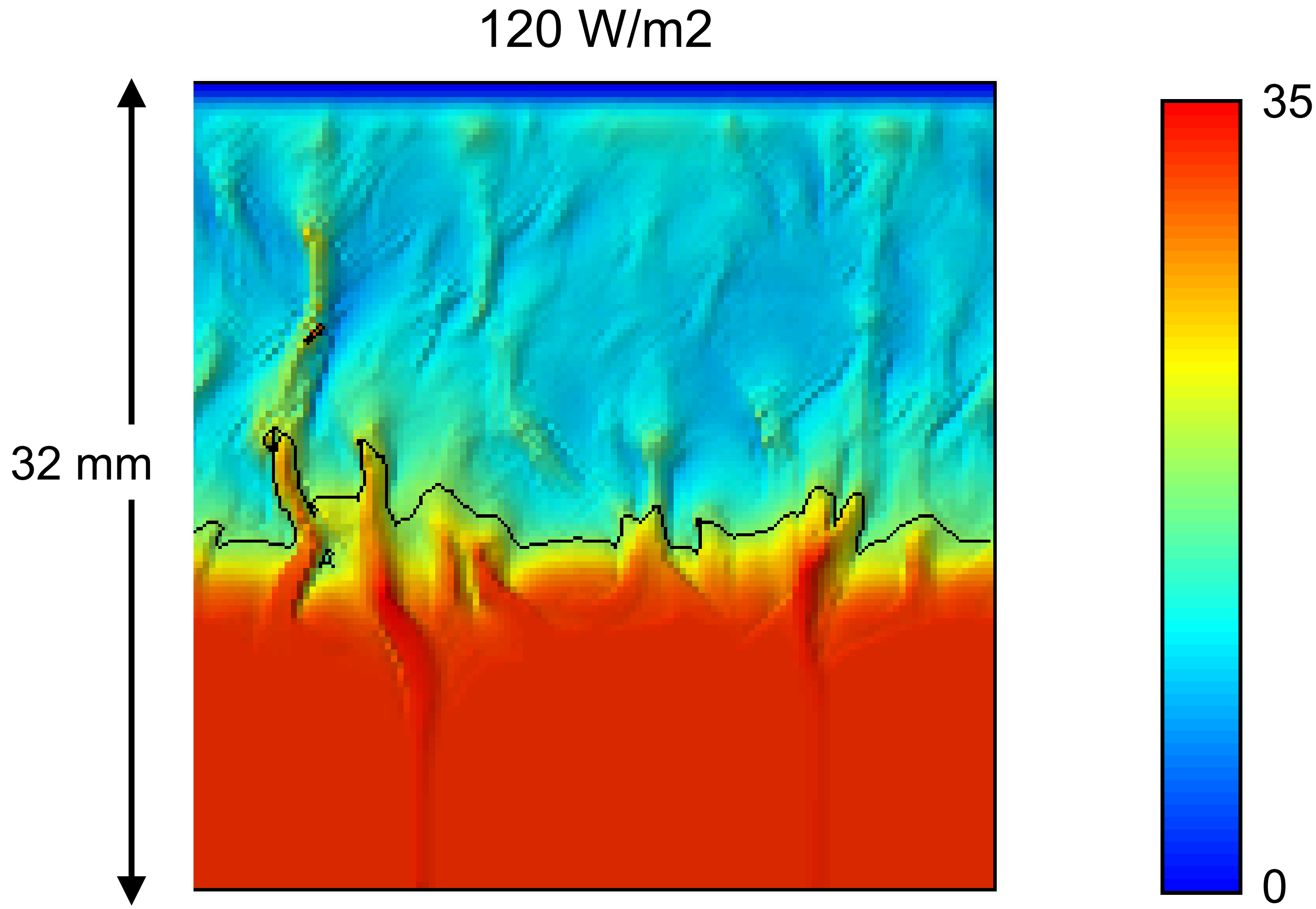
Temperature of brine entering domain: 10 mK above freezing point

Example bulk salinity distribution

as a function of permeability–porosity relationship



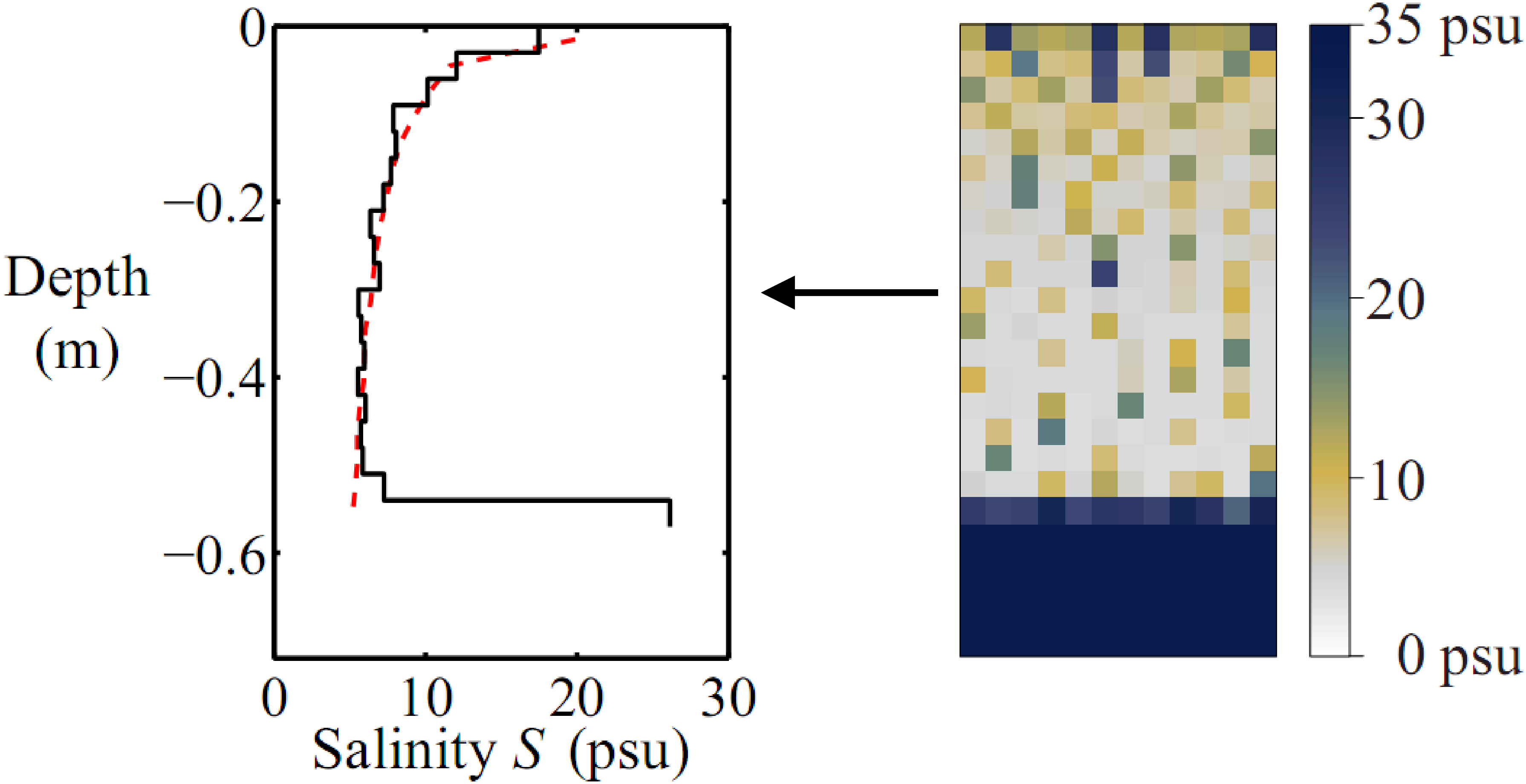
Example: bulk salinity on 250um grid



$$\Pi(\phi) = \phi^3\ 10^{-8}\,\mathrm{m}^2$$

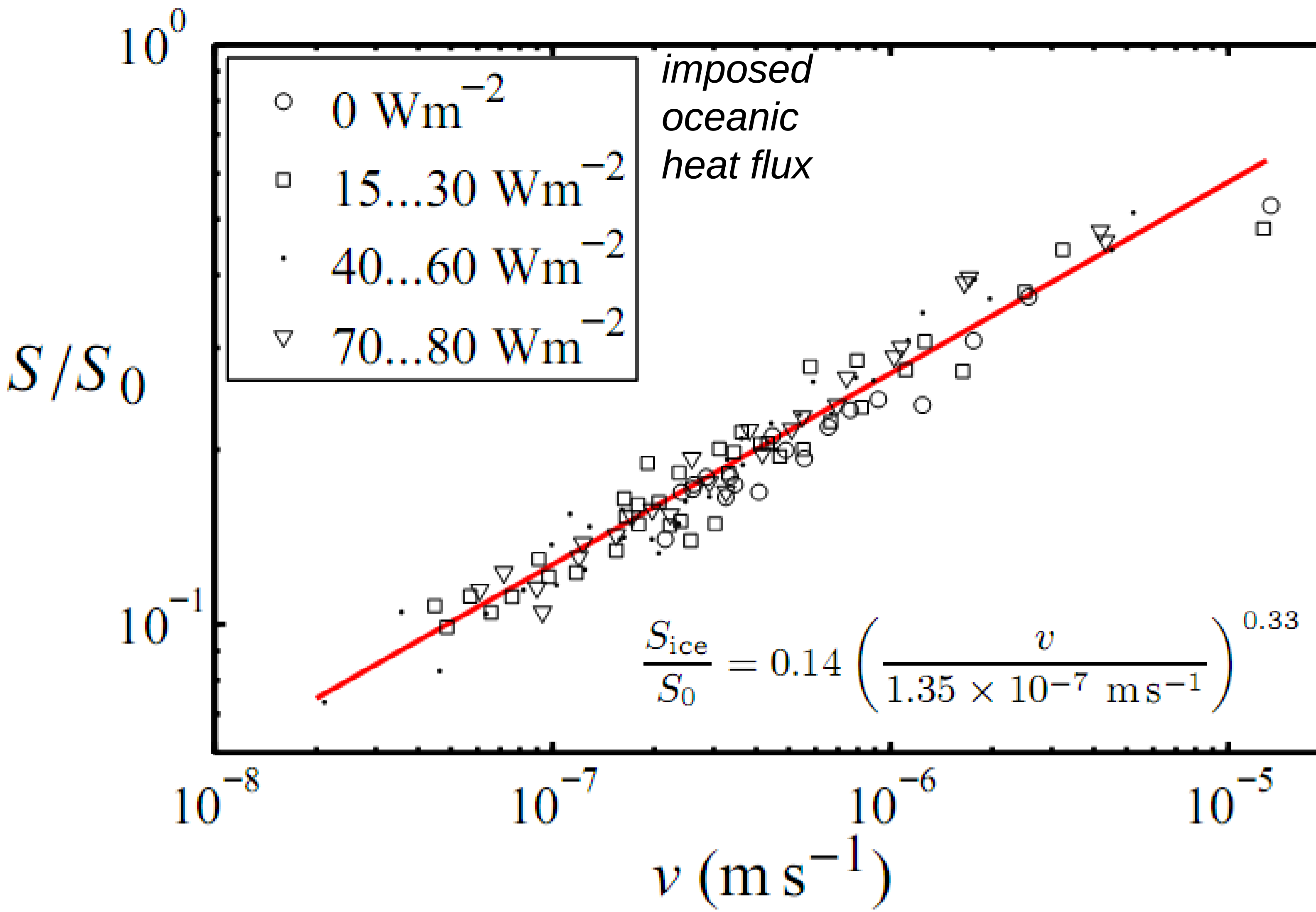
AR = 1

Averaged salinity profile



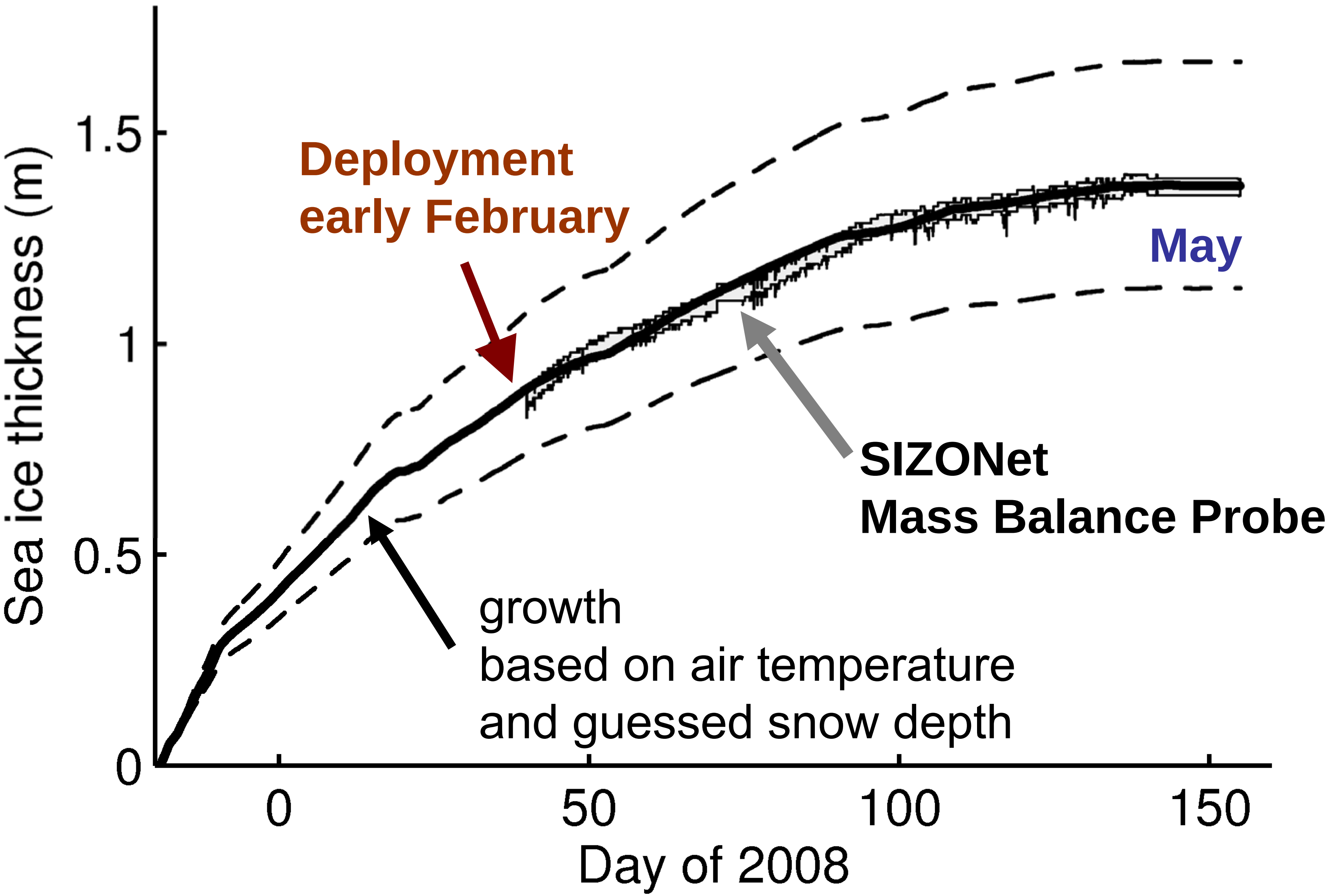
note: low growth rate → low bulk salinity

Steady-state bulk salinity as function of initial growth rate



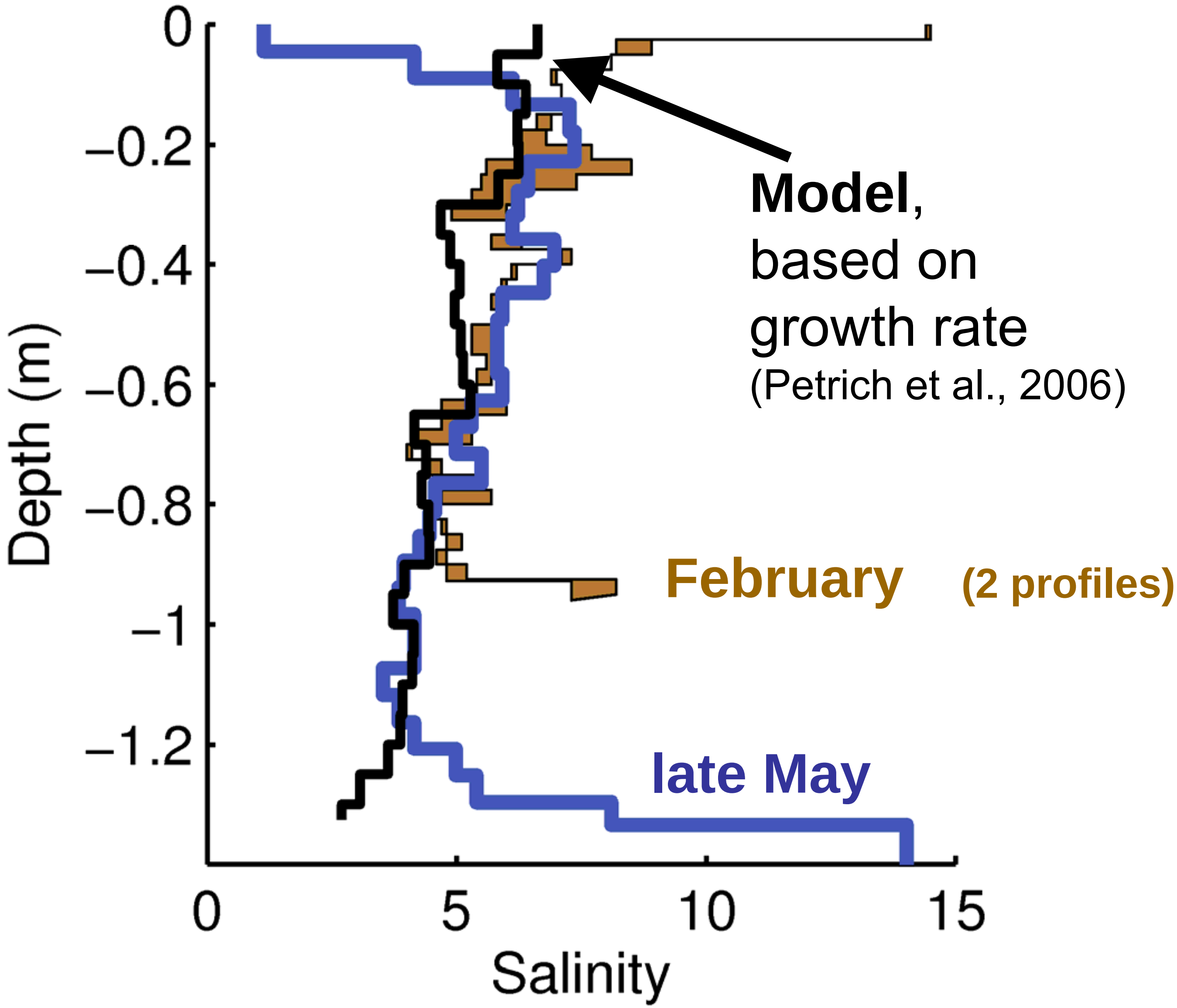
for various boundary conditions, grid sizes, permeability parameterizations

Barrow Sea Ice Growth



from: Petrich and Eicken in Thomas & Dieckmann, 2nd ed (2009)

Measured and modeled salinity, Barrow 2008



from: Petrich and Eicken in Thomas & Dieckmann, 2nd ed (2009)

Disclaimer: Landfast in Barrow may have originated elsewhere

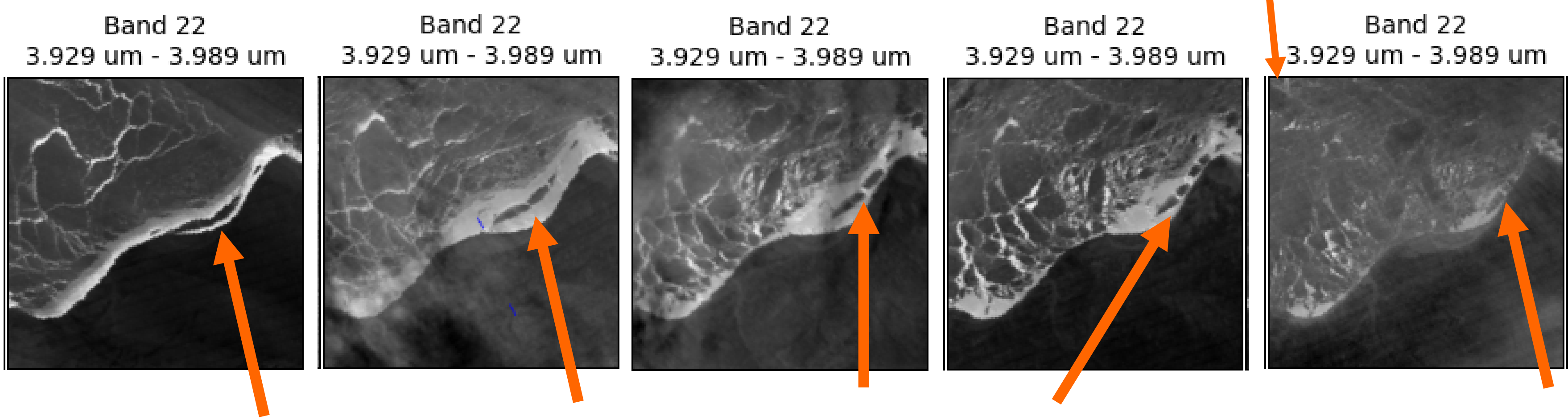
- Ice formation starting late October
- On-shore ice may break out and be replaced by ice formed elsewhere any time until late December

to illustrate this:

2009 MODIS sequence of relocating landfast ice

Terra MODIS, January 2009

Jan 22 06:30Z | Jan 23 07:10Z | Jan 23 23:50Z | Jan 24 07:55Z | Jan 26 07:40Z



coastal lead opens, landfast ice breaks out

chunk of ice drifts toward Barrow

coastal lead closes

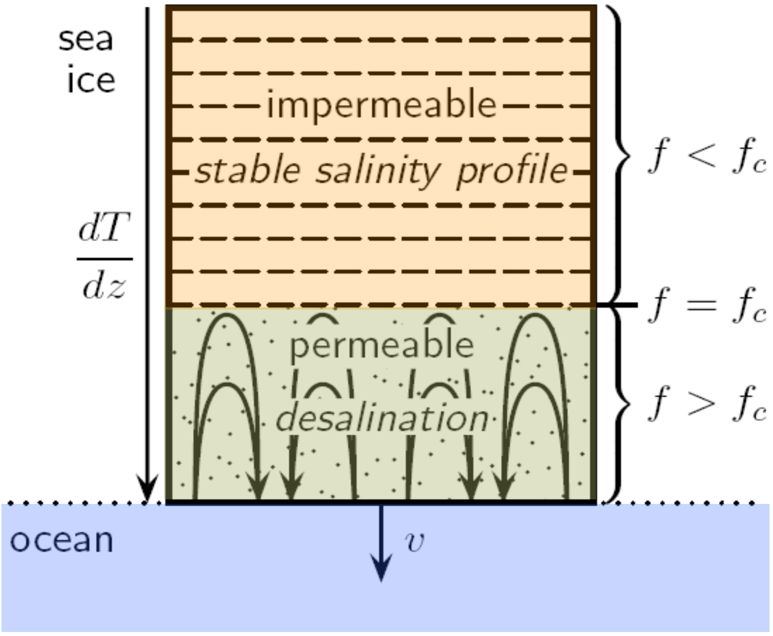
Toy model of desalination

- explicit solution for power-law permeability–porosity relationships

Result for “stable” bulk salinity:

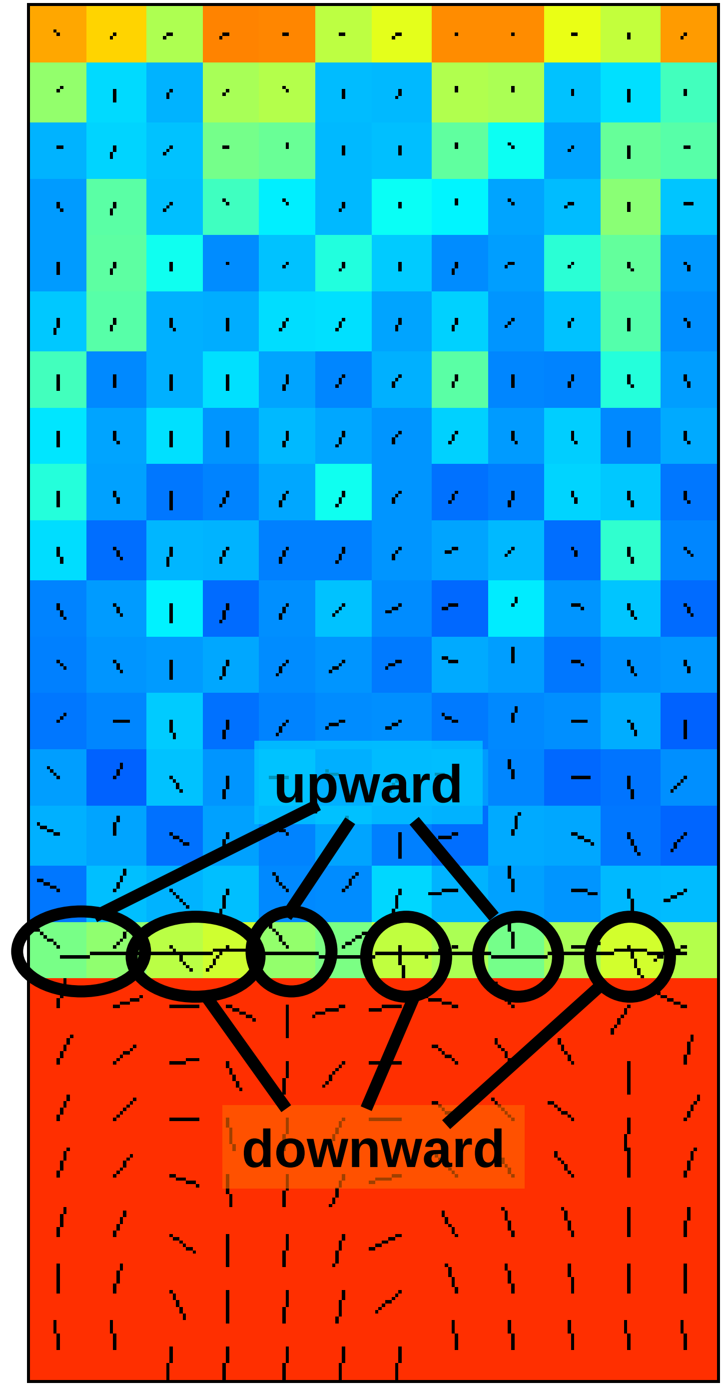
$$\frac{S_{si}}{S_0} \approx \frac{\rho_w}{\rho_i} f_c \sqrt{1 + \frac{v}{w_0}}$$

(independent of oceanic heat flux)

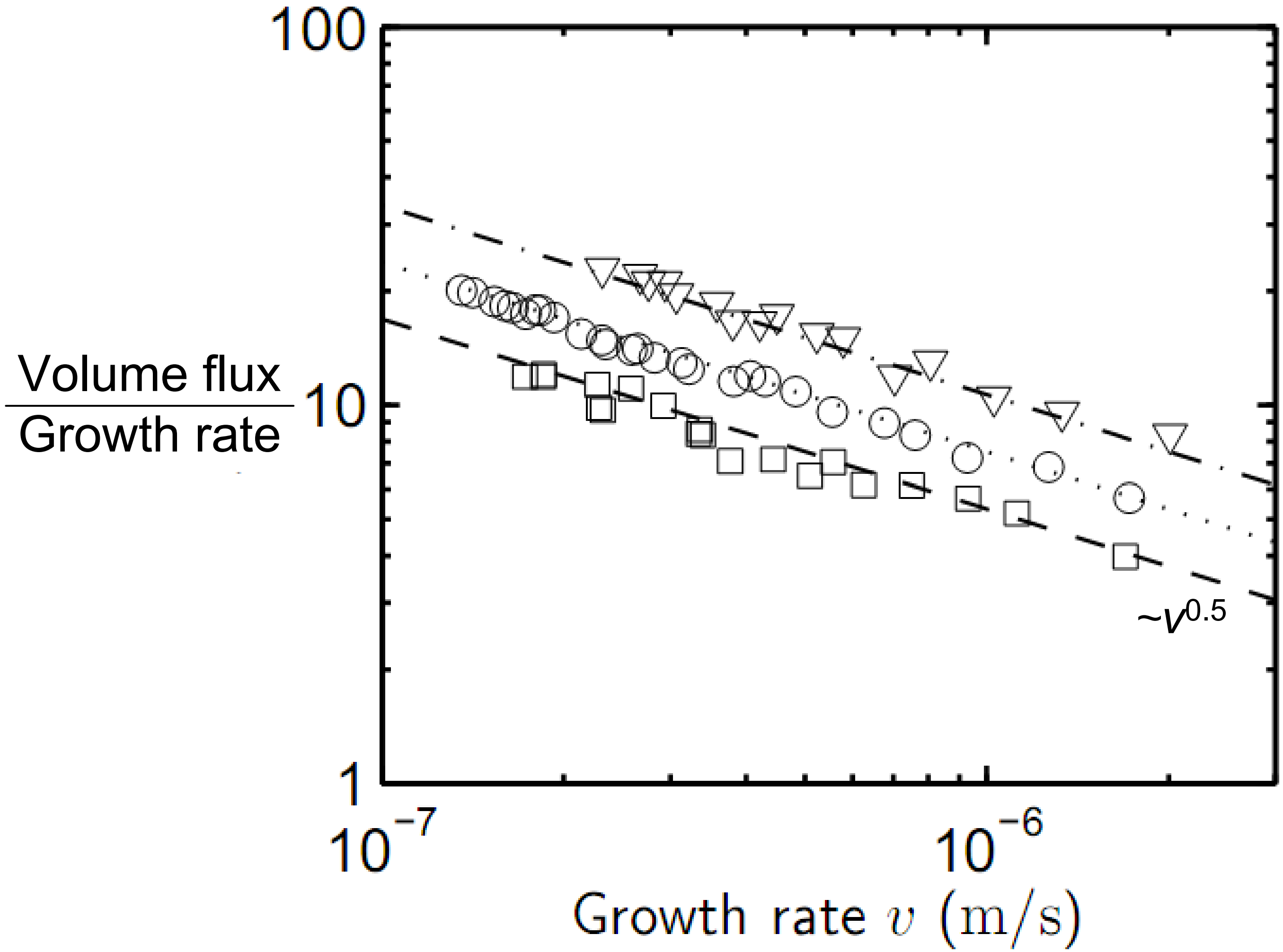


Advective ice—ocean interface flux from CFD model

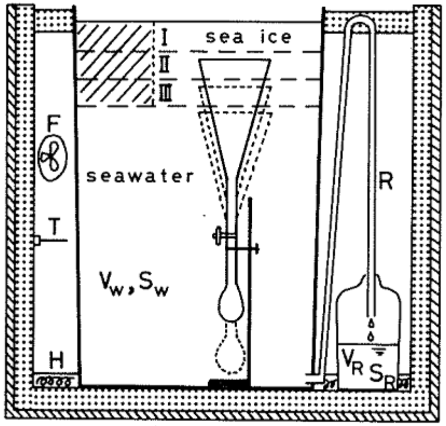
- log turbulent volume flux
  (i.e. flux less mean)
  at the ice—ocean interface
- plot as function of growth rate

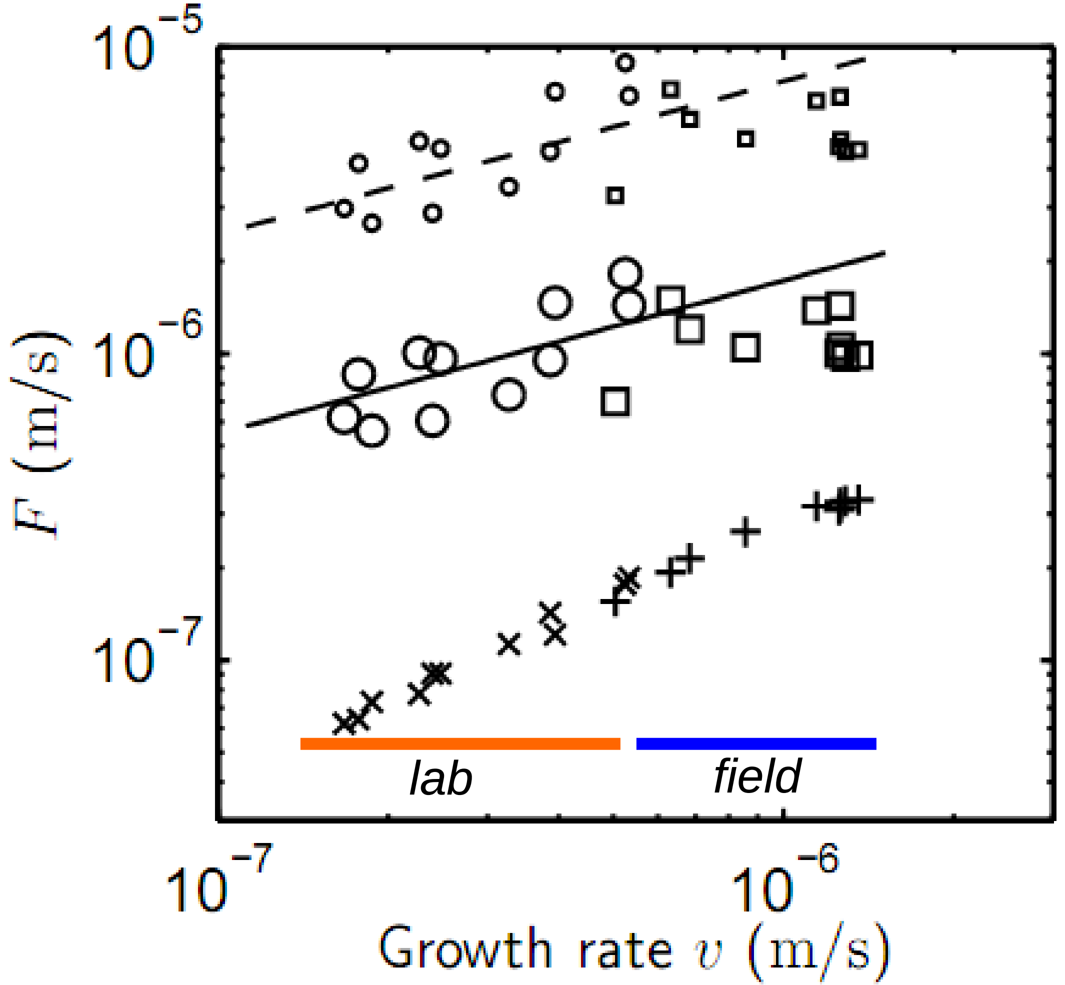


Potential “enrichment” of nutrients in sea ice



Wakatsuchi and Ono (1983): brine flux from experiments





recalculated, assuming more dilution

recalculated, assuming mixing as W&O

calculation by Wakatsuchi and Ono (1983)

Model Results

Parameter of interest in physical oceanography		winter salt flux, brine salinity		summer surface meltwater flux
Parameter to look at in sea ice model		“stable” salinity, ice–ocean flux	porosity profile	pore space (pockets, tubes)
permeability	$\Pi(\phi_c)$	✓	✓	✓
	$\frac{\Pi(\phi)}{\Pi(\phi_c)}$		✓	✓
	$\frac{\Pi_z(\phi)}{\Pi_x(\phi)}$			✓
growth conditions	growth rate	✓	✓	?
	ice temperature gradient (or ice–ocean heat flux)		✓	

Conclusions

- developed 2D 2-phase (solid–liquid) CFD model,
  capable of producing realistic
  - salinity profile
  - ice–ocean salt fluxes

  for sea ice growing in calm conditions

- developed toy model producing the same fluxes and profiles in a few ns

- Salt flux from growing first-year ice: typ. 28 kg/m3 * *v*, give or take 10%.
  systematically lower only in thin ice (e.g. leads, polynias)

- Salinity of rejected brine increases with growth rate →
  high in leads and polynias (?) → mixing???

- Ice–ocean volume flux large enough to support order-of-magnitude
  enrichment of nutrients.