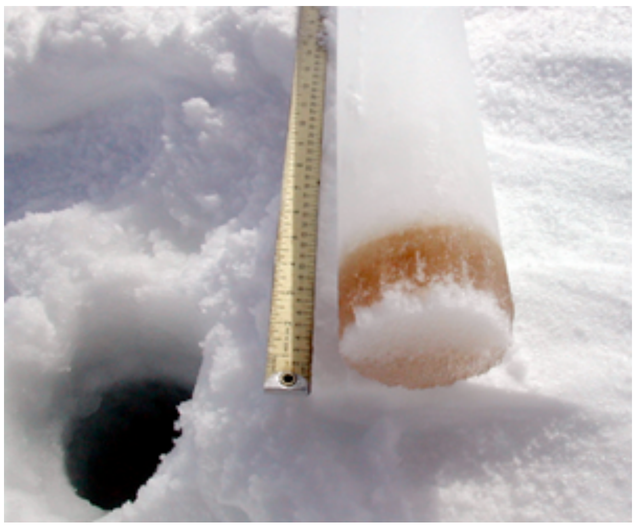
Salinity in CICE from a BGC Perspective

Nicole Jeffery



Elizabeth Hunke, Scott Elliott, Mat Maltrud, Adrian Turner (LANL)

In this talk

- A brief overview of BGC in sea ice
- Forget salinity for a minute… model the vertical transport of sea ice tracers (IceT) for BGC
- Summarize 1D simulations
- What do the results say about S?
- Apply a similar approach to model salinity in CICE for BGC
- 1D simulations
- Arctic simulations
- Conclusions and Outstanding Issues

Sea ice is a biogeochemically active medium

- Why?

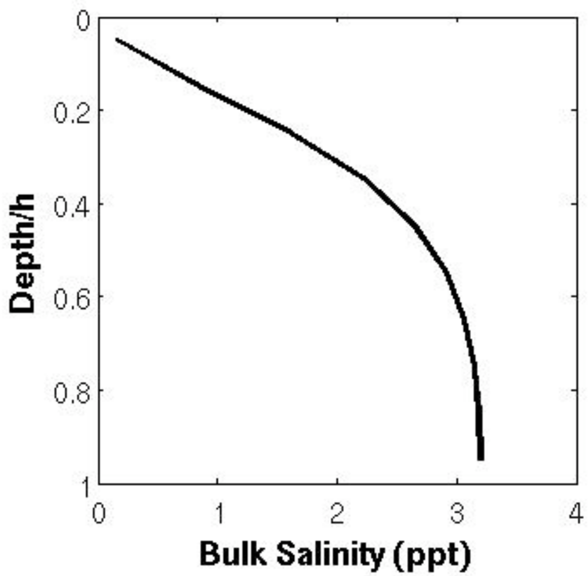
1. **Porous** – Salts and nutrients concentrate in liquid inclusions and channels as sea ice forms. Porosity (brine volume to total volume) varies with ice T and S. Ice can be permeable to atmosphere/ocean fluxes.
2. **Gravity Drainage** – A cold atmosphere concentrates higher salinity/density brine in upper layers of ice. When the brine pockets are connected, high density salt plumes mix with underlying brine and ocean water. Gravity drainage supplies ice algae with ocean nutrients during ice growth.
3. **Snow Loading** – Snow may force the ice surface below the water line, driving ocean water into the ice.
4. **Light** – Ice maintains algae near the ocean surface.

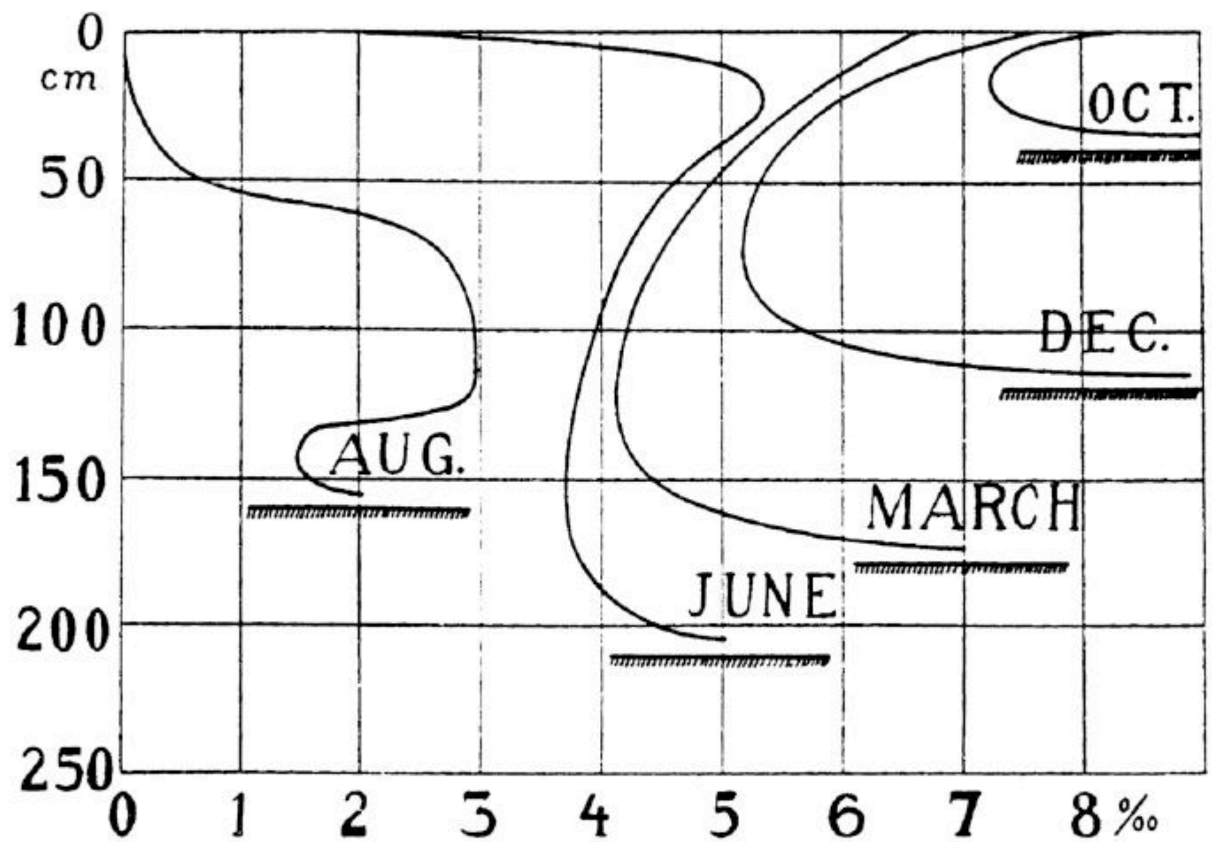
To model the physics of sea ice biogeochemistry…

- **Time-dependent and vertically resolved Porosity** - this is a known function of ice T and S
- **A "good" parameterization of gravity drainage** – this is the dominant mechanism of ocean/ice nutrient fluxes during ice growth (also the dominant mechanism of desalination). We've been testing parameterizations.
- **Pressure driven flow through porous media** – Darcy velocity is well accepted for laminar flow.

CICE does not, yet, solve for salinity

CICE fixed Salinity profile





Seasonal cycle of Salinity (Malmgren, 1927)

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Forget about salinity for a minute…

- Derive an equation for vertical transport of passive tracers

Darcy Velocity (flushing and flooding)

Molecular Diffusion

$$\phi \frac{\partial [c]}{\partial t} + \frac{\partial([c] < w >)}{\partial z} + \frac{\partial < \tilde{c}\tilde{w} >}{\partial z} = \frac{\partial}{\partial z}\left(\phi D_m \frac{\partial [c]}{\partial z}\right) + \mathrm{BGC}$$

Gravity Drainage

IceT
- Model brine concentration
- T, h, dh/dt (CICE)
- S prescribed

Gravity Drainage

$$< \tilde{c}\tilde{w} > \; = \; -D\frac{\partial}{\partial z}[c]$$

- Fluctuations represent dispersion (mechanical diffusion)
- Parameterizations for the dispersion coefficient:

Mixing Length Diffusivity (MLD)

$$D_{ml} \;=\; \begin{cases} \frac{g\Pi_o}{\mu}\phi^3\Delta\rho_b l & \text{if } \rho_b(z) \text{ is unstable} \\ 0 & \text{otherwise} \end{cases}$$

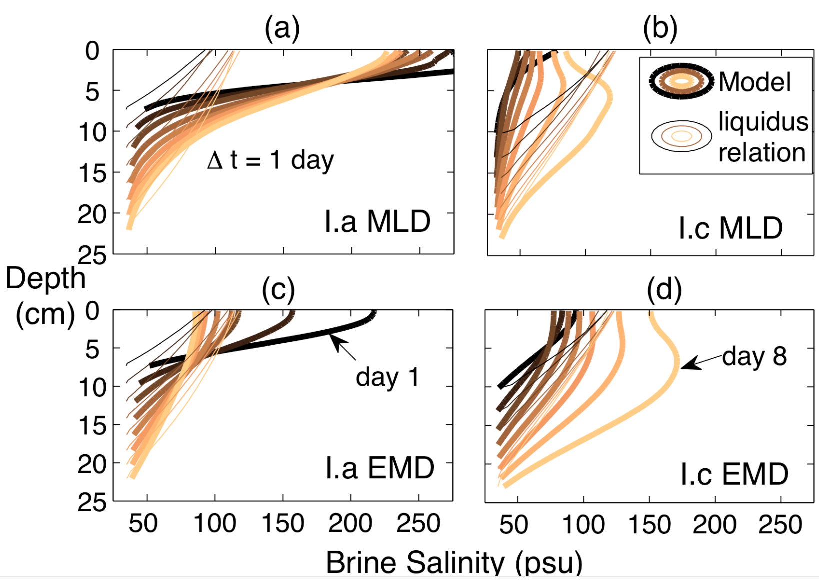
Enhanced Molecular Diffusivity (EMD)

$$D_e \;=\; \begin{cases} \phi\mathcal{D}_e & \text{if } \frac{dh}{dt} > 0 \\ 0 & \text{otherwise} \end{cases}$$

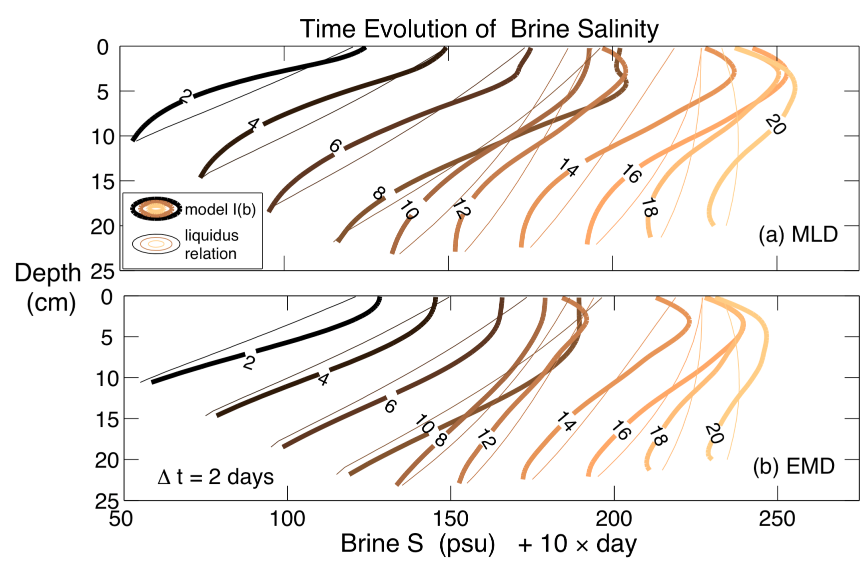
Results - 1D simulations of growing ice

- Without BGC reactions, brine concentration ([c]) should mirror brine salinity (S_b) **which is a function of T only.**
- Both parameterizations reproduce data/liquidus curves **if we chose a good prescription of bulk S.**

"Poor" S prescriptions



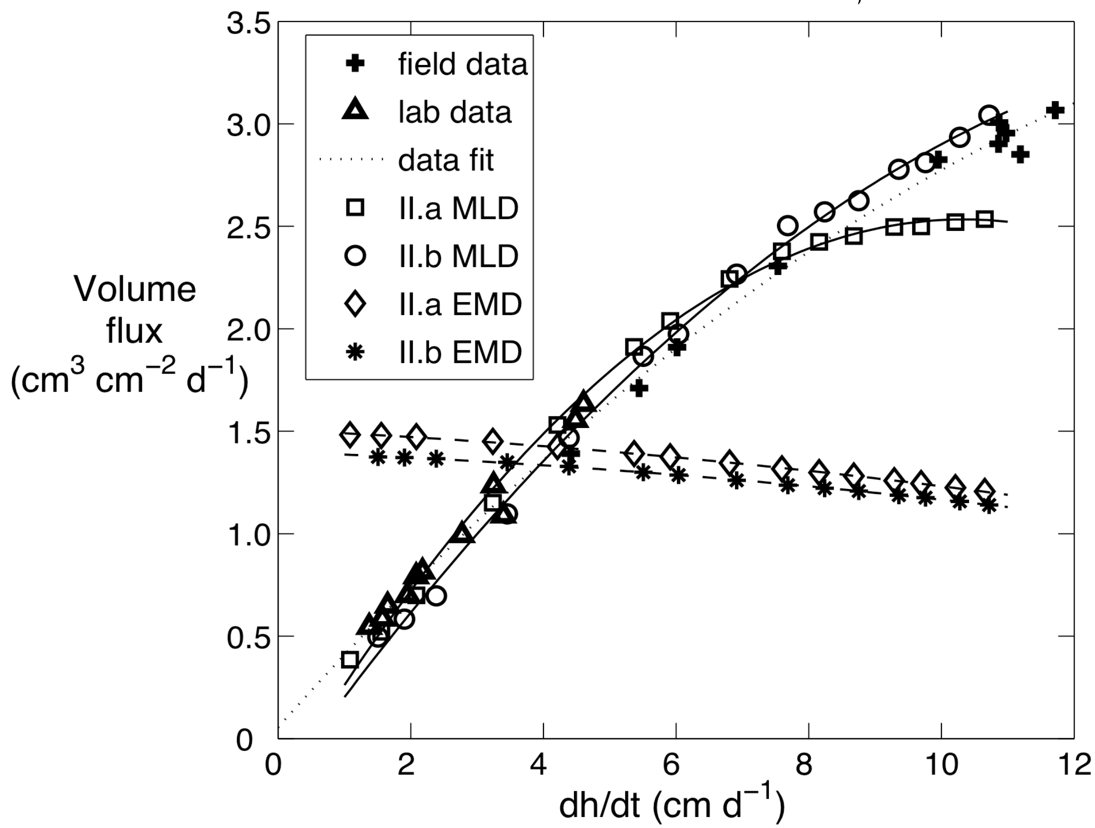
"Good" S prescription



Boundary Flux Simulations are more conclusive

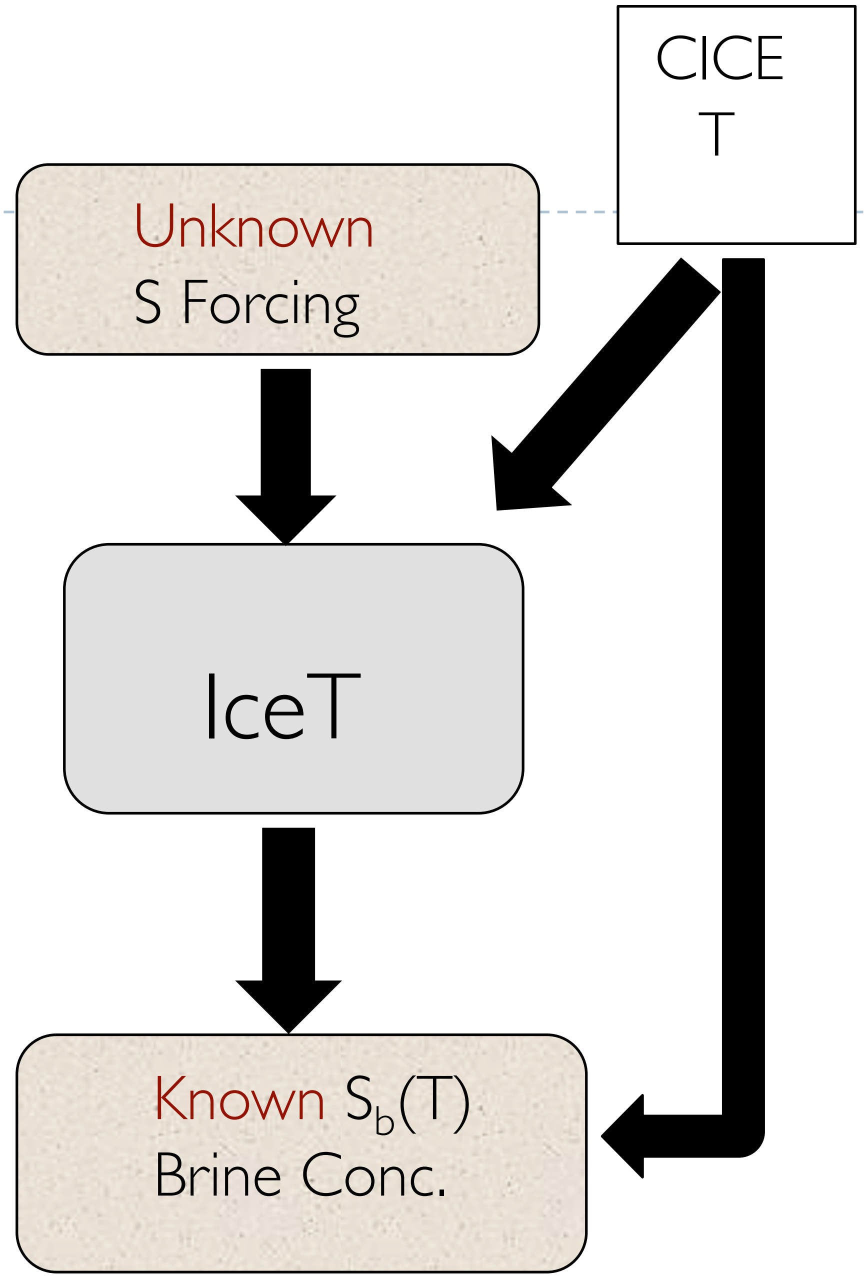
- MLD increases with dh/dt as measurements of bottom brine volume flux.
- EMD does not.

Data from Wakatsuchi & Ono, 1983

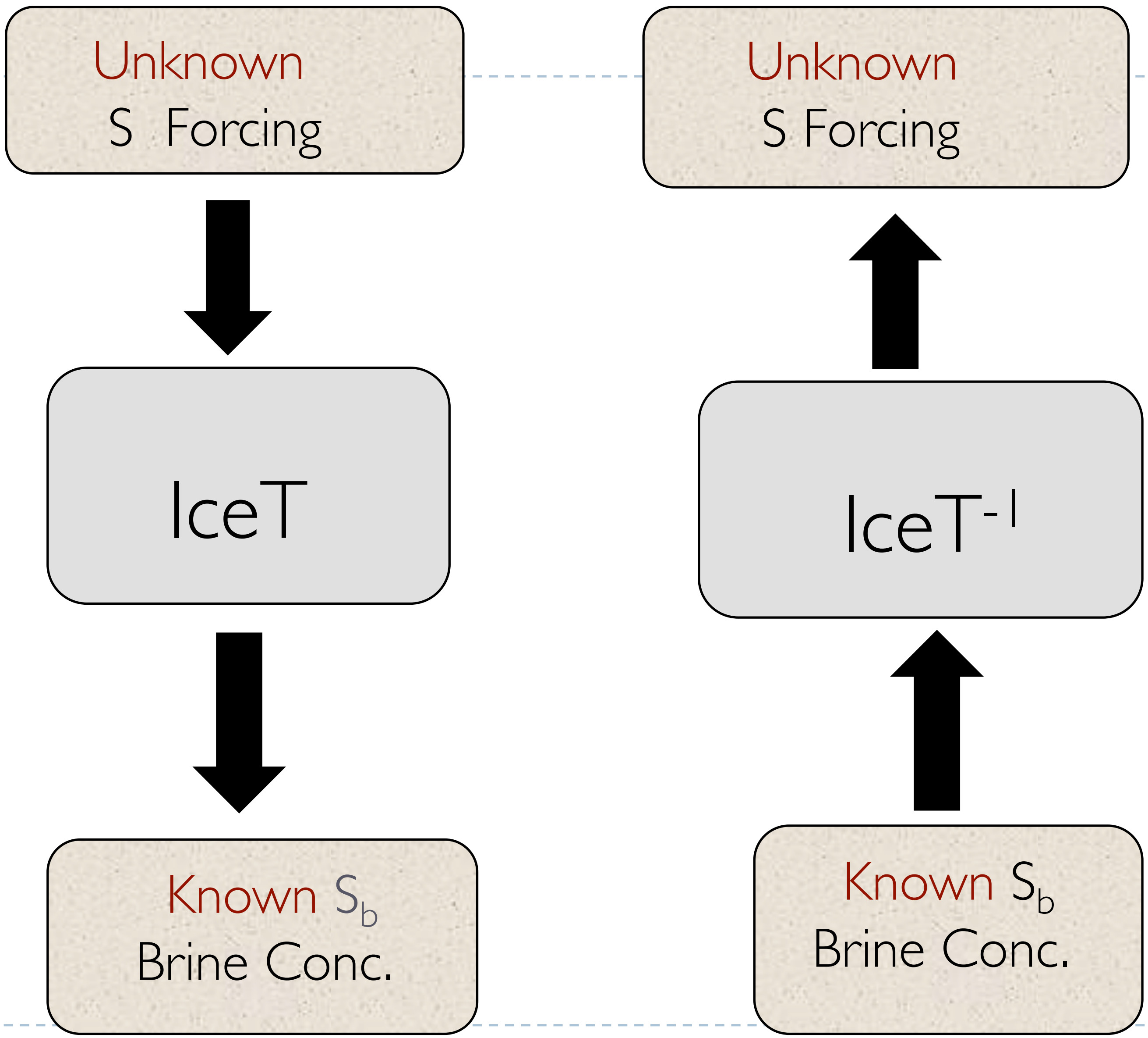


Back to the salinity problem…

- Do we have the data to prescribe salinity globally? No.
- IceT gave us information about which prescription of S was "good".
- Is the MLD (or EMD) parameterization sensitive enough to predict desalination at each time-step? Can we quantify "good"?

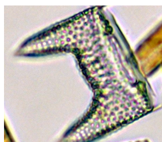

CICE
T
Unknown
S Forcing
IceT
Known $S_b(T)$
Brine Conc.

CICE
T


Unknown
S Forcing
IceT
Known S_b
Brine Conc.
Unknown
S Forcing
$IceT^{-1}$
Known S_b
Brine Conc.

CICE
T

Unknown
S Forcing



IceT

$IceT^{-1}$

Sea Ice Algae
at last!

Known Sb
Brine conc.

Note

- We want $IceT^{-1}$ to provide S forcing for BGC. It does not need to couple back to CICE via thermodynamics or mechanics.
- $IceT^{-1}$ has its own time-step and grid. It has its own minimum ice thickness criteria.
- However, it may be possible to feedback S solutions into heat capacity, thermal conductivity, melting temperature, and enthalpy without rewriting CICE thermodynamics.

IceT[-1]

Parameters depend on T, dh/dt, h

MLD
$$\frac{\partial S}{\partial t} = \left\{ \frac{\partial (\mathcal{A} S^3)}{\partial z} + \mathcal{E} \right\}$$

Gravity drainage

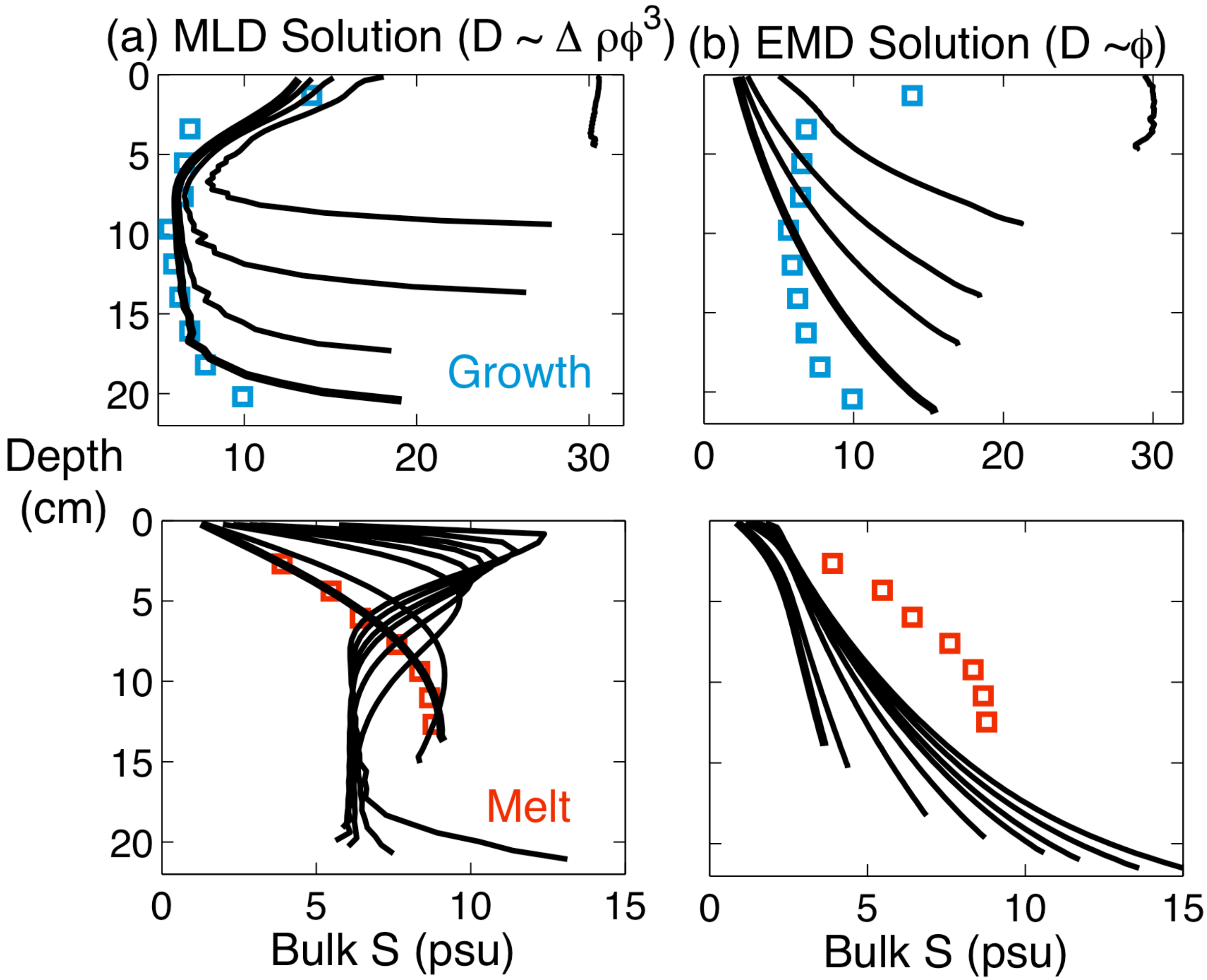
Flushing

EMD
$$\frac{\partial S}{\partial t} = \left\{ \frac{\partial (\mathcal{A}' S)}{\partial z} + \mathcal{E} \right\}$$

IceT
$$\phi \frac{\partial [c]}{\partial t} = \frac{\partial}{\partial z} \left(\mathcal{D} \frac{\partial [c]}{\partial z} \right) - < w > \frac{\partial [c]}{\partial z}$$

Parameters depend on T, dh/dt, h and **S**

IceT^{-1}



- MLD solution traps salt in the upper ice
- EMD does not contain Π information.

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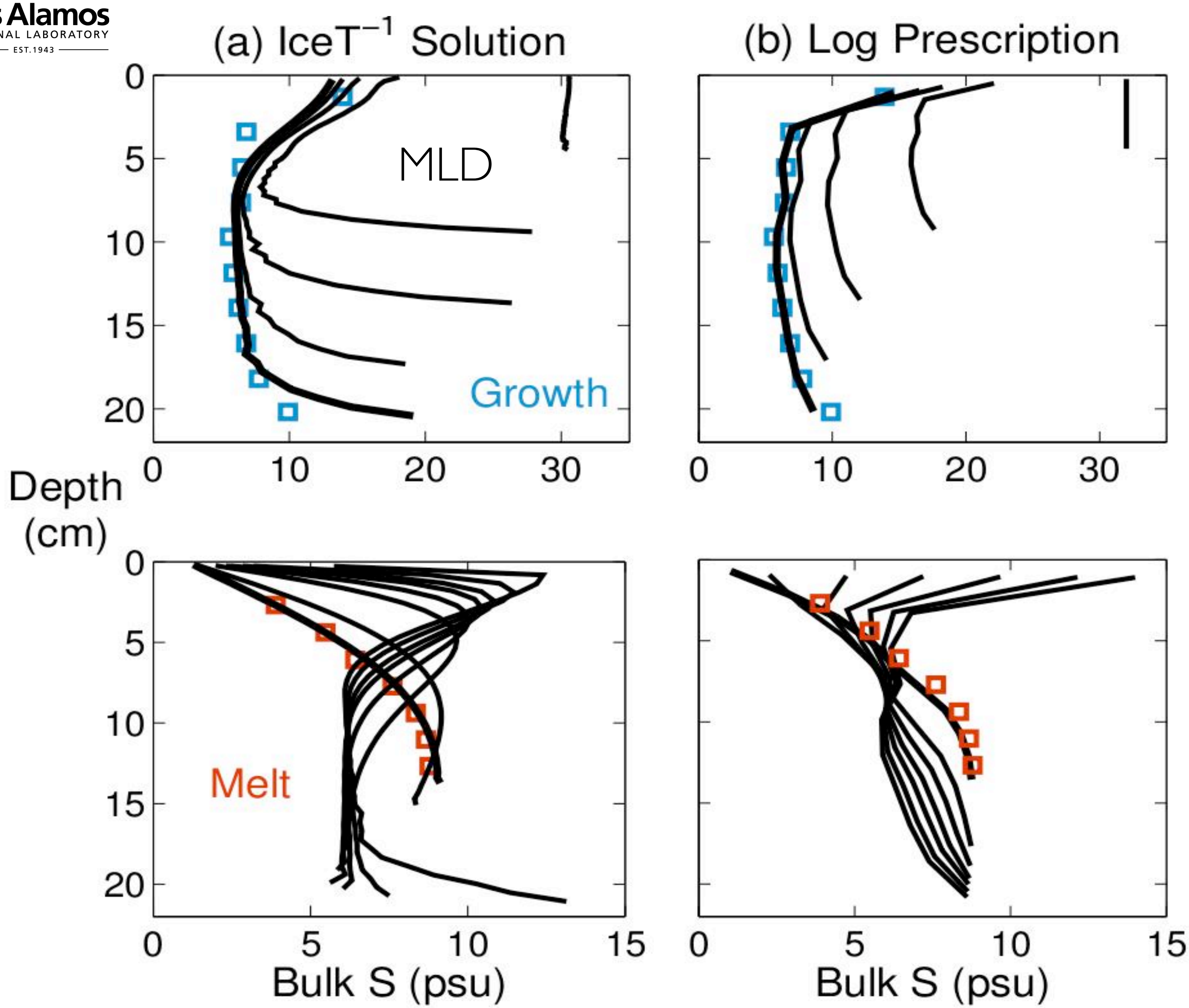
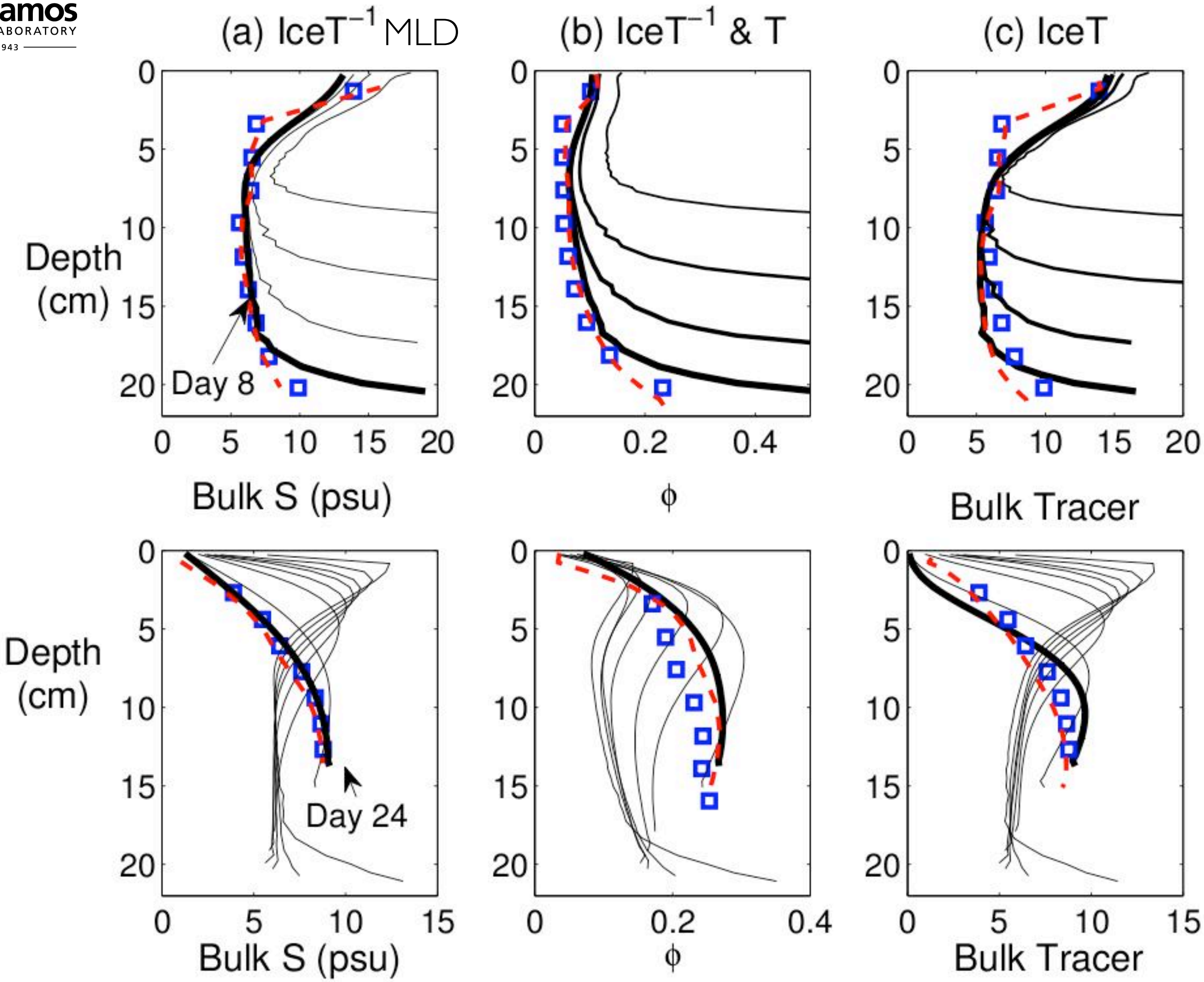
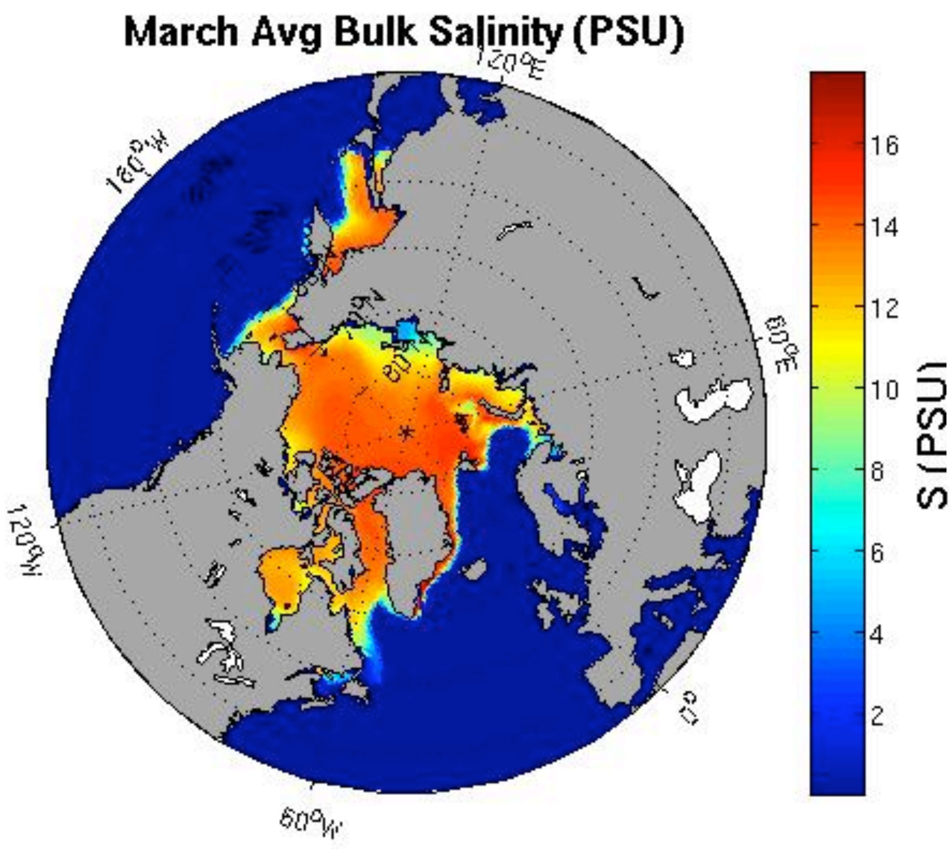
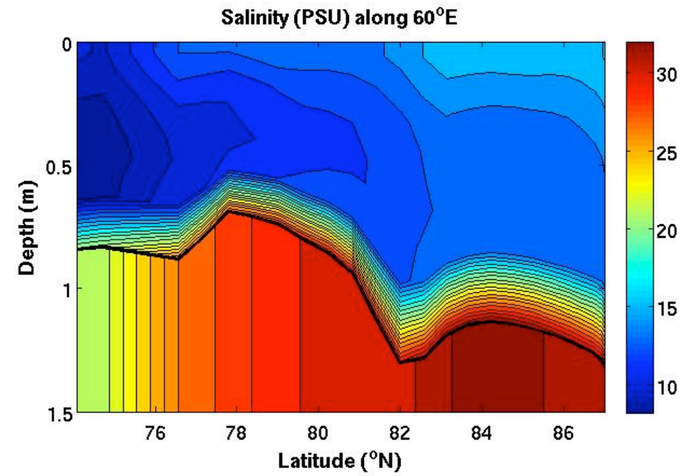
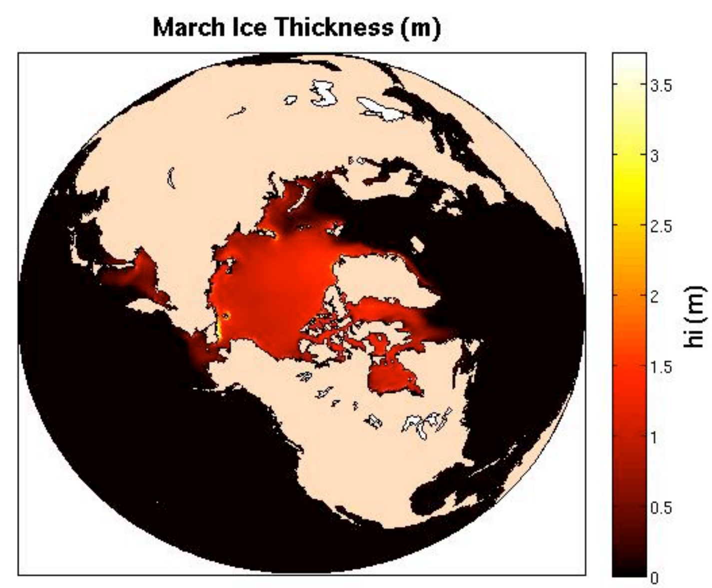



(a) IceT^{-1} MLD
(b) IceT^{-1} & T
(c) IceT
Depth (cm)
Day 8
Bulk S (psu)
ϕ
Bulk Tracer
Depth (cm)
Day 24
Bulk S (psu)
ϕ
Bulk Tracer

Salinity (no thermodynamic feedbacks)



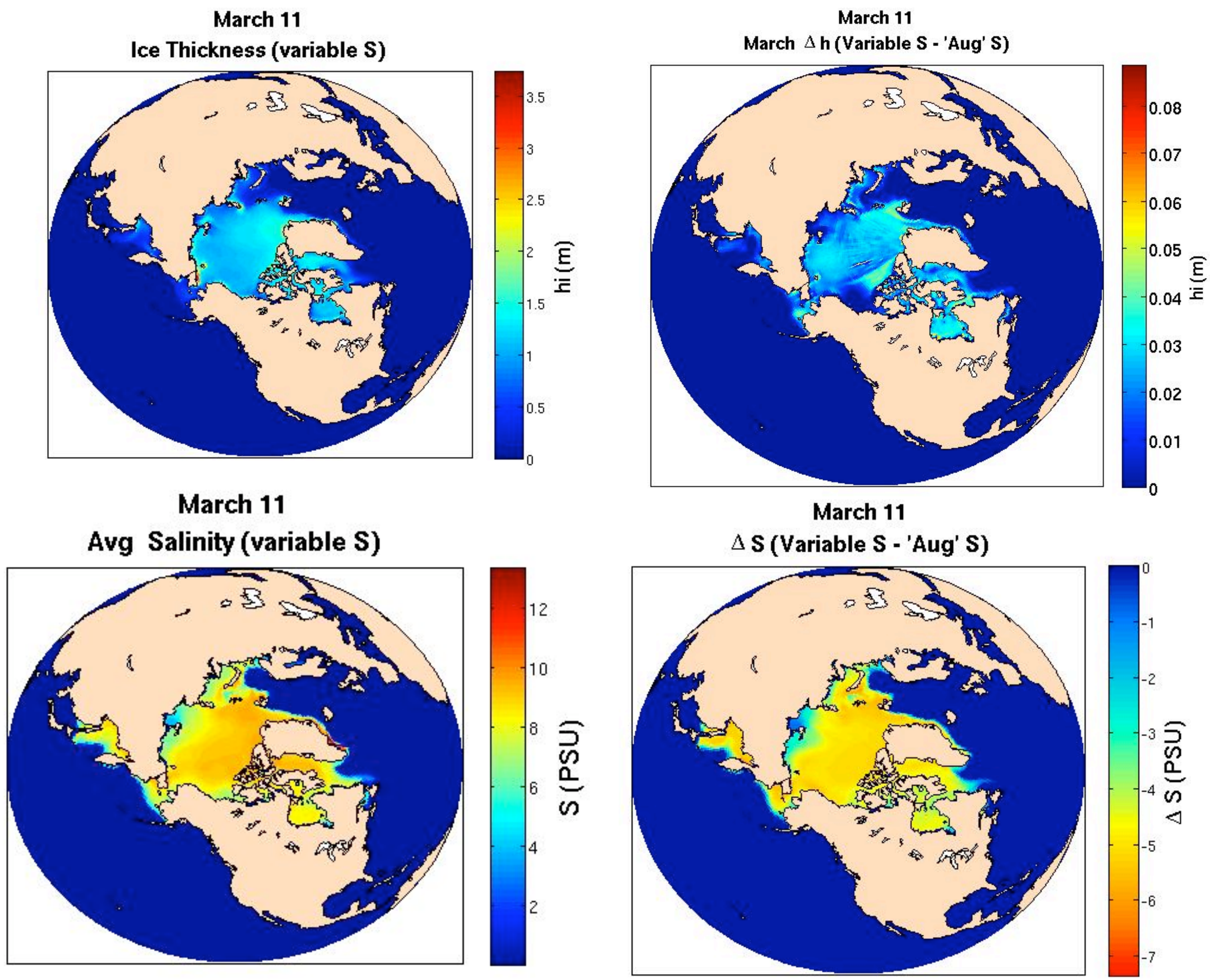




With thermodynamic feedbacks

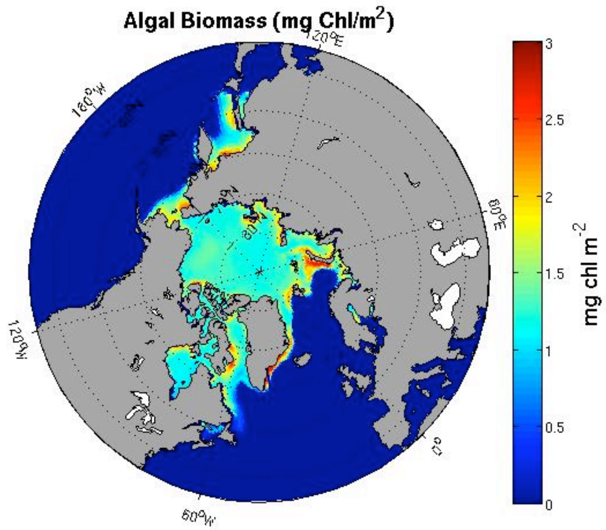
Ice Thickness

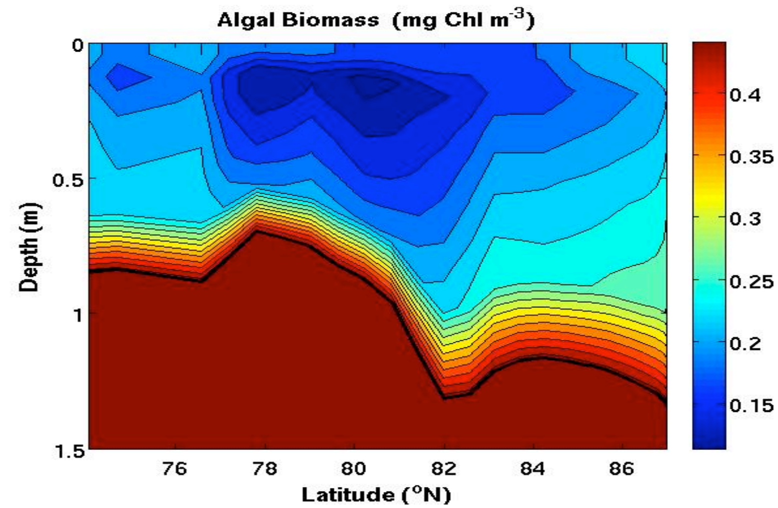
Salinity



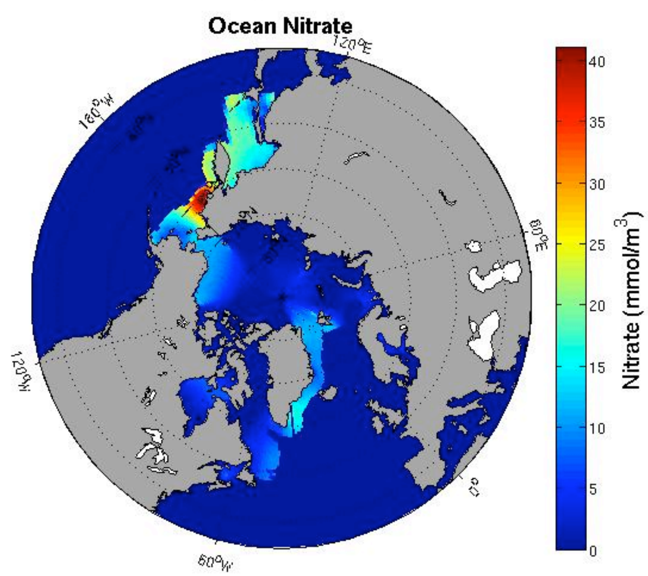
And BGC, but just the physics…

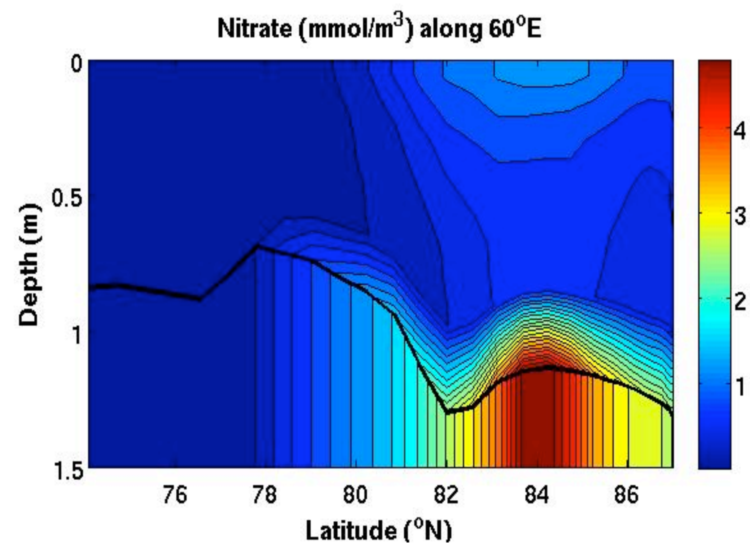
Chlorophyll





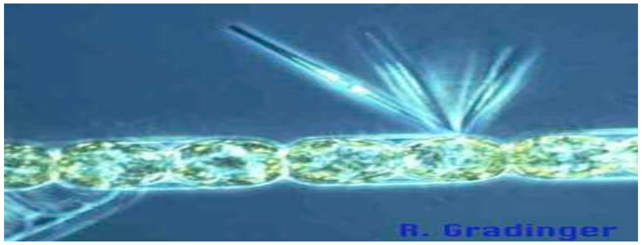
Nitrate





Conclusions, concerns…

- The MLD is a "good" gravity drainage parameterization for the vertical transport of passive tracers (IceT) and for use in modeling the desalination of sea ice.
- MLD is a diffusion term in the passive tracer problem, but becomes a non-linear advective term in the salinity problem. Salinity is much more sensitive to the parameterization.
- With current CICE output (T, dh/dt, h), we can solve for S and run IceT with bgc. No need to feed-back S into CICE.
- However 2-way coupling in the current CICE framework has begun and looks promising.



Thermodynamic challenges:

- Still need to include enthalpy change due to S fluxes
- Heat conduction can increase high salinity interior ice temperatures above their melting point.
- What's going on near the the ice surface? Do T and S "see" the same surface?