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ABSTRACT

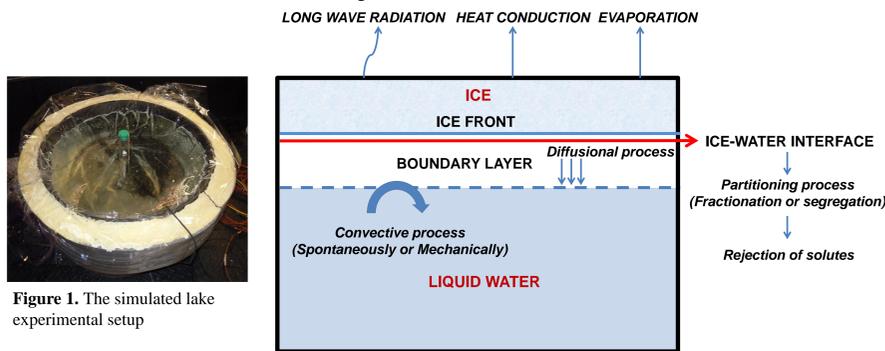
The thick ice covers on polar lakes play a major role in the physical, chemical and biological properties of these lakes. Of particular importance is the partitioning of chemical and biological constituents between the water and ice, which can produce highly concentrated brines beneath the overlying ice and influence the biogeophysical properties of the ice itself. As water molecules freeze they create a crystalline lattice that repels most of the solutes and particulate matter that was in the water. The materials that are trapped in the ice typically concentrate in localized inclusions or concentrate between the ice grains. Despite much contemporary interest in the habitability of icy systems at Earth's poles, little is known about how constituents partition between the liquid and solid phase. We conducted a series of controlled freezing experiments using water from selected Arctic and Antarctic lakes to investigate chemical and biological fractionation between ice and water as the lake water freezes.

OBJECTIVES AND HYPOTHESES

Overarching objective: To define the biogeochemical dynamics of ice and liquid phase changes during formation and growth of ice covers of Antarctic and Arctic Lakes.

Hypotheses:

- Solutes will be incorporated into the ice based on their respective affinities: $Cl^- > F^- \sim NH_4^+ > NO_3^- > Na^+ \sim K^+ > Ca^{2+} > SO_4^{2-}$ (Eichler et al., 2001).
- The relative magnitude of segregation coefficients ($Mg^{2+} > Ca^{2+}$) is attributed to interstitial incorporation (coupled with HCO_3^-) in the ice lattice, and controlled by ion size (Killawee et al., 1998)
- The relative evolution of water and ice chemistry during freezing will depend on the partitioning process at the ice-water interface and on the redistribution of the solutes under diffusional and convective processes in the water reservoir (Lock et al., 1990).



METHODS

Field Sampling:

Samples were collected during the 2009-2010 field seasons from Barrow (**BAR II**), AK and the 6m depth of Lake Fryxell (**FRX**), Taylor Valley, Antarctica. Barrow lakes are seasonally ice covered (~1 m) and Lake Fryxell is permanently ice covered (4 m).

Experimental Design:

A 75 L tank was lined with Teflon and 50 L of lake water was added (Fig. 1). The system was incubated for ~4 days at -10°C with a "cold sky" set at -50°C to simulate a cold night sky. A clean drill bit was used to penetrate the ice cover and liquid samples were taken over time. The ice phase was sampled after freezing was complete by band-saw layer separation.

Sample Analysis:

Ions, stable isotopes of water, nutrients, TOC, and biological samples were collected at 4-7 time points throughout the experiment from both the liquid and ice phases. Concentrations from the two phases were compared and a segregation coefficient computed for each analyte.

RESULTS



Figure 3. Ice section from BAR freeze-down experiments.

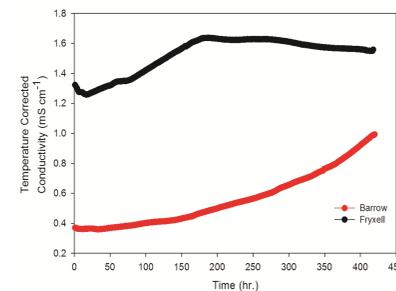


Figure 4. Conductivity at the bottom of the simulated lake over the course of the FRX and BAR freeze-down experiments (Freezing rate for BAR = 2.7 mm hr⁻¹; FRX = 2.2 mm hr⁻¹)

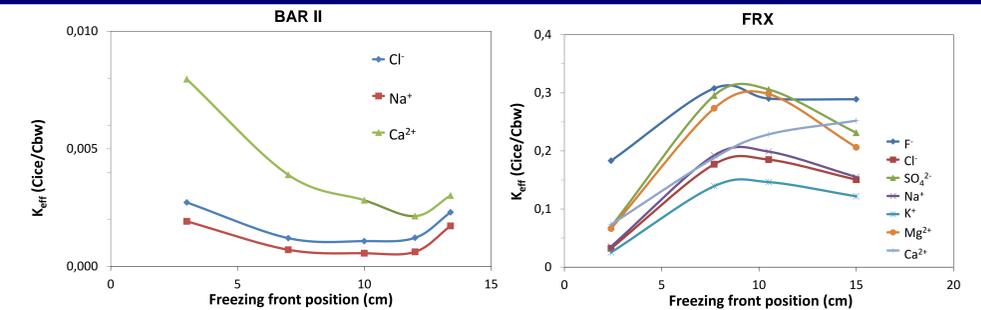


Figure 5. Variations with depth of effective segregation coefficient (K_{eff} (Cice/Cbw)) in Barrow (BAR II) and Fryxell (FRX) freeze-down experiments. The relative evolution of liquid water and ice chemistry is illustrated by the variation with depth of the effective segregation coefficient (k_{eff} (i)). These changes are primarily related to incorporation of solute in ice.

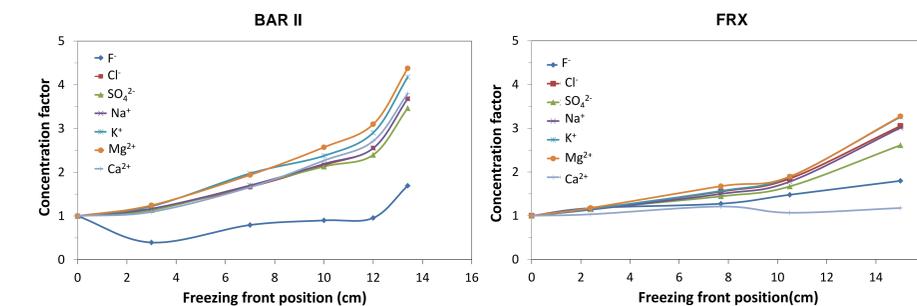


Figure 6. Concentration factor (T_i divided by T_0 concentration) of chemical species in the liquid phase of FRX and BAR freeze-down experiments.

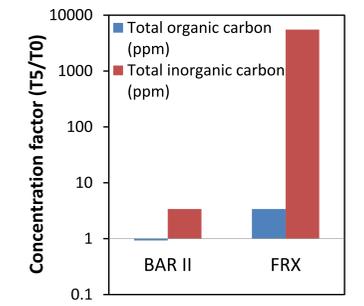


Figure 7. Concentration factor of total organic carbon and inorganic carbon between the T_{final} liquid phase divided by concentration at T_0 .

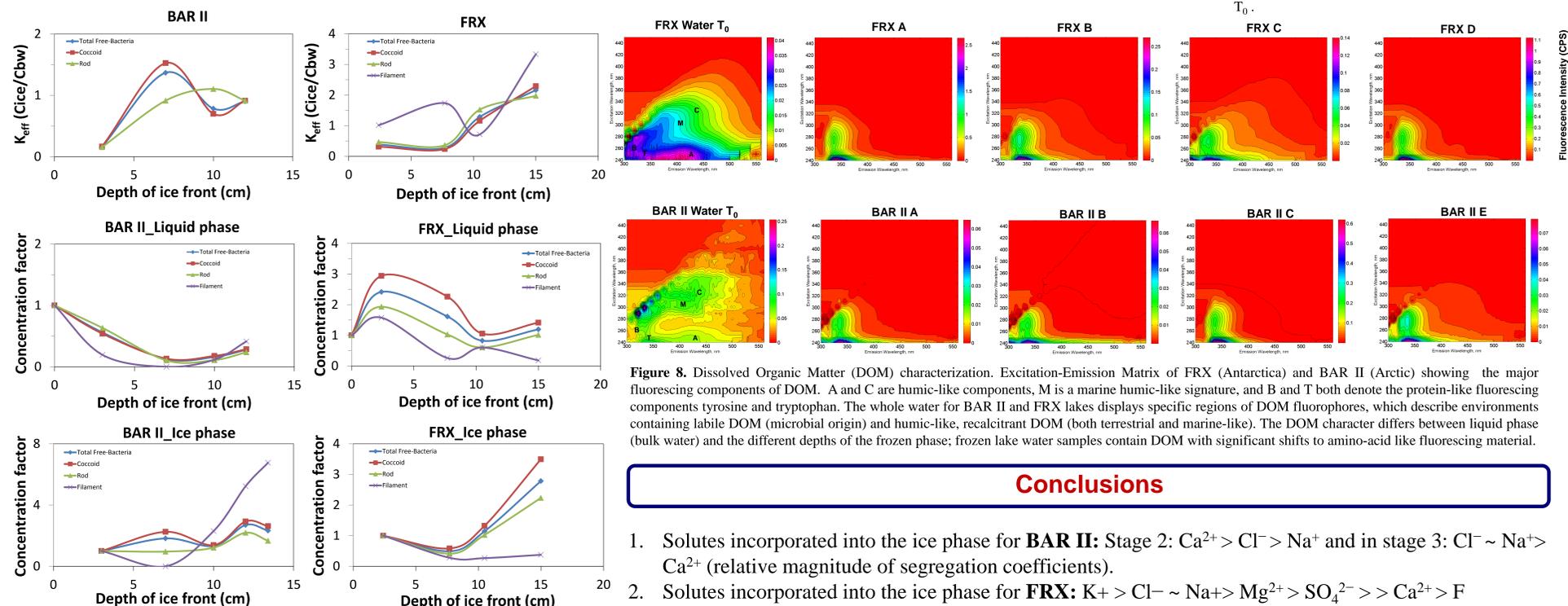


Figure 8. Dissolved Organic Matter (DOM) characterization. Excitation-Emission Matrix of FRX (Antarctica) and BAR II (Arctic) showing the major fluorescing components of DOM. A and C are humic-like components, M is a marine humic-like signature, and B and T both denote the protein-like fluorescing components tyrosine and tryptophan. The whole water for BAR II and FRX lakes displays specific regions of DOM fluorophores, which describe environments containing labile DOM (microbial origin) and humic-like, recalcitrant DOM (both terrestrial and marine-like). The DOM character differs between liquid phase (bulk water) and the different depths of the frozen phase; frozen lake water samples contain DOM with significant shifts to amino-acid like fluorescing material.

Conclusions

- Solutes incorporated into the ice phase for **BAR II**: Stage 2: $Ca^{2+} > Cl^- > Na^+$ and in stage 3: $Cl^- \sim Na^+ > Ca^{2+}$ (relative magnitude of segregation coefficients).
- Solutes incorporated into the ice phase for **FRX**: $K^+ > Cl^- \sim Na^+ > Mg^{2+} > SO_4^{2-} > Ca^{2+} > F^-$
- More conservative** species in **BAR II** liquid phase: $Mg^{2+} > K^+ > Ca^{2+} > Na^+ \sim Cl^- > SO_4^{2-} > F^-$
- More conservative** species in **FRX** liquid phase: $Mg^{2+} \sim K^+ > Na^+ \sim Cl^- > SO_4^{2-} > F^- > Ca^{2+}$
- BAR II** segregation coefficients: Stage 2: $Ca^{2+} = 0,0029$, $Cl^- = 0,0012$, $Na^+ = 0,0006$.
- BAR II** shows the three stages of ice formation. The solute-poor ice (stage 2) presents effective segregation coefficients between ice and bulk solution in the range of 0,0006 and 0,0029 for Ca^{2+} , Cl^- and Na^+ (Fig. 5). The ice from **BAR II** was too pure to measure the other chemical species.
- FRX** freeze-down experiment shows only the solute-rich stage 3 ice due to high initial concentration. **These data allow us to describe microhabitats in ice and liquid water based on the biogeochemical partitioning observed.**

Acknowledgements

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