BRITISH COLUMBIA'S UNASSUMING PLANETARY LABORATORY: HOW A HANDFUL OF FROZEN SALINE LAKES CAN HELP US UNDERSTAND BRINES ACROSS THE SOLAR SYSTEM. J. J. Buffo[1], E. K. Brown[2], A. Pontefract[3], B. E. Schmidt[4], B. Klempay[5], J. Lawrence[2], J. Bowman[5], M. Grantham[2], J. B. Glass[2], T. Plattner[2], C. Chivers[2], P. Doran[6], C. R. Meyer[1], M. E. Barklage[7], and B. Fluegel[8], [1]Dartmouth College (jacob.j.buffo@dartmouth.edu), [2]Georgia Institute of Technology, [3]Georgetown University, [4]Cornell University, [5]Scripps Institution of Oceanography, [6]Louisiana State University, [7]Illinois State Geological Survey, [8]Northwestern University.

Introduction: Mounting observational and theoretical evidence supports the ubiquity of brines across the solar system (e.g., ice-ocean worlds, Mars). This fact, combined with their indelible link to astrobiology, has led to the prioritization of improving our understanding of brine-rich systems in the lens of planetary exploration, planetary protection, resource identification, and the search for life beyond Earth.

A fundamental challenge in expanding our knowledge of solar system brines is the fact that all the proposed brine-bearing worlds (less Earth) reside beyond the frost line. As such, stable/metastable brines are buried beneath/within icy shells, caps, or regolith, complicating their direct measurement unless active plume or effusive processes are occurring, and placing any near surface brines in a perpetual battle against impending solidification. Until direct *in situ* missions (e.g., penetrators [1]) become consistently tenable, we will continue to rely upon our ability to relate remote sensing measurements of icy world surfaces to their subterranean brine properties and processes [2, 3].

While this has been our principal strategy thus far (e.g., predictions of interior ocean compositions from surface ice or plume particle chemistry), uncertainties in this inversion method, namely quantitatively linking ice and brine properties, continue to leave the compositions and concentrations of planetary brines significantly underconstrained [2, 3]. Compounding these challenges is the putative chemical diversity of planetary brines across the solar system (e.g., [4-6]). Concomitantly, given the likely importance of brines in governing both the geophysics and habitability of icy worlds, constraining the dynamics, longevity, habitability, and, crucially, the *observable signatures* of compositionally diverse and potentially habitable ice-brine environments are foundational goals of the planetary science community, as evidenced by the science priorities of upcoming spacecraft missions (e.g., Europa Clipper, JUICE, Dragonfly) [2, 3, 7].

Two primary strategies for improving our understanding of planetary ice-brine systems are the use of polar terrestrial analogs (e.g., sea ice, Antarctic Dry Valley lakes) and predictive theoretical models (e.g., [2, 3]). While terrestrial analog ice-brine systems provide exceptional compositional endmembers for understanding the relationship between ice characteristics and parent brine properties, they represent a small subset of potential planetary brine chemistries. Furthermore, the successful extension of terrestrial analog dynamics to the spatiotemporal scales and chemical diversity of planetary environments relies on the accuracy and applicability of numerical models – which in turn require benchmark data, such as measurements of analog environments, to validate.

Reactive transport models (which track the thermochemistry and multiphase processes of multicomponent systems) have been shown to succinctly capture the NaCl-dominated dynamics and evolution of our most well-studied terrestrial analog ice-brine system – sea ice – but validation against more compositionally diverse ice-brine systems remains lacking. This is in part due to a limited amount of data regarding chemically diverse naturally occurring ice-brine analogs [2, 3]. Expanding our existing catalog of ice-brine analog systems will provide an improved understanding of their dynamics and habitability and produce a test data set to validate reactive transport models designed to simulate planetary ice-brine environments, bolstering confidence in their application to planetary science and mission relevant problems.

Here we introduce the unique planetary analog lakes of south central British Columbia, describe our biogeochemical survey of these lakes and the novel data set we've accrued, discuss a two-dimensional reactive transport model we've adapted to accommodate diverse planetary ice-brine environments, validate the model against empirical lake data, and discuss the implications for the future of forecasting planetary brine properties and dynamics in the lens of planetary exploration and planetary protection.

Field Site/Work: The Cariboo Plateau of south-central British Columbia houses an array of compositionally diverse hypersaline lakes. Many of the chemistries represented in these systems are unique to the area (e.g., $MgSO_4$ and $NaCO_3$ dominated ice-brine systems) and may more closely represent the compositions of oceans and brines of icy worlds across the solar system than does our NaCl dominated ocean or the brines of other terrestrial analog ice-brine environments (e.g., Dry Valley lakes) [8].

The lakes form perennial ice covers, offering a unique opportunity to investigate the thermal and physicochemical properties of ices derived from unique planetary relevant brines as well as the characteristics of their parent fluid, their formation history, and thus the quantitative relation between ice observational properties and their underlying parent brines. We will present thermal, physical, and biogeochemical profiles of these unique ices (e.g., Figure 1) and discuss their relevance to the identification and characterization of planetary brines.

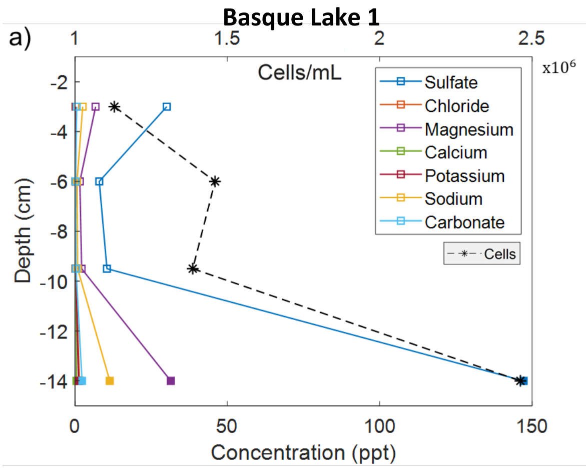

Figure 1 – Biogeochemical profiles of unique ice-brine systems. Ionic composition and cell density of the ice and brine (solid squares) in a hypersaline lake system [8].

2D Model of Planetary Ice-Brine Systems: To extend the knowledge garnered from these unique analog environments to planetary systems we have modified the two-dimensional multiphase reactive transport model SOFTBALL [9] to accommodate diverse brine chemistries and planetary environmental conditions [3]. The model tracks several habitability relevant parameters including water content and ice/brine compositions (e.g., Figure 2). Here we validate the numerical model against the physicochemical profiles of the hypersaline lakes, bolstering confidence in its application to a diverse array of planetary chemistries/environments, and discuss the significant implications the model's use will have in our ability to forecast the dynamics, evolution, and properties of ice-brine systems throughout the solar system.

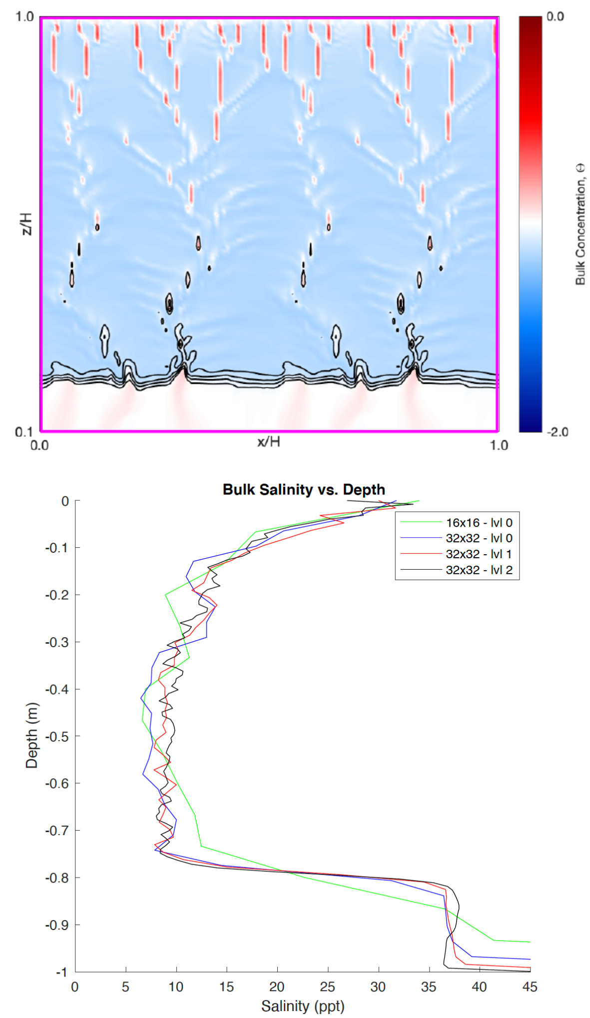

Figure 2 – Top) Two-dimensional profile of nondimensional bulk concentration (salinity) in sea ice simulated using the multiphase reactive transport model SOFTBALL – porosity contours in black [3]. **Bottom)** Horizontally averaged salinity profile of the 2D profile using different resolutions. Note the similarity of the 'c-shaped' profile produced by the model to that of the ionic concentration profiles of Figure 1.

References: [1] Bryson F. E. et al. (2020) *ASCENCD 2020*. [2] Buffo J. et al. (2020) *JGR: Planets*. [3] Buffo J. J. et al. (2021) *JGR: Planets*. [4] Postberg F. et al. (2009) 459, 1098-101. [5] Trumbo S. K. et al. (2019) *Sci. Adv.* 5, 7123. [6] Zolotov M.Y. and Shock E. L. (2001) *JGR: Planets*. 106, 32815-32827. [7] Vance S. D. et al. (2020) *JGR: Planets*. 6736. [8] Buffo J. et al. (*in review*) *Astrobiology*. [9] Parkinson J. G. R. et al. (2020) *JCP: X*. 5, 100043.