QUANTIFYING IMPURITY ENTRAINMENT AT ICE-LIQUID INTERFACES. J. J. Buffo[1], B. E. Schmidt[1], C. Huber[2], and C. C. Walker[3]. [1]Georgia Institute of Technology 311 Ferst Dr., ES&T 3120, Atlanta, GA 30318 (jacob.buffo@eas.gatech.edu), [2]Brown University 324 Brook St., Box 1846, Providence, RI 02912 (christian_huber@brown.edu), [3]Wood Hold Oceanographic Institution 266 Woods Hold Rd., MS#12, Woods Hole, MA 02543 (cwalker@whoi.edu).

Introduction: Impurities within the icy shells of ocean worlds have long been lauded as putative facilitators of geophysical processes and sustained subsurface ocean habitability [1-6]. Entrainment of solutes alters the physicochemical and thermal properties of ice, impacting its density, melting point, electrical, and mechanical behavior. Thermochemical convection in ductile ice mantles [1-3], the formation of intrashell hydrological features [8], subduction of brittle ice lithosphere [4], and redox cycling due to ice-surface interaction [6-7] all critically depend on the level of impurities entrained within the ice, yet current models of these processes rely on *a priori* assumptions of non-ice content.

On Earth, the composition of ice is determined by the dynamics of the ice-liquid interface during its formation [9-10]. In solute bearing systems (e.g. sea ice) a two-phase regime is formed near the interface, frequently termed a ‘mushy layer’, consisting of a porous ice matrix bathed in concentrated interstitial brine where heat a mass transport via diffusion, convection, and reaction mechanisms occur within the permeable medium. Numerical models have been successful at reproducing the ionic profiles of terrestrial ices, revealing that ion content within the ice is uniquely related to the thermochemical properties of the mushy layer at the time of solidification [9,11-12]. Recent research has shown that similar relationships may also be derived for the entrainment of bacteria and organic matter [13]. It stands to reason that the same physics could be applied to the ice-ocean/brine systems of other bodies within our solar system to provide improved constraints on planetary ice properties.

Results: Here we present a one-dimensional multiphase reactive transport model adapted from [11] to accommodate the thermochemical environment of Europa’s ice-ocean interface. The model simulates the dynamics governing mushy layers and produces profiles of temperature, pore fluid properties, liquid fraction, and bulk salinity. The model is validated against empirical measurements of terrestrial sea ice (Figure 1) before being used to simulate Europa’s ice-ocean interface. Multiple ocean compositions and concentrations are tested to investigate the impact on the resulting ice composition. Constitutive equations are derived which relate ice composition to the thermochemical environment at the time of solidification, which can be broadly applied to the Europa system without the need for computationally expensive explicit simulation. We investigate the predicted total salt content of Europa’s ice shell prior to the onset of convection, density gradients within the shell, and compositional heterogeneities in solidifying basal fractures and perched lenses. We discuss the implications of these results on Europa’s geodynamics and habitability as well as applications of the model to other ice-ocean/brine systems.

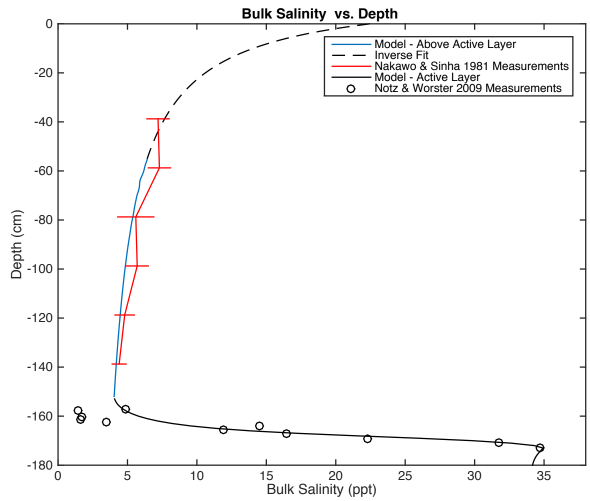

Figure 1: Modeled (blue and black solid lines), empirical (red line [14] and black circles [15]), and interpolated (black dashed line) bulk salinity profiles of terrestrial sea ice. The numerical model assumes a preexisting 50 cm thick layer of sea ice in conductive equilibrium (linear temperature profile) with an atmospheric temperature of 250K and an ocean temperature of 271.5K. A conductive heat flux is maintained throughout the simulation at the upper boundary. The model was run for 1.5×10^7 sec (~174 days, a typical sea ice annual cycle) with a time step of 100 sec. The dashed line is the product of a Levenberg-Marquardt algorithm fit to the function S(z)=a+b/(c-z), where S is bulk salinity, z is depth, and a, b, and c are constants, applied to the modeled bulk salinities above the active layer (blue solid line).

References: [1] Schubert G. et al. (2004) *Jupiter, 1,* 281-306. [2] Barr A. C. and McKinnon W. B. (2007) *JGR: Planets, 112.E2*. [3] McKinnon W. B. (1999) *GRL, 26.7,* 951-954. [4] Johnson B. C. et al. (2017) *JGR: Planets, 122.12,* 2765-2778. [5] Vance S. et al. (2016) *GRL, 43.10,* 4871-4879. [6] Vance S. et al. (2007) *Astrobio., 7.6,* 987-1005. [8] Schmidt B. E. et al. (2011) *Nature., 479*, 502-505. [9] Hunke E. et al. (2011) *The Cryosphere, 5.4,* 989-1009. [10] Feltham D. et al. (2006) *GRL, 33.14.* [11] Buffo J. J. et al. (2018) *JGR: Oceans, 123.1,* 324-345. [12] Buffo J. J. et al. (*in review*) *Nature: Comm.* [13] Santibanez P. A. et al. (2019) *JGR: Bio* [14] Nakawo M. and Sinha N. K. (1981) *JoG, 27.96,* 315-330. [15] Notz D. and Worster M. G. (2009) *JGR: Oceans, 114.C5.*