RADIATIVE TRANSFER MODELING OF LABORATORY DERIVED SALT-ICE MIXTURES: IMPLICATIONS FOR THE SPECTRAL MODELING OF EUROPA.

K.M. Robertson[1], S. Li[2]. [1]Dept. of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI, 02912, [2] Hawai'i Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI 96822.

Introduction: Chaos terrains are complex geologic features on Europa's icy surface [1,2] that are composed of 'rafts' (broken pieces of the ice shell) and a 'matrix' (hummocky plains surrounding the rafts). Two commonly accepted hypotheses suggest that 1) the interior thermal activities have locally melted the ice shell resulting in resolidification [3] and 2) large scale subsurface brine mobilization results in collapse of the ice-shell [1,4].

Both models can explain the observed morphologies but represent distinct formation mechanisms and will result in different distributions of ice and hydrated salt. The 'melt through' model predicts that elevated water ice content relative to salts would be found in the matrix [4] and chaos terrain boundaries while the 'brine mobilization model' predicts higher abundances of brine minerals in these regions [3]. Quantitative estimates of the compositional variability among the crustal units are pivotal to constraining these formation mechanisms.

Minor variations in hydration band shapes associated with mixtures of hydrated salts and ice can be difficult to identify with spectral parameters alone, therefore a more robust approach is required. The Hapke [5] radiative transfer model (RTM) is an established method for assessing modal mineralogy of airless bodies [6] and icy bodies [7] and is sensitive to subtle differences in hydration band parameters [8]. The Hapke model is well suited for assessing the modal mineralogy of Chaos terrains and will be ideal to quantify the distribution of the brine minerals and confirm formation mechanisms.

Here we test the Hapke model by applying it to a series of laboratory derived salt-ice mixtures to quantify their modal abundances. The validation of the model is discussed with applications to the Galileo NIMS data.

Methods: Fine-grained (45-75 μm) and coarse-grained (125-250 μm) ice powders were synthesized for this analysis. The fine powders were made by nebulizing water into an LN_2 bath and sieving the resulting slurry [9] while the coarse powders involved freezing water filled molds, processing through an industrial blender and sieving [10]. The ice samples were stored in a large walk-in freezer kept at -27℃.

Salts (epsomite, bloedite, mirabilite, trona) used in this work were chosen based on their relevance to Europa and their availability. Pure samples were obtained from Excalibur minerals, ground and sieved to the same particle sizes as the ice powders, and measured on an X-ray diffractometer to confirm purity.

Ices and salts of the same particle size ranges were mixed in varying abundances spanning from 10wt% to 65 wt% ice to test the Hapke model. High precision scales do not work in the freezer therefor we had to adopt a different methodology to determine the wt% for the mixtures. Salts were weighed in the lab (ranging from 50 mg to 250 mg) and placed in separate vials, then transferred to the freezer to equilibrate. We added the ice to the vials using fixed volumetric increments equivalent to ~100 mg. Once the spectral measurement was completed for a vial, the total sample was weighed and the salt weight was subtracted to determine the contribution from the ice and the resultant wt%.

After the samples were mixed they were transferred to an LN2 filled dewar and transported to the lab for measurement. Spectral measurements of ice-salt mixtures were taken in the VIS-NIR (300 - 2500 nm) wavelength range using an ASD Fieldspec3 field spectroradiometer. This unit is equipped with a QTH fiber optic light source and is housed on an optical bench with adjustable goniometers to control the viewing geometry (i=30°,e=0°). Samples were loaded into a Linkam Low-T environmental stage from Linkam Scientific and measured at -50°C. Laboratory controlled 'dry' air (-70°C dewpoint) was connected to the chamber to maintain relative humidity below saturation.

The parameterization of the Hapke model used in this study is the same as that of [11], where the model inputs are the measured reflectance data, viewing geometry (i, e, g), mineral densities, and endmember optical constants. Endmember optical constants were calculated from the pure mineral spectra using an optimization routine for multiple particle size ranges [8]. The modeled wt% values were then compared to the calculated values to test their limits of detection and uncertainties in modal mineralogy estimation.

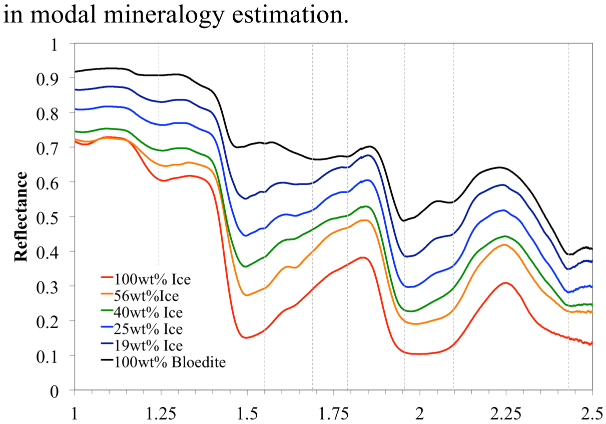

Fig.1. VIS-NIR spectra of a suite of coarse (125-250 μm) Bloedite-ice mixtures.

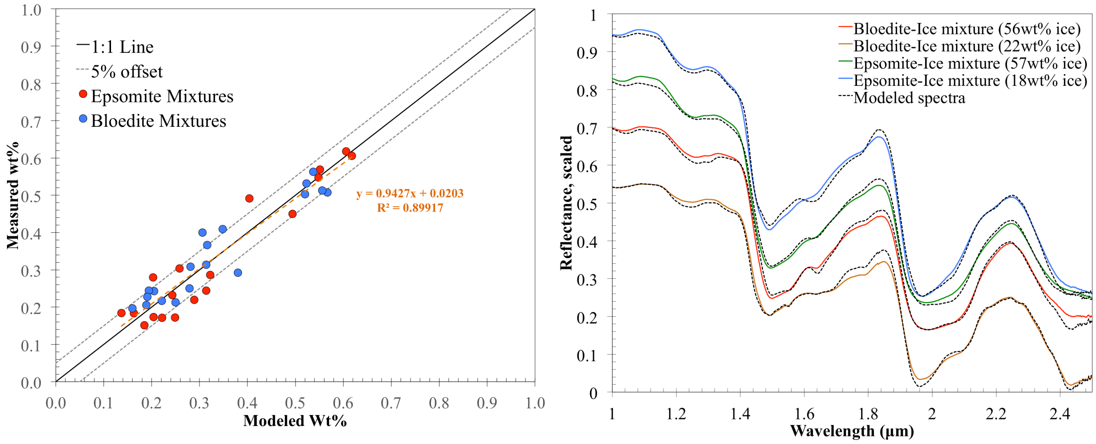

Fig.2. a) Comparison of modeled wt% Ice versus measured for mixtures with epsomite and bloedite. b) modeled and measured spectra for salt-ice mixtures for high ice (~55wt%) and low ice (~20wt%) mixtures.

Results: Spectral measurements of a suite of coarse (125-250 µm) bloedite-ice mixtures are shown in Fig.1. The stippled lines highlight the diagnostic absorption features as we transition from pure ice to pure bloedite. These subtle differences can be exploited by the RTMs to derive the modal abundances.

Unmixing results for the coarse mixtures of bloedite-ice and epsomite-ice are shown in Fig 2. The modeled wt% for ice is compared with the measured wt% (Fig.2a). Some variation is observed in the results however most are within the 5% offset margin and the plotted trendline follows closely to the 1:1 line. The modeled spectra (Fig.2b) are compared with the measured spectra for several bloedite and epsomite mixtures. The general shape of the diagnostic features are accounted for and the RMS error for all measurements were ~10^{-4} which is reasonable.

The spectra of Galileo NIMS data of the chaos terrains show distinct hydration features consistent with water ice and hydrated salts (Fig. 3). The observed spectra show subtle differences in hydration bands (shape, position, depth) that represent small differences in ice-mineral mixtures. The general shape of the spectra is consistent with water ice, however subtle diagnostic features can be used to infer other endmembers. For example, the small inflection and wide plateau at B and absorption at C could be indicative of mirabilite or bloedite, whereas the slope and shape of the 1.5 µm and 2 µm absorptions are suggestive of epsomite. Based on our laboratory testing, it should be possible to model these NIMS spectra to constrain the formation hypotheses of the chaos terrains.

Conclusion: In this work we present the preliminary analysis to assess the viability of using Hapke model on NIMS data to distinguish between formation mechanisms of the Chaos Terrain. Lab derived salt-ice mixtures for Europa relevant salts were measured on the ASD and modeled. Results show that the Hapke model is capable of distinguishing between the subtle variations in the diagnostic hydration bands suggesting that it is a viable method for spectral mixing of the surface of Europa. Future work will incorporate a wider range of salts to properly represent all potential minerals on the surface of Europa with the ultimate goal of quantifying the brine minerals in Chaos terrains to constrain their formation mechanism. **Acknowledgments:** The authors acknowledge the support of NASA SSW grant 80NSSC20K1043. **References:** [1] Carr, M.H., et al. Nature, 1998. [2] Schmidt, B.E., et al. Nature, 2011. [3] Greenberg, R., et al. Icarus, 1999. [4] Head, J.W. and R.T. Pappalardo. JGR, 1999. [5] Hapke, B. JGR, 1981. [6] De Sanctis et al., Science, 2012. [7] Protopapa et al., Icarus, 2017 [8] Robertson et al., Icarus, 2016. [9] Goldsby and Kohstedt, JGR, 1997. [10] Stern et al., JGR, 1997. [11] Li and Li, JGR , 2011.

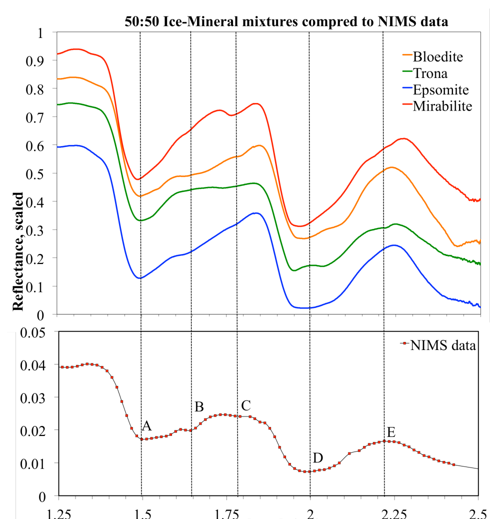

Fig.3. Comparison of 50:50 Ice-Mineral mixtures compared to NIMS data.