USING SURFACE THERMAL INERTIA TO ESTIMATE THE THICKNESS OF THE IAPETIAN DARK MATERIAL.
E. G. Rivera-Valentin[1], D. G. Blackburn[1], R. Ulrich[2], Arkansas Center for Space and Planetary Sciences (eriverav@uark.edu), [2]Dept. of Chemical Engineering, University of Arkansas.

Introduction: Iapetus' dramatic albedo dichotomy has been an astronomical wonder ever since its discovery in 1671. There exists two classes of hypothesis explaining the synthesis process: exogenic and endogenic. Exogenic hypotheses postulate that material, whose source maybe the recently observed Phoebe Ring [1], has accumulated on the leading hemisphere of Iapetus. Spencer and Denk [2], though, have recently reproduced many of the key albedo features using an endogenic process first suggested by Mendis and Axford [3]. Thermal segregation of water assumes there existed an initial dark seeding on the leading Iapetian hemisphere, which, due to higher solar energy absorption, increased sublimation rates. Intrinsic to this model is the assumption that surface albedo decreases as water leaves a dirty-ice material since impurities remain as a lag deposit; thus, suggesting that an albedo-thickness relationship may exist, which may also be true in the exogenic hypothesis. Dark material thickness measurements using radar and visual observations report depths greater than a 1 mm, less than 1 m, and on the order of decimeters [4-7] and, assuming an exogenic deposit from the Phoebe ring, perhaps on the order of 20 cm [1].

Assuming a heterogeneous surface material construct whereby dark material lies on top of an icy subsurface, we may, by applying the methodology used by Bandfield [8] on Mars to estimate ice table depths, provide estimates on dark material thicknesses and explore an albedo-thickness relationship. Owing to the recently produced global Iapetian bolometric Bond albedo map [9], we are at an advantageous position to accurately model local noon temperatures and thus better constrain the diurnal temperature amplitude required to study surface thermal inertia and surface ice proximity. Overburden thickness values are essential measurements when observing the current state of thermal migration on Iapetus.

Methods: Nighttime temperatures on a slowly rotating airless body, such as Iapetus, are a critical indicator of the surface thermal inertia since during this time the only heat source is the stored thermal energy within the material. Local noon temperatures, on the other hand, essentially reach equilibrium with available solar flux and thus are strongly dependent on the bolometric Bond albedo, which we now know accurately, and sun-body distance. For this reason, in our analysis we used night time temperature data collected from *Cassini* CIRS (Composite Infrared Spectrometer) and previously published data [10-11]. Since surface ice proximity strongly effects minimum temperatures due to its ability to act as an efficient thermal reservoir, we varied overburden thickness until simulated temperatures replicated data well for the same time and Japetographic location.

CIRS Spectra Analysis: Cassini CIRS FP1 spectra were retrieved using the Vanilla software package. We primarily used data sets from the 2004, 2005, and 2007 flybys of Iapetus. Japetographic and temporal data were also attained per data set as to accurately replicate surface temperatures. Since the spectral data is provided in large swaths, the average albedo for the given latitude was used in our thermal model.

Thermal Model: We used a finite element procedure to solve the heat transfer equations in a double geometric construct where a low thermal inertia material lay on top ice. The code runs an Iapetian year several times and is considered converged when the temperature with depth profile for two separate consecutive runs at the vernal equinox are < 1 K different. In this manner, we replicate both diurnal and annual temperature variations. We assume that the thermal inertia of the surface material is the lowest found in our previous study (9.5 J m^{-2} K^{-1} $s^{-1/2}$) [12-13] and that underlying ice has the thermal inertia of an amorphous or damaged crystalline state ice (46.8 J m^{-2} K^{-1} $s^{-1/2}$) [14-16].

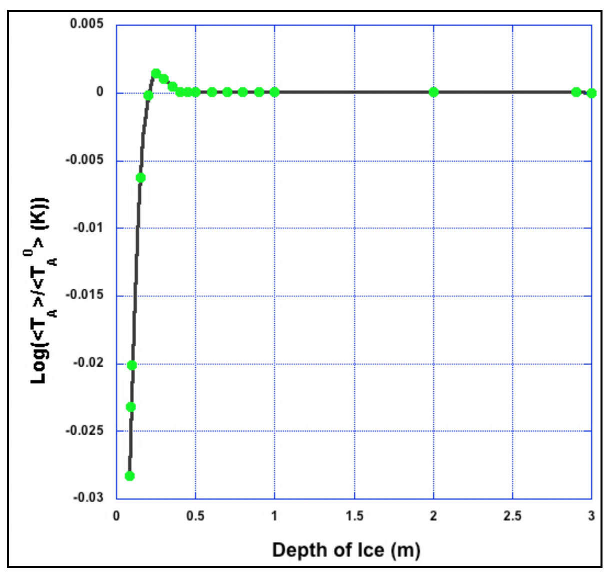

Fig. 1: Effect of surface ice proximity on average annual temperature amplitude (K).

Results: In order to study the effects of surface ice proximity on the seasonal maximum and minimum temperatures, we conducted a sensitivity study at 0° latitude in the dark material by varying overburden thickness from 0-3 m in small incremental steps. Results are presented in Fig. 1 where the y-axis is the log of the mean annual temperature amplitude ($<T_A>$) normalized with respect to the $<T_A>$ found with no underlying ice ($<T_A^0>$).

Thickness Measurements: Results of overburden depth measurements are shown in Fig. 2 versus albedo. Since our thermal inertia study [13] possessed an error of ± 1.5 J m^{-2} K^{-1} $s^{-1/2}$, we replicated surface temperatures for an overlying material with thermal inertia of 8 and 11 J m^{-2} K^{-1} $s^{-1/2}$ to estimate our data error, which is found to be -0.015 m and +0.02 m. Data and error is fit with a least squares fit technique such that the true albedo-thickness relationship most probably lies between the dashed lines.

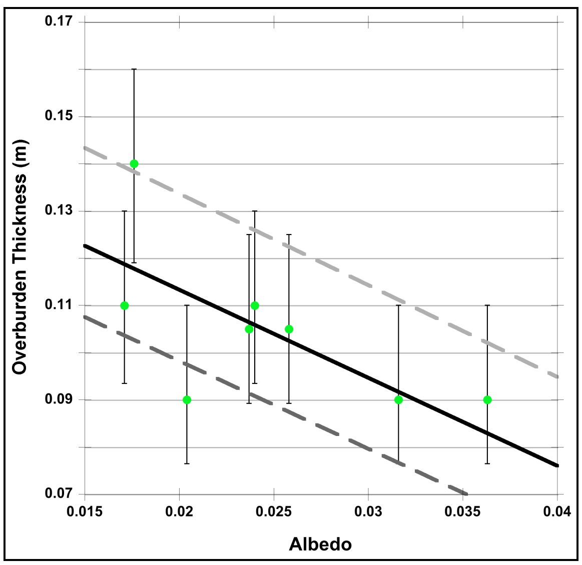

Fig. 1: Estimates of the dark material thickness for several sites. Data is in circle markers while the least squares fit to the data and error is presented with solid and dashed lines respectively.

Discussion: Fig. 1 shows the effects of surface ice proximity on the annual temperature amplitude is not a one-to-one function. Between 0.2 and 0.3 m for the same annual temperature amplitude, two different thicknesses may be inferred. At these depths, there exists an inflection in the temperature with depth profile at midnight as the maximum temperature wave from local noon, which itself dampens as it travels, traverses through the material. When the ice is within this range, it is yet again in contact with relatively high temperatures in time to affect the minimum surface temperatures, which occurs at local predawn. However, none of our direct measurements were in this zone and thus were not affected.

Our measurements for the albedo range of 0.036-0.017 show the overburden thickness varies between 0.16 and 0.08 m. These values correlate well with past radar and visual observation results [4-7]. The maximum value lies near Verbiscer *et al.* estimate, which assumed maximum deposition rates from the Phoebe ring [1]. The data demonstrates a negative relationship with increasing albedo, supporting Spencer's assumption regarding the darkening effects of water-ice sublimation from a dirty-ice surface [17]. Our measurements can also be well modeled by the equation set provided by Spencer and Denk [2], whereby solving for overburden thickness (*d*) provides:

$$d = me^{c/m}\left[1-\left(\frac{A-A_d}{A_l-A_d}\right)^{\frac{1}{q}}\right] \quad (1)$$

where m is a vertical mixing length (10 cm), A is the local albedo, A_d and A_l are the lowest and brightest albedo respectively, q describes the albedo effect and is set to 2, and c is the net ice condensation thickness found to be 2 for the best fit.

Conclusions: Using the methodology of Bandfield [8] we are able to provide measurements on dark material thicknesses corresponding well with both radar and visual observations [4-7] and exogenic predictions [1]. We find a distinct correlation between albedo and thickness, supporting past assumptions [17]. These values can be used to study the current state of thermal migration of water-ice on Iapetus by studying diffusion through these dark material depths.

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