CONSTRAINING SHALLOW VERTICAL HETEROGENEITY IN MARTIAN SURFACE MATERIALS FROM MARS ODYSSEY THEMIS DATA. A. A. Ahern[1], A.D. Rogers[1], J. L. Bandfield[2], C. S. Edwards[3], R. L. Fergason[4], [1]Stony Brook University Department of Geosciences, Earth and Space Science Building, Stony Brook, NY 11794, [2]Space Science Institute, Boulder, CO, [3]Northern Arizona University, Flagstaff, AZ, [4]USGS Astrogeology, Flagstaff, AZ, *alexandra.ahern@stonybrook.edu.*

Introduction: Accurate determination of near-surface physical properties is critical to Martian geological studies and to planning of future exploration efforts [e.g. 1]. Constraining the physical nature of martian surface materials can shed light onto the martian sediment cycle (e.g., weathering, transport, induration, and sedimentary rock formation), igneous processes (e.g. lava textures, pyroclastic materials), regolith-atmosphere exchange (e.g., frosts, salt formation and induration), and rover trafficability. Knowledge of physical properties is also critical to interpreting the origin and context of morphologically distinctive units observed in visible images and mineralogically distinctive units measured using spectral instruments.

On Mars, physical properties such as particle size, rock abundance, cohesion, and degree of induration exert strong control over a material's thermal inertia (TI), or, the ability of that material to conduct and store heat. TI, which can be estimated from surface temperature measurements, is defined as the square root of the product of a material's heat capacity, thermal conductivity, and density [1,2,3,4].

Surface temperature within the measurement field of view is partially controlled by the TI of all components in the near surface. Near-surface vertical heterogeneity in materials with differing thermal properties will result in unique diurnal and seasonal temperature functions compared to a physically homogenous subsurface (**Fig. 1**). Thus, temperature measurements acquired of the same surface at different times of both day and year can be used to identify and constrain the properties of vertical heterogeneities in the upper few cm of surface materials [1,2]. Types of vertical surface layer heterogeneity could include buried permafrost [5], dust coating or mantling, thin crusts, porosity and permeability variations, or bedform armoring [e.g., 4-6].

Typically, TI values are derived from a single temperature measurement, and the surface is assumed to be vertically and horizontally homogeneous. However, these assumptions are likely not valid for many regions of Mars, and several studies have illustrated the utility of multiple time-of-day and season temperature measurements in detecting surface heterogeneities [4-7].

The Mars Odyssey Thermal Emission Imaging System (THEMIS) instrument has acquired surface temperature measurements from multiple times of day, by way of multiple extended missions at differing local times between ~3-7 am and ~3-7 pm. In this work, we take advantage of the multiple time of day measurements from the THEMIS mission, as well as a recently implemented Davinci interface to the KRC thermal model [8], to constrain the style and depth of vertical heterogeneity for regions of interest on Mars. There are numerous potential applications for this technique; here we focus on developing a workflow for streamlined analysis of data. Example questions to be addressed include: Do chloride bearing units represent massive deposits or thin crusts? Do lateral spectral variations across bedrock units represent variable alteration, or variable dust mantling? Can spectral differences across morphologically similar regions be explained by variable induration? Do enigmatic bedforms, such as transverse aeolian ridges, show evidence for coarse-grained armoring?

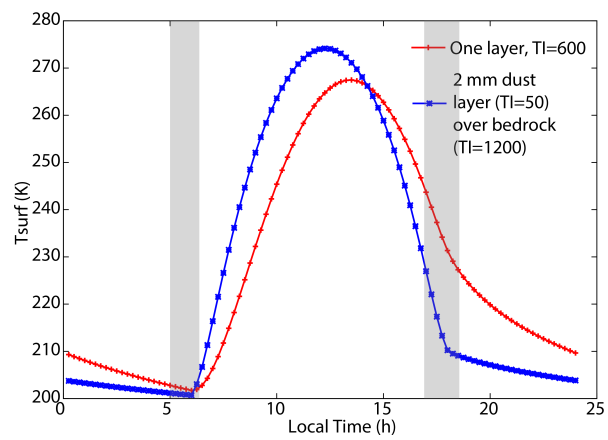

Figure 1. Example model diurnal temperature curves for a homogeneous surface with TI=500 J $m^{-2}K^{-1}s^{-1/2}$ and a bedrock surface with a 2mm thick layer of dust. Temperatures near 5am differ by <2K; using only a 5am temperature measurement, these surface scenarios would be difficult to distinguish. However, late afternoon/early evening temperatures differ by several K. Plots are for latitude=0°, longitude=0°, at Ls=0°

Thermal Model: The KRC (*K* for conductivity, *R*(*rho*) for density, *C* for specific heat—the terms in the TI equation) numerical model [8] has been widely used to calculate planetary surface kinetic and bolometric temperatures at any given season, location, or time of day. The model has been modified over five decades of planetary research [6,8], and most recently has been instrumental in analysis of data from the THEMIS and MER Mini-TES instruments [1, 5-8]. At present, KRC

(version 3.2.1 used in this work) can model surface temperatures for single layer and two-layer surfaces, where the thermophysical properties for each layer and the thickness for the top layer can be specified.

Methods: In this study, we compare observed THEMIS surface temperatures of five regions of interest with model results from the KRC model, incorporating both vertically homogeneous materials as well as two-layer scenarios. We picked several locations of interest based on unique morphological and spectral characteristics. These areas include chloride deposits detected in Tyrrehna Sirenum, anomalously high-albedo deposits on the western flank of Olympus Mons, variable-silica content surface materials in Tyrrhena Terra and Cimmeria Terra, and the Acidalia plains. In each of these locations, we selected laterally homogeneous areas with the maximum THEMIS diurnal coverage. Within these selected areas, we derived average surface temperatures from each THEMIS orbital measurement.

After compiling the measured temperatures from THEMIS, we compared these to those predicted by the KRC model for the latitude and longitude of each region of interest. Model scenarios include: 26 homogeneous surface cases, with TI values ranging between 50 and 1200 J $m^{-2}K^{-1}s^{-1/2}$, and four two-layer TI cases, where the upper layer thickness was varied for 10 different thicknesses. This combination of scenarios resulted in 66 model results for a single location. The two-layer scenarios used were: dust (50 J $m^{-2}K^{-1}s^{-1/2}$) cover over rock (1200 J $m^{-2}K^{-1}s^{-1/2}$), sand (220 J $m^{-2}K^{-1}s^{-1/}2$) cover over rock, indurated material (250 J $m^{-2}K^{-1}s^{-1/2}$ over sand, and sand cover over dust. For this work, we used the default albedo and elevation values from Thermal Emission Spectrometer (TES) and Mars Orbiter Laser Altimeter (MOLA) datasets, and the default values of 0º for slope and 0.30 for visible wavelength dust opacity. In future work we will incorporate dust opacity scaling and possibly use non-default albedo and slope values. For each model case, temperatures were calculated for 360 heliocentric longitude (L_s) values at 96 times of day (quarter-hour increments). Because surface temperature can vary as function of both Ls and time of day, we created a hybrid-time ("Ls.time", where, for example "280.36" = Ls 280, 36th time increment) for both the measured and modeled temperatures. This allows both parameters to be considered simultaneously and broadens the number of surface temperature measurements that can be used.

We then compared surface temperature measurements to those in the models, and identified the model scenario that best-matched the range of surface temperature measurements for that location. The best fit scenario was identified by finding the minimum Euclidean distance between measured and modeled temperatures, followed by visual inspection of the hybrid-time vs. temperature measured vs. modeled plots to evaluate the model fit. As this technique and input parameters are refined, the best fit scenario(s) should provide the most likely scenario of the various selected test surfaces—both the thickness of the upper layer (if there is one) and the nature of the layer(s) involved.

Preliminary Results: Example results for one region (Acidalia Planitia) are shown in **Figure 2**. Temperatures from ~25 THEMIS observations were compared with different model scenarios. The best fit across most THEMIS observations was a 1mm duricrust over sand. The best-fit homogeneous surface scenario (TI=180) is shown for comparison.

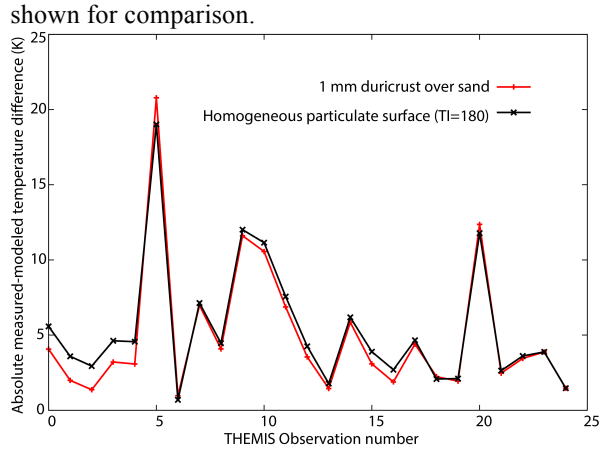

Figure 2. Absolute differences between measured and modeled temperatures for two of the best-fit model scenarios, across 25 THEMIS observations over a small spot in the Acidalia plains. Higher temperature offsets are likely due to incorrect dust opacity values used.

Conclusions: The methods presented in this study can be applied to any location on the surface of Mars. We plan to validate our results with those that have been ground-truthed by rover observation. This technique, using the KRC model with THEMIS surface temperature measurements, can provide a better idea of surface materials for locations where in-situ measurements are not available. Additional information about the geological and physical properties of Martian surface materials will lead to a greater understanding of past and present surface conditions on Mars.

References: [1] Fergason, R.L. et al. (2006a) *JGR, 111, E12004* [2] Kieffer, H.H. et al. (1977) *JGR, 82,* 4249-4291. [3] Piqueux and Christensen (2011) *JGR, 116*. [4] Audouard, J. et al. (2014) *Icarus, 233,* 194-213. [5] Bandfield, J.L (2007) *Nature, 447,* 64-67 [6] Putzig, N.E. and Mellon, M.T. (2007) *Icarus, 191*, 68-94. [7] Fergason, R.L. et al. (2006b) *JGR, 111, E02S21* [8] Kieffer, H.H. (2013) *JGR: Planets, 118,* 451-470.

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