THERMAL INERTIA OF ROCKS ON THE MOON. J. M. Martinez-Camacho[12], P. O. Hayne[3], C. M. Elder[1], [1]NASA Jet Propulstion Laboratory, California Institute of Technology, [2]California Polytechnic University, Pomona, [3]University of Colorado, Boulder

Introduction: Thermal inertia is an important quantity for understanding the density, porosity, and composition of rocks on the Moon. For instance, thermal inertia could reveal information about the volatile content and eruption styles of mare basalts, or the crystal sizes in rocks from the feldspathic highlands crust. Rocks with a higher thermal inertia remain warmer during the lunar night and cooler during the lunar day. Thus when the rock population is known, multispectral thermal infrared measurements may be capable of measuring the thermal inertia of lunar rocks.

Remote sensing observations conducted by the Diviner instrument onboard the Lunar Reconnaissance Orbiter (LRO) have been used to map rock abundances for locations within 60° of the equator with a resolution of 250 m by exploiting the differences in temperatures between regolith and rocks at lunar night [1]. However, this method is only sensitive to rocks with diameters ≥ 1 m. Here we use observed rock populations at Surveyor landing sites to test the hypothesis that small rocks also have a significant effect on Diviner observations. Sensitivity to smaller rocks, and therefore a more accurate calculation of rock abundances, can be achieved by incorporating thermal modeling of smaller rocks in [2]. However, the thermal inertia of lunar rocks is unknown *a priori*. With sufficient data, we can also extract thermal inertia from model fits.

Methods: To test the accuracy of our thermal model, we compared Diviner observations to the temperatures expected from thermal modeling of the rock population observed at the Surveyor landing sites. The Surveyor program, from 1966 to 1968, was primarily dedicated to demonstrating the feasibility of a soft landing on the moon. Five of the seven robotic spacecraft landed safely and were able to take television photographs of the lunar surface surrounding the landing sites. Shoemaker et al. (1969) [3] measured and counted the rocks in each photograph and published their results as graphs of cumulative number of rocks with diameter $\geq D$ per 100 m^2, $N(D)$, vs. rock diameter, D, for the Surveyor I, III, V, VI, and VII landing sites. The diameter bins for this rock size-frequency distribution (RSFD) range from 1 mm to 2 m in increment of powers of 2 mm [3]. Since $N(D)$ was obtained from photographs, [3] divided each landing site into multiple count areas, and the range of detectable diameters varies with the proximity of the count area to the lander. As a consequence, the typical graph published by [3] at each landing site contains three or more distinct $N(D)$ lines that correspond to smaller areas surounding the landing sites. To make use of the data and successfully compare ground measurements to Diviner observations, we must express Shoemaker's $N(D)$ as a fractional coverage, $A(D)$, and ensure that the observational areas are similar in size, i.e. Shoemaker's observed area should be close to a Diviner pixel. A qualitative investigation of LROC images suggest that the rockiness of Surveyor landing sites does not vary significantly on the scale of a Diviner observation except at Surveyor 3 and 7. Future work will also include rocks counted in LROC images over a larger area surrounding the Surveyor sites. We use Shoemaker's power-law fits to $N(D)$ at each landing site and a functional form for the cumulative fractional area, $A_{\text{cmt}}(D)$, derived in [3], to calculate the fractional area $A(D)$ (see figure 1) by:

$$A(D_i) = A_{\text{cmt}}(D_i) - A_{\text{cmt}}(D_{i+1})$$

We use $A(D)$ at the Surveyor landing sites to model the surface temperatures and compare them with Diviner observations. To accomplish this, we combine results from Shoemaker's RSFD analysis with thermal models of the lunar surface. The thermal model consists of a three-dimensional rock model [2] and a one-dimensional regolith model [4]. Using COMSOL Multiphysics, we compute the temperatures of hemispherical rocks with radii of 1 mm, 1 cm, 10 cm, and 1 m embedded in regolith at latitudes between 0° to 60° in increments of 10° for an entire diurnal cycle. The regolith diurnal temperature profile was modeled using a one-dimensional heat transfer model and thermophysical parameters from [4]. For the Surveyor sites, the albedo

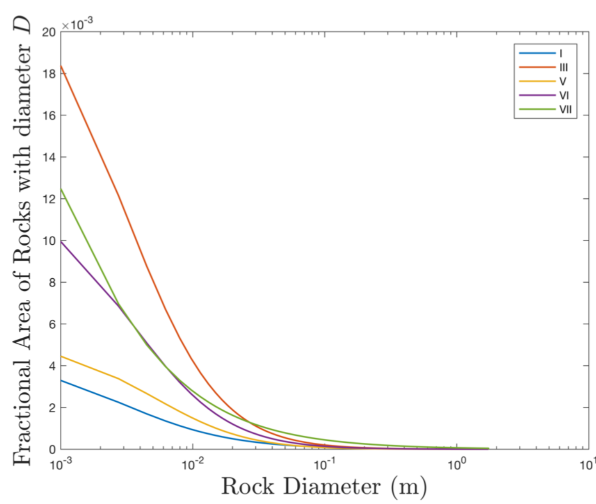

Figure 1: Fractional area of rocks with diameter D at each surveyor landing site derived from Shoemakers's fits to $N(D)$.

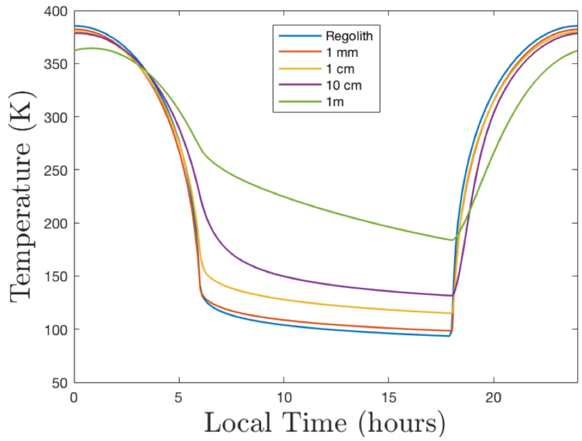

Figure 2: Diurnal temperature profiles of regolith and rocks at the equator derived from a 3D rock thermal model and a 1D regolith thermal model. This example shows the temperature of regolith with an albedo of 10%.

ranges from 0.0656 (Surveyor I) to 0.1527 (Surveyor VII). Figure 2 shows diurnal profiles for rocks and regolith at the equator.

We use a method similar to [1] to model the brightness temperature at each Surveyor landing site, but incorperate Shoemaker's rock counts and our thermal model results. We consider a surface containing a mixture of regolith and rocks. The channel radiance, B_c, of this surface as measured from the Diviner instrument is the sum of the channel radiances, $B_{c,k}$, of each distinct surface element, k, weighted by their fractional area, A_k:

$$B_c = \sum_{k=1}^{5} A_k B_{c,k}$$

where surface elements include regolith or rock of a certain diameter.

The radiance of an individual surface element measured by the Diviner instrument can be obtained by integrating the Planck function convolved with the spectral response function corresponding to a specific Diviner channel. For this study, we use channels 6, 7, and 8. We created a look-up table that converts the observed radiance to brightness temperature and show the results for the Surveyor VI and VII landing sites in Figure 3.

Discussion: The diurnal temperatue curves of figure 3 show a disagreement in the brightness temperature derived from our modeling and Diviner observations. For most landing sites, the modeled temperatures, when compared to Diviner measurements are slightly colder during the day and warmer during night. The agreement between model and observed temperatures is better at sites with fewer rocks. During the daytime, the model is ~20 K too cold, and at night ~6 K too warm at the rockier landing sites. We attribute this discrepancy to erroneous thermal rock properties used in our model; the rocks on the lunar surface appear to have lower thermal inertia than assumed by [1] and in our model. We will present improvements in the estimate of rock thermal inertia, and discuss its possible variations among different geologic features.

References: [1] Bandfield, J. L. et. al. (2011) *JGR*, 116, E00H02. [2] Elder, C. M., P. O. Hayne (2017) The Lunar Rock Size Frequency Distribution from Diviner Infrared Measurements. European Lunar Symposium. [3] Shoemaker, E. M. et. al. (1969) *Radio Sci.*, 5,#2,129-155. [4] Hayne, P. O. et al. *JGR*, DOI: 10.1002/2017JE005387.

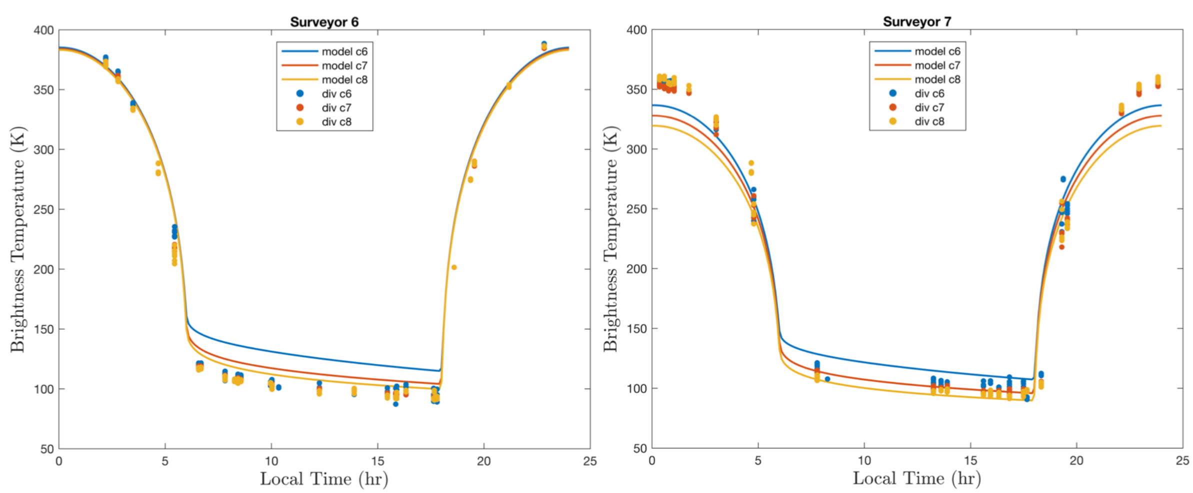

Figure 3: Modeled brightness temperatures (lines) compared to Diviner measurements (dots) for the Surveyor 6 (left) and 7 (right) landing sites. The Diviner observations we compared to our model results were within 300 meters of the landing site.