Interpreting LRO Diviner surface temperatures: Modeling lunar regolith thermophysical properties and topography in three-dimensions

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Introduction: The Diviner Lunar Radiometer Experiment on NASA's Lunar Reconnaissance Orbiter has been mapping the global thermal state of the Moon since July of 2009. The instrument has acquired solar reflectance and thermal emission data in nine spectral channels spanning a wavelength range from 0.3 to 400 microns [1] revealing the extreme nature of the lunar thermal environment [2]. Superposed on the large-scale trends due to latitude, time of day, and season, the surface temperature of the Moon can exhibit extreme spatial variations at length scales all the way down to that of the diurnal thermal skin depth (∼10 cm) due to the low thermal conductivity of the bulk of the regolith, the lack of an appreciable atmosphere, and the effects of slopes and shadowing [3]. Further, surface temperatures are highly sensitive to the thermophysical properties within the first few meters of the surface and thus spatial variations in density, thermal conductivity, heat capacity, albedo, and emissivity, will have an influence. This significantly complicates the interpretation of lunar thermal observations (Fig. 1).

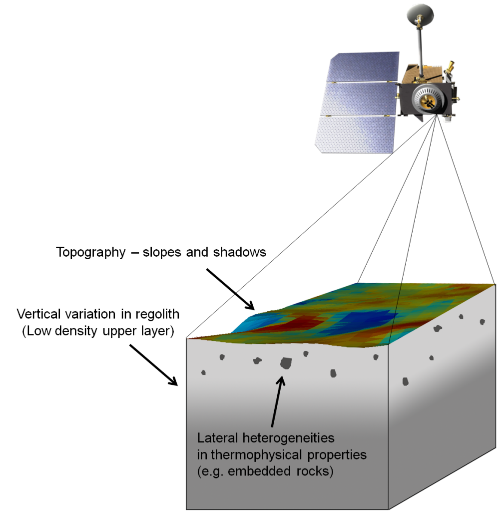

Figure 1: Within a Diviner surface footprint (∼ 250 × 250 m) temperatures can exhibit extreme variations with large thermal gradients maintained throughout the diurnal cycle due to the low thermal conductivity of the regolith and the lack of an appreciable atmosphere. The temperatures retrieved from Diviner will be an integration of this complex thermal environment within the instrument's footprint.

Model: To aid in our interpretation of Diviner data and higher level model dependent data products, we are developing a 3-diminsional finite difference model of the regolith to understand how small-scale slopes, shadows, and rocks within a Diviner surface footprint influence temperatures derived from Diviner observations. Our model includes topography and allows for variations both vertically and laterally of the thermophysical properties of the lunar regolith. This extends previous 1-dimisional modeling efforts which included vertical layering [4][5] to now capture lateral variability in topography and regolith properties which, in the lunar environment, can result in extreme thermal gradients over short length scales (10's cm). The model utilizes ray tracing of the illumination so that slopes and shadowing effects can be included. The thermophysical properties of the regolith are selected to match Apollo heat flow experiments [6][5] and include a 2 cm thick low density surface layer, ρ=1250 kg m^{-3}, atop layers increasing in density to ρ=1900 kg m^{-3} and temperature dependent thermal conductivity and specific heat.

Results: To explore the sensitivity of lunar surface temperatures throughout the diurnal cycle to rocks embedded within the regolith we run a model with no topography with hemispherical rocks of different diameters flush with the surface (Fig. 2). With no appreciable atmosphere to buffer surface temperatures, the nighttime environment is characterized by extreme cold with the sensible heat stored in the subsurface during the day being the only heat source to balance the loss of thermal radiation to space during the long lunar night [1][7]. As a result, surface temperatures are sensitive to rocks as they can remain warmer than the surrounding regolith throughout the lunar night. Larger rocks provide a larger reservoir of heat during the night and therefore remain warmer than smaller rocks of comparable thermophysical properties. For example, we find a 7 cm rock remains ∼25 K warmer and a 28 cm

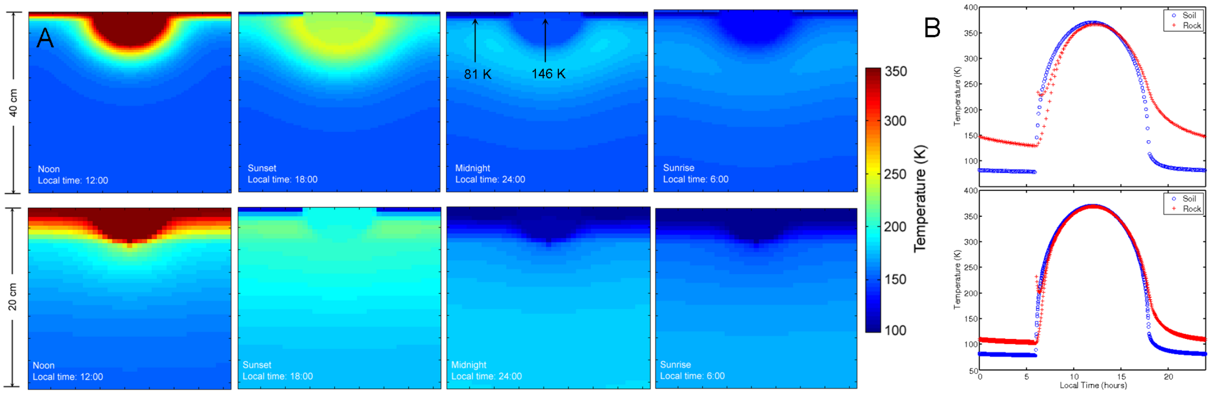

Figure 2: (A) *Top*: 81×81×81 node model of 28 cm diameter rock and *Bottom*: 41×41×41 node model of 7 cm diameter rock. Rock properties: $\rho = 3000$ kg m^{-3}, $k = 1.0$ W K^{-1} m^{-1}, $C_p = 1000$ J kg^{-1} K^{-1} (geothermal heat flow neglected). (B) Surface temperatures for the regolith and rocks for a diurnal cycle.

rock ∼50 K warmer at the end of the lunar night than the rock-free regolith (Fig. 2).

When we include topography (Fig. 3) we see that shadows and slopes result in more complex daytime temperatures and temperatures will vary with viewing geometry relative to the sun angle.

Summary: Our 3D finite element model is flexible in that we can explore an arbitrary number of nodes and length scales with arbitrary geometries of topography and embedded thermophysical properties to represent a rock as well as vertical layering to capture the temperature dependent conductivity in the top few centimeters of the regolith. Given a diurnal solar forcing function at the surface along with ray tracing we then can use this model to develop an understanding of the size range of rocks that the Diviner instrument should be sensitive to and characterize how rocks may influence the observations.

References: [1] D. Paige, et al. (2010) *Space Sci. Rev.* 150:125. [2] D. A. Paige, et al. (2010) *Science* 330:479. [3] D. A. Paige, et al. (2010) *Lunar Planet. Sci. Conf.* 41st. [4] A. R. Vasavada, et al. (1999) *Icarus* 141:179. [5] M. A. Siegler, et al. (2011) *J. Geophys. Res.* In Press. [6] S. J. Keihm (1984) *Icarus* 60:568. [7] J. L. Bandfield, et al. (2010) *Lunar Planet. Sci. Conf.* 41st.

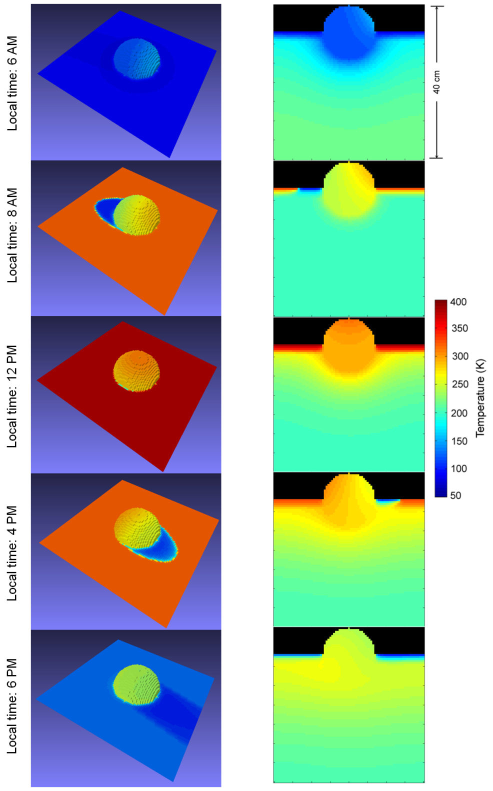

Figure 3: Model with topography and ray tracing demonstrating shadow and slope effects on daytime surface temperatures with 81×81×81 node model and 14 cm diameter spherical rock protruding from surface.