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Thermal modeling of airless bodies – lunar polar case

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Abstract

We present a numerical model for heat transport designed to study surface and and near-surface temperature evolution within airless bodies. We provide exemplary results for the Moon, for which temperature maps for both lunar poles are derived.

1. Introduction

The thermal environment of airless bodies, e.g. the Moon, is mainly driven by solar insolation (illumination) because no or no significant amount of atmospheric gas exists and hence the balancing effect of an atmosphere which enables efficient transport of heat on a global scale is missing. Illumination conditions near the lunar poles are quite extreme owing to the small lunar obliquity of just 1.54°. Here areas of near-continuous illumination can be found next to Permanently Shadowed Regions (PSRs), the coldest regions on the Moon where water-ice can accumulate and be stable over long time-scales. We present methods to synthetically illuminate [1] Lunar Orbiter Laser Altimeter (LOLA) Digital Terrain Models (DTMs) and subsequently use this information to derive temperatures [2]. We model direct sunlight while considering solar limb darkening, reflected light and thermal radiation from Earth, multiple scattering and a constant radiogenic heat source stemming from radioactive decay in the lunar interior. Polar temperatures are derived for the surface and down to two meter in the sub-surface.

2. Method

The mathematical model is based on the axiom of energy conservation in the form of the well-known heat equation. Since temperature gradients in directions orthogonal to the surface are expected to be much larger than in horizontal direction, we neglect horizontal heat transfer and describe the sub-surface by a set of one-dimensional columns. The lower boundary condition (sub-surface at two meter) is modeled via a constant radiogenic heat source and the upper boundary condition (surface) is described by the interactions with space, Sun, Earth and terrain. Insolation is derived treating the Sun as an extended source while considering the solar limb darkening effect. Thermal radiation into space is modeled via the Stefan-Boltzmann law. We model reflected light from the visible, sunlit part of Earth as well as thermal radiation from average temperature maps of Earth (pers. comment K. Trenberth and Y. Zhang). Multiple scattering of light and thermal radiation from nearby terrain is also incorporated in the model to ensure heat transport to PSRs and double shaded craters inside PSRs. To solve the partial differential equation we chose a finite-volume scheme for the spatial discretization and an implicit discretization scheme in time [2].

3. Data

In this study illumination and temperature are modeled using LOLA DTMs [1][2]. Polar DTMs, each spanning 400 x 400 km, were derived to properly model illumination for the chosen Regions of Interests (ROIs) of 50 x 50 km (Fig. 1) since obstruction of the solar disk by near- and far-field terrain needs to be considered.

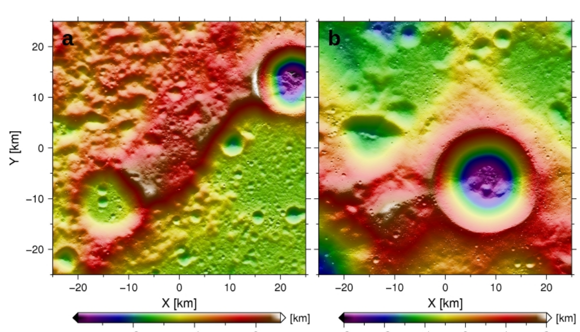

Figure 1: The polar LOLA DTMs at a resolution of 20 m/pix for the 50 x 50 km ROIs at the (a) north and (b) south pole.

4. Validation

We validated our illumination effort by comparing the synthetically illuminated DTMs with actual images of the lunar surface, e.g. Wide Angle Camera (WAC) images (Fig. 2). The WAC image (M172692029ME) well resembles the simulated scene rendered at the exact same time as when the image was taken, attesting the great performance of the tool and data.

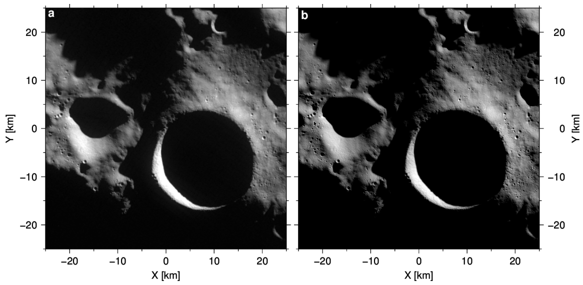

Figure 2: Illumination at the 50 x 50 km ROI at the south pole. (a) WAC image M172692029ME. (b) Synthetically illuminated LOLA DTM.

For the validation of temperature we used DIVINER data as ground-truth. We find that DIVINER temperature measurements, e.g. from orbit 2763 at February 2, 2010 at 01:20am and our modeled temperatures at the exact same time and location are in good agreement (Fig 3.)

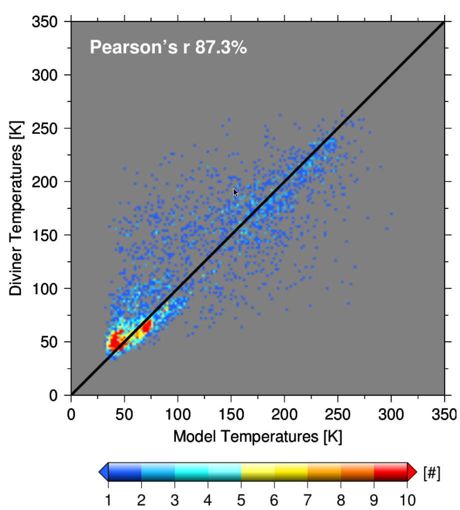

Figure 3: Scatter density plot (2 K step-size) of DIVINER temperature measurements versus our model temperatures. They correlate by ~90%.

5. Preliminary Results

Exemplary we derived illumination and temperature for both poles at January 01, 2010 at midnight UTC (Fig. 4).

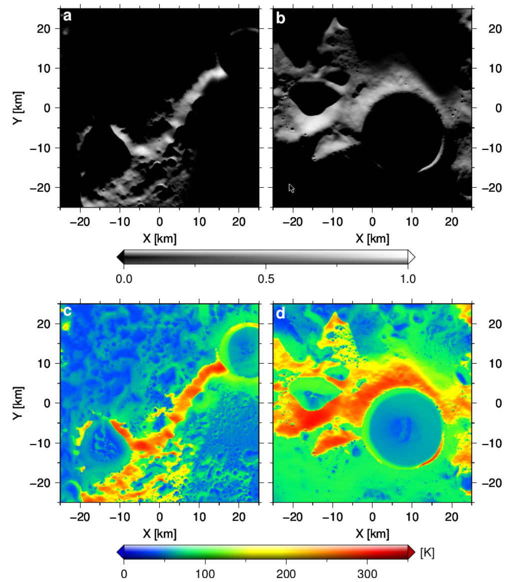

Figure 4: Illumination conditions and temperature at the (a),(c) north and (b),(d) south pole at January 01, 2010 at midnight.

6. Summary

We present sophisticated tools to derive illumination and (sub)-surface temperatures of airless bodies, which were cross-validated against DIVINER and WAC data. Furthermore, preliminary results for the lunar poles are presented.

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References

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