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Numerical simulation of illumination and thermal conditions at the lunar poles using LOLA DTMs

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Abstract

A numerical simulation of the lunar illumination and thermal environment was carried out for near-polar regions. As the foundation of this study high-resolution, twenty meters per pixel and 400 x 400 km large polar Digital Terrain Models (DTMs) were derived from Lunar Orbiter Laser Altimeter (LOLA) data. Illumination conditions were simulated by synthetically illuminating the LOLA DTMs using the horizon method considering the Sun as an extended source [1,6,7]. Areas receiving almost constant illumination near areas in permanent shadow were identified as potential exploration sites for future missions. Further, at each position the found illumination is used as an input to evaluate the one-dimensional heat equation for the upper two meters of regolith. First results seem to be in good agreement with heat maps created from the Diviner Lunar Radiometer Experiment (DLRE), most commonly known as Diviner.

1. Introduction

The lunar polar regions are the only regions on the Moon where Permanently Shadowed Regions (PSRs) can be found. This stems from the small 1.54° lunar rotational obliquity which in turn leads to extreme polar illumination conditions. Hence, directly at the poles the Sun appears to only move $\pm 1.54°$ about the horizon where crater floors are likely to be PSRs and crater rims and topographic highs in contrast receive extended illumination. PSRs were long predicted to exist and also to contain water-ice concentrations [2] which was now supported by several more recent studies [3,4,5]. Due to the proximity of possibly water-rich PSRs next to almost constant illuminated areas the lunar poles are a prime exploration target for future missions relying on solar power. This study focuses on a 50 x 50 km area centered on each pole using illumination data [6,7] to evaluate surface and sub-surface regolith temperatures as expected at candidate landing sites and nearby PSRs.

2. Method

Polar LOLA DTMs of 400 x 400 km and twenty meters per pixel were created to derive illumination for the central 50 x 50 km subsets while taking into account the far-field topography. Modeling polar illumination with the horizon method as described in [1,6] and using it as an input at each time-step (2 h), the heating of the lunar surface and subsequent conduction in the sub-surface can be evaluated. At surface level we balance the incoming insolation with the subsurface conduction and radiation into space, whereas in the sub-surface we consider conduction with an additional constant radiogenic heat source at the bottom of our two-meter layer. Density is modeled to be depth-dependent, the specific heat parameter to be temperature-dependent and the thermal conductivity to be depth- and temperature-dependent. We implemented a fully implicit finite-volume method in space and backward Euler scheme in time to solve the one-dimensional heat equation at each pixel in our 50 x 50 km DTM. Due to the non-linear dependencies of the parameters mentioned above, the Newton's method is employed as the non-linear solver together with the Gauss-Seidel method as the iterative linear solver in each Newton iteration. The software is written in OpenCL and runs in parallel on the GPU which allows for fast computation of large areas and long timescales.

3. Results

To start the numerical calculation of the surface temperatures, initial temperature values given for a certain time need to be supplied. We chose our simulation to start on January 1, 2010 with a homogeneous temperature distribution of 100 K in the respective upper two meter layer. The simulation determines the current illumination every two hours which serves as the input for the numerical temperature calculation. Since the homogeneous initial temperature values are far from reality the simulation needs some time to converge into a realistic temperature distribution. In our preliminary study we ran the simulation for a total of almost two years (23 months, 8300 steps), with the final heat map dating from December 1, 2011 (see Fig. 1). Where Diviner data are available, we compared temperature measurements with our model results which are in good agreement and will help refine our parameters.

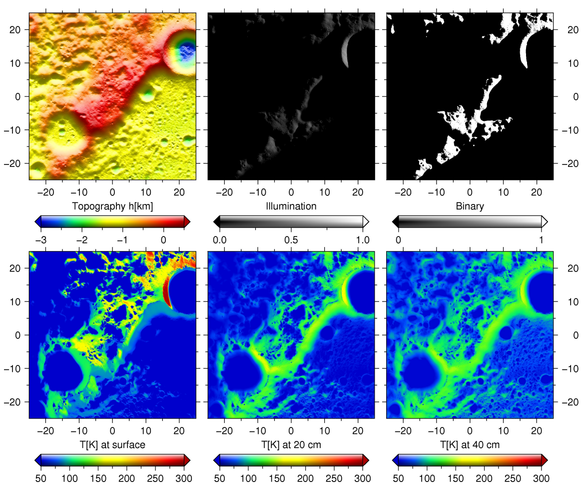

Figure 1: Top: LOLA DTM of the north pole (left), simulated illumination at December 1, 2011 18:00:00 UTC (middle), binary illumination (right). Bottom: Surface heat map (left), 20 cm sub-surface heat map (middle), 40 cm sub-surface heat map (right). All maps have a resolution of 20 m/pix and are presented in gnomonic map projection.

4. Summary and Conclusions

We successfully implemented a numerical model to solve the heat equation on the GPU in parallel which allows us to derive lunar polar temperature maps for any given time. First results are consistent with Diviner but further improvements to our model are necessary. As a next step we intend to incorporate the effect of scattered sunlight which might add a significant amount to the heat balance in the PSRs.

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