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

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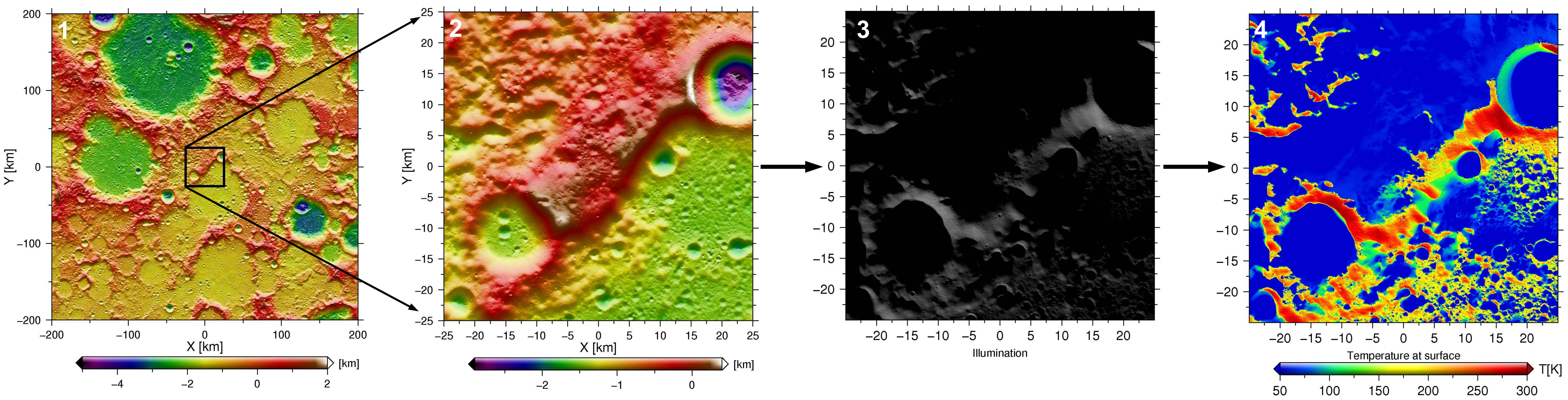
Motivation We are interested in illumination conditions and the temperature distribution within the upper two meters of regolith near the lunar poles. Here, areas exist receiving almost constant illumination near areas in permanent shadow, which were identified as potential exploration sites for future missions. For our study a numerical simulation of the illumination and thermal environment for lunar near-polar regions is needed.

Method Our study is based on high-resolution, twenty meters per pixel and 400 x 400 km large polar Digital Terrain Models (DTMs), which 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 [1,2,3]. We model polar illumination for the central 50 x 50 km subset and use it as an input at each time-step (2 h) to evaluate the heating of the lunar surface and subsequent conduction in the sub-surface. 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 as depth-dependent, the specific heat parameter as temperature-dependent and the thermal conductivity as 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, 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 cores, which allows for fast computation of large areas and long time scales.

From topography to illumination and temperature

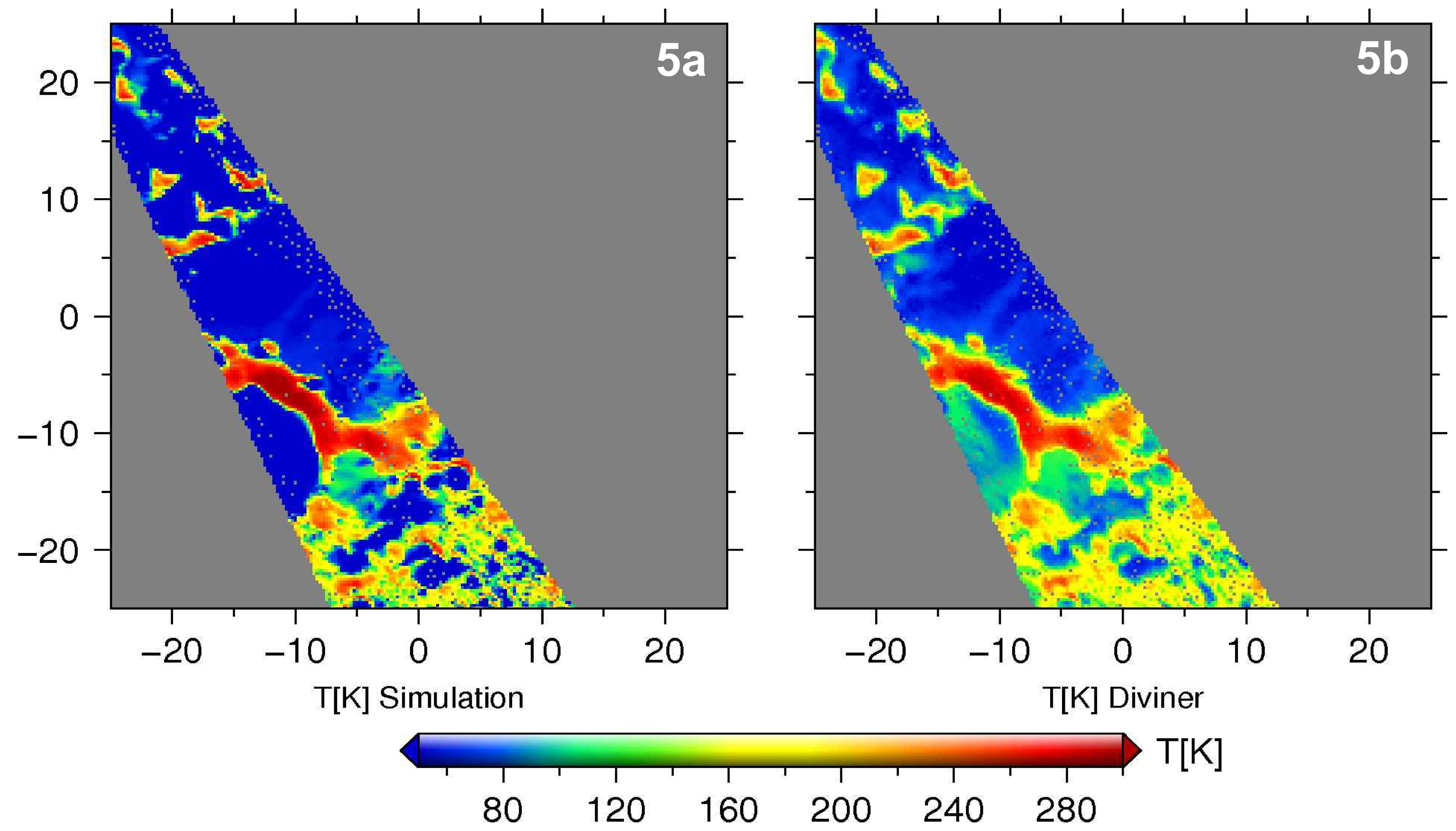


A 400 x 400 km LOLA DTM with 20 m/pixel resolution (Fig. 1) was created for the lunar north pole. The area for which illumination and temperature was derived is centered at the pole and spans 50 x 50 km (Fig. 2). To simulate illumination for the marked area the topography of the surrounding terrain needs to be known since mountains as a far as 100-150 km can obstruct the incoming sunlight.

Based on the large-scale DTM illumination can be derived for any time. In Fig. 3 illumination is shown for the central 50 x 50 km area on February 1st, 2010 at 00:00. Illumination maps can be used to calculate temperature at the surface (Fig. 4). Temperature at surface level is balanced by incoming sunlight, radiation into space and sub-surface conduction.

Comparison to Diviner data

To validate the resulting simulated temperatures we compared it to LRO Diviner Lunar Radiometer data. Diviner is a radiometer which can derive temperature measurements of the lunar surface. A composite of six Diviner ground tracks near the lunar north pole from February 01, 2010, 01:20 to 20:20 is shown in comparison to the simulated temperatures derived at the exact times of each orbit track (Fig. 5a,b.). Although the two temperature maps look similar they differ significantly in some regions, especially in the dark and cold crater floors. This might be indicative that scattered sunlight and infrared radiation from illuminated nearby terrain could play an important role which is currently not implemented in our model.



Summary 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 and infrared radiation from nearby terrain which might add a significant amount to the computation of the heat balance in permanently shadowed regions (PSRs).

References

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