LARGE-SCALE THERMAL MODELING AT THE LUNAR SOUTH POLE. Samuel F. Potter[1,2], Norbert Schörghofer[2], and Erwan Mazarico[3], [1]University of Maryland Department of Computer Science (sfp@umiacs.umd.edu), [2]Planetary Science Institute, [3]NASA Goddard Space Flight Center.

Introduction: The small obliquity of the Moon creates unique illumination conditions at the south pole, resulting in cold traps and permanently shadowed regions. Incorporating the occluding effect of fine topographic details on scattering is important for high-resolution thermal illumination modeling; reflection and reradiation have an effect on the surface temperature. Both long (thermal) and short (visible) radiation must be treated. In "high visibility" environments, such as the interior of a crater, the runtime of large thermal models is dominated by element-to-element flux calculations, typically $O(N^2)$ FLOPS, where N is the number of elements used in the discretization. In recent work [1, 2, 3], we presented preliminary results that used the radiosity method (a boundary element method) for large-scale thermal and Lambertian illumination modeling on small bodies and the Haworth crater at the lunar south pole (see Fig. 1). We develop and apply fast algorithms that let us solve the radiosity system of equations in $O(N \log N)$ time. There is a $O(N^2)$ setup cost that is quickly amortized over a large number of time steps (necessary for an accurate thermal simulation). See Fig. 2.

Outline: Focusing on the lunar south pole, we will: *1)* present scaled up models which take full advantage of the available high-resolution DEMs [4] of the lunar south pole, *2)* present a numerical study using a multiresolution hierarchy of DEMs to quickly spin up a thermal model (the 1D model from [5]) before time-stepping at full resolution (for an example of the same approach used with a high-resolution shape model of Vesta, see [1]), and *3)* show how far away topography can be incorporated at a coarser resolution using `distmesh` [6].

Preliminary results: In previous work, we presented preliminary models for small bodies (Vesta and Ceres) storing the radiosity system as a sparse matrix and solving it using a Gauss-Seidel iteration, with models containing up to 800,000 elements. In this case, since most elements are pairwise occluded, a sparse matrix approach allowed us to reach relatively large model sizes. More recently, we presented a proof of concept of the current approach, solving small systems containing at most 25,000 elements in a dense and highly visible environment (Haworth), demonstrating $O(N \log N)$ scaling.

Our solver works by using a spatial data structure (e.g., a quadtree or octree) to partition the shape model, inducing a recursive block partitioning on the view factor matrix. The off-diagonal blocks are low-rank and can be stored and multiplied in $O(N)$ time and space using an SVD or other low-rank matrix decomposition

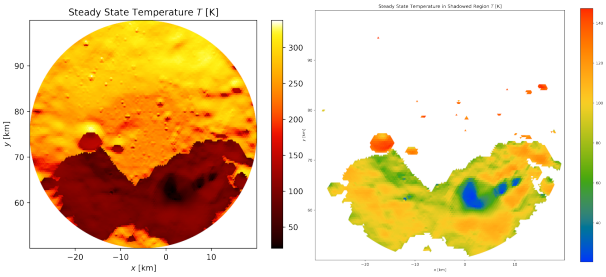

Figure 1: *Left*: equilibrium temperature of Haworth crater. *Right*: Steady state temperature in shadowed region.

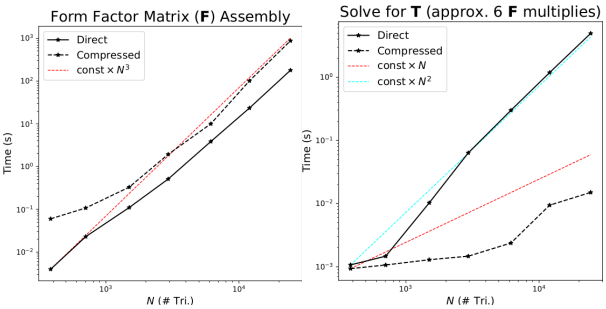

Figure 2: Numerical studies using a problem with a groundtruth solution, the bowl-shaped crater [7].

(e.g., CUR decomposition). Since the radiosity system can be solved in a small (3–6) number of iterations, an $O(N \log N)$ multiply gives an $O(N \log N)$ solve (this is what it means to be a "direct solver").We plan to demonstrate that this approach can scale to a large number of elements (i.e., greater than 1M elements) at the meeting.

References

[1] Samuel Francis Potter and Erwan M Mazarico. Illumination and thermal environment at (4) Vesta and (1) Ceres. In *AGU Fall Meeting Abstracts*. 2018.

[2] E Mazarico, et al. Illumination and thermal conditions at small bodies. In *Lunar and Planetary Science Conference*, volume 50. 2019.

[3] Samuel Francis Potter, et al. Illumination and temperature on rough terrain: Fast methods for solving the radiosity equation. In *AGU Fall Meeting 2019*. AGU, 2019.

[4] David E Smith, et al. Summary of the results from the lunar orbiter laser altimeter after seven years in lunar orbit. *Icarus*, 283:70–91, 2017.

[5] N Schörghofer. Planetary-Code-Collection: Thermal and ice evolution models for planetary surfaces v1.1.6, 2019.

[6] Per-Olof Persson and Gilbert Strang. A simple mesh generator in matlab. *SIAM review*, 46(2):329–345, 2004.

[7] Andrew P Ingersoll, et al. Stability of polar frosts in spherical bowl-shaped craters on the moon, mercury, and mars. *Icarus*, 100(1):40–47, 1992.