Mars Thermal Model for Mega-Pixel Digital Elevation Models

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Key Points:

- A thermal model has been developed for rugged topography on Mars that can process mega-pixel domains [1].
- It includes direct insolation, terrain shadowing, terrain irradiance, sky irradiance, and subsurface heat conduction.
- The model has been applied to Palikir Crater to calculate mean temperatures, peak temperatures, and the extent of seasonal water frost and seasonal CO_2 frost [2].

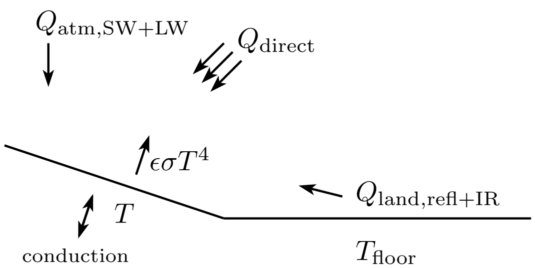

Figure 1: Contributions to the surface energy balance.

With 3-dimensional topography the surface energy balance is modified, compared to a horizontal unobstructed planar surface, for the following reasons:

Direct Irradiance

1) changed incidence angle
2) elevated horizons (terrain shadowing)

Terrain Irradiance

3) reflected sunlight from visible land surfaces
4) infrared emissions from visible land surfaces ("self-heating")

Sky Irradiance

5) restricted diffuse sky irradiance (short- and long-wavelength)

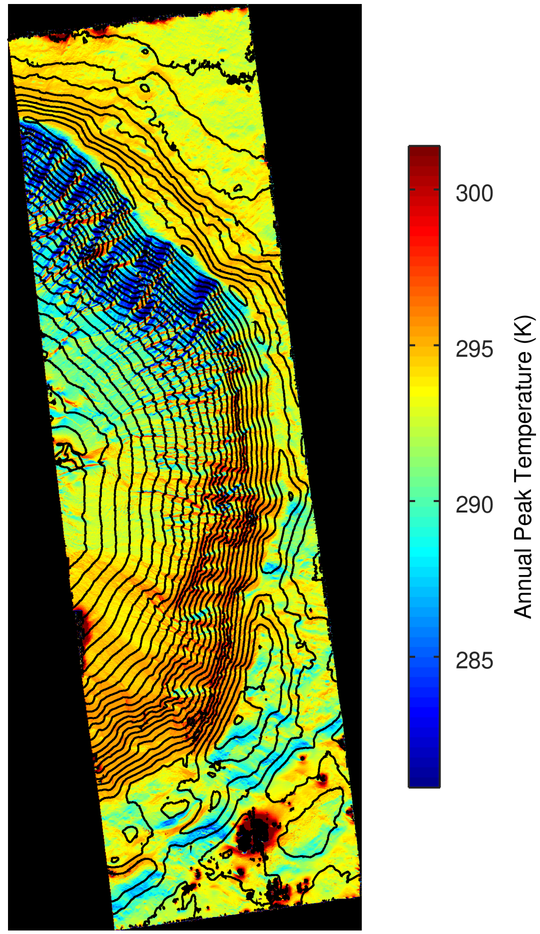

Figure 2: Annual maximum surface temperatures on the east rim of Palikir Crater, 42° S, based on a 8 m/pixel DEM with about ***1.42 million*** *valid* ***pixels****. This example illustrates the capabilities of the model. Further results are shown in Ref. [2].*

Use of spatial grids of various resolutions (multi-grid method) dramatically accelerates the determination of horizons, because facets that are far from the point of interest are larger and fewer. For a domain with N pixels, the computational cost is $O(N \log N)$ instead of $O(N^2)$.

The diffuse (Lambertian) sky irradiance is based on the view factor of the sky, and can be calculated from horizon heights [3].

The model also includes 1-dimensional subsurface heat conduction, using a Crank-Nicolson solver with nonlinear upper boundary condition.

The calculations are carried out in two stages. First the horizons are determined for all pixels. Segments of the spatial domain can be processed in parallel. In the second stage, the time evolution of irradiances and temperatures is simulated as the sun moves through the sky, with time steps of, e.g., 1/50th of a solar day, over several Mars years.

Why is this thermal model so fast?

- Semi-implicit solver for subsurface heat conduction
- Multi-grid accelerated horizons determination
- Approximation to terrain irradiance that is easily parallelized
- Overall computationally efficient implementation

The model is available on GitHub [1]. Suitable applications for the current implementation of the thermal model are gridded DEMs with a resolution coarser than the scale for lateral heat conduction $\gtrsim 5$ m/px (e.g., CTX-derived DEMs) and domains small enough to neglect changes in latitude and longitude, $\lesssim 60$ km. DEMs with over 10^6 pixels have been modeled on a single workstation (Fig. 2, [2]).

The model can be applied to the study of potentially temperature-dependent processes, such as gully activity, ice retreat, glacial flow, slope streaks, seasonal CO_2 frost, and thermal inertia mapping.

References: [1] https://github.com/nschorgh/Planetary-Code-Collection/ [2] Schorghofer, N., et al. (2019). *J. Geophys. Res.* 124: 2852. https://doi.org/10.1029/2019JE006083 [3] Dozier, J. & Frew, J. (1990). *IEEE Trans. Geosci. Remote Sensing* 28: 963.