**THEMIS-DERIVED THERMAL INERTIA ON MARS: IMPROVED AND FLEXIBLE ALGORITHM.** R. L. Fergason[1], J. R. Laura[1], and T. M. Hare[1]. [1]U.S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ, USA, rfergason@usgs.gov.

**Introduction:** The derivation of accurate surface temperature and thermophysical properties, with well quantified uncertainties, has proven essential for selecting scientifically interesting and safe landing site locations [e.g., 1-4] and to understand past and present martian geologic processes. This work significantly improves upon the algorithm developed by Fergason et al. [5], and addresses many of the limitations inherent in that technique. Specifically, these improvements include 1) utilization of the most recent KRC thermal model; 2) flexible and efficient software framework; 3) incorporation of slope and slope azimuth information at spatial scales comparable to temperature data; 4) incorporation of temporally relevant atmospheric dust opacity information; and 5) modernized interpolation structure. This work describes the software tool developed and used to support the estimation of thermal inertia values for the martian surface, and the discussed improvements directly result in a more accurate and scientifically useful product.

**KRC Thermal Model:** The thermal model used in this work is KRC [6], a well-established thermal model that has been used to derive thermophysical properties of Mars since the Viking mission [7]. An explicit forward finite-difference scheme calculates surface and subsurface temperatures by solving the heat conduction equation while satisfying a surface boundary condition that includes upward emission and downwelling thermal radiation, direct and diffuse insolation, and the latent heat of $CO_2$ if its saturation temperature is attained. Significant improvements to this model since its use by Fergason et al. [5] include the incorporation of temperature dependent conductivity and specific heat; the ability to specify non-Lambertian surface reflection, incorporate seasonal variable atmospheric tau and soil albedo, and incorporate N number of subsurface layers of varying thickness; and the detection and resolution of various bugs present in 2006. Although not all of these improvements are practical to include in the generation of a global data set, this version of KRC results in a considerably improved estimation of surface temperature values.

**Flexible and Efficient Software Framework:** A significant improvement over the previous algorithm [5] is that all input parameters are defined by the user and are flexible in that values from any source data set can be utilized. This flexibility was deemed necessary to enable future data sets (such as higher spatial resolution albedo) to be incorporated with minimal effort. This flexibility has been notably used in the evaluation of Mars 2020 landing sites where Context Camera (CTX)-scale digital terrain models are available to derive slope and slope azimuth information. CTX provides regional-scale slope and slope azimuth information, and can be utilized in this algorithm even when a global product is not available. With this flexibility, the responsibility is placed on the user to ensure accurate data registration, that identical data projections are used, and the data sets are of the same spatial resolution and location. In addition, although this algorithm was optimized for deriving thermal inertia values from Thermal Emission Imaging System (THEMIS) data, any temperature raster can be used as an input.

**Input Data Set Improvements:** When possible, the default data sets used to generate thermal inertia have been updated to incorporate the highest spatial resolution and data accuracy currently available. The input parameters required by this algorithm include season, local time, latitude, elevation, atmospheric dust opacity, slope, slope azimuth, albedo, and temperature; the default data sets are provided in Table 1.

**Table 1.** Default input data sets. Any of these defaults can be modified by the user.

| Input Parameter | Default Data Set |
|---|---|
| Season | Spacecraft ephemeris |
| Local Time | Spacecraft ephemeris |
| Latitude | Spacecraft ephemeris |
| Elevation | MOLA |
| Dust Opacity | TES, THEMIS, and MCS [8] |
| Slope | Combined MOLA and HRSC |
| Slope Azimuth | Combined MOLA and HRSC |
| Albedo | TES |
| Temperature | THEMIS |

*Higher Resolution Slope and Slope Azimuth:* Slope and slope azimuth information was incorporated at spatial scales comparable to THEMIS temperature data. The addition of these data sets allows more accurate thermal inertia values to be derived along sloping features, such as crater walls, enabling important science questions to be more fully addressed. We have generated global slope (0° to 90°) and slope azimuth (0°to 360°) maps by mosaicking available High-Resolution Stereo Camera (HRSC [9]) Digital Terrain Models (DTMs) (~40% of the planet) into the global 128 pixel/degree Mars Orbiter Laser Altimeter (MOLA [10-11]) DTM. The merging of these data sets allows for simplicity in automating the generation of thermal inertia values, and the usefulness of this product can be realized by the science community. HRSC DTMs are generated with a typical spatial resolution of ~50 m/pixel [12], whereas MOLA is released at 463 m/pixel spatial resolution globally. When HRSC DTM coverage is available it is superior to the MOLA DTM, which can contain kilometer-wide interpolated gaps from the original MOLA shot data. Due to the ubiquitous presence of artifacts on flat-lying surfaces in the HRSC DTM, we degraded the final resolution of the merged DTM to 200 m/pixel in an attempt to minimize these artifacts. The artifacts can be as high as 15°, and this level of introduced slop can pose a significant problem when deriving thermal inertia values. Despite these artifacts, this merged produce is a significant improvement over MOLA alone and contains slope and slope azimuth information at a spatial resolution comparable to the THEMIS IR data. To fit slope, we utilize a quadratic interpolation and define a truncated node set of 0°, 30°, and 60°. Although slopes higher than 60° are present on the martian surface, we note that the vast majority of slopes are well within this tolerance, and we sought to minimize error in the most commonly encountered data range.

*Dust opacity:* Dust opacity is the measure of the dampening of the of diurnal temperature cycle due to atmospheric dust. We utilize a seasonally dependent dust opacity estimation with varying spatial and temporal coverage [8]. Broadly, the data set covers 5° latitude increments for Mars Solar Longitude 690 through 3265 (i.e., martian years 24-31). This data set is an improvement over the previous default data set, which was a TES dust opacity map for a single Mars year without significant dust storms. This new data set utilizes tau values derived for data obtained at the same time as the temperature data was acquired, and significantly reduces the uncertainty in thermal inertia when tau deviates from the typical seasonal value.

**Modernized Interpolation Structure:** Utilizing lookup tables generated by the KRC model, we seek to achieve two goals (1) minimization of lookup table data size, and (2) minimization of interpolation error. For each parameter, we selected nodes based on one or two criteria. First, we selected nodes clustered at peaks in the parameter value distributions. Second, we selected node values in those areas where data analysis is most likely to occur (e.g., pre-dawn local time when THEMIS images are often acquired). In the case of the latter criteria, we are explicitly accepting a higher error outside of our target range. To determine final lookup table nodes for each parameter, we ran a number of single point, high-density lookup table generation operations over the full range of potential thermal inertia values. Given the required data endpoints, we tested all possible combinations of node spacing for first through third order polynomials to determine the interpolation strategy that both minimizes errors and reduces computational complexity. Once the final lookup table was generated, it was loaded into a Hierarchical Data Format (HDF5) data cube, which is optimized for high performance, scalable storage of numerical data. All interpolations are forced through the known data nodes. The most expensive, monotonic cubic interpolation is used only in instances where quadratic or cubic interpolations caused significant deviations from known constraints (e.g. significant 'overshoot' to minimum model temperature). Initial testing shows the maximum off node interpolation error to be between 0.02 K and 0.48 K. The maximum interpolation error, 0.48 K, is observed in the time dimension and intentionally forced to the evening twilight. That is, error is minimized in the predawn and dawn hours at the cost of increased twilight error. See [13] for additional details.

**Current and Future Mission Consideration:** As previously stated, the derivation of accurate thermal inertia values has proven essential for both landing site evaluation and to understand past and present martian geologic processes. The accuracy of, and therefore our confidence in, this critical data set is currently compromised by a lack of supporting data sets necessary to model the thermal response of the surface. Specifically, globally consistent and accurate slope and slope azimuth information and higher-resolution surface albedo at spatial scales similar to the temperature data utilized (currently 100 m/pxl) is greatly needed. Current data, such as slope and slope azimuth from HRSC and bond-equivalent albedo derived from OMEGA data, could fulfill the current needs provided adequate resources are made available to produce a globally accurately product with well characterized uncertainties. Future missions with infrared instrument payloads should also consider the need to obtain complementary data sets needed to derive secondary products (such as thermal inertia), and to fully realize the scientific value of the infrared data set.

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