EFFECTS OF SURFACE HETEROGENEITY ON THE APPARENT THERMAL INERTIA OF MARS.

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Introduction: Using a modified version of the algorithm described in Mellon et al. (2000) [1], we derived thermal inertia from three Mars years of brightness temperature observations by the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES). Global mapping results show seasonal and diurnal differences in apparent thermal inertia as large as 200-600 J m^{-2} K^{-1} $s^{-½}$ (units hereinafter assumed) or more over most of the surface. In this work we focus on examining potential root causes for these variations and their implications for the surface characteristics of Mars.

Current methods [1,2] for deriving thermal inertia generally assume that surface properties are horizontally and vertically uniform on the scale of the instrument's observational footprint and sensing depth. Due to the nonlinear relationship between temperature and thermal inertia, sub-pixel horizontal heterogeneity or near-surface layering may yield different apparent thermal inertia values at different seasons or times of day.

Additional modifications of the thermal model and algorithm were undertaken to characterize the expected thermal behavior of idealized mixed and layered surfaces. Comparison of the modeling results with the TES-derived mapping results indicates that much of the martian surface may be dominated by (1) horizontally mixed surfaces, such as those containing differing proportions of rocks, sand, dust, and duricrust; (2) lower thermal inertia layers over higher thermal inertia substrates, such as dust over rocks or dry soils over an ice table at depth; and (3) higher thermal inertia layers over lower thermal inertia substrates, such as duricrust or desert pavements over relatively unconsolidated finer materials.

Background: The thermal behavior of the martian surface can be represented as a boundary condition on the thermal diffusion equation, where radiative loss to space is balanced by subsurface conduction and heat flux due to insolation (F_{SUN}), down-welling atmospheric radiation (F_{IR}), and seasonal CO_2 condensation (F_{CO2}):

$$\varepsilon\sigma T_S^4 = I\,(\pi/P)^{½}\,(\partial T/\partial Z')|_{Z'=0} + F_{SUN,\,IR,\,CO2} \qquad (1)$$

where ε is the emissivity of the surface or CO_2 frost if present, σ is the Stefan-Boltzmann constant, T_S is surface temperature, I is thermal inertia, P is the diurnal period, T is subsurface temperature, and Z' is depth normalized to the thermal skin depth. From the subsurface conduction term in Eq. 1, it is evident that thermal inertia is the key material property controlling diurnal surface temperature variations. Thermal inertia is defined as a combination of the bulk material properties of thermal conductivity k, density ρ, and heat capacity C such that $I \equiv (k\rho C)^{½}$. For typical geological materials under Mars surface conditions, the conductivity tends to dominate and is controlled primarily by physical properties, such as particle size, porosity, and pore connectivity, within the top few centimeters of the subsurface.

In general, unconsolidated fines will have low values of thermal inertia, indurated dust and sand-sized particles will have intermediate values, and rocks and exposed bedrock will have high values. For observations made from orbit, the temperature of any given location on the surface is controlled by a variable mixture of such materials on the scale of the instrument resolution (~3 km for TES). To the extent that horizontal mixtures or near-surface layers of differing materials exist in the field of view, the apparent thermal inertia derived from such temperature observations will vary with time of day and season, due to the nonlinear relationship between temperature and thermal inertia given in Eq. 1.

Methodology: We revised the thermal model and algorithm described in Mellon et al. (2000) [1] to allow a greater range of thermal inertia (5-5000) and the use of concurrent dust opacity data [3] when reprocessing three Mars years of data from TES orbits 1583-24346. To investigate seasonal and diurnal thermal characteristics, we binned the apparent thermal inertia results into 36 10°-L_s nightside and dayside maps at 1/2° per pixel ('nightside' and 'dayside' refer respectively to the southbound and northbound legs of the MGS orbit and not necessarily to the position of the Sun with respect to the horizon. For example, observations of the polar regions in summer include periods when the Sun remains above the horizon throughout the day).

For examining the thermal characteristics of mixed surfaces, we used the same thermal model which was used in TES processing to obtain model component temperatures and then found effective surface temperatures by performing a linear mix of the Stefan-Boltzmann function:

$$\sigma T_{EFF}^4 = \sigma \sum (A_i T_i^4) \quad (2)$$

where A_i is the fractional area of the ith model component. For layered surfaces, we revised the thermal model to allow a two-layered subsurface with independent material properties in each layer. In both cases, apparent thermal inertia was determined by inputting model temperatures into the same thermal inertia derivation algorithm as was used for the TES data processing.

Results: TES mapping results show large, systematic seasonal variations in nightside and dayside apparent thermal inertia. The amplitude of variations ranges up to 200 at mid-latitudes (±60°N) and 600 or more in polar regions. Variations occur at nearly all locations at the mapped resolution (1/2° per pixel), generally with an annual period of 0.5 or 1.0 and a large phase delay between nightside and dayside results. Inter-annual variations are much smaller, which suggests that transient atmospheric phenomenon such as dust loading is not primarily responsible for the observed changes.

Model results for two-component horizontal mixtures representing dust, sand, duricrust, and rocks show seasonal variations with magnitude and periodicity similar to that of the TES results. In some regions, the model and data results correlate quite closely (Fig. 1). Layered model results may be subdivided into low-over-high and high-over-low thermal inertia classes, both of which again

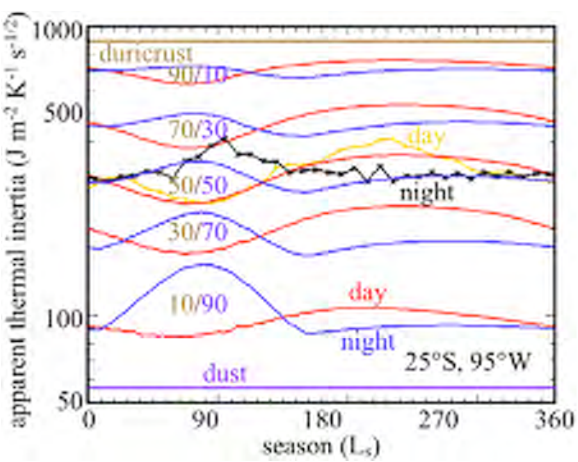

Figure 1. Comparison of dayside and nightside apparent thermal inertia results for TES data (yellow and black) with results from a horizontal mixture model (red and blue) for a 10°x10° region in Solis Planum. Curve sets represent different mix percentages between dust (I=56) and duricrust (I=889) components.

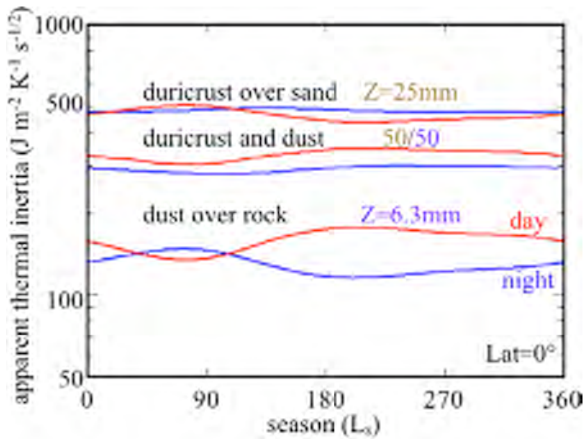

Figure 2. Comparison of dayside (red) and nightside (blue) apparent thermal inertia results for layered (top and bottom curve pairs) and horizontal mixture (middle curve pair) model results at the equator.

demonstrate seasonal variations qualitatively similar to those found in the TES results. The apparent thermal inertia variations for the two layered classes generally have the opposite sign and are distinct from the variations seen for horizontally mixed surfaces (Fig. 2). Thus, each of these three classes of surface heterogeneity models is distinguishable from the others, suggesting that mapping of Mars surface heterogeneity may be possible, at least to the extent that these three classes of heterogeneity are representative of the surface.

In any case, the qualitative correspondence between TES and model results suggests that surface heterogeneity is widespread and plays an important role in determining the thermal behavior of the martian surface. While these results strongly caution against the common practice of using thermal inertia as a simple proxy for grain size or rock abundance (especially in the case of single-point observations), they also hold great promise for yielding quantitative constraints on the nature of mixed and layered surfaces.

References: [1] Mellon M. T. et al. (2000) *Icarus* 148. [2] Fergason R. L. and Christensen P. R. (2003) *LPS XXXIV*, Abstract 1785. [3] Smith M. D. et al. (2001) JGR 106 (E10).