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A Rough Surface Thermophysical Model

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Abstract

We present a new rough surface thermophysical model, *ATPM*, that describes the observed directional thermal emission from any airless planetary body. The model has been verified by accurately reproducing ground based directional thermal emission measurements of the lunar surface using surface properties that are consistent with the findings of the Apollo missions. The verified model is then used to determine the directional characteristics of thermal emission from various different planetary surfaces. The results have implications for spacecraft sampling site selection for an asteroid sample return mission, and the global characterization of surface thermal properties of a planetary body.

1. Introduction

Planetary surfaces illuminated by the Sun are in constant equilibrium between the absorbed solar radiation and the thermal radiation emitted from the surfaces themselves. The thermal flux is dependent on the surface temperature distribution, which in turn is dependent on several factors associated with the planetary body. These include heliocentric distance, rotation rate, orientation of the spin vector, global shape, and a number of different surface properties including albedo, thermal inertia, and roughness.

Thermal inertia and surface roughness are useful diagnostics to characterize a planetary surface. Since thermal inertia depends predominantly on regolith particle size and depth, degree of compaction, and exposure of solid rocks and boulders within the top few centimeters of the subsurface; it can be used to infer the presence or absence of loose material on the surface [1]. Roughness measures the irregularity of a surface at scales that are smaller than the global shape model resolution but larger than the thermal skin depth specified by the thermal inertia. Both properties significantly affect the observed planetary thermal emission.

Thermal inertia introduces a lag time between absorption and re-radiation of solar radiation. Increasing the thermal inertia decreases the day-side surface temperature distribution and increases it for the night-side. Roughness causes the surface to thermally emit in a non-lambertian way with a tendency to re-radiate the absorbed solar radiation back towards the Sun, an effect known as thermal infrared beaming. This effect increases with increasing degree of roughness.

Both properties affect the disk integrated measurements of many asteroids making their diameters difficult to determine [1]. The directional dependence of thermal emission due to surface roughness has been well observed in measurements of the lunar surface [2], and in images taken of Comet 9P/Tempel 1 by Deep Impact [3]. Many thermophysical models have been produced to investigate the disk integrated observations of asteroids but relatively few have been developed to investigate directional resolved measurements.

2. The *ATPM* Model

A new thermophysical model has been produced, the *Advanced Thermophysical Model* (*ATPM*), to investigate directional resolved thermal emission measurements. It is applicable to both spatially resolved and disk integrated measurements. It is a parallel 64-bit code written in C++ allowing extensive surface topographies to be solved. The code accepts global shape models in the triangular facet formalism. It also accepts a topography model which it uses to represent the unresolved surface roughness in the global shape model for each facet. Any representation of the surface roughness can be used in the topography map but hemispherical craters are preferred since they are easy to parameterize. For each global facet and surface roughness subfacet a 1D heat conduction equation is solved throughout a planetary rotation with a surface boundary condition. The surface boundary condition includes direct and multiple scattered solar radiation, shadowing, and re-absorbed thermal radiation from interfacing facets. The 1D heat conduction equation can be solved with and without temperature dependent surface thermal properties. The observed thermal emission is then determined by applying and summing the Planck function over each visible facet and subfacet.

3. Lunar Verification

The lunar surface has been extensively observed at various different observer and Sun elevation angles which clearly show the thermal infrared beaming effect occurring in the wavelength range 10-12 μm [2]. This is a unique data set allowing the new model to be tested and verified. To perform the test we assumed the surface thermal properties determined by in situ heat flow experiments conducted by Apollo astronauts [4], and tried several different topography maps to represent the surface roughness. This included craters of various opening angles and surfaces with Gaussian random height distributions. We varied the fraction of the surface represented by the rough surface shape model to find the best fit to all of the observations. All of the surface roughness model variants fitted the observations quite well but with different fractions of roughness. However, the mean RMS slope for each roughness variant and its associated best fit fraction resulted in similar values, suggesting the way surface roughness is represented does not influence the results. The best possible fit was obtained with a fraction of ~0.4 hemispherical craters (e.g. Figure 1) resulting in an RMS slope of ~31°. This is consistent with the surface roughness measured in some Apollo landing site images [5].

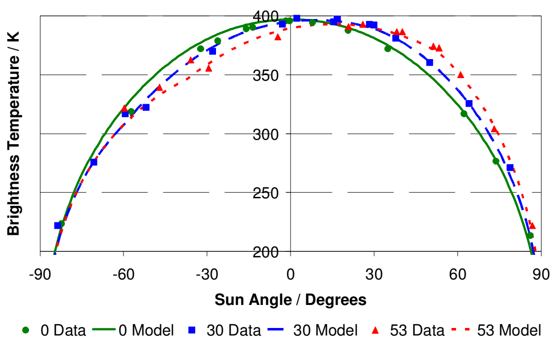

Figure 1: Observations of lunar thermal emission in three directions relative to the mean surface normal (0°, 30°, & 53°) as a function of illumination angle [2] compared with *ATPM* model predictions (lines).

4. Implications for Asteroids

To determine the thermal infrared beaming characteristics for asteroid surfaces we ran hundreds of models with different combinations of thermal inertia values, illumination and observation geometries, and observation wavelengths. Thermal beaming is highly dependant on the observation and illumination geometry, with the expected result that thermal beaming is greatest when the observation and illumination directions are the same i.e. when the observer is looking at sunlit surfaces. Contrary to expectation, the flux enhancement seen in disk integrated observations is dominated by limb surfaces rather than the subsolar region. Thermal beaming is also wavelength and thermal inertia dependent, as it decreases for both increasing wavelength and thermal inertia. This implies that the interpretation of spatially resolved thermal flux from an asteroid surface could be very inaccurate if this effect is not taken into account. A thermal mapping strategy (e.g. for sampling site selection or global characterization) should include a number of non-nadir observations to characterize the degree of surface roughness and the beaming effect.

5. Summary and Conclusions

A new rough surface thermophysical model has been demonstrated to accurately reproduce the thermal infrared beaming effect occurring on the lunar surface. By considering the huge range of potential asteroid surface properties, the model implies a beaming effect that cannot be described by a simple parameter or function. For accurate determination of surface thermal properties, surface roughness must be explicitly modeled and preferably aided with thermal measurements made at a number of different emission angles. Further implications of surface roughness and thermal infrared beaming will be discussed at the conference.

Acknowledgements

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