THERMAL INERTIA OF PLANETARY ANALOGS USING MODIS DIURNAL OBSERVATIONS.

S. A. Nowicki, UNLV Geoscience, 4505 S. Maryland Pkwy., Las Vegas, NV 89154-4010, scott.nowicki@unlv.edu.

Introduction: A major limitation in the interpretation and application of thermophysical datasets from Mars is that there is no laboratory that ideally recreates the Martian atmospheric and radiative environment. The major characteristics of the Martian environment are naturally varying (diurnally and seasonally) solar flux, a cold blackbody sky, and Mars' atmospheric composition and pressure. These conditions are difficult to attain in the laboratory primarily due to the variable radiance and blackbody sky constraints, and conditions found in a natural Earth environment have significant complications due to atmospheric pressure and composition, weather, and an abundance of water in the atmosphere and surface layer [1]. Due to these limitations, translating modeled thermal inertia values from instruments in orbit around Mars to surface material characteristics that would be quantitative enough for a geologist to make interpretations has been the source of much debate within the Mars thermal community [2,3,4]. Regardless, a generalized scale for relating inertia to sediment grain size based upon laboratory thermal conductivity experiments is regularly utilized [5]. While much work has been done to isolate the thermal conductivity component from the other bulk characteristics in a homogeneous material [6], the physical properties of granular, mixed, and complex materials have only been simply modeled [7,8]. The next step in interpreting naturally-occurring materials is to utilize terrestrial remotely sensed observations of thermally-cycling surfaces, and account for the change in atmospheric pressure and composition [9]. The greatest hurdle in this field is that weather can dominate the instantaneous temperature of the surface. Wind and rain can quickly cool a surface well beyond the diurnal and seasonal-derived temperatures. The application of "apparent thermal inertia", utilizing diurnal pairs (minimum and maximum temperature), has been well documented, but many early workers came to the conclusion that there is no way to go beyond a qualitative and not very accurate apparent thermal inertia, given the unknowns in the current weather conditions, recent weather, subsurface water content, and vegetation variability [10]. While these limitations remain, datasets that have been collected over the past decade make it possible to not only constrain these problematic natural conditions, but make a quantitative estimate of diurnal thermal inertia as would be used on Mars.

Datasets: The Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on board NASA Earth Observing System (EOS) Terra and Aqua satellites have generated large datasets ideally suited for thermal mapping on regional to global scales. Moderate-resolution (1km) MODIS thermal infrared (TIR) data with global coverage and a twice-daily repeat cycle, record the complex natural temperature cycles due to solar insolation and weather. Complete daily, 8-year, diurnal observations have been compiled using MODIS data to produce a comprehensive thermal dataset for much of the arid southwest, from the Colorado Plateau to the west coast of the US, which covers a number of sites used for Mars analog studies. This dataset is similar in scale and application to the Thermal Emission Spectrometer (TES) dataset from the Mars Global Surveyor spacecraft which mapped the surface in visible to TIR wavelengths, and generated the most complete thermophysical datasets for Mars [11].

Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) 90-meter resolution TIR and 30-meter visible to near-infrared (VNIR) satellite imagery provide the perspective for mapping surface properties at resolutions that can be directly applied to field and in-situ observations. The combination of these high temporal resolution MODIS data with high spatial resolution (but lower temporal resolution) ASTER data can be used to isolate the naturally-cycling thermal flux from anomalous thermal features due to weather, land-cover change, and other anomalies. ASTER is limited in repeat coverage and as a result, comprehensive temperature curves are not available using the higher resolution images, even for the most ideal regions.

Additionally, historical weather station observations complied by the National Oceanic and Atmospheric Administration provide a record of local conditions to identify and isolate weather effects and the resulting thermal anomalies (e.g. rain and the resulting cold, saturated soils). With this combination of both observed surface temperature and weather data, we can isolate the regions within MODIS scenes that have anomalously low temperatures that do not reflect thermophysical characteristics.

Beyond thermal models: The key to understanding the thermal response of surface characteristics is in data fusion of time-variable reflectance and thermal response, which until recently has been challenging due to the data volumes and processing capabilities required. With the evolution of data processing tools, and availability of MODIS observations, these problems are significantly simplified. The datasets that facilitate the generation of high-resolution regional mapping of morphoclimatic surfaces have already been collected and continue to be collected as part of the NASA EOS program. At 1-km spatial resolution, individual homogeneous surface types can be resolved in MODIS scenes, although additional ASTER imagery with 90-m spatial resolution is used to further differentiate areas for detailed analysis of thermal flux.

Rather than attempting to model the short temporal and spatial variations that occur in the natural Earth environment, such as wind, humidity, cloud cover, precipitation, and vegetation changes, a compilation of observations provides the thermal curves and observed weather-dependent anomalies. Instead of modeling the changes, we observe them over the course of years, and determine how applicable the data is as a function of time and location. Application of a thermal model following isolation of ideal surfaces and environments will allow us to relate temperature curves to a thermal inertia that corresponds to the values we have observed from Mars.

Testing the method: Not only are many of the Mars analog sites are located in the Colorado Plateau, Basin and Range and Mojave Desert, this region is the ideal environment for thermophysical experiments because if its arid climate and minimal vegetation. We generated a dataset of diurnal thermal infrared day and nighttime observations from MODIS. With a dataset that has minimized weather effects, the regions that provide the most consistent temperature variations were determined and the best candidates selected for thermophysical modeling.

Two preliminary tests were performed to determine the variability of thermal observations. In our region of interest, the surface water effects are minimized, allowing us to extract quantitative diurnally-variable temperatures and correlate with field observations. At very high resolution, hand-held radiometer temperatures are used to distinguish surfaces and fluxes at the meters to centimeter scale. The fusion of high-spatial/low-temporal resolution with low spatial/ high-repeat data allows us to map and isolate features not easily resolved in uniform datasets. The first experiment was spatially and temporally large in scale, spanning a year's worth of diurnal observations, and covering the entire MODIS southwestern US scene. A simple test was developed to determine the variability of diurnal temperature variation using MODIS observations of large-scale surfaces in the Mojave Desert. The daily temperature variations were calculated and the difference over a year were generated and compared between regions. Regions that experienced substantial precipitation and cloud cover showed drastically variable temperatures, and thus indicated poorly-modelable surfaces. Regions that showed little weather related temperature anomalies were compared with modeled solar insolation variations. The second experiment was very high spatial and temporal resolution, observing temperature change over a single diurnal cycle, looking at 10 cm spot sizes of geologically characterized sediment. This involved using stationary radiometers to measure the diurnal temperature variation of loose sand, cemented sandstone, and vegetation cover during a 24 hour period in March of 2009. Temperature curves collected for different material types showed drastically different thermal responses as a function of albedo and estimated inertia at a relative scale as would be expected on Mars [12].

Results: Preliminary results indicate that the application of a modelable thermal inertia is possible in the ideal conditions present in the most arid regions of the southwest that only receive precipitation on a seasonal basis. In the worst case, observations following wet winter storms were found to equilibrate within a week for non-saturated surfaces. This suggests that weather effects can be accounted for given a temporally large enough dataset. On the other hand, surfaces with a significant areal abundance of vegetation, probably on the order of 15-20% or more, showed non-inertia based temperature curves. In the second experiment, we observed diurnal curves that equilibrate much more rapidly than anticipated. As a result of these initial results, in ongoing experiments, a more controlled approach will be taken to quantitatively constrain the effects of light vegetation cover, short-term soil wetting, and variable cloud cover.

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