Quantifying the Areal Percentages of Dust, Sand, and Lava Outcrops in Daedalia Planum, Mars

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Introduction

Thermal infrared studies of lava flows in Daedalia Planum, Mars, suggest minor compositional variability in basaltic silica content may be detectable despite the high-albedo and high-dust cover index [1]. To investigate these potential variations, thermal properties are used to quantify the proportions of dust, sand, and lava outcrops. Modeled thermal conductivity measurements under Martian conditions suggest that low thermal inertia (TI) regions, such as Daedalia Planum, may be explained by a mixture of coarse plus fine-grained material [2-3]. For lava flows, low TI may be the result of larger lava outcrops with sand in low-lying regions and a spatially discontinuous layer of dust (Fig. 1).

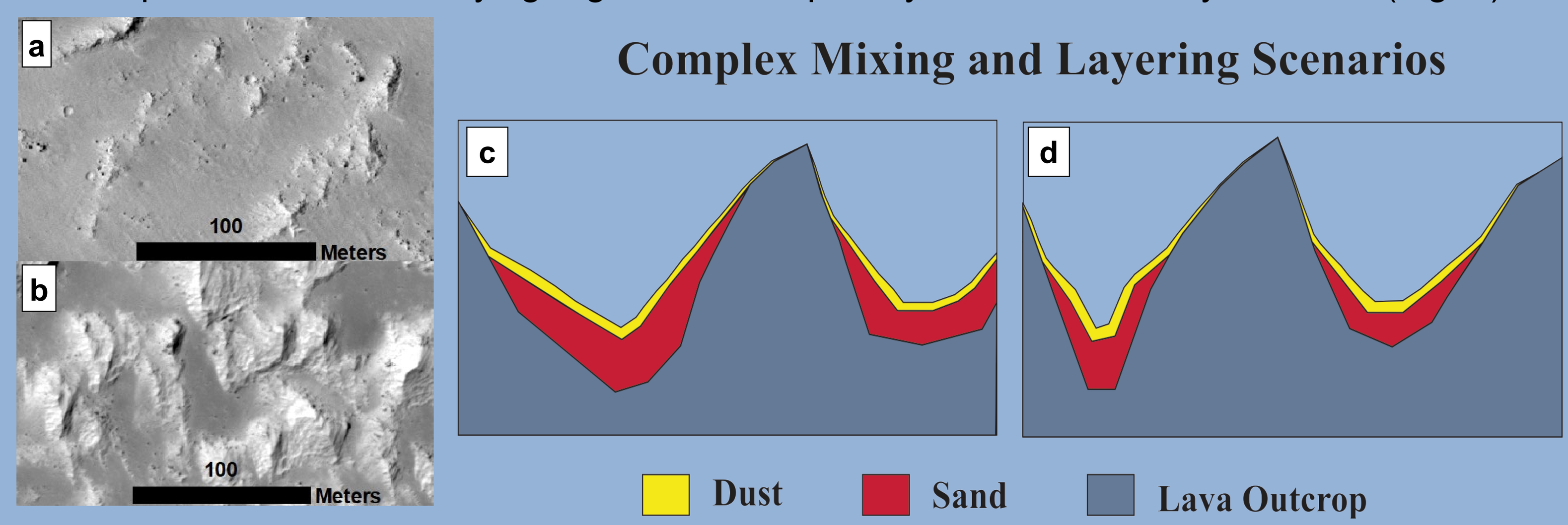

Fig. 1. (a-b) HiRISE images of complex horizontal mixing and vertical layering scenarios with sand deposited in low-lying regions of a lava flow surface. These may be explained as (c) rough flows with a greater areal coverage of sand and dust and (d) those with higher concentration of lava outcrops, respectively.

Study Area

Most likely basaltic in composition, the flow field in Daedalia Planum originates from the SW flank of Arsia Mons [4-6]. The region has extensive coverage by multiple datasets, lava flow fields, flow field mapping, and distinct thermophysical variations [7-9]. Recent detailed geologic mapping and thermophysical analysis suggests the presence of rugged lava flows with outcrops distinct from the fine-grained material in low lying regions [7,9].

Characterizing Thermophysical Responses

Flow boundary mapping and surface morphology identification using CTX and HiRISE data completed by Crown et al. [8-9] were used to understand the variability of the lava flows in Daedalia Planum. Flows were identified as either rugged (visible higher albedo) or smooth (visible lower albedo) surfaces. Over 1250 regions of interest (ROIs) of 500m x 500m were defined to assess the variability of TI [10] and surface temperature in the flow field (Fig. 2). From the statistical analysis (including ANOVA) of these ROI data, four categories were defined based on day and night THEMIS brightness temperature data (Table 1). The defined categories, TI, and surface morphology were then compared to identify areas with highest potential amount of unmantled lava outcrop exposures.

Category	Day Temp.	Night Temp.	Total # of Flows	Smooth Flows #	Smooth Flows %	Rough Flows #	Rough Flows %
A	High	High	1	0	0%	1	3.1%
B	High	Low	7	4	36.4%	3	9.4%
C	Low	High	25	6	54.5%	19	59.4%
D	Low	Low	10	1	9.1%	9	28.1%

Table 1. Four categories based on THEMIS-derived day and night brightness temperature data and statistical results of the relationship between thermophysical response and surface morphology (rugged or smooth) [7-9].

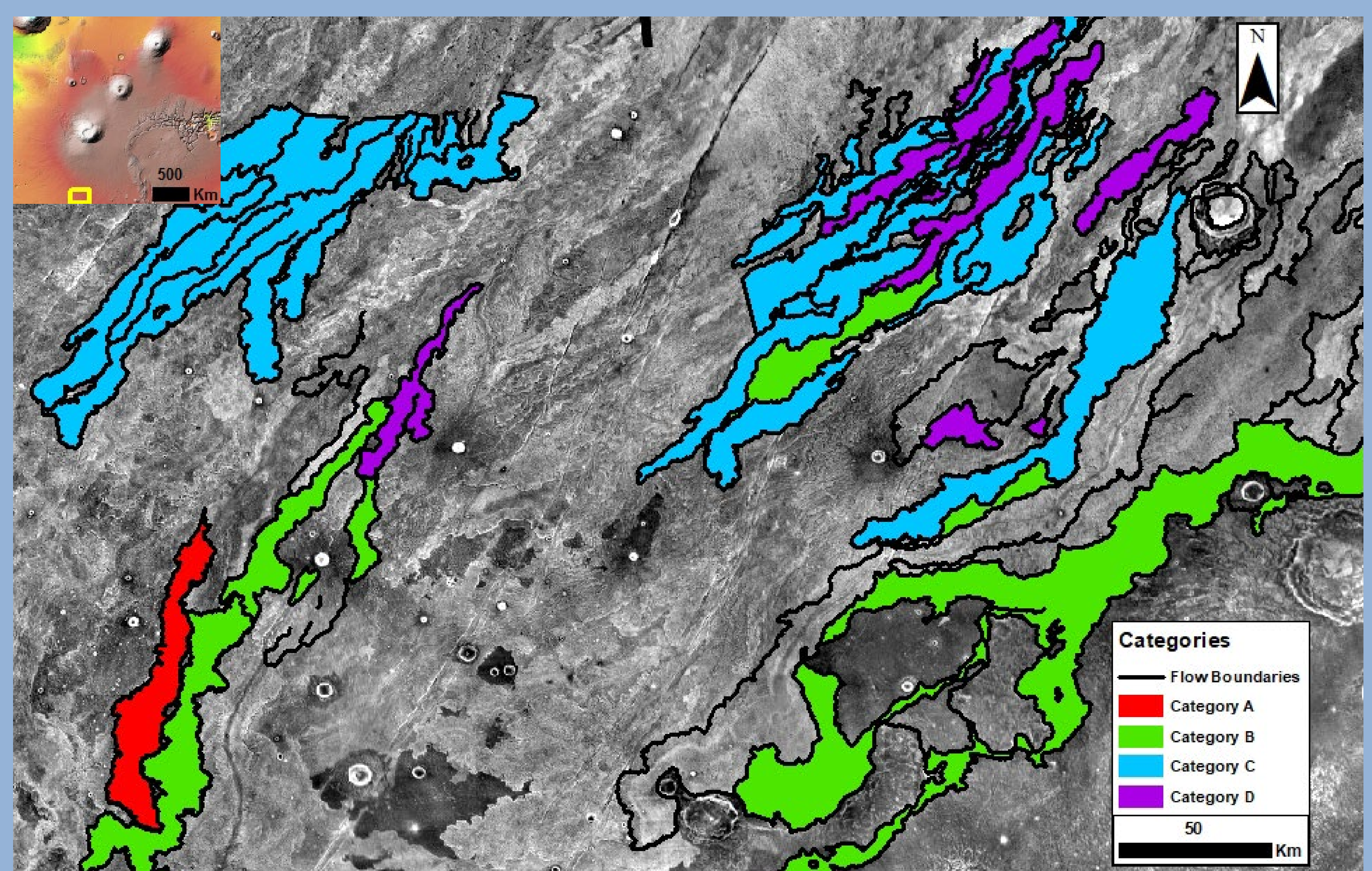

Fig. 2. Crown et al. [9] flow boundaries with colors corresponding to categories (see Table 1) overlain on THEMIS day brightness temperature mosaic [11]. MOLA color inset with yellow rectangle of study area.

Areal Percentages of Dust, Sand, and Lava Outcrops

The thermophysical analysis of these lava flows demonstrates that rough flows with Category C thermal response are the most likely to have a significant amount of exposed lava outcrops. The next step is to quantify the areal percentages of the major surface components to identify the maximum amount exposed lava outcrops (Fig. 3). The KRC thermal model is used to predict the diurnal temperature using these ideal surface components, all having basaltic composition but different particle sizes (Table 2). THEMIS derived temperatures can be matched to the diurnal curves to define the areal percentages.

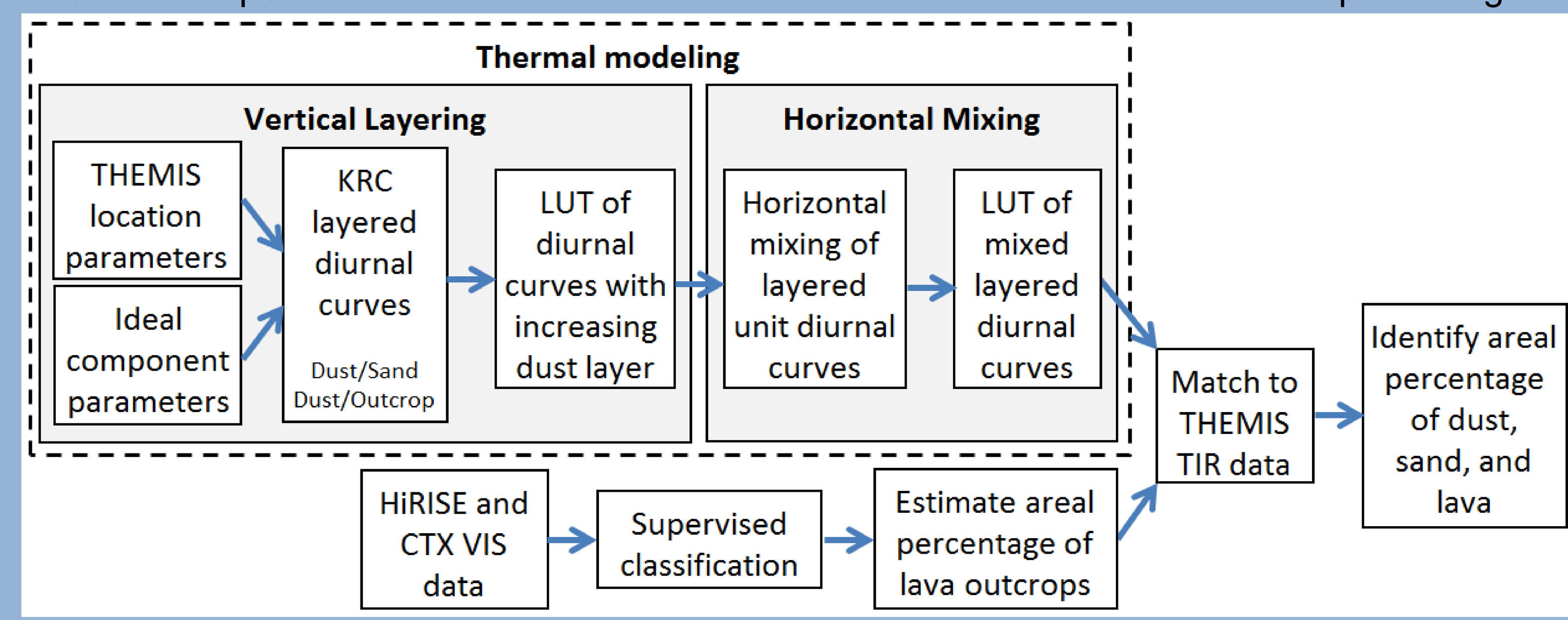

Fig. 3. Workflow of the method, including the KRC model, used to identify the areal percentages of dust, sand, and lava outcrops on the surface.

Material	Particle Size	TI	Porosity	Heat Capacity	Conductivity	Density
	(μm)	*(tiu)*	*(%)*	*(J kg^{-1} K^{-1})*	*(J s^{-1} k^{-1} m^{-1})*	*(Kg m^{-3})*
Dust	2 μm	56	53	837	0.003797	1386.5
Sand	295 μm	223	43	837	0.0496582	1681.5
Lava Outcrop	>1 m	2200	05	837	2.89987	2802.5

Table 2. Input parameters used in the KRC model, based on previous studies [10,12].

KRC Modelling of Layered Units

Diurnal curves were calculated for layered units of sand plus a layer of dust and lava outcrops plus a layer of dust using the KRC model [13]. Successive runs modeled an increasingly thicker dust layer. Figure 4 demonstrates that, comparatively, the signature of the lava outcrops is significantly more affected or masked by the presence of a dust layer.

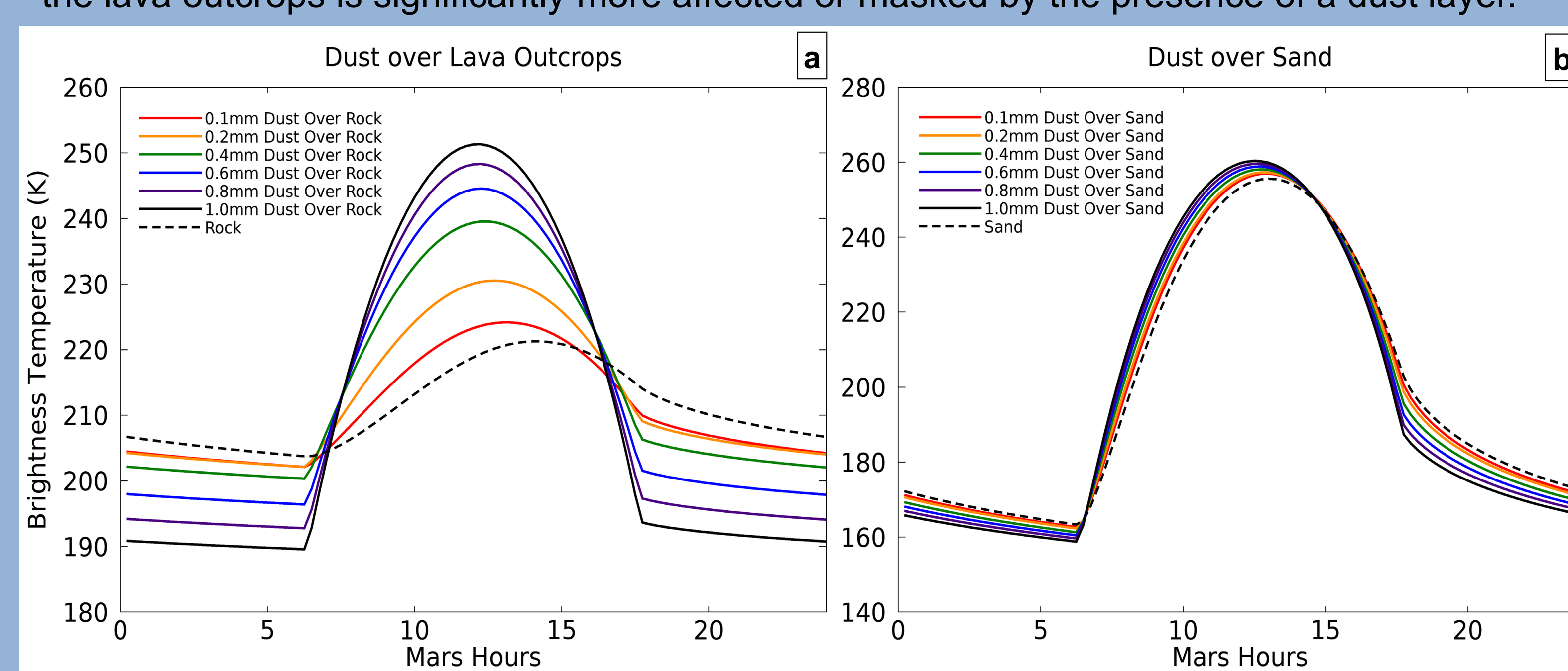

Fig. 4. Diurnal temperature curves of (a) rock (lava outcrop) with increasing thickness of dust cover and (b) sand with increasing thickness of dust cover. These plots show how increasing dust thickness masks the thermal signature of the lower layer and that the dust has a greater impact on the thermal response of rock.

Horizontal Mixing of Layered Units

The predicted diurnal cycles of the layered systems were next linearly mixed to simulate horizontal surface mixtures. The two layered components were combined with different areal percentages summing to 100% and successive runs varied the areal percentage of the two components by 5%. Initial runs mixed layered units with the same dust thickness over both sublayers and additional runs modeled a thicker dust layer over either lava outcrop or sand.

Quantifying Lava Outcrops in Visible Datasets

Supervised classifications of 15 HiRISE images into two classes (either rock or sand/dust) were used to further constrain the presence of lava outcrops on the flow surfaces within 70 ROIs (Fig. 5). This is necessary because multiple thermal model diurnal predictions may match with the THEMIS temperature data. This classification technique identified potential areas of exposed lava outcrops by utilizing the distinct appearance in the HiRISE data. Lava outcrops are identified by a brighter appearance and potential compliment of minor shadowing. Sand or dusty areas have a darker, smooth appearance with minor variations.

The supervised classifications were used to estimate the areal percentage of lava outcrops within the ROIs, defined in the thermophysical study, overlapping the HiRISE data.

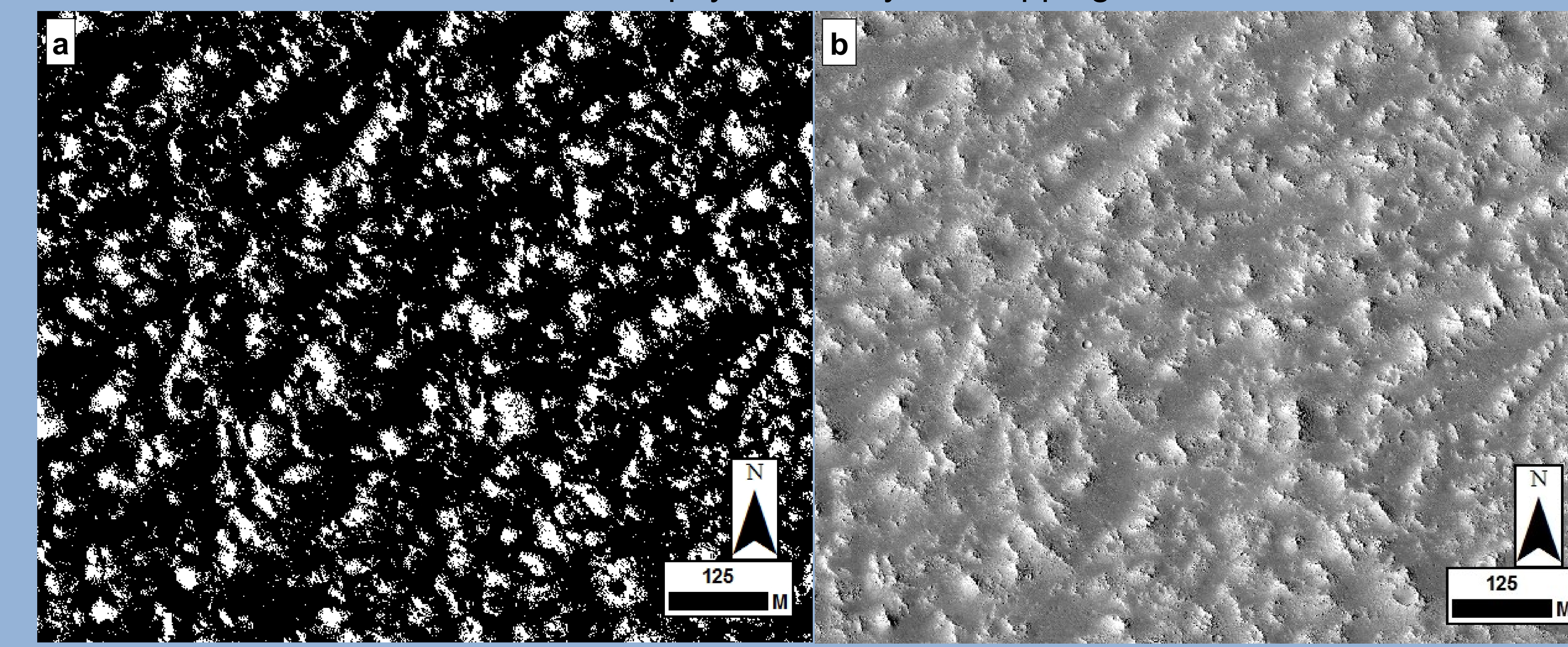

Fig. 5. (a) Supervised classification of a rough category C flow with ~40% lava outcrops in white and sand/dust in black and (b) HiRISE data from which the supervised classification was derived (PSP_002711_1550).

Results: Identifying Areal Percentages

The results of the dust/sand and dust/rock layered mixed runs were compared with the average day and night brightness temperatures calculated from the ROIs placed on THEMIS data for the rough category C flows. The estimated areal percentage calculated from the supervised classification of HiRISE data further constrained the possible areal percentages of these surface components. Comparison of the model results, THEMIS data of the category C rough flows, and supervised classification percentages constrains the presence of up to 40% rock (lava outcrops) on these flows, which can be targeted for future detailed compositional investigation (Fig. 6). This corresponds with a maximum dust thickness over the outcrops of approximately 0.2 mm and 4-5 mm over the sand. Previous studies in this region overestimated the amount of dust covering all lava flows by assuming that only a single layered unit was present (dust over rock). With the incorporation of two layered units, the complexity of the flow surface can now be measured. If lava outcrops were not present, THEMIS data would only match model runs with 0% rock abundance. These results demonstrate that the lava flow surfaces in Daedalia Planum do in fact have a complex combination of vertical layering and horizontal mixing of dust, sand, and exposed lava.

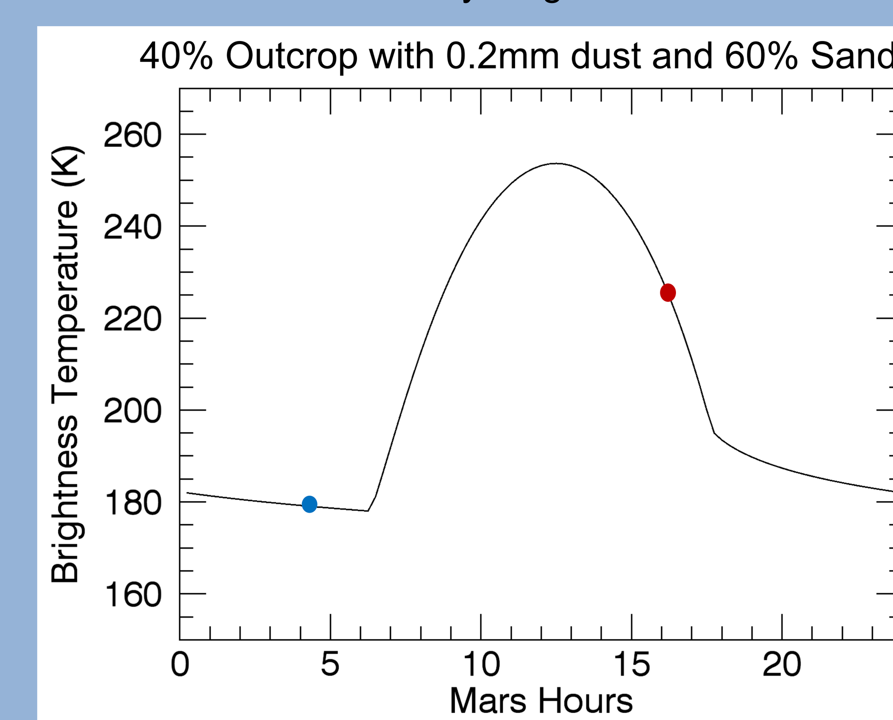

Fig. 6. Diurnal curve of a horizontally mixed layered system that best matches the THEMIS data for category C rough flows 5,18, and 29. The local time for THEMIS stamps are shown (day: 16:31 and night: 4:46). The results in the table are from matching the predicted diurnal curves with THEMIS derived day and night temperatures (the bold percentages corresponding to the HiRISE classification results).

Rough Category C Flows			
Dust layer over outcrop	Dust layer over sand	Sand Areal %	Outcrop Areal %
(mm)	*(mm)*	*(%)*	*(%)*
0.2	***4-5***	***60***	***40***
0.6	3-3.5	50	50
0.7	2.5-3.5	50	50
0.7	4-4.5	45	55
0.75	2.5-4	45	55
0.8	2.5-3.5	45	55
0.8	4-5	40	60
0.85	2.5-3	45	55
0.85	3.5-4.5	40	60
0.9	3.5-5	40	60
0.95	2-4	40	60
0.95	4-5	35	65
1	2-3	40	60
1	3.5-4.5	35	65
1.5	0.85-2.5	20	80

Summary and Future Work

Results of the thermal model and HiRISE classification method demonstrate that the dust layer covering the sand is thicker than that covering the lava outcrop and that a significant amount of those outcrops are exposed. This situation may occur where wind is strong enough to clear the lava rising above the surrounding dust covered surface.

This study developed a method to identify the areal percentages of dust, sand, and lava outcrop components on the flow surfaces. This information will next be used to identify and separate the spectral signature of the lava using a spectral deconvolution approach. These results should constrain any changes in the down-flow composition and ultimately the emplacement process over time. Such an approach is also applicable to similar-regions on Mars previously considered too dusty for thermal studies.

Acknowledgements

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