OPTICAL ATMOSPHERIC EFFECTS AS VIEWED BY THE MSL CHEMCAM REMOTE MICRO-IMAGER.

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Introduction

The Mars Science Laboratory (MSL) Remote Micro-Imager (RMI) has a high-resolution and highly limited field-of-view designed for close-up observations of ChemCam sample targets [1]. Yet with its long focal-length, RMI has proven increasingly useful for capturing long-distance (100s m - 10s km) imagery of geomorphological features [2]. In the time since MSL's landing in Gale Crater, significant improvements have been made to RMI image processing procedures using masking to diminish light scattering and image stacking to resample to a higher resolution [3]. However, image aberrations of unknown cause persist. Given long light paths through the atmosphere at high magnification, RMI long-distance imagery are particularly sensitive, compared to other MSL imagers, to various atmospheric optical effects. Highly variable line-of-sight opacity from dust aerosols can often affect viewing conditions, in extreme cases obscuring the crater rim and the majority of nearby Aeolis Palus during global dust events [4]. Though fogs are unlikely given relative humidities observed at Gale Crater, enhancement of dust haze by water-ice coating of dust aerosols may be possible as well [5]. In addition to opacity variations, a less explored impact on imagery is that of thermal effects from strong daytime temperature gradients present near the surface [6]. Though theoretically possible, it remains unclear if optical phenomena such as heat shimmer or mirages exist on present day Mars and if they could have a noticeable effect on high resolution images over long distances [7]. With a growing knowledge of the long-term variability of dust and meteorological conditions in Gale Crater [8][9], along with the intense mission scheduling demands for MSL instruments, there is a need to better characterize typical long-distance viewing conditions to guide image acquisition strategy. Also, the sensitivity of long-distance imagery to these effects may provide a novel way to study near-surface thermal and dust conditions. The work presented here seeks to better understand how daily and seasonal changes in the near-surface environment impact RMI long-distance imagery. We focus on methods to detect possible thermal effects and estimate their spatial and temporal variability.

Thermal Effects

The thin, dry, and dusty Martian atmosphere yields near-surface temperature and turbulence profiles largely unique from those typical on Earth [10]. In particular, the low air density limits the cooling (or heating) of the surface by turbulence, often supporting super-adiabatic daytime temperature gradients in the lowest meters to 10s of meters above the surface [11][12]. Theoretically such strong temperature gradients are capable of producing inferior mirages at distances of $\sim$1-2 km from imagers depending on terrain and viewing geometry [7]. Gradient driven refraction might produce a full mirage, where features are shifted from true position, or it may simply distort portions of a landscape scene slightly, such as distant background features viewed over the top of a closer foreground. On Earth such temperature gradients may produce scintillation or "heat shimmer" from coherent convective structures and turbulent eddies, but is unclear if this is the case on present day Mars. The atmosphere's low density, dust aerosols, and CO_2-rich composition result in near-surface turbulence being driven less by surface sensible heat and more by internal longwave radiative heating such that turbulent heat fluxes peak a few hundred meters above the surface (as opposed to a few meters such as on Earth)[13]. This is still in the line-of-sight of some long distance observations, though it is unknown if such turbulence produces a significant optical effect again given the density. Furthermore, 3-D large-eddy simulations of the martian boundary layer suggest that thermal convection in concert with radiative heating of dust may work to aggregate dust aerosols in convective plumes affecting the intensity and heterogeneity of dust opacity under certain conditions [14]. Large-scale increases in dust opacity, however, likely work to shade the surface limiting temperature gradients and associated thermal effects. In short, less explored thermal phenomena could influence long-distance viewing conditions through both static and dynamic distortions.

Methodology

The analyses presented rely on reviewing RMI long-distance imagery previously captured during the mission. Focus is placed on stacks of successive RMI images taken over short time intervals (seconds to minutes) from the same viewing geometry, often these stacks having been captured in efforts to increase image resolution. A circular mask is applied to address blurring and overexposure issues near the outer rim of RMI images. A number of image processing techniques are tested to analyze pixel variability between images, comparable to other cloud, dust devil, and dune movement detection methods. Image-to-image differencing and mean image subtraction are used to assess time variations across entire images/scenes and also portions of scenes of varying distance (foreground, crater floor, crater rim). Particular attention is given to viewing geometries that yield a distinct near foreground and distant backgound separated by a sharp horizon edge in order to examine the line-of-sight passing above the foreground for distortions that vary with time. In the case of sharp nearby horizons or prominent individual features such as a high contrast boulder, the edges of the horizon or feature are defined via an algorithm in the first image of a stack and then variations of this edge are tracked through successive images. Consideration is given in the above mentioned methods to distinguish secular movement of the entire scene, which may suggest motion of the rover and imager, versus other variations. Finally, we compare image quality and image analysis results for sets of RMI long-distance imagery to the time of day and season, available dust opacity observations [5][9], and temperature and humidity measurements from the Rover Environmental Monitoring Station (REMS) [15] to give context of the environmental conditions.

Summary and Future Work

The impact of various atmospheric effects on MSL RMI long-distance imagery remains under-explored. This study examines methods to characterize these effects with a focus on searching for thermally driven optical distortions. Results support the collection of future RMI long-distance image stacks specifically aimed at capturing and monitoring thermal effects. Future work seeks to better understand and codify the diurnal and seasonal variability of viewing conditions for distant surface features helping to inform scheduling of ChemCam and other MSL imagery, streamline mission logistics, and ensure excellent scientific data collection. Leveraging optical distortions in long-distance imagery helps expand the capabilities of existing instrumentation and provides novel information about near-surface thermal environment and turbulence which impact aeolian processes, surface energy balance, and volatile cycling such as H_2O-regolith exchange. Also given similar instrumentation, mission strategy, and landing site, results may help inform Mars 2020 Perseverance rover mission imaging as well, while providing further ways to probe the martian atmosphere.

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