RETRIEVAL OF CRISM SINGLE SCATTERING ALBEDOS FROM 1-3.8 µm OVER THE CURIOSITY ROVER TRAVERSE.

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Introduction: We have produced single scattering albedo (SSA) spectra from 1-3.8 µm for multiple CRISM [1] scenes over the Curiosity rover traverse in Gale Crater (Fig. 1). At typical Mars surface temperatures, CRISM I/F data contain solar reflection, plus thermal emission at wavelengths >~2.6 µm. Without accurate knowledge of surface kinetic temperature, retrieving surface albedo becomes an underdetermined problem, and fully constraining mineralogy using this longer wavelength region is precluded. Accurate temperature estimates allow us to remove thermal effects from long wavelengths and to accurately map the broad H_2O- and H_2O-ice related absorption features near 3 µm.

Modeling: We use the DISORT radiative transfer code [2] to model surface emission and reflectance for a scene-specific range of surface temperatures, atmospheric aerosols, and lighting and viewing geometries. Modeling of atmospheric gases is optionally included and otherwise the volcano scan method [e.g., 3] is used for atmospheric correction. DISORT produces a multidimensional lookup table that can be interpolated to solve for SSA from I/F. For shorter wavelengths containing reflectance only, there is a unique solution. For longer wavelengths, the unknown temperature allows for a range of possible SSA curves for each pixel.

Neural Network: We use a neural network approach to solve for the surface kinetic temperature for each pixel in the CRISM scene and then retrieve SSA spectra. We then validate our results against independent estimates of temperature.

The neural network is trained using the following methodology. Training includes use of approximately 300,000 training spectra created from linear combinations of laboratory-based data for a wide range of candidate Mars analog rocks and soils. The training spectra are combined with lighting and viewing geometry, and random values of temperature, to create simulated I/F spectra using a multidimensional DISORT-based look-up table processed for a given scene or set of scenes. The simulated I/F spectra, along with the < 2.6-µm SSA spectra determined uniquely using the look-up table, are then used to seed the neural network. We compute the least squares residuals between the initial and output temperatures and simulated IOF spectra and then back-propagate, iterating until the system converges on values sufficiently close to the input data.

The trained neural network is then given as input actual CRISM I/F spectra, SSA values <2.6 µm, and lighting and viewing geometries, and solves for temperature and SSA at >2.6 µm at each pixel. The output temperature map is then used as one of the inputs to solve for SSA for the entire wavelength region using the DISORT table. Subsequently, these SSA cubes have egregious spikes removed, and iterative maximum log-likelihood (MLM) [4,5] processing is applied for noise suppression and spatial regularization to 12 m/pixel.

Validation: Mars Odyssey THEMIS [6] operates in the thermal IR with a lower spatial resolution than CRISM (~100 m/pixel versus ~18 m/pixel). THEMIS daytime thermal IR observations are acquired in late afternoon (16:00 – 17:30 LST) and are a good proxy for temperatures expected in CRISM data, as low-albedo and low thermal inertia surfaces will be hotter than bright high thermal inertia surfaces. The comparisons at this point are qualitative, given that CRISM data are typically acquired at ~15:00 LST. The thermal patterns for resolvable features are generally consistent between THEMIS IR brightness data and CRISM-derived temperature maps (Fig. 2).

Onboard Curiosity, REMS [7] employs a thermal radiometer to measure surface temperatures along traverses at multiple times per day. These values can be correlated to the same season and time of day as the CRISM observations. Derived temperatures are typically within 5 to 10 K of REMS-based estimates for the same locations, seasons, and LSTs as observed by Curiosity, providing an important independent check on the neural network results.

Results: We apply our neural network method to CRISM scenes over Gale Crater that cover the Curiosity traverse to date and its expected future route (Fig. 1). CRISM FRT0000B6F1 derived data are shown here for mapping (Fig. 3) while example spectra are shown from along-track oversampled observation FRT0001FD99 (Fig. 4).

Standard CRISM parameter maps were generated from temperature-corrected SSA data [8] (Fig. 3). For example, the SINDEX2 parameter was used to map hydrated sulfates, and the BD1900R2 parameter was used to map the extent of hydration. A new parameter is the temperature-corrected BD3000, which measures the depth of the broad H_2O/OH-related 3-µm absorption.

A composite parameter map for FRT0000B6F1 (Fig. 3) shows that lower Mount Sharp strata are hydrated, with discernable absorptions in both the 1900 and 3000 nm range. The 3-µm feature is present in all spectra to some degree, but some areas such as the smectite-rich valley [9] it is deeper. As shown in Fig. 4, it is not possible to map at the longer wavelengths without correction for temperature effects. Further, the hydrated sulfate strata show a range of parameter values indicative of sulfates with varying hydration states that are stratigraphically controlled.

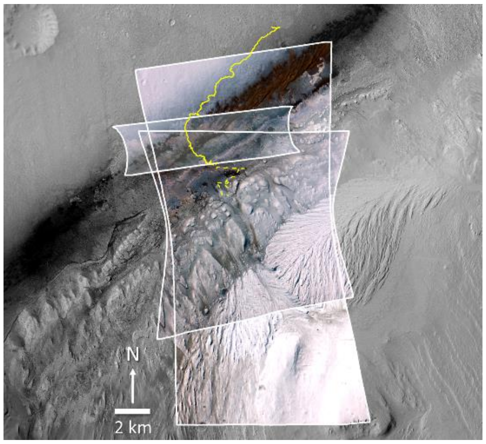

Figure 1: Lower Mount Sharp with CRISM scenes HRL0000BABA, FRT0000B6F1 and FRT0001FD99 overlaid on HiRISE mosaic. RGB = 2.53, 1.51, 1.06 µm. The Curiosity traverse through Sol 1910 is shown as a solid yellow line and the nominal future path as a dashed line.

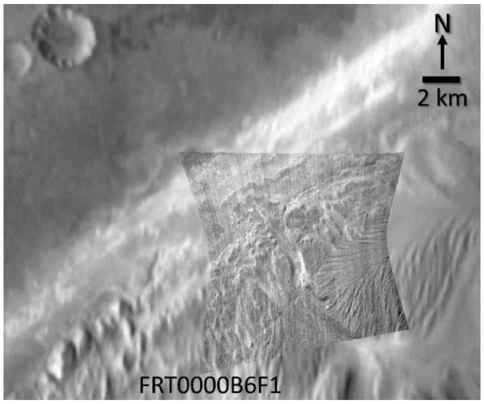

Figure 2: Left - THEMIS Day IR brightness mosaic overlaid with temperature maps retrieved from two CRISM scenes using our neural network approach. Note the correlation between brightness patterns for data for the two instruments.

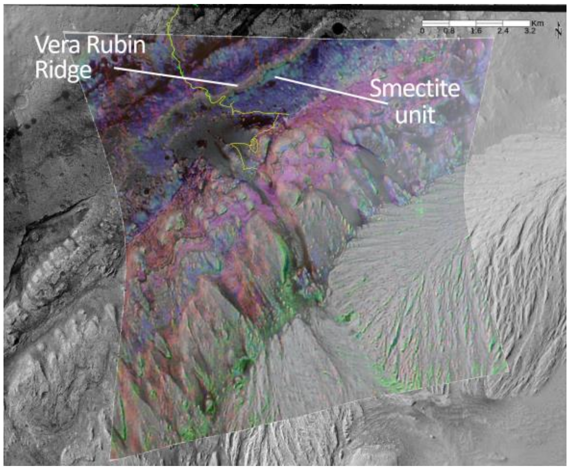

Figure 3: CRISM FRT0000B6F1 parameter map overlaid on HiRISE mosaic. Red=SINDEX2, Green=BD3000, Blue=BD1900R2 [8]. Color patterns reflect changes in mineralogy along the section. Hematite-rich Vera Rubin Ridge and the fan-shaped features are relatively dehydrated. Sulfates with variable hydration states appear as orange, pink, and blue, and green.

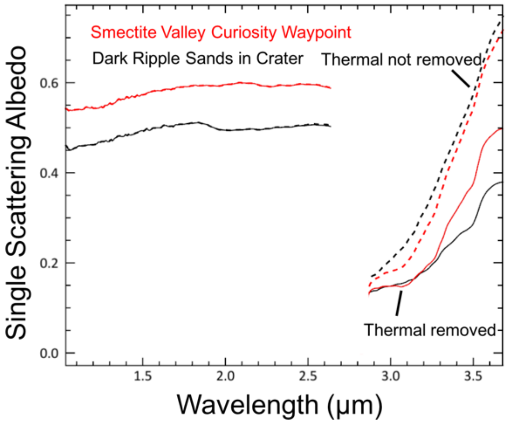

Figure 4: FRT0001FD99 SSA spectra are shown with (solid lines) and without (dashed lines) accounting for thermal effects in the DISORT retrieval. The smectite spectrum (red) has a deeper 3 µm absorption than nearby dark sands (black). Without thermal removal, this feature is masked by temperature effects.

References: [1] Murchie, S., et al. (2007) *JGR*, *112*, E05S03. [2] Stamnes K. et al. (1998) Appl. Opt., 27. [3] Murchie, S., et al. (2009), *JGR*, *114*, E00D06. [4] Kreisch, C.D. et al. (2017) *Icarus*, *282*, 136-151. [5] He, L., et al. (2017) *Imaging & App. Optics*, JTu5A.16, [6] Christensen, P.R. et al. (2004), *Space Sci. Rev.*, *11* 85-130. [7] Gómez-Elvira, J., et al. (2012), *Space Sci. Rev.*, *170* 583-640. [8] Viviano-Beck, C. E. et al. (2014) *JGR-Planets*, *119*, 1403-1431. [9] Fraeman, A. A., et al. (2016) *JGR-Planets*, *121*, 1713-1736.