PIPELINE FOR RETRIEVAL OF SURFACE TEMPERATURES AND SINGLE SCATTERING ALBEDOS.

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Introduction: We have developed an end to end processing pipeline for hyperspectral imaging data acquired by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) hyperspectral instrument on the Mars Reconnaissance Orbiter (MRO) [1] and the Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité (OMEGA) hyperspectral instrument on Mars Express (MEX) [2]. The WUSTL Pipeline approach models atmospheric aerosols and gases, and both solar and thermal contributions to spectral radiance on sensor. Hapke [3] single scattering albedo (SSA) spectra for the surface are retrieved for each pixel. The approach also produces sensor space and map-projected cubes that have been denoised using log maximum likelihood processing [4]. An option also exists to model the surface using a Lambert Albedo approach.

Methodology: The processing can be broken down into two phases: the derivation of SSA hyperspectral cubes and temperature maps and further refinement to retrieve the best estimates of SSA values in the presence of Poisson noise. Optionally, these steps are followed by the derivation of spectral parameter summary products [5].

SSA Derivation The radiative transfer program DISORT [6] is used to model the effects that that surface and atmospheric temperatures, atmospheric aerosols and gases, and lighting and viewing geometry have on detected radiance values, with the Hapke function used as a surface boundary condition. A multidimensional lookup table is constructed from the DISORT runs that serves as a mapping from SSA, surface temperature, and geometric values to IOF radiance values. The Hapke Function simulates modest surface backscattering with surface bidirectional reflection for solar-dominated wavelengths and directional-hemispherical for emission.

Surface temperature retrievals are an underdetermined and ill-posed system and are solved via a neural network (NN) approach which is trained using simulated surface data derived from laboratory spectra of Martian minerals with random temperature values [7]. The simulated data includes both constructed SSA spectra and corresponding radiance spectra created via the DISORT look-up table. Once trained for a given scene the NN is used with actual radiance and geometry data to retrieve a temperature map and SSA spectra for the complete wavelength regions covered by the instruments.

SSA Refinement The SSA values are next passed through a median filter based on the design of Eliason and McEwen [8] to remove spikes caused by, e.g., the degradation of cooler function in the instruments. A maximum likelihood method (MLM) algorithm is then applied to the filtered SSA values [9]. This algorithm both generates map-projected estimates of SSA spectra and accounts for Poisson-based noise, and the blurring effect of the instrument's spatial and spectral transfer functions. With the completion of this step, we have finished deriving sensor-space SSA hyperspectral cubes and map-projected cubes (which for CRISM along track oversampled (ATO) data can have resolution as high as 12 m/pixel). Surface temperature maps are also generated in sensor space and map-projected forms. Map projected product examples are shown in Figs. 1-4. Thermal maps are presented in [10].

After these main processing steps, summary products are produced. These include a subset of the parameter maps described in [5] and implemented in the CRISM Analysis Tool (CAT) (pds-geosciences.wustl.edu/missions/mro/crism.htm).

Software Interface: These steps are grouped together in the WUSTL Pipeline, a single piece of software. The user can operate the software from a graphical user interface (GUI) or directly from parameter values specified in JSON data-interchange format. The program displays progress via console output. The final data cubes, as well as many intermediate results between the steps described above, are stored to disk as raw arrays with ENVI-compatible header files.

Presently, most of the code used in the Pipeline is written in MATLAB, with certain segments written in C++ (for high performance on computationally intensive tasks) and Python (to take advantage of machine learning capabilities that are not yet available in MATLAB). It is also a goal of the project to avoid the expense of a MATLAB license by converting the bulk of the code to Python.

Future Work: We intend to release the WUSTL Pipeline and its source code as free software (both libre and gratis) as a service to the community. This release will occur through the Planetary Data System's (PDS) Geosciences Node (pds-geosciences.wustl.edu). This will include, either together, or separately, support for processing CRISM and OMEGA observations. The pipeline will be available as a stand-alone package and as a drop-down menu in CAT. We also plan to develop

and release software which applies a similar methodology to the Mars Odyssey THEMIS (Thermal Emission Imaging System) and Mars Global Surveyor TES (Thermal Emission Spectrometer) instruments.

Prior to release, we will implement an alternate processing flow in the software as follows. The original radiance product will be converted to pseudo-Lambert Albedo via volcano scan correction, and this product will be the input for the maximum likelihood algorithm instead of SSA as described above. This avoids the need to generate a DISORT lookup table, which is often beyond the scope of user-based research.

References: [1] Murchie S. L. et al. (2007) *JGR, 112.E05S03*. [2] Bibring J-P. et al. (2004) *ESA SP-1240*. [3] Hapke B. (2012) *Theory of Reflectance and Emittance Spectroscopy*, Cambridge University Press, New York. [4] Politte D. V. et al. (2018) LPSC 49, Abstract #2063. [5] Viviano-Beck, C. E. et al. (2014) *JGR-Planets, 119,* 1403-1431. [6] Stamnes K. et al. (1988), *Applied Optics*, *27*, 2502-2509. [7] Powell K. E. et al. (2018) LPSC 49, Abstract #2113. [8] Eliason E. M. and McEwen A. S. (1990) *Photogramm. Eng. & Remote Sens., 56.4*, 453-458. [9] Kreisch C. D. et al. (2017*) Icarus, 282,* 136-151. [10] He L. et al. (2019) these abstracts.

Figure 1. Sensor space view before pipeline processing for CRISM ATO FRT0001FD99 showing the extensive along-track over-sampling.
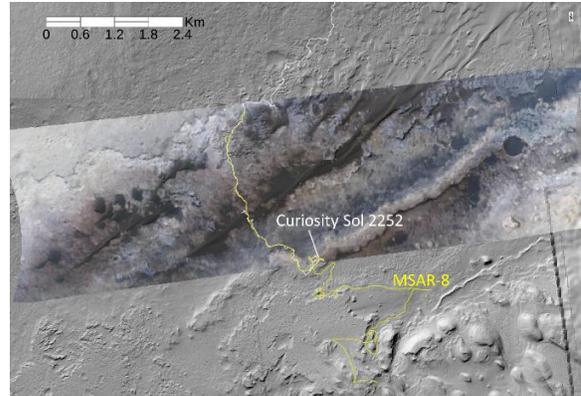

Figure 2. Pipeline processed FRT0001FD99 in map projected form for S data with RGB as bands 0.707, 0.5889, 0.5337 μm. Data are overlain on shaded relief map generated from HiRISE mosaic data. Curiosity's path is shown in white and yellow shows MSAR-8, the strategic path.
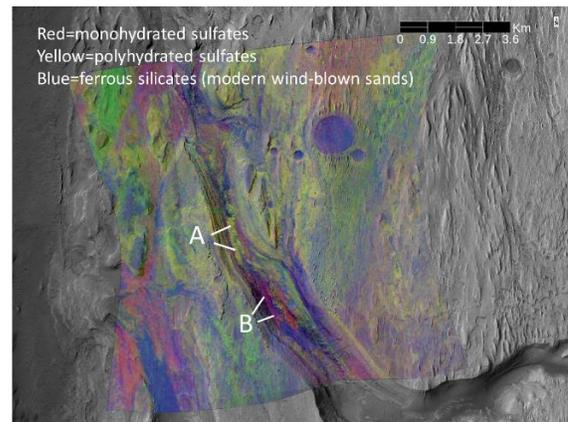

Figure 3. Pipeline processed FRT000095EE spectral parameter data are show overlain onto a HiRISE mosaic for a portion of Aeolis Mons Grand Canyon. Areas A and B are regions for which spectra are shown in Figure 4.
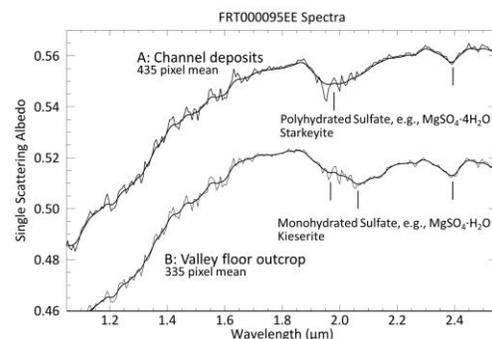

Figure 4. Spectra retrieved from locations A and B are labeled with regard to inferred mineralogy. The thicker lines were generated from the MLM processed data whereas the thinner lines (noisy spectra) are before MLM processing.