CRISM GLOBAL MULTISPECTRAL AND HYPERSPECTRAL MAP PRODUCTS. F. P. Seelos[1], R. T. Poffenbarger[1], K. M. Hancock[1], C. D. Hash[1], S. L. Murchie[1], and S. F. A. Cartwright[2], [1] Johns Hopkins Applied Physics Laboratory, 11100 Johns Hopkins Rd, Laurel, MD 20723, (frank.seelos@jhuapl.edu), [2]University of Nevada, Reno.

Introduction: The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [1] is a visible through short-wave infrared hyperspectral imaging spectrometer (VNIR S-detector: 364-1055 nm; IR L-detector: 1001-3936 nm; ~6.55 nm sampling) that has been in operation on the Mars Reconnaissance Orbiter (MRO) [2] since 2006. Over the course of the MRO mission CRISM has acquired ~375,000 individual mapping observation segments (mapping strips) with a variety of observing modes (VNIR/IR; ~90/180 m/pxl; multi-/hyper-spectral – Table 1) over a wide range of observing conditions (atmospheric state, observation geometry, instrument state). With the retirement of the CRISM cryosystem in early 2018, the acquisition of IR data was suspended with global ~180 m/pxl multispectral mapping coverage at ~87%. VNIR data acquisition has continued and achieved ~100% coverage with ~180 m/pxl multispectral mapping data, and ~95% coverage with ~90 m/pxl hyperspectral mapping data.

The CRISM team delivers mosaicked mapping data to the Planetary Data System (PDS) as a set of 1,964 globe-spanning roughly equal-area regional map tiles [3], where observation-specific corrections have been applied to the constituent mapping strips prior to mosaic assembly. Here we describe two sets of CRISM map tiles: 1) the Multispectral Reduced Data Record (MRDR) product set (e.g. Figure 1); and 2) the VNIR hyperspectral map tile product set (cf. Figure 2). The MRDRs are constructed from simultaneously acquired VNIR and IR multispectral survey (MSP) and hyperspectral survey (HSP) mapping observations resulting in full spectral range (S+L-detector; ~410-3923 nm), multispectral (72 channels), ~180 m/pxl tile products. The VNIR hyperspectral map tiles have the spatial/spectral sampling characteristics of the MSV data (VNIR S-detector, 371-1017 nm, 90 channels, hyperspectral, ~90 m/pxl), with gaps filled by ~180 m/pxl HSV data.

Map Tile Assembly: The CRISM map tile data processing and mosaic assembly workflow is tasked with taking as input a set of mapping strips that intersect a given map tile area, and producing as output spectral, parameter, and browse [3] mosaic products where the spatial/spectral structure is self-consistent across the tile and reflective of surface spectral and mineralogical characteristics rather than observation circumstances (e.g. atmospheric optical depth, observation geometry) or instrument state (e.g. detector operating temperature). The requisite intra- and inter- tile radiometric consistency is realized through an empirical optimization approach that leverages inter-observation spatial intersections and proximal relationships to construct graph theory and linear algebra matrices that encode the mosaic structure and radiometric discrepancies. The graph theory abstraction allows the spatial and radiometric configuration of the mosaic to be evaluated, and the corresponding optimization problem to be well-posed and efficiently configured. Linear and non-linear least squares optimization are then employed to derive a set of observation- and wavelength- specific model parameters for transform functions that minimize the total radiometric discrepancy across the mosaic.

Class Type	Pixel Size (m/pxl)	VNIR Bands	IR Bands	Observations [Target IDs]	VNIR Segments	IR Segments
MSP	*~180*	*19*	*55*	*41786*	*63012*	*63092*
MSW	~90	19	55	2557	2565	2562
HSP	*~180*	*107*	*154*	*16419*	*20119*	*20176*
HSV	~180	107	N/A	60268	90446	N/A
MSV	~90	90	N/A	79587	113485	N/A
			Total:	200617	289627	85830

Table 1. Summary of CRISM mapping data acquired through 01/09/2022 (2022_009).

Photometric, atmospheric, and residual correction. The correction of the observed top-of-atmosphere (TOA) spectral reflectance to atmospherically and photometrically corrected surface spectral reflectance takes one of two paths: a radiative transfer (RT) model based correction [4] or an empirical set of corrections in-family with the CRISM Analysis Toolkit (CAT) [5]. CRISM-derived atmospheric state information (sourced from emission phase function (EPF) data) is only available through late 2012, which limits the applicable range of the RT correction. For the MRDRs, these alternate correction pathways necessitate a radiometric optimization configured to not only minimize inter-observation radiometric discrepancy, but also transform the empirically corrected data to the RT-established surface spectral radiometric framework. The mapping strip-specific processing also includes corrections that address instrument noise and calibration residuals that have been adapted from existing CRISM SOC workflows (e.g. empirical smile correction [ESC]) [6], or developed specifically in support of tile construction (e.g. frame set correction [FSC]) [7].

Mosaic spatial relationships. CRISM Derived Data Record (DDR) pixel-specific geospatial (lat, lon) information is used to identify all spatial intersections in the mosaic observation set. A network of inter-observation relationships based on spatial proximity is also constructed. The relationships among the constituent observations can be treated as a graph, with observations as nodes and relationships as edges. The corresponding adjacency matrices allow the structure of the graph (mosaic) to be evaluated. The mosaic optimization is dependent on the construction of a fully-connected graph (a mosaic without any isolated observation subsets). The scope of the proximal relationships is adjusted to efficiently but completely address gaps or weak connections in the network of spatial inter-sections.

Optimization system scoring. The score for a given inter-observation relationship is calculated either from sample set distribution summary statistic discrepancies or from the discrepancy in the cumulative distribution functions (CDFs) for the sampled data. The figure of merit for the mosaic system is the weighted total of the individual scores with the weighting set by the area of each sample, moderated by inter-sample distance for proximal relationships.

Mosaic optimization. Linear optimization of the mosaic system is calculated by singular value decomposition (SVD) of a weighted design matrix that encodes the constituent mapping strip relationships with the decomposition applied to a data vector that encodes the summary statistic discrepancies. Non-linear least squares optimization is conducted with the Levenberg-Marquardt method. The CDF discrepancy calculation allows the full shape of the underlying data distribution to inform the optimization process

Mosaic assembly. The final state configuration yields the optimization parameters for each mapping strip that, when applied to the source data, minimize the figure of merit for the mosaic system. The mosaic stacking order is then governed by observation quality and optimization performance metrics.

CRISM Map Tile Applications: The optimized CRISM map tiles are of sufficient quality and consistency to support GIS mapping (e.g. Figure 1) and further spectral data processing, analysis, and classification of the spectral and parameter tiles. An overview of the current state of MRDR and VNIR hyperspectral map tile production and PDS delivery will be presented, including the use of selected MRDR spectral summary parameter tile products in support of ongoing Mars In-Situ Resource Utilization (ISRU) inventory characterization.

References: [1] Murchie S. L. et al. (2007) *JGR, 112,* E05, S03. [2] Zurek R. W. and Smrekar S. E. (2007) JGR, E05, S01. [3] Murchie S. L. et al (2016) CRISM DPSIS. [4] McGuire P. C. et al. (2008) *Transactions on Geosciences and Remote Sensing, 46,* 12. [5] Morgan F. M. et al. (2017) 3rd Planetary Data Workshop, Abstract #7121. [6] Seelos F. P. et al (2016) LPSC XLVII, Abstract #1783. [7] Frizzell K. R. et al. (2020) LPSC LI, Abstract #2377.

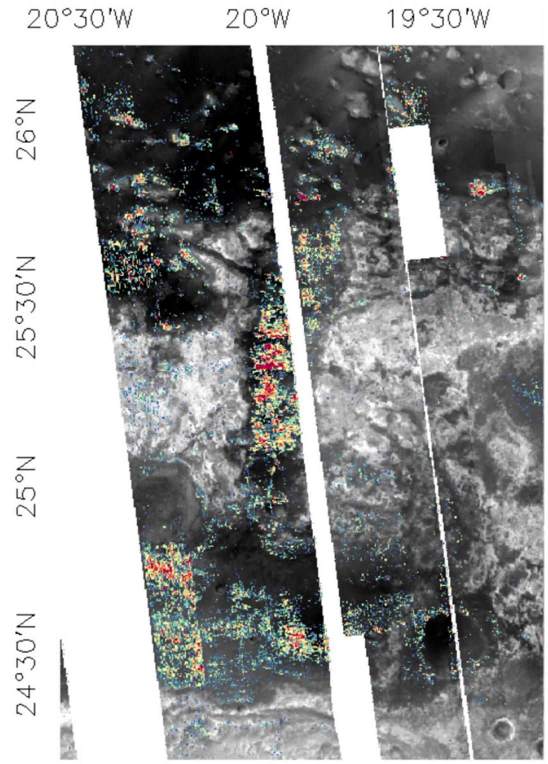

Figure 2. CRISM mapping 920-nm band depth parameter (BD920 – crystalline ferric minerals; LCP) over reflectance at 770 nm (VNA – albedo proxy) for a portion of Mawrth Vallis.

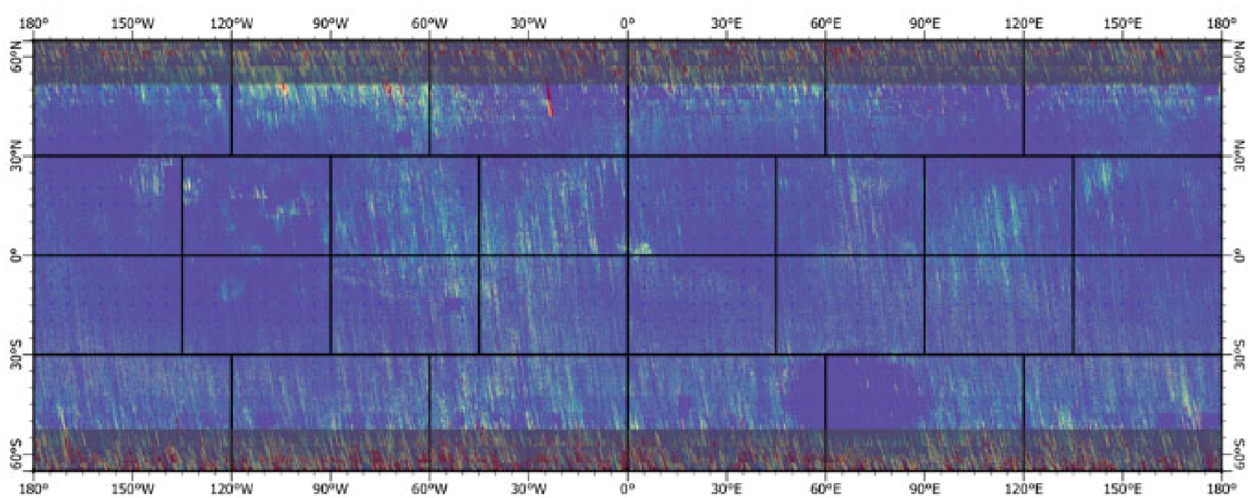

Figure 1. CRISM MRDR global mapping 1900-nm band depth parameter (BD1900 – bound molecular H_2O; [0.00, 0.05] linear stretch; rainbow color ramp) (prototype data product). Mars Chart (MC) mapping boundaries are overlaid. This product consists of 1,764 map tiles that populate MC02-MC29. High latitude regions affected by seasonal CO_2 ice have been greyed out.