CRISM MAPPING DATA EMPIRICAL RADIOMETRIC RECONCILIATION FOR THE NEXT-GENERATION MARS GLOBAL MULTISPECTRAL MAP. F. P. Seelos[1] and S. L. Murchie[1], Johns Hopkins Applied Physics Laboratory, 11100 Johns Hopkins Rd, Laurel, MD 20723, frank.seelos@jhuapl.edu.

Introduction: The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [1] is a visible through short-wave infrared hyperspectral imaging spectrometer (VNIR: 364-1055 nm; IR: 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 (e.g. Figure 1) CRISM has acquired nearly 298,000 individual segments of nadir-pointed, reduced-resolution mapping data with a variety of data characteristics (Table 1) over a wide range of observing conditions (atmospheric state, illumination geometry, instrument state). CRISM mapping data coverage density varies primarily with latitude and secondarily due to seasonal and operational considerations. The aggregate global IR mapping data coverage currently stands at ~87% (~80% at the equator with ~45% repeat sampling – Figure 2), which is sufficient spatial sampling density to support the construction of empirically optimized mosaic products in which inter-strip residuals are largely mitigated.

Motivation: The CRISM team delivers mosaicked mapping data to the PDS as Multispectral Reduced Data Record (MRDR) map tiles [3], to which observation-specific radiometric calibration and corrections for atmospheric effects are applied prior to mosaic assembly. With the collection of IR mapping data now completed, this data product set is being redelivered using all available high-quality mapping data that include the 72 VNIR and IR bands that form the MRDR products.

Atmospheric and photometric correction and data processing residuals in current-generation MRDRs manifest as inter-observation radiometric discrepancies (e.g. Figure 3A). The empirical approach to reconciling these residuals leverages inter-observation spatial overlaps 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 underling 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 (e.g. Figure 3B).

Workflow: Given a set of CRISM mapping mosaic segments that have been calibrated to observed I/F, downselected for data quality, and preprocessed to extract the 72 MRDR spectral bands, the radiometric reconciliation workflow proceeds as follows:

Photometric and atmospheric correction. The approach employed for the atmospheric and photometric correction of CRISM mapping data is a significant branch point in the mapping mosaic workflow. The MRDR data processing pipeline includes a radiative transfer model based correction of the observed top-of-atmosphere (TOA) I/F spectra to surface spectral Lambert albedo. This correction is dependent on accurate atmospheric state parameters (e.g. dust and ice aerosol optical depth). Ice opacity is derived from contemporaneous MARCI data, and dust opacity is retrieved from CRISM targeted observations that include emission phase functions (EPFs). EPF acquisition was suspended on DOY 2012-275 due to the onset of gimbal range of motion restrictions. In the context of the MRDR inter-strip radiometric reconciliation, this sets up a two-stage problem: (a) data acquired early in the mission are corrected to surface Lambert albedo and empirically reconciled to address correction residuals; and (b) strips acquired after the EPF cut-off date are incorporated into the mosaic with the radiometric reconciliation being used to empirically transform the data from corrected TOA I/F into the established surface Lambert albedo radiometric framework.

Mosaic spatial relationships. CRISM Derived Data Records (DDRs) have pixel-specific geospatial information that is used to identify all binary intersections in the mosaic observation set and to generate corresponding spatial sampling masks. A network of inter-observation binary relationships based on spatial proximity is also constructed, with the weight assigned to proximal relationships decaying with increasing inter-sample distance. The established relationships among the constituent observations can be treated as a graph, with each observation acting as a node and each inter-observation relationship acting as an edge. The corresponding adjacency and Laplacian 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). In practice the scope of the proximal relationships is adjusted to efficiently but completely address gaps or weak connections in the network of inter-observation overlaps.

Data sampling and system scoring. The sampling masks are used to isolate paired sample sets that correspond to the observation intersections and proximal relationships. The score for a given inter-sample relationship is calculated either from sample set distribution summary statistic discrepancies for linear least squares optimization, or from the discrepancy in the cumulative distribution functions (CDFs) for the sampled data for non-linear least squares optimization. In either case, 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 corresponding data vector that encodes the summary statistic discrepancies. The linear optimization provides an initial configuration for the subsequent non-linear least squares optimization which is conducted with the IDL MPFIT [4] implementation of the Levenberg-Marquardt method [5]. The CDF-based relationship residual calculation allows the full shape of the underlying data distribution to inform the optimization process. A high quality (low atmospheric optical depth, S/C roll, incidence angle, and IR detector temperature) well-connected reference segment is held constant during the optimization process to maintain radiometric stability.

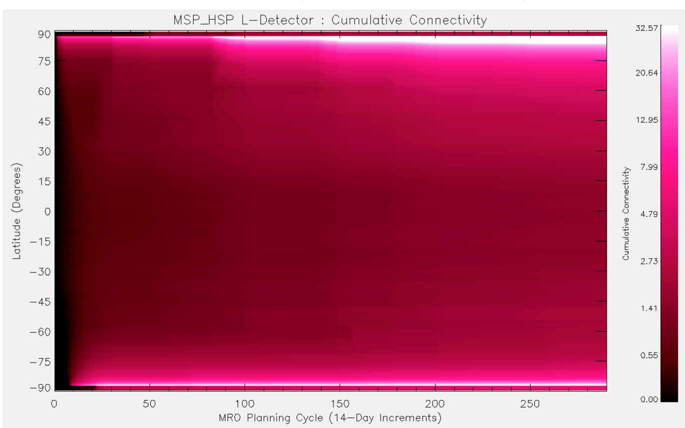
Mosaic assembly. The final Levenberg-Marquardt state configuration yields the optimization parameters for each segment that, when applied to the source data, minimize the figure of merit for the mosaic system. The mosaic stacking order is then governed by observation quality metrics, optimization performance metrics, or can be configured manually.

Summary: This empirical approach to CRISM mapping data radiometric reconciliation supports the construction of next-generation MRDRs with minimal inter-observation radiometric residuals.

References: [1] Murchie S. L. et al. (2007) *JGR, 112*, E5, S03. [2] Zurek R. W. and Smrekar S. E. (2007) *JGR, 112*, E5, S01. [3] McGuire P. C. at al. (2008) *IEEE Remote Sens., 46, 12*, 4020–4040. [4] Markwardt C. B. (2009) *ArXiv09022850.* [5] Moré J. J. (1978) *Numerical Analysis*, 105-116.

Class Type	Pixel Size (m/pxl)	VNIR Bands	IR Bands	Observations [Target IDs]	VNIR Segments	IR Segments
MSP	~200	19	55	41607	62827	62908
MSW	~100	19	55	2557	2565	2562
HSP	~200	107	154	16289	19981	20038
HSV	~200	107	N/A	48489	73792	N/A
MSV	~100	90	N/A	38853	53023	N/A
			Total:	147795	212188	85508

Table 1. CRISM mapping data acquired through 2018-007.



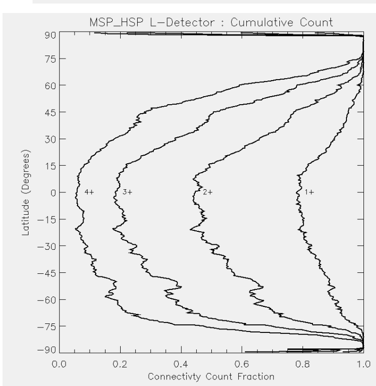


Figure 1. (Above) CRISM MSP/HSP IR data acquisition history. Data set connectivity is the longitudinally averaged number of observations that sample a given ground location. Spatial connectivity increases dramatically approaching the poles (color ramp on a log scale).

Figure 2. (Left). Accumulated CRISM MSP/HSP IR sampling density as a function of latitude.

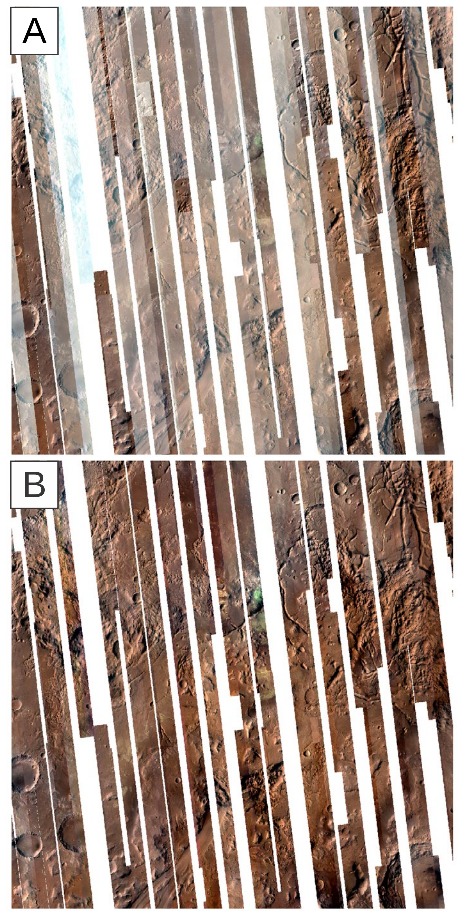


Figure 3. Illustration of the empirical radiometric reconciliation procedure applied to MSP/HSP data for map tile T0870 in Margaritifer Terra. The input (A) and resultant (B) mosaics are presented as RGB composites (R: 2530 nm; G:1510 nm; B: 1080 nm) with a common 1% stretch applied to each band calculated from (B).