EMPIRICAL GEOMETRIC NORMALIZATION FOR TER/MTRDR PROCESSING OF CRISM RESTRICTED GIMBAL RANGE TARGETED OBSERVATIONS.

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Introduction: The Mars Reconnaissance Orbiter (MRO) [1] Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [2] Targeted Empirical Records (TERs) and Map Projected Targeted Reduced Data Records (MTRDRs) [3,4] are high-level analysis and visualization data product suites derived from CRISM hyperspectral targeted observations. The Empirical Geometric Normalization (EGN) procedure [1,2] is a key component of the TER/MTRDR data processing pipeline which characterizes and corrects wavelength-dependent along-track intensity gradients present in the acquired image cubes. These gradients are primarily caused by intra-image variation in atmospheric scattering and absorption due to the gimbal motion and continuously changing observation geometry intrinsic to the acquisition of CRISM targeted observation data.

The current EGN procedure depends on Emission Phase Function (EPF) data – spatially binned samples of the surface/atmosphere system acquired at bracketing emission/phase angle geometries – that early in the mission accompanied the high spatial resolution central scan in each targeted observation dataset. In mid-2012 the acquisition of accompanying EPFs was suspended due to aging of the gimbal and the onset of angular range restrictions. As a result, CRISM hyperspectral targeted observations acquired since that time cannot be corrected using the original EGN procedure. To overcome this limitation we have developed a modified “proxy” EGN approach that does not rely on accompanying EPFs and allows for the production of TER/MTRDR data product suites for the restricted gimbal range later-mission targeted observations.

Proxy EGN Concept: The current EGN procedure approximates the gradient with a polynomial function of two of the observation angles, the cosine of emission angle (proportional to atmospheric path length) and phase angle (aerosol scattering dependence). Due to the lack of EPF scans and limited gimbal motion in targeted observations acquired after mid-2012, it is difficult to directly estimate the underlying intensity gradient caused by the varying observation angles. Instead, the proxy EGN correction transfers gradient models reliably obtained from early-mission observations to the gimbal-restricted later-mission observations. The successful transfer of the EGN gradient model requires the identification of earlier observations whose gradient models can approximate that of a given later-mission EPF-free observation of interest. Since the gradient is mainly caused by atmospheric interactions, observations with a transferrable model should be collected under atmospheric conditions close to that of the scene of interest. In particular, the scattering characteristics of the atmosphere significantly affect the shape of the gradient. The intensity typically increases with emission angle, implying the gradient is strongly correlated with atmospheric path length and the amount of atmospheric scattering. In addition, the gradient models can more successfully transfer to the scene of interest if they are obtained in a similar observation geometry (incidence, emission, and phase angles). The accuracy of the polynomial function is only guaranteed within or near the domain of the observation geometry during the acquisition of the image, as it is an empirical rather than a physical model. Additional observation attributes such as geographic proximity and seasonal similarity can also inform the proxy identification.

Proxy EGN Implementation: The set of early-mission observations have been down-selected based on the complexity of the scenes to retain only sufficiently uniform images that allow the most accurate modeling of the EGN gradient. We identified 2589 early-mission Full Resolution Targeted (FRT) and Half Resolution Long (HRL) observations that are sufficiently spatially uniform to support the calculation of an accurate reference gradient model for all wavelength bands of the Visible and Near Infrared (VNIR) and Infrared (IR) image cubes. To ensure similar scattering properties between the target scene and a candidate scene, we inspect a set of the shortest wavelength bands (410-440 nm) of the VNIR image cube. These bands contain the most distinct gradients across the CRISM wavelength range even in topographically and mineralogically complex scenes due to strong atmospheric scattering and minimal surface visibility. Thanks to these properties, the shape of these short-wavelength gradients can be used to indirectly assess the scattering characteristic of the atmosphere.

The model gradients are obtained by a tailored convex optimization that operates on the short-wavelength bands of the EPF-free later-mission observations. The optimization problem learns underlying vertical (along-track) variation/curvature commonly present across the image columns that largely corresponds to the gradient. Polynomial fitting to the uniform observations is also performed on the gradient model to minimize the effect of surface variability and accurately fit the geometric dependence.

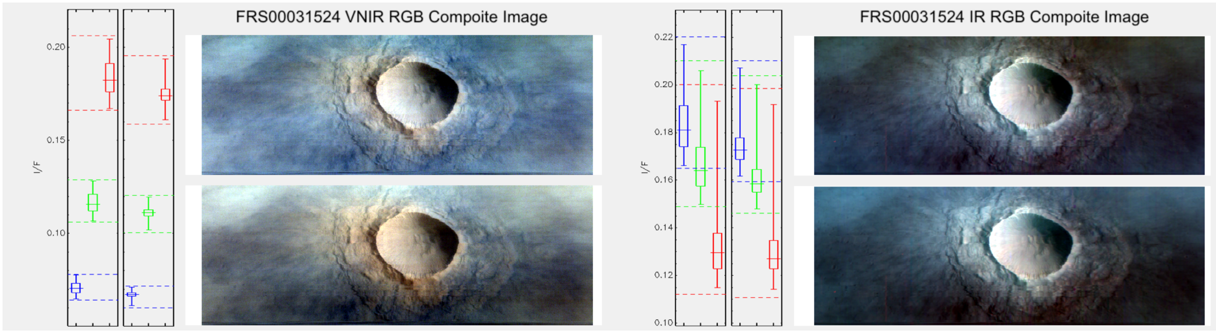

Figure 1. Comparison of the RGB composite images of FRS00031524 VNIR (left; R: band 37 (599 nm), G: band 26 (527 nm), B: band 13 (443 nm)) and IR (right; R: band 206 (2530 nm), G: band 351 (1572 nm), B: band 426 (1080 nm)) data before (bottom) and after (top) the proxy EGN correction. The columns on the left of the VNIR and IR RGB images are the boxplot of the intensity statistics of each RGB band image before (left) and after (right) the correction.

The similarity in observation geometry is computed using pixelwise observation angles stored in the Derived Data Records (DDRs). Similarity in incidence angle is measured by the scene-average as it is a slowly varying quantity over a scene (typically less than one degree). The configuration of emission and phase angles is represented by the vectorized profile of the pair of angles along the boresight pixel in each frame, as these angles primarily change with gimbal motion. In order to compare geometric configurations between scenes, the vector profile is resampled to integer emission angles in degrees. The similarity of a candidate profile to the target scene profile is then measured in terms of the number of shared emission angle samples, and the consistency of the phase angles associated with the shared emission angles.

Once a proximal observation is identified, its gradient model is applied to the scene of interest for each band. The reference models are appropriately scaled with a single wavelength-independent factor obtained from the fit of the gradient model to the reference short wavelength band images. The gradient model is then shifted to be zero valued at the smallest emission angle in the scene, and the correction is subtracted from the image of interest.

Results and Application: The new proxy EGN algorithm is being applied to the post-May 2012 restricted gimbal range targeted observations including the Full Resolution Short (FRS), Along Track Oversampled (ATO), and Along Track Undersampled (ATU) class types that do not have accompanying EPF measurements. Figure 1 shows a comparison of the RGB composite images for both the VNIR and IR image cubes for scene FRS00031524 before and after the correction is applied. The proxy EGN method successfully removes and flattens the vertical gradient (brighter toward the top of the image) in both data sets. The distribution of the image intensity shown in the RGB boxplots confirms the mitigation of geometric dependence. Figure 2 shows the red band image of the VNIR RGB composite in Figure 1 before and after the correction and a surface plot of the image with the derived correction model. The model successfully approximates the geometrically-dependent structure of this observation even in the presence of considerable surface variability.

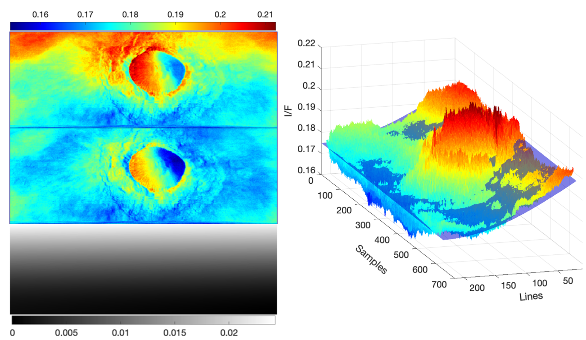

Figure 2. Left: I/F image of band 37 of FRS00031524 before (top) and after (middle) the correction (they are equally scaled). The bottom image is the correction component corresponding to the difference between the above two. Right: Surface plot of the same I/F band image before correction with the estimated gradient model (semi-transparent blue).

The proxy EGN correction is being integrated into the larger TER/MTRDR data processing workflow to support the production, review, and Planetary Data System (PDS) delivery of the TER/MTRDR data product suites for the post-May 2012 EPF-free CRISM hyperspectral targeted observations.

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References: [1] Zurek R. W. and Smrekar S. E. (2007) *JGR*, *112(E05),* S01. [2] Murchie S. L. et al. (2007) *JGR, 112(E05),* S03. [3] Seelos F. P. et al. (2012) *Planetary Data Workshop*. [4] Seelos F. P. et al. (2016) *LPSC XLIII,* Abstract #1783.