MARS-EXPRESS/HRSC SPECTRAL DATA OF MER LANDING SITES ANALYZED BY A MULTIPLE-ENDMEMBER LINEAR SPECTRAL LINEAR UNMIXING MODEL (MELSUM)

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Introduction:

The High-Resolution Stereo Camera (HRSC) [1] onboard the Mars-Express spacecraft has provided a unique dataset of multispectral images that covers most of the planet with a spatial resolution better than 200 m/pixel. We performed spectral analysis of those data in order to provide compositional and surface property information at that scale. This has been done only a few times before [e.g. 2, 3], because of the complex processing steps the dataset requires. The MER landing sites provide us the opportunity to compare image analysis to in-situ observations. The present study is applied on the MER Spirit landing site.

HRSC spectral data: The spectral data are image mosaics of five broadband spectral channels centered respectively at 440, 530, 650, 750 and 970 nm. The third channel (nadir image) has a typical pixel size of 12.5 m, 25 m or 50 m. The other channels have a usual pixel size of 50 m, 100 m or 200 m that determines the spatial sampling of the spectral dataset.These data are acquired by five separeted cameras oriented with a different angle to the normal to the surface (-3°, +3°, 0° (nadir), -16° and +16° respectively). This implies that a given spectrum results from different proportions of shade at each wavelength. Indeed, sub-pixel topographic slopes that are oriented toward the instrument represent a higher proportion in the signal. Thus, shade affects the shape of HRSC spectra on a different way from pixel to pixel. This contribution has to be considered when performing spectral analysis.

Spectral mixing analysis: Most of image spectra result from contributions of a few surface materials plus shade [2]. Subsequently, they can be modeled by linear combination of spectral endmembers in order to provide maps of pure components [4, 5].

Surface spectral endmembers. HRSC spectral data have been found to be modeled by two main types of surface spectra [2, 3, 5] over the whole globe. Bright red materials are rich in iron oxides and are supposed to be essentially dust that covers most of the plains. Dark materials are relatively unoxidized mixtures of pyroxenes or olivine, and are present as eolian deposits inside craters and in many chasmata. These two spectral endmembers have to be collected from well-illuminated smooth surfaces in order to minimize the local effect of shade.

Shade. This spectral endmember may be calculated from pixels that contain only bright material but varying amounts of shade [3]. A linear regression is calculated from a 2-D scatter plot between two image bands. However, the derived spectral shape may not be representative of all types of shade spectra within an image, depending on the geometry of illumination and observation. The alternative proposed here is 1) to use a flat spectrum set to zero values for shade as input in the spectral unmixing, and 2) to analyze the residual spectral shapes in function of the geometry of illumination and observation.

Spectral mixture analysis algorithm. Mixing coefficients are calculated by mean-square minimization [5, 6, 7]. However, negative coefficients may occur, which is not physically acceptable. To avoid this, the MELSUM [5] explores unmixing results for all possible combinations of spectral endmembers and retains the best fit provided by positive coefficients only. When using image spectral endmembesr, the sum of the coefficients may be constrained to equal one, to make them close to areal proportions of components.

Mixing coefficient images: Image fractions of surface materials are expected to provide information on their spatial distribution and the way they are mixed. Results for shade and residuals are related to topography, surface roughness, aerosol scattering, the geometry of illumination/observation and instrumental noise.

Surface materials. The image fractions show basically the same pattern of material distribution than a single grayscale HRSC image (Figure 1 a), except the image fraction Figure 1 b has less contribution from the topography, because these results are close to areal proportions of materials.

Residuals. In Figure 1 c, a strong across-track variation can be seen in the residual at 650 nm. The intensity is different for each wavelength, but the main direction of variation is the same, either increasing or decreasing from left to right (Figure 2). This is expected from small-scale topography effects and/or aerosol scattering combined with different geometries of observation. Consequently, spectral residuals may be analyzed to evaluate photometric properties, especially the surface roughness.

Shade. Since the spectral shape varies due to shade, the image fraction for the flat shade component is not representative of the actual illumination variations. Most of the information related to shading/shadowing, scattering and illumination/observation geometry is present in the residuals.

Retrieving spectral variations and surface roughness information: Since across-track profiles of the residuals showed in Figure 2 are mostly linear, it is possible to describe spectral variations of those residuals by linear regression. As a result, two residual spectral shapes can be calculated, associated respectively to the intercept and to the slope of the linear regression.

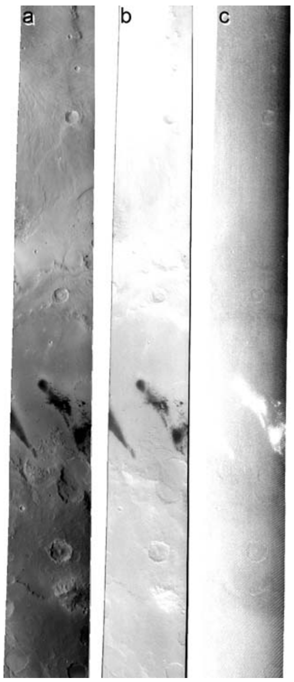

Figure 1. Portion of HRSC image 0024 centered on the MER Spirit landing site – a. Radiance factor (I/F) at 650 nm (nadir image) - b,c. Results of the MELSUM –b. Image fraction for the bright material – c. Residual at 650 nm.

The MELSUM is used a second time with the same spectral surface components plus the two spectral shapes derived from the linear regression. Figure 3 summarizes the results. The slope of this regression (Figure 3 a) appears to be mainly associated to across-track effects, and thus, to the geometry of observation of a rough surface or of a scattering atmosphere.

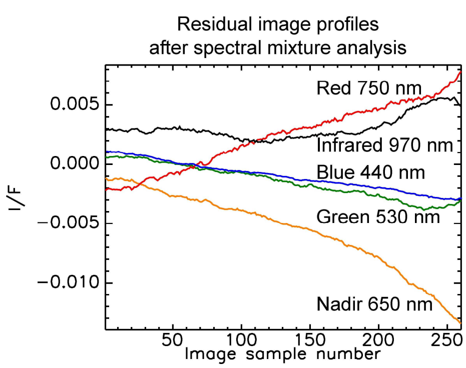

Figure 2. Average profiles of spectral mixing analysis residuals show linear dependence across the image. This behavior is expected for a rough surface observed with different viewing angles.

The intercept (Figure 3 b) appears highly related to the topography, which means this criterion is sensitive to illumination variations. The shaded image in Figure 3 c in displayed for comparison. However, the two maps are not completely correlated, which may indicate the intercept of the regression is sensitive to the surface roughness or aerosol-scattering properties. In this case, a large areas surrounding the streaks of dark materials and the central area at the bottom of the image may have similar photometric properties. Other variations in the north are neither related to surface albedo nor large-scale topographic features.

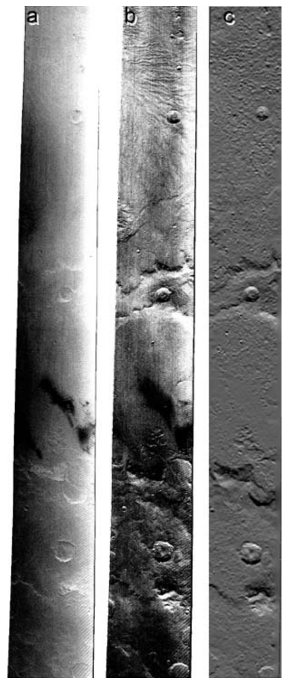

Figure 3. Results of the MELSUM accounting for surface roughness variations: Images of the mixing coefficient associated to the spectrum derived from the slope (a) and the intercept (b) of the accross-track linear regression of the residuals – c. Shaded image of the digital Elevation Model with solar elevation = 15° and solar azimuth = 180°.

Perspectives: These results still have to be analyzed and interpreted with the knowledge of the geometries and illumination and observation for each pixel. The final objective is to provide estimates of the photometric properties and maps of the main spectral components. Results will be compared to the MER observations as well as previous studies based on photometric models [e.g. 8, 9] in order to to interpret photometric properties of the surface and the atmosphere. An improvement of the method will be to derive a variable spectral shape for shade depending on the pixel location with respect to the spectra.

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