IMPROVED ALGORITHM FOR CRISM VOLCANO SCAN ATMOSPHERIC CORRECTION.

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Introduction: The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [1] is a visible-infrared imaging spectrograph onboard the Mars Reconnaissance Orbiter spacecraft. CRISM observes sunlight scattered from the Martian surface and atmosphere, generating hyperspectral imagery in which distinctive absorption features reveal interesting aspects of Mars' surface mineralogy.

In addition to surface mineralogical features, CRISM spectra include absorption features and aerosol scattering from the path of sunlight through the Martian atmosphere. In particular, a strong CO_2 absorption near 2.0 μm can obscure important surface features due to water and CO_2 ices, and hydrated minerals. This feature can be partially removed from observed spectra using an empirical "volcano scan" atmospheric correction pioneered by the MEX/OMEGA team [2]. In that technique, an estimate of atmospheric transmission is derived from data acquired from the summit and base of Olympus Mons. The empirical atmospheric transmission spectrum is scaled to match observed scene spectra and divided out, removing atmospheric features to first order. However, as a result of variations in the shape of the 2.0 micron absorption feature, the original volcano scan correction left an artifact comparable in amplitude to many surface features of interest. Here we describe an improved algorithm for volcano scan atmospheric correction which corrects this artifact.

Original Volcano Scan Correction: The volcano scan atmospheric correction uses empirical atmospheric transmission spectra derived from data acquired while flying over the Olympus Mons volcano. Spectra are acquired in a nadir viewing geometry on a swath approximately 400 km long, extending from the plains south of Olympus Mons (surface elevation near 0), up the flank of the volcano and over the summit (elevation approximately 21 km). Sunlight scattered from the summit travels through much less atmosphere than light scattered from the plains, but surface reflectance spectra from dusty surfaces in the two regions are similar. Dividing a spectrum from the low elevation plains by a spectrum from the summit provides an empirical estimate of the atmospheric transmission spectrum as observed by the CRISM spectrograph.

In order to remove atmospheric features from a spectrum observed in a scene of interest, the empirical transmission is scaled to match the scene spectrum and then divided into it. Under a Beer's law assumption, this transmission spectrum can be scaled to different atmospheric path lengths by exponentiation. The scaling exponent is selected to make the corrected spectrum equal at two wavelengths. The wavelengths must have different transmission in the empirical spectrum. Ideally, they should be expected to show identical surface albedo. Since mineralogical features are typically broad compared to atmospheric gas absorption, both conditions can be reasonably approximated. To the extent that the surface albedo is identical at the two wavelengths, the scaling criteria of equivalence in the corrected spectrum yields the best correction.

At CRISM resolution, the CO_2 transmission spectrum appears as a strong central band about 20 nm wide near 2.0 microns, flanked by two weaker bands about half as deep on either side (Figure 1). CRISM's implementation of the volcano scan correction uses a "peak" wavelength, λ_p, near the strongest absorption and a "reference" wavelength, λ_r, where the CO_2 absorption is weaker. The exponent for scaling the empirical transmission is

$$x = \ln\left(I_p / I_r\right) / \ln\left(T_p / T_r\right)$$

where I_p and I_r are scene I/F at the peak and reference wavelengths, respectively, and T_p and T_r are the empirical transmissions at those wavelengths.

In CRISM's initial implementation, wavelengths 2.011 and 1.89 μm were selected for λ_p and λ_r. This placed the reference wavelength outside the region of significant CO_2 effect in CRISM spectra. In later work, the recommended wavelength pair was modified to 2.007 and 1.98 μm [3]. This improves identification of surface features in the 1.9-2.1 μm range, since the surface albedos are more likely to be similar at the closer wavelength pair.

2.0 μm artifact. Empirical atmospheric correction of CRISM spectra reveals a pervasive artifact at 2.0 μm (Figure 2). The artifact appears as a broad dip in the corrected spectrum. The depth of the artifact ranges from very shallow to ~10% of the continuum. The artifact can obscure or distort important mineralogical features in the 1.9-2.1 μm range. The artifact occurs with either peak/reference wavelength pair, but is most clear with the newer, more closely spaced wavelengths. With the old wavelength pair, the peak wavelength near the center of the artifact is forced up to match the reference wavelength in the unabsorbed continuum, forming a spike that partially obscures the artifact. With the newer wavelengths, both points are inside the range affected by the artifact and no obscuring spikes are produced.

The artifact results from variation in the shape of the CO_2 absorption spectrum. Differential saturation of the individual molecular lines, affected significantly by Doppler broadening, causes the shape of the CO_2 spectrum at CRISM resolution (spectral FWHM ~13 nm near 2.0 μm) to vary with altitude and temperature. Exponential scaling of the CRISM spectrum from one surface elevation cannot reproduce the spectrum from a different elevation, even if the surfaces are identical. Dividing plains spectra by summit spectra to form the empirical volcano scan transmission spectrum combines two spectra with slightly different underlying shapes. This introduces a bias in the empirical transmission that produces the 2.0 μm artifact. Simulation of the volcano scan correction using DiSORT radiative transfer modeling has reproduced artifacts similar to those observed [4].

Improved Algorithm: A new algorithm is under development to correct the 2.0 μm artifact. First, a nonlinear fit to volcano scan data is computed, from which transmission spectra at any surface elevation can be generated. Second, transmission spectra are generated from the fit for a number of elevations. Spectra cannot be drawn directly from the volcano scan observation, because many areas are at elevations below those sampled by the volcano scan observation. A model fit is required to extrapolate transmission spectra for lower elevations. Finally, a spectrum of interest from a different observation is corrected as before, using the transmission spectrum that minimizes the artifact. This selects the transmission spectrum that best matches the observation.

Empirical model. All spectra recorded over the volcano scan swath are normalized to a power law fit through continuum wavelengths, to remove a dust aerosol-like curvature of the spectrum. Then, at each wavelength, the normalized I/F values sampled over the length of the volcano scan swath are fit to an empirical function of surface elevation,

$$I(z) = b + \tfrac{1}{2}R\left[1 + \tanh\left(\tfrac{1}{2}a\left[z - z_0\right]\right)\right]$$

where z is the surface elevation from which I/F=I(z) is observed, and b, R, a, and z_0 are parameters adjusted to achieve the best fit. This model converges to I=b at very low elevations, and I=b+R at very high elevations. In a simple model, the parameters can be thought of as follows: b is an instrumental baseline offset, R is the surface albedo at the wavelength of interest, a is like an inverse scale height, and z_0 is the elevation at which atmospheric extinction is 50%. However, retrieved values do not really correspond to these physical parameters because the simple model in which those interpretations would be valid does not account for dust aerosol scattering, temperature profile variability, or other effects. This model matches the expected form for convolved absorption spectra in the weak-line limit, and converges to zero reflectance for strong lines as expected. A transmission spectrum can be reconstructed at arbitrary surface elevation, using the model parameters retrieved for each wavelength with R replaced by 1. Setting R=1 for transmission evaluation isolates atmospheric extinction, achieving the same goal as the base/summit ratio in the original analysis.

Figure 2 compares the corrections of one spectrum using the old and new algorithms. The new algorithm consistently reduces the artifact depth. Tuning of the spectral fitting process continues.

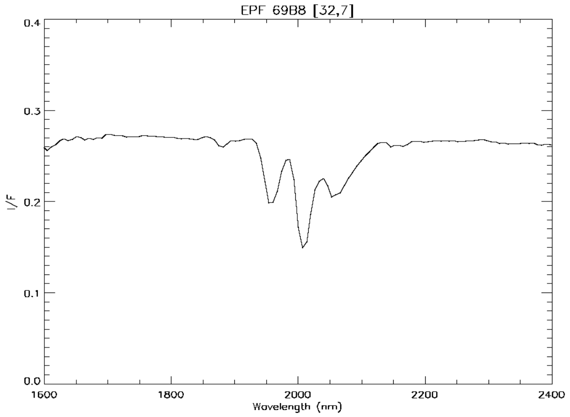

Figure 1. Typical CRISM I/F spectrum in the 2.0 μm region.

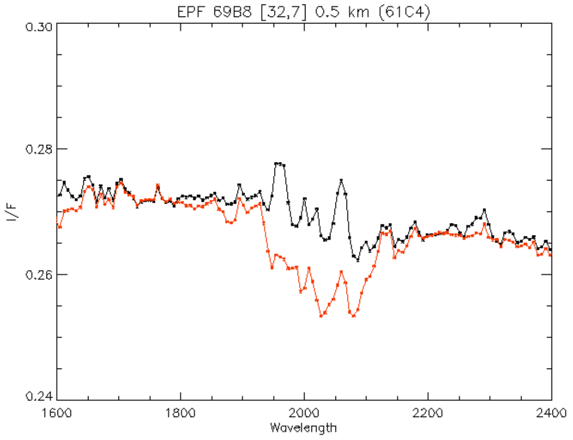

Figure 2. Comparison of correction using old volcano scan algorithm (red) and the new algorithm (black).

References: [1] Murchie S. et al. (2004) *SPIE*, 5660, 66. [2] Langevin Y. et al. (2005) *Science*, 307, 1584. [3] McGuire P. et al. (2009) *Planet. Space Sci.*, 57, 809. [4] Wiseman S. M. (2010) *LPS XLI*, 2461.