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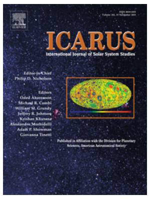

Characterization of artifacts introduced by the empirical volcano-scan atmospheric correction commonly applied to CRISM and OMEGA near-infrared spectra

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ABSTRACT

The empirical 'volcano-scan' atmospheric correction is widely applied to martian near infrared CRISM and OMEGA spectra between ~1000 and ~2600 nm to remove prominent atmospheric gas absorptions with minimal computational investment. This correction method employs division by a scaled empirically-derived atmospheric transmission spectrum that is generated from observations of the martian surface in which different path lengths through the atmosphere were measured and transmission calculated using the Beer–Lambert Law. Identifying and characterizing both artifacts and residual atmospheric features left by the volcano-scan correction is important for robust interpretation of CRISM and OMEGA volcano-scan corrected spectra. In order to identify and determine the cause of spectral artifacts introduced by the volcano-scan correction, we simulated this correction using a multiple scattering radiative transfer algorithm (DISORT). Simulated transmission spectra that are similar to actual CRISM- and OMEGA-derived transmission spectra were generated from modeled Olympus Mons base and summit spectra. Results from the simulations were used to investigate the validity of assumptions inherent in the volcano-scan correction and to identify artifacts introduced by this method of atmospheric correction. We found that the most prominent artifact, a bowl-shaped feature centered near 2000 nm, is caused by the inaccurate assumption that absorption coefficients of CO_2 in the martian atmosphere are independent of column density. In addition, spectral albedo and slope are modified by atmospheric aerosols. Residual atmospheric contributions that are caused by variable amounts of dust aerosols, ice aerosols, and water vapor are characterized by the analysis of CRISM volcano-scan corrected spectra from the same location acquired at different times under variable atmospheric conditions.

1. Introduction

Images of the martian surface acquired by the NASA Mars Reconnaissance Orbiter (MRO) Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) (Murchie et al., 2007) and the Mars Express Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité (OMEGA) (Bibring et al., 2004, 2005) measure solar light that was attenuated and scattered as it traversed down through the martian atmosphere, interacted with the surface, and traversed up through the atmosphere. Therefore, each spectrum from standard CRISM and OMEGA observations contains contributions from atmospheric gases (e.g., CO_2, CO, and H_2O), atmospheric aerosols (e.g., dust and water ice), and the surface. Atmospheric gas contributions dominate the spectrum at wavelengths that CO_2 absorbs (Fig. 1).

The empirical 'volcano-scan' correction (Bibring et al., 1989; Langevin et al., 2005; McGuire et al., 2009) is widely applied to

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CRISM and OMEGA near infrared (NIR) spectra between ~1000 and ~2600 nm to remove prominent atmospheric gas absorptions with minimal computational investment. The volcano-scan correction method employs division by a scaled atmospheric transmission spectrum that is generated from observations of the martian surface in which different path lengths through the atmosphere were measured. Low and high altitude spectra acquired over the base and summit of the Olympus Mons volcano were used, giving the correction its name. Transmission is calculated empirically using the Beer–Lambert Law, as detailed in Section 2.2.

Although the volcano-scan correction removes prominent gas absorptions to first order, closer inspection reveals that corrected spectra exhibit spurious features in areas of strong gas absorption. The most prominent artifact is a bowl-shaped feature that overlaps with the CO_2 triplet centered near 2000 nm (Fig. 1). The volcano-scan correction can be applied automatically to CRISM images using publically available CRISM Analysis Tools (CAT) software released through the Planetary Data System (PDS). The current version of CAT at this time (version 7.2.1) includes an option to empirically correct the 2000 nm bowl-shaped artifact that is evident in volcano-scan corrected images on a pixel by pixel basis.

The occurrence of the apparent bowl-shaped artifact at 2000 nm could have several causes. There are three major assumptions implicit in deriving empirical transmission spectra: (1) surface contributions to the low and high altitude spectra used to create transmission spectra are equivalent and therefore cancel out, (2) aerosol contributions to low and high altitude spectra can be ignored both within and outside of gas absorption lines and therefore empirical transmission spectra contain molecular absorption only, (3) absorption coefficients of CO_2 in the martian atmosphere are independent of column density and absorption strength therefore scales exponentially with column density.

In order to identify and determine the cause of artifacts introduced by the volcano-scan correction method, we simulated this correction using a multiple scattering radiative transfer algorithm. Discrete Ordinate Radiative Transfer (DISORT) modeling allows for the explicit treatment of aerosol, gas, and surface contributions simultaneously (Stamnes et al., 1988; Thomas and Stamnes, 2002). The DISORT radiative transfer model was used to calculate modeled high and low altitude spectra similar to martian spectra of Olympus Mons. Simulated transmission spectra were derived from these modeled spectra using the same method that was used to produce CRISM- and OMEGA-derived transmission spectra. Generating simulated transmission spectra in this manner and applying them to modeled martian spectra using the volcano-scan correction method allows the variables related to the three major assumptions described above to be controlled and analyzed.

Because the volcano-scan correction is designed to remove absorptions from atmospheric CO_2, this correction does not specifically address contribution from other atmospheric species, including dust and ice aerosols and gaseous water vapor. CO absorption is minor (Fig. 1, gray arrow) and will not be considered. Aerosol and water vapor atmospheric contributions are particularly important because they are spatially and temporally variable (e.g., Smith, 2008) and produce noticeable features in CRISM and OMEGA spectra (e.g., Smith et al., 2009). Dust aerosol contributions affect spectral slope and amplitude and ice aerosols also have distinct absorption features in the NIR. In addition, aerosol scattering within gas absorption lines alters absorption features. Atmospheric water vapor absorptions that occur in empirically derived transmission spectra cannot be scaled separately from CO_2 absorptions in the transmission spectrum that is scaled during the volcano-scan correction. Failure to explicitly address atmospheric water vapor can cause under- and over-corrected water vapor features in volcano-scan corrected spectra.

Identifying and characterizing both artifacts and residual atmospheric features left by the volcano-scan correction is important for proper interpretation of CRISM and OMEGA volcano-scan corrected spectra. Results from the simulated volcano-scan correction are used to investigate the validity of assumptions inherent in deriving and applying empirical transmission spectra and to identify and determine the causes of artifacts (e.g., 2000 nm

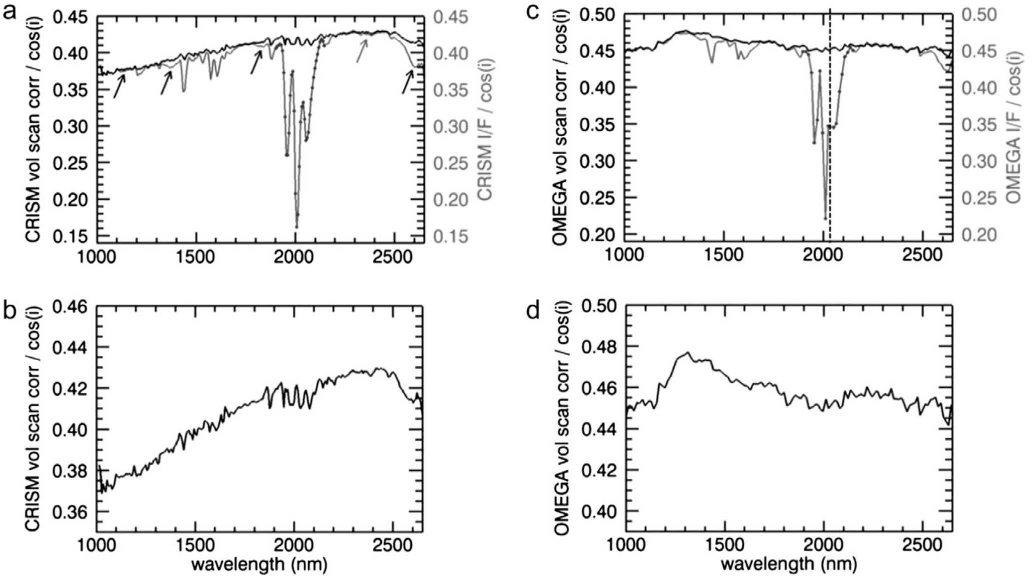

Fig. 1. (a) CRISM spectrum extracted from FFC000061C4 before (gray) and after (black) volcano-scan correction. Because the transmission spectrum and corrected spectrum were both derived from the same image, the temperature dependent wavelength shift is minimized. Gray dots show CRISM channel positions located between 1900 and 2150 nm (7 nm intervals). Black arrows indicate atmospheric H_2O vapor absorptions centered near 1130, 1380, 1880, and 2590 nm. A shallow CO feature near 2350 nm is also present. Unlabeled absorptions result from atmospheric CO_2. (b) Close up of the black CRISM spectrum shown in part (a). Note the bowl-shape and 'hash' in the 2000 nm region. (c) OMEGA spectrum extracted from ORB0037_2 before (gray) and after (black) volcano-scan correction. Gray dots indicate OMEGA channel positions located between 1900 and 2150 nm. OMEGA acquires data at 14 nm intervals; however the channel at 2040 nm (dotted line) is dead. Lack of data at this wavelength causes the longest wavelength minimum in the CO_2 triplet to appear less well defined in OMEGA spectra than CRISM spectra. (d) Close up of the black OMEGA spectrum shown in part (c). Both CRISM and OMEGA spectra were extracted from dust covered surfaces located to the south of Olympus Mons. Differences between the CRISM and OMEGA spectra shown in parts (b) and (d) could result from calibration characteristics as well as differences in viewing geometries and atmospheric conditions.