VERTICAL DISTRIBUTION OF AEROSOLS AND WATER VAPOR USING CRISM LIMB OBSERVATIONS.

Michael D. Smith, *NASA Goddard Space Flight Center, Greenbelt, MD, USA (Michael.D.Smith@nasa.gov)*, **Michael J. Wolff, R. Todd Clancy**, *Space Science Institute, Boulder, CO, USA.*

Introduction: Near-infrared spectra taken in a limb-viewing geometry by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [1] on-board the Mars Reconnaissance Orbiter (MRO) provide a useful tool for probing atmospheric structure. Specifically, the observed radiance as a function of wavelength and height above the limb allows the vertical distribution of both dust and ice aerosols to be retrieved. These data serve as an important supplement to the aerosol profiling provided by the MRO/MCS instrument [2] allowing independent validation and giving additional information on particle physical and scattering properties through multi-wavelength studies. The CRISM spectral range also contains the clear signature of CO_2, H_2O and CO gas, and O_2 singlet delta emission [3,4]. Here we describe preliminary work on the retrieval of vertical profiles of aerosols and water vapor from the CRISM limb observations.

Data Set: The first full set of CRISM limb observations was taken in July 2009, with at least six subsequent limb observation sets taken since then. These observations span approximately one-half of a Martian year, from Northern Hemisphere mid-winter to late summer (Ls=301° to 166°). In climatological terms, the first set was taken toward the end of the dusty perihelion season while the others were all taken during the aphelion season (see Table 1).

Table 1. CRISM Limb Observation Sets

Earth Date	Mars Date and Season
10 July 2009	MY 29, Ls=301°
10 February 2010	MY 30, Ls=50°
7 April 2010	MY 30, Ls=74°
28 April 2010	MY 30, Ls=84°
26 May 2010	MY 30, Ls=96°
22 August 2010	MY 30, Ls=137°
17 October 2010	MY 30, Ls=166°

Each set of limb observations nominally contains about four dozen scans across the limb giving pole-to-pole coverage for two orbits at roughly 100° and 290° W longitude over the Tharsis and Syrtis/Hellas regions, respectively. At each longitude, limb scans are spaced roughly 10° apart in latitude. Figure 1 shows a map giving the latitude/longitude locations of a typical set of CRISM limb observations. The limb observations are taken in a mode that spatially averages 10 pixels, but this still provides a spatial resolution on the limb of roughly 800 m. Each limb scan includes coverage from below the limb to at least 100 km above the limb. The wavelength region sampled by CRISM covers the visible and near-infrared from 362 to 3920 nm with a spectral resolution of typically 10-15 nm in the near-infrared.

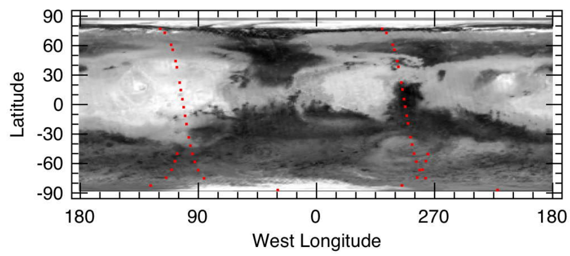

Figure 1. Latitude/longitude location of CRISM limb observations for the July 2009 set of limb observations. Other sets have very similar distribution.

Retrieval: Radiative transfer modeling taking account of aerosol scattering in the limb-viewing geometry is used to model the observations. The observed radiance above the limb comes from sunlight scattered by aerosols into the line-of-sight of the spacecraft. At the near-infrared wavelengths sampled by CRISM, there is essentially no contribution to the signal by direct thermal emission. Therefore, an accounting of both the spherical geometry and multiple scattering by aerosols is essential.

We compute synthetic CRISM limb spectra using a discrete-ordinates radiative transfer code that accounts for multiple scattering from aerosols and accounts for spherical geometry of the limb observations by integrating the source functions along curved paths in that coordinate system. Aerosol size and scattering properties are taken from CRISM nadir-geometry results [5]. Gas absorption is handled using the correlated-k approximation with gas absorption coefficients taken from the HITRAN database.

The vertical distribution of aerosols is retrieved by finding the best fit between observed and computed radiance as a function of height at nine widely spaced wavelengths chosen to avoid gas absorption features. Figure 2 shows a set of CRISM limb geometry observations from July 2009 (Ls=301°). The vertical lines indicate the nine wavelengths used in the retrieval. Parameters fit for are the surface albedo at the nine wavelengths, dust column optical depth and Conrath parameter (or “top” of the dust distribution), and a 14-point water ice aerosol vertical profile with resolution of 0.4 scale heights between one and six scale heights above the surface.

Figure 3 shows a cross-section of observed and best-fit radiances at one particular wavelength (2220 nm) for the July 2009 observations at ~300° W longitude. There is generally very good agreement between observed and computed radiance indicating that there are sufficient parameters in the model to adequately explain the general characteristics of the atmospheric aerosols.

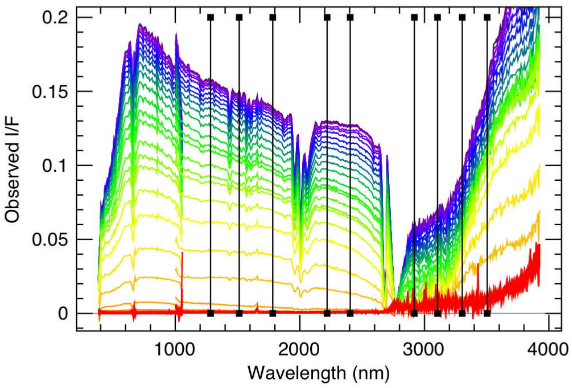

Figure 2. A set of CRISM limb observations from July 2009 (MY 29, Ls=301°, 19° S latitude, 290° W longitude). Color indicates height above the surface, from purple (0 km) to red (50 km). The black vertical lines indicate the nine wavelengths used to retrieve aerosol vertical distribution.

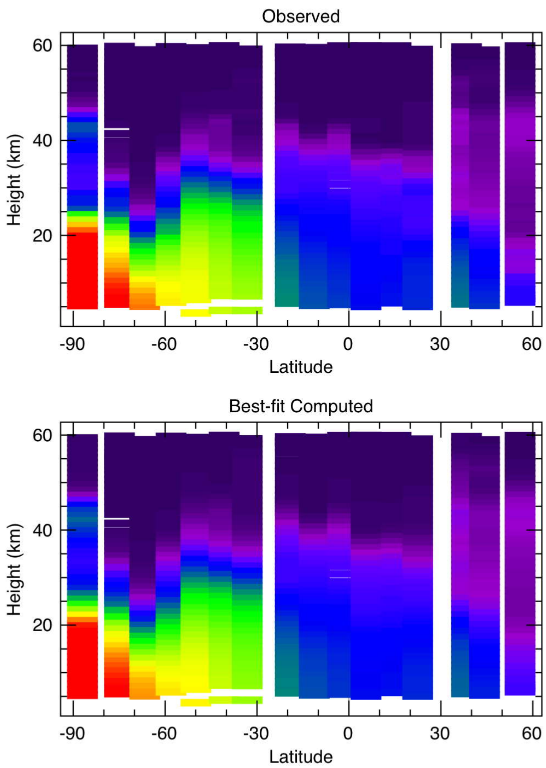

Figure 3. A comparison of observed and best-fit radiance at 2220 nm for the July 2009 limb set at ~290° W longitude. The modeled parameters can account for essentially all the observed variation of radiance.

After the aerosol retrieval is completed, the abundances of CO_2 and H_2O gas are retrieved by matching the depth of absorption bands at 2000 nm for carbon dioxide and at 2600 nm for water vapor. Since carbon dioxide is the principal component of the atmosphere its vertical distribution is given by hydrostatic balance by definition, and the abundance of CO_2 leads directly to an estimate of surface pressure. In addition to the column abundance of water vapor, limited information on its vertical structure can also be retrieved depending on the signal available from aerosol scattering.

Results: Figures 4 and 5 show the results of the aerosol profile retrievals for the July 2009 (Ls=301°) and May 2010 (Ls=96°) CRISM limb sets, respectively. The figures display dust and water ice aerosol mixing ratio for the orbit near 290° W longitude (see Figure 1), covering the Syrtis Major and Hellas regions. In this representation, a well-mixed aerosol would have a constant value as a function of height.

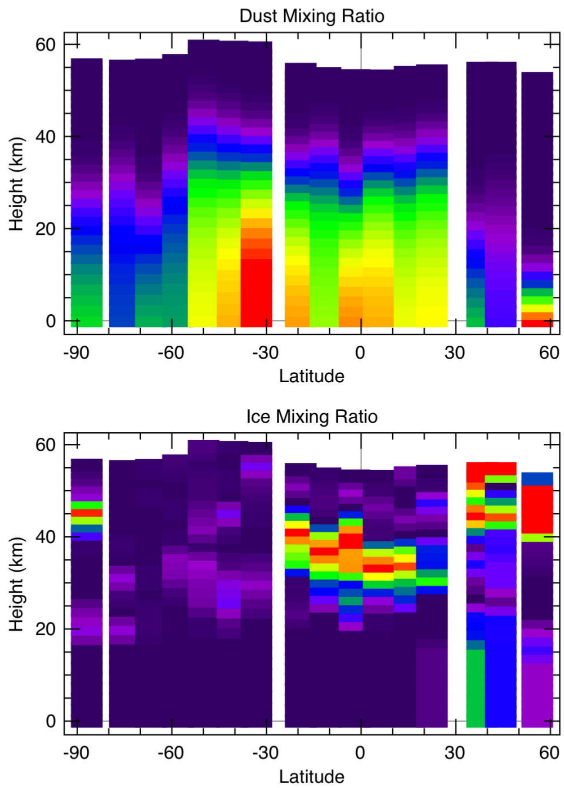

Figure 4. The retrieved cross-sections of dust (top) and water ice (bottom) aerosol from the limb set taken during July 2009 (MY 29, Ls=301°). Shown are the cross-sections of aerosol mixing ratio for the orbit near 290° W longitude (see Fig. 1).

The results from July 2009 (Figure 4) show a relatively dusty atmosphere (column-integrated visible-wavelength dust optical depth of 0.5-1.0 at low latitudes). The "top" of the dust distribution is at about 30-40 km altitude between 50° S and 30° N latitude, but drops to about 25 km over the summer (southern) high latitudes and to about 10-15 km over the winter (northern) mid and high latitudes. Except in the far north, ice aerosols are confined to thin layers at high altitudes, often capping the dust layer.

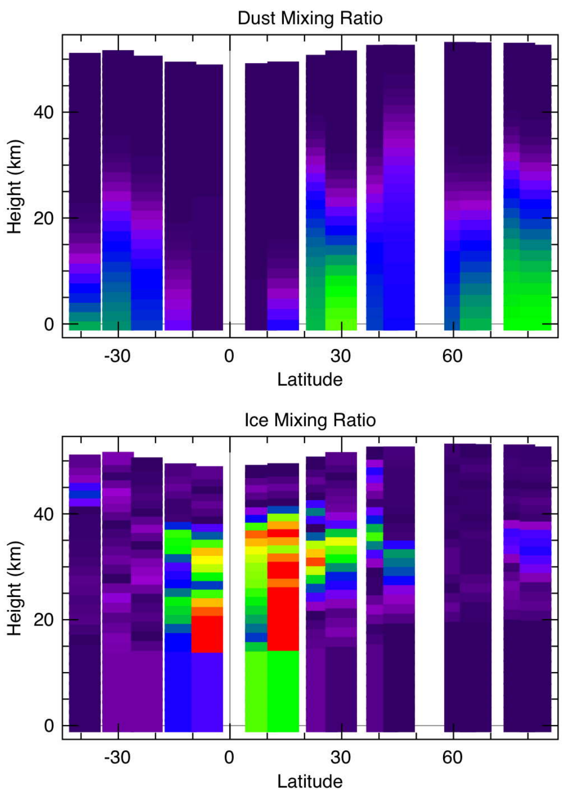

Figure 5. The retrieved cross-sections of dust (top) and water ice (bottom) aerosol from the limb set taken during May 2010 (MY 30, Ls=96°). Shown are the cross-sections of aerosol mixing ratio for the orbit near 290° W longitude (see Fig. 1). The color scales for Figures 4 and 5 are the same for ease of comparison.

The results from May 2010 (Figure 5) reveal an atmosphere with much less dust, but with a prominent water ice cloud at low latitudes. The small amount of dust that is present is confined below 20 km at all latitudes with highest opacity near the summer (north) pole. The low-latitude water ice cloud extends from 20° S to 20° N latitude and has a vertical depth of at least one scale height with possible internal vertical structure. A weak ice cloud isolated above the summer (north) pole at 35 km altitude mirrors a stronger isolated water ice cloud at 45 km altitude observed over the summer (south) pole during July 2009.

The two longitudes observed for each CRISM limb set allow for a rough comparison of longitude variability, which is enhanced by the strong topographic differences between the two observed longitudes (Tharsis vs. Syrtis/Hellas). And indeed, retrieved aerosol cross-sections do show significant differences in the details of the vertical structure although the overall distribution is often similar.

Retrieval of CO_2 abundance (or surface pressure) is straightforward because of the strength of the CO_2 absorption features at 2000 nm (see Figure 2) and the known vertical profile. The retrieved surface pressure can essentially be used as a verification of the retrieval process (including aerosols) by comparing against the expected surface pressure for the given season and location.

The water vapor absorption at 2600 nm is much weaker (typically a couple percent at strongest) and is complicated by an extremely strong CO_2 absorption band at 2700 nm that prevents a clear continuum level to be evaluated on the long-wavelength side of the water vapor band. In addition, observation of the water vapor absorption requires a background signal provided the presence of aerosol scattering, which limits the height range and latitude extent of where the water vapor signature can be observed. Still, by using the additional knowledge of the column-integrated water vapor column retrieved from concurrent CRISM nadir-geometry observations at nearby seasons and locations [3], an estimate of the vertical extent of water vapor is possible. For the July 2009 limb set the retrieval is consistent with well-mixed water vapor to at least two scale heights altitude above the surface (and likely higher to the water condensation level) at all latitudes south of 30°N. To the north, water vapor appears to be confined near the surface, to within the lowest scale height above the surface. For the May 2010 observations water vapor appears to be confined near the surface outside the low-latitude ice cloud and well mixed to the cloud level within the cloud band.

Summary: The CRISM limb-geometry observations support the quantitative retrieval of aerosol and gas vertical profiles. These quantities cannot be retrieved using nadir observations, and they enable the study of important new science questions. The CRISM limbs also serve as a valuable supplement to the MRO/MCS limb profiles, enabling validation and multi-wavelength comparisons. Additional CRISM limb-geometry sets will continue to be taken approximately every two months (~30° of Ls) as operations allow.

References: [1] Murchie, S., et al., JGR, 112, E05S03, doi:10.1029/2006JE002682, 2007. [2] McCleese et al. JGR, 112, E05S06, doi:10.1029/2006JE002790, 2007. [3] Smith et al., JGR, 114, E00D03, doi:10.1029/2008JE003288, 2009. [4] Clancy et al. "MRO CRISM and MARCI Observations of Mars Ozone", 4th Intl. Workshop on the Mars Atmosphere. [5] Wolff et al., JGR, 114, E00D04, doi:10.1029/2009JE003350, 2009.