MARS ODYSSEY THEMIS-VIS: SURFACE-ATMOSPHERE SEPARATION AND DERIVATION OF AEROSOL PROPERTIES. T. H. McConnochie[1], J. F. Bell III[1], M. J. Wolff[2], M. D. Smith[3], J. L. Bandfield[4], M. I. Richardson[5], P. R. Christensen[4], [1]Dept. of Astronomy, Cornell University, Ithaca, NY 14853 (mcconnoc@astro.cornell.edu), [2]Space Science Institute, [3]Goddard Space Flight Center, [4]Arizona State University, [5]California Institute of Technology.

Introduction: Scattering by atmospheric aerosols can contribute a substantial fraction of the visible-light radiance observed in any remote sensing of Mars. Our objective is to develop techniques to separate this aerosol component from the surface-reflectance component in Mars Odyssey's THEMIS Visible Imaging Subsystem (THEMIS-VIS) dataset. The primary purpose of this study is the production of accurate surface reflectance data in order to allow for reliable color and mineralogical unit mapping. The second principal goal is to study the feasibility of using VIS measurements to derive quantitative information about ice and dust aerosol properties such as particle size and optical depth.

The Mars Odyssey THEMIS investigation is described by Christensen et al. [1]. THEMIS has multispectral imaging detectors that operate in the infrared (THEMIS-IR) between 6.5 and 15 microns, and in the visible (THEMIS-VIS). The THEMIS-VIS instrument, and the goals of visible wavelength reflectance mapping, have been described by Bell et al. [2]. VIS is 1024x1024 interline transfer CCD camera that acquires high spatial resolution images (18, 36, or 72 meters per pixel), through five filters with bandpasses centered at 425, 540, 654, 749, and 860 nm, and bandwidths of ~50 nm.

Motivation: Surface-atmosphere separation is necessary for the production of reliable surface reflectance measurements. Furthermore, the radiative transfer modeling needed to accomplish this separation may yield new information on the properties of the aerosols themselves.

Surface Reflectance. Surface reflectance mapping in the five bandpasses can provide information on the composition, distribution, and physical properties of ferric (Fe^{3+}) and ferrous (Fe^{2+}) iron-bearing rocks and minerals, and of frosts and ices [2]. However, during dusty conditions (i.e., near perihelion), aerosol scattering can easily contribute a significant fraction of the radiance at these wavelengths [*e.g.,* 3-5], particularly over dark surfaces. Even in relatively clear atmospheric conditions, dust and/or ice aerosols will be a significant contribution to the 425 nm band radiance.

Radiative transfer modeling and optical depth measurements spanning one martian year by Clancy et al. [6] suggest that this contribution is never less than 15% of total radiance at the equator. Zonal-mean broadband visible optical depths of the Martian atmosphere, as measured by the Mars Global Surveyor Thermal Emission Spectrometer (MGS-TES) visible bolometric channel, span a continuum from 0.1 to more than 1.0 over the course of a Martian year, with the highest values occurring at equatorial latitudes near perihelion, and the lowest values occurring in the southern highlands near aphelion [6]. Thus, in extreme circumstances, the Martian surface may well be completely obscured in all five VIS filters. More generally, measured radiances will include a highly variable aerosol scattering component that would lead to apparent surface reflectances that are quantitatively inaccurate and qualitatively inconsistent. Moreover, these apparent reflectances would be biased as a function of elevation, region, and season. Therefore, in order to produce a high quality surface reflectance data set, the aerosol scattering component of the radiance in each image must be modeled and removed.

Aerosol Properties. The current nadir-only viewing geometry of THEMIS severely limits the number of parameters that can be retrieved using multiple-scattering radiative transfer models. It is likely that for many VIS observations, surface reflectance will be the only parameter that can be derived. However, given the importance of aerosols in the Martian climate system, it is worthwhile to explore the possibility of placing some constraints on aerosol properties at the uniquely high spatial resolution provided by THEMIS.

Method: We perform radiative transfer modeling using the discrete ordinate multiple-scattering code DISORT [7]. DISORT is a one-dimensional model with vertical discretization of atmospheric properties, and angular and vertical discretization of radiance. DISORT computes observed radiance as a fraction of incoming solar radiation, i.e., I/F, for each bandpass. The inputs to the DISORT model are the normal reflectance and phase function of the surface, the solar azimuth and elevation angles, as well as, for each atmospheric layer, the optical depth, single-scattering albedo, and single-scattering phase function of the aerosols.

Solving for surface reflectance. In the simplest case, we model the observed radiance of each pixel in a VIS image independently in order to solve for a single parameter, the surface normal reflectance. With the aerosol properties and optical depths fixed, we iteratively adjust the surface reflectance until the radiance calculated by DISORT for the given THEMIS viewing geometry matches the observed radiance. For this type of modeling exercise the extinction optical depth in each VIS bandpass is fixed by coincident THEMIS-IR and/or MGS/TES measurements of dust and ice opacities using infrared-to-visible scaling factors derived by Clancy et al. [6]. The single-scatter phase functions and albedo values are also fixed in accordance with Clancy et al. [6]. For computational efficiency in the case of pixel-by-pixel corrections, we will be using pre-computed "cubes" of radiative transfer models. With carefully determined limits on the input parameters (e.g., emergence angles need not deviate far from nadir viewing), this approach can provide several orders of magnitude in required CPU time.

Solving for aerosol properties. Clearly, in order to directly retrieve aerosol properties from the THEMIS-VIS data set, we must identify ways to add additional constraints to our models. We are (or will soon be) exploring the following techniques:

1) Extremely high optical depths. Careful planning may allow us to observe localized events where the aerosol optical depths are greater than unity and the contribution of surface reflectance is small. In these cases, the observed radiance is primarily a function of the single scattering albedo (SSA) allowing us to fit for SSA directly.

2) Shadow modeling. Areas not illuminated by direct sunlight are still illuminated by atmosphere-surface multiple scattering as well as by surface-surface multiple scattering [e.g., 8]. If the surface reflectance is assumed to be the same across shadow boundaries, then measurements of the radiance difference across the shadow boundaries should be diagnostic of the atmospheric scatterers. A full treatment of this problem requires a three-dimensional radiative transfer code. We have begun this work using a Monte-Carlo algorithm. However, in the interest of computational efficiency, we will look for empirical simplifications/modifications that might allow us to apply our one-dimensional DISORT model. By comparing the results of such 1D models to the full 3D cases, we can directly characterize the uncertainties introduced with any simplifications.

3) Spatially variable aerosols, uniform surface. If, by inspecting a THEMIS-VIS image, we can identify regions where cloud appears to be the main source of brightness variation in one or more channels, then we can fit for the optical depth as well as the surface reflectance.

4) Repeated Coverage. We can observe a region of the surface at two different times, obtaining two different radiances. Ideally, these two observations will b made at times of with the greatest possible contrast in aerosol loadings. If we assume the surface reflectance is constant with time, and also fix the optical depth of the first observation, then we can fit for the surface reflectance as well as the optical depth of the second observation.

Obtaining aerosol particle size. If, by one of the methods described above, we are able to solve for VIS optical depth in one or more of the five VIS filters, then we can use the ratio of the THEMIS-VIS optical depth to the THEMIS-IR opacity as a highly sensitive indicator of particle size. If we have a pair of optical depths, as in techniques 1 and 2, where we have solved for one by assuming the other, then by comparing the assumed VIS / IR ratio to the measured value, we could also identify changes in the particle size distribution.

Data: Figure 1 is an example of a VIS image to which several of our proposed aerosol modeling techniques may be applicable. For example, the brightest areas in the blue channel are likely water ice cloud. Since the surface features appear to be completely obscured in many areas of the blue, the optical depth may approach unity for the 425 nm region of the spectrum. As another example, the spatial structure of the clouds may enable us to make the uniform surface, spatially-variable aerosol assumption.

Figure 2 shows a dramatic example of the way that shadows are lit up by the Martian atmosphere. The boundary of the primary shadow falls more than 10 km away from the rim of the crater, and the radiance within the shadowed region is ranges from 60% to 80% of the sunlit radiance. The importance of atmospherically scattered light is evidenced by the persistence of morphological detail throughout the interior of the primary shadow. Interestingly, the sunward-facing walls of small craters *within* the primary shadow are noticeably brighter. This may be a manifestation of the forward-scattering halo that both Viking and Pathfinder observed around the Sun [3,9].

References: [1] Christensen, P.R. *et al.* (1999) *LPSC XXX*, Abstract #1470. [2] Bell III, J.F. *et al.*(2003) *LPSC XXXIV,* Abstract #1993. [3] Pollack, J.B. *et al* .(1979) *JGR, 84,*2929. [4] Ockert-Bell, M.E. *et al.*(1997) *JGR, 102,*9039. [5] Wolff, M.J. *et al.*(1999) *JGR, 104,* 9027. [6] Clancy, R.T. *et al.*(2003) *JGR,* in press. [7] Stamnes, K. *et al.* (1988) *Appl. Opt. 27,* 2502. [8] Ingersoll, A.P. *et al.* (1992) *Icarus, 100,* 40. [9] Tomasko, M. *et al.* (1999) *JGR, 104,* 8987.

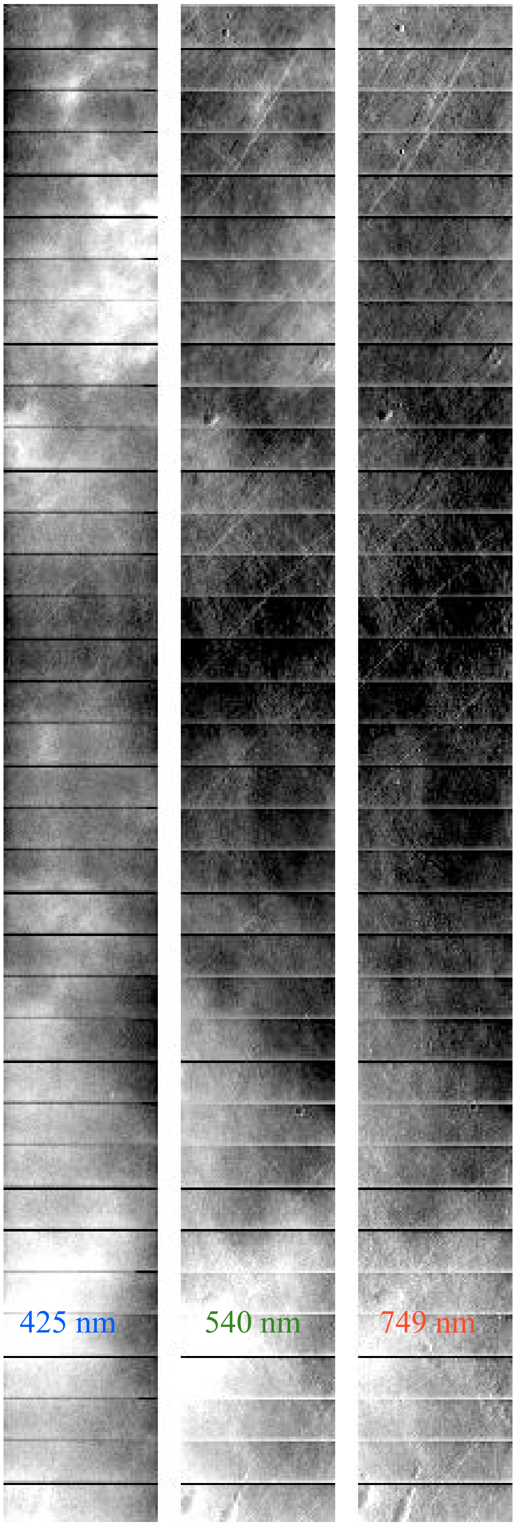

Figure 1: Clouds near Arsia Mons. Subframes of THEMIS image V05872002. The 425, 540, and 750 nm bands are shown from left to right. These data are neither map projected nor mosaicked. The horizontal lines are the boundaries between image segments. Each image segment is ~20 km wide and ~3.5 km from top to bottom. North is roughly towards the top of the image.

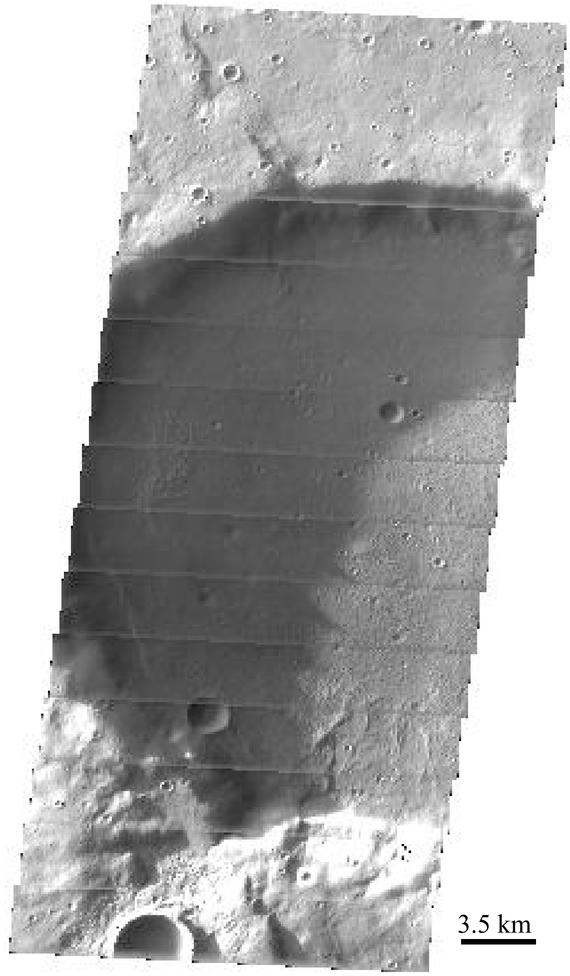

Figure 2: Shadows within shadows in Noachis Terra. 654 nm band from THEMIS V04270003, map projected with north at the top.