Sundry Atmospheric Observations with the Mars Exploration Rovers: Over-flights, Refractive Indices, Clouds, and All That Jazz

M. J. Wolff, *Space Science Institute, Boulder, CO, USA (wolff@spacescience.org),* **M. D. Smith**, *NASA Goddard Space Flight Center, Greenbelt, MD, USA,* **R. T. Clancy, B. A. Whitney,** *Space Science Institute, Boulder, CO, USA,* **N. Spanovich**, *Jet Propulsion Lab, Pasadena, CA, USA,* **K. Cuozzo, D. Banfield**, *Cornell University, Ithaca, NY, USA,* **M. T. Lemmon,** *Texas A&M University, College Station, TX, USA,* **A. Ghosh**, *Tharsis Inc., Gaithersburg, MD, USA,* **G. Landis,** *NASA Glenn Research Center, Cleveland, OH, USA,* **J. Bandfield**, *Arizona State University, Tempe, AZ, USA,* **and the Athena Science Team.**

Introduction: The Mars Exploration Rovers (MER) have been obtaining atmospheric observations since January 2004. The two best-known classes of synoptic (atmospheric) measurements/retrievals by MER are solar disk imaging with the Panoramic Camera (Pancam, providing direct optical depth measurements in the visible; e.g., Lemmon et al. [2004]) and thermal sounding with Miniature Thermal Emission Spectrometer (Mini-TES, providing temperature profiles in the bottom of the Planetary Boundary Layer (PBL) and infrared optical depth; Smith et al. [2004; 2006]). However, there are several other types of observations and datasets that provide insight into atmospheric processes on Mars, including over-flights by orbiting spacecraft such as the Mars Global Surveyor (MGS) and the Mars Express (MEX) and multi-image sequences of the sky (here, of clouds, specifically) using the Pancam and the Navigation Camera (Navcam). It is these two types upon which we will focus.

Over-flights: Over-flights by orbiting spacecraft provide an opportunity for probing the atmosphere from the surface up to 30-40 km or more in a way not possible by using either MER or the orbiter data in isolation. For example, MGS Thermal Emission Spectrometer (TES) infrared retrievals have very limited resolution (and precision) in the bottom scale-height of the atmosphere while the Mini-TES temperature retrievals have little sensitivity above 3 km or so. In addition, Mini-TES aerosol retrievals rely heavily upon the temperature distribution (as well as the aerosol vertical distribution) above this height. Thus, by combining MER and orbital data, one is able to construct more complete temperature profiles and better constrain aerosol properties such as optical properties as a function of wavelength, vertical distribution, and, to a lesser degree, particle size.

Data. The analysis that we present here will be limited to orbital data obtained by the MGS/TES solar band bolometers and the infrared (IR) spectrometer. The TES surface-pointing data is taken from sequences that are simultaneous (or nearly so) with MER Mini-TES and Pancam observations. The sparser TES limb data are required to be as close as possible in space and time to the coinicident over-flight events, with their primary use being the constraint of the vertical distribution of aerosols in the 15-40 km range.

Modeling. We utilize three distinct modeling approaches: a doubling-adding code for the MER and the surface-pointing TES IR data (REFLEX, cf. Wolff and Clancy 2003), a DISORT-based code for the optical MER and TES non-limb solar band data [Stamnes et al. 1988], and a 3-D Monte Carlo code for the limb observations (Whitney et al. 1999). The temperature profiles utilized are those generated by the TES and Mini-TES standard algorithms [Conrath et al. 2000; Smith et al. 2004, 2006]. Particles size choices are made by direct inversion, if possible. However, they are typically guided by climatology and visible-to-infrared optical depth ratios.

Some Initial Results. Two additional inputs typically required for radiative transfer modeling are the wavelength-dependent optical properties and the vertical distribution of the aerosols. Starting with the refractive indices of Wolff and Clancy [2003] and using Hansen [2003, k=0.4 case] as a guide for the long-wave Imag(m), we iteratively constrain the imaginary index of refraction and the aerosol vertical profile. Example limb fits for the Opportunity sol 22 over-flight are shown in Figure 1. The indices of refraction resulting from the analyses of several early mission over-flights are given in Figure 2. The differences between the mini-TES and TES-derived indices are striking for Imag(m). This will be discussed further, but it is worth mentioning at this point that these values are consistent with analyses of TES limb data by Clancy and by Smith [private communication]; as well as by the limb analyses done for this work (e.g., Figure 1).

Clouds: The MER extended mission has allowed for atmospheric observations during the classical aphelion “cloud belt” period. Despite the pervasive nature of this phenomenon as perceived from orbit, direct detection of water ice clouds by the rovers has been less frequent than one (or at least I) might have anticipated. Mini-TES detections appear to be limited by signal-to-noise issues (3 K space background provides lower contrast than a 270 K surface), though the recent recalibration efforts of Smith et al. [2006] may provide additional leverage. The detection frequency for the MER camera systems on Opportunity is shown in Figure 3. Detections by Spirit are essentially non-existent. In contrast, orbital data – including TES spectra and bolometer products as well as Mars Observer Camera imagery -- show clouds in close proximity to the both rovers with a much higher frequency. A sample of this data will be presented. We will also discuss several possible explanations for this apparent disparity. In addition, the results of radiative transfer modeling will be presented for both the Pancam and Navcam cloud images.

References:

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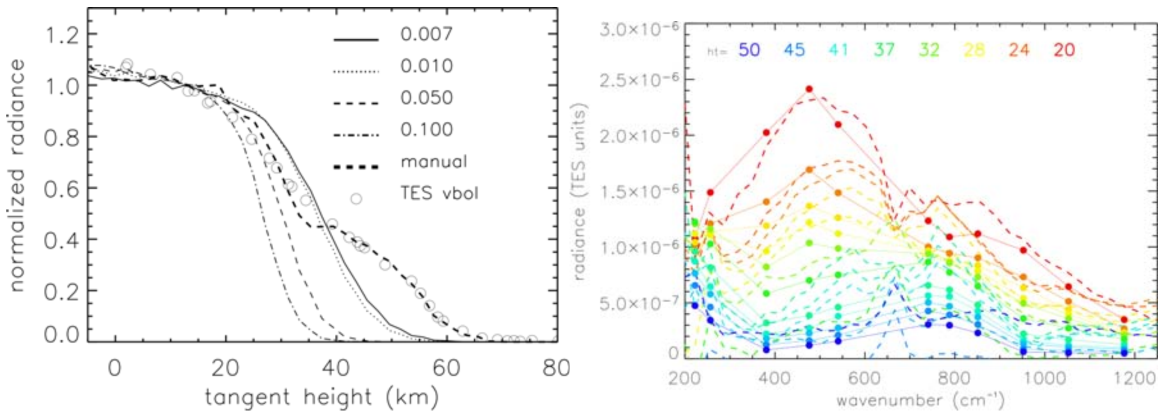

Figure 1 – Model comparisons with TES limb data taken near the Opportunity landing site, just before an MGS overflight on sol 22. Left – Solar band data (circles) are compared with monte carlo models using 4 analytical dust vertical distributions ("Conrath" ν parameters are given in legend) and a "best-fit" vertical distribution which includes dust and a high altitude cloud layer (~40-60 km). The limb profiles are normalized at 13 km in order to eliminate minimize issues with the lower-scale height. The "manual" case and the data are in good agreement also in absolute units (I/F) as well. Right – IR spectra data (dashed-lines) are compared against a model (solid circles and lines) using the same "best-fit" vertical distribution employed in the "manual" case Left Panel. The color codes the height of the tangent point, as indicated in the legend at the top of the panel.

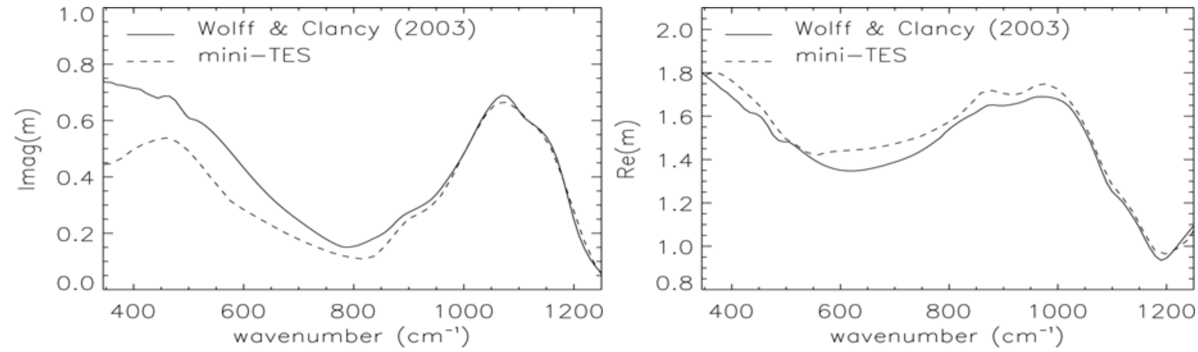

Figure 2 – Refractive indices derived from mini-TES observations, using additional constraints provided by MGS/TES overflight data (e.g., Figure 1) and Pancam solar imaging. A subtractive Kramer-Kronig algorithm is used to derive the Re(m) [e.g., Snook 1999].

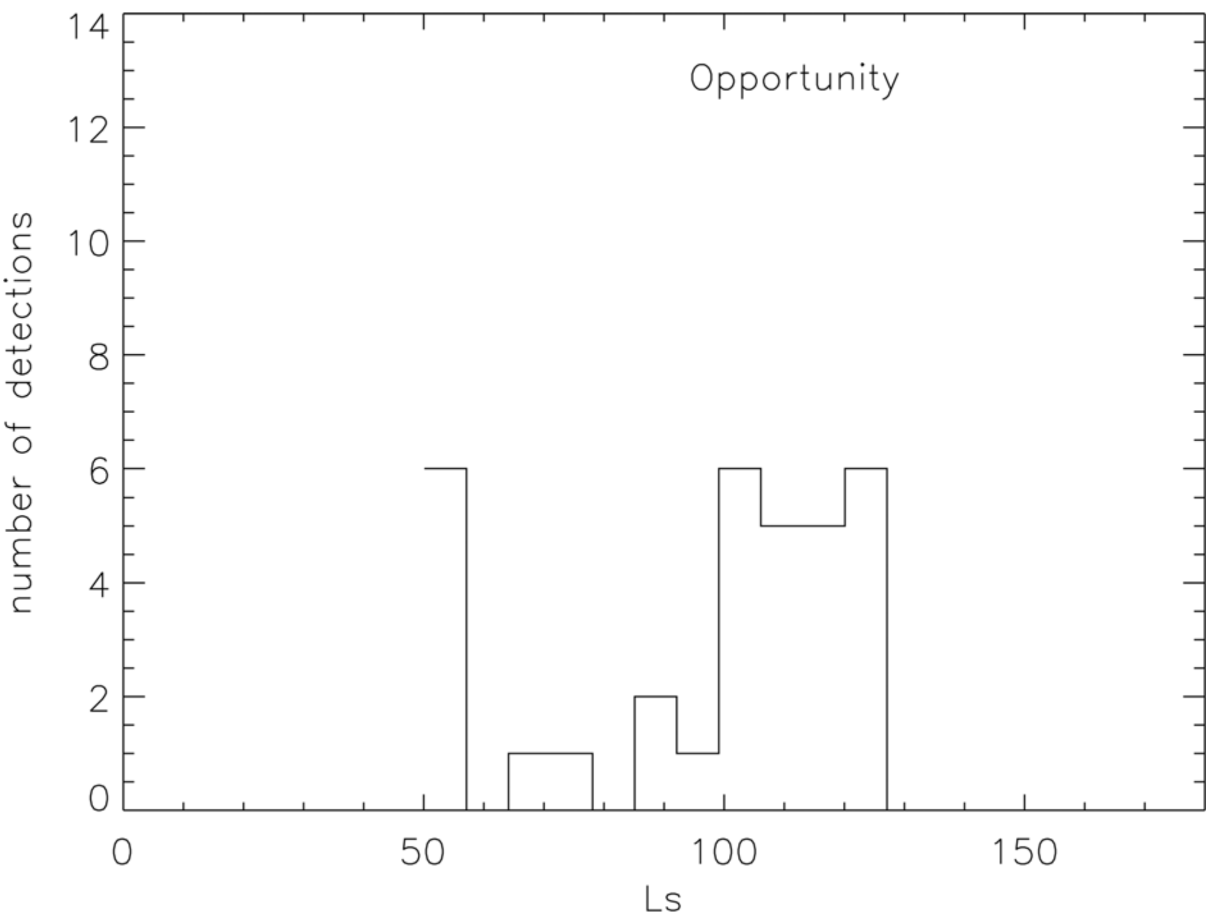

Figure 3 – Histogram of cloud detections at Opportunity (through Ls=180). A single detection can include multiple images within a observational block. That is to say, 10 images of clouds taken within a quarter-day (i.e., 10h00-12h00) block would be count as a single detection. Observations were not sufficiently frequent that this represent a particular challenge for counting statistics. No detections by Spirit were made over this temporal range.

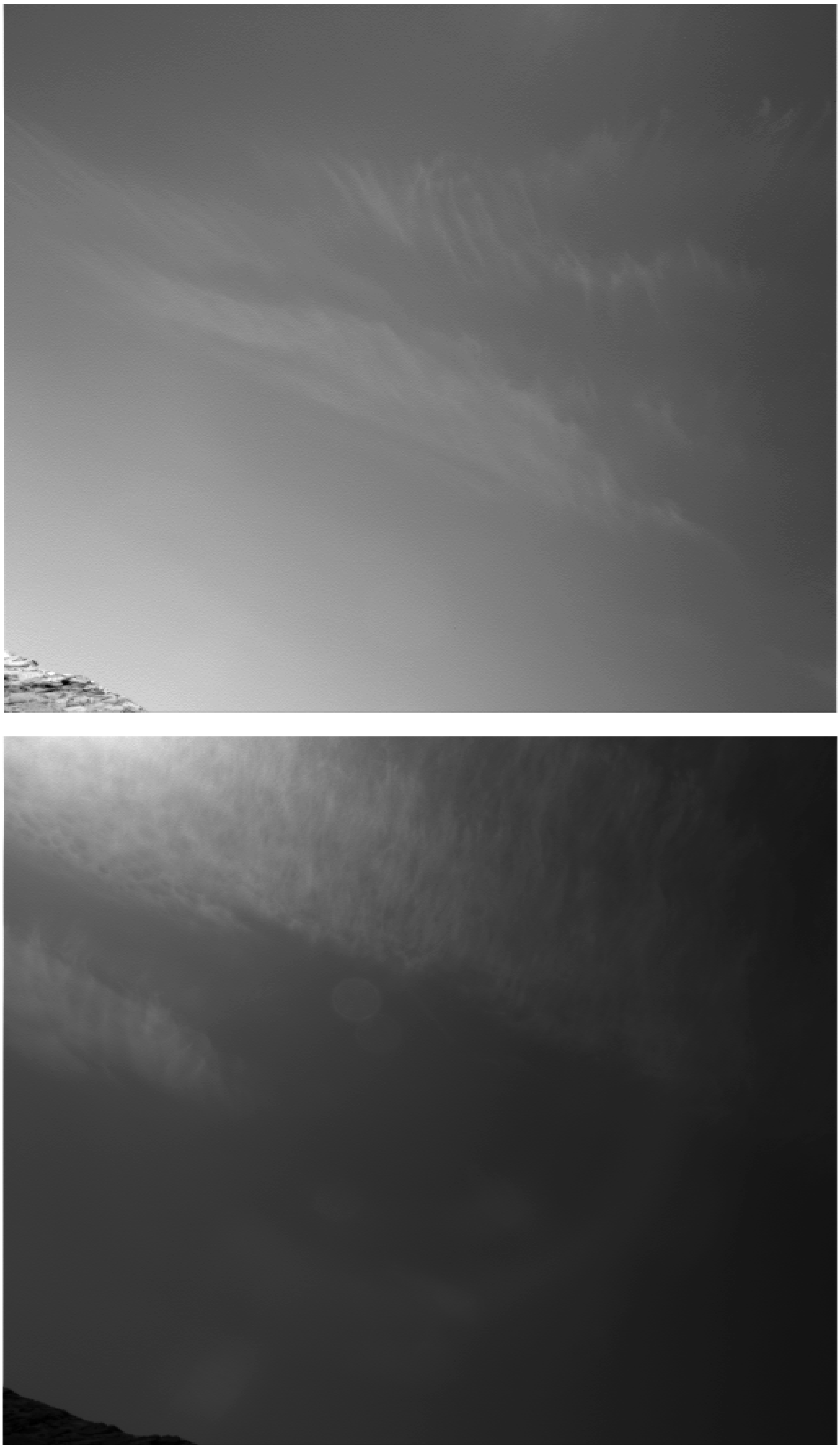

Figure 4 – Opportunity Navcam images of clouds obtained on sols 290 (Top) and 291 (Bottom). Although the cirrus-

like nature of the clouds was expected from previous observational and modeling efforts, the morphological similarities to terrestrial cirrus remains striking (well, at least to me).