TEMPORAL VARIATIONS IN THE SIZE DISTRIBUTION OF MARTIAN ATMOSPHERIC DUST FROM MARS EXPLORATION ROVER NAVCAM OBSERVATIONS.

J. M. Soderblom[1a], M. J. Wolff[2], and J. F. Bell III[1], [1]Cornell University, Space Science Building, Ithaca, NY 14853, jasons@lpl.arizona.edu, [2]Space Science Institute, Boulder, CO, [a] now at the University of Arizona, Lunar and Planetary Laboratory, Tucson, AZ 85721.

Introduction: Atmospheric dust plays an important role in modulating the global radiation balance of Mars, absorbing solar radiation and both absorbing and emitting thermal radiation [*e.g.*, 1]. The details of this physics are controlled in part by the particle size distribution of the dust, described by the first two moments of the distribution: the geometric cross-section-weighted mean radius (effective radius, or r_{eff}) and its variance (effective variance, or v_{eff}) [cf., 2]. Despite robust predictions of spatial and temporal variations in the dust size distribution [3], only recently have data been adequate to quantitatively observe these variations [4, 5, 6].

The MER Navcams provide an unprecedented capability to observe the martian sky very close to the Sun. In-flight tests have revealed little-to-no debilitating internal instrumental scattered light during near-Sun imaging, enabling measurements of the martian sky down to scattering angles of ~2°. Previous efforts using Viking Lander [7], Mars Pathfinder [8], and MER Pancam images [9] have only been able to observed the brightness of the martian sky at scattering angles >7°. These new observations allow better constraints on the size distribution of dust suspended in the martian atmosphere. Furthermore, as these observations span approximately two martian years, these data provide the opportunity to examine temporal variations in the dust size distribution.

Data: The atmospheric scattering function at scattering angles closest to the Sun is dominated by singly scattered radiation [*e.g.*, 7, 10]. Several authors [*e.g.*, 2, 11, 12, 13] have demonstrated that, at small scattering angles, the single-scattering phase function is primarily controlled by the particle size distribution, and depends little on particle shape.

The current study makes use of the extensive set of MER Navcam data acquired by the *Spirit* and *Opportunity* spacecraft over the previous two martian years. These cameras have effective bandpass wavelength of ~650 nm, a full-width half-max of ~140 nm [14] and a FOV of 45°. ~50 Navcam images that contain the Sun in the frame and had no detectible clouds were selected for this work. Because the scattering code used here to model these data assumes a plane-parallel atmosphere, the data selected were limited to solar elevations > 20°.

A strip of pixel values was extracted from each image extending from the Sun to the furthest corner of the CCD in order to sample the largest range of scattering angles possible.

Calibration. These data were calibrated to units of *I/F* using the new Navcam calibration pipeline described in [15]. The absolute accuracy of the calibration is conservatively estimated to be 20%, while the relative pixel-to-pixel precision is estimated to be ~2.5%. Because this study is concerned with the shape of the atmospheric scattering function, the relative calibration is of greater importance.

The data were geometrically reduced using the geometric camera models developed by [14]. Because the knowledge of the rover's absolute position is updated only occasionally and degrades as the rover moves across the martian surface, uncertainties in the calculated azimuth and elevation can be up to ~2°. This level of error becomes problematic at angles very near the Sun. For this reason, *i*, *e*, and phase were calculated using the solar azimuth and elevation directly measured from the image rather than the values derived from the rover orientation. The precision of the solar azimuth and elevation estimated in this way can be estimated by examining the observed intensity of the sky as a function of scattering angle; precision of the solar positions is estimated to be better than 0.1°.

Model: Radiative transfer in the martian atmosphere was modeled using the DISORT package of [16], adapted to the martian atmosphere [*e.g.*, 4, 6, 17, 18]. The adaptation of the DISORT package used in this study employs a 40-layer atmosphere, with the layers becoming more closely spaced near the surface. Dust is uniformly distributed among these layers with a constant volume-mixing ratio. Solutions were calculated using 64 streams, and 64 Legendre polynomials to represent the single particle scattering function.

As the study presented here is interested in scattering angles very near the Sun, Mie theory has been adopted, rather than a more computationally intensive non-spherical scattering theory [*e.g.*, 12]. The single-scattering phase function was modeled using a Fortran routine, built upon DMiLay (the double-precision version of MieLay), a Mie scattering algorithm developed by W. Wiscombe (Goddard Space Flight Center) that uses the scattering algorithms presented by [19].

Because the relative contributions of dust and ice aerosols cannot be decoupled using the Navcam data alone, a single population of scattering particles is modeled. While the term 'dust' is used in this paper, it should be noted that the conclusions derived by this work regarding the size distribution of aerosols apply to the total aerosol population observable in the visible. With this being said, care has been taken to exclude any data that contain clouds in the frame, thus minimizing the water-ice contribution to the signal.

A dust single-scattering albedo of $\omega_0 = 0.935$, derived from MGS TES EPF observations [4, 5], was used in the model. The optical depth (τ) of the atmosphere used in the model for a given observation was taken from values derived from Pancam 440 nm and 880 nm neutral-density solar filter images of the Sun acquired close in time to each Navcam observation [9].

At small scattering angles the atmospheric scattering function is dominated by single scattering [7, 10]; multiple scattering from the surface accounts for a minimal amount of the total intensity. The atmospheric scattering model is relatively insensitive to the specific form or details of the surface scattering function. The surface was assumed to be Lambertian with the average surface albedos of the *Spirit* and *Opportunity* landing sites calculated from calibrated Pancam images acquired through filter L1, a broadband filter (739 ± 338 nm) reported by [20, 21], respectively.

For many particle size distributions, nearly identical single-scattering properties are observed when the first two moments (r_{eff} and v_{eff}) of the size distributions are the same [*e.g.*, 2]. That is, the modeled single-scattering properties of a distribution of particles are insensitive to the specific function used to describe the size distribution of the particles. The current work employs the gamma distribution function described by [2, Eq. (2.56)] for the dust size distribution. As the shape (and not the magnitude) of the scattering function is sensitive to the size distribution, the model was scaled to the observed sky radiance at $\theta = 25°$ to $30°$; this correction was typically on order 10%. This approach also minimizes any effects that the uncertainties in the absolute calibration might introduce in the model fits. A similar approach was employed by [8].

To identify the best-fit values of r_{eff} and v_{eff} from each of these observations, r_{eff} was stepped from 0.5 μm to 3 μm in 0.05 μm steps. The best-fit solution was identified as the model with the value of r_{eff} that produced the minimum χ_ν^2 value. This procedure was repeated a total of four times with v_{eff} = 0.2, 0.3, 0.4, and 0.5 (the range of values considered by [8]).

Results & Conclusions: Typical values of r_{eff} observed at the *Spirit* and *Opportunity* landing sites range from ~1.3–1.7 μm and ~1.4–1.8 μm, respectively, with v_{eff} = 0.4–0.5. Uncertainty in these derived values is ~0.10–0.15 μm.

While it is difficult to find a consensus in the literature for a common value of v_{eff}, due in large part to the difficulties in simultaneously constraining both r_{eff} and v_{eff} [*cf.*, 7, 8], the results of this work are consistent with recent results cited in the literature, including other studies using MER instruments: the work of [9] modeling MER Pancam images and the work of [6] modeling coordinated MER Mini-TES and MGS TES observations.

Spatial/Temporal Variations in Dust Size Distribution. Plotting the best-fit values of r_{eff} as a function of τ (as measured by Pancam) suggests a relationship between r_{eff} and τ. This hypothesis has been tested by calculating the Pearson correlation coefficients for these results. A statistically significant correlation (measured at 99% probability) was identified between r_{eff} and τ demonstrating that r_{eff} varies with dust load in the atmosphere. This is consistent with the most recent results from MER and MGS [4, 5, 6, 9]. Comparisons of r_{eff} values retrieved from observations acquired under relatively high optical depths (τ ~1.24 and 1.64 respectively) to values of r_{eff} extrapolated from r_{eff} values retried from observations acquired under lower optical are suggestive of gravitational settling of the largest particles following injections of dust into the atmosphere.

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