MARS' ATMOSPHERIC OPTICAL DEPTH FROM MARS EXPRESS HRSC AND MARS EXPLORATION ROVERS – A COMPARISON.

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Introduction: The Martian atmosphere is thin when compared to Earth or Venus but nevertheless it keeps dust and ice aerosols suspended over considerable time scales. On Mars aerosols and clouds invoke an optical depth in the visible that is commonly in the range 0.3-1.0. Airborne dust also plays a vital role in the thermodynamics of the Martian atmosphere. Optical depth is a key quantity to assess atmospheric aerosol content for climate research and for the atmospheric correction of orbiter images.

From the surface, instruments on the MER and Curiosity rovers have accurately measured the optical depth in the visible. However, obviously these measurements only offer the optical depth at the exploration sites of the rovers.

From orbit, the optical depth can be measured with the so called `shadow-method´. [1] used this method on images taken by Mars Express' High Resolution Stereo Camera (HRSC) and by MRO's HiRISE. They found that the shadow-method typically has an accuracy of ±8-15%.

For this study we used the shadow-method to measure the atmospheric optical depth from several dozen HRSC orbiter images and then compared the results with rover measurements. The images were usually taken far away from the rover sites, covering much of the Martian globe. The higher latitudes are only sparsely covered in our dataset.

Method: *The shadow method.* The shadow method, as described by [1], estimates the optical depth from brightness differences between sunlit and shadowed regions in orbiter images of Mars:

$$\tau = C\frac{\mu_0\mu}{\mu_0+\mu}\ln\left(\frac{\Delta I}{\mu_0\frac{F}{\pi}R_S}\right)$$

Where τ is the optical depth, *C* is an empirical fitting factor, μ is the cosine of the emission angle, μ_0 is the cosine of the incidence angle, *F* is the direct solar flux onto surface, and R_s is the surface albedo.

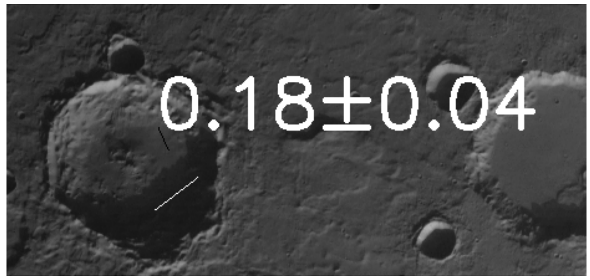

Figure 1: Example of shadow method use for optical depth derivation. An optical depth of $\tau = 0.18 \pm 0.04$ is found.

The shadow method needs well resolved shadows. This limits its use to regions that were observed while the sun was low in the sky. However, as a result of the orbital evolution of MEX, these days many HRSC images contain well resolved shadows. Nowadays there are many usable images and the number is still growing. For this study we used 77 HRSC images. Figure 1 shows an example of how shadows are selected.

Rover Measurements. The Mars Exploration Rovers Spirit and Opportunity (have) measure(d) optical depth with the PANCAM instrument [2], [3]. We obtained these datasets from [4]. The rovers are close to the equator on opposite sides of Mars. They measure optical depth by pointing at the sun and then measuring the solar flux [2]. Most measurements are taken around noon.

Data Processing. The optical depth measurements from HRSC images and by the MERs usually deal with different locations and different times. The comparingly few cases of co-location were used to calibrate the shadow method [1]. To compare other cases as well, inter- and extrapolation of time and location have to be made. At the rover site that means to interpolate opacity to HRSC observation times, to extrapolate to 0 m altitude, using a scale height of Hs=11 km. At the HRSC observation site (footprint), the optical depth had to be extrapolated to 0 m altitude. Subsequently, we spatially interpolated the rover data to the HRSC observation site.

Results: Figure 2 and 3 show optical depth from shadow method retrievals as a function of rover τ. Figure 2 compares τ directly. Fig. 3 shows the extrapolated values at the 0 m reference height.

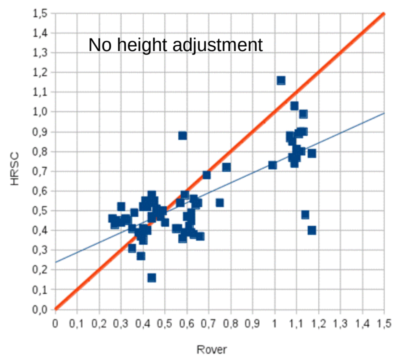

Figure 2: Optical depth from rover measurements interpolated to HRSC observation sites, versus shadow method measurements from the corresponding HRSC images. No altitude adjustment. The blue line shows a linear least squares fit.

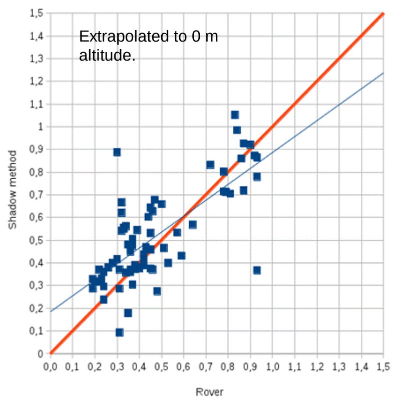

Figure 3: Similar to Figure 2 but now extrapolated to 0m altitude. Scale height= 11 km. The blue line shows a linear least squares fit.

To investigate, whether or not the time of day at which the HRSC observations were taken play a role we compared just the evening (Fig. 4) and the morning (Fig. 5) observations:

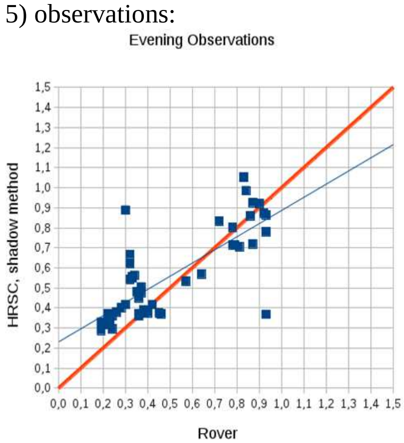

Figure 4: Like Fig. 2 but for evening observations only. HRSC shows during evening in low dust regimes often slightly higher τ than the rovers. Without the clear outliers the fit is much better. Note that there are not yet many shadow method retrievals from polar regions.

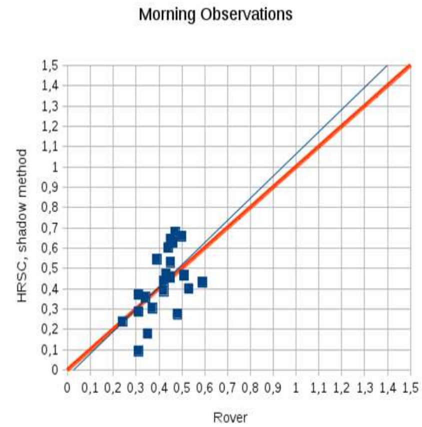

Figure 5: Like Fig. 2 but for Morning observations only.

Conclusions: We compared measurements of the optical depth by the MER rovers with measurements of the optical depth with the shadow method of regions that often were at large distances from the rovers. There is a clear relation between these measurements, even without correcting for surface altitude. If the optical depth is extrapolated to zero meters altitude, then the correlation further improves. So one can say, at least tentatively, that apart from some weather effects, optical depth is largely a global phenomenon. This is not only true for global dust storms but also in cases of generally low atmospheric opacity.

References: [1] Hoekzema N. M., M. Garcia-Comas, O.J. Stenzel, E.V. Petrova, N. Thomas, W.J. Markiewicz, K. Gwinner, H.U. Keller, W.A. Delamere (2011) *Icarus*, 214(2) 447-461. DOI: 10.1016/j.icarus.2011.06.009. [2] Lemmon M. T. et al. (2004) *Science* Vol. 306 no. 5702 pp. 1753-1756 DOI: 10.1126/science.1104474. [3] Bell III J. F. et al., (2004), *Science* Vol. 306 no. 5702 pp. 1703-1709, DOI: 10.1126/science.1105245. [4] Analyst's Notebook, http://an.rsl.wustl.edu/, Produced by NASA's PDS Geosciences Node at Washington University in St. Louis.