Status of the Remote Sensing of Martian Aerosols

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Abstract

We present a brief overview of the current state of the remote sensing of Martian aerosols, including an even briefer historical context as provided by the pre-1990 missions (i.e., Mariner 9, Viking, Phobos). We also outline the new directions that aerosol studies can (and should) take as a result of data sets now being acquired.

1 Introduction

The recent (and continuing) confluence of data from Mars-based spacecraft offers significant opportunities to improve our understanding of Martian aerosols. Such advancements are (and will continue to be) motivated by more than the simple acquisition of additional data. More specifically, the flotilla of Mars-based spacecraft provide the powerful combination of multi-wavelength coverage (ultraviolet through the thermal infrared) and systematic spatial/temporal sampling (e.g., seasonal coverage including nadir, "emission phase function", limb views). When such data are combined with robust, sophisticated radiative transfer and electromagnetic scattering algorithms, one is able to explore/constrain aspects of Martian aerosols that would not have been possible even only a few years ago. Given the list of current (and recently) operating platforms -- Mars Global Surveyor (MGS, deceased Nov. 2006), Mars Odyssey, Mars Express (MEx), Mars Exploration Rovers (MER, Spirit and Opportunity), and the recently arrived Mars Reconnaissance Orbiter (MRO) -- and the availability of computing resources, the primary inhibitor in Martian aerosol studies is the small number of people engaged in it. It is the beginning of a very exciting time and we hope that this presentation will stimulate you to consider working on the many aspects of Martian aerosols. We encourage everyone to contact us (wolff@spacescience.org) with any questions that you might have regarding the Mars data available for the synthesis of state-of-the-art electromagnetic scattering and radiative transfer analyses.

2 What We Will Say

In order to properly frame the current epoch of remote sensing within previous efforts, we begin with a review of aerosol remote sensing from Mariner 9, Viking 1 and 2 (both landers and orbiters), Phobos missions. To some degree, this represents a "classic" phase of Martian aerosol work. We follow up with the "neoclassical" period, which we define as ending before the arrival of Mars Express and the landing of the Mars Exploration Rovers. For these two distinct epochs remote sensing, we highlight both the results and the limitations of the datasets, including the algorithms previously employed. Finally, for the remainder of the time (hopefully, at least 50% of the total allocation), we concentrate on the current period of observations. In keeping with the silliness of our nomenclature, we refer to it as the "modern" era. One defines this period by both the capabilities of the spacecraft as well as the focus/capability of the algorithms available for remote sensing studies. As a result, we group the individual components of the remaining presentation in the following manner.

2.1 "Ground-Truth," Simultaneous, and Novel Observations

Remote sensing observations of the Martian atmosphere do not easily lend themselves to the notion of ground truth. While one might consider a high fidelity measurement from a surface platform (such as optical depth from direct solar imaging) to represent some degree of ground truth, connecting a series of orbital spacecraft observations to those of a surface station requires a temporal, as well as a spatial, overlap to account for the dynamical nature of the atmosphere. While concept of an ``overflight'' was first exploited during the Viking era, these observations were fundamentally limited by two aspects: the absence of multi-instrument coordinated (i.e., simultaneous, or nearly so) observations, and the lack of similar instrument capabilities on both the surface and the orbital platforms (See [1] for a brief historical review). Fortunately, one is able to remedy such issues in the current epoch through the use of MEx or MGS (in orbit) in conjunction with MER (on the surface). In addition to "ground-truth," the combination of MGS-MEX and MER instruments provides for leveraged atmospheric studies. That is to say, by combining the data from both platforms, one obtains a more complete picture than would be possible from analysis of each dataset independently. As an example, Figure 1 shows the differing sensitivity of an orbital thermal IR spectrometer (Thermal Emission Spectrometer – TES – onboard MGS) versus an upward viewing surface instrument (Minature TES -- Mini-TES – onboard MER). It is only with the Mini-TES that one becomes sensitive to the "scattering" aspect of the aerosols (ignoring limb geometry for now). We will present additional detail of how this can be exploited, with one set of results being an improved set of effective indices of refraction for Martian dust aerosols (shown in Figure 2). A final aspect of these type of observations is the physical scales captured by the solid angles of each orbital geometry, e.g., the view of ice clouds. Athough the "cirrus-like" aspect of Martian ice clouds, as seen in Figure 3, has been inferred from microphysical retrievals and orbital imaging, it is only with high resolution surface observations that the morphological similarity is seen.

2.2 Multi-spectra, "high" spectral resolution Emission Phase function

The emission phase function (EPF) observation sequence traces its origin to the Viking era, with significant application found during the neoclassical MGS operations. However, both of these datasets suffer from spatial registration and spectral issues that prevent the full exploitation of their capability for aerosol studies. Fortunately, with the advent of MRO and its Compact Reconnaissance Imaging Spectrometer for Mars, both of these two problems can be overcome. We outline the available datasets and the progress-to-date with respect to both dust and water ice aerosols.

2.3 Limb Observations (including Occultations)

From an electromagnetic scattering point of view, limb observations hold extreme promise in that this geometry accentuates both the important of particle size and shape. From a remote sensing retrieval point of view, one's enthusiasm may be damped by the same factors as combined with the spectre of vertically variation in such particle properties as well as the aerosol number density. As such, this type of observation was taken extensively by MGS, limb observations represent one of the "untapped" reservoirs of Martian aerosol work. Thus, these data represent one of the exciting "new" areas for Martian aerosols. We again outline the available datsets and provide the progress-to-date review. We also include a synopsis of the stellar occultation observations that are part of the MEx dataset.

Acknowledgments

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References

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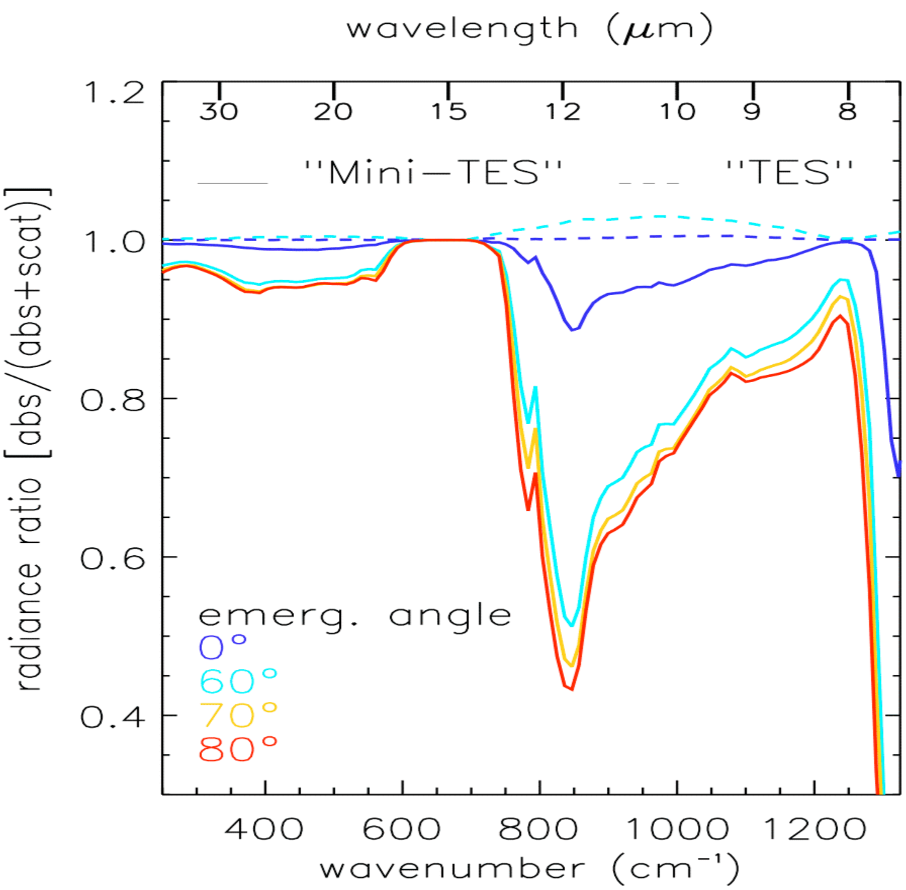

Figure 1 – The effect of scattering: MGS/TES versus MER/Mini-TES observing geometries. Synthetic spectra are calculated using the temperature profile from the Sol 46 of the Spirit mission (late southern summer), but using a 9.3 micron dust optical depth 0.3 (See [1] for more details). For convenience, we give only the emergence angles as defined for TES viewing geometry; for Mini-TES atmospheric viewing, the emergence angles are the supplement to those of TES (i.e., $_{eMini\text{-}TES} = 180\text{-}e_{TES}$). The ratio plotted is that of the ``absorbing atmosphere" radiance relative to the full multiple scattering radiance. The solid lines represent the Mini-TES view (downwelling) while the dashed lines show the TES view (upwelling). The relative importance of scattering between the two view points is quite distinctive.

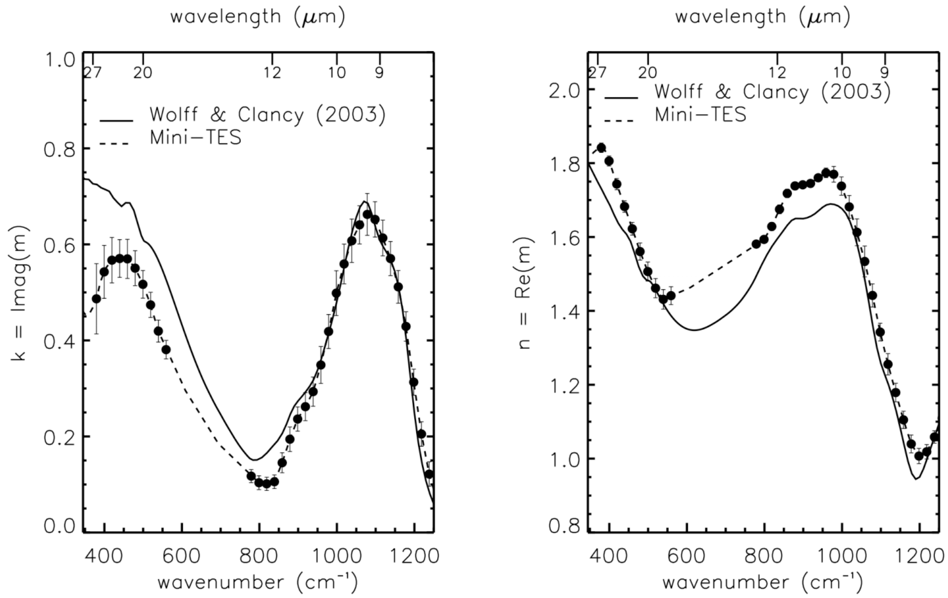

Figure 2 Complex indices of refraction from the combined TES-Mini-TES overflight analyses. Left Panel: Imaginary indices of refraction (dashed line, k = Im(m)) compared with the starting values (solid line) from Wolff and Clancy (2003). The filled circles indicate the position of each Mini-TES channel, with the error bars representing the averaged formal retrieval precision and the standard deviation among the k values from all seven datasets, added in quadrature assuming no correlation. Right Panel: As for Left Panel, but for the real indices of refraction.

Figure 3 – 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).