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Observations of a bimodal size distribution for the aerosol particles on Mars by SPICAM/MEX

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Abstract

We present first results of simultaneous analysis of the ultraviolet (UV) and infrared (IR) atmospheric extinctions obtained by SPICAM on Mars Express by means of solar occultations in the Martian atmosphere in the beginning of the northern summer (L_s=56-97°) at the middle northern and southern latitudes. Based on Mie scattering theory with adequate refraction indices for dust and H_2O ice, a bimodal distribution of aerosol has been inferred from the SPICAM measurements at the altitudes from 10 to 50 km. The coarser mode exists for both H_2O and dust particles with average radius of 1.3 and 0.7 µm, respectively, with number density from 0.01 to 10 particles to cm^3. In addition, a small mode has been detected in both hemispheres with a radius of 0.03-0.07 µm and a number density from 1 cm^{-3} at 60 km to 1,000 cm^{-3} at 10-20 km.

1. Introduction

Dust aerosols play an important role in the Martian climate system. The spatial and temporal variability and optical properties of atmospheric aerosols has been a target of almost every major spacecraft mission to Mars. Airborne dust is composed mostly of mineral particles lifted from the surface by near-surface winds and presumably by "dust devils", small-scale convective vortex. Dust participates in heating and cooling of different atmospheric layers absorbing, scattering and reemitting in thermal IR solar radiation [1, 2]. Aerosol particles serve also as cloud condensation nuclei (CCN) in the Martian atmosphere and thus help regulate the transfer of water between the hemispheres [3].

Since condensate clouds were observed in Martian atmosphere, besides the main micron-size mode extended microphysical modeling requires a small dust particle population in the higher region of the atmosphere in order to form a clouds agreeing with data. Some observations supported the bimodal distribution against the mono-modal mostly used to characterize the Martian dust. Based on Viking limb radiance observations and microphysical modeling, Montmessin et al. (2002) [4] have derived a bimodal distribution at L_s=176° / 15°S (shortly before the dust storm), featuring two maxima with r_{eff}=1.8 µm and v_{eff}=0.5 µm for the large mode and <0.2 µm for the small mode, with a ratio of populations (small to large) around 25. Recently Markiewicz et al. (2011) have reported a possible presence of bimodal distribution based on the Imager for Mars Pathfinder (IMP) data on the midday sky brightness in visible-near-IR filters at L_s~156° [5].

2. Data analysis

The spectral range of SPICAM IR (1-1.7 µm) includes three relatively strong CO_2 absorption bands (1.43, 1.57 and 1.6 µm) and the 1.37-µm H_2O band [6]. To reduce the number of spectral sampling points in solar occultation, the IR spectrum consists of three "windows" and a set of several continuum points [see 6-7 for details]. We used the set of 10 continuum wavelengths outside gaseous absorption bands: 996.4, 1093.7, 1158.2, 1197.0, 1241.4, 1272.9, 1304.4, 1321.9, 1514.6 and 1552.2 nm.

The UV spectrometer measures a spectrum from 118 to 310 nm and includes the absorption bands of CO_2, O_3 and continuum extinction by aerosols. The retrieval method separates the various species in a way described in [8-9]. For the present study, aerosol extinctions at wavelengths of 200, 250 and 300 nm have been used.

The hypothesis of a bimodal size distribution for Martian dust, the main motivation of this work, has been tested against observations chosen at the beginning of summer in the northern hemisphere in

MY29 (L_s=56-97°). This season is especially interesting due to the recent detection of supersaturation of water vapour that was previously discussed for its link to the size and nature of dust condensation nuclei [10]. The series of observations consists of 9 profiles in the northern hemisphere (fig.1) and 11 at the southern hemisphere at latitudes of 40-65°N and 30-62°S respectively. The latitudes cover cold dust-clear area near the polar night in the southern hemisphere and the middle and high northern latitudes corresponding to the edge of aphelion cloud belt and the gap of clouds at 60°N.

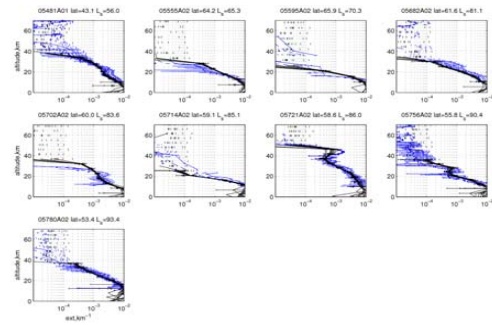

Figure 1. The IR and UV extinctions for the Northern hemisphere. Black lines are IR extinctions for 10 wavelengths, and blue lines are UV extinctions for 3 wavelengths.

The interpretation of the profiles using Mie scattering theory with adequate refractive indices of Martian dust and H_2O ice particles allows to retrieve a particle size distribution and number density [7]. Figure 2 presents vertical distributions of particle size for dust, ice and small fraction and number density profiles for 5 orbits in the Northern hemisphere for latitudes >60N, L_s=65-85° as an example.

3. Summary

The main mode of the distribution has been determined both for H_2O and dust particles with a retrieved average radius of 1.3 and 0.7 µm, respectively. We are unable to separate ice and dust from SPICAM observations, so we based our interpretation on MCS observations for the same season [11].

A small mode of submicron particles has been detected for both hemispheres. The average radius is 0.04 µm and number density varies from 2 cm^{-3} at 60 km to 10^4 cm^{-3} at 20 km for the Northern hemisphere. The average radius is 0.07 µm and the number density ranges from 1 cm^{-3} at 60 km to 10^3 cm^{-3} at 20 km for the southern hemisphere. The small mode extends vertically up to 70 km in the southern hemisphere where as it remains around 30-40 km in the northern hemisphere.

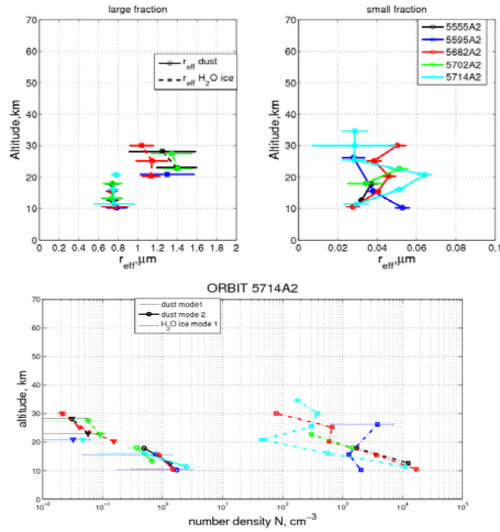

Figure 2. The vertical distributions of particle size for dust, ice and small fraction and number density profiles for 5 orbits in the Northern hemisphere for latitudes >60N.

The highest level of supersaturation at the Northern hemisphere at altitudes of 30-50 km reported by [10] for latitudes > 60°N is consistent with the observed absence of any particles (small or large) above 30 km in our database. For latitudes<60°N it is more difficult to explain the supersaturation due to at least 10-100 cm^{-3} particles has been observed at 30-50 km with r_{eff} of 0.05 µm at average. Our estimation of critical saturation ratio based on nucleation rate calculation gives S_{crit}~2 for particles from 0.01 to 0.1 µm. The explanation of high supersaturation could be related to the high values of S_{crit} for low temperature reported by several authors [12]. In case of southern hemisphere the small particles are always presented but S_{crit}<3 observed by [10] can be inside the uncertainties of nucleation rate and temperature dependence.

Brownian-led coagulation quickly removes particles with r<0.1 µm and number density ≥1000 cm^{-3}. For the small mode with r_{eff}=0.04-0.07 µm in the northern hemisphere a source of particles is required to balance loss by coagulation. However, micrometeorites cannot provide such sources based on current mass flow estimation whereas a surface source from (wind stress dust lifting and dust devils) appears more possible. Similar to Earth aerosol distribution, coagulation of small particles could explain the bimodal type of distribution.

Mars-Express is working on the orbit of the planet and will continue to study the distribution of water vapor and aerosol in occultations [10, 13]. Further analysis of IR and UV spectral range in solar occultation will constrain the seasonal and spatial variations of the small and large modes of aerosols. Considering the impact of aerosols on present-day Mars climate, the present study opens a new path of exploration for modelers in their research.

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