A study of dust properties from a dust storm seen by MEx/OMEGA and MEx/PFS

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Introduction

One of the major climatic cycles of Mars is the dust cycle. A variable amount of dust is present in the Martian atmosphere. The dust is lifted by the winds from the dry, desert, solid surface of the planet, and transported, both horizontally and vertically, by the atmospheric circulation. In a thin atmosphere like the one of Mars, the dust optical depth strongly affects the radiative budget and the atmospheric heating rates. For example, when a global dust storm occurs, the atmospheric temperature can rise by as much as 40 K [1]. On the other hand, the boundary layer of Mars turns more neutrally stratified, because the dust also shadows the surface, which does not heat up so dramatically as with a dust-free atmosphere. The radiative effects of dust need to be taken carefully into account when modelling the Martian atmosphere, and thus information of the optical properties of dust is needed.

Our project aims at providing new constraints on the optical properties of Martian dust. Our study uses observations of a local dust storm observed by the spectro-imaging system OMEGA (Observatoire pour la mineralogie, l'eau, la glace et l'activite) and PFS (Planetary Fourier Spectrometer) aboard the Mars Express spacecraft.

Methods

OMEGA [2] is a spectro-imaging system aboard the Mars Express satellite, which has been on orbit of Mars since December 2003. Mars Express is a European Space Agency mission, and OMEGA has been built as collaboration of several laboratories, including LESIA in Observatoire de Paris, France, and Institut d'astrophysique spatiale in Orsay, France (P.I. Jean- Pierre Bibring). The instrument is observing in the spectral range of 0.35-5.1 μm. The spectral resolution is 0.01- 0.02 μm and the spatial resolution can go down to 300m/pixel. The Planetary Fourier Spectrometer (PFS) provides spectra of the planet between 250 and 8000 cm^{-1} at a spectral resolution of 1.3 cm^{-1} and at a spatial resolution down to 12 km at periapsis [3]. It allows us to probe the atmospheric temperature from the surface up to 20 Pa.

Our topic was to study two orbits only 3 sols apart, 1201 and 1212, which fly over the same geographical area, but in which the atmospheric state is very different. The orbit 1201 is clear and calm, and the dust optical depth is small. This orbit can be used to retrieve the surface albedo and the surface pressure, which are important components of the following retrieval of dust properties. The orbit 1212 instead shows a very dusty region around the equator, and we use the data from the two orbits to retrieve the dust properties from the orbit 1212.

We used the ability of OMEGA to observe the atmospheric dust loading and its variations. Normally in nadir viewing it is difficult to separate the signal of the surface from that of the atmosphere, but some methods are available. At some wavelengths the CO_2 atmosphere absorbs all the photons on their way through the atmosphere to the surface, so no reflection from the surface is seen. In this case any reflection seen must come from atmospheric scatterers, like dust. However, this method sees only above a certain altitude (15-20 km), and assumptions must be made considering the dust distribution below this altitude. We retrieved the surface albedo from orbit 1201, and the surface pressure retrieved from OMEGA observations was provided by A. Spiga and F. Forget in Laboratoire de météorologie dynamique in Paris [4, 5]. For the retrieval we used, however, the surface pressure from the Mars Climate Database [6], since the retrieved values and the database were in good agreement.

The retrieval is based on the very large dust optical depth observed in the dust storm region in orbit 1212. The optical thickness is so high that the reflectance of the dust is decoupled from the surface albedo: the optical thickness can be assumed quasi-infinite. We fit the single-scattering properties of dust (single-scattering albedo) using the spectrum of the highest observed reflectance on this orbit, after which we retrieve the dust optical depth from all of the observed dust storm spectra. The fits are made for nearly the whole OMEGA wavelegth range (0.5-4.0 micron). We have also performed an Independet Component Analysis (ICA) to compare the orbits. The method is able to find those independent sources whose linear mixing produces the observed signal. The analysis was done to point out that

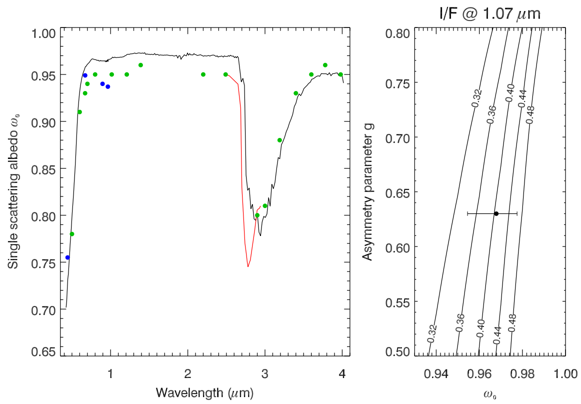

Figure 1: Left: The single-scattering albedo retrieved in this study (solid black line) and comparison with previous studies. Fedorova et al. (2002): solid red line. Ockert-Bell et al. (1997), green dots. Tomasko et al. (1999), blue dots. Right: I/F contours as a function of single-scattering albedo and asymmetry parameter for an infinite optical depth. The black dot shows the single-scattering albedo at 1.07 μm retrieved in this study. The error bar shows the uncertainty due to the 15% calibration uncertainty of OMEGA.

the dust cloud is, indeed, decoupled from the surface reflectance. The ICA confirmed that this assumption, crucial for our study, is valid.

Results

The results show that the dust storm observed on orbit 1212 is very localized, possibly due to topography. The storm is located over a slope and close to a very steep boundary in albedo. Possibly the two effects of topography and albedo have had an influence on the formation of the storm via surface-induced circulations related to slopes and differential heating.

The optical properties retrieved (See Fig. 1) differ from the commonly used Ockert-Bell et al. (1997) [7] values. We also do not see the absorption feature at 2.8 μm seen by Fedorova et al. (2002) [8]. We believe this is due to [8] Fedorova et al. (2002) observing the full disk of Mars (planet-average observations) and at a quiescent dust season, when the optical thickness was low and the dust was more confined to the surface, making it more difficult to determine the single-scattering albedo in the CO_2 absorption band.

Even though the optical thickness of the storm is considered quasi-infinite, it has a finite maximum value that can be retrieved from the brightest spectrum observed. This retrieved dust optical depth maximum is very high: $\tau(1\mu\text{m})=10.0$. Such high values of dust optical thickness can be perhaps related to the local nature of the storm, its temporal scale (developed in less than 3 sols) and the fact that this storm seems to be very strong and convective in nature. The storm area is about 180 km in latitudinal direction and 60 km in the longitudinal direction, although our view in this direction is limited by the width of the OMEGA observation. The smallest details (tops of the dust plumes) seen in the dust optical thickness maps are of the order of few kilometers.

The effect of the dust storm is also seen in the temperature cross-section retrieved from PFS for the dusty orbit 1212 (see Fig. 2): The thick, suspended dust cloud shadows the surface and the lower atmosphere, thus cooling the near-surface temperatures, but it warms the middle atmosphere.

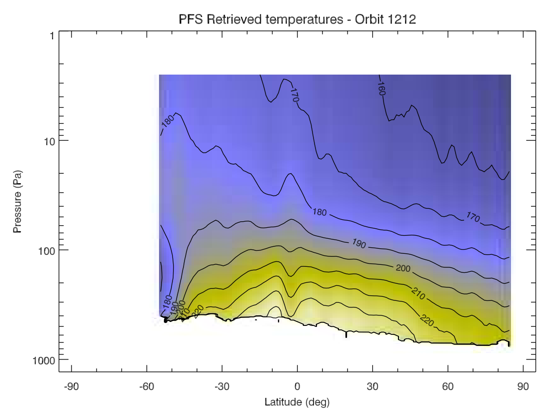

Figure 2: The latitude-pressure cross-section of temperature inverted from PFS observations on the dust storm orbit 1212. The dust storm is centered at around 3°S. The dust heats the upper atmosphere and cools the lower atmosphere.

We performed one-dimensional atmospheric modelling on the effect of the dust storm on atmospheric temperatures with the 1-D models of the University of Helsinki [9, 10] and Laboratoire de Météorologie Dynamique. We noticed that with well-mixed dust throughout the atmosphere the middle atmosphere temperatures are too warm, and we were forced to change the dust vertical distribution to be able to produce temperature profiles similar to the one retrieved from the PFS data. The modelling results point to the dust storm being confined in the lowest scale height instead of being well-mixed. However, in that case the OMEGA reflectance in the CO_2 absorption bands would be difficult to fit with $\tau = 10$, but a higher dust optical thickness would be needed. We have not yet resolved this question.

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