# Microphysics and radiative effect of water ice clouds on Mars: Modeling with the LMD/GCM and insights from the OMEGA/MEx data set.

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## 1. Introduction

The role played by water ice clouds in the energy budget of the Mars and Earth [1] atmospheres is key to understanding and predicting climate variations of both planets. Their crystal size and shape, microphysics of formation, and variations in space and time are all issues that can now be addressed using climate modeling and data from several remote sensors.

Different authors, for example Rodin et al. [2] or Montmessin et al. [3], have studied the microphysics and radiative impact of water ice clouds using one-dimensional models, and underlined the complex coupling between radiation and cloud dynamics. After being introduced in GCMs by using different microphysical schemes [4, 5], the impact of radiatively active clouds on atmospheric temperatures was further emphasized. For example, Hinson and Wilson [6] found a strong coupling between thermal tides and radiatively active clouds by comparing Radio Science occultation made by MGS and results from the GFDL/MGCM.

More recently, Wilson et al. [7] used the TES/MGS surface temperatures and nighttime cloud maps of the MOLA/MGS altimeter to explain the warm nighttime surface temperature of the tropics induced by clouds, and assess their thermal forcing. Further evidence of this forcing emerged from the TES/MGS temperature reanalysis of Montabone et al. [8], in which Wilson et al. [9] found warmer zonal mean temperatures during the Aphelion season than in a control simulation forced by dust distribution alone. Finally, Colaprete et al. [10] also underlined the significant role played by clouds in shaping the temperature structure of the southern polar night.

In an attempt to refine our understanding of cloud formation and forcing, radiative transfer through the clouds has been implemented in the LMD/GCM, with varying effective radius in connection with the microphysical model [5]. Resulting climate changes have been compared to the TES/MGS observations. In parallel, we have developed an algorithm to retrieve cloud particle size and near infrared opacity by inversion of the OMEGA/MEx data, and started to compare them to the LMD/GCM predictions.

## 2. Implementing radiatively active clouds in the LMD/GCM

Our main goal is here to couple radiative calculations to the cloud microphysical scheme [5], and to compute varying scattering properties as a function of ice crystal size during the GCM run. Scattering properties are loaded for different particle size in a look-up table, that is generated using a Mie code and optical indices from Warren [11]. At each time step, connection with the microphysical scheme is established by integrating these scattering properties over a given size distribution with the effective radius predicted by the microphysics in each grid box.

Simulations are run under present-day conditions, using the dust opacity acquired by TES/MGS during the martian year 24 (1999-2000, Smith [12]) and a water-ice reservoir corresponding to the north polar cap. Resolution is $5.625 \times 3.75$-degree in the horizontal with 25 levels in the vertical, covering the lower atmosphere (from the ground to $\simeq 80$ km).

## 3. Model sensitivity, results and comparison with TES/MGS

At the time of this writing, developments and sensitivity tests are still underway to assess the radiative effect of clouds in the case of varying effective radius of the ice particles in connection with the microphysical model. First results obtained with a fixed effective radius of 4 $\mu$m show the same effects as those reported in previous studies [7, 9, 10], i.e. improved temperatures in the tropics at aphelion and in the south polar night. However, seasonal distribution of water vapor and clouds is significantly modified, largely due to enhanced cloud formation in the polar regions.

During the workshop, we will report on the results obtained with varying scattering properties of the cloud particles, compare with the TES/MGS data and further explore the link between microphysics and radiative forcing.

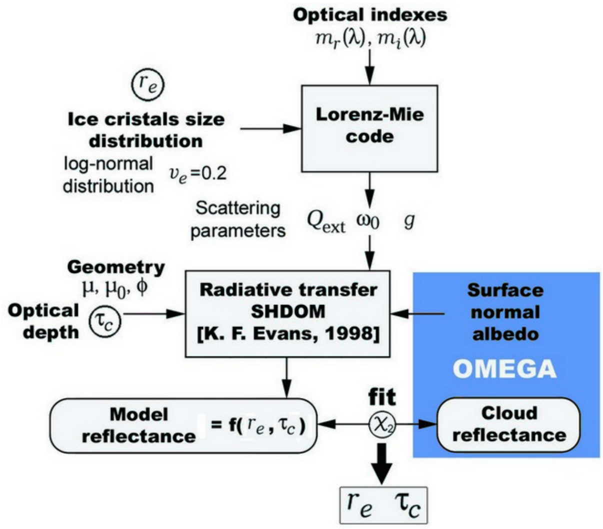


Figure 1: Schematic drawing of the water-ice crystals size $r_{eff}$ and cloud optical depth $\tau_c$ retrieval method.

## 4. Comparison with the OMEGA/MEx retrievals of cloud particle size and opacity

**Method:** In parallel to the water cycle modeling, an inversion method is being developed to retrieve cloud particle size and opacity in the near infrared, using the OMEGA/MEx imaging spectrometer. OMEGA data are spectral image cubes (x,$\lambda$,y) of the atmosphere and the surface both in the visible and near infrared, spanning 0.35 to 5.1 $\mu$m with a spectral sampling of 0.013-0.020 $\mu$m and kilometer-scale spatial resolution. Spectral range includes water ice absorption bands at 1.25, 1.5, 2 and 3 $\mu$m that can be used to detect water-ice clouds and derive their microphysical properties.

Fig.1 illustrates the inversion method. The model minimizes the difference between a simulated reflectance and the observed cloud reflectance by using a downhill simplex method and a least-squares criterion. The free parameters are the optical depth of the cloud at 1.5 $\mu$m ($\tau_c$) and the effective radius of ice particles ($r_{eff}$). These two parameters are fitted during the inversion by calculating the radiative transfer through a single-layer atmosphere using the Spherical Harmonics Discrete Ordinate Method [13]. Scattering parameters are given by a Lorenz-Mie code which uses the recent ice optical constants at 180K of Grundy and Schmitt [14], and assumes that the ice crystals are spherical and follow a unimodal lognormal distribution.

The main difficulty lies in providing good surface spectra to the inversion algorithm. Thanks to the extensive coverage that has been achieved by OMEGA and recovering of the data acquired under non-nominal conditions by Jouglet et al. [15], large number of overlapping orbits now allow us to cover identical regions under clear-sky and cloudy conditions. After defining the clear-sky spectra as surface albedo in the radiative transfer code, we can isolate cloud contribution to the signal using the inversion method described above, and calculate the two free parameters $r_{eff}$ and $\tau_c$. Dust impact on both spectra has to be taken into account, and is determined using a method developed by Vincendon et al. [16].

**Results:** Fig.2.a is an image of convective clouds as seen by the HRSC camera in the blue channel (kindly provided by H. Hoffmann, DLR). Corresponding OMEGA observation in the visible channel is given in Fig.2.b, along with measured spectra (plain line) and inversion result (crosses) in Fig.2.c. Joint study by the two instruments gives high spatial and spectral resolution, and allows us to study both cloud morphology and microphysics. Similar analyses performed over the Tharsis plateau during the aphelion season reveal a seasonal evolution from thick hazes of $\sim$ 3 $\mu$m-size particles at $L_S$ = 54° to convective clouds at $L_S$ = 95° containing crystals of more than 5 $\mu$m.

## 5. Perspectives

Radiatively active cloud microphysics predicted by the LMD/GCM will be compared to the near-infrared and thermal infrared opacities measured by OMEGA/MEx and TES/MGS respectively, and to particle size retrieved by the OMEGA data inversion method. Improvements of the inversion model are underway to take into account the retrieval uncertainties, and to quantitatively map the microphysical properties over an entire orbit. This will allow regional cloud structures to be interpreted with the help of the new LMD mesoscale model developed by Spiga and Forget [17].

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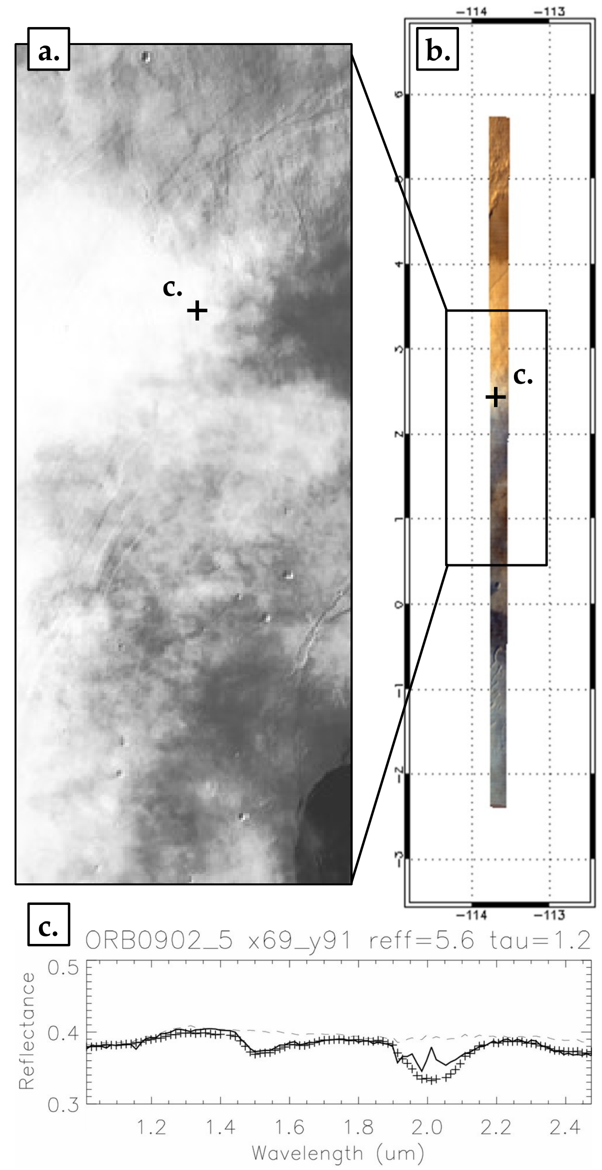


Figure 2: **a.** Convective clouds seen in HRSC blue channel (courtesy of H. Hoffmann, DLR), north-west of Pavonis Mons. Orbit #902_5 Local time: 3:40PM, $L_S$=95.2°. **b.** Simultaneous imaging by OMEGA, here shown in the visible. The cross indicates the location of the spectra used for the inversion. **c.** *Dotted line:* Measured spectra under clear-sky conditions; *Plain line*: Measured cloudy spectra; *Crosses:* Modeled spectra after convergence of the inversion algorithm ($r_{eff}$ = 5.6 $\mu$m, $\tau_c$ = 1.2).


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