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Analysis of high altitude clouds in the martian atmosphere based on Mars Climate Sounder observations

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Abstract.

High altitude clouds have been observed in the Martian atmosphere. However, their properties still remain to be characterized. Mars Climate Sounder (MCS) aboard Mars Reconnaissance Orbiter (MRO) is an instrument that measures radiances in the thermal infrared, both in limb and nadir views. It allows us to retrieve vertical profiles of radiance, temperature and aerosols. Using the MCS data and radiative transfer model coupled with an automated inversion routine, we can investigate the chemical composition of the high altitude clouds. We will present the first results on the properties of the clouds. CO₂ ice is the best candidate to be the main component of some high altitude clouds due to the most similar spectral variation compared to water ice or dust, in agreement with previous studies. Using cloud composition of contaminated CO₂ ice (dust core surrounded by CO₂ ice) might improve the fitting result, but further study is needed.

1. Introduction

Martian climate has been an issue of scientific curiosity for centuries and that clouds exist in Martian atmosphere has been known for some considerable time. In the past 10 years, surprising high altitude clouds (50-100 km) above the Martian surface have been discovered (see [1, 2, 11, 10, 7]). These clouds are most likely composed of carbon dioxide (CO₂) (see [10]), but their chemical properties still remain to be characterized.

Mars Climate Sounder (MCS) aboard the Mars Reconnaissance Orbiter (MRO) spacecraft (see [8, 13]), is an instrument that measures radiances in nine different channels in the thermal infrared, both in limb and nadir views (see Fig. 1). It has been able to retrieve vertical profiles of temperature and aerosols (see [6]). The high altitude clouds have also been observed using MCS (see [5, 12]). We will describe the first results on the properties of the high altitude clouds based on MCS data and using radiative transfer model coupled with an automated inversion routine developed by [4].



Table 1. MCS Channels, band passes, band center, and main absorbers (Table is adapted from [8, 6]).

Channel	Band Pass (cm^{-1})	Band Center (μm)	Main Absorbers
A1	595-615	16.5	CO_2
A2	615-645	15.9	CO_2
A3	635-665	15.4	CO_2
A4	820-870	11.8	H_2O ice
A5	400-500	22.2	dust
A6	3300-33000	1.65	
B1	290-340	31.7	dust
B2	220-260	41.7	H_2O vapor, H_2O ice
B3	230-245	42.1	H_2O vapor, H_2O ice

2. Mars Climate Sounder (MCS) observations

The MCS observes in 9 channels across the visible and infrared ranges of the electromagnetic spectrum (0.3 - 45 μm). Those channels, from two telescopes of the MCS, are A1-6, and B1-3 (see Fig. 1 and Table 1). A1-3 channels are sensitive to CO_2 gas, A4 is to water ice, A5 is to dust, whereas B1-3 are to dust, water vapor, and water ice. As previously mentioned, the MCS acquires nadir and limb observations. We used results only from the limb observation (the vertical profiles). Each channel of MCS is composed of 21 detectors. In limb observation, each detector has a vertical resolution of ~ 5 km. Thus, it can observe from the surface to the high altitude. Position of a detector corresponds to a certain altitude in Martian atmosphere.

We used data from the first MCS observations that are during Mars Year (MY) 28, Season 4 or Solar Longitude 115-133. From ~ 200 selected vertical profiles, we detected ~ 50 observations with evidence of clouds. The Martian clouds are characterized by a local maximum at high altitude in the radiance profiles due to the emission and scattering process by the clouds (see Fig. 2).

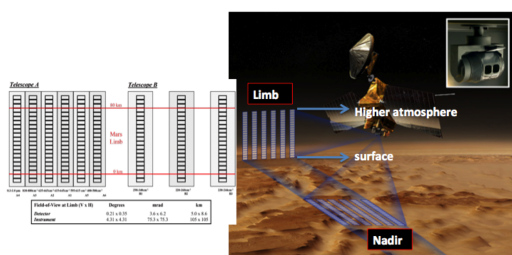


Figure 1. The nine channels of MCS Instrument A1-6 and B1-3. Each channel has 21 detectors. In limb observation, position of a detector corresponds to a certain altitude (image is taken from [8]).

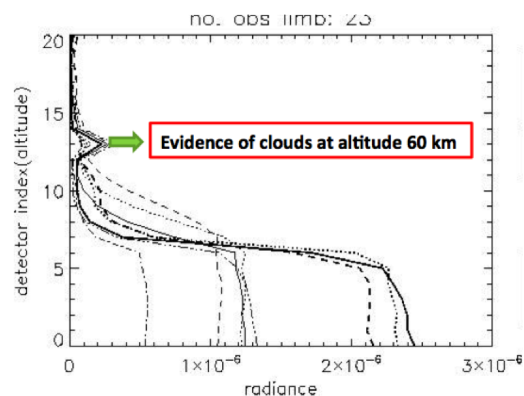


Figure 2. An evidence of the high altitude clouds is a local maximum in the vertical profile of radiance from limb observation of MCS. Different line types correspond to different channels.

3. Method

To analyze the properties of the clouds, we use the MCS data together with radiative transfer model, coupled with automated inversion routine (see [4]). There are two codes in the analysis: (1) radiative transfer code (direct model) to calculate the radiance profile, and (2) inversion code that adjust the radiance profile to retrieve temperature and aerosols profiles. We started with temperature and aerosols (dust and water ice only) profiles from Mars Climate Database (MCD) (see [3]) and added a pre-defined CO₂ ice profile to get a realistic input for the inversion routine (*a priori* profile). Optical parameters (extinction factor, scattering albedo, etc) were obtained using T-Matrix code (see [9]). We selected a radiance profile from MCS data that showed the signature of the high altitude clouds. We ran the inversion code that calculated synthetic radiance profile and compared it with the observed radiance profile. The code can vary the temperature and dust profiles to adjust the radiance profile. Aerosols information in the inversion routine is noncompulsory. However, since aerosols make a significant contribution to the radiance profile, they should be included. From the inversion, we can obtain the new vertical temperature and aerosols profiles. We used these new profiles from the inversion and added with cloud layer (CO₂ ice, water ice, or dust profil at high altitude) to adjust the radiance at the cloud altitude.

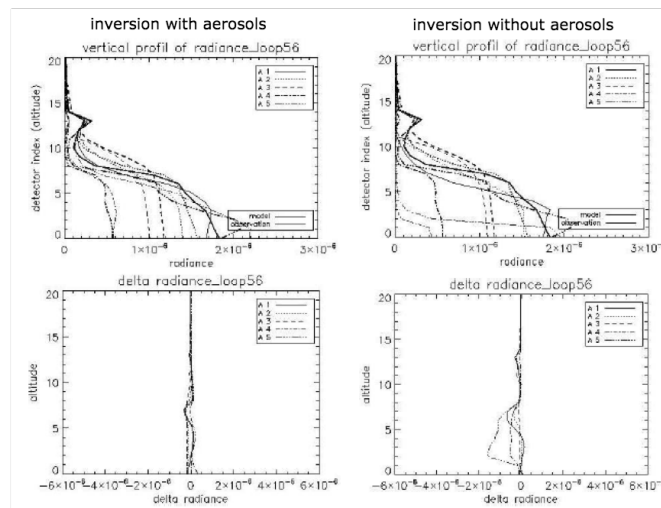


Figure 3. A test of the inversion routine. Upper figures are the vertical radiance profiles (detector index vs. observed and synthetic radiances of different channels shown in different line types; the synthetic radiances are shown in bold lines). Lower figures show the difference between the observed and the synthetic radiance. The need to include aerosols in the inversion can be clearly seen from this figure (see lower right figure).

4. Results and discussions

- An example of the fitting from the inversion routine can be seen in Fig. 3 (upper left).
- We tested the inversion routine with and without taking aerosols into account. We remark that aerosols play important role in modifying thermal structure of martian atmosphere, especially at the lower altitude (see Fig. 3). We noticed strong differences between the observed and the obtained radiance profile of channel A4 and A5, showing the non-negligible quantity of water ice and dust at the lower altitude (see Fig. 3, lower right).
- CO₂ ice is the best candidate to be main component of the high altitude clouds due to the most similar spectral variation compared to water ice or dust (see Fig. 4).

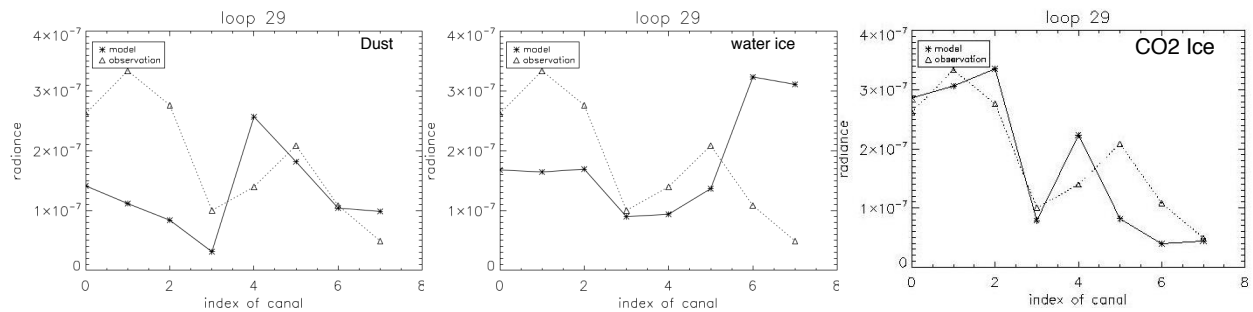


Figure 4. Spectral variations of radiance at the altitude of the clouds as a function of the MCS channels (A1-5, B1-3). The figure shows a test of the routine for searching the most probable composition of the high altitude clouds. The CO₂ ice has the most similar spectral variation to the observed variation and thus is our primary candidate for the cloud composition in this observation.

- From the spectral variations of radiance at the altitude of the cloud layer (see Fig. 4, right), we remark that our fitting results tend to be under- or overestimate in some channels. This suggest that properties of the clouds might be slightly different from our prediction. For example, they might not be pure CO₂ ice. Dust core surrounded by CO₂ ice might improve the fit, but further study is needed.
- Because of the poor fits to the radiances, we could not derive effective radius (r_{eff}) of the cloud, but approximations with $r_{eff} = 1.5, 2.3$ and $3 \mu\text{m}$ show that the radiance model is quite similar to the observed radiance.

To improve our results, we need a more complex calculation to estimate optical properties of the component of the cloud.

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