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Formation of mesospheric clouds on Mars: new model results based on updated parameters

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Abstract

Mesospheric clouds have been observed on Mars for about 15 years. Microphysical modeling studies have provided evidence that an exogenous Ice Nucleus (IN) source is needed to form these clouds. These IN are probably Meteor Smoke Particles (MSPs) as in the Earth's mesosphere. Recent studies have provided new information on the properties of the MSPs and of CO_2 ice: we are presenting here updated results using these new parameters.

1. Introduction

Martian mesospheric CO_2 clouds were detected and imaged in 2007 by [1], after first hints of their actual existence from infrared spectroscopy [2]. Several observational datasets on mesospheric clouds have been accumulated over the years (with and without composition retrieval) [3-9] and a long climatology can be established. Global Climate Modeling has shown that the mesospheric clouds form in the temperature minima of migrating and non-migrating tides, but they are not sufficient to cool the atmosphere below the condensation temperature of CO_2 [10]. It was shown [11] that mesospheric cloud observations correlate with the privileged zones of gravity wave propagation to the mesosphere, giving strong evidence of a link between the two phenomena. Subsequent microphysical modeling [12-13] in one dimension showed that using temperature profiles accounting for the effects of thermal tides and gravity waves resulted in observed-like clouds, if the profiles were cooled by some degrees and if a mesospheric IN source was added in the simulation.

1.1 The microphysical model

The microphysical model is based on the work by [14] and was adapted to Martian CO_2 ice clouds by [12-13]. This sectional cloud model describes the processes of cloud crystal formation by heterogeneous (deposition mode) nucleation onto IN, their condensational growth or evaporation, and sedimentation and vertical mixing by eddy diffusion.

1.2 New parameters

Recently published experimental results [15] show that the contact parameter (*m*) of CO_2 ice that was previously used in the models is too favorable for nucleation of CO_2 ice on dust. The previously measured value for this parameter (*m*=0.952) came from [16], who studied CO_2 ice nucleation on a flat water ice substrate. When [15] used nanometer-size MSP and Mars dust analogs as IN in their nucleation experiment, they found a much lower value of *m*=0.78. They also measured a new value for the desorption energy of CO_2 on the IN. In another study [17] the CO_2 ice density was measured at low temperatures showing a clear dependence on temperature. In this work, we are applying the updated values of the aforementioned parameters in our microphysical model [13] to quantify their effect on cloud formation.

2. Results

The new contact parameter has a large influence on the supersaturation necessary to activate the IN. Figure 1 shows the nucleation probability (giving the fraction of the activated IN) for CO_2 ice as a function of saturation ratio and the corresponding temperature deviation below the condensation temperature. The results are shown for four IN radii at the conditions prevailing around 75 km (atmospheric pressure 0.01 Pa). It is clearly seen that the new contact parameter [15] has a profound effect on nucleation: for all studied particle sizes, the saturation ratios required to activate the IN increase by one order of magnitude compared to the contact parameter of [16].

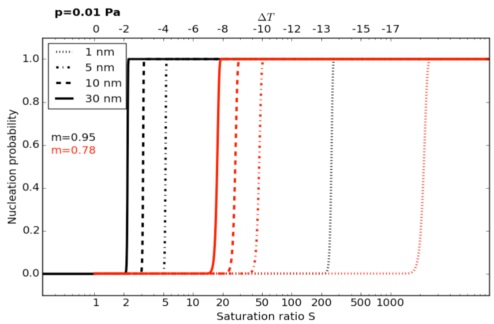

Figure 1: Nucleation probability for four IN radii as a function of the saturation ratio and the corresponding deviation below the condensation temperature. The atmospheric pressure is 0.01 Pa (as around 75 km). The black lines show the results for contact parameter *m*=0.95 and the red lines for *m*=0.78.

Figure 2 shows the required temperature deviation below saturation as a function of the IN radius, and includes also the two other parameters, CO_2 ice density and desorption energy of CO_2. For IN of 10 nm radius, the temperatures need to be decreased by 6 K to activate them compared to the old value of *m*. It can be seen that the other parameters have a minor role on the activation temperature deviation.

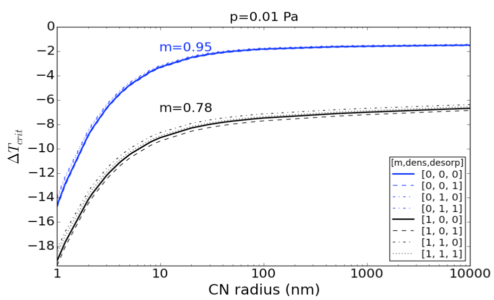

Figure 2: The temperature deviation below saturation required for IN activation as a function of the IN radius. The atmospheric pressure is 0.01 Pa (75 km). The blue lines show the results for contact parameter *m*=0.95 and the black lines for *m*=0.78. The legend shows the variation of the different parameters: 0=old value, 1=new value.

We have also looked at the 1D results for the clouds. We chose a good simulation of a daytime cloud from [13] and rerun it with the new parameters. The IN profile of the simulation includes the climatological dust profile and a MSP source in the mesosphere. Figure 3 shows the results of the simulation with the old contact parameter and two simulations with the new one.

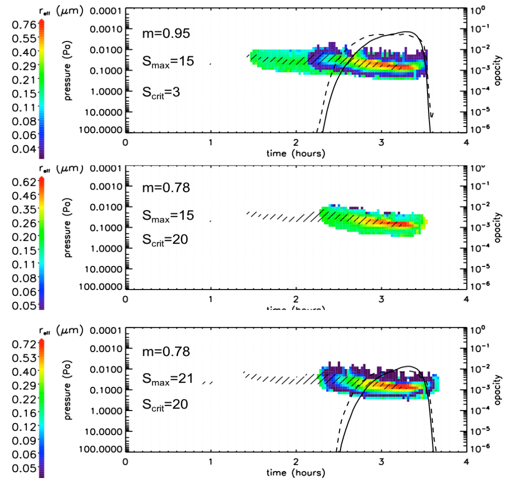

Figure 3: Effective radius (color) and opacity (lines: solid at 1 μm, dashed at 500 nm) of the cloud as a function of pressure and time from the start of the simulation. The IN are injected at the supersaturated region (dashed) and are of 10 nm radius. Upper panel: *m*=0.95; middle and lower panel: *m*=0.78. S_{crit} indicates the saturation ratio required for activation of the IN, and S_{max} the maximum supersaturation reached during the simulation.

The upper panel reproduces the results of [13] and shows the formation of a cloud within the supersaturated pocket for a critical saturation ratio of three (S_{crit}=3) with the old value of *m*. The middle panel shows that for the same saturation conditions (S_{max}=15) the formed cloud is much thinner (opacity<10^{-6}). This indicates that the small IN are actually not activated, since the reached saturation ratios (Smax=15) are only enough to activate the larger particles of the dust lifted from the surface, which is present in very small concentrations (as constrained by the Mars Climate Database [18]). The small number concentration of the activated IN leads to the very small opacity. The lower panel shows that a realistic cloud can be simulated if the cooling is increased (S_{max}=21) so that the new critical saturation ratio (S_{crit}=20) can be reached: in this case, the MSP particles can also be activated as IN (at S_{crit}=20) and the observed cloud opacities are attained.

3. Summary and Conclusions

In the light of new measurements on CO_2 ice properties, modeling results show that the martian mesospheric CO_2 ice clouds are very difficult to form, requiring very high saturation ratios (and thus very low temperatures). The critical saturation ratios increase by an order of magnitude when using the new contact parameter to activate the available IN and to form clouds with observed properties. The first results suggest that the clouds would strongly rely on the maximum saturation ratio reached within the cold pocket, leading to threshold effects making those clouds even more difficult to form. We are currently implementing the microphysics into the LMD GCM [19-20].

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