A COMPLETE CO_2 ICE CLOUDS MODEL FOR GCMs AND MESOSCALE MODELS

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Introduction:

Since the first claimed detection of Martian CO_2 clouds (*Herr and Pimentel, 1970*), numerous observations (e.g. *Clancy and Sandor, 1998* ; *Montmessin et al., 2006, 2007* ; *Määttänen et al., 2010* ; *Vincendon et al., 2011*), theoretical advances and modeling works (*Määttänen et al., 2005, 2007* ; *Colaprete et al., 2008* ; *Spiga et al., 2012* ; *Listowski et al., 2013, 2014*) have improved our understanding of CO_2 cloud formation and dynamics on Mars. These clouds, less frequently observed than the water ice clouds, form in the troposphere at the poles during winter and at equatorial latitudes in the mesosphere (60 – 110 km).

Atmospheric CO_2 condensation requires extremely low temperatures to produce supersaturation. Such low temperatures are reached during the polar night and have been observed at low latitudes in the mesosphere (*Schofield et al., 1997 ; Montmessin et al., 2006 ; Forget et al., 2009*). These cold pockets are most likely produced by gravity waves propagating to the upper atmosphere (*Spiga et al., 2012*), at the altitudes of the temperature minima caused by the thermal tides.

Moreover, aerosol particles must be present for the CO_2 to condense on them by the mean of heterogeneous nucleation. At high mesospheric altitudes and such low pressures (typically 0.01 Pa), it is unknown whether dust lifted from the surface or particles coming from above (such as meteoritic dust) prevail. CO_2 clouds are short-lived and do not last long after the favorable conditions vanish (about a dozen of minutes, *Listowski et al., 2014*).

Towards understanding Martian CO_2 cloud formation, abundance and features, including their formation and evolution in a Global Climate Model (GCM) is necessary. Their precise radiative impact on the climate throughout the history of the planet is especially of prime importance due to the backscattering of the infrared photons by the CO_2 ice crystals that might have contributed to a greenhouse effect.

The purpose of this work is to include a complete and validated CO_2 cloud scheme (developped by *Listowski et al., 2013, 2014*) in the GCM of the Laboratoire de Météorologie Dynamique (LMD) (*Forget et al., 1999*). We hereafter present the key steps of this coupling and the first results.

CO_2 clouds microphysics:

Martian mesospheric CO_2 clouds have the specificity to form from the main atmospheric component, at very low pressures (~0.01 Pa) and temperatures.

Aerosol particles must be present to trigger the CO_2 condensation in a supersaturated environment

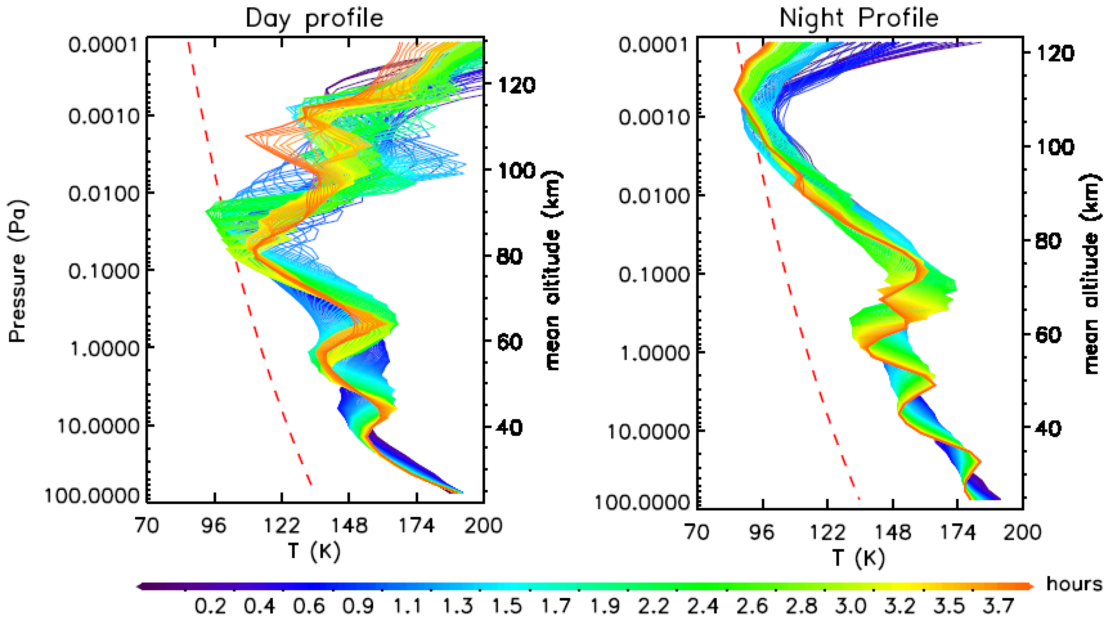

Fig. 1 : *Atmospheric temperature profiles with gravity-wave induced cold pockets simulated by the LMD Mesoscale model (Spiga and Forget, 2009 ; Spiga et al., 2012). The red dotted line is the CO2 saturation curve. From Listowski et al., (2014)*

such as S > 1, where S is the saturation ratio defined as the CO_2 partial pressure over the CO_2 saturation vapor pressure. Following the work on nucleation of *Määttänen et al.* (2005; 2007) and the water ice cloud model of *Montmessin et al.* (2002), a specific bin microphysics scheme has been developped by *Listowski et al.* (2013; 2014). It uses heterogeneous nucleation with a contact parameter m=0.952 and then computes at each time step the growth rate (condensation or sublimation) of the activated CO_2 ice particle.

Global Climate Model:

We want to implement the CO_2 cloud microphysics scheme of *Listowki et al.* (2013, 2014) into the LMD-GCM presented in *Forget et al.* (1999).

As it is, the GCM does not include a realistic gravity wave parametrization and hence can not produce mesospheric temperatures low enough to trigger CO_2 cloud formation.

In order to validate our implementation, we therefore use the 1-D version of the GCM. The physic implied is shared with the 3-D global and mesoscale versions but the 1-D version allow us to control more freely the different inputs to produce ideal scenari for CO_2 cloud formation, such as the temperature and dust profiles in the atmosphere.

The CO_2 microphysics scheme is implemented in the code inside a microphysical time loop equal to 1/30th of the physical time step (i.e. ~ 30s). At each microphysical time step, we compute the saturation ratio, the nucleation probability and growth rate of the particles and thus the evolution of three specific tracers : the CO_2 ice mass ratio, the activated condensation nuclei concentration and mass ratio. The latent heat released by the CO_2 condensation is taken into account. In contrast with *Listowski et al.* (2014)'s bin model, our model is a two-moment bulk parameterisation scheme that predicts the total mass and number density of CO_2 ice crystals.

In our implementation of CO_2 cloud microphysics, the dust population is discretized in 40 different bin sizes ranging from 1 nm to 50 µm. Each bin is populated with regards to the current atmospheric profiles of the dust concentration and mass.

The gravitational sedimentation of the CO_2 ice particles and activated condensation nuclei is performed inside the microphysical sub-time loop.

Mesosphere cold pockets:

Wind blowing on the surface topography propagates a short-lived temperature wave (or gravity wave) to the upper atmosphere. When it reaches the mesosphere, the resulting cold pockets can be below the CO_2 saturation curve (function of P and T). A mesospheric model such as *Spiga and Forget* (2009) can simulate these gravity waves and produce atmospheric temperature profiles presented in Fig. 1. These gravity wave-induced mesospheric cold pockets provide a good environment for CO_2 cloud formation and growth, provided enough condensation nuclei are present. They also account for the large scale atmospheric state (including the thermal tides).

In order to validate our CO_2 microphysic implementation in the LMD-GCM, we use the temperature profiles of Fig. 1 as input to our 1-D runs, hence producing ideal conditions for CO_2 clouds formation in the mesosphere.

Moreover, in order to explore the sensitivity of the CO_2 microphysics scheme to the saturation ratio, we can subtract or add a few Kelvins to the temperature profiles presented in Fig. 1.

First simulations:

As input to our 1-D simulations using the LMD-GCM, we choose the atmospheric dust profiles (concentration and mass ratio) in order to explore a plausible range of aerosols available for CO_2 condensation in the mesosphere. Our chosen dust size profiles decreases with altitude by the mean of an exponential law.

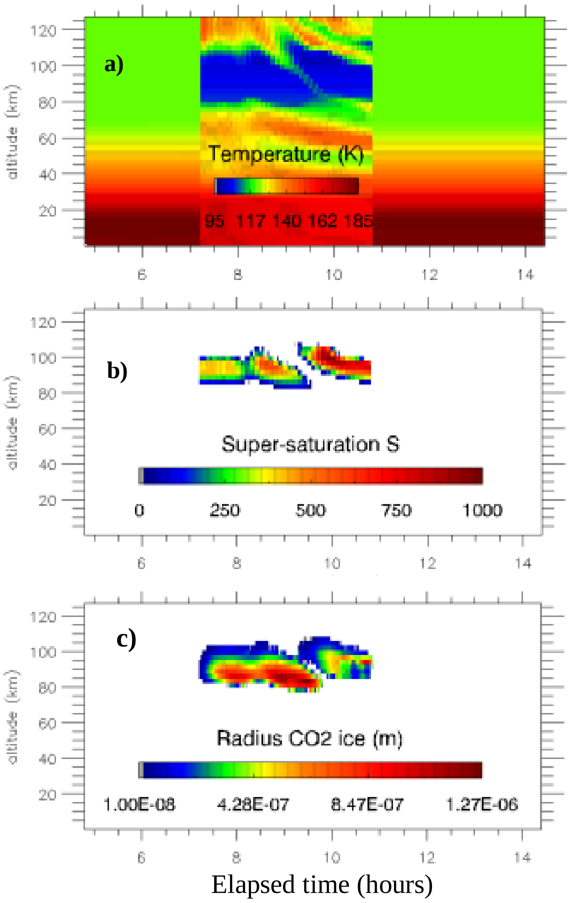

Fig. 2 : *Ideal conditions simulation of CO_2 clouds.* ***(a)*** *The atmospheric temperature is imposed from fig. 1 (Gravity-wave induced cold pockets) at 7.2 local time and last ~3.6 hours ;* ***(b)*** *corresponding saturation ratio S ;* ***(c)*** *produced cloud, indicated by the CO_2 ice particles radi.*

Our test simulations last less than 1 sol, and at a given time, we use the gravity wave-perturbed atmospheric temperature profiles of Fig. 1 as input. These profiles evolve for 3.6 hours and are forced from a given time, as can be seen in Fig. 2a.

This setup produces cold pockets in the mesosphere, below the CO_2 saturation curve and thus supersaturation (Fig. 2b). When the condition $S > 1$ is reached, the CO_2 microphysics scheme is called by the model and a cloud can form and evolve. The cloud rapidly decays when the super-saturation disappears (Fig 2c).

With this method reproducing ideal conditions for CO_2 cloud formation, we are able to produce realistic cloud properties (altitude, radius, dynamics) with regards to the observations (e.g. *Määttänen et al., 2010*). We observe a strong dependency of the resulting cloud properties on the input parameters, especially the saturation ratio (i.e. the amplitude of the cold pocket) and the dust abundance and particle size in the mesosphere.

We then investigate the sensitivity of simulated CO_2 clouds to super-saturation and dust size and abundance in the mesosphere.

We perform the same kind of idealized simulations with different values for the dust size and the saturation ratio for a fixed dust content. We report the mean and maximum values of the obtained CO_2 clouds particle size and concentration in Fig. 3.

Fig 3a show the mean CO_2 ice particle size (inside the cloud) as a function of the aerosol size in the mesosphere and the saturation. Fig 3b represent the same simulation set, with the max CO_2 ice particle size as a function of saturation and aerosol size. These two diagrams show an expected behaviour: the cloud particles are larger as the saturation increases and as the aerosols available for heterogeneous nucleation are larger.

The CO_2 ice particles radius are at most a few µm, in agreement with retrievals from observations (*Määttänen et al., 2010*) and simulation decoupled from a GCM using the same CO_2 microphysics scheme and temperature profiles in a radius bin model (*Listowski et al., 2014*).

Fig 3c shows the variations of the CO_2 ice particle concentration as a function of the saturation ratio and aerosol size. Here also, the behaviour depicted is expected : large aerosol particles imply less but bigger CO_2 ice particles, and more as the saturation increases.

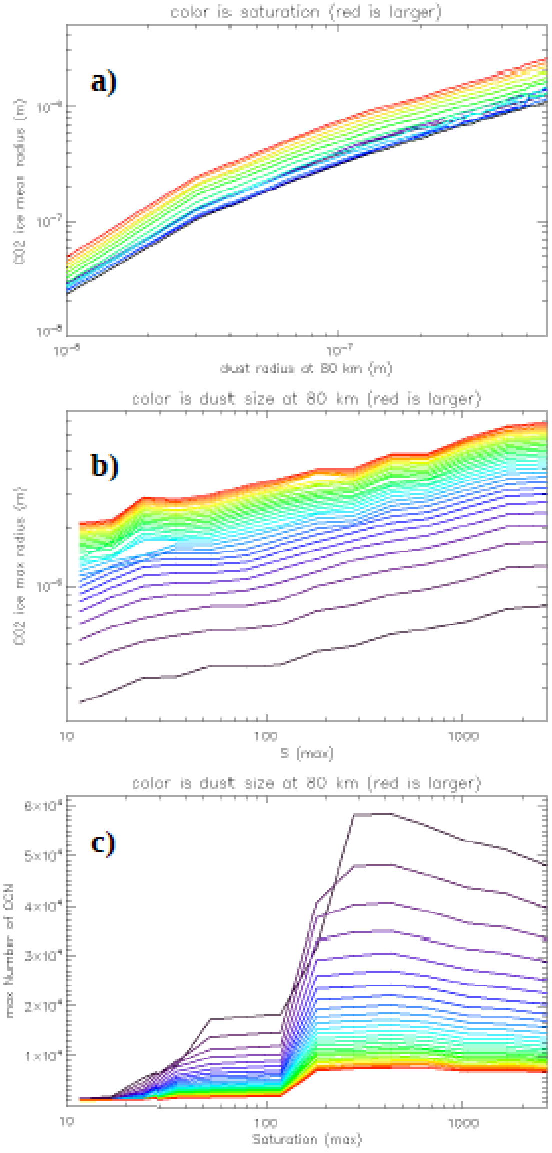

Fig. 3 : *Variations of the CO2 ice particle mean* ***(a)****, maximum* ***(b)*** *radius and maximum concentration* ***(c)*** *as a function of saturation ratio S and aerosol particle size in the mesosphere.*

Conclusions and prospects :

We have implemented a specific two moments CO_2 ice clouds microphysics scheme in the LMD-GCM.

First results using the 1-D version of the LMD-GCM and idealized conditions produce clouds with realistic properties and behaviour.

The produced clouds are very sensitive to especially the aerosol abundance and radius in the mesosphere on which the CO_2 condenses.

We now have a tool for simulating CO_2 clouds coupled to the LMD-GCM. We look forward to simulating clouds with the mesoscale version of the LMD-GCM. This will allow to reproduce the real Martian mesospheric conditions accurately, and hence to study where, when and why we have or should be able to observe clouds in the Martian mesosphere.

We also plan to study the polar tropospheric CO_2 clouds in the future and we will report on our advancement at the conference.

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