GLOBAL MARTIAN CO_2 CLOUD MODELLING IMPROVEMENTS: METEORIC FLUX AS CONDENSATION NUCLEI AND RADIATIVELY ACTIVE CO_2 CLOUDS.

C. Mathé, *LATMOS/IPSL, Sorbonne université, UVSQ Université Paris-Saclay, CNRS, Paris, France. Currently at: LMD*, **A. Määttänen,** *LATMOS/IPSL, Sorbonne université, UVSQ Université Paris-Saclay, CNRS, Paris, France*, **L. Falletti,** *LATMOS/IPSL, Sorbonne université, UVSQ Université Paris-Saclay, CNRS, Paris, France*, **A. Spiga,** *Laboratoire de Météorologie Dynamique / Institut Pierre-Simon Laplace (LMD/IPSL), Sorbonne Université, Centre National de la Recherche Scientifique (CNRS), École Polytechnique, École Normale Supérieure (ENS), Paris, France. Institut Universitaire de France (IUF), Paris, France*, **F. Forget, E. Millour,** *Laboratoire de Météorologie Dynamique / Institut Pierre-Simon Laplace (LMD/IPSL), Sorbonne Université, Centre National de la Recherche Scientifique (CNRS), École Polytechnique, École Normale Supérieure (ENS), Paris, France*, **J. Plane,** *School of Chemistry, Univ. of Leeds, Leeds, UK*.

Introduction

Mars is the only place where it has been observed that the main atmospheric constituent, carbon dioxide, condenses as clouds. Modeling these clouds remains a challenge in the community, especially for mesospheric CO_2 clouds as the conditions in this layer of the atmosphere is difficult to constrain with observations and our knowledge of the cloud formation processes in these conditions remains limited.

The recent study on CO_2 cloud modeling shows the need for water ice clouds as cloud condensation nuclei (CCN) in the formation of CO_2 mesospheric clouds [Määttänen et al., 2022] (see also Määttänen et al.'s abstract). The climatology of the simulated clouds was in good agreement with observations. However, no clouds were formed during the afternoon and optical depths of simulated clouds remained lower than observations. They supposed two missing elements for the lack of mesospheric clouds: small-scale waves (as gravity waves) that perturb the thermal structure allowing colder temperatures to form locally [Spiga et al., 2012, Yigit et al., 2015], and a new source of CCN allowing to increase the optical depth of CO_2 clouds. The suggested most likely CCN source is meteoric particles [Listowski et al., 2014, Plane et al., 2018], that have been recently reported by Mars Atmosphere and Volatile evolutioN Mission (MAVEN) [Crismani et al., 2017].

In the [Määttänen et al., 2022]'s work, CO_2 ice clouds were radiatively passive. When CO_2 ice clouds are radiatively active, atmospheric temperatures at the edge of the winter northern polar troposphere decrease in a few Kelvins, leading to CO_2 ice clouds thickness larger than CO_2 ice clouds radiatively passive [Kuroda, 2020], and so larger cloud particle size and reduced column cloud opacities [Dequaire et al., 2014]. This latter author shows also that CO2 ice clouds radiatively active do not change the CO_2 cycle in its shape, but reduced the direct deposition of CO_2 ice [Dequaire et al., 2014].

We present our latest improvements on the global martian CO_2 ice cloud modeling: (i) adding the missing source of CCN meteoric particles in collaboration with J. Plane's team who works on Martian meteoric flux modeling, and (ii) adding the contribution of CO_2 ice clouds on the radiative budget of the Martian atmosphere.

Models and simulations

The microphysical model of CO_2 cloud formation has been developed during the last decade at LATMOS and includes nucleation on CCN, condensation/sublimation, and sedimentation [Listowski et al., 2014]. CCN sources for CO_2 ice cloud formation are dust particles, H_2O ice cloud particles, and now also meteoric particles. The particle size distribution is described with the moment method allowing to compute the effect of the microphysical processes on the average properties of the distribution. For more details about the microphysical processes of CO_2 clouds, we invite the reader to the work of [Listowski et al., 2013], [Listowski et al., 2014], and [Määttänen et al., 2022].

The LMD Martian Global Climate Model (MGCM) is based on the primitive equations of meteorology in σ coordinates [Forget et al., 1999]. The model is described in [Navarro et al., 2014, Pottier et al., 2017], including water ice cloud microphysics. Simulations with this MGCM can be done with different settings: by activating or deactivating certain physical processes via options. Regarding the microphysical CO_2 cloud formation part, we describe three options used in this study: co2useh2o option enables H_2O ice as CCN; meteo_flux option enables meteoric particles as CCN; and activeco2ice option enables the contribution of CO_2 ice clouds in the radiative budget.

For this study, we performed three simulations: simulation named REF to serve as a comparison with the adding meteoric particles source as CCN; simulation named METEOFLUX to investigate the impact of the source of the meteoric particles as CCN; simulation

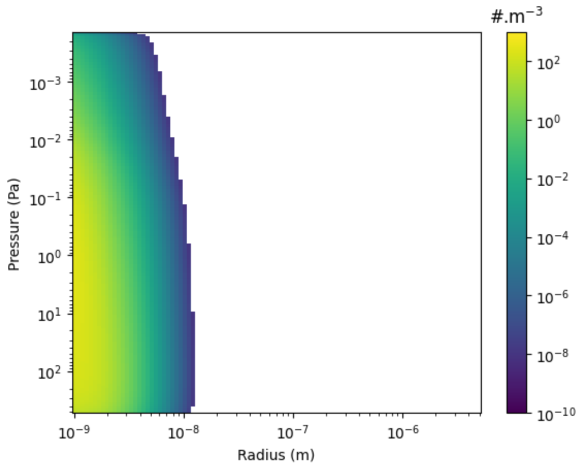

Figure 1: Input file of the distribution of the number density of meteoric particles used in the microphysical models. White areas correspond to a zero value.

named METEOFLUX+RT to investigate the impact of CO_2 ice cloud on the radiative budget. Meteoric particle flux comes from [Plane et al., 2018] work and is adapted to the radius grid of the microphysical model (Fig. 1). All simulations were performed using a horizontal resolution grid of 5.6258° longitude by 3.758° latitude. The atmosphere is divided into 32 vertical layers from the surface to the top of the atmosphere (~120 km). At each call of physical processes (every 15 minutes), the microphysics of CO_2 cloud formation is called 50 times leading to a time resolution of 18 seconds to resolve the very rapid microphysical processes. We have used a mean dust scenario, called 'climatology', built with observations from several instruments (more details on [Montabone et al., 2015].

Name	co2useh2o	meteo_flux	activeco2ice
REF	yes	-	-
METEOFLUX	yes	yes	-
METEOFLUX+RT	yes	yes	yes

Table 1: List of simulations performed for this study with activated flags: co2useh2o option enables H_2O ice as CCN; meteo_flux option enables meteoric particles as CCN; and activeco2ice option enables the contribution of CO_2 ice clouds in the radiative budget.

Meteoric particles as CCN for CO_2 cloud formation

The zonal and diurnal mean of CO_2 ice column density for each simulation is shown in figure 2: the top panel refers to REF simulation, the middle one refers to METEOFLUX simulation and the bottom one refers to METEOFLUX+RT simulation. The black solid line is the boundary of the area inside which MCS has observed atmospheric temperatures below the CO_2 condensation temperature ([Hu et al., 2012], table 4). The black dots show available mesospheric CO_2 cloud observations from several instruments [Clancy et al. 2007, Montmessin et al., 2006, Montmessin et al., 2007, Määttänen et al., 2010, McConnochie et al., 2010, Scholten et al., 2010, Vincendon et al., 2011, Aoki et al., 2018, Clancy et al., 2019, Jiang et al., 2019].

The CO_2 cycle for REF and METEOFLUX simulations is quite the same. However, there are more CO_2 ice clouds on a wider latitude range at the end of the year in the METEOFLUX simulation. The addition of meteoric particles as CCN seems to not impact strongly the CO_2 ice cloud formation, but further investigations will be brought to the conference such as CO_2 ice particles size, the thickness of clouds, local time duration, and opacities of clouds.

Contribution of CO_2 ice clouds on the radiative budget

Figure 3 shows the zonal mean of surface temperature on a latitude - solar longitude map. The top panel refers to TES climatology data [Smith, 2006], the middle one refers to METEOFLUX simulation and the bottom one refers to METEOFLUX+RT simulation. We observed that on the northern winter pole surface temperature increase by $\sim$ 20 K when we activate CO_2 ice cloud on the radiative budget, as in the southern winter pole the increased temperature is lower and ends after $\sim$ 2 months. The greenhouse effect from CO_2 ice clouds is predominant in the northern polar region.

Back to fig.2, the simulation METEOFLUX+RT formed CO_2 ice clouds during three main periods: $\sim$ 5° - 40° solar longitude (sl), $\sim$ 170° - 230° sl, and $\sim$ 330° - 360° sl. Also, the formation of CO_2 ice clouds at the northern winter polar region ends earlier at $\sim$ 20° sl with CO_2 ice radiatively active than at $\sim$ 60° sl with CO_2 ice clouds radiatively passive.

Activated radiatively CO_2 ice clouds have a strong impact on the CO_2 cycle, and further investigations such as CO_2 ice particles size, thickness of clouds, local time duration, and opacities of clouds will be brought to the conference.

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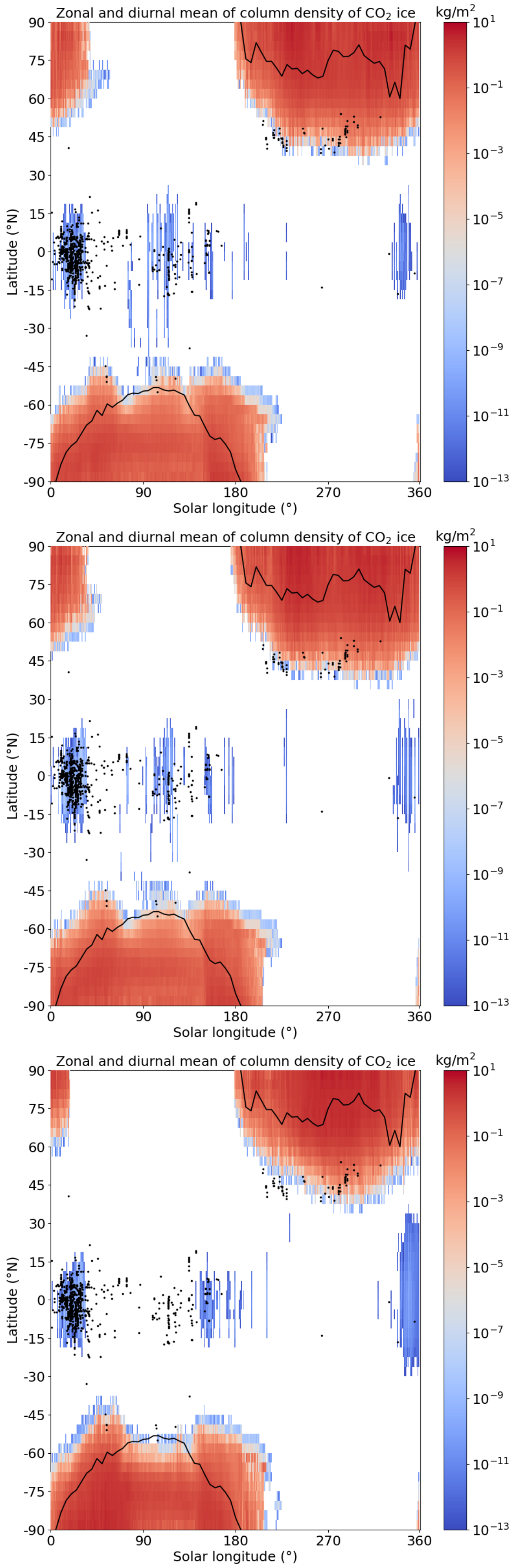

Figure 2: Zonal and diurnal mean of column density of CO_2 ice. Top panel refers to REF simulation. The middle one refers to METEOFLUX simulation. The bottom one refers to METEOFLUX+RT simulation. See text for details.

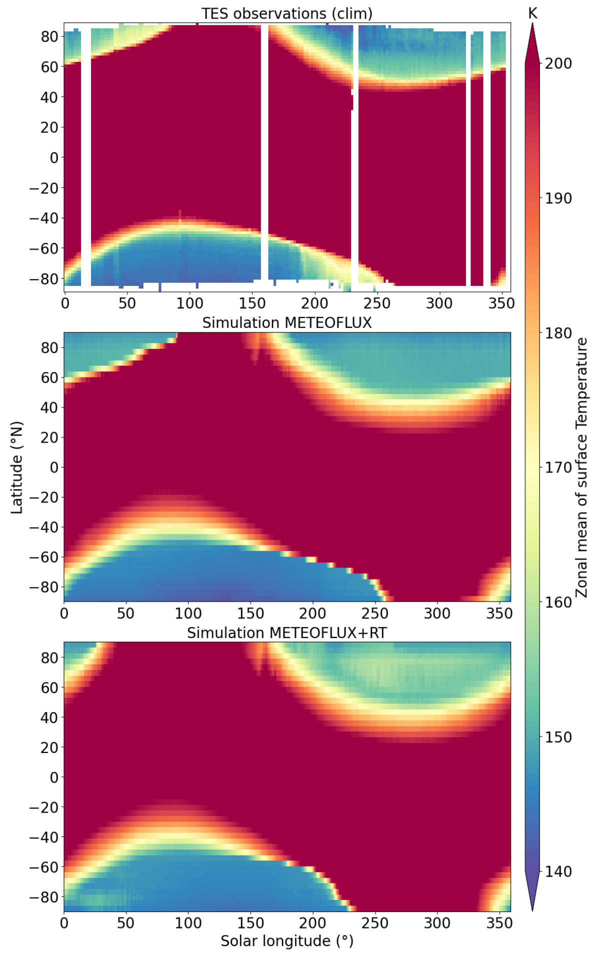

Figure 3: Zonal and diurnal mean of surface temperatures. Top panel refers to TES observations using the climatology data. The middle panel refers to METEOFLUX simulation. The bottom panel refers to METEOFLUX+RT simulation.

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