



**HAL**  
open science

## Global 3D modelling of Martian CO<sub>2</sub> clouds

Christophe Mathé, Anni Määttänen, Joachim Audouard, Constantino Listowski, Ehouarn Millour, Francois, Forget, Aymeric Spiga, Déborah Bardet, Lucas Teinturier, Lola Falletti, et al.

► **To cite this version:**

Christophe Mathé, Anni Määttänen, Joachim Audouard, Constantino Listowski, Ehouarn Millour, et al.. Global 3D modelling of Martian CO<sub>2</sub> clouds. Europlanet Science Congress 2020, Sep 2020, Virtual Meeting, France. 14, pp.EPSC2020-751, 2020, EPSC Abstracts. 10.5194/epsc2020-751 . insu-03457140

**HAL Id: insu-03457140**

**<https://insu.hal.science/insu-03457140v1>**

Submitted on 30 Nov 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



## Global 3D modelling of Martian CO<sub>2</sub> clouds

**Christophe Mathé**<sup>1</sup>, Anni Määttänen<sup>1</sup>, Joachim Audouard<sup>1,2</sup>, Constantino Listowski<sup>3</sup>, Ehouarn Millour<sup>4</sup>, François Forget<sup>4</sup>, Aymeric Spiga<sup>4</sup>, Déborah Bardet<sup>4</sup>, Lucas Teinturier<sup>1</sup>, Lola Falletti<sup>1</sup>, Margaux Vals<sup>6</sup>, Francisco González-Galindo<sup>5</sup>, and Franck Montmessin<sup>6</sup>

<sup>1</sup>CNRS, LATMOS, France ([christophe.mathe@latmos.ipsl.fr](mailto:christophe.mathe@latmos.ipsl.fr))

<sup>2</sup>Currently at: WPO, Paris, France

<sup>3</sup>now at : CEA/DAM/DIF, Arpajon, France

<sup>4</sup>LMD/IPSL, Sorbonne Université, CNRS, Paris, France

<sup>5</sup>Instituto de Astrofísica de Andalucía, CSIC, Granada, Spain

<sup>6</sup>LATMOS/IPSL, UVSQ Université Paris-Saclay, Sorbonne université, CNRS, Guyancourt, France

### Introduction

The martian atmosphere is mainly composed of CO<sub>2</sub> (~ 95 %). The first spectral confirmation of CO<sub>2</sub> cloud was acquired by Montmessin et al. [2007] using the 4.26 μm band of the ν<sub>3</sub> fundamental asymmetric stretching mode of CO<sub>2</sub> from OMEGA data onboard Mars Express.

Since then, numerous observational studies have constrained the climatology of CO<sub>2</sub> cloud in the martian atmosphere [Määttänen et al., 2013]. There are two different types of clouds involving different formation processes: (i) those located in the troposphere at the winter polar region, and (ii) those located in the mesosphere at low and mid-latitudes during the martian year [Määttänen et al., 2013]. Microphysical processes of formation of these clouds are still not fully understood. However, modeling studies revealed processes necessary for their formation: the requirement of waves that perturb the atmosphere leading to a temperature below the condensation of CO<sub>2</sub> (transient planetary waves for tropospheric clouds [Kuroda et al., 2013], thermal tides [González-Galindo et al., 2011] and gravity waves for mesospheric clouds [Spiga et al., 2012]).

We use our microphysical model of CO<sub>2</sub> cloud formation to investigate the occurrence of these CO<sub>2</sub> cloud by coupling it with the Global Climate Model (GCM) of the Institut Pierre Simon Laplace (IPSL) [Forget et al., 1999]. We focus our efforts on the modeling of the tropospheric clouds during the winter in the polar regions.

### Model description

The microphysical model of CO<sub>2</sub> cloud formation of LATMOS includes nucleation on crystals on cloud condensation nuclei (CCN), condensation/sublimation, and sedimentation. Sources of CCN for CO<sub>2</sub> are mainly dust particles, secondarily water ice 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. This method is the same as used for water ice clouds microphysics in the MGCM-IPSL [Madeleine et al., 2014, Navarro et al., 2014]. For more details about the microphysical processes of CO<sub>2</sub> clouds, we invite the reader to the work of Listowski et al.

[2013, 2014].

The MGCM-IPSL is a finite difference model based on the primitive equations of meteorology in  $\sigma$  coordinates [Forget et al., 1999]. The horizontal resolution grid used is  $64 \times 48$ , corresponding to  $5.6258^\circ$  longitude by  $3.758^\circ$  latitude, respectively. The top of the atmosphere was extended to  $\sim 120$  km to describe well the processes in the mesosphere. The atmosphere is divided into 32 vertical layers from the surface to the top of the atmosphere. At each call of physical processes (every 15 minutes), the microphysics of  $\text{CO}_2$  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 dust scenario from the MY29.

## Results

We present our first results on 3D modeling  $\text{CO}_2$  clouds in the Martian atmosphere. Figure 1 shows the zonal mean density column of atmospheric  $\text{CO}_2$  ice as simulated by the model during a Martian year. The maximum columns of  $\text{CO}_2$  clouds are found in winter polar regions. In the northern polar region,  $\text{CO}_2$  ice clouds form from around  $L_s = 220^\circ$  at highest northern latitude, reaching the latitude of  $50^\circ\text{N}$  around  $L_s = 270^\circ$ , and disappear slightly before the northern spring equinox at  $L_s = 350^\circ$ . In the southern polar region,  $\text{CO}_2$  clouds are formed from around  $L_s = 0^\circ$  at highest southern latitude, reaching the latitude of  $54^\circ\text{S}$  around  $L_s = 130^\circ$ , and disappear at  $L_s = 190^\circ$ .

This result is quite consistent with MCS for MY29 observation which showed  $\text{CO}_2$  ice cloud up to  $68^\circ\text{N}$  (Fig. 1a from Kuroda et al. [2013]) during the period  $L_s = 255^\circ$ - $285^\circ$ . Note that their observational data came from MRO-MCS Derived Data Version 2 [Kleinböhl et al., 2009], where the dust profiles retrieved in winter polar regions are likely to be caused by  $\text{CO}_2$  ice clouds [McCleese et al., 2010]. Our  $\text{CO}_2$  ice clouds simulated are also qualitatively consistent with those observed from the Mars Orbiter Laser Altimeter (MOLA) (see Figure 2). The temporal distribution of simulated clouds in winter polar regions are in good agreement with MOLA observations.

Figure 3 and 4 show the zonal mean  $\text{CO}_2$  mass mixing ratio in both winter polar regions: between  $60^\circ$ - $90^\circ\text{N}$  averaged in time between  $L_s = 180^\circ$ - $360^\circ$ , and between  $60^\circ$ - $90^\circ\text{S}$  averaged in time between  $L_s = 0^\circ$ - $180^\circ$ , respectively. The density of  $\text{CO}_2$  ice clouds simulated are in agreement with the distribution of winter polar clouds observed by MOLA during the same  $L_s$  period (Fig. 8 from Neumann et al. [2003]). The thickness of  $\text{CO}_2$  saturation layer observed by MCS during the MY29 is around 8 km in the northern polar region between  $L_s = 180^\circ$ - $360^\circ$  [Hu et al., 2012], lower than our  $\text{CO}_2$  ice cloud extension in altitude reaching around 20 km altitude. But the thickness of  $\text{CO}_2$  saturation layer in the southern polar region observed by MCS for the same year is around 15 km, nearly equal to our top of  $\text{CO}_2$  ice cloud below 15 km altitude.

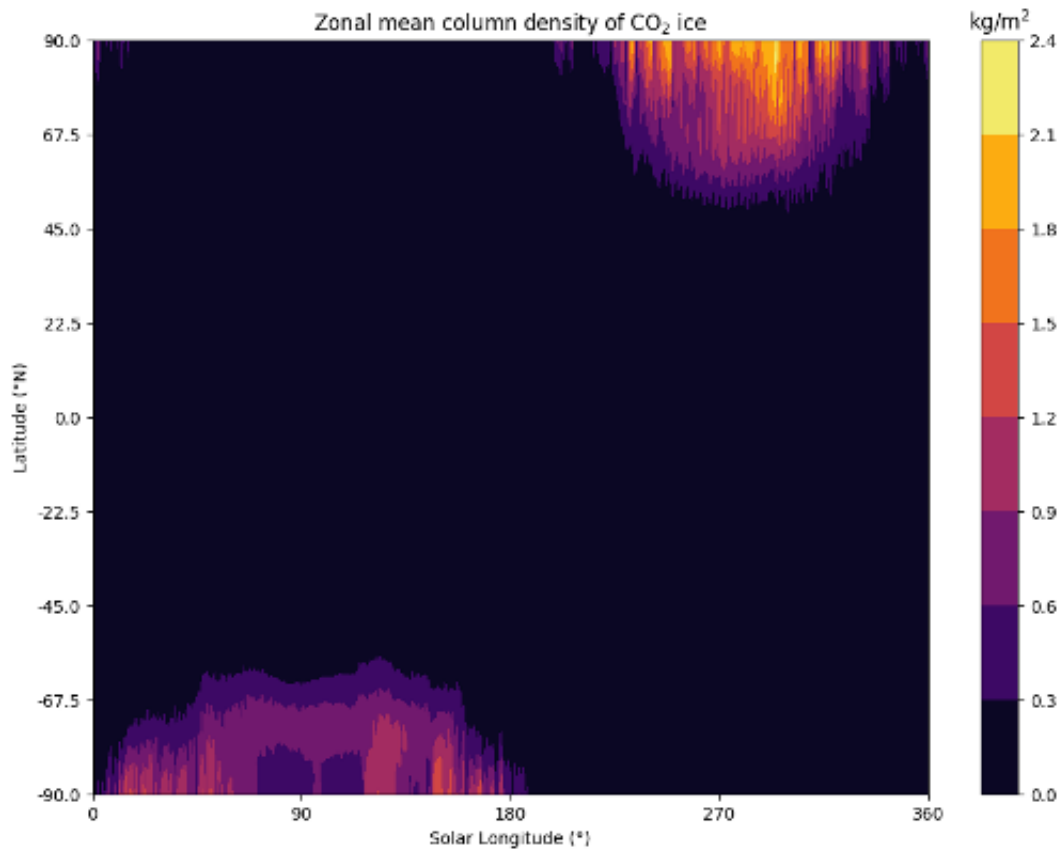


Figure 1: Zonal mean density column of CO<sub>2</sub> ice during one Martian year.

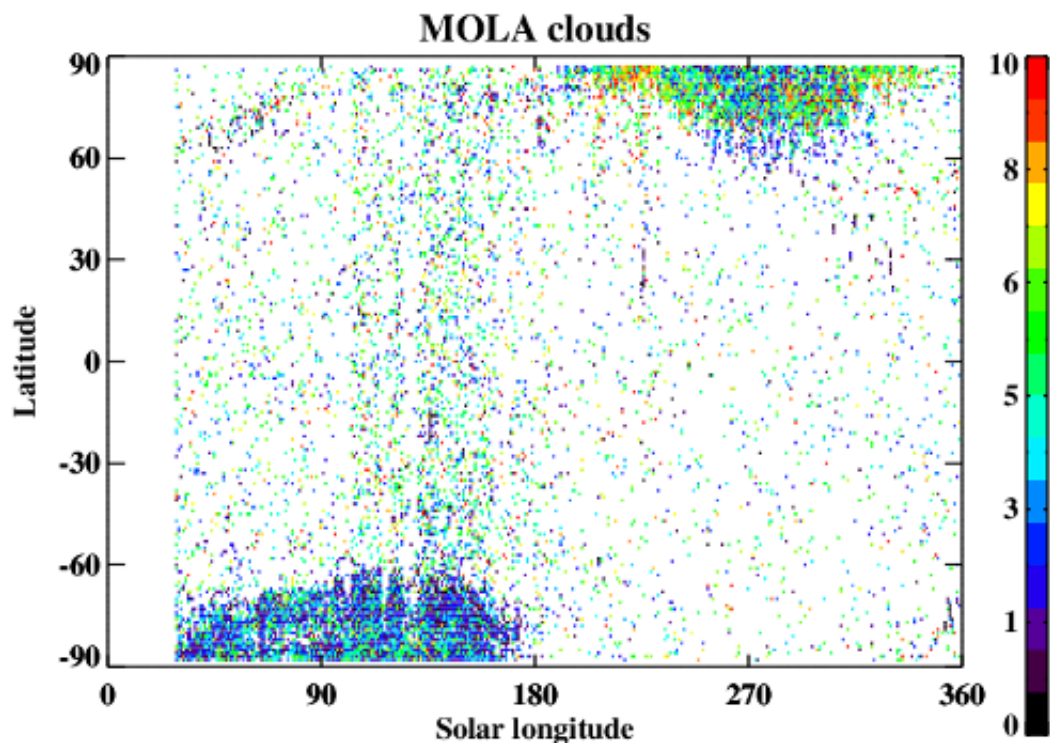


Figure 2: Cloud top altitude (km) from MOLA observations binned in 1°x1° latitude-solar longitude grid.

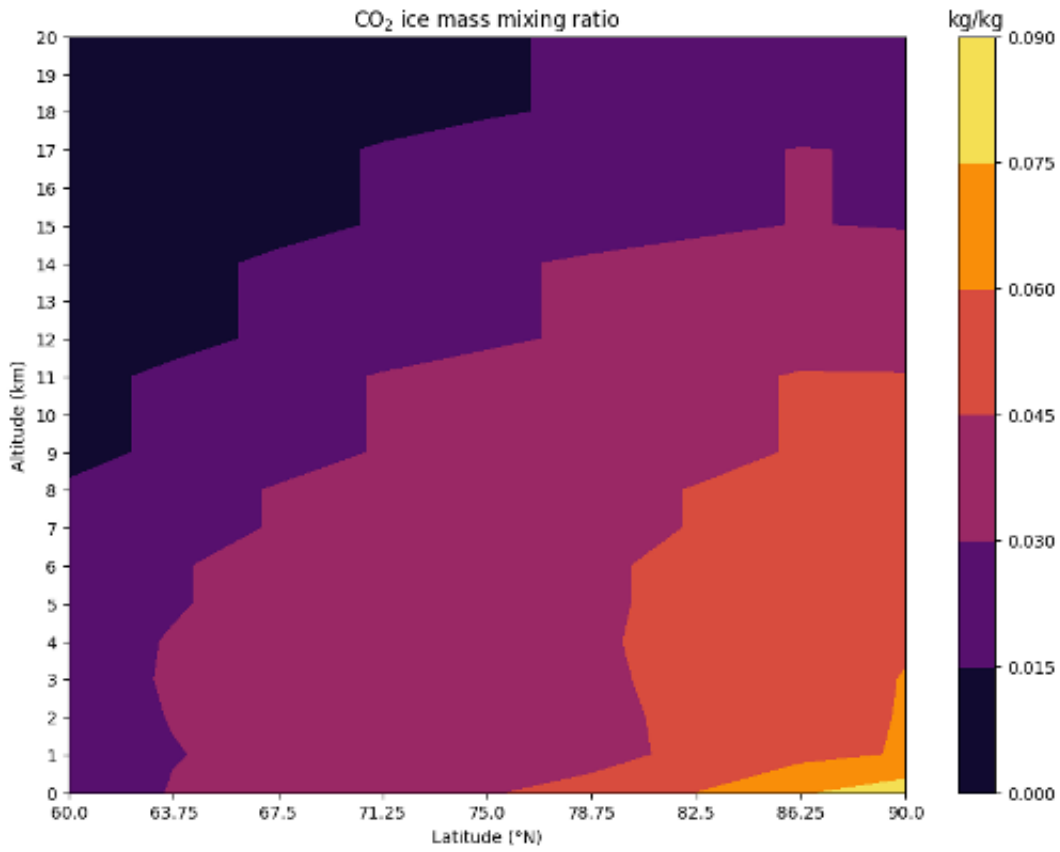


Figure 3: Zonal mean CO<sub>2</sub> mass mixing ratio in the northern polar region as a function of altitude, averaged between L<sub>s</sub> = 180° to 360°.

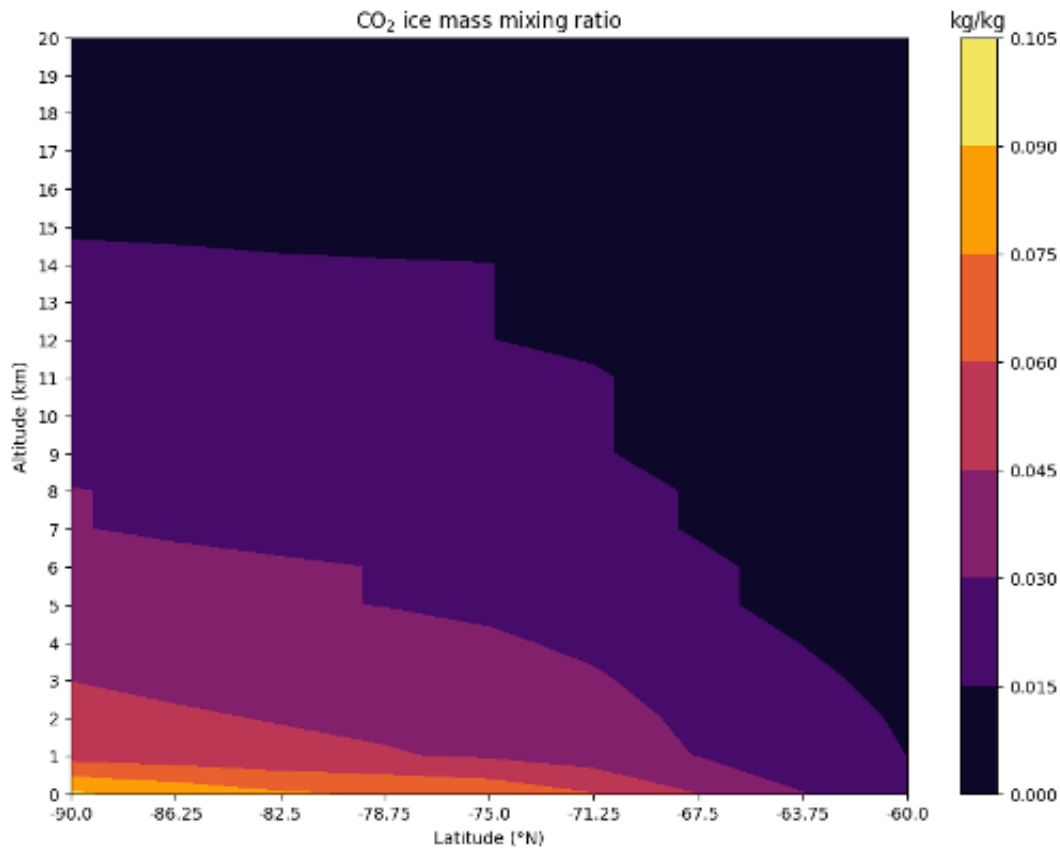


Figure 4: Same as Fig. 3, except for the south pole during  $L_s = 0^\circ$  to  $180^\circ$ .

### Conclusion

The microphysical module for  $\text{CO}_2$  clouds of LATMOS coupled with the Martian Global Climate Model of the Institut Pierre Simon Laplace has reproduced qualitatively the  $\text{CO}_2$  ice clouds in winter polar regions in the first full-year simulations. Further analysis needs to be done to complete the study of these  $\text{CO}_2$  ice clouds and compare more quantitatively to the observational data. We will also study more in detail the formation of mesospheric clouds in the martian atmosphere in the near future.

### Acknowledgments

We thank our funders, the Agence National de la Recherche (project MECCOM, ANR-18-CE31-0013), the Laboratoire d'Excellence ESEP, and the French space agency CNES.