



HAL
open science

Modeling CO₂ Clouds Convection in the Martian Polar Nights with Large-Eddy Simulations.

Vincent Caillé, Aymeric, Spiga, Anni Määttänen, Christophe Mathé, Lola Falletti

► **To cite this version:**

Vincent Caillé, Aymeric, Spiga, Anni Määttänen, Christophe Mathé, Lola Falletti. Modeling CO₂ Clouds Convection in the Martian Polar Nights with Large-Eddy Simulations.. Seventh international workshop on the Mars atmosphere: Modelling and observations, Jun 2022, Paris, France. insu-03695496

HAL Id: insu-03695496

<https://insu.hal.science/insu-03695496>

Submitted on 14 Jun 2022

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.

MODELING CO₂ CLOUDS CONVECTION IN THE MARTIAN POLAR NIGHTS WITH LARGE-EDDY SIMULATIONS.

V. Caillé, LATMOS, Sorbonne Université, UVSQ Paris-Saclay, CNRS, Paris, France (vincent.caille@latmos.ipsl.fr), A. Spiga, LMD/IPSL, Sorbonne Université, Paris, France - Institut Universitaire de France, France, A. Määttänen, LATMOS, Sorbonne Université, UVSQ Paris-Saclay, CNRS, Paris, France, C. Mathé, LATMOS, Sorbonne Université, UVSQ Paris-Saclay, CNRS, Paris, France, L. Falletti, LATMOS, Sorbonne Université, UVSQ Paris-Saclay, CNRS, Paris, France.

Introduction

CO₂ is the main component of the Martian atmosphere. It condenses both at the surface as the polar caps and in the atmosphere as clouds. Clouds play a crucial role in the CO₂ cycle at different spatial scales, from nucleation to large clouds structure, but their modeling were restrained because of the lack of observations. However, around twenty years ago, the Mars Orbiter Laser Altimeter was the first instrument to observe CO₂ ice clouds and snowfall [Neumann et al., 2003, Ivanov and Muhleman, 2001] and gave, alongside Mars Climate Sounder observations, the only properties we have about polar CO₂ ice clouds. [Colaprete and Toon, 2002] were able to determine CO₂ ice clouds formation processes and required atmospheric conditions but did not study clouds dynamics. Both the scarcity of condensation nuclei in the mesosphere and the strong coupling between convective clouds dynamics and latent heat release led to rethink microphysical theories to match the observations. In particular, CO₂ theories should be adapted to the Martian atmosphere. Modeling convective clouds also imply that we need to use a very high resolution model due to the scale at which some phenomenon occur. It is the first time that the impact of latent heat release on polar clouds dynamics through CO₂ convection is studied with a modeling technique where convecting motions are resolved.

Model

We use a model made of physical parameterizations from the Mars Global Climate Model (MGCM) developed at the Laboratoire de Météorologie Dynamique (LMD) coupled to a dynamical core from the Weather Research and Forecast (WRF) hydrodynamical solver [Skamarock and Klemp, 2008]. Domain size, spatial and temporal resolutions are fixed to run WRF in idealized Large-Eddy Simulations (LES) mode [Spiga and Forget, 2009, Spiga et al., 2017]. Principle of LES is to solve the Navier-Stokes equation at a high enough resolution filtering the smallest length scales to resolve the largest turbulent eddies, and thus the latent heat release. Initial profile is a flat plain with periodic borders along the two horizontal axis. A new model of CO₂ ice clouds

microphysics, developed at LATMOS [Listowski et al., 2012, Listowski et al., 2013] has been coupled to the MGCM (Määttänen & al., 2022 ; see abstract Mathé & al. in this conference). This notably includes nucleation of CO₂ on both water ice nuclei and dust particles, accounting for sedimentation and atmospheric conditions being impacted by condensation/evaporation. We adapted this coupling for the LES mode by adapting mass and available CO₂ calculation formulas and the required list of tracers transported by the resolved convective dynamics.

Model is here thought to run idealized simulations. The horizontal domain is set up as a 60x60 grid with a 50m step in both directions. Top of the model is 8000m above ground with 60 vertical layers. We run the model on a typical polar night initial profile obtained from the MGCM, thus a near-saturation initial temperature profile. Thermal inertia and albedo used for surface temperature calculations are respectively fixed at 260 J.m⁻².K⁻¹.s^{-1/2} and 0.26. A thermal perturbation is added in the atmosphere, around 2000m, to eventually trigger CO₂ condensation. We refer to our perturbation with the chosen delta of potential temperature, at the center of the perturbation. Potential temperature gradually decreases from the center in every directions. First simulations are made with no environment horizontal winds.

Simulations

Our reference run uses a perturbation of -2K (fig 1), what seems to be realistic in agreement with [Hu et al., 2012] temperature profiles in the polar night and could potentially be caused by gravity waves. We will show that this perturbation is enough to form a CO₂ ice cloud. Latent heat released by the phase change end up being important enough to warm up the atmosphere and trigger a convective upward movement (fig 3). “Strength” of the convection is quantified by analysing the associated vertical winds (fig 4). Because the condensation is more important at the center of the perturbation, the cloud is quickly distorted (fig 2). CO₂ precipitation can also be observed in our simulation.

We then study the impact of certain parameters on CO₂ condensation and cloud convection. A colder ini-

Modeling CO₂ Clouds Convection in the Martian Polar Nights with Large-Eddy Simulations

tial perturbation leads to more CO₂ condensing into the cloud. The cloud seems to be heavier and slightly move downward before the latent heat release is strong enough to trigger the upward convection. Convection does not seem to be stronger for a colder perturbation, ie the cloud does not reach a higher altitude. However, temperature of the perturbation seems to play an important role on the timescale, convection starting faster for a colder perturbation. Perturbation temperature is then pushed to extreme and unrealistic values to reveal eventual model numerical limits. We also study the impact of modifying the initial dust profile or activating the horizontal winds.

Acknowledgements

We thank the Agence National de la Recherche for funding (projet MECCOM, ANR-18-CE31-0013). This work was performed using HPC computing resources from GENCI-CINES (Grant 2021-A0100110391), and resources at the ESPRI mesocentre of the IPSL institute

Figures

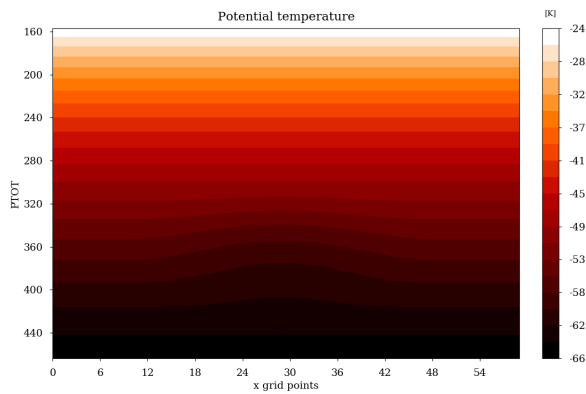


Figure 1: Initial potential temperature profile (pressure against east-west axis), from a north polar night with a perturbation of -2K around 2000m

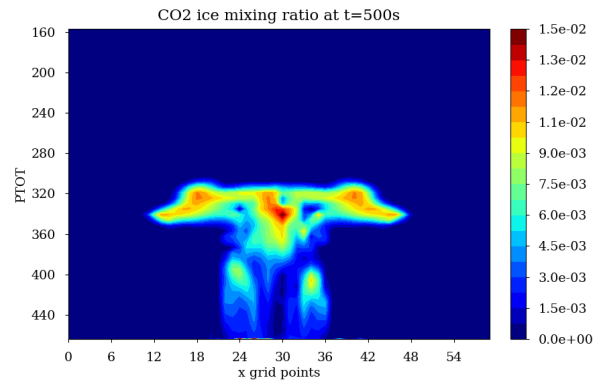


Figure 2: CO₂ ice mixing ratio profile at 500s (pressure against east-west axis). Cloud moved upward because of the convection, that also changed its global form by not being as important at the center and at the borders.

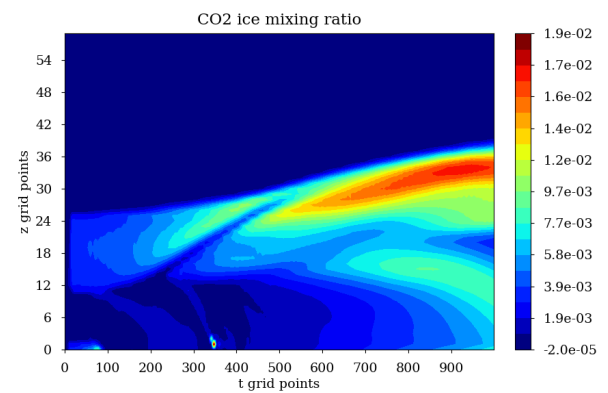


Figure 3: CO₂ ice mixing ratio for a -2K simulation, altitude against time, CO₂ cloud starts forming instantaneously. Values are averaged on the center of the perturbation layers. Convection and precipitation can be observed.

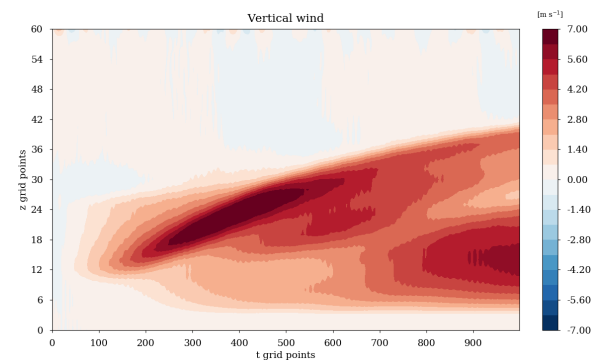


Figure 4: Vertical wind for a -2K simulation, altitude against time. Positive winds starting around 200s and ending around 500s are responsible for the cloud convection.

REFERENCES

References

- [Colaprete and Toon, 2002] Colaprete, A. and Toon, O. B. (2002). Carbon dioxide snow storms during the polar night on mars. *Journal of Geophysical Research: Planets*, 107(E7):5–1–5–16.
- [Hu et al., 2012] Hu, R., Cahoy, K., and Zuber, M. T. (2012). Mars atmospheric CO₂ condensation above the north and south poles as revealed by radio occultation, climate sounder, and laser ranging observations. *Journal of Geophysical Research: Planets*, 117(E7).
- [Ivanov and Muhleman, 2001] Ivanov, A. B. and Muhleman, D. O. (2001). Cloud reflection observations: Results from the Mars orbiter laser altimeter. *Icarus*, 154(1):190–206.
- [Listowski et al., 2012] Listowski, C., Määttänen, A., Montmessin, F., and Lefèvre, F. (2012). Modelling the microphysics of Martian CO₂ ice clouds. EAC 2012, European Aerosol Conference. Poster.
- [Listowski et al., 2013] Listowski, C., Määttänen, A., Riipinen, I., Montmessin, F., and Lefèvre, F. (2013). Near-pure vapor condensation in the Martian atmosphere: CO₂ ice crystal growth. *Journal of Geophysical Research: Planets*, 118(10):2153–2171.
- [Neumann et al., 2003] Neumann, G. A., Smith, D. E., and Zuber, M. T. (2003). Two Mars years of clouds detected by the Mars Orbiter Laser Altimeter. *Journal of Geophysical Research (Planets)*, 108(E4):5023.
- [Skamarock and Klemp, 2008] Skamarock, W. C. and Klemp, J. B. (2008). A time-split nonhydrostatic atmospheric model for weather research and forecasting applications. *Journal of Computational Physics*, 227(7):3465–3485. Predicting weather, climate and extreme events.
- [Spiga and Forget, 2009] Spiga, A. and Forget, F. (2009). A new model to simulate the martian mesoscale and microscale atmospheric circulation: Validation and first results. *Journal of Geophysical Research: Planets*, 114(E2).
- [Spiga et al., 2017] Spiga, A., Hinson, D. P., Madeleine, J.-B., Navarro, T., Millour, E., Forget, F., and Montmessin, F. (2017). Snow precipitation on Mars driven by cloud-induced night-time convection. *Nature Geoscience*, 10(9):652 – 657.