MODELING CO_2 CLOUDS CONVECTION IN THE MARTIAN POLAR NIGHTS WITH LARGE-EDDY SIMULATIONS.

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Introduction

CO_2 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 CO_2 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 CO_2 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 CO_2 ice clouds. [Colaprete and Toon, 2002] were able to determine CO_2 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, CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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). CO_2 precipitation can also be observed in our simulation.

We then study the impact of certain parameters on CO_2 condensation and cloud convection. A colder initial perturbation leads to more CO_2 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.

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Figures

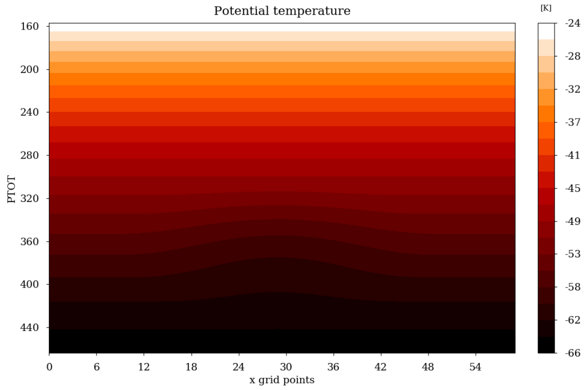

Figure 1: Initial potential temperature profile (pressure against east-west axis), from a north polar night with a perturbation of -2K around 2000m

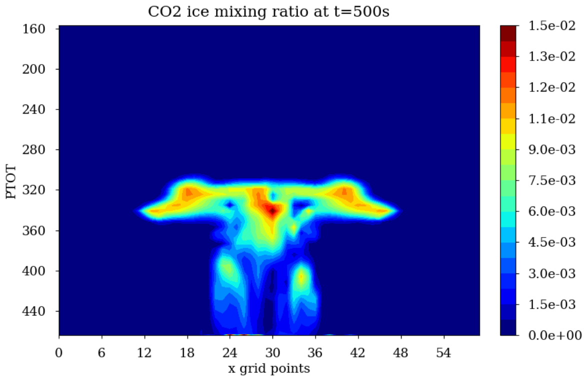

Figure 2: CO_2 ice mixing ratio profile at 500s (pressure against east-west axis). Cloud moved upward because of the convection, that also changed its global form by not being as important at the center and at the borders.

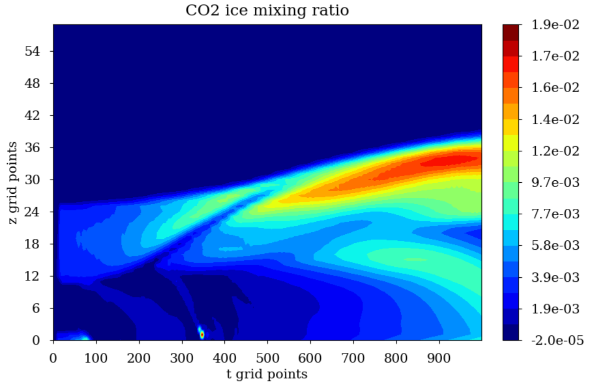

Figure 3: CO_2 ice mixing ratio for a -2K simulation, altitude against time, CO_2 cloud starts forming instantaneously. Values are averaged on the center of the perturbation layers. Convection and precipitation can be observed.

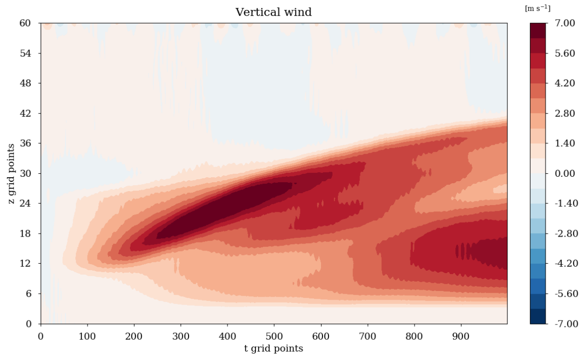

Figure 4: Vertical wind for a -2K simulation, altitude against time. Positive winds starting around 200s and ending around 500s are responsible for the cloud convection.

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