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Investigating the formation of detached layers of dust on Mars with a global climate model

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Abstract

The Martian dust cycle is of great importance for the current climate of Mars. Recently, detached layers of dust on Mars have been observed by Mars Climate Sounder (MCS), as well as the Thermal Emission Spectrometer (TES) and Compact Reconnaissance Imaging Spectrometer for Mars (CRISM). The origin of the detached layers is poorly understood. They cannot be reproduced by the traditional Global Climate Model (GCM). In this work, we parameterize strong convective dust storms (called rocket dust storms) in the GCM developed at the Laboratoire de Météorologie Dynamique (LMD). And the model outputs show that the detached layers of dust observed by the MCS are successfully predicted by the GCM with this new parameterization.

1. Introduction

Several atmospheric processes have been proposed for explaining the formation of the observed detached layers of dust, including small-scale dust lifting [1], slope winds [2], scavenging of the dust particles by water ice clouds [3] and rocket dust storm [4].

In LMD GCM, a new water cycle has been parameterized by taking into account the scavenging of water ice clouds [3]. However, this process didn't yield to satisfying results in the GCM. In LMD Martian Mesoscale Model (MMM), a detached layer was successfully reproduced [4]. In the MMM simulation, a rocket dust storm governed by deep convective motions which lead to the lifting and injection of dust at high altitudes in the Martian troposphere (∼30-50 km) was firstly resolved by the MMM. Combined to horizontal transport by large-scale winds, rocket dust storms produce a detached layer at high altitudes. But this process cannot be replicated by the GCM due to the low spatial resolution, which is typically ∼200 km. So for the purpose of reproducing the detached layers of dust in LMD GCM, we parameterize the rocket dust storm in LMD GCM to inject dust at high altitudes and see how this process couples with large-scale circulation to form detached layers.

2. Modeling method

2.1 Model description

The LMD Mars GCM is used with various recent improvements, including dust, carbon dioxide and water cycles. The model is also used with a thermal plume model parameterized in the planetary boundary layer, yielding sub-grid scale convection. A "semi-interactive" scheme is used for guiding the evolution of dust, where the total amount integrated along the vertical axis is rescaled to a prescribed dust map, but the shape of the vertical profile of dust is free to evolve.

2.2 Rocket dust storm parameterization

This is a sub-grid parameterization. For each mesh, two dust trace species were defined, i.e. dust corresponding to environmental dust (background-dust) and dust associated to the rocket dust storm (storm-dust).

1. Dust injection scheme: The storm-dust were injected in a GCM mesh only when strong dust column optical depth gradient $\Delta\tau$ are observed (typically $\Delta\tau > 0.2$, based on specific dust scenario). The spatial and temporal distributions of storms thus obtained in GCM are in line with observations.
2. Definition of the mesh fraction where the dust storm is concentrated, for each GCM level.
3. Calculation of radiative transfer through the mesh (background-dust) and through the storm (storm-dust + background-dust). Heating rates inside and outside the storm are thus obtained.
4. Considering that the increase of radiative energy related to the presence of a storm is entirely converted to adiabatic cooling, the vertical velocity of storm-dust can be directly deduced from the

extra dust radiative heating. This storm-dust is then transported vertically in the GCM.

5. Detrainment within the storm: conversion of storm-dust into background-dust and control of the ascent of the storm.
6. Horizontal transport: the dust injected in the higher layers of the GCM is transported horizontally by large scale GCM winds.

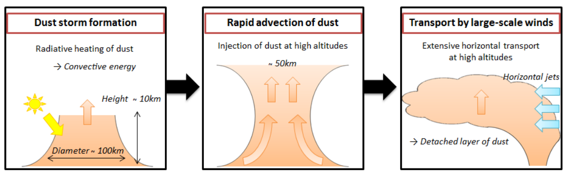

Figure 1: The principle of the parameterization of rocket dust storm

3. Results and conclusions

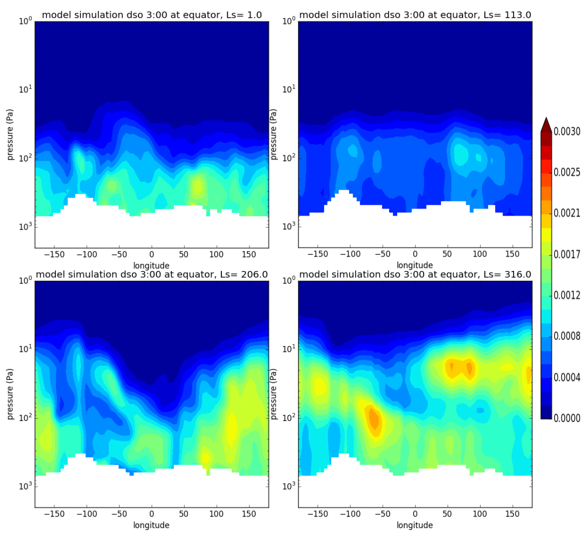

Figure 2: The model derived nightside (3h00) dust vertical distribution at equator at L_s=1.° (upleft), 113.° (upright), 206.° (downleft), and 316.° (downright).

The Figure 2 shows four cross-sections at equator about longitudinal and vertical distribution of model derived dust density scaled opacity (DSO). The detached layers can be easily identified. The altitude of the detached layers in Figure 2 reach a altitude ranging from ∼15 km to ∼ 60 km. Therefore, the rocket dust storm can produce detached layers of dust in the GCM. It should be noticed that not all the rocket dust storm will result in detached layers. The reason is that when the convective energy is not strong enough, the dust cannot be injected at high altitudes. Thus, it will stay below the planetary boundary layer and then mixes with the atmosphere.

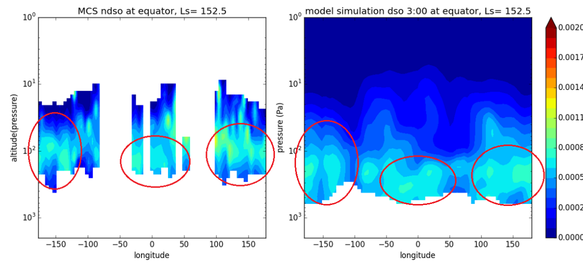

Figure 3: Comparison between MCS observation and Model simulation: nighttime dust DSO (3h00) at equator averaged from L_s=150.∼155.°.

u The comparison between MCS observation and model outputs has also been implemented. The Figure 3 shows the comparison of averaged dust DSO from L_s=150∼155°. The longitudinal distribution are quite matched between observation and simulation. But the altitude of the model derived detached layers are lower than observation. This could be caused by a strong sedimentation and/or insufficient injection of dust in GCM.

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