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Improvements to dust and aerosols in GEM-Mars GCM simulations: Results from the RoadMap project

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Abstract

We present our progress on improvements to the GEM-Mars GCM in the context of the Horizon 2020 RoadMap Project. Through an integrated approach involving lab measurements, micro-modelling, global climate modelling and remote sensing observations, the project aims to better understand the role and impact of dust and clouds on the Martian atmosphere.

Within this project, we use the data from lab experiments and micro-modelling to improve the GEM-Mars Global Climate Model (GCM), with a focus on dust optical properties, mechanisms for dust lifting and microphysical processes.

Introduction

There are still many unknowns and limitations in GCM simulations which cause inaccuracies in the modelled fields, and many of the uncertainties are related to aerosols in the Mars atmosphere. For example, the size distribution and radiative properties of dust and water ice particles are not well known. Through better characterisation of dust from laboratory measurements, we can improve the GCM simulations, and therefore improve the a priori required for data retrieval. As dust is the condensation nuclei for water ice clouds, we can also improve the microphysical representation of these clouds in the model, which in turn will provide more realistic temperatures and global circulation. The interactions in the RoadMap project will also allow to improve the representation of dust lifting, and better define the locations where dust is lifted from the surface, and when.

The GEM-Mars GCM

GEM-Mars is a three-dimensional grid-point based global climate model for the atmosphere of Mars. The physical processes and atmospheric chemistry included are described in Daerden et al., (2019) and Neary and Daerden (2018). GEM-Mars has been applied and evaluated to several recent science investigations including Smith et al. (2021), Bouche et al. (2021), Aoki et al. (2019), Aoki et al. (2022) and Trompet et al. (2022). The impacts of the 2018 global dust storm on the Martian atmosphere were explored in Neary et al. (2019), Daerden et al. (2022a,b) and Khayat et al. (2021). GEM-Mars also participated in a joint modelling exercise for the meteorological conditions at the landing site of the Mars 2020 mission (Newman et al., 2021).

Dust lifting and aerosol properties

Lab experiments using Martian analogue soils were performed by our partners at Aarhus University and the University of Duisburg-Essen and have contributed to an updated formulation of threshold wind stress to describe when lifting may occur. With the same analogue soils (prepared at the Insituto de Ceramica y Vidrio, CSIC-ICV), the scattering properties are being investigated by our partners at the Instituto de Astrofisica de Andalucia (CSIC-IAA). Results from both these lab experiments are then applied and tested in the GEM-Mars GCM.

Microphysics

Currently, GEM-Mars applies a simple dust and cloud scheme. Dust is lifted from the surface in 3 size bins (0.1, 1.5 and 10 μm) and transported by advection, mixing and sedimentation across the atmosphere. Water ice is formed at saturation (100% RH) and condensed into a single Ice Water Content (IWC) tracer. Sedimentation and radiative effects of water ice are calculated by prescribing a fixed particle radius, and assuming the particles are spherical. To obtain a reasonable water cycle over the planet and over the Martian year, the water ice sizes have to vary over altitude. In the current GEM version, these are: 1 μm above 10 km, 2 μm between 5 and 10 km, and 8 μm below 10 km. In addition, to prevent the formation of optically thick clouds over the north polar water ice cap, particle sizes are set to 150 μm below 10 km in summer (Ls = 80°–150°) (Daerden et al., 2022a).

As part of the RoadMap project, we implement a more sophisticated microphysical representation of the formation of ice clouds based on the work of Daerden et al. (2010). The scheme includes the nucleation of water ice on dust particles, deposition and sublimation of water vapour on size-resolved ice and the sedimentation of particles. In Daerden et al. (2010), a one-dimensional model with 100 particle size bins was used. Sensitivity tests using this model helped to improve the computational time for implementation in the 3D GCM. By using fewer particle size bins, we can maintain the basic features of cloud formation while greatly reducing the computational time.

Summary

We will present our progress on the implementation of new dust lifting parameters, and on the development of the size-resolved microphysical representation of dust and clouds. We will first focus on the radiative impact of the increased number of dust particle sizes on the overall global dust cycle.

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