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Modelling Martian dust storms: Feedbacks between dust and atmospheric circulation at a hierarchy of scales

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Abstract

We employ numerical models of Mars at spatial scales ranging from global to a few metres in order to investigate both the impact of increasing dust loading on atmospheric circulations and the role of different atmospheric circulation components on dust lifting, transport and on dust storm decay.

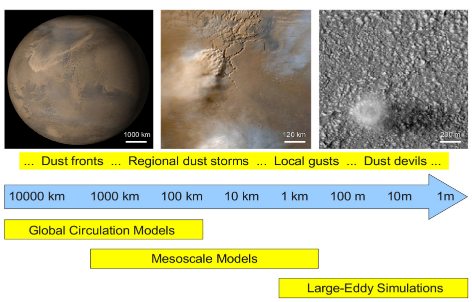

Figure 1: Typical dust lifting events, relevant spatial scales and meteorological models suitable for their analysis.

1. Introduction

Dust suspended in the Martian atmosphere has a profound influence on the atmospheric circulation, which itself in turn instigates dust lifting and determines the distribution of dust in the atmosphere through transport processes. Many key questions remain concerning the role of global, mesoscale and microscale processes in dust lifting, how the feedback from dust loading affects global [e.g. 2, 3], mesoscale and microscale circulations and how small-scale phenomena might impact on the large-scale circulation. We combine results from a Global Circulation Model (GCM) [1, 5], a mesoscale and a microscale (or Large-Eddy Simulation, LES) [8], each of which employ a similar set of physical parameterizations, in an attempt to begin to address some of these questions at a variety of spatial scales. Output from the GCM is used to supply time-dependent boundary conditions for the mesoscale model, introducing global-scale effects.

2. The influence of dust on atmospheric circulations

We first focus on the influence of dust storms on circulations. Mesoscale simulations are run in the Meridiani Terra region and we analyze modifications of wind speed with increasing atmospheric dust loading. We find that it is not possible to draw a simple conclusion, with general monotonic trends in wind speed with varying dust loading. These results underline the usefulness of detailed modeling studies e.g. for analysis of atmospheric hazards at candidate spacecraft landing sites. For smaller-scale turbulent motions, we alternatively run several large-eddy simulations in similar terrains. In these cases, the impact of dust on convective circulation is more straightforward to describe. We show how boundary layer convection is shut down by increasing dust and discuss the influence of surface temperature, atmospheric stability and radiative heating within the planetary boundary layer. This negative feedback has to be combined in the complex overall picture with other positive feedbacks, such as that found for mesoscale dust storms which can develop hurricanelike behaviour under the radiative influence of lifted dust [6].

3. The influence of atmospheric circulations on dust lifting

We then focus on the influence of atmospheric circulations on dust lifting. Dust lifting in the GCM at low and medium (climate modeling) resolutions is strongly dependent on model resolution, not only for its ability to resolve topographic slopes, but also baroclinic 'flushing' storms and the regions of high vorticity associated with them. The GCM on its own also does not reproduce the same degree of interannual variability that is observed in the martian atmosphere [4].In the mesoscale model, slope winds play a key role, modulated by thermal tides. Broadly consistent results are found between the two different dynamical strategies, if the resolution of the GCM is increased: mesoscale modelling and high-resolution (~ 40 km grid) global circulation modelling.

On the microscale, both daytime convective gusts and vortices contribute to lifting, though the latter are more efficient. Large-eddy simulations show in addition that near-surface friction velocity would be expected to be significantly larger in high plateaus than in low plains [9]. The influence of background winds on convective turbulent circulations is discussed.

4. Summary and further work

This work only represent a tentative first step towards understanding the coupling between dust and winds. Many further simulations are planned, including: (a) running longer climate experiments with GCMs under conditions appropriate to Mars both in the present day and with varying orbital parameters; (b) running global circulation models with enhanced dust in certain regions, such as Tharsis, where lifting and dust transport is thought to occur (cf. Arsia example in [7]) in order to examine the influence on large-scale climate; and, (c), running large-eddy simulations with radiatively-active, dusty convective vortices (dust devils) so as to study the influence of transported dust on dust devil characteristics.

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