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Large Eddy Simulations of the Dusty Martian Boundary Layer with MarsWRF

Zhaopeng Wu (1, 2), Mark I. Richardson (3), Christopher Lee (4), Xi Zhang (5), Claire E. Newman (3), Nicholas G. Heavens (6), Anthony D. Toigo (7), Marcin Witek (8), Tao Li (2), Jun Cui (1)
(1) Sun Yat-Sen University, Guangzhou, China, (2) University of Science and Technology of China, Hefei, China, (3) Aeolis Research, Pasadena CA, USA, (4) University of Toronto, Ontario, Canada, (5) University of California Santa Cruz, USA, (6) Hampton University, Hampton VA, USA, (7) Applied Physics Laboratory Johns Hopkins Laurel MD, USA, (8) Caltech-JPL, Pasadena CA, USA

(ustcwzp@mail.ustc.edu.cn)

Abstract

Large eddy simulations (LES) of meteorological processes and dust transport in the Martian convective boundary layer (CBL) are performed using a Mars version of the Weather Research and Forecasting model, MarsWRF, adapted to use periodic boundary conditions. A dust lifting scheme with a constant threshold wind stress is then used to examine dust lifting processes, where the lifted dust is entrained into updrafts. The radiative effects of dust lifting on CBL processes are also examined. The uniformly distributed dust in the atmosphere reduces the sunlight reaching the surface and enhances the static stability of the lower atmosphere, thus weakens the convection process (shading effect). However, the nonuniformly distributed dust perturbed by the intense convection processes will enhance both the vertical and horizontal thermal contrast at the surface and in the atmosphere and introduce more energy into the CBL by increasing the production of buoyancy (inhomogeneous effect).

1. Introduction

Strong vertical motions within convective boundary layer (CBL) can occur on multiple horizontal scales, ranging from many kilometers (e.g., deep, quasi-cellular thermal convection) to meters (e.g., small dust devils). The spatial and temporal distributions of dust lifted within these multi-scale systems are attributed to strong diurnal variation of CBL depth, and they may significantly modify boundary layer motions presented in a clear atmosphere. This study is motivated by a desire to understand the effectiveness of dust transport across the boundary layer and the role of radiative-dynamical dust feedbacks on boundary layer motions.

In this study, we use the Mars Weather Research and Forecasting (MarsWRF) model [1,2] in its microscale or large eddy simulation (LES) configuration to directly resolve motions in the CBL. The meteorological "microscale" is conventionally defined to include all motions up to the largest CBL eddies, which have horizontal scales up to about 5km on Mars.

2. Results and Discussions

The influence of the dust optical depth on the CBL is first investigated assuming a uniform dust distribution. Figure 1a suggests that the CBL height decreases as the dust optical depth increases. We can see from Figures 1b and 1c that the mixed layer potential temperature increases while the surface temperature decreases with dust optical depth. This suggests that as the airborne dust increases, it absorbs more visible sunlight and heats the atmosphere while allowing less downward shortwave energy to reach the surface. Hence the surface temperature is anti-correlated with the mixed layer potential temperature. As a result, the upward heat flux at the surface, the vertical eddy heat flux, and the turbulent kinetic energy are weakened as well. Figure 1d shows the evolution of the mean vertical wind velocity in the updraft and we can see that it becomes weaker in dustier conditions. In reality, this negative feedback of dust on the CBL convective motion will further depress the dust lifting process and prevent the dust optical depth from continuously increasing [3].

Then we examine how dust is mixed within the CBL and evaluate the correlation between dust distribution and vertical motion profiles. Figure 2 shows the variation of the correlation index with local time and altitude. If we define a correlation index larger than 0.5 as showing 'correlation' between the two variables then the 'correlated' region grows higher with local time until 15:00, after which it begins to fall. In fact, the evolution of the 'correlated' region with altitude and local time reminds us of the variations of the vertical eddy heat flux, the turbulent kinetic energy and the maximum vertical velocity shown in Figure 1 of [4]. In conclusion, the dust concentration in the updrafts occurs along with the evolution of the CBL and plays an important role in it.

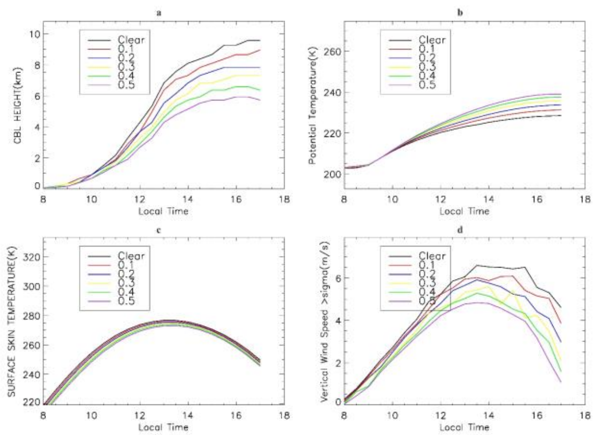

Figure 1: Variations of (a) CBL height (km), (b) mixed-layer potential temperature (K), (c) surface temperature (K) and (d) averaged vertical wind speed in the updrafts (m/s) with time for the uniform dust distribution cases with different dust optical depths (clear atmosphere, 0.1, 0.2, 0.3, 0.4 and 0.5).

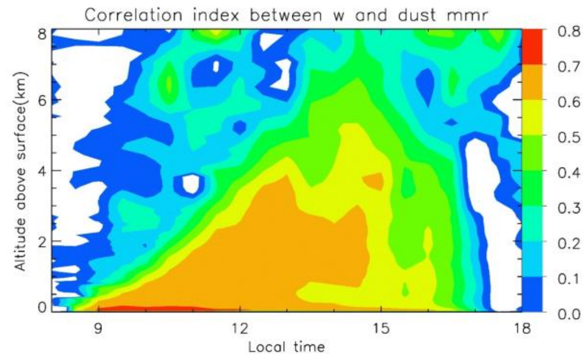

Figure 2: Variation of the correlation index between the vertical wind speed and the dust mass mixing ratio with local time and altitude.

We also examine how inhomogeneous dust distribution modifies the radiative heating on the scales of CBL turbulent motions and hence the degree to which dust amplifies CBL motions. If enough dust is lifted and perturbed sufficiently, the extra energy due to the inhomogeneous effect may compensate for the energy decrease due to the shading effect, with the overall effect being a higher CBL height at the end of the afternoon.

References

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