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Dust Devils in a Convective Mixed Layer Reproduced by a Large Eddy Simulation

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Dust devils are small-scale atmospheric vertical vortices that often occur in the daytime over bare land strongly heated by isolation. When they occur over a dessert, they can lift sand particles by their large tangential winds and are visualized as a dust column. It is known that, when a strong general wind prevails, dust storms develop and a large amount of sand is lifted into the free atmosphere. However, how much dust is lifted in the convective mixed layer in a clear day when the general wind is weak is not well understood. Furthermore, although several hypotheses for the vorticity source of dust devils have been proposed, the mechanism for their genesis has not been clarified.

In the present study, a large eddy simulation (LES) model is used to reproduce a convective mixed layer and associated dust devils near the surface, and their characteristics are examined. The domain used for the simulation is several kilometers by several kilometers in each direction, and the grid size is several tens meters in all directions. The sub-grid turbulence parameterization is based on the Smagorinsky model. The boundary condition is periodic in the horizontal directions, free-slip and adiabatic at the top. At the lower boundary, the bulk formula is used for the momentum flux and a diurnally varying heat flux is prescribed. Results of six experiments with three different general wind speeds and two kinds of the heat fluxes show that dust devils occur most frequently when general wind is weak and the heat flux is large. Furthermore, they tend to occur during the time period between 1400 and 1500 LST (local standard time) when the convective mixed layer develops deeply. These results are consistent with previous observational studies.

Since our experiment has been started from a horizontally homogeneous configuration, no vertical vorticity is present initially. A back-trajectory analyses for parcels in a dust devil shows that a stretching of vertical vorticity by a convergence of cellular convection has a dominating effect for the vortex intensification. There have been several hypothesis for the origin of the vertical vorticity later stretched to form a dust devil: 1) tilting of horizontal vorticity associated with horizontal gradient of vertical velocity by an updraft of the cellular convection (Kanak et al., 2000), 2) horizontal shear associated with non-uniform horizontal flows on the both sides of updraft in an updraft, and 3) weak vertical vorticity associated with nearly dissipated dust devils. Although it is not easy to clarify which process contributes to the origin of the vertical vorticity when convection becomes very active, a backward trajectory analysis shows that the first mechanism is dominant at the early stage.

Lastly, performed is a preliminary simulation of dust particles, the radius of which is between several and several tens micrometers, lifted by dust devils. Dust flux at the surface is determined by an empirical formula based on observations. Dependence of gravitational settling velocity of dust particles on the particle size is also considered. The results show that, even without a general wind, dust devils cause locally strong winds beyond 7m/s, which is sufficient for lifting dust particles, after 1130 LST. Dust devils quickly transport dust particles to the top of the convective mixed layer, spread them horizontally, and carry them in the downdraft regions (See the Figure, where dust particle concentration at 1400 LST is shown. The unit in the Figure is mg/m^3). Dust particles spreads over the whole convective mixed layer by 1500 LST, and continue to float even after 1600 LST when strong dust devils cease to occur.