Large Eddy Simulation on Dust Devils

Junshi Ito[1], Hiroshi Niino[1], and Mikio Nakanishi[2]
[1]Atmosphere and Ocean Research Institute, The University of Tokyo
[2]National Defense Academy
(Junshi Ito, junshi@aori.u-tokyo.ac.jp)

1. Introduction

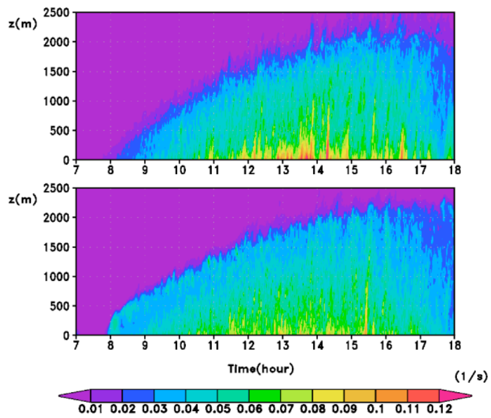
Dust Devils are small-scale vertical vortices that often occur in a convective mixed layer over a bare land or a desert. They become visible by dust particles lifted by their strong winds. Recently, several numerical studies have succeeded in reproducing dust devils by means of a large eddy simulation (LES). In this paper, we use a LES to Investigate environmental conditions favorable for dust devil occurrences and their characteristics. An extensive analysis of the LES results suggests a possible mechanism for the generation of dust devils.

2. LES model

A three-dimensional LES incorporating the conventional Smagorinsky subgrid model (Nakanishi 2000; Ito et al. 2010) is used for the present study. The grid interval is homogeneous in all directions, and is 50m in Sec. 3, 20m in Sec. 4, and 5m in Sec. 5, respectively. The size of the computation domain is several kilometers in all directions so as to accommodate several convection cells. In order to simulate a diurnally varying convective mixed layer, the surface heat flux is given by $Q_{max}\sin(t\text{-}7/11)$, where Q_{max} is the maximum value of the heat fluxes at 1230 Local Standard Time and t is time.

3. Favorable environment for occurrences of dust devils

A series of sensitivity experiments of the LES clarify the favorable environment for occurrences of dust devils. Dust devils appear most frequently under the weak general wind conditions and in the early afternoon when the convective velocity w_* becomes large (Fig. 1). These findings are consistent with field observations on dust devils (e.g. Sinclair 1969).



Fig, 1 Time variation of maximum vertical vorticity at each height with general winds of 0.5 m s^{-1} (top) and 15 m s^{-1} (bottom)

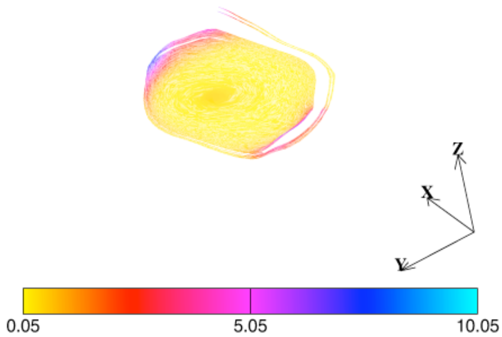
4. Sensitivity to the ways surface heat fluxes is imposed

In Sec. 3, horizontally uniform surface heat flux has been imposed. In reality, however, surface heat fluxes can depend on the wind speed. Strong tangential winds of dust devils may increase heat flux below the vortices, which, in turn, may strengthen the vortices. Ohno and Takemi (2010) showed an intensification of dust devils when the dependence of heat flux on general winds is considered with a conventional bulk method. This may be partly due to a rapid growth of a convective mixed layer. We use a quasi-bulk method, which keeps the total heat flux same but introduces a dependence of the surface heat flux on the wind speed. The LES results show that the minimum pressure depression at the core of the dust devils decreases by about 50 Pa.

5. Formation mechanism of dust devils

There have been a number of studies that discuss formation mechanism of dust devils. However, no quantitative analysis on their formation has been made. In the present study, a horizontal material surface is placed in a dust devil and is tracked backward in order to explore the origin of circulation in dust devils.

The results of the analysis show that the material surface evolves from a wide horizontal plane (Fig. 2). Both a circulation that consists of weak vertical vorticity distributed over the downdraft regions near the surface and convergent flows toward the updraft region contribute to the generation of dust devils.



Fig, 2 Three-dimensional image of the material surface 75 s before it constitutes a horizontal material surface in a dust devil. The shadings indicate the height above the surface.

6. Conclusions

A LES on dust devils has been preformed to clarify various characteristics of dust devils. Dust devils favor environments with weak general winds and large surface heat fluxes. Locally intensified surface heat flux under dust devils can additionally enhance their strength. A quantitative analysis on the formation mechanism of dust devils shows that both circulations which are commonly present in a convective mixed layer and horizontally convergent flows that transport the circulations from downdraft regions to updraft regions are important for the generations of dust devils.

References

Ito, J., R. Tanaka, H. Niino and M. Nakanishi, 2010: Large eddy simulation of dust devils in a diurnally-varying convective mixed layer, J. Meteor. Soc. Japan, **88**, 63-77.

Nakanishi, M., 2000: Large-eddy simulation of radiation fog, Boundary-Layer Meteor., **94**, 461-493

Ohno, H. and T. Takemi, 2010: Numerical study for the effects of mean wind on the intensity and evolution of dust devils, SOLA, **6A**, 5-8

Sinclair, P. C., 1969: General characteristics of dust devils, J. Appl. Meteor., **8**, 32-45