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Numerical study for the structure, intensification, and maintenance of dust devils

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In this study, an LES of a well developed CBL with a constant heat flux at the surface under no mean wind condition was conducted. In the simulated turbulent field, there are many vortices with both negative and positive vorticity: when vortices with the same sign of vorticity approach with each other they merge to become a more intensified vortex. It was found that the merger of multiple vortices with the same sign is an important mechanism for strengthening and maintaining intense vortices. It is noted that the merger of multiple vortices does not frequently occur, since both cyclonic and anti-cyclonic vortices equally exist and vortices with the same sign do not frequently approach with each other within the turbulent CBL. However, if vortices with the same sign happens to get closer with each other, the merger takes place to become a single intensified vortex. In maintaining or further intensifying the vortices, the tilting of horizontal vorticity and the stretching of vertical vorticity also play an important role.
We also conducted LESs for a CBL with four kinds of mean wind and identified all intense vortices individually to examine the effects of mean wind on the intensity and structure of dust devils. Vertical vortices are more generated and developed in the medium wind (5-10 m/s) conditions, where the most intense vortex whose maximum pressure deficit reached 78 Pa was generated. Even in the highest-shear condition, however, a rapidly intensifying and decaying vortex was found. A significant difference among the different mean wind cases is that the number of vortices significantly decreases with the increase in mean wind. It is also found that the lifetime of each vortex becomes shorter as mean wind is stronger. These results indicating dependence of vortices on mean winds are considered to be due to a couple of competing factors as follows: more distorted and disorganized structure of convective cells; stronger dissipation due to wind fluctuations; and a higher heat flux and hence a higher CBL activity.
These factors control the intensity and evolution of strong vortices under mean wind conditions. Some vortices are slanted rightward or leftward relative to the streamwise direction and then produce a pair of updraft and downdraft along those axes. The vortices are advected with the flow around itself at the lowest level and are slanted due to the vertical shear in the lower layer. These characteristics indicate that there is no preference of moving direction relative to the streamwise direction.

Keywords: dust devil, convective boundary layer, large eddy simulation, vortex