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Origin of vertical vorticity in dust devils

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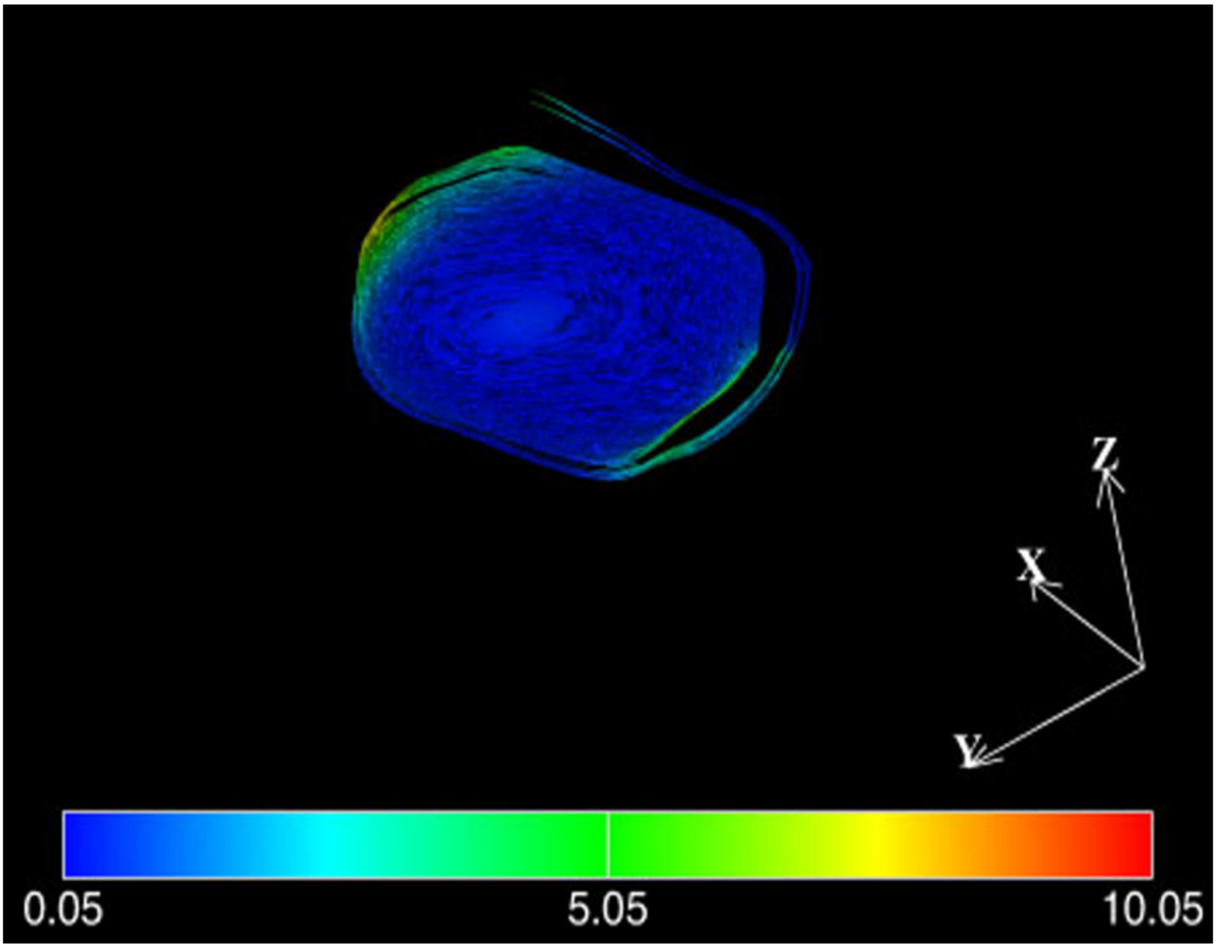

Dust devils are small-scale vortices that often occur in deserts and bare land in fine weather conditions, in which convective mixed layers develop. Previous observational and numerical studies suggested several hypotheses for the origin of strong vertical vorticity in dust devils: 1) stretching of small environmental vertical vorticity (Williams 1948), 2) tilting of horizontal vorticity associated with vertical shear of general winds (Maxworthy 1973), 3) tilting of horizontal vorticity associated with cellular convection (Kanak et al. 2000), and 4) stretching of vertical vorticity associated with horizontal shear of non-uniform convective outflows near the ground (Kanak 2005). However, no quantitative study on the source of vertical vorticity in dust devils has been preformed.

In this study, the source of rotation in dust devils is examined quantitatively. Instead of using vorticity, which has been examined in the previous studies, however, circulation, which is conserved following fluid particles in the absence of turbulent mixing, is analyzed here. We put a horizontal material surface (MS) in the core of a dust devil, which is reproduced in our Large Eddy

Simulation (Ito et al. 2010) with the grid size of 5 m, and examined the circulation associated with the MS as time goes back. In order to track the MS backward, the MS is divided into several ten thousands patches and their backward-trajectories are obtained. In our previous study (Ito et al., JpGU 2009), we tracked the MS for several minutes and made a preliminary estimate of the circulation in the MS. In the present study, a refined procedure for the estimate is introduced: when any patch expands to a critical size, it is divided two patches. A three-dimensional visualization of the MS is shown in the Figure, in which the color shade denotes height of each element.

Our analysis suggests that the MS converges toward dust devils while conserving circulation, although some variation of circulation due to turbulent mixing is seen. A drastic decrease of the horizontal area of the MS implies a strong stretching of vertical vorticity, whereas tilting of vorticity which is suggested in the mechanism of 2) and 3) is found to be insignificant. The circulation available for forming dust devils is found to exist in the downdraft regions surrounding the dust devils. The magnitude of the circulation is found to be scaled by the product of the depth of convective mixed layer and the convective velocity scale.

Keywords: dust devil, vortex, circulation, convective mixed layer, vertical vorticity, cellular convection