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On the interaction between physically produced downbursts and atmospheric boundary layer winds

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Introduction

Downbursts develop from thunderstorm clouds as buoyancy-driven downdrafts of cold and dense air. The impact with the ground produces a radially diverging horizontal outflow that can exceed 75 m s^{-1} in wind speed and cause profound damages on natural and built environment. The very localized characteristics in space and time limit the available measurements of the phenomenon in nature. A degree more of complexity is brought by the non-linear superposition of flows that finally compose the downburst system measured at the near-ground level. With these premises, a large experimental campaign recently took place at the WindEEE Dome simulator, namely the largest ad-hoc wind tunnel capable to reproduce extreme wind events, such as thunderstorm winds. This study qualitatively and quantitatively assesses the flow interface that develops upon the downburst embedment into the horizontal background wind, which composes the atmospheric boundary layer (ABL) near the ground.

1 Experimental setup

WindEEE Dome generates downburst (DB) as a large-scale impinging jet (IJ) that travels downward through a bell mouth (diameter $D = 3.2$ m) from an upper chamber (H = 3.8 m above the floor) to the testing chamber of equivalent diameter 25 m. Here, upon impingement on the ground, a radial outflow forms and is led by the primary vortex (PV) that induces the observed maximum horizontal velocities in the flow field at the boundary with the ground. Furthermore, a set of louvres at the bell mouth level allows to reproduce the effect of a travelling thunderstorm cloud by setting the IJ axis inclination to a non-vertical angle θ. In our study, $\theta = 30°$ in agreement to full-scale observations of moving microbursts in the United States (Fujita, 1985). The ABL wind is supplied by running a matrix of 6 × 15 fans located in one of the six peripheral walls of the testing chamber. This study investigates the interplay between DB and ABL winds in the case of vertical IJ axis (stationary DB) and inclined 30°-IJ axis (travelling DB) (Figure 1a,b).

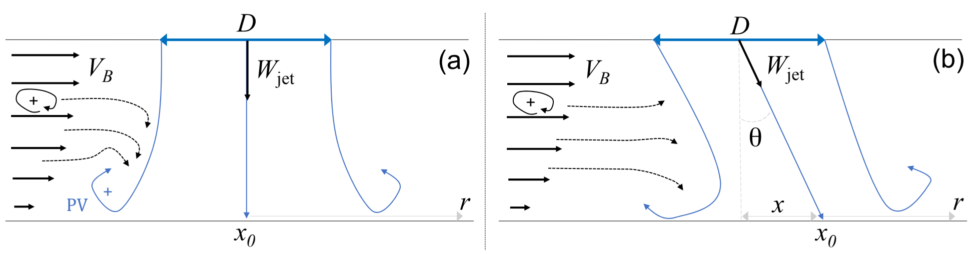

Figure 1. Downburst-like configurations tested at the WindEEE Dome (side view). Here, W_{jet} and V_B are the jet centreline velocity and characteristic ABL wind velocity, respectively.

Velocity measurements were performed using Cobra probes at a sampling frequency of 2500 Hz. A total of 8 to 10 probes were installed along a vertical stiff mast in the height range between z = 0.04 and 0.90 m above the floor. In the horizontal plane, the mast was then displaced azimuthally from α = 0° to 180° (0° corresponds to the direction of the incoming ABL flow) with incremental steps of Δα = 30°, and radially from *r/D* = 0.2 to 2.0 (*r/D* = 0 corresponds to the geometric position of jet touchdown) with increment Δ*r/D* = 0.2. The results can be mirrored to the other half of the circular domain due the symmetry. In addition to this analysis, the time and space evolution of the interface between opposite DB and ABL flows (α = 0° to 60°) was assessed by means of Particle Image Velocimetry (PIV) technique. The horizontal field of view (FOV) had size 2.40 m by 0.70 m, which was later widened by rotating it to a 60° angle and quadrupled by moving the bell mouth at 4 different *r/D* locations (Figure 2a).

2 Preview of main findings

The same relative circulation (i.e., vorticity sign) of ABL and outgoing PV at their interface makes this latter entrain the ABL flow (Figure 1a). Consequently, the rotational speed of PV increases and so does the horizontal flow underneath its structure. Meanwhile, the PV remains stagnant at the same approximate position due to the overall counter direction of ABL wind. The flow speed-up effect due to PV-ABL interaction vanishes in case of travelling DB where the particular IJ tilting at the ground distorts the PV formation at the front with ABL.

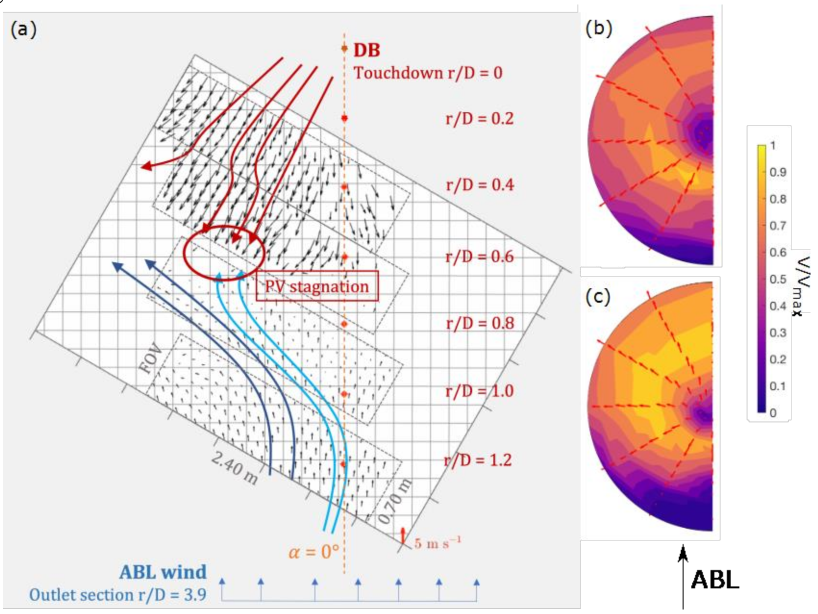

Figure 2. Horizontal velocity flow field at $z = 0.1$ m from (a) PIV (stationary DB) and (b,c) Cobra probes (stationary and travelling DB, respectively).

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