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Large-scale experimental characterization of the flow interactions throughout the occurrence of downburst winds

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ABSTRACT

In nature downburst outflows at the ground keep memory of the translation velocity of the parent cloud aloft, which inherently affects intensity and direction of the surface winds. Furthermore, the moving thunderstorm cloud as well as the developing downdraft are embedded into the background atmospheric boundary layer (ABL) winds. Only limited research has been done on how to properly account for the superposition of these effects. The limited number of anemometric stations makes the spatial reconstruction of these phenomena still difficult. This is even more true for reconstructing the complex interactions mentioned above.

The physical approaches to create downburst-like flows in wind simulators are mainly based on the impinging jet (IJ) technique. Currently, the largest geometric scales of physically produced IJs are achieved at the WindEEE Dome (~1:250 or more). Here, an unique experimental campaign was recently carried out where the mutual interplay among the different component flows was investigated by means of a very refined three-dimensional grid of Cobra probes (Figure 1b,c) and thanks to the capability of the WindEEE Dome to superimpose the three independent contributions simultaneously. Figure 1a schematically shows the 4 tested configurations of downburst-like flows: (1) reproduces the typical vertical downburst case (radial symmetric outflow); (2) is the same of case (1) but superimposed with background ABL-like flow; (3) investigates the inclination of the jet axis to replicate the effect of thunderstorm translation; finally, (4) combines the three above contributions. Measurements were performed only for half of the circle, i.e., from 0° to 180° (step 30°). Due to the symmetry, the results can be mirrored to the other half.

Figure 2 shows the velocity peak envelops in the horizontal plane for the four cases discussed. The jet inclination at the ground produces an elliptical outflow, with an intensification of the forward side and weakening of the backward side. Case (2) surprisingly shows maximum horizontal velocities at the boundary between the opposite directed downburst and ABL flows due to the same horizontal vorticity sign of the two systems; we postulate that this flow interplay causes the entrainment of the ABL winds into the downburst primary vortex and consequent flow speed-up underneath the vortex itself. This behavior is less evident in case (4) where, because of the jet inclination, the vortex at the rear-wind part partly loses its coherent and symmetric structure needed for the ABL wind entrainment.

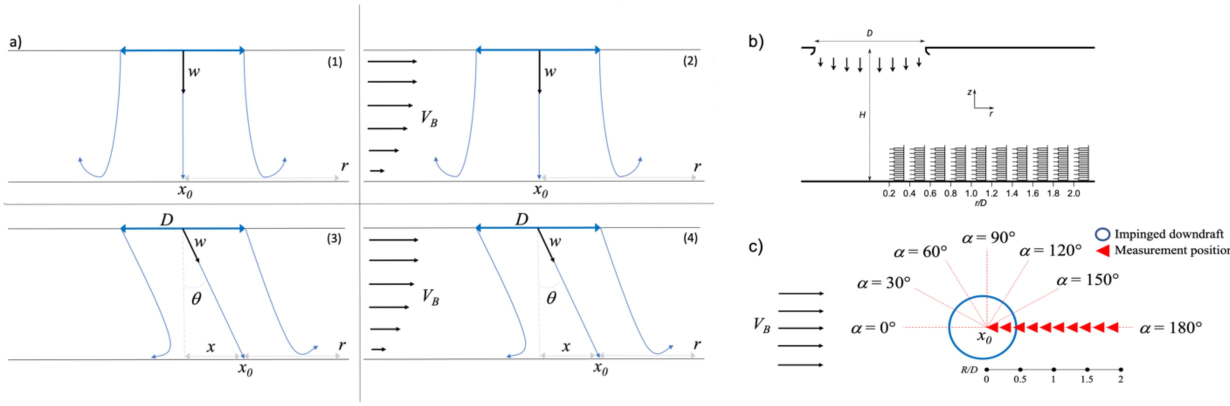

Figure 1. (a) Downburst-like configurations tested at the WindEEE Dome (side view), V_B is the ABL flow, D the jet diameter, x_0 the touchdown of the jet axis, and θ the jet-axis inclination; (b) side and (c) top views of measurement locations, α and r/D are the azimuthal and radial locations of Cobra probes, respectively.

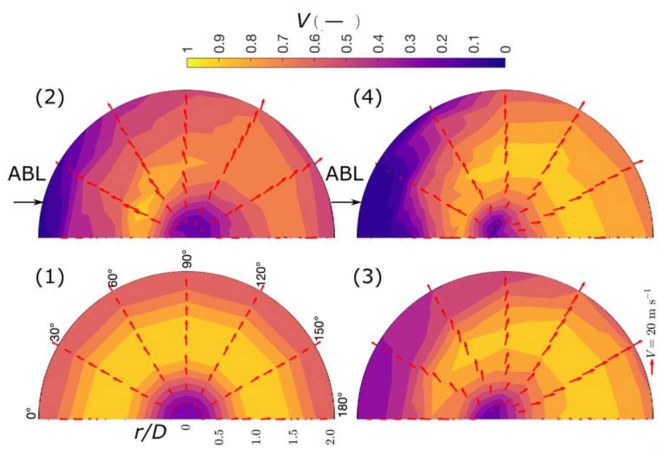

Figure 2. Downburst outflow field (horizontal plane $r - \alpha$) of primary peak envelops at $z = 0.1$ m for cases (1)–(4). Red vectors represent the actual peak wind speeds as measured by Cobra probes while the overall flow fields are obtained from their interpolation. Velocity is normalized by the absolute maximum wind speed of the respective case.

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