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CFD reconstruction of the thunderstorm downburst event of the August 14, 2018 in Genoa (Italy)

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SUMMARY:
The present study aims to numerically reproduce by means of Computational Fluid Dynamics (CFD) the recorded full-scale thunderstorm downburst event which took place in Genoa (Italy) on August 14, 2018. At the present stage, the event was reconstructed by considering the translating thunderstorm cell on the flat terrain without considering the complex topography and surrounding urban environment. The CFD results were compared with the available LiDAR profiler data in terms of radial velocity vertical profiles. The wind velocity contours presented in horizontal and vertical planes indicate high-speed wind regions to form downstream the storm translation trajectory. Similarities found between the present case and the full-scale observations suggest promising future work potential.

Keywords: Thunderstorm downburst, full-scale event, CFD simulations

1. INTRODUCTION

There is a continuously growing interest in studying thunderstorm downbursts due to the threat they might pose to severely impact the structural safety. Difficulties in recording them makes the available datasets of full-scale events rather scarce, commonly limiting the literature advancements to comparisons between numerical and reduced-scale experimental impinging jets. Although that approach has the potential to bring new insights, the impinging jets may, but also may not describe the realistic event up to the desired degree of accuracy. That lack of recorded data has recently boosted the installation of LiDARs and anemometer stations to track the evolution of such full-scale events. This is the case of the wind monitoring network installed in the Ligurian Sea which recorded a significant number of events up to date (Repetto et al., 2018; Solari et al., 2020). In that perspective the usage of the available full-scale data is found crucial to determine whether the numerical models could realistically represent the full-scale event. This study focuses on one of the events recorded by the installed LiDAR profiler and Radar system, more specificaly on the event ocurred in Genoa (Italy) on August 14, 2018. Moreover, it aims to recreate the case numerically by means of the CFD, reveal the flow structure, and finally address the applicability of the CFD approach for analyzing the downburst flow by comparing the results with the measured data.

2. FULL-SCALE EVENT

The wind monitoring network has recorded a significant number of thunderstorm events. This study considers the thunderstorm downburst event that hit Genoa (Italy) on August 14, 2018. The relevant thunderstorm characteristics were gathered based on the available Radar images and LiDAR data. In particular, the storm was found to be translating at the angle α of 30° with respect to the north from the initial touchdown location (indicated by the cross mark in Fig. 1a). The storm translation velocity V_{storm} was found to be in the range between 4 and 6 m/s, while the downdraft diameter D was estimated to 4km. The storm trajectory, initial touchdown location and the LiDAR location were presented in Fig. 1a. The LiDAR station which recorded the full-scale data is presented in Fig. 1b. Detailed report on the weather conditions during the thunderstorm event and downburst characteristics were reported by Burlando et al. (2020).

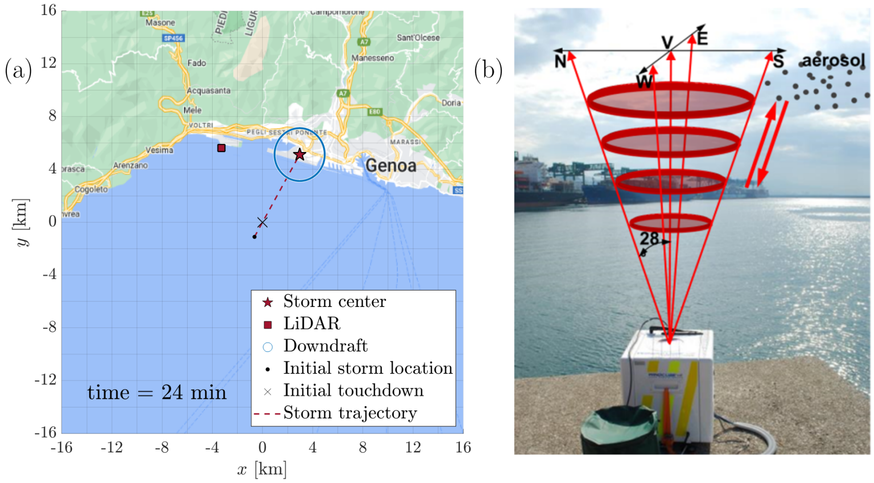

Figure 1. Downburst event occurred in Genoa on August 14, 2018: (a) storm trajectory with the indication of the initial downburst touchdown, position of the LiDAR profiler, and instantaneous storm center location with the downdraft moving along the trajectory (hereby presented for $t = 24$ min); (b) LiDAR profiler in the Port of Genoa.

3. CFD SIMULATIONS

The computational domain was created to cover the area of interest as indicated by Fig. 1a. The domain has dimensions of 32 km (width, W) x 32 km (length, L) x 2.8 km (height, H) and is presented in Fig. 2a. The vertical extent of the domain was set according to the cloud base level reported by Burlando et al. (2020). The grid counts 40 million cells characterized by a grid stretching in vertical direction (Fig. 2b), and uniform distribution in horizontal plane (Fig. 2c). A Scale-Adaptive Simulation (SAS) was carried out in order to simulate the real storm for a duration of 24 min, namely the time required for the storm to reach the coast (red star in Fig. 1a) from the initial location (black dot in Fig. 1a). The storm was set to move with the constant translational speed V_{storm} of 5 m/s at the angle α, and only the cells at the upper boundary located inside the downdraft D for a given timestep (blue circle in Fig. 1a) were treated as inlet patch faces. The vertical component of the inflow jet velocity was estimated based on the maximum radial velocity observed by LiDAR profiler, and its non-dimensional ratio with the jet velocity for the given distance from the inital touchdown location followed by the work of Žužul et al. (2023). No-slip conditions were set at the bottom, while the lateral sides were treated as the outflow.

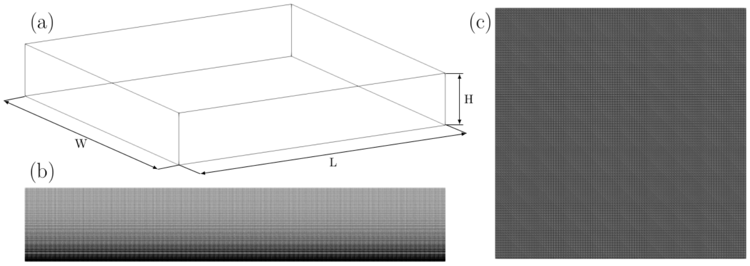

Figure 2. Schematics of the computational domain (a), and computational grid: front view (b); top view (c).

4. RESULTS

The SAS results are summarized in Fig. 3. Fig. 3a shows the wind velocity contours in the vertical plane along the storm trajectory for two selected timesteps t, namely 14 min and 22 min. The contours were made dimensionless by the inflow jet velocity magnitude V_{jet} (12 m/s). As presented, the downburst yields the asymmetric flow structure with the downdraft maintaining its vertical column as the storm propagates. The presence of the characteristic ring vortex is also observed, which is associated with the strongest wind speeds during the event occurring downstream. The upstream section of the ring vortex is found to separate from the parent storm. Similarly, Fig. 3b shows the velocity contours but in the vertical plane defined by the LiDAR (black line) and the moving storm center. At the $t = 14$ min the storm develops high-speed winds towards the LiDAR, while they occur at the opposite side at $t = 22$ min. That is indeed the case since the storm at the early stages moves (relatively) towards the LiDAR, while it moves away from it later. Figs. 3c and 3d present the velocity contours in the horizontal plane at height z of 40 m for two timesteps and show the gradual outflow spread with the indicative high-speed regions ocurring downstream. Fig. 3e shows the comparison of the radial velocity vertical profiles with the LiDAR data. Hereby, the radial velocity U is made dimensionless by V_{jet}, while z is normalized by Z_{max} (the height of LiDAR data associated with the radial velocity maximum). The SAS profiles are indicated by solid lines, while the dashed lines relate to the LiDAR data. The profile comparison is presented for three timesteps demonstrating relatively good match in time, magnitude and profile shape.

5. CONCLUSIONS AND FUTURE WORK

This study presented the preliminary results of the case aiming to numerically replicate a full-scale translating downburst by means of SAS. More specifically, the analysis covers the thunderstorm event that hit Genoa (Italy) on August 14, 2018. The velocity contours in the vertical and horizontal planes revealed the asymmetry in flow structure with the strongest winds in the direction of storm propagation. Although the presented study covers the preliminary and simplified case on a flat terrain, the simulated vertical profiles of radial velocity showed a relatively good agreement with the measured LiDAR data. The future work will lean towards further increasing the complexity of the present case to make it even more representative of reality. In that perspective, the case will consider the influence of the background atmospheric boundary layer winds, but also the presence of the complex surrounding terrain and urban environment. In its final extent, the analysis will therefore assume the detailed numerical representation of the event aiming to provide the full-field flow data, which might also provide the additional context for the possible downburst contribution to the collapse of the Morandi Bridge during the very same event.

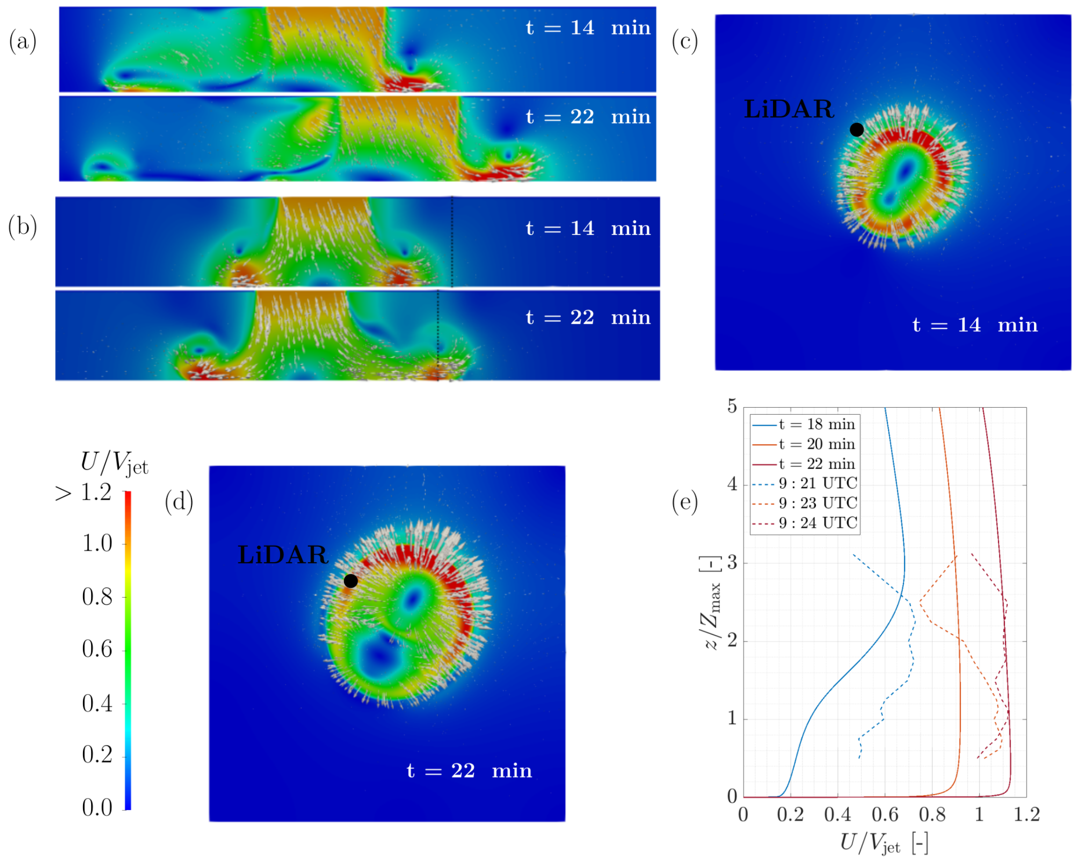

Figure 3. Velocity contours in the vertical plane along the storm trajectory (a); velocity contours in the vertical plane between the LiDAR (black line) and the storm center (b); velocity contours with the wind velocity vectors in the horizontal plane at the 40 m height in the time instance $t = 14$ min (c), and $t = 22$ min (d). Black dot represents the LiDAR; comparison of vertical profiles of radial velocity with the LiDAR profiler data (e).

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