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Assessing Ligurian downslope winds using LiDAR observations and CFD simulations

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SUMMARY

Understanding the impact of the wind on build environments is a driving force of the wind engineering community. While the impact of strong atmospheric boundary layer (ABL) winds on structures and infrastructures has been widely investigated, less attention has been given to non-synoptic extreme winds like downbursts, tornados and downslope winds (DWs). In the past, the wind engineering community has focused on downbursts and tornados, while less attention was given to DWs. These winds are a dominant wind climate in some parts of the world. For instance, DWs in Liguria are driven by the pressure gradients between cold continental air and warmer maritime air, and similarly to other extreme winds, are characterized by high velocity near the ground. In this paper preliminary results of Computational Fluid Dynamics (CFD) simulations and Light Detection And Ranging (LiDAR) measurements of DWs are compared for the case of DW near the city of Genoa, Italy. Among other results, both CFD and field measurements depict the characteristic nose-shape vertical profile of velocity component parallel to the mountain slope.

Keywords: *downslope winds, CFD simulations, LiDAR measurements, urban areas*

1. INTRODUCTION

Downslope winds (DWs) are non-synoptic winds that can have significant impact on bult environments. Most used international codes and standards for designing wind resistant structures are based on atmospheric boundary layer (ABL) winds. Though ABL winds can reach high velocities, they are sometimes characterized by lower mean wind velocities near the ground compared to other wind systems such as thunderstorm downbursts, tornados and downslope winds. DWs are generated when a cold layer of the air is forced over topography and flows along the downslope side of the relief (Durran, 2003), developing very strong surface winds when the lee slope is very steep (Figure 1a). Such winds are known to occur in different parts of the world with different local names, including for instance the Alpine foehn (Föhn), the Rocky Mountain Chinook, the Croatian Bora (Bura), Santa Ana in California and Argentine Zonda (e.g. Kozmar et al., 2012; Durran, 2014; Lepri et al., 2015). In the Ligurian valleys (Italy) near Genoa, Italy, a specific type of DW develops when the wind blows down the lee slope from the Maritime Alps and Apennines mountains towards the Mediterranean Sea (Burlando et al., 2017). The phenomenon is driven by the large-scale pressure gradient directed from the colder continental air over the mountain ridges towards the warm maritime air over the sea. Normal city operations are often adversely affected during these windstorms, which can sometimes last for several days. Thus, assessing the nature and impact of DWs on the structures and infrastructure is imperative.

In the present study, a Light Detection and Ranging (LiDAR) scanner installed in the port of Genoa will provide insight into the kinematics of DWs, while Computational Fluid Dynamics (CFD) simulations will provide a numerical assessment of the flow dynamic and kinematics. It is worth noting that, while DWs are typically simulated by using mesoscale numerical weather forecast models, the application of CFD in this field is underutilized and deserves more research. Therefore, the application of the CFD methodology to simulate this phenomenon also represents an innovative aspect of the present project. In the full paper, the results of the ongoing analyses related to CFD simulations and LiDAR measurements will be discussed more extensively.

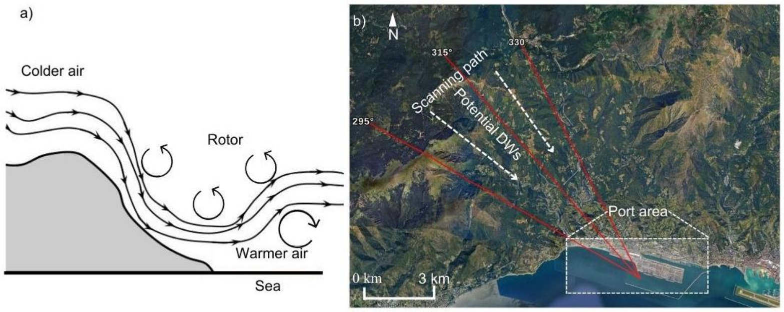

Figure 1: a) Schematics view of DWs; b) Areal view of the city of Genoa with the azimuthal sector covered with LiDAR Plain Position Indicator scans. The azimuthal angle of 315° corresponds to the measurement angle shown in the subsequent sections.

2. FIELD MEASUREMENTS

DWs occurring in the Turchino Valley (Italy) are stronger in winter than other times of the year. Thus, a measurement campaign was carried out between December 2024 to March 2025 under the "ERIES-LIDAR" transnational access project. The LiDAR scanner operates in a range of 14 km and a gate resolution set to 75 m. It is installed at the end of a long quay, 5 m above the mean sea level. Azimuthal scanning range was in the interval 295°–330°, which is best suited for measuring DWs approaching the LiDAR from the north-west direction (Figure 1b). Multiple DWs events were captured during this measurement campaign.

3. CFD SIMULATIONS

Steady Reynolds-Averaged Navier-Stokes (RANS) simulations were performed on a simplified 2.5-dimensional computational domain. The simplification of geometry was carried out in two steps. First, the orography was used to retrieve characteristic slopes by "slicing" the area of interest (Figure 2a) and saving the coordinates of each characteristic slope (Figure 2b). In Step 2, the extracted coordinates of characteristic slopes were imported in the open-source software Blender, where slopes were simplified using the decimate modifier to merge vertices without losing overall terrain shape (Figure 2c). The computational grid was constructed using the *blockMesh* dictionary of OpenFOAM (v2412). It is a structured mesh comprising approximately 8.8 million cells.

A logarithmic mean wind velocity profile was imposed at the inlet to characterize approaching ABL wind, with aerodynamic roughness length (z_0) of 0.05 m, and reference wind velocity of 10 m/s at 660 m above the mean sea level (friction velocity u_*=0.773 m/s) . The temperature inside the domain as well as the temperature on the walls was set to decrease with height, following the standard atmospheric lapse rate (6.5 K/km). The temperature at the inlet is also decreasing with height but following a different lapse rate of 6.07 K/km to mimic the colder air coming from the upwind side of the mountain. The temperatures shown in Figure 2d are chosen to represent a DW event that occurred in Genoa on the 13th and 14th of December 2024. The *buoyanSimpleFoam* solver, with $k - \varepsilon$ turbulence closure model was used to perform the simulations.

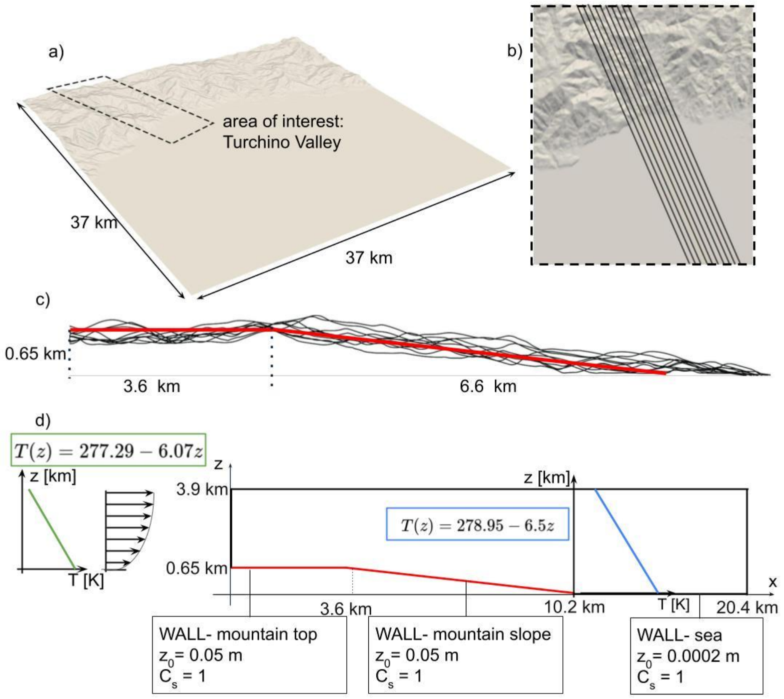

Figure 2: a) 3D orography of the municipality of Genoa with the area of interest (dashed box); b) Area of interest sliced in 10 sections which were used to define c) the characteristic slopes along the valley (black lines) and calculate a simplified average slope (red line) used in CFD simulations; d) simplified geometry constructed with the simplified slope, boundary and initial conditions for temperature gradient and mean wind velocity at the inlet.

4. RESULTS AND CONCLUDING REMARKS

Figure 3a shows the development of the nose-shape vertical profiles (i.e., normal to the mountain slope) DW profiles simulated at three points inside the computational domain. The velocity profiles are normalized with the maximum velocity (U_{max}) sampled at each sampling point. The height is also normalized with the maximum height of the domain (z_{max}). The figure shows that the maximum velocity of the nose-shape profiles moves towards the ground while the wind blows further down the slope.

Figure 3b shows the comparison between the CFD profile at point P3 and three LiDAR-measured vertical profiles of radial velocity at the same position. There is always a significant nose shape vertical profile of wind speed, even if the height of the maximum wind speed changes in the throughout the event. Moreover, the comparison with CFD results shows that the maximum velocity in CFD is closer to the ground compared to the measurements. However, considering the high level of simplification introduced in the computational model, the first qualitative comparison of CFD and LiDAR in terms of vertical profiles seems promising. Additional results will be shown during the presentation.

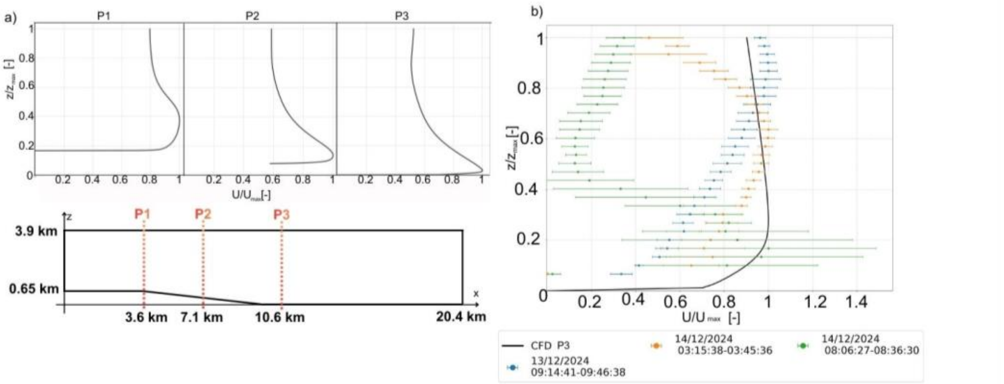

Figure 3: a) Simulated nose-shape profile of DW along the computational domain at three sampling points; b) comparison of CFD results with the 30 min averaged radial velocity profiles from the LiDAR scanner at 3 different time steps during DW event.

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