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WIND TUNNEL TESTING OF RAIN GAUGES AND DISDROMETERS TO VALIDATE NUMERICAL SIMULATION

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KEY POINTS

- *Wind tunnel measurements and numerical simulations were performed to assess the wind-induced bias on rainfall measurements from traditional rain gauges and disdrometers*
- *The comparison between observed and simulated trajectories validated the numerical model used to derive adjustment curves*

ABSTRACT

Atmospheric precipitation measurements are affected by systematic errors due to the impact of wind. This work presents the evidence of the wind-induced bias for both traditional rain gauges and disdrometers in controlled wind tunnel conditions. A physical full-scale experimental set-up was designed and implemented in the wind tunnel facility of Politecnico di Milano (hereafter GVPM) to reproduce and capture the trajectories of falling water drops when approaching the collector and the sensing area of traditional rain gauges and laser disdrometers, respectively. The experiments allowed to collect a large data set of high-resolution footages of the deviation of such trajectories used for the validation of Computational Fluid Dynamics simulations. The numerical approach allows to derive correction curves for each instrument geometry under various wind speed, wind direction, rainfall intensity and drop size distribution combinations.

INTRODUCTION

Precipitation measurement instruments exposed to the wind behave like bluff body obstacles producing aerodynamic disturbances on the surrounding airflow field (Jevons, 1861). These airflow features, strictly dependent on the instrument outer shape, produce deformation of the falling drop trajectories generally resulting in a lower collection of precipitation than in the absence of wind and in unexpected combinations between the drop fall velocity and the drop size sensed by disdrometers. Disdrometers present a complex and non-radially symmetric shape that makes the wind-induced bias dependent on wind direction.

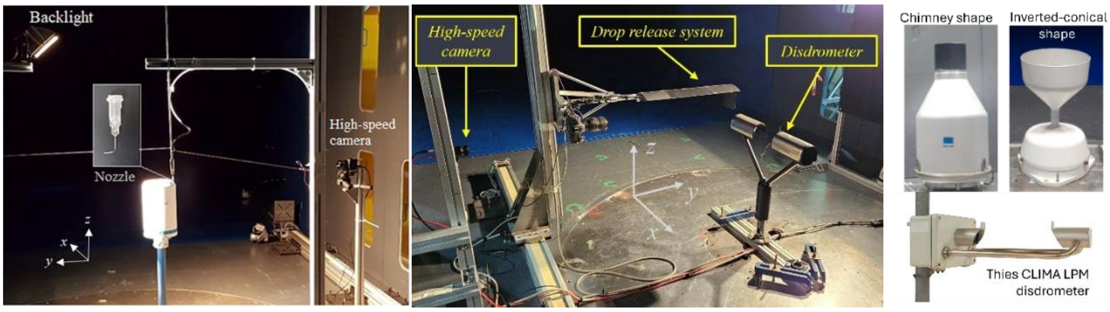

Figure 1. Experimental setups in the GVPM used to release drops and photograph their trajectories with installed a cylindrical rain gauge (left-hand panel) and the OTT Parsivel² disdrometer (central-hand panel). Wind is along the *x* direction. Further instruments tested are shown in right-hand panel.

Adjustments for the wind-induced bias are traditionally derived from field experiments but a numerical approach, based on Computational Fluid Dynamics (CFD) simulations, allows to investigate a wider variety of instrument shape, wind and precipitation climatology. The two Wind Tunnel (WT) experimental campaigns conducted within the framework of the Italian national projects PRIN20154WX5NA and PRIN2022MYTKP4 for traditional rain gauges and disdrometers, respectively, provide evidence of the wind/instrument body interaction on the drop trajectories and allowed to collect a rich dataset for the validation of CFD results.

METHODOLOGY

Full-scale tests were conducted in the high-speed, low-frequency test section of the GVPM. The chamber (4m wide, 3.8m high and 6m long) is characterized by a nearly laminar flow (i.e. the along-wind turbulence intensity is lower than 0.2%) and a boundary layer extending approximately 0.1 meters from the walls.

During each test the instrument was fixed on the floor of the test chamber, centered in the along-wind direction. To calibrate the release position of water drops, the generator was mounted on an automated traversing, allowing the movement in the longitudinal and vertical directions. The purpose-built drop generator allows to release on demand water drops into the wind flow. The apparatus includes a control unit, a syringe pump, and an electrostatic release system. The detachment of the drop from the tip of the needle is achieved by applying a 5 kV potential difference between the needle and a metallic ring positioned few millimetres below. This drop generator was designed and used to test the disdrometers during the recent experimental campaign (in September 2024), while during the previous experimental campaign, where only traditional rain gauges were tested, a simpler drop realising system based on the adjustment of the releasing frequence of a series of drops was employed (see Cauteruccio et al., 2021a and 2021b for details). In both cases the trajectory of each released drop on the along-wind vertical plane was recorded above the instrument sensing area by using a high-speed camera set to 1000 fps. The images of each drop recorded by the camera were converted to greyscale and binarized to remove the background. A combination of a Gaussian and Laplacian filter was applied. Using a moving window over the image, the center of the drop was identified and stored. Knowing the time interval between two subsequent images the drop velocity in the 2-D shooting plane was calculated.

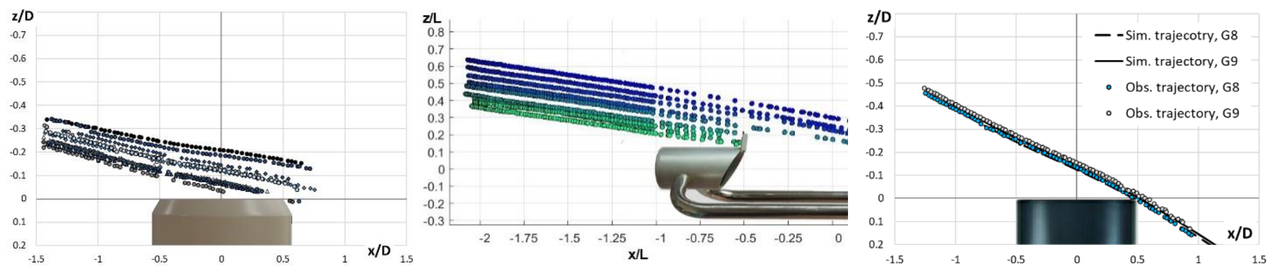

Figure 2. Sample sets of drop trajectories shot at 1000 fps, as observed above the collector of the cylindrical gauge (left-hand panel) and the Thies CLIMA LPM disdrometer (central panel) at wind speed equal to 12.5 m/s and 10 m/s, respectively. Wind travels from left to right, D is the collector diameter and L the length of the laser sheet. On the right-hand panel a comparison between two simulated (lines) and observed (dots) trajectories above the collector of the chimney shaped gauge at wind speed equal to 10.2 m/s is reported. [source: Cauteruccio et al., 2021b].

The three most typical outer shapes of commercial traditional rain gauges, namely the cylindrical, the "chimney" and the inverted-conical shape, were investigated during the PRIN20154WX5NA experimental campaign while recently (during the PRIN2022MYTKP4 activities) the Thies CLIMA LPM and the OTT

Parsivel[2] laser disdrometers were tested (see Figure 1). These disdrometers use an optical principle to derive the size and velocity of each drop that crosses the sensing area (a thin infrared laser sheet). Experiments were conducted for wind speed from 8.5 m/s to 13.5 m/s and drop diameters between 0.9 mm and 1.2 mm. Different releasing heights were also tested and for the two disdrometers, that are characterized by a not radially symmetrical shape, three different wind direction were also tested: 0°, 90° and 180°.

RESULTS AND DISCUSSION

The recorded drop trajectories (see Figure 2) provide evidence of the particle-fluid interaction that is responsible for a significant deviation of the trajectories close to the instrument. A few undisturbed trajectories aiming at entering the collector close to the downwind edge overtake its rim and fall outside of the gauge. The good repeatability of the experimental setup was demonstrated by comparing the trajectories of very similar drops: the observed trajectories characterized by very similar initial conditions were indeed very close to each other, and they experienced similar deviations above the instrument. The validation of the numerical model (described in Cauteruccio et al., 2021b) was obtained by comparison between observed and simulated trajectories (see an example in Figure 2). The differences between the position of observed and simulated trajectories are comparable with the drop size, therefore with the uncertainty in the assessment of the drop position, identified as a bright moving object in each frame. Simulated trajectories show that the numerical model can replicate even the small variations due to slight differences in the initial drop velocity.

CONCLUSIONS

The present work provides evidence of the wind effect on rainfall measurements by shedding additional light on the wind exposure problem. Indeed, the WT validation of the numerical approach supports the derivation of adjustment curves that can be used operationally to correct precipitation measurements obtained in windy conditions. In the work of Cauteruccio et al. (2024) and Chinchella et al. (2024) adjustment curves for the most common outer shapes of traditional rain gauges and for the Thies CLIMA LPM disdrometer are presented.

ACKNOWLEDGMENTS

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