Università di Genova | DICCA DIPARTIMENTO DI INGEGNERIA CIVILE, CHIMICA E AMBIENTALE

EGU General Assembly 2020

The role of free-stream turbulence on the collection performance of catching type precipitation gauges

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May, 7th 2020

The exposure problem

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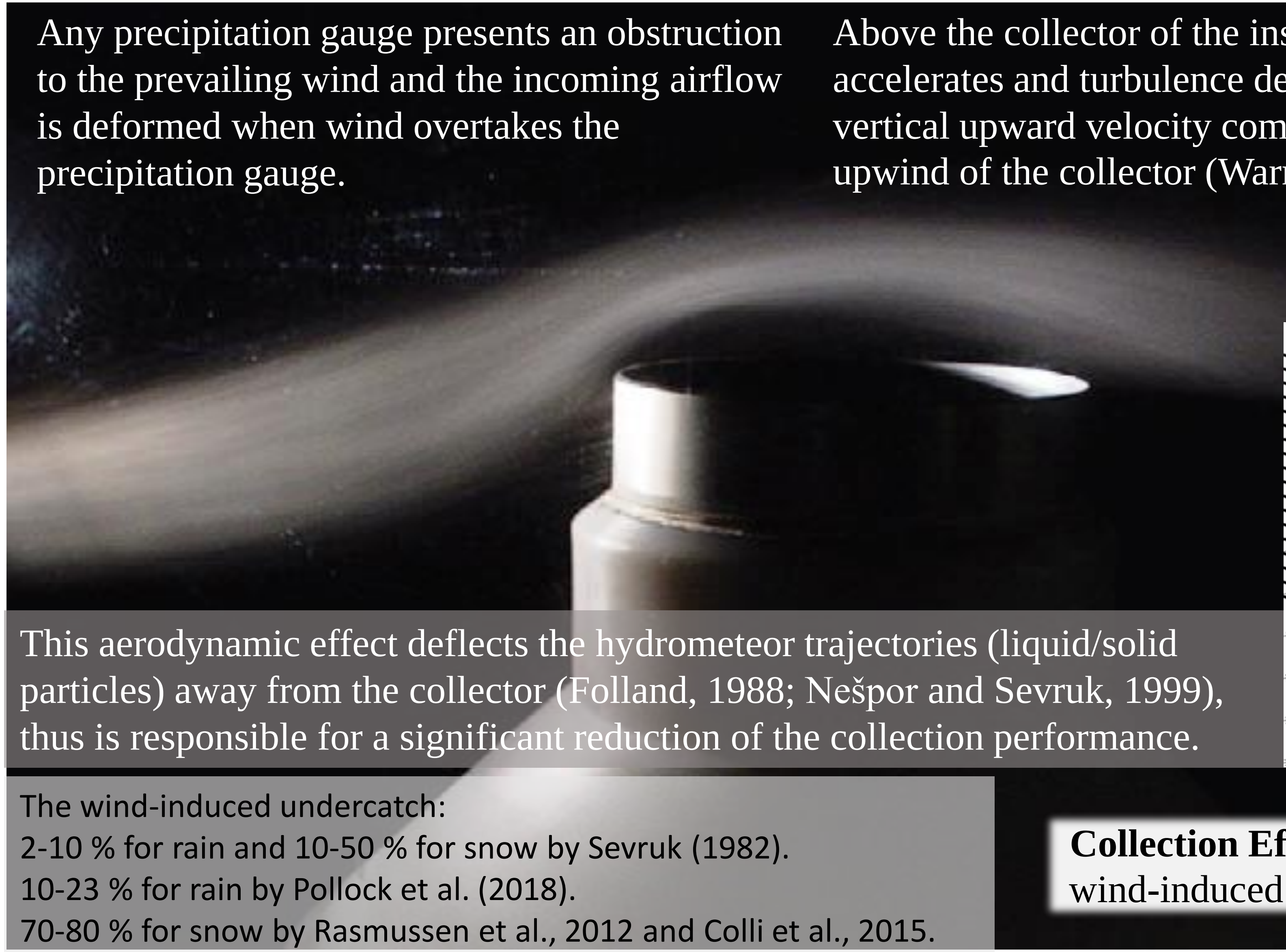
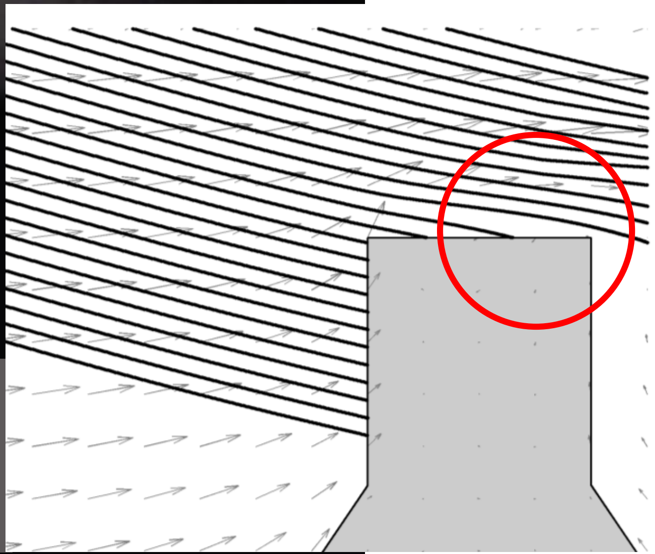
For catching type precipitation gauges, **WIND** is the major environmental source of precipitation measurement biases



Any precipitation gauge presents an obstruction to the prevailing wind and the incoming airflow is deformed when wind overtakes the precipitation gauge.

Above the collector of the instrument, wind accelerates and turbulence develops, while vertical upward velocity components arise upwind of the collector (Warnick, 1953).



This aerodynamic effect deflects the hydrometeor trajectories (liquid/solid particles) away from the collector (Folland, 1988; Nešpor and Sevruk, 1999), thus is responsible for a significant reduction of the collection performance.

The wind-induced undercatch:
2-10 % for rain and 10-50 % for snow by Sevruk (1982).
10-23 % for rain by Pollock et al. (2018).
70-80 % for snow by Rasmussen et al., 2012 and Colli et al., 2015.

Collection Efficiency curves allow to correct wind-induced errors for operational purposes.

Collection Efficiency

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The Collection Efficiency (CE) depends on the gauge geometry, wind speed (U_{ref}), type of precipitation (Rain or Snow), Particle Size Distribution (PSD) and precipitation intensity (*RI* or *SI*)

Snow gauge in operational conditions

WMO

DFIR is the reference for snow measurements

In the **field**:

$$CE(U_{ref}) = \frac{h_m(U_{ref})}{h_r}$$

h_m is the gauge measurement in operational conditions

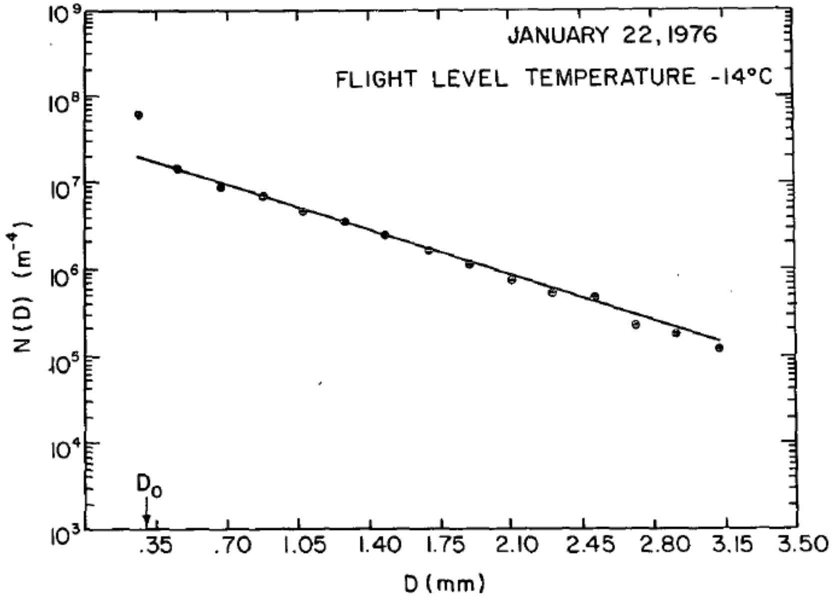
h_r is the reference measurement

In the **theoretical CE** the precipitation collected in disturbed airflow conditions is calculated as the integral over the range of diameters of the number of collected particles per each size ($n(d)$), weighted by the number of such particles in the PSD, ($N(d)$)

$$CE(U_{ref}) = \frac{\int_0^d \rho_p \, V_p \, n(d) \, N(d) \, \mathrm{dd}}{\int_0^d \rho_p \, V_p \, n_{max} \, N(d) \, \mathrm{dd}}$$

$$N(d) = N_0 e^{-\Lambda d}$$

(Marshall & Palmer, 1948)



Example of measured PSD data
(Houze et al. 1979)

Method of investigation: CFD simulations

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One-way coupled approach

1) Eulerian airflow model

Computational Fluid Dynamics Simulations (CFD): RANS and LES

Result:

- Air velocity ($\mathbf{v_a}$)
- Local turbulence that develops due to the gauge body obstruction

2) Lagrangian Particle Tracking (LPT) model

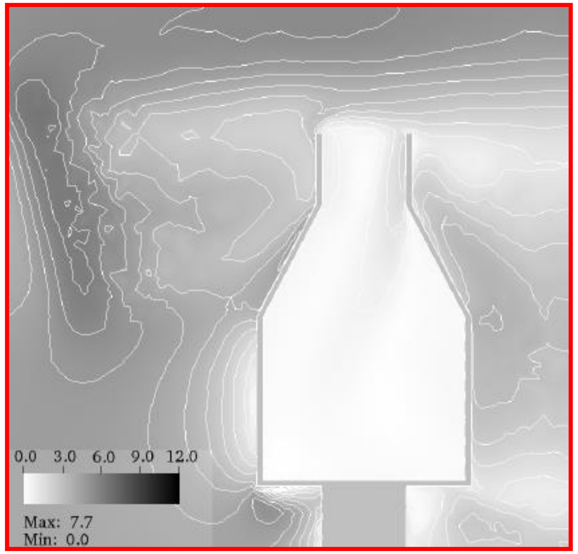
Equation of motion

$$V_p \rho_p \mathbf{a_p} = -C_D A_p \rho_a 0.5 (\mathbf{v_p} - \mathbf{v_a}) |\mathbf{v_p} - \mathbf{v_a}| + V_p (\rho_p - \rho_a) \mathbf{g}$$

number of particles $n(d)$ of each size, d, collected in disturbed airflow conditions

PSD ⇒ **Numerical CE**

State-of-the-art



Steady and uniform incoming flow in the CFD

Nešpor & Sevruk (1999), *Thériault et al.* (2012), *Colli et al.* (2016 a,b) conducted both RANS and LES simulations for various shielded and unshielded gauges an by using a fixed value of the particle drag coefficient C_D along the trajectory as a function of the particle size.

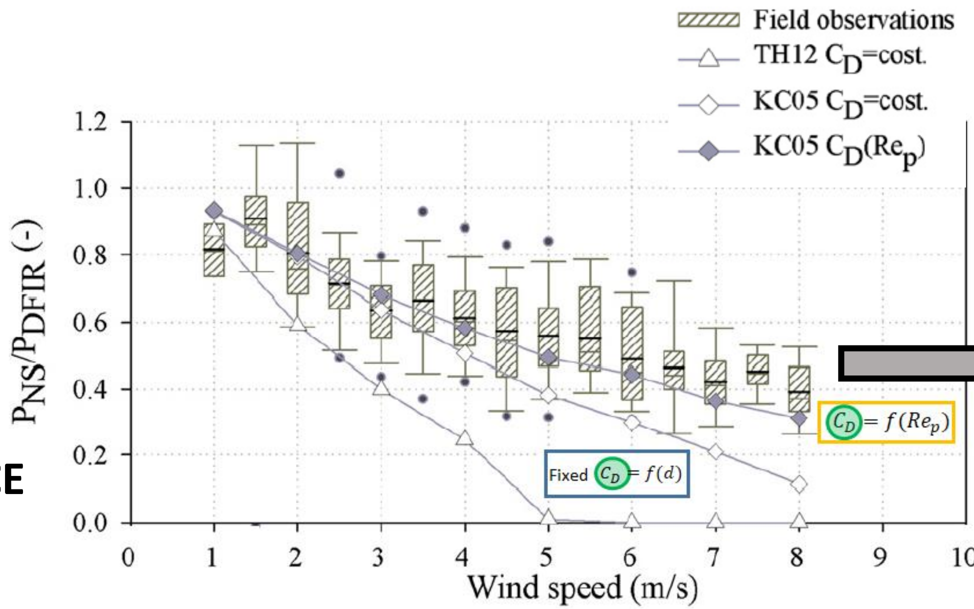
Fixed $C_D = f(d)$

Improved trajectory model

Colli et al. (2015) on solid precipitation

$$C_D = f(Re_p) \qquad Re_p = \frac{|\mathbf{v}_p - \mathbf{v}_a| d}{\upsilon_a}$$

The C_D is updated along the trajectory at every time step as a function of the local Reynolds number of the particle (Re_p).



This method overestimates the wind-induced error

because literature numerical studies assume that turbulence is only generated by the wind/gauge-body interaction

Free-stream turbulence

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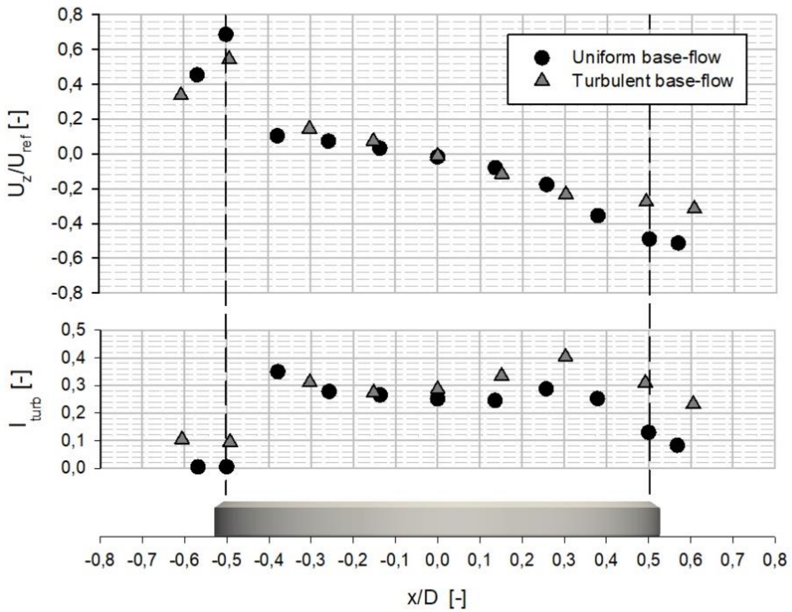
Wind is turbulent in nature due to the roughness of the site and the presence of obstacles. Therefore, in operational conditions, precipitation gauges are immersed in a turbulent flow.

Turbulent incoming flow in the CFD

State-of-the-art: *Cauteruccio et al. 2020*

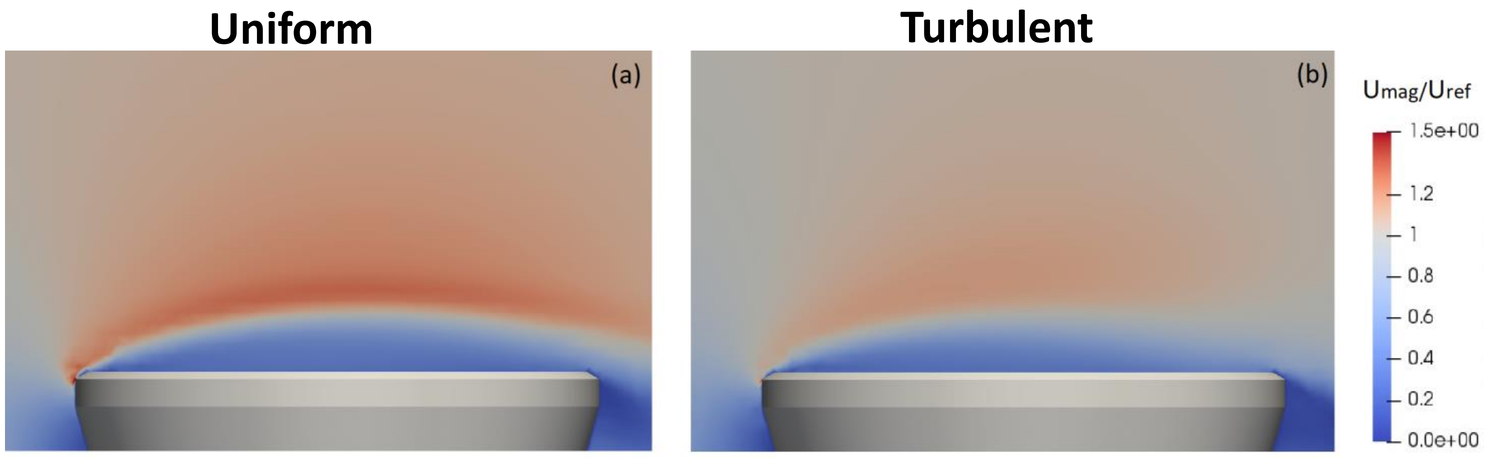
1 The normalized updraft in the upwind part and the downdraft in the downwind part of the collector are less accentuated in the turbulent free-stream configuration than in uniform free-stream conditions.

Wind tunnel measurements



2 The dissipative effect of the free-stream turbulence has a damping role on the acceleration of the flow above the collector.

CFD results



… and which is the overall effect on the gauge collection performance?

Field evaluation of the free-stream turbulence at the precipitation gauge elevation

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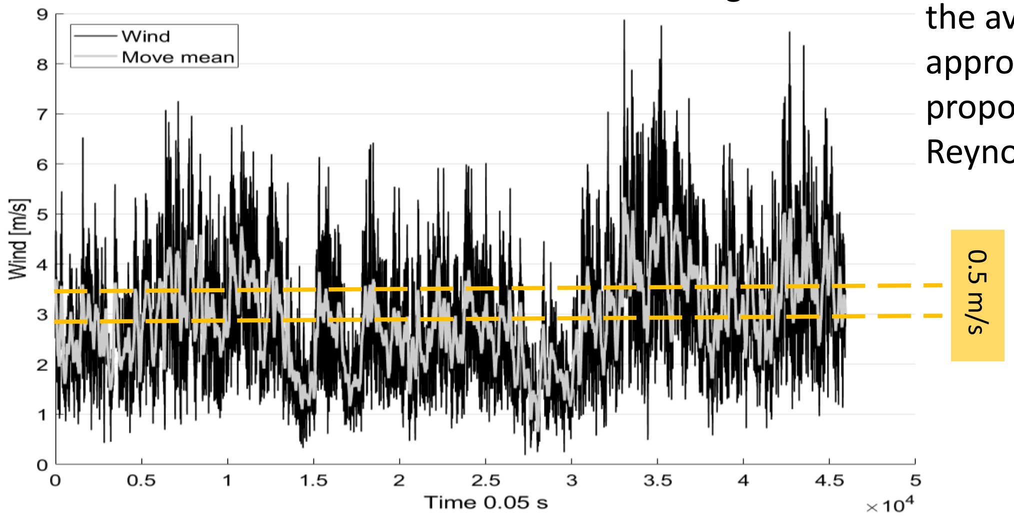
EML© → Nafferton (UK), experimental site

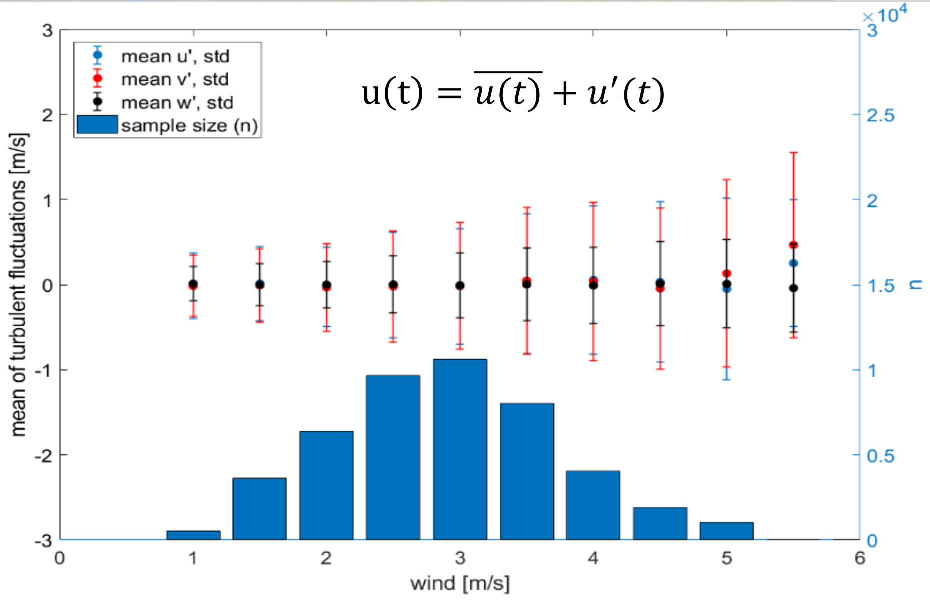
38 minutes of high frequency 3D sonic anemometer measurements (20 Hz)

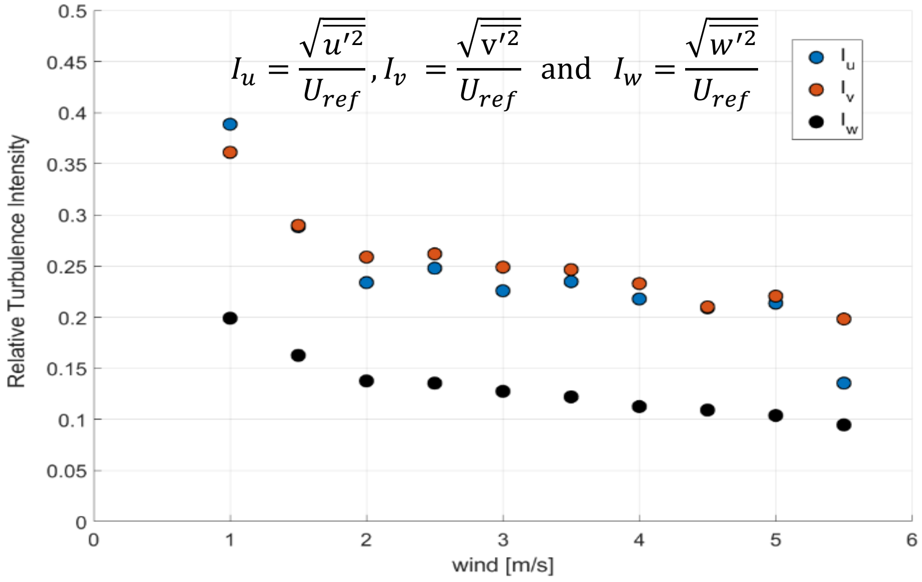
Wind measurements were divided in wind classes (0.5 m/s bins), based on the moving average value.

N=125 size of the moving window



consistent with the average approach proposed by Reynolds





Numerical generation of free-stream turbulence for the chimney shaped gauge

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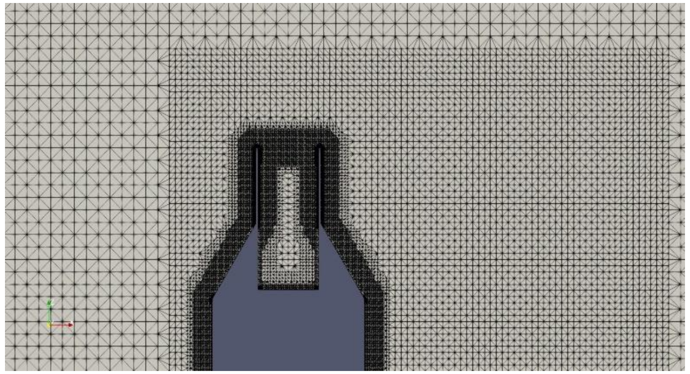
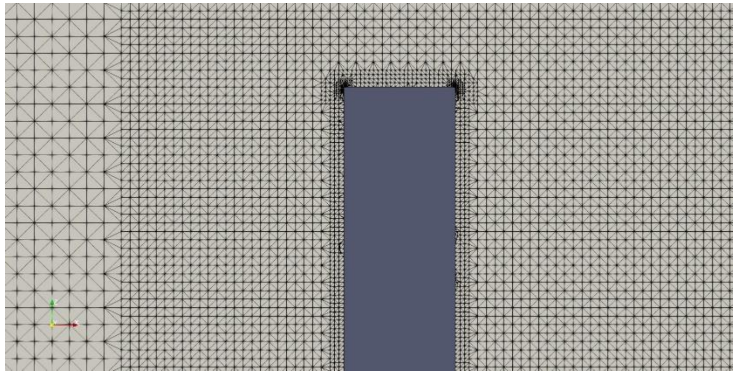
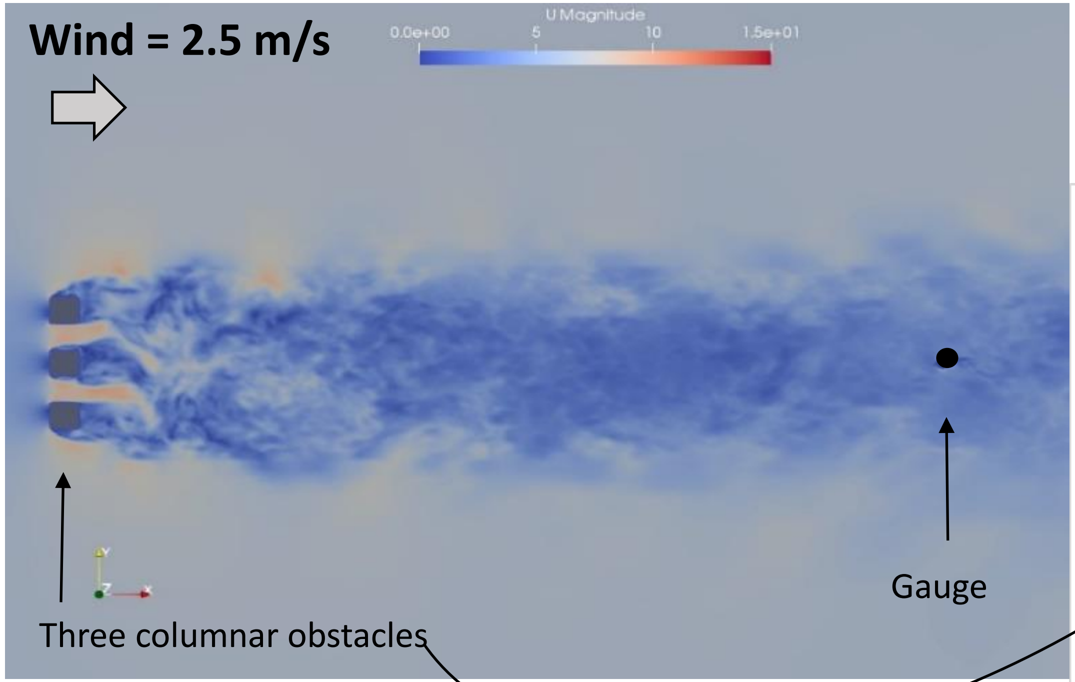
LES simulations

Free-stream condition	N. cells
Uniform	12 millions
Turbulent	14 millions

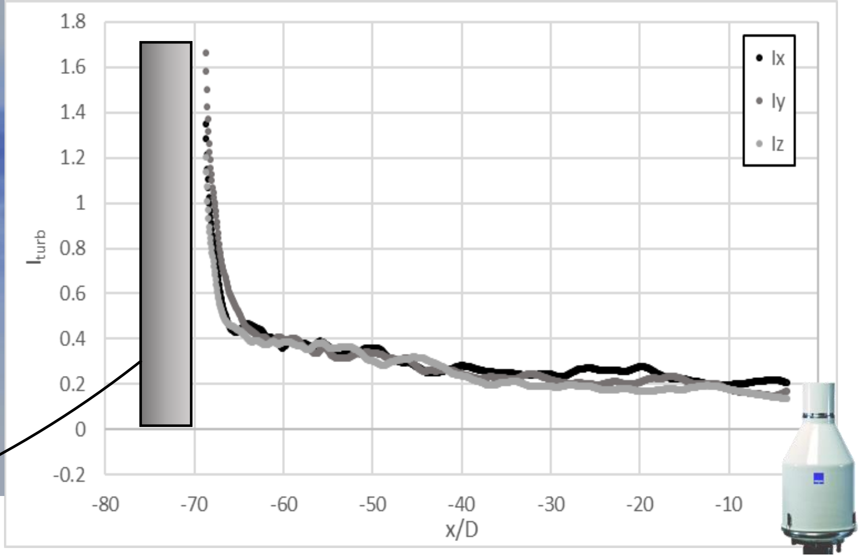
Details of the computational mesh







The distance between the three obstacles and the gauge was calibrated in order to obtain the desired level of turbulence as measured in the *Nafferton* site



The Free-stream turbulence:

1. introduces velocity fluctuations in all directions
2. reduces the aerodynamic effect of the wind-gauge interaction → lower velocity components near the gauge body

The free-stream turbulence effect on solid particles dynamics

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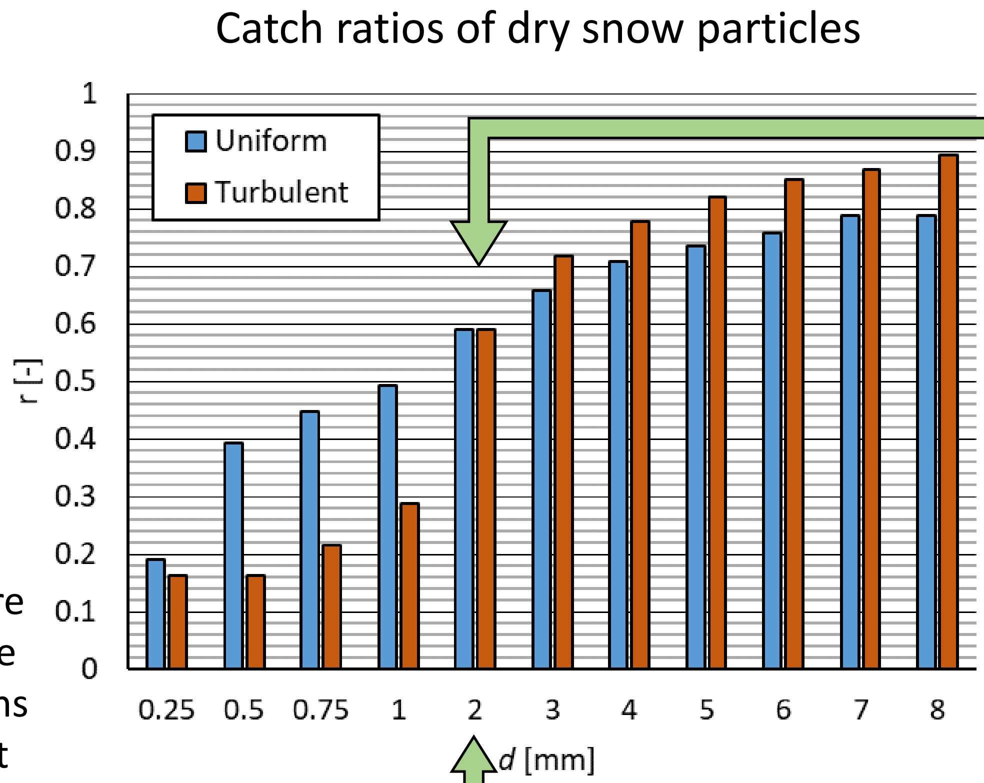
Catch ratio: $r(d) = \frac{n(d)}{n_{max}}$

is the ratio between the number of particles, which are captured by the gauge collector in disturbed airflow conditions, $n(d)$, and the maximum number of particles, n_{max}, captured in undisturbed conditions.



d < 2mm particles are more sensitive to the turbulent fluctuations and are deviated out of the collector

With increasing the particle size, and therefore its terminal velocity, particle trajectories are less sensitive to the turbulent fluctuations. Moreover, in turbulent free-stream conditions, they cross a less disturbed airflow field.

Overall effect

Particle Size Distribution (PSD) proposed by Houze et al. (1979) with $N_0 = 5 \times 10^6 m^{-4}$ and $\Lambda = 0.5\ mm^{-1}$

Free-stream condition	Collection Efficiency
Uniform	0.70
Turbulent	0.76

Neglecting the free-stream turbulence effect leads to an overestimation of the catch error

Conclusions

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This work allowed to investigate the role of the free-stream turbulence, inherent to the natural wind field, on the particle-fluid interaction

When the particle size is small catch ratios in uniform free-stream conditions are larger than in turbulent conditions. With increasing the particle size the catch ratios become larger in turbulent free-stream conditions than in uniform ones

The overall effect of the free stream turbulence on the collection performance of the gauge was quantified by computing the Collection Efficiency as the integral of the catch ratio on the range of diameters after the introduction of a suitable Particle Size Distribution. The resulting CE values demonstrated that neglecting the role of free-stream turbulence, like in current literature approaches, overestimates the wind-induced undercatch of precipitation gauges

Acknowledgments

This work was developed in the framework of the Italian National Project PRIN 2015-4WX5NA
"Reconciling precipitation with runoff: The role of understated measurement biases in the modelling of hydrological processes."

References

Cauteruccio A., M. Colli, A. Freda, M. Stagnaro, and L.G. Lanza, 2020: The role of the free-stream turbulence in attenuating the wind updraft above the collector of precipitation gauges. *J. Atmos. Oceanic Technol.*, **37**, 103–113. DOI:10.1175/JTECH-D-19-0089.1.

Colli, M., L.G. Lanza, R. Rasmussen, J.M. Thériault, B.C. Baker, and J. Kochendorfer, 2015: An improved trajectory model to evaluate the collection performance of snow gauges. *J. Appl. Meteor. Climatol.*, **54**, 1826–1836.

Colli, M., L.G. Lanza, R. Rasmussen, and J.M. Thériault, 2016a: The collection efficiency of shielded and unshielded precipitation gauges. Part I: CFD airflow modelling. *J. Hydrometeor.*, **17**, 231–243.

Colli, M., L.G. Lanza, R. Rasmussen and J.M. Thériault, 2016b: The collection efficiency of unshielded precipitation gauges. Part II: modeling particle trajectories. *J. Hydrometeor.*, **17**, 245–255.

Folland, C.K., 1988: Numerical models of the raingauge exposure problem, field experiments and an improved collector design. *Q.J.R. Meteorol. Soc*., **114**, 1485–1516.

Houze, R.A., P.V. Hobbs, P.H. Herzegh, and D.B. Parsons, 1979: Size distributions of precipitation particles in frontal clouds. *J. Atmos. Sci*., **36,** 156–162.

Marshall, J.S. and W.M.K. Palmer, 1948: The distribution of raindrops with size. *J. Meteorol.*, **5,** 165–166.

Nešpor, V. and B. Sevruk, 1999: Estimation of wind-induced error of rainfall gauge measurements using a numerical simulation. *J. Atmos. Ocean. Technol.*, **16**, 450 - 464.

Øistad, I.S., 2015: Analysis of the Turbulence Intensity at Skipheia Measurement Station, *Master thesis*, Norwegian University of Science and Technology.

Pollock, M.D., G. O'Donnell, P. Quinn, M. Dutton, A. Black, M.E. Wilkinson, M. Colli, M. Stagnaro, L.G. Lanza, E. Lewis, C.G. Kilsby, and P. E. O'Connell, 2018: Quantifying and mitigating wind-induced undercatch in rainfall measurements. *Water Resour. Res*., **54**, 3863 - 3875.

Rasmussen, R., B. Baker, J. Kochendorfer, T. Meyers, S. Landolt, A. P. Fischer, J. Black, J. M. Theriault, P. Kucera, D. Gochis, C. Smith, R. Nitu, M. Hall, K. Ikeda, and E. Gutmann, 2012: How well are we measuring snow: The NOAA/FAA/NCAR winter precipitation test bed, *Bulletin of the American Meteorological Society,* **93**(6), 811-829.

Sevruk, B., 1982: Methods of correction for systematic error in point precipitation measurement for operational use. *World Meteorological Organization,* Rep. **21**, 106 pp.

Thériault, J.M., R. Rasmussen, K. Ikeda, and S. Landolt, 2012: Dependence of snow gauge collection efficiency on snowflake characteristics. *J. Appl. Meteor. Climatol*., **51**, 745–762.

Warnik, C.C., 1953: Experiments with windshields for precipitation gages. *Transactions of the American Geophysical Union*, **34**(3), 379 – 388.