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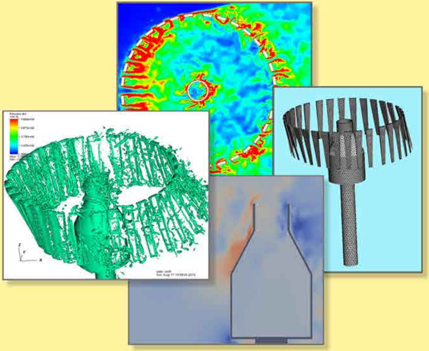
A CFD evaluation of wind induced errors in solid precipitation measurements



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METEOMET
Metrology for Meteorology

12th March, Genova

Objective

Quantification of the precipitation measurements errors caused by the wind ***exposure*** *of catching type gauges by means of fluid-dynamics simulations.*

An under-estimation of the precipitation measurements is generally observed in presence of significant wind regimes.

Laboratory experiment by John Kochendorfer, NOAA).

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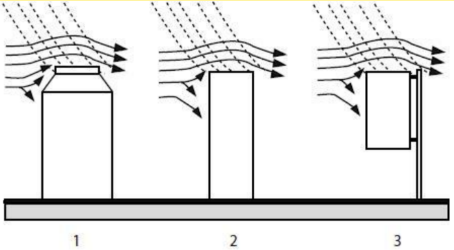


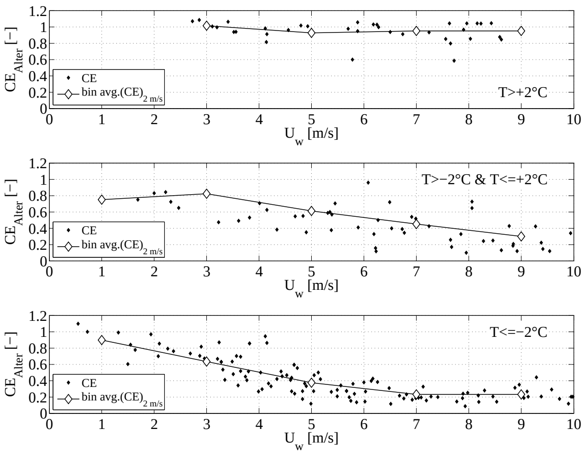
WMO *Guide to Meteorological Instruments and Methods of Observation.*

The **collection efficiency** CE is commonly represented by the ratio:

$$CE = \frac{h_{meas}}{h_{true}} \quad (1)$$

where h_{exp} (mm) is the precipitation measured by a gauge exposed to the wind and h_{ideal} (mm) the value obtained by an ideal instruments not affected by the wind exposure.

Currently available CE estimations are obtained by means of **comparisons between co-located gauges installed in experimental sites** of time-averaged numerical simulations (Nešpor and Sevruk, 1999; Thériault et. al, 2012)



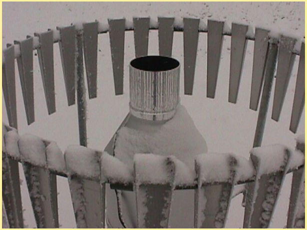
Courtesy of Dr. Mareile Wolff (Norwegian Meteorological Institute).

In many cases the infield CE estimates are evaluated by accepting as true the measurement obtained with a DFIR shielded gauge.

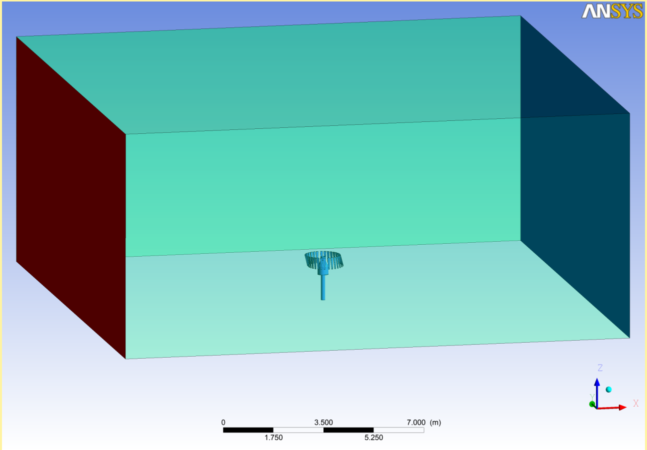

NCAR/FAA/NOAA field site in Marshall (Colorado, USA).

The 3D analysis of the air velocity fields has been conducted with two different finite volumes approaches:

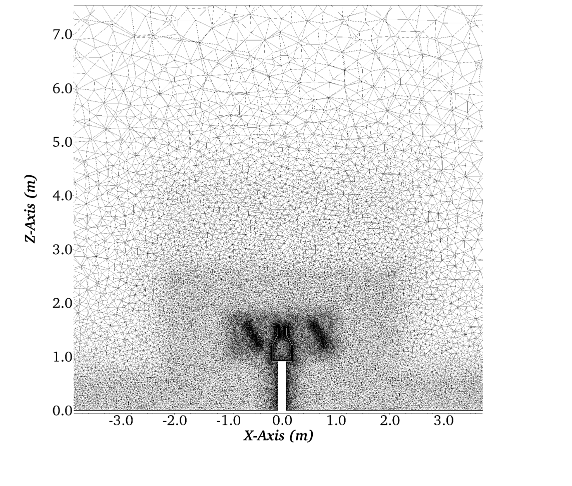
- Time-averaged numerical solutions computed by simulating different wind speed conditions U_w with a **Reynold Averaged Navier-Stokes equations** (RANS) SST k-ω model.
- Time-dependent analysis using **Large Eddy Simulations** (LES) with Smagorinsky model to solve spatial scales which are smaller than the cell dimension (*sub-grid scales* SGS).



This study focuses on the single Alter shielded Geonor T200B weighing gauge.

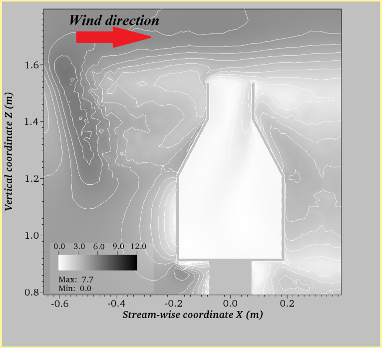


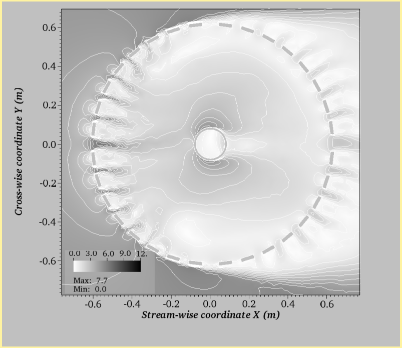
- The RANS meshes use variable number of elements (ranging from 2 mln to 6 mln) depending on the simulated geometries.
- The LES meshes are composed by 25/29 mln elements so as to obtain numerical convergence and accurate results.



Vertical section ($y = 0\ m$) of the spatial grid. The plane is parallel to U_w and passes through the center of the cylindric gauge geometry.

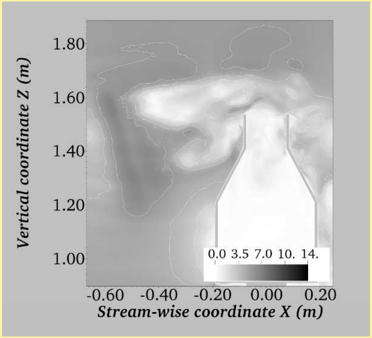
RANS - Wind speed $U_w = 5\ m/s$ case

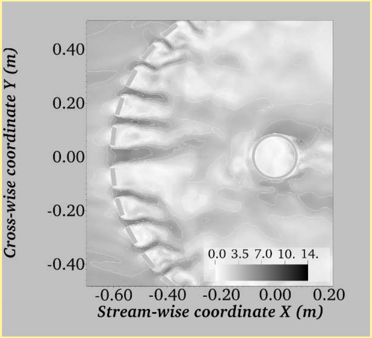




- Between the upwind windshield fences and the gauge, an attenuation of the time-averaged air velocity with respect to U_w is shown.
- The left figure shows an extended zone characterized by high air velocity values above the orifice of the gauge.
- A comparison with similar literature studies reveals a better level of details of the air velocity field thanks to the finer spatial grid.

LES - Wind speed $U_w = 5\ m/s$ case





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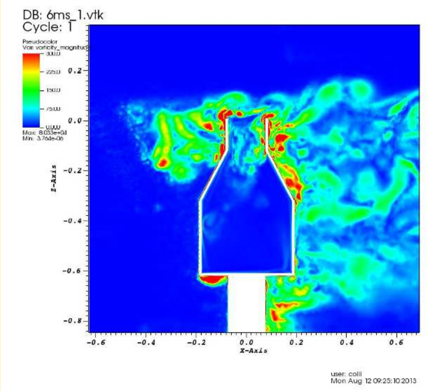


Vorticity color plots

- The windshield upwind elements entail a production of turbulence.
- The airflow transports eddies from the upwind windshield elements to the gauge collecting section with implications for the precipitation trajectories.

- **Parametrization of the snow particles** (based on Rasmussen et al., 1999):

$$X(d_p) = a_X d_p^{b_X} \tag{2}$$

where X represents the following quantities: terminal velocity of the particles (w_T), volume (V_p), density (ρ_p) and cross-sectional area (A_p). And a_x and b_x are empirical coefficients that depends on the crystal types (dry and wet snow).

- **Particles Size Distribution (PSD)**:

$$N(d_p) = N_0 exp(-\Lambda d_p) \tag{3}$$

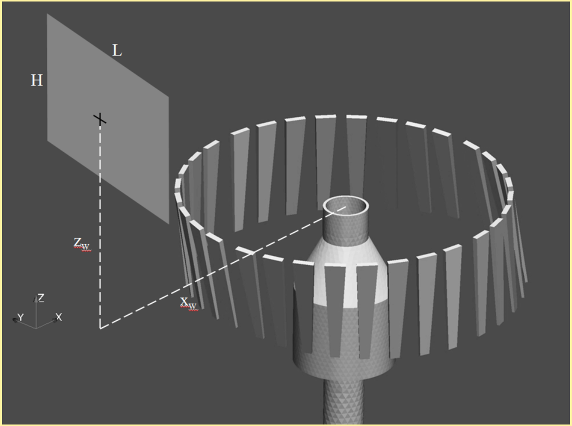
with $N_0 = 5 \cdot 10^6\ m^{-4}$ and $\Lambda = 0.5\ mm^{-1}$.

- **Total collection efficiency at given wind speed U_w**:

$$CE(U_w) = \frac{\int_0^{d_{p_{max}}} V_w(d_p) A_{inside}(d_p, U_w) N(d_p) d(d_p)}{\int_0^{d_{p_{max}}} V_w(d_p) A_{gauge}(d_p, U_w) N(d_p) d(d_p)} \tag{4}$$

where $V_w(d_p)$ is the water equivalent volume of the precipitation, $A_{inside}(d_p, U_w)$ the area of the collecting section associated with the entering particles and A_{gauge} the total area.

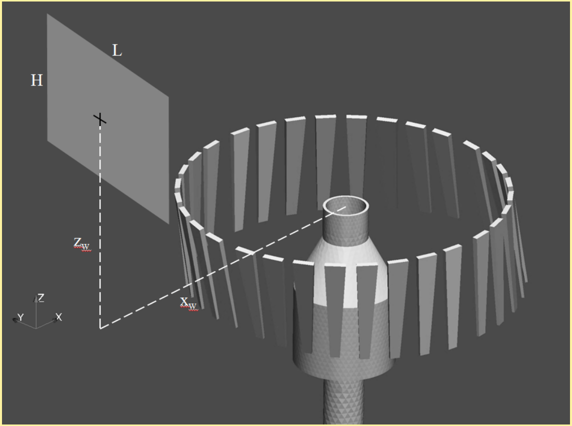
The initial position of the trajectories is defined on a vertical rectangular grid (a *seeding window* with length $L = 0.4\ m$ and variable height H) located upwind the gauge.



Location of the initial positions of the particles trajectories.

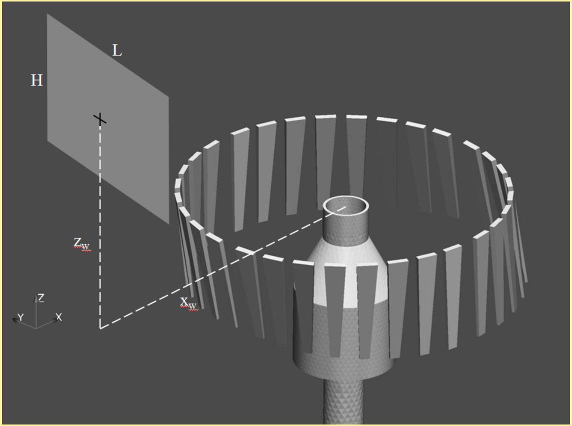
Particles number:

- The time-dependent tests **LES** model: 2400 trajectories each run
- Time-averaged **RANS** model: 3000 to 10000 trajectories



Location of the initial positions of the particles trajectories.

- 16 different particles diameters covering $0.25\ mm < d_p < 20\ mm$
- **Two different type of snow here considered: dry and wet**



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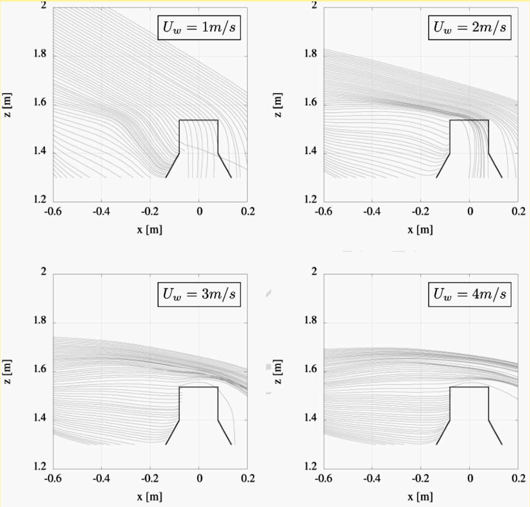
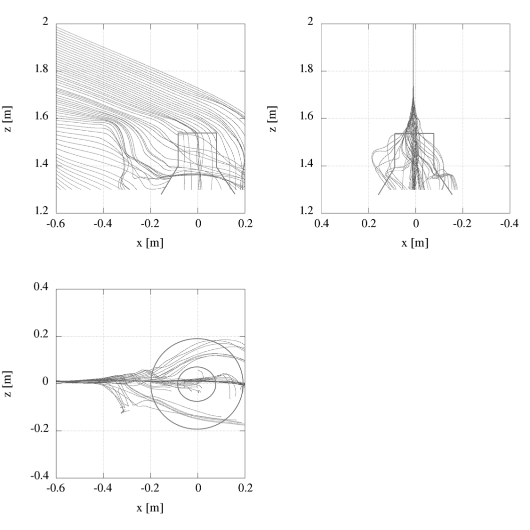
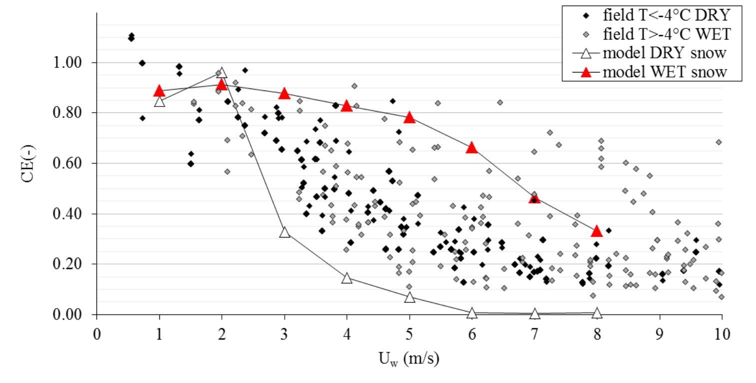


Time-invariant approach. Dry snow trajectories, $d_p = 1\ mm$



Time-variant approach. Orthogonal projection of a choice of **dry snow trajectories**, $d_p = 0.25\ mm$ and $U_w = 1\ m/s$.

Comparison between collection efficiency CE obtained with LES simulations (black curves with triangles) and infield observation (grey scale dots).



Courtesy of Dr. Mareile Wolff (Norwegian Meteorological Institute).

- **The simulation work highlighted a strong sensitivity of the gauge collection efficiency to the micro-physical characteristics of the precipitation particles**. Such sensitivity explains the variability observed in infield CE estimates.
- **It has been also revealed that the single Alter windshield must be considered as a source of turbulence**. Its presence increases the time-dependency of the problem and causes trajectories clustering phenomena.
- The time-dependent simulations described the time-spatial evolution of the trajectories. **The here adopted CFD simulations are a valuable tool to explain the fundamentals governing collection efficiency**.