EXAMINATION OF THE PERFORMANCE OF SINGLE ALTER SHIELDED AND UNSHIELDED SNOWGAUGES USING OBSERVATIONS FROM THE MARSHALL FIELD SITE DURING THE SPICE WMO FIELD PROGRAM AND NUMERICAL MODEL SIMULATIONS

Roy M. Rasmussen[1], Scott Landolt[1], Bruce Baker[2], John Kochendorfer[2], Bill Collins[2], Matteo Colli[3], Luca Lanza[3], and Julie Theriault[4]
(1) National Center for Atmospheric Research, USA
(2) National Oceanic and Atmospheric Administration, USA
(3) Univerisity of Genoa, Italy
(4) Université du Québec à Montréal, Canada

ABSTRACT

Precipitation is one of the most important atmospheric variables for ecosystem research, hydrological and weather forecasting and climate monitoring. Despite its importance, accurate measurements of precipitation remain a challenge. Measurement errors for solid precipitation, which are often ignored for automated systems, frequently range from 20% to 70% due to undercatch in windy conditions. While solid precipitation measurements have been the subject of many studies, there have been only a limited number of coordinated assessments on the accuracy, reliability, and repeatability of automatic precipitation measurements. The most recent comprehensive study, the “WMO Solid Precipitation Measurement Intercomparison” concluded in 1998 and focused on manual techniques of solid precipitation measurement. Precipitation gauge technology has changed considerably in the last 12 years and the focus has shifted to automated techniques. The Marshall Testbed site is a collaboration between NOAA, NCAR, NWS, and FAA to assess various solid precipitation measurement techniques. This site is being used to test new gauges and other solid precipitation measurement techniques in comparison to reference measurements from gauges with large wind-shields. This paper will highlight efforts to understand the catch efficiency of the unshielded and single Alter shielded snowgauge relative to the Double Fence Intercomparison Reference gauge using automated observations at the Marshall Field collected during the WMO Solid Precipitation InterComparison Experiment (SPICE) and from numerical model simulations.

1) MOTIVATION

Automated ground-based solid precipitation measuring systems, such as weighing and vibrating wires gauges, collect the snow particles and then evaluate the accumulation over given sampling intervals. When precipitation particles have to be collected the most severe environmental error is caused by the wind induced undercatch. It has been observed that the aerodynamic response of the gauge is responsible for a significant reduction of the snow gauge collection efficiency (Goodison et al., 1998; Rasmussen et al., 2012) due to the deflection of the trajectories in the proximity of the gauge orifice (a problem also known as "gauge exposure"). Since a comprehensive understanding of this systematic error has not been achieved yet, the assessment of the exposure problem for various wind shielded gauges has been recognized as a central objective of the current WMO SPICE field campaign (Nitu et al., 2012).

The snow precipitation measurements made by different co-located gauges and wind shield configurations in presence of significant wind show widely differing accumulations, as shown in Figure 1. This time series measured at the Marshall field site on February 24th 2013 highlights the significant under-estimate of snow accumulation by the single (SA) and no shield configurations with respect to the Double Fence International Reference (DFIR) shield system. In all three cases a 600 mm GEONOR standard gauge is used showing that the variability in the measurement is associated with the type of shield surrounding the gauge.

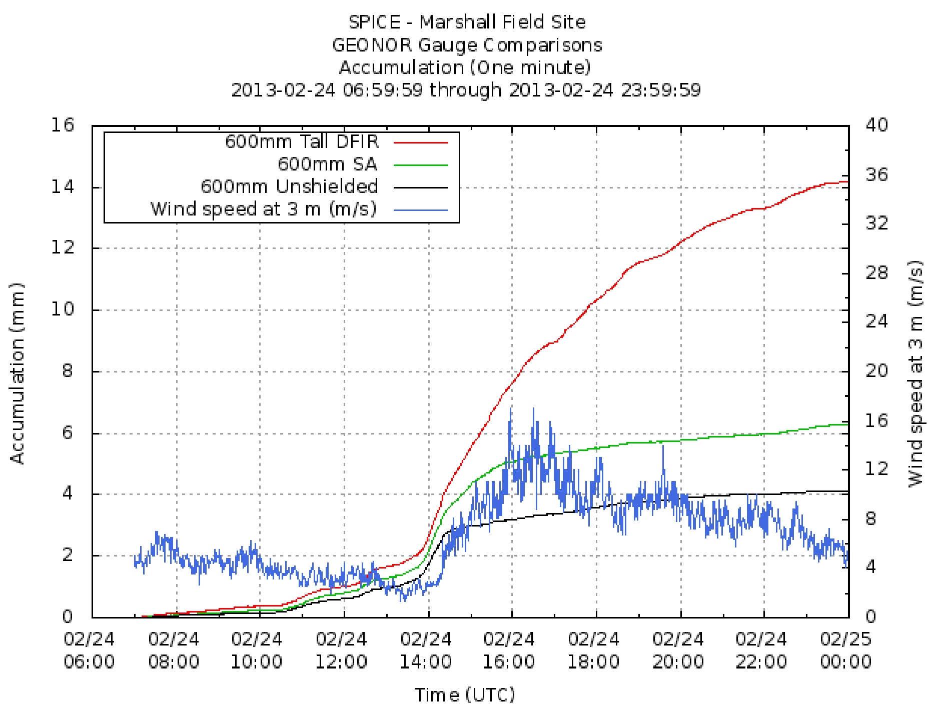

Fig. 1: Precipitation accumulation (left axis) measured by different shielded precipitation gauges and co-located wind speed (right axis) at the Marshall field site on 24 February 2013 snowfall event during SPICE.

Due to the strong dependence of the under-catch to wind speed, transfer functions can be derived to correct the undercatch. The evaluation of reliable collection efficiency (CE) curves as function of the wind speed represents a necessary step towards improving the accuracy of snow measurements. Development of robust transfer functions require a better understanding of the fundamental processes governing wind-induced undercatch such as the site climatology and the precipitation micro-physical characteristic (such as the snow crystal type and their size distribution). This is achievable by considering the information provided by co-located field observations and advanced numerical modelling to detail the hydrodynamic behaviour of different snow types under various wind regimes.

2) FIELD OBSERVATIONS

The *CE* curves of shielded and unshielded gauges are typically assessed by dividing the measurements (*P*) with observations performed by a reference system, often represented by a DFIR shielded gague (P_{DFIR}). This approach is certainly affected by a number of uncertainties. The variability of the wind and the precipitation within the sampling interval, the unsteady (turbulent) flow generated by the wind shields themselves, the variability of snowflake type, terminal velocity and size distribution are some of the possible uncertainty sources.

Figure 2 shows the ratios between snow precipitation measurements made by un-shielded (P_{NS}) and *DFIR* (P_{DFIR}) GEONOR T200Bs sampled with a 30-min time period binned over 0.5 m/s wind speed intervals between 2009 and 2013 from the Marshall site. A noticeable wind induced under-estimate of the precipitation accumulation is showed by the mean P_{NS}/ P_{DFIR} (red lines inside the plots) which quickly decrease passing from 1 to 6 m/s and tends to an asymptotic value of ~0.3 for winds larger than 6 m/s. In addition to the reduction of wind speed with increasing wind speed, the box plots show a wide scatter for a given wind speed. For instance, the width of the box plots distribution spans from 0.3 (at higher wind speeds) to 0.6 (observed when wind speed is equal to 2 and 3,5 m/s) and makes the application of a unified transfer function challenging.

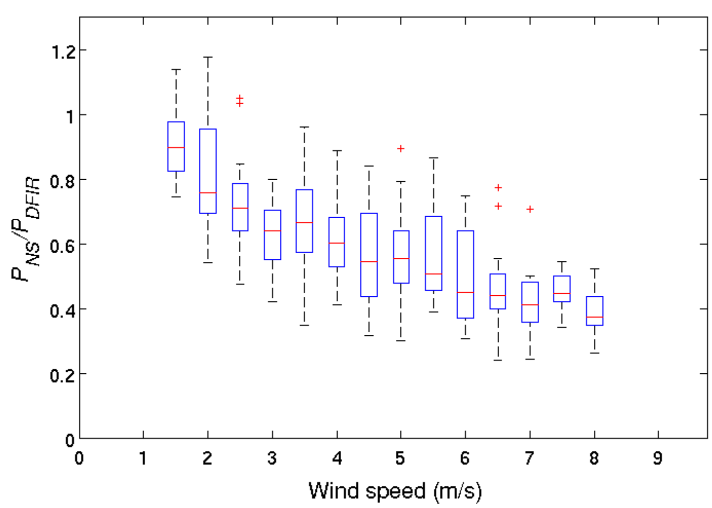

Fig. 2: Ratios between snow precipitation measurements made by an un-shielded (P_{NS}) and a DFIR shielded (P_{DFIR}) gauge vs. the wind speed. The data are sampled with a 30-min period and averaged over 0.5 m/s wind speeds bins.

A similar methodology is applied to single Alter GEONOR T200B measurements (P_{SA}) and reported in Figure 3. In this case the mean P_{SA}/ P_{DFIR} curve shows a slower decrease with respect to the unshielded case with higher values of collection efficiency initially, approaching similar values to the unshielded C.E. beyond 6 m/s.

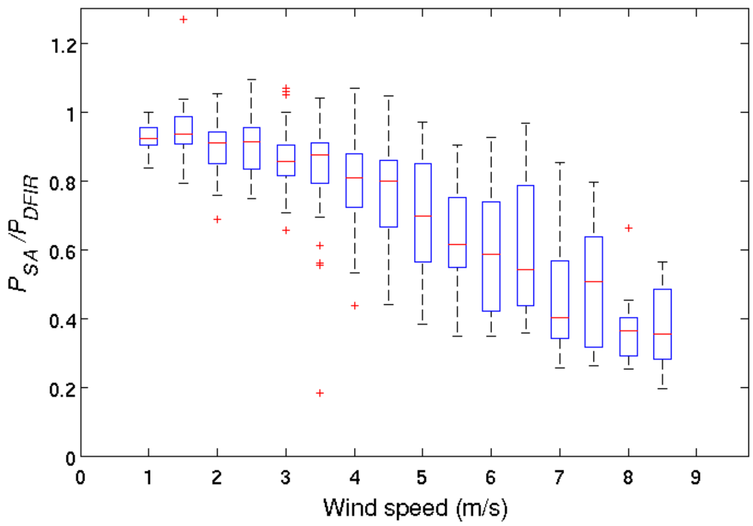

Fig. 3: Ratios between snow precipitation measurements made by a single Alter (P_{SA}) and a DFIR (P_{DFIR}) shielded gauge vs. the wind speed. The data are sampled with a 30-min period and averaged over 0.5 m/s wind speeds bins.

In general terms, the comparison between P_{NS}/ P_{DFIR} and P_{SA}/ P_{DFIR} reveals a different curvature of the decreasing mean values. The effects of the single Alter shield are summarized by an improvement of the collection efficiency and an increasing of the data scattering at intermediate wind speeds. This behaviour will be discussed in light of recent numerical modelling studies of flow and particles trajectories past single Alter and unshielded Alter gauges by Thériault et al. (2012), Colli (2014) and Colli et al. (2014) and in the next section.

3) NUMERICAL MODELS

The main advantage of studying the collection efficiency of various shielded gauges by means of CFD numerical models is the possibility to isolate the exposure effect from the other source of uncertainty occurring in the field. Following Nespor and Sevruk (1998), a finite volume method has been successfully adopted to solve on the three dimensional equations for the air flow around the single Alter (Thériault et al., 2012; Colli, 2014) and un-shielded GEONOR T200B gauge systems (Colli, 2014). The trajectories of dry and wet snow particles (as defined by Rasmussen et al., 1999) were tracked by means of a Lagrangian scheme for different time-averaged airflows computed by the Reynolds Averaged Navier-Stokes (RANS) k-ω SST model corresponding to ten wind speeds between 1 and 10 m/s.

Figure 4 shows the precipitation trajectories and the streamlines computed for a sample case with wind speed U_w equal to 4 m/s and dry snow particles with diameter d_p equal to 5 mm. The plot shows the deformation of the streamlines and the consequent deflection of the particle trajectories downwind of the single Alter shield. The actual influence of the single Alter on the collection efficiency of the gauge can be now quantified by adopting a Marshall-Palmer size distribution (N_0=5 x 10^6 m^4 and λ=0.5 mm^{-1}) and counting the precipitation volume associated with the collected particles.

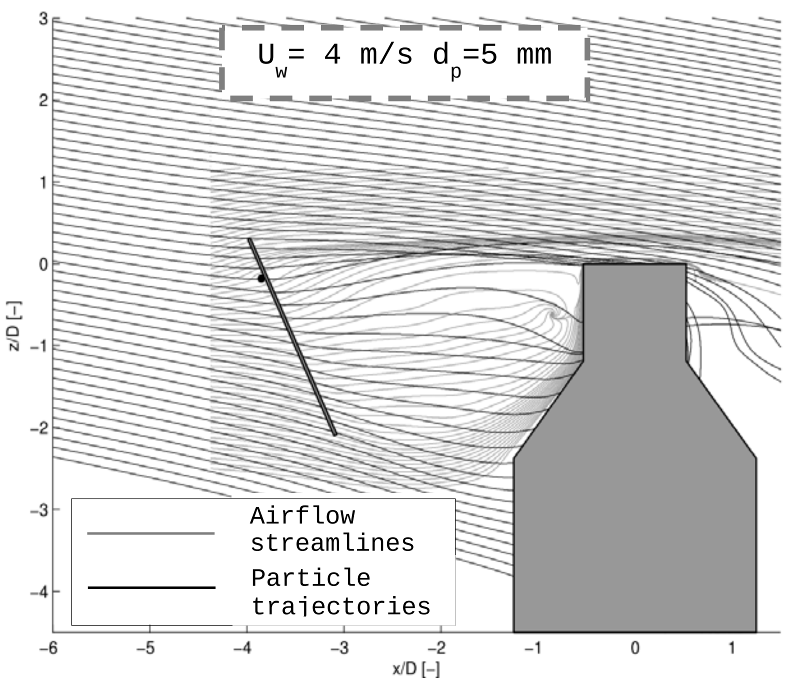

Fig. 4: Dry snow particle trajectories (black lines) and streamline (gray lines) computed by the RANS airflow and the Lagrangian tracking model. The plot represents a wind speed U_w equal to 4 m/s and a particle diameter d_p equal to 5 mm case.

The integral Collection Efficiency (*CE)* curves resulting for the dry and wet snow simulations are respectively reported in Figure 5 and 6 for both the single Alter and the un-shielded GEONOR T200B gauges. The benefit of the single Alter is confirmed over the whole wind speed domain for dry snow particles. A similar indication is confirmed by the wet snow curves when U_w is lower than 9 m/s, above that threshold the unshielded *CEs* is maintained stable around 0.3 meanwhile the single Alter curve converges to null values. A behaviour that is also found by the field observations reported in Figure 2 and 3. The abrupt decrease of the dry snow *CEs* in the single Alter simulations for winds speeds between 3 m/s $<U_w<$4 m/s is the object of ongoing studies.

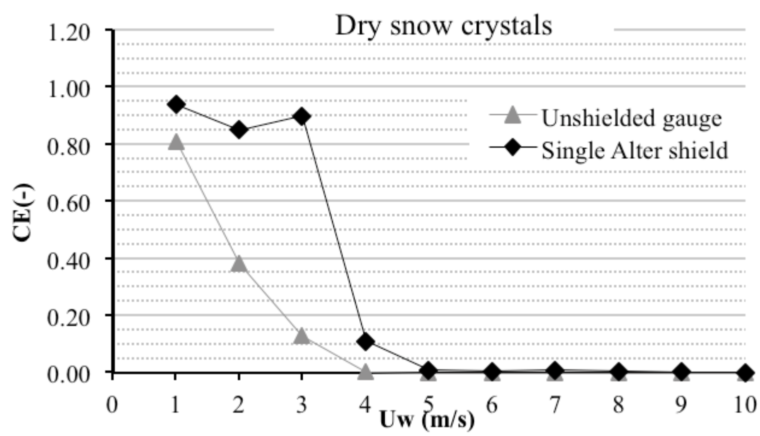

Fig. 5: Collection efficiency *CE(U_w)* curves for dry snow particles computed by the time-averaged RANS methodology for the single Alter and un-shielded GEONOR T200B.

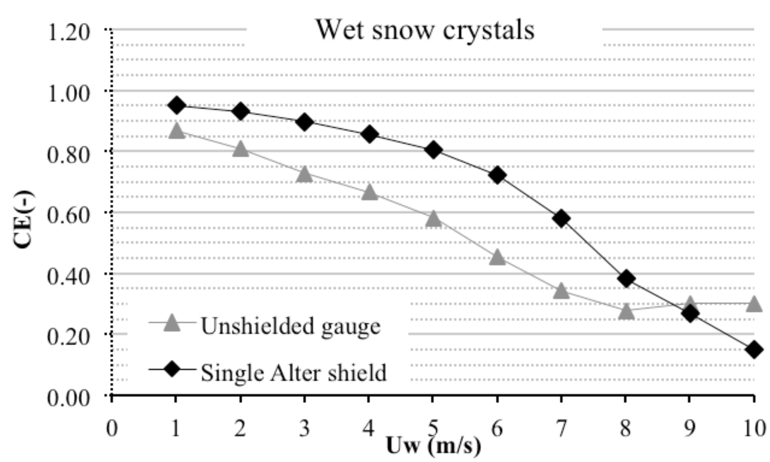

Fig. 6: Collection efficiency *CE(U_w)* curves for wet snow particles computed by the time-averaged RANS methodology for the single Alter and un-shielded GEONOR T200B.

Figure 7 provides the C.E.(*r*) of dry snow as a function of particle diameter for various wind speeds and wind shield configuration (unshielded and single Alter shielded gauges).

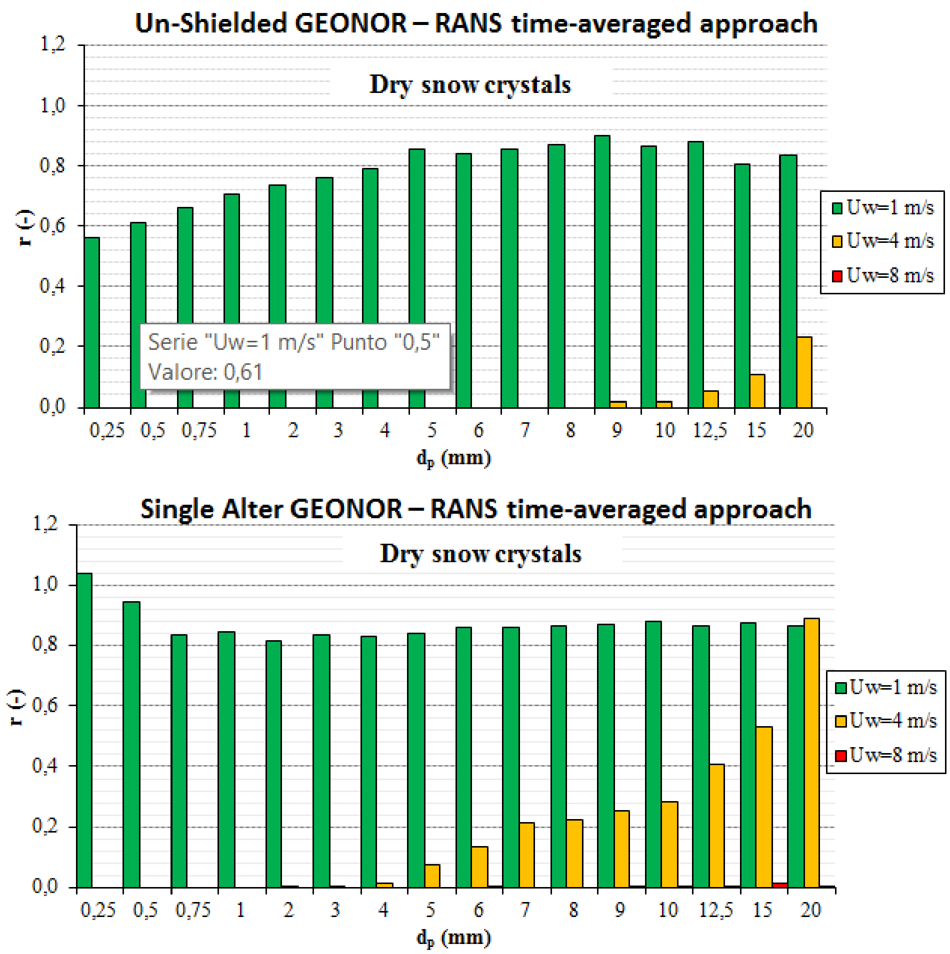

Fig. 7: Catch ratio $r(d_p)$ histograms for the un-shielded (upper panel) and single Alter shielded (bottom panel) GEONOR T200B computed by the time-averaged RANS model for a selection of three different wind speed.

This figure shows that the wind reduces the ability of the gauge to collect small particles. By increasing the wind speed to U_w=4 m/s a large reduction of *CE* occurs over the entire d_p domain. The better performance of the single Alter shield is confirmed but the U_w=8 m/s conditions shows the complete failure of the measuring system at high wind speed with respect to the exposure problem.

4) CONCLUSIONS

The numerical model methodology is a useful tool to understand the fundamentals of the wind-induced errors of solid precipitation measurements. The current results compare reasonably well with observations and provide insight into the reasons for the enhanced collection efficiency of a single Alter gauge system over an unshielded system. The role of boundary layer turbulence on *CE* is currently being analysed by means of more accurate time-dependent models, such as Large Eddy Simulation (Colli et al., 2014), and more realistic hydrodynamic schemes for the computation of the particles motion.

ACKNOWLEDGEMENTS

This research was supported through funding from NOAA,NSF the University of Genoa and the Université du Québec à Montréal.

REFERENCES

- Colli, M, Lanza, L.G., Rasmussen, R. and J.M. Thériault, 2014: A CFD evaluation of wind induced errors in solid precipitation measurements. Proceedings of WMO Technical Conference on meteorological and environmental instruments and methods of observations 2014, 7-9 July 2014, St. Petersburg, Russian Federation.
- Colli, M., 2014: Assessing the accuracy of precipitation gauges: a CFD approach to model wind induced errors. PhD dissertation, University of Genova, Italy.
- B. Goodison, P. Louie, and D.Yang. WMO solid precipitation measurement intercomparison: final report. WMO Tech. Document 872, World Meteorological Organization, Geneva, Switzerland, 1998
- Nešpor, V. and Sevruk, B., 1999: Estimation of wind-induced error of rainfall gauge measurements using a numerical simulation. Journal of Atmospheric and OceanicTechnology, 16(4):450–464
- Nitu, R., Rasmussen, R., Baker, B., Lanzinger, E., Joe, P., Yang, D., Smith, C., Roulet, Y., Goodison, B., Liang, H., Sabatini, F., Kochendorfer, J., Wolff, M., Hendrikx, J., Vuerich, E., Lanza, L., Aulamo, O., and V. Vuglinsky. WMO intercomparison of instruments and methods for the measurement of solid precipitation and snow on the ground: organization of the experiment. In WMO Technical Conference on meteorological and environmental instruments and methods of observations, pages 16–18, Brussels, Belgium, 2012. World Meteorological Organization
- Rasmussen, R., Vivekanandan, J., Cole, J., Myers, B. and Masters, C., 1999: The estimation of snowfall rate using visibility. Journal of Applied Meteorology, 38:1542–1563
- Rasmussen, R., Baker, B., Kochendorfer, J., Meyers, T., Landolt, S., Fischer, A.P., Black, J., Thériault, J.M., Kucera, P., Gochis, D., Smith, C., Nitu, R., Hall, M., Ikeda, K., Gutmann, E., 2012: How well are we measuring snow: The noaa/faa/ncar winter precipitation test bed. Bulletin of the American Meteorological Society, 93:811–829
- Thériault, J.M, Rasmussen, R., Ikeda, K. and Landolt, S., 2012: Dependence of snowgauge collection efficiency on snowflake characteristics. Journal of Applied Meteorology and Climatology, 51:745–762.