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A calibration device for non-catching rain gauges

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Abstract:

Non-Catching Gauges are increasingly adopted in precipitation monitoring networks. However, their rigorous testing and calibration are more challenging than for catching gauges. Individual hydrometeor characteristics like the particle size and fall velocity must be reproduced to provide the reference precipitation, while using an equivalent water flow (like in standardised methods available for catching-type gauges) is not a viable approach. Calibration is generally declared by the manufacturer using internal procedures, while no standard calibration methodology exists. The EURAMET project INCIPIT - "Calibration and accuracy of non-catching instruments to measure liquid/solid atmospheric precipitation", started to address such issues in 2019 and was recently completed.

Within the INCIPIT project, a dedicated device capable of releasing water drops on demand and measuring the characteristics of the generated drops in-flight was developed at the University of Genova. Water drops from 0.75 to 5.5 mm in diameter are produced to mimic natural raindrops. By means of a precision syringe pump, each drop is formed at the tip of a calibrated nozzle. High voltage is applied between the nozzle and a metallic ring, triggering the detachment of the drop. By varying the release height, various fractions of the terminal velocity can be achieved depending on the drop size. A high-resolution camera, positioned just above the sensing area of the instrument under calibration, takes a photograph of the falling drop. Three images of the same drop are captured in a single picture, using stroboscopic lights. Then, by means of a photogrammetric approach and the knowledge of the time between flashes, the size and fall velocity of each drop are computed. Instrumental bias is obtained by comparison between the camera and gauge measurements. In this work both laboratory tests to assess the performance of the calibration device and the results of preliminary calibration procedure are presented.

1. Introduction

After decades of scarce innovation, a new class of in-situ precipitation gauges called Non-Catching Gauges (NCGs), which detect the microphysical and dynamic characteristics of single or multiple hydrometeors are increasingly penetrating the market (Cauteruccio et al., 2021). Organisations in charge of the management of precipitation monitoring networks increasingly look at NCGs as a considerable improvement over more traditional instruments, notwithstanding the higher lifecycle cost. The reasons are their reduced maintenance burden, the high temporal resolution, the larger number of output parameters, and their suitability to be part of a fully automated monitoring network.

Still, NCGs come with some drawbacks that are primarily due to the higher complexity of the exploited technology that limits the end user control over the produced data. This is especially true since NCGs are generally calibrated by the manufacturers, using internal procedures developed for the specific technology employed. No widely agreed calibration procedure, nor any documentary standard exists within national or international institutions and limited information is generally provided by the manufacturer. For NCGs, having neither a funnel nor a container to collect rainwater, the use of an equivalent, reference flow rate (see e.g., Colli et al., 2014) is not possible. Rather, calibration of NCGs requires that individual water drops of a known size, shape and fall velocity are generated. Several attempts at calibrating NCGs are available in literature, either using simple water drop generators or by dropping calibrated media (see Lanza et al. 2021 for a review). A common limitation of those approaches is that, due to the complexity of releasing very small drops on demand, relatively large drops are used, above 2 or 3 mm in diameter. Large drops are, however, quite scarce in natural precipitation, accounting for a limited fraction of the total precipitation volume. Therefore, calibration of NCGs should also include drops in the lower size range, below 2 mm in diameter, which accounts for about 99% to 97% of the total number of drops, and 85% to 62% of the total water volume (see Caracciolo et al., 2008).

From a normative standpoint, the first experience on the calibration of precipitation gauges was the development of the Italian national standard UNI 11452:2012, and the follow-up extension of such initiative at the European scale, leading to the publication of the recent European standard EN 17277:2019. This is however limited to catching type gauges, while the ongoing normative effort at the European scale under CEN TC318 is that of extending that approach to the calibration of NCGs. The goal of this paper is to present a device capable of producing on demand drops of various sizes and taking independent measurements of both the drop size and fall velocity, as a basis to develop traceable calibration procedures for a wide range of NCGs.

2. The calibrated rain generator

The Calibrated Rain Generator (CRG) presented in this paper is a device capable of releasing drops of a given diameter, on demand, and independently verifying both their size and fall velocity in flight by means of an indirect method. It is composed by three main functional components, the Drop Releasing Head (DRH), the Photogrammetric Verification System (PVS) and the Motorized Alignment Gantry (MAG). The latter ensure a precise alignment between the DGH and PVS by two such systems, an upper one with the dispensing head attached and a lower one, identical to the first, with the camera attached. The choice of using separate gantries allows maximum flexibility of the system that can be used both mounted in a purposefully built enclosure, as shown in figure 1 or attached to other permanent or temporary structure for example to test higher fall distances.

Figure 1: 3D model (left-hand side) and photograph (right-hand side) of the proposed CRG,

2.1. The Drop Releasing Head

The DRH is composed of two high precision syringe pumps and an electrostatic detachment system. In the left-hand side of figure 1 a picture of the DRH attached to the MAG is shown. Single drops are generated at the tip of a needle, using one of the pumps to dispense the necessary volume and then forcibly release it by mean of a 5 kV potential difference. The two pumps in the DGH use a 1 ml and a 20 ml syringe respectively and were developed to be lightweight and compact, but still able to deliver very small and precise water volumes on demand. For the 1 ml syringe the plunger diameter is 4.5 mm and the volume resolution is 0.016 µl while for the 20 ml syringe the diameter is 20 mm and the volume resolution is 0.393 µl. In the right-hand side of figure 2 a cross section of the two pumps is presented. All components are off the shelf items or are 3D printed, meaning that the design is low-cost and can be easily reproduced and adapted if necessary. The second main component of the DGH is the electrostatic detachment system; this is composed of a 5V to 5kV DC-DC converter, the positive end of the high-voltage side is attached to a small metal ring positioned below each pump, while the negative pole is connected to the needle of each pump. Proper alignment between the metallic ring and the syringe needle is ensured by the alignment arm built in the system, also allowing to increase or decrease the distance between the two components.

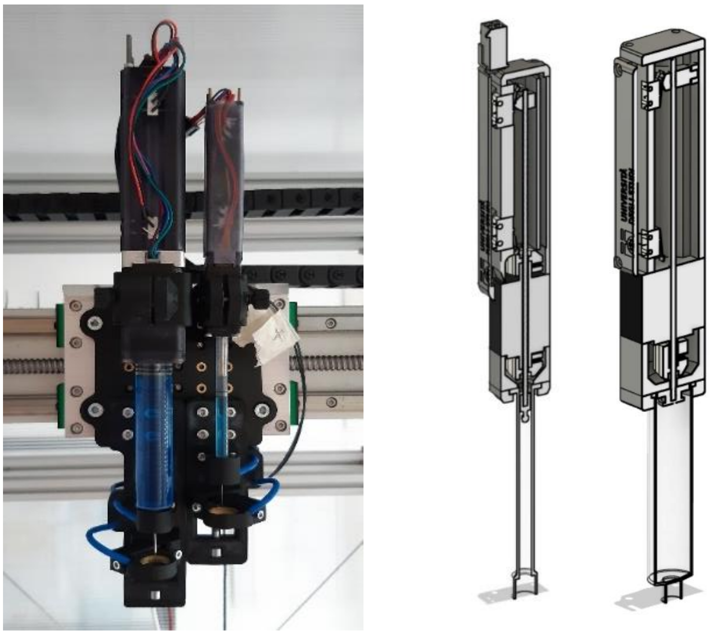


Figure 2: The DRG attached to the moving gantry (left-hand side), cross-section of the two syringe pumps (right-hand side).

2.2. The Photogrammetric Verification System

The PVS is used to measure the size and fall velocity of each generated drop. A photogrammetric approach is used, combined with high-speed photography techniques. The system is composed of a high-resolution digital camera (Sony a6100 with SEL 30 f3.5 macro lens) and two speedlights with a special diffuser. A picture of the system is shown in figure 3.

Figure 3: Picture of the PVS, with the camera, the two flashes and the diffuser.

Knowing the exact time of release of the drop, the camera shutter opens just before the drop enters the camera field of view, then both flashes are triggered thrice with a very short time delay (4.2 ms) capturing three images of the same drop, as shown for example in figure 4. Those images, once post-processed using a photogrammetry approach, constitute the reference measure for the calibration, both in terms of drop size and fall velocity. During the image post-processing, both the drop diameter and fall velocity are obtained since the time interval between flashes is known. Independent verification of the time interval between flash can be obtained using a photodiode. Post-processing of the images is automatized by mean of an image processing software specifically developed for the task. A considerable advantage of the presence of the PVS is that, since the actual size and velocity of each single drop are measured, the strict repeatability of the drop characteristics is a much less relevant issue. In fact, the measured diameter of each drop rather than the nominal one is used for comparison with the instrument output. Analogously, the knowledge of the fall velocity of each drop avoids resorting to theoretical formulations and the need to adopt very tall supporting structures to achieve the terminal velocity for the largest drops.

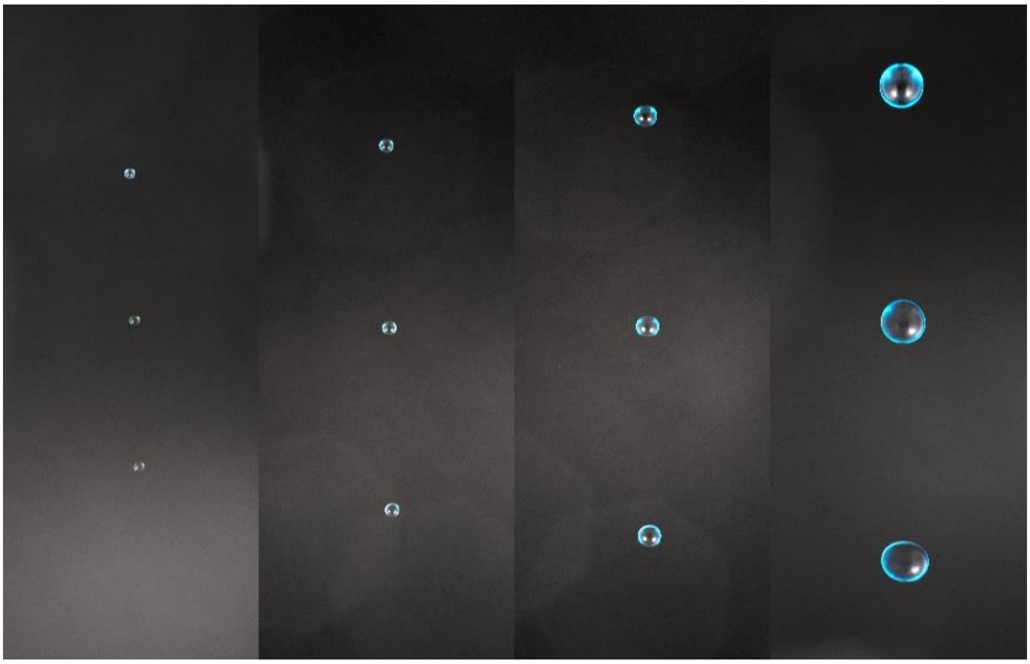


Figure 4: Example of drop images obtained from the PVS (the drop diameter is 0.75, 1, 2 and 3.5mm from left to right).

3. Performance of the CRG

To assess the performance of the CRG in terms of the generated drops size, several tests were performed by releasing drops of nominal size between 1 and 5.5 mm. Depending on the size, 50 to 180 drops were released (for D = 5.5mm and 1.0mm, respectively) from a height of 1.20 m above the centre of the measurement plane of the camera. Each released drop was photographed by the PVS. As a validation of drop size measurements, for each test, the total volume of samples of each diameter was also weighted by mean of a precision balance having a resolution of 0.001 g.

Photographs were processed using a dedicated code capable of detecting the size and positions of drops in the frame. For each independent image of the drop the code evaluates its 2D area and, under the hypothesis of axial symmetry, computes the equivolumetric diameter of the drop. It also evaluates the position of the centre of mass of each drop and computes the distance travelled after each flash. In figure 5, a sample captured image is shown (left-hand panel) while the same picture after software processing is presented in the right-hand panel to show the drop area(highlighted in blue), the equivolumetric circular shape of the drop (D1–D3, in red) and the travelled distances (L1 and L2). Each red circle plotted over each drop has a diameter equal to the computed one and its origin is positioned in the centre of mass estimated by the software.

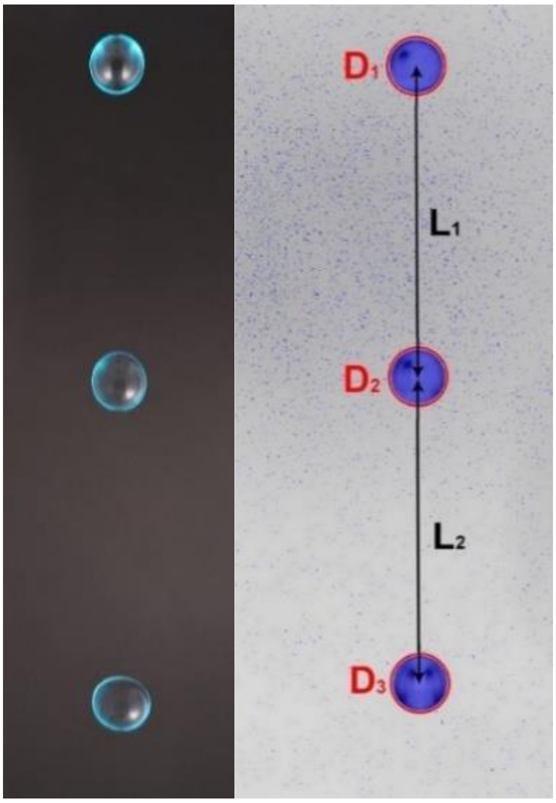


Figure 5: sample image of a single drop in flight as released by the DGH and captured by the PVS (left-hand side). In the right-hand panel the same image, after software processing elaboration, is reported.

Results are summarized in Table 1 in terms of the average drop diameter obtained from the PVS and the scale, and percentage error between PVS and scale measurements.

D nom	n° drops	D avg PVS	St dv PVS	D avg scale	St dv scale	e%
5.50	50	5.23	0.26	4.98	0.05	5.10
5.00	100	4.66	0.16	4.40	0.11	5.92
4.00	100	3.65	0.14	3.66	0.04	-0.20
3.00	100	2.83	0.11	2.66	0.03	6.65
2.00	110	2.08	0.06	2.04	0.01	2.28
1.00	180	1.03	0.06	0.97	0.05	6.22

Table 1: Results of the tests expressed as average diameter for both the PVS and scale measures.

Drops released with the larger pump (5.5 to 3 mm) tend to have a diameter below the expected one (about 10%) while drops released with the smaller pump (2 and 1 mm) are very close to the expected one. It is also visible that the diameter obtained with the PVS is in general larger than the one from the scale, with an average error of about 5%. This difference may be due to imperfect lighting of the drop contours in the pictures taken, which reduces the accuracy of the software in detecting the edge of the drop. Also, drops failing to approach the aerodynamic equilibrium during the flight, i.e., their terminal fall velocity, present oblate sections due to significant oscillations in their shape, which may render the hypothesis of axial symmetry not accurate. Standard deviations are quite low for both the PVS and the scale, indicating a good repeatability of the drop generation and release.

4. Field testing

Further to the laboratory validation, field testing of some available NCGs was performed at the experimental field test sites of Payerne – Switzerland, and Vigna di Valle – Italy, thanks to the availability and support of Metèo Swisse and the Italian Meteorological Service, respectively. In Payerne, at the end of March 2022, the CRG was used to test the installed Thies laser disdrometer, while in Vigna di Valle, in June 2022, it was used for the verification of the Biral light scatter disdrometer.

In Payerne, the metal supporting structure of the CRG was mounted around and above of the Thies LPM instrument. The structure was completed with protecting plastic panels for shielding the generator and the drop vertical trajectories against the wind. Field operations are shown in Figure 6a, where the instrument under test is clearly visible inside of the supporting structure. Once the mounting and alignment was completed, a first set of drops was generated with a nominal expected diameter of 3.5 mm. The drops were generated on demand, first individually and then in sequences at various frequencies. Sequences of 1, 5 and 10 drops per minute were generated.

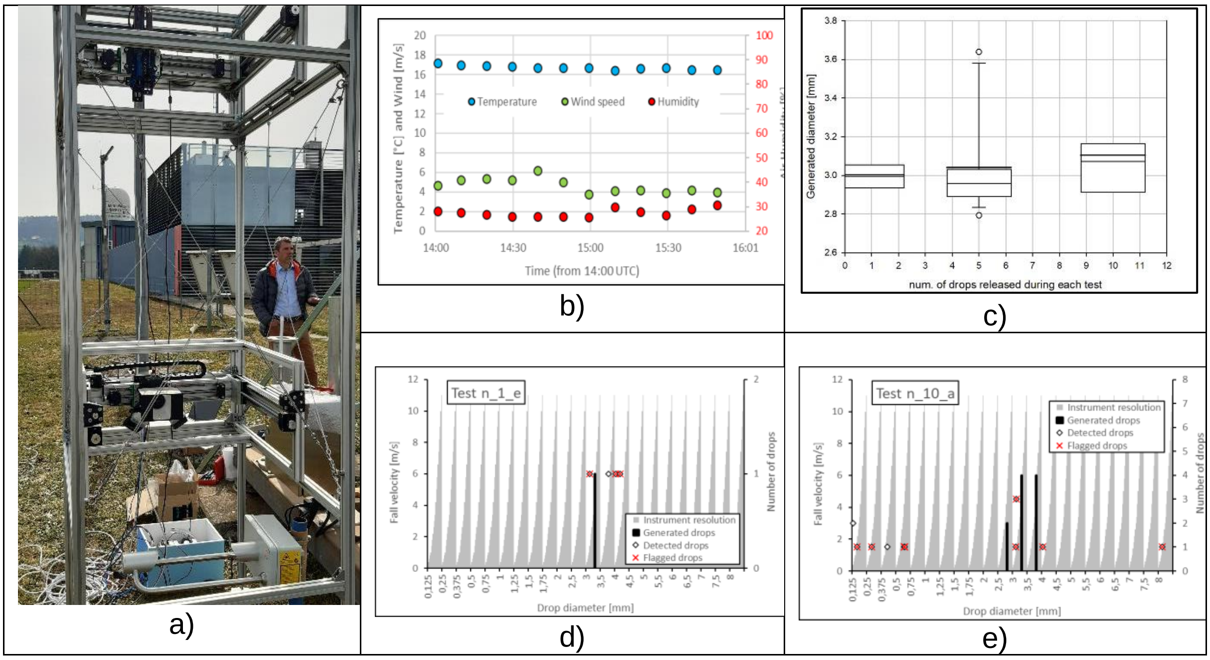
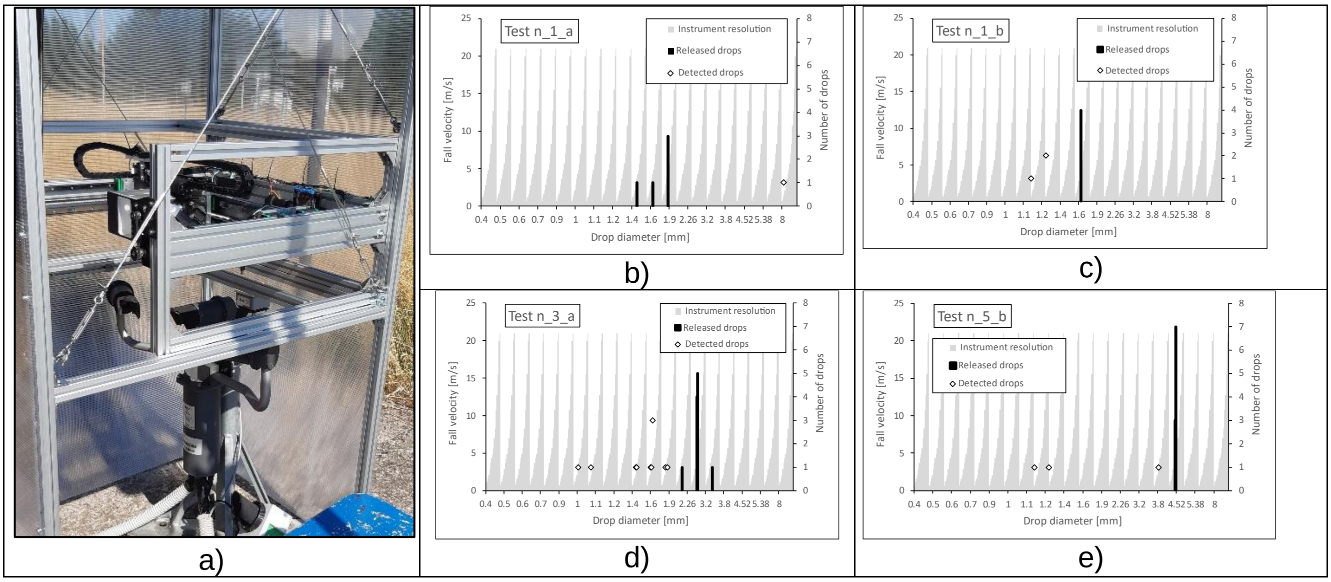


Figure 6: Field operations in Payerne (a) and sample results (b,c,d,e).

The meteorological conditions during the test were those of a sunny but windy morning, and the measured data of interest were obtained from the official meteorological station in Payerne (as shown in Figure 6b). The box-and-whiskers plot reported in Figure 6c indicates that the precision of the generated drop diameter is higher for individual drops than for series of 5 and 10 drops. This confirms that the drop generator is performing better for the release of single drops on demand. A graphical representation of sample test results as obtained in the field is also proposed in Figure 6d-e. The black bar indicates the released drop characteristics, white diamonds indicate the number and characteristics of the detected drops, red crosses indicate detected drops with inconsistent drop size/fall velocity characteristics. The grey background bars are the multiple drop size/fall velocity classes provided as the possible output of the instrument under test. The response of the Thies LPM in individual drop tests tended, in general, to overestimate the drop number by a factor of three, with the detection of some very large drops (≥ 8 mm) in most cases. However, part of these drops was discarded by the acquisition software since the relationship between the drop size and velocity was not in the acceptable range.

The CRG was also installed in Vigna di Valle (Rome, Italy), following the same procedure, shielding both the instrument and the CRG from wind by means of protective panels. A picture of the installed device is reported in Figure 7a (where the Biral instrument under test is visible inside the raindrop generator assembly), together with sample results of the detected drop size (Figure 7b-e). Tests were performed with short series of drops having a nominal diameter of 1, 3 and 5 mm. In this case, the response of the Biral disdrometer tended to underestimate both the drop number and the drop size, except in the case of the first test (Figure 7b) where the instrument only detected one very large hydrometeor, above 6.4mm in diameter. Also, the detected fall velocity was largely underestimated, reporting between half and one third of the actual fall velocity, measured by the PVS, even when associated with detected drops that are larger than the generated ones.



a) b) c) d) e)

Figure 7: Field operations in Vigna di Valle (a) and results (b,c,d,e).

5. Conclusions

The CRG system was shown to be capable of releasing on demand drops with varying diameter, by maintaining a good repeatability and in good accordance with scale measurements. Drops released with the 20ml pump tend to have a diameter about 10% lower than the expected one, possibly due to mechanical tolerances, this bias can however be easily addressed adding a correction coefficient to increase the volume released accordingly. Furthermore, overestimation of about 5% in drop diameters from the PVS is shown by the results for some of the diameters considered, this is being currently investigated but the main cause seems to be due to low accuracy of the software in identifying the drop edges when a non-uniform lighting of the image is present. This is being addressed by developing a new design of diffuser that will improve light uniformity and therefore the performances of the PVS.

In the field, it is possible to observe that the two gauges produce results that are far from the actual characteristics of the released drops and with an opposite behaviour, further highlighting the necessity of a calibration standard for this kind of gauges. Another lesson learned from the experiments performed in Payerne and Vigna di Valle is that calibration procedures for NCGs should be limited to the controlled laboratory environment. Indeed, the experienced wind and atmospheric humidity conditions proved to be challenging for the CRG. Ambient characteristics especially impact on the production (detachment) of the smallest drops and their fall trajectory (deviation from the vertical) towards the instrument sensing area. Also, for the largest drops, the relevant release height needed to reach a significant portion of the terminal velocity would require tall temporary support structures, whose installation and management is tough in field conditions. It is therefore recommended that this kind of calibration is only performed in the laboratory. In the field, on the other hand, only verification tests to check that the instrument does not deviate significantly from the original calibration may be performed, limiting the procedure to few intermediate drop sizes (in the order of 2-3 mm in diameter) and in case of low wind and humidity conditions.

6. References

1. *Caracciolo, C., Porcu, F., & Prodi, F.: Precipitation classification at mid-latitudes in terms of drop size distribution parameters, Advances in Geosciences, 16, 11-17,* ***2008****.*

2. *Cauteruccio, A., Colli, M., Stagnaro, M., Lanza, L.G. and E. Vuerich (****2021a****). In situ precipitation measurements in T. Foken (editor): Springer Handbook of Atmospheric Measurements, Part B: In-situ Measurement Techniques (in press), Springer Nature, pp. 35.*

3. *Colli, M., Lanza, L.G., La Barbera, P. and P.W. Chan (****2014****). Measurement accuracy of weighing and tipping-bucket rainfall intensity gauges under dynamic laboratory testing. Atmos. Res., 144, 186-194.*

4. *Lanza, L.G.; Merlone, A.; Cauteruccio, A.; Chinchella, E.; Stagnaro, M.; Dobre, M.; Garcia Izquierdo, M.C.; Nielsen, J.; Kjeldsen, H.; Roulet, Y.A.; et al. Calibration of non-catching precipitation measurement instruments: A review. J. Meteorol. Appl.* ***2021****, 28, e2002, doi:10.1002/met.2002.*