Calibration of non-catching type rain gauges: preliminary tests on an optical disdrometer

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Abstract:

The last WMO Field Intercomparison on Precipitation Intensity highlights that non-catching type rain gauges show limited performance, in terms of precision and accuracy of the measurements, when compared to the traditional catching type rain gauges.

Moreover, the performance of these instruments differ significantly from each other, this fact suggests that the lack of a standardized calibration procedure leads to different behaviour in field measurements.

Building on these results and in order to understand the causes of this behaviour, the CIMO Lead Centre on Precipitation Intensity has developed a rain drop generator, able to reproduce drops with various diameters.

The Thies LPM disdrometer has been tested using the rain drop generator and the results are presented in terms of total number of droplets detected by the instrument, droplets per diameter class, total accumulation volume and measured rainfall intensity.

Preliminary results show that the disdrometer detects a larger number of droplets than those actually generated. Most of them are attributed by the instrument to the lower diameter class, and have a low impact in the total volume account or rainfall intensity estimation, but could affect the shape of the Drop Size Distribution (DSD) provided by the instrument. Moreover, in many cases it has been found that the disdrometer assigns most of the real droplets to the upper diameter class, therefore resulting in a significant overestimation of the rainfall amount and intensity.

These results, although still preliminary, reveal that a standardized and rigorous calibration procedure is needed for the non-catching type rain gauges to foster more reliable and comparable measurements.

Introduction

Despite the relevance of atmospheric liquid precipitation among the environmental variables, no relevant international standard yet exists to define rigorous methods and procedures for rain gauge calibration and for the evaluation of the associated uncertainty. The only existing standard in the field of rainfall measurement is at present the EN 13798:2010 "Hydrometry - Specification For a Reference Raingauge Pit". This standard addresses the construction characteristics of the so-called "pit gauge", the field reference adopted for comparison of liquid precipitation gauges, and its application is therefore limited to the design of research experiments or test beds.

The recently published Technical Report CEN/TR 16469:2012 "Hydrometry - Measurement of the rainfall intensity (liquid precipitation): requirements, calibration methods and field measurements", describes recent findings in rainfall intensity (RI) measurements for catching-type instruments only, and the related accuracy aspects, following the results and outcomes of the most recent international RI gauges intercomparison organized by the WMO (Vuerich et al., 2009; Lanza and Vuerich, 2009). This technical report also provides informative documentation (in annexes) containing methods for laboratory calibrations, field tests and reference field measurements for catching type gauges.

Based on the above technical report, a new work item called “Hydrometry - Measurement of rainfall intensity (liquid precipitation) - Metrological requirements and test methods for catching type rain gauges” is now adopted by CEN TC318. The coverage of this standard project is limited to catching type gauges, which – due to the presence of the rain collector – can be calibrated using a known flow rate generated in the laboratory as the reference.

However, non-catching type instruments are increasingly addressed and employed by National Weather Services (NWS), due to the lower maintenance required and unattended operation capabilities, in particular when automatic weather stations are used. Non-catching type instruments have a number of advantages over the more common catching-type gauges, including the possibility to provide further information than the precipitation intensity alone (e.g. the Drop Size Distribution, visibility, etc.), and are especially suitable for Automatic Weather Stations. Having no funnel to collect the rainwater, traceability chain, the calibration and uncertainty evaluation is more difficult than in the catching type gauges and the use of an equivalent, reference flow rate is not possible. Rather, for an appropriate metrological characterization of non-catching gauge instruments, the actual rain event characteristics have to be reproduced, including water temperature, drop size distribution, drop frequency, and fall velocities. This requires a considerable metrological effort to investigate traceability and uncertainty issues to support new calibration methods and laboratory rainfall generators.

In order to support their wider use, and as a development beyond the recent item adopted under CEN TC318 for catching type gauges, traceable instrument calibration methods for non-catching gauges used to measure precipitation amount and intensity must be developed. This would allow establishing a sound metrological basis for the evaluation of standard uncertainty for the relevant sources of uncertainty in the instrument calibration procedure. In addition, suitable laboratory tests are needed to determine the Type-A evaluation of standard uncertainty, based on valid statistical methods. Standardised procedures for the laboratory calibration of non-catching type instruments are also needed, with the associated calibration uncertainty assessment and repeatability features.

Non-catching type instruments were implemented in the recent WMO SPICE (Solid Precipitation InterComparison Experiment) and tested against the DFIR (Double Fence Intercomparison Reference) in the field at various test sites. The study concludes that further analysis is needed to better understand the behavior of these sensors, especially working with the raw data (drop size and fall speed distribution), and exploiting the full capacity of such sensors, which provide much more information than the precipitation accumulation (precipitation type, SYNOP and METAR code, etc.). Field tests on SPICE reference sites have been continued in that sense after the official end of the project, and will enhance the knowledge on the operational use of non-catching type instruments in winter conditions.

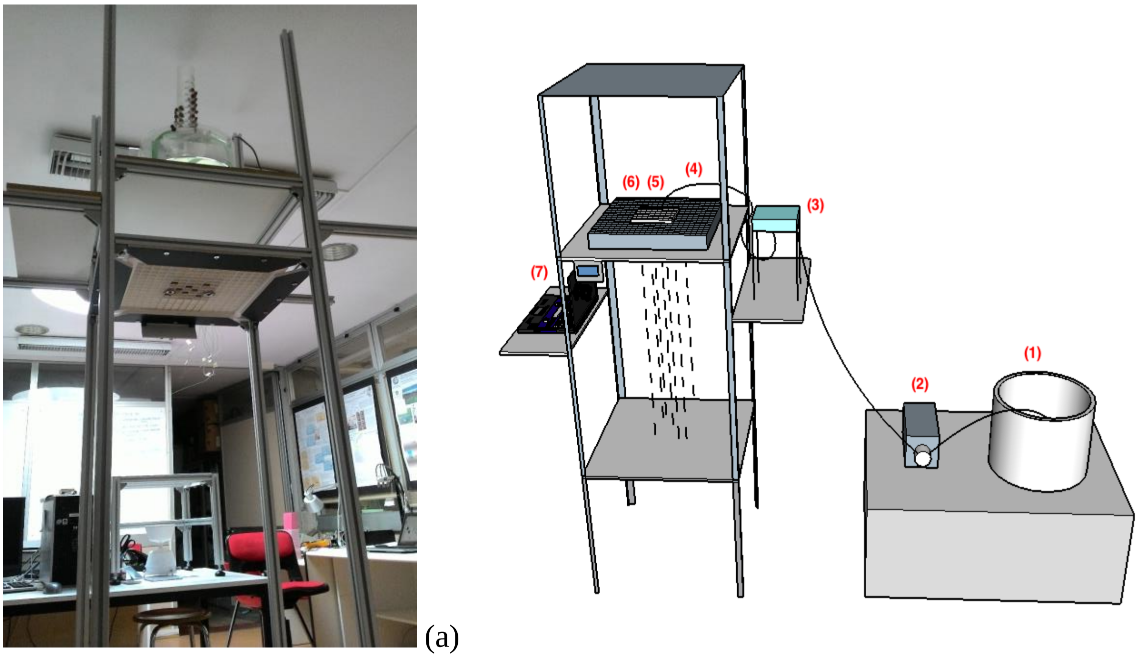
Drop generator characterization

The drop generator is composed by multiple nozzles for the simulation of an artificial rainfall characterized by a given drop size distribution. The head pressure at the nozzle is maintained constant by means of variable speed gear pumps ISMATEC Reglo Z, which feeds the constant head distribution chambers with water. Multiple nozzles of the same internal diameter size DI are connected to the same head distribution chamber. The head pressure chambers’ function is to distribute the head pressure among the conduits, which feed the nozzles.

The scheme of the Rainfall Simulator (RS) is presented in Figure 1. A rain tower includes all the devices that compose the RS:

(1) Constant head tank;
(2) Pumping system;
(3) Head pressure distribution chamber;

(4) Single nozzle conduits;
(5) Supporting grid;
(6) Infra-Red proximity sensors;
(7) Automatic acquisition system.



(a) (b)

Figure 1: Picture (a) and schematics (b) of the rain simulator developed at the University of Genova for testing non-catching type gauges.

The rainfall simulation occurs by discretization of the water flows generated by an isolated pumping system through a selected number of calibrated nozzles. Each isolated pumping system (2) takes water from the constant head tank (1) and transfers it into a system of head-pressure distribution chambers (3). Using up to three pump, it is possible to three drop sizes, with different working frequencies and number of nozzles, in order to reproduce a discrete DSD. Each nozzle of the same diameter is connected to the same head pressure distribution chamber through a dedicated tubes (4).

Each pump can feed up to 15 nozzles with a specific diameter at the same time, therefore a specific droplet size. We employ four types of nozzles of different internal diameters in order to be able to generate droplets of different sizes. The yellow nozzles are characterized by an internal diameter of 0.102 mm, the orange ones by an internal diameter of 0.330 mm, the pink ones by a diameter of 0.610 mm and the green ones by an internal diameter of 0.830 mm. The capability to generate different droplets sizes is fundamental in order to recreate a discrete form of the precipitation drop size distribution (DSD) for a limited number of diameters.

Constant flow rates Q (ml/min) tests highlighted steady drops dispensing frequency (Hz) from a single nozzle after an initial transient due to the hydraulic system warm-up. The time response of the pumping units has been previously estimated by means of dedicated laboratory tests reported by Colli et al. (2013).

The drop diameter D_{drop} (mm) generated by a specific nozzle is a function of the drop dispensing frequency Freq (Hz). Figure 2a reports the D_{drop} values assessed for different DI (expressed in 10^{-3}mm) and measured by means of an Infra-Red proximity sensor and a precision balance Mettler Toledo PB4002 (sensitivity equal to 0.01g). Figure 2b shows the good agreement between the overall generated volume of the total number of drops against the reference water weight.

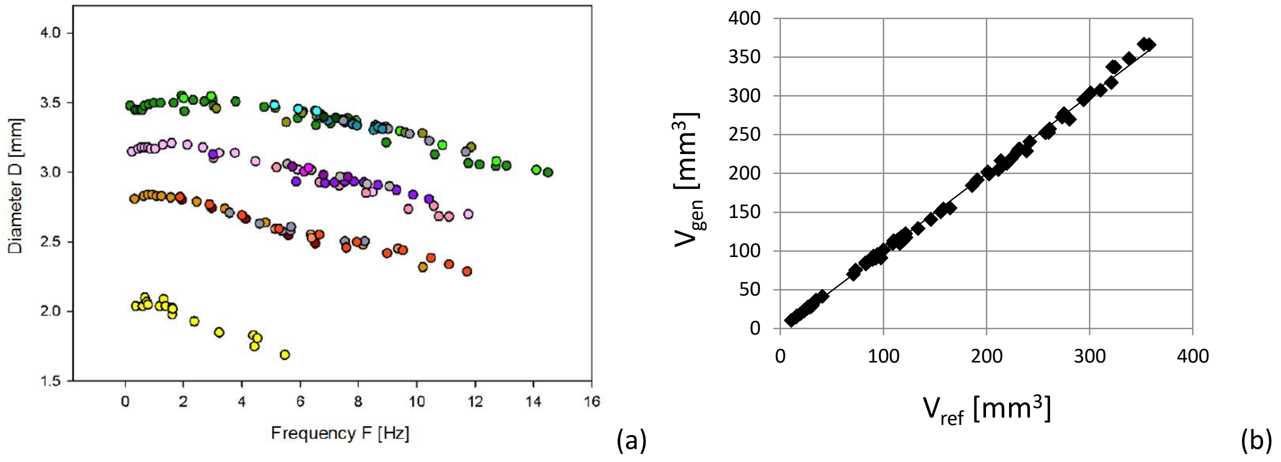


Figure 2: Generated drop diameter as a function of the dispensing frequency (a) for different nozzles (colour coded) and number of nozzles used contemporarily (colour shades), and check of the overall generated volume (b) against the reference water weight

Testing of an optical commercial sensor

The disdrometer used for these tests is the laser precipitation monitor, Thies LPM, whose performances had already been analysed during the WMO Field Intercomparison of Rain Intensity Gauges (Vuerich et al., 2009). The instrument is characterized by a laser optical beaming source that produces an infrared parallel light-beam, of measuring area A=45.6 cm^2. When precipitation particles fall through the light beam, the receiving signal is reduced. The diameter of the particle is calculated from the amplitude of the reduction, whereas the falling speed of the particle is determined from the duration of the reduced signal.

The type of precipitation is determined from the statistic proportion of all particles referring to diameter and velocity. In addition, temperature is included in order to improve the identification. Precipitation with a temperature of above 9°C are automatically accepted as liquid, and with a temperature of below -4°C as solid. In between this temperature range, all forms of precipitation might occur.

The instrument provides many output data on a one minute time scale, including the five minutes and the one minute mean values of the rain intensity, the number of fallen particles that are and are not hydrometeor, the volume values divided for each class of particles, the temperature, the wind speed and direction, and many more. In addition, it identifies different classes depending on the particle shape and falling speed.

From the instrument output we can easily derive the average diameter measured on a one minute scale and compare it with the generated average diameter as registered by the sensors. Moreover, the rain intensity on a one minute scale as well as the total volume measured by the instrument can be compared with the generated ones. In fact, the disdrometer rainfall-rates and volume values for different time intervals are computed from the one-minute drop matrix representing the particle drop classes (Prata de Moraes Frasson et al., 2011).

To obtain the rainfall-rate, one divides the accumulated volume of water by the horizontally projected area, A, and the duration of the integration interval, t, as shown in the following equation.

$$R = \frac{1}{A\cdot\left(\frac{t}{60}\right)}\sum_{j=1}^{t}\sum_{i=1}^{440} N_i \frac{4\pi}{3}\cdot\left(\frac{D_i}{2}\right)^3$$

The interior summation accumulates the volume of the drops recorded by the instrument during the minute j, where N_i represents the number of drops of the current drop class i, and D_i represents the central class diameter in millimetres. The exterior summation accumulates the volume of water that passed during all j minutes, which is one of the t minutes inside the current integration interval.

In this work, tests have been conducted using one nozzle at the time and choosing different frequency values. In this way, the rainfall simulator produces only one drop at a time and it has been possible to check the disdrometer behaviour.

Further tests have been conducted using two nozzles of the same type at a time and choosing different frequency values. During these tests it was important to ensure that all drops actually fall in the laser beam and that the drops are not perfectly aligned.

Results

First, analysing the drop diameter classes given by the instrument we noticed that, in many tests, the instrument detected a large number of drops belonging to the first class that characterizes drops with a range of diameter between 0,125 mm and 0.250 mm. These micro-drops are actually not generated by the rainfall simulator and, indeed, not registered by the sensors. This error is not significant to the calculation of the volume and the rain intensity but it is relevant for the total amount of drops and the resulting drop size distribution.

Figure 3a compares the total volumes registered by the sensors and the one calculated from the disdrometer output (excluding the spurious drops). We can notice that the values registered by the two instruments are similar, with a little overestimation by the disdrometer.

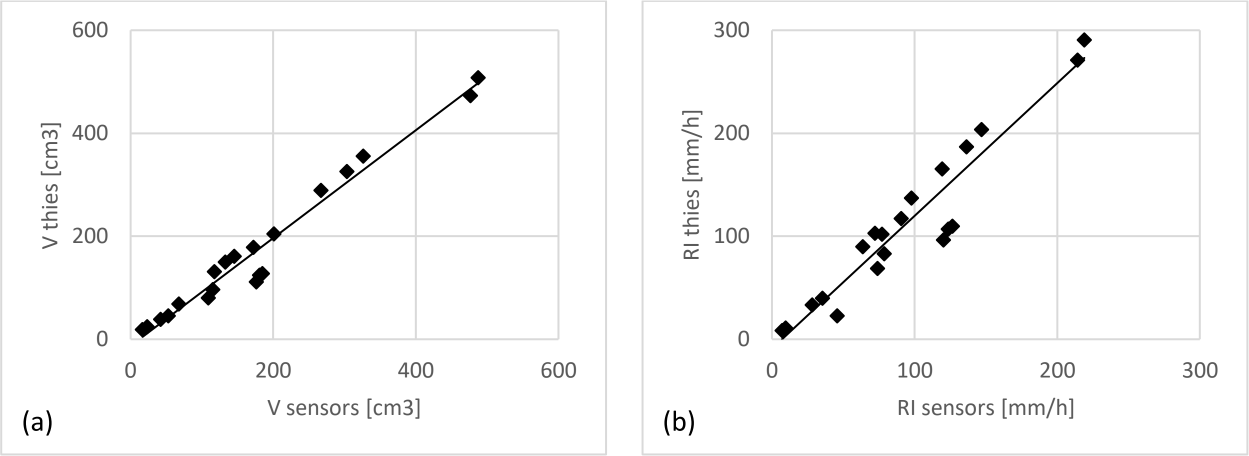
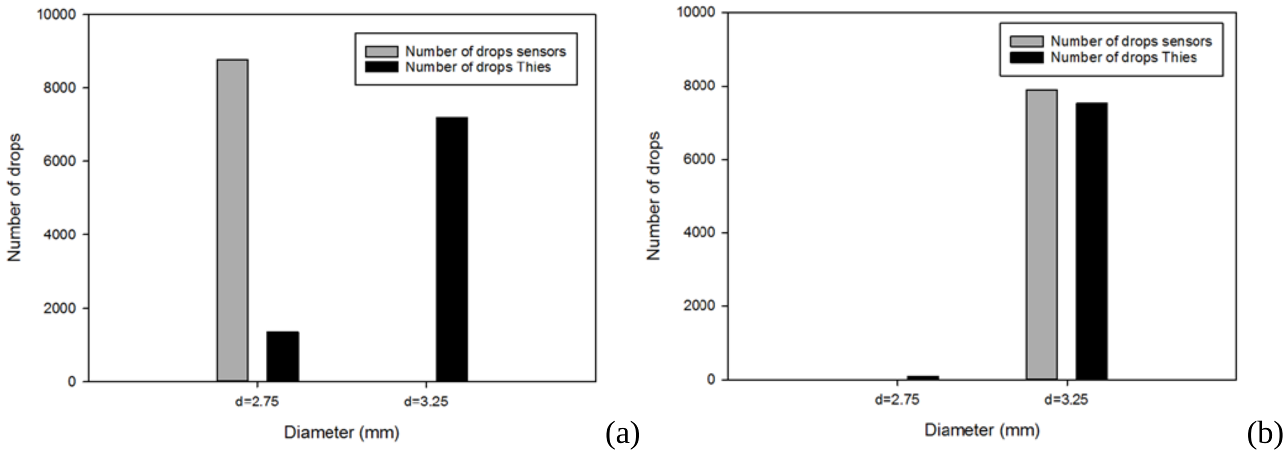


Figure 3: Scatter plot of the drop volume (a) and the rain intensity (b) as produced by the rain generator and measured by the disdrometer (Channels n° 17 and 14 of the Thies Telegram 5).

Figure 3b shows the rainfall intensity registered by the sensors and the one provided in output by the disdrometer, highlighting a general overestimation. The variability around the best-fit line is preserved, therefore tests characterized by an underestimation of volume are also affected by and underestimation as regards the rain intensity values and vice-versa. The overestimation seems to be associated with the high number of spurious drops that are not produced by the rain generator while appears in the disdrometer output data.

In fact, in tests where we observe an overestimation both in the volume values and in the rain intensity values, the drop diameter classes registered by the sensors are different from the classes acquired by the disdrometer. For instance, table **Errore. L'origine riferimento non è stata trovata.** shows the number of drops of the different classes registered with one minute resolution during one of the conducted tests. All the drops registered by the sensors belong to class 11, and are characterize by diameters in the range between 2.5 mm and 3 mm, while the drops registered by the disdrometer stay not only in class 11 but also in class 12, characterized by diameters in the range between 3 mm and 3.5 mm.



(a) (b)

Figure 4: Examples of the number of drops per each class as generated by the system in two events where either an underestimation (a) or overestimation (b) is observed.

Conclusions

In this work, a laboratory rainfall simulator was first validated by checking its ability to provide the necessary response time and accuracy in generating expected values of flow rates. The aim is to use this rainfall simulator for calibrating non catching type rain gauges, since so far no standard calibration procedure exists for this kind of instruments.

First, the associated drop frequency – diameter curves were derived. The relationship between drop frequencies and diameters is essential for the estimation of the rain intensity and the generated drop size distribution. Results show that the curves have different trends according to the number of nozzles used and to the frequency value of the single drop. Further tests were conducted to validate the system by comparing the data acquired by the rainfall simulator sensors and those acquired by the reference system, i.e. the precision balance.

The rainfall simulator was used to test the behaviour of a commercially available disdrometer manufactured by Thies, and results are compared with those recorded during the WMO Field Intercomparison of Rain Intensity gauges. The instrument behaviour has been determined by analysing the output data acquired by the disdrometer and comparing them with those acquired by the rainfall simulator sensors.

In many tests, the instrument detected a large number of drops belonging to the first class, that characterizes drops with a diameter ranging between 0,125 and 0.250 mm. These micro-drops are actually not generated by the rainfall simulator and, indeed, not registered by the sensors. Then, the total amount of fallen drops and the average diameter value registered by the two instruments have been found similar.

Finally, a general overestimation by the disdrometer have been observed, in agreement with what previously noticed during the WMO Field Intercomparison of RI gauges. This behaviour is explained by checking the number of drops detected in a certain class. We observed that this overestimation was due to the fact the disdrometer registered some of the drops as belonging to a higher diameter class than the actual drops registered by the rainfall simulator sensors. This can be due to the assumptions about the geometrical shape of the drop assumed by the disdrometer.

In conclusion, proper functioning of the rainfall simulator was demonstrated. Remarkably, the results obtained represent the basis for further developments. The system could be improved by using a precision dispenser for the generation of the drops.

Currently, no standard calibration procedure suitable for non-catching type gauges exists; therefore, the improved rainfall simulator can be used to define a new technical standard for the calibration of these instruments. Hence, the improved rainfall simulator will hopefully become an important tool for increasing the accuracy and reliability in rainfall intensity measurements.

References

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