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Measurement accuracy of weighing and tipping-bucket rainfall intensity gauges under dynamic laboratory testing

M. Colli [a], L.G. Lanza [a,c,*], P. La Barbera [a], P.W. Chan [b]

[a] University of Genova, Department of Civil, Chemical and Environmental Engineering, Via Montallegro 1, 16145 Genoa, Italy
[b] Hong Kong Observatory, 134A Nathan Road, Kowloonx, Italy
[c] WMO/CIMO Lead Centre "B. Castelli" on Precipitation Intensity, Genoa, Italy

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A B S T R A C T

The contribution of any single uncertainty factor in the resulting performance of infield rain gauge measurements still has to be comprehensively assessed due to the high number of real world error sources involved, such as the intrinsic variability of rainfall intensity (RI), wind effects, wetting losses, the ambient temperature, etc. In recent years the World Meteorological Organization (WMO) addressed these issues by fostering dedicated investigations, which revealed further difficulties in assessing the actual reference rainfall intensity in the field.

This work reports on an extensive assessment of the OTT Pluvio2 weighing gauge accuracy when measuring rainfall intensity under laboratory dynamic conditions (time varying reference flow rates). The results obtained from the weighing rain gauge (WG) were also compared with a MTX tipping-bucket rain gauge (TBR) under the same test conditions. Tests were carried out by simulating various artificial precipitation events, with unsteady rainfall intensity, using a suitable dynamic rainfall generator. Real world rainfall data measured by an Ogawa catching-type drop counter at a field test site located within the Hong Kong International Airport (HKIA) were used as a reference for the artificial rain generation system.

Results demonstrate that the differences observed between the laboratory and field performance of catching-type gauges are only partially attributable to the weather and operational conditions in the field. The dynamics of real world precipitation events is responsible for a large part of the measurement errors, which can be accurately assessed in the laboratory under controlled environmental conditions. This allows for new testing methodologies and the development of instruments with enhanced performance in the field.

1. Introduction

Modern ground-based monitoring techniques for the automatic measurement of solid and liquid precipitations are devised to require sporadic human intervention in-situ and to provide high resolution measurements. The introduction of printed circuit assembly boards embedded within the instruments and more powerful data logging stations allows not only the storage of raw data measured in short time intervals, but also immediate computation of the derived quantities and their correction for systematic errors (e.g., the well-known mechanical underestimation error of tipping-bucket rain gauges). Sophisticated acquisition boards can be programmed to execute quality checks, diagnostic protocols and data storage applications providing a real-time tracking of the status of the measurement system.

Despite the noticeable technological benefits achieved by the modern gauge and acquisition systems, a number of open issues related to the correct interpretation of the strong variability in

* Corresponding author at: University of Genova, Department of Civil, Chemical and Environmental Engineering, Via Montallegro 1, 16145 Genoa, Italy. Tel.: +39 0103532123; fax: +39 0103532481.
E-mail addresses: matteo.colli@unige.it (M. Colli), luca.lanza@unige.it (L.G. Lanza), paolo.labarbera@unige.it (P. La Barbera), pwchan@hko.gov.hk (P.W. Chan).

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time of precipitation are still to be definitively addressed in the common practice.

The weighing gauges (WG) probably constitute the most promising modern automatic technique for performing on site measurements, primarily due to the high sensitivity which is expected to easily overcome the sampling limitations of traditional tipping bucket rain gauges (TBR) (see e.g. Habib et al., 2001; Colli et al., 2013a). The environmental factors that typically affect liquid and solid precipitation measurements, such as wind speed, temperature and the physical state of the hydrometeors, still have to be accounted for in the calculation of corrected liquid and solid precipitation amounts (Thériault et al., 2012; Savina et al., 2012; Sevruk and Chvíla, 2005, Seibert and Morén, 1999; MacDonald and Pomeroy, 2008). Recent attempts addressed specific problems related to the assessment of accurate measurements with a high temporal resolution, in particular those related to the dynamic response of the WGs (Colli et al., 2013b), and to the sensor signal noise for light rain assessment (Lamb and Durocher, 2004). These factors are highly related to the nature of the measuring principle adopted by the examined weighing gauge, which is generally based on the employment of load cell transducers or, as an alternative, vibrating wires techniques (see e.g. Lanza and Vuerich, 2009; Duchon, 2008).

In the past, the World Meteorological Organization (WMO) supported several experimental activities with the aim of obtaining comparative analyses of the performance of existing on-site measurement techniques and to provide methods and recommendations about the gauge set-up and its measurement accuracy. Within the laboratory phase of the first WMO Field Intercomparison of Rainfall Intensity (RI) Gauges, Lanza and Stagi (2009) obtained very promising results from the WGs in terms of average errors in steady state conditions; the investigation was performed in the laboratory by simulating constant RI events. Good agreements were confirmed during the field phase of the same Intercomparison (Lanza and Vuerich, 2009) where two WGs were selected to be part of the set of four instruments installed inside the reference pit: the T200B vibrating wires and the Pluvio load cell gauge, manufactured respectively by GEONOR and OTT.

However, the preliminary laboratory calibration and verification efforts raised some first evidences that additional uncertainties were ascribable to the dynamic response of the instrument, occurring when rapid transitions between consecutive reference RI values were generated by the testing system (Vuerich et al., 2009). The quantification of the dynamic response induced uncertainties in high resolution RI measurements is nowadays recognized as an important objective for future investigations. It is worth stressing here that the infield comparative experiments still remain affected by noticeable difficulties in determining the reference RI, usually obtained as the weighted combination of measurements made by a selection of best performing instruments. Experiments on these issues are being performed within the start-up phase of SPICE, the Solid Precipitation InterComparison Experiment of the WMO (focused on the improvement of snow and mixed precipitation measuring techniques). In this context, the WMO Lead Centre (LC) “B. Castelli” on Precipitation Intensity (Italy) and the National Center for Atmospheric Research (Colorado, USA) laboratories are carrying out dedicated WG testing in a cold room environment taking advantage of accurate low rainfall intensity generators and an artificial solid precipitation generator.

The present work reports on the outcomes of laboratory experiments performed at the LC, consisting of the indoor simulation of the temporal variability of liquid precipitation. The main expected advantage is the possibility of distinguishing between the various error sources affecting the gauge performance when moving from the initial steady state laboratory tests to the field campaign. The effect of time varying RI events on the WG measurement performance is addressed here, irrespective of the typical wind induced rainfall under-catching and other catching-type errors that are typically claimed to explain the observed difference in performance between the laboratory and the field experiments.

The goal of this research is to provide indications about the potential improvement of rainfall intensity measurements that are achievable by switching from the traditional tipping bucket gauges to more modern weighing gauges after including the results of laboratory simulations of real world RI time series.

2. Methodology

The investigation of the dynamic behavior of rain intensity gauges in the laboratory requires the availability of a flow rate generation system suitably designed to perform a response time significantly shorter than the typical time resolution of the instruments under test. The laboratory apparatus must also demonstrate repeatability of the generated flow rates, so as to ensure sound dynamic performance when unsteady RI are simulated.

2.1. The flow rate generation system

A fully-controlled automatic generator of variable flow rates was designed to perform laboratory simulations of the temporal patterns of typical rainfall events, based on the use of two high-precision volumetric pumps (Fig. 1a). A precision balance was used to validate the water volumes generated in a given time interval, with a computer-supported data acquisition system devoted to the storage of outputs produced by the instruments under test and the balance, and to automatically control the pumps as well. The characteristic accuracy (measured by the average relative deviation between the generated and the imposed flow rate) and repeatability (represented by the standard deviation of the flow rate values) of the flow rates generated by the two pumps were calculated to assess the capability of the rainfall simulation system to produce the expected flow rates. Moreover, a calibration curve was obtained and implemented into the control software to correctly drive the two pumps. Flow rates below 18 ml/min are obtained from the dedicated low-intensity pump while for intensities greater than that limit the second high-intensity pump is activated.

Another important uncertainty source when the reliable simulation of time-varying reference intensities is sought is the overall response time of the experimental system as a whole. In order to assess the possible delays of the water flow following the activation and deactivation of the pumps a video tracking technique had been preliminarily employed so as to detect the water level vertical fluctuations inside a see-through reservoir connected to the pump outlet (already