Atmospheric Research 131 (2013) 3–12

Contents lists available at SciVerse ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Performance of a weighing rain gauge under laboratory simulated time-varying reference rainfall rates

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ARTICLE INFO

Article history:
Received 18 June 2012
Received in revised form 16 April 2013
Accepted 19 April 2013

Keywords:
Rain gauge
Accuracy
Tipping-bucket
Weighing gauge

ABSTRACT

The available calibration experiences about rain intensity gauges relying on the weighing measuring principle are based on laboratory tests performed under constant reference flow rate conditions. Although the Weighing Gauges (WG) do provide better performance than more traditional Tipping Bucket Rain Gauges (TBR) under constant reference flow rates, dynamic effects do impact on the accuracy of WG measurements under real-world/time-varying rainfall conditions. The most relevant biases are due to the response time of the measurement system and the derived systematic delay in assessing the exact weight of the volume of cumulated precipitation collected in the container. This delay assumes a relevant role in case high resolution rainfall intensity (RI) time series are sought from the instrument, as is the case of many hydrologic and meteo-climatic applications (the one-minute time resolution recommended by the WMO for rainfall intensity measurements is here assumed). A significant sampling error is also attributable to some kind of weighing gauge, which affects the low intensity range as well.

A laboratory investigation of the accuracy and precision of a modern weighing gauge manufactured by OTT (Pluvio^2) under unsteady-state reference RI conditions is here addressed. Three different laboratory test conditions are applied: single and double step variations of the reference flow rate and a simulated real-world event. The preliminary development and validation of a suitable rainfall simulator for the generation of time-variable reference intensities is presented. The generator is demonstrated to have a sufficiently short time response with respect to the expected instrument behavior in order to ensure effective comparison of the measured vs. reference intensities.

The measurements obtained from the WG are compared with those derived from a traditional TBR (manufactured by Casella) under the same laboratory conditions. The TBR measurements have been corrected to account for systematic mechanical errors and comparison is also proposed after applying further algorithms to reduce the sampling errors. Results indicate that the performance of the investigated WG under unsteady (real world) conditions in the laboratory is comparable or even lower than what can be obtained from more traditional TBRs, even in case corrections for sampling errors are not applied.

1. Introduction

Weighing Gauges (WG) have been largely tested in the laboratory under constant flow rate (steady state) conditions, e.g. during the recent Intercomparison initiatives of the World Meteorological Organisation (WMO) in 2004–2005 and 2007–2009. Tests under time-varying (unsteady) conditions were performed in the field during the second intercomparison

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http://dx.doi.org/10.1016/j.atmosres.2013.04.006

against a composite field reference obtained from multiple pit gauges where two weighing gauges were also part of the field reference itself (see e.g. Lanza and Vuerich, 2009). The issue of assessing the dynamic response of this type of gauges in case of time-varying rainfall events emerged clearly in that occasion, and an attempt to evaluate the associated time constant was initiated by introducing specific tests. However, the laboratory equipment was not fully suited to perform such tests and various specific issues remained unresolved. The most relevant one was related to the time response of the laboratory equipment itself, actually unknown at that time and difficult to assess for that kind of equipment.

In recent years the WMO Commission for Instruments and Methods of Observation (CIMO) promoted noticeable advancements in this field by providing recommendations on the standardization of equipment and exposure, instrument calibration and data correction as a consequence of various comparative campaigns involving manufacturers and National Meteorological Services (NMS) from the participating countries (WMO, 2008).

The WMO/CIMO Lead Centre "Benedetto Castelli" on Precipitation Intensity, established in 2010, has been continuatively performing laboratory and field tests on weighing gauges in the last years with a specific emphasis on the dynamic performance of such instruments. In particular, the performance of WGs under laboratory simulated time-varying reference rainfall rates was investigated and preliminary results are here presented and discussed.

First, the characteristics of the equipment used to generate the time-varying reference flow rates in the laboratory are reported in this paper, together with the preliminary tests performed to demonstrate the inherent dynamic behavior (time constant) of the generator. Based on such results, full testing of the dynamic behavior of a typical WG was extensively possible over a wide range of dynamic conditions, and the associated measuring errors could be determined.

The main error sources affecting the one-minute rainfall intensity (RI) measurements of a typical WG derive from the delay of the embedded acquisition system in providing the measured RI due to the algorithms used for filtering of the noise and to the sampling requirements of the gauge which needs to wait a minimum period of time in order to collect a sufficient amount of precipitation.

Additional drawbacks in the measurement accuracy are observed when evaluating the rain gauge performance under real-world operational conditions, with a number of field biasing factors such as wind induced undercatch (Sevruk et al., 2000), temperature (Duchon, 2008) and turbulence effects, and wetting losses (Savina et al., 2012). The development of a novel correction algorithm, able to cope with the precipitation undercatch and the instrumental noise issue as well, is one of the goals of the ongoing WMO Solid Precipitation InterComparison Experiment (see e.g. Nitu et al., 2012). The correction technique should incorporate information provided by ancillary measurements such as environmental, sensor and catching orifice temperatures and the mean wind speed.

In this paper we report the results obtained while testing the OTT Pluvio^2 weighing gauge in the laboratory under single step, multiple step and event-like conditions. The associated dynamic behavior of the instrument is quantified by evaluating the average errors and their deviations under repeated test runs or throughout the event. Finally these data are compared with the error figures obtained under the same conditions from a traditional TBR, manufactured by Casella (UK).

2. Methods

2.1. The laboratory setup

Calibration and testing of catching type rain gauges have been extensively performed at the University of Genova (recently in the framework of the WMO/CIMO Lead Centre on Precipitation Intensity) since the 1970s (Becchi, 1970). Researches on methods to enhance the quality of RI measurements required prototyping a dedicated Qualification Module for Rain Intensity Measurement instruments, also called QM-RIM. This device is devoted to the automatic generation of constant and controlled flow rates (representing equivalent rainfall intensities for any given catching-type gauge) for the derivation of suitable calibration curves based on a sequence of tests performed at fixed reference rainfall intensities.

Recent developments require investigating the dynamic response of precipitation gauges and its impact on the accuracy of the derived RI measurements. A new flow rate generation system suitably endowed with a response time significantly shorter than the typical resolution in time of the instruments under test is therefore necessary to this aim. A high repeatability of the generated flow rate values is another key-factor to ensure sound dynamic tests involving transient (unsteady) RI conditions.

A laboratory test system was therefore designed to involve a fully-controlled automatic flow rate generator of time-variable rainfall intensities based on the cooperative contribution of two high-precision volumetric pumps (Fig. 1) supplied from a constant-head input reservoir, a precision balance as a validation device and a dedicated software for digital acquisition of experimental data and their further processing. Table 1 reports the pump models used and the associated range of achievable flow rates.

The validation of the water volumes actually generated is obtained by using a Mettler Toledo precision balance with a resolution of 0.01 g, a value which is deemed appropriate for end-of-test cumulative validation. The acquisition of the output of any rain gauge under test and of the balance, as well as the automatic control of the pumps, are performed using a PC supported software implemented with National Instrument (NI) LabVIEW whereas the communication with the test devices is carried out throughout NI DAQ hardware and NI Serial Ports.

The two pumps were subject to a series of tests to investigate the average errors committed in realizing the desired flow rate values (see Eq. (1)) and the repeatability (precision) of the pump in producing the expected flow rates (measured by the standard deviation of relative deviations). In this work the relative percentage error between a measured quantity, here Q_m, and its true value, Q_{ref}, is calculated as:

$$e_{res}[\%] = \frac{Q_m - Q_{ref}}{Q_{ref}} \cdot 100 \quad (1)$$

A calibration curve for the pumping system was obtained and implemented into the control software to correctly drive the two pumps. In Table 2 the average percentage relative