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Non-parametric analysis of one-minute rain intensity measurements from the WMO Field Intercomparison

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ABSTRACT

The analysis of counting and catching errors of both catching and non-catching types of rain intensity (RI) gauges was possible for the first time over a wide variety of measuring principles and instrument design solutions based on the recent Field Intercomparison of Rainfall Intensity Gauges promoted by WMO, the World Meteorological Organisation. This paper investigates the frequency distribution of the observed deviations of one-minute RI measurements from the assumed reference value (a weighted average of four selected pit gauges) obtained in real world conditions during the measurement campaign in the field.

The presented non-parametric analysis of these deviations confirms that the accuracy of the investigated RI gauges is generally high and contained within the limits established by WMO. Exceptions are the majority of non-catching gauges, especially the optical and acoustic disdrometers, which show significant biases.

The intermediate measurement precision was also investigated revealing that the frequency distribution of deviations around their mean value is not indicative of an underlying Gaussian population, being much more peaked in most cases than what can be expected from samples extracted from a Gaussian distribution and indicative of a better precision. Non-catching gauges showed a markedly different behaviour. The analysis of variance (one-way ANOVA), assuming the instrument model as the only potentially affecting factor, does not confirm the hypothesis of a single common underlying distribution for all instruments. Pair-wise multiple comparisons revealed that this hypothesis is generally acceptable for two paired instruments. The cases where significant differences are observed could be easily identified.

1. Introduction

Rainfall is the forcing input of the land phase of the hydrological cycle. The knowledge of rainfall, its variability and the observed/expected patterns of rain events, in both space and time, are of paramount importance for most hydrological studies; a large number of consequences of such studies on the engineering practice are exploited in the everyday technical operation (see e.g. La Barbera et al., 2002; Molini et al., 2005a).

The accuracy of rainfall intensity measurements obtained from tipping-bucket and other types of rain gauges, as well as their comparative performance, is a topical issue in hydrology and meteorology (see e.g., Tokai et al., 2003; Molini et al., 2001, 2005b; Pavlyukov, 2007; Ren and Li, 2007; Keefer et al., 2008). The importance of surface measurements of precipitation has been stated by Michaelides (2009): "measurements at the ground have been proved indispensable, despite advances in several areas of remotely sensing of precipitation. Ground truth seems to be inseparable from any study on precipitation. A better understanding of the behaviour of precipitation on the ground with direct measurements can lead to more effective estimations by using other methodologies".

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The quality of rainfall intensity measurements is subject to various types of errors, arising from the counting and catching performance of the specific measurement instrument, on the one hand, and the measuring principle employed, on the other hand.

The errors due to the weather conditions at the collector, as well as those related to wetting, splashing and evaporation processes are referred to as catching errors. They all indicate the ability of the instrument to collect the exact amount of water that applies from the definition of precipitation at the ground, i.e. the total amount of water falling over the projection of the collector's area at ground level. Non-catching instruments (which are based upon a contact-less measurement) have no collector and may also show "catching" errors, which in this case implies that the instrument is not able to detect the full amount of water passing through the atmospheric volume where the measurement is taken.

Errors due to the "counting" performance are related to the ability of the instrument to correctly quantifying the amount of water that is collected or detected by the instrument. They can be experienced both in catching and non-catching types of instruments, although in the latter case the assessment of such errors is very difficult and hard to be performed in controlled laboratory conditions. These errors may originate from the very different aspects of the sensing phase, since all the instruments may differ from each other in the measuring principle applied, construction details, operational solutions, etc.

Thorough analysis of counting and catching errors of both catching and non-catching types of rain gauges was possible for the first time over a wide variety of measuring principles and instrument design solutions based on the work performed during the recent Field Intercomparison of Rainfall Intensity Gauges, promoted by WMO (the World Meteorological Organisation). The analysis reported in this paper concerns the assessment of accuracy and precision of various types of instruments based on the measurement campaign performed under real world conditions at a field test site in Vigna di Valle (Rome) in the period 2007–2009 (Lanza and Vuerich, 2009). The performance of the sole catching type gauges under extensive calibration tests performed in the laboratory during the first phase of the WMO Intercomparison are addressed elsewhere (Lanza and Stagi, 2009).

Both catching and counting errors are therefore expected to affect the measurements obtained during the field campaign, although the contribution of counting errors was preliminarily quantified in the laboratory. However, since the knowledge of the true rainfall intensity is not possible in real world conditions, the term "errors" is replaced here by "deviations" to indicate that these are evaluated as simple (rough) differences from an assumed reference rainfall intensity. This is constrainedly derived from the measurements themselves rather than from an independent source of information, as it may be possible in the laboratory for the catching type gauges. The average of all figures obtained from the investigated measurement instruments was used in other works (see e.g., Ciach, 2003) as the reference intensity; otherwise, a single best-quality gauge could be used as an alternative. For the WMO Intercomparison, a composite reference intensity value was derived at each time step, as a weighted average of the one-minute RI measurements obtained from four selected best performing instruments installed in a pit, according to EN 13798:2010 "*Hydrometry — Specification for a reference raingauge pit*" (see Vuerich et al., 2009 for details on how the reference was defined and calculated). In the present paper, we concentrate our analysis on the deviations from this composite reference value observed per each of the investigated rain intensity gauges (25 different instruments were installed beside the four reference gauges installed in the pit).

Since it was obviously not possible to have any control on the frequency distribution of rainfall intensities during the measurement campaign, absolute (rough) rather than relative deviations are addressed in this study of measurement precision, so as to avoid the influence of the non-uniform distribution of the forcing variable on the results. The observed frequency distribution of real rainfall events clearly favours low to medium rain rates.

2. Rationale and methods

The analyses presented in this paper focus on both accuracy and precision of the catching and non-catching types of instruments based on the intercomparison data obtained during the WMO measurement campaign. The investigated variable, the rough deviation from the reference intensity e_{dev} [mm], is here defined as:

$$e_{dev}[mm] = I_{meas} - I_{ref}$$

with I_{meas} [mm·h^{-1}] the rainfall intensity measured by the instrument and I_{ref} [mm·h^{-1}] the composite reference rainfall intensity (assumed as the true rainfall being calculated from the four instruments installed as pit gauges). One-minute rainfall intensity figures are considered here, as recorded and validated during the measurement campaign in the field.

These data constitute a sample of deviations, suitable for investigating accuracy and precision and to statistically comparing the behaviour of different rain gauges. In order to highlight differences in the performance of the investigated gauges, these have been grouped in three categories according to the relevant measuring principle: tipping-bucket rain gauges (TBRGs), weighing gauges (WGs) and other gauges (OTH) based on different measuring principles, including the non-catching types of gauges, such as optical and acoustic disdrometers.

It is assumed that a sufficient accuracy, with the WMO specifications being referred to in this respect, is an indication of acceptable average measurement performance with no relevant biases involved; therefore the calibration of the instrument is also acceptable (although the potential for improvement may still be significant). Precision is related to the random component of the measurement, therefore a good precision is intended as a characteristic of the instrument design and the measuring principle adopted rather than of the methods and algorithms used to elaborate on the rough measured data. Although we recognise that the interpretation provided is not strictly rigorous within the measurement sciences, in the following we will adopt this simplified view.