THE ACCURACY OF RAIN INTENSITY MEASUREMENTS AND ITS INFLUENCE ON EXTREME EVENTS STATISTICS

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Abstract

As an outcome of the recent intercomparison of rainfall intensity (RI) gauges organized by the World Meteorological Organization (WMO), it has been recommended that RI measurements be standardized at an international level based on knowledge obtained from those initiatives. During the WMO instrument intercomparison in the field and the associated laboratory tests, highly accurate RI measurements have been collected and made available for scientific investigation. The resulting high quality data set (contemporary one-minute RI data from 26 gauges based on various measuring principles) was an important resource to provide insights into the expected behaviour of RI gauges in operational conditions and further useful information for National Meteorological Services and other users. Errors in measurements from operational rain gauges are here reported and the propagation of measurement errors into the most common statistics of rainfall extremes is recalled based on previous work.

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1 Introduction

The attention paid to accuracy and reliability in rainfall intensity (RI) measurements is currently increasing, following the increased awareness of scientific and practical issues related to the assessment of possible climatic trends, the mitigation of natural disasters (including flash floods), the hindering of desertification, the design of structures (building, construction works) and drainage infrastructure. This notwithstanding, the effects of inaccurate rainfall data on the information derived from rain records is not much documented in the literature.

The World Meteorological Organisation (WMO) recognised these emerging needs and promoted a first Expert Meeting on rainfall intensity in 2001 in Bratislava (Slovakia). Further to the definition of rainfall intensity and the related reference accuracy and resolution, the convened experts suggested to organise an international intercomparison of RI measurement instruments, to be held first in the laboratory and then in the field. The first Intercomparison started in 2004 and was concluded in 2005. An international standardized procedure for laboratory calibration of catching type RI gauges and the reference instruments to be used for the Intercomparison in the Field have become recommendations of the WMO Commission for Instruments and Methods of Observation (CIMO/WMO). Final results are available on the WMO Web site, and have been published elsewhere (Lanza *et al.*, 2005; Lanza and Stagi, 2008).

Note that some RI gauges were properly modified by manufacturers or NMHS (National Meteo-Hydrological Services) after the results of the first Laboratory Intercomparison and before taking part into the Field Intercomparison, by improving their performance in terms of accuracy and according to the above-mentioned international recommendations, demonstrating the immediate usefulness of the intercomparison results.

The main objective of the follow-up Field Intercomparison was to test the performance of rainfall intensity measurement instruments in real world conditions and with a special focus on high rainfall rates. In terms of accuracy, both the Laboratory and Field Intercomparison efforts have contributed to a quantitative evaluation of counting errors (systematic - "ability to sense") and catching errors (weather related, wetting, splashing, evaporation - "ability to collect") of RI gauges. Comparison of several rain gauges demonstrated the possibility to evaluate the performance of RI gauges at one-minute resolution in time, as recommended by CIMO/WMO.

2 The WMO Intercomparison of RI gauges

The WMO Field Intercomparison of RI gauges was held at the Centre of Meteorological Instruments Experimentations and historic observatory (RESMA) of the Italian Air Force sited in Vigna di Valle (Rome). The field site selected to host the Intercomparison is a green grass area of 400 m^2, equipped with 34 evenly positioned concrete platforms for data acquisition (see Figure 1), and a central pit with four positions, used for the installation of the working reference – a set of four RI gauges as identified and recommended in the previous WMO Laboratory Intercomparison.

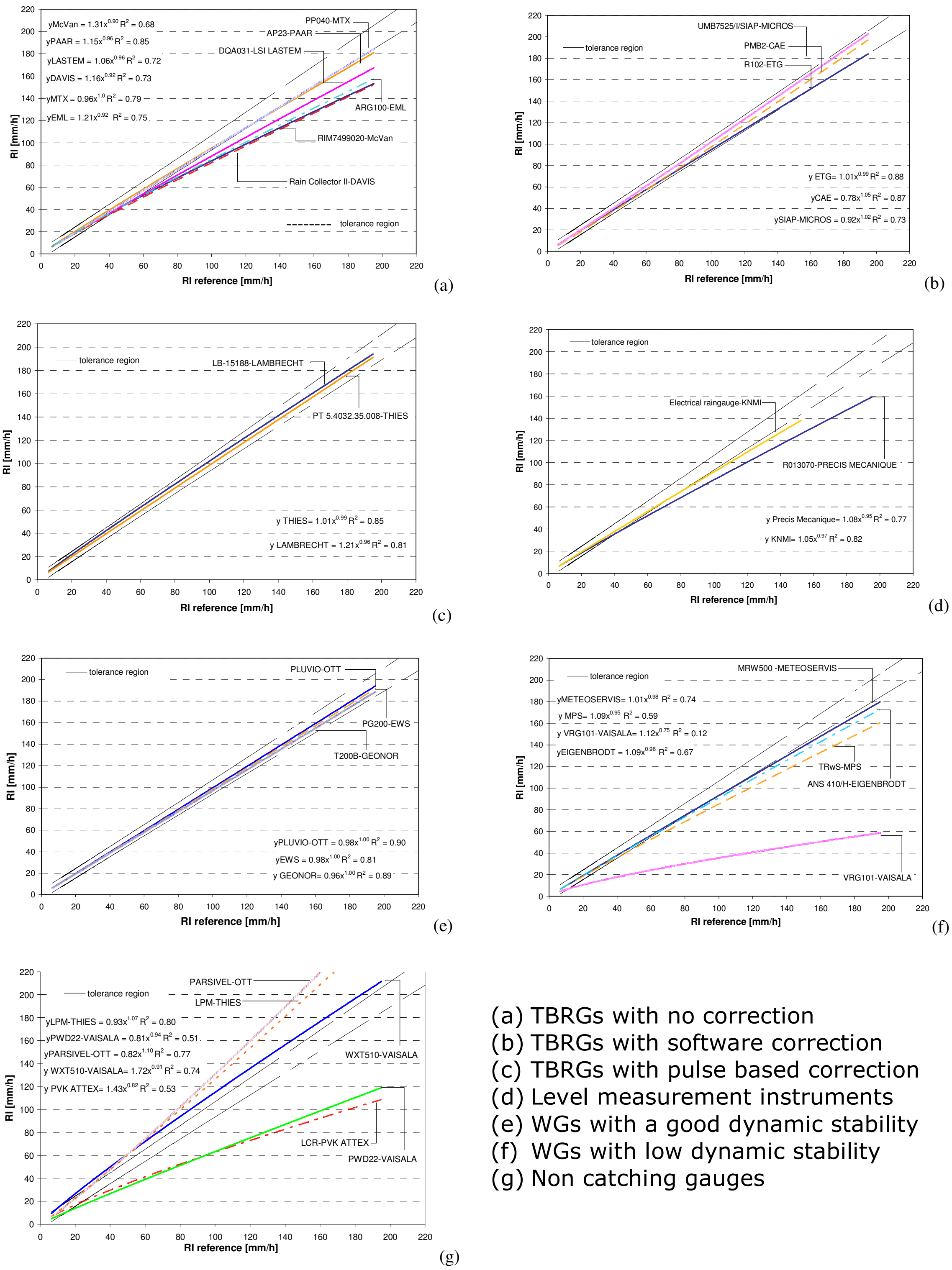
The working reference gauges were inserted in a four-fold Reference Rain Gauge Pit with gauge collectors at the ground level, according to the standard EN13798: "Specifications for a reference rain gauge pit". The combined analysis of the reference gauges did provide the best possible estimation of RI in the field, based on their demonstrated performance during the previous Laboratory Intercomparison. Based on results of the WMO Laboratory Intercomparison of RI gauges, corrected tipping bucket rain gauges (TBRG) and weighing gauges (WG) with a short step response and low uncertainty were used as working reference instruments.

Those catching type instruments, out of the selected rain gauges based on various measuring principles, and the four rain gauges selected as reference instruments to be installed in a pit, were preliminarily calibrated in the laboratory before their final installation at the Field Intercomparison site. The recognized WMO laboratory at the University of Genoa was involved in this task (Lanza and Stagi, 2009), using the same standard tests adopted for the previously held WMO Laboratory Intercomparison of RI gauges. Further tests were performed to investigated the one-minute performance of the involved instruments.

The results reported in this section illustrate the trend of each instrument compared to the RI composite working reference, where the trend line is obtained from a power law fitting of the experimental data in the (RI, RI_{ref}) domain. In order to assess the accuracy of field measurements compared to the reference, the lines of the tolerance region, calculated with the procedure described in Vuerich *et al.* (2009), are represented in dashed lines. For easier comparison, the instruments have been grouped according to the measurement technique, as shown in Figure 2.

Figure 1. The experimental field in Vigna di Valle (Italy).

Results (see e.g. Lanza and Vuerich, 2009) indicate that one-minute synchronized TBRGs, corrected by internal algorithms, and WGs with the better dynamical stability and shortest step response are the most accurate instruments for one-minute RI measurement, since providing the highest measurement accuracy with respect to the reference chosen.



(a) TBRGs with no correction
(b) TBRGs with software correction
(c) TBRGs with pulse based correction
(d) Level measurement instruments
(e) WGs with a good dynamic stability
(f) WGs with low dynamic stability
(g) Non catching gauges

Figure 2. Performance of the various instruments against the reference RI.

Pulse-corrected TBRGs show similar, but less accurate results. The non-corrected TBRGs, can apply corrections via a post processing software or provide a correction curve/table to be almost as accurate as the corrected ones. WGs with lower dynamical stability or lack of synchronization/large step response at the one minute time scale are less accurate. None of the non-catching rain gauges agreed well with the reference. Disdrometers tended to overestimate the rainfall intensity. The microwave radar and the optical / capacitive sensor tended to underestimate the rainfall intensity.

3 Error propagation and its impact on statistics

The impact of inaccurate rainfall measurements on the results of scientific investigation in rainfall related fields is not yet fully clear nor quantified. With the exception of very few dedicated papers and/or various papers dealing with the analysis of measurement errors themselves, the issue of how deeply affected are the obtained results by the actual accuracy of the data sources is rarely addressed. The scarce attention paid at the quality of data often poses serious doubts about the significance of both experimental and theoretical results made available in the literature.

The effects are not always dramatic, since the error propagation could be negligible as well, depending on the application. Nonetheless scientific soundness requires that all possible uncertainties are properly taken into account, and the quality of basic data sources – such as rainfall measurements – should not be an exception. Also, certified accuracy is needed for operational meteo-hydrological networks operating within the framework of a quality assurance system.

La Barbera *et al.* (2002) investigated the propagation of measurement errors into the most common statistics of rainfall extremes and found that systematic mechanical errors of tipping-bucket rain gauges may lead to biases, e.g. in the assessment of the return period T (or the related nonexceedance probability) of short-duration/high intensity events. The bias introduced by systematic mechanical errors of tipping bucket rain gauges in the estimation of return periods and other statistics of rainfall extremes was quantified in that work and in Molini *et al.* (2001), based on the error figures obtained after laboratory tests over a wide set of operational rain gauges from the network of the Liguria region of Italy. An equivalent sample size was defined as a simple index that practitioner engineers can use to measure the influence of systematic mechanical errors on common hydrological practice and the derived hydraulic engineering design.

The development of standard limits for the accuracy of rainfall measurements obtained from tipping-bucket and other types of gauges was proposed for use in scientific investigations and as a reference for operational rain gauge networks to comply with quality assurance systems in meteorological observations (Lanza and Stagi, 2008).

Molini *et al.* (2005 a,b) estimated the effect of systematic mechanical errors on the assessment of design rainfall for urban scale applications based on two rain rate data sets recorded at very different resolution in time. A random cascade downscaling algorithm was used for the processing of coarse resolution data so that correction could be applied at suitable time scales. The resulting depth-duration-frequency curves obtained from the original and corrected data sets were derived to quantify the impact of non corrected rain intensity measurements on design rainfall and the related statistical parameters.

4 Conclusions

The bias induced by systematic mechanical errors of tipping-bucket rain gauges is usually neglected in the hydrological practice, based on the assumption that it has little influence on the total recorded rainfall depth. It has been demonstrated in recent works that, since the error increases with rainfall intensity, the assumption is not acceptable for the assessment of design rainfall in hydrological applications. Indeed, the high resolution required for the monitoring of rainfall intensities (due to the very short response time of small size catchment basins) amplifies the influence of mechanical errors on the derived statistics of rainfall extremes, with a bias that can be quantified as an underestimation of about 60 to 100% on the assessment of the return period of design rainfall for duration one hour and return periods from 20 to 200 years.

The WMO Field Intercomparison of Rainfall Intensity Gauges was the first intercomparison of quantitative rainfall intensity measurements in field conditions and one of the most extensive in terms of the number of instruments involved. The results of the intercomparison confirmed the feasibility to measure and compare rainfall intensities on a one minute time scale as required by users and recommended by CIMO and provided information on the achievable measurement uncertainties.

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