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WMO FIELD INTERCOMPARISON OF RAINFALL INTENSITY GAUGES AT VIGNA DI VALLE (ITALY): PRELIMINARY LABORATORY CALIBRATION AND VERIFICATION OF THE GAUGES USING A FIELD CALIBRATION DEVICE

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ABSTRACT

The WMO Field Intercomparison of Rainfall Intensity (RI) Gauges started on October, 1st 2007 at Vigna di Valle (Italy). Those catching type instruments, out of the 30 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, using the same standard tests adopted for the previously held WMO Laboratory Intercomparison of RI gauges. Further tests were performed to investigate the one-minute performances of the involved instruments. The objectives of this initial phase of the Intercomparison were to single out the counting errors associated with each instrument, so as to allow identifying the residual catching errors due to the operation of the instrument in the field during the second phase. Results and comments on the preliminary laboratory calibration exercise are reported in this paper together with their implications for the analysis of the outcome of the Intercomparison in the Field. The paper also describes the verification of the instruments as installed in the field (at the test site) using a suitable field calibration device specifically developed at the University of Genoa. All gauges of the catching type were tested using this portable calibration device after installation, simulating an ordinary calibration inspection in the field.

Keywords: rainfall intensity, WMO Intercomparison, rain gauges,

Introduction

The first WMO Field Intercomparison of RI gauges was started in October 2007 in Vigna di Valle, Rome (Italy). A total number of 29 instruments have been accepted in this Field Intercomparison, including catching and non-catching types of instruments. Installation of the instruments in the field was preceded by the laboratory calibration of all submitted catching type rain gauges at the University of Genoa.

The need for a WMO Intercomparison of Rainfall Intensity (RI) gauges goes back to the two Expert Meetings on Rainfall Intensity Measurements respectively held in Bratislava, Slovak Republic, 23-25 April 2001 and in Geneva, Switzerland, 5-9 December 2005 [1][2]: the former was mainly focused on the calibration of rain gauges and the general aspects of RI measurements (I phase); the latter gave priority especially to the objectives and the operational aspects of the Field Intercomparison, allowing both the catchment and non-catchment types of rain gauges to take part in the Field Intercomparison (II phase).

Before the meeting in Bratislava, there was a general lack of knowledge, practise, standardization and recommendation with respect to RI measurements. At the end of the meeting a standard definition of RI was adopted as the amount of precipitation collected per unit time interval expressed in millimetres per hour. The range of measurements, the required uncertainties and the output averaging time were also defined. In particular, an uncertainty of 5% in the range 2-2000 mm/h and an output averaging time of 1 minute were recommended, so we generally refer to RI [mm/h] on 1 minute averaging time interval [4]. It has been recognised by users that 1MIN-RI is particular suitable for hydro-meteorological warnings, interfacing hydrological and meteorological models, flood forecasting, disaster prevention and mitigation, urban hydrology and engineering design.

Previous international intercomparison efforts about rain gauges were focused on accumulated amounts of precipitation, low intensity rainfall (snow) and sometimes only on qualitative RI information (light, moderate, heavy). The analyses therein performed did not focus in particular on quantitative values of RI and no intercomparison of a large number of RI measuring instruments had yet been conducted first in the laboratory and then in field conditions. It was therefore considered as the first and necessary step to organize an intercomparison of such instruments first in the laboratory then in the field [4] [5]. In terms of accuracy, the Laboratory and Field RI Intercomparison will together contribute to a quantitative evaluation of counting errors (systematic - "ability to sense") and catching errors (weather related, wetting, splashing, evaporation - "ability to collect") of RI rain gauges. This specific aspect will allow further definition of the general principles of measurement accuracy to be applied in RI measurements [4].

The Laboratory Intercomparison started in 2004 and was concluded in 2005. An international standardized procedure for laboratory calibration of catchment type RI gauges and the reference instruments to be used for Field RI Intercomparison initiatives have become recommendations of the fourteenth session of the Commission for Instruments and Methods of Observation (WMO-CIMO) [3]. It should be noted that a few RI rainfall intensity gauges were properly modified by manufacturers or NMHS (National Meteo-Hydrological Services) after the results of the first phase (the 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.

An additional laboratory phase was therefore deemed necessary within the presently ongoing Field Intercomparison, as a preliminary step to assess the actual counting performances of the gauges. Obviously this phase was limited at the catching type instruments selected, and was duly performed before the installation of the gauges in the field. The spare part instruments provided by the manufacturers have been tested as well, so that they are ready to replace their companion instrument in case of any malfunction. This paper anticipates synthetic results from this preliminary laboratory phase, therefore describing the counting performances of the participating catching type gauges as obtained under constant flow rates in controlled conditions.

Procedure for the laboratory calibration

The main objective of the laboratory phase was to perform tests on the participating catching-type rain gauges according to the procedures developed during the WMO Laboratory Intercomparison of RI Gauges and to assess the accuracy performance of such gauges with respect to WMO limits prior to their installation in the field [4]. The same calibration methodology was here adopted, based on the generation of a constant water flow from a suitable hydraulic device within the range of operational use declared by the instrument's manufacturer. The water is conveyed to the funnel of the instrument under test in order to simulate a constant rainfall intensity. The flow is measured by weighing the water over a given period of time. The output of the instrument under test is measured at regular periods of time or when a pulse occurs. The two measurements are compared in order to assess the difference between the actual flow of water conveyed through the instrument and the "rain intensity" measured by the instrument itself. The relative difference between each measured and actual "rain intensity" figure is assumed as the relative error of the instrument for the given reference flow rate.

This methodology provided a basis for the development of a standardized procedure for generating consistent and repeatable precipitation flow rates for possible adoption as a laboratory standard for calibration of catching type rainfall intensity gauges. At the laboratory of the Department of Environmental Engineering of the University of Genova, in particular, an automatic device was designed and realised as a prototype. The device, named Qualification Module for RI Measurement instruments (QM-RIM), is based on the principle of generating controlled water flows at a constant rate from the bottom orifice of a container where the water level is varied using a cylindrical bellow and the water level and the orifice diameter are controlled by software in order to generate the desired flow rate.

Fig. 1: The Qualification Module for Rain Intensity Measurement Instruments developed at the University of Genova.

The QM-RIM calibration procedure is based on the capability of the system to produce a constant water flow. This flow is provided to the RI gauge under test and the duration and the total weight of water that flows through the instrument are automatically recorded by the acquisition system. The weight is determined using a precision balance. During the test the ensemble precision balance/weighing tank is protected by a plastic structure which also supports the RI gauges under calibration. The duration of the tests and the mass measurement are controlling factors for determining the uncertainty of the test. Therefore, mass and duration used for each test were chosen so that the uncertainty of the reference intensity was less than 1%, taking also into account the resolution of the instrument.

In this second laboratory calibration the tests were extended to cover the one-minute resolution instrument behaviour rather than just focusing on the average response under a constant reference flow rate, thus provide better insights into the measurement performances of such instruments. This was also due to the fact that, during the ongoing intercomparison in the field, the one-minute resolution rainfall intensity are considered under real world conditions, since this time resolution was adopted by CIMO-XIII as a recommendation for precipitation intensity measurements – with a maximum uncertainty of 5% – and published in the last revision of the WMO Guide to Instruments and Methods of Observation (WMO-No. 8, 7th edition).

Nineteen catching type gauges are involved in the Field Intercomparison, out of the total number of 29 participating instruments. Two individuals per each model have been testes, with the exception of the four gauges that were selected as reference instruments, for which three individuals were tested.

ID	Model	Nation	Measuring principle
1	7499020BoMV2/RIMCO	AUSTRALIA	Tipping bucket
2	AP23/PAAR	AUSTRIA	Tipping bucket
3	R01 3070/PRECIS-MECANIQUE	FRANCE	Tipping bucket
4	PT 5.4032.35.008/THIES	GERMANY	Tipping bucket
5	**R 102 ETG**	**ITALY**	**Tipping bucket**
6	DQA031/LSI LASTEM	ITALY	Tipping bucket
7	T-PLUV UM7525/I/SIAP-MICROS	ITALY	Tipping bucket
8	**PM B2 CAE**	**ITALY**	**Tipping bucket**
9	RAIN COLLECTOR II7852 DAVIS	USA	Tipping bucket
10	15188/LAMBRECHT	GERMANY	Tipping bucket
11	PP040/MTX	ITALY	Tipping bucket
12	ARG100/ENV. MEAS. Lmt.	BRASIL / UK	Tipping bucket
13	**MRW500 METEOSERVIS**	**CZECH REP.**	**Weighing gauge**
14	VRG101/VAISALA	FINLAND	Weighing gauge
15	PLUVIO/OTT	GERMANY	Weighing gauge
16	**T-200B / GEONOR**	**NORVAY**	**Weighing gauge**
17	TRwS/MPS	SVOLACK REP.	Weighing gauge
18	ANS 410-H/EIGENBRODT	GERMANY	Pressure sensor
19	Electrical rain gauge/KNMI	NETHERLAND	Level sensor

Table 1 – WMO Field Intercomparison of RI gauges: list of catching type instruments involved in the preliminary laboratory phase.

Summary results

The results of the preliminary laboratory tests were synthesised in the form of two types of graphs: in the first form – used in this paper – the relative error for a sample gauge is plotted versus the reference intensity obtained as specified above, while in the second form calibration curves are presented, where the measured intensity is plotted against the reference one. The relative error is calculated as follows:

$$e = \frac{I_m - I_r}{I_r} \cdot 100 \ \ \%$$

where I_m is the intensity measured by the instrument and I_r the actual reference intensity.
An error curve can be fitted to the experimental data in the (e, I_m) space, a second order polynomial being usually suited to represent the behaviour of the gauges over the whole range of operation of the investigated instrument. The error curve is expressed as follows:

$$e(I_m) = a \cdot I_m^2 + b \cdot I_m + c$$

where the coefficients a, b, c are experimentally determined.
In Figure 2, sample results for a well-calibrated tipping-bucket rain gauge installed in the pit are presented, and a comparison is shown between the observed performances on aggregation scales of 1 and 10 minutes for rainfall intensity figures (bars indicate the range and standard deviation of all tests performed). In the graph, the two dashed horizontal lines indicate the ± 5% accuracy limits that were originally proposed by WMO for assessing the performance of rainfall intensity gauges [1]. Since the gauge is in this case one of the selected working reference instruments, performances are very good and the actual accuracy is even better than the requirements set by WMO.

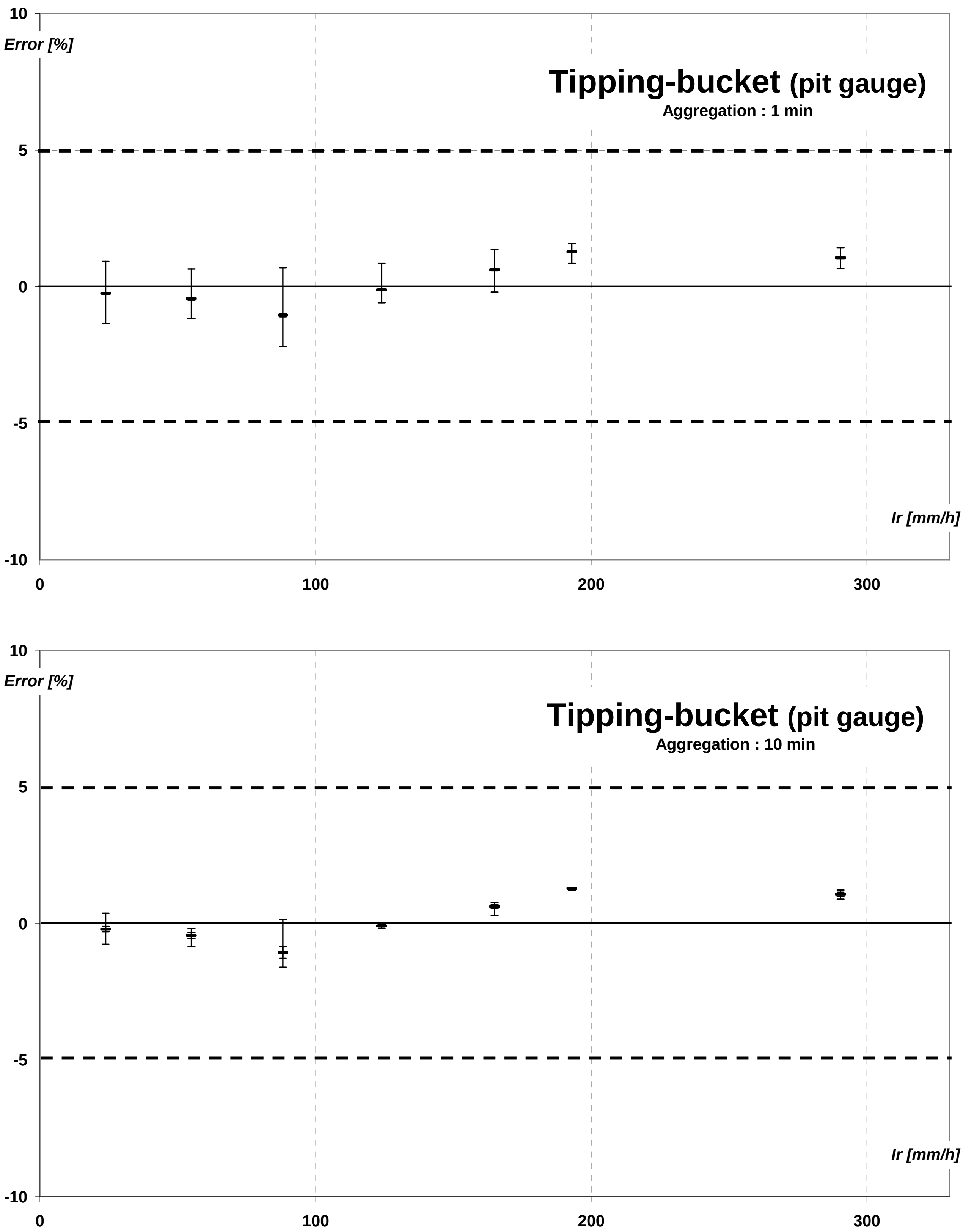
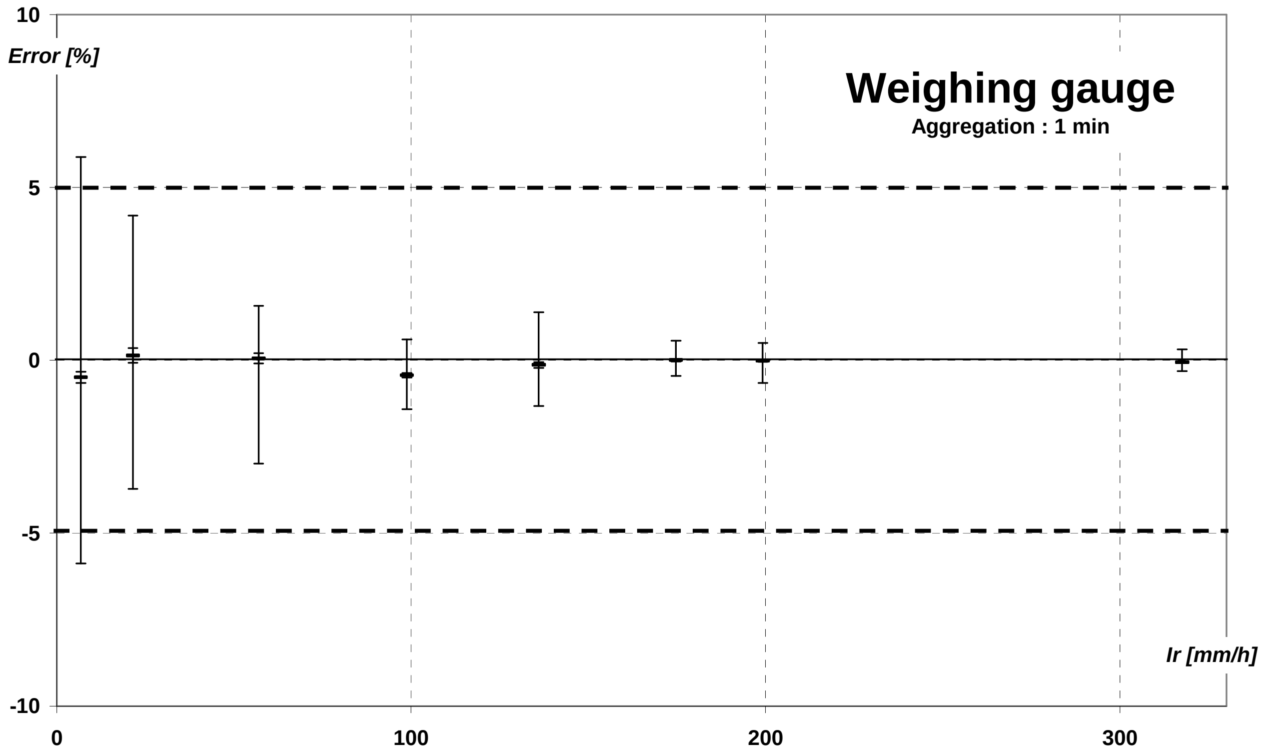


Fig. 2: Sample results from the laboratory phase, for a well-calibrated tipping-bucket rain gauge installed in the pit, and comparison between the observed performances on aggregation scales of 1 and 10 minutes for rainfall intensity figures (bars indicate the range and standard deviation of all tests performed).



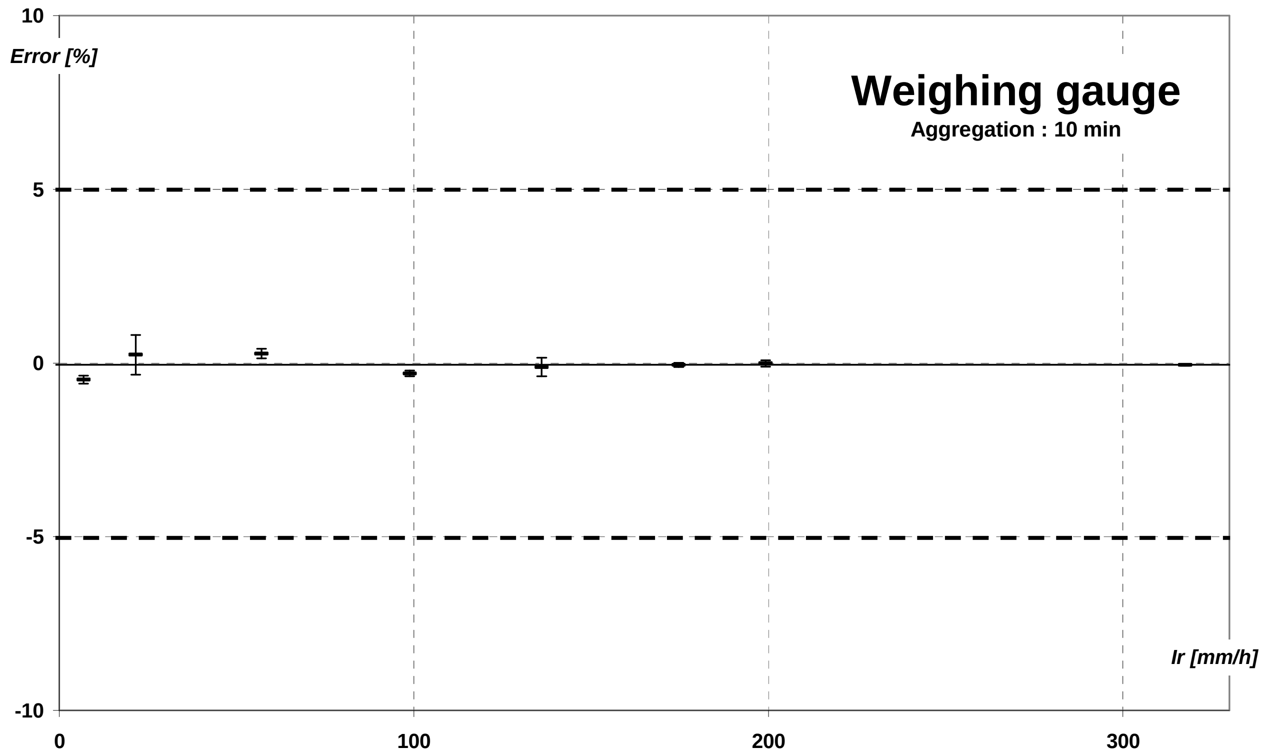


Fig. 3: Sample results from the laboratory phase, for a weighing gauge with a short response time, and comparison between the observed performances on aggregation scales of 1 and 10 minutes for rainfall intensity figures (bars indicate the range and standard deviation of all tests performed).

The main contribution of these first two graphs (whose results in terms of the overall accuracy were already obtained for this specific gauge within the WMO Laboratory Intercomparison) is that the variability of the one-minute rainfall intensity is here fully reported, as well as the variability of the ten minutes aggregation. Apart from the trivial conclusion that aggregation will lead to a reduced variability, so that the rainfall intensity at ten minutes time intervals can be measured with a higher accuracy than the same process at the one-minute resolution, we can see from the graphs that this rain gauge is also good in resolving the high resolution variability of the rainfall process in time. This is evident from the fact that not only the average figures, but also the standard deviation and range bars are well within the limits of the required accuracy for rain intensity measurements.

In Figure 3, sample results for a weighing rain gauge with a short response time are presented, and a comparison is shown between the observed performances on aggregation scales of 1 and 10 minutes for rainfall intensity figures (bars indicate the range and standard deviation of all tests performed). In the graph, again, the two dashed horizontal lines indicate the ± 5% accuracy limits that were originally proposed by WMO for assessing the performance of rainfall intensity gauges.

In this second case the variability of error values at one-minute resolution is a bit more spread around the average figures, with some higher variability observed at the low rain rates. Also in this case, as expected, the aggregation leads to a reduced variability, so that the rainfall intensity at ten minutes time intervals can be measured with a higher accuracy than the same process at the one-minute resolution. Although this type of graph is less significant for a weighing gauge, where the response time was identified in the previous WMO Laboratory Intercomparison as the critical factor, it is also evident that the accuracy of the average figures is very high, and is generally better than the one shown by any tipping-bucket rain gauge.

The conclusion is that currently available instruments (in this case one traditional tipping-bucket gauge and one weighing gauge) have the potential to allow high resolution rain intensity measurements with sufficient accuracy, at least in the controlled laboratory conditions. In many cases, like the one presented in Figure 2, such performances are actually obtained by the instrument as provided from the manufacturer, while in other cases – to be accounted for in the Final Report of the Field Intercomparison expected within June 2009 – additional adjustments are required either in the hardware or software components, although the objective can be easily met by the manufacturer. Exceptions can be observed for some specific type of instruments, e.g. some non-catching type of rain gauges, which however could not be tested in the laboratory, since their performances in the field drift away from the behaviour of both the working reference and other type of gauges [6].

A second synthetic result presented in this paper is the ensemble of the error curves obtained after the laboratory tests for all catching type gauges – including the companion instruments submitted as spare parts and the working reference gauges – plotted against the reference intensity (see Figure 4). It can be noticed that the set of curves remains confined in between the ± 5% accuracy limits for most of the instruments under test, some of the curves actually comply with those limits only for a reduced range of reference intensities, while only few of them lay completely outside the acceptable range.

In Figures 5 and 6 the same curves are presented in a separate form for the two main categories of measuring principles involved in the Intercomparison, namely the tipping-bucket rain gauges and the weighing rain gauges. Evidenced in green are the curves obtained for the reference instruments pertaining to the relevant category. The tipping-bucket category clearly shows a larger variability in the behaviour of the various instruments, and also larger errors for some of the instruments involved. However, a few well calibrated instruments do demonstrate very good performances. The weighing gauges show in general less disperse curves, although the response time characteristics of such instruments should be taken as well into account.

Finally, in Figure 7 the ensemble of the calibration curves obtained in the laboratory phase for the working reference gauges, including the spare instruments, compared with the ± 5% accuracy limits defined by WMO are reported (one of such instruments was later excluded from the working reference set due to the observed reduced performances).

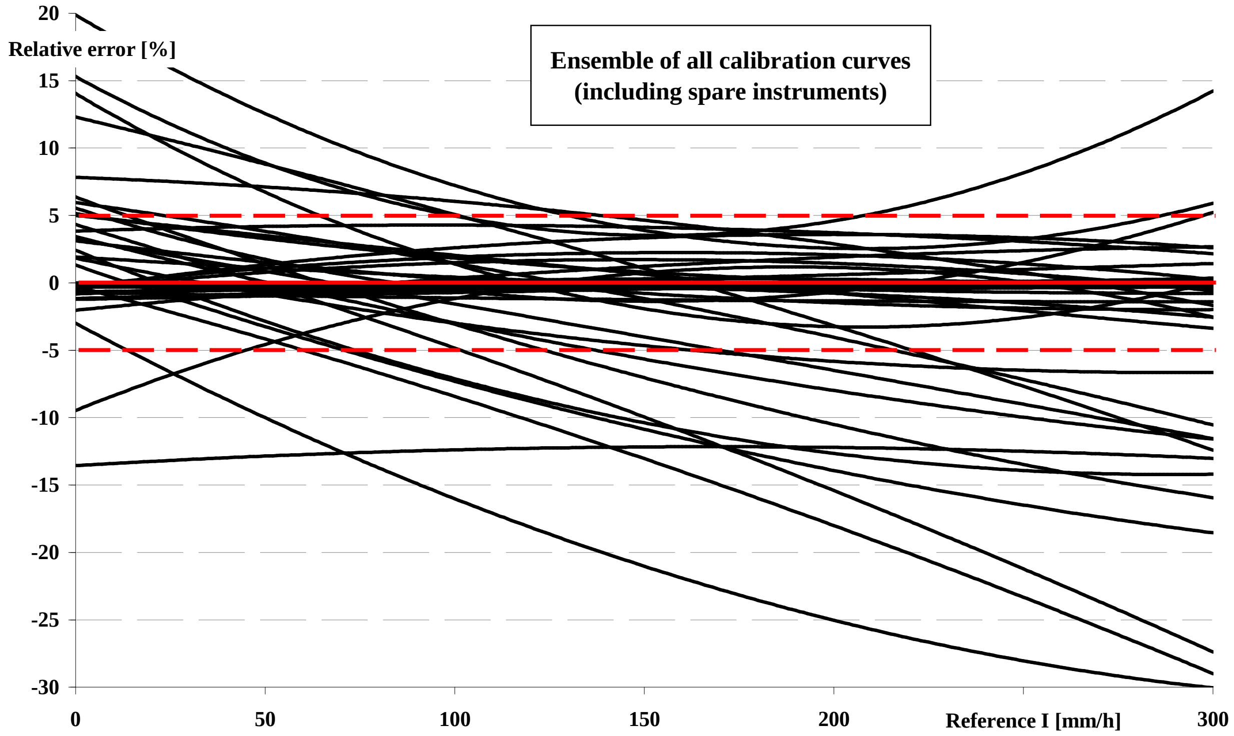


Fig. 4: Ensemble of the calibration curves obtained in the laboratory phase for all catching type gauges, including the spare instruments, compared with the ±5% accuracy limits defined by WMO.

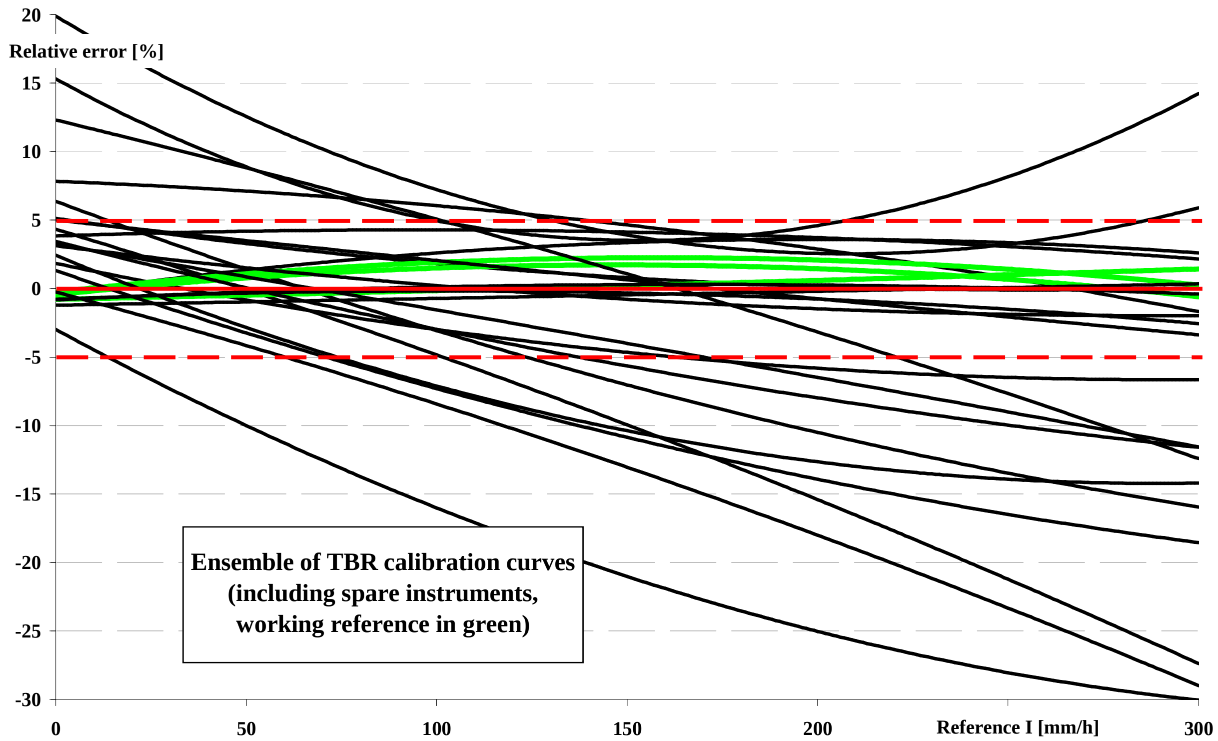


Fig. 5: Ensemble of the calibration curves obtained in the laboratory phase for all Tipping-bucket rain gauges, including the spare instruments, compared with the ±5% accuracy limits defined by WMO.

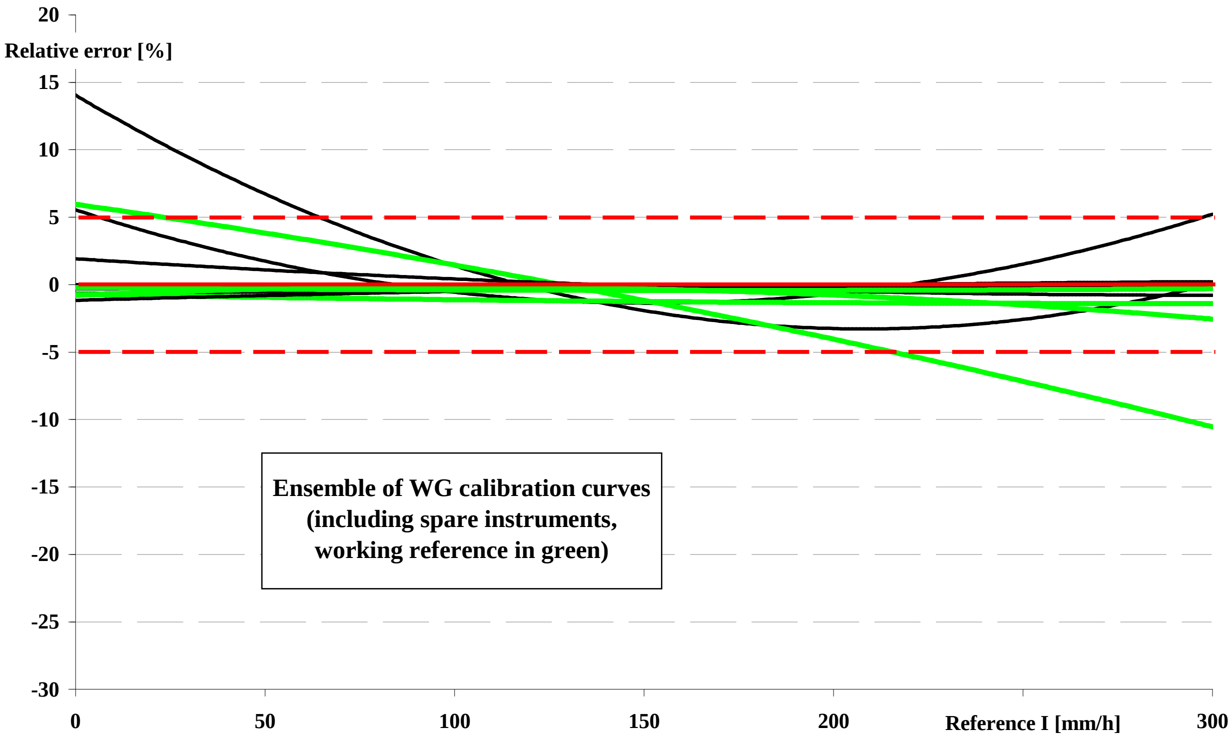


Fig. 6: Ensemble of the calibration curves obtained in the laboratory phase for all weighing gauges, including the spare instruments, compared with the ±5% accuracy limits defined by WMO.

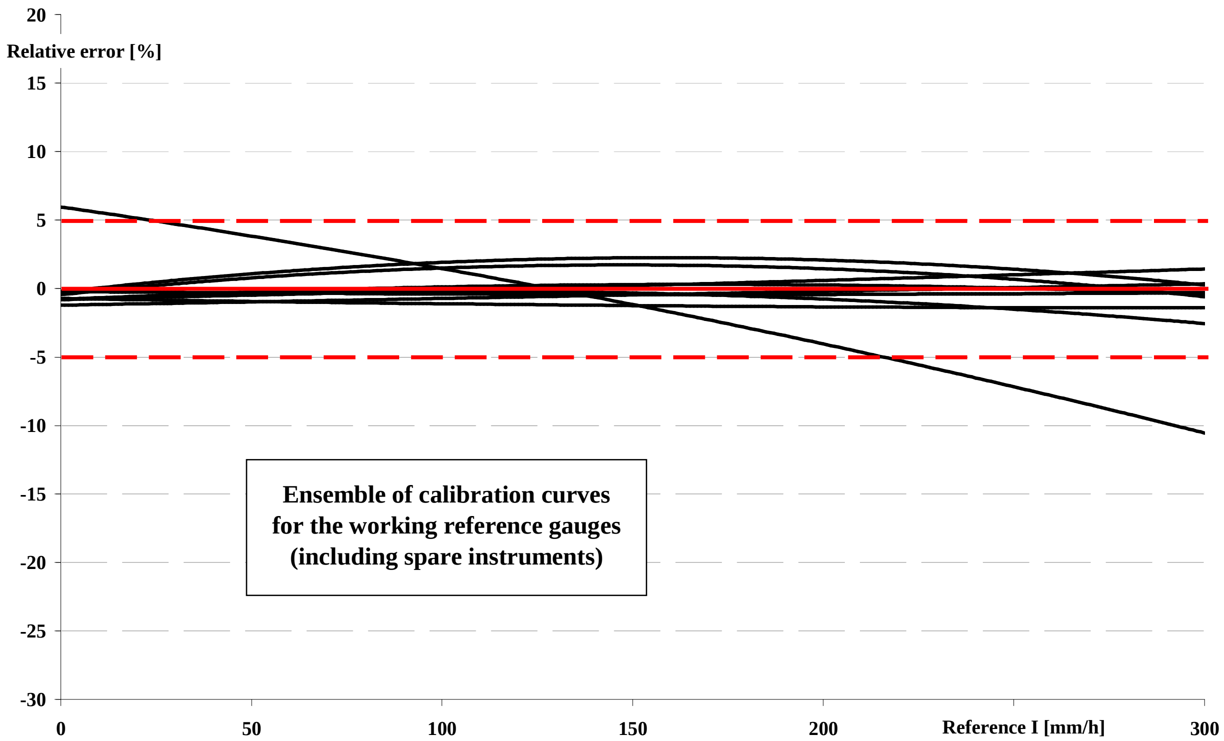


Fig. 7: Ensemble of the calibration curves obtained in the laboratory phase for the working reference gauges, including the spare instruments, compared with the ±5% accuracy limits defined by WMO (one of such instruments was later excluded from the working reference set due to the observed reduced performances).

On-site calibration using a portable device

Instruments were also tested on site, on a regular basis, during the field Intercomparison using a portable calibration device (see Figure 8). Field tests and checks performed by this device had several purposes, such as verifying the operational status of catchment-type gauges, investigating possible drifts in calibration/operation status with respect to the laboratory phase and, as a consequence, providing as much information as possible for the quality control of data. In particular, tests results helped in understanding and better evaluating real rain events and the related intensity measurements.
The portable device was developed at the University of Genoa [7] with the aim of providing the on-site capability of performing the same kind of tests that were preliminarily used for verification of the calibration of all submitted catching type rain gauges under controlled conditions in the laboratory.

Fig. 8: The portable device for field calibration of catching type gauges in use during the WMO Field Intercomparison of RI gauges.

The same methodology is indeed adopted, based on the generation of a constant water flow from a suitable hydraulic device within the range of operational use declared by the instrument's manufacturer. The water is conveyed to the funnel of the instrument under test in order to simulate a constant rainfall intensity. The relative difference between the actual flow of water conveyed through the instrument and the "rain intensity" measured by the instrument itself is assumed as the relative error of the instrument for the given reference flow rate.
The principle exploited by this portable device is that of preserving a constant hydraulic head over a given orifice area by ensuring the automatic and continuous pressure adaptation of the air/water contained inside a closed container. The transit time of the water level between two fixed limits is the only variable to be measured to complete the test at any reference rainfall intensity. In order to reduce the sampling error, with reference to e.g. a tipping-bucket rain gauge having a resolution of 0,2 mm (bucket volume of 20 g) and a collector's area of 0,1 m^2, the container should be filled in with at least 2 litres of water, so that at least 100 tips of the buckets will occur.
The developed portable device allows to perform:

- high precision tests for rain intensity measurement uncertainties rather than for the sole rain accumulation over a given time period;

- dynamic calibration tests rather than just volumetric or single intensity tests;
- the generation of rigorously constant water flows for the entire duration of each test;
- the entire calibration procedure recommended by WMO for rain intensity measurement instruments, with one single apparatus and on-site;
- non invasive tests that do not require modifications of the instrument and changes from its current operational conditions;
- tests that are immediately available, since no special post-processing of the data measured during the tests is required.

From the operational viewpoint the portable device has the advantages to avoid taking down the rain gauge for delivery to the laboratory, to perform the tests rapidly – with durations that are comparable to the usual time spent for ordinary maintenance interventions, and to require non specially trained personnel to perform the tests – due to the very simple operations required. Also, the portable device is well suited for use in less industrialised countries, where simple and readily understandable technologies are required, with no need for any sophisticated component and just a limited volume of water required to perform the tests.
Finally, the proposed portable device is an ideal and cost effective solution for metrological qualification of rain intensity instruments within the framework of the quality assurance procedures that are now widely adopted by the organisations in charge of managing meteorological measurement networks at the regional, national and international levels.

A few considerations on standard rainfall intensity measurements

The results of the two Intercomparison efforts undertaken within WMO seem to provide the basis for the development of recommendations for the use of rainfall intensity gauges that are currently under consideration within national and international standardization bodies, in close collaboration with the WMO Expert Team members. Indeed, by inspection of the presented (even preliminary) results, it is clear that most of the catching type instruments involved behave (or have the potential to behave) quite accurately in measuring rainfall intensity, both in the laboratory and in the field (see e.g. Figure 4).
Although with some exceptions, and regardless of the measuring principle involved, the currently available gauges from various manufacturers demonstrated to be suitable for measuring rainfall intensity at the resolution of one minute with reasonable accuracy. The limits for such a reasonable accuracy were already defined at the Expert Meeting on Rainfall Intensity Measurements held in Bratislava in 2001 [1], and it is now confirmed after the Intercomparison results that they can be set within ± 5% under laboratory conditions. It is also expected that the accuracy obtained in the laboratory can be approximately confirmed for operational use in the field, although no reference is available to fully demonstrate such figures in that case.
Moreover, the one-minute time resolution for the measurement of rainfall intensity is confirmed as a feasible requirement, and obviously any aggregation performed at larger time scales starting from data obtained at such resolution would simply lead to a better accuracy and reduced variability (see e.g. Figures 2 and 3). It is clear however that not all applications will require such a detailed information about the rainfall process and the user will be able to select gauges with lower performances in any other cases, with consideration given to other relevant economic and/or operational factors.
Following the above indications, it seems reasonable to avoid thinking at the development of a standard rain gauge station, but rather propose that rain gauges suitable to any specific use will have standard performances to be guaranteed by proper calibration procedures. The expected performances can be initially quantified based on the demonstrated behaviour during the two Intercomparison efforts, and instruments can be classified accordingly. Finally the calibration procedures (already recommended by WMO) can be standardised as well for both the related laboratory and field tests.

All such matters are presently the subject of a joint initial CEN/WMO standardisation process, within the framework of CEN/TC318 – Hydrometry, where a Technical Report is in preparation to synthesise these concepts and to start the possible development of a new standard on rainfall intensity measurements. A possible joint effort will be soon proposed within ISO.

Conclusions

The laboratory phase of the RI Field Intercomparison proved to be very useful in providing basic information on the behaviour of the catching type instruments involved. The tests were performed under known and constant flow rates in closely controlled conditions, according to the recommended procedures developed during the previous WMO Laboratory Intercomparison of RI gauges. The results of the laboratory calibration generally confirm the findings of the Laboratory Intercomparison, although with significant differences due to the fact that a larger number of instruments were involved here, and also that some of the instruments have been upgraded by the manufacturers in the time period between the Laboratory and the Field Intercomparison. All such information is now under consideration by the relevant Expert Team / International Organising Committee, for proper use within the ongoing data acquisition and analysis effort at the Vigna di Valle test site, in Italy.

In particular, the objective is now to exploit the knowledge gained from the laboratory phase in order to single out counting errors from the assessment of the overall accuracy of the instruments, with specific reference to their catching errors and uncertainties due to the operating conditions (dynamic performances, wind and atmospheric conditions, etc.). In this view the laboratory calibration tests were performed at the resolution of one and ten minutes, so that the spreading of the errors around their average value already investigated during the previous Laboratory Intercomparison could be also evaluated. The derived calibration curves were not applied to the output data obtained from the individual gauges, since only the manufacturer's calibration was allowed for the Intercomparison purposes. As for the reference rain gauges, installed in the pit, calibration curves were provided to assess the residual counting errors and their spreading as a function of the rainfall intensity. For all other catching type gauges the curves will be useful to assess the potential improvement that can be attained by any possible additional software correction that the manufacturer might wish to implement for better accuracy.

The development of a portable Field Calibration Device to be used for checking the instruments as installed – with no need to return them to the laboratory where standard calibration tests can be performed – was very effective in keeping the behaviour of the instruments under control throughout the measurement campaign. The operational procedure is that of comparing on a regular basis the calibration data of each instrument at a few calibration points (constant flow rates) with the full calibration curves preliminarily obtained in the laboratory, and this is currently used as a criterion to assess the correct behaviour of that particular instrument. The device was also used to perform rapid assessment of the functionality of the instruments when relevant rain intensity events were expected from weather forecasts over the test area.

It was clear from the experience derived from this second RI Intercomparison that the synergy of the laboratory and field tests was really useful and appropriate, and it is recommended that both kind of tests are performed in future performance assessment of rainfall intensity gauges. Moreover the possibility of performing calibration tests of the instruments as installed, using the developed portable device, significantly improved the management of the installation and data quality control.

References

[1] Expert Meeting (2001). Final Report of the Expert Meeting on Rainfall Intensity Measurements, Bratislava, Slovakia, 23-25 April 2001
(available at http://www.wmo.int/pages/prog/www/IMOP/reports.html)

[2] Final Report of the second session of the Expert Team Meeting CIMO-SBII&CM, Geneva (Switzerland) 5-9 December 2005
(available at http://www.wmo.int/pages/prog/www/IMOP/reports.html)

[3] Final Report of the fourteenth session of the Commission for Instruments and Methods of Observation of the WMO – Geneva (Switzerland) 7-14 December 2006; WMO n.1019
(available at http://www.wmo.int/pages/prog/www/IMOP/reports.html)

[4] Final Report WMO Laboratory Intercomparison of Rainfall Intensity Gauges; De Bilt (The Netherlands), Genoa (Italy), Trappes (France); September 2004 – September 2005
(available at http://www.wmo.int/pages/prog/www/IMOP/reports.html)

[5] Goodison, B.E., Louie, P.Y.T. and Yang, D. (1998). WMO Solid Precipitation Measurement Intercomparison - Final Report. Instruments and Observing methods Report No. 67, WMO/TD-No. 872.

[6] E. Vuerich, C. Monesi, F. Malaspina e L.G. Lanza, (2008) "The WMO Field Intercomparison of RI Gauges: measurements and preliminary results", TECO 2008.

[7] L. G. Lanza, L. Stagi, E. Vuerich (2008) "A portable device for dynamic calibration of catching type rain gauges in the field ", EGU - General Assembly, Vienna 14-18 April 2008.