RESULTS OF THE WMO LABORATORY INTERCOMPARISON OF RAINFALL INTENSITY GAUGES

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Abstract

The first Laboratory Intercomparison of Rainfall Intensity Gauges was performed by the World Meteorological Organisation (WMO) from September 2004 to September 2005. The intercomparison was held simultaneously in the laboratories of the Royal Netherlands Meteorological Institute, MétéoFrance and the Department of Environmental Engineering (University of Genoa). The 19 pairs of participating instruments from 18 manufacturers were divided into three groups, with each group being tested for a period of about three to six months in each of the laboratories, in order to obtain a high degree of confidence in the results.

The main objective of this laboratory intercomparison was to test the performances of catchment type rainfall intensity gauges of different measuring principles under constant flow rate conditions. Other objectives were to define a standardized procedure for laboratory calibration of catchment type rain gauges, to comment on the need to proceed with a field intercomparison of catchment type of rainfall intensity gauges and to identify and recommend the most suitable method and equipment for reference purposes within the field intercomparison of catching and non-catching types of gauges. Finally the aim was to provide information on different measurement systems relevant to improving the homogeneity of rainfall time series with special consideration given to high rainfall intensities.

The results of the Intercomparison show that only those tipping-bucket rain gauges that apply proper correction to account for mechanical errors comply with the WMO specifications on the required accuracy for rainfall intensity measurements. As for the performance of weighing gauges, their accuracy is generally higher than tipping-bucket rain gauges, although many of them are subject to a quite long delay in response, with large errors applying to rainfall intensity measurements, so that the WMO requirements are not met. Other measuring principles were also tested, but the small number of instrument submitted (two) did not allow to obtain any conclusive information.

Introduction

The correct measurement of liquid precipitation (rain) and other meteorological and hydrological variables, as well as the correct interpretation of historical data, will be of foremost importance in the future for the prediction of changes in weather patterns affecting the whole climate of the Earth. In this respect, rain gauges provide the only direct measurements of rainfall intensity at the ground and are usually referred to as the "ground truth" in rainfall monitoring. Newly developed techniques for extensive rainfall observations based on remote sensing (essentially weather radar, airborne radiometers and satellites) provide a space-time description of rainfall fields, but still require the use of rainfall measurements from rain gauges for calibration and validation purposes. Improvement of the reliability of Rain Intensity measurements as obtained by traditional Tipping-Bucket Rain Gauges (TBRG) and other types of gauges (optical, weighing, floating/siphoning, etc.) is therefore required for use in climatologic and hydrological studies and operationally, e.g. in flood frequency analysis for engineering design. Standardization of high quality rainfall measurements is also required to provide a basis for the exchange and evaluation of rainfall data sets among different countries, especially in case of trans-boundary problems such as severe weather/flood forecasting, river management, and water quality control.

The measurement of rainfall intensity is subject to a number of uncertainties and instrumental errors. The WMO Laboratory Intercomparison focused on the inherent mechanical and/or electronic errors and uncertainties of rainfall intensity gauges. The traditional assessment of errors in precipitation gauges refers to the so-called weather related errors. It is well recognized that the measurement of liquid precipitation at the ground is affected by different sources of both systematic and random errors, mainly due to wind, wetting and evaporation induced losses (e.g. Sevruk, 1982) which make the measurement of light to moderate rainfall scarcely reliable in the absence of an accurate calibration. Wind induced errors still have an influence on rainfall intensities of the order of 20-50 mm·h^{-1} with an incidence around 5% observed in a few intercomparison stations in central Europe (Sevruk and Hamon, 1984, pp. 86). Solid precipitation measurements (snow) are even more difficult as snow is more sensitive than rain to weather related errors. Sampling errors due to the discrete nature of the rain measurement are also recognized to be dependent on the bucket size and sampling interval, though not on rain intensity, and can be analytically evaluated.

In precipitation measurements, systematic errors are commonly accounted for by means of correction models that can be generally expressed in the form:

$$P_c = k[P_g + \sum_i \Delta P_{gi}],$$

where P_c is the corrected figure, P_g is the gauge measured precipitation, $\Sigma_i\ \Delta P_{gi}$ is the sum of correction terms for various error sources, and k is the wind deformation coefficient. The detailed model, originally proposed by Sevruk (1982), was later modified by Legates and Willmott (1990) to account for both liquid and solid precipitation and can be written as:

$$P_c = k_r(P_{gr} + \Delta P_{wr} + \Delta P_{er} + \Delta P_{mr}) + k_s(P_{gs} + \Delta P_{ws} + \Delta P_{es} + \Delta P_{ms})$$

where ΔP_w, ΔP_e and ΔP_m are the correction terms for wetting, evaporation and mechanical errors respectively, while subscripts *r* and *s* refer to liquid (rain) and solid (snow) precipitation.

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 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 water falling over the projection of the collector's area over the ground. Non-catching instruments may also show "catching" errors although they do not have any collector for rain water and the water is simply observed while falling through the sensing volume of the instrument.

Counting errors are on the other hand related to the ability of the instrument to "sense" correctly the amount of water that is collected by the instrument. They can be experienced both in catching and non-catching type of instruments, although in the latter case the assessment of such errors is very difficult, and is hard to be performed in laboratory conditions.

The WMO Laboratory Intercomparison concentrated on the counting errors of the catching type of instruments. Obviously, these errors may derive from very different aspects of the sensing phase since the instruments may differ in the measuring principle applied, construction details, operational solutions, etc.

Background

The thirteenth session of the Commission for Instruments and Methods of Observation (CIMO-XIII), Bratislava, Slovakia, 23 September - 3 October 2002, noted with appreciation the results of the Expert Meeting on Rainfall Intensity Measurements, Bratislava, Slovakia, April 2001, which formulated "present and future requirements for rainfall intensity (RI) measurements" because no such requirements and related guidance were available. In that regard, the Commission recommended that:

(a) A standardized procedure for generating consistent and laboratory-reproducible flow rates designated for use as the laboratory standard for rainfall intensity calibration of catchment type gauges be developed. That should include calibration equipment and its proper configuration, and the expected performance as well as standard method(s) of testing, taking into account the variability of conditions including intermittence of the test facilities;

(b) Appropriate correction procedures and instrument specific factors for the application on long-term data series to maintain temporal homogeneity be developed with a special consideration to extreme values.

The Commission, recognizing the needs for further instrument comparisons and evaluation tests, agreed on the programme of WMO intercomparisons including the WMO Rainfall Intensity Intercomparison.

The CIMO-XIII noted that, as a result of an Expert Meeting held in Bratislava, Slovakia, in 2001, significant efforts had been made to initiate an International Rainfall Intensity Measurement Intercomparison. It was agreed that, as the first step in obtaining the required information, intercomparison of suitable types of rain gauges should be carried out in at least two independent recognized laboratories, with the aim of determining performance characteristics and, depending on the results, to consider both organizing a field test and the development of a secondary standard suitable for field tests. Depending on those results, field tests under the required climatologic conditions might be undertaken.

While laboratory tests were performed under the controlled environment, the field intercomparisons should be preferably conducted in an area where there is a high probability of high intensity rainfall events. Only in situ catchment types of instruments were considered for the laboratory intercomparisons, while both the catchment and non-catchment types would be allowed to participate in the field intercomparison.

The ET/IOC-1 requested the WMO Secretariat to initiate actions to start the WMO Laboratory intercomparisons of RI Gauges in September 2004. The field intercomparison should preferably start as soon as the laboratory intercomparisons are concluded.

Methods and procedures

A general methodology was 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 rain water 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.

Tipping Bucket

The duration of the test and the mass measurement were 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. These masses and durations were noted and reported, together with the number of tips involved in each test. Each test was performed at least at seven reference flow rates. However, since the higher rainfall intensities are of utmost importance for the intercomparison, the whole range of operation declared by the manufacturer was also investigated. In particular:

- Seven reference intensities were fixed at 2, 20, 50, 90, 130, 170, 200 $mm \cdot h^{-1}$;
- If the maximum declared intensity was less or equal to 500 $mm \cdot h^{-1}$, further reference intensities were determined at 300 and 500 $mm \cdot h^{-1}$.
- Otherwise, three further reference intensities were determined within the remaining range of operation of the instruments by dividing it logarithmically from 200 $mm \cdot h^{-1}$ up to the maximum declared intensity.

Since some of the instruments could show serious problems at the higher intensities (or due to any specific reason) the Site Managers had the possibility to increase the number of testing points at their own judgment.

In case water storage should occur for an intensity below the maximum declared intensity, the intensity at which water storage begins was reported and intensities above this limit were not been taken into account. The reference intensities were obtained within the following limits:

- 1.5 – 4 mm·h^{-1} at 2 mm·h^{-1}
- 15 – 25 mm·h^{-1} at 20 mm·h^{-1}

and within a limit of ± 10 % at higher intensities.

Weighing gauges

In addition to measurements based on constant flow rates, the step response of each instrument was checked based on the devices developed by each laboratory. The step response of the weighing gauges were measured by switching between two different constant flows, namely from 0 mm·h^{-1} to 200 mm·h^{-1} and back to 0 mm·h^{-1}. The constant flow was applied until the output signal of the weighing rain gauge was stabilized. The sampling rate was at least one per minute or higher for those instruments that allowed it. Precautions were taken to minimize the effects of vibrations.

Level measurement gauges

In addition to measurements based on constant flow rates, the step response of each instrument was tested based on the devices developed by each laboratory. Attention was paid to assess the effects of water conductivity and the siphoning process in cases of large rainfall intensities.

The testing devices

Each laboratory developed its own testing device, with some differences in the principle and technology used to generate a constant water flow, as well as in the way the water is weighed in the device. These 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 catchment type rainfall intensity gauges.

Participating instruments

The three laboratories involved in the WMO Laboratory Intercomparison of RI Gauges tested the performance of 19 rain gauges, with usually 2 instruments of the same type (see Table 1). All instruments were tested in each laboratory.

MANUFACTURER (PROPOSED BY)	**MODEL TYPE**	**PRINCIPLE**	**Number of instruments**
MC VAN Instruments (Australia)	RIMCO 7499	Tipping Bucket	2
Hydrological Services (Australia/HMEI)	TB-3	Tipping Bucket	2
PAAR (Austria)	AP23	Tipping Bucket	1
AXYS Environmental Systems (Canada)	ALLUVION 100	Water Level	2
METEOSERVIS (Czech Republic)	MR3H	Tipping Bucket	2
METEOSERVIS (Czech Republic)	MRW500	Weighing	2
VAISALA (Finland)	VRG101	Weighing	2
SEROSI (France)	SEROSI	Water Level	2
Germany, OTT HYDROMETRY	Pluvio	Weighing	2
India Meteorological Dept. (India)	TBRG	Tipping Bucket	2
CAE (Italy)	PMB2	Tipping Bucket	2
ETG (Italy)	R102	Tipping Bucket	2
SIAP (Italy)	UM7525	Tipping Bucket	2
YOKOGAWA DENSHI KIKI (HMEI)	WMB01	Tipping Bucket	2
GEONOR (Norway/HMEI)	T-200B	Weighing	2
MPS SYSTEM (Slovakia)	TRWS	Weighing	2
LAMBRECHT (Switzerland)	1518 H3	Tipping Bucket	2
CASELLA (United Kingdom/HMEI)	100000E	Tipping Bucket	2
WATERLOG (USA/HMEI)	H340 – SDI	Tipping Bucket	1

Table 1: The participating instruments, listed by country and measuring principle.

Results of the intercomparison

The results are presented in the form of two graphs, which are derived as follows:

1) First graph:

- The error is evaluated for each reference flow rate as:

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

  where I_m is the intensity measured by the instrument and I_r the actual reference intensity provided to the instrument;
- Five tests were performed for each set of reference intensities, so that five error figures are associated with each instrument;

  The average error and the average values of I_r and I_m are obtained by discarding the minimum and the maximum value of e obtained for each reference flow rate, then evaluating the arithmetic mean of the three remaining errors and reference intensity values.

  On the same graph, the average error curve obtained at each of the three laboratories is plotted.
- For each reference intensity of each laboratory, an error bar encompassing all the five error values used to obtain the average figures is reported.

2) Second graph:

- For each laboratory, I_r versus I_m is plotted, with linear scales for X and Y axis;
- I_m and I_r are average values, calculated as indicated above;
- All data are fitted with a power law trend line:

$$I_m = a \cdot I_r^b ,$$

  where a, b are constants.

Tipping-Bucket Rain Gauges

The results obtained for the tipping-bucket rain gauges cannot be considered as a comparable set for all twelve instruments. Large differences in the uncertainty of the measurement are encountered depending on whether the instrument correction procedure is internally applied based on the dynamic calibration. Residual errors after using the correction can be ten times smaller than the original figures, at least at the highest rain intensities.

The gauges were classified into two groups based on applying the dynamic calibration. Results for instruments with and without corrections are discussed separately.

Tipping bucket gauges without corrections

The majority of the tipping-bucket rain gauges analysed (seven out of twelve) do not apply any correction based on dynamic calibration. Single point calibration is applied in some cases at a single rain intensity around 30-50 mmh^{-1}. This is used to obtain a relative error very close to zero at a given rainfall intensity that is of practical interest for operational purposes. Outside of this range the errors are not generally within the limits of ± 5 % defined by WMO for the required uncertainty of rainfall intensity measurements.

The most relevant characteristic of this group of instruments is the large error associated with the highest rain rates (up to 15-20 % at intensities of around 300 $\text{mm}\cdot\text{h}^{-1}$). The relative error increases with rainfall intensity and is well fitted by a second order polynomial.

In Figure 1 the overall response curves are presented for all instruments with no correction applied and derived by averaging the measured data obtained at all three laboratories for the two identical instruments when applicable. Each curve is therefore representative for the observed behaviour of one particular instrument. Clearly, significant deviations from the reference value can be expected at high intensities for most of these instruments.

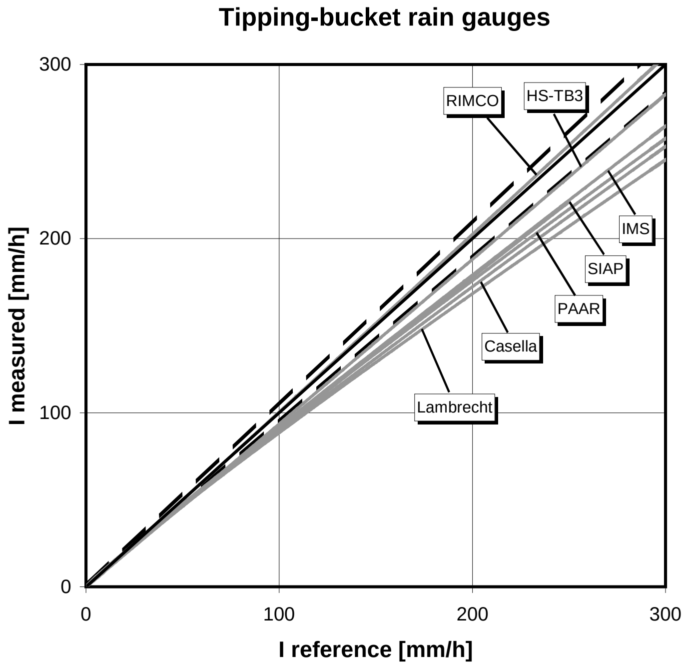


Figure 1: Ensemble of response curves for the non corrected TBRG (dashed lines indicate ±5%).

It should be noted that some of the rain gauges analysed can apply corrections via a post-processing software that was not submitted to the Intercomparison, or just provide a correction curve in the form of a graph or table, its application being left to the user.

Tipping bucket gauges with corrections

The second group of tipping-bucket rain gauges contains those instruments (five out of twelve) that apply some correction, which tends to reduce the relative error over the whole range of measurement of the instrument.

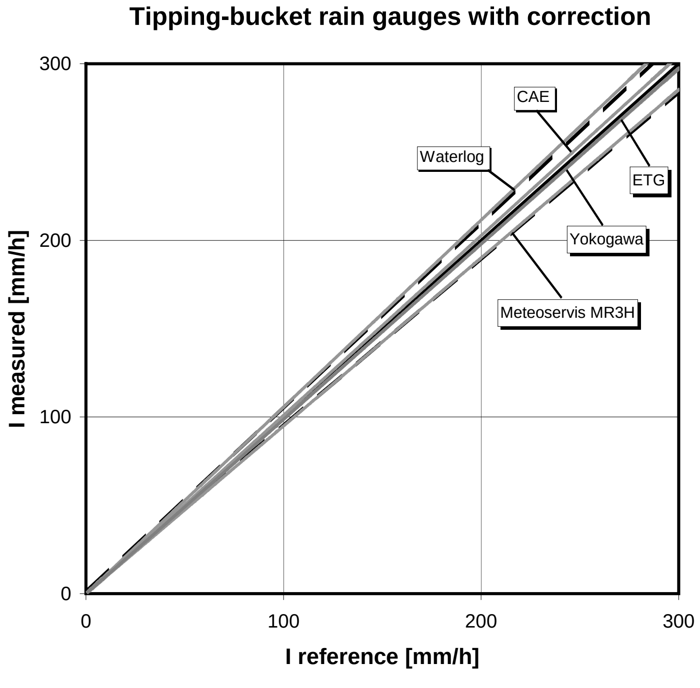


Figure 2: Ensemble of calibration curves for corrected TBRG (dashed lines indicate ±5%) over the range of reference rainfall intensities from 0 to 300 mm·h^{-1}.

These instruments have lower relative errors but a larger variability in the resulting error curve, which depends on the type of correction applied and its effectiveness in improving the rain measurement performance. The correction proposed by the manufacturer and implemented was able to reduce the errors in most cases so as to fall within the limits ± 5% defined by WMO for the required uncertainty of rainfall intensity measurements.

In Figure 2 the overall calibration curves are presented for all instruments with dynamic calibration applied, each of them being derived by averaging the experimental data obtained at all three laboratories. Each curve is therefore representative of the expected behaviour of one particular instrument.

By inspection of the various curves, it is evident that the errors are generally smaller with respect to the non-corrected gauges; it can be said that the ETG and CAE gauges (Italy) are the most accurate for the measurement of rainfall intensity since providing the less relevant errors over the respective actual range of intensities.

In both the corrected and non-corrected groups of rainfall intensity gauges, storage was observed within some instrument. Storage heavily affects the rain intensity measurement since, as soon as water starts accumulating in the funnel, it generates the flow of a “false” rainfall intensity towards the buckets that depends on the water head established over the orifice rather than on the real rain intensity. Due to this fundamental drawback the initiation of storage determines the inability of the instrument to further measure the rain intensity.

The actual range of measurement of a given instrument was therefore determined within the intercomparison by assuming the reference intensity where storage occurred as the upper limit of the measuring range. Storage was observed in four out of the twelve instruments analysed.

Weighing Gauges

All of the weighing gauges analysed can be grouped together and their performance discussed with reference to common parameters. It was decided by the ET/IOC that also the step response of the gauge should be evaluated. In general, the uncertainty of this type of gauge in terms of relative errors is less than uncorrected tipping-bucket rain gauges over the entire range of intensities (see below in Figure 6).

The assessment of the step response of the weighing gauges illustrates some of the drawbacks that can affect their suitability for rainfall intensity measurement. Tests were performed in order to investigate the step response behaviour of the weighing gauges submitted to the intercomparison. The reference intensity provided to the gauge was a constant flow rate, obtained by switching from 0 to 200 $mm \cdot h^{-1}$ and then back to zero flow, with the duration of the input flow being decided based on the time needed for stabilization. The constant flow had therefore been applied until the output signal of the weighing rain gauge was stabilized.

The results of these further tests are presented below for the weighing gauges analysed. There was a definite time delay with respect to the sudden variation in intensity (the step response). This delay varies between 0.33 and 9 minutes, being around 3-4 minutes for the majority of the instruments.

Only in one case (0.33 minutes) the delay can be considered as acceptable for the measurement of rainfall intensity with a resolution of one minute. The best performing gauge of the weighing type in this respect is the Meteoservis MRW500 (Czech Republic). The step response for the best performing weighing gauge is reported in Figure 3.

CIMO-XIII approved an output averaging time of 60 seconds for the determination of RI. This implies that RI, reported by an ideal RI-gauge capturing a step-function alike RI, should be as indicated in Fig. 3 (dotted line). As a consequence, only those instruments with a sufficiently rapid response time (like the gauge shown in the figure) comply with this requirement.

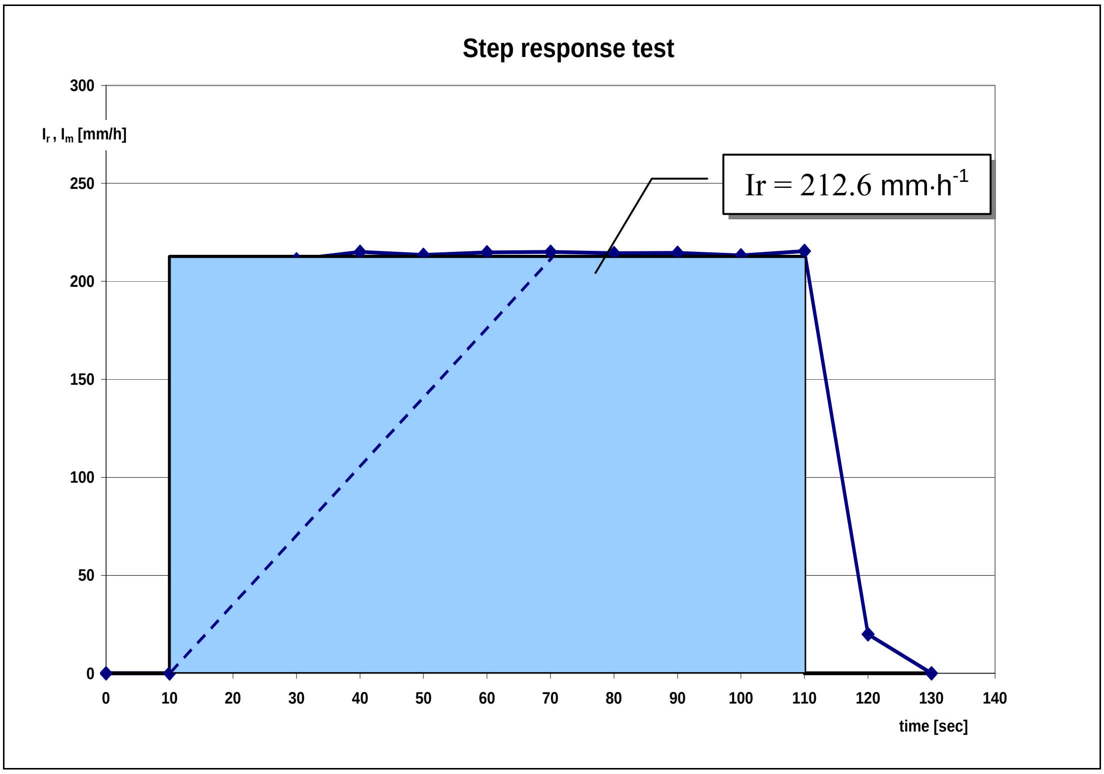


Figure 3: Step response for the Meteoservis MRW500 weighing gauge, showing a delay in sensing the rain rate signal of about 20 seconds. The dotted line shows the response curve to be reported by an ideal RI-gauge, based on the defined averaging interval of 60 s.

The response tests were performed by sudden application of a constant flow obtained at the reference intensity, and then waiting until the instrument is stabilized. The errors reported in the calibration curves are therefore related to such an "ideal" rainfall event with constant intensity and practically infinite duration in time.

Following the significant delay observed for some of the instruments under test, it was decided to perform additional tests on the weighing gauge showing the longest delay, i.e. the OTT Pluvio, so as to infer the impact of such behaviour on real rain intensity measurements.

It is well known that rainfall intensity is a highly variable signal in time, with fluctuations at even smaller scales than one minute. This was taken into account by assuming a common minimum-averaging interval of one minute for all instruments involved in the intercomparison.

Figure 4 shows the response of the OTT Pluvio rain gauge to a pulse with increasing duration, from 1 to 10 minutes. No time was allowed for the stabilization of the output intensity measured by the instrument. It is evident from Figure 4 that the response function of the instrument varies with the duration of the test pulse. Large errors are evident at the reference resolution of one minute and decrease with the increasing duration of the constant pulse. This delay in response is relevant when accurate measurements of rainfall intensity are required. This must be taken into account when comparing the graphs later in this section. The step response delay parameters play the most important role in assessing the performance of the instrument and even its overall suitability for rainfall intensity measurements.

Finally, in Figure 5, the error estimated as the relative difference between the reference and measured rainfall intensity averaged over the period of the rainfall event is plotted as a function of the duration of the rainfall event, again for the OTT Pluvio gauge, and compared to the error obtained by averaging over a sufficient period of time.

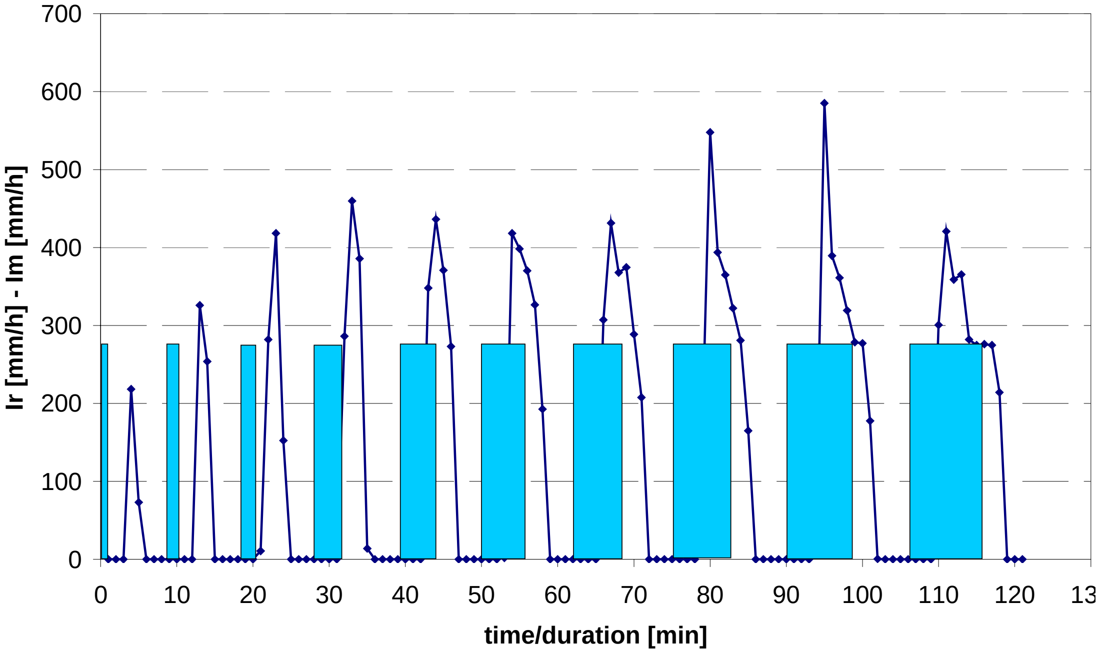


Figure 4: Step response for the OTT Pluvio weighing rain gauge, at varying pulse duration but the same reference intensity. The data points indicate the rain intensity values reported by the instrument with a resolution of one minute.

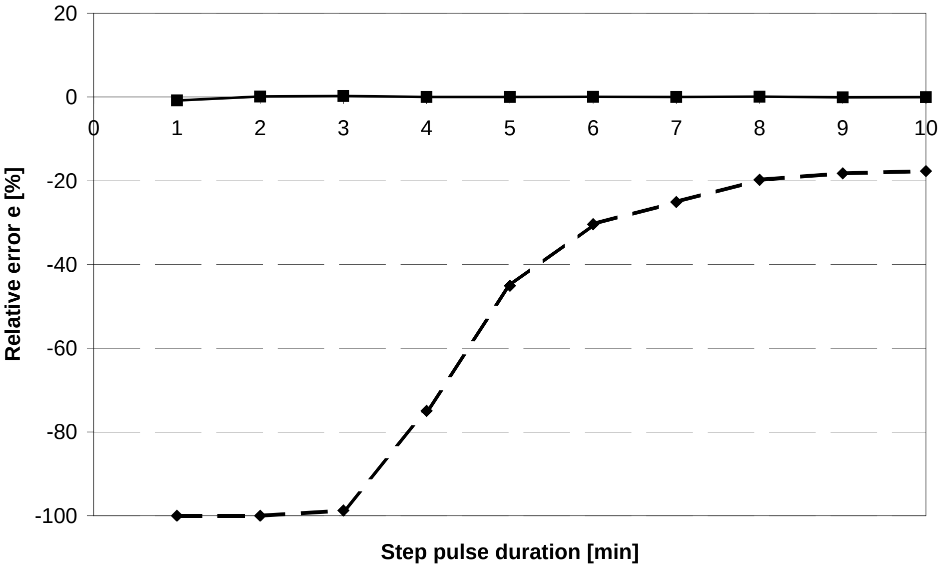


Figure 5: Relative errors (diamonds) as a function of the time interval that is used as the averaging period for calculation of the intensity (under constant flow rate). The squares indicate the relative errors obtained after waiting a sufficient period of time after the end of the rain pulse.

Water Level Gauges

Two other instruments are based on the measurement of water level, by using the conductivity of water to detect the level with several stacked detectors. The two instruments analysed showed different performances, mainly related to the efficiency of water siphoning or draining.

One instrument sometimes presented a continuous activation of the siphon.

One model gave results within the +/- 5% WMO limits.

These instruments are potentially sensitive to the water conductivity, if it falls outside the stated limits.

It is advisable that both of them are included in the foreseen follow-on intercomparison in the field for additional investigations involving real rain-water and operational environmental conditions.

Overall comparison of gauges

The below figures show comparisons between all gauges involved in the laboratory intercomparison.

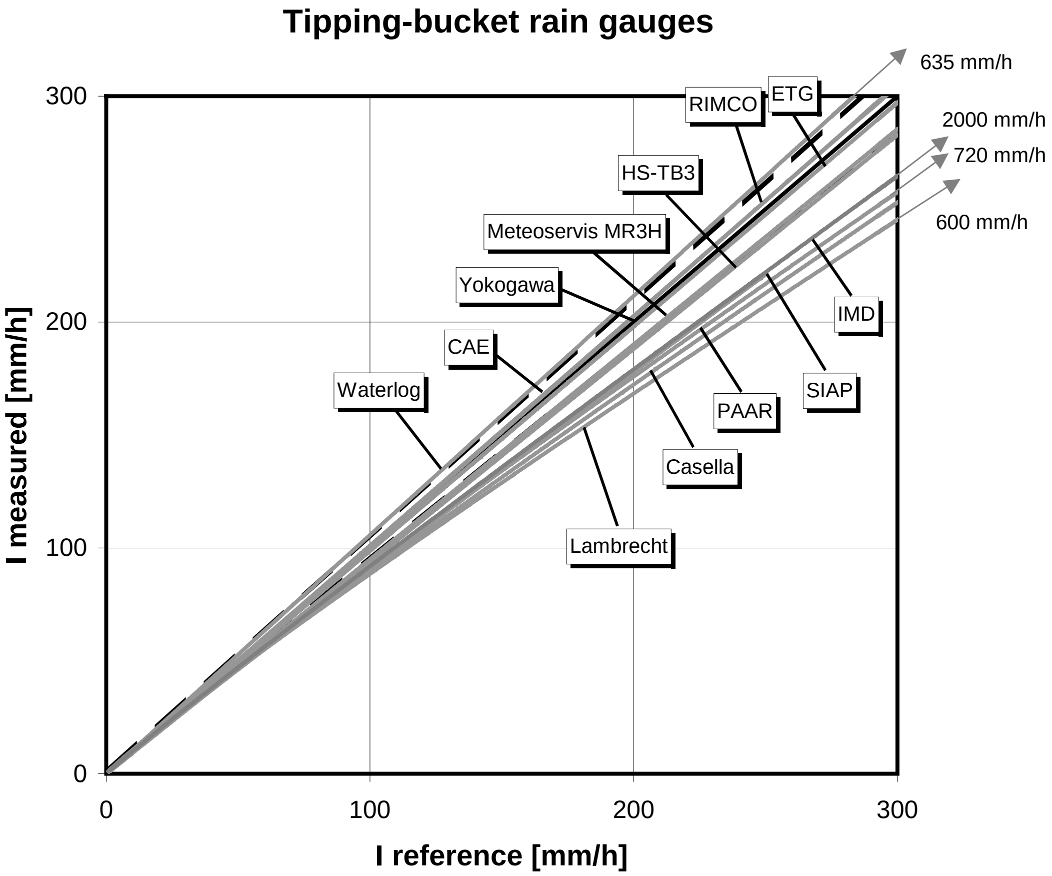
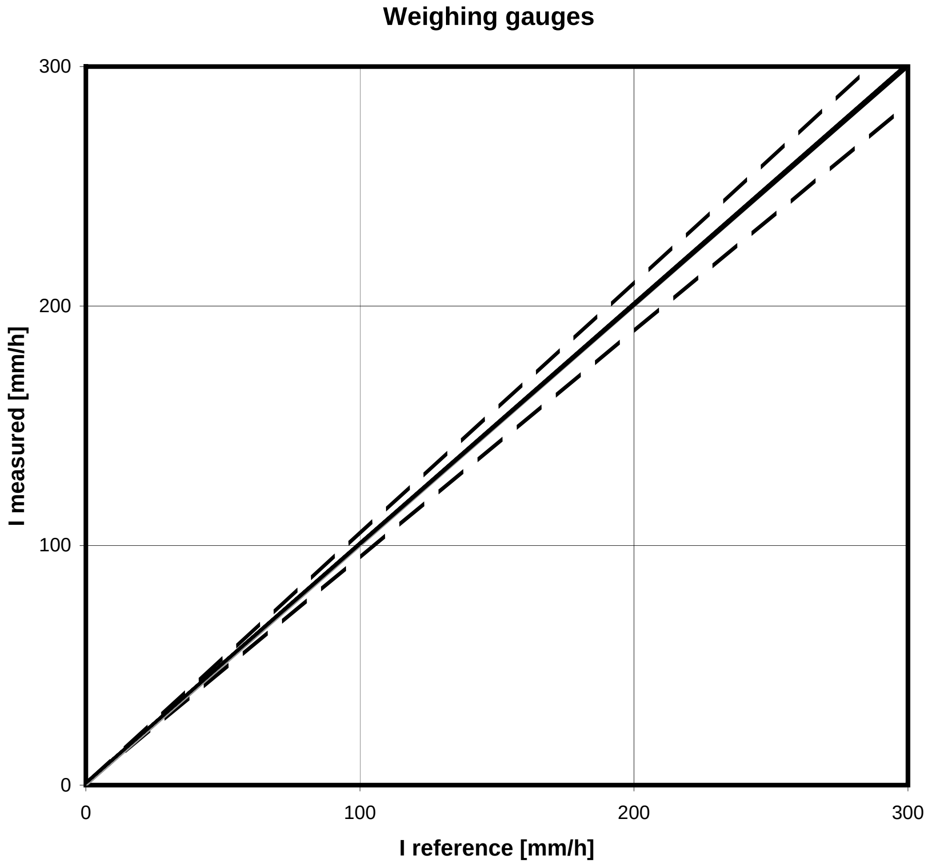


Figure 6a: Overall comparison of all tipping-bucket rain gauges analysed over different ranges.



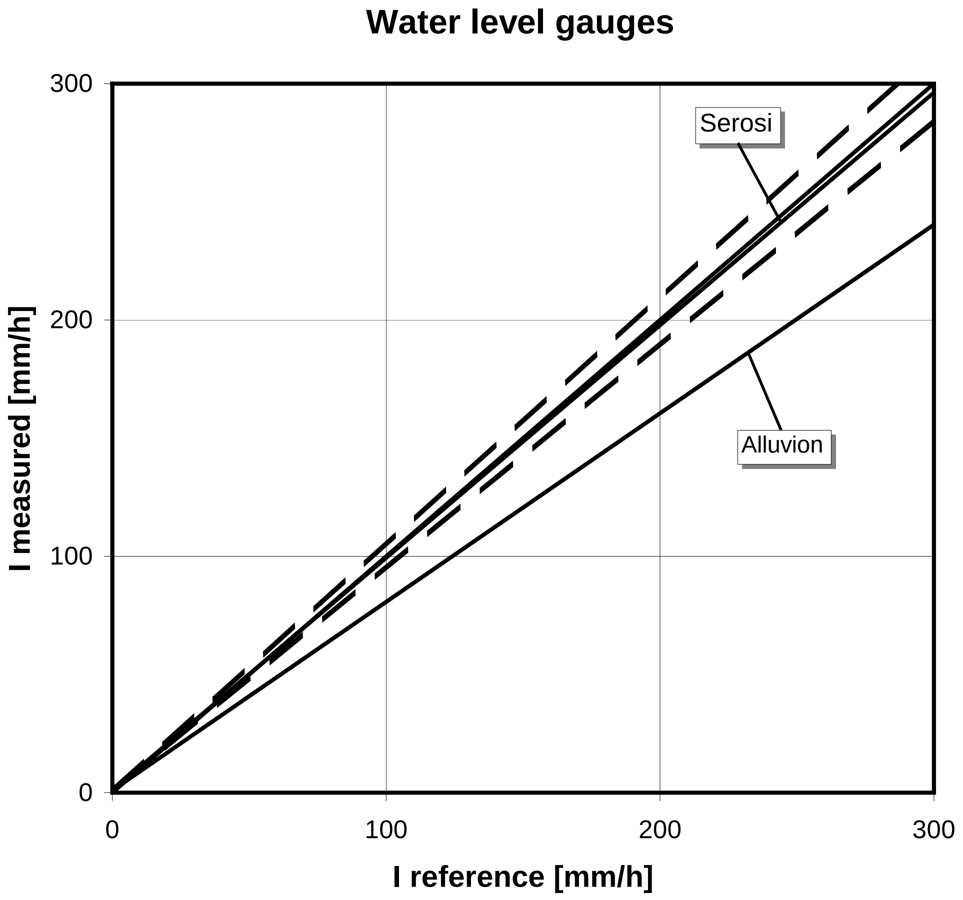


Figure 6b, c: Overall comparison of all weighing and water level gauges over different ranges.

In order to compare at a glance the performances of the various rainfall intensity gauges submitted to the Intercomparison, the average relative error over the range of measurement of the instrument was calculated.

This can be defined as the relative difference between the total area A_m subtended by the power law fitting of the calibration curve in the graphs reported above and the reference total area A_r subtended by the bisector of the same graphs, which represent the expected behaviour or the "perfect" instrument. The average error e_{avg} is therefore defined as:

$$e_{avg} = \frac{(A_m - A_r)}{A_r}$$

The first value is calculated by integrating the power law calibration curve within the limits from 0 to 300 mm·h^{-1}, while the second is simply given by $0.5 \cdot I^2_{max}$, having in this case I_{max} = 300 mm·h^{-1}. The complement to one of the above ratio is reported in Figure 7 for all gauges investigated.

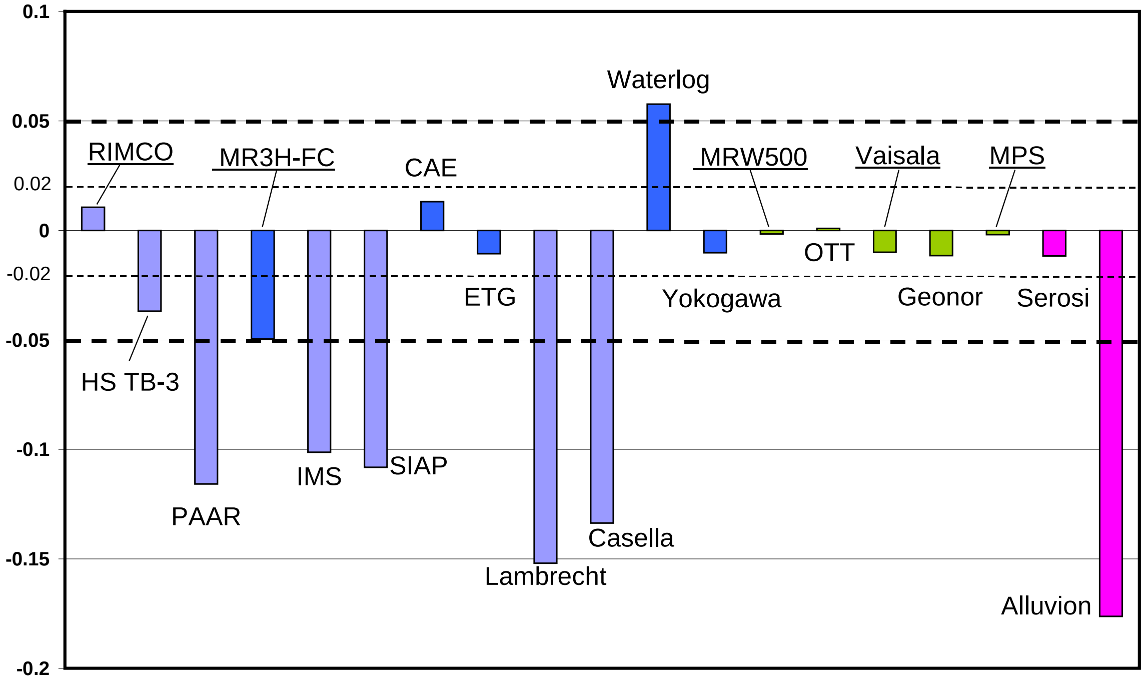


Figure 7: Average relative error over the whole range of measurement of all instruments analyzed.

Conclusions

This Laboratory Intercomparison of RI Gauges is the very first attempt at understanding of their performance, thus providing quantitative information regarding various errors associated with this measurement. The results certainly constitutes a basic step for the planning of the WMO Field Intercomparison of RI gauges to be started in 2007 in Vigna di Valle, Rome (Italy).

The Final Report of the Laboratory Intercomparison is now available as IOM Report No. 84 (Lanza et al., 2005), and can be found on the Internet at the following address: http://www.wmo.int/web/www/IMOP/reports/2003-2007/RI-IC_Final_Report.pdf.

All instruments analysed are subject to errors and uncertainties in the measurement of rainfall intensity, and the selection of the best suited rain gauge must be performed according to its intended use and operational conditions.

The tipping-bucket rain gauges that were equipped with proper correction software provided good quality rainfall intensity measurements. The gauges where no correction was applied had larger errors. In some cases problems of water storage in the funnel occurred that could limit the usable range for rain intensity measurement.

The uncertainty of the rainfall intensity is generally less for weighing gauges than for the tipping-bucket rain gauges under constant flow rate conditions, provided there is a sufficient time to stabilize the instrument. The measurement of rainfall intensity is affected by the response time of the acquisition system. Significant delays were observed in "sensing" the variation in time of the rain intensity. The delay is the result of the internal software which is intended to filter the noise. Only one instrument had a delay that met the WMO 1-minute rainfall intensity requirement.

The two gauges using a conductivity measurement for determining water level showed good performances in terms of uncertainty under these controlled laboratory conditions. Siphoning problems for one gauge limits its ability to measure a wide range of rainfall intensity. For the other one, a limitation is related to the emptying mechanism, in which case 2-minute delay was observed. These gauges are potentially sensitive to the water conductivity, but with no demonstrated problems during the laboratories' tests.

In many cases significant differences were recorded between two identical instruments. Tests on a large number of gauges, say at least 30, would provide a better assessment of the uncertainty.

The laboratory tests were performed under controlled conditions and constant flow rates (rain intensities) so as to determine the intrinsic counting errors. It must be considered that rainfall intensity is highly variable in time. Furthermore, catching errors may have a strong influence on the overall uncertainty of the measurement. The catching errors in the atmosphere are dependent on the wind field and during any field comparison tests the spatial variability of the precipitation must be considered in the interpretation of the results.

The weather related conditions (wind, wetting, evaporation, etc.) that may produce significant catching errors could hardly be reproduced in the laboratory, unless very large economical and human resources are involved. The same is true for calibration of non-catching types of gauges that were excluded for this reason from the Laboratory Intercomparison, although of great interest to the meteorological community.

The need to combine the assessment of both counting and catching errors for the instrument analysed in the laboratory is paramount. Provided the instrument is properly installed in the field, according to the WMO specifications, the question to be answered is what kind of instrument (measuring principle, manufacturer, model) is the most suited to the specific requirements of the user. This question cannot be answered based on the Laboratory Intercomparison alone, although the results obtained can provide preliminary information to manufacturers and the first-step selection criterion for the user.

Therefore the quality assessment procedure for rain intensity gauges initiated in the laboratory will continue by organizing a follow-up intercomparison in the field where the instruments tested in the laboratory will have priority. This will allow continuity in the performance assessment procedure and result in the estimation of the overall operational error to be expected in the measurement of rainfall intensity in the field. Other instruments will be included in the field intercomparison, even if not tested in the previous laboratory phase, with priority given in this case to the non-catching type of instruments.

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