THE WMO LABORATORY INTERCOMPARISON OF RAINFALL INTENSITY (RI) GAUGES

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Abstract

The Joint Expert Team on Surface-Based Instrument Intercomparison and Calibration Methods (ET on SBII&CM) and International Organizing Committee (IOC) on Surface-Based Instrument Intercomparison, according to the CIMO Plan of WMO intercomparisons, started in September 2004 the WMO Laboratory Intercomparison of Rainfall Intensity (RI) Gauges. The Intercomparison was held at the recognized laboratories of the Royal Netherlands Meteorological Institute (KNMI), the Netherlands, Météo France, France, and the University of Genoa, Italy.

The main objective of the laboratory intercomparison was to test the performances of catchment type rainfall intensity gauges of different measuring principles under documented conditions. Further objectives can be summarized as follows:

- To define a standardized procedure for laboratory calibration of catchment type rain gauges, including uncertainty of laboratory testing devices within the range from 2 to 2000 mm/h;
- To evaluate the performance of the instruments under test;
- To comment on the need to proceed with a field intercomparison of catchment type of rainfall intensity gauges;
- 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;
- To provide information on different measurement systems relevant to improving the homogeneity of rainfall time series with special consideration given to high rainfall intensities.

Only catchment type of instruments that are currently being used in national observing networks or are being considered for use in national networks and are capable of measuring rainfall intensity of at least 200 mm/h at a time resolution of 1 minute were tested.

Nineteen (19) types of instruments had been selected, with usually 2 instruments of the same type, produced by 18 different manufacturers. Fifteen countries were represented; out of them 10 from Europe and five non-European countries. All instruments were tested in each laboratory.

This paper describes the main objectives of the Intercomparison, the adopted methods, and expected/obtained results, also with a view of the foreseen Field Intercomparison of Rainfall Intensity Gauges in Various Climatic Regions.

Introduction

The need for a WMO Intercomparison of RI gauges goes back to the Expert Meeting on Rainfall Intensity Measurements (EM), held in Bratislava, Slovak Republic, 23-25 April 2001. The meeting, giving a high priority especially to RI, agreed that the calibration of rain gauges was a high priority task. Calibration techniques for catchment type gauges have been described in the literature (e.g. Calder and Kidd, 1978; Marsalek, 1981; Niemczynowicz, 1986; La Barbera *et al.*, 2002), however at the present there is no standardized calibration equipment or procedure suitable for general application. Therefore the development and testing of a standardized calibration technique has to be developed first in well-certified laboratories.

The EM discussed in depth the advantages and disadvantages of the various performance characteristics of various measuring techniques used for RI observations. The *in situ* non-catchment type of sensors were not considered further because, at the time, the primary use of these sensor was generally not for RI measurements but rather for present weather observations and research applications. In addition, laboratory calibration / intercomparison of these sensors were not considered to be feasible or at best, very difficult to design for the full range of rainfall intensities at the available laboratories.

With a reference to the proposals developed for present and future requirements related to RI measurements, it was considered that there had been a particular need to compare gauges for high RI rates, since their performance related to low intensities was tested at various national and global WMO intercomparisons. The general performance characteristics of various types of rain gauges had been sufficiently documented for low RI range. Taking into account the difficulties related to organization and conducting of a field intercomparison in a climatic region with the required high RI during a comparison period, the unavailability of suitable and well recognized reference instruments, it was agreed to start first with a laboratory RI Intercomparison, before other, more comprehensive, field RI intercomparison would be considered. A decision towards a field intercomparison should then be made based on the results of the initial laboratory comparison.

The EM proposed to test the same types of rain gauges in at least two independent certified laboratories. It was the opinion of the experts that there is no need to check the performance at a measuring range less than 0.2 $mm \cdot h^{-1}$ at all while preference should be given to the full range above 2 $mm \cdot h^{-1}$. The Expert Meeting also proposed that a standardized procedure for generating consistent and repeatable laboratory flow rates be developed and designated for use as the laboratory standard for RI calibration of catchment type gauges (e.g. Lanza and Stagi, 2003). This should include definitions on accuracy and range requirements; the recommended 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 of the test facilities.

Taking into consideration the results of the laboratory test and expectations that any new correction and calibration factors of gauges might be derived which have not been considered earlier, the Expert Meeting recommended that appropriate correction procedures and instrument specific factors should be developed by the user community for the application on long-term data series to maintain temporal homogeneity. Special consideration should be given to extreme values (see e.g. La Barbera *et al.*, 2002; Molini *et al.*, 2001).

The proposal of the EM was included in the CIMO Plan of WMO Intercomparisons and the International Organizing Committee on Surface-Based Instrument Intercomparison (IOC) have been established by the President of CIMO for the organization and conduct of the intercomparison. The first session of the Joint meeting of the Expert Team on Surface-based Instrument

Intercomparisons and Calibration Methods (ET) and the IOC was held in Trappes, France, 24-28 November 2003. The ET/IOC, in addition to the general rules and procedures for WMO Intercomparisons as defined in the Guide to Instruments and Methods of Observation, WMO - No.8, Part III, Chapter 5, Annex 5.A and 5.B, agreed upon specific rules and procedures, which are described in the final report of that meeting and can be found on the CIMO/IMOP website: http://www.wmo.int/web/www/IMOP/reports.html

Selection of Instruments

Due to limited resources, the number of participating instruments was initially limited to a maximum of twelve pairs of gauges. However, given the higher demand and based on the proposal of the project leader, the ET/IOC had selected nineteen instruments, based on the following criteria:

a) Instruments are to be selected in a way to cover a variety of measurement techniques;
b) Preference should be given to new promising measuring techniques;
c) Preference should be given to instruments that are widely in use in member countries.

The list of selected instruments is recalled in Table 1.

The three laboratories involved in the WMO Laboratory Intercomparison of RI Gauges therefore tested the performances of 19 rain gauges, with usually 2 instruments of the same type. All instruments have been calibrated in each laboratory. That means that about 6 models have been calibrated in each laboratory during a period of about 2 months and then the instruments were shifted from one laboratory to another one, for a new period of 2 months and so forth until all instruments have been calibrated in all laboratories.

COUNTRY & MANUFACTURER	MODEL TYPE	MEAS. PRINCIPLE	Number of instruments
ITALY - SIAP	UM7525	TIPPING BUCKET	2
ITALY – CAE	PMB2	TIPPING BUCKET	2
ITALY – ETG	R102	TIPPING BUCKET	2
CZECH REPUBLIC – METEOSERVIS	MR3H	TIPPING BUCKET	2
SWITZERLAND – LAMBRECHT	1518 H3	TIPPING BUCKET	2
UNITED KINGDOM – CASELLA	100000E	TIPPING BUCKET	2
INDIA – INDIA MET DEPT	TBRG	TIPPING BUCKET	2
AUSTRIA – PAAR	AP23	TIPPING BUCKET	1
USA – DESIGN ANALYSIS ASSOC	H340 – SDI	TIPPING BUCKET	1
JAPAN – YOKOGAWA DENSHI KIKI	WMB01	TIPPING BUCKET	2
AUSTRALIA – MC VAN Instr.	RIMCO 7499	TIPPING BUCKET	2
AUSTRALIA – Hydrol. Serv.	TB-3	TIPPING BUCKET	2
CZECH REPUBLIC – METEOSERVIS	MRW500	WEIGHTING	2
SLOVAKIA – MPS SYSTEM	TRWS	WEIGHTING	2
GERMANY – OTT HYDROMETRY	OTT	WEIGHTING	2
FINLAND - VAISALA	VRG101	WEIGHTING	1
NORWAY - GEONOR	T-200B	WEIGHTING	2
FRANCE – SEROSI	SEROSI	CONDUCTIVITY	2
CANADA – AXYS Env. Syst	ALLUVION 100	WATER LEVEL	2

Table 1: List of instruments selected for the WMO Laboratory Intercomparison of RI Gauges.

Methods and procedures

The Intercomparison of RI gauges were conducted at the recognized laboratories under the supervision of the Site Managers appointed by the host laboratories.. Per each of the instruments involved in the intercomparison, each laboratory performed five calibration tests according to the different calibration/testing instruments used and to the experience of the Site Managers. The number of tests performed per each of the instruments, their description and duration (in terms of time units and/or number of tippings, etc.) was noted and reported.

For each calibration test the following environmental parameters were noted and recorded:

- date and hour (start/end);
- air temperature [°C];
- water temperature [°C];
- atmospheric pressure [hPa];
- ambient humidity [%];
- any special condition that may be relevant for the single calibration (e.g. vibrations)

The calibration was different according to the type of instrument analyzed, namely its measuring principle. In the following a description is given per categories.

Tipping Bucket

The calibration test consists of providing the gauge with a constant water flow, generated by a suitable device, by calculating the average intensity from the measurement of the total amount of water actually provided within a given period of time and by comparing this amount with the average intensity measured by the instrument in the same period (see Fig. 1).

The duration of the test and the mass measurement are controlling factors for determining the accuracy of the calibration. A mass and a duration used for each test must be chosen so that the uncertainty of the reference intensity is less than 1%, taking also into account the resolution of the instrument. These masses and durations have been noted and reported, together with the number of tips involved in each test.

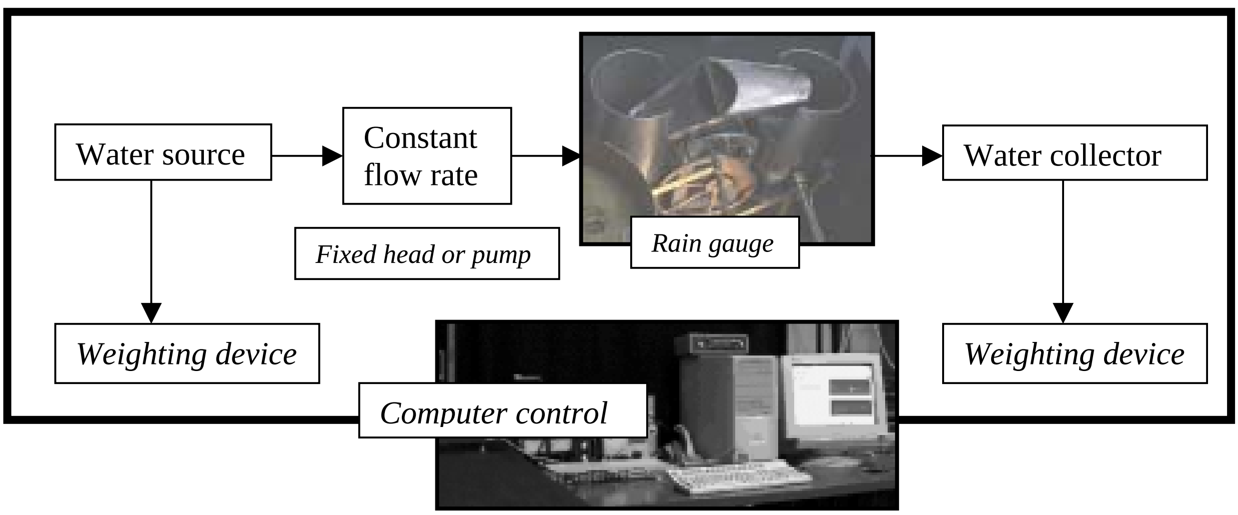

Figure 1: Rationale of the testing device for calibration purposes within the Intercomparison.

Each calibration 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 the following rules have been agreed upon:

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

In case of water storage (in the funnel above the bucket) for an intensity below the maximum declared intensity, the intensity at which water storage begins was reported and intensities above this limit were taken into account.

The reference intensity has been 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.

Weighting 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 was 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 time resolution of the measurement was higher than 1 minute, e.g. 10 seconds, and the possible delay was evaluated by determining the first time interval when the measure is stabilized, within a maximum period of 10 minutes. Attention was paid in particular to assess the effects of vibrations and to reduce them in order that their impact on the measurement was less than 1%.

Other measuring principles

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. Full description of the method and instruments adopted in each specific case was provided by every Site Manager.

Attention was paid in particular to assess the effects of the following potential error sources:

- conductivity measure
- time between the water falls in the gauge and the level is adapted
- water level not stabilized
- water retention in the funnel and in the pipes
- etc.

Presentation of the results

The results are presented in the form of an average error curve that is derived as follows:

- The error is evaluated per 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 calibration tests are performed per each set of reference intensities, so that five error curves are associated with each instrument;

- An average error curve is obtained by discarding the minimum and maximum error value obtained per each reference flow rate, then evaluating the arithmetic mean of the three remaining error and reference values, and finally fitting these average values within the range of reference intensities with a second order polynomial as below, over the whole range of operation of the instrument:

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

  with *a, b* and *c* suitable numeric coefficients;

- In this curve the reference flow rates used for fitting the average curve are the average values of the three reference intensity values.

Preliminary results

At the time of writing only the first phase of the Intercomparison was completed, with all rain gauges being tested in at least one of the three involved laboratory. Preliminary results are therefore available and are synthesized here. The second phase is in course and the first indications confirm that the results obtained in different laboratories are consistent with each other, although different calibration devices are used (see e.g. the Qualification Module for RI Measurement developed at the DIAM laboratory in Figure 2).

As an example of the results obtained hitherto, two average error curves are presented in Figure 3 and 4 from two different tipping-bucket rain gauges respectively tested in the laboratories of Météo France and DIAM. Although the absolute value of the involved errors at corresponding reference intensities differs by a factor of ten and the two ranges investigated are quite different, an analogous behavior is observed. Note that the second graph refers to a rain gauges that is automatically corrected by software before an output intensity is provided, and this is the reason of the very good performances shown during the test (absolute error $\leq$ 1%). This result confirms that dynamic calibration allows increasing the performances of tipping-bucket rain gauges up to the limits requested by WMO.

In Figure 5 the average error curve obtained for a tipping-bucket rain gauge tested in the laboratory of KNMI is also presented. For this instrument the error at the lowest intensities is much higher than in the above cases due to the presence of irregular tips. Also at intensities higher than 200 $mm \cdot h^{-1}$, water accumulates in the funnel.

Figure 2*:* A tipping-bucket rain gage under test at the laboratory of DIAM (University of Genoa).

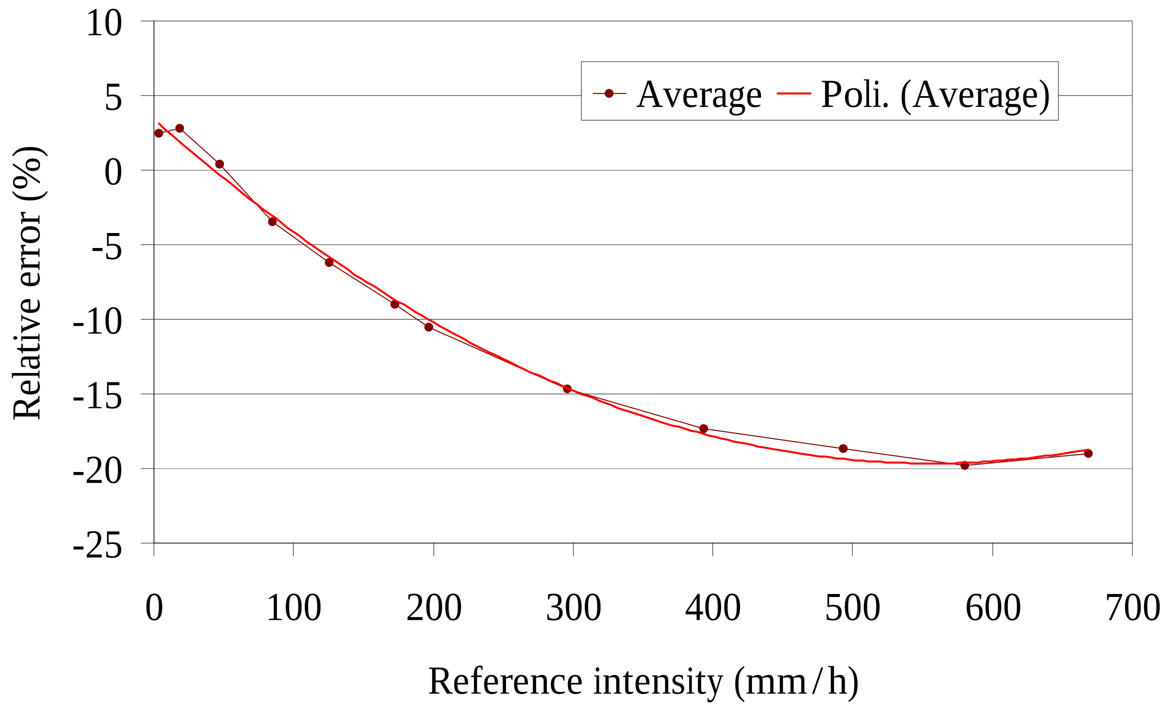

Figure 3: Example of an average and interpolated error curve obtained at the laboratory of Météo France for a tipping bucket rain gauge.

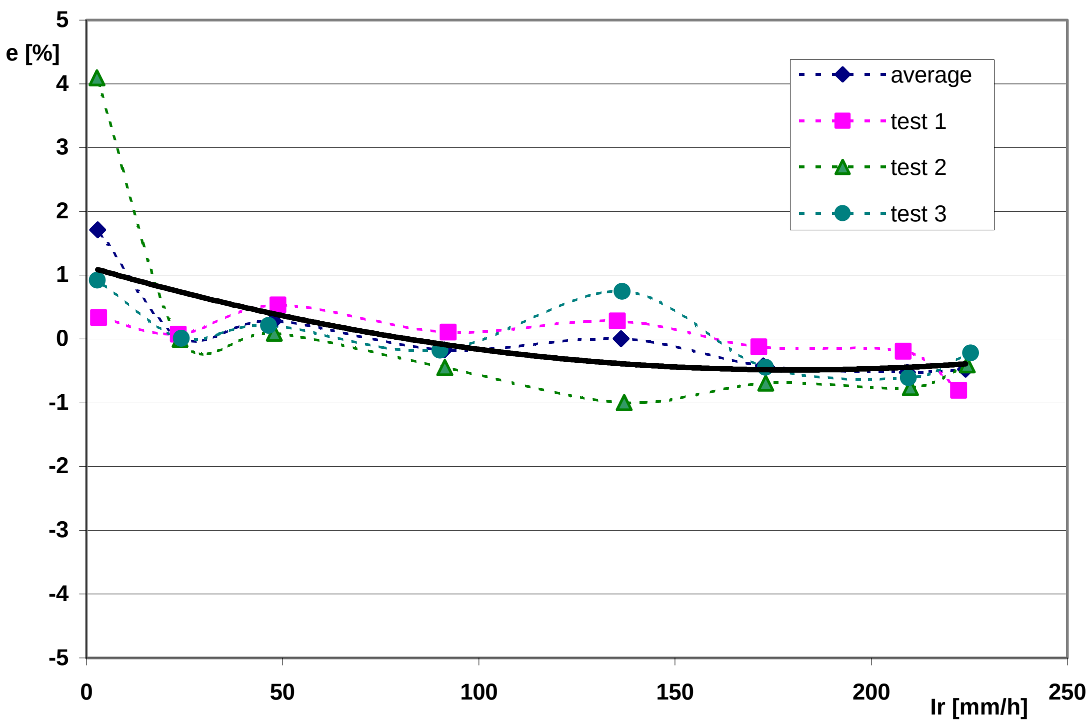

Figure 4: Example of single test and average error curves obtained at the laboratory of DIAM for a tipping bucket rain gauge.

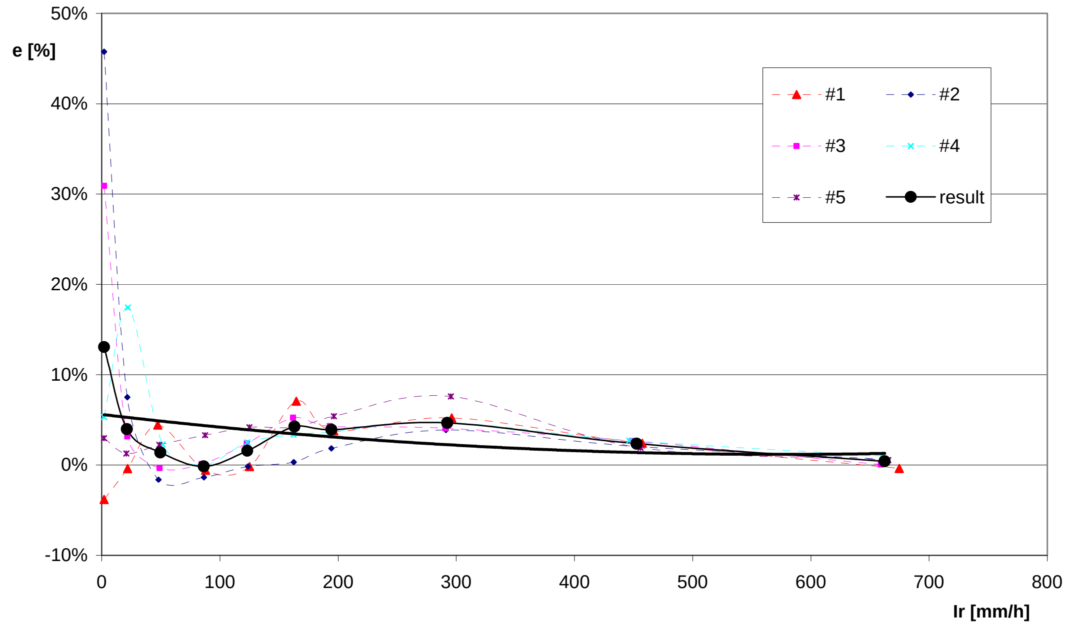

Figure 5: Example of single test and average error curves obtained at the laboratory of KNMI for a tipping bucket rain gauge.

ERROR (%)								
Reference intensity	**2.75 (1.5-4)**	**20 (15-25)**	**50 (45-55)**	**90 (81-99)**	**130 (117-143)**	**170 (153-187)**	**200 (180-220)**	**max**
TBR 1	*+1.45*	*+0.93*	*-0.85*	*-1.93*	*-2.93*	*-3.37*	*-5.28*	*-5.61*
TBR 2	*+0.11*	*-1.20*	*-2.27*	*-0.67*	*-1.21*	*-1.13*	*+0.57*	*+3.63*
TBR 3	*-1.72*	*-1.75*	*-0.08*	*+0.63*	*-0.59*	*-1.24*	*-0.76*	*-2.52*
WG 1	*-0.46*	*-0.09*	*-0.26*	*-0.17*	*-0.21*	*+0.16*	*+0.10*	*+0.06*
WG 2	*-0.93*	*-0.87*	*-4.21*	*-3.37*	*-4.40*	*-3.41*	*-2.89*	*- **
TBR 4	*+1.71*	*+0.03*	*+0.28*	*-0.18*	*+0.01*	*-0.42*	*-0.52*	*-0.48*

TBR = Tipping Bucket, WG = Weighting Gauge ** = storage observed in the funnel*
max = max. declared intensity

Table 2: Average error figures for a sample set of rain gauges at various reference intensities.

	a	***b***	***c***	***R^2***
TBR 1	*4·10-5*	*- 0.04*	*1.5059*	*0.98*
TBR 2	*1·10-4*	*- 0.019*	*- 0.4295*	*0.89*
TBR 3	*5·10-5*	*- 0.018*	*1.14*	*0.70*
TBR 4	*7·10-5*	*-0.097*	*2.62*	*0.99*
TBR 5	*-1·10-5*	*-0.019*	*-5.37*	*0.99*
TBR 6	*7·10-5*	*-0.083*	*3.40*	*0.99*

Table 3: Set of parameters of the polynomial error curve for a sample group of tipping-bucket rain gauges tested in two of the involved laboratories.

Conclusions

The WMO Laboratory Intercomparison of Rain Intensity (RI) Gauges is in progress at the time of writing, with the laboratory tests on the 19 instruments involved to be completed within Summer 2005. A glance on the methodologies used at all three laboratories in charge of the intercomparison at Météo France, KNMI (The Netherlands) and the University of Genoa (Italy) has been provided in this paper, together with some preliminary results on the tests already performed.

The wide response obtained in the launching phase of the intercomparison, the large number of instruments proposed and the spreading of such instruments among various measurement principles and techniques is very promising and the final results of the intercomparison will be certainly of interest for both the meteorological and the hydrological communities.

From the initial data obtained in all three laboratories, we can say that – as expected – tipping bucket rain gauges that do apply correction for systematic mechanical errors by means of some post-processing technique dramatically reduce the errors and seems to accommodate for the [-5%, 5%] relative error requirements, while non-corrected gauges show much larger errors while progressively increasing the reference rain rates (up to 20% at the highest intensities). As for the weighting gauges, the main problem seems to be the step response though this will need additional data before conclusions can be drawn.

References

Calder, I.R. and C.H.R. Kidd (1978). A note on the dynamic calibration of tipping-bucket gauges. *J. Hydrology*, **39**, 383-386.

La Barbera, P., L.G. Lanza and L. Stagi (2002). Influence of systematic mechanical errors of tipping-bucket rain gauges on the statistics of rainfall extremes. *Water Sci. Techn.*, **45**(2), 1-9.

Lombardo, F. and Stagi, L. (1997). Dynamic calibration of rain gauges in order to check errors due to heavy rain rates. Proc. Int. Conf. On '*Water in the Mediterranean*', Istanbul, 25-29 November. In press.

Marsalek, J. (1981). Calibration of the tipping bucket raingauge. *J. Hydrology*, **53**, 343-354.

Molini, A., La Barbera, P., Lanza, L.G. and L. Stagi (2001). Rainfall intermittency and the sampling error of tipping-bucket rain gauges. *Phys. Chem. Earth*, **26**(10-12), 737-742.

Niemczynowicz, J. (1986). The dynamic calibration of tipping-bucket raingauges. *Nordic Hydrology*, **17**, 203-214.

Sevruk, B. (1989). Reliability of precipitation measurement. In: *Instruments and Observing Methods*. Proc. Int. Workshop on Precipitation Measurements. WMO Rep. N° 48, p. 13-19.