WMO LABORATORY INTERCOMPARISON OF RAIN INTENSITY GAUGES

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In response to the request of CIMO-XIII, the first session at Trappes in November 2003 of the joint **E**xpert **T**eam on Instruments Intercomparisons and Calibrations methods on surface–based instruments and **I**nternational **O**rganizing **C**ommittee on surface–based instruments defined, among many others objectives, a standardized procedure for laboratory calibration of catchment type rain gauge, including uncertainty of laboratory testing devices within the range from 2 to 2000mm/h. Three laboratories (France, Netherlands, Italy) involved in the WMO Intercomparison of Rain Intensity Gauges will be evaluating the performances of 19 rain gauges, with usually 2 instruments of the same type.

First tests were carried out from the 2nd of September 2004 to the 10th of December 2004 in the Laboratory of Trappes (France) on 7 different rain gauges and 3 types of measuring techniques: weighing, tipping buckets, and conductivity. Five calibrations were carried out for each device at different intensities, with an uncertainty on calibration bench intensity less than 1%.

1) CALIBRATION BENCH AND ASSOCIATED UNCERTAINTY ON GENERATED CONSTANT INTENSITY

To establish an error curve, a calibration bench is used by the laboratory of Météo-France, at Trappes. An error exists with high intensities with tipping buckets gauges because the bucket tip is not instantaneous. Water falling during the tip may be lost. For example, for a rainfall rate of 120 mm/h, we have a tip every 6 s (with a 0.2 mm resolution). If the tip has a duration of 300 ms, the loss will be 5% (0.3/6). The duration of the tip depends on the inertia of the system (the inertia momentum related to the swing axe) and the momentum generated by water inside the bucket. All this is design dependent. The smaller is the inertia; the faster is the tip. The measurement resolution is also a factor. A bucket adjusted for 0.1 mm will tip 2 times more than for 0.2 mm and the loss of water may be doubled. The loss increases with intensity as the period between 2 tips decreases. The loss should be proportional to the intensity; but at high intensity, the dynamic of water falling into the bucket helps the tip. Therefore, the loss is reduced.

That leads to the need of a bench calibration to plot the error curve with intensity. Note, for weighing rain gauge and conductivity measurement, that relative error do not increases with intensity

1-1) Calibration bench

We use a bench composed of an electronic weighing machine, a peristaltic pump, both connected to a standard PC with dedicated software. The electronic weighing machine has a 0.01 g resolution, a 5 kg range and outputs the measurements on an RS232 line to the PC, 7 times per second. A water container is weighed. A tube injects water into the buckets through a peristaltic pump. This pump is also controlled by the PC, both for its speed and start and stop. With (8 g, 0.2mm) buckets, this bench allows the generation of 3 mm/h to 250 mm/h intensity range with one tube. The range may be adjusted by increasing the number of tubes. The tip detector such as a contact closure for tipping bucket, the measure of mass for weighing gauge or the conductivity converted in rain accumulation for SEROSI rain gauge, is connected to a junction signal of an RS232 line of the PC. The dedicated software controls the pump, sets a given intensity, counts a selected number of tips, or mass, or conductivity, and gets the mass variation of the water container. It outputs the rain gauge measured precipitation quantity, compared to the decrease in mass on the balance, and calculates the difference expressed in %. A succession of tests at various intensities may be programmed, leading to an automatic establishment of an error curve with intensity.

1-2) Uncertainty about constant intensity generated by bench calibration

The uncertainty calculation of intensity is mainly dependent on the duration of the test and on total mass of water used.

1) Duration of test
   Electronic weighing machine outputs a message each 0.17s: we get a new weight each 0.17s. A maximal error on mass is choosen as 0.1%, therefore the duration of test must be at least 170 s. An uncertainty $\mathbf{U_1}$ about this error on mass is calculated.

2) Total mass of water to use
   Errors of calibration with reference weights, repeatability, drift depending on temperature and resolution according to specifications of the manufacturer, allows to calculate an uncertainty on mass $\mathbf{U_2}$. Total uncertainty **U** is square-law addition of U_1 and U_2 and we applied a enlargement factor **c =2** :

$$\mathbf{U = c\sqrt{U_1^2 + U_2^2}}$$

   Finally, the mass of water **M** is chosen for one intensity so that $\mathbf{U/M \leq 1\%}$.

2) STANDARDIZED PROCEDURE FOR CALIBRATION

Each calibration has been performed at least at seven reference flow rates. However, since the higher rainfall intensities are of outmost importance for the intercomparison, the whole range of operation declared by the manufacturer has also been investigated. In particular, seven fixed reference intensities have been set at 2, 20, 50, 90, 130, 170, 200 mm/h.

Further reference intensities are set at 300 mm/h and 500mm/h, if the maximum declared intensity is 500mm/h. Otherwise, three further reference intensities are determined within the remaining range of operation of the instruments by dividing it logarithmically from 200 mm/h up to the maximum declared intensity. (*For this presentation, the calibration points for plotting error curve have been choosen each 200mm/h, from 200mm/h to 2000mm/h, for Indian TBRG).*

For weighing principle, in addition to measurements based on constant flow rates, the step response of instrument has been checked, based on the devices developed by each laboratory.

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 values and the reference values, and finally fitting these average values 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;

3) ENVIRONMENTAL MEASUREMENTS AND CAUTIONS FOR CALIBRATIONS

Water used for the experiments was tap water, with a limited change of temperature. However, the SEROSI rain gauge requires pure water, close to rain.

Minimum time for one tip measurement without "bounce" effect in signal acquisition was adapted according to the specifications of the transducer of each rain gauge.

We took into account the time needed to stabilise the pump flow rate before data acquisition.
At each beginning of test, at least two tips used for wetting the buckets were discarded.

Tests were carried out with a maximum water flow rate of 8000 g/h for each tube, according to the specifications of the pump manufacturer. A variable number of tubes were used to cover the needed range of intensity (1 to 10 tubes).

In the rain gauge, tubes were put as close as possible to the nozzle of the funnel.

For some rain gauges data, scattering occurs, depending on performance characteristics of the sensor itself.

With our calibration bench, at low intensity with uncertainty of 1%, only 2 tips can be used for calibrate some device: it's not adequate. So, standard deviation of mass buckets is calculated according to number of tips, until it becomes more or less stable: it happens for a fit minimum number tips for calibration (4 to 10 tips, depending on device).

Water temperature, air temperature, relative humidity, atmospheric pressure were recorded during the calibrations.

4) ERROR CURVES AND COMMENTS ON DEVICES UNDER CALIBRATION

4-1) CONDUCTIVITY MEASUREMENT

SEROSI RAIN GAUGE

Measurement principle: rainfall water flows in a tube where water level is measured by conductivity. When the water level is equivalent to 6 mm of rain, an electromagnetic sluice gate stops water and a peristaltic pump drains water off from the tube. This rain gauge is not heated.

Aperture	400 cm^2
Resolution	0.1 mm for the OMM test
Funnel mean wetting loss	9.8 g
Maximum intensity (according to manufacturer)	360 mm/h
Outer geometry	Cylindrical

A software supplied by Serosi specially for the OMM tests enable to acquire every round minute both the measure of the water weighted and the rain gauge measure.

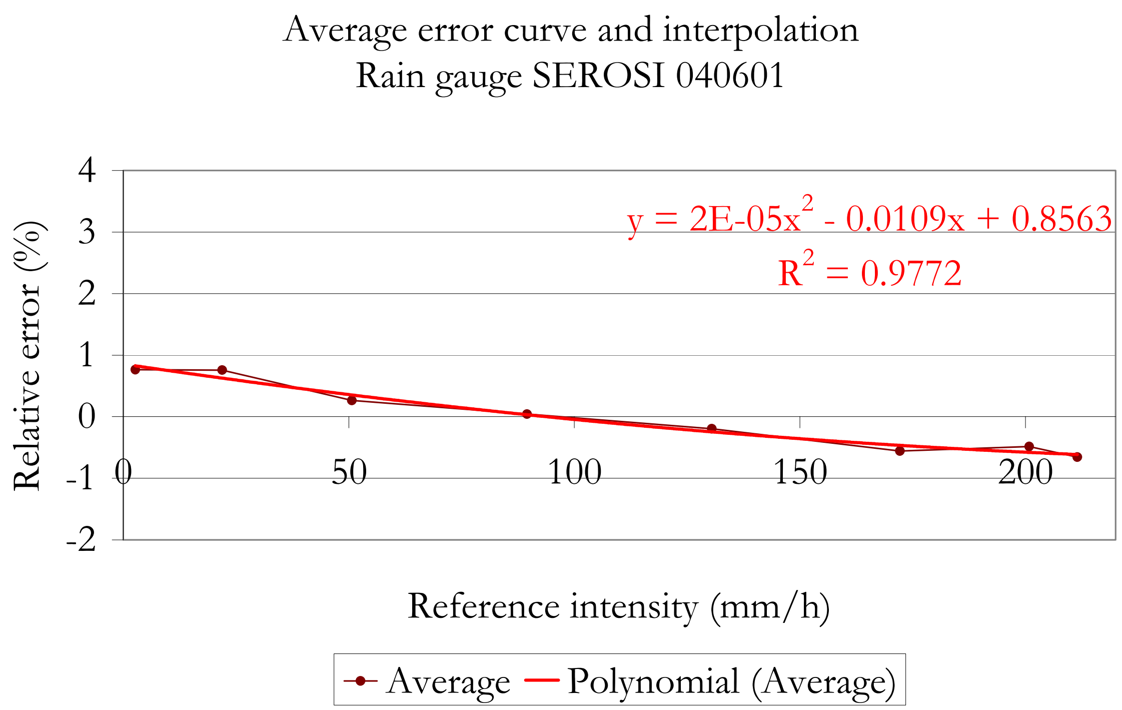
Laboratory tests are carried out with demineralized water, mixed with 5 % of tap water. The nominal resolution of this rain gauge is 0.01 mm but a resolution of 0.1 mm is enough for the test. It was possible to measured intensities up to 210 mm/h with the standard secondary funnel. For greater intensities, water overflows, because the electromagnetic sluice gate is closed during 30 s. This rain gauge can measure intensities up to 360 mm/h with a larger secondary funnel.

The error calculation for this rain gauge is done using 15 minutes of measurement for the intensity of 2 mm/h and using 10 minutes for other intensities. With each duration, we remove 1 minute at the beginning (time for pump stabilisation and because the beginning of the test is not exactly at round minute), or even 2 minutes if water empties out at the first minute. Indeed, if the tube is currently drained at the round minute, the water level measured by the rain gauge is the same as the water level at the previous minute. Because of that, the last minute of the test must not have the same water level than the previous minute. In this case, we decide that the end of the test is the last minute we measure. If the last minute of the test has the same water level than the previous minute, we decide that the end of the test is the penultimate minute.

For low intensities, the Serosi rain gauge gives a great error, comparable to tipping buckets rain gauges because:

1. The constant resolution of 0.1 mm is important for low water levels with low intensities. It gives a larger percentage of error than for the one for a high intensity (in this case, the test duration to decrease uncertainty on intensity makes large water level variations).
2. The tube that brings water from the pump to the rain gauge was put as close as possible of the nozzle, but it did not take into account the retention of the circuit where water flows until the measurement tube.

Repeatability is not good at low same intensity for two same devices: with SEROSI n°2 under calibration at 2 mm/h, we have got a maximum relative error of 33% for first serie and a minimum relative error of –19.7% for fifth serie.



4-2) WEIGHING MEASUREMENT

OTT RAIN GAUGE

A software from manufacturer inputs primary data from weighing and rules out effects of the wind (vibration and surpression-depression).

Due to the filtering software, this rain gauge provides intensity and rain accumulation some minutes later and not instanteanously. This rain gauge is more useful for rain accumulation than intensity. This device my be heated.

Aperture	200 cm^2
Outer geometry	cylindrical
Maximum intensity (according to manufacturer)	1200 mm/h

As one of the main objective of the intercomparison is to compare instruments capable of measuring rainfall intensity at a time resolution of 1 minute, we have :

1) To verify if rain accumulation is right at constant given flow rate (step response, rain intensity provided by the device).

   We have to wait 2 minutes after given flow rate stops for obtaining right results: before, rain accumulation is undervalued.

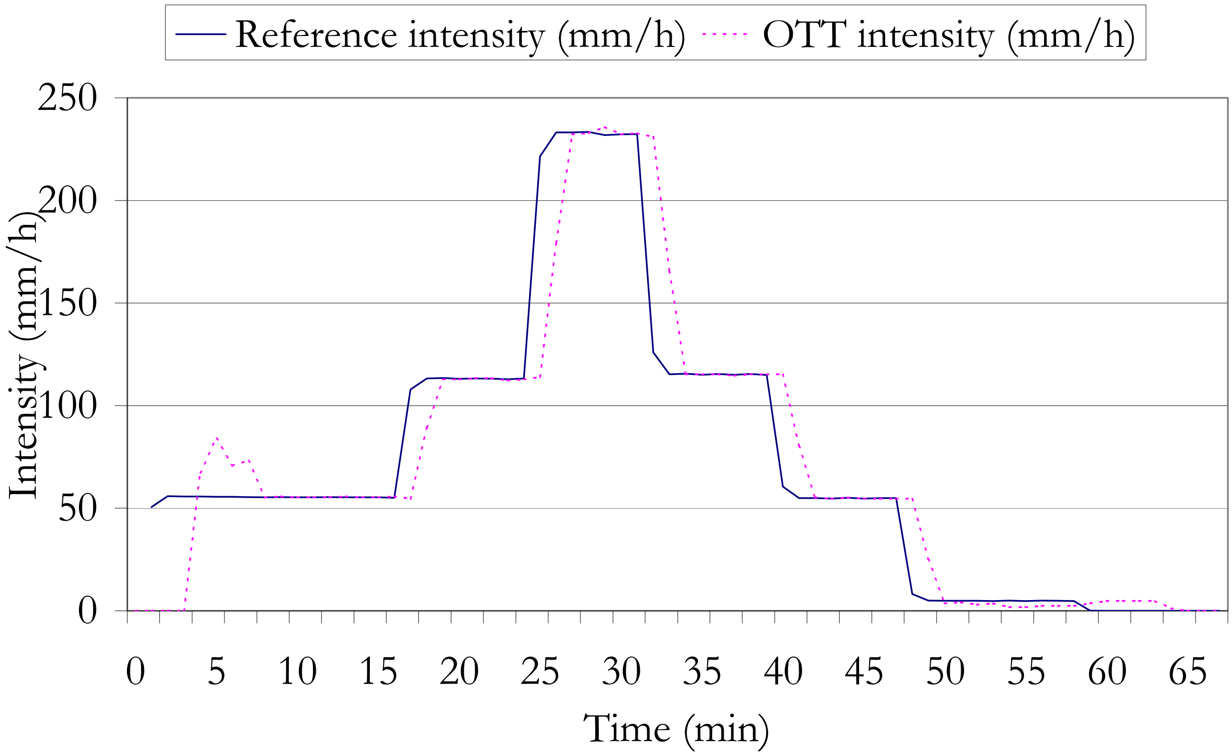
   Intensity is right but after 8 to 9 minutes for stabilisation: it needs 4 minutes after the beginning of rain fall for having minute intensity which is false (about +40%) and 4 at 5 minutes more for stabilization, that is to say 8 to 9 minutes for obtaining right intensity after the test starts.

   It means that a short and strong shower which begins with high intensity will not be recorded correctly, rules considering intensity (water accumulation will be correct).

2) To verify if rain accumulation is right at non-constant given flow rate (step response, rain intensity provided by the device). For tests, if flow rate changed during the test, it was at each beginning of minute.

   Provided by this rain gauge, rain accumulation is right, intensity delayed of 2 minutes except for the first intensity given 4 minutes after the start of given flow rate: it is overvalued for having a valid rain accumulation.

   Stop record of rain accumulation finishes 2 minutes after given flow rate stops and it's only at this time than rain accumulation is perfectly right. Relative error is close to 1%. Just at the time rain fall stops, rain accumulation provided by the software of this rain gauge is false.



<u>Comments on the tests</u>
Vibrations generated by impacts far and close to the rain gauge and light shocks on this rain gauge don't disturb intensity provided.
A specific software made by our laboratory staff:
1) sets a given flow rate synchronised with recording start of rain gauge
2) inputs in a PC both synchronised

- RS485 of this rain gauge transformed into RS232 signal
- mass variation of the weighing machine.

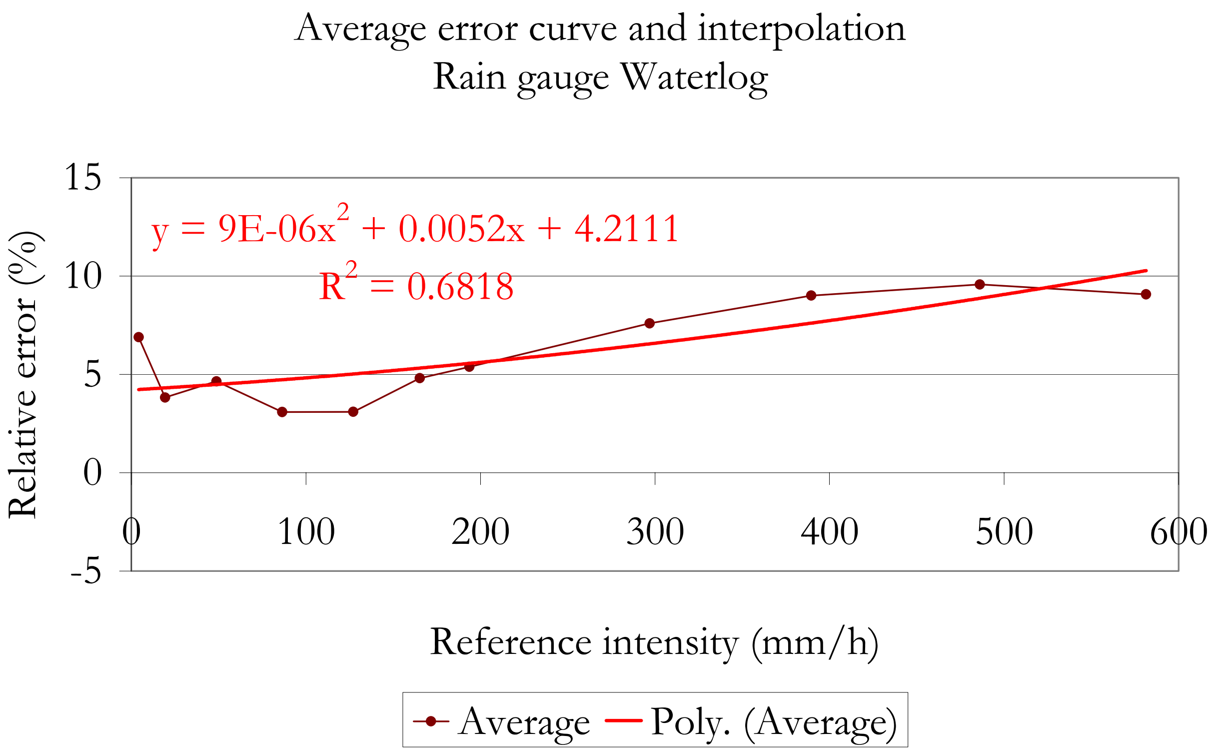
4-3) TIPPING BUCKET MEASUREMENT

4-3-1) H340-SDI

Measurement principle : a magnet on the bucket closes a reed switch at each tip.
A software from manufacturer included in the sensor inputs primary data from tips and provides mathematical correction for bucket volume errors due to varying rainfall rate. Bucket pivot pins are mounted on bearings.

This rain gauge is not heated.

Aperture	324.3 cm^2
Mass per tip	8 gr
Outer geometry	Cylindrical
Maximum intensity (according to manufacturer)	635 mm/h
Only one device was provided by the manufacturer.	



The correction about tips is calculated as a function of the frequency of tips. This correction is overestimated. It remains an error after this correction, due to software correction, adjusting and repeatability (friction).

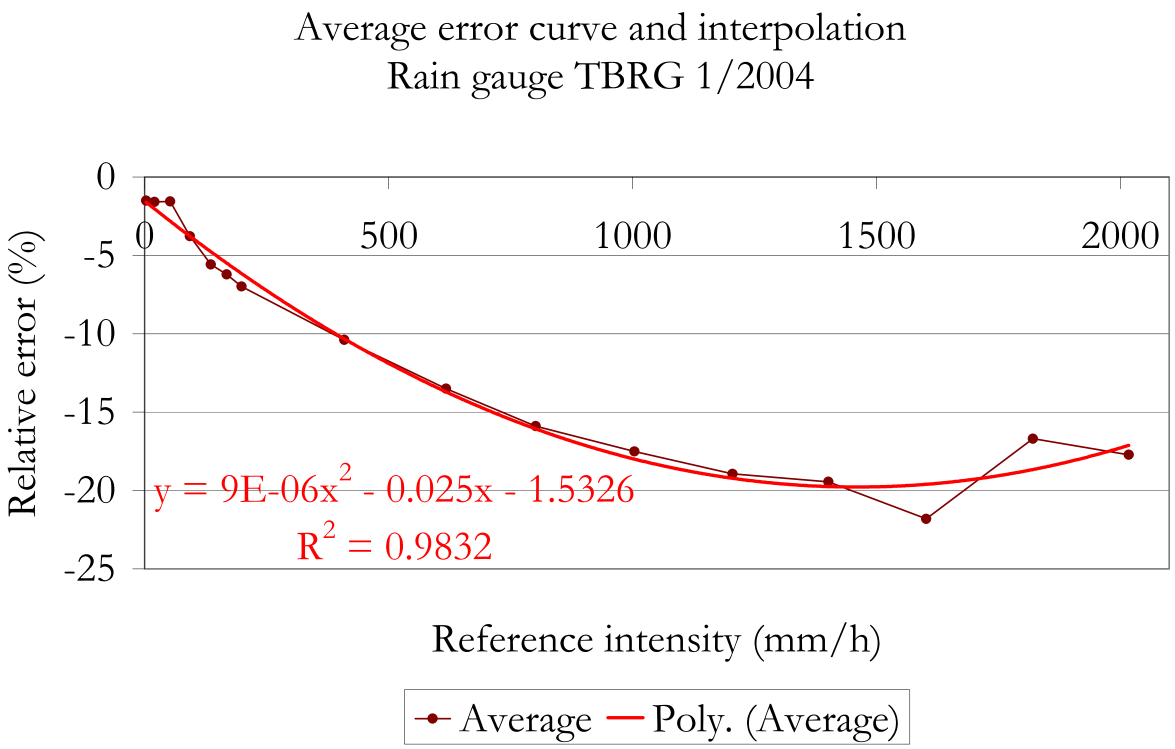
4-3-2) Indian rain gauge (TBRG)

Measurement principle : a magnet on the bucket closes a reed switch at each tip.

This rain gauge is not heated.

Aperture	324.3 cm^2
Mass per tip	16.21 gr
Outer geometry	cone put on cylinder
Maximum intensity (according to manufacturer)	/////

Monsoon in India involves rain gauges can measure high intensities and rain accumulation.



An intensity up to 1700 mm/h can be measured correctly and maximum error is got for 1700mm/h. Between 1700 mm/h and 3000 mm/h, error value varies to –15% to –23%. It's probably due to the secondary funnel above buckets which loads up to an intensity which is maybe 1700mm/h.

Conclusion:

Three types of measurement for rain gauges have been under tests :

1) Weighing
2) A right rain accumulation is got by the OTT weighing system but with an shifted intensity on time.
3) Tipping buckets, tipping buckets with mathematical correction provided by software
4) A software correction according to variable intensity is an amelioration for high intensities.
5) Conductivity
6) At low intensity with a low rain accumulation:
7) for the same intensity generated by calibration bench, the second device provides a larger difference of relative error (errors from -20% to +33%) than the first (errors from –2% to 4%).
8) with a resolution of 01.mm, relative error on intensity recorded by conductivity system is identical to tipping buckets
9) High intensities recorded by this device are very close to reference intensity, with a low relative error.

Tests in the field on these same rain gauges in 2005-2006 will be a very interesting additional information

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