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Analysis of the calibration history of the standards of a pluviometry laboratory

Márcio A. A. Santana[1], **Luiz F. M. Ferreira**[2]

[1] Environmental Metrology, INPE, Cachoeira Paulista, 12630-000, Brazil
[2] Faculty of Mechanical Engineering, Unisal, Lorena, 12600-100, Brazil

Corresponding author's e-mail: marcio.santana@inpe.br

Abstract. The critical analysis of the calibration history of the working standards of a laboratory is an important tool to verify or meet the metrological requirements, evaluate the technical characteristics of the instruments over time and guarantee the calibration results. In this article, the history over more than 10 years is presented through tables and control graphs for 8 working standards of a pluviometry laboratory of a Research Institute. With the results of the analysis, it is possible to evaluate if the standards are adequate for the application, i.e., for the calibration of rain gauges by the gravimetric method.

Resumo. A análise crítica do histórico de calibração dos padrões de trabalho de um laboratório é uma ferramenta importante para verificar o atendimento aos requisitos metrológicos, avaliar as características técnicas dos instrumentos ao longo do tempo e garantir os resultados da calibração. Neste artigo, o histórico com mais de 10 anos é apresentado através de tabelas e gráficos de controle para 8 padrões de trabalho de um laboratório de pluviometria de um Instituto de Pesquisa. Com os resultados da análise é possível avaliar se os padrões são adequados para a aplicação, ou seja, para a calibração de pluviômetros pelo método gravimétrico.

Keywords: Calibration history, working standard, pluviometry, rain gauge, environmental metrology

1. Introduction

The critical analysis of the calibration history of the standards of a pluviometry laboratory allows verifying compliance with the metrological technical requirements, identifying systematic errors and uncertainties of the measurement systems, validating the periodicity of calibration of the standards and guaranteeing the quality and reliability of the results of rain gauge calibrations [1].

A standard calibration history is a documented record of calibrations performed on reference and working standards over time [2]. Normally, control charts or tables are used to demonstrate a summary of the calibration history [3].

This work presents an analysis of the history of more than 10 years of the calibrations of the 8 working standards of a pluviometry laboratory of an Institute that carries out research with several environmental monitoring systems, including applied research in the area of metrology focused on meteorological instrumentation. From the measurement function of the calibration of rain gauges by the gravimetric method for amount of rain in mm and intensity of rain in mm/h, it is possible to verify the contribution of the calibration results of the working standards over time.

2. Rain gauge calibration

Figure 1 illustrates the setup of the TBRG (Tipping Bucket Rain Gauge) calibration by the gravimetric method or output method. The rain gauge emits a pulse with each specific amount of rain, which is equivalent to the volume of water in each compartment of the bascule [4]. In the case of calibration, rainfall is simulated by a peristaltic pump and the data acquisition system (datalogger) records the pulses, as well as measurements of water mass, water temperature, air temperature, air relative humidity and atmospheric pressure [5].

Figure 1 – Setup of calibration of rain gauge

Equation (1) of the calibration of Rain Gauge by the gravimetric method shows that the amount of rain ***Q*** is obtained through the ratio of the volume of rain over the area of rain catchment. The volume is obtained by weighting the water ***W*** on the difference in the densities of water δ_{water} and air δ_{air} by measuring water temperature t_{water}, air temperature t_{air}, atmospheric pressure ***P*** and relative humidity of air ***Hr***. The diameter ***d*** is used to calculate the area. The rain intensity ***RI*** is expressed by equation (2), where ***t*** is the time interval between the tips, recorded by a data acquisition system or datalogger.

$$Q = \frac{\frac{W}{\delta_{water}(t_{water}) - \delta_{air}\left(t_{air,P,Hr}\right)}}{\pi.\left(\frac{d}{2}\right)^2} \tag{1}$$

$$RI = \frac{Q}{t} \tag{2}$$

2.1. History of calibrations of working standards

The Calibration Certificates of the working standards (barometer, caliper, datalogger, hygrometer, standard mass, thermometer - air, thermometer - water and weighing scale) of the Pluviometry laboratory of the Environmental Metrology area of COMIT/CGIP of INPE – National Institute of Space Research - Brazil, during the period from 2010 to 2022 were analyzed. Although the validities of the calibrations are 5 years for the standard weight and 2 years for the others, the standards were calibrated according to the work demand of the various laboratories (pressure, rain, relative humidity, soil moisture, solar radiation, temperature, wind, etc.) of the area of Environmental Metrology. In other words, the demand for calibrations depended on the experiments carried out in the Institute's various research projects, and not all projects had the rain variable under study, so there was no regularity in the calibrations of the rainfall laboratory standards and, consequently, of the rain gauges. The time intervals between calibrations (periodicity) were initially defined according to manufacturers' specifications and World Meteorological Organization – WMO guidelines [6].

Working standards are traceable to the SI, as illustrated in Figure 2. The standards were calibrated at the National Institute of Metrology of Brazil (Inmetro) or in accredited laboratories of Brazilian Calibration Network - RBC. The acceptance criteria (decision rule) of the calibration results of the caliper, weighing and datalogger are based (compared) on the manufacturers' specifications.

In the calibration of rain gauges the largest contributions of type B uncertainty [7] related only to the calibrations of the standards are presented in the following order: 1. digital weighing (until > 50% for small amounts of rain), 2. thermometer – water (< 5 %), 3. thermometer – air, air relative humidity and atmospheric pressure (< 3 %), 4. caliper – dimensional (< 1 %) [8].

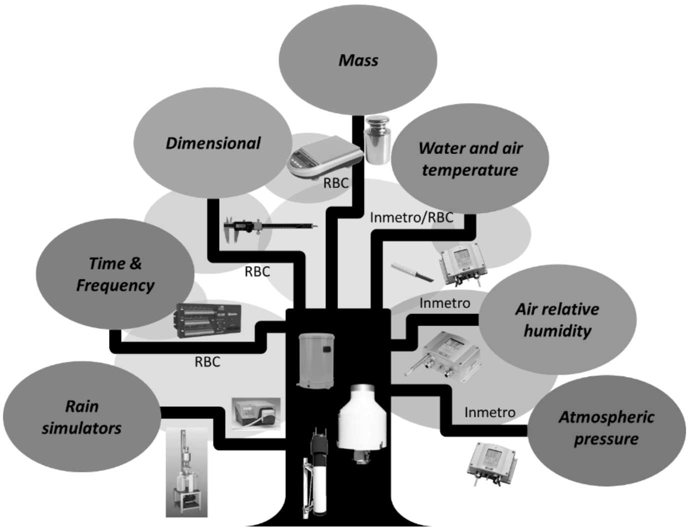

Figure 2 – Traceability diagram of the Pluviometry laboratory

The standard weight Quanto Brasil of 1 kg, class M1, serial number 08112 is used for the verification of the weighing scale and the peristaltic pump before and after the realization of a rain gauge calibration. This standard weight was calibrated by Padrão Balanças (2012) and Presertec (2019). The greatest correction was 0,014 g and the greatest uncertainty was 0,0015 g (k=1).

Figure 3 shows a summary of the calibration history of the Digimed digital weighing scale, model DG-15W, serial number 10LB45. The digital weighing scale is calibrated on site, i.e. at the place of operation. The history covers the period from 2010 to 2022. In this period the standard was calibrated 6 times and by 3 different laboratories (Digimed in December 2010, April 2011, November 2012 and April 2015, Brancotec in April 2019 and INPE – Mechanical Metrology in June 2022). The selection of the laboratory providing calibration service depends on the Calibration and Measurement Capability CMC [9], the costs involved and the availability of the laboratory. Calibration was performed at 6 nominal points in 2010 and 2011. In 2012 and 2015 calibration was performed at 10 nominal points, in 2019 at 6 points and in 2022 at 9 points. The standard was not calibrated in 2021 due to the COVID-19 pandemic. The graphic illustrates the correction and uncertainty values (coverage factor k = 1) [7] for the values of 10 g, 100 g and 1000 g and the acceptance criteria before calibration results stipulated as +/- 0,22 g. The uncertainties remained the same in this period and the largest correction and drift was 0,12 mm.

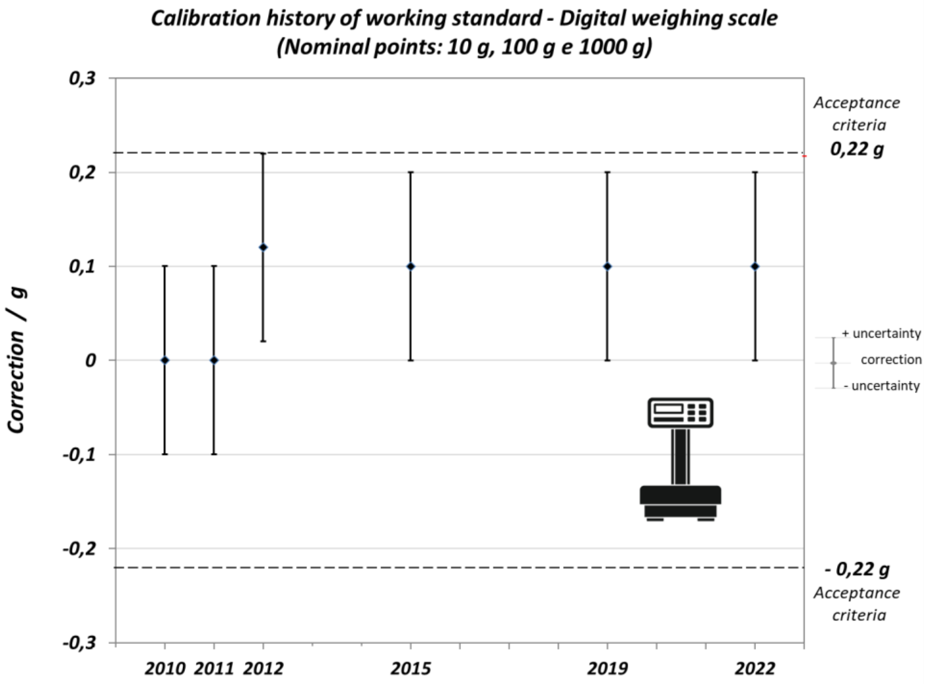

Figure 3 – History of the calibration of the digital weighing scale

Table 1 – History of calibration of thermometers, hygrometer and barometer

	Calibration range: 15 °C to 30 °C				*Calibration range: 10 °C to 35 °C*			
	Air Temperature / °C				*Water Temperature / °C*			
	correction min	correction max	U min	U max	correction min	correction max	U min	U max
2010	0,26	0,57	0,25	0,32	0,26	0,65	0,24	0,32
2011	0,04	0,11	0,29	0,31	0,00	0,32	0,07	0,07
2013	-0,04	0,12	0,24	0,33	0,10	0,29	0,22	0,40
2015	0,22	0,22	0,06	0,06	0,18	0,21	0,10	0,13
2017	0,51	0,80	0,12	0,97	0,31	0,82	0,12	0,27
2022	0,32	0,33	0,06	0,06	0,32	0,49	0,06	0,06
	Acceptance criteria: 3 °C				Acceptance criteria: 3 °C			

	Calibration range: 900 hPa to 1000 hPa				*Calibration range: 40 % r.h to 70 % r.h.*			
	Atmospheric Pressure / hPa				*Air Relative Humidity / % r.h.*			
	correction min	correction max	U min	U max	correction min	correction max	U min	U max
2010	0,09	0,10	0,060	0,070	-2,20	-0,80	2,00	2,50
2011	0,08	0,10	0,024	0,027	-2,50	0,70	1,80	2,10
2013	0,10	0,15	0,024	0,025	-1,90	-0,40	2,00	2,10
2015	0,19	0,23	0,04	0,05	0,50	0,69	0,33	0,33
2017	-0,26	-0,21	0,21	0,21	-0,70	-0,50	1,80	2,10
2022	0,10	0,20	1,30	1,50	-0,70	-0,50	1,80	2,10
	Acceptance criteria: 5 hPa				Acceptance criteria: 10 % r.h.			

Table 1 shows a summary of the calibration history of the working standards that are used during calibration for the estimation of water and air densities. In the laboratory, Campbell thermometers, models 107 and 108 L, Rotronic thermohygrometers, model S, serial number 53344121, Vaisala barometer, model PT220TS, serial number A120002 and Vaisala barothermohygrometers, models PTU303 and PTU307, serial numbers F0520001, F2910028, F2910067 and F2910080 were used. The history shows the correction and uncertainty ranges (k=2,00) [7] of the instruments used for the rain gauge calibrations. In the case of water temperature, the Campbell thermometer is set calibrated with the Campbell datalogger, model CR1000, serial number 13219. One of the Vaisala thermometers is also used for measuring water temperature. The acceptance criterias ACs were stipulated based on the application of these standards, that is, to estimate water and air densities. The estimates of the densities remain the same for the calibration ranges of the working standards, but the ranges used for the calibration of the rain gauges are narrower, T_{air}=[20;26] °C, T_{water}=[19;27] °C, P=[940;960] hPa and Hr=[40;60]% r.h. According to the history, the largest contributions of uncertainty (k=1) were: - $uc(_{Tair})$=0,95 °C; $uc(_{Twater})$= 0,61 °C; $uc(_{P})$=0,87 hPa and $uc(_{Hr})$= 1,45 % r.h. The evaluation of the combined uncertainties uc of the calibration results of the standards was based on the highest correction (considering rectangular probability density function PDF) and the highest expanded uncertainty of measurement U (normal PDF and for probability of coverage of 95,45 %) [7]. These working standards were calibrated in Inmetro (Lahig, Lapre and Later) and in the laboratories of Environmental Metrology and Physical Metrology of INPE.

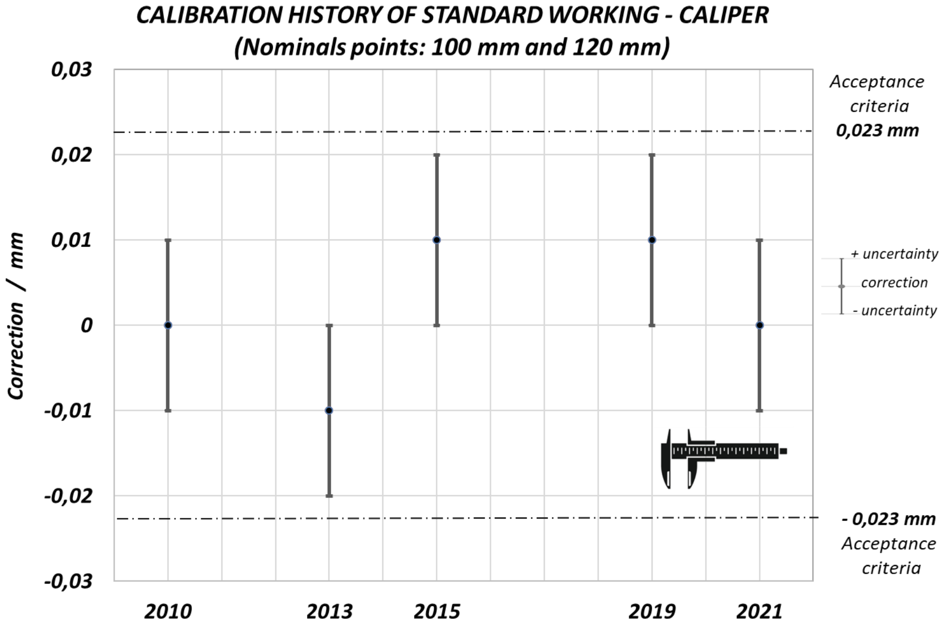

Figure 4 – Calibration history of the standard caliper used to measure the diameter of the rain catchment area of the TBRG

In the graph of Figure 4 is presenting a summary of the calibration history of the Digimess caliper, model 100.178 BL, serial number 140409 used as a working standard in the laboratory at the nominal points 100 mm and 120 mm, but the calibration was performed at 5 nominal points in the first two years, at 6 points in 2015 and 2019 and 3 points at the last calibration. In this history the correction was in the range of -0,01 mm to + 0,01 mm and the uncertainty of 0,1 mm (k=1). In this period the instrument was calibrated 5 times and by 3 different laboratories (Instemac in December 2010 and February 2013, Presertec in April 2015 and May 2019 and INPE in January 2021). The selection of the laboratory providing calibration service depends on the CMC, the costs involved and the availability of the laboratory. Figure 5 shows the air temperature ranges during caliper calibration.

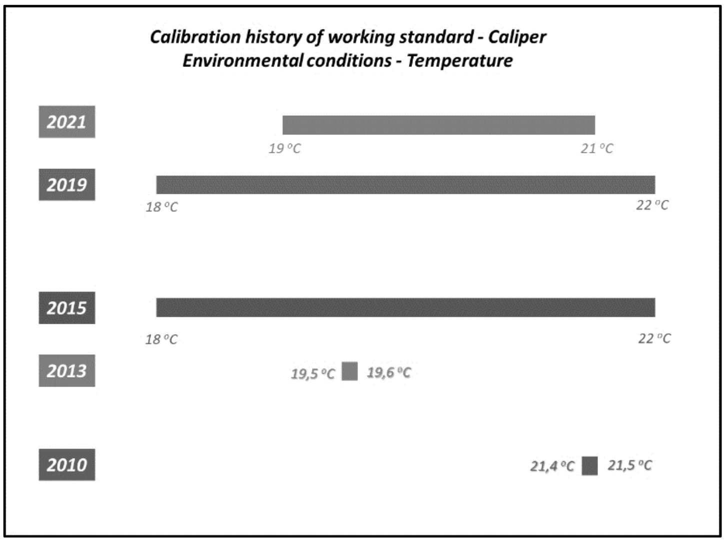

Figure 5 – Environmental conditions during the calibrations of the standard caliper.

It is used as a data acquisition system in the calibration of RGs, Campbell dataloggers, model CR1000, serial numbers 13219 and 32919. Table 2 shows the uncertainties *U* (pdf normal, coverage probability of 95,45%; coverage factor k=2,00) of the results of the calibration of frequency and electrical voltage in direct current for the nominal values of 1 Hz and 1V, respectively. The dataloggers were calibrated at INPE's Electrical and Time & Frequency Metrology laboratories, accredited by RBC. The frequency values are only used in the cases of calibration of rain intensity *RI* and the values of electrical voltage when the thermometers are calibrated separately from the datalogger. Most calibrations of TBRGs are performed only in amount of rain *Q*.

Table 2 – Summary of history of calibration of datalogger (frequencymeter and voltmeter)

Year	***Conventional value /V***	***Indicated value /V***	***Correction /V***	***U /V***	***k -***
2010	1,000000	0,999000	-0,001000	0,000010	2,00
2013	1,000000	1,000022	0,000022	0,000010	2,00
2016	1,000000	1,000041	0,000041	0,000010	2,00
2022	1,0000000	1,0001847	0,000185	0,0000098	2,00
Acceptance criteria = 0,0026 V (k=1,00)					
Year	***Conventional value /Hz***	***Indicated value /Hz***	***Correction /Hz***	***U / %***	***k -***
2010	50,000000	50,000000	0	0,000012	2,00
2013	50,000000	50,000000	0	0,000012	2,00
2016	50,00	50,00	0	0,12	2,00
2022	50,000	50,000	0	0,058	2,00
Acceptance criteria = 0,0063 % of indicated value (k=1,00)					

3. Conclusions

Considering the analysis of the history of calibrations of working standards of the pluviometry laboratory, it is concluded that:

- Even though the calibration interval was not periodic, the laboratory complied with all the requests and performed the calibrations of the rain gauges respecting the validity of the calibrations of the standards.

- Other calibrations of the standard weight should be performed to obtain a better evaluation of this standard, and if necessary, include as a contribution of uncertainty in the calibration of rain gauges.

- The results of the calibrations of the digital weighing were stable over time, even if performed by 3 different laboratories. As it is the largest contribution of type B uncertainty in the calibration of rain gauges, it is interesting to perform an experiment with a balance of higher accuracy class for a possible substitution.

- The results of the calibrations (corrections and uncertainties) of the thermometers, hygrometer and barometer presented in this history and used in the estimates of water and air densities did not imply an increase in the combined uncertainty in the calibration of the rain gauges.

- The results of the caliper calibrations showed stable, that is, within the technical specifications of the manufacturer, even being performed by three laboratories with different temperature ranges during calibration.

- The calibration results of the dataloggers were shown to be different over time for dataloggers with different serial numbers.

- Excluding the standard weight and the datalogger, the time intervals between calibrations, even if not periodic, did not contribute significantly to the calibration results.

The result of the historical analysis of the calibrations shows that the working standards are suitable for the application over time, i.e., for the calibration of rain gauges by the gravimetric method.

The analysis of the calibration history of working standards has become an important tool for the pluviometry laboratory to stipulate its CMC and ensure the quality and reliability of the results of the calibrations of the rain gauges. The CMC for tipping rain gauges using the gravimetric method for the range from 15 mm.h^{-1} to 180 mm^{-1} is 1% of the measurement (amount rainfall) for a coverage probability of 95,45%, t distribution and coverage factor k=2,00 and is in accordance with WMO recommendations.

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