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Hydrometry — Measurement of the rainfall intensity (liquid precipitation): requirements, calibration methods and field measurements

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National foreword

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Mesurage de l'intensité pluviométrique (précipitations liquides) : exigences, méthodes d'étalonnage et mesures de terrain

Hydrometrie - Messung der Regenintensität (flüssiger Niederschlag): Anforderungen, Kalibrierverfahren und Feldmessungen

This Technical Report was approved by CEN on 27 November 2012. It has been drawn up by the Technical Committee CEN/TC 318.

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Foreword

This document (CEN/TR 16469:2013) has been prepared by Technical Committee CEN/TC 318 “Hydrometry”, the secretariat of which is held by BSI.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

The Executive Council of the WMO, noting the working arrangements between the ISO and WMO formally adopted on 16 September 2008, recognised the wide ranging benefits to National Meteorological and Hydrological Services and user communities resulting from the implementation of common Standards relevant for meteorology and hydrology and the need to established the benefit/cost implication to WMO Members of elevating an existing Technical Regulation/Manual/Guide to a common Standard. The EC finally approved procedures to be followed in proposing common technical standards (Resolution 8, Abridged Final Report of the sixty-first session of the WMO Executive Council).

This document is not a European Standard but a Technical Report. It is a document to describe recent findings in rainfall intensity (RI) measurements and related accuracy aspects, following the results and outcomes of the most recent international RI gauges intercomparison organised by the World Meteorological Organisation (WMO). The Technical Report also provides informative documentation (in annexes) containing methods for laboratory calibrations, field tests and reference field measurements.

In consideration of the requirement for general standardization and homogeneity of precipitation intensity measurements and the need for instruments development to promote worldwide instrument compatibility and interoperability, the WMO Lead Centre on Precipitation Intensity “B. Castelli” (Italy) has been designated by the WMO Commission of Instruments and Methods of Observation (CIMO General Summary of the fifteen Session, Helsinki, Finland, 2 - 8 September 2011). The Lead Centre is intended as a Centre of Excellence for instrument development and testing which would be established with the purpose of providing the scientific community with specific guidance and standard procedures about instrument calibration and their achievable uncertainty, performing laboratory and field tests and the intercomparison of instruments, and providing research advances and technical developments about the measurement of precipitation intensity and the related data analysis and interpretation.

Introduction

The need for, and the importance of accurate and reliable rainfall intensity (RI) measurements is ever increasing. This is the result of a number of factors, including the increased recognition of scientific and practical issues related to the assessment of possible climatic trends, the mitigation of natural disasters (e.g. storms and floods), the slowing down of desertification and the design of structures (buildings, construction works) and infrastructure (drainage). This has resulted in more rigorous and enhanced quality requirements for RI measurements.

The volume of rainfall received by a collector through an orifice of known surface area in a given period of time has traditionally been adopted as the reference variable, namely the rainfall depth. Under the restrictive hypothesis that rainfall is constant over the accumulation period, a derived variable, “the rainfall rate, or intensity (RI)”, can be calculated. The estimated RI should get closer to the actual flow of water ultimately reaching the ground as the recording time interval decreases. In view of the very high variability of RI, field measurements at short time scales (e.g. 1 min) are crucial to enable high quality measurement be taken to mitigate the impact of severe events and save lives, property and infrastructures. As the probability of heavy rainfall events is small, long-term records of RI are required to estimate the frequency of occurrence of very intense rainfall at a given location and time.

On completion of the most recent RI gauges intercomparison organised by the World Meteorological Organisation (WMO), it has been recommended that RI measurements should be covered by International Standards. These standards should be based on the knowledge obtained from those latest WMO intercomparison and other current research and good practice. The adoption of such an approach will assist rainfall data collection practitioners to obtain homogeneous and compatible data sets. The procedure adopted for performing calibration tests in the laboratory should become a standard method to be used for assessing the instruments’ performance. Acceptance tests could be based on the adopted laboratory procedures and standards. A classification of instrument performance should also be developed to help users in selecting the most appropriate instrument for their applications.

1 Scope

This Technical Report describes a method for calibrating rainfall intensity (RI) gauges and the measurement requirements to obtain accurate and compatible data sets from hydro-meteorological networks, as a forerunner to the development of full hydro-meteorological data collection standards.

This Technical Report deals exclusively with catching-type RI gauges (see Clause 3). It concentrates on the generic calibration, performance checking and estimation of uncertainties for RI gauges. It does not cover specific gauge measurement principles, technical characteristics and technology adopted in the design of RI gauges

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13798, *Hydrometry – Specification for a reference raingauge pit*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
catching raingauge
a raingauge which collects precipitation through an orifice, often a funnel, of well-defined size and measure its water equivalent, volume, mass or weight that has been accumulated in a certain amount of time

Note 1 to entry: This type of gauge includes storage, level monitoring, tipping bucket and weighing raingauges. This is the most common type of recording raingauge in use in operational networks at the time of preparing this Technical Report.

3.2
delay time of the output of a RI measuring gauge
delay of the output message of some RI measuring raingauges

Note 1 to entry: The internal calculation of the rainfall intensity in some raingauges can cause a delay of the output data message (e.g. 1 minute) which can easily be shifted automatically to the correct time without any degradation in measurement accuracy. This is typical of software corrected tipping bucket raingauges through embedded electronic chips or interfaces. The delay time should not be confused with the time constant. If real-time output is not needed, software induced delay times are less critical than longer time constants or any other effects, because delay times can easily be corrected to retrieve the original RI information.

[SOURCE: Adapted from WMO – IOM 2009]

3.3
measurand
quantity intended to be measured

[SOURCE: VIM:2008]

3.4
measurement uncertainty
non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

[SOURCE: VIM:2008]

Note 1 to entry: The parameter may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

Note 2 to entry: Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterised by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterised by standard deviations, evaluated from probability density functions based on experience or other information:

a) Instrumental measurement uncertainty (VIM 2008): component of measurement uncertainty arising from a measuring instrument or measuring system in use.

   Instrumental measurement uncertainty is obtained through calibration of a measuring instrument or measuring system, except for a primary measurement standard for which other means are used.

   Instrumental uncertainty is used in a Type B evaluation of measurement uncertainty.

   Information relevant to instrumental measurement uncertainty may be given in the instrument specifications.

b) Achievable measurement uncertainty (WMO no. 8, Part I Annex 1.B): it is intended as the measurement uncertainty achievable in field and/or operational conditions.

3.5
non-catching raingauge
raingauge where the rain is not collected in a container/vessel

Note 1 to entry: The rainfall intensity or amount is either determined by a contact-less measurement using optical or radar techniques or by an impact measurement. This type of gauge includes optical disdrometers, impact disdrometers, microwave radar disdrometers, optical/capacitive sensors.

3.6
resolution
smallest change in a quantity being measured that causes a perceptible change in the corresponding indication

[SOURCE: VIM:2008]

3.7
step function / heaviside function or unit step function
an input signal that switches on at a specified time and stays switched on indefinitely for determining the response (output) of a dynamic instrument system

3.8
step response
the time-varying response of an instrument system to a step function (heaviside function)

3.9
step response time
duration between the instant when an input quantity value of a measuring instrument or measuring system is subjected to an abrupt change between two specified constant quantity values and the instant when a corresponding indication settles within specified limits around its final steady value

[SOURCE: VIM:2008]

3.10
time constant
risetime characterizing the response of a instrument classified as a system of first order response (the way the system responds is approximated by a first order differential equation)

Note 1 to entry: It represents the time that the step response of an instrument system takes to reach the (1-1/e)•100[%] ≈ 63 % of the final or asymptotic value.

4 Standardization of RI raingauge calibration and field requirements

An RI international intercomparison organised by the WMO was conducted in a laboratory and in the field. The results have been published as IOM series (Instruments and Observing Methods), respectively the IOM 84 (RI laboratory intercomparison, 2004-2005) and IOM99 (RI Field intercomparison, 2007-2009). This concluded that a standardization of RI measurements is recommended, in terms of uncertainty evaluation for laboratory calibration and field measurements in order to improve the measurement accuracy of meteorological network instruments. This should be based on the achievable RI measurement performance (accuracy) rather than on the involved measuring principle or gauge design/technical solutions.

The following activities are recommended.

a) The WMO procedure, or similar, adopted for performing calibration tests in the laboratory should become a standard method to be used for assessing the instruments' performance.

b) A classification of instrument performance should be developed, possibly based on the results of laboratory tests and on user application requirements.

c) Field calibration procedures used, or similar to those, for the WMO field intercomparison of the catching type gauges should be adopted as a standard procedure for operational assessment of instrument's performance in the field.

d) Necessary steps should also be made towards common WMO – international standard(s).

5 Accuracy of rainfall intensity

5.1 Fundamentals and requirements

The performance of a raingauge should be assessed according to its accuracy in a given measurement range, in order to select the optimal raingauge for the required application. The accuracy of the RI instruments should be evaluated according to:

a) the measurement uncertainty in stationary conditions (laboratory calibration);

b) the step response to a step function/heaviside function (see Clause 3);

c) the achievable measurement uncertainty in dynamic/real conditions (field measurements).

The measurement uncertainty is obtained by means of calibration in a certificated laboratory under a constant flow regime (reference rainfall intensity). Water can be 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 rainfall intensity measured by the instrument itself. The relative percentage difference between each measured and actual "rainfall intensity" figure is assumed as the relative percentage error (e_{rel}) of the instrument for the given reference flow rate. Within the RI output or averaging time (e.g. 1 min), the relative percentage error e_{rel} can be expressed as follows:

$$e_{\text{rel}} = \frac{I_{\text{mis}} - I_{\text{ref}}}{I_{\text{ref}}} \cdot 100$$

where

I_{mis} is the rainfall intensity measured by the instrument;

I_{ref} is the rainfall intensity produced by the reference constant flow.

By performing (or repeating) the test for a certain amount of time (minimum 30 min, 30 samples), it is possible to determinate the mean relative error for each level of reference rainfall intensity. The uncertainty can be finally determined in terms of expanded uncertainty calculated by the standard deviation of the relative error (estimated by the sample standard deviation, type A measurement uncertainty).

The step response (see Clause 3) is characterised by the determination of the raingauge time constant (if it can be treated as a first-order response instrument) by means of a variable water flow (unsteady conditions) such as a step-function input (see Clause 3). If the rainfall intensity is evaluated or calculated or reported over 1 min intervals, the time constant of the raingauge should be as short as possible compared to 1 min: It indicates the capability of the instrument to better represent the variability of precipitation over reduced time scales. The instrument response should be also negligibly affected by oscillations and/or overshooting and/or noise. A short time constant and lack of oscillations guarantee the best representation of the variability of the natural RI flow. The time constant should not to be confused with the data output delay that can be easily corrected through a time shift to retrieve the original RI information.

The achievable measurement uncertainty is determined in field comparisons of the RI gauges output to a reference RI instrument or a composite RI reference (consisting of more than 1 instrument) operated and maintained according to standards. Such reference systems are or will be established, e.g. at instrument centres that are recognised by WMO (such as a WMO-CIMO Lead Centre).

A more detailed description of the method applied for the evaluation of RI accuracy is provided in the following subclauses.

5.2 Laboratory calibration method (constant flow and step response)

According to Annex 1 included in the Report of the 15th WMO CIMO Session, which recalled the Recommendation no. 2 of the Abridged Report of the 14th WMO CIMO Session (Geneva, 7-14 December 2006), namely WMO No. 1019 Part 1, a standardised procedure has been recommended for use by National Hydro-meteorological data collection organisations for laboratory calibration of operational, catching-type raingauges. In addition to a well designed calibration system, the calibration set-up and procedures should be documented in full detail and staff should be well prepared before starting any calibration activity.

RI raingauges should be calibrated using a calibration system that:

a) has the capability of generating a constant water flow at various flow rates corresponding to the entire operational range of measurement (recommended range: from 0,2 mm/hup to 2 000 mm/hor up to the gauge RI limit; Typical WMO reference flows for calibration: 2, 20, 50, 70, 90, 130, 170, 200, 300, 500, 800, 1 200, 2 000 mm/hor the upper gauge RI limit);

b) is able to measure the reference flow by weighing the amount of water, i.e. the fluid mass generated over a given period of time (measurement of weight and time);

c) is able to measure the output of the calibrated instrument at regular intervals (1 min as minimum) or when a pulse occurs, which is typical for the majority of raingauges with a tipping-bucket measuring principle.

To characterise the performance of an RI gauge the calibration procedure should be able to:

1) synchronise the raingauges and clearing of buffered (or stored) amounts of rain inside the gauge before the start of constant flow;

2) determine the response of the raingauge to the constant reference flow by a graphical or numeric representation of the difference between the measured RI values and the reference RI for the calibration range;

3) determine the response of the raingauge to a reference step input by a graphical or numeric representation for the calibration range (determination of the time constant and overshooting/oscillating behaviour).

Additional, specific calibration tests could also be performed to evaluate the balancing of the bucket element of tipping-bucket raingauges or to evaluate the stability of the weighing element of weighing raingauges in absence of incoming reference flow.

The calibration system should be designed to obtain uncertainties less than 1 % with respect to each generated RI, and such performance should be reported and detailed. The result of any calibration will be a calibration certificate presenting the results of the calibration (including corrections to be applied), allowing a compliance check with the relevant recommendations. This certificate should also contain the measurement uncertainty for RI; it should document the traceability of the RI reference, the environmental conditions (such as temperature, date and time, etc.) and the applied time averaging method to retrieve RI over a defined time base.

Further details of the laboratory calibration method are contained in Annex A.

5.3 Classification of gauges according to accuracy performances

A standard classification of raingauges performance should be developed. This classification should be based on the results of laboratory tests and on user application requirements. The different classes of instruments would help users in selecting the proper instrument for their applications. Different classes may also apply to different ranges of rainfall intensity. In particular, the required accuracy performance of an RI gauge for assigning a specific class should be determined according to the measurement uncertainty in constant flow conditions and to the time constant in step input conditions. Applying specific criteria to accuracy performance results should determine the instruments classification and the consequent user application.

5.4 Field calibration method (calibration verification)

The main purpose of this activity should be to verify the operational status of raingauges, to detect malfunctions, output anomalies and calibration drifts during the operational use. These calibrations also provide valuable insight into data analysis and interpretation. The field calibration should be performed by means of a portable field calibration based on the same principles as laboratory calibration using the generation of constant rainfall intensity within the range of operational use (stationary flow). From the operational viewpoint the portable field calibrator should permit rapid tests and it should not contain any sophisticated components in order to provide a cost effective solution for metrological verification of RI instruments. The repeatability of the field calibrator (and its accuracy) should be assessed in a laboratory before the operational use and its uncertainty (expanded uncertainty) should be suitable for the raingauge to be tested in field.

During the WMO Field Intercomparison of Rainfall Intensity Gauges (Vigna di Valle, Italy, 2007-2009) a dedicated portable calibrator was designed and successfully used for calibration verification. Performances and results are described in the Final Report of the intercomparison (WMO/TD no.1504 IOM no.99) for further information.

Further details of the field calibration method are contained in Annex B.

5.5 Traceability of the RI measurements

In order to effectively develop the homogeneity and standardization of RI measurements on a national and international scale, a system of national and international standards should be adopted. Moreover a specific traceability of RI measurements should be defined in order to related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties. In this context, the WMO-CIMO recommended procedures adopted for both the WMO Laboratory and Field Inter-comparisons of Rainfall Intensity gauges (2004-2005 and 2007-2009) and the designation of a WMO leading centre should be exploited in order to establish the requirements for international (or primary) RI standards and to finally guarantee the international traceability of RI measurements, through periodical calibrations or inter-comparisons of raingauges against measurement standards or travelling standards.

6 Field rainfall intensity measurements

6.1 References gauges and field intercomparisons

In chapter 6 of the WMO no. 8 (CIMO Guide), the WMO established that during any field intercomparison ground-level gauges are used as reference gauges for liquid precipitation measurement. In meteorology a field reference instrument is generally accepted as having a suitably small measurement uncertainty, to be used as a basis for comparison with values of quantities of the same kind (as similarly in metrology for “reference values”, VIM 2008 par. 5.18). Ground-level gauges generally record more precipitation than any elevated gauge due to the absence of wind-induced error. The buried or “sunken” gauge is expected to show a higher rainfall reading than an above the ground gauge. When both types of instrument are performing well and accurately, above-ground gauges can underestimate the ground-level gauge amounts by 10 % or greater (Koschmieder, 1934). The ground-level gauge should be placed in a pit (for further details see EN 13798).

In WMO recognised centres for RI (such as WMO-CIMO Lead Centre, see Final Report of the WMO – CIMO 15th Session, Helsinki, Finland, 2-8 September 2010) or during international intercomparisons, ground-level gauges should be used as reference gauges. Moreover a set of reference gauges should be preferred instead of a single reference instrument. Any other raingauge can be compared with the working reference group and its achievable accuracy can be assessed.

6.2 Relevant operational requirements for field RI measurements

Heavy rainfall is generally the origin of flash floods. In view of the very high variability of the rainfall intensity, 1 min rainfall intensity measurements could be crucial to enable proper measures be taken to mitigate the impact of such events and save lives, property and infrastructure. As extreme rainfall events are rare, large long-term records of rainfall intensity data are needed to estimate the probability of occurrence of heavy rainfall at a given location and time. One minute rainfall intensity measurements should be carried out in critical areas to allow proper action for disaster risk reduction. Such measurements would also be used for better design of structures (building, construction works) and infrastructure (drainage) to mitigate severe weather impact.

Following the outcomes of the WMO Field Intercomparison of Rainfall Intensity Gauges (2007-2009) and the recent recommendations of the WMO Commission of Instruments and Methods of Observation (Annex I and II of the CIMO Fifteenth Session Report, Helsinki, Finland, 2-8 September 2010) the specific recommendations below can be provided. Terminology and related concepts are also consistent with the WMO no. 8 (CIMO Guide, ed. 2008) Part I chap.6 – Part III chap. 2-3-4, with GUM 1995 and VIM 2008.

RI over 1 min should only be measured in a station and used for further analysis if all 1 min data are transmitted and used (1 min RI intensity should not be used in a temporal sampling scheme, i.e. one synoptic measurement every hour or 3 hours as a single 1 min RI value is not representative of a longer period of time) and a very good time synchronisation, better than 10 s, is achieved, both between the reference time and the different instruments of the observing station.

To develop and improve rainfall intensity measurement the following should be undertaken:

a) The minimum list of technical parameters provided below should be included in the user manual of each instrument and sufficient advice on the best choice of output values should be provided to use for different applications (see Clause 3):

— measurement range;

— delay time;

— linearity;

— instrumental measurement uncertainty, for the whole measurement range;

— resolution;

— step response time;

— threshold;

— time constant for those instruments classified first-order response instruments;

— internal calculation cycles (if any) and data reporting interval.

b) Tipping bucket raingauges should be corrected to compensate for underestimation of high RI. Software correction methods that take into account the timestamp of each tip provide the best results.

c) For all catching-type gauges a time response measurement of RI less than 1 min should be achieved (short time constant, see 5.1).

d) The calculation of rainfall intensity and the total accumulation should be separated and both values reported.

e) The use of algorithms that increase the time constant should be avoided.

f) Quality information should be provided in the output data provided by the raingauges.

g) The design of instruments should be improved to reduce the uncertainty of 1 min rain intensity measurements at low rainfall intensities (especially below 20 mm/h).

For operational measurement requirements, achievable measurement uncertainties (WMO no. 8, Part 1 Annex 1.B) for RI should be:

— Under constant flow conditions in laboratory: (a) 5 % above 2 mm/h; (b) 2 % above 10 mm/h;

— In field conditions: (a) 5 mm/h; (b) 5 % above 100 mm/h.

6.3 General requirements for siting and exposure (as indicated by WMO-No. 8, 7th edition)

Reference gauges for liquid precipitation (and rainfall intensity) are installed at the ground level to reduce the wind-induced error to a negligible level. Such gauges are placed in a pit with the gauge rim at ground level, sufficiently distant from the nearest edge of the pit to avoid in-splashing. A strong plastic or metal anti-splash grid with a central opening for the gauge should span the pit. EN 13798 provides detailed specifications.

The location of precipitation stations within the area of interest is important, because the number and locations of the gauge sites determine how well the measurements represent the actual amount of precipitation falling in the area.

The effects on the wind field of the immediate surroundings of the site can give rise to local excesses and deficiencies in precipitation. In general, objects should not be closer to the gauge than a distance of twice their height above the gauge orifice. For each site, the average vertical angle of obstacles should be estimated, and a site plan should be made. Sites on a slope or the roof of a building should be avoided. Sites selected for measuring snowfall and/or snow cover should be in areas sheltered as much as possible from the wind.

The best sites are often found in clearings within forests or orchards, among trees, in scrub or shrub forests, or where other objects act as an effective wind-break for winds from all directions. Preferably, however, the effects of the wind, and of the site on the wind, can be reduced by using a ground-level gauge for liquid precipitation or by making the air-flow horizontal above the gauge orifice using the following techniques (listed in order of decreasing effectiveness):

- in areas with homogeneous dense vegetation; the height of such vegetation should be kept at the same level as the gauge orifice by regular clipping;

- in other areas, by simulating the effect in (a) through the use of appropriate fence structures;

- by using windshields around the gauge.

The surface surrounding the precipitation gauge can be covered with short grass, gravel or shingle, but hard, flat surfaces, such as concrete, should be avoided to prevent excessive in-splashing.

6.4 International field intercomparisons: role and outcomes

According to the WMO no.8 - 7th ed. (2008), intercomparisons of instruments and observing systems, along with agreed quality-control procedures, are essential for the establishment of compatible data sets. All inter-comparisons should be planned and carried out carefully in order to maintain an adequate and uniform quality level of measurements of each meteorological variable. Many meteorological quantities cannot be directly compared with metrological standards and hence to absolute references e.g. precipitation. For such quantities, intercomparisons are of great value and the related outcomes provide guidance for the standardization of procedures and methods, the improvement of measurement accuracy and the technological development.

The Laboratory and Field Intercomparisons of rainfall intensity gauges, both organised by the WMO from 2004 to 2009, actually represent an advanced knowledge about RI measurements and their accuracy to be exploited for the implementation of standards.

Annex A
(informative)

Laboratory tests

A.1 Example of a laboratory device

During the WMO Laboratory and Field Intercomparisons of RI Gauges, the same calibration procedure was used, which is based on the generation of a constant water flow from a suitable hydraulic device (see Figure A.1) within the range of operational use declared by the instrument's manufacturer. 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 "rainfall intensity" measured by the instrument itself. The relative difference between each measured and actual "rainfall intensity" figure is assumed as the relative error of the instrument for the given reference flow rate.

Tests are extended to cover the 1 min resolution instrument behaviour rather than just focusing on the average response under a constant reference flow rate, thus providing better insights into the measurement performance of such instruments. This was also due to the fact that, during the measurements in the field, the 1 min resolution rainfall intensity is considered under real outdoors conditions.

The objective is to perform tests at a minimum of seven reference flow rates, at 2, 20, 50, 90, 130, 170, 200 mm/h. Alternatively, if the higher rainfall intensities are of utmost importance, the whole range of operation declared by the manufacturer may be also investigated.

The reference intensities could be adjusted to the set-point within the following precision limits:

— 1,5 mm/h to 4 mm/h , at 2 mm/h;

— 15 mm/h to 25 mm/h, at 20 mm/h; and

— ± 10 % at higher intensities.

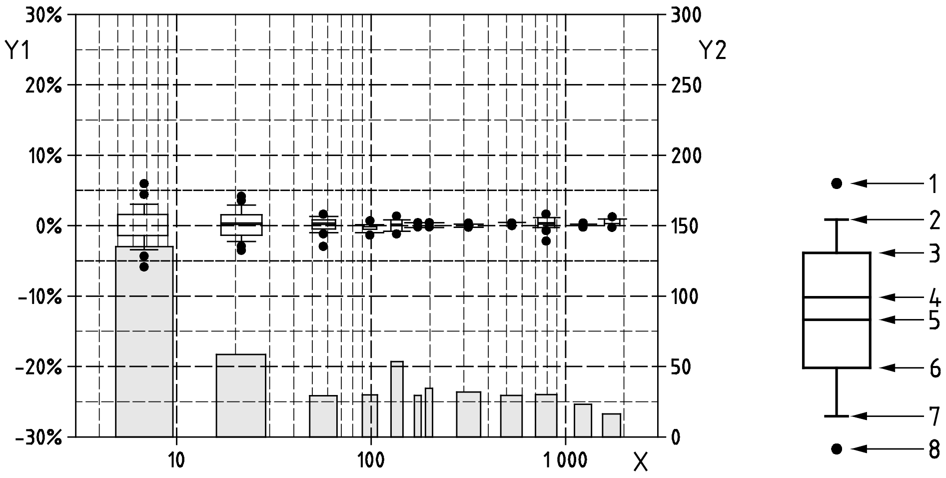
The uncertainty of the laboratory device, expressed as relative expanded uncertainty (95 % confidence level), is 0,45 % of RI flow generated. Tests were performed at 1 min resolution for a variable duration that was tuned to the individual instrument and the reference flow rate used. The average errors were obtained by discarding the minimum and the maximum value obtained for each reference flow rate, then evaluating the arithmetic mean of the remaining errors and reference intensity values. The average values were used to derive the error and correction curves.

Figure A.1 — Qualification module for rainfall intensity measurement instruments developed at the University of Genova, and used in the laboratory calibrations

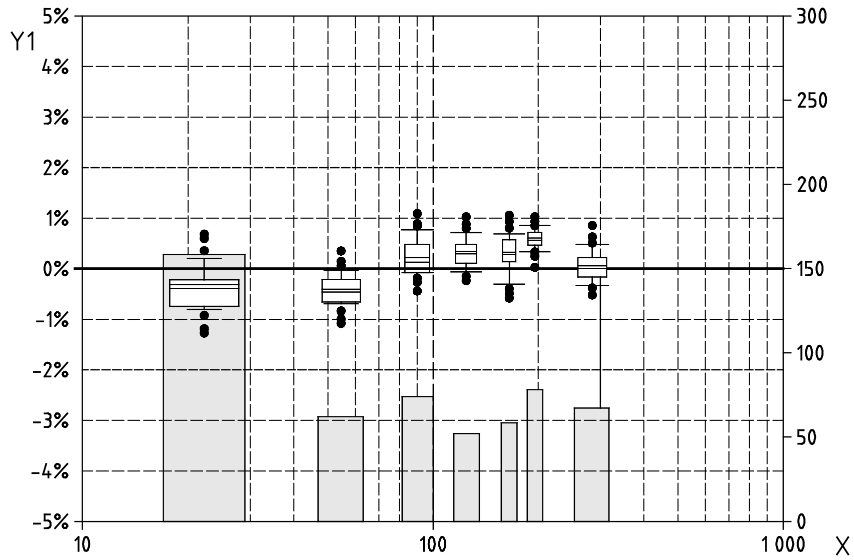
A.2 Example of graphical representation of laboratory tests results

The results of laboratory tests are shown using different graphs. Here two different plots are proposed: the constant flow response plot, where the relative error (e_{rel}) for each single gauge is plotted versus the laboratory reference intensity (I_{ref}) , and the step response plot, where the ratio I_{mis} (measured RI) / I_{ref} (laboratory reference RI) is plotted versus time.

The constant flow response is presented in the form of a superimposed box-plot and vertical bars, respectively reporting the 1 min variability of the observed instruments performances and the size of the sample used for calculation of the statistics at each reference intensity. Box plots synthetically indicate the values obtained for the mean (solid line), median (thin line), 25-75th percentiles (box limits), 10-90th percentiles (whisker caps) and outliers (black circles) per each series of one-minute data obtained during the tests. The shaded vertical bars indicate the sample size according to the scale reported on the right hand side of the graph (see Figure A.2).



(a)



(b)

Key

X I_{ref}

Y1 (left hand side) e_{rel}

Y2 (right hand side) Sample size

1 95th percentile

2 90th percentile

3 75th percentile

4 mean

5 median

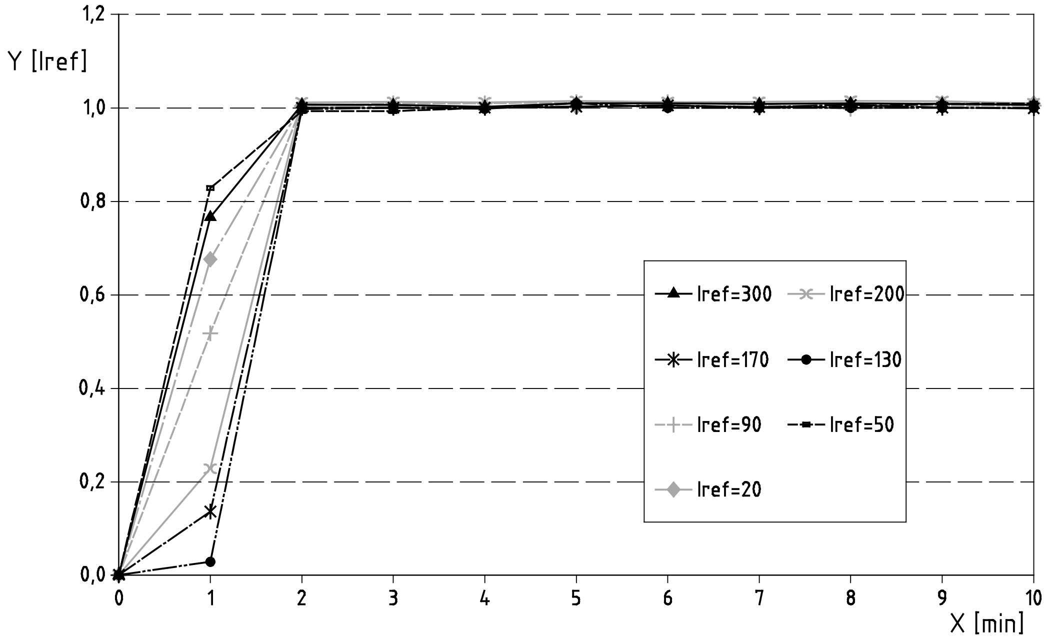
6 25th percentile

7 10th percentile

8 5th percentile

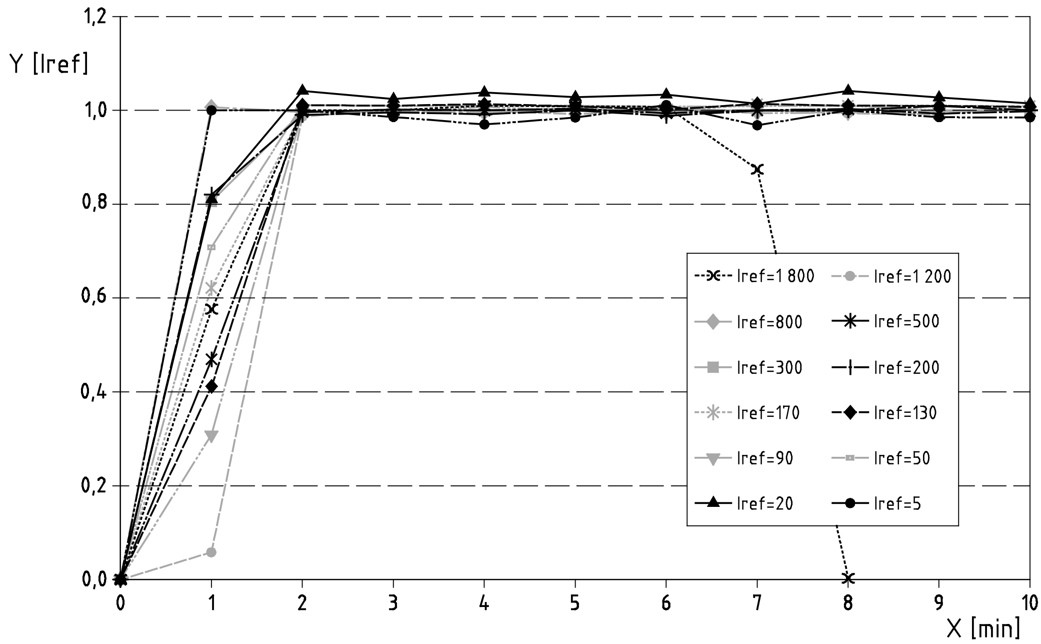
Figure A.2 — Examples of laboratory results displayed in the forms of “box plots”

The step response reflects the dynamic behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graphs below (see Figure A.3). The step response is presented in the form of superimposed and normalised response curves corresponding to different laboratory reference RI values. In the following examples (see Figure A.3), the observed behaviour of the first minute is not reliable, being affected by non synchronisation effects between the internal clock and the laboratory acquisition system, and should be neglected.



Key

X time (min)
Y I_{mis}/I_{ref}
(a) normalised step response



Key

X time (min)
Y I_{mis}/I_{ref}
(b) superimposed response curve

Figure A.3 — Superimposed and normalised response curves

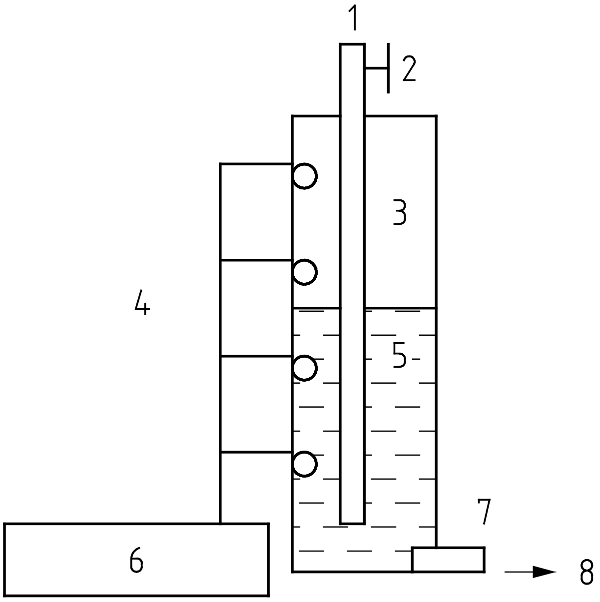
Annex B
(informative)

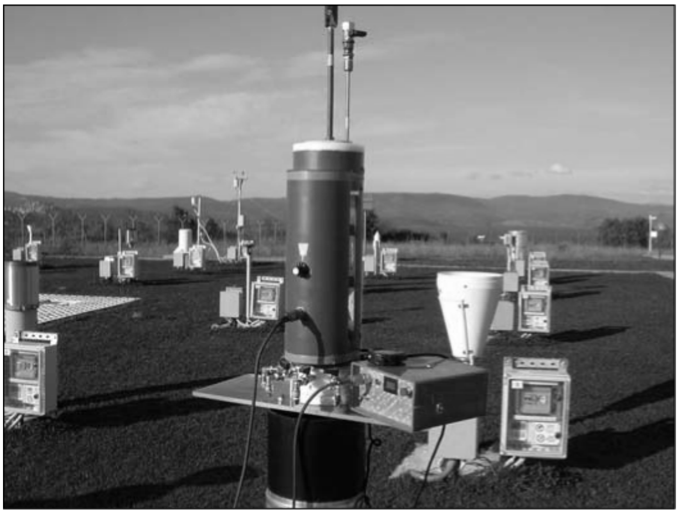
Field measurements

B.1 Example of man-portable device for calibration verifications in field

The field calibration should be part of a quality assurance plan. The main purpose of this activity should be to verify the operational status of raingauges, to detect malfunctions, output anomalies and calibration drifts throughout time. These calibrations provided valuable insight to data analysis and data interpretation. The field calibration is based on the same principles as laboratory calibration using the generation of constant rainfall intensity within the range of operational use (stationary flow).

The Laboratory of the University of Genoa designed a portable field calibrator to perform field calibrations tests of all catching type raingauges. The field calibrator is composed of a cylindrical 6 500 g water tank, a combination of air intakes and output nozzles for different rainfall intensities, and an electronic system to calculate the emptying time (see Figure B.1). According to the raingauge collector size and the value of rainfall intensity chosen for the calibration, the suitable combination of air intakes and nozzles should be selected. By opening the top tap and the bottom nozzle, a constant flow starts to be conveyed to the funnel of the raingauge and, through the time of emptying and a conversion table (volume-time-intensity), it is possible to retrieve the RI produced within the instrument uncertainty reported below. Air intakes provide the pressure compensation, thus keeping a constant push.





Key
1 air intake
2 tap
3 air
4 electrodes for emptying time
5 water
6 electronic timer
7 nozzle
8 I_{ref} (mm/h) = const

(a) Simplified scheme

(b) Field set up during field calibration at Vigna di Valle, Italy

Figure B.1 — Portable field calibrator

From an operational viewpoint the portable field calibrator permits rapid tests due to its very simple operation. The calibrator does not contain any sophisticated components, therefore it provides a cost effective solution for the metrological verification of rainfall intensity instruments.

The repeatability of the field calibrator (and its accuracy) was assessed in a laboratory before the operational use. The uncertainty for each raingauge collector size was expressed as relative expanded uncertainty (U_{rel}) in relation to the statistical coverage interval. The 95 % confidence level (k=2) was used and leaded to the following values:

Raingauges collector size	**1000 cm^2**	**500 cm^2**	**400 cm^2**	**325 cm^2**	**200 cm^2**
$U_{rel}(I_{ref})$ %	**1.0**	**1.5**	**0.4**	**1.8**	**1.8**

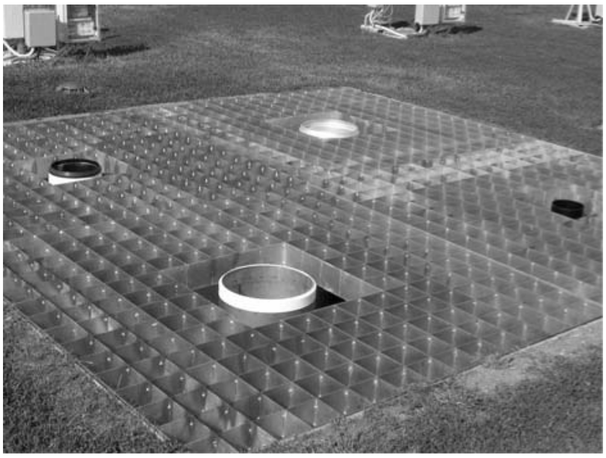
For each field calibration, several test series should be performed to investigate possible reasons of suspect malfunctioning or doubtful data, for at least 25-30 data points of RI All tests should be accomplished in environmental conditions without precipitation or fog and at low wind speeds (to avoid dynamic pressure perturbations to air intake).

B.2 Example of field set-up of a RI measurement reference instrumentation

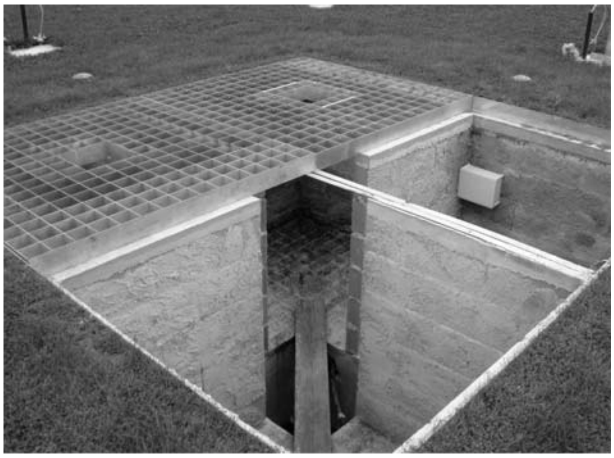
Ground-level gauges, also referred to as "pit gauges", should be used as reference gauges for liquid precipitation measurement (see Figure B.2). The use of one single reference instrument for international intercomparisons or in reference Centres should be avoided, so a set of working reference gauges should be used their combined readings should provide the best possible estimation of reference RI in the field.

The selected references should be installed in pits according to EN 13798, in order to minimise environmental interference on measured rainfall intensities and to protect against in-splash by a metal or plastic grid.

Figure B.2 shows a possible set-up of RI reference instruments.



(a) Details of gratings



(b) Internal walls and pit recesses for drainage

Figure B.2 — Examples of reference raingauge pits

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