WORLD METEOROLOGICAL ORGANIZATION

INSTRUMENTS AND OBSERVING METHODS

REPORT No. 99

WMO FIELD INTERCOMPARISON OF RAINFALL INTENSITY GAUGES

(Vigna di Valle, Italy)

October 2007 – April 2009

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WMO/TD-No. 1504

2009

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FOREWORD

The WMO Field Intercomparison of Rainfall Intensity Gauges was carried out in Vigna di Valle, Italy from October 2007 to April 2009, at the kind invitation of the Italian Meteorological Service. This intercomparison is following up on the Laboratory Intercomparison of Rainfall Intensity Gauges. CIMO-XIV recommended that well-defined and accepted reference instruments and procedures were needed for the field intercomparison. CIMO-XIV agreed that such reference might be based on a set of high quality devices applying different measuring techniques and had adopted a recommendation to that effect.

The main objective of this intercomparison was to intercompare the performance of in situ rainfall intensity instruments of different measuring principles in high rainfall intensity conditions. An International Organizing Committee was set up to determine and agree on the rules of the intercomparison and to support its preparation and execution. The IOC was also tasked to agree on the procedures used for the evaluation of the results and to review and agree on their presentation in the final report of the intercomparison.

This report presents in a detailed manner the procedure that was adopted to determine the reference rainfall intensity, based on the measurements of 3 instruments placed in a pit. It also contains datasheets for each of the participating instruments, which provide exhaustive information on their performances throughout the intercomparison period in the field, as well as under laboratory conditions. The final conclusions of the report highlight the challenges that this type of measurements represents due to the high variability of rainfall intensity at a 1-minute time scale. A number of recommendations were drawn from the results and address topics such as how to make best use of existing instruments, how to improve the design and documentation of the instruments as well as matters like the standardization of rainfall intensity measurements. Consequently, they are relevant to users, manufacturers and the meteorological community as a whole.

I wish to express my since appreciation, and that of CIMO, to the Italian Meteorological Service, for hosting this intercomparison, providing outstanding facilities and for the dedicated and competent support provided by its staff members, in particular to Dr E. Vuerich, the Site Manager, and to Prof. L.E. Lanza, who led the laboratory calibration of the instruments. I should also like to mention and acknowledge the significant work done by all the members of the IOC, in particular the Project Leader, Mr E. Lanzinger, and the IOC Chair, Mr M. Leroy, who provided regular advice and feed-back on the conduction of the intercomparison and its evaluation.

I am confident that WMO Members and other network managers, as well as data users and manufacturers of such instruments will find this report very useful. It will provide a better understanding of their characteristics and potential use and will contribute to improving rainfall intensity measurements that are of crucial importance to mitigate the impact of severe weather events, such as flash floods for example.

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EXECUTIVE SUMMARY

The WMO Field Intercomparison of Rainfall Intensity (RI) Gauges was conducted from 1 October 2007 to 30 April 2009, in the Centre of Meteorological Experimentations (ReSMA) of the Italian Meteorological Service, in Vigna di Valle, Italy. It was organized following the request of users and the recommendation of CIMO-XIV.

Heavy rainfall is generally the origin of flash floods. In view of the very high variability of the rainfall intensity, measurements at a 1-minute time scale are crucial to enable proper measures be taken to mitigate the impact of such events and save lives, property and infrastructures. As the return period of heavy rainfall events is 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. Such measurements would also be used for better design of structures (building, construction works) and infrastructure (drainage) to mitigate severe weather impact.

This intercomparison hosted 25 different rainfall intensity gauges. The majority of these instruments were catching type gauges comprising tipping-bucket gauges, weighing gauges and one water level gauge. Non-catching rain gauges were represented by optical and impact disdrometers, one optical/capacitive gauge and one microwave radar gauge. This intercomparison was unique as to the number of instruments and variability of techniques used.

The main objective of this intercomparison was to intercompare the performance of in-situ rainfall intensity instruments of different measuring principles, with special consideration given to high rainfall intensities. Further objectives were to offer advice on improvements of instruments and precipitation measurements.

Prior to installation in the field all reference gauges and the catching type instruments were calibrated in the WMO recognized laboratory at the University of Genoa. Calibration procedures were based on recommendations of the previous WMO Laboratory Intercomparison of RI Gauges (2004-2005) which were further developed to allow an assessment of the 1-minute measurement uncertainty under constant flow conditions. Additionally all catching gauges were subject to a step response test to assess their dynamic response.

In the field, all gauges were compared with a RI composite working reference consisting of a set of three reference rain gauges in a standard pit.

The results of the intercomparison confirmed the feasibility to measure and compare rainfall intensities on a one minute time scale and provided information on the achievable measurement uncertainties. Due to the very high variability of rainfall intensity, the time synchronization of the instruments is crucial to compare their measurements and to design the measurement systems, as two successive 1-minute rainfall intensity measurements can differ much more than the measurements of two well synchronized instruments.

The uncertainty of the RI composite working reference in the pit was evaluated to be 4.3 mm/h, leading to a relative uncertainty below 5% above 90 mm/h and higher than the 5% measurement uncertainty required by WMO below 90 mm/h.

It is recommended that rainfall intensity measurements be further standardized at an international level and based on knowledge obtained from this intercomparison to allow the users 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 proper instrument for their applications.

The intercomparison results confirmed that uncorrected tipping bucket rain gauges should be corrected. Very good results can be achieved by software correction methods. Catching gauges that do not use a funnel are sensitive to environmental factors, affecting the measurements of some instruments. It was found that proper techniques can be used to reduce the noise in the measurements.

It was found that manufacturers need to improve their documentation, and users should contact manufacturers for additional guidance, as how to best operate their instruments for various applications.

The Intercomparison high quality data set (1-min rainfall intensity data) constitutes an important scientific resource that should be further exploited beyond the objectives of the present data analysis.

It is also recommended that the developed expertise and the infrastructure of the sites, both the field and the laboratory facilities, be further exploited within WMO.

CHAPTER 1

BACKGROUND

The attention paid to accuracy and reliability in rainfall measurements is currently increasing, following 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 hindering of desertification, etc. A reliable quantitative knowledge of the liquid atmospheric precipitation at a specific site on the territory, or over more or less extended regions (catchment basins), is indeed fundamental to a number of investigation threads, especially within the atmospheric and hydrological applications.

Rainfall is the forcing input of the land phase of the hydrological cycle. The knowledge of rainfall, its variability and the observed/expected patterns of rain events in space and time, are of paramount importance for most meteorological and hydrological studies, and a large number of consequences of such studies are exploited in the everyday technical operation.

Traditionally, the volume of rainfall received by a collector through an orifice of known surface area in a given period of time is assumed 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 – can be easily calculated. The shorter the time interval used for the calculation, the nearer to the real flow of water ultimately reaching the ground is the estimated intensity. This approximate measure of the rainfall rate has been accepted for a long time as sufficiently accurate to meet the requirements of both scientific and technical applications. Reasons for this are on the one hand that most traditional applications in hydrology operate at the basin scale, thus dealing with a process of rainfall aggregation on large space and time scales, while on the other hand the available technology of measurement instruments – especially in terms of data storage and transmission capabilities – was lower than presently exploited.

Nowadays the requirements are tighter and applications increasingly require enhanced quality in rainfall intensity (RI) measurements. The interpretation of rainfall patterns, rainfall event modelling and forecasting efforts, everyday meteorological and engineering applications, etc., are all based on the analysis of rainfall intensity arrays that are recorded at very fine intervals in time. Therefore the relevance of rainfall intensity measurements is dramatically increased and very high values of such “new” variable are recorded, due to the shortening of the reference time frame.

Errors in measurements from traditional and recently developed rain gauges are reported by various authors (*Becchi, 1970; Calder and Kidd, 1978; Marsalek, 1981; Adami and Da Deppo, 1985; Niemczynowicz, 1986; Maksimović et al., 1991; Humphrey et al., 1997; La Barbera et al., 2002; Siek et al., 2007*), together with suitable proposed methods for either “a posteriori” correction of the measured figures *(*see e.g. *Molini et al., 2005b*) or calibration of the gauges.

This notwithstanding, the effects of inaccurate rainfall data on the information derived from rain records is not much documented in the literature (see e.g. *Frankhauser, 1997; Molini et al., 2005a, b*). La Barbera et al. (2002) investigated the propagation of measurement errors into the most common statistics of rainfall extremes and found that systematic mechanical errors of tipping-bucket rain gauges may lead to biases, e.g. in the assessment of the return period T (or the related non-exceedance probability) of short-duration/high intensity events, quantified as 100% for T = 100 years. In that work an equivalent sample size is also defined in order to quantify the equivalent number of correct data that would be needed to achieve the same statistical uncertainty introduced by the influence of errors on inaccurate records.

In a recent work the development of standard limits for the accuracy of rainfall intensity measurements obtained from tipping-bucket and other types of gauges was also proposed *(Lanza and Stagi, 2008*), to be used in scientific investigations and as a reference accuracy for operational rain gauge networks to comply with quality assurance systems in meteorological observations.

The focus on precipitation amount is however the major characteristic for most of the available literature reference studies, and reflects the fact that the total accumulated rainfall over periods of time from 3 to 6 hours has been the traditional way to account for the precipitation variable up to very recent times in meteorology. Following the increased need to investigate rapidly evolving events at the local to regional scale, with potential tremendous impact at the ground and e.g. civil protection consequences, much consideration has been recently given to rainfall intensity as a new variable.

Precipitation intensity is defined (*WMO, 1992a*) as the amount of precipitation collected per unit time interval. According to this definition, precipitation intensity data can be derived from the measurement of precipitation amount using an ordinary precipitation gauge. In that sense, precipitation intensity is a secondary parameter, derived from the primary parameter precipitation amount. However, precipitation intensity can also be measured directly. For instance, using a gauge and measuring the flow of the captured water, or the increase of collected water as a function of time. A number of measurement techniques for the determination of the amount of precipitation are based on these direct intensity measurements by integrating the measured intensity over a certain time interval.

It is worth noting that the time scales required for calculation of rainfall intensity at the ground are now much shorter than in traditional applications. The design and management of urban drainage systems, flash flood forecasting and mitigation, transport safety measures, and in general most of the applications where rainfall data are sought in real-time, call for enhanced resolution in time (and space) of such information, even down to the scale of one minute in many cases.

The World Meteorological Organisation (WMO) recognised these emerging needs and promoted a first Expert Meeting on Rainfall Intensity (*WMO, 2001*) already in 2001 in Bratislava (Slovakia), a location where great part of the activities developed within WMO about atmospheric precipitation had been held in previous years (see e.g. *Sevruk, 1982*; *Sevruk and Hamon, 1984; Sevruk and Klemm, 1989*).

The meeting was really fruitful and the outcome recommendations (*WMO, 2001*) are publicly available on the WMO Web site. Further to the definition of rainfall intensity and the related reference accuracy and resolution, the convened experts suggested to organise an international intercomparison of rainfall intensity measurement instruments, to be held first in the laboratory and then in the field.

The history of instrument intercomparisons in the case of rainfall measurements dates back significantly in the last centuries, experiments in the field being reported by Stow (1871) – see Fig. 1, 2 – and recently by Goodison et al. (1998). This is in line with the well-established awareness of the relevance of intercomparison in atmospheric sciences, since Father Francesco Denza, member of the Italian Meteorological Society, already stated in 1872 that "… in order that meteorological studies produce advantages for human beings … it is not only necessary to have lots of observatories and observations/measurements be done with intelligence and accuracy, but it is moreover requested a meteorological investigation with same methodology and with well compared instruments".

Previous international rain gauges intercomparison efforts were however focused on accumulated amounts of precipitation, low intensity events (including solid precipitation) and sometimes only on qualitative RI information (light, moderate, heavy).

Table 1 (from *Sevruk et al., 2009*) gives an outlook of the four past WMO precipitation measurement intercomparisons including different gauge types as related to the legend, further the reference standard measurement used, the participating countries and the results obtained. It provides a short description of each intercomparison.

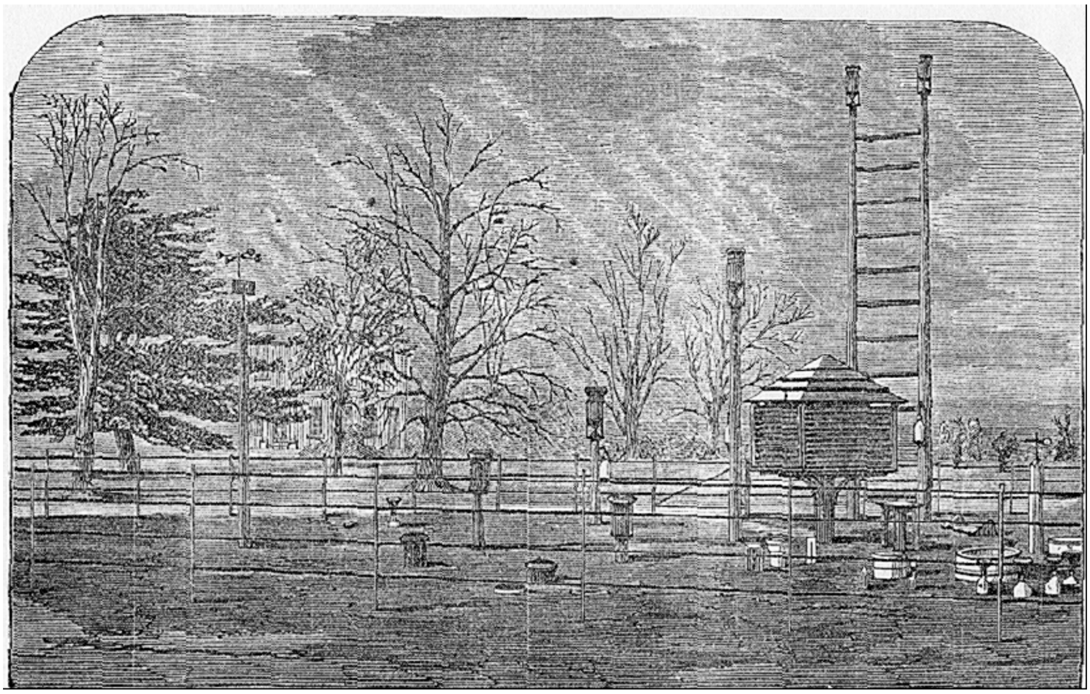


Fig. 1: Experiments to investigate the effect of measurement height on rainfall measures (by Symons in 1862) as quoted by Goodison et al., 1998.

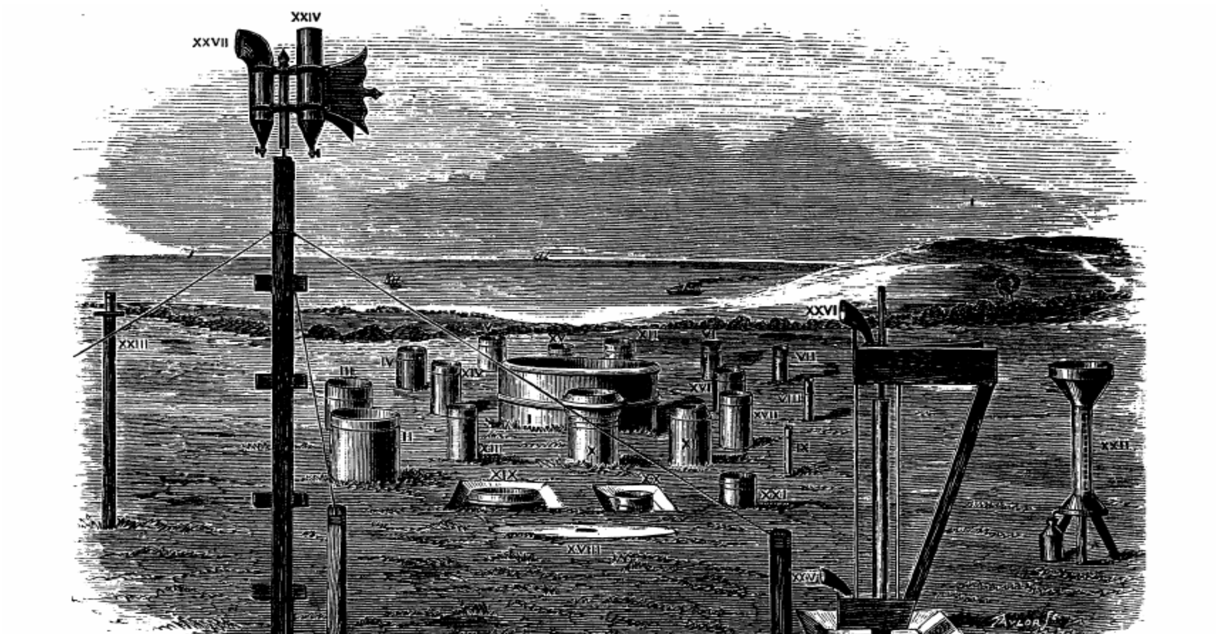


Fig. 2: Symons realizes the first intercomparison of rain gauge instruments at Hawskers - Yorkshire, UK in 1858 (from Stow, 1871 as reported by Goodison et al., 1998).

Comparison	I	II	III	IV
Subject	Precipitation	Rain	Snow	Rain intensity
Period	1955–1975	1972–1976	1986–1993	2004–2008
Purpose	Reduction coefficients between the catches of various types of national gauges	Rain catch differences between various types of national gauges and the pit gauge (Fig. 1). Correction procedures developed	Wind-induced error and standard correction procedures. (Wetting and evaporation losses considered)	Performance of different principles used to measure rainfall intensity (inherent mechanical and electronic errors)
Reference standard (Fig. 1)	Mk 2 gauge[a] elevated 1 m above the ground and equipped with the Alter wind shield	Pit gauge (Mk2)[a] installed in a pit, the orifice flush with ground and surrounded by anti-splash grid	Double-Fence Inter-national Reference, DFIR (Fig. 1)bc	Calibration in three independent laboratories in France, Italy and Netherlands for different rain intensities and field tests in Italy
Participants	Belgium, Czecho-Slovakia, Hungary, Israel, USA, Russia	Basic stations: 22 countries. Evaluation stations: Australia, Denmark, Finland, USA	Canada, China, Croatia, Denmark, Finland, Germany, Norway, Russia, Sweden, USA	12 tipping-bucket gauge models, 5 weighing gauges and 2 water level gauges, all from 15 countries[d]
Results	Non-conclusive	Wind-induced loss depends on wind speed, rain intensity and type of gauge. It amounts on average to 3% (up to 20%) and to 4–6% if wetting and evaporation losses are accounted for	Wind-induced loss depends on wind speed, temperature and type of gauge. Non-shielded gauges show greater losses as shielded ones (up to 80% vs. 40% for wind speed of 5 m/s and $t > -8$ °C)	Tipping-bucket gauges where no proper correction software was applied had larger errors than the weighing gauges. Problems of water storage in the funnel also occurred that could limit the range of measurements
Reference	Poncelet (1959) Struzer (1971)	Sevruk and Hamon (1984)	Goodison et al. (1998)	Lanza et al. (2005)

[a] British Meteorological Office standard gauge of Snowdon type.
[b] The Tretyakov gauge is the Russian standard gauge.
[c] The diameter of inner fence is 4 m and of the outer fence is 12 m. The respective heights are 3 and 3.5 m above ground (Fig. 1). The Tretyakov gauge without fence is the secondary standard.
[d] Australia, Austria, Canada, Czech Republic, Finland, France, Germany, India, Italy, Japan, Norway, Slovakia, Switzerland, UK, USA. The types of gauges are shown in Sevruk and Klemm (1989).

Table 1: The WMO international precipitation measurement intercomparisons.

Precipitation intercomparison, 1955–1975

The objective of the first intercomparison was to obtain reduction coefficients between the catches of various types of national gauges. The WMO and the International Association of Hydrological Sciences jointly organized it. The UK Snowdon gauge was chosen as the International Reference Precipitation Gauge (IRPG). It was elevated 1.0 m above the ground and equipped with the Alter wind shield. Such a gauge, however, was subject to a considerable extent to the wind field deformation and consequently, did not show the correct amount of precipitation. This could be why the first international intercomparison failed (*Struzer, 1971*) but its results (*Poncelet, 1959*) have been used to develop the first map of corrected global precipitation (*UNESCO, 1978*).

Rain intercomparison, 1972–1976

The objective of the second intercomparison was to evaluate wind correction factors for rainfall and to develop correction of systematic errors using the pit gauge surrounded by the anti-splash protection as the WMO standard reference. Pit gauges are hardly affected by wind, and if corrected for wetting and evaporation losses they give reliable results. The results showed that the point rainfall measurement is subject to the systematic wind-induced loss, which is on the order of 4–6% depending on the gauge type and the latitude and altitude of the gauge site. This error can be corrected using an empirical model based on meteorological variables such as wind speed and the intensity of precipitation (*Sevruk and Hamon, 1984*).

Snow intercomparison, 1986–1993

The aim was to determine the wind-induced error of different shielded and unshielded national standard gauges and to derive correction procedures for solid and mixed precipitation measurements considering wetting and evaporation losses. From the numerous snowfall measurement techniques the precipitation gauges shielded by fences appeared to be the most promising. The Russian double fence was finally selected as the WMO reference standard (DFIR). It consists of the shielded Tretyakov gauge encircled by two octagonal lath-fences with a diameter of 4 and 12 m and respective heights of 3 and 3.5 m. The results for snow and mixed precipitation are given in Goodison et al. (1998). It is shown that due to the wind-induced losses during snowfall unshielded gauges catch considerably less precipitation (Pm) than the shielded ones and the reference gauge DFIR (Pr).

The analyses performed in these Intercomparison efforts did not focus in particular on quantitative values of RI and no intercomparison of a large number of RI measuring instruments had yet been conducted first in the laboratory and then in field conditions. For such reasons the WMO considered as the first and necessary step to organize an intercomparison of such instruments, first in the laboratory, and then in the field.

Rainfall intensity intercomparison, 2004–2009

The latest international intercomparison effort had the objective to assess and compare quantification and catching errors of both catching and non-catching type of rainfall intensity measuring instruments with the emphasis on high rainfall intensity.

Following the recommendations of the CIMO Expert Meeting on Rainfall Intensity held in Bratislava, Slovakia, in 2001, the Joint CIMO Expert Team on Surface-Based Instrument Intercomparison and Calibration Methods (ET-SBII&CM) and the International Organizing Committee (IOC) on Surface-Based Instrument Intercomparison, according to the CIMO Plan of WMO Intercomparisons, organized at first a Laboratory Intercomparison, followed by a Field Intercomparison.

The Laboratory Intercomparison (2004-2005) was held at the recognised laboratories of Météo France, KNMI (The Netherlands), and the University of Genoa (Italy). The results are available on the WMO Web site, and were published elsewhere (*Lanza, 2005a, b; Lanza and Stagi, 2008*). The developed procedure for laboratory calibration of catchment type RI gauges and the reference instruments to be used for Field RI Intercomparison initiatives have become recommendations of the fourteenth session of the WMO Commission for Instruments and Methods of Observation (*WMO, 2007a*).

The subsequent WMO Field Intercomparison of Rainfall Intensity Gauges that is documented in this Final Report started on the 1 October 2007 and ended on the 30 April 2009. The campaign was hosted, upon invitation of the Permanent Representative of Italy, at the Centre of Meteorological Experimentations (ReSMA) of the Italian Meteorological Service, in Vigna di Valle, Italy.

The main objective of this Field Intercomparison is to intercompare the performance of in situ rainfall intensity instruments of different measuring principles in high RI conditions.

Further objectives as identified by the ET-SBII&CM and the IOC (ET/IOC) are as follows:

a. To evaluate the performance of the instruments in field conditions;

b. To offer advice on the need for additional laboratory tests especially for the non-catching types of rain gauges;

c. To provide guidance material for further improvements of intercomparisons of instruments for precipitation measurements;

d. To provide guidance to improving the homogeneity of long-term records of rainfall with special consideration given to high rainfall intensities;

e. To draft recommendations for consideration by CIMO.

CHAPTER 2

INSTRUMENTS AND REFERENCE

2.1. SELECTION PROCEDURE

The ET/IOC agreed on the procedures for the selection of the participating instruments. It prepared two questionnaires (see Annex I and II) to assist in the selection procedure, the first one aimed at receiving proposals on potential participants from WMO Members and the second one seeking more detailed information on selecting instruments.

Participation in the Field Intercomparison of RI was accepted based on the following main requirements:

a) Only in situ, both catchment and non-catchment, RI instruments that were currently being used in national networks or being considered for use in national networks were included;

b) Only instruments that were capable of measuring rainfall intensities as high as 200 mm/h at a time resolution of 1 minute were accepted;

c) Preferences were given to two identical instruments, one for testing, one as a spare, however it was not a condition for participation;

d) Participants had to agree that their instruments (only catching types) would be calibrated/tested in the laboratories of Météo France and /or Genoa before the Intercomparison (Laboratory Phase). No adjustments be made to the instruments after the laboratory phase.

Fifty-four (54) instruments were proposed. The capacity of the field site was limited to 31 rain gauges (including four reference instruments in a pit and four of the same type in the field). Because the number of instruments proposed exceeded the capacity, the ET/IOC selected the instruments for participation based on the following additional criteria:

a) Instruments were selected to cover a variety of measurement principles;

b) Preference was given to new promising measuring principles;

c) Preference was given to instruments that were widely used;

d) For those equipment tested in the WMO Laboratory Intercomparison, results of the laboratory tests were taken into consideration.

The list of selected instruments approved by the ET/IOC chairman is presented in Annex III.

According to the results of the WMO Laboratory Intercomparison of RI gauges (2004-2005) and the Recommendation 2 of CIMO-XIV (*WMO, 2007a*), corrected tipping bucket rain gauges (TBRG) and weighing gauges (WG) with the shortest step response and the lowest uncertainty were used as working reference instruments. The following requirements were preferably applied in selection of the reference gauges (*see Annex III, WMO 2005 - Final Report of the second session of the CIMO ET/IOC-SBII&CM, Geneva (Switzerland), 5-9 December 2005*):

a) Uncertainty of the gauge in laboratory tests must satisfy the WMO requirement of +/- 5 % over the range of rainfall intensities expected at the test site, i.e. 2 - 400 mm/h;

b) Minimum resolution of 0.1 mm;

c) Time delay (intended as step response) less than 1 minute;

d) Correction of a tipping bucket gauge should be applied on each tip, rather than delivering an extra pulse (catching type).

According to the above-mentioned requirements for the reference instruments, rain gauges #5(R102-ETG), #8(PMB2-CAE), #13(MRW500-METEOSERVIS) and #17(T200B-GEONOR) were selected as “working reference gauges”, inserted in a pit and also installed in the open field in order to quantify the effect of wind losses.

Windshields were not requested, but all participants were requested to calibrate their instruments against any suitable recognized standard before shipment and to provide appropriate calibration certificates. Participants provided their assistance for installation and during the Intercomparison. A Meeting of participants, HMEI representative and local staff (*HMEI 2008*) was held in Vigna di Valle, 21-22 May 2008, according to the Intercomparison Quality Assurance Plan, and was intended to check that Participants’ instruments were operated according to the recommended procedures. Participants were given a possibility to examine the data acquisition system, the instruments’ installation and the data sampling strategy and advised the site manager on the best synchronization of data.

2.2. RAINFALL INTENSITY GAUGES: PHYSICAL PRINCIPLES

All types of rain gauges can fall in two main groups: (a) catching, and (b) non-catching types of rainfall intensity measuring instruments. Gauges of the first group collect precipitation through an orifice of well-defined size and measure its water equivalent volume, mass or weight that has been accumulated in a certain amount of time. At present catching rain gauges are widely used in operational networks to measure rainfall intensities and amounts. Instruments of the second group determine rainfall intensity or amount either by a contactless measurement using optical or radar techniques or by an impact measurement.

At the present there is the WMO standardized procedure for Laboratory Calibration of catchment type rain gauges by using a calibration system which produces a constant volume flow of water in time. However, a standardized procedure for the calibration of non-catching rain gauges is not yet available. Nevertheless, some calibration practices have been developed by the respective instrument manufacturers. The findings of the Field RI intercomparisons (see Chapter 6) could be used for improving these practises and consequently the field measurement accuracy and the performance.

2.2.1 Catching rain gauges

Catching rain gauges can be characterized as follows:

- They can be calibrated in the laboratory;
- They are able to measure RI within sampling time intervals ranging from a few seconds to several minutes;
- They have finite resolution ranging from 0.001 mm to 1 mm;
- They have reasonably good reproducibility and long-term stability;
- They are widely used in operational practice and are cost effective;
- They are prone to wind-induced catching losses (depending on appropriate wind shielding);
- They are prone to wetting and evaporation losses, especially in low RI.

Regular maintenance, annual calibration and servicing, is needed to obtain high quality measurements.

a) Tipping-bucket rain gauges (TBRG) without correction

The following participating instruments from the list in Annex III belong to this group: RIM 749020-McVan (Australia), AP23-PAAR (Austria), DQA031-LSI LASTEM (Italy), Rain Collector II-DAVIS (USA), PP040-MTX (Italy), ARG100-EML (UK).

A tipping bucket rain gauge uses a metallic or plastic twin bucket balance to measure the incoming water in portions of equal weight. When one bucket is full, its centre of mass is outside the pivot and the balance tips, dumping the collected water and bringing the other bucket into position to collect. The water mass content of the bucket is constant (m [g]), therefore by using the density of water (ρ=1g/cm^3) the corresponding volume (V [cm^3]) is derived from the weight of the water and, consequently the corresponding accumulation height (h ≡ RA [mm]) is retrieved by using the surface of the area collector (S [cm^2]). The equation will be: V=mass/ρ=h*S and, by using the density of water, h is calculated, where 1mm corresponds to 1g of water over 10cm^2 of surface.

The raw output is a contact closure (reed switch) so each tip produces an electrical impulse as signal output which must be recorded by a data-logger or by an analogue-digital converter (data acquisition system equipped with Reed-switches reading ports). This mechanism provides a continuous measurement without manual interaction. In particular, for the field Intercomparison, the rainfall intensity of non-corrected TBRG is calculated considering the number of tips every 10 seconds (periodic sampling rate) and averaging over a chosen time interval (e.g. 1 minute). In this way the RI is available every minute and it is referred to the RI of the past minute. The scheme of sampling reduces the uncertainty of the average *(see Part III, C.2, par.2.4.2., Guide to Meteorological Instruments and Methods of Observation (WMO, 2008a)* hereafter called *CIMO Guide*) and the RI resolution depends on the size of the bucket and the chosen time interval: for example, a tip equivalent to 0.2 mm leads to one-minute RI resolution of 12 mm/h which is constant over the measurement range of the gauge.

TBR gauges generally suffer from systematic non-linear and significant measuring errors, strongly dependent on rainfall rate *(see Report of WMO Laboratory Intercomparison of Rainfall Intensity Gauges, 2004-2005, Lanza et al. 2005b)*. Especially with higher intensities these errors can amount to 20% for some types of tipping bucket gauges. According to the results of the RI Laboratory Intercomparison, it was shown that these errors could be reduced by applying a correction.

b) Tipping-bucket rain gauges with correction algorithm (TBRG-SC)

The following participating instruments from the list of Annex III belong to this group: R102-ETG (Italy), UMB7525/I-SIAP-MICROS (Italy), PMB2-CAE (Italy).

To overcome the underestimation of RI for high rainfall rates and the overestimation of RI for low rainfall rate both typical of non-corrected TBRG, a suitable rainfall intensity dependent correction has to be applied, e.g. in the data acquisition system by a software correction (SC) or an algorithm. Participating TBRG-SC applied this correction in real time operation through built-in electronics or a dedicated data-logger connected to the gauge which data outputs every minute (one-minute RI [mm/h] and other variables). The correction algorithm could be alternatively run on the data acquisition system and it generally consists in a RI dependent correction which can improve RI uncertainty to ≤ 2% in laboratory conditions. If the RI is calculated by taking into account the timestamp of each tip, the resolution of RI is increased: this procedure is causing a time 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.

c) Tipping-bucket rain gauges with extra pulse correction (TBRG-PC)

The following participating instruments from the list in Annex III belong to this group: PT 5.4032.35.008-THIES (Germany), LB-15188-LAMBRECHT (Germany).

To reduce the measurement errors, a linearization is carried out in a built-in electronics circuit. The RI dependent linearization procedure is based on a pulse-number-correction that adds extra electrical impulses to the output signal. This addition of extra pulses corrects quite well the accumulated amount of precipitation. For RI over a period of one minute, the correction is usually either too low (no correction, because of no additional pulse) or too high (one additional pulse in the minute to correct losses over several previous minutes). Therefore, this type of correction is well suited for amount of precipitation but less for RI measurements.

d) Tipping-bucket rain gauges with mechanical correction (TBRG-MC)

The following participating instrument from the list of Annex III belongs to this group: R01 3070-PRECIS MECANIQUE (France).

To reduce the measurement errors, tipping bucket gauges of this group use a mechanism to prevent the loss of water during the tip of the balance. Small deflectors induce a dynamic pressure increasing with rainfall intensity which allows the tip to occur before the bucket is full. The effect compensates for the loss of water during the movement of the balance and greatly minimizes the RI underestimation during high RI events.

e) Level measurement rain gauges (LRG)

The following participating instrument from the list of Annex III belongs to this group: ELECTRICAL RAINGAUGE-KNMI (ER-KNMI, The Netherlands).

Water is collected in a tube of specified diameter. By measuring the water level in the tube the volume of collected water is directly measured. The level measurement can be done by a conductivity measurement, an acoustic distance measurement or by a floater. The water level can thus be measured with any desired temporal resolution. The measurement resolution is typically between 0.01 mm and 0.1 mm leading to a one-minute RI resolution between 0.6 mm/h and 6 mm/h. At a maximum level, the tube can be siphoned, providing an almost continuous measurement without manual intervention. Due to the siphoning process the measurement can be interrupted for about 1 minute and rainfall data is derived by interpolation as in the case of the ER-KNMI.

f) Weighing rain gauges with pressure measurement (WG-PRG)

The following participating instrument from the list of Annex III belongs to this group: ANS 410/H-EIGENBRODT (Germany).

Instruments that use a pressure sensor need to collect the rainfall water by a funnel in order to channel it into a thin sampling cylinder of known diameter. A differential pressure sensor mounted at the bottom measures the pressure p exerted by the weight of water column of known surface base and height h. Because the pressure p is defined as weight/surface, by using the density of water and the gravitational acceleration g, the height h (≡ *RA [mm]*) can be derived from the measured pressure p. Therefore the only difference between the WG and WG-PRG is that with pressure measurement the result is correlated to the base area of the sampling cylinder.

These gauges are sometimes equipped with an automatic emptying mechanism.

g) Weighing rain gauges (WG)

The following participating instruments from the list of Annex III belong to this group: MRW500-METEOSERVIS (Czech Republic), VRG101-VAISALA (FINLAND), PLUVIO-OTT (Germany), PG200-EWS (Hungary), T200B-GEONOR (Norway), TRwS-MPS (Slovak Republic).

In all weighing rain gauges, precipitation is collected and continuously weighed. The volume of water is derived by using the gravitational acceleration g and the density of water.

These rain gauges do not use any moving mechanical parts in the weighing mechanism, only elastic deformation occurs. Therefore, mechanical degradation and consequently the need for maintenance are significantly reduced.

The weighing is accomplished by various methods, e.g. a frequency measurement of a string suspension, a strain gauge. The digitized output signal is generally averaged and filtered. From the differences of two or more consecutive weight measurements, RI can be calculated.

Such weighing gauges are particularly useful for recording solid and liquid precipitation as well as mixtures of both, since the solid precipitation does not require melting before it can be recorded. Certain systematic errors, particularly evaporation and wetting loss, can be minimized compared to other gauges.

Weighing gauges may exhibit some temperature sensitivity in the weighing mechanism that adds a component to the output that is proportional to the diurnal temperature cycle. These gauges may also be sensitive to wind flow (wind pumping) over the gauge that can induce transients in the signal and may falsely be recorded as rain. Data processing can account for these conditions. Noise in the weight measurement due to the precipitation impact has to be filtered out.

Weighing rain gauges have to be manually emptied periodically, except when equipped with siphoning/pumping system (e.g. level pumps in MRW500-METEOSERVIS and siphoning in PG200-EWS).

As this Intercomparison is focused on RI measurements on 1-minute time interval, a fundamental characteristic of all participating WGs is the response time (filtering process included) which determines a RI measurement error (*for details see Laboratory tests, section 4.1*)**.** The response times, available in operation manuals or evaluated during the Laboratory tests, were of the order of 6 seconds to approximately 4 minutes.

The 1-minute RI resolution for WGs can be very different from gauge to gauge and depends on the transducer resolution (*see Table 6 in Chapter 6*).

Many WGs have data output that contain diagnostic parameters which are very useful for further evaluations of measured data and for data quality control.

2.2.2 Non-Catching precipitation sensors

Non-catching precipitation sensors are mainly used for Present Weather observations including rainfall intensity measurements. Non-catching type rain gauges require low maintenance and very few periodic checks. Therefore, they can be considered particularly suitable for AWS or generally unmanned meteorological stations. Some of them have the advantage to determine the type of precipitation, to distinguish between solid and liquid precipitation, to provide Present Weather information (e.g., METAR and SYNOP codes) and to determine the rain droplets spectra.

Many instruments belonging to this group have data output containing diagnostic parameters which are very useful for further evaluations of measured data and for data quality controls.

a) Optical disdrometers

The following participating instruments from the list of Annex III belong to this group: PARSIVEL-OTT (Germany); LPM-THIES (Germany).

Optical disdrometers use one or two thin laser light beams to detect particles crossing it. Each particle within the beam blocks the transmitted light intensity to an amount proportional to its diameter. The volume of each droplet is derived from its diameter by respecting its size dependent shape. The measurement range for particle diameters is typically 0.2 mm to > 8 mm. RI can be directly calculated by integration over the volumes of the detected particles over a time period ranging from 15 seconds to one minute. The RI resolution is typically 0.001-0.005 mm/h (drizzle events). One possible error source arises from coincident drops, which are detected as one “large” drop (undercount of smaller drops). This leads to a systematic overestimation of the determined water volume for which a statistical correction has to be applied. The upper limit of the measurement range could also be restricted by this effect (to 250 mm/h in some cases). Another error source is due to droplets hitting the rim of the light sheet that are interpreted as too small particles. Disdrometers are also able to measure the falling speed of each individual drop from the time during which a particle blocks the beam, which results in a matrix of falling speed versus particle diameter. By cluster analysis of this matrix, the type of precipitation can be assigned which is used for Present Weather information. The long-term stability of these instruments has to be demonstrated but is expected to be in the range of years.

b) Impact disdrometers

The following participating instrument from the list of Annex III belongs to this group: WXT510-VAISALA (Finland).

For this type of sensors a membrane of plastic or metal is used as the measurement surface to sense the impact of single precipitation particles. In some systems the mechanical movement of the membrane generates elastic waves to the sensor plate and further on to a piezoelectric sensor: the mechanical stresses are converted in electrical signals proportional to the droplets size or hail size. Other systems detect the amplitude and analyze the frequency spectrum generated by precipitation particles hitting the membrane to determine the number and the size of the drops. The output signal is normally converted in accumulated precipitation. Integration of this parameter leads to RI over a selected period of time. The peak intensity and rain event duration can also be measured. Filtering techniques are used to filter out signals originating from sources other than rain drops.

These disdrometers are not capable to measure the smallest droplets of diameters less than 0.3 mm (for the WXT510-VAISALA the minimum size is 0.8mm). Moreover, snowflakes of low mass density may not be detected.

c) Microwave radar disdrometers

The following participating instrument from the list of Annex III belongs to this group: LCR “DROP”-PVK ATTEX (Russian Federation).

Small radars can be used to determine the spectrum of the signal backscattered by falling particles. Their principle of operation is generally based on measurement of fall velocity of rain drops and its volumetric backscattering. It is known that the raindrop fall velocity is defined by their size and is in a range from 1.5 up to 9.0 m/s (DSD = drop size distribution). The spectrum is related to the Doppler shift associated with the fall velocity of these particles. The intensity of the backscattered signal is related to the number of particles and/or their water content. A Fourier processing of the signal is typically executed inside a processor that calculates average spectrum, retrieves drop size distribution from this spectrum and finally calculates rain accumulation on an output averaging time (typically from 1 minute to ten minutes). The micro wave radar installed for the Intercomparison is characterized by a low power radiation emission at the frequency 11GHZ. Moreover, it was focused on accumulation of all advantages provided by Doppler Radar Gauges but with the goal to reduce its cost.

Radar disdrometers have RI resolutions up to 0.1mm/h.

d) Optical/Capacitive sensors

The following participating instrument from the list of Annex III belongs to this group: PRESENT WEATHER DETECTOR PWD22-VAISALA (Finland).

Optical sensors are normally designed for providing meteorological visibility (MOR) by measurement of atmospheric forward scattering. By means of an additional rain sensor (RAINCAP, capacity sensor in the case of PWD22-VAISALA) they provide precipitation amount and intensity by retrieving the scattering due to rain droplets passing through a given volume. Some optical sensors, including PWD22-VAISALA, are also able to determine the type of precipitation and, by applying specific internal algorithms and temperature measurements, they provide present weather information in METAR and SYNOP codes.

2.3. ANCILLARY INSTRUMENTS

The Field Intercomparison site was equipped with meteorological measurements to monitor environmental conditions and to provide metadata for diagnostic purposes and further evaluations such as wind-induced effects on precipitation measurements. The meteorological data were provided by the following ancillary instruments:

- Four propeller-vane anemometers (05106-Young) at the testbed's external positions;
- Four wetness sensors (DRD11A-Vaisala) for detecting rain events;
- One temperature/relative humidity probe (M101A-Rotronic);
- One atmospheric pressure sensor (61020L-Young)
- One global irradiance pyranometer (200X- Li-Cor);
- One ultrasonic anemometer (Windsonic-Gill) at a testbed's position very close to the reference rain gauges.

See Fig. 10 for instruments positioning.

2.4. REFERENCE RAIN GAUGE PIT (RRGP)

A reference can be defined as a virtual device based on a set of measuring instruments and, according to VIM (the Vocabulary in Metrology), a working reference is a calibrated set of instruments used for controlling/making comparison with measuring instruments.

According to the CIMO Guide (*WMO, 2008a*), the main feature of reference gauge design is to reduce or control the effect of wind on the catch, which is the most serious influence factor for gauges. The use of one single reference instrument in the field intercomparison should be avoided so a set of working reference gauges was used in this intercomparison and their combined readings provided the best possible estimation of reference RI in the field. These selected reference gauges had demonstrated their performance during the previous Laboratory Intercomparison (2004-2005) and were installed in a pit according to the EN-13798:2002 "Reference Rain Gauge Pit", as adopted by ISO, to minimize environmental interference on measured rainfall intensities and to protect against in-splash by a metal or plastic grid.

Gauges are typically mounted at some distance above the ground to reduce debris (dust, needles and leaves) being blown into the orifice. A standing gauge acts as a disturbance to the air flow. This wind-induced effect has been known from more than one century and it is described as *JEVONS effect* (1861) (*see Koschmieder, 1934*). The effect of flow deflection and the associated eddies and turbulence around the gauge cause some of the rain drops (particularly smaller ones) to miss the orifice area. The resulting rainfall catch error depends on the ambient wind speed, the rainfall drop size distribution (DSD) and the gauge design. The buried or "sunken" gauge (e.g. *Koschmider, 1934* and *Sieck et al., 2007)* is expected to show a higher rainfall reading than the gauge above the ground, with differences potentially 10% or more, when both instruments work perfectly and accurately. The effect is enhanced in snowfall.

In the case of a RRGP, this influence is minimized. Moreover, the influence of the turbulent vertical movements is likewise reduced to a minimum, since these disappear at the earth's surface.

Following Recommendation 2 (CIMO-XIV), rain gauges R102-ETG (TBRG-SC), PMB2-CAE (TBRG-SC), MRW500-METEOSERVIS (WG) and T200B-GEONOR (WG) were selected as “working reference gauges” and properly installed in four well-drained pits according to the requirements of the ISO/EN-13798:2002 as shown in Fig. 3.

The design of the pit took into account dimensions of the gauges and a method of installation of the respective gauge. The sides of the pit are formed of bricks and concrete and they are supported to prevent collapse. As a result, a large pit of 170 cm depth was built and divided in four parts for installing the reference rain gauges (Fig. 3, 4). Supporting walls were built around the edges and four galvanized steel grating of 187,5 x 187,5 x 12,0 cm (LxWxH) were rested on pit walls. The base of the pit is deep enough to allow the correct installation of the rain gauge and its levelling. The base of the pit has a recess (extra pit) to allow water to be drained by an electric pumping system (Fig. 4).

The grating is strong enough to walk on, to maintain its shape without distortion and it was made in two sections to allow part of it to be lifted, to give access to the rain gauge. The grating was made of galvanised sheet steel. The grating has a central open square for the correct and levelled installation of the rain gauge. To prevent in-splash from the top surface of the grating, the strips of the grating are 0.3 cm thick and the distance between the edge of this central square and the ground is greater than 60 cm.

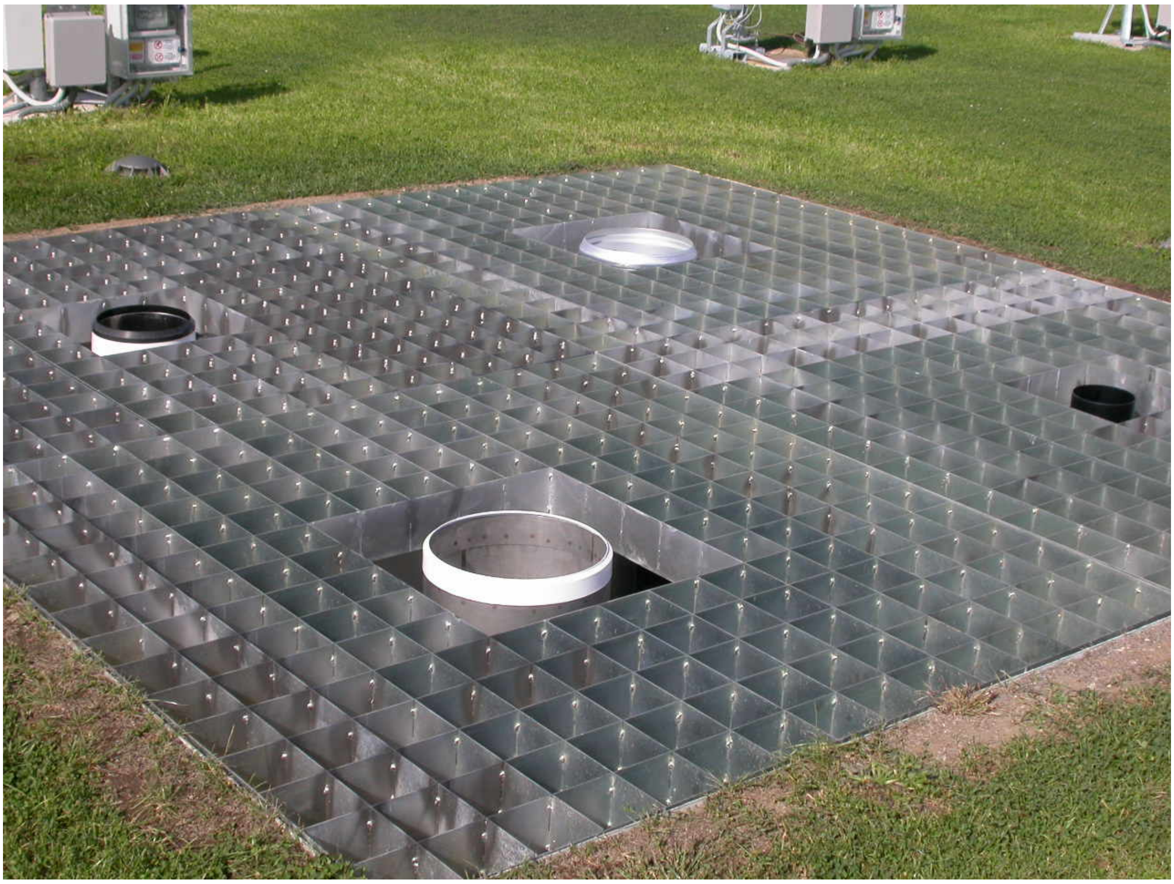


Fig. 3: The realization of the Reference Rain Gauge Pits at Vigna di Valle, Italy (2007).

Fig. 4: The gratings, the pit internal walls and the pit recess for drainage (Vigna di Valle, Italy, 2007).

The Technical Committee No. 318 “Hydrometry” of the European Commission for Normalization (CEN) is presently revising the standard “EN-13798:2002” based on the experience gained in this intercomparison. The Convenor of the working group charged of this revision was Dr Emanuele Vuerich, the Site Manager of the WMO Field Intercomparison of RI. Following the CEN development stages, the revised standard would be available in November 2010. As a practice, European norms (CEN) are transferred into ISO standards according to the Vienna Agreement. Following the publication of the revised standard, WMO should update relevant regulatory material.

CHAPTER 3

METHODOLOGY AND ORGANIZATION

3.1. SITE DESCRIPTION

The intercomparison campaign was held at the Centre of Meteorological Experimentations (ReSMA) of the Italian Meteorological Service at Vigna di Valle, Italy (42.083 N, 12.217 W). The Centre is located on the top of a hill at 262 meters above the sea level. It is close to Bracciano Lake and 12 km far from an isolated mountain chain in north direction (600-900 m above msl). The location is generally characterized by a wind regime of dominant flows during the year from SW (warm-humid air masses) and from NE (cold-dry air masses). The most intense rainy period is from October to December, however spring and summer intense events are also possible. During the rainy period or in strong spring events, the maximum recorded rainfall intensity (RI [mm/h]) last at least 20-30 minutes and generally depends on rain thunderstorms and showers due to combination of cold and warm fronts mainly coming from SE-SW. The worst weather conditions normally occur when perturbations meet a strong Lake humidity condition (beginning of autumn, early spring, hottest summer days). The situation is similar during summer: intense precipitation events (but less frequent) occur mainly with dominant winds from E and from Rome “hot island” zone (50 km from Vigna di Valle).

During precipitation events, an average wind speed of 5m/s is generally recorded, except in cases of enhanced Tower Cumulus (TCU) clouds or Cumulonimbus (CB) outflows (stronger winds) that usually precede intense showers for several minutes.

The intercomparison site was built in the experimental area of ReSMA (Fig. 5). It is a flat 400m^2 grass field which is equipped with 34 concrete platforms (4 corner-platforms and 30 evenly distributed platforms) and a central 4-fold ISO standard pit for the installation of the set of reference RI gauges (Fig. 6). Each platform is supplied with power supply (AC and VDC), serial communication converters, 8 free and 8 coupled high quality double shielded acquisition cables and low voltage threshold discharge protections.

Fig. 5: Experimental area of ReSMA and the Intercomparison test bed– Vigna di Valle, Italy

Fig. 6: WMO Field Intercomparison test bed – Vigna di Valle (Italy).

The following plots were used by the ET/IOC on SCII&CM (Geneva,5-9 December 2005) to assess the suitability of the Vigna di Valle for the Field Intercomparison of RI measuring instruments.

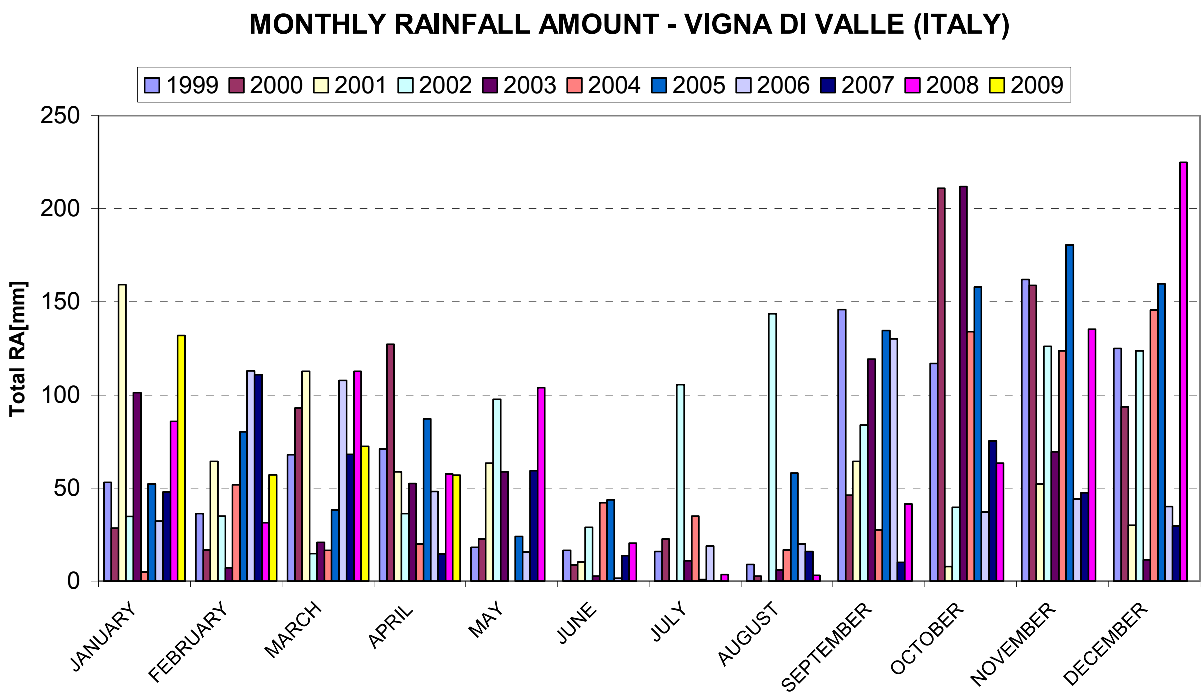


Fig. 7: The monthly rainfall accumulation distribution measured by the meteorological station of Vigna di Valle during the period Jan1999-Apr2009.

Figure 7 represents the monthly distribution of cumulated precipitation over the last 10 years; Figures 8 and 9 show the statistical determination of the likelihood [%] and the time of return (Tr [years]) for RI [mm/h] extreme events according to the Gumbel max value asymptotic cumulated distribution (Gumbel type I). The Gumbel parameters for both plots are calculated by using experimental data.

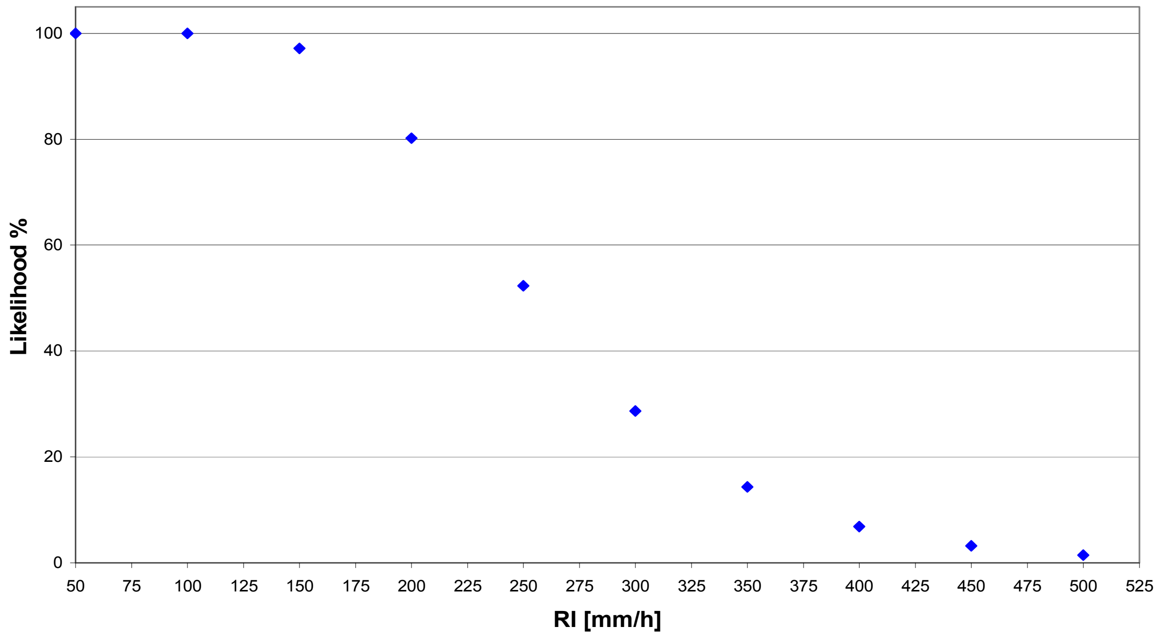


Fig. 8: Likelihood versus one minute rainfall intensity for Vigna di Valle, according to a Gumbel max value asymptotic type I cumulative distribution: the likelihood is the probability (0-100%) to have a value ≥ RI value on bottom axis.

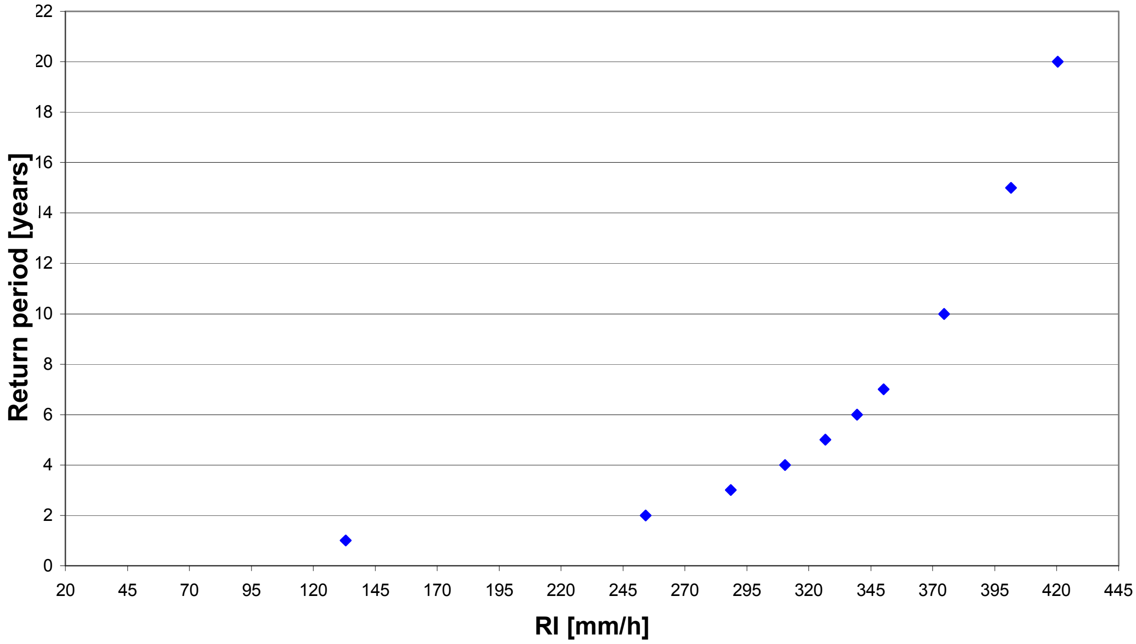


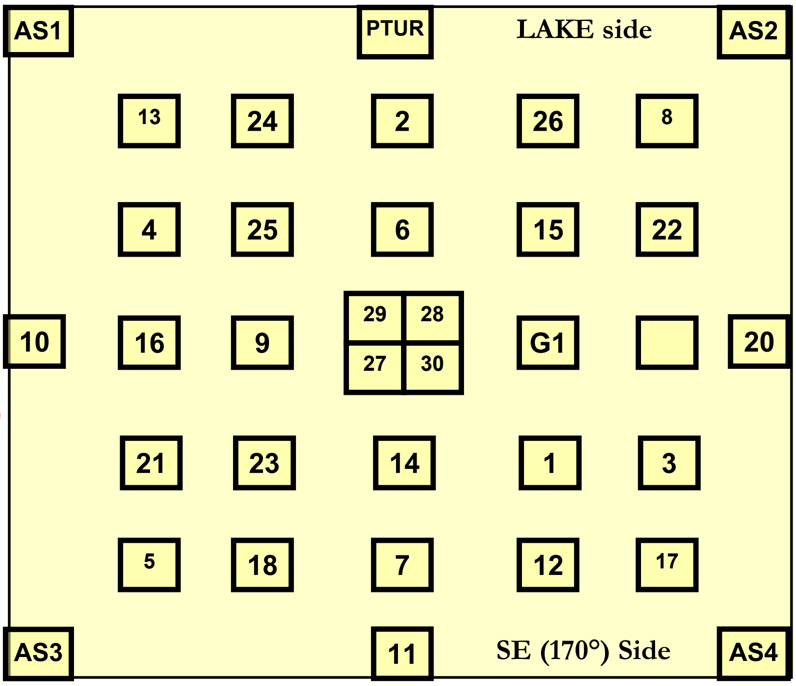
Fig. 9: The return period of several one minute rainfall intensity values for Vigna di Valle, according to a Gumbel max value asymptotic type I cumulative distribution.

3.2. POSITIONING OF INSTRUMENTS AND INSTALLATION PROCEDURES

Agreed positioning of the participating rainfall intensity gauges, as well as of ancillary sensors are in Fig. 10 (*see WMO 2007b*). The following criteria for positioning were applied by ET/IOC: a) Almost random distribution of gauges with different measuring principles; b) No clustering of large gauges in order to prevent mutual disturbance of the wind field.

RAIN GAUGES

1 RIM7499020-McVan (TBRG)
2 AP23-Paar (TBRG)
3 Précis Mecanique (TBRG)
4 PT 5.4032.35.008-THIES (TBRG)
5/27 R102-ETG A, B (TBRG)
6 DQA031-LSI LASTEM (TBRG)
7 UM7525/I -SIAP (TBRG)
8/28 PMB2-CAE A, B (TBRG)
9 Rain collector II-Davis (TBRG)
10 LB-15188-Lambrecht (TBRG)
11 PP040-MTX (TBRG)
12 ARG100-EML (TBRG)
13/29 MRW500- Meteoservis A, B (WG)
14 VRG101-VAISALA (WG)
15 PLUVIO-OTT (WG)
16 PG200-EWS (WG)
17/30 T200B-GEONOR A, B (WG)
18 TRwS-MPS (WG)
20 PWD22-VAISALA (Optical)
21 PARSIVEL-OTT (OD)
22 LPM-THIES (OD)
23 WXT510-VAISALA (Impact disdr)
24 ANS 410/H-EIGENBRODT (WG-P)
25 Electrical Raingauge-KNMI (Level)
26 LCR "DROP"-PVK ATTEX (Radar disdr)



ANCILLARY SENSORS

G1 **windsonic-Gill (ultrasonic wind sensor)**
ASn **Four 05106-Young (Wind sensors) and four DRD11A -Vaisala (Wetness/Rain detectors)**
PTUR **M101A- Rotronic (T/RH) + 61020-L-Young (Press) + 200X-LI-COR (Sol. Irrad.)**

Fig. 10: Instrument positioning

The ET/IOC decided to exclude windshields to provide uniform measurements for all gauges and to install all rain gauges and wind/wetness sensors at 1 meter height and other ancillary sensors (T, RH, solar radiation, atmospheric pressure) at heights recommended in CIMO Guide (*see WMO 2007b*). A spare instrument was provided my manufacturers to allow uninterrupted measurements. Manufacturers were also requested to provide an appropriate mast for installation of their instruments so that the “orifice/sensing” height was at 1 m over the ground or at the same level with the top of gratings in case of RRGP. The only exception was PWD22-VAISALA (position #20) which was installed at 1.8m height to best correspond to practical installation.

Catching rain gauges were calibrated in the DICAT Laboratory of the University of Genoa prior to field installation (April-June 2007). The field installation took place during July and August 2007 and many Participants assisted in the installation of their instruments. According to the agreed plan an evaluation phase was performed from August to September 2007, when first instruments had been connected to the data acquisition system and others were gradually added

The following picture shows some aspects of the field installation such as concrete platforms set-up and cabling.

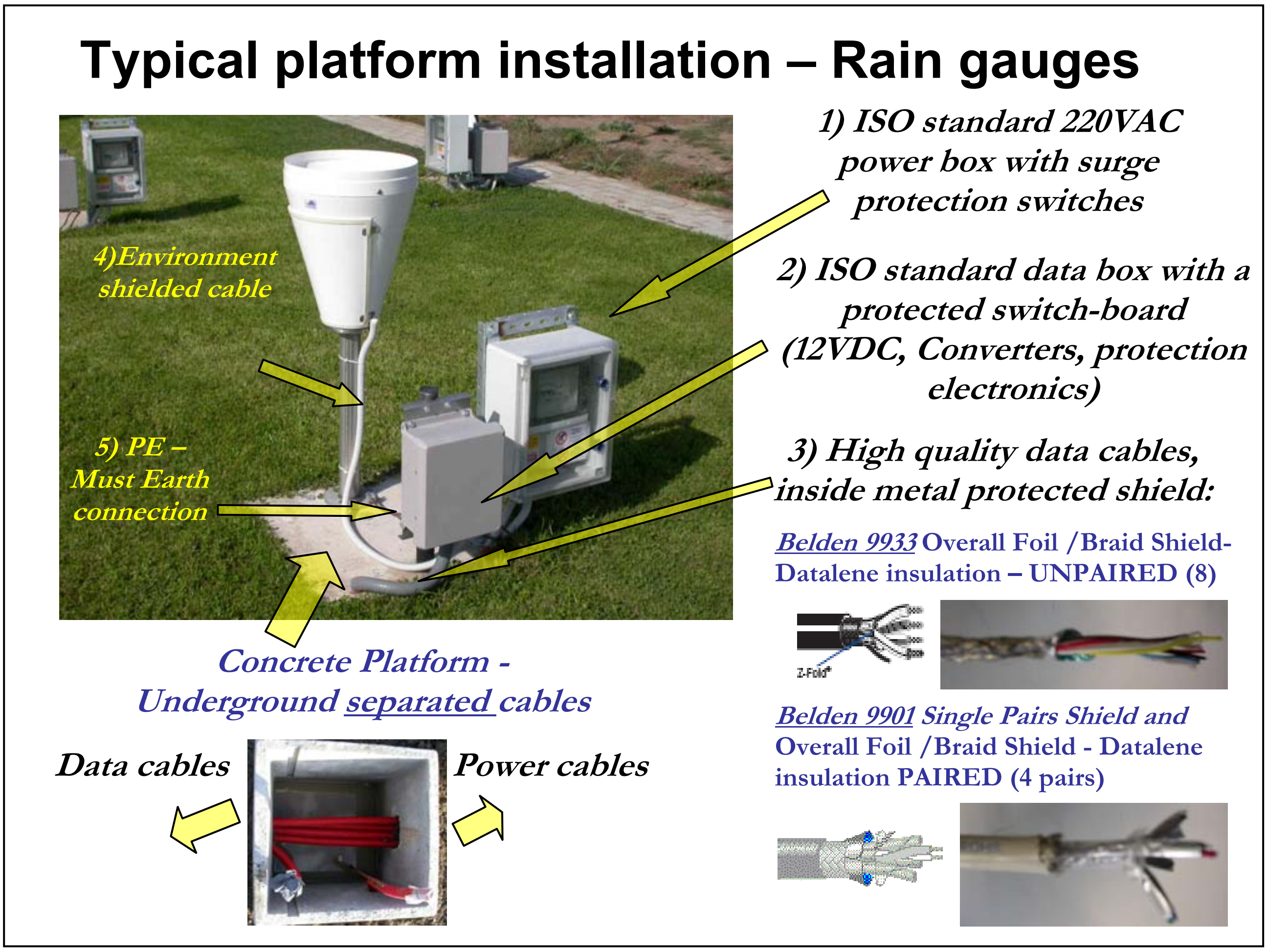


Fig. 11: The setup of the installation platforms and cabling.

The Field Intercomparison of RI officially started on the 1st October 2007. The originally envisaged intercomparison period of 12 months was extended to 18 months and the intercomparison campaign was closed on the 30th of April 2009. For QA purposes, a meeting of Participants, HMEI and local staff was held during the intercomparison (21-22 May 2008) in Vigna di Valle (*HMEI 2008*).

3.3. DATA ACQUISITION

The data acquisition (DAQ) system chosen was a Campbell Scientific CR1000 data-logger equipped with peripherals suitable serial and analogue signals (*see WMO 2007b*). A complete description of the DAQ is provided in Annex IV.

The DAQ system was programmed for performing direct measurements (for switch closure gauges, vibrating wire rain gauges, pulse emitting rain gauges, wind monitoring sensors, temperature/RH sensors, etc.) and serial output acquisition for string emitting rain gauges.

The clock of the CR1000 was the official timestamp used for optimal synchronization, especially relevant for the evaluation of 1-minute data.

The acquisition for rain gauges consisted of a record of raw data from the rain gauges with a sampling time of 10 seconds or 1 minute, depending on the output time interval of the rain gauges. In case the RI (rainfall rate at 1 minute) was not directly provided as an output of the measurement, a transfer function given by the manufacturers was applied to derive RI at 1-min time resolution. The acquisition of ancillary sensors consisted of a record of raw data with a sampling time of 10 seconds.

The raw data contain all data delivered by the sensors, including diagnostic data, and they were processed in near-real time by the Automatic Quality Control (AQC) implemented on a separated CPU in order to provide quality checked 1-minute RI data, quality controlled 1-minute ancillary data and QC information (e.g. flags, suspect data, erroneous data, etc.) to be used for data analysis and evaluation of results (see Chapter 5 for data processing and quality control).

The focus of the RI Intercomparison was on liquid precipitation. For this reason only liquid precipitation events were evaluated. The identification of the precipitation type was based on the SYNOP, METAR and SPECI messages created by ReSMA H24 weather station (WMO ID 16224).

The following metadata were used to improve the interpretation of the Intercomparison results:

a) RI output, response time, time delays and factory's calibration certificate and procedures (if any) according to all operating manuals of selected instruments;

b) Results of the laboratory phase;

c) Record of all actions performed and observations made concerning the functionality of the instruments in a form of an electronic logbook operated by local staff;

d) Special observations recorded by the ReSMA 24H Met Observer, especially during precipitation events.

3.4. QUALITY ASSURANCE AND SUPERVISION OF INSTRUMENTS

The AQC was part of the Quality Assurance plan to ensure proper data and metadata acquisition, storage, processing and analysis. All information on visual inspection, observations, maintenance and repair was stored in an electronic logbook. The local staff performed a daily visual check, cleaning of instruments when necessary, and calibration status checks when required by instruments technical manuals. The local weather forecast was used for planning of preventive maintenance. A suitable portable device for field calibration of catching type instruments was provided by the DICAT Laboratory to ReSMA and was used for performing field tests (see section 4.2).

During the Intercomparison period QA reports were produced by the site manager with all relevant information about QA operations and field tests results.

3.5. DATA POLICY

The following is the guidance principles for data policy of the intercomparison that was agreed by the ET/IOC:

- The WMO has the copyright on the intercomparison dataset.
- The complete intercomparison dataset is kept by WMO Secretariat, the ET/IOC chair, the Project Leader and Site Managers. WMO may, if requested by the ET/IOC, export whole or part of the comparison dataset on to the CIMO/IMOP website, or other website controlled by the ET/IOC members, as soon as the Final Report is published. In particular, the Data Sheets prepared for each of the instrument involved can be published on the Web site as soon as the Final Report is published.
- After the Intercomparison, every participant could get a copy of the comparison dataset, containing any further raw data obtained during the tests, related to its own instruments.

- The WMO authorizes the Project Leader (in collaboration with site managers and data processing manager), with the agreement of the ET/IOC chair, to publish full results in a Final Report of the intercomparison on behalf of the ET/IOC.
- The ET/IOC members may publish their partial scientific results if demanded by the scientific community before the end of the intercomparison, provided the publication was authorized by the Project Leader and that the participating instruments remain anonymous in that publication.
- The comparison dataset may be provided to other parties for the purpose of scientific studies on the subject. This requires an approval of the ET/IOC chair, and is possible only after the full results of the intercomparison have been published.
- For publication and for presentation to third parties, the participants are only allowed to use data of their own instrument. In doing so, they will avoid qualitative assessment of their instruments in comparison with other participating instruments.

CHAPTER 4

INSTRUMENTS CALIBRATION

All twenty catching type instruments, including the four rain gauges selected as reference instruments, were calibrated in the laboratory before their final installation at the Field Intercomparison site. The WMO recognized laboratory at the University of Genoa performed the calibration using the same standard tests adopted for the previously held WMO Laboratory Intercomparison of RI Gauges. Further tests were performed to investigate the dynamic performance of the involved instruments at the resolution of one minute.

The objectives of this initial phase of the Intercomparison were to single out the quantification errors associated with each instrument, so as to help to understand the results obtained in the field during the subsequent phase. Results and comments on the laboratory calibration exercise are reported in this chapter, together with their implications for the analysis of the outcome of the Intercomparison in the field.

Section 4.2 also describes the verification of the instruments installed in the field (at the test site) using a suitable field calibration device specifically developed at the University of Genoa. All gauges of the catching type were tested using this portable calibration device after installation, simulating ordinary calibration inspections in the field.

4.1 LABORATORY CALIBRATION

4.1.1 Rationale

The WMO Field Intercomparison of Rainfall Intensity Gauges had the objective to assess and compare quantification and catching errors of both catching and non-catching type of rainfall intensity gauges.

The errors due to the weather conditions at the collector, as well as those related to wetting, splashing and evaporation processes, are referred to as catching errors. They indicate the ability of the instrument to collect the exact amount of water that applies from the definition of precipitation at the ground, i.e. the total water falling over the projection of the collector's area over the ground. Non-catching instruments, which are based upon a contactless measurement, have no collector and may also show "catching" errors which in this case means that the instrument does not *detect* the full amount of water within the measurement volume.

On the other hand quantification errors are related to the ability of the instrument to correctly quantify the amount of water that is collected or detected by the instrument. They can be experienced both in catching and non-catching type of instruments, although in the latter case the assessment of such errors is very difficult, and hard to be performed in controlled laboratory conditions. These errors may originate from the very different aspects of the sensing phase since the instruments may differ in the measuring principle applied, construction details, operational solutions, etc.

The present chapter focuses on the laboratory tests that were performed at the beginning of the intercomparison campaign to obtain specific information on the various gauges participating in the field tests.

The fourteenth session of the WMO Commission for Instruments and Methods of Observation (*WMO, 2007a*) has recommended a procedure for the laboratory calibration of catchment type RI gauges. Based on this recommendation, laboratory tests of catching type of instruments (#20) were performed before the installation in the field. Laboratory tests were performed at the WMO recognized laboratory of the University of Genoa. Its laboratory equipment and facilities allow for the basic and applied research as well as for experimental activities in the different fields of hydraulics (fluid mechanics, fluvial and maritime engineering, hydrology and environmental monitoring) as well as the characterization and qualification of instruments and processes relevant for environmental protection. The Laboratory is classified as highly qualified according to the Italian Decree by Law 297/99.

The spare part instruments provided by the manufacturers were also tested, so as to replace their companion instrument in case of malfunction. It should be noted that derived calibration curves were not applied to the output data obtained from the individual gauges during the field intercomparison, since only the manufacturer's calibration was considered for the Intercomparison purposes. This chapter reports the results from this laboratory phase, therefore describing the quantification performance of the participating catching type gauges as obtained under constant flow rates in controlled conditions.

The innovative aspect of the performed laboratory tests with respect to the literature and even previous WMO intercomparison initiatives is the analysis performed at one minute resolution in time. Performing laboratory tests at such high resolution introduces some difficulties since noise in measurements is enhanced. However, it allows a better understanding of the intrinsic performance of the various instruments and their ability to sense the rainfall intensity in the field conditions, which is known to be highly variable in space and time.

4.1.2 Methods

According to the recommendations developed during the previous WMO Laboratory Intercomparison of RI Gauges (Lanza *et al., 2005b*), the same calibration methodology used, which is based on the generation of a constant water flow from a suitable hydraulic device (see Fig. 12) 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 (see Lanza *et al., 2005b* for details).

Tests were extended to cover the one-minute 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 ongoing intercomparison in the field, the one-minute resolution rainfall intensity is considered under real world conditions, since this time resolution was adopted by CIMO-XIII as a recommendation for precipitation intensity measurements, with a maximum uncertainty of 5%, and published in the last revision of the CIMO Guide (*WMO, 2008a*).

It should be noted that some rainfall intensity gauges were modified by manufacturers or NMHS (National Meteorological and Hydrological Services) following the results of the first Laboratory Intercomparison (2004-2005), and before the Field Intercomparison, to improve their performance. This explains the reason of possible differences between the results of the former (2004-2005) and the latter (2007-2009) laboratory tests.

The objective was to perform tests at least at seven reference flow rates, at 2, 20, 50, 90, 130, 170, 200 $mm \cdot h^{-1}$. 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.

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

- 1.5 – 4 $mm \cdot h^{-1}$, at 2 $mm \cdot h^{-1}$;
- 15 – 25 $mm \cdot h^{-1}$, at 20 $mm \cdot h^{-1}$; and

- ± 10 % at higher intensities.

Tests were performed at one minute 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.

Fig. 12: The Qualification Module for Rainfall Intensity Measurement Instruments developed at the University of Genova, and used in the laboratory calibration phase.

Model	Measuring principle
RIM7499020-McVan	Tipping bucket
AP23-PAAR	Tipping bucket
R01 3070-PRECIS-MECANIQUE	Tipping bucket
PT 5.4032.35.008-THIES	Tipping bucket
R 102-ETG	Tipping bucket
DQA031-LSI LASTEM	Tipping bucket
UMB7525/I-SIAP-MICROS	Tipping bucket
PMB2-CAE	Tipping bucket
RAIN COLLECTOR II-DAVIS	Tipping bucket
LB-15188-LAMBRECHT	Tipping bucket
PP040-MTX	Tipping bucket
ARG100-EML	Tipping bucket
MRW500-METEOSERVIS	Weighing gauge
VRG101-VAISALA	Weighing gauge
PLUVIO-OTT	Weighing gauge
PG200-EWS	Weighing gauge
T200B - GEONOR	Weighing gauge
TRwS-MPS	Weighing gauge
ANS 410/H-EIGENBRODT	Pressure sensor
Electrical rain gauge-KNMI	Level sensor

Table 2: List of catching rain gauges calibrated in the laboratory of Genoa University

A summary of the total number of tests performed at each single flow rate and their main characteristics is reported in Fig. 13, where the deviations of the reference intensities from their target values are indicated in the form of box plots. The values obtained for the mean (solid line), median (thin line), 25th -75th percentiles (box limits), 10th -90th percentiles (whisker caps) and outliers (black circles) per each series of one-minute actual flow rates obtained at the individual reference flow rates are synthetically illustrated.

The accepted limits for a given reference intensity value already defined in the former Laboratory Intercomparison are recalled below the graph. The laboratory exercise was quite successful in keeping to those limits, even with the 10th-90th percentiles in most cases, the exception occurring at the lowest flow rates and at 50 mm·h^{-1} (note that these deviations indicate the capability to generate repeatable flow rates for performing the tests, the major deviations being sometimes due to the limited time available to test a large number of instruments).

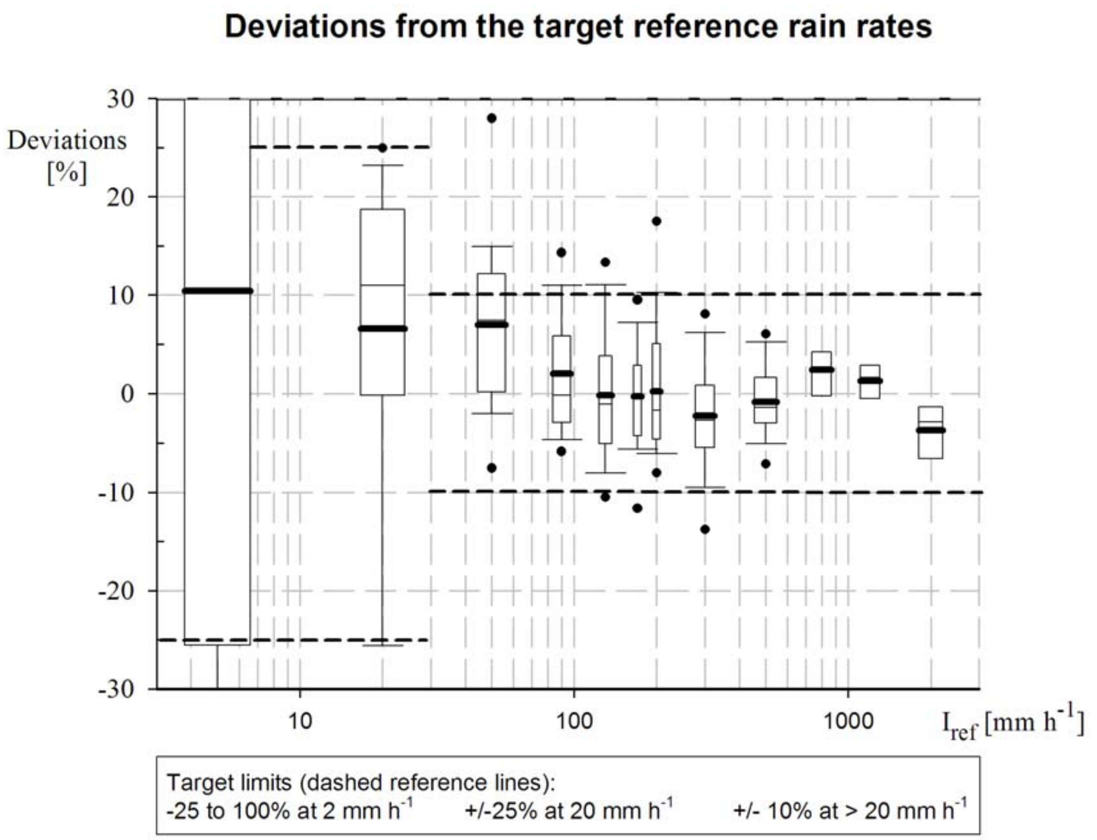


Fig. 13: Summary of the deviations of reference intensities from their target values for all tests performed.

4.1.3 Data analysis

The results of the laboratory tests are synthesised in this report in the form of two types of graphs: (a) in the first type, the relative error for a few sample gauges is plotted versus the reference intensity; (b) in the second type, calibration curves are presented, where the measured intensity is plotted against the reference one. The relative error is calculated as follows:

$$e = \frac{I_{meas} - I_{ref}}{I_{ref}} \cdot 100 \quad \%$$

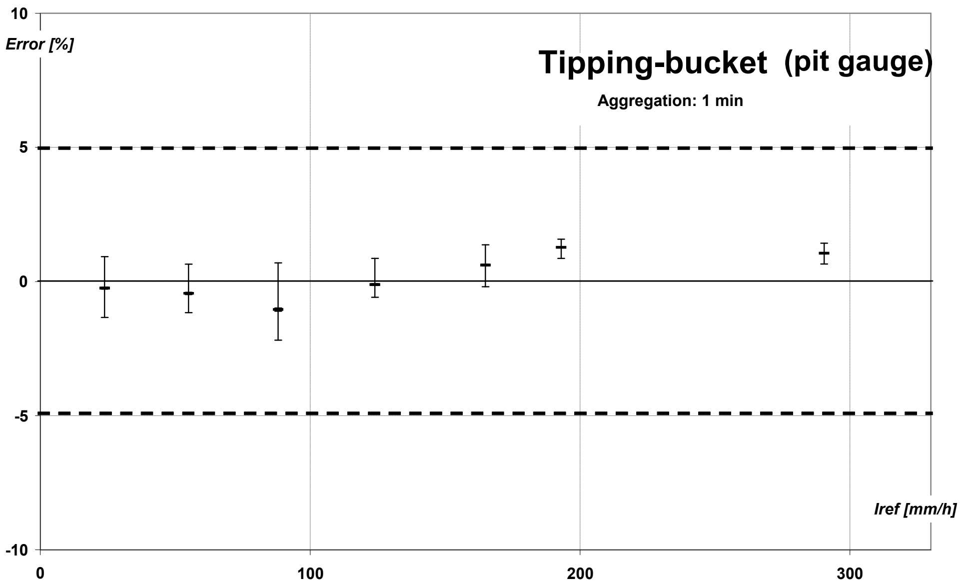
where I_{meas} is the intensity measured by the instrument and I_{ref} the actual reference intensity.

An error curve can be fitted to the experimental data in the (e, I_{meas}) space, a second order polynomial being suited to represent the behaviour of the gauges over the whole range of operation of the investigated instrument. Also, results can be provided in terms of the calibration curve, obtained by fitting the measured rainfall intensities to the reference ones with for example a power law curve.

In Fig. 14, sample results for a well-calibrated tipping-bucket rain gauge to be installed in the pit and a well performing weighing gauge at one minute resolution are shown (bars indicate the range and standard deviation of all tests performed). In both graphs, the two dashed horizontal lines indicate the ± 5% uncertainty limits that were originally proposed by WMO for assessing the performance of rainfall intensity gauges. The TBRG illustrated in the upper graph of Fig. 14a is one of the selected working reference instruments that performed within the requirements set by CIMO.

The main contribution of these first two graphs is that the variability of the one-minute rainfall intensity can be reported. Results for those gauges, in terms of the average accuracy – mean error figures, are available for these specific gauges from the WMO Laboratory Intercomparison of RI Gauges (2004-2005). From the graphs below, it is evident that not only the average figures, but also the standard deviation and range bars are well within the limits of the required accuracy for rainfall intensity measurements. In Fig. 14b, the variability of error values at one-minute resolution is a bit more spread around the average figures, with some higher variability observed at the low rainfall rates. Although this type of graph is less significant for a weighing gauge, where the response time was identified in the previous WMO Laboratory Intercomparison as the critical factor, it is also evident that the accuracy of the average figures is very high, and is generally better than the one shown by most tipping-bucket rain gauges.

14(a)



14(b)

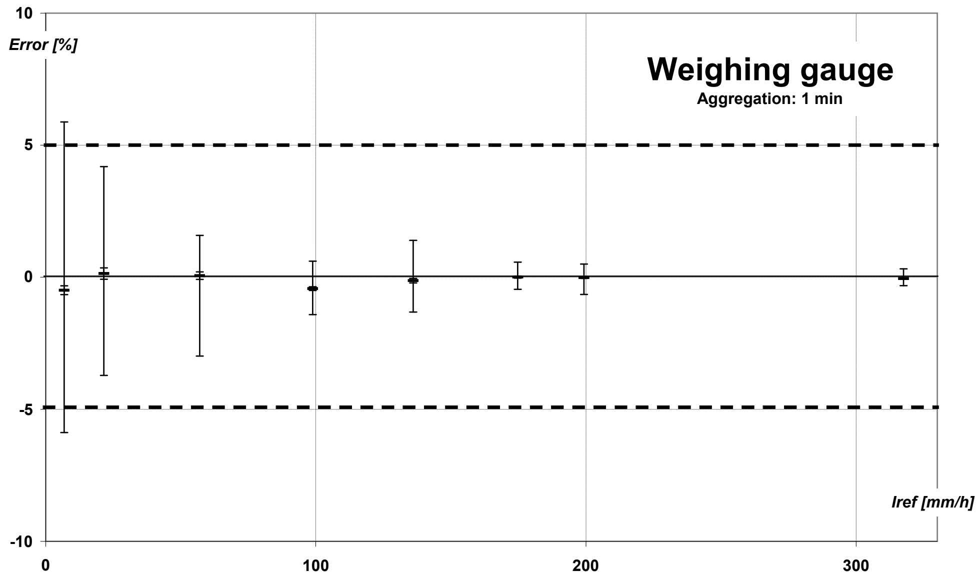


Fig. 14 (a), (b): Sample pit gauge TBR and WG instruments showing very good performance at the one-minute aggregation scale.

A second result presented in this chapter is the ensemble of the error curves obtained after the laboratory tests for all catching type gauges, including the spare instruments, plotted against the reference intensity.

In Fig. 15 and 16, the curves are presented separately for the two main categories of measuring principles, namely the tipping-bucket and the weighing rain gauges. Green curves relate to the reference instruments of the respective category. It can be noticed that the set of curves remains confined in between the ± 5% uncertainty limits for most of the instruments under test, some of the curves actually lay within those limits only for a reduced range of reference intensities, while only few of them lay completely outside the acceptable range. The tipping-bucket category clearly shows a larger variability in the behaviour between various instruments, and also larger errors for some of the instruments involved. However, a few well calibrated instruments demonstrated a very good performance. The weighing gauges showed in general less disperse curves. The response time characteristics of such instruments will be discussed later in this chapter.

Finally, in Fig. 17, the ensemble of the error curves obtained in the laboratory phase for the working reference gauges, including the spare instruments, compared with the ± 5% uncertainty limits are reported.

In order to highlight the high resolution performance of each instrument, in particular the variability of one-minute data around the long-term mean value, a further representation is used. Results are presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute variability of the observed instruments performance and the size of the sample used for calculation at each reference intensity. Box plots synthetically indicate the values obtained for the mean (solid line), median (thin line), 25^{th}-75^{th} percentiles (box limits), 10^{th}-90^{th} percentiles (whisker caps) and outliers (black circles) per each series of one-minute data obtained during the tests. Grey shaded vertical bars indicate the sample size according to the scale reported on the right hand side of the graph.

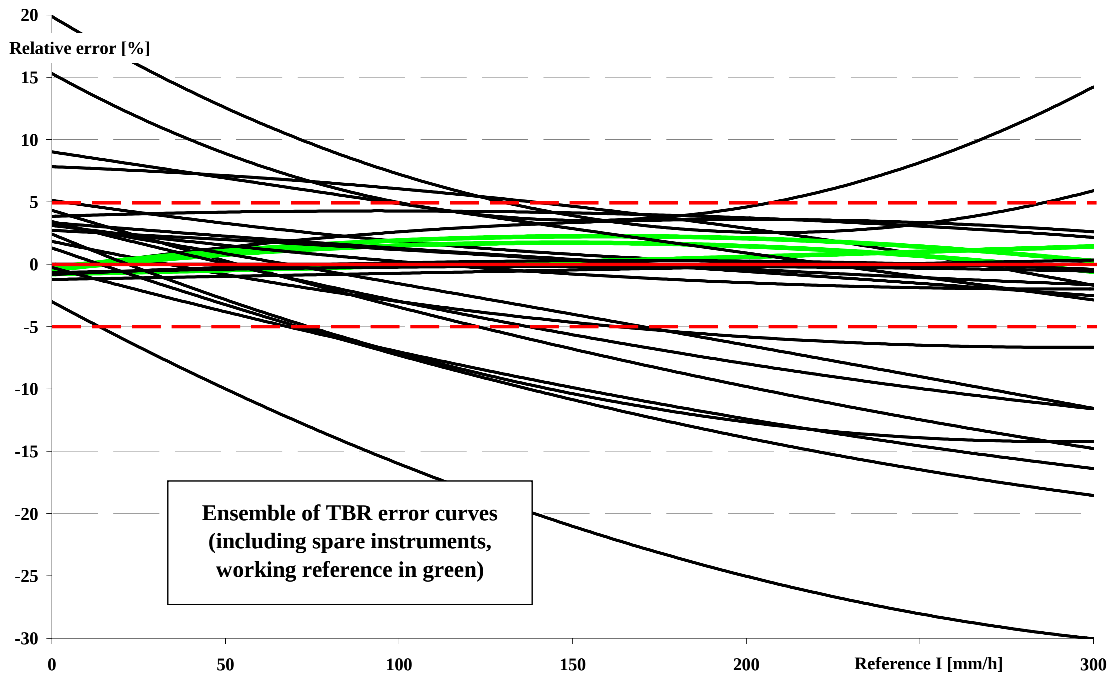


Fig. 15: Ensemble of the error curves obtained in the laboratory phase for all Tipping-bucket rain gauges, including the spare instruments, compared with the ±5% uncertainty limits.

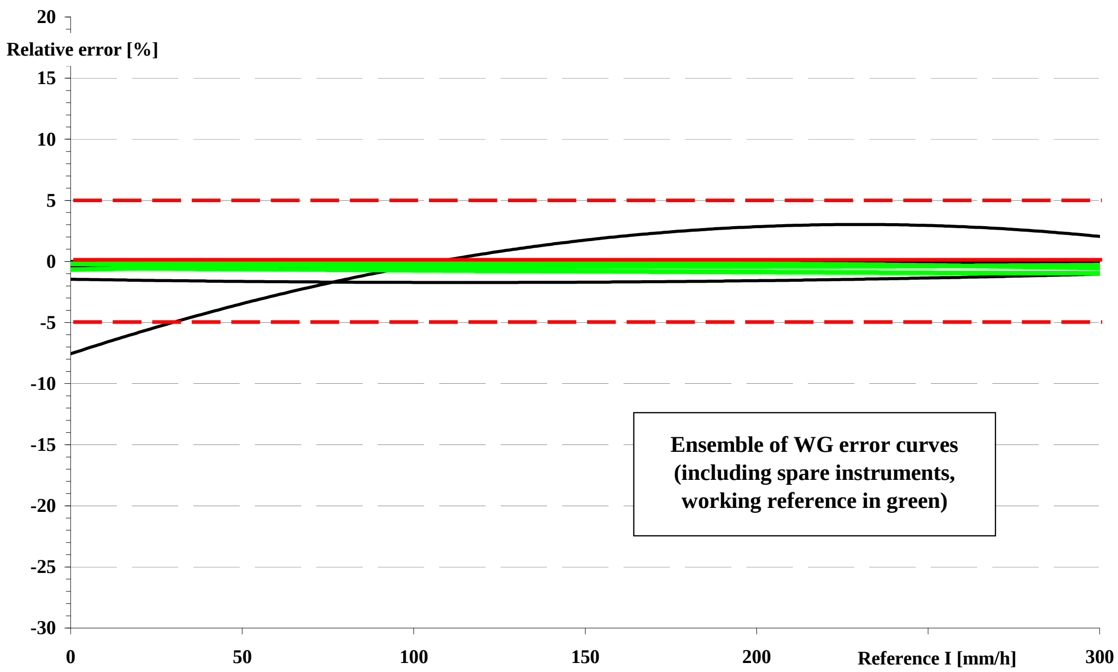


Fig. 16: Ensemble of the error curves obtained in the laboratory phase for all weighing gauges, including the spare instruments, compared with the ±5% uncertainty limits.

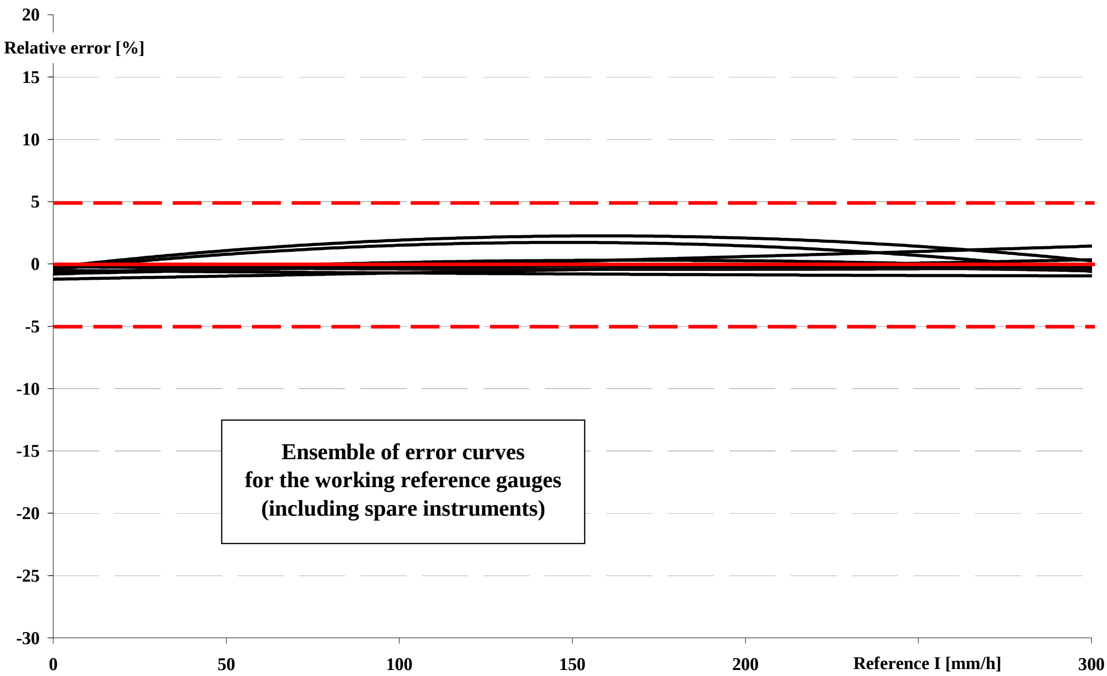


Fig. 17: Ensemble of the error curves obtained in the laboratory phase for the working reference gauges, including the spare instruments, compared with the ±5% uncertainty limits.

These graphs are reported in Fig. 18 to 22, for a set of sample rain gauges with different measuring principles involved. The full set of graphs is reported in the data sheets for each single instrument. Traditional Tipping-Bucket Rain gauges – TBR (Fig. 18-20), Weighing Gauges – WG (Fig. 21) and strain detection (weighing) gauges (Fig. 22), are illustrated here and compared to each other.

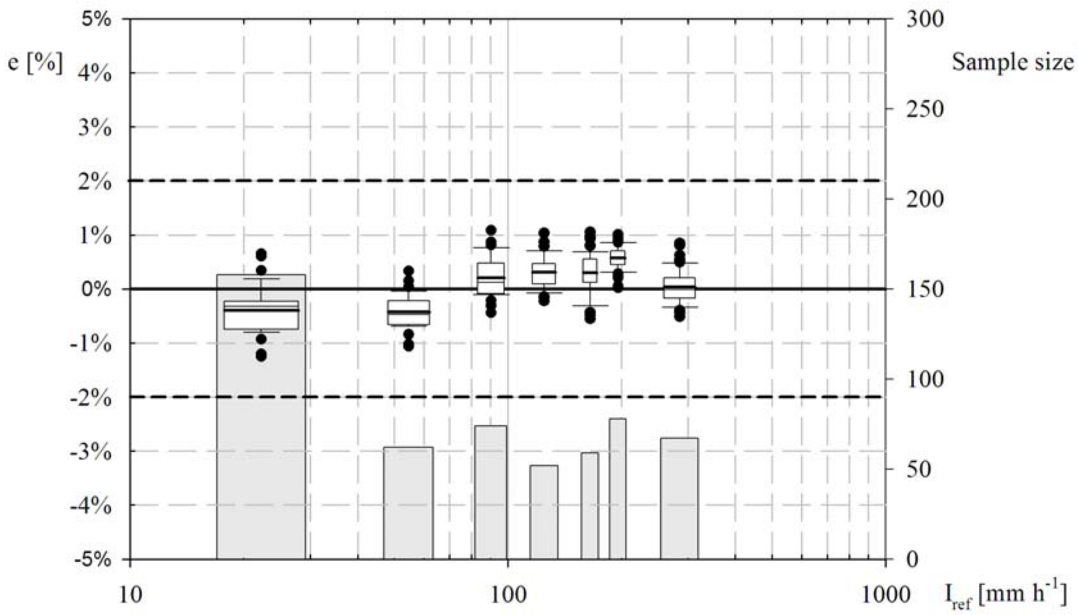


Fig. 18 One-minute variability for a sample corrected TBRG observed performance and the size of the sample used for calculation of the statistics at each reference intensity.

Note that in few cases a reduced range is used for the scale of relative errors (Fig. 18, 21 and 22) in order to zoom further into the best performance region observed for some of the instruments. In particular, it is here confirmed that properly calibrated TBRGs have the potential to behave at the utmost accuracy, even the outliers being included in some cases within very restricted error bands (below 2%). WGs are generally better in terms of the long-term average figures, although they still show some more enhanced variability, especially at the low to medium rainfall rates.

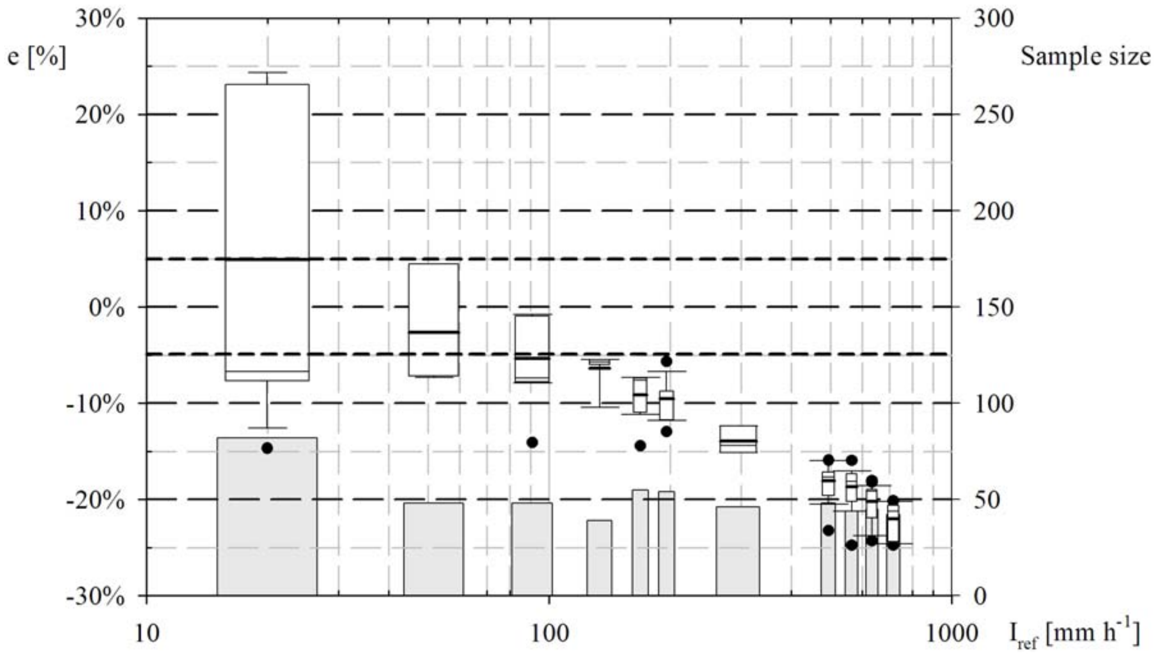


Fig. 19: One-minute variability for a sample not corrected TBRG observed performance and the size of the sample used for calculation of the statistics at each reference intensity.

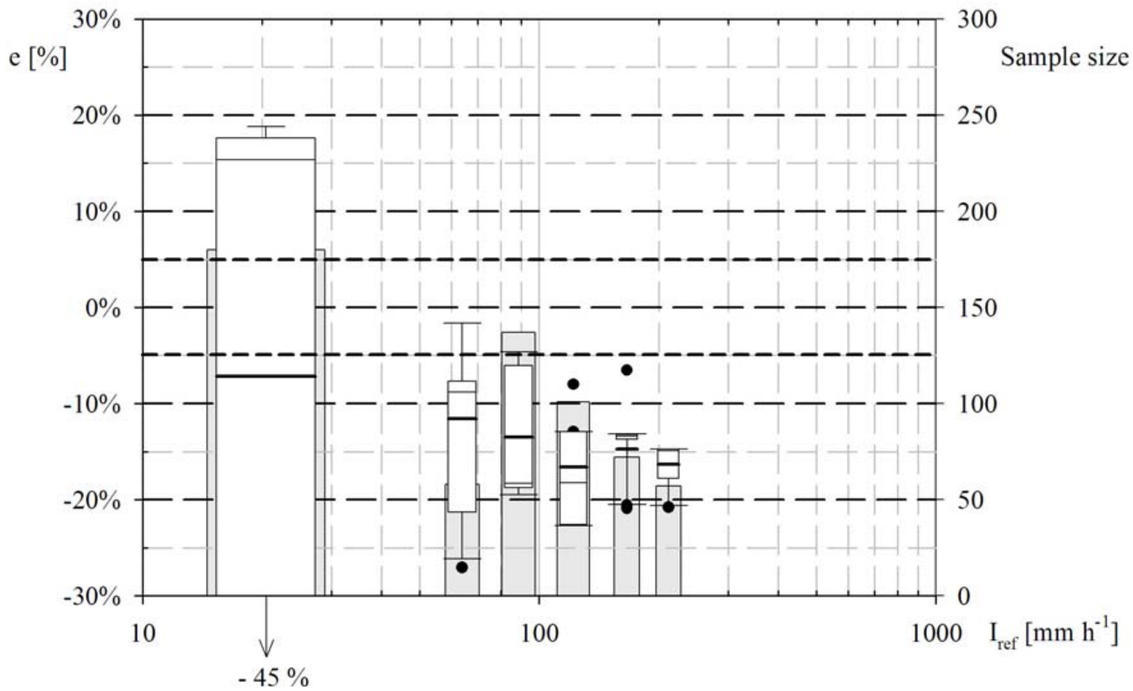


Fig. 20: One-minute variability for a sample not corrected TBRG observed performance and the size of the sample used for calculation of the statistics at each reference intensity.

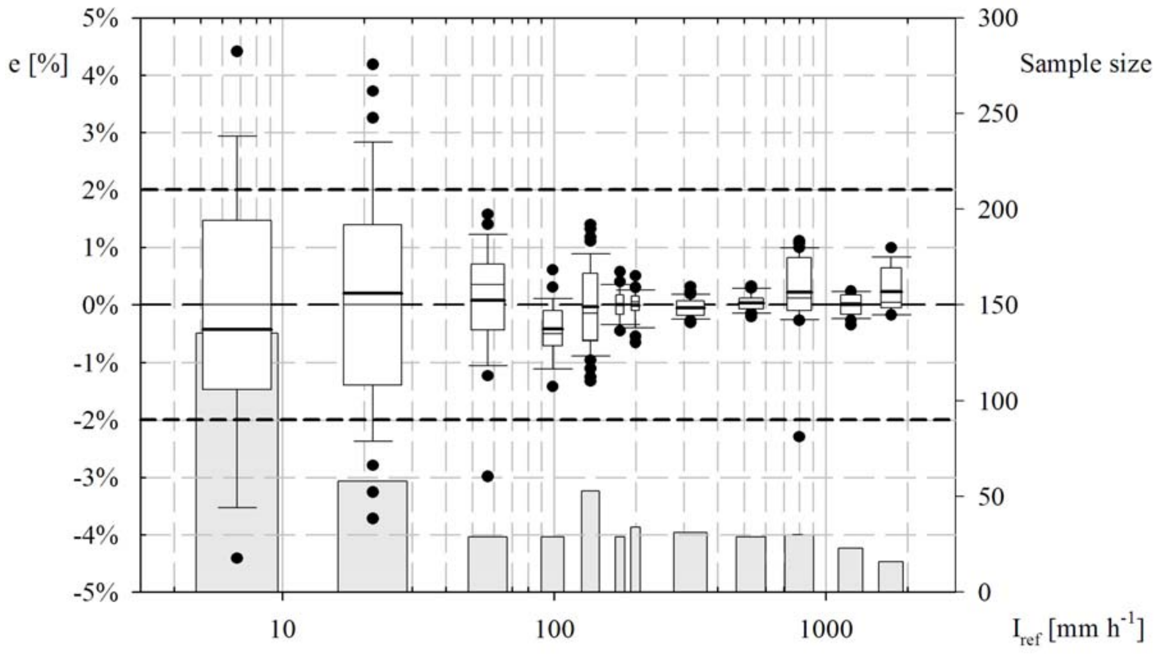


Fig. 21: One-minute variability for a sample WG observed performance and the size of the sample used for calculation of the statistics at each reference intensity.

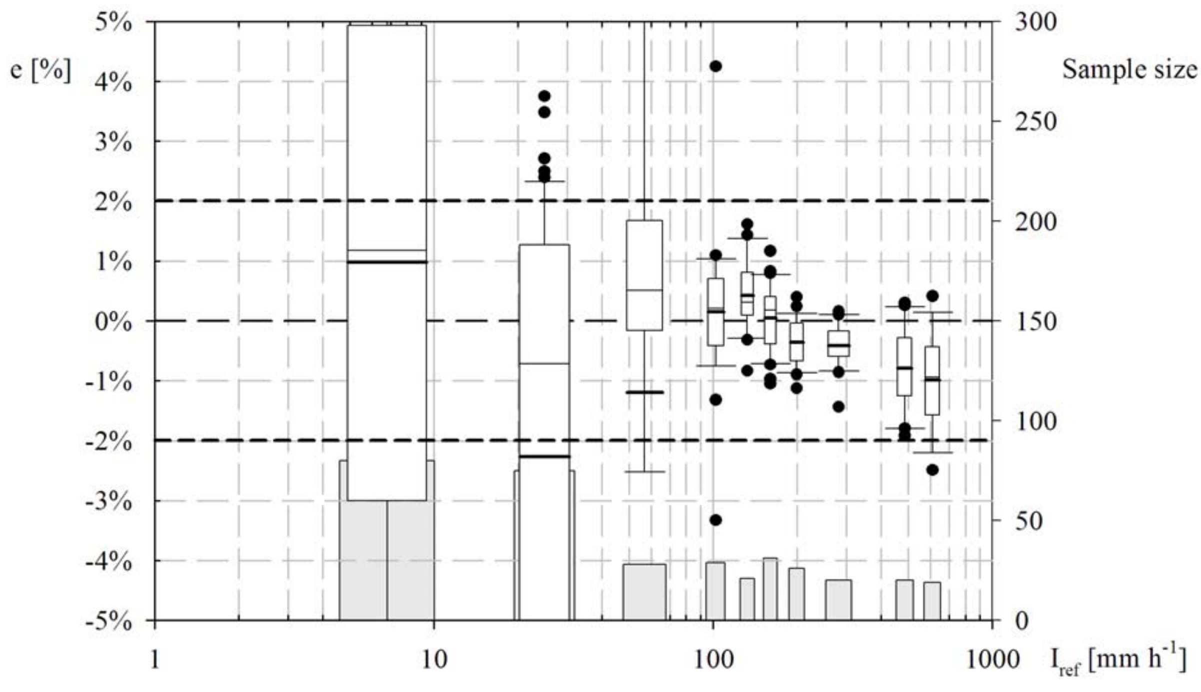


Fig. 22: One-minute variability for a sample strain detection WG observed performance and the size of the sample used for calculation of the statistics at each reference intensity.

On the contrary, non-corrected or poorly corrected TBRGs may show larger errors with increasing reference intensity, and are therefore unsuitable to measure heavy rainfall rates without an additional software correction. This indicates that a proper dynamic calibration is essential to ensure accurate performance of TBRGs, and also raises the need for appropriate standardisation of the calibration procedures and certification of the measurement accuracy (*Lanza and Stagi, 2008*).

The performance of weighing gauge based on vibrating wire transducer is significantly lower than the one observed for both calibrated TBRGs and WGs, in terms of both the average (long term) rain figures and the deviations at the one-minute resolution in time.

The sample graphs presented in Fig. 18 to 22 are chosen for illustration purposes only. The significant differences in one-minute rainfall intensity measurements were observed even between the two "identical" gauges provided by manufacturers. This means that in future some variability should be introduced in tests as individual gauges might not behave precisely as their belonging "family" (calibrated TBRG, non calibrated TBRG, WG, etc.) may suggest.

However, the results of the laboratory tests are encouraging in the sense that many catching type rainfall intensity gauges were found to comply with the WMO accuracy specifications for the one-minute resolution under steady flow rate. This was not evident at the beginning of this laboratory tests. Also, many other gauges that were found not complying with the accuracy recommendations have a potential to be properly calibrated and to attain very good performance after suitable correction is applied.

The conclusion is that instruments that are already available on the market and not developed for RI measurements (some traditional tipping-bucket gauges and one weighing gauge) have the potential to allow high resolution rainfall intensity measurements with a sufficient accuracy, at least in controlled laboratory conditions. In many cases, like those presented in Fig. 14, performance of instruments was tested as provided from the manufacturer, while in other cases additional adjustments were required either in the hardware or software components.

The associated issue of the resolution of measurements (quantization noise) must be considered into account for residual uncertainty. Most WGs and LRGs have a good resolution below 6 $mm \cdot h^{-1}$, whereas most TBRGs provide a resolution between 6 $mm \cdot h^{-1}$ and 12 $mm \cdot h^{-1}$. Some manufacturers of TBRGs already employed suitable correction techniques to reduce the quantization noise thus increasing the measurement accuracy at lower rain flow rates.

The overestimation observed for TBRGs at the lower intensities are generally due to the adjustment performed by a manufacturer or a user on the tipping bucket balance in order to reduce the weight of water needed to initiate its tipping movement, which is not affecting the counting unit (the so-called single point calibration). This moderate overestimation effect usually vanishes at about 30-50 $mm \cdot h^{-1}$ and changes into even large underestimation errors with increasing rainfall rates.

Typical counting errors of TBRGs come from the combination of different factors:

- The uncertainty of the weight of water in the bucket when the tipping movement is initiated;
- A disequilibrium of the tipping bucket balance;
- Too slow tipping due to the inertia of the balance;
- Water losses during the tipping movement of the bucket due to mechanical reasons.

The first source of error results from using a nominal weight (or derived volume of water) instead of the actual weight needed to calculate rainfall intensity starting from the number of tips in a given time window. This is used to compensate mechanical errors to possibly get zero errors at a given rainfall intensity. A disequilibrium of the balance results in a difference of the volumes measured by the two bucket compartments. This error decreases with increasing rainfall rates and may result in calculating different intensities depending on the number of tips recorded for each single compartment. As for the third source of error, it is well known that TBRGs underestimate rainfall amount and intensity, especially at higher intensities. This is due to the inertia of the balance leading to a loss of rainwater during the tipping movement of the bucket. The related biases are known as systematic mechanical errors and can be quantified on average as 10-15 % at rainfall intensities higher than 200 $mm \cdot h^{-1}$, which can be easily corrected using proper calibration.

Results of laboratory tests performed on good quality TBRGs indicate that correct balancing of the buckets is essential for good instrument performance at one-minute resolution, although the average behaviour is scarcely influenced. Precise calibration of the bucket capacity (and the momentum of the balance) is not essential, provided the actual volume is used in calculating the resulting rainfall intensity instead of the nominal figure (although this is difficult to achieve in operational gauges). The actual volume can be determined based on the performance observed at the lowest intensities, where mechanical errors are negligible.

The variability of individual rain gauges with respect to the average correction curve is reduced when the above conditions are met and an optimal correction curve can be suitably determined in the laboratory for each instrument. After proper correction is applied, the residual errors on rainfall intensity measurements are lower than ± 1% under steady flow rate for the best performing instruments and are comparable to those associated with weighing type of gauges (see e.g. Fig. 18).

4.1.4 Dynamic response

The assessment of the step response of the various gauges provides further information about their suitability for rainfall intensity measurement. Tests were performed in order to investigate the step response behaviour of the gauges submitted to the intercomparison. The step response of the gauges was measured by switching between two different constant flows, e.g. from 0 $mm \cdot h^{-1}$ to 200 $mm \cdot h^{-1}$ and back to 0 $mm \cdot h^{-1}$. The constant flow was applied until the output signal of the raingauge was stabilized. The sampling rate was at least one per minute or higher for those instruments that allowed it.

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

The results of these further tests are presented in Fig. 23 below for one sample gauge. Again, the full set of graphs is reported in the data sheets for each single instrument. Note that the step response tests performed in the laboratory could not be done at a correct sampling rate to determine the one-minute behaviour of the instruments. Instead, the actual output of each instrument every minute was used. Therefore, the observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.

There was a larger response time and/or time delay with respect to the applied intensity step for some of the instruments analyzed. The response time varies between less than 1 minute and 4 minutes, whereas the delay can range from less than 1 minute to 5 minutes.

From Fig. 23, it can be noted that the step response is strongly dependent on the reference intensity, which is a common behaviour for most of the instruments investigated, with a decreasing effect, illustrated in this figure, when moving from low to high rainfall intensities. The accuracy of the measurement is therefore higher at the highest intensities. The response time plays an important role in assessing the performance of the instrument and even its overall suitability for rainfall intensity measurements.

NORMALIZED STEP RESPONSE

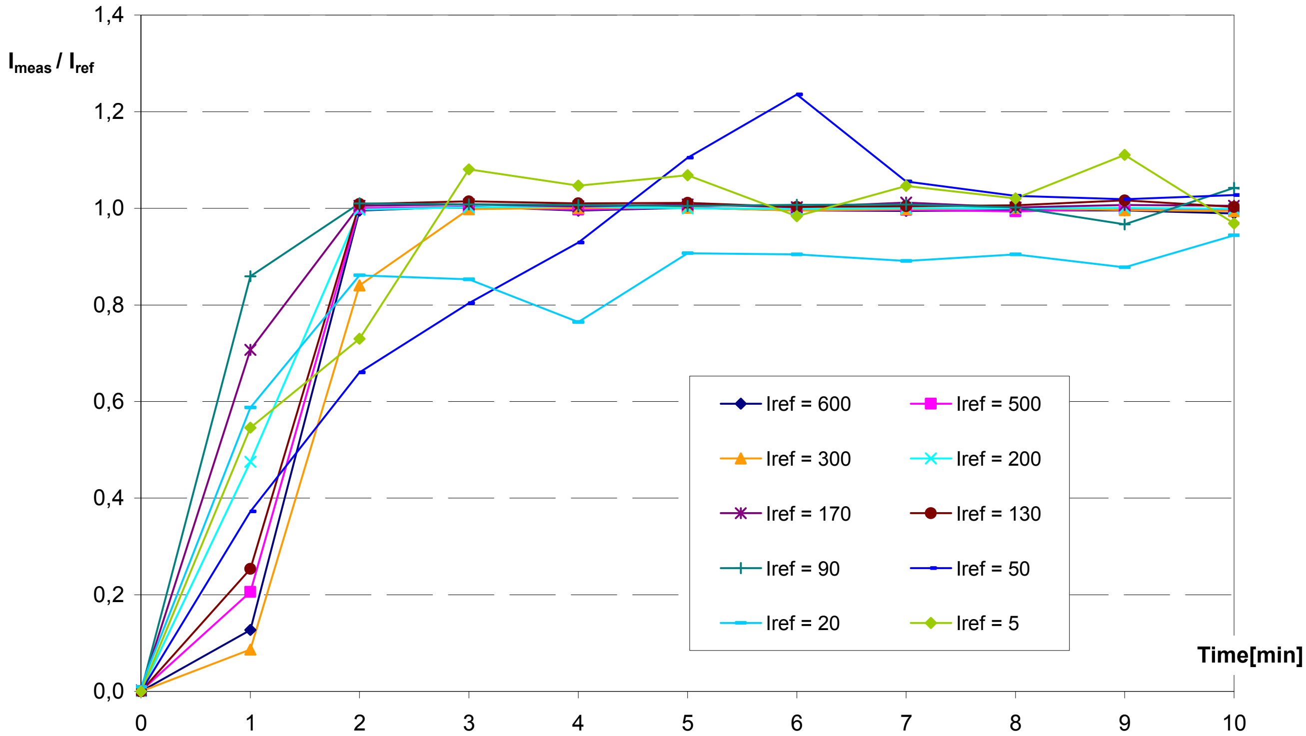


Fig. 23: Sample results from a step response test where the response curve for each single reference intensity is normalized and superimposed for better comparison.

4.1.5 Conclusions

The laboratory phase of the RI Field Intercomparison proved to be essential in providing basic information on the behaviour of the catching type instruments. The tests were performed under known and constant flow rates in closely controlled conditions, according to the recommended procedures developed during the WMO Laboratory Intercomparison of RI Gauges (2004-2005). The results of the laboratory calibration, done before the field intercomparison, generally confirm the findings of the Laboratory Intercomparison of RI Gauges. However, significant differences were observed due to the fact that design of some instruments has been changed by the manufacturers in the time period between the Laboratory and the Field Intercomparison to respond to the findings and recommendations of the Laboratory Intercomparison.

The laboratory tests were performed at the resolution of one minute, so that the spreading of the errors around their average value could also be evaluated. The derived calibration curves were not applied to the output data obtained in the field from the individual gauges, since only the manufacturer's calibration was allowed for the Intercomparison purposes. As for the reference rain gauges, to be installed in the pit, calibration curves were provided to assess the residual quantification errors and their spreading as a function of the rainfall intensity. For all other catching type gauges the curves will be useful to assess the potential improvement that can be attained by any possible additional hardware and/or software correction that the manufacturer might decide to implement for better accuracy.

4.2 FIELD CALIBRATION

At the end of 2007, the DICAT Laboratory of the University of Genoa provided the Field Site Manager (SM-FI) with a portable field calibrator to perform field calibrations tests of all catching type rain gauges during the intercomparison period[1]. The field calibration was part of the Quality Assurance plan adopted for this intercomparison (see Section 3.4). The main purpose of this activity was to verify the operational status of rain gauges, to detect malfunctions, output anomalies and calibration drifts throughout the field intercomparison. 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 field calibrator is composed of a cylindrical water tank, of about 6500 g of capacity, a combination of air intakes and output nozzles, for different rainfall intensities, and an electronic system to calculate the emptying time (see Fig. 24). According to the rain gauges collector size and the value of rainfall intensity chosen for the calibration, the suitable combination of air intakes and nozzles must be selected. By opening the top tap and the bottom nozzle, a constant flow starts to be conveyed to the funnel of the rain gauge and, through the time of emptying and the 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.

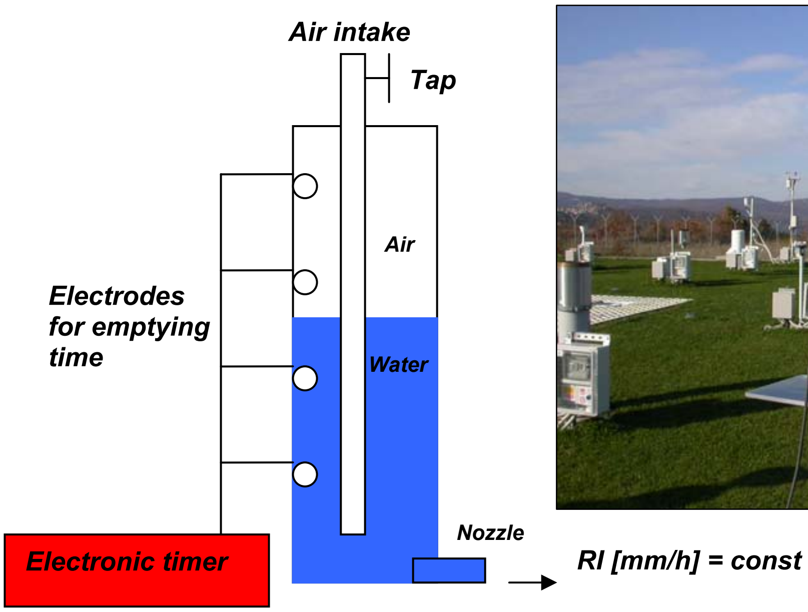


Fig. 24: The Portable Field Calibrator: the simplified scheme and the field setup during the Field Calibration at Vigna di Valle, Italy.

From the 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 cost effective solution for metrological verification of rainfall intensity instruments.

[1] The device was designed and developed by the DICAT Laboratory and patented on the 17th December 2006 (n°102006A00086). It was delivered as prototype version.

The repeatability of the field calibrator (and its accuracy) was assessed in a laboratory before the operational use. The uncertainty for each rain gauge 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:

Rain gauges collector size	*1000 cm^2*	*500 cm^2*	*400 cm^2*	*325 cm^2*	*200 cm^2*
$u_{rel}(RI_{ref})$ %	**1,0**	**1,5**	**0,4**	**1,8**	**1,8**

The field calibration was performed three times during the intercomparison period to verify the calibration status. Each time, several test series were done to investigate possible reasons of suspect malfunctioning or doubtful data. The range of generated RI used was 120-160 mm/h and at least 25-30 data points (1-MIN RI) were recorded for each rain gauge. All tests were performed in environmental conditions without precipitation or fog and with low wind speed (to avoid dynamic pressure perturbations to air intakes).

A statistical analysis of relative errors with respect to the field reference was elaborated for each rain gauge and reported in three Summary Tables (ST) (see Annex V). The following parameters were recorded in the ST:

- *Date and time*;
- *RI ref [mm/h*]: constant rainfall intensity generated by the field calibrator;
- *AVGRI [mm/h]*: average of 1-minute RI values (R^j_{1min} mm/h]) of the rain gauge during the calibration calculated as follows:

$$AVGRI = \frac{1}{N}\sum_{j=1}^{N}(RI^{j}_{1\min})$$

- *RI(+CL95%)* and *RI(-CL95%)* in [mm/h]: the 1-min RI extremes of an interval corresponding to the Confidence Level (CL) of 95%. Interval: [AVGRI - δ(95%) ; AVGRI + δ(95%)]. The amplitude δ(95%) is the confidence half width interval calculated according to a normal /T-Student probability distribution of samples;
- *AVG RE[%],* relative error of the AVGRI calculated as follows:

$$AVGRE = 100\cdot(\frac{AVGRI - RIref}{RIref})$$

- *RE(+CL95%)* and *RE(-CL95%),* relative errors [%] of RI(+CL95%) and RI(-CL95%) calculated as follows:

$$RE(+CL95\%) = 100\cdot(\frac{RI(+CL95\%) - RIref}{RIref})$$

$$RE(-CL95\%) = 100\cdot(\frac{RI(-CL95\%) - RIref}{RIref})$$

A reduced version of ST, containing the RIref [mm/h], AVGRE [%] and its 95% C.L. interval ([*RE(-CL95%); RE(+CL95%)]),* is reported into the catching type rain gauges Data Sheets. To show the general result of the field calibrations, the values of the AVGRE [%] and the 95% C.L. interval of all rain gauges were included in the three Summary Plots which are shown below (Fig. 25, 26, 27). Because the field calibrator was delivered in a prototype version and the principle of operation was improved during the intercomparison period, it was not always possible to reproduce, within known uncertainty, the same reference values of RI which were actually used in the laboratory of Genoa. Thus the laboratory relative errors can not be included in summary plots in a rigorous way by interpolation of laboratory data. For a direct comparison between field calibration and laboratory results shown in section 4.1, in all Summary Plots the reference RI generated during the field calibrations was additionally reported to the related relative error (AVGRE) and its 95% confidence level interval, as shown in Fig. 25-27. The name of rain gauges is replaced by the corresponsing ID number as indicated in the list of selected instruments in Annex III (in Summary Plot #3 – April 2009, number 29 is the PLUVIO-OTT). Through the evaluation of field calibration data, it was possible to summarize the following statements:

- By means of the first field calibration, it was found out that the PT 5.4032.35.008-THIES rain gauge (s/n 507650) had not been operated by means of the linearized output since the beginning of the campaign (1 October 2007), however, this was corrected as of 14 March 2008. ;
- During the first field calibration, the instability of the load cell was detected in the PG200-EWS (s/n CSM001107). During the Meeting of Participants, 21-22 May 2008, this instrument was replaced by the spare (s/n CSM001207);
- Field calibrations confirmed that MRW500-METEOSERVIS rain gauges suffered from a 1 minute oscillating step response (*see chapters 5.3.1, and 4.1 for laboratory tests*);
- The field calibrator was a powerful tool to check the operation and calibration status of catching rain gauges in case of suspected data or diagnostic alarms (few additional field tests);
- Within the calibrator measurement uncertainty and for the reference RI generated in the field, the general stability of calibration status could be confirmed for all catching rain gauges (except the cases above) throughout the Intercomparison period.

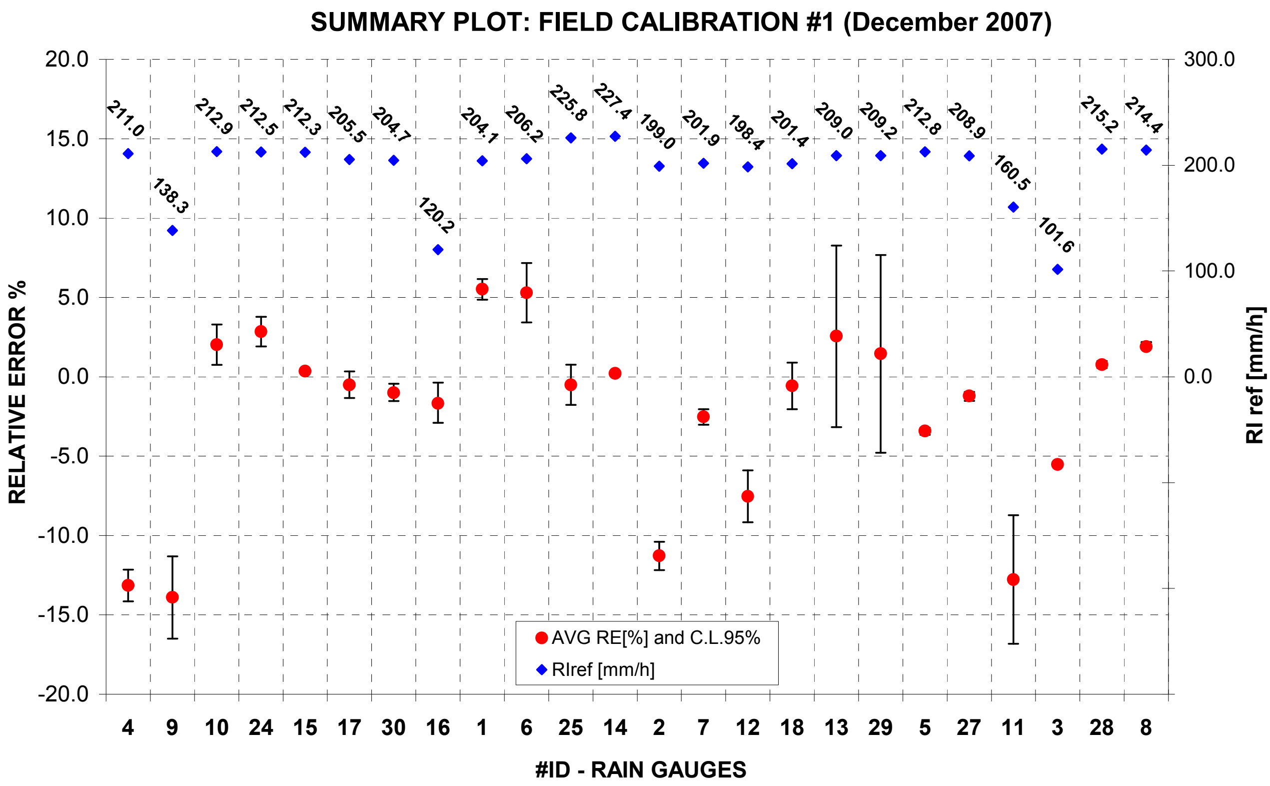


Fig. 25: The first field calibration (Vigna di Valle, Italy). The orange dots are the rain gauges relative errors with respect to the reference and whisker caps represents the 95% confidence level interval. Blue dots represent the reference RI generated during the field calibration

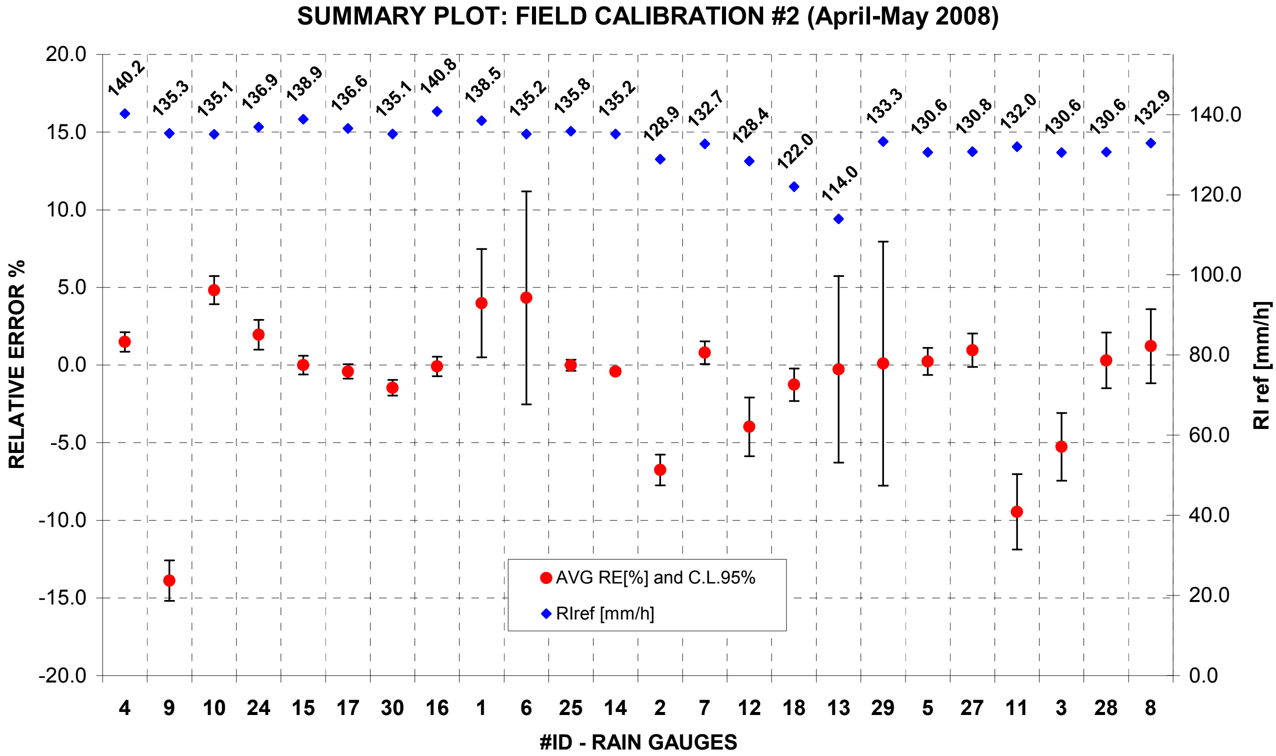


Fig. 26: The second field calibration (Vigna di Valle, Italy). The orange dots are the rain gauges relative errors with respect to the reference and whisker caps represents the 95% confidence level interval. Blue dots represent the reference RI generated during the field calibration

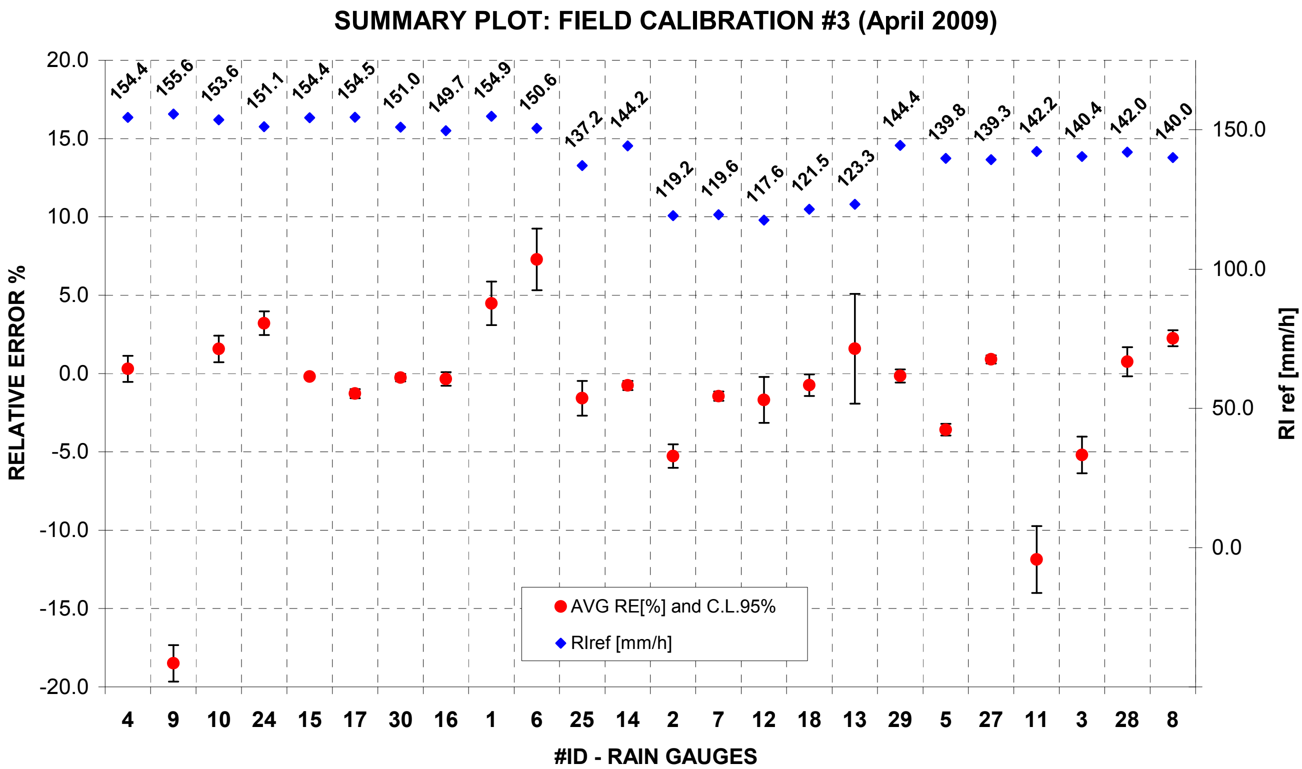


Fig. 27: The third field calibration (Vigna di Valle, Italy). The orange dots are the rain gauges relative errors with respect to the reference and whisker caps represents the 95% confidence level interval. Blue dots represent the reference RI generated during the field calibration. Here the #29 is the PLUVIO-OTT.

CHAPTER 5

DATA ANALYSIS AND RESULTS

5.1 QUALITY CONTROL AND DATA PROCESSING

Quality Control (QC) of data is a fundamental component of quality management systems and is important for the examination of data to detect errors and take follow-up actions. The general guidelines are described in the CIMO Guide (*WMO, 2008a*). The aim of a QC system is to verify the data and to prevent the recurrence of errors. These procedures can be applied both, in real time and in non-real time as a delayed action for data quality assurance.

The QC procedures have been implemented before the intercomparison so as validated data are provided to the Data Manager and tools for the control of the functioning of instruments are available to the Site Manager. According to the *WMO Manual on the Global Data-processing and Forecasting System, WMO-No. 485 (WMO 1992b), Appendix II-1, Table 1 "Minimum standards for quality control of data - both real time and not real time"*, possible errors are described in BUFR table 033020, "Quality control indication of following values" *(BUFR Reference Manual of ECMWF, 2006)*:

- Good #1, (accurate; data with errors less than or equal to a specified value);
- Inconsistent #2, (one or more parameters are inconsistent; the relationship between different elements does not satisfy defined criteria);
- Doubtful #3, (suspect);
- Erroneous #4, (wrong; data with errors exceeding a specific value);
- Missing data #5, (external error or "to be checked" during the event);
- Under maintenance #6, (data missing due to a maintenance action).

The raw data from the rain gauges were processed by DAQ in real-time to produce 1-minute RI data (see Chapter 3.3). Raw data from ancillary sensors were also by DAQ real-time to produce the 1-minute averages of wind speed and wind direction, maximum wind speed, temperature and standard deviation (STD), relative humidity and STD, output of wetness sensors, global irradiance and atmospheric pressure. The automatic quality control (AQC) procedures checked files coming from DAQ, namely the RI raw data and the 1-min RI data. Based on this the following, quality-controlled files were computed:

- The 1-minute RI data files (QC_RI_"yyyy-mm-dd.dat");
- QC information (QC_DATA_"yyyy-mm-dd.dat"- 1-min data with FLAGS; and
- The QC daily report for rain gauges performances monitoring (REPORT_DIAGNOSTIC_"yyyymmdd.dat")-;
- The 1-min ancillary data (QC_ANCILLARY_"yyyy-mm-dd.dat").

The AQC applied specific procedures were agreed by the CIMO ET-SBII&CM (*see WMO-2007c - Final Report of the fifth session of the Expert Team Meeting CIMO-SBII&CM, Vigna di Valle, Italy, 17-21 September 2007 and WMO 1992b)*.

"Good" 1-min RI data are labelled by FLAG=1 in the specific file with flags, otherwise FLAG≠1 and a value equal to -1 is reported, instead of the measured RI, in the QC_RI_"yyyy-mm-dd.dat" file. Those data whose flag means "doubtful" are evaluated "a-posterior" to determine if they can be restored for analysis. In the same way, "good" 1-min ancillary data are labelled by FLAG=1, otherwise FLAG≠1 and a value equal to -1 is reported in QC_ANCILLARY_"yyyy-mm-dd.dat".

One-minute QC data of RI and ancillary sensors (namely, QC_RI_"yyyy-mm-dd.dat" and QC_ANCILLARY_"yyyy-mm-dd.dat") are used for the analysis.

The implemented automatic QC procedures for rainfall intensity data are described in Annex VI. The QC procedures for RI data check:

1) Number of samples - MISSING DATA (FLAG=5);
2) Native errors- DOUBTFUL/ERRONEOUS DATA (FLAG=3,4): for those instruments that could provide diagnostic information;
3) Operational limits - DOUBTFUL/ERRONEOUS DATA (FLAG=3,4);
4) E-logbook reports - UNDER MAINTENANCE DATA (FLAG=6).

The AQC of ancillary data takes into account (a) the working limits of ancillary sensors, (b) the plausible values related to climatic conditions, (c) the "external" consistency conditions about the maximum and minimum time variability of the parameters, and (d) the "internal" consistency. The implemented automatic QC procedures for ancillary data are described in Annex VI. The QC procedures for ancillary data check:

1) Operational limits - ERRONEOUS DATA (FLAG=4);
2) Time consistency - DOUBTFUL/ERRONEOUS DATA (FLAG=3):
   a) check of the maximum allowed variability of the 1-minute value;
   b) check of the minimum required variability of 1-minute values during 1 hour;
3) Internal consistency - INCONSISTENT DATA (FLAG=2).

5.2 SUMMARY OF AVAILABLE DATA

The Field Intercomparison has been continuously managed for 18 months in all weather conditions. Excluding three scheduled and one extraordinary maintenance service of data acquisition system and field cabling (totally 23 days), and the periodic maintenance works of rain gauges (documented by the e-logbook). The total availability of 1-minute data was 95.4%, approximately $7.41 \cdot 10^5$ minute-data of all weather conditions (rain and no rain conditions).

The number of precipitation events (collected in daily files) was 162 (156 events with rain and 6 events with hail and mixed rain/hail).

The following selection criteria were applied to precipitation daily events in order to obtain the best dataset for the purpose of the Field RI Intercomparison: (*see also chapter 5.3.4*):

1. The events used for the analysis were chosen among those that occurred during the period from 13 May 2008 to 30 April 2009. Problems of synchronization and other critical malfunctions where all solved before 13 May 2008. The event of the 30 October 2007 was the only one included (the highest rainfall rate event) that occurred during the period with the problem of synchronization;
2. The events used to retrieve the weights for the calculation of the reference RI (see chapter 5.3.1) had to be characterized by rainfall data with at least 2 consecutive minutes with RI_{1min}>6 mm/h (isolated point/events or those with RI_{1min} < 6 mm/h were discarded).
3. The events used for the RI data analysis had to be characterized by rainfall data with at least 2 consecutive minutes and RI_{1min}>12 mm/h.

According to first criterion, the number of daily events considered for the Field Intercomparison was 85. This was the basis for the "reduced" Field Intercomparison (FI) dataset. According to the second criterion, 79 events (out of 85) were used for the calculation of reference RI. According to the third criterion, 43 events (out of 79) were used for the data analysis of all rain gauges.

According to the QC daily reports (described in sec.5.1 and Data Sheets) the total availability of valid data was 98.2%. The following table is a summary of available data for the Field Intercomparison.

Total availability of 1-min data (rain/no rain)	***1-min valid data (rain/no rain): percentage of available 1min data that are valid according to QC***	***Total numbers of precipitation daily events***	***Hail and Mixed Rain/Hail events***
T.A. = 95.4%	98.2% of T.A.	162 *(Full FI Dataset)*	6 events: 13th Jan, 4th Feb, 7th May, 30th Oct 2008; 1st Jan, 5th Mar 2009
Numbers of synchronized events	***Numbers of events for reference RI calculations***	***Number of events for data analysis of rain gauges***	***Rainfall accumulated over the intercomparison period***
85 *(Reduced FI Dataset)*	79 (28 0001-min data)	43 (740 1-min data)	1325 mm

Table 3: Summary of available data

In conclusion, Table 4 and the related plot (Fig. 28) show the 43 maxima values of reference rainfall intensity (RI) recorded in each event used for data analysis, sorted from higher to lower RI values.

Nr	***Date***	***Max [mm/h]***	***Nr***	***Date***	***Max [mm/h]***	***Nr***	***Date***	***Max [mm/h]***	***Nr***	***Date***	***Max [mm/h]***
1	04/11/2008	195,1	12	05/12/2009	69,8	23	31/10/2008	37,5	34	24/01/2009	23,7
2	20/05/2008	152,4	13	22/05/2008	63,5	24	06/12/2009	36,1	35	04/03/2009	23,2
3	28/11/2009	112,7	14	13/05/2008	62,1	25	10/12/2009	34,8	36	20/01/2009	22,2
4	28/10/2008	108,9	15	06/06/2008	61,7	26	29/11/2009	33,6	37	07/02/2009	20,8
5	30/11/2009	107,9	16	01/11/2008	54,9	27	27/04/2009	31,3	38	18/02/2009	17,9
6	23/04/2009	84,4	17	16/12/2009	52,4	28	28/04/2009	29,2	39	10/02/2009	17,4
7	07/01/2009	78,8	18	08/09/2008	47,0	29	24/11/2008	27,8	40	31/03/2009	16,6
8	15/12/2009	75,8	19	01/01/2009	43,9	30	12/11/2008	26,3	41	15/01/2009	13,7
9	15/09/2008	75,4	20	26/01/2009	42,3	31	11/12/2009	26,3	42	14/12/2008	13,6
10	02/03/2009	73,2	21	29/10/2008	39,1	32	01/04/2009	25,8	43	05/03/2009	12,3
11	30/10/2008	72,3	22	27/07/2008	38,3	33	29/03/2009	24,2			

Table 4: RI absolute maxima recorded in the data analysis dataset

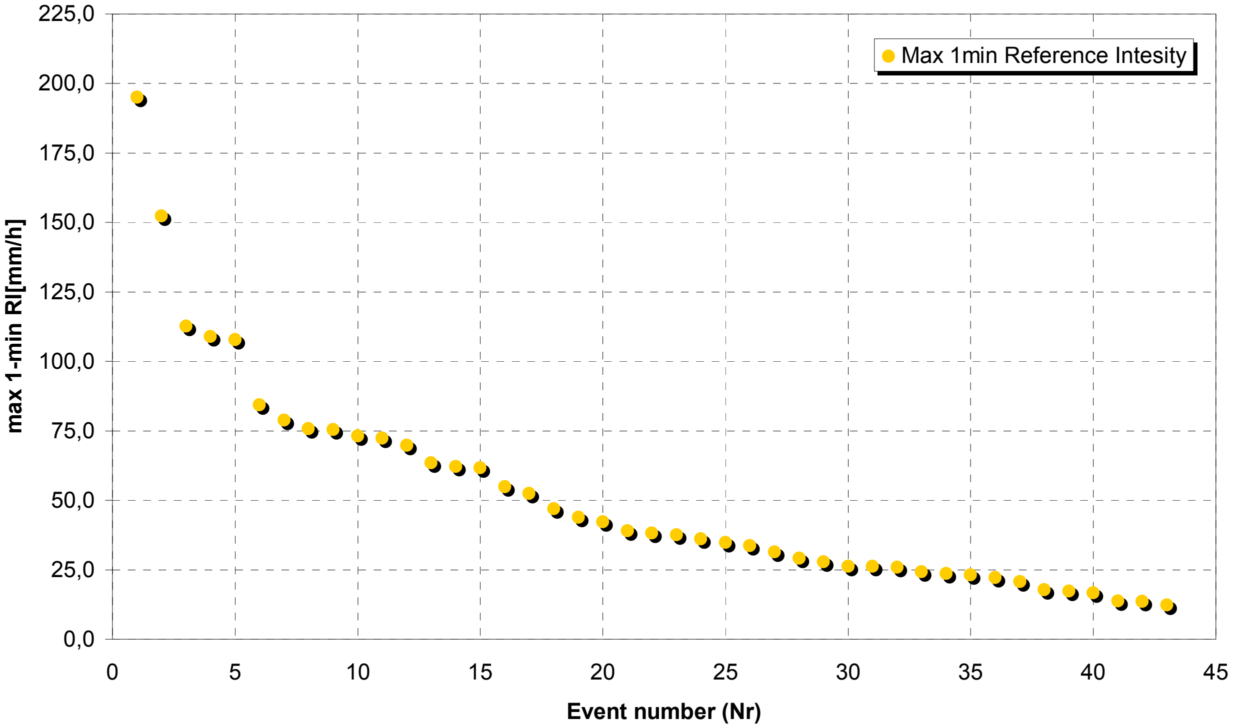


Fig. 28: The plot of Table 4

5.3 DATA ANALYSIS

In order to perform the best intercomparison of rainfall intensity instruments in the field conditions, it was necessary to develop the appropriate tools, to compare different instrumental responses during a wide range of rainfall events.

Therefore it was necessary to find a specific statistical approach, taking into account the complex nature of the observed phenomenon. The analysis of the 1-minute RI data was done through different steps:

a) First a reliable 1-min working RI reference made up from the four reference rain gauges installed in the pit (R102-ETG, PMB2-CAE, MRW500-METEOSERVIS, T200B-GEONOR) was determined.

b) Each rain gauge data were analysed in comparison with the calculated 1-min RI reference, and its performance and possible relation with weather conditions were evaluated.

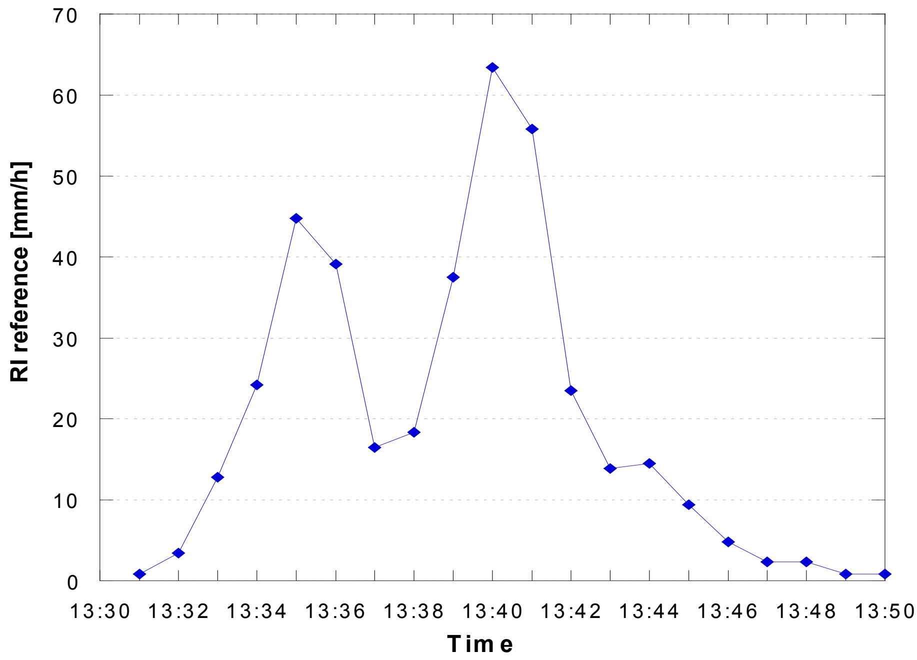
c) The guidelines of the RI data analysis were developed in the attempt to answer the following questions:

- Given the fact that there are four different rain gauges as references, should the RI reference be a simple average value or a more complex function of all the field conditions (rainfall intensity, ancillary data, etc)?

- How could the uncertainty of the reference value be defined? Compared to the situation in the Laboratory Intercomparison, the definition of a measurement uncertainty in field conditions is not trivial and should take into account unknown variables.

In order to determine the most appropriate way of analyzing the data, a representative group of RI events was studied first to test different procedures. A method developed in this way was applied to all the intercomparison selected events.

To illustrate the high temporal variability of RI and the difficulties related to the comparison of 1-minute data from all rain gauges, an example of rainfall intensity versus time is shown below.



5.3.1 Reference value

The RI reference is the best estimation of the 1-minute RI true value that can be obtained from the working reference gauges inside the RRGP, which are two corrected tipping bucket rain gauges (TBRG with correction algorithm) and two weighing gauges (WG) with the shortest step response and the highest accuracy obtained from the WMO Laboratory Intercomparison results (2004-2005).

The determination of a reference value of the rainfall intensity is fundamental for defining the baseline for the intercomparison. Since there are four instruments that were chosen as RI reference gauges, it was necessary to define how to convert their readings into to a RI composite working reference value. The best estimation of a RI composite working reference can be done using two different methods:

1. The use of the dynamic response of the set of reference gauges;
2. The statistical evaluation of the experimental data.

The first method requires specific laboratory or field tests with several step function inputs in a suitable range of RI to determine experimentally the step response function and the time constant of each instrument. The static characteristics of an instrument and measurements of the output must be made for different values of the input. During the transition from one static state to another, as during a precipitation event, the system becomes dynamic. The step response function of each reference rain gauge applied in field conditions would provide the best estimate of the 1-minute RI value within a tolerance that is a combination of the uncertainties evaluated experimentally in the laboratory through a standard procedure. The accuracy of some catching-type rain gauges could depend on their response to dynamic characteristics of the natural phenomenon of precipitation. This method was discarded because little information was available about the time constant of each instrument and its influence on the overall accuracy of the reference.

The second method consists of a statistical evaluation and was used for the estimation of a RI composite working reference, as follows:

The statistical evaluation of the 1-minute RI reference is made using a **Weighted Average** obtained from the rainfall intensities measured by the four references:

$$RI_{ref} = \frac{\sum_i \mu_i RI_i}{\sum_i \mu_i}$$

where μ_i is the weight of the reference rain gauge i (i = R102-ETG, PMB2-CAE, MRW500-METEOSERVIS, T200B-GEONOR). Calculation of weights is the most challenging issue. As it will be shown in the following graphs which represent high RI events in October 2008, a purely statistical evaluation is not sufficient, because it is necessary to take into account effects related both to dynamic internal characteristics and the possible lack of synchronization on 1-minute time base. For this reason the weights were calculated taking into account both a global statistical parameter, obtained from the whole data set, and also the evaluation of each single event from which the average is calculated:

$$\mu_i = \frac{S_i^{-1} \cdot F_i}{\sum_i S_i^{-1} \cdot F_i}$$

where $S_i = \sum_{k \neq i} \sigma_{ik}$ with k = R102-ETG, PMB2-CAE, MRW500-METEOSERVIS, T200B-GEONOR but $k \neq i$; σ_{ik} are 3 statistical parameters calculated for each reference gauge i compared to the other references rain gauges in RRGP throughout the database of all precipitation events as:

$$\sigma^2_{ik} = \frac{\sum_{j=1}^{N} (RI_j^i - RI_j^k)^2}{N}$$

where:

- RI_j^i the j^{th} 1-min intensity measured by the reference rain gauge i in the RRGP,
- RI_j^k the j^{th} 1-min intensity measured by the reference rain gauge k in the RRGP,
- N the number of experimental (1-minute RI) data of all the events.

The evaluation of each single event is introduced in the weights μ_i through the factor F_i, which is a "gross" parameter determined on the basis of a detailed examination of the RI data for that event. This parameter can be 1 or 0, it is 1 if the reference rain gauge under examination is not evidently affected by 1-minute lack of synchronization or high dynamic oscillation, otherwise it is 0, which means that pit gauge for that particular event is excluded from the calculation of the reference intensity.

Therefore after the examination of the laboratory/field tests for the response function determination, these functions could be used for accurately estimation of composite RI reference. The calculation of the F parameter can be more appropriate and the calculation of weights is a combination of a statistical and physical component.

The calculation of the statistical parameters S_i, according to the above-mentioned procedures, gives the following values:

S_{R102}^{-1}	S_{PMB2}^{-1}	S_{MRW500}^{-1}	S_{T200B}^{-1}
0.172	**0.192**	**0.226**	**0.238**

Looking at the values obtained for the S^{-1} parameter, it was found that the behaviour of the four reference rain gauges is such that their weights should be almost the same in the calculation of the RI composite working reference. The strongest difference is given instead by the other parameter *F* that is related to the behaviour of the instrument during each rainfall event.

In order to develop the best method for the calculation of the 1-min RI composite working reference, a selection of rainfall events was performed according to the criteria described in section 5.3. There were eleven 1-min RI events that matched the requirements and were selected from the complete database for the following analysis. These RI events represent the best example of the application of the statistical method described above and they show the effect of the 1-minute lack of synchronization and dynamic behaviour. These preliminary results were presented during the Sixth reduced Session of the CIMO ET/IOC meeting (*WMO, 2008b*) for evaluation and approval.

In order to analyze the behaviour of the four reference gauges in the considered rainfall events, the relative differences (RD) between the measured rainfall intensities and the RI composite working references on 1 minute time scale were computed as follows:

$$RD_i = \frac{RI_i - RI_{ref}}{RI_{ref}} \cdot 100\% \,.$$

RD_i were plotted versus a non-scaled ascending series of 1-minute RI composite working reference values calculated as the weighted averages of the RRGPs 1-minute measured intensities of the events (namely event #1 to #11), as shown in Fig. 29, 30 and 31.

The calculated weighted average is obtained assuming that all the instruments in the pit did not have synchronization or dynamical problems, therefore the *F* parameter is equal to 1 for all the instruments and events. In this case the weights are:

μ_{R102}	μ_{PMB2}	μ_{MRW500}	μ_{T200B}
0.27	**0.25**	**0.23**	**0.25**

Figure 29 illustrates that the R102-ETG and T200B-GEONOR gauges have a relative difference in most cases of ±20 %; in particular the R102 sensor is well within this limit, whereas the T200B-GEONOR shows wider variations. The PMB2-CAE and MRW500-METEOSERVIS gauges on the other hand show a different situation, because they have very high relative differences with big variation compared to the other two gauges.

After a detailed examination of events #1 to #11 it was concluded that in event #3 the PMB2-CAE reference gauge was strongly affected by 1-minute non-synchronization that did not permit a good estimation of composite working RI reference (relative differences of the four references are too high on average). To minimize the RD, the PMB2-CAE gauge was excluded in event #3 (F_{PMB2}=0). In events #1, 2, 4, 5, 6, 7, 8, 9, 10 and 11 this instrument was perfectly synchronized and the *F* parameter is set to 1. Unfortunately the MRW500-METEOSERVIS gauge, which is always synchronized, has shown an anomalous behaviour due to 1 minute oscillating step response that had not been observed during the previous Laboratory Intercomparison (2004-2005 , Lanza et al. 2005b). According to manufacturer, these oscillations were caused by the time beats between the rain gauge sampling period of 16 s and the output readout period of 60 s. Thus they were due to the fact that the measurement interval of 60 s did not coincide with the multiple of the sampling interval of 16 s of the rain gauge. Therefore, in all events this gauge was excluded from the calculation because its 1-min RI clearly deteriorated the accuracy of a RI composite working reference estimation.

During event #6, the R102-ETG gauge did not work properly; therefore *F was set to 0* for R102-ETG in this event. This is a typical “event based” criterion to assign the value of the “gross” parameter.

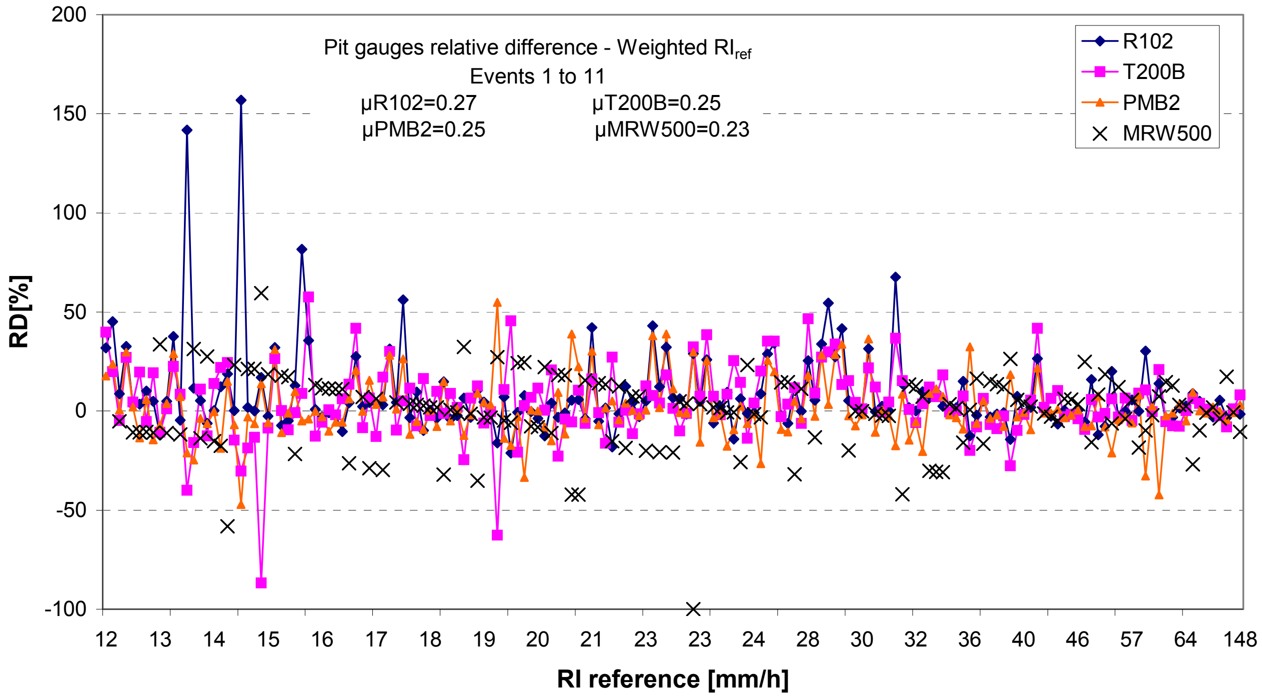


Fig. 29: RI relative difference of each working pit gauge with respect to the calculated composite working RI reference; the weights for the RI average are computed with $F_{R102} = F_{PMB2} = F_{MRW500} = F_{T200B} = 1$ for all the events.

The result of the RI reference calculated is shown in Fig. 30. In this graph, the *F* parameters for event 1, 2, 4, 5, 7, 8, 9, 10, 11 are $F_{R102} = F_{PMB2} = F_{T200B} = 1$ and $F_{MRW500} = 0$; for event 3 $F_{R102} = F_{T200B} = 1$ and $F_{PMB2} = F_{MRW500} = 0$; for event 6 $F_{PMB2} = F_{T200B} = 1$ and $F_{R102} = F_{MRW500} = 0$.

In this case the RI reference is not affected by the wide variations of MRW500-METEOSERVIS and by the lack of synchronization of PMB2-CAE in event #3. It is evident that the effect on the RD of R102-ETG and T200B-GEONOR gauges is dominant and it becomes smaller and decreases when RI increases. The RD of R102-ETG and T200B-GEONOR reduces to about 10%. Looking at the RI data without the PMB2 RD values of rainfall event #3, as shown in Fig. 31, it is evident that when the PMB2-CAE is synchronized it shows very good agreement with R102-ETG and T200B-GEONOR; with a RD in the range of ± 10%. Note also the higher the intensity the better the agreement. Some RD values corresponding to a larger variation of T200B-GEONOR gauge can be explained through the Laboratory tests results, where it was seen that the response time of this instrument is around 1 minute.

A very useful tool for the evaluation of the effects of non-synchronization and dynamical behaviour is the representation of the relative difference RD compared to the 1-minute RI reference variation:

$$\Delta = RI_{ref}(t) - RI_{ref}(t - 1\,\mathrm{min})$$

This parameter can be used to investigate a possible dependence of RD on the variation of the rainfall intensity on 1-minute time scale, for example a study of dynamic effects due to the transition from one state to another during a precipitation event.

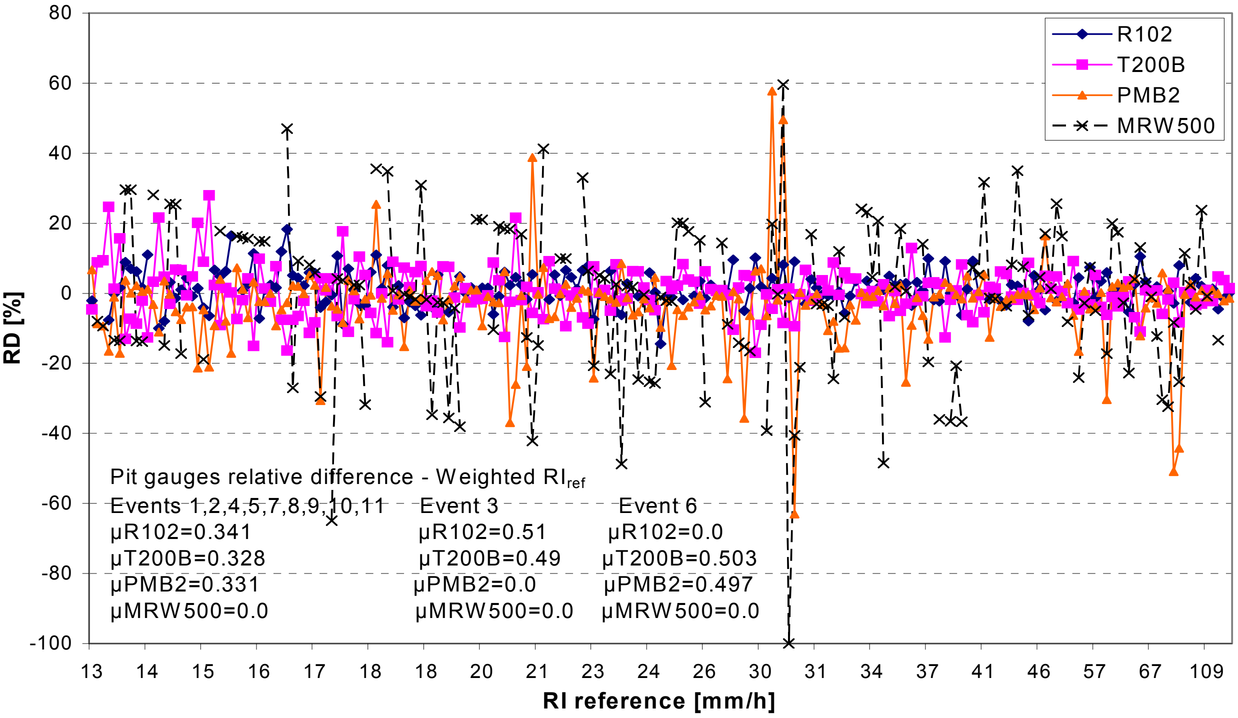


Fig. 30: RI relative difference: the weights for the RI average are computed with $F_{R102} = F_{PMB2} = F_{T200B} = 1$ for events 1, 2, 4, 5, 7, 8, 9, 10, 11; $F_{PMB2} = F_{MRW500} = 0$ and $F_{R102} = F_{T200B} = 1$ for event 3 and $F_{R102} = F_{MRW500} = 0$ and $F_{PMB2} = F_{T200B} = 1$ for event 6. Note that x-axis is non-linear.

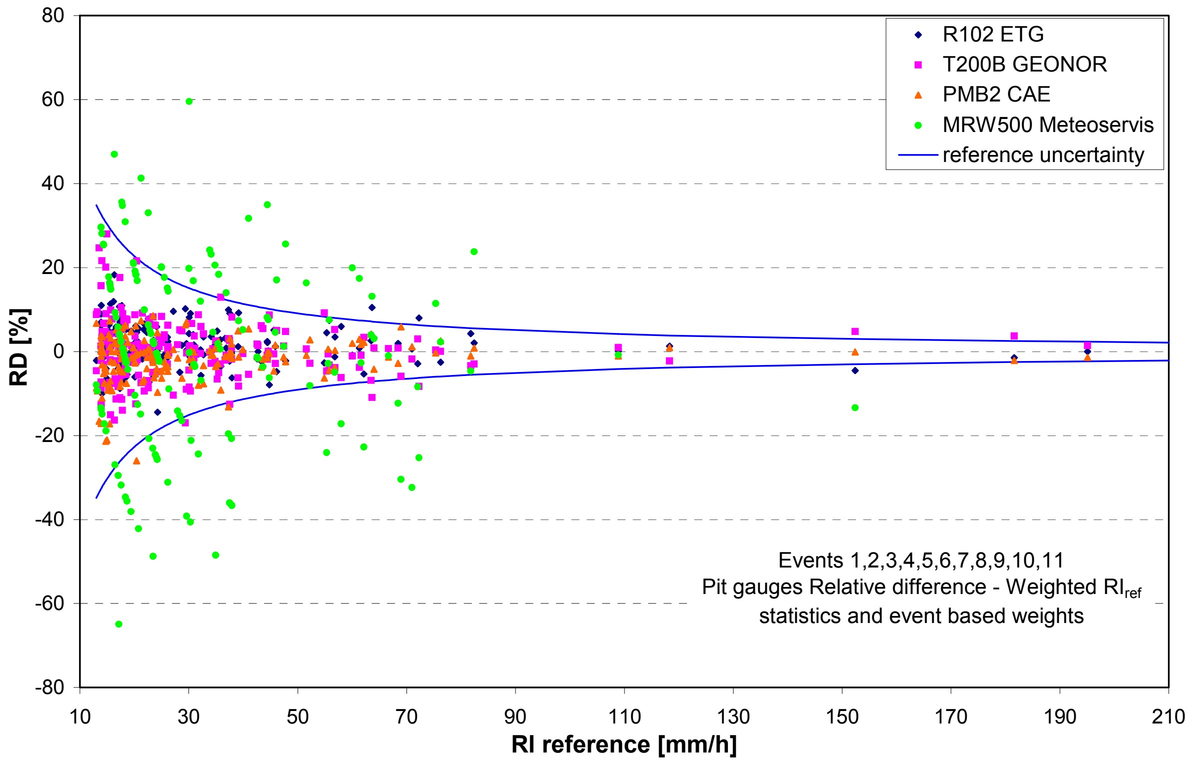


Fig. 31: RI relative difference: the weights for the RI average are computed with $F_{R102} = F_{PMB2} = F_{T200B} = 1$ for events 1, 2, 4, 5, 7, 8, 9, 10, 11, $F_{PMB2} = F_{MRW500} = 0$ and $F_{R102} = F_{T200B} = 1$ for event 3 and and $F_{R102} = F_{MRW500} = 0$ and $F_{PMB2} = F_{T200B} = 1$ for event 6. Data points of PMB2 gauge for event 3 are not represented. For reference uncertainty, see chapter 5.3.2.

From Fig. 32 and 33 is evident that R102-ETG and T200B-GEONOR do not show particular dependence on the RI variation parameter, therefore these two gauges represent the most reliable set of references through the evaluated events.

The distribution of RD experimental points for PMB2-CAE reference gauge shows a diagonal distribution in event #3 (Fig. 34), otherwise RD does not show particular dependence on the Δ variations for the other events. During event #3, when Δ > 0 then RD< 0 (RI_{PMB2} has not yet increased compared to the RI composite working reference) and when Δ < 0 then RD> 0 (RI_{PMB2} has not yet started decreasing compared to RI composite working reference); the transmission of the 1-min data from the instrument is delayed compared to the data acquisition timestamp. PMB2 represents the most reliable gauge for the four events (even better then R102-ETG and T200B-GEONOR) as graphs show, but it cannot be weighted for event #3 due to an evident non-synchronization on 1-minute time scale. This is confirmed by a detailed examination of raw data timestamp and can be explained by the data acquisition method; at the time when event #3 occurred, PMB2-CAE was set to automatic data transmission but the procedure to synchronize its internal clock with the main clock of the DAQ system was not in operation.

The distribution of experimental points of RD for gauge MRW500-METEOSERVIS (Fig. 35) does not show a dependence on RI variation but the values in Fig. 35 are very scattered due to a 1-minute oscillating step response which does not permit an accurate RI measurement or a RI composite working reference determination on a 1-minute time scale. Moreover, the low resolution of this gauge on 1-minute precipitation negatively affects the comparison between the four pit gauges.

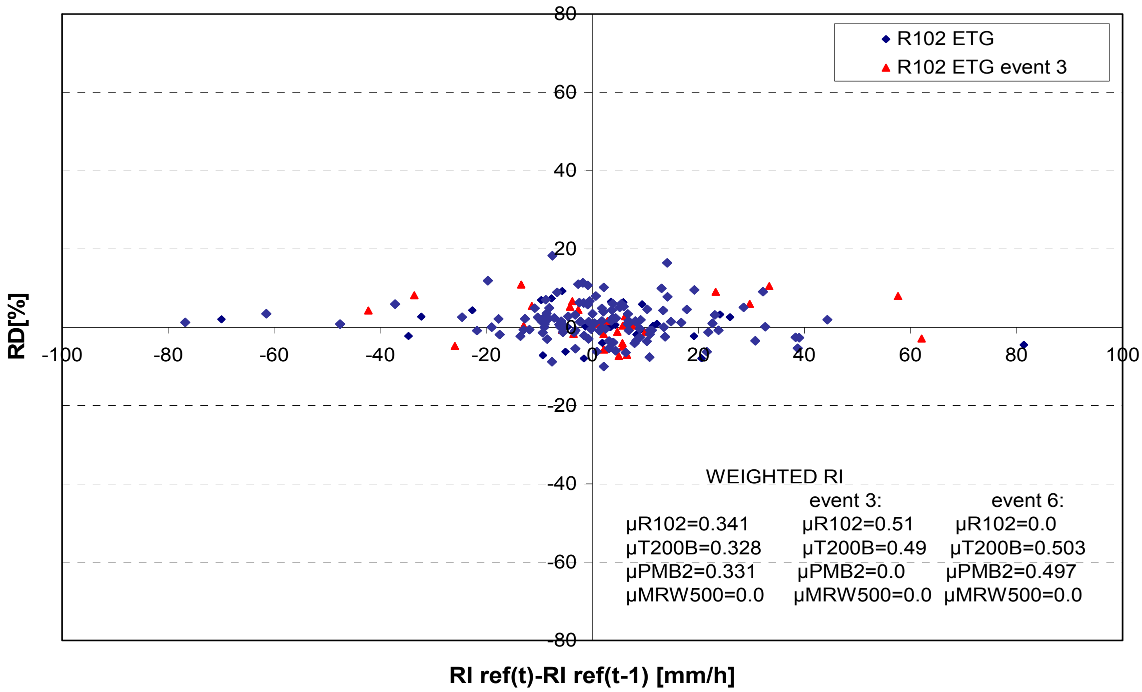


Fig. 32: Relative difference of R102-ETG compared to time variation of RI reference.

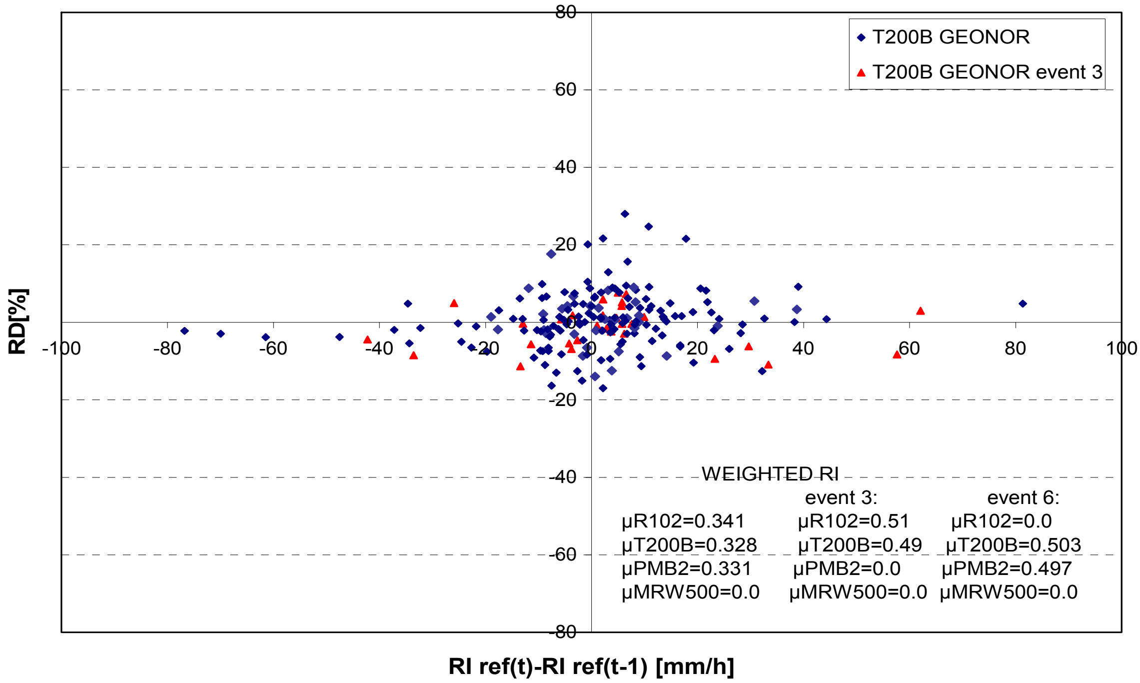


Fig. 33: Relative difference of T200B-GEONOR compared to time variation of RI reference.

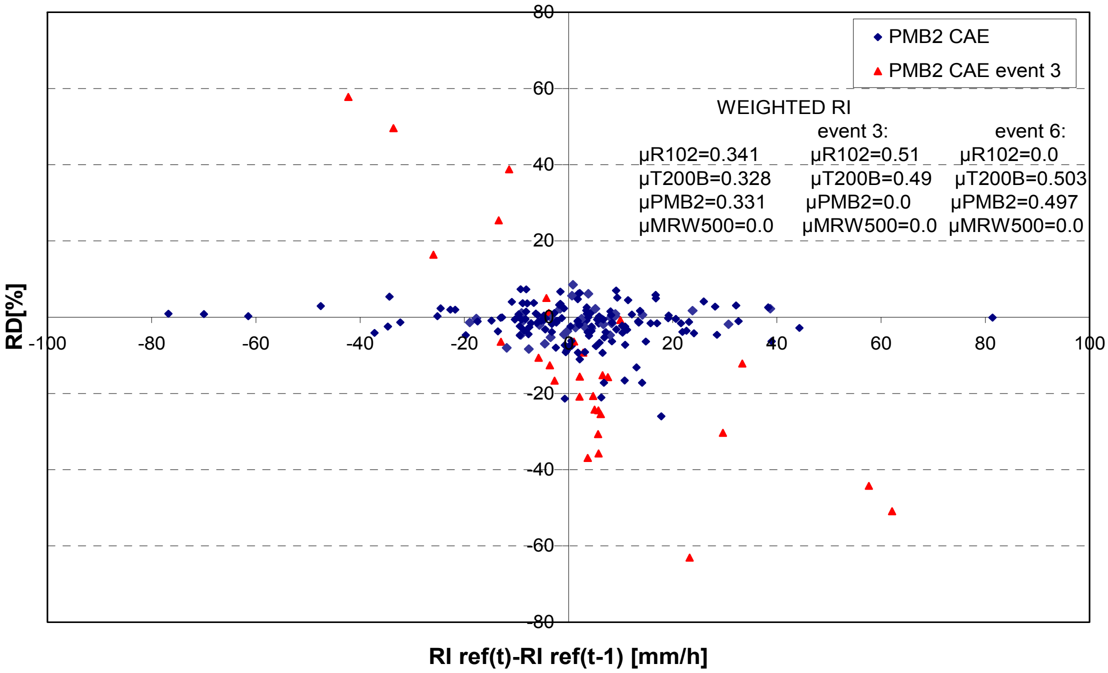


Fig. 34: Relative difference of PMB2-CAE compared to time variation of RI reference.

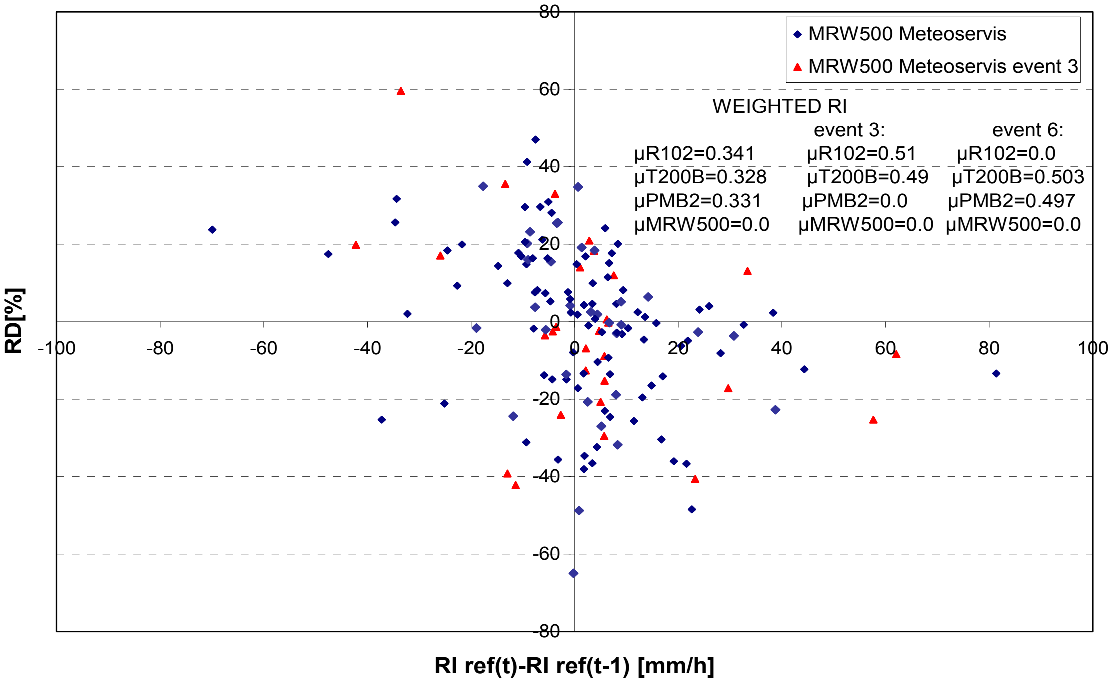


Fig. 35: Relative difference of MRW500-METEOSERVIS compared to time variation of RI reference.

The analysis of the laboratory calibrations on 1-min time basis performed during the preliminary phase of this intercomparison confirms the large dispersion of data due to the above-mentioned oscillating step response. This effect was not seen during the previous WMO Laboratory Intercomparison and explains why the MRW500-METEOSERVIS was at that time selected for participating to the reference group. Therefore the CIMO ET/IOC decided to exclude the MWR500-METEOSERVIS pit rain gauge from the calculation of the 1-min RI composite working reference (*see WMO 2008b: Chapter 3.3.2 and 3.3.3, Final Report of the sixth session of the Expert Team Meeting CIMO-ET-IOC-SBII, Vigna di Valle (Italy) 15-17 September 2008*).

5.3.2 Uncertainty of the reference

The method described above permits to calculate 1-minute RI composite working reference as the best estimation of the 1-minute RI true value. The evaluation of the uncertainty of this reference value is very complex because the physical contributions due to the dynamics of the instruments, their response functions and environmental related effects are not known, therefore, in order to evaluate the uncertainty of the calculated RI composite working reference**,** it was decided to proceed as follows:

A normal distribution of the deviations of the rainfall intensity measurements of the pit gauges is assumed and the standard deviation of the distribution with respect to the reference intensity is calculated according to $\sigma=[\sum(RI-RI_{ref})^2/N]^{1/2}$, where the sum is extended for all the RI>12 mm/h of the three reference gauges. It is common practice in metrology to express the uncertainty as "expanded uncertainty" in relation to the "statistical coverage interval", therefore the 95% confidence level, or k=2, is used for all measurements. Since the measurement uncertainty is assumed to be independent on the rainfall intensity, the RI reference expanded uncertainty (95%) is calculated as $U(RI_{ref})= 2\sigma$. The relative uncertainty (k=2) is thus $u_{rel}(RI_{ref})= (U(RI_{ref}) / RI_{ref})\cdot 100$ and it is plotted in Fig. 31. The 95% of all experimental points are inside the uncertainty limits and the formula to calculate the relative uncertainty of the reference intensity is a function of RI.

The extension of the results, derived from the sample of representative events in chapter 5.3.1, the dataset of the events of the RI-FI campaign gives the values of the weights that are used for the calculation of the reference rainfall intensity and determination of the uncertainty of the reference (Fig. 36). For the 1-minute data, the calculated uncertainty is $U(RI_{ref})$= 4.3 mm/h. Table of the weights is reported in Annex VII.

In Fig. 36, where the relative difference RD between the pit gauges' RI is represented as a function of the reference intensity, it is evident that the dispersion of data is higher for RI below 30 mm/h, where there is also the effect of short and sudden rainfall events. The response of the instruments in fact is not instantaneous, moreover the initial status of tipping buckets is very important, because some water could have remained in the bucket. When the intensity of the precipitation event increases, the dispersion reduces and it is very low for high intensity rate.

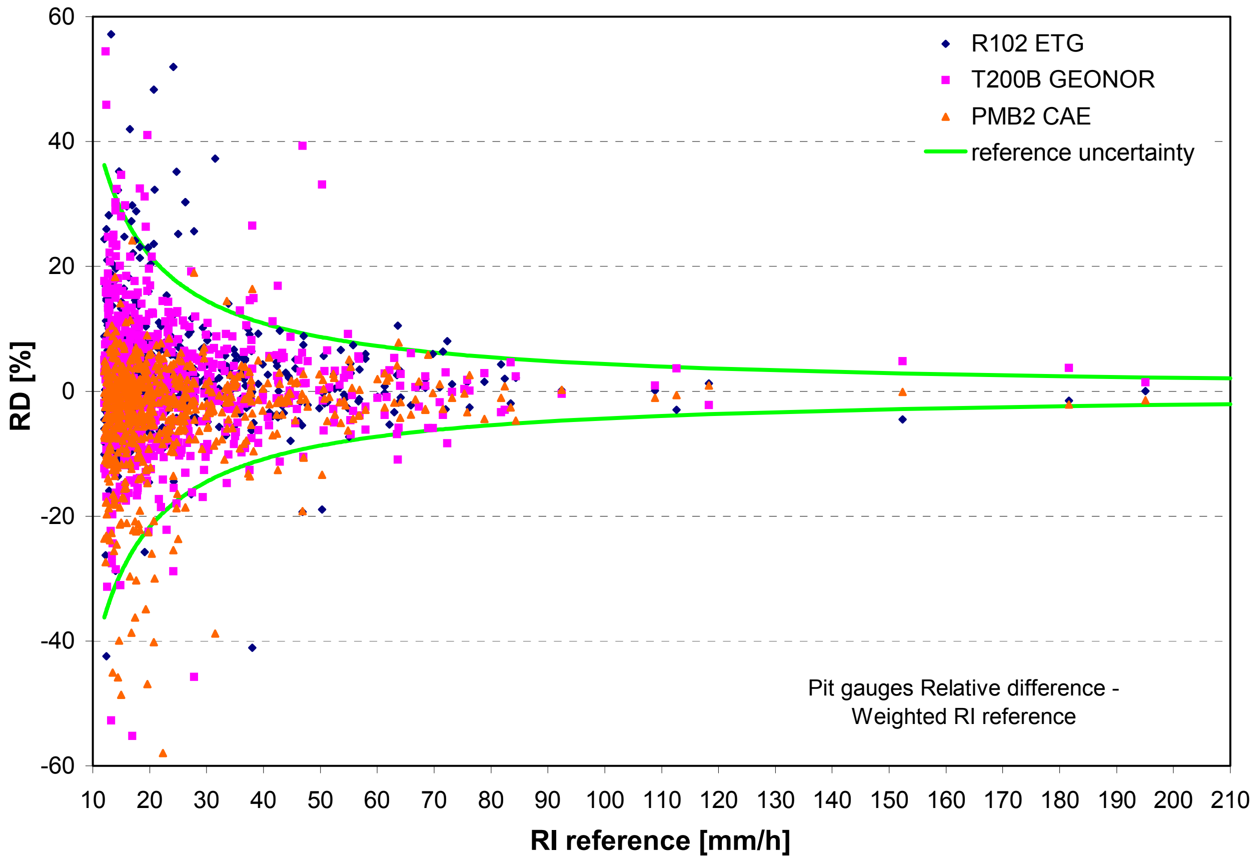


Fig. 36: RI relative difference: the weights for the RI average are computed from the whole dataset of events. Green lines delimit the region which includes the 95% of the experimental points according to u(RIref)= (2 σ/ RIref)·100.

5.3.3 Tolerance region

In order to compare the gauges to the reference and to assess their agreement with the user uncertainty requirement, a tolerance region was established. For the calculation of the tolerance region we assumed the WMO required measurement uncertainty, of 5% for each rainfall intensity gauge according to CIMO Guide (WMO, 2008a, Part I, Chap.1, Annex 1.B). The tolerance region is composed of this 5% uncertainty and of the uncertainty of the reference, thus its value is finally calculated as: $[u_{rel}(RI_{ref})^2+5^2]^{1/2}$ [%]. To show the results of the intercomparison, the tolerance region is represented by upper and lower lines which are drawn in the plots of the paragraph 5.3.5 and of Data Sheets.

The limits of performance of measuring devices are determined both by the characteristics of the devices and by the natural variability of the element to be measured. The tolerance region represents an indication of these limits. The required performance for RI measurements (required uncertainty) stated in the CIMO Guide (WMO, 2008a) is 5% above 2 mm/h. Due to the uncertainty of the reference, such a performance cannot be demonstrated, except for high RI values. The results of this intercomparison could provide advice on the achievable RI measurement uncertainty.

5.3.4 Synchronization

During the period of the intercomparison campaign, the problem of the synchronization between the internal clock of some rain gauges and the clock of the DAQ system was one of the hardest and most important to solve.

In order to compare the 1-minute RI data of all instruments, a synchronization of ±10 s was required, in other words the internal clock of the instrument should be within ±10 s compared to the DAQ system timestamp (nominal timestamp). If the difference/delay between the instrument's data output time and the nominal timestamp exceeds the required ±10 s time interval, the corresponding 1-minute RI is like the one shown for gauge B in Fig. 37, thus the result cannot be correctly compared to synchronized gauges.

In Fig. 37, 1-minute rainfall intensity curves of three sample gauges A, B and C are plotted versus time. For gauge A the difference/delay between the data output time and the nominal timestamp (i.e., hh:mm:00) is up to 6 seconds (case of PLUVIO-OTT). In this way gauge A can be always considered synchronized with the DAQ system. Gauge B internally updates data every minute but in this example the difference/delay between the data output time and the nominal timestamp is 30 seconds (hh:mm:30). Therefore, the comparison of the data for past precipitation events (i.e. non-synchronized PMB2-CAE) shows large differences due to this delay. For gauge C the difference/delay between the data output time and the nominal timestamp is equal to 0 (case of T200B-GEONOR). In this way gauge C is always perfectly synchronized with the DAQ system. This example demonstrates the problem to compare RI data of non synchronized rain gauges on 1-minute time basis. Moreover, an automatic post-synchronization of gauge B data is not possible, because the gauge B data output is shifted by 30 seconds. The lack of synchronization causes a different RI distribution in time, so it is impossible to compare rainfall intensities evaluated on the nominal timestamp. This effect is difficult to be detected by 1-minute data and the shift between data output and DAQ clock could be variable with time, so Intercomparison raw data (available every 10 s) should be firstly checked before applying the proper synchronization procedure. It is not realistic to find and apply the right "forward-backward shifting" of all gauges data for all precipitation events. The only way to obtain a correct synchronization of the data on 1-minute is automatically and periodically synchronizing the internal clock of those gauges which show that problem by sending synchronization commands at least once a day through the DAQ system.

a

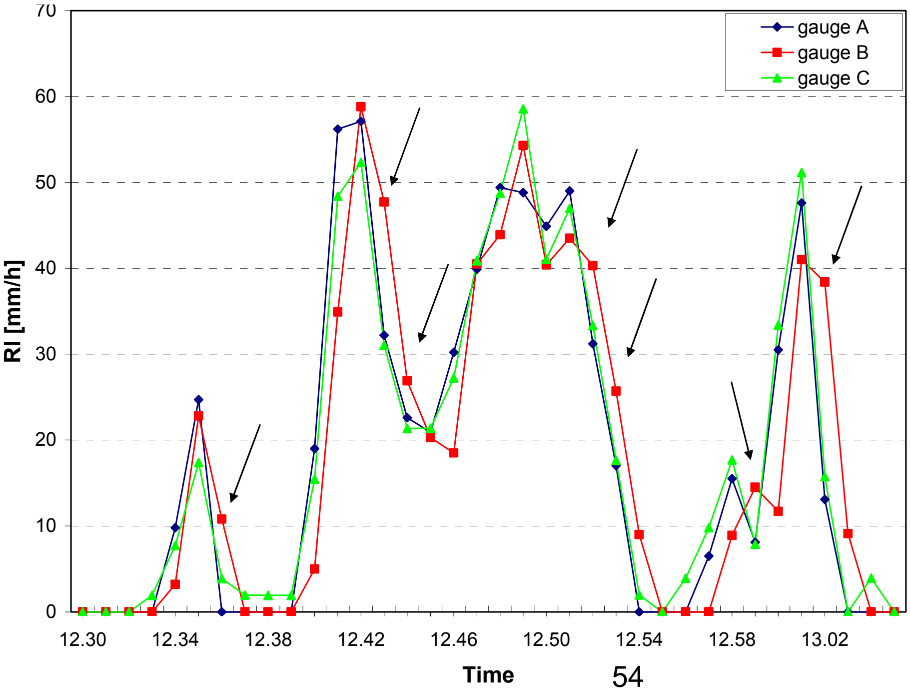


Fig. 37: Gauge A and C are synchronized with the DAQ system clock; gauge B has delay exceeding 10 seconds. Arrows indicate sample points of B with large difference due to non-synchronized data points of gauge B.

In the period from October to December 2007, the following rain gauges had shown the effects of non-synchronization, thus affecting the Intercomparison results: R102-ETG, PMB2-CAE, DQA031-LSI LASTEM, UMB7525/I-SIAP-MICROS, VRG101-VAISALA, PWD22-VAISALA, TRwS-MPS, LPM-THIES, ANS 410/H-EIGENBRODT, LCR “DROP”-PVK ATTEX. From January to May 2008 much effort was dedicated to the attempt of performing the best automatic synchronization throughout the DAQ system of the above-mentioned instruments. It was decided to perform the Intercomparison data analysis only on synchronized data (period after May 2008). However, for statistical reasons and only for pit gauges, the calculation of the weights μ for the determination of the RI reference was extended to all events, therefore the *F* parameter, described in paragraph 5.3.1, was introduced for a correct calculation of the 1-min RI composite working reference, in order to take into account the problem of synchronization by manually selecting only synchronized pit gauge data for each precipitation event (the operation was performed only for R102-ETG and PMB2-CAE reference pit gauges).

A further consideration must be done for the TBRG-SC gauges (R102-ETG, PMB2-CAE, UMB7525/I-SIAP-MICROS): their data had delay of 1 minute (factory set up, documented by manufacturers). This delay is not a lack of synchronization as the problem described above: after proper clock synchronization they must be further shifted by 1 minute backwards, in order to perform a correct comparison. During the Field Intercomparison, it was possible to apply a clock synchronization procedure by the DAQ system but not a 1 minute backward shift: the 1 minute shift was carried out by “a posterior” procedure before data analysis.

In Fig. 38, the precipitation event measured by the reference pit gauges on 30 October 2007 is presented. It shows a clear example of non-synchronized 1-minute RI data, in particular for PMB2-CAE rain gauge. MRW500-METEOSERVIS and T200B-GEONOR are perfectly synchronized, so their 1-min RI timestamps must be considered as the nominal timestamp. The R102-ETG is synchronized within 10 s of nominal timestamp (hh:mm:00) but RI data required a further backward shifted by 1 minute. The PMB2-CAE is not synchronized and RI data are shifted by 1 minute and 40 seconds with no possibility to apply a correct synchronization procedure and with no possibility to correctly compare its results to the others (in particular see the second peak intensity).

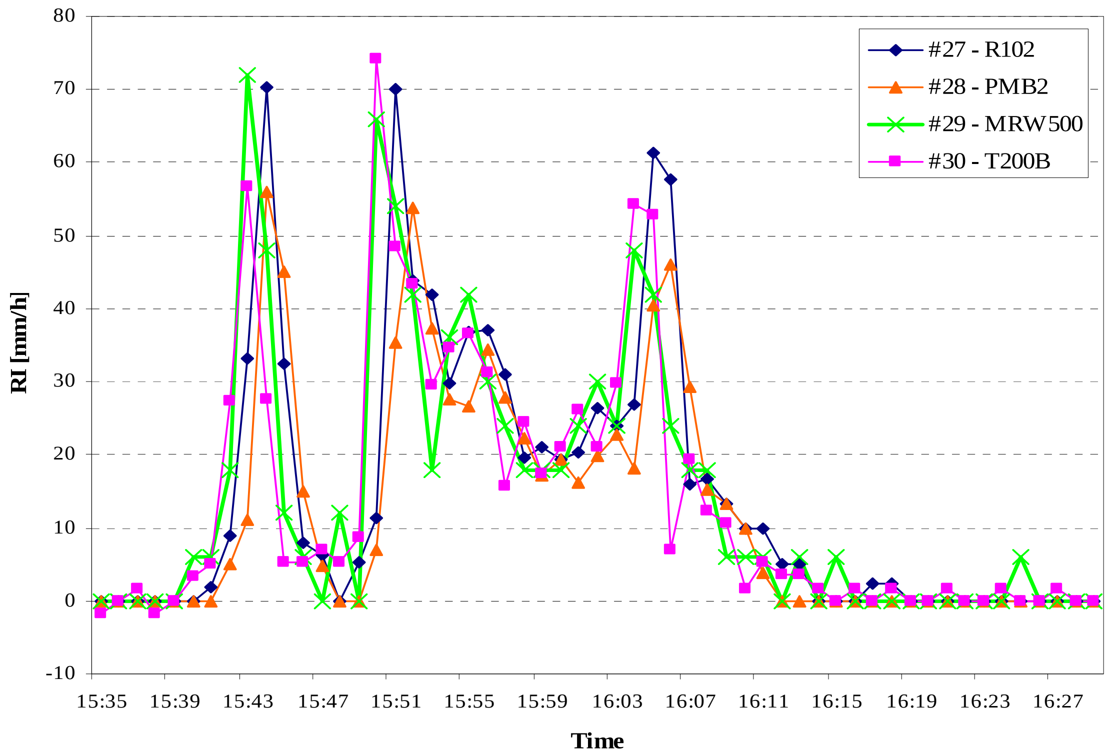


Fig. 38: Example of rainfall event: rainfall intensity measured by the working reference gauges.

5.3.5 Results and discussion

The following section and the related Appendix (Data Sheets) are dedicated to the results of the comparison between the RI measured by the rain gauges and the RI composite working reference. Different ways to show the behaviour of each instrument compared to the reference intensity are described:

a. Rain gauges are grouped according to the physical principle of measurement, to show the differences in the 1-min measurement related to these principles (Fig. 39-45);
b. The comparison of the RI experimental data with the RI composite working reference values for each gauge is shown in Data Sheets. In these graphs the experimental 1-min data are plotted together with the ideal line. The dashed lines drawn on each plot represent the tolerance lines, calculated according to the procedure described in paragraph 5.3.3;
c. The relative difference (RD) between the RI of each rain gauge and the reference intensity is plotted versus RI composite working reference and shown for each instrument in Data Sheets;
d. The relative difference (RD) for each instrument is compared to the time variation of RI reference (RI_{ref}(t)- RI_{ref}(t-1)) and shown for each instrument in Data Sheets. These graphs allow evaluating the response of each gauge with respect to the precipitation variation. They are useful for the evaluation of the dynamical behaviour of the instruments compared to the reference 1-minute RI measurements.

The plots reported in this section represent the trend of each instrument compared to RI composite working reference, where the trend line is obtained from a power law fitting of the experimental data:

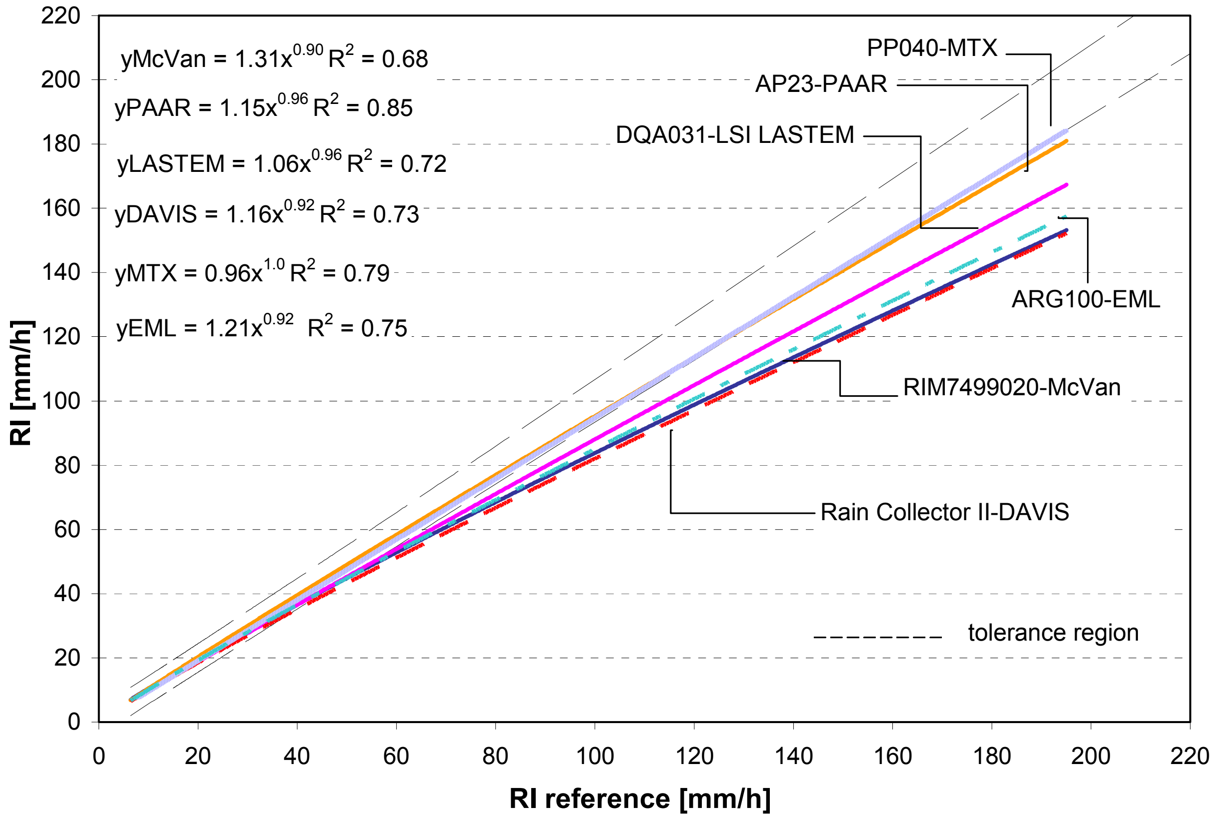
$$RI = a \cdot RI_{ref}{}^{b}$$

where *a* and *b* are constants. The corresponding best fit equations are reported on each plot (Fig. 39-45). The group parameters (a, b) and the related fitting correlation coefficients (R^2) are summarized in Table 5 and in a table included in the Data Sheets of each instrument. In order to assess the accuracy of field measurements compared to the reference, the lines of the tolerance region, calculated according to the procedure described in paragraph 5.3.3, are represented in dashed lines on each plot. The best fit curves must be interpreted with their corresponding correlation coefficient (R^2). A low R^2 value greatly reduces the representativity of the best fit curve.

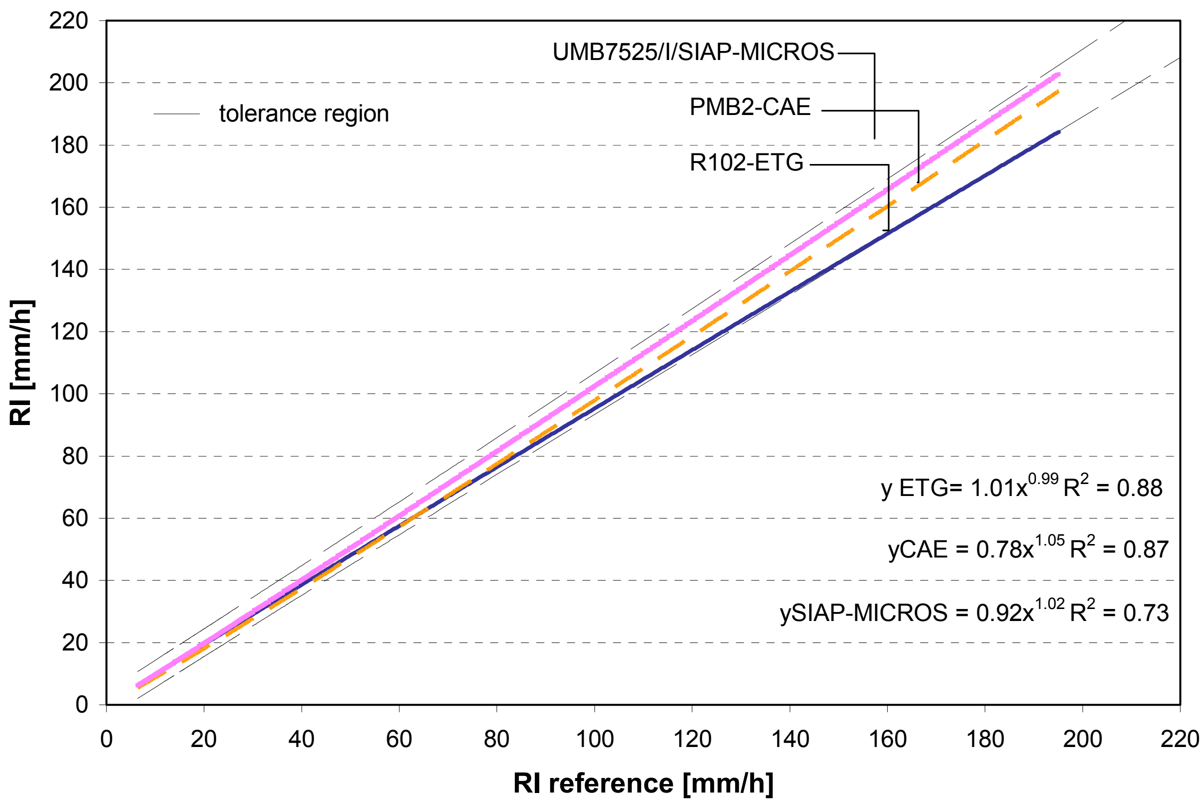
For easier comparison, the instruments have been divided into seven groups according to the measurement technique (see description in chapter 2). WG instruments are split in two groups for easier presentation of results.

Catching rain gauges

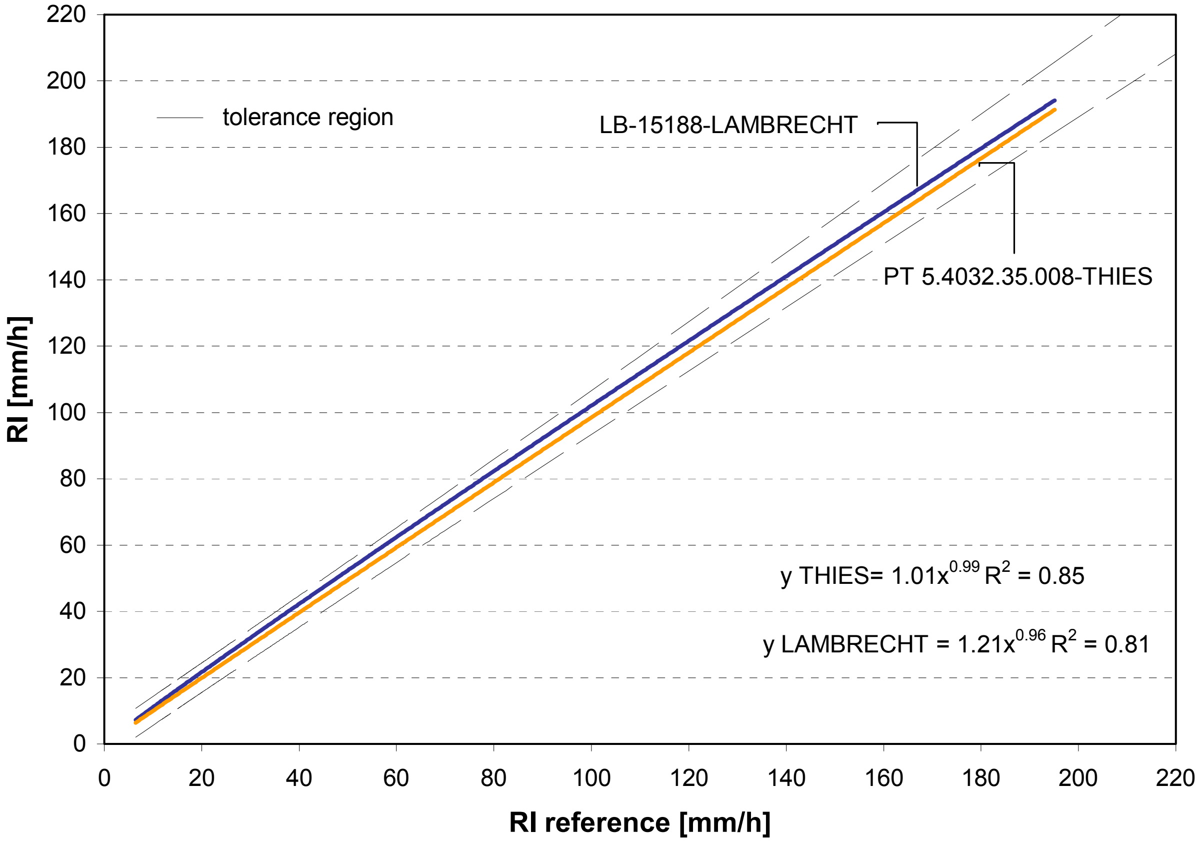
TBRG **Fig. 39**



TBRG-SC **Fig. 40**



TBRG-PC **Fig. 41**



TBRG-MC and LRG **Fig. 42**

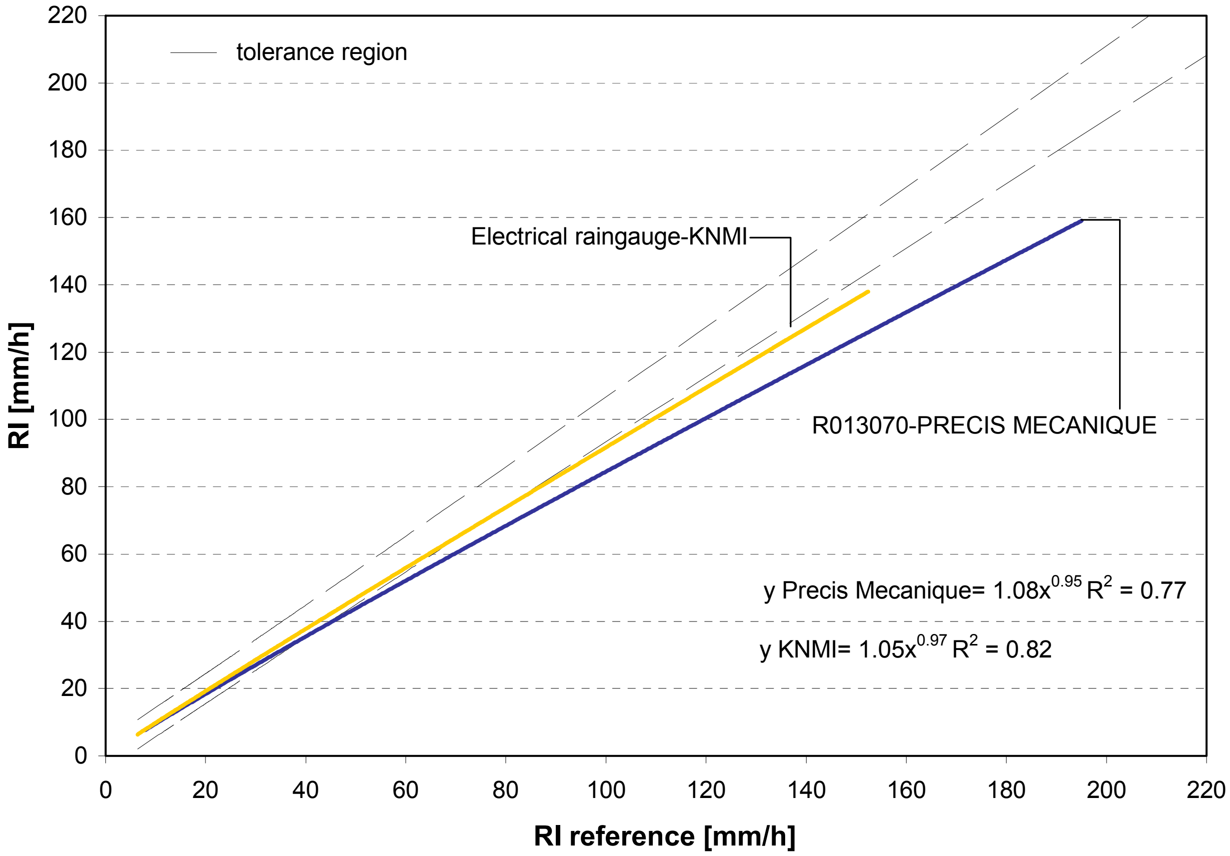


Fig. 43

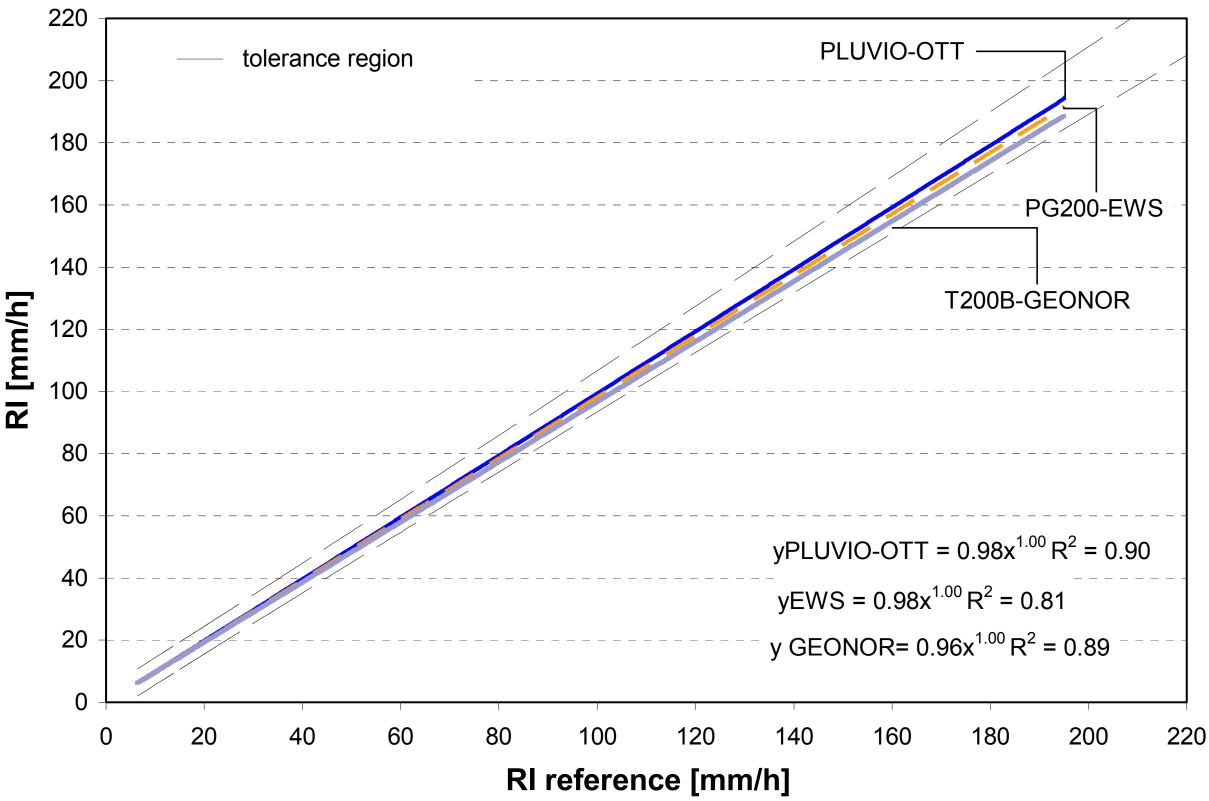
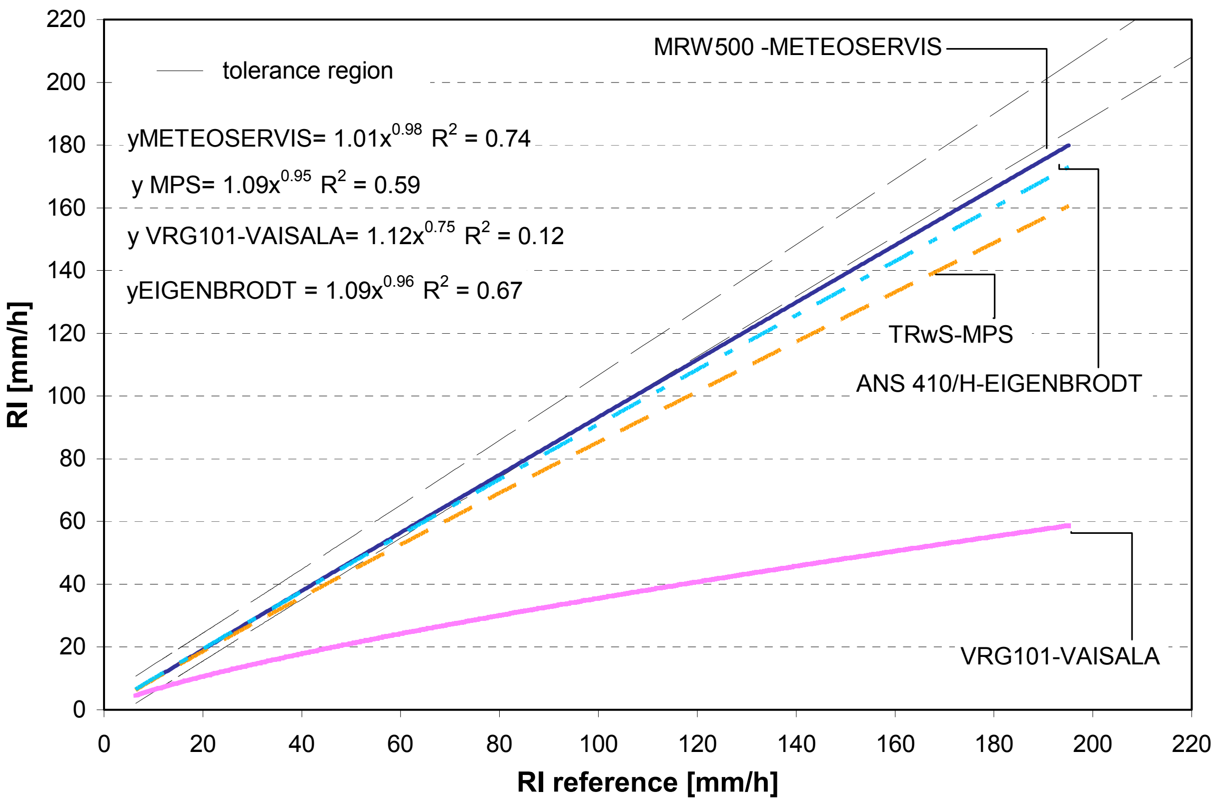
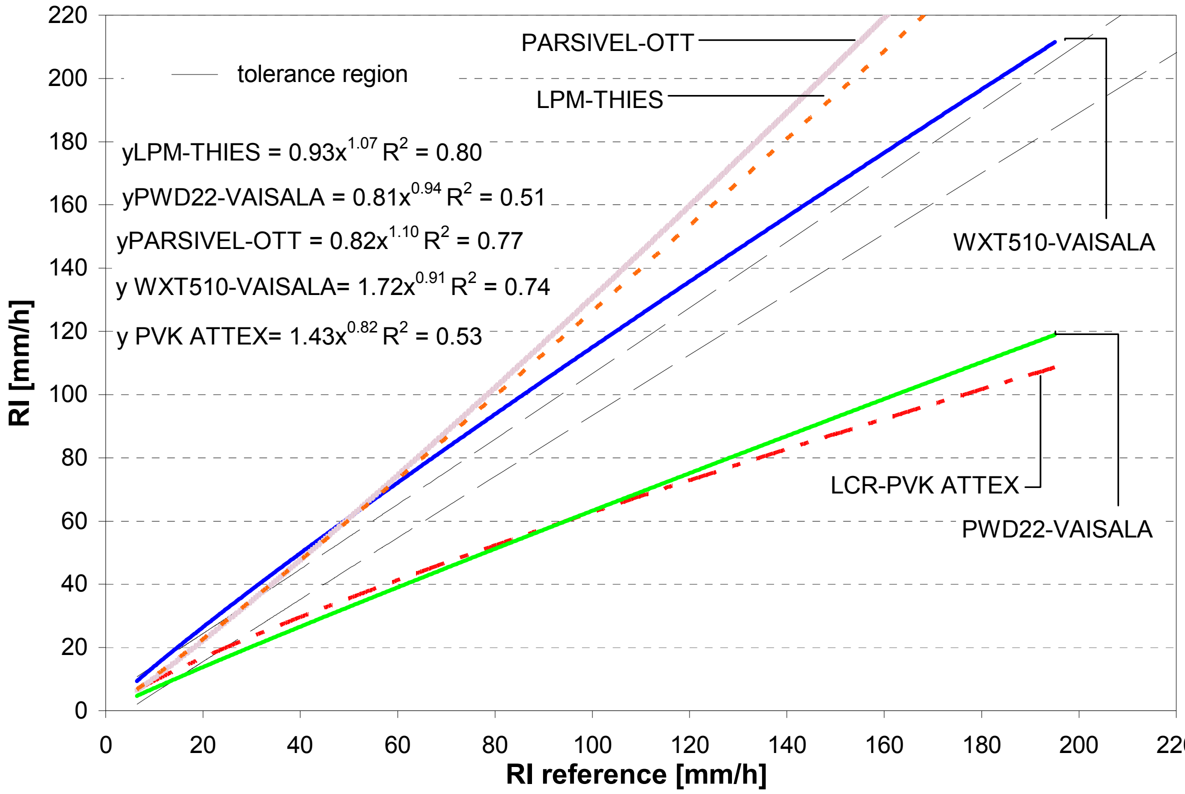

tolerance region
PLUVIO-OTT
PG200-EWS
T200B-GEONOR
yPLUVIO-OTT = 0.98x^1.00 R^2 = 0.90
yEWS = 0.98x^1.00 R^2 = 0.81
y GEONOR= 0.96x^1.00 R^2 = 0.89
RI [mm/h]
RI reference [mm/h]
0
20
40
60
80
100
120
140
160
180
200
220

Fig. 44


tolerance region
MRW500 -METEOSERVIS
yMETEOSERVIS= 1.01x^0.98 R^2 = 0.74
y MPS= 1.09x^0.95 R^2 = 0.59
y VRG101-VAISALA= 1.12x^0.75 R^2 = 0.12
yEIGENBRODT = 1.09x^0.96 R^2 = 0.67
TRwS-MPS
ANS 410/H-EIGENBRODT
VRG101-VAISALA
RI [mm/h]
RI reference [mm/h]
0
20
40
60
80
100
120
140
160
180
200
220

Non-Catching precipitation sensors

Fig. 45



The previous Fig. 39 to 45, containing the power law fits and the tolerance region, can be used to compare the various rain gauges participating in the Field Intercomparison and the corresponding measurement techniques on 1-minute time scale. Through their evaluation it is possible to provide the following general conclusion: this comparison at one minute time scale in field conditions demonstrates the possibility to evaluate the performance of RI gauges.

In order to understand the specific performance of each rain gauge in field conditions, a number of graphs and comments are provided in the Data Sheets of each instrument. They contain among others the following information:

- Rain gauges constant flow response;
- Rain gauges step response evaluation;
- Calibration stability throughout the Intercomparison period (field calibrations results);
- 1-minute comparison between rain gauges and the reference RI, showing the distribution of experimental points, the tolerance region and the ideal line;
- 1-minute comparison between RD [%] of rain gauges and the reference RI, showing the distribution of experimental points and the tolerance region;
- 1-minute comparison between rain gauges RD[%] and the time variation, showing the distribution of experimental points;
- 5-minutes comparison between rain gauges and the reference RI, showing the distribution of experimental points, the tolerance region and the ideal line;
- Quality Assurance information with all quality management aspects of each rain gauge, such as single instrument valid data availability, maintenance aspects and malfunctions during the intercomparison period.

Catching type rain gauges

Following a general overview of rain gauges Data Sheets and considering the findings of the WMO Laboratory Intercomparison (2004-2005), few remarks are provided below.

The achievable accuracy of WG can be improved in field conditions by means of the reduction of the response time below 1-minute and by appropriate filtering methods.

With regard to tipping bucket rain gauges, the method applied by TBRG-SC confirms the possibility to improve the 1-min RI resolution and to provide accurate field measurements for the whole RI range experienced during the Intercomparison.

With regard to tipping bucket rain gauges, the method applied by TBRG-PC revealed the possibility to provide accurate field measurements at higher RI, even if the performance is limited by their resolution at lower RI.

The correlation coefficient R^2 of the best fit curve for VRG101-VAISALA is very low, so the fit is not representative of this sensor. The use of raw mass data, also available from the VRG101-VAISALA sensor, could improve the results. See the VRG101 data sheet for more details.

Non catching type rain gauges

During the intercomparison period, the non-catching type rain gauges needed low maintenance and few periodic checks (especially for the impact disdrometers and the microwave radar), thus this kind of instruments is considered particularly suitable for AWS or generally unmanned meteorological stations. Moreover LPM-THIES, PWD22-VAISALA and PARSIVEL-OTT have the advantage to determine the type of precipitation, to distinguish between solid and liquid precipitation and to provide present weather information (METAR and SYNOP codes). For further investigations concerning these aspects, the observations of the Vigna di Valle H24 meteorological station are available to distinguish hail and rain events.

This intercomparison is the first WMO test bed where non-catching type rain sensors were compared to catching type rain gauges and to a pit RI composite working reference for the field measurement of 1-minute RI, however some analysis of RI was conducted during PREWIC Intercomparison (Leroy et al., 1998)

The non-catching type rain gauges were calibrated by the manufacturers prior to the start of the intercomparison. However, since no standard calibration procedure exists which is suitable for all the involved non-catching gauges, it was not possible to perform laboratory and field calibrations of these instruments. Therefore factory calibration reports and information about calibration methods provided by manufacturers were the only sources of information available on the achievable accuracy of these instruments.

According to the results of this section and Data Sheets, WXT510-VAISALA, LCR “DROP”-PVK ATTEX and PWD22-VAISALA rain gauges show a non-linear behaviour compared to the RI reference in the full range or within some intensity ranges and their data are more spread than the data of other gauges. In particular: LCR “DROP”-PVK ATTEX shows a strong non-linearity above 80mm/h (1 min); WXT510-VAISALA tends to overestimate RI and has a larger spread of data above 50 mm/h. On 1 minute time scale, PWD22-VAISALA tends to underestimate RI, with large dispersion of data. On the other hand, PARSIVEL-OTT and LPM-THIES optical disdrometers show a lower spread of data, a more linear behavior in the full range and an overestimation trend. The R^2 correlation coefficients of the best fit curves for PWD22-VAISALA and LCR “DROP”-PVK ATTEX are very low, so the fits are not representative of these sensors.

This field Intercomparison has shown the need to improve calibration methods adopted for non-catching rain gauges for 1-minute RI measurements.

Nr	*Parameters* *($RI=a\cdot(RIref)^b$)*	a	b	R^2
1	**RIM7499020-McVan**	1.31	0.90	0.68
2	**AP23-PAAR**	1.15	0.96	0.85
3	**R01 3070-PRECIS MECANIQUE**	1.08	0.95	0.77
4	**PT 5.4032.35.008-THIES**	1.01	0.99	0.85
5	**R 102 -ETG**	1.01	0.99	0.88
6	**DQA031-LSI LASTEM**	1.06	0.96	0.72
7	**UMB7525/I-SIAP-MICROS**	0.92	1.02	0.73
8	**PMB2 -CAE**	0.78	1.05	0.87
9	**RAIN COLLECTOR II -DAVIS**	1.16	0.92	0.73
10	**LB-15188-LAMBRECHT**	1.21	0.96	0.81
11	**PP040-MTX**	0.96	1.0	0.79
12	**ARG100-EML**	1.21	0.92	0.75
13	**MRW500-METEOSERVIS**	1.01	0.98	0.74
14	**VRG101-VAISALA**	1.12	0.75	0.12
15	**PLUVIO-OTT**	0.98	1.00	0.90
16	**PG200-EWS**	0.98	1.00	0.81
17	**T200B -GEONOR**	0.96	1.00	0.89
18	**TRwS-MPS**	1.09	0.95	0.59
20	**PWD22-VAISALA**	0.81	0.94	0.51
21	**PARSIVEL-OTT**	0.82	1.10	0.77
22	**LPM-THIES**	0.93	1.07	0.80
23	**WXT510-VAISALA**	1.72	0.91	0.74
24	**ANS 410/H-EIGENBRODT**	1.09	0.96	0.67
25	**Electrical raingauge-KNMI**	1.05	0.97	0.82
26	**LCR “ DROP “-PVK ATTEX**	1.43	0.82	0.53

Table 5: Fitting parameters**.**

5.3.6 Wind effect

This section is dedicated to the investigation about the possible effect of wind speed conditions on the RI measurements. The wind effect study on the 1-minute RI measurements was performed through the comparison of identical instruments that are placed inside and outside the pit. It is important to examine possible wind induced errors only on identical instruments to avoid effects due to the different measurement principles, that are especially evident on 1-min time basis. For a preliminary evaluation, the comparison between the two identical R102-ETG gauges and between the two T200B-GEONOR gauges is shown in Fig. 46 and 47. This comparison was made by the calculation of the ratio between the RI of the external gauge (RI_{out}) and the RI of the one inside the pit (RI_{pit}), plotted versus different values of wind speed. For a better analysis the plots of wind losses, it is also shown for 5-minute data (Fig. 47), to reduce the large dispersion of 1-minute RI measurements, especially for the T200B-GEONOR.

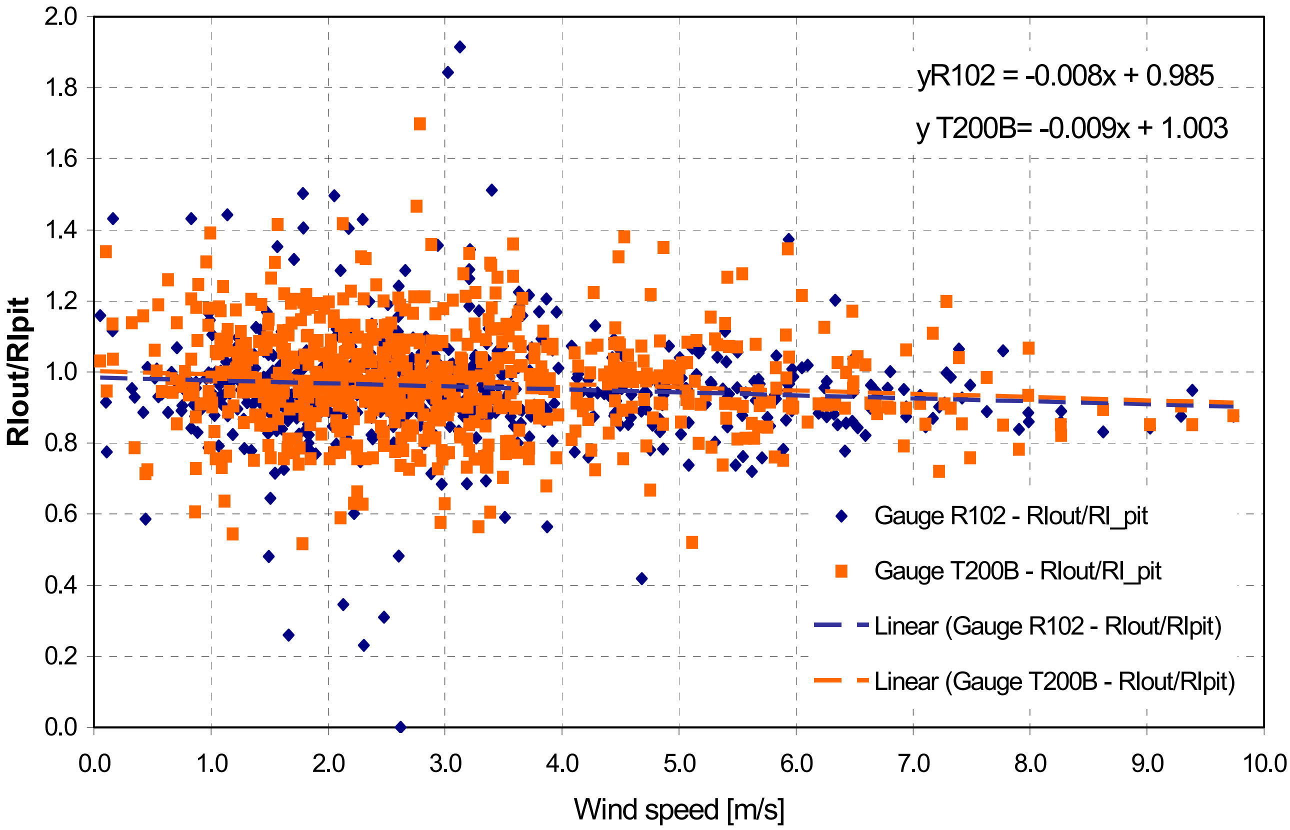


Fig. 46: Ratio between 1-min RI measured by the pit and RI measured by the identical gauge outside the pit.

As can be noted from Fig. 46 and 47, the data were measured at very low wind speeds, generally lower than 4 m/s. In Fig. 46 and 47 a linear trend is shown to point out the general behaviour of the ratio RI_{out}/ RI_{pit} with increasing wind.

The plots with all the rainfall intensity data measured in the period from October 2007 to April 2009 are shown in the Fig. 48 and 49, where RI_{out}/ RI_{pit} is reported for increasing values of RI_{pit}. These plots aim to point out possible differences in the ratio RI_{out}/ RI_{pit} due to the wind when the rainfall intensity increases. The 1-minute experimental points are represented in different colours and shapes according to the corresponding 1-minute wind speed (Fig. 48 and 49).

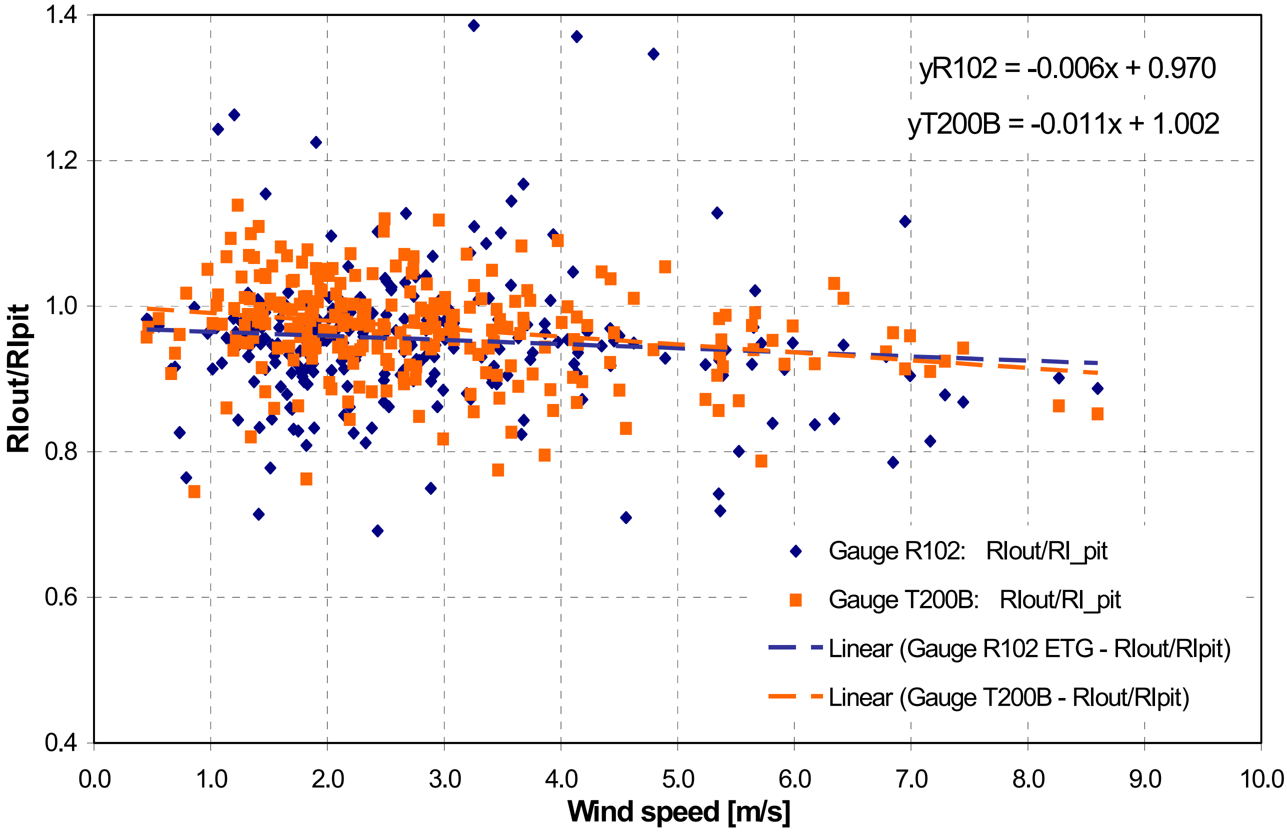


Fig. 47: Ratio between 5-min RI measured by the pit and RI measured by the identical gauge outside the pit.

Since the dispersion on the 1-minute RI values is quite large apart from the wind (Fig. 46, 48 and 49), a second group of graphs is shown where the 1-minute RI is averaged according to “classes” of RI values. At first, the RI data have been divided into groups of intensities (0-9 mm/h, 10-19 mm/h, …..200-209 mm/h), then the values in each group have been averaged and only the mean value for each class of intensity is plotted (Fig. 50 and 51). This operation is possible because we are not considering only a selection of representative rainfall events but all the events, therefore there are about 7000 experimental measurements for each instrument. The plots are shown for R102-ETG and T200B-GEONOR.

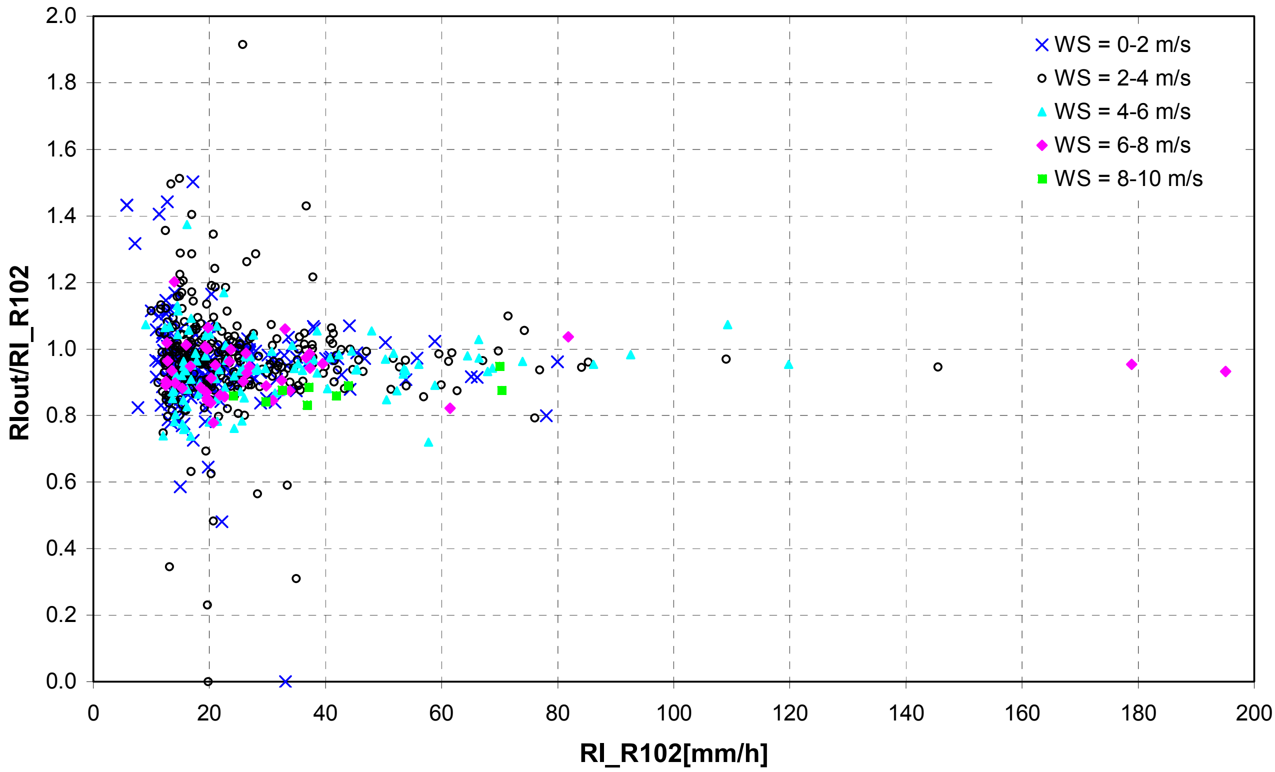


Fig. 48: 1-min R102-ETG RI; RI_{out}/RI_{pit} vs RI_{pit} is shown, divided in groups of wind speed conditions.

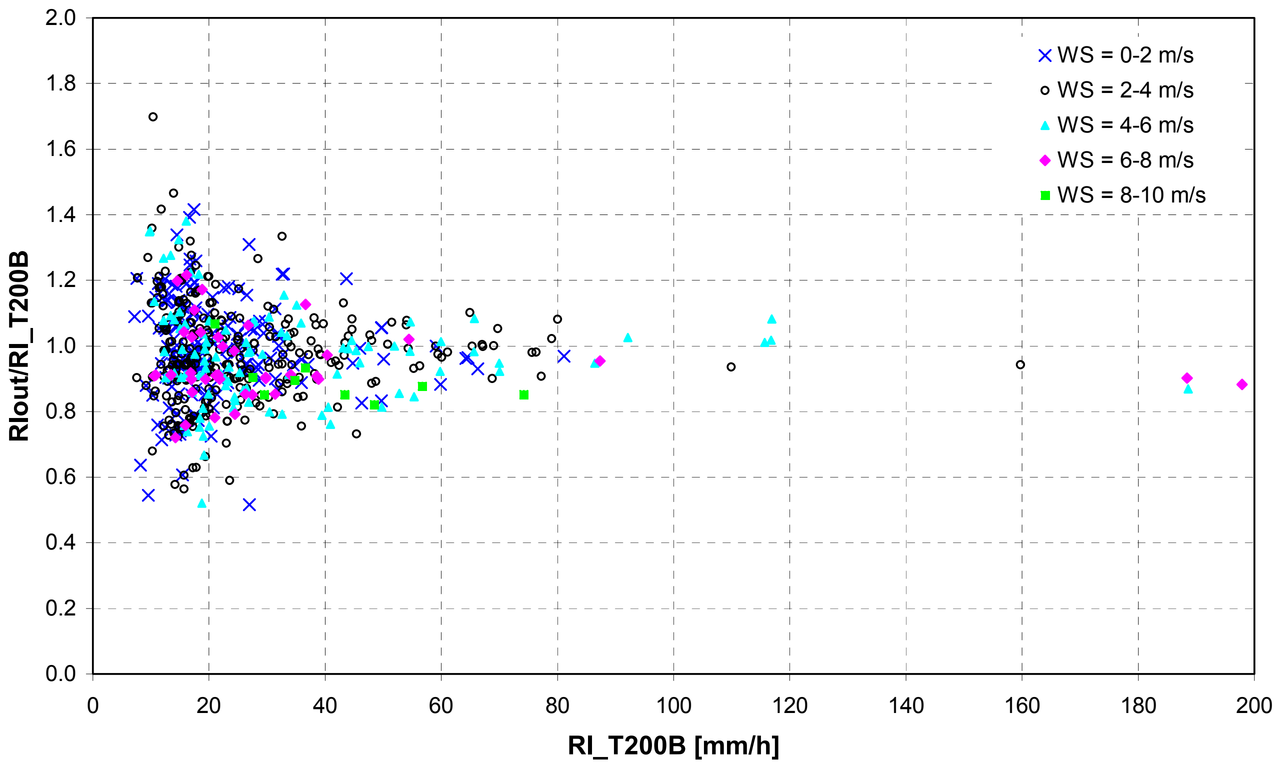


Fig. 49: 1-min T200B-GEONOR RI; RI_{out}/RI_{pit} vs RI_{pit} is shown, divided in groups of wind speed conditions

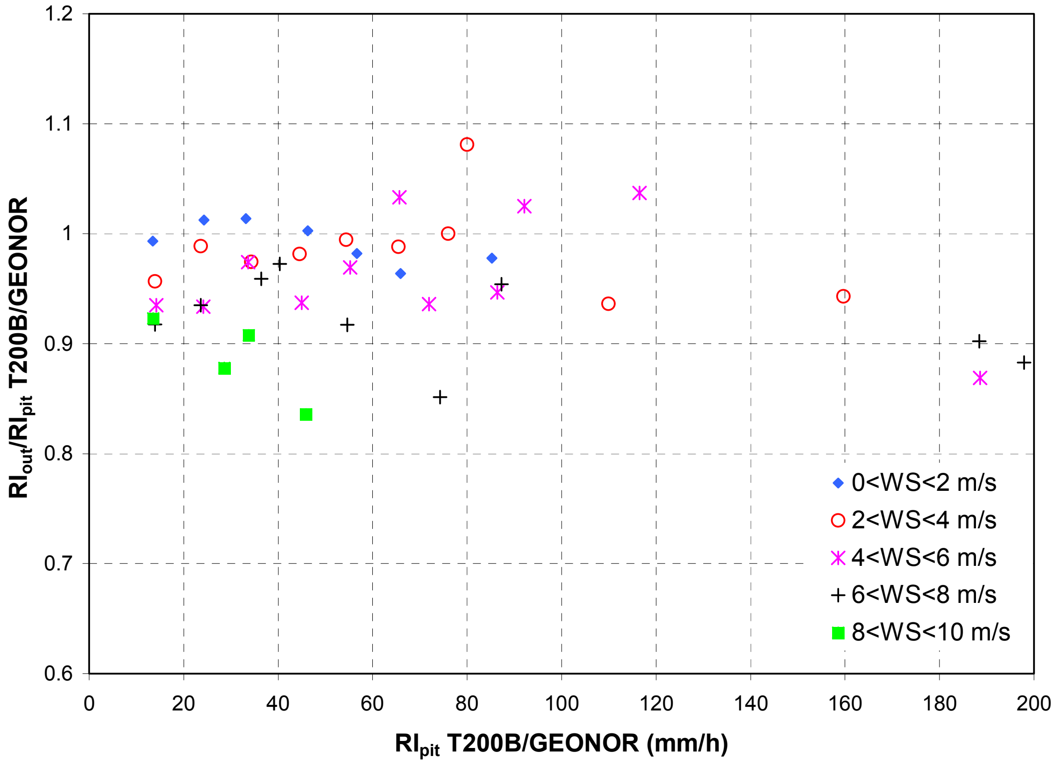


Fig. 50: 1-min T200B-GEONOR RI. RI_{out}/RI_{pit} vs RI_{pit}; RI is divided in groups according to the wind speed conditions, then divided in groups of intensity and averaged inside each group.

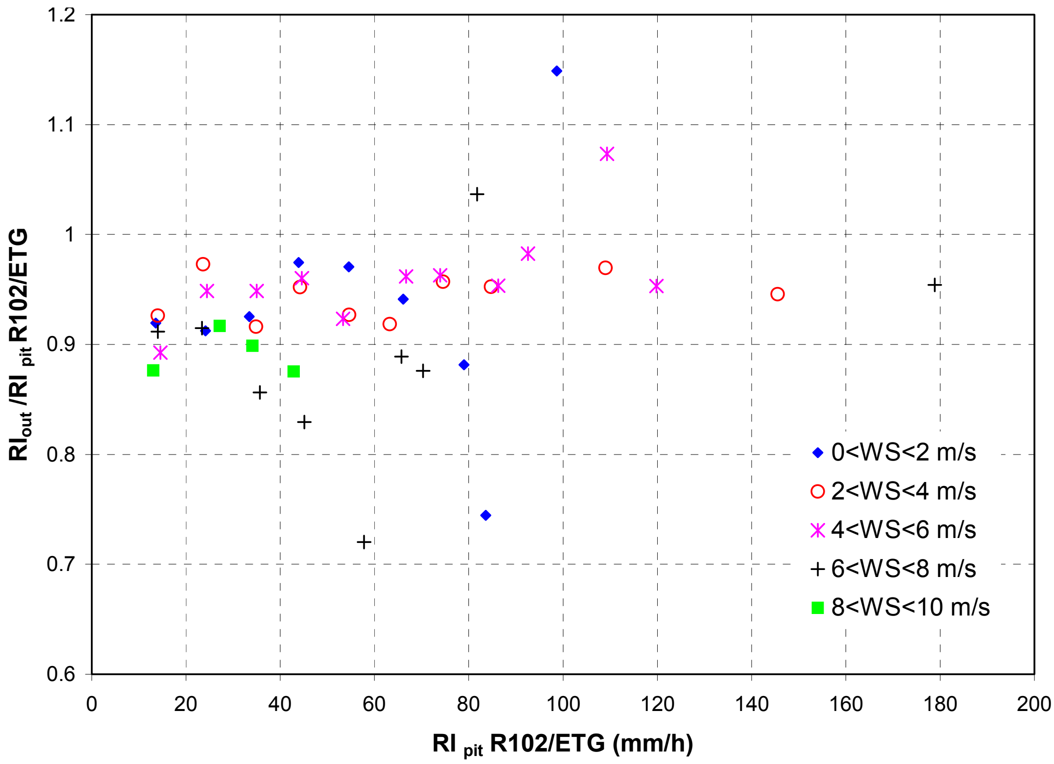


Fig. 51: 1-min R102-ETG RI. RI_{out}/RI_{pit} vs RI_{pit}; RI divided in groups according to the wind speed conditions, then divided in groups of intensity and averaged inside each group.

Looking at the previous results, the effect of the wind cannot be evaluated for low wind speed conditions because of the presence of the 1-min data dispersion mainly due to the differences of calibration between the two identical gauges, especially between GEONOR gauges (see Fig. 49 in the range 20-60 mm/h and the laboratory calibration plots in Data Sheet #17). On the other hand, during this intercomparison only few rainfall events happened with moderate or strong wind (wind speed above 5 m/s) and their number do not permit a complete evaluation of wind induced losses. Fig. 46 shows only a slight decrease of the 1-min ratio RI_{out}/ RI_{pit} with increasing wind speed. In Fig. 47, where 5-min ratio RI_{out}/ RI_{pit} is evaluated, the same trend can be more clearly detected but only for WS>5 m/s it is possible to see a trend of data. In Fig. 50 and 51, since the "noise" in RI is reduced by averaging the data in each class of rainfall intensity, a meaningful distribution of the ratio RI_{out}/ RI_{pit} becomes evident. The reference pit gauges generally measure higher rainfall intensities than their identical gauges installed outside but a correlation/relationship between wind speed and 1-min RI reduction cannot be determined. Thus, the effect due to wind losses cannot be quantitatively estimated. Therefore, it can be said that, for low wind speeds, the Jevons effect weakly affected the field intercomparison RI measurement and, for moderate-strong winds (WS>5 m/s), it was more intense but without a feasible quantitative determination.

In conclusion, since a relevant effect of the wind did not appear in this intercomparison, we are able to affirm that the wind is not affecting in a significant way the outer instruments compared to those installed in the pit, and in any case the possible wind induced effects have already been considered in the tolerance region reported for each gauges in the Chapter 5.3.5. Therefore it is reasonable to compare all the instruments without wind shields.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The Field Intercomparison of Rainfall Intensity Gauges held in Vigna di Valle, Italy, was the first intercomparison of quantitative rainfall intensity measurements in field conditions and one of the most extensive in terms of the number of instruments involved.

The Vigna di Valle intercomparison site confirmed its suitability for hosting this field intercomparison due to its climatology (the maximum rainfall intensity recorded was 195 mm/h) as well as its innovative and versatile design. The latter permitted a flexible set-up of the data acquisition system in order to comply with the various output protocols of the participating instruments and allowed for time synchronization of the measurements which was fundamental for the correct data interpretation.

Laboratory tests on the participating catching-type rain gauges were performed to assess their accuracy prior to their installation in the field, based on the procedures developed during the previous WMO Laboratory Intercomparison of Rainfall Intensity Gauges. These tests were innovative since the analysis was performed at one minute time resolution. Operating in the laboratory at such a high resolution introduced some difficulties since the noise was enhanced. The laboratory simulation of high rainfall rates at a one minute resolution provided a better understanding of the intrinsic performance of the various instruments and of their ability to measure high rainfall intensity rates.

For the best quality instruments, the achievable measurement uncertainty in laboratory, under constant flow conditions, was found to be 5% above 2 mm/h and 2% above 10 mm/h.

The field calibrations of catching type rain gauges was regularly performed and was based on the same method and principles as the laboratory tests. It confirmed the general stability of the instruments' calibration status, as no significant calibration drifts were detected.

It was the first time that four reference rain gauges in a standard pit were used to derive a rainfall intensity composite working reference. During the Intercomparison period, a resolution of the Technical Committee 318 ("Hydrometry") of CEN (European Commission for Normalization) was adopted in order to revise the current standard ISO/EN13798:2002 (Reference Rain Gauge Pit) to take into consideration the experiences gained during this intercomparison. The outcome of the enquiry of the proposed revision by the European Members was published on 18th June 2009 by CEN, reporting no objections. The revised document would become the new ISO/EN13798 standard, and would be available on November 2010. Following the publication of this standard, the relevant WMO regulatory material should be updated.

One of the most challenging aspects of the Intercomparison was the definition of a 1-minute field reference precipitation intensity. The reference rainfall intensity was calculated with weighted values of individual gauges in the pit and its uncertainty was evaluated. This procedure confirmed the suitability of R102-ETG, PMB2-CAE and T200B-GEONOR for the calculation of the reference.

The results of the intercomparison confirmed the feasibility to measure and compare rainfall intensities on a one minute time scale as required by users and recommended by CIMO and provided information on the achievable measurement uncertainties.

The rainfall intensity is highly variable from minute to minute. The correlation between two successive 1-minute rainfall intensity measurements is very low and much lower than the correlation between two different instruments that are well synchronized. Therefore, the time synchronization of the instruments is crucial to inter-compare their measurements and to design the measurement systems.

The wind effect was found to have a minor influence on the results primarily due to the low wind speeds observed during the precipitation events.

In field conditions, the uncertainty of the rainfall intensity composite working reference in the pit was evaluated to be 4.3 mm/h. Consequently, the relative uncertainty of the reference was found to be below 5% only for intensities above 90 mm/h. Below 90 mm/h, the relative uncertainty of the reference values was higher than the 5% required measurement uncertainty provided in the CIMO Guide.

The Meeting of Participants and Local Staff (Vigna di Valle, 21-22 May 2008) was fundamental for the success of the intercomparison. In particular, it allowed to confirm that the rain gauges were operated according to the recommended procedures and permitted to achieve the best possible data quality and instrument synchronization.

A summary of the general results of the intercomparison is shown in Table 6 to give information on the performance of the participating instruments. It should be noted that the criteria for performance in laboratory (constant flow) presented in that table took into account both the average values and the dispersion of the measurements. This dispersion had not been taken into account during the previous laboratory intercomparison which may account for the differences of some instruments' results with regard to the results that had been obtained during the previous Laboratory Intercomparison. It should also be noted that due to the variety of rain gauges and techniques involved, the range of prices for these instruments is quite large.

As previously found in the Laboratory Intercomparison, corrected Tipping Bucket Rain Gauges (TBRGs) performed better than uncorrected ones. The correction could be achieved either by electronically adding an extra pulse or by software based correction. The present laboratory and field results confirmed that software correction is the most appropriate method for the correction of TBRGs. Very good results with respect to linearity, resolution enhancement and noise reduction could be achieved.

Catching gauges that do not use a funnel are sensitive to external factors, like wind and splash, which could affect the measurements. As a consequence, their noise level is generally increased in comparison to gauges using a funnel. The necessary filter algorithms for noise reduction could introduce a delay, longer time constants or other effects on the RI output. However, proper techniques could be used to reduce the noise in the measurements without introducing a delay and/or a longer time constant.

Some rain gauges provided output data telegrams containing additional values (e.g. raw mass) that could be used to improve the RI measurements.

The best performing weighing gauges and TBRGs were found to be linear over their measurement range. However, weighing gauges generally cover a wider range.

None of the non-catching rain gauges agreed well with the reference.

Disdrometers tended to overestimate the rainfall intensity. Despite their very different calibration procedures, they agreed better to each other than to the reference. This indicated that they had a good degree of precision but were not as accurate as conventional gauges.

The microwave radar and the optical / capacitive sensor tended to underestimate the rainfall intensity.

For this intercomparison quality control and synchronization procedures were developed to ensure the high quality of the intercomparison data. These one-minute data would be available for further analysis.

#	NAME	Type	1-min RI resolution found (declared) [mm/h]	Measuring range found (declared) [mm/h]	Short comment	Performance in laboratory (constant flow)	Performance of 1 minute RI measurements
1	RIM 7499020 - Mc Van	TBRG with siphon	12 (12) insufficient	**0 – 300 (0 – 500)**	Under-estimation for high RI	***	***
2	AP23-PAAR	TBRG	6 (6) satisfactory	**0 – 720 (0 – 720)**	Under-estimation for high RI. Could be corrected	**	****
3	R01 3070-PRECIS-MECANIQUE	TBRG with mechanical correction	12 (12) insufficient	**0 – 200* (0 – 450)**	Under-estimation for high RI	**	***
4	PT 5.4032.35.008-THIES	TBRG with extra pulse	6 (6) satisfactory	**0 – 420 (0 – 420)**		***	****
5	R 102-ETG	TBRG with software correction	<0.1 (0.6) very good	**0 – 300 (0 – 300)**	Some large errors for low RI	*****	*****
6	DQA031-LSI LASTEM	TBRG with siphon	12 (12) insufficient	**0 – 300 (0 – 300)**		**	***
7	T- PLUV UMB7525/I-SIAP-MICROS	TBRG with software correction	<0.1 (0.2) very good	**0 – 300 (0 – 300)**	Some large errors for low RI	****	***
8	PMB2-CAE	TBRG with software correction	0.1 (0.1) very good	**0 – 300 (0 – 300)**		*****	*****
9	RAIN COLLECTOR II - DAVIS	TBRG	12 (12) insufficient	**0 – 250 (0 – 2540)**	Under-estimation for high RI. Could be corrected	**	***
10	LB-15188-LAMBRECHT	TBRG with extra pulse	6 (6) satisfactory	**0 – 600 (0 – 600)**	Overestimation under 100 mm/h	**	***
11	PP040-MTX	TBRG	12 (12) insufficient	**0 – 280 (0 – N/A)**	Under-estimation for high RI. Could be corrected	**	***
12	ARG100-ENV. MEAS. Ltd	TBRG	12 (12) insufficient	**0 – 300* (0 – N/A)**	Under-estimation for high RI. Could be corrected	**	***
13	MRW500-METEOSERVIS	WG	6 (6) satisfactory	**0 – 400 (0 – 400)**	Noisy for 1 minute RI	***	***
14	VRG101-VAISALA	WG	<0.1 (0.1) very good	**0 – 1200 (0 – 1200)**	Large errors due to internal integration	****	*

#	NAME	Type	1-min RI resolution found (declared) [mm/h]	Measuring range found (declared) [mm/h]	Short comment	Performance in laboratory (constant flow)	Performance of 1 minute RI measurements
15	PLUVIO-OTT	WG	0.1 (0.1) very good	**0 – 1800 (4.2 – 1800)**		*****	*****
16	PG200-EWS	WG	0.1 (3) very good	**0 – 300* (0 – 500)**		***	****
17	T200B-GEONOR	WG	<0.1 (0.1) very good	**0 – 600 (0 – 600)**		****	*****
18	TRwS-MPS	WG	0.06 (0.06) very good	**0 – 500* (0 – 3600)**	Noisy for 1 minute RI	****	**
20	PWD22-VAISALA	Optical / capacities sensor	0.01 (0.01) very good	**0 – N/A (0 – 999.99)**	Dispersion and under-estimation		**
21	PARSIVEL-OTT	Optical disdrometer	0.001 (0.001) very good	**0 – N/A (0 – 1200)**	Dispersion and over-estimation		***
22	LPM-THIES	Optical disdrometer	0.005 (0.005) very good	**0 – N/A (0 – 250)**	Dispersion and over-estimation		***
23	WXT510-VAISALA	Impact disdrometer	0.1 (0.1) very good	**0 – 80 (0 – 200)**	Dispersion, over-estimation and under-estimation		**
24	ANS 410/H-EIGENBRODT	WG pressure	0.6 (0.6) very good	**0 – 900 (0 – 1200)**	Numerous outliers	***	**
25	Electrical raingauge-KNMI	level measureme nt	1 (0.1) good	**0 – 300 (0 - 300)**		***	****
26	LCR DROP-PVK Attex	Microwave radar	0.1 (0.1) very good	**0 – N/A (0 - 150)**	Dispersion and under-estimation		**

Footnote:

* Under "Measuring range found", values with a star means these are the highest values tested in laboratory and not necessarily the measuring limits of the instruments

Table 6: Summary of the general results of the intercomparison

6.2 RECOMMENTDATIONS

Recommendation 1

The 1-min rainfall intensity (RI) is highly variable from minute to minute. Therefore, it is recommended that 1-min RI should only be measured in a station and used for further analysis if the following conditions are met:

- All 1-min data must be 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 values is not representative of a longer period of time.)
- A very good time synchronization, better than 10 s, is achieved, both between the reference time and the different instruments of the observing station.

Recommendation 2

Some sensors with internal software provide output data telegrams with several RI related parameters, which can be used to calculate 1-min RI. The user should carefully check the manufacturer's documentation about the characteristics of these parameters and ask for additional information, if necessary, as it appeared during the intercomparison that it is not always obvious to identify the parameters that should be used.

Recommendation 3

During the intercomparison, it appeared that in some cases important information was missing in the instrument manuals and that additional information had to be requested from the manufacturers to properly use their instruments for 1-min RI measurements. It is therefore recommended to manufacturers to state as a minimum the list of technical parameters below in the user manual and to provide sufficient advice on the best choice of output values to use for different applications:

- measurement range
- resolution
- linearity
- measurement uncertainty (for the whole measurement range)
- threshold
- dead time
- delay time
- time constant
- internal calculation or update cycle
- possible output cycles.

Recommendation 4

It is recommended to manufacturers and to users that tipping bucket rain gauges 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.

Recommendation 5

Due to the increased noise level of catching-type gauges that do not use a funnel it became evident that a fast response measurement of RI and an accurate measurement of rainfall accumulation (RA) are contradictory goals. If a consistency between RI and RA outputs degrades the performance of one of them, it is recommended to manufacturers that they separate the calculation of RI and RA and that they report both values.

Recommendation 6

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. It is recommended to manufacturers that they avoid the use of algorithms that increase the time constant.

Recommendation 7

Some sensors, or physical principles, provide a real-time measurement uncertainty or quality information for each RI value which can be used to assess the quality of the measurements. As an example the measurement uncertainty of RI could be derived from the raw values of a weighing gauge. It is recommended that the manufacturers provide these quality information in the output data telegram.

Recommendation 8

Although this intercomparison had its emphasis on high RI, it became obvious that most instruments needed to be improved in the lower RI range. It is recommended to manufacturers to improve the design of their instruments to reduce the uncertainty of 1-min RI measurements at intensities below 20mm/h.

Recommendation 9

Chapter 1, Annex 1.B (operational measurement uncertainty requirements and instrument performance) of the CIMO Guide (WMO-No.°8) includes a column for the achievable measurement uncertainty, based on sensor performance under nominal and recommended exposure that can be achieved in operational practice. This information is not currently documented for RI. It is recommended that the following changes be made to the CIMO Guide Table:

- Precipitation intensity (liquid):
  - Achievable measurement uncertainty: Under constant flow conditions in laboratory, 5% above 2 mm/h, 2% above 10 mm/h.
  - In field conditions, 5 mm/h, and 5% above 100 mm/h.
- Split column 8 (Achievable measurement uncertainty) to account for the different achievable measurement uncertainties under both laboratory and field conditions.

Recommendation 10

It is recommended that RI measurements be further standardized based on the advances in knowledge obtained from this intercomparison to allow the users to obtain homogeneous data sets. This should be based on the achievable RI measurement performance (accuracy) rather than on the involved measuring principle or the gauge design/technical solutions. It is recommended that:

- The procedure adopted for performing calibration tests in the laboratory should become a standard method to be used for assessing the instruments' performance. In particular it is recommended that specific procedure to perform the step response tests in the laboratory be further developed and proposed as a standard in order to better evaluate their time constant. Acceptance tests could be based on the adopted laboratory procedures/standard.
- Classification of instrument performance be developed. This could 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.
- The necessary steps be made towards common WMO-ISO international standard(s).

Recommendation 11

It is recommended that the procedure developed for field calibration of the catching type gauges be accepted as a standard procedure for operational assessment of instrument's performance in the field. The procedure allows reproducing in the field the same calibration method as is used in the laboratory. Standardization of the field calibration method would help developing proper quality control procedures based on periodic checking of the instruments in the field.

Recommendation 12

As a guideline for future Intercomparison initiatives involving instruments that can not be directly compared to a primary, secondary or reference standard, it is recommended that a "composite working reference" is derived using more than one instrument to provide the best estimate. This concept is based on the experience of the present Intercomparison of RI gauges, by selecting a number of instruments with the best observed/expected performance under independent assessment (e.g. from laboratory tests, or other available information) and to derive a "composite" measure from the combination of their respective measures using suitable statistic and/or conceptual tools.

Recommendation 13

Throughout the intercomparison, the International Organizing Committee (IOC) held regular teleconferences to monitor the progress of the intercomparison, to provide advice to the local host and to develop the final report. This proved to be extremely effective. It is therefore recommended that the IOC of future intercomparisons considers having regular teleconferences.

Recommendation 14

It is recommended that for future intercomparisons, a test period be held before the official start of the intercomparisons. After this test period a meeting with all participants could be organized to confirm and verify the setting of the instruments and data acquisition. If the data analysis procedure is already known at this time, it could also be presented to the participants for comments.

Recommendation 15

It is recommended that the developed expertise and the infrastructure at the Intercomparison sites (both the field and the laboratory components) and any related available facilities be further exploited within WMO beyond the time limits of this intercomparison.

Recommendation 16

Few events with intensities above 100 mm/h were measured during this intercomparison. It would therefore be of interest to consider a follow-up of this intercomparison to address higher intensities. It is recommended that future work on the subject be conducted in other climatological regions (tropics) and/or conducted over a much longer time period to increase the chance of measuring very high rainfall intensity events.

Recommendation 17

The Intercomparison data set (1-min rainfall intensity data) constitutes an important resource that should be considered as a valuable product of this intercomparison and that could possibly be exploited beyond the objectives of the present data analysis. Additional investigations from this data set would be possible and it is recommended that further use of this information be made with various possible objectives.

Recommendation 18

Heavy rainfall is generally the origin of flash floods. In view of the very high variability of the rainfall intensity, measurements at a 1-minute time scale are crucial to enable proper measures be taken to mitigate the impact of such events and save lives, property and infrastructures. As the return period of heavy rainfall events is 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. It is therefore recommended to Members to carry out 1-minute rainfall intensity measurements 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.

CHAPTER 7

REFERENCES:

Adami A. and Da Deppo L. (1985). On the systematic errors of tipping bucket recording raingauges. Proc. Int. Workshop on the Correction of Precipitation Measurements, Zurich, 1-3 April 1985.

Becchi I. (1970). On the possibility to improve the measurement of rainfall: the control of tippingbucket rain gauges (in Italian). Technical Report for CNR Grant n. 69.01919. University of Genova, pp. 11.

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

Fankhauser R. (1997). Measurement properties of tipping bucket rain gauges and their influence on urban runoff simulation. Wat. Sci. Tech., 36(8-9), 7-12.

Goodison, B.E., Louie, P.Y.T., and Yang, D. (1998): WMO Solid Precipitation Measurement Intercomparison: Final Report, Instruments and Observing Methods Report No. 67, WMO/TD-No. 872, Geneva.

HMEI (2008), HMEI Report, "Meeting of participants and local staff", Vigna di Valle (Italy), 21-22 May 2008
(available at http://www.hydrometeoindustry.org; Reports 2008);

Humphrey M.D., Istok J.D., Lee J.Y., Hevesi J.A. and Flint A.L. (1997). A new method for automated calibration of tipping-bucket rain gauges. J. Atmos. Oc. Techn., 14, 1513-1519.

ISO, (1995) GUM "Guide to the Expression of Uncertainty in Measurement".

Koschmieder, H. (1934), "Methods and results of definite rain measurements", Monthly Weather Review, III. Danzig Report (Germany).

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

Lanza, L.G. and Stagi, L. (2008). Certified accuracy of rainfall data as a standard requirement in scientific investigations. Advances in Geosciences, 16, 43-48.

Lanza, L.G., Leroy, M., Van Der Menlen, J. And M. Ondras, (2005a). The WMO Laboratory Intercomparison of Rainfall Intensity (RI) Gauges. WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2005), Bucharest, Romania, 4-7 May 2005 (published on CD-ROM).

Lanza, L.G., Leroy, M., Alexadropoulos, C., Stagi, L. and Wauben, W. (2005b). WMO Laboratory Intercomparison of Rainfall Intensity Gauges - Final Report. Instruments and Observing Methods Report No. 84, WMO/TD No. 1304 (available at http://www.wmo.int/pages/prog/www/IMOP/publications/IOM-84_Lab_RI/IOM-84_RIgauges_Sept2004-2005.pdf).

Leroy, M., Bellevaux, C. and Jacob, J.P. (1998). WMO Intercomparison of Present Weather Sensors/Systems - Final Report, Canada and France, 1993-1995. Instruments and Observing Methods Report No. 73, WMO/TD-No. 887

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

Maksimović Č., Bu.ek L. and Petrović J. (1991). Corrections of rainfall data obtained by tipping bucket rain gauge. Atmospheric Research, 27, 45-53.

Molini, A., Lanza, L.G., and La Barbera, P. (2005a). The impact of tipping-bucket raingauge measurement errors on design rainfall for urban-scale applications. Hydrol. Proc., 19, 1073-1088.

Molini, A., Lanza, L.G. and La Barbera, P. (2005b). Improving the uncertainty of rain intensità records by disaggregation techniques. Atmos. Res., 77, 203-217.

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

Poncelet, L., (1959). Comparison of rain gauges. World Meteorological Organization Bull., 8(4): 201-205.

Sevruk, B. (1982). Methods of Correction for Systematic Error in Point Precipitation Measurement for Operational Use. Operational Hydrology Report No. 21, WMO-No. 589, Geneva.

Sevruk, B. and Hamon W.R. (1984). International Comparison of National Precipitation Gauges with a Reference Pit Gauge. Instruments and Observing Methods Report No. 17, WMO/TD No. 38, Geneva.

Sevruk, B. and Klemm S. (1989): Catalogue of National Standard Precipitation Gauges. Instruments and Observing Methods Report No. 39, WMO/TD-No. 313, Geneva.

Sevruk, B., Ondras, M., and Chvila, B., (2009), The WMO precipitation measurement intercomparison. Atmos. Res., 92(3), 376-380

Sieck, Lisa C. et Al. (2007), “Challenges in obtaining reliable measurements of point rainfall”, Water Res. Res., vol. 43, W01420, 1-23.

Struzer, I. R. 1971. On the ways of account of precipitation gage errors caused by falling of false precipitation into precipitation gage during blizzards. Transactions of the Main Geophysical Observatory 260:35–60.

UNESCO,1978. World water balance and water resources of the earth. Studies and Reports in Hydrology 25. Paris, UNESCO, 663 pp.

WMO (1992a) - International meteorological vocabulary. WMO–No. 182, ISBN: 92-63-02182-1.

WMO (1992b): Manual on the Global Data-Processing and Forecasting System, WMO-No. 485.

WMO (2001). Final Report of the Expert Meeting on Rainfall Intensity Measurements, Bratislava, Slovakia, 23-25 April 2001
(Available at http://www.wmo.int/pages/prog/www/IMOP/reports/1999-2002/EM-Rainfall-Intensity-2001.pdf).

WMO (2005) - Final Report of the second session of the CIMO Expert Team Meeting SBII&CM, Geneva (Switzerland) 5-9 December 2005
(Available at http://www.wmo.int/pages/prog/www/IMOP/reports.html);

WMO (2007a) - Final Report of the fourteenth session of the Commission for Instruments and Methods of Observation of the WMO – Geneva (Switzerland) 7-14 December 2006; WMO-No.1019
(Available at http://www.wmo.int/pages/prog/www/IMOP/reports.html);

WMO (2007b) - Final Report of the third session of the CIMO Expert Team Meeting SBII&CM, Vigna di Valle (Italy) 26 February-2 March 2007
(Available at http://www.wmo.int/pages/prog/www/IMOP/reports.html);

WMO (2007c)- Final Report of the fifth session of the CIMO Expert Team Meeting SBII&CM, Vigna di Valle (Italy) 17-21 September 2007
(Available at http://www.wmo.int/pages/prog/www/IMOP/reports.html);

WMO (2008a). Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, 7th ed., World Meteorological Organization, Geneva, Switzerland
(Available at: http://www.wmo.int/pages/prog/www/IMOP/publications/CIMO-Guide/CIMO_Guide-7th_Edition-2008.html).

WMO (2008b) - Final Report of the sixth session of the CIMO Expert Team Meeting SBII&CM, Vigna di Valle (Italy) 15-17 September 2008
(Available at http://www.wmo.int/pages/prog/www/IMOP/reports.html);

Annex I

WORLD METEOROLOGICAL ORGANIZATION

QUESTIONNAIRE I

on potential participants
of the WMO field intercomparison of Rainfall Intensity (RI) gauges
Italy 2007-2008

1. Member Country:

2. Expert (point-of-contact) responsible for the intercomparison in your country:
   Name, First Name: ……………………………………………………………………………………….
   Address: ………………………………………………………………………………………………..
   Tel./Fax: ………………………………………………………………………………………………..
   E-mail: …………………………………………………………………………………………………..

3. Information on sensor/systems foreseen in the intercomparison:
   ………
   ………
   ………
   ………

3.1 **Model/Type I** (1) (highest priority for participation):

a) Model/Type: ………………………………………………………………………………………
b) Manufacturer: …………………………………… Country: …………………………………
c) Number of sites where the instrument is in operational use or intended to be in your country: ……………………………………………………………………………………….
d) Will you submit **one [ ]** or **two [ ]** instruments (2)
e) Principle of operation (2)(3)
   TB [ ] WG [ ] DC [ ] OT [ ] (4)
f) What kind of parameter does the sensor/system report (2)(5)
   RI [ ] RA [ ] TT [ ] (4)
g) What kind of output does the sensor/system provide
   DG [ ] PS [ ] OT [ ] (4)

3.2 **Model/Type II** (1)(7) (lower priority for participation):

a) Model/Type: ………………………………………………………………………………………

b) Manufacturer: …………………………………… Country: …………………………………

c) Number of sites where the instrument is in operational use or intended to be in your country: ………………………………………………………………………………………………

d) Will you submit **one [ ]** or **two [ ]** instruments (2)

e) Principle of operation (2)(3)

TB [ ] WG [ ] DC [ ] OT [ ] (4)

f) What kind of parameter does the sensor/system report (2)(5)

RI [ ] RA [ ] TT [ ]

g) What kind of output does the sensor/system provide (6)

DG [ ] PS [ ] OT [ ] (4)

______________________ ____________________________________

Date Signature of the Permanent Representative

NOTES:

Further information on organizational and technical issue for the preparation of the intercomparison will be distributed in due course to the experts designated by you, as appropriate.

(1) It is necessary to prioritize the submission on participation because of limited testing facilities.

(2) Submission of two identical instruments is preferred. Please tick the appropriate box.

(3) Principle of operation

TB = Tipping Bucket WG = Weighing Gauge DC = Drop counter OT = Other

(4) If "Other", please attach a brief description of the applied principle/sensor output.

(5) Parameters reported

RI = Rainfall Intensity RA = Rainfall Accumulation TT = Time of Tipping

(6) Sensor/System Output

DG = Digital Output PS = Pulse Signal OT = Other

(7) In case it is intended to submit more than two types of rainfall intensity gauges, attach another completed copy of this questionnaire.

Please return the completed questionnaire, as soon as possible, but not later than March 30, 2004 to the following address:

Secretary-General
World Meteorological Organization
P.O. Box 2300
1211 Geneva 2
Switzerland
Telefax: +41 32 7342326

Annex II

WORLD METEOROLOGICAL ORGANIZATION

QUESTIONNAIRE II

on potential participants
of the WMO field intercomparison of Rainfall Intensity (RI) gauges

Italy 2007-2008

Note: please complete a separate questionnaire for each type of Sensor /System.
If necessary, attach additional pages.

Electronic version of the Questionnaire is available at:
http://www.wmo.int/web/www/IMOP/intercomparisons.html

1.	Member country

2.	Name of participating institution/company
	Address

3.	Person responsible for the intercomparison	
	Surname	First name
	Tel.:	Fax:
	E-mail:	Other:

4.	Alternative contact person	
	Surname	First name
	Tel.:	Fax:
	E-mail:	Other:

5.	Name and address of the manufacturer *(if different from no.2 above)* Name
	Address

6.	**Shipment of participating instruments**	
	Approx. commercial value Euro	Total weight of consignment kg
	Number of boxes	Overall volume of boxes cm^3
	Overall dimension, in cm (i.e. for storage purposes) Length **x** Width **x** Height cm	
	Other information concerning shipping	

7.	**Instrument specifications** *Please enclose a diagram showing, preferably, the different elements (photos are welcomed).*
	Instrument name | Model/Type
	Number of sites where the instrument is in operational use or intended to be in your country: | Could you submit One ☐ or Two ☐ identical instruments? (Two identical instruments are preferred – one as backup.)
	Principle of operation: Tipping bucket ☐ Weighing gauge ☐ Drop counter ☐ Optical disdrometer ☐ Other ☐ please describe:
	Which parameter(s) does the sensor report? Rainfall Intensity ☐ Rainfall Accumulation ☐ Time of Tipping ☐
	Orifice area: cm².
	Rain Intensity (RI) range *(for a sensor measuring rain accumulation (RA), it should be possible to calculate RI over a period of one minute. RI range must be stated in such conditions).* RI from mm/h to mm/h
	Rain Intensity (RI) resolution *(for RI measured or calculated over a period of one minute):* mm/h.
	Delay time for Rain Intensity (RI) measurement: minutes.
	Internal update cycle for the output of a new measurement value: s.
	Rain accumulation limit *(if the sensor has an accumulation limit (i.e. weighing sensor), please indicate it and the related limitation for RI range (if relevant).* Accumulation limit mm, and corresponding RI range from mm/h to mm/h over a period of minutes.

8.	**Sensor/System Output**
	Serial Digital | RS485 ☐ RS422 ☐
	Note: If any other digital serial interface than RS485/422 is provided the participating institution/company should submit an appropriate converter (1 piece) with RS485/422 output.
	Analog | *Pulse* ☐ *Reed Relay* ☐ Current ☐ Voltage ☐
	Other ☐ Please describe
	Note: If any other than serial digital output (i.e. analog output) is provided, the participating institution/company should submit an appropriate converter (1 piece) with RS485/422 output.

9.	**Information for field installation**	
	Notes on the power supply: Sensors should be able to operate on 220V AC, 50 Hz or unregulated 12V DC (if power supply is necessary); *For other voltages, converters must be provided.*	
	Power supply/Voltage required	Maximum total power consumption (watts)
	...to be continued	

9.	**Information for field installation**	
	Notes on the amount of space for installation: there will be an area of 50 cm x 50 cm on a separate concrete foundation for each instrument.	
	Overall dimensions of the instrument, in cm Length **x** Width **x** Height cm	Total weight kg
	Is the instrument in operational use equipped with a windshield? Yes ☐ No ☐ *Note: In case of Yes you have to provide 1 windshield as used operationally in your network.*	
	Dimensions: Length **x** Width **x** Height (in cm); and Weight (in kg) of main elements	
	Part id L **x** W **x** H kg	
	Part id L **x** W **x** H kg	
	Part id L **x** W **x** H kg	
	Part id L **x** W **x** H kg	
	Part id L **x** W **x** H kg	

10.	**Sensor/System siting requirements**
	Installation alignment required Yes ☐ No ☐ Please describe
	Notes on the cable lengths: Cable lengths for power supply and signal cable should be at least 4 m.
	Cable length for power supply m for signal cable m
	It is expected, that an expert from the Member country will assist with the installation of the Sensor/System on the test field. Will an expert give that assistance with the field installation? Yes ☐ No ☐
	Will an installation tools kit accompany the shipment? Yes ☐ No ☐
	Any special tools required for the installation? Yes ☐ No ☐ Please describe
	Special fixtures required for the installation? Yes ☐ No ☐ Please describe
	Maintenance period / item:
	Any other special requirements? Yes ☐ No ☐ Please specify

11.	**Calibration**
	Calibration reference
	Calibration intervals
	Procedure

12.	**Any other relevant information.** For example, if internal processing software introduces corrections or smoothing over a period of time longer than 1 minute, this should be carefully documented.
	Documentation Appropriate documentation including all detailed instructions and manuals needed for installation, operation, calibration, and routine maintenance have to be provided in advance.

Date

Name/Signature of the Permanent Representative
or Name/Signature of a manufacturer if proposed by the HMEI

Please send the electronic version of the completed form as an E-mail Attachment and at the same time the hard copy by fax to Dr Ondras:

Dr Miroslav Ondras
Senior Scientific Officer
WMO/OMM
World Weather Watch
P.O. Box 2300
CH 1211 Geneva, Switzerland

E-mail: Mondras@wmo.int
Fax: +41 22 730 80 21

Annex III

LIST OF SELECTED INSTRUMENTS*

ID#	RAIN GAUGE MODEL	MANUFACTURER	COUNTRY of the Manufacturer	MEASURING PRINCIPLE	
1	RIM7499020	McVan	AUSTRALIA	TBRG	
2	AP23	PAAR	AUSTRIA	TBRG	
3	R01 3070	PRECIS-MECANIQUE	FRANCE	TBRG-MC	
4	PT 5.4032.35.008	THIES	GERMANY	TBRG-PC	
5,27	R 102	ETG	ITALY	TBRG-SC	REFERENCE RAIN GAUGE
6	DQA031	LSI LASTEM	ITALY	TBRG	
7	UMB7525/I	SIAP-MICROS	ITALY	TBRG-SC	
8,28	PMB2	CAE	ITALY	TBRG-SC	REFERENCE RAIN GAUGE
9	RAIN COLLECTOR II	DAVIS	USA	TBRG	
10	LB-15188	LAMBRECHT	GERMANY	TBRG-PC	
11	PP040	MTX	ITALY	TBRG	
12	ARG100	EML	UK	TBRG	
13,29	MRW500	METEOSERVIS	CZECH REPUBLIC	WG	REFERENCE RAIN GAUGE
14	VRG101	VAISALA	FINLAND	WG	
15	PLUVIO	OTT	GERMANY	WG	
16	PG200	EWS	HUNGARY	WG	
17,30	T200B	GEONOR	NORWAY	WG	REFERENCE RAIN GAUGE
18	TRwS	MPS	SLOVAK REPUBLIC	WG	
20	PWD22	VAISALA	FINLAND	OPTICAL SENSOR	
21	PARSIVEL	OTT	GERMANY	OPTICAL DISDROMETER	
22	Laser Precipitation Monitor (LPM)	THIES	GERMANY	OPTICAL DISDROMETER	
23	WXT510	VAISALA	FINLAND	IMPACT DISDROMETER	
24	ANS 410/H	EIGENBRODT	GERMANY	WG-PRG	
25	Electrical raingauge	KNMI	NETHERLANDS	LRG	
26	LCR "DROP"	PVK ATTEX	RUSSIAN FED.	RADAR DISDROMETER	
19	MPA-1M	SA "MIRRAD"	UKRAINE	WG	***Selected - Not Participating***
31	8367.01 R2S	LUFFT	GERMANY	RADAR DISDROMETER	***Selected - Not Participating***

***List of abbreviations used for the measuring principles:**
TBRG: Tipping-bucket rain gauges without correction

TBRG-PC: Tipping-bucket rain gauges with extra pulse correction
TBRG-MC: Tipping-bucket rain gauges with mechanical correction
LRG: Level measurement rain gauges
WG: Weighing rain gauges
WG-PRG: Weighing rain gauges with pressure measurement

Annex IV

DATA ACQUISITION SYSTEM (DAQ)

The chosen data acquisition (DAQ) system was a Campbell Scientific CR1000 data-logger (Fig. A) equipped with serial output filtering peripherals (SDM-SIO4), switch closure/open collector peripherals (SDM-SW8A), multiplexers peripherals (AM16/32A), memory cards (field data storage), converters for serial protocols (ADAM4520 - RS232-422-485), 2 battery packs, an UPS system and an Ethernet module for communication and data transfer to the main PC (second data storage). The main PC was also equipped with an UPS and a RAID1 hard disk systems for providing fail safe operations and an un-interrupted data acquisition. Moreover the system was equipped with a couple of external USB hard disks for full backup of raw data (third data storage).

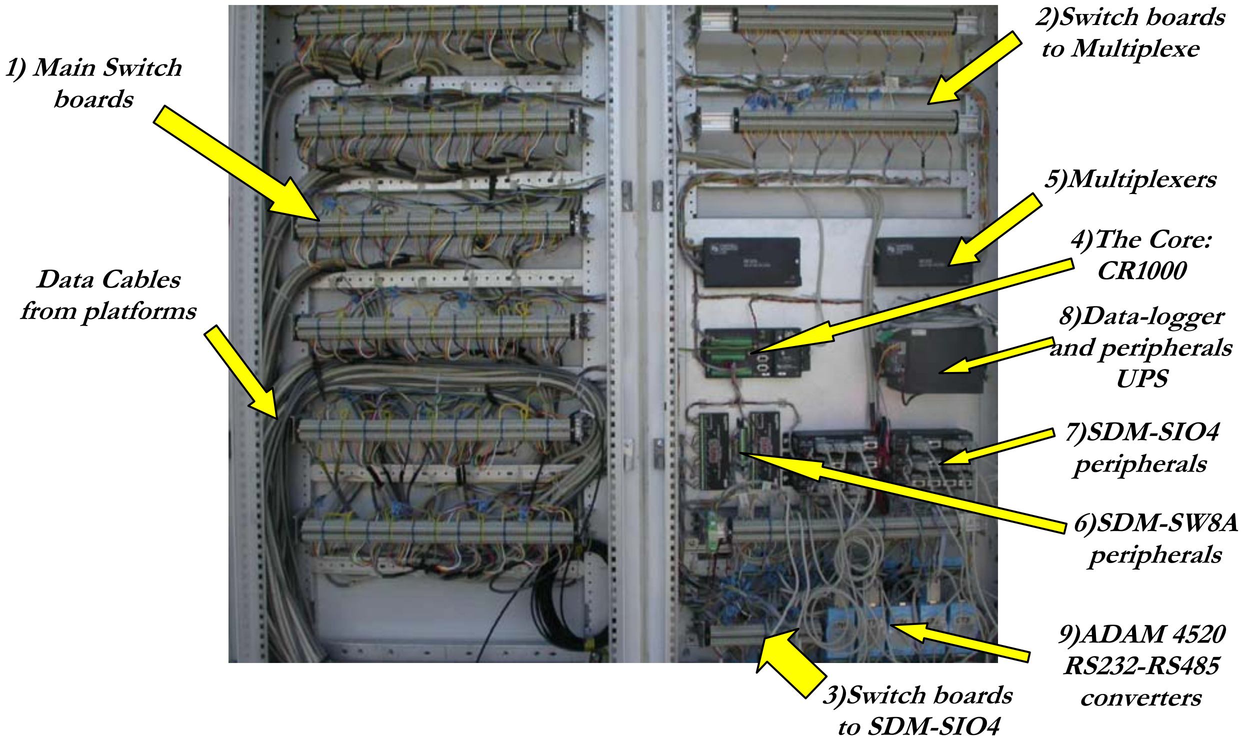


Fig. A - WMO Field Intercomparison of RI – Data Acquisition System

The DAQ system was programmed for performing direct measurements (for switch closure gauges, vibrating wire rain gauges, pulse emitting rain gauges, wind monitoring sensors, temperature/RH sensors, etc.) and serial output acquisition for string emitting rain gauges. In particular the serial acquisition was carried out by programming serial peripherals with dedicated string filters for the different serial strings emitted by each rain gauge in the field. Only 9 rain gauges out of 30 offered the possibility of a direct acquisition. The clock of the CR1000 was the official timestamp used for optimal synchronization, especially relevant for the evaluation of data at one-minute time base.

The acquisition for rain gauges consisted in a record of raw data from the rain gauges with a sampling time of 10 seconds or 1 minute, depending on the output time interval of the rain gauges. In case the RI (rainfall rate at 1 minute) is not directly provided as an output of the measurement, a transfer function given by manufacturers was applied to derive RI at 1-minute time resolution. The acquisition for ancillary sensors consisted in a record of raw data with a sampling time of 10 seconds.

Raw data from the rain gauges are processed for optimal time synchronization during data reduction and used for producing in real time the 1-minute RI [mm/h] for all gauges. Raw data from ancillary sensors are processed for optimal time synchronization during data reduction and used for producing in real time the 1-minute averages of wind speed and wind direction, max. wind speed, temperature and standard deviation (STD), relative humidity and STD, output of wetness sensors, global irradiance and atmospheric pressure. The raw data contain all data delivered by the sensors, including diagnostic data, and they are processed in near-real time by the Automatic Quality Control (AQC) implemented on a separated CPU in order to provide quality checked 1-minute RI data, quality controlled 1-minute ancillary data and QC information (e.g. flags, suspect data, erroneous data, etc.) to be used for data analysis and results evaluation. The AQC applied specific procedures agreed within the WMO ET.

Annex V

FIELD CALIBRATION RESULTS
SUMMARY TABLES (ST)

The following summary values were recorded in the tables below:

- *Date and time*;
- *RI ref [mm/h*]: constant rainfall intensity generated by the field calibrator;
- *AVGRI [mm/h]*: average of 1-minute RI values (R^j_{1min} mm/h]) of the rain gauge during the calibration calculated as follows:

$$AVGRI = \frac{1}{N}\sum_{j=1}^{N}(RI^{j}_{1\min})$$

- *RI(+CL95%)* and *RI(-CL95%)* in [mm/h]: the 1-min RI extremes of an interval corresponding to the Confidence Level of 95%. Interval: [AVGRI - δ(95%) ; AVGRI + δ(95%)]. The amplitude δ(95%) is the confidence half width interval calculated according to a normal /T-Student probability distribution of samples;
- *AVG RE[%],* relative error of the AVGRI calculated as follows:

$$AVGRE = 100 \cdot (\frac{AVGRI - RIref}{RIref})$$

- *RE(+CL95%)* and *RE(-CL95%),* relative errors [%] of RI(+CL95%) and RI(-CL95%) calculated as follows:

$$RE(+CL95\%) = 100 \cdot (\frac{RI(+CL95\%) - RIref}{RIref})$$

$$RE(-CL95\%) = 100 \cdot (\frac{RI(-CL95\%) - RIref}{RIref})$$

FIELD CALIBRATION #1 (2007)

RAIN GAUGE	Nr	DATE	TIME	RI ref	RI AVG	RI(+CL95%)	RI(-CL95%)	AVG RE	RE(+δ95%)	RE(-δ95%)
				mm/h	mm/h	mm/h	mm/h	%	%	%
PT5.4032.35.008-THIES	4	11/12/07	15:05	211,0	183,3	185,4	181,2	-13,1	-12,2	-14,1
Rain Collector II-DAVIS	9	13/12/07	10:45	138,3	119,1	122,7	115,5	-13,9	-11,3	-16,5
LB-15188-LAMBRECHT	10	11/12/07	15:33	212,9	217,2	219,9	214,5	2,0	3,3	0,8
ANS 410/H-EIGENBRODT	24	11/12/07	15:46	212,5	218,5	220,5	216,5	2,8	3,8	1,9
PLUVIO-OTT	15	11/12/07	16:00	212,3	213,1	213,2	212,9	0,3	0,4	0,3
T200B-GEONOR	17	12/12/07	13:59	205,5	204,5	206,2	202,8	-0,5	0,3	-1,3
T200B-GEONOR PIT	17A/30	13/12/07	14:15	204,7	202,6	203,7	201,5	-1,0	-0,4	-1,5
PG200-EWS	16	20/12/07	13:47	120,2	118,2	119,8	116,7	-1,7	-0,4	-2,9
RIM7499020-McVan	1	14/01/08	11:58	204,1	215,4	216,7	214,0	5,5	6,2	4,9
DQA031-LSI LASTEM	6	14/01/08	15:04	206,2	217,1	221,0	213,2	5,3	7,2	3,4
Electrical Raingauge-KNMI	25	11/12/07	13:34	225,8	224,6	227,5	221,8	-0,5	0,8	-1,8
VRG101-VAISALA	14	11/12/07	13:50	227,4	227,9	228,2	227,5	0,2	0,4	0,1
AP23-PAAR	2	11/12/07	13:13	199,0	176,6	178,4	174,8	-11,3	-10,4	-12,2
UMB7525/I-SIAP-MICROS	7	11/12/07	11:57	201,9	196,8	197,8	195,8	-2,5	-2,0	-3,0
ARG100-EML	12	11/12/07	12:16	198,4	183,4	186,7	180,2	-7,5	-5,9	-9,2
TRwS-MPS	18	11/12/07	10:46	201,4	200,3	203,3	197,3	-0,6	0,9	-2,0
MRW500-METEOSERVIS	13	14/01/08	11:29	209,0	214,4	226,3	202,4	2,6	8,3	-3,2
MRW500-METEOSERVIS PIT	13A/29	14/01/08	11:04	209,2	212,2	225,2	199,1	1,5	7,7	-4,8
R102-ETG	5	10/12/07	14:36	212,8	205,5	205,9	205,0	-3,4	-3,2	-3,7
R102-ETG PIT	5A/27	10/12/07	14:59	208,9	206,4	207,0	205,8	-1,2	-0,9	-1,5
PP040-MTX	11	14/01/08	15:32	160,5	140	146,5	133,5	-12,8	-8,7	-16,8
R01 3070-Precis Mecanique	3	13/12/07	9:59	101,6	96	96	96	-5,5	-5,5	-5,5
PMB2-CAE PIT	8A/28	10/12/07	15:16	215,2	216,8	217,3	216,3	0,8	1,0	0,5
PMB2-CAE	8	10/12/07	15:33	214,4	218,5	219,1	217,8	1,9	2,2	1,6

FIELD CALIBRATION #2 (2008)

RAIN GAUGE	Nr	Date	Time	RI ref	RI AVG	RI(+CL95%)	RI(-CL95%)	AVG RE	RE(+δ95%)	RE(-δ95%)
				mm/h	mm/h	mm/h	mm/h	%	%	%
PT5.4032.35.008-THIES	4	09/04/08	10:51	140,2	142,3	143,2	141,4	1,5	2,1	0,9
Rain Collector II-DAVIS	9	10/04/08	09:18	135,3	116,5	118,3	114,8	-13,9	-12,6	-15,2
LB-15188-LAMBRECHT	10	10/04/08	10:16	135,1	141,6	142,8	140,4	4,8	5,7	3,9
ANS 410/H-EIGENBRODT	24	10/04/08	11:11	136,9	139,6	140,9	138,3	2,0	2,9	1,0
PLUVIO-OTT	15	10/04/08	11:56	138,9	138,9	139,7	138,0	0,0	0,6	-0,6
T200B-GEONOR	17	10/04/08	14:38	136,6	136,0	136,6	135,4	-0,4	0,1	-0,9
T200B-GEONOR PIT	17A/30	10/04/08	15:26	135,1	133,2	133,8	132,5	-1,5	-1,0	-2,0
PG200-EWS	16	23/05/08	08:04	140,8	140,7	141,6	139,8	-0,1	0,5	-0,7
RIM7499202-McVan	1	27/05/08	13:06	138,5	144,0	148,8	139,2	4,0	7,5	0,5
DQA031LSI LASTEM	6	16/04/08	11:45	135,2	141,0	150,3	131,7	4,3	11,2	-2,5
Electrical Raingauge-KNMI	25	16/04/08	14:27	135,8	135,8	136,3	135,3	0,0	0,4	-0,4
VRG101-VAISALA	14	17/04/08	10:13	135,2	134,6	134,9	134,4	-0,4	-0,2	-0,6
AP23-PAAR	2	17/04/08	10:44	128,9	120,2	121,5	118,9	-6,8	-5,8	-7,7
UMB7525/I-SIAP-MICROS	7	27/05/08	09:16	132,7	133,8	134,7	132,8	0,8	1,5	0,1
ARG100-EML	12	27/05/08	10:39	128,4	123,3	125,7	120,8	-4,0	-2,1	-5,9
TRwS-MPS	18	27/05/08	11:12	122,0	120,5	121,7	119,2	-1,3	-0,2	-2,3
MRW500-METEOSERVIS	13	26/05/08	12:34	114,0	113,7	120,5	106,8	-0,3	5,7	-6,3
MRW500-METEOSERVIS PIT	13A/29	27/05/08	08:32	133,3	133,4	143,9	122,9	0,1	8,0	-7,8
R102-ETG	5	08/05/08	09:37	130,6	130,9	132,0	129,8	0,2	1,1	-0,6
R102-ETG PIT	5A/27	08/05/08	10:13	130,8	132,0	133,4	130,6	1,0	2,0	-0,1
PP040-MTX	11	08/05/08	10:33	132,0	119,5	122,7	116,3	-9,5	-7,0	-11,9
R01 3070-Precis Mecanique	3	08/05/08	11:14	130,6	123,7	126,5	120,8	-5,3	-3,1	-7,4
PMB2-CAE PIT	8A/28	08/05/08	16:37	130,6	131,0	133,4	128,7	0,3	2,1	-1,5
PMB2-CAE	8	09/05/08	12:16	132,9	134,5	137,7	131,3	1,2	3,6	-1,2

FIELD CALIBRATION #3 (2009)

RAIN GAUGE	Nr	Date	Time	RI ref	RI AVG	RI(+CL95%)	RI(-CL95%)	AVG RE	RE(+δ95%)	RE(-δ95%)
				mm/h	mm/h	mm/h	mm/h	%	%	%
PT5.4032.35.008-THIES	**4**	20/04/09	11:00	154,4	154,9	156,2	153,6	0,3	1,1	-0,5
Rain Collector II-DAVIS	**9**	15/04/09	09:22	155,6	126,9	128,7	125,0	-18,5	-17,3	-19,7
LB-15188-LAMBRECHT	**10**	15/04/09	10:12	153,6	156,0	157,3	154,7	1,6	2,4	0,7
ANS 410/H-EIGENBRODT	**24**	15/04/09	11:03	151,1	155,9	157,1	154,8	3,2	4,0	2,5
PLUVIO-OTT	**15**	15/04/09	11:54	154,4	154,1	154,2	154,0	-0,2	-0,1	-0,3
T200B-GEONOR	**17**	15/04/09	14:22	154,5	152,5	153,0	152,1	-1,3	-1,0	-1,6
T200B-GEONOR PIT	**17A/30**	15/04/09	15:14	151,0	150,6	151,0	150,3	-0,3	0,0	-0,5
PG200-EWS	**16**	15/04/09	16:07	149,7	149,2	149,8	148,5	-0,3	0,1	-0,8
RIM7499020-McVan	**1**	15/04/09	17:00	154,9	161,8	164,0	159,7	4,5	5,9	3,1
DQA031-LSI LASTEM	**6**	23/04/09	14:42	150,6	161,6	164,5	158,6	7,3	9,3	5,3
Electrical Raingauge-KNMI	**25**	20/04/09	09:55	137,2	135,0	136,5	133,5	-1,6	-0,5	-2,7
VRG101-VAISALA	**14**	20/04/09	10:28	144,2	143,1	143,6	142,7	-0,8	-0,5	-1,0
AP23-PAAR	**2**	22/04/09	08:38	119,2	112,9	113,8	112,0	-5,3	-4,5	-6,0
UMB7525/I-SIAP-MICROS	**7**	22/04/09	09:32	119,6	117,9	118,2	117,5	-1,4	-1,2	-1,7
ARG100-EML	**12**	22/04/09	11:02	117,6	115,6	117,4	113,9	-1,7	-0,2	-3,2
TRwS-MPS	**18**	22/04/09	11:55	121,5	120,6	121,4	119,7	-0,7	0,0	-1,4
MRW500-METEOSERVIS	**13**	24/04/09	09:19	123,3	125,2	129,5	120,9	1,6	5,1	-1,9
R102-ETG	**5**	22/04/09	15:27	139,8	134,8	135,3	134,2	-3,6	-3,2	-4,0
R102-ETG PIT	**5A/27**	22/04/09	16:06	139,3	140,6	140,9	140,2	0,9	1,2	0,6
PP040-MTX	**11**	22/04/09	16:43	142,2	125,3	128,4	122,3	-11,9	-9,7	-14,0
R01 3070-Precis Mecanique	**3**	22/04/09	17:19	140,4	133,1	134,8	131,5	-5,2	-4,0	-6,4
PMB2-CAE PIT	**8A/28**	24/04/09	10:12	142,0	143,1	144,4	141,8	0,8	1,7	-0,2
PMB2-CAE	**8**	24/04/09	10:46	140,0	143,2	143,9	142,5	2,3	2,8	1,7
PLUVIO-OTT PIT	**13A/29**	15/04/09	12:55	144,4	144,2	144,8	143,6	-0,2	0,3	-0,6

Annex VI

THE QUALITY CONTROL PROCEDURES FOR 1-MINUTE DATA

A. QC ON 1-MINUTE RI DATA

Rainfall Intensity on 1 minute time scale is obtained from the 10 seconds raw data acquired by the data logging system, Table A shows the minimum number of samples necessary to pass the missing QC flag. In particular, for sensors with automatic 1 minute output (#5, #7, #8, #14, and #24) the following basic rule was applied for the best synchronization and the determination of the 1 minute RI data:

- if no sample is detected on 1 minute time span, then also the 10 seconds following the given minute must be checked and if a sample is detected there, it must be attributed to the previous minute.

This rule can also be extended to all the instruments presenting automatic output as follows:

- if, on 1 minute time span, a number of samples equal to (expected number of samples - 1) is detected, then also the 10 seconds following that given minute must be checked and if a sample is detected there it must be attributed to the previous minute.

The control actions performed on the RI data are:

1) NUMBER OF SAMPLES QC - MISSING DATA (FLAG=5): depends on the number of samples expected by each instrument on 1 minute, according to Table A. The Minimum Number of samples, reported in Table A and used for 1 minute RI determination, was chosen according to the Final Report of the fifth session of the Expert Team Meeting CIMO-SBII&CM (Vigna di Valle, Italy, 17-21 September 2007).
If the number of samples collected in one minute is less than the Minimum Number of Samples of the considered gauge, that minute is tagged as "MISSING" and the flag is coded. The missing datum can be originated either by a problem occurred to the instrument or by a difference of the duration of the internal clock of the gauge with respect to the clock of the acquisition system.

2) NATIVE ERRORS QC - DOUBTFUL/ERRONEOUS DATA (FLAG=3,4): was determined from those instruments that could provide diagnostic information. The 1-minute datum can be doubtful or erroneous according to the corresponding diagnostic parameter reported on technical manuals. The total number of Diagnostic Data managed and stored by the acquisition system is 26 (see Datasheets in Annex). Only part of these diagnostic data could be processed by AQC to have quality checked rainfall intensity data available for analysis (see Table B and Datasheets). The remaining part of those diagnostic data was manually and periodically checked by local staff.

3) PLAUSIBLE VALUE CHECK - DOUBTFUL/ERRONEOUS DATA (FLAG=3,4): This is a range check performed on the 1 minute aggregated values for the gauges in Table C. The instrument operational range is assumed plausible as declared by the manufacturer and where it is not declared or declared unlimited, the WMO upper limit of 2000 mm/h is assumed (World Meteorological Organization, 2006).
If the RI value on 1 minute **exceeds** the upper limit of the range declared by the manufacturer (or the 2000 mm/h limit for undeclared or declared unlimited ranges), such datum is flagged as "DOUBTFUL" (FLAG=3); if the RI value on 1 minute is **negative**, such datum is flagged as "ERRONEOUS" (FLAG=4).

ID	MODEL-MANUFACTURER	EXPECTED SAMPLES	MINIMUM SAMPLES
1	RIM7499020-McVan	6	4
2	AP23-PAAR	6	4
3	R01 3070-PRECIS-MECANIQUE	6	4
4	PT 5.4032.35.008-THIES	6	4
5	R 102 -ETG	1	1
6	DQA031-LSI LASTEM	6	4
7	UMB7525/I-SIAP-MICROS	1	1
8	PMB2-CAE	1	1
9	RAIN COLLECTOR II-DAVIS	6	4
10	LB-15188-LAMBRECHT	6	4
11	PP040-MTX	6	4
12	ARG100-EML	6	4
13	MRW500 -METEOSERVIS	6	4
14	VRG101-VAISALA	1	1
15	PLUVIO-OTT	1	1
16	PG200-EWS	1	1
17	T200B -GEONOR	6	4
18	TRwS-MPS	1	1
20	PWD22-VAISALA	1	1
21	PARSIVEL-OTT	1	1
22	LPM-THIES	1	1
23	WXT510-VAISALA	1	1
24	ANS 410/H-EIGENBRODT	1	1
25	Electrical raingauge-KNMI	1	1
26	LCR “DROP”- PVX ATTEX	1	1

Table A: Expected and minimum number of samples for each gauge on 1 minute.

ID	MODEL-MANUFACTURER	DIAGNOSTIC PARAMETERS
14	VRG101-VAISALA	D1
15	PLUVIO-OTT	D1, D3
16	PG200-EWS	D1
20	PWD22-VAISALA	D1, D2
21	PARSIVEL-OTT	D1
22	LPM-THIES	D1, D2, D3, D4, D5
24	ANS 410/H-EIGENBRODT	D1
25	Electrical raingauge-KNMI	D1
26	LCR “DROP “-PVK ATTEX	D3

Table B: list of the rain gauges that provide diagnostic information

4) CHECK OF E-LOGBOOK REPORTS - UNDER MAINTENANCE DATA (FLAG=6): All the maintenance actions performed during the intercomparison period have been recorded in an electronic logbook, in order to exclude from data analysis and error statistics missing or erroneous data due to ordinary maintenance procedures. Moreover, to the purpose of an automatic quality control procedure, a machine readable version of the logbook was produced with the following record format:
/ Start date / Start time / End date / End time/ instrument id

Information derived from this Logbook summary are used for the automatic assignment of "UNDER MAINTENANCE" label (FLAG=6), directly coded with -2 value in the final controlled file QC_RI_"yyyy-mm-dd.dat".

ID	MODEL-MANUFACTURER	OPERATIONAL RANGE (mm/h)
1	RIM7499020-McVan	0 – 500
2	AP23-PAAR	0 – 720
3	R01 3070-PRECIS-MECANIQUE	0 – 450
4	PT 5.4032.35.008-THIES	0 – 420
5	R102 -ETG	0 – 300
6	DQA031-LSI LASTEM	0 – 300
7	UMB7525/I-SIAP-MICROS	0 – 300
8	PMB2-CAE	0 – 300
9	RAIN COLLECTOR II-DAVIS	0 – 2540
10	LB-15188-LAMBRECHT	0 – 600
11	PP040-MTX	0 – N/A
12	ARG100-EML	0 – N/A
13	MRW500 -METEOSERVIS	0 – 400
14	VRG101-VAISALA	0 – 1200
15	PLUVIO-OTT	0 – 1800
16	PG200-EWS	0 – 500
17	T200B-GEONOR	0 – 600
18	TRwS-MPS	0 – 3600
20	PWD22-VAISALA	0 – 999.99
21	PARSIVEL-OTT	0 – 1200
22	LPM-THIES	> 250
23	WXT510-VAISALA	0 – 200
24	ANS 410/H-EIGENBRODT	0 – 1200
25	Electrical raingauge-KNMI	0 - 300
26	LCR “DROP“-PVK ATTEX	0 - 150

Table C: Operational RI limits

B. QC ON 1-MINUTE ANCILLARY DATA

The AQC takes into account the working limits of ancillary sensors and the plausible values related to climatic conditions, the “external” consistency conditions about the maximum and minimum time variability of the parameters and the “internal” consistency.

1) PLAUSIBLE VALUE CHECK- ERRONEOUS DATA (FLAG=4):
The limit values implemented into the AQC, based on instrumental limits provided by the manufacturer and climatic limits, are the following:
Air temperature: -40 °C - +60 °C;
Relative Humidity: 0 - 100%;
Atmospheric Pressure: 600 - 1100 hPa;
Wind direction: 0 - 360 degrees;
Wind speed: 0 - 100 m/s (1-minute average);
Wind gust: 0 - 100 m/s;
Global solar radiation (irradiance): 0 - 1600 Wm^{-2}.

If the measured value is outside the acceptable range limit it is flagged as erroneous (FLAG=4).

2) TIME CONSISTENCY CHECK - DOUBTFUL/ERRONEOUS DATA (FLAG=3):
a) Check of the maximum allowed variability of the 1-minute value (a step test): if the current 1-minute value differs from the previous one by more than a specific limit (step), then the current 1-minute value fails the check and it is flagged as doubtful (suspect, FLAG=3). Limits of the maximum variability (the absolute value of the difference between two successive values) are reported in Table D.
b) Check of the minimum required variability of 1-minute values during 1 hour (a persistence test): once the measurement of the parameter has been done for at least 60 minutes, if the 1-minute values do not vary over the past at least 60 minutes by more than the specified limit (a threshold value) then the current 1-minute value fails the check.
Limits of the minimum required variability implemented into the AQC are:
Air temperature: above or equal to 0.1 °C over the past 60 minutes;
Relative Humidity: above or equal to 1% over the past 60 minutes when RH is above 50% and below 90%;
Wind direction: above or equal to 10 degrees over the past 60 minutes (limited to periods with wind speed greater than 0);
Wind speed: above or equal to 0.5 m/s over the past 60 minutes;
If the value fails the time consistency checks it is flagged as doubtful (FLAG=3).

parameter	Limit for suspect data	Limit for erroneous data
Air Temperature	5 °C	10 °C
Relative Humidity	10 %	15 %
Wind Speed	10 m/s	20 m/s
Global Solar Radiation (Irradiance)	800 W/m^2	1000 W/m^2

Table D: Limits of maximum variability for the time consistency check of ancillary data.

3) INTERNAL CONSISTENCY CHECK - INCONSISTENT DATA (FLAG=2): The following conditions must exist:

wind speed = 00 and wind direction = 00
wind speed ≠ 00 and wind direction ≠ 00
wind gust (speed) ≥ wind speed

If the datum fails the internal consistency check, it is flagged as inconsistent (FLAG=2).

TABLE OF WEIGHTS FOR RAINFALL INTENSITY REFERENCE CALCULATION

Event	μ_{R102}	μ_{PMB2}	μ_{T200B}
2007-10-30	**0.511**		0.489
2008-05-13 2008-05-20 2008-05-22 2008-06-06 2008-07-27 2008-08-09	**0.345**	**0.325**	0.33
2008-09-15		**0.495**	0.505
2008-10-28 2008-10-29 2008-10-31 2008-11-01 2008-11-04 2008-11-12 2008-11-24 2008-11-28 2008-11-29 2008-11-30 2008-12-05 2008-12-06 2008-12-10 2008-12-11 2008-12-14 2008-12-15 2008-12-16 2009-01-01 2009-01-07 2009-01-15 2009-01-20 2009-01-24 2009-01-26 2009-02-07 2009-02-10 2009-02-18 2009-03-02 2009-03-04 2009-03-05 2009-03-29 2009-03-31 2009-04-01 2009-04-23 2009-04-27 2009-04-28	0.345	0.325	0.33

RIM7499020-McVan
- Australia -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Siphon controlled Tipping bucket without correction (a siphon control unit discharges as steady stream).
- Collector area: 325 cm^2
- Range of measurement : 0-500 mm/h
- 1-minute resolution: 12 mm/h

Data output

- Output: Passive Reed Switch with dual switch.
- Data update cycle : 10 s (Data Acquisition System sampling time).
- Rainfall parameters: Rainfall accumulation (RA [mm]).
- Transfer function for 1-min RI: RI_{1min}[mm/h] = $pulses_{1min}$ 12[mm/h] ($pulses_{1min}$ =number of pulses of reed switch in 1 minute; 1 pulse = 0.2 mm)

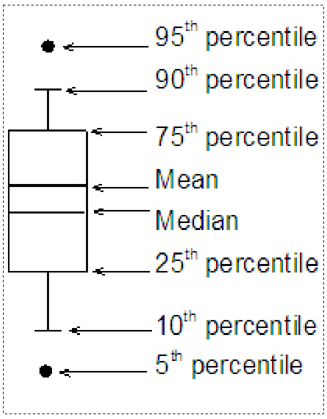
#1 –RIM7499020-McVan in the field

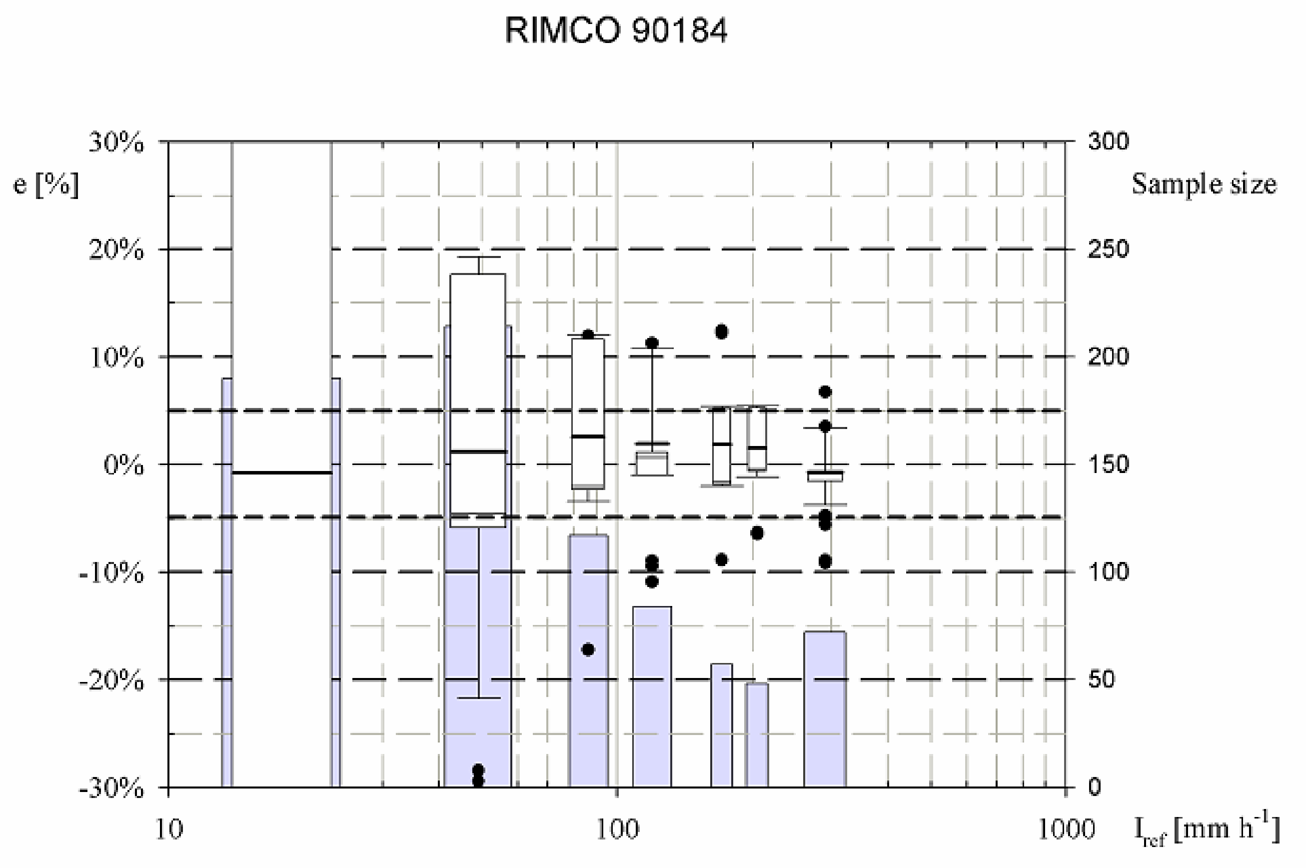
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute 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

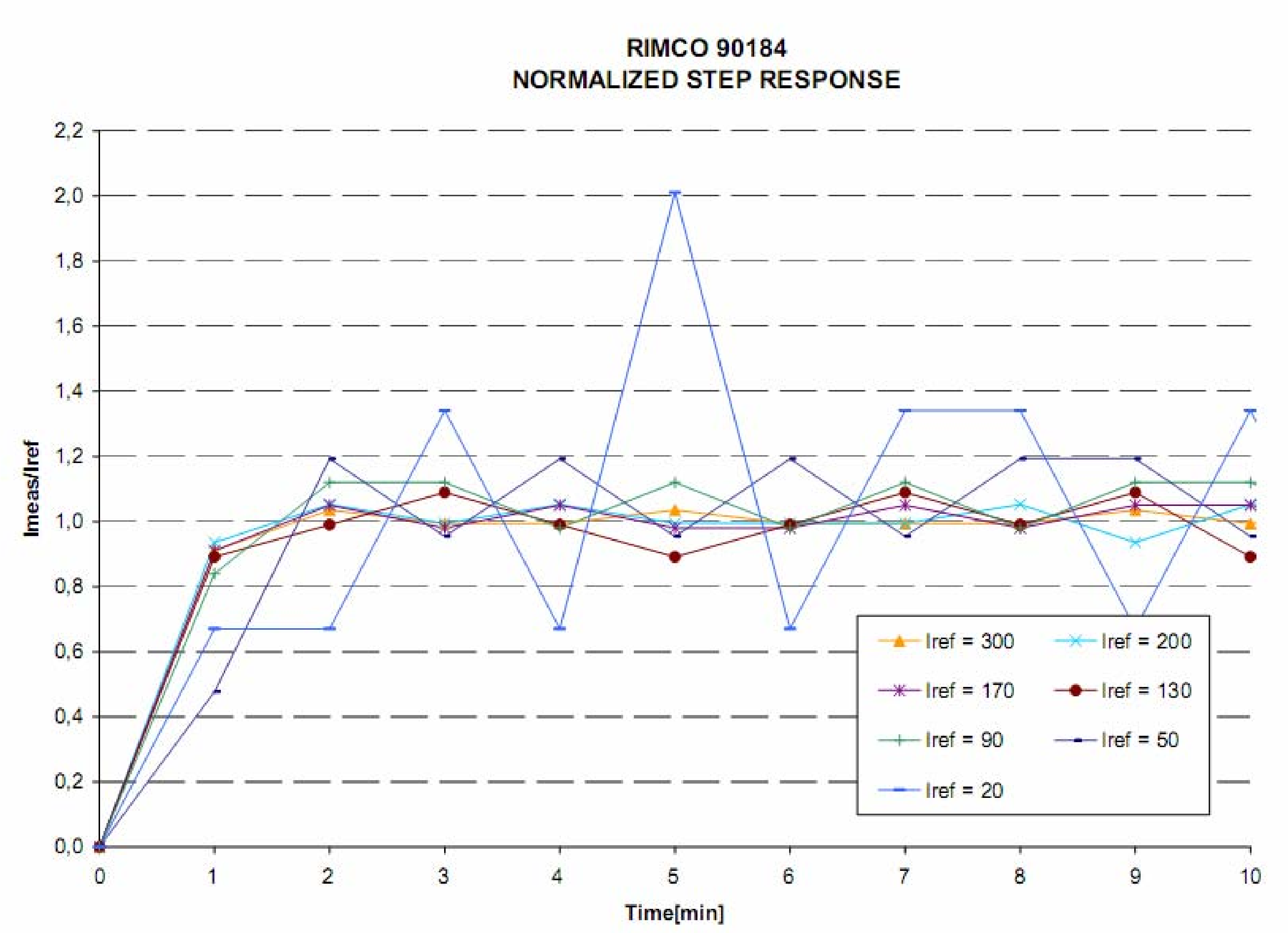




Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.

The “saw” response is mainly due to the measurement resolution.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a Portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

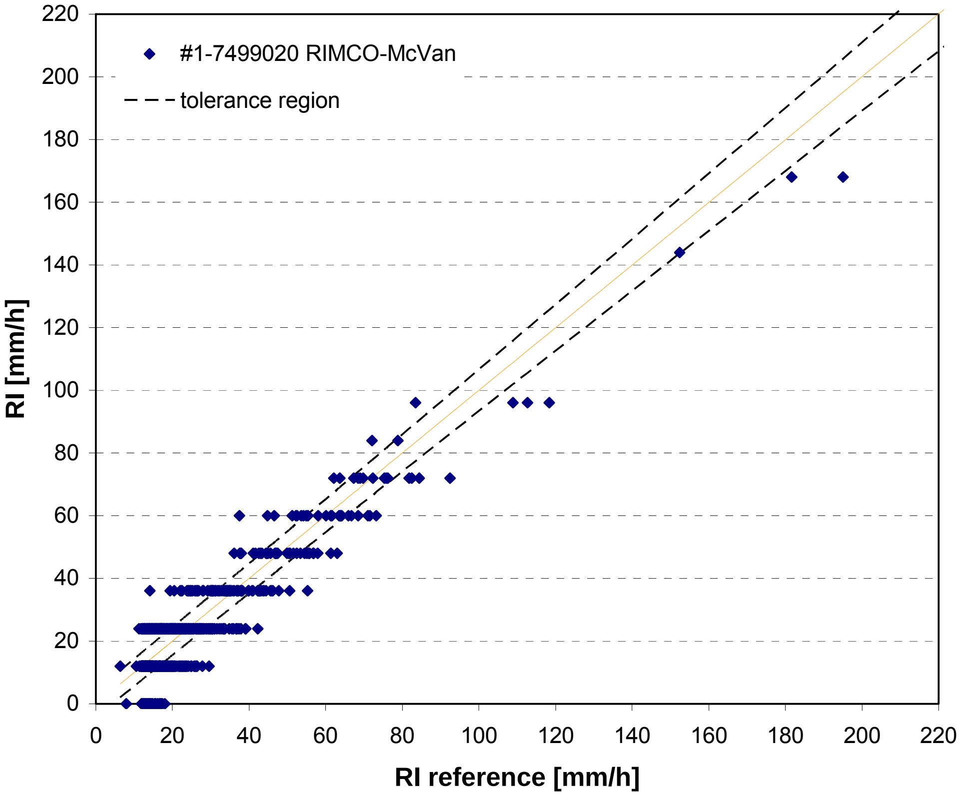
RIM7499020- McVan s/n 90184

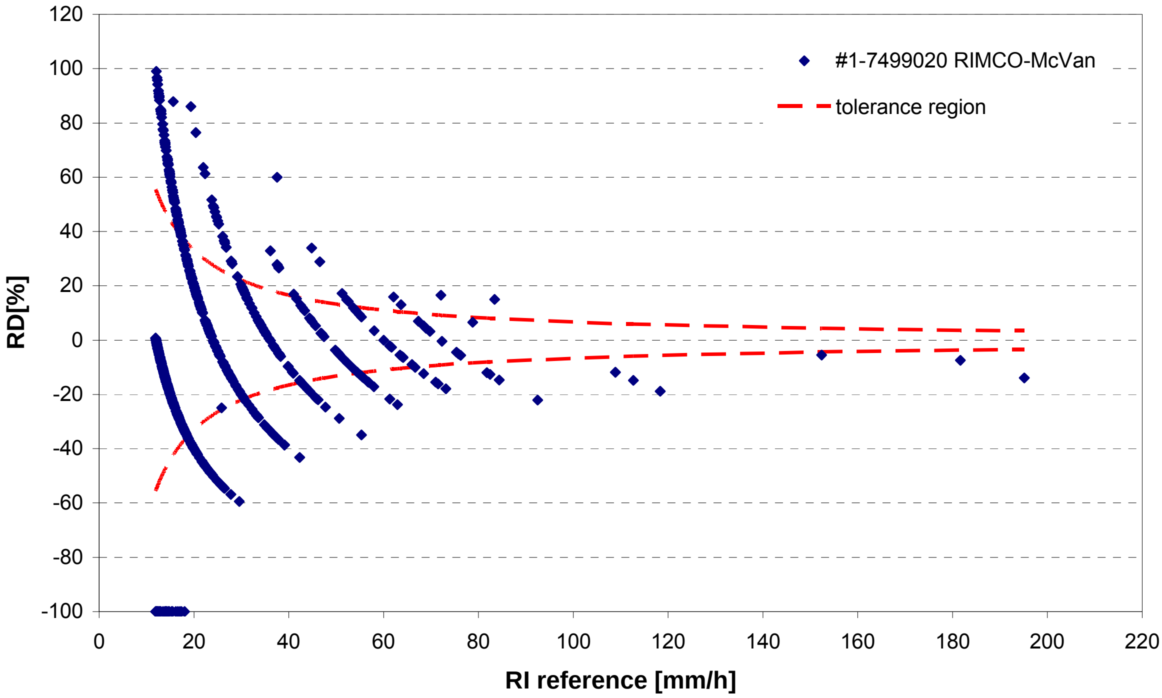
CALIBRATION	1° 14/01/08	2° 23/05/08	3° 15/04/09
RI ref [mm/h]	204.1	138.5	154.9
AVG RE [%]	5.5	4.0	4.5
[RE(-C.L.95%),RE(+C.L.95%)][%]	[4.9,6.2]	[0.5,7.5]	[3.1,5.9]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%)

Field Intercomparison Measurements

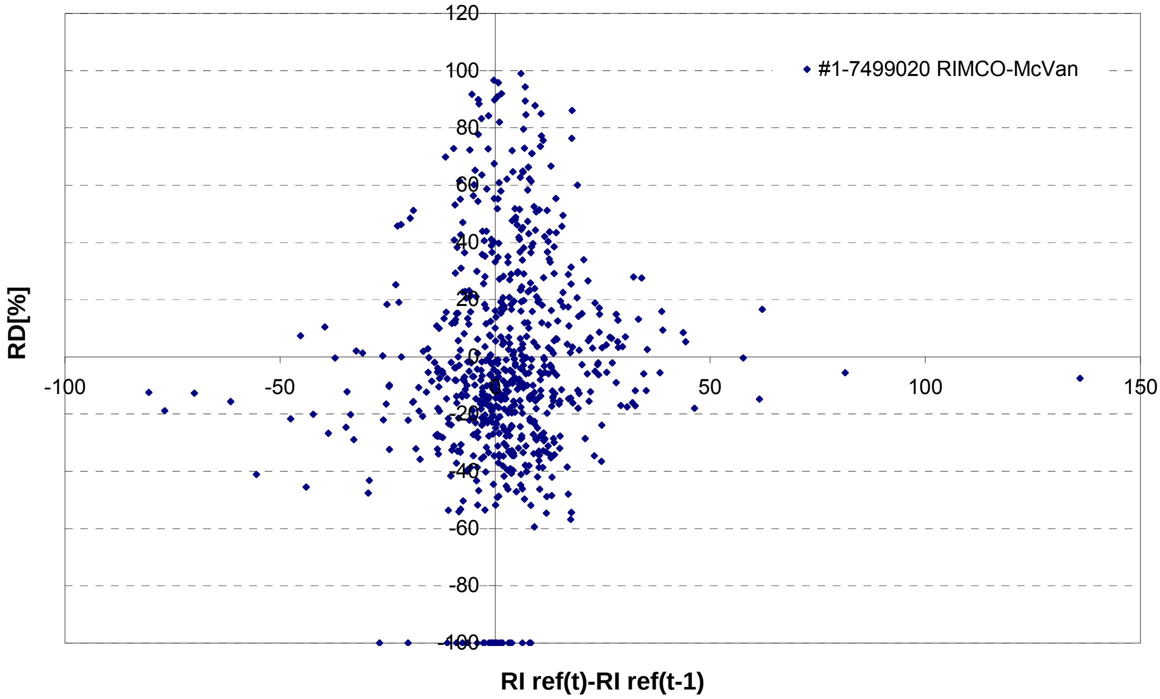
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by RIM7499020-McVan and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



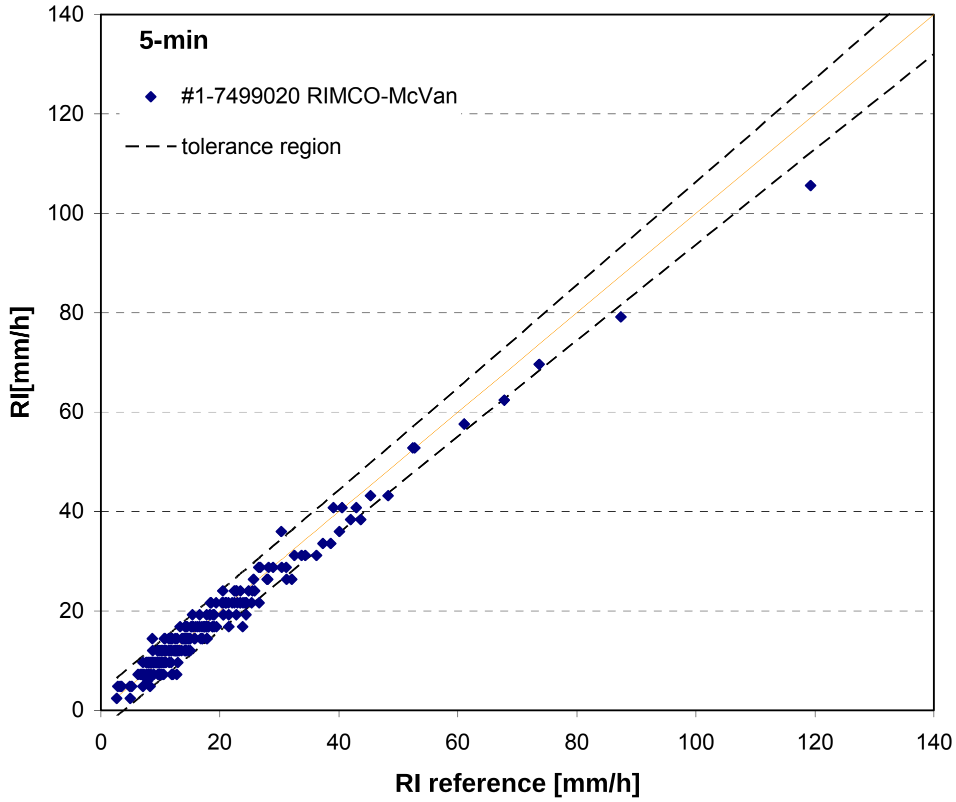


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$)



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by RIM7499020-McVan and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ***($RI=a\cdot(RIref)^b$)***	**a**	**b**	**R^2**
#1 **RIM7499020 McVan**	1.31	0.90	0.68

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

This is a siphon controlled tipping bucket rain gauge. The siphon allows the water to fall into the buckets always at the same "speed", independently of RI. Therefore, the laboratory calibration curve does not show under-estimation with high RI, usual for a non-corrected TBRG. In fact, the laboratory calibration shows an average overestimation less than 5% in the range 40-200 mm/h and a smaller average underestimation for the rest of the tested RI range.

The field calibration gives consistent results with the laboratory calibration. No drift detected under field calibration conditions.

The RI scatter plot shows an under estimation for RI_{ref} above 80 mm/h, not explained by the laboratory results. The 5 minutes RI scatter plot shows underestimation over 60 mm/h.

In the RI variation response plot several points at –100% show the fact that for low RI_{ref} values, the bucket does not tip (this could be amplified by the siphon storage).

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
No diagnostic data and error code.

Data availability (1 min):
- Valid Data: 100%.

Maintenance:
- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust; cleaning of the inside of bucket as recommended by Manufacturer.

Malfunctioning:
- None.

AP23 PAAR
- Austria -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Tipping bucket without correction.
- Collector area: 500 cm^2
- Range of measurement : 0-720 mm/h
- 1-minute resolution: 6 mm/h

Data output

- Output: Passive Reed Switch with dual switch.
- Data update cycle : 10 s (Data Acquisition System sampling time).
- Rainfall parameters: Rainfall accumulation (RA [mm]).
- Transfer function for 1-min RI: RI_{1min}[mm/h] = $pulses_{1min}$ 6[mm/h] ($pulses_{1min}$ =number of pulses of reed switch in 1 minute; 1 pulse = 0.1 mm)

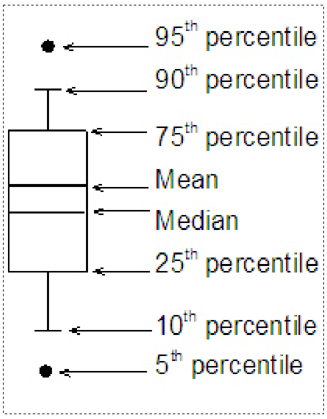
#2 AP23-PAAR in the field

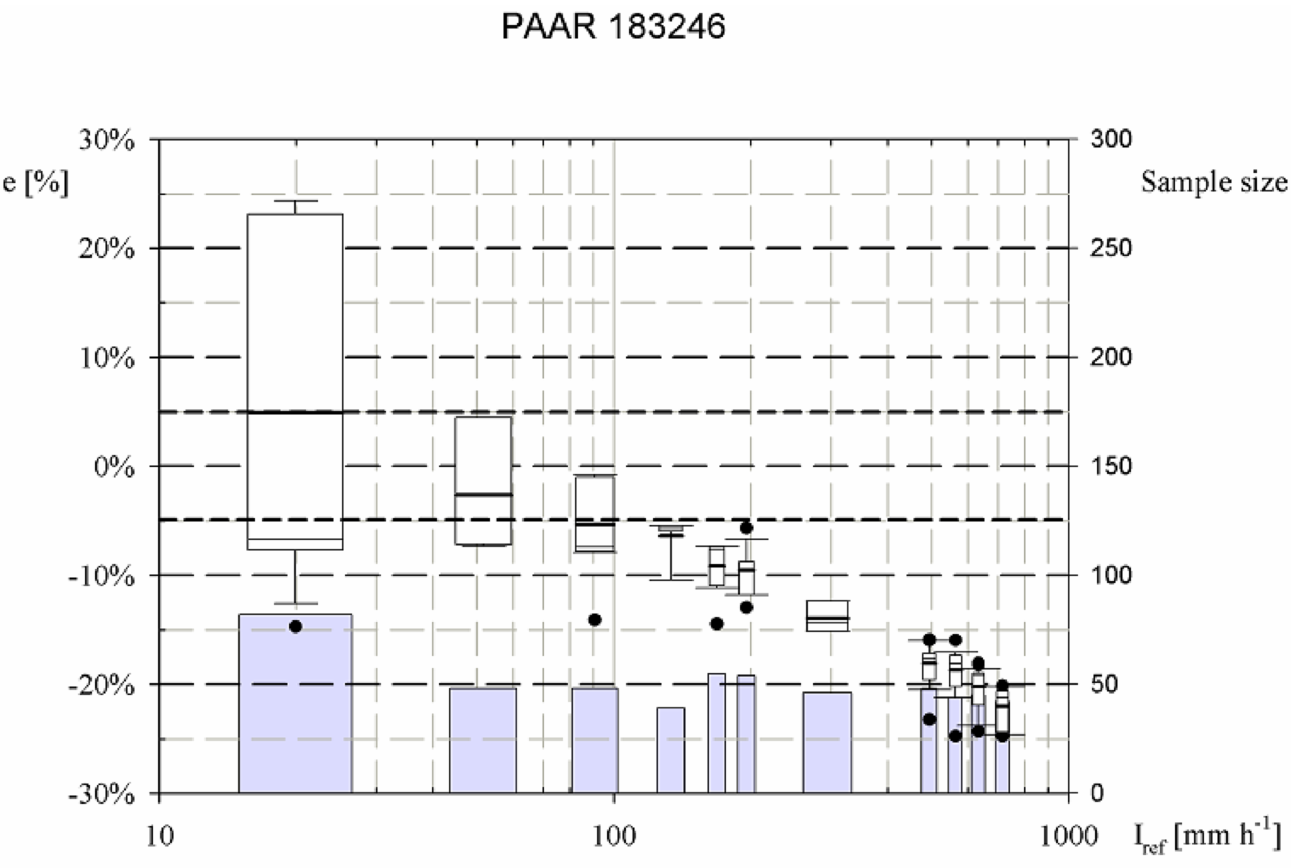
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute 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

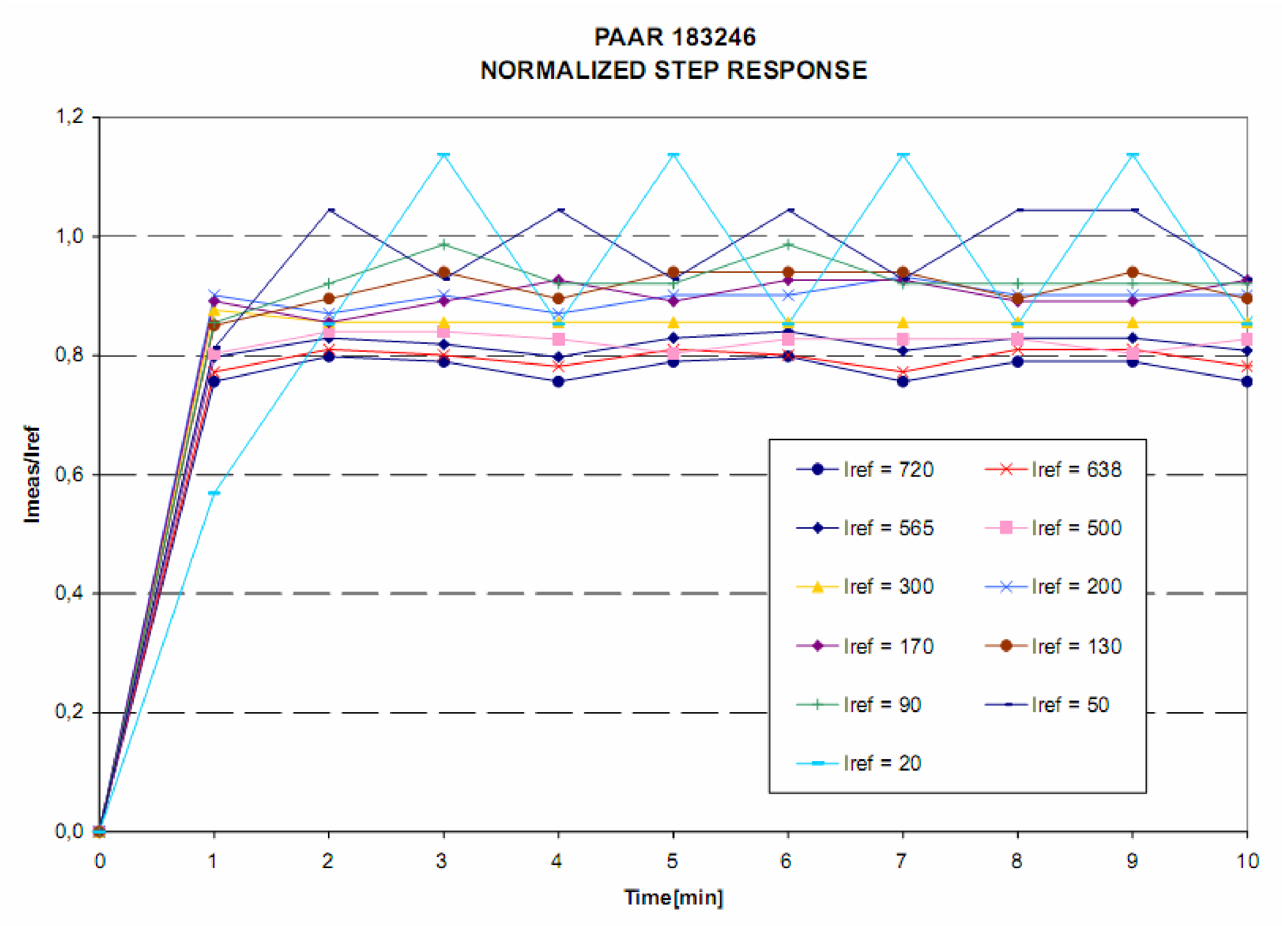




Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behavior of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.

The "saw" response is mainly due to the measurement resolution.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Device designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

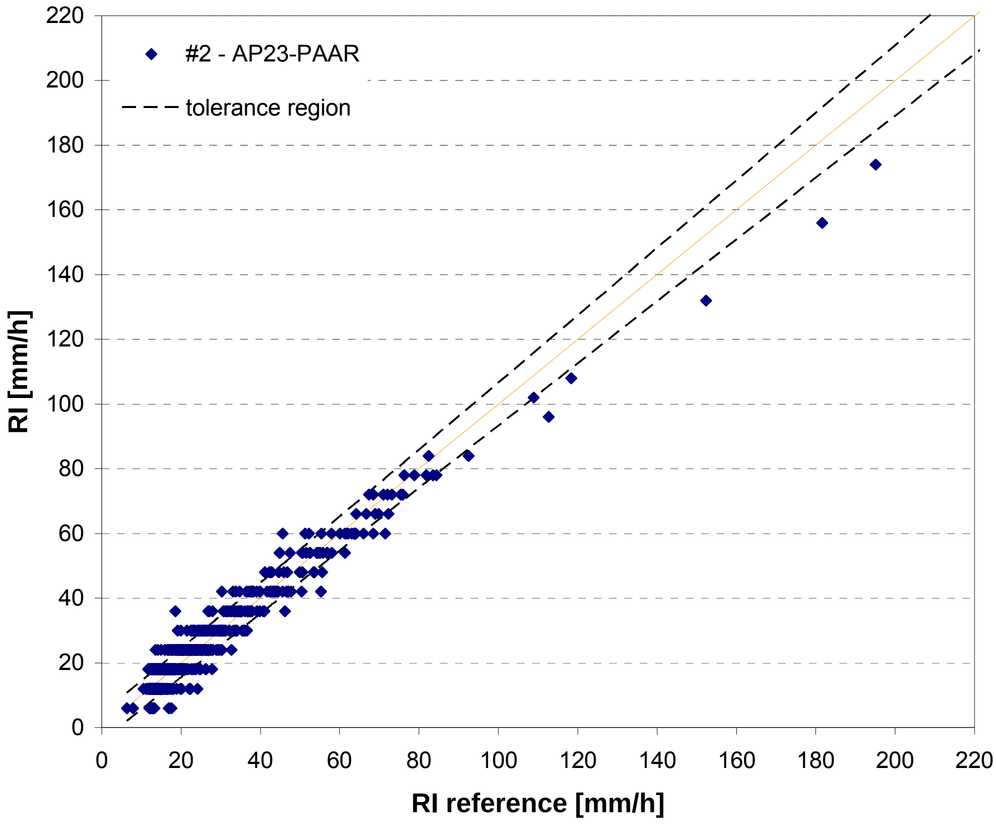
PAAR s/n 183246

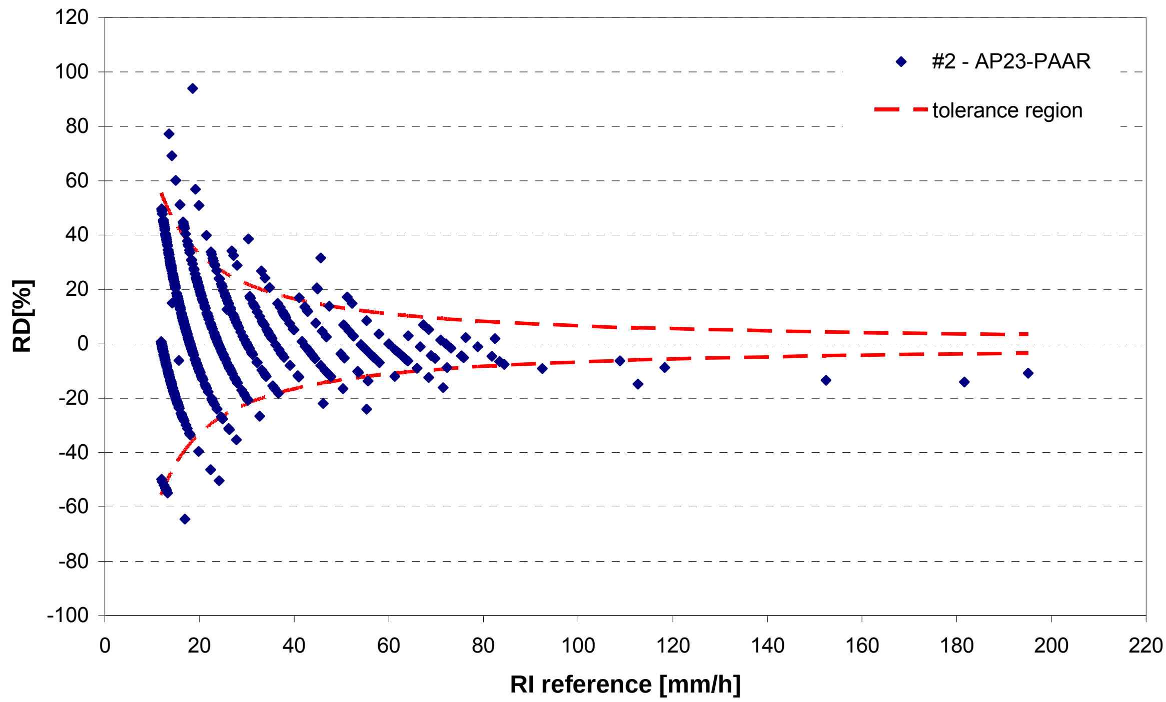
CALIBRATION	**1° 11/12/07**	**2° 17/04/08**	**3° 22/04/09**
RI ref [mm/h]	199.0	128.9	119.2
AVG RE [%]	-11.3	-6.8	-5.3
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-12.2,-10.4]	[-7.7,-5.8]	[-6.0,-4.5]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%).

Field Intercomparison Measurements

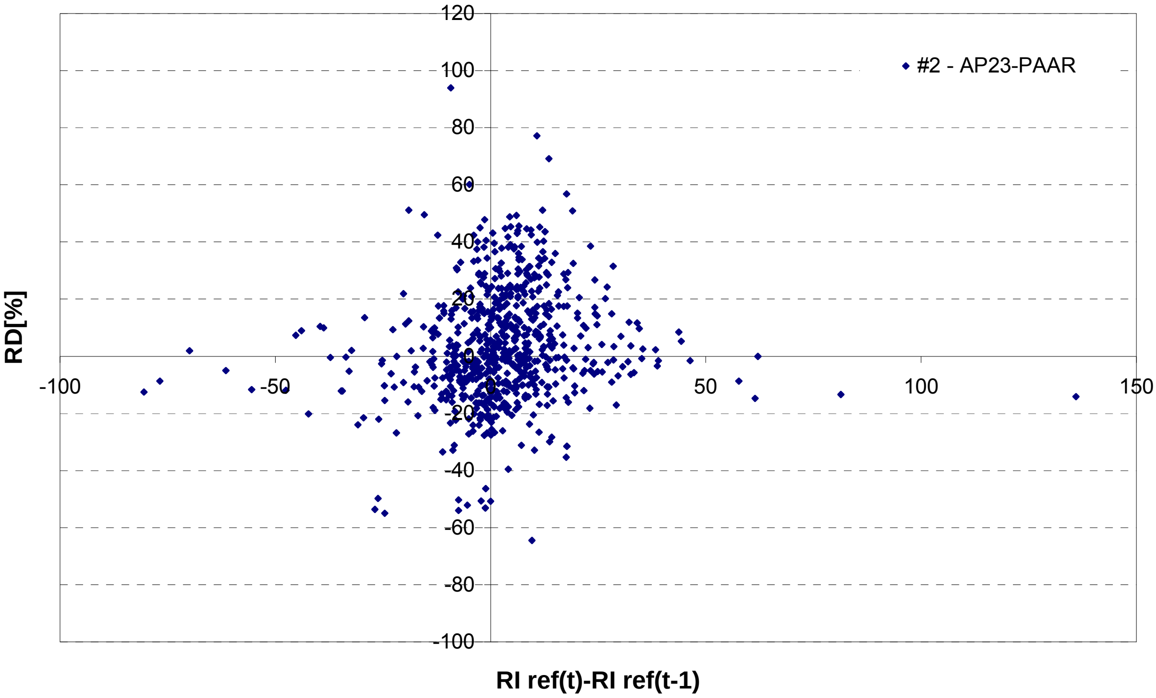
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by AP23-PAAR and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



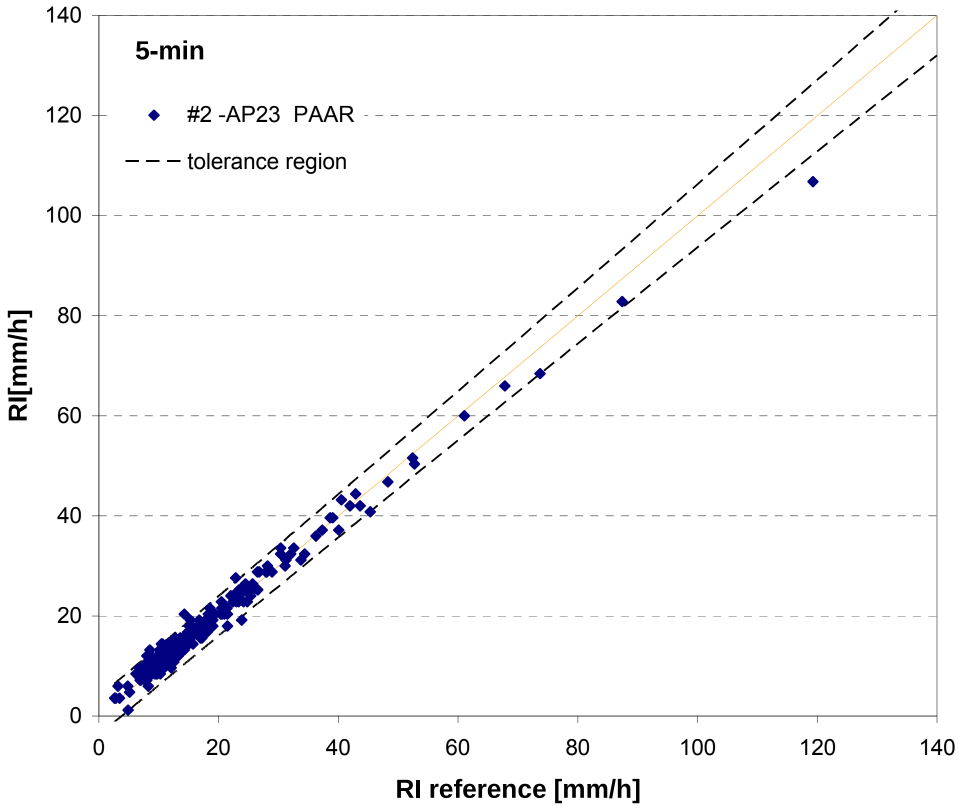


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$)



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by AP23-PAAR and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters *($RI=a\cdot(RIref)^b$)*	**a**	**b**	**R^2**
#2 **AP23 PAAR**	1.15	0.96	0.85

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The laboratory calibration for constant flows shows an average under-estimation with high RI (above 50 mm/h for PAAR), usual for not corrected TBRGs. The field calibrations give consistent results with the laboratory calibration. No drift detected from the field calibration.
In the field measurements, under-estimation is seen above 80 mm/h. At about 100 mm/h, the under-estimation is about 10 to 15%, which is at least 5% larger than the average underestimation seen in laboratory.

The RI variation response plot shows a good variation response.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
No diagnostic data and error code.

Data availability (1 min):
- Valid Data: 100%.

Maintenance:
- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust; cleaning of the inside of bucket as recommended by Manufacturer.

Malfunctioning:
- None.

R01 3070 Precis Mecanique
- France -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Tipping bucket with mechanical correction.
- Collector area: 1000 cm^2
- Range of measurement : 0-450 mm/h
- 1-minute resolution: 12 mm/h

Data output

- Output: Passive Sealed Reed Switch.
- Data update cycle : 10 s (Data Acquisition System sampling time)
- Rainfall parameters: Rainfall accumulation (RA [mm]).
- Transfer function for 1-min RI: RI_{1min}[mm/h] = $pulses_{1min}$ 12[mm/h] ($pulses_{1min}$ =number of pulses of reed switch in 1 minute; 1 pulse = 0.2 mm).

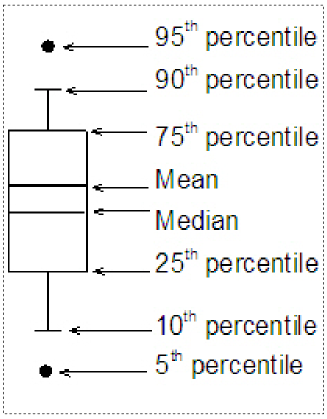
#3 R01 3070-Precis Mecanique in the field

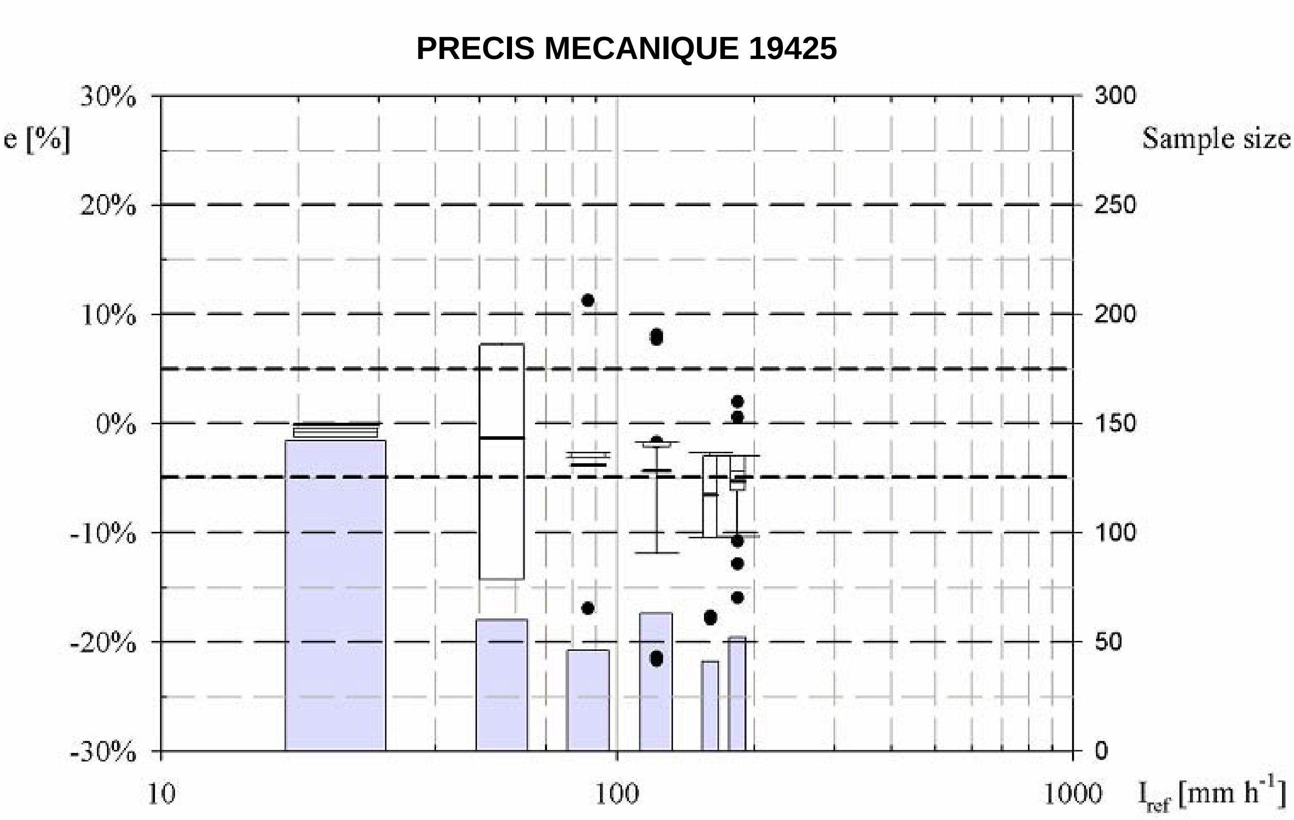
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute 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

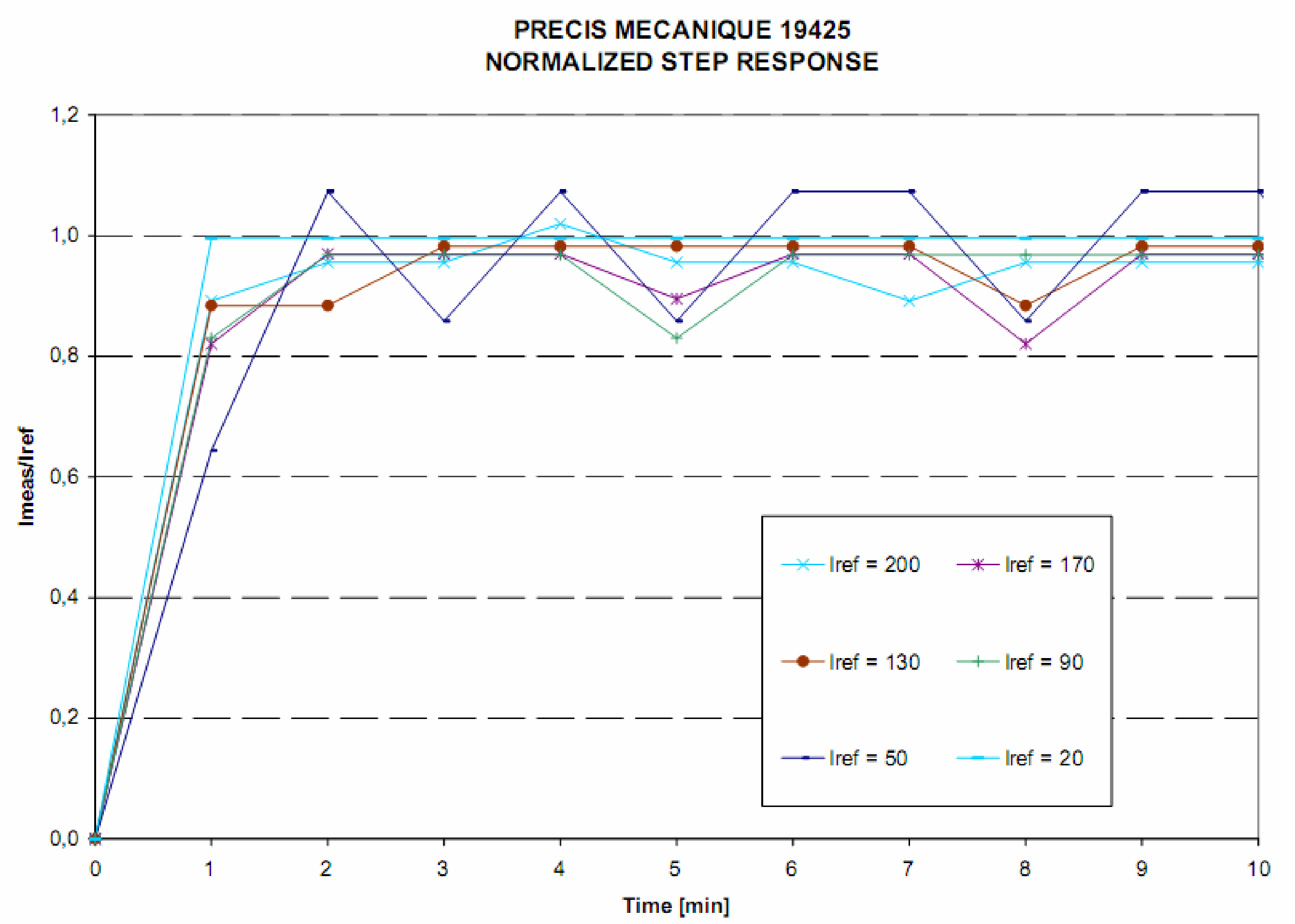




Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behavior of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.

The "saw" response is mainly due to the measurement resolution.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

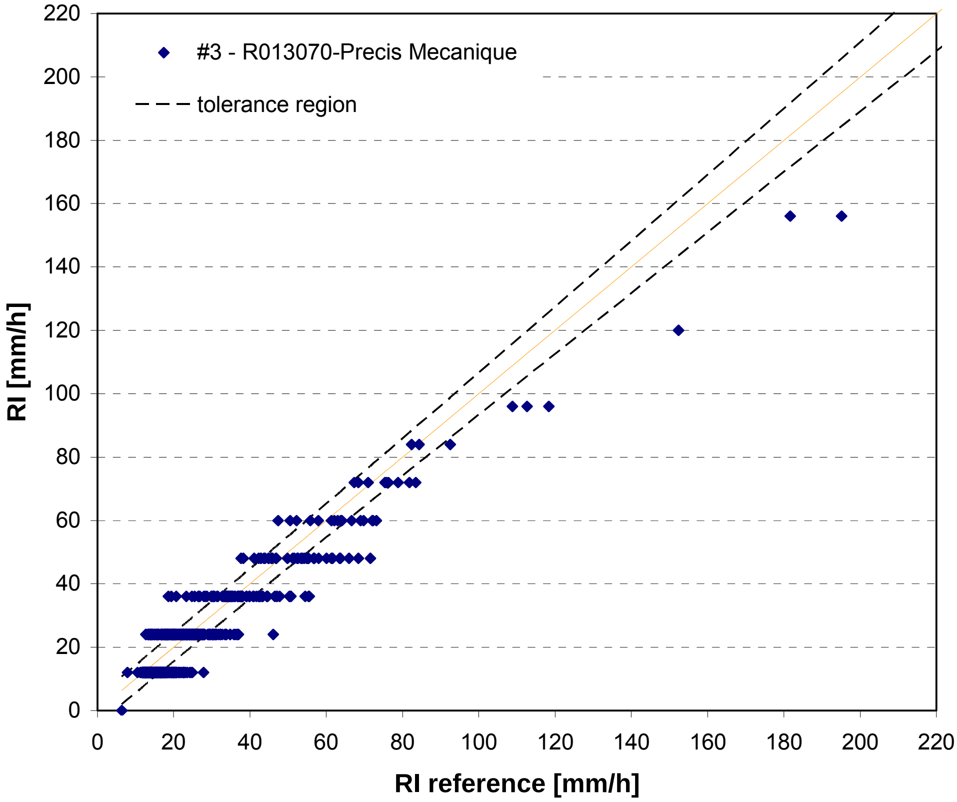
Precis Mecanique s/n 19425

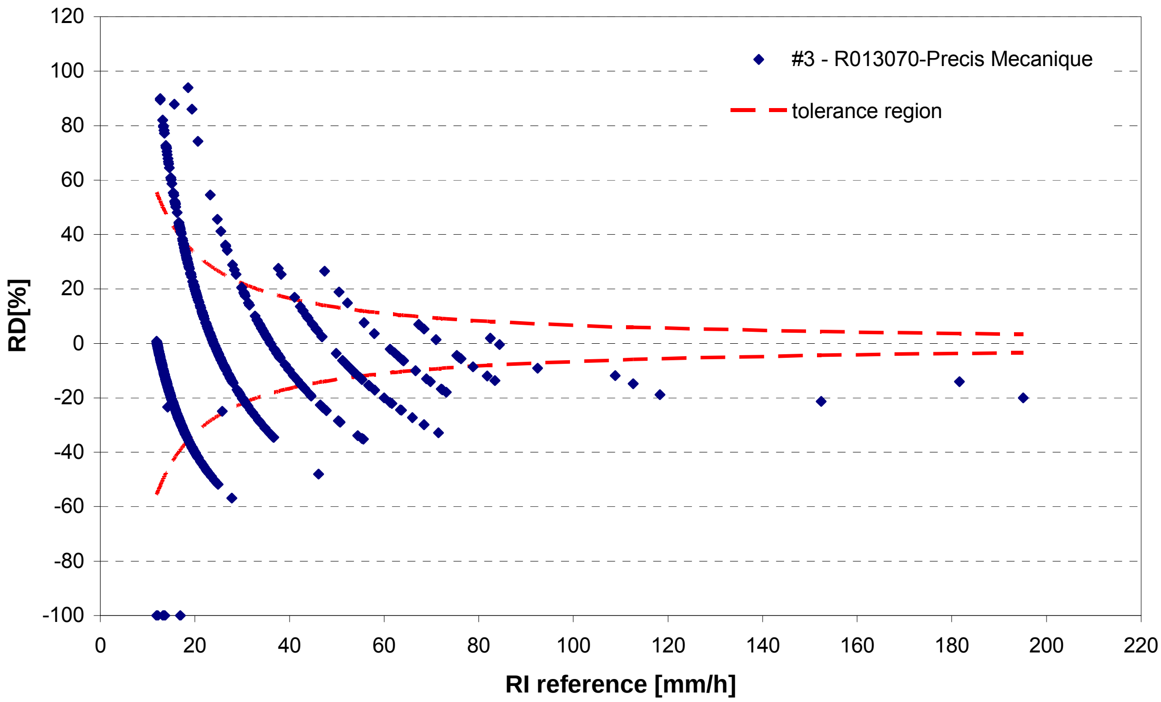
CALIBRATION	**1° 13/12/07**	**2° 08/05/08**	**3° 22/04/09**
RI ref [mm/h]	101.6	130.6	140.4
AVG RE [%]	-5.5	-5.3	-5.2
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-5.5,-5.5]	[-7.4,-3.1]	[-6.4,-4.0]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%).

Field Intercomparison Measurements

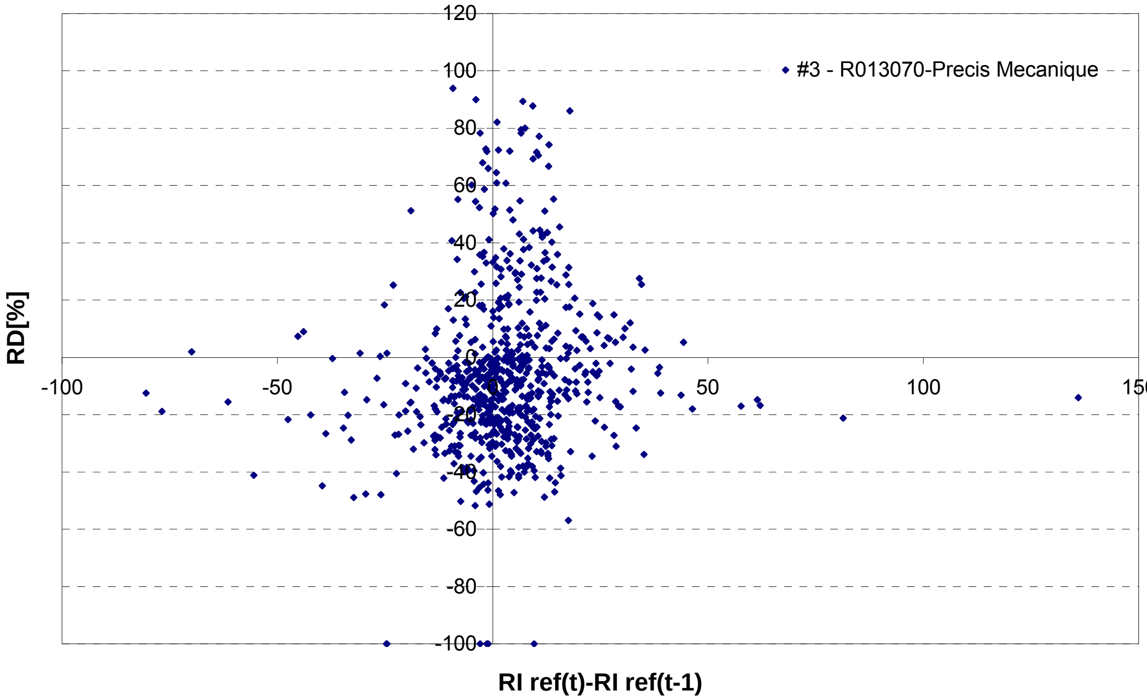
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by R01 3070-Precis Mecanique and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, 5.3.2-5.3.3.*



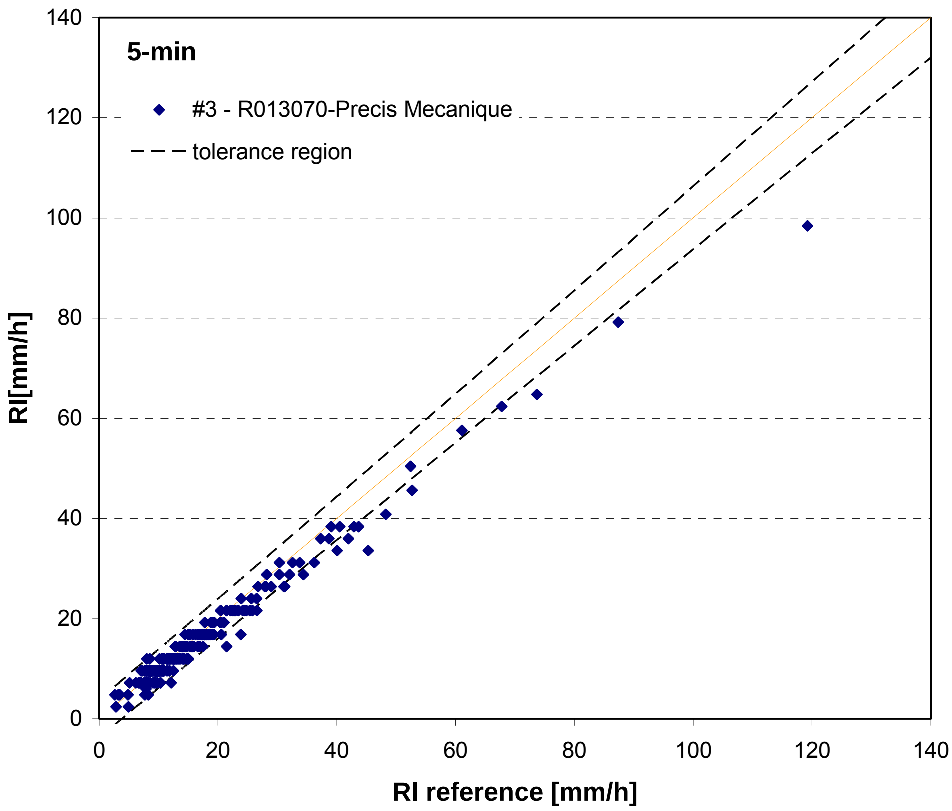


(Relative difference: RD=100(RI-RI$_{ref}$)/RI$_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$)



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by R01 3070 Precis Mecanique and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ***(RI=a·(RIref)^b)***	**a**	**b**	**R^2**
#3 **R01 3070** **Precis Mecanique**	1.08	0.95	0.77

(Parameters a, b, R^2 are determined by fitting the function RI=a·(RIref)^b, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

Due to the "mechanical" design, the average under-estimation with high RI is minimized in laboratory. The field calibrations give consistent results with the laboratory calibration. No drift detected from the field calibration.

In the field measurements, an under-estimation of about 15 to 20% is seen above 100 mm/h. These values are larger than the average underestimation seen in laboratory: at this stage no explanation can be given.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
No diagnostic data and error code.

Data availability (1 min):

- Valid Data: 100%.

Maintenance:

- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust; cleaning of the inside of bucket as recommended by Manufacturer.

Malfunctioning:

- None.

PT 5403235008 THIES
- Germany -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Tipping bucket with extra pulses correction (intensity-dependent linearization by means of the built-in electronics).
- Collector area: 200 cm^2
- Range of measurement : 0-420 mm/h
- 1-minute resolution: 6 mm/h

Data output

- Output: Reed Switch. (*Built-in electronics and software*: *version 021222/03/07*)
- Data update cycle : 10 s (Data Acquisition System sampling time).
- Rainfall parameters: Rainfall accumulation (RA [mm]).
- Transfer function for 1-min RI: RI_{1min}[mm/h] = $pulses_{1min}$ 6[mm/h] ($pulses_{1min}$ =number of pulses of reed switch in 1 minute; 1 pulse = 0.1 mm).

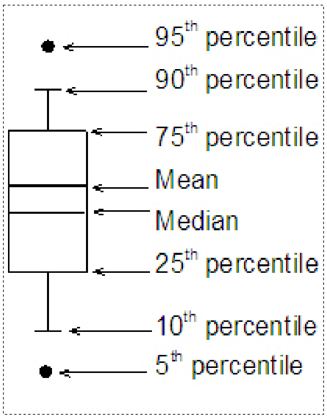
#4 PT 5403235008 – THIES in the field

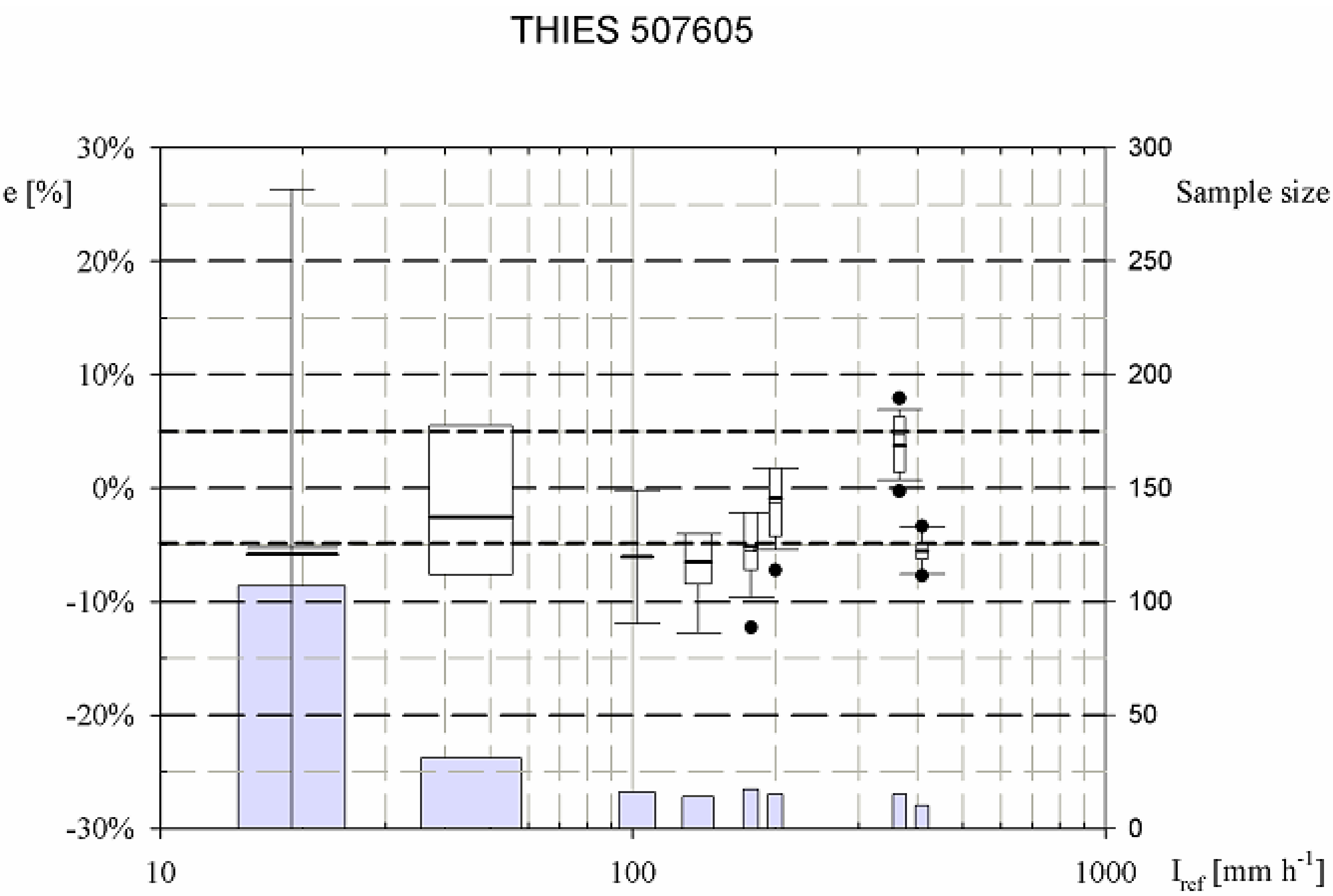
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

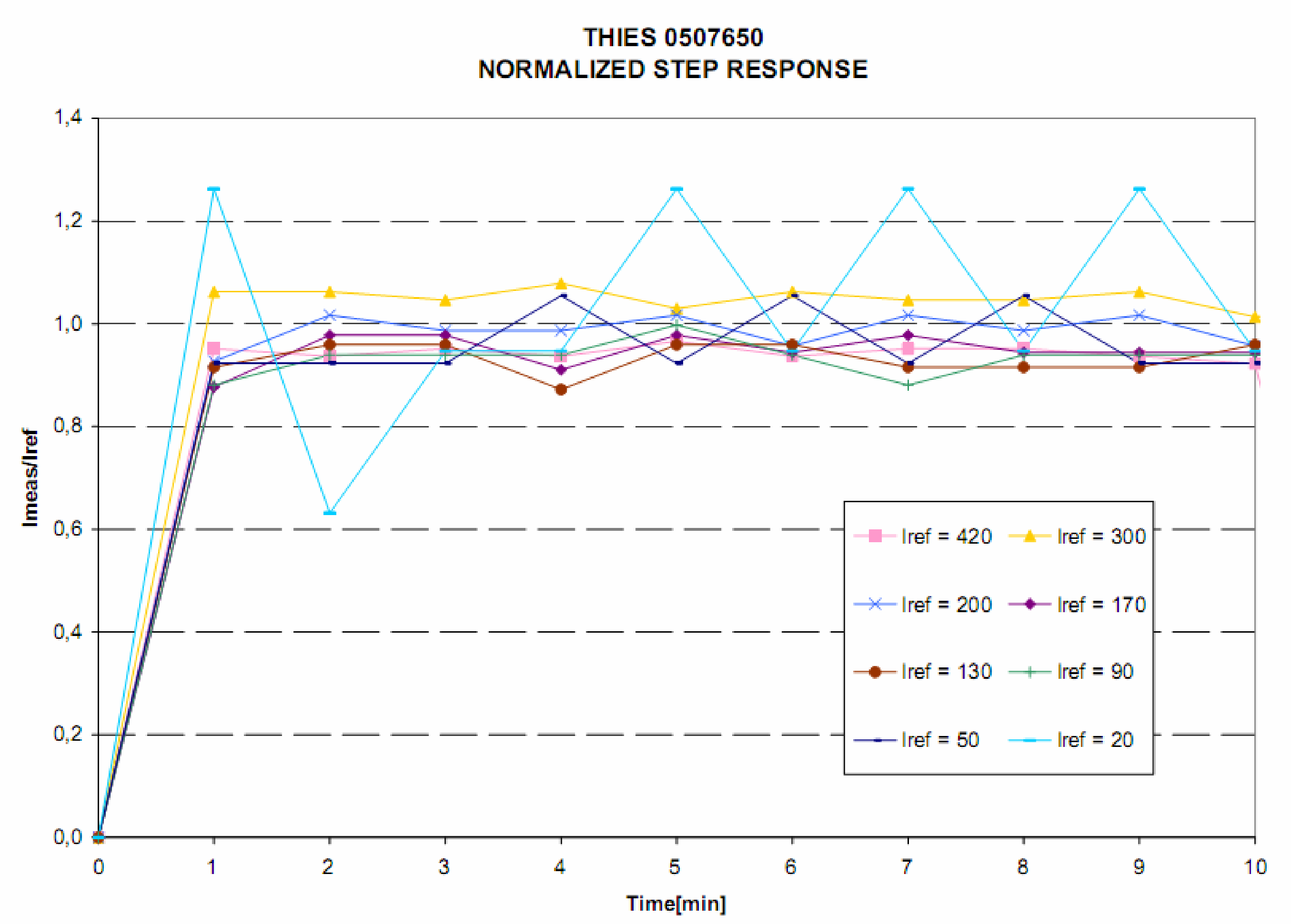
The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute variability of the observed instruments performances and the size of the sample used for calculation of the statistics at each reference intensity. Box plots synthetically 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.





Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behavior of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected. The “saw” response is mainly due to the measurement resolution.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

THIES s/n 507650

CALIBRATION	1° 11/12/07	2° 09/04/08	3° 20/04/09
RI ref [mm/h]	211.0	140.2	154.4
AVG RE [%]	-13.1	1.5	0.3
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-14.1,-12.2]	[0.9,2.1]	[-0.5,1.1]

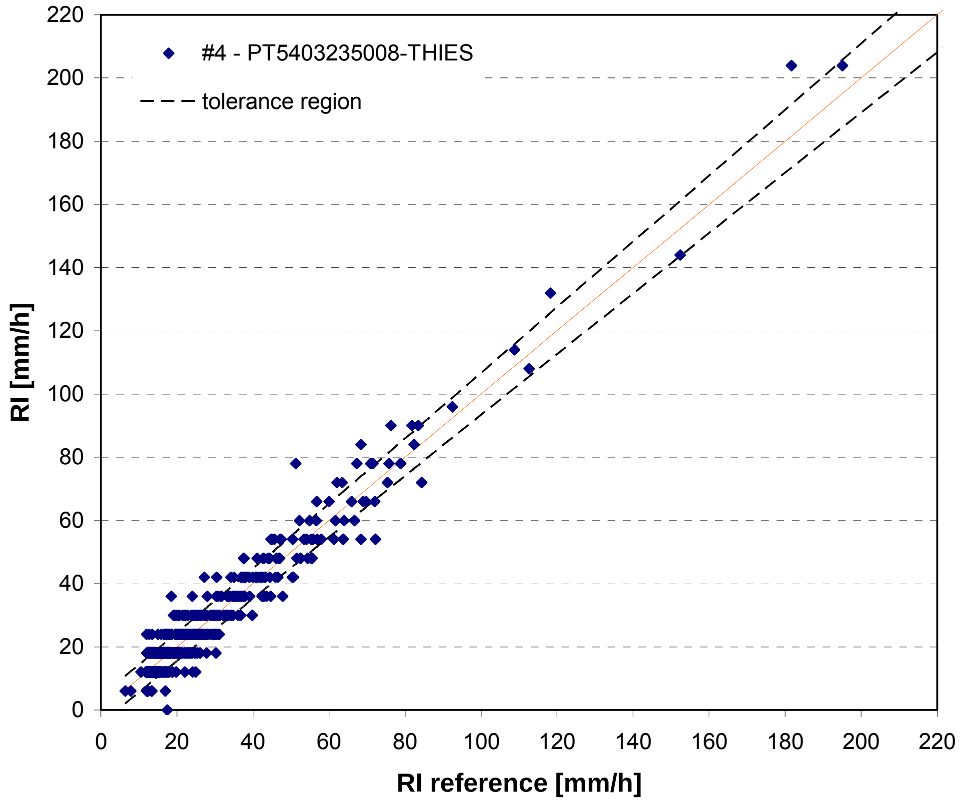
(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%).

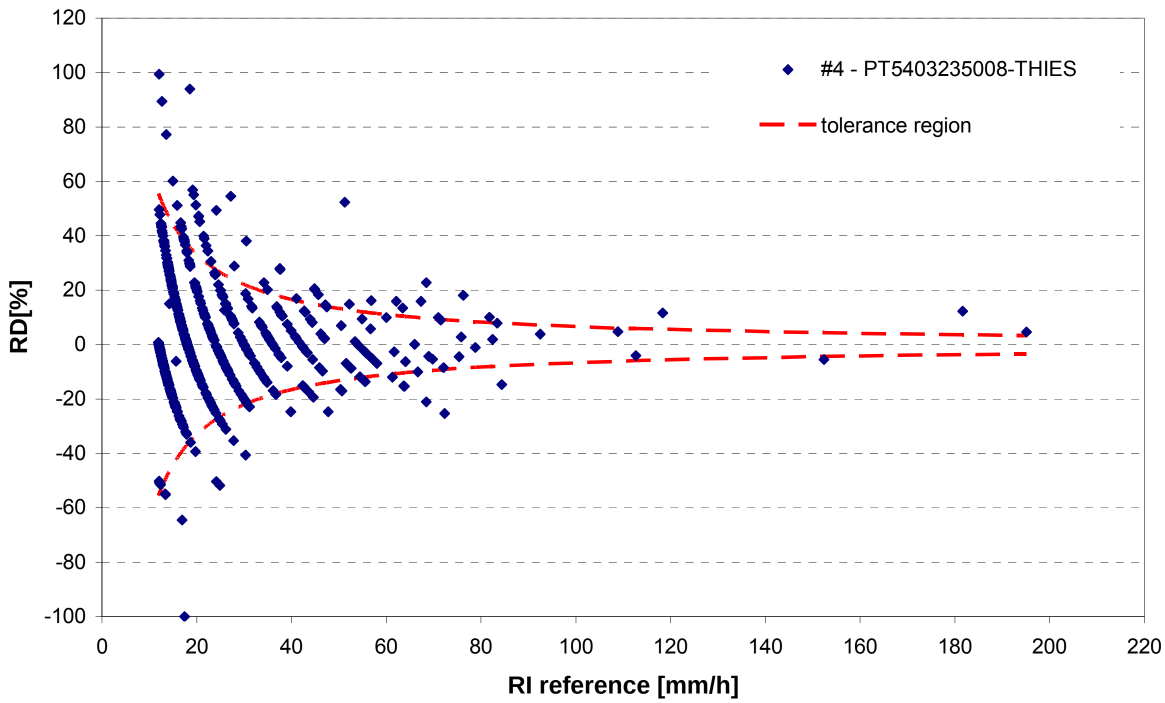
Comments

- By means of the first field calibration of the THIES S/N 507650 it was found that since the beginning of the campaign the instrument had not been operated by means of the linearized output. From 14/03/2008 the linearized output was used for data acquisition. A correction table was requested and delivered by the manufacturer during the Meeting of Participants and local staff (Vigna di Valle, May 21st-22nd 2008).
- The value of AVG RE of the first calibration is due non-linearized output used at that time. The second and third calibrations were performed using the linearized output.

Field Intercomparison Measurements

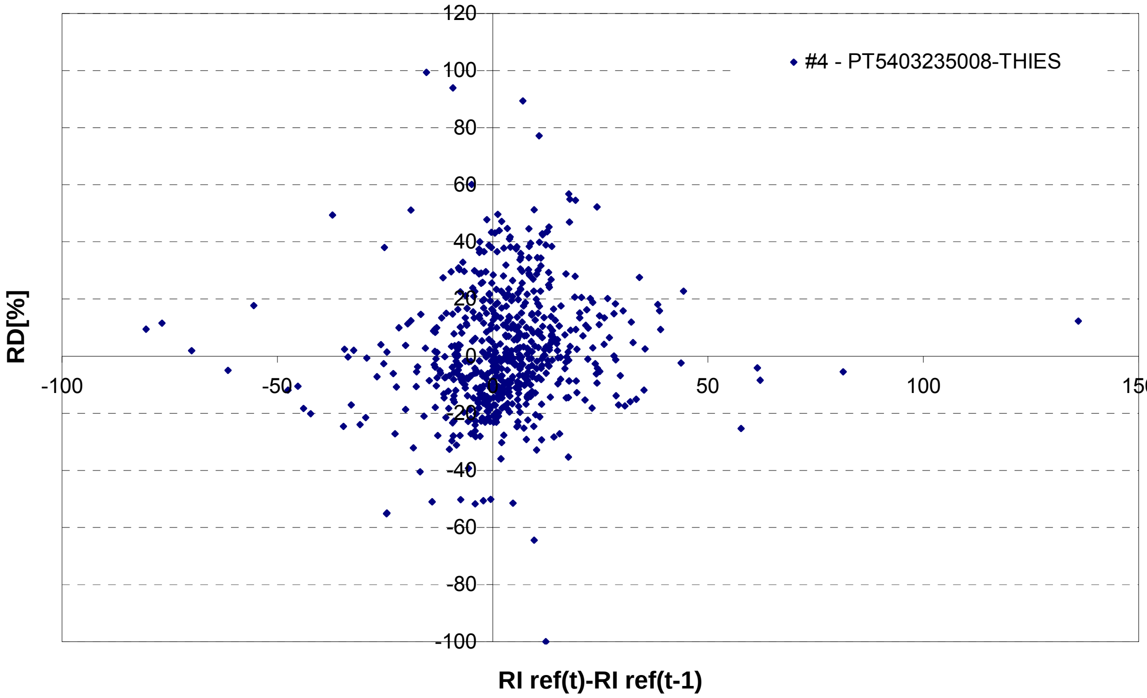
Comparison between 1-min rainfall intensity measured by PT 5403235008-THIES and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



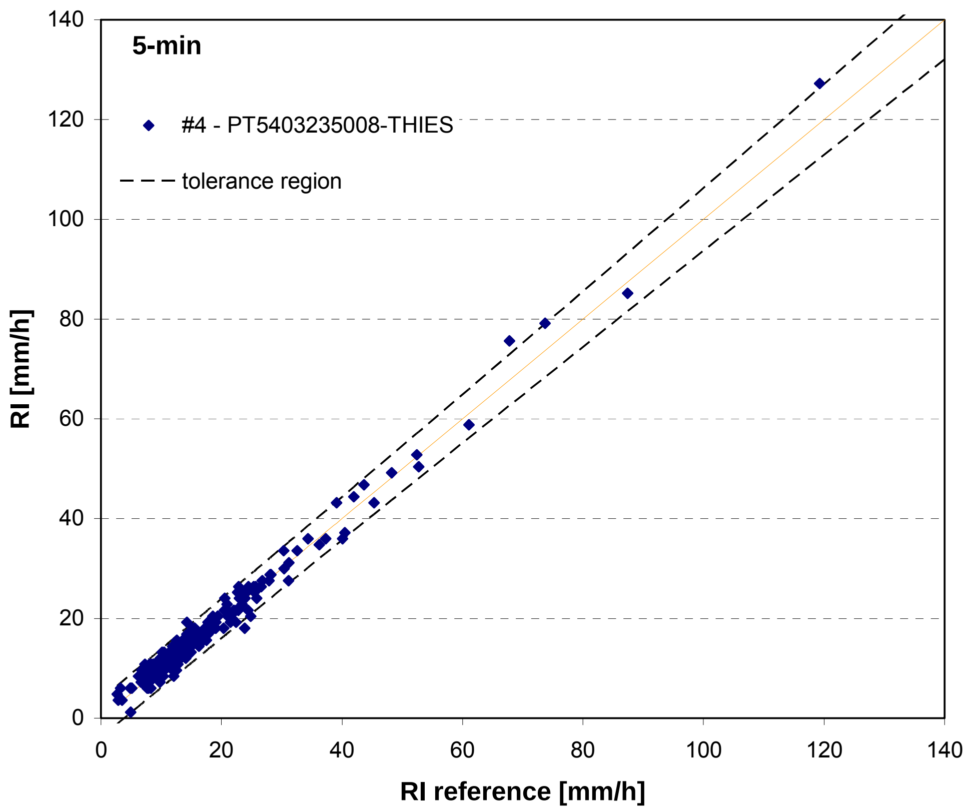


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$)



Comparison between 5-min rainfall intensity measured by PT 5403235008-THIES and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters *($RI=a\cdot(RIref)^b$)*	**a**	**b**	**R^2**
#4 **PT 5403235008** **THIES**	1.01	0.99	0.85

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The laboratory calibration shows a good compensation from the extra pulses. The field calibrations give consistent results with the laboratory calibration. No drift detected from the field calibration.
In the field measurements, the results do not show any bias and this behaviour is consistent with the calibration results. In the 5 min scatter plot, the noise is significantly lower.
The RI variation response plot shows generally a low noise figure but with quite few scattered points that cannot be explained.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
No diagnostic data and error code.

Data availability (1 min):

- Valid Data: 100%.

Maintenance:

- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust; cleaning of the inside of bucket as recommended by Manufacturer.

Malfunctioning:

- None.

R 102-ETG
- Italy -

Technical Specifications

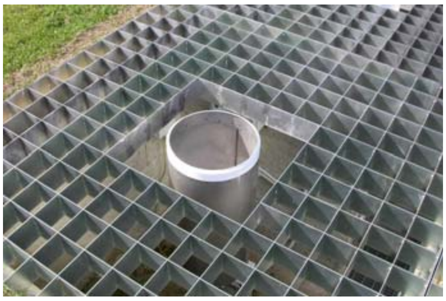
- Provided by the manufacturer -

- Physical principle: Tipping bucket with correction algorithm
- Collector area: 1000 cm^2
- Range of measurement : 0-300 mm/h
- 1-minute resolution: 0.6 mm/h.

Data output

- Output: data message by serial interface RS485 in ASCII protocol - Automatic mode (every minute). (*Software: MicroRec_OS ver 2.00*)
- Data update cycle : 1 min
- Rainfall parameters: 1 min RI [mm/h], corrected rainfall accumulation RA [mm].
- Transfer function for 1-min RI: none.

#5 - R 102 -ETG in the field
(s/n 1011)



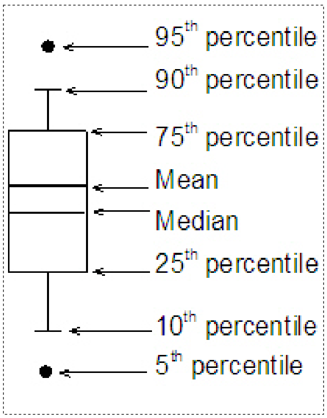
#27 R 102- ETG
Reference Pit Gauge
(s/n 1010)

Laboratory test

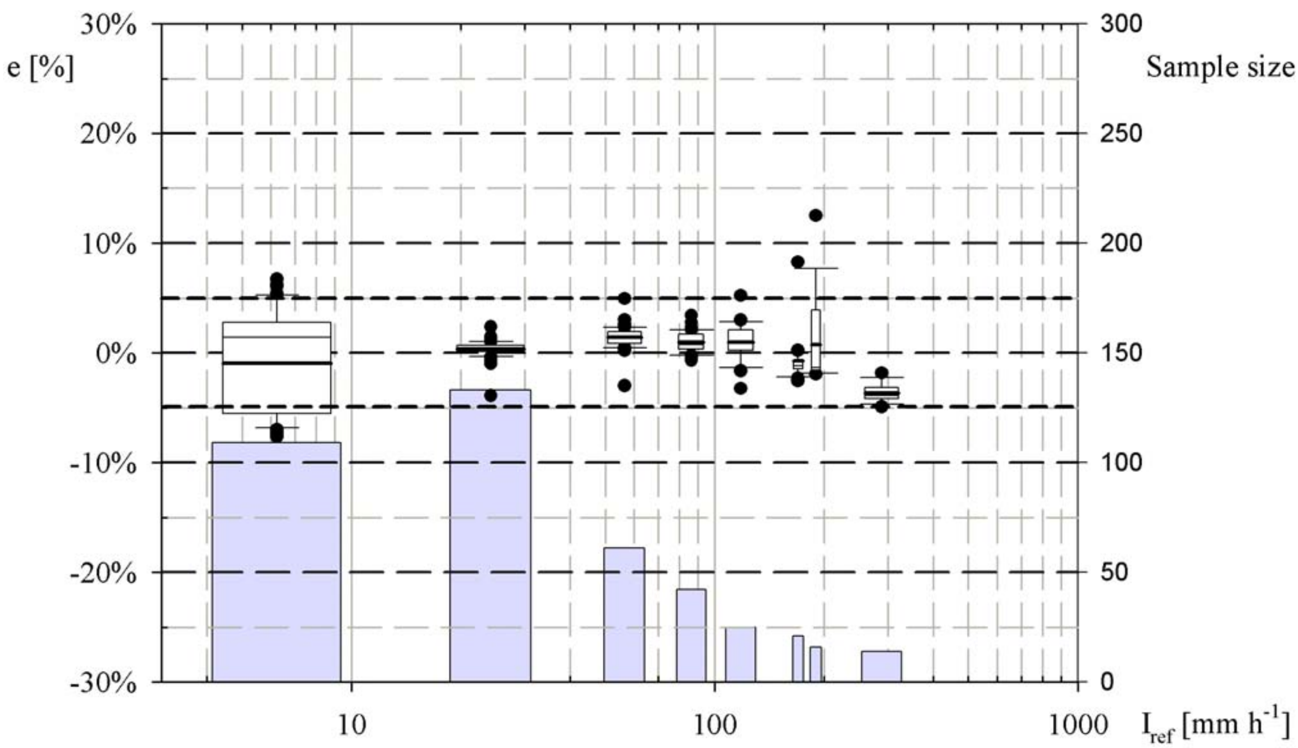
The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

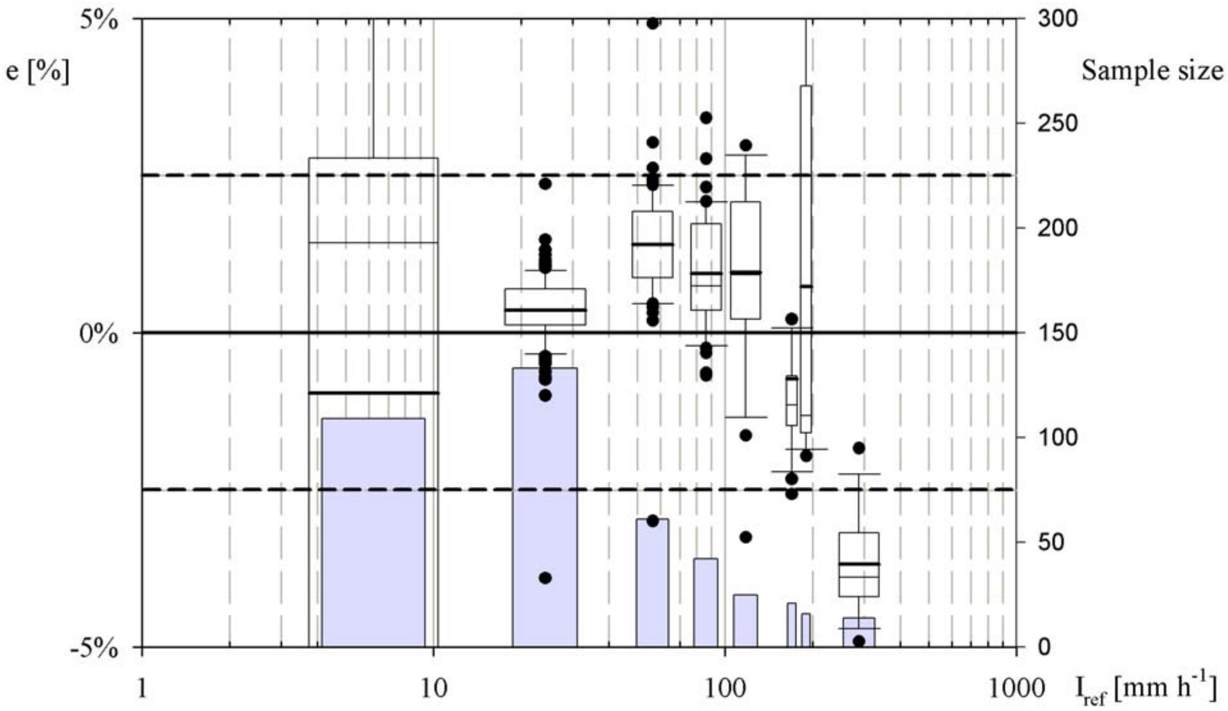
The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute variability of the observed instruments performances and the size of the sample used for calculation of the statistics at each reference intensity. Box plots synthetically 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



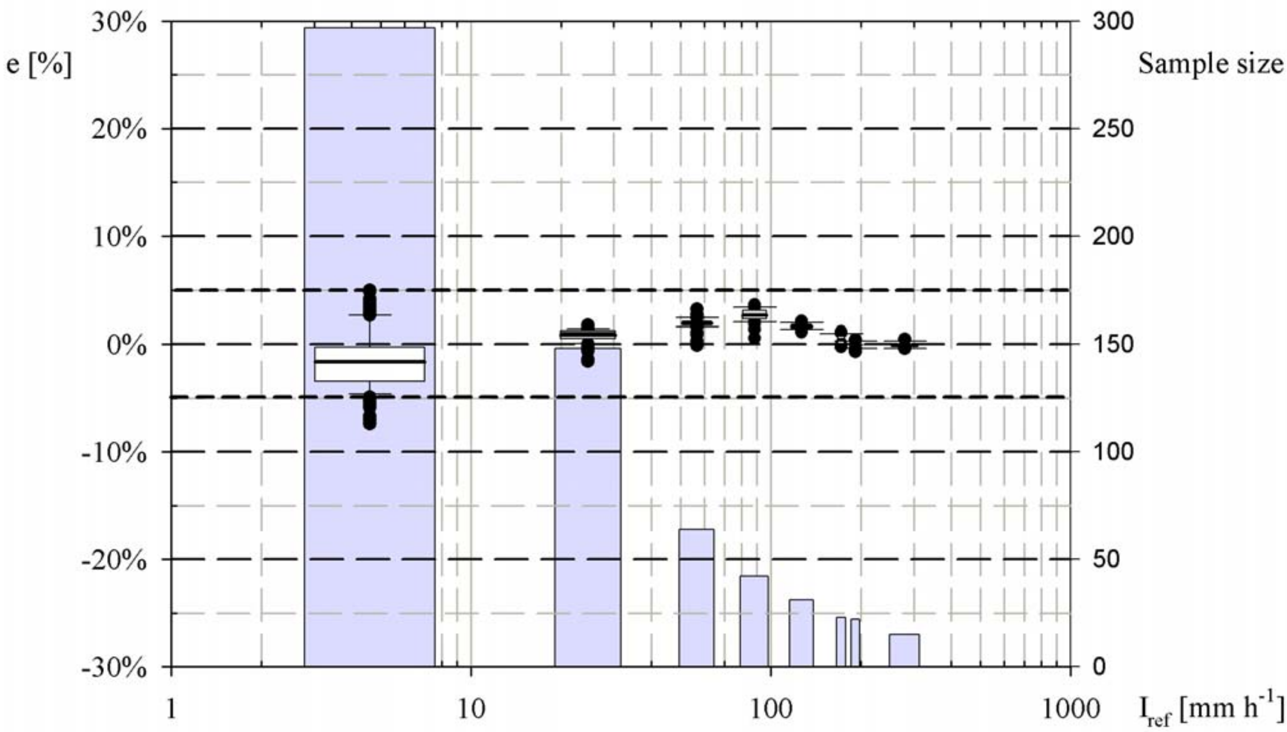
ETG 1011



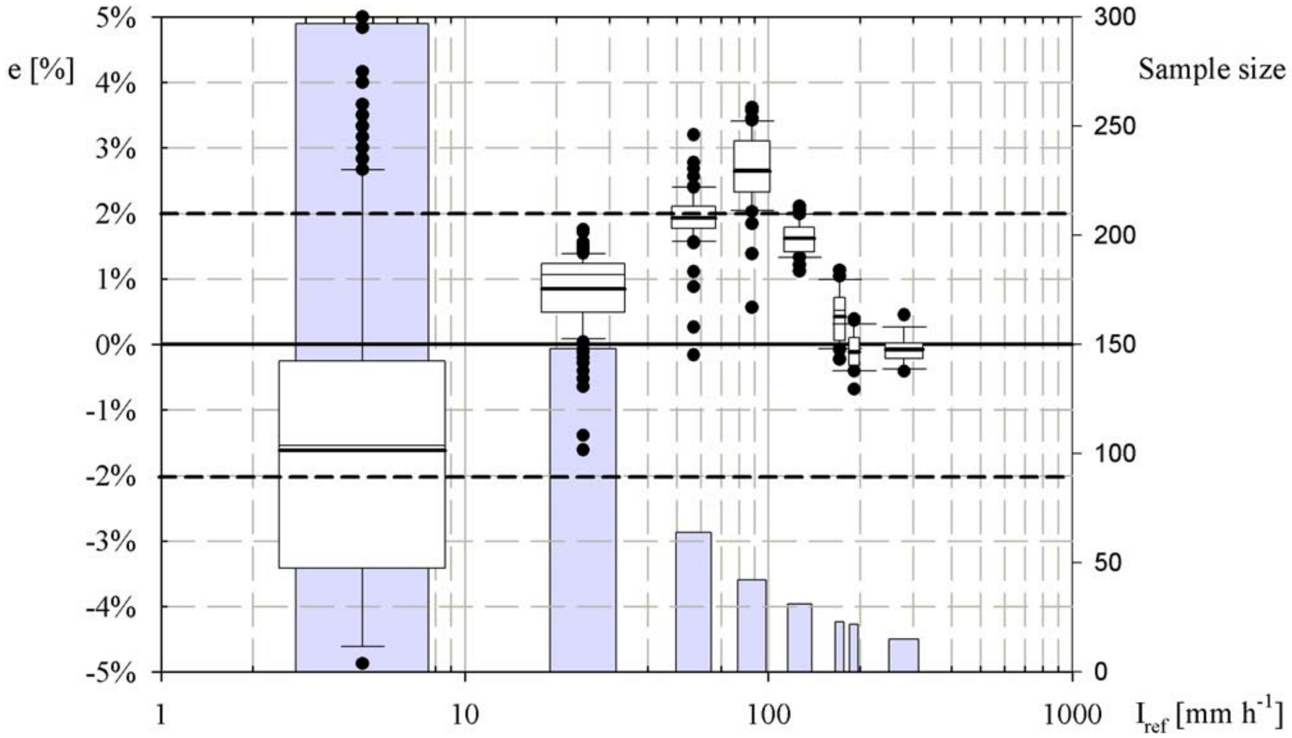
ETG 1011



ETG 1010

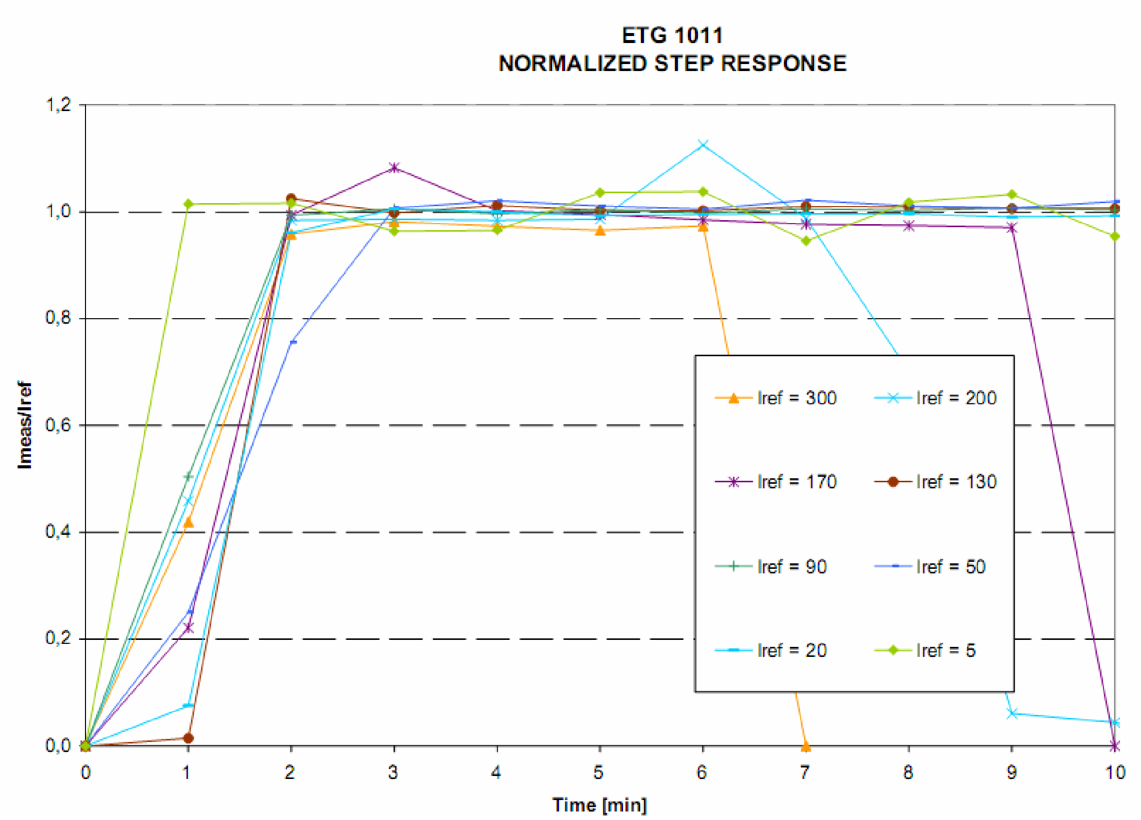


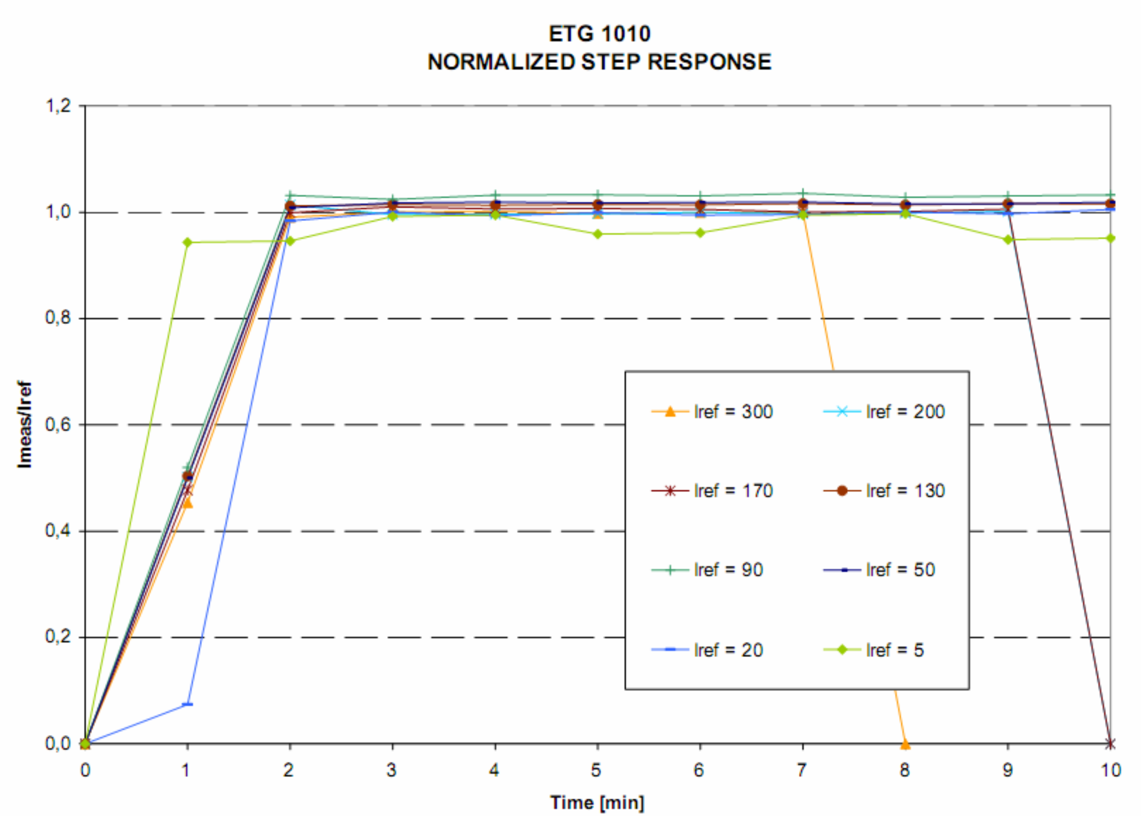
ETG 1010


e [%]
5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
300
250
200
150
100
50
0
Sample size
1
10
100
1000
I_{ref} [mm h^{-1}]

Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behavior of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.





Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

R102 ETG s/n GB1011 (#5)

CALIBRATION	1° 10/12/07	2° 08/05/08	3° 22/04/09
RI ref [mm/h]	212.8	130.6	139.8
AVG RE [%]	-3.4	0.2	-3.6
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-3.7,-3.2]	[-0.6,1.1]	[-4.0,-3.2]

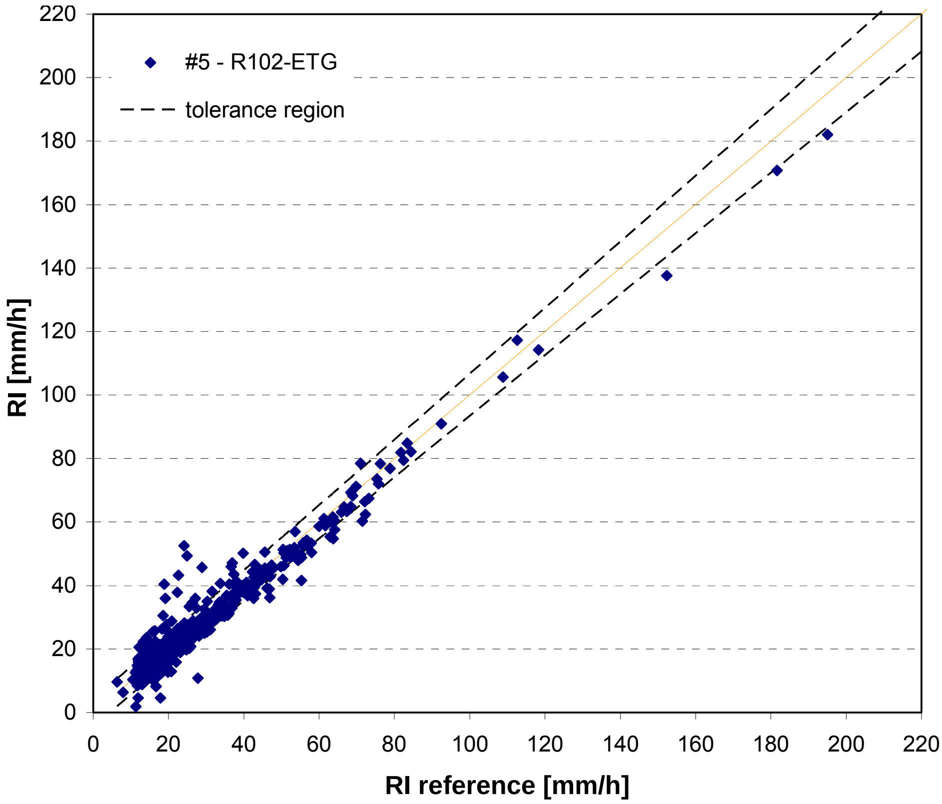
R102 ETG s/n GB1010 (#27, pit gauge)

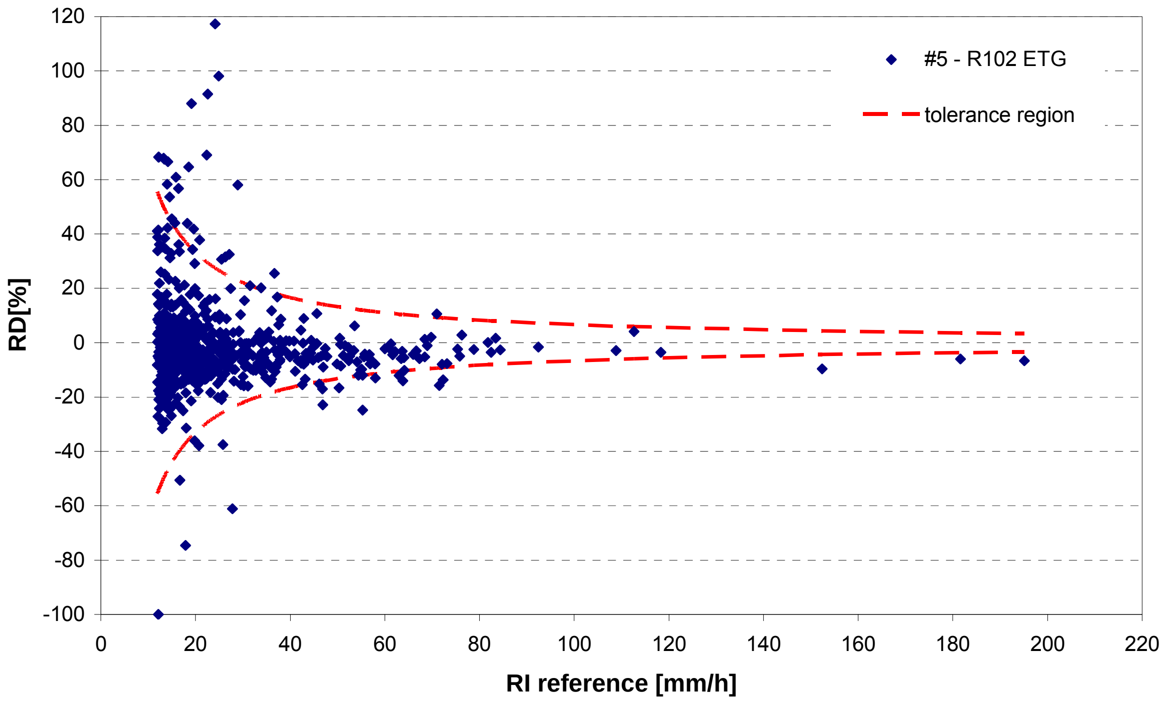
CALIBRATION	1° 10/12/07	2° 08/05/08	3° 22/04/09
RI ref [mm/h]	208.9	130.8	139.3
AVG RE [%]	-1.2	1.0	0.9
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-1.5,-0.9]	[-0.1,2.0]	[0.6,1.2]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%).

Field Intercomparison Measurements

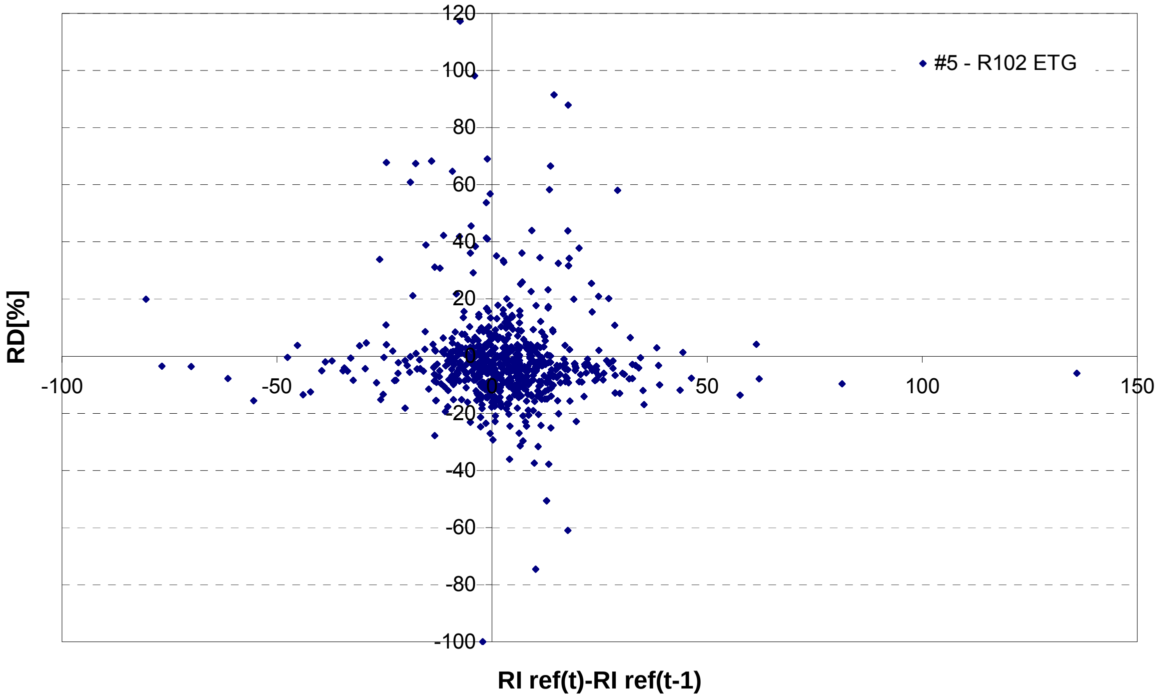
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by R 102-ETG and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5-3-3.*



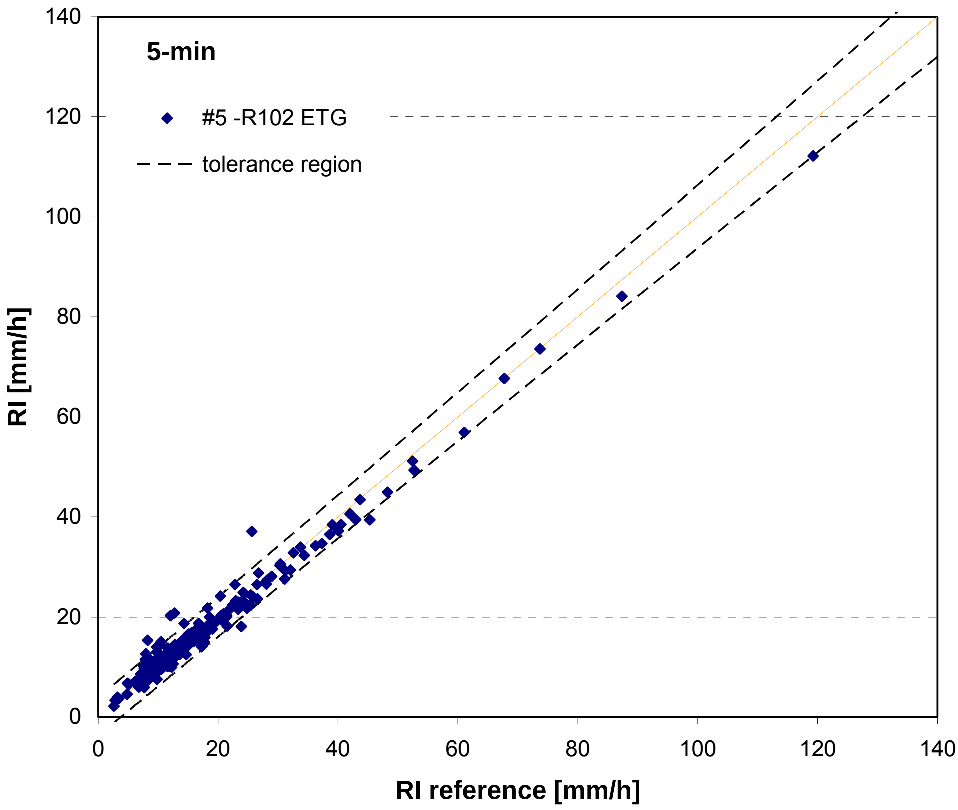


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$)



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by R 102-ETG and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5-3-3.*



Summary Table

Parameters ***($RI=a\cdot(RIref)^b$)***	**a**	**b**	**R^2**
#5,27 **R 102 ETG**	1.01	0.99	0.88

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

Very good accuracy in constant flow conditions with respect to linearization and noise: a) the laboratory calibration of the ETG used as reference gauge (s/n 1010) shows average relative errors within ±2.5% and outliers within ±5% except for RI=5 mm/h; the laboratory calibration of the ETG installed in the field (s/n 1011) shows average relative errors within ±2.5% and outliers within ±5% except for RI = 5, 170, 200 mm/h. The ETG used as reference is performing better than the gauge in the field with respect to linearization and noise.

The field calibrations give consistent results with the laboratory calibration. No drift detected from the field calibration for both gauges.

In the RD plot an under-estimation of RI starts above 150 mm/h which is consistent with calibration results. Field measurements confirm low noise figure but some outliers can be seen in RI scatter plot at 1 min and 5 min averages below 30 mm/h. The correction algorithm increases the RI resolution but for low RI the correction algorithm could lead to some degradation of results.

Apart from very few outliers for low RI, the correction algorithm applied by the ETG revealed to be very effective for the range of all RI experienced during the field Intercomparison.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
No diagnostic data and error code.

Data availability (1 min):

- Valid Data (rain gauge #5): 100%.
- Valid Data (pit rain gauge #27): 98.0%. Internal data logger failure from 09/09/2008 to 19/09/2008.

Maintenance:

- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust; cleaning of the inside of bucket as recommended by Manufacturer.

Malfunctioning:

- None.

DQA031-LSI LASTEM
- Italy -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Siphon controlled tipping bucket without correction.
- Collector area: 325 cm^2
- Range of measurement : 300 mm/h
- 1-minute resolution: 12 mm/h

Data output

- Output: Passive Reed Switch with dual switch (before 21/05/2008 the output was automatic with a timing of one minute by means of an internal data logger).
- Data update cycle : 10 s (Data Acquisition System sampling time).
- Rainfall parameters: Rainfall accumulation (RA [mm]).
- Transfer function for 1-min RI: RI_{1min}[mm/h] = $pulses_{1min}$ 12[mm/h] ($pulses_{1min}$ =number of pulses of reed switch in 1 minute; 1 pulse = 0.2 mm)

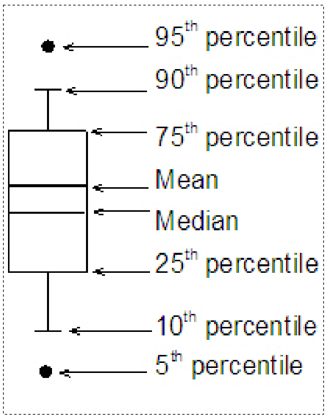
#6 DQA031 – LSI LASTEM in the field

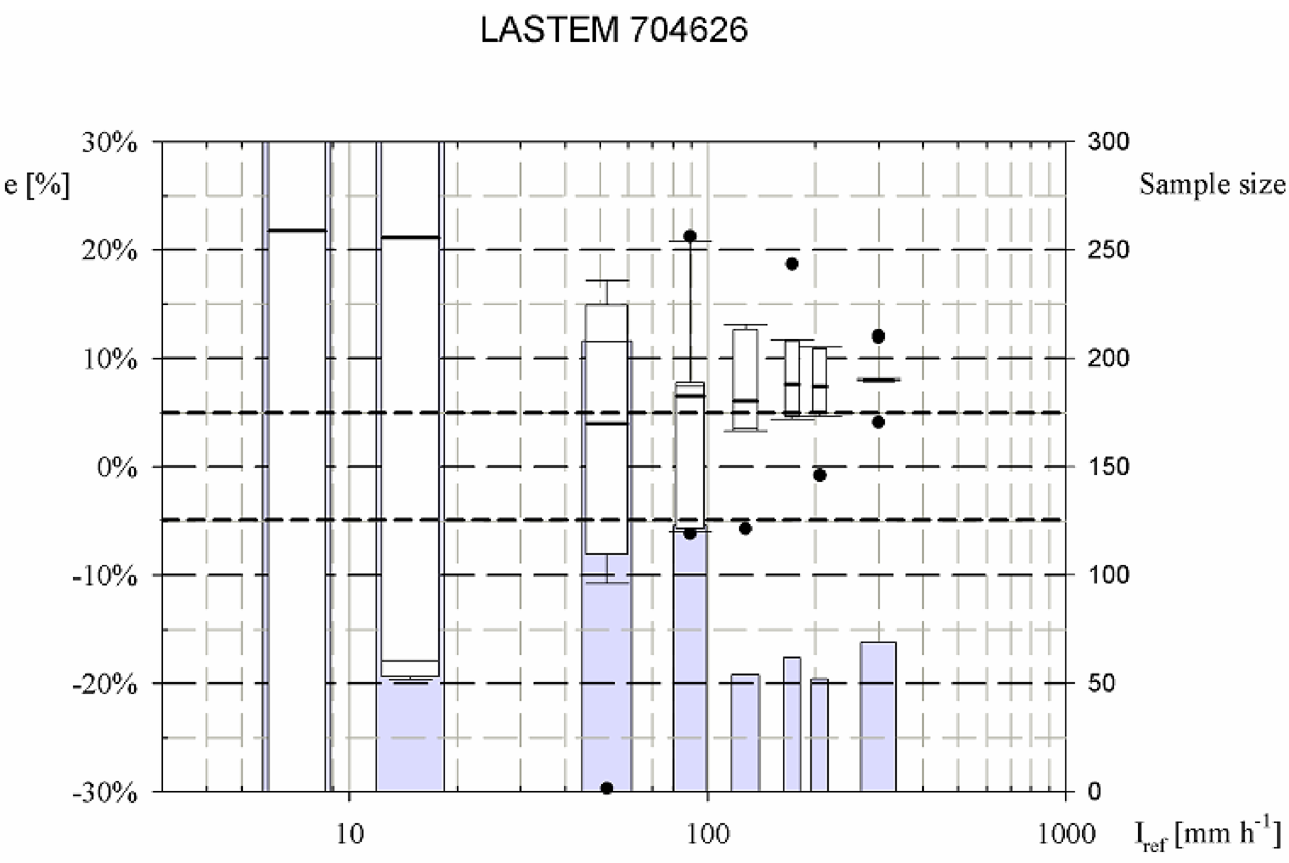
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

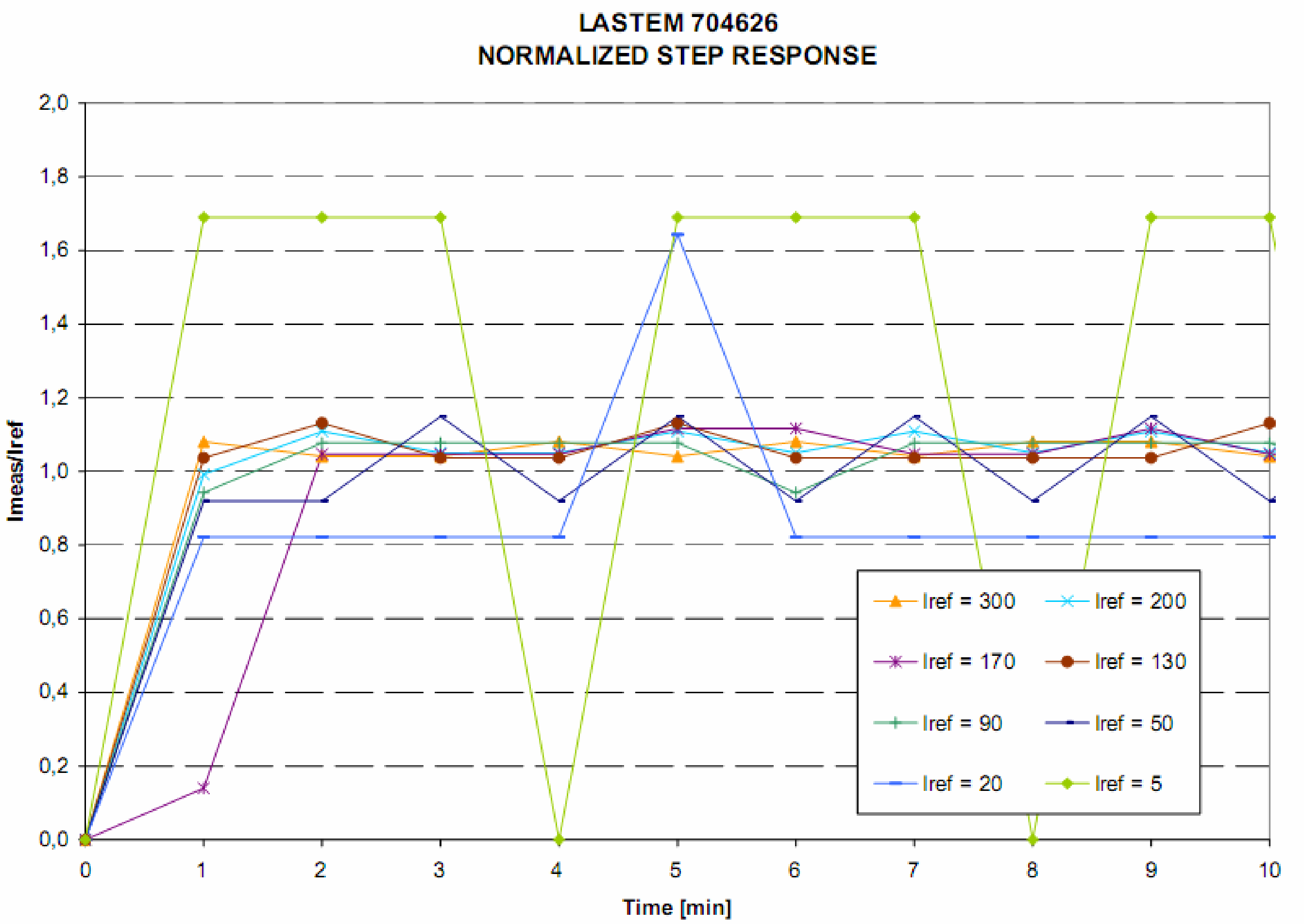
The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute variability of the observed instruments performances and the size of the sample used for calculation of the statistics at each reference intensity. Box plots synthetically 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





Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behavior of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected. The “saw” response is mainly due to the measurement resolution.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

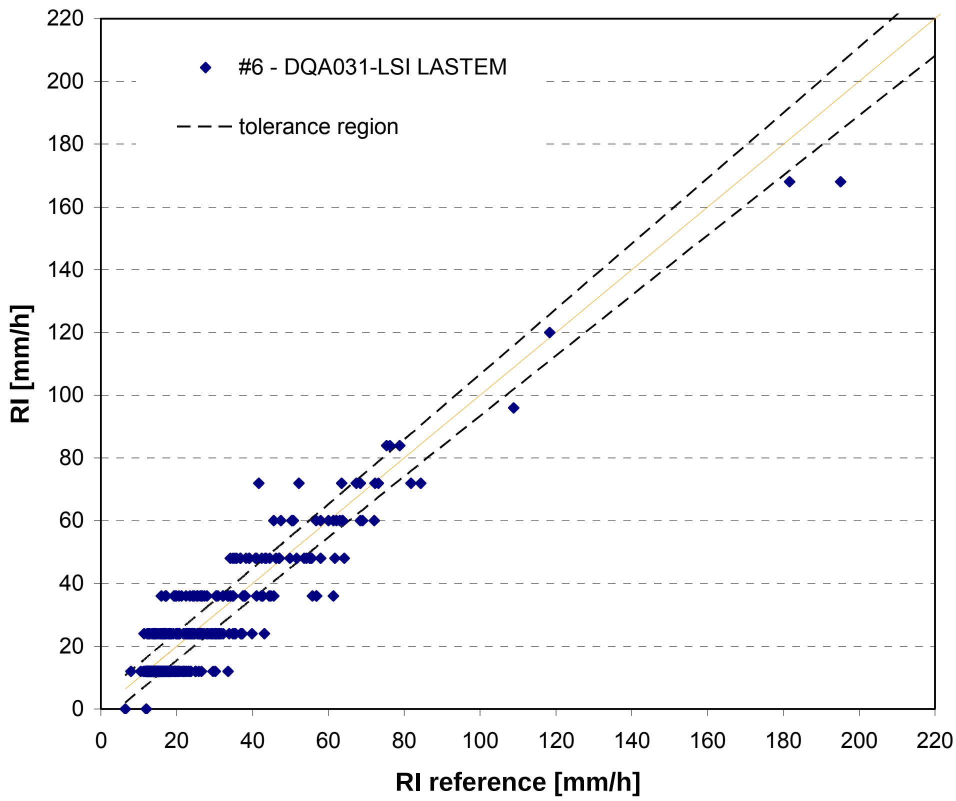
LSI LASTEM s/n P704626

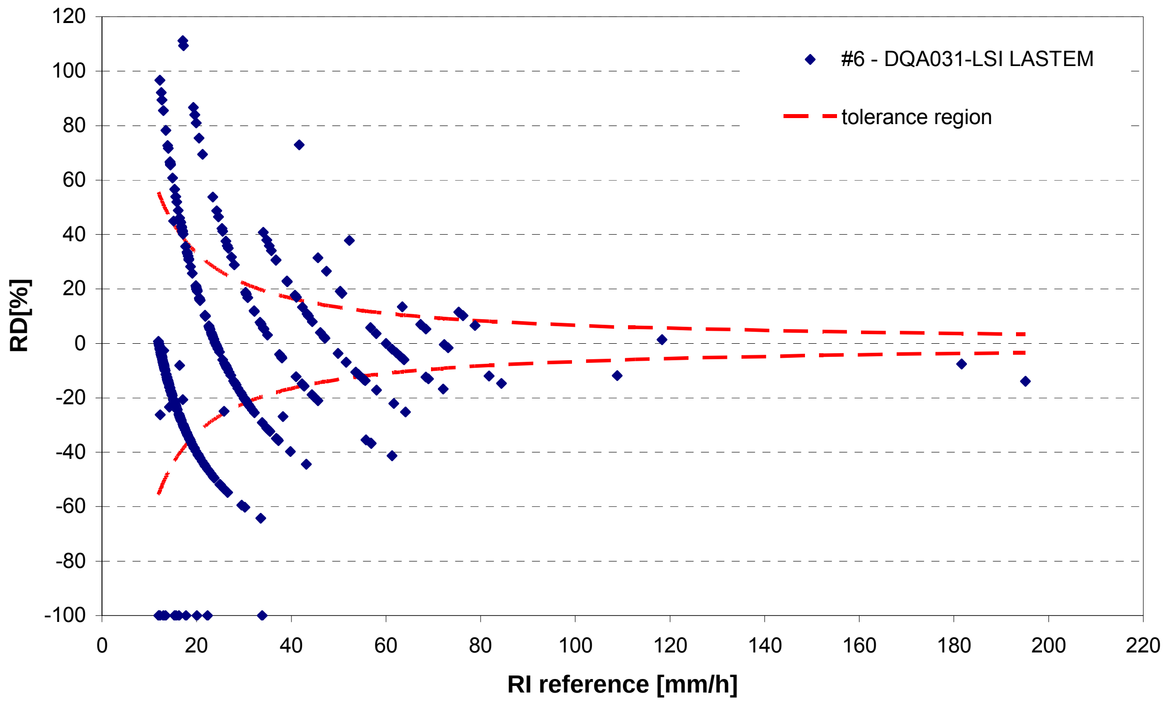
CALIBRATION	**1°** **14/01/08**	**2°** **16/04/08**	**3°** **23/04/09**
RI ref [mm/h]	206.2	135.2	150.6
AVG RE [%]	5.3	4.3	7.3
[RE(-C.L.95%),RE(+C.L.95%)][%]	[3.4,7.2]	[-2.5,11.2]	[5.3,9.3]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%)

Field Intercomparison Measurements

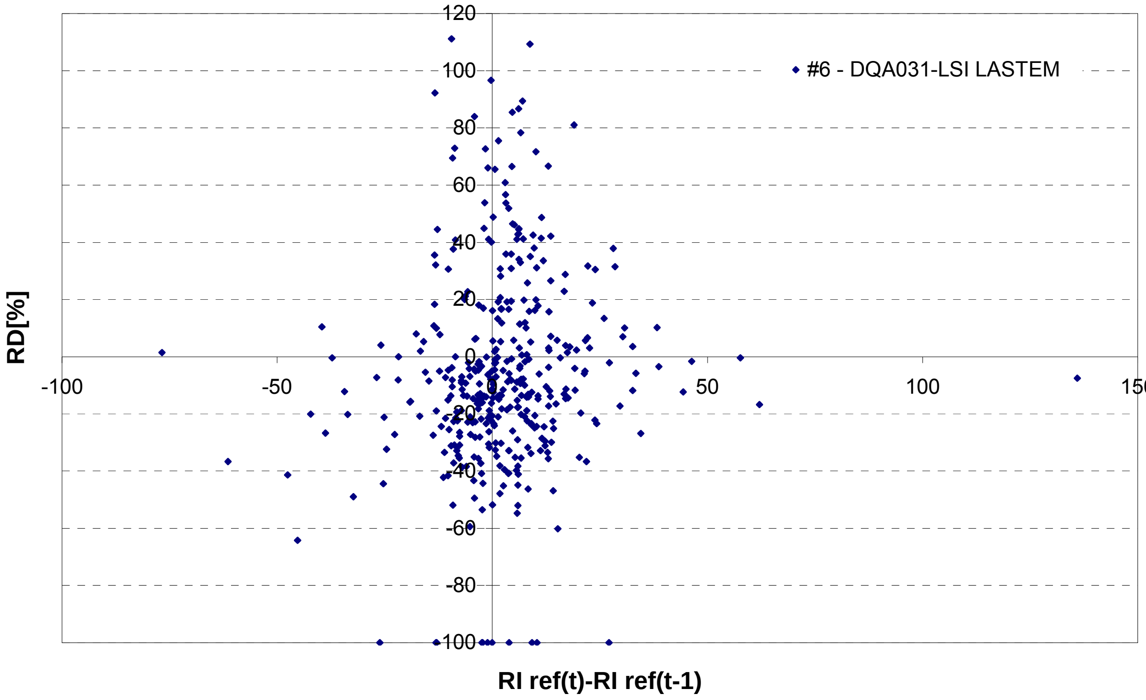
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by DQA031-LSI LASTEM and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



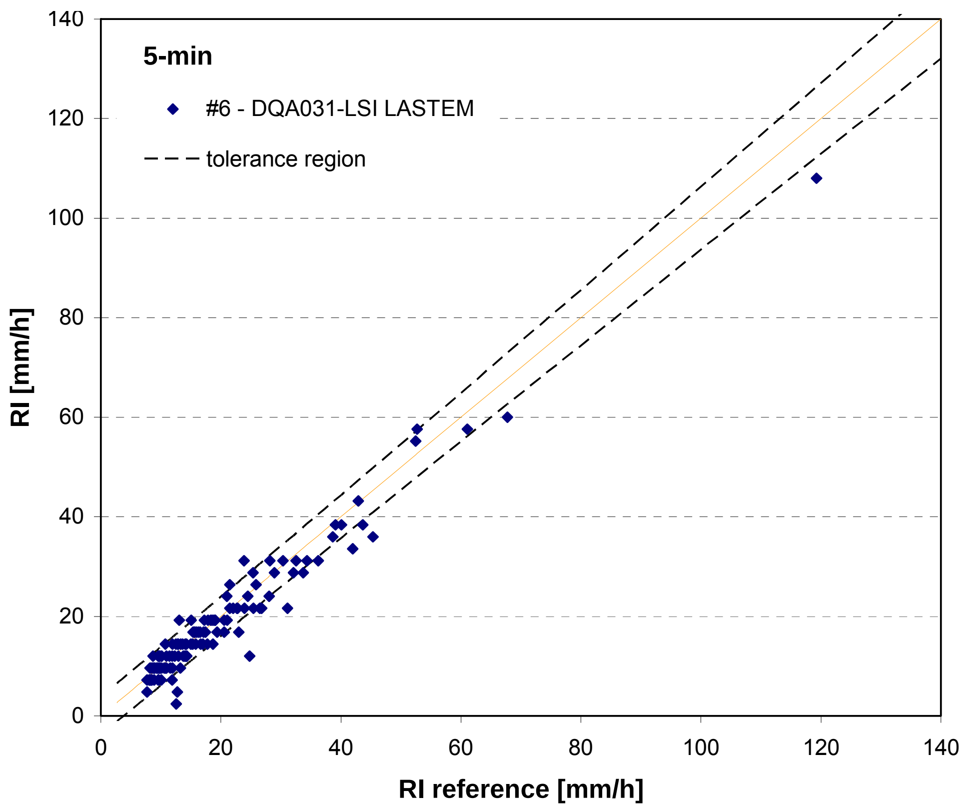


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$)



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by DQA031-LSI LASTEM and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters (RI=a·(RIref)^b)	**a**	**b**	**R^2**
#**6** **DQA031 LSI LASTEM**	1.06	0.96	0.72

(Parameters a, b, R^2 are determined by fitting the function RI=a·(RIref)^b, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

This rain gauge is equipped with a siphon placed on the cone's nozzle, having two functions: during light rain the drizzle falls on the bascule without moving it and therefore evaporates without being measured; during heavy rain, it regulates the flow into the bascule permitting all the water to fall inside. Therefore, the laboratory calibration curve does not show underestimation with high RI, usual for non-corrected TBRGs. The constant flow response reveals a +20% overestimation below 20 mm/h and around +6% for RI above 40 mm/h slightly increasing with RI. Field calibration is in agreement with laboratory calibration. No drift detected from the field calibration.

In the field measurements, for RI up to 70 mm/h, no particular effect of RI_{ref} is seen. For higher RI_{ref} values, there is underestimation, not explained by the laboratory results.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
No diagnostic data and error code.

Data availability (1 min):

- Valid Data: 95,9%
- Not Valid/Missing data during the period 12/11/2008 - 02/01/2009 due to a data acquisition problem (no instrument failures).

Maintenance:

- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust; cleaning of the inside of bucket as recommended by Manufacturer.

Malfunctioning:

- None.

UMB7525/I SIAP MICROS
- Italy -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Tipping bucket with correction algorithm.
- Collector area: 500 cm^2
- Range of measurement : 0-300 mm/h
- 1-minute resolution: 0.2 mm/h.

Data output

- Output: data message by serial interface RS485 in ASCII protocol - Automatic mode (every minute).
- Data update cycle : 1 min
- Rainfall parameters: 1 min RI [mm/h], corrected rainfall accumulation RA [mm].
- Transfer function for 1-min RI: none.

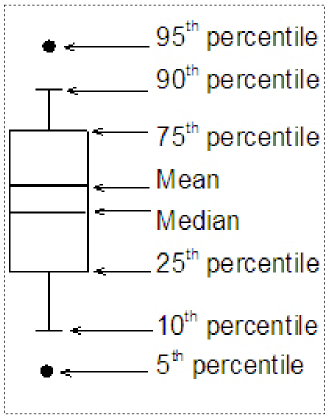
#7 UMB7525/I SIAP MICROS in the field

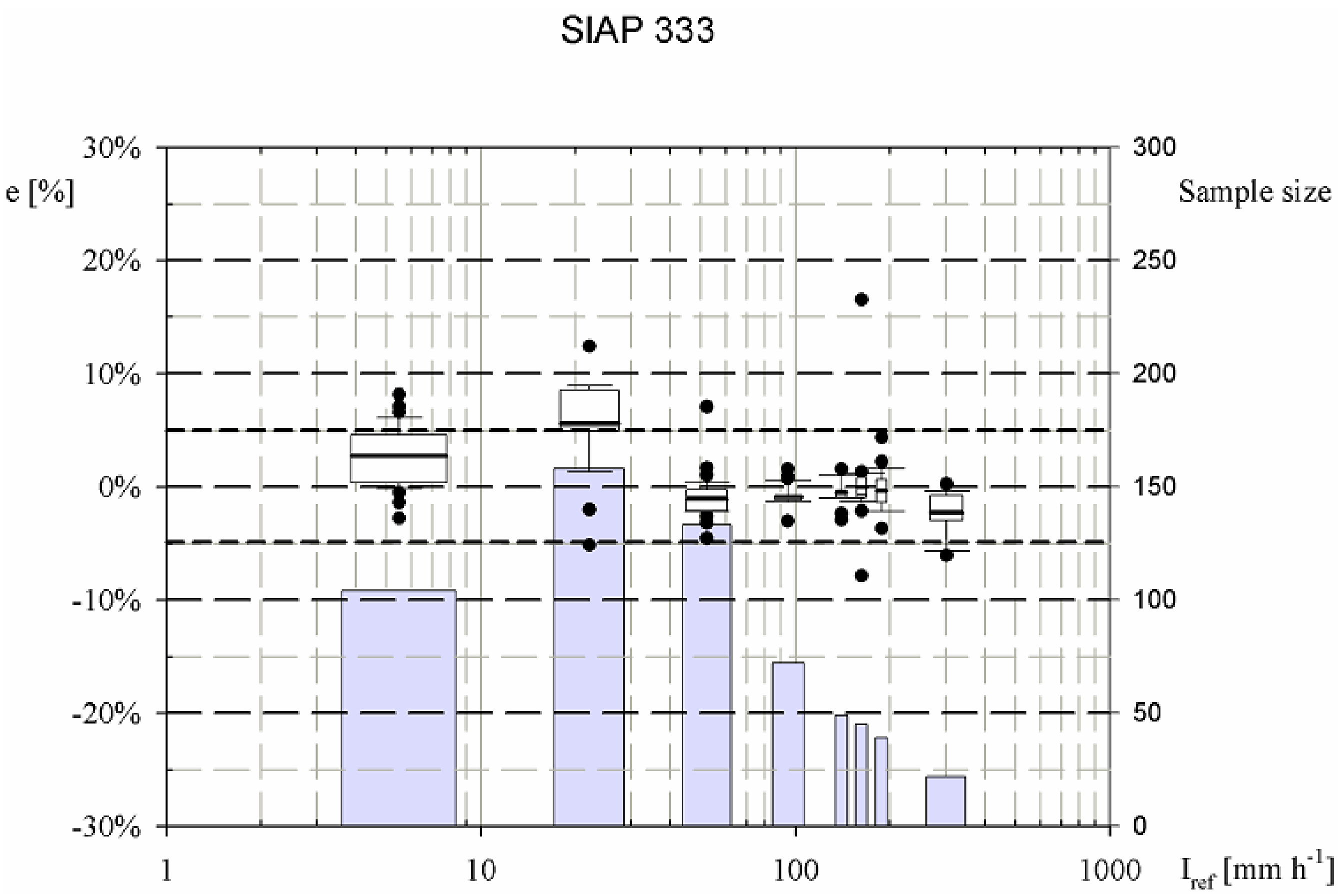
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

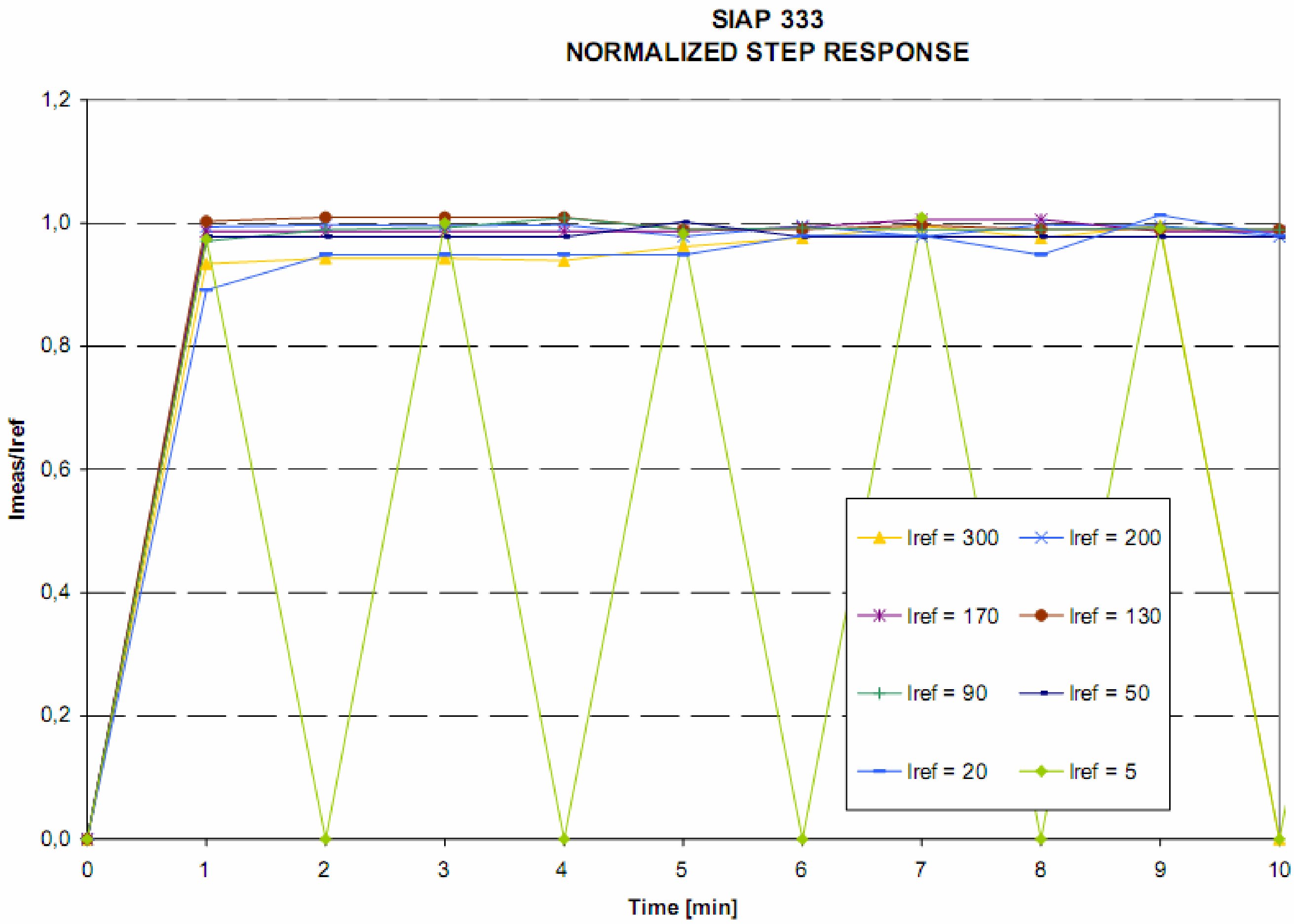
The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute variability of the observed instruments performances and the size of the sample used for calculation of the statistics at each reference intensity. Box plots synthetically 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.





Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behavior of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

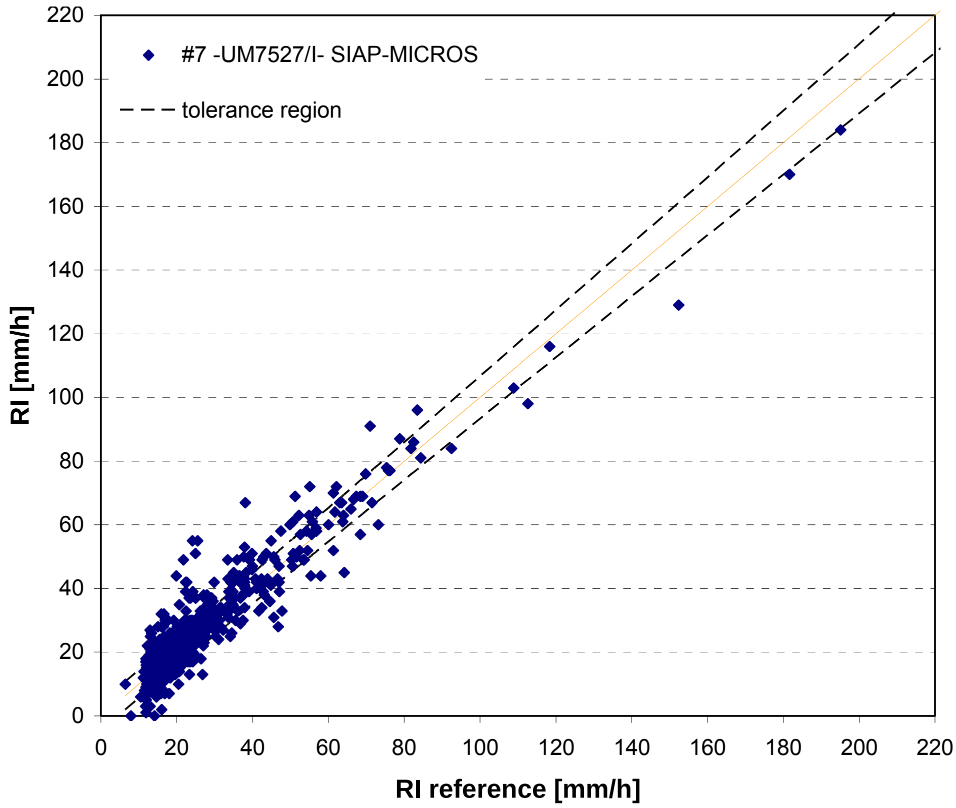
UMB7525/I SIAP-MICROS s/n333

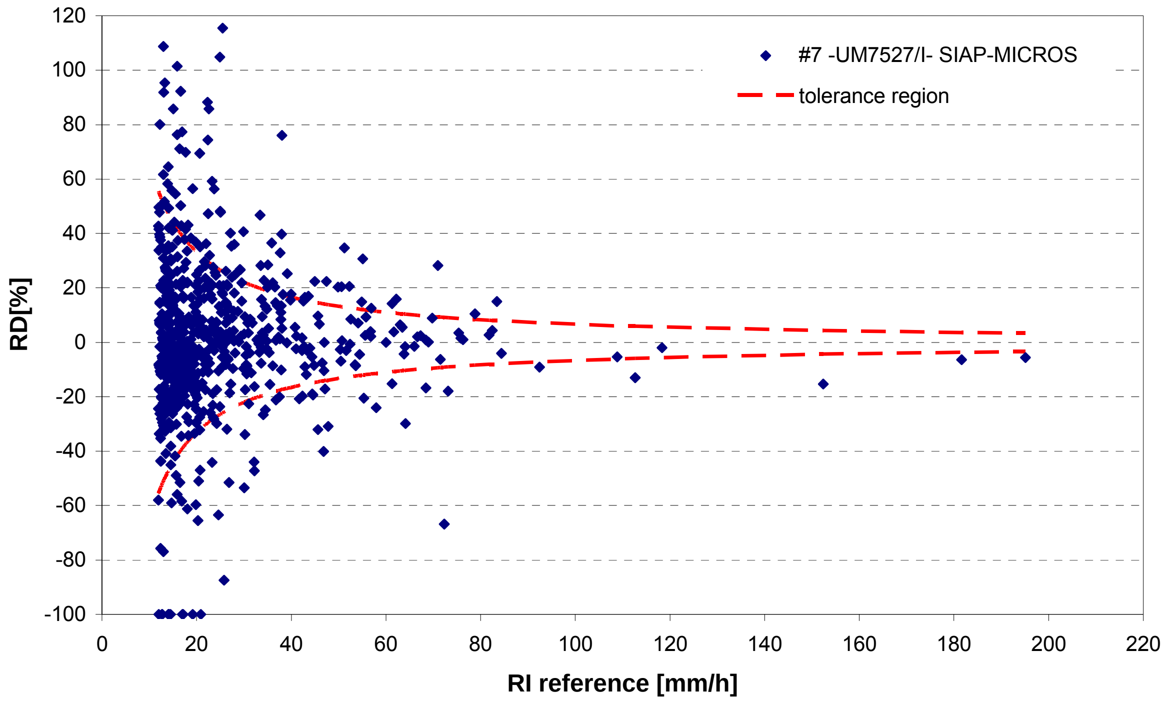
CALIBRATION	**1° 11/12/07**	**2° 27/05/08**	**3° 22/04/09**
RI ref [mm/h]	201,9	132.7	119.6
AVG RE [%]	-2.5	0.8	-1.4
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-3.0, -2.0]	[0.1, 1.5]	[-1.7, -1.2]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%

Field Intercomparison Measurements

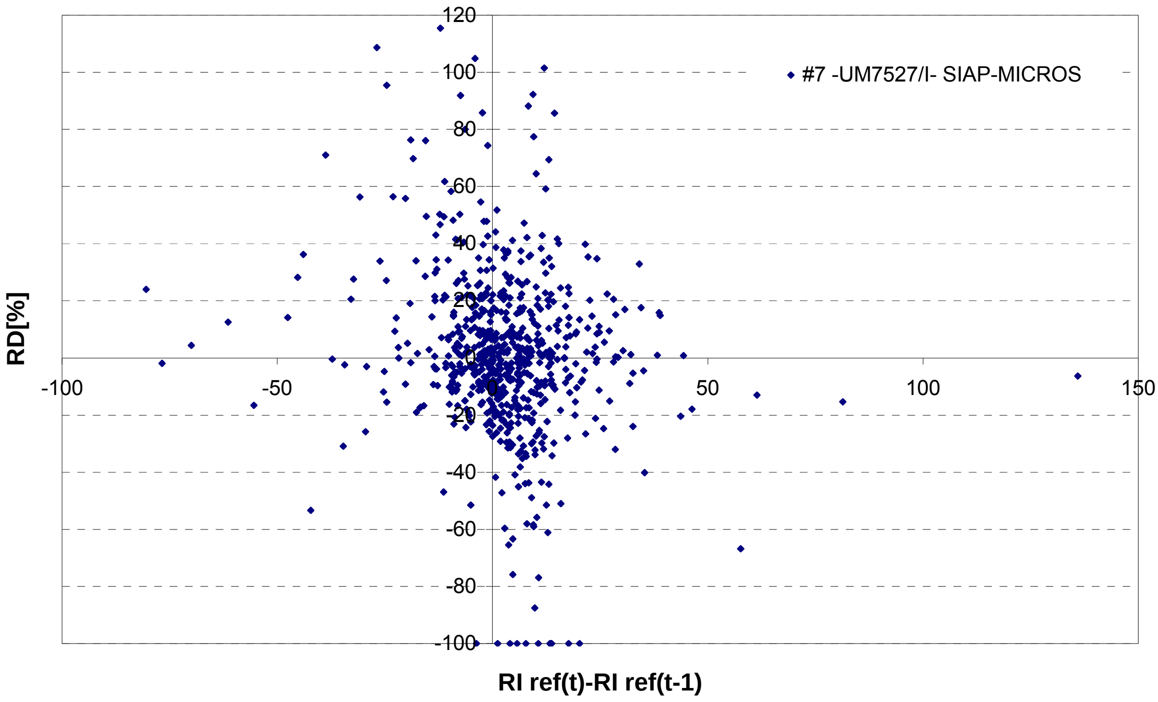
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by UMB7525/I-SIAP-MICROS and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



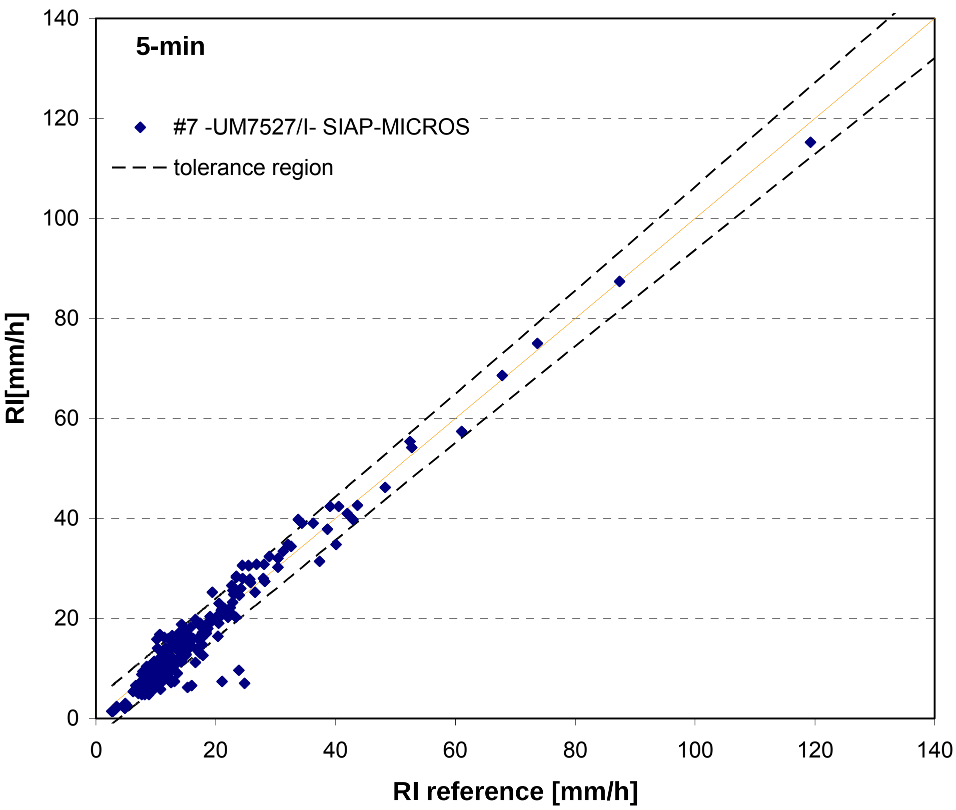


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t\text{-}1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by UMB7525/I SIAP-MICROS and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters *($RI=a\cdot(RIref)^b$)*	a	b	R^2
#7 UMB7525/I SIAP- MICROS	0.92	1.02	0.73

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

Very good accuracy in constant flow conditions with respect to linearization above 40 mm/h with average relative errors within ±2.5%. Maximum deviation (average relative error) from reference is around 5%. Laboratory results are confirmed by field calibration results. No drift detected from the field calibration.

The RD scatter plot and RI scatter plot show a minor under-estimation above 100 mm/h which cannot be seen in the 5 min RI scatter plot and which is larger than the laboratory calibration.

Field measurements show more noise and outliers can be seen in RI scatter plot at 1 min and 5 min averages below 30 mm/h. The correction algorithm increases the RI resolution but for low RI the correction algorithm could lead to some degradation of results.

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<u>QA/QC Information</u>

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
No diagnostic data and error code.

Data availability (1 min):

- Valid Data: 95.5%.
- Not valid and missing data during the period 13/08/2008 – 04/09/2008 due to a displacement of the bucket from the knife blade pivot, after a cleaning operation. Delay to fix the problem due to summer holiday period of the company.

Maintenance:

- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust; cleaning of the inside of bucket as recommended by Manufacturer.

Malfunctioning:

- Displacement of the bucket from the knife blade pivot, after a cleaning operation.

PMB2-CAE
- Italy -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Tipping bucket with correction algorithm.
- Collector area: 1000 cm^2
- Range of measurement : 0-300 mm/h
- 1-minute resolution: 0.1 mm/h.

Data output

- Output: data message by serial interface RS485 in ASCII protocol - Automatic mode (every minute). (*Software: version 2.17*).
- Data update cycle : 1 min
- Rainfall parameters: 1 min RI [mm/h], corrected rainfall accumulation RA [mm].
- Transfer function for 1-min RI: none.

#28 - PMB2 – CAE
Reference Pit Gauge
(s/n 21876)

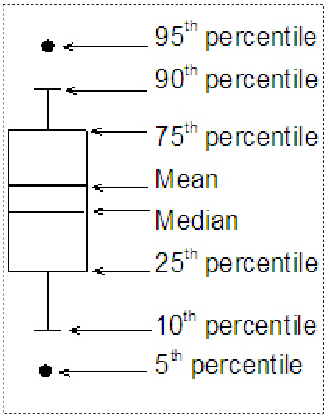
#8 PMB2 – CAE in the field (s/n 21858)

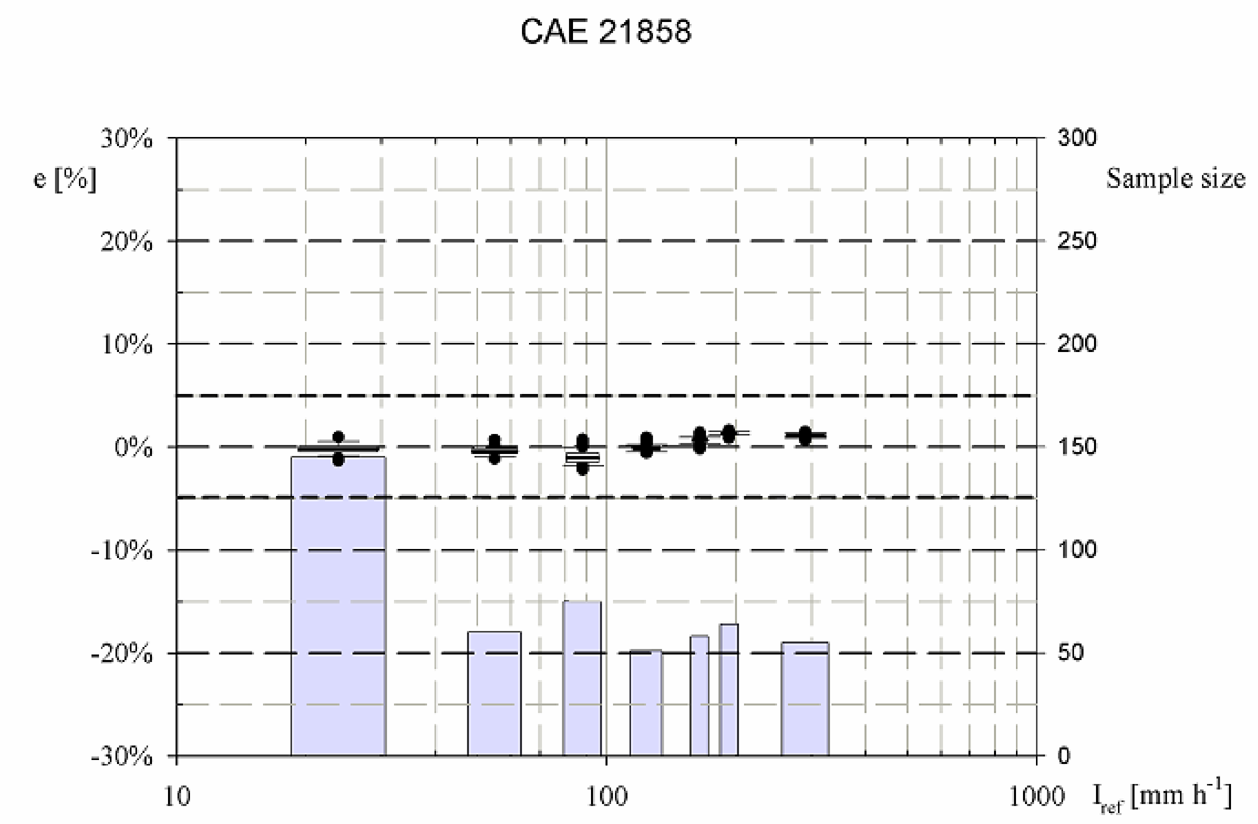
La

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

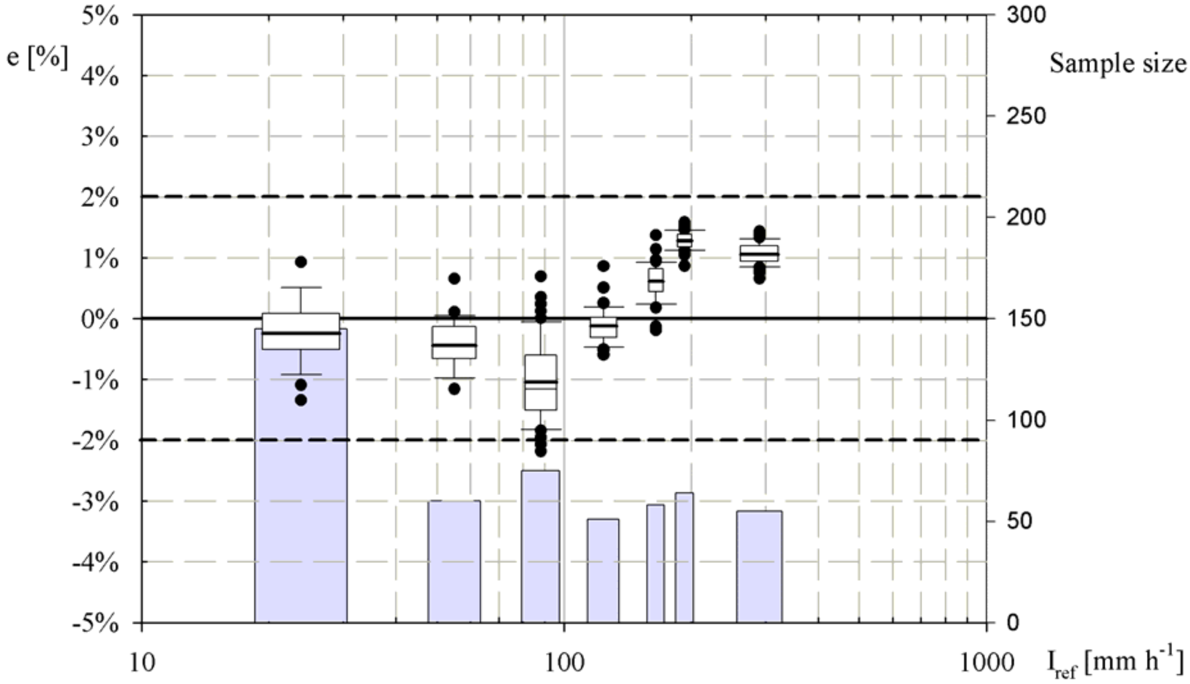
Constant flow response

The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute 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.

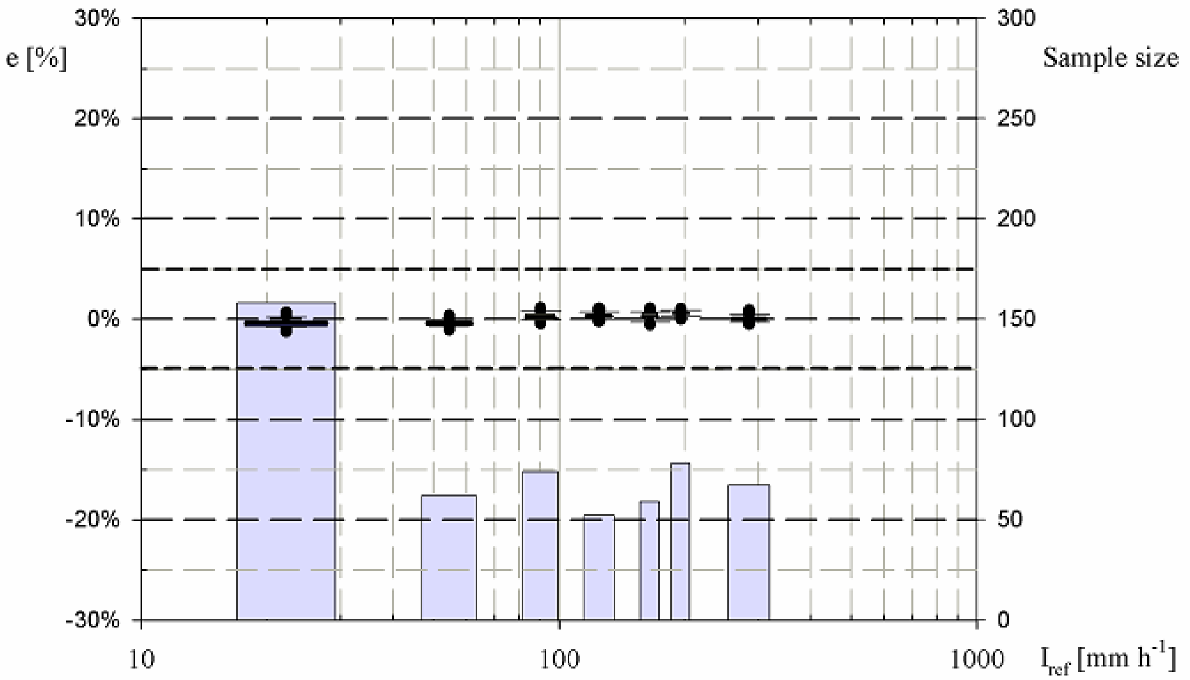




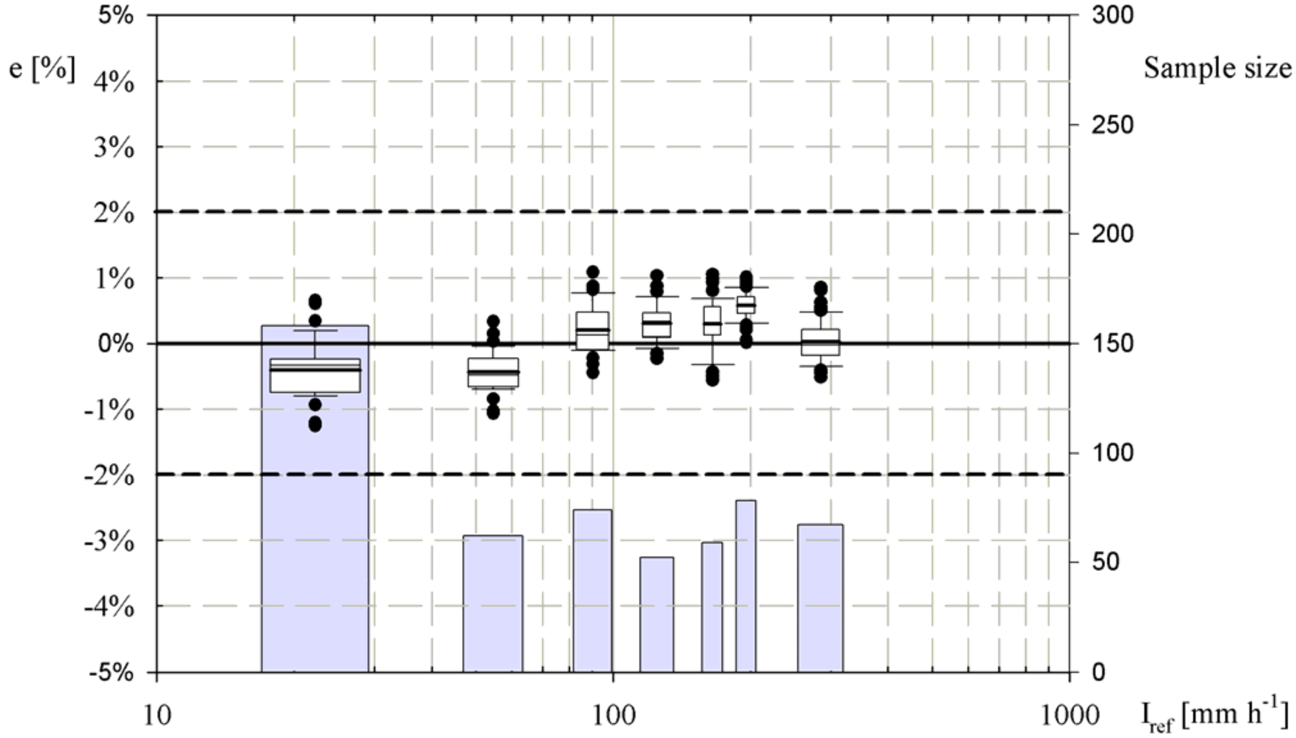
CAE 21858



CAE 21876



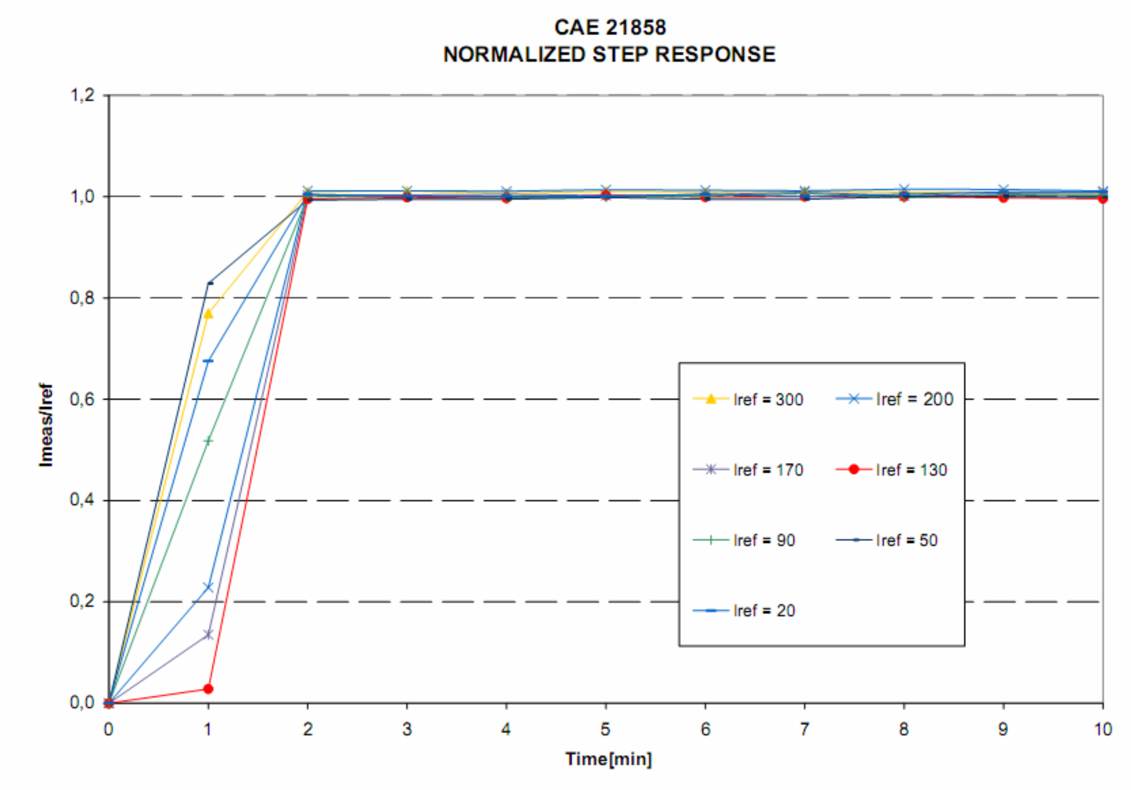
CAE 21876

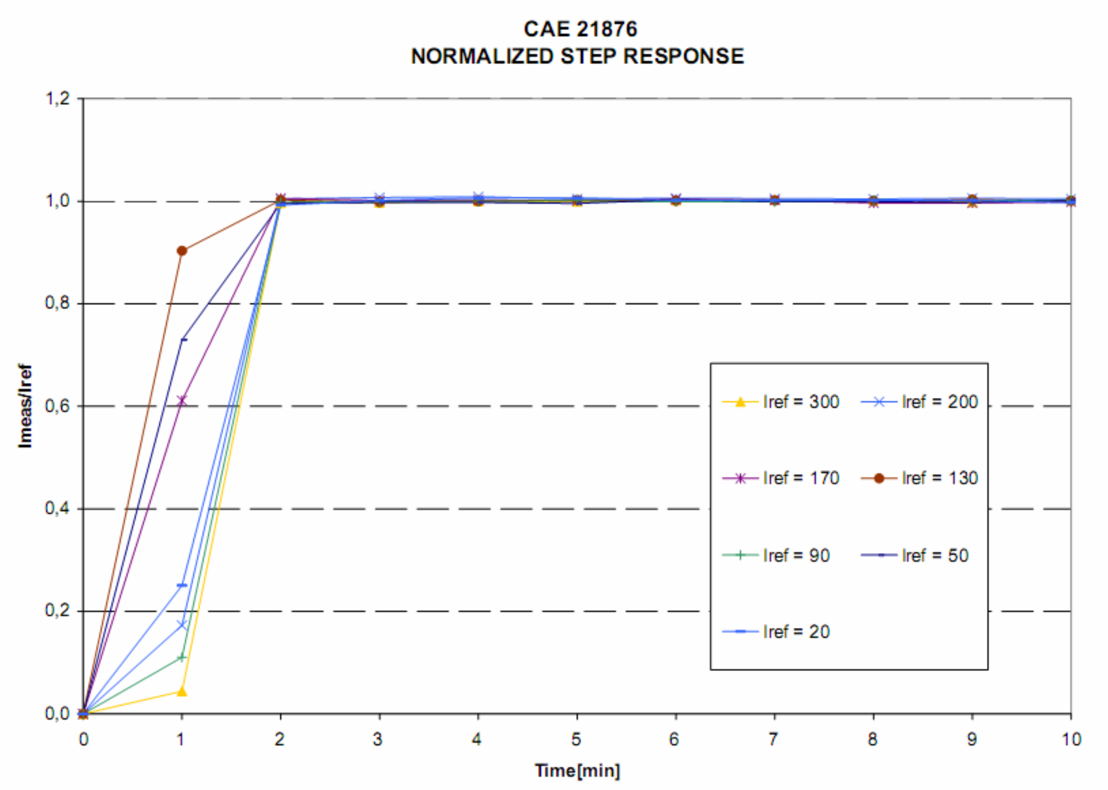


5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
e [%]
300
250
200
150
100
50
0
Sample size
10
100
1000
I_ref [mm h^-1]

Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behavior of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.





Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

PMB2 CAE s/n 21858

CALIBRATION	**1° 10/12/07**	**2° 23/05/08**	**3° 15/04/09**
RI ref [mm/h]	214.4	148.0	149.7
AVG RE [%]	1.9	1.2	2.3
[RE(-C.L.95%),RE(+C.L.95%)][%]	[1.6, 2.2]	[-1.2, 3.6]	[1.7, 2.8]

Results

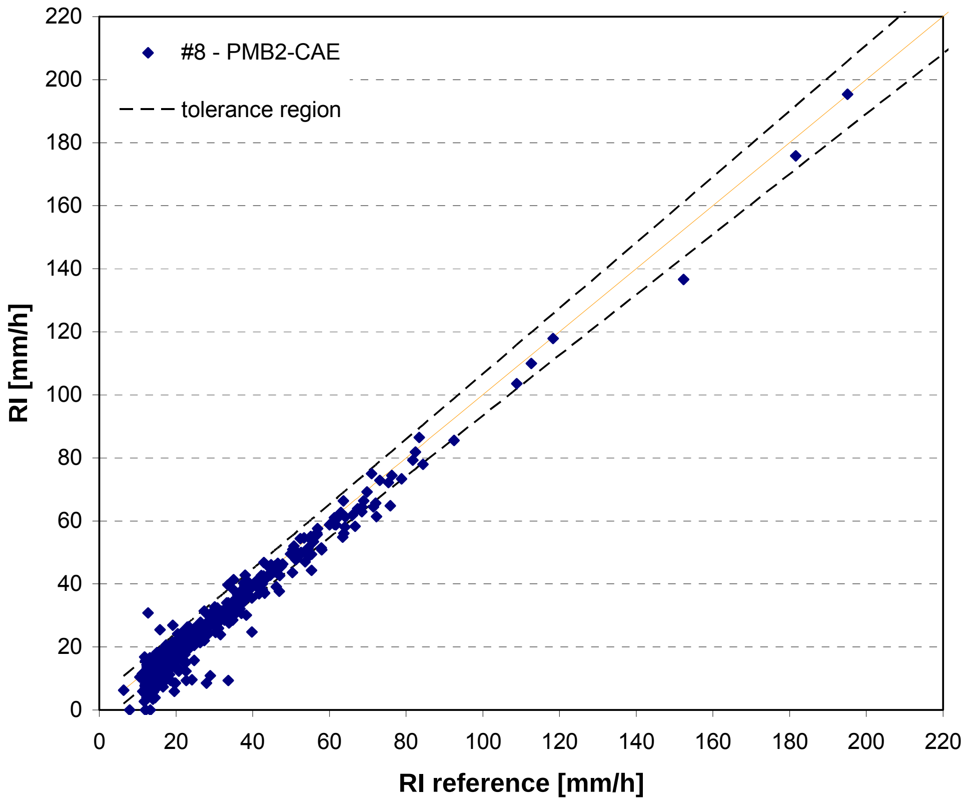
PMB2 CAE s/n 21876 (pit gauge)

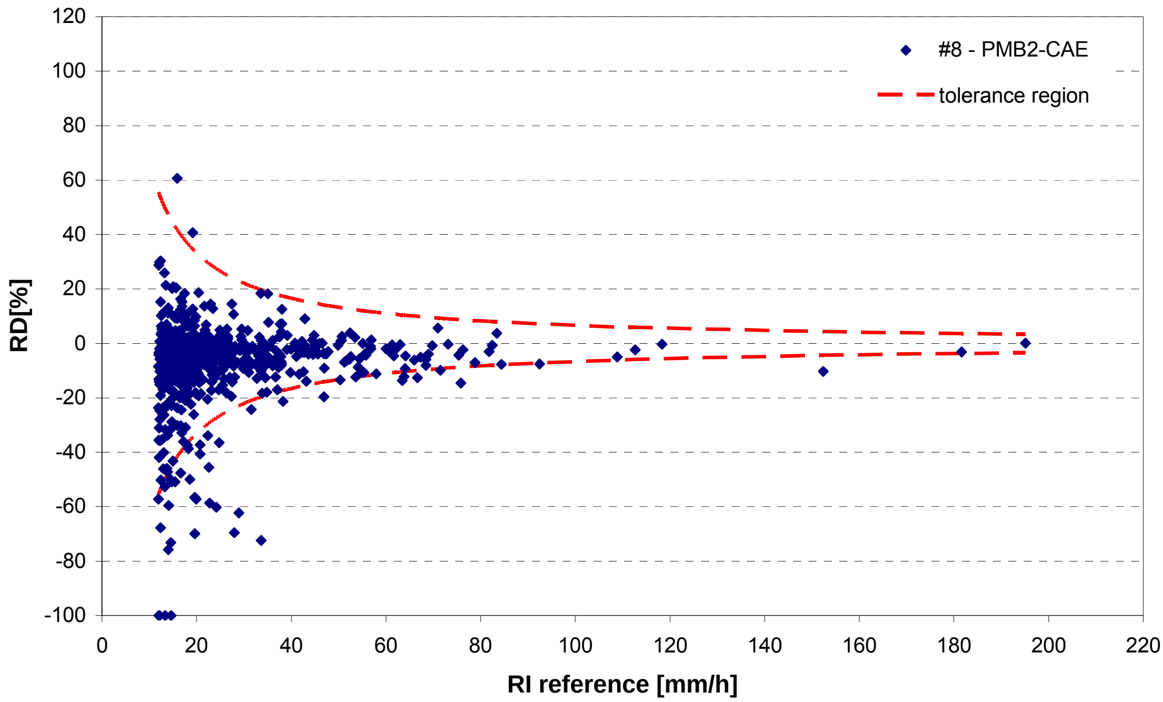
CALIBRATION	**1° 10/12/07**	**2° 08/05/08**	**3° 24/04/09**
RI ref [mm/h]	215.2	130.6	142.0
AVG RE [%]	0,8	0.3	0.8
[RE(-C.L.95%),RE(+C.L.95%)][%]	[0.5, 1.0]	[-1.5, 2.1]	[-0.2, 1.7]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%

Field Intercomparison Measurements

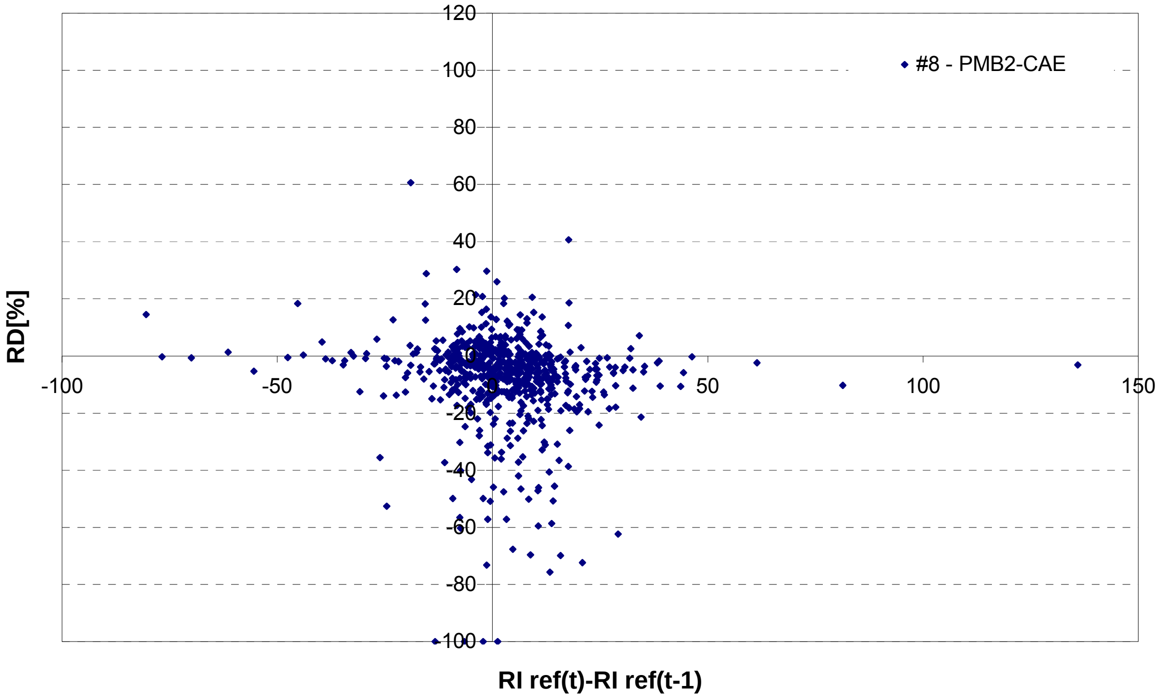
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by PMB2-CAE and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



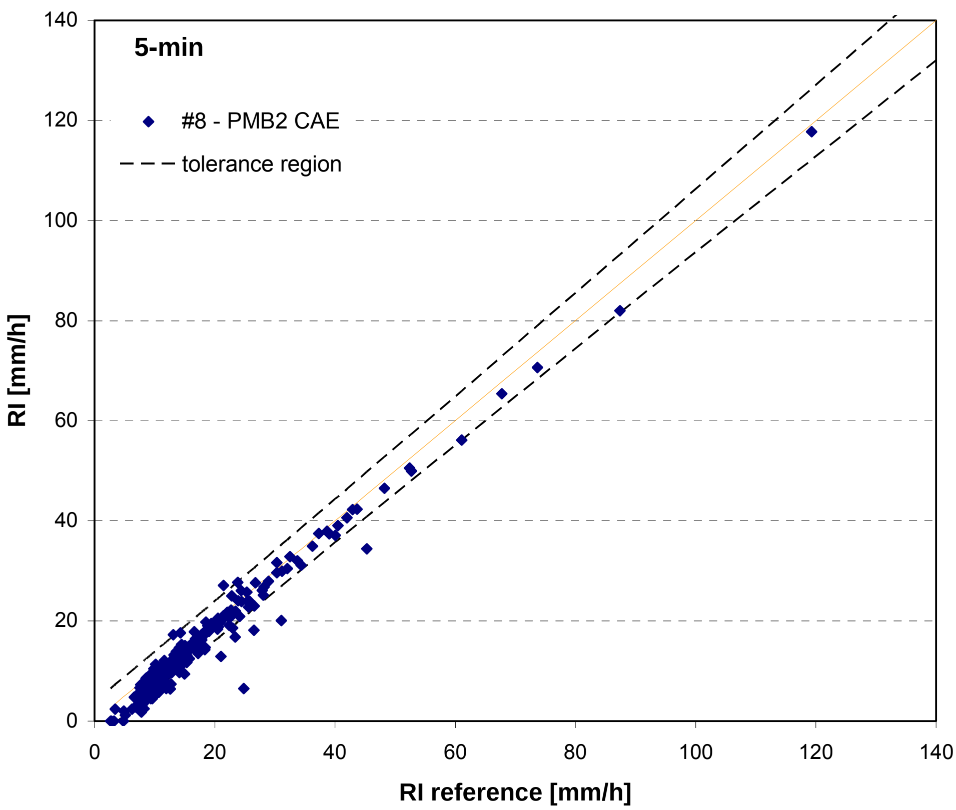


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by PMB2-CAE and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5-3-3.*



Summary Table

***Parameters* ($RI=a\cdot(RIref)^b$)**	**a**	**b**	**R^2**
#8 PMB2 CAE	0.78	1.05	0.87

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

Excellent accuracy in constant flow conditions with respect to linearization and noise for all laboratory reference RI: a) the laboratory calibration of the CAE used as reference gauge (s/n 21876) shows average relative errors within ±0.8% and outliers within ±1% for all tested reference intensities; b) the laboratory calibration of the CAE in the field (s/n 21858) shows average relative errors within ±1% and outliers within ±2% for all tested reference intensities. The CAE used as reference is performing better than the gauge in the field with respect to linearization and noise.

The field calibrations give consistent results with the laboratory calibration. No drift detected from the field calibration.

In the field measurements, a very small under-estimation is seen above 100 mm/h. This small underestimation is more visible with 5 minutes data. Noise figure is very low but like other gauges of this class of TBR-SC gauges it shows outliers below 30 mm/h.

The correction algorithm increases the RI resolution but for low RI the correction algorithm could lead to some degradation of results.

Apart from outliers for low intensities, the correction algorithm of CAE represented very well the highest intensities.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
No diagnostic data and error code.

Data availability (1 min):

- Valid Data (both rain gauges): 100%.

Maintenance:

- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust; cleaning of the inside of bucket as recommended by Manufacturer.

Malfunctioning:

- None.

Rain Collector II DAVIS mod.7852
- U.S.A. -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Tipping bucket without correction.
- Collector area: 214 cm^2
- Range of measurement : 0-2540 mm/h
- 1-minute resolution: 12 mm/h

Data output

- Output: Passive Reed Switch.
- Data update cycle : 10 s (Data Acquisition System sampling time).
- Rainfall parameters: Rainfall accumulation (RA [mm]).
- Transfer function for 1-min RI: RI_{1min}[mm/h] = $pulses_{1min}$ 12[mm/h] ($pulses_{1min}$ =number of pulses of reed switch in 1 minute; 1 pulse = 0.2 mm)

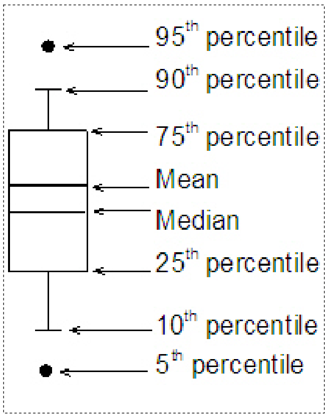
#9 Rain Collector II DAVIS in the field

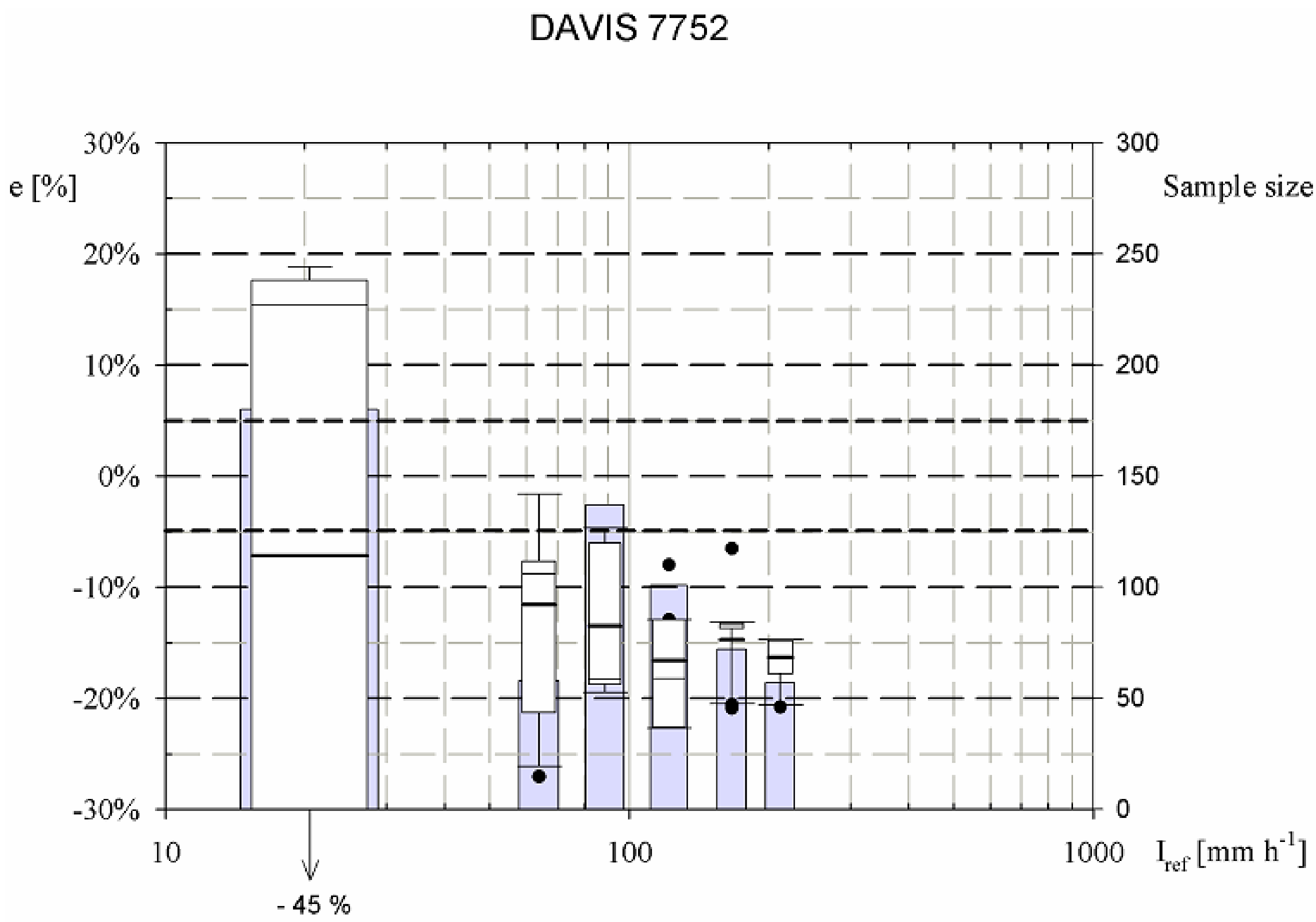
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute 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.

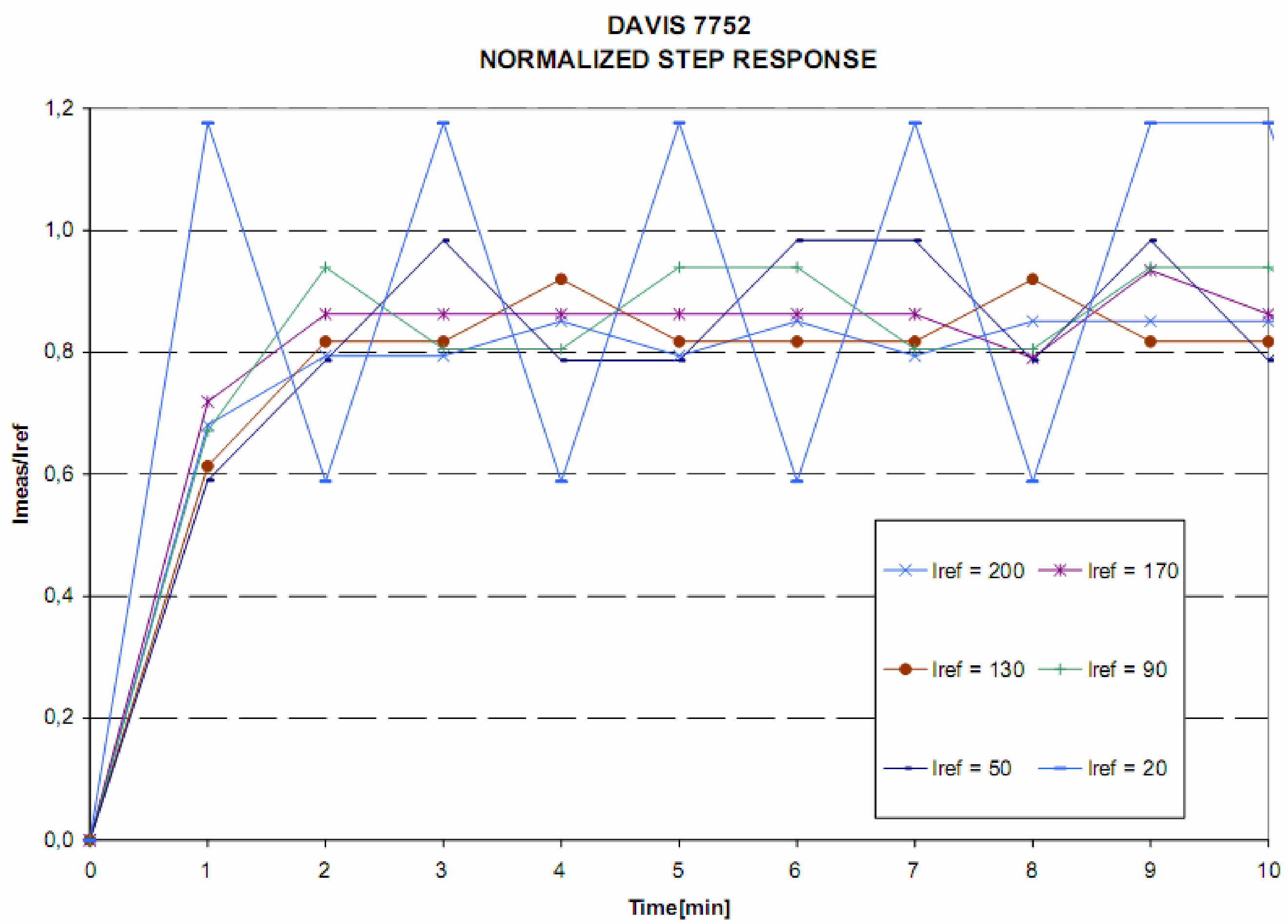




Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.

The “saw” response is mainly due to the measurement resolution.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

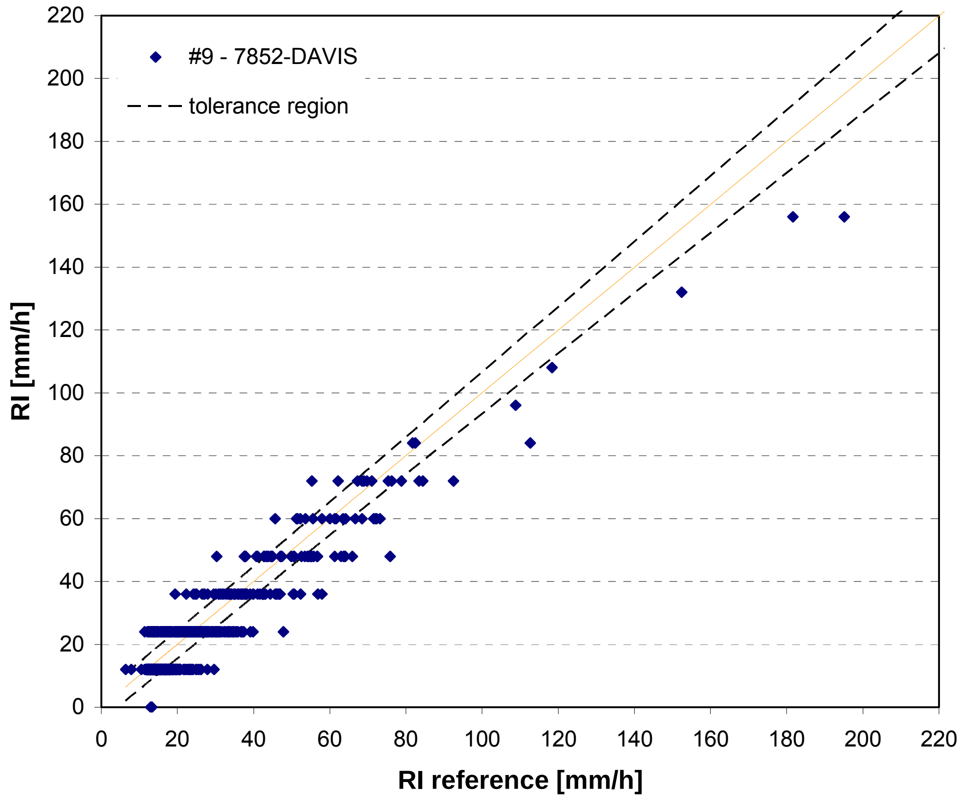
Rain Collector II-DAVIS s/n 7752

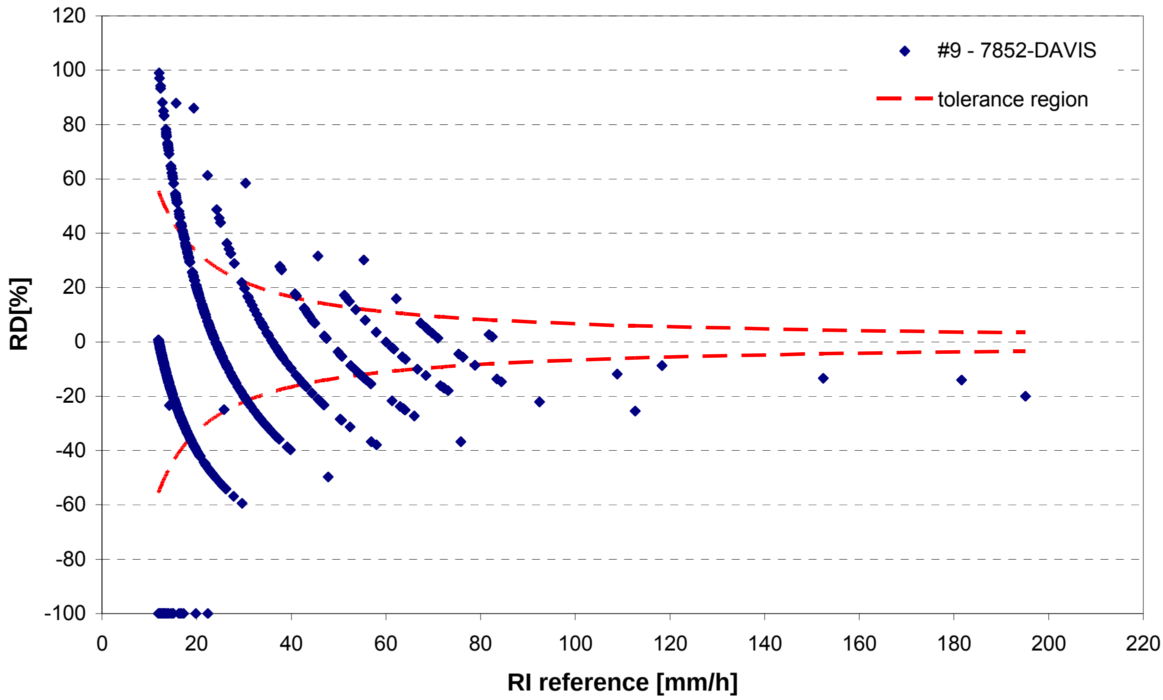
CALIBRATION	**1° 13/12/07**	**2° 10/04/08**	**3° 15/04/09**
RI ref [mm/h]	138.3	135.3	155.6
AVG RE [%]	-13.9	-13.9	-18.5
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-16.5,-11.3]	[-14.6,-12.6]	[-25.8,-17.3]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%).

Field Intercomparison Measurements

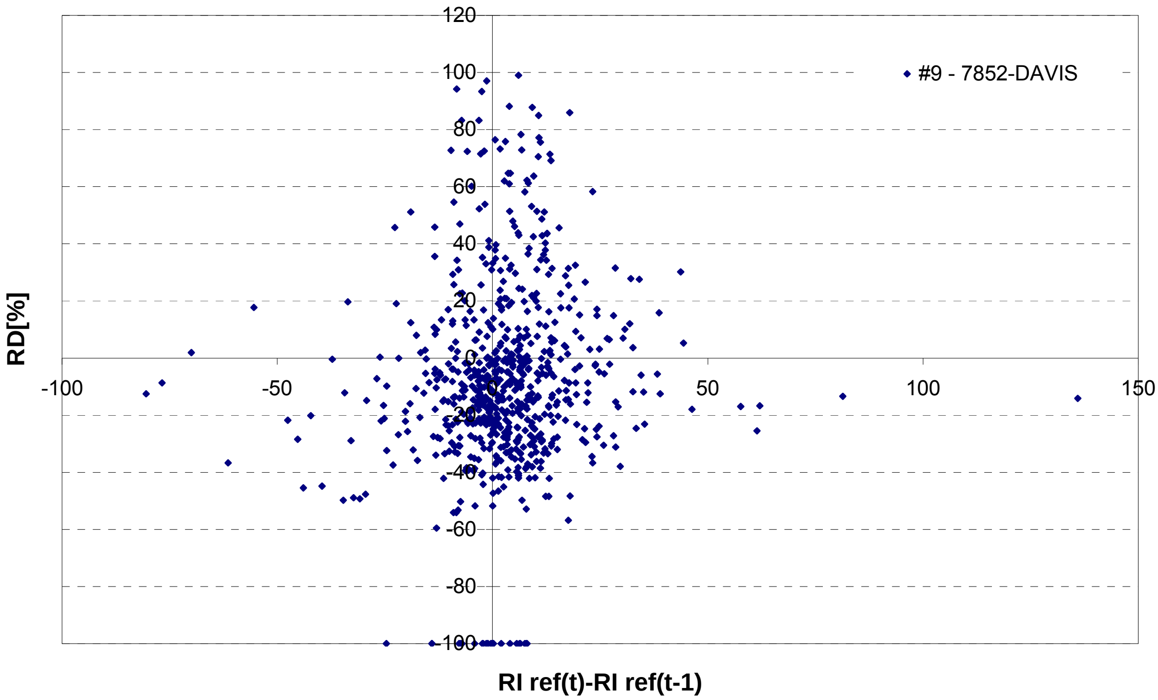
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by Rain Collector II-DAVIS and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5-3-3.*



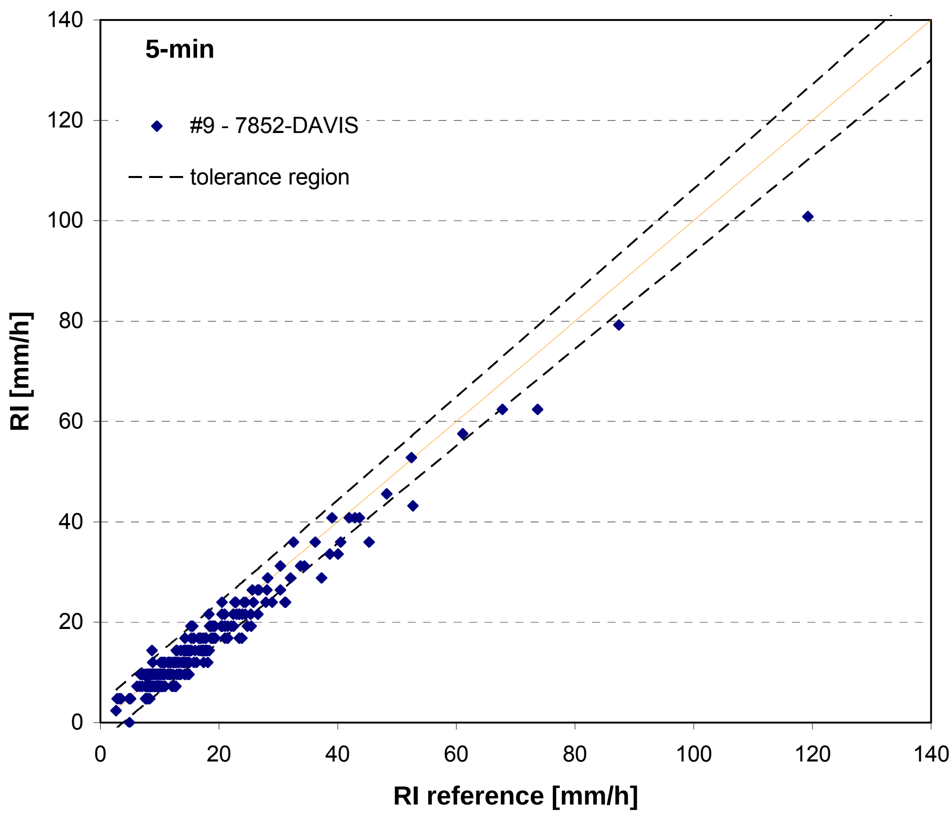


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by Rain Collector II- DAVIS and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5-3-3.*



Summary Table

Parameters (RI=a·(RIref)^b)	**a**	**b**	**R^2**
#9 Rain Collector II DAVIS	1.16	0.92	0.73

(Parameters a, b, R^2 are determined by fitting the function RI=a·(RIref)^b, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The constant flow response shows an underestimation increasing with RI, typical for uncorrected TBRGs. The field calibrations give consistent results with the laboratory calibration. No drift detected from the field calibration.

The field results show an underestimation, consistent with the calibration results.

The RI variation response plot shows noise at low RI due to 0.2 mm resolution of the bucket.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*

No diagnostic data and error code.

Data availability (1 min):

- Valid Data: 100%.

Maintenance:

- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust; cleaning of the inside of bucket as recommended by Manufacturer.

Malfunctioning:

- None.

LB-15188 LAMBRECHT
- Germany -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Tipping bucket with extra pulses correction (linearized pulse output).
- Collector area: 200 cm^2
- Range of measurement : 0-600 mm/h
- 1-minute resolution: 6 mm/h

Data output

- Output: Reed Switch.
- Data update cycle: 10 s (Data Acquisition System sampling time).
- Rainfall parameters: Rainfall accumulation (RA [mm]).
- Transfer function for 1-min RI: RI_{1min}[mm/h] = $pulses_{1min}$ 6[mm/h] ($pulses_{1min}$ =number of pulses of reed switch in 1 minute; 1 pulse = 0.1 mm)

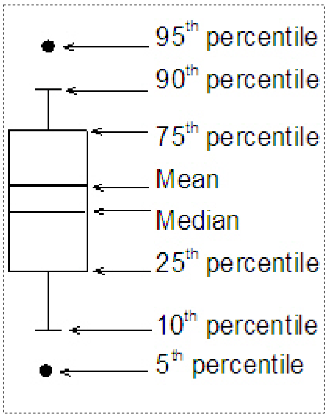
#10 LB-15188 - LAMBRECHT in the field

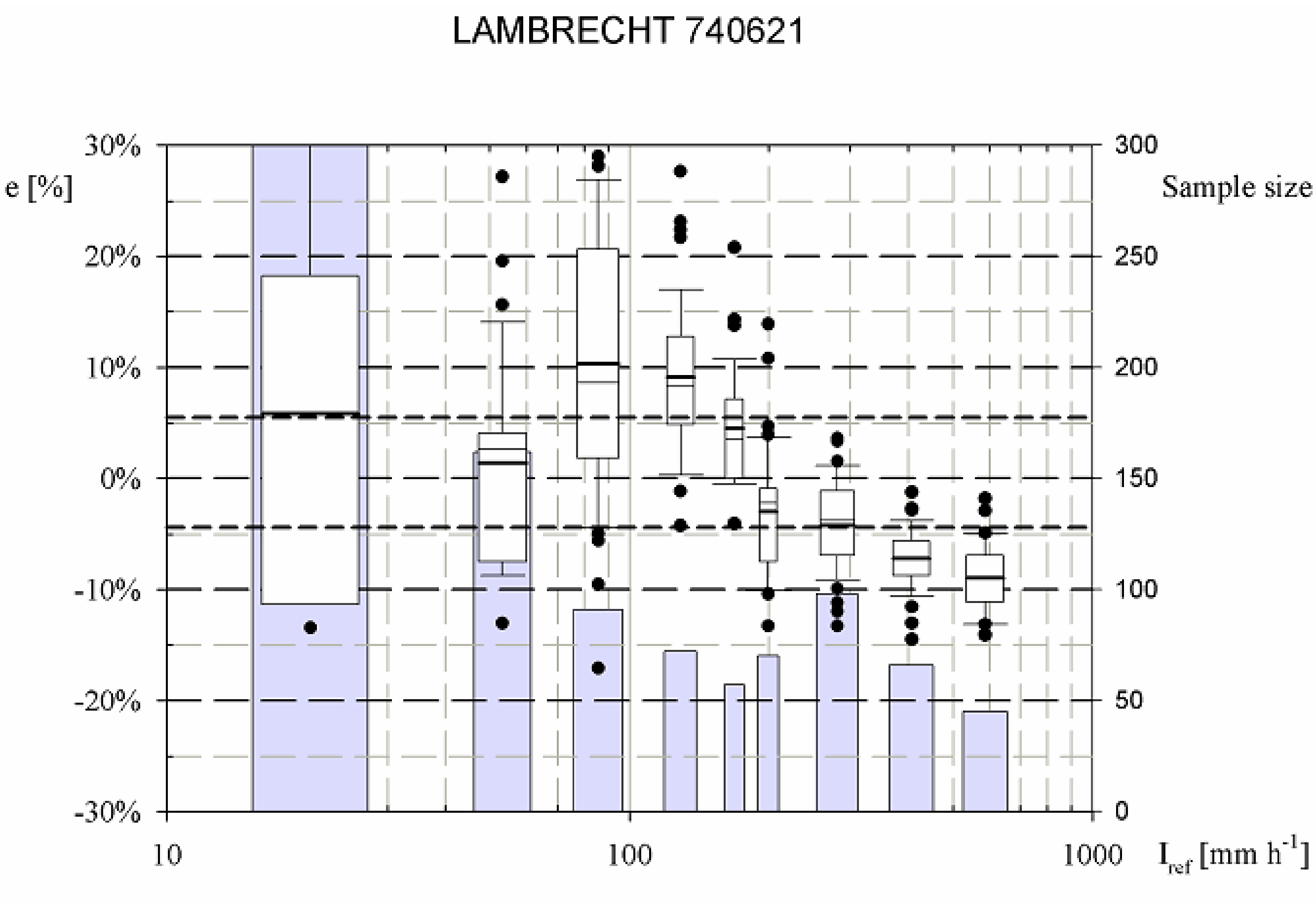
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute 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.

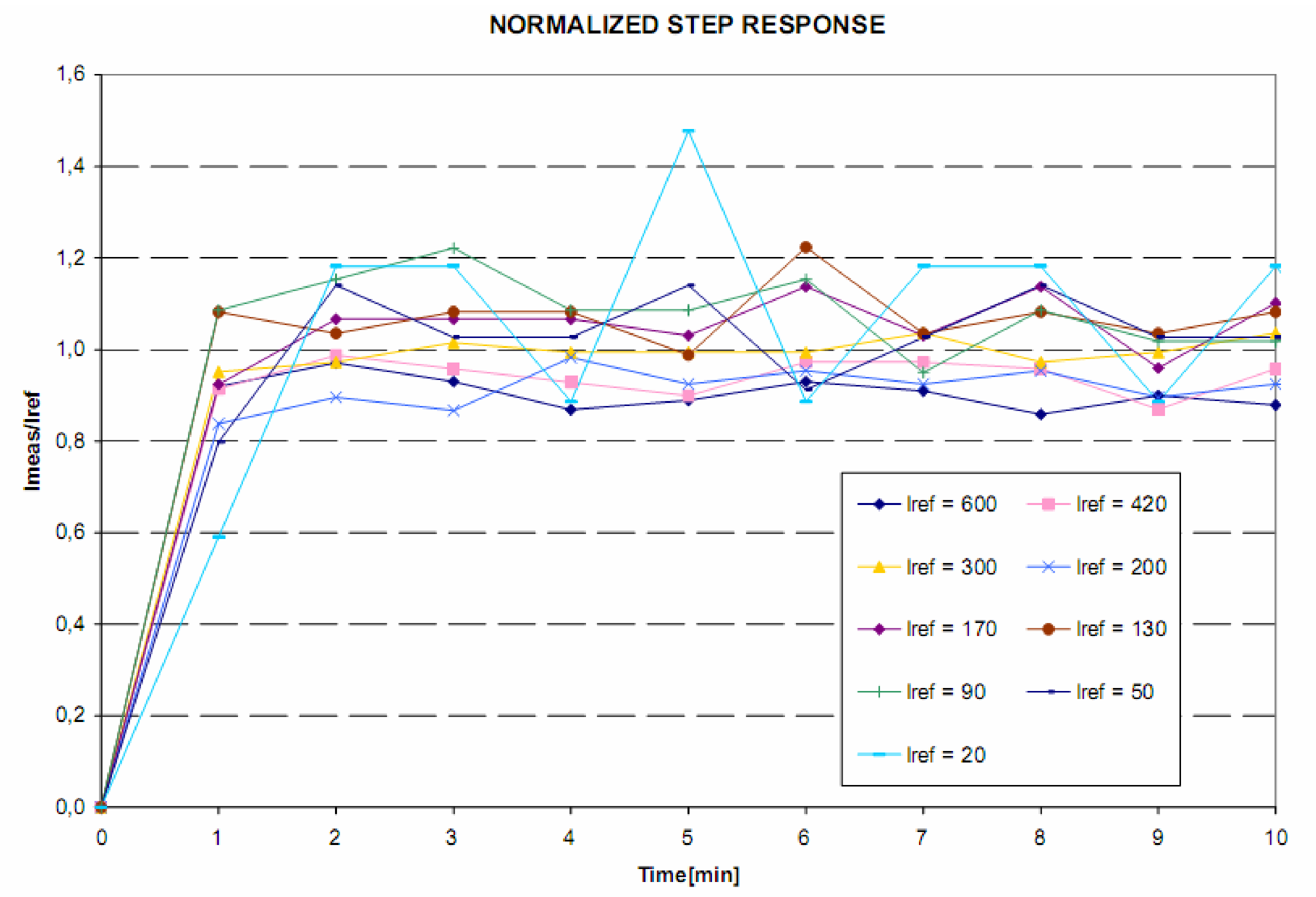




Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.

The “saw” response is mainly due to the measurement resolution.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

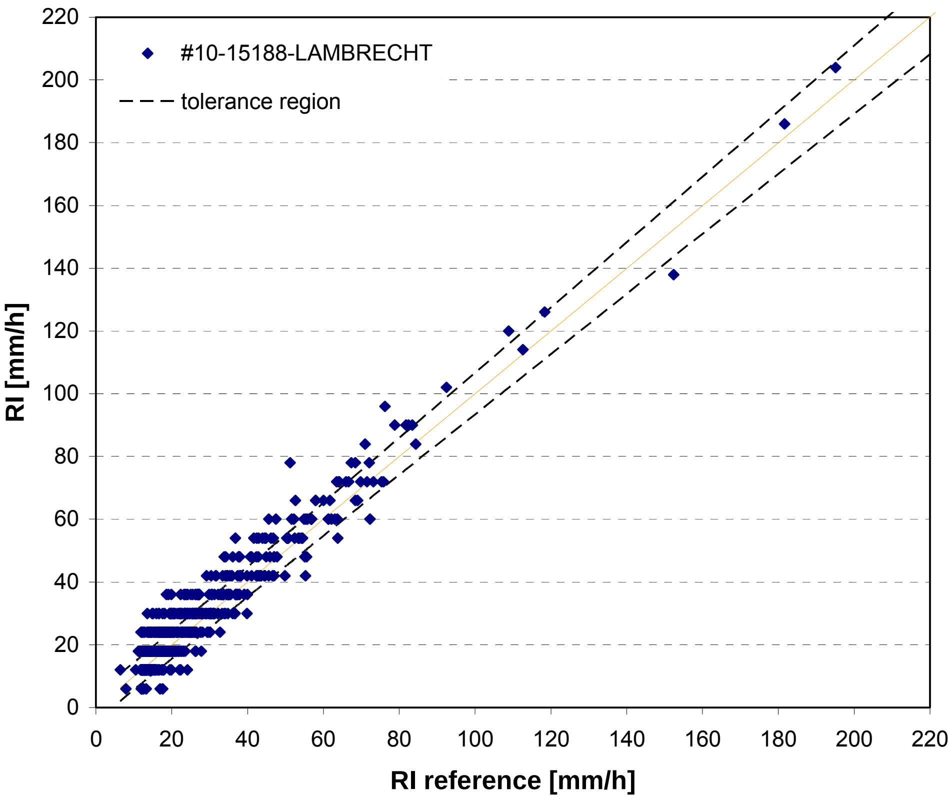
LAMBRECHT s/n 740621

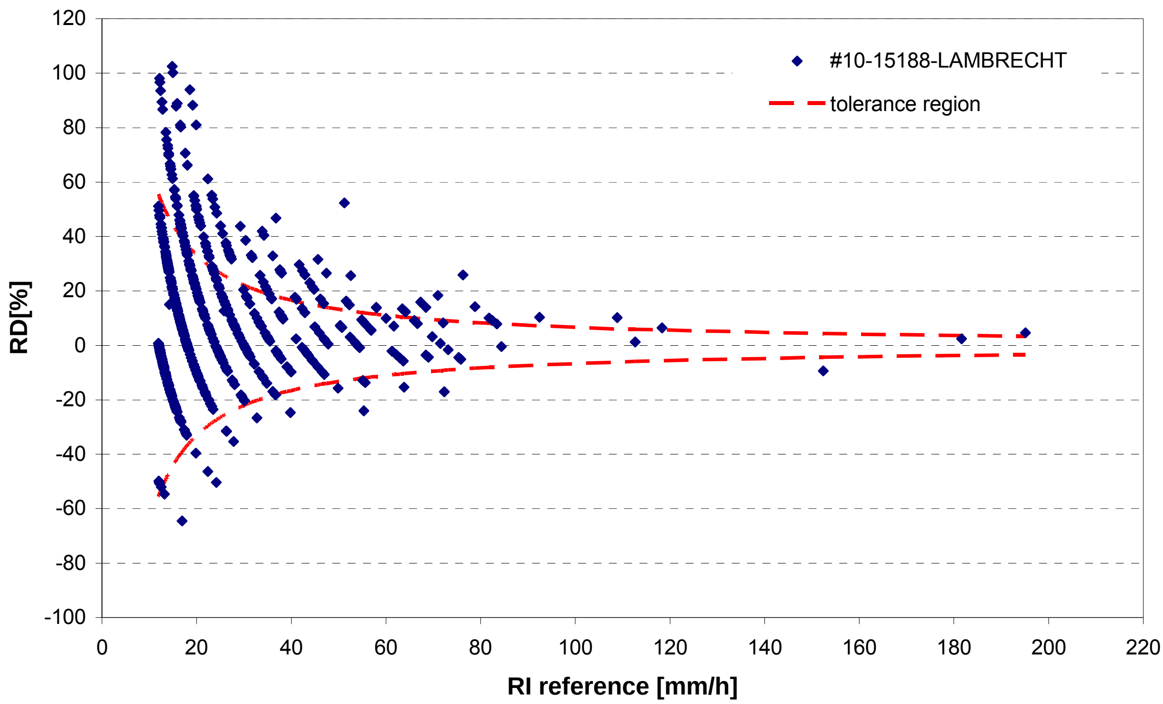
CALIBRATION	**1° 11/12/2007**	**2° 10/04/08**	**3° 15/04/09**
RI ref [mm/h]	212.9	135.1	153.6
AVG RE [%]	2.0	4.8	1.6
[RE(-C.L.95%),RE(+C.L.95%)][%]	[0.8,3.3]	[3.9,5.7]	[0.7,2.4]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%).

Field Intercomparison Measurements

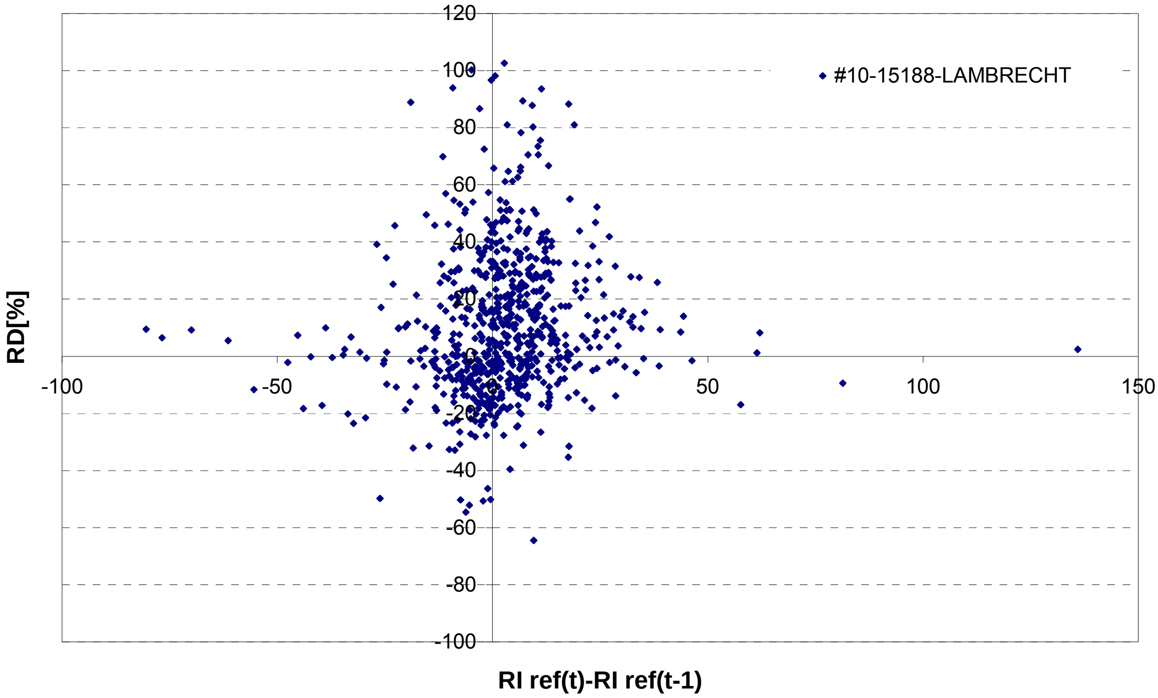
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by LB-15188-LAMBRECHT and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5-3-3.*



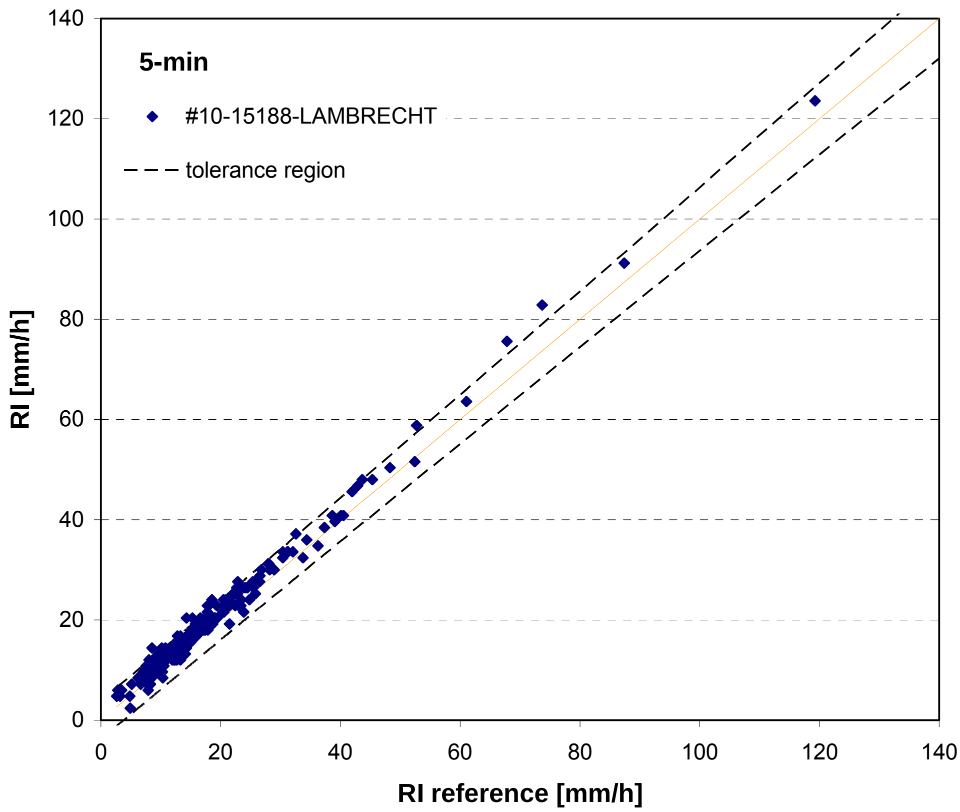


(Relative difference: RD=100(RI-RI$_{ref}$)/RI$_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)- RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by LB-15188 LAMBRECHT and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ***($RI=a\cdot(RIref)^b$)***	**a**	**b**	**R^2**
#10 LB-15188 LAMBRECHT	1.21	0.96	0.81

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The laboratory calibration shows an overestimation of lower RI up to 150 mm/h and an underestimation above 300 mm/h. The field calibrations give better results with higher values than the laboratory calibration. No drift detected from the field calibration.
Field measurements confirm these findings with good results up to 200 mm/h.
The RI variation response plot reveals higher noise level than e.g. for TBRG corrected by an algorithm.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
No diagnostic data and error code.

Data availability (1 min):
- Valid Data: 100%.

Maintenance:
- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust; cleaning of the inside of bucket as recommended by Manufacturer.

Malfunctioning:
- None.

PP040-MTX
- Italy -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Tipping bucket without correction.
- Collector area: 1000 cm^2
- Range of measurement : *not available*
- 1-minute resolution: 12 mm/h

Data output

- Output: Passive Reed Switch with dual switch.
- Data update cycle: 10 s (Data Acquisition System sampling time).
- Rainfall parameters: Rainfall accumulation (RA [mm]).
- Transfer function for 1-min RI: RI_{1min}[mm/h] = $pulses_{1min}$ 12[mm/h] ($pulses_{1min}$ =number of pulses of reed switch in 1 minute; 1 pulse = 0.2 mm)

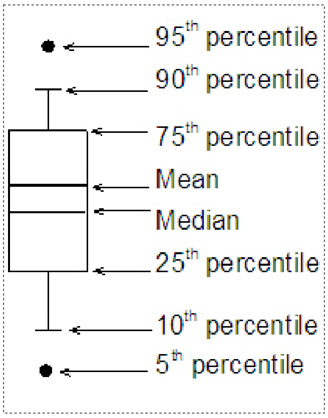
#11 PP040 – MTX in the field

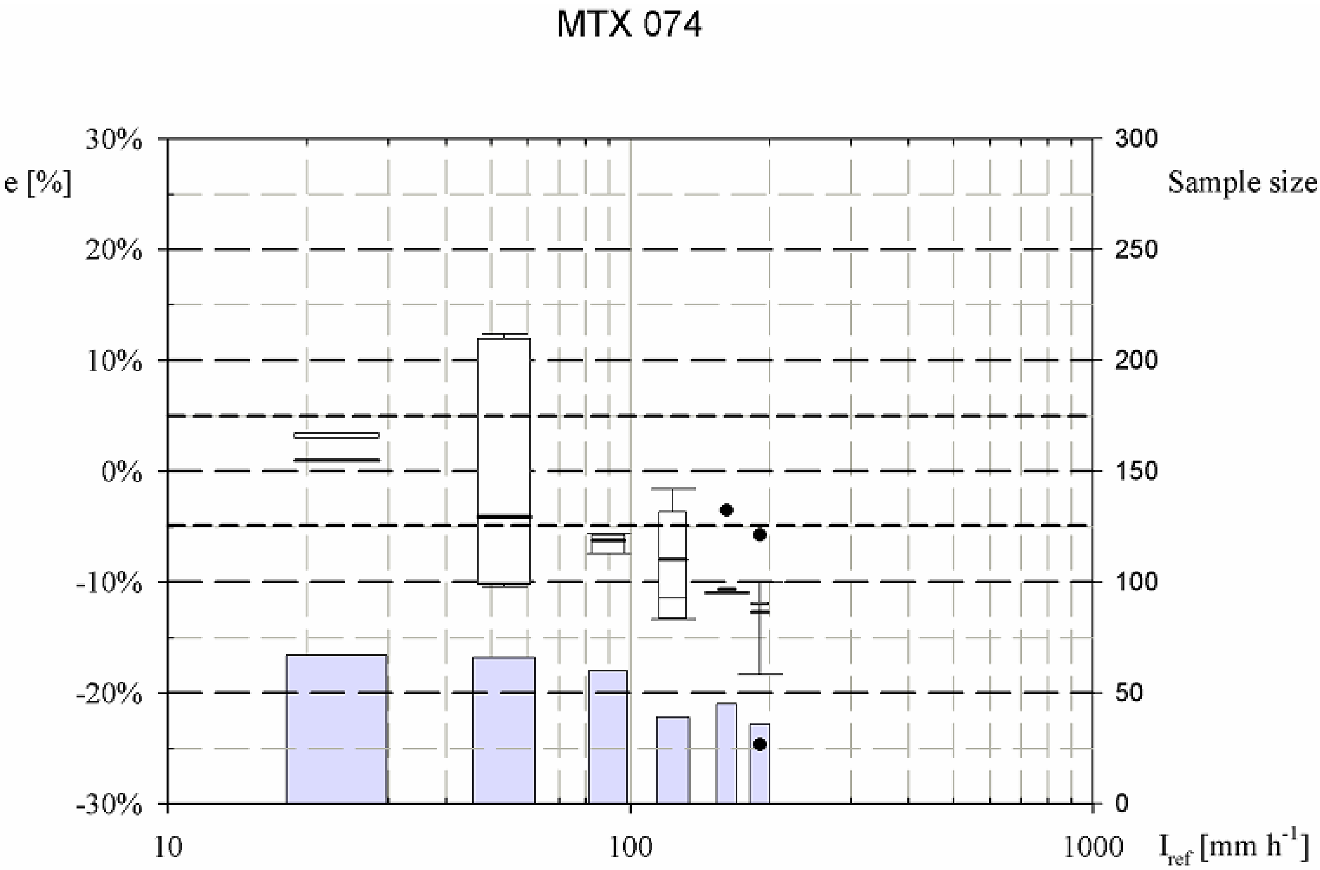
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute 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.

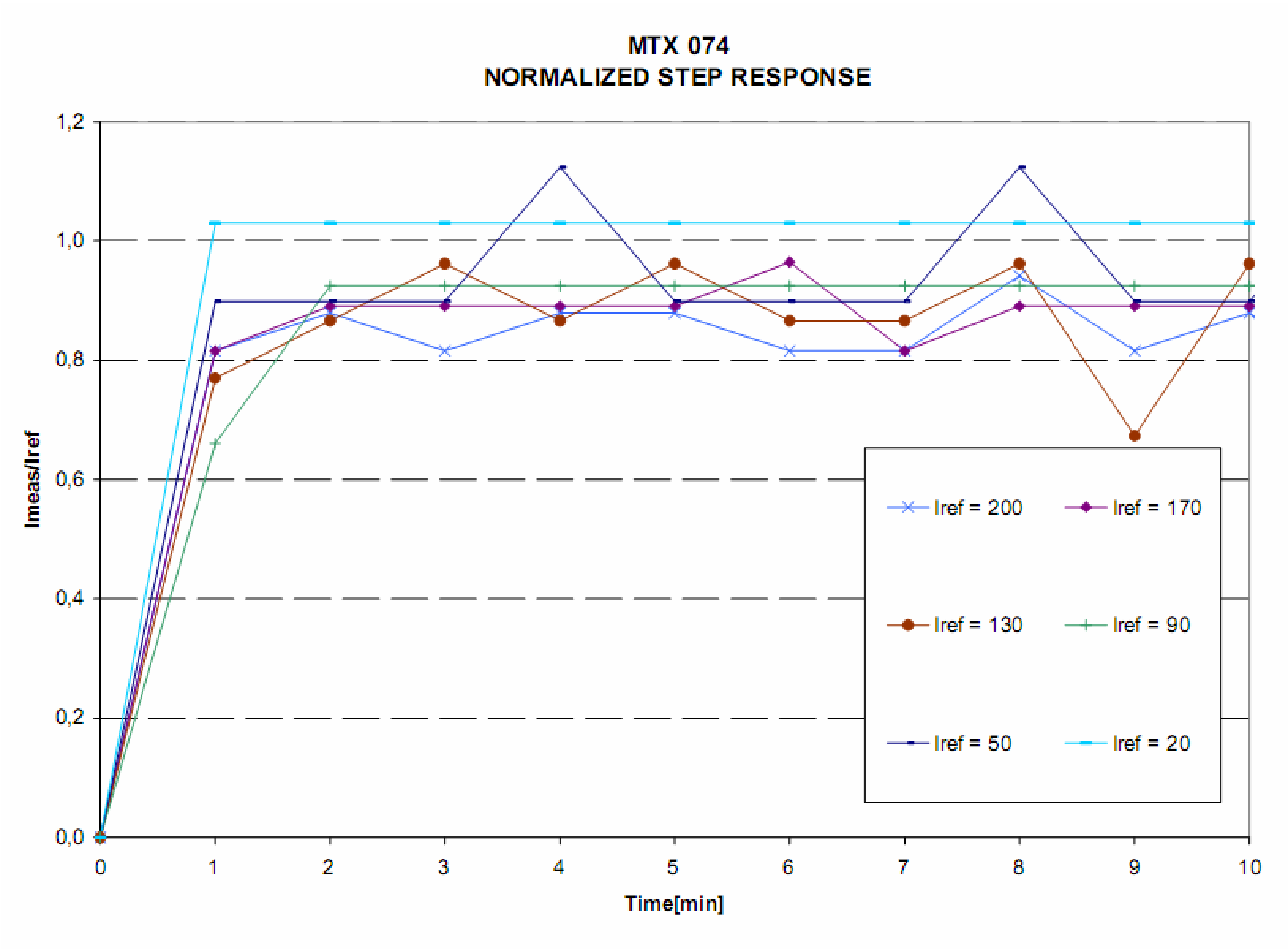




Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.

The “saw” response is mainly due to the measurement resolution.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

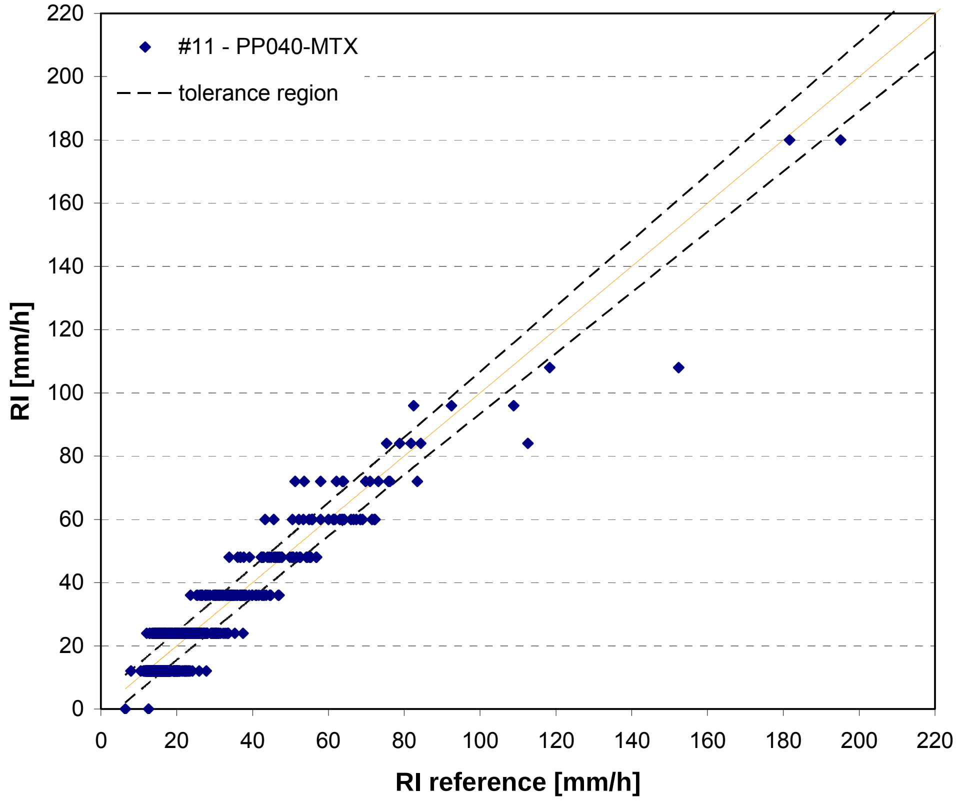
MTX s/n 07/074

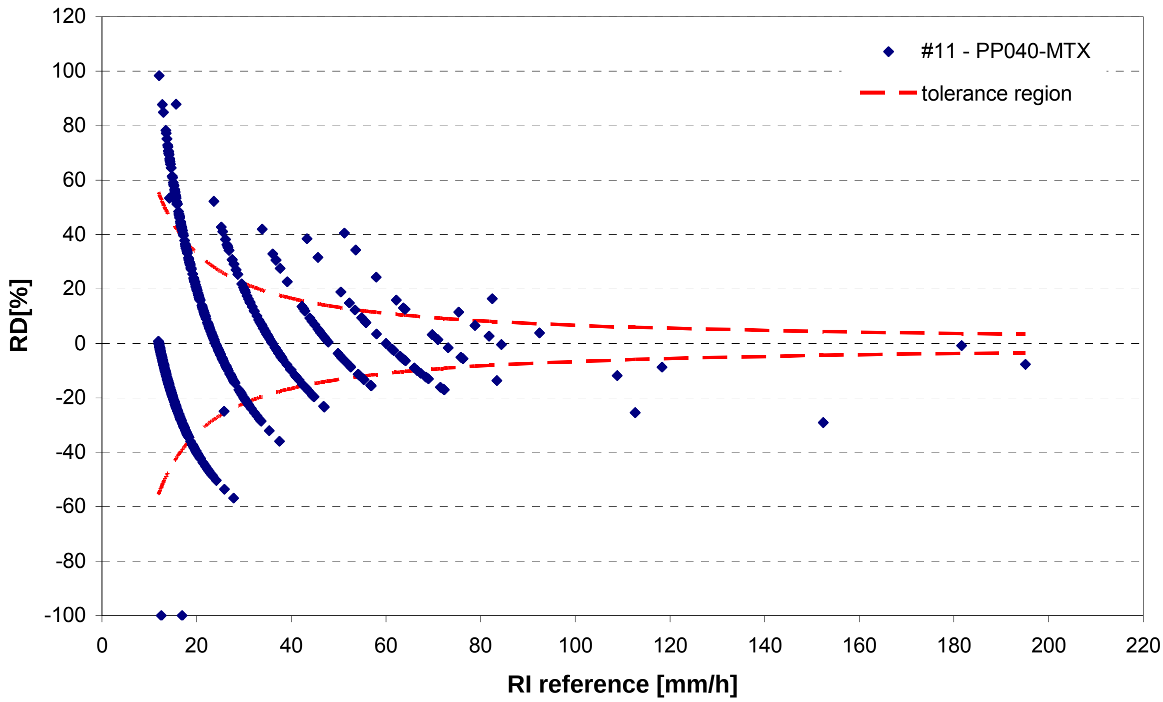
CALIBRATION	**1° 14/01/08**	**2° 08/05/08**	**3° 22/04/09**
RI ref [mm/h]	160.5	132.0	142.2
AVG RE [%]	-12.8	-9.5	-11.9
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-16.8,-8.7]	[-11.9,-7.0]	[-14.0,-9.7]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%

Field Intercomparison Measurements

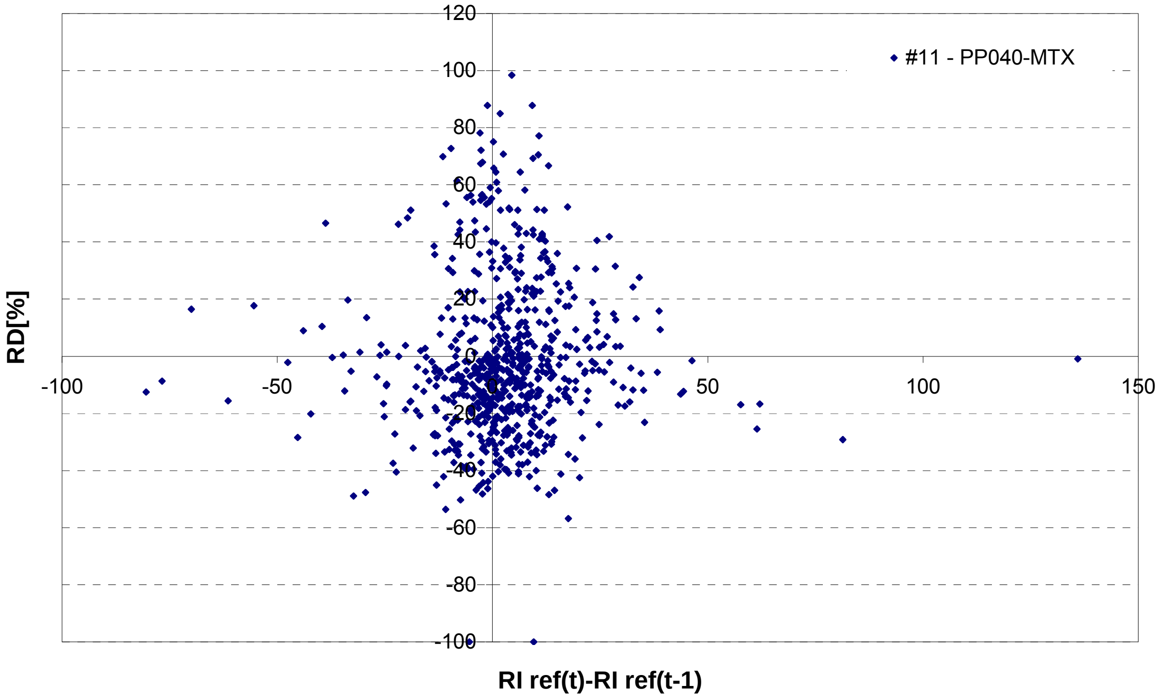
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by PP040-MTX and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5-3-3.*



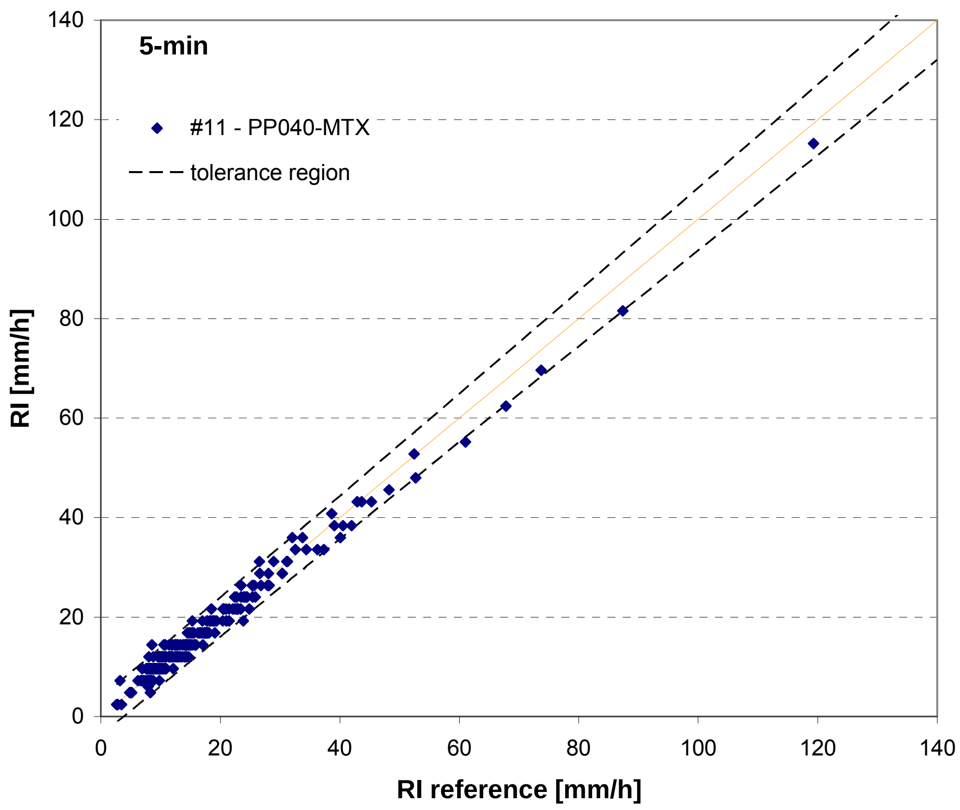


(Relative difference: RD=100(RI-RI$_{ref}$)/RI$_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by PP040-MTX and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters *($RI=a\cdot(RIref)^b$)*	a	b	R^2
#11 PP040 MTX	0.96	1.0	0.79

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The laboratory calibration for constant flows shows an average underestimation with high RI (from 50 mm/h up to 200 mm/h for MTX), typical of uncorrected TBRGs. The field calibrations give consistent results with the laboratory calibration: underestimation increasing with RI. No drift detected from the field calibration. Storage occurred in the funnel for RI = 280 mm/h during laboratory calibration.

The field results show a small overestimation for 20 mm/h < RI < 70 mm/h, unexpected from the laboratory calibration. For 70 mm/h < RI < 160 mm/h the underestimation is consistent with the calibration and for the experimental points above 180 mm/h the underestimation is less then -10%, unexpected from the laboratory calibration.

The 5 min scatter plot reduces noise significantly and provides a smaller underestimation.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*

No diagnostic data and error code.

Data availability (1 min):

- Valid Data: 100%.

Maintenance:

- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust; cleaning of the inside of bucket as recommended by Manufacturer.

Malfunctioning:

- None.

ARG100-EML
- Brazil/UK -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Tipping bucket without correction.
- Collector area: 500 cm^2
- Range of measurement : *not available*
- 1-minute resolution: 12 mm/h

Data output

- Output: Passive Reed Switch.
- Data update cycle: 10 s (Data Acquisition System sampling time).
- Rainfall parameters: Rainfall accumulation (RA [mm]).
- Transfer function for 1-min RI: RI_{1min}[mm/h] = $pulses_{1min}$ 12[mm/h] ($pulses_{1min}$ =number of pulses of reed switch in 1 minute; 1 pulse = 0.2 mm)

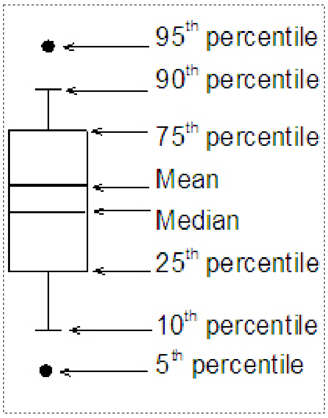
#12 ARG100 – EML in the field

Laboratory test

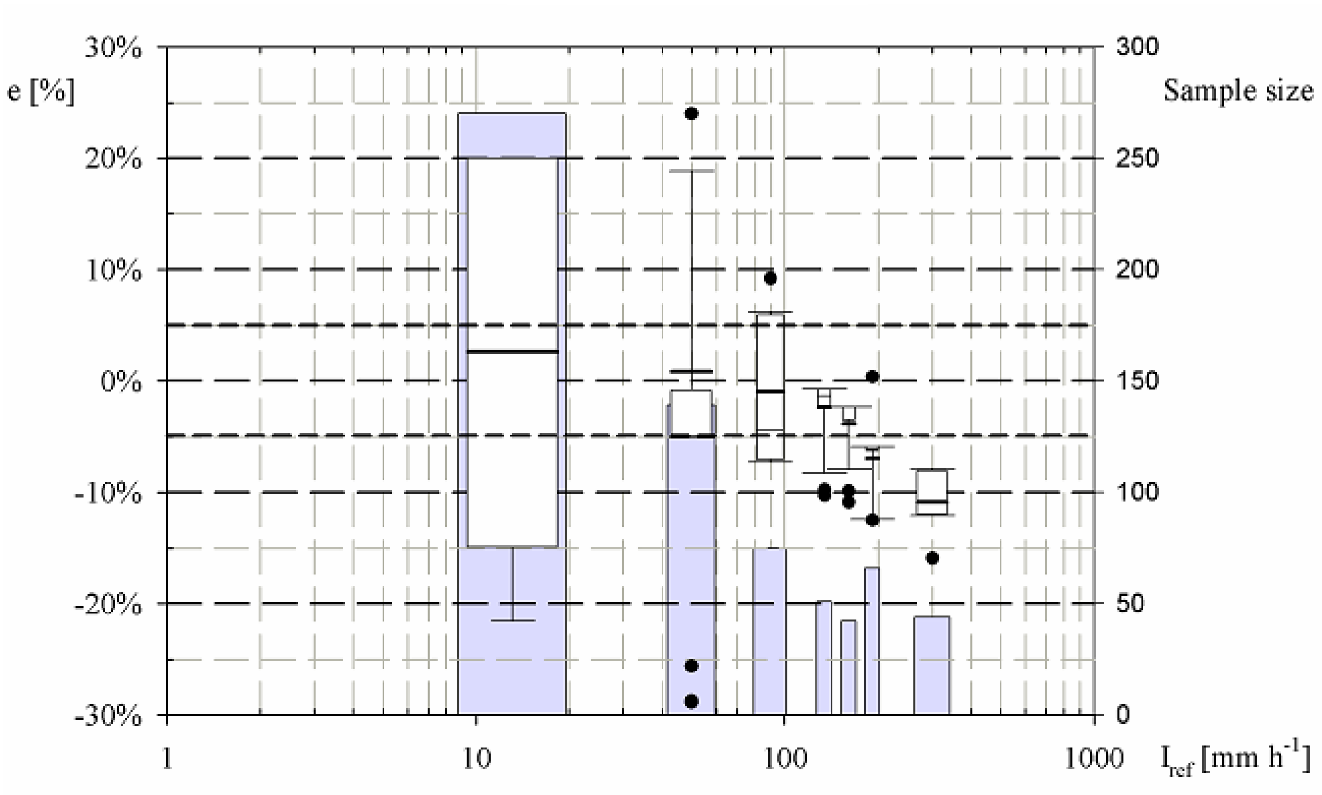
The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute 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.



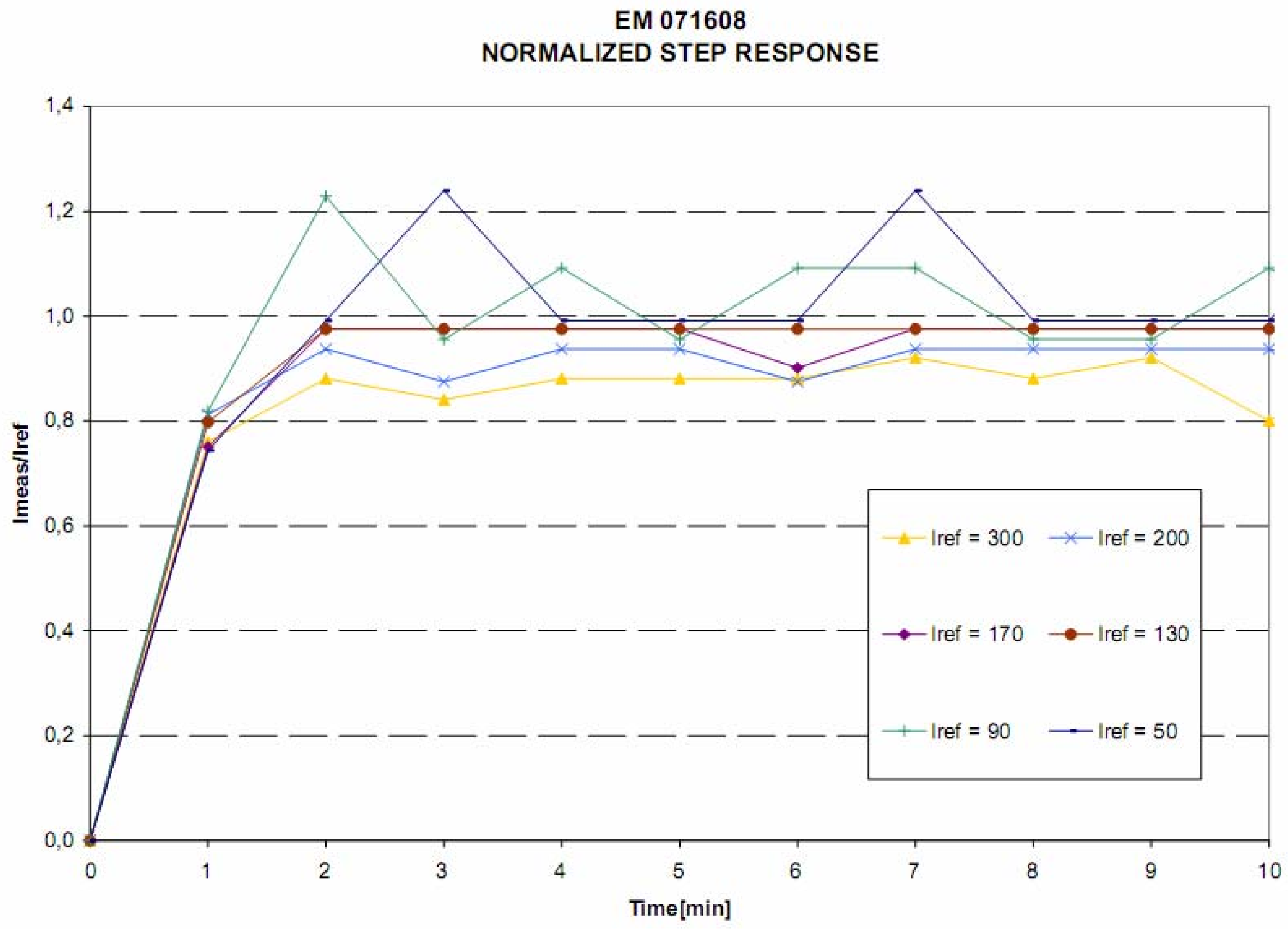
EM ARG100 71608



Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.

The “saw” response is mainly due to the measurement resolution.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

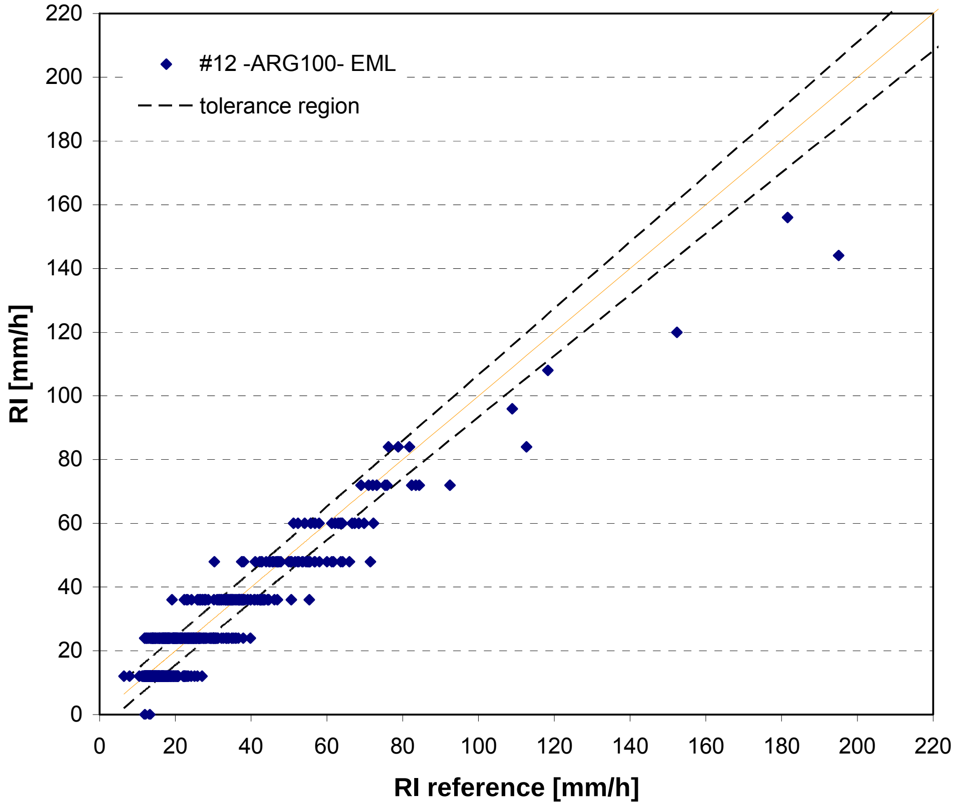
ARG100 EML s/n 071608

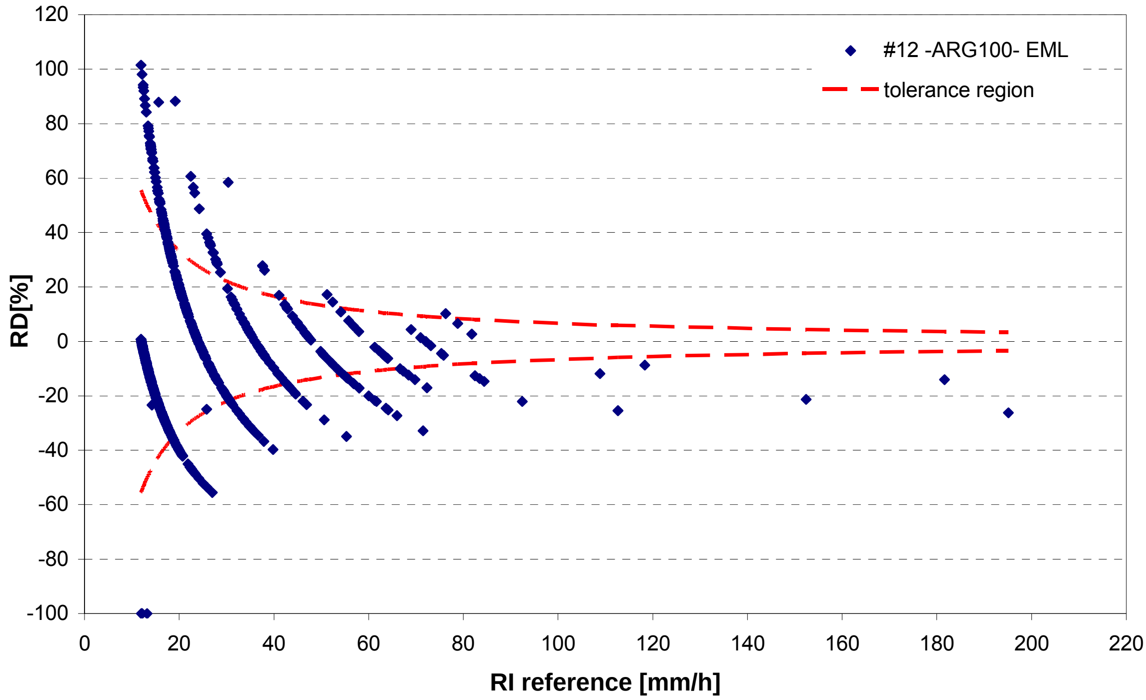
CALIBRATION	**1° 11/12/07**	**2° 27/05/08**	**3° 22/04/09**
RI ref [mm/h]	198.4	128.4	117.6
AVG RE [%]	-7.5	-4.0	-1.7
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-9.2,-5.9]	[-5.9,-2.1]	[-3.2,-0.2]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%).

Field Intercomparison Measurements

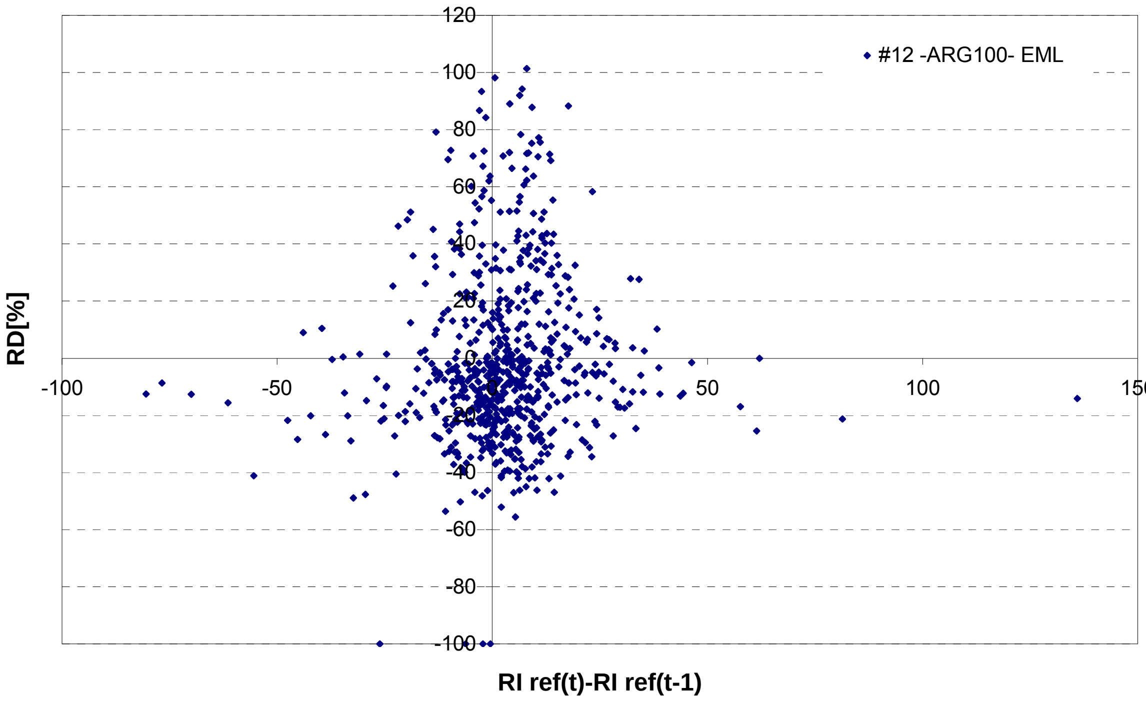
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by ARG100 EML and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



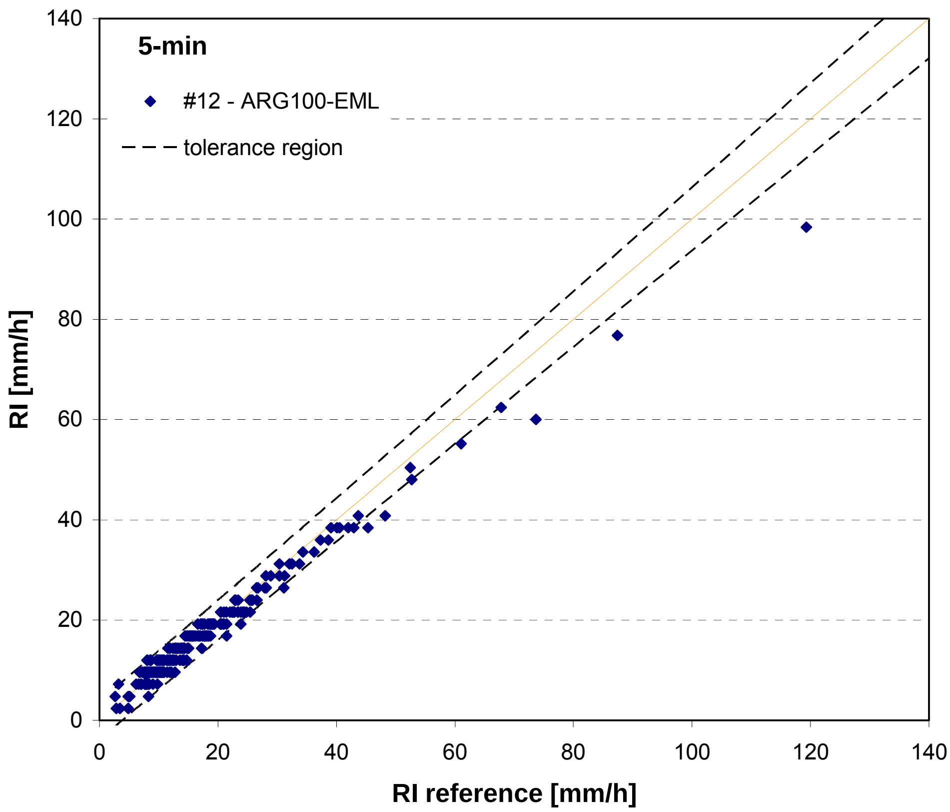


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by ARG100 EML and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ***($RI=a\cdot(RIref)^b$)***	**a**	**b**	**R^2**
#12 **ARG100 EML**	1.21	0.92	0.75

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The laboratory calibration for constant flows shows an average underestimation with high RI (from 90 mm/h for EM ARG100), typical of uncorrected TBRGs. The field calibrations give consistent results with the laboratory calibration: underestimation increasing with RI. No drift detected from the field calibration.

The field results show an underestimation consistent with the calibration results, except for few experimental points above 90 mm/h with underestimation close to -20% or more, unexpected from laboratory calibration.

The 5 min scatter plot reduces noise significantly and provides a smaller underestimation.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
No diagnostic data and error code.

Data availability (1 min):

- Valid Data: 100%.

Maintenance:

- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust; cleaning of the inside of bucket as recommended by Manufacturer.

Malfunctioning:

- None.

MRW500-METEOSERVIS
- Czech Republic -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: weighing rain gauge (strain gauge) equipped with two rain detectors (hardware and software for best accuracy in non-standard precipitation conditions) and automatic emptying system (fluids are transferred from upper vessel to lower-accumulator vessel via pumps; increased accumulation capacity).
- Collector area: 500 cm^2
- Range of measurement : 0 -400 mm/h
- 1-minute resolution: 6 mm/h

Data output

- Output: data message with serial interface RS232 in binary code (Polling mode) or pulse output (switching semiconductor).
- Data update cycle: 10s (Data Acquisition System sampling time).
- Rainfall parameters: precipitation operating value "Ov" (upper vessel total weight in unit 0.1mm); "Iv" instant level (*immediate measured value of weight in [mm]*); "Av" average level (*average value of the more measured "Iv" in [mm]*);
- Transfer function for 1-min RI: RI_{1min}[mm/h] = RA_{1min}[mm]/[min]*60[mm/h],

Where $RA_{1min}[mm] = (Ov^{60}_{10sec} – Ov^{00}_{10sec})*0.1[mm]$ and Ov^{60}_{10sec} and Ov^{00}_{10sec} are the 10sec-operating values respectively sampled at the beginning (00) and at the end (60) of each minute.

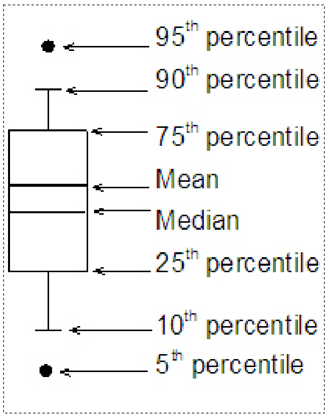
#13-MRW500 - METEOSERVIS in the field

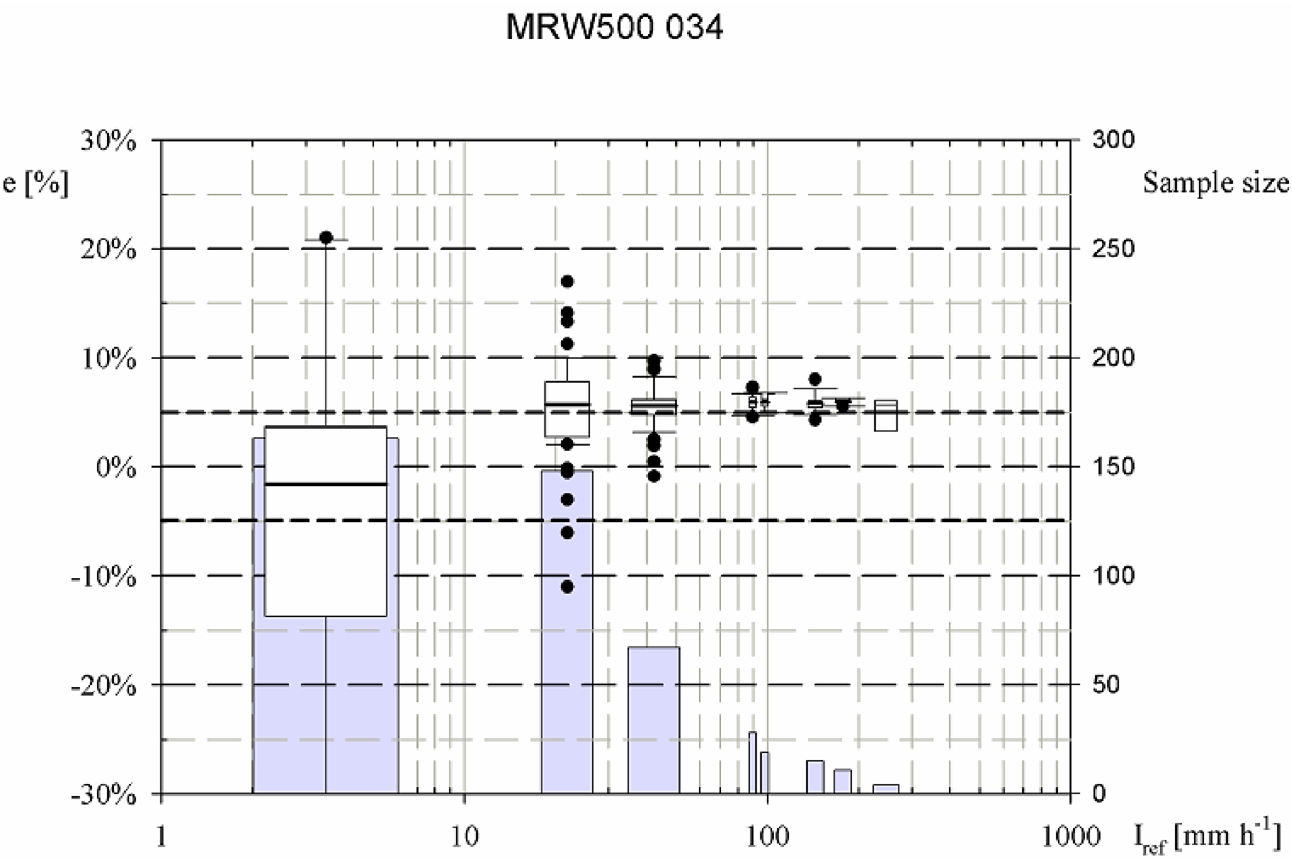
Laboratory test

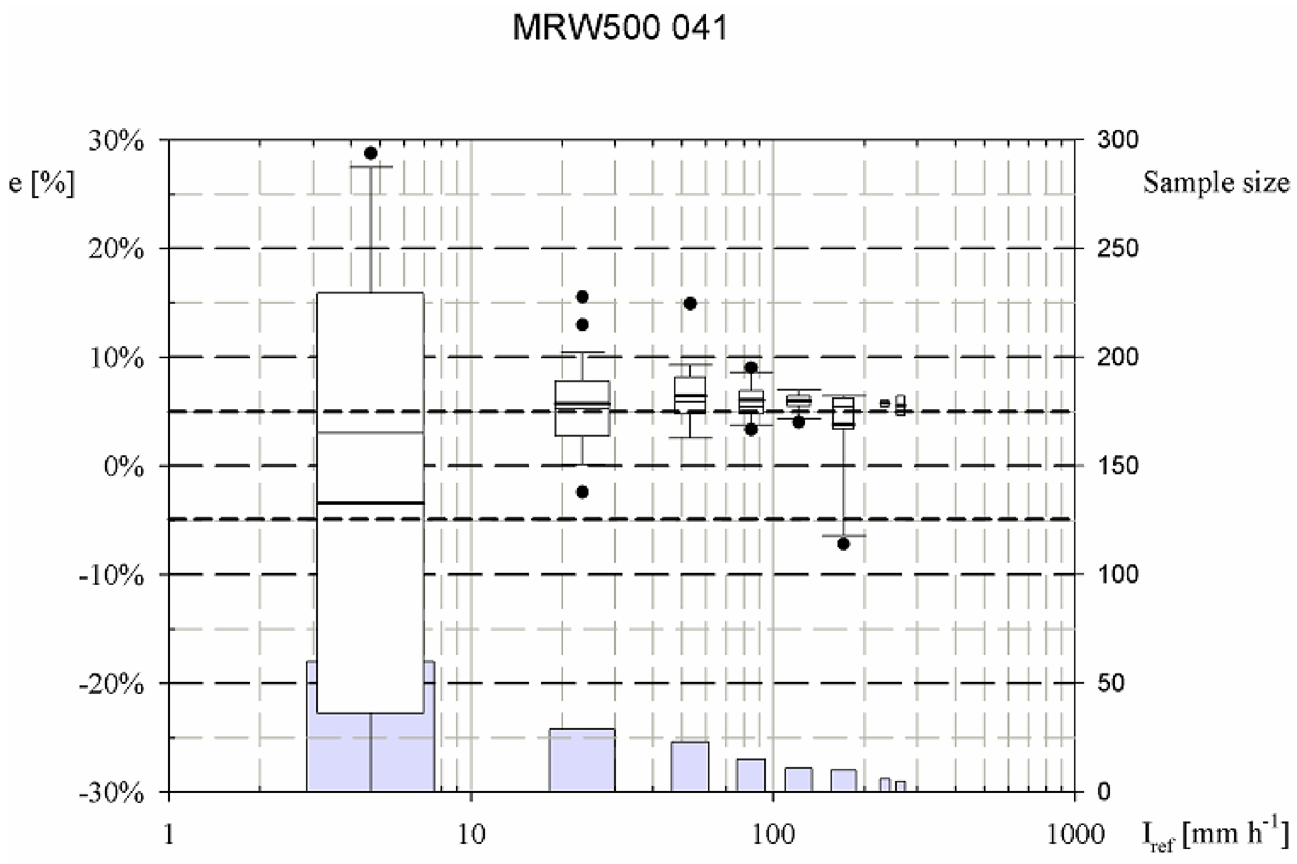
The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute 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.





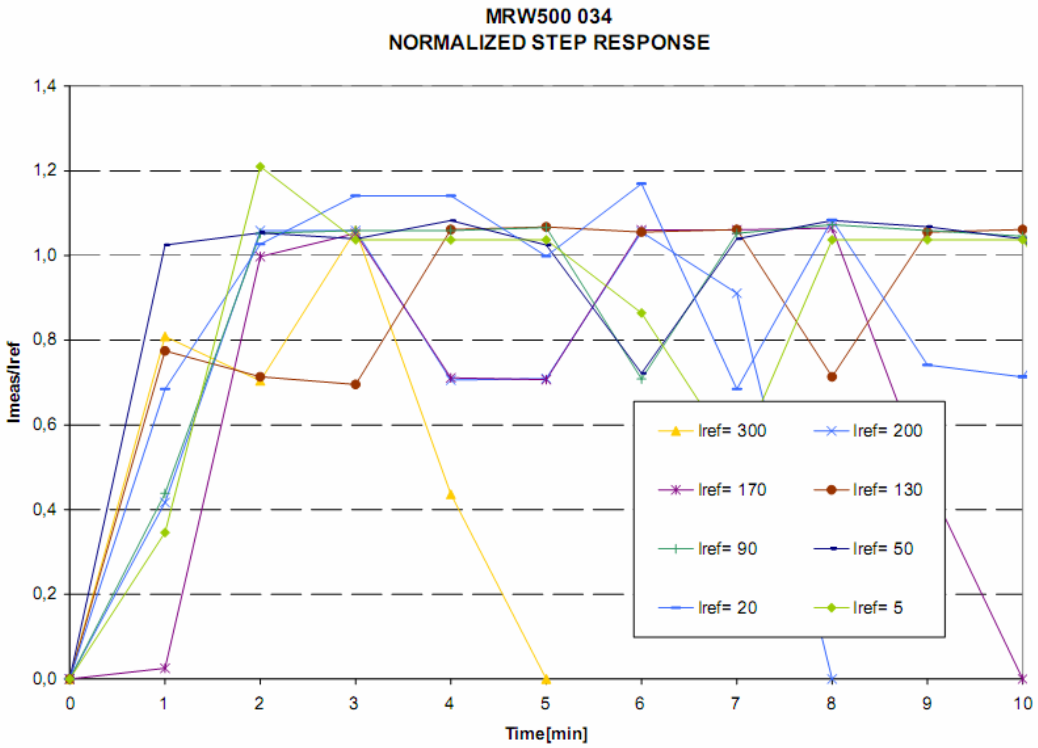


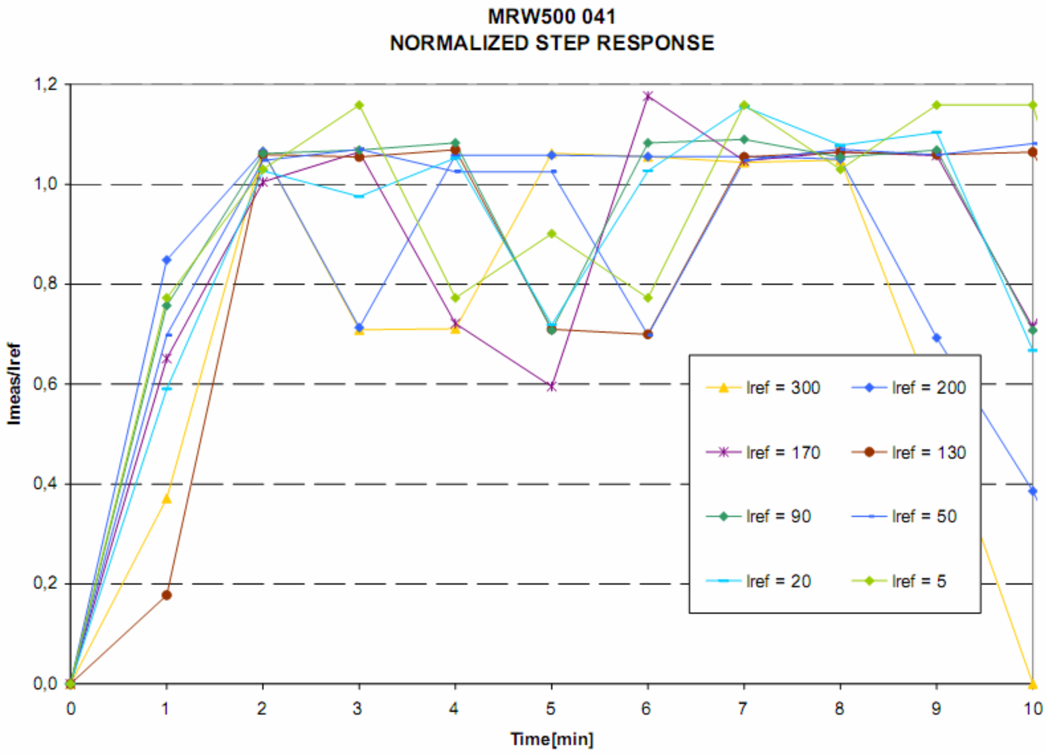
MRW500 041
e [%]
30%
20%
10%
0%
-10%
-20%
-30%
300
Sample size
250
200
150
100
50
0
1
10
100
1000
I_{ref} [mm h^{-1}]

Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.

The "saw" response is mainly due to the measurement resolution and to an oscillating step response.





Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

Meteoservis MRW500 s/n 41

CALIBRATION	1° 14/01/08	2° 26/05/08	3° 24/04/09
RI ref [mm/h]	209.0	114.0	123.3
AVG RE [%]	2.6	-0.3	1.6
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-3.2, 8.3]	[-6.3, 5.7]	[-1.9, 5.1]

Results

Meteoservis MRW500 s/n 34 (pit gauge before 12/11/2008)

CALIBRATION	1° 14/01/07	2° 27/05/08	
RI ref [mm/h]	209.0	133.3	
AVG RE [%]	1.5	0.1	
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-4.8, 7.7]	[-7.8, 8.0]	

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%)

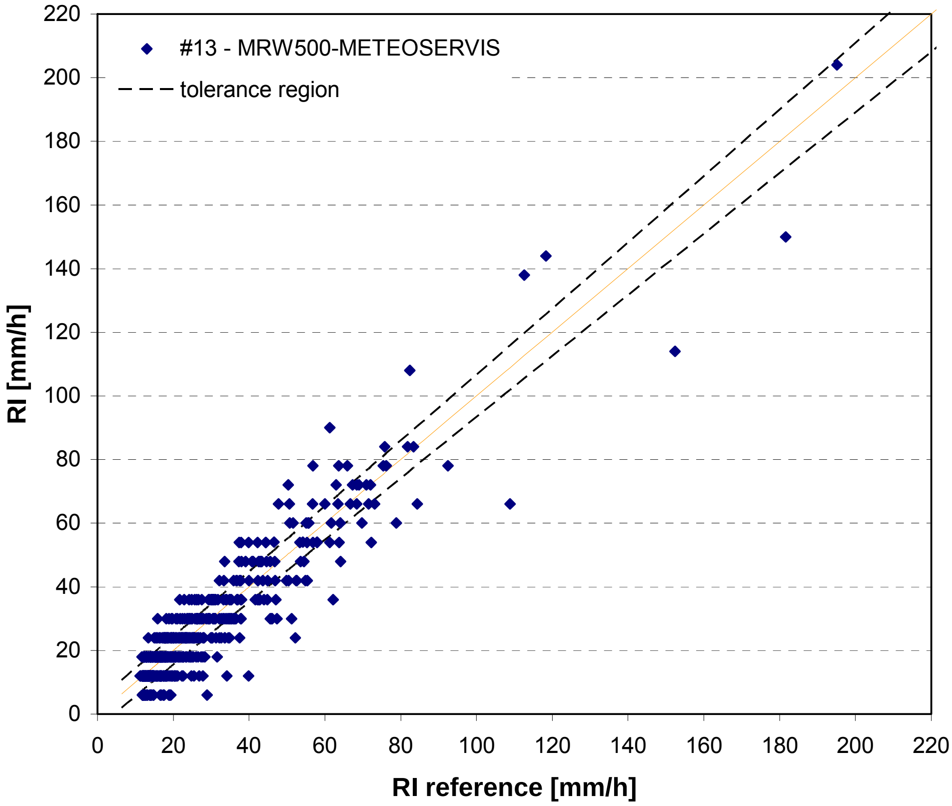
Comments

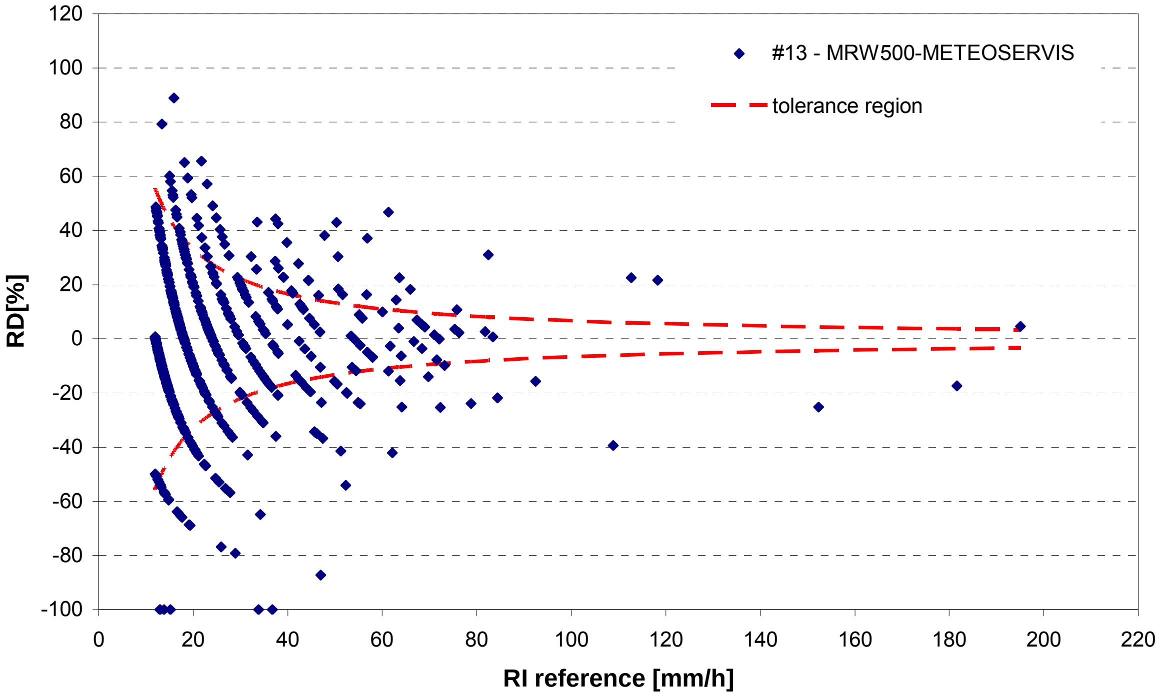
- Field calibrations confirmed that MRW500-METEOSERVIS gauge, which is always synchronized, has an anomalous behaviour due to 1 minute oscillating step response (*for details see Final Report, sec.5.3.1, and sec.4.2 for laboratory tests*).

<u>*Field Intercomparison Measurements*</u>

<u>*(MRW500 s/n 41)*</u>

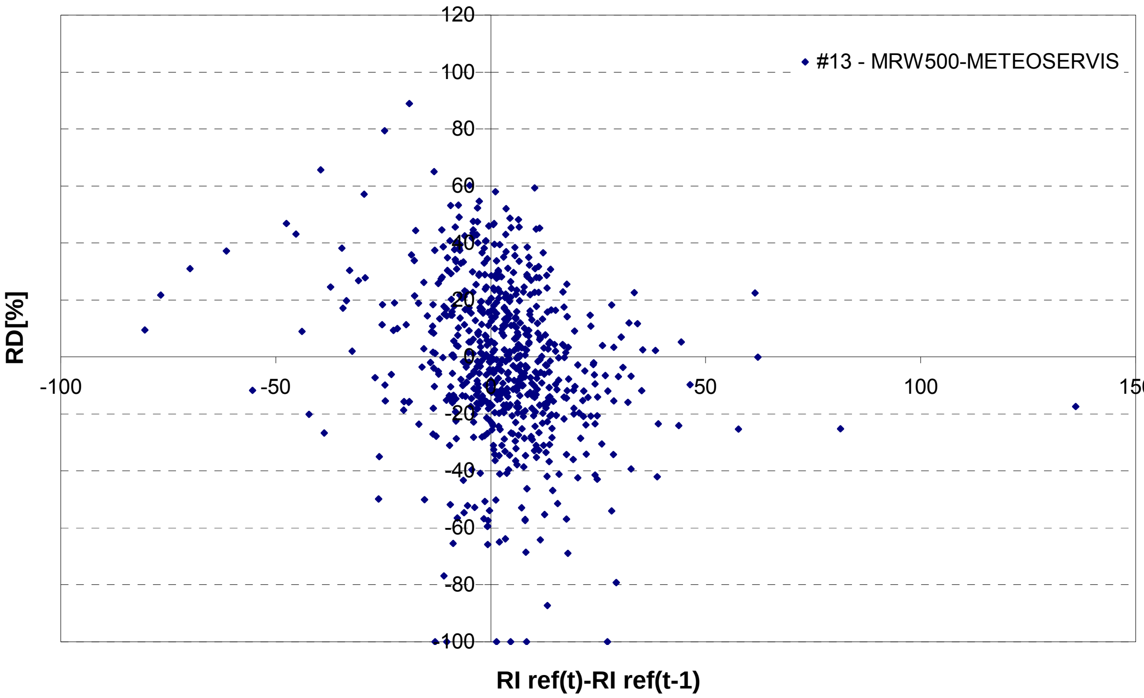
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by MRW500 METEOSERVIS and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



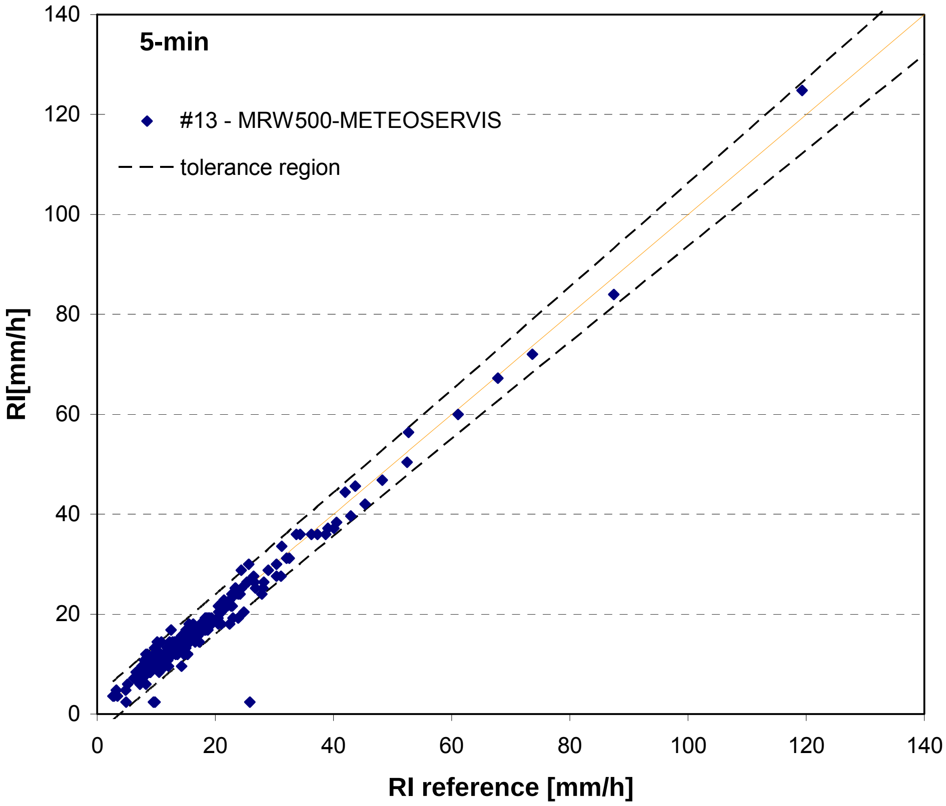


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t\text{-}1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by MRW500 METEOSERVIS and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ***($RI=a\cdot(RIref)^b$)***	**a**	**b**	**R^2**
#13 MRW500 METEOSERVIS	1.01	0.98	0.74

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The constant flow test shows constant overestimation of about 5%, although the linearity is very good. The field calibrations give consistent results with the laboratory calibration. No drift detected from the field calibration.
The step response test shows a fast response of the sensor, but with oscillating noise.
The field results show a large dispersion (noise), which is much reduced with 5 minutes data.
The RI variation response plot shows a tendency to underestimation for increasing RI values and to overestimation for decreasing RI values. This indicates the presence of an oscillating response in the sensor RI measurement (For details see Final Report, sec.5.3.1 and sec.4.2 for laboratory tests)

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
D1: Battery voltage
D2: Strain gauge temperature
D3: Temperature below upper vessel

Data availability (1 min):
- Valid Data (both rain gauges): 100%.
- Following the WMO ET/IOC decision (Vigna di Valle, 15-17 September 2008), the pit rain gauge (s/n 34) was disconnected and from 31/10/2008 the 1 minute data were not available any more (*For details see Final Report, sec. 5.3.1*).

Maintenance:
- Regular inspection (gauge, upper and lower vessels);
- Check of the upper vessel fluid level (water, antifreeze, oil) and regular refilling of silicon oil (to avoid evaporation);
- Calibration check by the RAIN-TEST program;
- Depending on local weather conditions: cleaning; removal of leaves, birds droppings and insects from upper vessel by the special sieve.

Malfunctioning:
- None.

VRG101-VAISALA
- Finland -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: weighing rain gauge
- Collector area: 400 cm^2
- Range of measurement : 0 -1200 mm/h
- 1-minute resolution: 0.1 mm/h

Data output

- Output: data message by serial interface RS485 in ASCII protocol - Automatic mode (every minute).
- Data update cycle : 1 min
- Rainfall parameters: minute rainfall intensity RI_{1min}[mm/h]; 1 minute rainfall accumulation RA_{1min}[mm]; 1; 1 minute basket total mass [g].
- Transfer function for 1-min RI: none.

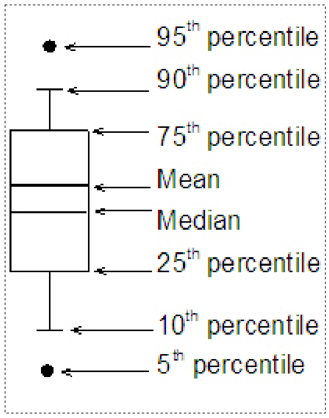
#14-VRG101 - VAISALA in the field

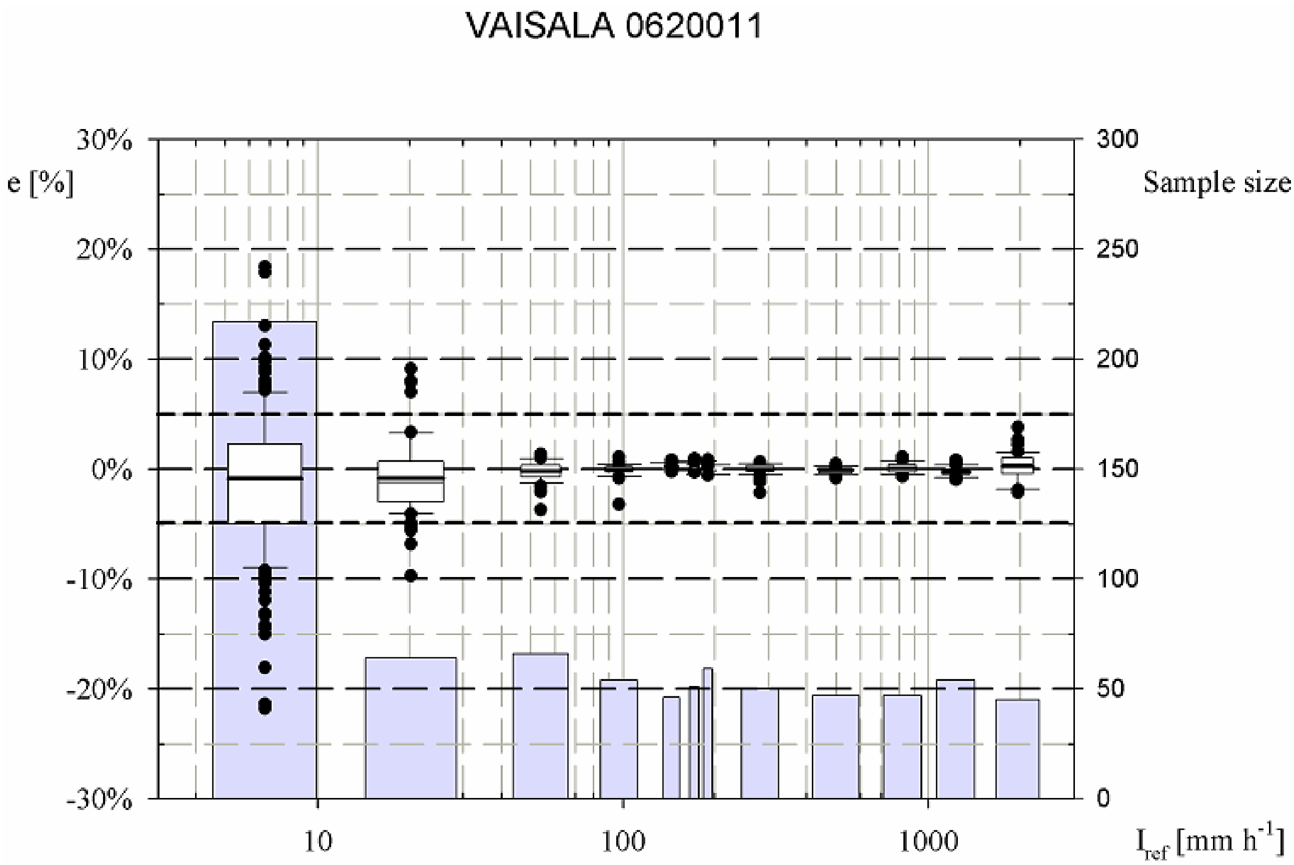
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

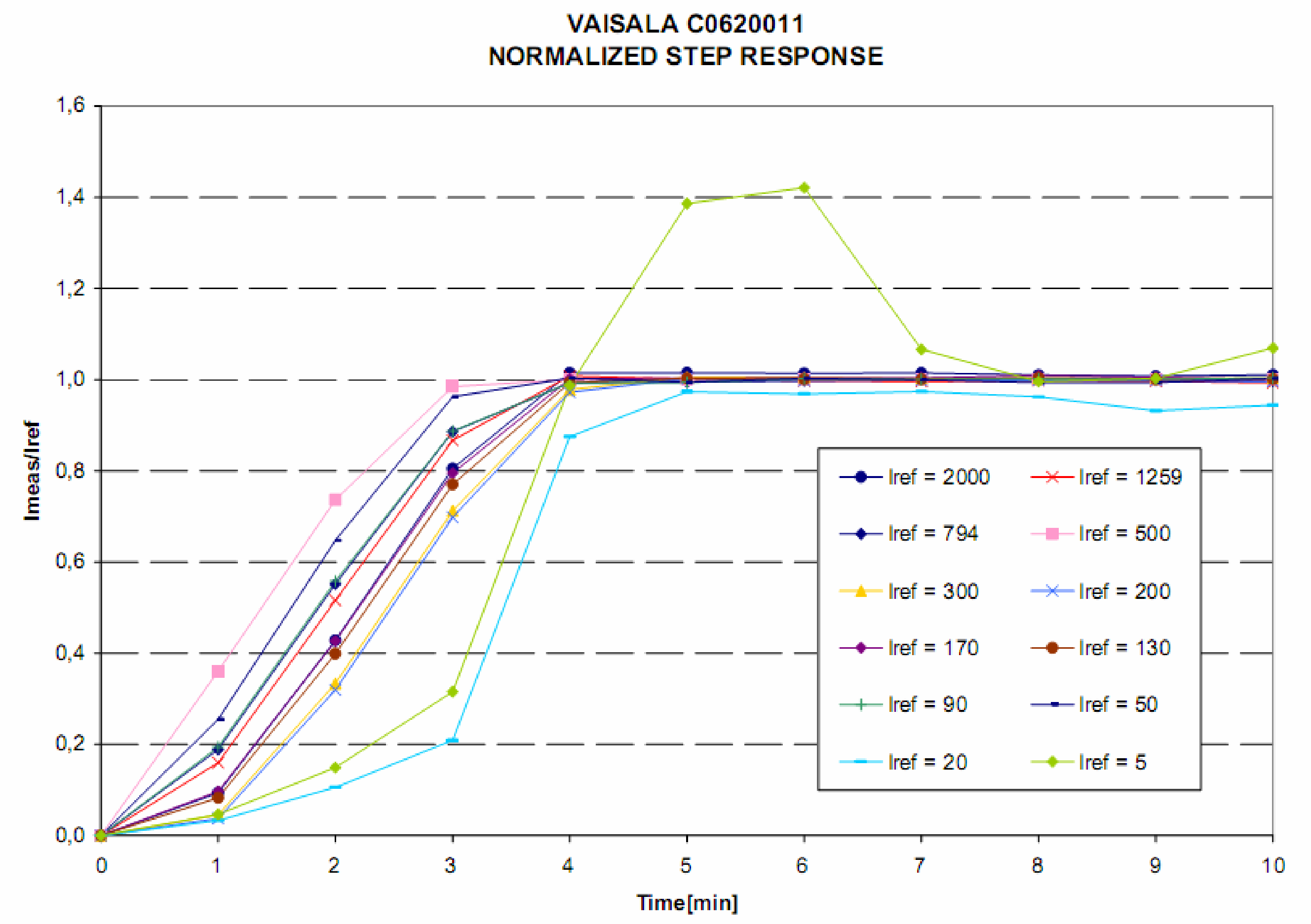
The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute variability of the observed instruments performances and the size of the sample used for calculation of the statistics at each reference intensity. Box plots synthetically 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.





Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

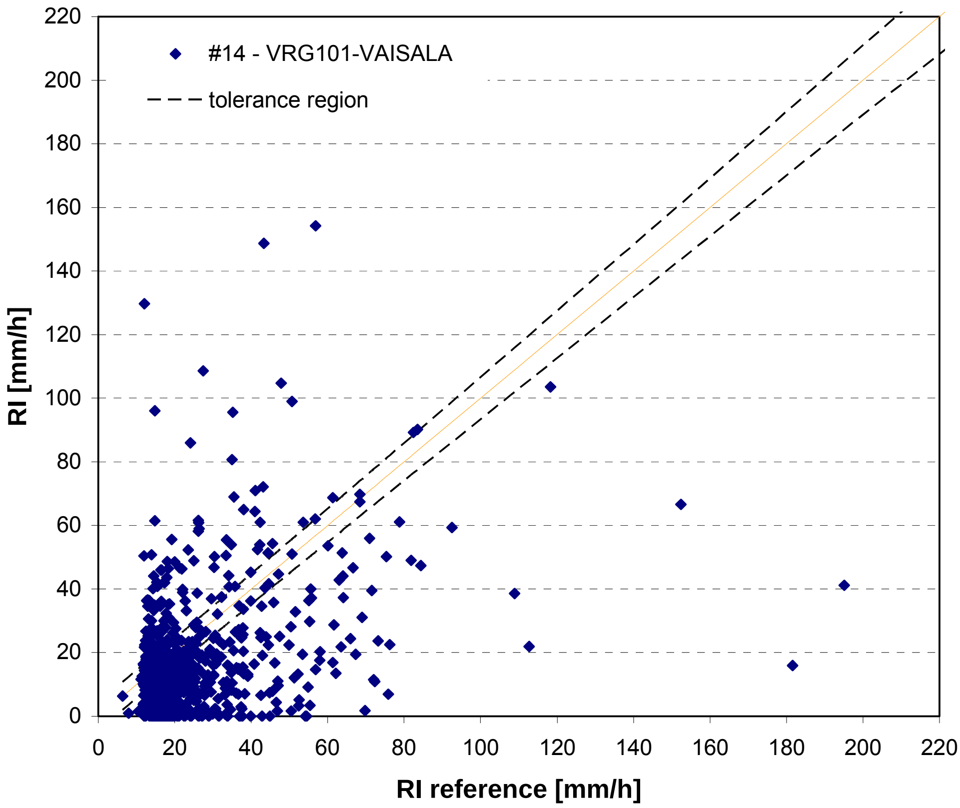
Vaisala VRG101 s/n C0620011

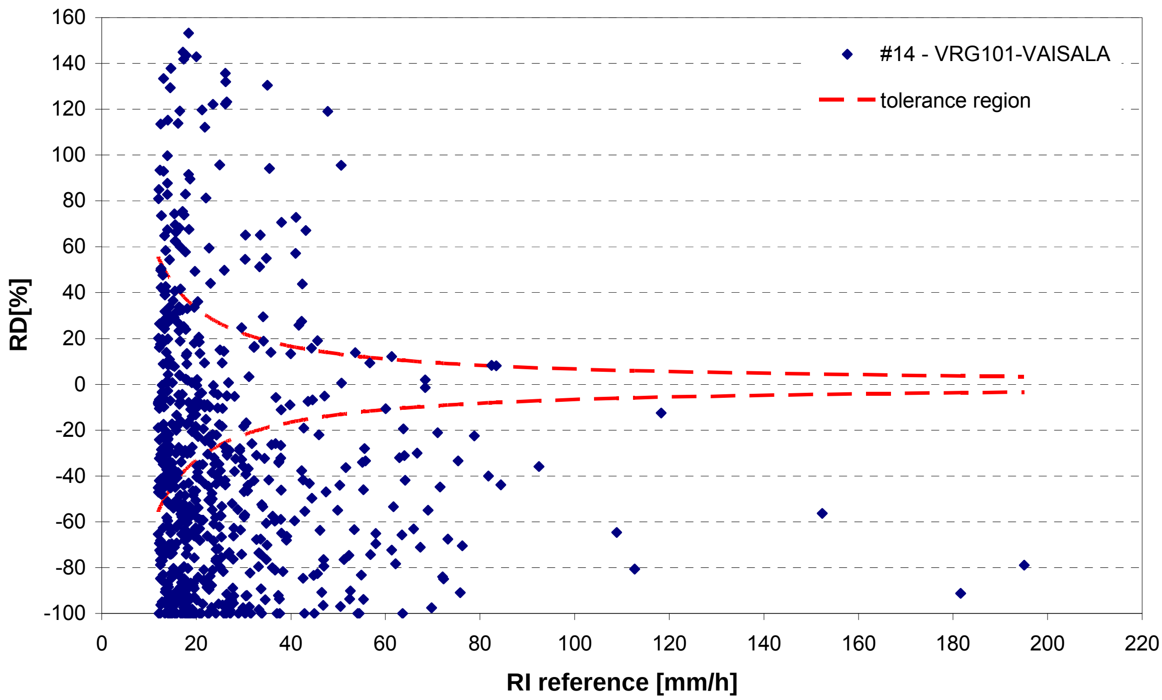
CALIBRATION	**1° 11/12/07**	**2° 17/04/08**	**3° 20/04/09**
RI ref [mm/h]	227.4	135.2	144.2
AVG RE [%]	0.2	-0.4	-0.8
[RE(-C.L.95%),RE(+C.L.95%)][%]	[0.1, 0.4]	[-0.6, -0.2]	[-1.0, -0.5]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%)

Field Intercomparison Measurements

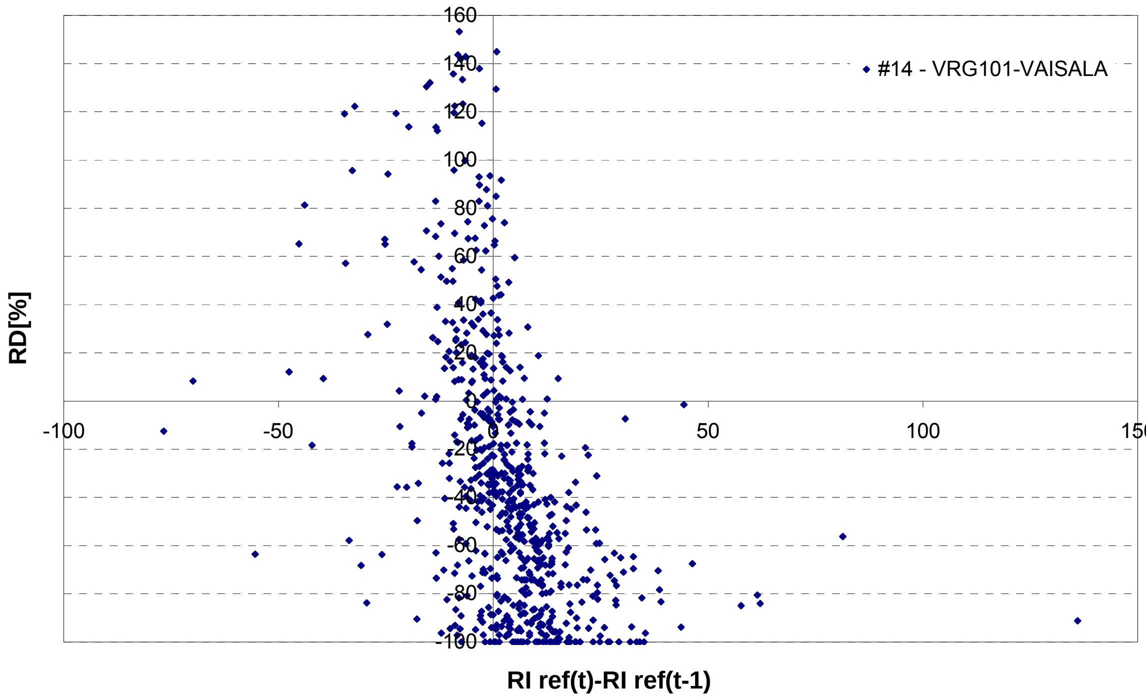
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by VRG101 VAISALA and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



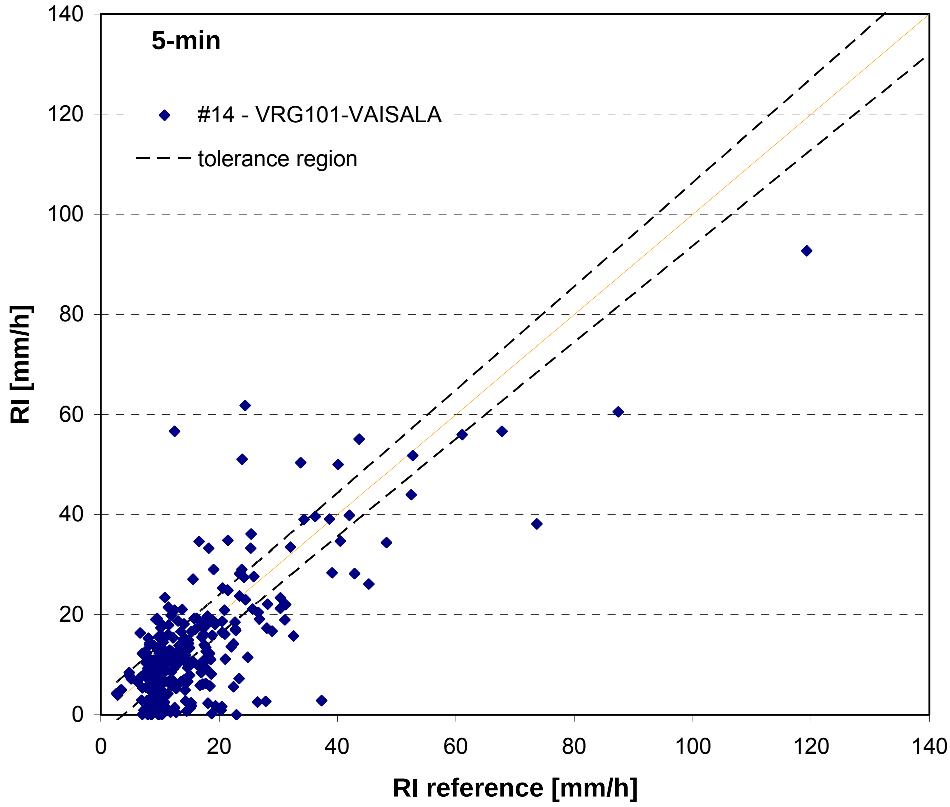


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by VRG101 VAISALA and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ***($RI=a\cdot(RIref)^b$)***	**a**	**b**	**R^2**
#14 VRG101 VAISALA	1.12	0.75	0.12

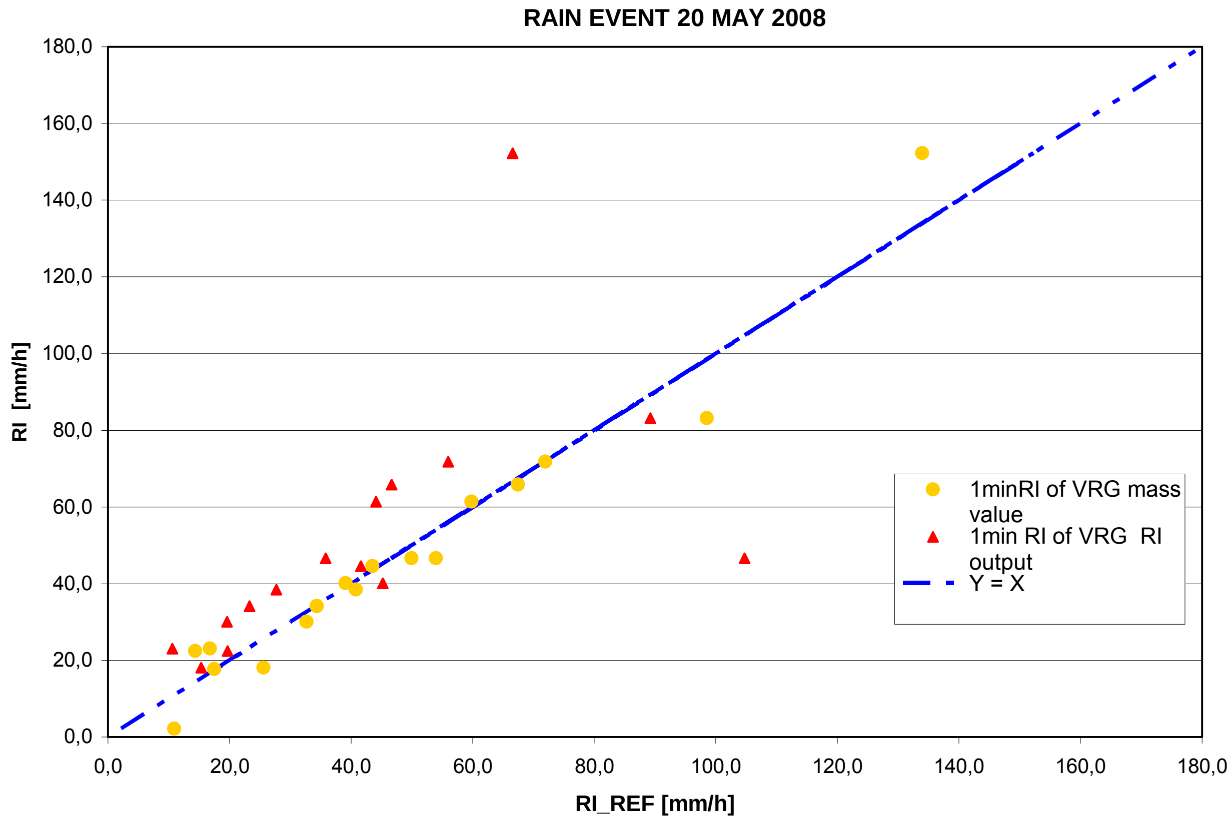
(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

Excellent accuracy in constant flow conditions with respect to linearization and noise above 50 mm/h. For lower intensities the linearization remains stable but the noise is increased (outliers above 10-15% relative errors). The laboratory results are also confirmed by field calibrations. No drift detected from the field calibration.

The RI variation response plot shows a clear underestimation for increasing RI values and an overestimation for decreasing RI values. This is due to the delay in the sensor response, delay of about 3 minutes, seen in the step response. Dynamic filtering leads to a variable and unpredictable step response and thus to unreliable 1 min RI values. The application of dynamic filtering seems to be depending on the reference RI. Even the 5 min averages show by far too large deviations from the reference RI. The variation response plot clearly reveals that the gauges is not able to follow even smaller variations of RI, resulting in too low values with increasing RI and too high values with decreasing RI.

The raw mass data are available for further post processing.The following plot (referred to the rain event occurred on May the 20th 2008) is provided to show that if the 1 min RI is calculated from the raw mass values [g] reported every minute (not averaged and not filtered raw output), the achievable accuracy of VRG101 is improved. The disadvantage is that the negative mass fluctuations (negative RI values) due to the impact of droplets on water surface are not automatically filtered out and the 1 min RI could be not properly calculated (in the example, filtering and synchronization were performed manually).



(1min RI of Vaisala VRG through mass value (orange circles) and through RI output (red triangles) are plotted versus the 1min REFERENCE RI. The Y=X line is reported to compare the results).

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*

D1: Status parameter (processed by the automatic QC)

If D1= 002 , 003 , 004 ,012 , 013 , 014 ,210 , 212
213, 214 , 200 , 202 , 203 , 204 → Doubtful

If D1=220 , 221 , 222 ,223 , 224 , 201 , 211 , 011
020 ,021 , 022 , 023 ,024 , 001, 1## → Error

D2: CPU - temperature

D3: Battery Voltage (power supply)

Data availability (1 min):

- Valid Data: 98.9%: the time of VRG data output telegram is characterized by a continuous delay of 0.625 seconds every 1 minute compared to the datalogger clock of the DAQ (nominal timestamp). This time shift leads to a lack of about 15 output telegrams per day

(0.625s*1440minutes/day = 900/60 = 15), in other words data are updated every 1,0104 minutes with respect to the nominal timestamp (other automatic gauges reported a typical shift of max 4 seconds per day = 0.0028sec/min): this delay could not be reduced by a polling procedure and a proper synchronization was not possible for the purposes of the field intercomparison. This characteristics must not be considered as a malfunctioning.

Maintenance:

- Regular inspection and powering check;
- Basket manual emptying when necessary and cleaning;
- Depending on local weather conditions: removal of dirt, leaves, birds droppings and insects from water surface.

Malfunctioning:

- The VRG101 gauge gave rare false reports of precipitation in dry conditions but with very small quantities.

PLUVIO OTT
- Germany -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: weighing rain gauge
- Collector area: 200 cm^2
- Range of measurement : 0-1800 mm/h
- 1-minute resolution: 0.1 mm/h

Data output

- Output: data message by serial interface RS485 in ASCII protocol - Polling mode (every minute). (*Firmware revision: 4.11*)
- Data update cycle : 6 s
- Rainfall parameters (the most important): 1 minute RI (real time precipitation intensity with threshold ≥ 4.2mm/h, it is a running average updated every 6s); non-real-time precipitation intensity (filtered output with a constant delay of 336s to calculate precise accumulated precipitation amounts);
- Transfer function for 1-min RI: none.

PLUVIO - OTT in the pit
(From 03/02/09 as #29)
(s/n 220332)

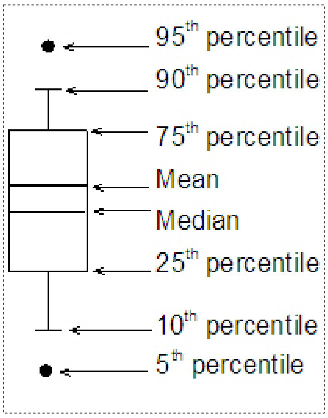
#15 PLUVIO - OTT in the field (s/n 2203331)

Laboratory test

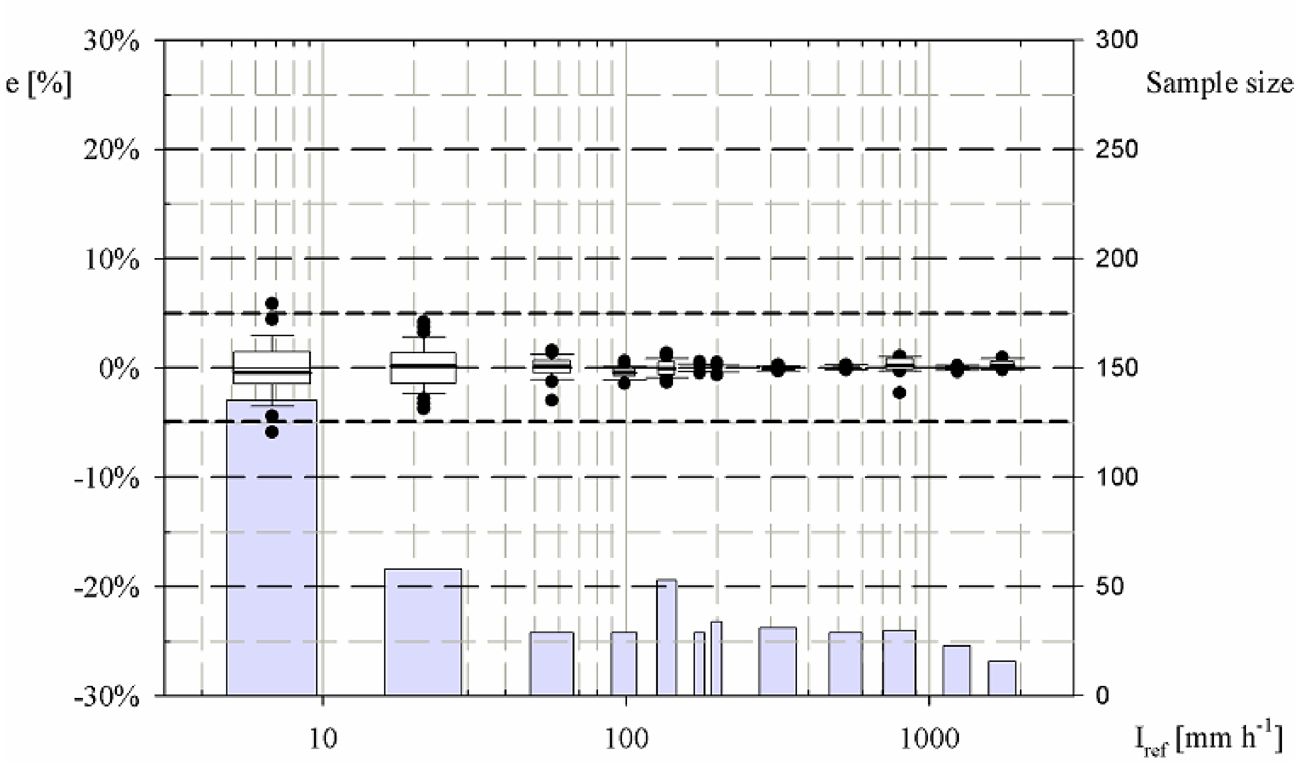
The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

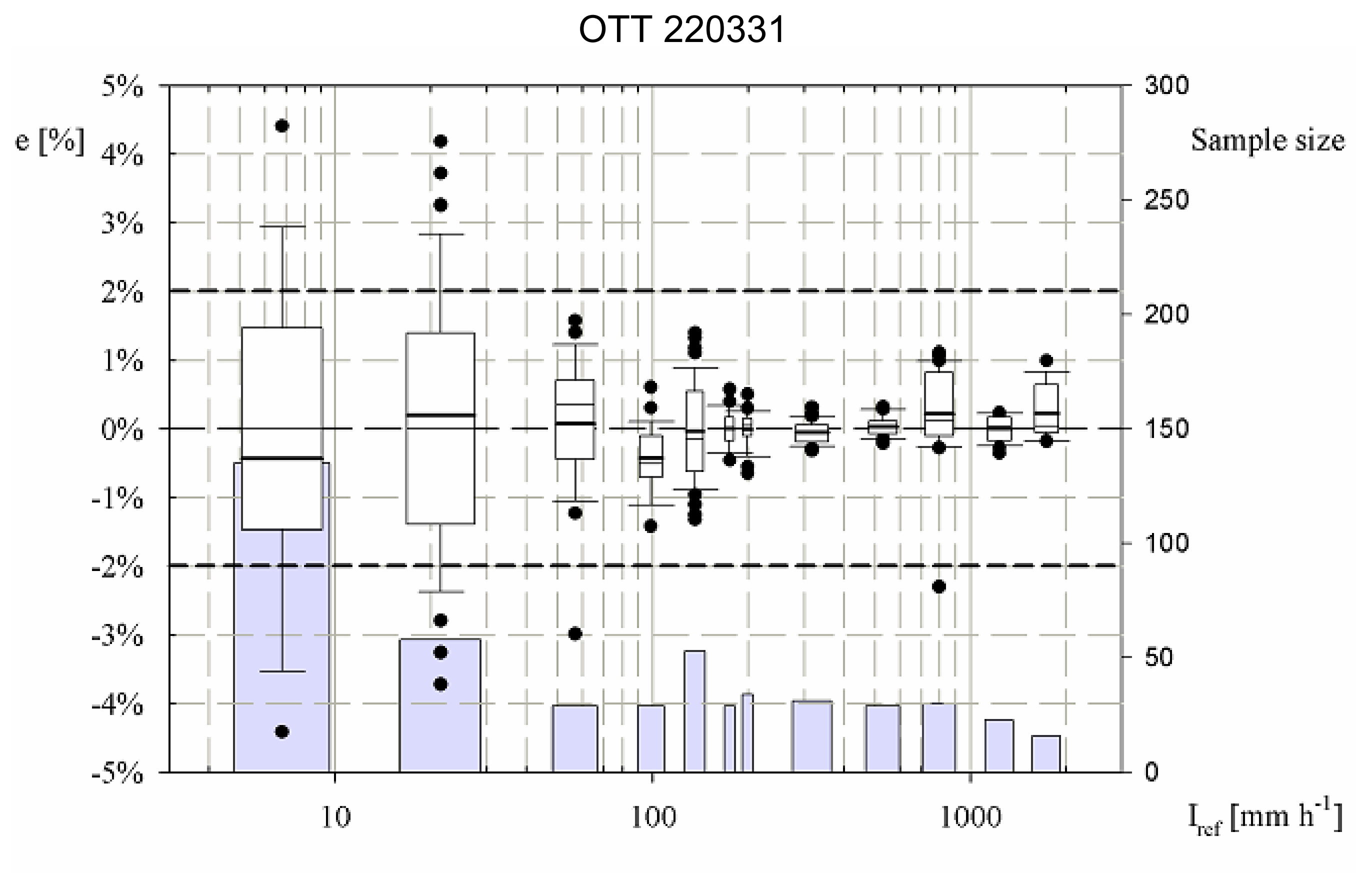
Constant flow response

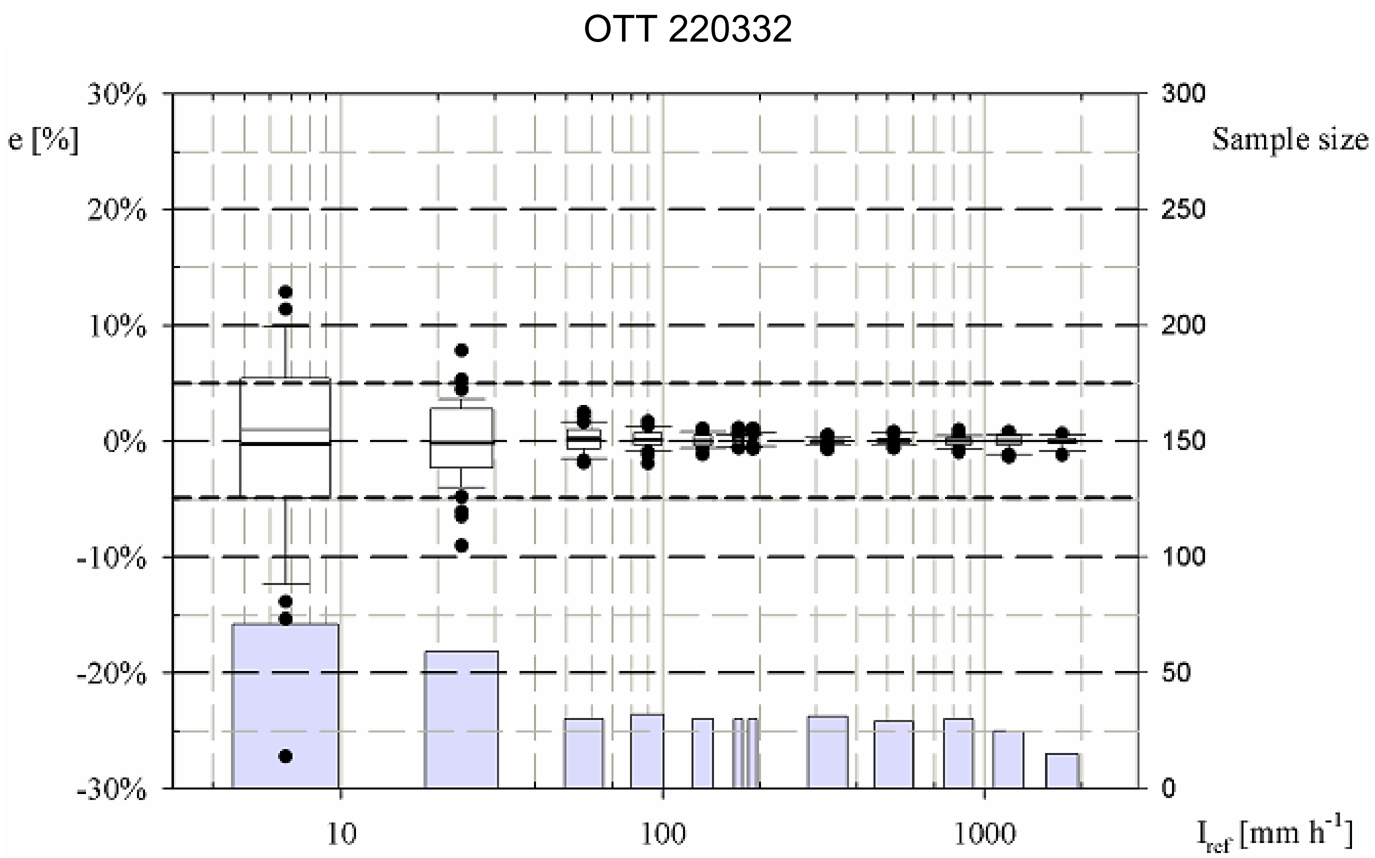
The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute variability of the observed instruments performances and the size of the sample used for calculation of the statistics at each reference intensity. Box plots synthetically 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.



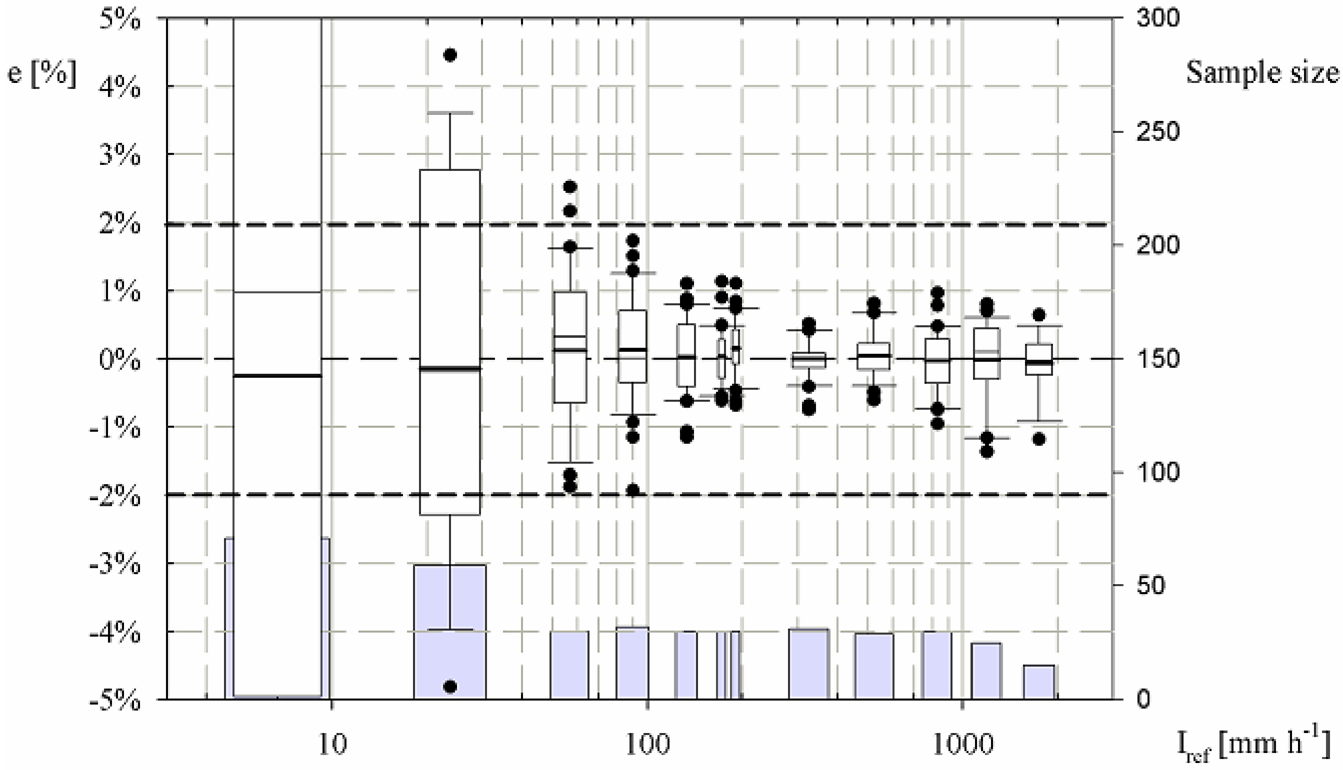
OTT 220331




OTT 220331
e [%]
5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
10
100
1000
300
250
200
150
100
50
0
Sample size
I_{ref} [mm h^{-1}]


OTT 220332
e [%]
30%
20%
10%
0%
-10%
-20%
-30%
10
100
1000
300
250
200
150
100
50
0
Sample size
I_{ref} [mm h^{-1}]

OTT 220332

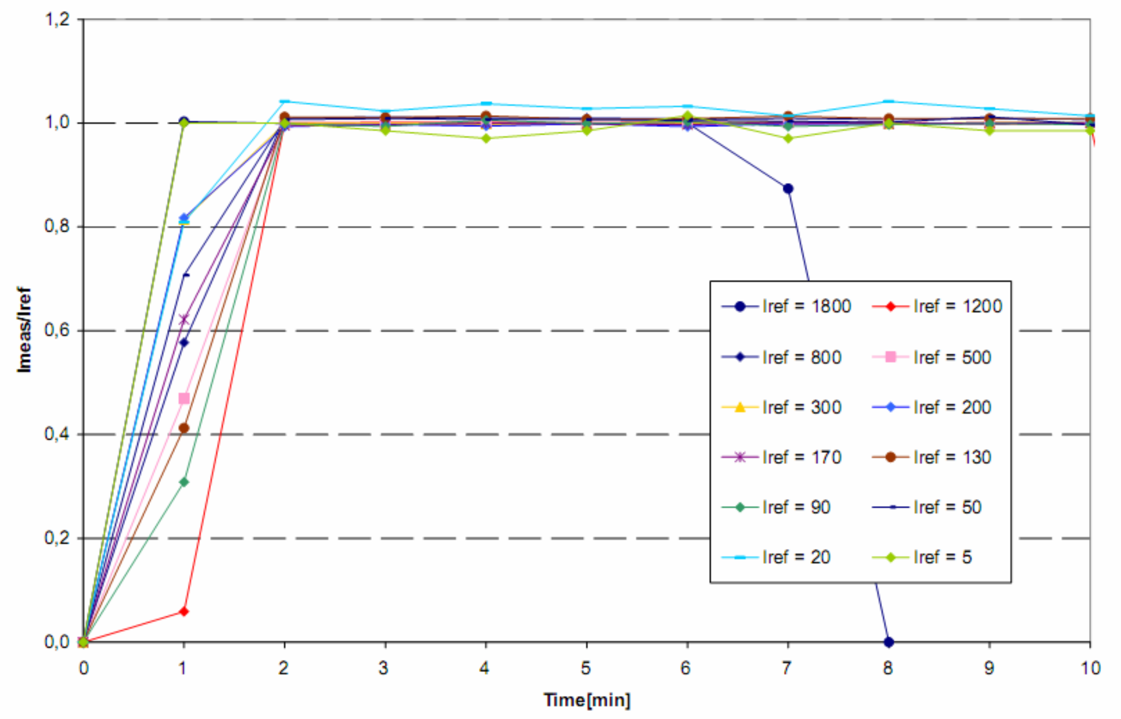


e [%]
5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
Sample size
300
250
200
150
100
50
0
10
100
1000
I_{ref} [mm h^{-1}]

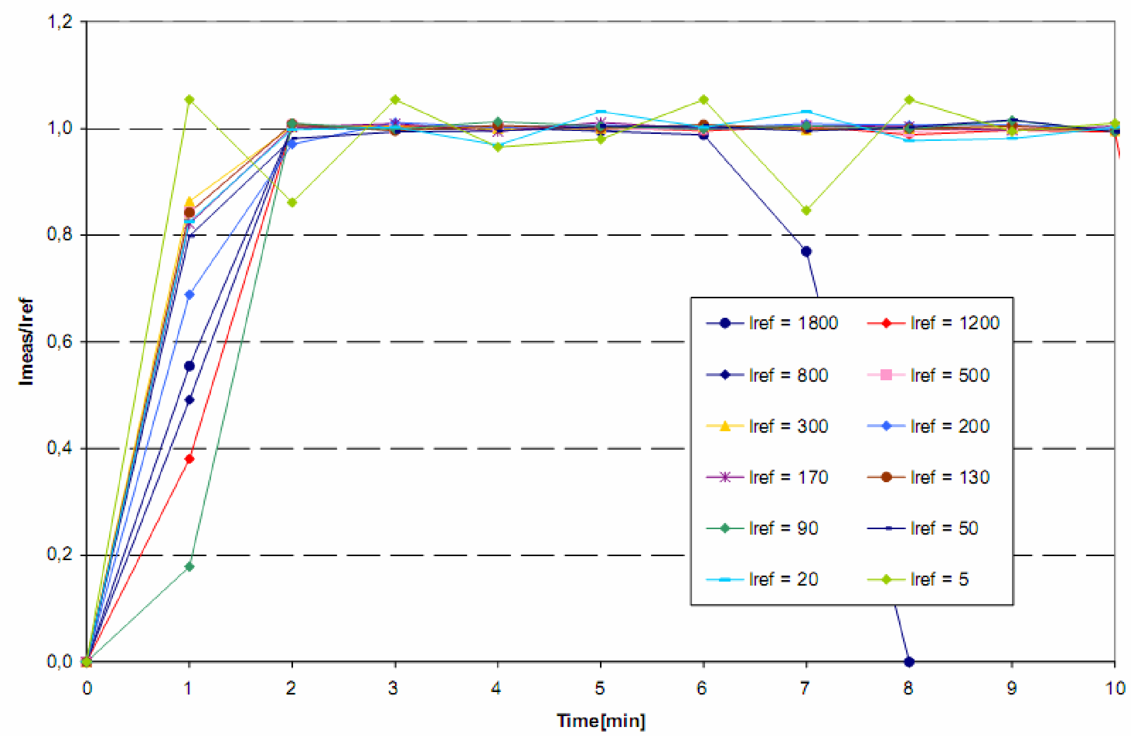
Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.

OTT 220331
NORMALIZED STEP RESPONSE



OTT 220332
NORMALIZED STEP RESPONSE



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

Pluvio- OTT s/n 220331

CALIBRATION	**1° 11/12/07**	**2° 10/04/08**	**3° 15/04/09**
RI ref [mm/h]	212.3	138.9	154.4
AVG RE [%]	0.3	0.0	-0.2
[RE(-C.L.95%),RE(+C.L.95%)][%]	[0.3, 0.4]	[-0.6, 0.6]	[-0.3, -0.1]

Results

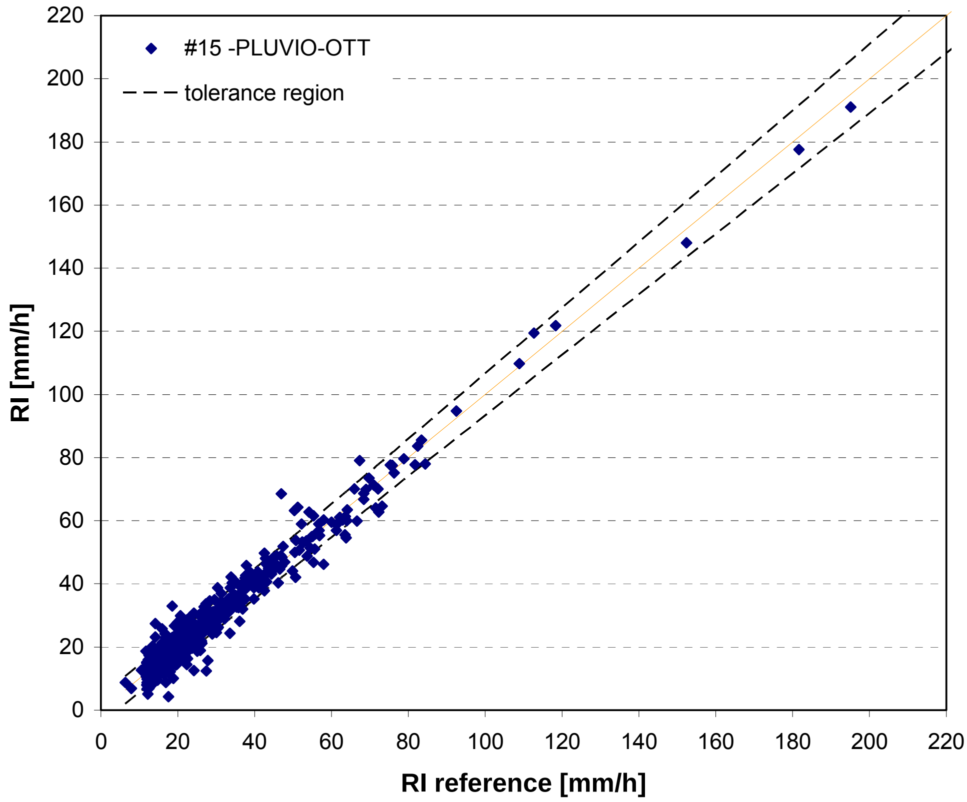
Pluvio-OTT s/n 220332 (pit gauge from 02/03/09)

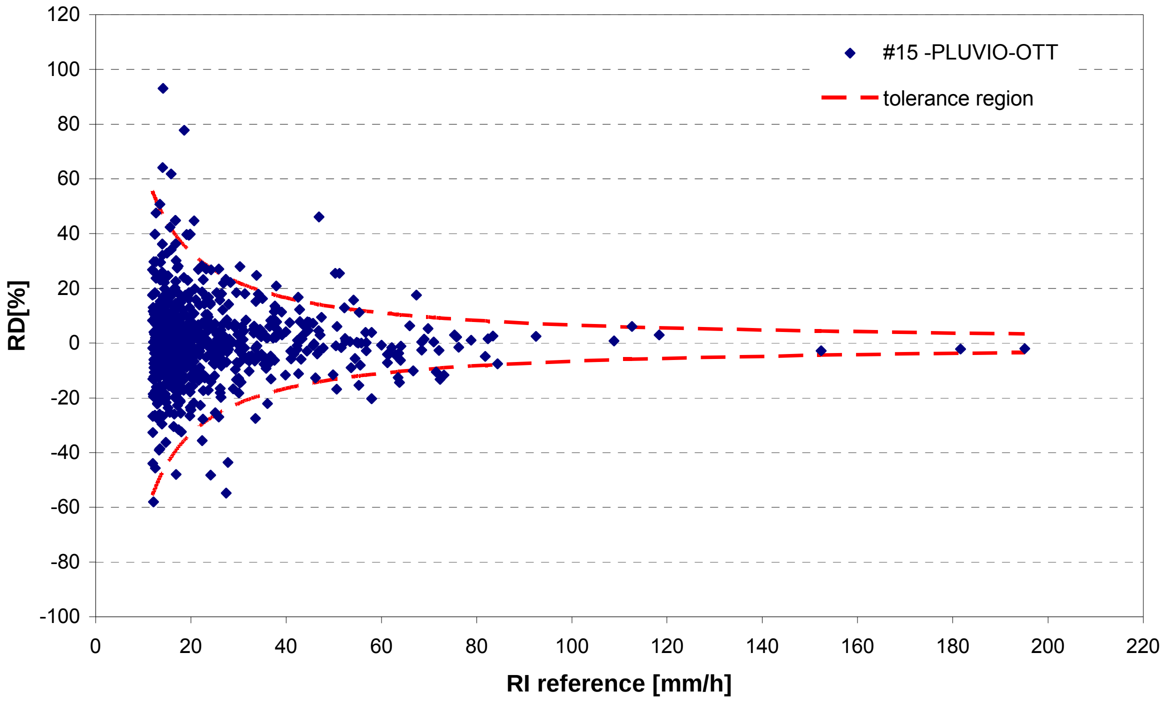
CALIBRATION	**1°**	**2°**	**3° 15/04/09**
RI ref [mm/h]			144.4
AVG RE [%]			-0.2
[RE(-C.L.95%),RE(+C.L.95%)][%]			[-0.6, 0.3]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%

Field Intercomparison Measurements

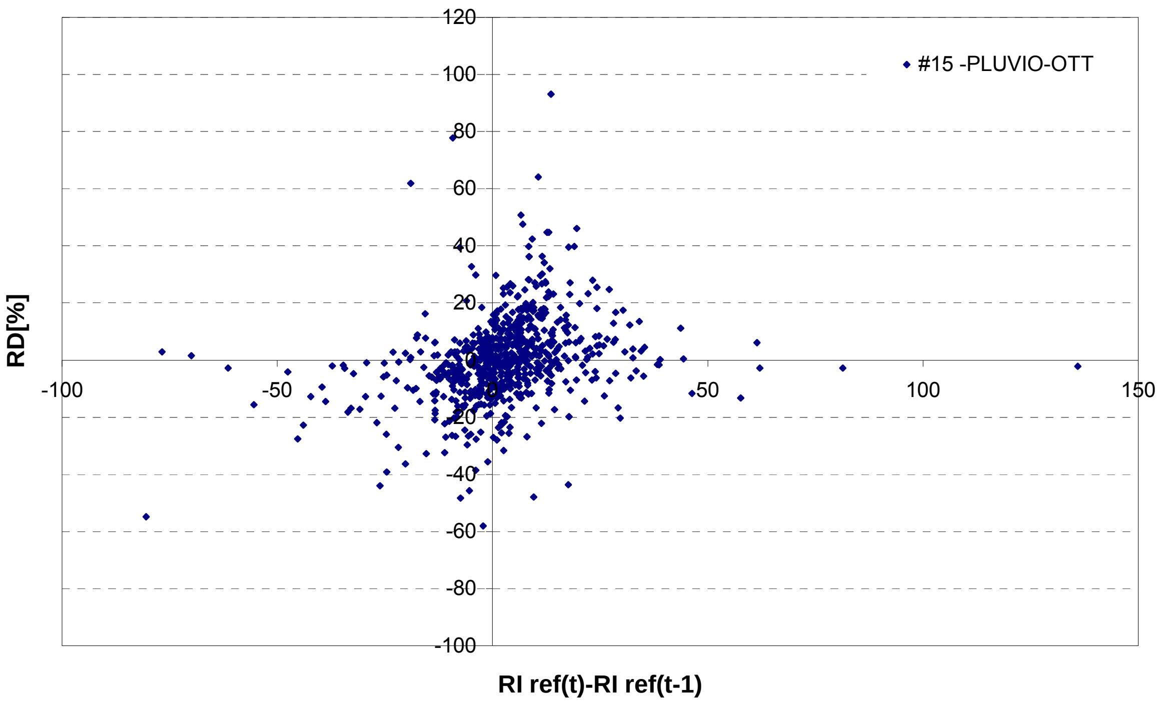
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by PUVIO-OTT and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



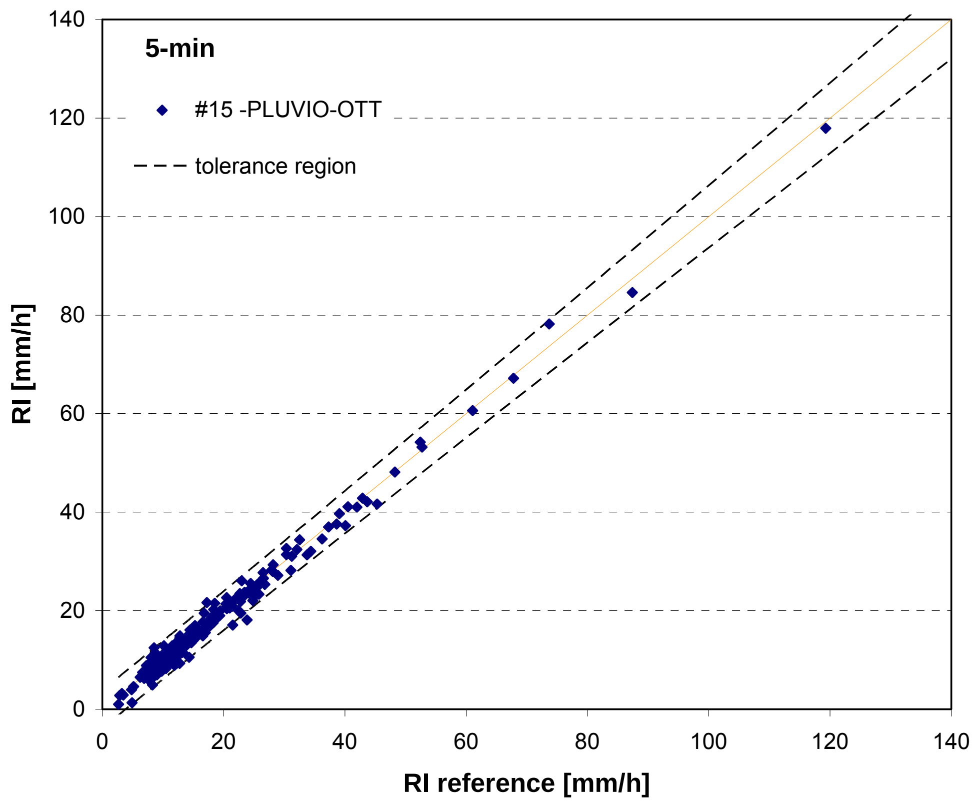


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by PUVIO-OTT and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ***(RI=a·(RIref)^b)***	**a**	**b**	**R^2**
#15 PUVIO OTT	0.98	1.00	0.90

(Parameters a, b, R^2 are determined by fitting the function RI=a·(RIref)^b, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

Excellent accuracy in constant flow conditions with respect to linearization: the laboratory calibration of the OTT (s/n 220331) shows average relative errors within ±0.5% and outliers within ±2% except for 5 and 20 mm/h. The OTT placed in the pit (s/n 220332) is slightly differing from the other one with respect to linearization and noise. The laboratory results are also confirmed by field calibrations. No drift detected from the field calibration.
No significant delay in step response detectable.
Field measurements confirm laboratory results but measurements above 150 mm/h (on 1 minute) are close to lower tolerance boundary which is not consistent with the calibration results. In the 5 min averages plot noise is reduced again so that almost all points are inside the tolerance region of the reference.
The RI variation response plot shows an oval shaped noise pattern with a tilted axis from the lower left to the upper right quadrant of the graph. The reason for this pattern must be investigated further.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
D1: Plausibility check parameter (processed by the automatic QC)
If D1≠0 → Doubtful
D2: Bucket content status
D3: Restart system parameter (processed by the automatic QC)
If D3=1 → Error

Data availability (1 min):
- Valid Data (both rain gauges): 100%.
- Because the storage of parameters in raw data files was limited to 13 (8 precipitation data and 5 diagnostic parameters) for each participating instrument, the complete OTT Pluvio output telegram content was stored in separated data files (#15_yyyy_nnn.dat; #15PIT_yyyy_nnn.dat) which will be provided together with the Intercomparison dataset.
- (*For s/n 220331)* Since 17/02/2008 the physical quantity in the original output telegram defined as RI = Precipitation Intensity REAL TIME (>THRESHOLD, 4.2mm/h) has been

correctly filtered by the DA logical serial filter (improved logical serial filter: upgraded filter for the correct interpretation of the character sign “+” which appears in the output telegram in case of rain conditions). The upgraded filter permitted a correct filtering of the precipitation data to be stored in raw data files and the correct retrieve of the 1-min RI for the Intercomparison analysis. However no data was lost since the beginning of the Intercomparison (all telegram data are stored in #15_yyyy_nnn.dat data files) and the 1-min data files processed by the Automatic Quality Control (QC_RI_"yyyy-mm-dd".dat) were corrected by manually inserting the correct value for 1-min RI (Precipitation Intensity REAL TIME; >THRESHOLD, 4.2mm/h) obtained through the #15_yyyy_nnn.dat data files since the beginning of the Intercomparison until 16/02/2008.

Maintenance:

- Regular inspection;
- Basket manual emptying before is 80% full and cleaning;
- Depending on local weather conditions: removal of dirt, leaves, birds droppings and insects from water surface.

Malfunctioning:

- None.

PG200 Electronic Weather System
- Hungary -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Weighing Gauge (single point load cell) equipped with rain sensor, tipping bucket converter and siphoning system (automatic emptying).
- Collector area: 200 cm^2
- Range of measurement : 0-500 mm/h
- 1-minute resolution: 3 mm/h

Data output

- Output: data message serial RS485/RS232 in ASCII protocol - Polling mode (every minute).
- Data update cycle : <10 s
- Rainfall parameters: precipitation status; average of the total weight; average 1 min amount of rain (RA_{1min}).
- Transfer function for 1-min RI: RI_{1min}[mm/h] = RA_{1min}[mm]/[min]·60[min/h]

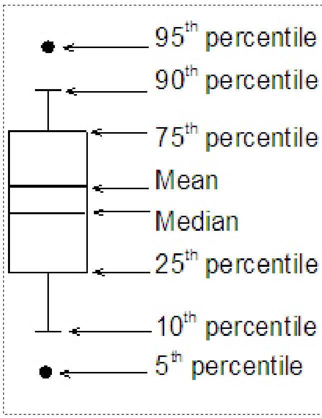
#16 PG200 EWS in the field

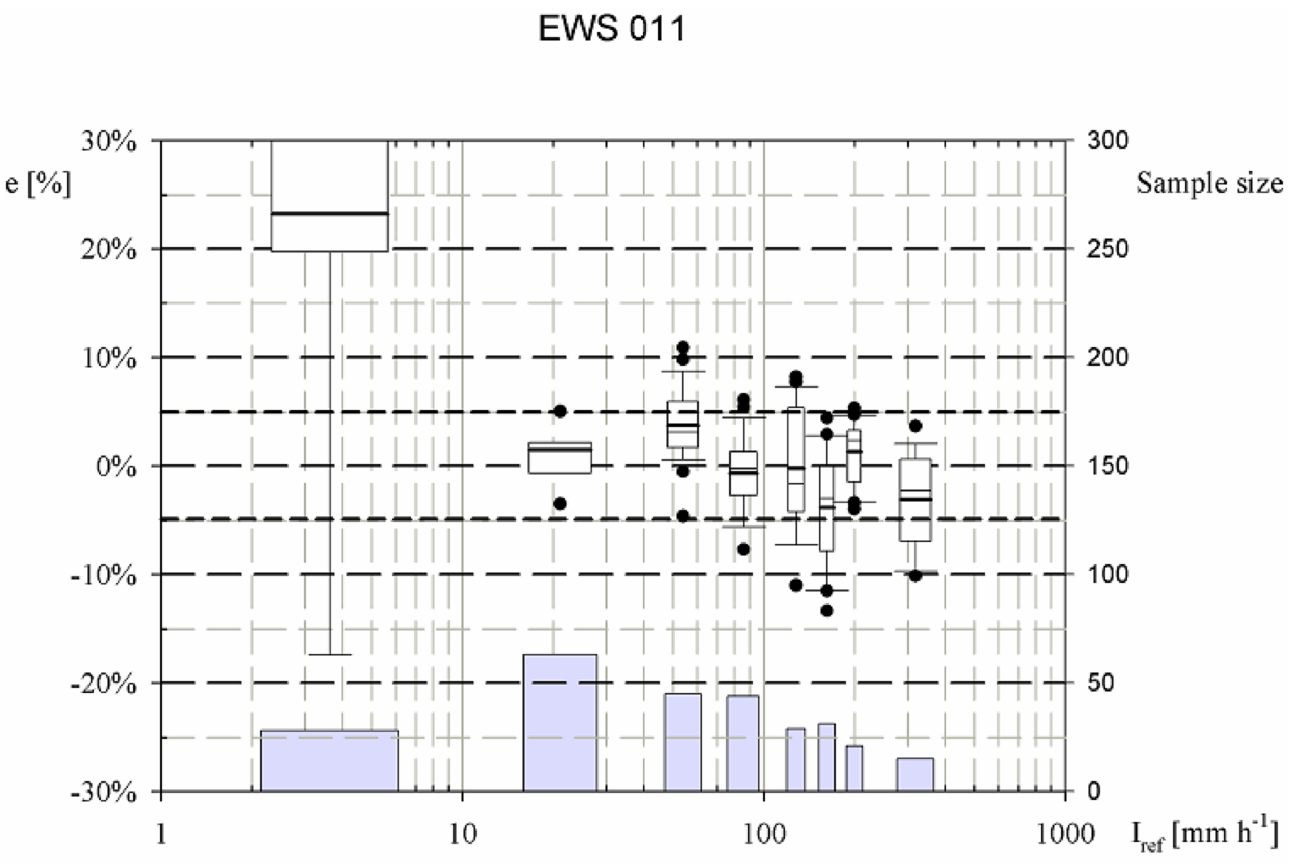
Laboratory test

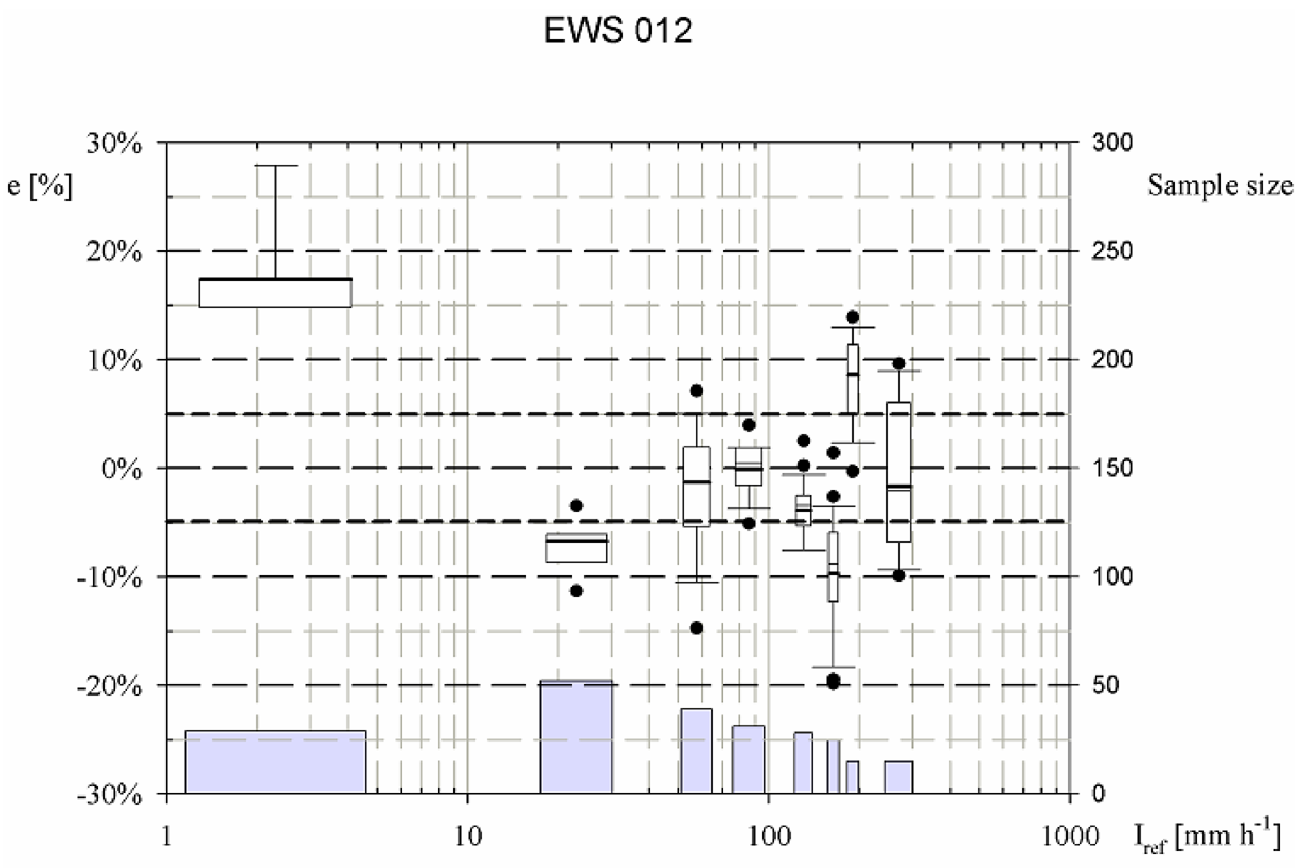
The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute 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.



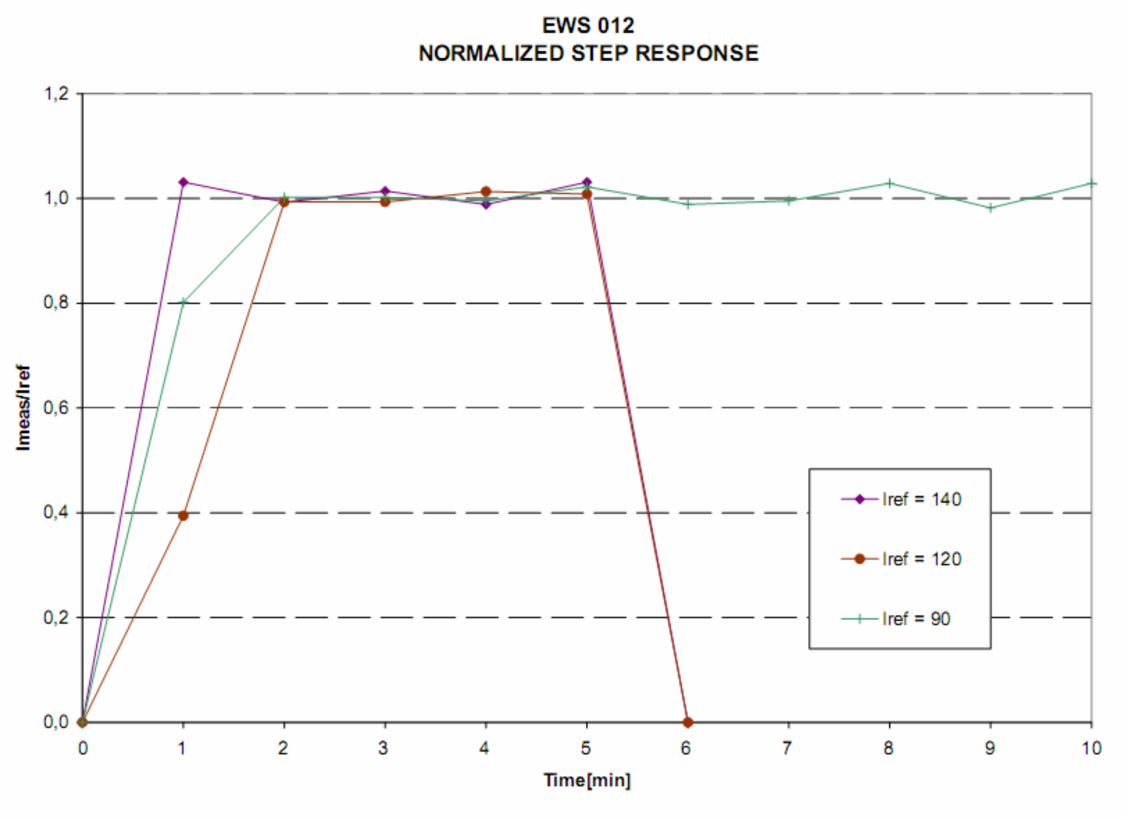


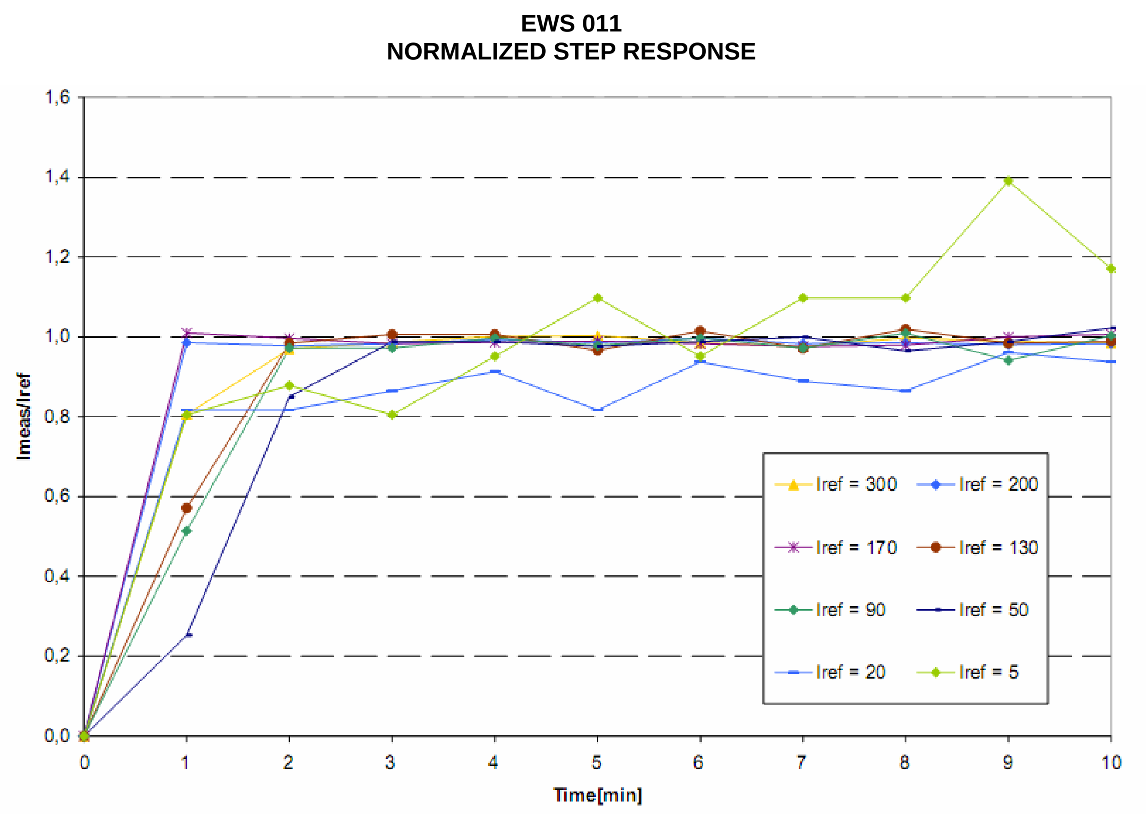


EWS 012
30%
20%
10%
0%
-10%
-20%
-30%
e [%]
300
250
200
150
100
50
0
Sample size
1
10
100
1000
I_{ref} [mm h^{-1}]

Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.





Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a Portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

PG200 s/n CSM0012/07

CALIBRATION	**1°**	**2° 23/05/08**	**3° 15/04/09**
RI ref [mm/h]	**/**	140.8	149.7
AVG RE [%]	**/**	-0.1	-0.3
[RE(-C.L.95%),RE(+C.L.95%)][%]	**/**	[-0.7, 0.5]	[-0.8, 0.1]

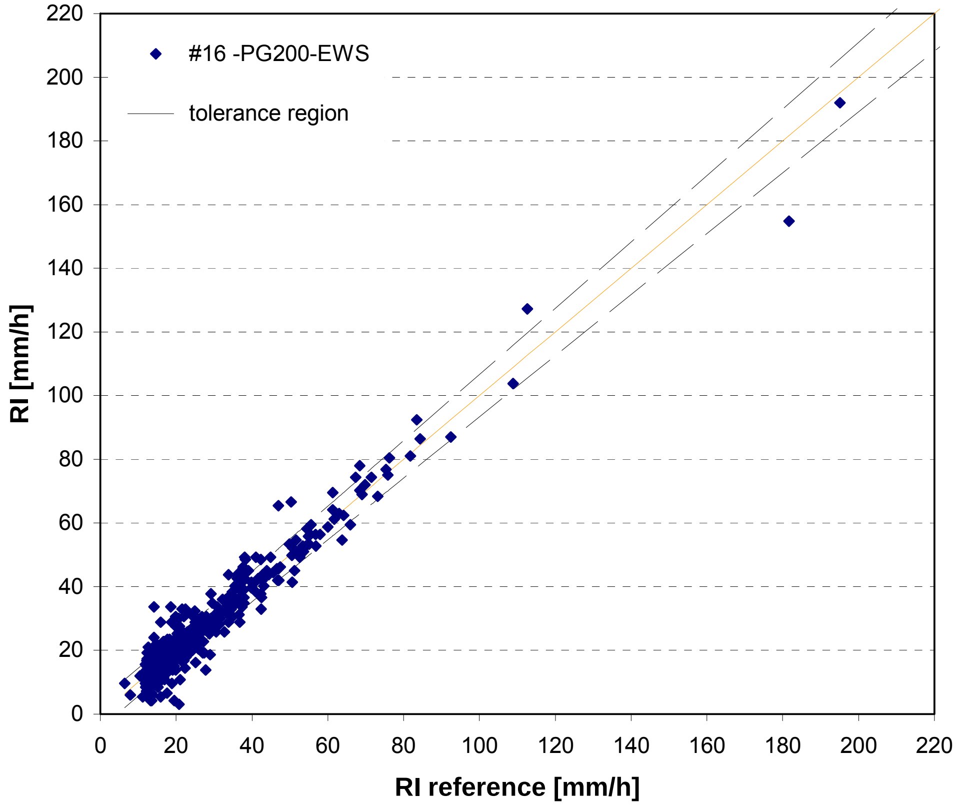
(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%)

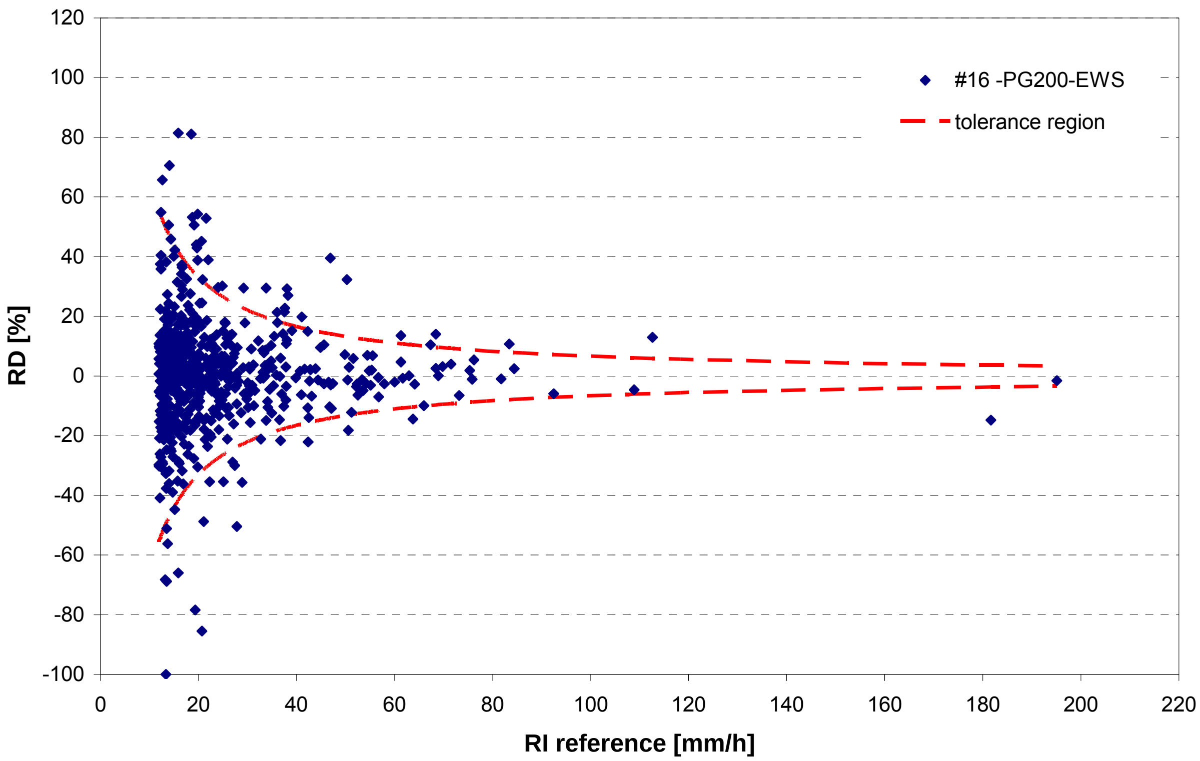
Comments

- By means of the first field calibration of the PG200 S/N CSM0011, the local staff and two Hungarian Met Service experts detected the instability of the load cell (May, 21st-22nd 2008 : Meeting of Participants and local staff). Therefore, the S/N 011/07 was replaced by S/N 012/07.
- The EWS S/N 012/07 was the only gauge used for the Field Intercomparison data analysis.

Field Intercomparison Measurements

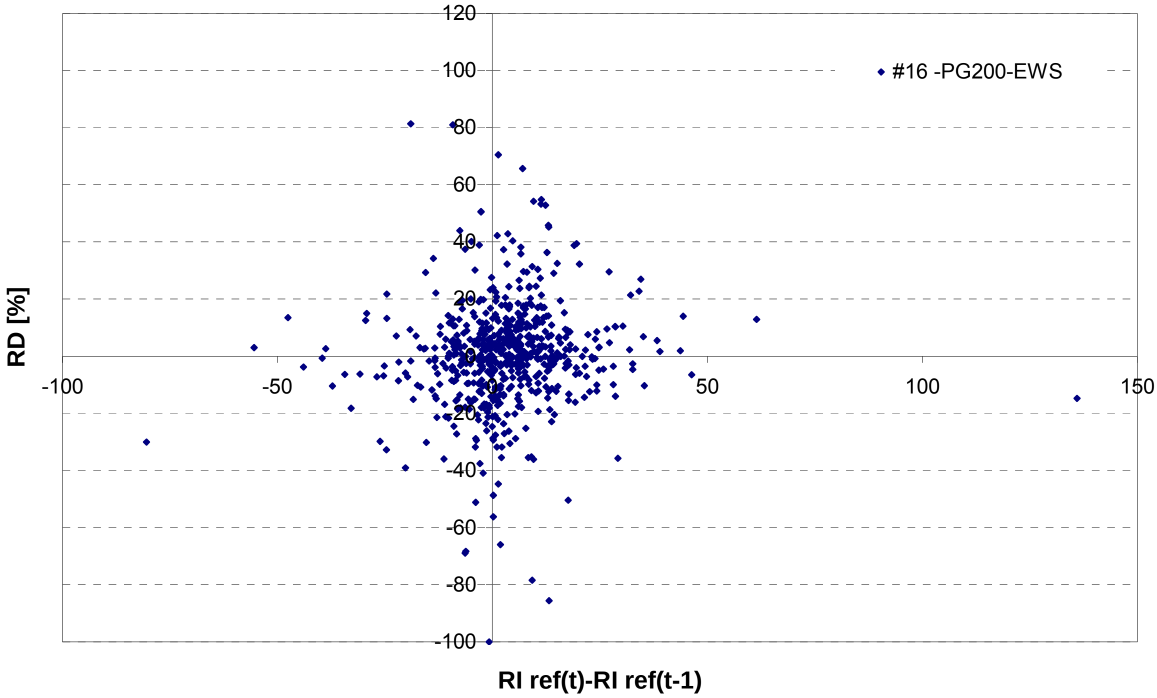
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by PG200-EWS and reference intensity. The tolerance curves are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



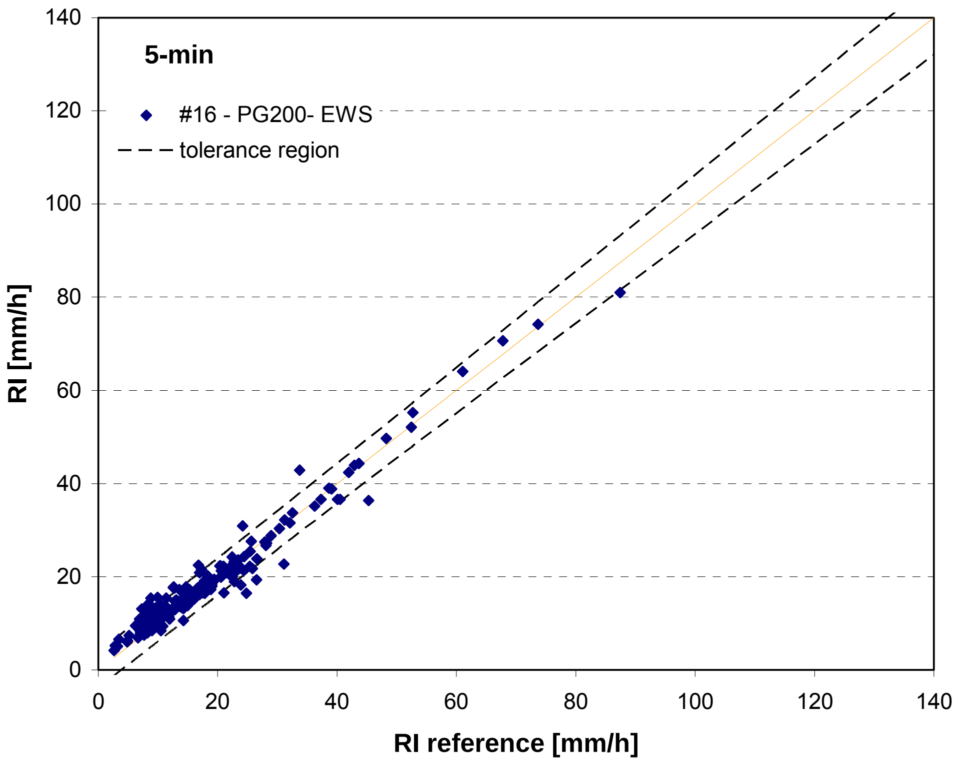


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by PG200-EWS and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters *($RI=a\cdot(RIref)^b$)*	**a**	**b**	**R^2**
#16 PG200 EWS	0.98	1.00	0.81

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The laboratory calibration shows good results, with some dispersion (for a weighing gauge). The step response plot shows a fast response of the sensor.
The field calibrations give consistent results with the laboratory calibration. No drift detected from the field calibration.
The field results are consistent with the calibration results and show little dispersion.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
D1: Status parameter (processed by the automatic QC)
If D1=2 and RI=0mm/h→ Error
If D1=0 and RI>0mm/h→ Error
D2: Load cell temperature

Data availability (1 min):
- Valid Data: 77.4%. Motivation: rain sensor reports precipitation in no rain conditions. (This behaviour does not affect the precipitation data).

Maintenance:
- Regular inspection;
- Cleaning of the rain sensor when necessary
- Calibration status check
- An extraordinary check of calibration status was performed on S/N CSM001107 during the Participants' Meeting (May, 2008) because of doubtful results of the first field calibration.

Malfunctioning:
- PG200 S/N CSM001107 was replaced by the **spare** (S/N CSM0012/07) on **22/05/2008** because the load cell was found unstable and calculation of 1-MIN RI was not correct.
- Correct calculation of RI verified by Met Hungarian Service personnel and EWS manufacturer (Participants' Meeting, 21-22 May 2008)

T200B-GEONOR
- Norway -
Technical Specifications

- Provided by the manufacturer -

- Physical principle: weighing rain gauge (vibrating wire load cell)
- Collector area: 200 cm^2
- Range of measurement : 0-600 mm/h
- 1-minute resolution: 0.1 mm/h

Data output

- Output: frequency
- Data update cycle : 10 s (Data Acquisition System sampling time).
- Rainfall parameters: the frequency output is converted in the gauge total depth/total accumulation (RA_{10sec}[mm]) by the DAQ every 10s through an equation provided by the manufacturer; rainfall intensity is calculated every 10 seconds:
  $RI_{10sec}[mm/h] = (RA_{10sec}[mm]_t - RA_{10sec}[mm]_{t-10sec}) * 360[sec/h]$,
  where $RA_{10sec}[mm]_t$ and $RA_{10sec}[mm]_{t-10sec}$ are the 10 sec-gauge total depths in [mm] at the time t and (t -10sec)
- Transfer function for 1-min RI (1 min averaging): $RI[mm/h] = AVERAGE\_RI[mm/h]_{10sec}$

#17 T-200B-GEONOR in the field (s/n 14607)

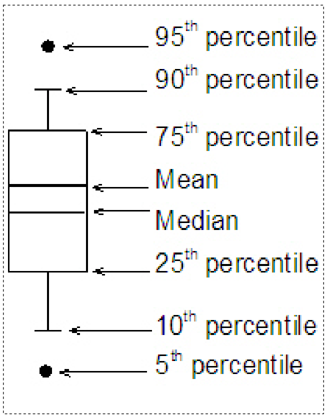
#30 T-200B-GEONOR Reference Pit Gauge (s/n 14707)

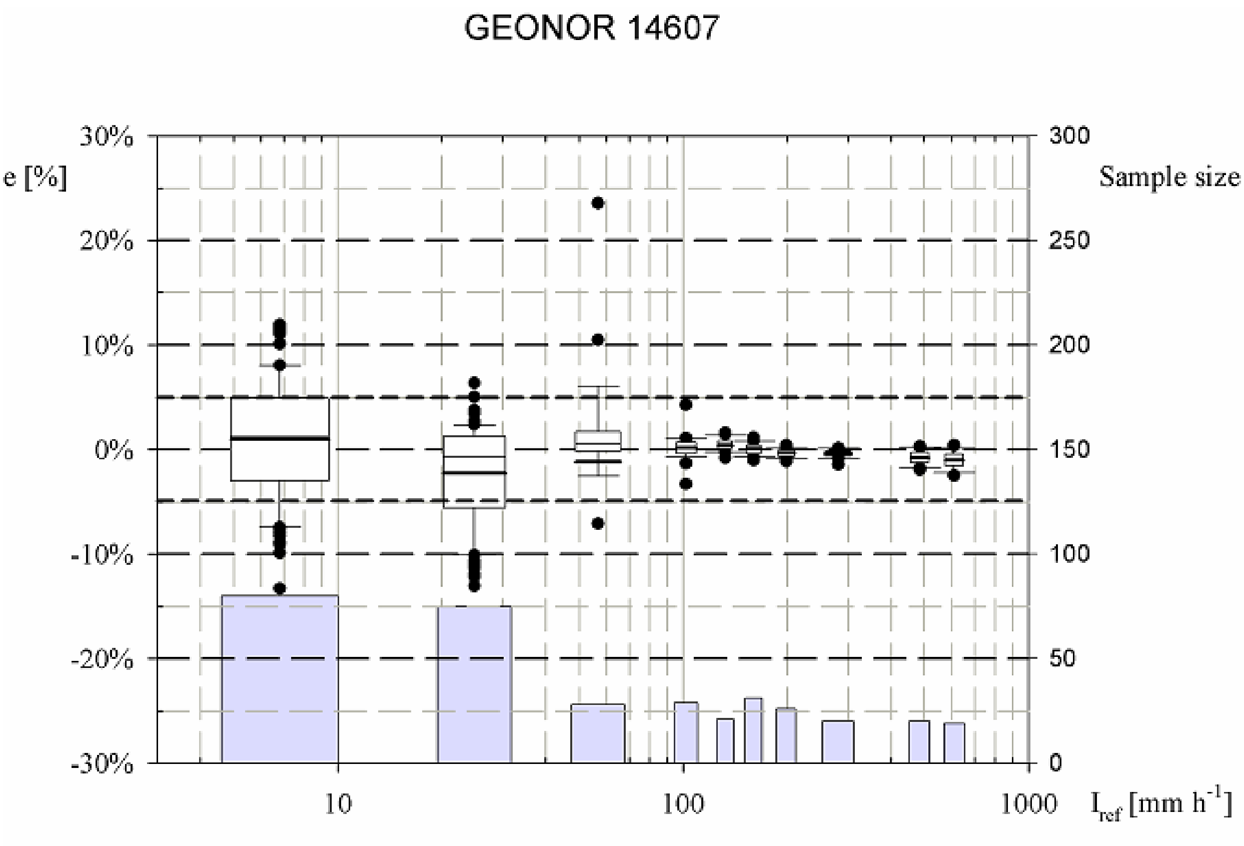
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

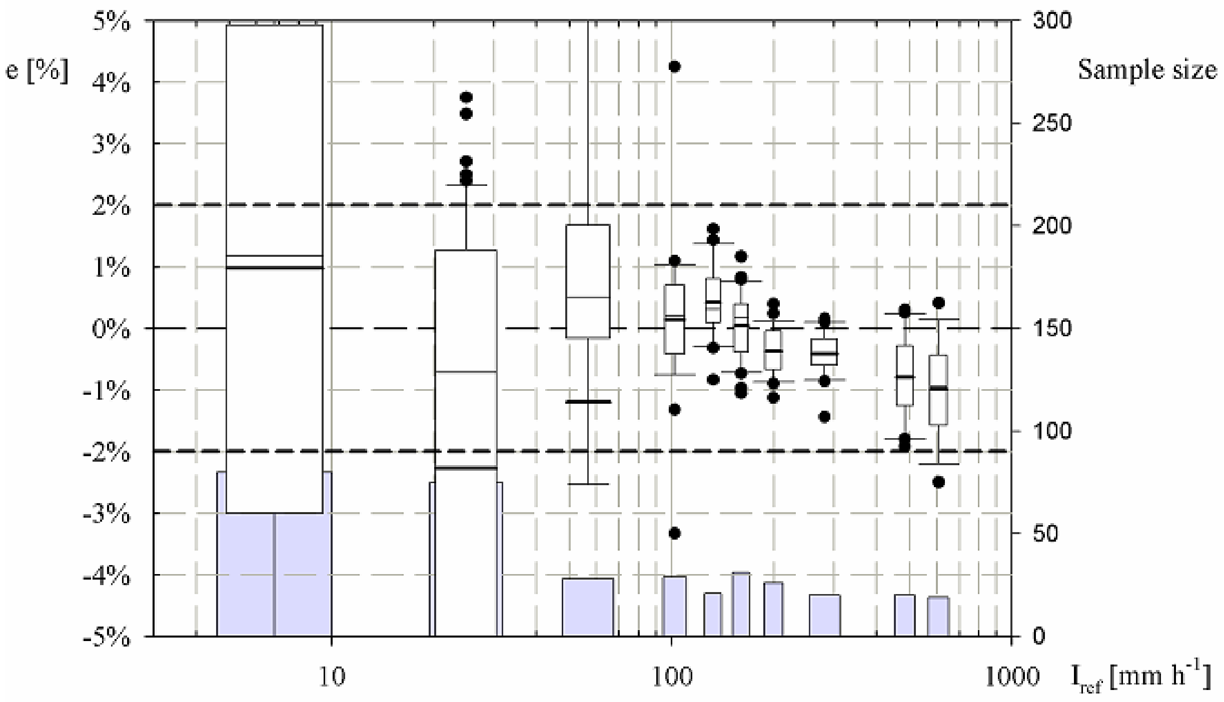
Constant flow response

The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute 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.

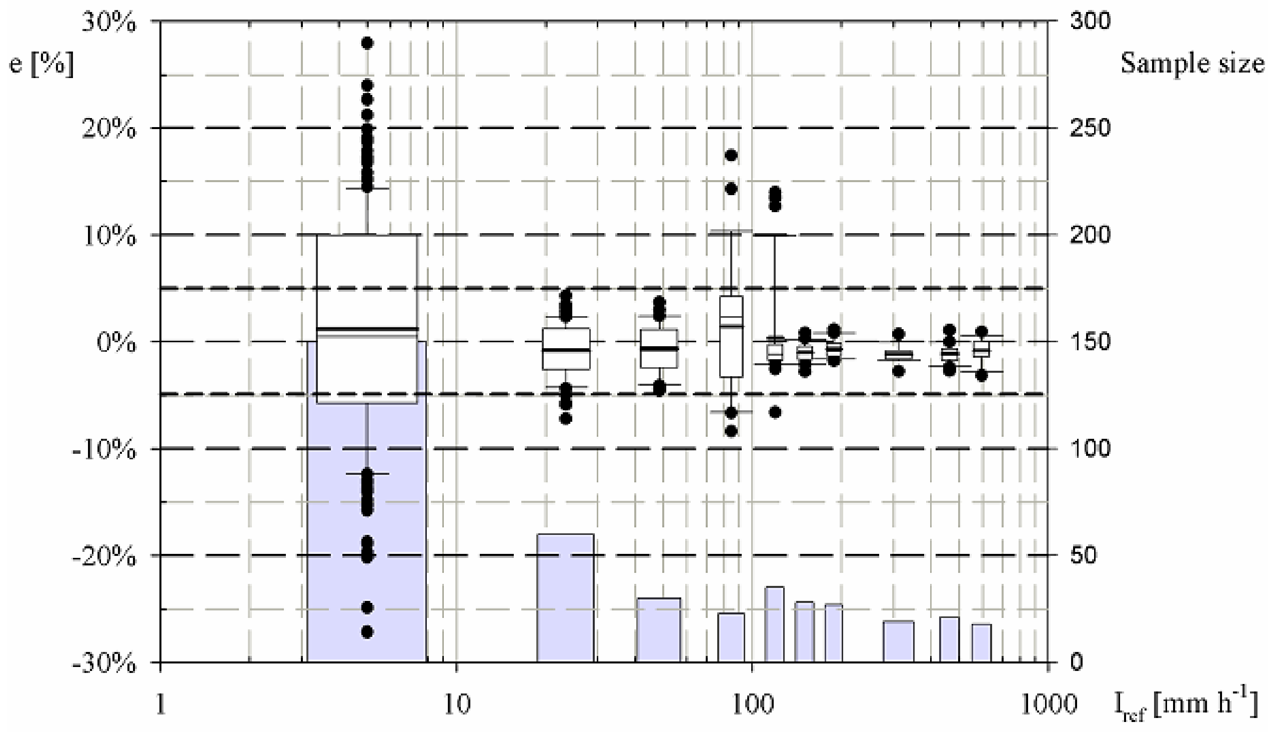




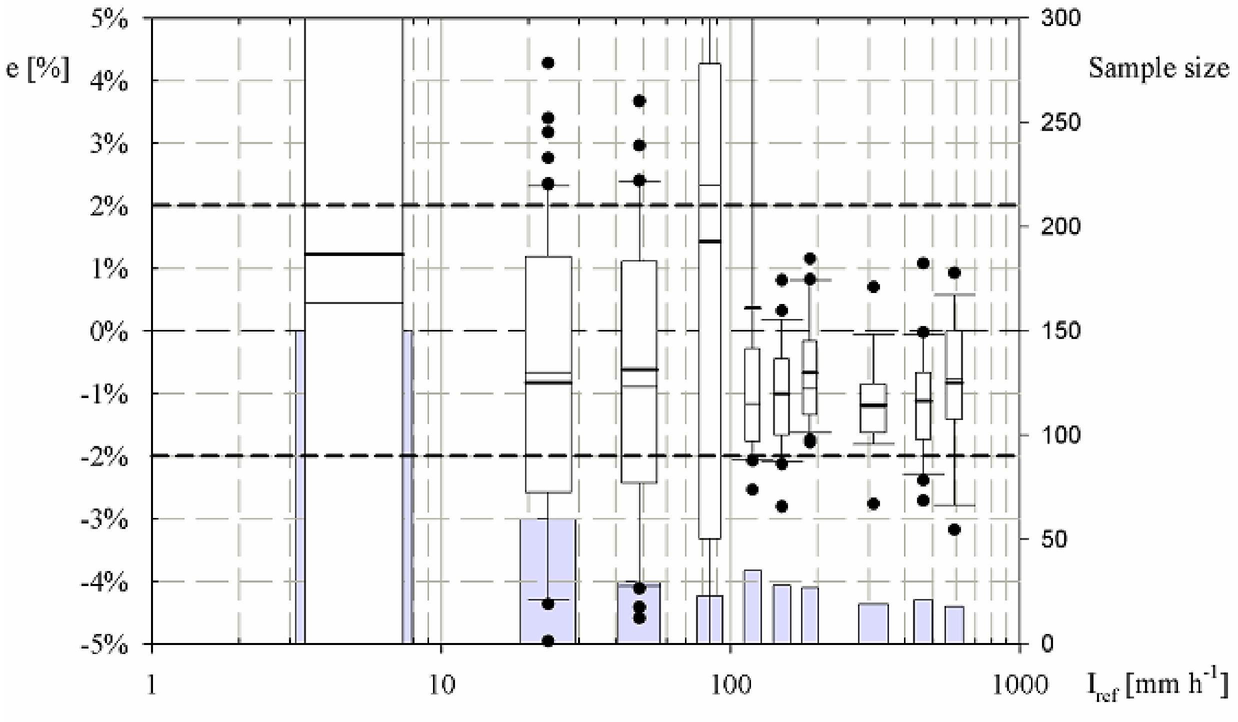
GEONOR 14607



GEONOR 14707

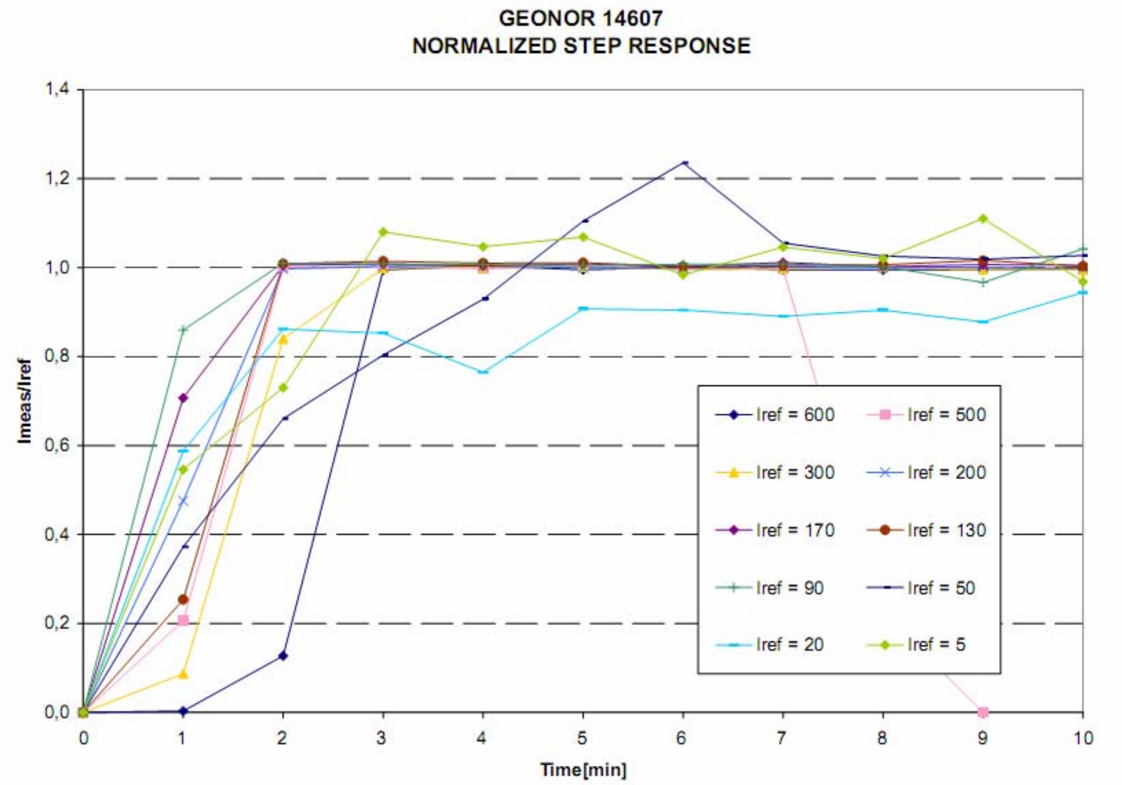


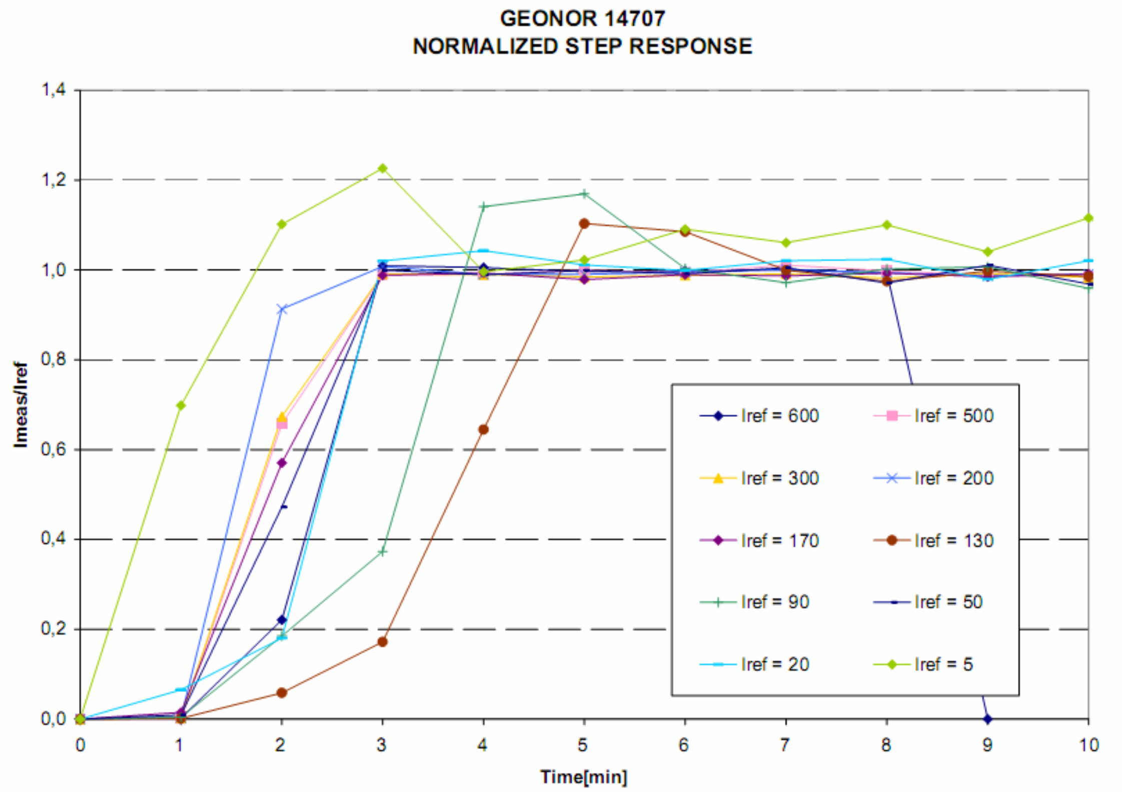
GEONOR 14707



Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behavior of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.





Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

T200-B GEONOR s/n 14607

CALIBRATION	1° 12/12/07	2° 10/04/08	3° 15/04/09
RI ref [mm/h]	205.5	136.6	154.5
AVG RE [%]	-0.5	-0.4	-1.3
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-1.3, 0.3]	[-0.9, 0.1]	[-1.6, -1.0]

Results

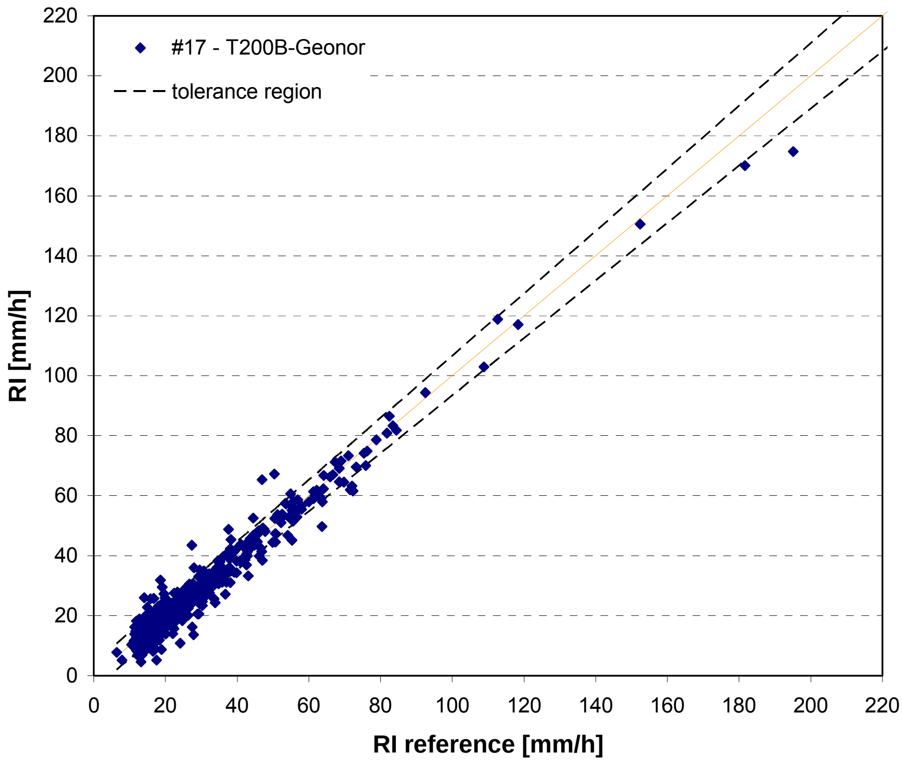
T200-B GEONOR s/n 14707 (pit gauge)

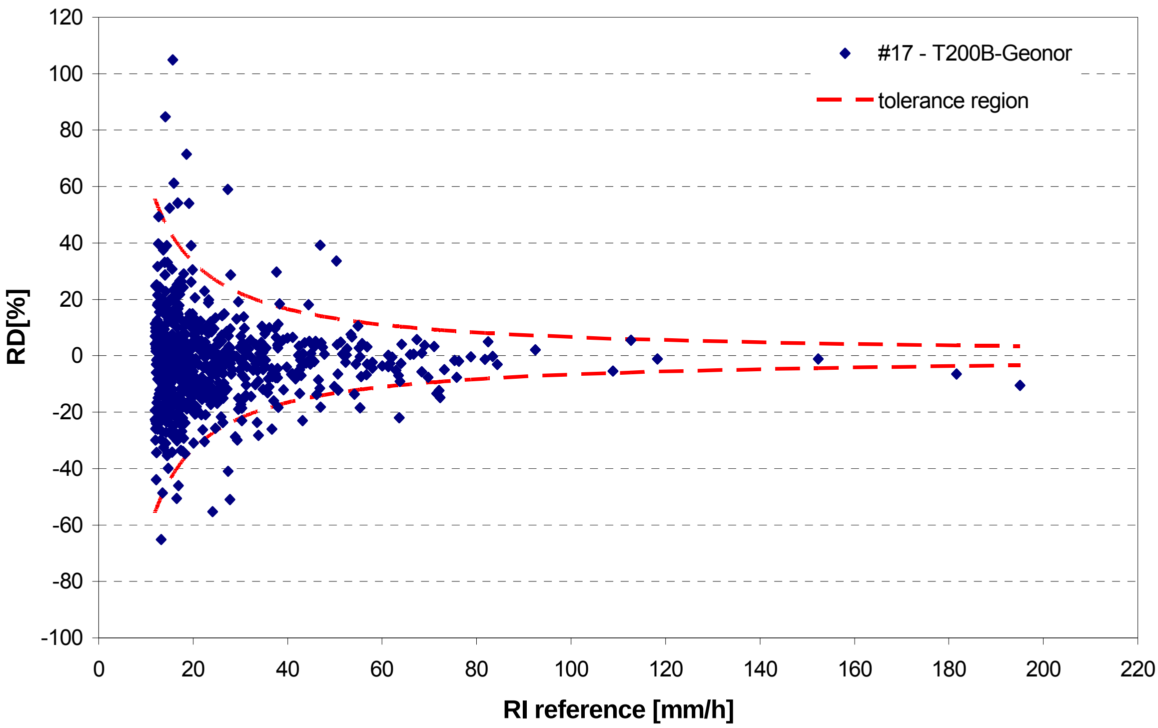
CALIBRATION	1° 13/12/07	2° 10/04/08	3° 15/04/09
RI ref [mm/h]	204.7	135.1	151.0
AVG RE [%]	-1.0	-1.5	-0.3
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-1.5, -0.4]	[-2.0, -1.0]	[-0.5, 0.0]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%

Field Intercomparison Measurements

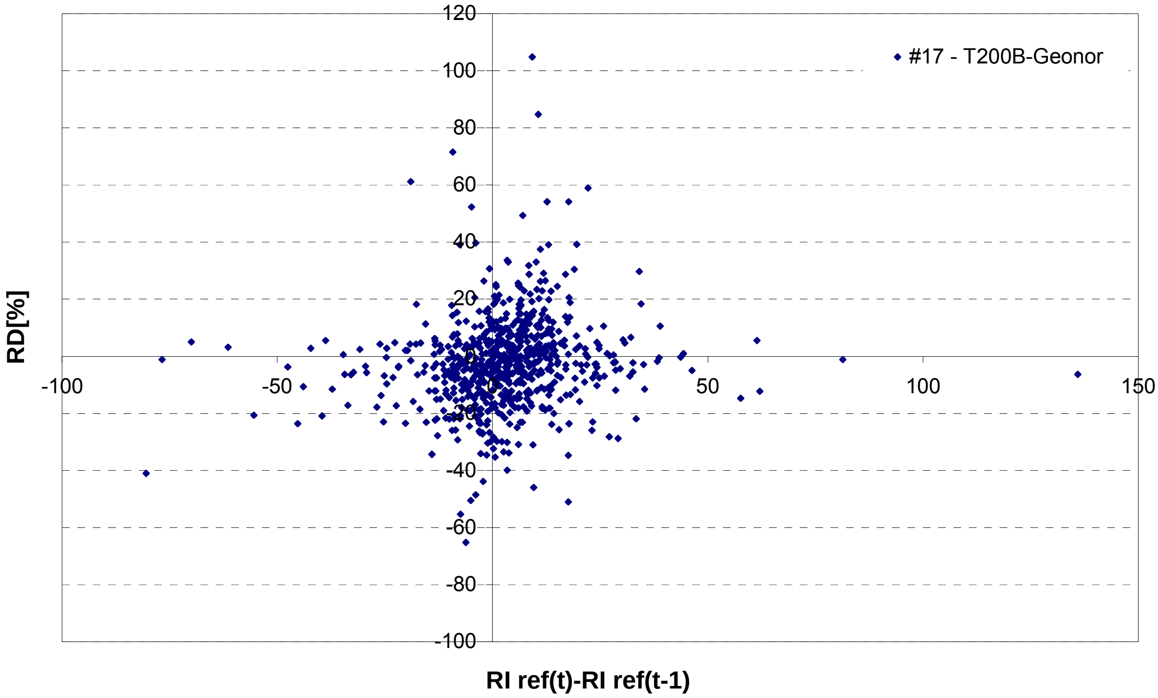
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by T-200B GEONOR and reference intensity. The tolerance curves are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



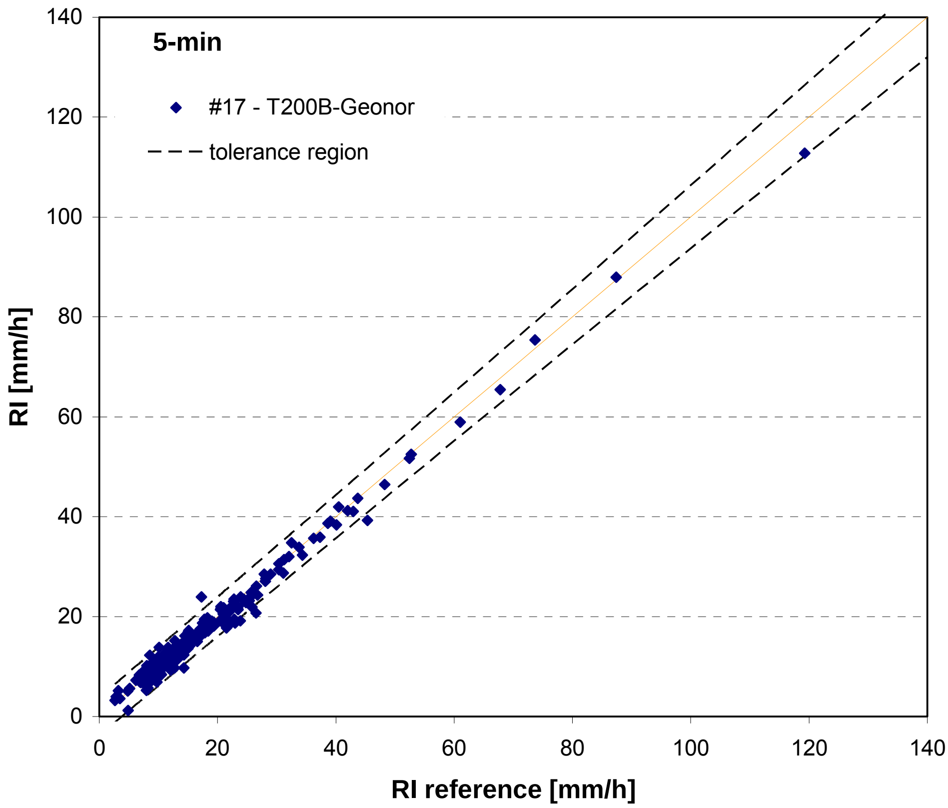


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t\text{-}1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by T-200B GEONOR and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ***($RI=a\cdot(RIref)^b$)***	**a**	**b**	**R^2**
#17 **T-200B GEONOR**	0.96	1.00	0.89

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

Very good accuracy in constant flow conditions with respect to linearization and noise: a) the laboratory calibration of the Geonor used as reference gaige (s/n 14707) shows average relative errors within ±2.0% and outliers above ±5% for few laboratory reference RI; the laboratory calibration of the Geonor installed in the field (s/n 14607) shows average relative errors within ±2.5% and outliers above ±5% below 100 mm/h. The field calibrations give consistent results with the laboratory calibration. No drift detected from the field calibration.
The field results are consistent with the calibration results and show very little dispersion.
The RI variation response plot shows an oval shaped noise pattern with a tilted axis from the lower left to the upper right quadrant of the graph. The reason for this pattern must be investigated further.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
No diagnostic data and error code.

Data availability (1 min):
- Valid Data: 100%.

Maintenance:
- Regular inspection;
- Regular addition of silicon oil for preventing evaporation losses (manufacturer's recommendation);
- Basket manual emptying when necessary and cleaning;
- Depending on local weather conditions: removal of dirt, leaves and insects from water surface.

Malfunctioning:
- The Geonor gauges gave false reports of precipitation probably due to wire noise and diurnal variations, wind pressure and small evaporation losses. The a-posteriori quality

control indicated dry situations where the Geonor gauges had detected precipitation, leading to a positive and negative 1 min RI values (below 2mm/h) in daily files . These false reports did not appear during precipitation events thus the Geonor gauges intercomparison performance is not affected at all. For operational use in meteorological networks a filtering algorithm is suggested.

TRWS-MPS
- Slovak Republic -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: weighing rain gauge
- Collector area: 500 cm^2
- Range of measurement : 0-3600 mm/h
- 1-minute resolution: 0.06 mm/h

Data output

- Output: data message serial RS485/RS232 in ASCII protocol - Polling mode (every minute). (*Software version: 2.14*)
- Data update cycle : 1 min
- Rainfall parameters: 1 minute total weight [mg]; 1 min rainfall accumulation RA_{1min}[μm]
- Transfer function for 1-min RI: RI_{1min}[mm/h] = RA_{1min}[μm]/[min]·10^{-3}[mm/μm] ·60[min/h]

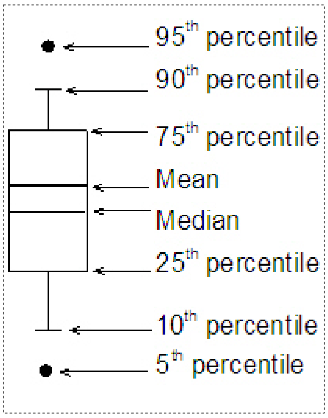
#18-TRWS – MPS in the field

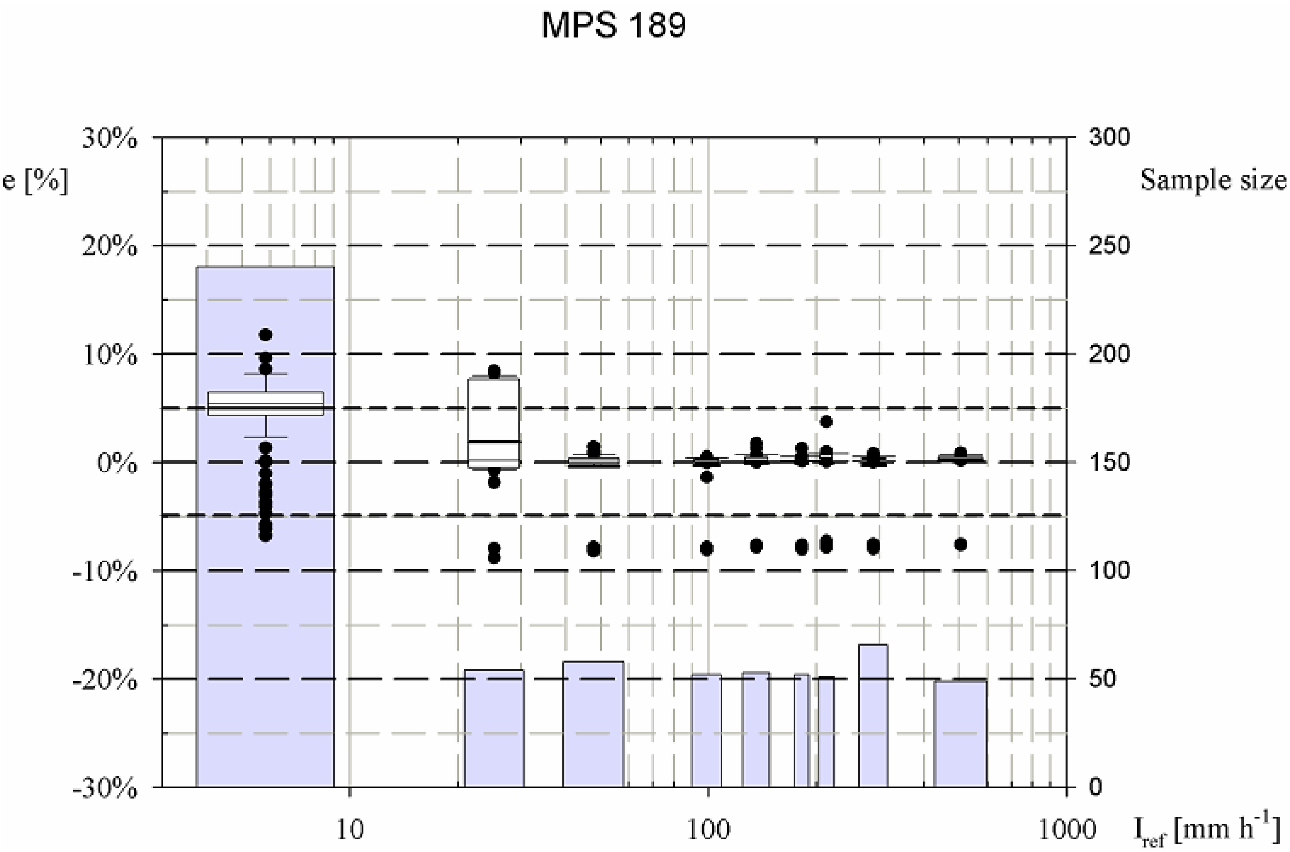
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

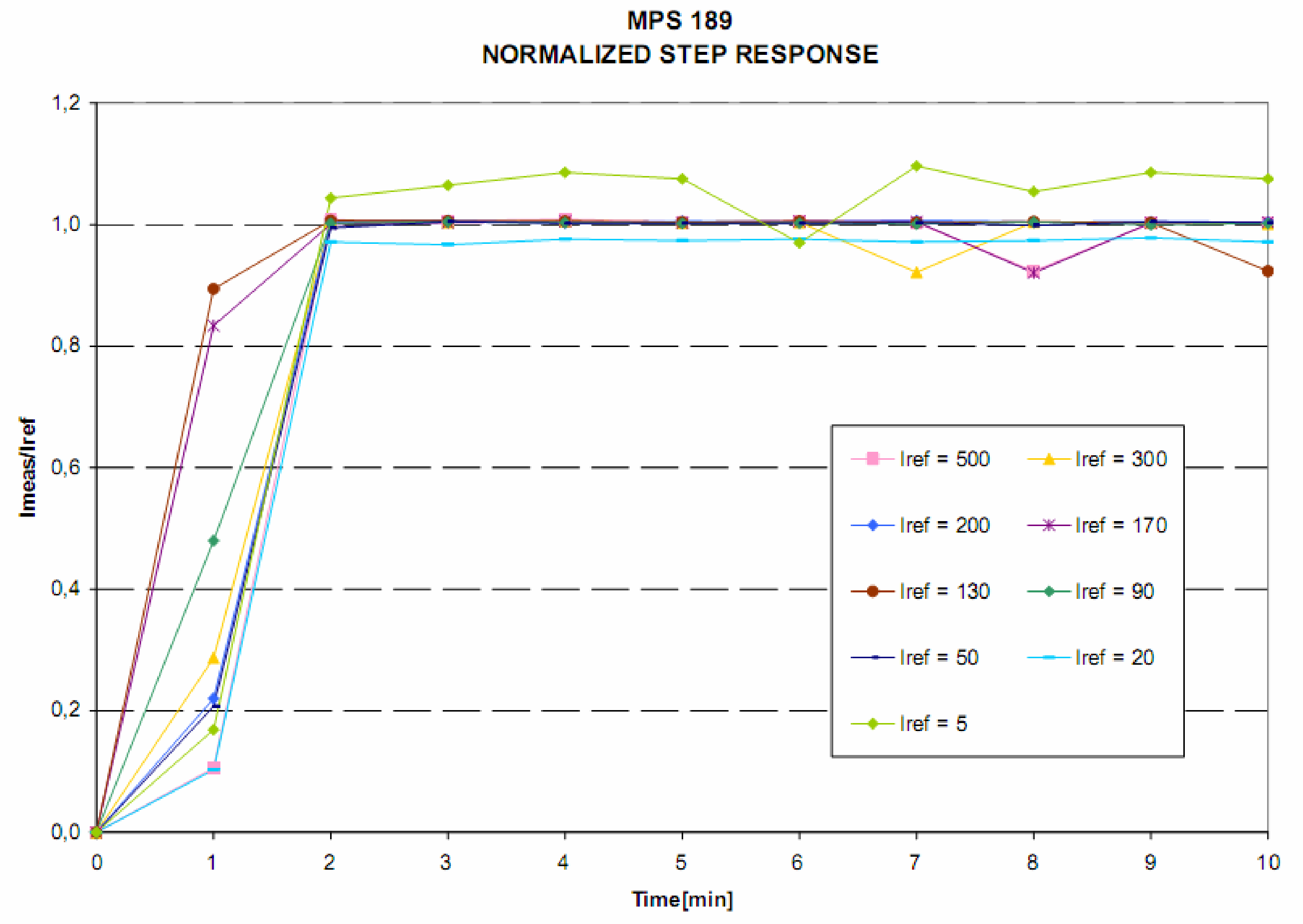
The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute variability of the observed instruments performances and the size of the sample used for calculation of the statistics at each reference intensity. Box plots synthetically 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.





Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

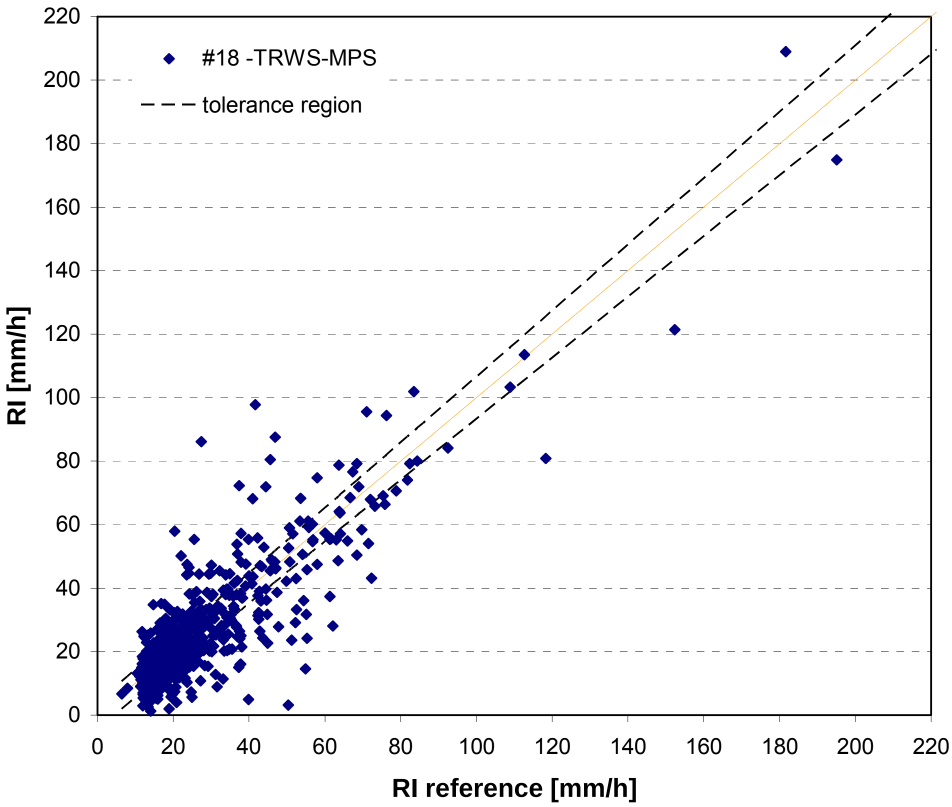
TRWs – MPS s/n 189

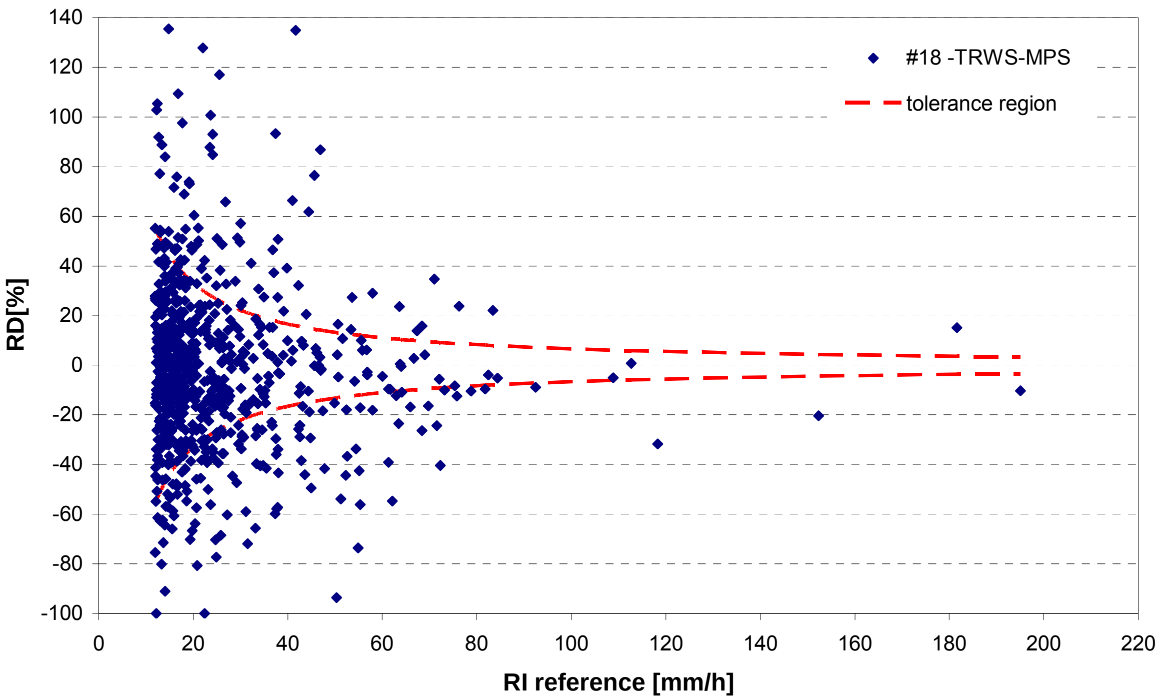
CALIBRATION	**1° 11/12/07**	**2° 27/05/08**	**3° 22/04/09**
RI ref [mm/h]	201.4	122.0	121.5
AVG RE [%]	-0.6	-1.3	-0.7
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-2.0, 0.9]	[-2.3, -0.2]	[-1.4, 0.0]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%

Field Intercomparison Measurements

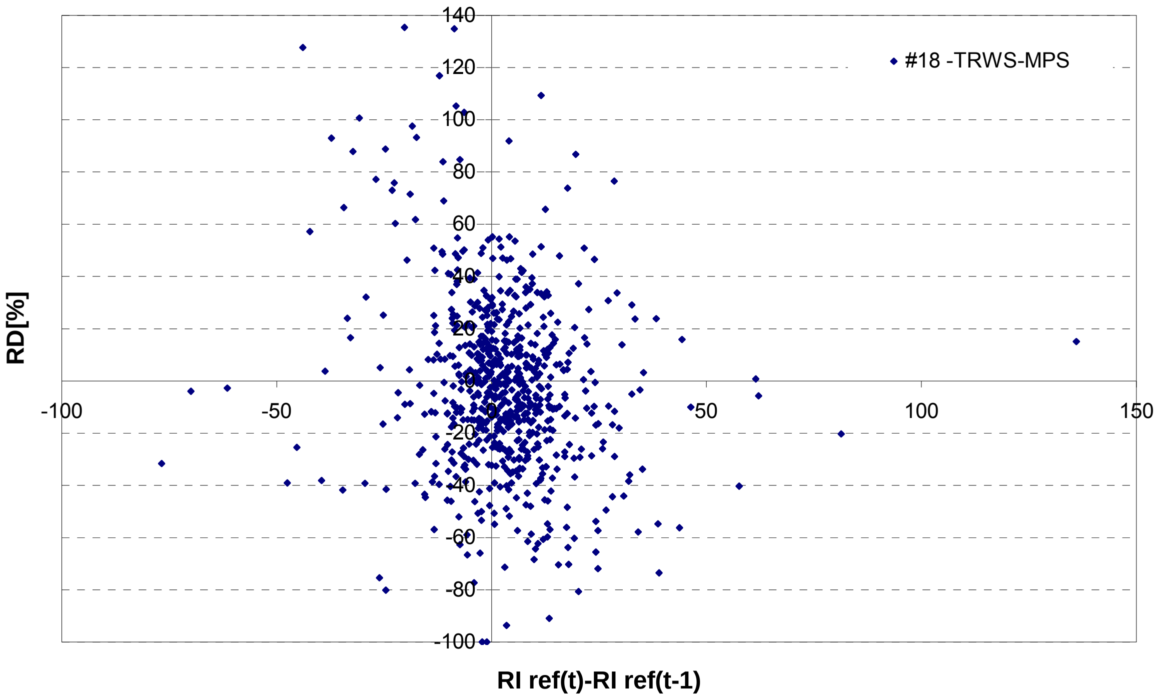
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by TRWS MPS and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



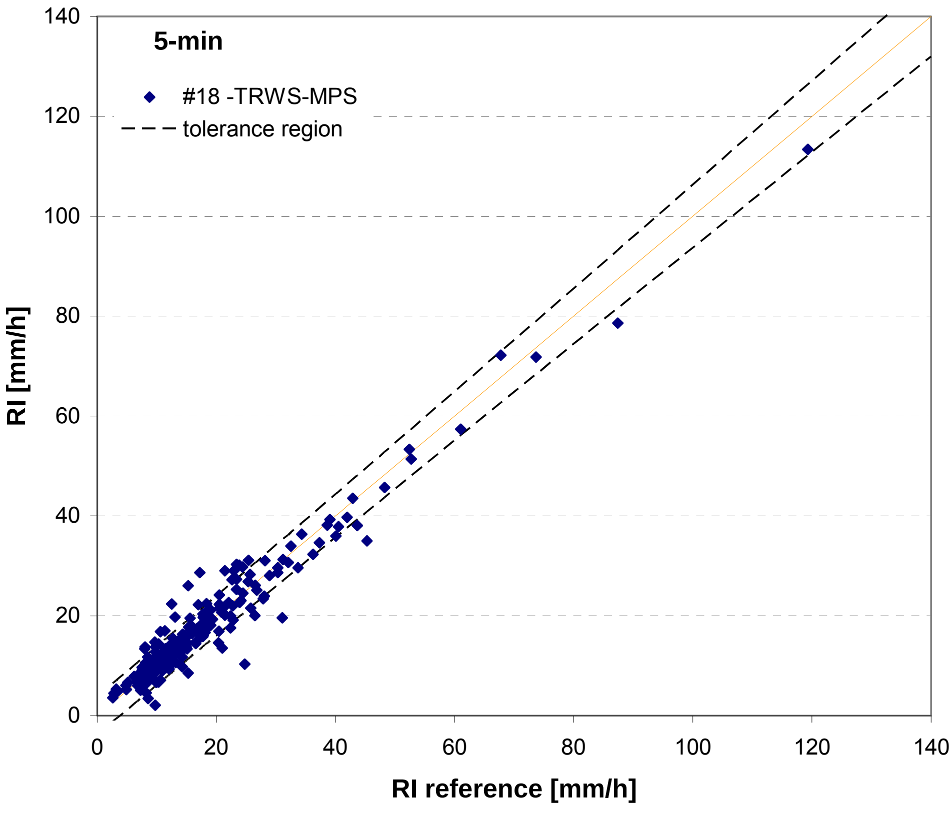


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by TRWS MPS and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ***($RI=a\cdot(RIref)^b$)***	**a**	**b**	**R^2**
#18 **TRWS MPS**	1.09	0.95	0.59

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The laboratory calibration shows excellent results with respect to linearization above 20mm/h (only very few outliers close to -8%). The average relative error is within ±5% for all tested reference intensities. The field calibrations give consistent results with the laboratory calibration. No drift detected from the field calibration.
The field results on 1 minute data show a large dispersion, unexpected from the laboratory calibration. The dispersion is much reduced on 5 minute data.
The RI variation response plot shows some "noise" existing on the measurement and a slight tendency to under-estimation for increasing RI values and to over-estimation for decreasing RI values. The reason for this noise pattern must be investigated further.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
D1: Sensor temperature
D2: Power supply parameter

Data availability (1 min):
- Valid Data: 99.9%.

Maintenance:
- Regular inspection;
- Basket manual emptying when necessary.

Malfunctioning:
- None.

PWD22-VAISALA
- Finland -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Optical sensor (Near Infrared diode 875nm) based on a forward scattering measurement and equipped with a capacitive rain sensor (Vaisala RAINCAP®).
- Measured values: visibility (MOR); quantity, intensity and type of precipitation (rain, freezing rain, drizzle, freezing drizzle, mixed rain/snow, snow, ice pellets, unknown) and weather type identification (fog, haze, clear).
- Range of measurement : 0-999.99 mm/h
- 1-minute resolution: 0.01 mm/h

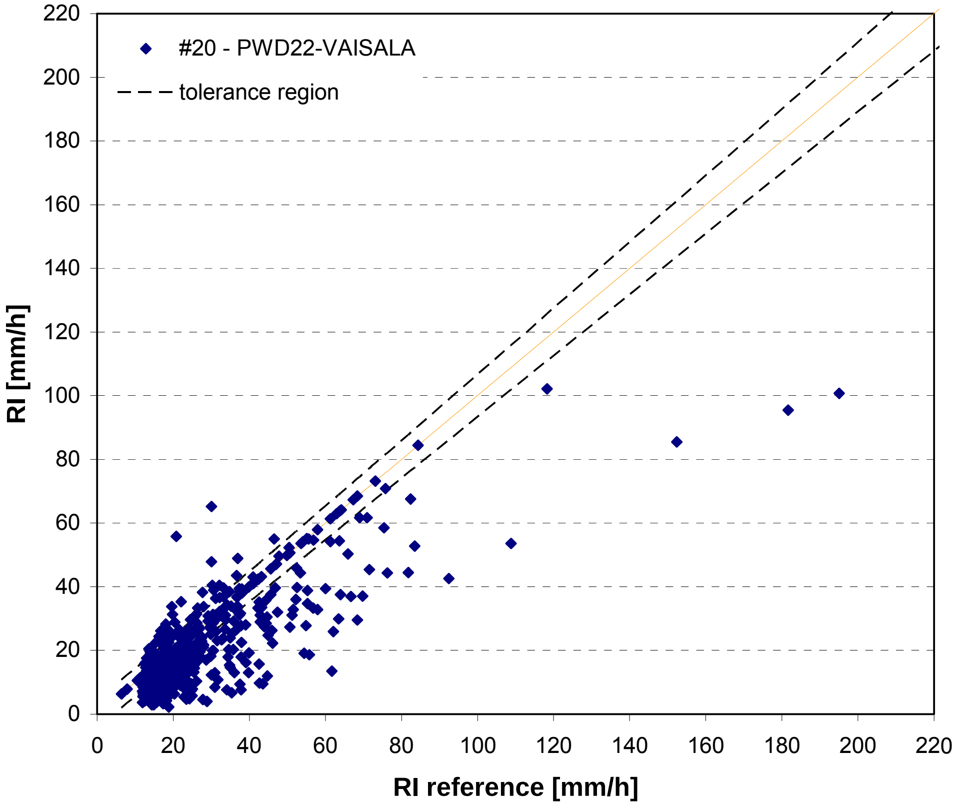
Data output

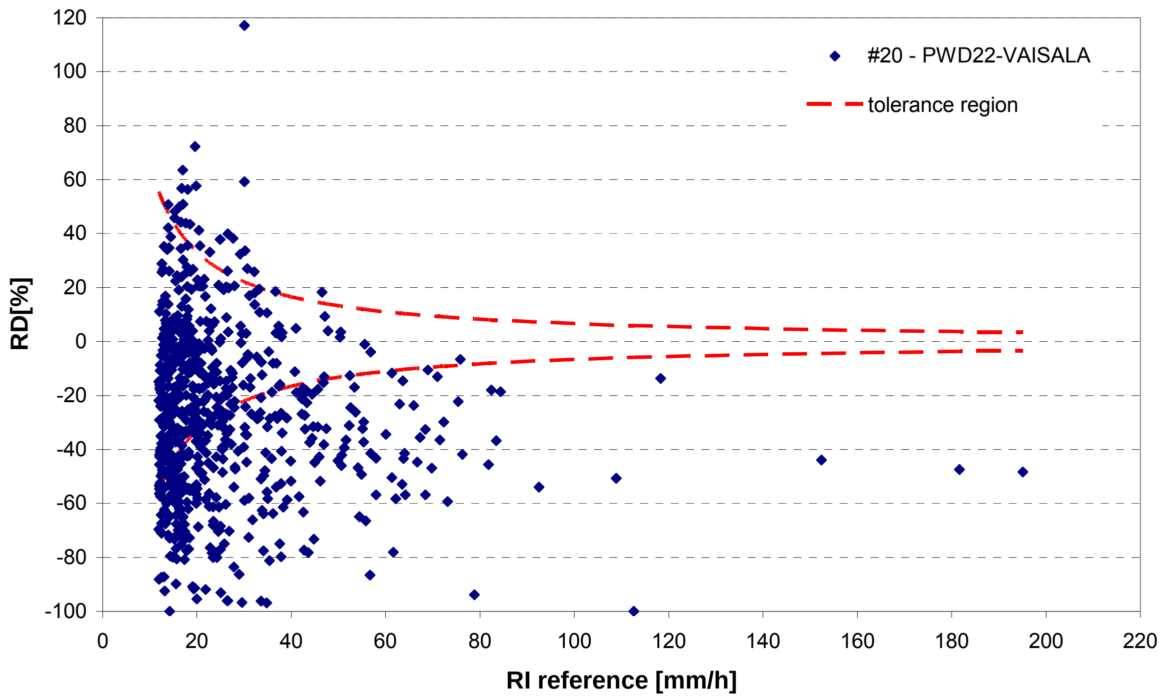
- Output: data message by serial interface RS485 in ASCII protocol - Polled mode (every 1min)
- Data update cycle : 15 sec (running average)
- Rainfall parameters: 1 min RI[mm/h] (running average updated evry 15 sec); rainfall accumulation [mm].
- Transfer function for 1-min RI: none.

#20- PWD22 –VAISALA in the field

Field Intercomparison Measurements

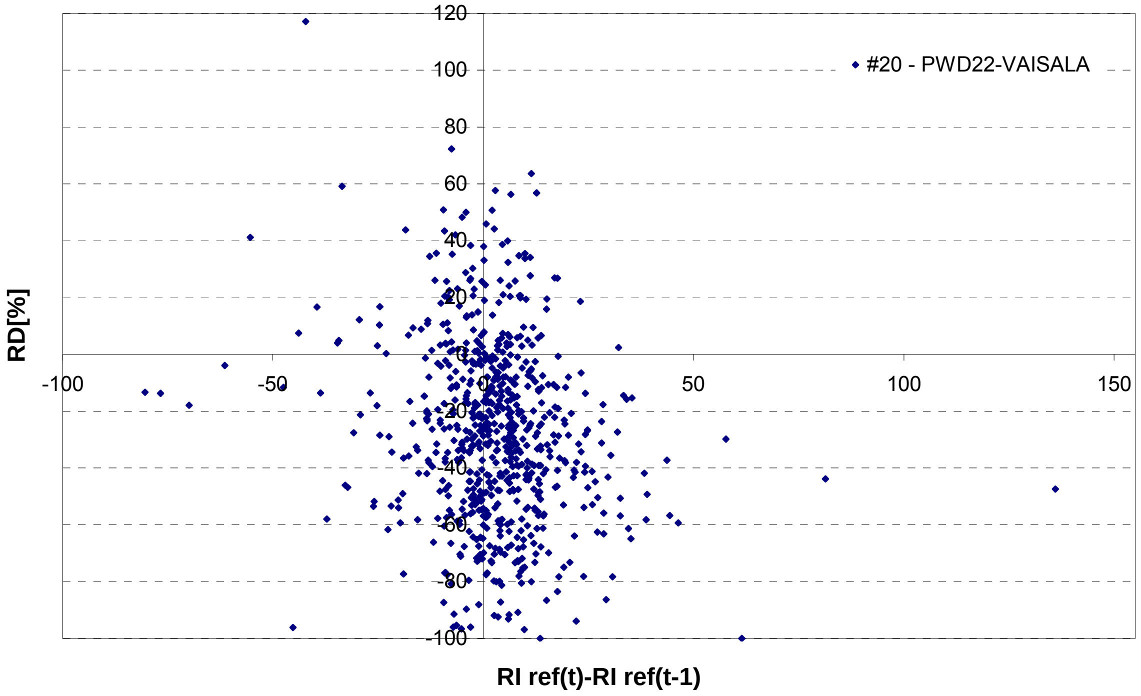
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by PWD22 VAISALA and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



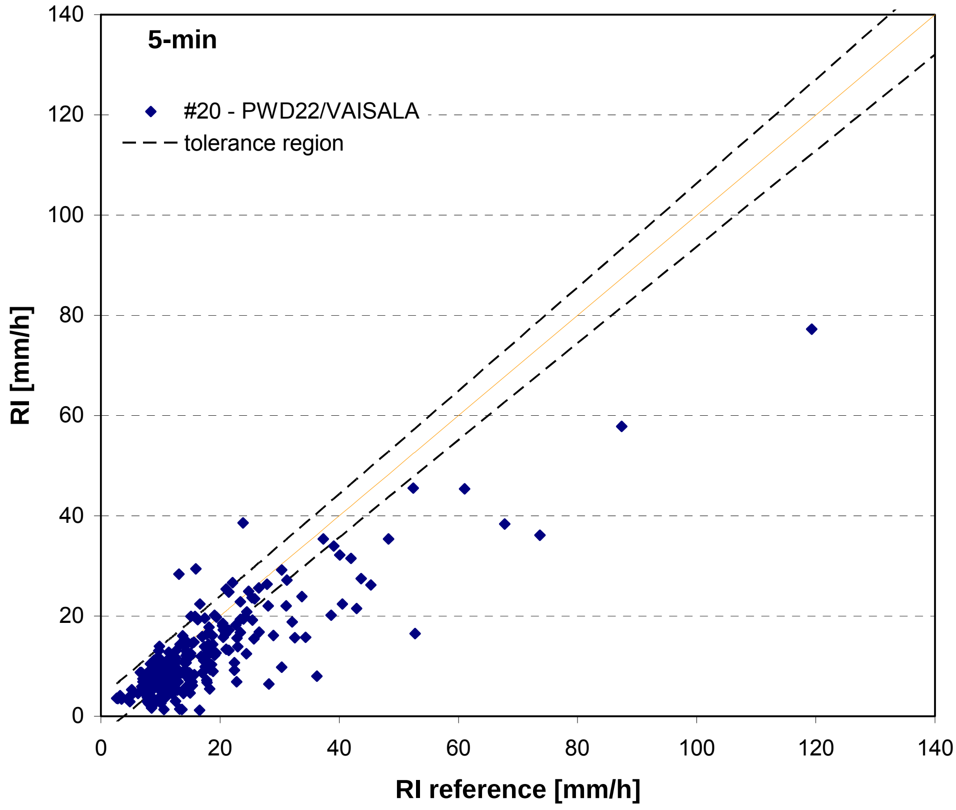


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by PWD22 VAISALA and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ***($RI=a\cdot(RIref)^b$)***	**a**	**b**	**R^2**
#20 **PWD22 VAISALA**	0.81	0.94	0.51

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

For technical reasons, the measurement height of PWD22 was 180 cm above ground (80 cm more then the other gauges) (For details see Final Report, sec. 3.2). This fact is not considered as a cause of additional errors.

The field results show an underestimation and some dispersion. The dispersion is slightly reduced on 5 minutes data and a linear underestimation trend is more visible, not really reduced on 5 minute data.

The underestimation is systematic above 40-50 mm/h (on 1 minute time scale).

This instrument has a possibility of user adjustement in the field, however this was not requested by manufacturer for this Intercomparison. Therefore, default value was used by the instrument.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*

D1: Status parameter (processed by the automatic QC)

If D1=1# → Error

If D1=01, 02, 03, 04, 2# → Doubtful (data to be checked for a-posteriori validation)

D2: Sensor of temperature (processed by the automatic QC)

If D2>55 → Error

Data availability (1 min):

- Valid Data: 100.0%. The automatic QC detected “warnings messages” from the status parameter values: cleaning of lenses and hoods was performed afterwards.

Maintenance:

- Regular visual inspection to lenses, hoods and rain detector;
- Regular visibility calibration checks and calibration (if needed) by means of the field calibrator Vaisala PWA11 according to the schedule recommended by Manufacturer;
- Depending on weather conditions, on visual checks reports and on status parameter warnings: cleaning of the transmitter and receiver lenses and hoods by means of the cleaning kit; cleaning of the rain detector and visibility calibration check.

Malfunctioning:

- The automatic QC detected several “warnings codes” from the status parameter on 16/10/2008: the lenses were cleaned and the calibration was checked afterwards but no calibration was necessary.

PARSIVEL OTT
- Germany -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Optical disdrometer (infrared laser diode, 650nm 3mW)
- Measurement surface: 54cm^2
- Measured values: intensity, quantity and type of precipitation (drizzle, rain, snow, soft hail, hail and mixed precipitation); visibility (MOR) in precipitation; radar reflectivity; number of detected particles; present weather codes.
- Range of measurement : 0-1200 mm/h
- 1-minute resolution: 0.001 mm/h

Data output

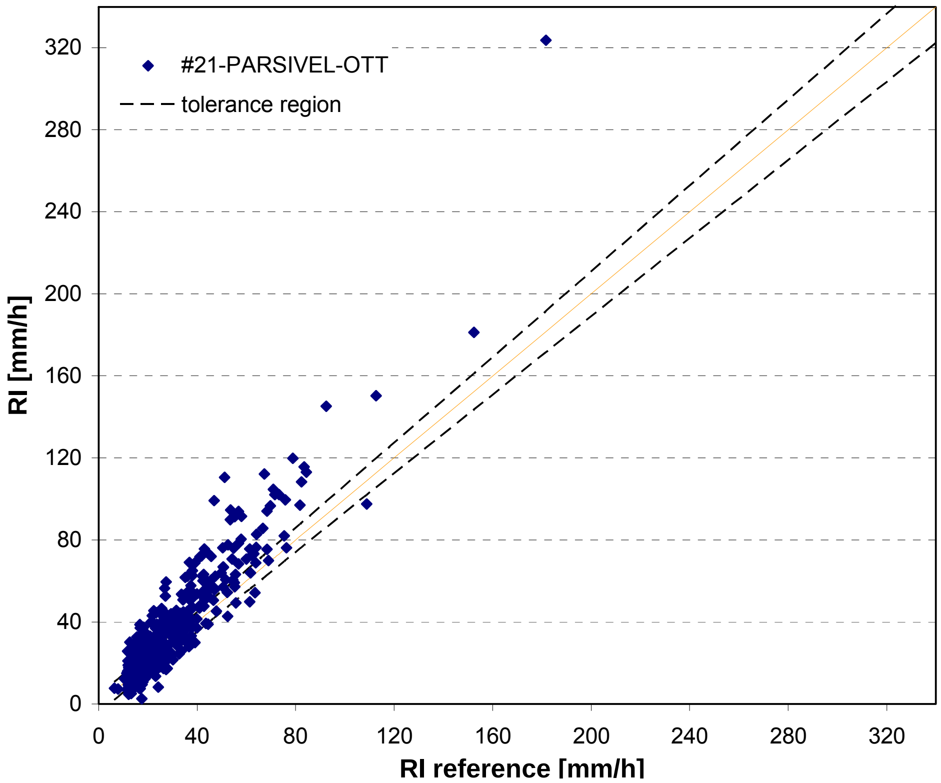
- Output: data message by serial interface RS485 in ASCII protocol - Polled mode (every 1min). (*Firmware version 1.04*).
- Data update cycle : 1 min (synchronized by the data acquisition polling command)
- Rainfall parameters: 1 min RI[mm/h]; rainfall amount [mm] (since start of device).
- Transfer function for 1-min RI: none

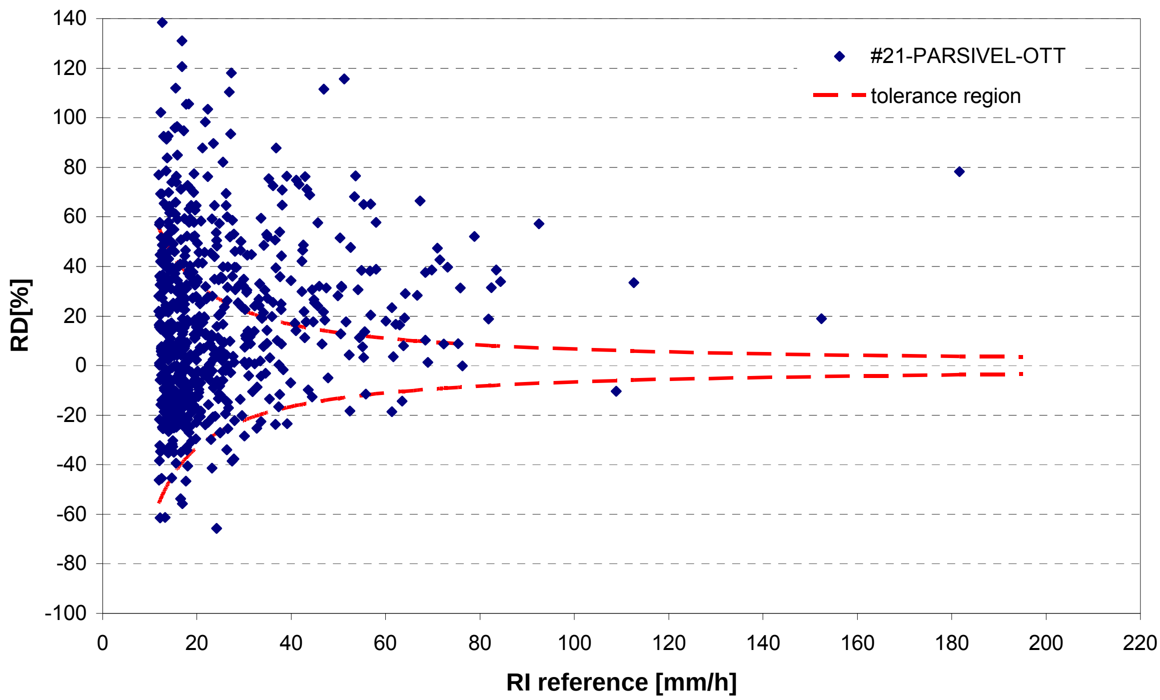
#21- PARSIVEL –OTT in the field

Field Intercomparison Measurements

(Parsivel s/n 192245)

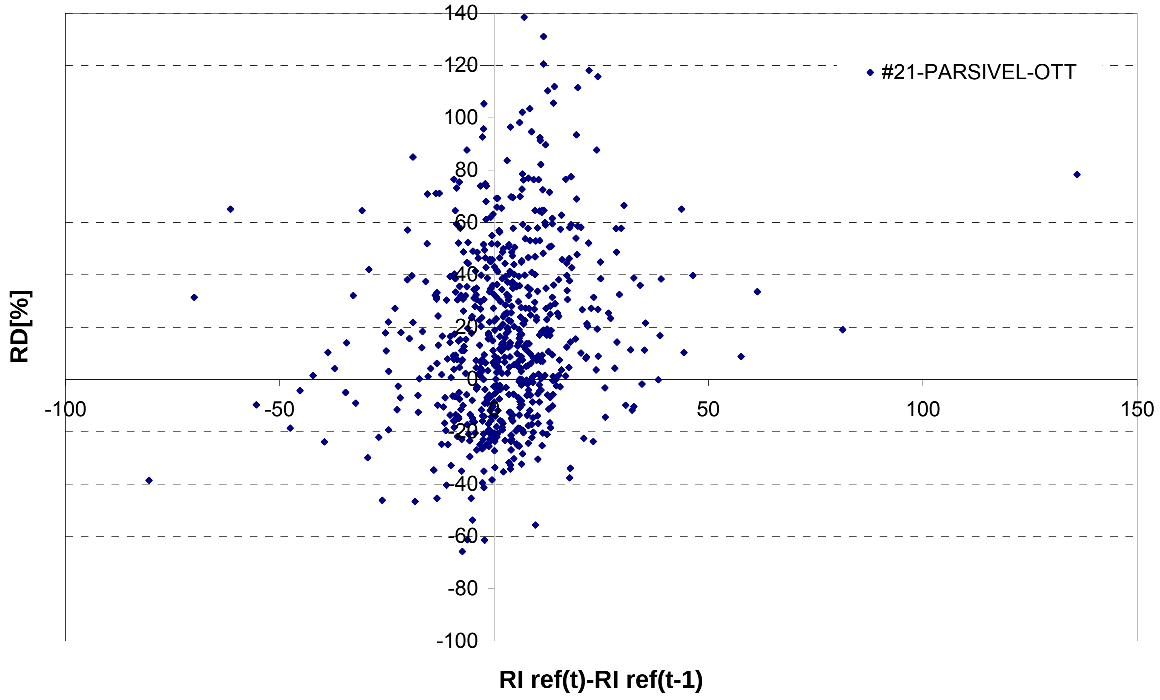
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by PARSIVEL OTT and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



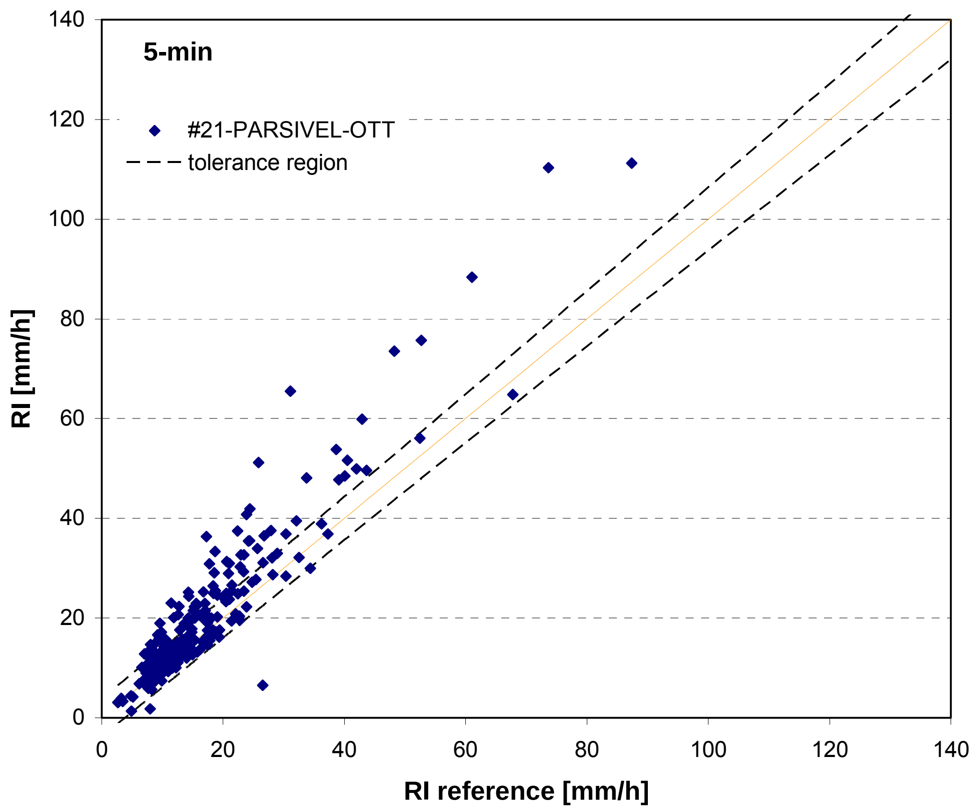


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by PARSIVEL OTT and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

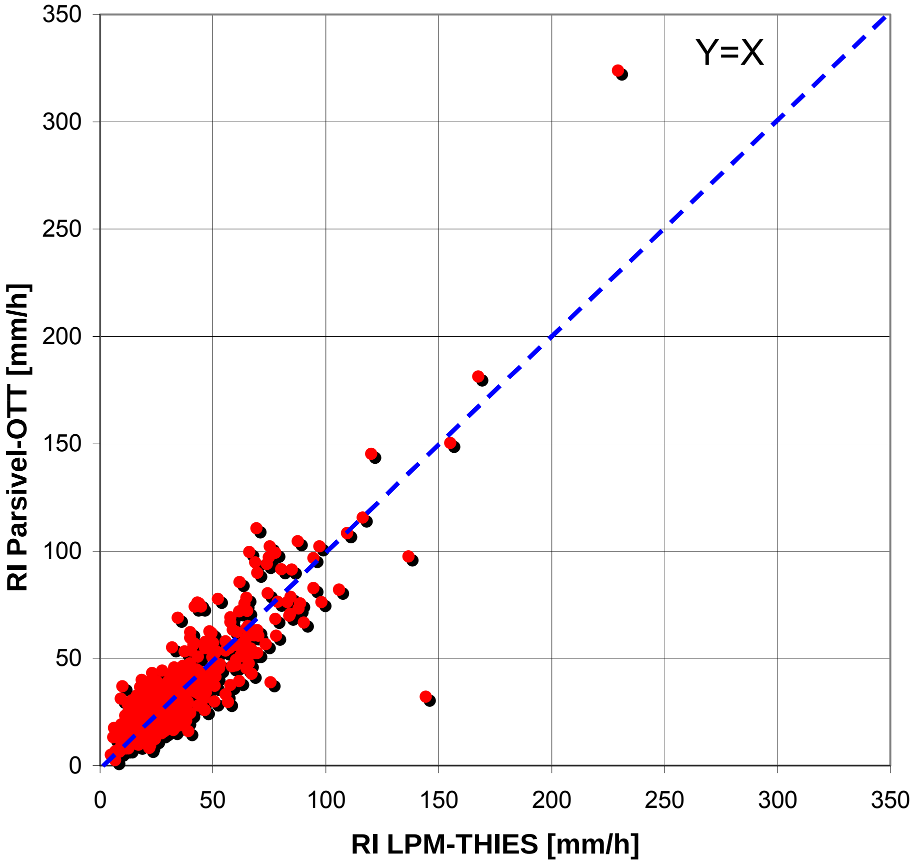
Parameters ***(RI=a·(RIref)^b)***	**a**	**b**	**R^2**
#21 PARSIVEL OTT	0.82	1.10	0.77

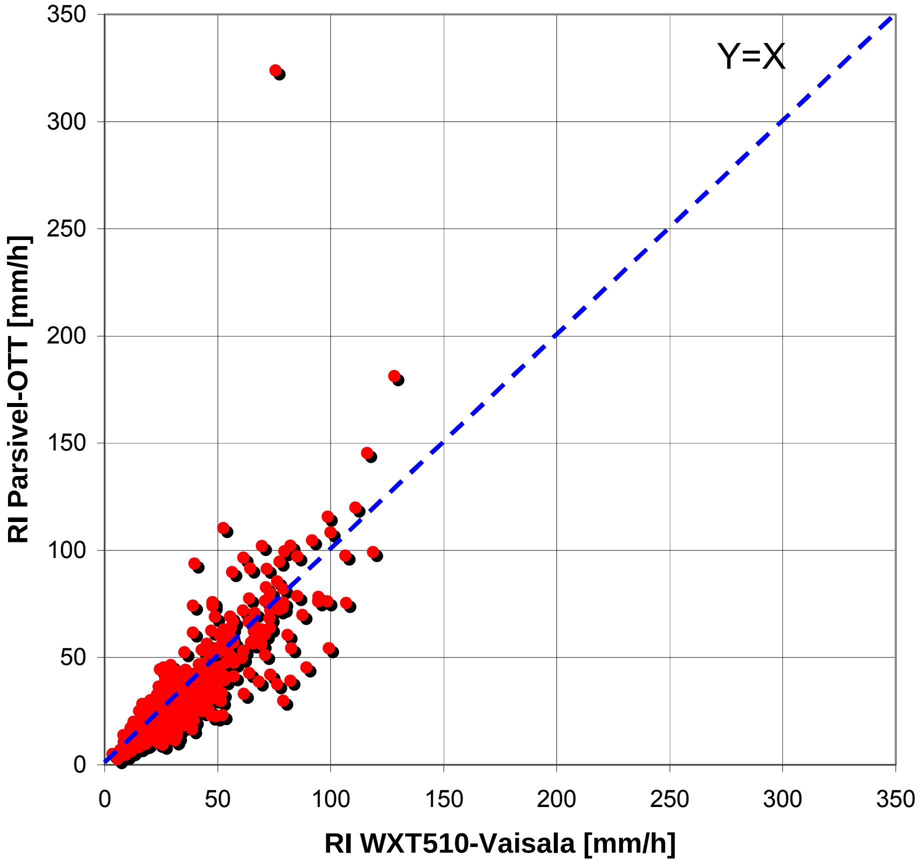
(Parameters a, b, R^2 are determined by fitting the function RI=a·(RIref)^b, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The field results show an over-estimation and a small dispersion, not reduced on 5 minute data. The results are close to the results of the THIES-LPM and WXT510-VAISALA optical disdrometers.

The graphs below compare the 1 minute RI data of these disdrometers.





Apart from really few outliers, the experimental points in the plots show a very comparable behaviour. It means that the measuring principle adopted by the optical disdrometers gives the same results with respect to the reference RI, though the manufacturer's calibration procedures are totally different.

(Due to few outliers, the range of the scatter plot for optical disdromiters is larger than the one on other Data Sheets).

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*

D1: Status parameter (processed by the automatic QC)

If D1≠0 → Doubtful (data to be checked for a-posteriori validation)

D2: Sensor of temperature

Data availability (1 min):

- Valid Data: 98.2%. Random diagnostic alarms (status parameter ≠0) detected by the automatic QC. Flagged data occurred randomly in all weather conditions, during nighttimes and daytimes. The data analysis of Parsivel OTT was performed though the spare instrument (s/n 192245).

Maintenance:

- Regular inspection;
- Sensor check by means of objects through the invisible laser beam and output verification (Precipitation not identified);
- Depending on local weather conditions and status parameter: cleaning of the laser's protective glass; removal of dirt and dust from the splash protector and removal of obstacles from light pathway (e.g. insect's nests, ect).

Malfunctioning:

- It was found out that AQC flagged data were related to a decrease of laser's signal amplitude, not related to the contamination of the laser's protective glasses. The first instrument (s/n 192244) was replaced by the spare on 10/04/2008.

THIES Laser Precipitation Monitor
- Germany -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: optical disdrometer (infrared laser diode, 785nm max0,5mW)
- Measuring area: 47 cm^2
- Measured values: intensity, quantity and type of precipitation (drizzle, rain, snow, soft hail, hail and mixed precipitation; particle spectrum (distribution of particles over classes of diameter and speed); visibility; radar reflectivity;
- Range of measurement : > 250 mm/h
- 1-minute resolution: 0.005 mm/h

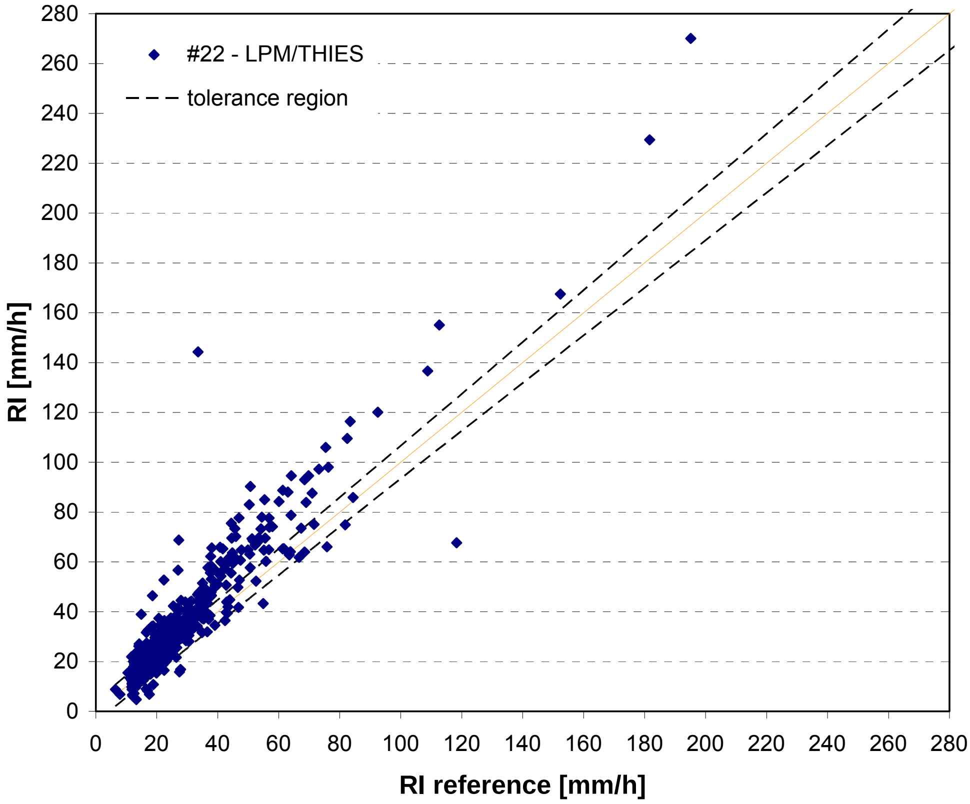
Data output

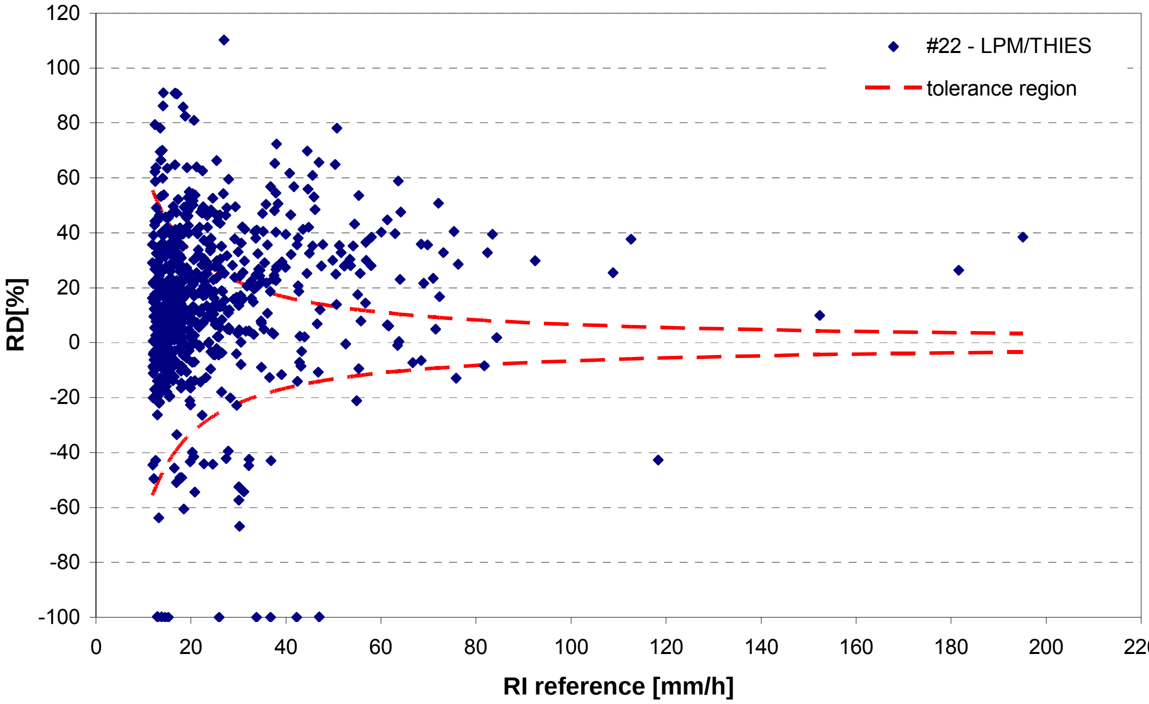
- Output: data message by serial interface RS485 in ASCII protocol - Automatic mode (every minute). (*Software version: V2.2x STD*)
- Data update cycle : 1 min
- Rainfall parameters: 1 minute intensity [mm/h] liquid precipitation (RI_{1min}[mm/h]);; precipitation amount [mm]; 1 minute intensity [mm/h] total (solid + liquid) and solid precipitation.
- Transfer function for 1-min RI: none.

#22- LPM –THIES in the field

Field Intercomparison Measurements (LPM s/n295)

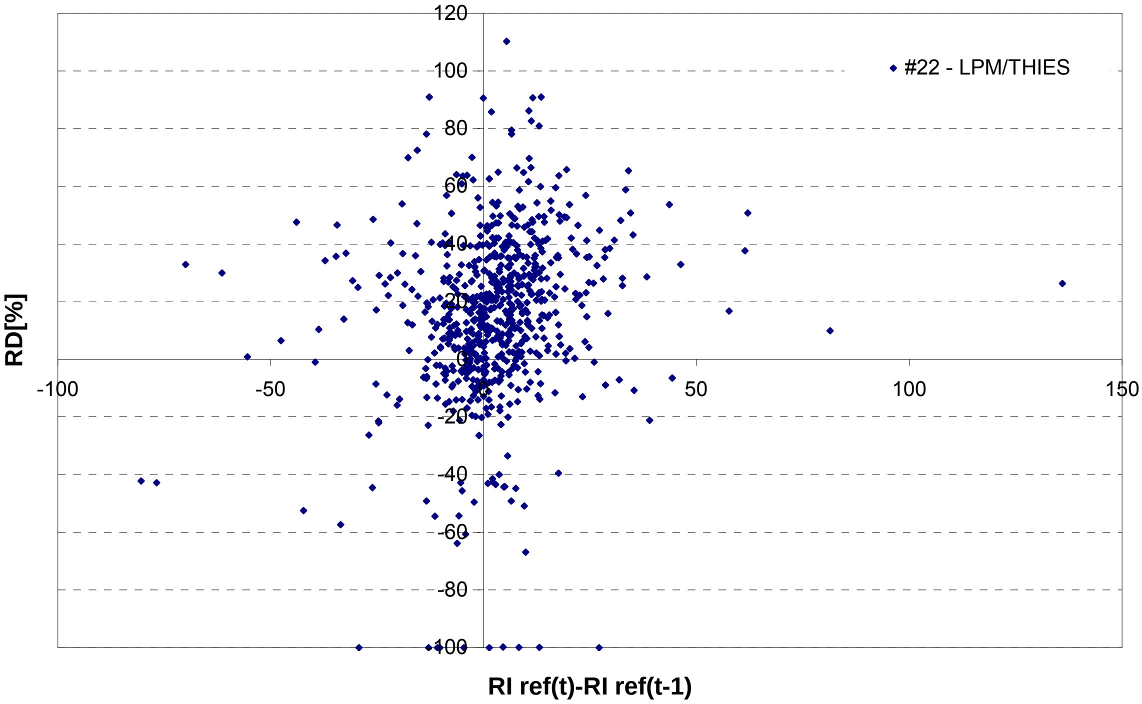
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by LPM-THIES and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



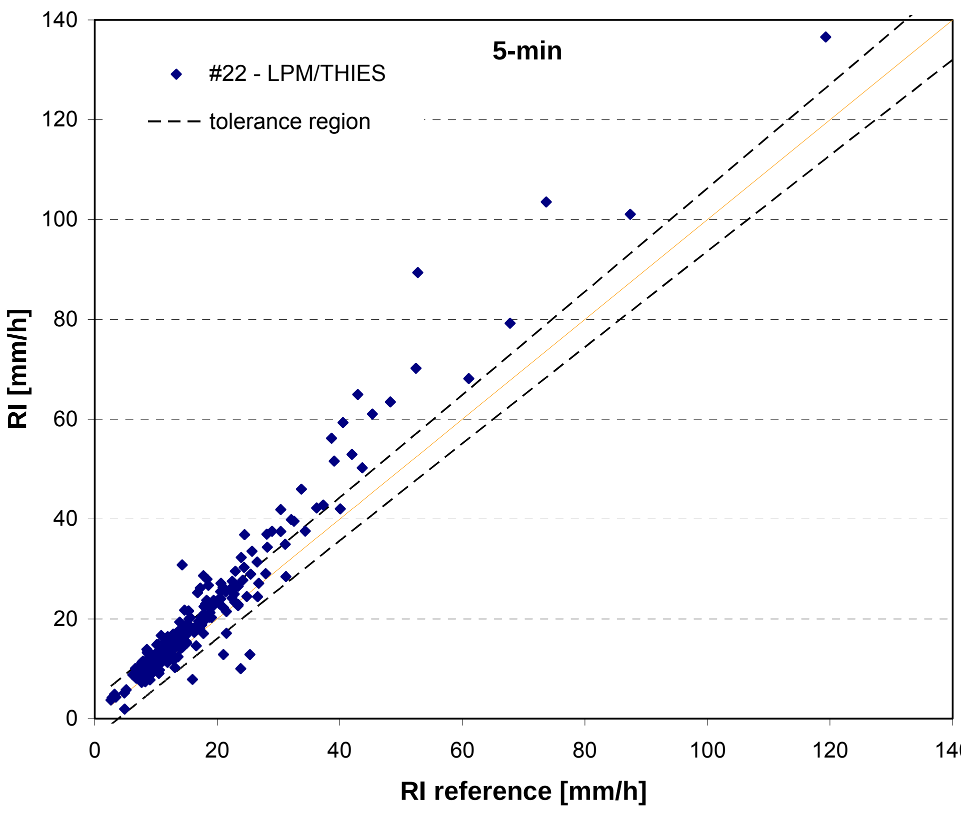


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by LPM-THIES and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



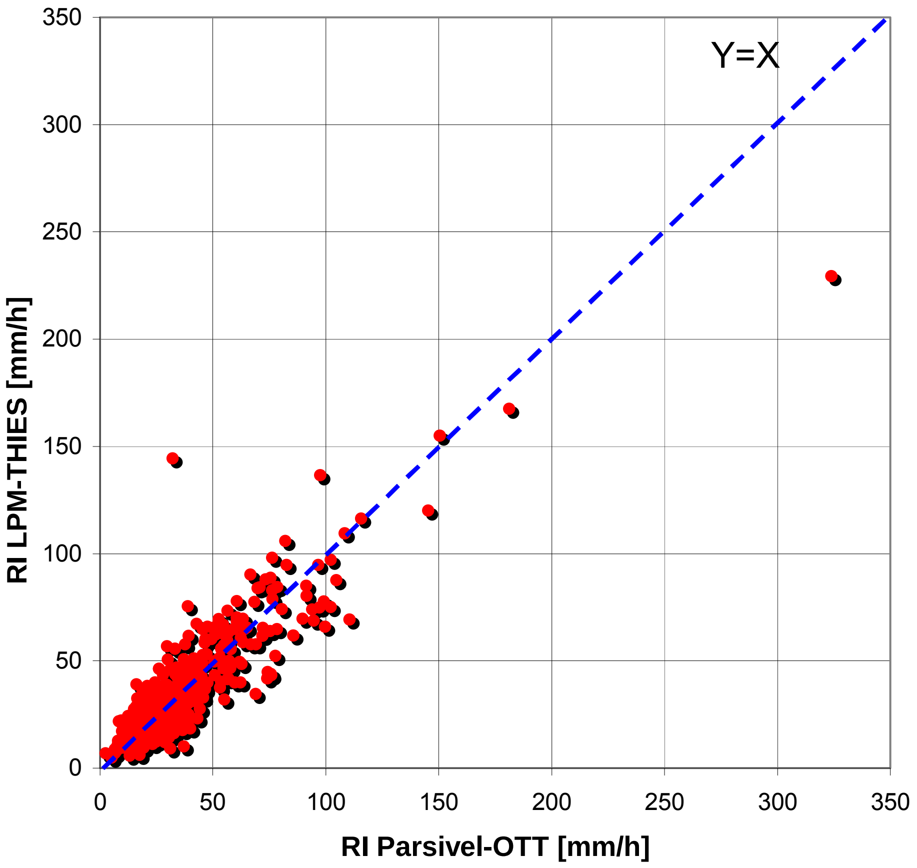
Summary Table

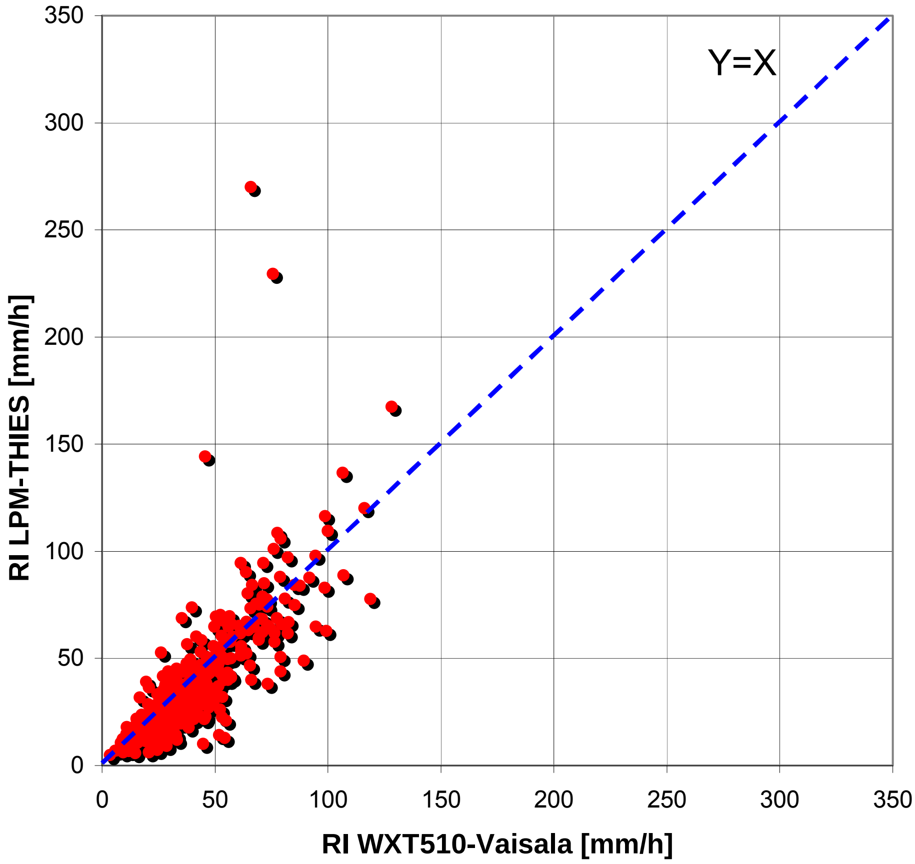
Parameters ***($RI=a\cdot(RIref)^b$)***	**a**	**b**	**R^2**
#22 **LPM THIES**	0.93	1.07	0.80

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The field results show an over-estimation and a small dispersion, not reduced on 5 minute data. The results are close to the results of the Parsivel-OTT and WXT510-VAISALA optical disdrometers. The graph below compares the 1 minute RI data of these disdrometers.





Apart from really few outliers, the experimental points in the plots show a very comparable behaviour. It means that the measuring principle adopted by the optical disdrometers gives the same results with respect to the reference RI, though the manufacturer's calibration procedures are totally different.

(Due to few outliers, the range of the scatter plot for optical disdromiters is larger than the one on other Data Sheets).

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*

D1: Measuring quality (processed by the automatic QC)

If D1>50 → Doubtful (data to be checked for a-posteriori validation)

D2: Laser status parameter (processed by the automatic QC)

If D2≠0 → Error

D3: (processed by the automatic QC)

If D3≠0 → Error

D4: Control voltage parameter (processed by the automatic QC)

If D4<4005 or D4>4015 → Error

D5: Optical control output (processed by the automatic QC)

If D5<2300 or D5>6500 → Error

Data availability (1 min):

- Valid Data: 99.9%: one missing data per day due to synchronization procedure; rare episodes with measuring quality<50% and control voltage out limits;
- Because the storage of parameters in raw data files was limited to 13 (8 precipitation data and 5 diagnostic parameters) for each participating instrument, a more extended THIES LPM output telegram content was stored in separated data files (file name: #22_yyyy_nnn.dat) which will be provided together with the Intercomparison dataset. (O*n 10th September 2007, the Participant agreed that telegram columns 81-520 (precipitation spectra) were not recorded because, for data acquisition technical reasons, the full telegram was impossible to be stored).*

Maintenance:

- Regular inspection and LED's control;
- Sensor check by means of objects through the invisible laser beam and output verification (Precipitation not identified);
- Depending on local weather conditions: cleaning of glass panes, removal of dirt, dust and insects nests.

Malfunctioning:

- On 06/05/2008 the first disdrometer (s/n 294) was removed and replaced by the spare (s/n 295) because of soft and transparent halos over glass panes and for accumulated sums of precipitation mostly less then the reference (unusual for this kind of instrument). The sensor s/n 294 was checked, calibrated and tested in the field by the manufacturer: no particular anomalies were detected. Data can be used without resctriction.

Weather Transmitter WXT510 VAISALA - Finland -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Impact disdrometer (Vaisala RAINCAP® sensor 2-technology, piezoelectric sensor with signal proportional to raindrops volume).
- Measured values: quantity, duration and type of precipitation (rain, hail); rain/hail intensity and peak intensity (computed parameters); pressure, temperature, humidity, wind speed and direction.
- Impacts collecting surface: 60 cm^2
- Range of measurement : 0-200 mm/h
- 1-minute resolution: 0.1 mm/h

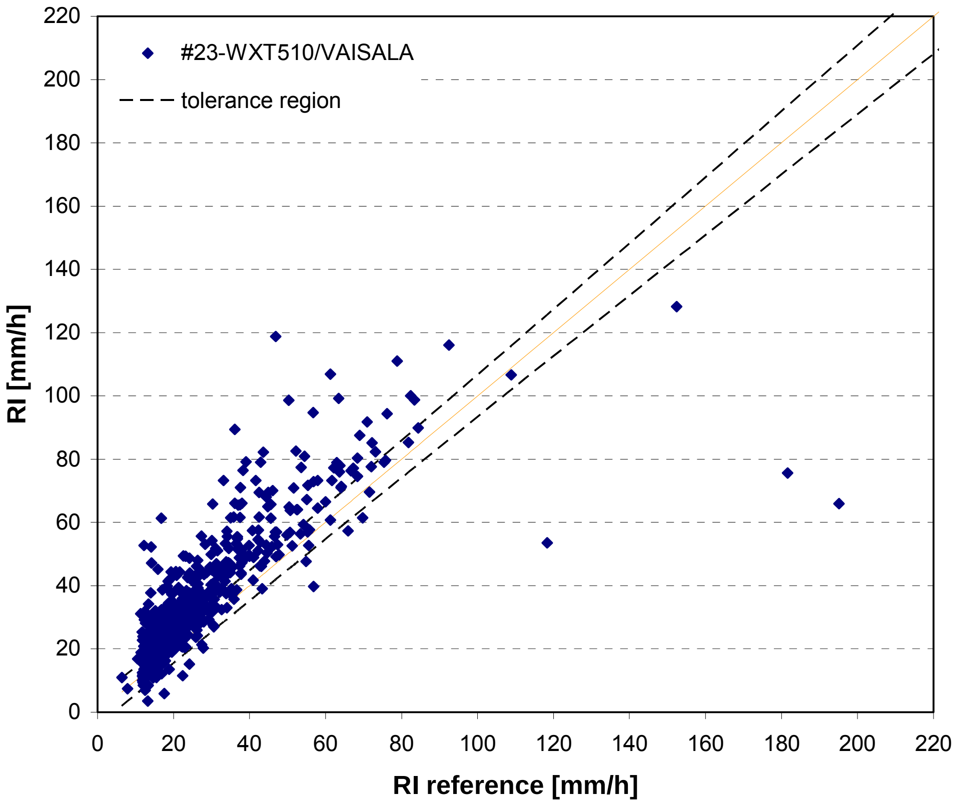
Data output

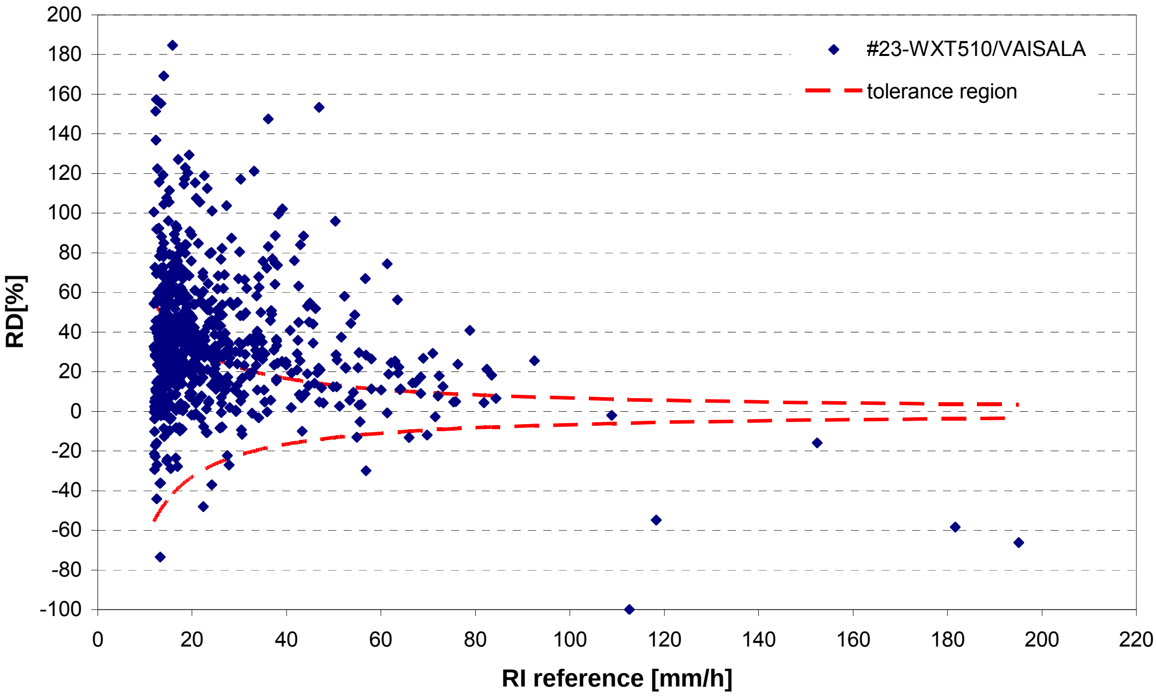
- Output: data message by serial interface RS485 in ASCII protocol – Polled mode (every minute)
- Data update cycle : 10s
- Rainfall parameters: rainfall accumulation [mm]; rainfall duration [s] (counting each 10-seconds increment whenever droplet detected); RI [mm/h] (running one minute average updated in 10-seconds steps).
- Transfer function for 1-min RI: none.

#23-WXT510 - VAISALA in the field

Field Intercomparison Measurements

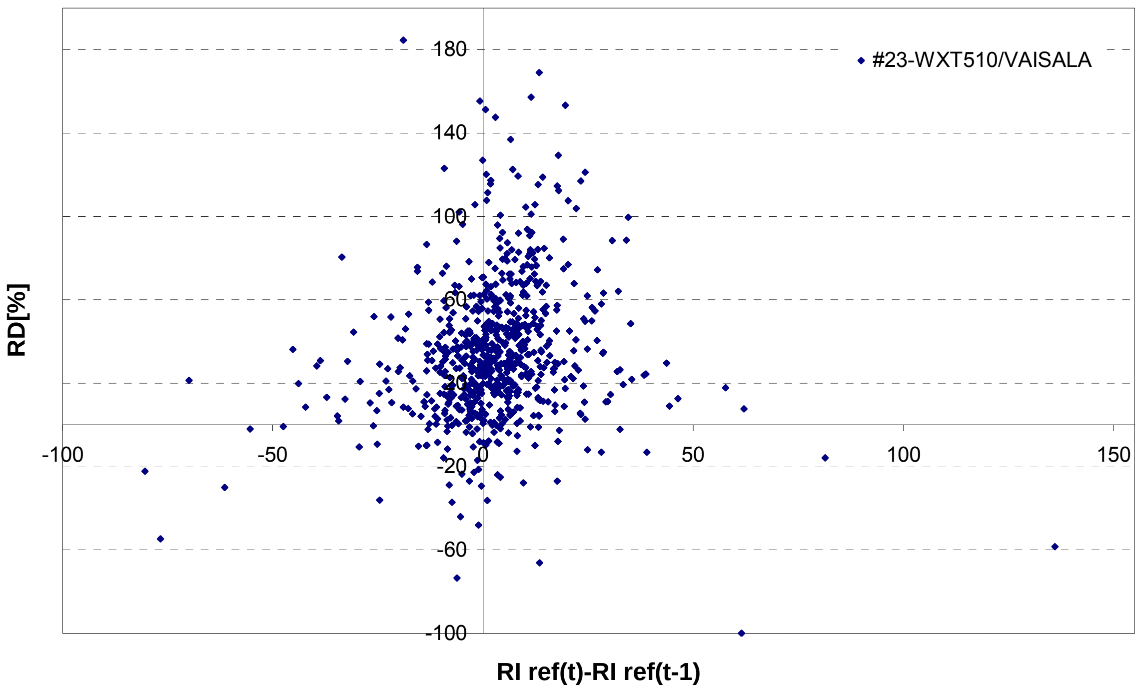
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by WXT510-VAISALA and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



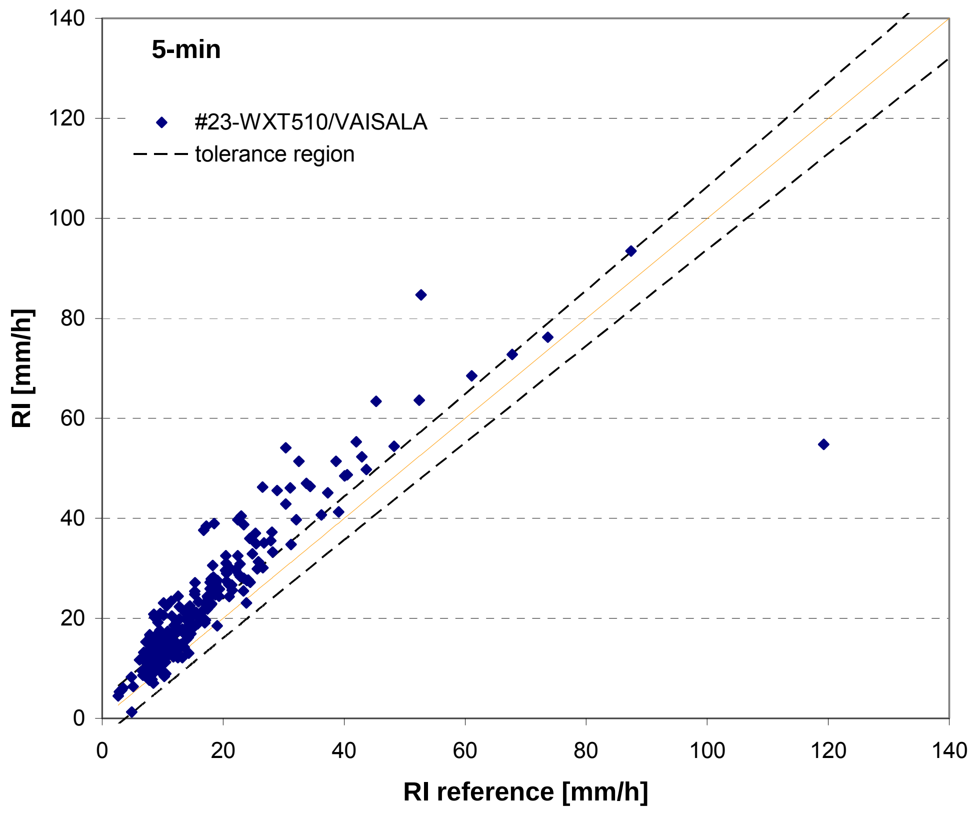


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by WXT510 VAISALA and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ***($RI=a\cdot(RIref)^b$)***	**a**	**b**	**R^2**
#23 WXT510 VAISALA	1.72	0.91	0.74

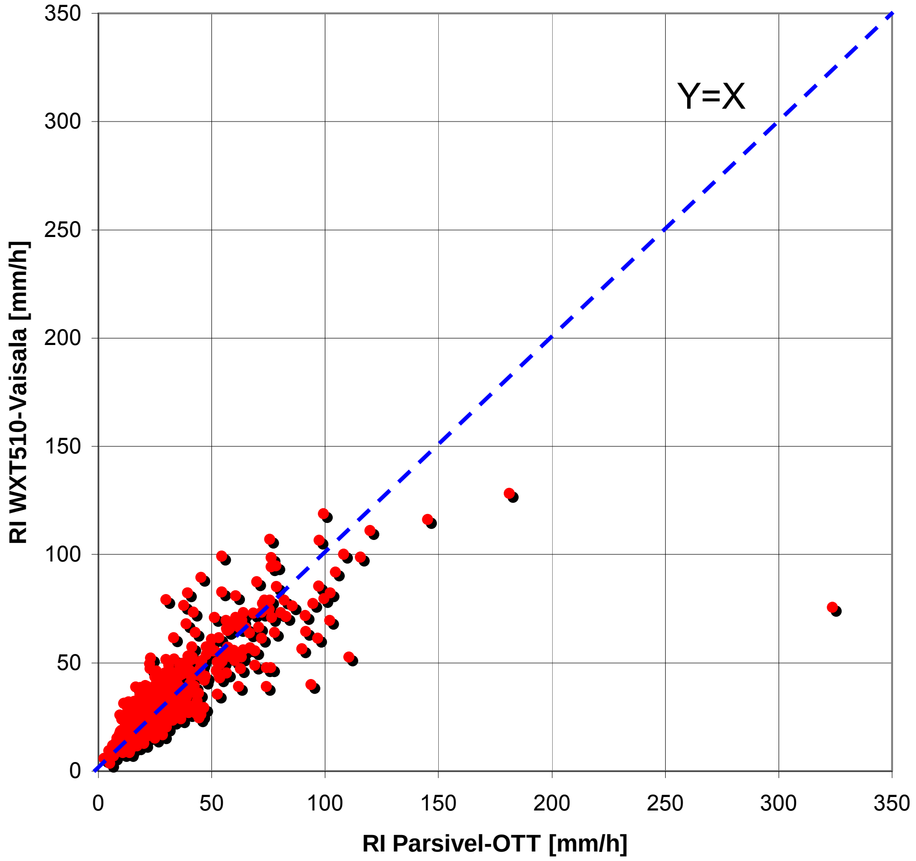
(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

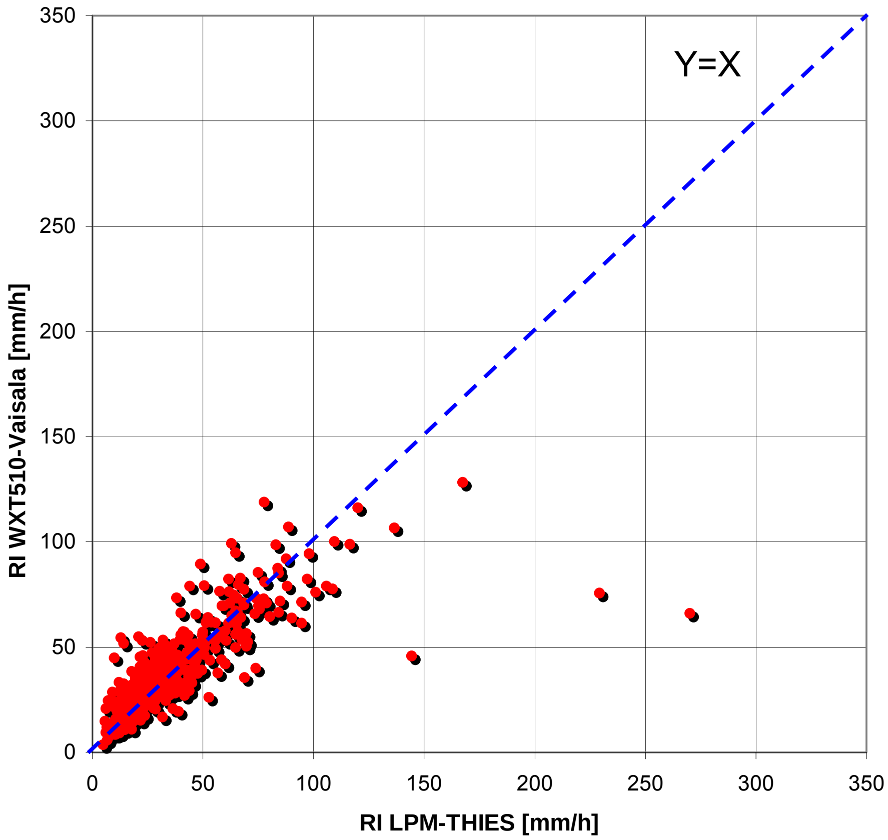
Comments

The field results show an overestimation (40 to 100%) for RI under 100 mm/h and an underestimation above. This underestimation for high RI may be caused by thin water layer on the detection plate, thus minimizing the impact of the droplets and the associated derived volume; for high RI, water my not drain off the convex detection plate fast enough.

The dispersion of data is reduced on 5 minutes data. The other disdrometers (optical) also show an overestimation.

The graph below compares the 1 minute RI data of Vaisala WXT510 with the optical disdrometers (LPM-Thies and Parsivel-OTT).





Apart few outliers, the experimental points in the comparison plots show reasonably similar behaviour. It means that the measuring principle adopted by the optical and impact disdrometers gives comparable results with respect to the reference RI, though the manufacturer's calibration procedures are totally different.

(Due to few outliers, the range of the scatter plot for optical disdromiters is larger than the one on other Data Sheets).

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
No diagnostic data and error code in data message

Data availability (1 min):

- Valid Data: 100%.

Maintenance:

- Regular visual inspection;
- Precipitation sensor cleaning (leaves or particles on the steel cover).

Malfunctioning:

- None

ANS410/H-EIGENBRODT
- Germany -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: weighing rain gauge with pressure measurement and equipped with siphoning system (automatic emptying).
- Collector area: 200 cm^2
- Range of measurement : 0-1200 mm/h
- 1-minute resolution: 0.6 mm/h

Data output

- Output: data message by serial interface RS485 in ASCII protocol - Polling mode (every minute).
- Data update cycle : 1 min
- Rainfall parameters: 1 minute rainfall accumulation RA_{1min}[mm]
- Transfer function for 1-min RI: $RI_{1min}[mm/h] = RA_{1min}[mm]/[min]\cdot 60[min/h]$

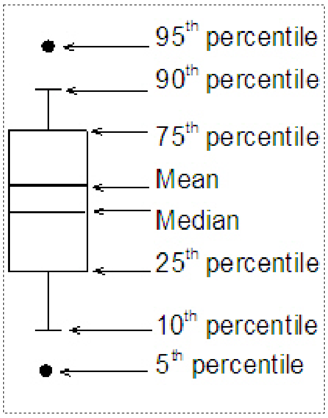
#24-ANS410/H - EIGENBRODT
in the field

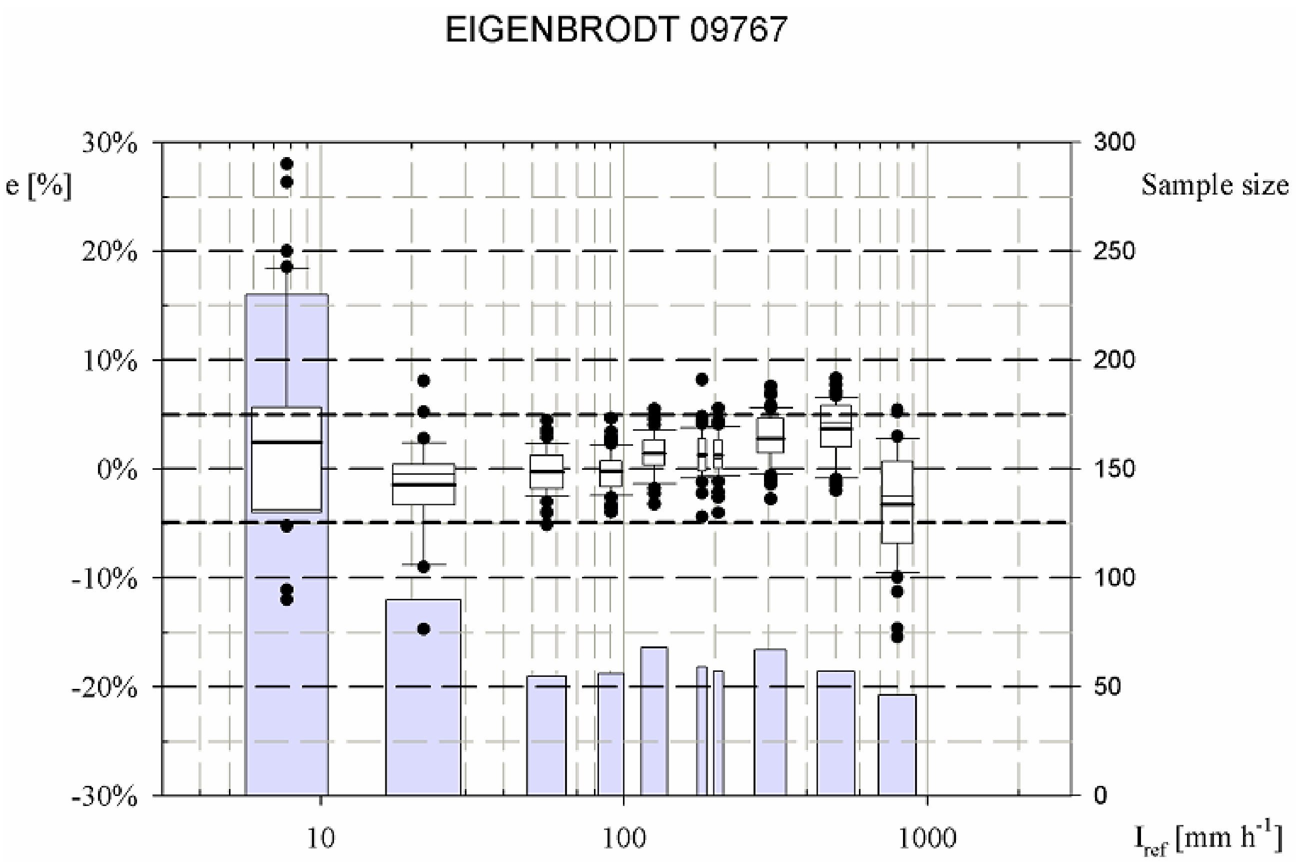
Laboratory test

The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

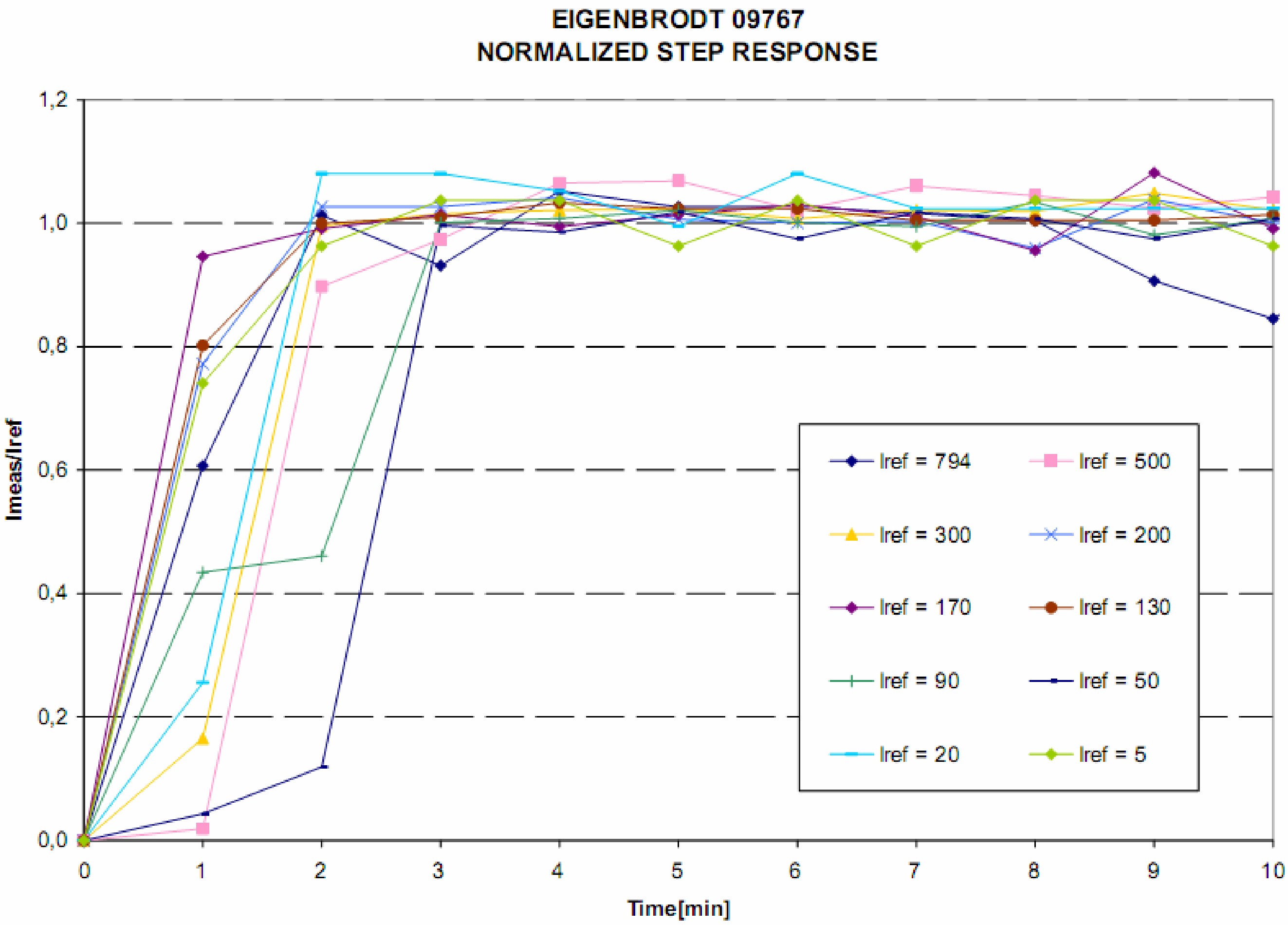
The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute variability of the observed instruments performances and the size of the sample used for calculation of the statistics at each reference intensity. Box plots synthetically 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.





Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.



Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a Portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

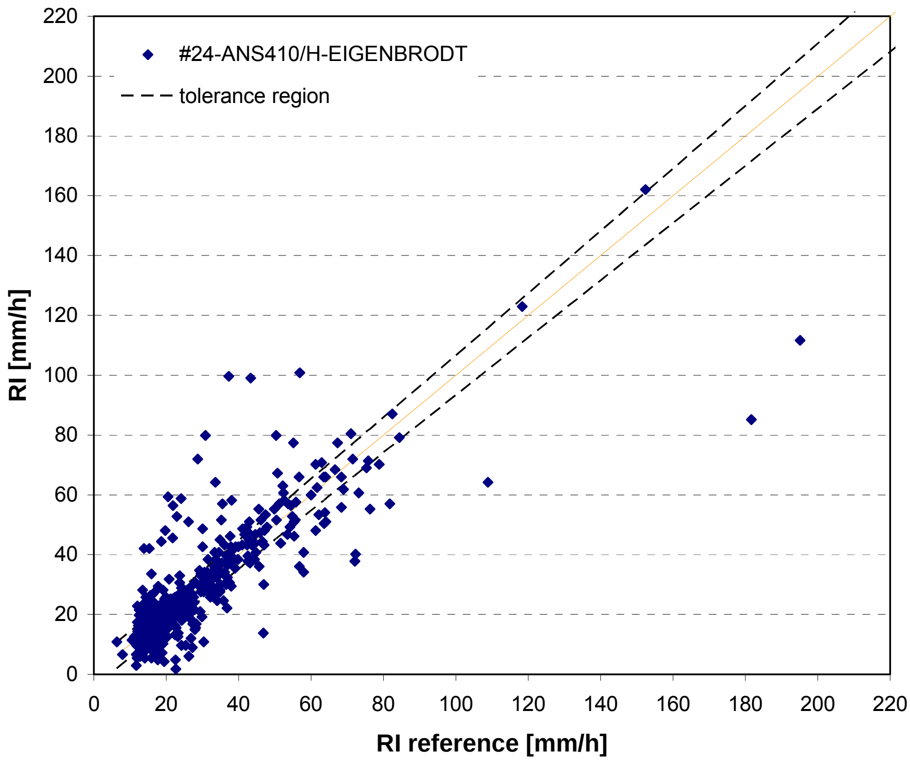
Eigenbrodt ANS410/H s/n 9767

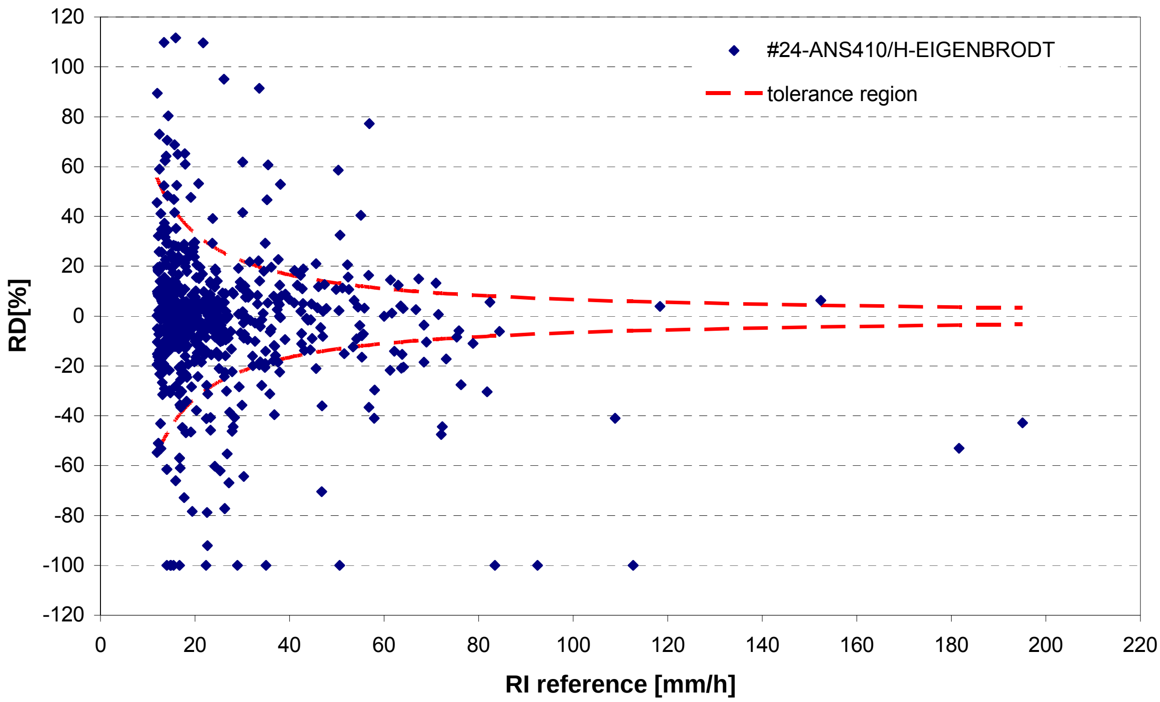
CALIBRATION	1° 11/12/07	2° 10/04/08	3° 15/04/09
RI ref [mm/h]	212.5	136.9	151.1
AVG RE [%]	2.8	2.0	3.2
[RE(-C.L.95%),RE(+C.L.95%)][%]	[1.9, 3.8]	[1.0, 2.9]	[2.5, 4.0]

(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%

Field Intercomparison Measurements

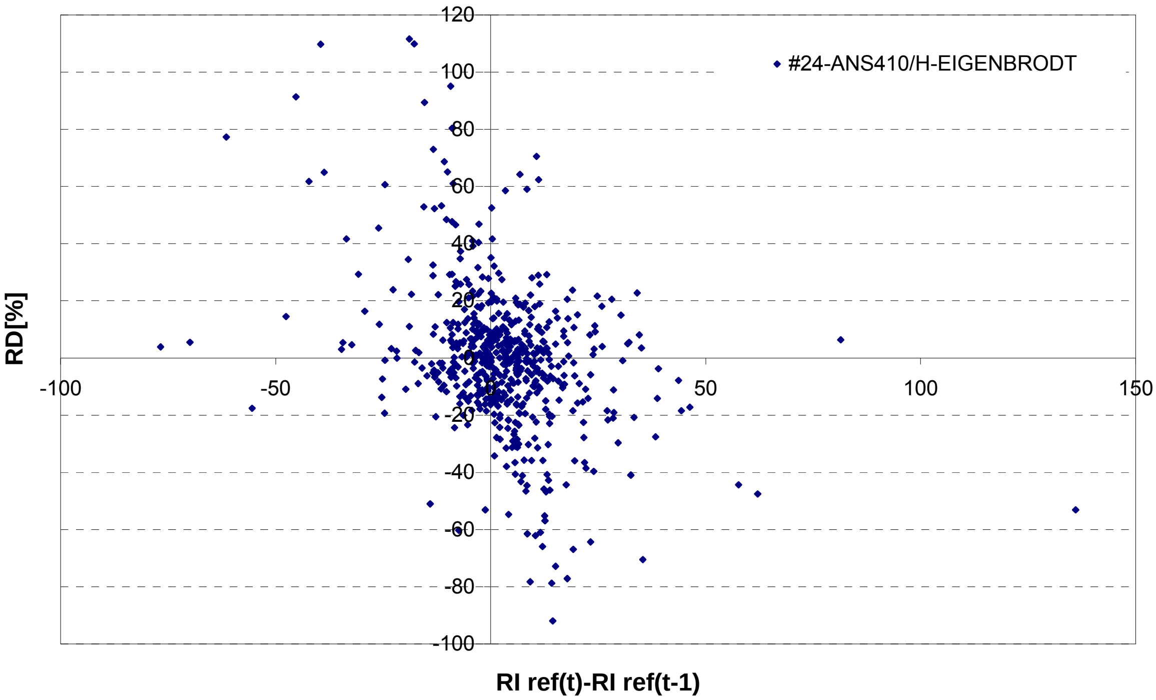
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by ANS410/H EIGENBRODT and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



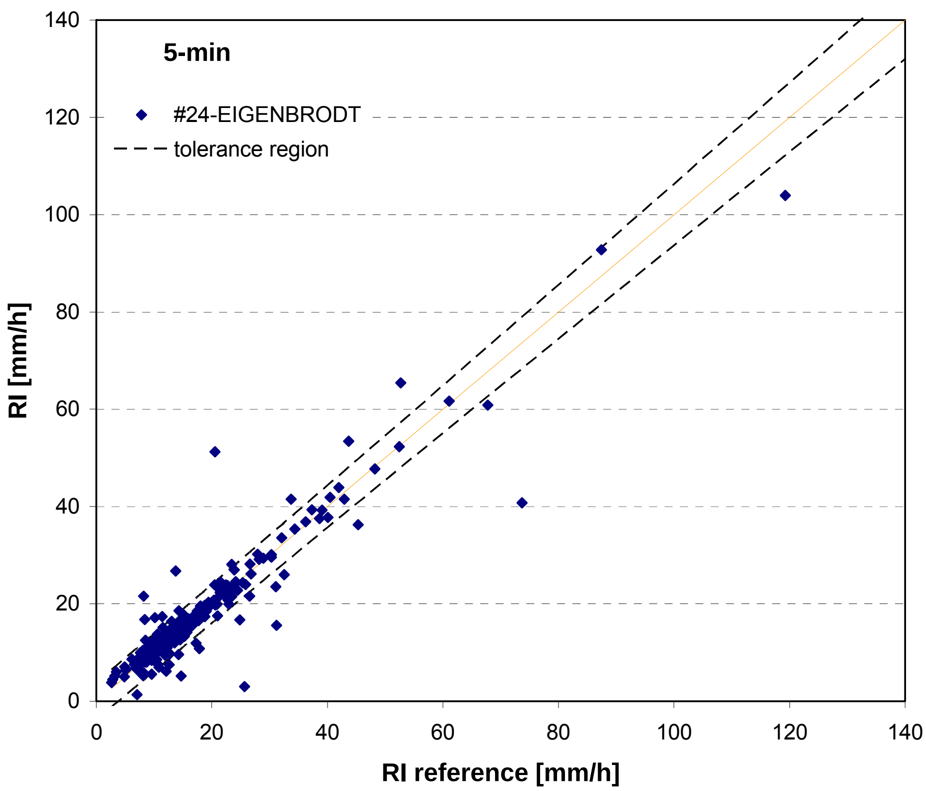


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by ANS410/H EIGENBRODT and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ($RI=a\cdot(RIref)^b$)	a	b	R^2
#24 ANS410/H EIGENBRODT	1.09	0.96	0.67

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The laboratory calibration shows good results, with a small average overestimation above 100 mm/h. The field calibrations give consistent results with the laboratory calibration. No drift detected from the field calibration.
The step response plot shows that the gauge response is affected by some "noise".
The field results show some dispersion, reduced but not eliminated on 5 minute data.
The RI variation response plot shows a prevalent behaviour to underestimation for increasing RI values and to overestimation for decreasing RI values. The reason for this noise pattern must be investigated further.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
D1: Status parameter (processed by the automatic QC)
If D1≠0 → Error

Data availability (1 min):

- Valid Data: 91.8%. Status errors and missing data due to a failure of the electronic communication interface. Not valid or missing data in 1min RI daily files produced by the DAQ during the periods: a) 27/11/2008 - 10/12/2008; b) 01/01/09 - 04/02/09. Daily data of 1min-RI for the period 01/01/09 - 09/01/09 (9 days) were retrieved from raw data stored into the instrument buffer memory and included into data analysis files. They are available as separated text files.

Maintenance:

- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust;

- Check of automatic emptying and cleaning of the inner part of the funnel as recommended by Manufacturer.

Malfunctioning:

- Communication problems (missing data) and status errors were reported by the intercomparison automatic quality control in two separate periods (see data availability). During the first period few checks and system tests suggested by the manufacturer were performed but no damages were found out and the system started working again on 11/12/2009. Failures reports occurred again from 01/01/09. Serial communication with the rain gauges was found malfunctioning due to the communication interface and the clock of the rain gauge was out of order without no possibility to set up again the system and without the possibility to retrieve data stored into the instrument memory buffer (except for the period mentioned above). To avoid the interruption of the data series of s/n 9796, the manufacturer decided to visit Vigna di Valle on the 3rd of February 2009 and, after the service works, created a special startup procedure for future failures. It was recognized that the problem originated from the communication interface and not from the sensor itself.

Electrical raingauge-KNMI
- The Netherlands -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: level measurement rain gauge (differential measurement of floating level) equipped with automatic emptying system (electric discharge valve).
- Collector area: 400 cm^2
- Range of measurement : 0-300 mm/h
- 1-minute resolution: 0.1 mm/h

Data output

- Output: data message by serial interface RS485 in ASCII protocol - Polling mode (every minute).
- Data update cycle : 12sec
- Rainfall parameters: RI_{12sec}[μm/h], average RI on 12sec; RI_{1min}[μm/h], average RI on 1 minute (running average updated every 12sec); max and min values of RI during last 10 minutes; precipitation duration during the last 12s, 1min and 10min. *Note: during emptying RI data are extrapolated not measured.*
- Transfer function for 1-min RI: RI_{1min} [mm/h] = RI_{1min}[μm/h] * 0.001[mm/ μm]

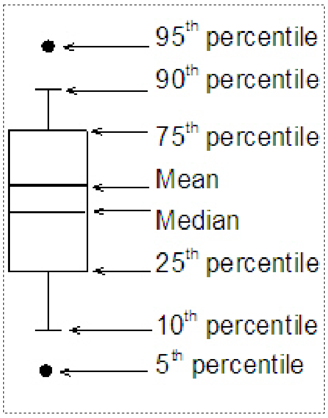
#25 Electrical raingauge-KNMI in the field

Laboratory test

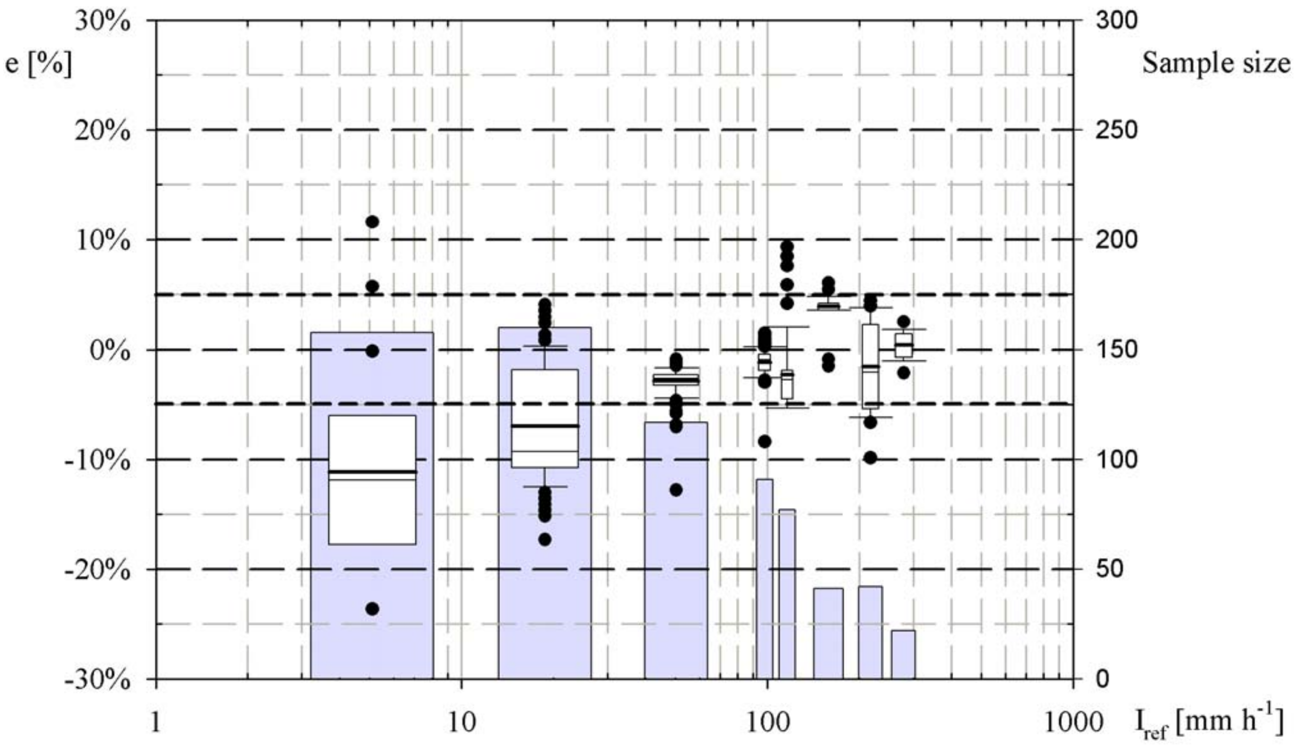
The results of the laboratory tests are shown using two different graphs: the *constant flow response plot*, where the relative error for each single gauge is plotted versus the laboratory reference intensity, and the *step response plot*, where the ratio I_{meas}(measured RI) / I_{ref} (laboratory reference RI) is plotted versus time. (*For details see Final Report, sec. 4.1.)*

Constant flow response

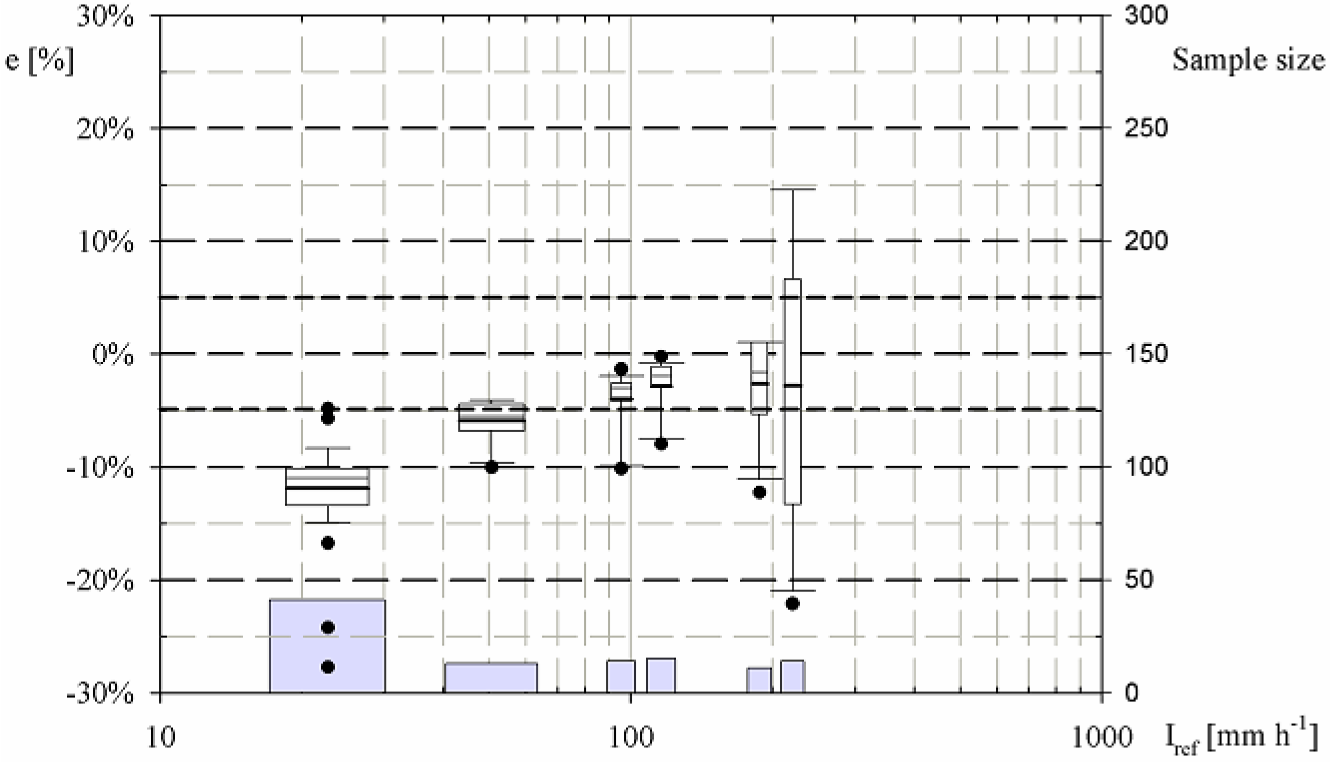
The constant flow response is presented in the form of superimposed box-plot and vertical bars, respectively reporting the one-minute variability of the observed instruments performances and the size of the sample used for calculation of the statistics at each reference intensity. Box plots synthetically 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.



KNMI 0108061_16

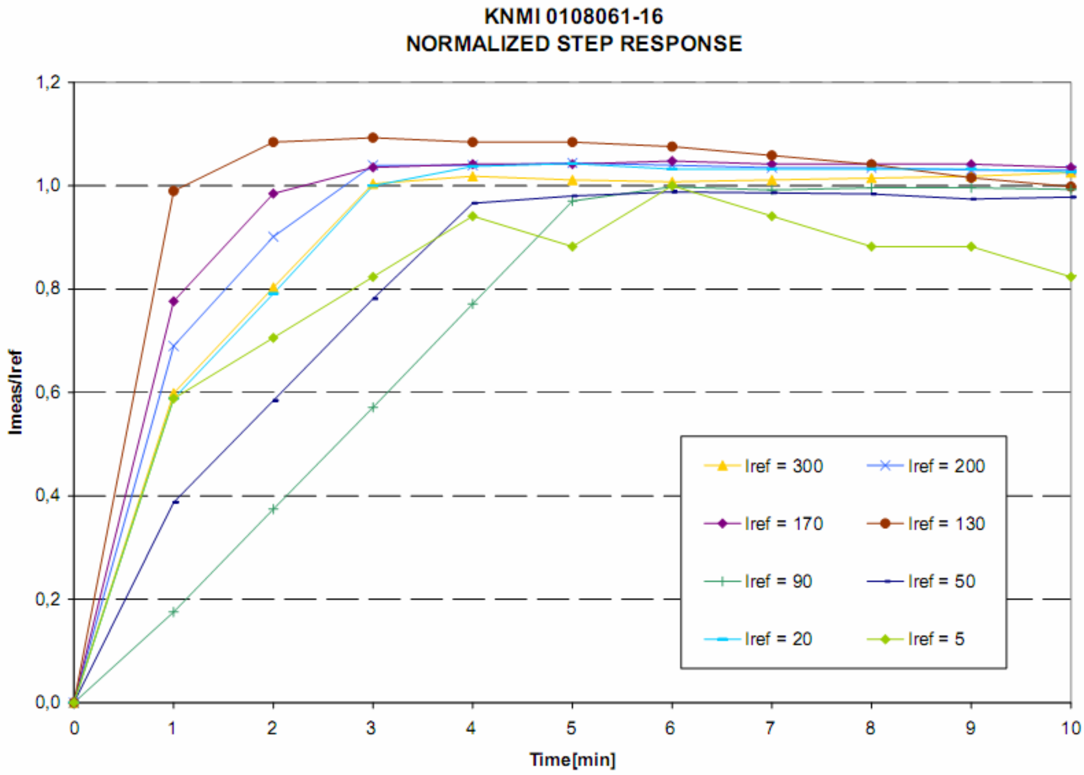


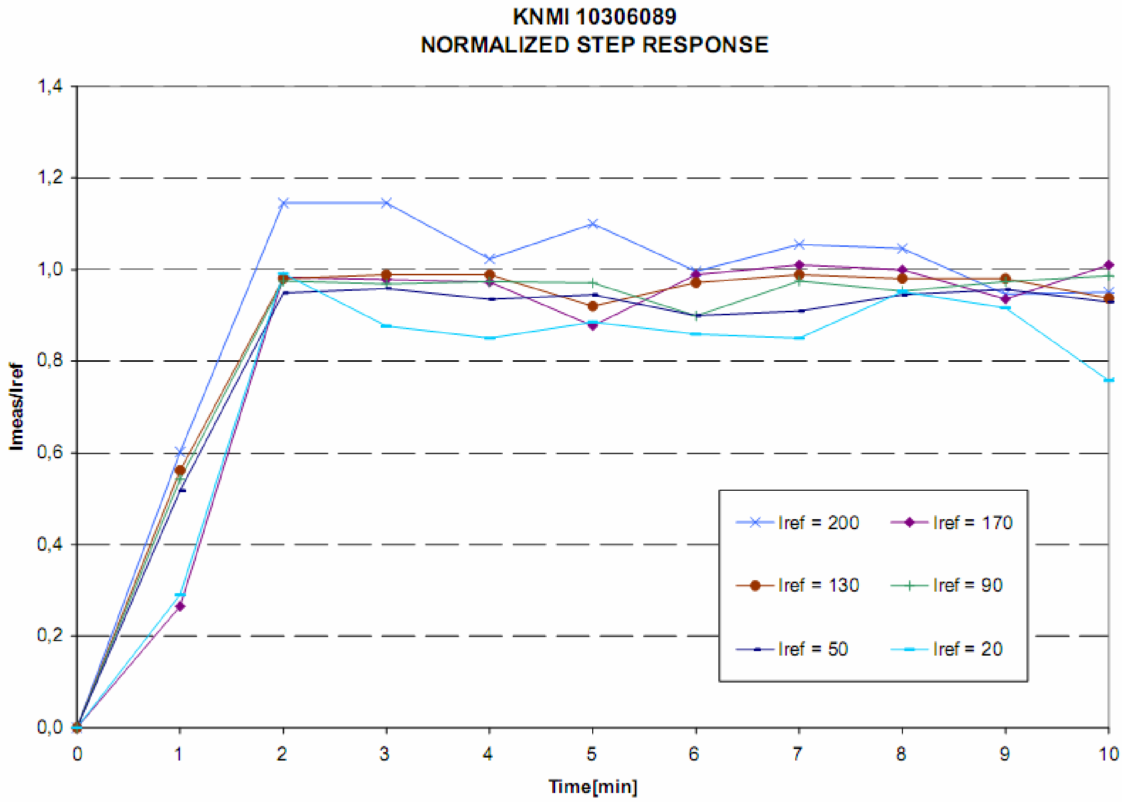
KNMI 10306089



Step response evaluation

The **step response** reflects the time behaviour of the gauge to a sudden increase of RI from 0 mm/h to a given RI as indicated in the graph. The step response is presented in the form of superimposed and normalized response curves corresponding to different laboratory reference RI. The observed behaviour of the first minute is not reliable, being affected by non synchronization effects between the internal clock and the laboratory acquisition system, and should be neglected.





Field calibration

In the framework of the Quality Assurance procedures adopted for the RI Field Intercomparison, three field calibrations where performed throughout the campaign by means of a portable Field Calibrator designed by the DICAT Laboratory (Genoa), in order to asses eventual drifts in calibration and to investigate reasons for observed or suspected malfunctioning. The field standard procedure is based on providing the rain gauge under test with a reference intensity for a certain time and on the evaluation of the relative error with respect to the field generated reference RI (WMO CIMO recommendation). *(For details see Final Report, sec. 4.2.)*

Results

Electrical Raingauge KNMI s/n 01.08.061.016

CALIBRATION	1° 11/12/07	2° 16/04/08	3°
RI ref [mm/h]	225.8	135.8	
AVG RE [%]	-0.5	0.0	
[RE(-C.L.95%),RE(+C.L.95%)][%]	[-1.8, 0.8]	[-0.4, 0.4]	

Results

Electrical Raingauge KNMI s/n 10306089 (spare)

CALIBRATION	1°	2°	3° 20/04/09
RI ref [mm/h]			137.2
AVG RE [%]			-1.6
[RE(-C.L.95%),RE(+C.L.95%)][%]			[-2.7, -0.5]

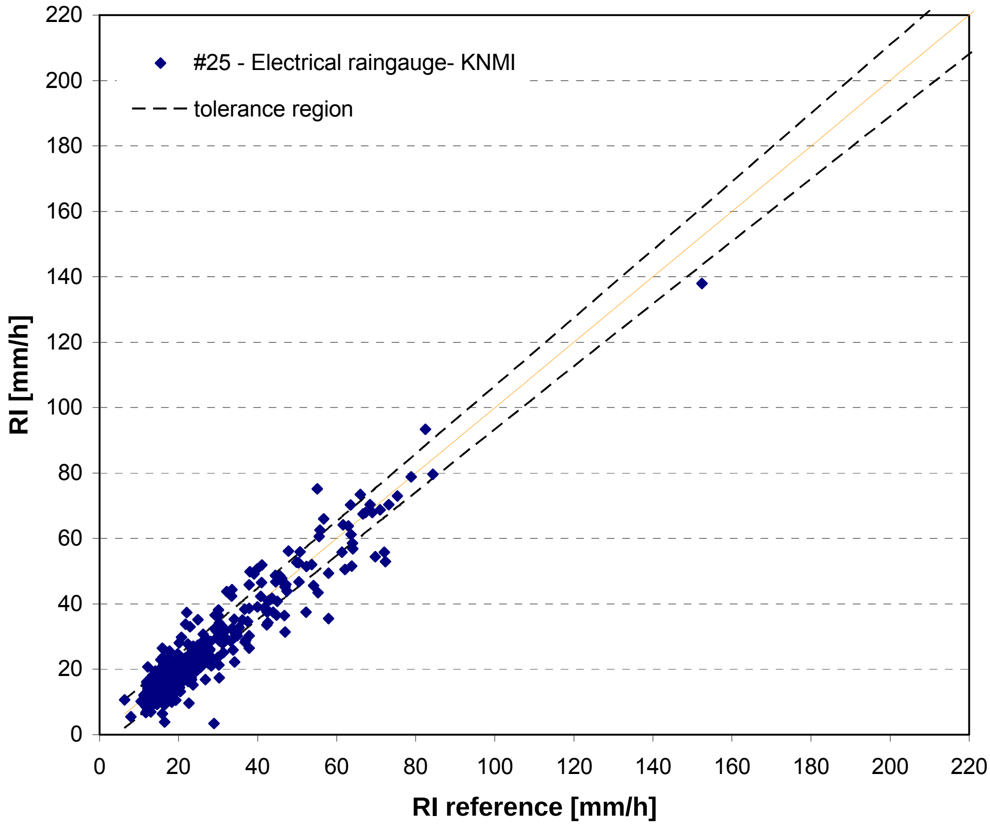
(In the table above: RI ref [mm/h] is the generated rainfall intensity by the field calibrator; AVG RE[%] is the relative error of the average 1-min RI (AVGRI) of the gauge during the calibrations 1°-3°; RE(-C.L.95%) and RE(+C.L.95%) are the 1-min RI extremes of an interval corresponding to a Confidence Level of 95%

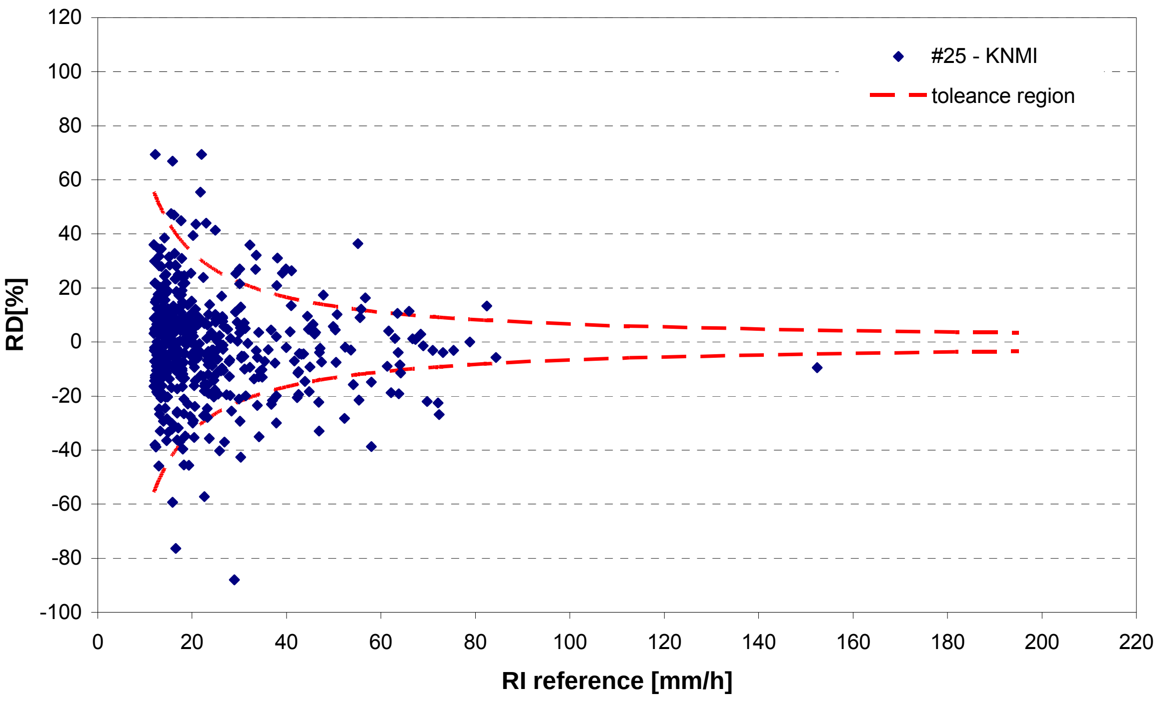
Comments

- The first rain gauge s/n 01.08.061.016 was replaced on 25/11/2008 because of malfunction.

Field Intercomparison Measurements

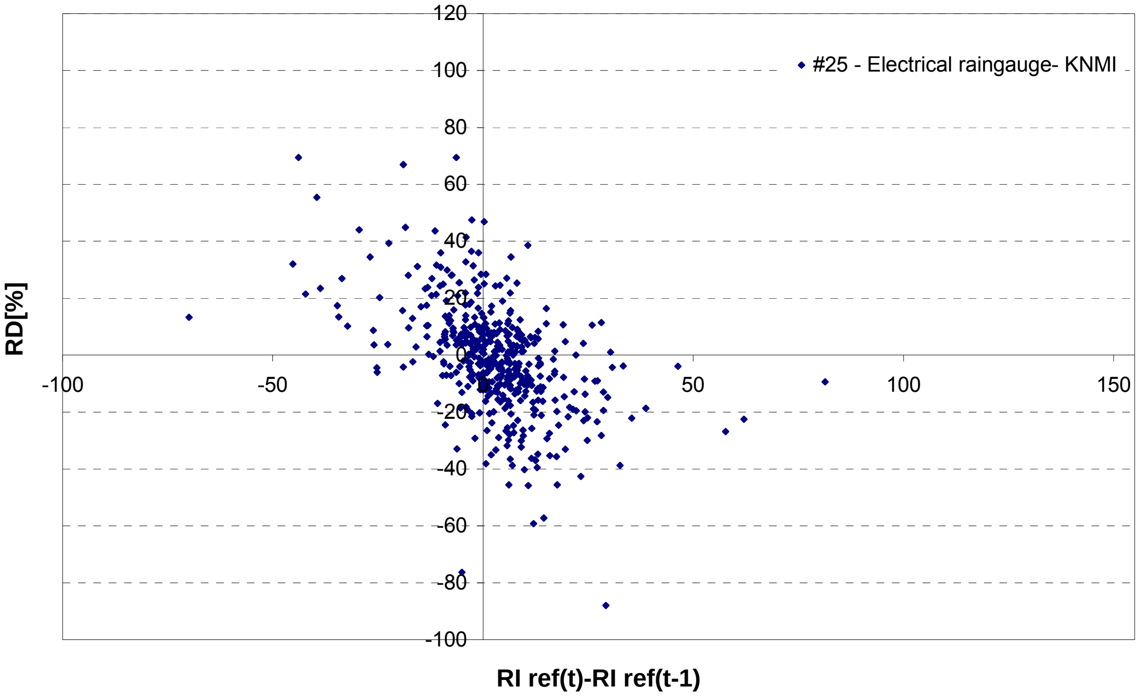
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by Electrical raingauge-KNM and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



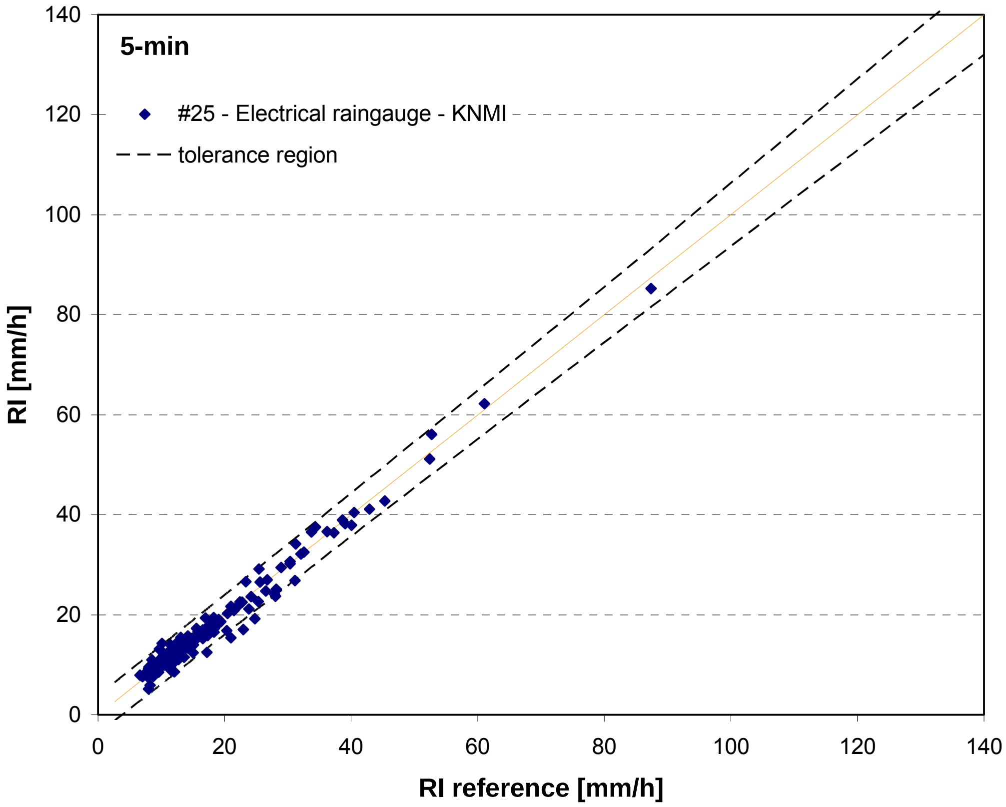


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)$- $RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by Electrical raingauge-KNM and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters ***($RI=a\cdot(RIref)^b$)***	**a**	**b**	**R^2**
#25 **Electrical raingauge** **KNMI**	1.05	0.97	0.82

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The laboratory calibration shows good results (average relative errors within ±5% above 50mm/h), although there is dispersion for low RI values.
The field calibrations give consistent results with the laboratory calibration. No drift detected from the field calibration.
The field results show little dispersion, greatly reduced on 5 minute data.
The RI variation response plot shows an oval shaped noise pattern with a prevalent behaviour to underestimation for increasing RI values and to overestimation for decreasing RI values. The reason for this noise pattern must be investigated further.

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*
D1: Status code (processed by the automatic QC)
If D1 ≠ **0** (ok), **1** (test), **3** (test), **121** (ASCII code for status letter "**y**" = emptying) then
Doubtful Data (data to be checked for a-posteriori validation)

Data availability (1 min):

- Valid Data: 92.0%. Alarms corresponding to status code "E" (leaking discharge valve) and status code "W" (too long emptying) and missing data because of interface module malfunction. No data are available during the period 28/10/08 - 04/12/09 (see details in the text below). Data before 28/10/09 were considered valid except for those ones flagged by the diagnostic alarm.

Maintenance:

- Regular inspection;
- Depending on local weather conditions: cleaning of collecting funnel and filter, removal of any dust and dirt;
- Checking of automatic emptying.

Malfunctioning:

- A failure of the external interface module and its built-in power supply for the rain gauge caused sporadic malfunctions of the electrical circuits of level measuring device and discharge valve of the rain gauge (diagnostic alarms described above). The discharge valve was checked many times but no systematic failures were found. On 28/10/2008 a complete damage of the electrical circuits of level measuring device and discharge valve occurred to the first instrument (s/n 01.08.061.016). The spare instrument (s/n 01.08.061.026) brought down as well during the attempt to replace the first instrument on 28/10/2008. The KNMI visited Vigna di Valle on 19/11/2008 to check rain gauges and to the external interface module: a second spare rain gauge (s/n 10306089) and a spare interface module were shipped later and the instrument started working again on 04/12/2008.

LCR "DROP" PVK ATTEX
- Russian Fed. -

Technical Specifications

- Provided by the manufacturer -

- Physical principle: Microwave radar disdrometer (volumetric backscattering of raindrops through a Gann diode generator with working freq 10.5GHz 0.5mW). (*Version: LCR-11*).
- Range of measurement : 0-150 mm/h
- 1-minute resolution: 0.1 mm/h

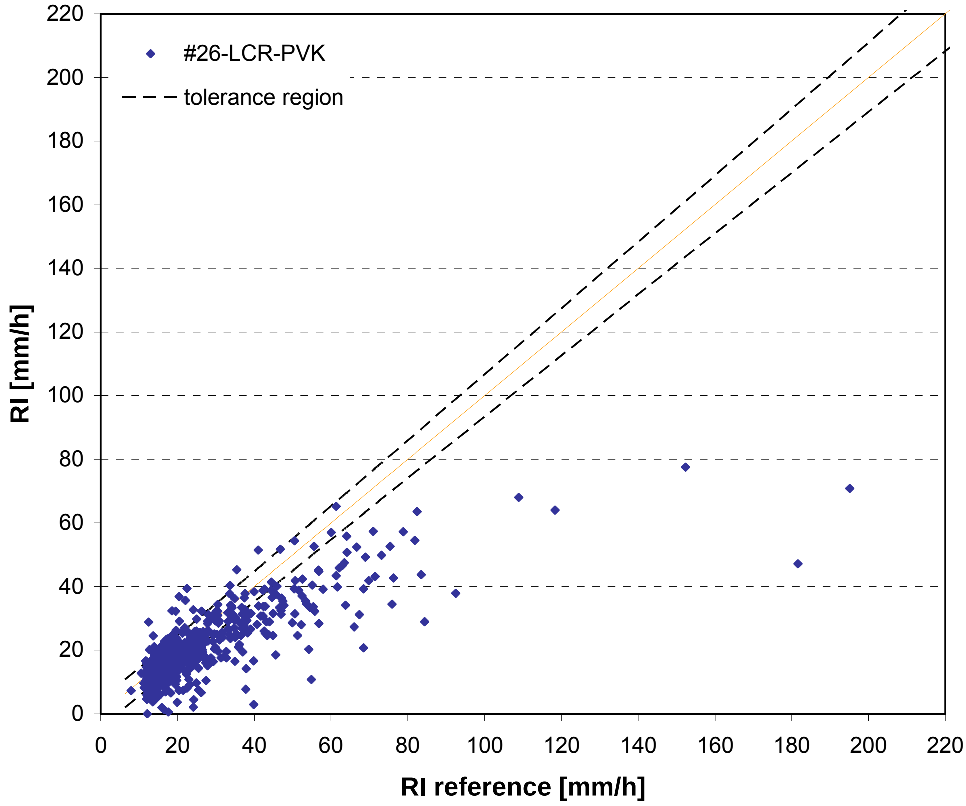
Data output

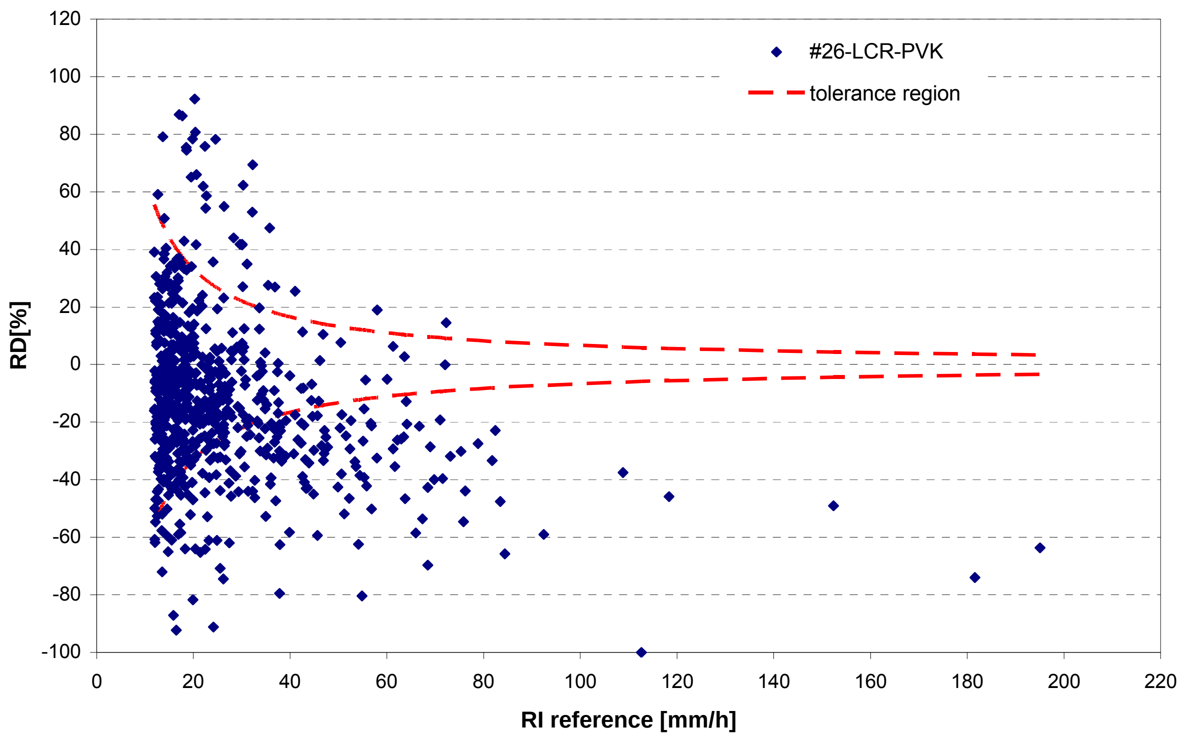
- Output: data message with serial interface RS485 in binary code - Polling mode (every minute).
- Data update cycle : 1 min
- Rainfall parameters: RA_{1min}[mm] liquid precipitation amount on one minute (for the intercomparison period before 20/12/2007); RI_{1min}[mm/h] rainfall intensity on 1 minute (after 20/12/2008, because of the new release of LCR-11 management software)
- Transfer function for 1-min RI: (a) RI_{1min}[mm/h] = RA_{1min}[mm]/[min]·60[min/h] (before 20/12/2007); (b) None (otherwise).

#26 LCR "DROP" PVK ATTEX in the field

Field Intercomparison Measurements

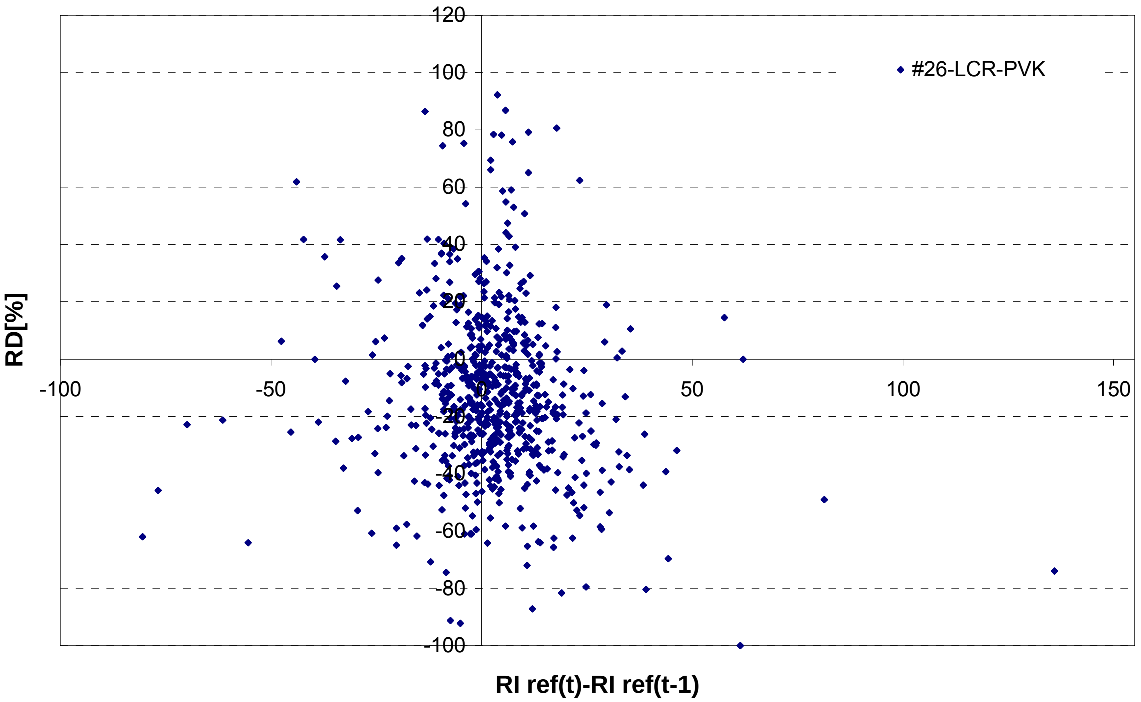
RI scatter plot (above) and **RD scatter plot** (below) display the results of the comparison of 1-min rainfall intensity measured by LCR "DROP"-PVK-ATTEX and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



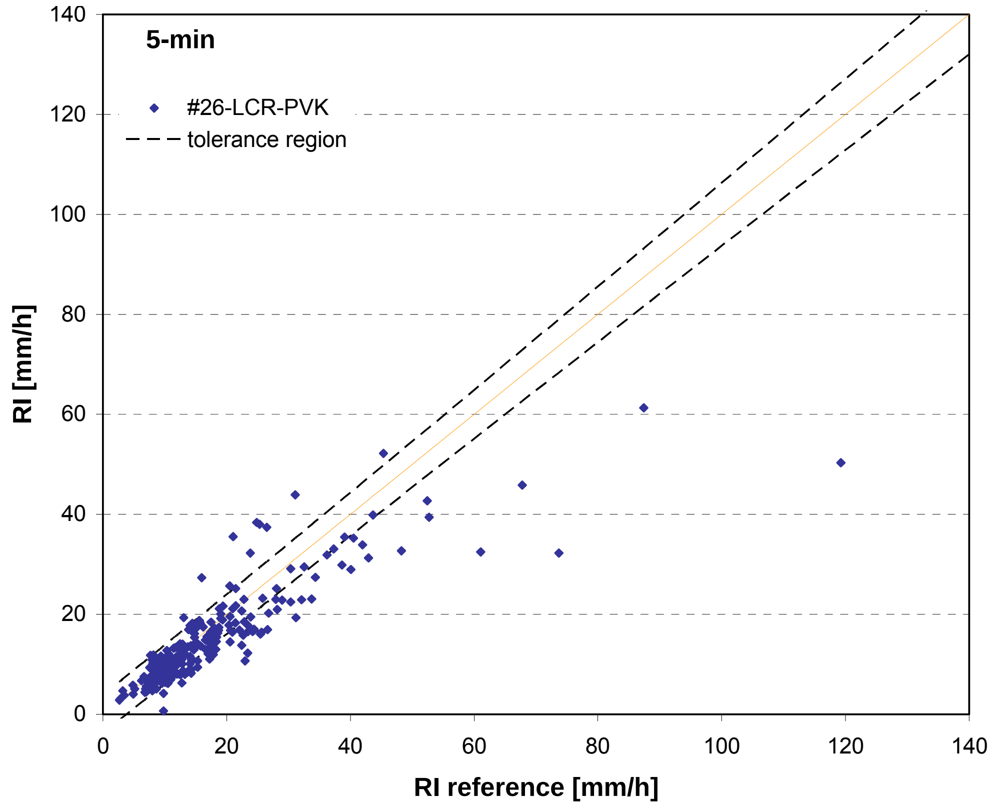


(Relative difference: $RD=100(RI-RI_{ref})/RI_{ref}$).

RI variation response plot: Comparison between relative difference (RD) and the time variation of RI reference ($RI_{ref}(t)- RI_{ref}(t-1)$).



5min RI scatter plot: Comparison between 5-min averages of rainfall intensity measured by LCR "DROP" PVK ATTEX and reference intensity. The uncertainty lines are calculated according to the procedure described in *Final Report, sec. 5.3.2-5.3.3.*



Summary Table

Parameters *($RI=a\cdot(RIref)^b$)*	**a**	**b**	**R^2**
#26 **LCR "DROP"** **PVK ATTEX**	1.43	0.82	0.53

(Parameters a, b, R^2 are determined by fitting the function $RI=a\cdot(RIref)^b$, for details see *Final Report, sec. 5.3.5.* The threshold RI≥12 mm/h is considered for the data analysis.)

Comments

The field results on 1 minute show that the LCR sensor tends to underestimate reference RI values up to 80 mm/h (with large dispersion of data) and it shows a strong non-linearity above 80mm/h. On 5 minutes, the LCR's data have a reduced dispersion, the sensor shows a linear behaviour (except for few data points) only up to 50mm/h (average on 5 min).

QA/QC Information

Diagnostic data and error codes (recorded in Raw Data): *(For details see Annex VI)*

D3: Status parameter (processed by the automatic QC)

If D1≠0→ Error

D1: current number of measurements since the first start (not processed by the automatic QC)

D2: current number of measurements since the last switch-off (not processed by the automatic QC)

Data availability (1 min):

- Valid Data: **93.1**%: (a) **6.8**% of not available data was due to a loss of LCR's configuration parameters during the period 14/11/07 – 20/12/07 caused by a conflict between the LCR software (used to download data) and the OS of the PC (used to run the software); (b) **0.01**% of not available data was due to missing data and false diagnostic alarms recorded by the automatic QC caused by an imperfect filter of the data acquisition system that was used to retrieve RI and diagnostic data from the binary output of the LCR.
- From the beginning to the end of the intercomparison, a continuous "off-line" download of data by means of the LCR-11 software was performed for two reasons: it was not possible to create the data filter for LCR's binary output before 17/02/2008 and, after the setup, this filter suffered from some operational limits. The integration of LCR into the

data acquisition system was a challenging task but at that time it was decided to proceed anyway.

- It is important to be noticed that those precipitation events occurred during the period 14/11/07 – 20/12/07 were not considered by data analysis (*for details see Final Report, Chap.5*). Moreover, precipitation data from the LCR had been downloaded separately (*filename: 0memyyyymmdd.dat*) after each precipitation event during the remaining period of the Intercomparison (20/12/07 – 30/04/09). Thus these very few data have been used to integrate 1-min data produced by the acquisition system in order to perform a correct data analysis. They will be made available together with the intercomparison dataset.

Maintenance:

- Regular visual inspection to the case of the LCR;
- Depending on weather conditions: cleaning of the radio transparent cap of the sensor
- In case of suspect measurement problem, checking of the raw spectrum of LCR by mean of the LCR software.

Malfunctioning:

- No instrument malfunction must be considered for not available data described above because they were due to a data acquisition management problem;
- Damage of the radio transparent cap of the sensor. The manufacturer suggested how to proceed in order to repair it. No problems to the validity of data.