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# THE WMO FIELD INTERCOMPARISON OF RAINFALL INTENSITY (RI) GAUGES: MEASUREMENTS AND PRELIMINARY RESULTS

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**ABSTRACT**

The Joint Expert Team on Surface-Based Instrument Intercomparison and Calibration Methods (ET on SBII&CM) and the International Organizing Committee (IOC) on Surface-Based Instrument Intercomparison, according to the CIMO Plan of WMO Intercomparisons, started the WMO Field Intercomparison of Rainfall Intensity (RI) Gauges on the 1^st of October 2007. The campaign is held at the Centre of Meteorological Experimentations (ReSMA) of the Italian Meteorological Service, Vigna di Valle, Italy. A group of 30 previously selected rain gauges based on different measuring principles were involved into the field Intercomparison. Moreover 13 additional meteorological sensors (ancillary information) and the observations and measurements performed by the GCOS/GAW meteorological station of Vigna di Valle were analyzed as metadata.

This paper is dedicated to the summary of preliminary results of Intercomparison measurements. It offers a view on the main achievements expected from the Intercomparison in evaluating the performances of the instruments in field conditions and offers advice on additional laboratory tests.

*Keywords: rainfall intensity, WMO Intercomparison, rain gauges,*

## Introduction

### *Background*

The need for a WMO Intercomparison of Rainfall Intensity (RI) gauges goes back to the two Expert Meetings on Rainfall Intensity Measurements respectively held in Bratislava, Slovak Republic, 23-25 April 2001 and in Geneva, Switzerland, 5-9 December 2005 [1][2]: the former was mainly focused on the calibration of rain gauges and the general aspects of RI measurements (I phase); the latter gave priority especially to the objectives and the operational aspects of the Field Intercomparison, allowing both the catchment and non-catchment types of rain gauges to take part in the Field Intercomparison (II phase). The first phase started in 2004 and was concluded in 2005. An international standardized procedure for laboratory calibration of catchment type RI gauges and the reference instruments to be used for Field RI Intercomparisons have become recommendations of the fourteenth session of the Commission for Instruments and Methods of Observation (WMO-CIMO) [3]. It should be noted that a few RI rainfall intensity gauges were properly modified by manufacturers or NMHS (National Meteo-Hydrological Services) after the results of the first phase (the Laboratory Intercomparison) and before taking part into the field Intercomparison, by improving their performance in terms of accuracy and according to the above-mentioned international recommendations.

Before the meeting in Bratislava, there was a general lack of knowledge, practise, standardization and recommendation with respect to RI measurements. At the end of the meeting a standard definition of RI was adopted as the amount of precipitation collected per unit time interval expressed in millimetres per hour. The range of measurements, the required uncertainties and the output averaging time were also defined. In particular, an uncertainty of 5% in the range 2-2000 mm/h and an output averaging time of 1 minute were recommended, so we generally refer to RI [mm/h] on 1 minute averaging time interval [4].

It has been recognised by users that 1MIN-RI is particular suitable for hydro-meteorological warnings, interfacing hydrological and meteorological models, flood forecasting, disaster prevention and mitigation, urban hydrology and engineering design.

Previous international intercomparisons of rain gauges were focused on accumulated amounts of precipitation, low intensity rainfall (snow) and sometimes only on qualitative RI information (light, moderate, heavy). The intercomparisons 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. It was therefore considered as the first and necessary step to organize an intercomparison of such instruments first in the laboratory then in the field [4] [5].

The field Intercomparison of RI rain gauges started on 1st October 2007 and will be concluded in October 2008 after a full year measurement period..

### *Objectives*

The main objective of the field intercomparison is to test the performance of rainfall intensity measuring instruments especially in high RI conditions. The objective of data analysis is to provide guidance on improving the homogeneity of long-term records of rainfall with special consideration given to high rainfall intensity. Further objectives are also to offer advice for RI uncertainty determination and for improving RI rain gauges measurements accuracy; to provide guidance material for further improvements in the area of Intercomparisons and to draft recommendation for consideration by the WMO-CIMO; to compare RI measurements in field conditions of non-catching type rain sensors with respect to catching type rain gauges [3] [4] [6]

In terms of accuracy, both laboratory and field RI Intercomparison have contributed to a quantitative evaluation of *counting errors* (systematic - "ability to sense") and *catching errors* (weather related, wetting, splashing, evaporation - "ability to collect") of RI rain gauges. This specific aspect will allow further definition of the general principles of measurement accuracy to be applied in RI measurements [4].

## Procedures and methods

### *Intercomparison site, standards and references*

The in-FIeld RI intercomparison (FI-RI) site adopted was positioned at the Centre of Meteorological Experimentation of the Italian Air Force Met Service, in Vigna di Valle (ITALY) (Fig.1). It is a flat, green grass area of 400 $m^2$, equipped with 34 acquisition concrete platforms, evenly distributed, and 4 central acquisition pits, close to each other, specifically used for the installation and acquisition of the FI-RI "**working references**" - a group of 4 recommended RI gauges. A total number of 26 different RI gauges were installed on dedicated ground platforms; 13 additional meteorological sensors for monitoring environmental conditions were installed on 6 ground platforms; at the centre of the area, the 4 "working reference gauges" were inserted in a 4-fold RRGP – Reference Rain Gauge Pit (collectors at ground level), according to the standard EN13798: "Specifications for a reference rain gauge pit" (Fig. 2) adopted for this Intercomparison. All recommended standards contained in the WMO-CIMO guide n.8, concerning precipitation measurements, instruments installation and procedures for conducting the Intercomparison, were adopted and inspected during two Expert Meetings, held in Vigna di Valle (3^ reduced session – 26 February-2 March 2007; 5^ reduced session 17-21 September 2007) [6] [7]. All standard procedures and equipment recommended for meteorological data acquisition were adopted with care as part of a general quality assurance framework [8]. A full description of the Intercomparison site can be found in [6]. A general description of Rainfall Intensity Gauges, measurement principles and principles, uncertainty sources and measurements errors is provided in [4].

**Fig.1 – Intercomparison site – Vigna di Valle (ITALY).**

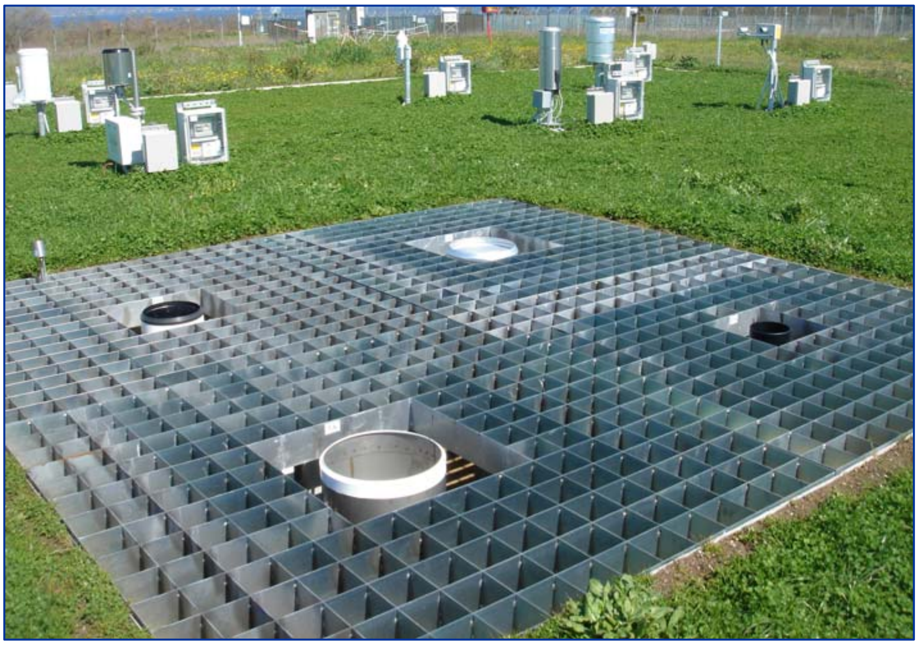


**Fig.2 – 4-fold RRGP – The 4 working reference RI gauges.**

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/make comparison with measuring instruments. For this Field Intercomparison of RI a set of gauges was recommended and the combined analysis of the reference gauges will provide the best possible estimation of RI in the field, giving their demonstrated performance during the previous Laboratory Intercomparison (2004-2005) [3]. For minimizing the weather related catching errors, the working reference rain gauges were inserted in a RRGP [3]. Weather related catching errors are mainly due to wind effect. The wind effect, caused by instrument disturbance, is know as the JEVONS effect (1861) [**9**]. Prof. Koschmider in 1934 realized the "sunken rain gauge", known as the first prototype of the RRGP, in order to investigate the wind effect induced by rain gauges shape disturbance on the air flow in the vicinity of the collector. With the RRGP the influence of the form of the rain gauge on the air currents disappears. The influence of the necessary catchment surface on the air currents in its vicinity is reduced to a minimum through the fact that this surface lies in the layer with the least air movement. Moreover, the influence of the turbulent vertical movements is likewise reduced to a minimum, since these disappear at the earth's surface. According to the results of the WMO Laboratory Intercomparison of RI gauges (2004-2005), 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 [3]. The below requirements were applied in selection of the reference gauges: a) Uncertainty of the gauge in laboratory tests must satisfy the WMO requirement of +/- 5 % over the range of rain intensities expected at the test site, i.e. 2 - 400 mm/h; b) Minimum resolution of 0.1 mm; c) Time delay 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) [2].

### *Instrument selection and general criteria*

Participation in the intercomparison was accepted based on the following conditions: a) Only in situ, both catchment and non-catchment, RI instruments that are currently being used in national networks or being considered for use in national networks were included; b) Only instruments that are capable of measuring rainfall intensities as high as 200 mm/h at a time resolution of 1 minute were accepted [2]. Because the number of instruments proposed exceeded the capacity of the field site, during the 3^ session of the CIMO Expert Team, held in Vigna di Valle on 26 February-2 March 2007, the instruments for participation were selected 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 [2] [6]. Windshields were not requested and the four instruments that were installed as reference gauges in the pits, were also installed in the open field in order to quantify the effect of wind losses. All participants were also 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, allowing the test to be carried out properly (a Participants Meeting was held in Vigna di Valle, on 21-22 May 2008).

The list of selected instruments is reported in table 1 [6].

According to the above-mentioned requirements for the references, rain gauges #5(ETG-R102), #8(CAE-PMB2), #13(Meteoservises-MRW500) and #17(GEONOR-T200B) were selected as "working reference gauges", inserted in the RRGPs and installed on 4 dedicated ground platforms [2] [3] [6].

The environmental conditions were monitored by the following ancillary sensors [6]:

- 4 propeller-vane anemometers mod. Young 05106 installed at the site corners;
- 4 wetness sensors mod. Vaisala DRD11A installed at the site corners;
- 1 Temperature/Relative Humidity sensor mod. Rotronic M101A, 1 atmospheric pressure sensor mod. Young 61020L and 1 global irradiance sensor mod. Lycor 200X all installed on a side position ground platform;
- 1 ultrasonic anemometer mod. Gill Windsonic installed on a ground platform close to the 4-fold RRGP.

| ID | MODEL/MANUFACTURER | TYPOLOGY |
|---|---|---|
| 1 | 7499020BoMV2/RIMCO | Tipping bucket |
| 2 | AP23/PAAR | Tipping bucket |
| 3 | R01 3070/PRECIS-MECANIQUE | Tipping bucket |
| 4 | PT 5.4032.35.008/THIES | Tipping bucket |
| 5 | R 102 (REFERENCE GAUGE)/ETG | Tipping bucket |
| 6 | DQA031/LSI LASTEM | Tipping bucket |
| 7 | T-PLUV UM7525/I/SIAP-MICROS | Tipping bucket |
| 8 | PM B2 (REFERENCE GAUGE)/CAE | Tipping bucket |
| 9 | RAIN COLLECTOR II (7852)/DAVIS | Tipping bucket |
| 10 | 15188/LAMBRECHT | Tipping bucket |
| 11 | PP040/MTX | Tipping bucket |
| 12 | ARG100/ENV. MEAS. Lmt. | Tipping bucket |
| 13 | MRW500(REFERENCE GAUGE)/METEOSERVIS | Weighing Gauge |
| 14 | VRG101/VAISALA | Weighing Gauge |
| 15 | PLUVIO/OTT | Weighing Gauge |
| 16 | PG200/EWS | Weighing Gauge |
| 17 | T-200B (REFERENCE GAUGE)/GEONOR | Weighing Gauge |
| 18 | TRwS/MPS | Weighing Gauge |
| 19 | MPA-1M/SA "MIRRAD" | Weighing Gauge |
| 20 | PWD22/ VAISALA | Optical Disdrometer |
| 21 | PARSIVEL/OTT | Optical Disdrometer |
| 22 | LPM/THIES | Optical Disdrometer |
| 23 | WXT510/VAISALA | Acoustic detection of individual rain drops |
| 24 | ANS 410-H/EIGENBRODT | Pressure sensor |
| 25 | Electrical raingauge/KNMI | Level sensor |
| 26 | DROP/PVK-ATTEX | Micro Doppler radar |

**Table 1 – WMO Field Intercomparison of RI – The list of participating instruments**

***Procedures for laboratory phase before the field intercomparison (Genoa, DICAT Laboratory, 2007-2008)***

The main objective of the laboratory phase was to perform tests on the participating catching-type rain gauges according to the procedures developed during the WMO Laboratory Intercomparison of RI Gauges and to assess the accuracy performance of such gauges with respect to WMO limits prior to their installation in the field [4]. The DICAT Laboratory of the University of Genoa (Italy) was the WMO recognised RI laboratory in charge of performing the preliminary tests. The WMO ET agreed that results of the laboratory calibration are not used for applying any correction or adjustment to the data during the field intercomparison period. It was stressed that a further aim of the laboratory phase was to help to distinguish between weather related effects and instrumental effects in the evaluation of the field intercomparison data. All laboratory tests were performed for operational rain gauges and their spares, in case of possible replacement for malfunctioning during the field measurements. The tests were performed in stationary conditions (constant flow rate) and values were derived from long-term average values. To shorten the time for test it was decided to use a RI of 5 mm/h as the lowest RI (instead of 2 mm/h as previously used in the WMO Laboratory Intercomparison of RI Gauges) [7].

The tests output data were evaluated with an averaging time interval of **1** and **10** minutes, and results are discussed in [10] and [11] with full details.

Furthermore, instruments were tested on a regular basis on site during the field test using a portable calibration device [12], designed by University of Genoa. Field tests and checks performed by this device had several purposes, such as verifying the operational status of catchment-type gauges, investigating possible drifts in calibration/operation status with respect to the laboratory phase and, as a consequence, providing as much information as possible for the quality control of data. In particular, tests results helped in understanding and better evaluating real rain events and the related intensity measurements.

## *Procedures for installation*

The decision was taken by the ET/IOC to exclude windshields to provide uniform measurements from all gauges. All gauges and ancillary sensors (wind, wetness) were installed at 1 m height. Other ancillary sensors (T, RH, solar radiation, atmospheric pressure) were installed at CIMO standard heights. The positioning of the 30 participating rainfall intensity gauges, as well as of 13 ancillary sensors, was discussed and adopted by the ET/IOC as displayed in fig. 3 [6] [7].

| | |
|---|---|
| **1** | **RIMCO 7499 (TB)** |
| **2** | **Paar AP23 (TB)** |
| **3** | **Précis-Mecanique (TB)** |
| **4** | **Thies PT (TB)** |
| **5/27** | **ETG R102 A, B (TB)** |
| **6** | **LSI DQO31 (TB)** |
| **7** | **SIAP UM7525/I (TB)** |
| **8/28** | **CAE PMB2 A, B (TB)** |
| **9** | **Davis Rain collector II (TB)** |
| **10** | **Lambrecht 15188 (TB)** |
| **11** | **PP040 MTX (TB)** |
| **12** | **ARG100 Env. Meas. Ltd (TB)** |
| **13/29** | **MRW500 A, B (WG)** |
| **14** | **Vaisala VRG101 (WG)** |
| **15** | **Ott PLUVIO (WG)** |
| **16** | **EWS PG200 (WG)** |
| **17/30** | **GEONOR T-200B3 A, B (WG)** |
| **18** | **MPS TRwS (WG)** |
| **19** | **SA „MIRRAD“ MPA-1M (WG)** |
| **20** | **Vaisala PWD22 (optical)** |
| **21** | **Ott PARSIVEL (OD)** |
| **22** | **Thies LPM (OD)** |
| **23** | **Vaisala WXT510 (acoustic)** |
| **24** | **Eigenbrodt ANS 410 (pressure)** |
| **25** | **KNMI electrical raingauge (level)** |
| **26** | **PVK ATTEX "DROP" (Radar)** |
| **ANCILLARY SENSORS** | |
| **G1** | **Gill windsonic (IMS-ReSMA)** |
| **AS** | **4 Young 05106 wind sensors + 4 Vaisala DRD11A Rain detectors (USA)** |
| **PTUR** | **RotronicM101A Temp/RH + Young 61020-L Press + Lycor200X rad. (IMS-ReSMA)** |

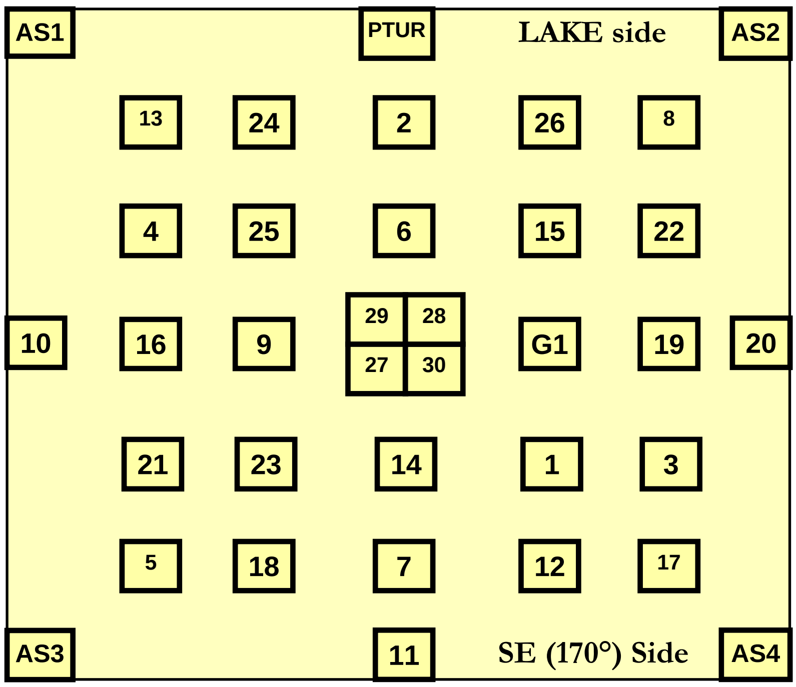



**Fig.3 – WMO Field Intercomparison: Instruments Positioning**

The following criteria for positioning were applied: 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 [6].

Very dedicated instructions and timetable for instruments shipping, custom clearance (temporary admission regime for non EU goods), transportation of instruments from Genoa Laboratory to Vigna di Valle test site and installation were presented by the field site manager (Mr Vuerich) during the 3rd session of the CIMO Expert Team, held in Vigna di Valle [6].

### ***Data acquisition, processing, analysis methodology and quality control of data***

The data acquisition (DAQ) system chosen was a Campbell Scientific CR1000 data-logger (fig.4) 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) [6] [7].

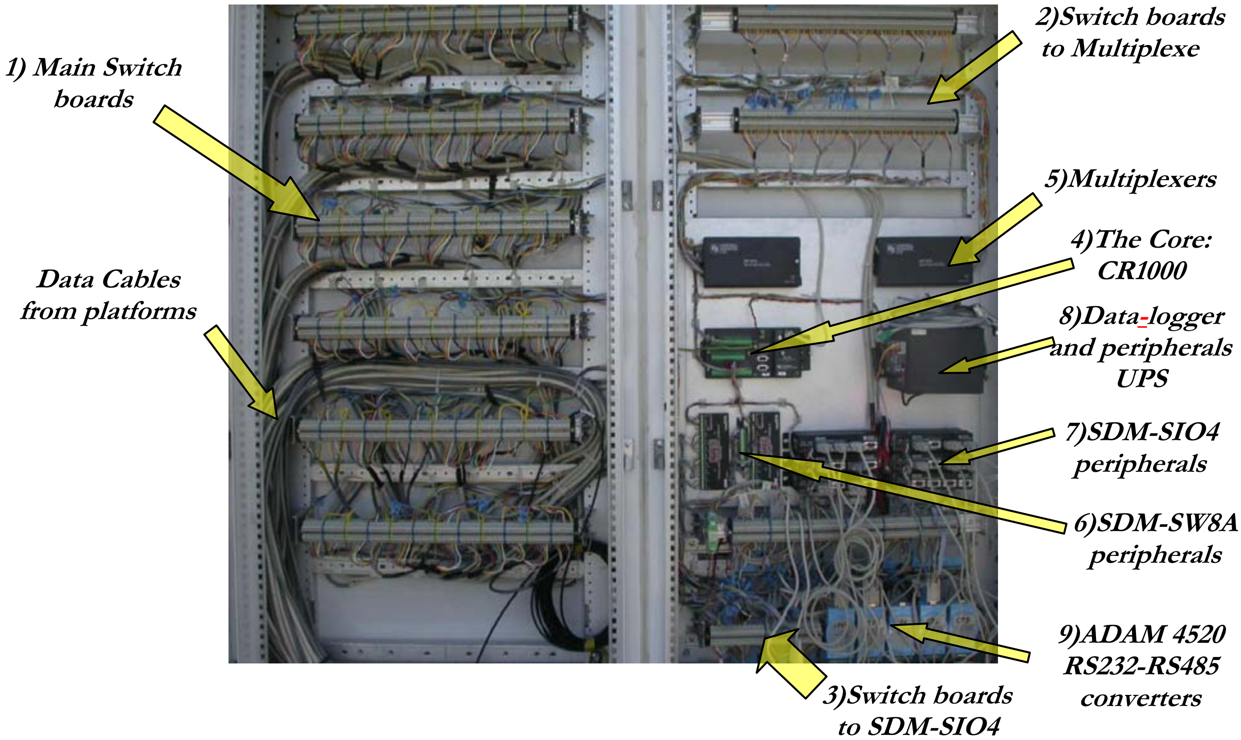



**Fig.4 – WMO Field Intercomparison of RI – Data Acquisition System**

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 [6].

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-min time resolution. The acquisition for ancillary sensors consisted in a record of raw data with a sampling time of 10 seconds [6] [7].

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 the main PC 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 [7] [13]..

The focus of the RI Intercomparison was on liquid precipitation. For this reason only liquid precipitation events were evaluated. Events containing particles of mixed or solid phase are discarded. This decision was based on the SYNOP, METAR and SPECI messages created by ReSMA H24 weather station (WMO ID 16224) [6] [7].

The ET/IOC adopted the use of the following meta data: a) Data from all ancillary sensors; b) All operating manuals of selected instruments; c) Results of the laboratory preliminary tests; d) 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; e) Regular and special observations recorded by the ReSMA 24H Met Observer, especially during precipitation events [7].

### *Quality assurance and supervision of instruments*

The AQC is part of a Quality Assurance plan adopted by local staff to ensure proper conditions and operation of data and metadata acquisition, data and metadata storage, the processing and data analysis of all instruments. The local staff stored all information on visual inspection, observations, maintenance and repair in an electronic logbook. The local staff provided a daily visual check, cleaning of instruments when necessary, calibration status checks when suggested by instruments technical manuals. Weather forecast was used for timely conduct of preventive maintenance to be prepared for the rainfall events. 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 every 3-4 months. During the Intercomparison period QA reports were produce by local staff with all relevant information about QA operations and field tests results. The procedures adopted for field tests were similar to laboratory tests and they were described in details in QA reports. QA reports were used for the improvement of data acquisition and the best data analysis and results evaluation.

## Data analysis

The main objective of the data analysis was to perform the best inter-comparison of in situ rainfall intensity instruments in high RI field conditions. The first step is the establishment of a suitable reference RI. The reference RI is the best estimation of the 1-minute RI true value obtained from the working reference gauges inside the RRGPs.

In the field intercomparison the reference RI is not unique but it is composed of 4 working reference gauges in a RRGP, namely 2 corrected TBRG (with correction algorithms) and 2 WG with the shortest step response and the lowest uncertainty with respect to the WMO Laboratory Intercomparison results (2004-2005). The best estimation can be assessed in two different ways:

- by evaluating the dynamic performance characteristics of the set of reference gauges;
- by statistically elaborating on the experimental data.

The first method consists in performing specific laboratory or field tests with several step function inputs in a suitable range of RI and experimentally deriving the step response function and the time delay of each instruments in terms of a function depending on dynamic parameters and time [14]. The energy distribution of a physical system like a specific rain gauge could not be constant, so the system is said to be in a static state. To determine static characteristics, measurements of the output must be made for many different values of the input with each measurement being made when the system is static. During the transition from one static state to another, as is the case during any precipitation event, the system is dynamic [14]. The time scale or the response time delay during which a rain gauge is dynamic should be evaluated experimentally by a suitable range of step function inputs in order to retrieve the value of the input (best estimation of 1 minute RI) during a precipitation event or a specific test. The step response functions of each reference rain gauge applied in field conditions will permit to retrieve the true 1-minute RI value within an uncertainty which is a proper combination of the uncertainties of rain gauges evaluated experimentally in laboratory through a standard procedure. This method could not be discarded in the management of the field Intercomparison, because the accuracy of some catching-type rain gauges such as WG (typically second-order systems) could depend strongly both on systematic errors and errors induced by dynamic characteristics of the natural phenomenon of precipitation: the related uncertainty could be degraded with respect to the uncertainty evaluated in laboratory in stationary conditions (steady flow rate). This is true especially at the 1-minute time scale, the output averaging time recommended for RI evaluation. At coarser time scales (5-10 minutes) the dynamic characteristic will be smoothed and the measurement uncertainty reduced. It could happen that some rain gauges can not be compared with the reference at 1-minute time scale because affected by a dynamic characteristic that only permits accurate measurements at larger time scales. Such gauges are preferably used for rainfall amount [mm] determination at the hourly/daily base or can be used for 1-min RI determination only after modification of the response function for 1 minute time scale and the reduction of the time delay in responding to the input rain signal.

The second method consists in a statistical evaluation of the dataset of the field Intercomparison. This methodology was used for the evaluation of preliminary results of the Intercomparison presented in the following. This methodology is particularly advantageous because it provides the data analyst with a first level analysis prior to perform ad hoc and accurate step response tests for dynamic characteristic determination. As the following graphs will show, this procedure is therefore advantageous to determine the 1 minute unique reference RI, to perform comparisons among the group of rain gauges under test and the reference RI (the purpose of the Intercomparison) and to detect the rain gauges particularly affected by dynamic characteristics of rainfall intensity, by synchronism or by the output delay time.

For evaluating statistically the 1 minute reference RI as the best estimation of 1 minute RI, a Weighted Average of the 1-min rainfall intensities measured by the 4 working reference gauges was calculated as:

$$RI\_REF = \frac{\sum_i \mu_i RI_i}{\sum_i \mu_i}$$

where $\mu_i$ is the weight of the working reference gauge $i$ (being $i$ = A, B, C, D the 4 working reference gauges). Calculation of weights is the most challenging issue. In order to take into account the effects related both to dynamic internal characteristics and the possible lack of synchronization at 1 minute time base, weights were calculated as:

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

where $S_i = \sum_{k \neq i} \sigma_{ik}$ with $k$ = A,B,C,D but $k \neq i$,

where $\sigma_{ik}$ are 3 statistical parameters calculated for each working reference gauge $i$ with respect to the other working references in RRGP throughout the database of all precipitation events as:

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

being:

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

and where F is a "gross" parameter assigned by the analyst to the working references on an event by event basis after a detailed examination of the measured data. The gross parameter will be equal to 0 or 1, respectively when the working reference gauge examined is evidently affected by 1 min a-synchronism or dynamic "defects" or not.

This procedure can be criticized at this stage, but after the examination of accurate laboratory/field tests for determination of the response function, these will be used for more accurate determination of the RI_REF as the best possible estimation or, as an alternative. the calculation of the gross parameter will be more appropriate and calculation of the weights will be definitively composed by a more accurate statistical and physical components.

## Preliminary results

The best 3 high peak 1min-RI events of the complete database were selected for the following preliminary analysis. A maximum intensity of 160[mm/h] was recorded according to the 99% likelihood predicted for a peak of above 100[mm/h] according to the climatology of the site in Vigna di Valle. So the interest of the present analysis is limited to the highest RI events (threshold at 12mm/h), as stated by the objectives of the Field RI Intercomparison.

We obviously recognize the need of analyzing all other monitored events, and the statistical parameter σ has been already calculated for all events till May 2008, but the present partial analysis of the 3 best events represents the will to provide a methodological guidance to be criticized and evaluated for the proper development of a final analysis procedure.

Since the Intercomparison is still in progress we only present here partial results in an anonymous way: working reference gauges are indicated as A,B,C,D and the couple of rain gauges analyzed in each graph is indicated as A, B.

The graphs presented below are manly oriented to compare the measurements results of several installed gauges with respect to the calculated (yet provisional) Reference RI . The 1 minute RI_m[mm/h] measured by rain gauges outside the RRGP were plotted with linear scales for X and Y versus the 1 minute RI_REF calculated as above for the three best events numbered as 1, 2, 3. All data are fitted with a power law trend curve:

$$RI = a \cdot RI\_REF^{b}$$

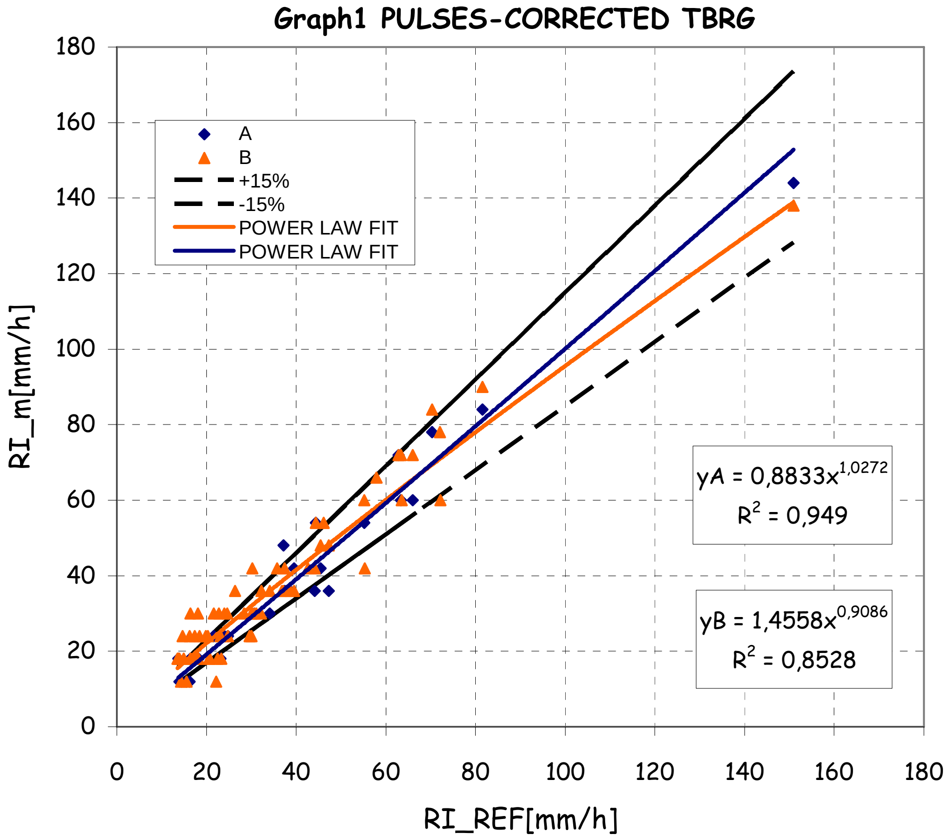
where a and b are constant parameters, whose numerical value is reported on each graph. After all precipitation events will be analyzed the ensemble of such constant parameters will be used for comparing at once the performances of the various rainfall intensity gauges submitted to the Field Intercomparison at the recommended 1-minute time scale. For the sake of better comparison, rain gauges were divided in 7 groups-categories according to the measurement technique or data output averaging time. In the following graphs, the 1-min RI behavior of two rain gauges (namely A,B) of the same group are plotted together and both fitted with a power law trend curve. Not all rain gauges data are reported in the graphs but only a representative group of all gauges. TBRG gauges are reported in three groups: not corrected, corrected by extra pulse delivery and curve-corrected (internal correction algorithm applied); moreover the two curve-corrected TBRG were reported in two graphs: before and after the application of a synchronization procedure. WGs are reported in two groups: WGs with 1 minute better dynamical stability/short response time and WGs with 1 minute reduced dynamical stability/large response time, being dynamic characteristics depending on oscillations/stability, step response time and time delay. The two last groups represent 2 rain gauges with optical measurements of RI (Optical disdrometers) and 2 rain gauges with other measurement principles (Doppler radar, pressure, level or acoustic impact).

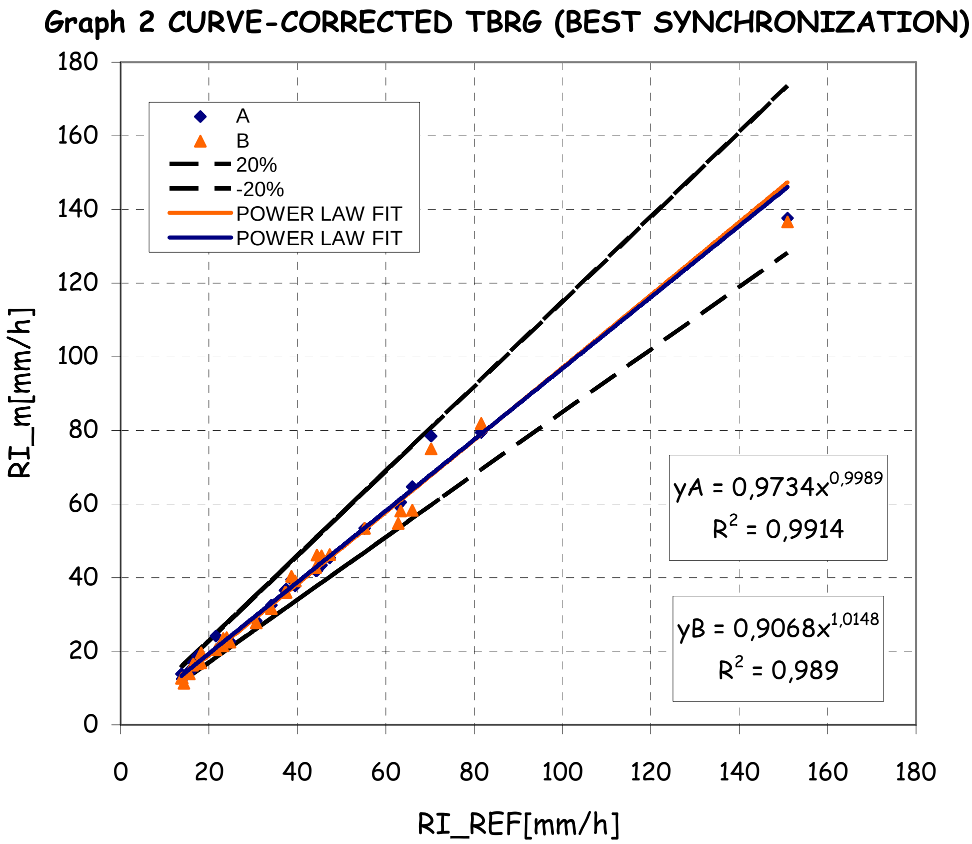
Dashed lines in all graphs indicate +/- 15% RI_REF.

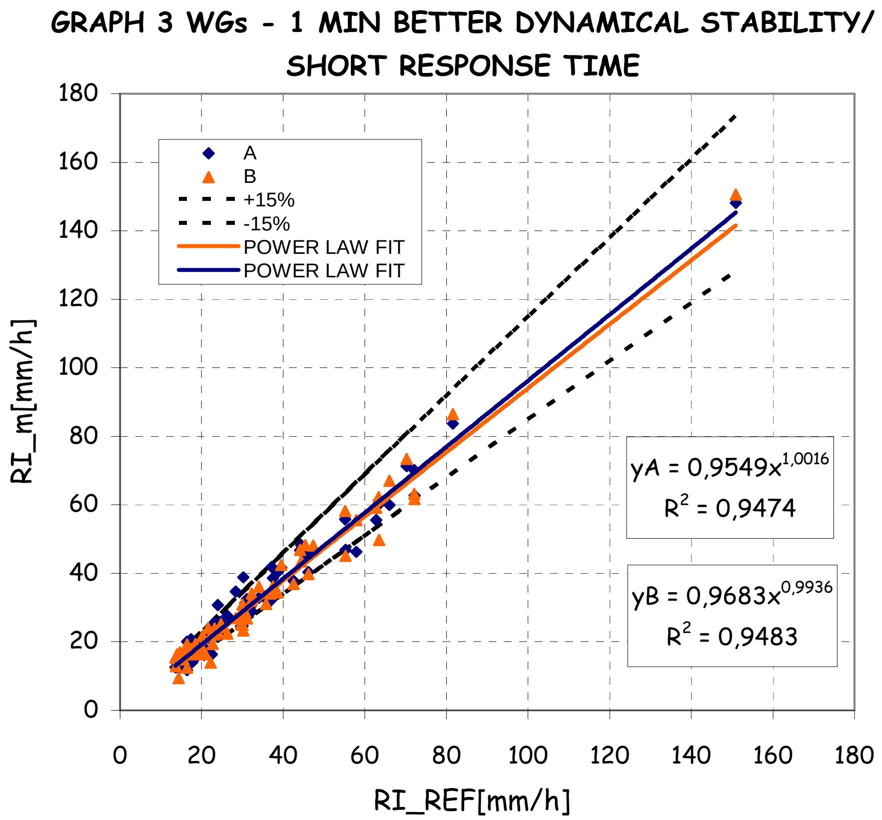
In the last graph, the 1 minute ratio of $RI_i^{OUT}$ and $RI_i$ is plotted with linear X and Y axis versus 1 minute wind speed (WS), with $RI_i^{OUT}$ being the rainfall intensity measured by the gauge installed on ground platform but identical to the corresponding pit rain gauge and in the following graphs $i$ =A and B. This graph is useful to assess the impact of wind losses, due to the Jevons effect, on the relative error with respect to the working reference (done for identical instruments). When all events will be analyzed (final results) it will be possible to evaluate the contribution of "wind induced errors" on the relative error and the results could be applied to the comparison between all external rain gauges and the reference RI. The Jevons effect appears clearly and it is more intense for moderate-strong winds (WS>6m/s) as expected. Ratio values of gauge A are more spread then gauge B and it could be related to the action of the Jevons effect on these two gauges that are very different in catching surfaces and shapes. However the number of data in moderate-strong winds range is still low and more data are needed for a better quantitative determination of the Jevons effect.

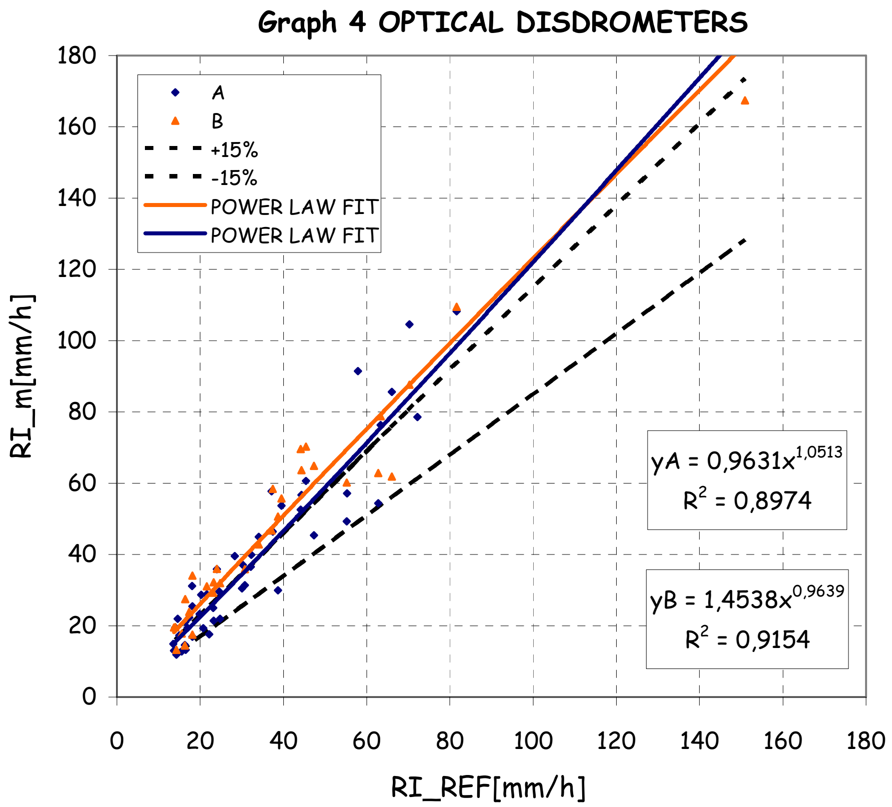
Another methods to determine the Jevons effect could be to evaluate wind losses on larger time scales (e.g. 5-10 minutes) or to evaluate, on an event basis, the differences in the total amount of precipitation [mm] between corresponding external and pit gauges.

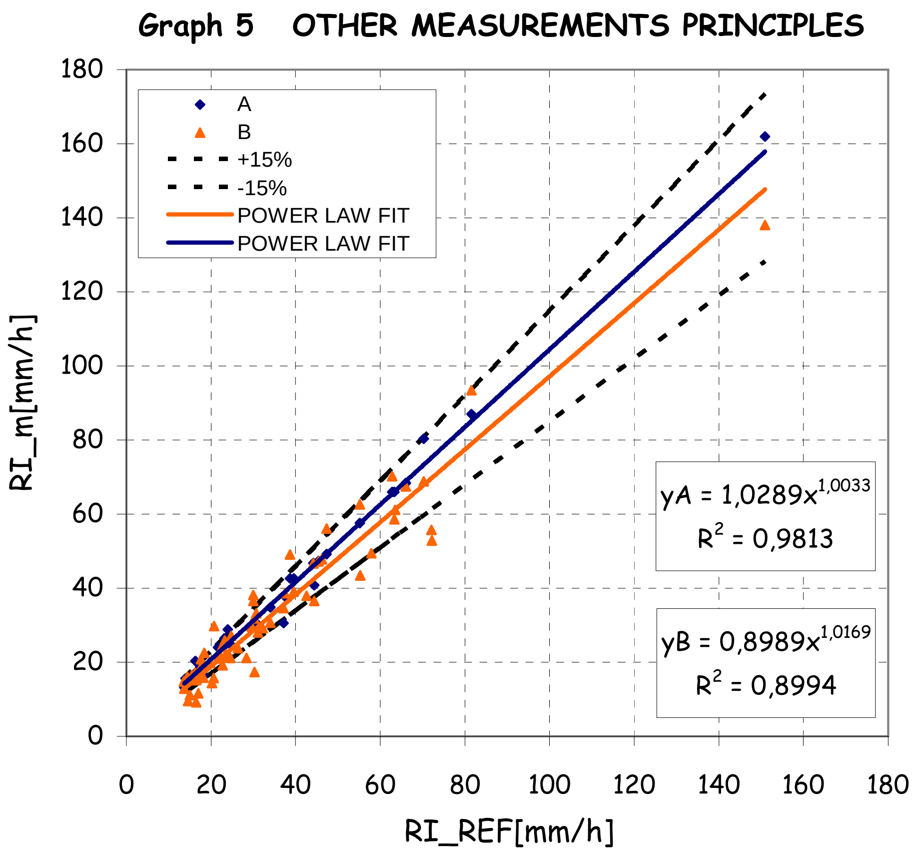
## GRAPHS SECTION

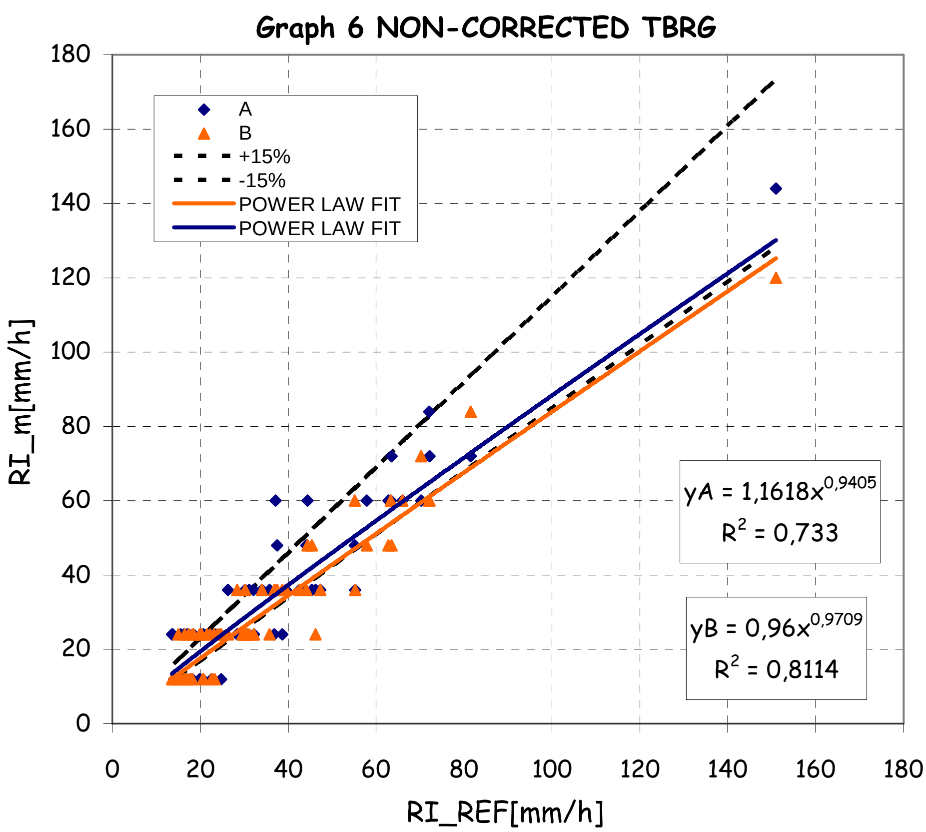


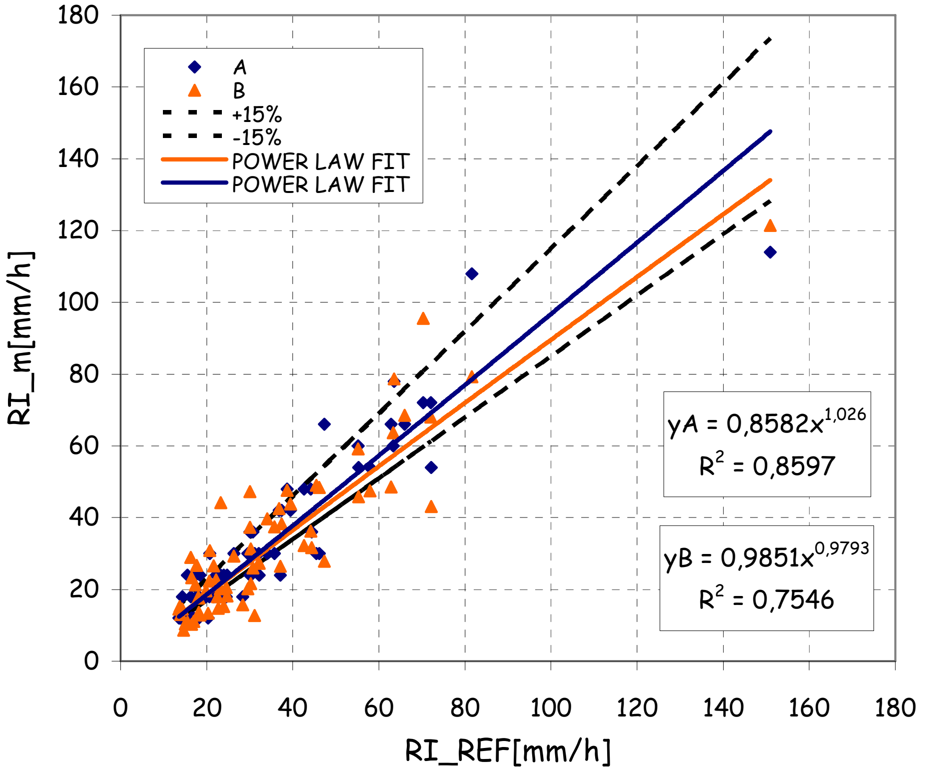

GRAPH 3 WGs - 1 MIN BETTER DYNAMICAL STABILITY/
SHORT RESPONSE TIME
A
B
+15%
-15%
POWER LAW FIT
POWER LAW FIT
yA = 0,9549x^1,0016
R^2 = 0,9474
yB = 0,9683x^0,9936
R^2 = 0,9483
RI_m[mm/h]
RI_REF[mm/h]
0
20
40
60
80
100
120
140
160
180


Graph 4 OPTICAL DISDROMETERS
A
B
+15%
-15%
POWER LAW FIT
POWER LAW FIT
yA = 0,9631x^1,0513
R^2 = 0,8974
yB = 1,4538x^0,9639
R^2 = 0,9154
RI_m[mm/h]
RI_REF[mm/h]
0
20
40
60
80
100
120
140
160
180

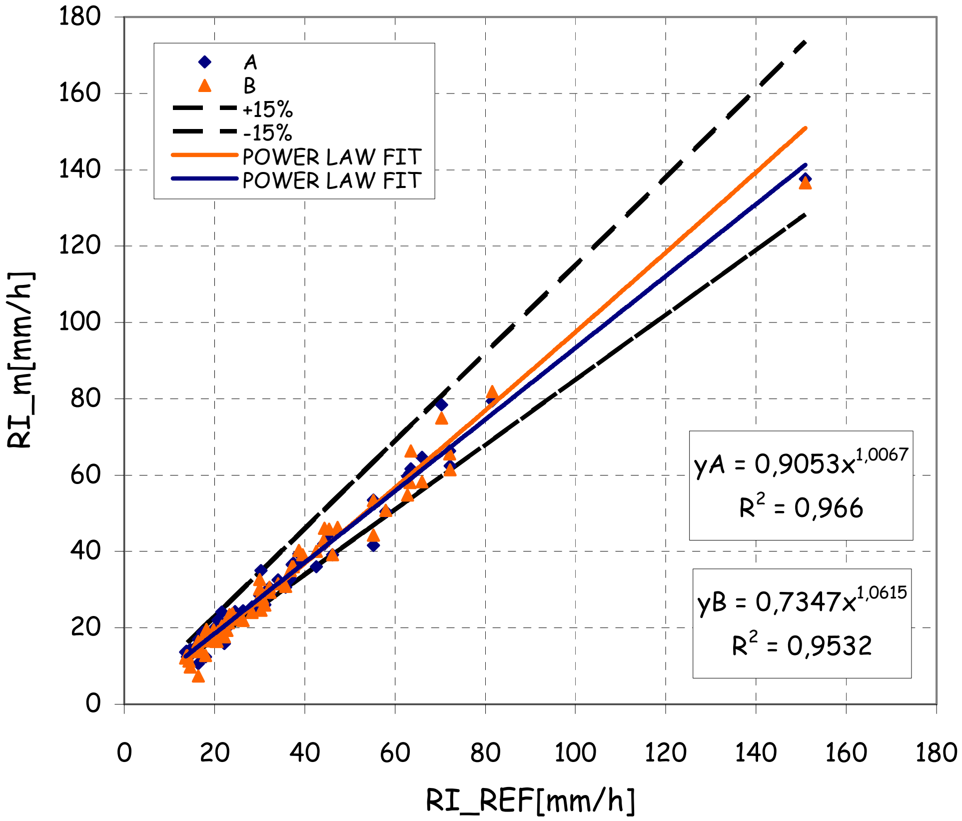

Graph 5 OTHER MEASUREMENTS PRINCIPLES
A
B
+15%
-15%
POWER LAW FIT
POWER LAW FIT
yA = 1,0289x^1,0033
R^2 = 0,9813
yB = 0,8989x^1,0169
R^2 = 0,8994
RI_m[mm/h]
RI_REF[mm/h]

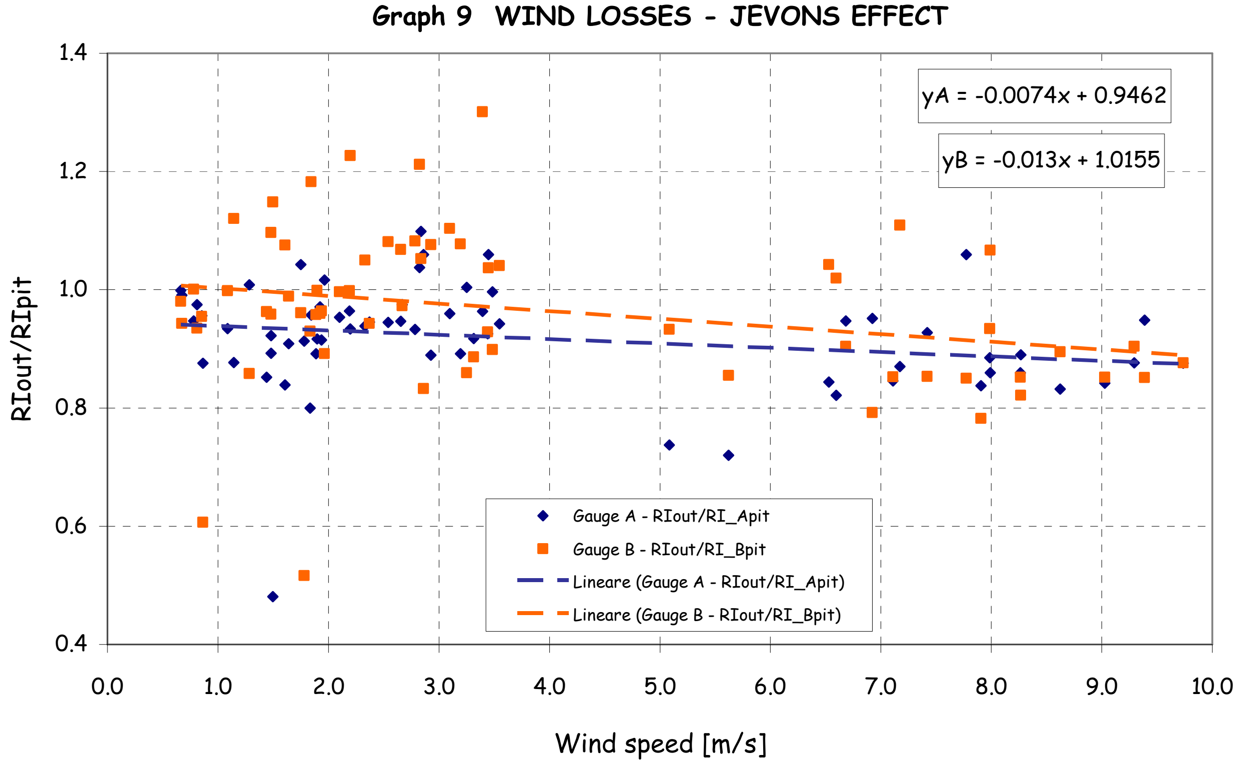

Graph 6 NON-CORRECTED TBRG
A
B
+15%
-15%
POWER LAW FIT
POWER LAW FIT
yA = 1,1618x^0,9405
R^2 = 0,733
yB = 0,96x^0,9709
R^2 = 0,8114
RI_m[mm/h]
RI_REF[mm/h]

## Graph 7 WGs - 1MIN REDUCED DYNAMICAL STABILIY/ LARGE RESPONSE TIME




## Graph 8 CURVE-CORRECTED TBRG (ALL DATA)






## Conclusions

1. This Field Intercomparison is the first Intercomparison for quantitative Rainfall Intensity measurements in field conditions and one of the most extensive in terms of the number of instruments involved (43).
2. It is the first time that four standard Reference Rain Gauge Pits are realized to derive a working reference RI.
3. The overall measurements site is considered very suitable to host Intercomparisons for its innovative, versatile design and acquisition system, thus it has been considered as "unique" in the world (ref. Report of the OPGA CO-CHAIRS at the 5$^{th}$ Session of CIMO Management Group, Geneva, Switzerland, 28-30 January 2008).
4. A maximum rainfall intensity of 160 mm/h and several rainfall events with peak intensities above 100 mm/h have been recorded since the beginning of the Intercomparison. From this point of view, Intercomparison results are fully satisfactory. However, a large number of RI events with peaks more than 100 mm/h would be desirable to meet the main Intercomparison objective (to inter-compare performances in high RI conditions).
5. The principle aim of data analysis was to perform the best intercomparison of in situ instruments through the determination of an accurate 1min Reference RI for the purpose.
6. Two methodologies are here suggested for determining the reference (statistics; physics of dynamics)
7. The sample application of the statistical methodology for the Reference RI and the consequent partial and preliminary evaluation of results done in this work constitute a guideline for the development of a complete data analysis of all precipitation events.
8. A preliminary comparison of several rain gauges at one minute time scale has been developed: results are very promising, thus the methodology demonstrates the possibility to evaluate the performance of RI rain gauges at 1 minute time scale, as recommended by CIMO, and the possibility to enlarge the evaluation to all monitored rain events.

In particular:

- The dynamic characteristics (oscillations/stability, step response function, time delay) and the synchronism could be considered the most important factors at 1 minute time scale for correctly determining of a reference RI (estimating the RI true value in field conditions);
- 1-min synchronized TBRG, corrected by internal algorithms, and WGs with 1 minute better dynamical stability are the most accurate for 1 min RI measurement since providing the less measurement uncertainty with respect to the reference chosen;
- Pulse-corrected TBRG show results similar to the previous gauges but a bit less accurate;
- Non-corrected TBRG analyzed, apart from the measurement resolution, can apply corrections via a post processing software or provide a correction curve/table to be as accurate as the corrected ones;
- WGs with less dynamical stability or lack of synchronism/large response time at 1 minute time scale are less accurate then WGs with 1 minute better dynamical stability with respect to the reference chosen.
- The two analyzed optical disdrometers show an overestimation trend with respect to the reference chosen and this trend has to be investigated and explained in details; it is demonstrated again how the 1 minute synchronization is important for the performance evaluation of RI gauges;
- The two analyzed rain gauges with other measurements principles (water level and pressure) show a very good performance in measuring 1 min RI.
- The proposed methodology or a more sophisticated one (step response function) allows suitable determination of the best reference and evaluation of the contribution of catching and counting errors on the overall measurement uncertainty by comparing the results of the preliminary laboratory phase and the final analysis of field phase.
- The impact of the wind losses (Jevons effect) on the overall uncertainty of the measurement could be also determined when more data in the interesting WS range will be available.

**9.** Following the previous considerations, already discussed during the period of the Intercomparison, the members of ET/IOC have decided that 5-minute RI averages are also of interest and worth to be analyzed as well with the purpose of reducing/filtering the noise observed at 1 minute time scale due to 1-min RI measurement resolution (non-corrected TBRG manly), dynamic characteristics and/or instability (WGs), time delay, response time and the lack of synchronism (automatic emitting instruments). The 5-minute RI data analysis will be treated in a separate session/report.

**References:**


[1] Expert Meeting (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.html)
[2] Final Report of the second session of the Expert Team Meeting CIMO-SBII&CM, Geneva (Switzerland) 5-9 December 2005
(available at http://www.wmo.int/pages/prog/www/IMOP/reports.html)
[3] 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 n.1019
(available at http://www.wmo.int/pages/prog/www/IMOP/reports.html)
[4] Final Report WMO Laboratory Intercomparison of Rainfall Intensity Gauges; De Bilt (The Netherlands), Genoa (Italy), Trappes (France); September 2004 – September 2005
(available at http://www.wmo.int/pages/prog/www/IMOP/reports.html)
[5]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
[6] Final Report of the third session of the Expert Team Meeting CIMO-SBII&CM, Vigna di Valle (Italy) 26 February-2 March 2007
(available at http://www.wmo.int/pages/prog/www/IMOP/reports.html)
[7] Final Report of the fifth session of the Expert Team Meeting CIMO-SBII&CM, Vigna di Valle (Italy) 17-21 September 2007
(available at http://www.wmo.int/pages/prog/www/IMOP/reports.html)
[8] Guide to meteorological instruments and methods of observation, WMO n.8, ed. 2006
[9] Prof. Dr. H. Koschmieder (1934), "Methods and results of definite rain measurements", Monthly Weather Review, Danzing (Germany)
[10] L. G. Lanza, L. Stagi, (2008) "High resolution performances of catching type rain gauges from the laboratory phase of the WMO Field Intercomparison of RI Gauges", EGU 2008 General Assembly, Vienna 14-18 April 2008.
[11] L. G. Lanza, L. Stagi, E. Vuerich (2008) "A portable device for dynamic calibration of catching type rain gauges in the field ", EGU - General Assembly, Vienna 14-18 April 2008.
[12] Lanza, L et al. (2008). WMO Field Intercomparison of rainfall intensity (RI) gauges at Vigna di Valle (Italy): Preliminary laboratory calibration and verification of the gauges as installed using a field calibration device (TECO 2008).
[13] WMO Manual 485 "Global Data-Processing system
[14] Meteorological Measurements Systems, F.V. Brock, S.J. Richardson, Oxford University Press, 2001;