QUALITY STANDARDS FOR RAIN INTENSITY MEASUREMENTS

Luca G. Lanza and Luigi Stagi
Department of Environmental Engineering, University of Genova, Via Montallegro 1, Genova, Italy
Tel. 39-010-3532123, Fax: 39-010-3532481, Email: luca@diam.unige.it

Abstract
A suitable qualification module for rain intensity measurement instruments is proposed based on an automatic procedure for dynamic calibration of traditional Tipping Bucket Raingauges (TBRs). Following an initial background of dedicated laboratory tests, which assisted in producing reference calibration curves for various types of commercial gauges from different manufacturing companies, the effects induced by systematic mechanical errors on the derivation of common statistics of rainfall extremes have been quantified. This research provides the needs and the requirements for the development of quality check procedures that can be easily shared among rain gauge manufacturers and implemented in view of the formulation of any suitable international standard. This would allow easy and accurate exchange of high quality precipitation data between organisations, e.g. in the framework of existing data exchange initiatives at the European and global scale.

Introduction

The correct measurement of liquid precipitation (rain) and other meteorological and hydrological variables, as well as the correct interpretation of historical data will be of foremost importance in the future for the prediction of changes in weather patterns affecting the whole climate of the Earth. In this respect, rain gauges provide the only direct measurements of rainfall intensity at the ground and are usually referred to as the “ground truth” in rainfall monitoring. Newly developed techniques for extensive rainfall observations based on remote sensing (essentially weather radar, airborne radiometers and satellites) provide a space-time description of rainfall fields, but still require the use of rainfall measurements from rain gauges for calibration and validation purposes.

Improvement of the reliability of Rain Intensity (RI) measurements as obtained by traditional tipping-bucket rain gauges (TBRs) and other types of gauges (optical, weighting, floating/siphoning, etc.) is therefore required for use in climatologic and hydrological studies and operationally e.g. in flood frequency analysis for engineering design. Standardisation of high quality rainfall measurements is also required to provide a basis for the exchange and valuation of rainfall data sets among different countries, especially in case transboundary problems such as severe-weather/flood forecasting, river management and water quality control are operationally involved.

Liquid precipitation measurements are affected by different sources of both systematic and random errors, due to wind, wetting and evaporation induced losses [e.g. Sevruk, 1989] which makes the measurement of light to moderate rainfall scarcely reliable without adequate correction. Snow measurements are even more difficult as snow is more sensitive than rainfall to weather related errors.

The traditional tipping-bucket rain gauge is also known to underestimate the higher rain rates because of the rainwater amount that is lost during the tipping movement of the bucket [Marsalek, 1981]. Though this inherent shortcoming can be easily remedied by means of dynamic calibration [Calder and Kidd, 1978; Niemczynowicz, 1986], the usual operational practice in meteorological services and instrument manufacturing companies relies on single-point calibration, based on the assumption that dynamic calibration has negligible influence on the total recorded rainfall depth. This results in systematic underestimation of intense rainfall rates that can be quantified – in the case of the SIAP family of rain gauge analysed in our survey – in the range 10-15% at rain rates higher than 200 mm/h.

The error increases as a function of the rain intensity and heavily affects the derived statistics, with non-negligible consequences on the numerical estimates of parameters involved in the common statistical tools that are used for the characterisation of extreme events (GEV and TCEV distributions, depth-duration-frequency curves, etc.).

The present paper focuses on both the development of a laboratory module for qualification and testing of rain intensity measurement instruments and the demonstration of the relevant biases associated with non calibrated gauges when addressing the estimation of statistical parameters used for characterisation of extreme rainfall rates and their probability of occurrence.
A laboratory qualification module for RI measurement instruments

The Final Report of the WMO Expert Meeting on Rainfall Intensity Measurement held in Bratislava during April 2001 includes as the main Recommendation that a laboratory calibration test is initiated in order to compare various state-of-the-art methods for rainfall intensity measurements. In order to undertake such an inter-comparison effort further recommendations requires that a standardized procedure for generating consistent and repeatable precipitation flow rates be developed for possible use as the laboratory standard for calibration of catchment type gauges.

At the laboratory of the Department of Environmental Engineering of the University of Genoa, an automatic device has been designed to satisfy such requirements and a prototype realised that is illustrated in Figure 1. The device, named “qualification module for RI measurement instruments”, is based on the principle of generating controlled water flows at a constant rate from the bottom orifice of a container where the water levels is varied using a cylindrical bellow. The water level and the orifice diameter are controlled by software in order to generate the desired flow rate. This is compared with the measure that is contemporary obtained by the RI measurement instrument under consideration and dynamic calibration is possible over the full range of rain rates usually addressed by operational rain gauges.

A wide survey of operational rain gauges has been performed in a previous work [Lombardo and Stagi, 1997] - both in meteorological stations and in laboratory tests - on some 60 instruments in the Liguria region of Italy, demonstrating the need of periodic checking using dynamic calibration. Forty out of the rain gauges analysed are currently used by the National Hydrographic Service in Genoa (Italy), while the others are from private enterprises or different organisations.

Calibration results are expressed in terms of the coefficient of the calibration curve, which is usually assumed as a power law in the form:

\[ I = \alpha \cdot I_R^\beta \] (1)

with I the true rainfall rate, I_R the rain rate measured by the gauge, and \( \alpha \) and \( \beta \) the calibration parameters that are synthetically reported in Table 1 for the set of instruments analysed.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Number of Gauges</th>
<th>Coefficient ( \alpha )</th>
<th>Exponent ( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIAP</td>
<td>37</td>
<td>0.860</td>
<td>1.046</td>
</tr>
<tr>
<td>MTX</td>
<td>1</td>
<td>0.759</td>
<td>1.076</td>
</tr>
<tr>
<td>CAE</td>
<td>1</td>
<td>0.824</td>
<td>1.058</td>
</tr>
<tr>
<td>SILIMET</td>
<td>1</td>
<td>0.960</td>
<td>1.037</td>
</tr>
<tr>
<td>LASTEM</td>
<td>9</td>
<td>1.063</td>
<td>1.058</td>
</tr>
<tr>
<td>MICROS</td>
<td>3</td>
<td>0.979</td>
<td>0.986</td>
</tr>
<tr>
<td>ETG</td>
<td>1</td>
<td>1.018</td>
<td>0.994</td>
</tr>
<tr>
<td>KIMOTO</td>
<td>1</td>
<td>0.663</td>
<td>1.133</td>
</tr>
<tr>
<td>ISCO</td>
<td>1</td>
<td>0.336</td>
<td>1.284</td>
</tr>
</tbody>
</table>

Table 1: Calibration parameters for various types of commercial TBRs.
The bias induced by systematic mechanical errors on rainfall statistics

The major consequence of biased measurements of rainfall is concerned with its propagation to hydrological analysis based on such measurements. The error evidence has been further analysed aiming at quantitative analysis of the bias propagation. The calibration procedure indicates which are the rainfall events to be considered significantly affected, and on that basis the analysis of historical data points out the extent to which rainfall statistical analysis, particularly extreme event analysis, can be affected by the bias.

The investigation provided quantitative estimation of how rainfall statistics can be affected by systematic error measurements. If the conjecture of higher errors on rainfall intensities observed for short duration is intuitive, it is difficult to find in the literature results from systematic studies that provide quantitative estimates of this. Most of the corrections methods are indeed used with respect to rainfall totals at large temporal scales of aggregation. The need for short term rainfall measurements and the importance of these in many engineering problems claim for improved methods that are designed to correct past rainfall observations.

Since mechanical errors mainly affect the higher intensities (i.e. rain amounts that are measured in very short intervals in time) the recovering of historical series is only possible when very fine resolution data are available. Unfortunately most of the historic information is either obtained from the interpretation of rain charts or at best stored in terms of cumulated values over time intervals of 30 to 60 minutes. Small-scale details of the rain process are definitively lost for most sites where suitably calibrated gauges are progressively installed. Any correction of past data sets must be therefore applied on disaggregated series at least down to 5 minutes in time, where the rain intensity is higher and the errors are significant. Such an exercise only permits statistical correction of the aggregated data and requires accurate studies of the temporal structure of the rain process at fine scales, and of specific processes – such as the intermittence – that might play a relevant role at such scales [Molini et al., 2001].

Accordingly, techniques to correct historical records of short duration rainfall observations after proper disaggregation of the original figures have been developed and, on the basis of the corrections resulting from application of the proposed techniques, the influence of the errors has been investigated with reference to one of the most popular tools used for the statistical characterisation of rainfall extremes, i.e. the depth-duration-frequency curves. These have been derived under the hypothesis of a Gumbel (EV1) distribution for rainfall extremes, and the results reported here refers to the meteorological station of the Historical Observatory of Chiavari (Italy) where rainfall data are have been continuously recorded since 1883 on a daily basis and since 1960 on a hourly basis.

Rainfall data have been disaggregated using a random cascade algorithm based on weighting parameters derived from the one minute data recorded at the nearby station of the University of Genoa (with data over the period 1990-2000). Monte Carlo simulations of the disaggregated data series have been performed for a total of 1000 runs, and the obtained rain series have been re-aggregated at suitable time scales. For each generated scenario the corresponding depth-duration-frequency curve has been derived and the set of curves obtained is plotted in Figure 2 against the original one (derived on the basis of non corrected data).

![Fig. 2](image-url)
It is evident from the diagrams in Figure 2 that rainfall events of any given duration are largely underestimated, with an error on the associated return period $T$ that can be estimated at about 100% for $T = 100$ years. More detailed results of this study are already published in La Barbera et al. [2002], where the so-called “equivalent sample size” is introduced as a suitable parameter to quantify the impact of such errors on the common hydrological practice.

**Standards and certification procedures for rain gauge instruments**

In the European Commission Working Document on Research and Standardisation (COM98/31), standards - being one of the tools to foster homogeneous quality - are recognised to be in a strategic position to promote the competitiveness and interoperability of products and services. Standards thus provide a bridge between the technical domain and the regulatory and economic framework. The development of new standards and their implementation however depend on considerable amount of preliminary research.

The opportunity to combine scientific and technological developments with investigations on pre-normative issues, provide a measure of the suitability of any newly developed instrument and calibration methodology to act as the basic technical references for a new European standard gauge.

This would complement the interests of CEN/TC 318 “Hydrometry”, aimed at “the standardisation of methods and instrumentation relating to techniques for hydrometric determination including (...) precipitation”. In CEN TC 318 an EN (European Standard that carries with it the obligation to be implemented at national level by being given the status of a national standard and by withdrawal of any conflicting national standards) on a standard reference rain gauge pit has been already prepared within the efforts of WG5 towards a “Reference rain gauge station”. At the knowledge of the authors there is no activity within ISO on this subject, although the subject in principle could be included under ISO/TC 113.

The economic impact of standardisation in this field is evident, recalling that the total turnover of the water industry in Europe is estimated to be EU 58,000 million of which the hydrometric element is estimated to be EU 190 million. Most national members have a selection of their own national standards within the scope of TC 318. For many years, the World Meteorological Organisation (WMO) has been publishing its own Technical Recommendations on some aspects of the work, and the International Organisation for Standardisation (ISO) has published, and continues to publish, a large number of International Standards and Technical Reports. Following the Terms of Reference of the WMO Commission for Instruments and Methods of Observations an expert meeting on rainfall intensity measurements was held and the organisation of a related laboratory inter-comparison is now suggested, together with the introduction of precipitation correction procedures and development of further correction procedures based on simulations. On these basis the need for some further steps towards homogenisation of standard quality of instruments as well as towards the establishment of criteria to assess data quality is more than evident.

The development of a qualification module for RI measurement instruments allowing quality assurance and metrological confirmation of rain gauges according to the European Standard ISO/EN30012-1 is just a first step ahead in this direction, although much work is still required in terms of the accuracy and range requirements, the proper configuration of the calibration equipment, the expected performances and the definition of a standard method of testing. Controlled laboratory conditions should be ensured and a common procedure established that can be easily repeated in any equipped laboratory.

**References**


