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Improving the accuracy of operational tipping-bucket rain gauges by calibration techniques

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This paper concentrates on the counting errors of tipping-bucket rain gauges (TBRs) and specifically on the correction procedures to be applied for appropriate post-processing of raw measured data. Although a residual uncertainty within $\pm$ 5% can be easily obtained for properly calibrated instruments, the errors observed under constant flow rate conditions are still higher than those associated with other types of gauges (e.g. weighing gauges). However, under variable (real) rain intensity, TBRs have the potential to perform much better than weighing gauges since they have practically no delay in sensing rainfall variations at sufficiently intense rain rates. The objective of the present work is to demonstrate that the residual errors of TBRs can be reduced to less than $\pm$ 1% provided accurate procedures are used for calibration and suitable post-processing is implemented. Typical counting errors of TBRs derive from the combination of different factors:

- the uncertainty about the real volume of the bucket when the tipping movement is initiated;
- the possible different behaviour of the two compartments of the bucket;
- the mechanical error due to the water losses during the tipping movement of the bucket.

The first source of error derives from using a nominal volume instead of the actual figure to calculate rainfall intensity starting from the number of tips in a given time window. This can be used to compensate mechanical errors in order to force a zero error condition at a given rain intensity (and this automatically produces an obvious

overestimation effect at the lower intensities). The second source is due to the difference in the actual volume of the two compartments, which may not be the same in case of inappropriate balancing of the tipping device. This error reduces with increasing rain 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 TBRs underestimate rainfall, especially at the higher intensities, because of the rainwater amount that is lost 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 rain intensities higher than 200 $mm \cdot h^{-1}$. The above-described errors were estimated by performing laboratory tests on a large number of gauges, so as to derive a common behaviour and to assess the variability of individual gauges with reference to the average behaviour.