STUDY OF THE ERRORS OF RAINFALL RECORDED AT THE BALEARIC A.W.S. THROUGH COMPARISON WITH TRADITIONAL RAIN GAUGES

José A. Guijarro

Instituto Nacional de Meteorología. Centro Meteorológico en Illes Balears, Muelle de Poniente s/n, Portopí. 07015-Palma de Mallorca. (pmd@inm.es)

Abstract

The automatic weather stations ruled by the Spanish Instituto Nacional de Meteorología at the Balearic Islands are located at conventional pluviometric stations, provided with a Hellmann gauge whose measures have been used to assess the reliability of the AWS tipping bucket records over the observational period of each station. The study has been carried out with the eight Balearic AWS with more than 200 days with at least 1 mm rainfall. Taking the conventional measures as the reference, the average correction factors to the different AWS range from 0.96 to 1.22. The influence of the rainfall intensity on these errors has also been considered. It is statistically significant in most of AWS, though its contribution to the errors is generally little and varied in nature.

Keywords: tipping bucket, rainfall, errors, Balearic islands.

1. INTRODUCTION

The tipping bucket rain gauge is widely used as the precipitation sensor in the Automatic Weather Stations (AWS) for its simplicity and easy maintenance. However, its measures can be affected by errors of different origin, most of them common to other types of rain gauges, but others specific, as the tendency of the bucket to tip before it is filled when the rainfall intensity is high.

Many studies have been devoted to these errors (for example: SEVRUK, 1996; FANKHAUSER, 1998; HABIB *et al.*, 2001; etc). In this work, advantage is taken from the fact that the Balearic AWS are located at conventional pluviometric stations, provided with a Hellmann gauge. These measures will act as references to assess the reliability of the tipping bucket records in different rainfall intensities, once overcome the difficulty of having different time resolutions (24 hours and 10 minutes, respectively).

2. METHODOLOGY

The rainfall measure comparisons have been carried out on eight AWS of the Balearic Islands, with data extending from 1989 to 2002 (table 1 and figure 1).

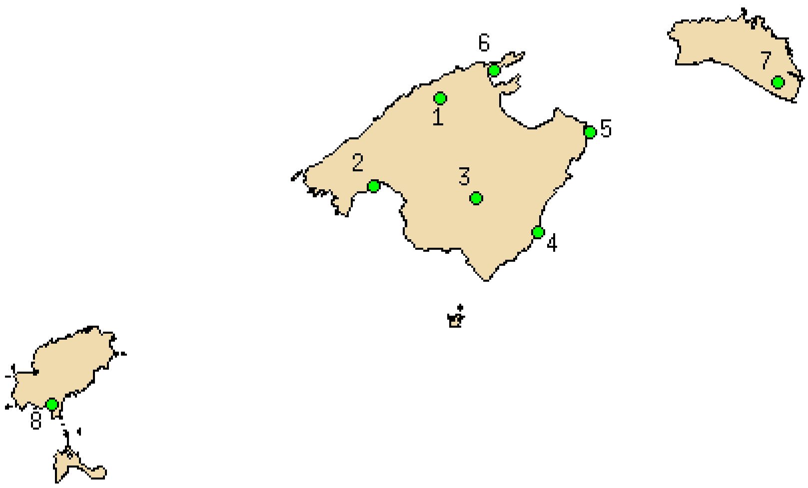
A first approximation to the relationship between the *true* precipitation (y) and that measured by a tipping-bucket gauge in 10 minute intervals (x) can be the linear expression: $y = b\,x$. The hypothesis to test is that b, rather than a constant, is also dependent on the intensity of the precipitation. If this dependence is linear: $b = c + d\,x$, and hence: $y = c\,x + d\,x^2$. Other polynomial expressions can be tried in search for a better adjustment.

But while the AWS tipping-bucket has a time resolution of 10 minutes, our best estimator of the true precipitation, the conventional rain gauge measures, are taken once a day (four times per day only in the principal observatories, stations 2, 7 and 8 of table 1). Therefore, Y, the 24 hours precipitation at conventional stations (measured from 7 to 7 hours UTC at the principal observatories and from 8 to 8 at the secondary ones), can only be related with summatories of different powers of the 10' data: $X_1 = \sum x_i$, $X_2 = \sum x_i^2$, and so on.

Table 1: Names, coordinates and observing periods of the studied Automatic Weather Stations.

N	Indic.	Name	Coordinates North Lat.	East Lon.	Altitude Z(m)	Period	Selected days
1	B013	Lluc	39°49'26"	2°53'08"	490	1993-02	269
2	B228	Palma Portopí	39°33'18"	2°37'35"	3	1989-02	329
3	B346A	Porreres Poliesportiu	39°31'10"	3°01'24"	120	1989-02	258
4	B434	Far de Portocolom	39°24'53"	3°16'19"	17	1993-02	230
5	B569	Far de Capdepera	39°43'00"	3°28'42"	66	1989-02	253
6	B780	Port de Pollença A.M.	39°54'38"	3°06'02"	2	1989-02	360
7	B893	Aeroport de Menorca	39°52'01"	4°13'35"	85	1993-02	230
8	B954	Aeroport d'Eivissa	38°52'38"	1°22'12"	11	1994-02	205

Fig. 1: Location of the eight AWS used in this study



Due to the different observation hours, together with some uncertainty in the time of the observation made by a human observer, the study has been made only on the rainy days with at least 1 mm precipitation in the conventional rain gauge, and with no more than 0.1 mm tipping-bucket precipitation between 7 and 8 hours in the same and the following days. This yielded a number of selected days ranging from 205 at Ibiza Airport to 360 at Port de Pollença. The method used to explore the relationships was multiple linear regression, performed with the R statistical package, running under Linux.

3. RESULTS AND DISCUSSION

An exploratory study made with the data from Palma Portopí tested the linear simple dependence $Y = b\,X$ and the binomial $Y = c\,X_1 + d\,X_2$, with powers in the vicinity of 2 ($X_2 = \Sigma\, x^q$, with q=1.6, 1.8, 2.0, 2.2 and 2.4). The fitting R-squared values obtained were 0.9917 for the linear equation and 0.9921 for all the binomial expressions, irrespective of their power value. The improvement of the binomial equation seems negligible, but the p-value is highly and increasingly significant, suggesting that, though the different powers give quite similar results, values greater than 2.4 might offer even better adjustments.

Therefore, a much wider range of powers were tried. 24 hours summatories of the 10' precipitations raised to powers 2 to 5 were computed, and multiple regression analysis were performed to fit the general model:

$$Y = b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5$$

Stepwise backwards elimination of the variables which were not significant at α= 0.05 resulted in different polynomial models been adjusted to each of the AWS. A summary of the results is offered in table 2.

Table 2: Results of the simple and multiple regression analysis. Only variables significant at α = 0.05 were retained in a backwards stepwise procedure.

Ind.	b	r^2	b_1	b_2	b_3	b_4	b_5	R^2
B013	1.0105	0.9832	1.063	-1.959e-1	-	-	-	0.9838
B228	1.2174	0.9917	1.198	-	1.347e-3	-	-	0.9921
B346a	1.1444	0.9589	-	-	-	-	-	-
B434	1.0237	0.9647	1.067	-1.750e-1	4.957e-2	-3.995e-3	9.679e-5	0.9765
B569	1.0752	0.9146	1.266	-4.691e-1	1.817e-1	-1.961e-2	5.842e-4	0.9232
B780	1.0284	0.9678	1.080	-	-8.411e-3	6.081e-4	-	0.9697
B893	0.9607	0.9780	0.970	-	-	-1.996e-5	-	0.9784
B954	1.0384	0.9947	1.031	-	-	-1.723e-4	1.344e-5	0.9964

The regression coefficients of the simple linear model are all but one greater than one, showing a general tendency of the tipping bucket rain gauge to underestimate rainfall (as compared to the Hellmann gauge). Five of the eight gauges studied keep their average errors under the 5% threshold, while two of them are greater than 10%, the maximum been as high as 21.7% (B228, Palma Portopí). The coefficients of determination report explained variances over 95%, except for B569, which only explains 91.5%.

Figures 2 and 3 show the fitted lines for the data of the stations that gave the best and worse results. In both of them, most of the points lay in the vicinity of the fitted line, while several outliers appear generally on the upper side of the line (tipping bucket underestimation). A dashed identity line (Y=X) acts as a visual reference to show the magnitude of the average correction to apply to the AWS precipitations.

The multiple correlation analysis yielded a variety of results, from the null improvement of one station (B346a - Porreres) to the significance of all the five terms of the polynomial model in other two (B434 and B569). The multiple coefficients of determination (adjusted to account for the different freedom degrees) make only slight improvements on the percentage of variance explained by the simple linear model.

Figure 4 presents the residuals of both the simple and polynomial models plotted against the fitted values, for the station B434 (Far de Portocolom), which is the site with greater fitting improvement (from r^2=0.9647 to R^2=0.9765). But this difference is still quite small, and only a pair of simple model residuals are greater than the polynomial ones.

According to these results, the influence of rainfall intensity on the tipping bucket records are different between the stations, but little enough to consider them as negligible. This is supported by the different degrees of the fitted polynomials, that resulted from establishing a significant level of acceptance of α = 0.05. Moreover, this kind of significance assessment is only of relative value in our case, since the precipitation data are quite far from having a normal frequency distribution.

Fig. 2: Best fitted simple linear regression

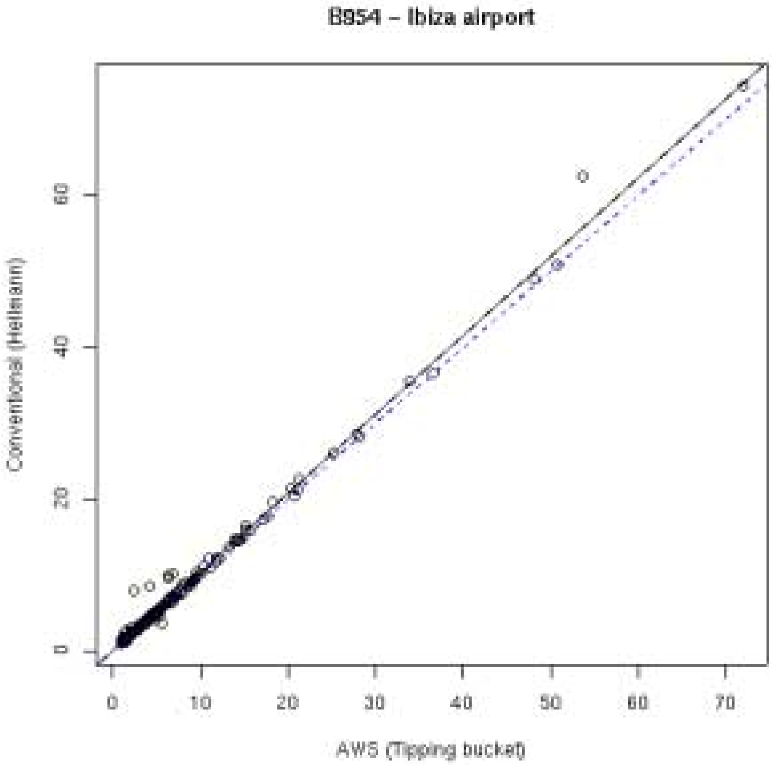


Fig. 3: Worse fitted simple linear regression

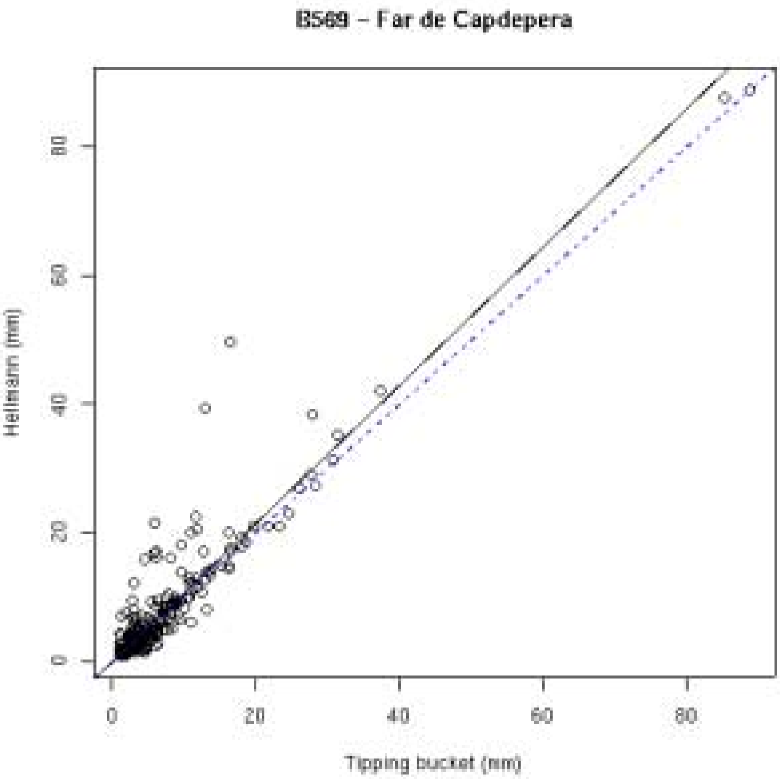
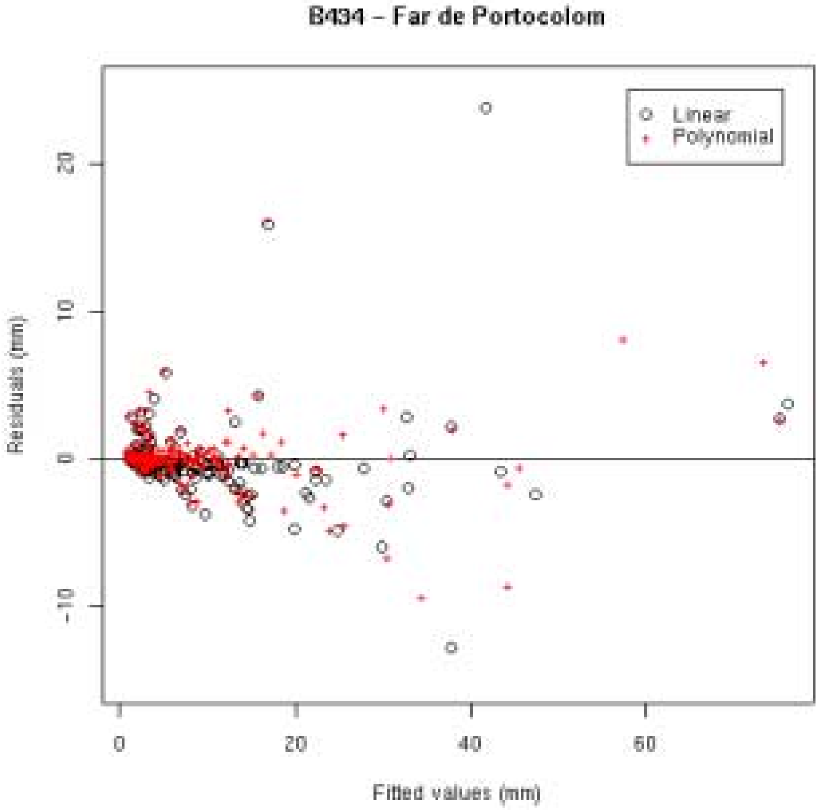


Fig. 4: Residuals vs. fitted values for the simple and polynomial models, at the station with greater difference in explained variance.

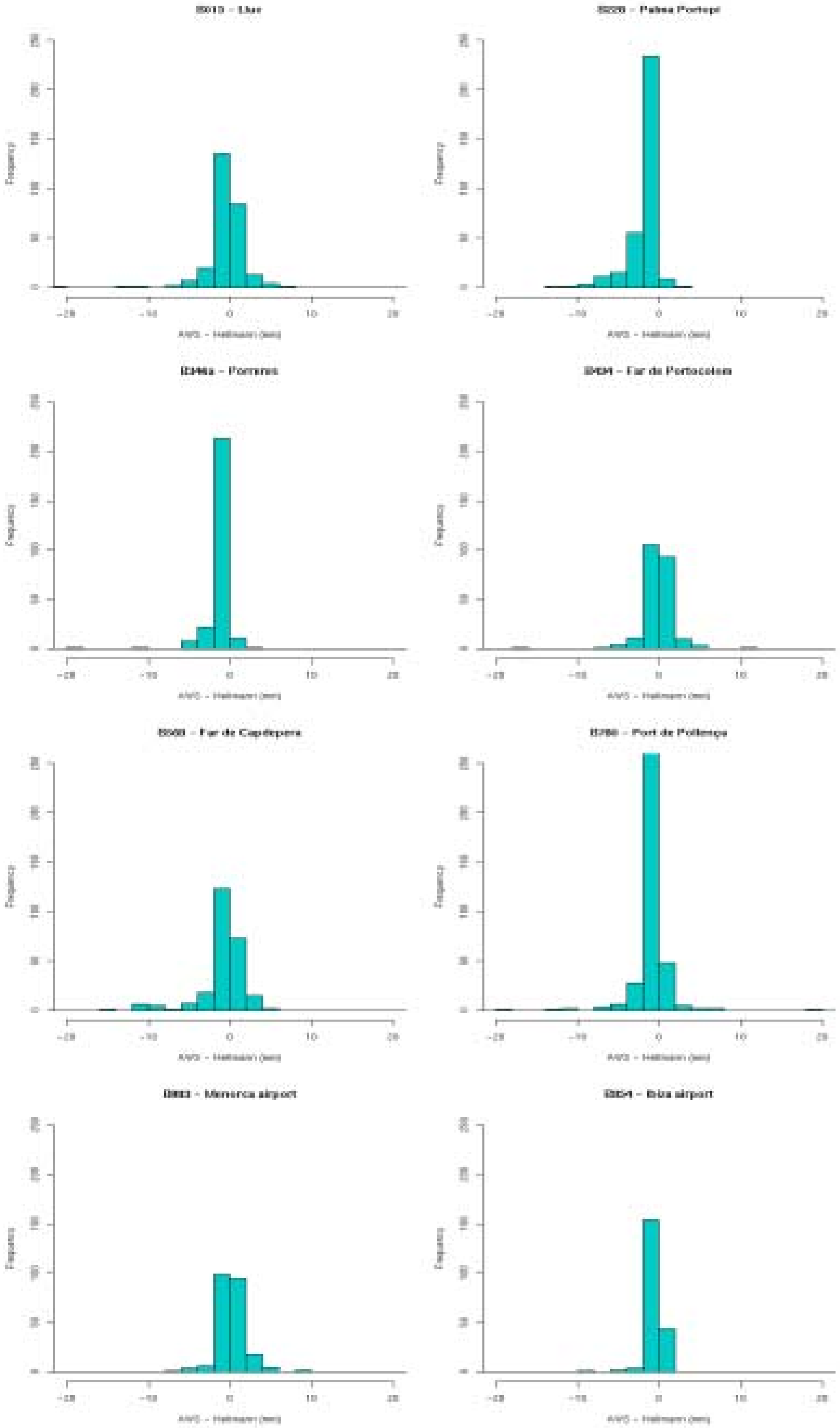


But the regression results discussed so far only give us information on the average errors of the data. Individual errors, or rather, deviations from the Hellmann measures, are greater, as shown in table 3 and figure 5. All the stations but one (B893 - Menorca airport) show left biased deviation distributions. Most of the deviations are of little absolute value (74 to 97% equal or under 2 mm), but there are outliers with deviations as large as +18.1 and –33.2 mm. These must be due to other kind of errors, either human or instrumental (obstruction of the gauge funnel, etc).

Table 3: Tipping bucket record deviations from the Hellmann rain gauge measures. Some statistics, and percentage of deviations with absolute value equal or under 2 mm.

Ind.	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	|D|<=2mm(%)
B013	-22.8	-0.6	-0.1	-0.40	0.3	7.0	81.8
B228	-12.4	-2.1	-0.7	-1.50	-0.3	3.3	74.2
B346a	-41.7	-1.1	-0.4	-1.08	-0.1	2.9	87.2
B434	-24.8	0.0	0.0	-0.03	0.4	11.9	87.0
B569	-33.2	-1.0	0.0	-0.90	0.5	5.2	77.9
B780	-18.0	-0.8	-0.2	-0.56	0.0	18.1	85.8
B893	-6.3	-0.5	0.1	0.21	0.6	9.7	84.3
B954	-8.8	-0.2	-0.1	-0.25	0.0	2.0	96.6

Fig. 5: Histograms of the AWS-Hellmann deviations in the eight studied stations



4. CONCLUSIONS

The tipping bucket rain gauges of the Balearic Automatic Weather Stations tend to underestimate rainfall, when compared to the traditional Hellmann rain gauges.

The intensity of the precipitation has a statistically significance on the errors of the tipping bucket, but the improvements of fitting polynomial models to take it in account are quite small, and the elimination of the non significant terms yield a variety of different models for the studied stations.

Therefore, rainfall intensity has a negligible effect on the differences between the Balearic AWS and the Hellmann precipitation measures.

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