One-minute integrated rainfall rate statistics from a rain gauge network in Colombia: accuracy of prediction methods

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Reliable rainfall rate complementary cumulative distributions are critical for the design of microwave communications systems operating above around 8 GHz. This Letter presents the results of the analysis of more than 5 years of 1-minute integrated rainfall accumulation data for 12 stations. This new dataset will prove useful considering the sharing analyses that must be executed for IMT services in the 24.25–27.5, 37–43.5, 45.5–47, 47.2–48.2 and 66–71 GHz spectrum bands. The resulting statistics can complement the entries in the database of ITU-R Study Group 3 for the region.

Introduction: Complementary cumulative distributions of point rainfall rate (henceforth referred to as $P(R)$) are the main input for the analysis of rain-induced attenuation. Regardless of whether the attenuation prediction model requires as input single value (as in the current ITU-R models) or a full distribution, the reliability of the predicted attenuation output is directly related to the accuracy of the input rainfall rate information. Noting the reduced number of reliable statistics available from equatorial regions in the ITU-R Study Group 3 database (known as DBSG3: out of 163 entries, only 41 are between ±30° latitude), the statistics provided in this Letter represent a useful and timely contribution for the development and testing of prediction methods. This activity is relevant given the variety of sharing studies that must be executed in the context of the use of the EHF bands for International Mobile Telecommunications (IMT) services.

Aburra Valley: The valley is located in the centre of the department of Antioquia (around 6° N, 75.6° W), on the central chain of the Andes mountain range, with an average elevation of 1538 m. The city of Medellin and its metropolitan area are in the valley and represent the second-largest urban centre in Colombia, second only to the metropolitan area of the Country's capital, Bogota. As [1] presents in detail, precipitation on the valley is dominated by the influence of the inter-tropical convergence zone (ITCZ), which results in two rainy seasons per year (April–May and September–October), and by the dynamics of three low-level jets in the region namely CHOCO, Caribbean, and Corriente de los Llanos Orientales (CAO). The orography of the valley reflects in differences in the diurnal cycle of rainfall.

Rain gauge network: The rain gauge network is part of the Sistema de Alerta Temprana de Medellín y el Valle de Aburrá (SIATA, https://siata.gov.co/) (Information and Early Warning System). The rain gauges are DAVIS model 7857 tipping bucket devices, with accumulation resolution of 0.01 inches.

Rain gauge data analysis: The precipitation time series are delivered as comma-separated files for a month's worth of data and contain a time stamp, the accumulated rainfall in a one-minute period and a quality indicator to determine if the data entry is valid or dubious. The data were post-processed to remove spurious events (events of high accumulation amidst an otherwise dry spell) and to apply the algorithm recommended in [2] by the ITU-R to process rain gauge tips. The 12 stations selected for the analysis contain more than 5 consecutive years of measurements, with uptime exceeding 95% of the experiment duration (see Table 1).

Fig. 1 illustrates the rainfall rate $P(R)$ for site number 11 in Table 1 (blue solid line).

Comparison against prediction methods: The measured $P(R)$s have been compared against the outputs of various prediction methods: the in-force ITU-R recommendation, P.837-7 [3], the previously enforced methods in P.837-6, -4, -1, and the MORSE [4] method (candidate during the testing and selection process towards recommendation 837-7). We have included 837-1 given that it is incorporated in the procedure for the determination of the coordination area, part of the coordination of satellite earth stations procedures set in the ITU-R Radio Regulations, Appendix 7 [5]. To evaluate the performance of each method, we use the relative error metric as defined in (1), together with the mean (E) and root-mean-square (RMS) values as set in (2) for each site, and in (3) for the multiple-site aggregate

$$\varepsilon_i(P_j) = \frac{R_{E_i}(P_j) - R_{M_i}(P_j)}{R_{M_i}(P_j)} \tag{1}$$

$$E_i = \frac{1}{n_i}\sum_{j=1}^{n_i} \varepsilon_i(P_j), \quad E = \frac{\sum_{i=1}^{N_s} \alpha_i n_i E_i}{\sum_{i=1}^{N_s} \alpha_i n_i} \tag{2}$$

$$\mathrm{RMS}_i = \sqrt{\frac{1}{n_i}\sum_{j=1}^{n_i} \varepsilon_i^2(P_j)}, \quad \mathrm{RMS} = \sqrt{\frac{\sum_{i=1}^{N_s} \alpha_i n_i \mathrm{RMS}_i^2}{\sum_{i=1}^{N_s} \alpha_i n_i}} \tag{3}$$

In (1), $R_{M_i}(P_j)$, $R_{E_i}(P_j)$ are the rain rates extracted, respectively, from the measured and estimated $P(R)$ for site i, at the same probability j, with $P(j) > 0.001\%$, and R limited to values greater than 2 mm/h to avoid large errors resulting from low, inaccurate, rainfall rates. n_i is the number of probability points available in the $P(R)$ for the site i. The E and RMS values in (2) and (3) are computed across N_s sites and weighted using the product of the experiment availability and duration (α_i).

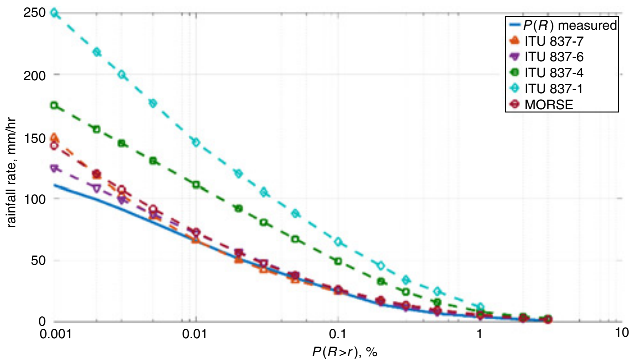

Fig. 1 *P(R) example for site 11 in Table 1: $R_{0.01\%}$ for the site is 65.7 mm/h and the duration is 6 years*

Table 2 lists E and RMS in (2) and (3), while Fig. 2 illustrates $\varepsilon_i(0.01\%)$ for each site, given the relevance of the rain rate exceeded for 0.01% in a year in the context of attenuation prediction using the ITU-R framework of recommendations P.530 and P.618.

Table 1: Coordinates of the rain gauge sites for which availability is >95% of the experiment's time. $R_{0.01\%}$ is the rain rate exceeded for 0.01% of the yearly time

ID	Lat, N	Lon, E	Availability, %	Duration, years	$R_{0.01\%}$, mm/h
1	6.25	−75.55	95.2	6.26	64.38
2	6.21	−75.60	96.0	7.02	73.14
3	6.26	−75.54	96.8	5.04	69.54
4	6.17	−75.64	95.1	7.02	83.61
5	6.21	−75.57	97.5	5.04	65.83
6	6.26	−75.59	97.1	5.02	65.23
7	6.27	−75.56	96.2	6.08	91.84
8	6.35	−75.50	96.2	6.08	82.82
9	6.22	−75.59	96.1	6.04	65.74
10	6.27	−75.63	96.0	6.08	90.77
11	6.36	−75.45	95.1	6.06	65.67
12	6.31	−75.57	95.5	6.06	61.61

Table 2: Values of E and RMS in (2) and (3) for each prediction method

Method	E in (2)	RMS in (3)
P.837-7	0.02	0.07
P.837-6	0.076	0.05
P.837-4	0.76	0.83
P.837-1	1.39	2.52
MORSE	0.15	0.10

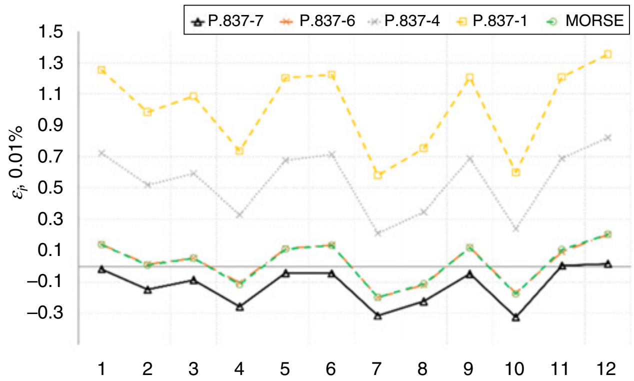

Fig. 2 *ε_i(0.01%) for each site*

Figs. 3 and 4 complement the performance analysis by showing, respectively, E_i in (2) for each site, and RMS (3) as a function of P, the latter obtained by setting different probability levels in (1).

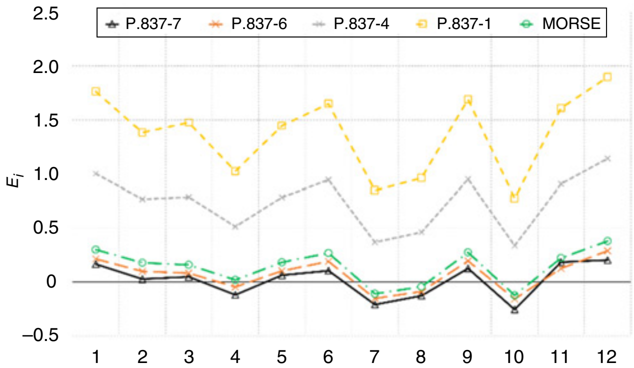

Fig. 3 *E_i for each site*

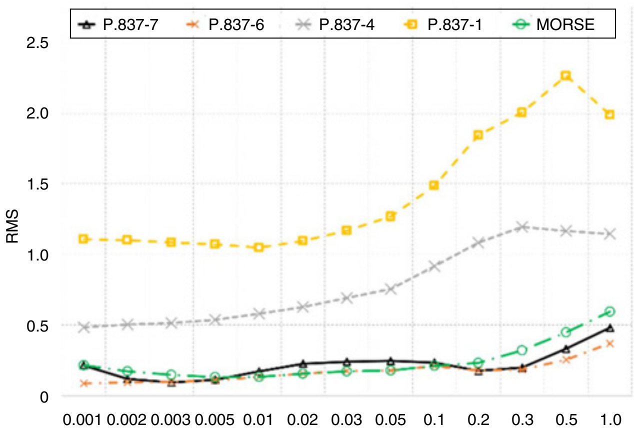

Fig. 4 *RMS in (3) obtained by setting different probability levels in (1)*

Comments on the results: It comes as no surprise that the performance of the prediction methods has improved with each revision. As shown in Figs. 2–4, the coarse region-distribution mapping of recommendation 837-1 is clearly unable to produce accurate results for the area under analysis; on the contrary, the most recent versions of the model, 837-7 and -6, provide much smaller deviations from the measured rainfall rate at 0.01%. MORSE and the P.837-6 model deliver very similar metrics, most likely because they both use as input the ERA-40 data for total accumulation and convective rain factor.

The prediction performance degrades at both ends of the probability range (Fig. 4): on the lower end, possibly due to the inaccuracies in the determination of the P_0 parameter (probability of having rain) underlying each formulation, and on the upper end due to both the shape of the predicted distributions (which increases at a higher rate than the measurements show) and due to the impact of the reduced statistical stability for lower exceedance probability levels: ideally, at least 10 years of continuous measurements would be necessary to model accurately the tail of the distribution. On the differences between versions -7 and -6 of the ITU-R recommendations, we must add that the latter included data from the Aburra Valley present in DBSG3 as part of its parameter optimisation process. Given that this new data comes from the same region, it is not surprising to see the -6 model performs well. The -7 model follows different principles and its parameters were not tuned using the rainfall distributions from the valley in the DBSG3. Nevertheless, model -7 delivers the second-best performance across sites and probability ranges. Finally, model -6 is more accurate in delivering predictions of $R_{0.01\%}$, which is the key information needed for system planning using ITU-R recommendations.

Conclusion: The results presented in this Letter evidence the continuous improvement of the ITU-R recommendation for rainfall statistic prediction in the region. For the purposes of sharing studies, recommendation P.837-6 provides the most accurate prediction, especially considering the rainfall rate exceeded for 0.01% of the yearly time, which is required as input to several rain attenuation prediction methods. Though not optimised on the basis of any data from the Aburra Valley (unlike method -6), 837-7 delivers a very good prediction performance across the sites and probability ranges (second-best overall). Finally, although still incorporated into the Radio Regulations, the use of the P.837-1 region-based model should be discouraged, in favour of the latest version of the recommendation or, for this region and in the absence of local distributions, in favour of version 6 of P.837.

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One or more of the Figures in this Letter are available in colour online.

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