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| **Radiocommunication Study Groups** |  |
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| CONCERNING ANNEX 3 ON RECOMMENDATION ITU-R P.837-6 | |
| PHYSICAL Modelling for THE conversion of rain rate statistics at different integration times | |

# 1 Introduction

Recognizing the importance that proper estimation of rainfall attenuation has on microwave system design at frequencies above 10 GHz, the ITU-R has developed a recommendation (Recommendation ITU-R P.837-6) that enables the user to estimate the local rainfall rate (*R* [mm/hr] at 1 minute integration time) statistical distribution (also known as *P*(*R*)) using as input either:

– Global digital maps of precipitation parameters derived from numerical weather prediction data (Annexes 1 and 2).

or

– Local measurements of rainfall accumulation with an integration time up to 60 minutes (see Annex 3).

As shown in previous works [1], the conversion of rainfall statistics is a relevant topic of discussion as:

– Operational rainfall measurements are routinely gathered worldwide, for hydrological and agricultural purposes, with a sample time of 60 minutes or less according to World Meteorological Organisation (WMO) guidelines [2].

– The use of local data at different integration times, coupled with an integration conversion model, provide a better approximation to the local 1-min integrated P(R) than the use of the global model proposed in Annex 1 of the current ITU-R Recommendation ITU-R P.837-5. The decrease in the RMS of ** can reach 20% in some regions (see [1]).

The considerations behind the adopted change to the recommendation are detailed in the remainder of this document, which is structured as follows: Section 2 describes the experimental data used for model testing which are in DB-SG3 Table IV-1 “Statistics of rain intensity” (Appendix A includes a detailed site by site description of the measurements used), Section 3 provides a short review of the models for conversion of statistics at different integration times; Section 4 presents the results of the testing activity of the models, and Section 5 provides conclusions.

# 2 Description of the Table IV-1 data used for model testing

Figure 1 illustrates the geographical location of the sites, for which measurements of *P*(*R*) at different integration times are available, and the experiment duration (years).

It is considered that the geographical distribution, the duration of measurements and the number of experiments for different integration times is statistically significant for assessing modelling accuracy on a global scale.

Figure 1

**Stations included in data used for model testing.   
The symbol indicates the number of years of measurement of each site**



# 3 Review of the selected models for conversion of rainfall rate statistics at different integration times

Among the several rain statistics conversion models available in the literature, only those which can be applied on a global basis and require as input only the cumulative distribution function (as currently available in the DB-SG 3 Table IV-1), have been selected, as discussed in [3].

The selected models can be classified as:

– Empirical, which make use of conversion coefficients to be determined using regression techniques on experimental data.

– Physical, which rely on the processes involved in the formation and development of rain and its evolution in time.

The following models have been considered:

A) Power Law relationship (PL method, see [4] and [5]).

See Recommendation ITU-R P.837-5 Annex 3; the method is based on:

 (1)

where:

*T* = integration time (min). *T* ≤ 30 minutes in Recommendation ITU-R P.837-5 Annex 3.

*P* = probability.

*R*1(*P*) and *RT*(*P*) = rain rate values, exceeded with the same probability *P*.

*a*(*T*) and *b*(*T*) = integration time dependant coefficients.

B) Conversion Factor modelled with Power Law (CF-PL method, see [4]).

It depends on *P* and is expressed as:

 (2)

*R*1(*P*)*, RT*(*P*)*,* *a*(*T*) and *b*(*T*) remain as defined for (1).

C) Lavergnat and Golé semi-empirical method (LG, see [6]).

The method is given by:

 (3)

with *α* being an empirical conversion parameter. *R*1(*P*)*, RT*(*P*)*,* *a*(*T*) and *b*(*T*) remain as defined for (1).

D) Recommendation ITU-R P.837-6 Annex 3.

It is a physical model, also called EXCELL Rainfall Statistics Conversion model (ERSC, see [7]), which is based on the simulation of the movement of rain cells over a virtual rain gauge. The assumptions on the shape of synthetic rain cells and on the statistical distribution of the associated parameters are described in [8]. Rain cell translation velocity depends on the type of precipitation (stratiform or convective) and the local yearly mean wind speed derived from the ECMWF ERA40 database.

The global average coefficients of empirical models (i.e. the PL, CF-PL and LG models) have been calculated for this analysis using the data described in the previous section. The process is outlined in Figure 2.

Figure 2

**Block diagram of the process used to derive the parameters of the PL,  
CF-PL and LG empirical models**



The empirical parameters are shown in Table 1.

Table 1

**Empirical parameters obtained by regression to the values in the measurement database**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **PL** | | **CF-PL** | | **LG** |
|  | ***a*** | ***b*** | ***a*** | ***b*** | ***a*** |
| 5 min to 1 min | 0.906 | 1.055 | 0.985 | −0.026 | 0.633 |
| 10 min to 1 min | 0.820 | 1.106 | 0.967 | −0.051 |
| 20 min to 1 min | 0.683 | 1.215 | 0.913 | −0.100 |
| 30 min to 1 min | 0.561 | 1.297 | 0.897 | −0.130 |
| 60 min to 1 min | 0.497 | 1.440 | 0.937 | −0.181 |

# 4 Results of model testing

The model relative error (%) at each value of probability and integration time, is calculated using:

 [%] (5)

where:

*Rm*(*P*)1 is the measured rain rate with 1-minute integration time and *Re*(*P*,*T*)1 is the rain rate estimated with 1-minute integration time using as input *T*-min integration time measured experimental distributions, *P*(*R*)*T*.

The performances of conversion models from A) to D) are evaluated by means of the relative error variable **(*P*,*T*) defined in (5), and compared by calculating the root mean square (RMS) value of **(*P*,*T*) over the interval [0.01%, 1%]. The RMS values have been weighted with respect to the duration of each experiment, as recommended in ITU-R P.311 [9].

Table 2 contains the results of the models testing over for percentages ranging from 0.01% to 1% and for percentage of time equal to 0.01%. Table 2 also contains the scores relative to the accuracy of Recommendation ITU-R P.837-6 Annex 1 in order to provide an indication of the relative performance of prediction of rainfall rate distributions, based either on global maps or on local measurements at different integration times.

It results that using a model to convert local measurements at different integration times always provides higher accuracy than the use of global digital maps.

It has to be noted that Recommendation ITU-R P.837-5 Annex 3 was limited to *T* lower or equal to 30 min, so its performance is not directly comparable with the other models that can be used up to *T* = 60 min.

The model characterised by the lowest global error is the CF-PL, with a RMS figure of 14.3% and 11%, in the [0.01%, 1%] interval and for *P* = 0.01%, respectively. This model is followed in terms of accuracy, with increasing RMS, by Recommendation ITU-R P.837-6 Annex 3, and the LG model. In general the differences between all models are small (about 3.5 %).

Table 2

**Results of the testing activity, per climatic region, over the interval [0.01%, 1%],  
and over all sites, considering all integration times (percentage values)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **[0.01% - 1%]** | | **0.01 %** | | |
|  | **RMS** | **Mean** | **RMS** | **Mean** |
| Recommendation ITU-R P.837-6 Annex 1 | 45 | −0.3 | 23.6 | −3.8 |
| Recommendation ITU-R P.837-5 Annex 3, (*T* *≤* 30 min) | 15.2 | 4.5 | 13.9 | 1.4 |
| PL | 19.5 | 4 | 21.8 | 4.2 |
| CF-PL | 14.3 | 2.2 | 11 | 1.1 |
| LG | 15.1 | 4.9 | 14.2 | −4 |
| Recommendation ITU-R P.837-6 Annex 3 | 15.0 | -2.3 | 13.9 | −3.9 |

Table 3, Table 4 and Figure 3 provide the results of model testing as a function of integration time.

Considering the current recommendations of the WMO, it is likely that the availability of measurements with 30 and 60 minute integration time will increase. Therefore the performance analysis shall be focused on these values.

Figure 3

**The evolution of RMS of the error variable, as a function of integration time, in the interval [0.01%, 1%]. (EXCELL-RSC = Recommendation ITU-R P.837-6 Annex 3)**



Table 3

**Results of the global coefficients testing activity, as a function of integration time  
(results in percentage), over the interval [0.01%, 1%]**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **5 to 1 min** | | **10 to 1 min** | | **20 to 1 min** | | **30 to 1 min** | | **60 to 1 min** | |
| **RMS** | **Mean** | **RMS** | **Mean** | **RMS** | **Mean** | **RMS** | **Mean** | **RMS** | **Mean** |
| Recommendation ITU‑R P.837-5 Annex 3 | 8.9 | 5.8 | 15.2 | 9.3 | 12.8 | −3 | 22.4 | 3.3 | N/A | N/A |
| PL | 6.9 | 1.9 | 12.1 | 2.8 | 14.7 | 4.3 | 23.7 | 5.3 | 35.6 | 12.6 |
| CF-PL | 6.8 | 1.2 | 10.2 | 1.7 | 13.5 | 2 | 15.1 | 2.2 | 22.1 | 5.5 |
| LG | 10.2 | 7.4 | 13.6 | 8.2 | 14.6 | 5.7 | 17.8 | 6.3 | 20.6 | 0.5 |
| Recommendation ITU‑R P.837-6 Annex 3 | 12.3 | -0.4 | 13.8 | -1 | 15.3 | -3.4 | 15.8 | −2.2 | 17.9 | −4.9 |

Table 4

**RMS of the relative error variable, in the 0.01% point, with respect to integration time**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **5 to 1 min** | | **10 to 1 min** | | **20 to 1 min** | | **30 to 1 min** | | **60 to 1 min** | |
| **RMS** | **Mean** | **RMS** | **Mean** | **RMS** | **Mean** | **RMS** | **Mean** | **RMS** | **Mean** |
| Recommendation ITU‑R 837-5 Annex 3 | 6.2 | 3.5 | 14.3 | 6.3 | 13.2 | −5 | 19.4 | −0.9 | N/A | N/A |
| PL | 5.7 | 1.7 | 13.2 | 2 | 15.2 | 5.1 | 20.4 | 1.9 | 41.3 | 11.6 |
| CF-PL | 4.7 | 0.2 | 9.9 | 0 | 9.9 | 1.3 | 10.9 | −0.1 | 17.2 | 4.8 |
| LG | 8.3 | 6.5 | 11.9 | 4.3 | 9.5 | −4 | 13.6 | −9.6 | 24.0 | −21.5 |
| Recommendation ITU‑R 837-6 Annex 3 | 6.6 | −0.7 | 11.1 | −0.6 | 12.4 | −4.1 | 15 | −5.7 | 20.8 | −9.3 |

Overall, the PL approach (which was also the baseline of Recommendation ITU-R P.837-5 Annex 3) exhibits the highest values of the error RMS of the error variable for *T* = 30 and 60 min.

The model displaying the lowest RMS values for conversion from *T* = 60 min over the [0.01%,1%] range is Recommendation ITU-R P.837-6 Annex 3, with 17.9%, followed by LG, with 20.6%. For *P* = 0.01%, the RMS values are 17.2% and 20.8% for CF-PL and ERSC, respectively.

Moreover, Recommendation ITU-R P.837-6 Annex 3 appears to be characterised by the lowest variation the error RMS for all the considered integration times (from 5 to 60 min).

# 5 Conclusions

Development of models to convert rain measurements collected with longer integration times to 1‑min integration time is essential to improve accuracy and applicability of radiowave propagation models.

It results that using a model to convert local measurements at different integration times always provides higher accuracy than the use of global digital maps.

The availability of local data with integration times between 30 and 60 minutes is likely to increase in the near future, given current WMO recommendations for rain accumulation measurements.

Considering these observations and because it performed better than the previous version, Recommendation ITU-R P.837-6 was adopted on October 2011.

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Appendix A

Table 5

**Locations and years of measurement available, per site**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Site** | **Lat (N)** | **Lon (E)** | **CCIR zone** | **Climate zone (Köppen)** | **Years of measurement** |
| Taejon | 36.38 | 127.36 | K | DWa | 6 |
| Bukit Timah | 1.21 | 103.40 | P | Af | 4 |
| Bangkok | 13.70 | 100.80 | P | Aw | 4 |
| Manila | 14.70 | 121.10 | N | Aw | 1 |
| Haikou | 20.03 | 110.35 | N | Cwa | 2 |
| Nanjing | 32.00 | 118.80 | K | Cfa | 2 |
| Xinxiang | 35.32 | 113.88 | K | DWa | 2 |
| Spino dAdda | 45.40 | 9.50 | K | Cfa | 8 |
| Rome | 41.87 | 12.48 | K | Csa | 8 |
| Prague | 50.10 | 14.44 | H | Dfb | 5 |
| Montreal | 45.52 | −73.57 | K | Dfa | 10 |
| Gometz-la-ville | 48.90 | 2.35 | H | Cfb | 1 |
| Houston | 29.77 | −95.73 | M | Cfa | 8 |
| Kwajalein | 8.79 | 167.62 | N | Af | 8 |
| Ji Parana | −10.35 | −62.58 | P | Af | 2 |
| Florida | 28.34 | −80.93 | N | Cfa | 8 |
| Chorillos | 6.30 | −75.51 | N | Aw | 4 |
| Cucaracho | 6.29 | −75.61 | N | Aw | 4 |
| Chilbolton | 51.14 | 358.56 | K | Cfb | 5 |
| Suva | −18.13 | 178.42 | N | Af | 1 |
| LAE | −6.75 | 147.00 | P | Af | 1 |
| Bandung | −8.17 | 111.78 | P | Am | 4 |
| Chang-chun | 43.90 | 125.22 | F | Dwa | 2 |
| Chong-qing | 29.58 | 106.47 | N | Cfa | 2 |
| Guang-Zhou | 23.13 | 113.32 | N | Cwa | 2 |
| Ottawa | 45.35 | −75.89 | K | Dfb | 4 |
| Madrid | 40.45 | −3.70 | H | Csa | 5 |
| Palau Pinang (Univ. Sains Malaysia) | 5.33 | 100.33 | P | Af | 4 |
| Luxembourg | 49.62 | 6.22 | E | Cfb | 10 |
| Brasilia | −15.48 | 312.17 | P | Aw | 1.9 |
| Mosqueiro | −1.40 | 309.31 | P | Af | 1.8 |
| Porto Alegre | −30.03 | 308.78 | N | Cfa | 0.8 |
| Recife | −8.05 | 325.10 | P | Aw | 1.9 |
| Sao Paulo | −23.55 | 313.37 | N | Cfa | 3 |
| Bolton | 53.58 | 357.57 | K | Cfb | 2 |

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