URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

5-year Results on Rainfall Rate and Attenuation with the Alphasat Experiment in Madrid

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Abstract

A propagation campaign of attenuation measurements with the 40-GHz Alphasat beacon signal is being conducted at the Universidad Politécnica de Madrid (UPM). Besides attenuation, rainfall rate data are collected with a rain gauge and a disdrometer. Rainfall rate and attenuation statistics can be used for assessment and development of attenuation prediction models for satellite radio links. In this paper, the results obtained from 5 years of rainfall rate and attenuation measurements are presented and compared with several relevant propagation models: the ITU-R P.837-6, ITU-R P.837-7 and MORSE models for rainfall rate and the ITU-R P.618-13 for attenuation. A moderate accuracy has been achieved with all models. The ITU-R P.837-7 and MORSE models improve the prediction for probabilities lower than approximately 0.01%, whereas for higher probabilities the three models show a similar performance.

1 Introduction

Satellite signals at millimeter wave frequencies are attenuated in the atmosphere through their propagation to a receiver on the ground. There are a number of meteorological phenomena, such as rain, clouds, gases and troposphere scintillation causing this mitigation to the signal, with rain being the major impairment above 20 GHz. In order to counteract such signal degradations produced along the propagation path, satellite operators need accurate methods for their estimation and prediction.

Regarding rainfall rate, some model comparisons have been reported [1] and a model assessment has been carried out at Madrid using 16 years of rain data [2]. The objective of this paper is to present the results obtained from 5 years of rainfall rate and attenuation measurements and to compare them with predictions of propagation models, such as the ITU-R P.837 (version 6 [3] and 7 [4]) and MORSE (Model for Rainfall Statistics Estimation) models in the case of rainfall rate and the ITU-R P. 618-13 model [5] in the case of attenuation. This 5-year period of attenuation measurements of the 40-GHz Alphasat beacon is one of the longest periods presented up to now for the Alphasat experiment.

The rest of this paper is structured as follows: In Section 2 the main experimental characteristics are given. Rainfall rate and attenuation results are presented in Section 3. Rainfall rate models are briefly presented and compared in Section 4 with the measurements. The ITU-R attenuation model is addressed in Section 5. Conclusions are given in Section 6.

2 Experimental setup and data processing

Since March 2014, the GTIC Research Group of Universidad Politécnica de Madrid (UPM) is measuring the 40-GHz (39.402 GHz) beacon signal coming from the Alphasat satellite. Up to now, five years of processed beacon measurements are available. The main characteristics of the Q-band Alphasat satellite beacon receiver (Fig. 1a) installed at UPM are given in Table 1; an extended version of this table is available in [6].

Table 1. Main experimental characteristics

Parameter	Values
Polarization	Linear, 45° tilted
Latitude	40.45° N
Longitude	3.73° W
Altitude	630 m amsl
Mean azimuth and elevation angles	139.5° and 34.5°
Measurement sampling frequency	18.78 Hz
Rain margin	< 35 dB

A reference signal is calculated on an event-by-event basis [6]. Latter, attenuation time series are calculated by substracting the received power and the reference.

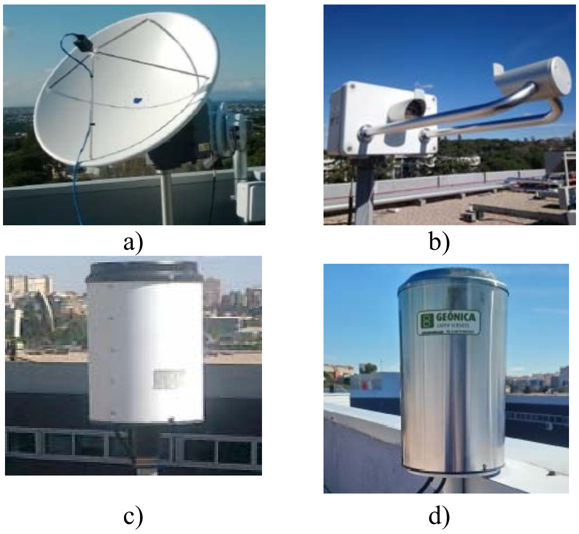
a) b) c) d)

Figure 1. Experimental setup, a) beacon receiver, b) disdrometer, c) typing-bucket rain gauge, d) weighing rain gauge

Ancillary meteorological equipment is deployed near the receiver unit in order to gather rainfall rate information. A tipping-bucket type rain gauge (Fig. 1c) was used for the first years of measurements. It was substituted by a weighing rain gauge in November 2017 (Fig. 1d). Also, an optical disdrometer (Fig. 1b) near the beacon receiver has been available for the entire period.

For the presented rainfall rate data, rain gauges have been used as the primary source of information, whereas the disdrometer has been used to fill some time gaps with no rain gauge data.

3 First order statistics results

The analyzed period of time extends from March 2014 to March 2019, excluding March 2017. Then Year 1 encompasses the period from March 2014 to February 2015, and Year 4 from April 2017 to March 2018, and so on. The availability for the 5-year period is about 99 % for rainfall measurements and 97.28 % for the attenuation measurements.

Rainfall rate and excess attenuation results (including the contributions of rain, clouds as well as scintillation) for each year and for the average year (*Ave. Year*) are presented in Figs. 2 and 3, respectively. From these results, a high year-to-year variability is observed, i.e. the experimental $R_{0.01}$ (point rainfall rate for 0.01 % time of the year) goes from 12.22 mm/h for Year 5 to 32.42 mm/h for Year 4; and its associated attenuation $A_{0.01}$ goes from 21.58 dB for Year 3 to 37.83 dB for Year 2. The average values of $R_{0.01}$ and $A_{0.01}$ are 20.34 mm/h and 28.08 dB, with probability of rain, P_0, of 2.04 % for the average year. The high rainfall rates observed at the smaller probabilities for years 2 and 4 are attributed to a relatively large number of convective events. In Fig. 3, the flattening of the curves at higher attenuation values are produced by outage of the dynamic range

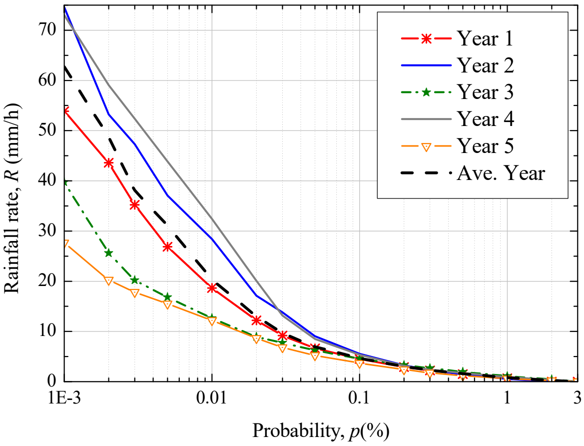

Figure 2. Rainfall rate for the period and individual years

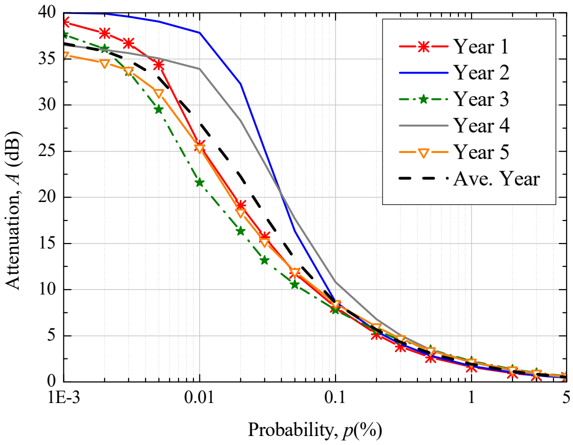

Figure 3. Attenuation for the period and individual years

4 Rainfall rate model comparison

When local rainfall rate measurements are not available, the rainfall rate distribution can be estimated by using some models based on large meteorological databases such as the DBSG3 (Data Base of the Study Group 3) of the ITU-R. Here, three rainfall rate models are briefly introduced: the ITU-R P. 837-6 [*3*], the ITU-R P. 837-7 [4] and the MORSE [7] models. They all have a strong site and frequency dependency.

A. ITU-R P.837-6

The model is recommended to estimate only the average year rainfall rate distribution. P_0 is calculated as:

$$P_0 = P_{r6}\left[1 - exp\left(-0.0079\frac{M_t(1-\beta)}{P_{r6}}\right)\right] \qquad (1)$$

where P_{r6}(the probability to have rain in 6 h slots), M_t (annual rainfall accumulation) and β (ratio between convective and total precipitation) are extracted or interpolated from ITU-R data files. The probability of exceeding a rainfall rate intensity R for the average year $P(R)$ is:

$$P(R) = P_0 exp\left(-1.09R\frac{1+bR}{1+cR}\right) \qquad (2)$$

with coefficients b and c depending on M_t and P_0.

B. MORSE model

The MORSE model [7] was developed to predict the spatial and temporal rain intensity with integration time of 1-minute for different time scales (monthly or yearly). The *MT* in the period of interest, and other input parameters can be obtained from the global ERA40 database [3]. $P(R)$ is calculated as:

$$P(R) = 100 \cdot P_0 \left[\ln\left(\frac{R_a + R_{low}}{R + R_{low}} \right) \right]^n \tag{3}$$

where P_0 defines the behavior of the curve when R goes to 0 mm/h and is calculated as:

$$P_0 = \frac{MT'}{(R_a + R_{low}) \cdot \gamma\left(n+1, \ \ln\left(\frac{R_a + R_{low}}{R_{low}}\right)\right)} \tag{4}$$

R_a is an asymptotic value of probability p directly related with the maximum measured point rain rate, n is mainly used to define the shape of the curve and R_{low} allows that the probability takes a finite value when the rainfall rate tends to 0 mm/h (as it is physically the case), γ is the incomplete gamma function and MT' is the accumulated total local amount of rain given in hours.

C. ITU-R P. 837-7 model

This recently adopted model is based on a French proposal prepared by ONERA (*Office National d'Etudes et Recherches Aérospatiales*) [8] to the Rec. ITU-R P.837. Its main feature is that it takes into account the monthly variability of rain and temperature. The probability of exceedance is calculated as:

$$P_{ii}(R) = P_{0_{ii}} \cdot Q\left(\frac{\ln(R) + 0.7938 - \ln(r_{ii})}{1.26} \right) \tag{5}$$

where ii represents the subscript of the month of the year (i.e. ii = 1,…,12), $P_{0_{ii}}$ is the monthly probability of rain and r_{ii} (in mm/h) is a parameter that depends on the monthly temperature. It also can be used for the average year by using annual values. The annual P_0 is calculated as:

$$P_{0_{annual}} = \left(\sum_{ii=1}^{12} N_{ii} \cdot P_{0_{ii}} \right) \Big/ 365.25 \tag{6}$$

where N_{ii} is the number of days for the ii-month.

Rainfall rate models are compared by using the testing variable recommended by the ITU-R [9].

$$\varepsilon(p) = \left(R_p(p) - R_m(p) \right) / R_m(p) \tag{7}$$

with $R_p(p)$ and $R_m(p)$ being the predicted and measured rainfall rate distribution values for probability p, respectively.

It is seen in Fig. 4 that MORSE and Rec. ITU-R P. 837-7 models introduce an improvement compared with the ITU-R P. 837-6 model for probability values lower than approximately 0.01 %.

Table 2 collects the RMS (root-mean-square), values of the testing variable of (7) associated to each model, calculated for probabilities from 0.001 % up to 2%. The predicted values of P_0 and $R_{0.01}$ can be compared with the measured value.

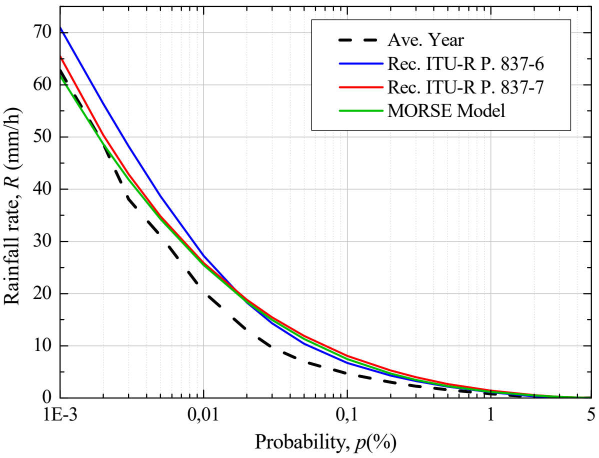

Figure 4. Rainfall rate model comparison

Table 2. Statistical values of the rainfall rate models (from 0.001 % to 2 % probability)

Models	P_0(%)	$R_{0.01}$(mm/h)	RMS(%)
Meas.	2.04	20.34	
P.837-6	2.72	27.29	37.78
P.837-7	3.99	25.86	71.29
MORSE	3.12	25.49	54.96

All models predict P_0 and $R_{0.01}$ much higher than the experimental values, and Rec. ITU-R P.837-6 gives the better RMS approximation.

5 Attenuation model

The ITU-R P.618-13 [5] model is used to predict rain attenuation along a slant path. This model is limited to percentages of time from 0.001 % up to 5 % and uses as input parameters the elevation angle, $R_{0.01}$ of the average year obtained by multiplying the effective path length and the specific attenuation of [10] and a parameter that depends on the probability, station latitude and elevation angle values.

The model uses the $R_{0.01}$ to calculate $A_{0.01}$ and then the cumulative distribution of attenuation $A(p)$, then it can be assessed by using the different $R_{0.01}$ obtained from the rainfall rate models and the experimental one. From Fig. 5, the best approximation is given from using the experimental $R_{0.01}$ (*Exp. R0.01*), at least down to probability of approximately 0.005 %. For lower values, the limitation in the dynamic range affects the certainty of the measurements (*Ave. Year*) giving a meaningless comparison. That is why the errors are calculated only for the 0.005 % to 2 % probability interval. The estimations derived on using the predicted $R_{0.01}$ value of each rainfall model (curves *ITU-R P.837-6*, *ITU-R P.837*-6 and *MORSE*) are quite similar.

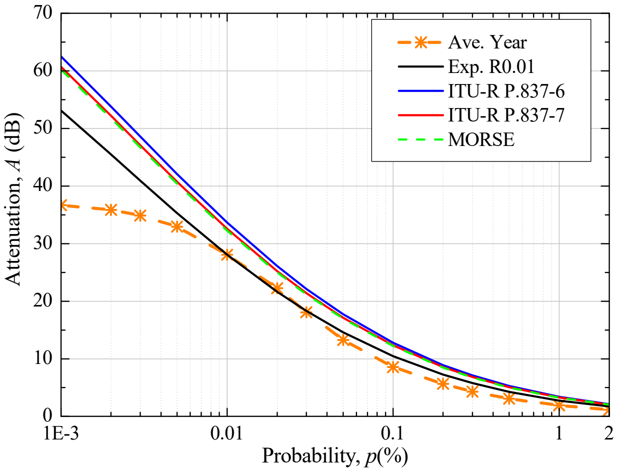

Figure 5. Rec. ITU-R P. 618-13 model predictions using different values of $\boldsymbol{R_{0.01}}$

The model errors are calculated using the testing variable of [9]. The ratio of predicted attenuation A_p (dB) to measured attenuation A_m(dB) is:

$$S = A_p / A_m \qquad (8)$$

and the test variable for the attenuation models is:

$$V = \begin{cases} \ln S (A_m/10)^{0.2}, & A_m < 10 \text{ dB} \\ \ln S, & A_m \geq 10 \text{ dB} \end{cases} \qquad (9)$$

If the experimental $R_{0.01}$ is used, the RMS of (9) is equal to 25.22 %; against 44.67 %, 41.05 % and 40.05 % for the Rec. ITU-R P.837-6, Rec. ITU-R P.837-7 and MORSE models respectively.

6 Conclusions

The presented rainfall rate and attenuation measurements for a long period of 5 years have a very high availability. Both rainfall rate and attenuation distributions present a high year to year variability, especially for low probabilities that correspond with high intensities. Nevertheless, the period can be considered as representative of Madrid conditions.

The assessed rainfall rate models MORSE and ITU-R P. 837-7 yield an improvement in the estimation of rainfall rate at probabilities lower than 0.01 %, but do not produce an enhancement for higher probability values when compared with the ITU-R P.837-6 model. The three models predict P_0 and $R_{0.01}$ values higher than the measured ones. Then, if these predicted values are used in the ITU-R attenuation model, an overestimation of predicted attenuation is produced. It must be noted that the dynamic range of the receiver does not allow a proper assessment of the ITU-R attenuation model for probabilities lower than, approximately, 0.005 % of the average year.

7 Acknowledgements

This work was supported in part by the Ministry of Science, Innovation and Universities of Spain through the RTI2018-098189-B-I00 project.

8 References

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