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

**Authors**

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# Presentation Outline

- Introduction
- Experimental setup and data processing
- First-order statistic results
  - Rainfall rate
  - Excess attenuation
- Rainfall rate model comparison
- ITU-R attenuation model
- Conclusions

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# INTRODUCTION

Most of the significant signal attenuation events in satellite links above 20 GHz are related to rain (at the receiver site or along the path).

In order to counteract the signal degradations produced in the propagation path, satellite operators need accurate methods and models for their estimation and prediction.

The UPM has been recording rainfall rain and Q-band Alphasat satellite attenuation measurements for a 5-year period (considered as a long period for this experiment), which allows to test available rainfall rate and rain attenuation prediction models.

The **objective** of this paper is to present the results obtained for 5-year of rainfall rate and attenuation measurements and to compare them with the model predictions, such as the ITU-R P.837 (version 6 and 7) and MORSE (Model for Rainfall Statistics Estimation) models in the case of rainfall rate and the ITU-R P. 618-13 model in the case of attenuation.

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## Equipment used to gather rainfall rate data:

Several ancillary meteorological piece of equipment are deployed near the receiver unit in order to gather rainfall rate information:


**Weighing Rain Gauge**
(from 2017- nowadays)

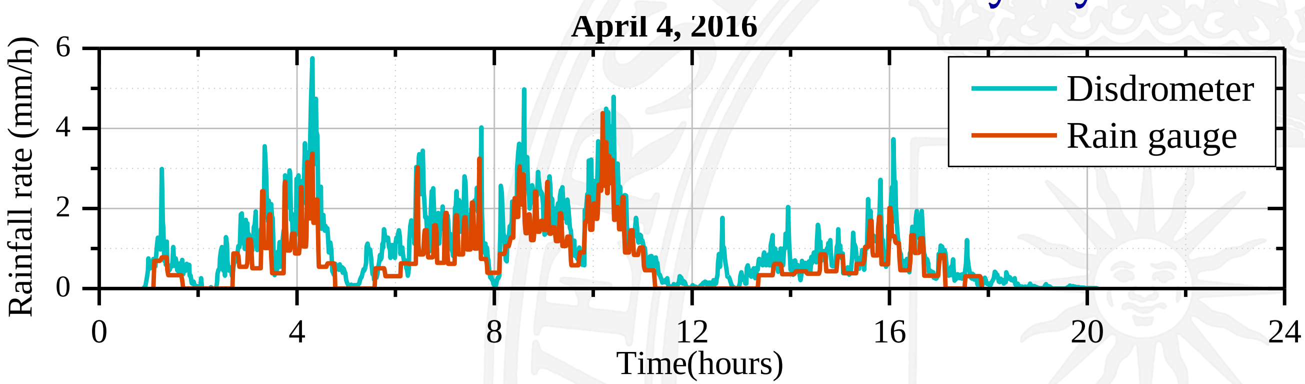
**Typing-Bucket Rain Gauge**
(untill Nov. 2017)

**Disdrometer**


**Rain Radar**

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

**Rainfall rate time series for a rainy day**

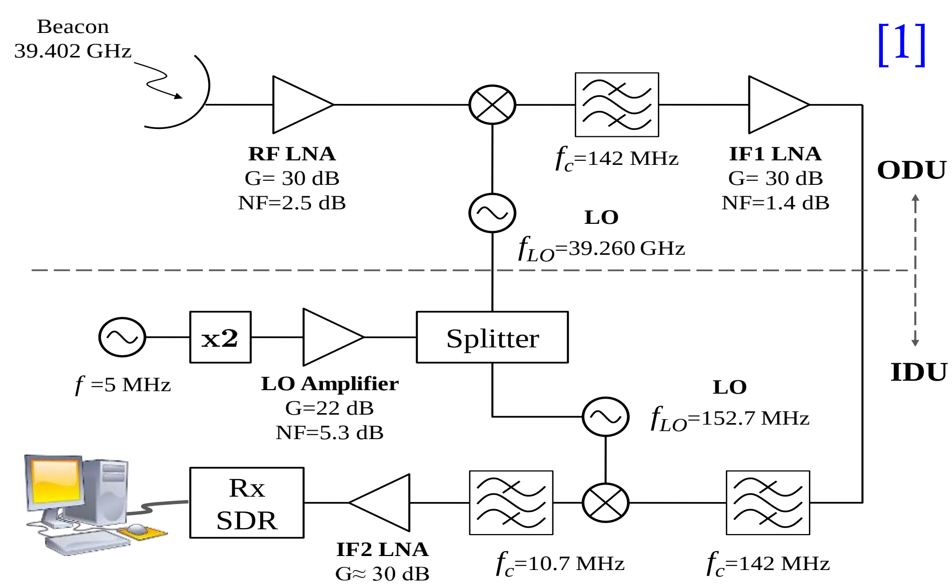


# The Q-band Alphasat satellite propagation experiment:

## 5 years of measurements

(from March 2014 to March 2019, excluding March 2017)

TDP-5 *Aldo Paraboni Q/V Communications and Propagation*

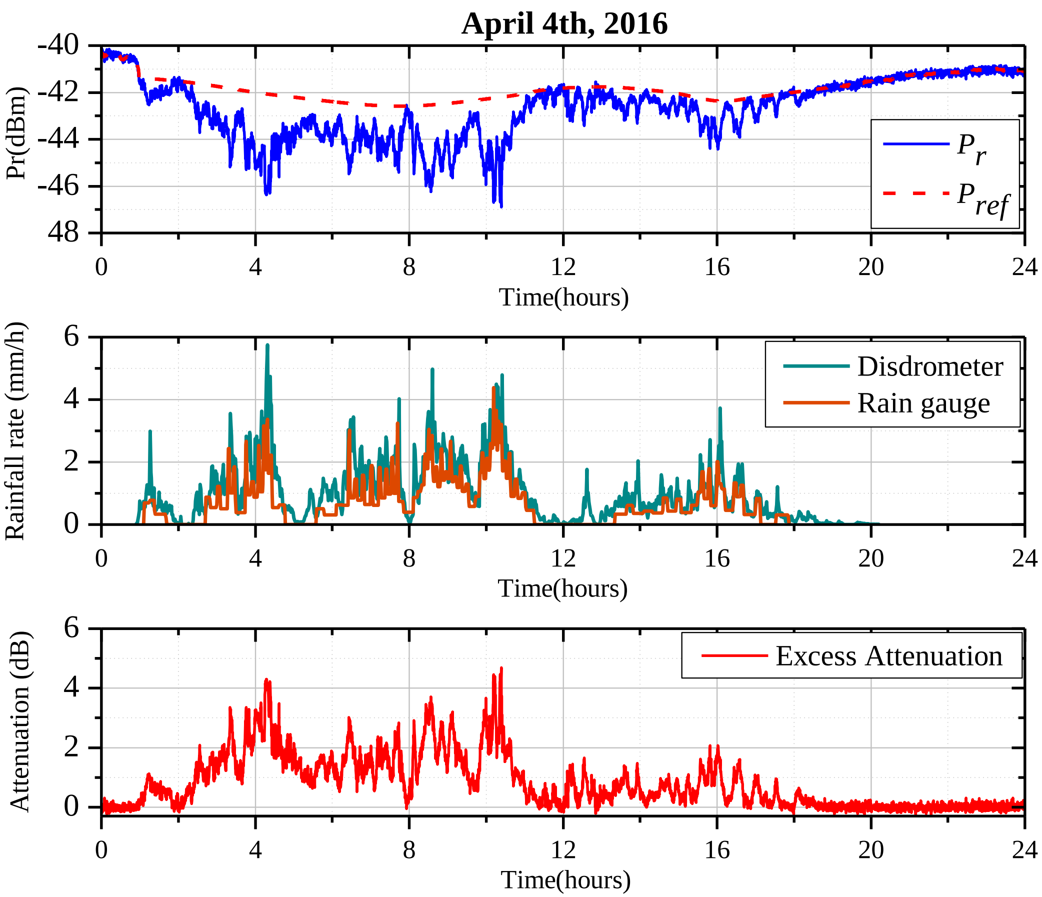



### Main experimental characteristics

| Parameter | Values |
|---|---|
| Polarization | Linear, 45° tilted |
| Latitude | 40.45° N |
| Longitude | 3.73° W |
| Altitude | 630 m amsl |
| Azimuth and elevation angles | 139.5° and 34.5° |
| Measurement sampling freq. | 18.78 Hz |
| Rain margin | >35 dB |


[1] D. Pimienta-del-Valle, J.M. Riera, P. Garcia-del-Pino, and G.A. Siles, "Three-year fade and inter-fade duration statistics from the Q-band Alphasat propagation experiment in Madrid," *International Journal of Satellite Communication and Networking*, vol. 37, no. 5, pp. 460-476, 2019.

# Excess Attenuation data processing:




A reference signal is calculated on an event-by-event basis, taking into consideration the rain and no-rain intervals.

Excess attenuation time series (have into account the rain, clouds and scintillation contributions) are calculated as:

$$A_{exc}(\text{dB}) = P_{ref} - P_r$$ [2]

[2] J.M. Riera, G.A. Siles, P. Garcia-del-Pino, and A. Benarroch, "Alphasat Propagation Experiment in Madrid: Processing of the First Year of Measurements," in *EuCAP 2016*, Davos, Switzerland, 2016.

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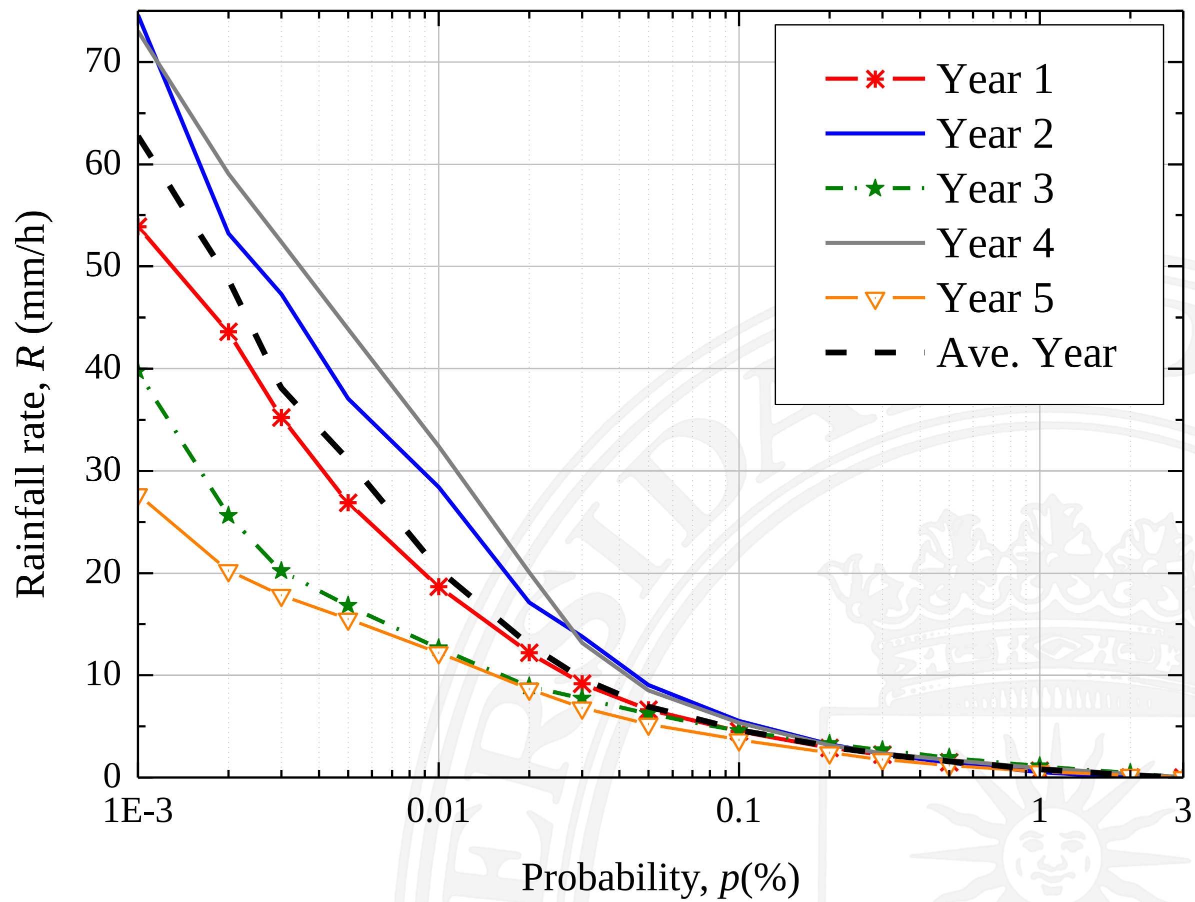
# Rainfall rate (*R*) results:

## Rainfall rate distributions

The availability for the 5-year period is about 99 %.

High year-to-year variability is observed.

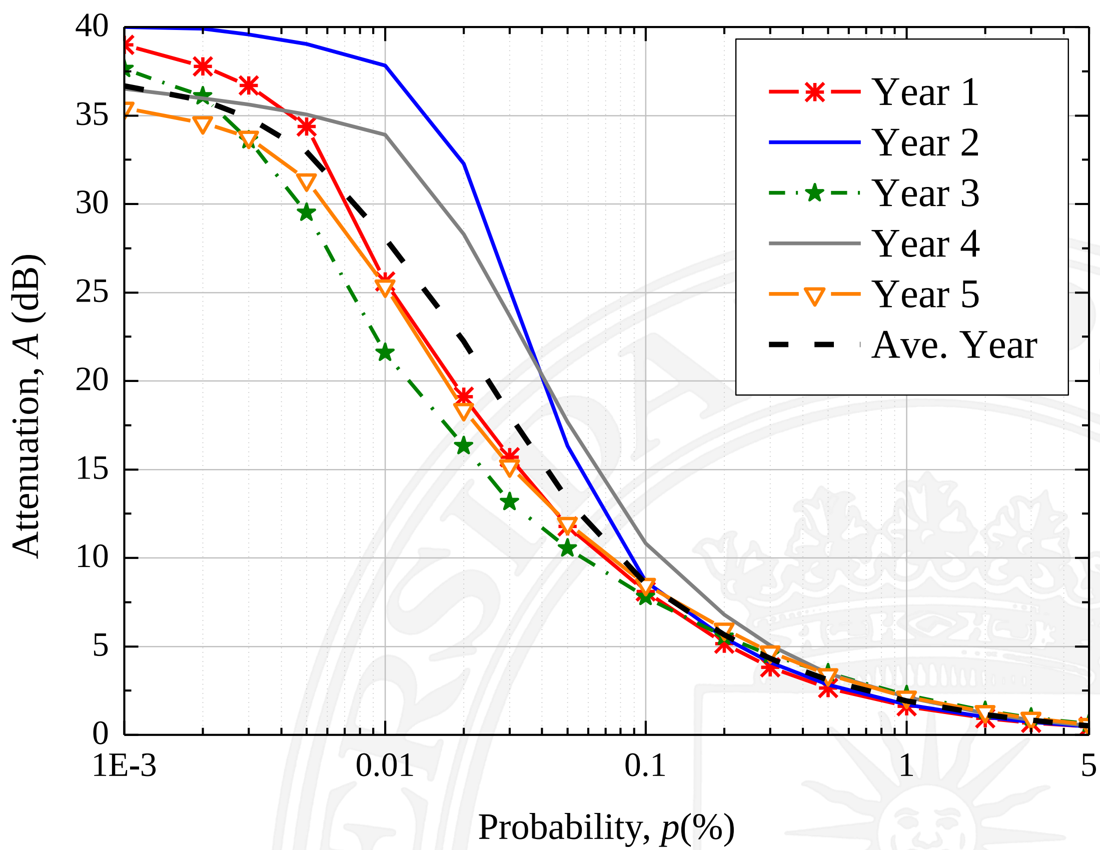


# Q-band attenuation results:

**Excess Attenuation Data Availability (in %)**

| Time Period | Availability |
|---|---|
| Year 1 | 97.12 |
| Year 2 | 96.03 |
| Year 3 | 98.61 |
| Year 4 | 98.67 |
| Year 5 | 95.94 |
| Ave. Period | 97.28 |

**The flattening of the distributions above 35 dB is due to the receiver dynamic range**



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## Rainfall rate models:

If local rainfall rate measurements are not available, the rainfall rate distribution can be estimated by using models based on large meteorological databases such as the DBSG3 (Data Base of the Study Group 3) of the ITU-R.

The three rainfall rate models treated here are:

I. *The ITU-R P. 837-6 model* .

II. *The MORSE model* .

III. *The ITU-R P. 837-7 model* .

They all have a strong site dependency.

## *ITU-R P.837-6 model*

The percentage probability of rain in an average year $P_0$ is calculated as:

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

Where the following parameters are extracted or interpolated from ITU-R data files:

$\boldsymbol{P_{r6}}$: the probability to have rain in 6 h slots.

$\boldsymbol{M_t}$ : annual rainfall accumulation.

$\boldsymbol{\beta}$ : ratio between convective and total precipitation .

The probability of exceeding a rainfall rate intensity $R$ for the average year $P(R)$ is:

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

with coefficients $b$ and $c$ depending on $M_t$ and $P_0$.

## *MORSE model*

It was developed to predict the spatial and temporal rain intensity with integration time of 1-minute for different time scales (monthly or yearly). $P(R)$ is calculated as:

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

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

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

$\boldsymbol{R_a}$ : asymptotic value of probability $p$ directly related with the maximum measured $R$.

$\boldsymbol{n}$ : mainly used to define the shape of the curve.

$\boldsymbol{R_{low}}$: allows that the probability takes a finite value when the $R$ tends to 0 mm/h.

$\boldsymbol{\gamma}$ : incomplete gamma function.

$\boldsymbol{MT'}$ : accumulated total local amount of rain given in hours.

## *ITU-R P.837-7 model*

Model recently adopted and based on an ONERA (*Office National d'Etudes et Recherches Aérospatiales*) proposal. It takes into account the monthly variability of rain and temperature. The probability of exceeding is calculated as:

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

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 depend on the monthly temperature. It also can be used for the average year by using annual values. The annual $P_0$ is calculated as:

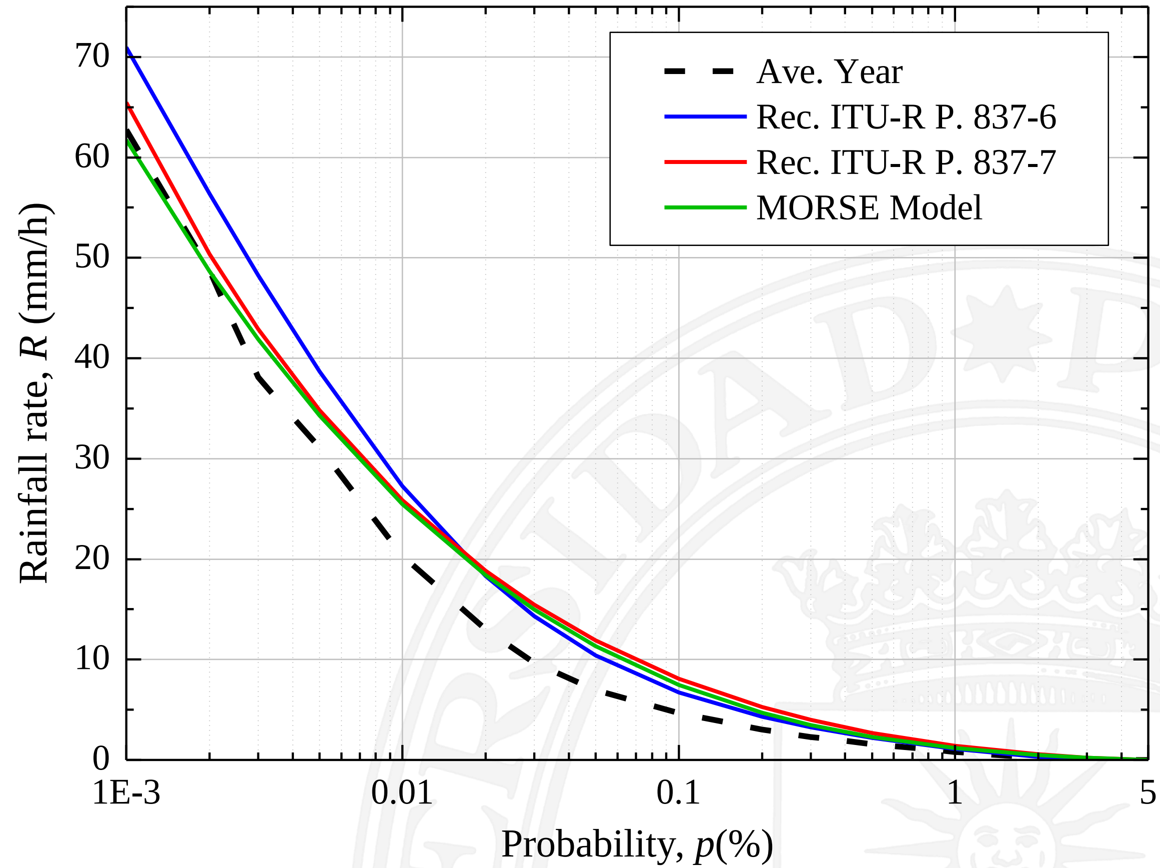
$$P_{0_{annual}} = \left(\sum_{ii=1}^{12} N_{ii} \cdot P_{0_{ii}}\right) \Big/ 365.25$$

# Rainfall rate model comparison:

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

$$\varepsilon(p) = \frac{R_p(p) - R_m(p)}{R_m(p)}$$ [3]

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



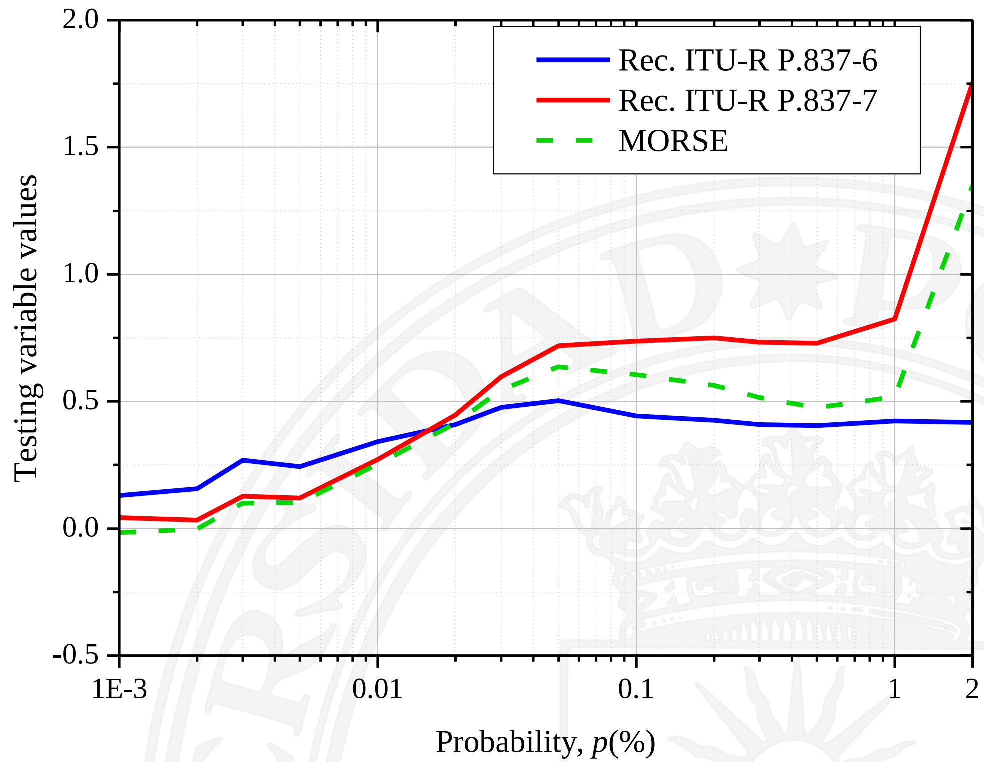

[3] ITU–R SG–3, "On testing variables used for the selection of prediction methods," ITU–R, Fascicle Document 3M/FAS/1–E, 2016.

## Rainfall rate model comparison:

**Relevant values of the rainfall rate models and the RMS values for the testing variable $\varepsilon(p)$ ( from 0.001 % to 2 %)**

| Models | $P_0$ (%) | $R_{0.01}$ (mm/h) | RMS (%) |
|---|---|---|---|
| **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 |

| | $P_0$ (%) | $R_{0.01}$ (mm/h) |
|---|---|---|
| **Measurement** | 2.04 | 20.34 |



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# ITU-R P.618-13 attenuation model:

The model is used to predict the attenuation due to precipitation and clouds along the slant path. This model is limited to percentages of time from 0.001 % up to 5 %.
The attenuation distribution is estimated as:

$$A(p) = A_{0.01}(p/0.01)^{\chi}$$

$$\chi = -(0.655 + 0.033 \ln p - 0.045 \ln A_{0.01} - \beta_0 (1 - p) \sin \theta)$$

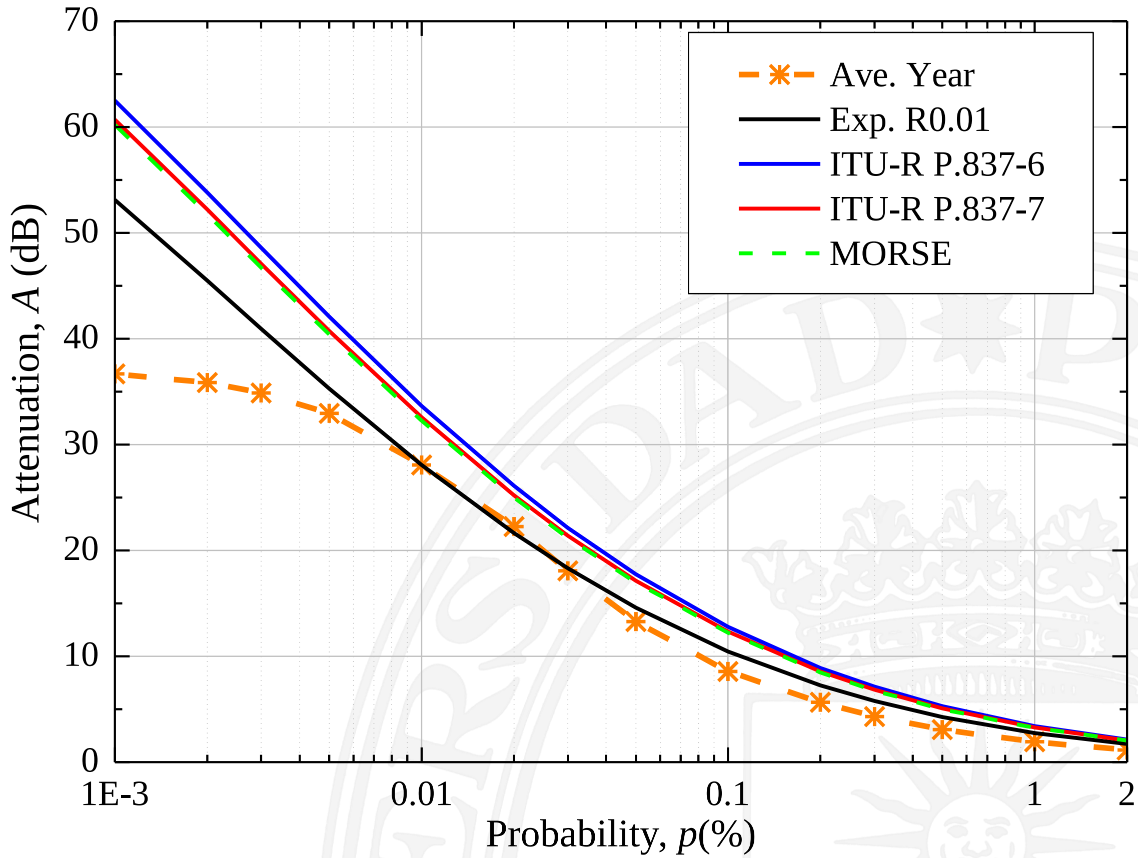
$\boldsymbol{\theta}$ : elevation angle.

$\boldsymbol{A_{0.01}}$: predicted attenuation exceeded for the 0.01 % of time of the average year obtained by multiplying the effective path length and the ITU-R specific attenuation.

$\boldsymbol{\beta_0}$: a value depending on the probability, station latitude and elevation angle values.

# ITU-R P.618-13 attenuation model results:

This model uses the $R_{0.01}$ to calculate $A_{0.01}$, then the model can be assessed by using the different $R_{0.01}$ obtained from the rainfall rate models and the experimental one.



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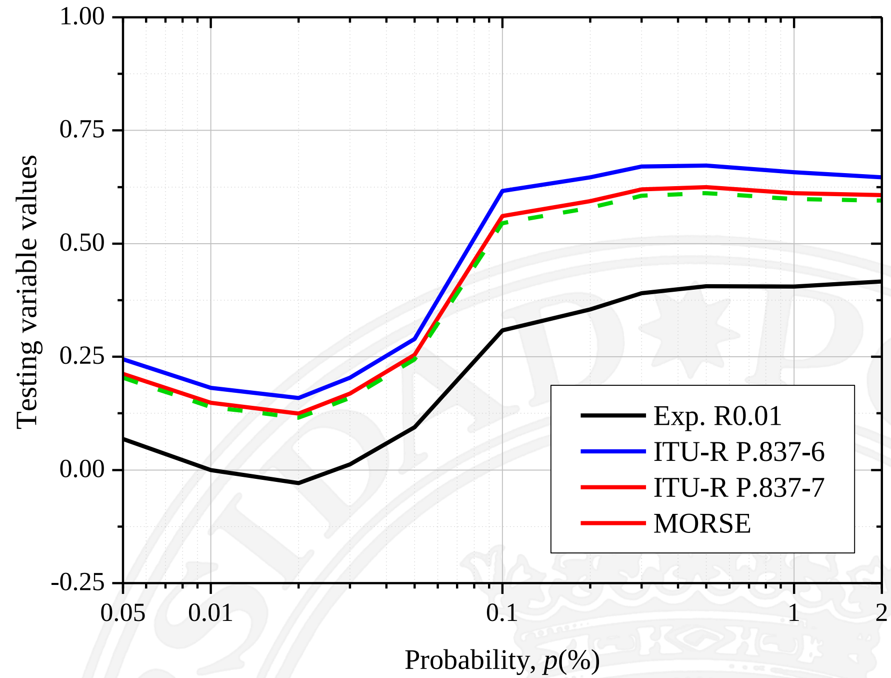
# Attenuation model errors:

The model errors are calculated using the ITU-R testing variable $V$.

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

Where the ratio of predicted attenuation $A_p$ (dB) to measured attenuation $A_m$(dB) is:

$$S = A_p / A_m$$




**RMS (in %) of $V$ using several $R_{0.01}$ values (from 0.005 % to 2 %)**

| | Experimental | ITU-R P.837-6 | ITU-R P.837-7 | MORSE |
|---|---|---|---|---|
| **RMS** | 25.22 | 44.67 | 41.05 | 40.05 |

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# CONCLUSIONS

- Rainfall rate measurements and satellite propagation attenuation measurements at the Q-band for a 5-year period have been presented .
- Both rainfall rate and attenuation distributions present high year to year variability, especially for low probabilities that correspond with high intensities. Nevertheless, the period can be considered as representative for 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. If these predicted values are used in the ITU-R attenuation model, an overestimation of the predicted attenuation is produced.
- 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. The model yields better predictions when the experimental $R_{0.01}$ is used.

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