Preliminary Study of Rain Attenuation Time Series Synthesizers for Tropical and Equatorial Areas

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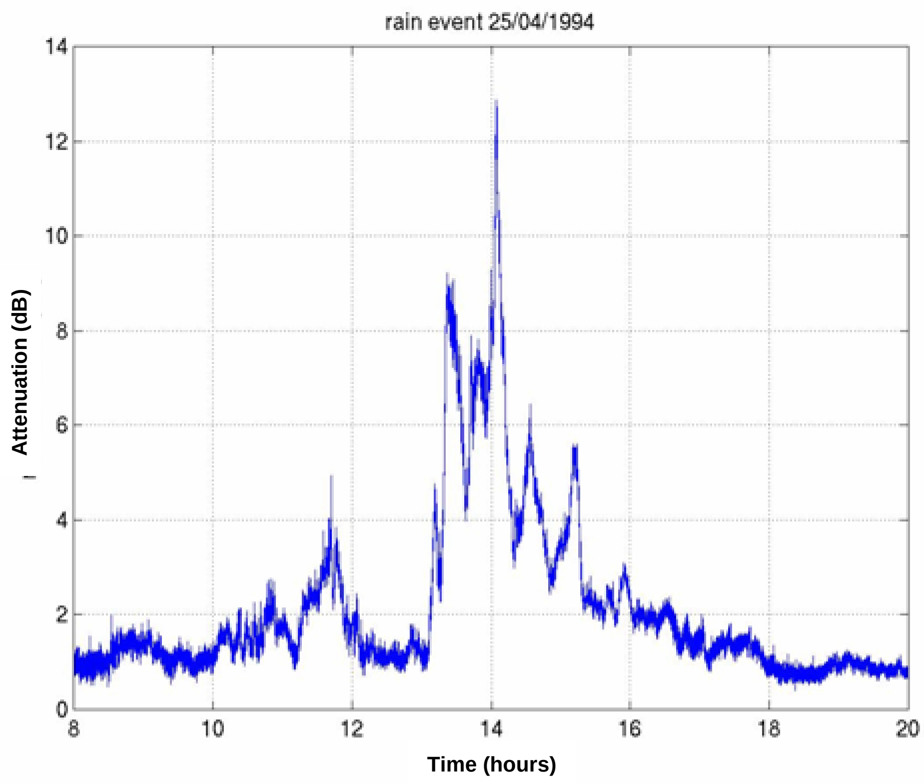
General context

- Ka-band and above : severe propagation impairments
  - Adaptive systems
    - Fade Mitigation Techniques
  - Need for time series of impairments (events, long term) to parameterize and test FMT control loops



- Maseng-Bakken approach is currently one of the most mature and popular theoretical model for this purpose

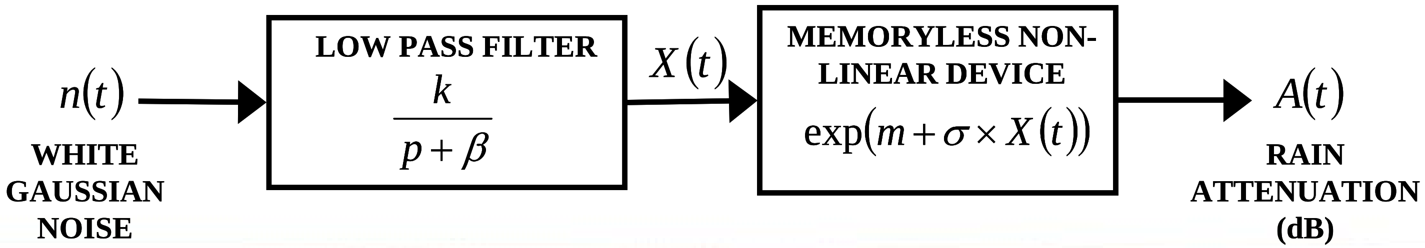
Contents

- **Channel Model**
  - **Based on Maseng-Bakken Model**
  - **Input Parameters retrieval**
- Testing Analysis with respect to Brazilian Data
  - Data description
  - Comparison between the model and real collected data with respect to long term statistics

Maseng-Bakken based modelling

- **Maseng-Bakken hypotheses:**
  - **Long term distribution of A_{rain} = log-normal (m, σ)**
  - $\dfrac{\ln A_{rain} - m}{\sigma}$ **= Gauss-Markov process**

- **3 input parameters for the original Maseng-Bakken model:**
  - **(m,σ) : Log-normal law parameters (← log normal fit on CCDF predicted by ITU-R recommendations)**
  - β **: describing the dynamics of A_{rain}**



Maseng-Bakken based modelling

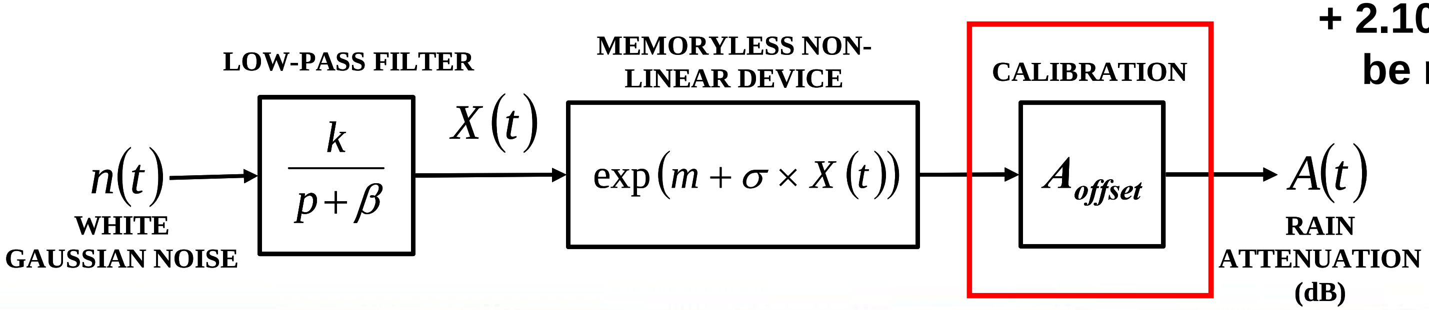
Maseng-Bakken hypotheses:

- Long term distribution of A_{rain} = log-normal (m, σ)
- $\dfrac{\ln A_{rain} - m}{\sigma}$ = Gauss-Markov process

4 input parameters for the enhanced Maseng-Bakken model:

- (m,σ) : Log-normal law parameters (← log normal fit on CCDF predicted by ITU-R recommendations)
- β : describing the dynamics of A_{rain} → Needed characterisation

+ A_{offset} parameter with respect to Maseng-Bakken: $A_{offset} = A(P_0)$
(significant better performances in FS & FD stats)

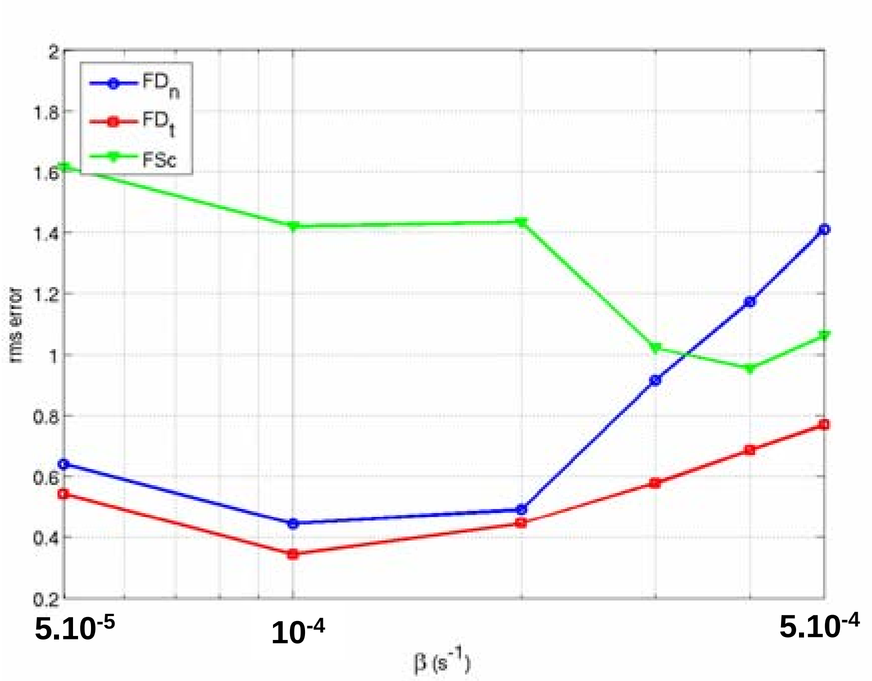


+ 2.10^5 first seconds to be removed due to low β value

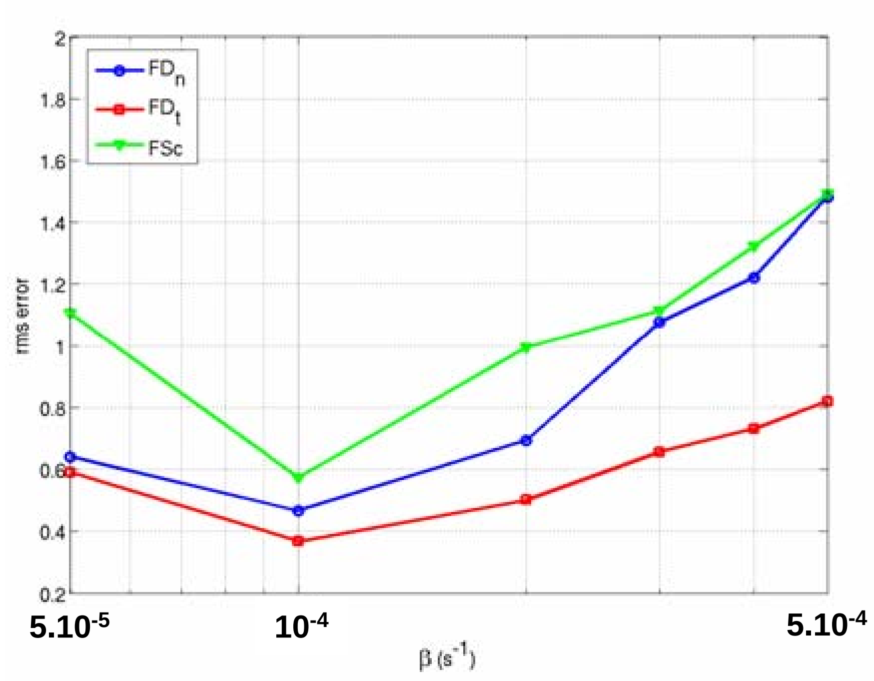
Optimum *β* value

- **Use of Italsat rain attenuation events measured in Spino d'Adda by PoliMi @ 19 GHz (6.5 years) to infer the β value**
- **Optimisation of β w.r.t to fade duration and fade slope statistics**

without A_{offset}



with A_{offset}



Huge processing time to infer the optimum β value with this method

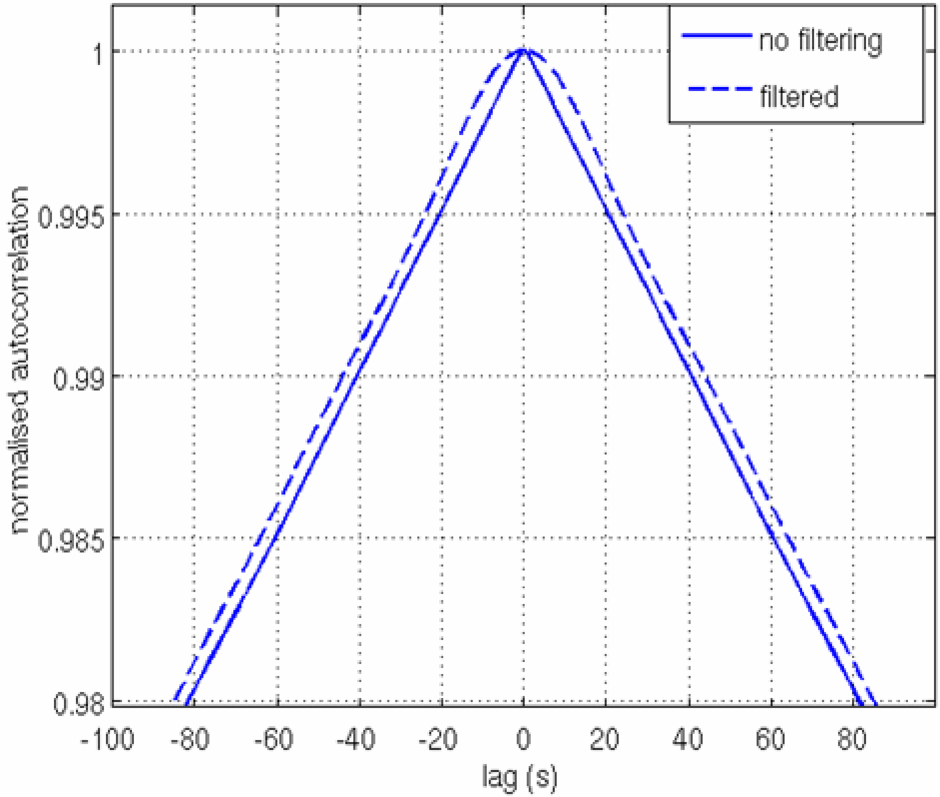
Maseng-bakken based log-autocorrelation

- Maseng-Bakken theory : $\ln\left(R_{\ln(A)-m}(\tau)\right) = \ln\sigma^2 - \beta|\tau|$

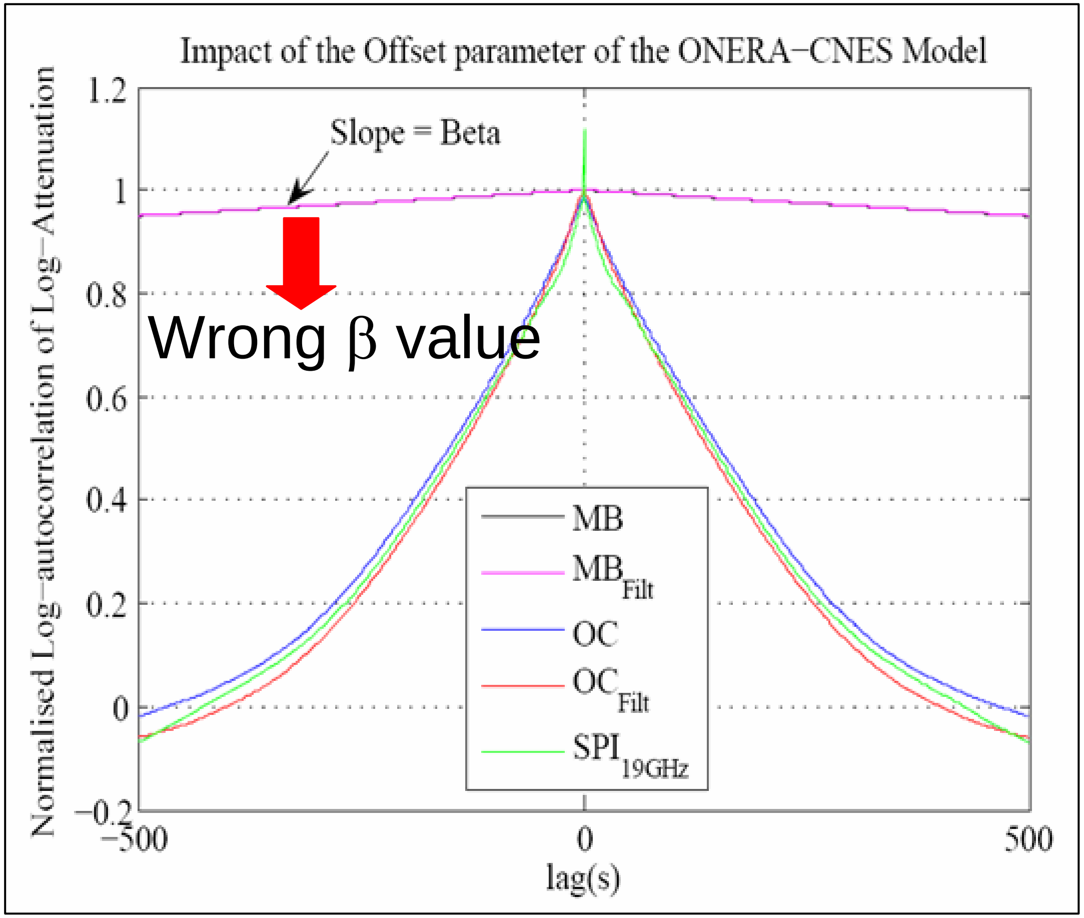
  $\Rightarrow$ Log-autocorrelation slope = β

- Enhanced model : influence of the A_{offset} parameter on the Maseng-Bakken theory

- Experimental time series generally low-pass-filtered to remove scintillation : influence on small time lags



Log-autocorrelation results



- Maseng-Bakken expression not valid
- Good performances of the modified model but no analytical expression to be used
- Short time lags affected by filtering (not usable)
- Higher time lags require a significant amount of data

Conclusion on correlation/spectral methods

- Log-autocorrelation method not easy to use (no analytical expression for the M-B approach)

- Log-autocorrelation method requires a significant amount of data

- Spectral methods (Grémont & Filip, 2004) based on the PSD cut-off frequency also tested:

  Only very long events usable (else not enough frequency resolution to determine precisely fc).

⇒ These methods do not seem relevant to assess β from experimental datasets.

Analysis tool to retrieve β value

- **Maseng-Bakken theory :**
  2nd order conditional moment of rain attenuation

$$K_{2A}(A) = \frac{E\left\{\left(A(t+\Delta t) - A(t)\right)^2 \middle| A(t)\right\}}{\Delta t} = 2\beta\sigma^2 A(t)^2 \quad , \quad \Delta t << \beta^{-1}$$

- **Method to retrieve β from experimental time series:**

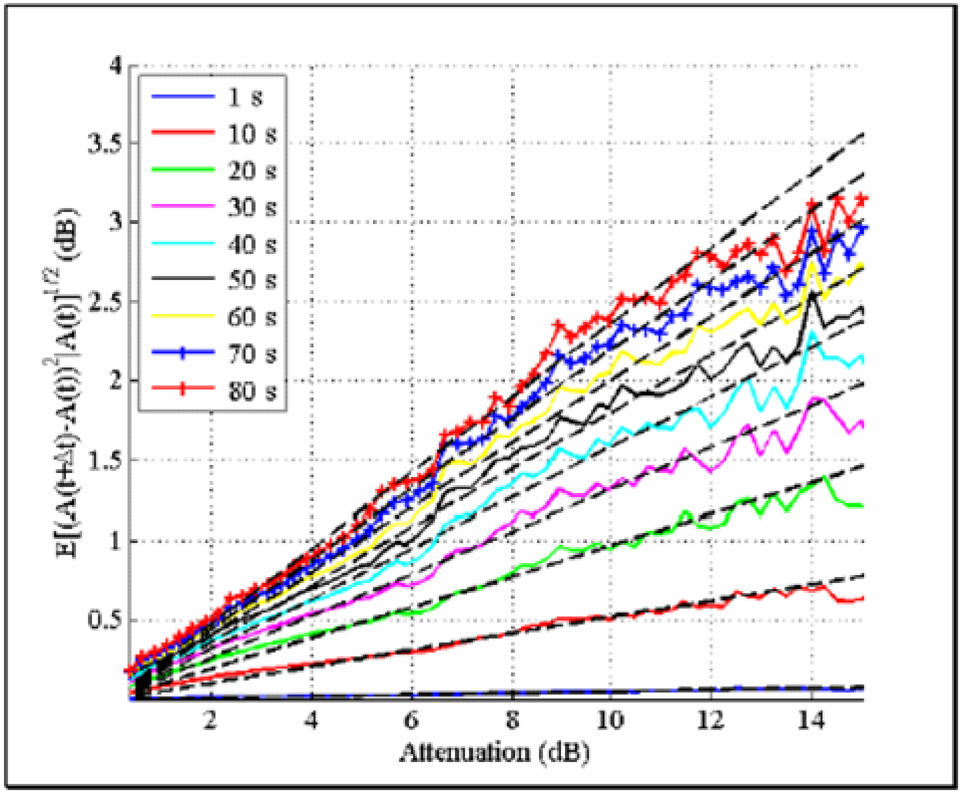
  1. **First linear regression w.r.t A for several Δt values:** $\sqrt{\Delta t . K_{2A}(A)} = \gamma(\Delta t).A$
  2. **Second linear regression w.r.t Δt :** $\gamma(t) = 2\beta\sigma^2\Delta t$

  Actually, compensation of low pas filtering effect: $\gamma(t) = 2\beta\sigma^2\Delta t \times F_{f_c,F_s}(\Delta t)$

with: $$F_{correct}(f_c, \Delta t) = \frac{\displaystyle\int_0^{\pi . f_c . \Delta t} \left(\frac{\sin x}{x}\right)^2 dx}{\displaystyle\int_0^{\frac{\pi . F_s . \Delta t}{2}} \left(\frac{\sin x}{x}\right)^2 dx}$$

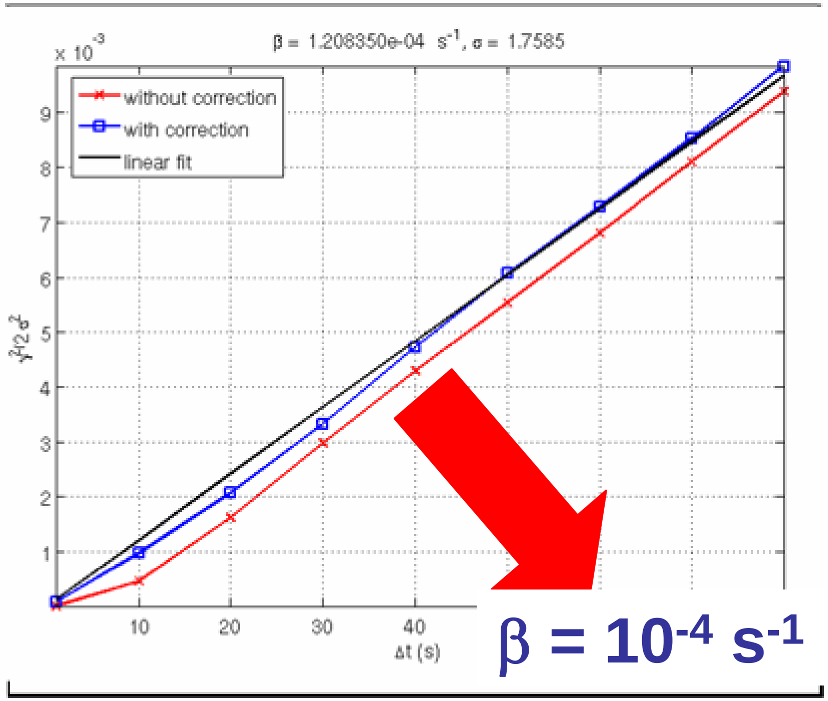
Example

SPI @ 19 GHz



Modified M-B $\beta = 10^{-4}$ s^{-1}

M-B $\beta = 10^{-4}$ s^{-1}



First regression: 2 dB < A < 8 dB

Second regression: 1 s < Δt < 80 s

A_{offset}

Overall results and further work

Data amount	Station	*freq* (GHz)	*ε* (°)	*β* (s^{-1})
7 years	Spino d'Adda (Italy)	19	37.8	9.5×10^{-5}
		40		1.03×10^{-4}
		50		6.5×10^{-5}
46 months	Sparsholt (UK)	19	29.9	3.15×10^{-4}
		40		2.63×10^{-4}
21 months	Louvain la Neuve (Belgium)	12.5	27.6	3.66×10^{-4}
		30		2.44×10^{-4}
2 years	Lessive (Belgium)	12.5	27.8	3.13×10^{-4}
		20		2.43×10^{-4}
4 years	Oberpfaffenhofen (Germany)	40	34.8	1.53×10^{-4}
1 year	Gometz la ville (France)	20	30.32	2.57×10^{-4}
		30		1.99×10^{-4}
1 year	La Folie Bessin (France)	20	30.33	1.74×10^{-4}
		30		1.45×10^{-4}
16 months	Eindhoven (Netherlands)	12.5	26.8	2.22×10^{-4}
		20		2.45×10^{-4}
		30		2.37×10^{-4}
13 months	Lannemezan (France	44	5	2.1×10^{-5}

- **Also results for short terrestrial links (Norway):**
  - **Maseng-Bakken framework seems to be valid also for terrestrial links**
  - **β = about 3.10^{-4} s^{-1}**
- **Semi or fully automatic software available**
  - ⇒ **Extension of the β assessment to available measurements**

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Propagation data collected in Brazil

Experimental propagation data

Station	Coordinates (degrees)	Altitude above sea level (m)	Link inclination (degrees)	Climate	ITU-R probability of rain (P_0 %)	Type of data	Beacon data sampling period (s)	Consecutive data periods
Mosqueiro (Pará state)	Lat: -1.40 Long: 309.31	16	87.5	Equatorial	13.3	Intelsat* beacon (11.5 GHz)	2	09/1996 to 08/1997 (up time : 90.4 %)
Rio de Janeiro (Rio de Janeiro state)	Lat: -22.92 Long: 316.05	30	62.2	Tropical	9.5			03/1998 to 02/1999 (up time : 87.4 %)

* Geostationary, 50° W.

- Data stored in steps of 0.5 dB

Work on experimental propagation data (with aid of rain gauge data)

- Manual removal of gaps and spikes not due to rain attenuation events
- Elimination of huge signal bias not due to rain attenuation events
- Processing for satellite movement compensation was not done at this time
  - For the data used, visual inspection shows it may not be a big concern
  - To validate affirmation above and to be prepared to further data, this processing should be implemented

Propagation data collected in Brazil

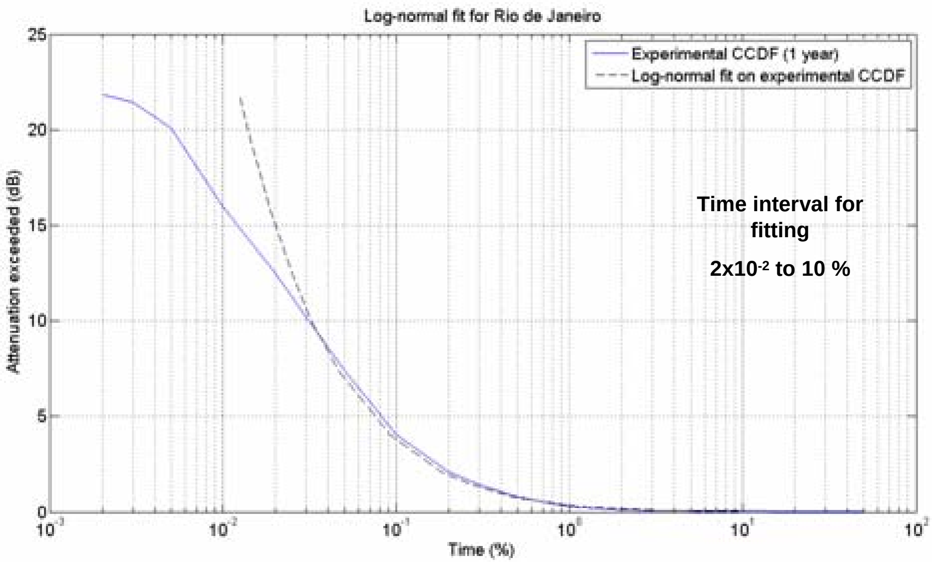
- **Experimental data consists of received beacon power level**
  - **Attenuation levels retrieval done by daily histogram (nominal level)**

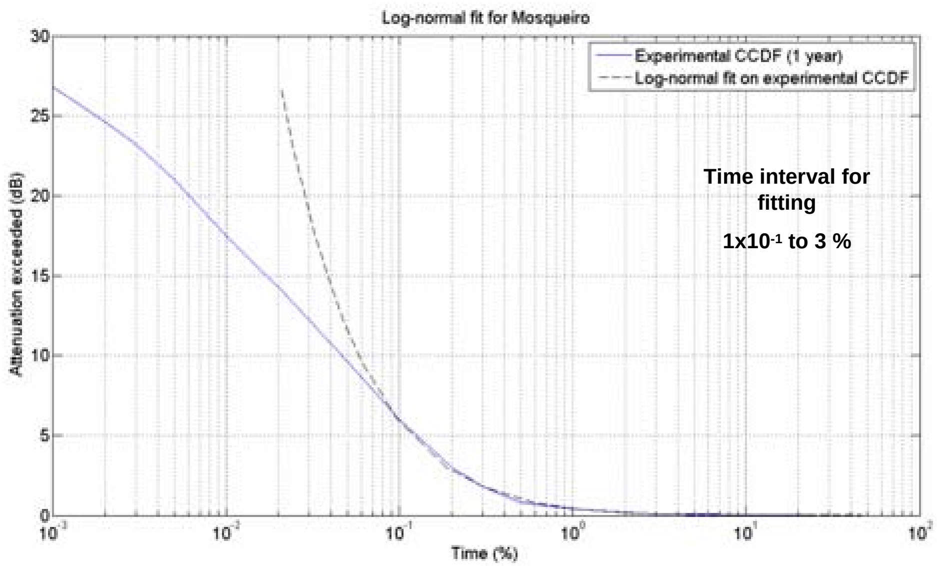
- **Statistics generation**
  - **As the long-term channel model to be used is the Enhanced Maseng-Bakken (Maseng-Bakken + offset) one, attenuation CCDF was adjusted to cross zero dB at P_0 (probability of rain as obtained by Rec. ITU-R P.837-5)**
    - Mosqueiro: attenuation time series subtracted by 0.5 dB
    - Rio de Janeiro: no calibration was necessary
  - **Attenuation CCDFs, fade duration and fade slope for the long-term (12 months) were generated, using the calibrated attenuation time series**

Preliminary long-term testing analysis

✈ Enhanced Maseng-Bakken channel model parameters (1/4)

➢ Retrieval of log-normal fitting parameters m and σ





⇨ For Rio de Janeiro, good fit is obtained for percentages of time above 0.03 % ; for Mosqueiro, fit is good for percentages of time higher than 0.08 %

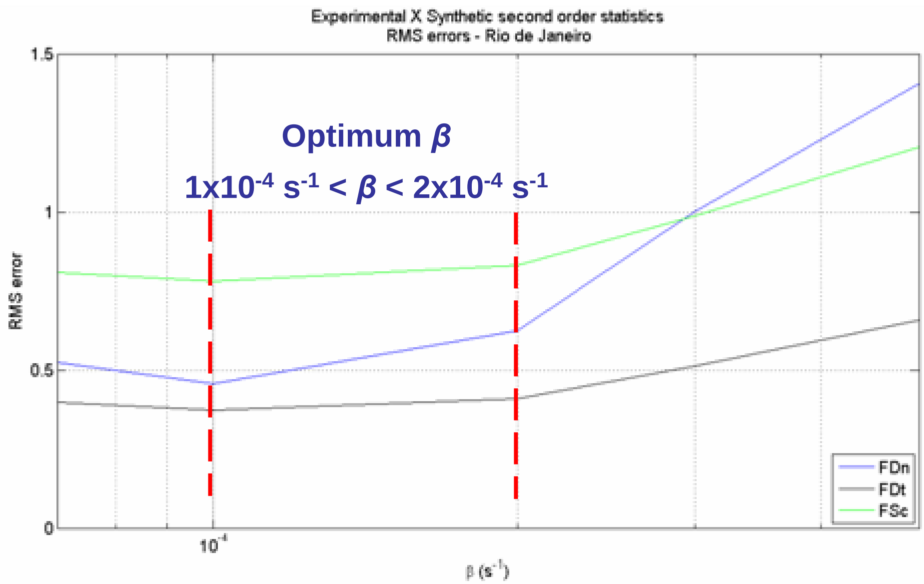
Station	Mean of log-normal CCDF, m	Standard deviation of log-normal CCDF, σ	Attenuation offset, A_{off}
Mosqueiro	-8.9462	3.4643 dB	0.0062 dB
Rio de Janeiro	-8.2133	3.0829 dB	0.0155 dB

Preliminary long-term testing analysis

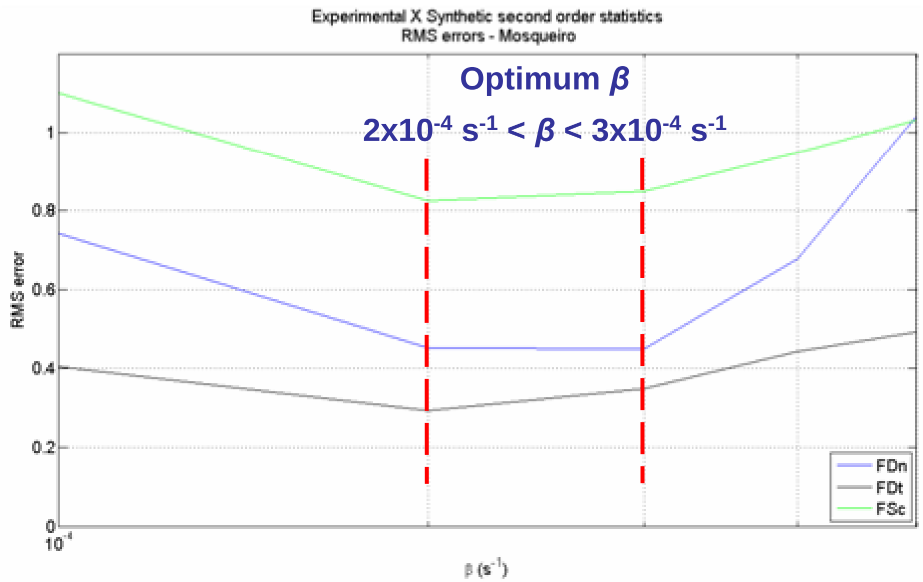
Enhanced Maseng-Bakken channel model parameters (2/4)

β parameter

Synthesis of 10 years (3650 days) of att. time series and comparison with experimental data (RMS error according to Rec. ITU-R P.311)



Chosen βs for Rio de Janeiro: 7e-5, 1e-4, 2e-4, 3e-4, 5e-4

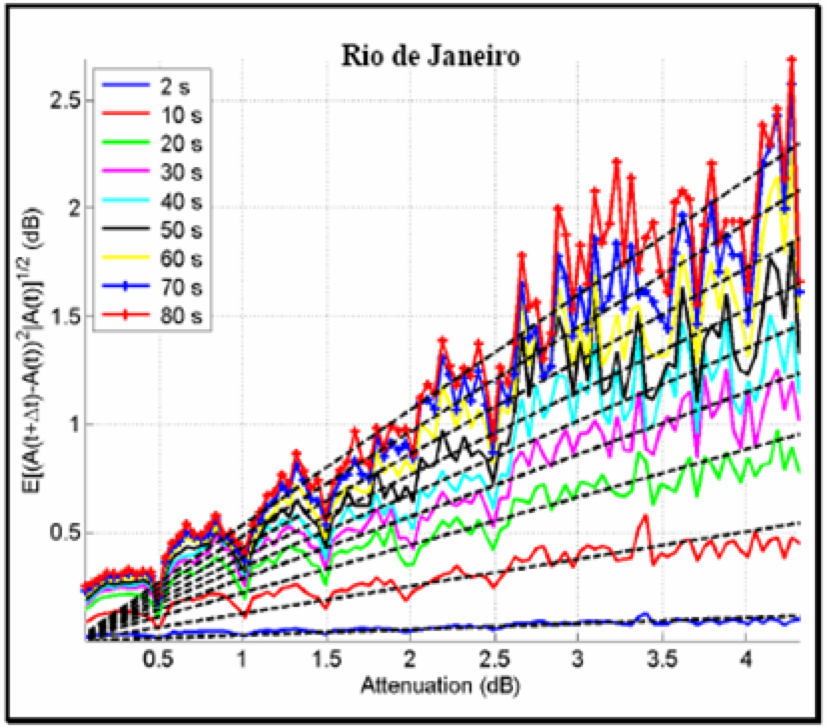


Chosen βs for Mosqueiro: 1e-4, 2e-4, 3e-4, 4e-4, 5e-4

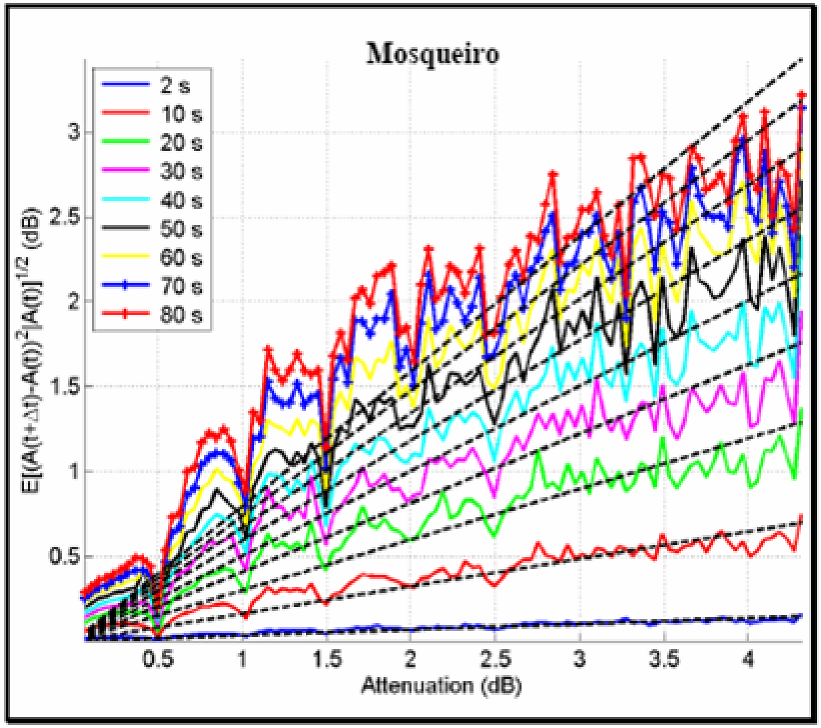
Channel model's β parameter retrieval

Enhanced Maseng-Bakken channel model parameters (3/4)

β parameter: retrieval by β extraction tool in Enhanced M-B model (1/2)



Attenuation domain for regression: 0.98 to 4.05 dB



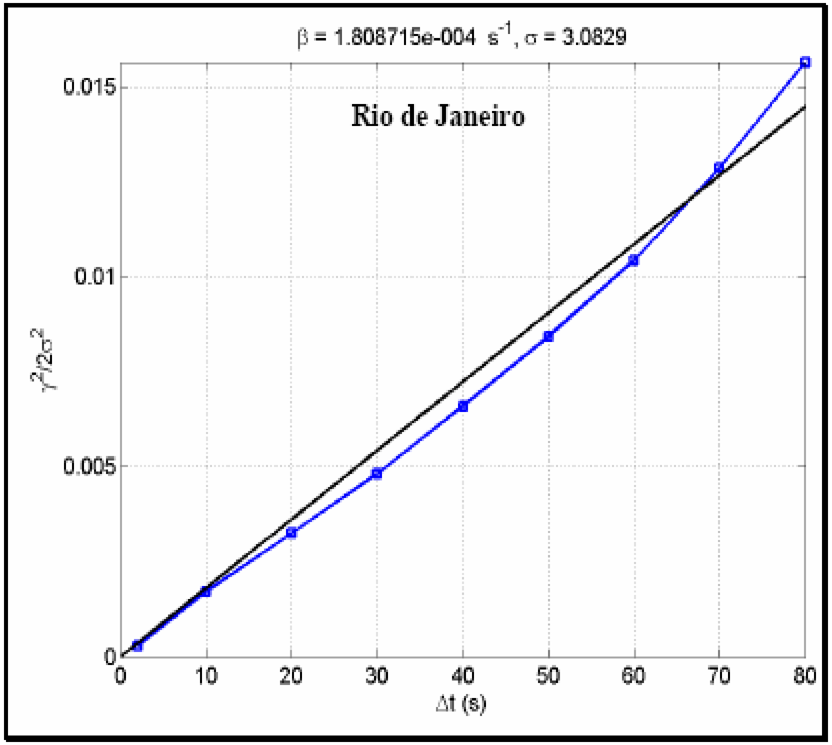
Attenuation domain for regression: 1.11 to 4.31 dB

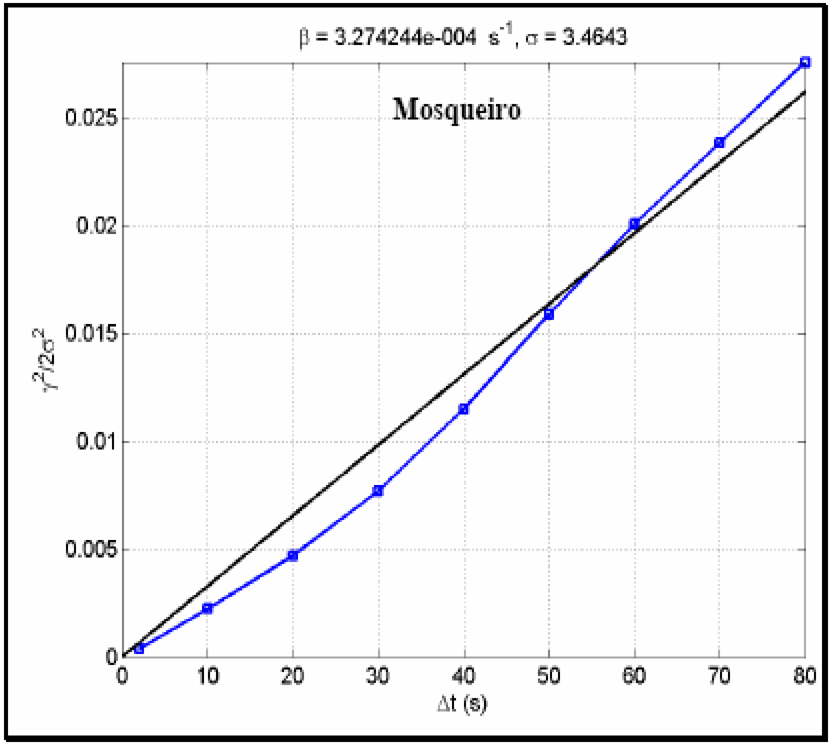
⇨ High variability of lines can be due to low quantity of experimental rain events to obtain statistical reliability

Channel model's β parameter retrieval

Enhanced Maseng-Bakken channel model parameters (4/4)

β parameter: retrieval by β extraction tool in Enhanced M-B model (2/2)





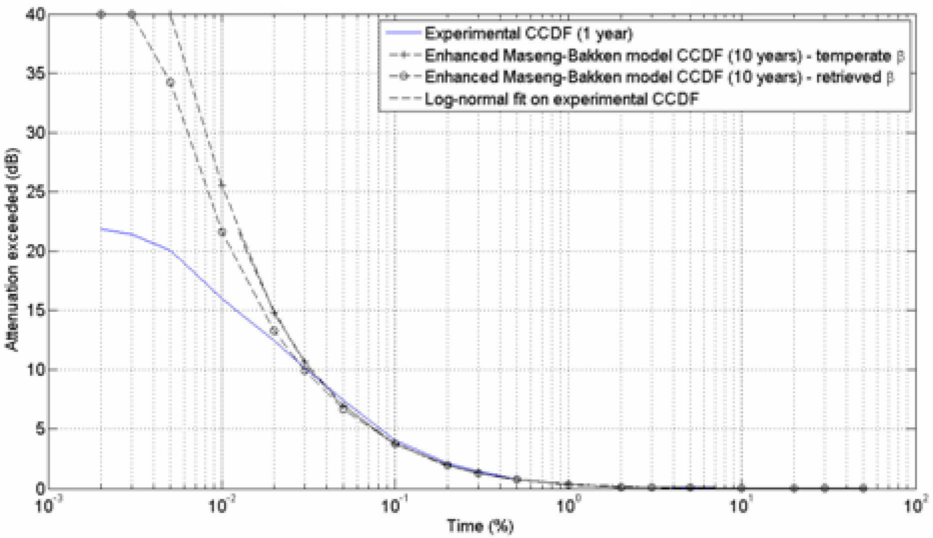
⇨ *β* for Rio de Janeiro: **1.8×10^{-4} s^{-1}**

⇨ *β* for Mosqueiro: **3.3×10^{-4} s^{-1}**

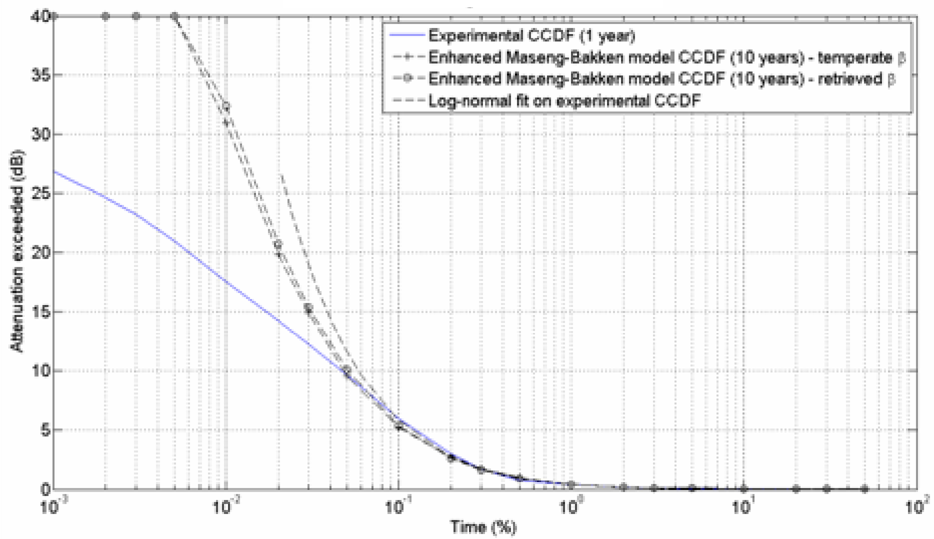
Statistics comparison – Experimental X Synthetic

✈ Comparisons of 1st order statistics

Rio de Janeiro



Mosqueiro

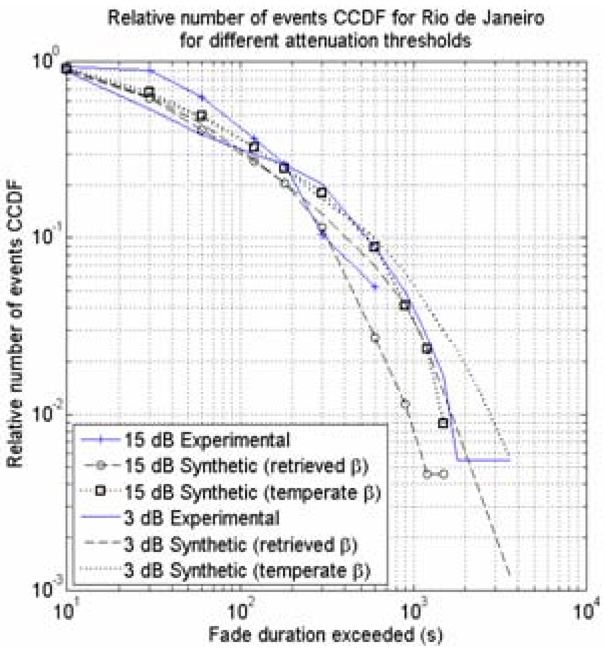


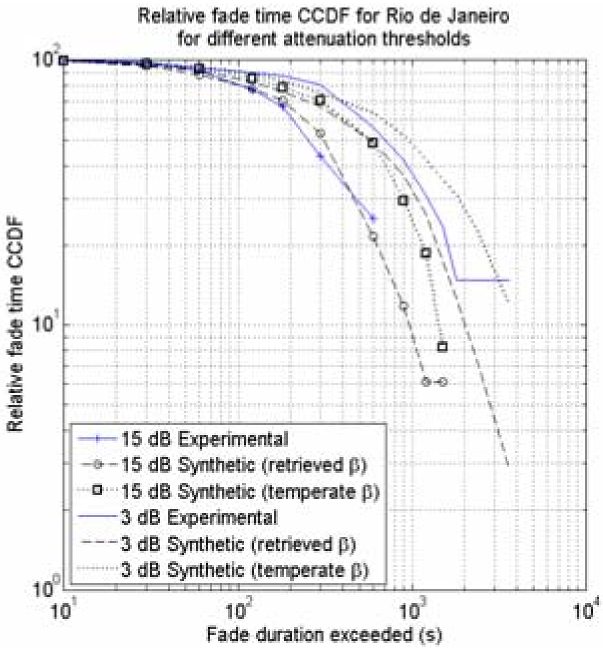
Temperate $\beta = 1x10^{-4}\ s^{-1}$

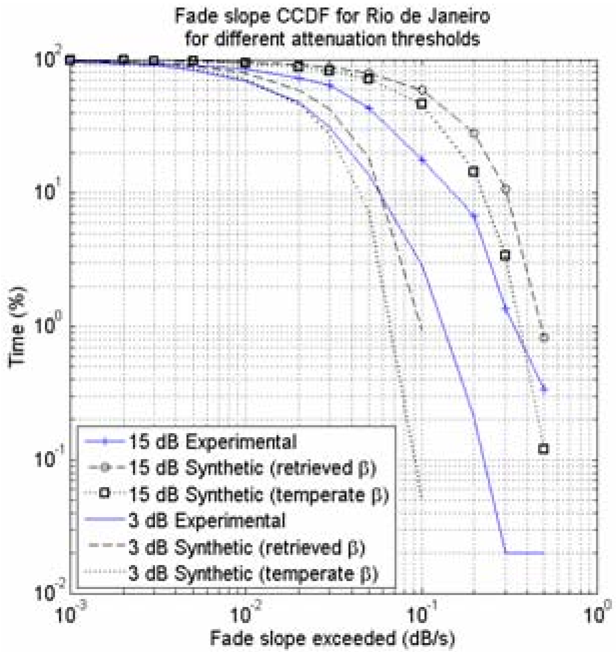
- **Considering both localities, good agreement between experimental and synthetic CCDFs is reached for percentages of time above 0.05 %**
- **For very low percentages of time, the model overestimates attenuation levels**

Statistics comparison – Experimental X Synthetic

✈ Comparisons of 2nd order statistics (Rio de Janeiro)





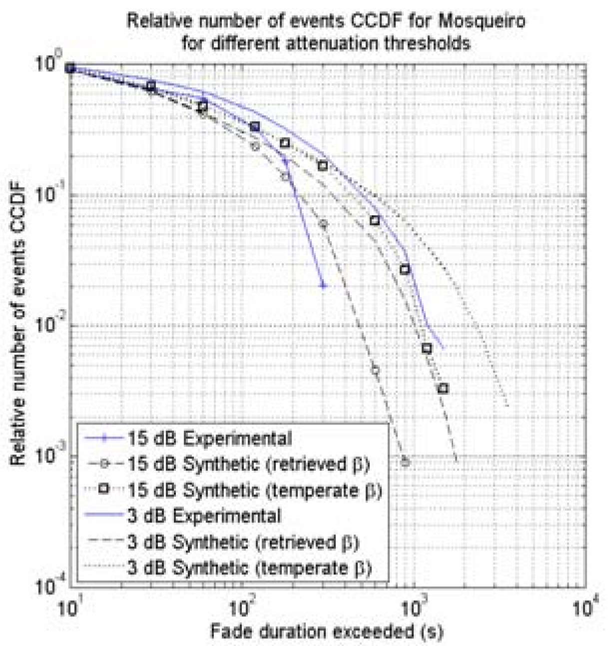


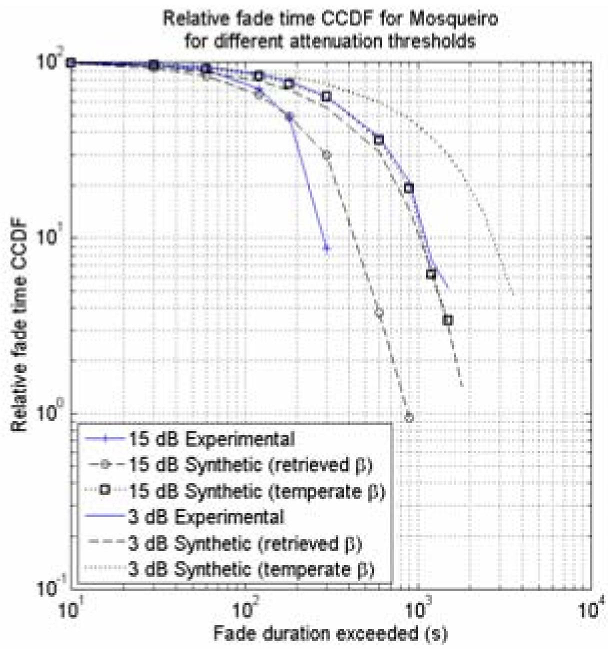
Temperate $\beta = 1x10^{-4}\ s^{-1}$

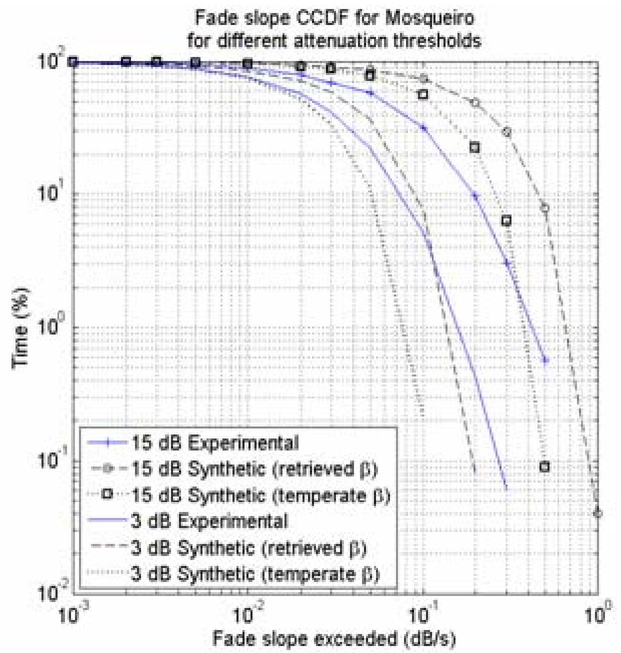
Cutoff frequency: 0.025 Hz ; Time interval for FS: 10 s

Statistics comparison – Experimental X Synthetic

✈ Comparisons of 2nd order statistics (Mosqueiro)







Temperate $\beta = 1 \times 10^{-4}\ s^{-1}$

Cutoff frequency: 0.025 Hz ; Time interval for FS: 10 s

- **In both localitions, fade duration and fade slope are overestimated for high attenuation thresholds**

Statistics comparison – Experimental X Synthetic

✈ RMS errors (according to test variables defined in Rec. ITU-R P.311)

β	Att. CCDF			FD_n			FD_t			FS_c		
	RIO	MOS	SPI	RIO	MOS	SPI	RIO	MOS	SPI	RIO	MOS	SPI
1e-4	0.285	0.332	0.170	0.458	0.743	0.379	0.374	0.405	0.340	0.781	1.102	0.748
Retrieved by the method in Enhanced M-B model	0.252	0.340		0.535	0.507		0.407	0.370		0.828	0.844	

"RIO" – Rio de Janeiro ; "MOS" – Mosqueiro ; "SPI" – Spino d'Adda

⇨ Spino d'Adda : temperate climate ; 18.7 GHz ; 37.8º link inclination ; 8 years

➢ No definite improvement was achieved with the retrieved β values for Brazilian data $\rightarrow$ further analysis is needed (lack of rain events)

Conclusion

- **Enhanced Maseng-Bakken model**
  - **Enhanced M-B model : very simple, good performances at Ku & Ka-band, popular approach, mature for havinf it standardized by ITU-R**
  - **Introduction of a new parameter to improve dynamics (w.r.t. exp^al^ data)**
  - **Critical issue : values of the β parameter**
    - Analysis tool relying on the 2nd order moment of the rain attenuation process
    - To be retrieved against experimental time series (tropical regions, low elevation)

- **Testing analysis w.r.t. tropical & equatorial data**
  - **Enhanced M-B model tested against Ku-band tropical & equatorial data**
  - **Preliminary retrieved *β* parameter values not too far from temperate ones**
  - **To arrive at definitive conclusions:**
    - Bigger quantity of experimental data (to improve statistical reliability)
    - Critical analysis of the *β* parameter retrieval (impact of ΔA, data processing)
    - Test of better distribution of rain attenuation: Gamma, Weibull ?

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