A COMPREHENSIVE STUDY OF SLANT-PATH ATTENUATION IN BRAZIL
SECOND PART: DYNAMIC STATISTICS

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ABSTRACT

In this paper, the results of the dynamic aspects of the statistical analysis of slant path attenuation at the Ku band in several sites throughout Brazil are presented and discussed. Results from radiometric measurements are compared with results from beacon data. Parametric estimation of the cumulative distribution function of event durations and number of events indicates that the Weibull distribution may provide the best overall fit. Regional differences on the location of events throughout the day completes the paper.

INTRODUCTION

The dynamic aspects of the statistics of attenuation are concerned with the probability distribution functions of two random variables: the number of events of a certain attenuation threshold being exceeded and the individual duration of such events. In short, it is the level crossing problem applied to the times series of attenuation. Unlike the cumulative distribution, from which little information can actually be drawn, the statistical analysis of individual attenuation thresholds provides a full dissection of the fading phenomenon. The information that the dynamic analysis provides can be of use in several key design issues such as building efficient adaptive power control algorithms, reliability evaluation of a link, availability calculations and more. In some of the sites a satellite beacon receiver and a radiometer at 12GHz, together with a tipping bucket raingauge were installed. In the remaining sites only a 12GHz radiometer was used. The sites are located within three of the four macroclimatic regions of Brazil as follows: Three sites in the equatorial climate region, ITU-R climate P, in a total of 9 years (5 with radiometric information only); Four sites in the tropical climate region , ITU-R climate N, in a total of 16 years (9 with radiometric information only) and two sites in the subtropical climate region, ITU-R climate N, in a total of 3 years. Among the results presented are the parametric estimation of the distributions of number and duration of events based on the two most used distributions in reliability theory: lognormal and Weibull. As is the case with the cumulative distribution of attenuation, the distributions of individual thresholds can also present more than one mode, mainly if the thresholds are located within regions in which effects of both stratiform and convective rain combine. To evaluate the existence of such modes and to what range in attenuation they span, a nonparametric analysis using adaptive histograms is applied together with a competitive risks approach. Finally, the diurnal distribution of events is also presented for all sites. This study allows the mapping of troublesome parts of the day, during which Earth-space communications are the most impaired.

EXPERIMENTAL SET-UP

The receiver sites are located throughout the Brazilian territory, from latitudes of –1 to –30 degrees. The sites descriptions are presented in Tab. 1. The receiver antennas have all a

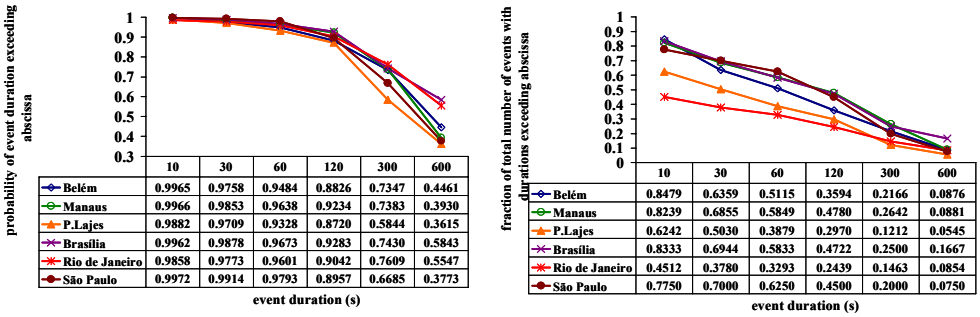
diameter of 3 metres. The antennas are pointed towards INTELSAT 705, located at 50°W. The beacon frequency is 11.452GHz and is clockwise circularly polarised. The beacon signals have a narrow bandwidth due to the lack of modulation. Since all the energy is contained close to the centre frequency, the receiver was built with a narrow bandwidth, thus reducing the noise. The dynamic range of the receivers are in excess of 30dB, being large enough to allow the observation of severe attenuation events. Tipping bucket raingauges with 0.1mm capacity and 1 minute integration time are placed near the antennas. The data is sampled at 1Hz and stored in a computer for posterior remote downloading. High frequency noise is reduced by the analysis software, which performs the smoothing of the data by averaging over 2 seconds, thus reducing the sampling rate from 1Hz to 0.5Hz. This sampling and logging computer is called Data Acquisition Unit (DAU). The DAU is designed for remote operation, allowing the deployment of several satellite beacon receiver units throughout the country for a more widespread coverage of different radioclimatic areas. Data is pre-processed to eliminate spurious effects that could masquerade the results, such as power cuts causing gaps on the received power being recorded.

STATISTICS OF DURATION AND NUMBER OF EVENTS – RADIOMETRIC AND BEACON DATA

Fig. 1 and 2 show the empirical cumulative probability distribution functions of duration and number of events exceeding 7dB obtained from radiometric and beacon data. Fig. 3 presents the cumulative duration and number of such 7dB and higher events. The morphological differences between the results from the two sources of data are very clear. Radiometric results present a much smoother profile which is probably due to the fact that radiometers do not pick up the effects of scintillation and other atmosphere-related effects to which beacon data is sensitive. Beacon events are much more uneven, as can be seen in the typical example shown in Fig. 4, which causes the distribution of durations to plunge rapidly as the event duration increases. The number of events, in the same fashion, also fall dramatically as the duration rises. Although the results presented are for the threshold of 7dB, they are representative of the general behaviour.

Site	*Geographic Characteristics.*	*Climate*	*Rad./Beacon*	*ITU-R Clim.*	*Lat*	*Lon*	*Alt. (m)*	*Elev. Angle*
Belém	Inland-Plain	Equatorial	yes/yes	P	-1	312	24	89°
Manaus	Inland-Plain	Equatorial	yes/no	P	-3			
P.Lajes	Inland-Plain	Equatorial	yes/no	P	-3			
Brasília	Inland-Highlds	Tropical	yes/no	N	-16			
Rio de Janeiro	Coastal-Plain	Tropical	yes/yes	N	-23	316	30	63°
São Paulo	Inland-Highlds	Tropical	yes/no	N	-24			
Curitiba	Inland-Highlds	Sub-Trop.	yes/yes	N	-25	311	915	55°
Porto Alegre	Inland-Plain	Sub-Trop.	no/yes	N	-30	309	75	51°

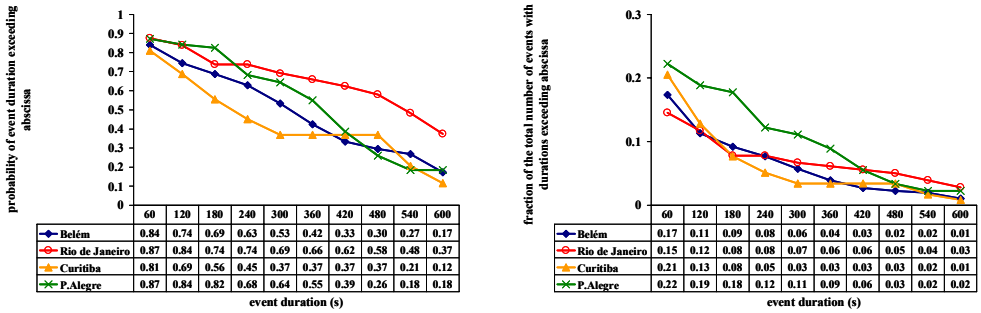
Tab. 1: Geoclimatic characteristics of the experimental sites.



	10	30	60	120	300	600
Belém	0.9965	0.9758	0.9484	0.8826	0.7347	0.4461
Manaus	0.9966	0.9853	0.9638	0.9234	0.7383	0.3930
P.Lajes	0.9882	0.9709	0.9328	0.8720	0.5844	0.3615
Brasília	0.9962	0.9878	0.9673	0.9283	0.7430	0.5843
Rio de Janeiro	0.9858	0.9773	0.9601	0.9042	0.7609	0.5547
São Paulo	0.9972	0.9914	0.9793	0.8957	0.6685	0.3773

	10	30	60	120	300	600
Belém	0.8479	0.6359	0.5115	0.3594	0.2166	0.0876
Manaus	0.8239	0.6855	0.5849	0.4780	0.2642	0.0881
P.Lajes	0.6242	0.5030	0.3879	0.2970	0.1212	0.0545
Brasília	0.8333	0.6944	0.5833	0.4722	0.2500	0.1667
Rio de Janeiro	0.4512	0.3780	0.3293	0.2439	0.1463	0.0854
São Paulo	0.7750	0.7000	0.6250	0.4500	0.2000	0.0750

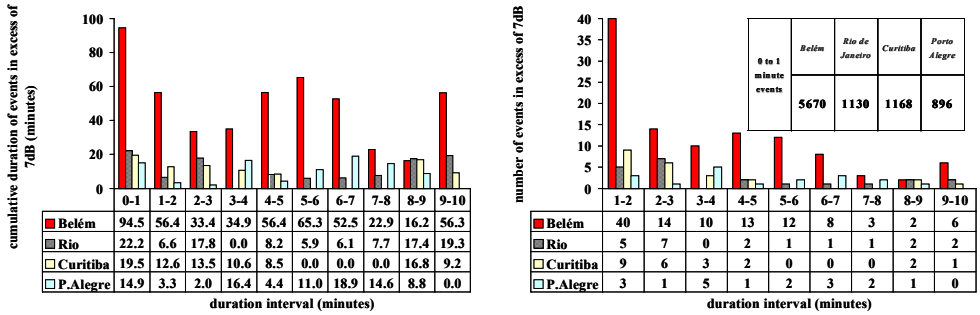
Fig. 1: Cumulative probability distribution functions of duration and number of attenuation events exceeding 7dB – *radiometric data*.



	60	120	180	240	300	360	420	480	540	600
Belém	0.84	0.74	0.69	0.63	0.53	0.42	0.33	0.30	0.27	0.17
Rio de Janeiro	0.87	0.84	0.74	0.74	0.69	0.66	0.62	0.58	0.48	0.37
Curitiba	0.81	0.69	0.56	0.45	0.37	0.37	0.37	0.37	0.21	0.12
P.Alegre	0.87	0.84	0.82	0.68	0.64	0.55	0.39	0.26	0.18	0.18

	60	120	180	240	300	360	420	480	540	600
Belém	0.17	0.11	0.09	0.08	0.06	0.04	0.03	0.02	0.02	0.01
Rio de Janeiro	0.15	0.12	0.08	0.08	0.07	0.06	0.06	0.05	0.04	0.03
Curitiba	0.21	0.13	0.08	0.05	0.03	0.03	0.03	0.03	0.02	0.01
P.Alegre	0.22	0.19	0.18	0.12	0.11	0.09	0.06	0.03	0.02	0.02

Fig.2: : Cumulative probability distribution functions of duration and number of attenuation events exceeding 7dB – *beacon data*.



	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Belém	94.5	56.4	33.4	34.9	56.4	65.3	52.5	22.9	16.2	56.3
Rio	22.2	6.6	17.8	0.0	8.2	5.9	6.1	7.7	17.4	19.3
Curitiba	19.5	12.6	13.5	10.6	8.5	0.0	0.0	0.0	16.8	9.2
P.Alegre	14.9	3.3	2.0	16.4	4.4	11.0	18.9	14.6	8.8	0.0

0 to 1 minute events	Belém	Rio de Janeiro	Curitiba	Porto Alegre
	5670	1130	1168	896

	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Belém	40	14	10	13	12	8	3	2	6
Rio	5	7	0	2	1	1	1	2	2
Curitiba	9	6	3	2	0	0	0	2	1
P.Alegre	3	1	5	1	2	3	2	1	0

Fig.3: Cumulative duration and number of events in excess of 7dB – *beacon data*.

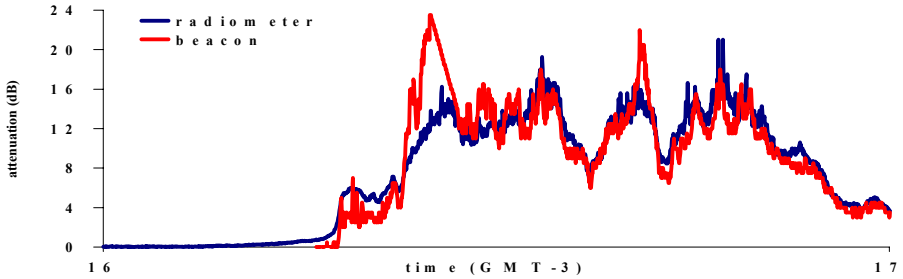


Fig.4: Typical attenuation event in Rio de Janeiro (01/03/1996)

PARAMETRIC ESTIMATION OF THE CUMULATIVE DISTRIBUTION FUNCTION OF DURATION AND NUMBER OF EVENTS

Fig.5 shows the cumulative probability distribution functions of event durations in Belém. The curves are plotted on Weibull scales [1]. Two hypothesis were tested in the search for the best fit to the distributions: lognormal and Weibull. These distributions are usually tested against each other in reliability studies. The advantages in using the Weibull distributions lie in its friendlier mathematical form. In fact, the hypotesis testing showed that the Weibull distribution is a better fit either to the distributions of events durations and number of events. Another common result found in every ensamble of distributions is that the Weibull lines appear to be paralel within specific ranges. This indicates that there may be a relationship between the parameters of the distributions within such ranges. The size of the ranges varies from site to site. In Belém the ranges are 5 to 10dB and from 12 to 20dB for the durations. For the number of events, the ranges are more thinly sliced, maybe because the influence of long lasting events is severely reduced: 5dB stands alone, 7 to 10 dB and above 10dB. This result may be important as it points the way towards a possible modelling tool, with which one could obtain the distribution of a given attenuation threshold by knowing a specific distribution.

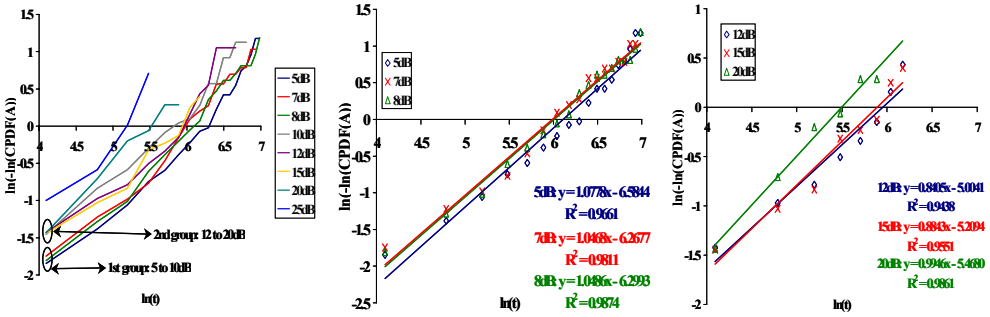


Fig. 5: Cumulative probability distribution functions of event durations plotted on Weibull scales. The site is Belém.

DAILY DISTRIBUTION OF ATTENUATION EVENTS

Fig. 6 shows the distribution of events exceeding 10dB in various regions of Brazil. Fig.6a presents the results at Belém (equatorial), Fig. 6b at Manaus (equatorial), Fig.6c at São Paulo (tropical - highlands) and Fig.6d at Rio de Janeiro (tropical - coastal). Events appear to be concentrated between late afternoon and dawn at all sites and with durations tending to be less than 2 minutes. In Rio de Janeiro (Fig. 6d), there is evidence of the influence of a few longer lasting events of high attenuation represented by the small peak at the long durations tail of the curve. São Paulo (Fig 6c) presented the lesser number of events higher than 10dB as is expected from its inland-highlands location, subjected to a weather which is much colder on average throughout the year than those of the other sites. Distribution in Belém (Fig. 6a) is multimodal as evidence of long lasting heavy rainfall events happening evenly during the year, as it is characteristic of the super-humid equatorial climate at the city. Manaus, (Fig. 6b) although also in equatorial climate, is located 1600km inland from Belém and has somewhat drier years, which explains the less pronounced peak at the long duration part of the curve.

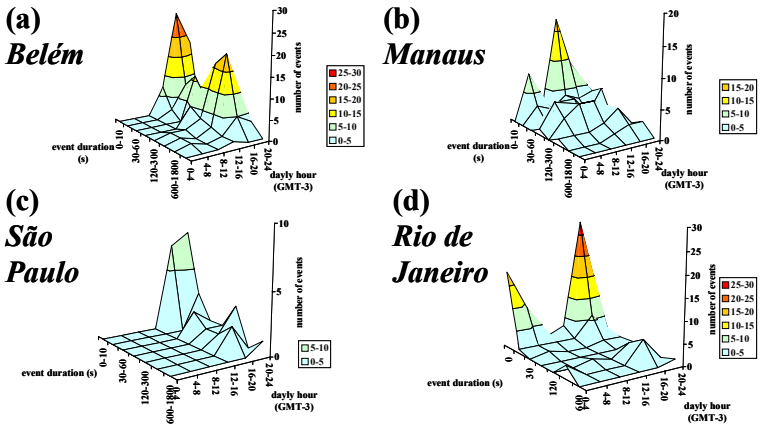


Fig.6: Daily distribution of events in excess of 10dB.

REFERENCES

[1]-Johnson, N., Kotz, S. and Balakrishnan, N."Continuous univariate distributions,"Vol.1, Wiley, New York, 1995.