

# Characteristics of Seasonal Attenuation and Fading for Line-of-Sight Links in South Africa

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**Abstract**— The characteristics of seasonal rain attenuation are studied for five different geographical locations in South Africa. This is to investigate particular features and behaviours associated with different seasons in the various locations. These five locations are chosen for study because of their unique climatic features which contribute significantly to their propagation behaviours and fading predictions. These locations are: Bloemfontein, Brandvlei, Cape Town, Durban, and Pretoria. The seasonal cumulative distributions of rain rate and rain attenuation are estimated for each location from a 5-year (2000-2004) point rainfall data collected directly by the South African Weather Services from each location (SAWS).

From these seasonal distributions, appropriate figures for fade margins are derived. These give the percentage of time for which a certain attenuation level is exceeded for different seasons in each location. These fade margins give the necessary allowance to accommodate expected fading that may want to occur on the LOS links in such locations. From the actual signal attenuation measurement recorded for one year in one of these five geographical locations with 6.73 km horizontally polarized 19.5 GHz terrestrial LOS link, the average attenuation for the year was computed. The experimental results show a good agreement with the ITU-R model.

**Index Terms**— seasonal rain attenuation, geographical locations, seasonal cumulative distribution of rain, rain attenuation, signal attenuation, fade margins, fading

## I. INTRODUCTION

In recent times, fluctuation or loss of signal has become a major concern for radio engineers especially with the increasing demand and establishment of more communications systems. Therefore, it has become paramount for radio engineers or network operators to predict the quality of service that will be provided to its customers. In order to do this, there must be good knowledge of the amount of time in a year that the service is available [1]. This will enable one to predict the amount of time, during a typical year that a transmission link will operate efficiently with little or no fluctuation of signals.

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Attenuation by rain is an important determinant of link unavailability on terrestrial line-of-sight links at frequencies above 10 GHz [2]. In tropical and equatorial climates, due to higher rainfall and larger raindrops than in the temperate climate, the effect of rainfall on radio links becomes important for frequencies as low as about 7 GHz [3, 4]. Attenuation due to rain can be obtained directly through measurement or predicted from the knowledge of rain rate, drop-size distribution and other relevant parameters of the radio path [5]. Rainfall, being a natural phenomenon that varies from time-to-time, location-to-location, and even seasons-to-seasons, needs to be adequately studied, for accurate propagation predictions in a particular geographical region. Also, the knowledge of rain-induced attenuation at the frequency of operation is necessary to design a reliable communication system for a particular geographical location [6].

Many methods proposed for predicting rain-induced attenuation make use of rainfall cumulative distributions measured at a point [2, 6]. The ITU-R [7] report has also suggested the use of the cumulative distribution of rain attenuation. These methods require the knowledge of 1-minute integration time rainfall rate exceeded for 0.01% of the time of an average year at the location of interest. The concept of an effective path length introduced is to take into account the non-uniformity profile of rainfall along actual path length.

This presentation looks into the seasonal characteristics of rain attenuation for the five major geographical locations in South Africa. These geographical locations are Durban which has coastal climatic features; Cape Town with its Mediterranean climatic nature; Brandvlei, a desert climate; Pretoria with temperate climate and Bloemfontein with its steppe climatic nature (Information from SAWS). Figure 1 shows the map of South Africa [13] highlighting the five locations while Table 1 shows their geographical location and climatic zones. In this work, the seasonal cumulative distributions of rainfall rate and the seasonal cumulative distribution of rain attenuation in each geographical location is presented using the rain rate statistics collected by the South African Weather Services for 5 years (2000-2004). From the seasonal attenuation distribution plots, figures for fade margin are derived at different percentages of time for which a certain attenuation level is exceeded for different seasons in each location. Also, the signal attenuation measurement recorded in Durban by Naicker et al [8] at 19.5 GHz in 2004 is used to determine the average attenuation for the year.

## II. CHARACTERISTICS OF SOUTH AFRICAN CLIMATE

South Africa, located on latitude 29°00'S and longitude 24°00'E, in the most southern tip of the African continent [9],

is climatically moderated by its surrounding oceans. The cold Benguela current that pushes northwards from the Antarctic along the Atlantic coastline runs up to the west coast, and a much warmer stream, the Agulhas current also moves southwards from the Indian Ocean which is the chief source of rain over most of the country. The Eastern seas' steady evaporation provides generous rainfall while the Benguela current retains its moisture to cause desert conditions in the west [10, 11]. South Africa has an average annual rainfall of 502 mm as against the world mean of 857 mm [10].

The climatic conditions in South Africa generally range from Mediterranean in the south-western corner of the country to temperate in the interior plateau, and subtropical in the northeast. A small area in the northwest has a desert climate while the center which is situated in the middle of high mountains has a steppe climate [12]. The mountains normally block moist air from the ocean from reaching the steppe; therefore this climate tends to go in cycles where there can be 10 years of rainfall and 10 years of drought. The difference between steppes and deserts is determined by the mean annual temperatures and precipitation. With a little less rain, the steppe could easily turn into a desert. With more rain, and it would be classified a prairie<sup>1</sup> [13].

South Africa seasons can be classified into 4 namely: summer, which occurs in mid-October to mid-February, autumn which is between mid-February and April; winter which occurs from May to July; and spring, which occurs from August to mid-October [11]. Most of the summer months are characterised by hot, sunny weather and the rainfall region are associated with violent convection storms accompanied by thunder, lightning, and often hail [10, 11]. Most rainfall in South Africa normally comes in the summer with the exception of Western Cape with its Mediterranean climate that gets its rain in winter [11]. The winter rain is often long lasting and not very intense except along the mountains, where the orographic effect may induce heavy showers. Between the winter and summer rainfall regions lies a transitional area; autumn and spring where rain comes in all seasons—that is, neither in winter nor in summer. This transitional area can be divided into two sub-regions: a southern coastal strip with annual total of 375 to 875 mm, and a drier inland corridor, behind the coastal, ranges with an annual total of 50 to 250 mm [9].

### III. SEASONAL DISTRIBUTIONS OF RAIN RATE AND RAIN ATTENUATION

The seasonal distributions of rain rate in the five geographical locations are determined from the 5-year (2000-2004) locally observed rainfall data in each location. The rainfall data supplied by the South African Weather Services (SAWS) are processed and converted to the ITU-R [15] recommended 1-minute integration time rain rate from previous work for all these locations [16, 17]. Also included are the cumulative distributions of rain rate for an average year observed in

locations that have different climatic rain zones in South Africa from a previous presentation [18].



Fig.1. Map of South Africa [14] highlighting the 5 locations in yellow

TABLE I: GEOGRAPHICAL LOCATION AND CLIMATIC REGION

Location	Latitude South	Longitude East	Climatic Regions (SAWS)
Bloemfontein	29°.10'	26°.30'	Steppe
Brandvlei	30°.47'	20°.48'	Desert
Cape Town	33°.97'	18°.60'	Mediterranean
Durban	29°.97'	30°.95'	Coastal Savannah
Pretoria	25°.73'	28°.18'	Temperate

The seasonal distributions of rain rate averaged over a period of five years studied in this paper give the percentage of time for which the rain rate which occurs in a particular season is exceeded. The rain distributions also show distinctively that each season in each location has its own unique features and characteristics which give a better view of what happens in the seasons over an average year. The distributions which are based on percentage of time show that the higher the rainfall rate, the lower the corresponding percentage of time recorded, and the lower the rainfall rate, the higher the percentage of time recorded [18], as shown in figures 2(a)-(e).

Using the ITU-R attenuation prediction model at 20 GHz [7, 19] on the determined seasonal cumulative distributions of rain rate produced the seasonal cumulative distributions of the rain attenuation. The average seasonal cumulative distributions provide a good insight into the behaviour of attenuation at different seasons in each zone. It is observed that attenuation strongly depends on the amount of rain that occurs in the seasons. Most of the summer and autumn seasons provide the largest amount of attenuation except at the Mediterranean climatic zone which has most of its rain in winter and spring. The attenuation produced in the summer

<sup>1</sup> grassland

and autumn seasons reflect the high degree of rains in that season especially in Durban which lies along the coastal region of South Africa. Plots in figures 2(a)-(e) show the distribution of the seasonal attenuation averaged over a period of 5 years.

In the case of Cape Town, (see Fig. 2(c)) the highest attenuation is in spring and winter. The winter is seen to lie close to spring and overlaps at 3.76dB. The lowest attenuation is recorded during the summer season. Pretoria, which has a temperate climate, also shows similar characteristics as that of Durban which lies in the coastal region. Both record their highest attenuation in the summer season. The plot of Pretoria (Fig. 2(b)) shows that the region just divides the season into two; summer/autumn and the winter/spring, are seen to overlap to a certain extent. Bloemfontein, which lies in the steppe region, also shows a little bit of similarity to Brandvlei which has a desert climate. These two geographical locations produce their highest rain in the autumn, which directly gives the highest attenuation in the season. Looking at the Bloemfontein distribution in Fig 2(d), it is observed that, the seasonal attenuation for the summer and autumn months overlap up to 3.63 dB, and above this, the autumn season records higher attenuation. Brandvlei records its lowest attenuation in the winter and spring seasons, but at 1.28 dB and above, the spring tends to record lower attenuation than winter for the average year.

#### IV. FADING AND LINK AVAILABILITY

The seasonal attenuation distributions shown in figures 2 (a)-(e), give appropriate fade margins figures for various levels of availability for different seasons in each of the geographical locations. These give the necessary allowance on any radio links system to accommodate any impairment caused by rain-induced fading. It is obvious that a fade margin design depends not only on the required availability over an averaged year, but also very much on the seasons [21]. This is because of the different characters displayed by each season in the various locations. That is, the fade margin required in a summer/autumn season is quite different from that required in spring/winter to guarantee a reasonable availability on transmission link for an averaged year.

Tables II (A)-(E) gives the required fade margin in dB at 20 GHz to guarantee the various levels of availability for an average of 5 years in different seasons for the five locations in South Africa. The tables show the fade margin that gives link availability for 99%, 99.5%, 99.9%, 99.95% and 99.99% for each season in each location. Generally, a link availability of 99%, 99.5%, 99.9%, 99.95% and 99.99% indicates a loss of service<sup>2</sup> on an average of 87.7 hours, 43.8 hours, 8.77 hours, 4.38 hours, and 0.88 hours (52.56 minutes) for an averaged year respectively [20, 21]. The ITU-R [7] recommends the 0.01% exceedance attenuation value which gives the 99.99% availability on a radio link. Fig. 3 gives the fade margin at 20 GHz for each season at 99.99% in South Africa.

<sup>2</sup> Loss of service does not necessarily imply that there is a complete loss of signal, but signal may be present at a reduced quality [20]

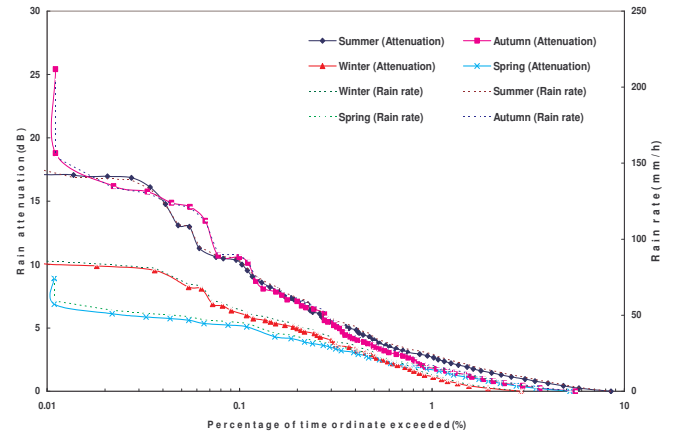


Fig. 2(a). Seasonal Distribution of rain and rain attenuation for Durban

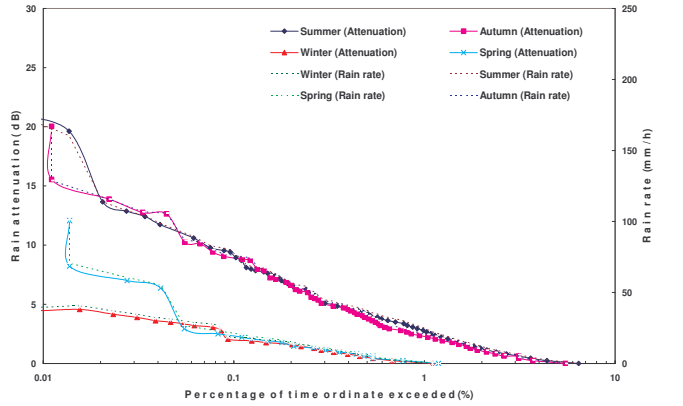


Fig. 2(b). Seasonal Distribution of rain and rain attenuation for Pretoria

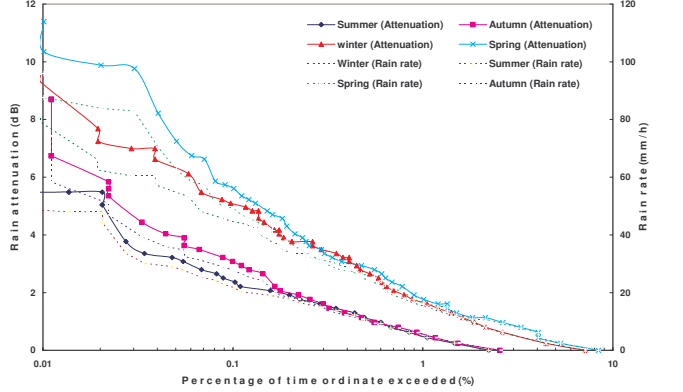


Fig. 2(c). Seasonal Distribution of rain and rain attenuation for Cape Town

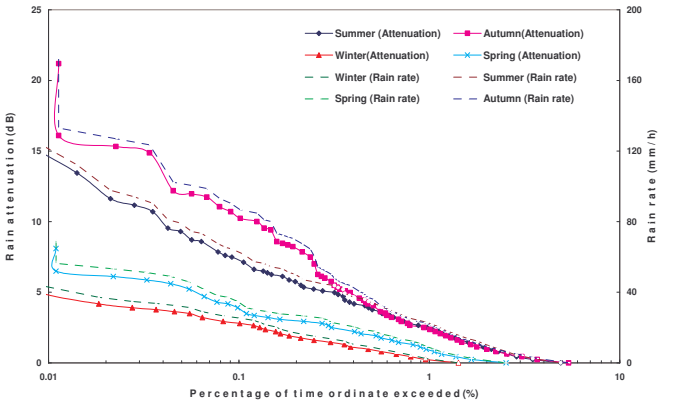


Fig. 2(d). Seasonal Distribution of rain and rain attenuation for Bloemfontein

It is observed that a relatively small fade margin is required when availability has to be guaranteed at 20 GHz during the winter and spring months. However, a large fade margin of up to 23 dB and more has to be implemented when a high degree of availability is required during the summer and autumn months in South Africa

## V. ITU-R RAIN ATTENUATION MODEL

The International Telecommunications Union outlines a method for predicting the long-term unavailability caused by rainfall in ITU-R 530-11 [7]. This method uses long-term rainfall intensity data, where the rainfall intensity data is averaged over 1-minute, to find the rainfall intensity that is exceeded for 0.01% of the time. The rainfall intensity value is then used to predict long-term attenuation expected for 0.01% of the time, at a particular frequency, polarization and path length [7]. The steps in applying this method are stated below:

1. Obtain the rain rate  $R_{0.01}$  exceeded for 0.01% of the time (with an integration time of 1-minute).
2. Compute the specific attenuation,  $\gamma_R$  (dB/km) for the rainfall rate at the frequency and polarization of the transmission. ITU-R P.838 [18] provides a method for achieving this by using the power-law relationship. The equation is stated below:

$$\gamma_R = KR^\alpha \quad (1)$$

The specific attenuation obtained is valid for a uniform rain medium. In order to account for the non-uniformity nature of rain, a reduction factor  $r$  is used, which takes the path length and the rainfall rate into consideration.

3. Compute the effective path length,  $d_{eff}$  of the link by multiplying the actual path length  $d$  by a distance factor  $r$ , with :

$$d_{eff} = rd \quad (2)$$

where  $d$  is the actual path length, and  $r$  is a factor which reduces in magnitude as  $d$  increases. It is given as:

$$r = \frac{1}{1 + d/d_0} \quad (3)$$

The quantity  $d_0$  is a rainfall-rate-dependent factor introduced to reflect the fact that the greater the intensity of rainfall in a storm, the smaller the physical dimensions of the storm are. It is given as [7], [22]:

$$d_0 = 35e^{-0.015R_{0.01}} \quad (4)$$

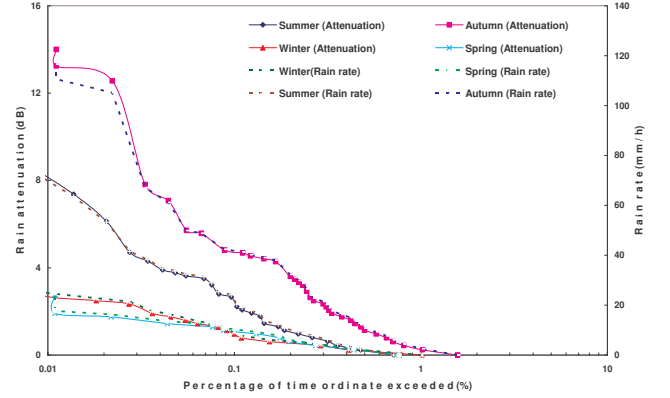


Fig.2 (e). Seasonal Distribution of rain and rain attenuation for Brandvlei

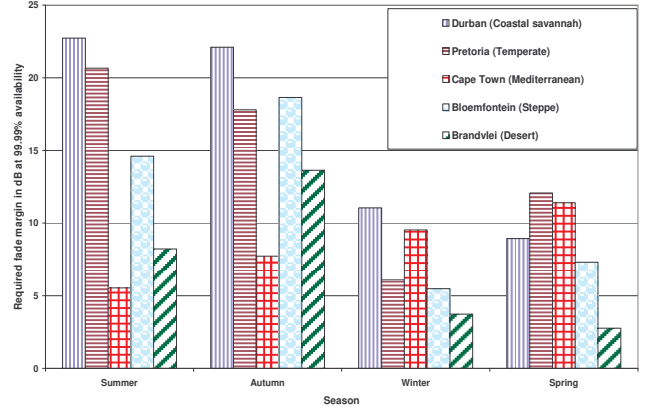


Fig.3. Required fade margin for 99.99% availability as a function of season

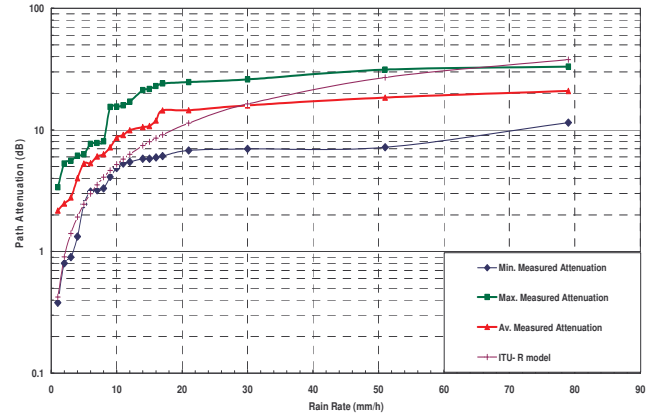


Fig.4. Rain attenuation for Durban along 6.73 km link at 19.5 GHz in 2004

When  $R_{0.01}$  is less than 100 mm/h,  $d_0$  should be calculated using the real rainfall value which is exceeded for 0.01% of the time. When  $R_{0.01}$  is greater than 100 mm/h, the value of 100 should be used for  $R_{0.01}$  in the equation, as this limits the effect of the reduction factor with increasing rainfall rate [7, 1].

4. Finally, the path attenuation exceeded for 0.01% of time is obtained from:

$$A_{0.01} = \gamma_R d_{eff} \quad dB \quad (5)$$

The prediction procedure outlined above is considered to be valid in all parts of the world for at least 40 GHz and path length of up to 60 km. The ITU-R 530-11 [7] provides a method for predicting fading for other percentages of time, once the  $A_{0.01}$  value has been obtained.

#### VI. ATTENUATION ALONG 6.73 KM, 19.5 GHZ, HORIZONTALLY POLARIZED LOS LINK IN DURBAN

A terrestrial radio link is set up in Durban (a coastal climate) at a frequency of 19.5 GHz and propagation path length of 6.73 km between two points; this records the rain rate at 1-min integration time and the signal attenuation for 1-year. Characteristics of the link have been published elsewhere [23, 8]. Here, the average path attenuation and the corresponding rain rate are determined over the year. These measurements are analysed and the minimum, average and maximum attenuation values per rain rate are determined. All these attenuation values are then compared with the results obtained from the ITU-R attenuation model [7] using the set of 1-minute rain rates recorded in this location.

Fig. 4 shows the measured maximum, average, and minimum rain attenuation values per rain rate and the ITU-R results for the entire year along the 6.73 km path at 19.5 GHz. It is observed in this figure that the ITU-R attenuation curves fall within the bounds (i.e. the minimum, maximum and average attenuation values) of rain rate of about 79 mm/h. This suggests that the ITU-R model can produce a justifiable result when used with the available rain data in South Africa especially when the rain rates are within these bounds. Nevertheless, longer measurements are needed to buttress these points.

#### VII. CONCLUSION

The 5-year point rainfall data obtained from the South African Weather Service (SAWS) for 5 geographical locations that falls within 5 different climatic zones in South Africa were analysed to identify and characterise the important features of seasonal attenuation and rain-induced fading on line-of sight links at a frequency of 20 GHz. From the 5-year point rainfall data, the seasonal cumulative distributions of rain rate were determined for the seasons in each location which helped to compute the season distribution of rain attenuation by using the ITU-R model. From the seasonal distribution graphs, it is observed that the each seasonal attenuation plots depended strongly on its rain distribution plots. That is, a high rainfall distribution gave a high attenuation distribution and vice versa.

The seasonal behaviour of attenuation for the seasons in each climatic zone was observed to be linked to their climatic characteristics. A high attenuation was observed in a high rain environments and season of high rain rate, such as the summer and autumn in all locations; except for Cape Town that had its rainy season during winter and spring due to its Mediterranean climate. Bloemfontein which had a steppe climate recorded a higher rainfall in the autumn season than in the summer. This

was similar to that of Brandvlei which was a desert, though the

TABLE II (A): REQUIRED FADE MARGIN AT 20 GHZ FOR DURBAN

Availability	99%	99.5%	99.9%	99.95%	99.99%
Fade margin in dB (Summer)	2.79	4.17	10.18	13.10	22.73
Fade margin in dB (Autumn)	1.92	3.62	10.12	14.54	22.10
Fade margin in dB (Winter)	1.30	2.14	6.38	8.88	11.04
Fade margin in dB (Spring)	1.77	2.65	5.23	5.74	8.93

TABLE II (B): REQUIRED FADE MARGIN AT 20 GHZ FOR PRETORIA

Availability	99%	99.5%	99.9%	99.95%	99.99%
Fade margin in dB (Summer)	2.66	4.17	8.94	11.16	20.66
Fade margin in dB (Autumn)	2.22	3.77	8.82	10.24	17.79
Fade margin in dB (Winter)	0.15	0.61	2.06	3.48	6.08
Fade margin in dB (Spring)	0.24	0.63	2.51	6.37	12.07

TABLE II (C): REQUIRED FADE MARGIN AT 20 GHZ FOR CAPE TOWN

Availability	99%	99.5%	99.9%	99.95%	99.99%
Fade margin in dB (Summer)	0.52	1.13	2.43	3.13	5.54
Fade margin in dB (Autumn)	0.62	1.05	3.00	3.85	7.72
Fade margin in dB (Winter)	1.76	2.79	5.09	6.36	9.52
Fade margin in dB (Spring)	1.83	2.86	5.60	7.24	11.39

TABLE II (D): REQUIRED FADE MARGIN AT 20 GHZ FOR BLOEMFONTEIN

Availability	99%	99.5%	99.9%	99.95%	99.99%
Fade margin in dB (Summer)	2.50	3.90	7.49	9.30	14.60
Fade margin in dB (Autumn)	2.40	4.10	10.23	12.08	18.64
Fade margin in dB (Winter)	0.24	0.88	2.86	3.56	5.48
Fade margin in dB (Spring)	0.97	1.91	3.90	5.41	7.30

TABLE II (E): REQUIRED FADE MARGIN AT 20 GHZ FOR BRANDVLEI

Availability	99%	99.5%	99.9%	99.95%	99.99%
Fade margin in dB (Summer)	0.09	0.24	2.43	3.78	8.21
Fade margin in dB (Autumn)	0.44	1.13	4.67	6.85	13.63
Fade margin in dB (Winter)	0.07	0.24	0.97	1.68	3.73
Fade margin in dB (Spring)	0.05	0.24	1.05	1.37	2.76

attenuation produced in the autumn season for Bloemfontein was higher than that of Brandvlei because of its higher rain

rate. Consequently, we inferred that the 5 year period during which the rain data was collected in Bloemfontein could be viewed as part of the 10 year cycle when there was rain [13].

The analysis of the fade margin from the seasonal attenuation distributions in each location were also linked to their climatic characteristics which dictated the impact of the season on the system design. These fade margin would give system operators or radio engineers an estimate of the allowance required on radio links to accommodate rain-induced fading in each season. With this, the fluctuation or loss of signal could be confined to very heavy and infrequent rainy seasons. This would improve the link availability and the quality of service provided to customers. Finally, the measurement recorded in Durban at 19.5 GHz on 6.73 km path length for a period of 1- year and the resulting prediction by the ITU-R model showed that the ITU-R model can thus be used reasonably to estimate rain attenuation for low to medium rain rates for different seasons in a year in South Africa and places that have similar seasonal characteristics.

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