International Journal of Infrared and Millimeter Waves, Vol. 7, No. 11, 1986

RAIN MAP FOR RADIOWAVE PROPAGATION DESIGN IN SAUDI ARABIA

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Received July 30, 1986

In the design of radiowave links, one of the major concerns is the amount of time for which the link is out of service. The outage could be due to equipment failure or propagation conditions. Our concern here is outage due to rain. For this reason a rain map for radiowave propagation in Saudi Arabia is developed. Based on 18-year rainfall data for all regions of Saudi Arabia, a rain map suitable for propagation studies is presented. According to this five climate regions have been established to describe the different regions of Saudi Arabia.

I. INTRODUCTION

Based on data pooled from the United States, CCIR gives an estimate of the cumulative distribution of rainfall rate for the entire globe by dividing the world into five rain-climatic zones. These climate regions represent rain climates typical of those found within the United States but do not adequately represent the much more intense rain rate region found in the wet tropical regions of Africa, South America, and Indonesia or the much less intense region found in the Arctic [1].

In the development of a new global rain climate model for use in communication system design, the number of regions chosen to represent the variation in rain rate was expanded from five to eight to better emphasize variation with latitude. The United States is still spanned by five regions [1]. Even so, this classification does not reflect the real cumulative distribution of rainfall rate for Saudi Arabia especially the South-Western region.

A glance over rain data for Saudi Arabia reveals that rainfall and rain rate vary considerably from region-to-region within the country. Hence, a regional rain map has to be developed to enable accurate radio link design at millimetric wave lengths, where attenuation due to rain is a major source of propagation outage.

In this paper 18-year rain data for Saudi Arabia is utilized to develop a rain map suitable for propagation studies. Section II outlines the source of data and steps taken to correct for missing and non-consistent data. Conversion of rainfall to rain rate is presented as well. Section III introduces a new measure of rain rate, selected to account for the variation of signal attenuation with rain rate as given by the known $A = bR^a$ relation. The measure is applied to rain rate data to develop the propagation map. Section IV presents the results in a form similar to the world's rain regions adopted by the CCIR.

II. RAIN DATA FOR SAUDI ARABIA

2.1 Rainfall Pattern in Saudi Arabia

Saudi Arabia lies in the tropical and sub-tropical zone between latitudes 16-32°N and longitudes 35-58°E. It has an extensive area of 2.2 million square kilometers which is characterized by a hot climate and scarce rainfall. The dry air masses developed in North Africa and in South Asia reach to Saudi Arabia without any appreciate moisture added from the Red Sea at the West and the Arabian Gulf at the East due to the small size of these water bodies [2].

Most of Saudi Arabia receives small amount of rainfall in the average of 100 mm per year except for the South-Western corner which receives more than 200 mm per year. The falls are usually of high intensity and short duration, lasting less than two hours. This meagre rainfall is associated with the Mediterranean low pressure and the Sudan quasi-monsoonal trough of low pressure extending northward over the kingdom.

Most of the rainfall is confined to the period from November to May, while summer months receive partially no rainfall except for the South-Western region. Typical to the characteristic of arid lands, the number of storms are limited from 0 to 10 storms per year in many areas, with high variability from year to year. A coefficient of variation of 61% and a relative variability of 113% have been obtained for Wadi Hanifa in the central region, while a relative variability as high as 174% has been reported for Jeddah [2].

2.2 The Data Source

The available rain fall intensity data consists of records from 137 recording rainfall stations for the period 1963-1980. These data represent the intensity portion of the rainfall data collected by the Hydrology Division, Ministry of Agriculture and Water (MAW) [3].

Individual storm data for each recording rainfall station were collected by picking from a continuous rain gauge chart, the maximum incremental rainfall which fell during the periods of ten, twenty, and thirty minutes, and one, two, three, six, and twelve hours. Recording rainfall gauges are located either alone or at a meteorological data-collecting site. Total rainfall, along with duration, was usually determined for each storm.

2.3 Excess Path Attenuation Based on Rain Data

For radio path engineering, a procedure is needed to calculate the rain attenuation distributions on millimetric radio paths from the available rainfall data.

Two different approaches to the estimation of rain attenuation are possible [4].

i) A theoretical method employing a uniform random distribution of rain drops modelled as water spheres or more complex shapes.

ii) An empirical procedure based on the approximate relation between specific attenuation (A) and rain rate (R):

$$A = b R^{a} \quad db/Km \qquad (1)$$

where R is the rain rate in mm/hr obtained from meteorological data. Parameters a and b are functions of frequency and polarization, and are obtained from experimental results. These values are given in both tabular and graphical form for the drop size distribution of Laws-Parsons, Marshall-Palmer, and Joss thunder storms.

The later approach is mostly used nowadays because a considerably larger data base is available for use in estimating the distribution functions required for modelling path attenuation [4].

2.4 Converting Rainfall into Exceeded Rain Rate

Rain attenuation is related to rain rate in (mm/hr) rather than rainfall intensity in (mm), hence, it is necessary to transfer the available rainfall data into rain rate.

Converting rainfall data into exceeded rain rate involves the following steps:

i) Divide the given data by the observation time (10 min, 20 minutes, etc.) using the following formula:

$$R_D = L * \frac{60}{T} \qquad (2)$$

where R_D is the rain rate in (mm/hr), L is the maximum rainfall in (mm) for the time interval T minutes. Table 1 shows, for example, the conversion process for the year 1963 in Riyadh.

Date	L : Maximum rainfall for the period of time indicated (mm). R : Rain Rate (mm/H)						
T	10	20	30	60	120	180	360
May 9; L	8	10	10	11.5	11.5	11.5	11.5
May 10; L	1.5	1.7	2	2.2	3.5	4	6
May 9; R	48	30	20	11.5	5.75	3.83	1.92
May 10; R	9	5.1	4	2.2	1.75	1.33	1

Table 1. Rainfall and rain rate for 1963 in Riyadh

ii) Define R_E as the rain rate exceeded in (mm/hr), with specific values of (1, 5, 10, ..., ..., ..., 130).

iii) Then for each event select R_D, and compare it with the nearest value of R_E which satisfies the relation $R_D \geqslant R_E$, then select this value of R_E which corresponds to the maximum rate exceeded in such event.

iv) The number of minutes T_{iE}, during the i-th event, for which a given rate R_D exceeds the value of R_E, equals the measuring time interval of the rainfall (mm) which corresponds to R_D (mm/hr).

v) Finally, the number of minutes per year for which a given rain rate R_E mm/hr was exceeded is found by summing over all rain events of the year to get:

$$T(R_E) = \sum_{i=1}^{n} T_{iE} \qquad (3)$$

where, n is the number of rain events of the year. T_{iE} is the number of minutes during the i-th rain event for which a given rate R_E was exceeded.

The number of minutes, per average year, for which rate R_E was exceeded is obtained by dividing $T(R_E)$'s by the number of recording years.

2.5 Calculation of the Missing Data

It is found that, for some events data are missing due to various reasons.

In order to obtain more reliable results, the missing data have to be estimated before processing the entire data set. Missing data have been calculated using the least square method of curve fitting.

Curve fitting

Examining rainfall intensity data, it has been found that experimental point rainfall rate distribution could be well approximated by a log-normal law [5,6,7]. By plotting rain rate (mm/hr) versus the percentage of time during which rain rate was exceeded, on a semi-log graph paper, the curve seems to behave like an exponential function of the form:

$$R = b\ e^{at} \tag{4}$$

where a,b are constants relating rain rate "R" (mm/hr) and percentage of time "t".

The plotted curve will be in a semi-log, so

let $t = \text{Log } T$
then, $R = b\ e^{a \text{Log} T}$
or, $R = b\ T^a$ (5)

The Least Square method is used to find the best curve which represents the measured data. Therefore, the missing rainfall rate values, in any event, are calculated by finding the parameters in equation (5) using the known rainfall rate values of that event. Then, equation (5) is used to find the missing rates by substituting for their corresponding time percentage (time in minutes divided by 5256 to get percentage of year).

Table 2 presents an example of finding the missing records for some events in Sabya in Jizan region.

Date	L : Maximum rainfall for the period of time indicated			
T	10	20	30	60
67: 7:30 L	0.00	0.00	19.40	19.40
L	19.40	19.40	19.40	19.40
68: 7:13 L	0.00	0.00	6.00	29.00
L	10.28	12.39	6.00	29.00
68: 7:14 L	0.00	8.00	8.00	8.00
L	8.00	8.00	8.00	8.00
Date	**L : Maximum rainfall for the period of time indicated**			
T	120	180	300	720 min
67: 7:30 L	19.40	19.40	19.40	19.40
L	19.40	19.40	19.40	19.40
68: 7:13 L	29.00	29.00	29.00	29.00
L	29.00	29.00	29.00	29.00
68: 7:14 L	8.00	8.00	8.00	8.00
L	8.00	8.00	8.00	8.00

Table 2. Calculation of missing data for some events in Sabya

2.6 Consistency of the Data

2.6.1 Errors in data

Meteorological data obtained from the MAW are subject to errors from many sources. Such errors can be due to:

(i) Equipment failure.

(ii) Human error in picking the rainfall precipitation from a continuous rain gauge chart.

(iii) Data entry error which may occur when entering the data into the computer to be processed.

2.6.2 Consistency criterion

Knowing that point rain rate distribution could be well approximated by equation (5), and that within a storm the value of point rain rate will be dropped to zero mm/hr from a maximum value, hence this fact can be used to examine how consistent the rain data are.

Now, consider $R(t_i)$ and $R(t_j)$ to be rain rates corresponding to rainfalls, within one storm, measured during periods t_i and t_j respectively, then:

$$R(t_i) \geq R(t_j) \qquad \text{if,} \quad t_i < t_j \qquad (i < j) \tag{6}$$

Hence, equation (6) is used to test the consistency of rainfall data as follows:

Rain rate records (mm/hr) in every event of the given data are checked to satisfy equation (6). If, for example, $R(t_i)$ and $R(t_j)$ donot satisfy the equation, then there should be an error in either one or both of them. Thus, both are checked with a third record, $R(t_k)$. Once the wrong record is detected, its correction is established using the linear interpolation formula:

$$R = \frac{R_k - R_j}{t_k - t_j} (t - t_k) + R_k \tag{7}$$

where t is the time in minutes during which rainfall, corresponding to R mm/hr, is measured.

On the other hand, if more than three consecutive errors are encountered in one event, curve fitting is used to fit the curve of rain rate versus time using the correct records, of the same event, which satisfy equation (6). Then, equation (5) is used to find the correct rates by substituting for their corresponding measuring time. Table 3 presents an example on correcting errors found in the rain rate data for some events in Sabya.

A computer program was used to check the consistency of the data, and perform the corrections.

Date	R : Rain rate for the period of time indicated (mm/H).			
T	10	20	30	50
68: 7:13 R	61.70	37.18	12.00	29.00
R	61.70	37.18	36.93	29.00
75: 8: 5 R	9.60	7.20	5.60	3.40
R	9.60	7.20	5.60	3.40
77:12:27 R	13.20	10.20	8.00	4.80
R	13.20	10.20	8.00	7.84

Date	R : Rain rate for the period of time indicated (mm/H).			
T	120	180	360	720 (min)
68: 7:13 R	14.50	9.67	4.83	2.42
R	14.50	9.67	4.83	2.42
75: 8: 5 R	1.70	2.17	1.08	0.54
R	3.26	2.17	1.08	0.54
77:12:27 R	5.30	3.93	2.03	1.02
R	5.30	3.93	2.03	1.02

Table 3. Data correction for some events in Sabya.

III. CLIMATIC ZONES OF SAUDI ARABIA

3.1 Regional Model

In engineering radio system, one of the major concerns is the amount of time the system will be out of work or that its performance will be below an acceptable level; this is known as outage time. For a reliable system, the amount of outage time must not exceed some desired objective and should be predictable.

System outage can be due to failure of the system equipment, and/or anomalous propagation conditions. Our main interest here is about outage due to rain.

To define a rain rate climate region, locations within such region will have the same rain rate distribution and should reflect the same mm-wave propagation reliability. Thus, a rain rate region is selected such that, for a mm-wave system, the outage time due to rain attenuation is the same for every location within that region. This can be achieved, for each location, by finding the number of minutes for which attenuation, caused by a certain rain rate, exceeds certain objective.

Another alternative here suggested aims at assigning the weight R_i to be associated with the number of minutes rain rate exceeded, $T(R_i)$, such that to reflect its probability to cause system outage.

The new alternative that is suggested to classify different locations into rain rate regions of the same outage time, is to use the proposed outage measure:

$$\text{Outage Measure} = \frac{\sum_i R_i \, T(R_i)}{\sum_i R_i} \qquad (8)$$

where, $T(R_i)$ is the number of minutes for which the rain rate R_i was exceeded.

Theoretical and numerical justification of the proposed measure are discussed in the following section.

3.2 Theoretical Justification of the Proposed Measure

Owing to the fact that probability of the rain rate to cause attenuation exceeding the pre-selected fade margin increases as rain rate intensity increases, then:

$$R \propto P_r \left\{ A(R) > FM \right\} \qquad (9)$$

where P_r is the probability that the rain rate R (mm/hr) causes attenuation A(R), in dB, greater than the fade margin (FM).

Moreover, the number of minutes rain rate R_E was exceeded equals the number of minutes rain rate R_i exceeds R_E plus the number of minutes R_i exceeds rates greater than R_E. Consequently, the rain rate intensity is inversely proportional to the number of minutes at which this rate was exceeded i.e.

$$R \propto \frac{1}{T\ (R)} \tag{10}$$

Joining equations (9) and (10) to get

$$R \propto \frac{P_r\ \{A(R) > FM\}}{T\ (R)}$$

or $$P_r\ \{A(R) > FM\} \propto R.T(R)$$

$$\sum_i P_r\{\ A(R_i) > FM\ \} \propto \Sigma\ R_i\ T(R_i) \tag{11}$$

where R_i's are the rain rates that cause attenuation that exceeds the fade margin.

On the other hand, the probability that $T(R_i)$ is the outage time equals the probability of the rain rate R_i to cause attenuation exceeds fade margin i.e.

$$P_r\ \{T(R_i) = \text{Outage time}\}\ =\ P_r\ \{A(R_i) > FM\} \tag{12}$$

Consequently,

$$P_r\ \{\text{Outage time} = \sum_i T(R_i)\} = \sum_i P_r\{\ A(R_i) > FM\ \} \tag{13}$$

From (11) and (13)

$$P_r\ \{\text{Outage time} = \sum_i T(R_i)\} \propto \sum_i R_i\ T(R_i) \tag{14}$$

The right hand side of equation (14) is the proposed measure, it is proportional to the probability of the real outage time measure, thus it can be used to distinguish between regions of different outage times due to rain.

For normalization, the outage measure is divided by the quantity $\Sigma\ R_i$, and becomes

$$\text{Outage Measure} = \frac{\sum_i R_i \, T(R_i)}{\sum_i R_i} \qquad (15)$$

3.3 Numerical Justification of the Proposed Measure

Having the number of minutes of an average year for which rainfall rate is exceeded at each location, consider a millimetric wave link operating at 40 GHz with (say) 10 km hop length between repeaters and 20 dB fade margin. Assume uniform rain rate distribution along the path, rain attenuation in dB/km can be obtained from the relation: $A = aR^b$. At 40 GHz, a and b have the values 0.325 and 0.990 respectively (Laws-Parsons) [8].

The outage time due to rain at each location is determined from the equation:

$$\text{Outage time} = \sum_i T(R_i) \ , \qquad 1 < i < N \quad (16)$$

where, N is the total number of rain rates exceeded, $T(R_i)$ is the number of minutes for which attenuation due to rain rate R_i exceeds the given fade margin. Hence, applying Eq. (16) to the data obtained from the Ministry of Agriculture and Water [7] a list of outage time due to rain is obtained at various locations. Another list of outage time is obtained by applying the proposed outage measure.

Comparison between the results of the two methods, shows satisfactory agreement since the results indicate that the trend from locations with maximum outage time to locations with minimum outage time is the same using either method. Therefore, the proposed measure is relevant and can be used to indicate the system outage time.

Maximum and minimum values of the outage measure are 127.8 at Harub and 1.36 at Tabarjal, respectively. Based on these values, define $T_{(E)}$ as the outage measure exceeded with the values (1,10,20, ..., 130). Locations having their outage measure satisfying the relation:

$$T_{i(E)} < T_{(E)} < T_{i+1(E)} \; ; \quad i = 1,2, \ldots 13$$

are said to lie within the same climate region. Thus a set of 13 rain rate climate regions have been obtained.

The median rain rate distribution for every region is obtained by finding the average total number of minutes for which the same value of R_E was exceeded at all locations within the region.

The number of regions chosen to represent the variation in rain rate was reduced from 13 to 5 since the rain rate distribution values versus percent of year rain rate is exceeded for the intermediate regions are close to each other.

IV. RESULTS

The developed rain rate climate model is presented in Fig. 1.

The resulting distributions for each of the five climate regions are depicted in Fig. 2. The rain rate distributions are also given in Table 4 for convenient reference.

Percentage of year	Rain rate climate regions 1	2	3	4	5
0.001	31.20	55.09	92.74	121.07	200.95
0.0025	19.61	34.64	57.52	75.73	118.33
0.0063	12.27	21.70	35.52	47.18	69.36
0.01	9.71	17.17	27.92	37.24	53.10
0.016	7.65	13.53	21.85	29.27	40.47
0.04	4.81	8.51	13.55	18.31	23.83
0.10	3.02	5.36	8.40	11.45	14.03
0.25	1.90	3.36	8.21	7.16	8.26

Table 4. Rain rate distribution values (mm/h) versus percent of year rain rate was exceeded.

Five climate regions have been established to describe rain climate regions for the Kingdom of Saudi

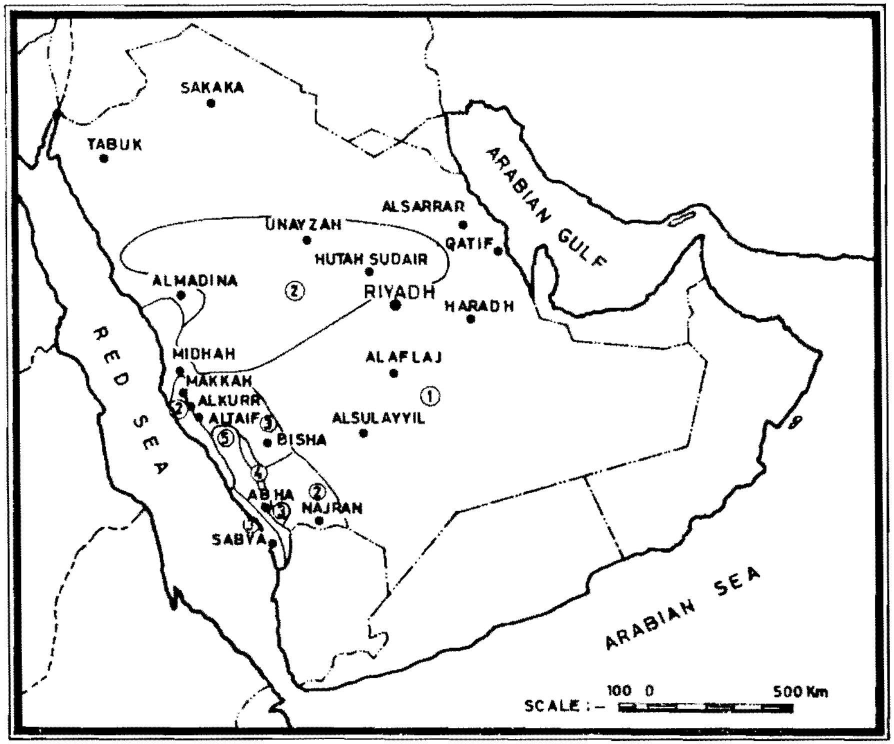

Fig. (1): Rain rate climate regions for Saudi Arabia.

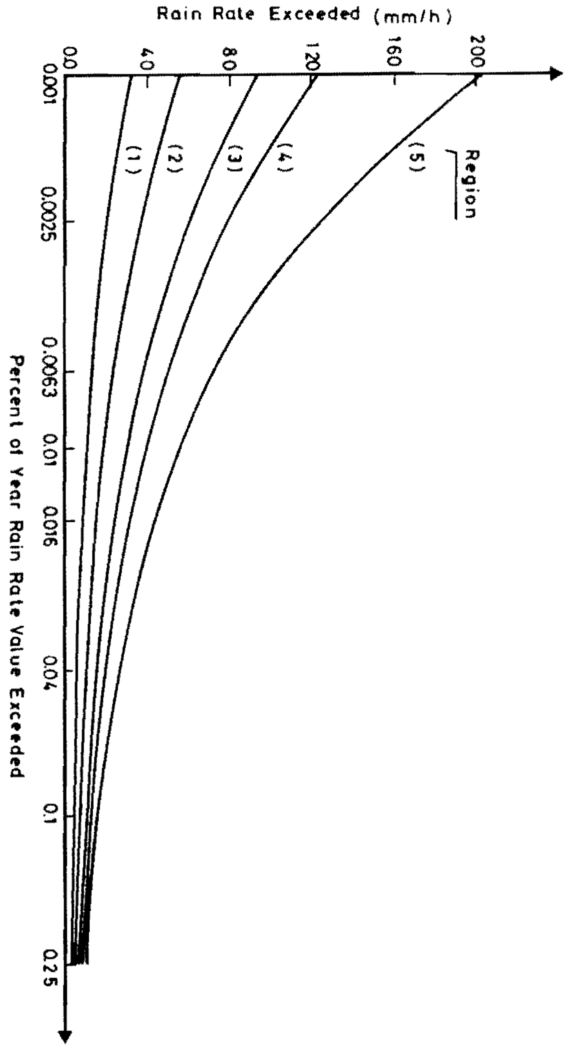

Fig. (2). Model rain rate distribution functions for the climate regions of Fig. (1).

Arabia. The available measured instantaneous rain rate distributions were pooled for each of the climate regions defined in Fig. 2 and used to construct a median rain rate distribution for the region.

The results show that the South-Western corner of Saudi Arabia spans a large range of rain rates at a given exceedence probability, and contains much intense rain rate distribution than that of the arid zones. This result shows satisfactory agreement with the available rainfall maps of the Kingdom [9].

V. ACKNOWLEDGEMENT

This project was financed by grant AR-5/29 from King Abdulaziz City for Science and Technology and grant 5/403 from College of Engineering Research Center, King Saud University.

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