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A New Rain Map for Radio Propagation in Saudi Arabia

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ABSTRACT. A new rain rate map suitable for radiowave propagation studies and radio link design in Saudi Arabia is presented. The map is developed utilizing 18-year rainfall data for all regions in Saudi Arabia (actual rainfall measurements in 101 recording stations). The new map is compatible with the global CCIR rain climatic zones. Such a map is needed where centimetric and millimetric wave radiocommunication systems are to be installed.

Radiocommunication Services are expanding at a rapid rate leading to bad congestion of the lower bands of the radio frequency spectrum. The microwave and millimetric bands (SHF and EHF) are considered best suited to accommodate the growing demands for radio services. Advantages of these bands include much wider range of frequencies (3-300 GHz:100 times the lower bands up to UHF), larger available bandwidth, effective frequency sharing, and small, cheap and efficient antennas. Unfortunately, as we go up in frequency other problems start to arise including worse receiver thermal noise, higher cost of hardware due to the fact that circuit components become less efficient and harder to design and build. Much more important, however, are propagation conditions which limit the communication range of microwaves considerably. Radiowaves above few gigahertz are greatly attenuated by absorption and scattering from atmospheric constituents, dust and rain in the radio path (Bem 1980 and Freeman 1981).

Rain is one of the more important factors affecting propagation of radiowaves in the centimetric and millimetric bands. The design of SHF and EHF radio links for both terrestrial and earth-space applications should take rain effects on radiowaves into account. Rainfall can cause noticeable attenuation (fading) in the radio signal through absorption and scattering of waves. In addition, it can cause cross-polarization, and hence, interference between orthogonally polarized radio systems sharing the same spectrum.

Attenuation due to rain is related to rain rate (in mm/h), rather than rainfall (in mm). The attenuation rate depends on frequency in addition to rain rate as shown in Fig. 1 (CCIR 1986). Olsen *et al.* (1978) give a power-law approximation of the relationship between the attenuation rate A (dB/km) and rain rate R (mm/h):

$$A = aR^{b} \tag{1}$$

where a and b are functions of frequency, polarization and rain temperature. Their values are given in several references [*e.g.* Olsen *et al.* (1978) and Report 721 in CCIR (1986)].

From the above discussion, it is clear that in order to be able to assess the effect of rainfall on radio link performance (*e.g.* estimate link reliability and outage time), accurate data on actual rain rates is needed. This paper presents a new rain rate map of Saudi Arabia based on actual 18-year rain intensity measurements in 101 stations distributed throughout the country. The new map is compatible with the CCIR world map. The following section discusses the CCIR classification of rain rate regions of the world. Next, the rain data for Saudi Arabia is presented and the conversion of this data into CCIR compatible format is explained. Results and conclusion are given in the last section.

The CCIR Rain Climatic Zones

The International Radio Consulative Committee (CCIR) is a permanent organ of the International Telecommunication Union (ITU) working as a technical advisory to the ITU on radio matters. The duties of CCIR include careful studies of the various technical and operating questions relating to radiocommunications. Its reports and recommendations are considered de-facto standards in radiocommunications throughout the world.

The CCIR studies radiowave propagation and the environmental conditions affecting it, including rain effects. In this regard, the CCIR in its Report 563-1 (CCIR 1978) divided the world into five rain climatic zones according to the cumulative distribution of the rain rate for each zone. This division was based on

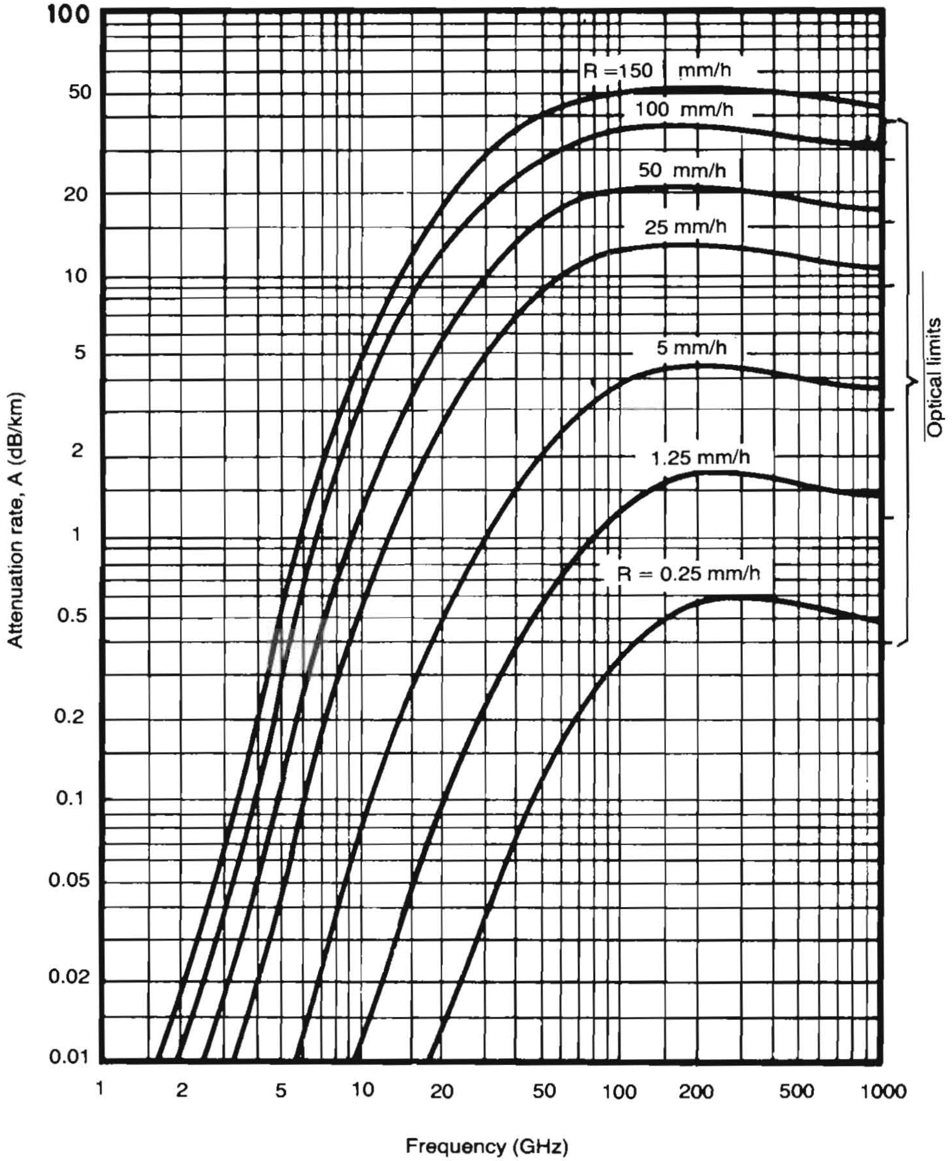

Fig. 1. Rain attenuation rate as a function of frequency and rain rate.

data pooled largely from the United States. Saudi Arabia was placed in the fifth zone which is characterized by the least intense rainfall rates. However, several researchers [*e.g.*, Crane (1980) and Segal (1980)] emphasized that such classification did not adequately represent rain climates in other parts of the world. Crane (1980) recommended that the number of regions chosen to represent the variation in rain rates be expanded from five to eight.

Subsequently, by utilizing more rainfall intensity data made available by a number of developed countries, the CCIR revised its classifications of world rain regions and extended the number of rain climatic zones from 5 to 14 (CCIR 1982). The mean cumulative rain rate distribution is presented in Table 1. According to the revised CCIR classification in Report 563-2, the Arabian Peninsula was divided into two zones. The inland is classified as Zone C which represents relatively scarce rainfall (Table 1), while the coastal area is assigned Zone A which represents the driest zone. This is clearly in error, since the wettest regions in the Arabian Peninsula of Asir, Yemen and Oman are highlands close to the cost while the central desert of ar-Rub' al-Khali (Empty Quarter) is one of the driest deserts of the world warranting zone A classification.

Four years later, the XVI Plenary Assembly of the CCIR adopted a revised version of its classification in Report 563-3, which contains an updated world rain rate map (CCIR 1986). The latest CCIR classification has, once again, changed the classification of Saudi Arabia as depicted in Fig. 2. Most of the peninsula including the highlands in the South West is now shown as Zone C, while a strip of the Central area is assigned Zone A. This classification does not reflect the real cumulative distribution for Saudi Arabia, especially in the more intense rain region in the south western corner of the country.

The CCIR worldwide rain map classified the different parts of the world by considering rainfall intensity measurements reported by different countries in North America, Europe and Japan. The classification was then extended by extrapolation to other parts of the world based on traditional geographic considerations and climatic similarities.

However, the CCIR results, as emphasized in Report 563-3, may be used in the absence of appropriate rainfall intensity data from local sources. Whenever such data exists for a certain location, these data should be used to determine the rainfall intensity probabilities. In addition, the CCIR is asking administrations to provide such data whenever available (CCIR 1986).

The CCIR world rain rate classification is considered a reference standard for SHF and EHF radiocommunication links design and studies. Many governments

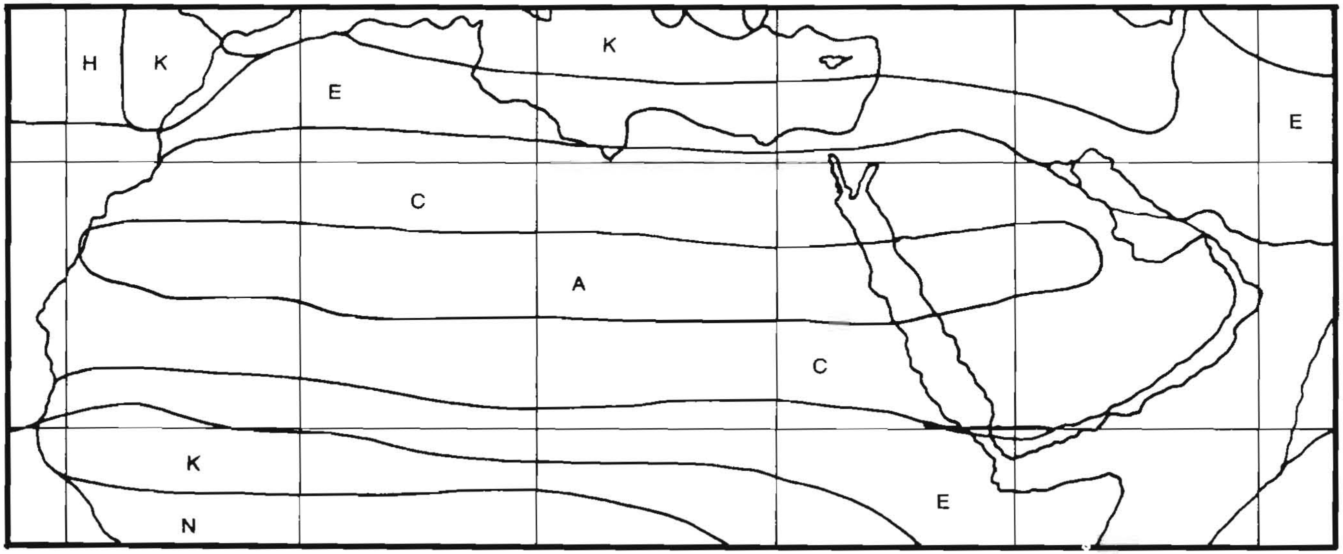

Fig. 2. An extraction from the CCIR's Report 563-3 showing the classification of rain zones of Saudi Arabia (see Table 1).

and communication companies require their microwave and millimetric wave links to meet the performance objective based on rain rates for their regions as given by the CCIR. As a result, researchers and engineers rely on those data in their design and analysis of radiolinks affected by rain. Ali *et al.* (1987) give global hop length analysis for all the fourteen CCIR rain climatic zones, and present a family of curves showing fade margins versus hop lengths for various reliability objectives.

New Rain Map for Saudi Arabia

Rainfall data for the period 1963-1980 are available from the Hydrology Division of the Saudi Ministry of Agriculture and Water (MAW 1980). The available data consists of rainfall records from 137 recording stations. The stations are not uniformly distributed but are carefully selected to give far greater density in the high precipitation areas of the highlands in the south western region of the Kingdom. Individual rain storm data for each station were obtained by reading from a continuous rain gauge chart the maximum incremental rainfall which fell during the periods of 10, 20, 30, 60, 120, 180, 360 and 720 minutes. Total rainfall and duration was usually given for each storm. Ali *et al.* (1986) have processed the data, filling in the missing records, performing consistency checks to correct erroneous records and converting the rainfall data (in mm) to exceeded rain rate

Table 1. CCIR Rain Climatic Zones

Rainfall intensity exceeded (mm/h)

Percentage of time (%)	A	B	C	D	E	F	G	H	J	K	L	M	N	P
1.0	<0.5	1	2	3	1	2	3	2	8	2	2	4	5	12
0.3	1	2	3	5	3	4	7	4	13	6	7	11	15	34
0.1	2	3	5	8	6	8	12	10	20	12	15	22	35	65
0.03	5	6	9	13	12	15	20	18	28	23	33	40	65	105
0.01	8	12	15	19	22	28	30	32	35	42	60	63	95	145
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250

(mm/h). They used a regional model based on an outage measure to classify different locations into rate regions. Their results are not given in the same format used by the CCIR.

Based on the same rainfall measurement data, a new rain rate map compatible with the CCIR classification will be given for Saudi Arabia. The country will be divided into regions, with each region assigned a CCIR rain climatic zone from Table 1. For better results, data from stations having recording periods less than 6 years were excluded, hence only rain data from 101 stations are considered.

In order to compare the distribution of rainfall intensity excceded, for the 101 stations, with the CCIR rain climatic zones of Table 1, the distribution of the exceeded rain rate as a function of percentage of time per average year has been fitted using the least squares method. The best approximation was found to be a log-normal distribution. Values of exceeded rain rate for each station are, therefore, easily computed at the specific values of percentage of time of Table 1 (namely 0.001, 0.003, 0.04, 0.03, 0.1, 0.3 and 1.0 percent).

Next, each station's data for rainfall intensity exceeded $R_j(t_i)$ is compared with the exceeded rain rate for each CCIR rain climatic zone R_{ck} by forming a squared error. The squared error is given by:

$$SE_j(k) = \sum_{i=1}^{7} [R_j(t_i) - R_{ck}(t_i)]^2 \qquad (2)$$

where j = recording station number (1,2,3,...101)

k = CCIR rain rain climatic zone designation (A,B,C,D,E,F,G,H,J,K,L,M,N,P).

t_i = percentages of time given in table 1.

= 0.01, 0.003, 0,001, 0,0003, 0.0001, 0,00003 and 0.000001 for i = 1,2,3,4,5,6, and 7 respectively.

$R_j(t_i)$ = exceeded rain rate for t_i percentage of time at station j (j=1,2,3,..., 101).

$R_{ck}(t_i)$ = exceeded rain rate for t_i percent of time of CCIR climatic zone k (k = A,B,C,... etc).

The square error is found for all k's and j's. For each station j, the CCIR climatic zones are arranged in the order of decreasing square error $SE_j(k)$. The climatic zones with smallest square error are the most likely classifications for station j. The three CCIR climatic zones with least square error are considered the most likely candidates to classify station j. The final decision regarding the actual classification of the station into a single climatic zone is made by considering a number of adjacent stations and averaging classifications amongst them. The averaging process is logically appealing for the following reasons:

1. Stations close to each other are most likely to have similar geography and climate.
2. The averaging process tends to compensate for data errors or inaccuracies.
3. The rain rate classifications are to be used for propagation reliability calculations for SHF and EHF systems in the region around and in between stations rather than on the stations themselves.

The comparison of measured exceeded rain rates with the 14 CCIR rain climatic zones is repeated for the 101 stations with 6 years of recording period or more which are distributed all over the country. The new rain rate map of Saudi Arabia is shown in Fig. 3. It represents the best approximation to the rain climate zones for Saudi Arabia, compatible with the CCIR classification.

Results and Conclusions

To define a rain climatic region, all locations within such a region have to have the same rain rate distribution and should reflect the same SHF and EHF propagation reliability. Based on this definition, and utilizing 18-year rainfall data for 101 stations distributed throughout Saudi Arabia, a new rain rate map suitable for radio propagation studies and compatible with the CCIR classification is presented in Fig. 3.

As can be seen in the figure, the east coastal area and most of the inland-area have the same distribution of rainfall intensity exceeded as the CCIR current designation, namely, climatic Zone C. The central western coastal area was classified as Zone A by the CCIR, but the new map clearly identifies it as Zone E. The south-western corner spans a large range of rain rates for a considerable part of the year and contains much more intense rain rate distribution than that of the arid zones. Such distribution is approximated to the CCIR Zones F, H, and K. The least intense rain rate regions in Saudi Arabia are the north-western and south-eastern regions which have a distribution of rain rate similar to the first CCIR climate Zone A. The current CCIR map classifies those dry areas as Zone C. The south-east "Zone A" region corresponds to the huge sand desert of the

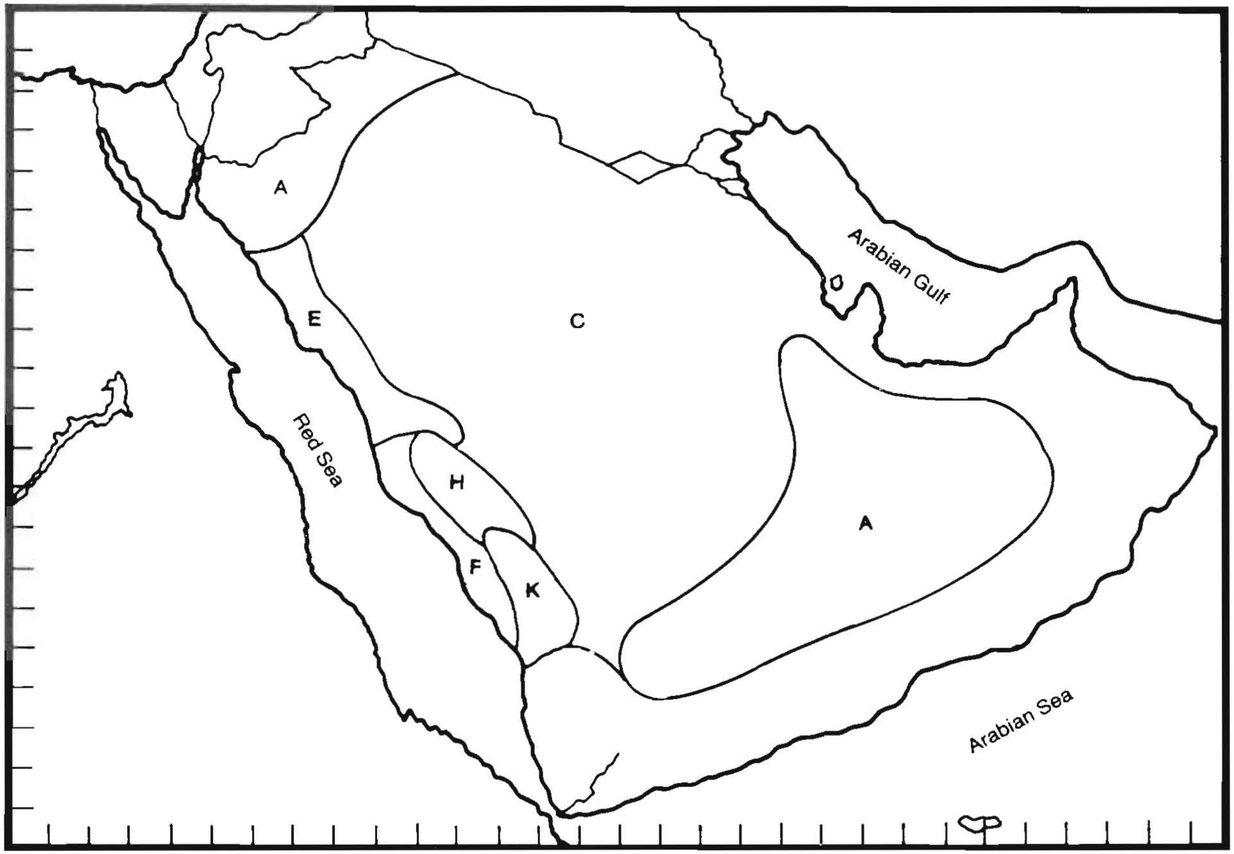

Fig. 3. The new rain map for Saudi Arabia using the CCIR rain climatic zone designation (see Table 1).

"Empty Quarter", which is one the largest, hottest and most arid deserts of the world.

To summarize, a new rain map for the Kingdom of Saudi Arabia, suitable for propagation studies, has been developed, based on actual rainfall data recorded in a large number of widely scattered recording stations. The map is compatible with the CCIR rain climatic zones, and can be considered as a correction to the CCIR rain map of Saudi Arabia which was based on extrapolation of rain distribution in Europe and other parts of the world.

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خريطة معدلات المطر في المملكة العربية السعودية لدراسة إنتشار الموجات اللاسلكية

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تكتسب الاتصالات أهمية متزايدة في عصرنا الحديث وبالذات في المناطق الصحراوية الصعبة ذات التجمعات السكنية المركزة والمتباعدة، حيث تساعد الاتصالات على التقليل من العزلة التي تفرضها التضاريس الجغرافية القاسية والمناخ المتطرف للصحاري، وتؤدي إلى دعم النشاطات الانتاجية لسكان هذه الصحاري. وبصفة خاصة، فإن الاتصالات اللاسلكية مثل شبكات الموجات الدقيقة (الميكرويف) والتوابع الصناعية تعتبر مناسبة جداً للدول النامية بسبب سهولة بنائها وإنخفاض تكاليفها بالمقارنة مع الاتصالات السلكية التي لابد أن تمر عبر مسافات شاسعة من الأراضي الصحراوية الصعبة والقليلة السكان.

ولابد من أجل تصميم أفضل لشبكات الاتصالات اللاسلكية ولاستخدامها بأكثر الطرق كفاءة من معرفة التأثيرات المختلفة للظروف البيئية وبالذات الظروف المناخية التي قد تتعرض لها مثل هذه الشبكات. ومن أهم هذه الظروف معدلات الأمطار التي تتعرض لها المناطق الصحراوية.

ورغم ندرة الأمطار في الصحاري (الصحراء ظاهرة مناخية تتميز بتطرف درجات الحرارة، وبنقص شديد في معدلات الرطوبة)، إلا أن عدم إنتظامها

وعدم القدرة على التنبؤ بتأثيراتها المحتملة قد تكون سبب إربـاك وربما شلل مؤقت لأنظمة الاتصالات السلكية في الموجات الدقيقة وما فوق.

وعليه فإن هذا البحث يهدف إلى إعطاء فكرة عن تـأثير الأمـطار على إنتشـار الموجات اللاسلكية بشكل عام، ثم إلى تقديم خريطة جديدة لمعدلات الأمطار في المملكة العربية السعوديـة. وقد تم تـطوير هـذه الخريـطة بالإعتمـاد على بيـانات معدلات الأمطار التي تم تجميعها على مدى ثمانية عشر سنة في ١٣٧ محـطة تابعـة لوزارة الزراعة وموزعة على مختلف مناطق المملكة. وقد أعدت الخـريطة للتـوافق مع التوزيع القياسي لمعدلات الأمطار التي تتبناه الهيئة الاستشارية الـدولية للراديـو (CCIR) التابعة للاتحاد الدولي للاتصالات. والمعروف أن الهيئة قد أعـدت خرائط لتوزيع معدلات الأمطار في كافة أنحاء العالم بالاعتماد عـلى قياسـات تمت في دول أوروبا الغربية وأمريكا الشمالية واليابـان ثم توسَّـع مدى هـذه المعدلات لتشمـل دولاً أخـرى لم تؤخذ منهـا قياسـات فعلية. وتعتـبر هذه الخـرائط مرجعـاً معتمـداً لمهندسي نظم الاتصالات والشركات الاستشارية وبالذات في الدول النامية في ظل غيـاب معلومات دقيقـة مبنية عـلى قياسـات فعلية. ولهـذا فإن الخـريطة الجـديدة لمعدلات الأمطار في المملكة تمثل جهـداً في هذا الاتجـاه، وتفيد في تصميم أنـظمة الاتصالات اللاسلكية في المملكة.