Statistics of one-minute rain rate distributions in India

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Conversion of hourly rain rate data to one-minute integration time is of immense importance. In this paper an attempt has been made to derive one-minute rain rate data from the hourly values obtained from India Meteorological Department for 11 stations over India.

1 Introduction
Rain causes severe degradation of radio signals having frequencies above 10 GHz owing to the attenuation and cross-polarization of signals. Therefore, quantitative understanding of rainfall statistics is very much necessary at regions where radio communication systems are to be established. Almost all of the attenuation prediction methods including the ITU-R method1 require one-minute rain rate values. The meteorological departments, all over the world, however, collect rain rate data at an hourly or longer integration time basis. So, conversion of hourly data to one-minute rain rate data is indispensable for the satellite communication system designers. Many efforts have been made by different groups1-6 working in the field to derive rain rate at shorter integration time. Global statistical models such as that of Crane2 and ITU-R model3 for predicting rain attenuation have divided the entire world into various zones depending upon the rain rate values. Both these models classify India into two regions which are not adequate to describe a vast region of varied climate like India.

One such attempt has been made by Sarkar et al.4 They have derived a power-law relating rain rate values at 15-min and 10-s integration times over New Delhi, India, collecting rain rate data, simultaneously, by using rain gauges having 10-s and 15-min integration times. Ajayi et al.5 have derived a power-law between the rain rate values at 10-s and 10-min integration times for Nigeria. In this paper, an attempt has been made to estimate cumulative time distribution of one-minute rainfall rate according to Karasawa et al.6

2 Data base
The basic data set for the present study is the five-year rain rate data at an hourly interval for Ahmedabad (23.03°N, 72.4°E, 55.0 m), Delhi (28.38°N, 77.12°E, 215.0 m), Calcutta (22.34°N, 88.24°E, 6.0 m), Trivandrum (8.29°N, 76.59°E, 25.0m), Madras (13.04°N, 80.17°E, 15.0 m), Bangalore (12.58°N, 77.38°E, 949.0m), Nagpur (21.09°N, 79.09°E, 453.0 m), Gangtok (27.20°N, 88.40°E, 3637.0 m), Jodhpur (28.18°N, 73.04°E, 368.0 m) and Allahabad (25.28°N, 81.54°E, 97 m). The last quantity in the parenthesis represents height of the station from the sea level. The details of hourly rain rate data for these stations are listed in Table 1. From the data supplied by India Meteorological Department it was not possible to attain the rain rate value at 0.001% of the time at stations except for those presented in Table 1. Frequency distribution has been calculated by analyzing the raw data set.

3 Software for the analysis of data
The first-stage data base storing the original rain rate data was obtained in magnetic disk and was transferred in a CPU (356 SX) (base memory size 640 KB, ext. memory size 1408 KB). The size of the data base is 8 MB. The entire handling and processing of the data base is done through dBASE. The following secondary data bases were also created for all locations.

(i) Total amount of rainfall for average year or month
(ii) Cumulative distribution of one-hour rain rate
(iii) Cumulative distribution of one-minute rain rate
Table I—Analysis of hourly rain rate data (mm/h)

<table>
<thead>
<tr>
<th>Location</th>
<th>Period</th>
<th>Percentage of time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.001</td>
</tr>
<tr>
<td>Calcutta</td>
<td>1984-1988</td>
<td>-</td>
</tr>
<tr>
<td>Allahabad</td>
<td>1983-1984</td>
<td>-</td>
</tr>
<tr>
<td>Allahabad</td>
<td>1986-1987</td>
<td>-</td>
</tr>
<tr>
<td>Ahmedabad</td>
<td>1985-1986</td>
<td>-</td>
</tr>
<tr>
<td>Jodhpur</td>
<td>1975-1979</td>
<td>-</td>
</tr>
<tr>
<td>Madras</td>
<td>1982-1986</td>
<td>80.0</td>
</tr>
<tr>
<td>Trivandrum</td>
<td>1988-1992</td>
<td>85.0</td>
</tr>
<tr>
<td>Bangalore</td>
<td>1988-1992</td>
<td>-</td>
</tr>
<tr>
<td>Cherrapunji</td>
<td>1971-1972</td>
<td>-</td>
</tr>
<tr>
<td>Nagpur</td>
<td>1984-1988</td>
<td>70.0</td>
</tr>
<tr>
<td>Gangtok</td>
<td>1983-1988</td>
<td>65.0</td>
</tr>
</tbody>
</table>

(iv) Maximum daily, monthly and yearly rain rate values
(v) Duration of the maximum rain rate value
(vi) Year-to-year variations of the above-mentioned annual statistics

4 Conversion method

The conversion method is due to Karasawa et al.

According to this method, $R_{0.01}$ for one-minute integration time has been calculated by using the formula

$$R_{0.01} = a R_{SH} + b R_{IOH}$$  \hspace{1cm} (1)

where, $R_{0.01}$ ($R_{SH}$) is the one-minute rain rate for 0.01 (0.1)% of each year, and $R_{SH}$ ($R_{IOH}$) is the mean of the largest five (ten) values [i.e., from highest to the fifth (tenth) value of the annual ranking]. Values of $a$ and $b$, according to Karasawa et al., are taken as 2.3 and 1.0, respectively.

The probability distribution is then obtained from Moufouma's distribution. The cumulative rain rate distribution, $P(R)$, in terms of $R_{0.01}$ and $R_{IOH}$ is given by,

$$P(R) = r/R \exp(-uR)\times 100$$

where,

$$u = \frac{1}{10} (R_{SH} - R_{0.01}) \ln \frac{10^4 R_{0.01}}{R_{SH}}$$

$$r = 10^{-4} R_{0.01} \exp(R_{0.01}u)$$  \hspace{1cm} (2)

Predicted one-minute statistics can be calculated by the following steps.

(i) Calculate $R_{SH}$ and $R_{IOH}$ of each year.
(ii) Calculate the mean values of $R_{SH}$ and $R_{IOH}$
(iii) Determine $R_{0.01}$ and $R_{IOH}$ from Eq. (1).

(iv) Calculate cumulative time distribution using Eq. (2).

5 Results of the analysis

Figure 1 shows the cumulative distribution of rain rate with one-minute integration time derived from the method of Karasawa et al. over Madras, Allahabad, Gangtok, Cherrapunji, Bangalore, Jodhpur, Calcutta, Trivandrum, Nagpur, Ahmedabad and Delhi. Figure 1 also shows that Cherrapunji mostly faces the highest rain rate, whereas Allahabad records the minimum rainfall.

5.1 Attenuation calculations

The rain rate values obtained by the above method are used to calculate the cumulative distribution of attenuation for Delhi using the following steps of ITU-R method.

Step 1: The specific attenuation $\gamma_R$ is calculated using the formula

$$\gamma_R = a R_b$$  \hspace{1cm} (3)

where, $\gamma_R$ is the specific attenuation, $R$ the rain rate with one-minute integration time and $a$ and $b$ the regression coefficients which depend on the frequency. The values of $a$ and $b$ are given by Nowland et al.

Step 2: The total attenuation is obtained using ITU-R model. Rain attenuation ($A_{0.01}$) for 0.01% of time is given by

$$A_{0.01} = \gamma_R L_S R_{0.01}$$  \hspace{1cm} (4)
where, $L_S$ is the slant path length and $r_{0.01}$ the path reduction factor for 0.01% of time. The slant path length is given by

$$L_S = \frac{(h_R - h_S)}{\sin \theta} \quad \text{... (5)}$$

where, $h_R$ the rain height, $h_S$ the height of earth station from the sea level and $\theta$ the elevation angle.

The parameter $h_R$ is given by

$$h_R = 3.0 + 0.028 \phi, \quad 0 \leq \phi < 36^\circ$$

$$= 4.0 - 0.075 (\phi - 36), \quad \phi \geq 36^\circ \quad \text{... (6)}$$

and $r_{0.01}$ is given by

$$r_{0.01} = \frac{1}{1 + \left(\frac{L_c}{L_o}\right)} \quad \text{... (7)}$$

where,

$$L_o = 35 \exp \left(-0.015 R_{0.01}\right) \quad \text{... (8)}$$

The horizontal projection, $L_c$, of the slant path length is given by

$$L_c = L_S \cos \theta \quad \text{km} \quad \text{... (9)}$$

Step 3: The attenuation at other percentages of time $P$ is obtained using the following equation

$$A_p/A_{0.01} = 0.12 P^{(-0.546-0.043 \log P)} \quad \text{... (10)}$$

The latitude of Delhi is 28.38°N. A frequency of
11 GHz and $\theta = 90^\circ$ is used in the calculation. The attenuation values obtained by using the Karasawa et al.\textsuperscript{6} model for prediction of one-minute rain rate statistics are compared with the measurements by Raina and Uppal\textsuperscript{10} in Fig.2. Figure 2 shows that the theoretical values of rain attenuation are in excellent agreement with the measured ones. For example, at 11 GHz and at $90^\circ$ elevation the attenuation values as calculated by us are 9.96 dB, 3.784 dB and 1.19 dB, respectively, at 0.01 %, 0.1 % and 1.0 % of time, whereas the same measured by Raina and Uppal\textsuperscript{10} are 9 dB, 4.5 dB and 1.25 dB, respectively. This shows that the model of Karasawa et al.\textsuperscript{6} is suitable for Delhi. This model is likely to be suitable for other Indian stations also. This can be tested for other Indian stations provided measured data are available at these stations. The model of Karasawa et al.\textsuperscript{6} has shown excellent result for Japanese climate. For a direct verification of the applicability of Karasawa et al.\textsuperscript{6} model in India, it is very much necessary to calculate the exact values of $a$ and $b$ of the model for this region. For this, a network of rain gauges with one-minute integration time is required to be established throughout India. However, in the present study the values $a = 2.3$, and $b = 1.0$ have been used as recommended by Karasawa in one of his personal correspondence with us.

6 Conclusions

In this paper one-minute rain rate distributions have been obtained for some stations in India using the conversion method of Karasawa et al.\textsuperscript{6}. The rain attenuation values derived from the rain rate values so obtained compare well with the measurements conducted over Delhi. It is believed that the theoretical rain attenuation values may match with the experimental ones for other Indian stations also. For a direct testing of the applicability of Karasawa et al.'s model\textsuperscript{6}, a number of rain gauges have to be installed throughout India.

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References