Dependence of Rain-Rate Distribution on Rain-Gauge Integration Time

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An important problem in designing terrestrial and earth-satellite radio systems at frequencies above 10 GHz is the radio outage caused by rain attenuation. Since rain-rate statistics vary significantly from year to year, long-term rain-rate distributions are needed in radio path engineering to meet a given reliability objective. This paper and Ref. 2 together describe a method and the necessary data sources to obtain 20-year distributions of 5-min rain rates at about 250 locations in the U. S. A.

In this paper, a "5-min rain rate" corresponds to the average value of the randomly varying rain rate in a 5-min interval and is calculated as $\Delta H/T$, where ΔH is the 5-min accumulated depth of rainfall and $T = 5$ min $= 1/12$ h is the rain-gauge integration time. Similarly, a "T-min rain rate" is the average rain rate in a T-min interval.

The "excessive short duration rainfall data" for about 250 locations in the U. S. A., published by the National Climatic Center,[1] records details of those rainfalls which exceed a threshold which is a function of rain-gauge integration time T as shown in Table I. For example, the thresholds are 76 and 20 mm/h for $T = 5$ and 60 min, respectively. A method for obtaining 5-min rain-rate distributions from these long-term ($\geqq$ 20 years) data is described in a companion paper.[2]

A straightforward extension of this method allows us to obtain rain-rate distributions appropriate to other integration times, such as 10, 15, 30, and 60 min. Figure 1 shows 20-year distributions with various integration time in the New York metropolitan area. The distributions for the New York metropolitan area represent an average of those obtained from LaGuardia Airport, Central Park, and Newark Airport.

The thresholds noted in Table I, however, indicate that the rain-rate distributions processed from these data are accurate only in the range above the thresholds. The 5-min rain-rate distribution above 76 mm/h is generally sufficient for engineering terrestrial radio paths at frequencies above 10 GHz in the eastern or midwestern U. S. A. For engineering long terrestrial paths in the western U. S. A. or for millimeter-wave satellite radio links, distributions for rain rates less than 76 mm/h are needed. Fortunately, the long-term hourly precipitation data published by The National Climatic Center[3,4] contain all rainfalls. As a result, the low-rain-rate portion of the 5-min rain-rate distribution

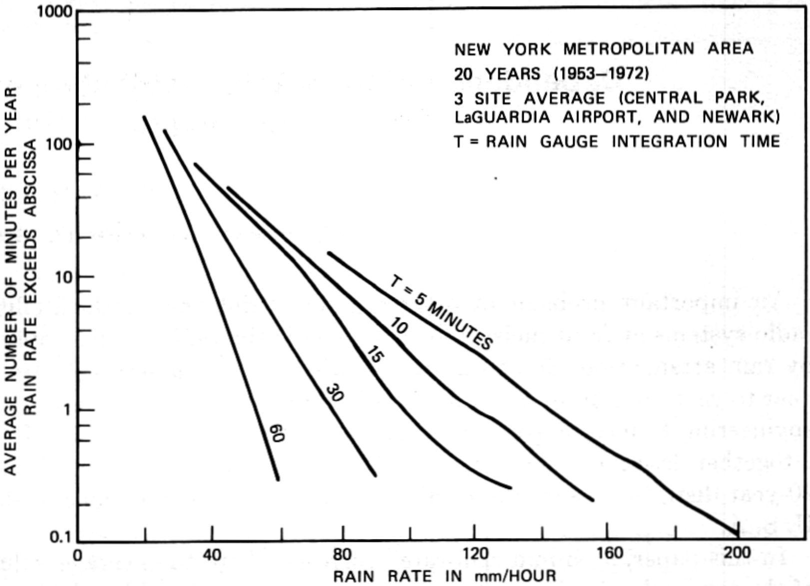

Fig. 1—20-year distributions of rain rates in the New York metropolitan area.

can be estimated by applying an empirical conversion factor, which we now derive, to the hourly rain-rate distribution.

From Fig. 1, we obtain the relationship between 5-min rain rate and 60-min rain rate at several probability levels. This is displayed in Fig. 2.

Table I — Thresholds of excessive short duration rainfalls

Duration T (min)	Minimum Depth of Recorded Rainfall (in.)	Threshold (T-Minute Average-Rain Rate, mm/hr)
5	0.25	76.2
10	0.30	45.7
15	0.35	35.6
20	0.40	30.5
30	0.50	25.4
45	0.65	22.0
60	0.80	20.3
80	1.00	19.1
100	1.20	18.3
120	1.40	17.8
150	1.70	17.3
180	2.00	16.9

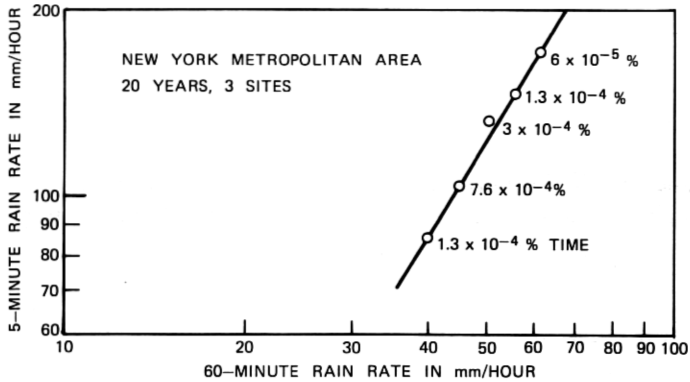

Fig. 2—Relationship between 5-min rain rate and 60-min rain rate at the same probability level in the New York metropolitan area.

Additional results from Miami, Florida and McGill Observatory, Canada,[5] shown in Fig. 3, indicate that this relationship varies significantly with geographic location. However, such geographic variations are removed if the rain rates of Fig. 3 are normalized with respect to

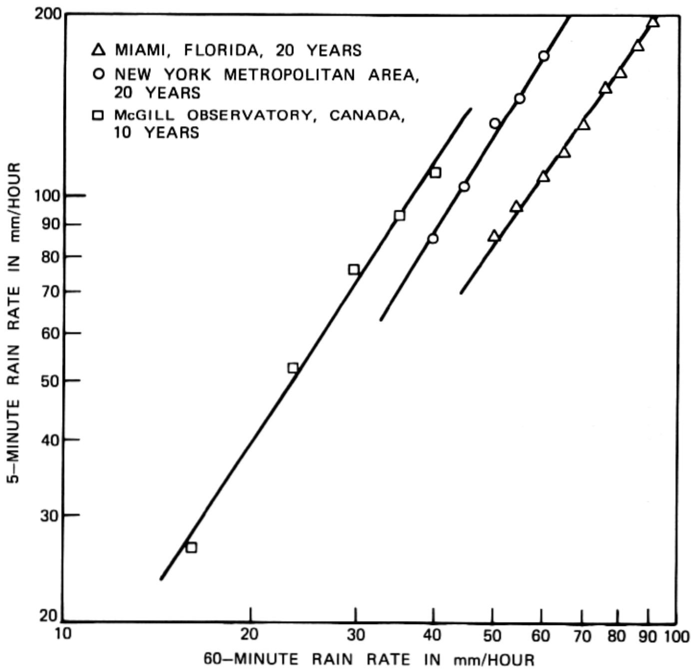

Fig. 3—Relationships between 5-min rain rate and 60-min rain rate at the same probability level in New York, Miami, and McGill Observatory.

a geographic-dependent, characteristic rain rate R_c. Let us define a dimensionless variable,

$$X(T) = \frac{R(T)}{R_c}, \tag{1}$$

as a measure of the normalized rain rate $R(T)$. Since the purpose of introducing R_c is to remove the geographic variable factor in the relationships in Fig. 3, R_c must be geographically dependent. A reasonable choice for R_c is the average 60-min rain rate $\bar{R}(60)$. For Miami, the New York metropolitan area, and McGill Observatory, $\bar{R}(60)$ is 3.6, 1.7, and 1.1 mm/h, respectively. Figure 4, which incorporates this normalization, indicates that the long-term relationship between $X(5)$ and $X(60)$ is almost the same for Miami, the New York metropolitan area, and McGill Observatory. Figure 5 shows similar results for $T = 10$ and 30 min. These relationships can be approximately described by

$$X(T) \simeq a(T) \cdot [X(60)]^{\eta(T)}, \tag{2}$$

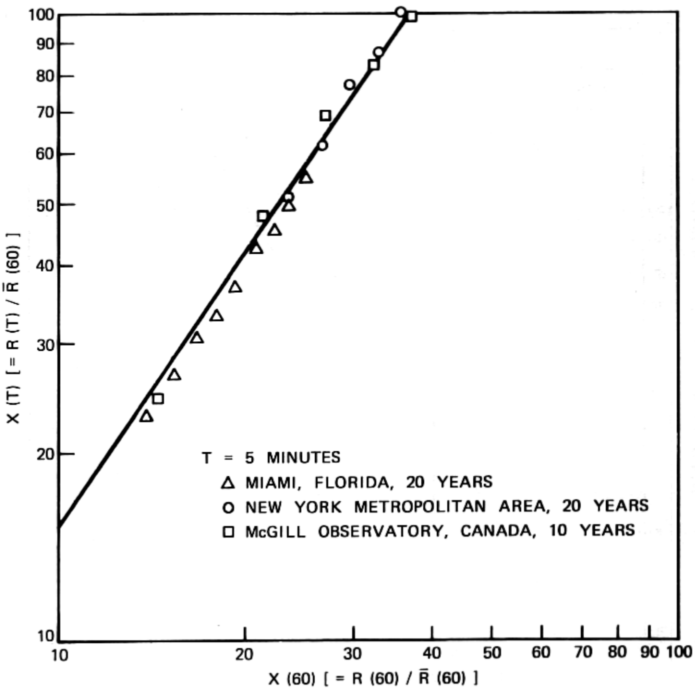

Fig. 4—Relationship between normalized 5-min rain rate and normalized 60-min rain rate at the same probability level.

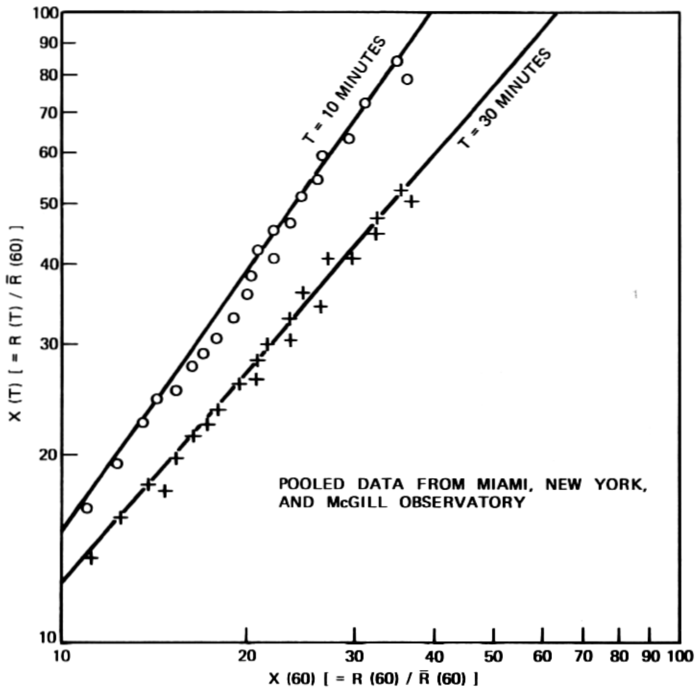

Fig. 5—Relationships among normalized 10-min, 30-min, and 60-min rain rates at the same probability level.

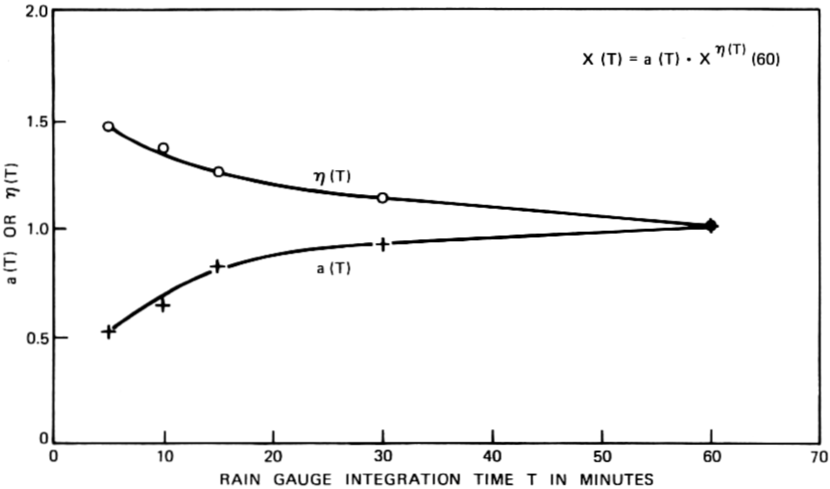

Fig. 6—Empirical dependence of normalized rain rate on rain-gauge integration time T at a given probability level.

where the coefficient $a(T)$ and the exponent $\eta(T)$, as functions of integration time T, are plotted in Fig. 6. We note that the relationships in Figs. 4 through 6 hold only in the long term (e.g., 20 years). The short-term (e.g., <5 years) results can deviate significantly from the long-term average relationship.

The moderate region (30 mm/h $\leqq R \leqq$ 76 mm/h) of the 5-min rain-rate distribution can be estimated by applying the empirical conversion factor to the 60-min rain-rate distribution whose threshold is 20 mm/h in the excessive short-duration rainfall data. Furthermore, long-term hourly precipitation data are available for about 3000 locations[3,4] in the U. S. A. The National Climatic Center has processed some of these raw data to obtain 10-yr (1951–1960) distributions of hourly precipitations at 105 locations.[4] Therefore, we have a procedure and the necessary data sources to obtain long-term distributions of 5-min rain rate covering the entire range of interest to the design of both terrestrial and earth-satellite radio systems. For example, Fig. 7 shows

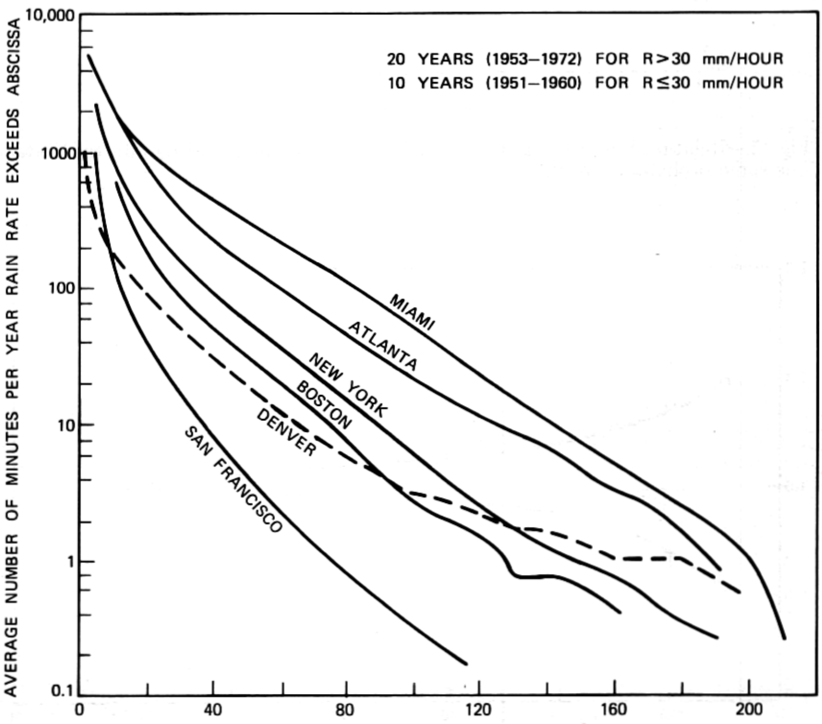

Fig. 7—Long-term distributions of 5-min rain rates in Miami, Atlanta, New York, Boston, Denver, and San Francisco.

the 5-min rain-rate distributions obtained by this method for Miami, Atlanta, New York, Denver, Boston, and San Francisco.

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