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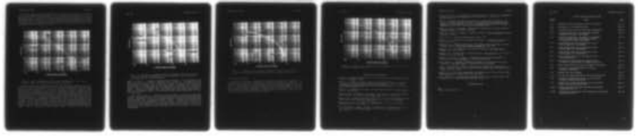

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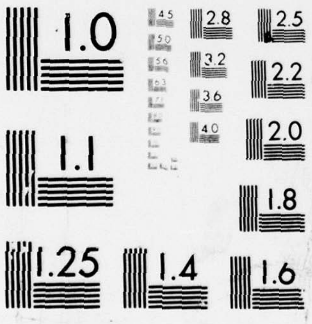

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A TECHNIQUE FOR ESTIMATING CLOCK TWO-HOURLY PRECIPITATION RATE DISTRIBUTIONS

by

Daniel J. McMorrow, Capt, USAF
7th Weather Wing
Scott AFB, IL 62225

MAY 1978

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Clock two-hourly precipitation rate distributions can be derived from distributions of clock-hourly precipitation rate distribution by using negative exponential functions. The analytical conversions are provided for 16 climatic regimes in the continental United States and Alaska. The clock-hourly and two-hourly precipitation rate distributions are also compared with instantaneous distributions measured over horizontal paths.

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Pocatello, ID
Denver, CO
Los Angeles, CA
Fresno, CA
San Francisco, CA
Boston, MA

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A TECHNIQUE FOR ESTIMATING CLOCK TWO-HOURLY PRECIPITATION RATE DISTRIBUTIONS

INTRODUCTION

Precipitation (particularly rainfall) is one of the most significant attenuators of microwave transmissions. This statement is especially true in the lower frequencies (1-20 GHz) which are routinely used for communications. Many investigators, such as Busey (1950), Medhurst (1965), Setzer (1970), Chu and Hogg (1968), and Benoit (1968), have studied this problem and published estimates of rainfall attenuation. Most of this research has dealt with attenuation over relatively short paths, less than 20 km.

Although many communication links consist of relatively short paths, there are also many applications where signals must be transmitted over long paths (50 to 100 km) through rain. Air-to-air, or air-to-ground transmissions over these distances are quite common. This paper presents a technique for estimating rainfall distributions over long path lengths.

BACKGROUND

Bussey (1950) published an interesting article that described a method for estimating mean rainfall rate distributions along lines of varying lengths. Using maps of half-hourly rainfall depths from a synchronized network of rain gauges near Mt. Vernon, Ohio, Bussey hypothesized that the mean clock-hourly rainfall rate distribution* is similar to the mean instantaneous rainfall rate distribution along a 50-km line. He further hypothesized that the mean one-minute rate distribution and the mean clock two-hourly rate distribution would be similar to the mean instantaneous rainfall rate distributions over 1-km and 100-km paths. Bussey did not have sufficient data to prove the universality of his time-space transform, but he did present an argument on the dynamics of storm cell movements that made his ideas seem very plausible.

Throughout the 1960's most of the work in precipitation research involved measurements of point distributions over varying time intervals; for example, Cole et al., (1965) and Briggs (1968). Some researchers, such as Briggs and Harker (1969), Lenhardt (1974), and Winner (1968), suggested ways of deriving synthetic instantaneous distributions (one-minute distributions) from clock-hour distributions.

Measurements of rainfall amounts along lines or within areas began in the late 1960's. Researchers at the Bell Telephone Laboratories (Semplak and Keller, 1969; Freeny and Semplac, 1969) working with data from a network near Holmdel, New Jersey were one the first groups to make this type of measurements. Other networks were set up in England, Italy (Fedi, 1972), Germany (Brever, 1973), and other locations in the United States. The Illinois State Water Survey conducted several rainfall rate studies with data from a rain gauge array in central Illinois, near Urbana. Sims and Jones (1977), using data from this network, have published estimates of the mean instantaneous rainfall rate distribution along lines as long as 62.2 km. Interestingly, no researcher has tried to experimentally verify Bussey's transform from the clock two-hourly rainfall rate distribution at a point to the mean instantaneous distribution along a 100-km line, Jones (1977).

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* A clock-hour rainfall rate is the amount of rain that falls in a clock-hour divided by 1 hour.

METHOD

One method of estimating the rainfall attenuation over long paths utilizes the clock-hourly rainfall rate distribution. The National Weather Service routinely records rainfall amounts over a one-hour period at many locations and these data are stored on magnetic tape at the National Meteorological Climatic Center (and USAFETAC OL-A) at Asheville, North Carolina. Table 1 illustrates two annual clock-hour rate distributions, in cumulative form, for Washington, DC and Key West, Florida. These data may also be summarized over a clock two-hour period resulting in a mean annual clock two-hourly distribution for a point (see Table 2). A comparison of Tables 1 and 2 reveals some interesting relationships. As expected, high rainfall rates occur more often at Key West, Florida than at Washington, DC. Also note that for each station the distributions cross over at approximately 2.5 mm/hr. The clock-hourly distribution has more hours of high rainfall rates than the clock two-hourly distribution, and the clock two-hourly distribution has more hours of low rainfall rates than the clock-hourly distribution. This "cross over" is consistent with the relationships found between the clock-hourly distributions and the one-minute distributions.

Table 1. Cumulative Mean Annual Clock-Hourly Distribution of the Number of Hours a Specified Rainfall Rate is Equaled or Exceeded.

Rate (mm/hr)	Washington, DC (No. of Hrs)	Key West, FL (No. of Hrs)
0.13	650.0	-----
0.25	570.0	335.0
1.3	230.0	160.0
2.5	105.0	110.0
7.6	22.0	40.0
12.7	8.0	19.0
17.8	3.6	10.0
25.4	1.4	5.0
50.8	0.09	0.48

Table 2. Cumulative Mean Annual Clock Two-Hourly Distribution of the Number of Hours a Specified Rainfall Rate is Equaled or Exceeded.

Rate (mm/hr)	Washington, DC (No. of Hrs)	Key West, FL (No. of Hrs)
0.13	740.0	506.0
0.25	620.0	401.0
1.3	240.0	195.0
2.5	105.0	120.0
7.6	20.0	35.0
12.7	5.0	13.2
17.8	1.8	6.0
25.4	0.47	2.0
50.8	0.02	---

After examining Tables 1 and 2 one might suspect that an analytical function might exist to convert the clock-hourly distribution to the clock two-hourly distribution, or vice versa.

Winner (1968) proposed a similar idea for converting the clock-hourly distribution into a one-minute distribution for locations in the midlatitudes. He suggested a graphical technique to do the conversion. Winner's model was based upon data from one location (Washington, DC) and he described the reliability of his graph as "questionable."

Reliability aside for the moment, Winner's graph can be approximated with an exponential curve fit

$$y = ae^{bx}, \; x > 0 \qquad (1)$$

where

y = multiplication factor to convert the number of hours of a clock-hourly rate distribution to the number of hours of a one-minute rate distribution.

x = rainfall rate (mm/hr)

a, b = coefficients

The results of this analysis, and a similar test for Miami, Florida data appear in Table 3. The data were also fitted to a power law function

$$y = ax^{b}, \; x > 0 \qquad (2)$$

and these results appear in Table 3.

Based upon the "good fits" of the exponential function (a Chi-Square Test was used to check the fit reliability), it seems logical to suppose that the mirror image of this function, an exponential function with a negative exponent

$$y = ae^{-bx}, \; x > 0 \qquad (3)$$

could be used to estimate the mean clock two-hourly distribution from the clock-hourly distribution. Data for Washington, DC and Key West, Florida (Tables 1 and 2) were used to test this hypothesis. The results appear in Table 4. Once again the correlation coefficients were high for both stations and the inverse exponential fit left very little unexplained variation. A Chi-Square Test revealed a reliable data fit at the 98 percent confidence level.

Table 3. Conversion of a Clock-Hourly Rainfall Rate Distribution to a One-Minute Rainfall Rate Distribution.

Washington, DC	Miami, FL
$y = 0.81\,x^{0.54}$	$y = 0.229\,x^{0.63}$
Corr Coeff = 0.868	Corr Coeff = 0.915
$y = 0.83e^{0.060x}$	$y = 0.39e^{0.059x}$
Corr Coeff = 0.997	Corr Coeff = 0.989

x = Rainfall rate (mm/hr).
y = Multiplication factor used to convert the number of hours of the clock-hourly distribution to the number of hours of the one-minute distribution.

Table 4. Conversion of a Clock-Hourly Rainfall Rate Distribution to a Clock Two-Hourly Rainfall Rate Distribution.

Washington, DC	Key West, FL
$y = 1.07e^{-0.036x}$	$y = 1.29e^{-0.048x}$
Corr Coeff = 0.980	Corr Coeff = 0.991

x = Rainfall rate (mm/hr).
y = Multiplication factor used to convert the number of hours of the clock-hourly distribution to the number of hours of the clock two-hourly distribution.

Based upon these preliminary results, the hypothesis was formulated that a negative exponential relationship between the clock-hourly and clock two-hourly distributions was valid for other locations. In an attempt to verify this hypothesis, 14 stations throughout the United States were selected as a test. These stations were not selected at random; each was chosen because it represented a different climatic regime. The annual clock-hourly and clock two-hourly rainfall rate distributions were summarized and the procedure described above was used to fit the data. The results are summarized in Table 5.

Table 5. Comparison of the Sample Annual Clock Two-Hour Precipitation Rate Distribution with the Estimated Annual Clock Two-Hour Rate Distribution.

Rate (x = mm/hr) (Equal to or Greater Than)	Clock 2-Hour (No. of Hrs)	Clock Hours (No. of Hrs)	Sample y Multiplier (y)	Rate (x) (mm/hr)	Estimated y Multiplier (y)	Estimated Clock 2-Hour (No. of Hours)
1) Location: New Orleans, LA				$y = ae^{bx}$ $y = 1.34e^{-0.046x}$		Corr coeff = 0.999 Chi Square = 1.02
50.8	0.1	0.8	0.13	50.8	0.13	0.10
25.4	2.2	5.7	0.39	25.4	0.41	2.36
12.7	18.7	25.0	0.75	12.7	0.75	18.63
6.35	64.8	61.7	1.05	6.35	1.00	61.70
3.175	138.2	120.0	1.15	3.175	1.16	139.09
1.727	224.5	175.0	1.28	1.727	1.24	216.93
0.635	376.1	300.0	1.25	0.635	1.30	391.20
2) Location: Anchorage, AK				$y = ae^{bx}$ $y = 0.96e^{-0.166x}$		Corr coeff = 0.954 Chi Square = 0.59
50.8						
25.4						
12.7						
6.35		0.1				
3.175	3.0	5.5	0.55	3.175	0.57	3.13
1.727	29.5	38.0	0.78	1.727	0.72	27.47
0.635	190.1	230.0	0.83	0.635	0.87	199.36
3) Location: Nashville, TN				$y = ae^{bx}$ $y = 1.20e^{-0.051x}$		Corr coeff = 0.991 Chi Square = 1.89
50.8		0.10				
25.4	0.55	1.60	0.34	25.4	0.32	0.51
12.7	5.45	9.70	0.56	12.7	0.62	6.03
6.35	34.05	41.1	0.83	6.35	0.86	35.52
3.175	111.8	109.0	1.15	3.175	1.02	111.07
1.727	230.1	195.0	1.18	1.727	1.10	214.20
0.635	431.5	370.0	1.17	0.635	1.16	430.14
4) Location: Seattle, WA				$y = ae^{bx}$ $y = 1.20e^{-1.26x}$		Corr coeff = 0.988 Chi Square = 0.51
50.8						
25.4						
12.7		0.2				
6.35	0.85	1.6	0.53	6.35	0.54	0.86
3.175	25.4	30.0	0.85	3.175	0.80	24.07
1.727	132.6	145.0	0.91	1.727	0.96	139.61
0.635	448.1	400.0	1.12	0.635	1.10	441.93

Table 5. Comparison of the Sample Annual Clock Two-Hour Precipitation Rate Distribution with the Estimated Annual Clock Two-Hour Rate Distribution. (Cont'd)

Rate (x = mm/hr) (Equal to or Greater Than)	Clock 2-Hour (No. of Hrs)	Clock Hours (No. of Hrs)	Sample y Multiplier (y)	Rate (x) (mm/hr)	Estimated y Multiplier (y)	Estimated Clock 2-Hour (No. of Hours)
5) Location: Watertown, NY				$y = ae^{bx}$ $y = 1.11e^{-.040x}$		Corr coeff = 0.956 Chi Square = 0.66
50.8	0.04					
25.4	0.11	0.3	0.37	25.4	0.40	0.12
12.7	1.65	2.7	0.83	12.7	0.67	1.80
6.35	9.10	11.7	0.78	6.35	0.86	10.09
3.175	40.7	44.0	0.93	3.175	0.98	43.13
1.727	118.5	110.0	1.08	1.727	1.04	114.29
0.635	348.6	330.0	1.06	0.635	1.09	358.29
6) Location: Albuquerque, NM				$y = ae^{bx}$ $y = 0.90e^{-0.023x}$		Corr coeff = 0.518 Chi Square = 6.87
50.8						
25.4	0.07	0.1	0.70	25.4	0.50	0.05
12.7	0.25	0.7	0.36	12.7	0.67	0.47
6.35	2.5	3.9	0.64	6.35	0.78	3.03
3.175	10.5	12.5	0.84	3.175	0.84	10.45
1.727	31.5	29.0	1.09	1.727	0.86	25.07
0.635	87.8	78.0	1.13	0.635	0.89	69.17
7) Location: Las Vegas, NV				$y = ae^{bx}$ $y = 0.937e^{-0.66x}$		Corr coeff = 0.920 Chi Square = 3.27
50.8						
25.4	0.04	0.2	0.20	25.4	0.18	0.04
12.7	0.23	0.6	0.38	12.7	0.41	0.24
6.35	0.80	2.0	0.40	6.35	0.62	1.23
3.175	3.75	5.6	0.67	3.175	0.76	4.26
1.727	15.30	13.7	1.12	1.727	0.84	11.46
0.635	44.95	41.0	1.10	0.635	0.90	36.87
8) Location: Des Moines, IA				$y = ae^{bx}$ $y = 1.20e^{-0.053x}$		Corr coeff = 0.991 Chi Square = 3.63
50.8						
25.4	0.37	1.2	0.31	25.4	0.31	0.37
12.7	4.0	7.0	0.57	12.7	0.61	4.25
6.35	18.6	20.5	0.91	6.35	0.85	17.46
3.175	60.1	56.0	1.07	3.175	1.01	56.51
1.727	129.8	115.0	1.13	1.727	1.09	125.39
0.635	280.7	270.0	1.04	0.635	1.16	312.10
9) Location: Pocatello, ID				$y = ae^{bx}$ $y = 1.57e^{-0.178x}$		Corr coeff = 0.95 Chi Square = 4.89
50.8						
25.4						
12.7						
6.35	0.48	1.00	0.48	6.35	0.51	0.51
3.175	6.26	6.75	0.93	3.175	0.89	6.02
1.727	31.7	23.0	1.38	1.727	1.16	26.59
0.635	143.0	120.0	1.19	0.635	1.41	168.63

Table 5. Comparison of the Sample Annual Clock Two-Hour Precipitation Rate Distribution with the Estimated Annual Clock Two-Hour Rate Distribution. (Cont'd)

Rate (x = mm/hr) (Equal to or Greater Than)	Clock 2-Hour (No. of Hrs)	Clock Hours (No. of Hrs)	Sample y Multiplier (y)	Rate (x) (mm/hr)	Estimated y Multiplier (y)	Estimated Clock 2-Hour (No. of Hours)
10) Location: Denver, CO				$y = ae^{bx}$ $y = 1.19e^{-0.082x}$		Corr coeff = 0.961 Chi Square = 4.65
50.8						
25.4	0.035	0.3	0.12	25.4	0.15	0.04
12.7	1.1	1.8	0.61	12.7	0.42	0.75
6.35	5.0	6.2	0.81	6.35	0.70	4.36
3.175	20.1	24.5	0.82	3.175	0.91	22.38
1.727	60.3	62.0	0.97	1.727	1.03	63.80
0.635	179.5	185.0	0.97	0.635	1.13	208.26
11) Location: Los Angeles, CA				$y = ae^{bx}$ $y = 1.03e^{-0.070x}$		Corr coeff = 0.946 Chi Square = 0.67
50.8						
25.4		0.1				
12.7	0.51	1.1	0.46	12.7	0.42	0.47
6.35	5.7	10.6	0.54	6.35	0.66	6.98
3.175	21.8	26.4	0.83	3.175	0.82	21.70
1.727	49.2	49.5	0.99	1.727	0.91	45.0
0.635	102.1	102.0	1.0	0.635	0.98	100.07
12) Location: Fresno, CA				$y = ae^{bx}$ $y = 0.88e^{-1.94x}$		Corr coeff = 0.837 Chi Square = 4.65
50.8						
25.4						
12.7	0.04	0.1	0.400	12.7	0.33	0.03
6.35	1.1	2.9	0.38	6.35	0.54	1.57
3.175	12.4	20.9	0.59	3.175	0.69	14.41
1.727	47.6	52.0	0.92	1.727	0.77	40.05
0.635	126.3	130.0	0.97	0.635	0.84	108.85
13) Location: San Francisco, CA				$y = ae^{bx}$ $y = 1.28e^{-2.67x}$		Corr coeff = 0.982 Chi Square = 3.93
50.8						
25.4						
12.7	0.18	0.5	0.36	12.7	0.34	0.17
6.35	5.05	8.6	0.59	6.35	0.66	5.65
3.175	34.8	40.0	0.87	3.175	0.92	36.72
1.727	92.9	90.0	1.03	1.727	1.07	96.21
0.635	214.5	157.0	1.37	0.635	1.20	188.28
14) Location: Boston, MA				$y = ae^{bx}$ $y = 1.07e^{-0.085x}$		Corr coeff = 0.996 Chi Square = 2.17
50.8						
25.4	0.18	1.5	0.12	25.4	0.12	0.19
12.7	2.40	6.0	0.40	12.7	0.36	2.18
6.35	18.45	31.7	0.58	6.35	0.62	19.77
3.175	87.5	113.0	0.77	3.175	0.82	92.35
1.727	216.6	215.0	1.01	1.727	0.92	198.74
0.635	466.9	470.0	0.99	0.635	1.01	476.77

With the exception of Albuquerque, New Mexico, all stations showed high correlations (coefficients greater than +0.75). The Albuquerque data showed an unusually low number of hours for the 25.4 mm/hr category in the clock-hour sample. This resulted in an anomalously high sample y multiplier and a poor fit. The sample distributions were not taken from simultaneous periods. The clock-hourly distribution came from a 10-year period of record while the clock two-hourly distributions came from periods of varying lengths, some as long as 28 years (see Table 6). Although sampling from different periods of time is not normally a problem when one samples climatological distributions, it can cause problems when comparing the extremes of the distributions. The Chi-Square Test was again used to check the data fit. The fit for all locations was satisfactory at the 98% confidence level. The variability of the relationship is obvious when one examines the coefficients of the negative exponential function. No two locations have the same coefficients. This is to be expected since no two locations have exactly the same rainfall rate distributions.

Table 6. Period of Record (POR) and Ratio of the Explained Variation to the Total Variation.

	Sample POR		
Station	Clock Hour (yr)	Clock 2-Hour (yr)	Explained Variation/ Total Variation
New Orleans, LA	10	22.0	1.00
Anchorage, AK	10	11.9	0.91
Nashville, TN	10	27.3	0.98
Seattle, WA	10	14.2	0.98
Watertown, NY	10	27.7	0.91
Albuquerque, NM	10	28.3	0.27
Las Vegas, NV	10	26.8	0.85
Des Moines, IA	10	27.4	0.98
Pocatello, ID	10	27.5	0.90
Denver, CO	10	27.4	0.93
Los Angeles, CA	10	27.5	0.89
Fresno, CA	10	27.5	0.70
San Francisco, CA	10	27.5	0.96
Boston, MA	10	27.7	0.99

APPLICATIONS

One application of the inverse exponential conversion of a clock-hourly distribution to a clock two-hourly distribution is apparent. Since clock-hourly data is readily available, clock two-hourly rate distributions can be computed for other stations by using the appropriate model relationship. It may not be best to select the geographically closest model station (Table 5) because rainfall rate distributions are not as homogeneous as other meteorological parameters. A comparison of the clock-hourly distributions for both stations may be a better method of deciding upon the best conversion equation to use.

Perhaps the most practical application of a point rainfall distribution, as Bussey (1950) suggested, lies in translating it into an instantaneous rainfall rate distribution along a line.

The next logical question is "How long a line?" Recall that Bussey (1950) believed that a clock two-hourly distribution at a point could be used to infer the instantaneous distribution along a 100-km line. Ideally, simultaneous rate distributions along a 100-km line and clock two-hourly data at the line midpoint would be required to verify this idea. Unfortunately, this type of data is not available, Jones (1977).

Sims and Jones (1973) have published mean rate data along lines of 23.9 km and 62.2 km near Urbana, Illinois (Figure 1). The data were recorded over a 125-day period from 1 April to 6 August 1970. This period is the rainy season in Illinois. Note that plots in Figure 1 are unconditional and they are consistent with similar measurements over shorter paths for other locations (Byers and Braham, 1949; Freeny and Gabbe, 1969). As with the cumulative point distributions that rotate clockwise as the time interval decreases, the cumulative line rate distributions also rotate clockwise as the line interval decreases.

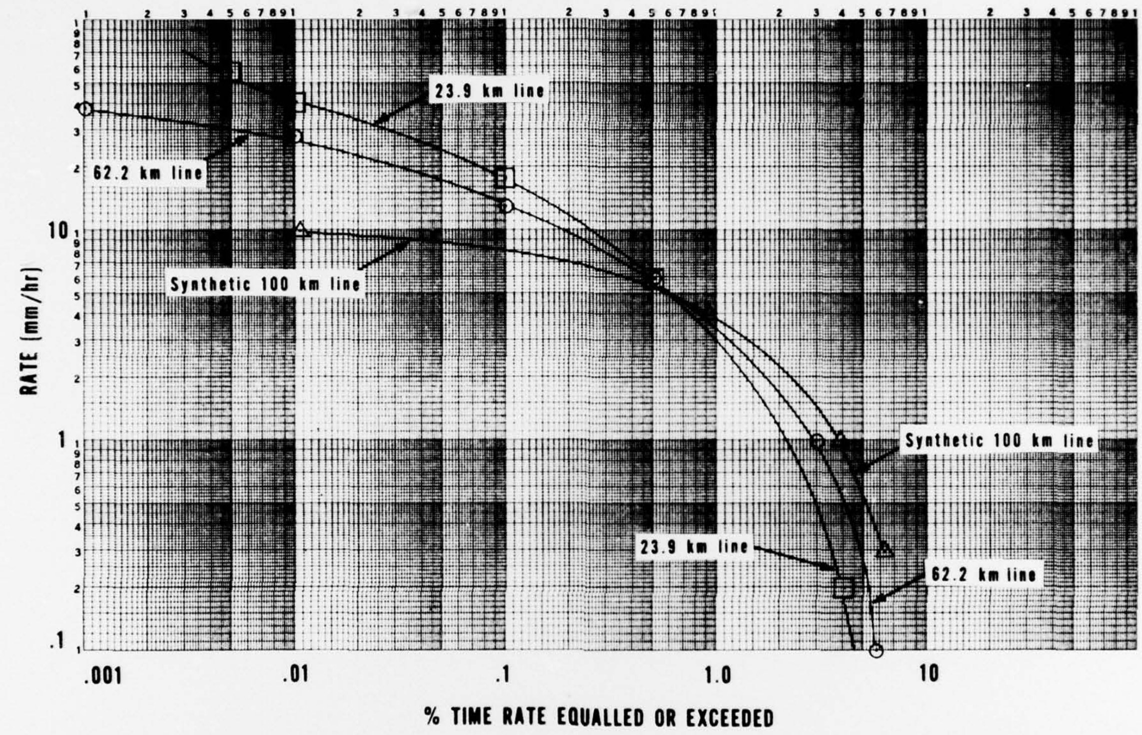

Figure 1. Mean Instantaneous Rainfall Rate Distributions Over Lines of Different Lengths at Urbana, Illinois (Spring and Summer).

If one assumes that the difference between the two Illinois lines can be interpolated at a constant rate of change, one can develop synthetic cumulative distributions for various path lengths. This logic was used to estimate a cumulative rate distribution for a 100-km line, (Figure 1). Figure 2 compares the synthetic 100-km line with the clock-hourly (CHR) and clock two-hourly (C 2HR) distributions for Urbana, Illinois from March through August. Although the sampling periods were not the same (both clock-hourly and clock two-hourly distributions were from a 10-year period 1965-1974), if we assume 1970 was a typical season, some conclusions can be drawn from Figure 2. If Bussey's hypotheses were valid, the clock two-hourly distribution and the mean instantaneous distribution over a 100-km line should be nearly equal. This is not the case. A plot of the clock two-hourly distribution with 62.2-km line distribution (not shown) reveals that these two distributions are very similar. By an iteration process one can estimate the instantaneous distribution along a path that best approximates the point clock two-hourly distribution for Urbana, Illinois during the spring/summer season. The results of this analysis

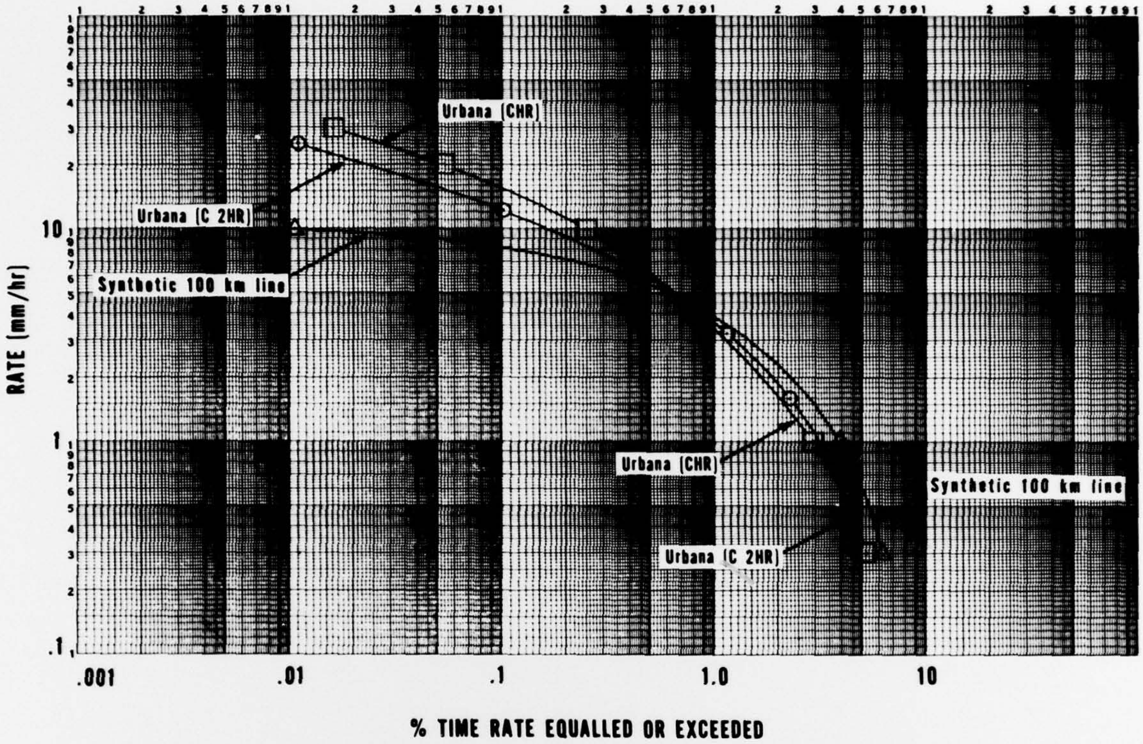

Figure 2. Comparison of Synthetic Mean Instantaneous Distribution for a 100-km Path and the Clock-Hourly and Clock Two-Hourly Point Distributions for Urbana, Illinois (Spring and Summer).

appear in Figure 3. A similar iteration was performed for the clock-hourly rate distribution and it is plotted in cumulative form in Figure 4. It appears that the clock two-hourly rainfall rate distribution at a point can be approximated by mean instantaneous distribution over a 65-km path length. Similarly, the clock-hourly distribution can be approximated by the instantaneous distribution over a 35-km path length. These line distances are considerably less than previously assumed by Bussey. According to Bussey (1950), the clock-hourly distribution approximates a 50-km path distribution and the clock two-hourly distribution approximates a 100-km path distribution.

These results cannot be considered conclusive proof of a different space/time rainfall rate transform, but they do raise some questions about some accepted (but unproven) hypotheses. Some of the assumptions made in this study could be rechecked with data taken from simultaneous periods of record. Perhaps the transform relationships found here are unique to central Illinois. It would also be interesting to see if the same transform held for the fall/winter seasons when precipitation is more uniform and widespread. The final check, however, will require actual measurements over long lines at several locations and at line mid-points to verify any relationship.

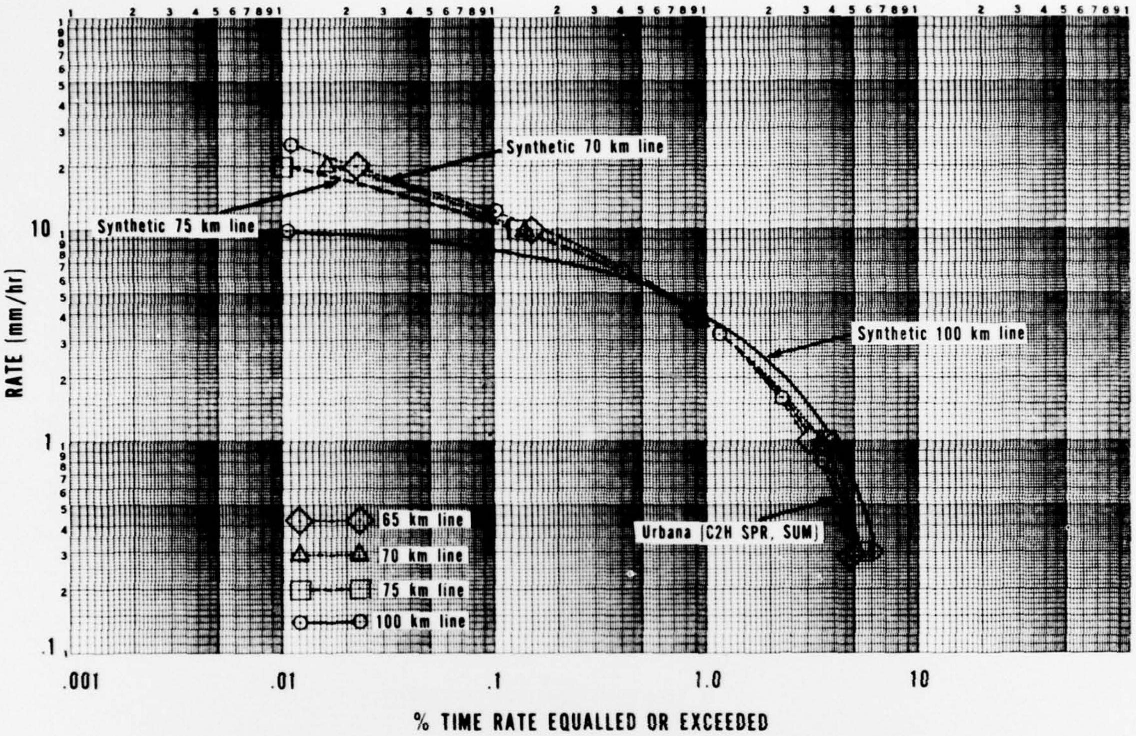

Figure 3. Comparison of the Clock Two-Hourly Distribution at Urbana, Illinois with the Average Rates Along Synthetic Lines (Spring and Summer).

SUMMARY AND CONCLUSIONS

This paper presents a technique for converting clock-hourly rainfall rate distributions to clock two-hourly rainfall rate distributions at 14 locations. In addition, by examining the instantaneous rainfall rate distribution along lines in central Illinois, Bussey's (1950) hypothesis of the point-time ergodicity of rainfall rate distributions may require some adjustment although the basic assumptions appear reasonably valid. Hopefully, increasing interest in rainfall rates over long lines will result in some measurements of the actual distributions. These measurements will be of great value in future research.

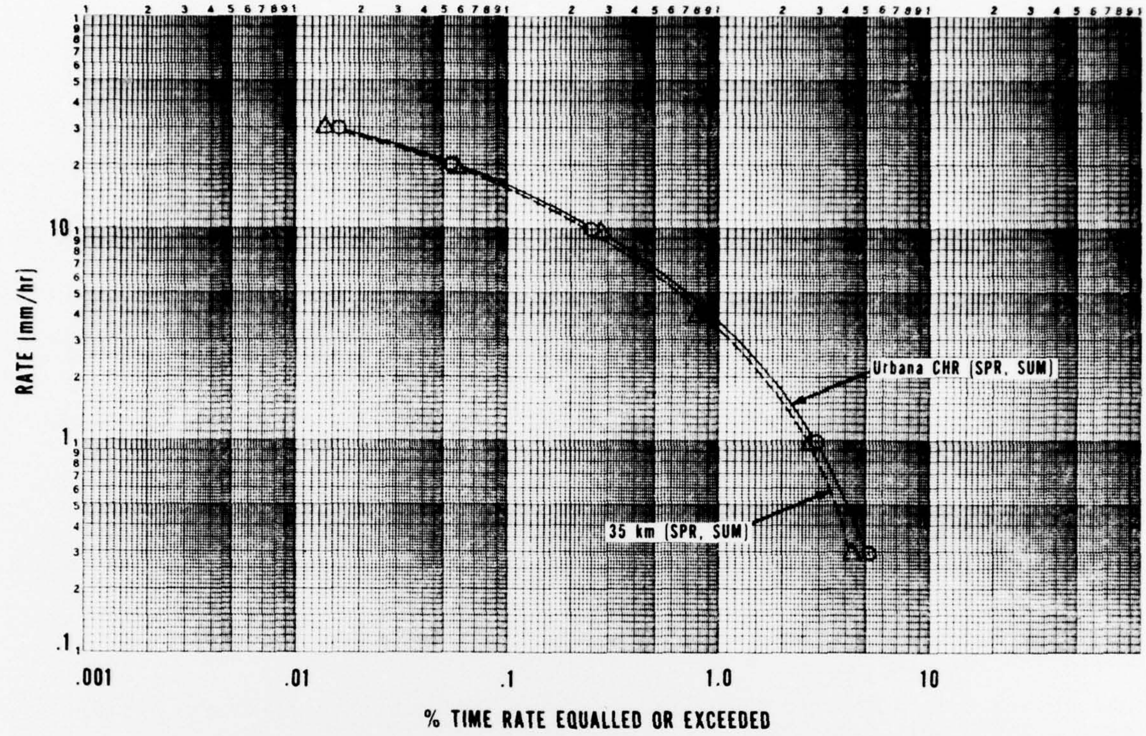

Figure 4. Comparison of Clock-Hourly Distribution and an Instantaneous Distribution Over a 35-km Line.

REFERENCES AND BIBLIOGRAPHY

Benoit, A.: "Signal Attenuation Due to Neutral Oxygen and Water Vapour, Rain and Clouds," Microwave J, 1968.

Brever, J. S., and R. K. Kreuls: "Rainfall Intensity Distributions, Drop Size Spectra, and Attenuation Measurements at Bonn, Germany," Preprint, IUCRM Colloquium on the Fine Scale Structure of Precipitation and E. M. Propagation, Nice, France, October 1973.

Briggs, J.: "Estimating the Duration of High Intensity Rainfall," Meteor. Mag., Vol. 97, pp. 289-293.

Briggs, J., and J. A. Harker: "Estimates of the Duration of Short Period Rainfall Rates Based on Clock-Hour Values," Meteor. Mag., Vol. 98, pp. 246-252.

Bussey, H. E.: "Microwave Attenuation Statistics Estimated from Rainfall and Water Vapor Statistics," Proc. Inst. Radio Engrs., Vol. 38, No. 7, pp. 781-785.

Beyers, H. R., and R. R. Braham: The Thunderstorm., U. S. Dept. of Commerce, Washington, D. C., 1949, 287 p.

Chu, T. S., and D. C. Hogg: "Effects of Precipitation on Propagation at 0.63, 3.5 and 10.6 Microns," Bell Sys. Tech. J., Vol. 47, No. 5, (May-June 1968), pp. 723-759.

Cole, A. E., et al.: "Surface Rates of Precipitation," in Chapter 5 of Handbook of Geophysics and Space Environments, McGraw-Hill Book Co., Inc., 1965, pp. 5-1 to 5-5.

Fedi, F.: "Criteria and Expected Accuracy of the Measurements Envisaged in the Research Programme Underway in Italy," Paper presented at technical meeting; Agard, E.M., Wave Propagation Panel on Telecommunications Aspects on Frequencies Between 10 and 100 GHz, Gausdal, Norway, September 1972.

Freeny, A. E., and J. D. Gabbe: "A Statistical Description of Intense Rainfall," Bell Sys. Tech. J., 1969, pp. 1789-1851.

Freeny, A. E., and R. A. Semplac: "Measuring rainfall," Bell Labs Record, November, 1969, pp. 315-319.

Jones, D. M. A.: "Personal Communication," June, 1977.

Lenhart, R. W.: "Precipitation Intensity and Extent," J. Recherches Atmos, Vol 8, 1974, pp. 375-384.

Medhurst, R. G.: "Rainfall Attenuation of Centimeter Waves: Comparison of Theory and Measurements," IEEE Trans. Antennas Propagation, July 1965.

Ruthoff, C. L.: "Rain Attenuation and Radio Path Design," Bell Sys. Tech. J., January 1970, pp. 121-135.

Semplak, R. A.: "A Rare Event of Intense Rainfall," Mon. Wea. Rev., Vol. 99, No. 2, February 1971, pp. 155-157.

Semplak, R. A., and H. E. Keller: "A Dense Network for Rapid Measurement of Rainfall Rate," Bell Sys. Tech. J., 1969, pp. 1745-1756.

Setzer, David E.: "Computed Transmission Through Rain at Microwave and Visible Frequencies," Bell Sys. Tech. J., October 1970, pp. 1873-1892.

Sims, A. L., and D. M. A. Jones: "Climatology of Instantaneous Precipitation Rates." AFCRL TR 73-0171, Final Report to AFCRL, Bedford, MA, State Water Survey, Urbana, IL, 1973, 75 pp.

Wilson, R. W.: "Sun Tracker Measurements of Attenuation by Rain at 16 and 30 GHz," Bell Sys. Tech. J., May-June 1969, pp. 1383-1404.

Winner, Donald C.: "Climatological Estimates of Clock-Hour Rainfall Rates," AWS TR 202, U.S. Air Forces, Hq AWS, June 1968, 24 pp.

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