ILLINOIS STATE WATER SURVEY
at the
University of Illinois
Urbana, Illinois

INVESTIGATION OF THE QUANTITATIVE DETERMINATION OF POINT AND AREAL PRECIPITATION BY RADAR ECHO MEASUREMENTS

Interim Report No. 2
1 April 1965 - 30 September 1965

Sponsored by
U. S. Army Electronics Command
Fort Monmouth, New Jersey

CONTRACT NO. DA-28-043 AMC-00032(E)
DA Project No. 1VO-14501-B-53A-07

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The general purpose of this contract is to determine the correlation between the amount and rate of precipitation and the intensity of the radar signal returned from the rain clouds. Detailed studies of correlations between radar signal, the amount of precipitation, and the drop spectra are being used to improve the accuracy and determine the reliability of radar-measured precipitation amounts for Army requirements.

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PURPOSE

The general purpose of this contract is to determine the correlation between the amount and rate of precipitation and the intensity of the radar signal returned from the rain clouds. Detailed studies of correlations between radar signal, the amount of precipitation, and the drop spectra are being used to improve the accuracy and determine the reliability of radar-measured precipitation amounts for Army requirements.

In addition and more specifically, the objectives of this research ares:

1, To develop new techniques or to modify existing techniques that will reflect the latest results in radar research activities,

2. These techniques will include the accuracy and stability of the radar parameters necessary to achieve the desired accuracy of rainfall measurements for Army applications. Accuracy as a function of range will be stated,

3. Preliminary study to determine rainfall rates for short periods of time that cause attenuation of the 3-cm radar signal will be made with data available from raindrop spectrometers and the East Central Illinois raingage network. Rainfall rates are to be considered in measured inches or millimeters for 5-minute periods,

4, Determination of the requirements for a weather radar network within a Field Army area, based on the currently available knowledge, will also be studied. This determination will include the number of radar sets and the spacing of the sets within an area of 150 miles by 300 miles (the smaller figure being the forward edge of the battle area), the frequency to be utilized, and the operating range of the sets.

ABSTRACT

Analysis procedures and some results are reported of the study to determine an adequate sample size for drop-size studies. The variance of rainfall rates in eight cubic meter samples indicates that 90 percent of the time, an accuracy of ±6 percent may be expected in calculations of rate.

The computer programs have been completed for the study of short period rainfall rates. Frequency curves for a small amount of data are presented. Further data processing is continuing.

Raindrop data collections and measurements have been completed. Analysis is continuing of the data from New Jersey and North Carolina.

PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

On April 6, 1965, E. A. Mueller visited Ft. Monmouth, New Jersey, and conferred with Dr. H. Weickmann.

RAINDROP DATA PROM REMOTE LOCATIONS

Synoptic classifications have been made for data from New Jersey and North Carolina. These will require further review before being entered Into the data cards. Then it is planned to examine the correlation between synoptic types and R-Z relationships, as has been done for other locations.

Calculations of positive area stability indices (PASI) were made previously for Majuro; Miami, Florida; and Corvallis, Oregon, radiosonde data on an IBM 650 computer. Since this computer Is no longer available here, this problem is being reprogrammed for the IBM 7094 computer. This will permit correlation of R-Z relationships and stability in storms at other locations where sampling was done more recently.

SAMPLE SIZE STUDIES

A major portion of the effort during this period has been directed towards the sample size studies. As was discussed in the previous interim report, the data were collected primarily during the summer of 1964. Other data were obtained during 1965 but no need for the analysis of this data has arisen. All of the data from 1964 have been measured and processed into distribution form. Thus, for the first time since 1957, the raindrop measuring tables are not being used and the three camera units are being stored. Initial reduction of the 1964 data has been accomplished so that the number-size distributions for each individual sample (1/7 cubic meter per sample) are available.

The second phase of this program consisted of estimating the probable error in the measurement of rainfall rate and radar reflectivity as a function of sample size. The computer program, described in the previous interim report, has been written, checked, and used on a part of the data. As a first attempt, the tendency for the rainfall rate to change during a minute was compensated for by determining a regression line of rate versus time. The correlation coefficient of the rate and time points was computed. If this coefficient was greater than 0.32, the correlation was considered significant and the trend in the data was removed. If the regression coefficients are A and B and if i represents the time, the regression line is given by

$$z = Ai + B$$

Normalization of the data was performed by dividing the individual values of rate by the value of the corresponding regression rate. If y_i is the normalized rate, it is given by,

$$y_i = \frac{r_i}{Ai + B}$$

This is a modification of the statistical device of using as a measurement unit the mean of the variable. In most cases this resulted in reasonable data in that the tendency for rate change was removed and the variances reduced over the variance of the unnormalized data. It was also comforting to note that the variances for a 14-frame sample from data in which no rate trend could be noted compared favorably with the variance of 14-frame samples which had undergone this type of transformation. However, in a few instances the regression line approached zero rainfall rate. When this occurs, the magnitude of the corrected measurement becomes quite large, resulting in fallaciously large variances. There were also instances where the regression line became negative resulting in the announcement of negative rainfall rates. Considering the possibility of having very large rates and negative rates, other analysis procedures are needed.

Two courses of action are proposed to eliminate these anomalies. The first suggestion is to discard all minutes of data in which there is an observable rainfall rate trend. Since this can easily be accomplished, it will be performed. The major drawback is a greater reduction in the total amount of data than may be tolerable. The second solution consists of determining the regression line of rate versus time as before and then considering the deviation of the actual points from this line in units of the mean. This technique will produce a large number of negative values, but it will not allow extreme excursions of the individual points. The variance obtained from this type of sample would be interpreted in the same manner as the variance of a non-trend sample, but the means of the two samples will be different. For the non-trend sample, a mean of 1.0 is found, while for a sample with the trend removed in this manner the mean will be zero. It would be possible to adjust the trend-removed sample by adding

1.0 to each measurement, thus obtaining a sample which would have the same mean and hopefully similar variances as the non-trend removed sample.

Normality of the Data

It was mentioned in the previous interim report that it was expected that as the size of the sample was increased the distribution of the means should approach the normal distribution if the only or the largest part of the error in any one sample was a result of sample size. This indeed appears to be true. Figures 1 and 2 are the results of samples of 4, 8, 16, and 32 frames plotted on probability paper. The ordinate represents the rainfall rate measured in units of the mean. Thus, the 50 percent probability point should be 1.0. On the figures the major deviations of the observed points from the line are at the end points indicating some skewness in the distribution.

Analysis of samples of 4, 8, 16, and 32 frames for radar reflectivity yields a similar result except that the variances are larger.

Results of Rate Analysis

The variances of the 4 and 14-frame samples of the storm of July 25, 1964, are shown in figure 3. One of the important results from this limited sample is that variances of each size sample is independent of rainfall rate for rates greater than about 3 mm/hr. This means that an adequate sample size for low rainfall rates is also adequate for high rates, or that the variability of nature in drop size distribution is of about the same magnitude at all rainfall rates.

On figure 3, there is also evidence of the increase in reliability that can be achieved by using larger sample sizes. Above 10 mm/hr the variance for the 14-frame samples averages about 0.02 and for the 4-frame sample 0.05. This yields estimates of the accuracy for an R point such that 90 percent of the time a 14-frame sample will indicate the "true" rate within ±22 percent; whereas the 4-frame sample will be within -35 percent of the "true" rate 90 percent of the time. By using samples as large as 56 frames, the accuracy increases to about -6 percent, 90 percent of the time. Thus, it would appear that drop size distributions are reasonably homogeneous for volumes greater than 56/7 or 8 cubic meters.

The next step in the process is to estimate similar accuracy statements for the radar reflectivity measurements. Then a reliability can be placed on the rate-reflectivity relationships. The exact details of this latter process are now undergoing examination. Since in the vast majority of drop size data samples of 7 frames (1 cubic meter) have been taken, the accuracies of this size sample must be found and used for determining the reliability or accuracy assignable to the various regression lines that have been found in various climatic regions. The confidence limits thus established should be interpreted as the upper limit of the accuracy with which a radar can measure instantaneous point rainfall rates. The radar may do still better for time and area

Integrated rates (amounts). That is, the errors in rainfall rates may average out when the rates are summed over a longer time period or larger area to obtain rainfall amounts.

RAINFALL RATE STATISTICS

The program to determine the line frequency of rainfall rates has been completed and sample data processed. This program determines the relative frequency of occurrences of precipitation attenuation along a line using 5-minute amounts as the rainfall rate. With the present data from the East Central Illinois (ECI) raingage network, a line length of 20 miles is used. Thus, the results must be considered as representative of attenuations along a 20-mile line only. As was indicated in the previous report, the missing raingage values have been estimated by using the values at the 4 surrounding gages. Corrections have been made so that the assumption of equally spaced gages is no longer made.

In the ECI network, there are eight directions in which lines may be drawn over 4 gages. For each of these directions, a frequency distribution is obtained. The eight frequency distributions thus obtained are then combined to form the non-directional average distribution.

Since not all of the raingage data has been measured on the semi-automatic chart reader, trial data consisting of 10 days from June 3, 1964, to June 13, 1964, have been processed by the program. Figure 4 is a plot of some of the results. Three of the frequency distributions are shown on this graph; the average, North-South, and the East-West frequency. The total rain time during this period was 12 hours and the ordinate on the figure is in percentage of the rain time.

If the desired statistic is the percentage of time a particular attenuation is encountered, the ordinate scale must be multiplied by 1/20 which is the fraction of the total time that rain was occurring.

Also in figure 4 are plotted the frequency for the N-S and E-W lines. It can be noted that the curves diverge for frequencies below about 20 percent occurrence with the attenuation being more severe along the E-W line than along the N-S line. This tendency reduces somewhat at higher values of attenuation although the limited data in the high attenuation region does not really permit many conclusions.

Single point rainfall rate frequencies for the same period were calculated using individual gages and also grouping the individual gages into two groups as to whether the gage number is even or odd. The single point rainfall frequencies indicate that considering the high rates, the period is too short. Two of the gages with highest rates of the 49 show disagreement in the distribution of the highest 7 percent of the recorded values (see figure 5). The point frequencies of the averaged gages still disagree somewhat. It is expected that when a larger sample of data is available this will no longer be noticeable.

Methods of deducing the line frequency given the point frequency have been examined. Using this data the ratio of line-rate to the point rate varies from about 8 or 9 to about 6 as the occurrence frequency changes from 10 percent to 0.1 percent. The value of this number can be related to the length of the average storm if a model of the rate variation along a line is assumed. For instance, if a model rate variation is considered to be such that the rate varies linearly with distance to the peak value at the center of the storm and if the value of 9 is applied at the 10 percent frequency occurrence, the storm would have a distance of 18 miles in width. As the frequency occurrence becomes smaller (more intense rate at center), the average length of the storm decreases to about 13 miles. If these ratios as a function of point rates turn out to be continuous with larger samples, this will provide means for extrapolating results. As more data is read by the chart reader, it will be used in this program to obtain statistically more significant results.

SUMMARY AND CONCLUSIONS

Measurement and preliminary calculations on all raindrop size data have been completed. The data from the summer of 1964 are being processed for evaluation of sample size representativeness. The data are reasonably represented by the normal frequency distribution when the sample size is at least 1/2-cubic meter in size.

The rainfall rate frequency program has been completed and has been run on limited data. This preliminary data has yielded information on the statistical size of a storm as being between 13 and 18 miles when considered from an attenuation through the storm viewpoint.

The rain storms from Island Beach, New Jersey, and Coweeta, North Carolina, have been classified according to synoptic type for separation of the data.

PROGRAM FOR NEXT INTERVAL

The sample size study should be completed allowing estimates to be made of the limiting reliability that can be placed on rainfall rate estimates made by radar.

Radar reflectivity - rainfall rate relationships for the different synoptic classes for the data from New Jersey and North Carolina will be performed. Separations according to thermodynamic instability will also be examined.

Analysis of raingage charts for inclusion in the line frequency analysis will continue.

It is anticipated that raingages to be Government Furnished Equipment will be received and installed at an intermediate range of about 75 miles. During the coming summer rainfall season, the radar will be operated over this network to check the accuracies obtainable by using a radar at this range.

PERSONNEL

The following personnel were engaged in the research during the period of this report:

Name and Title	Starting Date	Hours Worked	Terminated
G. E. Stout Project Director	10/1/64	102	
Eugene A. Mueller Electronic Engineer	10/1/64	383	
Arthur L. Sims Research Assistant	10/1/64	1020	
Marilyn Lougher Research Assistant	7/1/65	388	9/8/65
Stanley G. Peery Electronics Technician II	10/1/64	1020	
Ronald K. Tibbetts Electronics Technician II	3/1/65	1020	
Marian E. Adair Meteorological Aide I	11/1/64	1020	
Edna M. Anderson Meteorological Aide I	10/1/64	1020	
Mitchell S. Budniak Research Assistant	1/27/65	136	6/3/65
David E. Burns Laboratory Assistant	12/28/64	453	
John H. Dickerson Laboratory Assistant	12/21/64	120	5/7/65

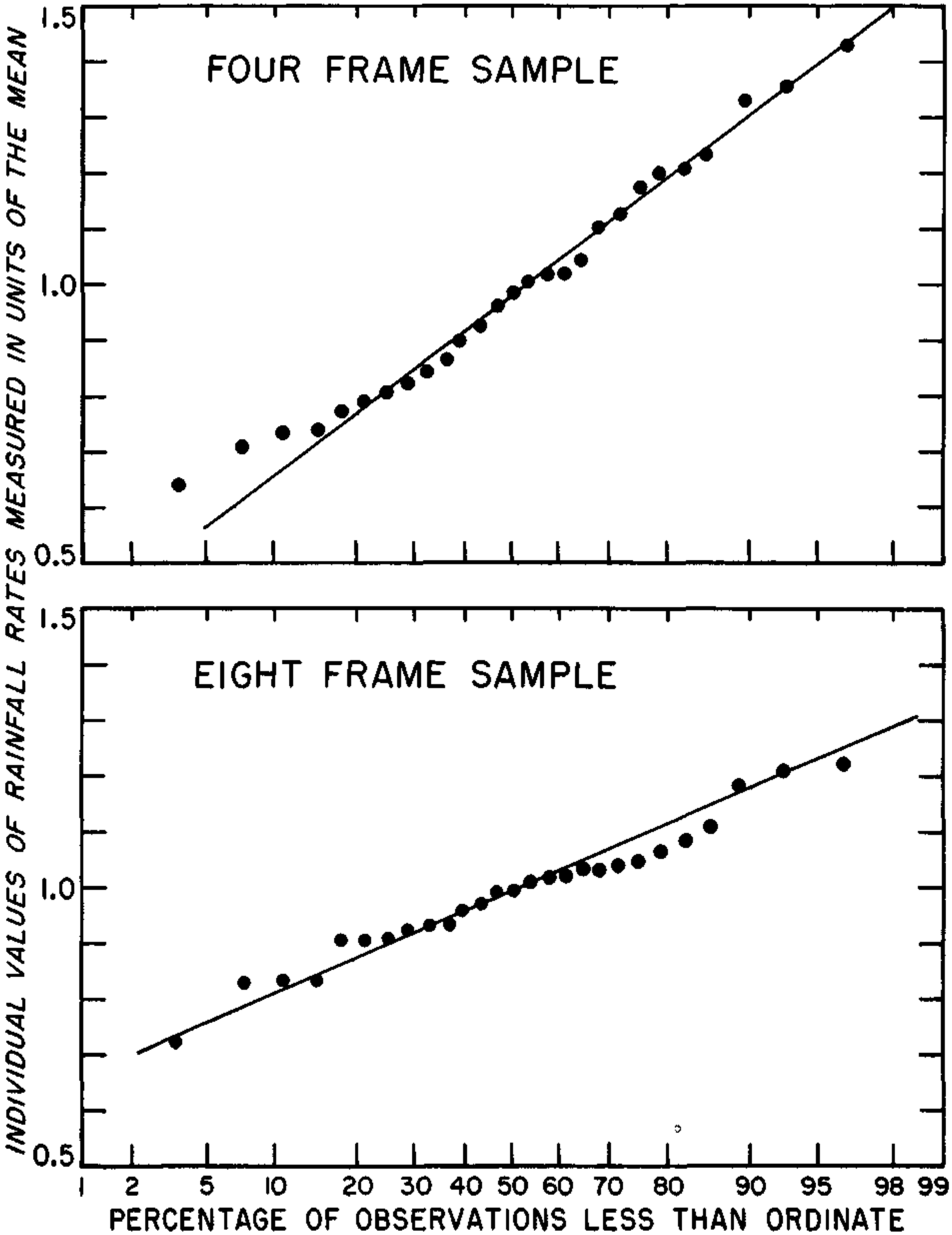

Figure I. PROBABILITY PLOTS OF 4 AND 8 FRAME SAMPLES

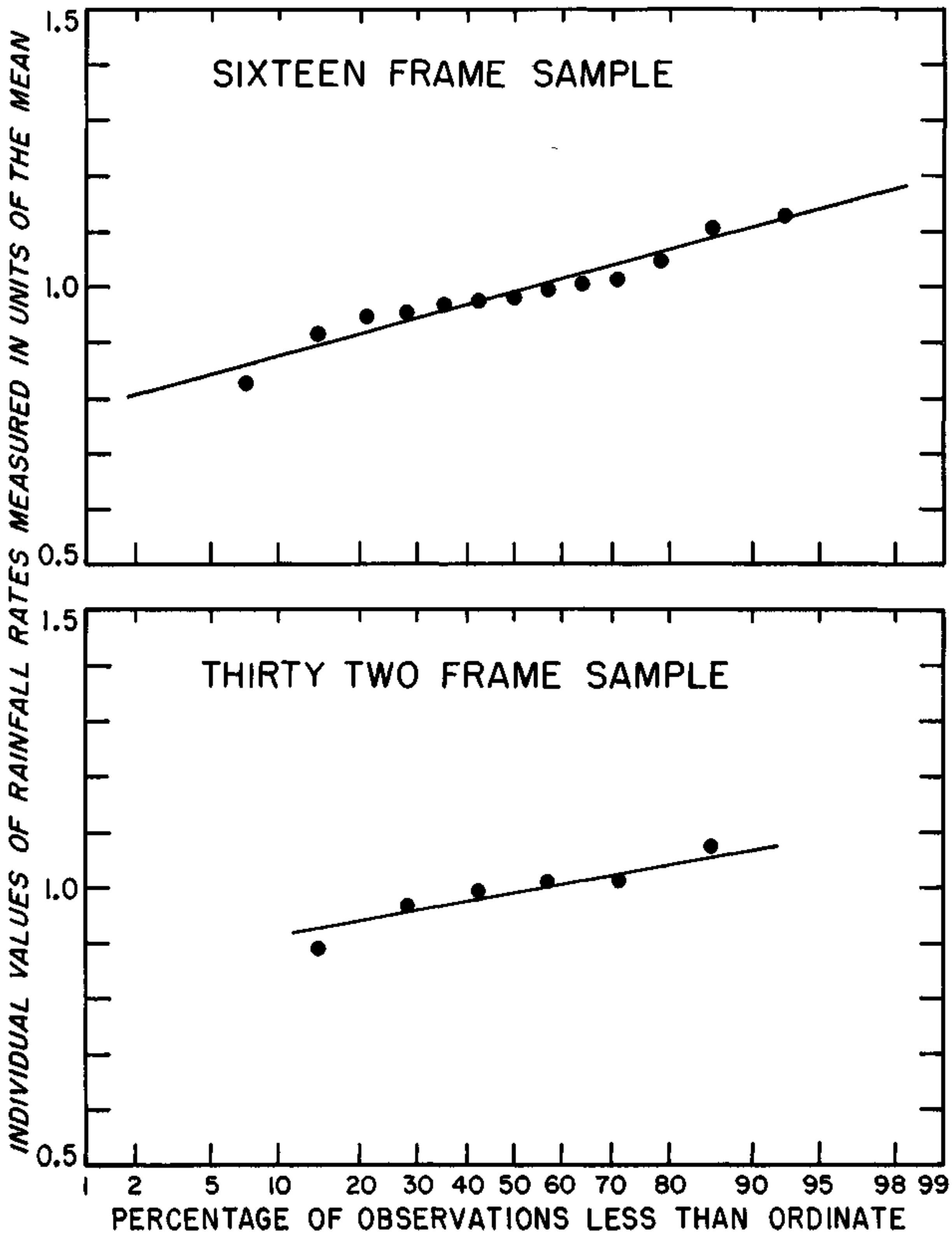

Figure 2. PROBABILITY PLOTS OF 16 AND 32 FRAME SAMPLES

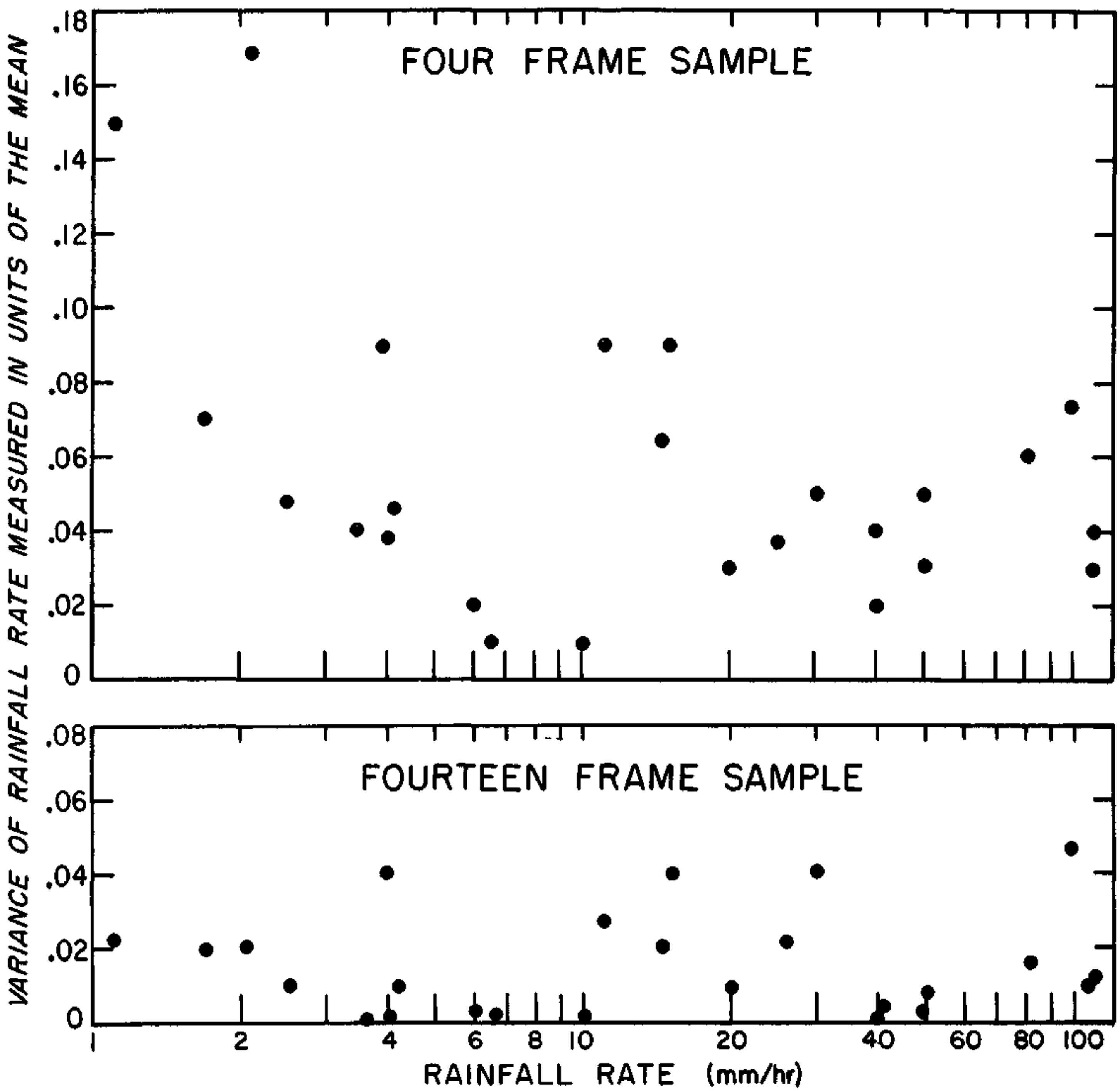

Figure 3. VARIANCE OF R AS A FUNCTION OF R FOR THE 25 JULY 1964 STORM

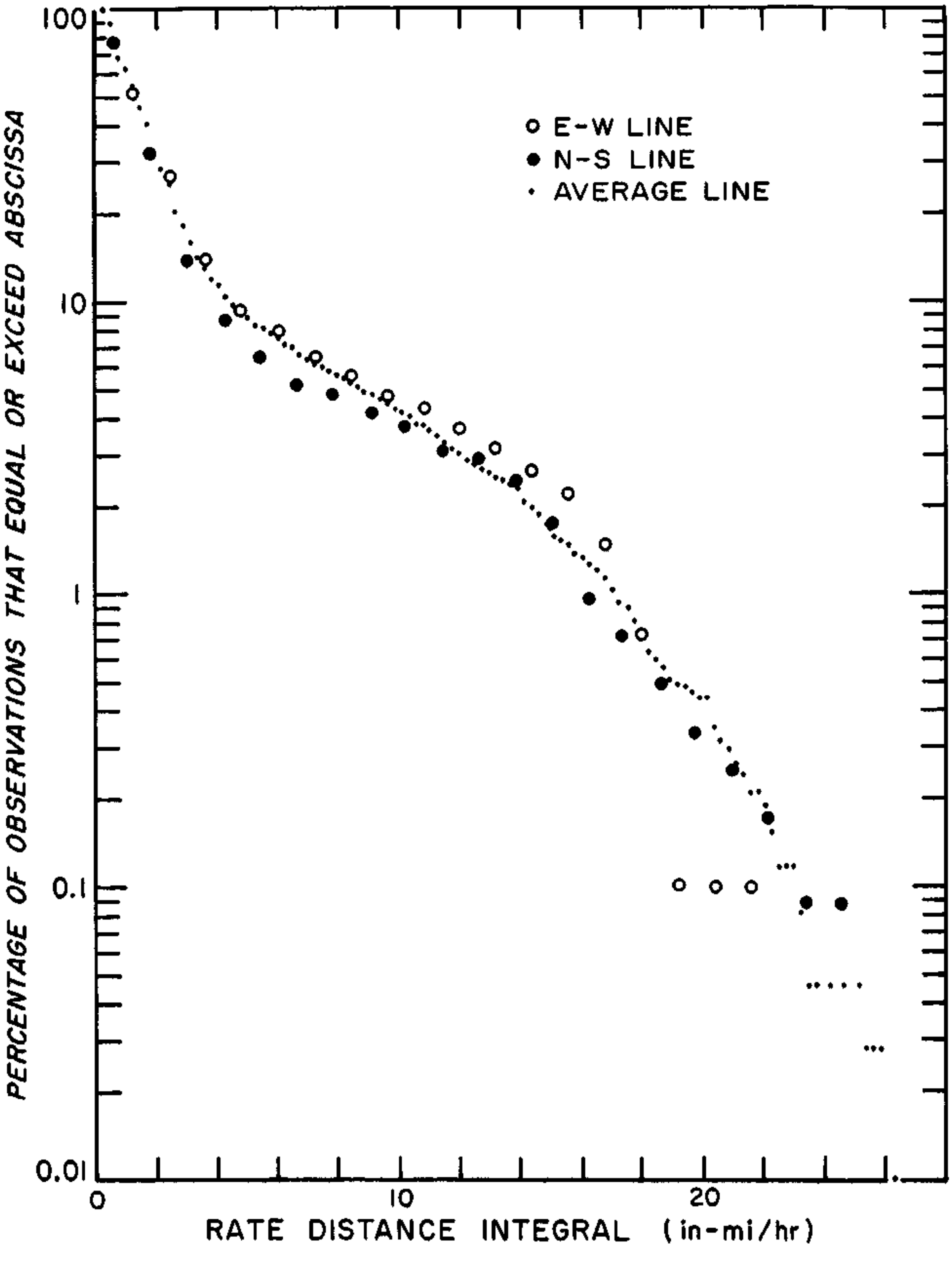

Figure 4. LINE FREQUENCY PLOTS FOR NORTH-SOUTH, EAST-WEST, AND AVERAGE LINES

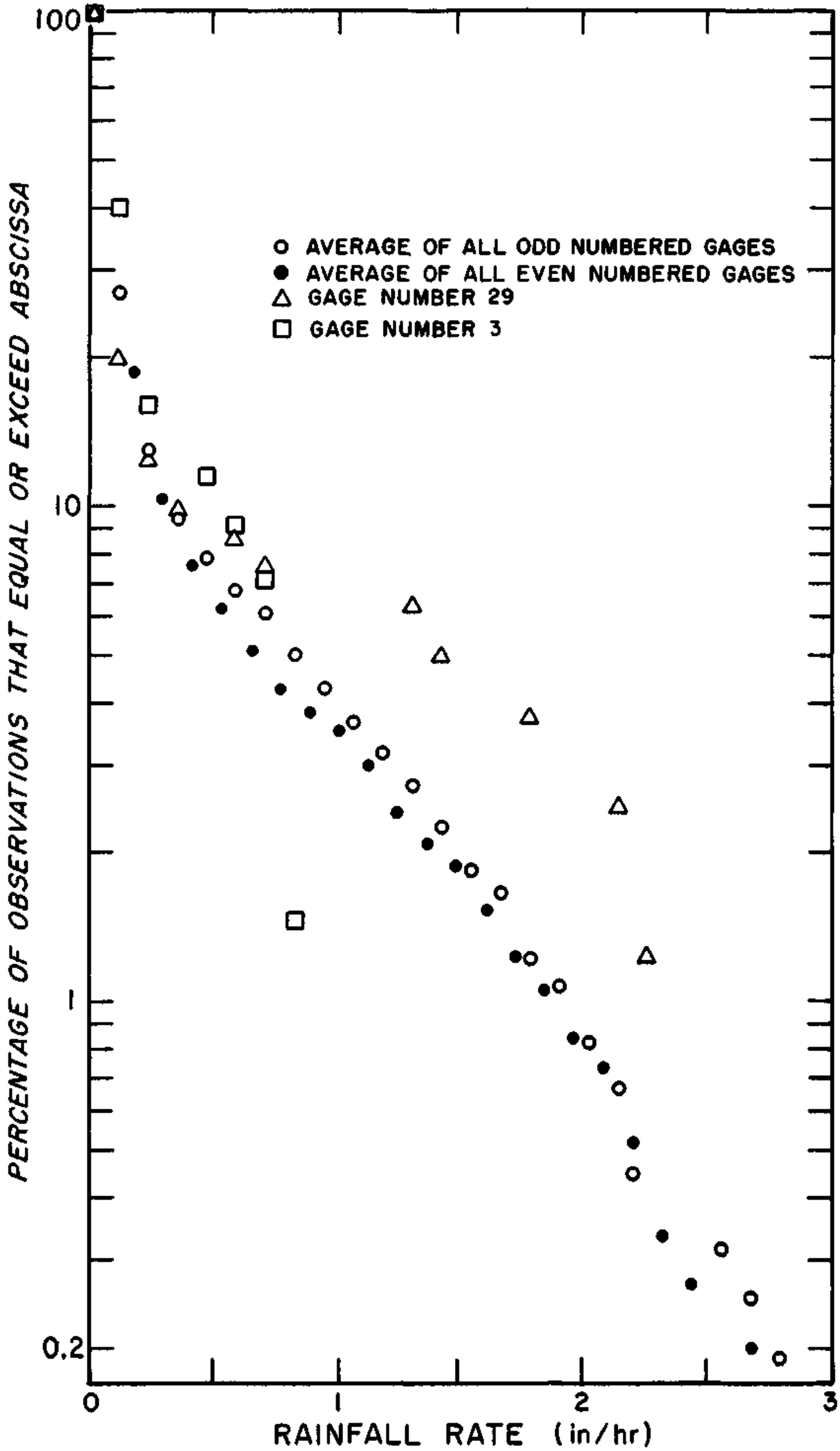

Figure 5. FREQUENCY CURVES FOR POINT RAINFALL RATES

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13 ABSTRACT

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