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MEASUREMENT OF THE SIMULATED RAINFALL AT THE HOLLOMAN TEST TRACK FACILITY

Eugene A. Mueller and Arthur L. Sims
Illinois State Water Survey
at the
University of Illinois
Urbana, Illinois 61801

Contract No. F19628-69-C-0206
Project No. 8624
Task No. 862401
Work Unit No. 86240101

FINAL REPORT

Period Covered: 1 April 1969 - 31 March 1970

April 1970

Contract Monitor: Allen E. Cole
Aerospace Instrumentation Laboratory

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AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
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ABSTRACT

The results of measurements of the simulated rainfall at the Holloman test track facility are presented. Raindrop spectra measurements were made with a drop camera and with an optical electronic drop spectrometer. A small amount of drop measurements using the flour pellet method were also made for comparison with the other methods.

The measurements of the simulated rainfall were compared with average natural rainfall data collected with the drop camera. The average spectra from the track has a liquid water content of 7.96 g/m^3 and an equivalent rainfall rate of 158.7 mm/hr. It does not correspond directly to any natural rainfall rate.

The natural rain data have been sorted into data from arctic, tropical, and temperate regions, and average raindrop spectra for various frequencies of occurrences calculated.

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INTRODUCTION

The primary objective of this contract was to obtain measurements of the artificial rain field which is in use at the test track facility at Holloman Air Force Base, New Mexico. It was also desired to compare measurements made with the University of Illinois drop camera and those from a drop spectrometer recently acquired by the Air Force from the Illinois Institute of Technology Research Institute (IITRI) so the two procedures of measuring raindrops could be compared. These data also would allow comparison of the IITRI spectrometer measurements with drop camera measurements of natural rain.

Two data collection trips were made to Holloman AFB. In June 1969 measurements consisting of four runs were made on the main track and 15 runs on a small rain field located on the "fitting track". In September, 1969, tests were made on the main track with much lighter winds than were experienced during the June tests.

A description of the rain field can be found in a report by Reynolds (1962). Briefly, it consists of 6000 feet of artificial rain produced alongside the test track. On both sides of the track there are water mains that deliver water to 400-foot long manifolds. Each of these manifolds has 50 risers with a spray nozzle attached to each riser. In this report a section of 400 feet refers to the section of one manifold.

This report describes the instrumentation employed, and compares the drop data from the two instruments under varying wind conditions, varying instrumental alignments, and varying positions along the track. Data collected by a "flour sampling technique" were also compared with those collected by the drop camera and the spectrometer. Drop-size data for actual rainfall in varying climatic zones are presented and compared with the simulated rain.

MEASUREMENTS OF STANDARD RAIN FIELD

Instrumentation

Data reported in this report were primarily from two instruments which measure the raindrop spectra. A third device, "the flour sampling technique", which provides limited information on drop size spectra, is also discussed in one section.

The prime instrument employed was the raindrop camera. Measurements with this instrument of natural raindrop spectra by the University of Illinois have been made in nine different world-wide locations. Over 23,000 1-m^3 samples of rain have been collected since 1957. These data were collected using a camera system consisting of a 29-inch diameter parabolic mirror and an electrically operated 70-mm camera. Four FT-503 flash tubes were used to illuminate the sampling volume.

For operation on the test track, it was decided that a smaller system would be necessary. The same 70-mm camera was used, but a parabolic mirror of 12 1/2 inch diameter was purchased. This mirror has a focal length of 100 inches instead of the 160 inches of the 29-inch mirror, thus producing a larger magnification on the film. A single FT-503 flash tube was found sufficient to light the smaller sample volume. The sample volume photographed on a single frame of film was 726 in^3 or 0.0119 m^3. The larger drop camera used previously had a sample volume of 0.14-3 m^3 per frame. The smaller sampling volume was a necessary consequence of making a smaller system, and this volume was considered acceptable due to the higher average concentration of raindrops expected in the test track rain field.

The optical configuration for the drop camera as used in these measurements is shown in Fig. 1. The. 12 1/2-inch mirror is the first element of a Newtonian telescope. The camera lens aperture is located at the focal point of the mirror, producing a telecentric system which eliminates most of the perspective effects. The volume of rain space photographed is a right circular cylinder that has a 12 1/2-inch diameter and a 6-inch depth. A small portion of this volume is eliminated by the obstructions of the diagonal mirror and its support.

The entire drop camera system was mounted on a 3-wheeled carriage provided by Holloman Air Force Base. This carriage was placed on the track and could be moved easily through the rain fields while photographs of the drops were being made.

After the film was processed, it was projected so that the drop images were three times the size of the original drops. Measurements of the horizontal and vertical sizes of the drops were then obtained using semi-automatic calipers. The measurements were averaged in the computer to obtain the best estimate of the diameter of the drop. At the same time, the computer obtains a drop-size spectra and computes the rainfall parameters of equivalent rainfall rate and liquid water content.

The second major instrument involved was the spectrometer purchased by the test track facility at Holloman Air Force Base from the Illinois Institute of Technology Research Institute (IITRI), hereafter referred to as the IITRI spectrometer. This instrument has an optical system similar to that of the drop camera except that a lens is used rather than the parabolic mirror. In order to provide higher levels for drop illumination, the IITRI spectrometer collimates the source of light with a second large lens. Instead of a film record, the spectrometer focuses the drop images on an image orthicon tube. Each drop focused on the orthicon is measured by counting the number of intersections of the horizontal sweep and the drop image. Thus, essentially, the vertical dimension of the drop is measured. These measurements are tallied in eight channels (classes) of drop sizes. The widths of these channels are variable; however, all data obtained with the IITRI spectrometer were with the 8:1 magnification and therefore with channel widths of 0.5 mm.

The IITRI spectrometer samples a volume 7.5 times each second. This volume is determined by the spacing of the shields to delineate a volume of sufficient size so that statistically reliable samples may be gathered. In all of these data, the shields were 6 inches apart and the device sampled 1820 in^3 or 0.0298 m^3 for each 10-second sample. The output of the spectrometer was a paper tape with the number of drops in each size class printed thereon. These numbers were punched into IBM cards and the analysis was performed in the computer.

The flour sampling technique provides a crude estimate of the drop size spectra. A sample is taken by exposing a tray of flour for a short (and unknown) time to the artificial rain. The resulting dough pellets are then screened, weighed, and then a relative number distribution is obtained. The preliminary data analysis was performed by Holloman personnel and resulted in a relative number distribution on a surface area.

Comparisons of Drop Camera Data with IITRI Spectrometer Data

One of the purposes of this contract was to determine how the drop spectra obtained by the IITRI spectrometer compared with the spectra as measured by the drop camera. This information was needed in order to know what adjustments would be needed to compare the IITRI spectrometer measured test track spectra with the vast amount of natural rain spectra obtained elsewhere using the drop camera.

Excellent agreement was found between the data of the two instruments. Figure 2 is a plot of the average drop spectra for the September test run number 1, as determined by the drop camera and by the IITRI spectrometer. These spectra are both presented in units of number of drops per m^3 per 0.1 mm increment of drop diameter, although the IITRI spectra are plotted only for 0.5 mm intervals of diameter. Similar results were found for run number 2. The two instruments were also in agreement as to the major variations in the spectra along the track.

The data taken in the main test track rain field in June were obtained with winds which were generally 3 mph or higher. Because of these relatively high winds, further testing was done in September under much more satisfactory light wind conditions. It is the data from the September runs which will be presented here as typical of the rain spectra being produced routinely on the test track.

Standard track conditions were in effect during these tests. The sections measured had been recently refurbished. That is, the sprinkler and supply pipes had been anchored to posts set into the ground. The standard Vee Jet H-l/4 U 8070 nozzles were used, and were adjusted to the usual 65 degrees. The water pressure was maintained at 9 psi. The winds remained quite calm. Runs number 1 and number 4 were made on the 400-foot section of the rain field between track stations 23432 and 23835. Runs number 2 and number 3 were between stations 22652 and 23065. The spectrometers were moved through the field at speeds around 30 ft/min.

Both the IITRI spectrometer and the University of Illinois drop camera functioned properly. Due to the excellent agreement between the data from the two instruments on the first two test runs, the second two runs of drop camera film were not measured. It was considered that the IITRI spectrometer data were sufficient to totally describe the spectra.

The spectra for run number 1 have already been presented (Fig. 2). Figure 3 shows the mean distribution for the average of each of the four test runs as measured by the IITRI spectrometer. Also on this figure are the high and low limits for these individual run averages. There is good consistency in the region of diameters equal to or greater than 2 mm. There is greater variability in sizes less than 2 mm, but even here, the scatter is not unreasonable. These small drops are. moved about by light winds to a much greater extent than the larger ones. Although these tests were made under basically calm conditions, a very light occasional breeze may account for the differences in the small drop numbers.

The numerical data from the runs, as measured by the IITRI spectrometer are presented in Table 1 together with the mean spectrum of the raw spectra of all the runs. This mean distribution is probably the best description of the rain field as it existed in September 1969. Also in Table 1 there are presented the coefficients of variation of the numbers in the eight size classes. The coefficient of variation as used here is defined as the ratio of the square root of the variance to the mean of the numbers in each of the size classes. It is a good statistical measure of the variability with respect to the mean. If the variability of drops in each of these classes was strictly a result of the sampling volume, the coefficient of variation should be smaller for samples with larger numbers of sampled items. In this case, the smaller drop classes should have appreciably smaller coefficients of variation. In practice, the two smallest size categories have the highest coefficients of variation, and since they also have the largest number of drops, the small categories seem to be significantly more variable than the larger drops. One very likely reason for this may be wind effects. Even though there were no measurable winds during these runs, it is believed that extremely light cross winds which affect the small drop concentrations were present.

Calm Wind Conditions

For purposes of data interpretation along the track, the mean distribution as given in figure 3 and Table 2 is considered to be applicable under no-wind conditions. In Table 2 the following parameters are available: the fraction of drops smaller than or equal to the diameter, percentage of liquid water contributed by drops smaller than or equal to the diameter, and the total liquid water in drops less than or equal to the diameter. Table 2 also summarizes some of the parameters for this average distribution, and figure 4 shows the distribution plotted on logarithmic probability paper. The data for this table was obtained from the smoothed curve of figure 3 by reading from the figure the numbers of drops at 0.1-mm intervals of diameter from 0.5 to 4.7 mm. Drop camera data was used to extrapolate the curve to 4.7 mm. Had sufficiently reliable data been available and used for sizes less than 0.5 mm, the total drop concentration would likely have been considerably greater, but these very small drops would increase only slightly the liquid water content and equivalent rainfall rate.

Table 1. Average drop size distributions as measured by the IITRI spectrometer, for the four September runs on the main track under standard conditions with no wind.

	Number of drops per m^3 per 0.1 mm drop diameter interval for indicated mean drop diameters in mm.							
Run No.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
1	370.87	212.32	186.61	88.85	28.63	9.02	1.51	0.41
2	542.31	191.36	241.69	125.21	34.71	7.40	1.37	0.29
3	637.98	340.20	249.18	111.85	30.15	7.58	1.56	0.37
4	922.87	584.34	305.80	101.25	22.57	4.98	1.28	0.39
Mean	618.51	332.06	245.82	106.79	29.02	7.25	1.43	0.37
Coeff. of Variation	.374	.543	0.198	0.145	0.173	0.23	.090	.144

The equivalent rainfall rate is defined as the rainfall rate which would be obtained if the drops of the measured spectra were traveling at their terminal velocities. In other places in this report the term accumulation rate has been used. This is defined as the actual rate of water passing -through a unit area in a given time and is the parameter commonly measured by the wedge gage instruments. Since the drops are traveling at less than terminal velocity, the accumulation rate is always less than the equivalent rainfall rate. In using these calibration data, it should be kept in mind that neither spectrometer measures the very small drops (less than 0.25 mm). The USAF spectrometer is capable of measuring smaller drops when operated on other magnifications, but this was not performed. Thus, if it is expected that the test item is responsive to the small drops further calibration of the smaller sizes is required.

Table 2. Parameters of the mean distribution under calm wind conditions for standard nozzle conditions.*

Drop Diameter (D) (mm)	No. Drops/m^3 $\leq$ D	Fraction of drops $\leq$ D	Liquid water in drops $\leq$ D (gm/m^3)	Fraction of liquid water in drops $\leq$ D
0.75	1450	0.29	0.209	0.026
1.25	3110	0.61	1.256	0.16
1.75	4345	0.86	3.617	0.45
2.25	4882	0.961	5.938	0.75
2.75	5032	0.9907	7.165	0.900
3.25	5068.9	0.9980	7.687	0.966
3.75	5076.6	0.99948	7.860	0.988
4.25	5078.6	0.99987	7.927	0.9961
4.75	5079.2	1.00	7.958	1.00

Other Miscellaneous Parameters

Equivalent rainfall rate = 158.7 mm/hr or 6.25 in/hr

Liquid water content = 7.96 gm/m^3 or 4.97 x 10^{-4} lbs/ft^3

Total drop concentration = 5079 $drops/m^3$ or 143.8 $drops/ft^3$

Mean volume diameter = 1.44 mm or 0.057 in

Median volume diameter = 1.80 mm or 0.071 in

* This table is based on drops larger than 0.5 mm in diameter.

In the present field great uncertainty in the small drop classes exist in 400 foot sections even under the calmest of winds. It is perhaps fortunate that most theories of destructive effects of raindrops depend upon the higher moments of the drop distribution. In these larger size classes there appear to be much less variability both within a 400 foot section and between sections.

Low Wind Conditions

During both data collection periods, a Beckman-Whitley sensitive recording anemometer was used to measure the wind speed and direction. This anemometer was located within 25 feet of the center of the fitting track where all of the wind data, which were used in this section, were obtained. This same instrument was installed alongside the main track during data collection periods. Winds with speeds of between 1 and 2 mph (0.5 to 1 m/s) are considered low winds in this report.

Preliminary results with varying winds seemed to indicate that the numbers of small drops increased with an increase in low wind as the wind increased at low wind speeds. After more analysis, it has become apparent that indeed the wind effect is most pronounced in the small drop categories as would be expected. However, it is also apparent that the magnitude of the change and even the direction of the change of the numbers of small drops vary erratically under changing wind conditions.

In order to remove the possibility of effects due to different track sections and/or effects due to different alignment of nozzles, the primary data used for the low wind analysis were from the fitting track. These data were all taken in June and no nozzle alignment changes were made. Four runs were obtained with cross winds between 0 and 2.4 mph, and figure 5 shows the results.

The spectrum with no winds is very close to the track standard distribution (Fig. 3) so the results from the fitting track should extrapolate well to the main track.

For the larger drop-size categories, and for winds up to about 2 mph, the number seems to decrease as the wind increases. However, in the sizes less than 1.75 mm the numbers of drops appear to be quite erratic and to vary over an order of magnitude. Runs "D" and "U" were both obtained with nearly identical winds (1.5 and 1.2 for "U" and "D", respectively), and yet the numbers of drops are quite different in the smaller classes. For example, at a diameter of 1 mm, the number of drops is about 4 times greater for run "D" than for run "U".

One probable cause for some of the wild fluctuations in the number of small drops may be the gustiness and turbulence associated with any wind. Thus, even though the wind instrument measured winds of less than 2 mph, the actual winds at the measuring site may have been different because of local turbulence. Both spectrometers are large and produce unknown effects on the winds in their near vicinities. Very slight changes in direction may be magnified by these obstructions and these local effects would be most strongly felt by the small drops.

These data, along with some data from the non-standard nozzle configuration are the only data for which the wind effects could be assessed. The paradox of the data collection is that an insufficient amount of data is available under light wind conditions and yet data collection was always terminated by high winds. It is recommended that more data be obtained in the future during low winds. At present, it must be concluded that winds of only. 2 mph seriously affect the small drop concentrations.

These winds produce an uncertainty of at least an order of magnitude for spectra at one point in space for drop categories less than 1.5 mm diameter. For drop categories greater than 2.0 mm, the effect of the light winds is less important and appears to reduce the concentration.

Since all of these data with respect to winds were obtained at essentially one point (averaged over six feet of track), it is possible that these data may be unduly pessimistic with respect to small drops. That is, the wide variations in the small drop frequency may cancel each other at different points along the track. On the other hand, the large drops appear to be systematically decreased for any cross wind component. Thus, a net reduction in intercepted water and amount of damage would undoubtedly result from any run with cross winds. On the basis of these data, it may be hopeless to estimate the small number concentration even if very detailed wind measurements are made at firing times.

Variations in Spectra with Respect to Position Relative to Rail

In order to assess the importance of instrumental position relative to the track and in the plane perpendicular to the track, all the drop camera photographs were divided into 10 sections for measuring.

Also, in June 1969, data were collected on the fitting track with the drop camera about 1 foot above the track, and 1 foot to the side of the track. Figure 6 shows the average concentrations, liquid water contents, and rainfall rates. These parameters are chosen as representative of the spectra rather than the spectra themselves for the ease inherent in single parameter analysis. In addition, the statistical noise involved appears to be sufficiently large that this, or some alternative smoothing or averaging, would be necessary to be able to recognize any systematic changes. As seen from figure 6, the parameters do not vary in a very orderly fashion. In general, average equivalent rainfall rates and liquid water contents are highest in the area "A", the area just over the track. Within each area, the parameters vary erractically, particularly the drop concentration, N. The drop concentration variations are largely variations in the numbers of the small drops. For example, in all the sections having greater than 10,000 drops/m^3, over half of these drops are 0.5 mm diameter or less. Variations in rainfall rate, R, and liquid water content, L, are not as large as the variations in drop concentration, since the very small drops contribute relatively little to the liquid water content and rainfall rate.

The occasional lack of consistency in the patterns of the spatial variations is probably due to the data for the three areas having been obtained on three separate runs rather than simultaneously. Also it may be due to the small sample sizes involved. The winds were less than 1.5 mph for all the runs, but they were from the southeast on run "P", from the north and northwest on run "M", and were near calm on run "0". These winds were such as to move more drops, particularly small ones, into area "C" during data run "M" than would be expected with calm conditions. Each of the small sections represent only 0.07 m^3 of space and even though reasonably homogeneous conditions are expected in the artificial field, sampling error is an important factor. Thus, the value of liquid water of 9.6 g/m^3 in the upper right of run "P" is undoubtedly fallacious. Since the wind affects small drops more than large ones, and since the concentration is overwhelmingly a measure of numbers of small drops, the concentration is considered to be unreliable and attention should be directed only to the results for liquid water content and the equivalent rainfall rate. This situation makes it impossible to make very specific conclusions as to the spatial variations in the rain field perpendicular to the track. But generally, the rain field reduces about 30% as the point of interest moves 12 inches inside the rail and by about 35% 18 inches above the rail.

Variations in Spectra Along Track

In addition to the average spectra for the runs, individual spectra were calculated for each frame of drop camera data. It had been expected that a periodic variation of the rain along the track might be found due to the spacing of the nozzles. This was checked by frequency analyses of the liquid water contents calculated for each single frame spectra. No significant periodic variations were found. Although the variability of the liquid water content measurement is quite large, this variability appears to be largely random in nature. Figure 7 is a histogram of the occurrence of various values of liquid water content on run 1. The mean liquid water content for this run was 6.7 g/m^3. About 55% of the values of LWC occur between 5 and 8 g/m^3. It should be realized that this variability is not all real variability in the rain field, but also includes the sampling errors in the measurements. Most of the sampling errors are probably averaged out in the run averages. Fortunately, it is likely that the average conditions are the most meaningful to the usual tests on the track.

Pressure and Nozzle Angle Effects

For the test runs of 23 September 1969, one section of the rain field was readjusted so that half of the section had nozzle angles of 55 degrees and the other half of the section had angles of 60 degrees. Measurements were made of this modified section and a standard section adjacent to it under varying water pressures. The pressures used were 8, 10, and the standard 9 psi.

A summary of the tests is contained in figure 8. The lightly shaded region on this figure shows the range of variability in the four standard runs made on 22 September and an additional standard run on 23 September. The darker shading is the additional variability with the runs made under the varying pressure and nozzle angle conditions. Only a small amount of variability is added by the changes in pressure and angles and most of this is in the very small and very large drop region of drop size. The added variability in the small drops is large due to increased number of small drops when the pressure was increased to 10 psi. The number of 0.5 mm drops was greatest at a 65° nozzle angle, but at all the tested angles, the smallest sized drops increased with pressure. Although less consistent, most of the distributions with the lowest numbers of larger drops occurred with the lower pressures, that is, 8 and 9 psi.

In general, it would appear that the variations in the drop distribution, which are due to either pressure or nozzle angles, are of little importance for the ranges tested. The amount of variability when only pressure, or only nozzle angle is changed, is quite similar to the variability in the five test runs which were made under standard track conditions. The wind during the tests of pressure and nozzle angle changes was light but increased slightly, and this may have caused some of the indicated variations.

FLOUR SAMPLE COMPARISONS

A method for determining drop-size spectra which has been in use for some time at the test tract at Holloman, is to expose a tray of flour to the. artificial rain. Preliminary analysis of this data was provided by Holloman and we were provided with fractional accumulation by volume.

In order to compare these flour sample distributions with the volume distributions obtained with the other instruments, a conversion of the surface distribution to a volume distribution must be made. The volume distribution is obtained from the surface distribution by dividing the surface distribution by the velocity of the drop.

To determine a first estimate of the velocity to be used, the difference between the accumulation rate and the distribution calculated rainfall rate must be considered. The accumulation rate was about 5.5 in/hr and the distribution rate is about 7.5 in/hr. This means that the drops are falling at about 70% of terminal velocity.

Cataneo and Semonin. (1969) showed that a fall distance of about 1.5 m results in drops of 2.0 mm reaching 70% of terminal velocity. Initially a height of 1.5 m is then assumed, and the velocity of each drop size is taken to be the velocity after 1.5 m of freefall. This seems reasonable from examination of the spray configuration, where the highest point of the spray appears about five feet above the sprinkler heads.

The surface diameter distribution is related to a surface mass distribution by a multiplicative constant containing the density of the water and the square of the diameter.

A normalized accumulative distribution of masses for each flour sample was known and from this the resulting normalized volume distribution was calculated. The total concentration of the spectra was then calculated using the measured accumulation rate from wedge gages. This is accomplished by using the normalized volume distribution and the same velocities as assumed earlier. This volume distribution is very sensitive in the small and large size categories to the method used for data interpolation and extrapolation. Through the middle categories ($1.0 < D < 2.5$) reasonably close agreement with the other spectrometers can be achieved. Again, when comparing point measurements, the statistical sample size becomes important and most of the discrepancies in the middle categories may easily be attributable to the limited sample size of both methods of measurement. Figure 9 is an example of how closely the flour sample was to the spectra measured by the USAF spectrometer.

Other data have been analyzed and about the same degree of correspondence noted. The flour sample in conjunction with wedge gage measurements of accumulation rates provide a relatively easy manner of providing spot checks as to the condition of the field. It would appear from drop camera data that the position of a sample relative to a spray nozzle is of little importance, but the accumulation rate should be obtained in the same location.

DROP-SIZE DISTRIBUTIONS IN NATURAL RAIN

A collection of drop-size distributions obtained in natural rains by the Illinois State Water Survey were used to determine average distributions corresponding to rainfall rates equalled or exceeded 0.01%, 0.1%, 0.5%, and 1.0% of the total time per year in various climatic regions.* The rates corresponding to these frequencies are tabulated in Table 3. These rates were determined from frequency curves prepared by D. M. A. Jones as part of the work of AFCRL Contract F19628-69-C-0070. The raingage data from Woody Island, Alaska were used to represent arctic regions, that from Panama to represent the tropics, and that from New Jersey to represent temperate climatic regions. The average annual frequency is based on the New Jersey, Florida, and Panama data. It was used to determine the appropriate rates for the overall average drop-size distributions.. These rainfall-rate frequencies were determined for 1-minute average rates measured by weighing bucket gages with 6-hour chart drives. Such data were available for about 1 year for each location used except at Panama. Only 104 days of data were available there. All these data were taken during the months of June through November, which are in Panama's rainy season. Had data for a full year been available, the occurrence frequencies of the various rates would, of course, have been lower.

* Data for this work provided by support from U. S. Army Atmospheric Science Laboratories, Fort Monmouth and Frankford Arsenal, Philadelphia, Pennsylvania.

The set of average distributions in figure 10 are for all data available. All the samples having rates within ± 12% of the desired average rate were included. Rainfall rates and other parameters were then calculated for the average distributions. The number of samples used in each average varies with rate ranging from 927 for the 5.2 mm/hr distribution to 154 samples for the 95.6 mm/hr distributions.

The data for the overall distributions came from nine locations. These locations are: Champaign, Illinois; Miami, Florida; Corvallis, Oregon; Majuro, Marshall Islands; Woody Island, Alaska (near Kodiak); Bogor, Indonesia; Island Beach, New Jersey; Franklin, North Carolina; and Fort Sherman, Canal Zone (which is generally referred to in this report as "Panama").

Table 3. Rainfall rates (mm/hr) equalled or exceeded for the indicated percentages of the time in various climatic regions.

	0.01%	0.1%	0.5%	1.0%
Arctic	9.0	5.4	3.7	3.0
Temperate	55.2	15.0	4.8	3.3
Tropical	135.0	84.0	27.0	8.4
Average	95.6	45.6	13.3	5.2

Figures 11, 12, and 13 show, respectively, similar average distributions for "temperate", "tropical", and "arctic" climates. The temperate curves are for the combination of Illinois, New Jersey, and North Carolina data, the tropical distributions are from Panama and Indonesia data. Only the data from Alaska were used in the arctic curves.

Several things can be noticed in these distributions. First, the frequencies of rainfall rates vary, as might be expected, with the various climatic regions. The shape of the distributions are different. The temperate curves have sharper peaks with modes in the 1.0 to 1.5 mm drop-size region, while the tropical distributions are more rounded. The arctic distributions are all very close together due to the very narrow range of rainfall rates that occur in such climates. Rates greater than 18 mm/hr, or 0.71 in/hr, occur for only 5 minutes per year. This rate would be exceeded in Panama 0.65% of the time, or 57 hours per year. The arctic drop distributions from Alaska have a bimodal characteristic for all rates greater than 7.5 mm/hr. A slight tendency to bimodal distributions has been noticed at several other locations, such as Panama, but not distinctly as in the Alaska data.

Figure 14 shows the average calm wind test track spectrum with the two regional natural rain averages which are most similar in rainfall rate. The test track spectrum has fewer drops than either natural rains in the larger drop sizes. The tropical rain spectrum has considerably fewer small drops than the simulated rain. The test track rain is more similar to the temperate spectrum, but the shortage of drops in the larger sizes may be important in some experiments on the test track.

CONCLUSIONS AND RECOMMENDATIONS.

The artificial rain field at the Holloman Rocket Test Track has been successfully calibrated. The results indicate that the most serious problem affecting rain field data and their interpretation of the results is one of wind conditions at the time of firing. If the particular test requires knowledge of the number of small water drops impinging on the specimens, winds of less than 1 mph are necessary. The large drop concentrations are considerably less affected and also the effect appears to be systematic. That is, the number of large drops consistently reduces as the cross winds increase.

Little or no effect could be noted with "along track" winds of less than 3 mph although the amount of data available supporting this statement is limited.

The spectrometer purchased by the Air Force from IITRI is a very impressive instrument. Rain drop measurements with this instrument compare favorably with those from the rain drop camera in all cases. Data handling with the IITRI spectrometer is simplified greatly by having automatic sizing and digital output. For tests in the main rain field the magnification of 8:1 is recommended for most purposes. An exception to this may be in the desire to obtain detailed information on drops smaller than 1.0 mm, if such a need exists. It is recommended that in the future the openings of the spectrometer be increased to about 10 to 12 inches. This change yields a larger sample volume in 10 seconds without undue danger of either channel overflow or multiple drop errors.

Two computer programs written in conjunction with this research have been furnished to the test track personnel at Holloman. One of these programs performs the conversion of surface cumulative mass distributions, as measured by flour samples, to volume size spectra in standard units. This program requires the flour sample data and the wedge gage accumulation rates as input.

The second program interprets the output of the USAF spectrometer. The input consists of the numbers produced by the spectrometer along with the spacing between the hoods. The output is the volume size spectra in standard units, the liquid water content, and the equivalent rainfall rate.

Average drop size spectra for three major climatic regimes have been obtained for 4 different frequencies of rain occurrences.

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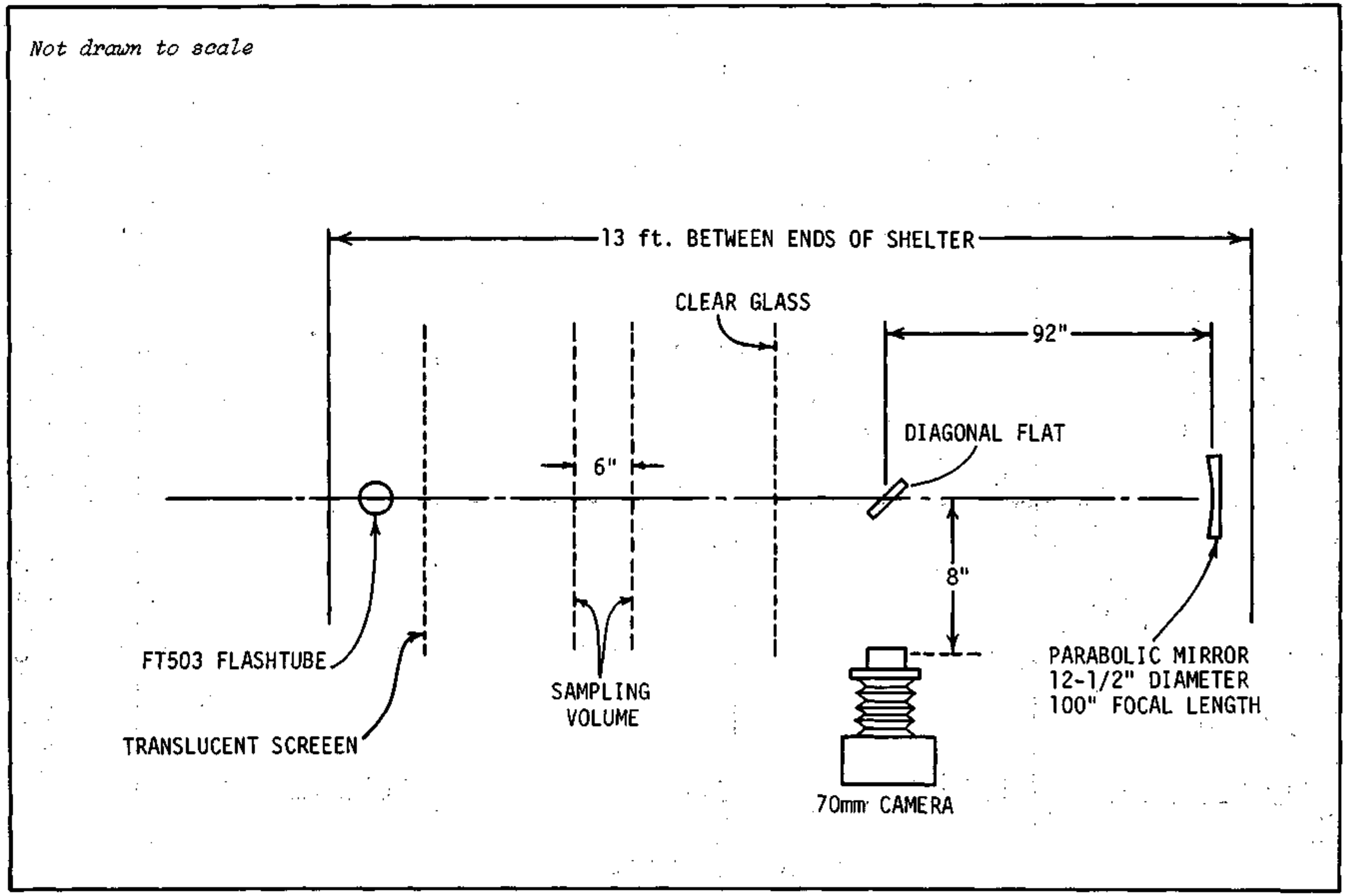
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Figure 1. Optical configuration of the drop camera

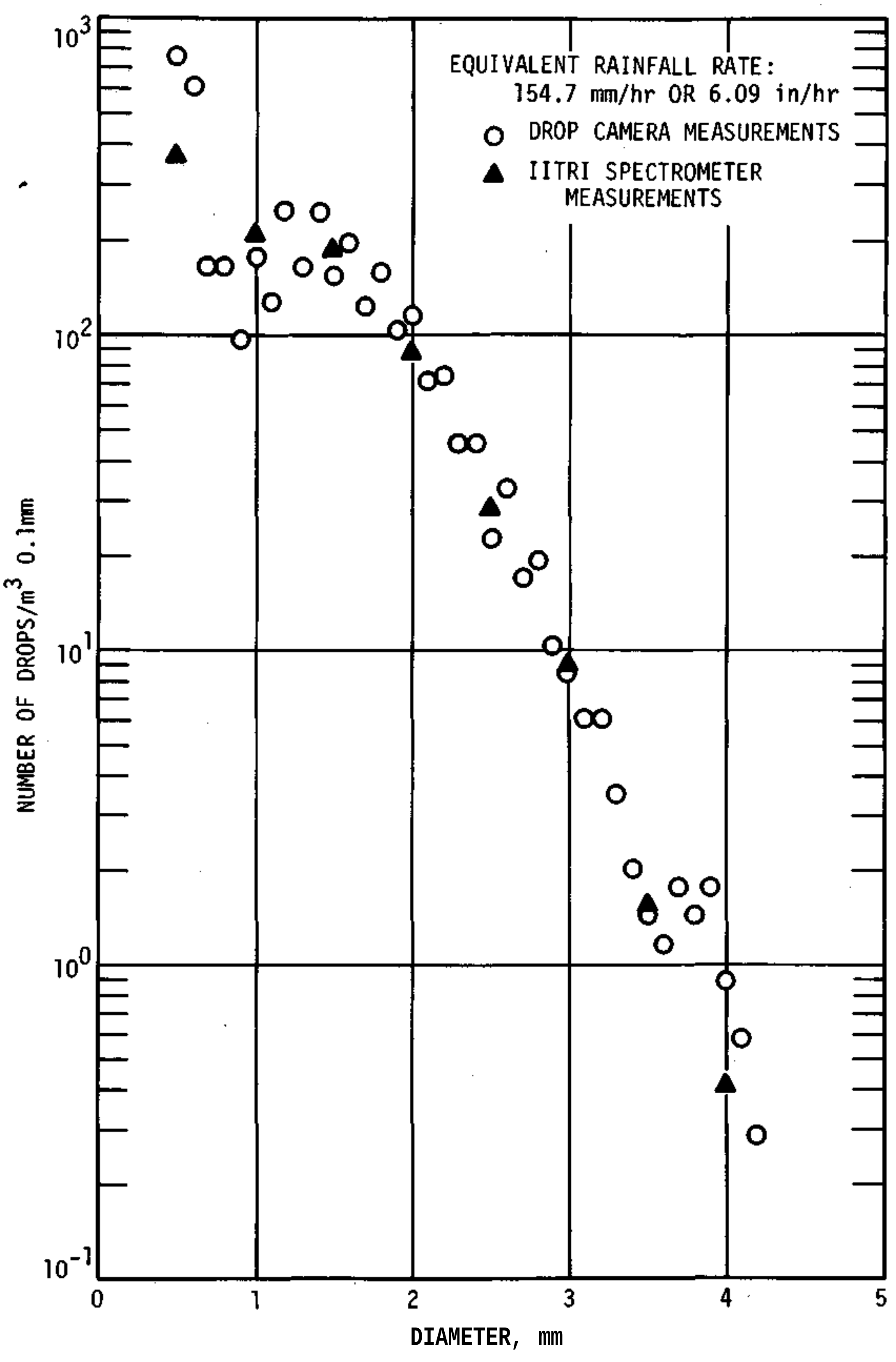

Figure 2. Drop spectra for September run 1 as determined by the drop camera and by the IITRI spectrometer

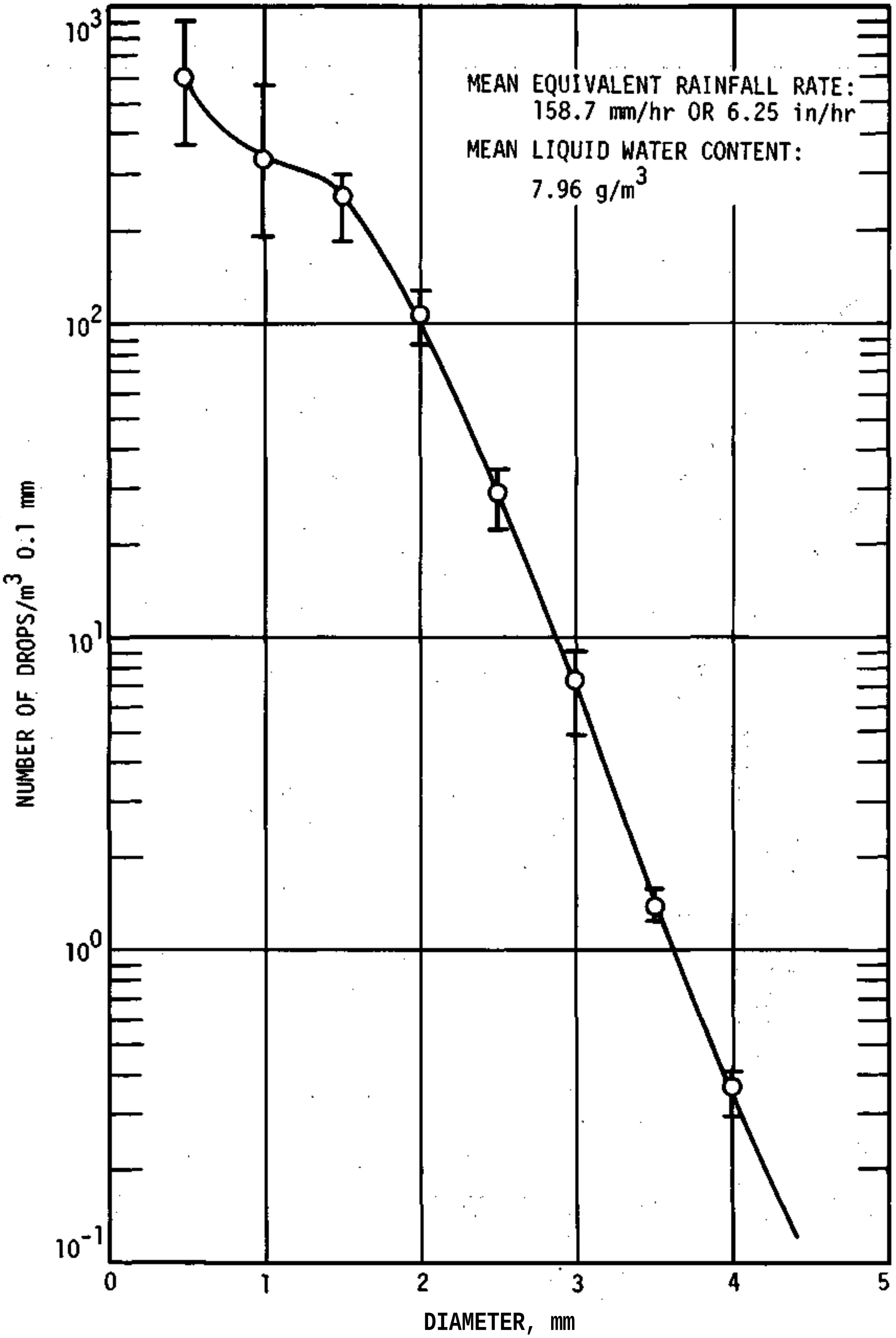

Figure 3. The mean spectrum for the four no-wind runs as measured by the IITRI spectrometer. The vertical bars show the range of measurements from the four runs

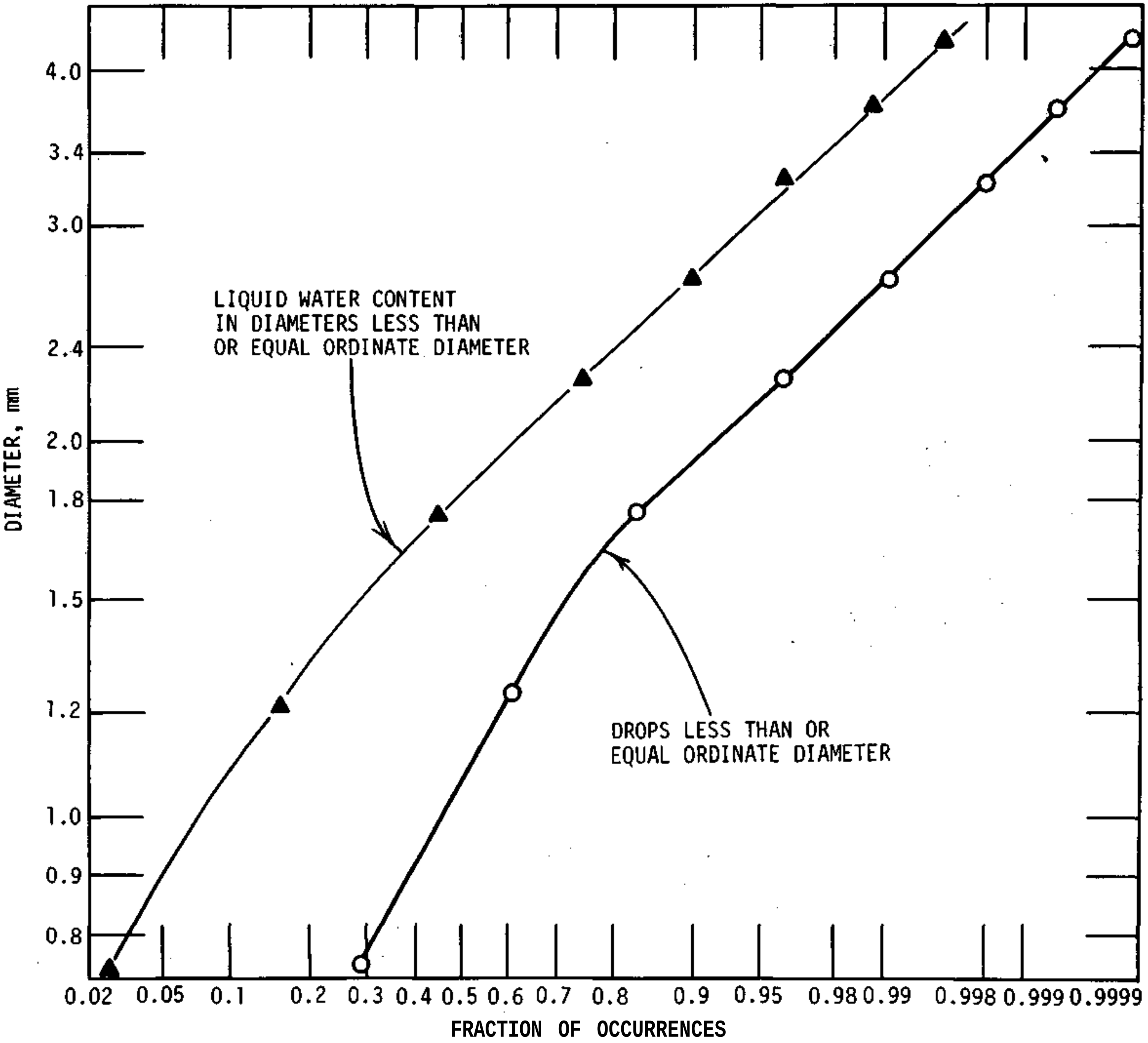

Figure 4. A logarithmic probability plot of the average USAF spectrometer drop-size spectrum

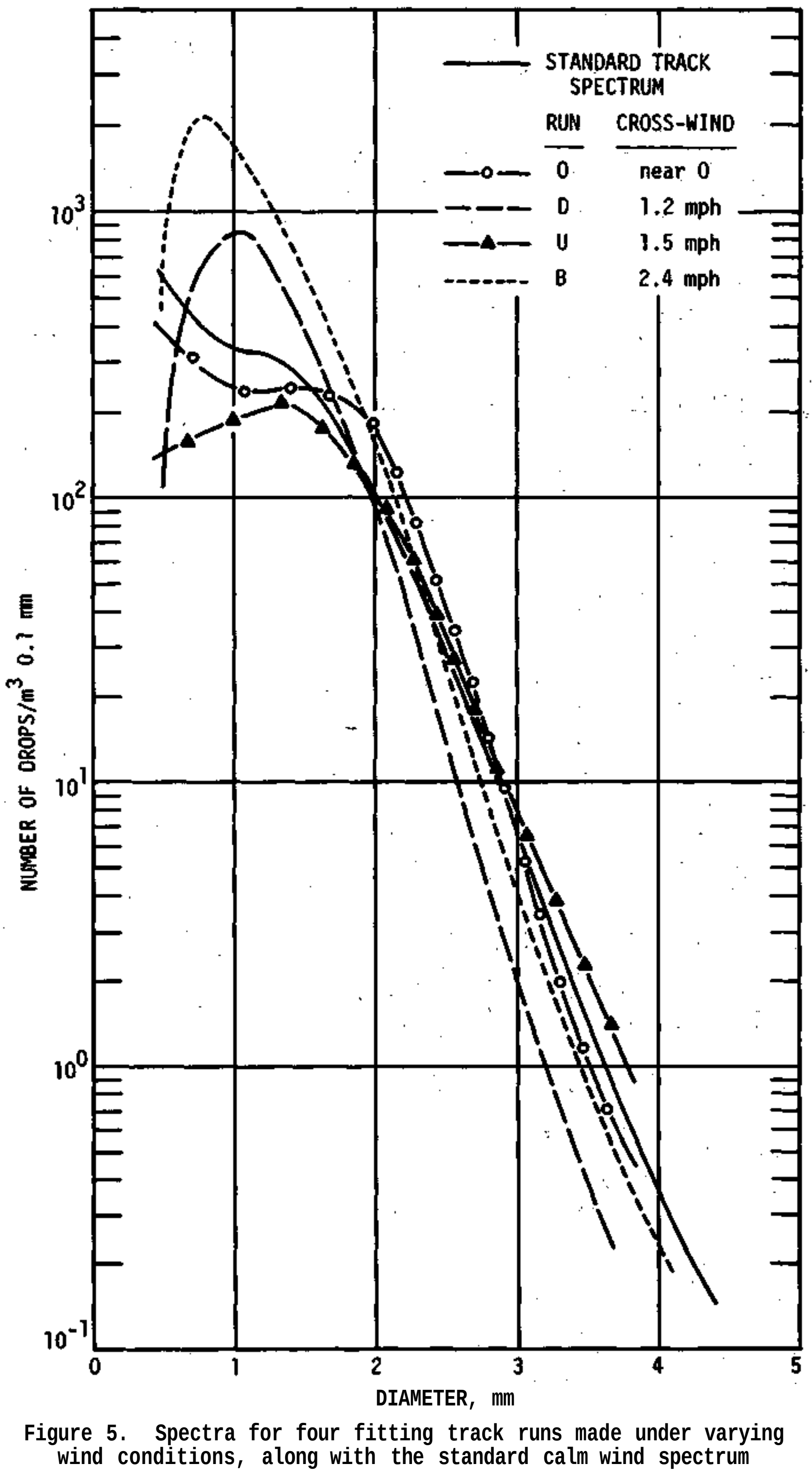

Figure 5. Spectra for four fitting track runs made under varying wind conditions, along with the standard calm wind spectrum

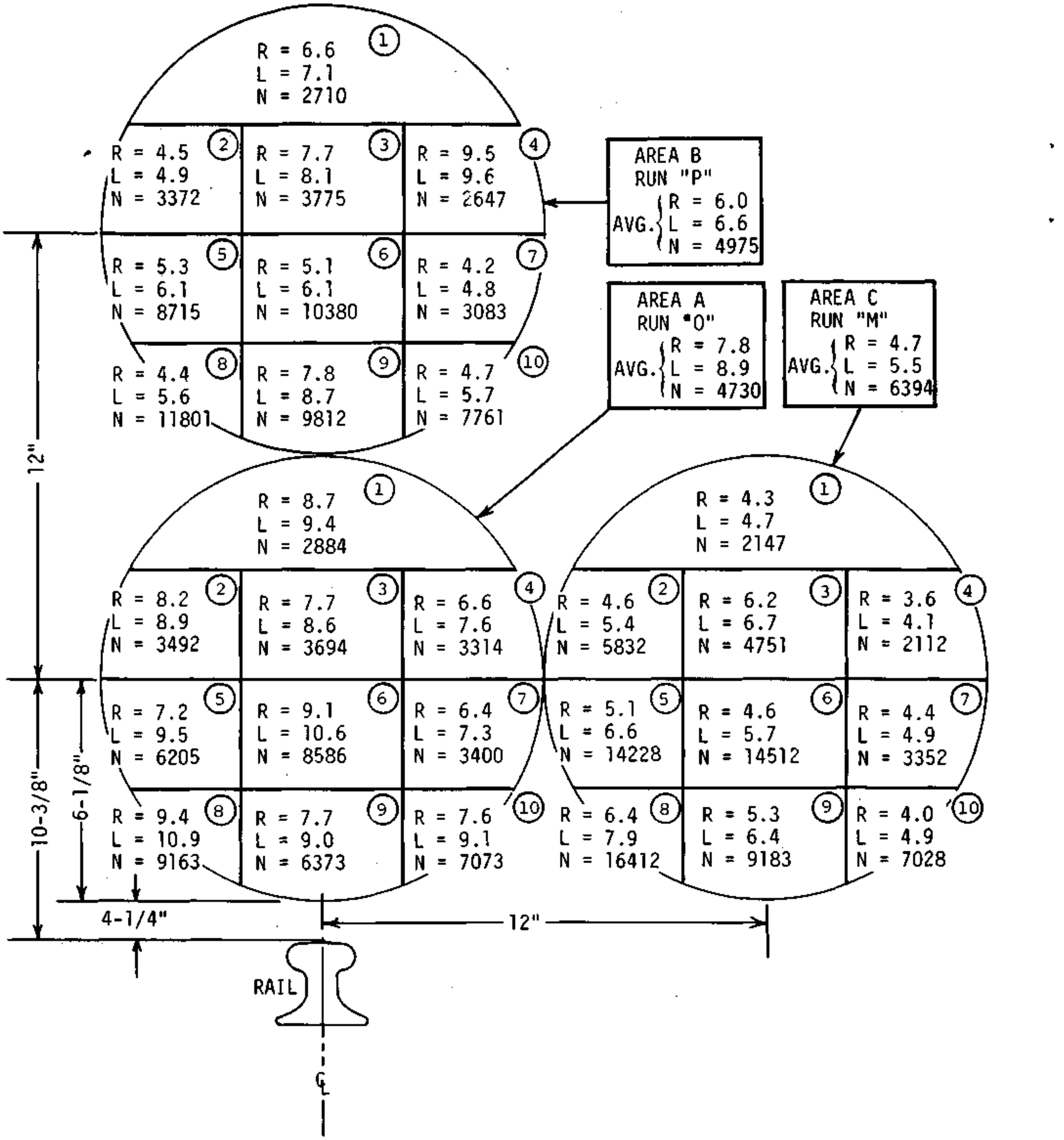

Figure 6. Drawing of the measurement sections showing the values of equivalent rainfall rate, R, liquid water content, L, and total drop concentration, N, for the data runs indicated. The parameter R is in in/hr, L is in g/m^3, and N is number/m^3. The circled numbers are the section numbers

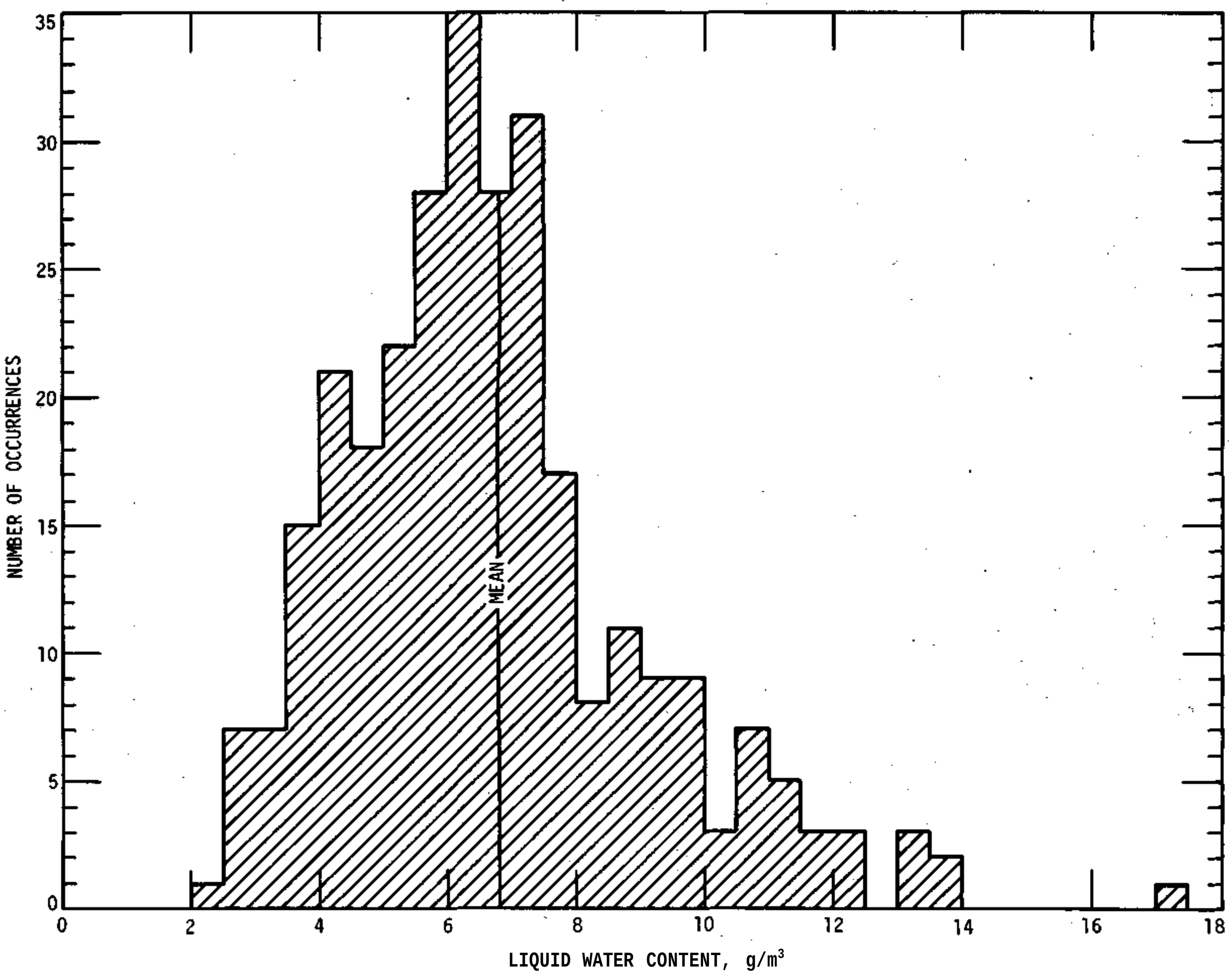

Figure 7. A histogram showing the number of occurrences of various values of liquid water content (Run 1, Sept 1969)

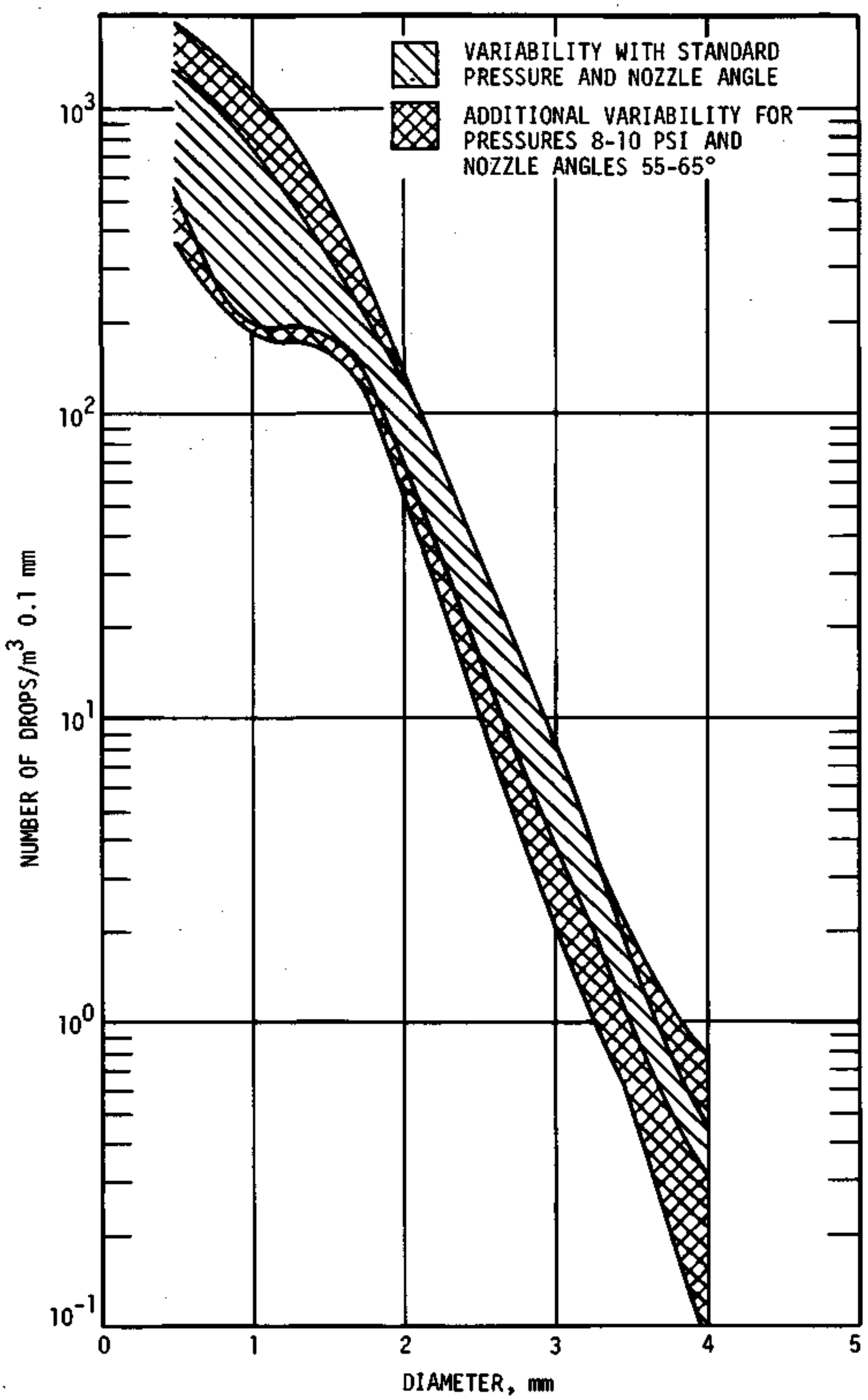

Figure 8. Drop spectra variability due to pressure and nozzle angle changes

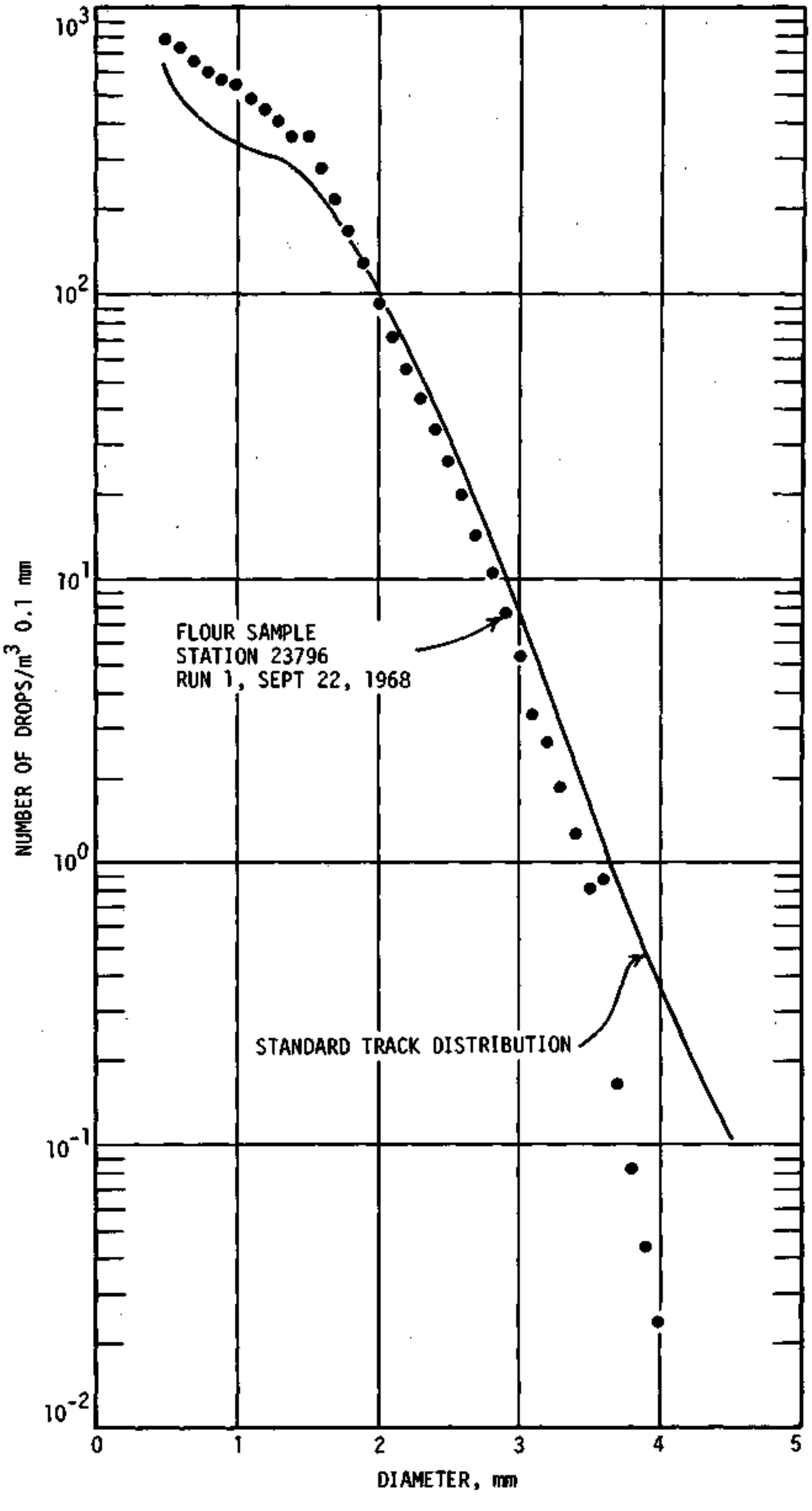

Figure 9. A flour sample drop spectrum with the average calm wind spectrum

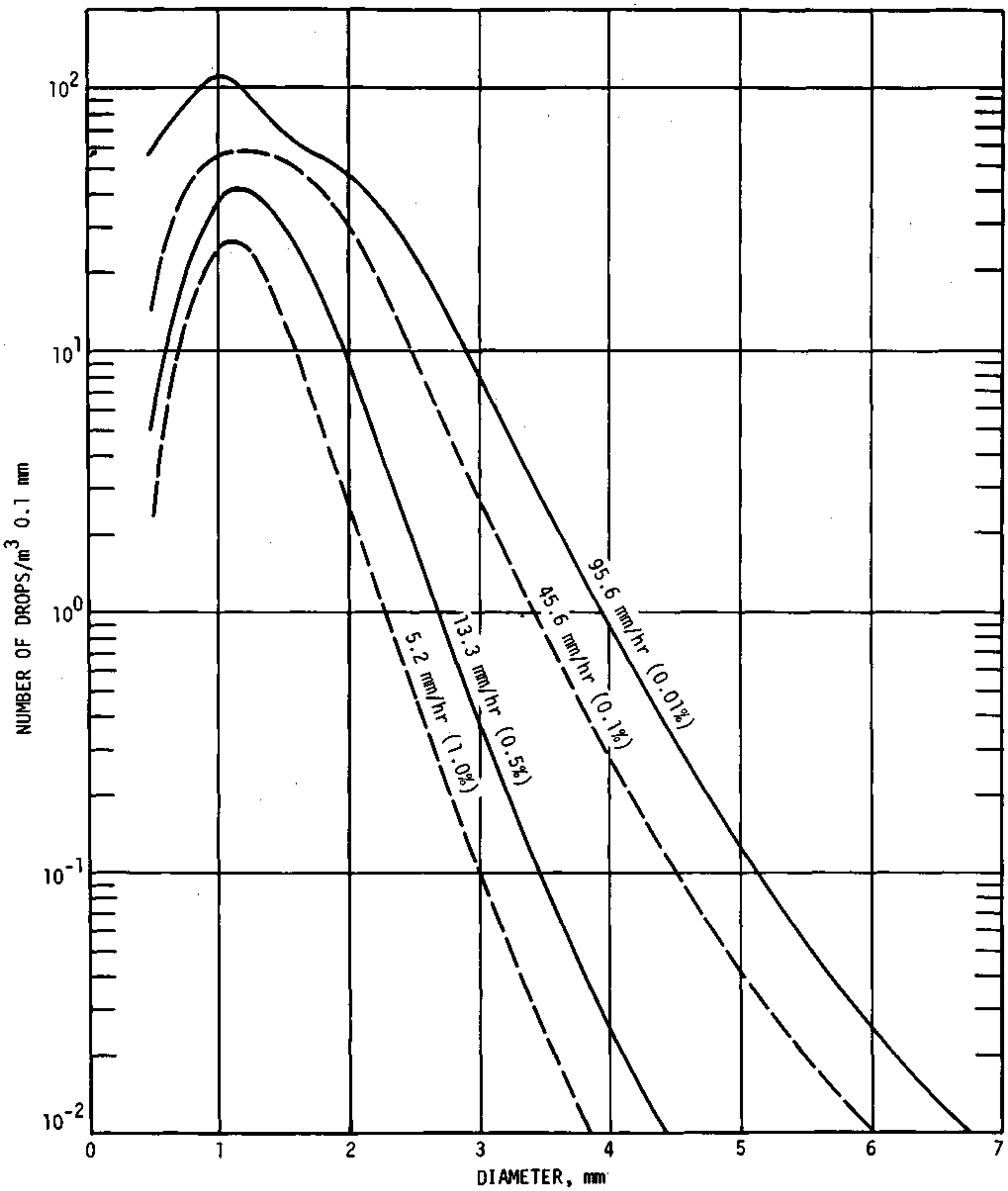

Figure 10. Average drop-size spectra for natural rainfall rates occurring 0.01, 0.1, 0.5, and 1.0% of the time. These curves are for all available data

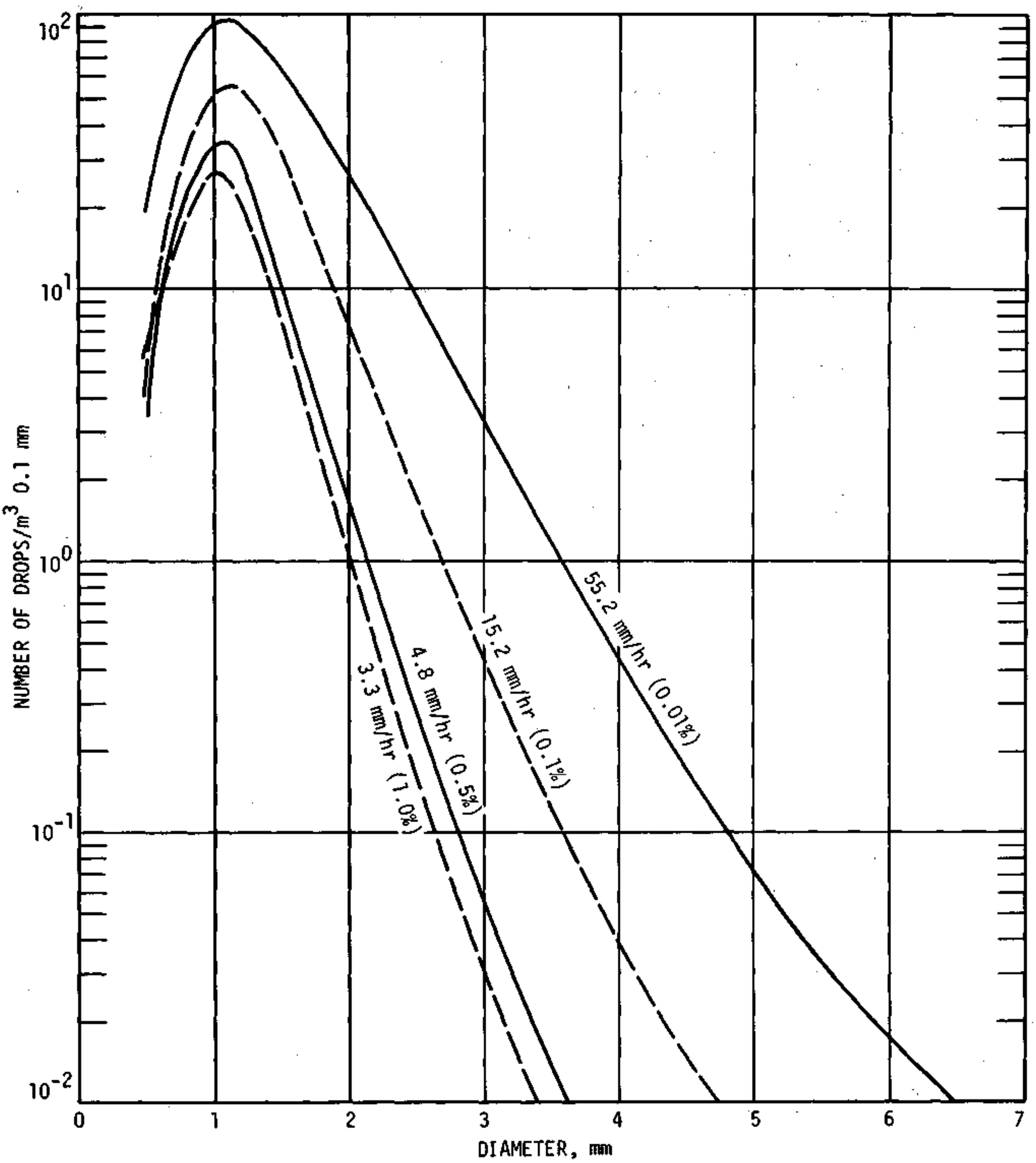

Figure 11. Average drop-size spectra for natural rainfall rates occurring 0.01, 0.1, 0.5, and 1.0% of the time. These curves are for temperate climates

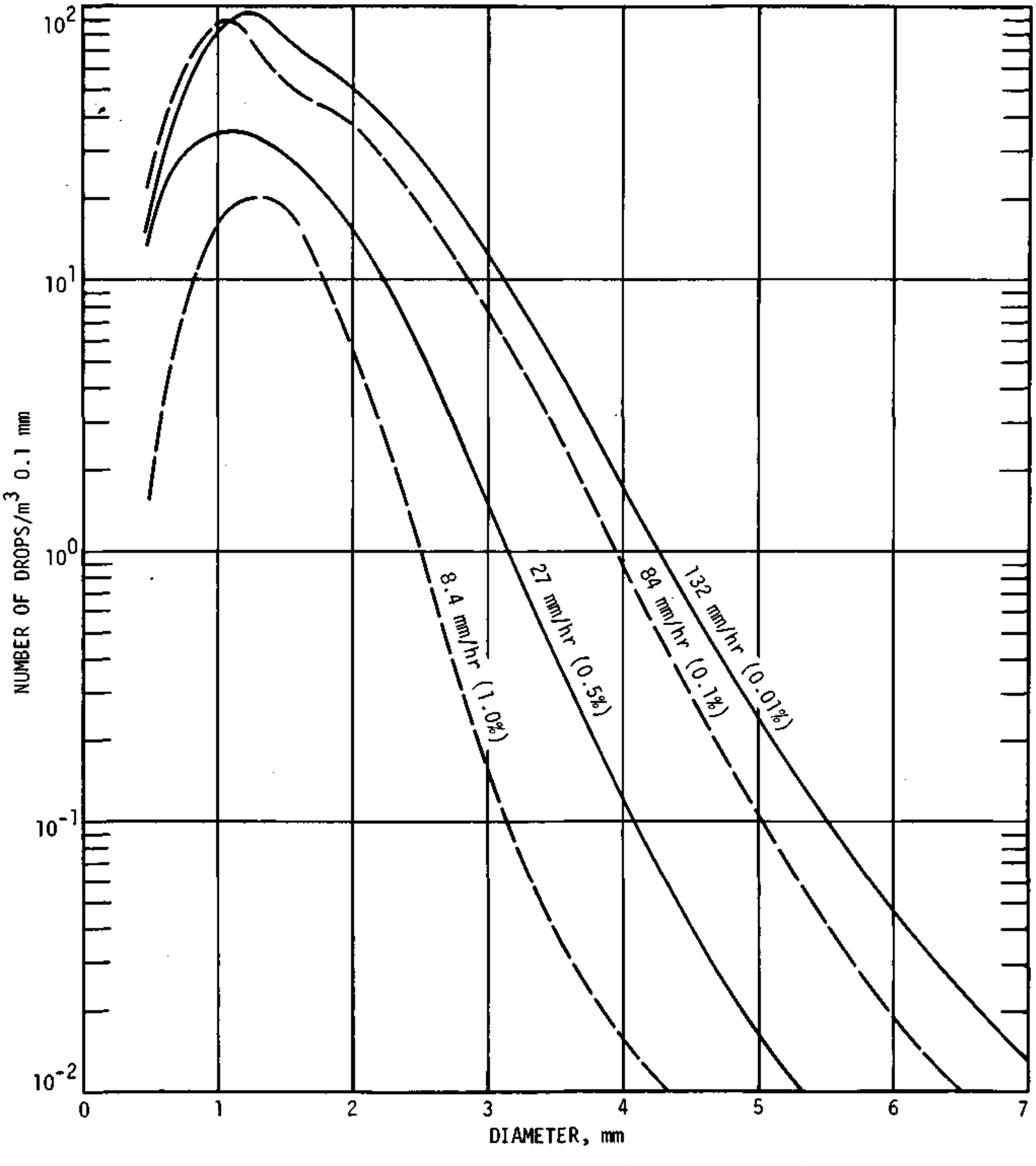

Figure 12. Average drop-size spectra for natural rainfall rates occurring 0.01, 0.1, 0.5, and 1.0% of the time. These curves are for tropical climates

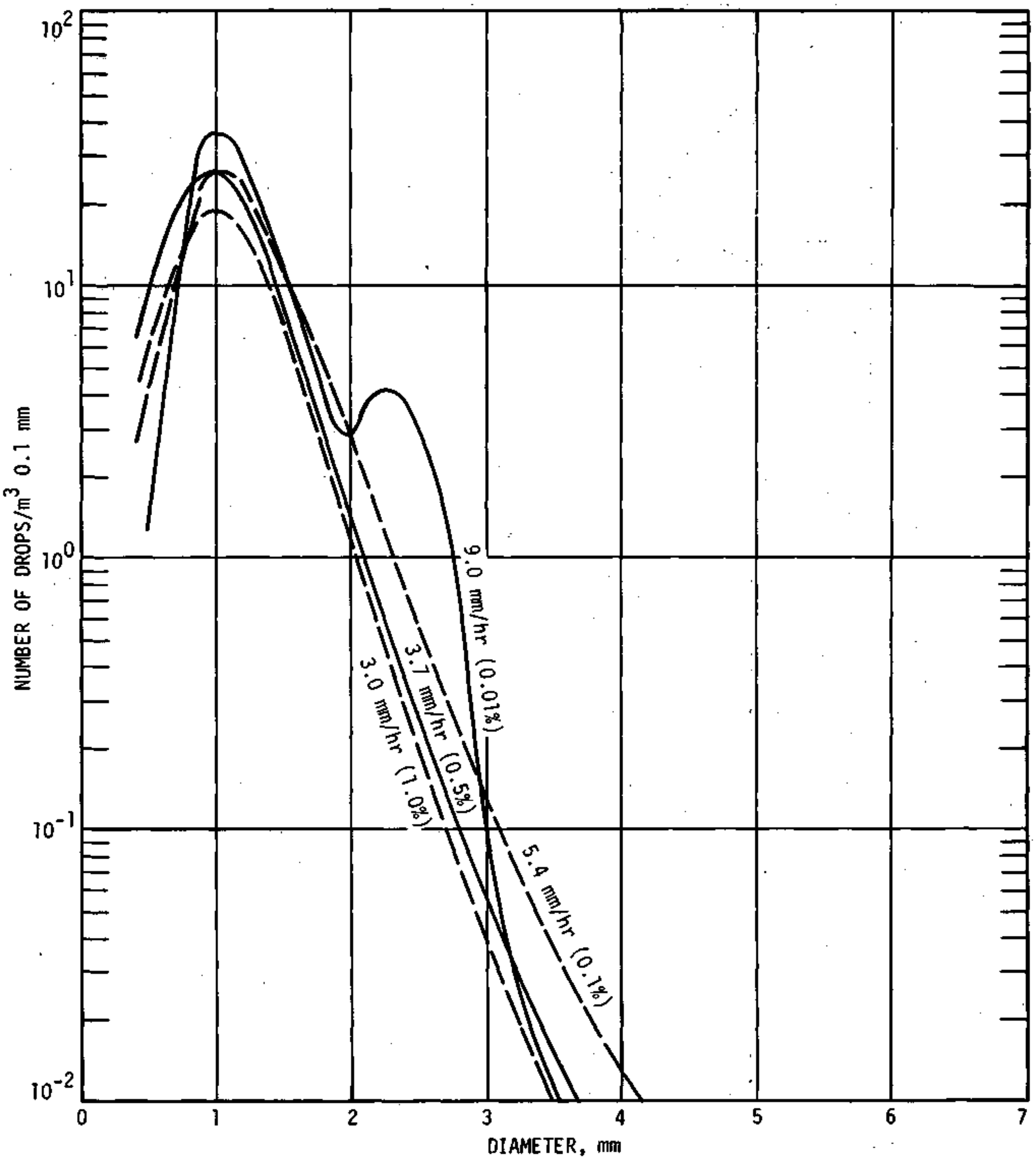

Figure 13. Average drop-size spectra for natural rainfall rates occurring 0.01, 0.1, 0.5, and 1.0% of the time. These curves are for arctic climates

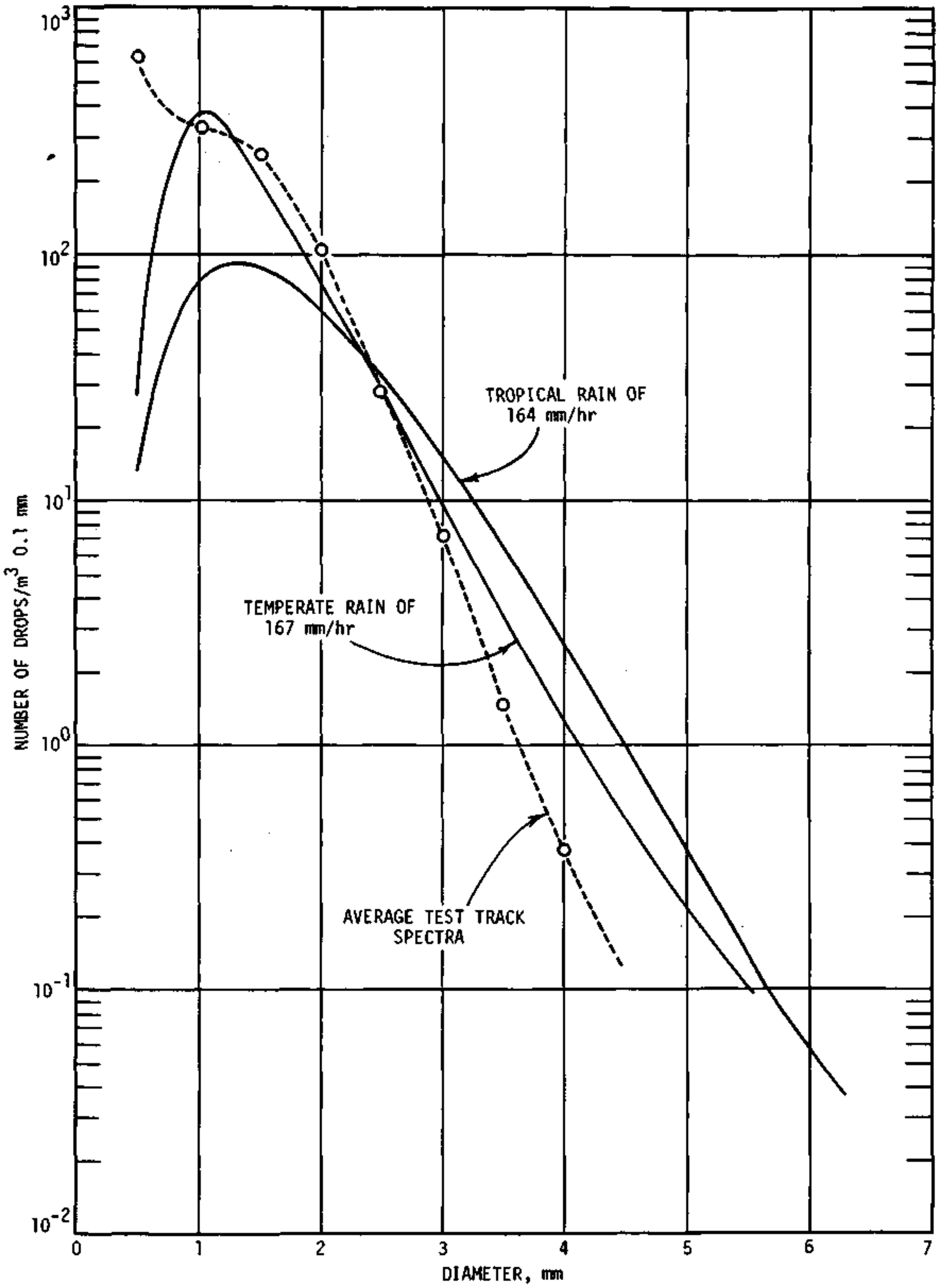

Figure 14. High rate drop-size spectra from tropical and temperate regions with the average calm wind test track spectra

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13. ABSTRACT

The results of measurements of the simulated rainfall at the Holloman test tract facility are presented. Raindrop spectra measurements were made with a drop camera and with an optical electronic drop spectrometer. A small amount of drop measurements using the flour pellet method were also made for comparison with the other methods.

The measurements of the simulated rainfall were compared with average natural rainfall data collected with the drop camera. The average spectra from the track has a liquid water content of 7.96 g/m^3 and an equivalent rainfall rate of 158.7 mm/hr. It does not correspond directly to any natural rainfall rate.

The natural rain data have been sorted into data from arctic, tropical, and temperate regions, and average raindrop spectra for various frequencies of occurrences calculated.

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