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STUDY ON INTENSITY OP SURFACE PRECIPITATION USING RADAR INSTRUMENTATION

TENTH QUARTERLY TECHNICAL REPORT

1 July 1960 - 30 September 1960

Signal Corps Contract: DA-36-039 SC-75055

DA Task 3-99-04-112

Sponsored by

U. S. Army
Signal Research and Development Laboratory
Port Monmouth, New Jersey

To record and analyze data on raindrop-size distribution in various parts of the world. These data will be correlated with appropriate radar parameters in order to improve the capability of radar in measuring surface rainfall intensities for Army applications such as radioactive rainout prediction, trafficability, and communication.

Prepared by

E. A. Mueller
Project Engineer

G. E. Stout
Project Director

William C. Ackermann, Chief
Illinois State Water Survey

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PURPOSE

The object of this research is to study the utility of radar equipment in measuring surface precipitation and to improve radar techniques in measuring precipitation for application by the Army to radioactive rainout prediction, trafficability, and communications. Considerable effort is being directed toward determining the correlation between radar variables and actual rainfall quantities by means of raindrop-size distribution.

ABSTRACT

A summary of the operation of raindrop cameras under this contract is given. Satisfactory operations of one year of raindrop cameras at Miami, Florida! Corvallis, Oregon; Majuro, Marshall Islands; and Woody Island, Alaska were obtained.

The means of reducing raindrop data has been reviewed. An automatic means of transferring measurements from the projection table to IBM cards has been built. Preliminary analysis of the drop data are reviewed. Some results are given from the Miami data.

A summary of the problem of rainout is discussed.

PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

Mr. E. A. Mueller visited Evans Signal Research and Development Laboratories on August 30, 31, 1960 to discuss the location of the drop camera in New Jersey area. Analysis means were also discussed.

INTRODUCTION

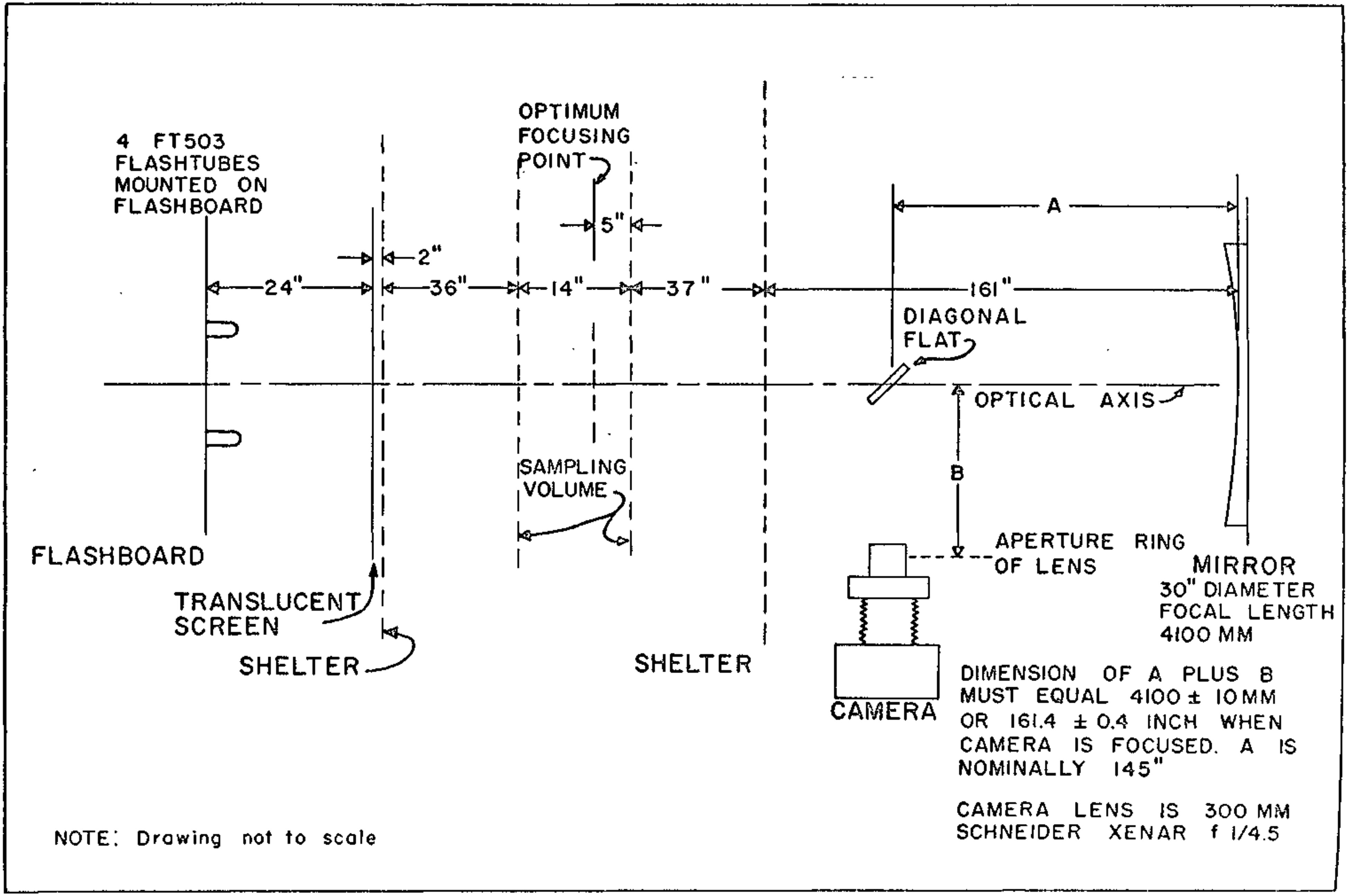
Since the original period for the present contract terminated on September 30, 1960, it was thought desirable to summarize operations of the first year and a half in this quarterly report. Included therefore is a brief review of the major work accomplished on the present contract, including a review of the completed subcontracts at Miami, Florida; and Corvallis, Oregon, for operation of the drop cameras, and some of the results of the analysis of the Florida data.

The general objective of the research under this contract was to determine the possibility of obtaining quantitative information on the distribution of precipitation intensity over large areas by use of radar techniques. Further, the possibility of using the radar for relating the radar echo directly to the scrubbing effect of the rain for atomic debris particles was to be investigated. The general approach to the problem of obtaining quantitative information on precipitation intensity, which was performed on previous contracts DA-36-039, SC-64723, and SC-42446, led to the determination that a large portion of the difficulty in interpreting the radar parameters was due to lack of detailed knowledge of the drop size distribution of the rainfall. Therefore, during the previous contracts, preliminary instrumentation to determine drop size distributions was proposed and designed. As continued information was gained on drop size distributions, it became apparent that not only did the drop size distributions vary appreciably from situation to situation but also that there were climatic differences in the distributions that mu3t be considered in the use of a radar set to accurately measure rainfall intensity.

In addition to the work directed towards determination of drop size distributions, continued work on means of calibrating the radar and in presenting and obtaining information from the radar was to be performed.

THE DROP CAMERA

On contract SC-42446 an optical system was devised to photograph raindrops. A Research Report Number 3 under that contract was issued which indicates the general principles of the optical system and the means used to obtain pictures of the raindrops. During contract SC-64723, the need for a reliable camera was noted. As a result, the original camera was set aside and a new drop camera designed using the same basic optical technique. Figure 1 shows the optical system used in the present drop cameras. The optical system is sometimes referred to as a telecentric optical system. Essentially, this consists of a first lens which in this case is represented by the paraboloidal mirror, with an aperture stop placed at the focal distance away from the first lens. A second lens is used by the camera to focus the image onto the film plane. The use of the diaphragm of the second lens as an aperture stop for the whole system at the focal point of the first lens forces the chief ray of every point in object space to be a ray that is parallel to the optical axis of the first lens. Since the chief rays are parallel to each other, there is very little effect of perspective in the final picture.



DIMENSION OF A PLUS B MUST EQUAL 4100 ± 10 MM OR 161.4 ± 0.4 INCH WHEN CAMERA IS FOCUSED. A IS NOMINALLY 145"

CAMERA LENS IS 300 MM SCHNEIDER XENAR f 1/4.5

NOTE: Drawing not to scale

FIG. I OPTICAL POSITIONING OF DROP CAMERA, TOP VIEW

The redesigned camera uses 70-mm film instead of the original 35-mm film. A 30-inch mirror is used instead of the original 12-inch mirror. The overall magnification of the system from object space to film plane is 0.075. The object space is illuminated with 4 flash tubes that are contained in the instrument shelter. These flash tubes provide back lighting for the raindrops. The flash from the flash tubes is approximately 10 microseconds long to the half light point. . These flash tubes are driven by a power supply which provides 3000 volts with 14 microfarads of capacity to produce a flash of 500 watt-seconds.

The overall resolution of the drop camera system has been determined to be i0.15 of a millimeter measured in the object space. This corresponds to a resolution of approximately 93 lines per millimeter on the film. This resolution on the film is obtainable only by fine grain development procedures. Therefore, it has not been found feasible to have the drop camera film processed by commercial laboratories. The film that has been recommended by Eastman Kodak Company and has given the most consistent results has been Plus X. This is the type of film that has been used on all of the 70-mm installations. During the earlier operations with the 35-mm camera, the resolution on the film had to be much higher and a much lower speed and fine grain film was necessary.

Three of the 70-mm cameras have been used for work on this contract. Two cameras were carried over from SC-64723 and a third camera was constructed on SC-75o55. Since the change to the 70-mm cameras, very few interruptions have occurred because of camera, power supply, or triggering circuit failure.

The drop camera samples rainfall by taking pictures at intervals of 1.5 seconds. Seven pictures are taken in the first 10.5 seconds of a minute. The camera is then turned off for 49.5 seconds until the beginning of the following minute when the sever samples are repeated. Each picture on the drop camera film represents a volume of approximately one-sixth of a cubic meter. The volume is a right circular cylinder 29 inches in diameter and 14 inches high. Using this sampling technique, a volume of air somewhat larger than one cubic meter is sampled at the beginning of each minute. The drop size distribution obtained from this one minute sample is referred to as one sample of the rain.

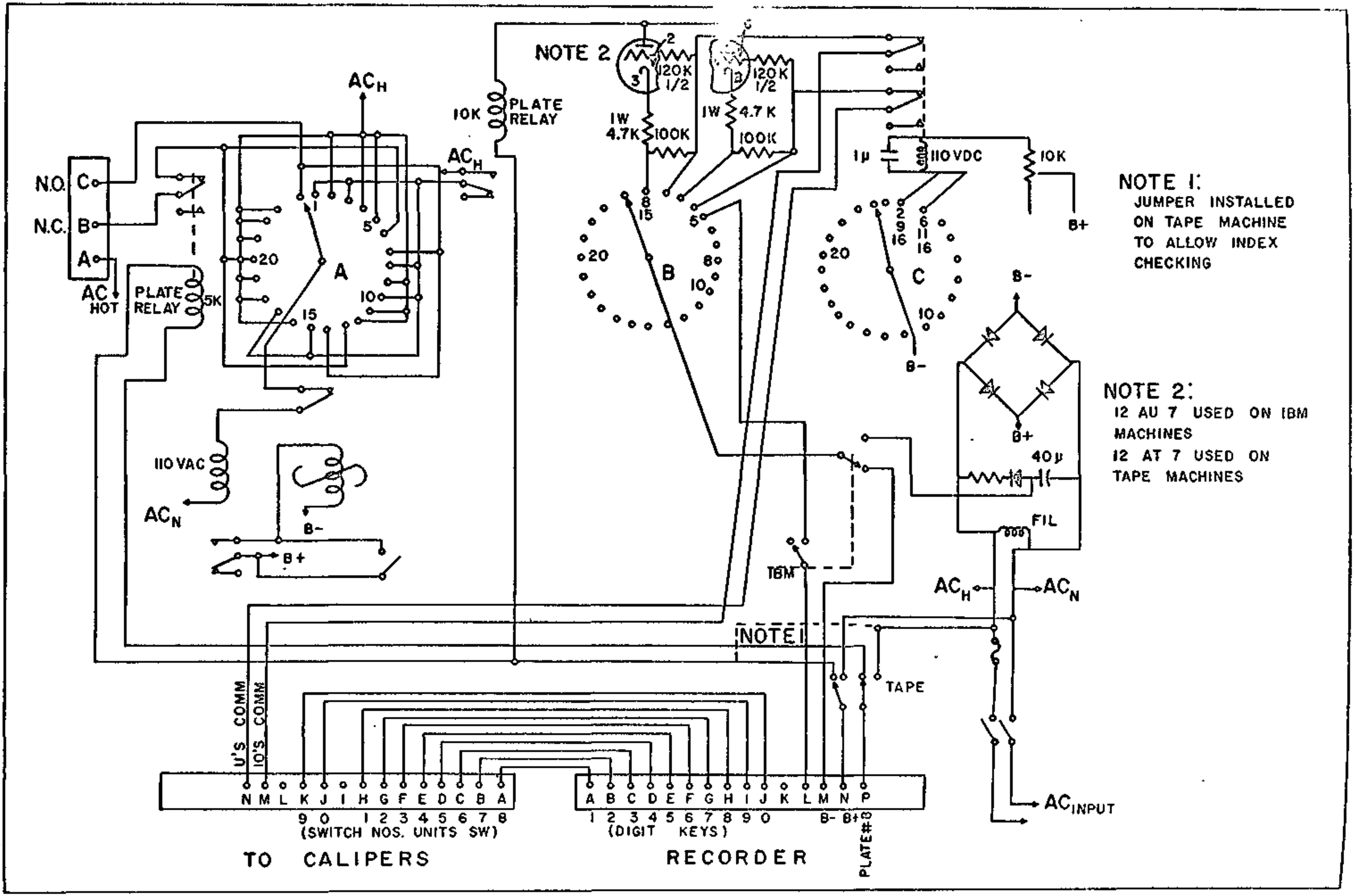
PROJECTION TABLES

Prior to this contract the drop camera film was measured by projecting the film onto a translucent screen and measuring the size of the raindrop with a caliper. The size of the drop was recorded by reading the vernier scale on the caliper. Later, a modification of this system was installed whereby the caliper was connected to a Veeder-Root counter by means of a flexible cable. In this system rotation of the lead screw on the calipers changed the position of the dials of the counter. When a measurement was desired, a foot-switch was pressed and the counter printed a number which was proportional to the size of the openings on the calipers. This method was faster than individual reading and recording, but still left much to be desired. The flexible cable which connected the calipers to the counter would change angular position as the calipers were moved around on the table. This produced a possibility of as much as a tenth of a millimeter error in the measurement. Also, the mechanical drag of the counter along with the • flexible cable made the operation of the caliper quite stiff which was fatiguing to the operator.

Early in the present contract it was determined that a more rapid means of processing the data must be accomplished. The present technique is to use a caliper which was designed and built specifically for counting raindrops. This caliper has two switches located on the back side of the caliper. It is connected by means of a 12-conductor flexible cable to a control box. As the caliper jaws are opened or closed, the position of the 10-position witches are changed in accordance with the size to which the jaws of the calipers are set. In the control box there are decoding relays and control relays which interpret the settings of the caliper switches and in turn supply pulses to an IBM 024 card punch. In this way it is possible to make measurements on the drops and have results automatically recorded into IBM cards. This saves considerable labor in the analysis.

Figure 2 is a schematic diagram of the control box which was designed for operation with an IBM 024 card punch. Built into this control box are several safety devices to prevent errors in counting. The vacuum tube along with its associated plate relay prevents operation of the control unit unless the caliper switches are properly indexed. This prevents the punching of blank columns in the IBM cards. It also prevents a possibility of double punching in a single column of the IBM card. There is an indexing relay which along with the program card on the IBM card punch prevents measurements of the raindrops from occurring in improper spaces on the IBM card. This was found to be necessary since occasionally the IBM card would advance one position more than required, and, as a result the drops were punched into the wrong fields which caused considerable errors in the analysis.

At present two tables using 021; card punches are in routine operation. A third table which has not as yet been supplied with an 024 punch is operating with a paper tape recorder. In other words, the same calipers and the same control box are being used, but the results are being printed on paper tape by means of a Victor adding machine.



NOTE 1:
JUMPER INSTALLED ON TAPE MACHINE TO ALLOW INDEX CHECKING

NOTE 2:
12 AU 7 USED ON IBM MACHINES
12 AT 7 USED ON TAPE MACHINES

FIG. 2 CALIPER CONTROL SCHEMATIC

CPS-9 RADAR

During the period of this contract the CPS-9 radar has been used for the collection of data for 2804 hours. A portion of this data was collected for comparisons of the predicted rainfall values from rainfall rate - radar reflectivity relationships with the rainfall values obtained from the rain gage network located northwest of the radar station. A portion of the operation of the CPS-9 has been supported by an Air Force contract AP 19(604)-4940. Operation of the CPS-9 for this project has been limited to the collection of data during times of severe weather. This Air Force contract also supported the modification of the CPS-9 antenna drive to permit elevation control of the antenna.

When the CPS-9 was obtained by the University of Illinois there was no azimuth or vertical drive included. At first the antennas were driven by means of amplidynes and direct current motors purchased on the surplus market. These drive systems were not satisfactory. There was no means of obtaining vertical control of the antenna as the dc motors obtained were too large to mount on the antenna. The azimuth drive was satisfactory except for inability to locate the antenna on a particular target. The antenna would rotate continuously, but this was the extent of the control possible. Antenna drive units from an abandoned SCR 545 were modified slightly and placed on the CPS-9 antenna. This permits excellent control of the CPS-9 antenna in azimuth and in elevation.

A program chassis to permit the operation of the CPS-9 antenna in a set manner was designed. This program chassis permits the photographing of the plan position indicator, PPI, at all gain levels successively at any of five possible tilt angles. Therefore, constant altitude plan position indicator pictures can be constructed from the resulting pictures. It was felt that antenna modification was helpful not only to the Air Force who supported the work but also to the effort to datermine rainout from reflectivities other than at ground elevation.

Complete drawings and schematics of the CPS-9 antenna modification are considered to be too limited to a particular CPS-9 to be included in any of the Quarterly or Final Reports. However, should any of this information be required, complete schematics are on file.

The CPS-9 has been calibrated on a regular interval of twice a week during the times of data collection. Calibration of the CPS-9 was performed by monitoring the transmitter power using a TS-147. A coupling wave-guide horn was mounted off to the side of the CPS-9 tower and coupled by wave-guide to the console of the CPS-9. By using this wave-guide and horn, both transmitter power and receiver sensitivity could be monitored at the console. Receiver sensitivity measurements were made by varying the output of the TS-147 in two decibel steps. The test signal was photographed at the time the calibrations were made so that a permanent record of the calibrations would be available. This method of calibrating the radar is considered superior to some of the other methods in that it allows frequent checking of the relative performance of the radar to a high degree of accuracy. In this way, troubles can be anticipated to some extent.

This means of calibrating, however, leaves completely unanswered the question as to the antenna gain. For this reason, it is recommended that some means of careful antenna pattern measurements, or measurements from a standard target on a tethered balloon, be made for absolute accuracies of radar calibrations.

Some consideration has been given to the design of a continuous monitoring calibrator for the CPS-9 using an electrically controlled attenuator. This device would put a test signal around the outer edge of the CPS-9 looking to a great extent like a range mark. The strength of the signal would be modulated by the antenna azimuth position. In this way, the azimuthal extent of the outer calibration signal would be a measure of the relative receiver sensitivity and transmitter power ratio. This is proposed for future work as a part of necessary radar instrumentation.

STREAK CAMERA

The Fifth Quarterly Technical Report indicates the general design considerations for an instrument to measure the raindrop size distributions in a different manner than is presently used in the drop camera. This method consists of a slit camera and proper lighting so that the drop images are streaked across the narrow dimension of the slit. It is hoped that this technique . when fully developed will lead to atuomatic measurements of the drop size distributions and eliminate the manual labor of individual drop measurements.

As time has permitted during this contract, a streak camera has been built using mercury vapor lamps for a light source and using a slit camera on loan from the Air Force. This installation has not been completed and, therefore, no results are available as to its operation at this time. Early attempts with photo floods as a light source indicated the need for considerable more light.

SUBCONTRACTS

Miami, Florida

During the previous contract, SC-64723, a subcontract of one year was negotiated with the University of Miami to collect raindrop samples in that area. The area represented a semi-tropical rainfall regime. Drop camera data were collected from the University of Miami between May 1, 1957 and August 31, 1958. During this time a total of 65 one-hundred-foot rolls of drop size data were obtained. The final report from the University of Miami on this subcontract is included as Appendix A, Quarterly Technical Report No. 2 on this contract.

Operation of the camera at the University of Miami indicated that several changes were necessary to obtain better data from future installation. It was found that for any installation where the humidity was as high as in Miami, better protection would be needed for the camera, the mirror, and the associated electronic equipment. As the result of this, the cameras that were placed at Majuro, Marshall Islands and Indonesia stations were tropicalized by using a recommended varnish. Also, a dehumidifier was included to lower the humidity inside the drop camera shelter. Also, after operation at Miami, it was determined that inclusion of a rain switch to turn the camera on in the absence of an operator would be desirable in both tropical locations. The rain switch that was used at Miami and which has been adopted for use in the other cameras depended for a sensing element on a standard tipping bucket rain gage.

Corvallis, Oregon

The subcontract to operate a raindrop camera with Oregon State College, Corvallis, Oregon, was initiated on SC-64723 and completed on the present contract. This subcontract ran from September 1, 1957 to August 31, 1958. During this time 95 rolls of drop camera data were obtained. However, a portion of this film was found to be of such poor quality due to operator error that it was not all measured. The mirror that was located at Oregon, like the mirror at Miami, was found to have deteriorated after the first year's operation and had to be resurfaced before using at another location.

A final report on the operation of the Oregon camera can be found as Appendix B to Quarterly Report No. 2 of this contract.

Also, included in Report No. 2, as Appendix C, is a paper that was written by one of the students who operated the camera at Oregon State College.

Majuro, Marshall Islands

A, raindrop camera was installed at Dalap International Airport on Majuro Island of the Marshall Island chain in February 1959. This camera was operated by personnel of the U. S. Weather Bureau stationed at this location. Data was obtained from this camera between March 1959 and April 29, 1960. During this period, 57 rolls of raindrop data were obtained.

Table 1 indicates the distribution by months of the data that was obtained. It can be seen that some data was taken in all months of the year. The samples are not well distributed at this location, with February showing a very small sample and April a large sample. It must be noted that April was a result of collection of data for a 2-month period whereas the other samples represent only one month of operation. The camera was returned from Majuro in June 1960. The addition of the tropicalizing varnish and the dehumidifier appeared to have solved the problems that were noted at the Miami installation regarding the deterioration of the mirror surface and the rusting of camera components. When returned the equipment appeared in good shape and only minor parts required replacement.

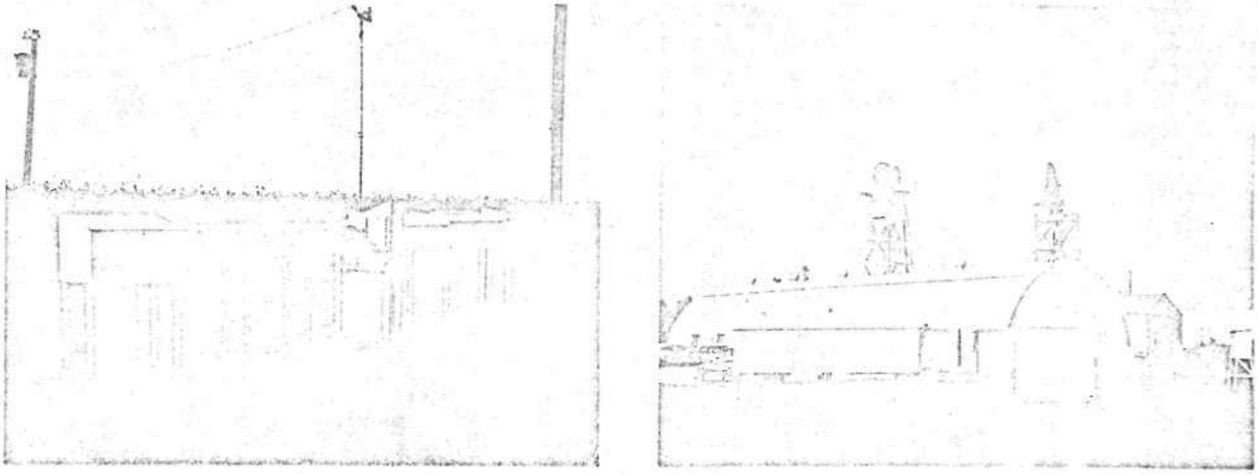
Woody Island, Alaska

A drop camera was installed at Woody Island offshore from Kodiak, Alaska, in June 1959. The Alaskan installation collected data between August 30, 1959 and August 14, 1960. During this time 74 rolls of data were obtained. Table 1 shows the distribution of this data by months. Again, the sample appears to be quite reasonable with only one month showing a particularly small sample.

TABLE 1

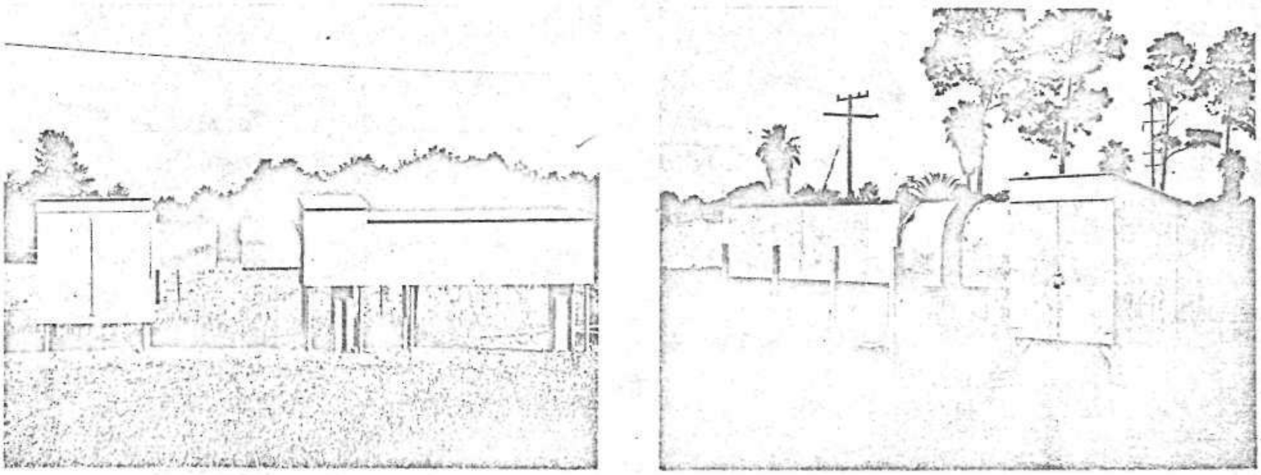
MONTHLY DISTRIBUTION OF ROLLS OF DATA OBTAINED

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Florida	11	1	7	2	7	3	5	11	2	7	4	5
Oregon	14	5	13	20	0	6	0	0	0	2	8	23
Marshall Island	5.5	0.5	2	12	6	9	6	8	3	3	2	3
Alaska	6	6	1	5	7	9	9	10	2	6	10	3
Indonesia	0	0	4	4	2	1	0.5	0.5	1	0	3	0



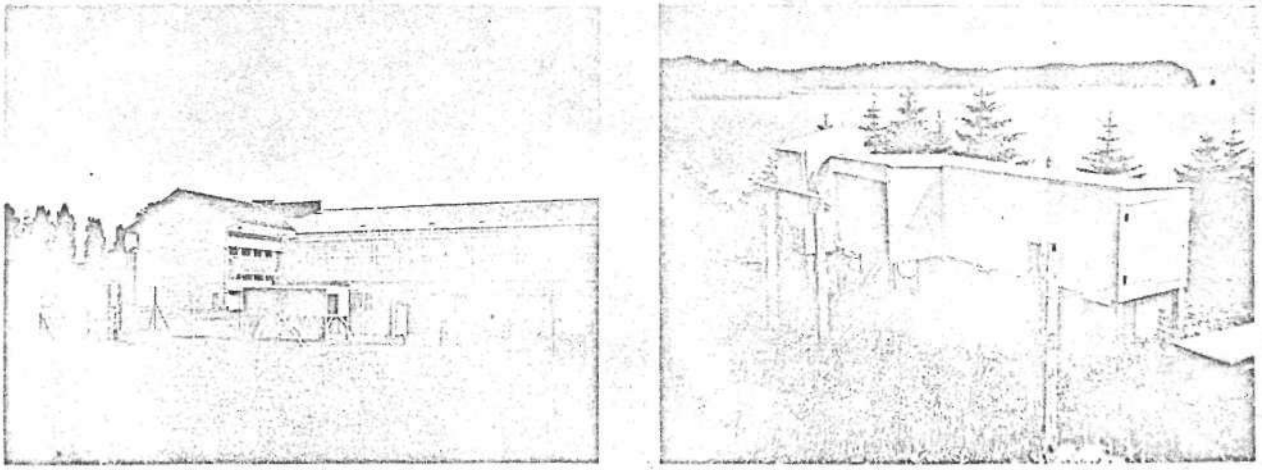
East - Central Illinois 1953-55

University of Illinois Airport 1959-60



Corvallis, Oregon

Miami, Florida



Bogor, Indonesia

Woody Island, Alaska

FIG. 3 PHOTOGRAPHS OF DROP CAMERA LOCATIONS

The mirror that was sent to Alaska was the third one that was obtained. Apparently, the manufacturer failed to produce a good surface on the mirror and it required resurfacing before data could be obtained. This produced some of the lag in obtaining the first data at the Alaskan installation. The camera was operated in Alaska by personnel of the Federal Aviation Agency stationed on Woody Island. Figure 3 shows a picture of the installation on Woody Island looking towards the west, as well as photographs of some of the other locations.

The Alaska installation was dismantled and returned to Illinois during September 1960. This camera also showed no appreciable wear from the operation. There was no dehumidifier on this particular camera.

Bogor, Indonesia

A subcontract with the University of Kentucky to supervise operation of a drop camera at Bogor, Indonesia, was signed in the fall of 1958. Due to considerable delay in communication and a considerable language barrier, plus a lack of cooperation from the Indonesians themselves, no data from this camera was obtained until October 3, 1959. From October 1959 to the present, 16 rolls of data have been obtained from the Indonesian installation. Table 1 indicates the monthly distribution of these rolls of film. Considering that climatological records indicate that Bogor, Indonesia, has more than 300 thunderstorm days per year, it seems that this is a very meager sample.

At present, it is expected that the Indonesian installation will be terminated in March 1961 and the equipment returned to Illinois.

ANALYSIS PROGRAM

Measurement of the Drop Camera Film

After the drop camera film is developed, the first step in analysis is to measure the sizes of the individual raindrops, as mentioned earlier. The film is projected twice life size and the drops are measured with a caliper. The horizontal and vertical measurement of the drop is made in order to obtain the best estimate of the equivalent spherical diameter that can be obtained with a two dimensional image. In considering the overall accuracy of the data, the measurement accuracy is the step which introduces the greatest uncertainty in the results. The task of measuring the raindrops individually is one that is quite boring; therefore operators tend to become fatigued and careless, and this produces inaccuracies in the measurements of the smaller droplets. This is indicated by measurements repeated on an individual minute. In general, agreement of the number in each class to within ± 10 per cent can be achieved easily on the drops from 0.8 millimeter up. The number of drops with diameters between 0.5 and 0.8 millimeters are frequently in considerably greater error. However, this is not an important drop size for calculation of the radar back-scattering cross section as this value is influenced to a great extent by the larger drops. At the same time, but to a lesser degree, the small drops do not influence the rainfall rate, the attenuation cross section, or the total rainout as much as do the larger drops. The measurement accuracy for each drop is assumed to be plus or minus one-tenth of a millimeter as indicated by the resolution of the optics of the camera, the resolution of the film, and the resetability of the calipers to the drop size image. Under some conditions, it is felt that the measurement accuracy may be much better than plus or minus one-tenth of a millimeter.

Occasionally, some measurements have been made under conditions which prohibit this accuracy. In particular, some measurements of drop camera film that were obtained under interesting synoptic conditions were made even though the glass on the shelters had become wet and caused some image blurring. The greatest danger in measuring under such conditions is that the blurring increases the possibility of missing the drop, especially a small one, completely.

Occasionally, because of a fault in the camera a sample is composed of less than 7 frames. In this case, if there are 6 frames which are measurable, measurements are made on the 6 and the results are extrapolated to a one cubic meter sample. All drop size measurements that have less than 8 drops per cubic meter have been discarded on the grounds that the sample is not representative and that the rainfall rate is much too low to be of any significance in total amount and/or rainout.

The number of drops that can be measured in a one minute sample has varied from the base of 8 drops per cubic meter to a maximum of 13,000 drops per cubic meter.

The one minute sample which produced the 13,000 drops is shown in table 2. The number of drops in each of the 7 frames is indicated as well as the total. This minute was unusual not only in the number of drops but also in the low reflectivity for the rainfall rate. This indicates a loading of drops into the smaller size classes. The variability of the drop distributions as computed from individual frame measurements is also apparent. This variability in fact is not eliminated when all 7 frames are combined. Initial work to determine sample size reliability has in-

TABLE 2

MIAMI
DROP-SIZE DISTRIBUTION FOR JUNE 21, 1958 AT 1105

Drop Size Dia. mm	Frame Number 1	2	3	4	5	6	7	Total
0.5	290	469	860	594	241	317	292	3063
0.6	187	215	133	129	294	272	302	1532
0.7	200	364	89	140	357	281	317	1748
0.8	143	542	103	115	349	275	286	1813
0.9	172	611	68	114	293	208	205	1671
1.0	104	616	46	104	200	132	160	1362
1.1	70	330	22	75	131	114	86	828
1.2	32	182	17	31	66	61	67	456
1.3	30	73	13	31	52	34	36	269
1.4	29	42	9	17	32	34	45	208
1.5	21	18	11	15	28	21	24	138
1.6	19	21	7	14	18	22	15	116
1.7	18	15	4	12	16	7	18	90
1.8	12	12	9	10	10	8	21	82
1.9	14	4	4	6	12	18	15	73
2.0	7	8	5	3	9	6	10	48
2.1	2	7	10	8	7	10	12	56
2.2	11	7	3	5	5	11	6	48
2.3	3	7	3	9	7	6	6	41
2.4	3	6	3	2	2	6	2	24
2.5	2	4	7	5	7	8	6	39
2.6	5	4	1	9	9	8	3	39
2.7	1	2	5	2	6	1	4	21
2.8	8	1	1	4	0	6	3	23
2.9	1	3	2	2	2	0	3	13
3.0	1	4	2	2	1	3	2	15
3.1	0	4	1	4	1	1	1	12
3.2	3	2	0	2	2	2	7	18
3.3	0	0	2	3	0	4	2	11
3.4	0	1	1	5	1	2	4	14
3.5	1	3	0	0	0	1	1	6
3.6	1	2	0	1	0	6	2	12
3.7	0	1	1	0	0	0	0	2
3.8	0	2	1	1	0	2	2	8
3.9	0	1	1	2	0		2	4

TABLE 2 (cont'd)

MIAMI
DROP-SIZE DISTRIBUTION FOR JUNE 21, 1958 AT 1105

Drop Size Dia. mm	Frame Number 1	2	3	4	5	6	7	Total
4.0	1	0		1	1		0	3
4.0	2	0		0			0	2
4.2	0	0		1			0	1
4.3	0	1		1			0	2
4.4	1	0		1			1	3
4.5		0						0
4.6		0						0
4.7		0						0
4.8		0						0
4.9		0						0
5.0		2						2
5.1		0						0
5.2		0						0
5.3		0						0
5.4		0						0
5.5		0						0
5.6		0						0
5.7		0						0
5.8		0						0
5.9		0						0
6.0		0						0
6.1		0						0
6.2		1						1
Total	1394	3587	1444	1478	2159	1887	1968	13,917

Rainfall Rate Calculated from Distribution = 229 mm/hr.

Radar Reflectivity = $3.93 \times 10^5 \text{mm}^6/\text{m}^3$

Liquid Water Content = 11.51 gm/m^3

Attenuation Cross Section = $1.56 \times 10^3 \text{mm}^2/\text{m}^3$

dicated that a sample near 10 cubic meters is required to produce a 90 per cent assurance that the mean of each size interval is within plus or minus 10 per cent of the parent population mean. This calculation has been performed from Students T distribution, assuming that samples, drawn from the same synoptic type at the same rainfall rate are drawn from the same parent population.

ANALYSIS OP DROP-SIZE DATA

Initial Data Reduction

After the drops have been measured and the IBM cards punched, the cards are processed on an IBM 650 computer. The equivalent spherical diameter for each drop is first calculated by averaging the horizontal and vertical dimension and rounding down to the nearest one-tenth millimeter. In order to maintain an accuracy of one-tenth millimeter, it was not necessary to calculate the geometric mean to determine the equivalent spherical diameter. For the majority of the drops, the nonsphericity was such that the arithmetic mean was adequate, and, since the arithmetic mean and rounding down yielded the same results and was approximately 10 times faster on the computer, this method was adopted.

After each of the equivalent spherical diameters has been determined, the computer counts the number of drops in each of the one-tenth millimeter size intervals starting at 0.5 millimeter and extending to 8.0 millimeters. This distribution of numbers is read out of the machine into distribution cards in the proper format. The format for these distribution cards is mentioned in the next section. The computer then calculates the rainfall rate, the radar reflectivity, the radar attenuation cross section, and the liquid water content. This part of the computation amounts to solving a matrix equation such as equation 1.

$$\begin{bmatrix} R \\ Z \\ L \\ Q_T \end{bmatrix} = \begin{bmatrix} R_{.5} & R_{.6} & R_{.7} & \cdots\cdots & R_{8.0} \\ Z_{.5} & Z_{.6} & Z_{.7} & \cdots\cdots & Z_{8.0} \\ L_{.5} & L_{.6} & L_{.7} & \cdots\cdots & L_{8.0} \\ Q_{.5} & Q_{.6} & Q_{.7} & \cdots\cdots & Q_{8.0} \end{bmatrix} \begin{bmatrix} N_{.5} \\ N_{.6} \\ N_{.7} \\ N_{8.0} \end{bmatrix} \qquad (1)$$

The constants in this matrix are shown in table 3. These constants have been determined by calculation. The rainfall rate constant is determined by application of the equation

$$R_D = \frac{\pi}{6} D^3 V_D \qquad (2)$$

This equation is solved at the end points of each interval. In other words, a value is determined for a drop of 1.45 millimeters and for a drop of 1.55 millimeters. The results of these two extremes are averaged to determine the coefficient which applied to the 1.5 millimeter drop. The fall velocity used in equation 2 is the terminal velocity of the drop as reported by Gunn and Kinzer, (1) and is also shown in table 3.

The values for Z, the radar reflectivity, are taken as the ΣD^6 over unit volume. Again, values for Z were calculated at the intermediate position between intervals and the two ends averaged arithmetically to determine the coefficient of each of the drop sizes. The units of the reflectivity, Z, are in mm^6 per cubic meter. However, it will be noted that on the summary card units of 10^2 mm^6 per cubic meter have been used in order to conserve columns on the cards. The attenuation cross-section has been-calculated from the Mie scattering equations for 3-centimeter radiation.(3, 4, 5,) The same procedure for determining the constant for each of the class intervals is followed for this coefficient. The units for the total cross section are given in mm^2 per cubic meter.

The constants of liquid water content are determined by the equation

$$L_D = \frac{\pi}{6} D^3 \qquad (3)$$

The units for the liquid water content are given in 10^{-2} grams per cubic meter.

After this matrix multiplication is performed, another multiplication of each of the resultant terms of the resultant matrix is multiplied by a term called the volume correction. For each drop camera location, the exact size of the volume of air sampled in 7 frames is determined by careful measurements of the distance between the shields and the amount of blocking due to the necessary optical components such as the diagonal flat and the mirror supports. After having determined the actual sampling volume, a correction is applied which produces the number of drops and the value of the variables as if one cubic meter was sampled. The size of the volume correction normally ranges between 0.97 and 1.1.

The values of these variables are then read from the computer and are combined with the observations made by the operator on location and with synoptic types determined by analysis of the

TABLE 3

CONSTANT MATRIX VALUES FOR EQUATION 1

Drop Size Dia. mm	Rainfall Rate	Power of 10	Radar Reflectivity	Power of 10	Liquid Water Content	Power of 10	Attenuation Cross Section	Power of 10	Terminal Velocity Gunn & Kinzer cm/sec
0.5	4.90	-4	1.50	-2	8.93	-5	1.00	-3	206
0.6	9.99	-4	4.70	-2	1.46	-4	2.00	-3	247
0.7	1.84	-3	1.18	-1	2.24	-4	3.00	-3	287
0.8	3.15	-3	2.62	-1	3.25	-4	4.00	-3	327
0.9	5.05	-3	5.31	-1	4.53	-4	5.00	-3	367
1.0	7.60	-3	1.00	0	6.10	-4	1.20	-2	403
1.1	1.09	-2	1.77	0	8.01	-4	1.80	-2	435
1.2	1.51	-2	2.99	0	1.03	-3	2.70	-2	464
1.3	2.03	-2	4.83	0	1.29	-3	3.80	-2	490
1.4	2.67	-2	7.53	0	1.60	-3	5.30	-2	517
1.5	3.42	-2	1.14	1	1.96	-3	7.40	-2	538
1.6	4.36	-2	1.68	1	2.36	-3	1.00	-1	565
1.7	5.43	-2	2.41	1	2.81	-3	1.36	-1	586
1.8	6.68	-2	3.40	1	3.32	-3	1.85	-1	608
1.9	8.11	-2	4.70	1	3.89	-3	2.51	-1	627
2.0	9.79	-2	6.40	1	4.52	-3	3.32	-1	649
2.1	1.17	-1	8.58	1	5.21	-3	4.34	-1	670
2.2	1.38	-1	1.13	2	5.97	-3	5.76	-1	690
2.3	1.63	-1	1.48	2	6.80	-3	7.60	-1	710
2.4	1.89	-1	1.91	2	7.71	-3	1.00	0	727
2.5	2.19	-1	2.44	2	8.69	-3	1.30	0	744
2.6	2.51	-1	3.09	2	9.75	-3	1.69	0	757
2.7	2.86	-1	3.87	2	1.09	-2	2.19	0	772
2.8	3.24	-1	4.82	2	1.21	-2	2.82	0	782
2.9	3.65	-1	5.95	2	1.35	-2	3.61	0	795
3.0	4.11	-1	7.29	2	1.49	-2	4.44	0	807
3.1	4.59	-1	8.88	2	1.64	-2	5.40	0	817
3.2	5.11	-1	1.07	3	1.80	-2	6.50	0	827
3.3	5.66	-1	1.29	3	1.97	-2	7.67	0	835
3.4	6.25	-1	1.54	3	2.15	-2	8.73	0	844
3.5	6.89	-1	1.84	3	2.34	-2	9.71	0	853
3.6	7.56	-1	2.18	3	2.55	-2	1.05	1	860
3.7	8.27	-1	2.57	3	2.76	-2	1.12	1	866
3.8	9.02	-1	3.01	3	2.99	-2	1.17	1	872
3.9	9.82	-1	3.52	3	3.23	-2	1.21	1	878
4.0	1.07	0	4.10	3	3.48	-2	1.24	1	883
4.1	1.15	0	4.75	3	3.74	-2	1.28	1	888
4.2	1.25	0	5.49	3	4.02	-2	1.32	1	892
4.3	1.34	0	6.32	3	4.31	-2	1.37	1	895
4.4	1.44	0	7.26	3	4.62	-2	1.43	1	898

TABLE 3 (cont'd)

CONSTANT MATRIX VALUES FOR EQUATION 1

Drop Size Dia. mm	Rainfall Rate	Power of 10	Radar Reflectivity	Power of 10	Liquid Water Content	Power of 10	Attenuation Cross Section	Power of 10	Terminal Velocity Gunn & Kinzer cm/sec
4.5	1.55	0	8.30	3	4.93	-2	1.50	1	901
4.6	1.66	0	9.47	3	5.27	-2	1.58	1	903
4.7	1.77	0	1.08	4	5.61	-2	1.68	1	905
4.8	1.89	0	1.22	4	5.98	-2	1.79	1	907
4.9	2.01	0	1.38	4	6.35	-2	1.90	1	908
5.0	2.14	0	1.56	4	6.75	-2	2.02	1	909
5.1	2.28	0	1.76	4	7.15	-2	2.15	1	911
5.2	2.42	0	1.98	4	7.58	-2	2.28	1	912
5.3	2.56	0	2.22	4	8.02	-2	2.43	1	913
	2.71	0	2.48	4	8.48	-2	2.59	1	914
5.5	2.87	0	2.77	4	8.95	-2	2.75	1	915
5.6	3.03	0	3.08	4	9.45	-2	2.90	1	916
5.7	3.20	0	3.43	4	9.96	-2	3.08	1	917
5.8	3.37	0	3.81	4	1.05	-1	3.27	1	917
5.9	3.55	0	4.22	4	1.10	-1	3.48	1	917
6.0	3.73	0	4.67	4	1.16	-1	3.70	1	917
6.1	3.93	0	5.15	4	1.22	-1	3.94	1	918
6.2	4.12	0	5.68	4	1.28	-1	4.19	1	918
6.3	4.33	0	6.25	4	1.34	-1	4.48	1	918
6.4	4.54	0	6.87	4	1.41	-1	4.79	1	918
6.5	4.75	0	7.54	4	1.47	-1	5.10	1	918
6.6	4.97	0	8.27	4	1.54	-1	5.43	1	918
6.7	5.20	0	9.05	4	1.61	-1	5.79	1	918
6.8	5.45	0	9.89	4	1.68	-1	6.19	1	919
6.9	5.69	0	1.08	5	1.76	-1	6.58	1	919
7.0	5.94	0	1.18	5	1.83	-1	6.99	1	919
7.1	6.20	0	1.28	5	1.91	-1	7.62	1	919
7.2	6.47	0	1.39	5	2.00	-1	7.85	1	919
7.3	6.74	0	1.51	5	2.08	-1	8.33	1	919
7.4	7.02	0	1.64	5	2.17	-1	8.80	1	919
7.5	7.31	0	1.78	5	2.25	-1	9.27	1	919
7.6	7.60	0	1.93	5	2.34	-1	9.74	1	919
7.7	7.92	0	2.08	5	2.44	-1	1.02	2	920
7.8	8.23	0	2.25	5	2.53	-1	1.07	2	920
7.9	8.55	0	2.43	5	2.63	-1	1.11	2	920
8.0	8.88	0	2.62	5	2.73	-1	1.16	2	920

conditions prevailing when the data was taken. This information is then repunched into summary and distribution cards.

Summary and Distribution Cards

The summary and distribution cards represent the final form of the data before regression analysis takes place. The information available on the summary cards is indicated in table 4. It may be noticed that a portion of the information on this card is information which is obtained from sources other than the drop camera. In particular, information from a weighing bucket rain gage in the near vicinity of the drop camera is located in columns 15 through 17. The wind speed and wind direction have been obtained in various manners. At some camera locations, information has been available roughly on the hour. At other locations, information in a more detailed manner has been available, and at times no information has been available on wind speed and wind direction.

Of particular interest is the recording of visibility. This measurement, although one of considerable importance for the performance of the requirements of this contract, has not been adequately made. The observations of visibility we have at present are those of the observers, usually taken when they turn the camera on or off. In order to better measure this term, a transmissometer has been ordered for installation at one of the drop camera sites in the future.

The synoptic type is determined in most cases by comparing surface charts at the time of data collection. The synoptic classification is given as table 5.

Table 6 indicates a code and set of criteria that was set up to type the distributions. At first, it was thought that this would be an all-encompassing typing. However, a great many distributions have been obtained that would not fit into this table.

The summary cards are used for all of the comparisons between the radar variables and meteorological variables except for the rainout.

The format for the distribution cards is shown in table 7. The distribution cards are used to obtain average drop size distributions by sorting the cards into equivalent rainfall rates and equivalent synoptic types. Then by averaging the number of drops in each of the individual fields of the cards, average distributions can be obtained. These average distributions have been used in the calculation of rainout and as an end product in themselves. It is felt that, in general, adequate results can be obtained by direct operation from the average distributions. Whether

TABLE 4

MINUTE SUMMARY CARDS

FIELD	COLUMN NO.	MARKINGS	REMARKS
Location	1	1 - 9	1 = Champaign; 2 = Miami; 3 = Oregon; 4 = Majuro; 5 = Alaska; 6 = Indonesia; 7 = Evans; 8 = Coweeta
Month	2 - 3	1-12	Jan. - Dec.
Day-	4 - 5	1-31	
Tear	6	7 - 9	1957 - 1959; 1960 - 1965
Hour	7 - 8	00-23	
Minute	9-10	00-59	Minute after hour
Synoptic type	12-13	00-39	See Table 5
Raingage rainfall rate	15 - 17	001 - 999	In mm/hr
Wind speed	19-20	00-99	0 to 99 mph
Wind direction	22	1 - 9	1 = calm; 2 = N; 3 = NE; 4 = E; 5 = SE; 6 = S; 7 = SW; 8 = W; 9 = NW
Temperature	24-25		OF
Dew point	27 - 28	00 - 99	
Rain type	30	0 - 9	0 = TRW; 1 = TRW+; 2 = TRW-; 3 = RW; 4 = RW+; 5 = RW-; 6 = R; 7 = R-; 8 = L; 9 = R+
Visibility	32 - 33	00 - 99	0 to 9.9 miles
Rainfall rate from drop data	35 - 37	000 - 999	In mm/hr
Z (reflectivity)	39 -43	00000 - 99999	In $10^2 mm^6/m^3$
Liquid water content	45 - 47	000 - 999	$10^{-2} gm/m^3$
Qt (Total cross section)	49 - 52	0000 - 9999	mm^2/m^3
Distribution type	54- 57		See Table 6
No. of non-spherical drops	62 - 64	000 - 999	non-spherical If $\left\lvert \begin{matrix}\text{horizontal-}\\ \text{vertical}\end{matrix} \right\rvert \geq 2$

TABEE 5

NUMBERING SYSTEM FOR RAINDROP SIMPLE SYNOPTIC TYPES

00 Air Mass

01 Air mass orographic

02 Pre-cold frontal

03 Pre-cold frontal orographic

04. Cold frontal

05 Cold frontal orographic

06 Post-cold frontal

07 Post-cold frontal orographic

08 Overrunning

09 Overrunning orographic

10 Farm frontal

11 Farm frontal orographic

12 Warm sector

13 Warm sector orographic

14 Gold type occlusion-concurrent

15 Cold type occlusion orographic - concurrent

16 Pre-cold occlusion

17 Pre-cold occlusion orographic

18 Post-cold occlusion

19 Post-cold occlusion orographic

20 Warm occlusion - concurrent

21 Warm occlusion orographic - concurrent

22 Pre-warm occlusion

23 Pre-warm occlusion orographic

24 Post-warm occlusion

25 Post-warm occlusion orographic

26 Upper cold front

27 Upper cold front orographic

30 Tropical depression or trough without associated air mass contrast

31 Tropical storm NE sector

32 Tropical storm NE sector orographic

33 Tropical storm SE sector

34 Tropical storm SE sector orographic

35 Tropical storm SW sector

36 Tropical storm S¥ sector orographic

37 Tropical storm NW sector

38 Tropical storm NW sector orographic

40 Easterly wave

41 Easterly wave orographic

50 Intertropical convergence zone

51 intertropical convergence zone orographic

60 Trough aloft

TABLE 6

DISTRIBUTION TYPE CODE

I. The first digit will indicate the general form of the distribution according to:

1. a unimodal distribution showing a mode value of greater than 0.7 mm with less than 1000 drops
2. a bimodal distribution with more than 0.5 mm between modes and less than 1000 drops
3. a monatonically decreasing number versus size (like number 1 except the mode is below 0.7 mm)
4. any distribution which will not fit categories 1, 2 or 3

5, 6, 7, 8. the same as 1, 2, 3, 4, respectively, except between 1000 and 2000 total drops

X overpunch on 1, 2, 3, 4, indicates total number of drops between 2000 and 3000.

II. The total number of drops to the nearest 100 is represented by the second digit when preceded by a 1, 2, 3, 4. When preceded by a 5, 6, 7, or 8 the second digit represents the number of drops to the nearest 100 plus 1000 drops. When preceded by a 1, 2, 3, or 4 with X overpunch, the second digit represents the number of drops to the nearest 100 plus 2000 drops.

III. Diameter of the drop corresponding to the mode of the. distribution according to the following code,, If distribution shows no mode, a dash is inserted and the column will be left blank. For a bimodal distribution (2 in first digit) the mode corresponding to the larger diameter is used.

Digit	Represents diameters in the range of	Digit	Represents diameters in the range of
1	1.0 - 1.19	6	2.0 - 2.19
2	1.2 - 1.39	7	2.2 - 2.39
3	1.4 - 1.59	8	2.4 - 2.59
4	1.6 - 1.79	9	2.6 - 2.79
5	1.8 - 1.99	0	2.8 and larger

IV. The" fourth digit represents the diameter corresponding to the point whose number of drops is one-half the number of drops of the mode according to the following coding table:

Digit	Diameter in the range
1	< 1.6
2	1.6 - 1.79
3	1.8 - 1.99
4	2.0 - 2.19
5	2.2 - 2.39
6	2.4 - 2.59
7	2.6 - 2.79
8	2.8 - 2.99
9	3.0 - 3.29
0	3.3 and larger

TABLE 7

DISTRIBUTION CARDS

CARD 1

1-10	Ident as before	47-49	1.5
11 - 12	Synoptic type	50 - 52	1.6
13 - 15	Rainfall rate	53 - 55	1.7
16	Card 1	56 - 58	1.8
17 - 19	0.5	59 - 61	1.9
20 - 22	0.6	62 - 64	2.0
23 - 25	0.7	65 - 67	2.1
26 - 28	0.8	68 - 69	2.2
29 - 31	0.9	70 - 71	2.3
32 - 34	1.0	72 - 73	2.4
35 - 37	1.1	74 - 75	2.5
38 - 40	1.2	76 - 77	2.6
41 - 43	1.3	78 - 79	2.7
44-- 46	1.4	80	

CARD 2

1-10	Identifier
11 - 12	Synoptic type
13 - 15	Rainfall Rate
16	Card type 2
17 - 18	2.8
19 - 20	2.9
21 - 22	3.0
23 - 24	3.1
25 - 26	3.2
27 - 28	3.3
29 - 30	3.4
31 - 32	3.5
33 - 34	3.6
35 - 36	3.7
37 - 38	3.8
39	3.9
40	4.0
41	4.1 etc.

After last drop in the distribution, regardless of which card, use X overpunch. Always include a card? 2 with identifier whether or not there are drops.

the variables are first calculated from the minute drop size samples and then averaged, or whether the minute drop size samples are averaged and then the variables calculated, is of little importance in the final result.

Rainfall Rate versus Radar Reflectivity Analyses

After discussion of the problem of correlating the rainfall rate to the radar reflectivity, Z, with technical personnel from Evans Signal Laboratory, it was felt that a criteria for the best fitting curve might be arrived at by a procedure somewhat different than the standard logarithmic least squares straight line fit.

The criteria for making the best estimate of rainfall rate, R_0, given a particular radar reflectivity, Z_0, was to select all observations (R_i, Z_i) such that $Z_0 - \Delta Z < Z_i < Z_0 + \Delta Z$ and select R_0 such that $\Sigma_i \mid R_i(R_i - R_o) \mid$ is a minimum. This criteria tends to increase the value of R_0 over that which would obtain from the more standard criteria of $\Sigma_i \ (R_i - R_0)^2$ be a minimum. The thought here is that it becomes more serious to underestimate a rainfall than to overestimate one.

A computer program for the digital computer, Illiac, was written to determine R_0. This program produces a minimization by repeated trial and correction procedure. Results from the computer always placed R_0 at an identical rainfall rate as one of the rainfall rates in the input sample. It can' be shown that this is a necessary result if a finite number of observations are present. Therefore, this criteria is not a good one if the number of observations in a particular Z class is small.

The data are separated according to synoptic type or according to rain type before being sent to the computer. Therefore, R_0-Z_0 relationships can be obtained for different synoptic types as well as for different rain types. The size of delta (one half Z range) to determine the class interval of Z for separation was usually chosen as 1.5 db. In other words, the size of the interval was allowed to vary with the size of Z_0. This was thought to be a more realistic means of determining delta since the radar measurement of Z probably would be specified with an accuracy in decibels. However, as a check on the effect of the logarithmic delta in the final estimates of R_0, some of the Miami data was run on an arithmetic delta of 200 mm^2 per cubic meter as well as in the logarithmic delta. There was not appreciable difference between these two results except for the inclusion of a great number of Z ranges that did not contain any observations.

As a comparison with the more standard criteria of logarithmic least squares fit, figure 4 is presented for warm frontal rains at Miami.

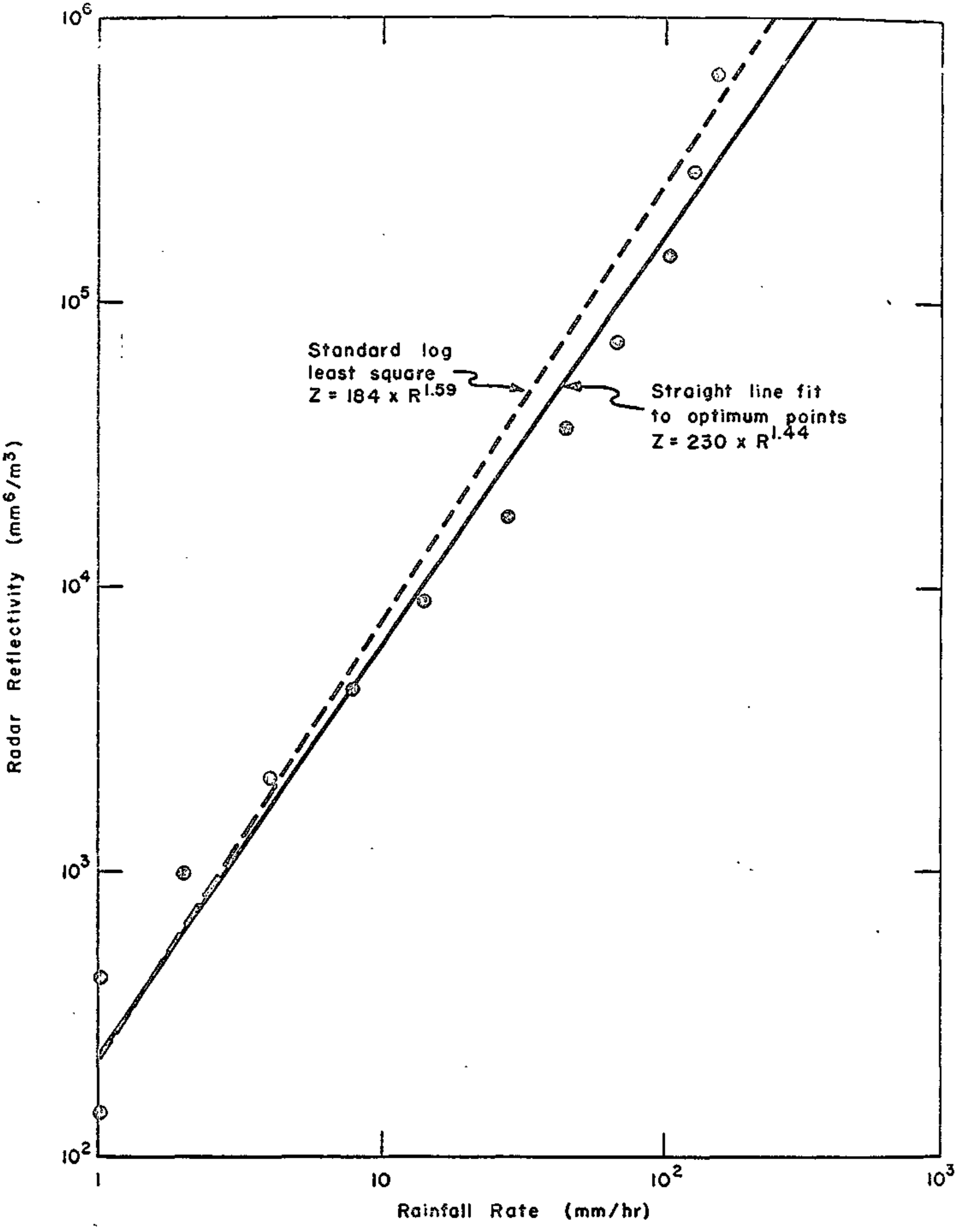


FIG. 4 COMPARISON OF REFLECTIVITY AND RAINFALL RATE FOR WARM FRONT ??TATION AT MIAMI

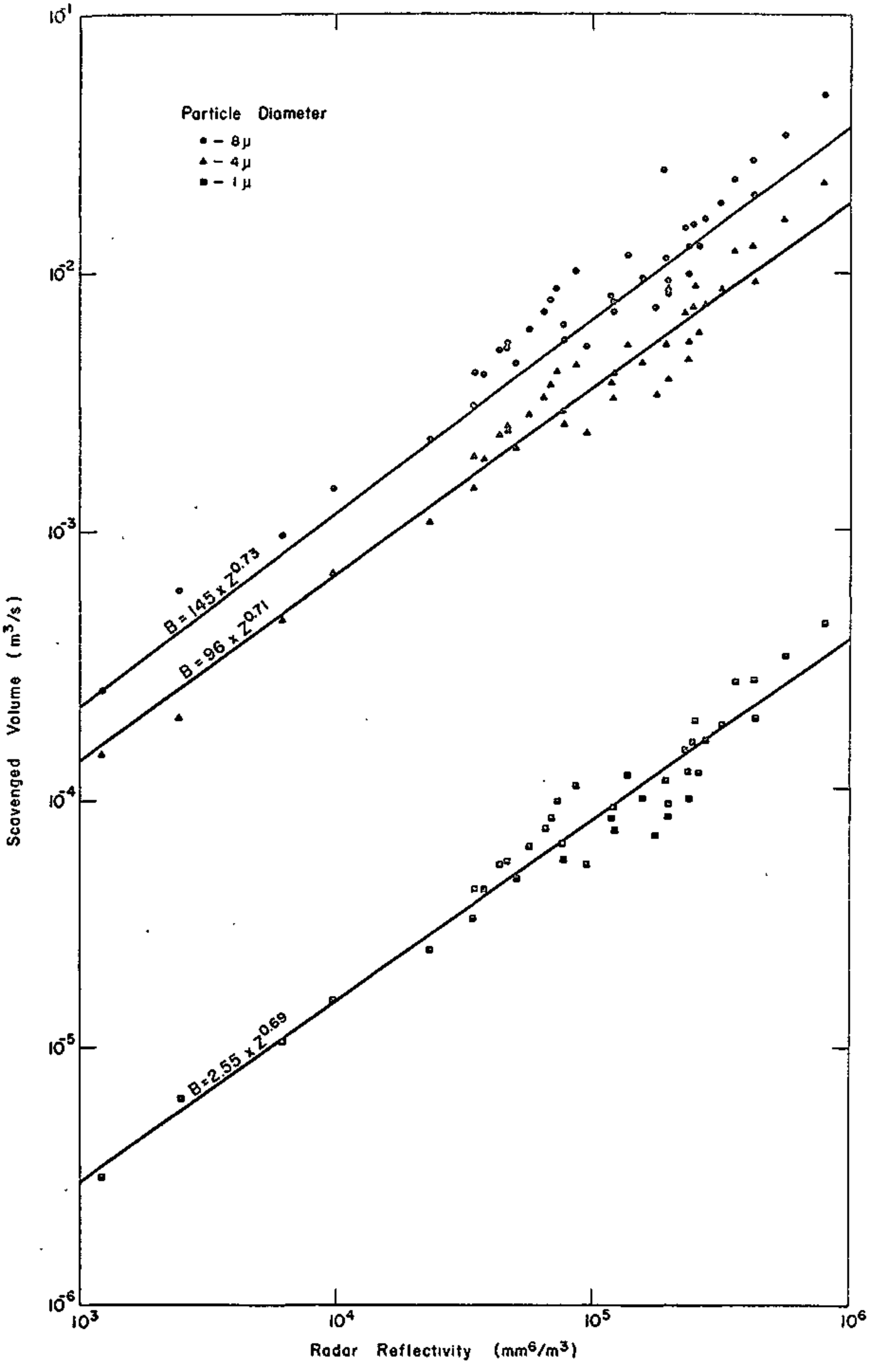


FIG. 5 COMPARISON OF SCAVENGED VOLUME VERSUS RADAR REFLECTIVITY FOR MIAMI THUNDERSTORMS

Collection Efficiency Calculationa

Collection efficiences of raindrops for atomic debris have been calculated for debris particles of diameter ranging from 0.5 microns to 450 microns. Results of these calculations are indicated in Quarterly Report No. 4 on this contract.

The equation $$B_{D,r} = \frac{\pi D^2}{4} V_T \, E(D,r) \qquad (4)$$

determines a constant which represents the cleansed volume of air per unit time for each of the individual particle sizes, r, and raindrop sizes, D. The value of E(D,r) is the collection efficiency as calculated using Langmuir's(2) equations. These constants are multiplied by the average raindrop size distribution to determine the cleansed volume per unit time. After obtaining the cleansed volume per unit time, a regression between this constant and the radar reflectivity is obtained. The best fitting results apparently are the comparison of the log B to the log Z; resulting in the relationship of $B = AZ^b$. In the analysis, the radar reflectivity Z is considered to be the independent variable and B, the cleansed volume, the dependent variable. Figure 5 shows a plotting of various B's for thunderstorm rainfall at Miami.

Table 8 is a table of the values of A and C obtained from the Miami data for different particle sizes and synoptic types.

The Sixth Quarterly Technical Report indicates the procedure for analysis of the raindrop data for the collection of atomic debris. Since this time, serious questions have been raised as to the desirability of presenting the final result in terms of the fraction of the original particle size which is collected by raindrops of a particular size as the drop falls through unit depth. Instead,' it is proposed that the equation (4) be used which yields the effective volume cleansed by a particular raindrop size for a particular particle size in unit time. The difficulty in deciding which of these parameters is the more appropriate becomes one of the manner in which the data is to be used in operation. Another difficulty comes in attempting to extrapolate the drop size distributions that are found at the ground to drop size distributions predicted aloft by means of various formula. This extrapolation leads to the more natural variable of cleansing volume per unit time. Further discussion of these differences in manner of presentation of output information will be made in the future.

The raindrop data is separated into different synoptic classes and into different rainfall rates before analysis of the cleansing volume per unit time is obtained. At present, no specific recommendations are made as to whether the synoptic class separation or the rain type separation is more significant.

TABLE 8

REGRESSION COEFFICIENTS FOR RAINOUT FOR MIAMI

$Z = AB^C$ Z $(10^2 mm^6/m^3)$ B $(10^{-8} m^3/s)$

$Z = A3^0$	Synoptic Type 00		Synoptic Type 02		Synoptic Type 04		Synoptic Type 08	
	A	C	A	C	A	G	A	C
B.25 - Z.5	2.223x10^{-2}	1.684	4.0738x10^{-3}	2.075	5.0933x10^{-3}	1.965	1.795x10^{-2}	1.692
B.5 - Z.5	2.735x10^{-4}	1.681	1.905x10^{-5}	2.062	3.516x10^{-5}	1.942	2.259x10^{-4}	1.684
B_1 - Z.5	7.816x10^{-6}	1.653	3.1478x10^{-7}	2.00	6.486x10^{-7}	1.898	6.918x10^{-6}	1.647
B_2 - Z.5	1.049x10^{-6}	1.608	3.936x10^{-3}	1.912	8.892x10^{-8}	1.818	1.014x10^{-6}	1.595
B_4 - Z.5	3.904x10^{-7}	1.590	1.486x10^{-8}	1.873	2.729x10^{-8}	1.802	3.707x10^{-7}	1.580
B_5 - Z.5	4.113x10^{-7}	1.575	1.694x10^{-8}	1.84.8	3.508x10^{-8}	1.770	4.130x10-^{7}	1.560
B_{10} - Z.5	3.483x10^{-7}	1.567	1.832x10^{-8}	1.832	2.965x10^{-8}	1.761	3.312x10^{-7}	1.558
B_{20} - Z.5	3.344x10^{-7}	1.565	1.349x10^{-8}	1.835	2.951x10^{-8}	1.754	3.281x10^{-7}	1.553
B_{60} - Z.5	3.258x10^{-7}	1.565	1.4355x10^{-7}	1.828	2.871x10^{-8}	1.754	3.006x10^{-7}	1.558
B_{100} - Z.5	3.304x10^{-7}	1.555	1.694x10^{-8}	1.805	3.492x10^{-8}	1.730	3.724x10^{-7}	1.531
B_{225} - Z.5	1.8837x10^{-7}	1.580	6.209x10^{-9}	1.862	1.462x10^{-8}	1.776	1.795x10^{-7}	1.570

TABLE 8 (cont'd)

REGRESSION COEFFICIENTS FOR RAINODT FOR MIAMI

$Z = AB^C$ Z $(10^2 m^6/m^3)$ B $(10^{-8} m^3/s)$

	Synoptic Type 10		Synoptic Type 40		Synoptic Type 60	
Z- AB^C	A	C	A	C	A	C
B.25 - Z.5	3.304x10^{-2}	1.603	1.6904x10^{-2}	1.675	1.076x10^{-2}	1.779
B.5 - Z.5	5.321x10^{-4}	1.592	2.128x10^{-4}	1.672	1.028x10^{-4}	1.776
B1 - Z.5	1.734x10^{-5}	1.570	6.7608x10^{-6}	1.637	2.698x10^{-5}	1.736
B2 - Z.5	2.618x10^{-6}	1.524	9.931x10^{-7}	1.587	3.598x10^{-7}	1.681
B4 - Z.5	9.078x10^{-7}	1.517	3.319x10^{-7}	1.580	1.297x10^{-7}	1.661
B5 - Z.5	1.052x10^{-6}	1.495	3.724x10^{-7}	1.560	1.542x10^{-7}	1.637
B10 - Z.5	9.247x10^{-7}	1.486	3.076x10^{-7}	1.555	1.262x10^{-7}	1.631
B20 - Z.5	8.874x10^{-7}	1.484	2.767x10^{-7}	1.558	1.167x10^{-7}	1.631
B60 - Z.5	8.670x10^{-7}	1.484	2.698x10~^{7}	1.558	1.135x10^{-7}	1.631
B100 - Z.5	9.099x10^{-7}	1.471	3.296x10^{-7}	1.534	1.383x10^{-7}	1.608
B225 - Z.5	5.212x10^{-7}	1.497	1.607x10^{-7}	1.570	6.1235x10^{-8}	1.650

CONCLUSIONS

Operations of raindrop cameras have been satisfactorily completed at Miami, Florida; Corvallis, Oregon; Majuro, Marshall Islands; and Woody Island, Alaska. All of these locations have yielded one year of data. The drop camera has operated satisfactorily with little maintenance required on location. It is felt that this instrument has shown its reliability and usefulness as a means of determining the drop size distribution in natural rainfall.

The drop size distribution data from Florida and from Oregon has been completely measured on the projection tables, and analysis has been completed on the Miami data. Work is continuing on the measurement of data from the other locations. A means has been developed to make the measurements as efficient as possible on the projection tables. The next step in sophistication of the measurement program would be to go to completely automatic scanning devices. It is not felt that this is practical for the drop size pictures as they are obtained with the present drop camera. Some work has been accomplished on a new type of instrument called the streak camera which should be more compatible with automatic measurement devices.

Analysis has indicated that the drop size distributions are sufficiently varied from the various locations to warrant further investigation of climatic differences in drop size distributions. This effect is particularly noticeable in rainfall rate versus reflectivity relationships.

Computer programs have been designed to obtain rainfall rate versus reflectivity correlations under the special criteria set forth by technical personnel at Evans Signal Laboratory. Other computer programs have been designed to permit rapid sorting and counting of the raw data, and to perform the matrix multiplications.

PROGRAM FOR NEXT INTERVAL

During the next interval drop cameras will be installed at Evans Signal Laboratory and Coweeta Hydrologic Laboratory. These cameras will operate for one year each in the collection of data.

A research report summarizing the results of the Miami data will be submitted to the Signal Corps for concurrence in printing.

Measurements of the drop data film from Majuro, Indonesia and Alaska will be continued. The preliminary calculations of radar reflectivity, liquid water content, radar back-scattering cross section, and rainfall rate will be kept current with the measurements.

Work will continue on the determination of extrapolation equations for the drop size distributions to higher levels of the atmosphere,

PERSONNEL

The following personnel were engaged in the work during the tenth quarter:

Name and Title	Starting Date	Hours Worked	Terminated
G. E. Stout Project Director	4/1/58		
Eugene A. Mueller Electronic Engineer	4/1/58	510	
Miyuki Fujiwara Research Assistant	3/16/59	510	
Ruth B. Wilk Meteorological Aide II	9/1/58		
Mohammad Akhtar Student Assistant	8/22/60	121	9/16/60
Edna M. Anderson Meteorological Aide I	3/23/59	510	
Sara P. Blankenstein Meteorological Aide I	9/26/60	20	
Sung P. Choi Student Assistant	10/15/58	353	
Marvin C. Clevenger Student Assistant	9/8/58	83	
Dorothy A. Gurney Meteorological Aide I	8/18/58	510	
George Lamich Meteorological Aide I	9/16/58	112	7/20/60

Name and Title	Starting Date	Hours Worked	Terminated
James L. Mathis Meteorological Aide I	7/5/60	303	8/26/60
Donald L. Mitten Student Assistant	6/23/60	495	
Charles A. Pennel Meteorological Aide I	6/13/60	112	7/8/60
Ahmad H. Qureshi Meteorological Aide I	6/23/60	288	8/19/60
Donna D. Rudig Student Assistant	6/16/58	164	8/5/60
Victor E. Schulze Student Assistant	9/21/59	315	
Donald H. Summers Electronics Technician II	9/1/60	170	
Carol D. Trump Meteorological Aide I	3/14/60	510	
Arthur E. Tuveson Student Assistant	7/24/60	333	
Daniel D. Watson Student Assistant	11/12/58	3	
Gilbert L. Wedekind Student Assistant	6/27/60	416	9/16/60

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