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ILLINOIS STATE WATER SURVEY

METEOROLOGIC LABORATORY

at the

University of Illinois

Urbana, Illinois

AN EVALUATION OF THE AREA INTEGRATOR

by

Eugene A. Mueller

prepared as

RESEARCH REPORT No. 7

sponsored by

U. S. ARMY SIGNAL RESEARCH and DEVELOPMENT LABORATORY
Fort Monmouth, New Jersey

CONTRACT NO. DA-36-039 SC-75055

DA Task 3-99-04-112

December 1958

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ABSTRACT

The operational results of the area integrator as developed by the Illinois State Water Survey are reported. The use of a range integrating device with radar as a solution to the incoherent return from precipitation is described and found to improve the area comparisons of the area integrator to the radar.

Results of the study indicate that better relationships between radar power return and precipitation rate must be determined before the area integrator becomes a useful tool. At present the quantitative amounts as determined by the area integrator are as accurate as the amounts obtained manually from the radar.

ACKNOWLEDGMENTS

This report was written under the direction of William' C. Ackermann, Chief of the Illinois State Water Survey. Research was accomplished under the general guidance of the Project Director, Glenn E. Stout, Head, Meteorology Section.

Credit for the original idea of the area integrator is due Gerald W. Parnsworth. Most of the routine analysis was accomplished by Ruth Cipelle.

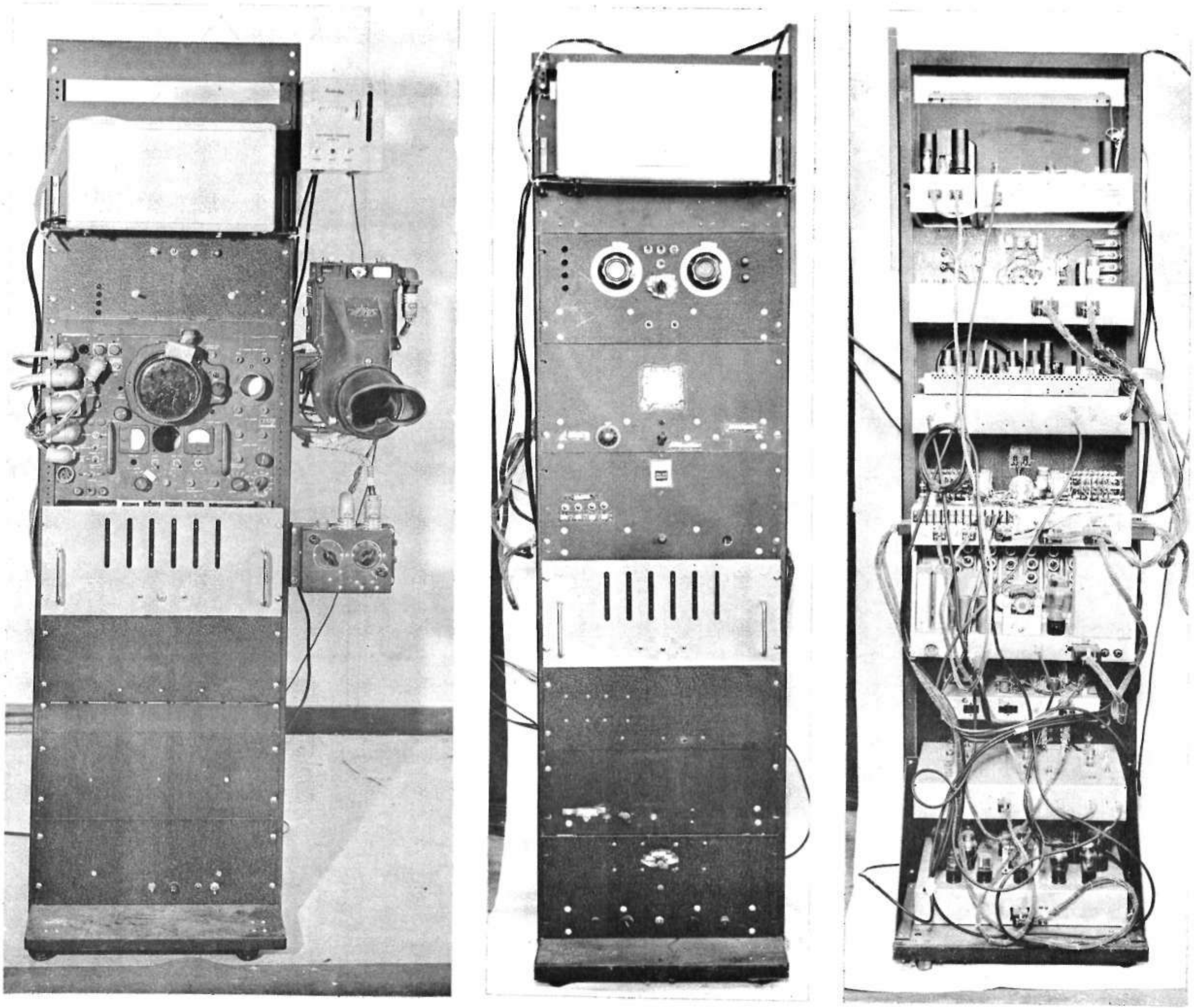
INTRODUCTION

The Illinois State Water Survey and the United States Signal Research and Development Laboratory have been jointly interested in developing a device to compute the areal mean rainfall from information supplied by radar. In 1952 a means for automatically determining the amount of rainfall from radar information was envisioned by G. W„ Farnsworth.[1] The first model was constructed in 1953. This device was used with an AN/APS-15 radar. Revision of the circuitry of the first model was completed late in 1954 and tested in 1955.

The revised version of this model worked satisfactorily except for one serious limitation. The device used as an operating signal the instantaneous power return from the radar. Theoretically, this is not the best signal for determining the rainfall from radar. The proper control should be a time average signal returned from a point in space. This average should be over a time length that would include at least 50 independent observations.[2]

A second and final model of the area integrator was constructed early in 1955 for use with the CPS-9 radar. Besides using an average power return as opposed to an instantaneous one, the new version had another means of gating the signal. Thus, it became possible to use the area integrator over any selected 100 square mile area within 150 miles of the radar set. Figure 1 shows the final form of both models.

Research Report No. 5[1] covered the theory of operation of the area integrator, and therefore no attempt will be made to repeat this material in the present report.



a. Front of First Model b. Front of Second Model c. Rear of Second Model

FIG. 1 AREA INTEGRATOR

RESULTS OP OPERATION WITH FIRST MODEL OF THE AREA INTEGRATOR

First Version

The major drawback in the first version of the area integrator was that it operated on instantaneous power return and not on the average power return. Owing to this factor, the area integrator consistently underestimated the area over which rainfall was falling.

The echo return from rain is incoherent. This means that at any particular point in space represented by any particular point in time on the radar, the signal will vary from no signal to a maximum signal which is greater than the average signal. Since the integrator is a time sampling device, the state of the signal at the instant of the integrator's interrogation of a particular point in time is measured. Thus, occasionally the signal will be below the true average level, and some of the time, the area integrator will fail to measure this area. Thus, for example, if the area integrator interrogation level is the average power return level of the signal, the area integrator will measure only half the proper area. Of course, this information is of no value to the analysis since it is not known *a priori* what the average signal level is.

The PPI was used in photographing the output of the coincidence amplifiers of the area integrator. Figure 2 is an example of a picture taken from this scope. It can be noted that the echo area has what might be termed "holes" within it. The signal on the PPI was all of the same average power but was of an incoherent nature. These holes are to be expected from the theory as indicated in Figure 3. This figure, which has been reprinted from McGill University Report MW-4 by J. Marshall and W. Hitschfeld,[2] represents a theoretical presentation of a brightness-modulated display of a weather echo under the assumption that a signal must be more than the average signal level to be displayed. This figure was constructed by Marshall and Hitschfeld by use of tables of randomly sequenced deviates. Comparison of Figures 2 and 3 indicated that the results obtained with the integrator were to be expected from the theory of randomly spaced scatterers.

Parts of Figure 2 which do not show evidence of the holes (such as the northeastern part of the echo) are due to the integrator's operating at a much lower level than the average return level.

The area of the echo is obtained by planimetering the entire area bounded by the extremes of signal on the PPI scope regardless of the holes in the area; this, ideally, is the area which the integrator should give as an answer. However, the area integrator measures only the signals which are seen on the picture. Thus, it can be seen that a large portion of the area is missed by the area integrator in this form.

Figure 4 shows a comparison of the areas as obtained by planimetering the entire area and as determined by the area integrator

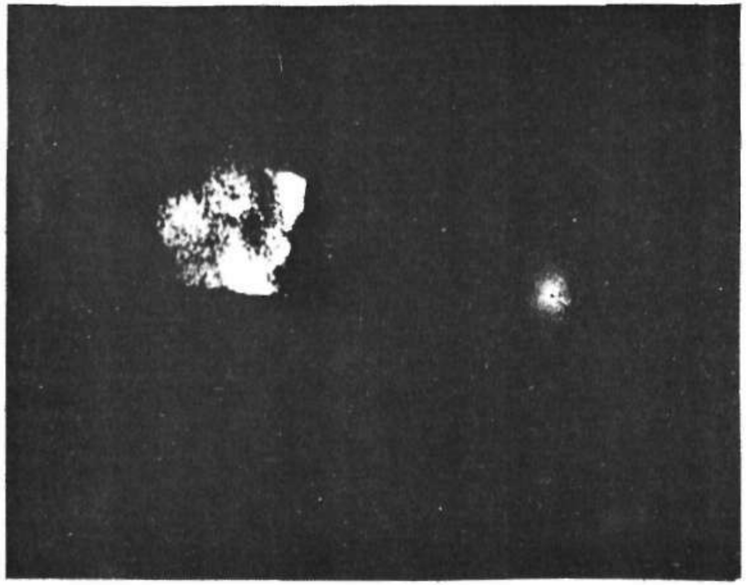


FIG. 2 TYPICAL APPEARANCE OF THE AREA INTEGRATOR SCOPE WITH PRECIPITATION ECHO

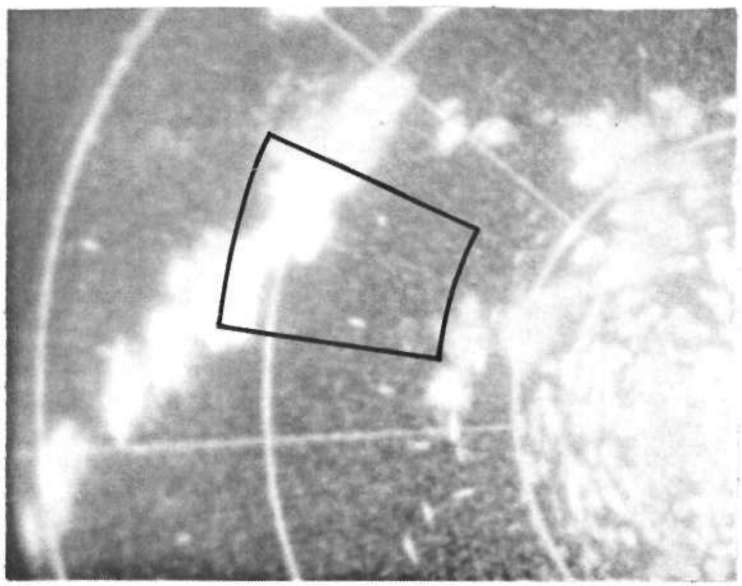


FIG. 5 APS-15 SCOPE PICTURE OF ECHO OVER ENCIRCLED WATERSHED

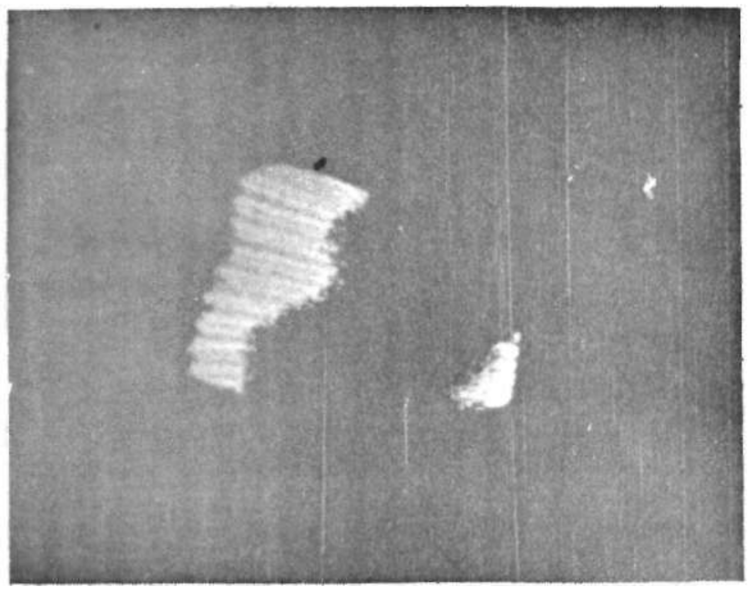


FIG. 6 AREA INTEGRATOR SCOPE PICTURE FOR SAME TIME APS-15 ECHO

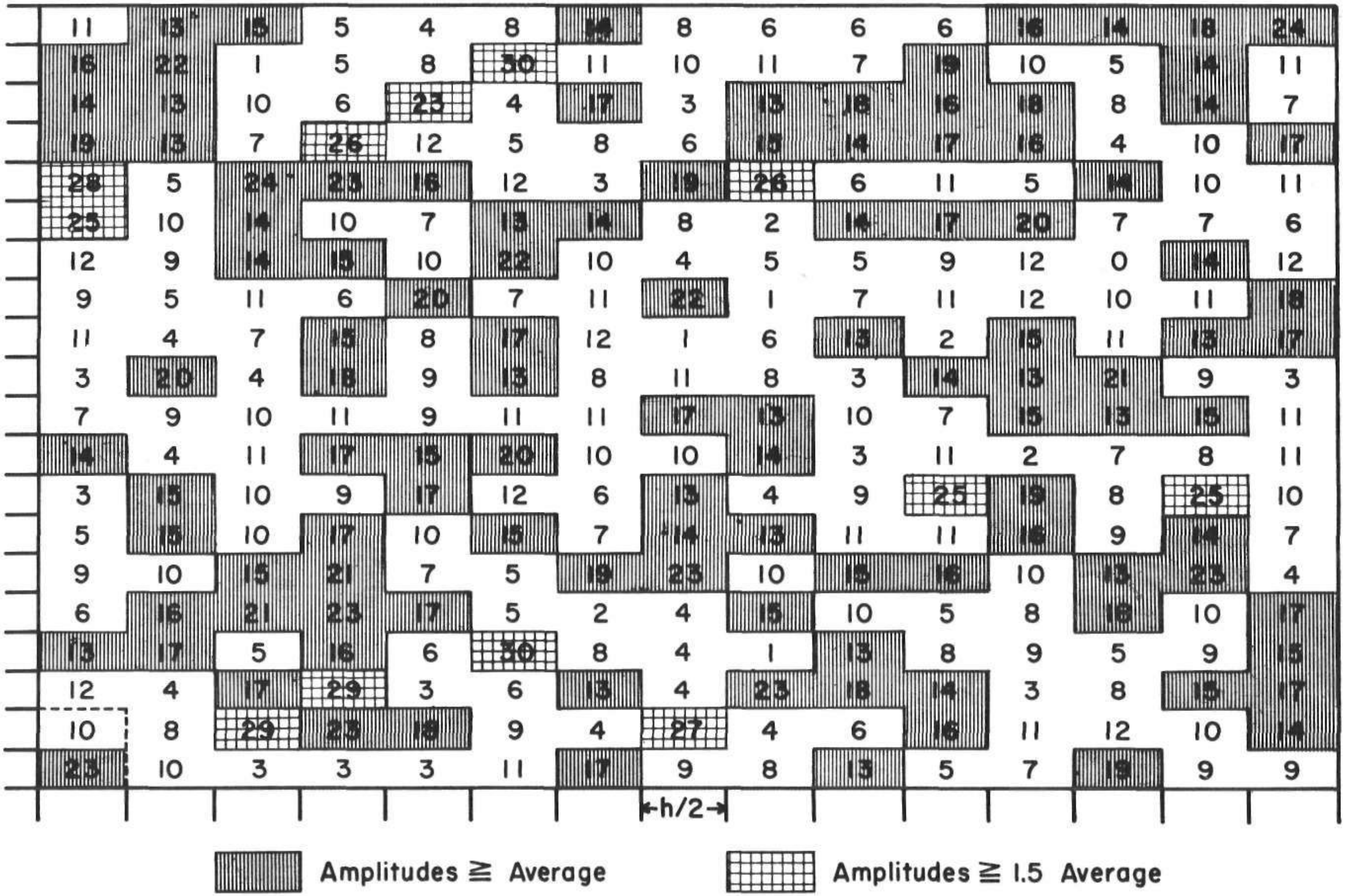


FIG. 3 TYPICAL APPEARANCE OF A SECTION OF A BRIGHTNESS-MODULATED DISPLAY. The Numbers Represent Amplitude Values Received From Element Of Area Resolved. (From McGIll Univ. Rep. M.W. 4)

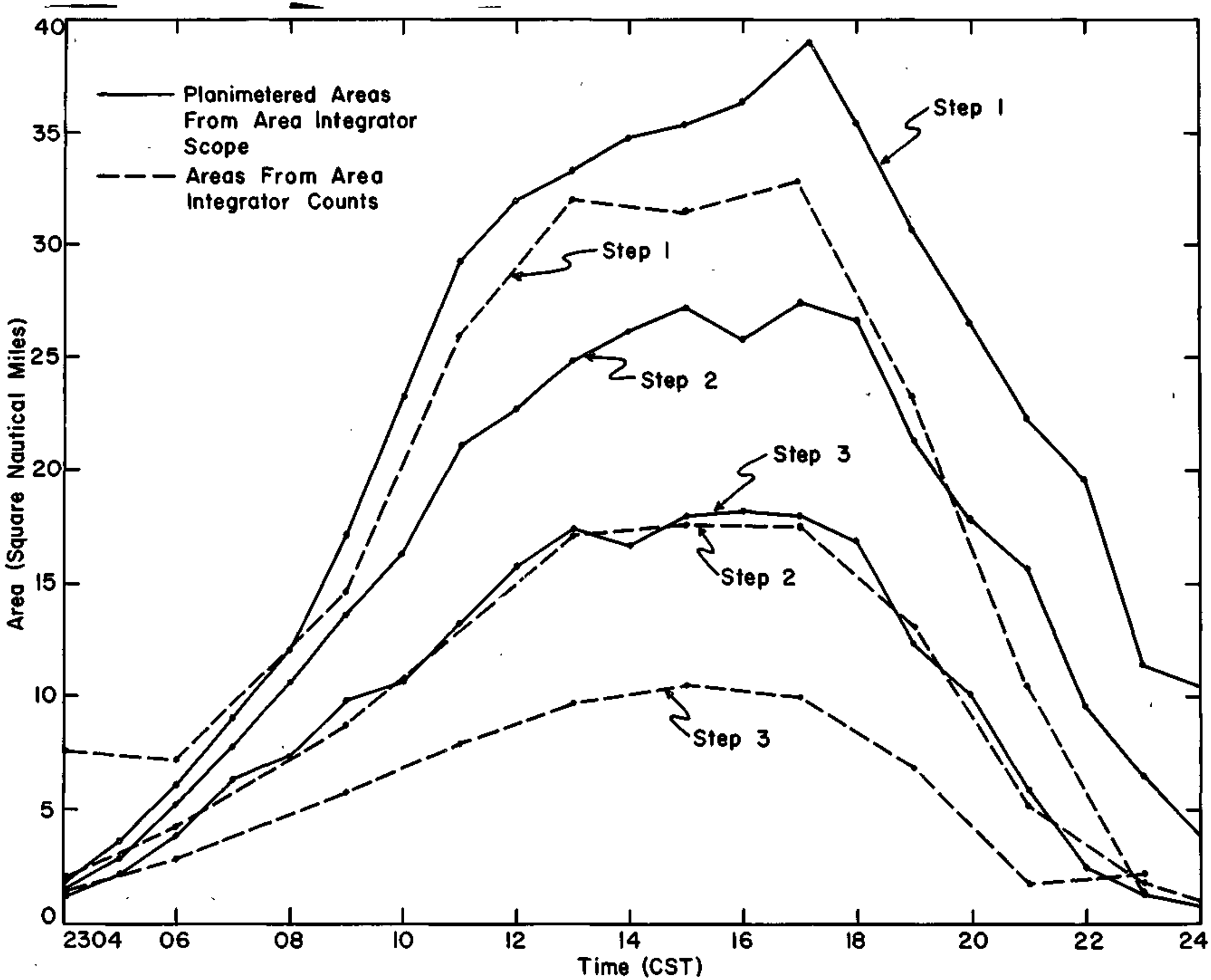


FIG. 4 COMPARISON OF AREAS FROM AREA INTEGRATOR FILM AND COMPUTER

for several different receiver sensitivities. Each of these sensitivity levels is called a step, with the highest sensitivity labeled step 1. It can be noticed that the amount of error that the integrator makes is dependent upon the amplitude of the average power return in respect to the signal level of the integrator. This is apparent by noticing the greater relative error on steps 2 and 3 than on step 1, It should also be noted that no single multiplication factor can be used to correct the differences between these curves.

Two methods of calibrating the area integrator were used. The first consisted of using a pulse microwave oscillator; the second, of using a 30-megacycle (mc) pulse noise generator. The use of a pulse microwave oscillator Is superior to the use of the noise generator as the microwave oscillator calibrates more nearly the entire system including a part of the radar. However, use of the microwave oscillator necessitates the use of a coherent signal for calibration. The coherent signal, as pointed out in previous paragraphs, does not produce the same results in the area integrator as does the incoherent signal. Calibration was performed in a routine manner using the microwave oscillator at frequent intervals during the time of collection of data.

Occasionally, a pulsed 30-mc noise generator was used for more nearly absolute calibration of the area integrator. This noise generator produced an incoherent signal more nearly of the quality of the rain signal. The use of the incoherent signal along with the correct average power level for the incoherent signal produces an accurate calibration on the area integrator from the i-f strip to the read out. However, this did not calibrate losses in the pre i-f and TR and ATR duplexer section,, Thus, this procedure was used only as a theoretical calibration to aid in the design of proper averaging devices.

Second Version

The stability of the first model left much to be desired, and thus, a second version was built redesigning some of the critical circuits. Calibration on the first version would vary as much as 6 to 7 decibels (db) between days and probably from 3 to 4 db during data collection. The second version was not quite as susceptible to drift, since calibrations showed a day to day variation of less than 2 db on individual steps. Calibration had to be maintained within at least this accuracy if the computing circuits of the area integrator were to have meaningful outputs.

The procedure used to calibrate the integrator using the noise source was as follows. A 30-mc noise generator was pulse modulated by means of a delay generator, a pulse generator, and a driver. The i-f strips of both the APS-15 and the area integrator were connected to the noise diode. A relative measure of noise power was obtained by noting the direct current through the diode with no modulation present. The actual noise power is proportional to the square of this current. The i-f strips were calibrated by means of the Measurements Corporation Model 80 Signal Generator. A pulsed 30-mc signal was fed into the strips and calibration frames were taken on the APS-15 and area integrator.

Results of one of these calibrations are shown in Table 1 and Table 2. An error was made during the calibration, which introduces the possibility of considerable error in the sensitivities stated for the APS-15 since it is only calibrated to the nearest 6 db. The area integrator, on the other hand, was calibrated directly from the Model 80, and thus its calibration should be accurate.

TABLE 1

CALIBRATION OP APS-15 AND AREA INTEGRATOR

Step	APS-15 microvolts	Area Integrator microvolts
1	158	64
2	158	210
3	256	572

The calibration for steps 1 and 2 on the APS-15 showed the same amount, but the resultant areas showed a great deal of difference.

In some respects, the data show an improvement over that observed previously. The area of step 1 of the integrator film compares well with the area of step 1 of the counts. The area of step 2 of the integrator counts is lower than step 2 areas of the integrator film. This is probably due to some holes in the areas

TAELE 2

AREA COMPARISONS FOR AREA INTEGRATOR AND APS-15

		Area in square miles		
		Integrator		Noise
Step	APS-15	Film	Counts	Generator Ma.
1	32.49	46.95	45.81	35
2	30.73*	28.21	14.30	
1	31.18	47.63	46.12	35
2	30.67*	28.35	14.86	
1	No signal	19.90	19.95	30

*Area traced only because observer knew it was present; independent observers did not see signal.

which are too light and small to distinguish on the film and planimeter; whereas, on step 1 the average power is higher than the threshold by a considerable amount. Thus, on step 1 the measurement is not affected by the holes. However, with the early model of the area integrator which was used with the APS-15, the instability of the radar was as important as the instability of the area integrator. Since the APS-15 did not exhibit stability, the computing circuits were never used with the APS-15.

After the circuits of the first model had been stabilized late in 1954, an averaging device was added to the video signal. This averaging device produced an average in time along a radial. Although this is not the type of averaging required by the theory, the averaging did help to reduce the effect of the incoherent signal. If the storms were such that they were homogeneous for three miles in length at all places within the storm, this type of averaging would produce an average which would be theoretically correct. Even though this is not the case, it was decided that the averaging was necessary in order to produce better area comparisons. This device produced successful results on the noise generator calibration. It did not produce significant errors in stretching of the main area.

Five storms were analyzed using the APS-15 and the revised model of the area integrator. These radar-indicated-rates were obtained from the Wexler[3] radar-rainfall equation corrected for the 7 db departure from theory, indicated by Austin and Williams.4 Results of this analysis are presented in Table 3.

TABLE 3

AREA INTEGRATOR AND RAINGAGE AREAL-MEAN RAINFALL COMPARISONS

Date 1954	Rainfall Duration (min.)	Gage Avg. (in.)	Integrator Avg. (in.)
9-19	14	0.02	0.02
10-4	24	0.09	0.27
10-10	35	0.22	0.53
10-10	10	0.13	0.07
10-11	41	0.06	0.14

Difficulties were encountered in the attempt to use the APS-15 to produce a calibration on the area integrator which would be similar in amplitude to the calibration on the APS-15 proper.

Thus, it was difficult to compare directly the areas from the area integrator with the areas from the APS-15. However, attempts were made to do this. Figures 5 and 6 show the effects of the averaging device. Figure 5 was taken of the APS-15 and Figure 6 of the area integrator scope. It will be noted that the area integrator scope produces echoes only over the watershed for which it is set. The APS-15, of course, produces echoes over the entire scope. The area outlined on Figure 5 is the area of the watershed which is the only area on which the integrator operates. The areas do not appear exactly the same since the APS-15 was some 4 to 5 db more sensitive than the area integrator on this day. The loss of sensitivity in the area integrator was due to the inability to perform integration on signals which are equal to or below noise level.

These pictures were taken after the addition of the averaging device and the differences between Figures 2, 5, and 6 are an indication of the success of the averaging device. Some stretching of the video is apparent, particularly in the southeast corner of the watershed. It should also be noted that since there is no averaging in azimuth, the holes have become more nearly radial lines.

THE AREA INTEGRATOR WITH THE CPS-9

A second model of the area integrator was constructed in early 1955 to operate with the CPS-9 radar. In the second area integrator a new method of obtaining gating signals was used. This method allowed the operator to select any 100 square mile area over which to collect data. Automatic time marks were placed on the area integrator read out in the second model. This allowed closer time comparison with the radar. The difficulties encountered with the APS-15 with regard to the radar stability were greatly reduced in using the CPS-9. Calibration remained constant to within the measurement error for weeks at a time. However, difficulty was encountered, the same as with the APS-15, in attempting to set the area integrator in a way that the calibration would be correct for use with the computing circuits. Thus, most of the data were taken without use of the computing circuits. The area determined by the integrator was multiplied by the rainfall rate by use of a standard desk calculator. Data from several storms were collected over the East Central Illinois raingage network (fig. 7).

General Analysis Procedure

The area as obtained by the area integrator for each of the individual step levels was multiplied by the theoretical rainfall intensity for each level. The values were then summed to determine the total amount of rainfall in the 100 square mile area. This number was compared with the rainfall as determined by the raingages.

The CPS-9 film was analyzed by tracing the echo over the area of interest. These tracings were then planimetered to determine the area of rainfall. The areas were multiplied by the theoretical rainfall intensity as determined from the radar calibrations and the equation developed by Wexler[3] without any correction factor.

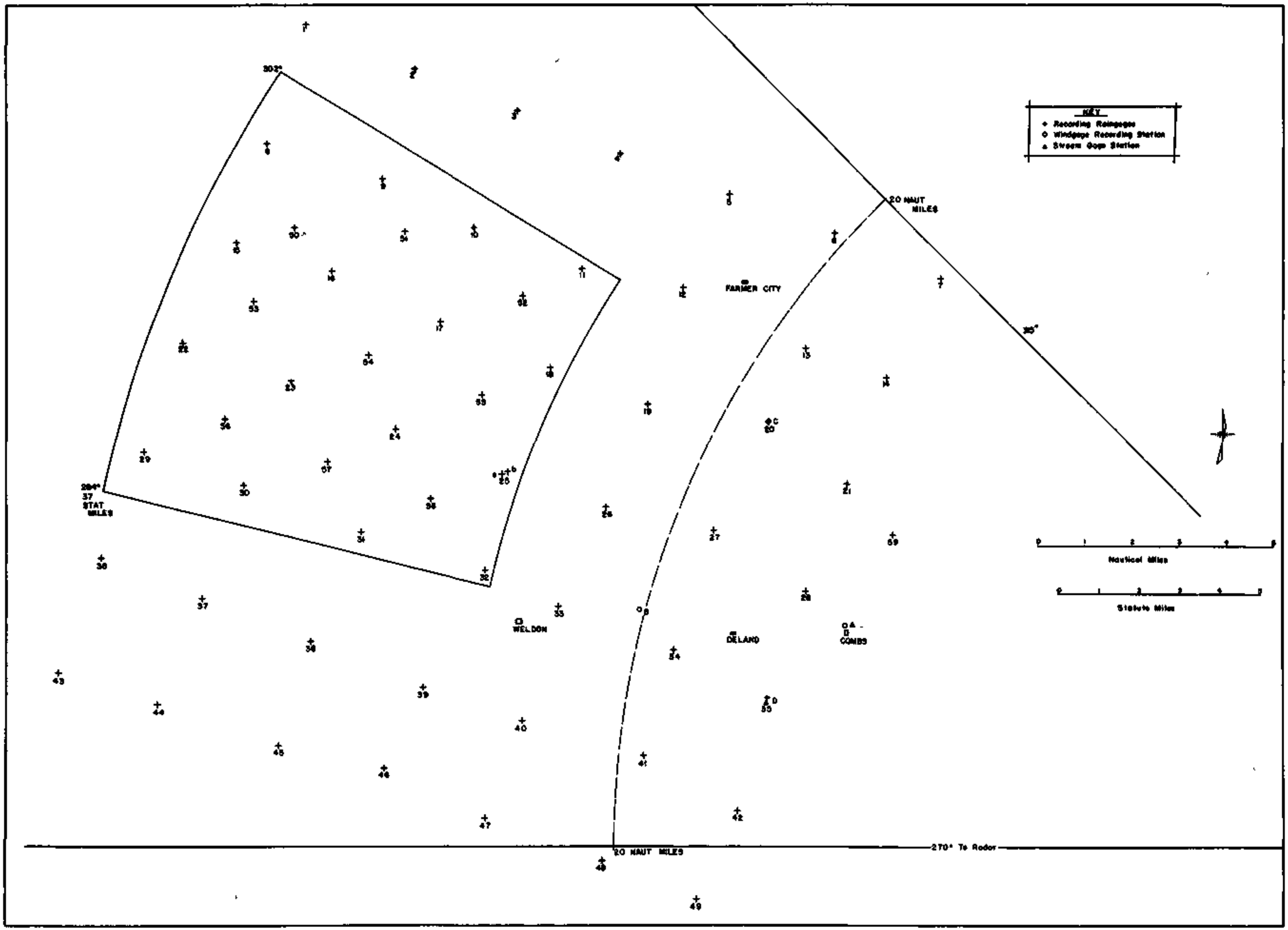


FIG.7 MAP OF EAST CENTRAL RAINGAGE NETWORK

Henceforth, values determined by this method will be referred to as the CPS-9.

Comparisons were made between the radar indicated amount, area integrator indicated amount, and raingage indicated amount. These comparisons were made both by minute-to-minute amounts and by total storm amounts. Comparisons were also made between the areas as obtained by the area integrator and manual computations from the CPS-9 radar scope photos.

Storm of August 29, 1956

Synoptic Conditions. At 0630 a wave was located near Minneapolis, Minnesota, with a warm front eastward to southern New York, and a cold front extending southeastward to another wave in western Kansas with the cold front continuing on southwestward into New Mexico. A squall line was located from just north of Muskegon, Michigan, southwestward to the vicinity of St. Louis. The general synoptic situation was one of slow change with Illinois remaining under the influence of southerly air flow from the gulf.

Area integrator data were taken in the morning between 0803 and 0951. This was a squall line situation in which an average of 0.14 inch of rain fell on the network.

Total Storm Comparisons. Table 4 is a summary of quantities totalized for the entire storm. Line 1 is the average rainfall as determined by the raingage, the radar, and the area integrator. It can be noticed here that both the radar and the area integrator severely underestimated the total amount of rainfall,, The area integrator produced approximately one-half the estimate from the radar. This storm was selected so as to eliminate the effects of attenuation. At no time during the storm was there intervening rainfall between the network and the radar. However, despite this fact, the storm proved to be the poorest analyzed, on the basis of the lack of agreement of radar and the area integrator. No explanation can be given for the poor estimate of rainfall by the radar or the even poorer estimate by the area integrator. The rainfall rates for this storm were quite small as determined by the raingages, the highest rate being less than 0.5 inch per hour.

TABLE 4.

COMPARISON OF RAINGAGE, RADAR, AND INTEGRATOR
FOR STORM OF AUGUST 29, 1956

	Raingage	CPS-9	Area Integrator
Average Rainfall (in.)	0.14	0.07	0.03
Step 2 (sq mi-min)	7180	1938	1332
Step 3 (sq mi-min)		68	111
Step 4 (sq mi-min)		2.0	6.32

Lines 2, 3, and 4. of Table 4 are determined by summing the areas for each of the individual steps throughout the storm period. Step 1 was not included since the radar and the area integrator did not have equivalent calibrations. By interpolating the area of the area integrator between step 1 and step 2, the calibration of step 2 of the radar could be matched by the area integrator calibration.

Thus, the second line represents the area of step 2 of the radar summed in minutes along with an interpolated area from the area integrator such that the calibrations are equivalent to step 2 of the radar. A similar procedure was followed to determine the area integrator areas for steps 3 and 4. of the radar. It can be noticed that the area integrator is underestimating the area on step 2 but is overestimating the areas on steps 3 and 4. This is due to the inability of the averaging device to correct completely for the incoherent or "lacey" rain signal. The rainfalls as predicted by the area integrator and the radar agree as closely as they do only because on the higher steps the area integrator shows more area than the radar. This is due to the fact that, although the area integrator level may be above the average power level returned, peaks of power will occur instantaneously which exceed the set level of the area integrator and, thus, area is measured. It will be noted that in some storms this tends to balance out the underestimation of the low rainfall rate areas. Since the rainfall rates were small, this storm represents the greatest deviation between the area-minutes on step 2 between the radar and area integrator.

Minute-to-Minute Comparisons. Figure 8 is a plot of step 2 areas from the area integrator and from the radar. In general the fluctuations of the areas are the same. That is, the peaks and valleys of the two curves fall at approximately the same position. As indicated previously, the area integrator area is less than the

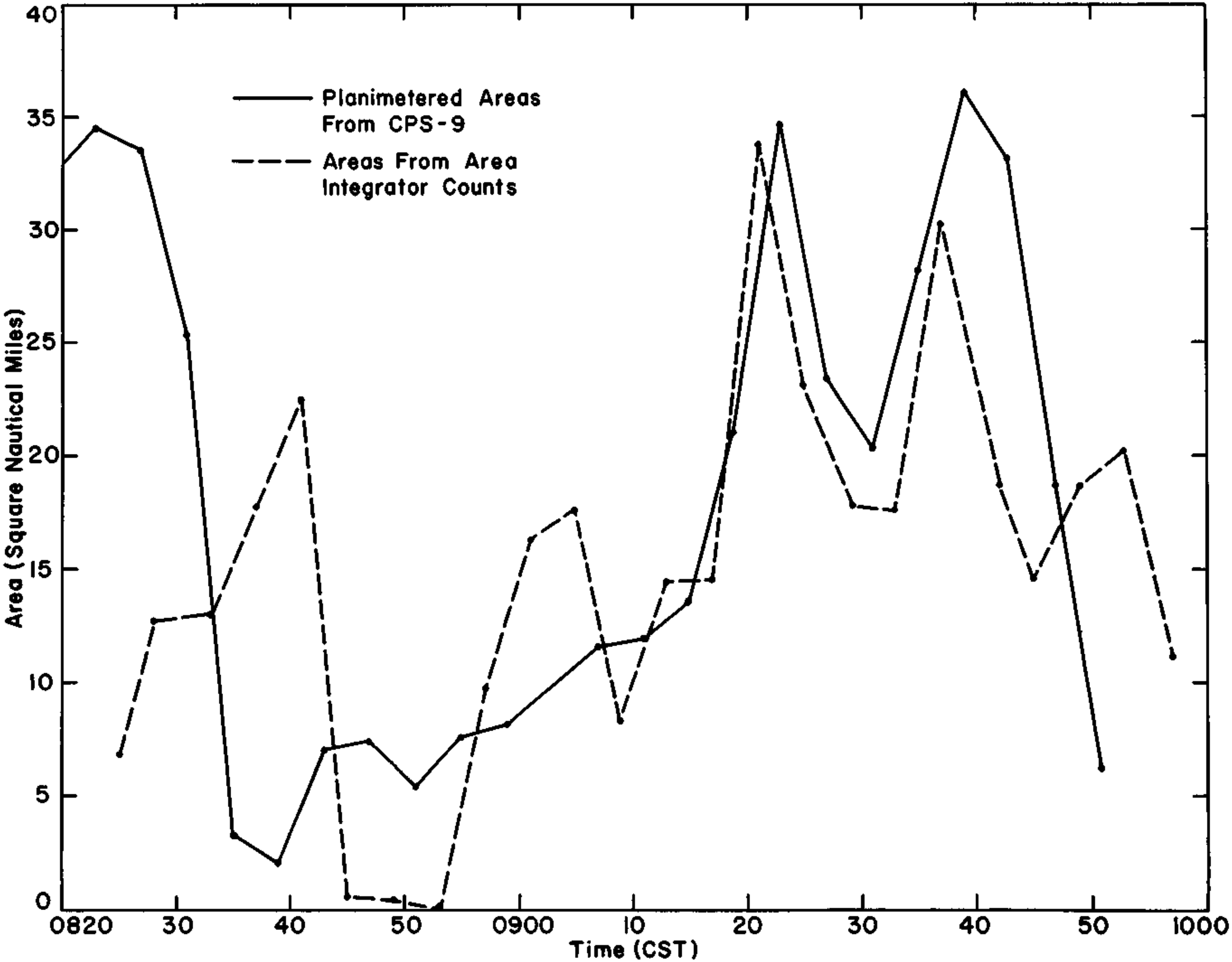


FIG.8 MINUTE BY MINUTE AREA COMPARISONS STORM OF AUGUST 29,1956

area as predicted by the radar. Unfortunately, there is no single constant that when multiplied by the area integrator area, gives the radar area. At the points along the curve where the area integrator area exceeds the radar area, the power returned is from a small area that is fairly strong. That is, if step 3 and step 4 were plotted on the same curves they would have nearly the same area for the radar values. Thus, when the return average signal is below threshold on both the PPI and the integrator, the area integrator, which measures the peak values, will measure the areas which are larger in extent than the areas noticed on a standard radar PPI.

Figure 9 is a minute-to-minute plot of the areas obtained by planimetering isohyetals obtained from the raingages. From Figures 8 and 9 it can readily be seen that the radar and the area integrator severely underestimated the total rainfall. Step 2 of the radar had a theoretical threshold level of 0.003 inch per hour. Thus, according to the raingages, step 2 of the radar should have covered the area for nearly the entire storm period. The reason for the discrepancy is not readily apparent, but must be attributed to our inability to correlate the radar signal return with precipitation amount.

Choosing a different rainfall rate to be represented by step 2 of the radar does not improve the pattern. It can be noted that the highest values obtained by radar were found to occur at 0940. The raingages show a peak at this time, but it is only approximately

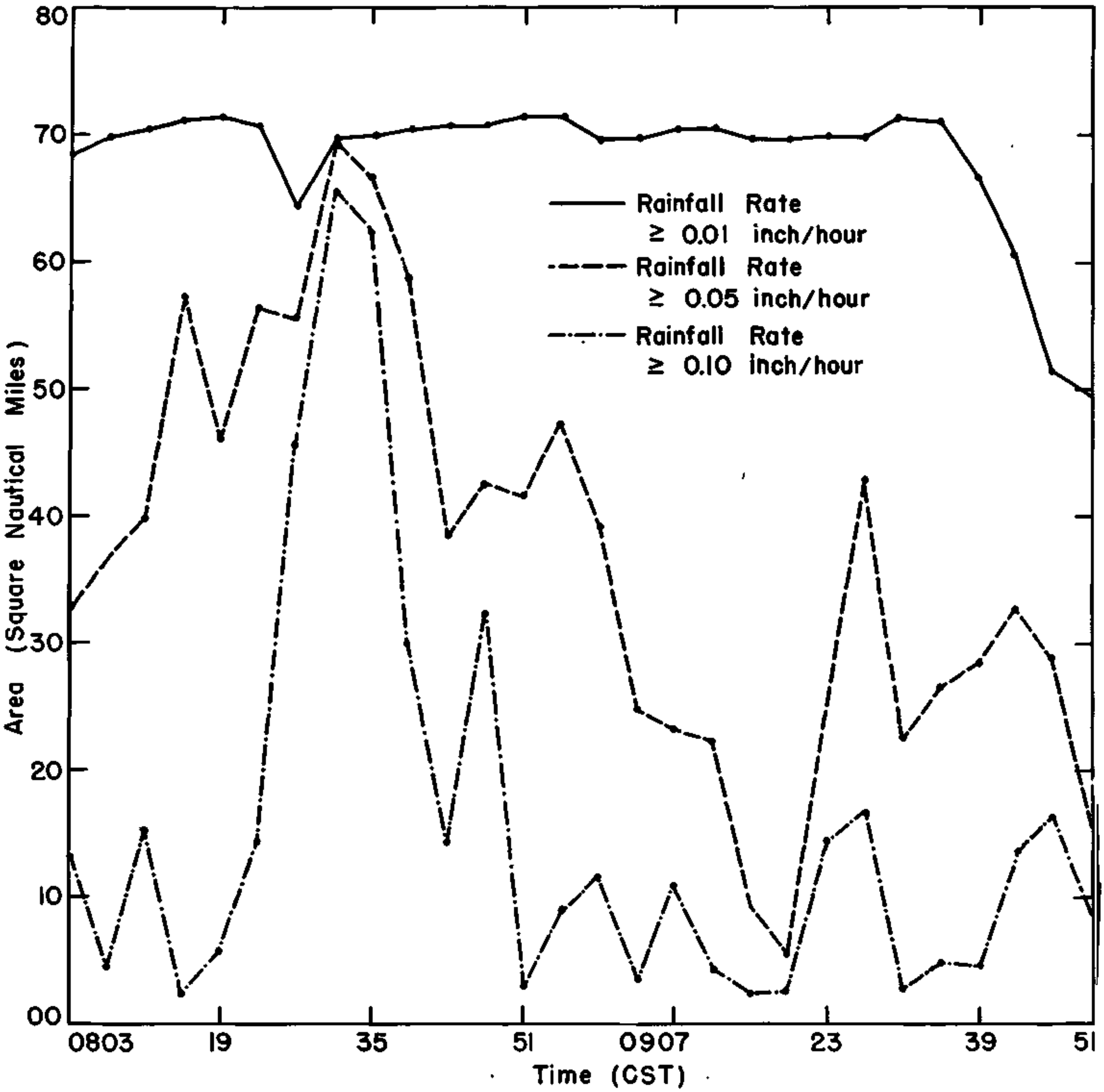


FIG. 9 AREAS FOR STORM OF AUGUST 29,1956 FROM THE ISOHYETALS

one-half of the amplitude of the peak of 0830. Thus, again, no multiplicative constant will correct the radar areas to those of the raingage. Apparently, the radar reflectivity for a given storm rainfall rate either changes appreciably during the storm, or drift in the rainfall causes an error in locating the rainfall measured by the radar on the ground.

Comparisons of rainfall rate by one minute amounts were not attempted since no significant difference would be obtained between the radar and the area integrator. Comparisons between the one minute rainfall amounts by radar and one minute rainfall amounts by raingage can be found in Research Report No. 4.[5]

If Figure 8 is compared with Figure 4, it will be noted that the averaging device has not brought the area, as determined by the area integrator, into complete agreement with the area as determined by radar. This storm is not a fair comparison, however, as later storms produce a much closer step 2 area. This storm resulted in the worst comparison of the area integrator to the radar that was obtained. It is included as the extreme which should ever occur. It is possible that the area integrator was not operating correctly on this day; however, all system checks fail to show any malfunctioning of either the integrator or the radar.

<u>Storm of August 30, 1956</u>

<u>Synoptic Conditions</u>. At 0630 CST a north-south trough was

located from the western shore of Hudson Bay southward to west central Texas. The cold front extended from north central Nebraska, westward to the vicinity of Eugene, Oregon. A stationary front extended from LaCrosse, Wisconsin, eastward to Belmar, New Jersey. Rain showers occurred over the Goose Creek network in Illinois between 0722 and 0926.

Total Storm Comparisons. Table 5 is a summary of the results of the comparisons between the radar, the raingages, and the area integrator for the total storm time of 68 minutes. The CPS-9 and the area integrator yield more nearly equal results on this storm. However, both underestimated the total rainfall by a large amount.

TABLE 5

COMPARISON OP RAINGAGE, RADAR, AND INTEGRATOR
FOR STORM OP AUGUST 30, 1956

	Raingage	CPS-9	Area Integrator
Average Rainfall	0.04	0.009	0.008
Step 2 (sq mi-min) (.01 in/hr for raingage)	3270	3600	2360
Step 3 (sq mi-min) (.05 in/hr for raingage)	1560	1.7	168.6
Step 4 (sq mi-min) (.1 in/hr for raingage)	474	0	25.2

This storm was made up of several heavy cells and some light continuous precipitation. The maximum rainfall rate as measured at any single raingage on the network was 3.8 inches per hour. The maximum rate predicted from the radar was 0.8 inch per hour and from the area integrator 2.70 inches per hour. The area integrator invariably gives a higher maximum rainfall rate than the radar, but as in this case, not always as high as recorded in the raingages.

Minute-to-Minute Comparisons. Figure 10 is a graph showing the area of rainfall as determined by the radar and by the area integrator. Step 2 of the radar is plotted and an intermediate step of the area integrator obtained by interpolation between step 1 and step 2 so that the comparisons are more nearly direct.

There are two parts of the curves which do not compare favorably. Between 0730 and 0736, the area integrator was lower than the radar and between 0746 and 0805 the radar was lower than the integrator.

One reason for the discrepancies may be a possible interpolation error. According to the raingages at 0758, rain was falling over 51 square miles but with low rainfall rates. Step 1 of the radar indicates an area of 65 square miles, some of which is possibly due to rain drifting off the network or due to virga or cloud detection. Nevertheless, this indicates that the rainfall gradients were very small and a slight error in calibration might cause the interpolation to deviate considerably.

Storm of November 6, 1956

Synoptic Conditions. At 0030 a secondary trough of low pressure had overtaken and reinforced a weak cold front oriented

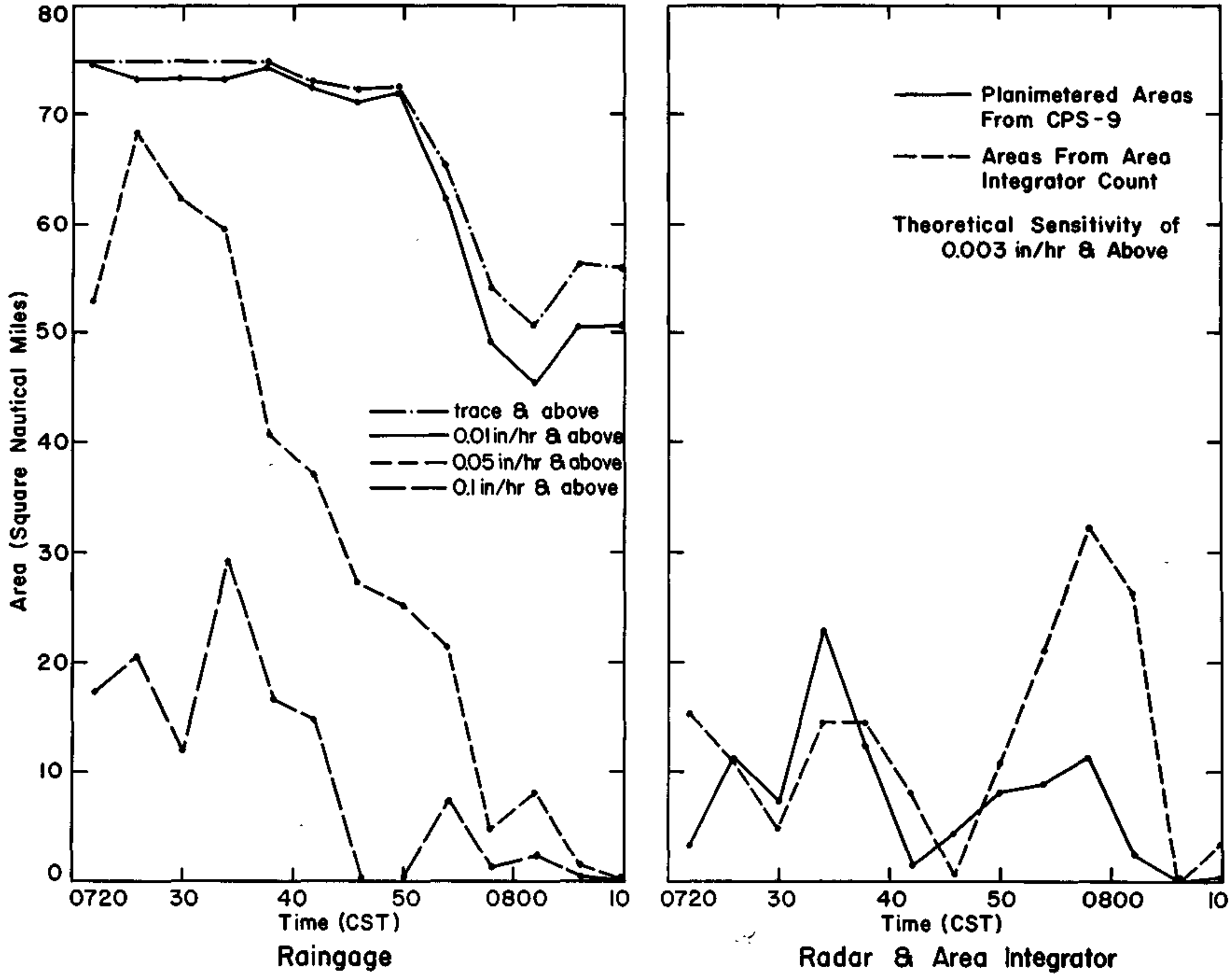


FIG.10 MINUTE BY MINUTE AREA COMPARISONS STORM OF AUGUST 30, 1956

north-south near Springfield, Illinois. Eastward movement of the front was accelerated from 14 knots to 20 knots placing its position in western Indiana at 0630. Integrator data were taken from 0030 to 0201. The rainfall over the area integrator network was characterized by light continuous rainfall for the entire period with cells imbedded in the continuous rain. Rainfall occurred over the network for the entire data collection period.

Total Storm Comparisons. This storm was included in the data analysis because it is one of the few storms in which the calibration of the radar and the area integrator were similar. Step 1 of the radar was 4 db more sensitive than step 1 of the integrator; however, steps 2 through 7 of the radar and the area integrator had exactly the same calibration. In Table 6 it will be noted that the area-minute amounts as determined by the radar were considerably higher than those determined by the area integrator on step 1. According to the raingages, the rainfall continued for the entire period and thus, the area-minute value for step 1 or for any rainfall rate would be 11,735. Thus, it can be noted that the radar did miss some of the rainfall that was occurring over the network. This may have been due to extremely light rainfall and/or attenuation.

Although the area integrator determined less than one-half the area on step 1 as did the radar, the predicted quantity of rainfall was higher from the area integrator than from the radar. This is explainable by noting that on steps 3, 4, and 5 the area integrator read appreciable area while the radar read no area.

TABLE 6

COMPARISON OP RADAR AND INTEGRATOR FOR
STORM OF NOVEMBER 6, 1956

	Ralngage	CPS-9	Area Integrator
Average Rainfall	0.37	0.0318	0.0465
Step 1 (sq mi-min)	11,735	10,500	5140
Step 2 (sq mi-min)		531	1542
Step 3 (sq mi-min)		0	753
Step 4 (sq mi-min)		0	64
Step 5 (sq mi-min)		0	3

Again the radar and the area integrator both underestimated the actual rainfall as determined by the raingages. The maximum rainfall rate in this storm at any particular gage was 1.6 inches per hour. With this rate and the theoretical radar rainfall equation, it can be shown that the radar should have seen this on step 5. During one minute of operation there was appreciable area over which rain was falling at or near 1.6 inches per hour. This did not show on the radar film. No explanation as to why this is lost in the radar can be advanced. Of course, the area integrator does register 3 square mile-minutes on step 5. These were not all obtained in any one minute of data. However, there were three consecutive minutes for which the area integrator tape showed area on step 5. These times correspond with the raingage times of maximum rainfall rate. Thus, it would seem that the averaging device of the area integrator may help to some extent in determining the rainfall rate in the storm. However, as pointed out earlier, the averaging device of the area integrator is not correct theoretically for rainfall rate, but it does seem to produce a better estimate than no averaging device whatsoever.

Minute-to-Minute Comparisons. Figure 11 is a minute-to-minute comparison of the area as shown by the area integrator and by the radar. The network area on this day was 93.5 square miles. It may be noted that the radar reaches saturation for about six minutes of the total storm time. The raingages indicate that the network was covered with rain for the entire period. The area integrator, on the other hand, reaches saturation for only one minute of the entire storm time. Even this is surprising considering the probabilities that the area integrator will underestimate at a particular point in space due to the characteristics of the return signal. This is one of the few observations where the area integrator actually indicated that the area was completely covered with precipitation. Also, it should be remembered that step 1 of the area integrator and step 1 of the radar are not the same sensitivity but are 4 db apart. However, step 2 of the radar and step 2 of the area integrator, which are also plotted in Figure 8, are the same sensitivity; and thus, they can be compared with one another directly. In these two curves, it might be noted that the area integrator tends to exaggerate trends. That is, the area integrator shows a higher area when the storm is on the increase and a lower area when the storm is on the decreasing portion

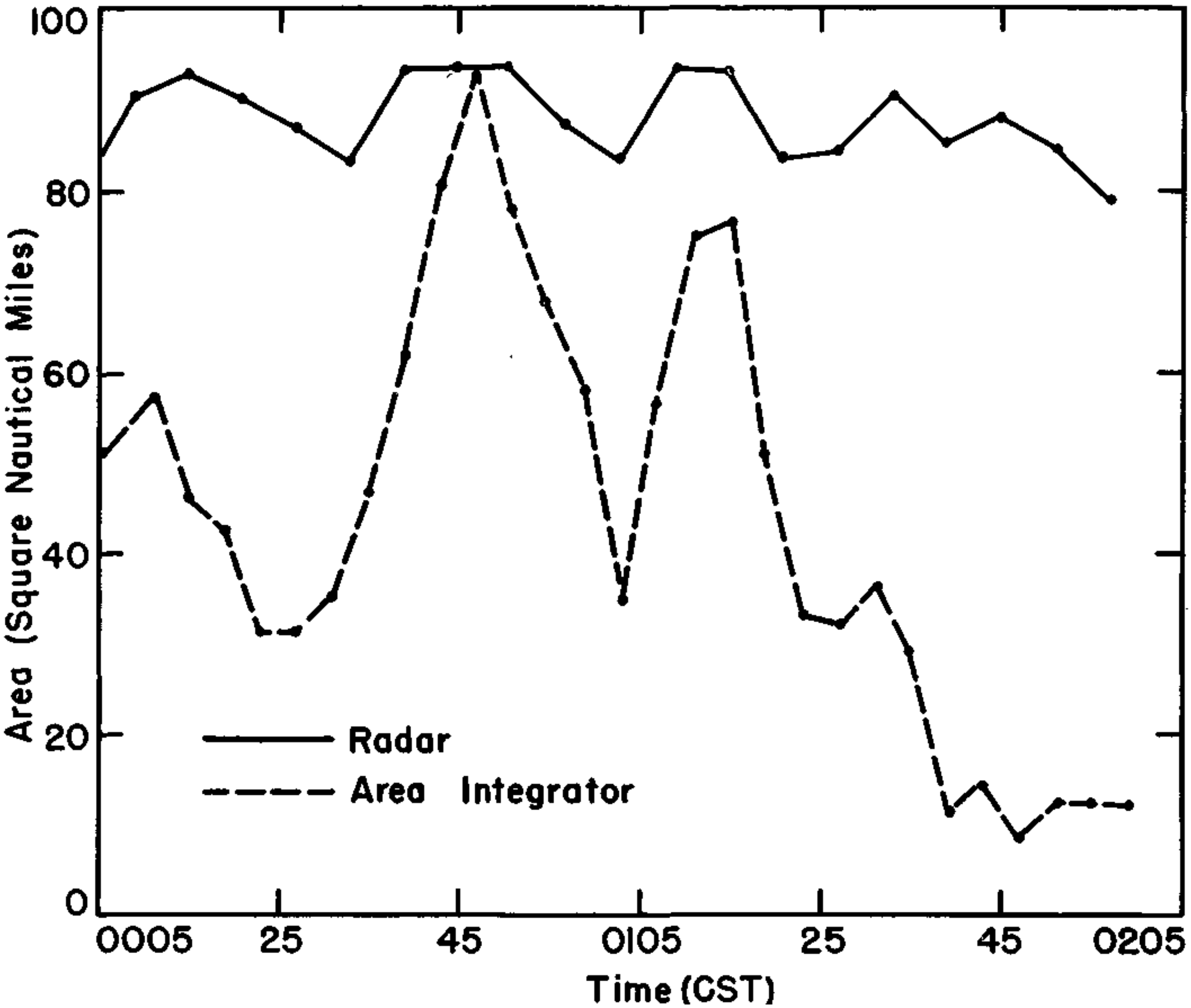


FIG. 11 MINUTE BY MINUTE AREA COMPARISONS
STORM OF NOVEMBER 6, 1956

of the cycle. There is one exception to this at 0045. The exaggeration of the trends might be an effect of the increasing rainfall rates in the cell causing the area integrator to measure more nearly the full percentage of the area over which the rainfall area is equal to or above the threshold level of the area integrator.

CONCLUSIONS AND RECOMMENDATIONS

One of the major drawbacks to the present area integrator is the means used to determine the average power. A better method of power averaging will be necessary. In fact, probably a better average is required to produce better estimates of the radar quantitative amounts also. Although the use of a better averaging device will not completely eliminate the scatter of the radar quantitative amounts, it should at least reduce the scatter to some extent. Two possible schemes to produce a better averaging would be to utilize cathode ray storage tube or a quartz delay line averaging device.

The elimination of precipitation attenuation which is present at wavelength of 5 cm or less will also be required to make the area integrator operationally useful under certain conditions,, The elimination of this precipitation attenuation might be accomplished by either changing the radar wave length to 10 cm or longer or by incorporating some means of correcting for the precipitation attenuation,, At the present stage in our knowledge of precipitation attenuation, it would appear that the former solution would be easier, but other considerations (power vs. antenna size, etc.) make the latter desirable. The storms analyzed in this report were selected to minimize the effects of precipitation attenuation. However, other storms which have been observed produce results which are at greater variance with the theoretical rainfall than any reported in this report. Some of these cases are undoubtedly due to precipitation attenuation.

A better relationship between the back scattering cross section and the rainfall rate must be determined. This is evident from work which has been accomplished under this research contract in using the radar for quantitative rainfall amounts. It is also evident in the storm of August 29, 1956. Before the rainfall measuring capability of radar can be improved, it will probably be necessary to relate the back scattered cross section to the rainfall rate as a function of the synoptic condition (and climatology) and also possibly to the stage of development of the precipitation. The incorporation of a range squared correction circuit is desirable on future equipment utilizing the area integrator. This appears to be feasible at the present state of knowledge. Due to the somewhat limited radial depth of the area of interest used in this study, no range squared correction was needed and thus none was applied. The maximum error that could be attained due to range on this area was about ±15 percent. However, since most of the storms passed through the entire network, the ±15 percent would average to a very small error.

Extending the Coverage of the Area Integrator

In this version of the area integrator, the area sampled for use in the analysis was variable from about 70 square miles to about 150 square miles. Since the raingages on the network were rather closely spaced, the area used in the analysis was about 100 square miles. There is no reason why the area over which the area integrator operates cannot be made as large as desired, provided that the radar is capable of producing a reasonable estimate of the rainfall rate occurring in the area. The second limitation of the size of the area is that the area must not include any ground return targets. The area integrator cannot distinguish between ground return targets and precipitation targets. However, as the area over which the area integrator operates is made larger, the exactness with which the operator realizes the position of the rainfall within the area is decreased. That is, the area integrator does not tell where the rainfall is falling within the area over which it is operating.

By use of some type of memory system the area integrator could be utilized to measure the rainfall over a number of sub-divisions. With the use of the memory system, the only portion of the area integrator which would need to be duplicated would be the summing circuits or storage circuits,, That is to say, the gating circuits and computing circuits could serve for several watersheds as long as the outputs from these sections could be stored in some sort of memory device and returned to the circuits at a later time. If all the area within 100 miles and outside of 20 miles of the radar were incorporated into subdivisions of 100 square miles area each, the required number of area3 or subdivisions would be 302 subdivisions. This would require a storage unit capable of approximately 5000 bits of information. This is not an unreasonably large storage device.

However, more importantly it would appear that the problems inherent in measuring rainfall quantitatively with radar require solution before further developmental work can be done on any type of area integrator,, When the state of the radar rainfall measurement art is sufficiently advanced, it may be feasible to use this area integrator to perform the routine calculations required to convert the radar information to rainfall amount.

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