NO. 19

WESTERN REGION TECHNICAL MEMORANDUM

A Grid Method for Estimating Precipitation Amounts by Using the WSR-57 Radar

by

R. Granger

DECEMBER 1966

ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
U. S. WEATHER BUREAU

Western Region Technical Memoranda:

No. 1 "Some Notes on Probability Forecasting" by Edward D. Diemer

No. 2 "Climatological Precipitation Probabilities" compiled by Lucianne Miller

No. 3 "Western Region Pre- and Post-FP-3 Program" by Edward D. Diemer

No. 4 "Use of Meteorological Satellite Data"

No. 5 "Station Descriptions of Local Effects on Synoptic Weather Patterns" by Philip Williams, Jr.

No. 6 "Improvement of Forecast Wording and Format" by C. L. Glenn

No. 7 "Final Report on Precipitation Probability Test Programs" by Edward D. Diemer

No. 8 "Interpreting the RAREP" by Herbert P. Benner

No. 9 "A Collection of Papers Related to the 1966 NMC Primitive-Equation Model"

No. 10 "Sonic Boom" by Loren Crow (6th Weather Wing, USAF, Pamphlet)

No. 11 "Some Electrical Processes in the Atmosphere" by J. Latham

No. 12 "A Comparison of Fog Incidence at Missoula, Montana, with Surrounding Locations" by Richard A. Dightman

No. 13 "A Collection of Technical Attachments on the 1966 NMC Primitive-Equation Model" by Leonard W. Snellman

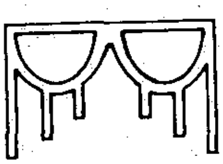
No. 14 "Applications of Net Radiometer Measurements to Short-Range Fog and Stratus Forecasting at Los Angeles" by Frederick Thomas

No. 15 "The Use of the Mean as an Estimate of 'Normal' Precipitation in an Arid Region" by Paul C. Kangieser

No. 16 "Some Notes on Acclimatization in Man" edited by Leonard W. Snellman

No. 17 "A Digitalized Summary of Radar Echoes Within 100 Miles of Sacramento, California" by J. A. Youngberg and L. B. Overaas

No. 18 "Limitations of Selected Meteorological Data"



A western Indian symbol for rain. It also symbolizes man's dependence on weather and environment in the West.

Western Regional Technical Memorandum No. 19, December 1966

A Grid Method for Estimating Precipitation Amounts by Using the WSR-57 Radar

by

R. Granger

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

A GRID METHOD FOR ESTIMATING PRECIPITATION AMOUNTS USING THE WSR-57 RADAR

R. Granger, WBAS, MIssoula, Montana

ABSTRACT

A method for estimating precipitation amounts based on radar reflectivity, from echoes which are predominately from snow, has been developed for operational use in the mountainous area around Missoula, Montana.

The method utilized empirically derived relationships of radar reflectivity and the water content of snow over a grid network 100 nautical miles in radius. The empirically established Z-S* relationships for the various gridded areas take into account range attenuation, topography and storm height.

Radar-determined estimates of precipitation amounts over the mountainous areas of northern Idaho and western Montana, utilizing this method, are being used routinely by the Weather Bureau's River Forecast Center at Portland, Oregon.

*Z-S is the relationship between radar reflectivity and snowfall intensity.

I INTRODUCTION

In the remote mountainous regions of northern Idaho and western Montana lie several major drainage basins of the upper Columbia River. In this area, comprising approximately 10,000 square miles, there are only a few widely scattered precipitation-measuring stations. Due to the remoteness of this area, real-time collection of rainfall data is not currently available, thus leaving a data void for operational hydrologic analysis.

The WSR-57 radar, located atop an 8,000-ft. peak near Missoula, Montana, overlooks much of this area. The inherent capability of the WSR-57 radar system to measure the reflectivity of precipitation targets and to display their areal distribution offers a potential for providing vital precipitation data input for operational use. The hydrologic problem in this section of the country is not one of flash flooding or of extremely heavy rains. Instead, the problem is one of snow pack accumulation in the mountains and rain or snow in the lower elevations. The hydrological situation becomes most acute during the spring runoff or during unseasonably warm periods in the winter when rainfall runoff is augmented by snow melt. Water-supply forecasting is also an important part of the hydrologic program throughout the winter and spring.

In order to estimate rainfall rates from radar returns, the Weather Bureau has adopted the empirical relationship: $Z=200R^{1.6}\,mm^6/m^3$ [1/], where Z is radar reflectivity in mm^6/m^3 and R is rainfall rate in mm/hr. While this relationship is considered representative for most rains,[2/] many factors affect its accuracy. For example, this relationship assumes that the antenna exposure is good, radar propagation is normal, and that the targets are composed of average-size rain droplets.

At Missoula these conditions are usually not fully met. The radar antenna is located on a high peak surrounded by many mountain ranges. The surrounding mountains produce a considerable amount of clutter on the radarscope and may partially or completely block the radar beam in certain areas. During the fall, winter and spring months, the radar searches into weather which is predominately snow and which may be very limited in vertical extent, thus failing to fill the radar beam. The relationship between radar reflectivity and snowfall rate has not yet been established satisfactorily. In fact the Weather Bureau does not assign an intensity value to radar echoes produced by snow [1/]. Thus a theoretical approach to the problem of estimating precipitation by radar under these conditions seems impractical.

The purpose of this empirical study was to develop an objective method for estimating precipitation amounts based on radar reflectivity from targets which are predominately snow. The approach was to establish by trial and error the relationship between radar reflectivity and snowfall by gridded area and thus indirectly compensate for terrain and propagation anomalies.

II METHOD

During the winter and spring of 1964 numerous comparisons were made between precipitation amounts collected in raingages and radar-estimated amounts. For the initial comparisons, radar-estimated precipitation amounts were based on the relationship: $Z=200R^{1.6} mm^6/m^3$. It was realized that this equation would not yield the desired results since it was derived for liquid precipitation, but was used here to provide a first estimate.

Radar data were recorded for comparison by contouring, at 30-minute intervals, the radar echoes on an overlay map gridded into 10 mm. squares. The radar echoes were contoured at eight levels of radar reflectivity as shown in Table 1. It was assumed that the instantaneous computed rainfall rates made at 30-minute intervals were representative of the succeeding 30-minute period. It will be noted from Table 1 that radar reflectivity measurements began at a high gain setting, -109 dbm. The maximum gain setting for the WSR-57 radar has been standardized at the -103 dbm level for Weather Bureau operational use [1/]. However, experience has shown that the maximum gain of the WSR-57 radar is required to detect snow under certain conditions, and that echoes barely visible at the maximum gain have resulted in accumulations up to an inch of liquid precipitation in six hours. Based on the performance of the Missoula WSR-57 radar, -109 dbm was a reasonable level near the maximum gain of the radar from which measurements could begin.

Radar-estimated precipitation rates obtained in the manner described were compared with rates recorded by eight recording raingages located within a 100-mile radius of the radar station. From these initial comparisons, average precipitation rates were assigned for a particular echo intensity at a particular range.

This relationship was then applied over the entire grid network to estimate 24-hour precipitation amounts. The estimated 24-hour accumulations were then compared with the 24-hour raingage catch at 53 locations in the test area. Examination of these data continued to show a rather broad scatter about the line of best fit. Precipitation amounts at many locations were overestimated, while others were underestimated. Assuming that range attenuation and topography were partly responsible for these errors, weighting factors were assigned to the radar reflectivity values.

Because of the extremely complex nature of the topography and its effect on radar beam propagation, adjustments or weighing had to be considered on an individual grid square basis. By trial and error, the closest relationship between echo reflectivity and precipitation rate was determined for each grid square.

Further refinement of these data was possible through consideration of the storm height. Analysis of the data revealed that storms should be divided into two classes: (1) those whose tops extend above 14,000 feet and (2) those with tops below 14,000 feet. In order to improve the correlations it was necessary to increase the value in class 2 over those in class 1. A plausible explanation would be the lack of complete beam filling in class 2 situations [2].

In essence, the final relationship deduced between radar reflectivity and precipitation rate assigned for a particular grid square or group of grid squares reflects the integration, through empirical means, of all the physical factors which may be influencing the detection of precipitation in that particular area.

Having developed the radar echo intensity precipitation relationship for each grid square, it was necessary to provide an operational technique for daily application. Two gridded overlay maps for the region were prepared: one for storm tops exceeding 14,000 ft., and another for storm tops below 14,000 ft. (see Figures 1 and 2). Each grid square on the overlays is placed in one of three classes designated by shading, cross-hatching, and "white area". These classes correspond to the precipitation values to be assigned to particular grid squares having certain radar echo intensities. Table 2 shows the radar reflectivity-rainfall rate for the three grid-square classifications. Note from Table 2 and Figures 1 and 2 how the relationship between radar reflectivity and precipitation rate changes with topography and storm height. The "white area" grid squares are invariably found at extended ranges and in the lee* of mountain ridges. Precipitation rates assigned to the white areas are roughly a factor of 2 greater than the shaded areas. Also reflected in Figures 1 and 2 is the importance of storm tops in the relationship. For example, notice how the shaded area is increased for storms with tops above 14,000 feet.

III OPERATIONAL APPLICATION

The operational procedure recommended to obtain precipitation accumulation estimates by radar is as follows: at 30-minute intervals precipitation echoes that are 10 miles in diameter or greater are outlined at the levels of reflectivity specified in Table 2. The contours of intensity are initially drawn on the face of the PPI scope in various colors. These outlines are then transferred onto a 100-nm range overlay map which is divided into 10-nm grid squares.

The appropriate precipitation echo intensity grid chart, Figure 1 or 2, is selected for use depending on the height of the echo tops. The precipitation-intensity grid chart is placed under the grid map showing the observed echo contours. A third grid map (blank) is placed over these two. By placing the combined charts on a light table it is possible to see through all three charts and thus assign the proper rain intensity to each grid and note it on the top chart in the appropriate grid square. The top chart becomes the summary chart and is used at successive observations to tally rainfall amounts in each grid square. Data are normally summarized for six-hour periods corresponding to synoptic observation times. At the end of each six-hour period the values in the grid squares are totaled.

*In respect to the radar beam

The grid square totals of one-tenth inch or more are made available to forecasters in a teletype message. The message, designated "RAPCPN", provides the location of the grid square in alpha numerics and the precipitation amount to the nearest tenth of an inch. An example of the RAPCPN message and the chart from which it was made is shown in Figure 3.

IV EVALUATION

Using the method described, radar estimates of precipitation amounts were made routinely from December 1964 through June 1965. These data were compared with raingage data collected for the same period from 51 stations within 100 nm of the radar.

Table 3 is the seasonal tabulation of precipitation as recorded at the 51 raingage sites and also the radar-estimated seasonal precipitation. Comparison of the radar estimates with actual measured amounts on a seasonal basis were rather good. This is evidenced by the scatter-gram plot of these data shown in Figure 4. A relatively high correlation coefficient of .88 was calculated for these data.

Correlations also were made for each of the 51 stations based on 24-hour amounts. Figures 5 and 6 are two scatter-grams representing the extremes of the coefficients calculated, .57 to .82.

In a broad sense, these data show essentially what others have found to be true, that point rainfall data for individual days usually correlate poorly with radar estimates [3/]. When the data are averaged over a longer time interval and over larger areas, the correlations are improved significantly.

Radar-estimated seasonal precipitation amounts were within a factor of 2 of the actual amounts at nearly all of the 51 stations. This is regarded as particularly significant since the radar measurements were made from echoes which were predominately snow and over terrain not ideally suited for radar weather detection.

V CONCLUSIONS

The method developed provides reasonable estimates of liquid water accumulation using radar reflectivities from echoes which are predominately snow.

By establishing empirical relationships between radar reflectivity and precipitation intensity on an individual grid square basis it was possible to reduce the errors in radar reflectivity produced by range attenuation, topography and precipitation state.

The method developed can be applied operationally on a daily routine basis.

Special Note:

The preparation of the RAPCPN message described in this report has been part of the routine operational program at the Weather Bureau radar station at Missoula, Montana, for the past two years. The special RAPCPN message is prepared at regular intervals and transmitted over Service A teletype to the River Forecast Center at Portland, Oregon. Through this means, vital precipitation data are provided for operational use for the otherwise data-sparse watershed of the Upper Columbia River.

VI REFERENCES

1. Weather Surveillance Radar Manual - Department of Commerce-ESSA-WB

2. Radar Meteorology - Battan, Louis J.

3. Results of Precipitation Measurements with Weather Bureau Radars
   Allen Flanders - Proceedings of the World Conference on
   Radio Meteorology incorporating the Eleventh Weather Radar
   Conference - AMS

VII ACKNOWLEDGMENTS

Much credit for this program is due to the radar staff at Missoula, Montana: W. H. Henning, R. L. Murray, J. P. Osborne, and M. L. Vick. Their many suggestions resulted in improved efficiency in data collection and evaluation.

Special efforts were put forth by the electronics staff: J. R. Bird, W. R. Stanley, and W. R. Reed to maintain the radar system at peak performance levels.

Constructive comments and assistance in the final preparation of this paper from the office of the Chief, Scientific Services, Western Region, especially Mr. H. Benner, were appreciated.

WSR-57 Gain antenuator set	Reflectivity mm^6/m^3*	Rainfall rate in/hr*
-109 dbm	1.2	.0017
-103 dbm	4.0	.0036
6 db	2.0×10^1	.0085
12 db	7.5×10^1	.020
15 db	1.6×10^2	.034
18 db	2.1×10^2	.050
21 db	7.0×10^2	.080
24 db	1.3×10^3	.130

Table 1 - *Data based on the WSR-57 radar system and the Theoretical Rainfall vs Radar Reflectivity Chart used by the Weather Bureau.

Echo Intensity	Precipitation Rate (inches/hour) in:		
	White Area	Cross Hatched Area	Shaded Area
-109 dbm	.02	.01	0
-103 dbm	.03	.02	.01
+6 db	.04	.03	.02
+12 db	.06	.05	.03
+15 db	.09	.08	.05
+18 db	.13	.12	.08
+21 db	.18	.17	.12
+24 db	.24	.23	.17

Table 2 - Precipitation Rates, Inches per half-hour for Figures 1 and 2.

TABLE 3

COMPARISON OF RADAR PRECIPITATION ESTIMATES WITH ACTUAL PRECIPITATION
DECEMBER 1, 1964 - JUNE 18, 1965

STATION	ELEVATION MSL	AZIMUTH (°)	RANGE NM	PRECIPITATION DAYS	RADAR PRECIPITATION	ACTUAL PRECIPITATION
Orofino, Idaho	1027	248	100	81	13.08	20.93
Kooskia, Idaho	1261	237	99	72	9.03	13.06
Kamiah, Idaho	1212	241	97	68	10.84	11.40
Elk City, Idaho	4058	220	95	66	10.06	14.18
Clarkia, Idaho	2810	269	94	80	11.77	25.75
Elk River, Idaho	2918	261	93	76	12.78	24.84
Kellogg, Idaho	2305	290	93	84	16.68	20.06
Whitefish, Mont.	3080	349	90	77	6.78	14.63
Fenn, Idaho	1585	229	88	70	17.36	23.61
West Glacier, Mont.	3154	001	88	81	5.06	20.91
Trout Creek, Mont.	2356	308	85	69	12.64	18.35
Wallace Woodland, Idaho	2950	290	83	82	14.49	24.02
Pierce, Idaho	3185	247	82	86	20.87	29.48
Headquarters, Idaho	3138	252	81	86	21.13	29.43
Burke, Idaho	4093	294	81	87	20.64	32.83
Hungry Horse, Mont.	3160	360	81	82	8.27	20.67
Mullen, Idaho	3586	290	79	83	16.56	29.19
Kalispell AP, Mont.	2965	351	78	71	5.96	10.22
Pleasant Valley, Mont.	3600	331	77	61	6.22	11.73
Libby 32 SSE, Mont.	3600	319	77	66	10.89	17.01
Avery, Idaho	2492	281	76	79	23.24	21.34
Kalispell City, Mont.	2971	349	72	72	6.33	9.79
Sula, Montana	4400	180	72	66	5.66	9.72
Elliston, Montana	5075	113	71	79	7.25	7.95
Creston, Montana	2991	357	70	73	7.11	10.26
Kila, Montana	3185	345	69	66	5.46	10.57
Thompson Falls, Mont.	2380	302	65	85	13.43	18.43
Deer Lodge, Montana	4850	128	64	55	2.13	5.16
Haugan, Montana	3150	290	63	90	19.08	24.51

TABLE 3 (Continued)

COMPARISON OF RADAR PRECIPITATION ESTIMATES WITH ACTUAL PRECIPITATION
DECEMBER 1, 1964 - JUNE 18, 1965

STATION	ELEVATION MSL	AZIMUTH (°)	RANGE NM	PRECIPITATION DAYS	RADAR PRECIPITATION	ACTUAL PRECIPITATION
Darby, Montana	3880	189	62	45	2.72	4.68
Silver Lake, Montana	6480	148	62	59	4.42	8.38
Big Fork 10S, Montana	3075	360	55	67	3.74	15.48
Swan Lake, Montana	3150	006	55	78	4.67	19.05
Lincoln, Montana	4540	097	54	84	7.86	12.98
Philipsburg, Montana	5270	143	51	57	2.15	6.96
Lonepine, Montana	2875	327	50	56	3.47	7.68
St. Regis, Montana	2680	291	48	75	7.31	16.64
Hamilton, Montana	3529	187	48	48	2.62	7.62
Powell, Idaho	3632	221	43	87	17.75	28.97
Drummond, Montana	3943	123	41	76	4.62	7.61
Paradise, Montana	2890	306	40	64	5.17	13.21
Polson Kerr Dam, Montana	2730	348	39	59	3.98	9.26
Superior, Montana	2710	286	39	63	6.47	13.80
Ovando 1SW, Montana	4100	090	34	76	5.02	10.88
Stevensville, Montana	3370	186	32	47	2.50	7.54
Ovando 7WNW, Montana	4000	084	30	70	5.52	11.01
Lolo Hot Springs, Montana	4055	234	27	61	7.51	12.33
Lindberg Lake, Montana	4500	027	25	73	10.39	17.69
Seeley Lake, Montana	4100	059	22	74	6.25	14.12
Alberton, Montana	3070	267	21	75	7.97	12.96
St. Ignatius, Montana	2900	346	18	67	6.78	10.66

Precipitation days are those on which the station or the radar or both reported precipitation.

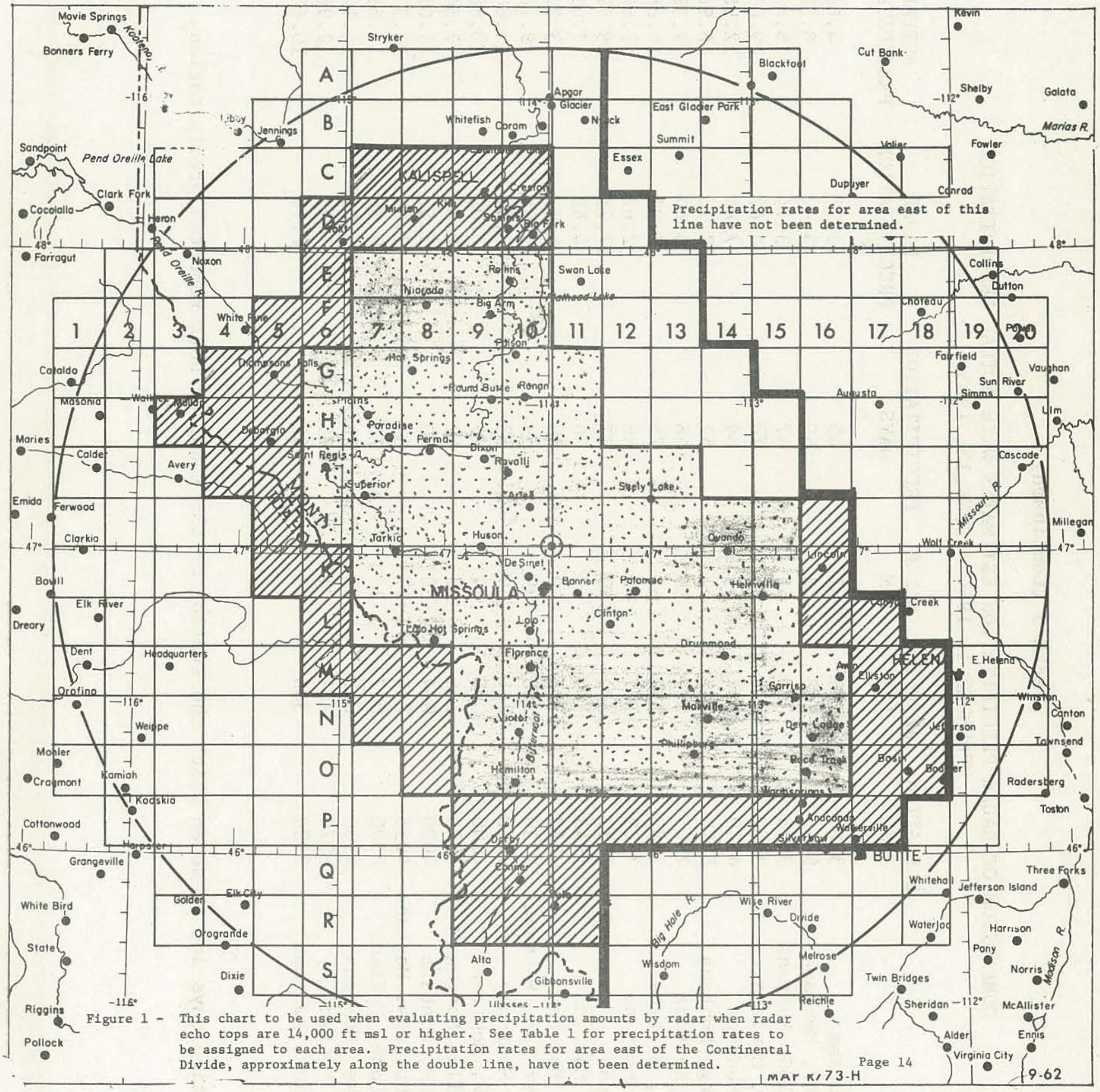


Figure 1 - This chart to be used when evaluating precipitation amounts by radar when radar echo tops are 14,000 ft msl or higher. See Table 1 for precipitation rates to be assigned to each area. Precipitation rates for area east of the Continental Divide, approximately along the double line, have not been determined.

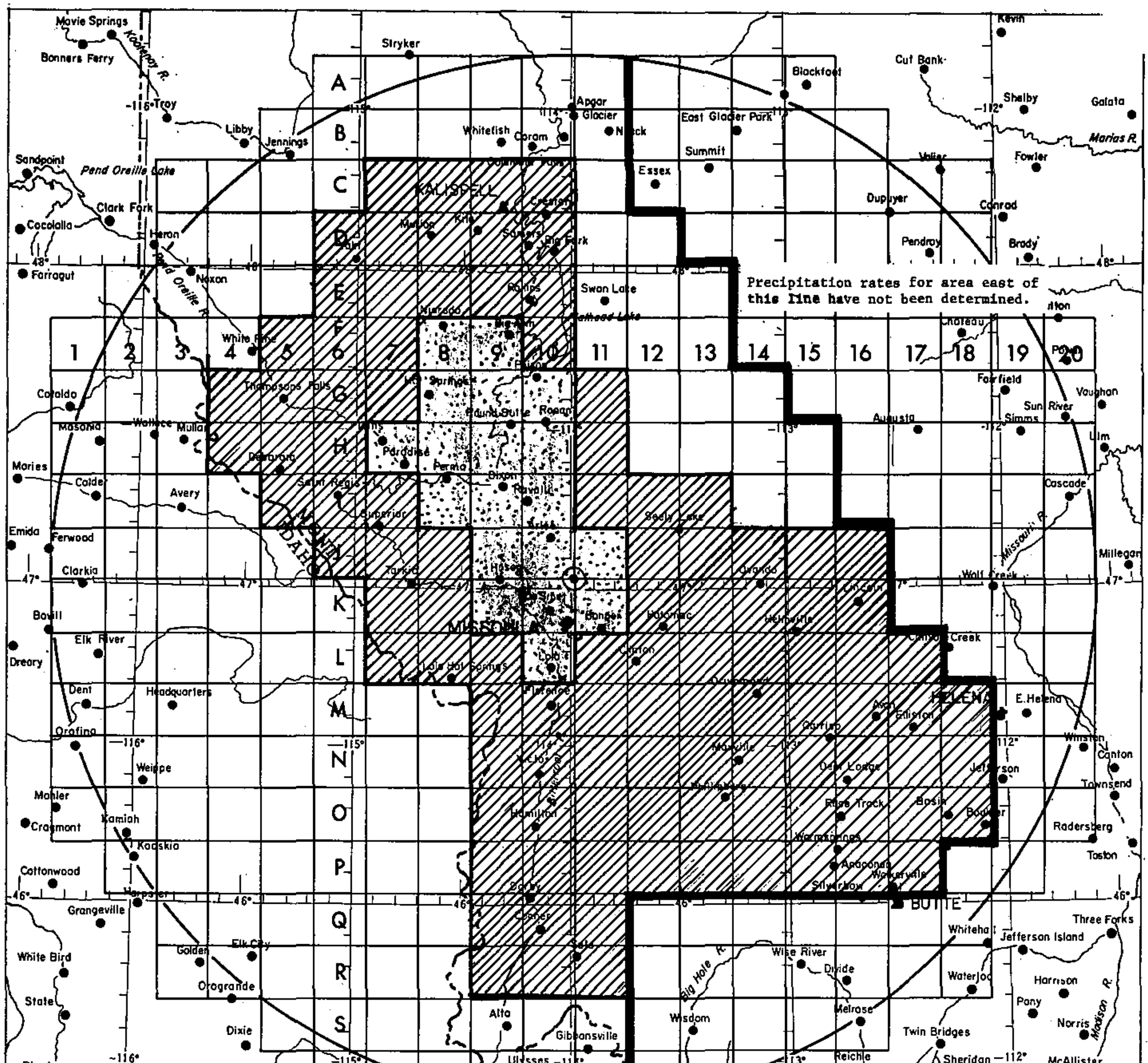
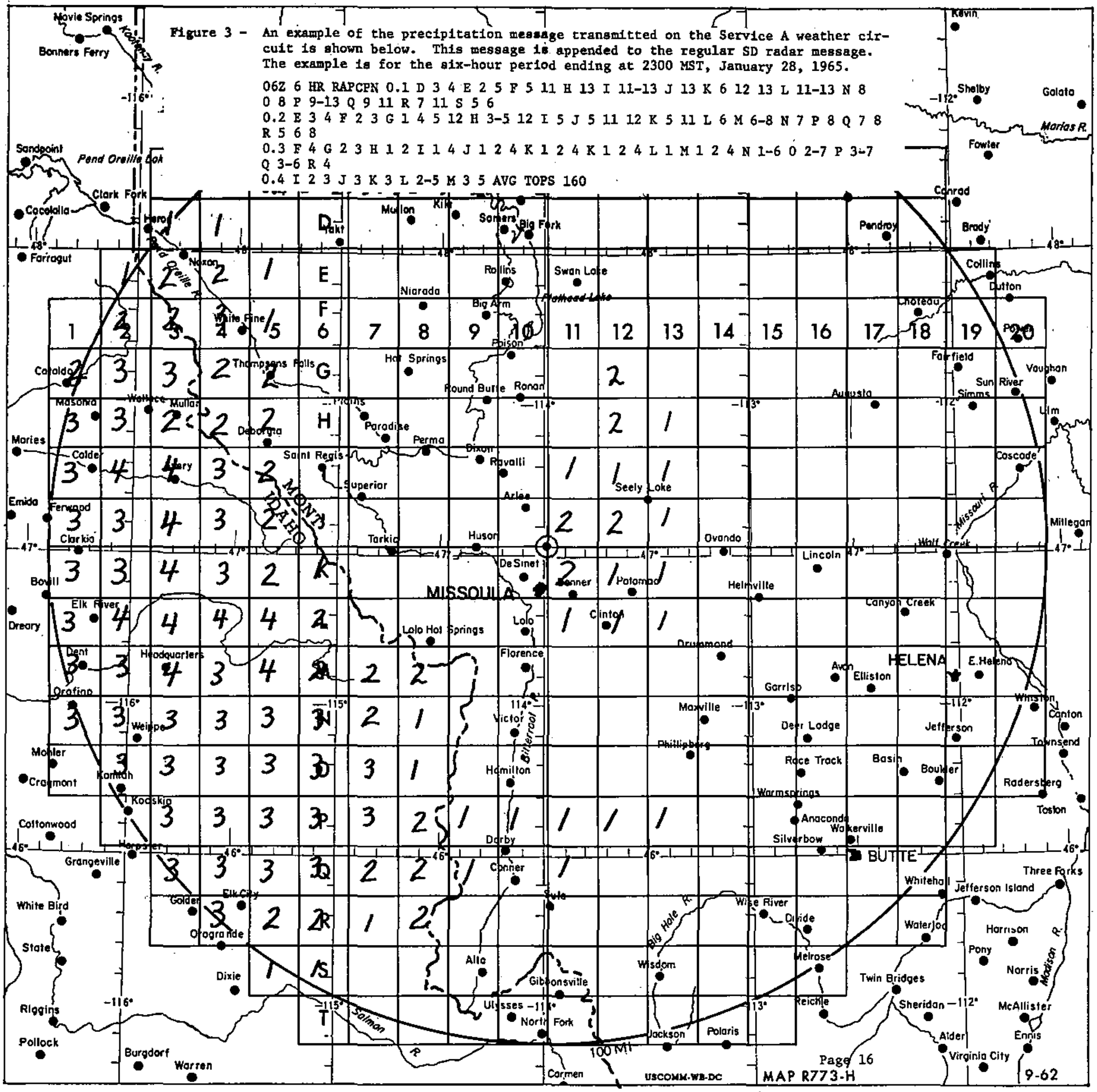


Figure 2 - This chart to be used when evaluating precipitation amounts by radar when radar echo tops are below 14,000 msl. See Table 1 for precipitation rates to be assigned to each area. Precipitation rates for area east of the Continental Divide, approximately along the double line, have not been determined.

9-6

Figure 3 - An example of the precipitation message transmitted on the Service A weather circuit is shown below. This message is appended to the regular SD radar message. The example is for the six-hour period ending at 2300 MST, January 28, 1965.

```
06Z 6 HR RAPCPN 0.1 D 3 4 E 2 5 F 5 11 H 13 I 11-13 J 13 K 6 12 13 L 11-13 N 8
0 8 P 9-13 Q 9 11 R 7 11 S 5 6
0.2 E 3 4 F 2 3 G 1 4 5 12 H 3-5 12 I 5 J 5 11 12 K 5 11 L 6 M 6-8 N 7 P 8 Q 7 8
R 5 6 8
0.3 F 4 G 2 3 H 1 2 I 1 4 J 1 2 4 K 1 2 4 K 1 2 4 L 1 M 1 2 4 N 1-6 0 2-7 P 3-7
Q 3-6 R 4
0.4 I 2 3 J 3 K 3 L 2-5 M 3 5 AVG TOPS 160
```



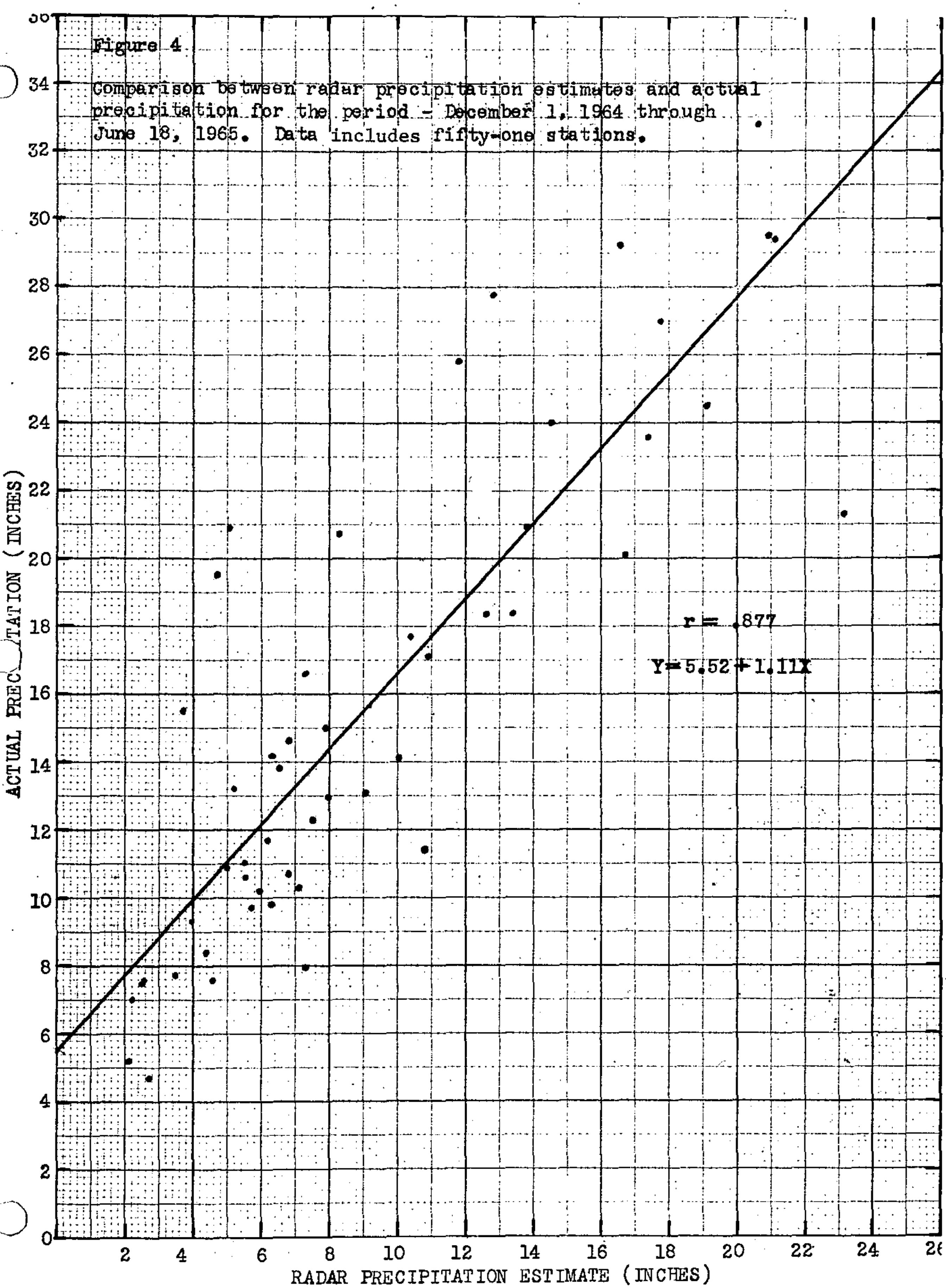


Figure 4
Comparison between radar precipitation estimates and actual precipitation for the period - December 1, 1964 through June 18, 1965. Data includes fifty-one stations.
r = .877
Y = 5.52 + 1.11X
ACTUAL PRECIPITATION (INCHES)
RADAR PRECIPITATION ESTIMATE (INCHES)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36

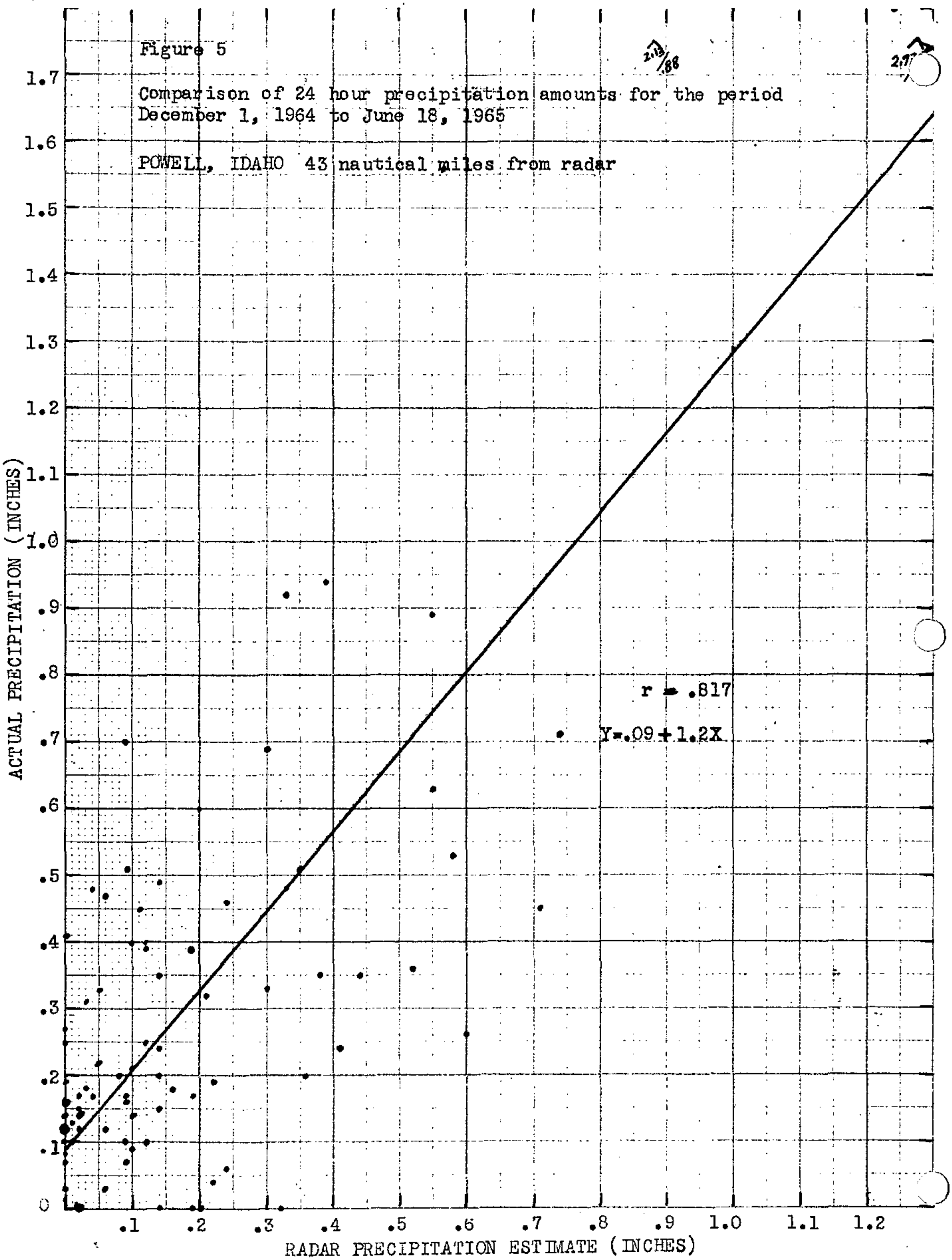


Figure 5
Comparison of 24 hour precipitation amounts for the period December 1, 1964 to June 18, 1965
POWELL, IDAHO 43 nautical miles from radar
r = .817
Y=.09+1.2X
ACTUAL PRECIPITATION (INCHES)
RADAR PRECIPITATION ESTIMATE (INCHES)
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7

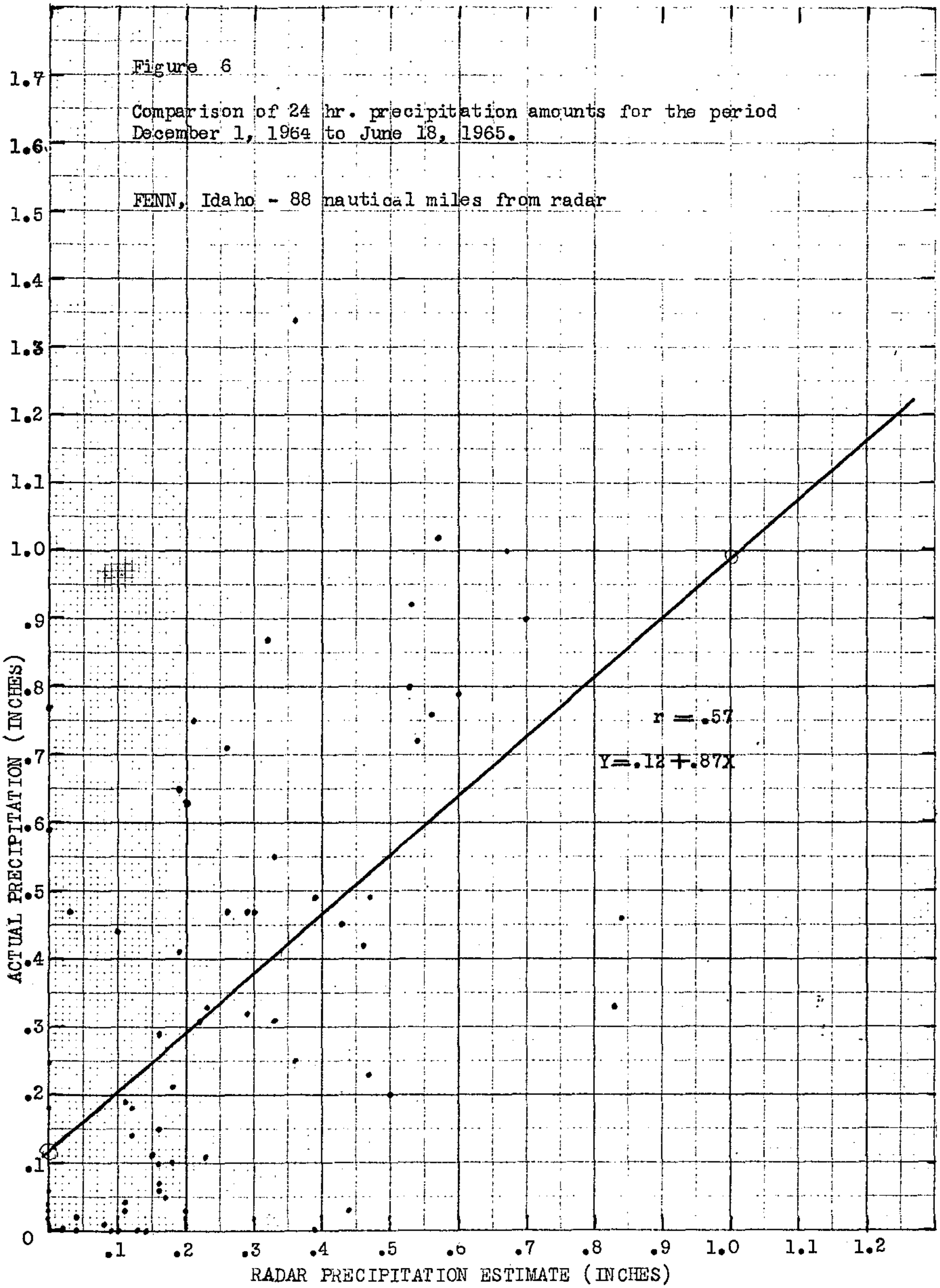


Figure 6
Comparison of 24 hr. precipitation amounts for the period
December 1, 1964 to June 18, 1965.
FENN, Idaho - 88 nautical miles from radar
r = .57
Y=.12+.87X
ACTUAL PRECIPITATION (INCHES)
RADAR PRECIPITATION ESTIMATE (INCHES)
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7