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ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Weather Bureau

Areal Coverage of Precipitation in Northwestern Utah

PHILIP WILLIAMS, JR. AND WERNER J. HECK

Western Region

SALT LAKE CITY,
UTAH

September 1970

WESTERN REGION TECHNICAL MEMORANDA

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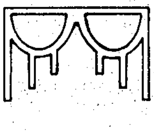

A western Indian symbol for rain. It also symbolizes man's dependence on weather and environment in the West.

U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

Weather Bureau Technical Memorandum WR-56

AREAL COVERAGE OF PRECIPITATION IN NORTHWESTERN UTAH

Philip Williams, Jr.
Scientific Services Division
Western Region Headquarters, Salt Lake City, Utah

Werner J. Heck
Scientific Services Division
Western Region Headquarters, Salt Lake City, Utah

WESTERN REGION
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AREAL COVERAGE OF PRECIPITATION IN NORTHWESTERN UTAH

I. INTRODUCTION

In the preparation of probability of precipitation (PoP) forecasts, consideration of areal coverage is important. While Weather Bureau PoPs are point probabilities, Hughes (1) and others have shown that point probability (Pp) may be expressed by Pp = CPa, where C is areal coverage (percent of area expected to be covered by precipitation, if precipitation occurs) and Pa is areal probability. (This assumes C and Pa to be independent.) Pa is dependent mainly on large-scale precipitation producing mechanisms; areal coverage is closely related to topography and precipitation type.

Curran and Hughes (2) studied areal coverage of precipitation regimes in central Kentucky during two warm seasons (April through October). They found that only 29% of the days had 100% areal precipitation coverage at 10 stations distributed over a circular area of 60 miles radius. This information was then used to compute maximum possible forecast skill-scores.

Areal coverage of precipitation in a dry region such as northwestern Utah would be expected to be lower than in a moist area like Kentucky. This small areal coverage would have a marked effect on the degree to which Salt Lake City PoP forecasts could improve over climatological forecasts. The purposes of this study are to determine: 1) the frequency distribution of areal coverage on precipitation days in northwestern Utah during various seasons of the year, and 2) the maximum possible improvement of forecast Brier Scores over climat Brier scores.

II. PROCEDURE

In order to study effects on different scales, two station networks were used. One, the "subsynoptic" network, covered a 100-mile north-south stretch along the Wasatch Front (Figure 1) with a 50-mile east-west span. The second, or "meso" net (Figure 2) included stations in the Salt Lake Valley only, about 30 miles north-south and 20 miles east-west. Data for five years, 1965-69 inclusive were used. For convenience, 10 stations were used in each network. Regular stations are shown by dark circles in Figures 1 and 2; alternate stations by open circles. Only two alternate stations were required for the subsynoptic net; Spanish Fork was used when either Provo or Payson was missing, and Echo Dam was used for Coalville and Morgan. Missing data were much more frequent in the mesonet. The nearest available alternate station was used when regular stations had missing data.

Station elevations are shown in Tables 1 and 2. For homogeneity no high mountain stations were used. Only stations with basic observation times at 5 or 6 p.m. were selected. However, two stations in the mesonet varied their observations from as early as 3 p.m. to as late as 7:30 p.m. during portions of the period. With the limited data available, there was no possibility of obtaining 10 sites where precipitation was recorded at exactly the same time.

III. RESULTS

The percent of stations in both networks reporting measurable (≥.01") precipitation each day (24-hour period ending at observation time) for the 5-year period was tabulated, and then summarized by months. Adjacent months with similar distributions were grouped into seasons as shown in Figures 3 and 4 for the subsynoptic and mesonets, respectively, and also in Tables 3 and 4. Spring consists of April-May-June; Summer, July-August; Fall, September-October-November; and Winter, December-March. For mesoscale network stations only, Figure 5 was prepared using a criterion of precipitation ≥.10 inch.

In Table 3 it can be seen that for all seasons but fall, approximately 1/2 of the days had a precipitation occurrence at one or more stations. During fall, approximately 2/3 of the days had no precipitation at any station. For the smaller mesonet (Table 4), only spring and winter had precipitation at one or more stations on half of the days, while totally dry days predominated in summer and fall. In both graphs and figures, areal coverage percentages refer only to days during which precipitation occurred at one or more stations.

The graphs (Figures 3, 4, and 5) show percent of areal coverage as abscissa plotted against percent frequency as ordinate. All distributions in Figure 4 show at least two maxima, and all have maxima at 10% and 100%. The summer curve in Figure 4 has a pronounced secondary maximum at 70%. Frequency distributions are more irregular in Figure 3, but all curves show primary maxima at 10% areal coverage.

IV. DISCUSSION

The most surprising feature of the subsynoptic distribution, Table 3 and Figure 3, is the low frequency (8%) of days with 100% areal coverage in winter. Spring and fall have slightly higher frequencies for 100% areal coverage. Winter storms are generally considered to have widespread areal coverage, but this is apparently not always the case in northwestern Utah. There are, of course, certain factors which tend to diminish the apparent areal coverage. One is the bias of substations [3], in underobserving small amounts of precipitation, due to evaporational loss, failure to note the occurrence of precipitation and thus failure to make a measurement, etc. Environmental Data Service (EDS) now publishes precipitation frequencies ≥.10 inch to eliminate this bias. However, the Weather Bureau verification scheme is based on precipitation ⩾.01 inch so this is the criterion that must be given primary consideration.

Table 5 shows total number of days with precipitation ⩾.01 at mesonet stations for the 5-year data period. Only stations with complete, or nearly complete records are listed (10 days were missing from the Knox station record; records from other stations in the table were complete). The Salt Lake City downtown record was from a weighing gauge, which accounts for its low number of days (difficulty in reading .01 inch). The high number of winter days with precipitation at Bingham is undoubtedly due to the relatively high elevation of the station. This would of course, contribute to the high frequency of winter days with only 10% areal coverage. The difference in precipitation frequency between Bingham and other stations in summer is probably not as great as in winter; an estimate from incomplete data gives 69 for total precipitation days at Bingham in summer (see other station summer values in Table 5).

Another factor reducing apparent areal coverage is the difference in observation times. Precipitation occurring between 5 and 6 p.m. for example, would be reported on one day at some stations and another day at others, depending on observation time. Still another factor is the distance between stations, about 100 miles in the extreme on the subsynoptic network. A storm moving from north to south would bring precipitation earlier to the more northerly stations than to the southerly ones, and this could make a difference of a day for the reported occurrence. If all stations made observations at precisely the same time, reported all measurable amounts, and the 24-hour observation period were adjusted to fit the storm period, frequencies shown in the tables would undoubtedly be much higher.

In Figure 3, the slightly greater frequencies at 100% areal coverage for spring and fall as compared to winter are probably due to the higher frequency of cold lows. This type of storm usually is associated with widespread precipitation. Post-cold-front precipitation, the most common type in all seasons but summer, is usually spotty and highly orographically dependent. The summer curve in Figure 3 is the one that turned out most like the expected curve, with a high frequency at 10% coverage (34%) and a very low value at 100% coverage (3%).

Referring to the mesoscale areal distribution curves in Figure 4, winter also shows lower frequencies at 100% coverage than spring or fall. Spring, fall, and winter curves all show higher frequencies at 100% areal coverage than at 10% coverage. Since the biases related to small precipitation amounts and different observation times mentioned in the discussion of Figure 3 also apply to Figure 4, the much greater frequencies at 100% coverage for the mesonet is likely due to the reduced size of the network. The summer maximum at 70% in Figure 4 is interesting. It suggests that when a good summer shower situation occurs, with plentiful moisture and instability, only about 70% of the stations in the Salt Lake Valley will report measurable precipitation. The most frequent shower situation, however, is the "widely scattered" one, with only 1 out of 10 stations reporting rain.

The frequency distribution of areal coverages for mesonet stations, using precipitation ≥.10 inch (Figure 5 and Table 6) is similar to Figure 4, with a shift of the curves toward lower areal coverages. Most pronounced is the increase in frequency of 10% areal coverage during summer. Thirty-seven percent of the precipitation days (≥.10 inch) show an areal coverage of 10% as compared to 26% for days ≥.01 inch. Fall, winter, and spring all show a marked decrease in frequency of 100% areal coverage. Fall alone shows a decrease in frequency of days with areal coverage of 10%. As in Figure 4, fall and spring also show greater frequencies of 100% areal coverage than winter.

From Table 6, it may be seen that only about one-fifth the days in fall had precipitation ≥.10 at one or more stations (compared to one-third of the days from Table 4, precipitation ≥.01). Winter, spring, and summer also show a marked decrease in precipitation days using a criterion of ≥.10 inch.

V. EFFECT ON BRIER SCORES

The limited areal coverage of precipitation in northwest Utah during all seasons has a profound effect on forecast Brier scores and maximum possible improvement over climat forecasts. The computations below follows the treatment given in [2].

The formula $B_c = \frac{1}{N} \sum_{i=1}^{m} C_i \ (1 - C_i) \ N_i$

can be used to compute the average climat Brier Score (Bc) for each season, where Ci is the 24-hour climat frequency (precipitation ≥.01) for each month in the season, Ni is number days in each month and N is sum of Ni's.

Thus, for summer (July, August) using Salt Lake City 24-hour climat values,

$$Bc = \frac{.11 \ (1 - .11) \ 31 + .16 \ (1 - .16) \ 31}{31 + 31} = .116$$

Values of Bc for all seasons are shown in the left-hand columns of Table 7.

The Brier Score for perfect forecasting (B max) can be found by assuming areal coverage is always correctly forecast, i.e., forecast probability equals observed areal coverage.

$$B \max = \frac{1}{N} \sum_{i=1}^{11} \left[(Fi - 1)^2 Ri + (Fi)^2 \, (NR)i \right]$$

Where Fi is forecast probability for the group considered (0%, 10%, ...100%), Ri is number of rain gages that received rain for forecasts of Fi (i.e., areal coverage) and NRi is number of gages that received no rain for forecasts of Fi. N is sum of Ri and NRi for all forecast categories.

For summer, N = 3100 (310 days x 10 gages). Using mesonet data, for the 0% category, there were 186 days with no rain (at any station) X 10 (gages) equals 1860 gages without rain.

For the 10% category, there were 32 days when 10% of the gages had rain. Since there were 10 gages, a total of 32 gages received rain, and the balance, 320 - 32 = 288 gages had no rain.

Repeating these calculations for the remaining categories, summing and averaging gives B max = .061. Thus, the max improvement over climat Brier Score (I max) in summer is

$$100 \; \frac{(Bc - B \max)}{Bc} = 100 \; \frac{(.116 - .061)}{.116} = 47\%.$$

Seasonal values of B max and I max are shown in the 2nd and 3rd columns of Table 7.

Curran and Hughes (2) found an I max of 64% for Kentucky in summer. The Kentucky data showed a much higher percentage of summer shower days with 100% areal coverage than the Salt Lake mesoscale data (23% vs. 11%). The Salt Lake subsynoptic data showed that only 3% of summer shower days had 100% areal coverage (the Kentucky network was about halfway in size between the Utah subsynoptic and mesonet). For spring (April, May) and fall (September-October) Curran and Hughes reported maximum possible improvements over climat of 70% and 66% respectively. These are a little lower than Salt Lake spring and fall I max values.

It is of interest to compare maximum possible improvement over climat with actual performance by local forecasters. The last column of Table 7 shows first-period improvement over climat (I_F) for Salt Lake City local forecasts for 1966-69 data* (It should be noted that these are forecasts for a 12-hour period, whereas I max was developed for a 24-hour period). However, it seems reasonable that skill in 24-hour forecasts should be approximately the same as 12-hour forecasts; the greater leeway allowable for timing precipitation events in the 24-hour period is compensated for by the further out in time the forecast extends. During summer, forecasters achieved only about 1/6 the maximum possible improvement over climat; during fall, about 1/4; winter about 2/3; and spring about 1/2 the maximum possible improvement.

*1965 data not available

Thus, winter forecasts show the most skill in Salt Lake City area; summer is the most difficult season.

One of the biggest difficulties in forecasting summer showers is the fact that the verification periods begin or end at 5 p.m. MST, which is the peak time of convective activity. Thus, even though a forecaster is reasonably sure that showers will occur, he seldom knows whether they will occur before or after 5 p.m. Changing the verification periods in summer to midnight to noon and noon to midnight should increase the improvement over climat score. (This change is not possible under present FP-NMC verification rules.)

As an indication of this, consider first period July-August PoP forecasts made by Western Region Headquarters personnel (5-10 meteorologists) following the daily morning map briefing. In 1965-66, when the first period covered 11 a.m. to 5 p.m., improvement over climat for WRH forecasts averaged 7.3% as shown in Table 8. The first period was later changed to include 11 a.m. to 11 p.m. MST, and Western Region Headquarters forecasts for 1968-69 and July 1970 then showed an average improvement of 17.5% over climat forecasts. Although an improving trend with time may also be noted in Table 8, a number of different meteorologists were involved in the forecasts at different times; thus the average experience for the Salt Lake City area probably did not change markedly. Applying this ratio of improvement over climat

$$\frac{17.5}{7.3} = 2.4$$

to the Salt Lake City WBFO summer I_F value of 8% gives an I_F value of 19.2%. It is, then, reasonable to assume that about a 20% improvement over climat could be achieved in summer if the forecast periods were adjusted to include "afternoon and evening" in the same period.

VI. CONCLUSIONS

Due to the scattered nature of precipitation in the mountain west, it is theoretically possible to achieve only a 60 - 75% improvement over climat forecasts in fall, winter, and spring, and slightly less than 50% in summer in the Salt Lake City area. Actual forecaster performance approaches this maximum in winter but falls short of this ideal in summer and autumn.

The number of days on which there is 100% areal coverage in the colder portion of the year is surprisingly small, especially for the subsynoptic network in winter (8%). Biases in observations do, however, contribute to the low values of areal coverage observed.

In future studies of this nature, it may be possible to utilize radar summaries to determine areal coverage of precipitation. At present, the grid employed in summarizing Salt Lake City radar is too coarse to use in a small-scale study such as this one.

VII. REFERENCES

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2. Curran, J., and Hughes, L. A., "The Importance of Areal Coverage in Precipitation Probability Forecasting", WBTM CR-24, September 1968.

3. Dale, R. F., and Shaw, R. H., "Low Precipitation Observational Bias at Cooperative Climat Stations", BAMS Volume 42, No. 8, 1961.

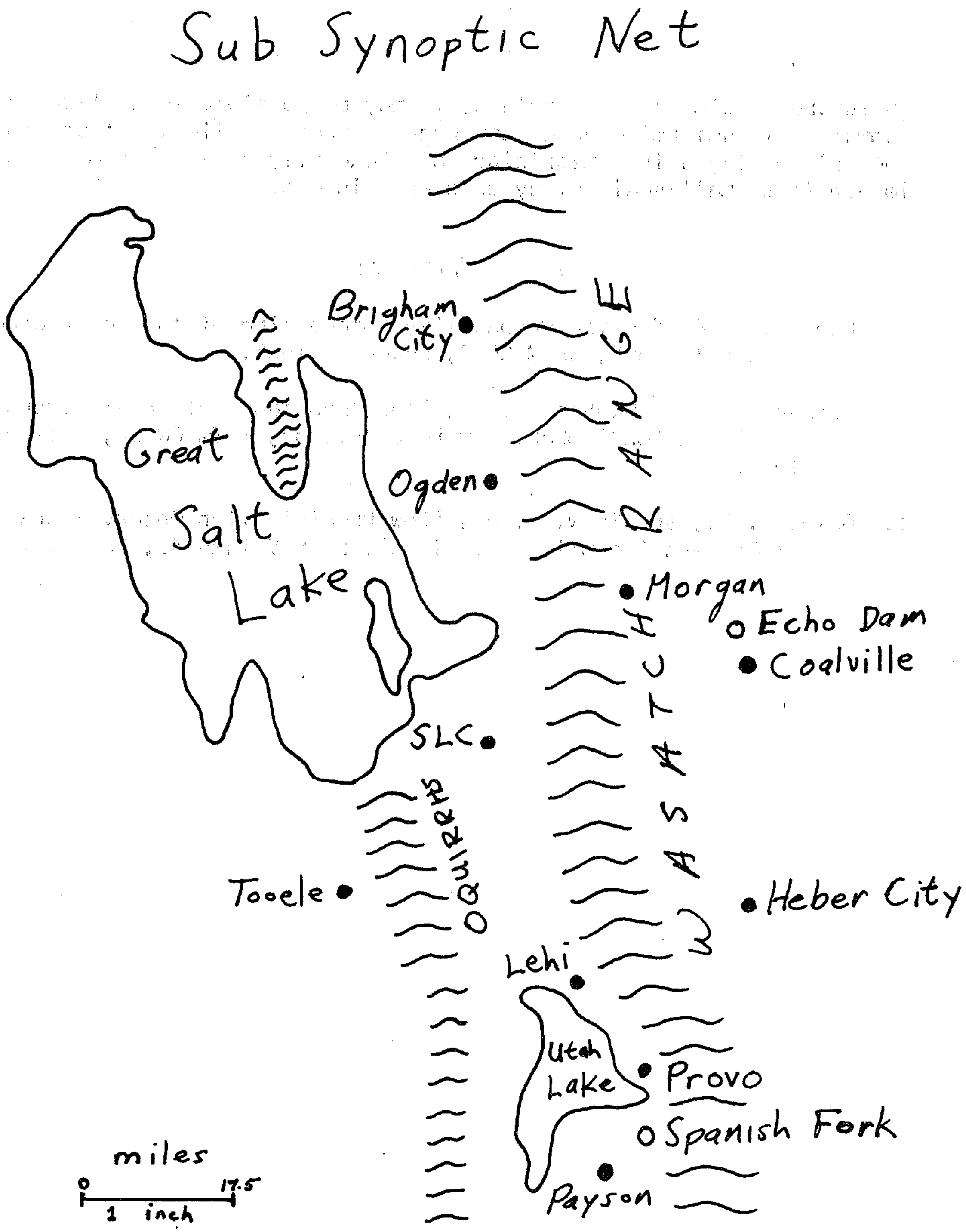

FIGURE 1. SUBSYNOPTIC NETWORK STATIONS (SOLID CIRCLES). OPEN CIRCLES ARE ALTERNATE STATIONS.

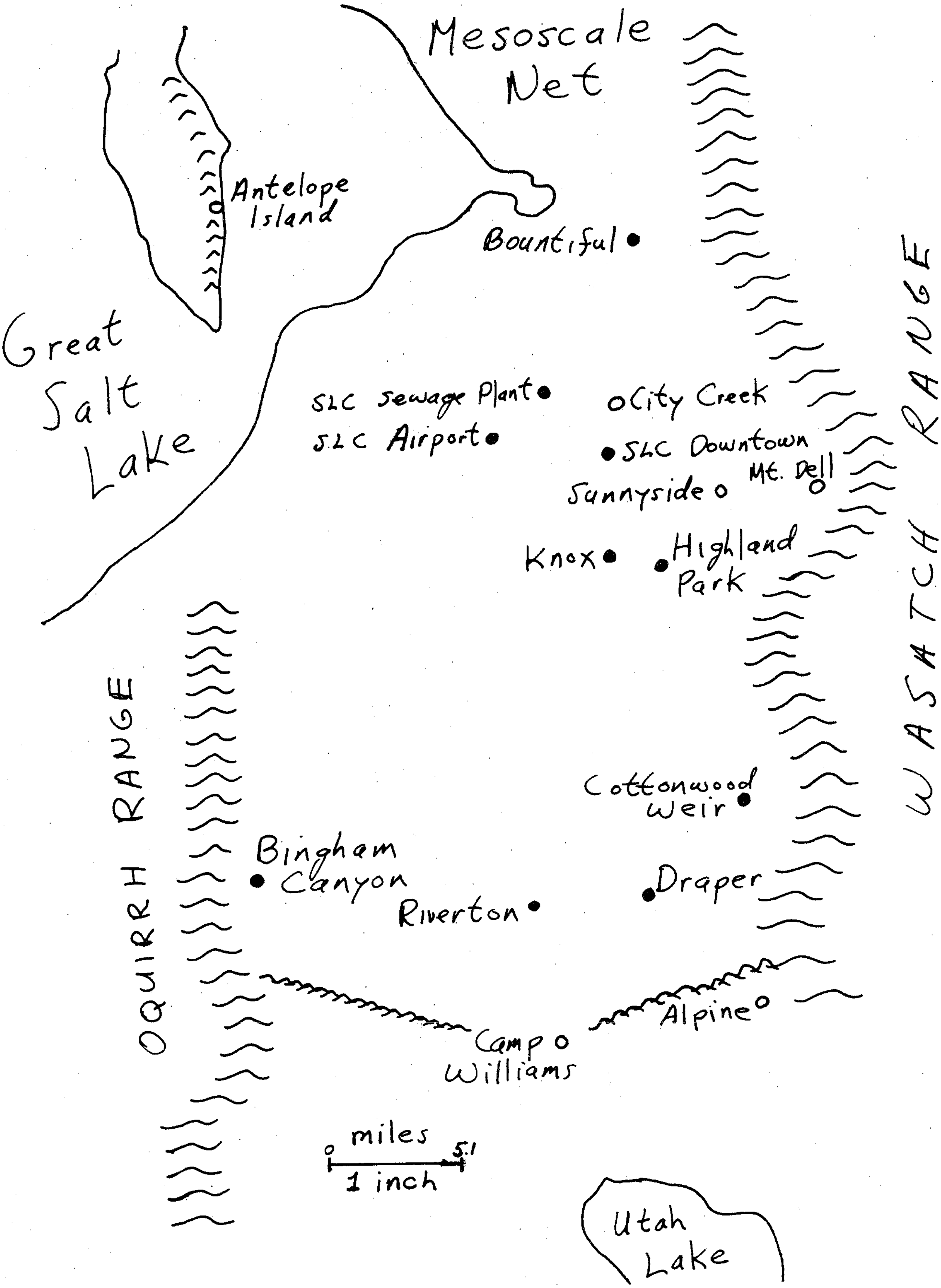

FIGURE 2. MESOSCALE NETWORK STATIONS (SOLID CIRCLES). OPEN CIRCLES ARE ALTERNATE STATIONS.

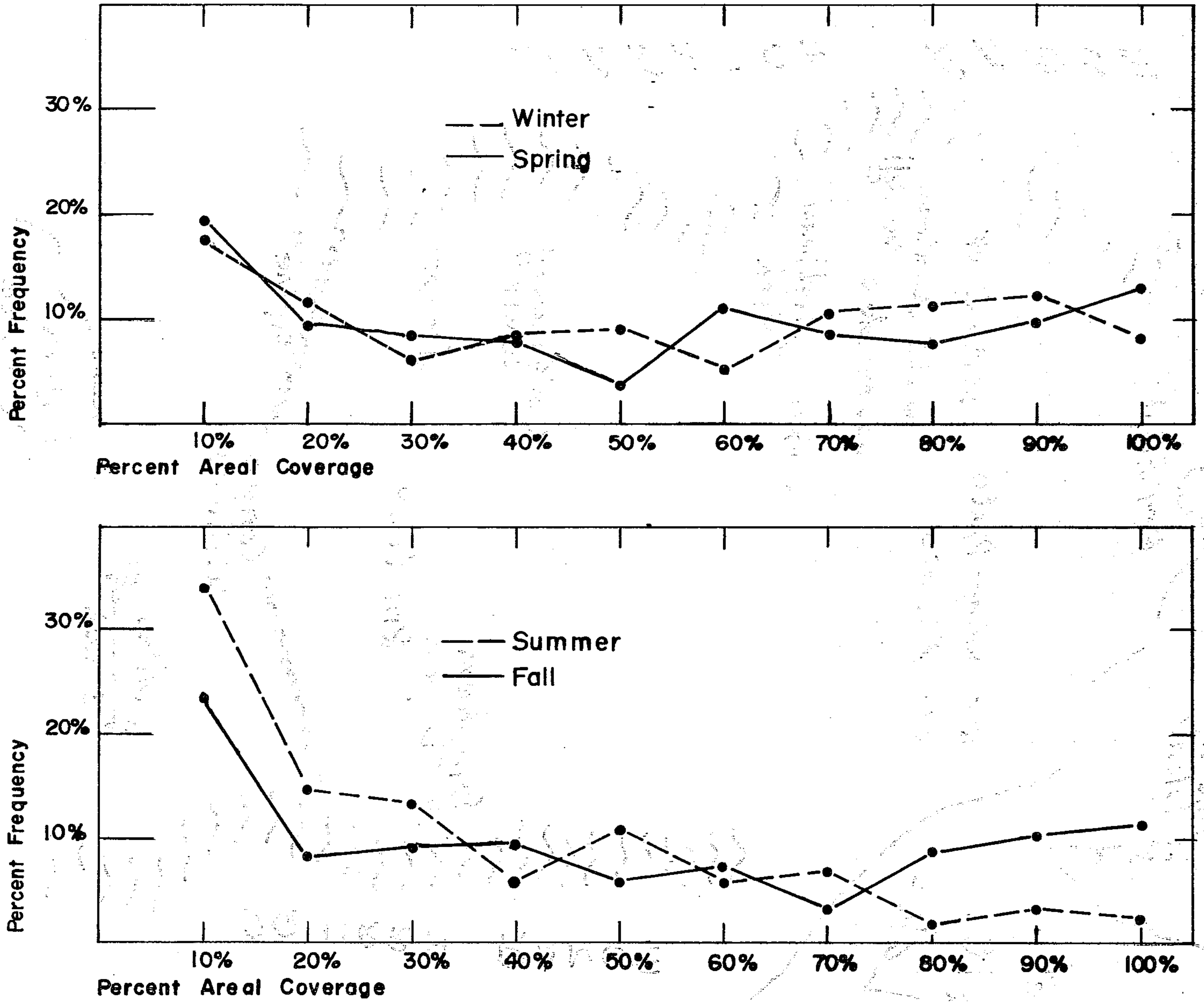

FIGURE 3. FREQUENCY DISTRIBUTION OF AREAL COVERAGES FOR PRECIPITATION $\geq$ .01 INCH DURING THE VARIOUS SEASONS FOR THE SUBSYNOPTIC NETWORK.

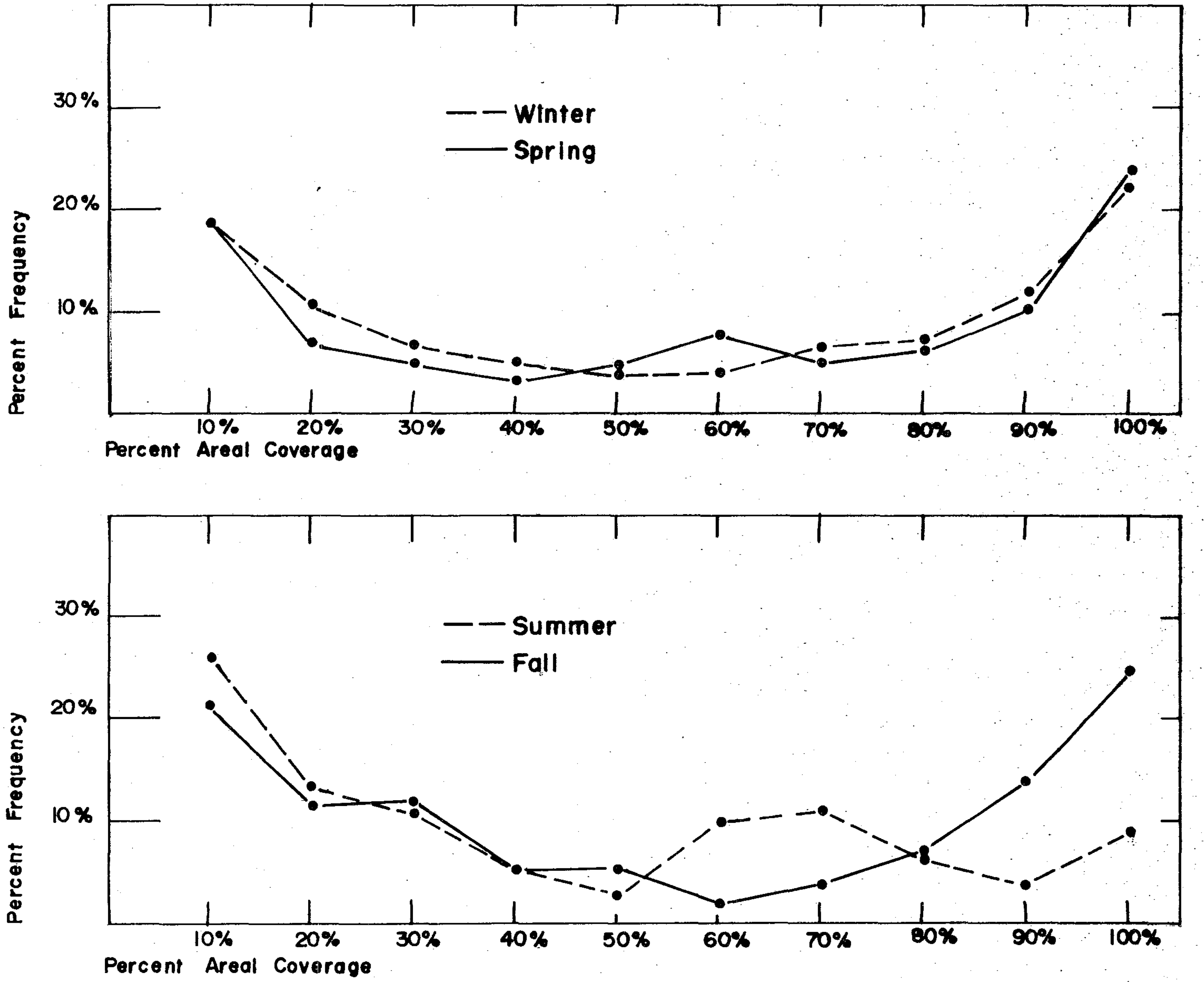

FIGURE 4. FREQUENCY DISTRIBUTION OF AREAL COVERAGE FOR PRECIPITATION ≥ .01 INCH DURING THE VARIOUS SEASONS FOR THE MESOSCALE NETWORK.

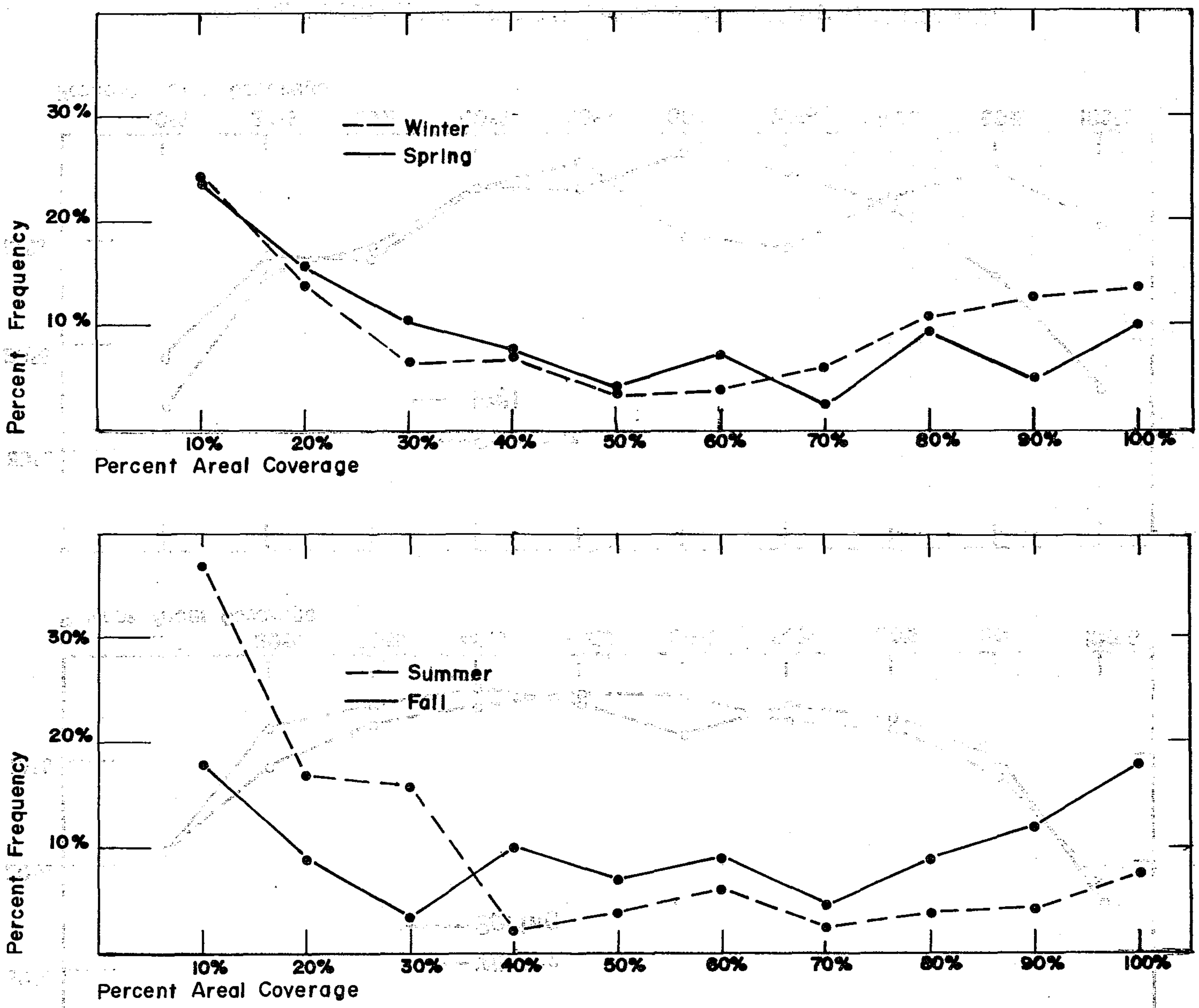

FIGURE 5. FREQUENCY DISTRIBUTION OF AREAL COVERAGES FOR PRECIPITATION ≥ .10 INCH DURING THE VARIOUS SEASONS FOR THE MESOSCALE NETWORK.

TABLE I

SUBSYNOPTIC NETWORK STATION ELEVATIONS

		(Ft)
1.	Brigham City	4335
2.	Ogden Sugar Factory	4280
3.	Morgan	5070
4.	Salt Lake Airport	4222
5.	Tooele	4820
6.	Coalville	5550
7.	Heber	5593
8.	Provo	4470
9.	Lehi-Utah Lake	4497
10.	Payson	4605

ALTERNATES

1.	Echo Dam	5500
2.	Spanish Fork Powerhouse	4711

TABLE 2

MESOSCALE NETWORK STATION ELEVATIONS

		(Ft)
1.	Salt Lake Airport WBFO	4222
2.	Salt Lake City (downtown)	4300
3.	Knox	4250
4.	Highland Park	4450
5.	SLC Suburban Sewage Plant	4235
6.	Bountiful	4800
7.	Draper	4635
8.	Riverton	4630
9.	Cottonwood Weir	4950
10.	Bingham Canyon	6095

ALTERNATES

1.	Camp Williams	4640
2.	Alpine	4935
3.	City Creek	5335
4.	Mountain Dell	5420
5.	Sunnyside Pumping Station	4800
6.	Antelope Island	4225

TABLE 3

FREQUENCIES OF AREAL COVERAGE - NORTHWESTERN UTAH SUBSYNOPTIC NET
(DAYS WITH PRECIPITATION ≥.01 IN.)

	AREAL COVERAGE	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	TOTAL PRECIP DAYS	NO-PRECIP DAYS	TOTAL
Winter	No. Days	54	35	20	26	29	16	31	33	37	25	306	300	606
	%	17.9	11.4	6.5	8.5	9.4	5.2	10.0	10.7	12.1	8.1	50.5	49.5	
Spring	No. Days	43	21	19	18	8	25	19	17	22	30	222	233	455
	%	19.4	9.5	8.6	8.1	3.6	11.3	8.6	7.7	9.9	13.5	48.8	51.2	
Summer	No. Days	50	22	20	9	16	9	10	3	5	4	148	162	310
	%	33.8	14.9	13.5	6.1	10.8	6.1	6.8	2.0	3.4	2.7	47.7	52.3	
Fall	No. Days	37	14	15	16	10	12	6	15	17	19	161	294	455
	%	23.0	8.7	9.3	9.9	6.2	7.5	3.7	9.3	10.6	11.8	35.4	64.6	

TABLE 4

FREQUENCIES OF AREAL COVERAGE - SALT LAKE VALLEY - MESONET
(DAYS WITH PRECIPITATION ≥.01 IN.)

	AREAL COVERAGE	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	TOTAL PRECIP DAYS	NO-PRECIP DAYS	TOTAL
Winter	No. Days	58	33	22	16	12	13	19	23	36	68	300	306	606
	%	19.3	11.0	7.3	5.3	4.0	4.3	6.3	7.6	12.0	22.6	49.5	50.5	
Spring	No. Days	46	18	12	9	12	19	13	16	25	57	227	228	455
	%	20.3	7.9	5.3	4.0	5.3	8.4	5.7	7.0	11.0	25.1	49.1	50.1	
Summer	No. Days	32	17	14	7	4	12	14	8	5	11	124	186	310
	%	25.8	13.7	11.3	5.6	3.2	9.7	11.3	6.5	4.0	8.9	40.0	60.0	
Fall	No. Days	34	18	11	9	9	3	6	11	21	39	158	297	455
	%	21.5	11.4	7.0	5.7	5.7	1.9	3.8	7.0	13.3	24.7	34.7	65.3	

TABLE 5

TOTAL NUMBER DAYS PRECIPITATION ≥ .01 IN., 1965 - 69

	Salt Lake City WBFO	Salt Lake City (Downtown)	Highland Park	Knox	Bingham
Spring	142	124	149	119	--
Summer	57	53	60	47	--
Fall	88	77	94	77	--
Winter	169	156	179	172	242
	456	410	482	415	

TABLE 6

FREQUENCIES OF AREAL COVERAGE - SALT LAKE VALLEY MESO NET (DAYS WITH PRECIPITATION ≥.10 IN.)

	AREAL COVERAGE	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	TOTAL PRECIP DAYS	NO-PRECIP DAYS	TOTAL
Winter	No. Days	48	28	13	15	7	8	12	21	25	20	197	409	606
	%	24.4	14.2	6.6	7.6	3.6	4.1	6.1	10.7	12.7	10.2	32.5	67.5	
Spring	No. Days	38	25	17	13	7	12	4	15	8	22	161	294	455
	%	23.6	15.5	10.6	8.1	4.3	7.5	2.5	9.3	5.0	13.7	35.4	64.6	
Summer	No. Days	30	14	13	2	3	5	2	3	3	6	81	219	310
	%	37.0	17.3	16.0	2.5	3.7	6.2	2.5	3.7	3.7	7.4	26.1	73.9	
Fall	No. Days	16	8	3	9	6	8	4	8	11	16	89	366	455
	%	18.0	9.0	3.4	10.1	6.7	9.0	4.5	9.0	12.4	18.0	19.5	80.5	

TABLE 7

CLIMAT BRIER SCORES (Bc), BRIER SCORES FOR PERFECT RELIABILITY FORECASTS (B_{max}), MAXIMUM POSSIBLE IMPROVEMENT OVER CLIMATOLOGICAL BRIER SCORES (I_{max}), AND IMPROVEMENT OVER CLIMATOLOGY FOR SALT LAKE CITY FIRST-PERIOD FORECASTS (I_F)

	Bc	B_{max}	I_{max}	I_F
Summer	.116	.061	47%	8%
Fall	.144	.059	73%	26%
Winter	.219	.070	62%	41%
Spring	.185	.037	74%	36%

TABLE 8

IMPROVEMENT OVER CLIMAT - WESTERN REGIONAL HEADUQARTERS
FIRST-PERIOD FORECASTS
JULY - AUGUST

	Improvement Over Climat Western Regional Headquarters	Forecast Period
1965	4.4%	1100 - 1700 MST
1966	10.2%	1100 - 1700 MST
Average	7.3%	
1967	Not Available	
1968	15.3%	1100 - 2300 MST
1969	19.1%	1100 - 2300 MST
1970 (JulY)	19.5%	1100 - 2300 MST
Average	17.5%	

TABLE 7

CLIMAT BRIER SCORES (Bc), BRIER SCORES FOR PERFECT RELIABILITY FORECASTS (B_{max}), MAXIMUM POSSIBLE IMPROVEMENT OVER CLIMATOLOGICAL BRIER SCORES (I_{max}), AND IMPROVEMENT OVER CLIMATOLOGY FOR SALT LAKE CITY FIRST-PERIOD FORECASTS (I_F)

	Bc	B_{max}	I_{max}	I_F
Summer	.116	.061	47%	8%
Fall	.144	.059	73%	26%
Winter	.219	.070	62%	41%
Spring	.185	.037	74%	36%

TABLE 8

IMPROVEMENT OVER CLIMAT - WESTERN REGIONAL HEADUQARTERS
FIRST-PERIOD FORECASTS
JULY - AUGUST

	Improvement Over Climat Western Regional Headquarters	Forecast Period
1965	4.4%	1100 - 1700 MST
1966	10.2%	1100 - 1700 MST
Average	7.3%	
1967	Not Available	
1968	15.3%	1100 - 2300 MST
1969	19.1%	1100 - 2300 MST
1970 (July)	19.5%	1100 - 2300 MST
Average	17.5%	

Western Region Technical Memoranda (Continued):

No. 28** Weather Extremes. R. J. Schmidli. April 1968. (PB-178 928)

No. 29 Small-Scale Analysis and Prediction. Philip Williams, Jr. May 1968. (PB-178 425)

No. 30 Numerical Weather Prediction and Synoptic Meteorology. Capt. Thomas D. Murphy, U.S.A.F. May 1968. (AD-673 365)

No. 31* Precipitation Detection Probabilities by Salt Lake ARTC Radars. Robert K. Belesky. July 1968. (PB-179 084)

No. 32 Probability Forecasting in the Portland Fire Weather District. Harold S. Ayer. July 1968. (PB-179 289)

No. 33 Objective Forecasting. Philip Williams, Jr. August 1968. (AD-680 425)

No. 34 The WSR-57 Radar Program at Missoula, Montana. R. Granger. October 1968. (PB-180 292)

No. 35** Joint ESSA/FAA ARTC Radar Weather Surveillance Program. Herbert P. Benner and DeVon B. Smith. December 1968. (AD-681 857)

No. 36* Temperature Trends in Sacramento--Another Heat Island. Anthony D. Lentini. February 1969. (PB-183 055)

No. 37 Disposal of Logging Residues Without Damage to Air Quality. Owen P. Cramer. March 1969. (PB-183 057)

No. 38 Climate of Phoenix, Arizona. R. J. Schmidli, P. C. Kangieser, and R. S. Ingram. April 1969. (PB-184 295)

No. 39 Upper-Air Lows Over Northwestern United States. A. L. Jacobson. April 1969. (PB-184 296)

No. 40 The Man-Machine Mix in Applied Weather Forecasting in the 1970s. L. W. Snellman. August 1969. (PB-185 068)

No. 41 High Resolution Radiosonde Observations. W. W. Johnson. August 1969. (PB-185 673)

No. 42 Analysis of the Southern California Santa Ana of January 15 - 17, 1966. Barry B. Aronovitch. August 1969. (PB-185 670)

No. 43 Forecasting Maximum Temperatures at Helena, Montana. David E. Olsen. October 1969. (PB-187 762)

No. 44 Estimated Return Periods for Short-Duration Precipitation in Arizona. Paul C. Kangieser. October 1969. (PB-187 763)

No. 45/1 Precipitation Probabilities in the Western Region Associated with Winter 500-mb Map Types. Richard P. Augulis. December 1969. (PB-188 248)

No. 45/2 Precipitation Probabilities in the Western Region Associated with Spring 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189 434)

No. 45/3 Precipitation Probabilities in the Western Region Associated with Summer 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189 414)

No. 45/4 Precipitation Probabilities in the Western Region Associated with Fall 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189 435)

No. 46 Applications of the Net Radiometer to Short-Range Fog and Stratus Forecasting at Eugene, Oregon. L. Yee and E. Bates. December 1969. PB-190 476)

No. 47 Statistical Analysis as a Flood Routing Tool. Robert J. C. Burnash. December 1969. (PB-188 744)

No. 48 Tsunami. Richard P. Augulis. February 1970. (PB-190 157)

No. 49 Predicting Precipitation Type. Robert J. C. Burnash and Floyd E. Hug. March 1970. (PB-190 962)

No. 50 Statistical Report of Aeroallergens (Pollens and Molds) Fort Huachuca, Arizona 1969. Wayne S. Johnson. April 1970. (PB-191 743)

No. 51 Western Region Sea State and Surf Forecaster's Manual. Gordon C. Shields and Gerald B. Burdwell. July 1970. (PB-193 102)

No. 52 Sacramento Weather Radar Climatology. R. G. Pappas and C. M. Veliquette. July 1970. (PB-193 347)

No. 53 Experimental Air Quality Forecasts in the Sacramento Valley. Norman S. Benes. August 1970.

No. 54 A Refinement of the Vorticity Field to Delineate Areas of Significant Precipitation. Barry B. Aronovitch. August 1970.

No. 55 Application of the SSARR Model to a Basin Without Discharge Record. Vail Schermerhorn and Donald W. Kuehl. August 1970.

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