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Weather Bureau

A Refinement of the Vorticity Field to Delineate Areas of Significant Precipitation

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Western Region

SALT LAKE CITY, UTAH

August 1970

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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-54

A REFINEMENT OF THE VORTICITY FIELD TO DELINEATE AREAS OF SIGNIFICANT PRECIPITATION

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WESTERN REGION
TECHNICAL MEMORANDUM NO. 54

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ABSTRACT

Vorticity fields on National Meteorological Center (NMC) charts can be refined by using interpolated 500-mb contours and isopleths of absolute vorticity. Careful interpolation results in the synthesis of Positive Vorticity Advection (PVA) areas which are more useful than those on the NMC charts for forecasting, on a smaller scale, areas which will receive more significant precipitation.

Precipitation data from July and August 1968 are analyzed to see if the more significant precipitation for those months occurred at stations which were within PVA areas.

I. INTRODUCTION

The concept of "forecasting by the numbers" is very appropriate and directly related to problems of fire-weather forecasting in western Washington. Here the area of responsibility is divided into twenty-three fire-weather zones, determined by orographic, climatological, and administrative considerations. Forecasts of temperature, relative humidity, wind speed, and wind directions are made for individual zones. Whenever applicable, the percentage probability of precipitation and/or lightning is included.

Forecasting areas of more significant amounts of rain is important to forest fire suppression. During a forest fire the fire boss must know not only the chance of precipitation falling on the fire, but also whether or not such precipitation will be effective in extinguishing the blaze, or prohibiting further spread of the fire. Precipitation also plays a role in slash burning--an important phase of any forest land management program. It plays still another role in the closure concept of forest protection. For these reasons fire-weather forecasters at the Olympia, Washington, Fire Weather Office attempt to delineate those zones within the Fire Districts which will receive significant, or "wetting" rains.

In this paper a procedure is investigated which should aid the forecaster in specifying those areas or fire zones most likely to receive the heavier amounts of rain.

II. REFINEMENT TECHNIQUE

A standard tool used in precipitation forecasting is the 500-mb contour and vorticity chart transmitted on the National Facsimile Circuit from the National Meteorological Center (NMC), Suitland, Maryland. Positive vorticity advection (PVA) areas consisting of quadrilaterals formed by the intersection of pairs 500-mb contours and pairs isopleths of absolute vorticity are used to denote, in general, areas of expected rainfall. Other meteorological parameters and conditions such as moisture and increase of wind with height are assumed to be present. For convenience such "bounded" or "closed" quadrilaterals will hereafter be referred to merely as PVA areas. Spacing of NMC grid points from which the 500-mb analysis and computations of vorticity are made result in a macro-scale vorticity advection field with relatively large PVA areas when compared to an area the size of western Washington on the scale of the facsimile chart. In many instances most or all fire zones in western Washington may be contained within one or two such PVA areas, with the result that a forecaster can make only a general statement about precipitation in western Washington and cannot specify which fire zone is likely to receive more rainfall than another, except as a result of orography.

In order to delineate PVA areas from which a judgment might be made as to which fire zones are more likely to receive the heavier amounts of rain, the vorticity advection field can be refined on a much larger scale chart. After the contours and vorticity isopleths have been transferred from the facsimile chart to the larger scale chart, intermediate contours and vorticity isopleths may be drawn by interpolation. This will produce PVA areas approximately one-half the size (geographically) of those originally on the facsimile chart. In many instances PVA areas are synthesized on the large-scale chart which would not be apparent on the small-scale chart. These smaller areas generally cover only a few fire zones and thus are potentially more useful in forecasting the location of more significant amounts of precipitation. Theoretically, one should be able to find the locale which would receive the heaviest amounts of precipitation as a result of positive vorticity advection by a series of further subdivisions (1), but this would probably be stretching the assumption of linearity in the 500-mb height and vorticity fields much too far.

This "refinement" of the vorticity advection field to the subsynoptic scale from the macroscale field by linear interpolation is, admittedly, open to serious question. The only justification is that it has been tried in this study and seems to offer promise in delineating areas of heavier rainfall from those areas with light or no rainfall.

Figures 1 - 4 illustrate procedures for refining the vorticity advection field. Figure 1 is the barotropic vorticity chart for 1200Z July 11, 1968 as received over facsimile from NMC. In Figure 2 the 500-mb contours and vorticity isopleths across Washington state have been transferred from the 1:20,000,000 scale facsimile chart to a large-scale (1:250,000) map of Washington. In Figure 3 the intermediate 573 and 579 decameter contours have been interpolated and the 9×10^{-5} and 11×10^{-5} sec^{-1} vorticity isopleths have been interpolated and transferred from the facsimile chart. Generally, this "first refinement" is sufficient to define closed vorticity advection areas sufficiently to be useful. In this particular case, however, the first refinement does not produce any bounded PVA areas; so a "second refinement" is made as shown in Figure 4. Here 20-meter contours have been interpolated (the 572, 574, and 578 contours), and the 11.5, 10.5, and 9.5 vorticity isopleths have been drawn. Two closed advection areas, labeled I and II, have been "generated" by this second refinement.

On Figure 4 are plotted 24-hour rainfall amounts at stations in western Washington which measure rainfall near 1600PST. The vorticity chart is thus near the midpoint of the 24-hour precipitation period. It is obvious that the heaviest amounts fall within the subsynoptic bounded vorticity advection areas generated by the refinement technique.

These refinement procedures will usually produce PVA areas which are "open-ended" at the edge of the large-scale chart; so one needs to refer back to the original NMC chart to determine if the two isolines could reasonably be expected to intersect, or whether they remain parallel or diverge. Normally, if the two isolines required to complete a bounded area appear to be parallel at the edge of the large-scale chart, the area is usually open-ended and is not considered to be a closed PVA area.

To determine if contours and isopleths of absolute vorticity could be properly transposed, with respect to spacing and location, onto maps used for refinement, transparancies were made of several original vorticity charts. These were superimposed by projection onto larger scale maps which already had the isolines transposed. A tolerable fit was found to exist. Thus the transfer method appears to be satisfactory.

III. DATA AND PROCEDURES

Refinement procedures described above were applied to both 0000Z and 1200Z NMC vorticity charts on rainy days in western Washington during July and August 1968 <u>except</u> on those days and times which exhibited neutral or negative vorticity advection. A rainy day was defined as rain of any amount at 15 or more stations in western Washington.

Twenty-four hour precipitation data for these months were obtained from CLIMATOLOGICAL DATA (2) (3). Although 97 precipitation reporting stations in western Washington are available (see Figure 5), only 84 of these were included in this study. Forty-seven percent of the 97 stations measure precipitation during the past 24 hours within an hour or two of 1600PST (0000Z); forty-three percent report within an hour or two of 0600PST (1400Z), and ten percent report at midnight (0800Z). In view of these difficulties, only those stations reporting near 1600PST and 0600PST were used. Precipitation amounts reported around 1600PST were related to vorticity advection at 1200Z, and amounts reported around 0600PST were related to vorticity advection at 0000Z. The refined vorticity charts were thus near the midpoint of the corresponding 24-hour precipitation periods.

The vorticity charts were refined first and then the appropriate precipitation amounts were plotted on the refined charts. Frequency distributions of rainfall amounts (including zero amounts) were then constructed for amounts falling "inside" and "outside" of refined PVA areas. Rainfall amounts were classified into five class intervals: 1) .00 to .09 inch, 2) .10 to .24 inch, 3) .25 to .49 inch, 4) .50 to .99 inch, and 5) ≥1.00 inch. These class intervals are hereafter referred to as Class 1, 2, 3, 4, and 5 rainfall events, respectively. For the purpose of this study Classes 4 and 5 (≥.50 inch) are defined as "significant" rainfall events.

IV. RESULTS

Results for each individual chart in the form of frequency distributions inside and outside bounded PVA areas are listed in Table 1. Summaries for all cases are presented in Figures 6 to 9. Figures 6 and 7 indicate the percent, by class interval, of the number of precipitation reports outside and inside closed PVA areas, respectively. Figure 8 indicates the percent, by class interval, of the <u>total</u> number of precipitation reports, both outside and inside PVA areas. In class 1, 2, and 3 events, the ratio of outside to inside varies from 2:1 to 3.5:1.0, whereas in class 4 and 5 (the significant events), the ratio of outside to inside drops to 1:4. This implies that significant amounts occur primarily within closed PVA areas.

This is brought out even more strikingly in Figure 9 which shows cumulative frequencies of amounts inside and outside PVA areas. For example, interpreting the cumulative percent frequency curves as empirical probability curves, the probability of observing .10 inch or more on a rainy day is 50% outside of refined PVA areas and about 77% inside such areas. More significant is the difference at the .50-inch level where the probability of .50 inch or more is only about 6% outside closed areas, but is about 43% inside, or seven times as great.

V. ILLUSTRATIVE EXAMPLES

Figures 10 through 14 are examples of refined vorticity charts with associated 24-hour precipitation plotted at the reporting stations. There were several instances when only one or two significant amounts were reported and these were almost invariably contained within a refined PVA area. In some cases (Figures 11 and 12) they occurred within the only closed PVA area on the map.

In Figure 14 there are 19 significant amounts and all but four occur within a single PVA area. One report, Mt. Vernon 3WNW (1.31 inches), falls within another closed area while the other three, Skamania Fish Hatchery (.88 inches), Longview (.55 inches), and McMillin Reservoir (.53 inch) fall outside of a closed area. Within the PVA area containing the preponderance of significant amounts, 15 of the 16 reporting stations received significant precipitation. At first glance one might assume that the large amounts were the result of orographic lifting, but further investigation shows that both the northern Cascades and the Olympics were under the same wind regime as that of the central and southern Cascades without a single report of significant precipitation.

VI. CONCLUSIONS

If the percent of precipitation reports outside closed PVA areas was relatively small, there would be little significance to the fact that the heavier amounts occur within PVA areas. However, with 530 reports outside and 330 reports inside such areas, the ratio of outside to inside is 1.0 to 0.6. This shows that almost twice as many precipitation events occurred outside as did inside. Furthermore, Figure 8 indicates that the ratio of class 1, 2, and 3 events inside to outside is 188/496 or 0.37 to 1.00, while in the significant classes 4 and 5 this ratio rises to 142/34 or 4.2 to 1.0.

These ratios imply that a refined vorticity field is a tool which enables the fire-weather forecaster to make a more definite and more accurate forecast as to where significant precipitation may be expected. The author does not wish to imply that all significant precipitation will fall within refined PVA areas, nor that the mere existence of PVA areas is sufficient to cause significant precipitation; however, results contained here should supply the forecaster with additional confidence. The concept of refined PVA areas may also prove useful in other facets of weather forecasting such as flash flooding, river, marine, aviation, construction, and weather modification.

VII. ACKNOWLEDGMENTS

The author wishes to express his gratitude to Woodrow W. Dickey of Scientific Services Division, U. S. Weather Bureau, Western Region, who critically reviewed this paper on several occasions and who offered many suggestions which helped improve the efficacy of the proposed method. The author is especially grateful for his suggestion to construct Figure 9.

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1. Application of Meteorological Satellite Data in Analysis and Forecasting. ESSA Technical Report NESC 51 pp. 3-A-1 and 3-A-2.

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3. Climatological Data. U. S. Department of Commerce, ESSA, EDS, August 1968, Volume 72, Number 8.

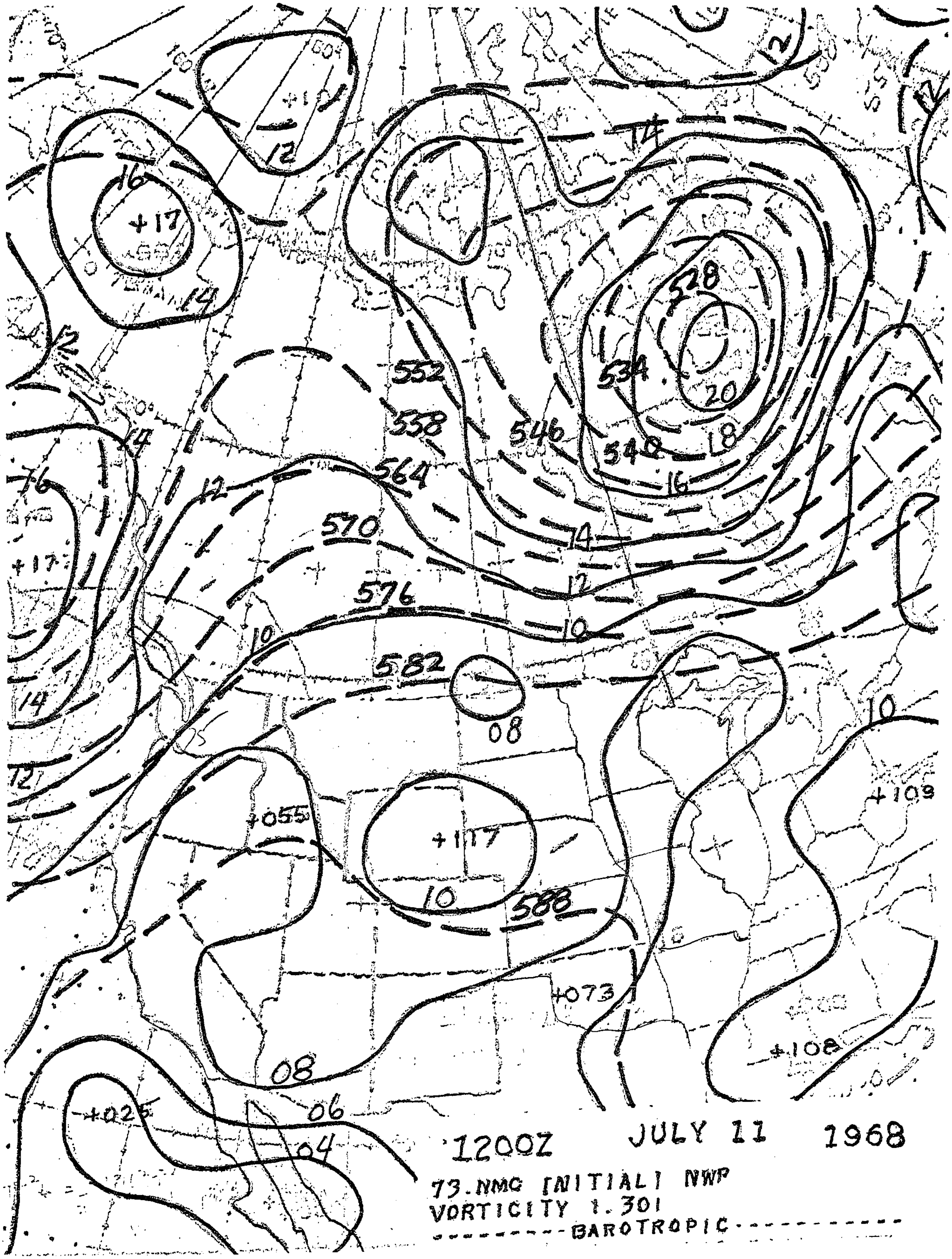

FIGURE 1. National Meteorological Center 500-mb analysis and vorticity chart for 1200Z, July 11, 1968 as received over National Facsimile Network.

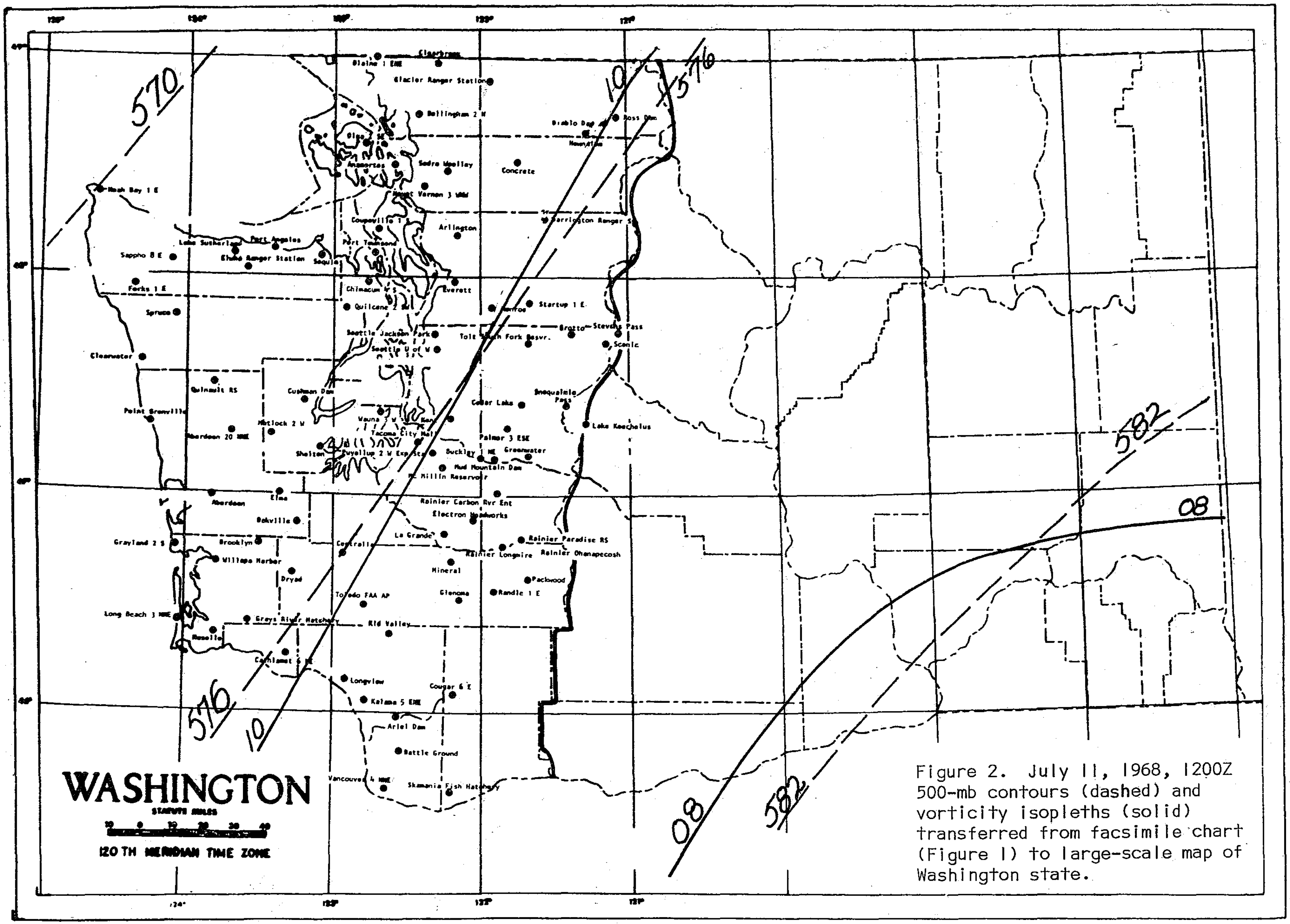

Figure 2. July 11, 1968, 1200Z 500-mb contours (dashed) and vorticity isopleths (solid) transferred from facsimile chart (Figure 1) to large-scale map of Washington state.

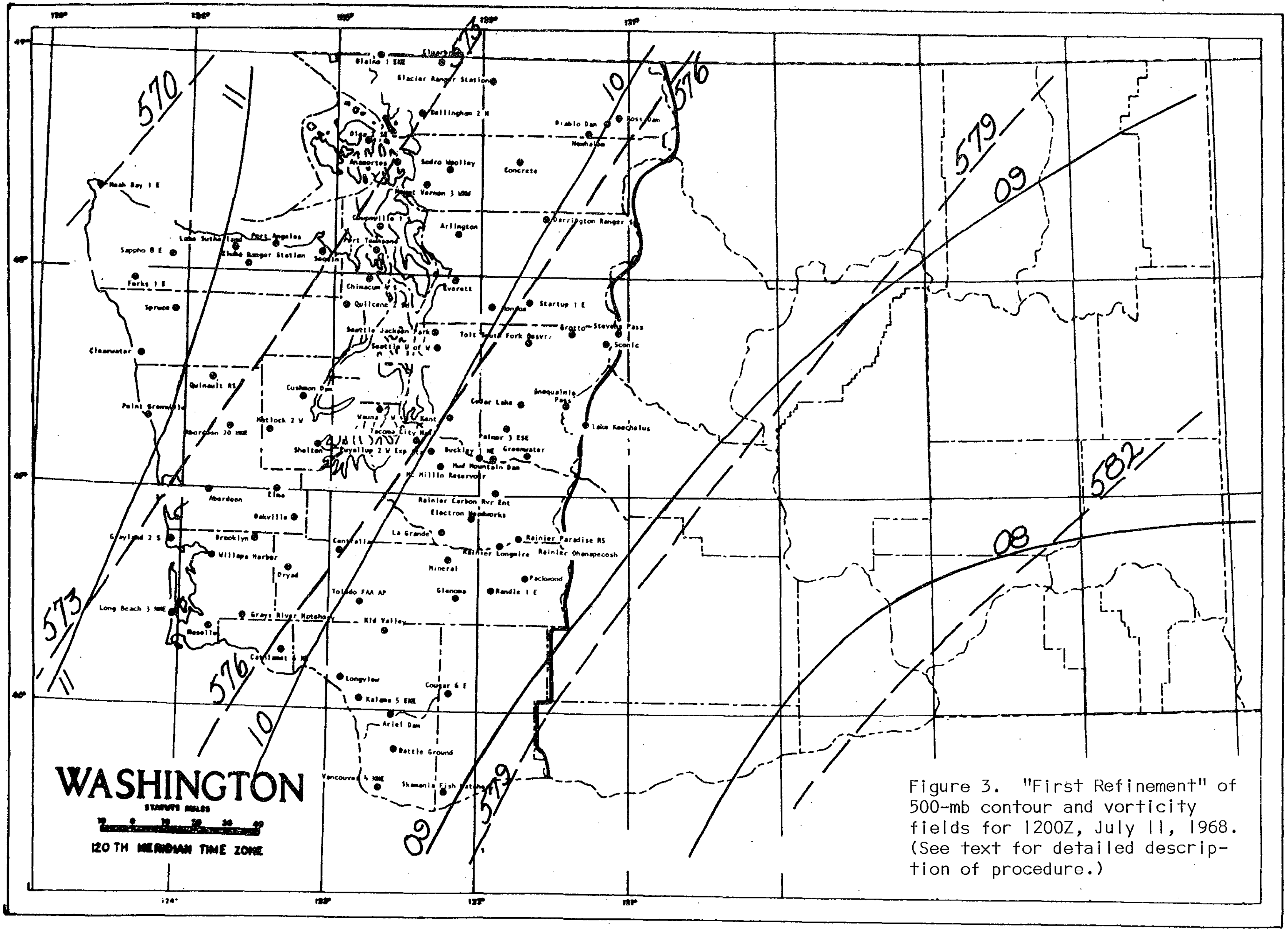

Figure 3. "First Refinement" of 500-mb contour and vorticity fields for 1200Z, July 11, 1968. (See text for detailed description of procedure.)

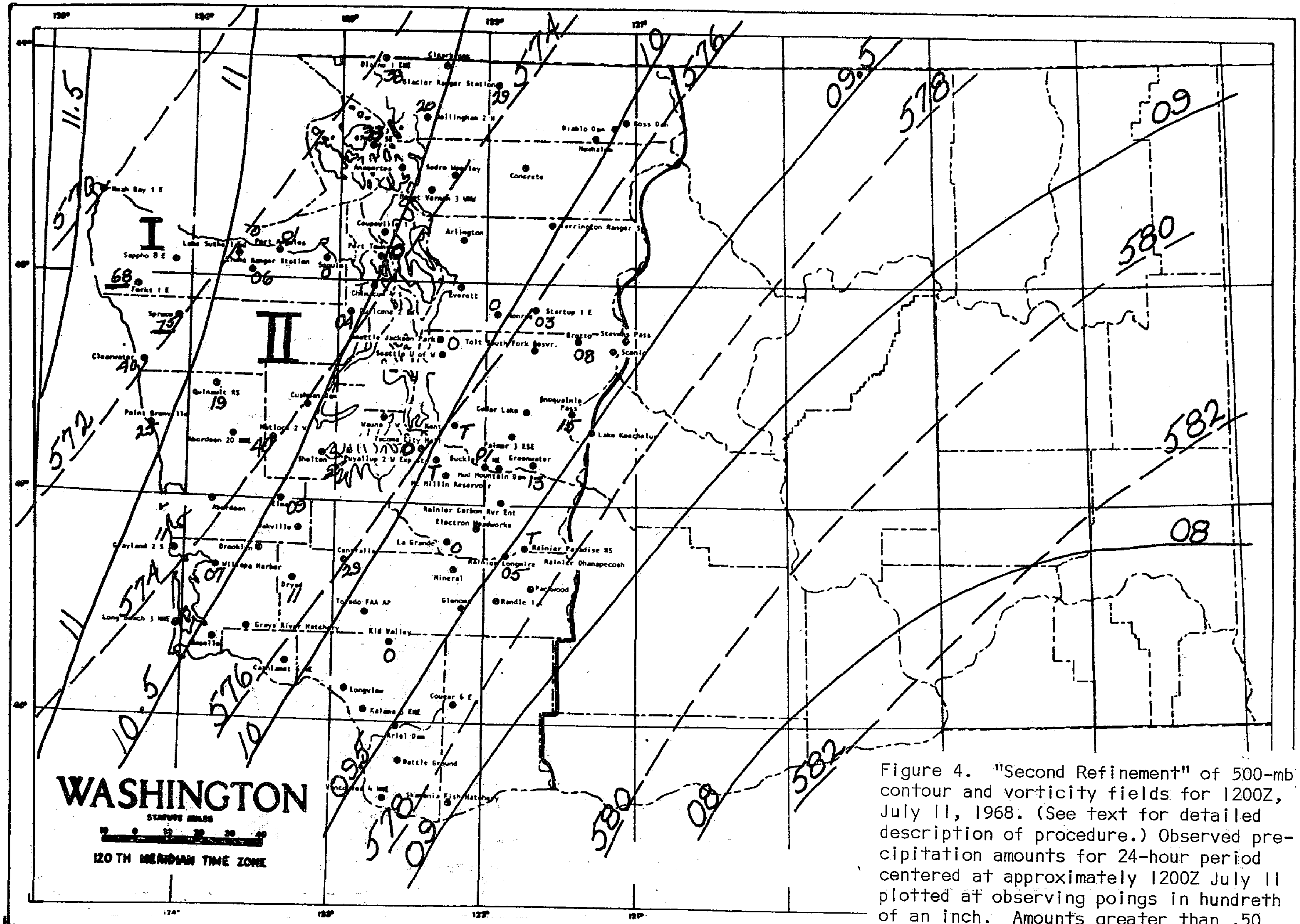

Figure 4. "Second Refinement" of 500-mb contour and vorticity fields for 1200Z, July 11, 1968. (See text for detailed description of procedure.) Observed precipitation amounts for 24-hour period centered at approximately 1200Z July 11 plotted at observing poings in hundreth of an inch. Amounts greater than .50 inch underlined.

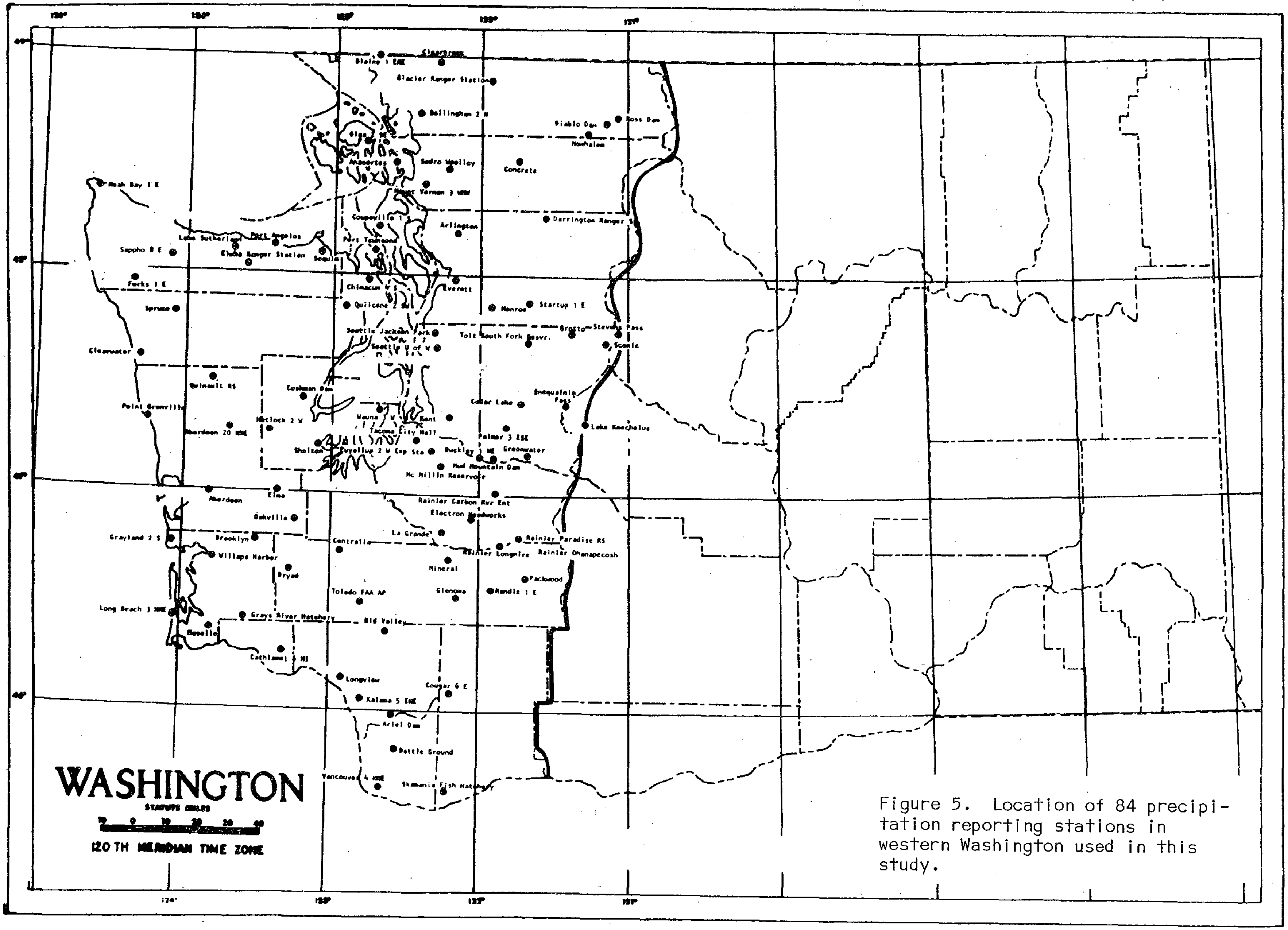

Figure 5. Location of 84 precipitation reporting stations in western Washington used in this study.

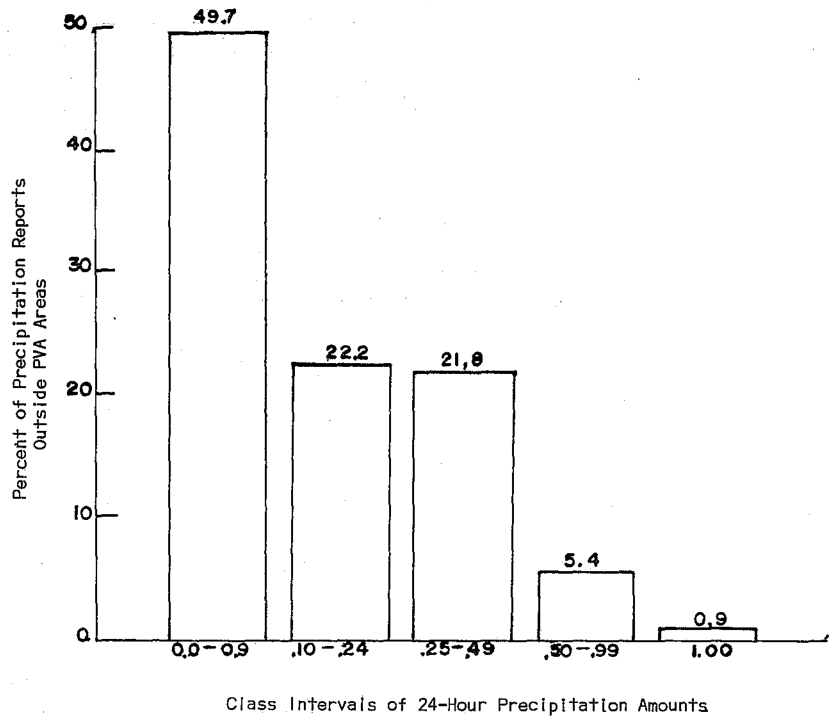

Figure 6. Percent frequency distribution of 24-hour precipitation amounts occurring outside PVA areas. Number of reports outside PVA areas 530. (See text for definition of PVA area.)

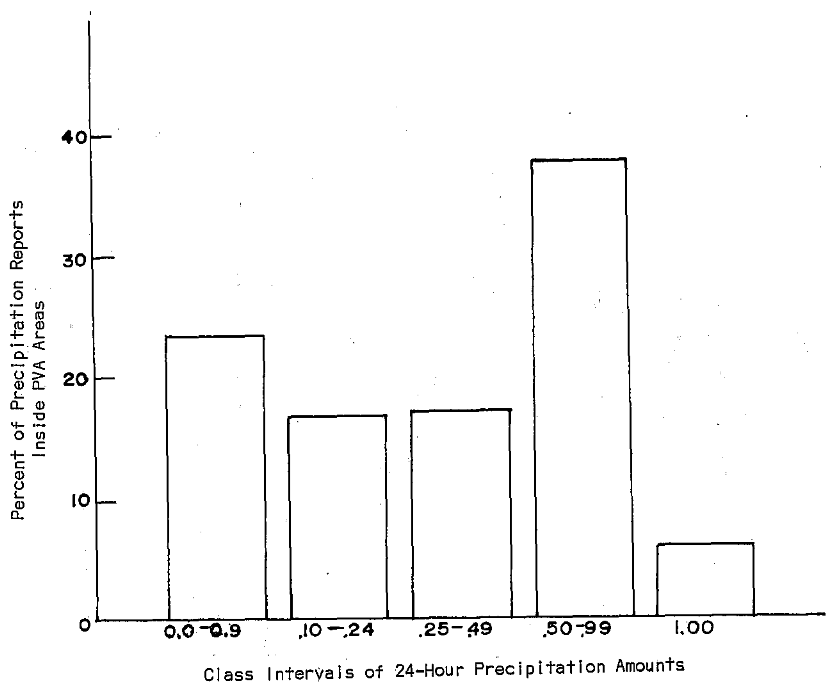

Figure 7. Percent frequency distribution of 24-hour precipitation amounts occurring inside PVA areas. Number of reports inside PVA areas 330. (See text for definition of PVA area.)

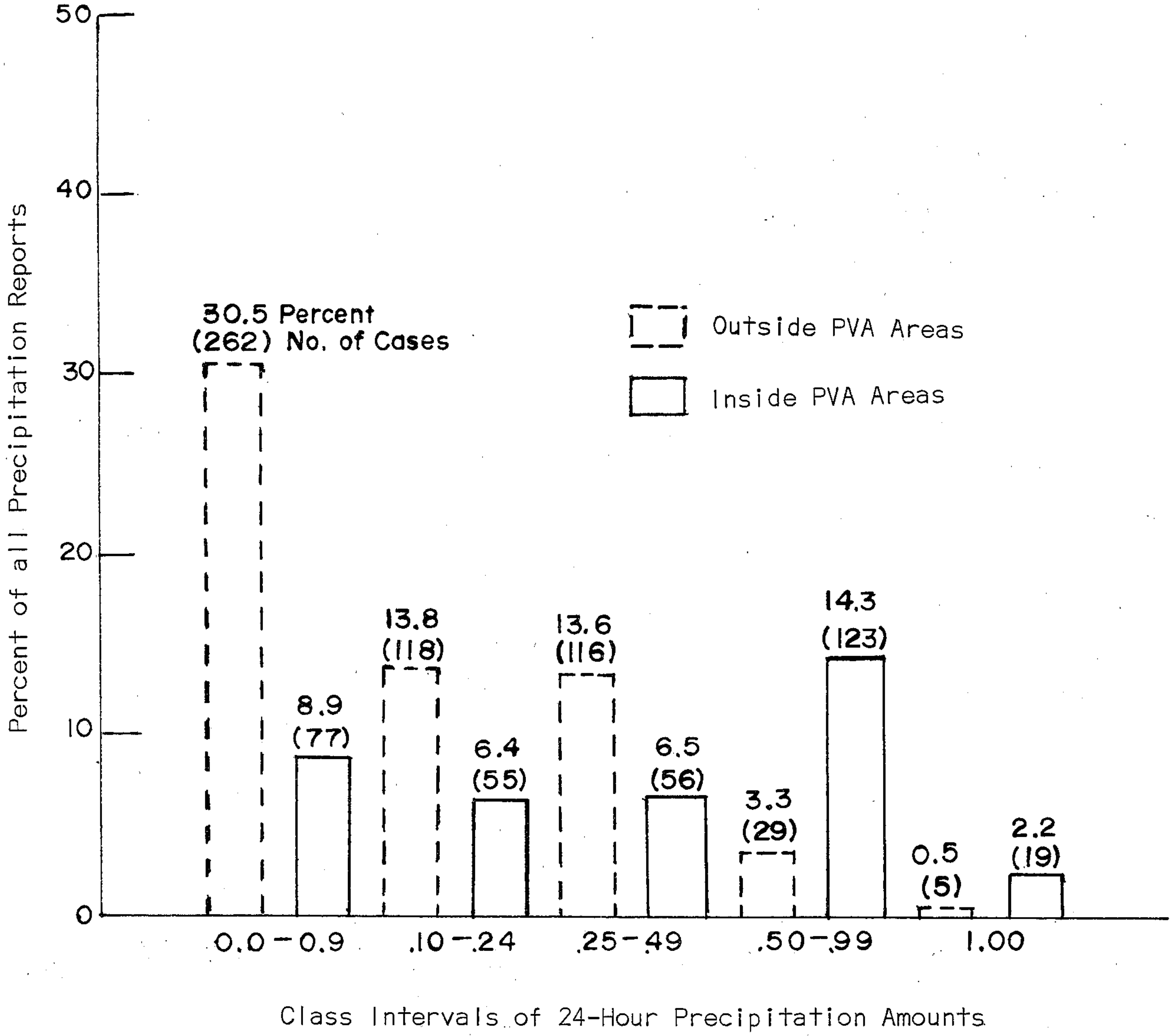

Figure 8. Percent of total number of precipitation reports outside PVA areas (dashed frequency distribution) and inside PVA areas (solid frequency distribution). Total number of reports 860. (See text for definition of PVA areas.)

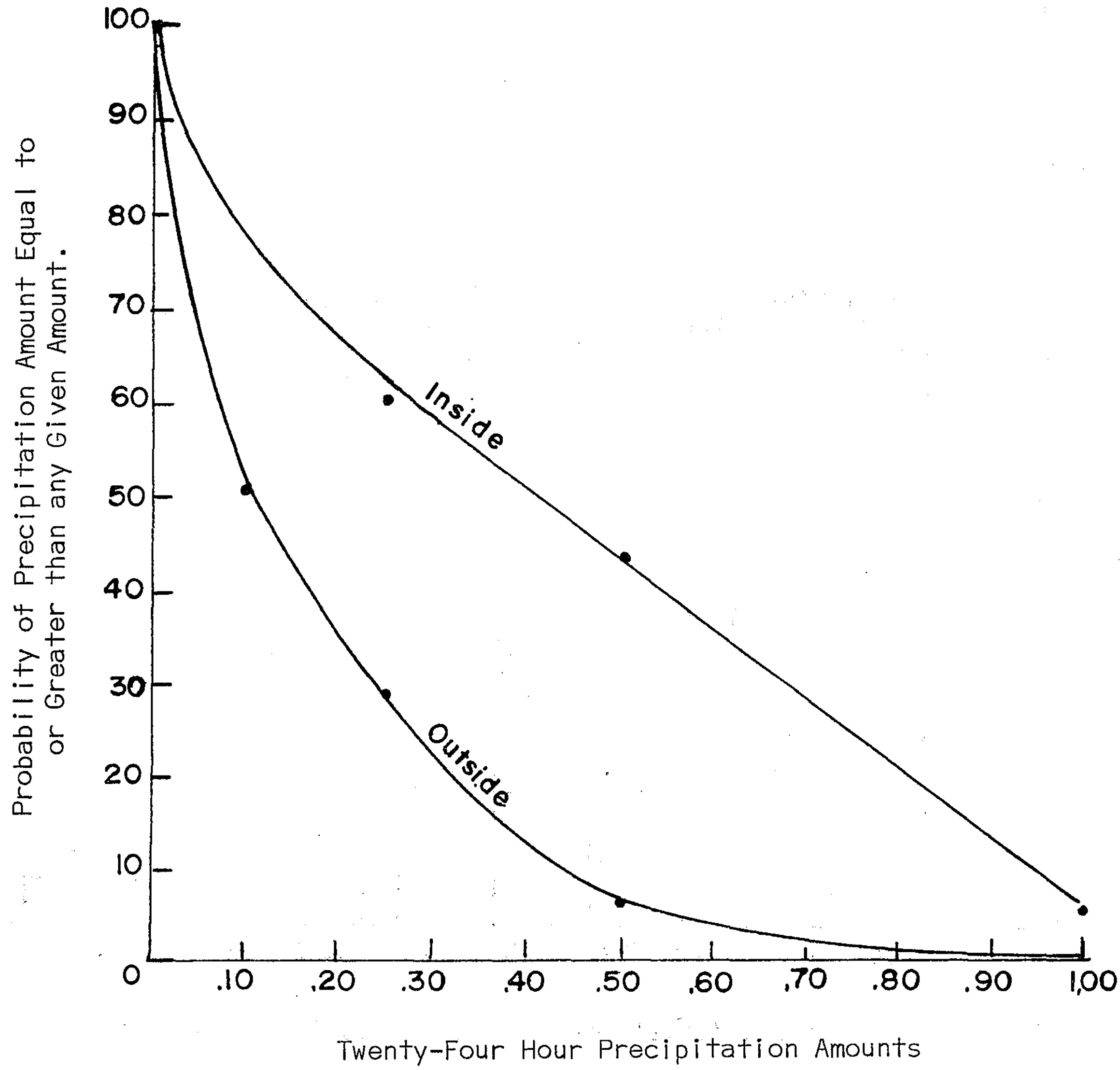

Figure 9. Cumulative percent frequency distributions of 24-hour precipitation amounts inside and outside of PVA areas.

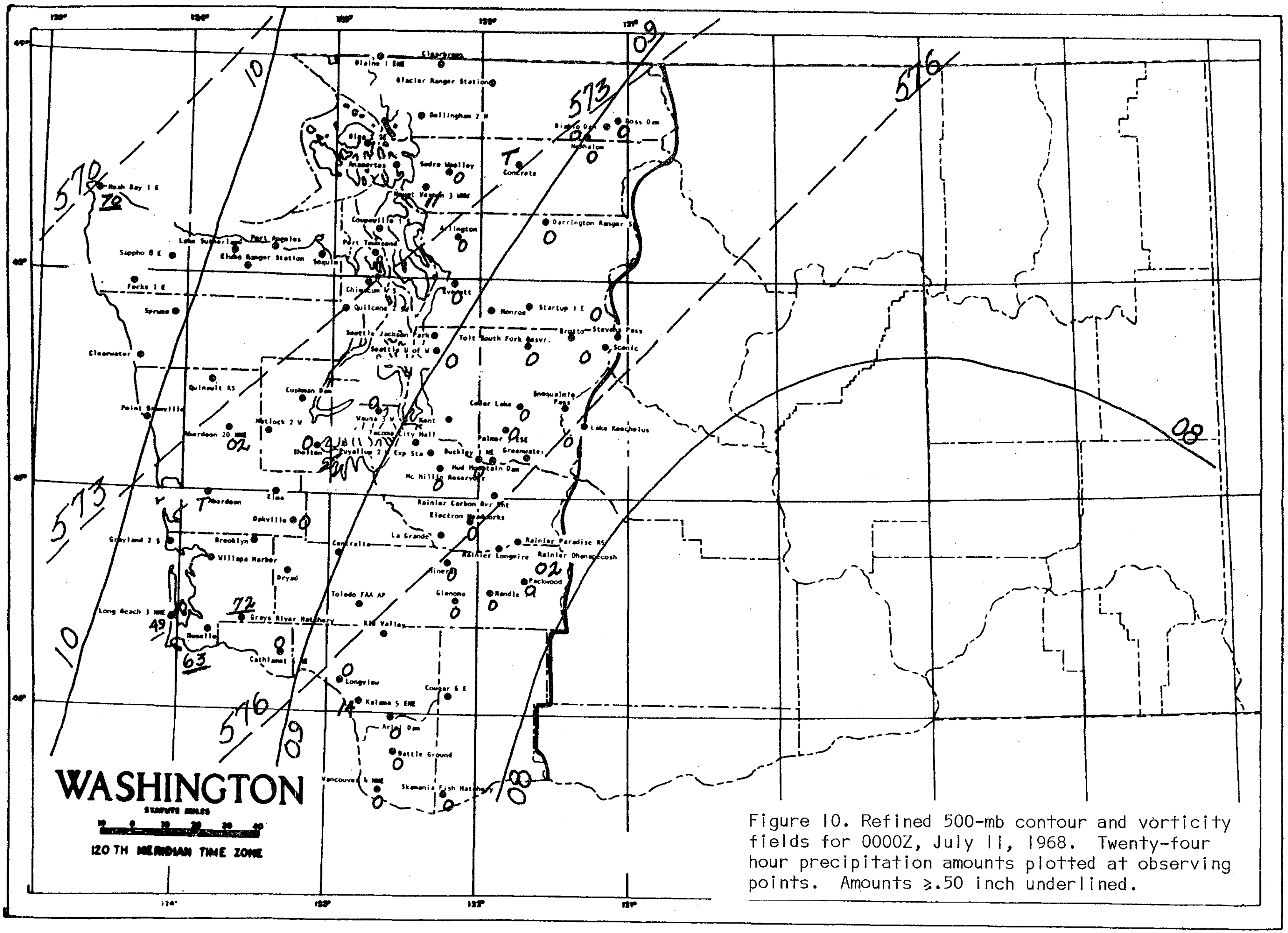

Figure 10. Refined 500-mb contour and vorticity fields for 0000Z, July 11, 1968. Twenty-four hour precipitation amounts plotted at observing points. Amounts ≥.50 inch underlined.

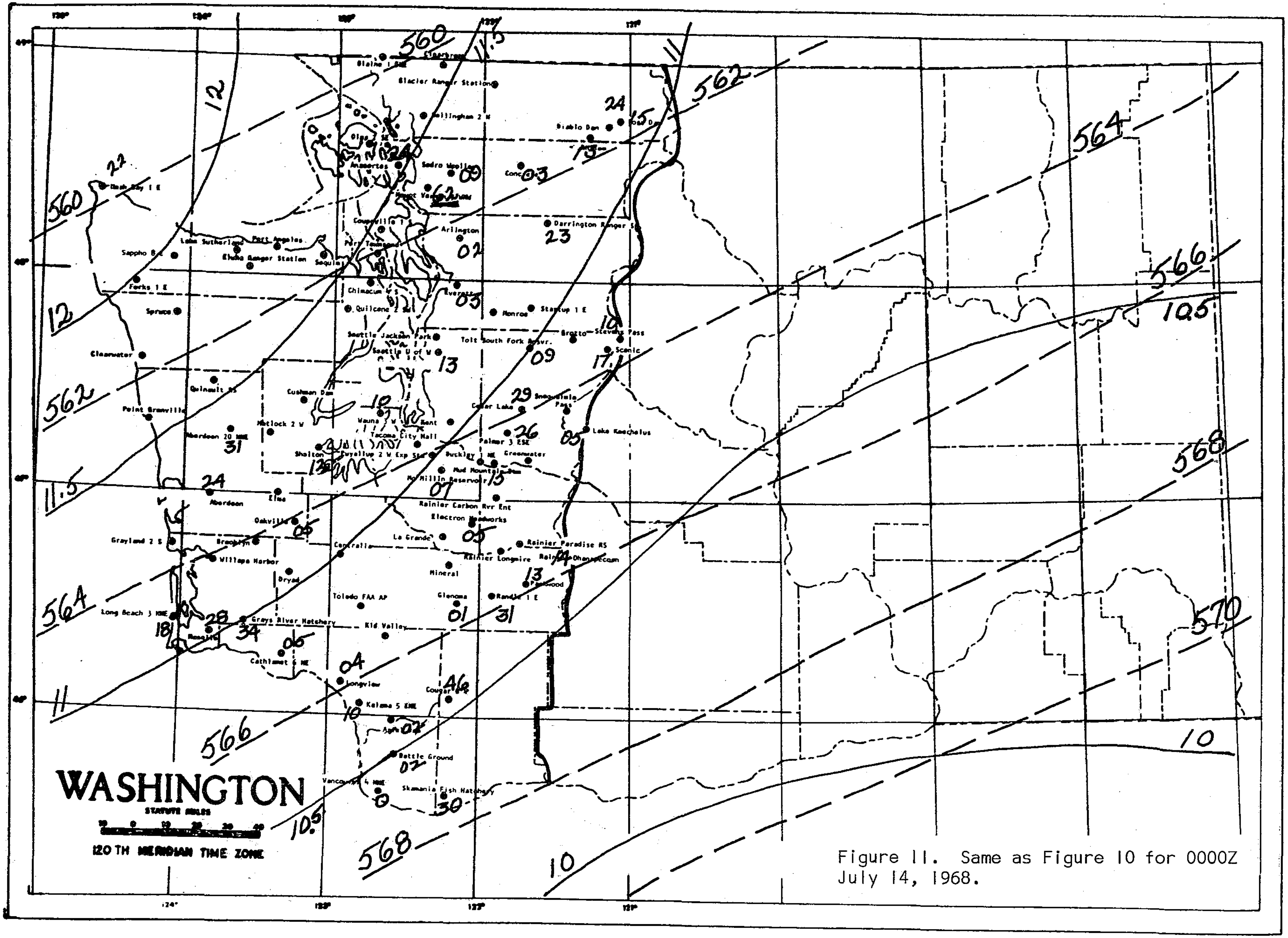

Figure 11. Same as Figure 10 for 0000Z July 14, 1968.

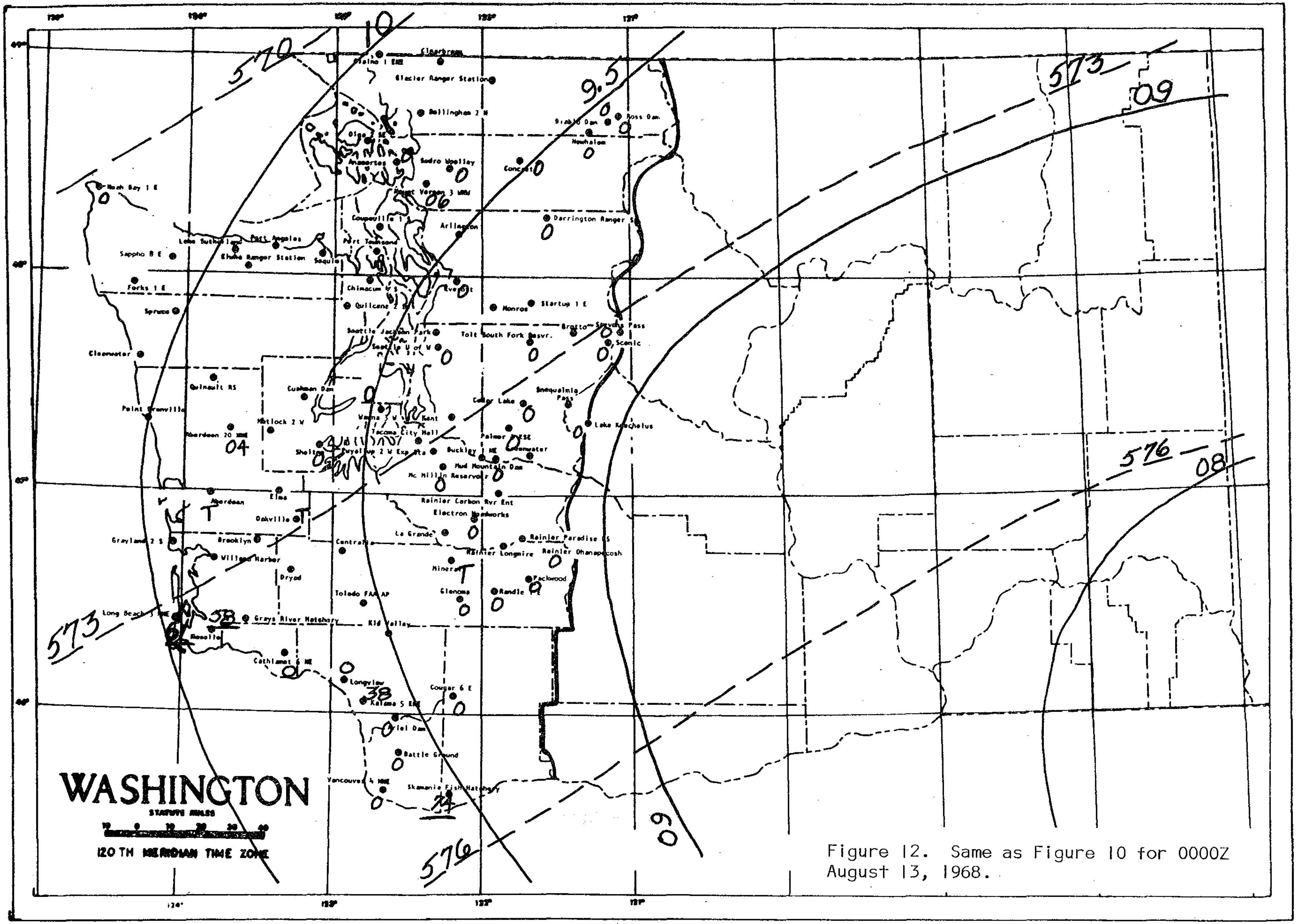

Figure 12. Same as Figure 10 for 0000Z August 13, 1968.

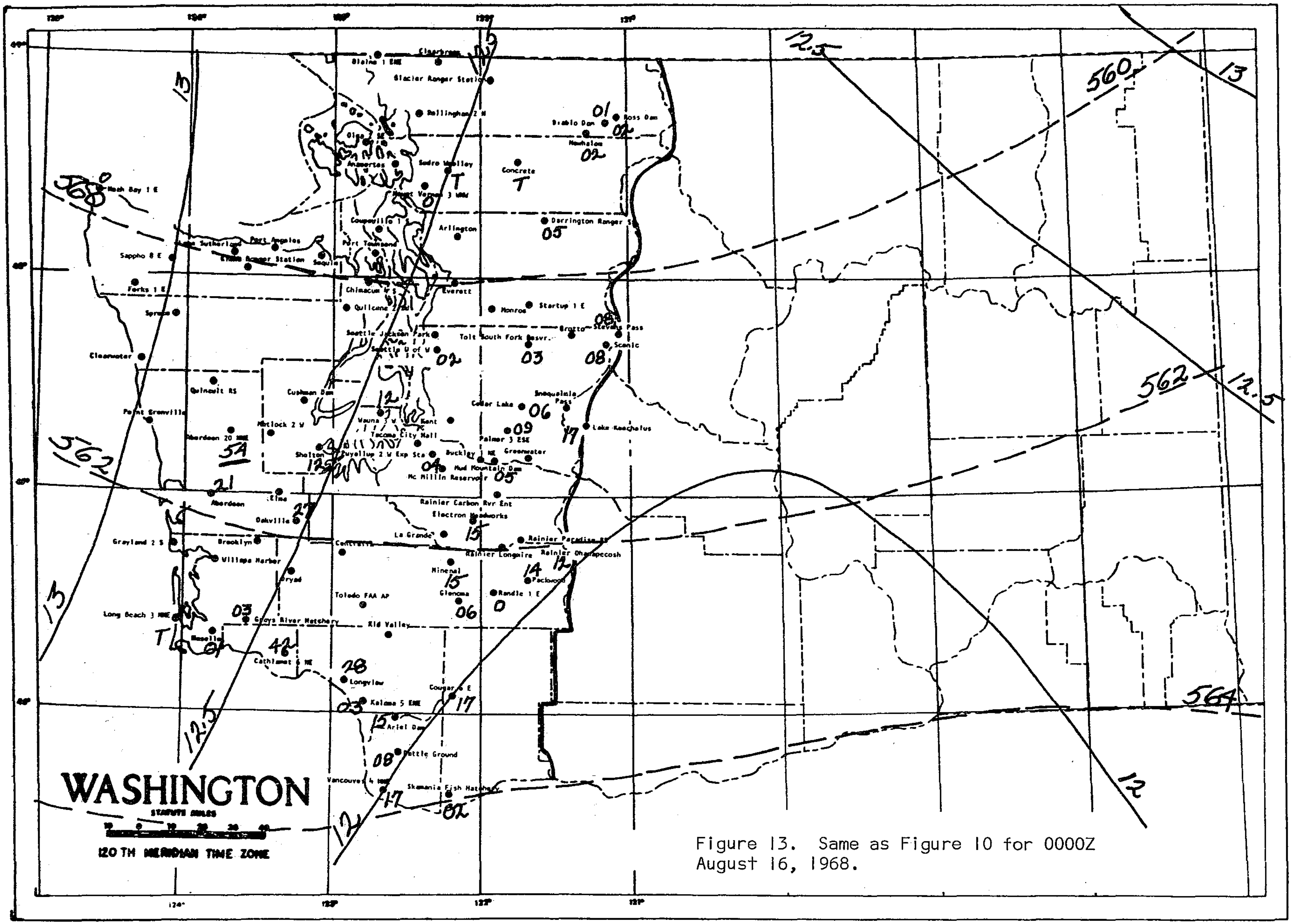

Figure 13. Same as Figure 10 for 0000Z August 16, 1968.

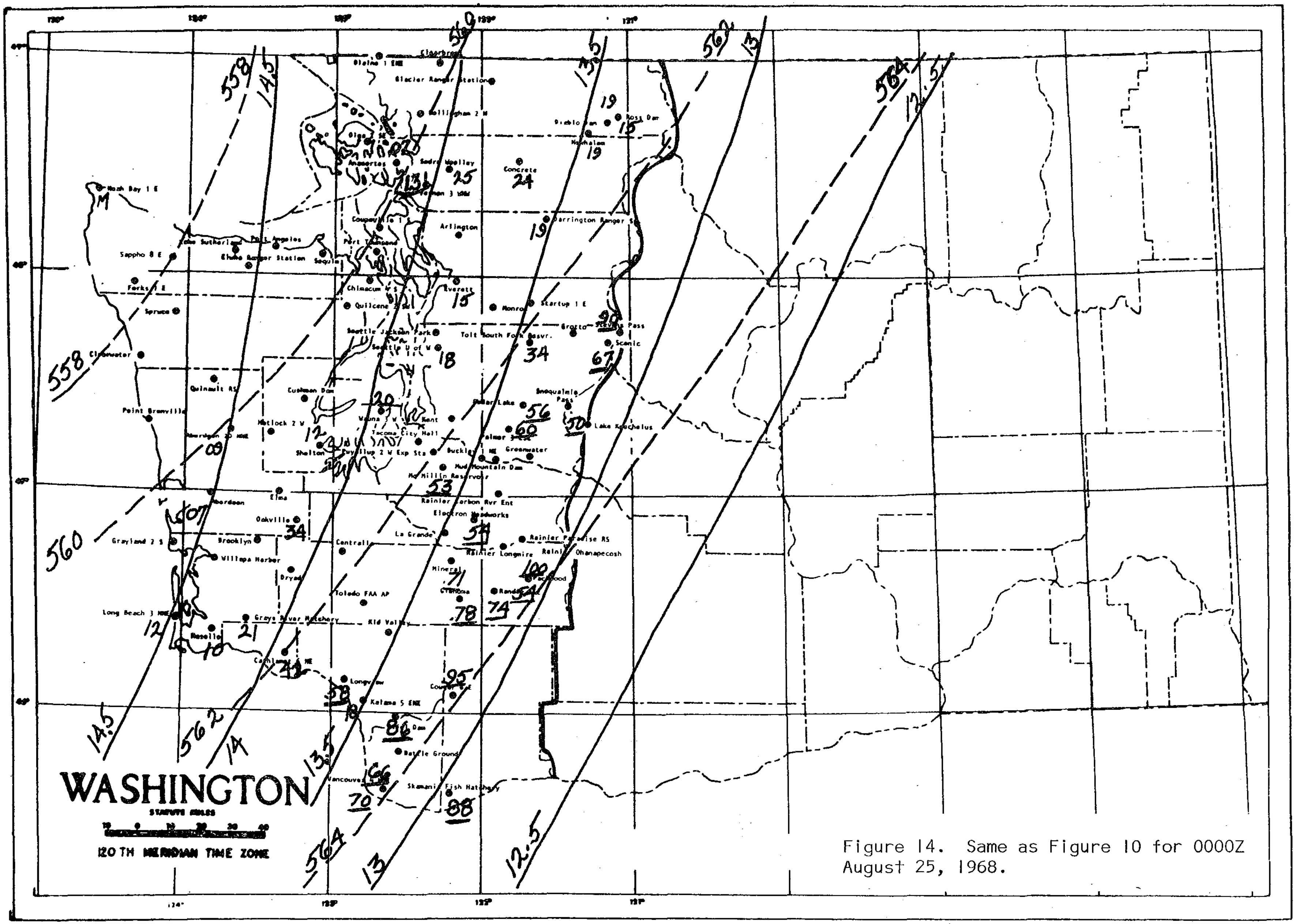

Figure 14. Same as Figure 10 for 0000Z August 25, 1968.

			Inside PVA Area			Outside PVA Area			
Date	Time	Class Interval	Freq.	% Freq.	Cumulative Frequency	Time	Freq.	% Freq.	Cumulative Frequency
7/11	00Z	.00 - .09	10	71.4	71.4	00Z	26	93.0	93.0
		.10 - .24	0	0.0	71.4		2	7.0	100
		.25 - .49	1	7.1	78.5		0	0.0	
		.50 - .99	3	21.5	100		0	0.0	
		≥1.00	0	0.0			0	0.0	
		Total	14	100			28	100	
7/11	12Z	.00 - .09	0	0	0	12Z	23	67.7	67.7
		.10 - .24	1	25.0	25.0		5	14.7	82.4
		.25 - .49	1	25.0	50.0		6	17.6	100
		.50 - .99	2	50.0	100		0	0.0	
		≥1.00	0	0.0			0	0.0	
		Total	4	100			34	100	
7/12	00Z	.00 - .09	0	0.0	0.0	00Z	11	37.9	37.9
		.10 - .24	3	25.0	25.0		7	24.2	62.1
		.25 - .49	2	16.6	41.6		10	34.4	96.5
		.50 - .99	6	50.0	91.6		1	3.5	100
		≥1.00	1	8.4	100		0	0.0	
		Total	12	100			29	100	
7/14	00Z	.00 - .09	2	33.3	33.3	00Z	14	38.8	38.8
		.10 - .24	3	50.0	83.3		14	38.8	87.6
		.25 - .49	0	0.0	83.3		8	22.4	100
		.50 - .99	1	16.7	100		0	0.0	
		≥1.00	0	0.0			0	0.0	
		Total	6	100			36	100	
7/14	12Z	.00 - .09	6	30.0	30.0		8	36.4	36.4
		.10 - .24	6	30.0	60.0		6	27.2	63.6
		.25 - .49	2	10.0	70.0		6	27.2	90.8
		.50 - .99	6	30.0	100		2	9.2	100
		≥1.00	0	0.0			0	0.0	
		Total	20	100			22	100	
7/15	12Z	.00 - .09	3	37.5	37.5		22	64.7	64.7
		.10 - .24	4	50.0	87.5		8	23.6	88.3
		.25 - .49	0	0.0	87.5		4	11.7	100
		.50 - .99	1	12.5	100		0	0.0	
		≥1.00	0	0.0			0	0.0	
		Total	8	100			34	100	
7/20	00Z	.00 - .09	4	19.0	19.0		11	52.4	52.4
		.10 - .24	6	28.7	47.7		5	23.8	76.2
		.25 - .49	7	33.3	81.0		5	23.8	100
		.50 - .99	4	19.0	100		0	0.0	
		≥1.00	0	0.0			0	0.0	
		Total	21	100			21	100	
8/13	00Z	.00 - .09	5	50.0	50.0	00Z	31	100	100
		.10 - .24	0	0.0	50.0		0	0.0	
		.25 - .49	1	10.0	60.0		0	0.0	
		.50 - .99	4	40.0	100		0	0.0	
		≥1.00	0	0.0			0	0.0	
		Total	10	100			31	100	

Table 1. Frequency distributions of precipitation amounts inside and outside PVA areas for individual charts. (See text for definition of PVA area.)

TABLE I (Continued)

			Inside PVA Area			Outside PVA Area			
Date	Time	Class Interval	Freq.	% Freq.	Cumulative Frequency	Time	Freq.	% Freq.	Cumulative Frequency
8/13	12Z	.00 - .09	4	22.3	22.3	12Z	17	71.2	71.2
		.10 - .24	5	27.9	50.2		3	12.5	83.7
		.25 - .49	6	33.3	83.5		4	16.3	100
		.50 - .99	3	16.5	100		0	0.0	
		≥1.00	0	0.0			0	0.0	
		Total	18	100			24	100	
8/14	00Z	.00 - .09	1	4.8	4.8	00Z	6	33.3	33.3
		.10 - .24	1	4.8	9.6		1	5.5	38.8
		.25 - .49	6	28.5	38.1		11	61.2	100
		.50 -.99	13	61.9	100		0	0.0	
		≥1.00	0	0.0			0	0.0	
		Total	21	100			18	100	
8/15	00Z	.00 - .09	5	31.2	31.2	00Z	11	44.0	44.0
		.10 - .24	1	6.3	37.5		5	20.0	64.0
		.25 - .49	1	6.3	43.8		8	32.0	96.0
		.50 - .99	6	37.5	81.3		1	4.0	100
		≥1.00	3	18.7	100		0	0.0	
		Total	16	100			25	100	
8/16	00Z	.00 - .09	7	39.0	39.0	00Z	17	77.3	77.3
		.10 - .24	7	39.0	78.0		5	22.7	100
		.25 - .49	3	16.5	94.5		0	0.0	
		.50 - .99	1	5.5	100		0	0.0	
		≥1.00	0	0.0			0	0.0	
		Total	18	100			22	100	
8/17	12Z	.00 - .09	9	64.3	64.3	12Z	18	66.6	66.6
		.10 - .24	2	14.3	78.6		8	29.7	96.3
		.25 - .49	0	0.0	78.6		1	3.7	100
		.50 - .99	3	21.4	100		0	0.0	
		≥1.00	0	0.0			0	0.0	
		Total	14	100			27	100	
8/18	00Z	.00 - .09	1	12.5	12.5	00Z	13	39.3	39.3
		.10 - .24	1	12.5	25.0		7	21.2	60.5
		.25 - .49	1	12.5	37.5		8	24.3	84.8
		.50 - .99	4	50.0	87.5		4	12.2	97.0
		≥1.00	1	12.5	100		1	3.0	100
		Total	8	100			33	100	
8/19	12Z	.00 - .09	3	12.0	12.0	12Z	9	53.0	53.0
		.10 - .24	4	16.0	28.0		5	29.5	82.5
		.25 - .49	9	36.0	64.0		2	11.6	94.1
		.50 - .99	9	36.0	100		0	0.0	94.1
		≥1.00	0	0.0			1	5.9	100
		Total	25	100			17	100	
8/20	12Z	.00 - .09	15	71.5	71.5	12Z	14	66.6	66.6
		.10 - .24	2	9.5	81.0		4	19.0	85.6
		.25 - .49	2	9.5	90.5		3	14.4	100
		.50 - .99	2	9.5	100		0	0.0	
		≥1.00	0	0.0			0	0.0	
		Total	21	100			21	100	

TABLE I (Continued)

			Inside PVA Area			Outside PVA Area			
Date	Time	Class Interval	Freq.	% Freq.	Cumulative Frequency	Time	Freq.	% Freq.	Cumulative Frequency
8/24	00Z	.00 - .09	1	6.3	6.3	00Z	4	16.6	16.6
		.10 - .24	1	6.3	12.6		4	16.7	33.3
		.25 - .49	1	6.3	18.9		12	50.0	83.3
		.50 - .99	7	43.7	62.6		4	16.7	100
		≥1.00	6	37.4	100		0	0.0	
		Total	16	100			24	100	
8/25	00Z	.00 - .09	0	0.0	0.0	00Z	3	17.6	17.6
		.10 - .24	4	17.4	17.4		9	52.9	70.5
		.25 - .49	2	8.7	26.1		2	11.9	82.4
		.50 - .99	15	65.2	91.3		3	17.6	100
		≥1.00	2	8.7	100		0	0.0	
		Total	23	100			17	100	
8/26	00Z	.00 - .09	0	0.0	0.0	00Z	1	4.2	4.2
		.10 - .24	1	6.3	6.3		5	20.8	25.0
		.25 - .49	4	25.0	31.3		14	58.2	83.2
		.50 - .99	10	62.4	93.7		4	16.8	100
		≥1.00	1	6.3	100		0	0.0	
		Total	16	100			24	100	
8/27	00Z	.00 - .09	0	0.0	0.0	00Z	1	4.7	4.7
		.10 - .24	0	0.0	0.0		6	28.5	33.2
		.25 - .49	5	25.0	25.0		4	19.1	52.3
		.50 - .99	11	55.0	80.0		8	38.3	90.6
		≥1.00	4	20.0	100		2	9.4	100
		Total	20	100			21	100	
8/27	12Z	.00 - .09	1	5.3	5.3		2	9.0	9.0
		.10 - .24	3	15.7	21.0		9	40.9	49.9
		.25 - .49	2	10.6	31.6		8	36.5	86.4
		.50 - .99	12	63.1	94.7		2	9.0	95.4
		≥1.00	1	5.3	100		1	4.6	100
		Total	19	100			22	100	

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.

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

*Out of Print
**Revised