DEVELOPMENT OF UPDATED WARM SEASON PRECIPITATION AND TEMPERATURE EQUATIONS FOR THE COLUMBIA RIVER BASIN

Robert J. Bermowitz
Edward A. Zurndorfer
J. Paul Dallavalle

Techniques Development Laboratory
Systems Development Office
National Weather Service
National Oceanic and Atmospheric Administration
Department of Commerce
Silver Spring, Maryland 20910

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INTRODUCTION

In previous reports, we have described developmental work to provide objective forecasts of probability of precipitation (PoP), probability of precipitation amount (PoPA), precipitation amount, and maximum and minimum (max/min) surface temperature for 70 stations in the Columbia River Basin. These forecasts for the warm season (April-September) (Bermowitz et. al., 1976a) and the cool season (October-March) (Bermowitz et. al., 1976b) are made from equations developed with application of the Model Output Statistics (MOS) technique (Glahn and Lowry, 1972). Since June 1976, these forecasts have been transmitted to the Portland Office of the Bonneville Power Administration via the Bureau of Reclamation computer in Denver.

This report describes our effort, funded by the Bonneville Power Administration, to update the warm season equations with use of an additional season of developmental data. By adding one more year of data, we feel that the equations we developed should be more stable. This is especially so for projections beyond 48 hours where fewer years of developmental data are available than at earlier projections. At the request of the Bonneville Power Administration we also expanded our present list of 70 stations at which forecasts are made to 93 by adding 22 Canadian and 1 U.S. station.

Six warm seasons, 1970-1975, of predictand data were available for development of precipitation and temperature equations. Data at 93 stations were used to develop max/min equations and data at 88 stations were used to develop both PoP and PoPA equations. Table 1 contains a list of these stations; Figure 1 shows their locations. Predictor data consisted of forecast fields from the primitive equation (PE) (Shuman and Hovermale, 1968) and trajectory (TRAJ) (Reap, 1972) models.

PRECIPITATION AMOUNT

PoPA warm season equations were developed for the categories $\geq .25$, $\geq .50$, and ≥ 1.0 inch for projections 0-24, 24-48, 48-72, and 72-96 hr after 0000 GMT and 12-36 and 36-60 hr after 1200 GMT. As was the case for the 1976 warm season, we could not derive equations for the category ≥ 2.0 inches because the data revealed 24-hr amounts of at least 2.0 inches seldom occurred in the Columbia Basin during the warm season. Once again, we used the REEP technique (Miller, 1958) to develop these equations. Five warm seasons, 1971-1975, out of the available six were used to develop all the 1200 GMT equations and the 0000 GMT equations out to 48 hours; 1970 data were not used because the PE model was anomalously dry. Beyond 48 hours, data from 1973-1975 were used.

Generalized operator equations were developed for each of the nine regions shown in Figure 2. As before, the regions were determined by a subjective analysis of the observed relative frequency of occurrence of $\geq$.25 inch in a 24-hr period when the PE model forecast $\geq$ .01 inch during the same period. Since the observation times of the majority of the Canadian stations were unknown, regions in Canada were determined mostly from a knowledge of the climatology and topography of the area. With the exception of the new ones in Canada, the PoPA regions are very similar to those used for the 1976 warm season. Regions 1, 3, and 7 are relatively wet; regions 4, 5, and 8 are relatively dry. Note that, as has been the case in the past, region 3 stations have their observations taken within a few hours of 1500 GMT and not 0000 GMT. Therefore, it should be remembered that region 3 PoPA equations give probabilities and amounts for 24-hr periods ending at 1500 GMT.

Predictors offered for screening were those that were found to be important in developing the 1976 warm season equations. These included precipitation amount, surface to 490-mb mean relative humidity, relative humidity from the top of the boundary layer to 720 mb, boundary layer u and v wind components, and moisture divergence, all from the PE model, and net vertical displacement and atmospheric stability from the TRAJ model. We also screened station elevation and the first and second harmonics of the day of the year. Relative frequencies of occurrence of 24-hr precipitation amounts were not screened; we found that these predictors have deteriorated the operational categorical forecasts at certain locations.

All PE and TRAJ predictors were used in binary and continuous form; this represents a change from previous work in which these predictors were used only in binary form. Recent work (Zurndorfer and Bermowitz, 1976) has shown that the use of continuous predictors with the usual binaries improves the PoPA forecasts. Furthermore, the addition of continuous predictors helps facilitate the choosing of threshold probabilities when the PoPA forecasts are transformed to categorical forecasts by maximizing the threat score. As before, predictors space smoothed with simple 5-, 9-, and 25-point averages were also offered for screening.

The most important predictors were found to be precipitation amount, surface to 490-mb mean relative humidity, and boundary layer wind from the PE model and 12-hr net vertical displacement from the TRAJ model. In general, continuous predictors were found to be more important than binaries. First and second harmonics of the day of year became increasingly important at later projections when the skill of the PE model deteriorates.

Table 2 shows the average reductions of variance for all regions combined for each category and projection. Note that the average reduction of variance for the category $\geq$ 1.0 inch does not include regions 4, 5, and 8 for projections beyond 48 hours after 0000 GMT. Equations for $\geq$ 1.0 were not developed for these regions since this event was very rare there and only three years of dependent data were available beyond 48 hours. The average reductions of variance for each projection are smaller than the corresponding values for the 1976 warm season (Bermowitz et. al., 1976a); this could be attributed in part to the additional Canadian stations where we have combined data with perhaps widely different observation times into the same region. Nevertheless, we feel that with the extra year of data, the equations should be more stable. Also, we have been able to derive equations for ≥ 1.0 inch for more regions than was possible for the 1976 warm season.

We continued to transform the PoPA forecasts to categorical forecasts in the same way as in the past--by maximizing the threat score. The additional year of data permitted us to derive threshold values for the higher categories in more regions than we were able to do for the 1976 warm season, especially at the later projections. However, determining stable threshold values was still difficult, and in some cases impossible, especially for the category ≥ 1.0 inch in dry regions at later projections. Table 3 summarizes in which regions the various categories can be forecast.

PROBABILITY OF PRECIPITATION

We developed equations for the probability of ≥ .01 inch for the same projections we used for the PoPA work. We screened predictors that were found to be important in developing the 1976 warm season equations; they were similar to those used for PoPA. As we did for PoPA, we screened smoothed and unsmoothed continuous predictors as well as binary predictors derived from smoothed and unsmoothed basic fields. The use of continuous predictors with the usual binaries has been shown to improve the MOS PoP forecasts (Glahn and Bocchieri, 1976).

The 17 regions used for PoP are shown in Figure 3. They were determined by a subjective analysis of the relative frequency of occurrence of ≥ .01 inch in a 24-hr period when the PE model forecast the surface to 490-mb mean relative humidity to be ≥ 75%.

The most important PE predictors for PoP were surface to 490-mb mean relative humidity, top of the boundary layer to 720-mb mean relative humidity, and 850-mb height; stability indices were the most important TRAJ predictors. The 850-mb height was most important at longer range projections and in dry regions.

Table 4 shows the average reductions of variance for all regions combined for each projection. As was the case for PoPA, the reductions of variance are smaller than the corresponding values for the 1976 warm season.

MAX/MIN TEMPERATURE

As we have done in the past, we developed single station max/min temperature forecast equations using multiple screening regression. We increased the number of stations from 70 to 93. Max/min forecasts made from these equations are valid for 24-hr periods that end at the local observation time. The forecasts extend out to about 96 hours (4 days) for the 0000 GMT cycle and about 60 hours (2 1/2 days) for the 1200 GMT cycle. Six warm seasons (1970-1975) of developmental data, amounting to over 900 cases, were used to develop all the 1200 GMT and the 0000 GMT equations out to 48 hours. Beyond 48 hours after 0000 GMT, three seasons (1973-1975) of data, consisting of about 450 days, were used.

Predictors offered to the screening regression program were those that are considered important in surface temperature forecasting. PE and TRAJ model predictors included pressure height, tropospheric temperature, thickness between pressure levels, wind, vertical velocity, layer relative humidity, divergence, stability parameters, vorticity at several levels, vorticity advection, precipitable water, and temperature advection. Also, the first and second harmonics of the day of the year were included to simulate the seasonal trend of temperature. Space smoothed 5-, 9-, and 25-point predictors were also used. All predictors were in continuous form.

Based on the frequency of selection and the order that the predictors were chosen, the 850- and 700-mb temperature, boundary layer potential temperature, thicknesses, some measure of relative humidity (either boundary layer, top of boundary layer to 720 mb, or from the surface to 490 mb), the lower level wind (boundary layer or 850 mb), cosine day of year and sine twice day of year were important predictors for both the max and min at all projections. The 500-mb height and the u component of the boundary layer wind were important predictors for the max while precipitable water was important for the min.

The standard errors of estimate and the reductions of variance averaged for the 93 stations are shown in Table 5. The standard errors for the min are the same as those obtained for the 1976 warm season (Bermowitz et al., 1976a); for the max they are 0.2° to 0.3°F larger than those for the 1976 warm season. Again, we feel that this may be partly due to the addition of the Canadian stations. However, as we have stated previously, these equations should be more stable than those used for the previous warm season. Note that the standard error for the max (and the min) increases nearly linearly with increasing projection as shown in Figure 4. For the same projection, the standard error for the min is always less than that of the max. For example, at the 24-hr projection the min (tonight's min from the 1200 GMT cycle) has a smaller standard error than the max (today's max from the 0000 GMT cycle). An examination of Table 5 shows that the standard error for the min is less than that of either the preceding or subsequent max. These features indicate that it is more difficult to forecast the max than the min during the warm season. As has been noted by Hammons et. al. (1976), the warm season max is influenced by local conditions such as convection; on the other hand, the warm season min seems more related to synoptic scale features that can be predicted by the synoptic scale numerical models.

OPERATIONAL ASPECTS

Forecasts made from the warm season equations should replace those made from the cool season equations on or around April 1, 1977. We plan to continue transmitting the precipitation and temperature forecasts to the Portland office of the Bonneville Power Administration via the Bureau of Reclamation computer in Denver. However, a few changes in the transmission will be made when the new equations are implemented.

From now on, an entry in the transmission will be made for each of the four PoPA categories for both warm and cool seasons. This will occur even though a probability forecast for a particular category is not available; these missing forecasts will be denoted by an "X". Previously, no entry was made for the category $\geq$ 2.0 inches in the warm season. In addition, a value of 0 was transmitted for probability forecasts for those categories where equations could not be developed in some of the regions. This new procedure will preclude changing the transmission program each season and will distinguish between a probability of 0 and a missing probability.

It should be pointed out that max/min forecasts for 17 of the 93 stations in the Bonneville set are also transmitted in the FOUS22 teletypewriter bulletin. Forecasts for these 17 stations on FOUS22 are made from equations developed on 3-month seasons; they are more accurate than those based on 6-month seasons (Hammons et. al., 1976). In our Bonneville transmission, forecasts based on 3-month seasons will be transmitted for all 17 stations for projections up to 72 hours from 0000 GMT. Only forecasts for the fourth day's minimum (84 hours) and maximum (96 hours) will be made from equations based on 6-month seasons. For all projections from 1200 GMT, forecasts based on 3-month seasons will be transmitted for all 17 stations.

As requested by the Bonneville Power Administration, we will be transmitting hourly temperature and wind observations for three cities--Spokane, Portland, and Seattle. This information will follow transmission of all forecasts. For the 0000 GMT transmission, 120 hours of data will be transmitted starting with the most recent observation and working backwards. For the 1200 GMT transmission, 12 hours of data will be sent starting with the most recent observation and working backwards.

A sample transmission of the hourly data is shown in Figure 5. The first line is a heading intended primarily to separate the forecast portion of the message from the observation portion. The hour shown next to the date gives the time of the most recent observation, in this example, 1300 GMT. The next six lines give 12 hours of temperature and wind observations in the standard format, starting at 1300 GMT and working backwards, for Spokane, Portland, and Seattle. Missing temperature observations are denoted by 999, missing wind directions by 99, and missing wind speeds by 99. Subsequent lines indicated by the dots provide the remaining 108 hours of data (12 hours per line) in the same station order as shown for the first six lines.

REFERENCES

Bermowitz, R. J., E. A. Zurndorfer, J. P. Dallavalle, and G. A. Hammons, 1976a: Development of warm season precipitation and temperature equations for the Columbia River Basin. Final Report, Phase I. Prepared for the Department of Interior, Bonneville Power Administration, Portland, Oregon, 21 pp.

_____, _____, _____, _____, 1976b: Development of cool season precipitation and temperature equations for the Columbia River Basin. Final Report, Phase II. Prepared for the Department of Interior, Bonneville Power Administration, Portland, Oregon, 18 pp.

Glahn, H. R., and D. A. Lowry, 1972: The use of model output statistics (MOS) in objective weather forecasting. J. Appl. Meteor., 11, 1203-1211.

_____, and J. R. Bocchieri, 1976: Testing the limited area fine mesh model for probability of precipitation forecasting. Mon. Wea. Rev., 104, 127-132.

Hammons, G. A., J. P. Dallavalle, and W. H. Klein, 1976: Automated guidance based on three month seasons. Mon. Wea. Rev., 104, 1557-1564.

Miller, H. G., 1958: The screening procedure (in studies in statistical weather prediction). Final report, Contract No. AF19(604)-1590 (Edited by Shorr), The Travelers Research Center, Inc., Hartford, Conn., 86-95.

Reap, R. M., 1972: An operational three-dimensional trajectory model. J. Appl. Meteor., 11, 1193-1202.

Shuman, F. G., and J. B. Hovermale, 1968: An operational six-layer primitive equation model. J. Appl. Meteor., 7, 525-547.

Zurndorfer, E. A., and R. J. Bermowitz, 1976: Determination of an optimum number of predictors for probability of precipitation amount forecasting. TDL Office Note 76-17, 7 pp.

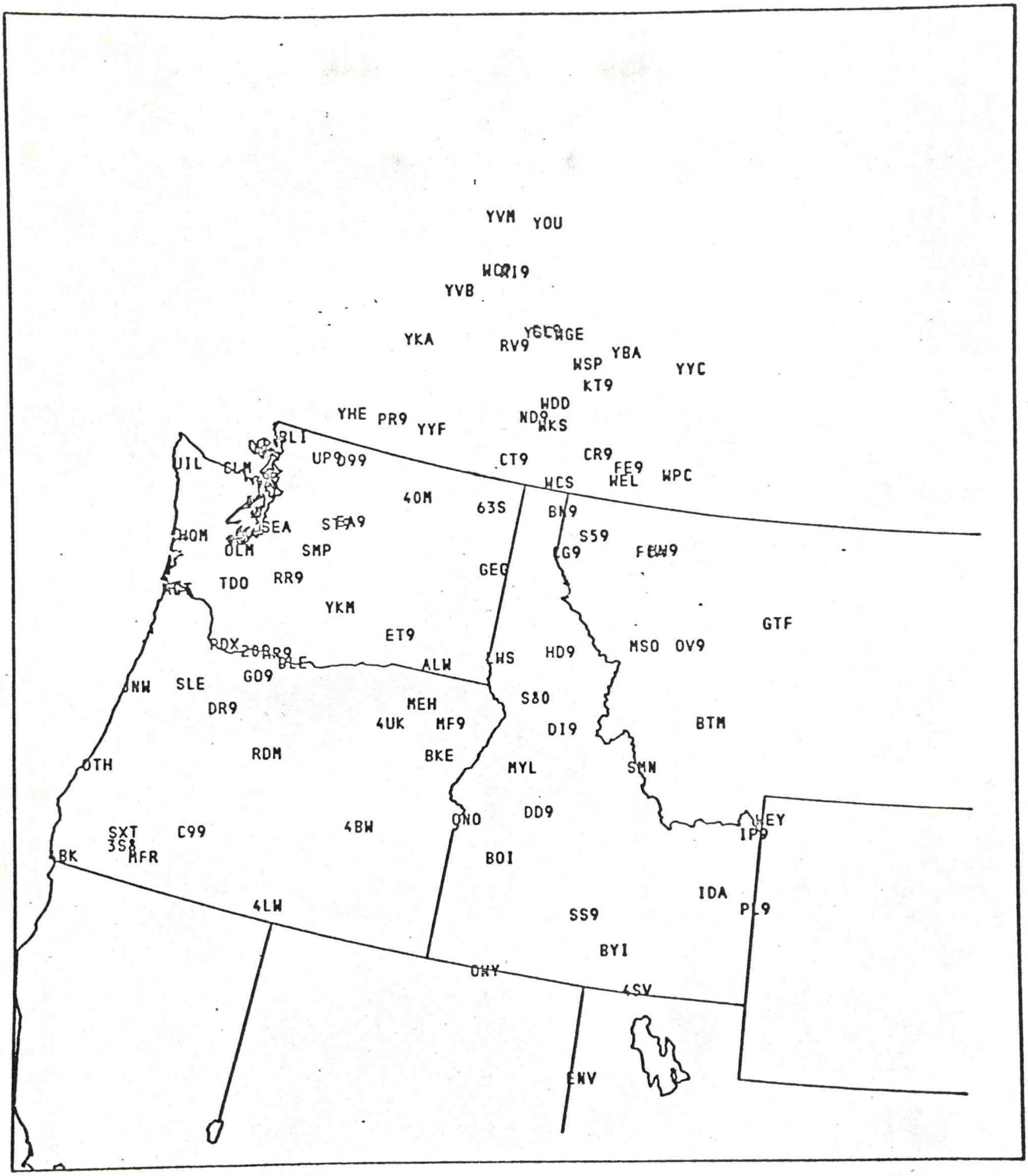

Figure 1. Locations of stations in the Columbia River Basin and adjacent areas for which data were used.

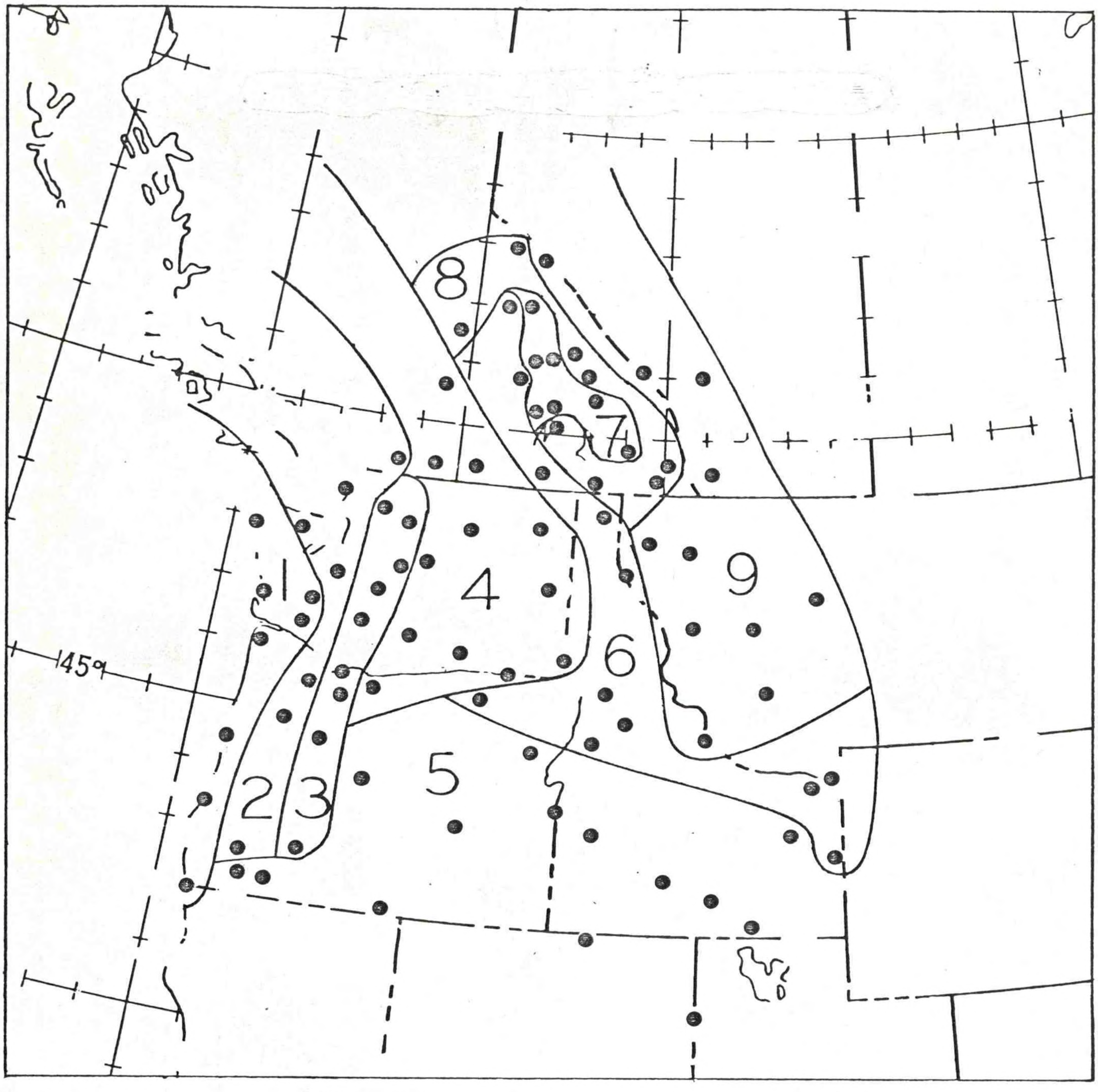

Figure 2. The nine regions used to develop PoPA equations for the 1977 warm season.

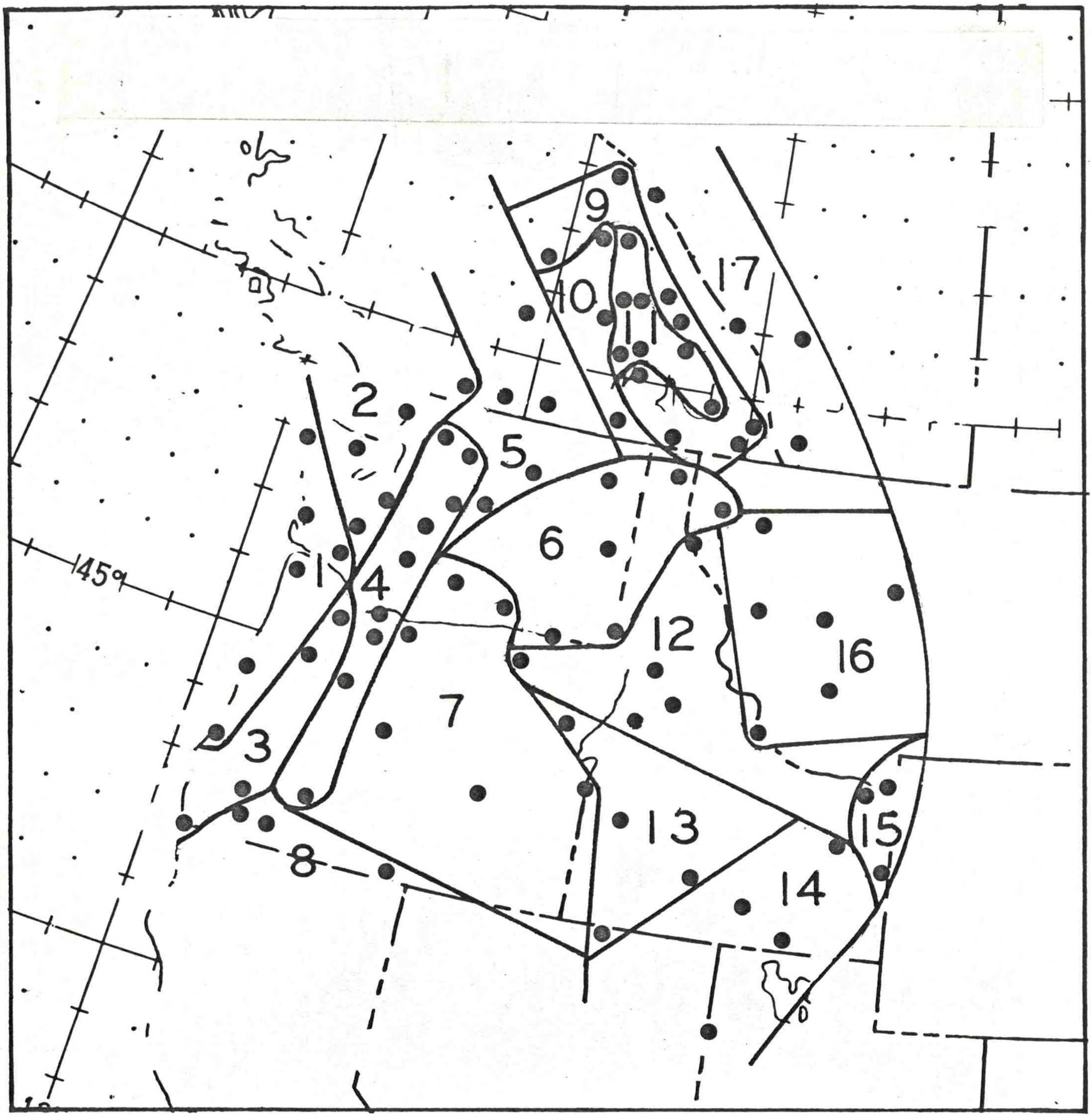

Figure 3. The 17 regions used to develop PoP equations for the 1977 warm season.

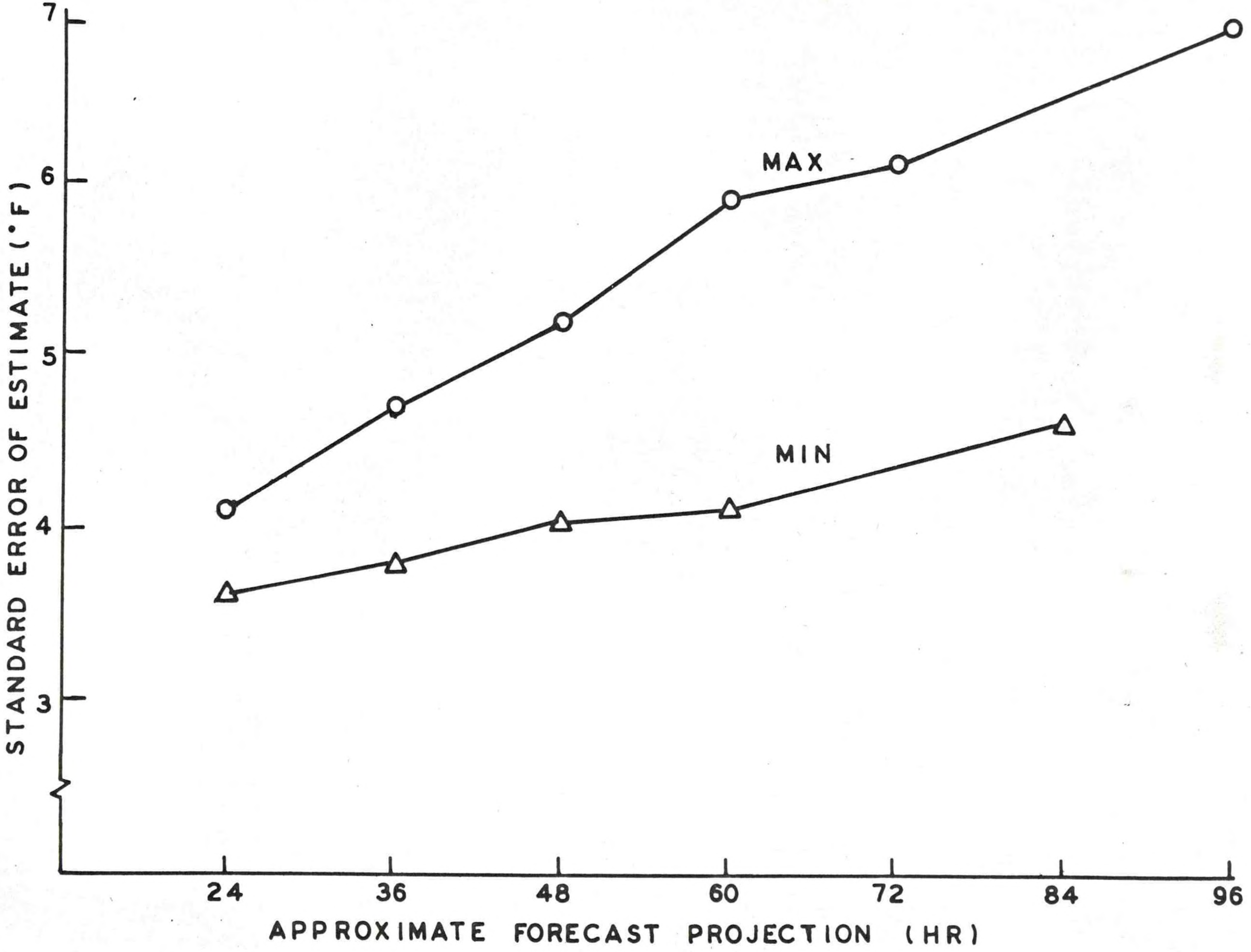

Figure 4. Standard error of estimate plotted as a function of projection. Both 0000 and 1200 GMT cycles are included.

Figure 5. Sample transmission of hourly temperature and wind observations for Spokane, Portland, and Seattle. See text for an explanation.

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HDNG  BONNEVILLE OBS     12/04/77 1300 GMT

GEG     25   25   25   25   25   25   25  999   26   26  999   27
      0903 3603 0000 0000 0000 2003 0000 9999 0103 0000 9999 3004

PDX     36   35   36   37   36   36   36   36   37   37   38   40
      1213 1210 0604 1210 1208 1108 1108 1210 1212 1213 1214 1213

SEA     45   45   46   46   45   44   45   45   47   49   48   50
      2003 1705 1404 0907 1009 2507 0810 1304 1111 0909 1408 0000

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Table 1. Stations used to develop PoP, PoPA, and max/min equations in the Columbia River Basin. Stations used only for temperature equations are denoted by *. Those used only for PoP and PoPA equations are denoted by **.

Name	Call Letters	Latitude	Longitude	Elevation (ft)
Blue River, BC	WCP	52 01	119 01	2240
Castlegar A, BC	CT9	44 18	117 38	1619
Cranbrook A, BC	CR9	49 37	115 47	3045
Creston, BC	WCS	49 06	116 31	1960
Duncan Dam, BC	WDD	50 15	116 58	1800
Elko, BC	WEL	49 18	115 06	3080
Fernie, BC	FE9	49 30	115 03	3305
Glacier Mt Fidelity, BC	YGC	51 14	117 42	6380
Glacier Rogers Pass, BC	GL9	51 17	117 31	4340
Golden, BC	WGE	51 18	116 58	2595
Hope, BC	YHE	49 23	121 26	152
Kamloops A, BC	YKA	50 43	120 25	1133
Kaslo, BC	WKS	49 55	116 55	1930
Kootenai Wesgate, BC	KT9	50 38	116 04	3000
Mica Creek, BC	MI9	52 03	118 35	1900
New Denver, BC	ND9	49 59	117 23	1850
Penticton A, BC	YYF	49 28	119 36	1121
Princeton, BC	PR9	49 28	120 31	2283
Revelstoke, BC	RV9	50 58	118 11	1467
Spillamacheen, BC	WSP	50 55	116 24	2685
Valemount, BC	YVM	52 49	119 15	2615
Vavenby, BC	YVB	51 35	119 47	1465
Banff, Alta	YBA	51 11	115 34	4583
Calgary Int A, Alta.	YYC	51 06	114 01	3590
Jasper, Alta.	YOU	52 53	118 04	3480
Pincher Creek, Alta.	WPC	49 30	113 57	3790
Boise, Idaho	BOI	43 34	116 13	2838
Bonners Ferry, Idaho	BN9	48 41	116 19	1860
Burley, Idaho	BYI	42 32	113 46	4146
Cabinet Gorge, Idaho	CG9	48 05	116 04	2257
Deadwood Dam, Idaho	DD9	44 19	115 38	5375
Dixie, Idaho*	DI9	45 33	115 28	5610
Grangeville, Idaho	S80	45 55	116 08	3355
Headquarters, Idaho*	HD9	46 38	115 48	3138
Idaho Falls, Idaho	IDA	43 31	112 04	4730
Island Park Dam, Idaho	IP9	44 25	111 24	6300
Lewiston, Idaho	LWS	46 23	117 01	1413
McCall, Idaho	MYL	44 54	116 07	5025
Palisades Dam, Idaho	PL9	43 21	111 13	5385
Salmon, Idaho	SMN	45 11	113 45	3970
Strevell, Idaho	4SV	42 01	113 15	5290
Shoshone, Idaho	SS9	42 58	114 26	3950
Butte, Mont.	BTM	45 57	112 30	5533
West Yellowstone, Mont.	WEY	44 39	111 06	6669
Hungry Horse Dam, Mont.*	HH9	48 21	114 00	3160

Table 1. Continued:

Name	Call Letters	Latitude	Longitude	Elevation (ft)
Kalispell, Mont.	FCA	48 18	114 16	2965
Libby, Mont.	S59	48 24	115 32	2080
Missoula, Mont.	MSO	46 55	114 05	3190
Great Falls, Mont.	GTF	47 29	111 22	3662
Ovando, Mont.	OV9	47 01	113 08	4109
Bellingham, Wash	BLI	48 48	122 32	159
Diablo Dam, Wash.	D99	48 43	121 09	890
Eltopia, Wash.	ET9	46 24	119 10	700
Hoquiam, Wash.	HQM	46 58	123 56	15
Port Angeles, Wash.	CLM	48 07	123 30	290
Quillayute, Wash.	UIL	47 57	124 33	205
Toledo, Wash.	TDO	46 29	122 48	379
Colville, Wash.	63S	48 32	117 53	1874
Dallesport, Wash.	DLE	45 37	121 09	222
Lake Wenatchee, Wash.**	EA9	47 50	120 48	2005
Olympia, Wash.	OLM	46 58	122 54	195
Omak, Wash.	40M	48 26	119 32	1228
Rainier Paradise, Wash.	RR9	46 47	121 44	5427
Seattle-Tacoma, Wash.	SEA	47 27	122 18	400
Spokane, Wash.	GEG	47 38	117 32	2349
Stevens Pass, Wash.	ST9	47 44	121 05	4070
Stampede Pass, Wash.	SMP	47 17	121 20	3958
Upper Baker Dam, Wash.	UP9	48 39	121 41	690
Walla Walla, Wash.	ALW	46 06	118 17	1170
Yakima, Wash.	YKM	46 34	120 32	1064
Astoria, Oreg.	AST	46 09	123 53	8
Baker, Oreg.	BKE	44 50	117 49	3368
Bonneville Dam, Oreg.	20S	45 38	121 57	60
Crater Lake Hq., Oreg.	C99	42 54	122 08	6475
Detroit Dam, Oreg.	DR9	44 43	122 15	1220
Government Camp, Oreg.	GO9	45 18	121 45	3980
Hood R. Exp. St., Oreg.*	HR9	45 41	121 31	500
Meacham, Oreg.	MEH	45 30	118 24	4058
Medford, Oreg.	MFR	42 22	122 52	1312
Mt. Fanny, Oreg.*	MF9	45 19	117 44	7022
Newport, Oreg.	JNW	44 38	124 03	154
North Bend, Oreg.	OTH	43 25	124 15	7
Portland, Oreg.	PDX	45 36	122 36	21
Redmond, Oreg.	RDM	44 16	121 09	3075
Salem, Oreg.	SLE	44 55	123 01	196
Ukiah, Oreg.*	4UK	45 08	118 56	3355
Brookings, Oreg.	4BK	42 03	124 17	85
Burns, Oreg.	4BW	43 35	119 03	4170
Grants Pass, Oreg.	3S8	42 26	123 19	930
Lakeview, Oreg.	4LW	42 11	120 21	4764
Ontario, Oreg.	ONO	44 01	117 01	2190
Sexton Summit, Oreg.	SXT	42 37	123 22	3841
Wendover, Utah	ENV	40 44	114 02	4239
Owyhee, Nev.	OWY	41 57	116 06	5401

Table 2. Average reduction of variance for all regions combined for the categories >.25, >.50, and >1.0 inch.

Projection (hr)	Category (inch)		
	>.25	>.50	>1.0
0000 GMT			
0-24	.184	.117	.044
24-48	.124	.080	.033
48-72	.096	.056	.034*
72-96	.068	.036	.024*
1200 GMT			
12-36	.153	.093	.034
36-60	.096	.056	.020

* Regions 1, 2, 3, 6, 7, and 9 only.

Table 3. Regions where categorical forecasts of precipitation amount are available.

Projection (hr)	Category (inch)		
	≥ .25	≥ .50	≥ 1.0
0000 GMT			
0-24	All	All	1,2,3,6,7,9
24-48	All	All	1,2,3,6,7,9
48-72	All	All	1,3,7
72-96	All	All	1,3,7
1200 GMT			
12-36	All	All	1,2,3,6,7,9
36-60	All	All	1,2,3,6,7,9

Table 4. Average reduction of variance for all regions combined for PoP.

Projection (hr)	Reduction of Variance
0000 GMT	
0-24	.344
24-48	.233
48-72	.185
72-96	.132
1200 GMT	
12-36	.298
36-60	.210

Table 5. Average standard error of estimate and the average reduction of variance for the max/min forecasts made at 93 stations during the warm season (April-September). Six warm seasons (1970-1975) of dependent data were used for all 1200 GMT forecasts and for 0000 GMT forecasts up to tomorrow's max. Three warm seasons (1973-1975) were used otherwise.

Forecast	Standard Error of Estimate (°F)	Reduction of Variance (%)
0000 GMT		
Today's max	4.1	89
Tonight's min	3.8	81
Tomorrow's max	5.2	82
Tomorrow night's min	4.1	77
Third day's max	6.1	74
Fourth day's min	4.6	72
Fourth day's max	6.9	67
1200 GMT		
Tonight's min	3.6	83
Tomorrow's max	4.7	85
Tomorrow night's min	4.1	79
Third day's max	5.9	78