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

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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by

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Since June 1976, objective forecasts of probability of precipitation (PoP), probability of precipitation amount (PoPA), precipitation amount, and maximum and minumum (max/min) surface temperature have been made twice daily at the National Meteorological Center for about 70 stations in the Columbia River Basin (Bermowitz et al., 1976). These forecasts, made from warm season (April-September) equations developed with application of the Model Output Statistics (MOS) technique (Glahn and Lowry, 1972), are transmitted to the Portland Office of the Bonneville Power Administration via the Bureau of Reclamation computer in Denver. This report summarizes our effort, funded by the Bonneville Power Administration, to develop cool season (October-March) equations for the same weather elements at the same stations in the Columbia River Basin.

Six cool seasons, 1969-1970 through 1974-1975, of predictand data were available for development of precipitation and temperature equations. Data at 70 stations were used to develop max/min equations and data at 65 stations were used to develop PoP and PoPA equations; both groups were identical to those used to develop warm season equations. Table 1 contains a list of these stations; Fig. 1 shows their locations.

Predictor data used consisted of the Techniques Development Laboratory's (TDL's) archived collection of forecast fields from the primitive equation (PE) (Shuman and Hovermale, 1968) and trajectory (TRAJ) (Reap, 1972) models. Cool season predictor data for forecast fields out to 48 hours have been archived since October 1969 and from 60 to 84 hours since October 1972.

PRECIPITATION AMOUNT

PoPA cool season equations were developed for the categories $\geq$.25, $\geq$.50, $\geq$1.0 and $\geq$2.0 inch for the 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 done for the warm season, we used an application of regression known as Regression Estimation of Event Probabilities (REEP) (Miller, 1958) to develop the cool season equations. Five out of the available six cool seasons of data were used to develop all the 1200 GMT equations and the 0000 GMT equations out to 48 hours; 1969-1970 cool season data were not used because the PE model was anomalously dry. Beyond 48 hours, data from the three available cool seasons were used.

Generalized operator equations were developed for each of the 7 regions shown in Fig. 2. These regions were determined by a subjective analysis of the observed relative frequency of occurrence of ≥.25 inch in a 24-hr period when the PE model forecast ≥.01 inch during the same period. PE precipitation amount was used since it was found to be the best single predictor in forecasting cool season precipitation amount (Bermowitz and Zurndorfer, 1975). These regions are similar to those used for the warm season. Regions 1, 2, and 3 are relatively wet; 5 and 7 are relatively dry. Note that, as was the case for the warm season, 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 included precipitation amount, relative humidity in layers, precipitable water, vertical velocity, boundary layer u and v wind components and moisture divergence from the PE model, and precipitation amount, humidity, net vertical displacement, and atmospheric stability from the TRAJ model. Also included were station elevation, sine and cosine of the day of year, and cool season relative frequencies of occurrence of 24-hr precipitation amounts of ≥.01, ≥.25, ≥.50, and ≥1.0 inch. With the exception of the climatic frequency of ≥1.0 inch, all of these predictors were the same as those used for the warm season. However, we added 850-, 700-, and 500-mb u and v wind components and 850-mb height from the PE model and 850- and 700-mb relative humidity from the TRAJ model.

All PE and TRAJ predictors were used in binary form. Also, predictors were chosen from the forecast fields space smoothed with simple 5-, 9-, and 25-point averages. Generally, the more heavily smoothed predictors were used to develop equations for the long range projections.

The most important predictors were found to be precipitation amount and boundary layer relative humidity from the PE model and 12-hr net vertical displacement from the TRAJ model. Climatic predictors were also important, but mostly in dry regions at later projections when the skill of the PE forecasts deteriorates.

Table 2 shows the average reduction of variance for all regions combined for each category and projection. As expected, the average reductions of variance decrease with increasing projection and for larger amounts and are greater in the cool season than in the warm season. Note that the average reductions of variance for the categories ≥1.0 and ≥2.0 inch do not include all regions. These events are very rare in certain regions. Equations for ≥1.0 inch could be derived for only regions 1, 2, 3, 4, and 6 for all projections. Equations for ≥2.0 inch could be derived for only regions 1, 2, 3, and 4 except for projections beyond 48 hours for the 0000 GMT cycle when they could be developed for only regions 1, 2, and 3.

Sample equations giving the forecast probabilities for the categories ≥.25, ≥.50, ≥1.0, and ≥2.0 inch for region 2 for the projection 0-24 hr after 0000 GMT are shown in Table 3. Note that the same predictors are used for all categories. The equations, by column, contain the constant (first line) and coefficients which are (1) the contributions to the probabilities for binary predictors less than or equal to the specified limits or (2) to be multiplied by the value of the predictor if the predictor is continuous (e.g. 24-hr frequency of $\geq$.50 inch).

For the cool season, PoPA forecasts were transformed to categorical forecasts in the same way as was done for the warm season--by maximizing the threat score. A set of threshold probabilities that maximize the threat score was derived for each region and each projection. Determining stable threshold values was also frequently difficult, and in some cases impossible, in the cool season because of small sample sizes. This was especially so for the higher categories, dry regions, and projections beyond 48 hours. However, many more cases of $\geq$1.0 inch in the cool season permitted derivation of threshold values for the category $\geq$1.0 inch in more regions than was possible in the warm season. As expected, threshold probabilities for the category $\geq$2.0 inch were derived in fewer regions than for the category $\geq$1.0 inch. Table 4 summarizes in which regions the various categories can be forecast.

PROBABILITY OF PRECIPITATION

We developed equations for the probability of $\geq$.01 inch for the same projections and screened the same predictors as we did for the PoPA work. However, we were able to divide the Columbia River Basin into twice as many regions for PoP than for PoPA because of the greater frequency of occurrence of $\geq$.01 inch.

The 14 regions used for PoP are shown in Fig. 3. They were determined by a subjective analysis of the observed relative frequency of occurrence of $\geq$.01 inch in a 24-hr period when the PE model forecast the mean relative humidity to be $\geq$75%. Mean relative humidity was used because our experience has revealed it to be the best single predictor for PoP during the cool season.

The most important predictors for PoP were 1000-500 mb mean relative humidity, precipitation amount and 850-mb heights--all forecast from the PE model, and the relative frequency of precipitation of $\geq$.01 inch in a 24-hr period. 850-mb height was most important at longer range projections and in dry regions.

Table 5 shows the average reduction of variance for each projection for PoP. As was the case for PoPA, the reduction of variance was larger in the cool season than in the warm season. By region, the reduction of variance ranged from .552 in region 1 for the projection 0-24 hr after 0000 GMT to .091 in region 13 for the projection 72-96 hr after 0000 GMT.

MAX/MIN TEMPERATURE

As we did for the warm season, we developed single station max/min temperature forecast equations for 70 stations using multiple screening regression. Max/min forecasts made from these equations are valid for 24-hr periods that end at the local observation time. They extend out to about 96 hours for the 0000 GMT cycle and about 60 hours for the 1200 GMT cycle.

Five cool seasons of data (1970-71 through 1974-75) that amounted to over 750 cases were used to develop the 1200 GMT equations and the 0000 GMT equations out to 48 hours. Beyond 48 hours, three seasons (1972-73 through 1974-75) of data consisting of about 450 cases were used.

Predictors offered to the screening regression program were the same ones used for the warm season. From the PE model, we offered forecasts of height, thickness, low-level temperature, u and v wind components in the lower atmosphere, relative vorticity, vertical velocity, atmospheric stability, layer relative humidity, precipitable water, boundary layer divergence, temperature advection, and the geostrophic vorticity advection. From the TRAJ model we offered low-level temperature and dew point, mean relative humidity, net vertical displacement, divergence at certain levels, and the K-index in developing equations for the shorter range projections. Space smoothed 5-, 9-, and 25-point predictors were also tried; in general, the fields were smoothed more as the forecasts went further out in time. Four trigonometric terms designed to capture the seasonal trend of temperature were also screened. All predictors were in continuous form.

Based on the frequency and order of selection in ten term equations, the most important predictors for both the max and min were forecasts of temperature fields at the surface, 1000 mb, 850 mb, and in the boundary layer; the 850-1000 mb thickness; layered relative humidities; dew points; boundary layer and 850-mb wind fields; and the cosine twice day of year. The PE 850-mb temperature and the cosine day of year were particularly important predictors for the max at all projections. Beyond 48 hours, the four trigonometric terms became important predictors for the max as the model forecasts decreased in accuracy. For the min, the cosine twice day of year was a very important predictor as was the PE boundary layer and 1000-500 mb mean relative humidity.

The standard error of estimate and the reduction of variance for the max/min forecasts averaged for the 70 stations are shown in Table 6. The standard errors of estimate are plotted as a function of projection in Fig. 4. Note that the standard error of estimate for the max and the min increased nearly linearly with increasing projection. As the figure and the table illustrate, the standard error for the min was always larger than the error for the max at the same projection. For example, at the 24-hr projection the min (tonight's min from the 1200 GMT cycle) has a larger standard error than the max (today's max from the 0000 cycle). An examination of Table 6 also shows that the standard error for the min was always greater, and the reduction of variance smaller, than that of the subsequent max. These features indicate that it is easier to forecast the max than the min during the cool season. This tendency has previously been noted in the cool season (Hammons et al., 1976) when small-scale effects such as drainage winds, snow cover, and stratus clouds make the daily variability of the min large. In contrast, the cool season max is governed more by synoptic-scale features that can be predicted by the numerical models. This difference is further illustrated by the fact that the range of standard error of estimate was much larger for the min than for the max. For the fourth day's min, several stations had standard errors in excess of 12° F.

A sample equation for today's max at Mt. Fanny, Oregon is shown in Table 7. The equation contains the constant (first line) and coefficients that are to be multiplied by the value of the predictor given in the first column.

OPERATIONAL ASPECTS

We plan to continue transmitting the precipitation and temperature forecasts in the current format to the Portland office of the Bonneville Power Adminisration via the Bureau of Reclamation computer in Denver. Forecasts made from cool season equations should replace those made from warm season equations on or around October 1, 1976.

REFERENCES

Bermowitz, R. J., and E. A. Zurndorfer, 1975: Current status of probability of precipitation amount (PoPA) forecasting. TDL Office Note 75-10, 6 pp.

_____, _____, J. P. Dallavalle, and G. A. Hammons, 1976: 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, 8 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.

Hammons, G. A., J. P. Dallavalle, and W. H. Klein, 1976: Automated temperature guidance based on three month seasons. Mon. Wea. Rev., (to be published).

Miller, R. 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.

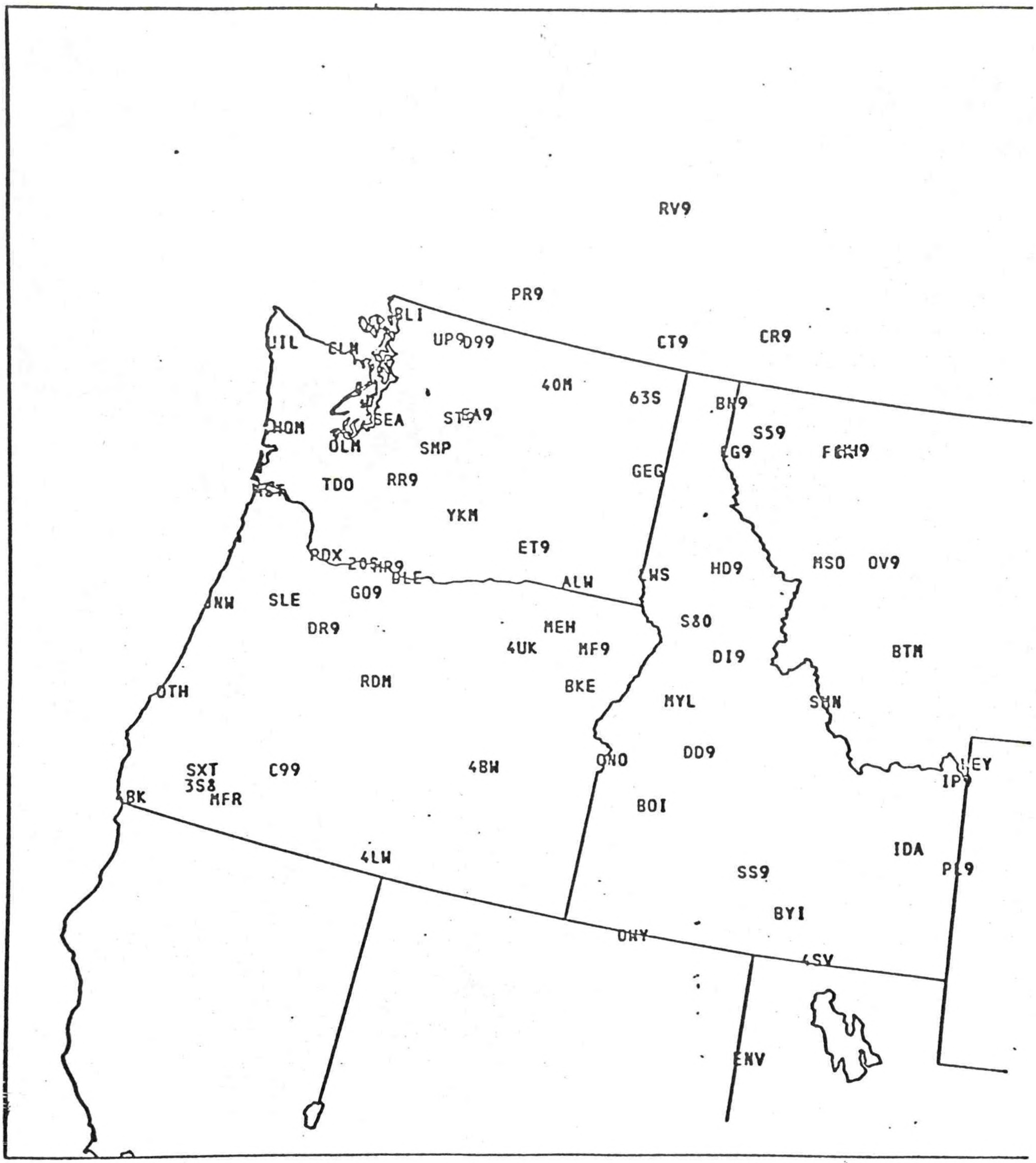

Figure 1. Locations of stations in the Columbia River Basin and adjacent areas for which data were used.

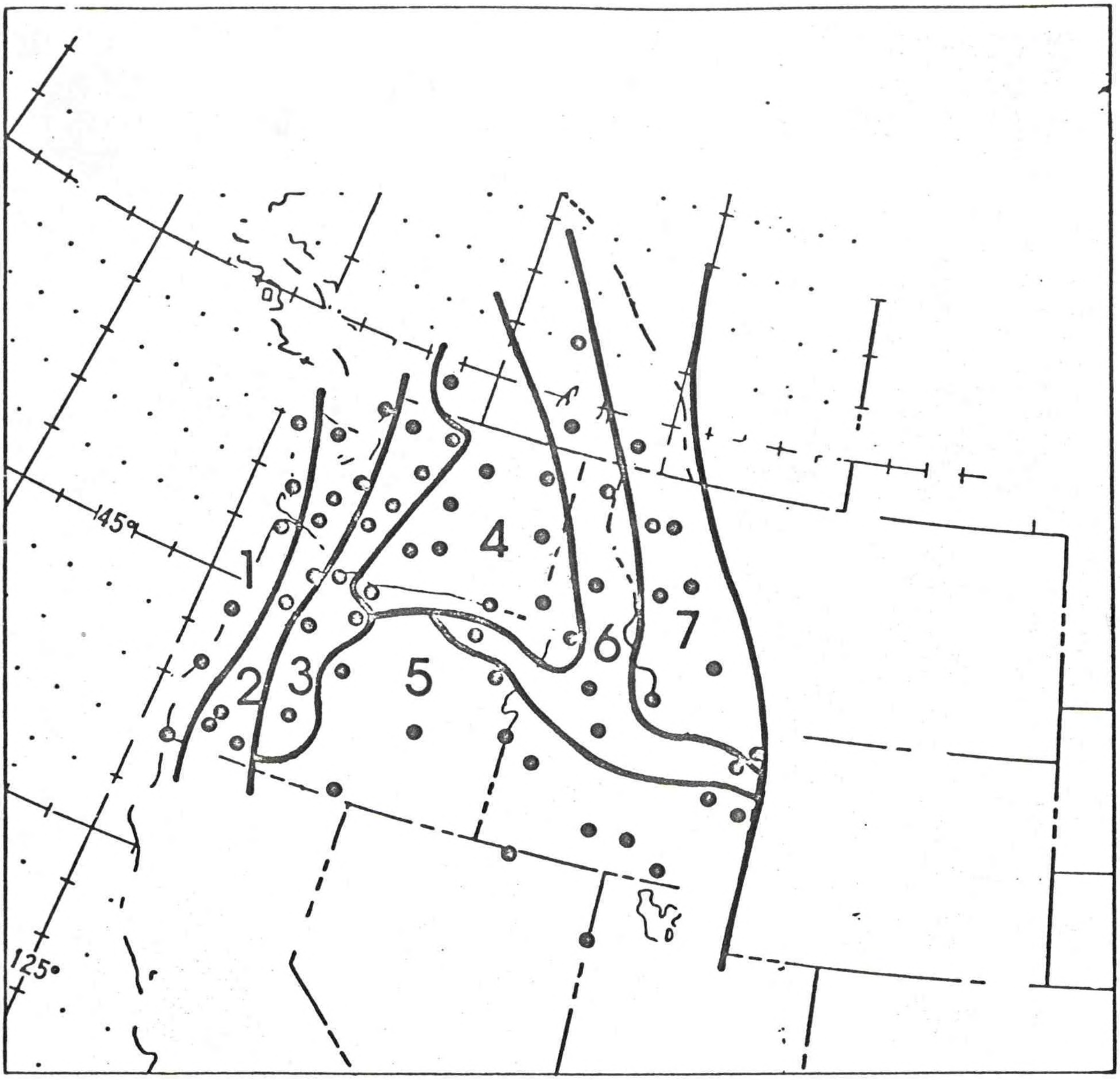

Figure 2. The 7 regions used to develop PoPA equations for the 1976-77 cool season.

Figure 3. The 14 regions used to develop PoP equations for the 1976-77 cool season.

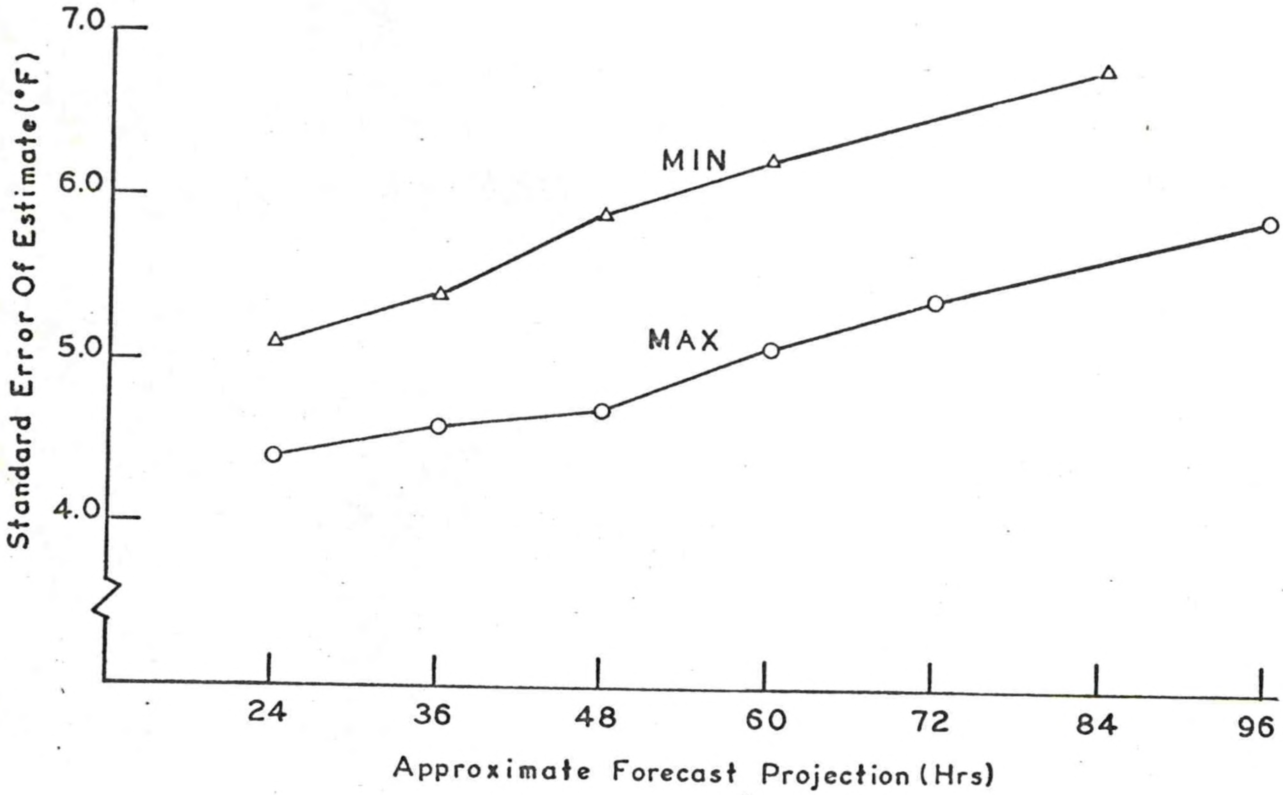

Figure 4. Standard error of estimate plotted as a function of projection. Both 0000 and 1200 GMT cycles are included.

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)
Castlegar A, BC	CT9	49 18	117 38	1619
Cranbrook A, BC	CR9	49 37	115 47	3045
Princeton, A, BC	PR9	49 28	120 31	2283
Revelstoke A, BC	RV9	50 58	118 11	1467
Boise, Idaho	BO1	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
Kalispell, Mont.	FCA	48 18	114 16	2965
Libby, Mont.	S59	48 24	115 32	2080
Missoula, Mont.	MSO	46 55	114 05	3190
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

Table 1. Continued:

Name	Call Letters	Latitude		Longitude		Elevation (ft.)
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, ≥ 1.0, and ≥ 2.0 inch.

Projection (hr)	Category (inch)			
	≥ .25	≥ .50	≥ 1.0	≥ 2.0
0000 GMT				
0-24	.282	.212	.179*	.094**
24-48	.208	.157	.126*	.061**
48-72	.161	.120	.096*	.050***
72-96	.111	.083	.063*	.031***
1200 GMT				
12-36	.230	.173	.134*	.059**
36-60	.146	.108	.087*	.032**

* Regions 1, 2, 3, 4, and 6 only.

** Regions 1, 2, 3, and 4 only.

*** Regions 1, 2, and 3 only.

Table 3. Sample PoPA equation for the categories ≥.25, ≥.50, ≥1.0, and ≥2.0 inch for region 2 for the projection 0-24 hr after 0000 GMT. A 5-point smoothed field is denoted by *. The total reduction of variance is given below each equation.

Predictor	Valid Time (hr after 0000 GMT)	Constant and Coefficients for Categories			
		≥.25 in	≥.50 in	≥1.0 in	≥ 2.0 in
		.825	.719	.483	.107
24-HR PE PREC AMT ≤.0127 METERS	24	-.121	-.040	.002	.002
24-HR PE PREC AMT* <.0254 METERS	24	-.173	-.285	-.217	-.067
PE MEAN REL HUM ≤85%	18	-.142	-.048	.009	.004
PE 500-MB U* ≤20 M/SEC	24	-.114	-.071	-.013	.001
24-HR FREQUENCY OF ≤.50 INCH	-	1.378	.959	.315	.084
PE 500-MB U* ≤30 M/SEC	24	-.010	-.119	-.095	-.032
TRAJ K INDEX ≤20°C	24	-.069	-.044	-.021	-.004
PE BOUND LAYER V* ≤ 10 M/SEC	18	.051	.020	-.044	-.006
24-HR PE PREC AMT* ≤.0127 METERS	24	-.097	-.103	-.041	-.000
12-HR PE PREC AMT* ≤.00635 METERS	36	-.078	-.065	-.027	-.008
PE BOUND LAYER V ≤10 M/SEC	06	-.086	-.075	-.023	-.006
TRAJ 850-MB REL HUM ≤60%	24	-.061	-.017	-.008	-.001
TOTAL RV		.341	.263	.156	.061

Table 4. Regions where categorical forecasts of precipitation amount are available.

Projection (hr)	Category (inch)			
	>.25	>.50	$\geq$1.0	$\geq$2.0
0000 GMT				
0-24	All	All	1,2,3,4,6	1,2,3
24-48	All	All	1,2,3,4,6	1,2,3
48-72	All	All	1,2,3,4,6	1,3
72-96	All	All	1,2,3,4,6	1,3
1200 GMT				
12-36	All	All	1,2,3,4,6	1,2,3
36-60	All	All	1,2,3,4,6	1,2,3

Table 5. Average reduction of variance for all regions combined for PoP.

Projection (hr)	Reduction of Variance
0000 GMT	
0-24	.406
24-48	.297
48-72	.231
72-96	.174
1200 GMT	
12-36	.339
36-60	.214

Table 6. Average standard error of estimate and the average reduction of variance for the max/min forecasts made at 70 stations during the cool season (October-March). Five cool seasons of dependent data were used for all 1200 GMT forecasts and for 0000 GMT forecasts up to tomorrow's max. Three seasons were used otherwise.

Forecast	Standard Error of Estimate (°F)	Reduction of Variance (%)
0000 GMT		
Today's max	4.4	85
Tonight's min	5.4	73
Tomorrow's max	4.7	82
Tomorrow night's min	6.2	64
Third day's max	5.4	77
Fourth day's min	6.8	58
Fourth day's max	5.9	72
1200 GMT		
Tonight's min	5.1	75
Tomorrow's max	4.6	83
Tomorrow night's min	5.9	67
Third day's max	5.1	79

Table 7. Sample temperature equation for today's max at Mt. Fanny, Oregon. A 5-point smoothed field is denoted by *. The total reduction of variance is .900 and the standard error of estimate is 3.6° F.

Predictor	Valid Time (hr after 0000 GMT)	Units	Constant and Coefficients
		°F	-413.9
PE 850-MB TEMP	12	°K	2.743
COSINE DAY OF YR	--	--	-4.660
PE SFC TO 490-MB MEAN RH*	36	%	.004
PE 1000-MB TEMP	24	°K	-.284
TRAJ 850-MB 24-HR NET VERT DISP	24	MB	.019
PE 1000-MB TEMP	12	°K	-.752
PE BOUNDARY LAYER V WIND	12	M/SEC	-.271
PE 500-850 MB THICKNESS	24	M	-.026
PE SFC TO 490-MB MEAN RH*	24	%	-.075
TRAJ SFC TEMP*	24	°K	.354