U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
SYSTEMS DEVELOPMENT OFFICE
TECHNIQUES DEVELOPMENT LABORATORY

TDL OFFICE NOTE 82-9

DEVELOPMENT OF AN IMPROVED AUTOMATED SYSTEM FOR FORECASTING THE PROBABILITY OF PRECIPITATION IN ALASKA

George Maglaras

October 1982

DEVELOPMENT OF AN IMPROVED AUTOMATED SYSTEM FOR FORECASTING THE PROBABILITY OF PRECIPITATION IN ALASKA

George J. Maglaras

1. INTRODUCTION

An automated system for forecasting probability of precipitation (PoP) for the 14 Alaskan stations listed in column one of Table 1 became operational within the National Weather Service (NWS) in April 1977 (Gilhousen, 1977; National Weather Service, 1977a). The precipitation event is defined as the occurrence of $\geq$.01 inches in a 6- or 12-h period at a station. To develop the forecast equations for PoP, we used the Model Output Statistics (MOS) technique (Glahn and Lowry, 1972) with output from the National Meteorological Center's (NMC's) Primitive Equation (PE) model (Shuman and Hovermale, 1968; National Weather Service, 1977b). On August 13, 1980, the PE model was replaced by a Spectral model (Sela, 1980; National Weather Service, 1980), so the operational PoP forecasts used output from the Spectral model.

The conversion to the Spectral model led to a deterioration of the MOS guidance for Alaska. In particular, a test performed for PoP on a sample of 10 cases showed forecasts derived from Spectral model output were on the average 6% worse than forecasts based on PE model output. In an effort to improve the PoP system, we developed a new, experimental set of PoP forecast equations, called EXP. EXP differs from the operational system, OPER, in several ways. First, EXP was developed with three winter seasons of output from the Limited-area Fine Mesh (LFM) model (Newell and Deaven, 1981; National Weather Service, 1977c); the developmental sample for OPER consisted of six winter seasons of PE model output. Second, EXP was developed with data from all 39 stations listed in Table 1 (also see Fig. 1); OPER was developed with data only from the 14 stations shown in column one of Table 1. Third, for EXP, we used the regionalized approach in which data from several stations within a region are combined to develop the forecast equations for the region; OPER used the single-station approach. Fourth, the winter season was redefined for the EXP system as November through March; in OPER, the winter season was defined as December through February. Fifth, EXP equations did not include boundary-layer (BL) predictors; OPER equations did. Sixth, EXP equations were developed with the Regression Estimation of Event Probability (REEP) statistical model (Miller, 1964); OPER was developed with the logit model (Brelsford and Jones, 1967; Jones, 1968). Finally, EXP used surface observations valid 3 hours after 0000 or 1200 GMT as predictors; OPER used observations valid 6 hours after 0000 or 1200 GMT as predictors.

We performed three experiments in the process of developing the EXP equations. In the first experiment, we derived one set of forecast equations using the REEP model and another set using the logit model. REEP is essentially a linear regression model while logit is non-linear; however, non-linear predictors can be used in either model. A comparative verification on independent data between the logit-based set and the REEP set indicated that, generally, there was little difference between the two. Therefore, REEP was used for further testing. In the second experiment, we compared REEP forecast equations which included BL predictors with forecast equations which didn't include BL predictors. Based on results on independent data, we chose to omit BL predictors in further developmental work. In the final experiment, we compared forecasts made from EXP equations to OPER system forecasts. The results on independent data showed that EXP was better than OPER. Therefore, we incorporated the features of the EXP equations in the derivation of new, operational PoP forecast equations for Alaska.

2. DEVELOPMENT OF THE EXP EQUATIONS

a. The Potential Predictors

Table 2 shows the potential predictors we used to develop the EXP equations. Model output variables valid for some or all of the 12-, 18-, 24-, 30-, 36-, 42-, and 48-h projections were included as potential predictors, depending on the variable. The surface weather elements were observed at 0300 or 1500 GMT. Table 2 also gives the acronyms by which the various predictors will be referred in this paper.

Model output variables used by EXP equations for the 12-h projection were unsmoothed; for the 18-, 24-, and 30-h projections, we used 5-point space-smoothed variables; and for the 36-, 42-, and 48-h projections, we used predictors that were 9-point space-smoothed.

b. Regionalization

Unlike the OPER system, which uses single station equations, we developed EXP equation sets for each of several geographic regions. Regionalization is especially desirable with precipitation because in some locations it's considered a rare event and grouping stations increases the sample size used to develop equations. In the MOS system, stations may be grouped into regions if they exhibit similar characteristics of the predictand in response to output from the numerical model. In particular, for each station, we determined the observed relative frequency of precipitation during the 12-24 h period after both 0000 and 1200 GMT for all cases when the LFM forecast of 12- to 24-h P AMT was $\geq .01$ inches (Fig. 2). The frequency was determined from a developmental sample of three winter seasons, 1977-78 through 1979-80. We also determined this frequency for all cases when the LFM forecast of MEAN RH for the 18-h projection was $\geq 65\%$ (Fig. 3). We chose P AMT and MEAN RH because, from experience, we've found that these are generally the most important predictors for PoP forecasting. Figs. 2 and 3 show the observed relative frequencies based on P AMT and MEAN RH, respectively; the plotted values are averages computed from both 0000 and 1200 GMT. Some of the stations used in the developmental data sample are not in operation 24 hours a day, so data are not available for certain projections. Stations without data for the projections shown in Figs. 2 and 3 are indicated by 999. The regions shown in Figs. 2 and 3 were determined by combining stations with similar frequency values for both P AMT and MEAN RH. The climatic frequency of precipitation for the developmental sample also played an important role in determining the regions when it was not clear as to which region the station belonged.

Examination of the six regions indicates that the regional boundaries are not necessarily consistent with geographical boundaries. This is not unusual since the purpose of regionalizing is to group together stations which exhibit similar statistical characteristics based on output from the LFM rather than solely from geographical patterns.

c. Development of Regionalized EXP Equations

For the purposes of the three experiments previously mentioned in the introduction, we developed three sets of EXP equations. For each set, we combined data from all stations within a region and developed separate sets of equations for 12-24 and 36-48 h periods from both 0000 and 1200 GMT. For the first two EXP equation sets, one was developed with the logit model while the other set consisted of linear regression equations developed with the REEP screening procedure. Both sets of equations included LFM BL predictors in the screening process. The third equation set was developed with REEP and didn't include BL predictors in the screening process. For all equations, the developmental sample was the same as that used to determine the regions. Data from the winter season of 1980-81 were set aside for use as an independent sample.

In the REEP screening procedure, a subset of effective predictors for use in linear-regression equations is objectively selected from a larger set of potential predictors. The equations developed give estimates of the probabilities of occurrence for a given set of binary-type predictands. In PoP, precipitation is divided into two binary-type predictands: precipitation amount $<.01$ inches and $\geq.01$ inches. The predictands are called binary because in the developmental phase each predictand was assigned a value of either 1 or 0 in a given case depending on whether or not $\geq.01$ inches of precipitation occurred. The potential predictors were either in binary or continuous form. The use of binary predictors helps to account for possible non-linear relationships between the predictand and predictor. A good description of the REEP screening procedure can be found in Glahn and Lowry (1972).

Our logit computer program doesn't have a screening option; therefore, the REEP screening procedure was used to determine the set of predictors to include in the logit model. Predictors are included in the logit equations in continuous form only. The REEP equation sets included 12 predictors. This number of predictors has been found to be optimal by other investigators for other forecast variables (Bocchieri and Glahn, 1972; Zurndorfer and Bermowitz, 1976; Bocchieri, 1982). We included a maximum of 10 predictors in the logit model derivations.

Table 3 lists the 10 most important predictors as given by the REEP screening procedure for the EXP equation sets that didn't include BL predictors. These predictors were determined by both the frequency and order of selection; for the purpose of this ranking, all predictor projections, smoothings, and binary limits were combined for each type of variable. Table 3 indicates that, as mentioned previously, P AMT was the most important LFM predictor for forecasting PoP. MEAN RH was also very important for the 12-24 h period but was relatively unimportant for the 36-48 h period. For this latter period, 1000 HGT was the second most important predictor. In general, other predictors chosen frequently were observed surface variables, U- and V-components, vertical velocity, relative vorticity, precipitable water, and moisture convergence.

3. VERIFICATION RESULTS

For the EXP equation sets, we performed three comparative verifications on independent data combined from 39 stations (14 for the final verification) for the period November 1980 through March 1981. In each experiment, we calculated the P-scores (Brier, 1950) for PoP forecasts for the 12-24 and 36-48 h periods from 0000 and 1200 GMT. We also examined the reliability of the probability forecasts for the comparison between REEP and logit. Reliable probability forecasts are such that for all of the PoP forecasts of 20%, say, the relative frequency of precipitation is close to 20%.

a. Comparison Between REEP and Logit

In testing the logit model for PoP forecasting in the United States, Gilhousen (1979) showed that the logit model was slightly better than REEP. As mentioned previously, the original operational PoP system in Alaska used logit model equations. However, the REEP model is more efficient because using logit involves the extra step of running the REEP model to determine the best predictors. Hence, we decided to compare REEP and logit PoP forecasts for Alaska.

Table 4 shows the P-scores for logit and REEP and the percent improvement of the logit over the REEP P-scores. The results indicate logit was 3.6% better than REEP for the 12-24 h period from 0000 GMT. For the other three periods, there was little difference between REEP and logit. Also, in terms of reliability, there was little difference between REEP and logit at all projections. Based on these results, we decided the slight improvement of logit over REEP did not justify continued use of the logit model to derive the PoP forecast equations for Alaska.

b. Test of the Usefulness of BL Predictors

For the second verification, we compared the REEP EXP equation set that included LFM BL predictors (WBL) with the REEP set that didn't include BL predictors (NBL). Our concern was that future NMC models may not include a boundary layer similar to that used in the present LFM model.

Table 5 shows the P-scores for WBL and NBL, and the percent improvement of WBL over NBL. The results indicate that WBL was 1.2% better than NBL for the 12-24 h period from 1200 GMT. For the other three periods, there was little difference between NBL and WBL. Based on the results, we decided not to use LFM BL predictors in the PoP forecast equations for Alaska.

c. Comparison Between EXP and OPER

The final comparative verification, between the NBL equation set and the OPER system, involved the 14 stations in column one of Table 1 because the OPER system produced forecasts for only these stations. It should be remembered that EXP equations use as predictors observed weather variables that are taken 3 hours prior to the observations used in OPER, and thus EXP is at a disadvantage. However, this allows the guidance to be received 3 hours earlier.

Table 6 shows the P-scores for EXP and OPER, and the percent improvement of EXP over OPER. The results indicate that EXP was better than OPER for all four periods. The EXP scores were 1.6% better than OPER for the 36-48 h period from 1200 GMT, 5.6% (5.8%) better for the 12-24 h period from 0000 (1200) GMT, and 11.7% better for the 36-48 h period from 0000 GMT. Based on these results, we decided to develop new operational PoP forecast equations which incorporate the features of EXP.

4. DEVELOPMENT OF NEW OPERATIONAL PoP FORECAST EQUATIONS FOR ALASKA

We developed new PoP forecast equations for 6-h and 12-h periods. The 6-h forecasts are valid for the 06-12, 12-18, 18-24, 24-30, 30-36, 36-42, 42-48, and 48-54 h periods from 0000 and 1200 GMT. The 12-h forecasts are valid for the 06-18, 18-30, 30-42, and 42-54 h periods from 0000 and 1200 GMT. The forecast periods for the new system differ from the old system in two ways. First, the new system's forecasts cover the period from 6 to 54 hours; the old system's forecasts covered the period from 12 to 60 hours. Second, 12-h forecasts for the new system are valid for either the 0600-1800 or 1800-0600 GMT periods; 12-h forecasts for the old system were valid for 0000-1200 or 1200-0000 GMT. Both changes were made at the request of the NWS Alaskan Region in order to have the 12-h periods better coincide with their definitions of day and night.

To develop the new PoP system, we combined the dependent and independent data samples used in the experiments discussed previously (four winter seasons of data, 1977-78 through 1980-81). We also used the same potential predictors (Table 2) and the same regions (Figs. 2 and 3) as were used to develop EXP. In order to determine changes in the most important predictors caused by using 12-h periods valid at different times and starting 6 hours earlier than the EXP equations, we ranked the predictors chosen by REEP in a manner similar to that used for Table 3. Table 7 shows the ranking for the 06-18 and 30-42 h periods from 0000 and 1200 GMT for the new system. The results indicate P AMT was the most important LFM predictor for forecasting PoP. MEAN RH also was an important predictor for the earlier periods. The most significant change (compared to the ranking of the EXP system in Table 3) is the greater importance of observed weather variables for the shorter range projections.

In order to provide more consistent PoP forecasts, equations for a given 12-h period were derived simultaneously with those for the two corresponding 6-h periods. With this procedure all three equations are comprised of the same predictors, but, of course, the individual regression coefficients differ. In addition to the "primary" sets of PoP equations, which contain surface observations valid at 0300 or 1500 GMT as predictors, we also developed "backup" equations which don't include observed predictors.

Table 8 shows the reductions of variance for the 06-18 and 30-42 h periods from 0000 GMT for both primary and backup equations. As expected, the reduction of variance is lower for the 30-42 h period than for the 06-18 h period. Also, the reduction of variance for backup equations is lower than for primary equations, especially for the 06-18 h period. Also, generally, the reduction of variance is lower for regions with lower relative frequencies of occurrence.

Table 9 shows the cumulative reductions of variance and equation coefficients for the 6-12, 12-18, and 6-18 h PoP's (0000 GMT cycle) for region six (see Fig. 2) during the winter months of November through March. Here, the 12-h LFM MEAN RH forecast was the first term selected by the regression procedure. This predictor reduced the variance by 27%, 24%, and 32% for the 6-12, 12-18, and 6-18 h periods, respectively. Other predictors included OBS W and OBS CIG from the surface observation taken at 0300 GMT, several variables from the LFM model, and STA LONG. LFM variables with valid times during and after the predictand valid period appear in these equations. The predictors are in both continuous and binary form. A binary predictor, such as the 850 R VOR, is given a value of 1 if it is less than or equal to a particular threshold value (e.g., -0.5); otherwise, the value of the predictor is set to 0.

5. SUMMARY

A system for forecasting PoP for Alaska became operational within the National Weather Service in April 1977. That system, called OPER, was developed with the MOS technique and output from the PE model. In an effort to improve OPER, we developed a new, experimental set of PoP forecast equations, called EXP, based on LFM model output.

Based on the results of several experiments, we determined that the final EXP equation set should be REEP-based with no LFM BL predictors and that this equation set was better than OPER. Therefore, we derived new operational PoP forecast equations, incorporating the features associated with the EXP equations. Separate sets of equations were derived for both forecast cycles (0000 and 1200 GMT) for the fall (September-October), winter (November-March), spring (April-May), and summer (June-August) seasons. These new equations were implemented in September 1982. PoP forecasts based on the new equations are being disseminated as guidance to NWS forecasters in Alaska via the FMAK1 teletype bulletin (National Weather Service, 1982).

6. ACKNOWLEDGEMENTS

I am grateful to Joe Bocchieri for his guidance in carrying out this project, and to the many other members of the Techniques Development Laboratory who contribute to the development and maintenance of the MOS system.

REFERENCES

Bocchieri, J. R., and H. R. Glahn, 1972: Use of Model Output Statistics for predicting ceiling height. Mon. Wea. Rev., 100, 869-879.

_____, 1982: Recent experiments in the use of Model Output Statistics for forecasting snow amounts. TDL Office Note 82-2, National Weather Service, NOAA, U.S. Department of Commerce, 18 pp.

Brelsford, W. M., and R. H. Jones, 1967: Estimating probabilities. Mon. Wea. Rev., 95, 570-576.

Brier, G. W., 1950: Verification of forecasts expressed in terms of probability. Mon. Wea. Rev., 78, 1-3.

Gilhousen, D. B., 1977: Automated prediction of the probability of precipitation (PoP) for Alaska--fall season. TDL Office Note 77-11, National Weather Service, NOAA, U.S. Department of Commerce, 6 pp.

_____, 1979: Testing the logit model for probability of precipitation forecasting. Preprints Sixth Conference on Probability and Statistics in Atmospheric Sciences, Banff, Amer. Meteor. Soc., 46-48.

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.

Jones, R. H., 1968: A nonlinear model for estimating probabilities of K events. Mon. Wea. Rev., 96, 383-384.

Miller, R. G., 1964: Regression estimation of event probabilities. Technical Report No. 1, Contract CWB-10704, The Travelers Research Center, Inc., Hartford, Conn., 153 pp.

National Weather Service, 1977a: Alaskan maximum/minimum temperature, surface wind, and probability of precipitation FMAK1 bulletin. NWS Technical Procedures Bulletin No. 202, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 5 pp.

_____, 1977b: The 7LPE model. NWS Technical Procedures Bulletin No. 218, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 14 pp.

_____, 1977c: High resolution LFM (LFM II). NWS Technical Procedures Bulletin No. 206, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 6 pp.

_____, 1980: Spectral modeling at NMC. NWS Technical Procedures Bulletin No. 282, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 10 pp.

_____, 1982: Alaskan temperature, surface wind, probability of precipitation, conditional probability of frozen precipitation, and cloud guidance (FMAK1 Bulletin). NWS Technical Procedures Bulletin No. 317, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 14 pp.

Newell, J. E., and D. G. Deaven, 1981: The LFM-II model--1980. NOAA Technical Memorandum NWS NMC-66, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 20 pp.

Sela, J. G., 1980: Spectral modeling at the National Meteorological Center. Mon. Wea. Rev., 108, 1279-1292.

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, National Weather Service, NOAA, U.S. Department of Commerce, 7 pp.

Table 1. Developmental data stations used in OPER and EXP systems (see Fig. 1).

Stations used by OPER and EXP		Additional stations used by EXP only	
Anchorage	ANC	Anchorage Elmendorf	PAED
Annette Island	ANN	Bettles	BTT
Barrow	BRW	Big Delta	BIG
Barter Island	BTI	Cape Lisburne	PALU
Bethel	BET	Cape Newenham	PAEH
Cold Bay	CDB	Cape Romanzof	PACZ
Fairbanks	FAI	Cordova	CDV
Juneau	JNU	Dillingham	DLG
King Salmon	AKN	Fairbanks Eielson	PAEI
Kotzebue	OTZ	Galena	PAGA
McGrath	MCG	Gulkana	GKN
Nome	OME	Homer	HOM
St. Paul Island	SNP	Indian Mountain	PAIM
Yakutat	YAK	Kenai	ENA
		Kodiak Island	ADQ
		Northway	ORT
		Petersburg	PSG
		Sitka	SIT
		Skagway	SGY
		Sparrevohn	PASV
		Talkeetna	TKA
		Tanana	TAL
		Tatalina	PATL
		Tin City	PATC
		Valdez	VDZ

Table 2. The potential predictors included in the development of the EXP forecast equations.

Definition	Acronym	Levels
a. Model Output Predictors		
East-west wind component	U	200 mb, 500 mb, 700 mb, 850 mb, BL
North-south wind component	V	200 mb, 500 mb, 700 mb, 850 mb, BL
Mean relative humidity	MEAN RH	SFC-500 mb
BL relative humidity	BL RH	--
Constant pressure height	HGT	500 mb, 700 mb, 850 mb, 1000 mb
Vertical Velocity	VV	500 mb, 700 mb, 850 mb
Precipitable Water	P WATER	SFC-500 mb
Precipitation Amount	P AMT	--
b. Model Output Derived Predictors		
Temperature-dew point depression	T-DP	500 mb, 700 mb, 850 mb
Temperature Advection	T ADV	500 mb, 850 mb
Vorticity Advection	ADVVOR	500 mb
Geostrophic Vorticity Advection	VORADV	500 mb
Geostrophic east-west wind component	GEO U	500 mb
Geostrophic north-south wind component	GEO V	500 mb
Relative Vorticity	R VOR	500 mb, 700 mb , 850 mb, BL
Wind Divergence	WD DV	500 mb, BL
Moisture Convergence	MCONV	850 mb
K Index	K INDEX	
G Index	G INDEX	
Total-Totals Index	TT INDEX	
c. Observed and Geoclimatic Predictors		
Observed weather	OBS W	
Oberved ceiling	OBS CIG	
Observed visibility	OBS VIS	
Observed total sky cover	OBS CLDS	
Observed east-west wind component	OBS U	
Observed north-south wind component	OBS V	
Observed Temperature	OBS T	
Observed Dew Point	OBS TD	
Sine of the day of the year	SIN DOY	
Cosine of the day of the year	COS DOY	
Station latitude	STA LAT	
Station longitude	STA LONG	

Table 3. The 10 most important predictor types as determined by the REEP screening procedure for the 12-24 and 36-48 h periods from 0000 and 1200 GMT for the EXP equation set that didn't include LFM BL predictors in the screening process. Ranking is based both on the order and frequency of selection. Predictor acronyms are defined in Table 2.

12-24 h Period	36-48 h Period
0000 GMT	
P AMT	P AMT
MEAN RH	1000 HGT
850 U	850 VV
850 VV	200 U
OBS CIG	500 U
700 VV	500 GEO V
200 U	700 VV
1000 HGT	700 R VOR
850 R VOR	MEAN RH
OBS W	850 MCONV
1200 GMT	
P AMT	P AMT
MEAN RH	1000 HGT
700 VV	850 VV
850 U	500 VV
OBS CIG	700 R VOR
850 VV	200 U
700 R VOR	700 VV
850 R VOR	850 HGT
OBS W	700 U
P WATER	MEAN RH

Table 4. P-scores for logit and REEP EXP equations sets for PoP forecasts for the 12-24 and 36-48 h periods from 0000 and 1200 GMT. The sample consisted of independent data combined from 39 stations for the period November 1980 through March 1981. The percent improvement of logit over REEP is also shown. The sample included an average of 3500 cases for each period.

System	Period			
	0000 GMT		1200 GMT	
	12-24 h	36-48 h	12-24 h	36-48 h
Logit	.244	.297	.243	.273
REEP	.253	.295	.243	.272
% Improvement Logit/REEP	+3.6	-0.7	0.0	-0.4

Table 5. Same as Table 4 except REEP EXP equations with BL predictors (WBL) and REEP EXP equations with no boundary layer predictors (NBL) are compared.

System	Period			
	0000 GMT		1200 GMT	
	12-24 h	36-48 h	12-24 h	36-48 h
WBL	.253	.293	.244	.272
NBL	.251	.292	.247	.272
% Improvement WBL/NBL	-0.7	-0.4	1.2	0.0

Table 6. Same as Table 4 except for REEP EXP equations with no boundary layer predictors (EXP) and OPER equations for 14 stations and an average of 1750 cases for each projection.

System	Period			
	0000 GMT		1200 GMT	
	12-24 h	36-48 h	12-24 h	36-48 h
EXP	.285	.324	.261	.299
OPER	.302	.367	.277	.304
% Improvement EXP/OPER	+5.6	+11.7	+5.8	+1.6

Table 7. Same as Table 3 except that the predictors are for the 06-18 and 30-42 h period for the new operational equations implemented in September 1982.

06-18 h Period	30-42 h Period
0000 GMT	
MEAN RH	P AMT
OBS W	850 U
P AMT	1000 HGT
OBS CIG	850 VV
850 U	700 R VOR
850 VV	700 VV
700 VV	TT INDEX
500 GEO V	500 GEO V
8.5T-8.5 DP	850 T ADV
850 R VOR	850 V
1200 GMT	
P AMT	P AMT
OBS W	700 VV
700 VV	500 R VOR
MEAN RH	850 U
850 R VOR	700 R VOR
850 U	500 VV
850 VV	850 VV
1000 HGT	1000 HGT
500 R VOR	500 VORAV
OBS CIG	200 U

Table 8. The reduction of variance for the new primary (backup) operational PoP equations for Alaska for the 06-18 and 30-42 h periods from 0000 GMT. For each region (Figs. 2 and 3) the total number of cases and the relative frequency of precipitation also are shown.

Projection (h)	Region	Total Number of Cases	Relative Frequency of Precipitation (%)	Reduction of Variance (%)
06-18	1	919 (1162)	10.2 (10.0)	23.9 (17.1)
	2	1602 (1785)	16.5 (15.9)	33.9 (28.9)
	3	4012 (4393)	20.4 (20.4)	34.0 (31.8)
	4	1677 (1890)	29.9 (30.9)	33.2 (30.3)
	5	1121 (2159)	11.1 (9.9)	29.0 (17.4)
	6	3305 (3699)	46.8 (47.5)	47.9 (43.7)
30-42	1	958 (1160)	10.0 (10.0)	13.2 (11.3)
	2	1647 (1771)	15.4 (15.7)	18.2 (17.8)
	3	4053 (4379)	20.3 (20.4)	21.4 (20.8)
	4	1677 (1877)	29.7 (30.5)	21.4 (21.0)
	5	1211 (2161)	10.4 (10.1)	16.8 (11.6)
	6	3357 (3689)	46.9 (47.6)	32.1 (32.0)

Table 9. The cumulative reductions of variance and equation coefficients for estimating the 06-12, 12-18, and 06-18 h PoP's (0000 GMT cycle) for region six (see Fig. 2) during the winter months of November through March.

Predictor (Units)	Projection (h)	Cumulative Reduction of Variance			Coefficients			Binary Threshold
		06-12	12-18	06-18	06-12	12-18	06-18	
MEAN RH (%)	12	0.269	0.239	0.318	0.0067	0.0014	0.0047	Continuous
OBS W (--)	03	0.353	0.258	0.389	-0.1736	-0.0711	-0.1867	≤1
850 VV (mb/sec)	12	0.387	0.292	0.428	-23.1400	-28.8500	-35.2600	Continuous
P AMT (m)	24	0.395	0.319	0.436	13.6700	21.4100	12.3000	Continuous
700 HGT (m)	12	0.405	0.334	0.455	-0.0002	-0.0003	-0.0004	Continuous
MEAN RH (%)	18	0.419	0.334	0.456	-0.0058	-0.0004	-0.0020	Continuous
850 VV (mb/sec)	12	0.428	0.342	0.464	0.1293	0.1229	0.1368	≤-0.0004
OBS CIG (ft x 100)	03	0.435	0.343	0.468	0.1037	0.0443	0.0836	≤30
P AMT (m)	12	0.441	0.343	0.469	-0.1038	-0.0094	-0.0247	≤0.002
850 R VOR ($sec^{-1} x 10^{-5}$)	12	0.443	0.347	0.471	-0.0556	-0.0741	-0.0621	≤-0.5
P AMT (m)	24	0.445	0.351	0.475	-0.0615	-0.0996	-0.1100	≤0.001
STA LONG (--)	--	0.445	0.351	0.479	0.0005	0.0012	0.0032	Continuous
Regression Constant					0.9287	1.0000	0.9254	
Total Standard Error of Estimate					0.3526	0.3835	0.3603	

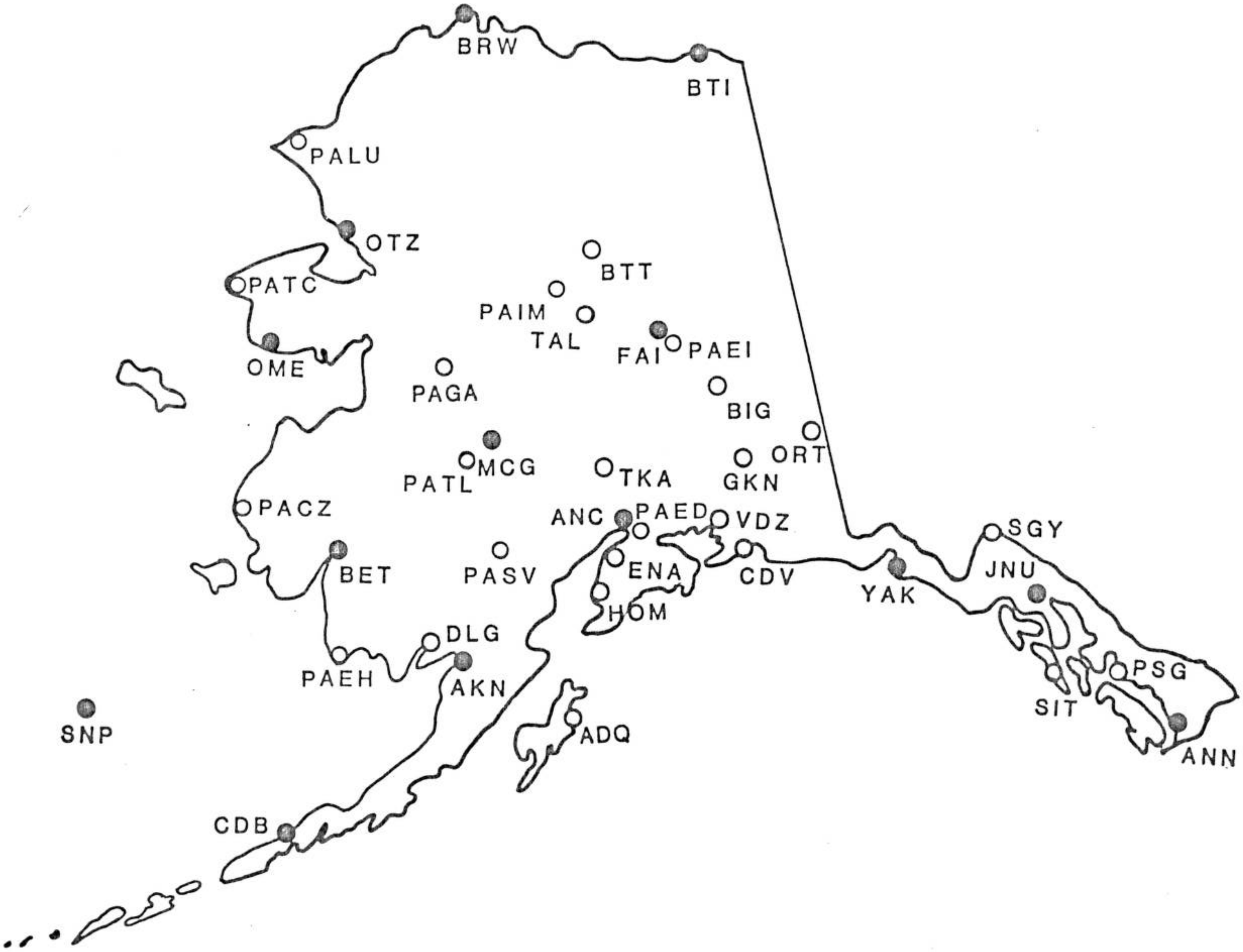

Figure 1. Stations used to develop the EXP system. Stations designated by closed circles comprised the OPER system.

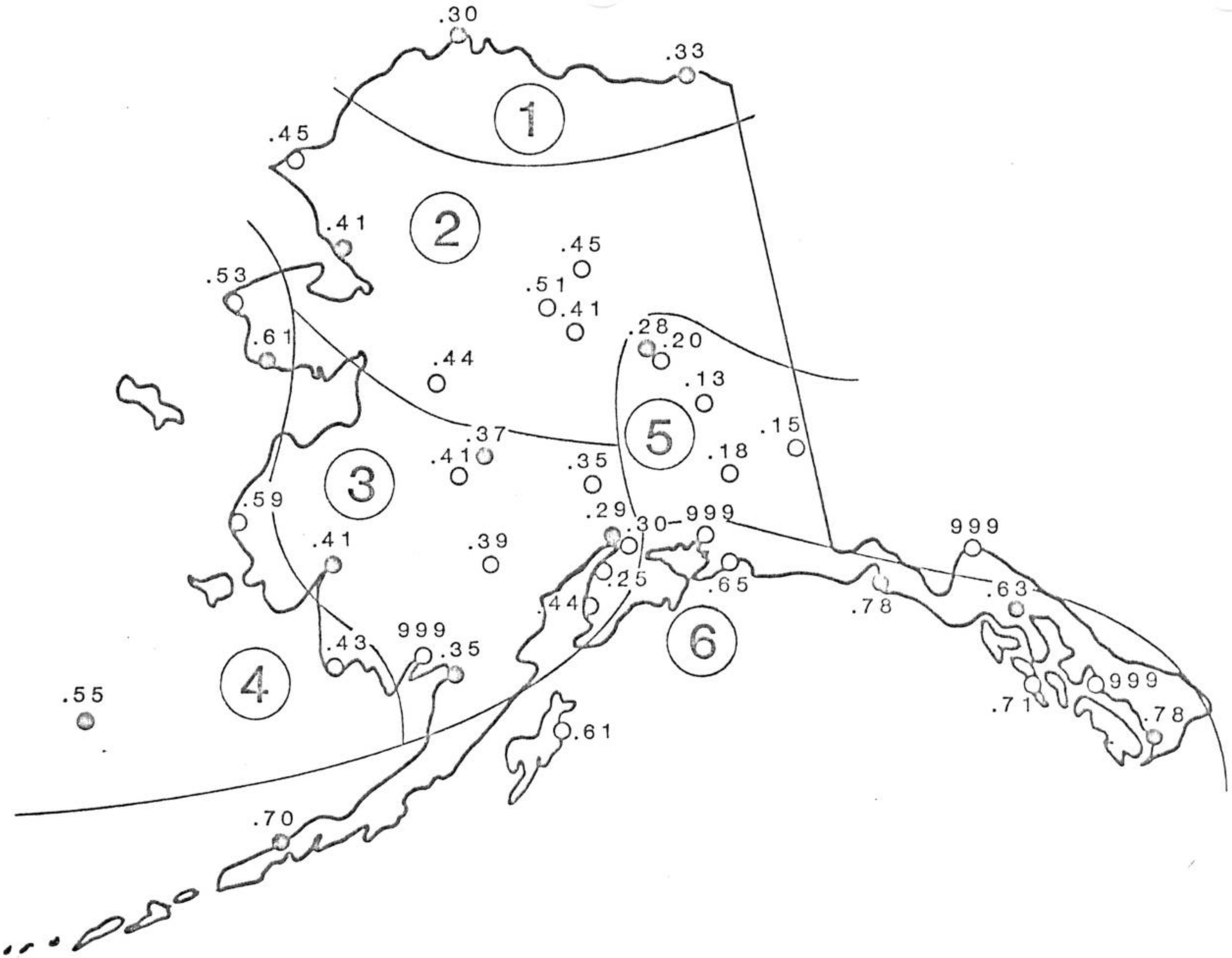

Figure 2. The observed relative frequency of precipitation during the 12-24 h period after both 0000 and 1200 GMT for all cases when the LFM forecast of 12-h P AMT for the 24-h projection was $\geq$ .01 inches. Also shown are the regional boundaries. 999 indicates missing values.

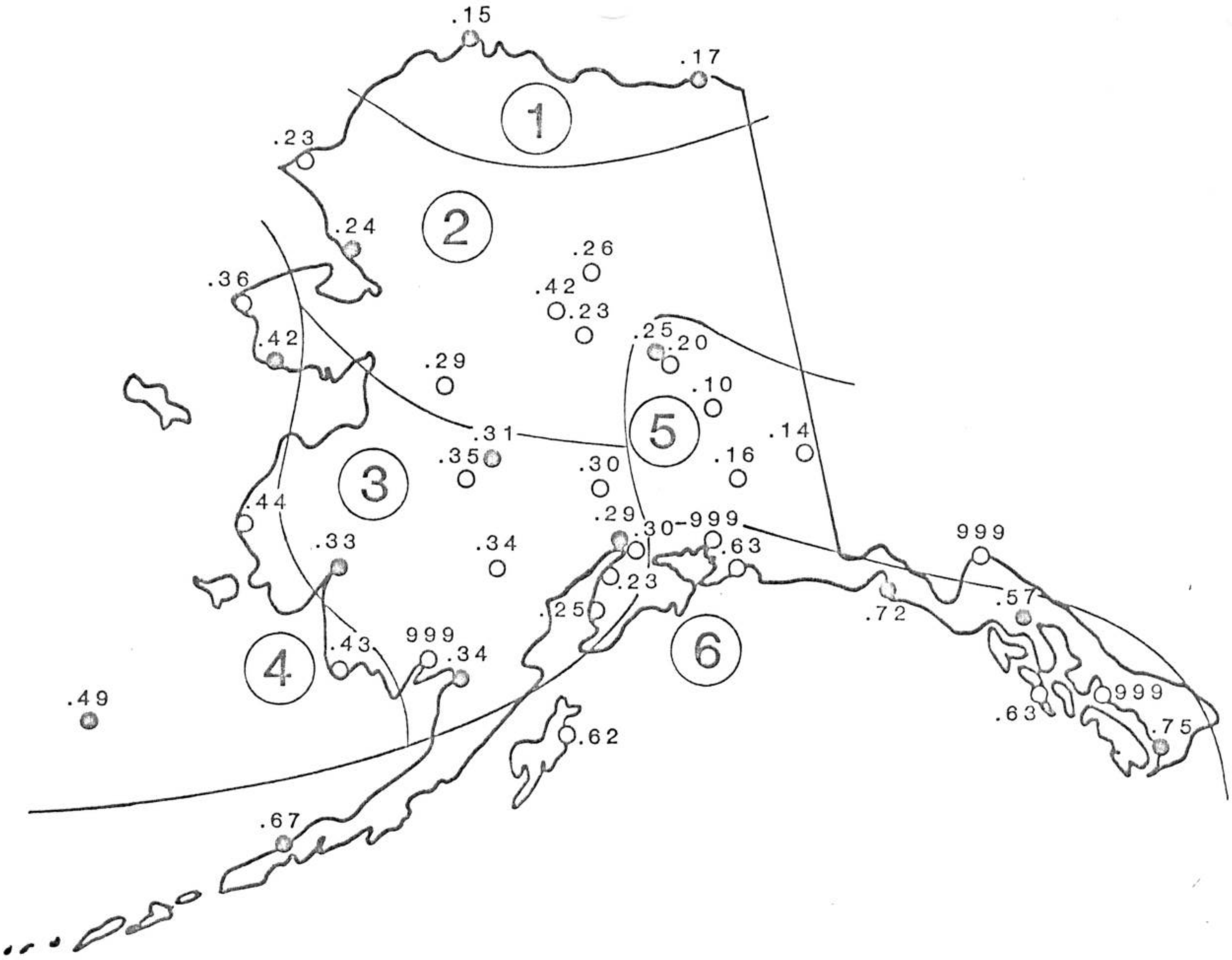

Figure 3. Same as Fig. 2 except for when the 18-h LFM forecasts of MEAN RH were ≥ 65%.