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

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1. INTRODUCTION

A new system for forecasting the conditional probability of frozen precipitation (PoF) for the 14 Alaskan stations listed in column one of Table 1 became operational within the National Weather Service (NWS) in September 1977 (Gilhousen, 1977; National Weather Service, 1977a). In PoF, frozen precipitation is defined as any form of snow or ice pellets; freezing rain or drizzle, rain or drizzle, and mixed precipitation types are considered non-frozen precipitation. The probability forecasts are conditional because the system assumes precipitation will occur; i.e., only precipitation cases were included in the developmental sample. To develop the original forecast equations for PoF, 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 the Spectral model (Sela, 1980; National Weather Service, 1980), so the Alaskan PoF forecasts were then based on the output from this new model.

Gilhousen (1977) tested the PoF system against the local forecasts for Juneau, Anchorage, and Fairbanks on 6 months of independent data from October 1976 through March 1977. The results of this test are reproduced in Table 2; they indicate the local forecasts were far superior to the PoF guidance in terms of percent correct, Heidke skill score (Panofsky and Brier, 1965), and threat score.[1] Only in terms of the bias by category did the guidance outperform the local forecasts.[2] Also, other testing has shown that conversion to the Spectral model led to a deterioration of the MOS probability of precipitation and temperature guidance. In an effort to improve the PoF system, we decided to develop a new set of PoF forecast equations.

The new set of PoF forecast equations, called NEW, differs from the operational system, OPER, in several ways. First, NEW uses seasonal equation sets; the warm season is from April through October, while the cool season is from November through March; OPER used the same set of equations year-round. Second, NEW was developed with more than four warm and cool seasons of output from the Limited-area Fine Mesh (LFM) model (Newell and Deaven, 1981; National

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[1] Threat score = H/(F + O - H) where H is the number of correct forecasts of a category, and F and O are the number of forecasts and observations of that category, respectively.

[2] Bias by category refers to the number of forecasts of a particular category (event) divided by the number of observations of that category. A value of 1.0 denotes unbiased forecasts for a particular category.

Weather Service, 1977c); OPER was developed with about 3 1/2 years of PE model data from October 1972 through March 1976. Third, NEW was developed with data from all 39 stations listed in Table 1 (also see Fig. 1); OPER was developed with data from only the 14 stations shown in column one of Table 1 . Fourth, the NEW equations were derived using the Regression Estimation of Event Probability (REEP) statistical model (Miller, 1964); OPER was developed with the logit model (Brelsford and Jones, 1967; Jones, 1968). Fifth, NEW uses observed surface variables and LFM u- and v-wind components at various levels as predictors; OPER did not use these predictors. Finally, with NEW, "50% values" of several LFM predictors were derived for each station using cool and warm season data combined into one, 4 1/2 year data sample; an additional constant, called "spread", also was developed. Both of these constants were obtained by fitting an S-shaped logit curve to the data. The 50% value is that value which indicates a 50-50 chance of frozen precipitation for a station, provided precipitation occurs. The spread constant defines the shape of the logit curve; that is, for a given predictor, some curves are quite steep while others are quite shallow depending on the station. Six of the LFM predictors used in the NEW system were transformed from their original values through application of these constants. In OPER, 50% values were derived for five PE model predictors only, and spread constants were not included.

As a preliminary test of the NEW system, we developed two sets of equations for the cool season. One set of equations was developed with the REEP model while the other set was developed with the logit model. REEP is essentially a linear model while logit is non-linear; however, both models can accomodate non-linear variables as predictors. Comparative verifications between the logit-based set and the REEP set on dependent and independent data indicated that REEP was better than logit for forecasting PoF. Based on these results, we decided to use the REEP model for further development of the new PoF equations for Alaska.

2. DEVELOPMENT OF NEW SYSTEM EQUATIONS

a. Potential Predictors

Table 3 shows the potential predictor variables used to develop the new equations. These included model output variables valid for 6-, 12-, 18-, 24-, 30-, 36-, 42-, and 48-h projections. The model output variables for projections ≤18 hours were unsmoothed and 5-point space-smoothed; for ≥24-h projections, a combination of unsmoothed, and 5- and 9-point space-smoothed variables were screened. All observed predictor variables were valid at 0300 and 1500 GMT. Table 3 gives the acronyms by which the various predictors will be referred in this paper.

For NEW, we improved the predictor transformation procedure. In the OPER and NEW systems, we transformed several variables into deviations from 50% values. Briefly, the 50% value of a variable is that value which indicates a 50-50 chance of frozen precipitation at a station; provided precipitation occurs. We determined the 50% value for a model output predictor for each station by using a logistic function to fit the data. As discussed by Gilhousen (1977), the 50% value of a variable can vary quite a bit from station to station depending on local factors. Our assumption was that a given deviation of a predictor from its 50% value should produce the same PoF at different stations. This assumption would be exact if the logit curve for a given predictor had the same shape for each station. Actually, this isn't true; that is, for a given predictor, some curves are quite steep while others are quite shallow. For example, for a steep logit curve, the difference in the 850 T between the 50% and 95% values on the curve might be 2 K; however, for a shallow logit curve, this difference might be 4 K. Bocchieri (1979) explained and illustrated these concepts in more detail and described experiments for stations in the conterminous United States which showed the accuracy of probability of SNOW forecasts is improved by transforming predictors to account not only for the difference in 50% values between stations, but also to account for the difference in steepness or spread of the logit curves. In this application, the BLPT, 850 T, 850 WBT, 10-8.5 TH, 10-5 TH, and 8.5-5 TH predictors were transformed by,

$$X_T = \frac{X - (50\%\ \text{value})}{\text{spread}} \qquad (1)$$

where X_T is the transformed predictor, X is the original value of the predictor, and spread is the difference in X units between the 95% point and the 50% point of the logit curve. We determined the 50% values and spread constants for each station by combining the cool and warm season data into one sample. We decided not to develop 50% values and spread constants for each season because in Alaska the northern stations do not have a sufficient number of non-frozen cases during the cool season, while the southern coastal stations do not have a sufficient number of frozen cases during the warm season to produce reliable 50% values and spread constants.

b. Regions

As in the OPER system, we developed NEW equation sets for each of several geographic regions. Regions were determined separately for the cool and warm seasons. Regionalization is desirable for the PoF system in Alaska because, as mentioned earlier, during the cool season, non-frozen precipitation is considered a rare event for northern stations, while for the warm season, frozen precipitation is considered a rare event for southern coastal stations.

In order to determine the regions, the REEP screening program was run on the four cool seasons (1977-78 through 1980-81) of data for the 12-, 24-, 36-, and 48-h projections from both 0000 and 1200 GMT with data combined from all 39 Alaskan stations--this is the so-called generalized-operator approach. We used these equations to produce PoF forecasts for each station of the developmental sample, and evaluated the forecasts by use of the relative probability bias. The relative probability bias for each station was computed by,

$$\text{Relative Probabilty Bias} = \frac{\overline{\text{PoF}} - \text{RF(FROZEN)},}{\text{RF(FROZEN)}} \qquad (2)$$

where $\overline{\text{PoF}}$ is the average PoF forecast for each station and RF(FROZEN) is the relative frequency of frozen precipitation for each station in the developmental sample.

Fig. 2 shows the relative probability bias averaged for the 12-, 24-, 36-, and 48-h projections from both 0000 and 1200 GMT and also shows the regions determined for the cool season. The analysis in Fig. 2 indicates that stations in region 1 have a uniformly low bias, while stations in region 3 have a high bias. In region 2, the pattern is not clear. By developing separate equations for each of these regions, our purpose was to reduce or eliminate the bias which was associated with the generalized-operator approach.

Fig. 3 is the same as Fig. 2, but for the warm season. The developmental data consisted of over four seasons of data from 1977 through 1981. We used the same approach as was used for the cool season. Here, the stations in regions 1, 2, and 3 have similar relative probability bias characteristics, but the regional boundaries are further north than those for the cool season.

For both seasons, the relative frequency of frozen precipitaton from the developmental sample played an important role in determining the regions when it was not clear as to which region the station belonged.

c. REEP vs. Logit

In testing the logit model for probability of precipitation type forecasting in the United States, Bocchieri and Maglaras (1982) showed that the logit model was better than REEP. As mentioned previously, the original operational PoF system in Alaska used logit equations. However, REEP is more efficient because using logit involves the extra step of running the REEP model to determine which predictors to include. Hence, we decided to do an extensive comparison of REEP and logit PoF forecasts for the cool season.

Having specified the appropriate regions, we developed two sets of equations by combining data from all stations within a region for the 12-, 24-, 36-, and 48-h projections from 0000 GMT. One set of equations consisted of linear regression equations developed with the REEP screening procedure, while the other set was developed with the logit model. For all equations, the developmental sample was the same as that used to develop the cool season regions.

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 give estimates of the probabilities of occurrence for a given set of binary-type predictands. In PoF, precipitation type is divided into two binary-type predictands: frozen precipitation and non-frozen precipitation. The predictands are called binary because in the developmental phase each predictand was assigned a value of either 1 or 0 in a given precipitation case depending on whether or not frozen precipitation occurred. The potential predictors were either in binary or continuous form. The use of binary predictors helps to account for non-linear relationships between 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 screening regression process for the REEP equation sets was continued as long as the addition of a new term added at least 0.1% to the reduction of variance for that region's equation or until a maximum of 12 terms had been selected.

For the NEW equation sets, we performed two comparative verifications; one on dependent data, the other on independent data combined from 39 stations for the period November 1981 through January 1982. The dependent data verification included all of the developmental sample. In each experiment, we calculated the P-scores (Brier, 1950) for PoF forecasts for the 12-, 24-, 36-, and 48-h projections from 0000 GMT. We also examined the reliability of the probability forecasts. Reliable probability forecasts have the characteristic that for all of the PoF forecasts of 20%, for instance, the relative frequency of frozen precipitation when precipitation occurs is close to 20%.

Tables 4 and 5 show the P-scores for logit and REEP and the percent improvement of the logit over the REEP P-scores for the dependent and independent data experiments, respectively. The results on dependent data indicate REEP ranged from 4% to 10% better, depending on the projection. On independent data, REEP was better than logit by 2.3%, 4.4%, and 0.7% for the 12-, 24-, and 36-h projections, respectively. Logit was better than REEP by 4.8% for the 48-h projection. In terms of reliability, for the independent data sample, REEP was more reliable than logit at all four projections. Based on these results, we decided to use REEP for further development of the PoF equations for Alaska.

d. Cool Season

We developed forecast equations for the cool season for the 6-, 12-, 18-, 24-, 30-, 36-, 42-, 48-, and 54-h projections from 0000 and 1200 GMT. We used the same data sample, potential predictors (Table 3), and regions (Fig. 2) as were used to develop the equations for the comparison between REEP and logit. Observed surface variables valid at 0300 or 1500 GMT were included in the equations for the 6 to 36 hour projections. In addition to these "primary" sets of PoF equations, we also developed "backup" equations which didn't include observed predictor variables.

Column one of Table 6 lists the 10 most important predictors as given by the REEP screening procedure for the cool season equations for all projections and cycles combined. These rankings were determined by both the frequency and order of selection; for this purpose, all projections, smoothings, and binary limits were combined for each type of variable. Table 6 indicates that the 850 WBT, 850 T, BLPT, and 10-8.5 TH from the LFM model are the most important predictors, all of which had been transformed. The most important observed predictors are the OBS T and the OBS TD. The observed predictors are important for the short-range projections, but are replaced by the four LFM variables as the most important predictors for the long-range projections. These six predictors, overall, account for most of the reduction of variance for the cool season equations. In particular, for each equation, the predictor chosen first, in most cases, accounts for about 80% of the total reduction of variance for the entire equation. Of the six predictors, only OBS TD was not chosen first at one time or another.

Fig. 4 (dashed lines) shows the reduction of variance for all projections from 0000 and 1200 GMT for the cool season primary equations for all three regions combined. As expected, the reduction of variance shows a downward trend as the time of the projection increases. Although not shown, the backup equations have lower reductions of variance than the primary equations, especially at the short-range projections.

e. Warm Season

We developed the PoF forecast equations for the warm season for the same projections and cycles as for the cool season. We also screened the same potential predictors (Table 3) that were used for the cool season, and we used the regions as shown in Fig. 3. Observed surface variables valid at 0300 or 1500 GMT were included in the equations for the 6 to 48 hour projections. As with the cool season, "backup" equations were developed for these projections.

Column two of Table 6 lists the 10 most important predictors as given by the REEP screening procedure for the warm season equations determined by the same method used for the cool season. Table 6 indicates that 10-8.5 TH, 850 WBT, BLPT, and 850 T are the most important LFM predictors. The most important observed predictors are OBS T and OBS TD. When compared to the cool season, observed predictors are more important for the warm season equations. Also 10-8.5 TH replaces 850 WBT as the most important predictor overall. These six predictors account for most of the reduction of variance, and the predictor chosen first for each equation, in most cases, accounts for about 80% of the total reduction of variance for the entire equation. Of the six predictors, only OBS TD was not chosen first at one time or another.

Fig. 4 (solid lines) shows the reduction of variance for all projections from 0000 and 1200 GMT for the warm season primary equations for the three regions combined. Again, the reduction of variance shows a downward trend as the time of the projection increases; however, when compared to the cool season, the reductions of variance are higher for the warm season.

Table 7 shows the warm season, 0000 GMT cycle, 12-h PoF equation cumulative reductions of variance and equation coefficients for region 3 (see Fig. 3). Here, the 12-h LFM 850 WBT was the first term selected by the regression procedure. This predictor reduced the variance by 40% and demonstrates the importance of the predictor chosen first because the remaining 11 predictors chosen add to the total reduction of variance only 17%, thus, the 850 WBT accounted for 70% of the reduction of variance produced by the entire equation. Other predictors chosen were OBS T and OBS TD from surface observations taken at 0300 GMT. The predictors are all in binary form, and some variables are chosen more than once with different projections or binary limits. A binary predictor, such as the OBS T, is given a value of 1 if it is less than or equal to a particular threshold value; otherwise, the value of the predictor is set to 0.

3. VERIFICATION OF FORECASTS FROM NEW SYSTEM EQUATIONS

To test the NEW equation sets, we performed two comparative verifications for the cool season on independent data combined from 14 stations (four stations for the second verification) for the period November 1981 through March 1982, and one verification for the warm season on independent data combined from 14 stations for the period April 1982 through July 1982.

a. Cool Season

In this verification we compared P-scores of the NEW forecasts to those of OPER for the 12-, 24-, 36-, and 48-h projections from 0000 GMT for the 14 stations shown in column one of Table 1. These are the only Alaskan stations for which the OPER system produced forecasts. Table 8 shows the P-scores for NEW and OPER and the percent improvement of NEW over OPER. The results indicate that NEW was 28.2%, 17.1%, 18.9%, and 11.6% better than OPER for the 12-, 24-, 36-, and 48-h projections, respectively.

Fig. 5 shows the reliability of NEW and OPER PoF forecasts for the 12- and 24-h projections from 0000 GMT. The results, for both projections, indicate that NEW forecasts are more reliable than OPER forecasts. Fig. 5 also indicates that NEW overforecasts probabilities of less than 45% and underforecasts probabilities of greater than 45%. It should be noted that for both systems, especially NEW, the probabilities are very reliable near 0% or 100%.

For the second cool season verification, we compared NEW forecasts to subjective local forecasts. The scores included percent correct, bias, skill score, and threat score for 18-, 30-, and 42-h projections from 0000 GMT for four stations (Fairbanks, Anchorage, Juneau, and Annette). These are the only Alaskan stations for which local forecasts were available.

Table 9 shows the percent correct, bias, skill score, and threat score for the NEW system and for the local forecasts. The results indicate that, in terms of percent correct, skill score, and threat score, the local forecasts for the 18- and 42-h projections were better than those from the NEW system. For the 30-h projection, NEW was better than the local forecasts. In terms of bias, NEW was the same as the local forecasts for the 18-h projection and better than the local forecasts for the 30- and 42-h projections. The results were quite encouraging because the previous verification which compared OPER system forecasts with local forecasts (Gilhousen, 1977) indicated OPER was much worse than local forecasts at that time.

b. Warm Season

The comparative verification, between NEW and OPER for the warm season, involved the same stations and projections used for the comparison between NEW and OPER for the cool season. Table 10 shows the P-scores for NEW and OPER and the percent improvement of NEW over OPER. The results indicate that NEW was 26.5%, 21.7%, 17.9%, and 17.9% better than OPER for the 12-, 24-, 36-, and 48-h projections, respectively. These results are similar to those for the cool season comparison between NEW and OPER.

Fig. 6 shows the reliability of NEW and OPER PoF forecasts for the 12- and 24-h projections from 0000 GMT. The results for the 12-h projection indicate that there was little difference between NEW and OPER. For the 24-h projection, Fig. 6 shows that NEW was much more reliable than OPER. The 12-h forecasts from the NEW system overforecast probabilities of less than 45% and underforecast probabilities of greater than 45%. For the 24-h projection, the NEW system reliability showed no clear trend. Similar to the cool season, it should be noted that both systems, especially NEW, are very reliable when forecasting probabilities near 0% or 100% and approximately two-thirds of the cases are near these extreme values.

4. REDERIVATION OF NEW SYSTEM EQUATIONS

a. Warm Season

The NEW system warm season equations were implemented operationally on September 29, 1982 (National Weather Service, 1982). By examining PoF forecasts produced by the NEW system equations during the month of October, we noticed that the probabilities, at times, fluctuated dramatically from projection to projection. This occurred even when other variables, such as the temperature forecasts, did not change so drastically. Although many times this occurred when probability of precipitation (PoP) forecasts were very low and the atmospheric condition was not representative of the developmental sample (only precipitation cases were included), there were enough large fluctuations during periods with relatively high PoP's that we were concerned local forecasters would consider the NEW system PoF guidance unreliable.

Examination of the equations for the warm season revealed two problems. First, in nearly all equations, every predictor chosen was a binary predictor even though continuous predictors were included in the predictor lists input to the REEP screening. Second, some of the coefficients associated with the binary predictors were very large. The sample equation given in Table 7 shows that the third, fourth, and sixth predictor terms have coefficients of .29, .27, and -.36, respectively, and that all the predictors are binary. As mentioned previously, a binary predictor is given a value of 1 if it is less than or equal to a particular threshold value; otherwise, the value of the predictor is set to 0. As a result, forecasts may fluctuate dramatically from projection to projection, even when only small changes occur in the forecast values of particular predictors.

The most frequent and severe problems associated with the large coefficients were evident in the forecasts for region 3. We think this is related to the small number of precipitation cases within the range of values of the predictor where the PoF changes the greatest, i.e., the critical range. Fig. 7 shows a hypothetical logit curve (S) for PoF as a function of the value of the transformed LFM predictor, 850 T, for region 3. In this diagram, 850 T is divided into intervals and the PoF for all the precipitation cases within each interval is plotted at the mid-point of the interval along with the number of precipitation cases for each interval. The 850 T is plotted in transformed units (X_t). The interval limits from -1 to 1 represent the threshold values we used to create binary predictors for 850 T. As shown by S, when $X_t = 0$, the PoF is 50%, when $X_t = -1$, the PoF is 95% , and when $X_t = 1$, the PoF is only 5%. Most of the useful information derived from the 850 T that discriminates between frozen and non-frozen precipitation lies within the -1 to 1 range, so binary predictors only from within this critical range were screened. As can be expected for region 3 during the warm season, most of the precipitation cases occur when X_t is well above 1. As a result, only a small number of cases are within the critical range. The dashed line (R) in Fig. 7, is our estimation of how a linear model (such as REEP) would attempt to fit these data. Examination of R reveals that a predictor in continuous form from a linear model can not account for the non-linear relationship between the predictand and predictor; this explains why binary predictors were selected almost exclusively.

In developing PoF equations for Alaska, we required that each binary predictor have a minimum of 30 cases before consideration for selection by the screening regression process. This was done in order to insure that the selected predictors would have stable regression coefficients. For all the transformed LFM predictors, we used the same threshold values. Fig. 7 shows that only five precipitation cases were observed when X_t for 850 T was less than or equal to the first threshold value of -1.0. The next threshold value, -0.6, included only four cases in the -1.0 to -0.6 interval. Continuing in this manner, a sufficient number of precipitation cases were not observed until the 0.4 threshold was reached. The PoF drops from 100% to 30% in the interval covered by this binary predictor. As a result, the regression coefficient must try to explain a 70% change in probability when X_t drops from >0.4 to ≤ 0.4. Because of interactions with other predictors in the equation, the coefficient will not necessarily be 70%, but it probably will be large. If predictors such as this exist in the equations for some or all of the projections, the result will be forecasts which fluctuate from projection to projection with only minor changes in the values of the predictors.

Despite the fact that the logit model provides a means for fitting data when the predictand is binary and the predictor continuous, the linear REEP model was better able to account for the non-linear relationship between the predictand and predictor when binary predictors were used. Because of the results of the verification between REEP and logit, we developed the equations using REEP, but, as just discussed, encountered problems with the probabilities forecast by these equations. Use of the logit model would not be the solution to this problem because the small number of precipitation cases for each projection would not produce reliable logit curves and S could vary greatly in position and shape from projection to projection. These changes in the position and shape of S would be reflected in the equations for each projection and could also result in forecasts which fluctuate from projection to projection. An example of this is the previous PoF forecasting system in Alaska, OPER, which was developed using the logit model, but produced forecasts that fluctuated nevertheless.

In order to reduce the number and the magnitude of the fluctuations, we decided to rederive the warm season PoF equations using the REEP model. This time, we forced the three best LFM predictors into the equation in continuous form and then allowed the screening process to continue until 12 terms had been selected. By forcing in the continuous predictors, the effect of the binary predictors was reduced because the continuous predictors accounted for a portion of the explained variance which would otherwise be associated with the binary predictors only.

In our rederivation of the warm season equations, we forced selection of the three best LFM predictors. For the 12-, 24-, 30-, 36-, 42-, 48-, and 54-h projections, we used 10-8.5 TH, 850 WBT, and 850 T. For the 6- and 18-h projections, we used BLPT instead of 850 WBT because 850 WBT was not available as a potential preditor for these projections. Column two of Table 6 shows that BLPT, not 850 T, was the third most important LFM predictor overall, but the problem of large coefficents was greatest in region 3 where 850 T was more important than BLPT. We also included additional developmental data from April through July 1982. Otherwise, we used the same developmental procedure as before with the exception of deriving sets of primary and backup equations for all projections out to and including 54 hours.

Examination of the rederived equations revealed that, in fact, the predictor terms with large coefficients did decrease in number and magnitude. The number of predictors with coefficients greater than .30 dropped from 34 to 9, and the largest coefficient dropped from .66 to .33. Despite this improvement, it is not enough to remove the possibility of any fluctuations in PoF forecasts, but they should be less frequent and not as noticeable.

Fig. 8 shows the reduction of variance for regions 1 and 3 for all projections from 0000 GMT for the original and rederived warm season equation sets. The results indicate that, for region 1 (solid lines), the reduction of variance for the original (no-forced predictor) equation set is slightly higher than for the rederived (forced predictor) set. For region 3 (dashed lines), the reduction of variance for the forced predictor equation set is higher than the no-forced predictor set. Based on these results and our examination of the rederived equations, these new equations were implemented at the start of the 1983 warm season.

b. Cool Season

The new cool season equations were implemented operationally on November 1, 1982 (National Weather Service, 1982). In order to have forecast equations that were developed in a consistent manner for both seasons, we decided to rederive these equations also. Although the cool season equations had problems similar to those for the warm season equations, the number of bad forecasts were fewer and lesser in magnitude and did not play a major role in our decision to rederive the cool season equations.

Similar to the warm season, but to a lesser degree, binary predictors with large coefficients occurred in the equations for regions where there were not a sufficient number of precipitation cases in the critical range. Region 1 (see Fig. 2) had this problem because most of the precipitation cases occurred when X_t, from Eq. (1), was well below -1.0. As a result, binary predictors in the critical range were forced to account for a large change in PoF.

In the cool season rederivation we forced the same predictors as were forced for the warm season. Column one of Table 6 shows that these three predictors were not the best predictors possible for the cool season, but in order to keep the two seasons consistent, the same predictors were forced. The period November 1981 through March 1982 was included as additional developmental data. We also derived both primary and backup equations for all the projections from 6 to 54 hours.

Examination of the rederived equations revealed that, overall, there was improvement in terms of the number of large equation coefficients, but the magnitude of some of the coefficients increased. The difference in the reduction of variance between forced and no-forced predictor equation sets varied from projection to projection, but there was little difference overall between the two sets of equations. The rederived cool season forecast equations will be implemented during the cool season of 1983-84.

5. SUMMARY

A system for forecasting PoF for Alaska became operational within the National Weather Service in September 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 set of PoF forecast equations, called NEW, which is based on LFM model output.

The results of an experiment between REEP and logit equations indicated the NEW PoF forecast equations should be derived with the REEP technique. We derived seperate sets of equations for both forecast cycles (0000 and 1200 . GMT) for the cool (November through March) and warm (April through October) seasons. Comparisons between the NEW and OPER equation sets for both seasons showed the seasonal, REEP-based, NEW equation sets were much better than the year-round, logit-based, OPER equations.

When the new warm season equations first began producing operational forecasts on September 29, 1982, it was noticed that the probabilities, at times, fluctuated a great deal from projection to projection. We determined that this problem was caused by the large coefficients associated with some of the binary predictors in the equations. In order to correct this problem, we rederived the NEW warm and cool season equation sets by forcing three continuous predictors into the equations for all projections. The rederived equations are now being used to produce the operational PoF guidance for Alaska.

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Table 1. Developmental data stations used in the OPER and NEW systems.

Stations used by OPER and NEW		Additional stations used by NEW 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. Percent correct, bias, skill score, and threat score for MOS and local PoF forecasts for the 24-h projection from 0000 GMT. The sample consisted of independent data combined for Juneau, Fairbanks, and Anchorage for the period October 1976 through March 1977. Reproduced from Gilhousen (1977).

Score	MOS	Locals
Percent Correct	85.6	93.8
Bias	1.00	0.86
Skill Score	0.80	0.92
Threat Score	0.60	0.79

Table 3. The potential predictors included in the development of the NEW equation sets.

Acronym	Definition
	a. Model Output Predictors
BLPT	Boundary-layer potential temperature
BL U	Boundary-layer west wind component
BL V	Boundary-layer south wind component
850 T	850-mb temperature
850 WBT	850-mb wet-bulb temperature
850 U	850-mb west wind component
850 V	850-mb south wind component
700 U	700-mb west wind component
700 V	700-mb south wind component
10-8.5 TH	1000-850 mb thickness
10-5 TH	1000-500 mb thickness
8.5-5 TH	850-500 mb thickness
	b. Observed and Miscellaneous Predictors
OBS T	Observed surface temperature
OBS TD	Observed surface dew-point temperature
OBS U	Observed surface west wind component
OBS V	Observed surface south wind component
STA ELEV	Station elevation
SIN DOY	Sine of the day of year
COS DOY	Cosine of the day of year

Table 4. P-scores for logit- and REEP-based cool season PoF forecasts for the 12-, 24-, 36- and 48-h projections from 0000 GMT. The sample consisted of dependent data combined from 39 stations for the four cool seasons 1977-78 through 1980-81. The percent improvement of logit over REEP is also shown. Each sample included an average of 3500 cases for each projection.

System	Projection			
	12-h	24-h	36-h	48-h
Logit	.144	.146	.181	.177
REEP	.131	.138	.165	.170
% Improvement Logit/REEP	-9.7	-5.9	-10.0	-4.1

Table 5. Same as Table 4 except for independent data for the period November 1981 through January 1982 and an average of 650 cases for each projection.

System	Projection			
	12-h	24-h	36-h	48-h
Logit	.122	.134	.146	.156
REEP	.120	.128	.145	.164
% Improvement Logit/REEP	-2.3	-4.4	-0.7	+4.8

Table 6. The 10 most important predictor types as determined by the REEP screening procedure for all projections and cycles combined for the NEW cool and warm season equation sets. Ranking is based both on the order and frequency of selection. Predictor acronyms are defined in Table 3.

Cool Season	Warm Season
850 WBT	10-8.5 TH
850 T	OBS T
BLPT	850 WBT
OBS T	BLPT
10-8.5 TH	OBS TD
OBS TD	850 T
700 U	COS DOY
BL V	10-5 TH
8.5-5 TH	850 U
850 V	8.5-5 TH

Table 7. The cumulative reductions of variance and equation coefficients for estimating the 12-h PoF's (0000 GMT cycle) for region 3 (see Fig. 3) during the warm season months of April through October. Predictor acronyms are defined in Table 3 and X_t is defined by Eq. (1).

Predictor (Units)	Projection (h)	Cumulative Reduction of Variance	Coefficients	Binary Threshold
850 WBT (X_t)	12	0.398	0.1711	$\le$ 0.0
OBS T (°F)	03	0.069	0.1617	$\le$ 36.0
850 T (X_t)	12	0.036	0.2943	$\le$ -0.4
10-8.5 TH (X_t)	18	0.020	0.2678	$\le$ 0.4
OBS TD (°F)	03	0.012	0.1156	$\le$ 29.0
10-8.5 TH (X_t)	12	0.007	-0.3589	$\le$ 0.4
10-8.5 TH (X_t)	06	0.007	0.0996	$\le$ 0.6
10-8.5 TH (X_t)	12	0.006	0.1491	$\le$ 0.2
8.5-5 TH (X_t)	18	0.006	-0.1611	$\le$ 0.2
850 T (X_t)	06	0.007	0.1869	$\le$ -0.2
850 T (X_t)	12	0.006	0.1661	$\le$ 0.2
BLPT (X_t)	12	0.003	-0.1168	$\le$ -0.2

Regression Constant	0.0007
Total Standard Error of Estimate	0.1210

Table 8. P-scores for cool season PoF forecasts from the NEW and OPER equation sets for the 12-, 24-, 36-, and 48-h projections from 0000 GMT. The sample consisted of independent data combined from 14 stations for the period November 1981 through March 1982. The percent improvement of NEW over OPER is also shown. Each sample included an average of 470 cases.

System	Projection			
	12-h	24-h	36-h	48-h
NEW	.168	.175	.197	.229
OPER	.234	.211	.243	.259
% Improvement NEW/OPER	28.2	17.1	18.9	11.6

Table 9. Percent correct, bias, skill score, and threat score for MOS and local PoF forecasts for the 18-, 30-, and 42-h projection from 0000 GMT for the cool season. The sample consisted of independent data combined for Juneau, Fairbanks, Anchorage, and Annette Island for the period November 1981 through March 1982.

Score	Projection					
	18-h		30-h		42-h	
	MOS	Locals	MOS	Locals	MOS	Locals
Percent Correct	81.8	86.0	85.9	83.8	77.3	79.3
Bias	1.10	1.10	1.06	1.14	1.09	1.14
Skill Score	0.62	0.70	0.64	0.55	0.52	0.55
Threat Score	0.74	0.78	0.83	0.81	0.69	0.72
No. of Cases	143	143	99	99	150	150

Table 10. Same as Table 8 except for the warm season independent data sample of April through July 1982 and an average of 330 cases for each projection.

System	Projection			
	12-h	24-h	36-h	48-h
NEW	.076	.126	.100	.141
OPER	.104	.161	.121	.172
% Improvement NEW/OPER	26.5	21.7	17.9	17.9

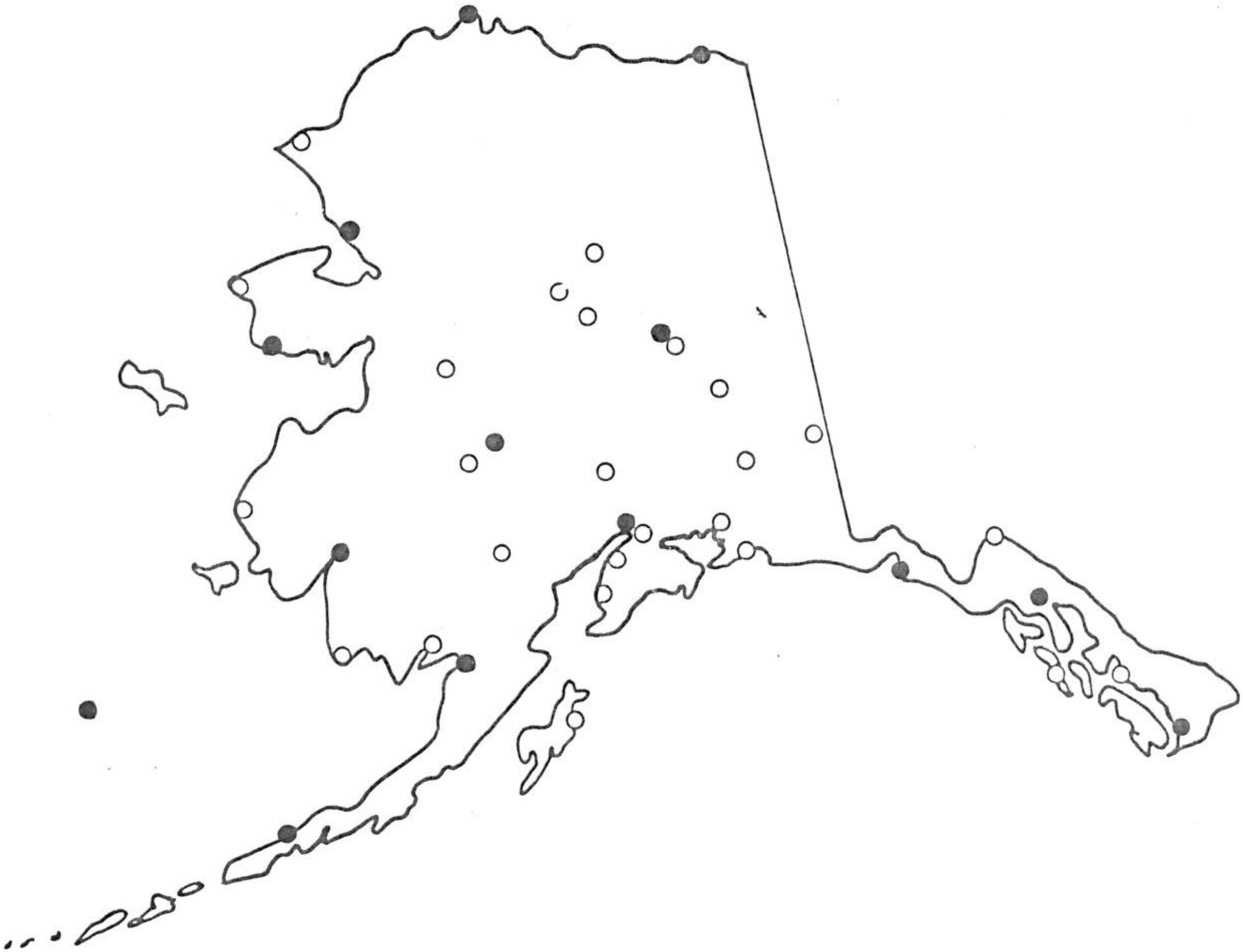

Figure 1. Stations used to develop the NEW system. Stations designated by closed circles comprised the OPER system.

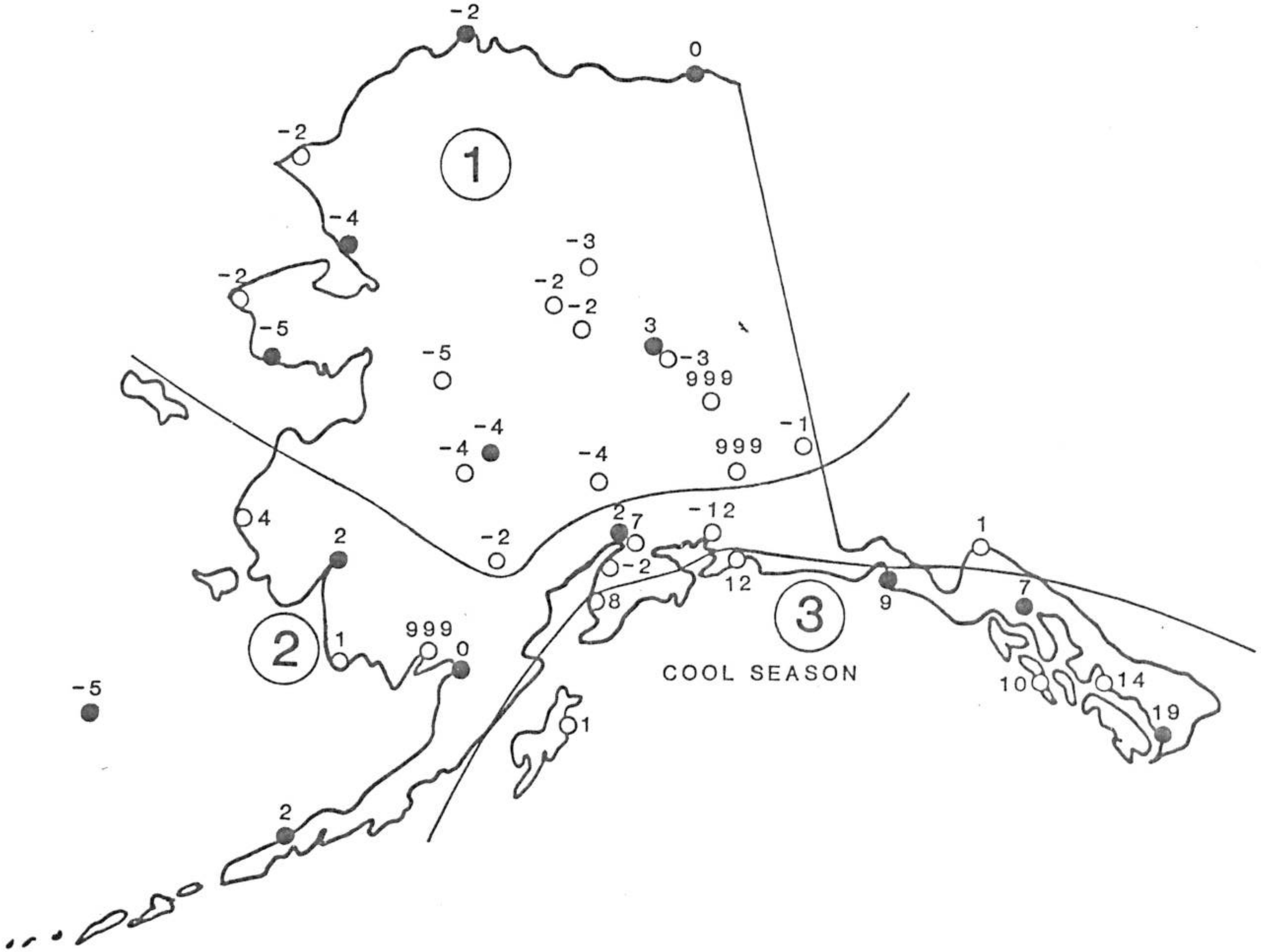

Figure 2. Cool season relative probability bias (%) (see text for definition) for frozen precipitation averaged for the 12-, 24-, 36-, and 48-h projections from both 0000 and 1200 GMT, and the regions used to develop NEW PoF equation sets. Values >0% (<0%) indicated overforecasting (underforecasting) of frozen precipitation.

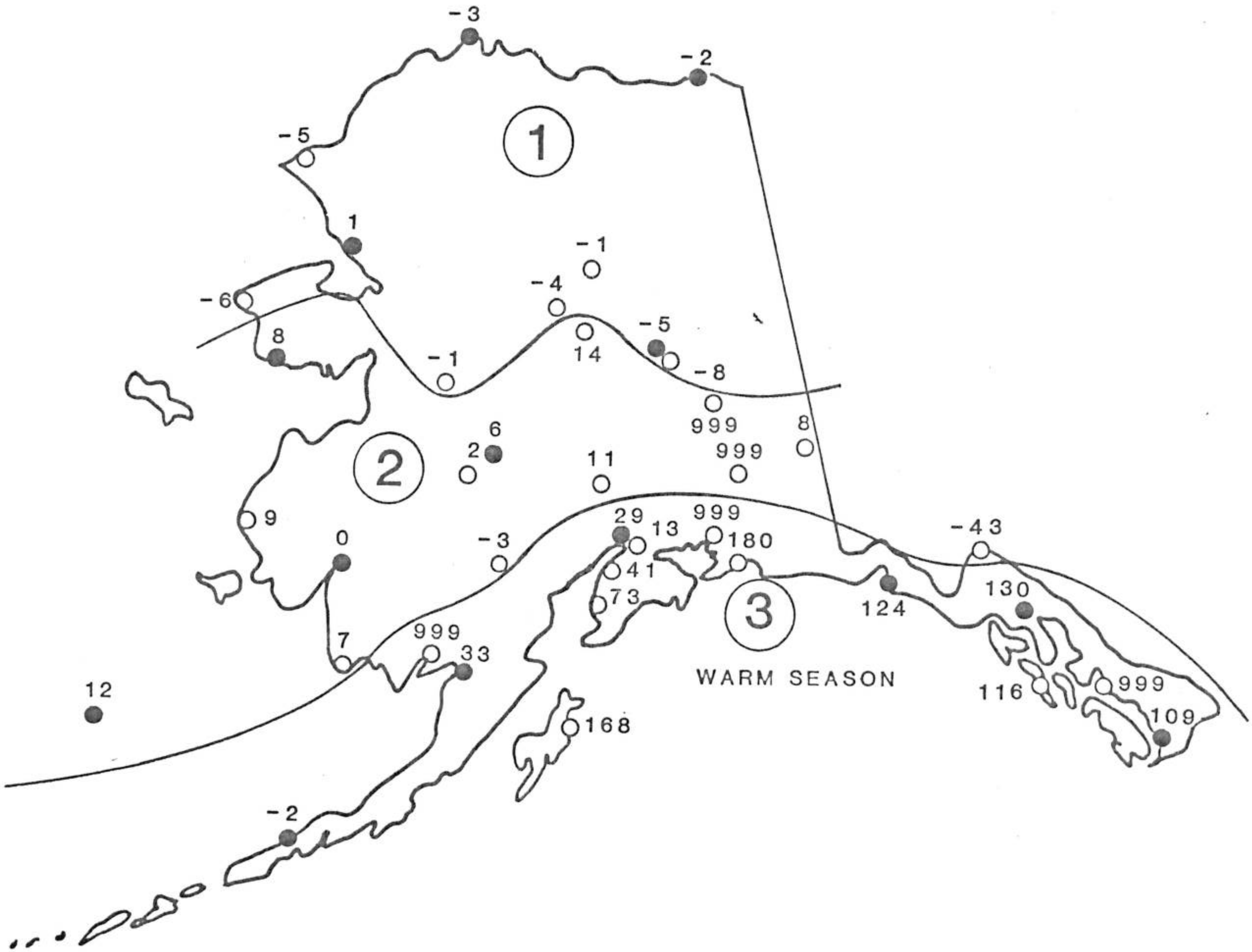

Figure 3. Same as Fig. 2 except for the warm season.

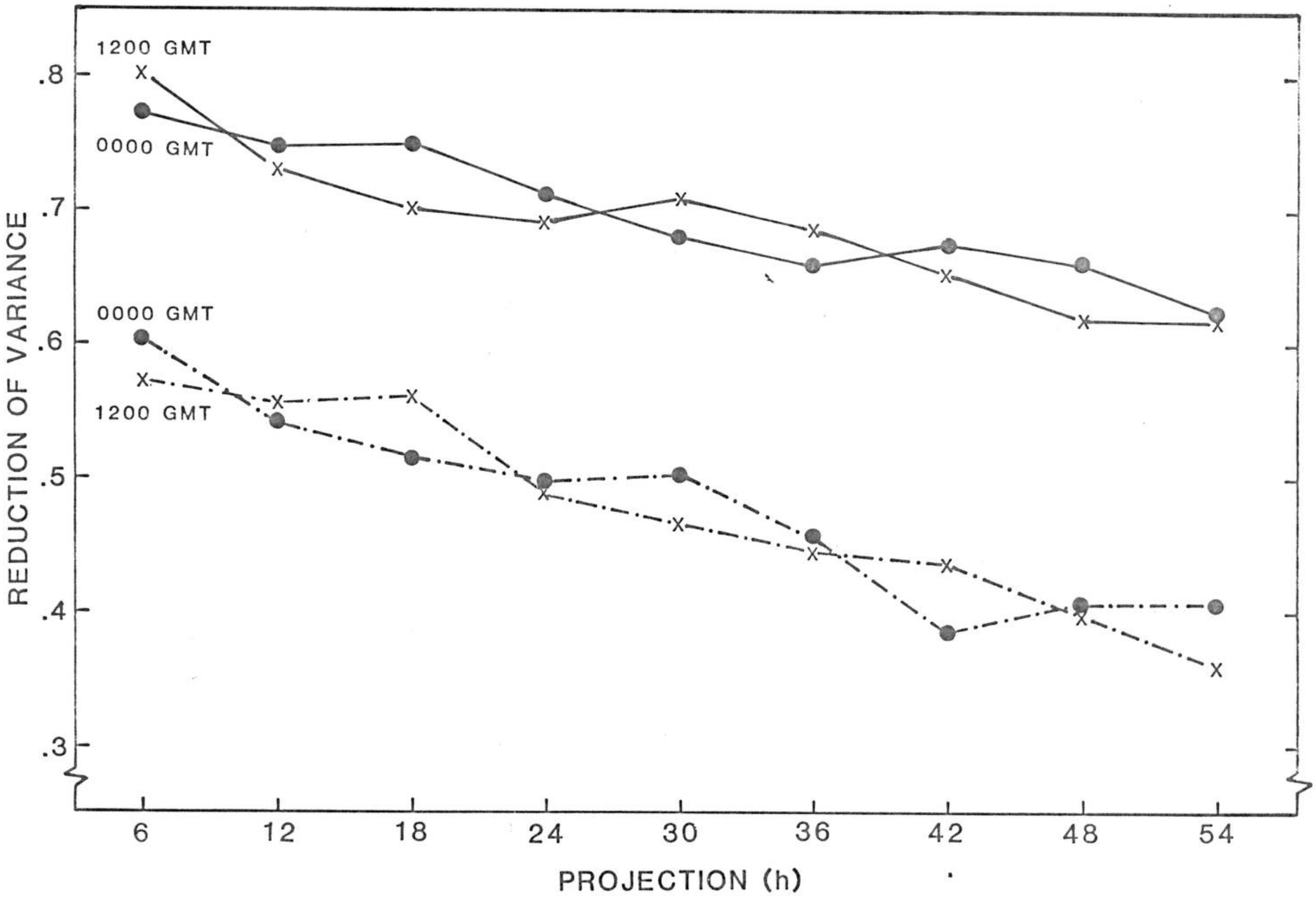

Figure 4. The reduction of variance for all projections for 0000 and 1200 GMT for the cool season (dashed lines) and the warm season (solid lines) equation sets.

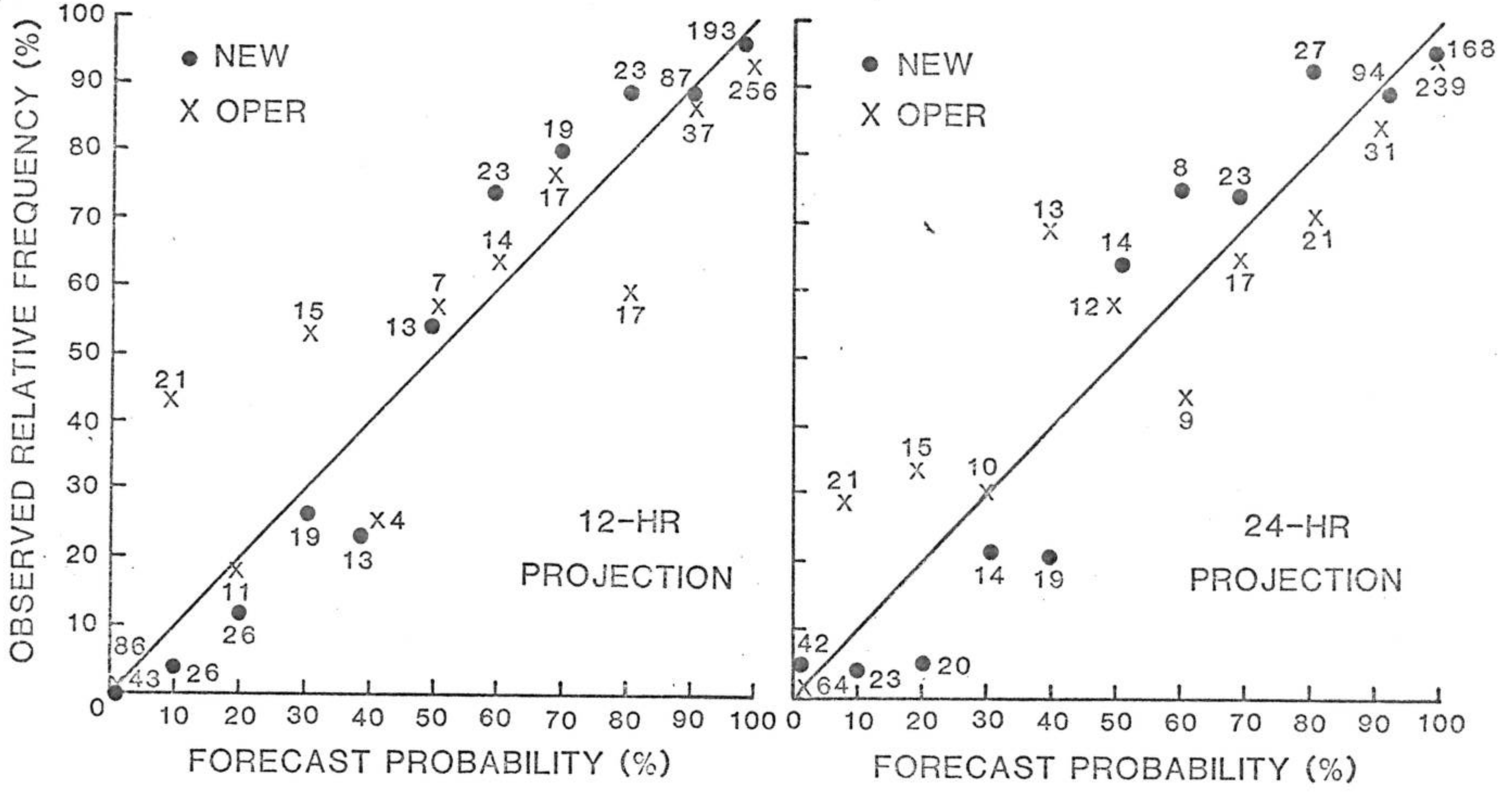

Figure 5. The reliability of the cool season PoF forecasts for the 12- and 24-h projections from 0000 GMT for NEW (dots) and OPER (crosses) forecasts. Data were combined from 14 stations for the period November 1981 through March 1982. The number of cases associated with each dot and cross are also shown. The line denotes perfect reliability.

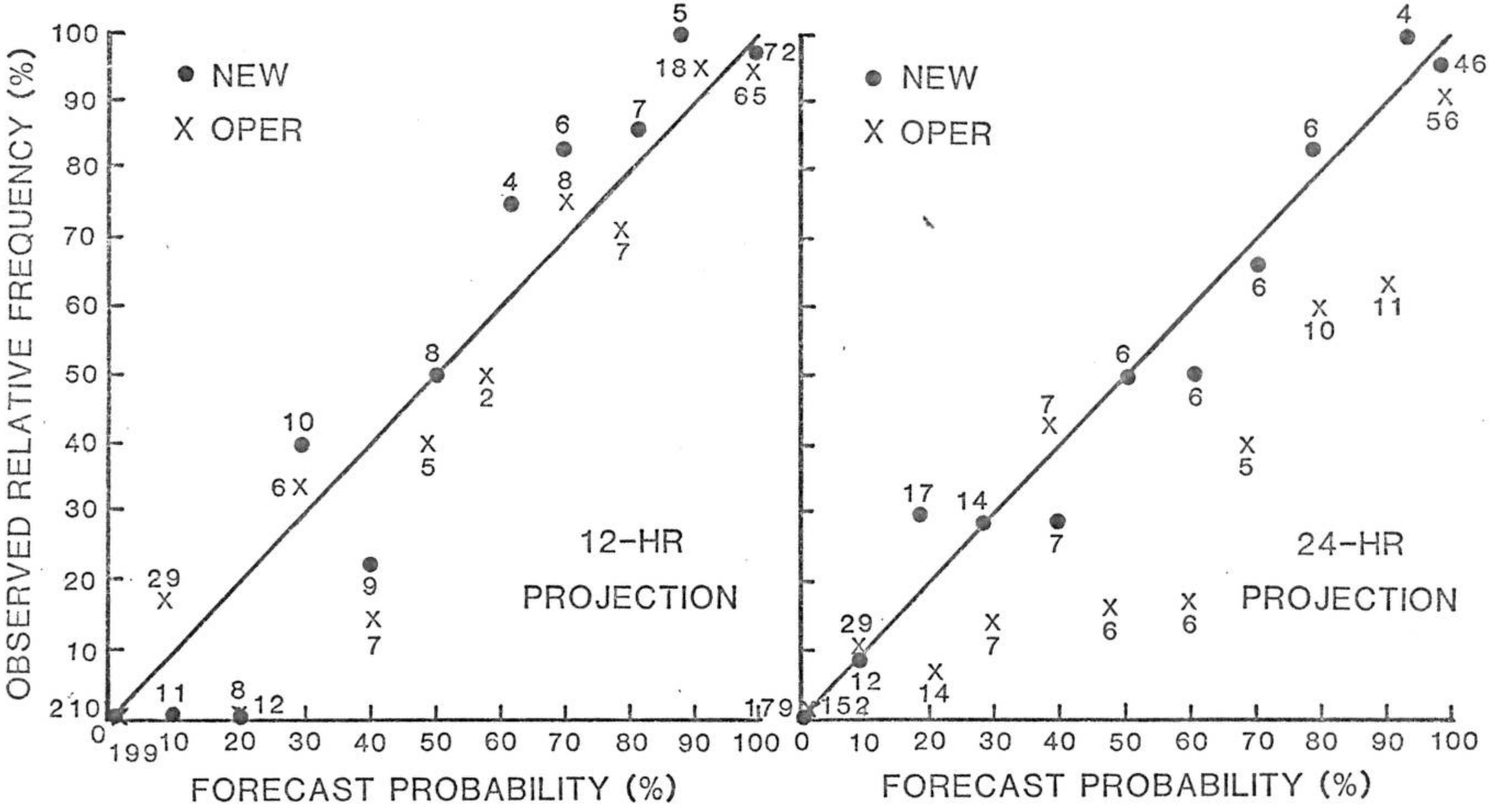

Figure 6. Same as Fig. 5 except for the warm season independent data sample of April 1982 through July 1982.

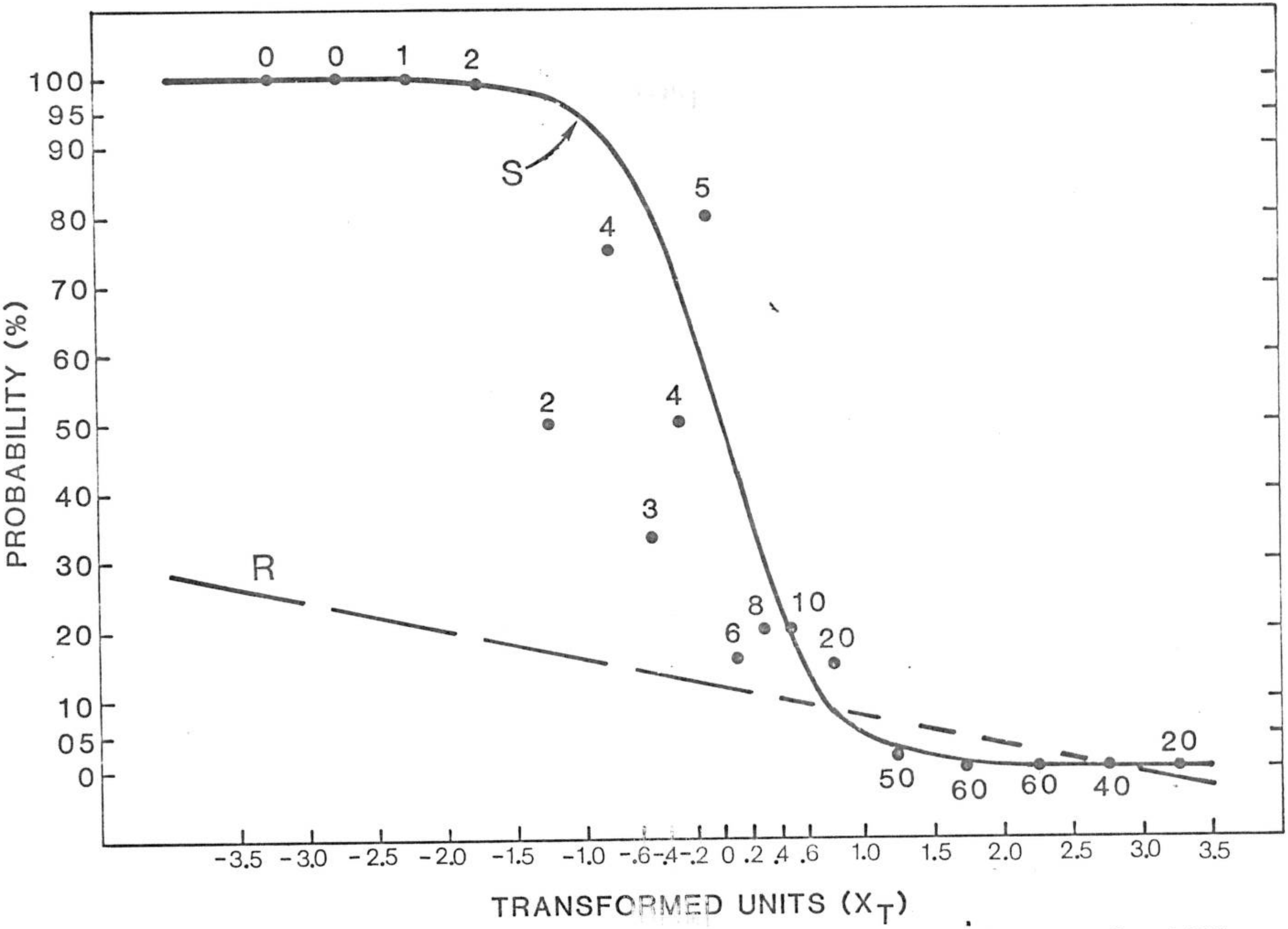

Figure 7. Hypothetical logit curve (S) and linear curve (R) for PoF as a function of the transformed LFM predictor, 850 T, for region 3 for the warm season. PoF is plotted at the mid-point of several 850 T intervals along with the number of precipitation cases for each interval.

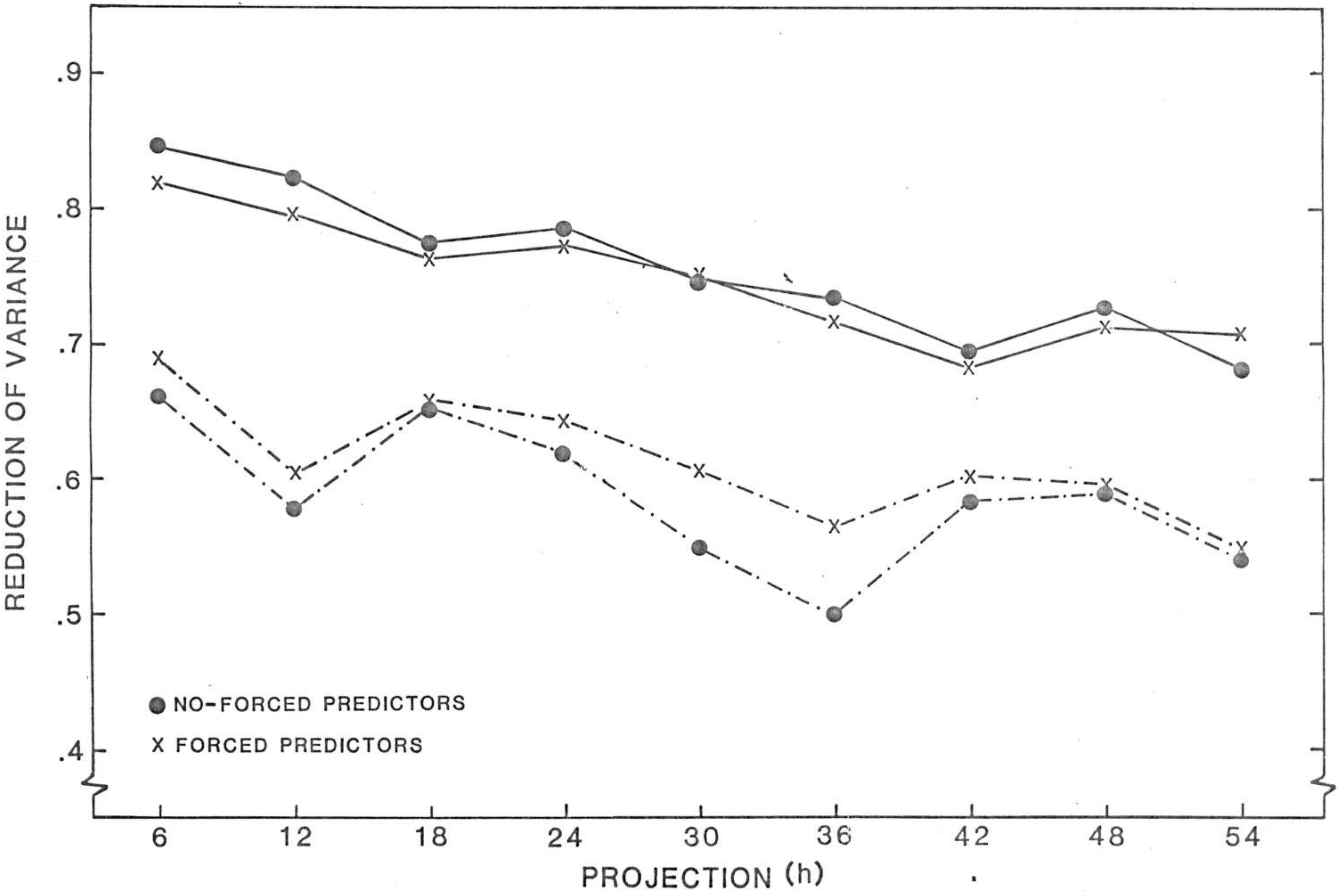

Figure 8. The reduction of variance for the 0000 GMT cycle forced and no-forced warm season equation sets for region 1 (solid lines) and for region 3 (dashed lines).