P222 LOGIT TRANSFORMS IN FORECASTING PRECIPITATION TYPE

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1. INTRODUCTION

Objective forecasts of the conditional probability of precipitation type (PoPT) using the Model Output Statistics (MOS) technique first became available in 1978 for the Limited-area Fine-mesh Model (LFM) (Bocchieri and Maglaras 1983). A PoPT system for the Nested Grid Model (NGM) was developed in 1992 (Erickson 1992), followed by the implementation of a MOS PoPT system for the Aviation Model (AVN) in September 2000 (Allen and Erickson 2001). Recently, the Meteorological Development Laboratory (MDL) completed an updated suite of MOS guidance for the Global Forecast System (GFS). As part of this new package, conditional PoPT equations for the 3-category short-range and 4-category medium-range products were redeveloped for the contiguous U.S. (CONUS) and Alaska.

This paper describes the development of the updated PoPT guidance, and focuses primarily on the 3-category product. Equations for the conditional probability of freezing, frozen, and liquid precipitation were developed for all model cycles for projections every 3 hours out to 84 hours, and extended out to 192 hours for the 0000 and 1200 UTC cycles to support the National Digital Guidance Database (NDGD). Seven cool seasons (1 September – 31 May) of GFS forecast data and present weather observations at 1243 reliable METAR stations were used to develop the equations. The skill of the PoPT guidance has been improved over that of the old operational system, due to the availability of a longer developmental sample, a more robust climatology, and the use of logit “50% values” and “transformed” predictors. The transformed variables account for climatological differences between stations. This allows data for all stations to be pooled together into one large region, with only minimal degradation in skill compared to that of a multiple region approach.

Section 2 describes the developmental process, including the computation of the logit “50% values” and transformed predictors, and the generation of gridded constant datasets. Verification scores are presented in Section 3 for a generalized and regionalized development, using a “k-fold” cross-validation procedure. An example gridded probability forecast is shown in Section 4.

2. EQUATION DEVELOPMENT

2.1 *Observations*

METAR present weather observations were examined for ~ 2000 stations in the CONUS and Alaska, for the period January 1999 through May 2009. Only stations which reported present weather reliably and which had a sufficiently long data record were included in the development of the PoPT guidance. Stations with less than 60% of possible reports over the 10-yr period, and stations with a questionably low number of precipitation reports, were excluded from the sample. “Part-time” stations (i.e., those that consistently report less than 60% of the time) also were excluded. This left 1243 stations that were found to be reliable enough to use in the development, of which 66 are Canadian and 47 are in Alaska. A map showing the locations of the developmental sites is provided in Fig. 1. Note that even stations that never (or rarely) report freezing or frozen precipitation still were included in the sample. This differs from previous developments which excluded some stations in Florida and California (e.g., Allen and Erickson 2001). Given the large number of reliable stations available that frequently experience wintry precipitation, the inclusion of these predominantly-rain stations did not negatively impact the quality of the guidance.

2.2 *Definition of predictand*

Present weather observations valid every 3 hours on the hour (i.e., 0000, 0300, …, 2100 UTC) were classified into one of three mutually exclusive binary predictands: freezing/no

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freezing, frozen/no frozen, or rain/no rain. A separate "null" category was used for cases when no precipitation of any type occurred, or when the exact type could not be determined (e.g., reports of unknown precipitation "UP"). All "null" category cases were treated as missing and not included in the development. Thus, only precipitation cases of discernable type comprised the developmental sample. Table 1 lists the definitions of each precipitation type category. As in previous developments, ice pellets were included with the freezing category, and any mixture of liquid precipitation with snow was classified as liquid. By defining the frozen category as snow events only, we believe this maximizes our ability to delineate snow from other precipitation types (Erickson 1992). Freezing events are rare, comprising only ~ 1.5% of all cool season precipitation cases over the CONUS, and ~ 0.5% of precipitation cases over Alaska.

2.3 *Conditional relative frequencies*

Monthly conditional relative frequencies of freezing, frozen, and liquid precipitation were calculated for each of the 1243 reliable stations, for use as geoclimatic predictors in the regression analysis. Climatology is a very good predictor particularly in the later forecast projections, and is useful for forecasting the freezing and frozen precipitation events (which are very rare in some parts of the country). The relative frequencies were calculated from 10 years of predictand data and are valid for the 12-h period centered on each forecast projection. The use of 12-h relative frequencies is consistent with previous PoPT developments (e.g., Allen and Erickson 2001).

2.4 *Derivation of 50% values*

The utility of 50% (or equal-probability) values to differentiate precipitation type has been well documented (e.g., Glahn and Bocchieri 1975, Bocchieri and Glahn 1976, Bocchieri and Maglaras 1983, Erickson 1992). For each station and time of day (i.e., 0000, 0300, …, 2100 UTC) the logit model was used to calculate 50% values for five variables known to be good discriminators of precipitation type. These are 2-m temperature, 850 hPa temperature, 1000-850 hPa thickness, 1000-500 hPa thickness, and freezing level. The logit model was used to fit a sigmoid curve to the relationship between the binary dependent variable (*Y*) and each of the five predictor variables (*X*). The probability (*P*) of the binary dependent variable having a value of 1 is given by

$$P[Y=1 \mid X] = \frac{1}{1+\exp(a+bX)} \ ,$$

where *a* and *b* are the regression coefficients determined (iteratively) by maximizing a log-likelihood function. Once the coefficients are determined, the value of the predictor variable (*X*) for which *P*[*Y*=1] = 50% is simply –*a*/*b*. Few stations contained a sufficient number of freezing precipitation cases for reliable 50% values to be determined for that category alone. Therefore, for purposes of this analysis, the freezing and frozen cases were combined such that the dependent variable (*Y*) was the occurrence of freezing *or* frozen precipitation. The predictor variables for each time of day (i.e., 0000, 0300, …, 2100 UTC) were obtained from the 0- or 3-h forecast projections of the GFS model cycle closest to each valid time. Thus, the 50% values are essentially station "constants" that vary by time of day only, and are independent of model forecast projection. An example logit curve for the probability of freezing or frozen precipitation as a function of 850 hPa temperature is shown in Fig. 2 for Dayton, Ohio (KDAY). The 50% value can easily be read from the curve as the value of 850 hPa temperature at which the probability of freezing or frozen precipitation is 50%. The resulting value for KDAY is 269.6 K.

Due to the rarity of freezing and frozen precipitation in some parts of the country (e.g., the southeast U.S. and parts of California), stable estimates for the 50% values could not be obtained for some stations and times. Thus, an objective procedure was used to obtain estimates at stations where the values could not be determined empirically. If values for at least two times were available at a station, a time interpolation was performed to assign values to the missing time(s). If time interpolation was not possible, the values were estimated from each variable's dependence on station elevation. An example of this relationship is shown in Fig. 3 for the variable 1000-850 hPa thickness (0000 UTC time). It is clear that the 50% values vary directly with station elevation, with a strong linear correlation (0.95). As explained in Glahn and Bocchieri (1975), this relationship arises due to the general dependence of free-air temperature on station elevation. For a given 1000-850 hPa thickness, low-level stations will (on average) have a warmer "melting layer" temperature than higher elevation stations, and therefore, will generally have a lower probability of wintry precipitation reaching the surface. Separate relationships were determined for each variable and time of day. The correlation of the 50% values with station elevation is much less for stations below 1500 ft., with a much higher correlation for stations above 1500 ft. (this breakpoint is indicated in Fig. 3). Thus, two different relationships were used to obtain estimates for the 50% values, depending on the elevation of the station.

2.5 *Predictors offered to regression analysis*

After deriving the 50% values, "transformed" predictors were calculated at each station for each of the five variables (i.e., 2-m temperature, 850 hPa temperature, 1000-850 hPa thickness, 1000-500 hPa thickness, and freezing level), by subtracting the corresponding 50% value from the model forecast of that variable (interpolated to the station). These transformed predictors account for climatological differences between stations within a given region. This concept is not new (e.g., Glahn and Bocchieri 1975, Bocchieri and Glahn 1976, Bocchieri and Maglaras 1983, Erickson 1992); however, this technique has never before been applied to develop MOS PoPT guidance for the GFS. A major advantage to transforming the predictors in this way is that it allows data for all stations (for which 50% values are available) to be pooled together into one or more large regions for development, while still retaining station specificity in the equations. The ability to combine data into larger samples is especially advantageous when forecasting rare events (such as freezing and frozen precipitation), when the number of cases available for development is very limited.

In addition to the transformed predictors described above, several GFS model fields and variables derived from the model fields were made available to the regression analysis. These include several thicknesses, temperature and wet-bulb temperature at various levels, temperature advection, u- and v-wind components, and wind speed. A predictor based on the vertical profile of wet-bulb temperature, called the "ZR predictor", also was offered. This predictor identifies cases where freezing precipitation is likely to occur based on the presence of a sufficiently cold surface layer, and a warm layer aloft that will allow melting of the frozen precipitation (Erickson 1992, Allen and Erickson 2001). The raw model fields and derived predictors valid at the forecast projection, as well as 3 hours before and 3 hours after the forecast projection, were included as candidate predictors. Geoclimatic predictors also were offered to the regression analysis, including the monthly conditional relative frequencies of freezing, frozen, and liquid precipitation (see Section 2.3), and the sine and cosine day of the year. Surface observations of temperature, dewpoint, and precipitation type valid at 3 hours past the model cycle time also were offered to the regression for the 6- through 18-h projections.

2.6 *Derivation of forecast equations*

PoPT guidance was developed for the cool season, defined as the period 1 September through 31 May. Seven cool seasons of GFS forecast data and present weather observations at the 1243 stations were available for the development. Equations for the three binary predictands (freezing, frozen, and liquid) were developed simultaneously, meaning that the three equations contain the same predictor variables but have different regression coefficients. This insures that the three probability forecasts are consistent and sum to 100%. As with previous PoPT developments, multiple linear regression was used to develop the forecast equations. This method, called "Regression Estimation of Event Probabilities" (REEP), relates the binary predictands to a linear combination of predictor variables, using a forward stepwise selection method (Miller, 1964). Variables were entered into the equation until none of the remaining predictors could reduce the variance by an additional 0.1%, or until a maximum of 10 predictors had been selected. As expected, the predictors most often selected were the transformed variables (of which 1000-850 hPa thickness was most popular), the ZR predictor, relative frequencies, 2-m wet bulb temperature, 850 hPa temperature, and the observed predictors (for the 6- through 18-h projections).

In order to develop stable forecast equations, stations were grouped into regions with separate sets of equations developed for each region. The resulting equations then are applicable to all stations within the region. This is called a "regionalized operator" approach. The regions used in the development are shown in Fig. 1, and are based on climatology and geographic similarity. There are four CONUS regions and two Alaska regions. The regions are nearly identical to those used in the previous PoPT development (Allen and Erickson 2001). For comparison, equations also were developed using a "generalized operator" approach, whereby stations within the four CONUS regions were combined into one large region and the two Alaska regions were combined in the same manner. Verification scores were computed separately for the regionalized and generalized equations, and are presented in Section 3. There were no observations of freezing or frozen precipitation for stations in Puerto Rico or Hawaii. Thus, these stations were not included in the developmental sample.

2.7 *Gridded relative frequencies & 50% values*

One may wish to generate PoPT forecasts at locations that were not included in the developmental sample. This requires that geoclimatic information (e.g., relative frequencies and logit 50% values) be available at these locations for input to the forecast equations. This can be accomplished by analyzing the station "constants" to points on a high-resolution grid. Once analyzed, the constant data then can be interpolated to *any* station (or point) where PoPT forecasts are desired.

To create the gridded constant datasets, the conditional relative frequencies and 50% values calculated at the 1243 METAR sites were analyzed to high-resolution grids over the CONUS and Alaska, using an enhanced Cressman-like analysis technique (Cressman 1959). The technique, called "BCDG" (named after the persons who developed it – Bergthorssen, Cressman, Doos, and Glahn), uses successive corrections to a first guess field and vertical adjustments to account for variations of a field with elevation. This technique is described in detail in Glahn et al. (2009). This is the same analysis technique currently being used to generate gridded MOS forecasts for NDGD, and also has been used to create gridded snowfall climatologies (Baker et al. 2009). The station data were analyzed to a 5-km Lambert Conformal grid over the CONUS and to a 3-km Polar Stereographic grid over Alaska, with variable radii set around each grid point depending on the density of stations surrounding each point.

The analyzed conditional relative frequency of frozen precipitation, valid on January 15 for the 12-h period 1800-0600 UTC, is shown in Figs. 4a and 4b, for the CONUS and Alaska, respectively. As one would expect, this field is characterized by a south-to-north gradient over the CONUS (4a), with relative frequencies exceeding 0.80 across the north and decreasing to < 0.05 in the far south and parts of California. Relative frequencies exceed 0.95 across much of the interior of Alaska (4b) with values decreasing sharply to < 0.30 near the southern coastline. The relative frequency of liquid precipitation for January (not shown) is the opposite of that for frozen, with lower values further north and higher values to the south. During January, freezing precipitation (not shown) is most likely in the Plains, Ohio Valley, and Mid-Atlantic States, but even here the relative frequencies are very small – generally less than 0.15. The relative frequencies do vary considerably by month, with higher frequencies of frozen precipitation retreating northward in early spring, and moving southward once again in late fall.

Analyzed logit 50% values for the variable 1000-850 hPa thickness for 0000 UTC are shown in Fig 5. Terrain effects are very evident here, with the highest 50% values (> 1400 m) found in the higher elevation, mountainous areas. In contrast, the lowest values (< 1300 m) are found at lower elevations and in areas with a strong marine influence such as the Pacific Northwest (Fig. 5a) and southeast Alaska (Fig. 5b). In these areas, the low-level air flow will usually have a recent overwater trajectory, resulting in a modified low-level temperature profile. Thus, the 50% thickness values will be lower at these stations than at stations without a marine influence.

3. VERIFICATION

In order to evaluate the skill of the new guidance, verification scores were calculated for an independent "test" sample and compared to scores obtained from climatology and the current operational system. For rare elements such as PoPT, it is desirable to have as large a verification sample as possible in order to minimize the effects of sampling variability on the results. This was accomplished using a "k-fold" cross-validation procedure, whereby each season of data was withheld as an independent sample and equations developed on the remaining seasons, repeated seven times. Scores then were calculated for the aggregate of all seven independent samples, which effectively averages out sampling variability.

P-scores were calculated for the new PoPT guidance, the old guidance, and climatology (Fig. 6). The P-score is the mean squared error for probability forecasts. Results for the regionalized equations (blue line) and the generalized operator equations (GOEs) (red line) are shown. For the CONUS (Fig. 6a), the results indicate that the new guidance is more accurate than the old system through 72 hours (note that the old guidance ends at 72 hours), and more accurate than climatology through the entire forecast period (192 hours). In this development, the 3-category product was extended out to 84 hours for consistency with other MOS elements, and also was developed out to 192 hours for the future generation of gridded PoPT guidance to support NDGD. It is also evident (Fig. 6a) that the regionalized equations provide only a slight improvement in forecast accuracy compared to the GOEs. This can mainly be attributed to the inclusion of the transformed predictors, which automatically build station specificity into the equations by capturing climatological variations between stations. Having one region (as opposed to several) alleviates the problem of boundary discontinuities between regions, and thus, ensures spatial consistency of the forecasts. Thus, given the minimal difference in accuracy between the regional and generalized equations (Fig. 6a), it was decided that the GOEs would be used to generate operational PoPT forecasts over the CONUS.

Forecasting PoPT in Alaska (Fig. 6b) is a more challenging problem due to the much smaller number of stations available for development. Nonetheless, the results indicate that the new guidance generally is more accurate than the old system at most projections through 72 hours, and more accurate than climatology through 192 hours. However, there appears to be more benefit to regionalizing in Alaska (as compared to the CONUS), especially in the extended projections.

Categorical forecasts of precipitation type, conditional on precipitation occurring, also are produced from the probability forecasts. Probability thresholds were determined that maximized the threat score on the dependent sample, while maintaining a bias between 0.98 and 1.02. This is consistent with previous developments (e.g., Allen and Erickson 2001). Verification of the categorical forecasts is shown in Fig. 7. The results indicate the new guidance is generally more accurate than the old through the 72 hour projection, over both the CONUS (Fig. 7a) and Alaska (Fig. 7b). Again, there is little difference between the regionalized and generalized results over the CONUS, with a slight preference toward the regionalized equations over Alaska.

4. FORECAST EXAMPLE

On December 8-9, 2009, a major early season winter storm developed over the Central Plains, intensified rapidly, and moved northeast into the Great Lakes. Very heavy snow and blizzard-like conditions affected a large swath of the upper Midwest during this time, especially Nebraska, Iowa, Minnesota, northern Illinois and much of Wisconsin. Forecast maps of the *unconditional* probability of frozen precipitation, obtained from the 0000 UTC run of the GFS on 8 December, 2009, are shown in Fig. 8 for the 24- (a), 30- (b), and 36-h (c) projections. The observed position of the surface low at each forecast time, obtained from surface analyses from the Hydrometeorological Prediction Center (HPC), is indicated on each map. The unconditional probabilities were computed by multiplying the conditional probability of frozen precipitation (from the new PoPT guidance) with the GFS MOS “on-the-hour” probability of precipitation (PoPO) forecast (see Dallavalle et al. 2004 for a description of PoPO). At present, gridded PoPT guidance is not available in NDGD (see Section 5 below for future plans). The probability maps shown in Fig. 8 were produced by interpolating the forecasts at the METAR stations to a raster dataset in GIS, and are meant to serve as a “prototype” to show how a gridded PoPT forecast *may* have looked in NDGD had it been available to National Weather Service forecasters at the time. Very high unconditional probabilities (> 90%) were forecast in areas where heavy snowfall was observed, including much of Iowa, Minnesota, and Wisconsin. The sharp gradient in probabilities to the southeast is consistent with the observed track of the surface low, with probabilities dropping off sharply toward the warm sector of the storm where rain was the predominant precipitation type.

5. PRODUCTS & FUTURE PLANS

Probabilistic and categorical precipitation type forecasts (conditional on the occurrence of precipitation) will be produced for nearly 1800 METAR sites in the CONUS, Alaska, and Canada, and are available in the short-range text messages for projections every 3 hours out to 72 hours. This represents a large increase in the number of stations at which PoPT forecasts can be made (as compared to the current ~ 1300 stations). This is now possible because of the availability of gridded constant datasets (Section 2.7), from which values can be interpolated to any station where PoPT forecasts are desired. GOEs are applied to all stations in the CONUS, while two regionalized sets of equations are applied to stations in Alaska (see Fig. 1). The 4-category medium-range product (not discussed in this paper) was also redeveloped, with probabilistic and categorical forecasts valid over 12-h periods from 24 to 192 hours in advance. See Allen (2001) for a complete description of the medium-range product. The anticipated implementation date for the updated PoPT guidance is late January 2010.

Future plans involve the addition of gridded probabilities of freezing, frozen, and liquid precipitation types to the suite of guidance available in NDGD. The gridded guidance will be available every 3 hours from 6 to 192 hours in advance for the 0000 and 1200 UTC cycles. We believe this new gridded guidance will be useful to forecasters and the general public.

6. SUMMARY AND CONCLUSIONS

Updated equations for the conditional probability of freezing, frozen, and liquid precipitation types have been developed for all cycles of the GFS out to 84 hours in advance, and for the 0000 and 1200 UTC cycles out to 192 hours. Verification results indicate that the skill of the new guidance has been improved over that of the current operational system. The improvement is due to the availability of a longer developmental sample, a more robust climatology, and the use of logit 50% values and transformed predictors in the equations. A major advantage to including transformed predictors is the ability to combine data into one large region (or generalized operator) for development, while still retaining station specificity in the equations. The development of gridded constant datasets allows geoclimatic data to be interpolated to any station where PoPT forecasts are desired (e.g., at stations that were not included in the developmental sample). The use of GOEs simplifies the generation of gridded probability forecasts for NDGD, and also alleviates the problem of boundary discontinuities between regions.

7. ACKNOWLEDGMENTS

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8. REFERENCES

Allen, R. L., and M. C. Erickson, 2001: AVN-based MOS precipitation type guidance for the United States. *NWS Technical Procedures Bulletin* No. 476, NOAA, U.S. Dept. of Commerce, 8 pp.

___, 2001: MRF-based MOS precipitation type guidance for the United States. *NWS Technical Procedures Bulletin* No. 485, NOAA, U.S. Dept. of Commerce, 8 pp.

Baker, M. N., K. L. Sheets, and G. A. Wagner, 2009: Using gridded MOS techniques to derive snowfall climatologies. Preprints*, 23rd Conf. Weather Analysis and Forecasting/19th Conf. Numerical Weather Prediction,* Omaha, NE, Amer. Meteor. Soc.

Bocchieri, J. R., and H. R. Glahn, 1976: Verification and further development of an operational model for forecasting the probability of frozen precipitation. *Mon. Wea. Rev.*, **104**, 691-701.

___, and G. J. Maglaras, 1983: An improved operational system for forecasting precipitation type. *Mon. Wea. Rev.*, **111**, 405-419.

Cressman, G. P., 1959: An operational objective analysis system. *Mon. Wea. Rev.*, **87**, 367-374.

Dallavalle, J. P., M. C. Erickson, and J. C. Maloney, 2004: Model Output Statistics (MOS) Guidance for Short-Range Projections. Preprints*, 20th Conference on Weather Analysis and Forecasting*, Seattle, Amer. Meteor. Soc.

Erickson, M. C., 1992: MOS Precipitation Type Forecasts Based on the Nested Grid Model. Preprints*, 12th Conference on Probability and Statistics in the Atmospheric Sciences*, Toronto, Canada, Amer. Meteor. Soc.

Glahn, H. R., and J. R. Bocchieri, 1975: Objective estimation of the conditional probability of frozen precipitation. *Mon. Wea. Rev.*, **103**, 3-15.

___, K. Gilbert, R. Cosgrove, D. P. Ruth, and K. Sheets, 2009: The gridding of MOS. *Wea. Forecasting*, **24**, 520-529.

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

Table 1. Definitions of GFS MOS precipitation type categories.

Freezing	**Frozen**	**Liquid**
Freezing rain (FZRA)	Snow (SN)	Rain/snow mix (RASN)
Freezing drizzle (FZDZ)	Snow showers (SHSN)	Rain/snow showers (SHRASN)
Ice pellets (PL)	Snow grains (SG)	Drizzle (DZ)
		Rain/drizzle (RADZ)
		Rain (RA)
		Rain shower (SHRA)
		Thunderstorm (TSRA)

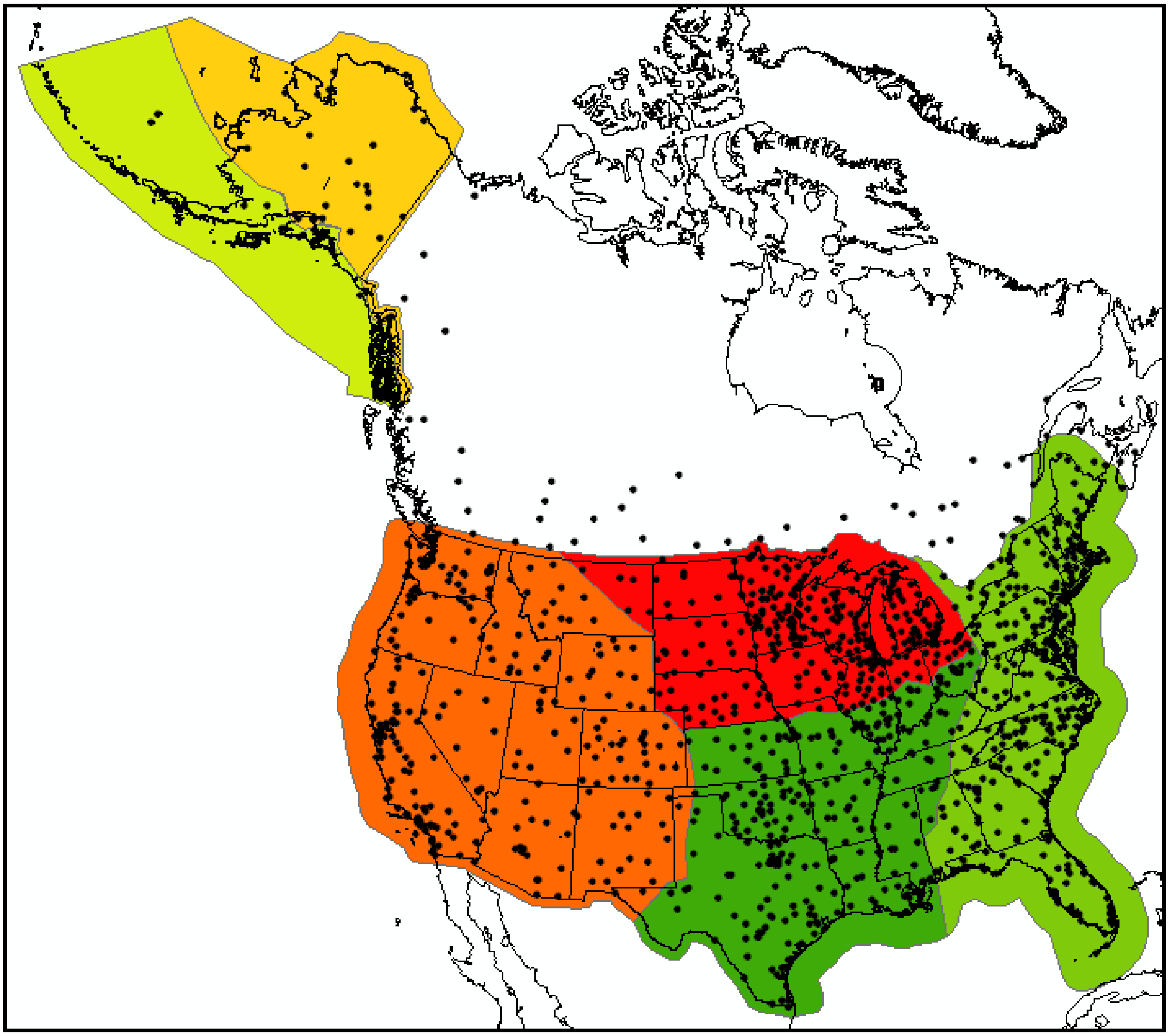


Figure 1. Geographic regions used in the development of the PoPT guidance (4 regions in the CONUS and 2 regions in Alaska). Generalized operator equations encompass all 4 regions of the CONUS and both regions in Alaska. The locations of the METAR sites used in the development are indicated by the black circles. Guidance was not developed for stations in Hawaii and Puerto Rico.

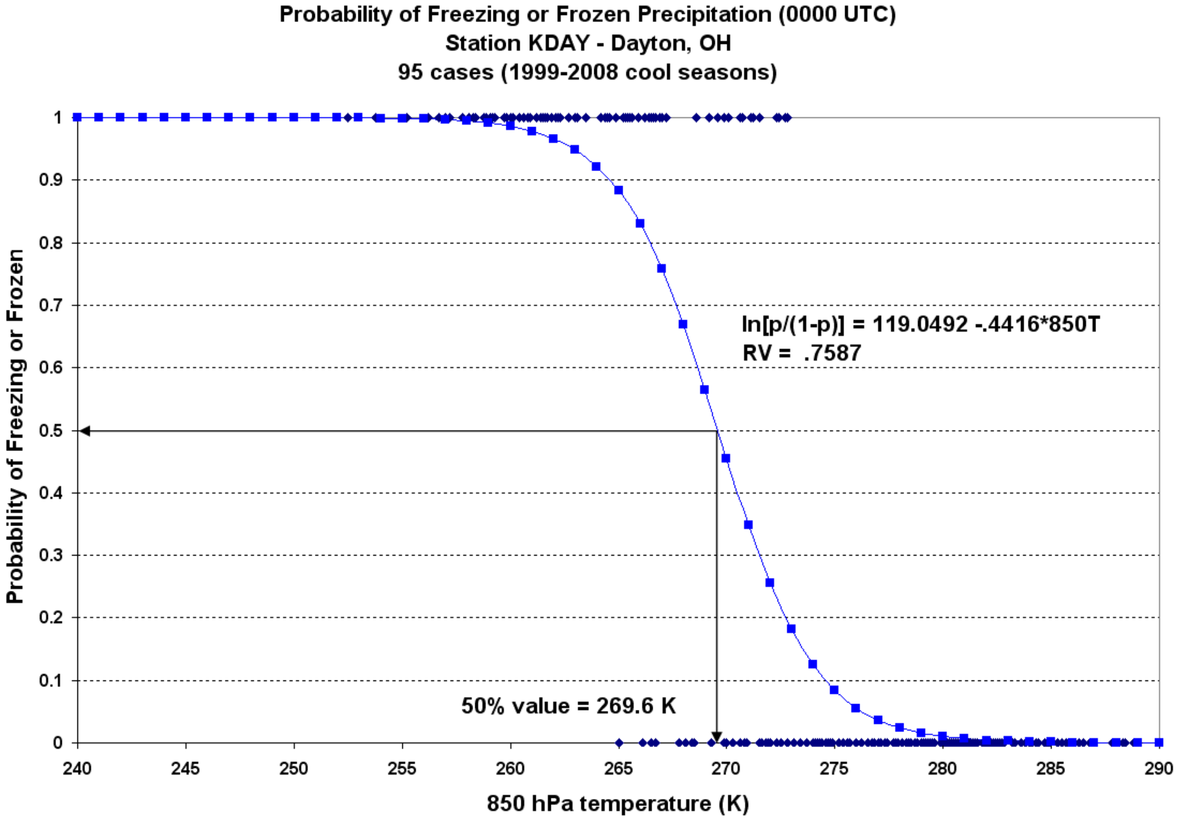


Figure 2. Logit curve for the probability of freezing or frozen precipitation as a function of 850 hPa temperature at Dayton, Ohio (KDAY) for 0000 UTC. Observations of freezing or frozen precipitation (*Y*=1) and liquid precipitation (*Y*=0) are plotted. The logit "50%" value is the value of 850 hPa temperature at which the probability of freezing or frozen precipitation is 50% (~ 270 K).

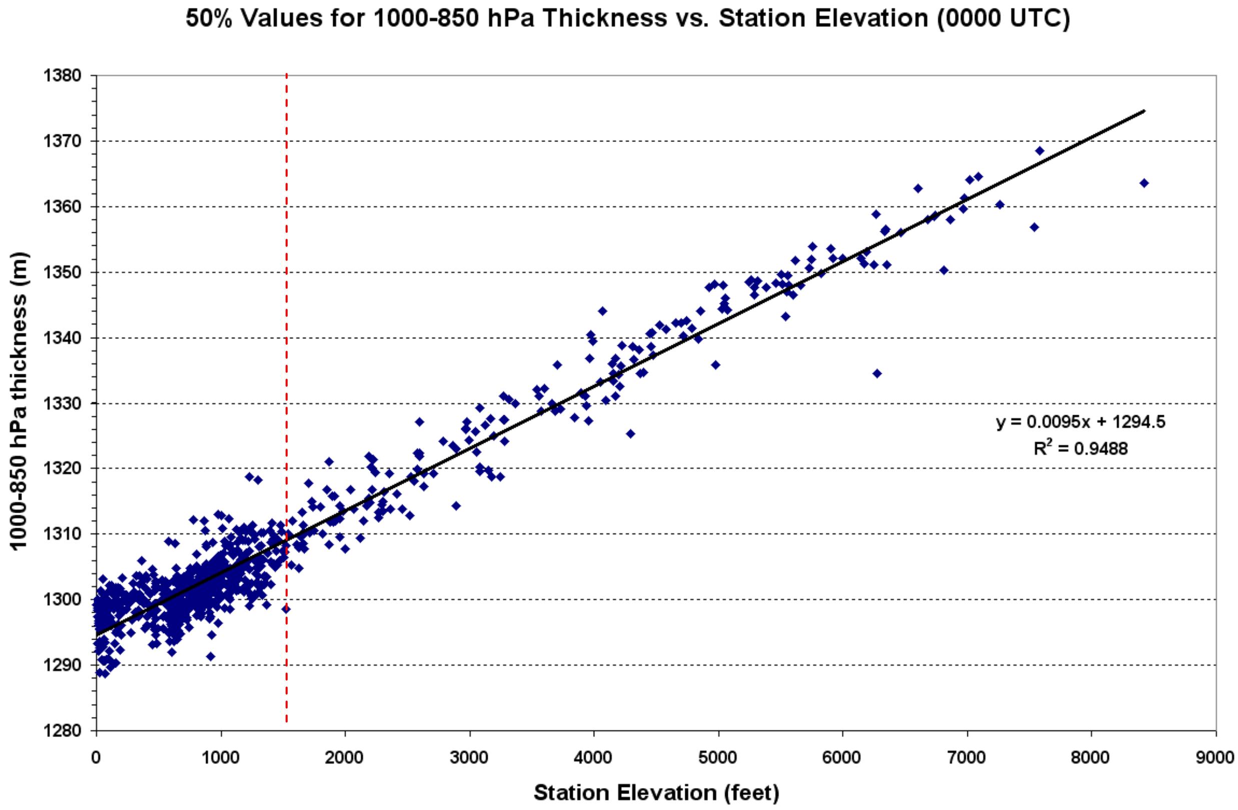


Figure 3. 50% values for 1000-850 hPa thickness (m) as a function of station elevation (feet), for 0000 UTC. Separate linear regression relationships were determined for stations below 1500 ft. and for stations above 1500 ft. (this threshold is indicated by the vertical dashed line on the graph).

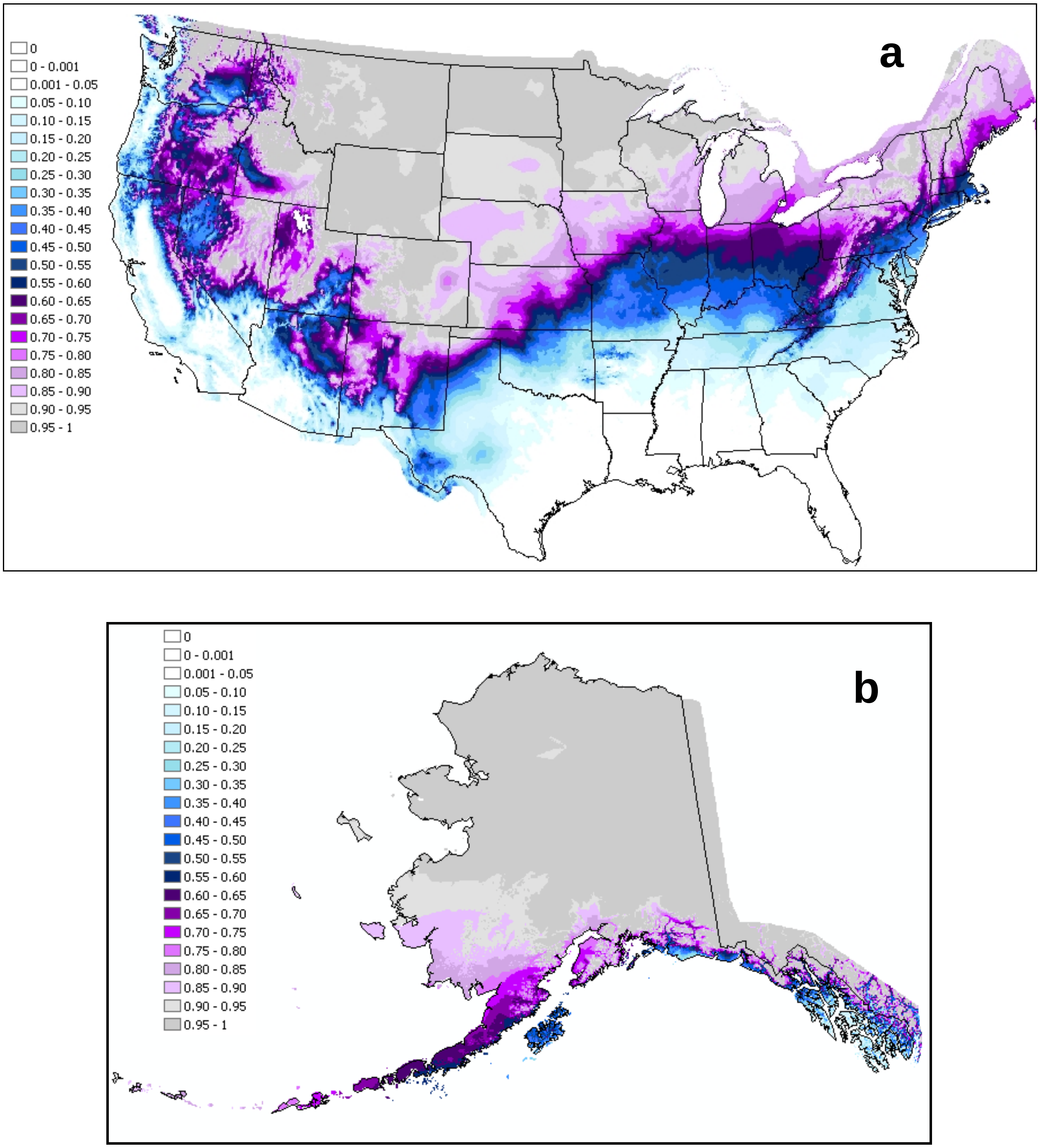
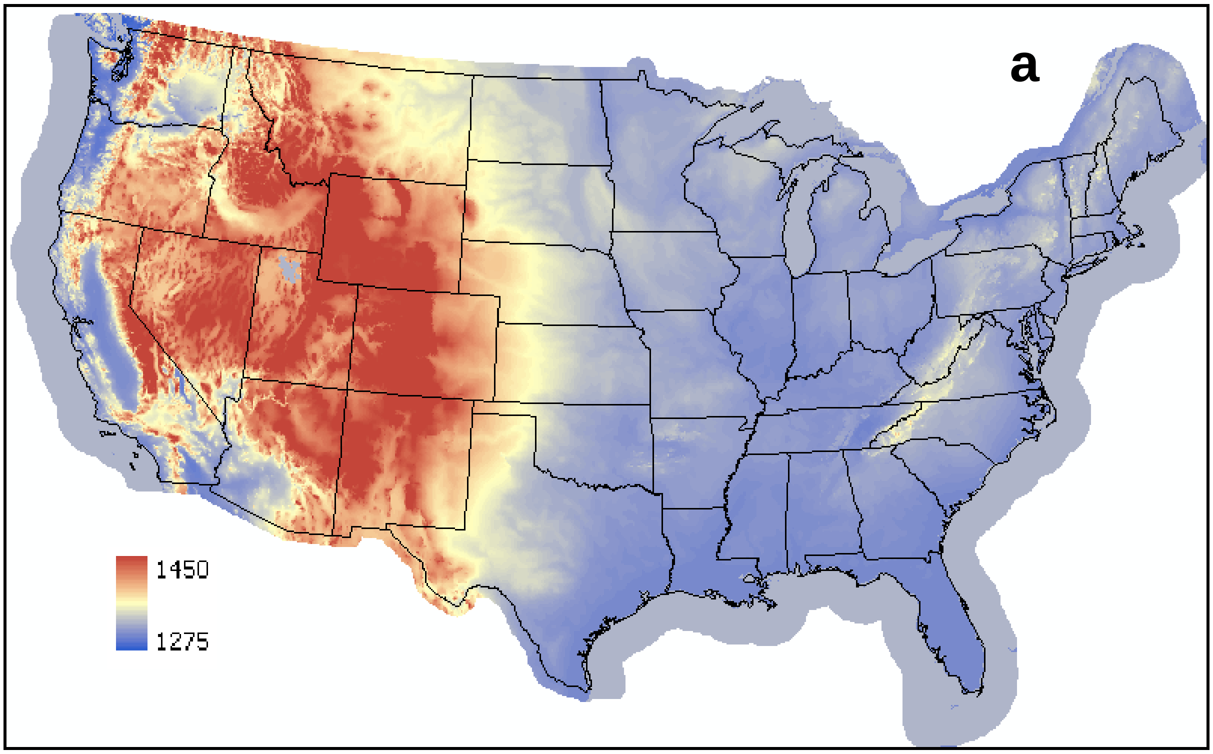


Figure 4. Analyzed conditional relative frequency of frozen precipitation for a) the CONUS and b) Alaska, valid January 15 for the 12-h period 1800-0600 UTC.



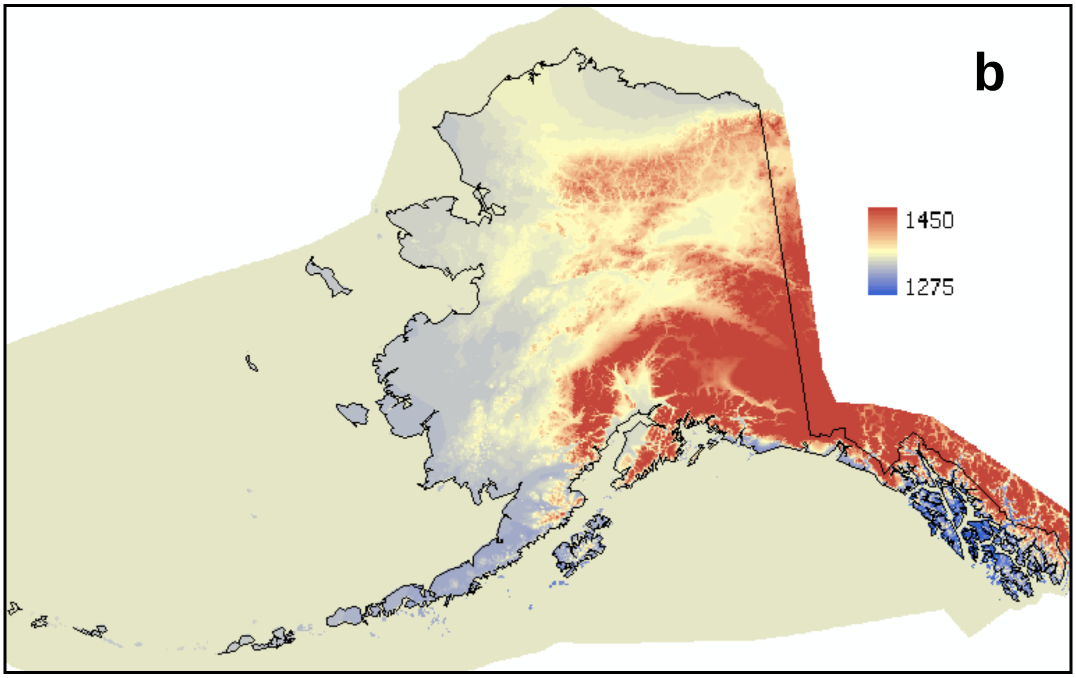


Figure 5. Analyzed 1000-850 hPa thickness 50% value (meters) for a) the CONUS and b) Alaska, valid for the 0000 UTC time.

Figure 6. P-scores for the new GFS MOS PoPT guidance (regionalized equations in blue, GOE in red), climatology (in green), and the operational system (pink), for the 0000 UTC model cycle.

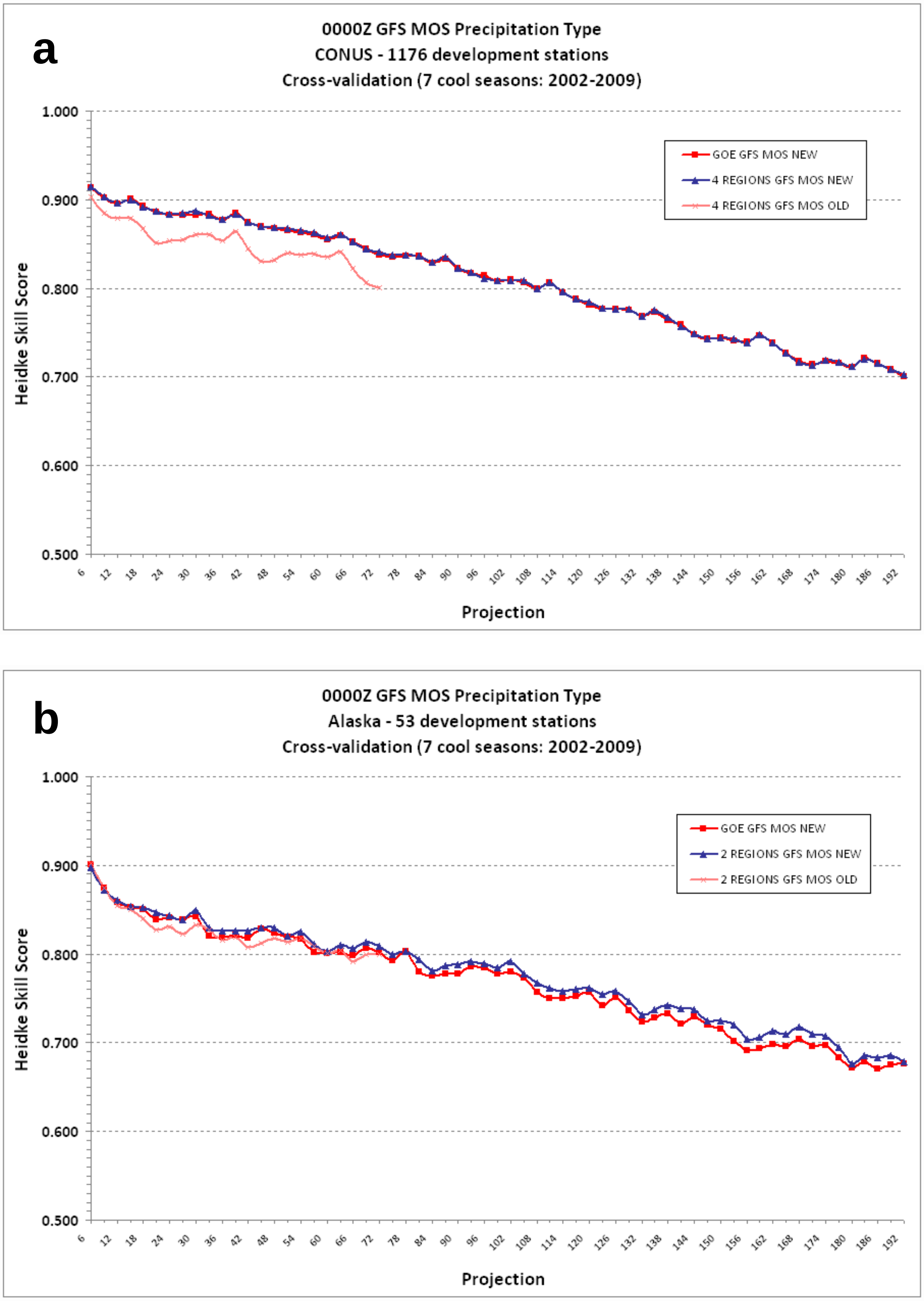


Figure 7. Heidke Skill Scores for the new GFS MOS categorical precipitation type guidance (regionalized equations in blue, GOE in red), and the operational system (pink), for the 0000 UTC model cycle.

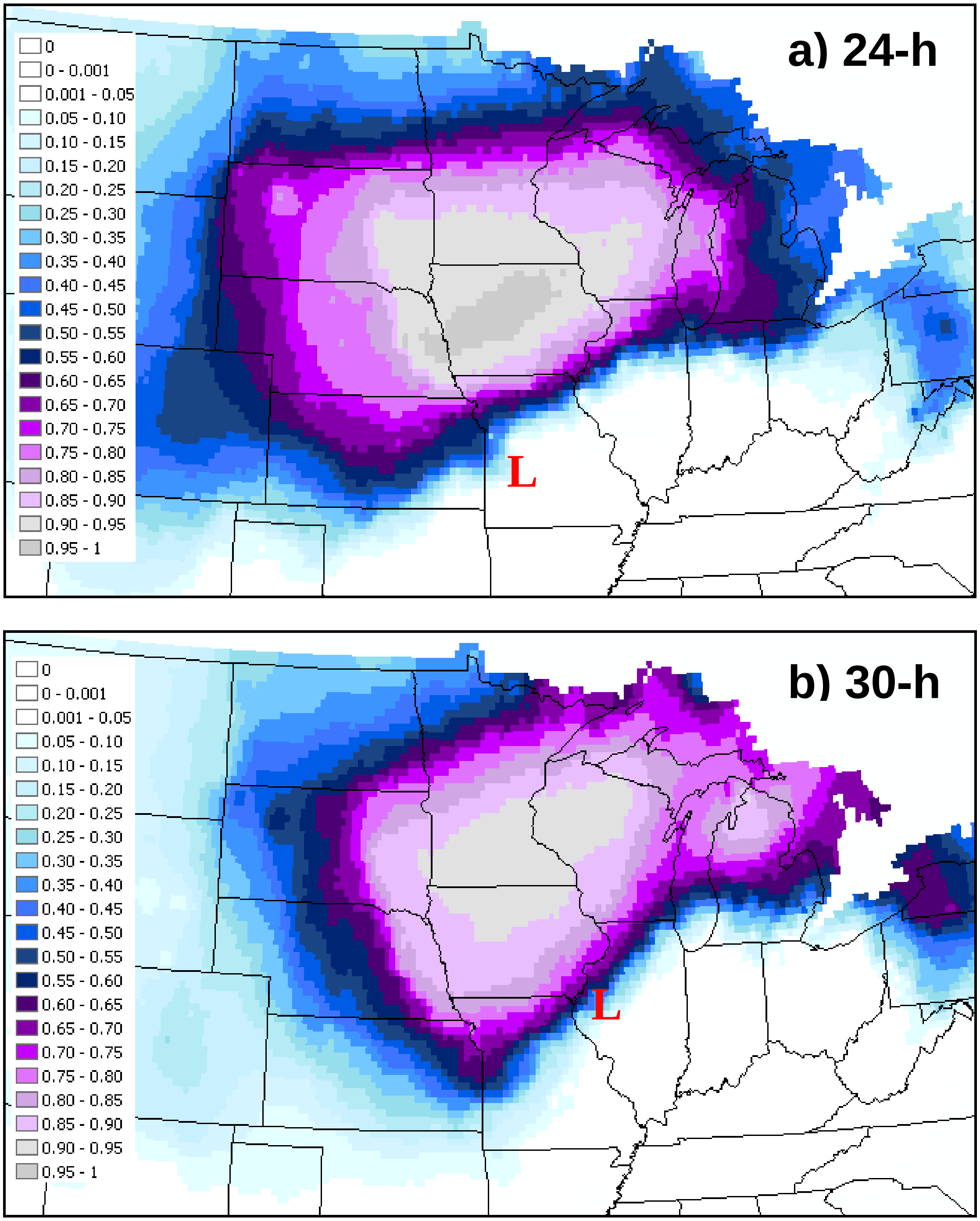


Figure 8. GFS MOS unconditional probability of frozen precipitation from the 0000 UTC run on 8 December 2009. Forecasts for the 24-h (a), 30-h (b), and 36-h (c) projections are shown. The observed position of the surface low at each forecast time is indicated by the red "L" on each plot.

Figure 8 continued.