1.4 DEVELOPMENT OF A NEW NAM-BASED MOS PRECIPITATION TYPE SYSTEM

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1. INTRODUCTION

The Meteorological Development Laboratory (MDL) has recently updated its suite of station-based Model Output Statistics (MOS) guidance based on the North American Mesoscale (NAM) model, adding a new precipitation type system. The MOS technique (Glahn and Lowry 1972) has been employed by MDL to post-process NWP output for several decades. MDL implemented the first Eta-based MOS system in the spring of 2002 (see Dallavalle and Erickson 2002). In 2006, the National Centers for Environmental Prediction (NCEP) replaced the Eta model with the Non-hydrostatic Mesoscale Model (NMM) core of the Weather Research and Forecasting (WRF) system, which is the model presently run in the NAM time slot of the NCEP production suite (Rogers et al. 2005). Shortly thereafter, a new suite of MOS guidance was developed for the WRF-NMM to replace the previous Eta-based system (see Antolik and Baker 2009, Maloney et al. 2009).

To date, statistically post-processed guidance for precipitation type has only been available as part of the Global Forecast System (GFS)-based MOS (see Allen and Erickson 2001, Shafer 2010), and more recently, for internal use by National Weather Service forecasters as part of the European Centre for Medium-Range Weather Forecasts (ECMWF) MOS system (see Shafer and Rudack 2014). In early 2016, the operational suite of NAM MOS will be enhanced with the addition of probabilistic and best category precipitation type guidance. A three-category NAM MOS precipitation type system has been developed at stations over the contiguous U.S. (CONUS) and Alaska, for the 0000 and 1200 UTC cycles. Equations for the conditional probability of freezing, frozen, and liquid precipitation types were developed for projections every 3 hours valid on the hour, out to 84 hours in advance. Best category forecasts are produced by applying statistically-derived thresholds to the probability forecasts.

This paper describes the development of the NAM-based MOS precipitation type system and its performance when compared to climatology and corresponding MOS forecasts from the GFS. Section 2 gives an overview of the methodology. Example forecast products are shown in Section 3. Verification scores are presented in Section 4. Finally, a summary is given in Section 5.

2. METHODOLOGY

The procedure described here for developing the NAM MOS precipitation type system follows closely the approach used for the GFS MOS (see Shafer 2010) and ECMWF MOS developments (see Shafer and Rudack 2014).

2.1 *Observations*

Present weather observations at METAR sites are used to define the MOS precipitation type predictand. Observations were examined for nearly 2600 stations in the CONUS and Alaska, covering the period September 2006 through April 2015. This nine-year period corresponds to the sample of NMM model data that was available for this development. To be included in the development sample, a station must have reported present weather on 50% or more of possible reporting times during the cool season (defined as September through May) for 3 or more seasons during the nine-year period. This requirement excludes most part time stations from consideration, and ensures that only stations that report present weather reliably are used in the development (Shafer 2010, Shafer and Rudack 2014). In addition, only stations located within the extent of the gridded geoclimatic datasets (described later in Section 2.3) were included in the sample. Of the original 2600 stations that were considered, roughly 1650 met the above-mentioned criteria for inclusion, of which 1555 are in the CONUS and 76 are in Alaska. As in previous developments, some reliable Canadian stations in close proximity to the

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CONUS and Alaska (totaling 16) were used to supplement the sample. Due to the lack of freezing and frozen cases in Hawaii and Puerto Rico, precipitation type guidance is not available for those areas.

2.2 *Predictand definition*

Present weather observations valid every three hours on the hour (i.e., 0000, 0300, 0600, … 2100 UTC) were classified into one of four mutually-exclusive categories: freezing, frozen, liquid, or no precipitation (i.e. a "null" category). The "null" category also included cases when the exact type of precipitation could not be determined (such as unknown precipitation or a missing observation). All "null" cases were treated as missing and not included in the development; thus, only precipitation cases of discernible type comprised the developmental sample. The present weather observations that correspond to each precipitation type category are listed in Table 1. These definitions are consistent with previous MOS precipitation type developments (e.g., Allen and Erickson 2001, Shafer 2010, Shafer and Rudack 2014). Correctly forecasting events of freezing rain and sleet is a challenge, as freezing events comprise only ~1.5% of all precipitation cases over the CONUS and only 0.5% of cases over Alaska.

2.3 *Gridded geoclimatic predictors*

Stations may have similar model forecasts but often experience vastly different weather due to localized effects that are not well-resolved on the model scale. One way to help capture these effects is to incorporate geoclimatic information as predictors in the regression analysis. Conditional relative frequencies of freezing, frozen, and liquid precipitation, valid for 12-h periods centered on each 3-h forecast valid time, were calculated at each METAR site from 10 years of observations as part of a recent GFS MOS development (see Shafer 2010). The relative frequencies then were analyzed to high resolution grids over the CONUS and Alaska using the "BCDG" analysis technique (named after the persons who developed it – Bergthorssen, Cressman, Doos, and Glahn). This technique is described in detail in Glahn et al. (2009). An example plot of the conditional relative frequency of frozen precipitation over the CONUS for the month of January is shown in Fig. 1. This plot reveals an expected south to north gradient in the relative frequency of frozen precipitation. Some terrain influences are also evident mainly over the Western U.S.; likely a result of the vertical adjustments applied by the BCDG technique.

Additional geoclimatic information was incorporated through the use of logit 50% (or equal-probability) values. The 50% values were calculated at each METAR site for several parameters that are generally considered to be good discriminators of precipitation type, including 2-m temperature, 850-hPa temperature, 1000-850 hPa thickness, 1000-500 hPa thickness, and freezing level (see Shafer 2010 for more details on how the 50% values were derived). The 50% value is then subtracted from the model forecast of that particular variable to obtain a new "logit transform" predictor that helps to account for climatological differences among stations (Shafer 2010). As with the relative frequencies, the BCDG technique was employed to analyze the 50% values to high resolution grids over the CONUS and Alaska.

An added benefit to incorporating geoclimatic information in the regression analysis is the ability to combine stations into one or more large regions for development, while still retaining some degree of station specificity in the equations. This is particularly important when forecasting rare events such as freezing precipitation, since the number of cases in the training sample is very limited. In addition, having the geoclimatic information available in gridded form allows values to be interpolated to any desired point; thus, MOS precipitation type forecasts can be made even at stations that were not included in the development sample.

2.4 *Regression analysis*

NAM MOS precipitation type guidance was developed for the cool season, defined as the period 01 September – 31 May over the CONUS and 01 September – 15 June over Alaska. Roughly nine cool seasons of NAM forecast output and present weather observations were available for the development (September 2006 through April 2015). Model data were comprised of a mix of retrospective output from the then current NAM version and output from previous model versions. As found by Antolik and Baker (2009), it can be beneficial to mix data from different configurations of the NWP model even if the bias characteristics of each version are somewhat different. The practice of combining data from different model versions is often a necessity when developing MOS for rare events, as there is often not enough retrospective output available from the latest model version to obtain stable equations.

Several model-derived predictors were offered to the regression analysis, including various thicknesses, temperature and wet-bulb temperature at various levels, temperature advection, and a predictor based on the vertical profile of wet-bulb temperature, called the "Z-R predictor" (Allen and Erickson 2001, Shafer 2010, Shafer and Rudack 2014). Geoclimatic predictors offered to the regression include the aforementioned logit transforms, monthly relative frequencies of freezing, frozen, and liquid precipitation, and the sine and cosine of the day of the year. For projections through 18 hours, observations of temperature, dewpoint, and precipitation type valid 1 h past the model cycle time also were offered as predictors (e.g., equations developed for the 0000 UTC cycle used observed predictors valid at 0100 UTC).

A multiple linear regression approach, known as "Regression Estimation of Event Probabilities" (REEP), was used to derive the equations (Allen and Erickson 2001, Shafer 2010, Shafer and Rudack 2014). This method relates the binary predictands to a linear combination of predictor variables using a forward stepwise selection procedure (Miller 1964). The equations for all predictands were developed simultaneously; that is, the equations contain the same predictor variables but have different regression coefficients. The most influential predictors include the logit transforms (transformed 1000-850 hPa thickness was most important), the Z-R predictor, the conditional relative frequencies of freezing, frozen, and liquid precipitation, 2-m wet bulb temperature, 850 hPa temperature, and observed precipitation type. A secondary set of equations was developed without observed predictors to serve as backup when there is no observation for a particular station.

In order to develop stable forecast equations, stations were combined into four regions over the CONUS and two regions over Alaska (regions are depicted in Fig. 2). This technique, known as a "regionalized operator" approach, is necessary because cases of freezing and frozen precipitation do not occur frequently enough at individual stations to obtain stable single-station equations. Pooling data into one or more regions in this way helps to increase the number of freezing and frozen cases in the sample, and the resulting regional equations are applicable to all stations within the respective region.

2.5 *Postprocessing*

The probability forecasts are first normalized by truncating any negative probabilities to zero and then dividing each by the sum of the positive probabilities to get the normalized probability (i.e. probabilities which sum to 100%). Next, a conditional best category forecast is produced by applying statistically-derived thresholds to the normalized probabilities. Here, the thresholds were chosen which maximized the threat score on the dependent sample, while constraining the bias to within a reasonable range (0.98 and 1.02).

3. GUIDANCE PRODUCTS

Equations for the conditional probability of freezing, frozen, and liquid precipitation types were developed for projections every 3 hours from 6 to 84 hours in advance for the 0000 and 1200 UTC cycles. Forecasts from these equations will be included in the NAM MOS alphanumeric text bulletins beginning in early 2016. An example text bulletin containing the precipitation type guidance is shown in Fig. 3 for Cleveland, Ohio (KCLE). The text bulletin contains probabilistic forecasts for the occurrence of freezing precipitation (labeled POZ) and snow (labeled POS), as well as a categorical forecast of the most likely precipitation type (labeled TYP). The conditional probability of liquid precipitation (not present) can be deduced by subtracting the sum of POZ and POS from 100.

The new NAM MOS precipitation type guidance is also available to forecasters experimentally in gridded format. The gridded guidance is produced by evaluating a generalized operator equation directly at each NDGD grid point over the CONUS and Alaska (at 2.5 km and 3 km resolution, respectively). An example gridded NAM MOS forecast for precipitation type best category is shown in Fig. 4 for the CONUS.

4. VERIFICATION

To assess the skill of the NAM MOS precipitation type guidance, verification scores were calculated for an independent sample and compared to climatology and operational GFS MOS forecasts. To minimize the effects of sampling variability on the results, it is desirable to have as large a verification sample as possible. This is especially true when forecasting rare events such as freezing and frozen precipitation. Similar to the procedure used for past precipitation type developments, this was accomplished using "k-fold" cross-validation whereby one season at a time was withheld as independent data (see Shafer 2010 and Shafer and Rudack 2014 for a more detailed description of this procedure). The results presented here (and shown in Figs. 5-7) are for the 0000 UTC cycle and are aggregated for all stations in the development. Testing was not performed for the 1200 UTC cycle, however it is assumed the results would be similar to 0000 UTC.

For comparison with operational GFS MOS and climatology, P-scores were calculated for the NAM MOS system, operational GFS MOS, and for a reference climatology forecast, over the whole nine-season sample. Here, climatology is simply the conditional relative frequency of freezing, frozen, and liquid precipitation computed from 10 cool seasons of observations (see Section 2.3). The p-score is essentially the mean squared error for the probability forecasts summed over each of the nominal binary events to which the probabilities relate (Wilks 2006). Fig. 5 shows the percent improvement in p-score over the reference climatology forecasts for the NAM MOS system (blue) and operational GFS MOS (red), for the nine independent cross-validated cool seasons. Overall, the NAM MOS system is comparable in skill to operational GFS MOS forecasts, with slightly superior skill through about 48 hours with the exception of the 6-h projection.

The best category forecasts were verified by computing the Heidke Skill Score (HSS). HSS is the fractional improvement in the number of correct forecasts of the system being verified over a random forecast, given the observed frequencies (Glahn et al. 2014). Scores are shown in Fig. 6 for the new NAM MOS system (blue) and operational GFS MOS (red). Bias for the freezing category is shown for each system in Fig. 7. The results indicate the NAM MOS is superior to GFS MOS when forecasting the most likely category (Fig. 6), with a substantially reduced over-forecasting bias for the rare freezing category compared to operational GFS MOS (Fig. 7). This could be attributed to the NAM having a better representation of the low-level thermal profile, which is critical to precipitation type forecasting. Also, the GFS model has undergone more drastic and frequent changes in recent years which may be degrading the GFS MOS forecasts to some extent.

5. SUMMARY

A new NAM MOS precipitation type system has been developed at stations for the 0000 and 1200 UTC model cycles. Probabilistic and best category precipitation type guidance will be made available in the NAM MOS alphanumeric text message beginning in early 2016, and is already available experimentally to forecasters in gridded format. Results from a k-fold cross-validation test indicate the NAM MOS precipitation type system is more skillful than corresponding GFS MOS forecasts out to 84 hours in advance, with improved discrimination of the most likely category relative to GFS MOS.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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Table 1. Definitions of NAM MOS precipitation type categories.

Freezing	Frozen	Liquid
Freezing rain (FZRA)	Snow (SN)	Drizzle (DZ)
Freezing drizzle (FZDZ)	Snow showers (SHSN)	Rain/drizzle (RADZ)
Ice pellets (PL)	Snow grains (SG)	Rain (RA)
Any precipitation in combination with any of the above.		Rain shower (SHRA)
		Thunderstorm (TSRA)
		Mixture of any of the above with snow.

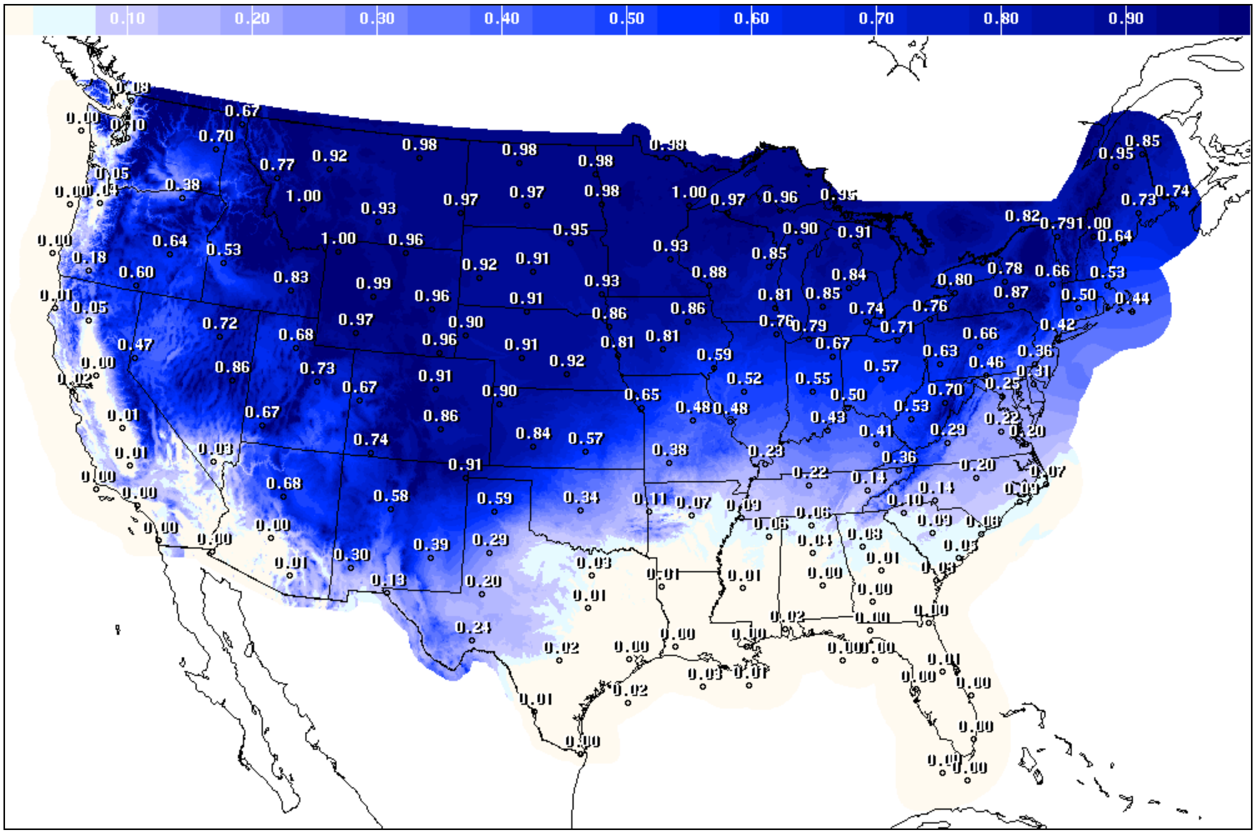

Figure 1. Example gridded precipitation type relative frequency for snow over the CONUS (January).

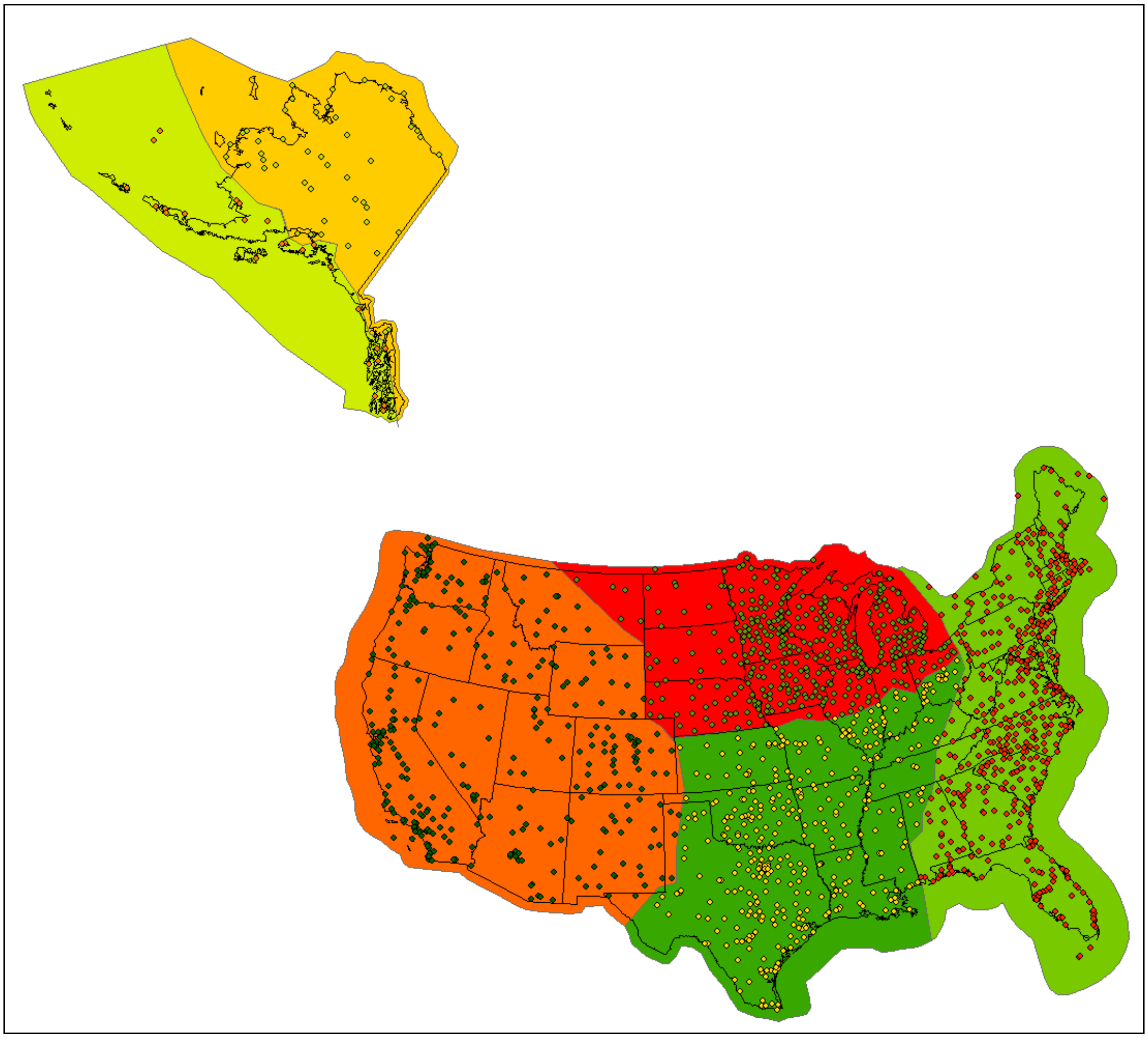

Figure 2. Regions used in the NAM MOS precipitation type development.

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KCLE   NAM MOS GUIDANCE   12/29/2015  0000 UTC
DT /DEC  29            /DEC  30                /DEC  31          /
HR   06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 18 00
X/N                    46          30          39          28    33
TMP  42 43 44 45 44 41 38 35 33 32 32 35 36 36 34 34 32 30 29 31 29
DPT  36 36 37 38 36 34 31 28 28 27 27 28 27 27 26 27 26 24 23 24 22
CLD  OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV
WDR  15 19 18 22 23 24 23 23 23 21 22 18 22 27 25 24 25 25 25 25 23
WSP  14 15 11 13 15 15 11 08 07 04 05 06 07 09 08 11 10 11 10 11 09
P06        71    23     3     2     5    38    57    18    27 20 25
P12                    30           7          81          30    25
Q06         1     0     0     0     0     1     1     0     0  0  0
Q12                     0           0           2           0     0
T06      3/ 3  0/ 7  0/ 2  0/ 0  0/ 7  0/ 1  0/ 4  0/ 1  0/ 1  0/ 3
T12            3/14        0/ 4        0/ 7        0/ 4     0/ 1
POZ   1  1  1  1  1  1  3  2  4  6  6  8  4  2  0  0  1  0  1  1  1
POS   0  0  0  0  0  0  0 18 19 24 23 11 11 20 41 63 87 88 92 94 93
TYP   R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  S  S  S  S  S  S
SNW                                 0                       1
CIG   4  3  4  3  4  6  6  5  6  5  4  3  3  3  3  3  4  4  4  4  4
VIS   7  6  5  5  7  7  7  7  7  7  7  7  5  4  5  7  7  7  7  7  7
OBV   N  N BR BR  N  N  N  N  N  N  N  N BR BR HZ  N  N  N  N  N  N
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Figure 3. Example NAM MOS text bulletin containing precipitation type guidance for Cleveland, Ohio (KCLE). The bulletin contains probabilities for the occurrence of freezing precipitation (labeled POZ) and snow (labeled POS), and the most likely precipitation type category (labeled TYP).

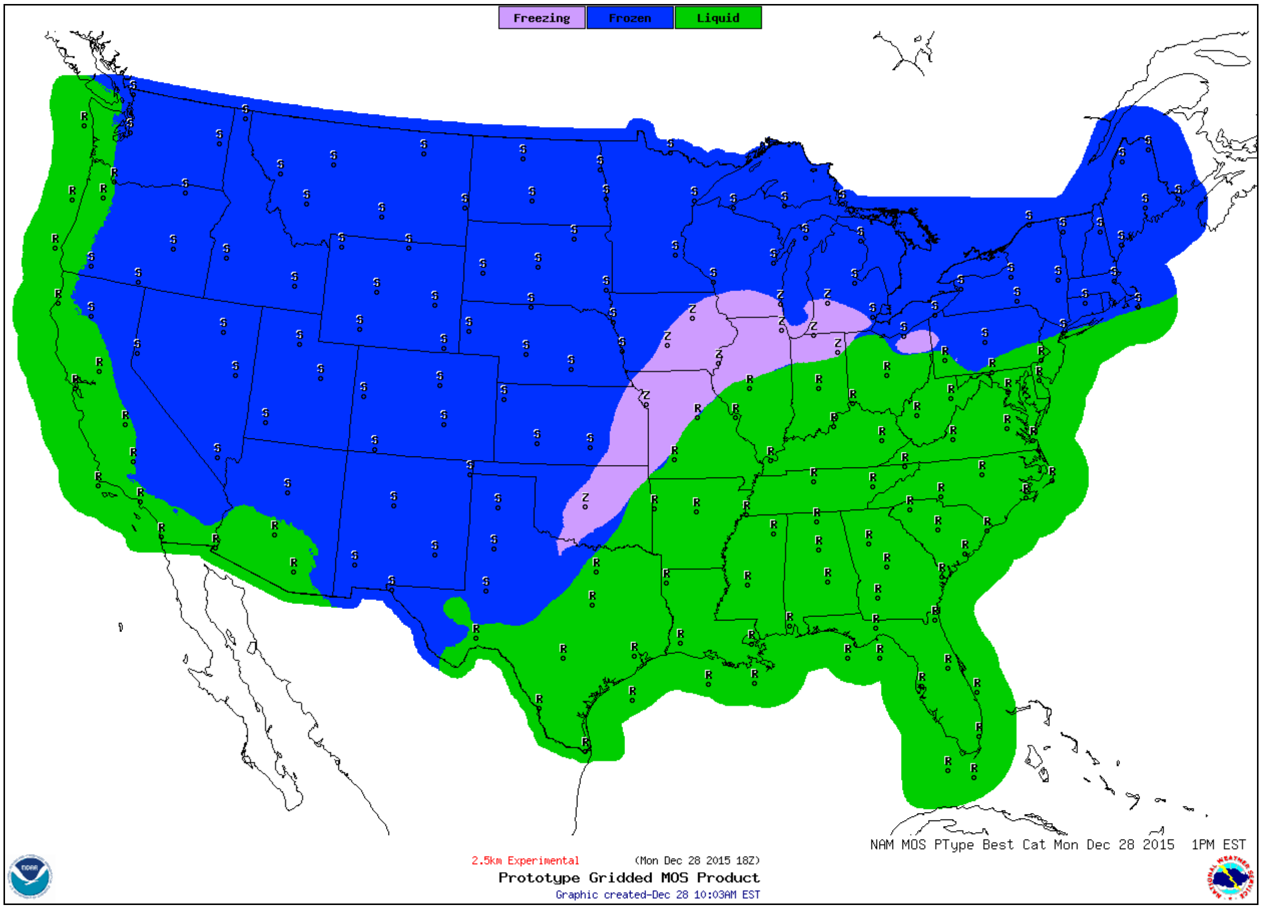

Figure 4. Example gridded NAM MOS precipitation type best category forecast.

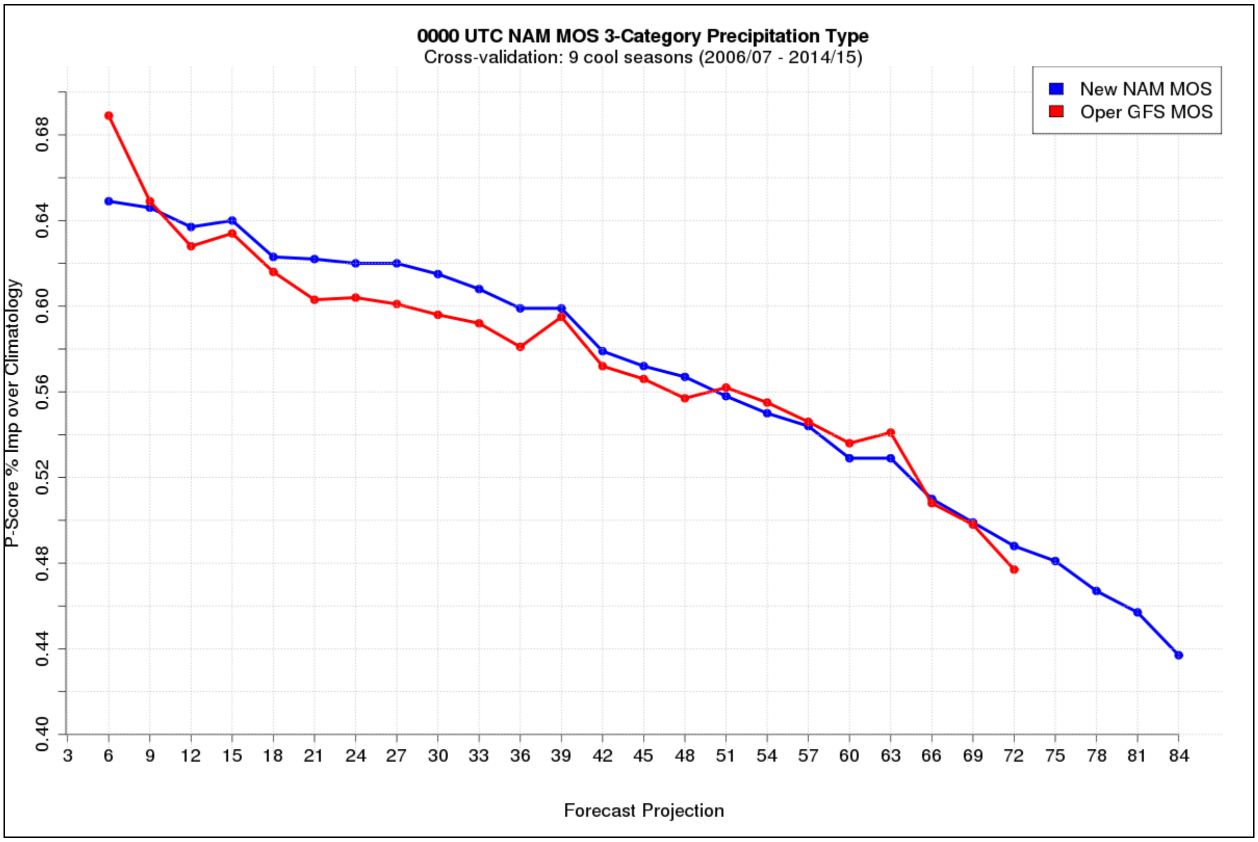

Figure 5. P-score percent improvement over climatology for the new NAM MOS precipitation type system (blue) and operational GFS MOS (red).

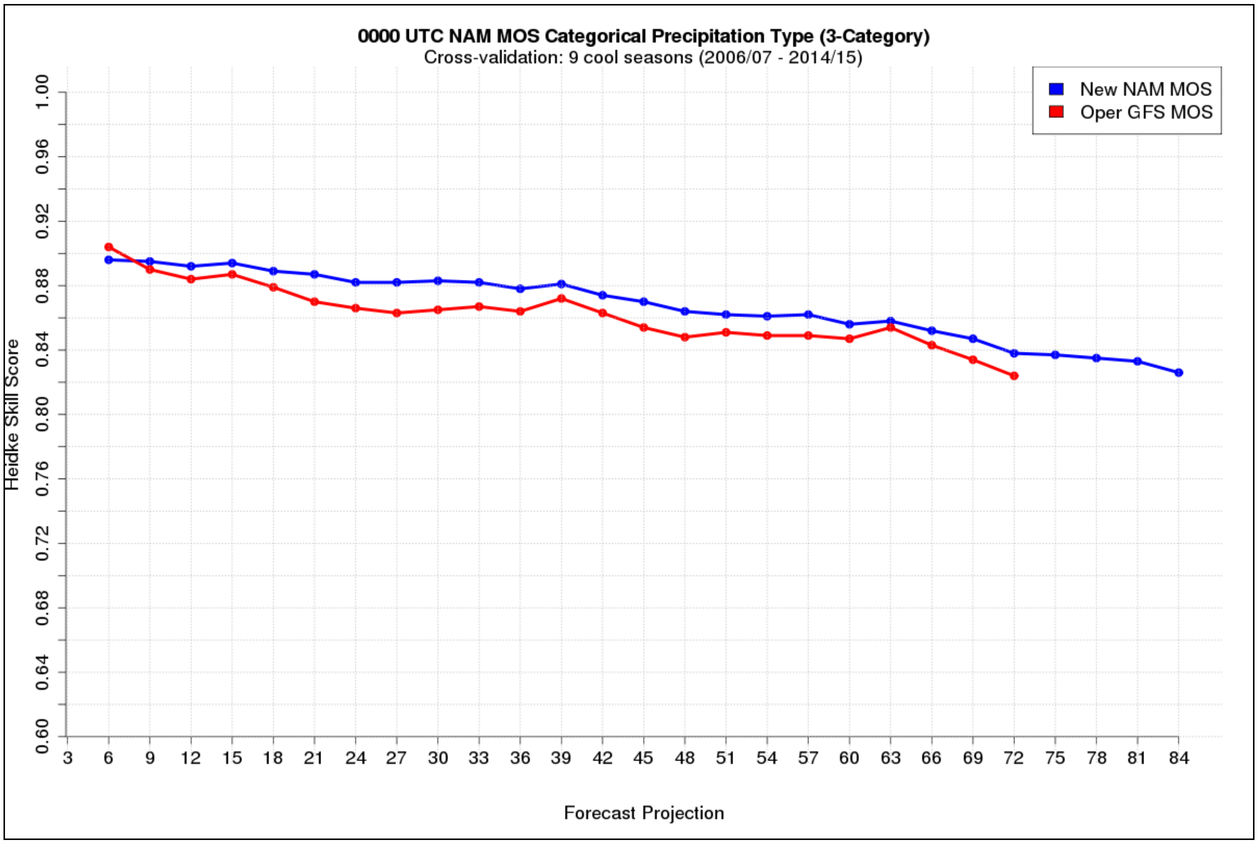

Figure 6. Heidke Skill Scores for the new NAM MOS precipitation type system (blue) and operational GFS MOS (red).

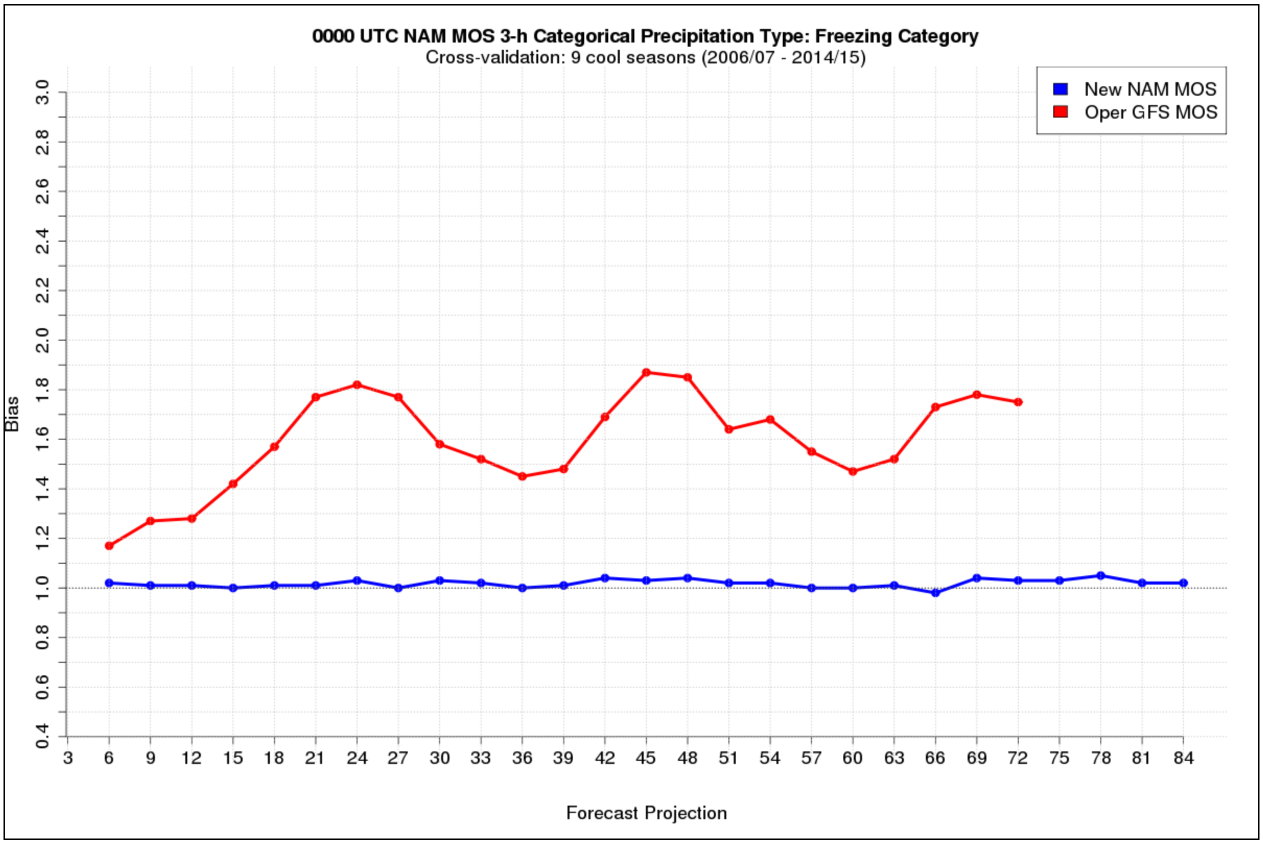

Figure 7. Bias for the freezing category.