UPDATED MRF-BASED MOS GUIDANCE:
ANOTHER STEP IN THE EVOLUTION OF OBJECTIVE MEDIUM-RANGE FORECASTS

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1. INTRODUCTION

Expectations for accuracy and detail in medium-range forecasts have changed substantially over the past 2 decades. When the Techniques Development Laboratory (TDL) began producing medium-range forecasts in the early 1970's, calendar day maximum and minimum forecasts 4 days in advance were the state of the art. Today's forecasters would like to see information such as precipitation amount and type -- even at days 5, 6, and 7. While TDL currently provides forecasts of maximum/ minimum temperature, probability of precipitation (PoP), mean clouds, mean winds, and the conditional probability of snow out to day 7, the equations which produce these forecasts were developed from the Medium Range Forecast (MRF) run of the Global Spectral Model (GSM; Kanamitsu 1989) from December 1988 to September 1994. We believe the MRF modifications since 1995 (see, for example, Derber et al. 1998), including enhancements to the analysis procedures, model physics, and resolution, will allow us to develop more extensive and accurate objective guidance. Therefore, TDL is developing updated objective medium-range guidance based on an improved archive of MRF output, with implementation of the temperature and PoP elements scheduled for November 1999. Our plans involve revising the guidance to include new weather elements, increasing the number of stations for which forecasts are provided, and modifying predictand definitions for the medium-range wind, cloud, and precipitation type forecasts to better suit the requirements of the forecasting community. In this paper, we present a historical review of medium-range forecasts developed by TDL, and discuss the weather elements we plan to include in the new medium-range statistical package as well as the techniques to be employed in developing the forecast equations. Finally, we discuss the schedule for implementation of the forecasts and various dissemination formats of the guidance.

2. HISTORY

TDL first produced objective medium-range forecasts over 25 years ago. Over the years, our developmental efforts have made use of a variety of statistical techniques, and a review of our experience demonstrates why we have arrived at our current policy of employing the Model Output Statistics (MOS) technique (Glahn and Lowry 1972) in producing objective guidance for the medium-range.

In the early 1970's, forecasts of the maximum (max) and minimum (min) temperature were provided for projections of 12 to 96 hours in advance. These forecasts were later extended out to 144 hours, and then to 192 hours by November 1982. The statistical equations which generated these forecasts were developed by using the Klein-Lewis (K-L) perfect prog technique (Klein and Lewis 1970). In April of 1985, a new system of medium-range forecast equations was developed by applying a simplified MOS technique (Dallavalle and Jensenius 1985) to output from the GSM. This effort marked the first time equations were developed to produce forecasts of the 24-h PoP in addition to the calendar day max and min temperature. These MOS equations were applied to the output of the new MRF model to produce forecasts for projections of 24 to 144 hours after 0000 UTC. The MOS temperature forecasts were never as accurate as the original K-L perfect prog forecasts, however, possibly due to the change to the MRF model.

Several years later, TDL decided to use a calibrated perfect prog approach (Jensenius et al. 1992) to overcome the problems associated with a frequently changing model. In 1992, new equations were developed to produce forecasts of the daytime max and nighttime min, as well as the 12-h PoP for projections ranging from 12 to 192 hours after 0000 UTC. In addition, the 12-h PoP's were objectively combined to produce a 24-h PoP. These forecasts did demonstrate improvement over forecasts generated by both the original K-L guidance as well as the simple MOS guidance. Because of problems inherent to the perfect prog technique, however, the MOS approach was used to develop equations to produce forecasts of mean opaque cloudiness, mean wind speed, and the conditional probability of snow. Subsequently, the max/ min temperature and 12-h PoP forecast equations were also redeveloped by using the MOS approach, and tests showed that the MRF-based MOS forecasts produced by these equations were more accurate than the calibrated perfect prog forecasts. The MOS equations were implemented, and since January 1995, the entire MRF-based statistical package has been based on the MOS approach. This guidance continues to be disseminated daily to National Weather Service (NWS), military, and private sector forecasters (Jensenius et al. 1993).

3. WEATHER ELEMENT DEFINITIONS

As part of our current redevelopment, we are revising the MRF MOS guidance to include new weather elements, and we are modifying the definitions of other weather elements to better meet requirements. Table 1 summarizes the weather elements and forecast projections proposed for our new medium-range package. Column 1 lists the weather element, and column 2 provides the forecast projections. The third column indicates how the operational and new systems differ for this weather element (are the definitions the same?, changed?, or is this a new element?), and the fourth column provides a brief definition of the predictand. Rather than discuss the entire table, we highlight the most important changes in the remainder of this section.

In an effort to respond to requirements for more temporal resolution in the temperature guidance (for users managing a digital database and energy organizations needing temperature and humidity traces), we plan to add forecasts of temperature and dew point every 6 hours from 12 to 192 hours after 0000 UTC. To further support the NWS initiatives for probabilistic quantitative precipitation forecasts (PQPF), we will add both probabilistic and categorical QPF forecasts. These forecasts will be made for both 12- and 24-h periods. To better serve the hydrological community (since the hydrological day is 1200 to 1200 UTC), the 24-h forecasts will be produced for periods ending at both 0000 and 1200 UTC. We will attempt to provide QPF forecasts out to 156 hours in advance, providing we can do so skillfully (Shirey 1999).

The wind and cloud forecasts in the current operational MRF MOS message predict the mean condition in a 12-h period. We have found that this predictand definition makes it difficult to forecast more extreme conditions and that forecasters do not find the predictions useful. Working with the Hydrometeorological Prediction Center of the National Centers for Environmental Prediction (NCEP), we have decided to re-work these predictands to more closely match what forecasters include in their outlooks. For clouds, we will predict the probability of the prevailing total cloud amount during a 12-h period being clear, mixed clouds and clear skies, and overcast. The 13 hourly cloud reports from 0000 to 1200 UTC (or 1200 to 0000 UTC) will be used to assign each case to one of the three categories, rather than averaging. Equations will then be developed to predict the probability of each category, and a categorical forecast will be produced from these probabilities.

Similarly, the definition of the wind element will be modified to focus on the maximum wind during a 12-h period rather than the mean condition. The maximum winds will be obtained by examining the hourly METAR reports containing the 2-minute average wind speed. The maximum wind report in each period will be classified as either light (0 - 10 kts), moderate (11 - 21 kts), or strong (≥ 22 kts) as defined by the Beaufort wind scale (Ahrens 1994). Equations will be developed to produce the probabilities of each of these three categories and a categorical forecast will be computed from these probabilities.

For precipitation type (PTYPE), the operational MRF MOS guidance includes the conditional probability of snow over a 12-h period. This element was defined as the probability that precipitation will be in the form of snow given that a significant precipitation event occurred. Observations of rain were assigned a value of 0, cases of freezing precipitation were assigned a value of 0.5, and cases of snow were assigned a value of 1 (Jensenius et al. 1995). Since the predictand in this case is not strictly binary, the interpretation of the probabilistic forecast of snow is somewhat difficult (i.e., does a 50% forecast indicate a moderate probability of snow or a mixed event?). To overcome this difficulty and refine the PTYPE element, we will now separate precipitation into three types: snow, rain, and mixed. With this definition, 12-h periods with observations of only snow will be classified as snow, periods with only liquid precipitation reports will be classified as rain, and periods reporting freezing precipitation or any mixture of liquid, freezing, or frozen precipitation will be classified as mixed. Forecasts of the conditional probability of each event will be produced, and a categorical forecast will be computed from these probabilities.

Although not included in Table 1, we also intend to include predictions of 12- and 24-h snow amount and 24-h probability of thunderstorms (Hughes 1999) in the MOS medium-range system. Obtaining an adequate sample of snowfall observations is one difficulty we face. We recently began archiving Surface Climatic Data reports, and will attempt to complement this data with cooperative observer reports. Due to this data limitation and tight resources, it is likely that forecasts of snow amount and thunderstorms will not be added to the system until late 2000.

Table 1. Weather elements and forecast projections of proposed MRF-based guidance products. Projections are given in hours after the initial cycle time of 0000 UTC. The third column indicates the status of the weather element as compared to the current operational MRF MOS guidance.

Element	Forecast Projections	Status	Comments
Max Temp	24 - 192, every 24 hrs	Same	Daytime Maximum (7 a.m. - 7 p.m. LST)
Min Temp	36 - 180, every 24 hrs	Same	Nighttime Minimum (7 p.m. - 8 a.m. LST)
Temperature	12 - 192, every 6 hrs	New	2-m Shelter Temperature
Dew Point	12 - 192, every 6 hrs	New	2-m Shelter Temperature
PoP (12-h)	24 - 192, every 12 hrs	Same	Probability of ≥ 0.01 inches of liquid- equivalent precipitation during a 12-h

			period.
PoP (24-h)	36 - 192, every 12 hrs; new system provides 24-h PoP ending at both 0000 and 1200 UTC.	Change	Probability of ≥ 0.01 inches of liquid- equivalent precipitation during a 24-h period. Current system combines 12-h PoP to get 24-h PoP; new system predicts 24-h value directly.
PQPF (12-h)	24 - 156, every 12 hrs	New	Probability of ≥ 0.10, 0.25, 0.50, 1.00, and 2.00 inches during a 12-h period. Categorical precipitation amount.
PQPF (24-h)	36 - 156, every 12 hrs; 24-h PQPF ending at both 0000 and 1200 UTC.	New	Probability of ≥ 0.10, 0.25, 0.50, 1.00, 2.00, and 3.00 inches during a 24-h period. Categorical precipitation amount.
Wind	24 - 192, every 12 hrs	Change	Current system predicts the mean wind over 12-h period; new system will provide the probability of the maximum wind during the 12-h period falling into three categories: ≤ 10 kts, 11 - 21 kts, ≥ 22 kts as well as a categorical forecast.
Clouds	24 - 192, every 12 hrs	Change	Current system predicts the mean cloudiness over a 12-h period; new system will provide the probability of the prevailing total sky cover falling into three categories: predominantly clear, some clouds, and predominantly overcast as well as a categorical forecast.
PTYPE	24 - 192, every 12 hrs	Change	Current system predicts the conditional probability of snow; new system will include the conditional probabilty of snow, rain, and "mixed" precipitation as well as a categorical forecast.

4. DEVELOPMENTAL TECHNIQUES

In the MOS approach, predictand data (local hourly observations) are correlated to predictors derived from direct model output, geographic or climatic values, and observations. In the MRF-based development, least squares linear regression is used to derive the relationships between the predictand and the predictors. Generally, no more than 10 predictors are allowed to be selected in each equation, and each predictor selected is required to contribute at least an additional 0.5% to the total reduction of variance. In addition to the statistical technique, we are also concerned with issues such as the length of the sample and seasonal stratification. The sections below deal with the decisions we have made to date for the medium-range objective forecast system.

4.1 Developmental Sample

Historical samples of both observed weather elements and numerical model predictions are essential for the application of the MOS technique. In April 1997, TDL established a new archive of MRF data. Initial and forecast fields for projections every 12 hours out to 192 hours generated from the 0000 UTC forecast cycle are saved on a grid with a resolution of 95.25 km at 60N. For projections from 204 to 384 hours, forecasts are saved on a coarser grid with a resolution of 190.5 km at 60N. These grid resolutions were chosen to approximate the resolution of MRF data on NCEP's 1 degree (T126 for projections out to 168 hours) and 2.5 degree (T62 for projections beyond 168 hours) latitude/longitude grids. To date, we have approximately 2.5 years of accumulated data. Since this is a somewhat small sample for MOS development, we have augmented our archive with forecasts from NCEP's re-analysis archive (Kalnay et al. 1996). Data from January 1992 through March 1997 were available from the T62 resolution MRF every 5th day for projections of 12 to 192 hours after 0000 UTC. These data were archived on our coarse (190.5 km) grid, and add approximately 1 year to our MRF developmental sample. The spatial resolution of our new archive is substantially finer than that available when the current operational MRF MOS system was developed. The operational system made use of data archived on a grid with 381 km resolution at 60N. We believe the increased resolution in the MRF will be useful for developing skillful MOS forecasts.

TDL's observational archive is obtained by saving and editing hourly surface observations stored by NCEP in the SAO (up to November 1996) or METAR (December 1996 - present) format. While the operational MRF MOS produces forecasts for over 200 stations, in the current development, data for over 1000 stations are used to derive the statistical forecast equations. The stations were chosen by examining the frequency of temperature and dew point observations reported between April 1997 and December 1998. A complete list of stations is available at the website: http://www.nws.noaa.gov/tdl/synop/stalst99.htm.

4.2 Seasonal Stratification

Data are stratified by season to increase the consistency of the sample, and in turn strengthen the relationship between the predictors and the predictand. While a finer stratification is useful for obtaining homogeneity, this must be weighed against the resulting decrease in the size of the sample. In this development, data are stratified into 6-mo warm (April - September) and cool (October - March) seasons for all weather elements except PTYPE. For PTYPE, only one season is used. We have generally found that temperature, dew point, and max/min equations benefit from a four-season stratification, and indeed the operational MRF MOS max/min equations were developed with this finer stratification. Once our archive sample increases, we will investigate the possibility of re-developing these equations by using 3-mo seasons.

4.3 Single Station and Regional Equations

Optimally, all statistical relationships would be derived for individual stations. This approach allows the regression analysis to be tuned more precisely to the correlation between the predictors and the nature of the weather element at that site. Several weather elements, however, occur infrequently enough that combining data for several stations in a geographical area provides a more stable statistical relationship. In this MRF MOS development, forecast equations for temperature, dew point, max/ min, and, possibly, wind will be developed for single stations. We have found these elements to be most sensitive to local conditions such as elevation, proximity to lakes or oceans, and heat island effects. In addition, since these elements are always reported, there is generally no difficulty with small samples. On the other hand, precipitation and specific types of precipitation, do not occur at a given site every hour and are often rare events. The forecast equations for PoP, QPF, Cloud, and PTYPE are, therefore, developed regionally. This means that stations are grouped based on similar correlations of the predictand to model predictors, relative frequencies of occurrence of the weather element of interest, and topographical features. Data from all the stations in a region are combined to develop one regression equation. To make a forecast for an individual station, the predictor values valid at that station are then used to evaluate the equation.

4.4 Predictors

In this MRF development, predictors will be offered to the regression analysis from several sources and in several forms. Although the specific predictors vary according to the weather element being predicted, certain practices are common to all predictands. Our predictors generally come from three sources: forecasts from the MRF, geographic or climatic values, and observations. Since most of our predictands are valid for a 12-h period in the medium-range, the MRF-based predictors will generally be time-averaged. This means that the 36-h and 48-h forecast of the 1000-mb temperature, for example, would be averaged together and used as a predictor for the max temperature ending at 48 hours. In addition, spatial filters will be applied to the model forecasts to smooth the data. We have found that averaging data over 25 gridpoints works fairly well out to 72 hours; additional smoothing is useful at the longer-range projections. We are currently applying two passes of the filter for the 84- through 192-h forecast fields. Since the grid used in the operational forecasts was 381 km, and we are now using a 95-km grid, the effective smoothing is significantly less. At the longest projections, it may be necessary to apply stronger filters to capture the appropriate model signal.

The geographical and climatic fields most frequently offered are the cosine and sine of the day of the year or twice day of the year, and relative frequencies of the weather element being predicted. These predictors provide information about the variation of the data within the 6-mo season, and the differences among stations within a region. They also provide an indication of the climatic value of the predictand which is useful at the longest projections.

The latest surface observations will generally be tested as potential predictors for projections out to 48 hours. In the temperature development, for example, we found that the persistence of the surface temperature observed at 0600 UTC is useful only out to 36 hours.

5. DISSEMINATION AND IMPLEMENTATION OF GUIDANCE

Development of the max/min, temperature, dew point, PoP, and QPF weather elements is underway, and we plan to implement these equations in November 1999. We plan to add the modified wind and cloud forecasts in April 2000, and include the PTYPE element by November 2000. Since we will be gradually adding the other weather elements, and to avoid any break in service to our users, we will disseminate these forecasts in addition to the current operational MRF predictions. Forecasts will likely be made available in an alphanumeric message, as well as a binary format (BUFR). It is also possible that some elements will be analyzed and provided on a grid in GRIB format. These formats will be useful for incorporating the products into the NWS AWIPS environment, and for allowing both plotted and contoured displays. A great degree of coordination will be required to establish new communications headers and ensure that the proper modifications are made to AWIPS to enter this new guidance into the digital database. For users outside the NWS, we expect that the new guidance will be available through NOAAPORT, the Family of Services, and specific military communication circuits.

Since we are including a number of additional weather elements in our new MRF package, the format of the alphanumeric message will have to be modified. This format has not been established to date, but one proposed format is shown in Fig. 1. This message includes the new temperature (TEMP), dew point (DEWPT), and QPF forecasts as well as the revised cloud (CLD) and wind (WND) forecasts. The best category cloud forecasts are indicated by the abbreviations CL for predominantly clear, PC for partly cloudy or mixed clouds and clear skies, and OV for predominantly overcast. The best category max wind forecasts are indicated by the abbreviations LT for light, MD for moderate, and ST for strong. The categorical PTYPE forecasts are represented by RN for rain, MX for freezing or mixed liquid and frozen precipitation, and SN for snow. Even though the probabilities will be included in the BUFR messages, we will also explore adding them to the alphanumeric message for elements such as QPF, clouds, wind, and PTYPE. With an increased emphasis on probabilistic forecasting, these values may assist forecasters in providing subjective probabilistic forecasts or in evaluating the categorical forecast.

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MRF-BASED OBJECTIVE GUIDANCE 12/08/99 0000 UTC
ALB       WED 08  /THU 09     /FRI 10     /SAT 11     /SUN 12     /MON 13     /TUE 14     /WED 15    /
HOUR      12     24     36     48     60     72     84     96    108    120    132    144    156    168    180    192
MX/MN            49     34     45     24     27      2     18      5     25     10     27     18     38     29     39
TEMP      40 45 48 40 35 40 44 30 26 26 26 13  5 10 17 11  6 14 24 18 11 19 25 20 29 24 35 30 30 36 38
DEWPT     35 40 42 38 35 38 40 29 24 24 24  8  0  2  5  5  1  8 12 12 08 10 15 17 21 22 28 28 28 32 33
CLD              PC     PC     OV     OV     PC     PC     PC     CL     CL     CL     CL     PC     PC     PC     PC
WND              LT     LT     MD     MD     ST     MD     LT     LT     LT     LT     LT     MD     MD     LT     LT
POP12            32     69    100     67     58     21      8      0      3     12     15     26     33     35     42
POP24                   75    100     89     81     42     25     10      3     19     21     30     46     50     55
QPF12/24          1    1/2    2/3    1/2    1/2    1/1    1/1    1/1    1/1    1/1    1/1    1/1
PTYPE            RN     RN     RN     MX     SN     SN     SN     SN     SN     SN     SN     SN     MX     SN     MX
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Figure 1. A proposed format for the alphanumeric message containing new MRF-based MOS guidance.

6. SUMMARY

Much testing, development, coordination, and implementation remains to be done to complete the new MRF MOS package. As this work is ongoing, we will also be converting our operations to the NWS's new IBM mainframe, so we will undoubtedly face some challenges along the way. Even so, we believe the increased resolution and detail of this objective medium-range guidance will better serve the needs of the forecast community. As each weather element is implemented, we will provide documentation of the developmental details and verification results to forecasters. Once the new MRF MOS package is approved and fully implemented, we will coordinate the removal of the current operational product. In addition, any deficiencies in the prediction of certain weather elements due to a small sample size, for example, will be addressed, and the equations to predict the element will be re-developed. Finally, we will continue to monitor the performance of the guidance, and provide forecasters with information on the effective use of the guidance.

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