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IFPS Gridded Forecast Verification Statistics at WFO Salt Lake City

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Introduction

National Weather Service (NWS) forecast offices are producing high resolution (up to 2.5 km grid spacing) forecast grids out to seven days through the use of the Graphical Forecast Editor (GFE) component of the Interactive Forecast Preparation System (IFPS). These grids contain information that allows NWS customers and partners to extract detailed forecasts in space and time. As resources are invested to use these grids, it is important that they represent an accurate forecast throughout the entire grid domain. Verification plays a critical role in helping to improve or maintain the accuracy of any forecast system. In addition, a gridded forecast system requires the development and implementation of new verification methods that can provide appropriate feedback for all forecast locations.

Current digital forecast verification examines forecast accuracy at standard observation reporting sites within each office's County Warning Area (CWA) - which only represents a very small portion of the forecast office's digital forecast area. Thus, this fails to describe forecast accuracy in between verification locations or in areas where there are no observations. As a result, this method does not provide enough information regarding the spatial errors in a forecast grid. Attempts have been made at verifying digital forecast grids through grid-to-point and grid-to-grid methods (Colin 2002, Dagostaro et al. 2004, Horel et al. 2004). While these methods might show forecasters in each office how well they performed overall, there is still a need to determine where, within the grid, the forecasts are most (or least) accurate. This is especially true in areas of complex terrain.

One of the first attempts at creating a gridded verification method to determine forecast errors within a CWA became available with the "ifpsVerify" software, the Western Region (WR) Gridded Verification System (Jordan and Cook 2003), which was developed by Jeff Davis and Kirby Cook, and which stores observed and forecast grids, then generates difference grids (forecast minus observation). While such a system allows forecasters to visually review the locations and magnitude of their errors, it does not provide a method to quantify these errors. To help address this system deficiency, efforts have been made at the Salt Lake City weather forecast office (WFO SLC) to derive verification metrics at any individual grid point or sets of grid point locations. The method used will be discussed first, followed by a presentation and discussion of the results from verifying maximum and minimum temperature (MaxT and MinT) forecasts produced by WFO SLC during the January-March period of 2004.

Methodology

Grids comprising the WFO SLC IFPS database have been regularly archived locally in netCDF format since late 2003. Specific grids archived include observational analysis grids (hereafter referred to as "Obs" grids), "Official" forecast grids, and model forecast grids derived from the National Centers for Environmental Prediction's Global Forecast System (GFS) model and an adjusted grid incorporating GFS Model Output Statistics (MOS). Note that at the time of archiving, the GFS was known as the Medium Range Forecast (MRF), with a horizontal resolution of 180 km.

The Obs grids used at WFO SLC are produced using the "MatchObsAll" system developed by Tim Barker (Foisy 2003). This program takes a background grid and then applies Tim Barker's and Les Colin's SERP tool (Barker 2004c) to fit the grid to a set of observations using a three-dimensional serpentine curve. This forces the analysis to the data points used in the corrections; thus at observation points, grid values exactly match the observations. The background grid initially comes from the MesoEta, but after the system has started running, an average grid comprised of the MesoEta and the previous hour's Obs grid is used for the background (Barker 2004a). Observations used to derive the analysis grid are obtained from the MesoWest high-density observation network (Horel et al. 2002), which is operated by the University of Utah's Cooperative Institute for Regional Prediction (CIRP) and includes METARs, RAWS, and other government- and privately-owned networks. Modifications are made locally to the standard Obs grids whereby MaxT and MinT observations from the NWS Regional Temperature and Precipitation (RTP) product, which is created twice daily, are serped into the standard MaxT and MinT Obs grids. The final MaxT and MinT Obs grids thus contain all available observations, including the actual MaxT and MinT observed at a number of sites. This is an improvement over the standard MaxT and MinT Obs grids which only use the maximum and minimum of the observed hourly temperatures and do not account for any spikes that may occur between hourly observations.

Once a forecaster "endorses" the forecast grids using the GFE, these grids become "Official." These are the forecast grids disseminated externally to become part of the database used by IFPS customers and partners. These grids are archived once per day after the Official forecast grids are used to generate afternoon text products – typically by 400 PM local time.

The GFS database contains forecasts derived from the 0000 UTC model run and are produced using a standard IFPS technique to downscale NCEP model data to the GFE grid, referred to in IFPS as "SmartInit." The IFPS SmartInit produces surface forecast fields by calculating atmospheric lapse rates at each grid point to extrapolate pressure level data down to the GFE surface. It is important to note that the model data available for the GFS SmartInit in this study was very coarse vertically and horizontally, often resulting in erroneous temperature values, especially in areas of complex terrain during the winter. Despite this handicap, temperature initialization remained unchanged from the original release, or BASE, version of the GFS SmartInit.

The second model source examined is the GFS data adjusted with GFS MOS through the use of the “MatchMOSAll” method, which employs a similar serpentine fit method to that used in MatchObsAll (Barker 2004b). Prior to January 2004, this grid incorporated MOS from 13 locations within the SLC CWA. After that time, however, additional MOS locations from the NWS cooperative observation network were added, increasing the total number of MOS sites within the SLC CWA by an order of magnitude.

The most important piece of any verification system is the observation, or in this case, the observational analysis. Given the scarcity of data in the Intermountain West, questions will arise regarding the choice of analysis scheme. For example, the MatchObsAll routine simply uses a three-dimensional serpentine curve to fit a grid to available observations. While it is designed to exactly match grid point values nearest to the supporting observations, there is still a degree of uncertainty as to the system’s ability to accurately depict conditions between observations, especially in data-sparse areas. Furthermore, currently the only quality-control method employed at SLC is to visually review the grids periodically and remove any observation that appears inconsistent with neighboring observations. An erroneous observation may be included in the analysis for several days before being noticed and subsequently removed. This removal only affects future grids; thus, grids with any erroneous observations may have already been archived. It is important to note that no effort was made to quality control the archived analysis grids prior to the calculation of verification statistics, so any errors in the grids were included in the generation of statistics. Despite these and other potential problems, the MatchObsAll method is the best that is currently available. The next best available option was to use the Advanced Regional Prediction System (ARPS) Data Assimilation System (ADAS) provided by CIRP (Lazarus et al. 2002). This system uses a more complicated, and perhaps better, analysis scheme with better quality control than MatchObsAll, but as with any analysis system, it can be erroneous between observations – although it is likely more accurate than MatchObsAll. However, ADAS currently lacks the ability to incorporate data from the RTP, and its analysis grids do not always match the available observations exactly. In addition, the 2.5 km ADAS grids were not received every hour at WFO SLC due complications with dissemination, although the 10 km version is more stable. However, the forecasts at WFO SLC are created on 2.5 km resolution grids, the same resolution used in MatchObsAll, so as a result the 10 km ADAS is less useful than MatchObsAll for this particular verification study. MatchObsAll was chosen as the primary analysis simply because it is a more reliable system, since it is controlled locally, and it uses the same resolution as the forecast grids.

To begin the verification process, the archived analysis and forecast grids valid for days one through seven beyond analysis time were loaded into a modified version of ifpsVerify via a GFE routine called “iscMosaic.” The modifications made to ifpsVerify include extending it to store grids for forecast lead times out through seven days rather than just the original three days, and to operate on MaxT and MinT for day shift forecasts only. Difference grids (forecast minus observation) were then created, after which a modified version of the “Stats_RIW” Smart Tool (Knutsvig 2004) was used to calculate verification statistics across specified sets of grid points on these grids. Mean absolute error (MAE) and mean error (or bias) statistics were produced for selected areas (defined using GFE edit areas) for each forecast source and for each day during the period of January through March 2004. These daily statistics were averaged over the entire period and separately for each month. This procedure was performed on a GFE server that is separate from the operational server so as to minimize interruption and slowdown to the normal forecast operations.

A set of eight areas was selected for this verification study: the entire WFO SLC CWA (containing 29244 grid points); grid points in the CWA above 7000 ft (7212 grid points); public forecast zones UTZ003 (629 grid points), which includes the Salt Lake and Tooele Valleys, and UTZ008 (863 grid points), which includes the Southern Wasatch Mountains; the single grid points nearest the Salt Lake City (KSLC) and Cedar City (KCDC) Automated Surface Observation System (ASOS) which are used for the Coded Cities Forecast (CCF) product that was also verified; and finally, the set of 24 individual grid points nearest the cities represented in the Tabular State Forecast (SFT) product produced by WFO SLC.

Results for the SLC CWA

Statistics for MaxT averaged over the entire SLC CWA and over the three-month period of January-March 2004 show a trend that is generally considered to be typical - MAE from the Official forecasts were lowest for the day 1 period and increased though the day 7 period. Also, the Official forecasts improved over the GFS MOS, which in turn improved over the GFS (Fig. 1). The MAE for MinT also improved with time for the Official forecasts; however the GFS MOS had lower MAE than the Official forecasts in the days 4 through 7 period, (which is typically known as the “extended” forecast period) (Fig. 2). The MinT MAE was also larger compared to MaxT MAE for the Official forecasts. Bias errors for the CWA for the same period were, in general, lower for the Official forecasts than for model guidance. For MaxT, bias errors for the Official forecasts hovered near zero for all seven days, while the GFS MOS was warmer and the GFS was much too cold (Fig. 3). For MinT, the Official forecasts were, on average, around one degree too cold. However, this time the GFS MOS had a cold bias while the GFS was considerably too warm (Fig. 4).

The trends for both MaxT and MinT MAE averaged over the individual months were, for the most part, similar to the three-month averages. There were a few exceptions, however. For example, figure 5 shows the MaxT MAE for the CWA for February 2004. Here, the GFS MOS performed worse than the GFS in the extended periods. During March 2004, the Official forecasts for MaxT had similar MAE compared to the GFS MOS, except for days 2, 3, 4, and 6 when the Official forecasts had larger errors (Fig. 6).

The bias errors for the individual months contained some variations from the three-month averages as well. For example, the GFS had bias errors closest to zero for MaxT from day 2 through day 6 (Fig. 7) in January. Both the Official forecasts and the GFS MOS had warm biases during this month. During March 2004, the GFS MOS had bias errors closest to zero for MaxT (Fig. 8). The Official forecasts and the GFS both had cold biases during this month. For MinT, the bias errors for January 2004 showed that all of the forecasts were generally too warm, with the exception of the Official and GFS MOS forecasts for day 1 (Fig. 9).

Results for Specific Areas

The ability to generate verification statistics for specific geographic areas in the CWA provides a way to determine where the greatest improvement is needed in digital forecast accuracy. As mentioned earlier, only eight edit areas, including the one covering the entire CWA, were used for this initial study, but the software design is flexible enough to allow any number of areas or area sizes. The following presents selected results for several of the specific areas within the CWA used in this study.

For the two mountainous areas (all grid points above 7000 ft and UTZ008), the results are quite similar, so only those figures for points above 7000 ft will be shown here. In these areas, the GFS MOS on average performed slightly better than the Official forecasts for MaxT with the GFS having the largest MAE (Fig. 10). During February 2004, however, the Official forecasts had lower MAE than the models in the extended periods, but in the short term, the GFS MOS still had lower errors (Fig. 11). MaxT bias errors show that the Official and GFS MOS forecasts had smaller bias than the GFS, which was much too cold (Fig. 12). Generally, the Official forecasts were slightly cooler than the GFS MOS. The exception was during January when the Official forecasts were warmer than guidance, at least in the short term, although they still carried an overall cold bias (Fig. 13). For MinT, the Official forecasts had a lower MAE than the guidance products in the short term, but were generally worse than the GFS MOS in the extended periods (Fig. 14). For the bias errors, the Official forecasts were closest to zero, with the GFS MOS being too cold and the GFS too warm (Fig. 15).

In UTZ003, a valley zone, the MaxT MAE for the Official forecasts improved quite a bit over the guidance products, especially in the short term (Fig. 16). The GFS, though, had lower errors than the GFS MOS in the extended period. Trends for January were similar to those of the three-month average. However, for February, the Official forecasts interestingly had errors comparable to those of the GFS, while errors were almost twice as large for the GFS MOS (Fig. 17). On the other hand, the opposite was true during March, whereby the Official forecasts were nearly as accurate as the GFS MOS, while the GFS had larger errors (Fig. 18). The GFS actually had the smallest bias for MaxT during the three-month period (Fig. 19). The Official and GFS MOS MaxT forecasts were generally too warm. This warm bias is especially evident during January and February (Figs. 20 and 21), months characterized by below-normal temperatures in this particular zone. For MinT, the Official forecasts had a similar MAE compared to the GFS MOS. Meanwhile, the GFS had the largest errors (Fig. 22).

Finally, Official and model forecast accuracy for the grid points located near selected cities were examined. Since forecasters have traditionally focused on forecasting for selected cities rather than an entire grid area, these results can potentially show how verification scores vary away from these locations. At KSLC, the trends were found to be very similar to those of UTZ003 (likely due to the relatively small geographic size of the zone), so those results will not be described here. At KCDC, the Official and GFS MOS MaxT forecasts had very similar MAE, and there was a significant increase in MAE going from day 1 through day 7 when computed over the three-month period (Fig. 23). The GFS MAE stayed relatively constant over the length of the forecast – though consistency large. For MinT, the MAE for the Official and GFS MOS forecasts increased less than that for MaxT going from day 1 through day 7, but the MAE for the GFS remained consistently large (Fig. 24). MaxT and MinT bias errors for KCDC were small for the Official forecasts during the three-month period and nearly constant across the forecast length (Figs. 25 and 26). However, when broken into individual months, it is evident that there were some large bias swings during this period. Figure 27 shows that, during January, the GFS had the smallest MaxT bias in the extended period where there was a relatively strong warm bias in the Official and GFS MOS forecasts. In March, the MaxT forecasts from all three sources were too cold, with the GFS MOS having the smallest bias and the GFS the largest (Fig. 28).

Comparing Errors by Area

In an effort to compare the magnitude of the errors in different areas, verification statistics for the Official forecasts from all eight areas were plotted together. For example, figures 29 and 30 show that, of the edit areas that were studied, MAEs averaged over the three-month period were lowest for the two CCF points, both individually and combined, for the day 1 and day 2 periods. However, errors at these points were not necessarily lower than those in the other areas in the extended period. This is perhaps an indication that forecasters are still focusing on the short term temperatures required for the pre-IFPS version of the CCF product. Also, forecasts were better at KSLC than for UTZ003 as a whole in the short term, but in the extended periods, they were worse, indicating that errors in the point forecast do not necessarily reflect the errors in the areal forecast. Interestingly, errors tended to be large for the SFT points over all forecast periods, especially for MinT. It was expected that the SFT points would have relatively low errors since, again, it is thought that forecasters typically spend more time on forecast values at these city locations, but the results indicate otherwise. Errors also tended to be larger in the high terrain in the short term periods than the lower elevation areas, although they were generally not any worse than the other areas in the extended periods.

MaxT bias results reveal that the Official forecasts were generally too cold in the mountains and too warm at KSLC and in UTZ003 (Fig. 31). MinT forecasts for the mountains were also too cold, but at UTZ003, KSLC, KCDC, and the SFT points, they were too warm except for day 1 (Fig. 32). Bias errors for MaxT in January were similar to those of the three-month average (Fig. 33). However, the warm bias in the valleys was much larger in January, especially in the extended periods. For MinT, the Official forecasts had a warm bias in all areas in January except during the day 1 period (Fig. 34). This strong warm bias can be attributed to the difficulties forecasting the below-normal temperatures resulting from the strong inversions present during this month. In contrast, during the month of March, which had above-normal temperatures, the Official forecasts were too cold in almost all areas for both MaxT and MinT (Figs. 35 and 36).

Discussion

This paper demonstrates a method to produce forecast verification statistics for a WFO gridded forecast system, in this case a forecast system covering an area of complex terrain. This method employs archived forecast and observation grids, and statistics are calculated from the difference (forecast minus observation) grids. The accuracy and reliability of these statistics are, of course, dependent upon the accuracy and reliability of the analysis, which in this case is the MatchObsAll method. Although there is room for improvement in the analysis scheme, it is the most operationally reliable product that currently exists.

The results of this study reveal several interesting trends and biases in the SLC WFO's performance in producing digital temperature forecast grids, and how those compare to certain model guidance. On average, the Official forecasts improved upon guidance products in this study. However, by verifying smaller areas within the CWA, deficiencies in the Official forecasts were uncovered. It was shown, for instance, that the Official forecasts did not improve upon the GFS MOS in the mountains. Also, in some areas, especially for MinT, MAE for the Official forecasts were very similar to those of the GFS MOS. However, it is important to note that differences in observation densities within the CWA could have an impact on the quality of the analysis in different areas, which in turn may influence these results. Results also showed that the forecasters' tendency of focusing on short-term temperatures at the CCF points paid off with lower errors. However, the SFT points had among the largest errors, possibly showing that beyond the CCF points, less attention is generally given to forecasts at these individual locations. These results emphasize the importance of providing forecasters with sufficient model data and grid editing tools to populate and generate grids.

These verification results also exposed some important model biases. The GFS was usually too cold on its MaxT and too warm on its MinT forecasts. This is the result of small diurnal temperature change, which is likely a product of the coarse vertical and horizontal resolution of the GFS made available to the SmartInit routines, or perhaps even deficiencies in the SmartInit routines themselves. The GFS usually had the largest errors, although it was shown that, in UTZ003 and KSLC during February 2004, the GFS had lower MAE than the GFS MOS. In fact, the GFS had errors that were comparable to those of the Official forecasts during this period and in these areas. The GFS MOS appeared to have had a difficult time handling the below-normal temperatures in these areas, which were due in part to strong inversions over the valleys and climatologically below normal temperatures. However, because of the existing cold bias of the GFS, its colder temperatures turned out to be more accurate than those of the warmer GFS MOS in the Salt Lake City area. This should not be viewed as an indication that the GFS has more skill in inversion situations, but merely a "right for the wrong reason."

The verification statistics shown in this paper provide just a small sample of what is possible with this system design. The results can be expanded upon to include other model forecasts, weather elements, and edit areas. An expanded form of the gridded verification scheme will continue to be developed and tested, and is expected to be made available for all WFOs to use operationally.

Acknowledgments

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References

Barker, T., 2004a: MatchObsAll Ver. 0.97 Documentation. [Available online at http://140.90.90.253/~applications/STR/generalappinfoout.php3?appnum=754].

Barker, T., 2004b: MatchMOSAll Ver. 1.9 Documentation. [Available online at http://140.90.90.253/~applications/STR/generalappinfoout.php3?appnum=785].

Barker, T., 2004c: Serp Ver. 1.12 Documentation. [Available online at http://140.90.90.253/~applications/STR/generalappinfoout.php3?appnum=755].

Colin, L., 2002: GFE-Based Temperature Verification – One Approach. Preprints, *19th Conf. on Wea. Anal. and Forecasting*, San Antonio, TX, Amer. Meteor. Soc.

Dagostaro, V. J., W. A. Shaffer, M. J. Schenk, and J. L. Gorline, 2004: A Prototype Verification System for Examining NDFD Forecasts. Preprints, *17th Conf. on Probability and Statistics in the Atmospheric Sciences*, Seattle, WA, Amer. Meteor. Soc.

Foisy, T., 2003: The MatchObsAll Analysis System. Western Region Technical Attachment No. 03-02. [Available online at http://www.wrh.noaa.gov/wrh/03TAs/0302/index.html].

Horel, J., M. Splitt, L. Dunn, J. Pechmann, B. White, C. Ciliberti, S. Lazarus, J. Slemmer, D. Zaff, J. Burks, 2002: MesoWest: Cooperative Mesonets in the Western United States. *Bull. Amer. Meteor. Soc.*, **83**, 211-226.

_____, B. Colman, and M. Jackson, 2004: Verification of NDFD Gridded Forecasts in the Western United States. Preprints, *20th Conf. on Wea. Anal. and Forecasting*, Seattle, WA, Amer. Meteor. Soc.

Jordan, C., and K. Cook, 2003: The Western Region Gridded Verification System. Western Region Technical Attachment No. 03-01. [Available online at http://www.wrh.noaa.gov/wrhq/03TAs/0301/index.html].

Knutsvig, R., 2004: Stats_RIW Ver. 1.0 Documentation. [Available online at http://140.90.90.253/~applications/STR/generalappinfoout.php3?appnum=734].

Lazarus, S. M., C. M. Ciliberti, J. D. Horel, and K. A. Brewster, 2002: Near-Real-Time Applications of a Mesoscale Analysis System to Complex Terrain. *Wea. Forecasting*, **17**, 971-1000.

Figures

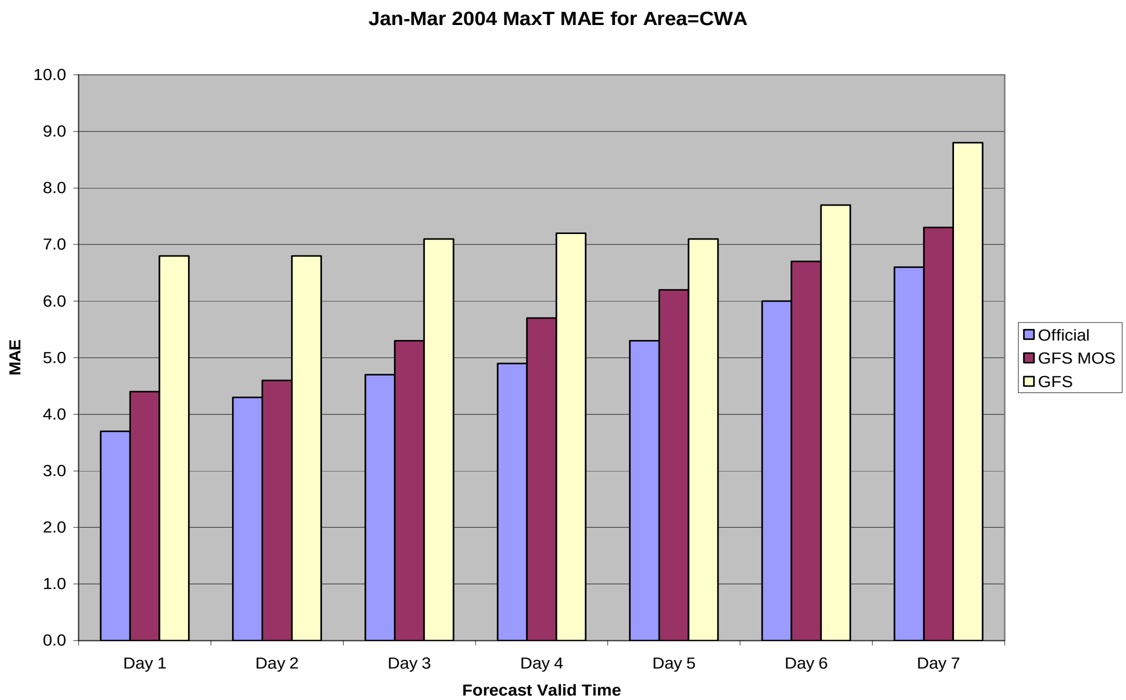

Figure 1. Mean absolute errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over the entire CWA for the period January-March 2004.

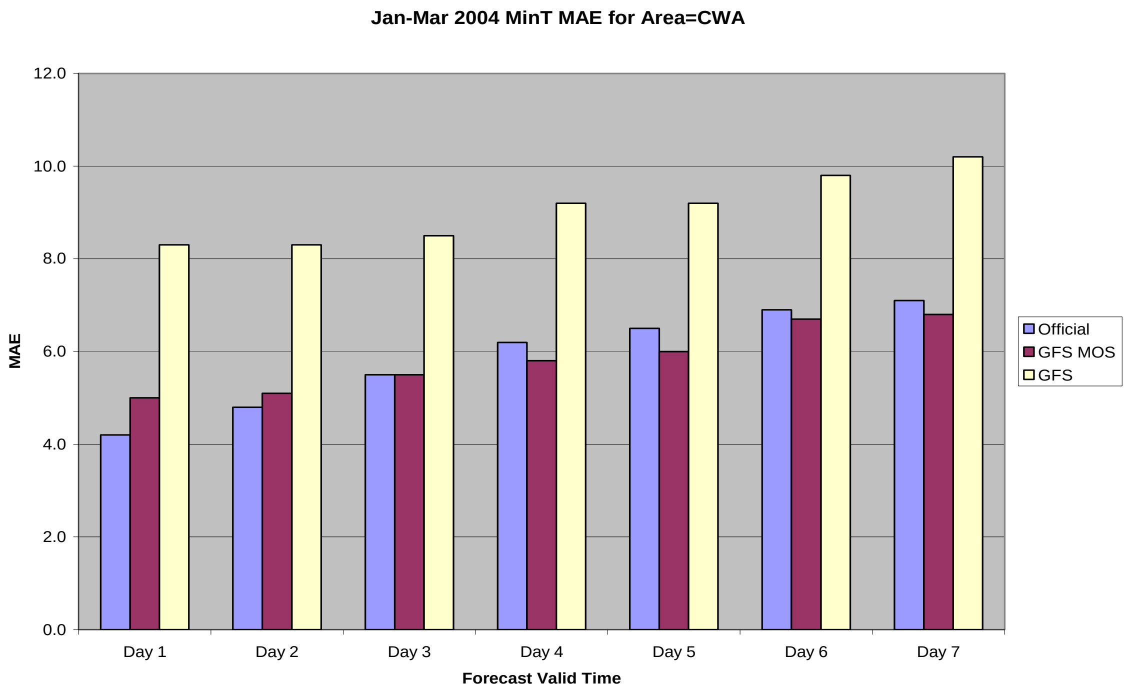

Figure 2. Mean absolute errors for the Official, GFS MOS, and GFS MinT forecasts averaged over the entire CWA for the period January-March 2004.

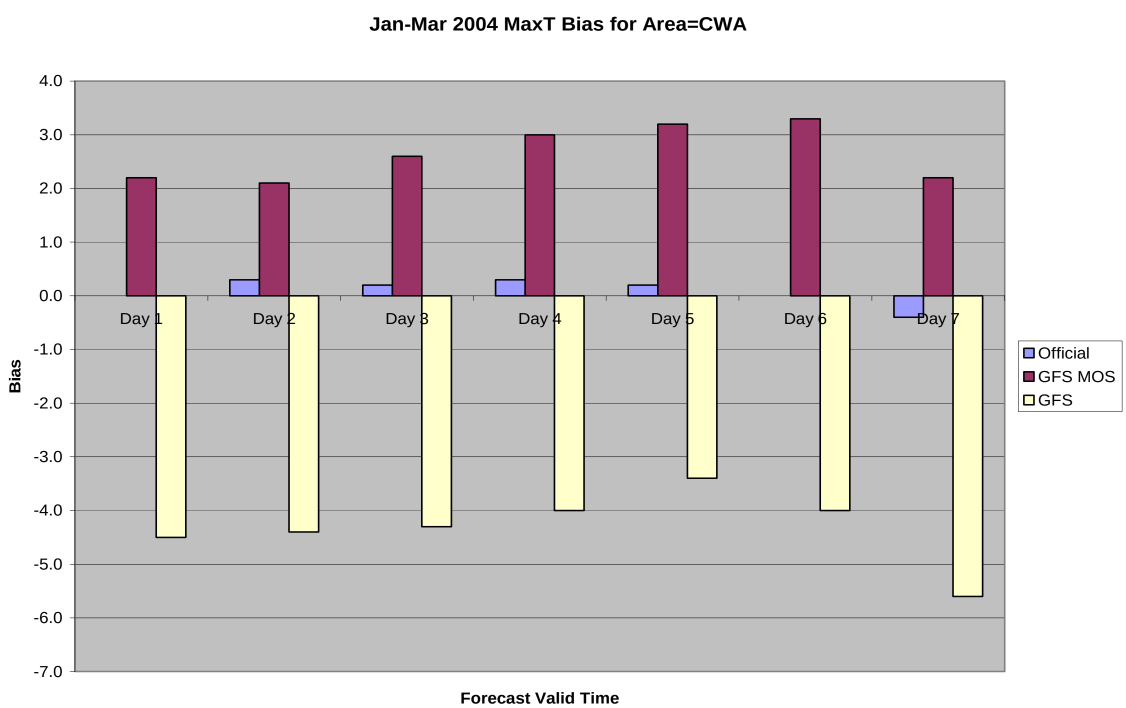

Figure 3. Bias errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over the entire CWA for the period January-March 2004.

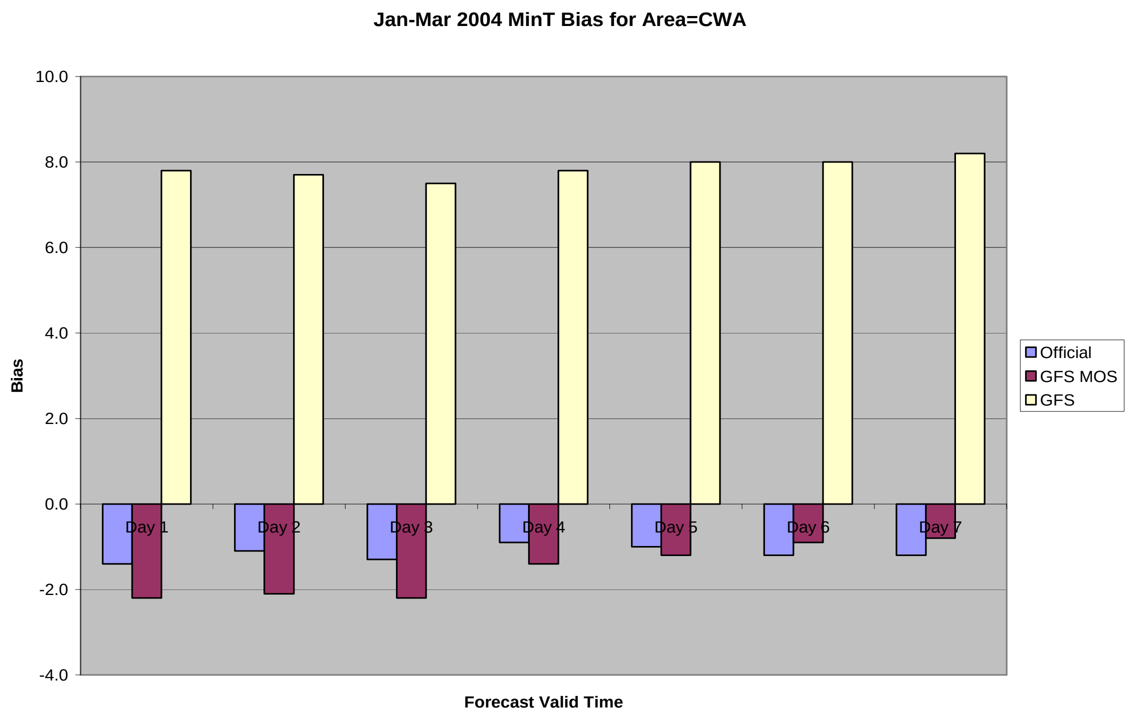

Figure 4. Bias errors for the Official, GFS MOS, and GFS MinT forecasts averaged over the entire CWA for the period January-March 2004.

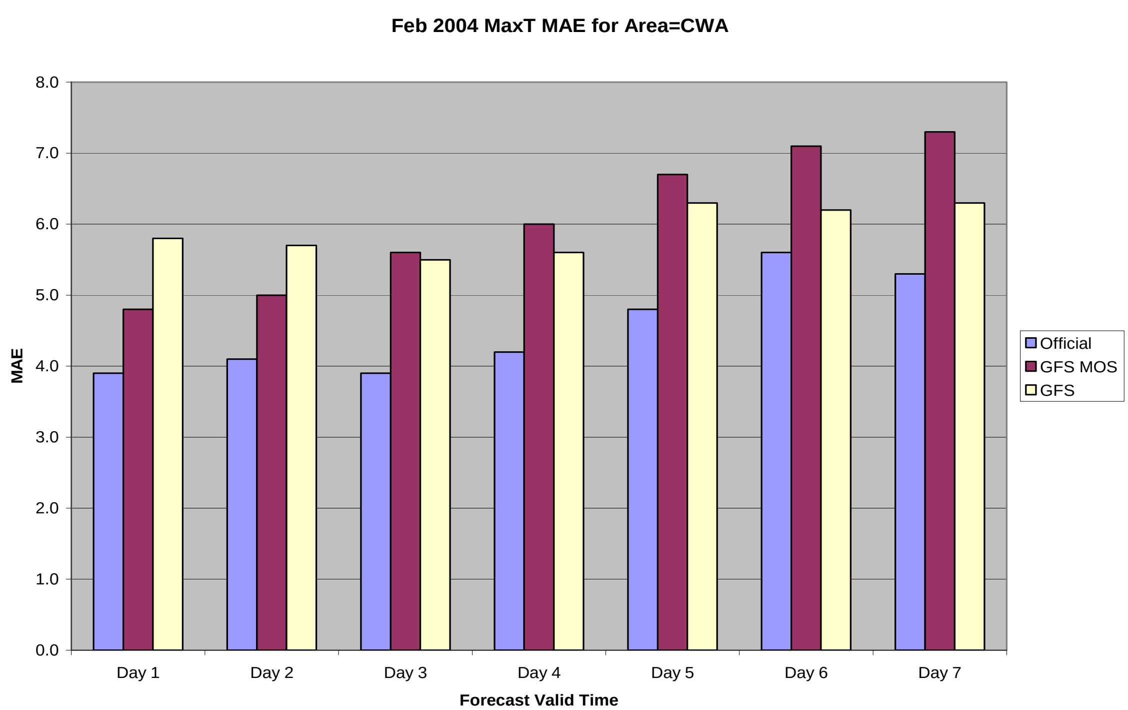

Figure 5. Mean absolute errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over the entire CWA for February 2004.

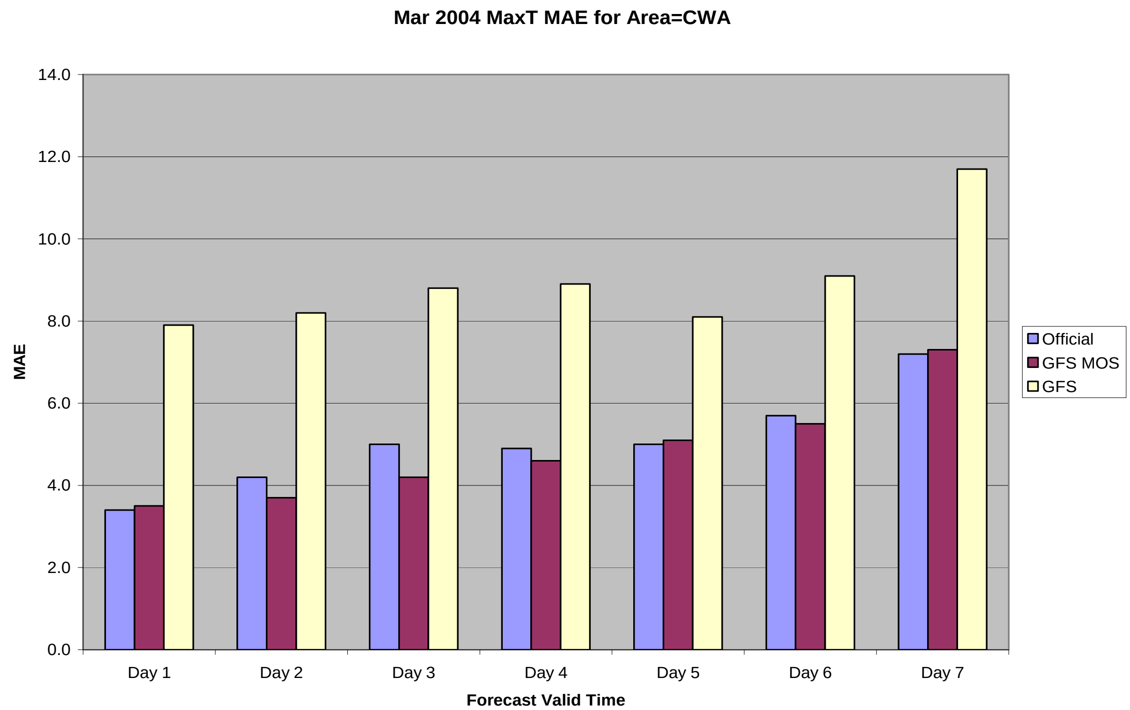

Figure 6. Mean absolute errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over the entire CWA for March 2004.

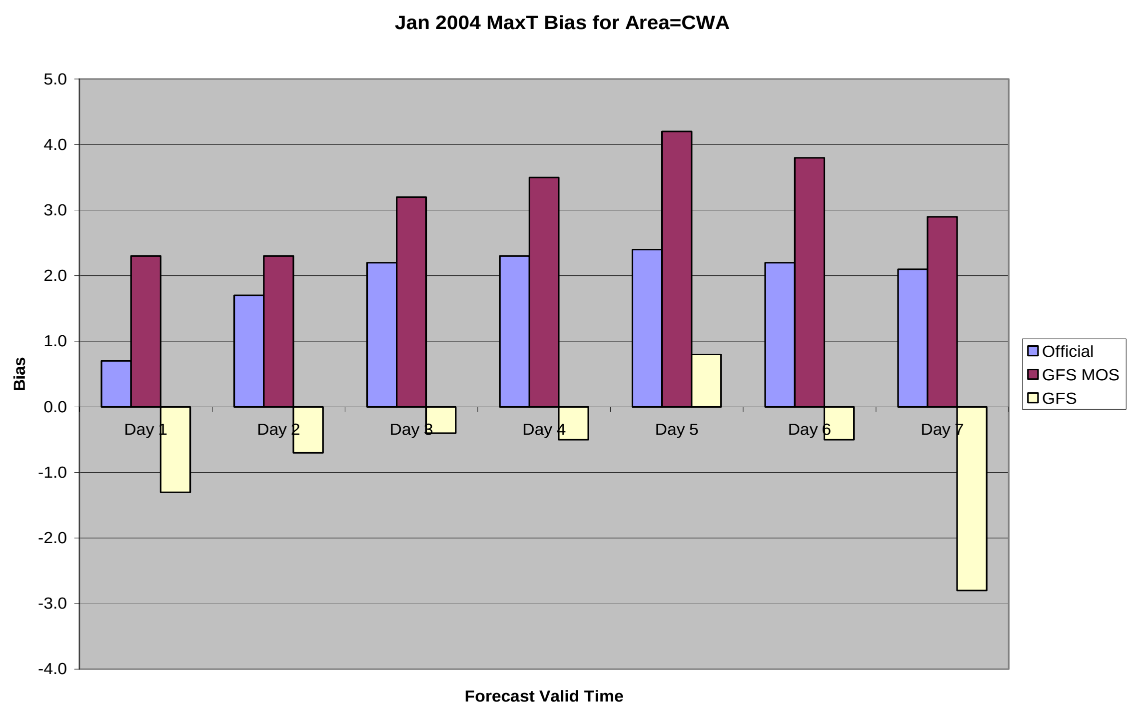

Figure 7. Bias errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over the entire CWA for January 2004.

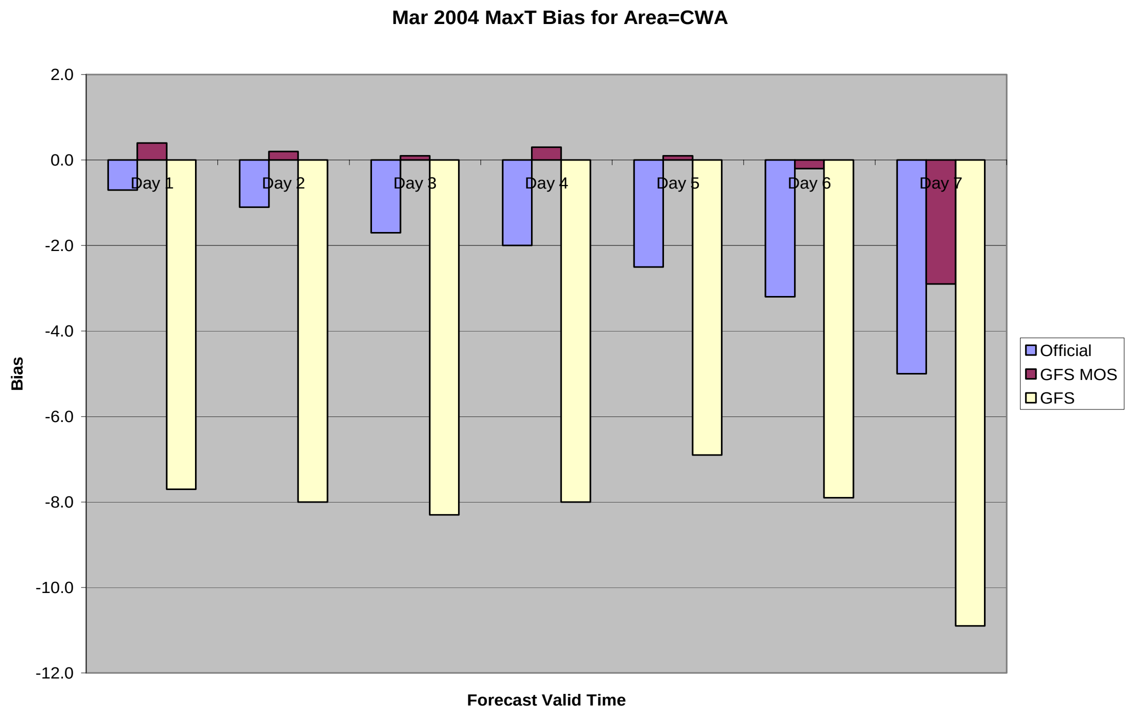

Figure 8. Bias errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over the entire CWA for March 2004.

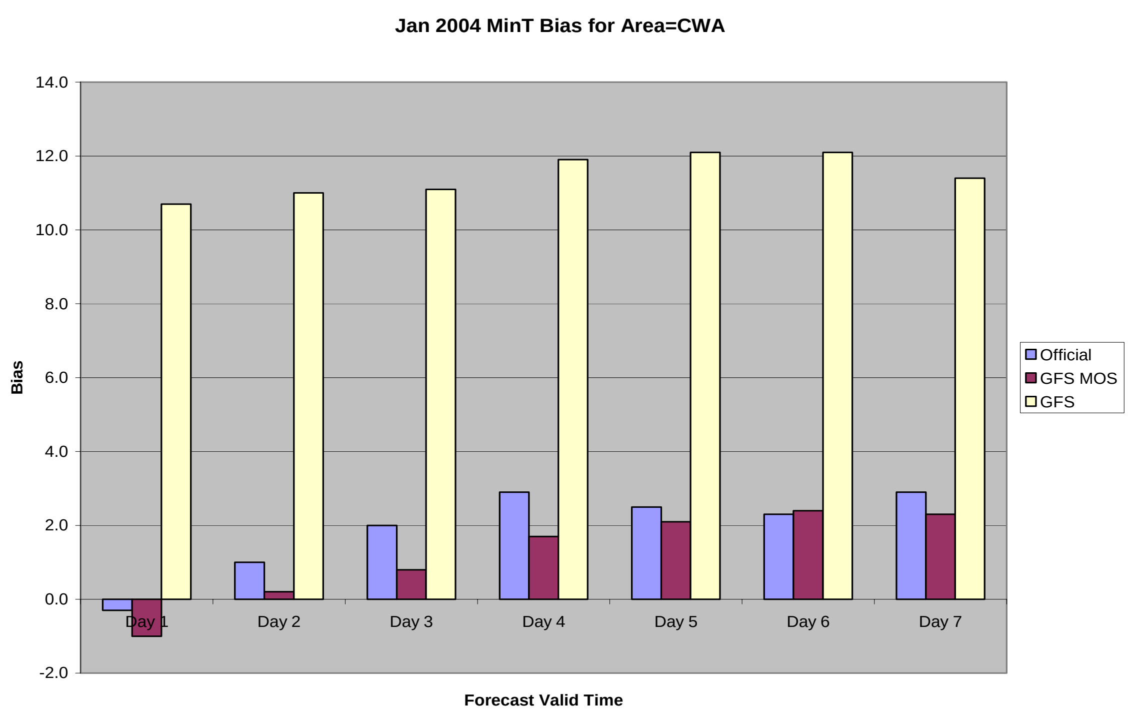

Figure 9. Bias errors for the Official, GFS MOS, and GFS MinT forecasts averaged over the entire CWA for January 2004.

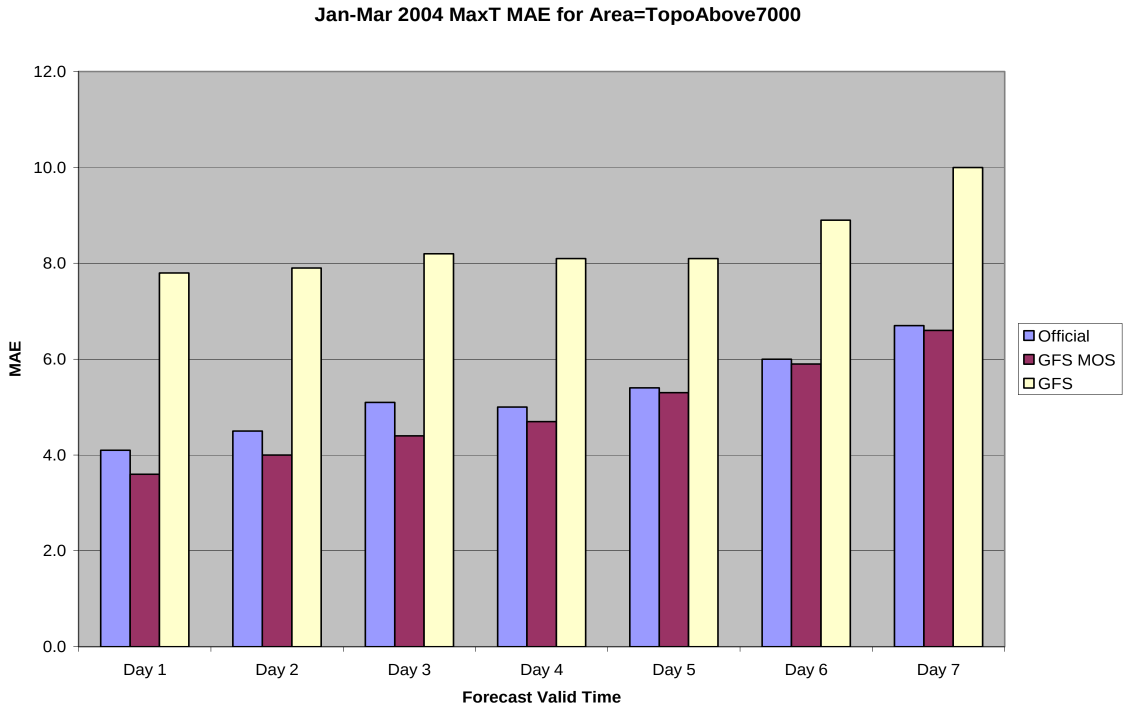

Figure 10. Mean absolute errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over all grid points in the CWA above 7000 feet for the period January-March 2004.

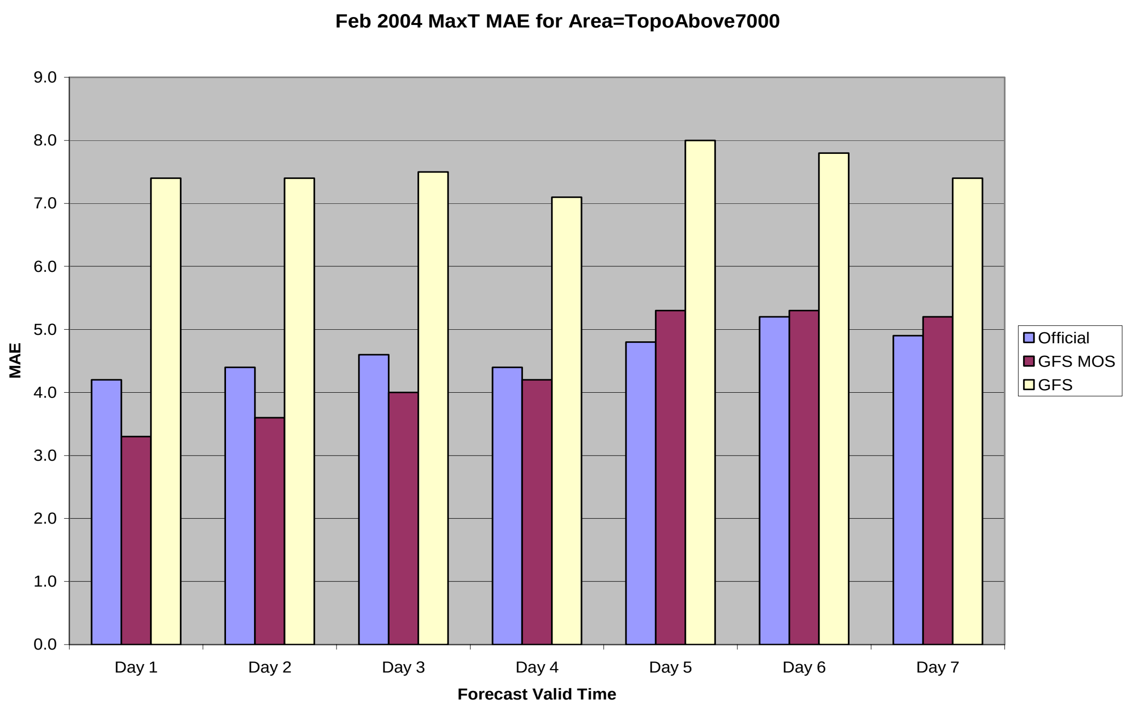

Figure 11. Mean absolute errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over all grid points in the CWA above 7000 feet for February 2004.

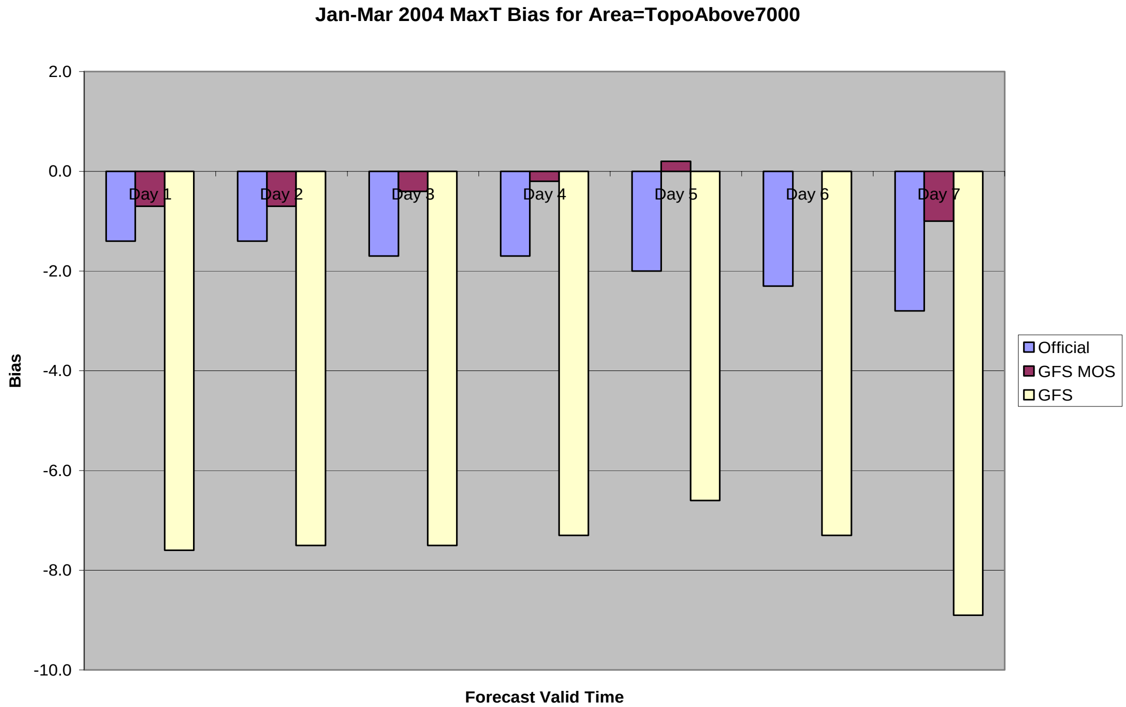

Figure 12. Bias errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over all grid points in the CWA above 7000 feet for the period January-March 2004.

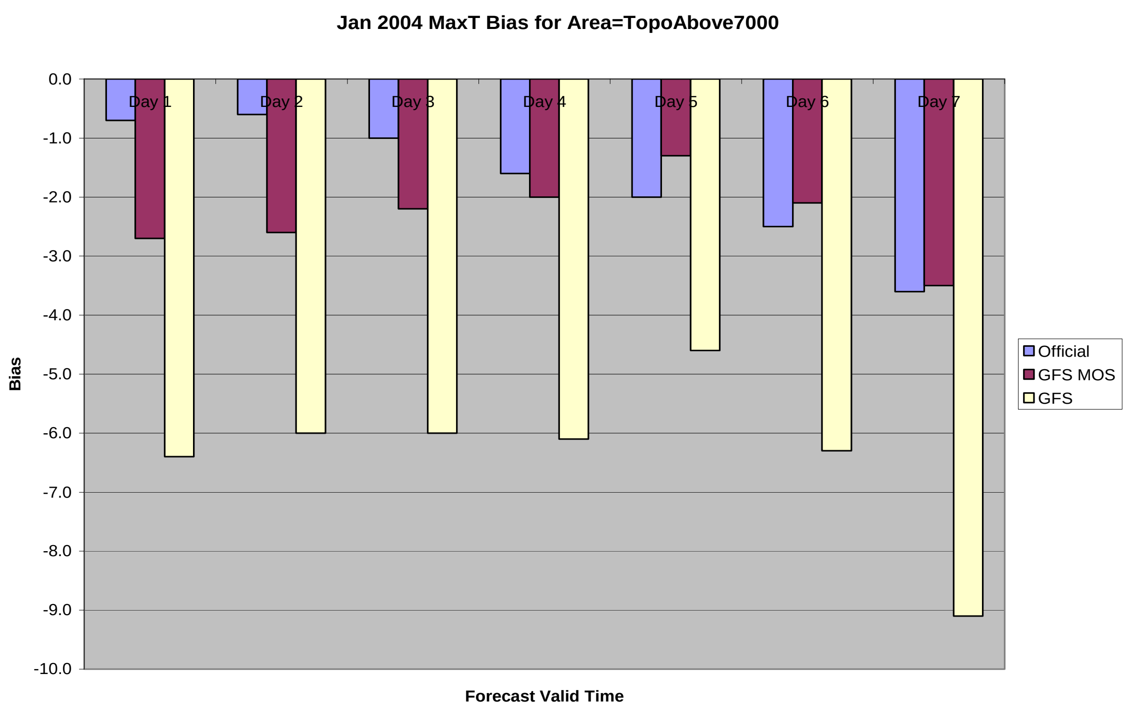

Figure 13. Bias errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over all grid points in the CWA above 7000 feet for January 2004.

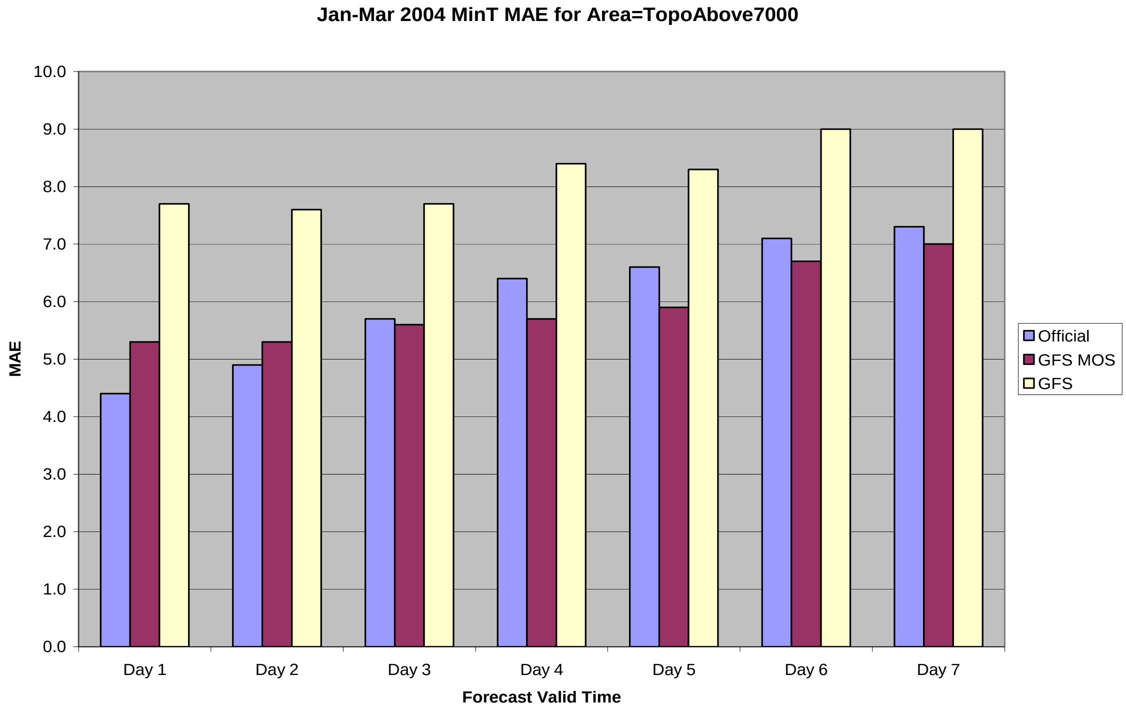

Figure 14. Mean absolute errors for the Official, GFS MOS, and GFS MinT forecasts averaged over all grid points in the CWA above 7000 feet for the period January-March 2004.

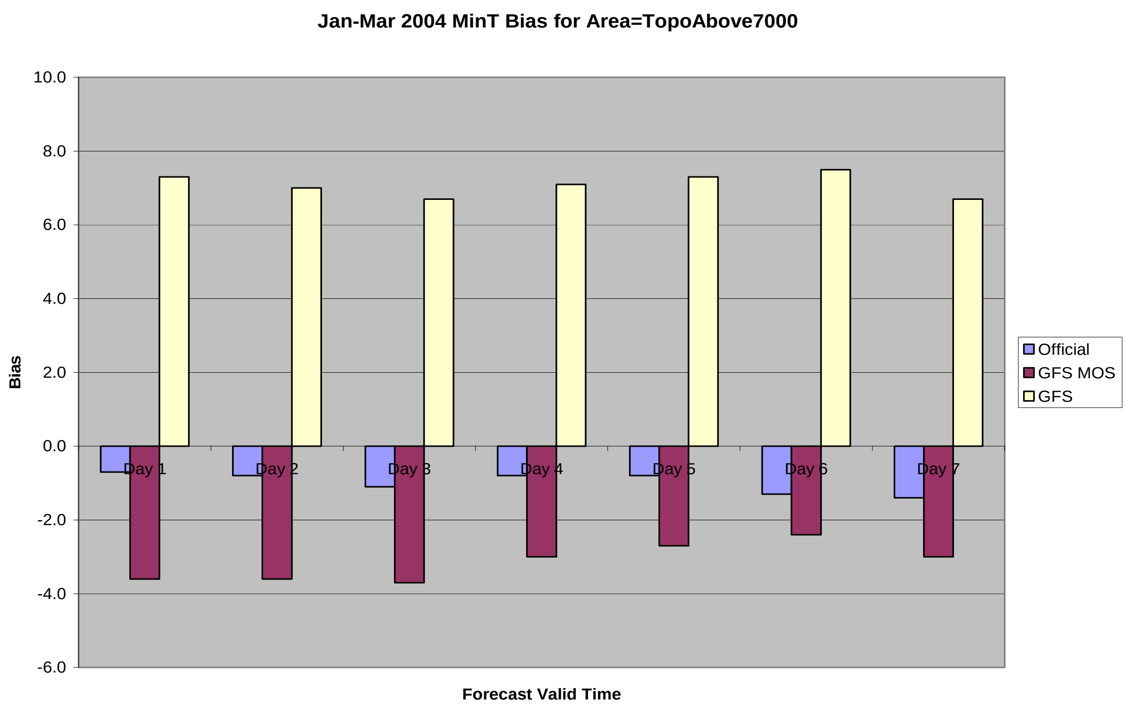

Figure 15. Bias errors for the Official, GFS MOS, and GFS MinT forecasts averaged over all grid points in the CWA above 7000 feet for the period January-March 2004.

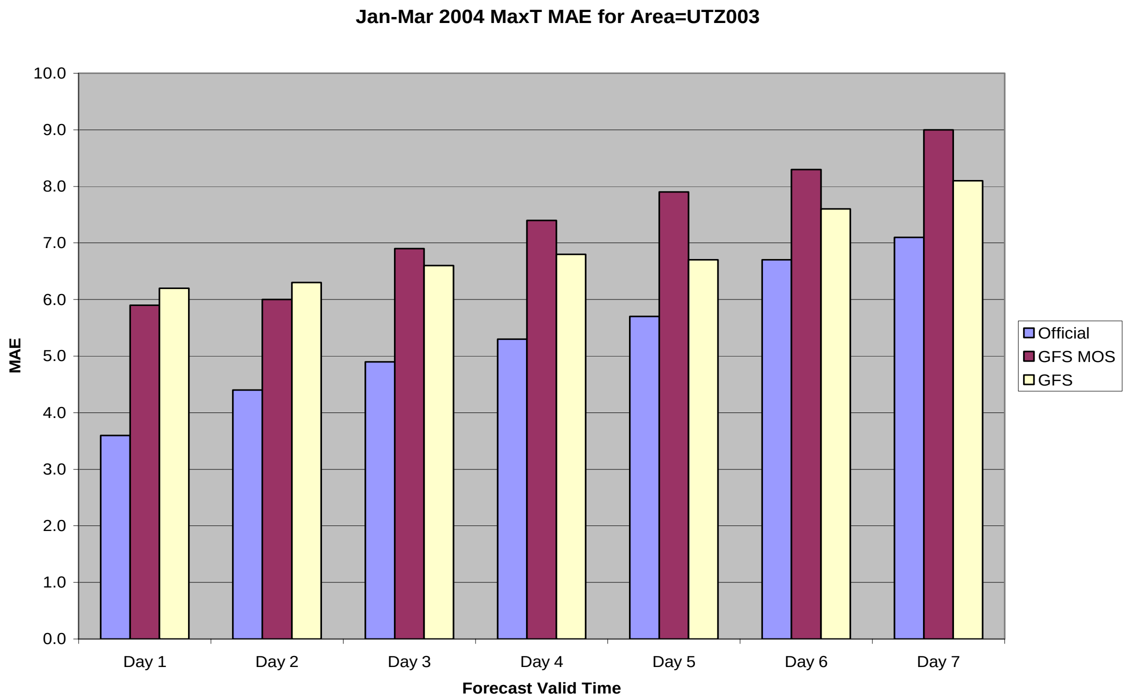

Figure 16. Mean absolute errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over all grid points in UTZ003 for the period January-March 2004.

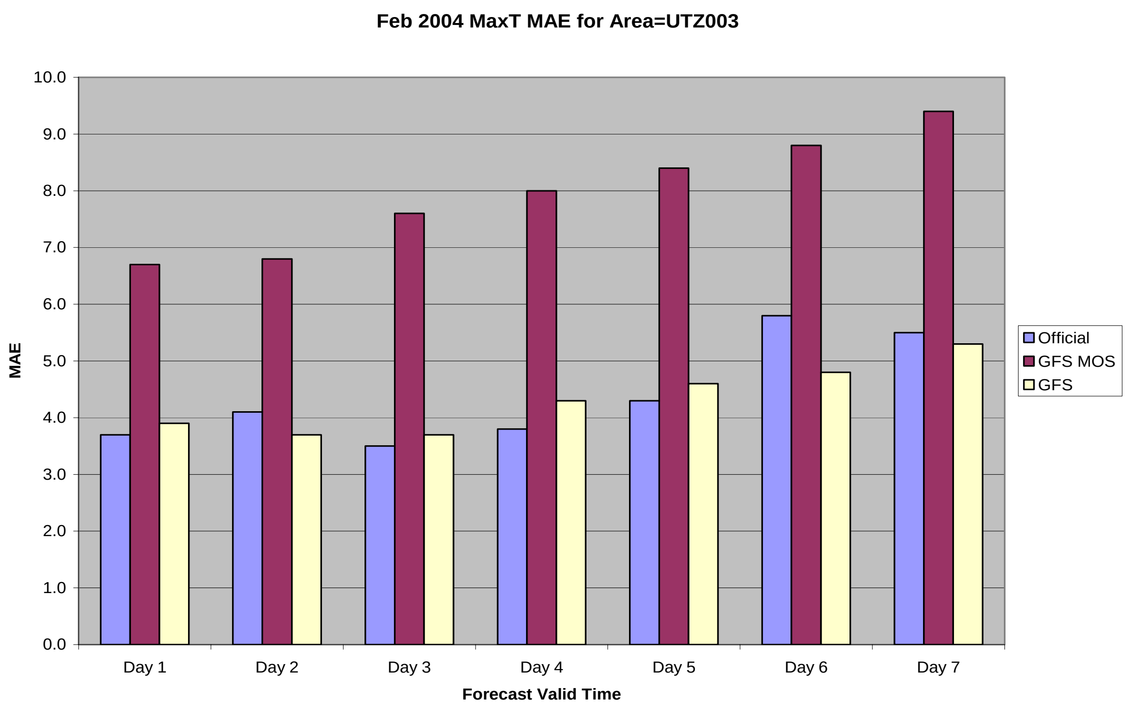

Figure 17. Mean absolute errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over all grid points in UTZ003 for February 2004.

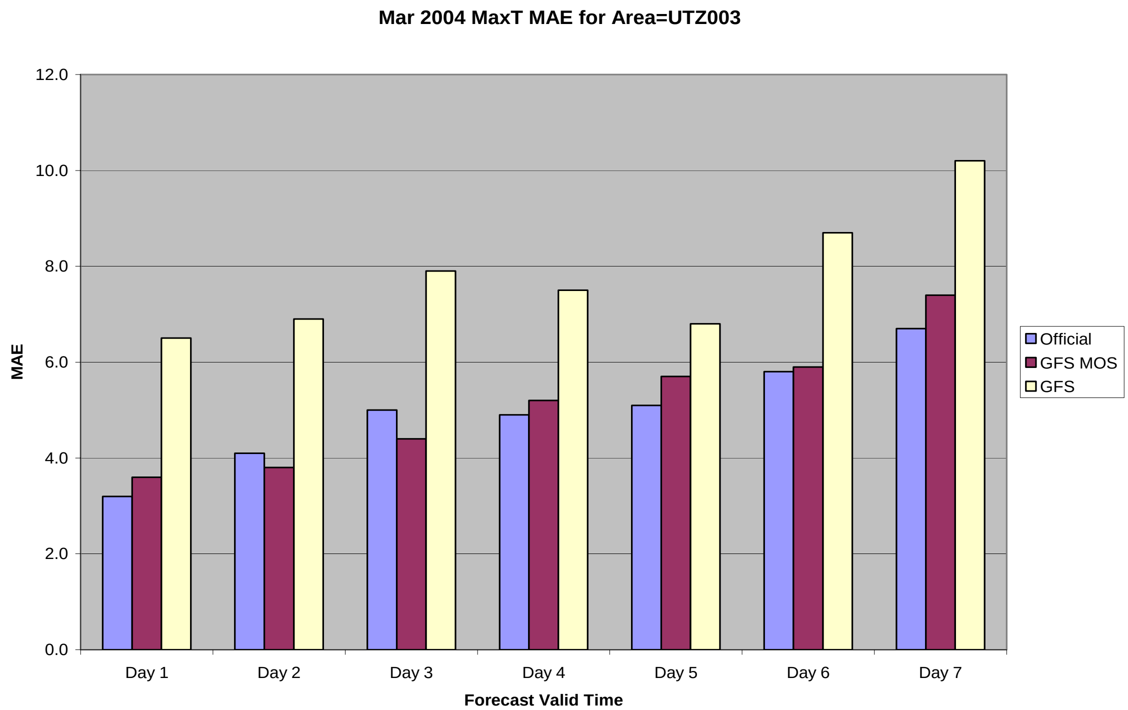

Figure 18. Mean absolute errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over all grid points in UTZ003 for March 2004.

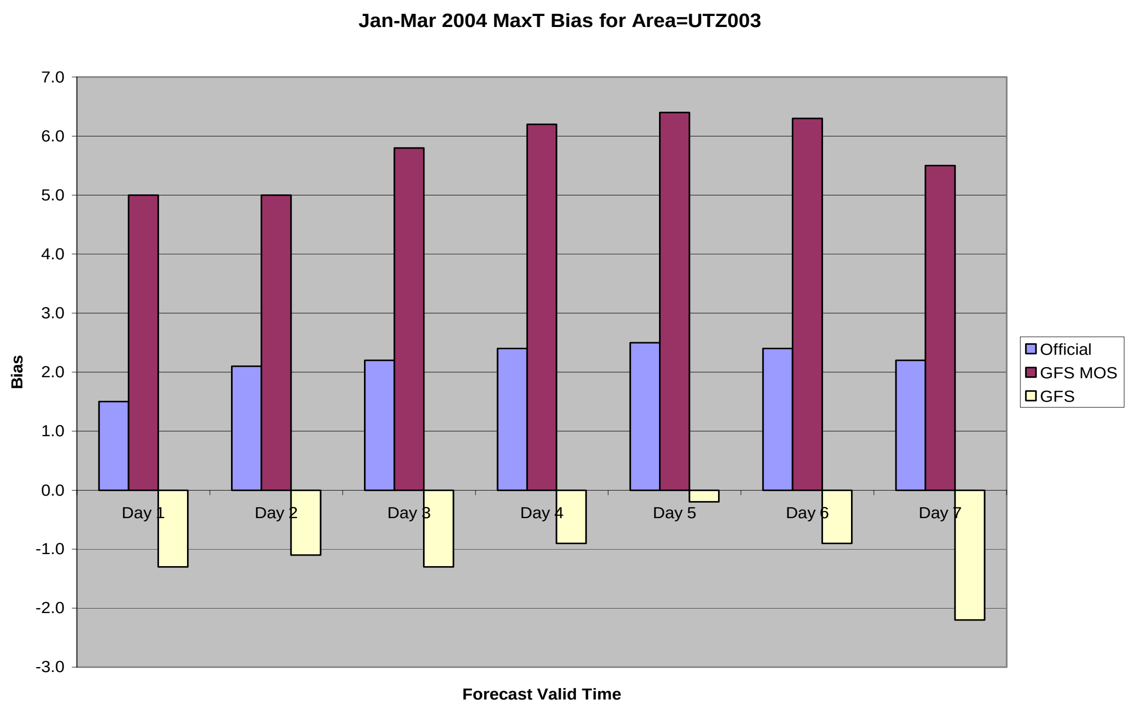

Figure 19. Bias errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over all grid points in UTZ003 for the period January-March 2004.

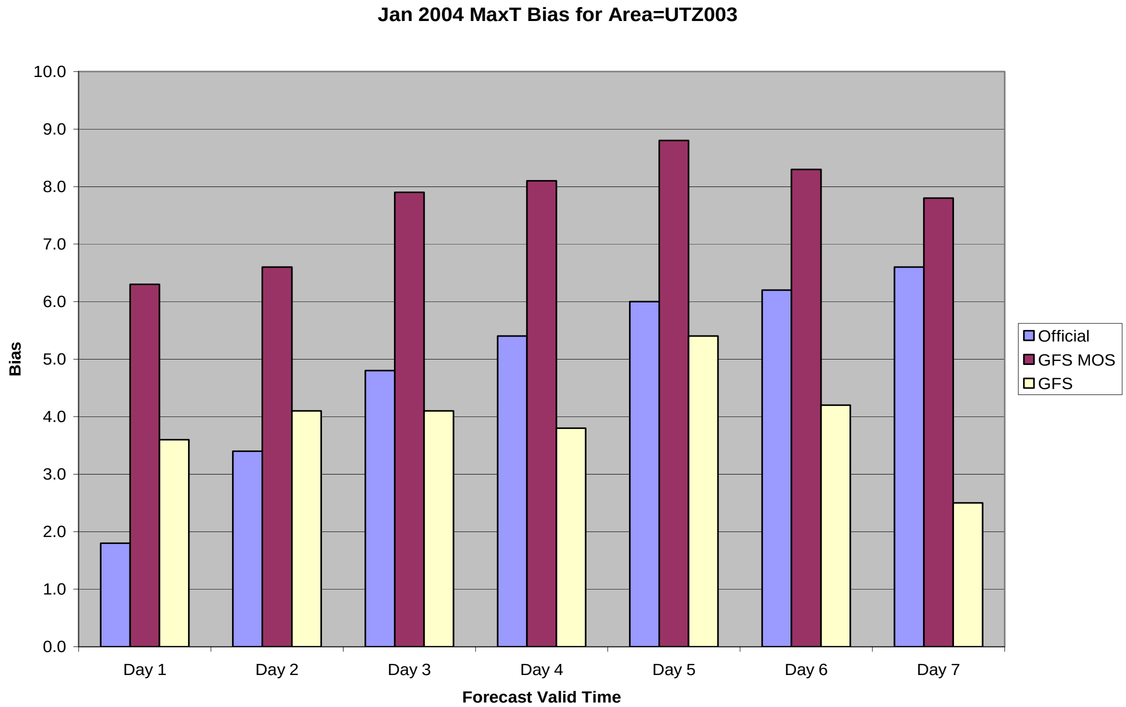

Figure 20. Bias errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over all grid points in UTZ003 for January 2004.

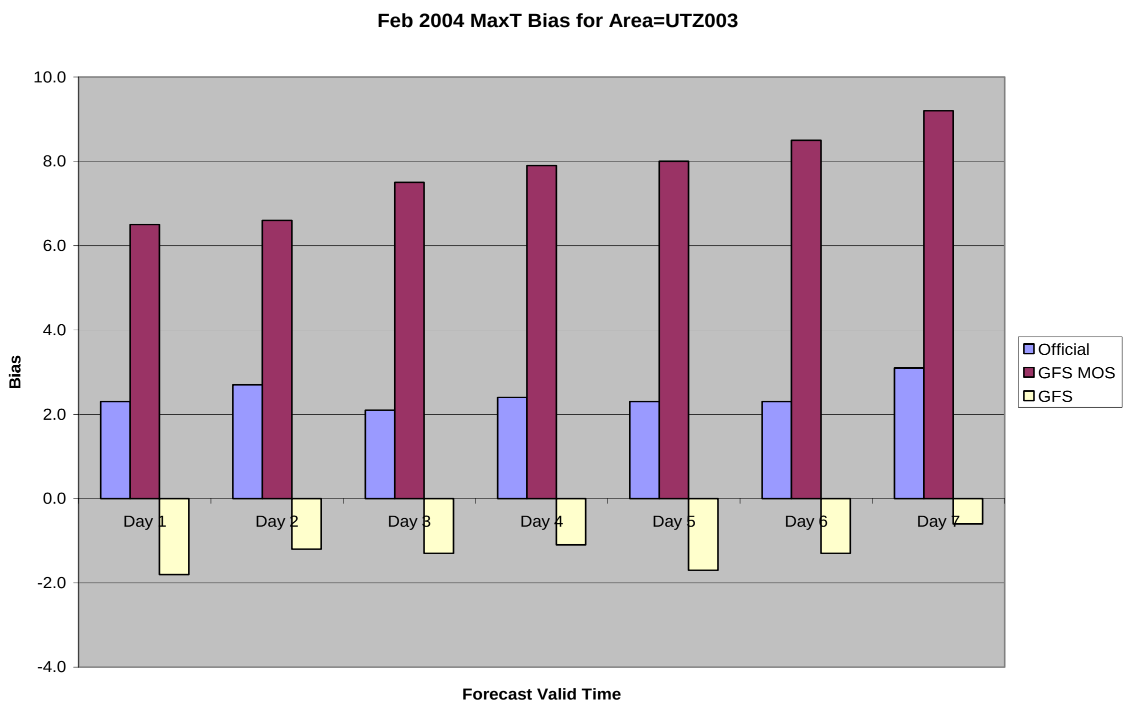

Figure 21. Bias errors for the Official, GFS MOS, and GFS MaxT forecasts averaged over all grid points in UTZ003 for February 2004.

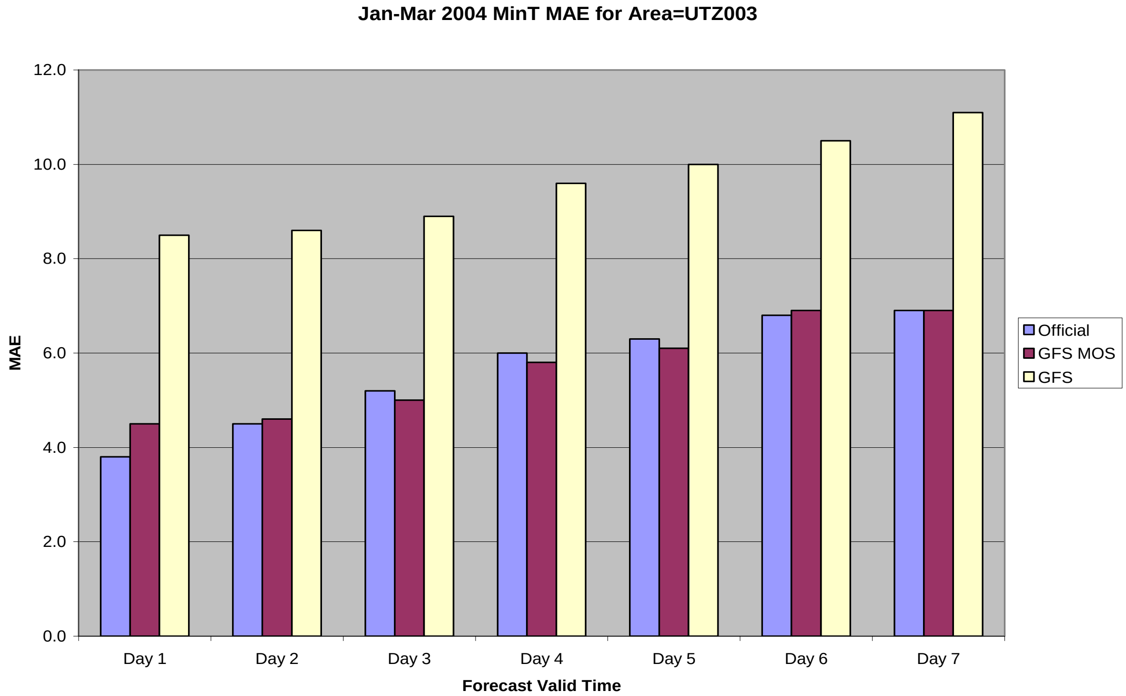

Figure 22. Mean absolute errors for the Official, GFS MOS, and GFS MinT forecasts averaged over all grid points in UTZ003 for the period January-March 2004.

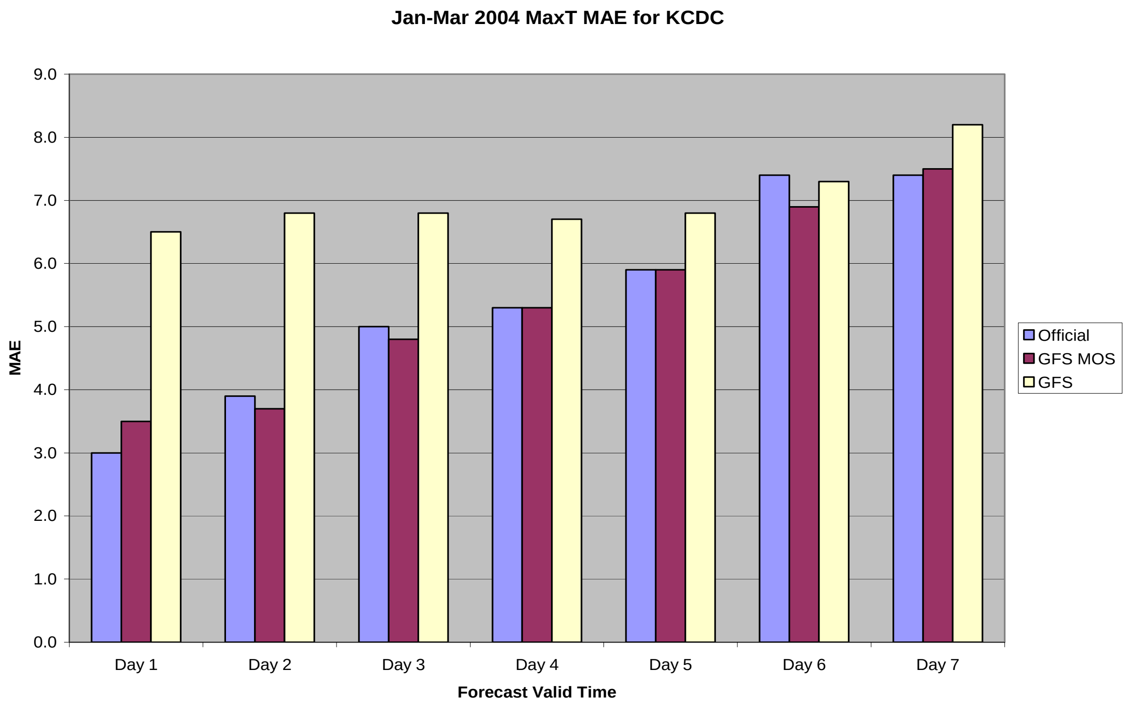

Figure 23. Mean absolute errors for the Official, GFS MOS, and GFS MaxT forecasts at KCDC for the period January-March 2004.

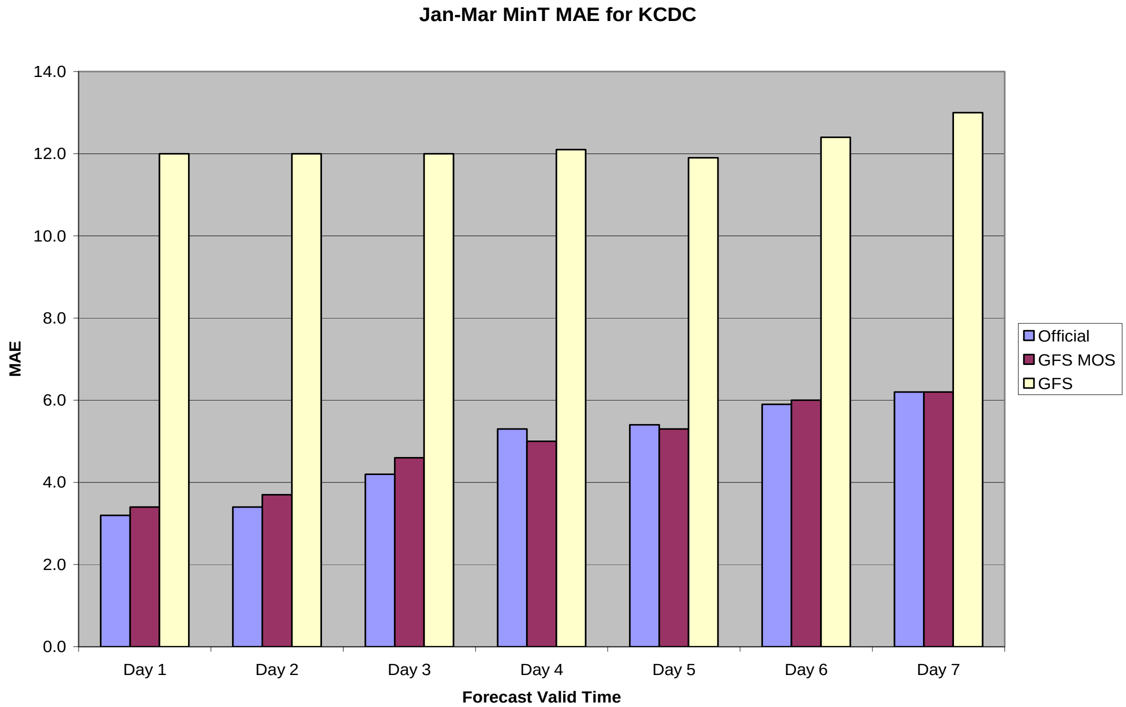

Figure 24. Mean absolute errors for the Official, GFS MOS, and GFS MinT forecasts at KCDC for the period January-March 2004.

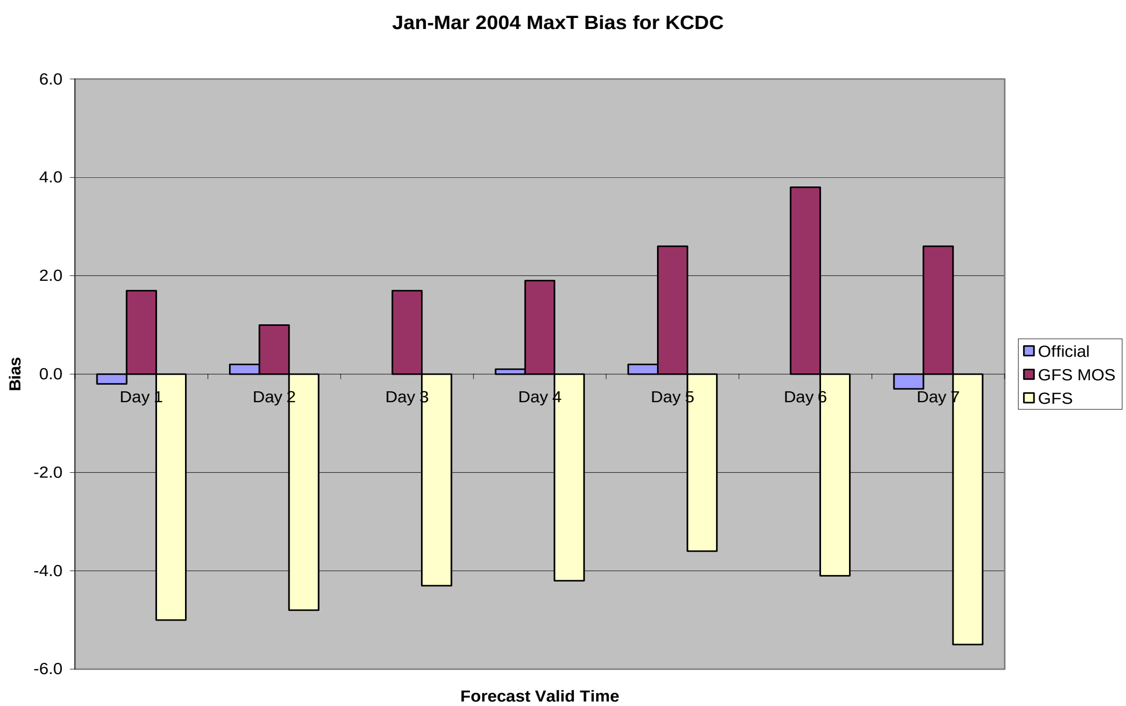

Figure 25. Bias errors for the Official, GFS MOS, and GFS MaxT forecasts at KCDC for the period January-March 2004.

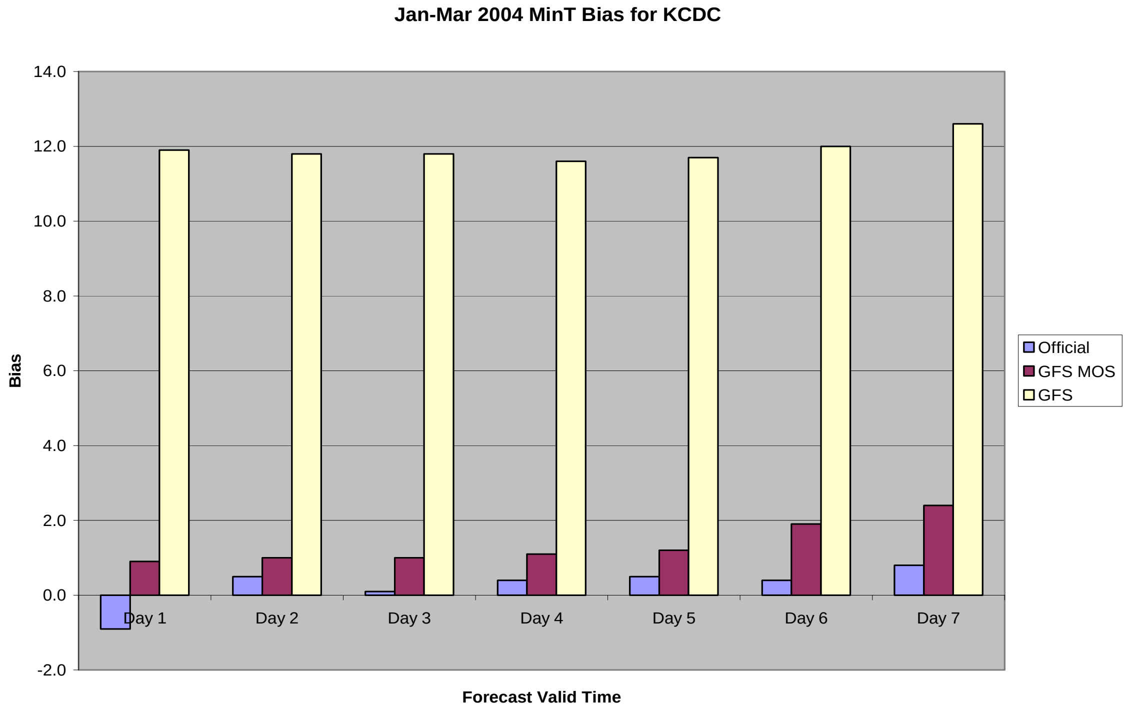

Figure 26. Bias errors for the Official, GFS MOS, and GFS MinT forecasts at KCDC for the period January-March 2004.

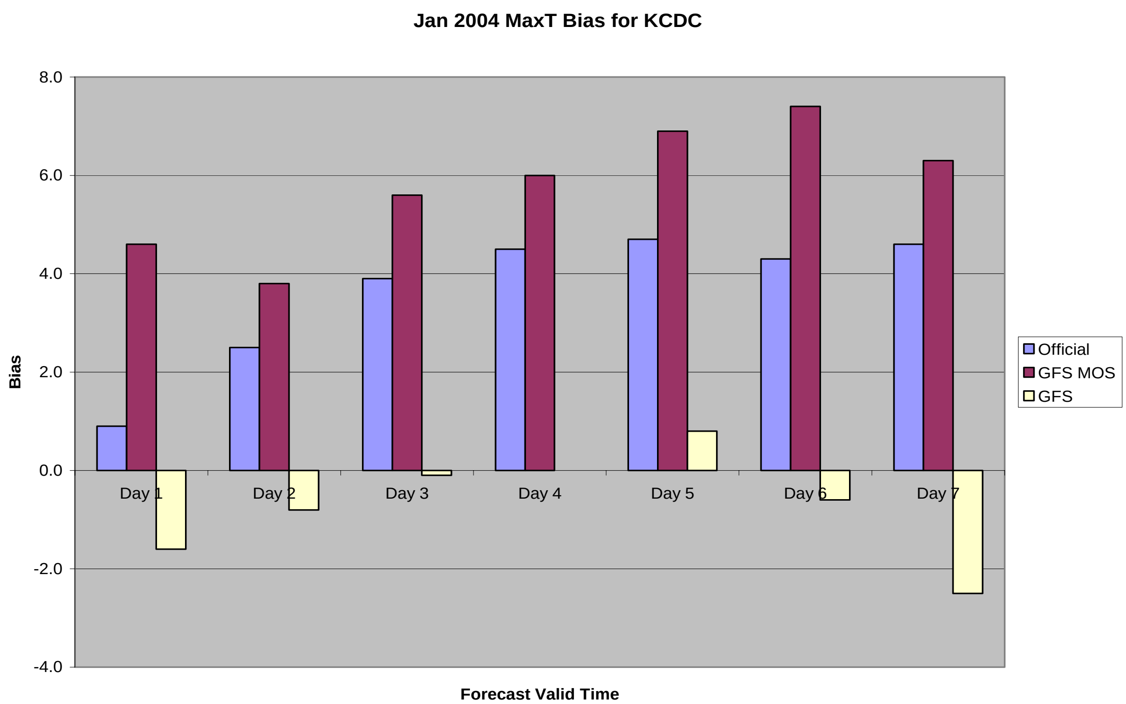

Figure 27. Bias errors for the Official, GFS MOS, and GFS MaxT forecasts at KCDC for January 2004.

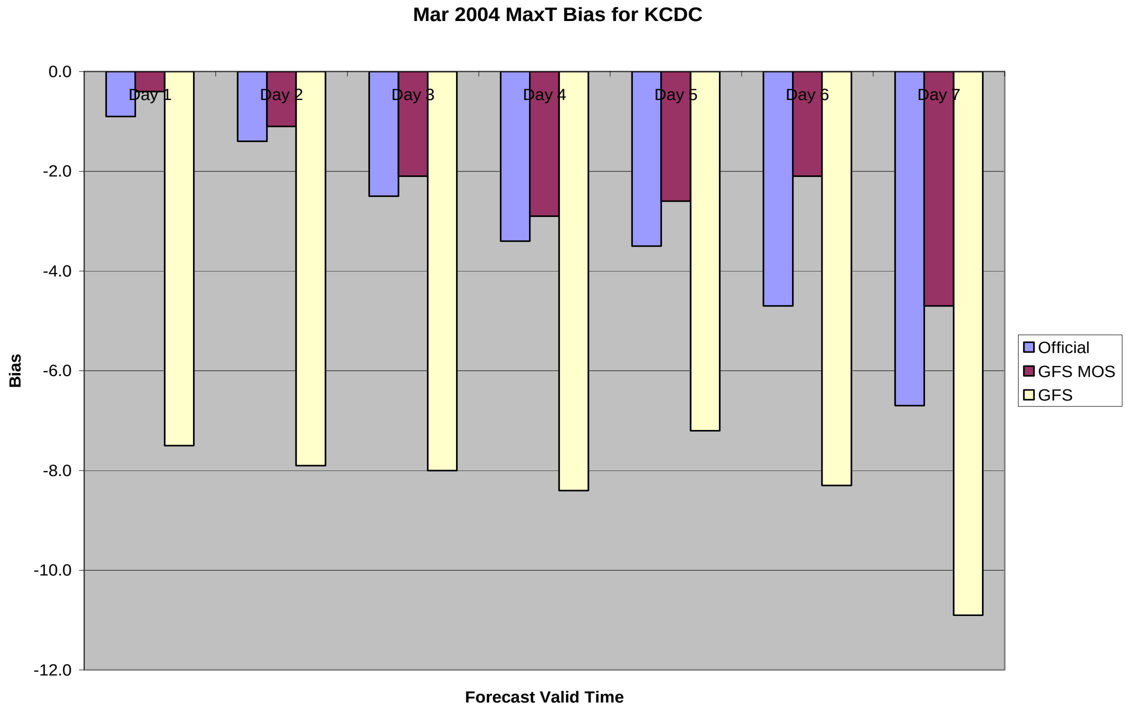

Figure 28. Bias errors for the Official, GFS MOS, and GFS MaxT forecasts at KCDC for March 2004.

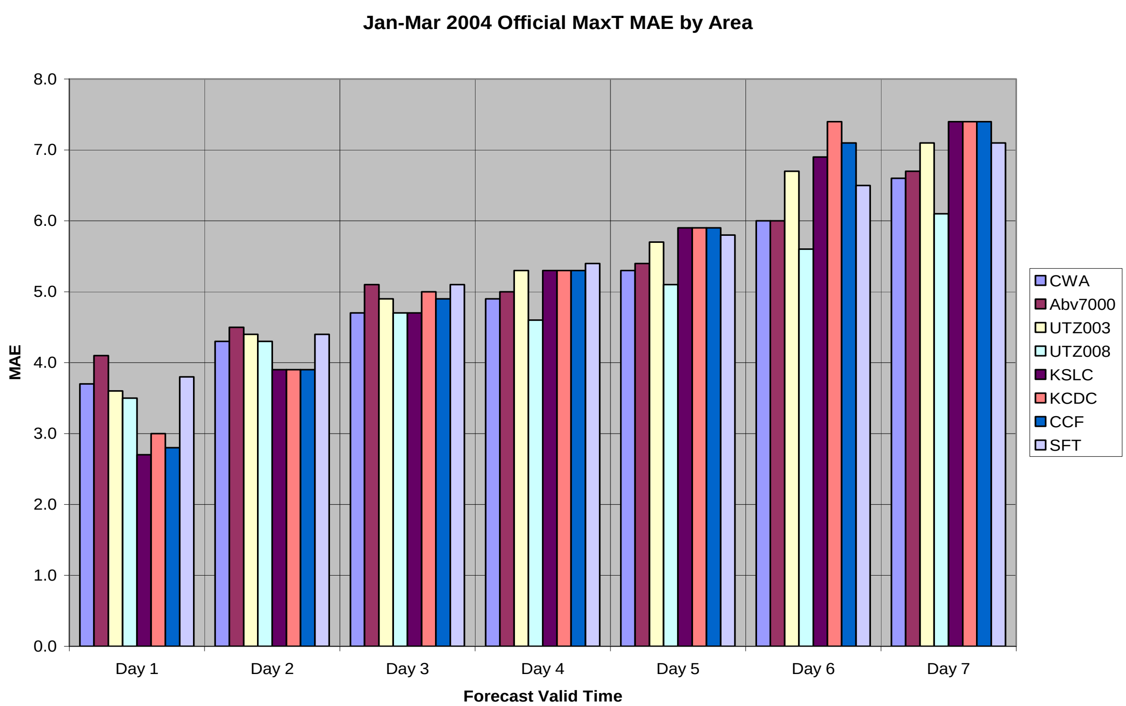

Figure 29. Mean absolute errors for the Official forecasts for MaxT over eight areas for the period January-March 2004.

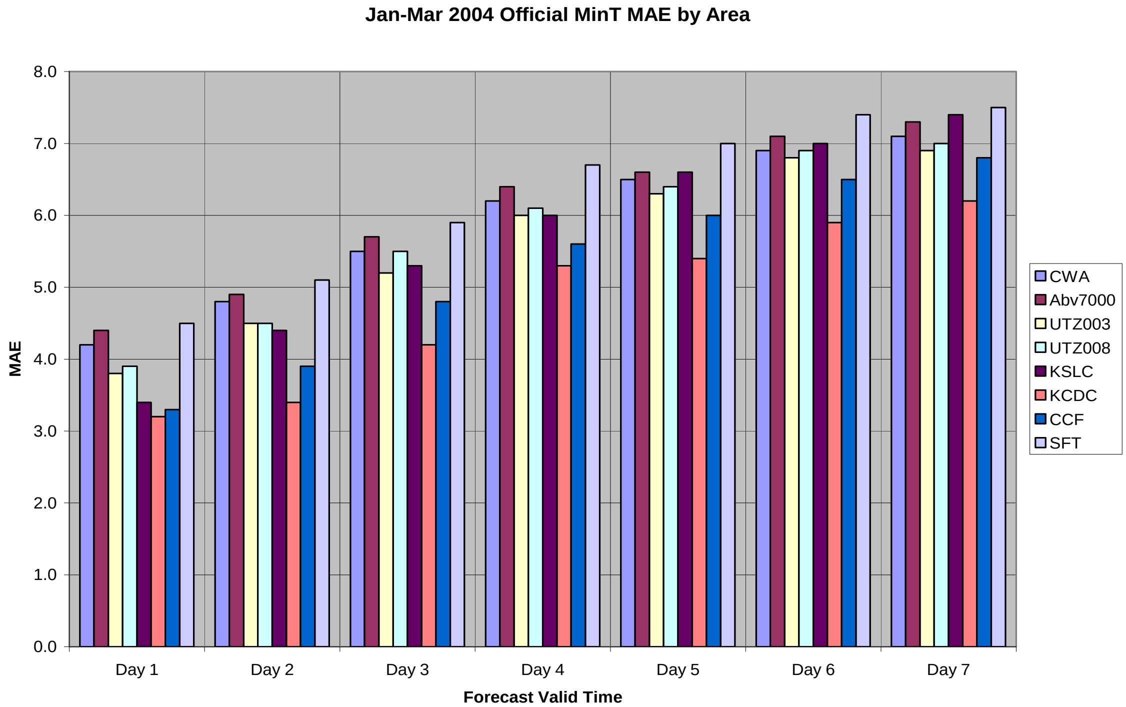

Figure 30. Mean absolute errors for the Official forecasts for MinT over eight areas for the period January-March 2004.

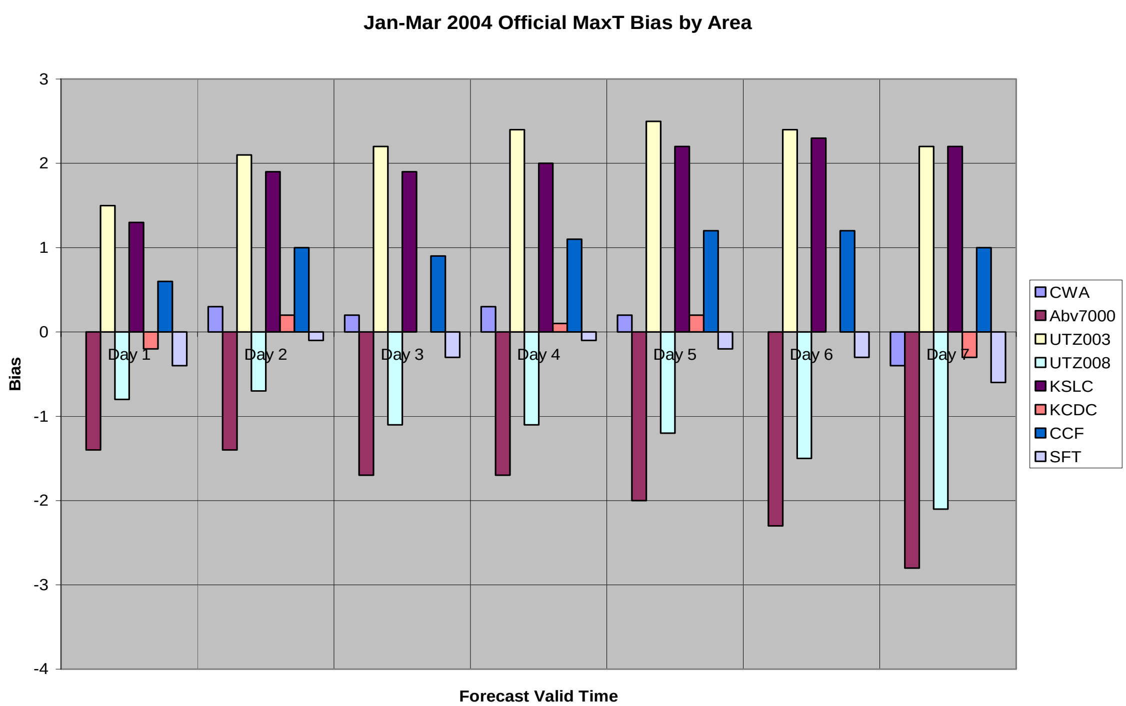

Figure 31. Bias errors for the Official forecasts for MaxT over eight areas for the period January-March 2004.

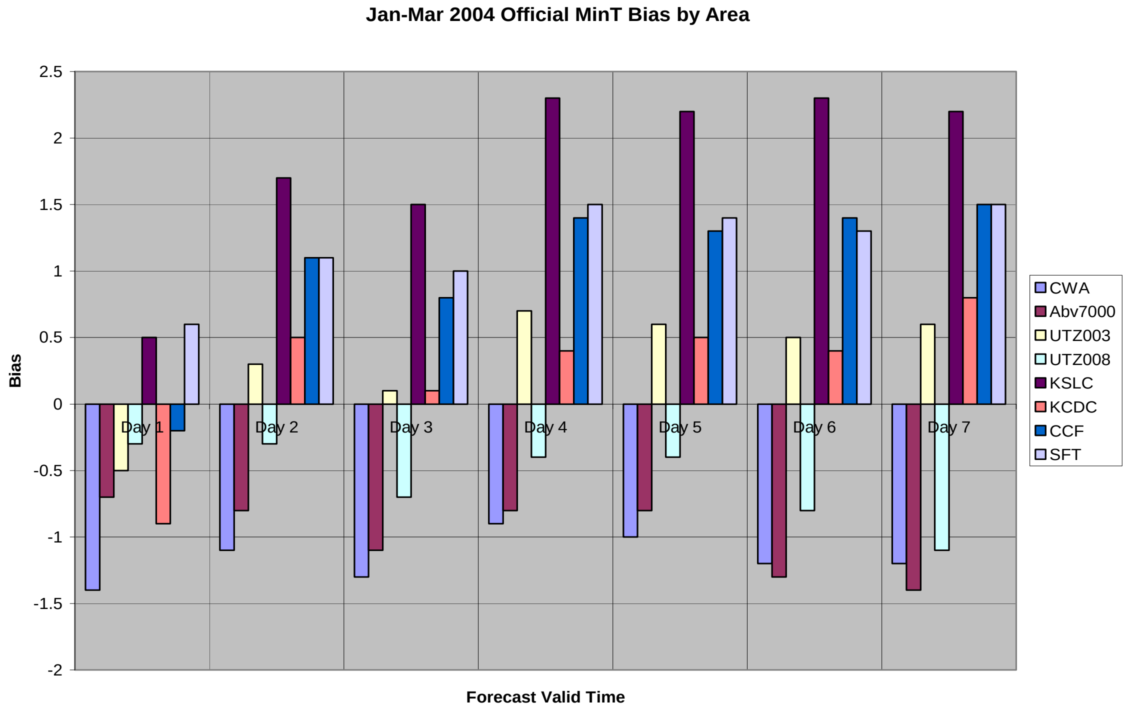

Figure 32. Bias errors for the Official forecasts for MinT over eight areas for the period January-March 2004.

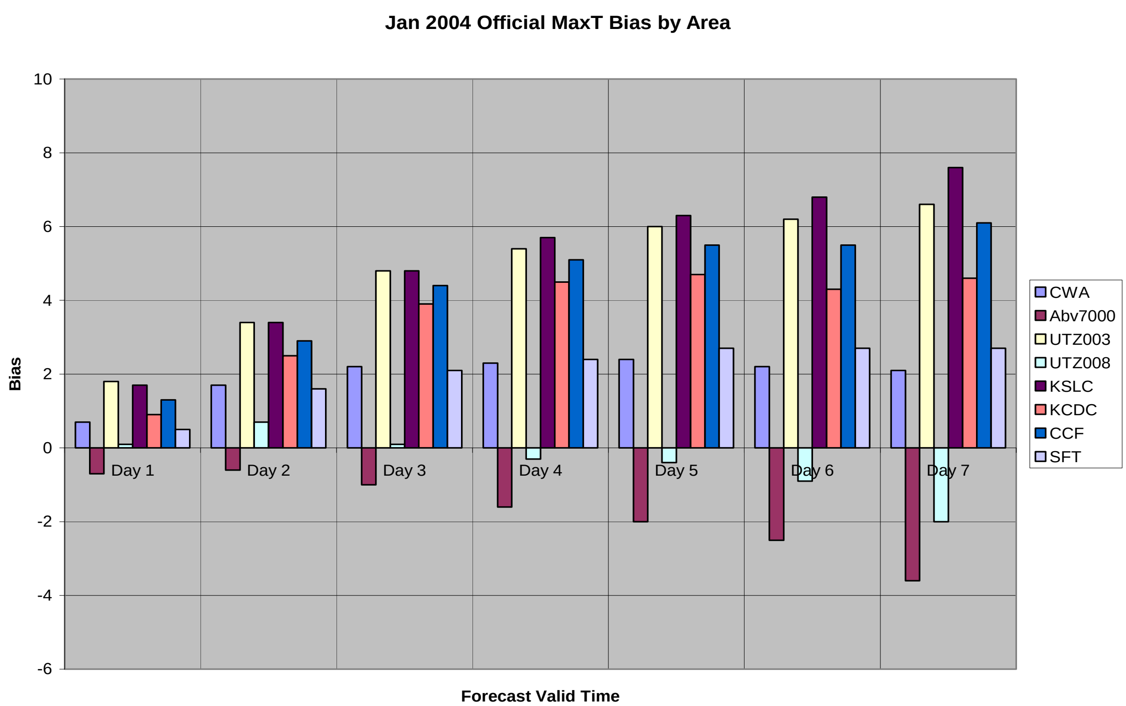

Figure 33. Bias errors for the Official forecasts for MaxT over eight areas for January 2004.

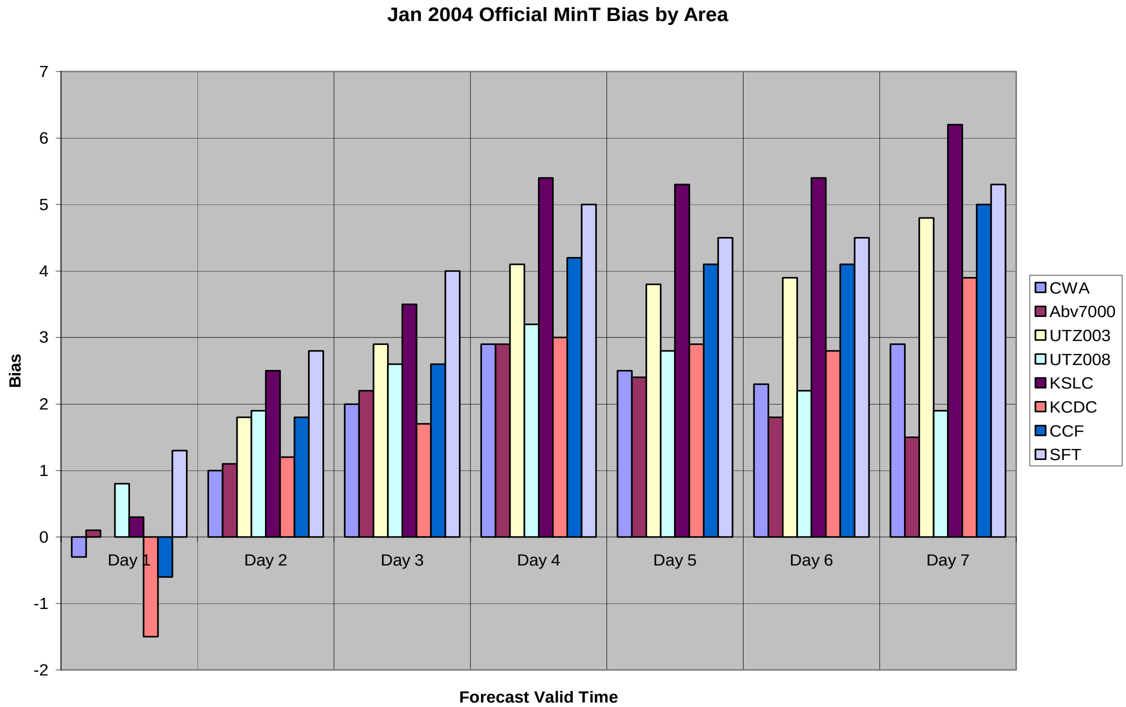

Figure 34. Bias errors for the Official forecasts for MinT over eight areas for January 2004.

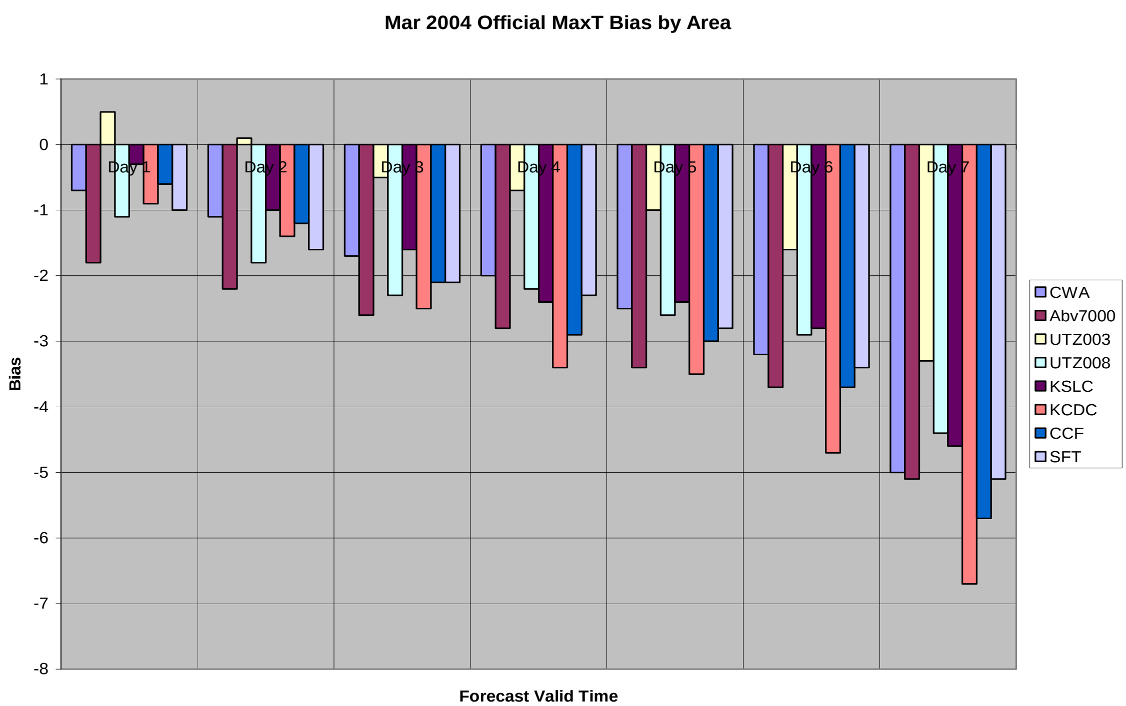

Figure 35. Bias errors for the Official forecasts for MaxT over eight areas for March 2004.

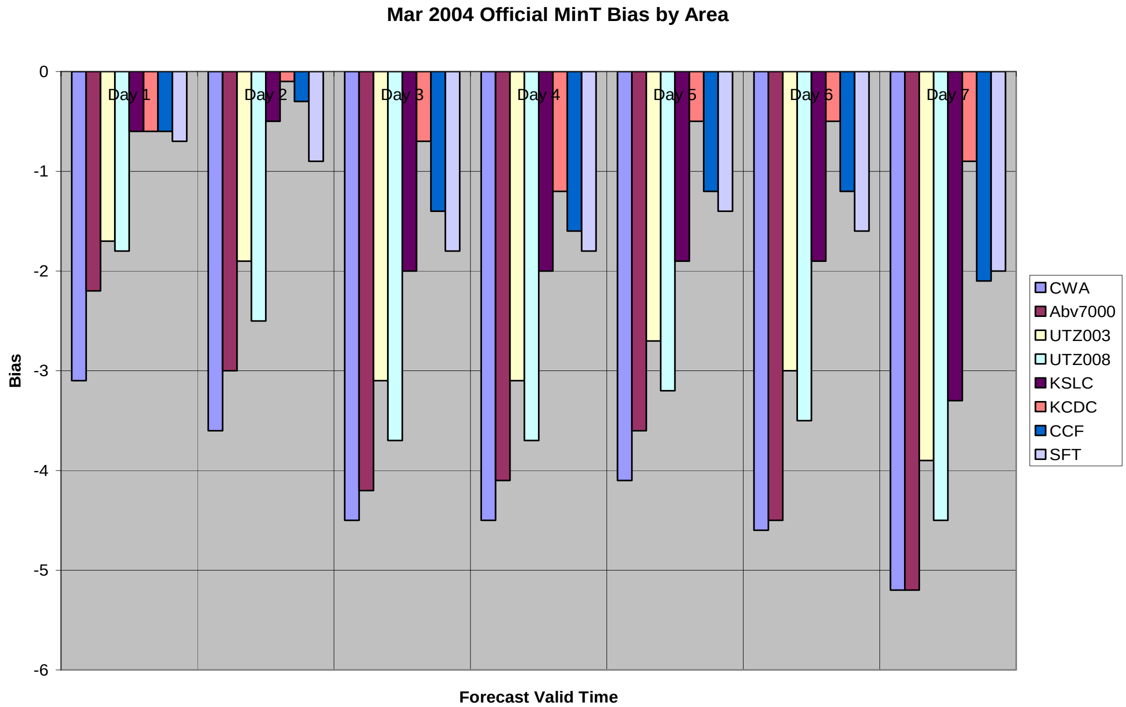

Figure 36. Bias errors for the Official forecasts for MinT over eight areas for March 2004.