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4.4 GRIDDED LOCALIZED AVIATION MOS PROGRAM (LAMP) GUIDANCE FOR AVIATION FORECASTING

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1. INTRODUCTION

The Meteorological Development Laboratory (MDL) of the National Weather Service (NWS) implemented the Localized Aviation Model Output Statistics (MOS) Program (LAMP) guidance into NWS operations beginning in 2006 (Ghirardelli and Glahn 2010). The LAMP guidance is produced hourly and provides guidance for the next 25 hours. The LAMP guidance is primarily used for the preparation of aviation weather forecasts.

The LAMP station guidance can be used in preparing Terminal Aerodrome Forecasts (TAFs) and other aviation forecasts. However, for the guidance to be the most useful to a variety of users and customers, it needs to also be available in gridded format. Select NWS Weather Forecast Offices (WFOs) are providing digital aviation services (Waldstreicher 2010), and objective guidance needs to be available in gridded format for efficient and effective use in the forecast process. In addition, gridded forecast guidance is needed in the Next Generation Air Transportation System's (NextGen) Four-dimensional Weather Data Cube (4-D Wx Data Cube), also known as the Weather Information Database (WIDB) (Souders et al. 2009; Abelman et al. 2009). Gridded guidance for a number of aviation elements, such as convection, winds, temperature, ceiling, and visibility, will be available in the 4-D Wx Data Cube in the future. While LAMP provides gridded guidance of "thunderstorms" over the contiguous United States (CONUS), where a thunderstorm is defined as at least one cloud-to-ground (CTG) lightning strike in a 20-km gridbox over a 2-hr period (Charba and Samplatsky 2009), the remainder of the forecast guidance has been valid only at stations and has not been available in gridded format.

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Given the requirements for gridded guidance in support of NWS production of digital aviation products, as well as NextGen's 4-D Data Cube, MDL began an endeavor to produce gridded LAMP guidance (GLMP) for aviation weather elements which will be in addition to the gridded thunderstorm guidance. Gridded LAMP guidance for the four elements of temperature, dewpoint, ceiling height, and visibility was made available experimentally in the NWS parallel jobstream at the National Centers for Environmental Prediction (NCEP) beginning in September 2010. This paper discusses the current GLMP products, their verification, and planned improvements.

2. GRIDDING METHODOLOGY

LAMP is developed following the MOS technique (Glahn and Lowry 1972). The technique employed to produce Gridded LAMP follows that used for the Gridded MOS (GMOS; Glahn et al. 2009) with some modifications. Because observations are key to the LAMP concept, and also due to the need for products to use for both diagnostic checkout and verification purposes, MDL is producing not only gridded guidance of LAMP forecasts, but also gridded observations (hereafter the gridded observations from LAMP will be referred to as 0-hr GLMP). Modifications to the GMOS software were needed for a number of reasons: GLMP needed to analyze some elements for which GMOS did not provide guidance, GMOS for some elements had more input points (i.e., station forecast data) than LAMP had, and GMOS did not provide analysis of observations.

The gridded LAMP guidance for thunderstorms was developed at gridpoints. This was possible because the observational field for the thunderstorm predictand, namely the observations of CTG lightning from the National Lightning Detection Network (NLDN; Cummins et al. 1998), can be represented in gridded format. Therefore the equations can be developed for gridpoints. However, all other LAMP forecast elements have predictand data which are obtained from the hourly aviation routine weather report (METAR; OFCM 1995) observations which are only available at stations (i.e., points). The station forecasts must be analyzed to a grid to produce gridded guidance, and this analysis technique we refer to as the BCDG method after the developers of the basic technique and those who have modified it to be the technique in use today: Bergthorssen and Doos (1955), Cressman (1959), and Glahn (Glahn et al. 2009; Glahn and Im 2011).

Many of the modifications to the gridded method that were necessary for LAMP and MOS are discussed in Glahn et al. (2009), Im et al. (2010), and Glahn and Im (2011). Some of these methods include the use of variable radii of influence, quality control criteria, the "spot remover," the "ray smoother" over the oceans, and the lapse rate adjustment. In addition, the land/water separation modification as well as the process of augmentation of the current hour's observations with the previous hour's observations in order to provide more input data points to analyze are used for the GLMP 0-hr analyses.

For the augmentation process, observations from the previous hour are used at stations that do not have observations at the current hour. Because the observations come in over the course of time, the number of observations received at run-time for a particular hour is less than the number that would be received if the processing ran at a later time. For this reason, at every run-time, the current hour's observations are collected, and the previous hour's observations are collected again. This results in more observations being available for the previous hour (since there has been more time for them to be received) than what is received at the current hour. For this augmentation process, at stations where there are no current hour observations, the previous hour's observations are adjusted to account for the temporal change expected between the previous and current hour observations. The current hour's observations are supplemented with the previous hour's (adjusted) observations via this augmentation process, which provides more input points to contribute to the analysis, resulting in a more spatially detailed analysis of the observations.

There is an additional modification unique to the temperature and dewpoint temperature GLMP forecasts. Testing found that the density of the LAMP stations alone across the CONUS was not sufficient to produce a spatially detailed analysis. The augmentation process described in Glahn and Im (2011) was applied to the forecasts, first using the MOS forecasts for augmentation in a similar way as the previous hour's observations are used to augment the current hour's observations for the 0-h GLMP analyses. However, it was found that the MOS forecasts also did not provide enough extra information to produce a spatially detailed analysis of the LAMP forecasts.

It was then decided to augment with temperature and dewpoint temperature model output fields from the Short-Range Ensemble Forecast system (SREF; Zhou et al. 2004). One can think of this augmentation using the SREF as calibrating the SREF to LAMP at non-LAMP stations in order to provide more spatial detail between the LAMP stations. One concern came up in the development– the SREF forecasts are in reference to the SREF model terrain, and not the 2.5-km terrain used in the BCDG method. To account for this difference, a delta was computed that depended on the elevation difference between the SREF model terrain and the actual terrain used in BCDG. Roughly 10,000 random points across the CONUS were identified as points at which to use SREF data for augmentation in addition to the LAMP CONUS stations. Figure 1a shows the LAMP stations used in the GLMP forecast analyses while Fig. 1b shows the SREF augmentation points. For augmentation points on land, the SREF values were calibrated with neighboring land LAMP data; for augmentation points in water, the SREF values were used without modification because there are no LAMP data over water.

Comparing the gridded analyses using only LAMP station data to those created with LAMP station data and augmented with SREF data shows that the SREF data contributed to the spatial detail in areas of sparse LAMP data and at higher elevations, as would be expected, with the analyses using augmentation providing more realistic results. The result of the augmentation at higher elevations was that the lapse rate influence was reduced and the high elevation temperatures were warmer. It was concluded from testing that the SREF data seemed adequate for augmenting the LAMP forecast data for GLMP temperature and dewpoint temperature.

Regarding GLMP for ceiling height and visibility forecasts, as noted in Glahn and Im (2011), the discontinuous nature of ceiling height and visibility observations and even categorical forecasts can cause special problems. The process outlined in

Glahn and Im (2011) is followed for the experimental GLMP forecasts for ceiling height and visibility in that the LAMP categorical forecasts for ceiling height and visibility are scaled using the corresponding probabilities of the chosen category. In this way the categorical forecasts of 1, 2, 3, …, 8 (for ceiling height) and 1, 2, 3, …, 7 (for visibility) are translated into continuous values from 1-9 (for ceiling height) and 1-8 (for visibility) before being analyzed. After being analyzed to the grid, the continuous forecast values for ceiling height and visibility (1-9 and 1-8 respectively) are converted back to continuous forecast values in hundreds of feet for ceiling height and miles for visibility. The observations are also scaled for analysis from continuous values in feet and miles to continuous values from 1-9 for ceiling height and 1-8 for visibility by linearly scaling the observation to its respective place on the 1-9 or 1-8 scale. For example, if the observed ceiling height is 100 feet, which is in the middle of the first LAMP ceiling height category (which is < 200 feet), the corresponding scaled value will be 1.5. The resulting gridded values are then converted back to hundreds of feet for ceiling height and miles for visibility.

3. PRODUCTS AND CURRENT STATUS

NCEP began running GLMP in the parallel jobstream of NWS operations on September 28, 2010. Gridded forecast guidance and gridded observations are being produced for the sensible weather elements of temperature, dewpoint temperature, ceiling height, and visibility. In addition, fields of error estimation of the temperature observation analysis and the dewpoint temperature observation analysis are available. For GLMP, error estimates are defined as "a measure of the inability to recover the data values on which the analysis is based from the gridded analysis by linear interpolation anywhere within the extent of the grid" (Glahn and Im 2010). The error estimates are provided in terms of absolute error.

The gridded observations represent the analysis of the current hour observations from METAR stations, mesonet, moored buoy, synoptic, Coastal-Automated Marine Network (C-MAN), and tide gauge stations for temperature and dewpoint temperature analyses (Im et al. 2010). The temperature and dewpoint data are augmented with previous hour observations where current observations are missing. For ceiling height analysis of observations, the observations are from METAR stations alone. For visibility analysis of observations, the observations are from both METAR and synoptic stations, with those from METAR stations being the vast majority. There is a wealth of observational data for temperature and dewpoint temperature, while there are far fewer observations for ceiling height and visibility. The gridded forecast data represent the analysis of 1445 LAMP station forecasts in the CONUS, augmented with SREF data for temperature and dewpoint temperature, and go out in time 25 hours at one-hour time steps.

The GLMP grids are produced hourly and made available in gridded binary (GRIB2) format in the experimental National Digital Guidance Database (NDGD) - a guidance database used along with the National Digital Forecast Database (NDFD; Glahn and Ruth 2003). The GLMP output grid aligns with the NDFD grid over the CONUS at 2.5-km resolution. Images of the GLMP analysis of observations and gridded guidance as well as error estimates can be found at http://www.mdl.nws.noaa.gov/~glmp/glmp_expr.php.

4. VERIFICATION RESULTS

In early 2011, MDL began verification studies to assess the performance of GLMP for a number of reasons: to ensure that the products had the expected quality, to provide performance metrics to assist with the decision to implement the products, and to identify areas for improvement. The verification methodology and results follow.

4.1 *Temperature and Dewpoint Temperature Verification*

Gridded forecasts can be verified on a grid only if observations representing the verifying "truth" also exist on the grid. For temperature and dewpoint temperature GLMP forecasts, there are corresponding observations on the grid from 0-hr GLMP. However, because the analysis method employed to create 0-hr GLMP is the same as that used to create GLMP forecasts, the verification results could be influenced by the fact that the same methodology was used to create both the gridded forecasts and gridded observations. Therefore, it was desirable to also verify with an independent verification "truth." For this purpose, the gridded observations of temperature and dewpoint temperature from the Real-Time Mesoscale Analysis (RTMA) (de Pondeca at al. 2011) were also used in the verification.

When verifying station-based LAMP forecasts, the improvement over the Global Forecast System (GFS; Kalnay et al. 1990) MOS is routinely computed. The typical LAMP verification result is that LAMP's accuracy is equal to or better than the accuracy of persistence at the early projections, and quickly improves on persistence beyond the first few projections. The corresponding typical result for LAMP compared to MOS is that LAMP is typically more accurate than MOS in the early periods, and the accuracy decreases to the accuracy of MOS or slightly better throughout the 25-hour forecast period (Ghirardelli and Glahn 2010). GLMP was verified against GMOS at gridpoints to determine if this typical result is also seen with the gridded forecasts.

For the verification, GLMP forecasts from the 0600 and 1800 UTC cycles, GMOS forecasts from the 0000 and 1200 UTC cycles, and RTMA observations for every hour were collected from November and December 2010. The 0000 UTC GMOS is what would have been available at the time that the 0600 UTC GLMP was produced, and the 1200 UTC GMOS is what would have been available at the time that the 1800 UTC GLMP was produced, so these cycles are what were retrieved for comparisons.

All gridded data were on the CONUS NDFD grid at 2.5-km resolution. Note that the operational GMOS over the CONUS is at 5-km resolution for this data period; however, MDL is running and archiving a prototype 2.5-km version of GMOS over the CONUS in preparation of implementation into NWS operations, and these data were used in this verification in order to have data of consistent resolutions. Also note that the 0-hr GLMP grids are created from observations available at the time GLMP ran. To get the closest approximation of the truth, the observations were retrieved retrospectively for November and December 2010 so as to collect as many of the observations as possible, and the 0-hr GLMP sample was created retrospectively for every hour in the November and December 2010 verification period from these more complete set of observations (this set of observations is more complete than what would have been available in real-time).

Verification was performed to calculate the Mean Absolute Error (MAE) of 0600/1800 UTC GLMP and corresponding 0000/1200 UTC GMOS forecasts when compared with both the 0-hr GLMP and RTMA as verifying truth. The verification was done at gridpoints, and also summarized as an average of all gridpoints in the CONUS, and by NWS region. Figure 2 shows the average MAE verification over all points for 0600 UTC GLMP compared to the 0000 UTC GMOS computed with the verifying observations of 0-hr GLMP (solid lines) and RTMA (dashed lines), and the same for 1800 UTC GLMP compared to 1200 UTC GMOS. This shows that GLMP on average is more accurate than GMOS in the early projections (comparing red and blue lines), and is comparable to or slightly better than GMOS at the middle and later projections. This result is supported from verification of both cycles, and regardless of verifying truth. In general, the MAE when computed with the 0-hr GLMP is lower than when computed with the RTMA, which is not surprising since GLMP, GMOS, and 0-hr GLMP gridded observations are developed with the same methodology.

This verification was also done according to NWS region. In general the results shown in Fig. 2 are similar to what was found in the regional verification, with the exception of the verification results from the Western Region (WR; Fig. 3). For the WR, the verification showed that over all the points in the WR, GLMP was slightly more accurate than or as accurate as GMOS at the 3, 6, and 9-hr projections, while GMOS was slightly more accurate for the 12-hr projection and onward when using 0-hr GLMP as the verifying observations. When using RTMA as the truth, the result is similar, with GLMP's improvement over GMOS being slightly better at the early projections compared to its improvement over GMOS when 0-hr GLMP is the verifying truth, and GMOS's improvement over GLMP thereafter being slightly less when RTMA is the verifying truth compared to when 0-hr GLMP is the verifying truth.

To summarize the result, the improvement of GLMP over GMOS when averaging all gridpoints is supported by all the regions, except WR for which GLMP is less accurate than GMOS on average for the middle and later projections. This result is somewhat unexpected, but further considerations have identified two potential reasons for this result. One possible explanation for this result is there are many more MOS stations with temperature and dewpoint temperature forecasts which contribute to GMOS (> 3,500) than LAMP stations with forecasts which contribute to GLMP (1445). This is especially true in the western CONUS. The additional MOS stations may be providing a significant amount of spatial detail in the GMOS analysis in the WR. Augmenting with

SREF data at many points is intended to assist GLMP in data sparse areas (i.e., areas with few LAMP stations), but the second thought is that the resolution of the SREF (40-km) may not be sufficient to well overcome this difficulty in the west. This is an area for potential improvement, which will be discussed in section 5.

Figure 4 shows the dewpoint temperature verification averaged over all the gridpoints for GLMP and GMOS using both 0-hr GLMP and RTMA as the verifying truths. The results show GLMP consistently exhibits a lower MAE than GMOS when averaged across all grid points, and the improvement of GLMP over GMOS is greater throughout the forecast period than the improvement seen in the temperature verification. This result is supported by both the 0-hr GLMP as well as the RTMA when used as verifying truth. In addition, the results in WR are consistent with those seen over the whole CONUS for the dewpoint temperature verification in that GLMP shows more accuracy than GMOS throughout the period.

The previous results showed the verification averaged over all the gridpoints. The verification results by gridpoint also show interesting findings. Figure 5 shows maps of the average improvement in MAE of 0600 UTC GLMP temperature forecasts over 0000 UTC GMOS temperature forecasts at each gridpoint in the CONUS when using 0-hr GLMP (Fig. 5a) and RTMA (Fig. 5b) as the verifying truth. These results are from the 3-h projection from the 0600 UTC LAMP start time. These results are similar to what was seen in the verification that averaged all the grid points by region, in that GLMP in general shows an improvement over GMOS in the east and central parts of the CONUS. However, in the western CONUS, there are more areas where GLMP does not show an improvement over GMOS. Also of note here is that there are areas off the coasts (most notably around Cape Hatteras, North Carolina, and the Gulf Coast) where GLMP is also less accurate than GMOS. We attribute this to the fact that GMOS uses MOS forecasts valid at buoy locations while GLMP does not use marine stations. This is also another area for future improvement.

Figure 6 shows the same results but for dewpoint temperature. Although there are still areas in the marine waters where GLMP is not improving on GMOS, in general GLMP's improvement over GMOS for dewpoint temperature does not differ as much by region as was seen in the temperature verification.

4.2 *Ceiling Height and Visibility Verification*

Unlike temperature and dewpoint temperature, there is no GMOS guidance for ceiling height and visibility, and at present, RTMA does not provide analyses of ceiling height and visibility observations. As a result, the GLMP ceiling height and visibility gridded forecasts could not be verified as they were in section 4.1. It was decided to investigate the accuracy of GLMP at stations, rather than on the grid. To determine if the GLMP processing was working as intended, the GLMP data were mapped to LAMP stations, and the resulting values were compared to the actual LAMP station values. Since the LAMP station values were used as input to GLMP, it is expected that the GLMP values at the stations would be comparable to LAMP forecasts at the stations, but for quality assurance of the process, verification was performed to determine if this was the case. It would be highly undesirable for GLMP forecasts near an input LAMP station to be less accurate than the LAMP station forecasts.

Data from the same period as used in the gridded verification were collected for 300 stations in the CONUS from the GLMP data of gridded ceiling height and visibility forecasts. A special modified "nearest-neighbor" interpolation, or mapping, was used to determine the station value from the gridded data. For each station, the value of the nearest grid point was assigned to the station, provided the nearest grid point was land if the station point was land, or water if the station point was water. Also, the elevation of the nearest grid point was compared to the elevation of the station, and the value at the nearest grid point was assigned to the station if the elevation differences were not too great. If the land/water type was different between the nearest grid point and station, or if the elevations were too different, then the next nearest grid point was likewise examined to assign a value to the station.

LAMP station data from the 0600 and 1800 UTC LAMP cycles, as well as METAR observations for every hour, were also collected for the period for the 300 stations. Threat scores for ceiling heights < 500 feet, < 1000 feet, and < 3000 feet, and threat scores for visibilities of < 1 mile and ≤ 3 miles were computed for GLMP mapped to LAMP stations as well as for the original LAMP data at the 300 LAMP stations. The verifying observations were from METAR reports at the stations.

Figure 7 shows the threat scores for 0600 UTC GLMP data mapped to the 300 stations compared to the threat scores for 0600 UTC LAMP data at those stations for (a) ceiling height < 1000 feet and (b) visibility < 3 miles. The results show that GLMP mapped to LAMP stations is as accurate as LAMP forecasts already at those stations for both ceiling height < 1000 feet and visibility < 3 miles. This result is consistent on average with what was found at the other categories verified (not shown). The threat scores for persistence (persisting the observation as if it were the forecast) are also shown, and this shows the typical results seen in LAMP (Ghirardelli and Glahn 2010) in that the LAMP scores are equal to those of persistence in the few projections, but the scores for persistence quickly decrease with time, until LAMP and GLMP show improvement over persistence, which in this case is around 4 hours into the forecast period. These results are consistent with what was found when verifying the 1800 UTC cycle (not shown).

This result is expected, but it does not indicate how accurate GLMP forecasts are away from LAMP stations. Both ceiling height and visibility are highly discontinuous weather elements in space which makes analyzing the forecast data to a grid challenging. In addition, we do not have augmentation points for ceiling height and visibility to assist with the analysis in between the LAMP stations. Preliminary plans included SREF data of ceiling height and visibility forecasts to be used in the system for augmentation of GLMP ceiling height and visibility forecasts, but testing proved them not to be adequate in helping provide the spatial detail. As a result, there is much question as to how accurate the GLMP forecasts are away from areas where there are LAMP station forecasts.

In an attempt to answer this question, GLMP was mapped to stations (similarly to how it was done above) where there were observations but no LAMP station guidance. 116 stations in the CONUS were added to the GFS MOS suite in March 2010, but these stations have not yet been added to the LAMP station guidance. 115 of these stations have ceiling height and visibility observations. Because these are MOS stations, we can assume that these stations have a reasonable sample of stable observations, and it was decided to map the GLMP forecasts to these 115 non-LAMP stations for verification. Figure 8 shows the placement of these 115 stations relative to the LAMP stations. This mimics what would have been done with a "with-held data" test in that these data did not contribute to the analysis, yet observations exist so that the gridded values can be verified at these stations.

Figure 9 shows that the 0600 UTC GLMP forecasts mapped to the 115 non-LAMP stations on average are less accurate than persistence for the first 4 hours of the forecast period. After that point and onward, GLMP forecasts have a higher threat score than persistence. This is not a surprising result since the discontinuous nature of these fields makes accurate analysis in areas between input points very challenging. It is encouraging that GLMP has a higher threat score than persistence in the middle and later periods at non-input points.

Verification of 1800 UTC GLMP yielded similar results (not shown). Also, as could be expected, as the events became less rare (for higher ceiling height and visibility categories), the cross-over point of GLMP and Persistence (when GLMP became as or more accurate than persistence) was earlier in the forecast periods, and for the lower ceiling height and visibility categories, the cross-over point was later in the forecast period (not shown). This is an indication that the accuracy of GLMP away from LAMP stations can be expected to be worse for rare categories which are by nature less spatially continuous than the higher categories of ceiling heights and visibilities.

In summary, overall GLMP mapped to LAMP stations shows no degradation when compared to the actual LAMP station values. On the other hand, GLMP is likely less accurate away from the LAMP stations that provided input into the analysis. However, it should be noted that even away from the LAMP stations, the GLMP still provides benefit over a forecast of persistence after the first few hours of the forecast period.

5. USER FEEDBACK

A Public Information Statement was released in September 2010 notifying users of the experimental GLMP products, how to access them, and soliciting public comments for a 60-day period. Web sites were set up to collect public comments regarding the data, and also the web displays. During that 60-day period, no comments were received regarding the data, and one favorable comment was received regarding the web displays.

Feedback from WFOs has been positive overall. GLMP can be used as a first guess field and easily modified using computer tools by the forecaster, thereby helping with the forecast creation process (A. Rezek 2011, personal communication). Some comments indicated that GLMP fields of temperature and dewpoint temperature are less useful than GLMP fields of ceiling height and visibility, and are at times inaccurate. (Potential improvements to overcome the issues seen with GLMP temperature and dewpoint temperature will be addressed in the next section.) Also, positive feedback has been received from the Federal Aviation Administration (FAA) regarding the GLMP ceiling height and visibility forecasts. MDL and FAA are currently coordinating efforts regarding gridded ceiling height and visibility efforts.

6. AREAS FOR IMPROVEMENT AND FUTURE PLANS

The above studies as well as on-going inspection of the GLMP products were helpful in determining areas of potential future improvement for the GLMP products. MDL is currently investigating and working on the following improvements.

6.1 *Persistence Effect*

Subjective inspection of the real-time loops of the 0-hr GLMP followed by the GLMP forecasts for temperature and dewpoint temperature showed that the 0-hr GLMP provided a highly detailed analysis while the GLMP forecasts were much smoother. Figure 10 shows the 0-hr GLMP temperature analysis valid at 2000 UTC (Fig. 10a), the 1-hr GLMP forecast valid at 2100 UTC (Fig. 10b), and the verifying observational analysis of the 0-hr GLMP valid at 2100 UTC (Fig. 10c). The difference in spatial detail can be seen between the 0-hr and the 1-hr GLMP images. This is no doubt due to the fact that there are so many observations available (10,000 – 12,000 per hour) for the 0-hr GLMP compared to the < 1500 LAMP stations that have forecast data. In addition, this indicates that the augmentation with the SREF data, while helpful, is not sufficient to produce realistic spatial detail in the forecast fields.

To improve on the spatial detail of the temperature and dewpoint temperature forecasts, MDL plans to implement what we refer to as the "Persistence Effect" where we will use the station observations to augment the LAMP forecasts instead of using SREF data for augmentation. In addition, in recognizing that part of the reason GLMP might be less accurate than GMOS in areas of the western CONUS, we plan to modify GLMP to also use MOS input data.

The new augmentation will be two-fold – first the data from LAMP stations will be augmented with data from MOS stations. Then hourly observations will be used to augment stations where there are observations, but neither LAMP nor MOS data. Since it is expected that the hourly observations will be useful early in the forecast period, and less so later on, the process will allow for weighting of the impact of the observations and MOS based on the projection; in this way, augmentation with the observations can have more of an impact in the early periods, and the MOS inputs can have a stronger impact at the later periods where the observations would be less useful.

6.2 *Re-developed Ceiling Height forecasts*

The station-based LAMP ceiling height has been redeveloped (but not yet implemented) in conjunction with the redevelopment of LAMP sky cover. The redeveloped ceiling height LAMP forecasts are 2-4% more accurate on average than current LAMP ceiling height forecasts (Weiss and Ghirardelli 2009). This improvement is due to the new ceiling height equations being developed separately from the LAMP sky cover (the current version of ceiling height equations were developed simultaneously with LAMP sky cover), as well as the inclusion of updated MOS ceiling height and sky cover forecasts. It is expected that any increase in the accuracy of LAMP forecasts at the stations will increase the accuracy of GLMP forecasts.

6.3 *Additional Stations*

It is reasonable to expect that increasing the number of input points will result in better spatial detail and more accuracy of the forecasts on the grid. For temperature and dewpoint temperature, redeveloping the equations to add additional stations is planned but extremely time intensive. Given that, for now, we hope to improve on these grids through better augmentation.

For the regionally developed elements such as ceiling height and visibility, stations can be added to the LAMP equations and thresholds in a much more timely manner. The requirement for adding a station is that MOS must be available for that station. Previously, when considering adding stations to the LAMP suite, we required that the station provide observations in real-time. The use of the most-recent observations is critical to providing an updated and more accurate forecast than what would be available from MOS. Given this, it would be unlikely to improve on MOS without an observation. However, in considering the accuracy of the gridded values, having more input points, even those that are as accurate but not significantly better than MOS, should be beneficial to both the spatial detail and accuracy of the gridded forecasts.

Given this, we plan to add stations to the ceiling height and visibility LAMP stations in order to provide more stations for gridding. Table 1 shows the types of stations we plan to add, as well as the number and if observations are expected to be available at those stations. (Note that "yes" for "Obs available?" in the table indicates that observations are available for some, but possibly not all, of the stations of that type.) Figure 11 shows this information in map form.

Table 1. Additional stations types to be added to the LAMP stations

Station Type	Count	Obs available?
New MOS stations	119 (116 in CONUS)	Yes
Marine stations	306	No
Canadian stations	274	Yes
New TAF stations	4	Yes
Air Force Stations	15 (13 in the CONUS)	No

The impact of including these new stations into GLMP is currently being investigated. As a test, the new MOS, marine, and Canadian stations were added to the LAMP suite, and GLMP forecast grids were created for the same period of November and December 2010. The new grids were then used to re-create the verification done in section 4.2 above, verifying GLMP at those 115 stations, and comparing the results to persistence. For that verification, it was found that the results are now consistent with the typical LAMP result, in that the accuracy of LAMP is equal or comparable to that of persistence at the first hour, and better than persistence thereafter. Results for ceiling height < 1000 feet show that, by including the 115 stations into the analysis, and then verifying GLMP at those points, GLMP is comparable to persistence in the early projections, and better than persistence starting at the 4-hr projection for the 0600 UTC cycle (not shown), and better than persistence starting at the 2-hr projection for the 1800 UTC cycle (not shown). These results are also seen in the verification of visibility < 3 miles for the respective cycles (not shown).

One goal of adding new LAMP stations is that GLMP forecasts over Canada might be improved. With the original implementation, there are no input points in Canada, but with the proposed addition of stations, 274 stations would be added over Canada. We investigated 11 of these stations that reported both ceiling height and visibility observations, and which were within the NDFD area. The results from the 0600 UTC verification can be seen in Figure 12. The forecasts from GLMP created by adding new stations are more accurate than GLMP forecasts created from the current station inputs (which do not include Canadian stations) through roughly the 7-hr projection for ceiling height < 1000 feet (Fig. 12a), and through the 10-hr projection for visibility < 3 miles (Fig. 12b). This is a very promising result that the additional station input will provide not only improved gridded guidance over Canada, but also will allow users to get accurate guidance at points by mapping the gridded guidance to points.

6.4 *Extension to 30 hours*

As of November 2008, TAFs for selected airports are required to cover a 30-hr period instead of the typical 24-hour period (NWS 2008). MDL has received inquiries about extending LAMP beyond 25 hours to cover the 30-hr TAF period. Because LAMP typically does not add significant value to MOS forecasts at 25 hours, LAMP would be unlikely to add value in the 26-30 hour period. However, there is a requirement for guidance beyond 25 hours, so in response MDL is modifying the BCDG method to use MOS guidance as input to GLMP beyond 25 hours, with the option to blend MOS into the GLMP forecasts prior to 26 hours, to provide gridded guidance for preparing 30-hour TAFs.

7. SUMMARY AND SCHEDULE

GLMP is providing hourly gridded guidance of observations and forecasts of temperature, dewpoint temperature, ceiling height, and visibility. Verification shows that in general the temperature and dewpoint temperature products overall improve on GMOS, with the exception of some areas in the western CONUS. Ceiling height and visibility verification shows that GLMP is as accurate as LAMP when mapped to LAMP stations, and less accurate than persistence in the first few projections when mapped to non-LAMP input stations. A number of improvements to the GLMP system have been identified and will be tested and implemented in 2012 if successful. Finally, GLMP has received favorable feedback from users and has shown to be useful in the creation of NWS digital aviation services.

GLMP is scheduled to become fully operational on September 27, 2011. At that point, the data will be available on the Satellite Broadcast Network/NOAAPORT. The data will also be available in the operational NDGD. Additional elements will be added to the GLMP product suite, with the next planned elements being winds, sky cover, and probabilities of ceiling height and visibility.

8. ACKNOWLEDGMENTS

The authors wish to acknowledge the efforts of David Miller, Mitch Weiss, and Chenjie Huang for developing all of the verification presented in this paper. The authors also wish to thank Joe Moore for his assistance with the figure preparation. We also wish to acknowledge Scott Scallion, Jung-Sun Im, and David Rudack for their assistance with the implementation of the GLMP project, and David Ruth for his leadership and ideas on improving the GLMP products.

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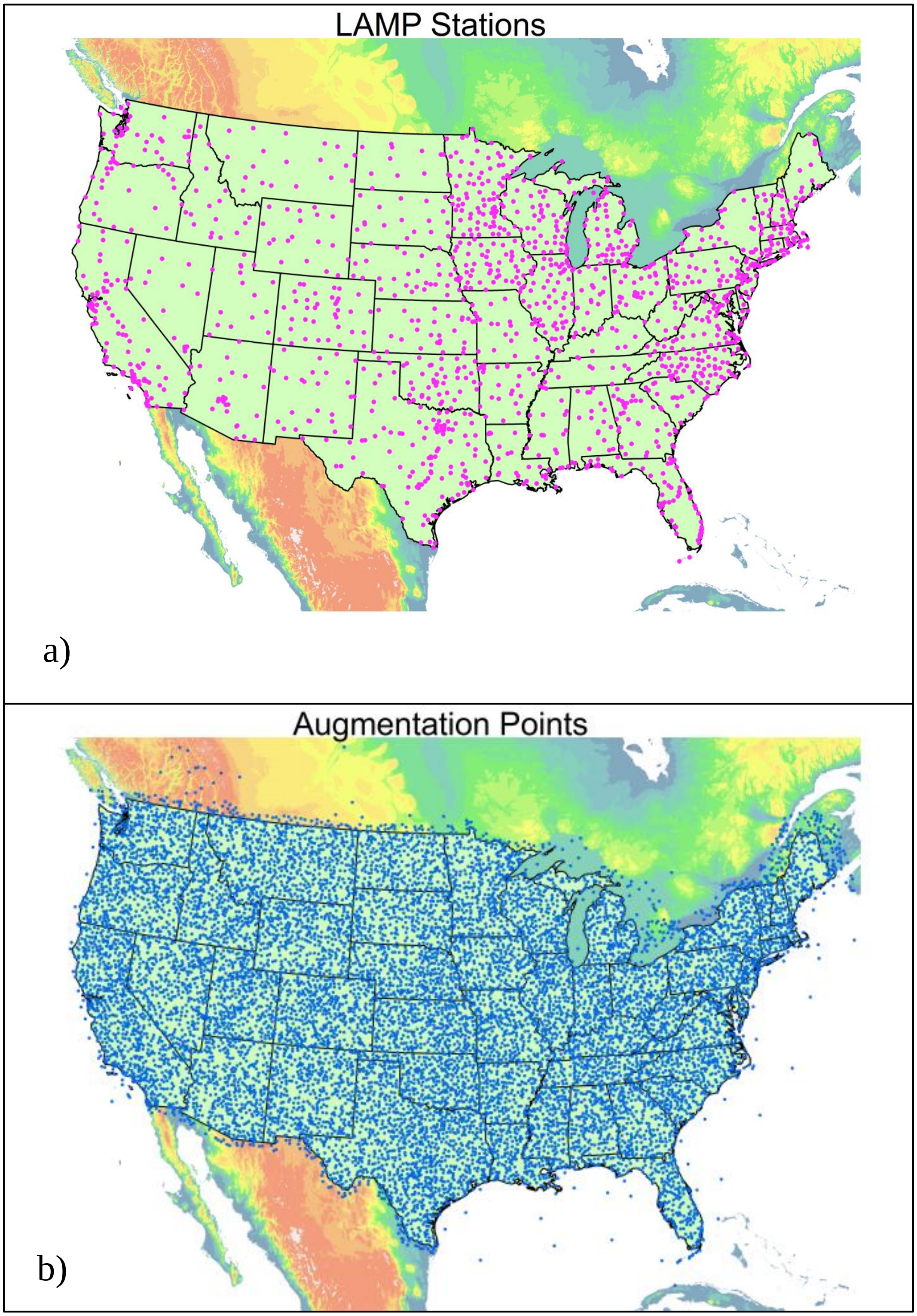

Figure 1. Maps of the points contributing the GLMP forecast gridded analyses: 1a) shows the LAMP station points in the CONUS which contribute to the LAMP forecast grids, and 1b) shows the augmentation points where SREF data are used.

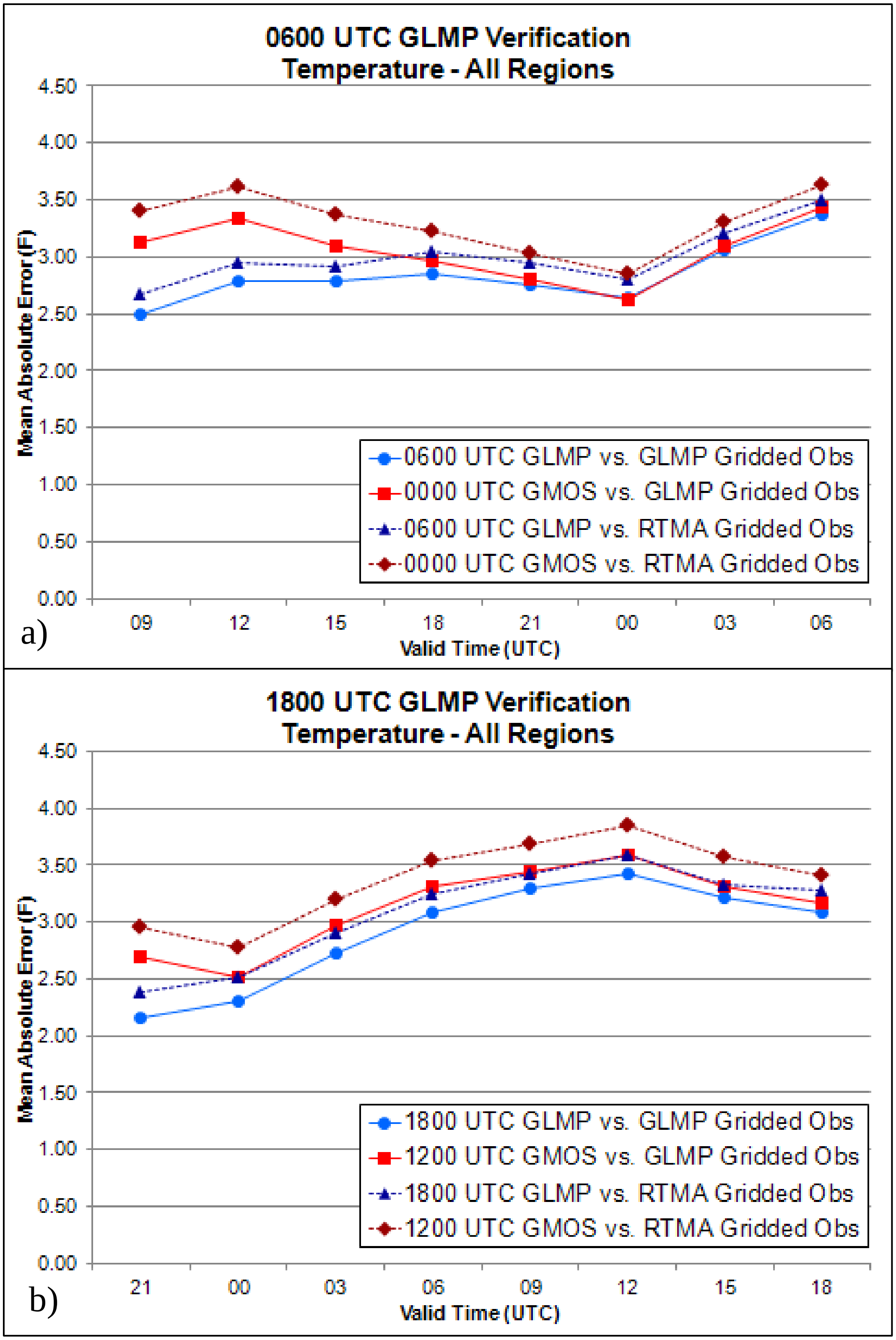

Figure 2. Temperature MAE for (a) 0600 UTC GLMP and 0000 UTC GMOS and (b) 1800 UTC GLMP and 0000 UTC GMOS averaged over all gridpoints, for all regions combined. GLMP MAE is shown by blue lines, and GMOS MAE is shown by red lines. Verification results using 0-hr GLMP gridded observations are shown as solid lines, and verification results using RTMA are shown as dashed lines.

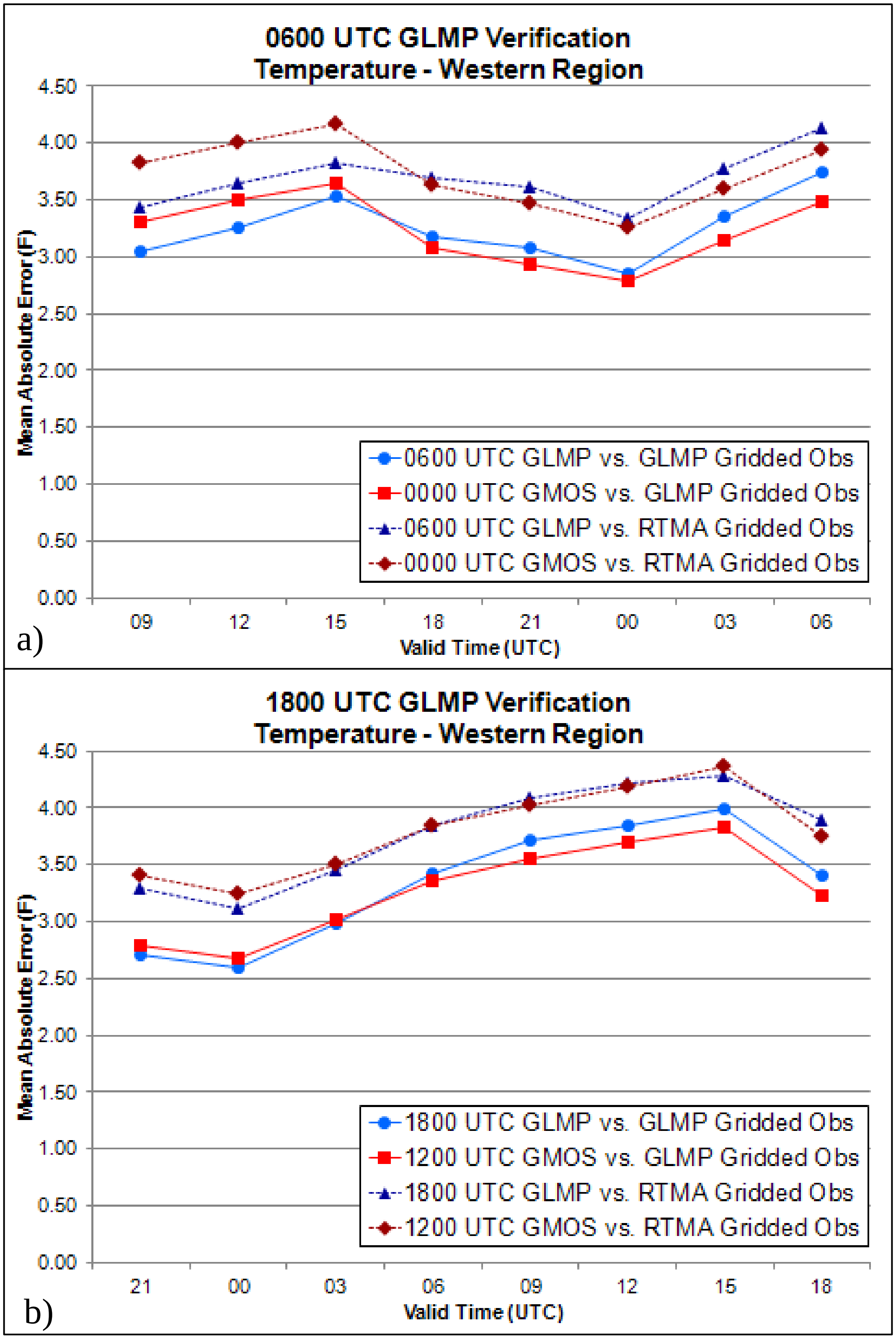

Figure 3. Same as Fig. 2 except for Western Region.

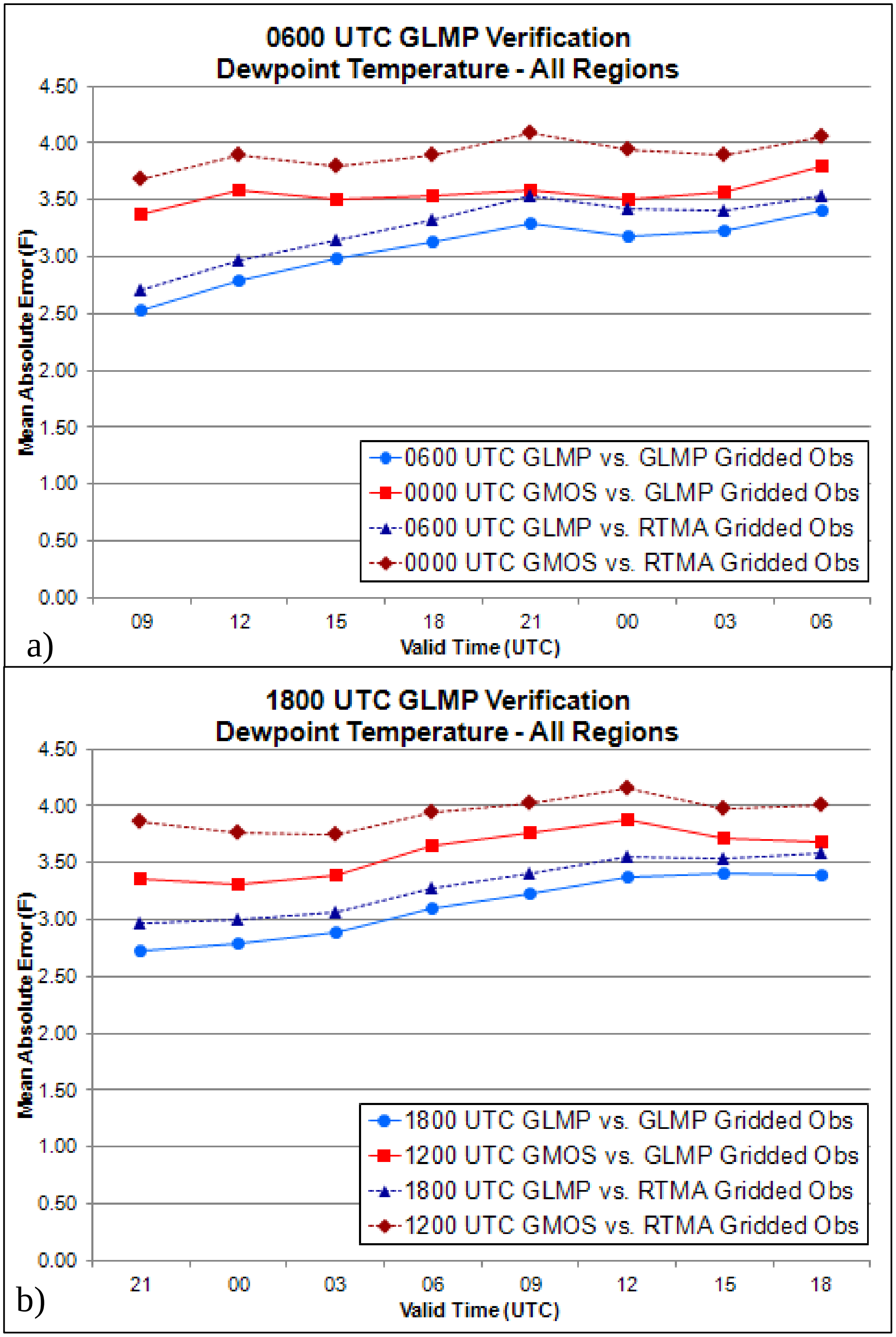

Figure 4. Same as Fig. 2 except for dewpoint temperature.

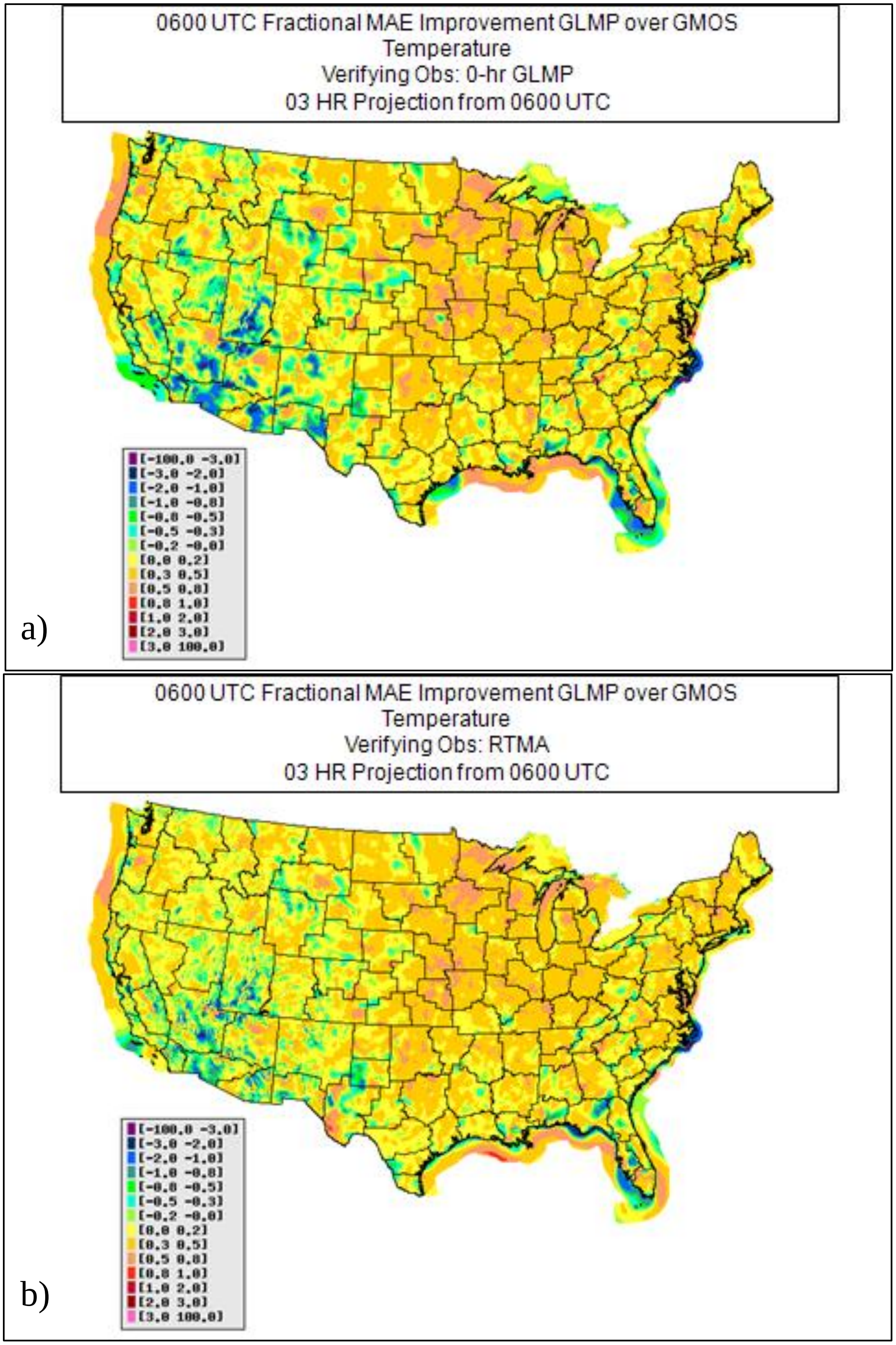

Figure 5. Maps showing fractional improvement in GLMP MAE over GMOS MAE for the 0600 UTC GLMP cycle compared with the 0000 UTC GMOS cycle, for temperature, valid at 0900 UTC. Verifying truth is the corresponding (a) 0-hr GLMP analysis and (b) the RTMA(a). Warmer colors of yellow, orange, red, and pink indicate areas where GLMP is improving on GMOS; cooler colors of green, blue, and purple indicate areas where GLMP is not improving on GMOS.

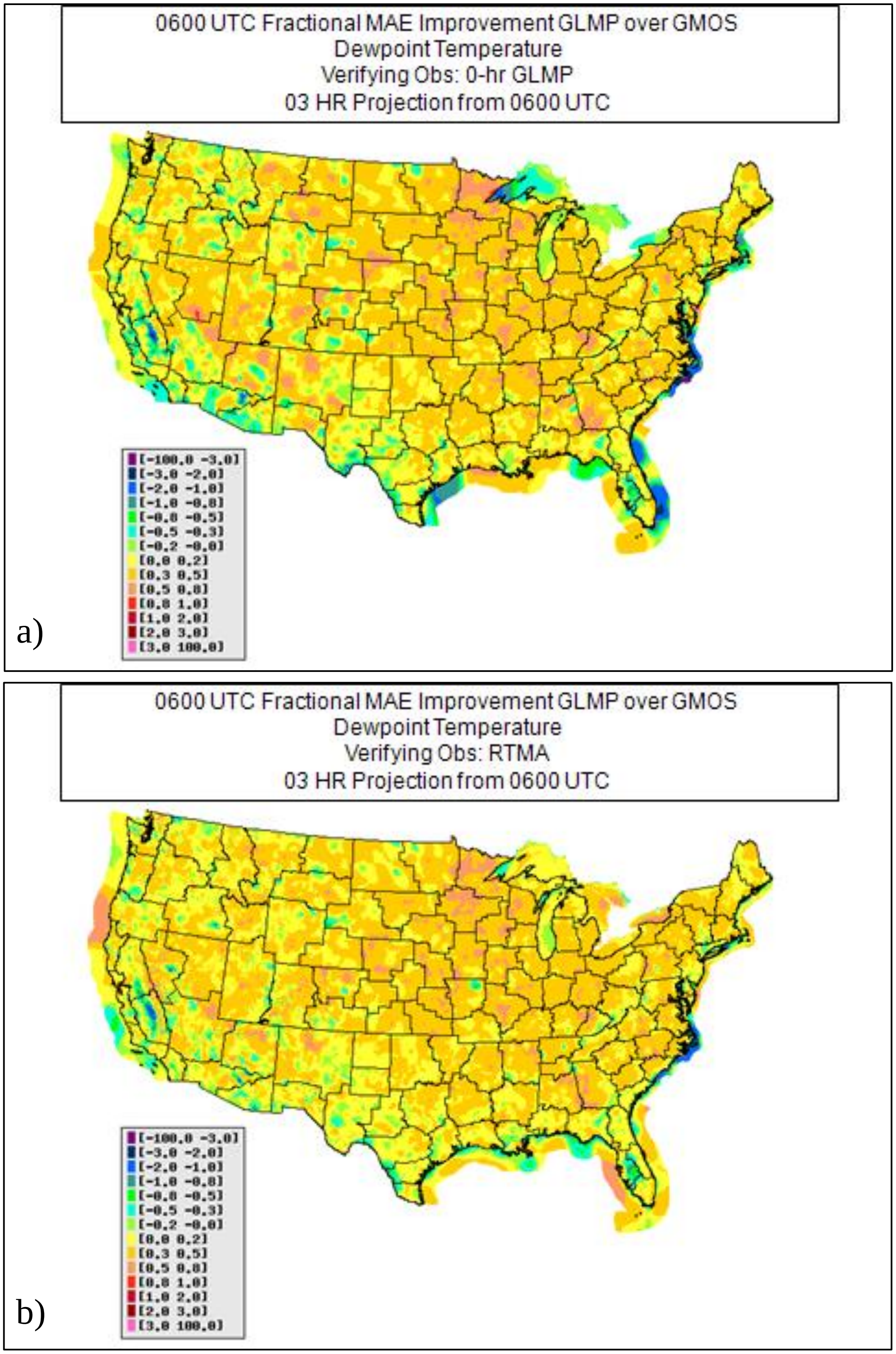

Figure 6. Same as Fig. 5 except for dewpoint temperature.

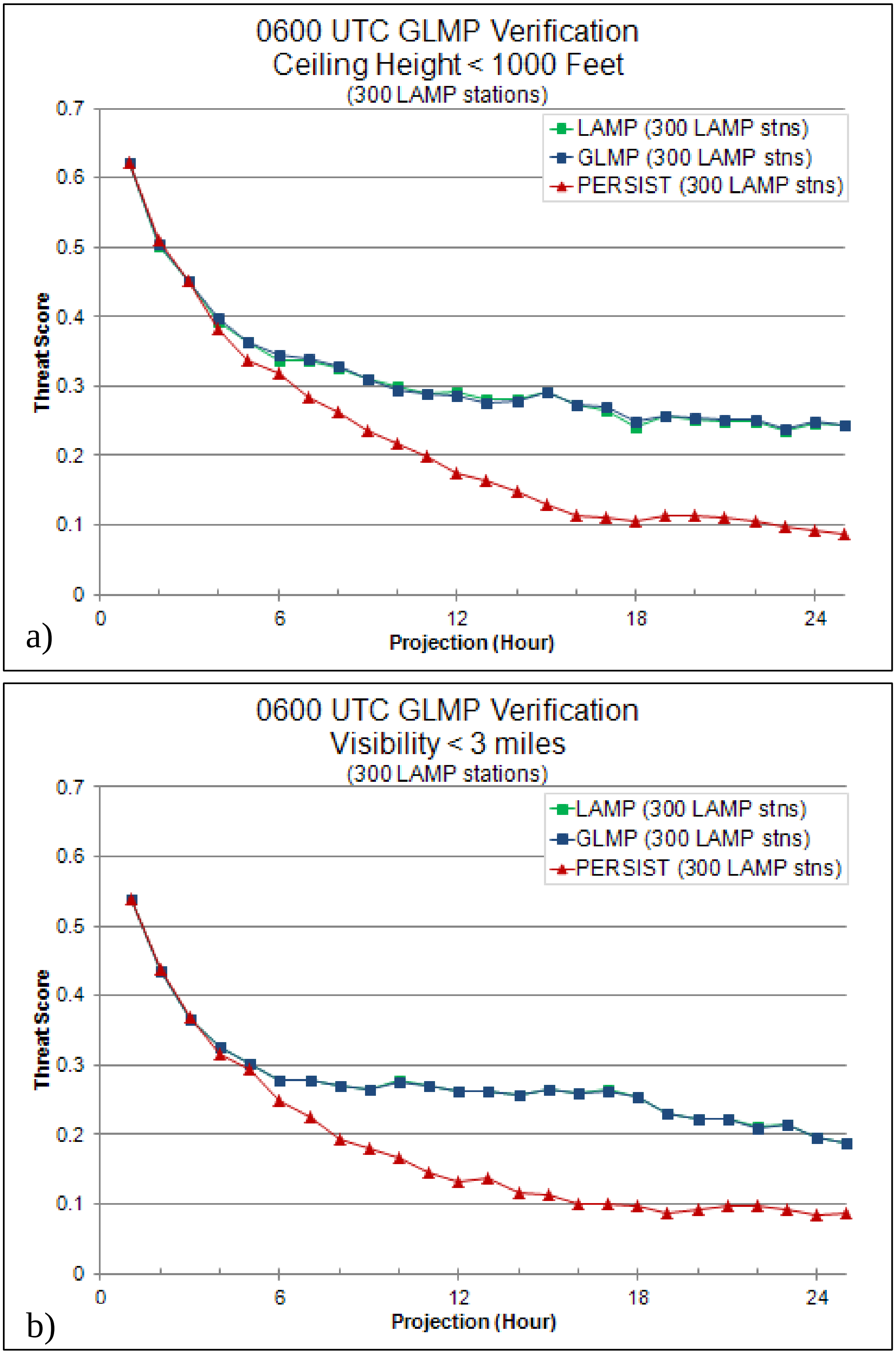

Figure 7. Threat scores for (a) ceiling height < 1000 feet and (b) visibility < 3 miles for 0600 UTC GLMP mapped to stations compared to LAMP at those stations. LAMP threat scores are shown in green, GLMP in blue, and persistence in red.

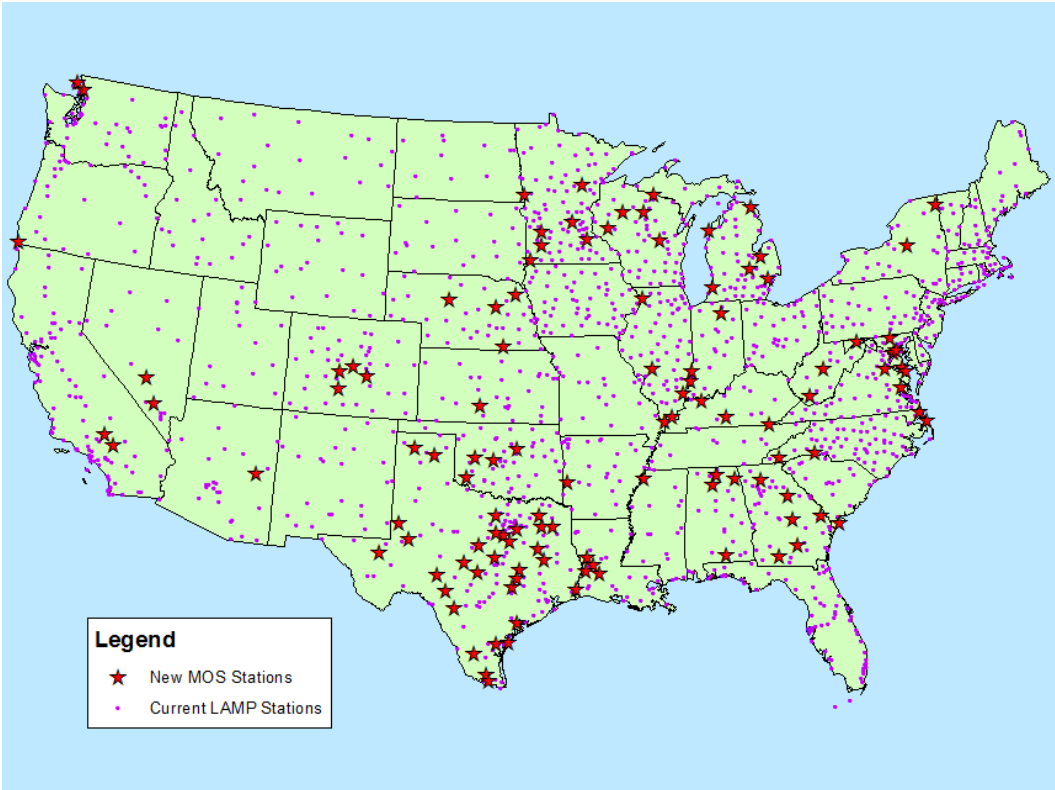

Figure 8. Map showing the 115 “non-LAMP” stations (red stars) used for verification. The current LAMP stations are shown by the pink dots.

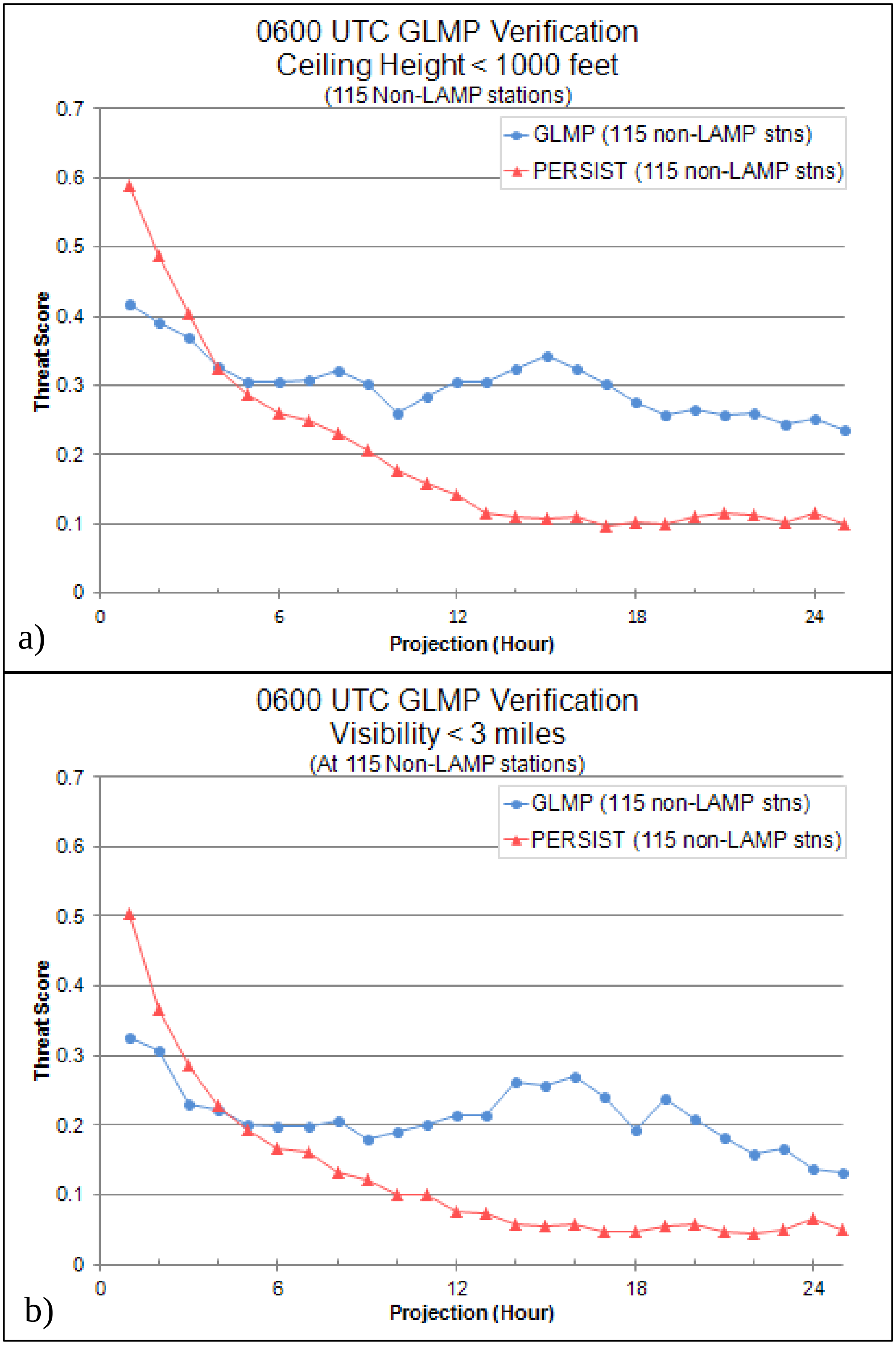

Figure 9. Threat scores for (a) ceiling height < 1000 feet and (b) visibility < 3 miles for 0600 UTC GLMP mapped to 115 non-LAMP stations. GLMP threat scores are in blue, and persistence in red.

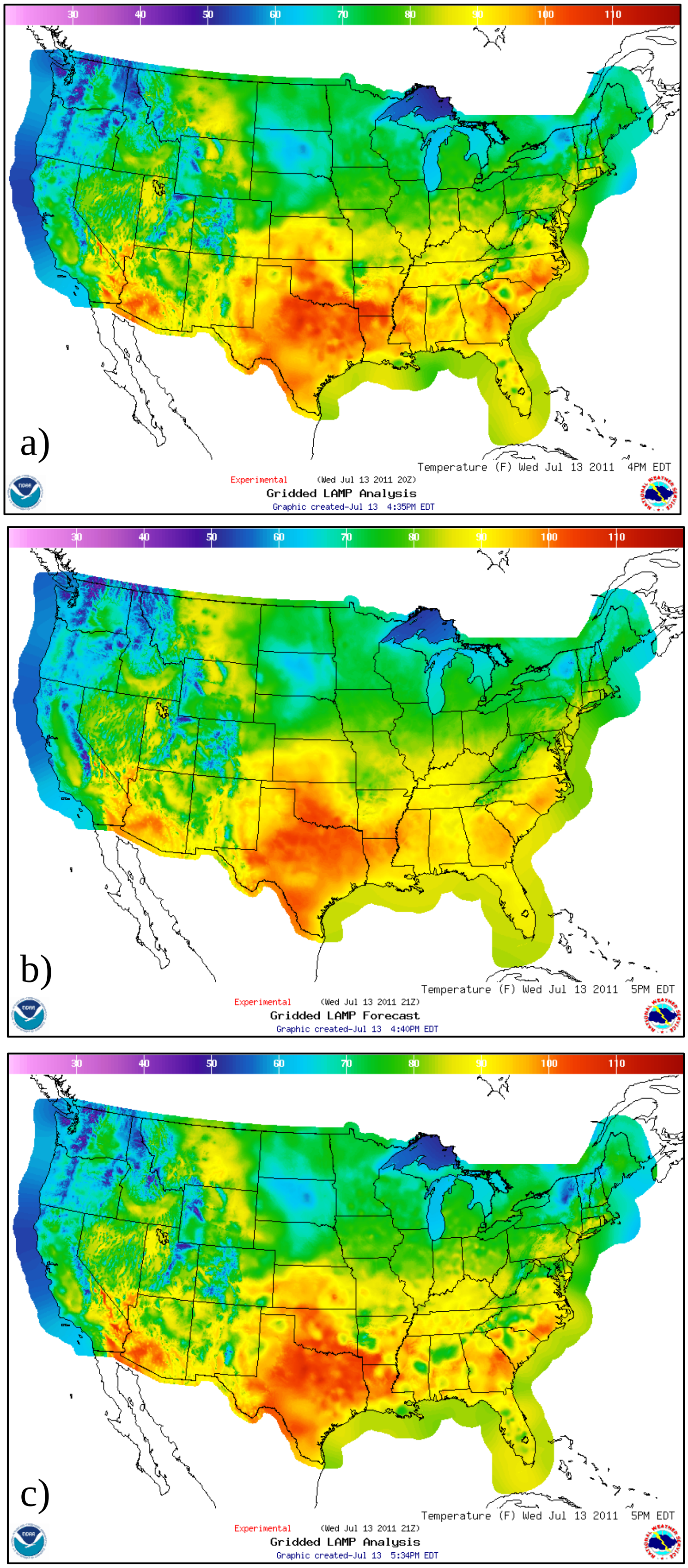

Figure 10. Maps of GLMP from July 13, 2011. The 0-hr GLMP valid at 2000 UTC is shown in (a); the 1-hr GLMP forecast from the 2000 UTC cycle representing the forecast valid at 2100 UTC is shown in (b); the verifying 0-hr GLMP valid at 2100 UTC is shown in (c).

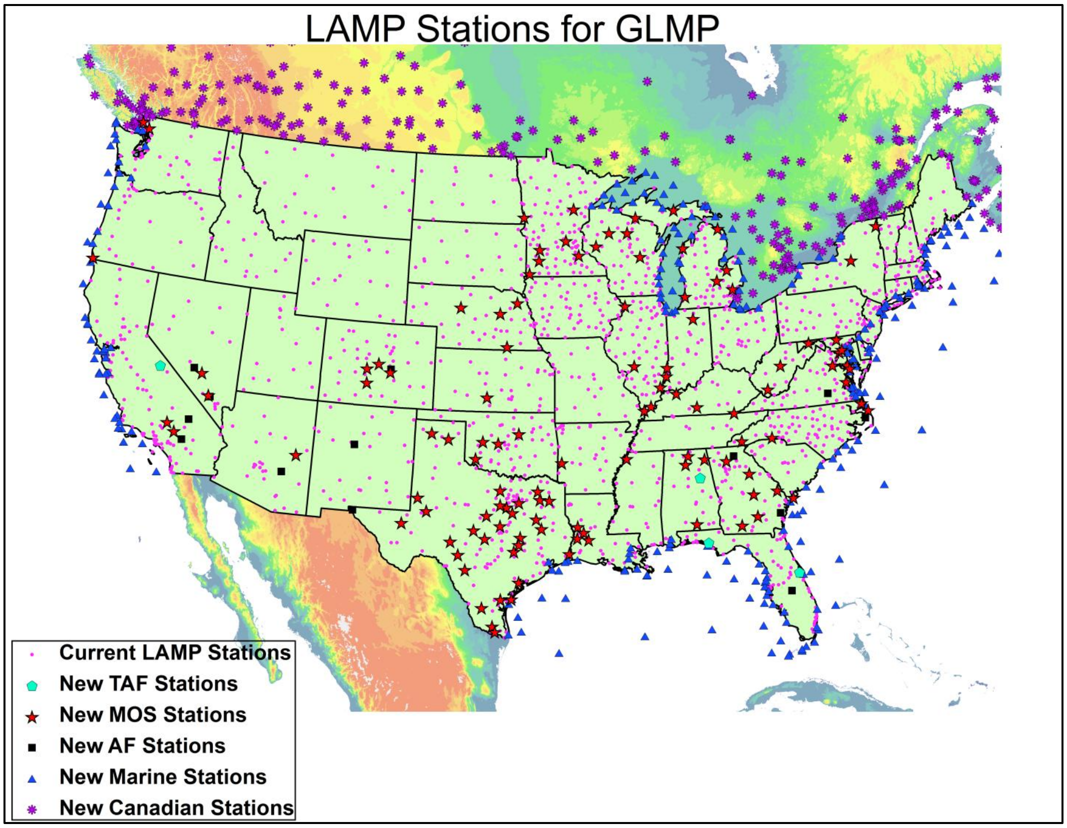

Figure 11. Map showing the current LAMP stations (pink dots), and the stations being added for input to GLMP: new TAF stations (cyan pentagon), new MOS stations (red stars), new Air Force stations (black squares), new marine stations (blue diamonds), and new Canadian stations (purple asterisks).

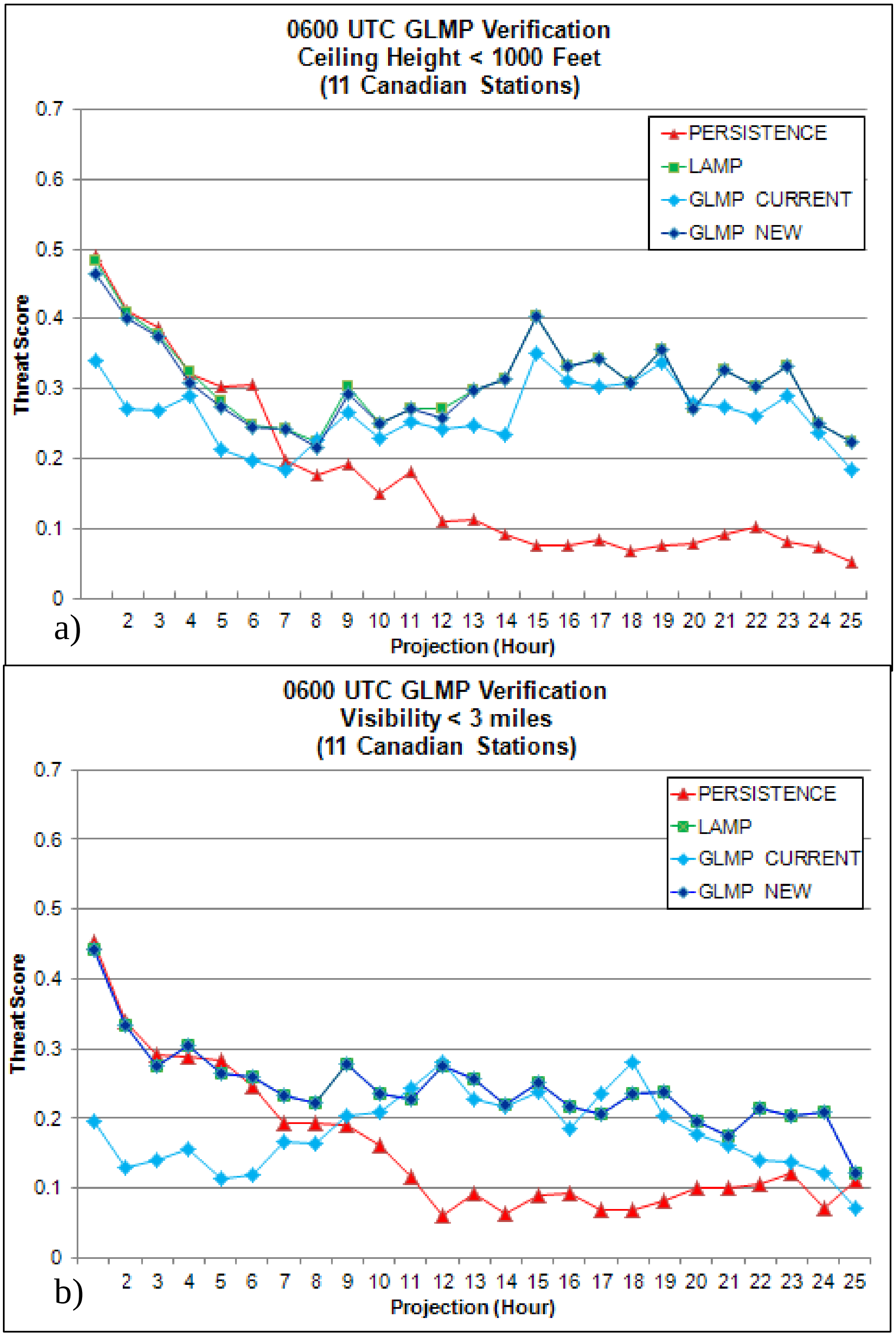

Figure 12. Threat scores for (a) ceiling height < 1000 feet and (b) visibility < 3 miles for 0600 UTC GLMP mapped to 11 Canadian stations for LAMP (green squares), Current GLMP (light blue diamonds), GLMP with new stations added (dark blue diamonds), and Persistence (red triangles).