6A.4 IMPROVEMENTS TO THE LOCALIZED AVIATION MOS PROGRAM (LAMP) STATISTICAL GUIDANCE FOR CEILING HEIGHT AND SKY COVER

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1. INTRODUCTION

In November 2008, the Meteorological Development Laboratory (MDL) of the National Weather Service completed implementation of the Global Forecast System (GFS) based Localized Aviation MOS Program (LAMP) guidance. The LAMP system runs every hour, with hourly forecasts generated out to the 25-h projection. The LAMP product provides short-term guidance focusing on aviation related meteorological variables, and also serves as an update to the GFS-based MOS guidance.

LAMP guidance is derived by the same basic technique used to develop MOS (Glahn and Lowry 1972). LAMP regression equations provide probabilistic guidance for ceiling height (CIG) and sky cover (SC) categories, as well as other aviation elements. Potential predictors for these equations include the GFS MOS probability forecasts, the most recent METAR (roughly translated as Aviation Routine Weather Report; OFCM 1995) observations, and advection model output. A post processing procedure is used to generate a best category forecast for LAMP CIG and SC from the LAMP probability forecasts. Forecasts are produced for 1591 sites over the contiguous United States (CONUS), Alaska, Hawaii, and Puerto Rico (Ghirardelli 2005).

In 2007, redevelopment began for the GFS-based MOS SC and CIG guidance. The redevelopment resulted in an increase of skill for both the MOS SC and CIG guidance (Yan and Zhao 2009). In addition, the MOS definition for sky cover changed from an assumption that all clouds are opaque (total sky cover) to a definition where sky cover is dependent on cloud opacity (opaque sky cover). Since LAMP serves as an update to MOS, redevelopment of the LAMP sky cover and ceiling height guidance was required.

This study's purpose is to test and evaluate regression equations to use to redevelop LAMP SC and CIG, with the objective of improving forecast skill. The LAMP sky cover definition also was changed to opaque sky cover (OSC). To improve forecast skill, the following four factors were investigated: (1) separate development of LAMP CIG and OSC, (2) a new set of MOS CIG and OSC probability forecast predictors generated from the new MOS guidance, (3) a more meteorologically objective sky cover observation, and (4) single station equations instead of regional equations. Test regression equations were developed in "stages", where each factor is added on to the next set of test equations to determine the overall improvement. Henceforth, test regression equations for stage 1 includes factor (1), stage 2 includes factors (1) and (2), and so on. Additional detail on equation testing is given in section 4.

In this paper, we discuss the procedure used to develop the LAMP guidance, and analyze the effect of the four factors mentioned above on forecast skill. We compare the accuracy and skill of the 1000 UTC LAMP and 0600 UTC GFS MOS (the most recent GFS MOS guidance available at 1000 UTC) best category forecasts, along with persistence of the 1000 UTC observation. The comparison is done on an independent sample period, where the Threat Score is used to measure the forecast accuracy of low ceiling heights, and the Heidke Skill Score is used to estimate opaque sky cover forecast skill.

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2. PREDICTAND AND PREDICTOR VARIABLE DEFINITIONS

The CIG and OSC predictands are divided into distinct categories. The observed ceiling height is divided into seven binary cumulative predictands representing the ceiling heights of < 200 feet, < 500 feet, < 1000 feet, < 2000 feet, ≤ 3000 feet, ≤ 6500 feet, and ≤ 12000 feet. For aviation interests, a CIG of < 500 feet matches the definition for Limited Instrument Flight Rules (LIFR) conditions, < 1000 ceiling heights represent Instrument Flight Rules (IFR) conditions, and ≤ 3000 feet ceiling heights represent Marginal Visual Flight Rules (MVFR) conditions (NWS 2008). Ceiling heights above 12000 feet are not measured due to the limits of the Automatic Surface Observing System (ASOS) reports.

The estimated opaque sky cover is divided into four binary cumulative predictands representing the cloud coverages of < 1/8 for clear, < 3/8 for few, < 5/8 for scattered, and < 8/8 for broken. Since ASOS reports are limited to 12000 feet, OSC estimates are complemented with a derived satellite cloud product (SCP) (Kluepfel et al. 1994) to obtain cloud cover estimates over 12000 feet. The Effective Cloud Amount (ECA) is used to generate cloud amount estimates based on cloud opacity.

Three primary data sources make up the list of predictors used to develop the CIG and OSC equations. GFS MOS 3-h predictors from the 0600 UTC cycle consist of probability forecasts for CIG, OSC, visibility, obstruction to vision, surface temperature, dew point, and wind speed. These probability forecasts were linearly interpolated to a 1-h resolution. Another source of predictors is the most recent surface observations, which include temperature, dew point, dew point depression, ceiling height, and sky cover. A detailed discussion of the sky cover observation predictors is given in section 3. The third set of predictors includes advected ceiling height, total sky cover, surface temperature, and dew point which were generated by the advective model (Glahn and Unger 1986).

3. EQUATION DEVELOPMENT AND POST PROCESSING

Equations are developed for two seasons: warm (April-September) and cool (October-March). The development data period ranges from 2000 to 2005 for the warm season and 2000-01 to 2005-06 for the cool season. The 2006 warm season and 2006-07 cool season serve as independent samples for verification.

3.1 *Equation Development*

Equations developed for this study generally follow the rules and methods of the current LAMP system (Weiss and Ghirardelli 2005). In this study, LAMP CIG regression equations are developed separately from OSC regression equations (see section 4). The regression equations for the four OSC predictands contain a different set of predictors from the seven CIG predictands. For each set of four OSC and seven CIG regression equations, the predictors are the same. The coefficients and constants are different for each predictand's equation, and the regression equations contain the same predictors for all 25-hour projections. The values of GFS MOS 3-h and advective model predictors vary with the projection hour. Regionally developed equations use a total of 31 and 30 regions, respectively, for warm and cool season development. During equation development, the variable selection process allowed a maximum of 15 predictors to be chosen, or until none of the remaining predictors contributed an additional 0.1% reduction of variance to any of the four OSC or seven CIG predictands.

3.2 *Post Processing*

The raw probability forecasts generated from the CIG and OSC regression equations are post processed to produce best category forecasts. First, the probabilities are post processed to ensure the values range between zero and one. The final step involves transforming the adjusted probability forecasts to a best category forecast. An intermediate step involves generating threshold values (probability thresholds) for each category. Probability thresholds are generated from the developmental sample of data. For OSC, the probability thresholds are obtained through an iterative process that attempts to create unbiased forecasts (the number of forecasts and observations are approximately equal). For CIG, the probability thresholds are obtained through an iterative process that maximizes the Threat Score within a targeted bias range. Maximizing the Threat Score yields more accurate forecasts for rarer events such as low ceiling heights, than the approach used for OSC.

Once the thresholds are determined, best category forecasts are generated for each case.

The CIG and OSC LAMP categories are listed in Tables 1 and 2, respectively. These categories are identical to those used in the GFS MOS. For CIG and OSC the best category is determined in a cumulative manner. This procedure commences with the probability forecast for the lowest CIG category (ceiling heights < 200 feet) or OSC category (clear). If the probability forecast does not exceed the probability threshold of the lowest category, the probability forecast for the next highest category is compared to the next highest probability threshold. If this process continues until all probability thresholds are exhausted, the default category (CIG category of > 12000 feet or unlimited ceiling; OSC category of overcast) is chosen as the best category.

Table 1. Category definitions of LAMP Ceiling Height forecasts

Category	Ceiling Height (Feet)
1	< 200
2	200 – 400
3	500 – 900
4	1000 – 1900
5	2000 – 3000
6	3100 – 6500
7	6600 – 12000
8	> 12000 or unlimited ceiling

Table 2. Category definitions of LAMP Opaque Sky Cover forecasts.

Category	Cloud Cover
Clear	zero cloud coverage
Few	1/8 – 2/8
Scattered	3/8 – 4/8
Broken	5/8 – 7/8
Overcast	8/8 cloud coverage

4. EQUATION TESTING

For this study, test equations were developed corresponding to the four factors stated in Section 1. For stage 1, regression equations for the seven CIG and four OSC predictands were developed separately. This is referred to a "non-simultaneous development." The current LAMP CIG and SC guidance was developed simultaneously. For stage 2 equation testing, we build on to the stage 1 test by replacing the GFS MOS CIG and SC probability forecast predictors with probability forecasts representing the new GFS MOS CIG and OSC guidance.

For stage 3 equation testing, the SC observation predictor is replaced with a new, more objective, SC observation predictor. The old SC predictor is defined as the current hour "uncomplemented" SC observation which does not include cloud information above 12000 feet or consider the opacity of the cloud. The new SC predictor represents a one-hour old "complemented" OSC observation to use as a predictor. The new SC predictor values are generated with the same calculating method used for the OSC predictand (see section 2). The current hour OSC observation is not used due to the unavailability of current hour SCP data at LAMP run-time. The new SC predictor is considered to be more representative of the opaque sky cover at LAMP run-time than the presently used SC predictor. The stage 3 regression equations were built on to the stage 2 model. Test equations were generated for OSC, but were not for CIG. The presently used SC predictor is considered more appropriate for CIG development since cloud information above 12000 feet is not required.

For stage 4 equation testing, we considered the use of single station equations. Both MOS and LAMP development of certain weather elements have demonstrated that single station equation based forecasts are more skillful than forecasts generated from regionalized equations. For a given sampling period, the single station approach requires that adequate numbers of observations be present for all forecast projection hours and categories. Based on these requirements, the single station approach was tested for OSC, but not for CIG since too few stations would qualify. Stations not qualifying for OSC single station development were developed regionally. To maintain the stability of the regionalized equations, data from all stations were included.

To summarize, LAMP CIG regression equations were tested only for stages 1 and 2. LAMP OSC regression equations were tested for all stages.

5. RESULTS

The LAMP and GFS MOS best category forecasts for CIG and OSC are compared along with persistence. Since the LAMP and MOS CIG and OSC category definitions are the same, we can compare verification scores between the LAMP and MOS systems.

5.1 *Ceiling Height Results*

The Threat Score was used to evaluate the accuracy of the CIG forecasts. A higher threat score indicates a more accurate forecast. The Threat Score plots for CIG categories < 1000 feet and ≤ 3000 feet are shown, which are of interest to aviation.

Figs. 1 through 4 show the Threat Scores for CIG categories < 1000 feet and ≤ 3000 feet representing the 2006 warm season and the 2006-07 cool season. Each figure shows the CIG forecasts from the 1000 UTC LAMP and 0600 UTC GFS MOS for the 1591 stations pooled from the CONUS, Alaska, Hawaii, and Puerto Rico. In these figures, the stage 2 LAMP CIG is compared with the present LAMP CIG, the GFS MOS CIG, and persistence. The stage 1 results (not shown) account for approximately 25% of the improved accuracy shown by the stage 2 results. The improvement in forecast accuracy from the present LAMP averages 2-4%, but is consistent over almost all projection hours for both the warm and cool seasons. As noted previously by Weiss and Ghirardelli (2005), the LAMP in the very short range demonstrates either similar or better accuracy than persistence. These plot show that the redeveloped LAMP CIG is more accurate than the GFS MOS CIG, and has equal or better accuracy than persistence, which are both goals of LAMP.

5.2 *Opaque Sky Cover Results*

The Heidke Skill Score (HSS) was used to verify OSC for the same independent periods and 1591 stations noted earlier in this section. The HSS is a positively oriented skill score, measured over all categories of OSC and not any one specific SC category. Figures 5 and 6 show the HSS for the warm and cool seasons respectively. In these plots stage 1, stage 2, and stage 4 LAMP OSC are compared with the present LAMP SC. We note that the present LAMP SC was developed to predict total sky cover. Since the verifying observation for these plots is OSC, this puts the present LAMP SC at a slight disadvantage because it is being verified against an observation it was not intended to predict. Therefore the HSS of the present LAMP SC guidance are slightly lower than would be observed if the verifying observation was total sky cover. In these plots the stage 2 results improve on the present LAMP by 7-8% on average. The new GFS MOS CIG and OSC probability predictors are a major source of improved skill. The stage 1 results account for approximately 25 -50% of stage 2's improved skill. A considerable portion of this skill improvement is due to the change in the LAMP sky cover definition from total sky cover to OSC rather than the affects of non-simultaneous development.

A substantial increase in skill is observed between stage 2 and stage 4 results for the projections 1-h through 3-h for the cool and warm seasons. The improved skill for these projections hours is due to the use of the new SC observation predictor (stage 3). The stage 3 results are not shown, since the HSS scores are almost identical to stage 2 beyond the 4-h projection. The improvement in forecast skill between stage 2 and 4 beyond the 4-h projection is about 1 percent, but consistent over almost all projection hours for both the warm and cool seasons. This small increase in skill is the result of using single station OSC development.

Figures 7 and 8 also show the HSS plots for the warm and cool season respectively. In these figures, the stage 4 LAMP OSC is compared with the present LAMP SC, the GFS MOS OSC, and persistence. Persistence in this plot is the un-complemented SC estimate (see Section 3), which represents the observation available at LAMP run-time for the present LAMP SC. For the early projection hours, the stage 4 OSC results illustrate that the un-complemented SC estimate no longer represents persistence due primarily to the skill gained by using the new SC observation predictor. What is clearly evident is the substantial increase in skill of the GFS MOS and stage 4 LAMP OSC results from the present LAMP SC guidance. These plots show that the redeveloped LAMP OSC is more skillful than the GFS MOS OSC, particularly in the early projection hours.

6. SUMMARY AND CONCLUSIONS

In this paper, we have increased the accuracy of the LAMP CIG guidance by 2 to 4 % by developing LAMP CIG equations separately from OSC and by using the updated GFS MOS CIG and OSC probability predictors. The updated GFS MOS CIG and OSC probability predictors were a major source of increased skill for the LAMP OSC. Developing LAMP OSC separately from CIG also contributed some additional skill. Substantial increases in skill for LAMP OSC occurred for projections 1-h through 3-h as a result of using the new SC observation predictor. The skill contributed by single station OSC development was minimal. The redevelopment of both LAMP CIG and OSC is compatible with the LAMP goal of serving as an update to the GFS MOS system. An overall improvement in skill of the LAMP CIG and OSC guidance is essential to maintain that goal.

7. FUTURE WORK

The redevelopment of the LAMP CIG and OSC guidance is expected to be completed in the spring of 2010. Future plans also include the development of Gridded LAMP for the aviation weather elements which include ceiling height and sky cover. This task will include a coordinated effort with the Federal Aviation Administration (FAA) to provide gridded probabilistic forecast guidance of aviation elements required for the FAA's Next Generation Air Transportation System (NextGen) (Ghirardelli and Glahn 2009).

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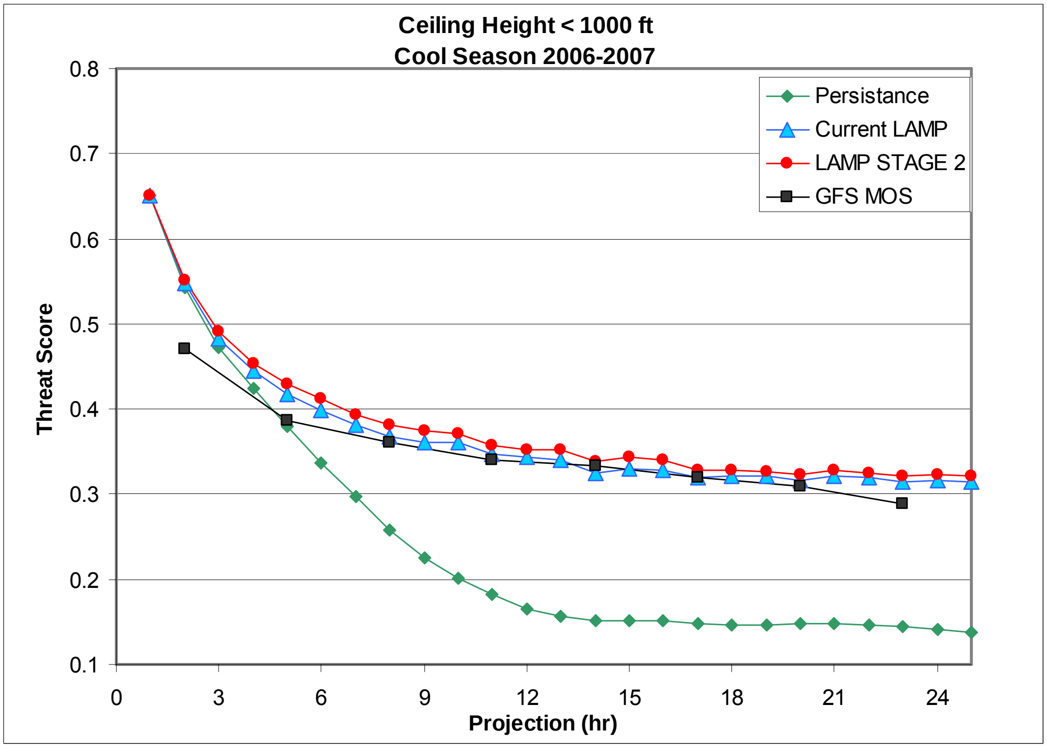

Figure 1. Threat Scores for categorical ceiling height forecasts of < 1000 feet for the 2006-07 cool season. Forecasts were generated from the 1000 UTC LAMP and 0600 UTC GFS MOS.

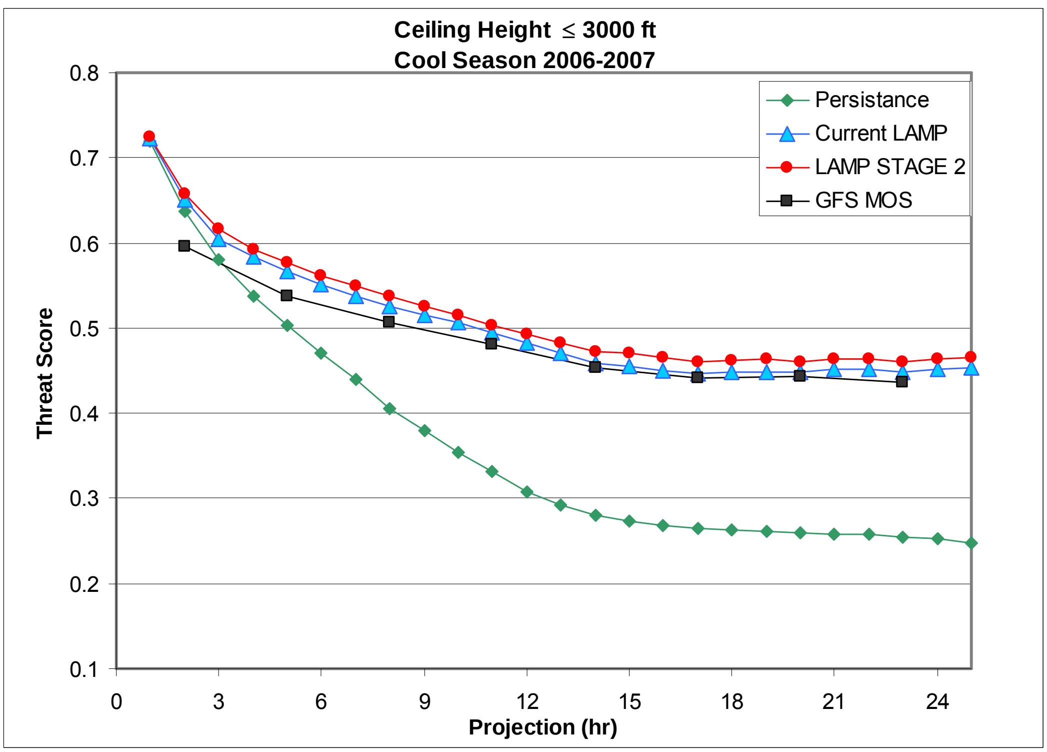

Figure 2. Same as Fig. 1 except for ceiling height forecasts of ≤ 3000 feet.

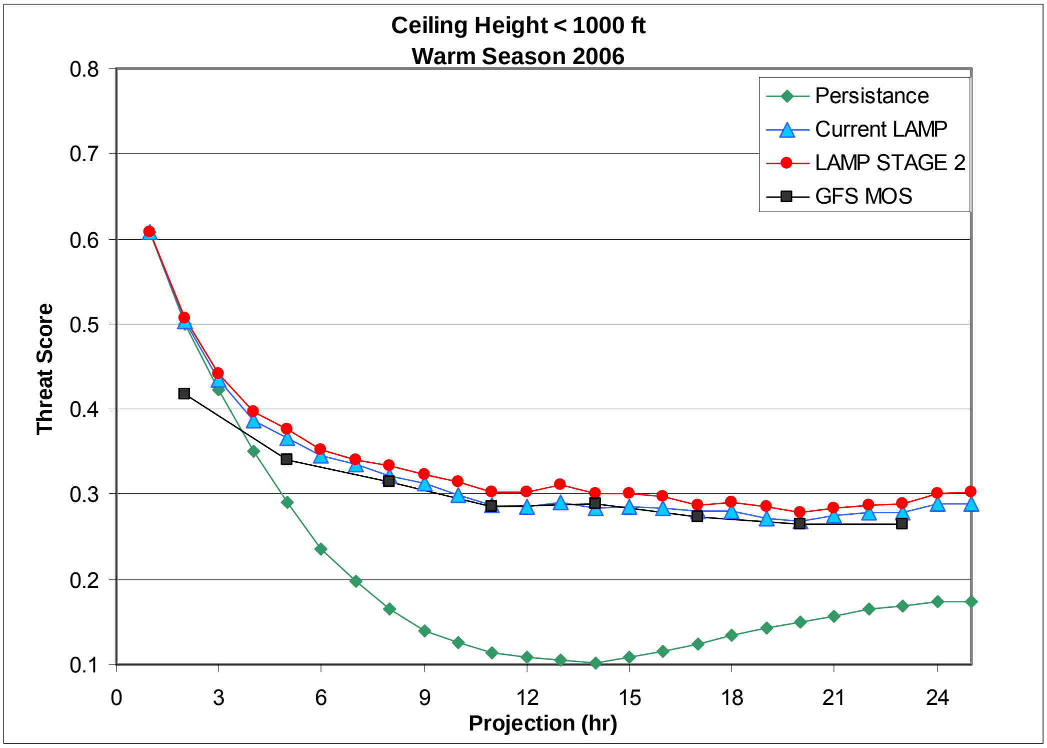

Figure 3. Threat Scores for categorical ceiling height forecasts of < 1000 feet for the 2006 warm season. Forecasts were generated from the 1000 UTC LAMP and 0600 UTC GFS MOS.

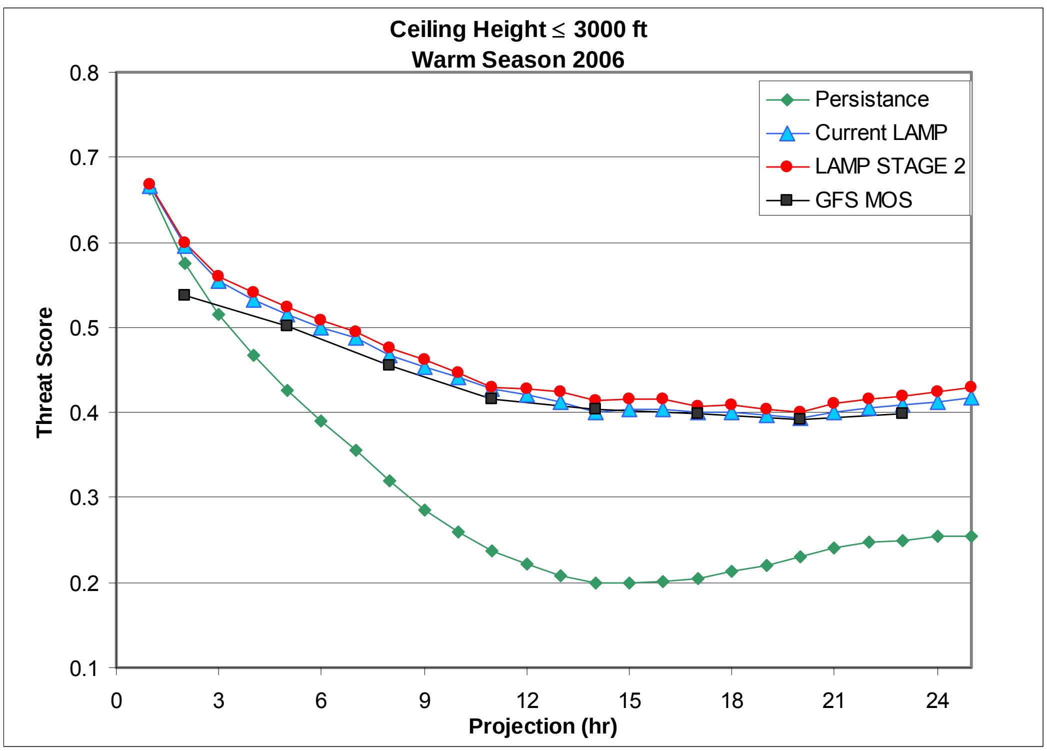

Figure 4. Same as Fig. 3 except for ceiling height forecasts of ≤ 3000 feet.

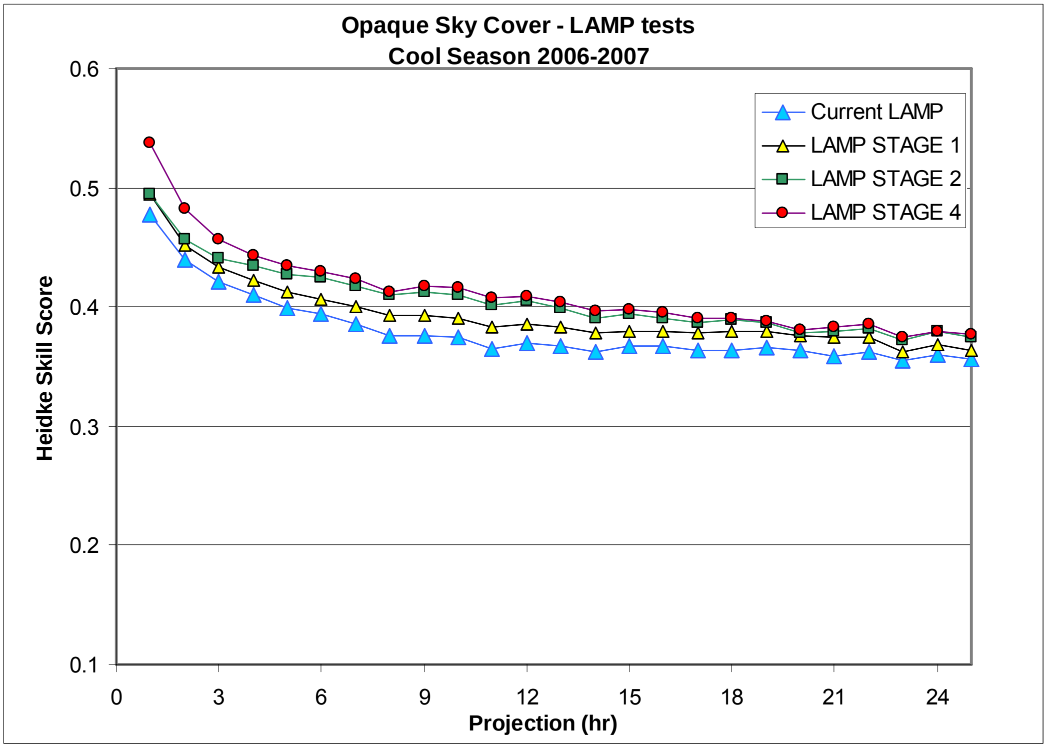

Figure 5. Heidke Skill Scores for test equation categorical opaque sky cover forecasts for the 2006-07 cool season. Forecasts were generated from the 1000 UTC LAMP and 0600 UTC GFS MOS.

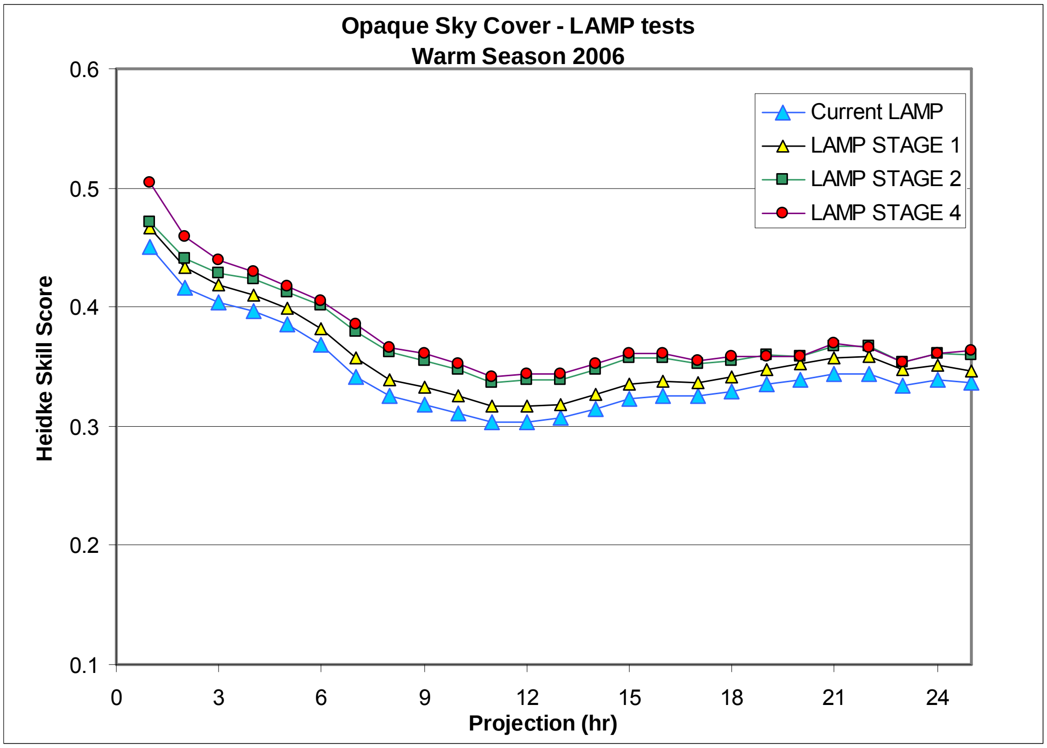

Figure 6. Same as Fig. 5 except for the 2006 warm season.

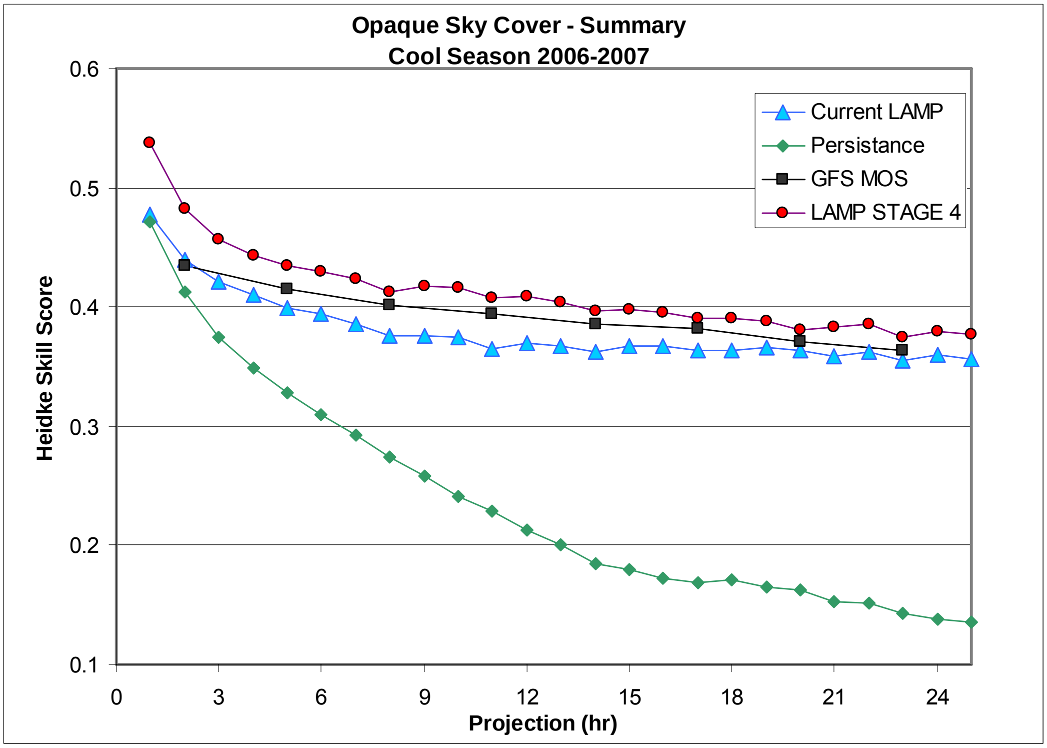

Figure 7. Heidke Skill Scores for GFS MOS/LAMP categorical opaque sky cover forecasts for the 2006-07 cool season. Forecasts were generated from the 1000 UTC LAMP and 0600 UTC GFS MOS.

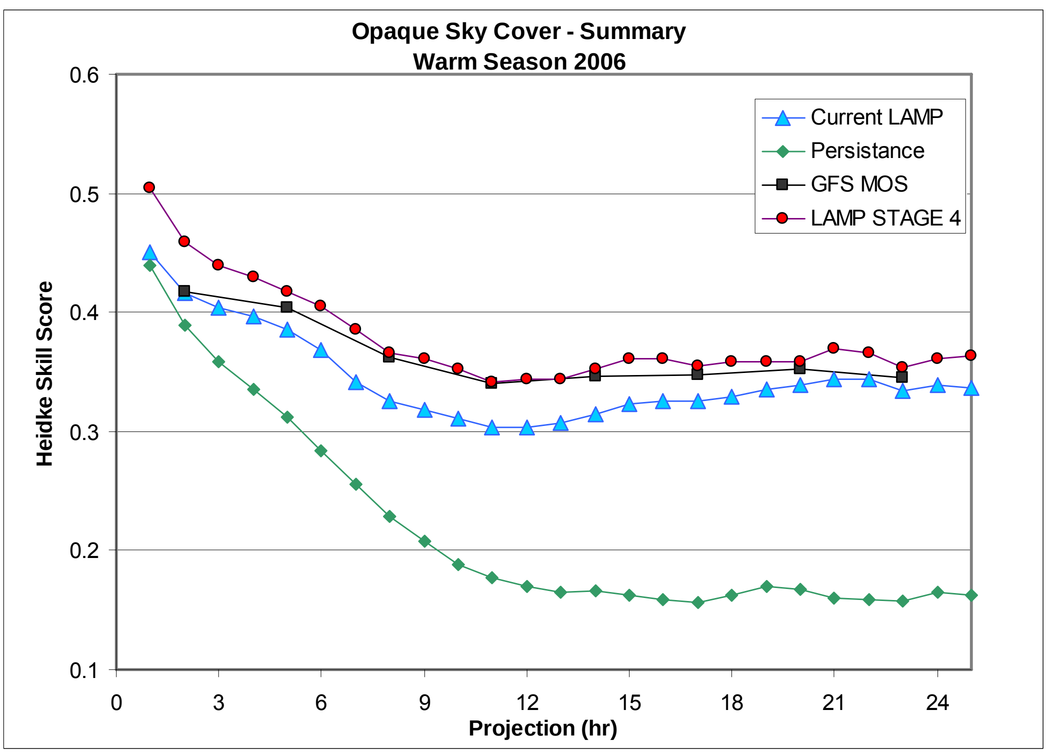

Figure 8. Same as Fig. 7 except for the 2006 warm season.