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CLOUD LAYER FORECASTING
WITHIN THE LOCAL AWIPS MOS PROGRAM (LAMP)

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1. INTRODUCTION

Forecasts of ceiling height and cloud amount by layer are essential to the aviation community. The National Weather Service (NWS) forecast offices are required to issue aviation terminal forecasts (TAFs) every 6 hours. TAFs require forecasts of cloud height and cloud amount for up to three layers of clouds.

The NWS has been producing objective probabilistic forecast guidance of both ceiling height and cloud cover since the early 1970's as part of the Model Output Statistics (MOS) (Glahn and Lowry 1972). However, MOS guidance is produced only every 12 hours, while the terminal forecast must be issued every 6 hours. Furthermore, MOS does not provide detailed guidance about cloud layers.

The Techniques Development Laboratory (TDL) of the NWS is developing a cloud layer forecasting algorithm to be used in the Local AWIPS MOS Program (LAMP). LAMP is a new guidance system to be used at the forecast office. As part of LAMP, a new cloud layer algorithm is being developed. This algorithm uses a decision tree to produce cloud layer guidance and will supply forecasts of cloud height and amount for up to three layers of clouds.

A forecast of persisting the observation into the forecast period (referred to as persistence) is often a very good, if not the best, forecast at the early hours. In verifying the aviation terminal forecasts, persistence was more skillful than the local NWS forecasters for ceiling forecasts at the 3-h projection (Dallavalle and Dagostaro 1995). In another ceiling verification study, persistence was more skillful than the NGM MOS at the 6-h projection (Miller 1995). In light of this, there is a 'Persistence Decision' built into LAMP's Cloud Layer Algorithm (CLA).

Because LAMP runs hourly, uses the most recent observations, provides more detailed cloud guidance than does the NGM MOS, and takes advantage of the skillful persistence forecasts at early hours, this new guidance should provide valuable information to the aviation forecaster for TAF generation. Also, it is used to initialize the Interactive Computer Worded Forecast (ICWF) system for both public and aviation forecasts (Oberfield and Ruth 1997). In this paper, an overview of LAMP is given, LAMP's equations are explained, and the CLA is described in detail. Preliminary results are also presented.

2. OVERVIEW OF LAMP

LAMP is a short range MOS guidance system designed to provide detailed statistical weather forecasts (Unger et al. 1989). LAMP guidance is currently produced on the AWIPS Government Development Platforms in Silver Spring, Maryland, every 3 hours. For each 3-hourly run, called a "start time," LAMP produces forecasts for the next 20 hours. For example, the 0500 UTC start time runs shortly after 0500 UTC, and produces guidance for every hour from 0600 to 0100 UTC the next day. In the future, LAMP guidance will be produced hourly. LAMP forecasts are produced for all locations in the contiguous United States currently receiving MOS guidance, and also for 275 additional locations (Fig. 1).

LAMP uses regression equations to forecast sensible weather. There are three types of predictor inputs to the equations: the most recent surface

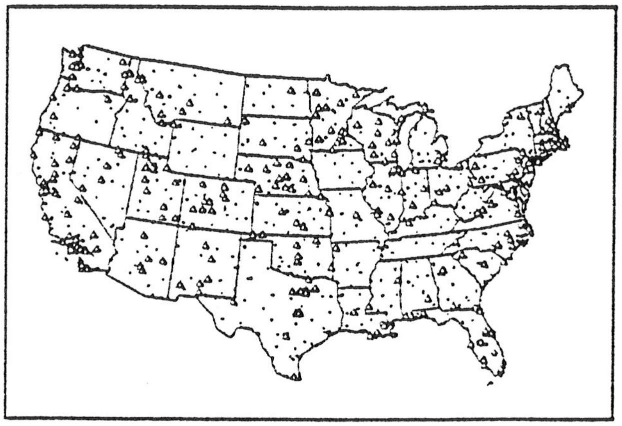

Figure 1. LAMP locations with NGM MOS (•) and those without (Δ).

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observations; simple, locally run advective models; and the NGM MOS forecasts. One of the advective models advects cloud amount, ceiling height, visibility, and precipitation type (Glahn and Unger 1982). The most recent surface observations have more influence in the early projections, while the NGM MOS forecasts have more influence toward the end of the 20-h forecast period. In this way, LAMP acts as an update to MOS, blending the recent information provided by the observations with the information from the centrally produced MOS.

LAMP provides forecast guidance for many weather elements currently being forecast by the NGM MOS, namely temperature, dew point, probability of precipitation in a 6-h period, obstruction to vision, categorical visibility, and wind speed and direction. With these elements, the benefit of LAMP over MOS is that LAMP provides forecasts of finer temporal (every hour) and spacial (more locations) resolution, and the LAMP forecasts are produced every 3 hours (every hour in the future), opposed to MOS's 12-hourly issuances.

In addition, LAMP provides some unique guidance, such as the probability of precipitation occurring on the hour; the categorical forecast of precipitation occurring (yes/no) on the hour; the categorical precipitation type including the three types which MOS forecasts (liquid, freezing, frozen), and two new categories of mixed precipitation (mixed liquid and frozen, and mixed freezing and frozen) (Carroll 1992); and continuous cloud height and sky cover for up to three cloud layers.

NGM MOS provides guidance for categorical ceilings, and indicates that the ceiling will be in one of seven ceiling height categories; a specific height is not forecast (Miller 1995). No information is provided about how many cloud layers to forecast, or their heights or amounts by layer. LAMP does provide this information, and will supply needed guidance to the aviation forecaster.

3. EQUATIONS

The inputs into the CLA are the LAMP forecasts of total opaque sky cover, ceiling, and lowest and highest cloud height. The cloud heights are continuous forecasts, meaning that a specific height in feet is forecast, while sky cover is a categorical forecast of either clear, scattered, broken or overcast skies derived from probabilistic guidance.

The equations were developed by using multiple linear regression on the National Oceanic and Atmospheric Administration's central computing facility. Because NGM MOS guidance for ceiling was not available until January 1993 (Miller 1995), the NGM MOS sample size was inadequate for development of regression equations; therefore MOS guidance from the Limited-area Fine Mesh (LFM) model was used. Equations were developed for start times every 3 hours (0200 UTC, 0500 UTC, etc.) and for two seasons (the warm season of April through September, the cool season of October through March), resulting in 16 sets of equations for each forecast element. The equations were developed with approximately 9 years of cool season data and 7 years of warm season data.

Regional equations were developed for the cloud heights and sky cover elements. Data for climatologically similar stations were combined into regions for equation development. For each equation set, there is an equation for each of the 20 projections in the forecast period, and for each region.

A forward selection screening regression procedure was used to determine the best predictors to use in the equations. These predictors were then examined in order to determine a common set that could be used for all the equations for a given element, regardless of region or projection. These predictors were then offered in a multiple linear regression procedure to derive a set of equations which use the same predictors in the same order for all equations for a given element, except that the projections of the predictors match the projections of the predictands. Using the same predictors in the same order minimizes inconsistency between projections.

3.1 *Cloud Height Equations*

Regression equations were developed to forecast the lowest, highest, and ceiling cloud heights. For the cloud height equations to respond best to the lower cloud heights, a logarithmic transformation of cloud heights was used (Unger 1987).

The cloud height forecasts obtained from the regression equations were post-processed to produce forecasts whose distribution resembles the observed distribution of the cloud heights. This is necessary because the regression procedure chooses its forecast on the basis of least squared errors between forecast and observations, which produces a highly distorted distribution of cloud heights when compared to the observations. A scaling procedure was used to force the cumulative forecast distribution to match the cumulative observed distribution at certain critical levels. Thresholds were produced from the dependent data for each of six critical levels of the atmosphere. A threshold value for the forecast cloud height was obtained such that the same number of forecasts occurred below that value as were observed to occur below the critical level in the atmosphere which it represents (e.g., 3000 ft). Thresholds were obtained separately for each region, projection, start time, and cloud height element. The continuous cloud height forecasts are then "scaled" by applying the critical values at the forecast thresholds and by assuming a proportional transformation when the forecast is between the threshold values.

3.2 *Total Opaque Sky Cover Equations*

Regional regression equations were developed to predict the total opaque sky cover as one of four categories (clear, scattered, broken, or overcast). The equations were developed for each start time, season and region. For each equation set, there are four equations which produce probabilities for each of the four categories. In addition there are 20 equations for each projection.

The selection of a best category forecast is made by a binary tree method comparing the categorical probabilities to thresholds (Fig. 2). The thresholds were developed such that using this selection method produces forecasts for each sky category as often as it is observed (unit bias).

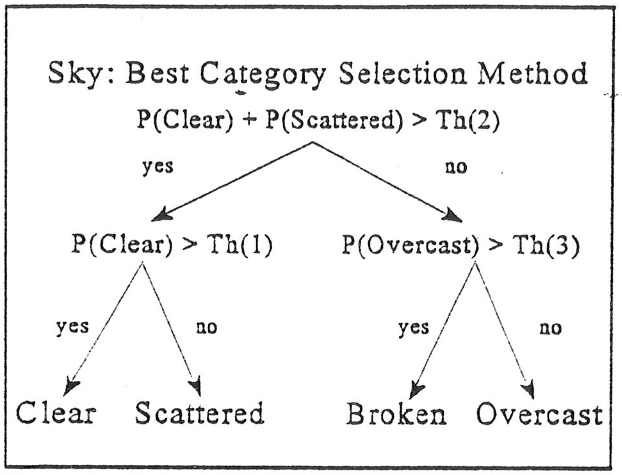

Figure 2. Binary tree method for sky cover selection.

4. THE CLOUD LAYER ALGORITHM THRESHOLDS

4.1 *Persistence Thresholds*

Cloud layers and ceiling heights tend to persist often enough that persistence of the initial observation is a very accurate forecast in the first few hours of the forecast. Forecasts of these elements, however, tend to change abruptly. Verification data demonstrates that the raw cloud height forecasts do not give adequate weight to the persistence observation. In the CLA, a persistence capability is supplied under the assumption that the closer the forecast is to the initial observation, the more likely it is that the guidance is actually forecasting persistence of the initial layer.

The persistence thresholds are used to facilitate the decision of whether to accept LAMP's forecasted cloud heights, or instead forecast persistence for that element. The thresholds are designed such that the LAMP forecast is accepted in those situations when LAMP has historically produced a forecast which was better than persistence more than 50% of the time; otherwise, persistence is forecast. The method of threshold development is the same for all three cloud height elements; for simplicity persistence thresholds only for ceiling will be discussed.

The cases were stratified by initial ceiling height (I, where I is the initial ceiling height) (six bins) and height difference between the LAMP forecast and the initial observation (F-I, where F is the LAMP forecast) (36 bins). In developing the thresholds, the LAMP scaled ceiling forecast was compared to the verifying ceiling observation to produce the absolute LAMP error (F-O, where O is the verifying observation). A persistence error was likewise computed (I-O). Only those cases where there was a ceiling both initially and at the verifying projection were used. The probability P of LAMP having the better forecast for each bin was determined, where:

$$P = \frac{(\#\ of\ times\ |F-O|<|I-O|)}{(\#\ of\ cases\ in\ bin)} \times 100$$

To avoid storing all the probabilities, two thresholds per initial ceiling bin were determined. The threshold is defined as the value of (F-I) which separates the probabilities greater than 50% from those less than 50%. There are two thresholds for each initial height bin, one for the positive F-I differences and one for the negative differences. The thresholds are smoothed to ensure that they strictly decrease by projection. This thresholding is done for each initial height bin, projection, region, 3-hourly start time, season, and cloud height element. A schematic of theoretic thresholds for one initial height bin is shown in Fig. 3.

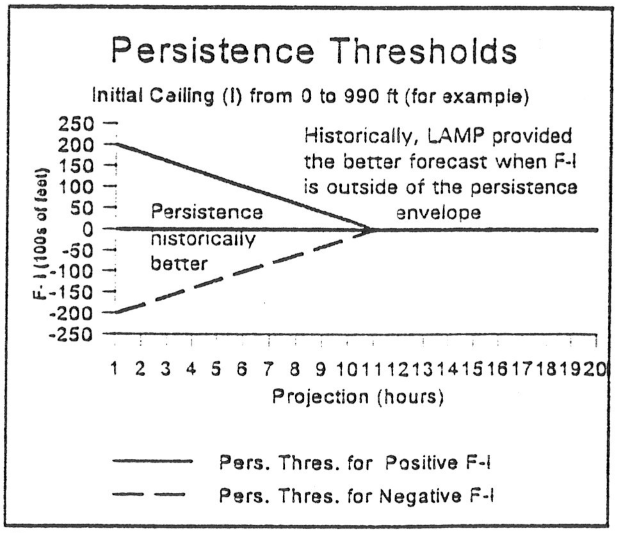

Figure 3. Theoretical persistence thresholds for a given initial ceiling bin.

The thresholds are applied in this way: if the F-I falls between the thresholds, historically persistence was a better forecast more than 50% of the time, and the decision is to forecast persistence rather than accept the LAMP forecast. Alternately, if the F-I difference is not between the thresholds, historically LAMP was the better forecast more often, and the LAMP forecast would be accepted. Because the thresholds approach zero as the projection increases, it is easier for this system to select persistence at early projections, and more difficult at the middle and later projections. This is reasonable since the skill of persistence decreases with time.

4.2 *Layer Separation Thresholds*

Forecasts for sky cover, and lowest, ceiling, and highest cloud heights are always available from the LAMP guidance. A method was devised to process this information into a forecast of up to three layers of clouds. An important aspect of this method is to determine how many layers are present. The method is based on the assumption that the closer the forecast heights of the potential layers, the more likely it is that they refer to the same layer. Once again, thresholds are derived from historical data to help decide the minimum layer separation required to forecast two separate layers of clouds.

The LAMP forecasted cloud cases are stratified into the same bin demarcations as were used in the persistence threshold development. The thresholds are developed for each region, start time, season and for each of the three possible combinations of cloud layers (ceiling and lowest; ceiling and highest; lowest and highest). For simplicity, the development of the ceiling and lowest combination thresholds only will be discussed. Henceforth, the LAMP forecasts of ceiling will be referred to as CLG, lowest cloud layer as LOW and highest cloud layer as HIGH, and total opaque sky cover as SKY.

The layer decision is designed to forecast as many layers as are historically observed given LAMP's forecasted cloud heights. To develop the CLG - LOW thresholds, the LAMP forecasted CLG cases are stratified into bins. For each bin, the observational probability P_O is defined as:

$$P_O = \frac{\text{(\# of cases when observed clg = observed lowest cld)}}{\text{(\# of observed ceiling cases)}} \times 100$$

P_O is the probability that the ceiling is the lowest layer, given that a ceiling is observed. Next the forecasted probability P_{fx} is determined for a given difference CLG - LOW, and is defined as:

$$P_{fx} = \frac{\text{(\# of cases when observed clg = observed lowest cld)}}{\text{(\# of cases when LAMP's forecasted CLG - LOW = x)}} \times 100$$

P_{fx} is the probability that the ceiling is the lowest layer, given LAMP's forecasted CLG - LOW. P_{fx} is computed for CLG - LOW differences spanning the interval from 0 to 25,000 feet. A cumulative forecast frequency P_F is determined by summing the P_{fx} probabilities. In general the probability that ceiling is the lowest layer will be high when CLG and LOW are close to each other, indicating LAMP is forecasting the ceiling to be the lowest layer. The probability will be low when CLG and LOW differ greatly, indicating LAMP is forecasting two distinct layers.

The threshold for a given ceiling bin and projection is defined as the intersection between the P_O line and the P_F curve, as depicted in Fig.4. This method is designed to produce an unbiased number of layers. This method is similarly followed to produce thresholds for the combinations of CLG and HIGH, and of LOW and HIGH.

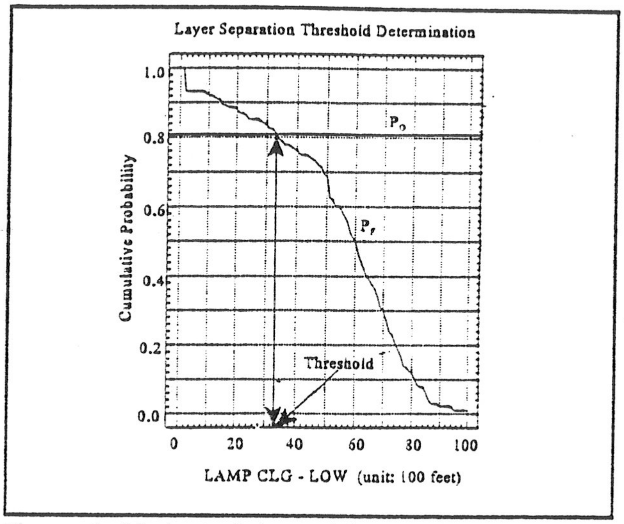

Figure 4. Method of determining the layer separation threshold for a given ceiling height bin.

5. THE CLOUD LAYER ALGORITHM (CLA)

The CLA processes the information provided by the cloud height forecast and sky cover forecast to create a forecast for up to three layers of clouds that includes the height and amount by layer. This information is logically processed with aid of the decision tree shown in Fig. 5.

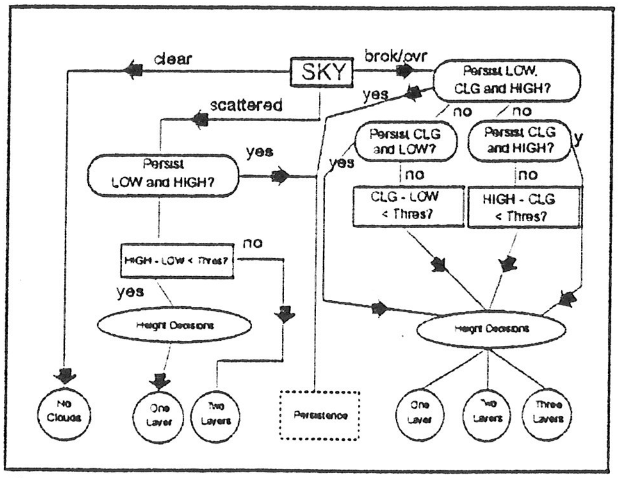

Figure 5. Decision tree for the Cloud Layer Algorithm.

The CLA can be broken up into four steps. The first is to examine LAMP's forecasted SKY. This determines the possible state that the cloud layer forecasts can take. A SKY forecast of clear skies produces a forecast of no cloud layers, the trivial case. A forecast of scattered clouds can yield a forecast of either one or two scattered layers, while a forecast of either broken or overcast can yield one, two, or three layers of varying amount, depending on the layer separation decision (the third step) and the total SKY forecast.

The second step is to consider persistence. If scattered skies are forecast, the LOW and HIGH forecasts are compared to their persistence thresholds; if either broken or overcast skies are forecast, all of the LOW, CLG and HIGH forecasts are compared to their thresholds. Again, if the forecasted height is between the persistence thresholds, persistence historically has proven to be the better forecast, and therefore is forecast. Otherwise, LAMP's forecast is accepted.

The third step is to determine how many layers of clouds to forecast. If the skies are forecast to be scattered, the LOW and HIGH forecasted difference is examined. If it exceeds the layer separation threshold, this indicates that the layer separation is great enough to indicate two distinct layers. Otherwise the layer separation is not great enough, and one layer of clouds is indicated. If the skies are forecast to be either broken or overcast, by definition there is a ceiling; therefore the layer separations of LOW and CLG, and CLG and HIGH, are compared to their thresholds, yielding either one, two or three layers.

The last step is to determine the heights and amounts of the layers which will be forecast. For the total sky forecast of scattered, if there are two layers forecast, they are of the heights of LOW and HIGH. If one layer is forecast, it is either the height of LOW, HIGH, or an average of the two, depending on a simple height rule. The rule was determined based on the observations that the highest layer forecast performs better when the value of the LAMP's HIGH forecast is "high" (greater than 10,000 feet), and the lowest layer forecast performs better when the value of the LAMP's LOW forecast is "low" (less than 7,500 feet). If the LOW and HIGH layers are between these determining heights, they are averaged to produce the height of the one layer.

For the total sky forecast of either broken or overcast, if there are three layers forecast, they would be of the heights of LOW, CLG and HIGH. If only one layer is forecast, it must be that of CLG. If two are forecast, the heights are those of LOW and CLG, or CLG and HIGH, depending on the outcome of the layer separation decision.

Determining the cloud amounts is somewhat intuitive. For a forecast of total sky cover of scattered, the one or two layers must be scattered. For total sky cover forecasted to be broken or overcast, any layer below the ceiling must be scattered, and any layer above the ceiling must be either broken or overcast. The ceiling is always either broken or overcast. Scattered clouds can never be forecast above broken or overcast layers, and no layers can be forecast above the overcast layer, which is consistent with TAF requirements. The total SKY helps determine these amounts specifically. These rules determine the cloud amounts by layer.

It should be noted that the algorithm is incapable of forecasting three layers of scattered clouds. Also note that the persistence decision is more important than the layer separation decision in that if it is ever decided to forecast persistence for any element, the final result will include a persisted layer for that element.

6. RESULTS

At the time of this writing, the persistence thresholds for all cloud elements for one start time have been developed and preliminary verification has been done for the ceiling element. Note that while the layer separation thresholds have not yet been developed, and the resulting layers have not been verified, the algorithm is designed so that the persistence decision is the most important. Once it has decided to persist ceiling, the resultant ceiling forecast will not be changed by the layer separation decision. Therefore verifying the persistence decision for ceiling provides a good measure of the skill of the total algorithm in forecasting ceiling, but not of the skill of the layer decision.

Fig. 6 shows the Heidke Skill Score for the persistence modified ceiling for the first ten projections for the eastern region of the United States. This verification is from 1100 UTC of the 1993 to 1994 cool season, and includes only cases when an initial ceiling existed. Also shown are the scores for the unmodified LAMP ceiling (before the persistence decision) and for persistence. At the 1- and 4-h projections, the persistence modified forecast is about as skillful as persistence and more skillful than the unmodified LAMP ceiling forecast. At the 2- and 3-h projections, persistence is marginally better than the modified

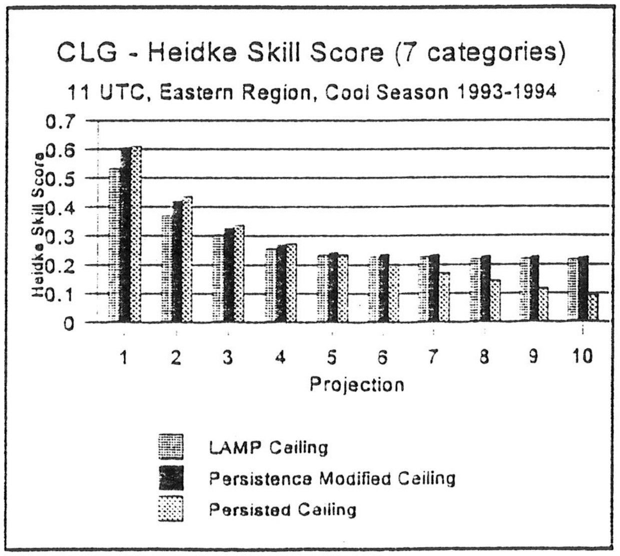

Figure 6. Heidke Skill Score for ceiling. Higher scores indicate greater skill.

LAMP. From the 5-h projection onward, the persistence modified forecast is more skillful than persistence.

It is very difficult to select the LAMP forecast at the early hours, so persistence is selected very often. Later on, it is more difficult to select persistence, and the LAMP forecast is accepted more often.

Studies with the dependent sample showed that for the first projection for the eastern region, 1100 UTC cool season, the decision was made 95.2% of the time to accept persistence at the first projection, compared to 76.9% at the second projection. Further studies showed that at the first projection, persistence was being chosen over some of the more skillful LAMP forecasts. In other words, this scheme was not taking advantage of the good LAMP forecasts at the early hours, because LAMP was not better than persistence more than 50% of time (which is the criterion the persistence threshold development uses). However, it was better about 30% of the time at the first projection, but these skillful forecasts were rejected in favor of persistence. This is because the persistence decision discourages selecting LAMP at the early projections.

The following modification for the earliest projections is currently being evaluated: after it has been decided to accept persistence via the persistence thresholds, examine the observations immediately preceding the start time. If those observations have all persisted (i.e., the same ceiling height was observed for the 3 preceding hours), then accept persistence. Otherwise, accept LAMP. This would make the persistence decision stricter, and we anticipate that this would cause LAMP to be forecast in cases where it is more skillful, even if it is not better more than 50% of the time. The danger with this is that persistence might not be accepted at times when it is the better forecast. Further work will determine the validity of this modification.

7. CONCLUSIONS

The CLA provides cloud height and amount forecasts for up to three cloud layers. This guidance can be used by the NWS aviation forecaster to produce TAFs every 6 hours. The algorithm includes decisions to explicitly select persistence or accept the LAMP forecasted cloud element heights, and to determine the number of layers LAMP is indicating. The resulting forecasts are consistent with the LAMP forecasted total opaque sky cover forecast.

Preliminary results indicate that this method produces ceiling forecasts that are as skillful as persistence and more skillful than the unmodified LAMP at the early hours. At the middle and later hours, this method is more skillful than both persistence and the unmodified LAMP forecasts. There are indications that the skill could be improved further at the early hours, and a modification to the current scheme is being investigated. This modification would augment the persistence decision described here.

To conclude, this new guidance product will provide the aviation forecaster with more information than is currently available from MOS. It is successful in blending the persistence forecast with the LAMP forecast to provide a forecast which has benefited from the skill of both forecast systems.

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