

Aviation Weather Observations vs. LAMP Forecasts with the Onset of Precipitation

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To the casual observer, precipitation events are associated with reduced horizontal visibilities and/or lower cloud ceiling height.¹ This agrees with our experience that poor visibility and/or low ceiling heights are generally accompanied by a moisture-laden atmosphere. The astute observer would also notice occasions when horizontal visibilities improve and/or ceiling heights rise at the onset of precipitation for both trace and measurable precipitation events. Understanding the relative frequency distribution of both the lowering and rising of visibility and ceiling height in a window just prior to and shortly after precipitation begins is beneficial from a purely academic standpoint and crucial for generating accurate aviation forecasts in less than ideal weather conditions.

Aviation flying conditions are delineated into specific flight categories: Very Low Instrument Flight

¹ The *Glossary of Meteorology* defines ceiling height as “the height ascribed to the lowest layer of clouds or obscuring phenomena when it is reported as broken, overcast, or obscuration and not classified as ‘thin’ or ‘partial.’” Visibility is defined as “the greatest distance in a given direction at which it is just possible to see and identify with the unaided eye. . . . After visibilities have been determined around the entire horizon circle, they are resolved into a single value of prevailing visibility for reporting purposes.”

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TABLE 1. Definition of aviation flight categories.

Flight category	Ceiling height (ft)	Visibility (miles)
VLIFR	< 200 and/or	< 0.5
LIFR	> 200 to < 500 and/or	0.5–1
IFR	> 500 to < 1,000 and/or	1–3
MVFR	> 1,000 to < 3,000 and/or	3–5
VFR	> 3,000 and	> 5

Rules (VLIFR), Low Instrument Flight Rules (LIFR), Instrument Flight Rules (IFR), Marginal Visual Flight Rules (MVFR), and Visual Flight Rules (VFR). Table 1 outlines the ceiling and visibility conditions that define each one of these flight categories. Since IFR, LIFR, and VLIFR conditions adversely affect the aviation industry, they comprise a common group of hazardous conditions. As such, it is convenient to delineate the five flight groups into two categories: 1) IFR, LIFR, and VLIFR (hereafter referred to as IFR or worse), and 2) MVFR and VFR. Understanding the variations in the relative frequency distributions of visibility, ceiling height, and aviation flight categories just prior to and shortly after precipitation begins is crucial for generating accurate aviation forecasts.

BACKGROUND. The Meteorological Development Laboratory (MDL)’s Localized Aviation Model Output Statistics (MOS) Program (LAMP) forecast system is designed to update the Global Forecast System (GFS)-based MOS by running every hour and generate hourly resolution forecasts of weather elements that directly affect aviation interests for projections out to 25 hours in advance (see Ghirardelli 2005 for a comprehensive discussion of the GFS-based

LAMP system). Included in the LAMP suite of forecast elements are ceiling height and visibility. These two forecast elements are issued in terms of categories as shown in Table 2.² Note that LAMP categorical forecasts are not explicitly generated. Rather, LAMP forecast probabilities are compared to predefined thresholds to determine a “best” categorical forecast. LAMP generates ceiling height and visibility forecasts at each projection irrespective of whether precipitation is or is not anticipated to occur. LAMP also generates ceiling height and visibility forecasts contingent upon precipitation falling at each projection. These latter forecasts convey the influence precipitation would have on the ceiling height and/or visibility. The former forecasts are referred to as unconditional while the latter forecasts are referred to as conditional. Regression equations for the unconditional event are developed on both observed precipitating and nonprecipitating cases. For the conditional event, the regression equations are developed only for those cases where precipitation was reported. However, the master input list of predictors used by the regression program to model both the unconditional and conditional events is identical.

Statistical weather guidance can sometimes produce forecasts that are meteorologically inconsistent. To ensure consistency among LAMP forecasts for related weather elements, cross-checks for certain elements are performed. For example, LAMP temperature forecasts are always checked to ensure that they are greater than or equal to their corresponding dew point temperature forecast. Other LAMP forecasts such as ceiling height and visibility are not currently checked for inconsistencies. As such, the author questioned whether or not such consistency checks should also be extended to ceiling height and visibility forecasts. In particular, should LAMP conditional ceiling height and visibility forecasts be checked to ensure that they are always less than or equal to their unconditional counterpart? In order to resolve this issue, two additional questions need to be answered:

- 1) Do the observed ceiling heights and/or visibilities increase by at least one category at the onset of precipitation frequently enough in nature to accept an apparent inconsistency in the forecast product?

TABLE 2. LAMP ceiling height and visibility forecast categories.

Category	Ceiling height (ft)
1	< 200
2	200–400
3	500–900
4	1,000–1,900
5	2,000–3,000
6	3,100–6,500
7	6,600–12,000
8	> 12,000 or unlimited ceiling
Category	Visibility (miles)
1	< 0.5
2	0.5–1
3	1–2
4	2–3
5	3–5
6	6
7	> 6

- 2) Does the percentage of times that the observed ceiling heights and/or visibilities increase and decrease by at least one category just after the onset of precipitation match the percentage of times LAMP forecasts these types of events?

These two questions are also examined in the context of aviation flight categories. That is to say, prior to the onset of precipitation, when IFR or worse conditions prevail, what are the percentages of times IFR or worse conditions persist or improve after precipitation begins? Although examining IFR conditions in this context does not answer the question of whether or not ceiling height and visibility forecasts should be checked to ensure that they are always less than or equal to their unconditional counterpart, it is believed that performing such an analysis does provide valu-

² Real-time hourly updated GFS-based LAMP forecasts are available at <http://weather.govmdl/gfslamp/gfslamp.shtml>.

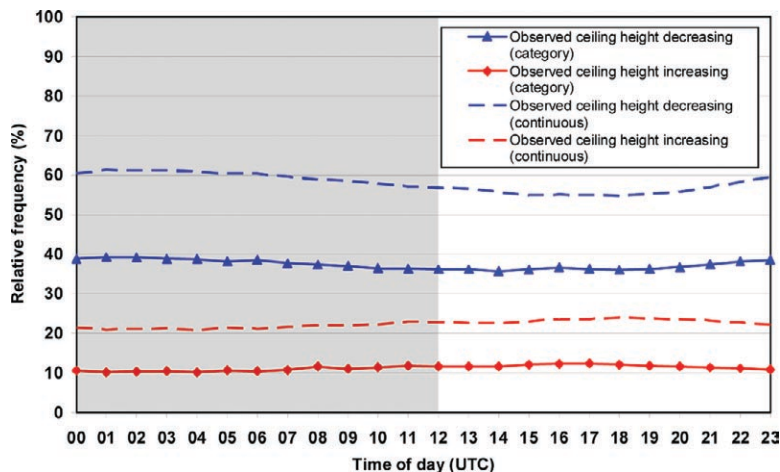


FIG. 1. The percentage of times ceiling height decreases (blue dashed line) and increases (red dashed line) by any amount when precipitation was observed at the current hour but not at the previous hour. Also shown are the percentage of times ceiling height decreases (blue line) and increases (red line) by at least one category when precipitation was observed at the current hour but not at the previous hour. The general nighttime period is shaded in gray. The climatological sample covers the 2000/01 through 2007/08 cool seasons.

able insight into the behavior of IFR conditions that are so integral to flight planning.

DATA AND METHODOLOGY. Data for this study were stratified into an 8-yr and 2-yr sample. The purpose of this stratification is two-fold: 1) to examine the behavior of the data over a relatively long climatological sample, and 2) to demonstrate that the 2-yr sample is representative of the overall 8-yr climatological sample when comparisons are made between LAMP (see below) and the observations over the shorter 2-yr period.

The observational data for this study incorporated hourly observations of ceiling height and visibility extracted from MDL's archive of Meteorological Aviation Report (METAR) reports. The sample was composed of eight cool seasons (1 October–31 March) spanning the period of 2000/01 through 2007/08. Observations for 1,522 stations from the United States and Puerto Rico were used to establish a representative value for each hour of the day. The cool season, as opposed to the warm season (1 April–30 September), was examined because reduced ceiling heights, lower visibilities, and precipitation events are more common during the cool season. Observed flight conditions such as IFR were generated by categorizing ceiling height and visibility observations into specific bins (Table 2). These categorical ceiling

height and visibility observations were then used to generate flight categories (Table 1). The reader should note that observations taken at unscheduled times (SPECT's) were not included in this study because these data are not available in MDL's observational archive. As such, intrahour variability of ceiling height, visibility, and flight categories are not represented in this study.

To examine the utility of LAMP in the context of this paper, LAMP operational categorical ceiling height and visibility forecasts spanning the 2006/07 and 2007/08 cool seasons were used. LAMP forecasts from the 0900 and 2100 UTC cycles were chosen because they represent a sample of nighttime and daytime forecasts, respectively. The LAMP categorical ceiling height and visibility forecasts (Table 2) were then used to generate flight category forecasts (Table 1).

RESULTS. Ceiling height and visibility. Figure 1 shows the percentage of times that the observed ceiling height lowers and rises by any amount and by at least one category as a function of time of day conditioned on precipitation being reported on the hour but not at the previous hour. The percentage of times ceiling height lowers by any amount (approximately 55%–60% of the time) is always greater than the percentage of times ceiling height drops by at least one category (37%–40% of the time). Note also that although there is very little diurnal variation, both curves vary together in a consistent manner. The two sets of percentage values shown in Figure 1, continuous and categorical, infer that there are times when the ceiling height either remains constant (approximately 20% of the time) or changes less than one category (approximately 50% of the time), respectively. But the values of greatest importance in Figure 1 for our purposes are those indicating the percentage of times when ceiling heights rise by any amount (between 21% and 24% of the time) and ceiling heights that rise by at least one category (approximately 10%–12% of the time).

Figure 2 displays the temporal behavior of horizontal visibility for the analogous situations shown in Fig. 1. The percentage of times throughout the day when the visibility lowers by any amount following

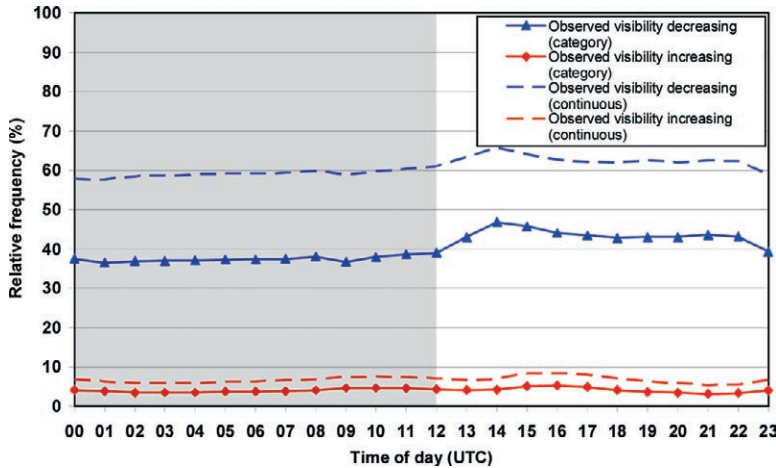
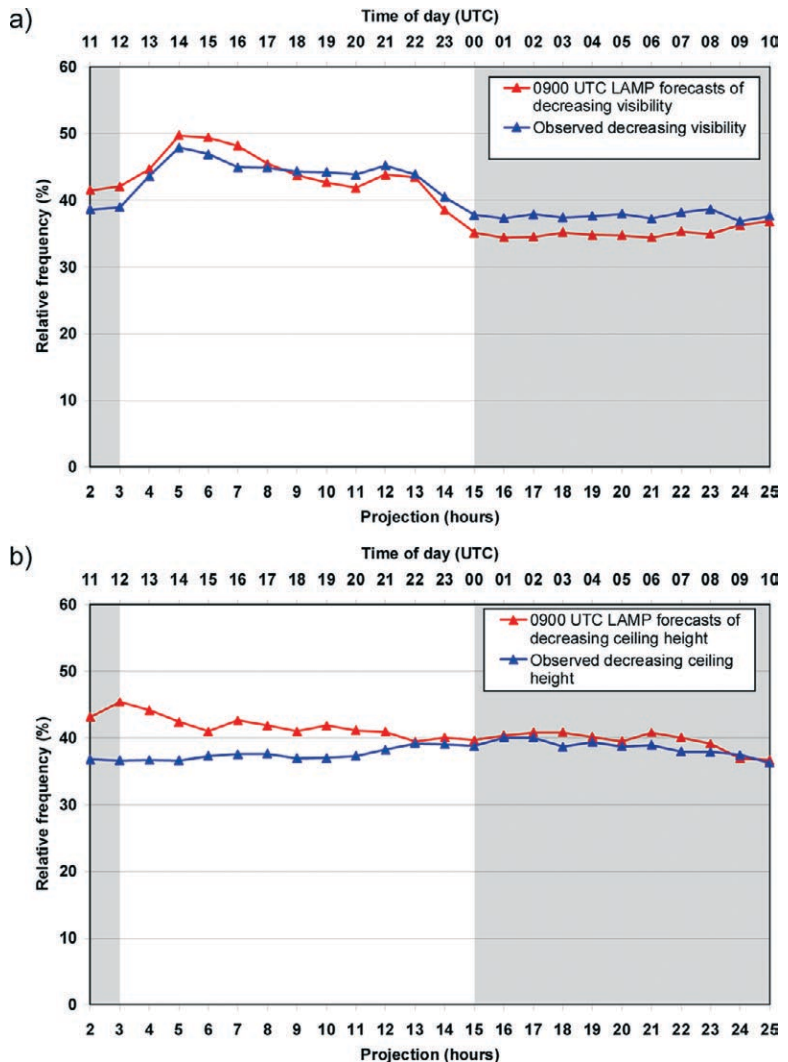


FIG. 2 (above). The percentage of times visibility decreases (blue dashed line) and increases (red dashed line) by any amount when precipitation was observed at the current hour but not at the previous hour. Also shown are the percentage of times visibility decreases (blue line) and increases (red line) by at least one category when precipitation was observed at the current hour but not at the previous hour. The general nighttime period is shaded in gray. The climatological sample covers the 2000/01 through 2007/08 cool seasons.

the onset of precipitation is approximately 60%, while the visibility drops by at least one category approximately 40% of the time. Similar to ceiling height (Fig. 1), the difference between the two curves is approximately 20% throughout the 24-h period. Observed visibility is less likely than observed ceiling height to increase at the onset of precipitation events, as evidenced by the lower percentage values shown in Fig. 2. In this instance, visibility rises approximately 8% of the time for those cases where visibility changes by any amount and 5% of the time for those

FIG. 3 (right). The percentage of times when (a) visibility and (b) ceiling height decrease by at least one category as forecast by the 0900 UTC LAMP system. Only cases when precipitation was observed at the valid hour but not at the previous hour were included. The general nighttime period is shaded in gray. The climatological sample covers the 2006/07 and 2007/08 cool seasons.



cases where the visibility rises by at least one category. Consequently, the percentage of times visibility remains unchanged is approximately 32% for those cases where the visibility changes by any amount and approximately 55% for those cases where the visibility changes by at least one category.

The second question of how well LAMP forecasts the frequency of occurrences of either an increase or decrease in ceiling heights/visibility at the onset of precipitation was evaluated in the following manner. Since the objective is to assess the performance of LAMP ceiling height and visibility forecasts during the onset of observed precipitation events, the

conditioning statement is evaluated in terms of observed precipitation occurrence. As such, cases were identified where observed precipitation occurred at the verifying projection and not at the preceding projection. For these conditions, a percentage tally was generated for those cases where the LAMP conditional ceiling height/visibility forecast valid at the verifying projection decreased or increased by at least one category relative to LAMP's unconditional ceiling height/visibility forecasts valid at the previous hour. In this manner, LAMP forecast climatologies for each projection were calculated and compared to the corresponding observed climatology at that particular time of the day. Since LAMP does not issue a 0-h forecast, LAMP climatologies were not calculated for the 1-h projection. For verification purposes, a matched observed climatology for two cool seasons was developed in the same manner as the 8-year observed climatology discussed above. The reader should note that LAMP does not explicitly forecast the change in ceiling height and visibility. Rather, the LAMP categorical forecasts of unconditional and conditional ceiling height and visibility valid at each projection hour are used to explore the behavior of the conditioning event defined in this study.

Figures 3 and 4 display the percentage of times 0900 and 2100 UTC LAMP visibility and ceiling height categorical forecasts decrease by at least one category, respectively. The forecasts are on independent data and span a period of two cool seasons for the stratified conditions outlined above. Note that LAMP visibility percentages for both cycles closely shadow climatology for the same stratified conditions over the same period at most projection hours. This is true even when small daytime oscillations are evident. The difference between the observed and LAMP forecast frequencies for all projections (2–25 h) and both cycles (0900 and 2100 UTC) are generally less than 7% (Figs. 3a, 3b, 4a, and 4b). For both cycles, LAMP tends to slightly underforecast

the number of times visibility lowers by at least one category during the nighttime hours. The tendency to underforecast or overforecast is mixed for the daytime depending upon cycle start time. The observed percentages for ceiling height exhibit a small diurnal oscillation, albeit much less than for observed visibility. Common to both LAMP cycles is the percentage of times ceiling heights decrease (albeit, negligibly) throughout the entire forecast period. It is also noteworthy that the relative frequencies associated with the decrease in ceiling height by at least one category differ more substantially during the 2–10-h projections (for both cycles) (Figs. 3b and 4b) than for the element of visibility (Figs. 3a and 4a).

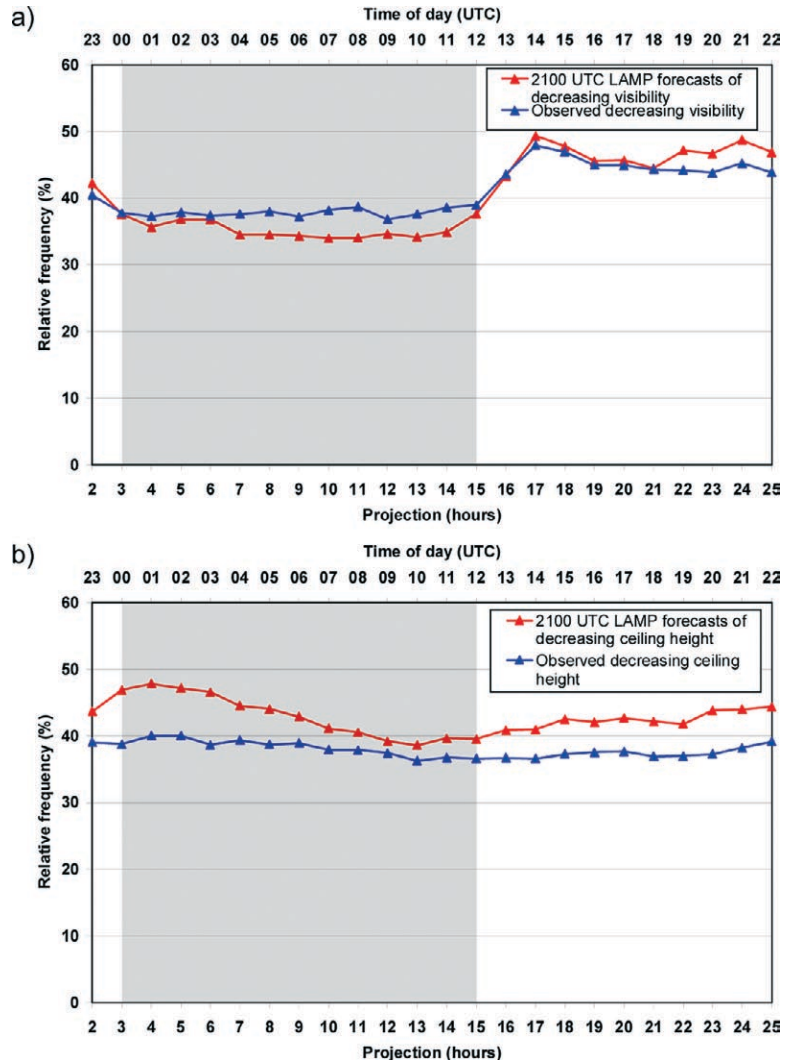


FIG. 4. Same as Fig. 3 except for the 2100 UTC LAMP cycle.

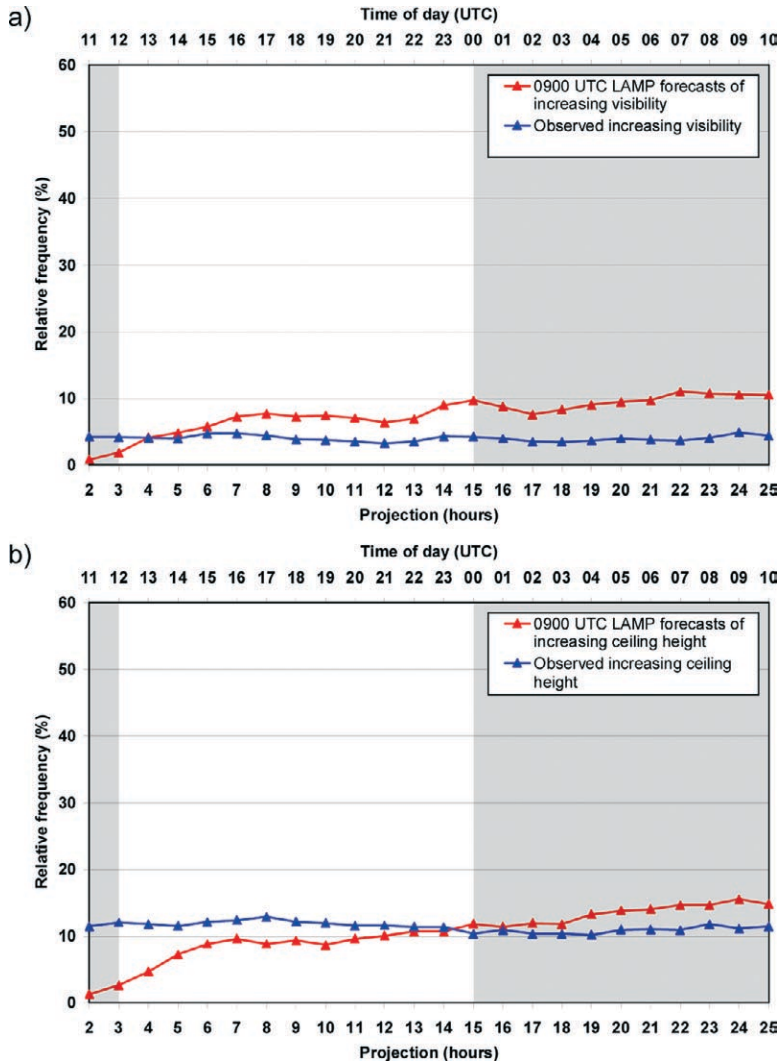


FIG. 5. The percentage of times when (a) visibility and (b) ceiling height increase by at least one category as forecast by the 0900 UTC LAMP system. Only cases when precipitation was observed at the valid hour but not at the previous hour were included. The general nighttime period is shaded in gray. The climatological sample covers the 2006/07 and 2007/08 cool seasons.

A similar analysis was performed for those instances when ceiling heights and visibilities increased at the onset of precipitation (Figs. 5 and 6). The percentage of times observed visibilities increase is approximately 3%–5%. Except for the 2- and 3-h projections, LAMP (for both cycles) slightly overforecasts when compared to the observed climatology (Figs. 5a and 6a). Unlike LAMP visibility forecasts, LAMP ceiling height forecasts do not shadow the observed climatology as well (Figs. 5b and 6b). Beginning with the earliest projection, LAMP tends to first underforecast and then overforecast the percentage of times

ceiling heights increase. Despite this behavior, the differences do not exceed 10% and are primarily concentrated in the range of 1%–5%.

Interestingly, the LAMP relative frequency values in the early projections (2–7 h) for both ceiling height and visibility shown in Figs. 5 and 6 are relatively small as compared to the middle and later projections. A possible explanation for this can be attributed to the influence of the observation in the early projections. LAMP persists the effect of the observation through the early forecast projections, mitigating the number of times ceiling height and/or visibility forecasts increase and decrease. Consequently, these LAMP relative frequencies are understandably small during those early projections. Although the relative frequencies do remain relatively small, they do monotonically increase in the early projections. This behavior can be attributed to the diminishing influence of the observation in the early projections and the growing influence of the MOS forecasts at the middle and later projections. The MOS forecasts at these projections are not as heavily influenced by the observation and therefore allow for more variability in the LAMP forecasts.

Flight categories. Figures 7 and 8 show the 24-h observed relative frequencies for instances where IFR or worse con-

TABLE 3. Precipitation type categories. This classification is consistent with the GFS MOS system.

Precipitation Type	Description
Frozen	Pure snow or snow grains
Freezing	Freezing rain/drizzle, ice pellets, or anything mixed with freezing precipitation
Liquid	Pure rain/drizzle or rain mixed with snow

ditions persist or improve following the onset of precipitation for the 2000/01 through 2007/08 cool seasons. The relative frequencies were stratified by the following three precipitation type categories: frozen, freezing, and liquid (see Table 3). It is interesting that for both scenarios of IFR or worse conditions persisting or improving, a majority of the relative frequency percentage differences between these cases rarely exceeds 10%.

Figure 9 shows the 0900 and 2100 UTC LAMP relative frequencies associated with instances where IFR conditions or worse persist following the onset of precipitation (given that IFR or worse conditions were present prior to the onset of precipitation), respectively. LAMP, when compared to the observed relative frequencies, has a tendency to overpersist IFR or worse conditions following the onset of precipitation throughout the entire forecast period. LAMP's relative frequencies are generally 5%–10% higher than the observations except during the late morning and early afternoon periods (1500–2100 UTC). The narrowed gap between observations and the LAMP relative frequencies during the midday hours appears to be caused by a discernable diurnal cycle in the LAMP relative frequencies. Relative frequencies corresponding to the converse of this condition (i.e., where conditions

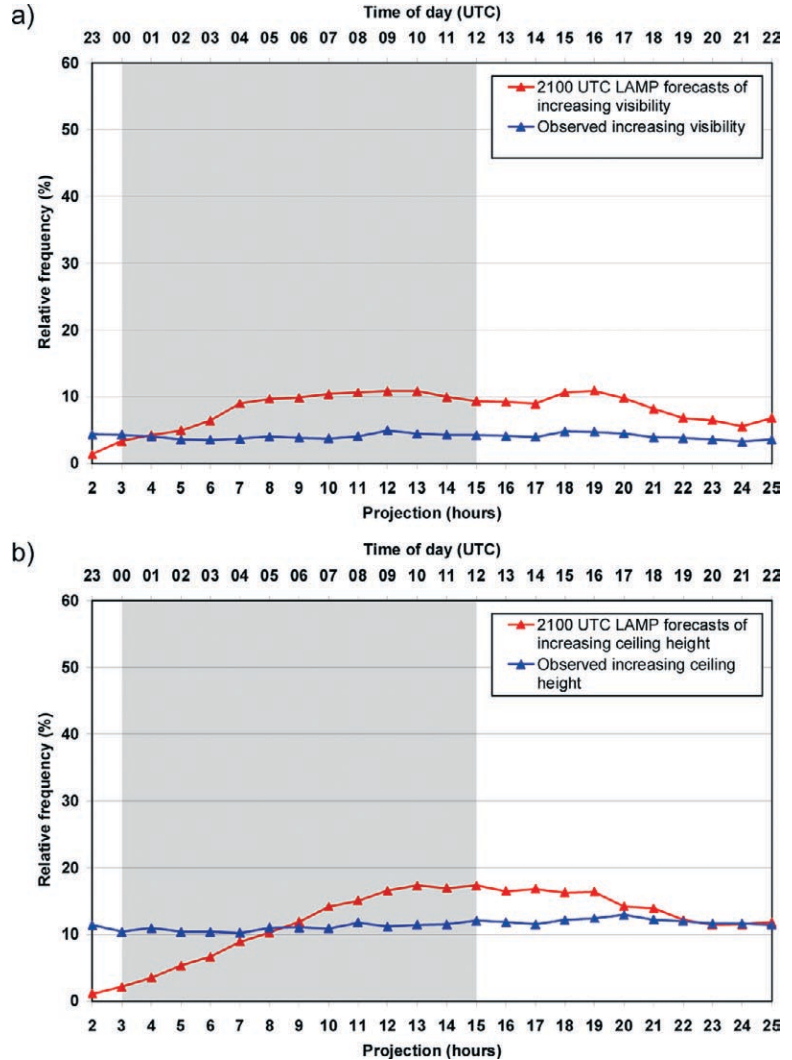


FIG. 6. Same as Fig. 5 except for the 2100 UTC LAMP cycle.

improve to MVFR or VFR following the onset of precipitation given that IFR or worse conditions were present prior to the onset of precipitation) are shown in Fig. 10.

Both the 0900 and 2100 UTC LAMP

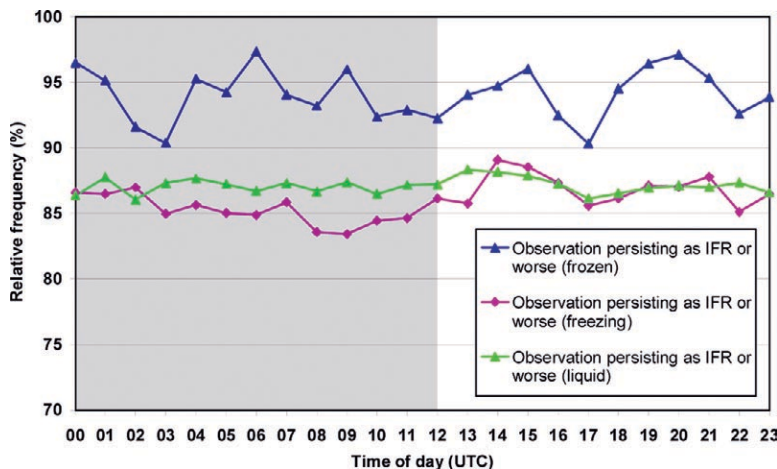


FIG. 7. The percentage of times observed IFR or worse flight conditions persist when precipitation was observed at the current hour but not at the previous hour for frozen (blue line), freezing (pink line), and liquid precipitation (green line). Only cases when precipitation was observed at the valid hour but not at the previous hour were included. The general nighttime period is shaded in gray. The climatological sample covers the 2000/01 through 2007/08 cool seasons.

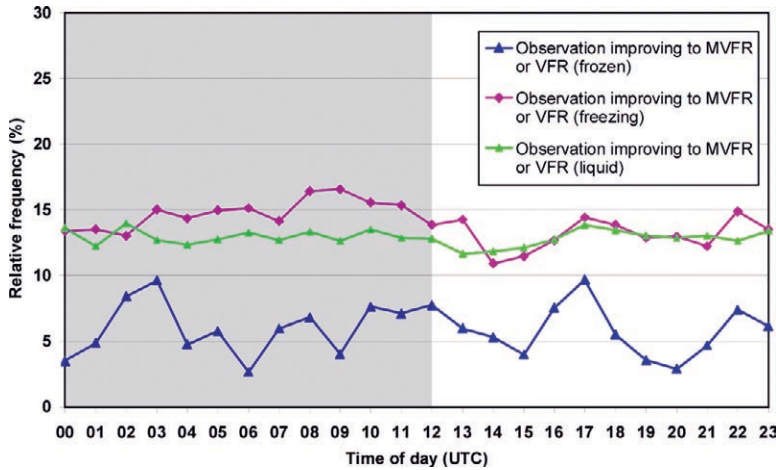
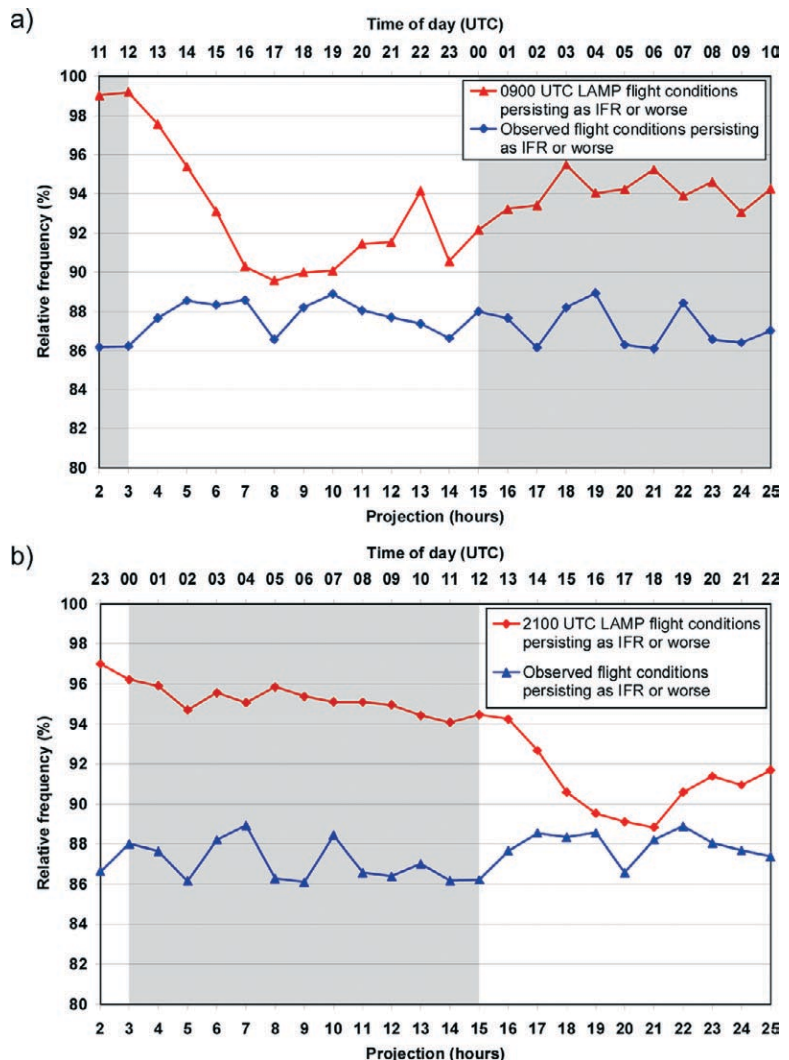


FIG. 8. The percentage of times flight conditions improve to MVFR or VFR when precipitation was observed at the current hour but not at the previous hour, and IFR or worse conditions existed at the previous hour for frozen (blue line), freezing (pink line), and liquid precipitation (green line). Only cases when precipitation was observed at the valid hour but not at the previous hour were included. The general nighttime period is shaded in gray. The climatological sample covers the 2000/01 through 2007/08 cool seasons.

cycles for most projections (except for the late morning and early afternoon projections) generally underforecast improving flight conditions by 8%-10% when compared to the observed relative frequencies. Once again, the gap between the observed and the LAMP relative frequency values narrows during this period because of the presence of a diurnal cycle in the LAMP relative frequencies.

FIG. 9. The percentage of times flight conditions persist as IFR or worse when precipitation was observed at the current hour but not at the previous hour for (a) the 0900 UTC LAMP (red line) and corresponding observation (blue line) and (b) the 2100 UTC LAMP (red line) and corresponding observation (blue line). Only cases when precipitation was observed at the valid hour but not at the previous hour were included. The general nighttime period is shaded in gray. The climatological sample covers the 2006/07 and 2007/08 cool seasons.



CONCLUSION. This short study has quantified the percentage of times visibilities, ceiling heights, and flight categories decrease and increase at the onset of precipitation events for 1,522 stations located in the United States and Puerto Rico. Percentages have been calculated for both a 2- and 8-yr sample of cool-season observations and a 2-yr independent sample of 0900 and 2100 UTC cool-season LAMP forecasts. When precipitation began, observed ceiling heights decreased by at least one category between 35% and 40% of the time while visibilities decreased by at least one category between 35% and 50% of the time.

As one would expect, the percentage of times when the observed ceiling height and/or visibility increased with the onset of precipitation was significantly less, but still nonzero. Observed ceiling heights increased by at least one category approximately 10% of the time, while observed visibilities increased by at least one category approximately 5% of the time following the onset of precipitation. Moreover, a diurnal signal is evident in the observation frequency associated with the increase and decrease of visibility and to a lesser extent ceiling height prior to the onset of precipitation. When compared to the corresponding observed climatology, LAMP captures this diurnal cycle, albeit more readily for visibility than for ceiling height. Another attribute of the LAMP relative frequencies in this context is its overforecasting of instances where visibilities increase in all but the first few forecast projections. This attribute of overforecasting is also present for ceiling height, but is not as pronounced. Nonetheless, the underforecasting or overforecasting by LAMP when compared to the observed climatology varies by no more than 10%.

Observed relative frequency values describing the percentage of times IFR or worse flight conditions persisted or improved just after the onset of precipitation as a function of precipitation type was also investigated. An 8-yr, cool-season climatological sample shows some relative frequency variation between frozen, freezing, and liquid events for flight conditions persisting (85%–95%) and improving (5%–15%) following the onset of precipitation throughout the 24-h day.

A shorter sample of two cool seasons (2006/07 and 2007/08) composed of LAMP categorical forecasts of visibility and ceiling was used to generate relative frequencies describing the percentage of times IFR or worse flight conditions persisted or improved just after the onset of precipitation stratified on precipitation occurrence (not precipitation

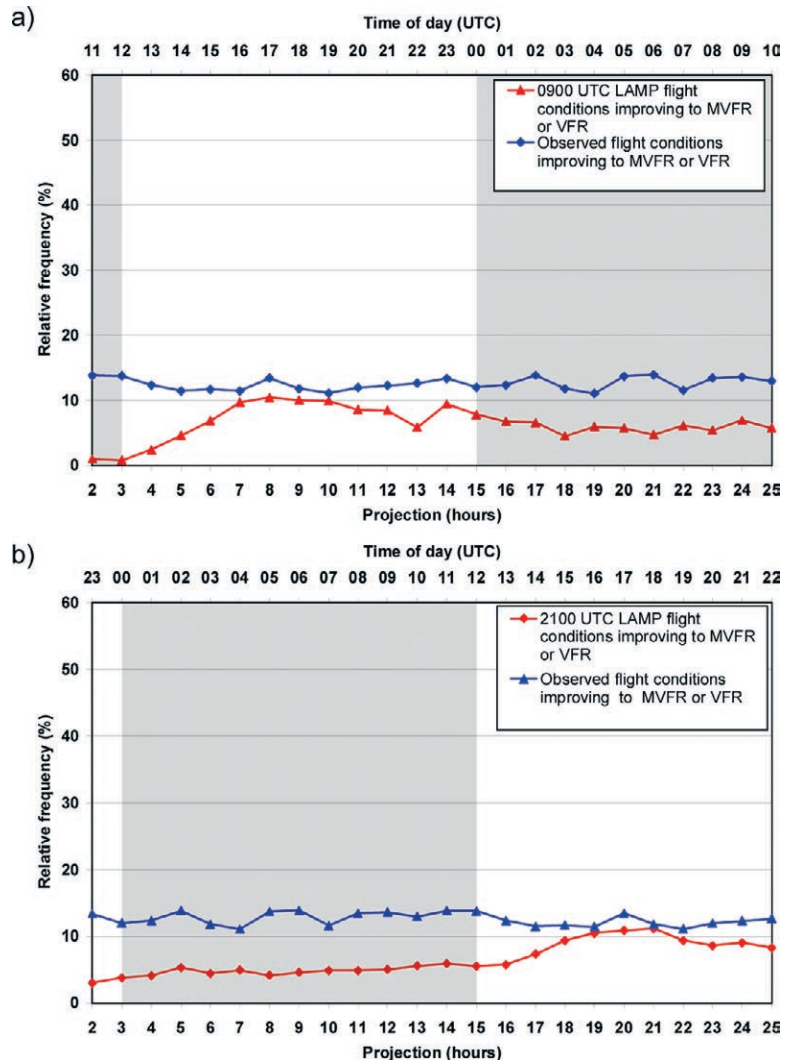


FIG. 10. Same as Fig. 9 except for flight conditions improving to MVFR or VFR.

type). When compared to the verifying relative frequencies, LAMP persists IFR or worse conditions more frequently than is observed and improves to MVFR or VFR conditions less frequently than is observed. The discrepancy is most pronounced during the first few hours and can be attributed to the increased weight LAMP gives to the observations at the shorter projections.

This study has demonstrated that observed visibility, ceiling height, and flight categories do increase following the onset of precipitation. Hence, those LAMP categorical forecasts of conditional ceiling height and/or visibility that are greater than their unconditional counterpart should not necessarily be deemed meteorologically inconsistent. As

such, if future postprocessing crosschecks are to take place between these unconditional and conditional elements, careful attention must be given to preserve these categorical conditional ceiling height and visibility forecasts. Perhaps focusing on those transitional periods when LAMP is forecasting a precipitation event might assist in this postprocessing step. Although in reality the forecaster does not know with certainty when precipitation will begin, he/she can still surmise the timing of the event using statistical guidance such as LAMP, which provides hourly categorical forecasts of precipitation occurrence (yes/no), or dynamical models. This information, along with LAMP conditional ceiling height and conditional visibility forecasts, can provide guidance in predicting the lowering or rising of ceiling heights, visibilities, and flight categories.

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FOR FURTHER READING

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