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THE LAMP AND HRRR CEILING HEIGHT AND VISIBILITY MELD

Bob Glahn, Adam D. Schnapp, and Jung-Sun Im

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1. INTRODUCTION

The National Weather Service (NWS) has been disseminating a suite of weather forecast guidance products from the Localized Aviation MOS Program (LAMP) for a couple of decades. The primary purpose of LAMP is to support aviation interests, and included in that suite are forecasts of ceiling height and visibility at specific sites that report those variables, predominantly METAR (OFCM 1995) sites. LAMP provides forecasts each hour, available about 40 minutes after the hour, at projections each hour out to 25 h. More recently since 2010, LAMP gridded forecasts over the conterminous United States (CONUS) have been put into the National Digital Guidance Database (NDGD), the guidance companion to the National Digital Forecast Database (NDFD) (Glahn and Ruth 2003). A number of numerical models also produce forecasts of ceiling and visibility, including some that are run operationally at the National Centers for Environmental Prediction (NCEP). Glahn et al. (2014) studied the feasibility of statistically combining (melding) visibility forecasts from LAMP and the High-Resolution Rapid Refresh (HRRR) model to produce forecasts superior to both LAMP and HRRR. The results were positive, showing that for the cool-season sample available, Meld improvements in the threat score (TS) (Palmer and Allen 1949; Wilks, 2011)[1] were in the 15% to 30% range over LAMP alone for projections $\geq$ 4 h, and even greater over HRRR alone.

This Meteorological Development Laboratory (MDL) office note documents results of a similar procedure for both ceiling height and visibility on warm season data. For this work, 2 seasons of data were available for the months April to September, 2013 and 2014. The HRRR does not cover Alaska, Hawaii, or Puerto Rico, so the development was for the CONUS only.

2. THE LAMP MODEL

LAMP is described in Ghirardelli and Glahn (2010). Basically, it follows the MOS (Glahn and Lowry 1972) paradigm, whereby a predictand, usually composed of observations (obs) of a weather variable, is related to a variety of predictors. The predictors used in LAMP for ceiling and visibility prediction come from three sources: (1) the current observation of the variable being forecast, (2) the output from simple advective models, and (3) the MOS forecasts based on NCEP's Global Forecast System (GFS) (Dallavalle et al. 2004). Very short range forecasts (i.e., on the order of an hour or two) must be heavily based on the current observation for the forecasts to compete favorably with the observation itself as a forecast (persistence). Essentially, the LAMP model furnishes a blending mechanism from the obs at initial time to MOS at the longest projections.

When dealing with violently non-normal distributions such as ceiling and visibility, MDL has found the Regression Estimation of Event Probabilities (REEP) (Miller 1958; Wilks 2011) method of development works better than dealing with a continuous predictand (e.g., Bocchieri and Glahn

[1] Palmer and Allen suggested the name because the event being forecasted and evaluated was thought to be a threat. The TS is the same as the Critical Success Index proposed by Donaldson et al. 1975 and discussed by Shaffer 1990.

1972, p. 877; Unger and Glahn[2]). The predictand is divided into several categories, say M, and REEP estimates the probability of occurrence of each category. A predictand category that occurs is given the value of 1, and 0 if it doesn't; this defines the binary predictand necessary for REEP. The categories can be either discrete or cumulative (from above or below). For development purposes, it is better to use cumulative binaries (Glahn 1965, p. 125, 126), but for provision to users, discrete categories are many times preferred. It is also customary for many or all of the predictors in this regression to be binary, and generally, cumulative binary.

The M REEP equations are used to estimate the probability of each of the M predictand categories. However, usually a specific, single value forecast of ceiling and of visibility is preferred, even required, by users of aviation forecasts. In order to produce such categorical forecasts, a probability threshold for each category is computed in such a manner that the bias[3] of the category falls within prescribed limits, and within those limits, the TS is maximized. These thresholds are then used to make the cumulative forecasts from which the discrete forecasts of the M categories can be derived. The categories used by LAMP are indicated in Table 1. The lowest category of ceiling and of visibility were the lowest for which sufficient observations were available to develop stable equations.

The LAMP forecasts are made from REEP equations developed on a regional basis. That is, stations within a geographic region for which it was thought the predictand/predictor relationships were similar were grouped, and all such stations share the same equations. The predictand data for producing the LAMP equations were the METAR obs. Equations for ceiling and also for visibility were developed for all projections 1 through 25 h simultaneously so that the predictors for all projections were as consistent as could be achieved (see Glahn and Wiedenfeld 2006 and Ghirardelli and Glahn 2010 for details). The predictors were selected by specialized software (Glahn and Dallavalle 2000, Chapter U602 with attachments and updates). Forecasts are made each hour for hourly projections out to 25 h for about 1562 stations, the stations that had METAR obs when the equations were developed.

3. THE HRRR MODEL

The HRRR numerical (dynamic) model is described in: http://ruc.noaa.gov/pdf/NCEP_PSR_2013_RAP_FINAL_v5.pdf. It produces ceiling and visibility forecasts according to internal algorithms for projections 1 through 15 hours. The forecasts are for specific values in meters, and ceiling height is above sea level.

4. DATA AVAILABILITY AND PREPARATION

LAMP probability and categorical forecasts are made for specific locations (stations) and are archived. Gridded specific value forecasts are also available on the NDGD grid, but not gridded probability forecasts; however, gridded probability forecasts could be produced for the sample if needed. HRRR forecasts are available on a 3-km grid and could be interpolated either to stations

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2 Unpublished. The developers did much work in the early part of the LAMP project using various transformations of the quasi-continuous visibility and ceiling height observations as predictands. This work was largely unsuccessful; reliable and skillful forecasts could not be made, especially of the lowest values.

3 Bias for a categorical variable (event) is defined as the number of forecast events divided by the number of observed events.

or to the NDGD grid. The obs are available at stations, but could be put (analyzed) onto a grid. Therefore, the matching of predictands and predictors for the statistical analysis could be done either at stations or at gridpoints. Because the predictand is at stations, there is no reason to grid the obs and do the statistical analysis at gridpoints, because all the predictand information is in the station values; an analysis of them adds no information, and the information at gridpoints, not being obs but being interpolated values, would be less accurate than the station values themselves. Therefore, the regression analysis was done at stations.

A. LAMP Forecasts

Operational LAMP ceiling and visibility forecasts have been archived in both the probabilistic and categorical forms for the seven development categories of ceiling and six categories of visibility shown in Table 1.

After development of the regression equations based on the then available data, some other stations were later added within the CONUS regions and also over southern Canada as extensions of the adjacent regions. For those added stations that do not have obs, LAMP "backup" equations are used that do not include obs as predictors. No LAMP equations could be developed for locations over water because of lack of obs, but some forecasts over water have been added by using nearby land backup equations. These point forecasts are gridded with the BCDG method (Glahn et al. 2009; Im and Glahn 2012; Glahn and Im 2015) for guidance for forecasters in preparing grids for the NDFD; an example of these gridded forecasts is shown in Fig. 1. The example shown in Fig. 1 was chosen without reference to forecasts, but rather on the basis of a well-defined frontal system in the central part of the U.S., as shown in Fig. 2. However, neither these gridded LAMP forecasts nor the forecasts produced by backup equations for the added stations were used in the regression meld of LAMP and HRRR data.

B. HRRR Forecasts

Two warm seasons of HRRR data were available, months April through September, 2013 and 2014. Of these 12 months, 8 were used for development and the remainder for a reasonably independent test sample. Table 2 shows the 4 months used for testing.

The HRRR ceiling and visibility forecasts are available each hour at hourly increments on a 3-km Lambert conformal grid covering the CONUS for projections 1 through 15 h. To furnish the regression dataset, interpolation was done into the HRRR grid to the LAMP points. The meld of HRRR and LAMP forecasts should be distributed very shortly after LAMP is currently available, about 40 minutes after the top of the hour. The HRRR run is not completed for nearly an hour later, so for any given LAMP start time (cycle), the HRRR must be used from the hour previous. For instance, for the 1200 UTC LAMP cycle, the HRRR 1100 UTC cycle is used. The HRRR ceiling forecasts are in reference to sea level, so the HRRR terrain was used to adjust the forecasts to above ground level, the way ceiling heights are expressed for aviation uses. In addition, visibility was converted from m to mi and ceiling was converted from m to hundreds of ft, the conventional units used in aviation.

The HRRR forecasts have much detail, detail that looks synoptically realistic, but much of it is beyond the realm of predictability at the present time. For instance, visibilities that vary from 8.0 mi to 0.5 mi within the space of 10 km or so are possible, but are not generally observed or forecastable on this scale. Therefore, a preprocessor (to the melding) was run on the HRRR data that essentially eliminated "spots" of $\leq$ 7.5 km. This has the effect of coalescing the smaller spots into larger ones, which are still of marginal predictability, but more plausible.[4] Figures 3 (before) and 4 (after) show the effect of this "spot removal." The HRRR Lambert grid on the files available remapped to the LAMP/NDGD grid does not fully fill the rectangle.

C. Observations

METAR and other obs have been archived by MDL in standard aviation units. They were accessed to extract the needed data.

5. REGRESSION ANALYSIS

REEP was used to develop equations with predictors from the LAMP and HRRR models and obs to produce Meld forecasts for projections 1 through 25 h. The predictors are the same in the Meld equations for each projection, except that the model predictor projections "march" with the predictands. For instance, for a 1200 UTC cycle, and for a 6-h projection, the observation at 1800 UTC (the predictand) is matched with the LAMP 6-h forecast made with 1200 UTC data and the HRRR 7-h forecast made from 1100 UTC data. As noted earlier, a 1-h old HRRR run has to be used to meet timeliness requirements. The predictors in the Meld regression equations were chosen by forward selection. At each selection step, the next predictor was chosen based on the highest added reduction of variance (RV) afforded by any potential predictor for any projection and any predictand category. The selection stopped when no potential predictor reduced any predictand variance by $\geq$ 0.5%.

In order to keep the process reasonably simple, and especially because of the limited data sample, a generalized approach was used, where all stations were grouped together. It was determined by Glahn et al. (2014) that the LAMP probability forecasts are much better predictors than the categorical ones, so only the probabilities were used for the Meld equations.

The LAMP forecasts have only a few categories, sufficient for providing forecasts to users in matrix form. However, for a gridded product, more definition is desirable, so we used an expanded set of categories shown in Table 3. Two categories of visibility and one category of ceiling were added below those for which LAMP forecasts are available. For visibility, there is a category for each reportable value below 10 mi, except the very lowest ones. For ceiling, every reportable value has a category below 1,000 ft, and at meaningful thresholds above that. The "threshold in equation" in the table is an exact value to be used when dealing with the equations. The Meld produces a probability of each category. Using the same procedure as was used in LAMP, we developed thresholds to produce categorical forecasts with biases in the range 1.0 to 1.2. This process is explained fully in Ghirardelli and Glahn (2010). Because some of the categories cover more than one reportable value, the values put on the grid are sometimes averages; the values for the grid are shown in the 4th and 7th columns of Table 3. Also shown in Table 3 are the limits for Instrument Flight Rules (IFR), Very Low IFR (VLIFR), Low IFR (LIFR), and Marginal Visual Flight Rules (MVFR); any value above MVFR indicates Visual Flight Rules.

[4] While the spot removal has some characteristics of smoothing, it is not smoothing in the usual sense where averages are computed. The integrity of "unusual" values is maintained when the area covered is of sufficient size or a number of unusual values are close together, even though not contiguous. No change of value is made unless the elevation difference among the points involved is < 100 m, so that variations that may be due to terrain are maintained.

It is of considerable importance that the forecasts are not only consistent from projection to projection, but also from the analysis (0-h projection) to the 1-h projection. Much care was taken in developing the LAMP regression equations in this regard. To enhance continuity of the Meld, the initial obs were used in developing the MELD equations for all projections, as they had been in developing the LAMP equations.

We were also concerned about the possible lack of continuity between the 14-h projection, the longest projection for which the HRRR is available, and the 15-h and following projections. Therefore, we used the HRRR 14-h projection, not only for the 14-h Meld projection, but for all projections 15 h through 25 h.

A. Ceiling Height

Grouping all stations together gave a large number of predictand-predictor pairs (sample size) varying from about 335,000 for the 1-h projection to 297,000 for projections 14 to 25 h. The decrease of sample size with projection was due to missing HRRR data. The low relative frequencies of low ceilings restricted the development method to generalized operator (Bocchieri and Glahn 1972, p. 970). For instance, there were < 100 occurrences of ceiling < 100 ft and < 300 occurrences of ceiling < 200 ft in the 8-month sample for all stations combined, so further stratification would not be feasible unless the two lower categories were eliminated.

We were concerned that if all potential predictors—LAMP, HRRR, and obs—were offered together for selection, the HRRR might be overwhelmed by the obs, which are well-known for their importance in the early projections. Therefore, we made an initial screening of only the seven LAMP predictors and the 12 binary HRRR predictors shown in Table 4 for projections 1 through 14 h. All seven LAMP predictors and five of the 12 potential HRRR predictors were selected with the 0.5% RV cutoff criterion. We then forced these 12 predictors and added the 15 potential obs predictors. The six observation categories indicated in Table 4 were selected. Another regression run was made for projections 14 through 25. All 18 of those previously selected were "forced," but were included only if the additional RV was > .01%. One of the obs, < 8 mi, was not included in the equations for these projections. These are the equations used for the independent verification.

One could speculate why these specific predictors were chosen. It is clear that the obs were furnishing information for the very low categories, for which LAMP and HRRR did not do an adequate job. Also, they were chosen for the very short-range projections. The RVs for the categories below which LAMP is available were higher than for the other categories indicating the equations were likely somewhat unstable because of the low number of cases.

B. Visibility

The developmental process was the same for visibility as for ceiling.

Besides the six LAMP predictors, the HRRR and obs used as predictors are shown in Table 5. Previous work (see Glahn et al. 2014) showed that higher HRRR thresholds were not useful. A trial regression run was made where all LAMP and HRRR predictors were screened together; all six LAMP predictors were selected and only three HRRR predictors. The final regression run was made by forcing the six LAMP and the three HRRR predictors selected in the trial run. Five observation predictors were selected from the set shown in Table 5. The HRRR and observations as predictors are shown in Table 5 in red and marked with an asterisk.

As with ceiling, the lower categories of observations were chosen for the low categories. In addition, three others were chosen, indicating the importance of persistence in visibility prediction. Also, similarly to ceiling, the lower two categories had unexpectedly high RVs showing them to likely be unstable.

6. EVALUATION ON INDEPENDENT DATA

As described earlier, the development was done at stations—discrete points where the predictand data applied. For implementation and evaluation, three options were considered:

(1) Interpolate the HRRR forecasts to the LAMP stations, apply the equations and thresholds at the LAMP stations, and analyze the probabilities (if they are desired) and categorical forecasts to the LAMP grid,

(2) analyze the LAMP station probabilities and observations to the LAMP grid, interpolate the HRRR forecasts to the same grid, and apply the equations and thresholds on the grid, or

(3) interpolate the HRRR forecasts to the LAMP stations, evaluate the equations at the LAMP stations, analyze the Meld probabilities and apply the thresholds at the gridpoints.

Any one of the three processes will work and it is not known which is best; we chose (2) for the implementation process, but for the test sample verification, we applied the equations and thresholds at stations.

We applied the implementation process to the April 11, 2013, 7-h forecast from 1200 UTC data. The results looked reasonable. Features of both LAMP and the HRRR could be seen, the LAMP being more apparent because LAMP furnished better predictors than did HRRR. However, in concert with the suspected instability of the lowest category equations, some “blobs” of category 1 forecasts were made in unexpected places. Such features detract from the overall usefulness of the Meld. Rather than not use the suspect equations, we chose to mitigate the effect by developing thresholds with biases between 0.4 and 0.6 for the two lower categories.

The developmental equations were evaluated on the 4 months of test data indicated in Table 2. The specific months used for the test provided a rather severe test because 2 or the 4 months were at the ends of the 6-month season, months for which the equations derived may be less applicable than for other months. The primary scores were bias and TS for several categories, although the probability of detection, false alarm ratio, and Gerrity score (Gerrity 1992) were also computed. In all the verification graphs shown, LAMP is the original LAMP forecasts; the equations on which the forecasts are based were developed several years before the test sample. The HRRR forecasts were interpolated from the HRRR grid to LAMP stations and for verification did not include the preprocessing that was done for the regression analysis. All comparisons were on matched samples, differing only by projection. As discussed above, the predictand categories were defined as cumulative from below. Verification scores were also computed for cumulative categories, except for bias where noted. The primary verification used the categories for which LAMP forecasts were available, and comparative verification could be done.

A. Ceiling Height

Figures 5 and 6 show, respectively, the bias and TS for ceilings < 200 ft; these are for events that were reported as either 0 or 100 ft. Such events were few, but the combination of LAMP and HRRR shows quite a large improvement over LAMP alone for projections 4 through about 19. For this cycle, the persistence bias is very high, and the HRRR bias is also high; persistence and HRRR do not give good TS's, except for persistence at the 1- and 2-h projections. LAMP bias is surprisingly high, but the Meld bias is excellent.

Figures 7 and 8 are the same as Figs. 5 and 6, except the bias is for the discrete ≥ 200- to < 500-ft category and the TS is for < 500 ft. LAMP and Meld biases are good, although a bit high for projections 10 through 14, persistence continues to be high, and HRRR biases are somewhat low. For the very early projections, HRRR forecasts only about 70% as many events in this category as occur. The Meld TS again shows improvement over LAMP and HRRR, except in the very short (< 3-h) projections, and beyond 18 h when the HRRR 14-h forecast is not useful.

Figures 9 and 10 are the same as Figs. 5 and 6, except for the < 1,000-ft category. LAMP and Meld biases are good, and the HRRR biases are reasonable. The improvement of Meld over LAMP and HRRR is still pronounced in the same projection range as seen previously.

Figures 11 and 12 are the same as Figs. 5 and 6, except for the ≤ 3,000-ft category. The improvement of Meld TS over LAMP is still sizeable. LAMP alone continues to be better than HRRR. There is even some indication that the Meld improves over persistence and LAMP at the very early projections.

B. Visibility

Biases and TS's are shown for four operationally significant visibility levels. Figures 13 and 14 show, respectively, the bias and TS for the event < 0.5 mi. The number of cases is relatively rare, being < 100 for these 4 months. As with ceiling, persistence bias is very high for this cycle. HRRR bias is also quite high being 4.0 and above for most projections. LAMP has considerable bias, forecasting only half as many events below 0.5 mi as occurred for several projections and 70% more than occurred at other projections. Meld bias was good, and it didn't matter much whether or not the obs were included in the equations. The TS for HRRR and persistence were very low, except for persistence at the first projection. Including the HRRR with LAMP actually decreased the TS for some projections, whether or not the obs were included.

Figures 15 and 16 are the same as Figs. 13 and 14 except for the discrete ≥ 0.5- and < 1.0-mi category for bias and < 1.0 mi for TS. Persistence bias is quite high. HRRR bias tended to be somewhat low. As with the < 0.5-mi category, LAMP had considerable variability in bias, being very low for several projections. The Meld bias was relatively good. For TS, LAMP was better than HRRR at all projections. The Meld was better than LAMP for projections 6 through 18, and was better than persistence even at the 1- and 2-h projections.

Figures 17 and 18 are the same as Figs. 13 and 14 except for the < 2.0-mi category. LAMP and HRRR biases are reasonable, but LAMP showed more variability than expected. Meld bias was good. The HRRR TS was lower than that for LAMP except at two projections. The Meld TS was better than LAMP for all projections after 1 h except after the effect of the HRRR forecast faded out.

Figures 19 and 20 are the same as Figs. 13 and 14 except for bias for the discrete ≥ 2.0- and < 3.0-mi category and TS for < 3.0 mi. The HRRR bias is low and persistence bias is high except for a few projections. LAMP and the Meld biases are good, except for > 15 hours were LAMP is quite high. TS's for this category showed generally the same characteristics as the < 2.0-mi category, except the Meld improvement over LAMP was smaller.

Figures 21 and 22 show the bias and TS, respectively, for the two lowest categories made with the thresholds developed with biases between 0.4 and 0.6. Matching forecasts from the HRRR and persistence are also shown; LAMP has no forecasts for these categories. The Meld biases are good, being near 0.5 as desired. The Meld TS's are a bit erratic, emphasizing the small number of events in these categories. Even so, they are positive and about the same as persistence for the < 0.005-mi category except for the early projections, and generally much better than persistence for the < 0.025-mi category. HRRR makes no forecasts of the lowest category, so the biases and TS's were zero.

7. EQUATIONS FOR DAILY USE

A. Ceiling Height

The equations for daily use were developed on all 12 months of data. For projections 1-14 h, the full set of potential predictors was offered for selection. The same 18 were selected as were used in the 8-month test equations with the exception the HRRR category 7 (< 1,500 ft) was selected instead of category 8 (< 2,000 ft). This seemed like an even better set of predictors than were used in testing. These final predictors are also in the equations for projections 15-25 h, and are marked in table 4 with "12m".

A Meld forecast, depicted in Fig. 23, was made with the 12-month equations for the same case as shown in Figs. 1 through 4; features of both LAMP and HRRR can be seen. The Meld forecast contains some very small-scale features that are not forecastable, so spot removal software[5] was applied to produce the slightly less "choppy" one shown in Fig. 24. The frontal detail shown by HRRR in Fig. 3 is generally present in Fig. 24. The blue spot in northeastern Texas is caused by one LAMP station having a low ceiling forecast, and the spot is larger than what the software will remove; being a valid LAMP forecast, it is not obvious that it should be removed, even though it does not agree with its neighboring stations. Projection 7, depicted in these maps, is one where HRRR is expected to contribute strongly. Both verification and maps (not shown) indicate that the HRRR is much less influential at very short projections, and also past about projection 18.

[5] This postprocessing removes spots as large as 12.5-km across, while the preprocessing removes 7.5-km spots.

B. Visibility

As with ceiling, the equations for daily use were developed on all 12 months of data. For projections 1-14 h, the six LAMP and 11 HRRR predictors were offered for selection. All six LAMP predictors and only three HRRR predictors were selected. These are marked “12m” in Table 5. These 9 predictors were then forced when developing for all 25 projections. Five obs were chosen, making a total of 14 predictors in the equations. Those selected are indicated in Table 5.

A Meld forecast, shown in Fig. 25, was made with the 12-month equations for the same case shown in Figs. 1 through 4. As with ceiling, a few small spots can be the result of the binary process we use for making the forecasts. The probability forecasts made directly from the equations are thresholded to make specific value forecasts. When the probability is near the threshold for that category, it may get “tripped” for one gridpoint, but not for a neighboring one. The spot remover postprocessing routine was run on the grid depicted in Fig. 25 to give the one shown in Fig. 26.

8. SUMMARY AND CONCLUSIONS

A system for making objective ceiling height and visibility forecasts at gridpoints based on a meld of the LAMP and HRRR predictions of those weather elements has been developed, tested, and readied for daily use. Observations at initial time were also included in the regression equations, primarily for continuity from the analysis of observations at initial time to the 1-h forecast. Because of time constraints, this warm season system was developed for only one cycle, 1200 UTC. The conclusions here pertain to only that cycle and the warm season, but are consistent with what was found for a previous cool season 0000 UTC development (Glahn et al. 2014).

Overall, the Meld approach seems to be viable, the Meld biases and TS’s being generally markedly better than HRRR or persistence alone, except for the 1-h forecast were persistence is a strong competitor. The Meld is also better than LAMP alone except for the first hour or two and after about 18 h when the 14-h HRRR forecast is no longer useful. The Meld forecasts show characteristics of both LAMP and HRRR. The HRRR has much very small-scale detail, some of which needs to be disregarded for specific point forecasts. While such detail might be reasonable at a 1-h projection, HRRR is not good at that range. At projections of several hours, where HRRR is closer to competitive with LAMP, pinpointing variations in ceiling and visibility on the order of 10-km is beyond forecasting ability, and the smaller spots of this size are removed. However, larger-scale detail, such as the low ceilings and visibilities associated with the frontal structure east of the lower Mississippi River is kept (see Figs. 3, 4, 23, and 24). We believe that this is about the best that can be done in combining LAMP and HRRR for ceiling height and visibility forecasting.

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Table 1. Category definitions of LAMP ceiling height and visibility. Ceilings are observed (reported) in hundreds (hd) of feet (ft). Visibilities are observed to fractions of a mile (mi) when the visibility is low.

Category Number	Verification Categories		Development Categories	
	Ceiling (hd ft)	Visibility (mi)	Ceiling (hd ft)	Visibility (mi)
1	< 2	< 0.5	< 2	< 0.5
2	2-4	≥ 0.5 and < 1.0	< 5	< 1.0
3	5-9	≥ 1.0 and < 2.0	< 10	< 2.0
4	10-19	≥ 2.0 and < 3.0	< 20	< 3.0
5	20-30	≥ 3.0 and ≤ 5.0	≤ 30	≤ 5.0
6	31-65	> 5.0 and ≤ 6.0	≤ 65	≤ 6.0
7	66-120	> 6.0	≤ 120	
8	>120			

Table 2. The months with an X are those used for independent testing.

Year	April	May	June	July	August	September
2013	X				X	
2014			X			X

Table 3. The 16 predictand cumulative from below category upper limits for visibility and 24 for ceiling, and the associated values for the grid used in the Meld. There is a category above the last one in the table of ≥ 10 mi for visibility and > 12,000 ft for ceiling, the last including unlimited ceiling. The categories for which LAMP forecasts exist are in red and marked with an asterisk.[6]

Category No.	Visibility Upper Category Limit		Visibility Value on Grid (mi)	Ceiling Upper Category Limit		Ceiling Value on Grid (hd ft)
	Threshold in Equation (mi)	Nominal (mi)		Threshold in Equation (hd ft)	Nominal (ft)	
1	.005	= 0	0	.0095	< 100	0
2	.245	< 1/4	.125	1.5	< 200 (VLIFR)*	1
3	.495	< ½ (VLIFR)*	.25	2.5	<300	2
4	.745	< 3/4	.5	3.5	< 400	3
5	.995	< 1 (LIFR)*	.75	4.5	<500 (LIFR)*	4
6	1.495	< 1 ½	1.12	5.5	< 600	5
7	1.995	< 2*	1.62	6.5	< 700	6
8	2.495	< 2 ½	2.0	7.5	< 800	7
9	2.995	<3 (IFR)*	2.5	8.5	< 900	8
10	3.005	≤ 3	3	9.5	< 1,000 (IFR)*	9
11	4.005	≤ 4	4	11.5	<1,200	11
12	5.005	≤ 5 (MVFR)*	5	14.5	<1,500	13
13	6.005	≤ 6*	6	16.5	<1,700	15
14	7.005	≤ 7	7	19.5	<2,000*	18
15	8.005	≤ 8	8	24.5	< 2,500	22
16	9.995	< 10	9	30.5	≤ 3000 (MVFR)*	27
17				40.5	≤ 4,000	35
18				49.5	< 5000	45
19				65.5	≤ 6,500*	58
20				80.5	≤ 8,000	73
21				90.5	≤ 9000	85
22				100.5	≤ 10,000	95
23				110.5	≤ 11,000	110
24				120.5	≤ 12,000*	120

[6] If it is desired ceiling category 18 be ≤ 5000 ft instead of < 5,000 ft, change the 49.5 in column 5 to 50.5 and use that in the regression.

Table 4. The 12 HRRR ceiling height forecasts and 15 ceiling height observations offered as predictors for predicting ceiling. The five HRRR and six obs predictors selected by screening on the 8-month developmental sample are shown in red and marked with an asterisk. The one observation predictor shown with a double asterisk was not included for projections 15 through 25. The predictors marked with "12m" are in the final 12-month equations.

Predictor No.	HRRR Predictor	Observation Predictor
1	< 2	< 2* 12m
2	< 3	< 3* 12m
3	< 5* 12m	< 5
4	< 6	< 6* 12m
5	<8* 12m	< 8** 12m
6	< 10	< 9
7	<15 12m	< 10
8	< 20*	< 15* 12m
9	≤ 30* 12m	< 20
10	≤ 65	≤ 30
11	≤ 100	≤ 50* 12m
12	≤ 120* 12m	≤ 65
13		≤ 80
14		≤ 100
15		≤ 120

Table 5. The 11 HRRR visibility forecasts and 15 visibility observations offered as predictors for predicting visibility. The three HRRR and five obs selected by screening on the 8-month developmental sample are shown in red and marked with an asterisk. The predictors marked with "12m" are in the final 12-month equations.

Predictor No.	HRRR Predictor	Observation Predictor
1	< 0.25	< 0.25* 12m
2	< 0.5	< 0.5* 12m
3	< 1.0	< 0.75
4	< 2.0* 12m	< 1.0
5	< 3.0	< 1.5
6	≤ 4.0	< 2.0
7	≤ 5.0	< 2.5
8	≤ 6.0* 12m	<3.0
9	≤ 7.0 12m	≤ 3.0
10	≤ 8.0*	≤ 4.0* 12m
11	≤ 10.0	≤ 5.0
12		≤ 6.0
13		≤ 7.0* 12m
14		≤ 8.0
15		≤ 10.0* 12m

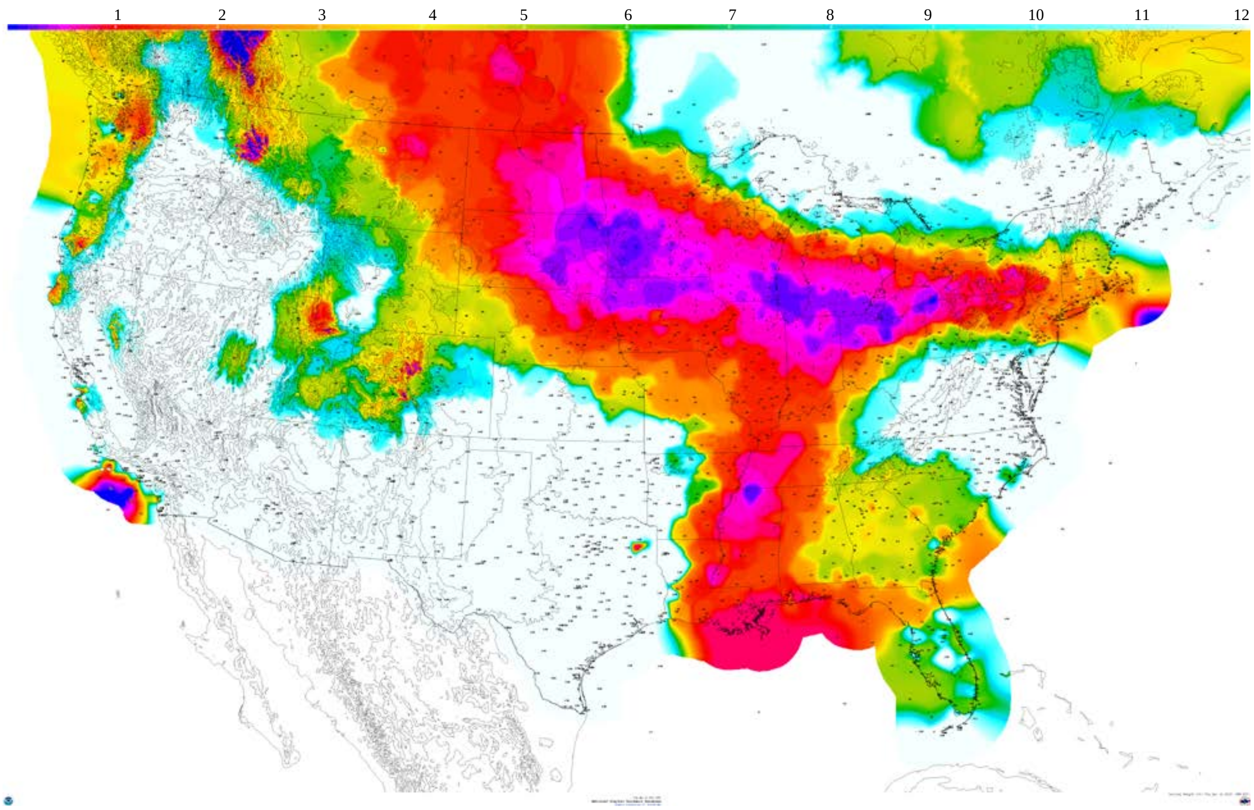

Figure 1. The LAMP categorical ceiling height forecast, 7-h projection from April 11, 2013, 1200 UTC. Color bar is in thousands of ft.

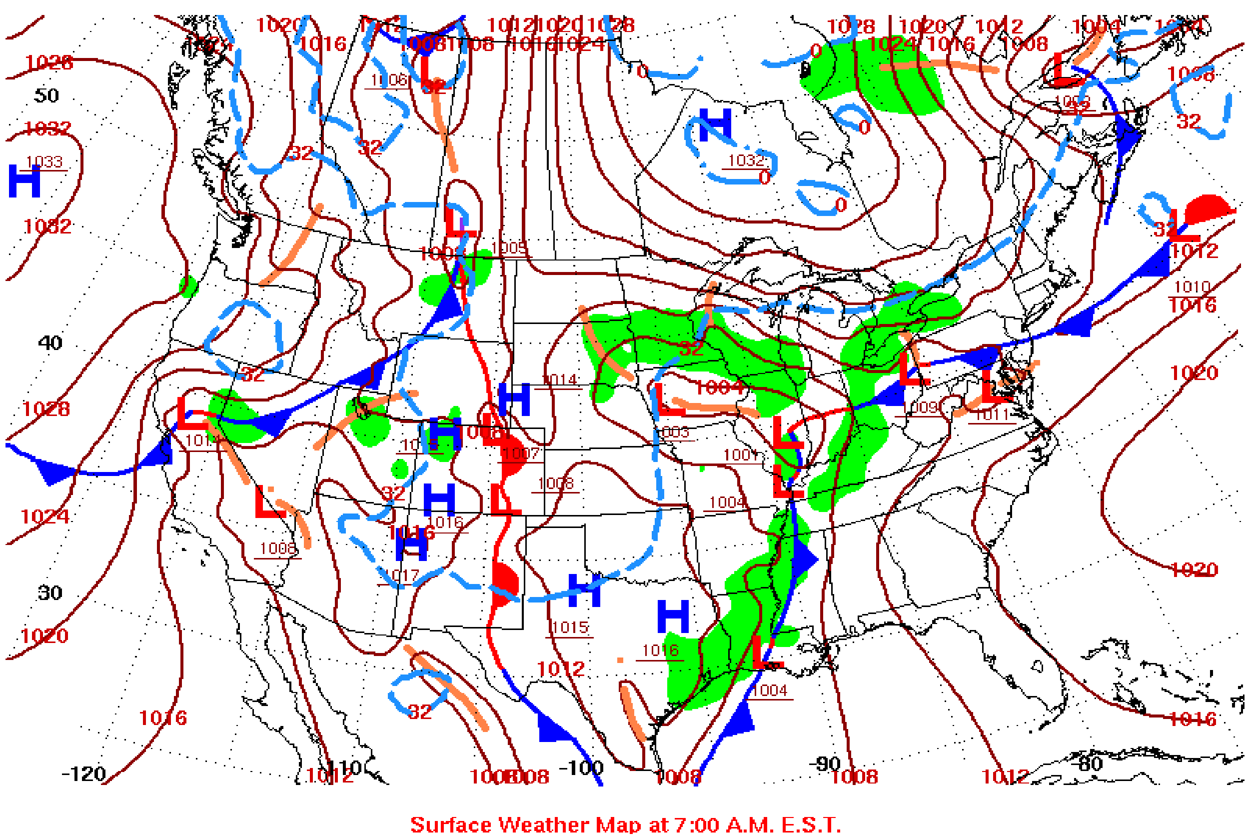

Figure 2. Sea level pressures and fronts for April 11, 2013, 1200 UTC.

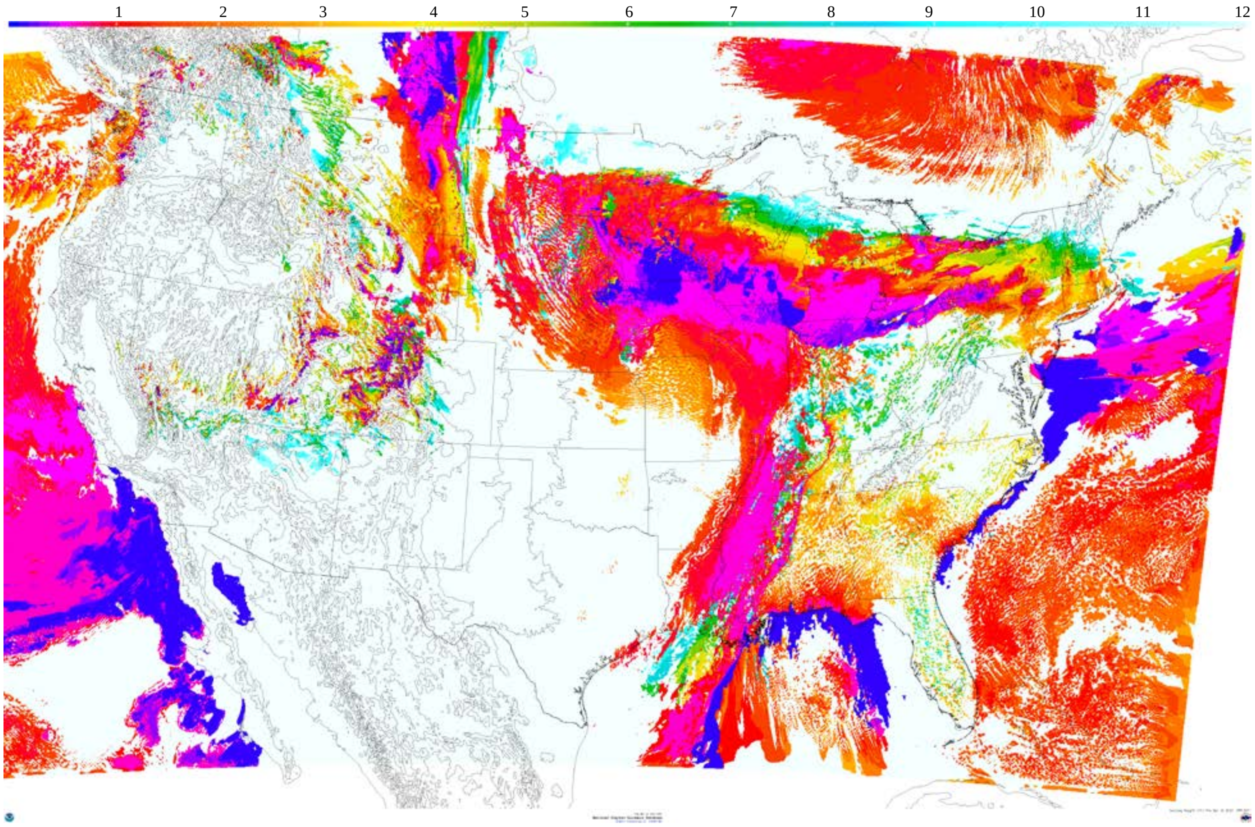

Figure 3. The HRRR ceiling height forecast for April 11, 2013, 8-h projection from 1100 UTC. Color bar is in thousands of ft.

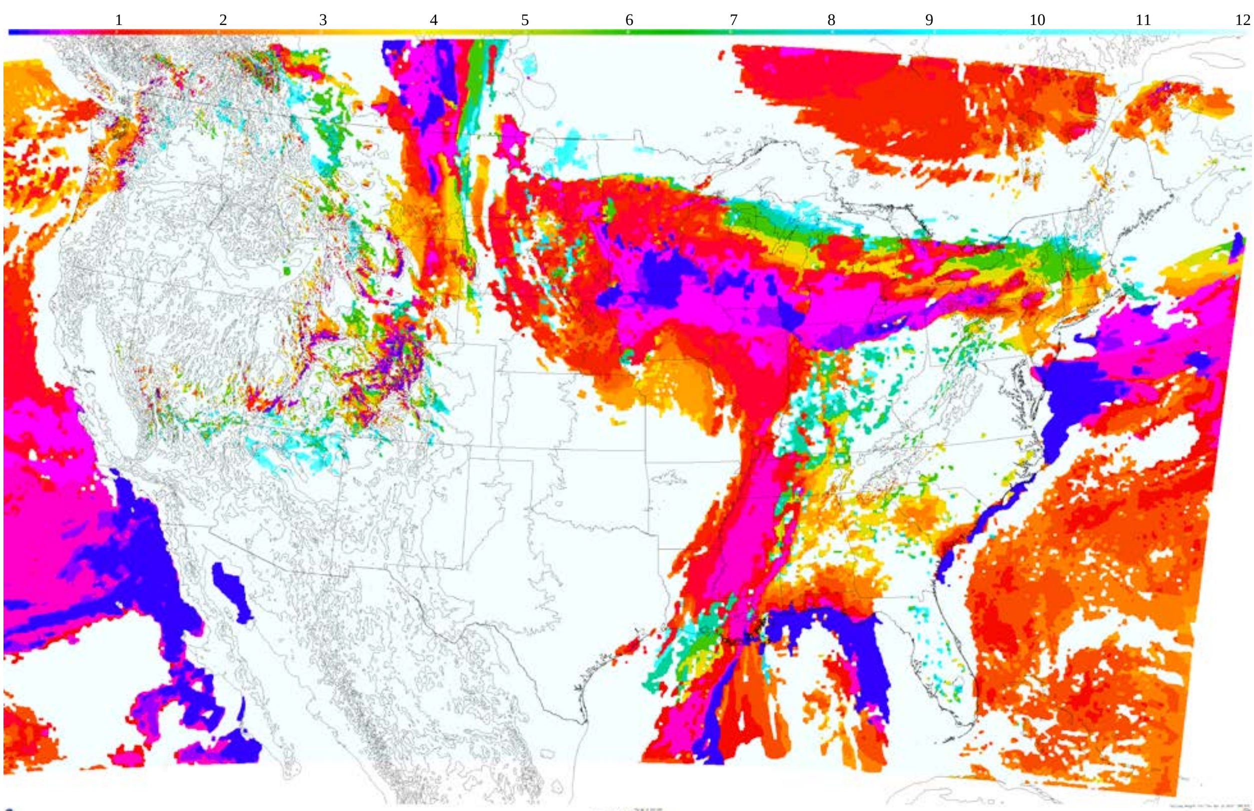

Figure 4. The HRRR ceiling height forecast as shown above but after removal or coalescing of small spots. Color bar is in thousands of ft.

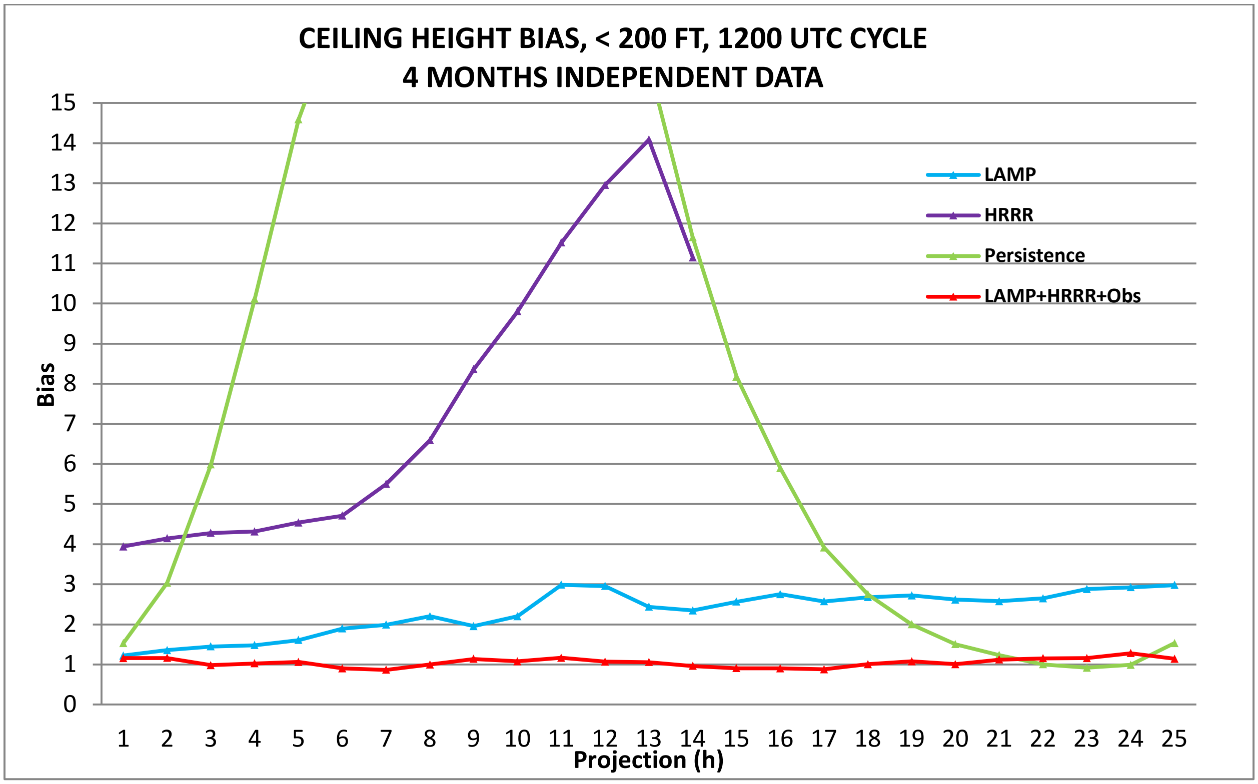

Figure 5. Ceiling height bias for events < 200 ft, 4 months independent data.

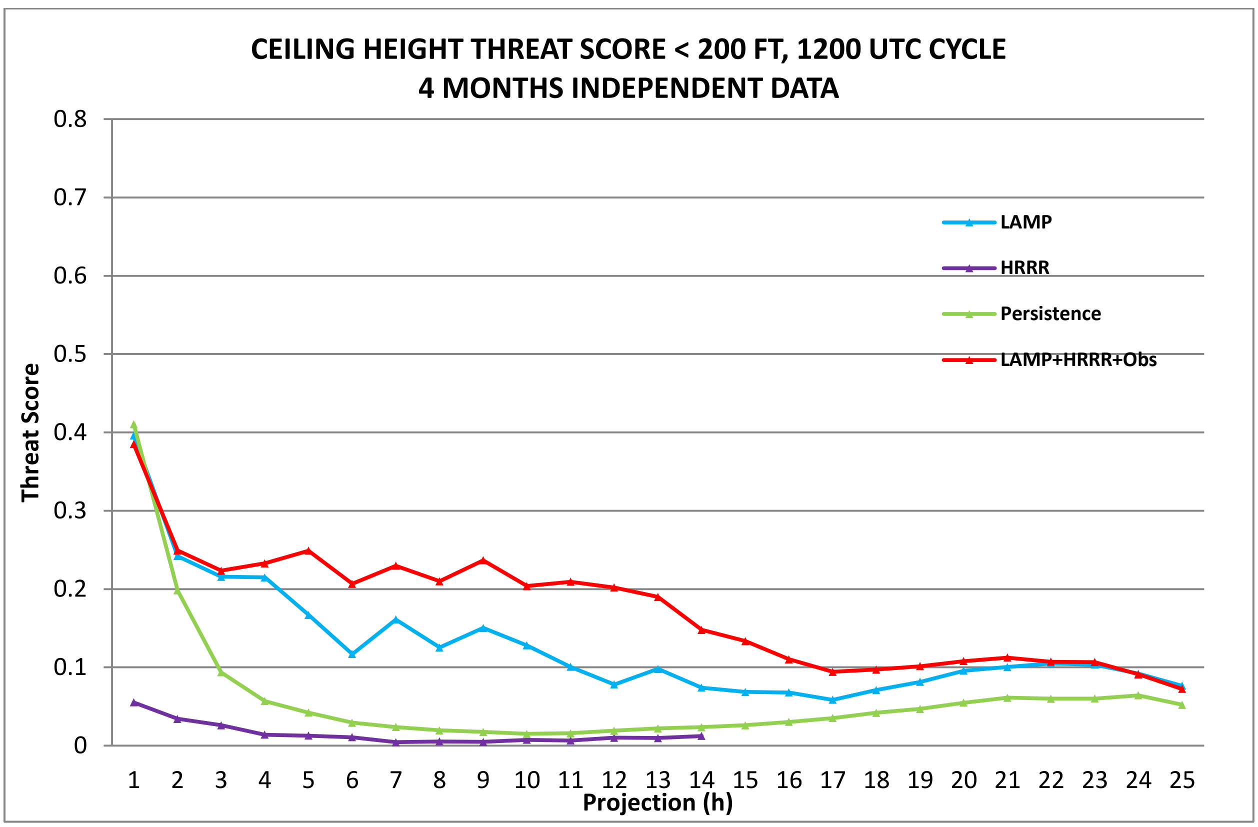

Figure 6. Ceiling height TS for events < 200 ft, 4 months independent data.

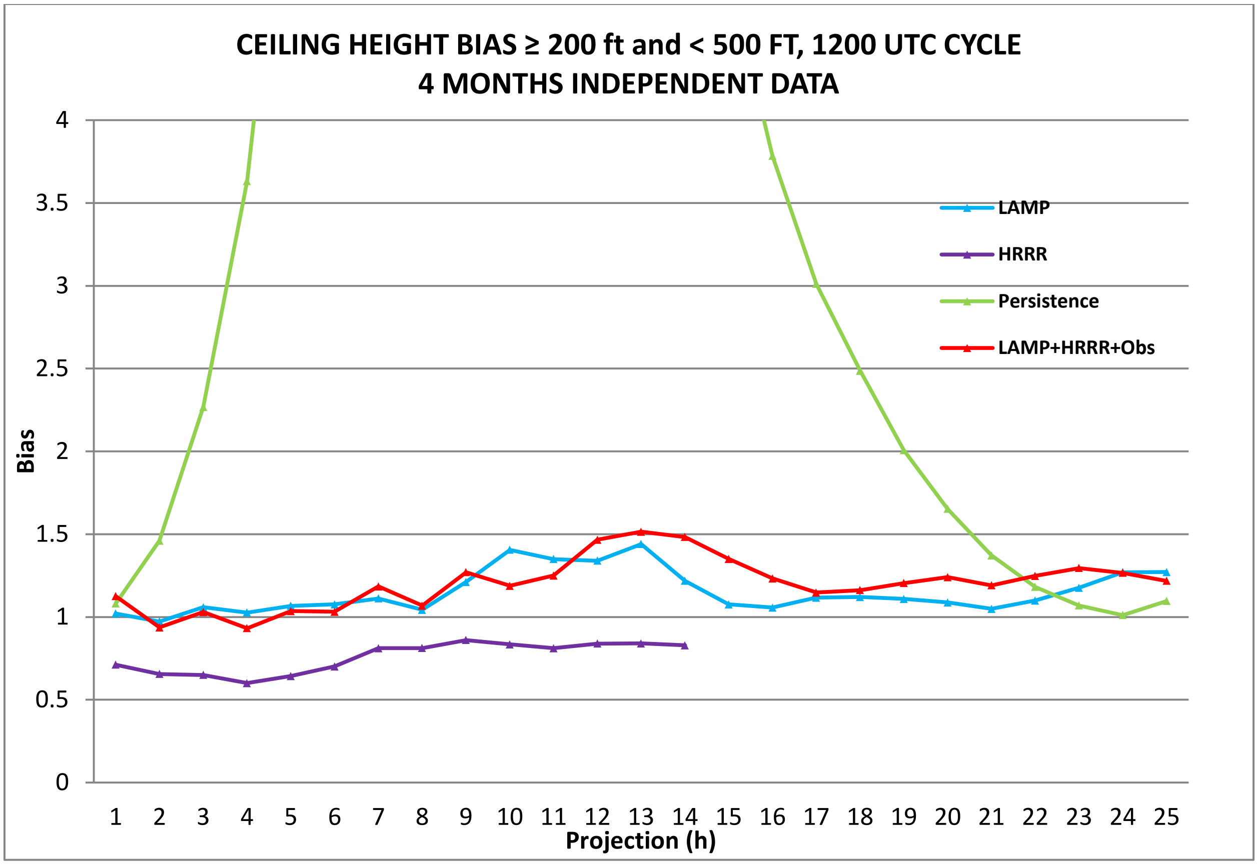

Figure 7. Ceiling height bias for events > 200 ft and < 500 ft, 4 months independent data.

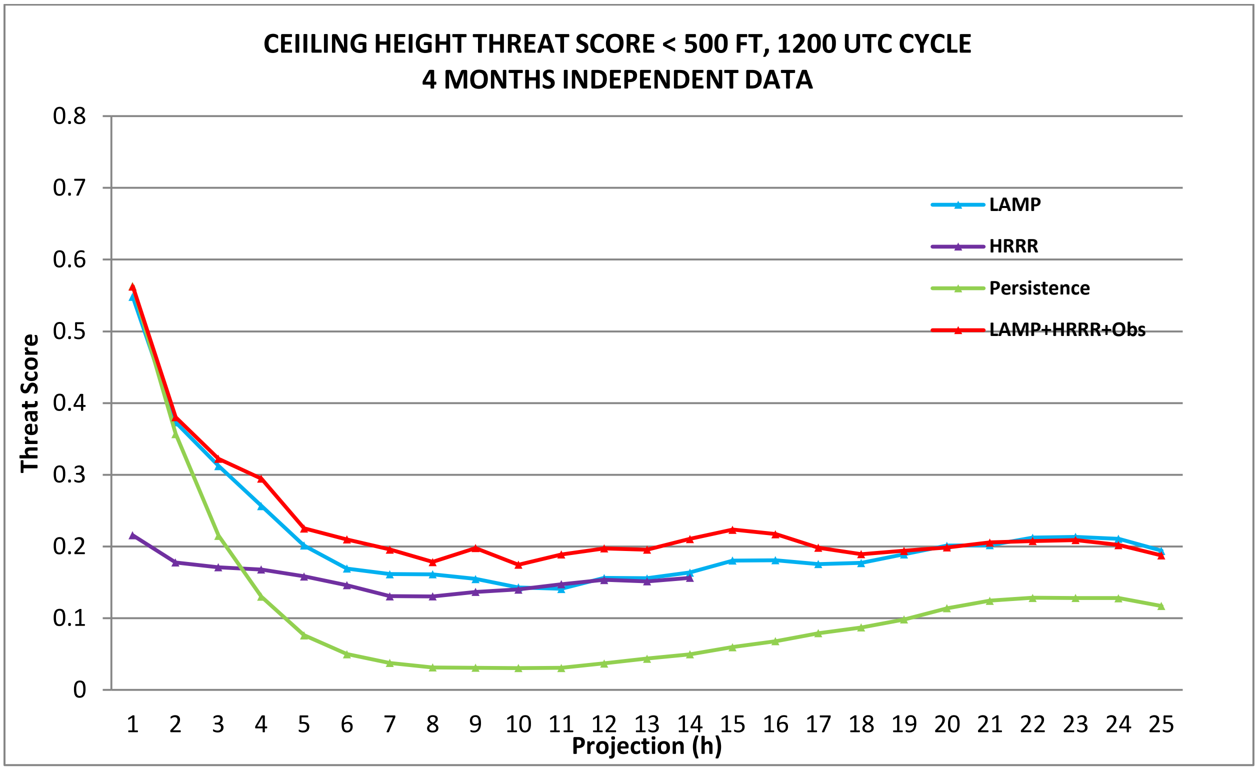

Figure 8. Ceiling height TS for events < 500 ft, 4 months independent data.

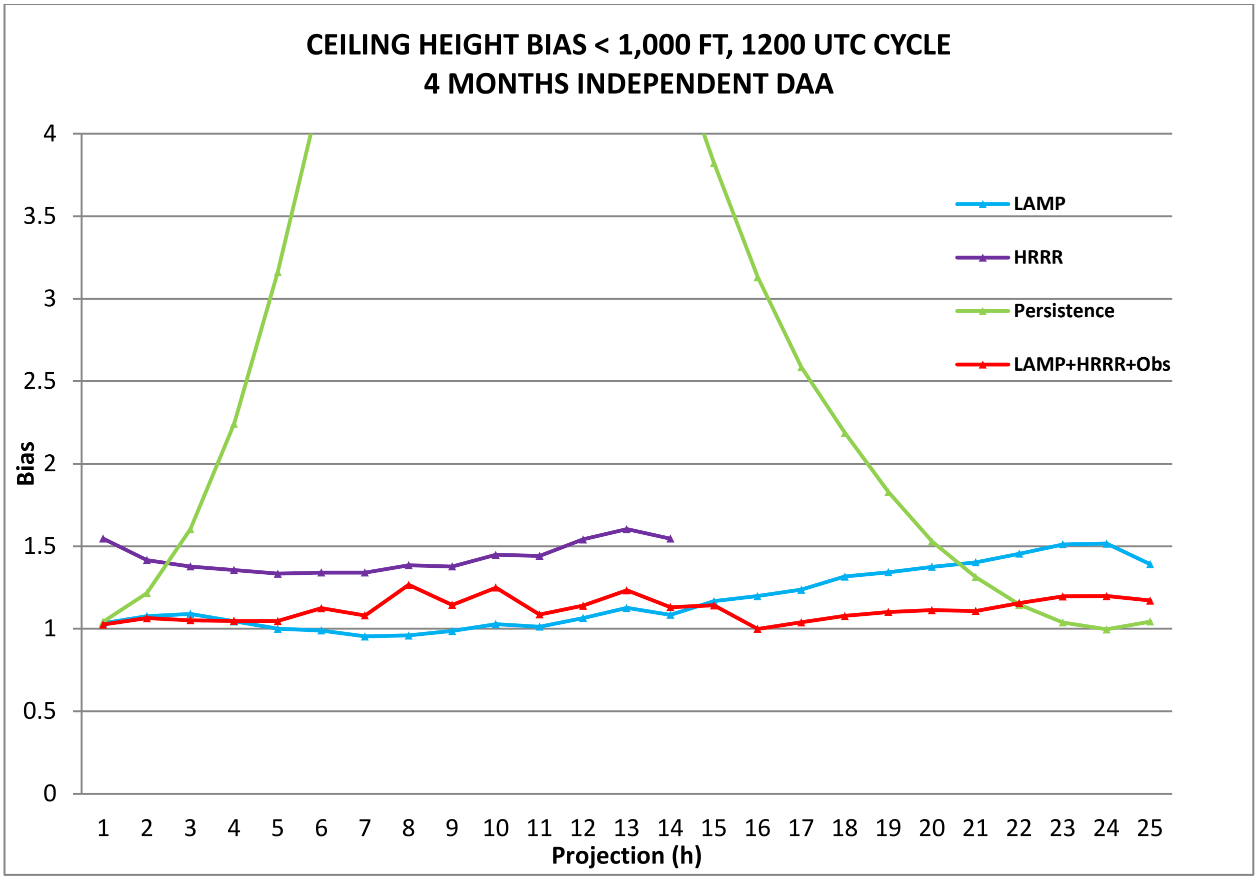

Figure 9. Ceiling height bias for events < 1,000 ft, 4 months independent data.

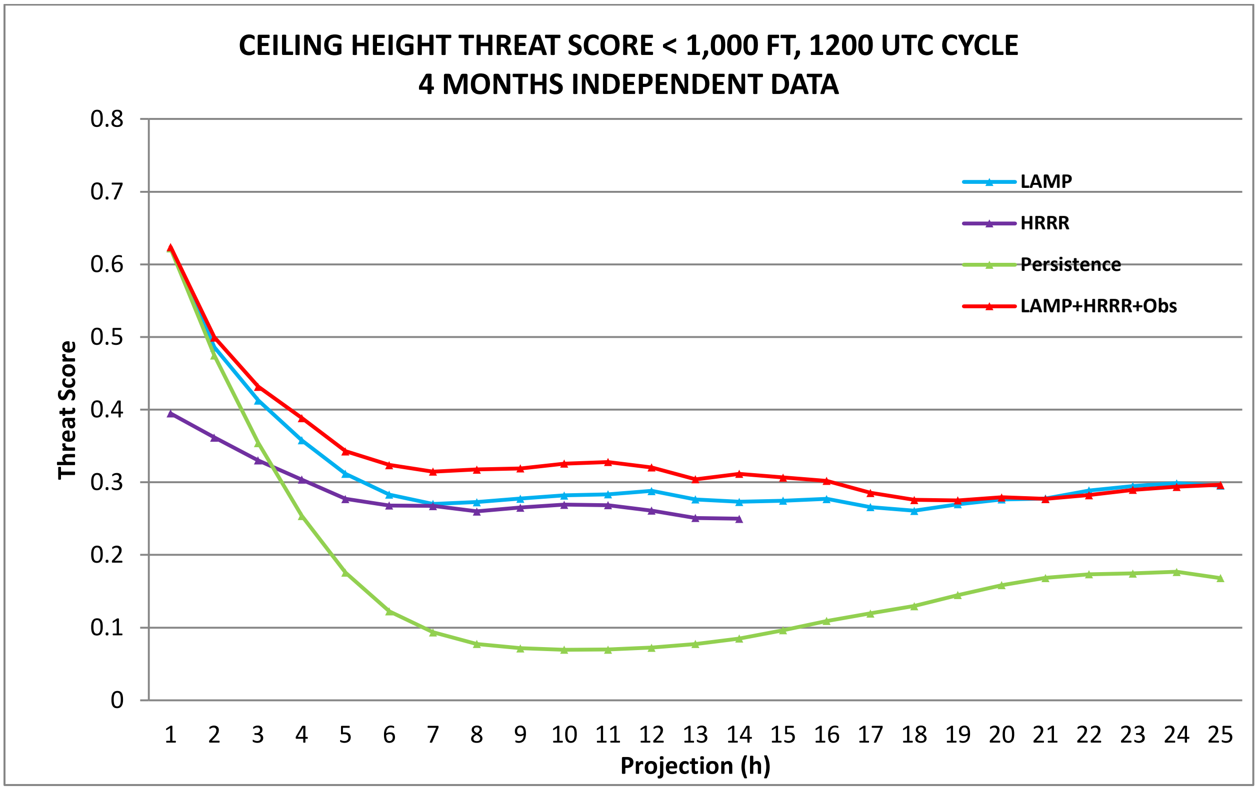

Figure 10. Ceiling height TS for events < 1,000 ft, 4 months independent data.

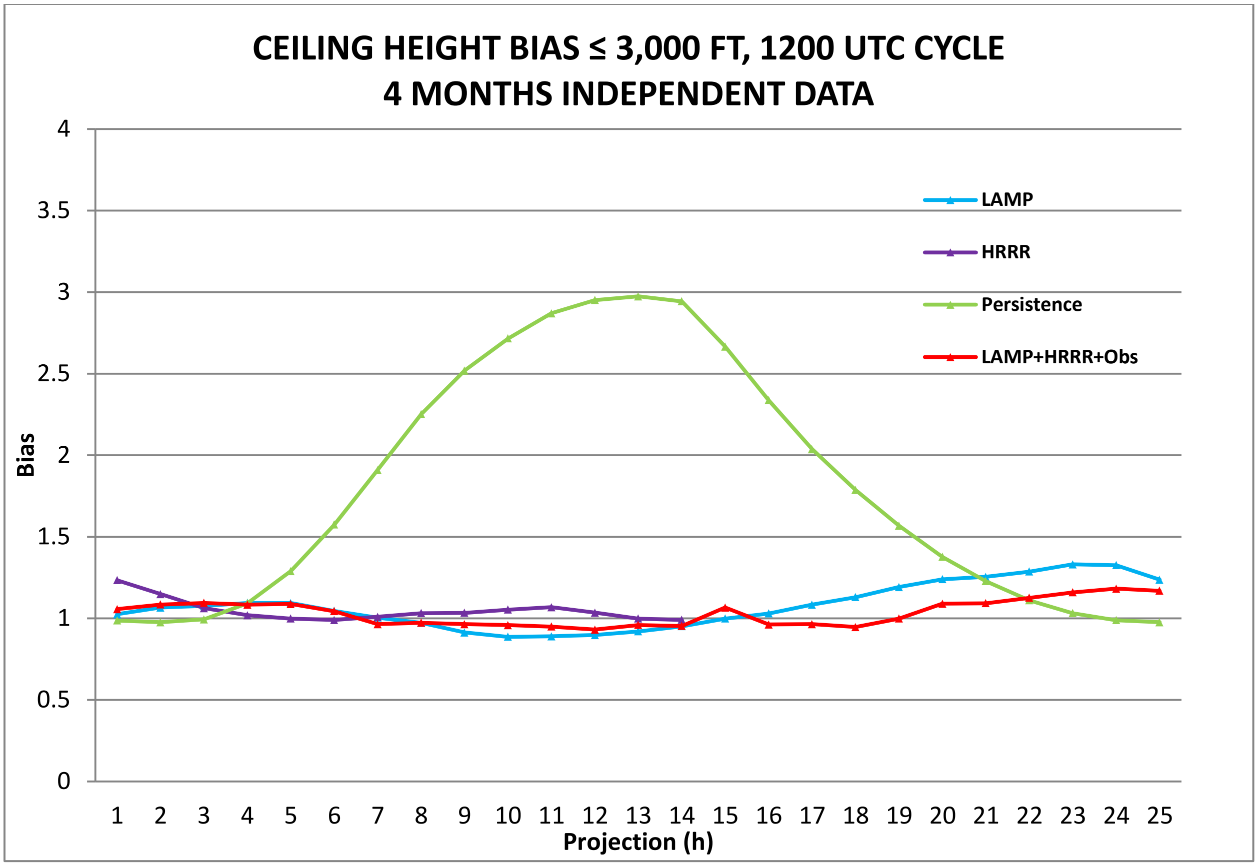

Figure 11. Ceiling height bias for events ≤ 3,000 ft, 4 months independent data.

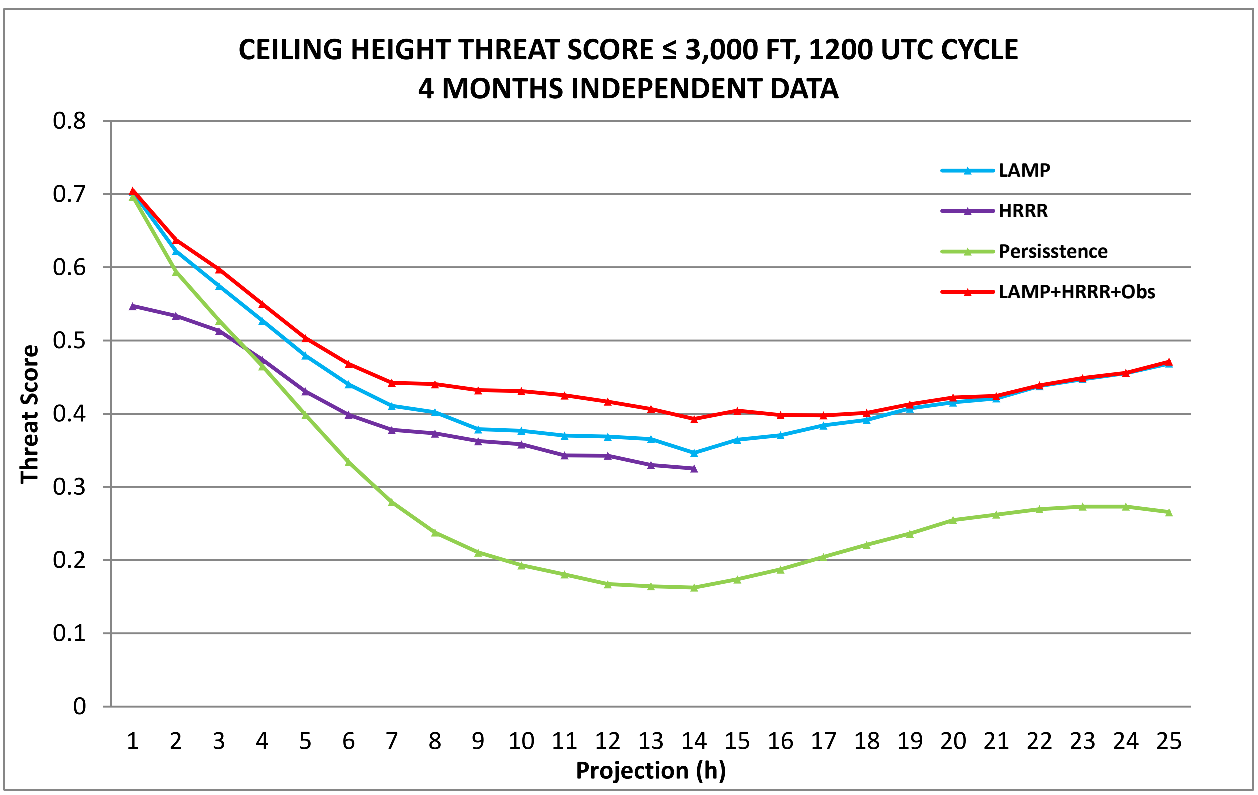

Figure 12. Ceiling height TS for events ≤ 3,000 ft, 4 months independent data.

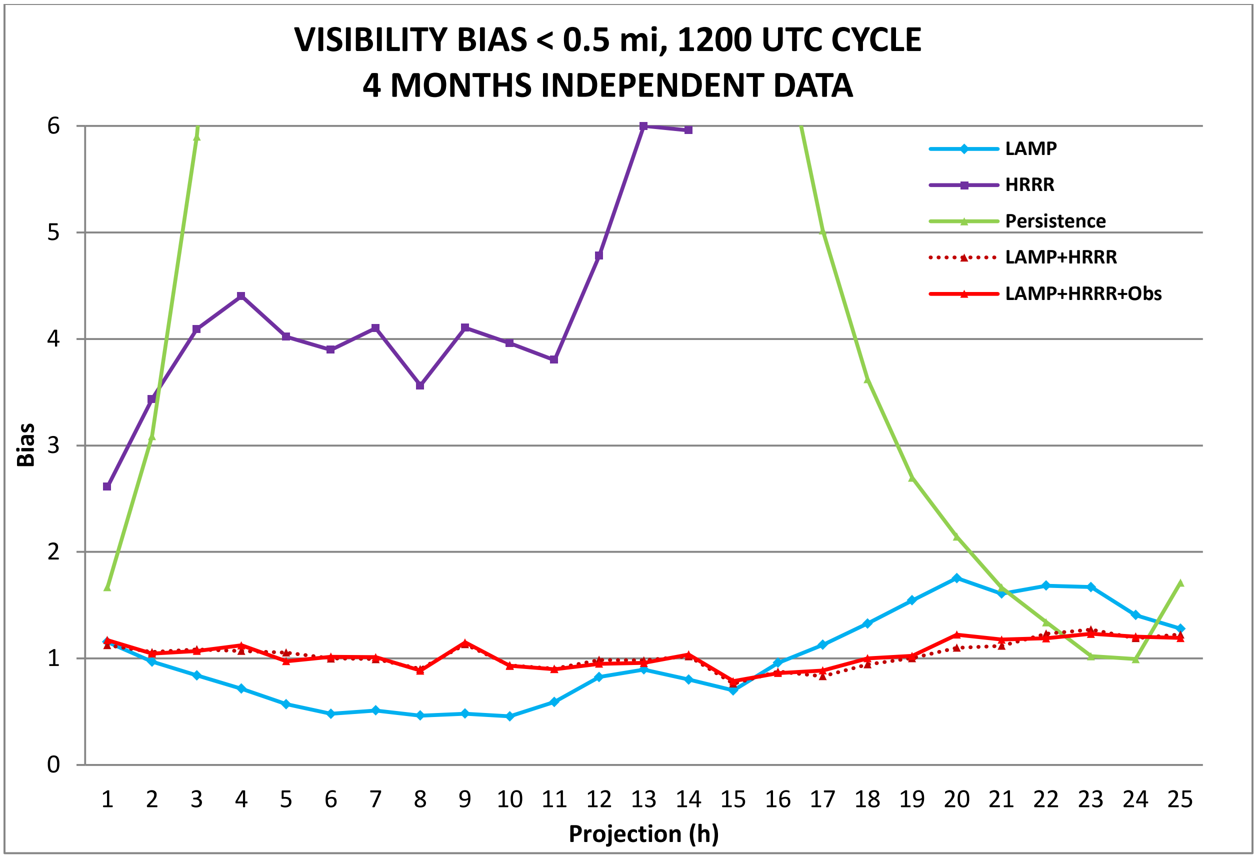

Figure 13. Visibility bias for events <0.5 mi, 4 months independent data.

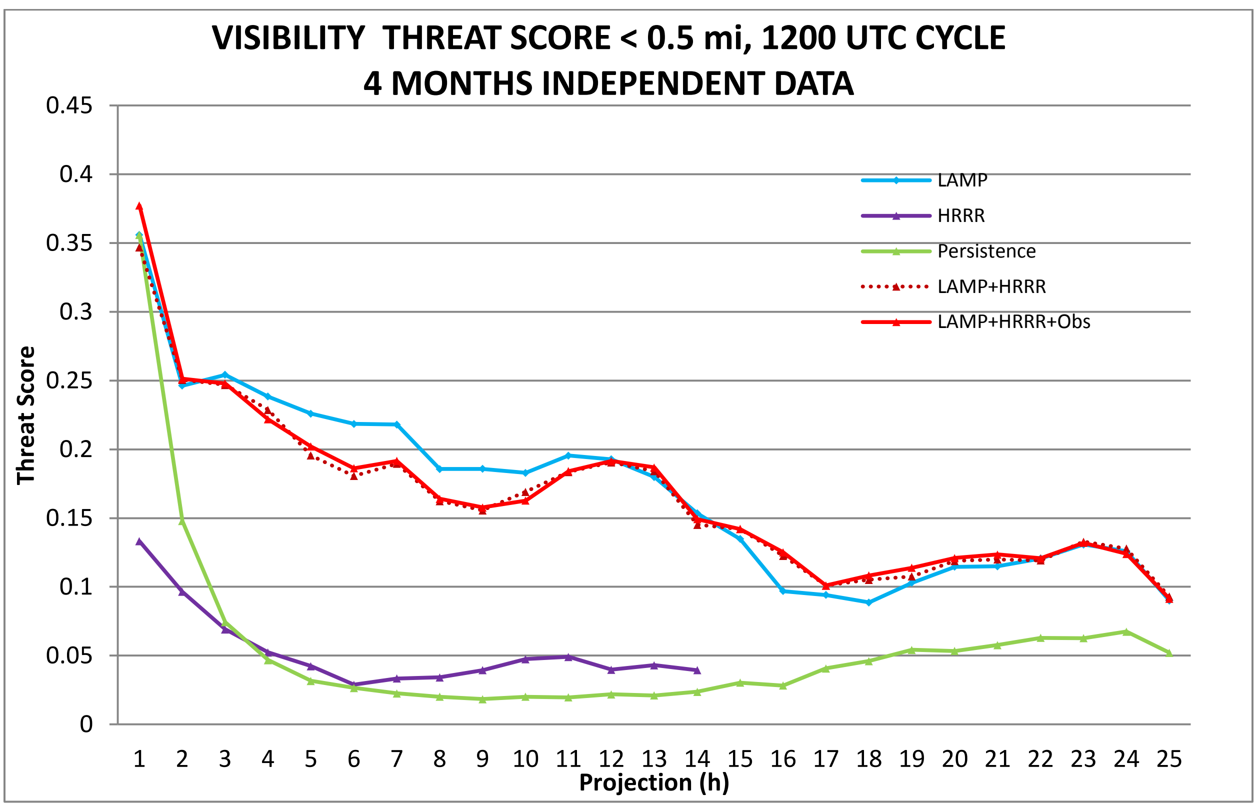

Figure 14. Visibility TS for events < 0.5 mi, 4 months independent data.

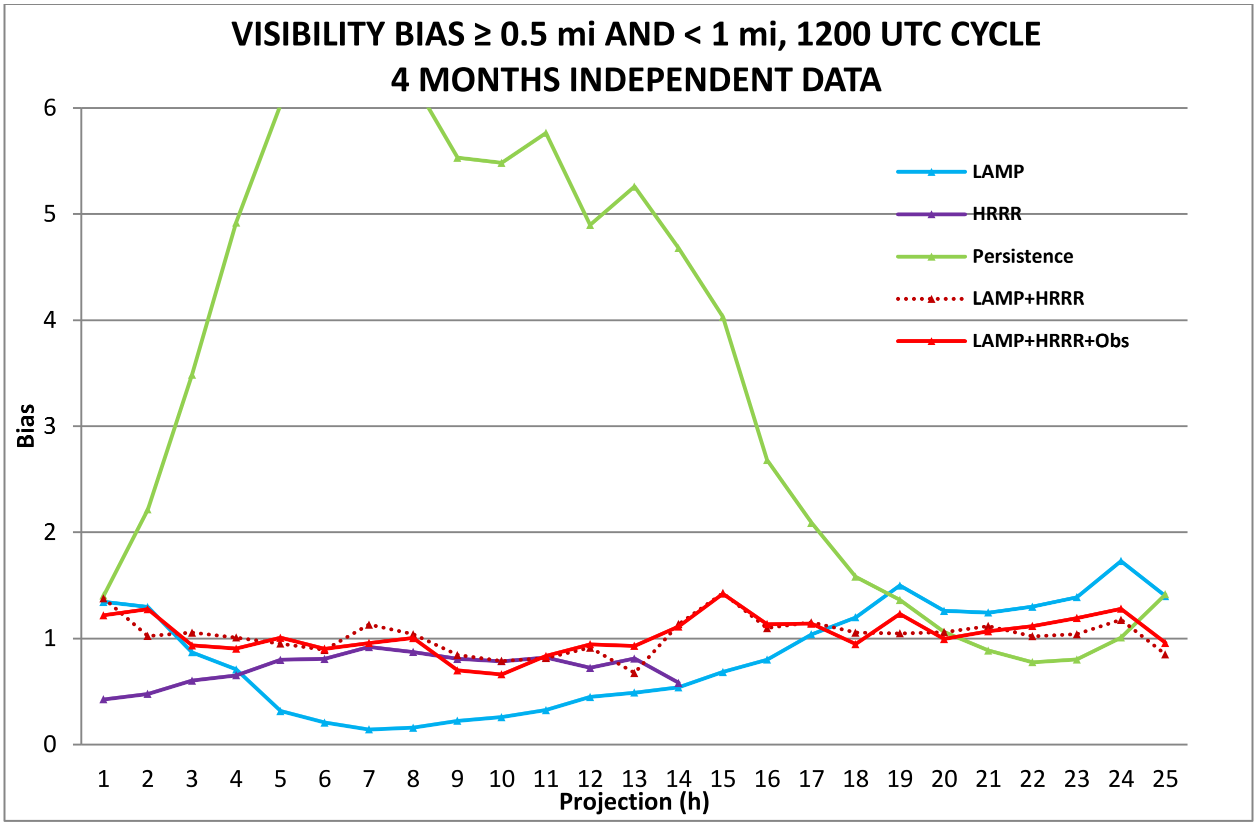

Figure 15. Visibility bias for events $\geq$ 0.5 mi and < 1.0 mi, 4 months independent data.

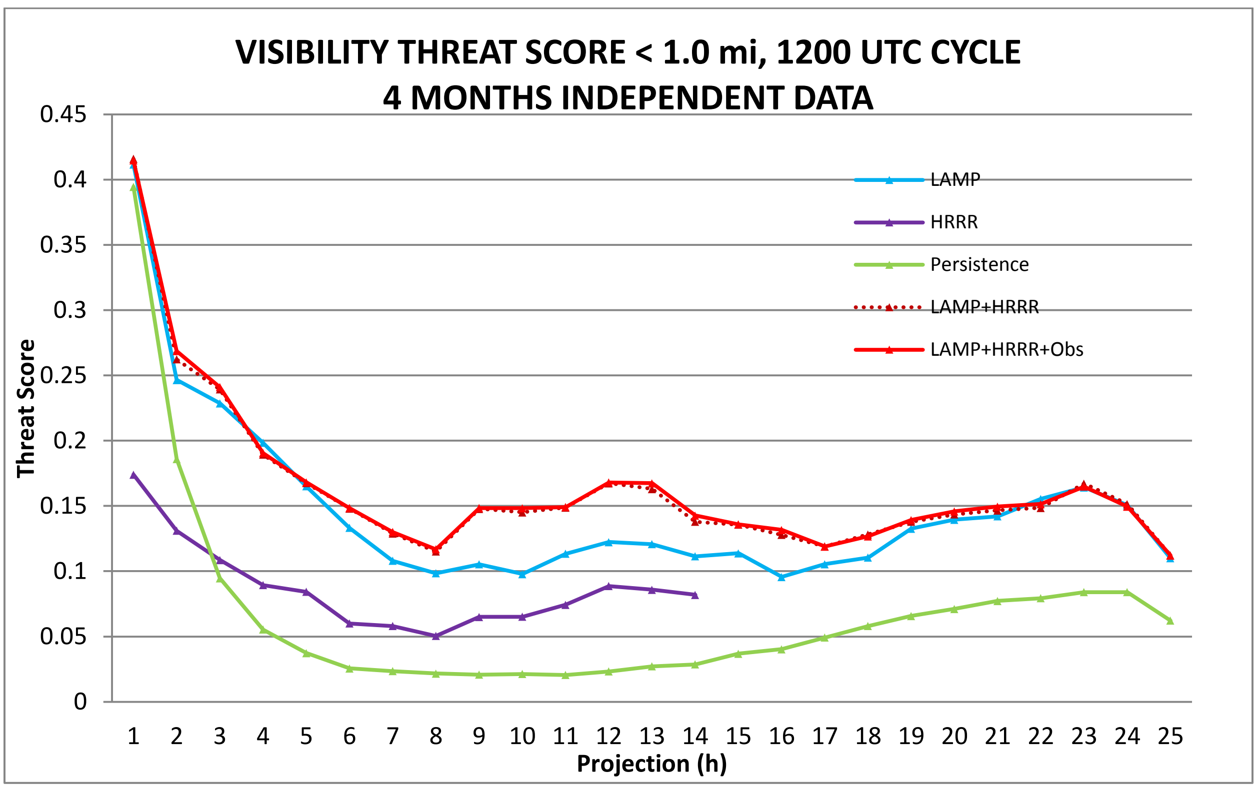

Figure 16. Visibility TS for events < 1.0 mi, 4 months independent data.

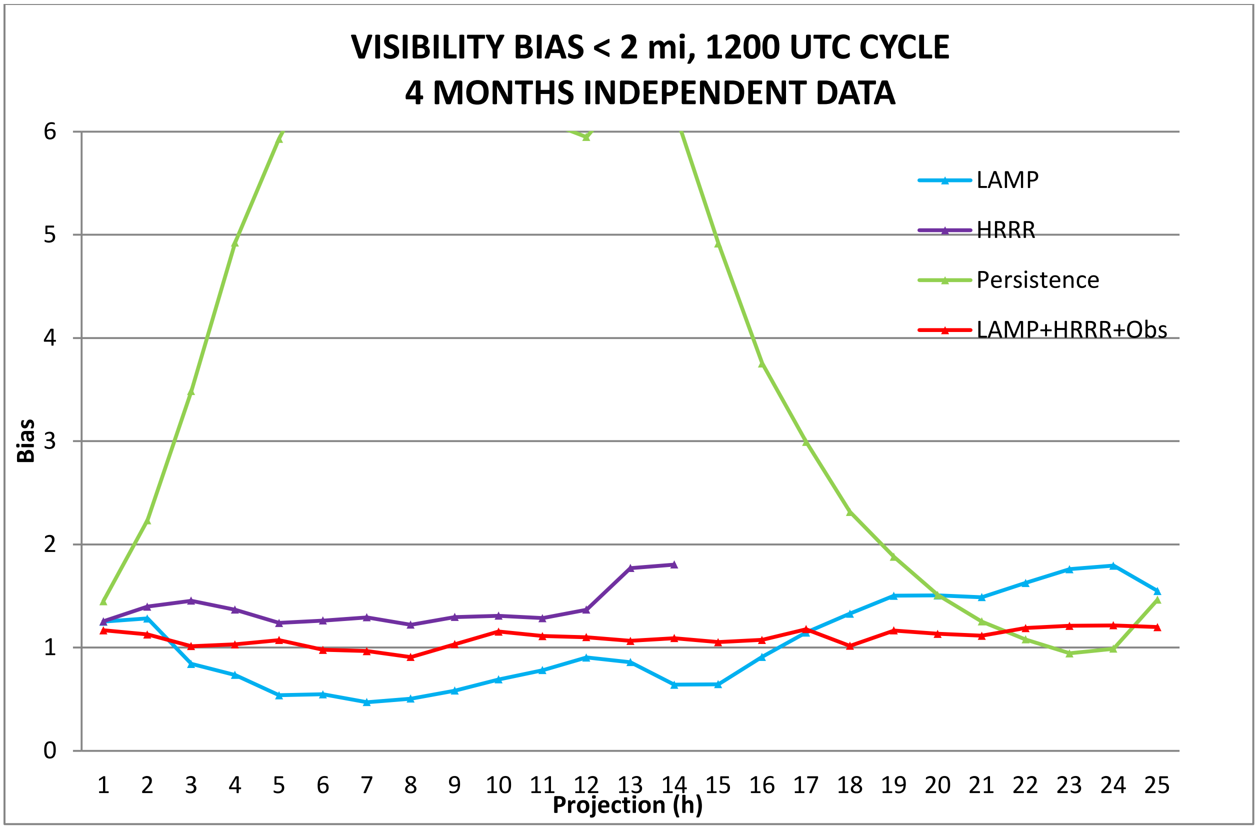

Figure 17. Visibility bias for events < 2.0 mi, 4 months independent data.

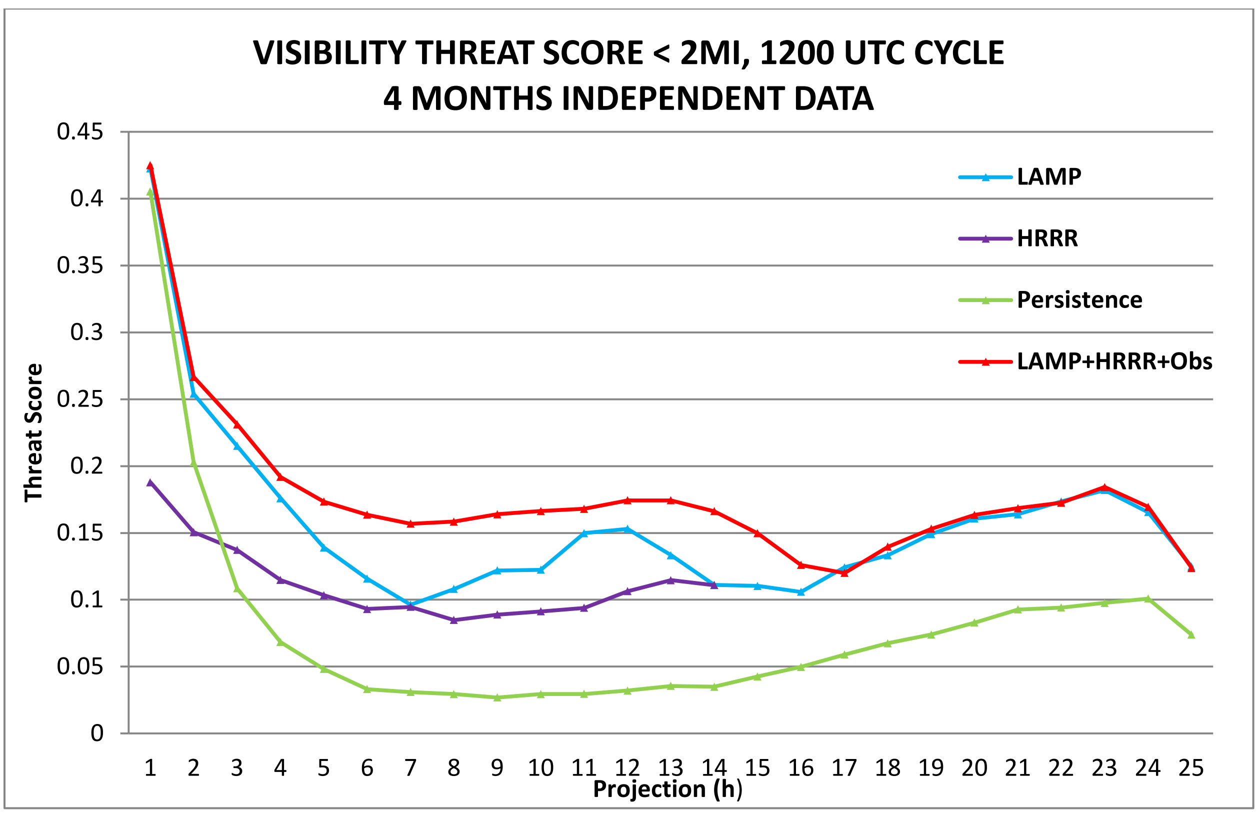

Figure 18. Visibility TS for events < 2.0 mi, 4 months independent data.

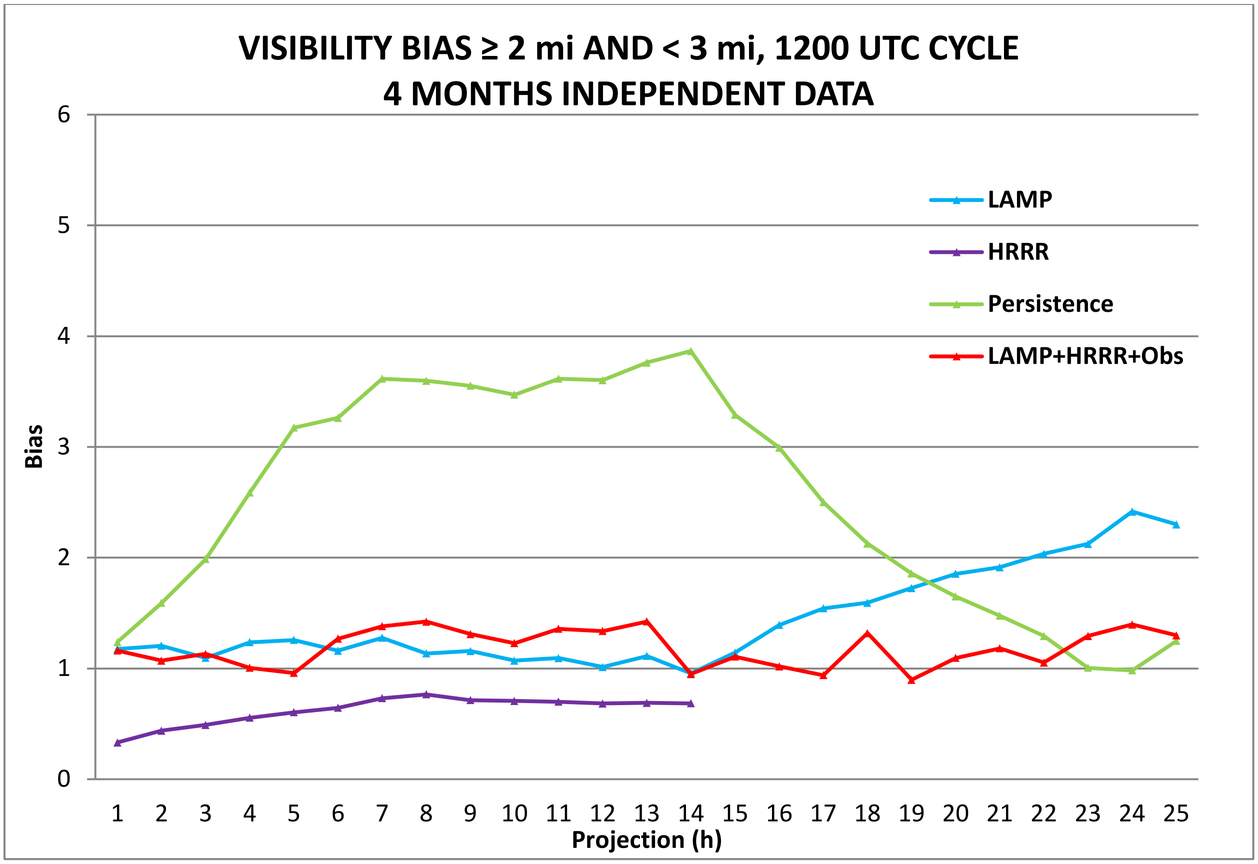

Figure 19. Visibility bias for events ≥ 2.0 mi and < 3.0 mi, 4 months independent data.

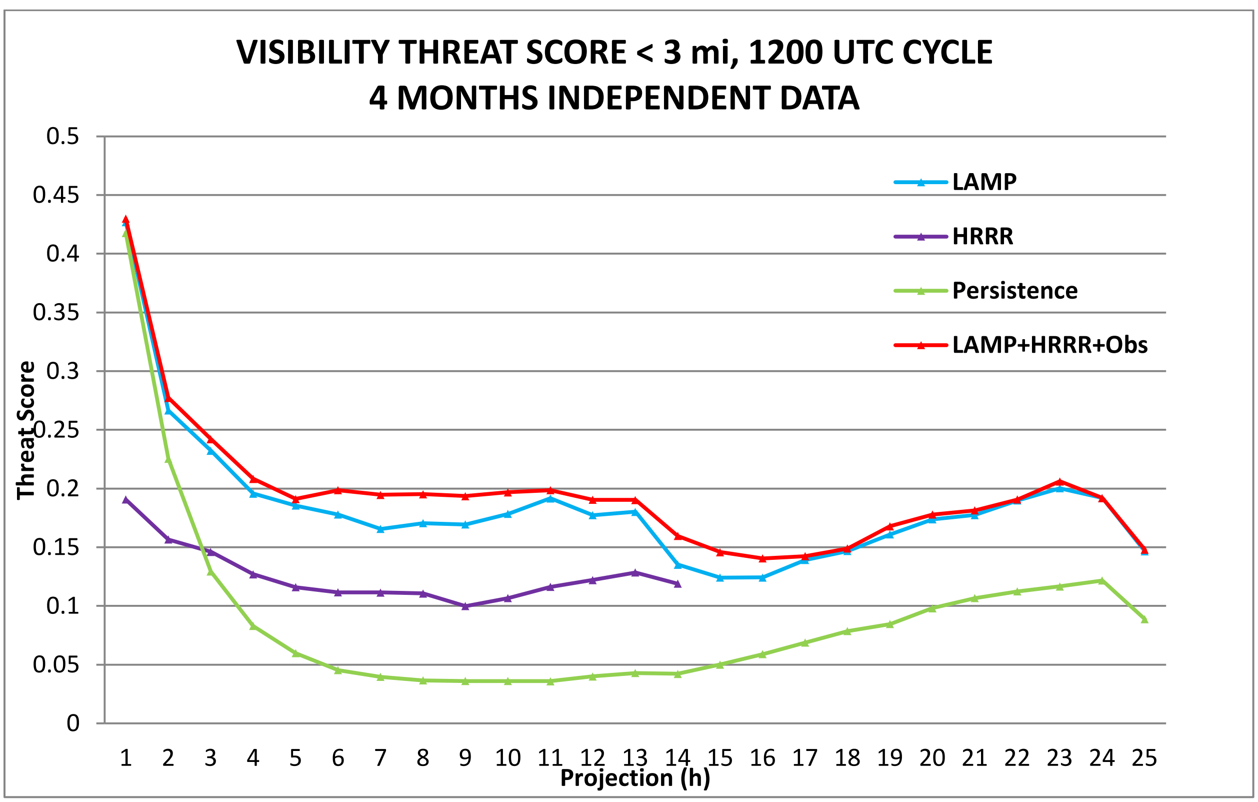

Figure 20. Visibility TS for events < 3.0 mi, 4 months independent data.

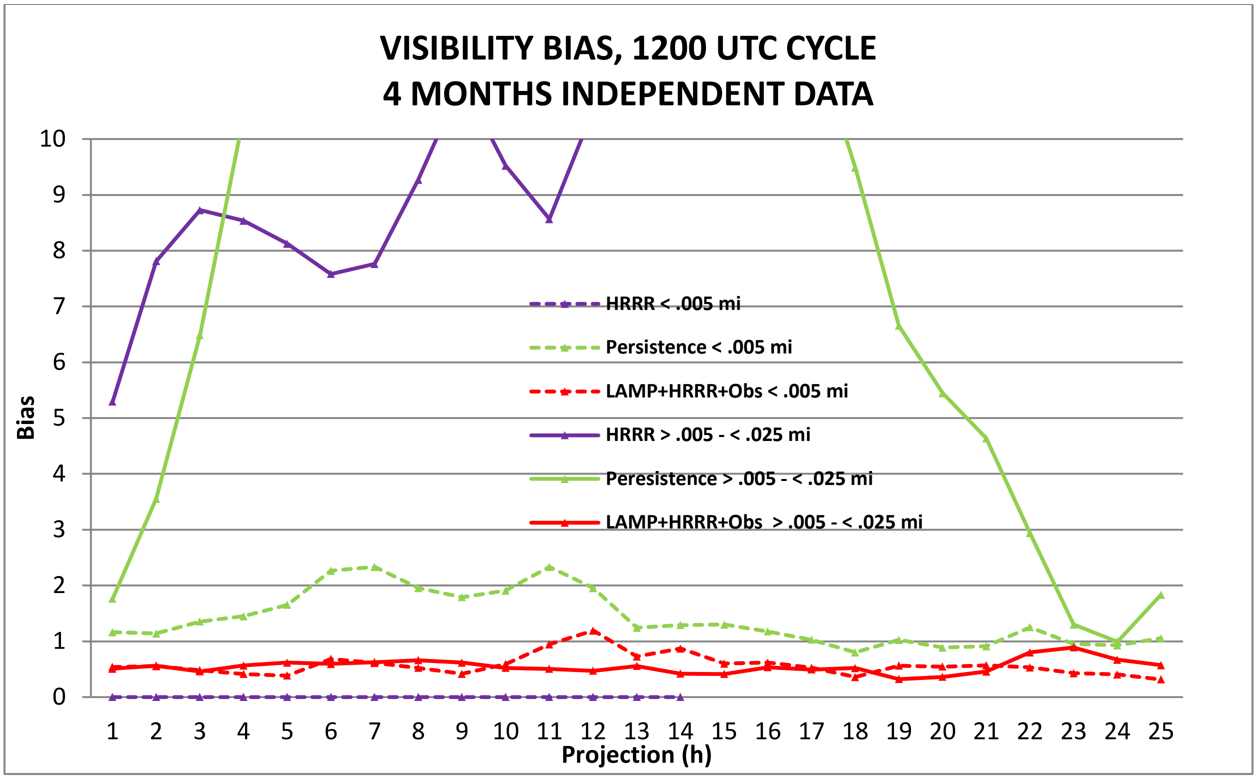

Figure 21. Visibility bias for events < 0.005 and for ≥ .0005 and < 0.25 mi, 4 months independent data.

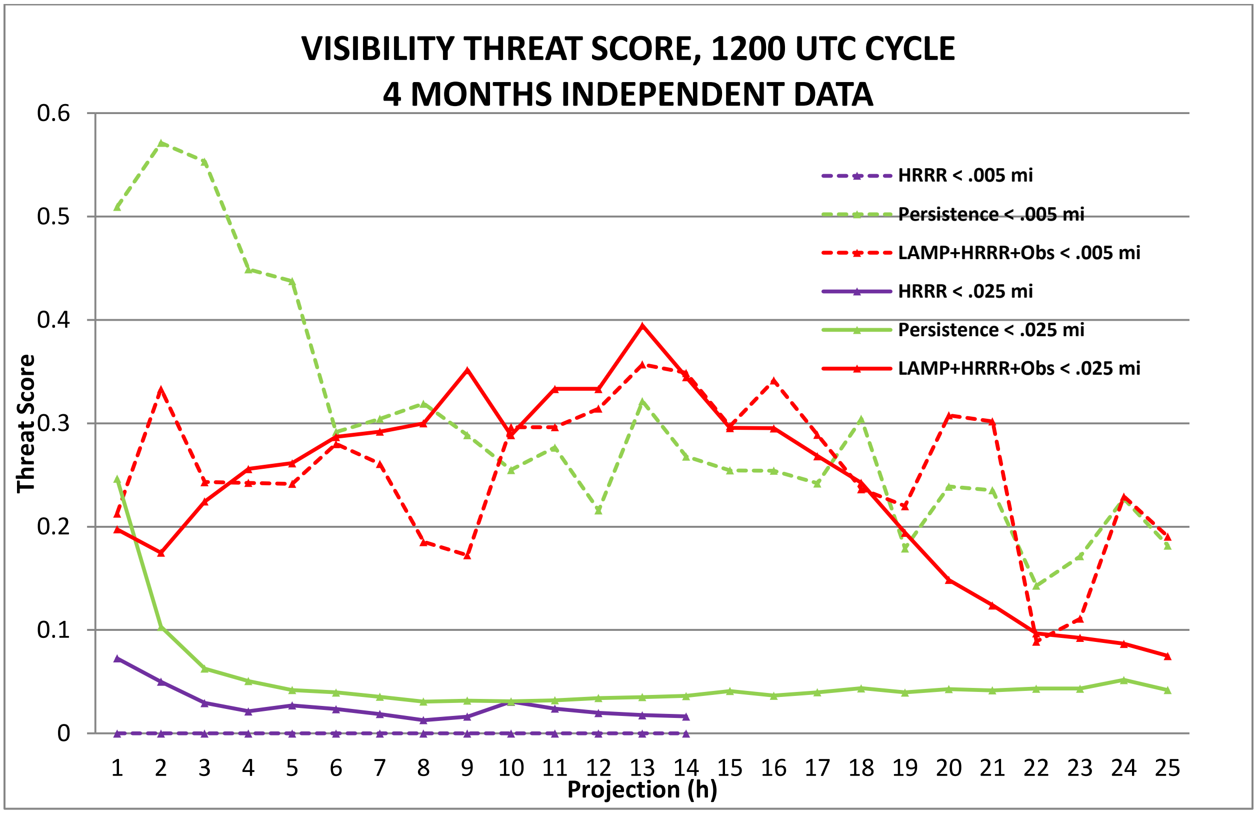

Figure 22. Visibility TS for events < 0.005 and for < 0.25 mi, 4 months independent data.

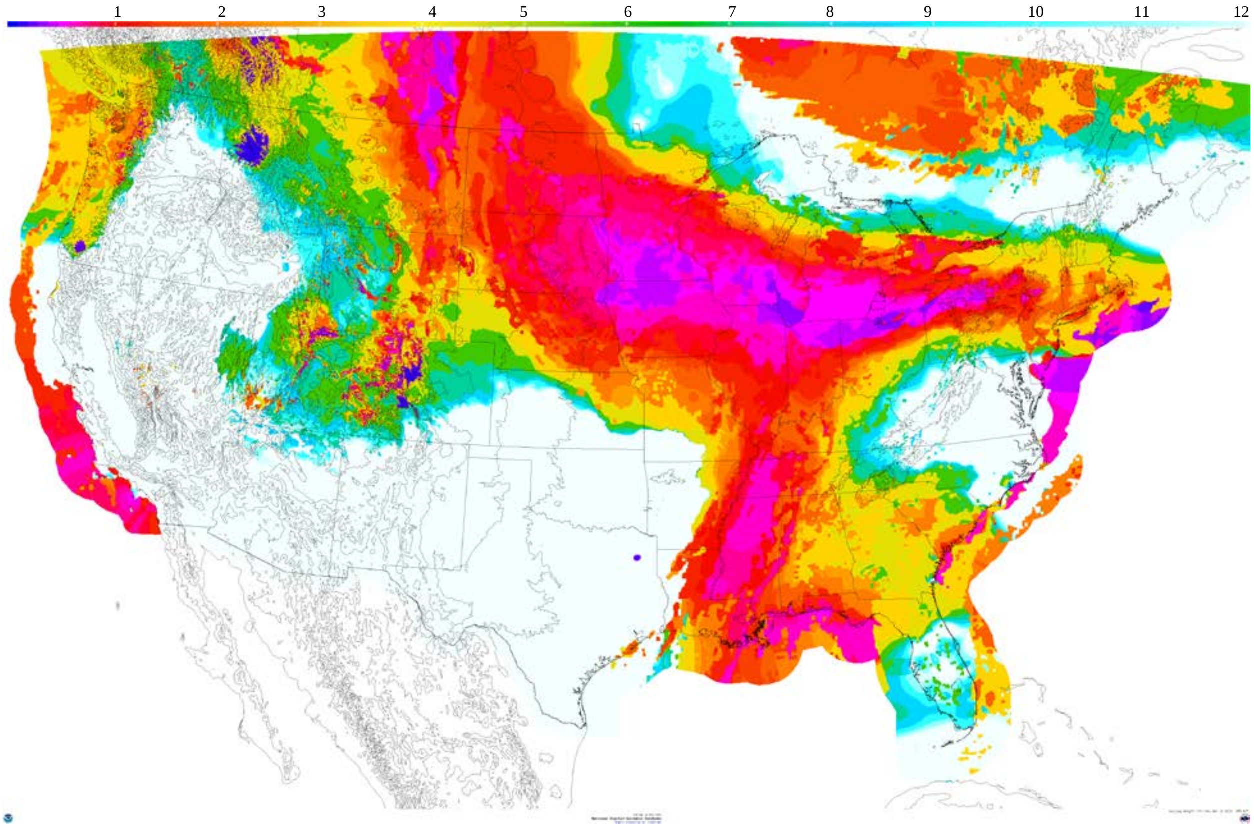

Figure 23. The ceiling 7-h Meld forecast from April 11, 2013, 1200 UTC. Color bar in thousands of ft.

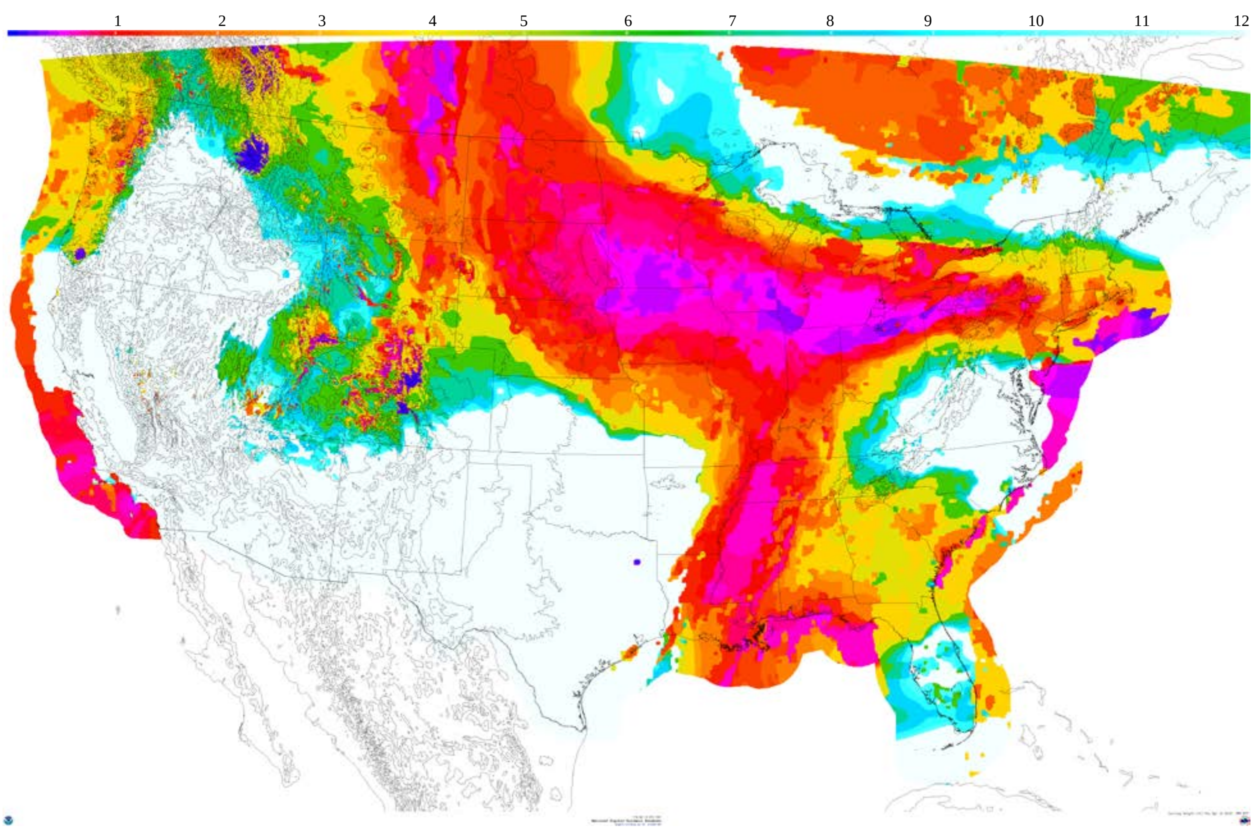

Figure 24. The same as Fig. 23, except after removal or coalescing of spots. Color bar in thousands of ft.

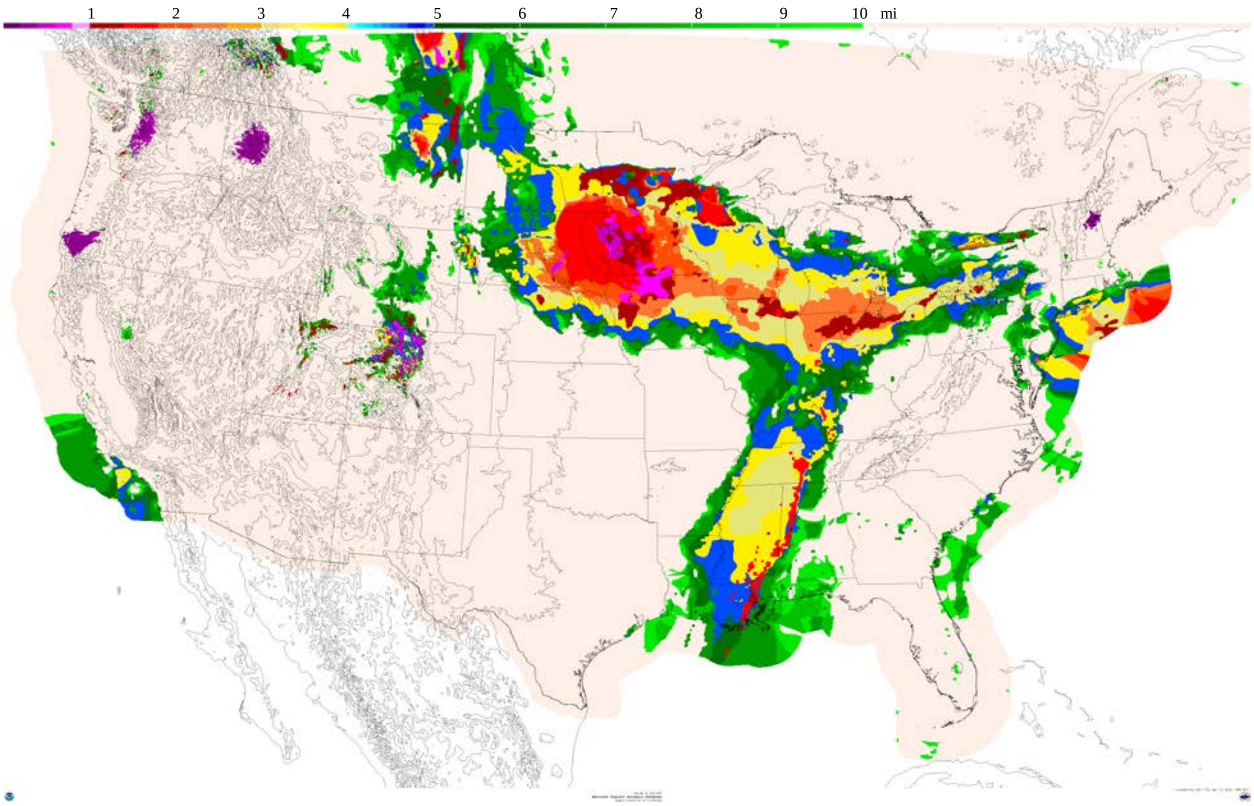

Figure 25. The visibility 7-h Meld forecast from April 11, 2013, 1200 UTC. Color bar in miles.

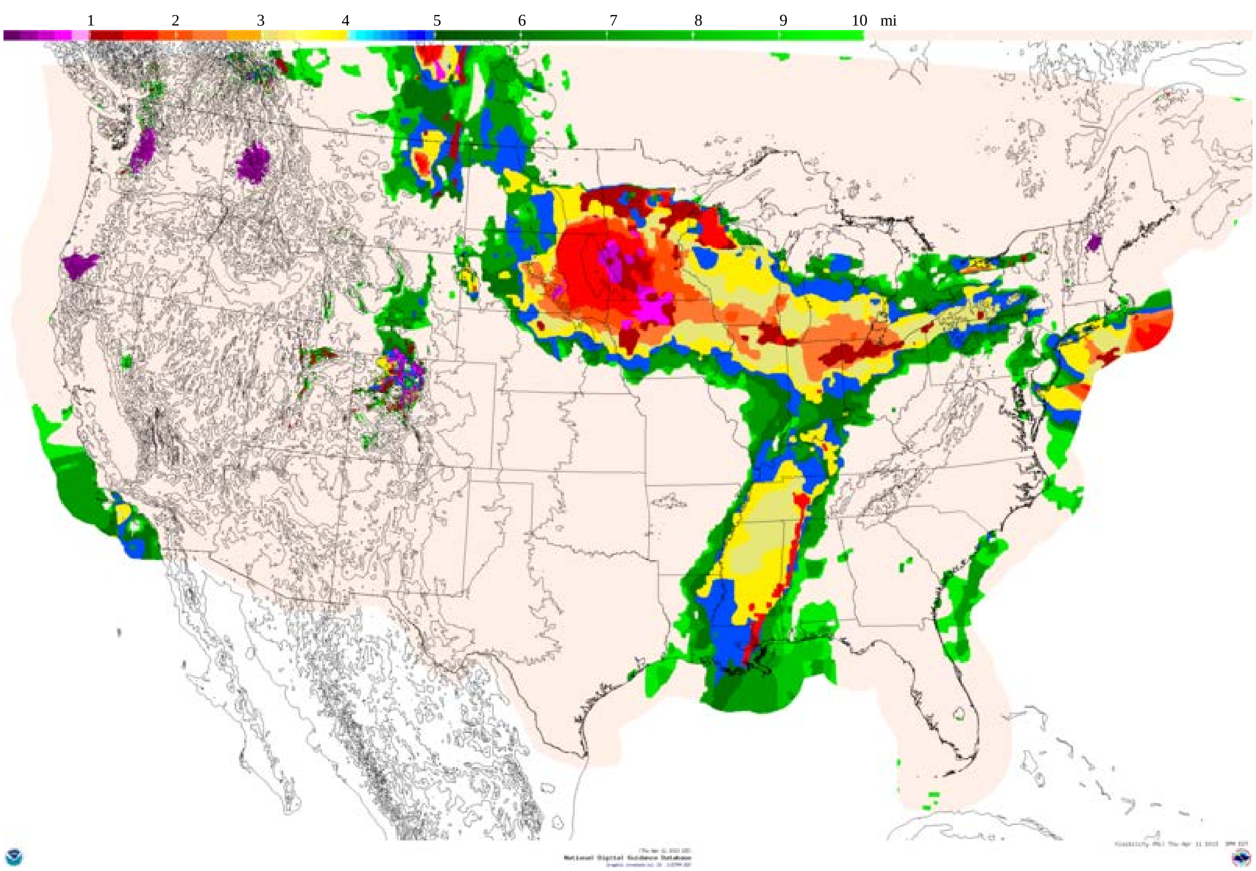

Figure 26. The same as Fig. 25, except after removal or coalescing of spots. Color bar in miles.