5.4 USING PROBABILISTIC FORECAST GUIDANCE AND AN UPDATE TECHNIQUE TO GENERATE TERMINAL AERODROME FORECASTS

Mark G. Oberfield* and Matthew R. Peroutka
Meteorological Development Laboratory
Office of Science and Technology
National Weather Service, NOAA
Silver Spring, Maryland

Cynthia Abelman
Aviation Services Branch
Office of Climate, Water and Weather Services
National Weather Service, NOAA
Silver Spring, Maryland

1. INTRODUCTION

Since the early 1970's, the Meteorological Development Laboratory (MDL) has provided objective guidance for weather elements of importance to aviation primarily to assist forecasters in creating Terminal Aerodrome Forecasts (TAFs). Since that time, MDL's aviation guidance has steadily evolved and expanded as computing power increased. MDL's latest efforts have created short-term statistical aviation guidance at hourly resolution.

In addition to developing statistical guidance for aviation needs, MDL developed and currently maintains the Aviation Forecast Preparation System (AvnFPS). As described by Peroutka et al. (2005), this software assists aviation forecasters in the National Weather Service (NWS) Weather Forecast Offices (WFOs) in the preparation and monitoring of their TAFs. AvnFPS software has been deployed to all 122 WFOs as part of the NWS's Advanced Weather Interactive Processing System (AWIPS) (Seguin 2002).

This paper describes the design and implementation of a new algorithm within AvnFPS to judiciously combine the latest Localized Aviation MOS Program (LAMP) guidance with the current TAF to create a new guidance TAF. This guidance TAF will enhance forecast continuity by incorporating decisions already made by aviation forecasters and, thus, be more readily acceptable for use and dissemination.

2. LAMP

Overall description, development and implementation of the latest LAMP guidance are described by Ghirardelli (2005) and briefly recounted here.

LAMP guidance is objective statistical output tailored to address the requirements of aviation forecasters at the WFOs. LAMP uses surface observations, radar, lightning data, simple advective models, and the latest GFS MOS as inputs to regression equations to create a 25-h forecast at hourly resolution. In addition to producing best category forecasts of categorical elements, such as ceiling heights and visibility, the probability of occurrence of the individual categories is available as well. These probabilistic data are not shown in the LAMP guidance text bulletins, but can be viewed in AvnFPS and play an important part in our algorithm described below.

As of this writing, LAMP guidance is generated 12 times per day and will be produced every hour by early 2009. Until now, LAMP development efforts were focused mostly on creating guidance in the early morning hours, reflecting the importance of the 0600 and 1200 UTC TAF issuances in pilots' and airspace traffic managers' plans for the day.

AvnFPS uses LAMP guidance as delivered to AWIPS in the Binary Universal Format for data Records (BUFR) messages. These messages are received and decoded automatically in AWIPS and

* Corresponding author's address: Mark G. Oberfield, NOAA's National Weather Service, Meteorological Development Laboratory, 1325 East-West Highway, W/OST24, Silver Spring, MD 20910; email: Mark.Oberfield@noaa.gov

contain the additional hourly probability data on two sets of ceiling height and visibility categories, total sky cover category, probability of precipitation occurring on the hour, and 2-h thunderstorm occurrence. Figure 1 shows the probability values associated with various categorical elements in the LAMP BUFR message as displayed in AvnFPS. Two sets of categorical visibility data are shown in Fig. 1. These are needed to describe separately the "dry" (no precipitation occurring) and the "wet" (precipitation occurring) conditions. LAMP also provides ceiling height guidance for "dry" and "wet" conditions as well. LAMP breakpoints for ceiling height and visibility correspond closely to aviation flight categories and are shown in Table 1 and 2, respectively.

Table 1. LAMP Ceiling Height Category Definitions

Category	Ceiling Height
1	< 200 feet
2	200 – 400 feet
3	500 – 900 feet
4	1000 – 1900 feet
5	2000 – 3000 feet
6	3100 – 6500 feet
7	6600 – 12,000 feet
8	> 12,000 feet or unlimited

Table 2. LAMP Visibility Category Definitions

Category	Visibility
1	< ½ mile
2	½ - < 1 miles
3	1 - < 2 miles
4	2 - < 3 miles
5	3 – 5 miles
6	6 miles
7	> 6 miles

3. AVNFPS

AvnFPS is a heavily used tool within the NWS for TAF preparation and dissemination (unpublished MDL survey, 2007). Besides assisting in the aviation forecaster's "weather watch" activities (NWS 2007), AvnFPS provides access to observations, guidance, and climatological datasets to support TAF preparation. Observations include surface observations, both METARs and SPECIs, lightning strikes, and wind data obtained from aircraft, profilers, and Doppler radars for detection of non-convective low-level wind shears (LLWS) near airports. Guidance includes direct model output from the North American Mesoscale Model, ETA-, NGM- and GFS-MOS, and LAMP for the WFO's TAF sites.

AvnFPS can display MOS guidance in a table or convert it into a TAF format. Not surprisingly TAFs based solely on data contained within MOS bulletins are not particularly good as the timing and duration of events are artificially constrained due to the bulletins' relatively coarse 3-h resolution. LAMP guidance, with its 1-h resolution out to 25 hours, including additional elements useful for aviation, can be transformed into a more usable TAF. However, even with the increased temporal resolution and the additional parameters, the TAF based on LAMP guidance—although a considerable improvement over those derived from traditional MOS—still has some drawbacks that limit its usefulness. For example, sky condition, when not clear, is a single cloud layer at fixed, predefined heights. LAMP cannot forecast showers or thunderstorms "in the vicinity," (VCSH, VCTS), nor can it indicate "build ups" of convective clouds, i.e., "CB" modifier to a cloud layer. These missing elements are important cues to pilots, particularly to those licensed to fly under visual flight rules. Aviation forecasters must add these elements manually and this limits their acceptance of automated guidance TAFs in many weather situations.

4. TAF UPDATE TECHNIQUE

To overcome these limitations of creating TAFs with only LAMP guidance, we used the current, official TAF as an additional source of information when generating a new TAF; in effect we update the current forecast with LAMP guidance. This technique has the advantage of incorporating multiple cloud layers and other elements not available in LAMP guidance when the aviation forecaster judges they should be present in the TAF. Also, the official TAF provides hints to the algorithm as to how the new TAF should be summarized into a concise form. Finally, this technique introduces forecast continuity into the composition process, provided the current TAF and LAMP guidance do not disagree too much.

While LAMP guidance shows probability values for the various categories and binary elements, additional parameters are given in the bulletin to present the "best" category or a "yes/no" decision to the forecaster. These parameters are chosen in a manner that maximizes some measure of performance using either the threat or bias scores (Wilks 2006).

In deciding a "yes/no" decision or selecting a "best" category, additional information, called threshold values, in combination with the probability values provided in the LAMP bulletin is required. These threshold values are created during the development phase of each LAMP cycle and, until now, have not been disseminated. These threshold values provide a means to quantitatively measure the amount of "disagreement" between LAMP probabilistic guidance and the current TAF and make adjustments accordingly for the new guidance TAF.

To illustrate this and the use of thresholds in determining "best" visibility category for dry conditions in LAMP guidance, we'll demonstrate with the values shown in Fig. 1 and redisplayed in Table 3 along with the threshold values for the particular hour.

Table 3. Illustration of Best Category Selection. 1800 UTC LAMP Visibility Category Forecast valid at 0900 UTC 31 August 2007 for Tri-State Airport, Huntington, West Virginia, (KHTS)

Category	CP (%)	T (%)	CP≥T	P (%)
1	12	14.2	**No**	12
2	18	18.3	**No**	6
3	27	21.3	**Yes**	9
4	40	25.0		13
5	79	33.2		39
6	88	33.7		9
7	100			12

The first two columns denote the category and cumulative probability, CP, for visibility at a forecast hour 0900 UTC for KHTS. The third column shows the threshold value, T, needed to be met or exceeded in order to select this category as the "best" one. The algorithm to determine the "best" category proceeds by comparing the categories in order, beginning with category 1 (the most restrictive one). The first category that surpasses its threshold value is chosen as the "best" one and the algorithm stops there. The fourth column shows the results. Category 3 is selected as the best category for this hour as indicated in the table and shown in Fig. 1.

The fifth column shows the discrete probability of occurrence, P, for each category for this hour. This is determined by computing the difference between the current and the previous, lower, category probability. Although visibility category 5 has the highest discrete probability in this instance (39%), the use of thresholds allows the relatively infrequent and lower category 3 to be chosen instead. The selection of "best" ceiling height category is done in an identical manner.

Threshold values are unique to each forecast cycle and projections therein and are tuned during LAMP development. In the case of ceiling height and visibility, thresholds are tuned to minimize bias. For binary, i.e. "yes/no", predictands, such as precipitation occurring at the top of hour and 2-h thunderstorm occurrence, the decision is determined simply by comparing whether the forecasted probability exceeds its threshold value for that forecast time. If it is exceeded, then the binary predictand becomes "yes", otherwise "no." The threshold values for these two LAMP elements were tuned to maximize the threat score.

As shown in Table 3, the selection of category 2 as "best" visibility category was missed by only 0.3%. In a hypothetical situation, for this particular time, if the official TAF was forecasting visibility within category 1 or 2 would the differences in visibility between the official forecast and LAMP guidance be considered significant? In this case, given the slender margins that category 1 and 2 (2.2% and 0.3%, respectively) were not chosen as the best category, the answer would likely be "no."

Using LAMP threshold values, we can determine, quantitatively, just how significant differences are between the TAF and LAMP guidance for a given hour and can better decide whether to keep a particular element of the current TAF or use LAMP guidance instead.

5. IMPLEMENTATION

We have developed an algorithm for updating TAFs with LAMP guidance for the following categorical weather elements and in the order they are to be evaluated: precipitation and thunderstorm occurrence; ceiling height and visibility; and obstruction-to-vision. Wind direction, speed and wind gust are accepted unconditionally from LAMP guidance and are used to replace the wind forecast in the TAF as they show good skill particularly in the initial 2- to 6-h period (Wiedenfeld 2005). Other elements that occasionally appear in the TAF, such as LLWS and NSW (No Significant Weather) groups are kept in the updated TAF.

The algorithm decodes the current TAF into its separate components, valid times, wind, visibility, weather, etc., and proceeds to compare them hour-by-hour to the corresponding LAMP element. The number of hours to compare is determined by whether the forecaster wants to generate an amendment to the current TAF (less than 24-h duration) or needs to generate a routine TAF for the 0000, 0600, 1200, and 1800 UTC issuance times (normally 24-h duration).

5.1 *Precipitation and Thunderstorms*

Updates to precipitation and thunderstorm occurrence in the TAF are done first, as the presence of either element after evaluation subsequently affects whether the “dry” or “wet” ceiling height and visibility information in LAMP guidance will be used. If the current TAF and LAMP elements both agree with respect to thunderstorms and precipitation occurrence, the current TAF forecasts for these elements are accepted. If there is disagreement, the difference between actual probability and the threshold value to trigger its occurrence is determined. If the difference is not significant, then the official forecast of precipitation and/or thunderstorms (or their absence) is carried over in the updated TAF for that hour. Choosing the probability value that determines whether TAF and LAMP differences are significant will require some tuning before deployment. Our limited testing to date suggests that a value between 5% and 10% will yield good results.

However, if LAMP guidance is strongly indicating precipitation or thunderstorms will occur for a particular hour but are absent in the current TAF, then the appropriate elements are added to the updated TAF. The opposite case, where the current TAF is forecasting either thunderstorms or precipitation occurring for that hour, but LAMP does not indicate it, is a bit more complicated. This is because LAMP forecasts the probability of precipitation occurring at the top of the hour, but the TAF forecasts whether precipitation will occur during the hour.

Only if LAMP guidance is strongly indicating that precipitation or thunderstorms will not occur: hourly POP, 2-h thunderstorm occurrence, and 6-h POP (not shown in Fig. 1 but available in the BUFR message) near zero, will the algorithm actually remove precipitation and thunder from the updated TAF. Otherwise, the algorithm may “demote” the precipitation or thunderstorm occurrence in the current TAF instead. Precipitation or thunderstorms in the prevailing group of the current TAF would be moved to a TEMPO or PROB30 group or from a TEMPO to a PROB30 group in the new guidance TAF. The degree of “demotion” is chosen to best fit what LAMP probabilities indicate for that particular hour and what is allowed by NWS policy (PROB30 groups are not permitted within the first 9 hours of the TAF) (NWS 2007).

5.2 *Ceiling Heights*

Once precipitation and thunderstorms, if any, are determined in the updated TAF, the appropriate ceiling height guidance in LAMP, either the “dry” or “wet” conditions, are consulted. For the prevailing group and any TEMPO or PROB30 groups, if the ceiling height categories for the current TAF and LAMP guidance are in agreement, then the sky condition in the TAF is preserved for the updated TAF.

If the ceiling height categories are not the same, the difference is computed between the ceiling height category probability of the current TAF and its corresponding threshold value. If the difference is significant, the algorithm will copy the cloud layers of the current TAF and adjust them to be consistent with LAMP guidance. There are two scenarios to consider. If LAMP guidance is forecasting a ceiling higher than what is currently being forecast, then the ceiling layer in the current TAF is changed to scattered and any layer above that moved upwards to fall within LAMP ceiling height category. Conversely, if guidance indicates ceilings to be in a lower category that what is being forecasted, then any few or scattered cloud layer(s) that fall within the LAMP category are changed to broken, which indicates a ceiling. Finally, in those cases where the current TAF does not have a cloud layer within the LAMP ceiling height category, the algorithm will add one to the updated TAF.

Once the adjustment to cloud layers is complete for the updated TAF for that hour, a “cleanup” pass is done to remove any excessive layers—no more than three—and ensure that cloud layer coverage increases with height, e.g. no scattered layers above a broken layer. Any “CB”’ modifier to a cloud layer in the current TAF is preserved, although it may be moved to a different height in the updated TAF. This technique allows for multiple cloud layers in the updated TAF and still be consistent with LAMP guidance.

5.3 *Visibilities*

Like ceiling height, LAMP guidance provides two sets of visibility categories corresponding to the "dry" and "wet" conditions. Unlike ceiling height, adjustment to visibility when significant differences are found between the current TAF and LAMP guidance is more straightforward with only a single value to consider. While the visibility may be simply changed upward or downward, it can have implications on the obstruction-to-vision type and/or precipitation intensity and the algorithm must account for this in the updated TAF.

When visibility in the updated TAF is ≤ ½ statute miles, any occurrence of mist (BR) is changed to dense fog (FG). Also if snowfall or drizzle is forecasted, its intensity cannot be light in these situations and is changed to moderate or heavy intensity as appropriate for the visibility (OFCM 2005). Conversely, in situations where the visibility has been adjusted upward to > ½ statute miles for the updated TAF, intensity of snow and drizzle, if forecasted, are adjusted accordingly and dense fog is changed to mist.

5.4 *Other elements*

The same basic algorithm can be applied to precipitation type and obstruction-to-vision. However, experience has shown the best category forecasts for these weather elements can vary from hour to hour more often than forecasters find acceptable. This seems to happen most often when choosing between haze and mist. To address this issue, the algorithm will preferentially accept the obstruction-to-vision and precipitation types found in the current TAF when they are needed in the updated TAF. This approach is used for smoke, blowing snow and dust, and volcanic ash. An exception is made for freezing precipitation. Given its significant impact on aviation safety and airport operations, if LAMP indicates freezing precipitation (e. g., freezing rain or sleet) and it is not present in the current TAF, freezing precipitation will appear in the updated TAF.

6. CURRENT PLANS

TAFs updated with LAMP guidance based on this algorithm and threshold files will be made available to NWS aviation forecasters in mid 2008. Within AvnFPS, it will be generated "on-the-fly" and can be viewed as another guidance source in the TAF Editor. These guidance TAFs can be readily copied from the text window into AvnFPS editor for further modifications and eventual dissemination.

MDL will provide the required threshold files as part of the AWIPS installation process. While these thresholds values, once determined, are relatively static, as part of the continuing efforts here at MDL, additional LAMP cycles will continue to be developed and disseminated from NCEP as BUFR bulletins. As these new cycles become available during the year, the threshold files for each TAF site will be updated. The WFOs will be able to download the updated threshold files containing the new forecast cycles for their TAF sites from MDL's web server.

The threshold values for each TAF site are encoded into a Hierarchical Data Format file (THG 2007). As of this writing, 12 LAMP cycles are being disseminated operationally from NCEP. The threshold files are approximately 20 KB in size for each TAF site, and will eventually reach a size of approximately 40 KB when all LAMP cycles are being produced. Each file contains thresholds for all categorical and most binary predictands, seasons, and projections for a particular station.

As new LAMP cycles become available later this year and in 2009, the files will be updated. Besides posting them on the MDL web server for downloading, the WFOs will receive them as part of the AWIPS software installation process. Installation software will use versioning information contained within these threshold files to prevent newer ones from being overwritten by files created at an earlier date.

MDL has archived LAMP guidance and surface observations for several years. The Office of Climate, Water and Weather Services Performance Branch has an archive of past TAF issuances. Given these datasets of past guidance, forecasts, and observations, we intend to run this algorithm to generate new TAFs from them. Careful examination and evaluation of these forecasts will allow us to further refine this technique to produce maximally useful TAFs for the NWS forecasters.

7. CONCLUSIONS

We have presented a new algorithm that uses the probabilistic data available in LAMP guidance, threshold values, and the official TAF to create a new guidance TAF within AvnFPS. By judiciously combining elements of the current forecast and

LAMP output, this new guidance TAF can incorporate prior decisions made by NWS aviation forecasters and, thus, will be more readily used than TAFs generated from guidance alone.

8. ACKNOWLEGEMENT

The authors wish to acknowledge David Ruth's original idea of using the current, official forecast as input into the TAF update technique.

9. REFERENCES

Ghirardelli, J.E., 2005: An overview of the redeveloped localized aviation MOS program (LAMP) for short-range forecasting. Preprints, *21st Conference on Weather Analysis and Forecasting*. Washington, D.C., Amer. Meteor. Soc., 13B.5.

National Weather Service, 2007: Terminal Aerodrome Forecasts. National Weather Service Instruction 10-813, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, 59 pp.

Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM), 1995: *Federal Meteorological Handbook* No. 1: Surface Weather Observations and Reports. National Oceanic and Atmospheric Administration, U. S. Department of Commerce.

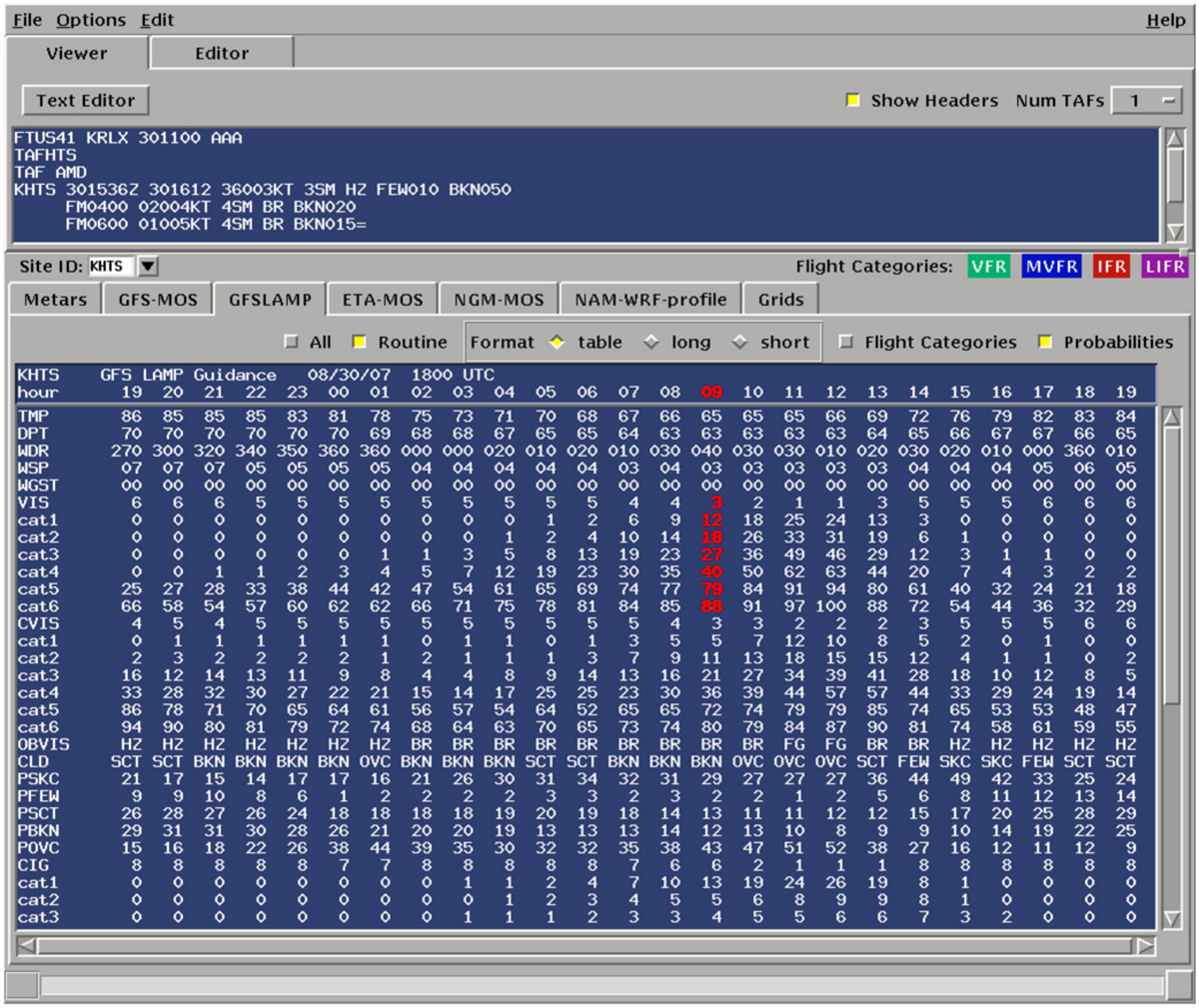
Peroutka, M.R., M.G. Oberfield, M. Graf, G. Trojan, and B. Li, 2005: The aviation forecast preparation system of the National Weather Service. Extended Abstract, *12th Conference on Aviation Range and Aerospace Meteorology.* San Diego, CA, Amer. Meteor. Soc., 15.10

Seguin, W., 2002: AWIPS—An end-to-end look. Preprints, *18th International Conference on IIPS.* Orlando, FL, Amer. Meteor. Soc., J1.3

The Hierarchical Group, 2007: *HDF5 Reference's Guide.* The Hierarchical Group, 418 pp.

Wiedenfeld, J.R., 2005: Localized aviation MOS program (LAMP): Statistical guidance of wind speed, direction, and gusts for aviation weather. Preprints, *21st Conference on Weather Analysis and Forecasting*. Washington, D.C., Amer. Meteor. Soc., P1.48.

Wilks, D.S., 2006: *Statistical Methods in the Atmospheric Sciences.* Academic Press, 627 pp.



hour	19	20	21	22	23	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19
TMP	86	85	85	85	83	81	78	75	73	71	70	68	67	66	65	65	65	66	69	72	76	79	82	83	84
DPT	70	70	70	70	70	70	69	68	68	67	65	65	64	63	63	63	63	63	64	65	66	67	67	66	65
WDR	270	300	320	340	350	360	360	000	000	020	010	020	010	030	040	030	030	010	020	030	020	010	000	360	010
WSP	07	07	07	05	05	05	05	04	04	04	04	04	03	04	03	03	03	03	03	04	04	04	05	06	05
WGST	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
VIS	6	6	6	5	5	5	5	5	5	5	5	5	4	4	3	2	1	1	3	5	5	5	6	6	6
cat1	0	0	0	0	0	0	0	0	0	0	1	2	6	9	12	18	25	24	13	3	0	0	0	0	0
cat2	0	0	0	0	0	0	0	0	0	1	2	4	10	14	18	26	33	31	19	6	1	0	0	0	0
cat3	0	0	0	0	0	0	1	1	3	5	8	13	19	23	27	36	49	46	29	12	3	1	1	0	0
cat4	0	0	1	1	2	3	4	5	7	12	19	23	30	35	40	50	62	63	44	20	7	4	3	2	2
cat5	25	27	28	33	38	44	42	47	54	61	65	69	74	77	79	84	91	94	80	61	40	32	24	21	18
cat6	66	58	54	57	60	62	62	66	71	75	78	81	84	85	88	91	97	100	88	72	54	44	36	32	29
CVIS	4	5	4	5	5	5	5	5	5	5	5	5	5	4	3	3	2	2	2	3	5	5	5	6	6
cat1	0	1	1	1	1	1	1	0	1	1	0	1	3	5	5	7	12	10	8	5	2	0	1	0	0
cat2	2	3	2	2	2	2	1	2	1	1	1	3	7	9	11	13	18	15	15	12	4	1	1	0	2
cat3	16	12	14	13	11	9	8	4	4	8	9	14	13	16	21	27	34	39	41	28	18	10	12	8	5
cat4	33	28	32	30	27	22	21	15	14	17	25	25	23	30	36	39	44	57	57	44	33	29	24	19	14
cat5	86	78	71	70	65	64	61	56	57	54	64	52	65	65	72	74	79	79	85	74	65	53	53	48	47
cat6	94	90	80	81	79	72	74	68	64	63	70	65	73	74	80	79	84	87	90	81	74	58	61	59	55
OBVIS	HZ	HZ	HZ	HZ	HZ	HZ	HZ	BR	BR	BR	BR	BR	BR	BR	BR	BR	FG	FG	BR	BR	HZ	HZ	HZ	HZ	HZ
CLD	SCT	SCT	BKN	BKN	BKN	BKN	OVC	BKN	BKN	BKN	SCT	SCT	BKN	BKN	BKN	OVC	OVC	OVC	SCT	FEW	SKC	SKC	FEW	SCT	SCT
PSKC	21	17	15	14	17	17	16	21	26	30	31	34	32	31	29	27	27	27	36	44	49	42	33	25	24
PFEW	9	9	10	8	6	1	2	2	2	2	3	3	2	3	2	2	1	2	5	6	8	11	12	13	14
PSCT	26	28	27	26	24	18	18	18	18	19	20	19	18	14	13	11	11	12	12	15	17	20	25	28	29
PBKN	29	31	31	30	28	26	21	20	20	19	13	13	13	14	12	13	10	8	9	9	10	14	19	22	25
POVC	15	16	18	22	26	38	44	39	35	30	32	32	35	38	43	47	51	52	38	27	16	12	11	12	9
CIG	8	8	8	8	8	7	7	8	8	8	8	8	7	6	6	2	1	1	1	8	8	8	8	8	8
cat1	0	0	0	0	0	0	0	0	1	1	2	4	7	10	13	19	24	26	19	8	1	0	0	0	0
cat2	0	0	0	0	0	0	0	0	0	1	2	3	4	5	5	6	8	9	9	8	1	0	0	0	0
cat3	0	0	0	0	0	0	0	0	1	1	1	2	3	3	4	5	5	6	6	7	3	2	0	0	0

Figure 1. Portion of LAMP guidance as displayed in AvnFPS for Tri-State Airport, Huntington, West Virginia, (KHTS) showing probability values for categorical elements. "Best" visibility category and cumulative probability for visibility categories for the non-precipitating case valid at 0900 UTC 31 August 2007 are shown in red.