4A.3 SHORT-TERM PROBABILISTIC FORECASTS OF CEILING AND VISIBILITY UTILIZING HIGH-FREQUENCY SURFACE OBSERVATIONS

Stephen M. Leyton * and J. Michael Fritsch
Pennsylvania State University, University Park, Pennsylvania

1. INTRODUCTION

Adverse weather conditions result in a significant number of airport delays across the United States. Not only do they affect departures of aircraft from the airport where the conditions exist but also the numerous airports from which the airplanes are arriving as well. One significant contributor to these delays is the presence of low ceiling and/or visibility. With this in mind, it is intuitive that with improvements in forecast skill of the timing and duration of these phenomena, airport efficiency could be increased, which, in turn, leads to money saved.

The primary source of guidance for forecasting surface weather conditions has traditionally been statistically post-processed numerical model output (i.e. MOS derived from the NGM and AVN models). However, Vislocky and Fritsch (1997; hereafter VF) demonstrated that an "observations-based" system possesses greater skill than MOS for short-term forecasts of ceiling and visibility, even when initialized at the same time. This result implies that the improvement over MOS would be even greater for the hours between numerical model run times.

While the statistical forecast system developed by VF focused solely on the benefit of *hourly* surface weather observations, it is possible that additional forecast skill could be attained if higher frequency observations were available in addition to the hourly observations. Archiving of five-minute observations began in the mid-1990's at select Automated Surface Observation Systems (ASOS) and Automated Weather Observation Systems (AWOS) around the U.S. This established a five-year archive of high-frequency observations; a suitable database to examine whether higher frequency surface weather observations may yield further improvements in observations-based statistical forecasting systems. Therefore, a study was undertaken to quantify whether or not the increased temporal resolution of surface observing networks yields improvements in the short-term forecasts of ceiling and visibility.

2. DATA

2.1 *Data Sets*

Three data sets are utilized to develop the statistical forecast equations; two possessing hourly observations and one containing these "new" five-minute observations. The hourly observations archives span from October to March of 1982-83 through 1995-96 and 1996-97 through 2000-01 and include observations of temperature, dew point, wind speed and direction, cloud cover, ceiling, visibility and precipitation at various sites around the United States. The earlier data set is used solely to develop the climatology of all sites whereas the latter is utilized for both climatology and equation development. In addition, the archive of five-minute ASOS observations, obtained from the National Climatic Data Center (NCDC), spans from November to February, 1996-97 through 2000-01, and includes the same weather parameters as listed above. Only high-frequency observing sites in the New York City area are considered.

2.2 *Data Preprocessing*

When deriving observations-based statistical forecast equations, it is imperative to always utilize the best possible data. Ensuring this requires checking for "bad" data (i.e. inconsistencies in the data set), identifying instances of missing data and developing techniques for the replacement of the bad or missing data with surrogate values.

Leyton and Fritsch (2002; hereafter LF) outlined techniques for replacing bad or missing hourly observations using a combination of climatology, conditional climatology, persistence and nearest-neighbor data. However, other techniques had to be considered for replacing bad or missing high-frequency observations.

The replacement techniques described by LF for the bad or missing hourly observations were also applied to missing five-minute observations at the top of each hour. Other procedures are considered for observing times other than "hourly" times (i.e. the high-frequency values). Departure from climatology (conditional climatology for ceiling and visibility) for a given hour is applied to the climatology (conditional climatology) for the following hour. Then, a change in value from the

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* *Corresponding author address:* Stephen M. Leyton, 503 Walker Building, University Park, PA 16802; e-mail: leyton@psu.edu

actual observation to the "projected" observation is calculated. Linear interpolation is then applied so that this change is equally spread through the hour. If at any time a real "non-hourly" observation is reported, a new "projected" observation for the top of the following hour is determined, a new change in value is calculated and linear interpolation is reapplied. Following the work of Hilliker (2002), if 30 minutes elapse without a real "non-hourly" observation, then nearest neighbor techniques are used to replace that observation. If a real "non-hourly" observation exists at any time following this 30-minute period, then linear extrapolation techniques are resumed.

2.3 *Predictands*

Many locations in the northeastern United States are affected by low ceilings and visibilities throughout the winter. While developing and testing forecast equations for all sites in this region would be a tedious task, a sufficient number of stations must be considered in order to properly identify the forecast improvements provided by these new data sets. Therefore, since the focus of this study is the benefits of high frequency observations, all five high-frequency observing sites in the New York City area (BDR, EWR, JFK, LGA, and NYC) were used to develop and test forecast equations.

Ceiling and visibility thresholds were selected based on criteria currently used by the FAA to determine flight rules. Therefore, ceiling heights of 500 ft., 1000 ft. and 3000 ft. as well as visibilities of 1 mi. and 3 mi. are considered as predictand thresholds at each site.

2.4 *Predictors*

Consistent with the work of VF and LF, the final set of predictors includes the predictand value (in binary format) at the forecast site and its 10 nearest neighbors, the 26 other observational terms from the forecast site, the smoothed values for non-predictand variables (average of forecast site and nearest neighbor conditions) and several climatic terms, including sine and cosine of the day of year as well as the climatology of the predictand at the forecast site. These predictors were utilized when developing 1-h forecast equations at the high-frequency observing sites.

The inclusion of the high-frequency observations in addition to the standard "hourly" observations required additional consideration in order to maintain a manageable pool of predictors. To include the observational terms at the forecast site for each five-minute interval would, however, overwhelm the statistical program formulating the equations. Therefore, the information provided by these five-minute observations must be condensed into fewer but still valuable terms.

Because the most recent observation of the predictand at the forecast site and nearest neighbors provide the most predictive information, the following ceiling and visibility "statistics" were calculated: trend, standard deviation and fraction of observations exceeding the threshold. These statistics were computed for the 15, 30 and 60 minutes prior to the most recent five-minute observation.

Therefore, when developing 1-h forecasts, these high-frequency statistics were made available in addition to the data provided by standard hourly observations: the observational data from the forecast site, the predictand value at each nearest neighbor, the smoothed observational values and the climatic terms. Meanwhile, when making forecasts at shorter intervals, the pool of potential predictors included the most recent five-minute observation at the forecast site, the predictand value at the other five-minute sites, the smoothed values from the most recent five-minute observations and the statistics.

2.5 *Equation Development*

Because the need to make a 1-h forecast can arise at any time (not just at the top of each hour), an accurate test of the additional predictability obtained by using high-frequency observations is to make forecasts between hourly observations. Therefore, forecast equations were developed for not only the top of the hour, but at 15, 30 and 45 minutes past the hour as well. The baseline forecasting system uses the high frequency observations to obtain the predictand but only the standard hourly observations in the pool of potential predictors. Meanwhile, the alternative forecasting system considers the high-frequency observation statistics in addition to the standard hourly observations.

When making forecasts at intervals shorter than 1 h, the data provided by the five-minute observations at the forecast site and its neighbors becomes increasingly more valuable than the hourly observations. Moreover, if new observational data is made available at such short intervals, a rapid-update forecast system should utilize these observations to improve upon its most recent forecast. For instance, if the system makes a 1-h forecast at 1800 UTC for 1900 UTC, when the 1805 UTC observation becomes available, the system should make a 55-minute forecast for 1900 UTC. As each new observation becomes available, the forecast should be updated until it reaches a five-minute forecast. Therefore, a rapid-update forecast system is developed for lead times ranging from 5 minutes to 55 minutes.

3. RESULTS

3.1 *Application to Independent Data*

Independent data sets were used to evaluate the skill of the forecast systems. A cross-validation technique was utilized to develop multiple independent data sets, such that one winter period was used as the independent data set for the equations created from the other four winter periods combined (the dependent data set). Any observation in the independent data set that contained a surrogate value (i.e. not a real value) for the predictand was eliminated from the verification data set. However, observations with surrogate predictors were retained.

3.2 *Verification of Forecasts*

Forecast skill is expressed as the percent improvement in mean squared error (MSE) over persistence climatology by both the baseline and high-frequency forecast systems. The MSE is calculated by averaging the squared difference between the forecast probability (0 to 1, inclusive) and the verification (0 or 1) for each of the cases in the independent data set. The skill of the observations-based forecast systems is then expressed as a percent improvement of MSE over persistence climatology.

The skill of the rapid-update forecast system was also evaluated by a comparison to the performance of persistence. While persistence climatology will always be a more formidable benchmark than persistence for measuring forecast skill, as the lead time decreases from 1 h, this difference between the skill of persistence and persistence climatology will also decrease. Therefore, the rapid-update forecasts were compared to both methods in order to identify whether significant improvements exist for very short lead times.

3.3 *Hourly Forecasting System Using High-Frequency Observations*

Probabilistic forecasts were computed for each of the five stations in the New York City area. One-hour forecasts for five different predictands were computed at the top of the hour, as well as at 15, 30 and 45 minutes past the hour.

The results of this study indicate that the improvement of the high-frequency system over the baseline system increases as the forecast initialization time deviates from the top of the hour. For 1-h forecasts made at the top of the hour, the utilization of high-frequency observations provided an additional 1.5-4.5% reduction in MSE to that of the baseline forecasting system (Fig. 1). By 45 minutes past the hour, this reduction increased to 14-17% (Fig. 2). As the threshold of the predictand increases toward the climatology of that phenomenon, the percent improvement over persistence climatology also increases. This is due to the MSE of the persistence climatology forecasts increasing more rapidly than the MSE of the statistical forecast system.

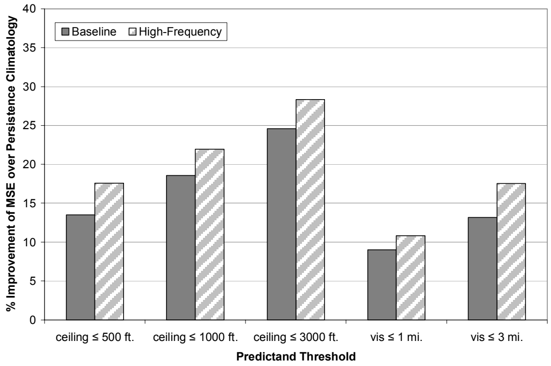

Figure 1: Summary of results for 1-h forecasts made at the top of the hour.

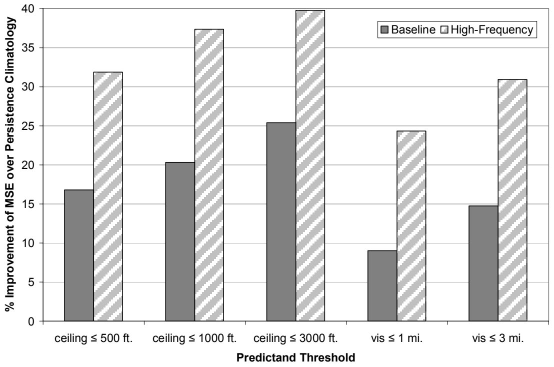

Figure 2: Summary of results for 1-h forecasts made at 45 minutes past the hour.

3.4 *Rapid-Update Forecasting System Using High-Frequency Observations*

Probabilistic forecasts were computed for each of the five stations in the New York City domain. Rapid-update forecasts ranging from 5- to 55-minute lead times were derived for each of the five predictands discussed previously.

Figure 3 details the performance of the rapid-update system when compared to the performance of persistence and persistence climatology for forecasts of ceiling ≤ 1000 ft. at all lead times. The results of this study indicate that the rapid-update forecasting system shows improvement over persistence and persistence climatology for all lead times. Improvements of the rapid-update forecasting system over persistence increased from an average of 3% for a 5-minute lead time to an average of around 22% for a 55-

minute lead time. Improvements of the rapid-update forecasting system over persistence climatology increased from an average of 1.5% for a 5-minute lead time to an average of nearly 14% for a 55-minute lead time.

It is evident from this study that when low ceiling/visibility events are not persistent, an observations-based system is beneficial for forecasts with lead times of as little as five minutes. Moreover, this study indicates that aviation traffic flow managers, with access to high-frequency observations, can make more accurate short-term decisions for takeoff and landing procedures.

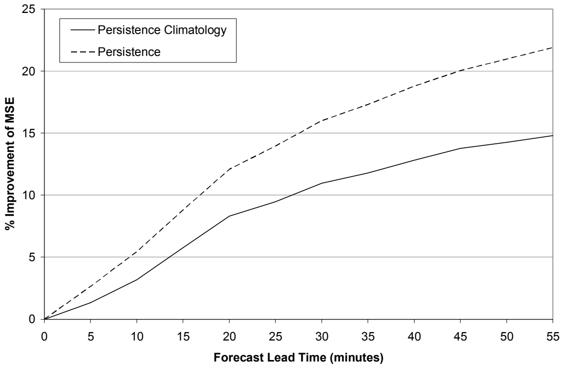

Figure 3: Summary of results for ceiling ≤ 1000 ft. forecasts with lead times of 5- to 55-minutes.

4. SUMMARY

Low ceilings and visibilities plague the northeastern United States throughout the winter. These impeding phenomena impact airports across the region due to departure delays from that airport as well as the arrival of aircraft from across the country. Therefore, air traffic management needs accurate short-term probabilistic forecasts of low ceiling and visibility to maximize airport efficiency. Vislocky and Fritsch (1997) demonstrated that additional forecast skill of ceiling and visibility could be attained by utilizing a forecast system based solely on hourly surface observations. Since their study, high-frequency observations have become available for use in a statistical forecasting system. Therefore, this study investigated whether additional forecast skill could be obtained by incorporating these "new" observations into a forecast system utilizing only hourly observations. In addition, another goal was to examine whether these high-frequency observations could be used to make forecasts with lead times of less than 1-h. The New York City area was chosen for the study since five sites providing these high-frequency observations are in close proximity to one another.

For each high-frequency observation site, a single forecast equation was derived for all hours of the day and each of five predictands; three ceiling and two visibility thresholds. Lead times of 1-h as well as 5-minutes to 55-minutes were considered. Skill scores were computed that represent the percent improvement of the mean squared error over persistence climatology by the probabilistic forecasts. For lead times shorter than 1 h, improvements over persistence were also calculated.

This study revealed that the availability of high-frequency observations provides additional skill relative to that for 1-h forecasts derived from only hourly observations. Because the need to make a forecast can arise at any time, 1-h forecasts were initialized at times other than the top of the hour. For forecasts made at the top of the hour, these additional observations reduce the MSE by an additional 2-4% over the baseline system. For 1-h forecasts made at 15, 30 and 45 minutes past the hour, this reduction in MSE gradually increases to 5-10%, 10-15% and 14-18%, respectively.

Moreover, the availability of high-frequency observations allows forecasts to be made with lead times of less than 1-h. For just a 5-minute forecast, the observations-based forecasting system reduced the MSE by 0-3% over persistence climatology and 1.5-4% over persistence. As the lead time increases, so does the reduction in MSE over persistence climatology and persistence, such that with a 55-minute lead time, the reductions are 11.5-19% and 21-24%, respectively.

In general, these results indicate that more skillful short-term weather forecasts can be attained by incorporating high-frequency surface observations in conjunction with standard hourly observations in current observations-based forecast methods. An updated observation every five minutes reduces the likelihood of mischaracterizing an event and, therefore, results in more accurate probabilistic categorical forecasts.

5. REFERENCES

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