P1.15 TERMINAL CEILING & VISIBILITY PRODUCT DEVELOPMENT FOR NORTHEAST AIRPORTS[†]

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1. INTRODUCTION

Within the FAA Aviation Weather Research Program (AWRP), the Terminal Ceiling and Visibility Product Development Team (TC&V PDT) is responsible for development of forecast guidance products to mitigate the loss of terminal operating capacity associated with low ceiling and visibility restrictions. In particular, accurate anticipation of the onset and cessation of Instrument Meteorological Conditions (IMC) allows the opportunity for air traffic managers to effectively regulate traffic to utilize available capacity. The TC&V PDT approach is to develop forecast guidance solutions that are specific to individual high volume terminals that experience substantial loss of capacity. Due to the inter-hub dependencies of traffic flow, efficiency gains at individual key airports translate to a general reduction of total aircraft delay through the entire National Airspace System. The first key airport targeted was San Francisco International Airport (SFO). A system was developed to provide forecast guidance of the clearing time of stratus cloud that frequently restricts approach capacity during the summer months (Clark, 2002). This prototype system was transferred to the National Weather Service in 2004 (Ivaldi et al., 2006)

The current focus of the Terminal C&V PDT is on ceiling and visibility restrictions associated with synoptic-scale transient weather systems that regularly impact the Northeast U.S. during the winter months, typically from November through April. The runway configuration and instrumentation at many of the major northeast terminals (Boston, New York Laguardia and Kennedy, Newark, Philadelphia, etc.) are very susceptible to IMC weather, resulting in a dramatic reduction in operating capacity.

The multitude of phenomena contributing to IMC (e.g. frontal cloud shields, advection and radiation fog, precipitation of varying intensity and type, etc.) poses a difficult forecasting challenge. The Terminal C&V PDT is pursuing a variety of candidate technologies that will be integrated to provide a comprehensive solution. Trials of these forecast technologies are being developed using the NYC airspace as an experimental domain for both weather and operations. Development is progressing on two fronts: 1) improvement in the delivery of existing C&V information, and 2) development of new forecast technologies. The ultimate objective is integration of forecasts with operational information to provide a complete decision guidance tool.

This paper introduces an experimental display tool and distribution mechanism for delivering C&V data and forecasts, focused on the NYC airspace. Initially, this tool relies on routinely available weather observations and forecasts. The intent of providing such a tool early in the product development stage is to engage the operational community (forecasters, dispatchers, and traffic managers) in the assessment and selection of candidate forecast technologies that are most appropriate for supporting operational decision-making. During development, these technologies will be inserted into the display framework to evaluate their effectiveness in real time trials. An overview of the technologies under consideration is provided.

2. USER NEEDS ASSESSMENT

In March 2002, a meeting of potential product users was held in order to assess the needs of the operational community early in the conceptual stage of product development. The meeting included representation from New York area air traffic management, aviation weather forecasters, commercial airlines, research laboratories, system evaluators, program managers, air traffic requirements, and facilities operations. Topics of discussion included existing aviation weather

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projects, New York City area air traffic flow, the impact of C&V on traffic management decisions, the current paradigm for providing weather information support, and the perspective of commercial airlines regarding the impact of C&V on traffic scheduling and dispatch.

Several conclusions were drawn from the meeting. First, it was recognized that an immediate deficiency existed in the manner in which C&V information is conveyed to operational users. Non-verbal communication of forecast information still relied on the encoded text of the Terminal Aerodrome Forecasts (TAFs) generated by the National Weather Service. Oral communication typically consisted of periodic briefings, with no formal repository for operational decision-makers to review briefed information. Updates or revisions to forecasts needed to be initiated proactively by either a traffic manager or forecaster, and the aggressiveness of such action varied greatly by individual. Since the initial users meeting, there has been renewed effort, including that by the National Weather Service, to improve content delivery, particularly through graphic representation of information.

A second conclusion from the meeting focused on the direct application of the C&V forecasts. Three fundamental applications were cited; the first two were anticipation of both the beginning and ends of C&V restrictions for managing traffic flow, particularly in the administration of Ground Delay Programs. Forecast information was cited as distinctly important at both the strategic time horizon (up to 12 hours) for daily planning of delay program implementation, and the tactical time frame (2 or 3 hours) for modifying plans in the face of changing conditions. Forecasting the end time of C&V restrictions was identified as more important, where available capacity is likely to go unutilized if improving conditions are not anticipated. In addition to forecasting the beginning and end times of events, traffic managers from NY also indicated that there were also times where accurate forecasts of intermittent improvements to conditions (of at least 30 minutes duration) could be exploited during the course of long duration events, if they were reliably anticipated in the tactical time frame.

Another important conclusion drawn from the user community was the benefit of combining weather and operational information to provide an automated guidance tool. For example, rather than simply forecasting a period of C&V impact, a decision tool would identify the appropriate runway configuration, determine the corresponding operating capacity, and match it against the scheduled traffic demand to provide specific guidance on implementation of delay programs.

Based on these conclusions, and through continuing communication with the operational community, the product development team is pursuing development along three parallel lines:

1) Establish a mechanism for delivery of C&V content to serve as a prototype for information presentation, that will engage the operational community in the product development process

2) Pursue candidate technologies that will allow for frequent update (at least hourly) of accurate C&V diagnosis and forecast information targeted for individual key terminals. Integrate these technologies to provide a single presentation of anticipated operational capacity out to 12 hours.

3) Combine forecasts with operational information to create a decision tool for traffic management decisions

This paper focuses on the progress of the first two items, as described in Sections 3.0 and 4.0.

3.0 EXPERIMENTAL DISPLAY

A baseline experimental display was established in early 2005 for delivery of trial C&V products. Two versions of the display are maintained. The first (operational version) is for broader distribution of tested products to participating users within the operational and extended research community. The second is a test version used for development and test of new forecast technologies and display options. The test version is only made available to the primary research and development scientists.

3.1 *Display Description*

The prototype Northeast C&V display has been implemented using the real time data stream from the Corridor Integrated Weather System (CIWS) prototype built and maintained at MIT Lincoln Laboratory. This display consists of two panels:

1) A Regional Situation Display panel showing current C&V conditions in the northeast, and
2) A Terminal Forecast Display panel providing a 12-hour outlook of expected C&V conditions for selected individual northeast terminals.

The baseline version of the display uses only existing standard observation and forecast information, i.e. hourly and special NWS surface observations, radar and satellite images, and NWS TAFs. The display application has been designed with the flexibility to add new observations (e.g. 1-minute surface observations) and forecasts (e.g. those derived from new research and development) as they become available.

The two-panel display is shown in Figure 1. The upper portion shows the Regional Situation Display panel. The information in the display panel is derived from standard surface reporting station observations, radar data, and satellite data. Display of these data types is user selectable from the Configure Layers box in the upper right portion of the display.

Surface observations are displayed using a pre-defined station plot configuration, whereby the user can select to display any configuration of the following parameters: flight category as a color-coded box at the station location, a wind barb plot (also color-coded by flight category), ceiling height, visibility, temperature, dew point, and observed weather type (rain, snow, fog).

The radar overlay option is consistent with the prototype CIWS display, in that it allows either the standard 6-level display, or the 8-level winter display, where Level 1 is broadened to include lower reflectivities and subdivided into three color levels. The satellite overlay is a depiction of cloud coverage at four intensity levels.

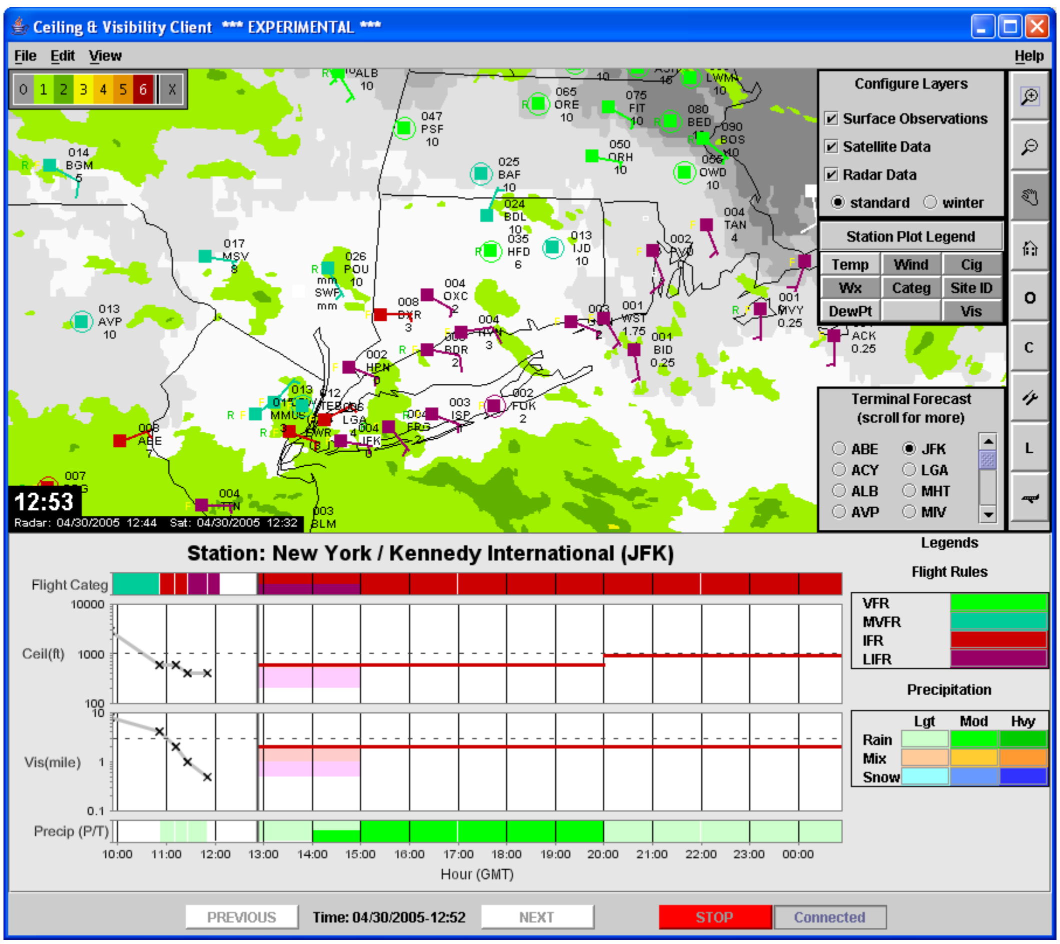

Figure 1. Experimental Ceiling and Visibility Display Product. Upper portion is the Regional Situation Display panel, and the lower portion is the Terminal Forecast panel

The lower portion is the Terminal Forecast panel, which presents observation and forecast information for individual terminals. The current operational version uses existing NWS-generated Terminal Aerodrome Forecasts (TAFs) as input. The panel shows a sliding 15-hour time line which includes the most recent 3-hours of observations, and the forecast out to 12 hours. The forecast panel plots four parameters in the vertical. On top is a color-coded representation of the flight category (VFR, MVFR, IFR, LIFR). Next are the value plots of ceiling and visibility. On the bottom is a color-coded plot of precipitation, including both intensity and type.

The ceiling and visibility plots are presented as a range of values. This was initially done to accommodate the structure of the TAF format, which includes both a prevailing value (shown as a bold horizontal line on the display) and intermittent values (shown as shaded regions). Both the prevailing and intermittent values are color-coded on the display to correspond to the appropriate flight category, to visually represent a forecast change that crosses an aviation-sensitive boundary.

In parallel, a modified test version of the display is available to the development team. This version accepts and displays terminal forecasts from a number of sources, so that the candidate forecast technologies under development (described in 4.0) can be compared and tested in both real time and offline modes.

3.2 *Display Delivery*

The real time source data to support the experimental display is acquired from the data stream for the prototype CIWS system that is hosted at MIT Lincoln Laboratory. Delivery of the experimental display is achieved through local installation of a commercial application (PowerUpdate) that allows data acquisition and software updates via the Internet. Thus, the display is not currently hosted by any single, pre-existing system platform. Participating display users (traffic managers, forecasters, developers, etc.) are directed to a web site to download the application and install it on a local computer. Windows, Unix, and Linux operating systems are all supported by the application. Once installed, the password-protected application is opened to launch the display software and initiate Internet connectivity with a web server at MIT/LL for data acquisition. The application periodically polls for new data every few minutes; newly available data are then "pulled" to update the display. This is shown schematically in Figure 2. In addition to viewing real time information, the display application also allows viewing of historical data that is maintained on the MIT/LL file system.

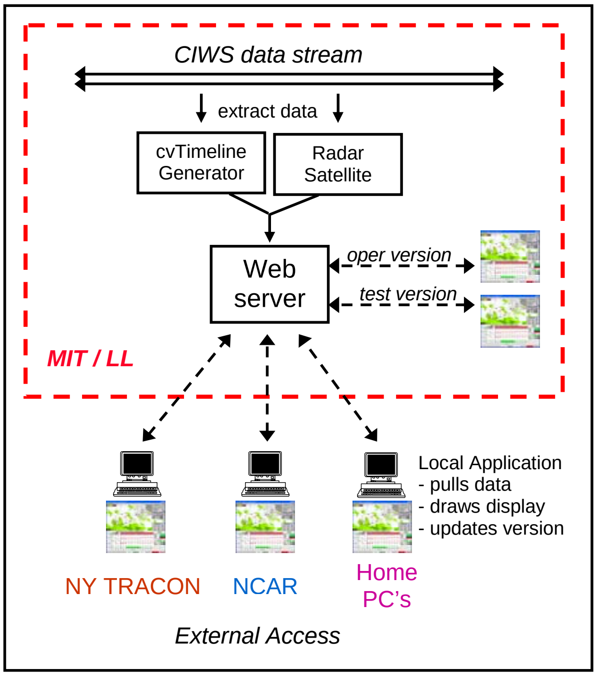

Figure 2. Data acquisition, product generation, and display delivery.

The PowerUpdate application also allows for automated delivery and local installation of any display software updates. When the application is opened, it checks for available software versions that are newer than the currently installed version. If found, the user is prompted to re-start the application. This initiates download and installation of the updated version. This is a particularly useful feature for an experimental display, which is expected to evolve over many iterations.

The first widely released version of the display was made available to external users in February 2005. Particularly of note, the experimental display has been installed on a general purpose computer at the NYC TRACON for voluntary viewing (Allan et al., 2004). Traffic managers at the TRACON are able to comment on the utility of the display presentation and content to help direct ongoing research.

4.0 DEVELOPMENT OF CANDIDATE FORECAST TECHNOLOGY

The TC&V development team is working on a number of independent forecast technologies designed to improve forecasts at specific high impact terminals. The pursuit of multiple technologies is driven by the need to address 1) all of the various physical phenomena contributing to Northeast winter C&V conditions, and 2) both tactical (0-3 hours) and strategic (up to 12 hours) forecast requirements, for which differing technologies are suitable.

The physical phenomena vary by type and spatial scale, for which differing observational data and forecast techniques are appropriate. As for the forecast horizon, it is presumed that the tactical forecast horizon is best served by relying heavily on tracking and trending of high resolution (time and space) observations, while the strategic forecast horizon will necessarily rely more on more holistic numerical weather prediction model applications.

The specific technologies under investigation include:

1) Terminal-specific applications of NWP model output (12-hour horizon).
2) Statistical forecasts using routinely available surface and upper air data (4-8 hour horizon).
3) Application of radar and surface data to forecast visibility reduction in precipitation (0-3 hour horizon).
4) Application of satellite and surface data to estimate and forecast aviation-impacting cloud (0-3 hour horizon).
5) A one-dimensional physical model for forecasting ceiling and visibility dominated by local influences (4-8 hour horizon).

These technologies are being investigated from a terminal-centric perspective, rather than for a more global application (e.g. over a larger horizontal domain). The intent is that each be designed to make a discrete point forecasts of ceiling and visibility, initially at a minimum one-hour resolution, and ultimately at a quarter-hour resolution. Upon successful optimization and testing of these "component" technologies, the individual forecasts will be integrated through an arbitration process to provided a unified objective 12-hour forecast that can be produced automatically and updated with at least an hourly frequency.

An overview of each of the component technologies under development as contributing candidates to the integrated forecast is provided in the remainder of this section.

4.1 *NWP Model Applications*

In order to satisfy the requirement of a 12-hour forecast horizon to meet strategic planning needs, Numerical Weather Prediction (NWP) model forecasts are presumed to be an integral part of a comprehensive solution. This is particularly true beyond the 3-hour horizon, which exceeds the effective range of the observation-based forecasts.

The prolific development and improvement of NWP models for operational application continues to receive abundant attention at the forefront of the meteorological research community. Examples of this are this are the continual improvements in resolution and parameterization being made to the NCEP operational models (in particular, the North American Model-NAM, formerly ETA), the Rapid Update Cycle (RUC) model under development by NOAA Global Systems Division (GSD, formerly Forecast Systems Laboratory), the Navy Research Laboratory's COAMPS mesoscale model, the widely-adapted MM5 regional model originally developed at the Pennsylvania State University, and the regional Weather Research & Forecasting (WARF) model under development for the National Weather Service.

Most of these continuing efforts are focused on making global improvements (i.e. over the entire model domain), through changes in data assimilation methodology, parameterization schemes, model physics, etc. In contrast, the TC&V effort is focused on tailoring terminal-specific applications of model output, with the job of intrinsic model improvements left to the modelers. On this front, two stages of development have been defined:

1) Derive a skillful baseline 12-hour terminal (point) forecast based on an intelligent selection of source model(s), grid point(s), smoothing, historical bias adjustment, etc. optimized for performance at specific locations.

2) Dynamically adjust an NWP-based terminal forecast based on a real time comparison of model output and observed trends.

This effort began with a preliminary statistical assessment of C&V point forecast performance of candidate NWP models, using the corresponding NWS TAFs and Persistence forecasts as a comparative baseline (Bieringer et al., 2006). The candidate models included the operational RUC model and the fifth generation Penn State/NCAR MM5 mesoscale model. The target points for the assessment were four NY-area terminals (Newark, JFK, LaGuardia, and Macarthur-Islip). The MM5 model was run in a nested configuration that provided 27, 9, and 3 km horizontal resolution forecasts centered over New York City (NYC).

In brief, the ceiling height forecasts were found to be more accurate than those of visibility. Ceiling forecasts exhibited a categorical accuracy similar to the TAFs beyond 6 hours; however, the standard deviation of the error distributions was much broader. Performance was more favorable when the spatial variability of the ceiling forecast field was small. As expected, the TAFs outperformed the NWP-derived forecasts in the 1-5 hour time frame.

The statistics for the NWP visibility forecasts were more problematic. The translation algorithms used to characterize visibility from the NWP forecasts showed a distinct low bias. The standard deviation of the categorical forecast errors and the bimodal distribution suggest that the forecasts and/or translation algorithms are not very robust. It is evident that the visibility forecast accuracy will need to be significantly improved, beginning with a deeper examination of the translation algorithms and the type of situations which lead to the bimodal distribution.

Focus now turns toward strategies for improvement, based on recommendations drawn from the initial analysis. Software has been developed which extracts 12-hour terminal ceiling and visibility forecasts from the NWP models and packages them into an operational data stream to feed the prototype terminal C&V display. This will allow for real time monitoring of event evolution and model performance comparison during the winter of 2005-06. Development of bias identification and correction algorithms along with the testing and refinement of the NWP-based terminal C&V display product will be a major thrust of near- and medium-term development.

4.2 *Statistical Forecast Development*

This class of forecast technology seeks to apply statistical forecast approaches using routinely available weather observations, such as standard NWS hourly surface observations and twice-daily upper air balloon soundings. (Robasky and Wilson, 2006). As such, it lends itself to broad-scale adaptation to most medium to large airport terminals within the NAS, provided that a sufficient database of surface and upper air observations are available. This approach was successfully demonstrated in support of the SFO Marine Stratus Forecast System. (Clark, 2002). It is based on non-linear regression and includes unique components for optimized predictor scaling, predictor subset selection, and the identification of synergy between predictor pairs. The intent is to adapt the SFO technology to meet the specific forecast needs of the Northeast terminals.

This adaptation will need to account for the differing nature of the predictands. For SFO, the objective was to make a deterministic forecast of a single daily event, i.e. clearing time of stratus clouds from the approach zone. In contrast, the desired result for the northeast C&V application will be hourly-updated predictions of specific ceiling and visibility values with a minimum one hour time resolution out to at least an 8-hour forecast horizon.

An important element of the statistical approach that will be retained is the establishment of a suitable methodology for case stratification. In a real time operational system, this consists of dynamic assessment of the current weather regime, and application of the corresponding set of statistical forecast equations. This challenge of determining an appropriate day-type classification will draw upon the Northeast C&V climatological analysis performed by Tardif (2006).

The initial trial application for this technology during the winter of 2005-06 will be an hourly ceiling forecast for New York's LaGuardia airport. Details of this trial and preliminary model development results are provided in Robasky and Wilson (2006).

4.3 *Radar-based estimate of visibility reduction due to precipitation*

This technology seeks to exploit the availability of high resolution radar and surface data in order to estimate short term (less than 3-hours) changes in terminal visibility resulting from precipitation. This development has two primary components. The first is correlation of radar intensities to observed surface visibilities, and subsequent tracking to forecast terminal-specific impact. The second is an accurate discrimination and forecast of precipitation phase or type (rain, snow, mix) upon which the radar-visibility correlation is dependent.

The visibility correlation and tracking work will be adapted from the results of Dixon et al. (2005). The premise is that radar reflectivity can be dynamically correlated to observed surface visibilities, and tracked to forecast impact on individual terminals. The correlation component has two parts. First is a proper identification of the observed radar return with the appropriate surface weather station for which observed visibility is available. This spatial identification requires an accurate estimate of height of the observed radar echo, the particle fall speed, and the local vertical wind profile for properly estimating the particle fall trajectory. This is illustrated schematically in Figure 3.

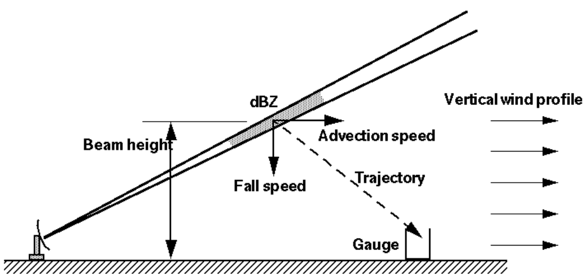

Figure 3. Particle trajectory for wind profile with no wind shear. (Dixon et al., 2005).

The second part of the correlation is the calibration of the Radar-Visibility relationship. This is done by examining visibility extinction coefficients from the surface observation and correlating them with the observed reflectivity echo. Since this relationship varies with the nature of the precipitation (water content and phase), the process is done dynamically to achieve the proper calibration.

Once the appropriate radar-visibility relationship has been established, the visibility impact on a specific terminal is forecast via extrapolation using echo tracking vectors. A real time feasibility trial of this technology is planned for the winter of 2005-06.

The other important aspect of radar-based visibility estimation is proper discrimination and forecast of precipitation type (i.e. liquid or frozen water phase). An example of the variability of surface visibility with precipitation phase is shown in Figure 4.

Toward this end, a parallel effort is underway to improve this capability using readily available real time information and technology (i.e. independent of potential sensor-based improvements, such as dual-polarized radar). This effort seeks to derive an empirical relationship between a host of observed meteorological parameters and observations of precipitation type. These relationships are used in a weighted formula to compute the conditional (upon the observation of precipitation) probability of precipitation type at individual points within a gridded field. These probabilities are then quantized to a deterministic precipitation type (rain, snow, or mix), and mapped to a corresponding radar echo image to generate a precipitation type display (Figure 5). Tracking vectors are used to generate a forecast map of precipitation type.

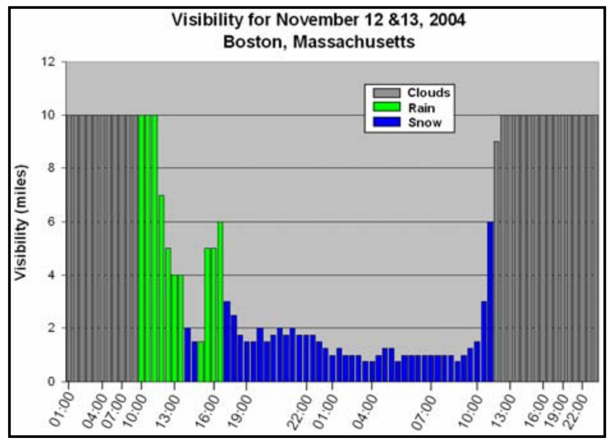

Figure 4. Variation in observed surface visibility during transition from rain to snow during winter event at Boston Logan International Airport.

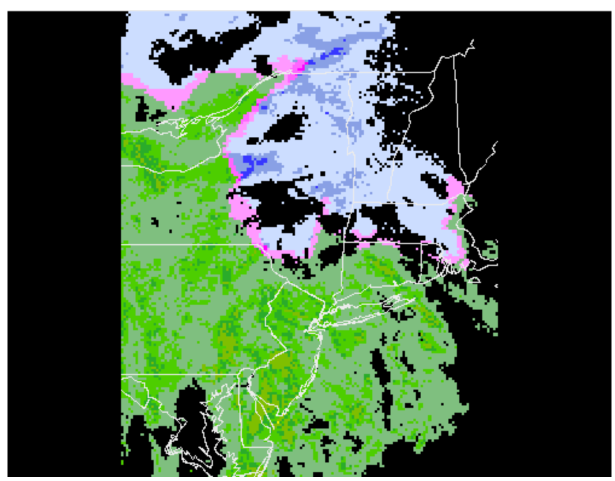

Figure 5. Precipitation type depiction; blue shades indicate snow, pink mix, and green rain.

A satisfactory algorithm for generating precipitation type via a parameter-weighted formula was developed and tested during 2005. The algorithm showed good performance in discriminating both snow and rain. Instances of mixed phase precipitation, as expected, were found to be more difficult to identify accurately.

Both the precipitation discrimination and tracking methodologies will be tested and implemented during the winter of 2005-06 as part of the enhanced winter mode forecast within the prototype CIWS system. The precipitation phase discrimination product will also replace the existing precipitation overlay on the Regional Situation panel of the experimental C&V display.

4.4 *Satellite-based estimate of ceiling height*

Improvement in satellite sensing technology offers promise for use in automated monitoring of cloud shield impact in terminal airspace in the tactical forecast horizon time frame (0-3 hours). A first order challenge is to use satellite imagery to generate a cloud mask product that provides an accurate representation of cloud-free airspace. This objective will be expanded to provide an assessment of aviation-impacting cloud shields (i.e. cloud with sufficiently low bases to impose terminal capacity restrictions), developed in combination with surface ceilometer reports. This effort follows the work done at Naval Research Laboratory (Bankert et al., 2004), where a cloud ceiling estimate system is being developed that exclusively uses satellite data for regions where no local observations are available. The initial step will be an accurate plan-view diagnosis of aviation-impacting cloud, with the intent to develop a predictive product that exploits real time tracking methodologies.

The cloud mask work will begin in 2006, expanding on previous efforts performed in this area. Two cloud mask algorithms are under consideration for implementation on the satellite ground station hosted at MIT Lincoln Laboratory. The first is from the Support of Environmental Requirements for Cloud Analysis and Archive (SERCAA) program (Gustafson, et al., 1994), in which cloud analysis algorithms for both polar-orbiting and geostationary weather satellites were developed to support climate and global change studies. The second algorithm under consideration was developed at NASA/MSFC Global Hydrology and Climate Center (GHCC) as part of a program known as the Short-term Prediction and Research Transition (SPoRT) to infuse products developed from NOAA and NASA research into NWS forecast operations and decision-making at regional and local levels (Jedlovec and Laws, 2003).

4.5 *One-dimensional physical model*

A known deficiency in the technologies described up to this point is limited skill in instances where low clouds and fog are predominantly driven by local influences such as topography and proximity to maritime air. Toward this end, the suite of candidate technologies under development includes a one-dimensional (column) physical model to mimic the evolution of the heat and moisture budget in the atmospheric boundary layer in order to capture these local effects.

This effort builds upon previous applications of the COBEL (**Co**uche **B**rouillard **E**au **L**iquid) model. COBEL was originally developed for forecasting the onset of radiation fog in northern France (Guedalia and Bergot, 1994). It has since been adapted as one of the component forecast models for forecasting the time of cloud dissipation as part of the SFO Marine Stratus Forecast system (Tardif and Zwack, 1994; Clark, 2002).

COBEL requires as input an accurate estimate of the initial structure of the lower atmosphere, then applies high resolution calculations of boundary layer physical processes in order to model the vertical evolution of fine scale structure on the local scale.

A rudimentary trial of this capability for northeast C&V applications was demonstrated by the University of Quebec at Montreal (UQAM) for the NYC area during the winter of 2004-2005. The model was run twice daily using a variety of initialization schemes: 1) NWS sounding from Brookhaven, NY, 2) RUC model initialization field, and 3) observations from an instrumented tower at Brookhaven National Laboratory (Tardif et al., 2004). The model provided forecasts of changes to the vertical profile of liquid water content; an example time-height profile is shown in Figure 6.

This initial feasibility trial will be expanded in 2005-06 in order to make the model more suitable for providing accurate real time forecasts. The operational COBEL implementation for forecasting low ceilings and fog at Charles DeGaulle International Airport in Paris (Bergot, 2004) is being used as a template for moving forward. Through the initial feasibility trial and Bergot's work, it is evident that an important component for future success will be the capability to apply a variational data assimilation scheme using local observations to initialize the model. Also, an improved translation algorithm will be required for converting liquid water content into a corresponding surface visibility.

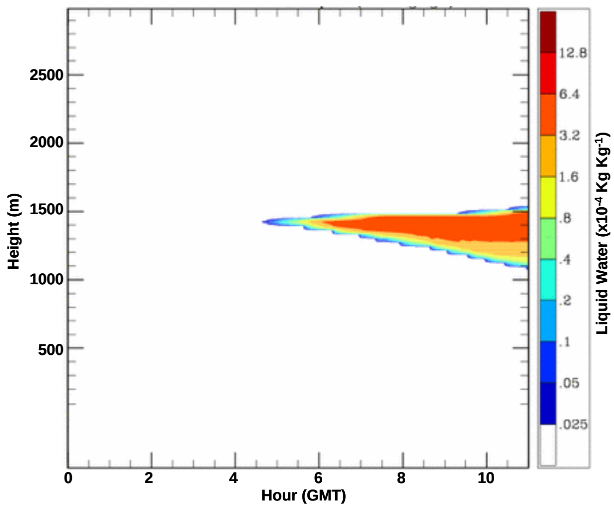

Figure 6. Time height profile showing deepening layer of liquid water content, based on COBEL model output for Brookhaven, NY, initialized at 00 GMT on 8 May 2005.

5.0 SUMMARY

The Terminal C&V Product Development Team has established a flexible framework for development of forecast technologies that will serve as components in a comprehensive tool to aid traffic management decision-making. The experimental display and delivery application allows for continual contact with the operational community during the development process, and provides a vehicle for testing and comparing candidate forecast performance both in real time and in review mode.

Most of the technical effort in advancing C&V forecast capability thus far has been focused on investigating the feasibility of selected candidate technologies, and laying the groundwork for more extensive analysis. Attention can now be directed toward refining the individual forecast applications, and assessing the suitability of each in contributing toward an integrated terminal ceiling and visibility forecast product.

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