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3.2 ADVANCED TERMINAL WEATHER PRODUCTS DEMONSTRATION IN NEW YORK*

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1. INTRODUCTION

Weather continues to be a significant source of delay for aircraft destined to and departing from the New York metropolitan area, with weather delays through the first half of 2004 reaching levels not seen since 2000. In Allan et al. (2001), it was shown that total arrival delays on days with low ceiling and visibility at Newark Airport (EWR) averaged 210 hours, increasing to an average of 280 hours on days with thunderstorms impacting EWR operations. An analysis of Ground Delay Programs (GDPs) due to weather in the National Airspace System was performed for 2002-2003[1]. Low ceilings, thunderstorms, snow, and wind were all shown to be significant sources of delay (Figure 1). These same weather conditions that lead to GDPs often also lead to holding and long departure delays.

In 1998, demonstration of a prototype Integrated Terminal Weather System (ITWS) began in the New York area, helping significantly reduce terminal delays from convection, high surface winds, and vertical wind shear (Allan et al., 2001). In 2002, a new demonstration system, the Corridor Integrated Weather System (CIWS), was introduced at New York Center (ZNY) to help mitigate convective weather delays in the enroute airspace. Substantial benefits were realized from this system and are documented in Robinson et al. (2004).

While systems such as ITWS and CIWS have helped significantly with convective weather, much has been learned during the field-testing of these systems about areas where existing research and technology could be leveraged to reduce weather delay in areas that have not been addressed previously. This paper will discuss four experimental products that recently have been or will be fielded in the NY area and how they are expected to benefit the aviation system. Enhancements to the Terminal Convective Weather Forecast (TCWF) address delays in convective weather, snowstorms, and steady rain. The newly fielded Route Availability Planning Tool (RAPT) addresses departure delays in convective weather. The Ceiling and Visibility (C&V) Diagnosis and Prediction Product will address delay due to low ceiling and visibility. The Path-Based Shear Detection (PSD) tool is expected to help both to reduce delays on days with high winds and to indicate regions of potential low altitude turbulence.

2. TERMINAL CONVECTIVE WEATHER FORECAST

Developed by MIT Lincoln Laboratory under the FAA Aviation Weather Research Program, the Terminal Convective Weather Forecast (TCWF) has been operational in NY since 1999. During this time period, it has seen a number of enhancements brought about in part by NY traffic manager requests. Recent upgrades included forecast improvements and a new "winter" forecast mode. Since the forecast improvements are discussed in another paper (Wolfson et al., 2004), this paper will only discuss the new "winter" forecast mode and its benefits.

New York users requested in the winter of 2002-2003 that the TCWF be modified to make it more useable on days when snow was affecting the airports. Because it was developed with convective weather usage in mind, TCWF represented past and current weather in the standard representation of six-level reflectivity. Likewise the forecast display was designed to show forecast regions of convective weather. This presentation was problematic for users during the winter when snow fell. The reflectivity values for snow are typically much lower than liquid precipitation. Light snow would often fall at the airports, yet the display would show very little precipitation. In addition, the color scale used previously by TCWF was not sufficient to depict the banding structure of most snowstorms. Regions of heavier snowfall were often indistinguishable from regions of lighter snowfall, making it difficult for traffic managers to determine when to reduce demand in response to lowered capacity in heavier snow.

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[1]Dates and causes of GDPs were supplied by the Air Traffic Control System Command Center (ATCSCC). Hours of delay were calculated from the Estimated Departure Clearance Time (EDCT) delay minutes for the corresponding dates from ASPM. Where EDCT delay was recorded but did not match a GDP, the total number of unexplained EDCT delay was distributed to each delay cause in proportion to the explained EDCT cause.

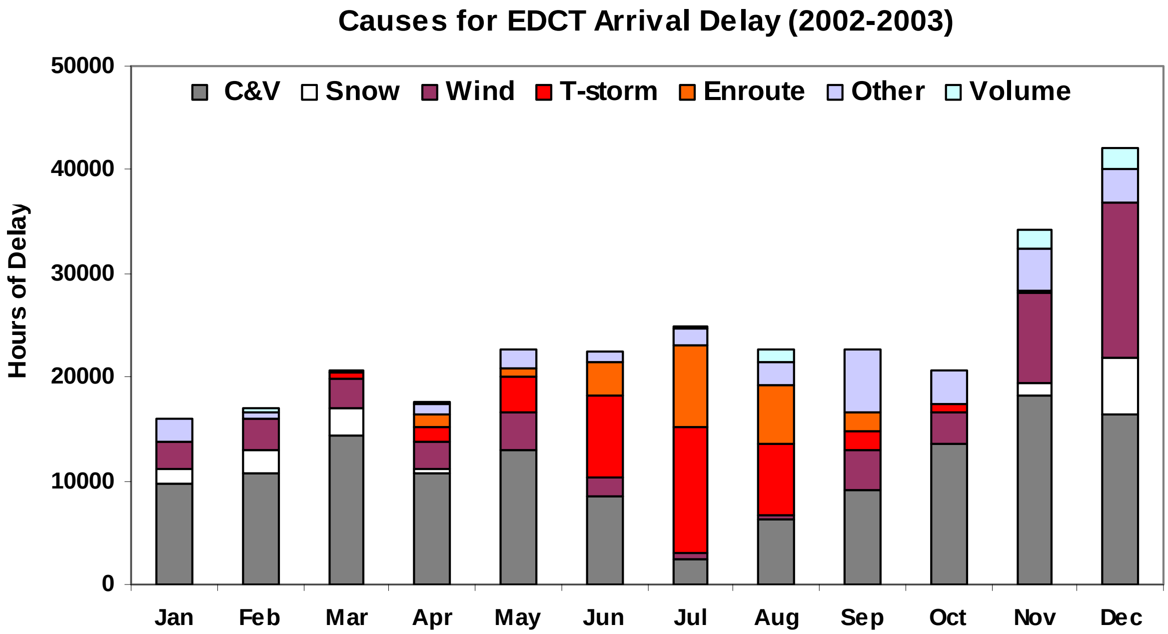

Figure 1. Hours of EDCT delay in the NAS by cause for each month. In cases where the cause of the GDP is given as Enroute, the real cause is usually due to thunderstorms in the enroute domain.

Because of the suggestion by the NY TRACON (N90) for an improved winter display, TCWF was modified for the winter seasons of 2002-2003 and 2003-2004. The new winter mode of TCWF made it easier to see and track the spatial variations in snowfall. TCWF was further modified to track precipitation using composite reflectivity, and data from the Terminal Doppler Weather Radars from EWR and JFK were added to the radar mosaic. Figure 2 illustrates the new display during a snowstorm on 10 February 2002. The standard TCWF presentation would have made it difficult to differentiate between the heavier snow falling in southern New Jersey and the lighter snow falling over New York City and Long Island..

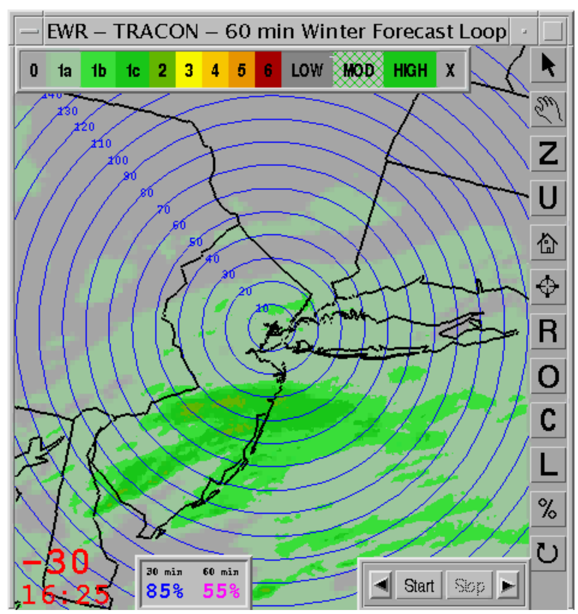

Figure 2. Image from TCWF image loop on 10 February 2002 showing weather 30 minutes prior to current time of 16:55.

2.1 Operational Benefits of Winter TCWF

The snowfall in the New York area was well above average during the winters of 2002-2003 and 2003-2004, and the benefit to users of the modified TCWF was immediate. There were multiple cases where traffic managers told us they used the winter forecast to avoid implementing ground delay programs (GDPs) at the airports for snow, or to shorten the length of GDPs. In addition, dispatchers at the Continental ramp tower were able to use the forecast to change their de-icing fluids and reduce holdover times for aircraft. On 10 February 2002 (Figure 2), GDPs were avoided by using TCWF to determine that the heaviest snow bands would remain south of the New York airports. The New York TRACON estimated that airlines saved over $1,000,000 in direct operating costs as a result. In 2003, there were 4 days documented where GDPs were either cancelled (3 times) or shortened (twice) as a direct result of the winter forecast.

In the spring of 2004, a new release of the convective forecast was made to ITWS. One of the items included in the release was to make the winter mode of the forecast available to users year-round. This was to avoid manually turning the winter mode off and on each spring and winter. Additionally, the winter mode was shown to provide benefits during stratiform rain events occurring outside the winter season. Further details can be found in Wolfson et al. (2004).

3. ROUTE AVAILABILITY PLANNING TOOL

Developed by MIT Lincoln Laboratory with funding from the Port Authority of NY and NJ, the Route Availability Planning Tool (DeLaura and Allan 2003) has been operational in the New York area since late summer 2002 and is available to users of the New York ITWS. It helps traffic managers and airlines determine whether departing aircraft will encounter hazardous weather along their intended flight plan in order to improve airport departure rates and alleviate long departure queues during convective weather.

RAPT provides a timeline that shows the departure route status as a function of departure time. The route status is derived from three inputs: convective weather forecast from CIWS, an echo top forecast calculated from the CIWS echo tops field, and 4-D flight trajectories for jets on each departure route. The route status for each departure is color coded similar to a traffic light: red if the route is blocked, yellow if there is significant risk of route blockage, and green if the route is open.

Because convective weather often moves rapidly, RAPT includes an estimate of the departure aircraft trajectory, so that, for example, a route is shown as open if the forecast indicates that the blockage will have cleared by the time the departure reaches that portion of the route. Figure 3 is an example of the RAPT display.

While demonstrating RAPT in New York, several days were identified where routes were shown as blocked in association with high VIL, but where traffic continued to fly the routes because the storm tops were low enough to fly over. Robinson et al. (2004) reported that one of the biggest benefits from the CIWS was a high resolution graphical echo tops product that allowed traffic managers to identify this situation: regions of convective activity where storm tops were low enough for aircraft to fly over. In order to more accurately depict route blockage that takes into account both weather level and storm height, an echo top forecast derived from the CIWS VIL forecast and echo top product was developed. We briefly describe its main features in the next section.

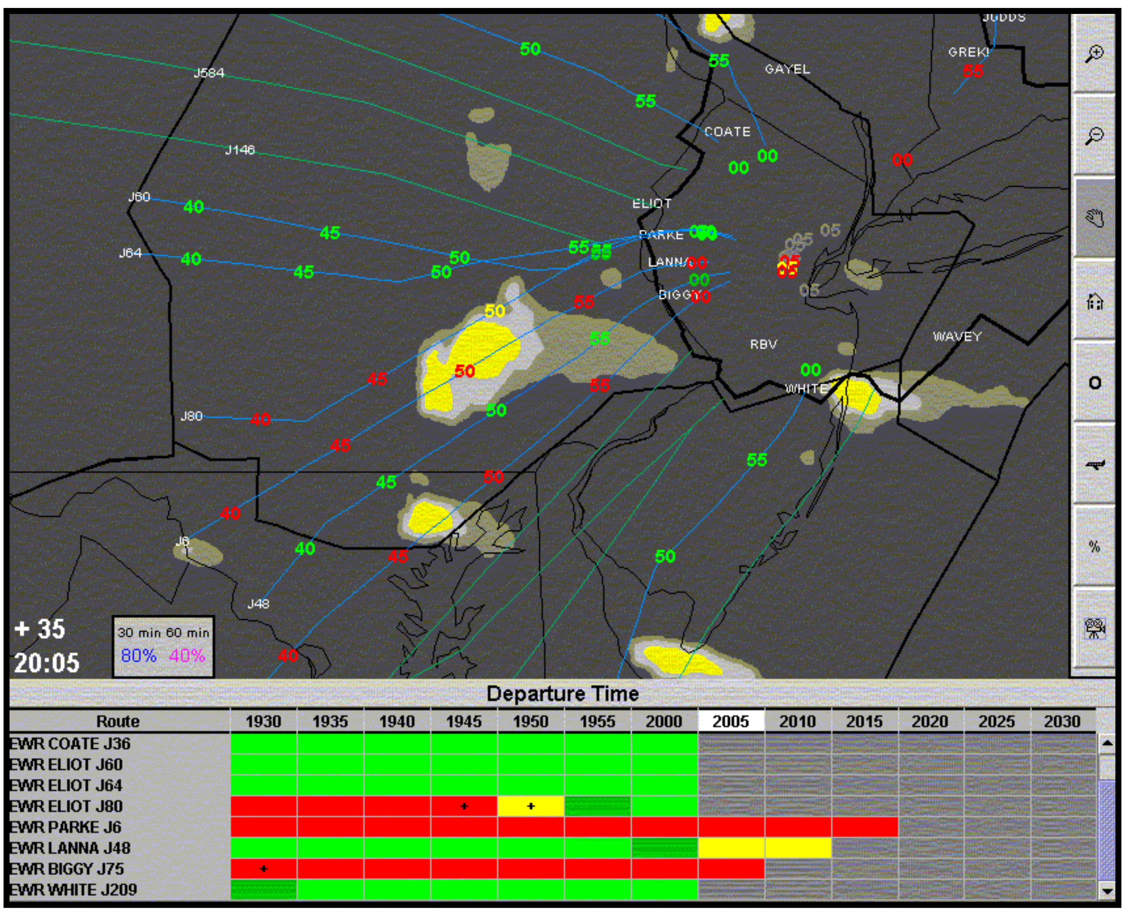

Figure 3. Example of RAPT display. Forecast movie loop display shows animated hazardous weather forecast with projected departures (colored numbers) overlaid. Departure route status timeline is shown in the lower half. Colored numbers in the animation correspond to future departure times and route status shown in the timeline. Pluses (+) in the timeline indicate where a departure status warning level has been increased due to high echo tops.

3.1 RAPT Echo Top Forecast Algorithm

An operational echo tops prediction algorithm has requirements that are closely related to flight parameters. For example, an echo tops forecast that accurately predicts the time and location of operationally significant "low echo tops" (<25,000 feet) provides considerable value even if there is appreciable error in the height; in these cases, any predicted height less than 25,000 feet is acceptable. Likewise for high tops; a prediction is acceptable if it predicts significantly high echo tops (>35,000 feet). An operational echo tops prediction is most sensitive to errors when the echo top heights are in the range between 25,000 and 35,000 feet where it is most difficult to determine if storms characterized by high levels of precipitation can be safely flown over.

With these requirements in mind, we developed an echo top forecast algorithm to support the RAPT in New York. The forecast algorithm is based on two broad assumptions:

1) *Echo top heights throughout a region are correlated with VIL (Vertically Integrated Liquid)*. This assumption is based on observational experience. There are many times when this assumption does not hold such as on a day with convection embedded in heavy stratiform precipitation. The algorithm will not perform well when this assumption does not hold.

2) *The correlation between VIL and echo tops varies slowly in time and space*. The initial goal was to provide value on days where echo tops were low across a sizeable region but where convection was still able to develop. On this type of day, large-scale atmospheric features, which vary slowly, are generally responsible for keeping echo tops low. This assumption is not expected to be valid on mid-summer days where the dominant convective type is pop-corn.

The algorithm calculates trends in the correlation between echo tops and VIL and then uses the VIL forecast from CIWS to assign echo top values to pixels in the VIL forecast

At each time, all pixels are separated into 'convective' and 'non-convective' partitions using the RUC Convective Cloud Top Potential (CCTP) product. Using data from the previous hour, an echo top vs. VIL trend is calculated for each CCTP partition. The trend is then extrapolated to the next hour. Note that the predicted echo top height is bounded by CCTP at the top. The echo top height vs. VIL mapping that is predicted by the extrapolated trend is then used to assign an echo top height to each pixel in the VIL forecast. The forecast is currently being applied to an operational domain that roughly covers southern NY, NJ and eastern and central PA.

Figures 4 and 5 show the Echo Tops forecast results from 23 September 2003, in which a strong line of precipitation passed across PA and southern NY over a period of several hours. Echo tops remained low throughout the event, and traffic flowed freely despite the high VIL that persisted throughout the event. Figures 4 and 5 show truth, 30-minute prediction and errors, and 60-minute prediction and errors valid at 1245Z.

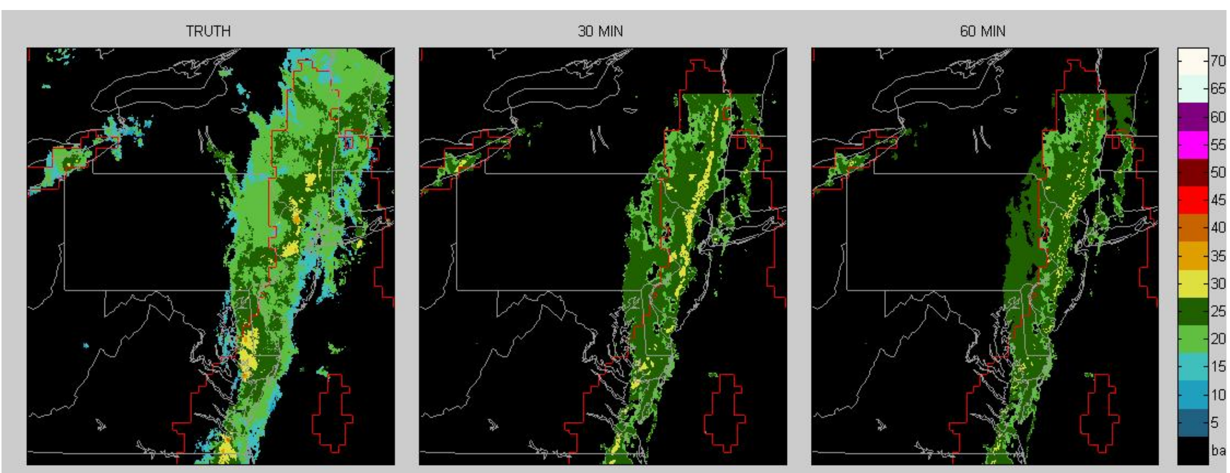

Figure 4. Echo tops for 23 September 2003 a) Verification b) 30 min forecast, and c) 60 minute forecast.

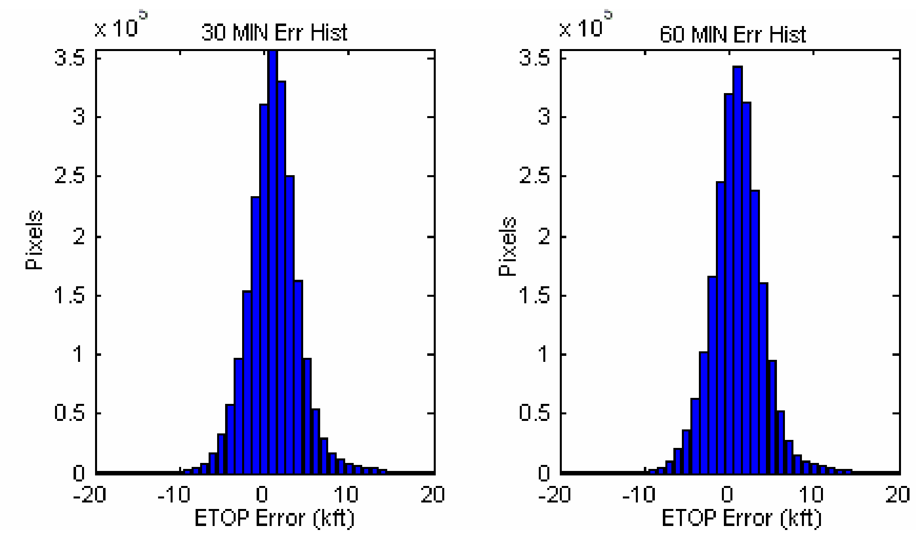

Figure 5. Histogram of echo top forecast errors for 23 September 2003. Error distributions for the 30 and 60 min forecasts are virtually identical due to the stability of the echo top to VIL relationship throughout the day.

The operational echo tops prediction was deployed in June, 2004. Performance statistics gathered over the summer include both echo top height prediction errors and changes in route availability guidance as a result of echo top prediction. Future work includes the development of improved pixel partitioning and better trending techniques to determine the VIL to echo top mapping.

3.2 Operational Benefits of RAPT

In 2003 alone, more than 800 hours of primary delay was avoided through the use of RAPT. The most common reported benefit was opening a route early, or averting a route stoppage. Airlines have been using it to brief pilots, who have taxied out, on the status of their filed routes and what can be expected within the following hour. Coded Departure Route status was added in the spring of 2004 that should make it easier for airlines to identify reroute alternatives rapidly.

Evaluation of benefits in 2004 is ongoing, and usage has been up considerably from 2003. Future work will focus on improvements to the echo top forecast, and continuing the integration process by ingesting live traffic data from ETMS or other sources and providing aircraft specific timelines of departure opportunities.

4. CEILING AND VISIBILITY DIAGNOSIS AND PREDICTION

Low ceilings and poor visibility often accompany the widespread frontal storms and smaller-scale fog, cloud and precipitation systems that dominate adverse weather in the Northeast U.S, particularly from late autumn through early spring. These ceiling and visibility (C&V) events impose major restrictions on the air traffic capacity and efficiency of terminal-area and regional airspace. The high density of air operations and frequency of winter season events make the New York City area a potential beneficiary and excellent candidate for applied research and development to address improved techniques for diagnosis, prediction and aviation decision-making under adverse C&V conditions.

Reduction in delay associated with these conditions is possible on two fronts. First, more accurate anticipation of the start and stop times of long-duration C&V events would allow for efficient implementation of Ground Delay Programs which do not incur unnecessary delay (see Figure 1). This is particularly important at the tail end of extended events when there is often reluctance to end delay programs in anticipation of improving conditions. Second, within a long duration event, there is opportunity to exploit anticipated temporary improvement in conditions for periods of 30 minutes or more. Since delay accumulates exponentially with the amount of time operating in a deficit capacity condition, even temporary increases in capacity can have a significant impact on delay reduction.

Through the FAA's Aviation Weather Research Program, product development to exploit these potential benefits has been initiated along two parallel fronts. First, there is an effort underway to package existing C&V information and forecasts to better communicate to air traffic managers the expected capacity-impacting conditions in both the tactical (0-3 hours) and strategic (out to 12 hours) time horizons. Second, research initiatives are underway to exploit technological advances in weather sensing and modeling in order to improve the content of C&V forecasts that impact aviation operations and traffic management.

4.1 Information Delivery

The first tangible effort in this direction is the processing and packaging of existing C&V forecasts to better serve the air traffic management decision-making process. The aviation community currently uses the Terminal Aerodrome Forecasts (TAF) provided by the National Weather Service. These forecasts are issued routinely four times per day (at 00, 06, 12, and 18 GMT), and amended throughout the day as necessary. There is currently opportunity for improvement in the delivery of this information, both in terms of presentation and timeliness. The raw TAF is made available to the user community via an encoded alphanumeric message, which is difficult to interpret. Air traffic managers rely on this information to be conveyed via conference or briefing with meteorological staff or aviation weather services. Furthermore, there is no mechanism readily available for quick review of previously briefed information. The timeliness in receiving amended information during rapidly changing conditions is hindered by both the latency in generating the amendment, as well as the additional time required to deliver the information to the end users.

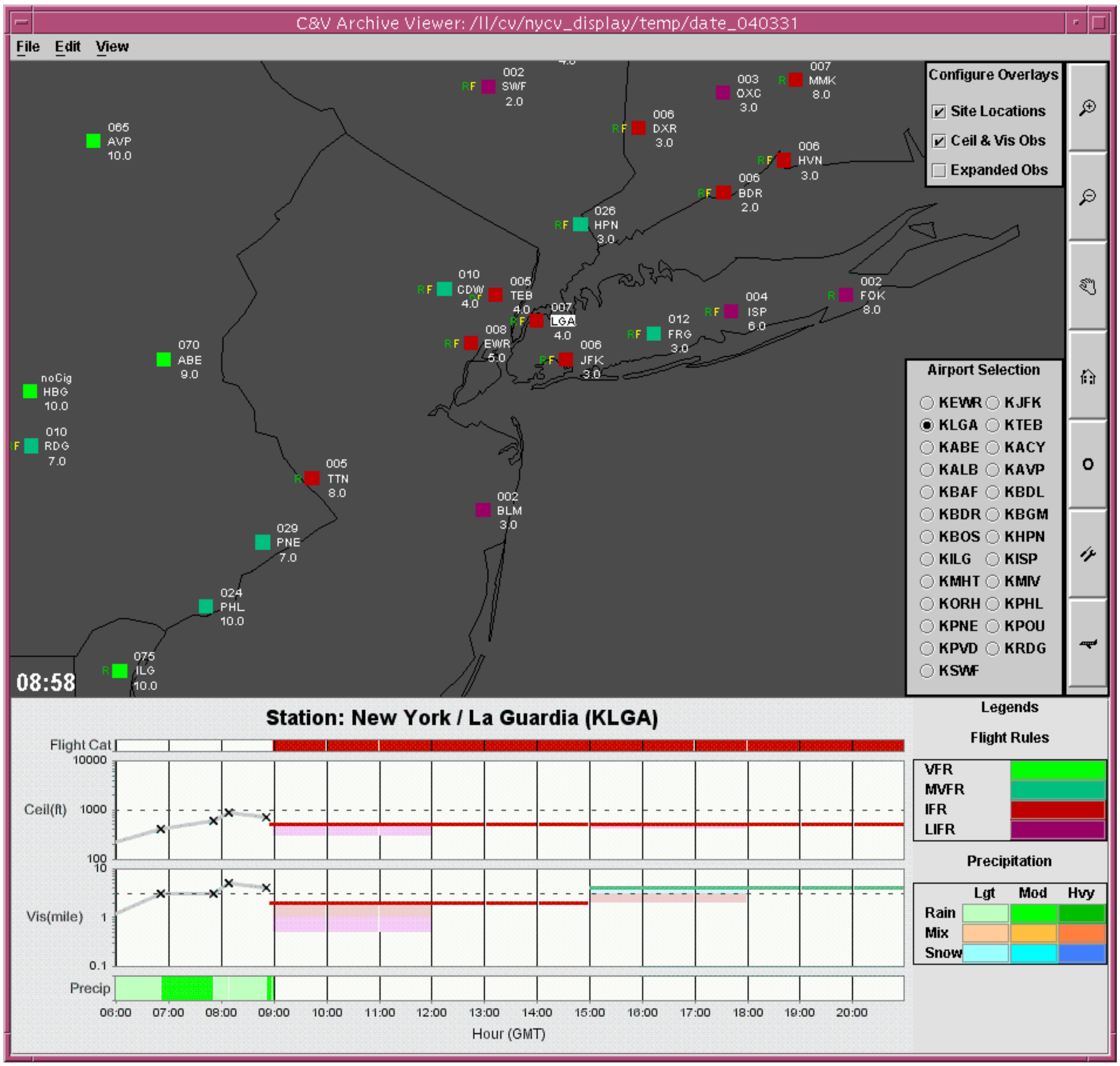

Figure 6. Baseline Ceiling & Visibility display for the New York area airspace.

These issues may be allayed by automatic generation, delivery, and update of a graphical C&V product based on the existing text-based forecast. As part of the AWRP-sponsored effort, a baseline version has been developed for application within the terminal air traffic control community, as illustrated in Figure 6.

The upper frame of the product provides a regional representation of the most recent reports of ceiling and visibility, color-coded by flight category. The lower frame provides forecast information distilled from the TAF for individual, user-selectable airport terminals. The horizontal scale is a time axis ranging from 3 hours in the past (to indicate recent observations) out to a 12-hour forecast horizon. The time window updates automatically every 15 minutes, based on the most current available TAF and surface observations. In addition to log-scale plots of both ceiling and visibility values, color-coded indicators of flight category and precipitation impact are also presented. The display is designed to graphically represent both prevailing conditions and intermittent forecast conditions (as per the “FROM” and “TEMPO” portions of the TAF). The plots are color-coded to indicate when aviation-sensitive thresholds of ceiling or visibility are expected to be crossed.

This product is currently being developed as a web-based product for more general distribution. In the web-based environment, an individual user’s personal computer would host the data acquisition and display software, which would query for new data periodically via the internet to update the display. This capability is scheduled to be available for operational testing beginning in the fall of 2004.

4.2 Applications of New Forecast Technologies

In addition to providing an effective mechanism for information delivery, research is underway to apply new technologies that would also improve forecasts of C&V. For short term tactical forecasts (0-3 hours), the opportunities lie in exploiting the availability of high time- and space-resolution data, particularly radar, satellite, and surface observations. These data will be integrated and processed as part of an automated rapidly updated analysis, via statistical and tracking methodologies, in order to take advantage of short term trend information.

For the forecast horizons out to 12 hours necessary for strategic air traffic planning, recent advances in numerical weather prediction (e.g. higher resolution NCEP models, regional mesoscale models, point forecasts models) will be adapted for airport terminal-specific forecasting. A challenge will be a seamless melding of the observational-based forecasts whose strengths are in the short term, with the longer horizon model forecasts. Efforts, which began in 2004, are expected to continue as part of a multi-year program using the New York area as a focal point for technical development.

5. PATH BASED SHEAR DETECTION TOOL

Path-based Shear Detection (PSD) for the New York area was developed under sponsorship of the Port Authority of NY & NJ, in response to terminal area events involving both compression/expansion of arrival flows and aircraft encounters with a type of hazardous turbulence that would not normally be detected by ITWS. One such encounter with hazardous turbulence occurred on 28 April 2002 with an arrival into JFK International Airport. As it made the turn onto final approach into JFK, it encountered an elevated region of wind shear and rapidly lost altitude before recovering. Isaminger et al. (2003) and Bieringer et al. (2004) documented the event and meteorological events surrounding it.

The PSD algorithm computes headwind/tailwind along the path of arrival corridors into the New York airports, and indicates where along the arrival path significant gains or losses will be experienced. The PSD display plots the geographical location of the arrival paths of interest and highlights the segments along those paths where excessive gains and losses have been calculated (Figure 7). PSD is a decision support tool that takes the large volume of gridded wind information available through the ITWS Terminal Winds (Twinds) product (Cole and Wilson 1994), extracts only the relevant portions, and presents it in a form more easily interpreted by those air traffic controllers at the New York Airports and N90.

5.1 Algorithm Description

Given a set of nominal 3-D arrival paths to a given airport, PSD interpolates the gridded horizontal wind information ($V_{2\text{-}D}$) provided by Twinds to points along those paths. Interpolation is achieved via linear interpolation in the horizontal and in the vertical through the use of a cubic spline. Operationally in New York, Twinds outputs wind information on Cartesian grids with horizontal resolution of 2 km and 10 km, both with vertical resolution of 25 mb. To maximize the resolution of the Twinds grids, nominal paths have points spaced roughly 0.5 km apart.

With a known arrival 2-D unit heading vector ($\hat{h}$) at each point, the headwind/tailwind is calculated as the dot product between $V_{2\text{-}D}$ and $\hat{h}$.

$$\text{Headwind/Tailwind} = -\,(V_{2\text{-}D} \cdot \hat{h})$$

Positive quantities indicate a calculated headwind at each point along the given path; negative quantities indicate a calculated tailwind. These quantities are then combined along the full path length to produce the path’s headwind profile. This result is then smoothed with an iterative 5-point centered sliding window to remove artifacts in the headwind profile. The smoothed headwind profile is used to determine segments of operationally excessive loss or gain along each nominal arrival path. An operationally excessive loss or gain is defined as a change in headwind/tailwind of 20kts per 1000 ft of descent along an arrival path.

Given a headwind profile, the PSD algorithm iteratively examines the point calculations of headwind/tailwind to find local mins and maxes in the profile while excluding those mins/maxes that do not exceed a noise threshold of ±2 kts. If the difference between a local min-max pair meets the operational definition of excessive loss or gain, that difference and corresponding path segment are depicted by the PSD display. Also depicted by the PSD display are the headwind/tailwind calculations at 1000 ft descent intervals and the calculated headwind/tailwind ±1000 ft of the arrival path altitude at those intervals.

Figure 7 is an example of the prototype PSD display over New York airspace. Selection menus are available to toggle and select overlay choices, make arrival path selections, and configure display quantities of headwind/tailwind or loss/gain values. In this example, arrival paths for runway 13L of JFK International Airport have been selected as the paths of interest. Arrival paths are plotted in solid black with headwind/tailwind calculations displayed at 1000 ft intervals. At this particular update time (2004, 13 January at 17:15), surface winds are strong out of the south and increase in velocity as they veer 40° to 20000 ft. Two of the three approach paths have calculated losses that exceed the 20 kt/1000 ft threshold and are indicated in red; their loss values are also displayed. Due to route configuration and the strong southerly flow, a loss of 103 kts between altitudes 5500 ft and 2500 ft has been calculated for the northernmost route approaching 13L. Where the three arrival paths merge onto final approach, excessive losses reverse to excessive gains as a function of wind speed, wind direction, and approach heading. The excessive gain of 73 kts between 2500 ft and the surface is highlighted in blue.

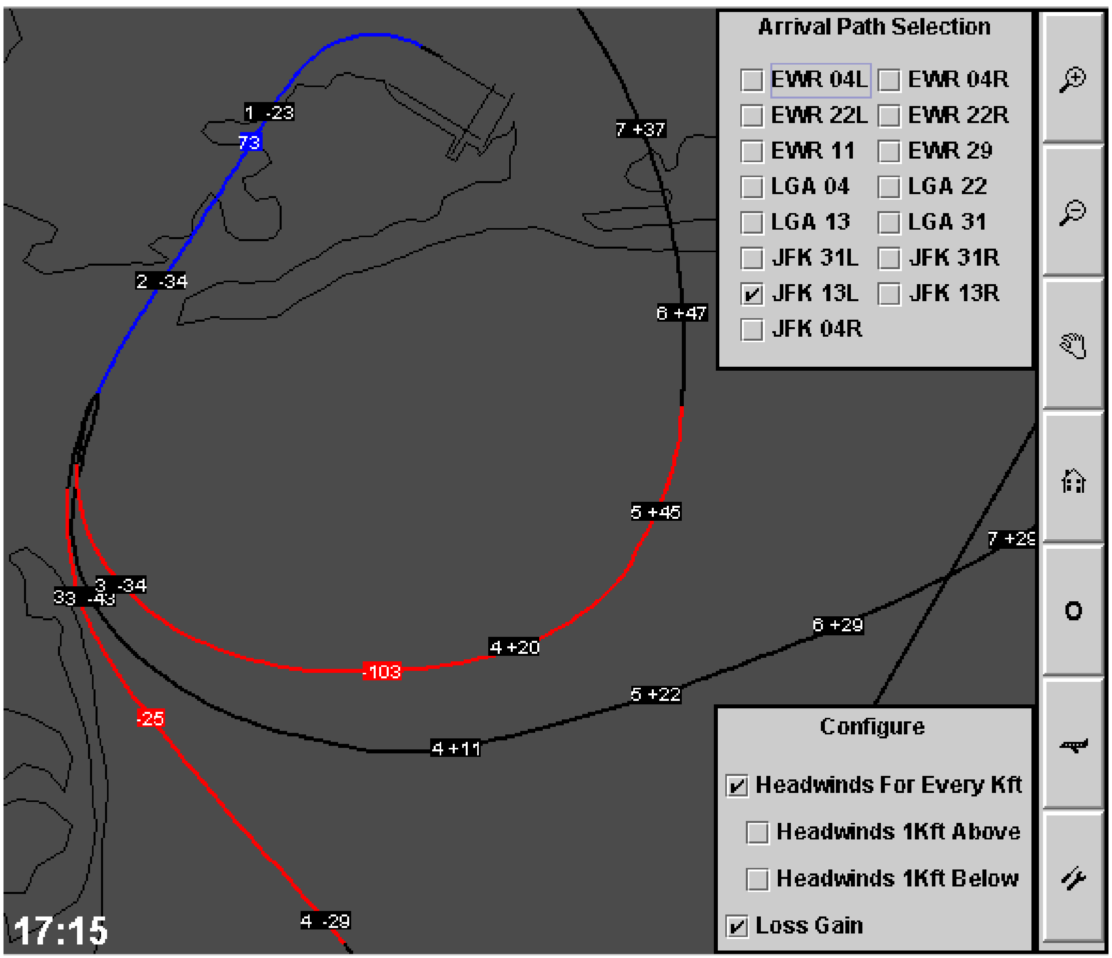

Figure 7. Display of PSD Tool with approach paths into JFK on runway 13L displayed. Arrival path segments where significant loss in headwinds is expected are colored in red. Arrival path segments where significant gain in headwind is expected are colored in blue. Numbers in the colored boxes indicate the total gain (blue) or loss in headwinds along the colored segments. Numbers in black boxes indicate headwinds at 1000 feet altitude intervals. For example, the annotation '4 + 11' indicates headwind of 11 knots at 4000 feet.

Path-based shear detection has been developed out of the need to supply air traffic controllers with support tools that address complications that arise during high wind and turbulent wind events. The tool provides specific wind information, derived from the ITWS Terminal Winds product, along arrival paths within terminal airspace. It helps indicate where problems may arise, and is designed to aid controllers in their routing and configuration decisions when anomalous wind events make those decisions difficult. Real-time experimental testing of the PSD is planned for the fall of 2004, when the web-based infrastructure now under development at LL will be available.

6. SUMMARY

Weather related delays reached record levels through the first half of 2004. Extensive knowledge on NY-specific problems related to capacity-reducing weather has been gained through working with FAA traffic managers and airlines through the field programs of ITWS and CIWS. As a result, improved forecast technologies and products aimed at the integration of traffic management and forecasts have been developed and are being field tested in the New York area with encouraging results.

This paper has briefly summarized four products. Two of them, RAPT and enhancements to TCWF, are currently available to users with significant documented benefits. RAPT is targeted at departure management and provides explicit forecasts of when routes will open/close relative to flight trajectories. An echo top forecast was developed for use by RAPT in 2004 to address instances where aircraft could fly over thunderstorms. The winter mode of TCWF has saved airlines millions of dollars through an improved forecast and representation of winter storms.

The C&V product and PSD tool have been developed and are being field-tested offline with experimental real-time demonstration expected later in 2004. The C&V product will provide a graphical display of TAF forecasts, along with current conditions at localities in and around New York. In addition it will verify past performance of TAFs and seek to add incremental improvements in the ceiling and visibility forecast. Benefits are expected to be significant. PSD will allow traffic managers to identify regions of significant loss/gain in airspeed along the approach into New York airports.

There is a clear need for emerging technologies to directly address the impact that adverse weather has on traffic management. This will make it easier for traffic managers to develop and execute appropriate risk mitigation strategies. Several of the advanced products discussed in this paper take a first step at targeting the operational decisions that are affected by adverse weather and future research and development will continue to address the integration of weather and operations.

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