CIWS, CoSPA and RAPT: Providing Benefits Now *and* Building Technology for the Next Generation

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Introduction

Flight delays caused by thunderstorms are a significant and growing problem for airlines and the flying public. Thunderstorms disrupt the structured, preplanned flight routing and control process that is used to handle dense air traffic streams in congested airspace. Today's coping strategies are developed by traffic flow management specialists who interpret weather forecasts and develop traffic management initiatives (e.g., delaying and/or rerouting flights) to reduce the weather impact. The improved weather information discussed below is now helping with development of improved TMIs. In the longer term, more effective response strategies can be developed with decision support tools that translate the weather forecasts into capacity impact forecasts and, when possible, provide explicit guidance for TMIs. Corridor Integrated Weather System (CIWS)

CIWS is an FAA demonstration prototype designed at the outset to support the development and execution of convective weather impact mitigation plans for congested airspace. It provides FAA traffic managers, ARTCC area supervisors and airlines with high-resolution, accurate and timely depictions of four different kinds of current thunderstorm information: Precipitation maps, "Echo Tops" maps (the altitude of the tops of storms that pilots seek to avoid), explicit depictions of thunderstorm growth and decay trends, and storm motion information. By integrating this data from the nation's weather radars with satellite data, surface observations and numerical weather models, CIWS also provides high-resolution forecast loops of both Precipitation and Echo Tops out to two hours in the future to support proactive traffic planning. The full CIWS product suite is described by Evans and Ducot (2006).

CIWS prototype operations began in 2001 in the Great Lakes and Northeast Corridors, and the geographical coverage and product suite have grown almost every year since then based on user feedback, new capability requests and targeted R&D (Figure 1). It is only through this focused prototyping process that achievable user requirements for a decision support system like CIWS could be discovered. Over the last three years, the original demonstration system was re-engineered to enable long-term trouble-free operations. On June 3, 2008, the re-engineering effort was sufficient to permit the FAA to significantly expand the geographical coverage of CIWS to include the entire continental U.S. (CONUS) and southern Canada (Figure 2). This expanded coverage is a key requirement that was needed prior to completion of a CIWS technology transfer package. The technology transfer package is vital to the implementation of an FAA National Airspace System operational CIWS capability.

Using CIWS, traffic flow decision makers are able to keep air routes open longer before being impacted by weather, as well as reopen them earlier after weather impacts. CIWS provides better knowledge of future storm positions, which allows for more efficient rerouting around storms. Information on current and predicted storm tops allows users to find opportunities to safely fly above storm areas. Benefits analyses show that traffic managers using the CIWS forecast have made a paradigm shift from reactive flow management based on pilot reports to proactive flow

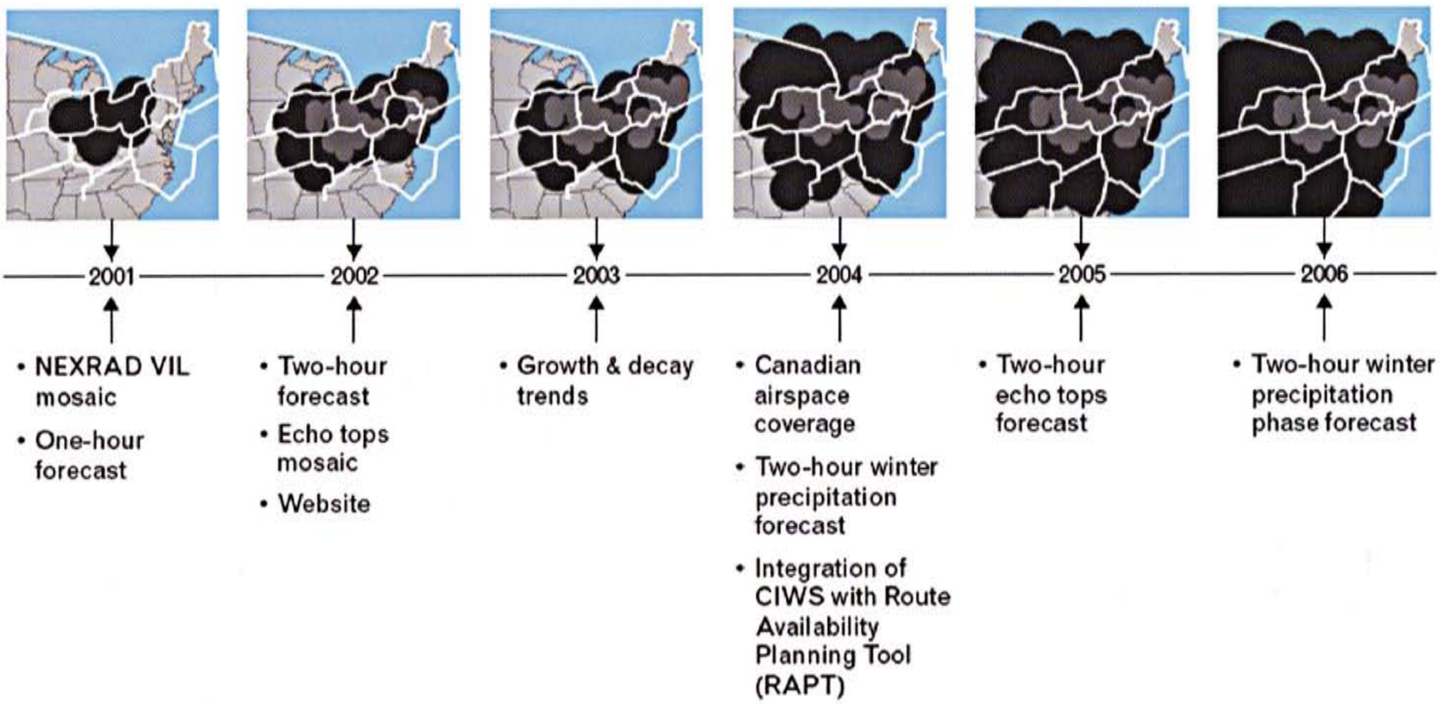


Figure 1. Milestones in the evolution of the CIWS demonstration system. The evolution of the system included both an expansion in the region covered and in the products provided to the users. The lighter grey regions are those covered by ASR-9 radars, and the darker grey areas indicate those covered by NEXRAD and Canadian radars. Re-engineering of CIWS permitted CONUS-wide coverage for 2008, but without the ASR-9 radars.

management based on forecasts (Robinson et al., 2004; see sidebar).

CIWS is now in use via its dedicated displays at numerous locations in the northeast, including the Air Traffic Control System Command Center in Herndon, VA, eight Air Route Traffic Control Center facilities, six large Terminal Radar Approach Control facilities, as well as several airline operations centers. Other Centers and TRACONs can access CIWS via the web through an approved user account if they wish to do so. The web display offers users nearly the same functionality that a dedicated display offers.

The System Operations Services' Programs Directorate is currently developing the business case for deploying an FAA operated and maintained CIWS in the 2011 timeframe. In addition, plans are underway to integrate the CIWS weather products into the Traffic Flow Management System (TFMS) to provide a national CIWS display capability and to integrate CIWS weather products into other appropriate traffic flow management decision support tools.

The NextGen Network Enabled Weather program is currently defining common formats and the service oriented architecture that will be used for aviation-wide access to the CIWS data. Because access will be net-enabled, other systems like the FAA's ERAM, ITWS and ACE-IDS, the DoD's JET, NOAA's AWIPS, and others could quickly and efficiently incorporate all or part of the CIWS data suite.

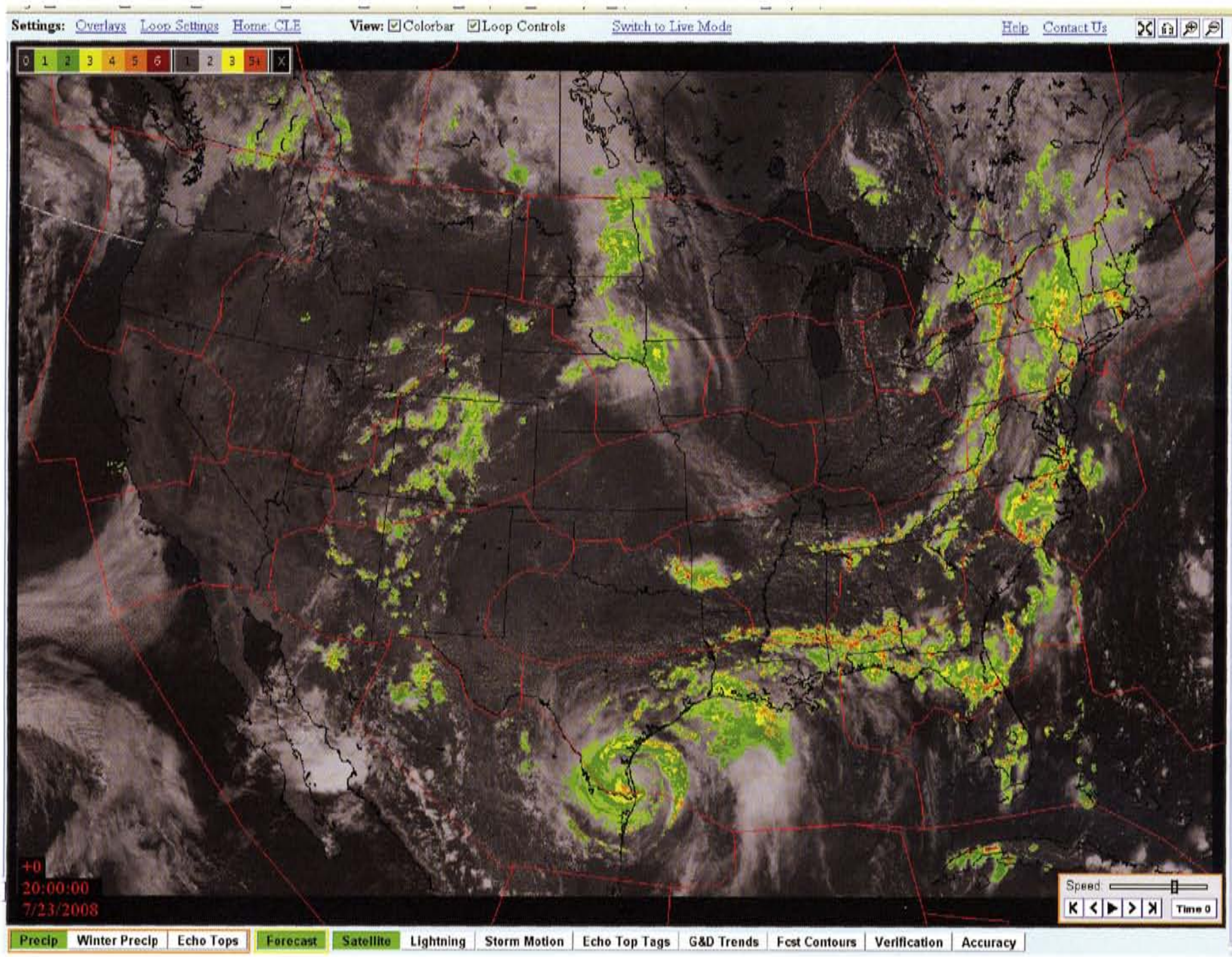
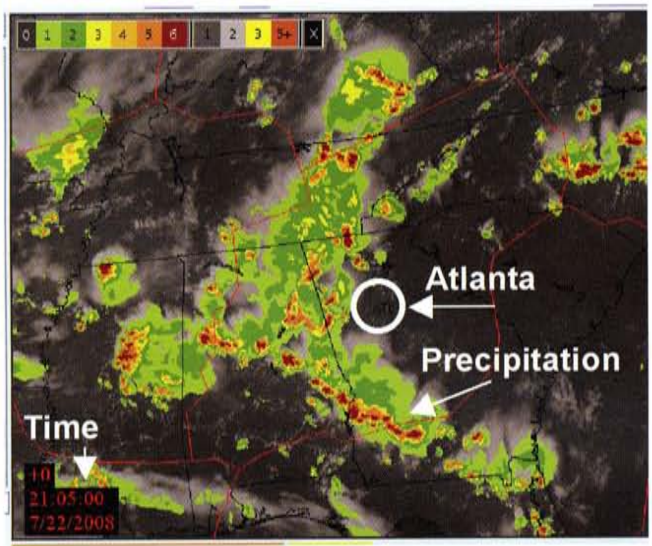
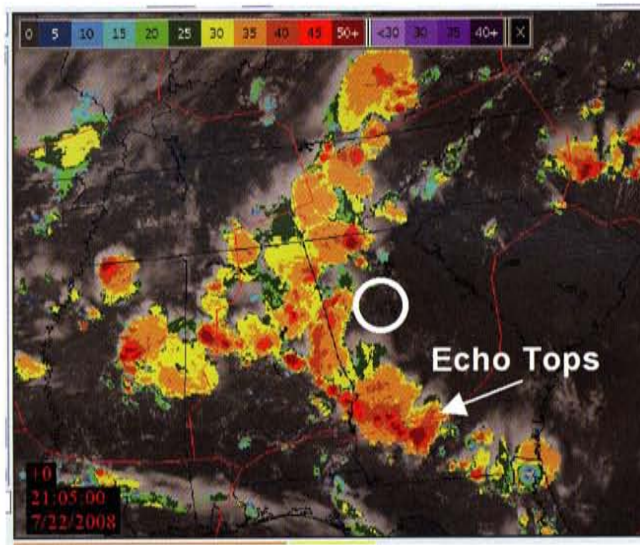


Figure 2. Example of CIWS CONUS coverage on 23 July 2008, when hurricane Dolly hit the Texas coast. The new CIWS Precipitation mosaic has 1-km horizontal resolution and updates every 2.5 min. The display can fully pan and zoom to provide the resolution needed, and the forecast loop is activated via the control box at the lower right. Various CIWS products are selectable via buttons along the bottom.

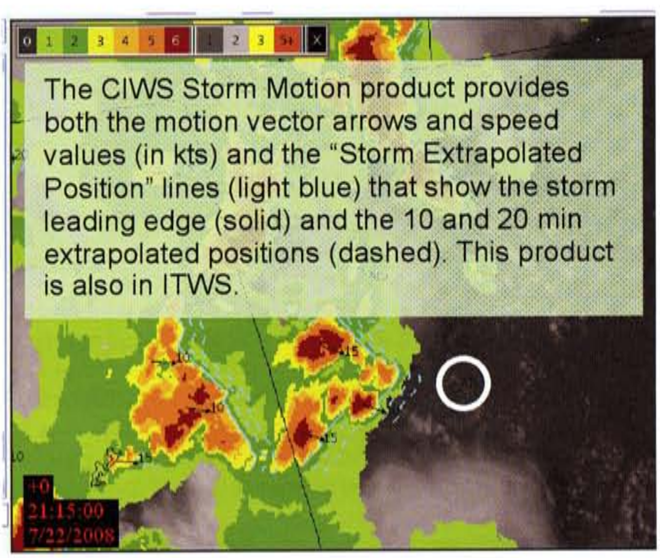
Example of how CIWS provides ATC benefits:

Use of CIWS at ATC System Command Center to Plan Ground Stop at Atlanta
22 July 2008

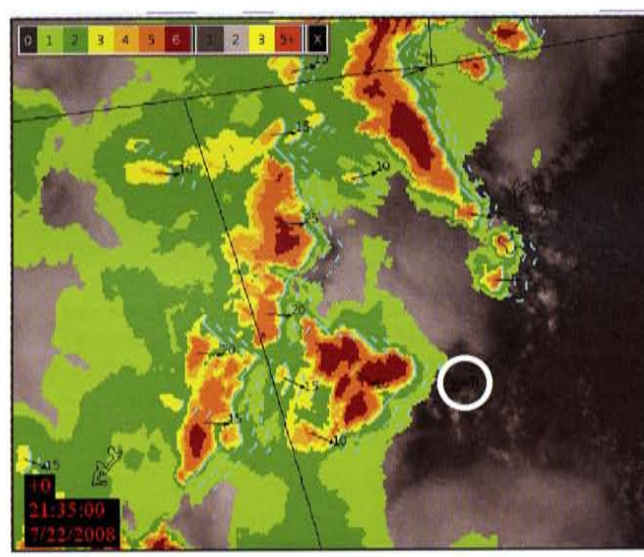




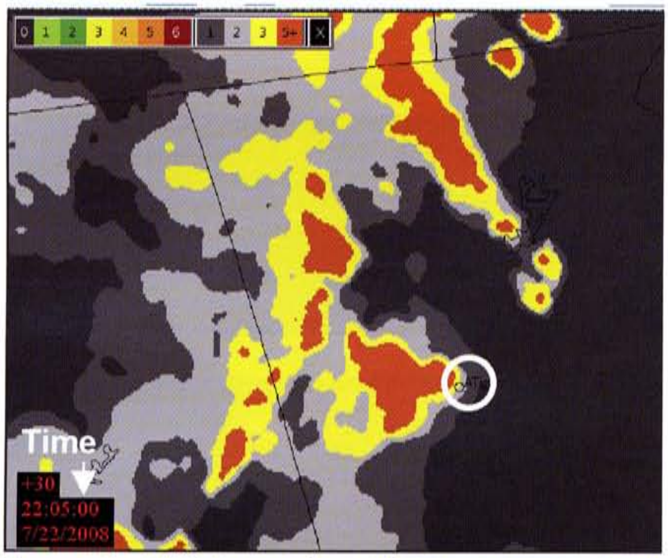
At 21:05, the CIWS display of Precipitation and Echo Tops showed storms in northwest Georgia progressing eastward, shutting off all arrivals into Atlanta from the west. The severe storms had tops greater than 50K ft. Many discussions took place as traffic managers at the ATC System Command Center prepared to hold the Strategic Planning Telecon (SPT) at 21:15. A potential future ground stop at Atlanta was briefly mentioned.



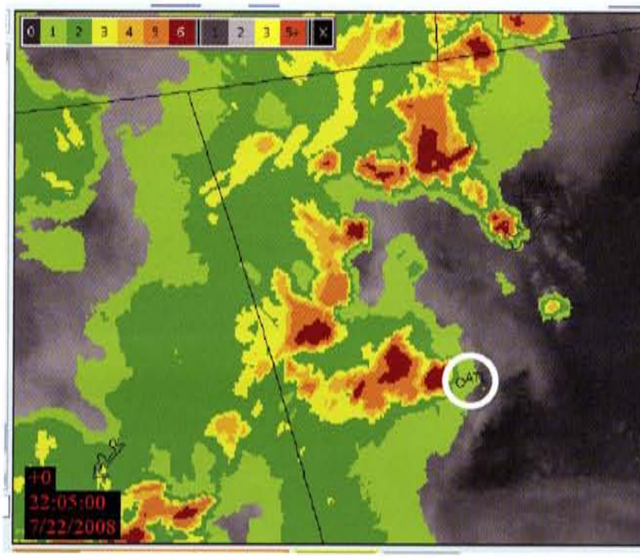
At 21:15, the SPT was held. ZTL Center referenced ITWS (they do not have dedicated CIWS displays), and were aware that a significant weather impact at ATL was imminent. The Command Center Planner set up a sidebar telecon with the NSST SE position, ZTL and A80 to follow the SPT.



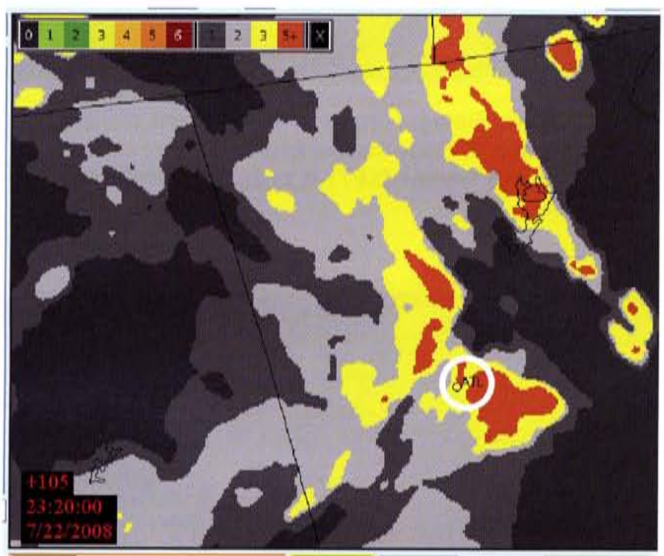
At 21:35, the sidebar telecon took place with Delta and Airtran also joining. Referencing forecasts from both CIWS and Atlanta's ITWS, participants were expecting impact to **start at 22:05** and **end at 23:15**. A ground stop was issued for 2nd tier including Tampa and Dallas, noting that it could be lifted early if needed.



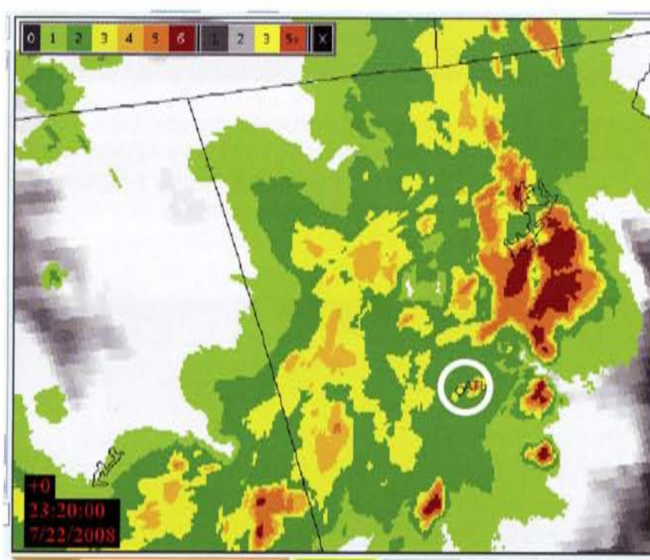
At 21:35, the CIWS forecast (30 min) that was viewed during the sidebar telecon showing the leading edge of the storms first impacting Atlanta airport at 22:05, with heavier weather (level 5-6) close behind.



At 22:05, the actual CIWS Precipitation showed a very similar storm configuration to that which was forecasted. Time of direct Level 6 impact on the runways was 22:11, within 6 minutes of forecasted time. The SE position noted the forecast accuracy in the NTML log as "very impressive". Arrivals were stopped at this time, but departures to the southeast were able to keep running on Atlanta's southernmost E-W runway.



At 21:35, the CIWS forecast (105 min) that was viewed during the sidebar telecon showed the trailing edge of the storms departing Atlanta airport around 23:20. Although ITWS has a forecast out to 60 min, only CIWS provides forecasts at longer time horizons (currently out to 120 min).



At 23:20, the actual CIWS Precipitation showed a basically similar storm pattern to that which was forecasted nearly 2 hrs earlier, although the accuracy of the 105 min forecast was (as usual) not quite as good as the 0-60 min forecasts. The first flight arriving after the ground stop ended came in from the southeast arrival fix, landing at **23:17** – very close to the original estimated end of impact time of 23:15.

Summary: Despite the very intense thunderstorms impacting Atlanta on this day, costly aircraft diversions were kept to a minimum of only 24. Various users called the Command Center after the ground stop ended, thanking them for their great coordination and planning. The users estimated there might have been "dozens more diversions" without the Command Center coordination effort, using CIWS and ITWS.

Consolidated Storm Prediction for Aviation (CoSPA)

A major challenge in developing improved air traffic management (ATM) during convective weather is the difficulty in accurately forecasting severe weather impacts on airspace capacity hours in advance. Research on the advanced algorithm components of CIWS, in particular the 0-2 hr tactical forecasts of Precipitation and Echo Tops, under the auspices of the FAA's Operations Planning Organization, Aviation Weather Office, Aviation Weather Research Program (AWRP; Wolfson et al., 2004; Dupree et al., 2006). Under AWRP's Consolidated Storm Prediction for Aviation (CoSPA) effort, providing high quality forecasts from 2 to 6+ hours lead time for strategic planning that are seamlessly connected to the CIWS tactical 0-2 hr forecast is the top priority (Wolfson et al., 2008).

The FAA's investment in CoSPA includes research efforts from the National Center for Atmospheric Research and the Massachusetts Institute of Technology, Lincoln Laboratory. In addition, NOAA is playing a significant role through its Earth System Research Laboratory Global Systems Division and its Meteorological Development Laboratory. NASA is also participating both through the Advanced Satellite Aviation weather Products (ASAP) program, and its Ames Research Center.

Future enhancements to CoSPA will focus on increasing the utility of storm forecasts for air traffic management. As mentioned, the CoSPA objective is developing consolidated accurate, high-resolution storm forecasts (including both summer and winter storms) out to 6+ hours in the future that update at least every hour for strategic planning purposes. In addition, reliable estimates of forecast uncertainty must accompany the existing/planned deterministic forecasts for probabilistic traffic flow planning (by TFM specialists and/or by automated decision support systems); verification methodologies that relate to the likelihood of airspace usability are needed for meaningful assessments of forecast performance; and future terminal weather products such as wind shift forecasts, ceiling and visibility forecasts, etc. are needed for effective runway configuration and ultimately terminal arrival/departure management.

Testing and research on a fully automated deterministic 6-hr CoSPA forecast that updates once per hour is taking place during the summer of 2008 with a collaboration that involves MIT Lincoln Laboratory, National Center for Atmospheric Research and NOAA Earth System Research Laboratory Global Systems Division. An illustration of a CoSPA 6-hr forecast is shown in Figure 3, where one forecast on 20 July 2008 is depicted along with the weather both at the issuance time of 13:00 UTC and at the valid time of 19:00 UTC. For comparison, the matching 6-hr weather forecast used operationally for ATC strategic planning called the Collaborative Convective Forecast Product (CCFP) is also shown.

As shown, both the CCFP and the CoSPA 6-hr forecasts depict heavy weather in NY and PA, and both basically get the orientation right. However, the CoSPA forecast correctly suggests the overall line storm shape of this convection and that the thinnest part of the line will be just north of the border between NY and PA. The CoSPA forecast improves upon CCFP for meeting real operational user needs: predicting capacity on various jet routes, overall sector impacts, and likely traffic flows. The 19Z truth shows small but strong storms in Boston, and neither forecast has predicted these correctly. However the CoSPA forecast does produce a few spots of weak convection in the Boston area and also in Connecticut and various places in the Midwest, all of which are present to some degree at 19Z.

In general, the depiction of storm forecasts for ATM as "radar forward" (essentially what the radar map will look like some amount of time in advance) has been well received by traffic management personnel. The research challenge is to ensure these forecasts depict the *most probable* deterministic scenario, and also to convey the uncertainty associated with each portion of the forecast. This will allow the system to be adapted to both human and automated users, and to support the transition from complete human-in-the-loop operations to NextGen automation.

The CoSPA 6-hr forecast product being tested in 2008 has 3-km resolution, updates once per hour, and animates in 1-hr steps so that the evolution of the weather is apparent. The CoSPA forecast agrees exactly with the CIWS forecast at 1 hr and 2 hr lead times, and then animates further out to 3, 4, 5 and 6 hrs. Integration of this new forecast, to enhance strategic planning, with the same data being used for tactical planning (CIWS) is necessary to support dynamic decision-making. Although the 2008 research test of CoSPA covers only the northeast corridor, the ATO-Planning Weather Office is considering investing in a larger prototype test of the CoSPA.

Route Availability Planning Tool (RAPT)

Departure delays from major terminal complexes are typically much higher during convective weather than arrival delays, occasionally leading to near gridlock conditions on the airport surface. The ability to predict impacts of

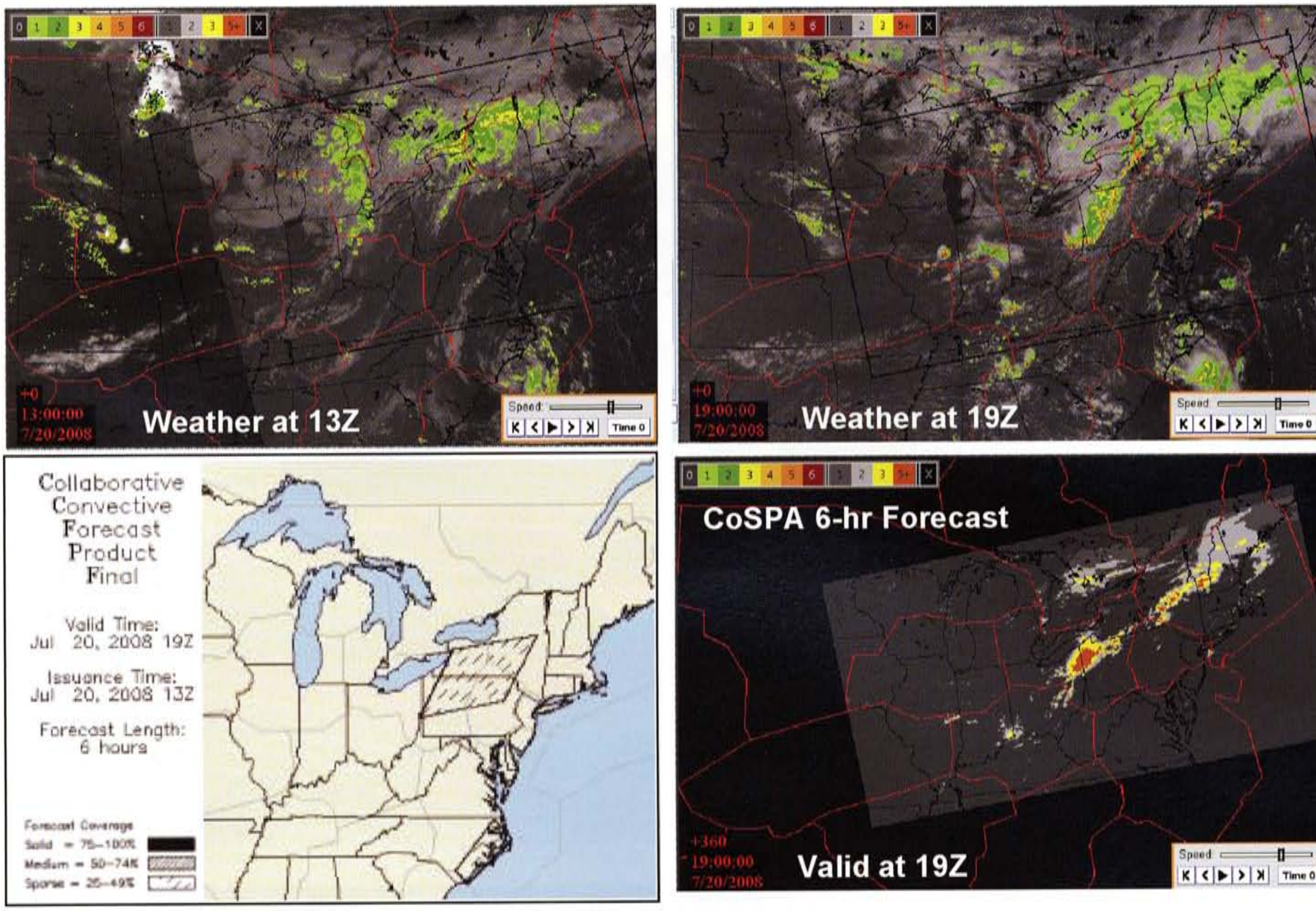


Figure 3. Example of the CoSPA 6-hr forecast on 20 July 2008 compared with the actual weather both at issuance and valid time and the CCFP 6-hr forecast for the same time.

convective weather on departure routes from major airports, and to better exploit the safe departure opportunities, is a fundamental need in departure management. The Route Availability Planning Tool (RAPT; DeLaura et al., 2008a) is an automated decision support tool intended to help air traffic controllers and airline dispatchers determine the specific departure routes and departure times that will be affected by operationally significant convective weather. It also represents our initial experience with operationally translating weather forecasts into capacity impact forecasts.

This process of translating weather forecasts into air traffic impacts was highlighted by the FAA Research, Engineering and Development Advisory Committee (REDAC) Weather - ATM Integration Working Group (WAIWG) in their well-received 2007 report (FAA, 2007). They found that "a risk management approach with adaptive, incremental decision making, based on automatically translating weather forecasts into air traffic impacts, presents a major new opportunity for reducing weather related delays in the future NAS."

RAPT helps users to determine when departure routes or fixes should be opened or closed and to identify alternative departure routes that are free of convective weather (Figure 4). The tool assigns a status color - RED (blocked), YELLOW (impacted), DARK GREEN (insignificant weather encountered) or GREEN (clear) - to each route for departure times up to 30 minutes into the future. The route status is determined by first using CIWS forecasts and a model to calculate forecasted regions of airspace that pilots will seek to avoid (DeLaura et al., 2008b) and combining them with a route blockage algorithm that incorporates a model for departure airspace usage. The airspace usage model includes departure route definitions that take into account route density and average departure trajectories. The route blockage model calculates the severity of convective weather impact on departure traffic along the first 60 minutes of flight

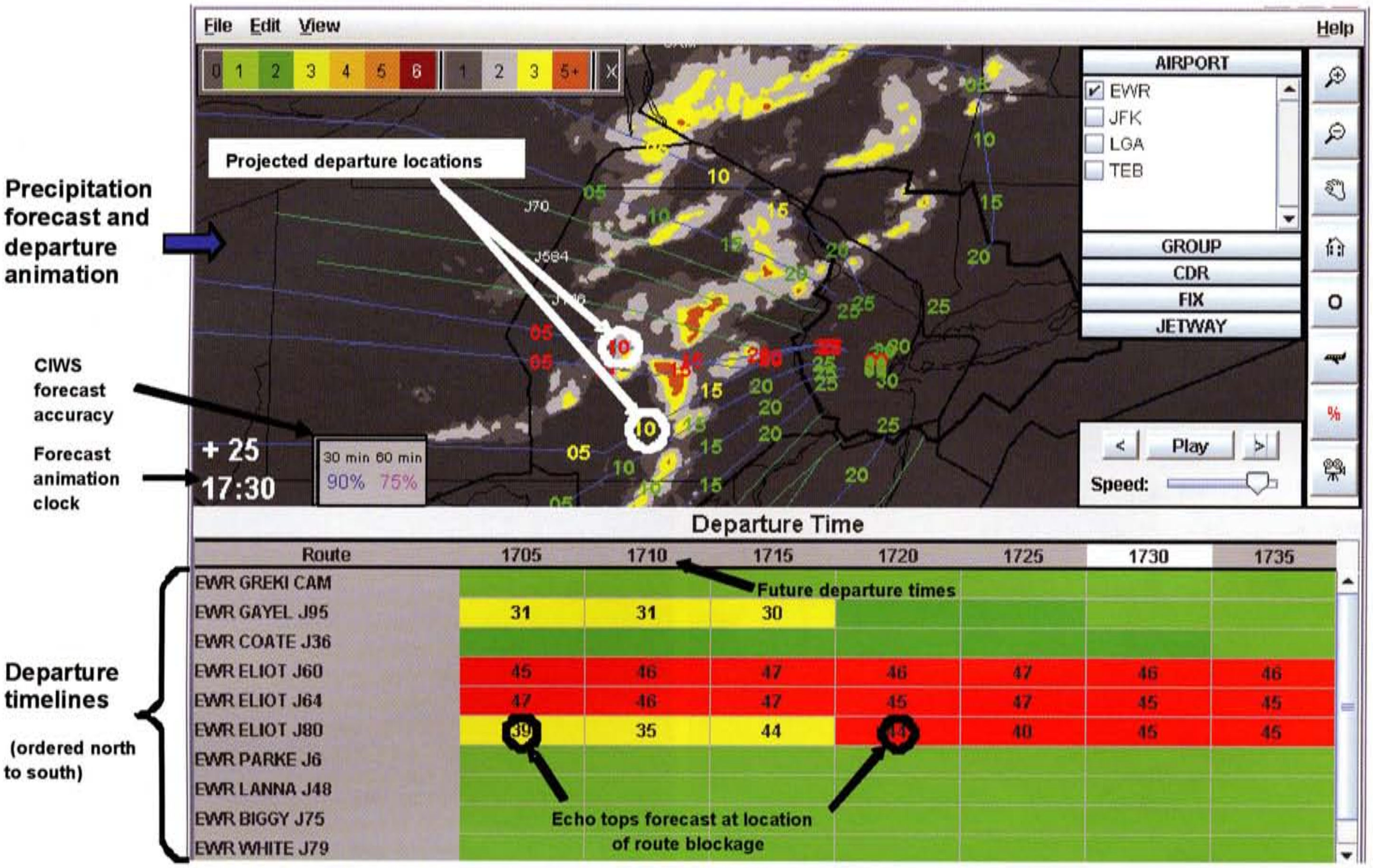


Figure 4. Example of the RAPT dedicated user display showing storms forecasted for the New York area. The weather and the forecast animate in the top panel. The route blockage (red, yellow, dark green or green) is shown as a function of departure time in the lower panel for some of the departure fixes and jet routes out of New York. RAPT products can be accessed both from a dedicated user display and from an interactive web display.

time of the departure route. An empirical aircraft departure flight trajectory model is then used to translate the route blockage forecasts into guidance for takeoff times along a departure route that will avoid aircraft-storm intersections.

RAPT prototype operations began in August 2002, and the system has evolved since in response to feedback from operational users, real time observations of both RAPT usage and traffic flow decision making during Severe Weather Avoidance Programs, and post event analysis of RAPT performance (Robinson et al., 2008). We learned two important lessons that apply broadly to the use of integrated weather – ATM decision support systems. First, it is not sufficient to just provide explicit guidance for TMIs (e.g., the departure times shown in Figure 4)…the users also must be able to understand why the decision support tool reached its conclusions. Second, users need an explicit confidence metric to help quickly evaluate the quality of the guidance provided by the tool.

Our post-event analyses have shown that RAPT provided significant operational benefits at NY in 2007 (e.g., a 2,300 hours of delay reduction with a monetary cost savings in excess of $ 7 M). There is a potential for achieving significant (4-fold) increases in operational benefits provided that a number of issues are addressed. These include improving the various underlying models, providing full access to RAPT for key decision makers, providing explicit forecasts of arrival route blockage (since departure route availability can be adversely impacted by arrivals deviating into departure route airspace), improving real time common situational awareness on the status of departure routes, and improving both inter- and intra-facility cooperation and coordination.

Finally, estimating the uncertainty in route blockage given measures of forecast uncertainty such as error estimates for each pixel is virtually impossible. Furthermore, critical characteristics of forecasts, such as the spatial correlation between forecast pixels and the relative magnitude of different forecast errors (motion, storm growth/decay, etc.), are not well understood. More research is needed to understand and characterize weather forecast uncertainty in a way that can be readily translated into route blockage uncertainty. This work will also support the application of RAPT-like technology to other evolving NAS initiatives (such as AFPs and automated rerouting in enroute airspace), which are very much focused on the management of specific traffic flows.

Summary

The problem of air traffic management in severe convective weather is very important for the future of NextGen. Delays due to convective weather have continued to grow in the past six years despite many meaningful traffic flow initiatives. Improving weather forecasting capability and the ability to translate weather forecasts into both capacity impact forecasts and recommendations for ATM impact mitigation actions are critical to improving the efficiency of today's operations. Ultimately the ability to functionally operate the NAS in the future (if predicted increases in air traffic really do materialize) may depend on successfully solving this problem.

An update on the demonstration Corridor Integrated Weather System, in use today by Traffic Flow Managers and Area Supervisors at several ARTCCs, TRACONs and at the ATC System Command Center, via both dedicated and web-based situation displays has been provided. New for 2008 is expansion of the CIWS domain from only the northeast quadrant of the US to coverage of the entire CONUS. Plans are being made to incorporate the CIWS data into the TFMS, since having the weather/forecasts and flight data together in one system will significantly improve operational decision-making. Network enabling the CIWS data feed will open the opportunity to integrate the identical weather/forecasts into other government and private vendor systems that support aviation decision-making.

Also provided was a look at two key areas of research that dovetail with CIWS. First, the research to provide high resolution, rapidly updating forecasts in the 2-6 hr domain that can be used for strategic planning has commenced via CoSPA, with a real-time research-only demonstration in the northeast for 2008. Results are already so promising that plans are being made to extend the demonstration and perhaps make it available as a prototype in the very near future. It should be realized, however, that no matter how much improvement can be accomplished in the realm of 2-6 hr forecasting, convective weather capacity impacts cannot be forecast *in detail* for lead times > 2 hrs. Thus the CoSPA research efforts continue to improve the essential complementary tactical 0-2 hr forecast as well.

Second, research and development on translation of convective weather forecasts into capacity impact forecasts as well as explicit guidance for traffic flow actions is underway. RAPT, a decision support tool providing guidance on departures during weather impacts in New York has undergone several iterations with the users and the technology continues to evolve as various difficult technical and operational usage problems are being addressed. For example, understanding how the forecast uncertainty and route blockage uncertainty can be characterized and assessed in a meaningful way for route planning is fundamental.

Of course, adverse weather really only exacerbates problems that are already in play in high density airspace and at large airports: inter- and intra-facility coordination, controller workload, lack of common situational awareness, surface management and arrival/departure load balancing at airports, metroplex interactions (at places like NYC), etc. These weather tools are helpful, but they must ultimately be integrated with the broader set of NextGen ATM development activities to truly provide robust performance during off-nominal conditions.

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Acronyms

A80	Atlanta TRACON
ACE-IDS	ASOS Controller Equipment — Information Display System
ASAP	Advanced Satellite Aviation weather Products
ASOS	Automated Surface Observing System
ATC	Air Traffic Control
ATM	Air Traffic Management
ATO	Air Traffic Organization
AWIPS	Advanced Weather Interactive Processing System
AWRP	Aviation Weather Research Program (FAA ATO-Planning)
CIWS	Corridor Integrated Weather System
CONUS	Continental United States
CoSPA	Consolidated Storm Prediction for Aviation
ITWS	Integrated Terminal Weather System
DoD	Department of Defense
ERAM	En Route Automation Modernization
JET	Joint Environmental Toolkit
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NOAA	National Oceanic and Atmospheric Administration
NSST	National System Strategy Team
NTML	National Traffic Management Log
RAPT	Route Availability Planning Tool
REDAC	FAA Research, Engineering and Development Advisory Committee
SPT	Strategic Planning Telecon
SWAP	Severe Weather Avoidance Procedures
TFM	Traffic Flow Management
TFMS	Traffic Flow Management System
TMI	Traffic Management Initiative
WAIWG	Weather — ATM Integration Working Group
ZTL	Atlanta Air Route Traffic Control Center