CONVECTIVE WEATHER FORECASTING FOR FAA APPLICATIONS*‡

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1. INTRODUCTION

The Convective Weather Product Development Team (PDT) was formed in 1996 as part of the reorganization of the FAA Aviation Weather Research Program, to provide an effective way to conduct critical applied research in a collaborative and rational fashion. Detecting and predicting convective weather is extremely important to aviation, since approximately half of the national airspace delay in the warm season is caused by thunderstorms. Reliable 0–6 hr storm predictions are essential for aviation users to achieve safe and efficient use of the airspace, as well as for future air traffic control automation systems.

Our goal on this PDT is to direct our research and development activities toward operationally useful convective weather detection and forecast products, and *delivery* of those products, so that users can receive benefits on an immediate and continual basis. Given that we have many more initiatives than funding, we have chosen to prioritize our activities according to near–term achievable benefits to users. Our hope is that the success of initial planned demonstrations will help the FAA identify a consistent level of long–term R&D funding, so that we can make real progress towards achieving our full set of goals.

In this paper, we present our statement of the FAA Convective Weather Forecasting problem, evidence of the need for forecasts in the National Airspace System (NAS), and an illustration of the air traffic delay caused by convective weather. We then discuss our research plan and rationale, and outline our main initiatives for the upcoming year.

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2. PROBLEM STATEMENT

Forecasts of convective weather are needed for each of the spatial and temporal domains listed in the matrix below, and for each of the users listed, that are accurate enough to produce improved efficiency (quantifiable reductions in air traffic delay) and increased safety (separations of aircraft from convective weather). These improvements will represent the "benefit" which can then be weighed against the "cost" of fielding the proposed convective weather forecasting algorithm(s).

PROBLEM STATEMENT MATRIX

Time Scale	TERMINAL	ENROUTE	OCEANIC
< 1 hr	all but 4, 7	all but 12, 13	4,5,7,9,10,11
1–6 hrs	all but 5,6,12	all but 1,12,13	4,5,7,9,10,11

	USERS
1	Terminal ATC
2	TMC (TRACON)
3	TMU (ARTCC)
4	Central Flow (enroute)
5	Commercial Pilots
6	GA Pilots
7	Flight Service Stations
8	AWC
9	CWSU (ARTCC)
10	Airline Dispatcher
11	Airline Met. Operations
12	Ground Operations (Airport)
13	TATCA/CTAS

The spatial scales have been selected to cover the interfaces between traffic control regions, where tactical planning and decision making takes place:

Scale	Interface	Range from Airport
TERMINAL	Tower–TRACON	40–100 nm
ENROUTE	TRACON–ARTCC and ARTCC–CF	100–300 nm (national)
OCEANIC	ARTCCs (coastal)	trans–oceanic

Note: Acronyms are defined on the last page.

3. EVIDENCE OF NEED FOR CONVECTIVE FORECAST PRODUCT

As a first step toward determining the benefit of convective weather forecasts to aviation, we have collected some recent, important stated requirements and recommendations. The following quotes, gathered over the past three years, demonstrate there is a widely recognized need for timely observations and accurate forecasts of convective weather, as well as effective dissemination of the information to users of the NAS. In all prioritized lists, improved convective weather information was ranked at or near the top.

Aviation Weather Users Forum

During December 1993, the FAA sponsored a National Aviation Weather Users Forum that included a wide range of aviation weather users. The 33 highest priority recommendations generated by the users forum fell into 17 categories, one of which was:

- convective activity
  (observations, forecasts, and dissemination)

There were 6 specific user recommendations pertaining to convective activity (UR 6–11 out of 33 total).
[Report prioritizing recommendations from 1993 National Aviation Weather Users Forum: "FAA Aviation Weather Priorities and Plan to Address Industry Recommendations," September 1995]

Integrated Terminal Weather System

Users of the IOC ITWS prototype systems estimated that ITWS would be *twice as useful* with a reliable 30 minute convective growth and decay product. They commented that "you don't want to get many aircraft in the terminal area when you are not confident about where the weather is" and that "without a forecast, you plan for the worst." The ITWS annual benefit was estimated at $200M per year.
[ITWS KDP–3 Cost Benefit Study, Volpe TSC, 1994]

Air Traffic Requirements

"We request the following products be developed as part of a near term post IOC ITWS. The post IOC products are listed in the development priority required by Air Traffic.

a. Growth and decay forecast of convective weather activity.
b. ...

[FAA Memo from Manager, Advanced Systems and Facilities Division, ATR–300 to Manager, Aviation Weather Development Program Office, ARD–80, October 17, 1994.]

Air Traffic Requirements

Current convective activity, and forecasts of convective activity including storm growth and decay, are required in all phases of flight and for almost all tactical air traffic control decisions.
[US DOT FAA Order 7032.15, initiated by ATR–300, October 1994]

National Research Council

"Recommendation 1: The individual National Weather Service and Federal Aviation Administration initiatives for improving weather information services to all sectors of aviation address urgent needs and take advantage of existing concepts and technology; they should be pursued with resolve and implemented surely and swiftly."
(Note: ITWS was one of the "initiatives" considered.)
["Weather for Those Who Fly," National Research Council, National Weather Service Modernization Committee, March, 1994]

FAA Advisory Committee

" (from list of findings...)
5. A clear need exists for prudently selected research and development in the following areas to provide operationally useful products, determined by the users to be of high priority:

—Thunderstorm movement, growth and decay
— ..."

[FAA Research, Engineering & Development Advisory Committee, Aviation Weather Subcommittee, October, 1995]

Terminal Air Traffic Control Automation

"Terminal area traffic delays, and the resulting ripple effects throughout the national airspace system, are often the result of inclement weather. This is because traffic throughput is significantly reduced as it becomes more difficult for controllers to use the airspace efficiently in heavy weather. Thus the quantitative benefits to using improved storm forecasts in terminal area ATC are significant. Our results show that a primitive forecast improves throughput by about 3 aircraft per runway–hour. This is almost 10% of the runway's total capacity. In addition, there remains the potential for another 5–10 aircraft per runway–hour as the forecast is further improved."
["Effects of Storm Forecasting Errors on Air Traffic Control Automation System Performance," by G. Hunter and R. Bortins, Seagull Technology, Inc., February, 1995]

National Research Council

"Most domestic flights last less than 5 hours. Therefore, short–term forecasts that cover the next 6 hours or so are of particular interest to aviation. In addition, airport "nowcasts," which cover the next 30–60 minutes, are especially important to allow air traffic controllers and pilots to coordinate the position of arriving aircraft to accommodate

short–term weather phenomena such as thunderstorms and windshear."
[Aviation Weather Services – A Call for Leadership and Action. National Research Council, National Aviation Weather Services Committee, December 1995]

Free Flight

"**Recommendation 23** (Near Term Recommendation) Develop the capability — starting with existing capabilities — to generate more accurate forecasts on convective weather for use in flight and operational planning."
[RTCA Task Force 3, Free Flight Implementation, Final Report, 1996]

4. DELAY CAUSED BY CONVECTIVE STORMS

To understand the nature of the problem convection causes for aviation operations, we studied summer convective weather and air traffic delay at 6 major US airports. The delay on clear days versus days on which convective weather impacted the airport is shown for Atlanta in Figure 1. (All days from April to September, 1994 were used.) There are always certain times of day when the average delay per plane is high regardless of the weather because the airport is operating at or near capacity at those times. The delay when convective weather occurs at these same capacity–limited times is often severe.

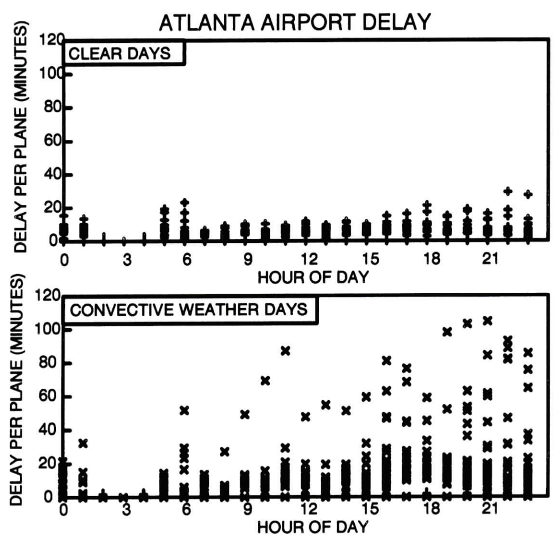

Figure 1. Average delay per plane for aircraft flying into and out of Atlanta during the Summer of 1994 (April to September). Each data point represents the average delay per plane for that hour on one day. Convective weather was determined by hourly surface observations and radar scans, and delay was determined by government–collected Airline Service Quality Performance (ASQP) statistics.

The total delay due to weather at the 6 airports is listed in Table 1. Our data show that, on average, almost 60% of the total air traffic delay in the summer months is due to weather, and close to 50% is specifically due to convective weather. (Other types of summer weather were tropical storms or extratropical rain systems that originated as tropical storms.)

AIRPORT	TOTAL HOURS (K) DELAY	% DUE TO WX	% DUE TO CONVECTIVE WX
Dallas/Ft. Worth	36	60	49
Chicago	32	55	39
Atlanta	32	57	48
Newark	26	67	52
New York (LGA)	15	54	46
New York (JFK)	9	61	49
AVERAGE	**25**	**59**	**47**

Table 1. Delay statistics for 6 major airports for 6 months (April to September, 1994). Delay is given in units of thousands of hours. ASQP delay statistics were used.

Total delay due to weather is a good indication of the magnitude of the operational problem, but we cannot automatically infer that even a perfect prediction of the weather would lead to a drastic reduction in this delay. For example, a blizzard that impacts all airports on the east coast might be perfectly predicted, but no improvement in airport capacity during the blizzard could possibly be realized. To understand how much delay caused by the presence of convective weather could be mitigated in an operational setting, Hunter and Bortins (referenced in the previous section) developed an automated terminal air traffic control model, that accepted weather as input, to simulate various air traffic scenarios. Their study gives us reason to believe that good forecasts of convective weather could indeed lead to a large increase of throughput at the runway (with effective traffic management). This is because the convection is actually impacting the runway for only a short period of time in most storms, and because there are often safe paths around the storm cells. Much of the convective weather delay comes from not anticipating properly when ground stops will be put into effect or lifted, and from the unanticipated closure of arrival and departure gates in the TRACON.

5. 1997 RESEARCH PLAN AND RATIONALE

Our PDT believes the development of operationally effective convective weather forecasts requires:

- a good understanding of the ATC user benefit from prediction of various types of convective weather, on various time and space scales,

- a sound scientific understanding of the initiation, growth, decay and movement of convective precipitation events,
- the development of forecasting techniques that are based on scientific understanding and statistical refinements,
- the development of real–time displays that can be interpreted and effectively utilized by the end users,
- both scientific and user validation of the product, and
- a close working relationship with the users.

We believe that by combining the national expertise in Convective Weather into a single Product Development Team, it will be possible to efficiently and economically produce reliable, operationally useful products for FAA applications.

Our long–term plan is to provide accurate 0–6 hour forecasts of convective weather to the users of the NAS. Our short–term plan heeds the recommendation of several aviation weather advisory bodies, and seeks "fast–track" implementation of near–mature convective weather forecasting algorithms that have resulted from FAA funding over the past 10 years. This research provides some immediate solutions to the < 1 hr forecast problem.

Unfortunately, our immediate plan sacrifices *nearly all* long–term research, which will be required to produce more accurate forecasts and forecasts with lead times in the 1–6 hour range. We feel this is very unwise in the long run, for research is the key to our future capabilities. However, we feel this approach is imperative given our budgetary restrictions and the need to respond to the "no return for our investment" criticisms of Aviation Weather Research. Our ultimate goal is to establish a pipeline in which long–term research can be systematically capitalized upon and applied in ongoing demonstrations and nationally implemented FAA systems for end–users.

5.1. ITWS P^{3}I Growth and Decay

The first part of our plan is to demonstrate ~20–30 min forecasts of convective weather in real–time at the ITWS prototype sites (Memphis, Dallas, and Orlando) as soon as possible (likely 1998). This will be our first step in solving the <1 hr forecast problem at the TERMINAL and CENTER scales. ITWS currently pro-

PROBLEM STATEMENT MATRIX

Time Scale	TERMINAL	ENROUTE	OCEANIC
< 1 hr	X		
1–6 hrs			

vides 10 and 20 min extrapolated positions of storms, but these are often in error because they do not account for storm evolution (Fig. 2). If traffic managers and controllers were given accurate 20–30 min predictions of storm growth and decay, they could achieve improved separations of aircraft from hazardous weather (and thus increase safety), as well as more efficient use of the airspace (thus reducing delay). Reliable short–term predictions are also essential for terminal automation and free–flight initiatives.

A multi–dimensional core team has been established to meet the challenges of developing the ITWS Growth & Decay algorithm. Team members include scientists and engineers from NCAR, NSSL, and MIT LL, who bring complimentary strengths to the project. Technical feasibility for the 30 min predictions is viewed as very high due to past demonstrated successes with the NCAR Autonowcaster identifying regions of convective initiation and trends in storm evolution (Henry and Wilson, 1995), and the FAA ITWS Microburst Prediction algorithm identifying

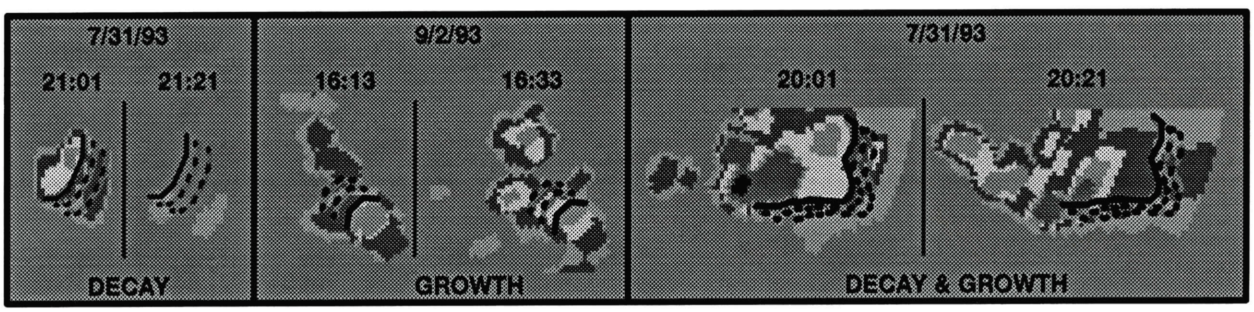

Figure 2. Examples of ITWS Storm Extrapolated Position leading edge contours (of level 3 precip) and dashed 10 and 20 min predictions on storms that were growing and/or decaying. The original precip map is shown at the left for each case, and the 20–min verification map is shown at the right.

growing and decaying cells (Wolfson, et al., 1994). The team deployed pieces of various algorithms at the ITWS prototype site in Memphis in 1996 to assess their performance in the "information–rich" terminal environment. Primary sensors utilized included NEXRAD, TDWR, ASR–9, and GOES–8 satellite. [A description of the demonstration is presented by Henry et al. (1997).]

In following years, these TERMINAL and CENTER forecasts will be improved and extended in time, out to 1 hour and beyond, as our techniques improve and as scientific research results are brought to bear. Initiatives include recognition of early cumulus growth from satellite data, and the coupling of ITWS Terminal Winds (Cole and Wilson, 1994) to a numerical boundary layer model to forecast future surface divergence fields (Crook and Cole, 1994). Explicit numerical modelling of convection will be an important future component of convective weather forecasts, especially at > 1hr time scales. The ITWS display concept we develop will allow for easy extension of the lead time as the product undergoes future development. This forecast product will provide immediate benefit to the NAS as it operates at the ITWS prototypes, and will eventually be tested in an operational demonstration and made part of the pre–planned product improvement cycle of the ITWS system.

5.2. Improved Convective SIGMET

We also plan to develop and demonstrate an ENROUTE Convective SIGMET product that is created by AWC forecasters with guidance from a storm extrapolation algorithm. Convective SIGMETs are lines

PROBLEM STATEMENT MATRIX

Time Scale	TERMINAL	ENROUTE	OCEANIC
< 1 hr		X	
1–6 hrs			

or polygonal regions described using VORs on the Inflight Advisory Plotting Chart. They are distributed by AWC as text, where they are picked up by Flight Service Stations, airlines, private vendors of weather information and other users. The ARTCC controllers read the Convective SIGMETs onto a tape to be broadcast on HIWAS. The text product can be shown graphically (Fig. 3) if the user has suitable software and a display, but AWC does not disseminate a graphical product directly.

AWC forecasters primarily use the national radar mosaic, lightning information, and satellite imagery to determine the Convective SIGMET regions. A set of 6 phenomena qualify as "sigmet–able":

1. tornadoes
2. hail ≥ 3/4 inch
3. isolated severe thunderstorms
4. embedded thunderstorms
5. a line of thunderstorms, and
6. thunderstorms of ≥ VIP level 4, affecting ≥ 40% of area ≥ 3000 sq. mi.

Currently Convective SIGMETs are created "by hand" without the help of automated storm extrapolation guidance, using data collected at 30 minutes after the hour. The process can take up to 30 min, whereupon the SIGMETs are disseminated at the top of the hour. Thus the SIGMETs are 30 min old when issued, and they stand valid for 1 hour. With the guidance provided by our extrapolation algorithm, forecasters will be able to generate more accurate Convective SIGMETS, and perhaps update them more frequently (e.g., every 30 min). To ensure consistency across the ATC system, we intend to use the same algorithm selected for use in the Advanced Traffic Management System (ATMS) now deployed at Central Flow and at 20 ARTCCs (Jackson and Jesuroga, 1995).

We view this work at AWC as a small step toward improving the Convective SIGMETs in their textual form, and ultimately toward developing a graphically disseminated product. Eventually we would like to develop software that would determine the "sigmet–able" storms, draw the regions, and provide AWC forecasters the results for review. With an automated product, Convective SIGMETs could be generated in 5 min, assessed by AWC forecasters in 10 min, and issued every 15 min. In future years, we will incorporate growth and decay forecasts into the product to make it even more accurate and timely.

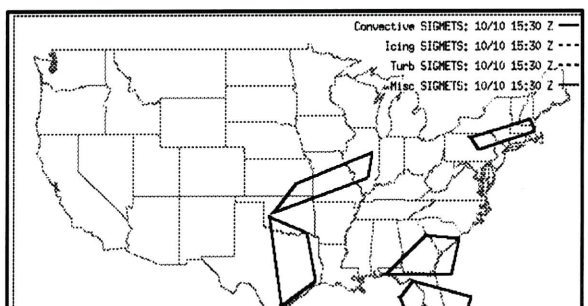

Figure 3. Example of Convective SIGMETs issued by Aviation Weather Center for October 10, 1996 at 15:30 Z. All polygons shown are Convective SIGMETS; there were no Icing, Turbulence, or Miscellaneous SIGMETs issued at this time.

5.3. Long lead–time forecasts

Users of the NAS also need forecasts on time scales >1 hr. We firmly believe we will need guidance, as well as explicit storm forecasts, from numerical models to achieve acceptable accuracy at these time scales. Thus we plan to emphasize research in this area over the long–term. One of the primary limitations of numerical modelling has been the sparse data on initial atmospheric conditions. It is our hope that the new GOES–8 satellite imager and sounder data will begin to provide these measurements, with some directed scientific research.

5.4. Dissemination Mechanisms

Our PDT has been given sponsor permission to explore any product dissemination mechanisms that will provide information to the end users in a convenient, accessible form. Our goal is to present graphical convective weather information of appropriate lead time to users of the NAS. Our vehicles will not be limited to ITWS and the AWC product streams. They may also include: Data Link, WARP, DUATS, OASIS, the Aircraft Situation Display, private vendors, direct delivery to airline meteorology and/or dispatch offices, internet, and/or cable television.

5.5. Convective Weather Users Group

Finally, our PDT realizes that a Convective Weather Users Group, with diverse membership from operational users, needs to be organized to achieve our goal of providing operationally effective convective weather detections and forecasts.

6. SUMMARY

The FAA Aviation Weather Research Program has reorganized its efforts into Product Development Teams. The Convective Weather PDT 1997 program consists of two major initiatives, both designed to immediately improve convective weather forecast information to NAS users. We have many other important scientific initiatives that satisfy stated requirements and/or that appear to be very promising areas of research, but they could not be funded this year. We look forward to near–term successes that will aid the FAA in identifying a consistent level of long–term R&D funding, so that we can make real progress towards achieving our full set of goals.

7. ACRONYM LIST

ARTCC	Air Route Traffic Control Center
ASQP	Airline Service Quality Performance
ATC	Air Traffic Control
ATMS	Advanced Traffic Management System
AWC	Aviation Weather Center (Kansas City)
CF	Central Flow
CTAS	Center Traffic Advisory Service
CWSU	Center Weather Service Unit
DOT	Department of Transportation
DUATS	Direct User Access Terminal Service
FAA	Federal Aviation Administration
GA	General Aviation
HIWAS	Hazardous Inflight Weather Advisory Service
IOC	Interim Operational Capability
ITWS	Integrated Terminal Weather System
KDP	Key Decision Point
LL	Lincoln Laboratory
MIT	Massachusetts Institute of Technology
NAS	National Airspace System
NCAR	National Center for Atmospheric Research
NEXRAD	Next Generation Weather Radar (WSR–88D)
NSSL	National Severe Storms Laboratory
OASIS	Operational and Supportability Implementation System
TATCA	Terminal Air Traffic Control Automation
TMC	Traffic Management Coordinator
TMU	Traffic Management Unit (in TRACON)
TRACON	Terminal Radar Approach Control
TSC	Transportation System Center
UR	User recommendations
P^3I	Pre–Planned Product Improvement
PDT	Product Development Team
R&D	Research and Development
VOR	very–high–frequency omni range (station)
WARP	Weather and Radar Processor

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