Presented at the American Meteorological Society 79th Annual Conference
Wyndham Anatole Hotel, Dallas, TX January 10-15, 1999

14.4 AVIATION USER NEEDS FOR CONVECTIVE WEATHER FORECASTS*†

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1. INTRODUCTION

The prediction of convective weather is very important to aviation, since almost half of the serious delay at major airports in the warm season is caused by thunderstorms. The need for accurate 0-6 hr forecasts for NAS users has been the subject of extensive publications, forums, and advisory committees in the aviation weather community over the last several years (Wolfson, *et al*; 1997).

The Convective Weather Product Development Team (PDT), a core team of scientists and engineers from NCAR, NSSL, and MIT LL, was formed in 1996 as part of the reorganization of the FAA Aviation Weather Research Program. The team is developing convective weather forecast algorithms that produce operationally useful products for both the terminal area and enroute airspace. The products are designed to meet specific users' air traffic planning and safety needs.

Before major algorithm development began, PDT members visited terminal and enroute Air Traffic (AT) personnel and airline dispatchers to understand the forecast products that were currently available to them and their needs for a near future product. Also, in order to reach the pilot community, a pilot survey about existing convective weather information and how to improve it, was created and distributed at the OshKosh Fly-In in August of 1997. This needs assessment took advantage of interviewees that had extensively used state-of-the-art weather information products (ITWS) in an operational setting for years. Their requirements, based on personal experiences with operational products during convective weather events, were less stringent than those reported in the recent requirements document pertaining to ARTCC TMUs (Browne, *et al*; 1999).

The results of these investigations were used in the creation of the DFW Terminal Convective Weather Forecast (TCWF) product and the National Convective Weather Forecast (NCWF) products that were demonstrated throughout the summer of 1998 (Hallowell, *et al*; 1999; Mueller, *et al*; 1999). These demonstrations also provided additional insight into user needs. In this paper we describe Air Traffic users and their specific responsibilities. We then summarize AT and airline needs based on interviews conducted in 1997 and 1998. Information on pilots' needs for convective weather information is presented at the end.

2. TERMINAL AND ENROUTE USERS OF CONVECTIVE WEATHER FORECASTS

AT users of forecast products are responsible for the safe and efficient movement of air traffic both enroute through the centers and in the airspace in and around airport TRACONs. A diagram (not to scale) of a typical TRACON and ARTCC is shown in Figure 1.

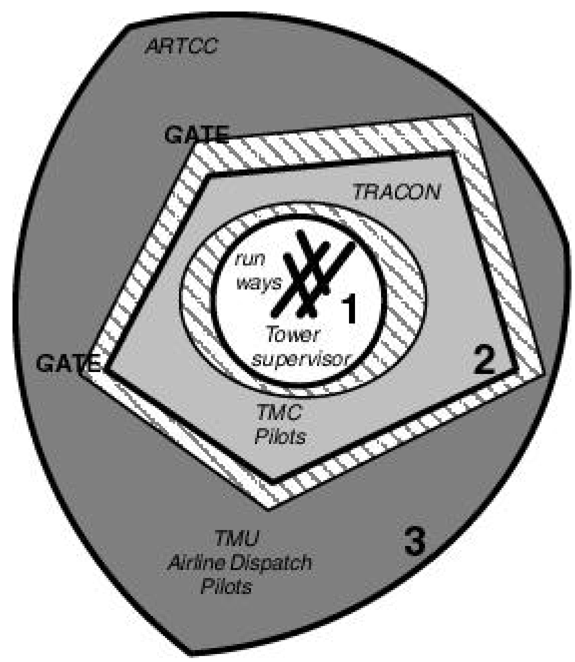

Figure 1. A typical TRACON and ARTCC; region 1 is tower airspace; region 2 is the TRACON airspace; region 3 is the enroute space; hatched areas are transition regions where adjacent users interact (tower/TMC, TMC/TMU). Forecast users in each region are also shown.

The airspace is divided into 3 regions. Region 1 includes the airspace nearest the airport (the runways) and is the responsibility of the AT tower personnel, who need current and only very short-term weather forecast information. Region 2 includes the airspace from the edge of region 1 to the boundaries of the TRACON. For the purposes of this paper, the enroute airspace, region 3, is considered to be the ARTCC that contains

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* This work was sponsored by the Federal Aviation Administration under contract no. F19628-95-C-0002. The views expressed are those of the authors and do not reflect the official policy or position of the U.S. Government.

† Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Air Force.

Note: Acronyms are defined on the last page.

the TRACON. As can be seen in Figure 1, these regions overlap; the overlap areas are transition regions in which aircraft are "handed over" to adjacent regions. Handoffs also occur from ARTCC to ARTCC. The AT personnel responsible for adjacent regions interact with each other when performing their tasks.

The personnel responsible for traffic flow in the TRACON are Traffic Management Coordinators (TMCs). In the TRACONs that do not have this position (i.e., Memphis, where the majority of interviews were conducted), the controller supervisors are responsible for traffic flow. For the remainder of this paper, TRACON forecast users will be referred to as TMCs. The ARTCC forecast users are part of the Traffic Management Unit (TMU). The tasks performed by TMCs and TMUs that require convective weather forecasts differ primarily because they are performed for different areas of responsibility. Their tasks are listed below:

- Change or pre-plan runway closures/configurations.
- Determine arrival and departure paths and gates (includes opening/closing gates and coordinating SWAPs).
- Balance traffic flow and maximize utilization of airspace.
- Implement flow restriction (miles-in-trail, holding).
- Interact with appropriate persons for task coordination (TMCs with TMUs; TMUs with CWSUs).

Airline dispatchers interact with TMUs and TMCs when performing the tasks that are listed below:

- Authorize, regulate, and monitor flights in accordance with FAA and company regulations.
- Compute amount of fuel for a flight.
- Interact with AT to adjust flight routes and to determine flight delay and/or cancellation.

3. RESULTS OF USER INTERVIEWS

The LL PDT members interviewed TMCs, TMUs, and airline dispatchers to determine their needs for a convective weather forecast product. Many of the AT users were from Memphis. Airline dispatchers from Northwest, TWA, Delta, United, USAirways, and Continental were also interviewed. The FAA W. J. Hughes Technical Center personnel interviewed TMCs and TMUs participating in the Terminal Convective Weather Forecast demonstration, and were able to further elucidate these users' needs (WJHTC, 1998).

The major questions that were asked during the interviews pertained to the forecast product's spatial extent, lead time, and accuracy. The interviewees were also asked about which features of different types of convection, air mass and line storms, were most important to their decision making.

3.1. Product Spatial Extent

The users that had ITWS available to them (all AT users and some airline users) were asked about the frequency of use and utility of the ITWS 50 nm and 200 nm precipitation products. All the users were asked if these ranges were sufficient for a forecast product. They were then shown a 500 nm NEXRAD reflectivity image and asked if they needed a forecast product of that spatial extent.

The majority of TMCs stated that they keep the ITWS display set to 50 nm and only use the long range product for a "quick look" at the approaching weather. One user commented that since he works with the TMU who uses the long range product, it is helpful to have it available. Only one out of four TMCs expressed the need for a 500 nm product. He commented that he "would love a 500 nm view" and that he would use it for planning at the beginning of a push. The others agreed that a forecast product with ranges of 50 nm and 200 nm was adequate for most storms, winter as well as summer. After the demonstration of the TCWF in DFW, many users felt that a 100 nm range product (available in ITWS but not TCWF) that allowed them to see just beyond the TRACON would have been useful.

The majority of the TMUs in the ARTCC also stated that they keep the ITWS display on the 50 nm product and "flip" to the long range product to see the extent of the weather and then "flip" back. (WJHTC found 65-70% of time on 50 nm; 30-35% on 200 nm.) However, most stated that ITWS was "a tower product" and in order for a forecast product to be useful it had to "go out further in distance". They needed the situational awareness of a 200 nm forecast in order to route planes away from convection, establish holding patterns, and open and/or close approach and departure gates. These users found the 60 min forecast of the TCWF and the trailing edge information very useful. Approximately 50% of the TMUs said they would use a 500 nm forecast if it were available.

The airline dispatchers that have ITWS available to them use the 50 nm and 200 nm products in the same way as the TMCs and TMUs; they look at the long range product very quickly and then go back to the 50 nm product. Most indicated that these ranges are sufficient for a terminal forecast since they have access to other products that give them more of a national view.

3.2. Product Lead Time

The TRACON TMCs stated that the optimal forecast lead time needed to manage current traffic is 30 min. In fact, many TMCs were satisfied that the ITWS 10 and 20 min storm leading edge forecasts (Storm Extrapolated Position product) provided sufficient lead time for their tasks. (The information that was lacking included the "pop-up" and decay of new cells on runways and gates, and especially tracking the trailing edge or "backside" of the storms.) However, the TMCs commented that they could also use a forecast out to 60 min for planning traffic flow within the TRACON.

The TMUs need forecast lead times of 60-90 min. With a 60 min forecast, they can plan aircraft reroutes further upstream, allowing planes to fly a more efficient trajectory. A 60 min lead time also enables the TMUs to keep approach and departure gates open as long as possible in order to get "the last few planes in or out of the terminal area" before it becomes weather-impacted. This proactive upstream planning greatly reduces delay and prevents last minute chaos. The ITWS 10 and 20 min product could only be used for last minute reroutes in a reactive manner. After using the 60 min forecast for 2 months during the TCWF, 33% of the ARTCC users felt they needed ≥90 min forecasts.

Airline dispatchers "optimally" want forecast lead times of 2 hr plus the length of the flight so that they can hold planes on the ground (more economical than diverting or rerouting). Realistically, they need a 2-6 hr forecast: 2-4 hr lead time for hub operations and 4-6 hr lead time for cross-country and international flights. A 2 hr forecast is sufficient to catch short haul flights on the ground. If airborne planes are low on fuel, it is enough time for dispatchers to issue them a stop to refuel and hold on the ground until the weather clears.

3.3. Product Accuracy

The terminal users in the tower need forecast accuracy ≥ 90% in order to open, close, or reconfigure a runway. They need such high accuracy because their area of responsibility is small and an incorrect decision is extremely costly. (The ITWS 10 and 20 min leading edge storm forecasts are also completely sufficient for tower use.) On the other hand, TRACON TMCs stated that they would be satisfied with forecast accuracy > 70% since they have more leeway at and around arrival and departure paths and gates.

The TMUs said that forecast accuracy ≥ 50% was sufficient. One TMU commented that he would use a forecast with lower accuracy for tasks that were easy to implement and had minor negative implications. He said, "we move planes unnecessarily all the time; it is worse not to have moved them when we should have—then we have chaos". Most TMUs also said that they would accept a forecast with an accuracy within ± 5 nm and ±10 min.

Airline dispatchers expressed need for long lead time forecasts that would also provide a reasonable accuracy. Most agreed that a forecast with accuracy > 30% would be acceptable since currently they have no forecast information. One said, "I'll take whatever you'll give me! It's better than what we've got."

The previous discussion of users' needs for forecast spatial extent, lead time and accuracy are summarized in Figure 2.

3.4. Storm Characteristics

In addition to answering questions about their needs for a forecast product, users were asked to comment about which features of air mass and line storms were most critical to their decision making. Figure 3 provides a schematic illustration (not to scale) of how different types of convection can impact the terminal and enroute airspace. The various scenarios (1-6), presented in Figure 3 and referred to below, illustrate the different effects that storms have on air traffic depending upon their location.

Air Mass Storms

The users commented that air mass storms with explosive new growth on runways (1) were the most troublesome and the cause of major delay, especially when the cells remained stationary. When new "pop-ups" occurred enroute (3), and on arrival and departure paths and gates (2), planes could usually deviate around them.

Also, knowing when convection will decay is very important. According to Evans (1997), a significant initial benefit of convective weather forecasts should come from accurately forecasting when convection will *stop* impacting a runway. In addition, if a ground hold is imposed by the TMU because convection caused a drop in terminal and/or enroute capacity, it is *most important* to predict the *end of the capacity constraining convection*.

Users also wanted to know which air mass storms would organize into line storms (4) and if there was wind shear associated with the "pop-ups."

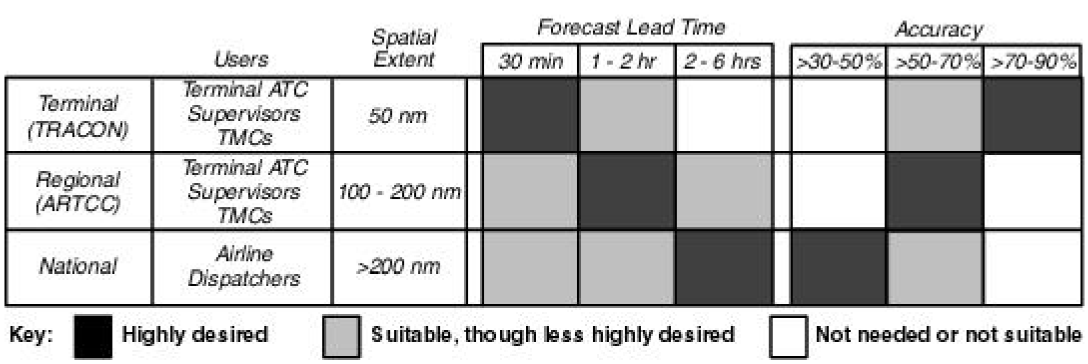

Figure 2. Summary of users by region, and their needs for convective weather forecasts.

Line Storms

The users all agreed that line storms cause the most consistent NAS problems. The features of line storms that are most important to users' decision making include the width, density, length, speed, intensity, and echo top of the line.

They commented that the width of the line, and knowing when the back edge of the storm would clear their critical area of responsibility (5), were most important. They needed to know about gaps in the line (6), to decide whether to route the pilots around the entire storm or through it. The users remarked that some pilots preferred to go over storm tops, rather than through a gap. However, the pilots would be more inclined to fly through a hole in the line if a) the storm were decaying, rather than growing, b) if they trusted the controller, and c) if other planes had already gone through.

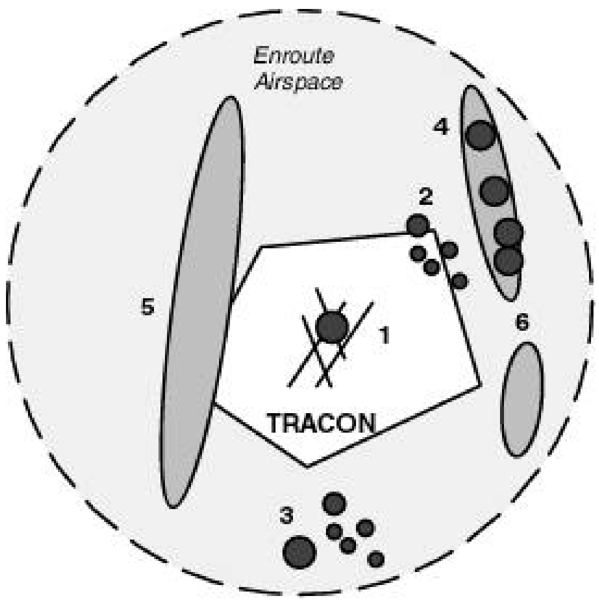

Figure 3. Problems to enroute and terminal airspace caused by different types of convection.

4. PILOT S SURVEY ON CONVECTIVE WEATHER NEEDS

Pilots are also key users of convective weather forecast information. To understand their needs, we developed a post-card sized survey questionnaire, and distributed it at the 1997 OshKosh Fly-In. Five hundred cards were distributed and 25% were returned in the mail. We chose to present results here by stratifying them according to the type of license held by the respondents. These included Air Transport (ATP), Commercial, Private, and Student. All but the student pilot's responses are included in this analysis. The pilot population is summarized in Table 1.

Table 1. Population of Respondents.

License	Number of responses	Avg. years as pilot	Avg IMC hrs
ATP	27	25	825
Commercial	45	20	283
Private	54	14	69

The pilots were asked how they usually piece together a picture of current and forecast thunderstorms before they fly. They were given multiple choices and asked which were most important. Their choices were: FSS Briefing, Convective SIGMETs, Pilot Reports, Area Forecasts, Terminal Forecasts, TV/Weather Channel, Radar Summaries (DUATS), Surface Observations, FBO Weather Graphics, and user supplied choice. Figure 4 contains a summary of the source they felt was most important. It is clear that the air transport pilots are frequently getting their weather information on-line via graphical displays (internet category; comments indicated private vendors and other graphical sources), while the commercial and private pilots rely heavily on their local FSS.

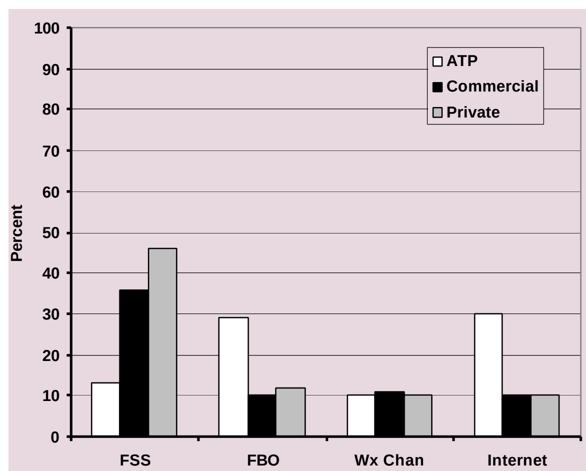

*Figure 4. Most important sources of current and forecast thunderstorms, **before flight**.*

The pilots were also asked how they obtained updates on thunderstorms while enroute. Their choices were: HIWAS, Pilot Reports, ATIS, On-board Weather Radar, FSS/Flight Watch, Stormscope/Strike Finder, Controllers, and user supplied choice. Figure 5 contains a summary of the choice they felt was most important. Again, FSS/Flight Watch is shown to be a very valuable source of weather information for commercial and private pilots.

The Integrated Terminal Weather System prototype has been provided to only one Flight Service Station (Ft. Worth) on an experimental basis, where it has proven very useful. Waite (1998) found that ITWS "proved to be the most accurate piece of weather radar equipment they have. ...Pilots not only verified the accuracy of the information, but put it to use in making reroute decisions." We estimate that at least 40% of GA pilots fly within areas covered by ITWS. (Agricultural and rural users would probably not fall within ITWS coverage very often, but business GA would definitely fly within ITWS coverage on many of their flights.) Although ITWS is now in full scale production, the FAA still has no plans to provide the ITWS to the Flight Service Stations.

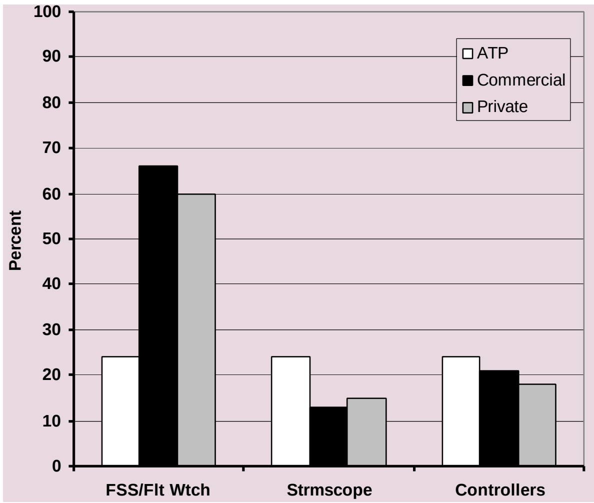

Figure 5. Most important sources of thunderstorm updates while ***enroute****.*

Pilots were asked specifically about the Convective SIGMET product generated by the Aviation Weather Center in Kansas City. This product represents the official NOAA/NWS convective weather forecast for the flying public. There has been some confusion as to whether the Convective SIGMET indicates only where storms are now, or whether it represents a forecast. (Officially, the product describes the location of significant thunderstorms up to 2 hours in the future.) Figure 6 shows that most pilots believe the SIGMET represents current storms, or at most a 1 hour forecast.

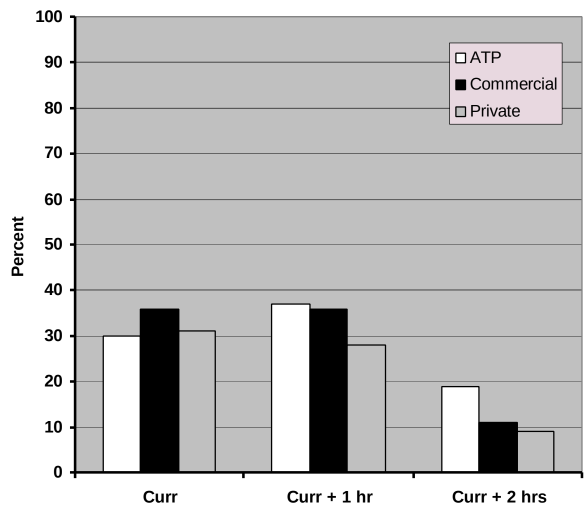

Figure 6. Interpretation of Convective SIGMETS.

Figure 7 shows that pilot satisfaction with Convective SIGMETs is neutral, with no users "very satisfied". Their comments (not included here) indicate there is much room for improving this product. The Convective Weather PDT has demonstrated, and continues to develop, a National Convective Weather Forecast Product that could be used to aid in the generation of Convective SIGMETs in the future (Mueller, et al., 1999). The forecasters at the Aviation Weather Center have been actively involved in this product development.

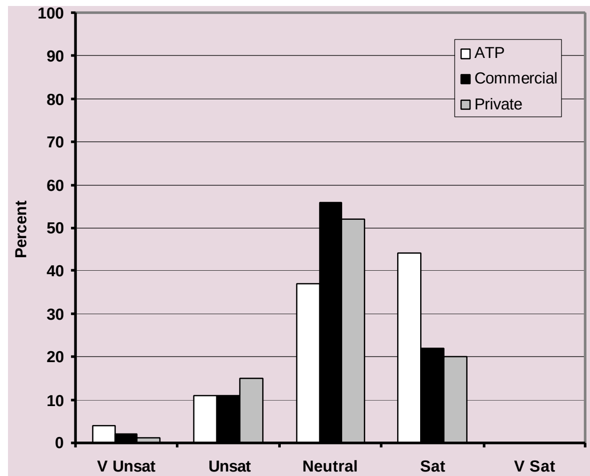

Figure 7. Pilot satisfaction with convective SIGMETs.

Finally, the pilots were asked to rank the following sources of weather information for improving airspace safety: A) more precise forecasts, B) more frequent HIWAS/ATIS updates, C) better real-time weather display for controllers, D) better in-flight access to FSS, and E) real-time graphical cockpit weather display. The percentage of #1 responses for each source is shown in Figure 8. Pilots clearly recognized the high potential value of a Real-Time Graphical Cockpit Weather

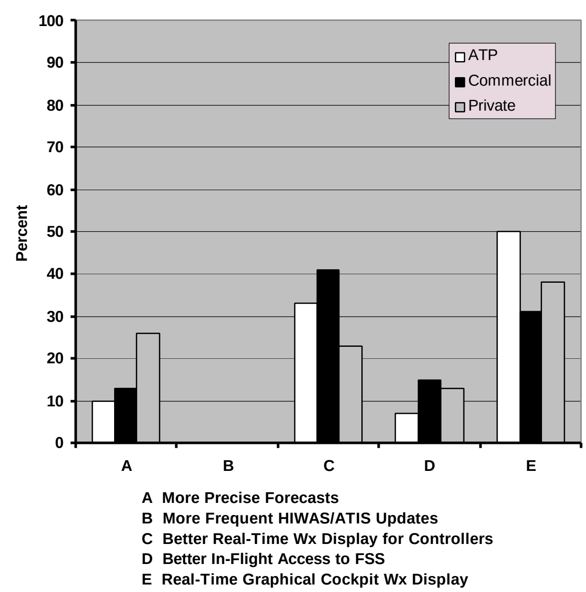

Figure 8. Percent of ***# 1 responses*** *for importance in improving safety of each source of Wx information.*

Display (E). The frequent choice of Better Real-Time Weather Display for Controllers (C) reveals that the pilots, while airborne, rely on controllers to ensure their safety in changing convective weather situations. This suggests the controllers may need better weather displays, but may also be interpreted as the pilots' desire for the controllers to *impart* better weather information via radio.

5. SUMMARY

The most significant information that the PDT learned from this user needs assessment was that ARTCC TMUs and airline dispatchers were willing to trade-off forecast accuracy for longer lead times, especially for low risk tasks that were easy to implement. Insight gained from users enabled the PDT to begin developing forecast algorithms and display concepts that met their needs. In 1998, both Terminal and National Convective Weather Forecast Demonstrations of a 1 hour forecast took place and were well received. Research will continue to further improve the 1 hour forecast product, but, at the same time, a quantitative assessment still needs to be made of how extending these initial forecast products (to address additional user needs in Figure 2) will improve the quality of air traffic service.

6. ACRONYM LIST

ARTCC	Air Route Traffic Control Center
AT	Air Traffic
ATIS	Automatic Terminal Information Service
ATP	Air Transport Pilot
CWSU	Center Weather Service Unit
DFW	Dallas/Fort Worth
DUATS	Direct User Access Terminal Service
FAA	Federal Aviation Administration
FBO	Fixed Base Operator
FSS	Flight Service Station
GA	General Aviation
HIWAS	Hazardous Inflight Weather Advisory Service
IMC	Instrument Meteorological Conditions
ITWS	Integrated Terminal Weather System
LL	Lincoln Laboratory
MIT	Massachusetts Institute of Technology
NAS	National Airspace System
NCAR	National Center for Atmospheric Research
NCWF	National Convective Weather Forecast
NEXRAD	Next Generation Weather Radar (WSR-88D)
NOAA	National Oceanic and Atmospheric Administration
NSSL	National Severe Storms Laboratory
NWS	National Weather Service
PDT	Product Development Team
SIGMET	Significant Meteorological Information
SWAP	Severe Weather Avoidance Procedures
TCWF	Terminal Convective Weather Forecast
TMC	Traffic Management Coordinator
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control
WJHTC	W. J. Hughes Technical Center

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