WEATHER AVOIDANCE PLANNING AND COLLABORATIVE ROUTING DECISIONS

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Abstract

Shared situation awareness of weather phenomena in the Federal Aviation Administration's (FAA's) Traffic Flow Management (TFM) and Airline Flight Dispatch (AFD) operations is critical to improve aviation safety. Safety depends on complex communication chains that currently provide weather awareness to users. Many of the processes in these communication sequences have been repeatedly identified in National Transportation Safety Board reports as precursors to judgement errors about weather situations, contributing to aviation accidents.[1] This paper contends that shared situation awareness could be improved. If weather information were more procedurally relevant to effective operations, it would be perceived as economically advantageous to use.

Introduction

Everyone agrees that the service providing components of the publicly owned and operated air traffic control system and its certification and regulatory organs, as well as the service using components of for-profit, airline organizations, must operate together if commerce and airspace capacity are to continue to grow. This is equally true of public weather service providers and private weather service users in aviation. Unfortunately, policy justifies the public weather service infrastructure and national forecasting capabilities as almost entirely for the public's safety, while user concerns about improved services are almost entirely economic.[2] The National Weather Service (NWS) Aviation Weather Center (AWC) and the FAA are trying to be more responsive to these user needs. Both the AWC and the FAA are supporting the development of more user-friendly, aviation weather products.

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Major airlines have implemented weather technology innovations mainly to improve regulatory compliance. Federal regulations governing aviation weather requirements for flight operations focus exclusively on public safety. Sometimes applying required weather information could improve airline's operating effectiveness, but few weather-related, decision support tools are designed for this purpose.

To a great extent, improved meteorological services have been imposed on airlines as regulatory and certification requirements resulting from aviation accidents. Accident reports of the National Transportation Safety Board (NTSB) are replete with precursor conditions relating to missing, untimely, unintelligible, and erroneous, weather information contributing to faulty situation awareness by flight crews, flight dispatchers, and controllers, and resulting in poor decisions that caused weather-related accidents. Over the past 20 years, about 40 percent of all NTSB reported commercial airline fatalities have been associated with weather as a factor.[3] Because of the association of safety with Federal regulatory and certification requirements, a NASA-Aviation Safety Investment Strategy Team (ASIST) identified the dissemination and display of hazardous weather products and decision aides for traffic managers, dispatchers, air traffic controllers, and flight crews as the highest current priority for investment.[4]

Not surprisingly, successful aviation weather products for commercial airlines have reduced the cost of regulatory compliance. However, resulting safety improvements from products available today have been difficult to quantify.[5]

Federal Aviation Regulation (FAR) 121.101 states that all domestic carriers must show that enough weather reporting services are available along each route of flight to ensure reports and forecasts necessary for flight operations.[6] The regulation also says that all US flight operations must use weather reports prepared by the NWS or sources approved by the NWS. Finally, the regulation requires that each domestic carrier have an approved system in place for obtaining forecasts and reports of adverse weather phenomena that may affect the safety of flight, such as clear air turbulence, thunderstorms, and low altitude windshear.

FAR 121.629 precludes the dispatch or release, or continued operation of an aircraft when, in the opinion of the pilot or dispatcher, icing conditions are met, or likely, that may effect the safety of flight.

FAR 121.601 requires that before a flight, the aircraft dispatcher must provide the pilot all available weather reports and forecasts of weather phenomena that may affect the safety of flight, including adverse weather phenomena, that may be encountered for every route and each airport in the flight plan. During flight, aircraft dispatch is to provide pilots any additional, available information on meteorological conditions, including adverse weather conditions, and irregularities of facilities and services that may effect the safety of flight.

The FAR regulations make explicit and repeated references to both the pilot and the dispatcher responsibility for independently terminating flight plans because either believes conditions are unsafe.[7] These regulations provide the basis for most of the public and commercial weather products used by airlines and TFM today.

In contrast to the FARs, airlines think *improved* weather information services and products should assist them in selecting more efficient routes, improving aircraft performance, and avoiding schedule delays. For years there were no FAA or NWS services to address these kinds of weather considerations. Now these agencies have employed experts to prove that many of their developmental weather products are economically beneficial to users.[8]

In response to these claims and in order to give meaning to free flight concepts for planning, routing, and maneuvering aircraft,[9] TFM at the FAA Air Traffic Control System Command Center (ATCSCC) and AFD at Airline Operations Centers (AOCs) are redefining the nature of weather services. They hope to accomplish this by creating shared weather situation awareness among FAA traffic managers and airline dispatchers to support collaborative operating procedures for weather impacted operations. Specifically, they hope to enhance the FAA's ground delay program and improve collaborative routing around adverse weather.

Safety will not be further improved, nor greater shared awareness of weather situations created, until weather information is routinely perceived as being economically consequential. To be so perceived, it must be tied to operating procedures that support economically consequential decisions. Such procedures govern how crucial air sector capacity decisions are made, such as those for ground delay program enactment, miles-in-trail restrictions, aircraft re-routes, or flight plan re-filing. Until weather information supports these procedures, the service providing components of the publicly owned and operated air traffic control and weather information systems and the service using components of privately owned airline organizations will not have sufficient incentive to create shared weather situation awareness.

The collaborative paradigm for FAA and airline weather-related decision making has three distinct parts.[10] First, a shared knowledge of system constraints through data exchange and common situation awareness must be created. Next, mutually understood rule sets or procedures for making decisions have to be agreed upon for recognized situations. Finally, decision support tools for the decision makers' review of constraints and development of strategies for managing resources must be developed.

Airline Weather Avoidance Routes

The absence of shared weather situation awareness, and satisfactory procedures for resolving weather-related congestion, as well as appropriate decision aides, have resulted in inefficient route selections and costly ground delays for commercial airlines.[11] The airlines would like to implement procedures and technologies to reduce these losses. They believe that this could be accomplished by coordinating TFM functions and AFD operations better. To do this, they are cooperating with the FAA in a unique program called Collaborative Decision Making (CDM).

Inadequate facility staffing, informal controller workload practice, or too many flight plans to transit an airspace sector at a given time can cause capacity alerts. FAA decisions to declare capacity alerts can be highly varied, so that the number of planned flights creating a capacity alert is not always the same, even for the same airspace sector. Moreover, among airspace sectors, the number of flight plans creating a capacity alert for a high altitude sector is probably not the same as the number creating a capacity alert over a departure or arrival fix at a major airport.

As a practical matter, the operational capacity of an airspace sector is exceeded whenever the FAA will not allow all the flight plans of airspace users of that airspace to be executed as filed. The reason why the FAA cannot accommodate all these user-preferred flight plans is that the demand for the sector at a particular time has been deemed to exceed its "safe" capacity. This FAA determination results in further FAA decisions to re-route aircraft around the sector or delay their entry into it. These decisions, in turn, cascade throughout other airspace sectors and airport arrival times. The agency has taken the position that its safe airspace capacity determinations are not subject to collaboration.

The FARs preclude planned or continuing flight operations in areas where defined weather hazards are observed or forecast, greatly reducing operational airspace capacity. However, the FARs also allow airlines to use forecasts from NWS-certified meteorological departments, certified meteorological service providers, or certified FAA electronic forecast enhancements, potentially overriding any NWS-certified weather forecast product when the weather is characterized differently. Different organizational objectives reinforce differing meteorological interpretations to support their perceptions of where flight operations are or will be permissible. Such differences about the location and timing of weather hazards can result in contradictory weather re-route plans and flight plan filings among AOCs, TMUs, and ATCSCC, all of which must be reconciled.

The fact that airlines with certified met departments routinely file flight plans to transit airspace and depart or arrive at airports at times that NWS forecasts deem them to be adversely affected by weather, suggests that common weather situation awareness is lacking. Without shared situation awareness and agreed upon procedures, the data exchange necessary to reconcile airline airspace demand with TFM airspace supply is difficult and slow.

Major meteorological causes of airline delays are shown in table 1. The table contrasts the severity classification of these meteorological delays to current capabilities detecting and communicating the occurrence of these weather phenomena. It also compares meteorological delay severity and detection capability with current modeling and forecast skill for these phenomena, and with current operating displays and decision support systems of airline dispatchers and traffic managers. The table suggests that the most severe weather causes of aviation delays are well detected and communicated. They are forecast only moderately well as a group, and the forecast skills deteriorate rapidly over time. However, these weather phenomena detection and forecast capabilities are not displayed to flight dispatchers and traffic managers, so that they can form common situation awareness.

The absence of weather situation awareness to support collaborative routing procedures makes the occurrence of potentially adverse weather along planned flight routes de-stabilizing. It creates very large economic uncertainties in airline flight operations and FAA traffic flow management, and very different airline strategies for dealing with them. Because FAA capacity alerts due to weather can result in economically consequential flight plan re-filings, airborne holding and re-routing, and ground delay decisions, AFD and TFM are discussing procedures to ensure that the decision makers' selection of strategies are efficient and equitable. The FAA has acknowledged that some of its weather strategies solve the supply problem only from its perspective, but adversely affect airlines in ways that could be avoided.[12]

Both TFM and AFD operations agree that efficiency is achieved when proposed flights do not exceed the operational capacity of the airspace at any time. If this were the case, then there would be no weather related FAA re-routes, nor airline flight plan re-filings. To achieve this goal, AFD and TFM need a common understanding of weather situations, agreed upon procedures for exchanging flight planning and routing information, and decision support tools.

ATCSCC would like airlines to file flight plans earlier, so that it could coordinate necessary re-routing with all the relevant center and terminal control TFM units and thereby alleviate sector capacity alerts. AFD would like the FAA to accept more efficient airline weather re-routes, requested in flight plan filings. Both agree that the operating procedures for exchanging data to assess airspace sector demand and forecast airspace capacity are inadequate.

FAA initial weather consensus forecast

The capacity of the TFM system is measured by the realized flow through the system over a period of time, as constrained by operational uncertainties.[13] One of the most important sources of uncertainty for daily traffic flow planning is weather. On "weather days" the ATCSCC needs 5 or 6 hours to coordinate and resolve all airspace sector capacity alerts, where filed flight plans demanding a particular parcel of airspace at a given time exceed what the FAA determines to be its safe capacity. But some dispatchers contend that flight plans filed 4-6 hours prior to flight are likely to be so inaccurate as to require costly re-filing.[14] They would prefer to file flight plans as late as one hour before departure to have the best awareness of changing weather conditions and the most accurate information for determining aircraft loading and fuel requirements, and the least impact on scheduled operations.

Recent data seem to support this airline dispatch inclination to file flight plans as late as possible in atypical situations. Researchers found that as many as one-fourth of the flight plans of a major airline's delayed flights, and 17 percent of all its flight plans were completed and filed less than 25 minutes prior to departure.[15]

In 1997, the Severe Weather unit (SVRW) at the ATCSCC worked with the airlines to address weather-impacted airspace and re-routing problems. It solicited a convection diagnosis from air carrier and NWS meteorologists in a 5:00 AM teleconference to create a common awareness of the weather situation, called a consensus forecast by participants. The teleconference was at least 2 hours in advance of most airline initial departures and 4-6 hours ahead of most of their departures. The ATCSCC hoped to use a consensus convection forecast to influence strategic weather re-routes, and related airline dispatch plans.

A consensus approach to re-routes would reduce the number of sector capacity alerts generated by flight plans filed for weather-constrained airspace, and thereby reduce ATCSCC and FAA facility traffic management coordination time. To foster agreement on proactive regional and national routing strategies, the AOCs and the ATCSCC imagined that the critical timeframe for a consensus convection forecast would have to be the same as the time required for current "weather day" coordination, or about 6 hours.

The SVRW approach to consensus forecasting was visionary in its simplicity, but naive. Because they did not allow for reduced coordination time that could result from a shared weather consensus, the AOC-ATCSCC requirement for an accurate 6-hour convection forecast exceeds current scientific capabilities. The consensus sometimes represented a majority of erroneous forecasts, and the SVRW lacked the technical expertise to recognize and persuade others of a more appropriate outlook. Other times when there was a consensus weather outlook, the weather consensus did not change or clarify how the airlines wanted flight dispatch and flight operations to deal with the situation. While the SVRW focused on differences in airline weather forecasts, it could not resolve differences in airline strategy for filing flight plans.

The airlines and the ATCSCC agree that current convection forecasts are inadequate for forging a strategic consensus on weather re-routes and flight plan filings. Without a shared view of forecast weather, the ATCSCC will remain involved in arbitrating airline flight plan strategies and local disputes among air carriers and terminal and en-route traffic management and air traffic control units. A consensus approach to weather situations, rather than forecast accuracy improvements, is the key to developing operating procedures for weather re-routing and reducing coordination time.

Severe Weather Advisory Plans (SWAP)

SWAPs have existed for years. In 1998 TFM units and the airlines initiated a plan to try using probabilistic one, two, four, and six-hour convection forecasts to create consensus and initiate SWAPs. A CDM program also attempted to consolidate agreed upon SWAP procedures in a national SWAP plan. The variations in convection forecasts in the earlier, SVRW program allowed different airline strategies. SWAP 98 recognized that both airline strategies and the amount of time that FAA needed for coordinating traffic re-routes depended on improved information exchanges and shared displays. Taking such displays as a given, the SWAPs 98 program postulated that connecting the agreed upon operating procedures for weather situations in previously defined locations to national weather re-route plans would be a logical step for collaborative, traffic flow management.

Better convection forecasts address similar ATCSCC and AOC perspectives about how flight dispatch and traffic management organizations interact. Subjectively probable, convection forecasts could allow each to invoke previously agreed upon, local procedures for weather-related re-routing and flight plan filing. To invoke these procedures, AOCs and ATCSCC needed shared awareness of weather, and decision-support tools. SWAP 98 tried to transfer weather information from FAA facilities to airspace users, and vice versa, by imagining common weather displays. Paralleling these efforts, web-based, shared weather awareness products were developed by the AWC, the National Center for Atmospheric Research (NCAR), and Northwest Airlines.

Procedurally, the collaborative routing program incorporated and shared information on past and continuing efforts of individual airlines to develop active SWAP routes in terminal control areas like New York, and emphasized more equitable alternative routes in weather situations.[16] SWAP agreements on alternate routes in weather situations and how they can be invoked involve local TFM coordinators, controllers, and AFD units. Some agreements state that when certain weather situations occur, airline pilots and dispatchers can simply request numbered alternative approach and departure routes to avoid congestion and delays. If the FAA accepts the situation as appropriate, then all the requests are automatically granted. Such SWAPs identify alternative departure routes, physical airspace limits of the plan's jurisdiction, and traffic flows responsive to local climatology and traffic management procedures.

Many of these plans originated in unique airline hub strategies for weather contingencies. However, if they were consolidated at the national level by the ATCSCC, they could be implemented to augment national TFM. This approach would shift the focus of TFM coordination from terminal and en route traffic management agreements to ATCSCC weather re-routes. It requires that airlines meet well-defined notification requirements for modified flight operations, and that the ATCSCC invoke the conditions that would greatly simplify the process for airlines to receive weather re-routes. Local TFM acceptance and coordination time for SWAP routes would be greatly reduced.

The SWAP 98 weather procedures consolidation effort included regional approaches to weather situations called tunneling. Regional TFM and AFD personnel in Florida, Texas, and New York had developed a technique for making full use of the so-called "non-optimal" vertical airspace. Tunneling puts jet aircraft on relatively low altitude, longer approach and departure trajectories. For the airlines, delays caused by weather and airspace congestion are reduced. The beneficial effect of these regional tunneling routes for the FAA is reduced center, TRACON, and terminal control area coordination for the previously agreed upon re-routes to and from arrival and departure fixes. Tunneling saves time and improves airspace capacity.

Consolidating existing SWAP and tunneling agreements in a national program has proven difficult. To date, only the goals and objectives of a national program have been defined, along with a glossary and definition of terms. A national program would provide rules for both providers and users of these routes, including notification procedures to alert traffic managers, controllers, and dispatchers. The idea is that at or below certain altitudes in specific airspace sectors, the ATCSCC and AOCs could invoke these agreements for properly equipped aircraft. Common weather situation awareness is a necessary first step for such a plan to succeed.

The CDM Program

The new CDM paradigm addresses the question how improved meteorological products can make TFM and AFD functions more effective, efficient, and equitable. AFD currently has limited access to information used by TFM in identifying and formulating solutions to problems resolved through re-routes.[17] To the extent that AFD has little opportunity to influence TFM routing resolution strategies, its execution of flight planning and flight dispatch is constrained.

CDM is attempting to develop procedures and techniques for marrying new technologies associated with Free Flight Phase One (FFP1) systems to AFD and TFM functions. The objective is to schedule and manage traffic flows more efficiently, in light of the shared situation awareness that will result from new information and FFP1 systems. The program has created a communication system that connects nine AOCs to one another (AOC net), and to selected Enhanced Traffic Management System (ETMS) data fields used by TFM units, and the ATCSCC. This enables airlines and the ATCSCC to share schedule, traffic, and delay information.

All parties currently use the Aircraft Situation Display (ASD) and ETMS data to monitor traffic, and the Flight Schedule Monitor (FSM) to exchange airport flight schedule and capacity information with the ATCSCC. Such shared information is used to update airport demand, and thereby minimize FAA ground delay programs. The benefits of these collaborative activities to date have been very significant improvements in FAA's ground delay program, generating large airline operating cost savings.[18] These savings are a result of increasing operating airspace capacity.

CDM is striving to define, display, and communicate critical weather parameters needed for AFD and TFM decisions. Such shared weather awareness would support TFM procedures and policies for making more efficient and effective use of airspace. A critical element in developing more effective procedures is a shared mental model of weather-impacted operations. One problem creating this shared awareness is that currently observed and forecast weather is not sufficiently adapted for AFD and TFM procedures.

Another problem creating shared situation awareness is the complexity of roles and responsibilities in large airline and FAA organizations. This can create competing information objectives within the same organization. For example, data on communications between the FAA and a major airline during a significant and costly weather event suggest that roles within each organization may have been more consequential to effective communication of the weather situation than displays and decision aides.[19]

The current CDM work plan calls for adapted, weather displays for three different phases of flight in order to define improved operating procedures and policies for the new FFP1 systems.[20] The work plan seeks to develop improved weather displays as part of three tool sets for airport, en route, and visual collaborative routing. These tool sets attempt to relate shared display information to the operating policies and procedures governing TFM for each of the phases of flight. The work plan proposes to introduce experimental weather detection and forecast information in AOCs, and the ATCSCC to accomplish this purpose.

Airport tool set

The airport tool set addresses three different, weather-related problems: fix loading, active runways, and de-icing queues. Because NCAR was deeply involved with the technical weather solutions that the work plan proposes to apply to three new decision-making domains, it has become a source of technical advice for these CDM efforts.

Fix loading

In order to display the impact of weather conditions on critical arrival and departure fixes, the work plan proposes Integrated Terminal Weather System (ITWS) and Terminal Doppler Weather Radar (TDWR) displays in all AOCs and appropriate FAA TFM units. NCAR conducted the atmospheric science research and developed the necessary algorithms for successfully displaying weather phenomena for the TDWR system under FAA research and development programs. We are currently collaborating with MIT Lincoln Laboratory to develop improved products for ITWS.

In order to develop the requirements for these previously unknown systems and their displays, and to refine the systems to meet operational requirements, NCAR made extensive use of air traffic control operators and airline users in TDWR user groups. This approach is the key collaborative element in the CDM program for refining weather displays and “fix loading” procedures.

Active runways

The work plan also calls for Low Level Wind Shear Alert System (LLWAS) and Low Level Wind Shear (LLWS) system alerts to be displayed at all AOCs and appropriate TMUs in order to develop policies and procedures for the use of active runways impacted by low level wind. NCAR worked with Air Traffic Operations and airline representatives to develop the algorithms for defining wind shear and microburst alerts for both of these systems under the FAA research and development program. We hold patents for the LLWAS warning algorithms, and we can meaningfully contribute to the development of consistent flight dispatch and TFM alerts and displays to support TFM procedures.

De-icing queues

The work plan’s airport tool set also calls for better means of coordination between air traffic control and airlines during airport icing and winter storm conditions to reduce post-de-icing exposure and optimize de-icing operations at the airport. Here too, NCAR has developed a sensing and forecast system for aircraft de-icing with FAA funding called Weather Support for Deicing Decision Making (WSDDM). The system was successfully demonstrated at La Guardia airport over the last two winters and previously had been demonstrated at O’Hare, Denver International, and Denver Stapleton airports.

In demonstrations, the major airlines, airport authorities, and FAA controllers have used the system to coordinate their respective dispatch, runway clearance, and traffic flow management operations. In order to rapidly commercialize this technology and promote its widespread use, NCAR has exclusively licensed it at no cost to ARINC.

En route tool set

The CDM work plan recognizes weather as a major potential constraint on airspace capacity. The question posed by CDM when all flights cannot be flown as filed, is how should the FAA and users go about re-routing aircraft or delaying their airspace entry to achieve the safest, most operationally efficient, and equitable, routes?

As in the case of CDM enhancements to the FAA ground delay program, the airlines have the most knowledge about the relative economic importance of each of their scheduled flights. They could take pre-emptive actions to substitute only high priority flights for others, trading accepted flight plans (slots) with other airlines, and/or filing altered flight plans to avoid anticipated airspace constraints. However, to do any of these things, airlines would have to know more precisely when and where airspace capacity constraints (and their related FAA re-routings) were likely to occur. Quite possibly the collaborative airline reactions, by themselves, would be sufficient to mitigate the potential airspace capacity constraint and it's associated FAA re-routings and delays. AFD needs improved, en route weather situation awareness as proxy information on potential air sector alerts. ATCSCC needs information on airline flight plan intentions and flight cancellations in reaction to this weather information, to coordinate TFM.

The CDM work plan calls for display of current and forecast thunderstorms and the flight constraints that would be associated with them to all AOCs and appropriate TFM facilities. It also would display all non-convection weather hazards to en route flight, such as airborne icing and turbulence diagnostic and prognostic products, to TFM and AFD users. The challenge is to provide all the effects of these weather phenomena to support appropriate TFM procedures for airspace operations.

Visual collaborative routing tool

The CDM work plan calls for airlines and the FAA to use commercial software (Netmeeting ©) to organize net-based, collaborative discussions of weather and air traffic display tools necessary to create a shared situation awareness. Collaborative routing requires that ATCSCC and AOCs have the same picture of adverse weather conditions so that they can minimize confusion and accommodate users' routing needs.[21] Collaborative routing supports program tools and procedures testing, and the use of prototype systems to replay weather events with operations personnel in order to evaluate why routing decisions were made and how they might be improved with better information.

NCAR is supporting the CDM collaborative routing workshops for AFD and TFM personnel. The intent of the workshops is to discuss the weather information and forecasts then available, and how particularly costly routing and dispatch decisions taken at the time might have been avoided.[22] By looking at these cases, participants can evaluate both the accuracy and timeliness of the weather information available, and the operational use they might have made of it.

The CDM program is supporting a weather demonstration and evaluation project by NCAR. The project will help to establish the product content for ATCSCC and AOC weather discussions and procedures.[23]

Weather Demonstration and Evaluation Project

The FAA Strategic Plan recognizes proactive approaches to new data sources as a key strategy for intervening in potential accident causal chains.[24] It would replace the communication chains contributing to errors in weather-related judgements with shared weather awareness. This paper contends that this will not happen unless such weather information is perceived as necessary for more effective flight operations, and unless this perception is incorporated in TFM operating procedures.

The technology transfer concept for demonstrating, evaluating, and enhancing weather detection and forecast products could take three years. It would transition from specialized weather displays provided by NCAR to the Volpe National Transportation System Center (VNTSC) in the first year, to a fully autonomous prototype system operating at this facility in the third year.

During the first year, the data sources, 3-dimensional weather data grids, and product display algorithms, will be on an NCAR server and product display files will be transmitted via landline to VNTSC. These product files will be accessible to ATCSCC traffic managers and AOC flight dispatchers using computer workstations. In the second year, NCAR will install the 3-dimensional weather data grids and product display algorithms on a product server at VNTSC to service AOC and TMU workstations. NCAR will enhance the weather products based upon user evaluations, and maintain the weather data feed to the product server. In the third year, NCAR will complete the prototype system to be operated and maintained by VNTSC by identifying and facilitating the provision of data feeds directly to the VNTSC server, which will provide selected, fully evaluated, weather products to users.

A pathway will be established initially linking NCAR to the VNTSC and hence the jATCSCC and AOCs. VNTSC will become the hub connecting ATCSCC and the AOCs for common weather display capabilities. The first year demonstration products will be distributed and maintained from an NCAR server, transparent to the users, and restricted to AOC, ATCSCC, and VNTSC users. This initial pathway would provide convection and icing products.

Convection product

The convection product would provide graphical information regarding the current and forecast locations of thunderstorms. Convective SIGMETs and convective outlooks have been alpha numeric, detection and 6-hour forecast products. They covered large geographic areas (based on actual convection events and 40km resolution numerical weather prediction models). The NCAR demonstration products will provide information on an en route scale (4km) and the capability to zoom into a terminal area scale (1km) for select airports. Information available at the national scale includes convection detection based on lightning and radar data, one-hour forecast, storm tops, and movement vectors. Terminal scale products would include 1-km storm detection and forecast locations. The national product would provide a 60 minute extrapolation forecast of thunderstorm activity based on real-time lightning, radar reflectivity, and echo tops. Such a product was demonstrated at Delta and Northwest airline dispatch last summer. To this national-scale convection detection and forecast, we would add more highly resolved terminal area convection products for traffic flow management and flight dispatch.[25] Menus would permit users to select displays for air traffic control center and terminal area airspace.

In addition to these displays at AOCs, ATCSCC, and VNTSC, NCAR is installing the national convective weather product software at the AWC this year. This software will be incorporated in the NOAA-AWIPS forecaster workstation for NWS aviation forecasters. It will automatically insert the storm motion vectors and cloud tops into NWS SIGMETs.[26]

The convection products are based upon commercially available and other existing data sources. Data are derived from National Weather Service WSR 88-D (NEXRAD) radar Level-3 NIDS provided by WSI Inc., and the National Lightning Detection Network data from Global Inc., provided by Kavouras. They are combined in a gridded storm severity interest field from lightning stroke frequency and radar reflectivity. NCAR would use the Level-3 NIDS radar data and ITWS grids provided by MIT Lincoln Laboratory next summer to create 1-kilometer-resolution convection products for the Chicago O'Hare airport terminal area.

Thunderstorms assemble just about every known hazard to aviation in one place. Lightning, turbulence, hail, rain, poor visibility, and winds require that airline dispatchers and flight crews provide legally required "safe" separation between these phenomena and aircraft operations.[27] ATCSCC must accommodate these regulatory restrictions on AFD in its TFM plans. A line of thunderstorms crossing the airspace of a major traffic fix, for example, can produce miles-in-trail restrictions, airborne holding, and ground delay holds that alter national traffic flows. An example of this kind of situation is shown in Figure 1. The convection forecast product shown in Figure 2 is a one hour national extrapolation forecast of lightning and radar interest fields. The forecasts outlined in blue colored boxes have been verified as significantly better than persistence forecasts.[28]

Integrated icing product

NCAR also would demonstrate integrated airborne icing algorithms for prognostic and forecast products indicting potential icing areas throughout the country. Like convection, legal constraints govern the dispatch and operation of aircraft into known icing conditions and forecast moderate to severe icing conditions. Thus, the quality of icing diagnostics[29] and forecasts are pivotal to safe and efficient flight planning and dispatch, as well as the conduct of flight operations. They also are consequential for traffic management.

Airborne icing is not a singular phenomenon, but the result of variations in a number of meteorological and physical state-of-the-atmosphere parameters. No single kind of sensor observation or model parameter appears to reliably describe its occurrence. As a result of the complexity of icing occurrences in the atmosphere, current NWS forecast products may be significantly over-forecast potential airborne icing conditions, removing potentially useful airspace from flight operations. In spite of over-forecasting, however, current icing forecasts may miss about 25 percent of the pilot icing reports.[30]

Three critical variables govern the occurrence of an airborne icing hazard - liquid water content, temperature, and droplet size. We will demonstrate icing algorithm products that address all three. The current diagnostic product combines model output with surface observations, satellite imagery, and WSR-88D (NEXRAD) mosaics, to accurately depict icing potential. The horizontal resolution of this icing diagnostic product is 5 kilometers for much of the Eastern United States. The forecast icing product would be based on the NCAR "stovepipe" algorithm, which is the most accurate and reliable forecast product available.[31] Resolution of the icing forecast product will be 28 kilometers.

Such icing product demonstrations will result in automated, airborne icing hazard products for diagnosing and forecasting the icing potential of the national airspace. These airborne icing products initially will be shown in a 2-dimensional display of grid coordinates that map the plan view and vertical cross section of any portion of any route of flight and altitude over the U.S. The algorithm will run every hour for icing diagnosis, and the icing forecast will run once every 3 hours, and be displayed every hour for the 0-6 hour forecast.[32] (An Integrated Icing Product for flight level 100 is shown in Figure 3.)

Summary of demonstration and evaluation capabilities

NCAR product files will be transmitted to VNTSC over a landline. They will show convection and icing display products and menus for national and select regional areas. These product files can be accessed by AOCs and the ATCSCC from VNTSC, using commercially available hardware. In the second year, successful products will be produced on a VNTSC server, fed by an NCAR data stream. They will be available over the AOC net and to all participating airline and TFM personnel. TFM and AFD users would be able to interact with these weather data and product algorithms in near real-time through the VNTSC server. They could configure products to route-specific altitudes and areas of interest and transmitting these data files to others for collaborative discussion and decision making.

Table 1: Weather Information Status

Delay Impact	*Current Weather Systems Technologies*	Strategic Weather Information Capabilities		Weather SA and Operational Communication
Transport Category Aircraft	Weather Conditions	Detection and Communication Capabilities	Forecasting and Modeling Capabilities	Dispatch - ATC Weather Display and Decision Aides
1	**Ceiling & Visibility**			
1	Fog/Haze	3	1	1
2	Precipitation	3	2	2
1	Ceiling	2	1	2
1	**Convection**			
1	Thunderstorms	3	2	1
2	Hail	2	1	1
1	Heavy Rain	3	2	1
2	Microburst	2	1	1
2	**Turbulence**			
2	Convection	1	1	1
2	Terrain Induced	1	2	1
1	Frontal	1	1	1
2	**Icing**			
2	In-Flight	1	1	1
1	Ground	2	1	1
1	**Wake Vortex**	1	1	1
1	**Runway Surface**	3	1	2
1	Significant Contributor to Delays		1	Inadequate Capability Now
2	Moderate Contributor to Delays		2	Demonstrated Capability Now
3	Minimal Contributor to Delays		3	Adequate Capability Now

Figure 1: Weather Routing and Aircraft Tracks

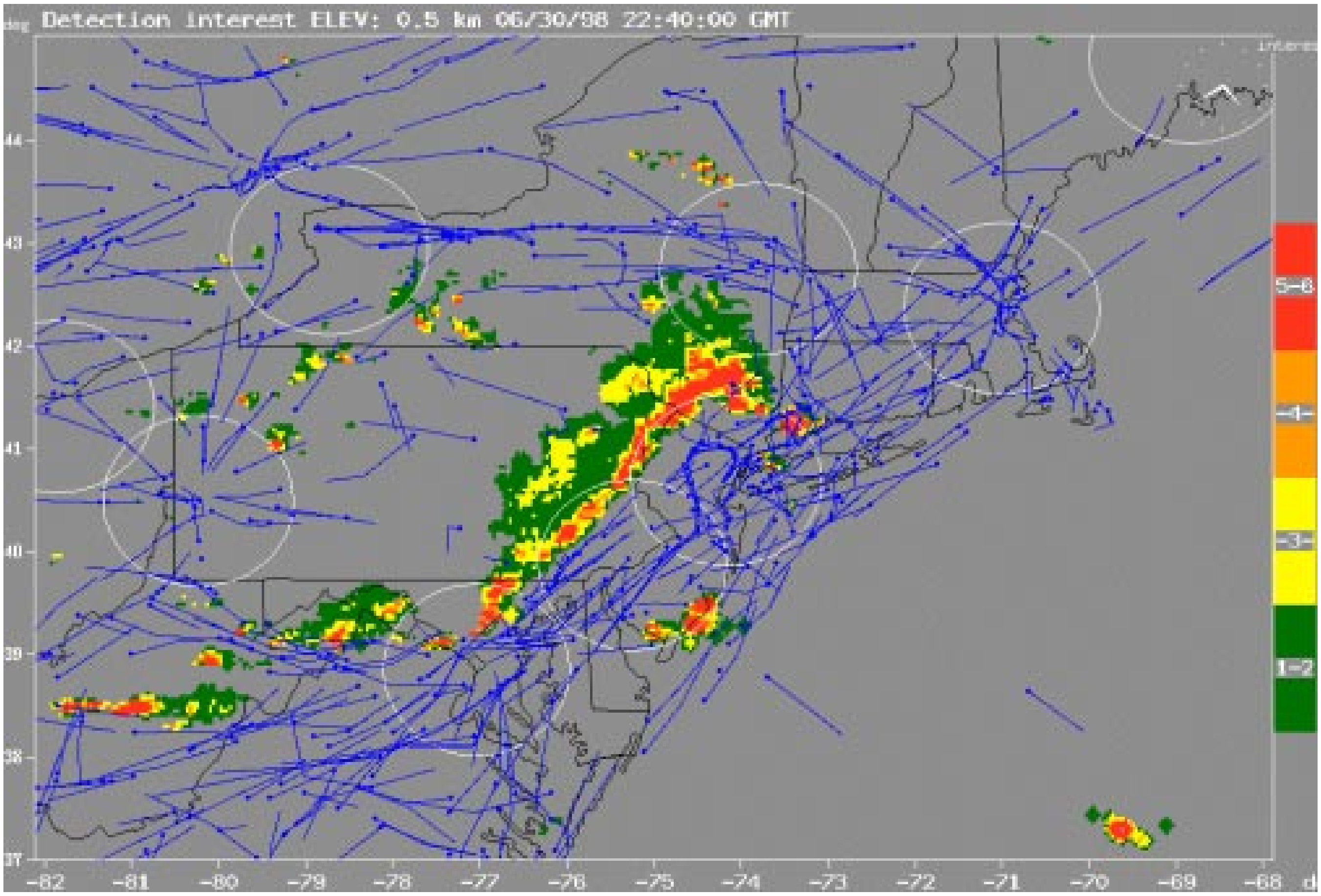


Figure 2: Convection Forecast Product

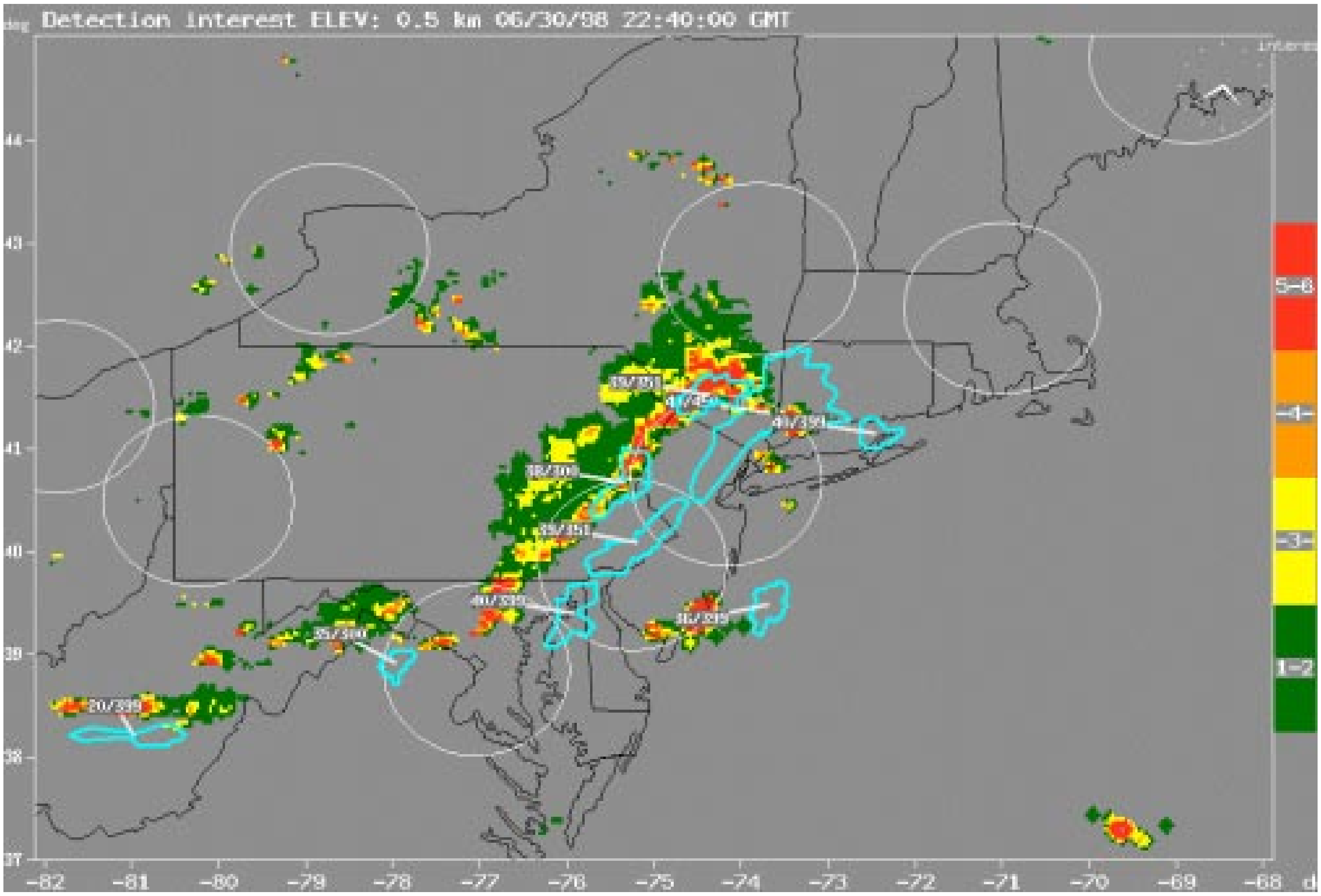
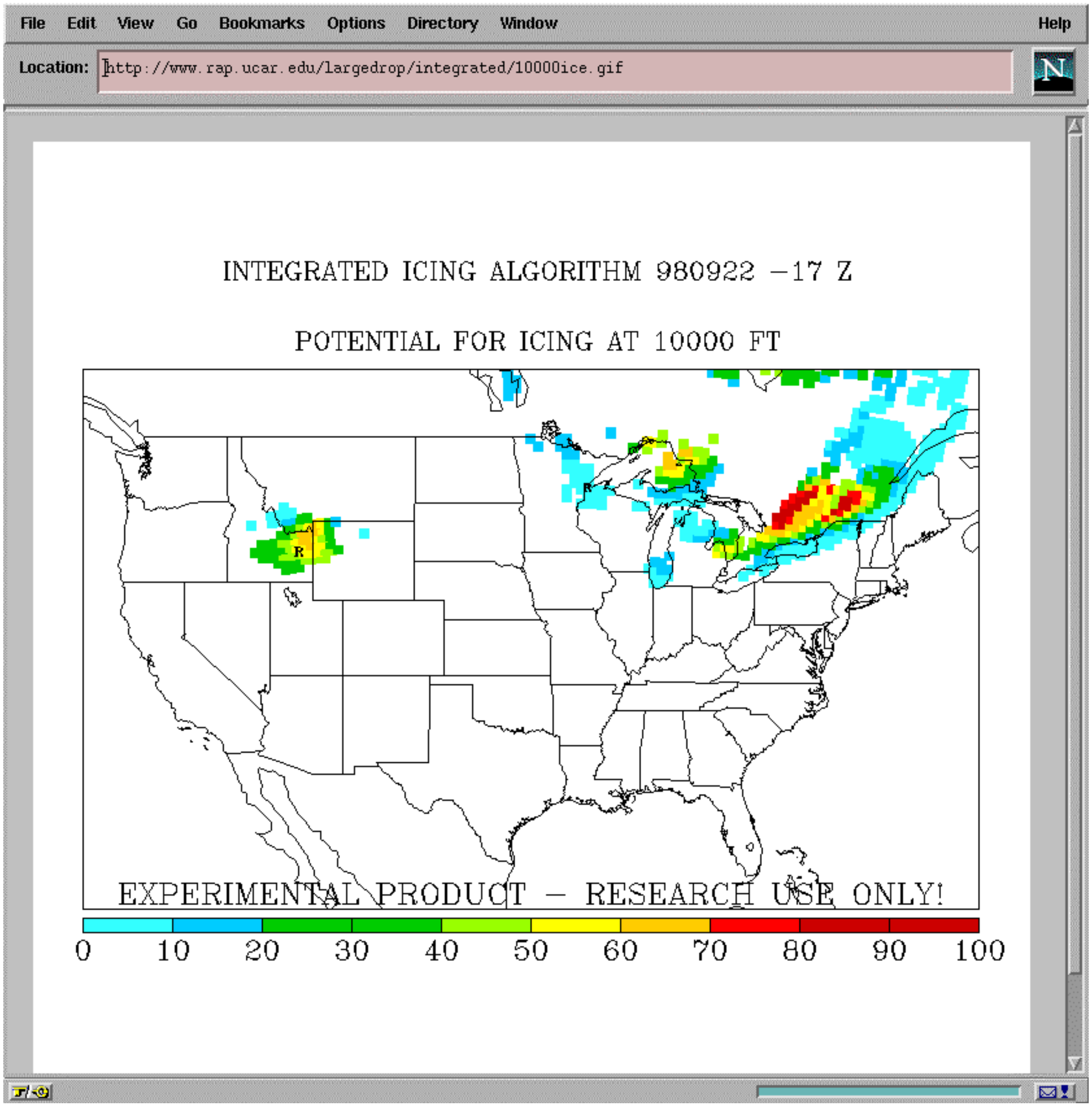


Figure 3: Integrated Icing Product



References

[1] Numerous NTSB reports cite the failure of airline dispatch, or pilots, to acquire current weather information, or to understand the content of the information. For examples, see: Caisse, Steven, " The Accident Risk Scale: Managing Risk with Operational Control" (unpublished), Airline Dispatch Federation (ADF) Symposium, Denver, October 1997.

[2] Mandated flight dispatch and flight operations weather safety functions, though critical, are relatively remote to daily operators, compared to economic and capacity concerns. This is because weather-related, commercial aviation accidents are relatively rare events that do not dominate individuals' day-to-day task awareness. Conversely, the economic parameters of their task performance are measured every day. The complex causal sequence of weather-related miscommunications contributing to judgement errors occasionally result in aviation accidents. But the same causal sequences also occur all the time without apparent consequences. This makes the causes of such errors difficult to recognize.

[3] Office of Integrated Safety analysis and Safety Information Promotion, "Special Review: Aviation Weather", Associate Administrator for Aviation Safety, FAA, November 1993.

[4] Huettner, Charles H., and Michael S. Lewis, "Aviation Safety Program: Report to Industry", Washington, D.C., August 13, 1997.

[5] The NASA-industry aviation safety task force attributed this problem to complex causal sequences of factors that contribute to judgement errors which, in critical situations, resulted in aviation accidents. Since these factors do not always result in judgement errors, and judgement errors do not always result in accidents, the statistical relationship among primary factors cited in NTSB accident reports and accidents might also occur with aircraft that do not have accidents. Consequently, it is difficult to measure the benefits of measures taken in response to these accident reports, as distinct from major technology changes, like jet engines, flight simulators, or radar. See: Huettner and Lewis.

[6] Code of Federal Regulations (CFR) 14, "Aeronautics and Space: Parts 60-139", Office of Federal Register, National Archives and Record Service, GPO, Washington, DC.

[7] FAR 121.533 concerning operational responsibilities, FAR 121.601 regarding dispatcher information to the pilot, FAR 121.627 concerning continuing flight in unsafe conditions, and FAR 121.629 concerning operation in icing conditions.

[8] Both the AWC and the FAA's aviation weather program have hired professional skills to make users more aware of the potential economic significance of their experimental and developmental products.

[9] Free flight concepts were defined in "The Final Report of RTCA Task Force 3: Free Flight Implementation", (RTCA Inc., Washington, DC, October 1995). The report defined the concept of free flight operations, evaluated the system architecture and technology development and implementation status, and identified transitional steps to achieve free flight. These ideas have been further developed by three subsequent RTCA, Inc., reports: "Free Flight Action Plan" (August 1996), "Government-Industry Operational Concept for the Evolution of Free Flight" (December 1997), and "Free Flight Action Plan: Update" (April 1998) and (December 1998).

[10] Kollman, Kevin, Kupper, Kapri, and Wetherly, James, "Collaborative Decision Making in Aviation Transportation: Improving Decisions Through Shared Information", Brussels, 1997.

[11] See: "Charter: Collaborative Routing Working Group", September 1997; also see: United States General Accounting Office, "Aviation Safety: FAA has Not Fully implemented Weather-Related Recommendations", GAO/RCED-98-130, June 1998. According to the GAO report, schedule delays cost the airlines $3.9 Billion in 1996 and weather accounted for 74 percent of all delays greater than 15 minutes between 1993 and 1997. p.45.

[12] Chambliss, Anthony, et. al., "Midterm FAA-Airspace User Collaborative Routing Operational Concept", MITRE Technical Report (MP98 W0000123), McLean Virginia, August 1998, p.1-2.

[13] Haroldsdottir, Auslag, Schwab, Robert W., and Alcabin, Monica S., "Air Traffic Management Capacity-Driven Operational Concept Through 2015", 2nd USA/Europe Air Traffic Management R&D Seminar, Orlando, December 1998.

[14] Moffatt, John, "Collaborative Routing – Dealing with Congested Airspace", Memorandum to Collaborative Routing Subgroup, (undated).

[15] Pujet, Nicolas, and Feron, Eric, "Modeling An Airline Operations Center", 2nd USA/Europe Air Traffic Management R&D Seminar, Orlando, December 1998.

[16] Data for Newark, Teterboro, Kennedy, and LaGuardia airports comparing the number of SWAP operations for the months of April, May, and June between 1993 and 1998 show consistently high use of SWAP, ranging from about 345,000 operations for the three month period in 1994 to about 360,000 operations in 1998.

[17] Chambliss, et. al., p.1-2.

[18] The FAA estimated a $2.6 Billion reduction in costs to the airlines over 20 years, without including the value of passenger time, as a result of collaborative data exchanges and decision making with respect to Ground Delay Program enhancements and more efficient re-routing and airspace use (ASD-400 Evaluation, 1997). CDM-Ground Delay Program Enhancements shortened 145 ground delay programs and saved an average of more than 400,000 minutes per month at only 4 airports over the first seven months of this year. They avoided initiating 196 additional ground delay programs (Alvania, Stephen, "TFM R&D/CDM", Office of Special Program: Free Flight Phase One, September 1998).

These FAA-identified benefits do not include the effects of the initial aircraft delay propagating throughout the airline schedule. Estimates of the delay multiplier resulting from an initial schedule delay appear to be very large and dependent upon the time of day of the initial delay. Delays that occur early in the day create total delays in airline schedules more than 6.5 times as large as the initial delay, and those occurring late in the day have a multiplier of about 2.5 times the initial delay. (Beatty, et.al., "Preliminary Evaluation of Flight Delay Propagation Through an Airline Schedule", ORNL, April 1998).

[19] Smith, Kip, "Case Study of May 15", Kansas State University, (unpublished).

[20] Participants' DRAFT CDM Work Plan, Air Transport Association, August, 1998.

[21] MacDonald, Laura, "Collaborative Decision making in Aviation", The Journal of Air traffic Control, Vol.40, no.3 (April-June), 1998, p.15.

[22] NCAR participation in these workshops is supported by a grant from the CDM program office in the FAA.

[23] Shantz, Arthur A., "Aviation Weather Products Demonstration and Evaluation for Traffic Flow Management and Flight Dispatch: A Technology Transfer White Paper for the Federal Aviation Administration", September 1998.

[24] FAA, "Building Tomorrow's Aerospace System: A Structure for Accomplishments", Office of Publications, Washington, DC, March 1998.

[25] In general, the seasonally sequenced demonstrations of the NCAR weather product algorithms would be run from NCAR during the demonstration period. They would be transferred via a landline to VNTSC, and hence to the ATCSCC and AOCs. NCAR would begin development of an operational weather product server for the VNTSC and ATCSCC prototypes to support the establishment of ATCSCC-AOC collaborative practices regarding weather situations during the second year.

[26] Mueller, Cynthia, et.al., "National Convective Weather Forecast Product", 8th Conference on Aviation, Range, and Aerospace Meteorology, American Meteorological Society, Dallas, 1999. (Forthcoming)

[27] Currently, there are no quantifiable standards for safe distances. There are guidance numbers for some phenomena, like 10 miles from the leading edge of a thunderstorm, but safe distance and usable airspace – like beauty – is essentially in the eye of the beholder, until an accident determines that the distance was unsafe.

[28] Roberts, Rita, et.al., "Operational Applications and Use of NCAR's Thunderstorm Nowcasting System", 8th Conference on Aviation, Range, and Aerospace Meteorology, American Meteorological Society, Dallas, 1999. (Forthcoming)

[29] Currently, there is some evidence suggesting that NCAR's integrated icing diagnostic product is about as skillful as the NWS meteorologists' AIRMET in detecting airborne icing conditions. See: Brown, Barbara G., et. al., "Evidence of Improvements in the Quality of In-Flight Icing Algorithms", 8th Conference on Aviation, Range, and Aerospace Meteorology, American Meteorological Society, Dallas, 1999. (Forthcoming)

[30] Brown, Barbara G., et. al., figure 1a.

[31] Brown, Barbara G., et. al., figure 1a..

[32] These intervals were selected because it would be very computer intensive to produce diagnostic and predictive output and ship it to VNTSC more frequently, and because shorter term differences in these products probably would add little value for aviation users.