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Weather Information for En Route Controllers

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Technical Report

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16. Abstract

In this study, a team of Engineering Research Psychologists and Subject Matter Experts reviewed weather information available at the en route controller workstation and the area of specialization. Using an analysis framework outlined by Ahlstrom (2004), we assessed how controllers use weather information during operations to highlight instances where information is missing or inadequately disseminated. To obtain feedback from the field, we conducted a survey where en route Front Line Managers (a) rated the impact on controller operations from different weather phenomena, (b) rated the frequency of use of weather information, and (c) provided suggestions for the development of future weather displays. Our review shows that en route controllers have access to a variety of weather information sources during operations. However, our review also suggests that en route controllers do not have an accurate or timely weather display for precipitation areas at their workstation. We discuss possible enhancements for future weather displays, recommend enhancements to controller precipitation displays, and suggest further research to evaluate enhancements for the dissemination of weather advisories to pilots.

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Executive Summary

In this study, a team of Engineering Research Psychologists and Subject Matter Experts from the Federal Aviation Administration William J. Hughes Technical Center reviewed weather information available at the en route controller workstation and the area of specialization. Using an analysis framework outlined by Ahlstrom (2004), we assessed how controllers use weather information during operations to highlight instances where information is missing or inadequately disseminated. To get feedback from the field, we conducted a survey where en route Front Line Managers (FLMs) rated the impact on controller operations from adverse winds, in-flight icing, low visibility, mountain wave, non-convective turbulence, and thunderstorms. The results showed that (a) thunderstorms received the highest impact rating, (b) adverse winds, in-flight icing, low visibility, and non-convective turbulence received a moderate impact rating, and (c) mountain wave received the lowest impact rating.

We also asked FLMs to rate the frequency of use of weather information at the area of specialization and the perceived accuracy of controller precipitation displays. Furthermore, FLMs provided suggestions for improvements to the current weather information flow and suggested alternative information sources for future weather displays.

Our review of current research on en route weather information showed little advancement in new concepts and displays beyond that reported by Ahlstrom and Della Rocco (2003). Besides papers on the future National Airspace System weather architecture and weather concepts of operations, the majority of research deals with improvements to radar mosaic generation algorithms and forecast methods rather than displays.

We conclude that en route controllers have access to a variety of weather information during operations. At the workstation, controllers have access to precipitation and wind information, weather advisories, and weather observations. In each area of specialization, supervisors can tailor displays to show different types of information such as weather loops, chop forecasts, predicted thunderstorm movements, and icing forecasts. However, results of the survey suggest that en route controllers do not have an accurate and timely display of precipitation areas at their workstation. Reported problems include inaccurate positional display and limitations in the selection and display of relevant vertical precipitation strata.

We discuss needed enhancements, such as improvements in the display, accuracy of precipitation areas on the Display System Replacement, and the possibility to display lightning and cloud tops information. We also discuss alternatives for future controller weather displays such as an automated weather probe that provides severe weather warnings and route solutions that controllers can view, amend, or, if deemed appropriate, act upon directly.

1. INTRODUCTION

Hazardous weather conditions affect the National Airspace System (NAS) in many ways. They create safety hazards for pilots, constrain the usable airspace for Air Traffic Control (ATC), and reduce the overall capacity of NAS operations. To mitigate these effects, a great deal of research has gone into developing weather information displays for pilots, flight dispatchers, and air traffic management. However, very little research has explored the operational impact of weather information on controller operations (Ahlstrom & Della Rocco, 2003).

To investigate the benefits and human factors issues associated with displaying weather information on Terminal Radar Approach Control (TRACON) controller displays, researchers from the Human Factors Research and Engineering Group (HFREG) Human Factors Team – Atlantic City (ATO-P) conducted a weather research project at the Federal Aviation Administration (FAA) William J. Hughes Technical Center Research Development and Human Factors Laboratory. In an initial project phase, researchers conducted a Cognitive Work Analysis of the TRACON domain to assess terminal controllers' weather information needs (Ahlstrom, 2004). Researchers then used this Cognitive Work Analysis for the development of a Weather Information Display System (Ahlstrom, Keen, & Mieskolainen, 2004) and a high-fidelity simulation capability. During the Human-in-the-Loop (HITL) weather simulation, researchers manipulated the display of advanced weather information (i.e., storm motion forecasts) and compared this to a control condition where controllers had precipitation information but no storm motion forecasts (current field operations). While performing ATC operations during these weather scenarios, controllers were responsible for keeping all aircraft away from heavy and extreme precipitation areas (i.e., severe weather avoidance).

The results showed that when controllers had access to storm motion forecasts at their workstation, they increased the average sector throughput by 6-10% compared to conditions where no storm motion forecasts were available (Ahlstrom & Friedman-Berg, 2006). Furthermore, because storm forecasts were available, controllers handled more aircraft without a corresponding increase in their ratings of cognitive workload. Additionally, this study provided data that researchers used to develop recommendations for the display of weather information and the use of color palettes in ATC displays (Ahlstrom & Arend, 2005; Friedman-Berg & Ahlstrom, 2005).

The previously mentioned weather project showed that TRACON controllers benefit from storm forecast displays during ATC operations. The question arises whether en route controllers could also benefit from additional weather information during current operations. To investigate this issue, we need to review what weather information en route controllers currently have in the field and how they use this information operationally (Ahlstrom, 2007). Although the Ahlstrom and Friedman-Berg (2006) study found evidence of an increased operational efficiency from storm forecast displays in the TRACON domain, it is not certain that forecast displays provide the same benefits in the en route domain.

There are several reasons why the weather information needs may differ between TRACON and en route controllers. One example is the difference in operating altitudes between these two domains. Because en route operations are at higher altitudes, en route controllers have an advantage over TRACON controllers in their increased flexibility to vector aircraft over or around storm cells. However, the higher operating altitudes can also be a disadvantage because airplanes cannot always accommodate quick changes in speed and direction (i.e., due to flight envelope characteristics). Therefore, for the en route controllers, the difficulty of rapid tactical maneuvers increases with increasing altitude. For the TRACON controllers, there is a disadvantage with the lower operating altitude and the fact that all airplanes are aiming at one point in 3D airspace (i.e., the runway). There is also a speed limit for aircraft below 10,000 feet, but no such limit above 10,000 feet. Another factor of importance during adverse weather conditions is the differential restriction on aircraft routes between the en route and TRACON environment. For the TRACON controllers, as aircraft gets closer to the runway, there is an increased restriction on the controllers' ability to direct aircraft (i.e., aircraft have to be over a fix or the outer marker at a certain time). For the en route controllers, there are many less restrictions and therefore much more flexibility for route deviations. Finally, although en route and TRACON controllers handle a mix of aircraft types with decreasing altitudes, the TRACON controllers handle more low-performance aircraft.

1.1 Literature Review

While reviewing previous research on the use of weather information and weather displays, we found very few published studies of weather information tailored for the en route controllers. Besides papers on the future NAS weather architecture (Souders & Showalter, 2006) and weather concepts of operations (Souders, McGettigan, Dash, & May, 2006), the majority of research deals with precipitation displays and presentation formats.

For example, Wickens, Campbell, Liang, and Merwin (1995) explored the relative merits of presenting weather information on 2D versus 3D displays. In this study, researchers used weather displays where color coding depicted areas of rain, icing, turbulence, and other conditions hazardous to flight. The participants' task was to determine, as fast as possible, whether an aircraft target would penetrate a hazardous weather area. The results showed that both displays produced similar accuracy in discriminating weather penetrations from safe vectors, although the 2D display produced more rapid discriminations.

Hanson (1997) extended the analysis of 2D versus 3D displays to include the potential benefits of presenting weather information on 3D volumetric displays. According to Hanson, the volumetric display could potentially allow controllers to take advantage of *holes* in weather areas that otherwise would have gone unnoticed on a 2D weather display. A similar display framework by Dang (2006) describes a virtual environment that allows a controller to view airspace, terrain, and weather areas in 3D stereoscopic visualizations.

Researchers have also reported on the benefits from shared Next Generation Weather Radar (NEXRAD) on controller/pilot interactions. Farley, Hansman, Endsley, Amonlirdviman, and Vigeant-Langlois (1998) examined the importance of traffic and weather information in re-routing situations. During the simulation, participants resolved traffic and weather conflicts in scenarios where researchers manipulated the sharing of traffic and weather data provided by digital data link. The researchers found that when no weather displays were available, the controllers' responses indicated an awareness of only 40% of the weather-related conditions.

On the contrary, in conditions where controllers had access to shared weather displays, controllers demonstrated a 93% awareness of weather-related conditions. Hansman and Davison (2000) reported similar results for controller/pilot interactions during convective weather scenarios.

Amis (2002) provided early reports of the benefits of displaying precipitation from the Display System Replacement (DSR) Weather and Radar Processor (WARP) on en route controller displays at the Fort Worth Air Route Traffic Control Center (ARTCC). According to Amis, Center Weather Service Unit (CWSU) meteorologists, supervisors, and controllers were all in favor of the new technology. The WARP on DSR gave controllers a real sense of situation awareness regarding weather and traffic, which in turn increased controllers' confidence levels.

Although early reports of the new en route weather display were favorable, more recent reports have raised operational issues related to the inaccuracy of the displayed information (Aircraft Owners and Pilots Association [AOPA], 2006c; Boyette, 2006). For example, a quality assurance bulletin from Cleveland ARTCC describes DSR WARP weather display anomalies resulting from the combination of unusually high winds and the delay inherent in weather radar systems (see Appendix A). During operations, controllers observed that aircraft were deviating into what appeared to be areas of extreme precipitation on their DSR display. However, the actual location of the weather was 6 to 8 miles away from the location displayed on controller workstations.

At present, there are issues with NEXRAD data quality, although work is ongoing to increase the product quality and to improve the update rate (Bumgarner & Shema, 2003; Weber, 2006). Likewise, researchers have developed experimental versions of NEXRAD with simulated high-resolution reflectivity forecasts for 6 to 36 hours into the future (Dennstaedt, 2006). These forecasts are important in that they could visualize the mesoscale features that are going to develop in the future, allowing NAS users to see the details of the forecasted thunderstorm structures. There is also work on improving radar mosaic generation algorithms (Lang, Stobie, & Yarber, 2005) and the possibility of replacing NEXRAD with a phased array scanning radar (McCarthy, 2006). For the DSR WARP, enhancements such as detecting lightning information, improving data quality (e.g., removing anomalous propagation), using alternative NEXRAD mosaics, and including enhanced echo tops are also underway (Moosakhanian, Higginbotham, & Stobie, 2005).

During operations in adverse weather conditions, controllers use the WARP display when informing pilots of basic precipitation coverage and height. When requested by the pilot, controllers also provide radar navigational guidance and/or approve deviations around weather areas (Ahlstrom, 2007). This usage largely corresponds to a tactical moment-to-moment management of air traffic within the airspace. However, according to Heagy and Kirk (2003) and Kirk and Bolczak (2003), there is operational evidence of a move from tactical ATC (radar data) toward strategic operations (flight plans and aircraft trajectories). In line with these observations, MITRE has developed a set of User Request Evaluation Tool (URET) enhancements (i.e., problem resolution support capabilities) that will support controllers during strategic ATC (Heagy & Kirk, 2003, 2006; Kirk & Bolczak; Kirk, Bowen, Heagy, Rozen, & Viets, 2001). These support capabilities called Problem Analysis, Resolution, and Ranking (PARR) will include analysis and resolution support for severe weather avoidance. By displaying current and forecasted weather areas, these enhancements will support the controllers by displaying aircraft that are in or are about to enter areas of weather. This allows the controllers to perform trial planning and to come up with route resolutions that are clear of weather. The National Weather Service (NWS) National Convective Weather Forecast product provides the weather prediction data used by this tool. This is a NEXRAD product with a 5-minute update rate. Using the URET enhancements, controllers can probe current plans for weather areas 20 minutes into the future, and trial plans for the next 40 minutes. Future PARR enhancements under consideration include information about areas of known and forecast icing and turbulence (Heagy & Kirk, 2003).

During URET enhancement evaluations at the Center for Advanced Aviation System Development, participating controllers indicated that these weather enhancements were operationally acceptable and that they could provide benefits to controllers (Heagy & Kirk, 2003; Kirk & Bolczak, 2003). Among the benefits mentioned were enhanced situational awareness, more timely reroutes, and less negotiation with pilots when routing aircraft around weather areas. However, the participants also indicated that these operational assumptions are contingent upon the accuracy of the tool for weather detection and prediction.

Researchers designed URET to enhance the controllers' ability to perform strategic ATC planning by focusing on flight plans and trajectories. During use, URET provides flight data and alert information for all aircraft currently in the sector as well as aircraft predicted to enter the sector in the next 20 minutes. Likewise, the URET enhancements for severe weather avoidance probe current plans for weather areas 20 minutes into the future. Although some researchers have found some evidence of a move to strategic operations by controllers, other studies have found mixed results from examinations of controllers' adoption and adaptation of URET. For example, Bolic and Hansen (2005) found that different sector teams use URET in different ways. They also found that the operational usage of URET differs from the intended usage for this tool. Furthermore, Bolic and Hansen found that the URET usage varies from one en route center to the other. At some centers, URET solely functions as an electronic flight strip replacement. The comment from controllers is that strategic solutions are not applicable in a highly dynamic environment.

1.2 Purpose

The main purpose of this study is to evaluate current weather information for en route controllers. A secondary purpose is to gather feedback from the field on the need for additional weather information, the use of current products, and suggestions for improvements to future weather products.

1.3 Weather Information at the En Route Controller Workstation

En route controllers have direct access to several sources of weather information at their DSR or Microprocessor-En Route Automated Radar Tracking System (Micro-EARTS) workstation. Figure 1 shows what types of information is available, and how the controllers can access information such as Center Weather Advisory (CWA), Airman's Meteorological Information (AIRMET), Significant Meteorological Information (SIGMET), and Pilot Reports (PIREPs). Controllers can also access wind information from the URET and weather reports from the Computer Readout Display (CRD). In the following sections, we specify these weather sources and provide examples of how controllers use this information during operations.

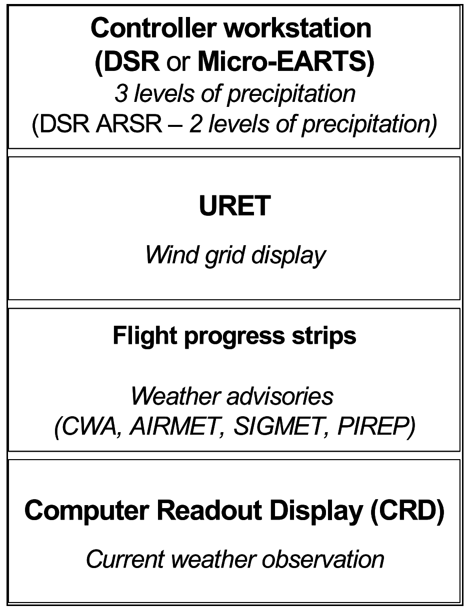

Figure 1. Weather information available at the en route controller workstation.

1.3.1 Precipitation Information

En route controllers have access to precipitation information provided to the DSR via the WARP using NEXRAD data (Moosakhanian et al., 2005). The precipitation display can show three levels of precipitation and the display assign these levels to different colors: Royal Blue, Checkered Cyan, and Cyan. The Royal Blue represents **MODERATE** intensity (30-40 dBZ), the Checkered Cyan represents **HEAVY** intensity (40-50 dBZ), and the Cyan represents **EXTREME** intensity (50+ dBZ). In addition, controllers have the option to show precipitation intensities at different pre-set altitude strata. Four strata are available: 0-60,000 ft, 0-24,000 ft, 24,000-33,000 ft, and 33,000-60,000 ft (Moosakhanian et al.). If a controller is displaying primary radar (ARSR) precipitation on the DSR, only two precipitation intensities are available. Similar to the DSR WARP, the Micro-EARTS) used by some en route controllers also displays three levels of precipitation.

Controllers use the precipitation display when guiding pilots around weather and when informing pilots on basic precipitation coverage and height. Controllers also use the precipitation display when suggesting headings and routes to keep aircraft clear of weather areas.

1.3.2 Wind and Temperature Information

URET provides a visual representation of forecast winds and temperatures at selected altitudes. The wind grid display shows the wind data overlaid on a sector map that includes boundaries and fixes. Arrows indicate wind direction and a number in combination with the arrow length indicate the wind speed. Controllers use the wind information to plan vectors, taking into account the speed and direction of the wind.

1.3.3 Weather Advisories

En route controllers receive weather advisories such as the CWA, SIGMET, AIRMET, Convective SIGMET (WST), and Urgent Pilot Weather Reports (UUA) on flight progress strips (as shown in Figure 1). Controllers use weather advisories when broadcasting important weather conditions to pilots.

1.3.4 Current Weather Observations

Controllers can access current weather observations (i.e., surface observations) from the CRD. These Aviation Routine Weather Reports (METARs) usually come from airports. In general, these reports are generated once an hour; but if weather conditions change significantly, they are updated in special reports. METARs contain information about winds, visibility, present weather and obscurations, sky condition, temperature and dew point, and altimeter/pressure.

If a controller provides approach control services, the controller uses the weather observations to advise pilots on current weather conditions before an approach clearance. At the pilots' requests, controllers provide weather observations for destinations that are outside the range of the local Automated Weather Observing System and the Automatic Terminal Information Service information.

1.3.5 Pilot Reports

PIREPs are direct observations of various weather conditions that pilots encounter during flight. These reports usually include information about turbulence, icing and outside air temperature, height of cloud layers, and in-flight visibility. PIREPs are highly useful for establishing where hazardous aviation weather conditions are occurring. En route controllers receive PIREPs via radio communications with pilots or as information disseminated from other controllers or the facility weather coordinator. Controllers use PIREPs to relay pertinent information to concerned aircraft and other controllers.

1.3.6 Weather Information Flow in the En Route Domain

The NWS provides weather data and products that form a national information database and infrastructure. The FAA is using this infrastructure to feed weather data and weather products into the en route weather information flow (see Figure 2). The Enhanced Traffic Management System (ETMS) provides the Traffic Management Unit (TMU) with tools such as the Traffic Situation Display (TSD) and traffic counts for airspace sectors, airports, and fixes. Supervisors can also display weather information on an Enhanced Status Information System (ESIS) in each area of specialization. In Figure 2, we outline the weather information flow between the en route controller, supervisor, TMU, CWSU, and the NWS.

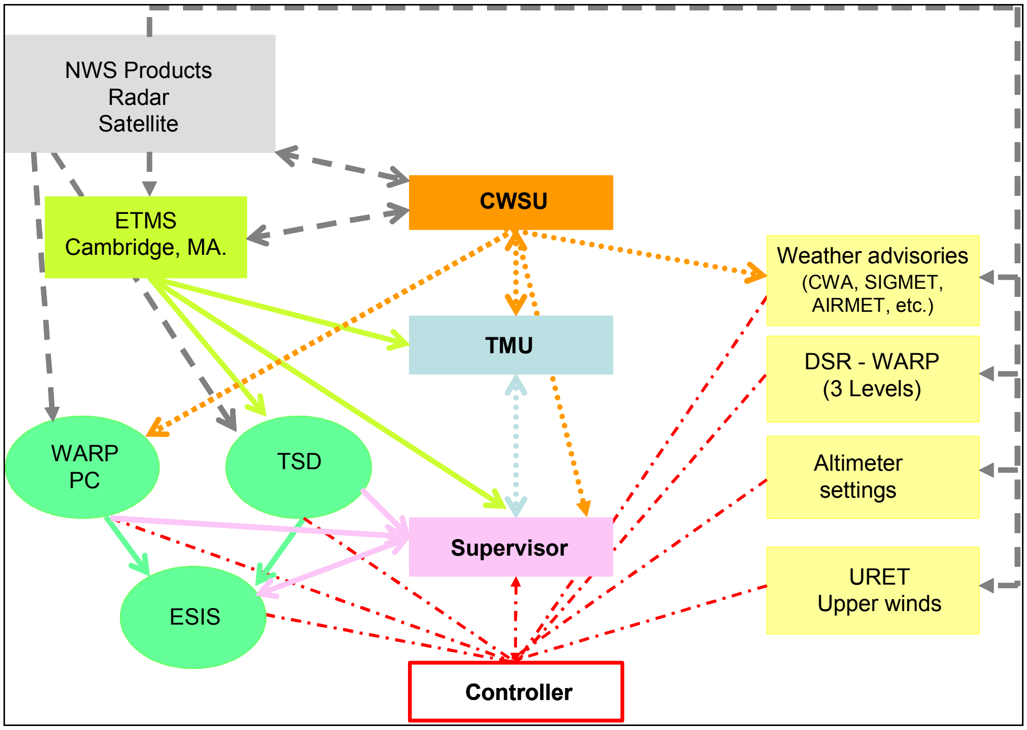

Figure 2. An illustration of the weather information flow in the en route domain.

As Figure 2 shows, in addition to the weather information at the DSR workstation, en route controllers have access to weather information on an ESIS display. Although there are some differences in the location and size of the ESIS display between centers, the display is either a projection screen or a flat panel display that is at least 45 inches horizontally. The ESIS display is located on the end wall in each area of specialization (approximately 9 feet from the floor). The distance from the display to the controller closest to the end wall is only a few feet, with the controller looking up at the display on an angle.

The controller farthest away from the end wall is approximately 20 feet away from the display. The supervisor may configure the ESIS display to show information that is operationally useful for each area (Nadler, 2005). Examples of information are NEXRAD loops, chop forecasts, predicted thunderstorm movements, and icing forecasts. In Appendix B, we provide an example of ESIS display information from the Indianapolis ARTCC.

1.4 Analysis of En Route Controller Weather Tasks

The analysis team also reviewed the work domain analysis performed by Ahlstrom (2004) for TRACON weather control tasks, to assess if this analysis also applies to the en route domain. Ahlstrom proposed general control actions for various adverse weather conditions such as thunderstorms, in-flight icing, low ceiling and visibility, adverse winds, snow and ice, and wake vortex. Ahlstrom further described the weather information sources available in the terminal domain and outlined the weather information flow between the controller, the supervisor, and the traffic management. Because en route controllers also perform approach control services, we conclude that the control task analysis (i.e., controller actions during adverse weather) and the strategies analysis (i.e., different control options for handling a given situation) proposed by Ahlstrom also apply to the en route domain. However, the most relevant case for en route controllers is deviation requests during thunderstorms. Also, the weather information sources in the terminal domain and the en route domain are quite different. In Table 1, we illustrate an example of a general scenario for how en route controllers handle deviation requests during a thunderstorm. We outline the general tasks performed by the controllers and the weather information sources available during this scenario.

Table 1. Control Tasks for Deviation Requests During Thunderstorms

Weather Phenomena	Example Scenario / Control Tasks	Weather Information Sources
Thunderstorms Deviation requests	1. Pilot contacts ATC. 2. Controller evaluates pilot request. 3. Controller coordinates with other sectors. 4. Controller grants request with changes necessary based on sector traffic. 5. Controller moves other traffic to accommodate deviating traffic. 6. Controller coordinates flow rates and deviations (with supervisor, TMU, TRACON, adjacent sectors, etc., regarding deviations around weather). 7. New weather advisories need to be issued to aircraft as required. *Note*: More restrictions apply with increasing proximity to higher density airports.	1. DSR WARP 2. ESIS 3. PIREPs 4. TMU playbooks

2. METHOD

For this study, a team of Engineering Research Psychologists and Subject Matter Experts from the FAA HFREG performed an analysis of weather information needs and weather information flow in the en route domain. In an initial project phase, we reviewed current research on weather information displays for en route controllers and assessed whether the weather task analysis performed by Ahlstrom (2004) also applies to the en route domain. As part of this analysis, we describe the weather information available at the en route controller workstation and outline what additional weather information is available in each area of specialization.

2.1 Procedure

To get operational feedback on the use of weather information at en route facilities, we conducted a limited questionnaire survey. The survey consisted of eight questions and two statements that we asked Front Line Managers (FLMs) to rate using an anchored 10-point scale (see Appendix C for the complete survey).

The purpose of the survey was threefold. First, we were interested in the operational impact from different weather phenomena on en route controller operations. Second, we were seeking feedback on how frequently controllers use area weather information during operations, and their perceived accuracy of the DSR WARP display. Third, we also wanted to get feedback regarding weather information that is currently unavailable but that may be of importance for future weather displays.

2.2 Survey Participants and Data Collection

Thirty FLMs from 13 en route ARTCCs participated in the survey. To reduce the cost and enhance the ease of survey management, we distributed the survey (see Appendix C) as a Lotus Notes© e-mail attachment. We sent out the survey to 90 FLMs covering all 21 ARTCCs, of which 30 responded within 2 weeks, thereby yielding a survey response rate of 33.3%.

3. SURVEY RESULTS

3.1 The Impact of Adverse Weather Phenomena on En Route Operations

Ahlstrom (2004) investigated the relative impact of 11 weather phenomena on TRACON controller operations. He found that thunderstorms, snow and ice, and adverse winds had the largest impact on controller operations. For our survey, we used a subset of these weather phenomena. Specifically, we asked FLMs to rate the impact on en route controller operations from adverse winds, in-flight icing, low visibility, mountain wave, non-convective turbulence, and thunderstorms. In the questionnaire survey, we asked FLMs to rate the following question: "To what degree do these weather phenomena affect en route controller operations and controller workload?" For the ratings, participants used a 10-point scale with the anchors 1 (*Not At All*) and 10 (*A Great Deal*).

Figure 3 shows the mean impact ratings from six weather phenomena on en route controller operations. Initially, we had hoped for a fairly even number of responses from each en route center. This would allow us to make a reasonable estimate of the differential impact of the weather phenomena for different centers across the United States. However, we did not receive an equal number of responses from the en route centers. Therefore, we present the impact ratings using the data from all 30 FLMs.

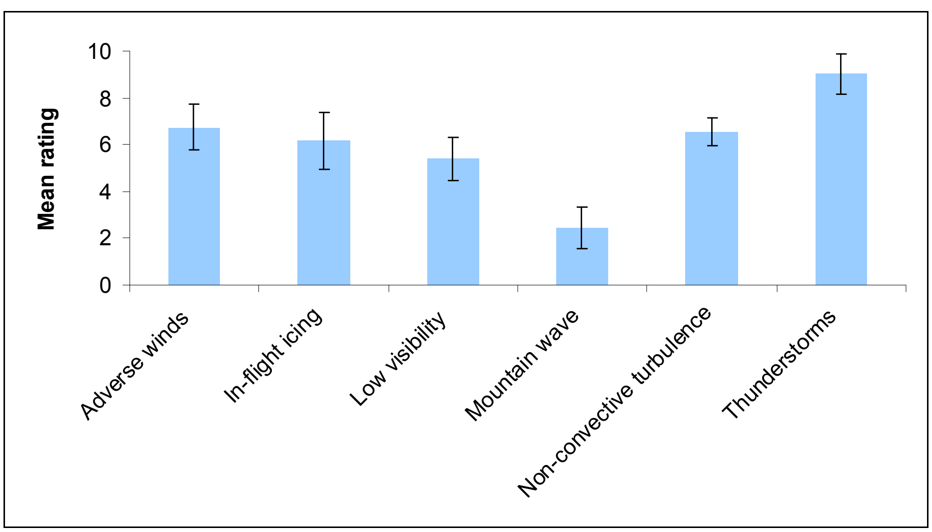

Figure 3. Mean impact ratings for six weather phenomena. The error bars represent 95% confidence intervals.

As Figure 3 shows, the thunderstorm rating (*M* = 9.03, *SD* = 1.66, *n* = 30) implies that thunderstorms have the highest impact on controller operations of all weather phenomena in Figure 3. The mean ratings for adverse winds, in-flight icing, low visibility, and non-convective turbulence are similar (*M* = 5.4 to *M* = 6.73). Given the 10-point scale, these ratings roughly imply a moderate impact from these weather phenomena on en route controller operations. The mean rating for mountain wave (*M* = 2.43, *SD* = 2.45, *n* = 30) implies that this phenomenon has the lowest impact of all weather phenomena on controller operations.

Mountain waves do not affect all en route centers due to their specific geographic location. Therefore, we sorted the total number of ratings into three groups corresponding to en route centers located within the Western, Central, and Eastern en route service areas. We only used this analysis for exploratory purposes; our data samples do not allow us to make definitive conclusions from this comparison. Nevertheless, this analysis could point to issues that we need to analyze in detail in future studies. While performing this analysis, we found that although the impact ratings for mountain wave from the Central (*M* = 1.39, *SD* = .78, *n* = 18) and Eastern (*M* = 1.86, *SD* = 1.46, *n* = 7) service areas were low, the impact rating for mountain wave from the Western area was high (*M* = 7.0, *SD* = 2.45, *n* = 5). This makes sense because mountain waves are more detrimental to en route operations around the Rocky Mountains in the Western en route service area. Furthermore, although all service areas rated the impact from thunderstorms as high, the Western area had a lower rating (*M* = 7.40, *SD* = 3.44, *n* = 5) compared to the Central area (*M* = 9.44, *SD* = .78, *n* = 18) and the Eastern area (*M* = 9.17, *SD* = .75, *n* = 7). Again, this makes sense from the point of view of convective activity because the traffic density is higher in the Central and Eastern areas, causing a more detrimental effect on the traffic flow (i.e., less room to maneuver aircraft). We also found that the impact rating for in-flight icing was higher for the Western area (*M* = 8.2, *SD* = 2.05, *n* = 5) compared to the Central area (*M* = 5.61, *SD* = 2.70, *n* = 18) and the Eastern area (*M* = 6.14, *SD* = 2.48, *n* = 7). Again, this makes sense because of weather patterns and the geographical location of en route center sectors in the Western service area.

In conclusion, the present results show that the effect on en route controller operations from thunderstorms receives the highest impact rating. The effects from adverse winds, in-flight icing, low visibility, and non-convective turbulence on controller operations receive a moderate rating. The effect on controller operations from mountain wave receives the lowest impact rating. These results are similar to the TRACON controllers' ratings found by Ahlstrom (2004), with the exception that TRACON controllers had rated the impact from adverse winds much higher. We also analyzed the data according to en route centers that belong to one of three en route service areas. Here, we found an indication that some weather phenomena might affect en route operations differently, depending on the center's geographical location. However, because of our sample limitations, we cannot make definitive conclusions on this issue. Nevertheless, it points to an important issue for future evaluations of weather information needs for centers across the United States.

3.2 The Use of Weather Information in En Route Field Operations

In the following sections, we present results from the questionnaire survey regarding weather information that FLMs report en route controllers use. First, we were interested in how frequently controllers use the ESIS information during adverse weather conditions, and whether it would be more beneficial for controllers to have this information displayed directly on the

DSR. The ESIS has the capability to display different types of weather information, but the controller has to integrate the weather information shown on this auxiliary display with traffic data on the DSR workstation. Second, we asked whether it is just as useful to receive weather briefings from the supervisor or CWSU as it is to have access to the same information on a display. Third, because of the recent controversies regarding the DSR WARP display, we were interested in how users rate the accuracy of this display. During operations, en route controllers receive feedback from pilots when they advise them on basic precipitation coverage and height and when they suggest routings to keep aircraft clear of weather. Sometimes, the controller display shows precipitation coverage that pilots cannot see and vice versa (AOPA, 2006c; Hansman & Davison, 2000; Lang et al., 2005). Therefore, we were also interested in how confident controllers are regarding the accuracy of their advisories to pilots. Finally, we were interested in the perceived utility of URET weather probe capabilities (i.e., the severe weather avoidance capability in PARR) for today's en route operations and the perceived usefulness of the upper-level wind information provided by URET.

3.2.1 ESIS Display Usage

To assess how frequently controllers use the ESIS display, we asked the question: "How frequently do you use the weather information presented on the ESIS (e.g., chop forecast, thunderstorm forecast, WARP display) while controlling traffic during adverse weather conditions?" Figure 4 shows the ratings for each level of the 10-point scale. For these ratings, the *Mdn* = 7.5 (Interquartile Range [*IQR*] = 6 to 10) implies a relatively frequent use of the ESIS display by controllers.

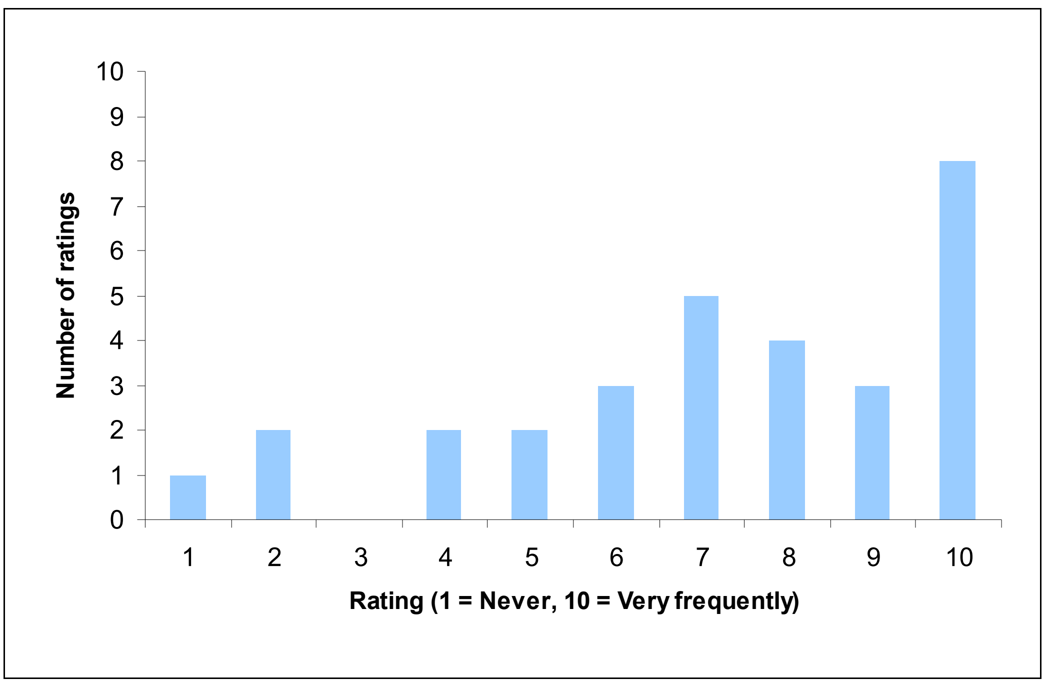

Figure 4. Ratings for the ESIS usage by controllers.

3.2.2 Weather Information Displayed on the DSR

In a recent HITL weather simulation, researchers found that TRACON controllers benefited from a direct access to weather information either on their workstation or on an auxiliary display (Ahlstrom & Friedman-Berg, 2006). In current operations, en route controllers in most areas of specialization have access to information on the auxiliary ESIS display. The ESIS display is located on the end wall in the area of specialization some distance away from the controllers. When controllers use this display, they have to integrate information from the ESIS display (which can be 20 or more feet away) with information on their DSR display. Potentially, this spatial separation of weather and traffic information can work against a quick and effortless controller Weather Situation Awareness (WSA). To assess whether spatial integration of weather information on the DSR could improve controller operations, we asked FLMs: "How much of an operational benefit would it be for controllers to have weather information (e.g., storm and chop forecasts) displayed directly on the DSR instead of looking over at the ESIS or Weather Display?"

Figure 5 shows the ratings for each level of the 10-point scale. The FLM ratings (*Mdn* = 7, *IQR* = 2 to 9) show no consensus on the benefit of having weather information displayed directly on the DSR. There are almost an equal number of ratings that imply a high benefit as there are ratings that imply a low benefit.

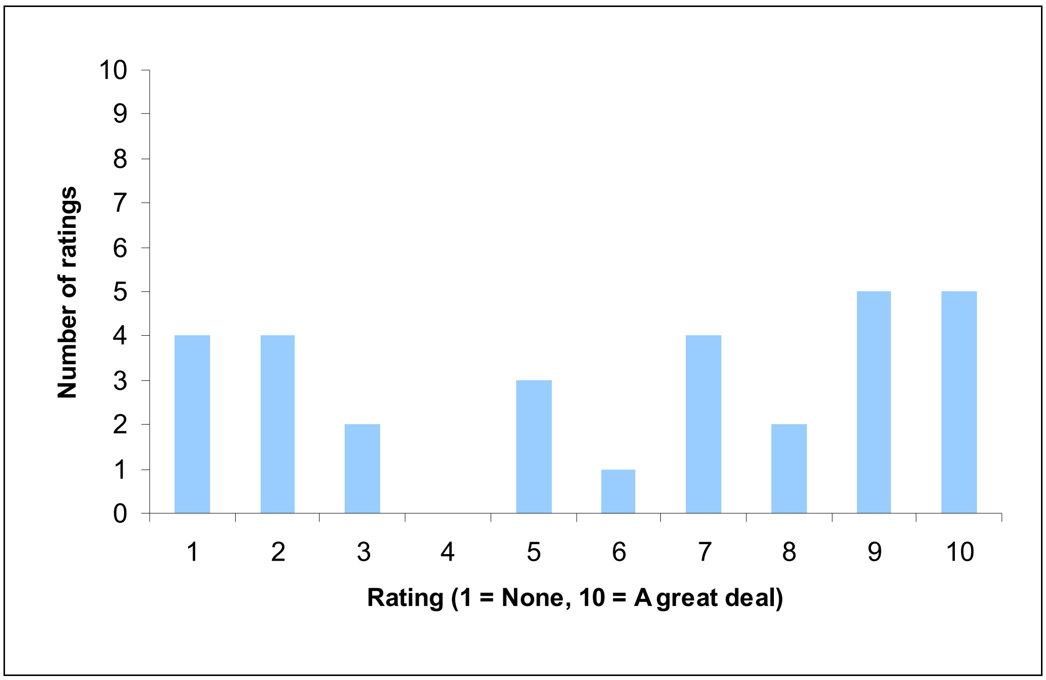

Figure 5. Ratings for the display of weather information on the DSR.

Feedback from FLMs indicates a potential clutter problem from displaying additional weather information on the DSR. However, the clutter effect depends on what type of information is added to the traffic data on the DSR. For example, graphical animations of thunderstorm movements could cover large areas of the screen and potentially be disruptive during operations. On the other hand, small-scale graphics used for coding of weather advisory information might not. The current ESIS information is operationally useful when displayed on an auxiliary screen but potentially inadequate or operationally unsuitable when integrated with traffic data on the DSR.

3.2.3 Weather Briefings from the Supervisor or the CWSU

The FLMs rate the use of ESIS by controllers as frequent, but they also rate that there is only a moderate benefit of having this information displayed directly on the DSR. As shown in Figure 2, in addition to the weather information sources available to the controllers, there is also a flow of weather information from the CWSU and supervisor to the controllers. The question is how useful it is for the controllers to receive this information verbally, compared to having the same information on a display. To assess this question, we asked our participants to rate the following statement: "Receiving weather briefings from the Supervisor or CWSU is just as useful as having direct access to the same information on a display."

Figure 6 shows the ratings for each level of the 10-point scale. The ratings (*Mdn* = 4, *IQR* = 3 to 5) imply a disagreement with the statement that receiving weather briefings verbally is just as useful as having the same information on a display. Information that is verbally presented requires some kind of processing by the receiver, whereas viewing the same information on a display reduces the chance of miscommunication or misunderstanding on part of the controllers (Ahlstrom & Friedman-Berg, 2006).

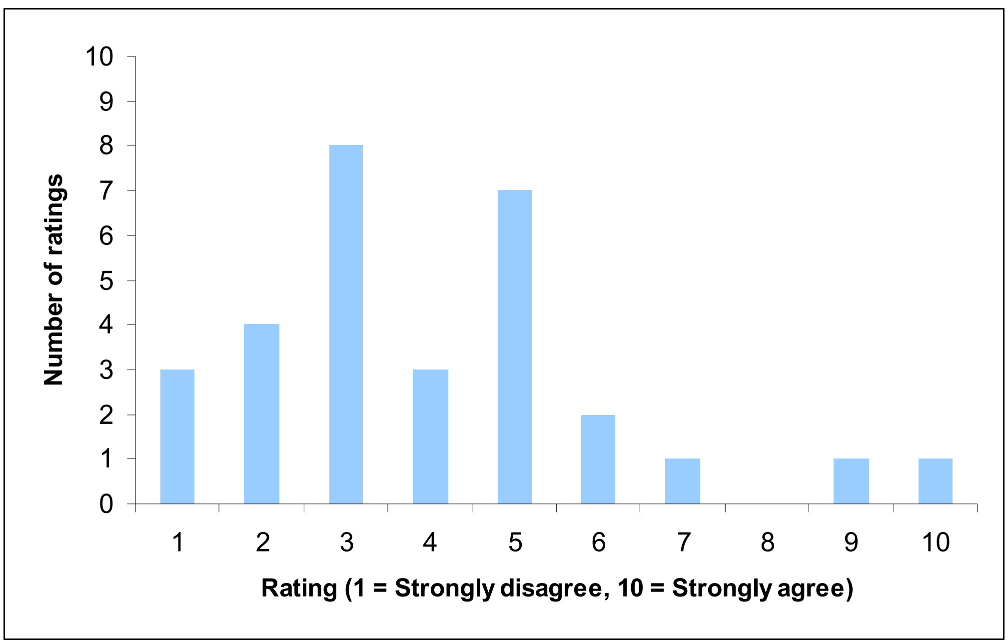

Figure 6. Ratings for the perceived equivalence of supervisor briefings and weather displays.

Furthermore, controllers find it easier to control traffic around visual aids compared to doing the same task using mental maps. Also, visually presented weather information may enhance alternative action interpretations of the same traffic situation.

3.2.4 DSR WARP Display Accuracy

Recent reports from the field have highlighted DSR WARP display anomalies (see Appendix A) that can result in an incorrect display location of precipitation areas. To assess the perceived accuracy of the DSR WARP, we asked the question: "What is your perception of the display accuracy for the location of precipitation levels on the DSR (i.e., the displayed location of precipitation levels on the DSR correspond to the *true* location of precipitation in the airspace)?"

Figure 7 shows the ratings for each level of the 10-point scale. The ratings (*Mdn* = 6, *IQR* = 4 to 7) imply a moderate accuracy for the DSR WARP display. Although 46.7% of all ratings fall between 7 to 10 on the scale (i.e., high accuracy), 53.3% of all ratings fall between 1 and 6 on the scale, which implies a perceived accuracy that only ranges from no accuracy at all to a moderate accuracy.

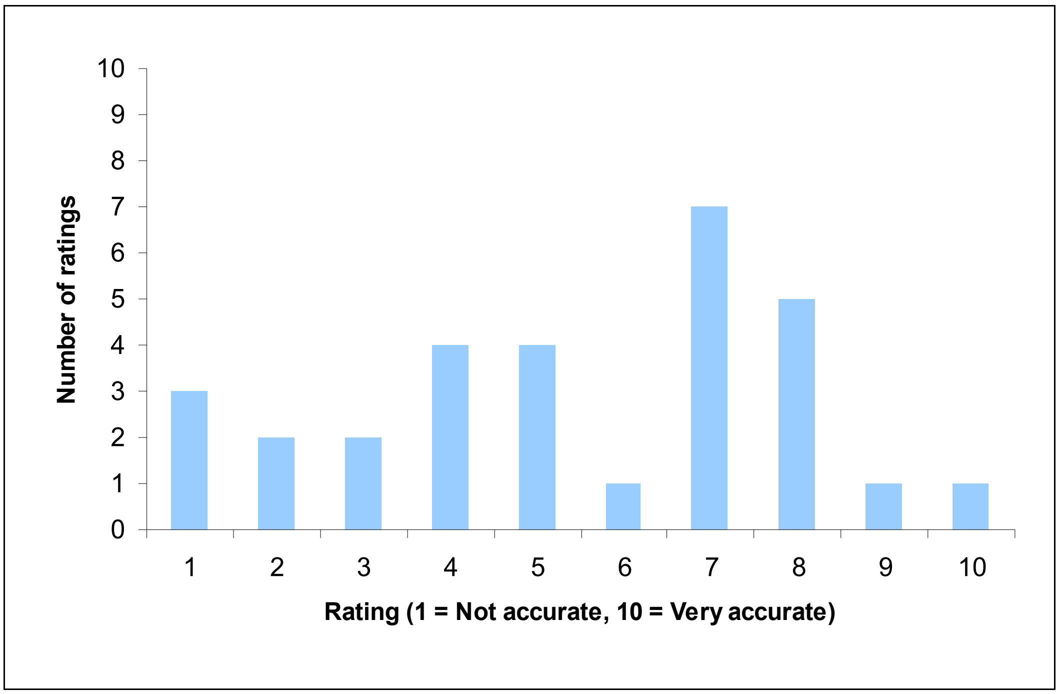

Figure 7. Ratings for the accuracy of the DSR WARP display.

Although we expect high accuracy ratings for an operational system, the ratings in the low end of the scale are not as encouraging. However, many factors could contribute to the controllers' perception of the DSR WARP display accuracy. During operations in adverse weather, controllers communicate with pilots and provide advisories on precipitation areas displayed by the DSR WARP. At the same time, controllers receive feedback from pilots about the status of these areas as pilots encounter them in flight. Therefore, these communications serve as a *gauge* for the controllers to determine how well the precipitation display depicts true areas of precipitation in the airspace.

Another important factor is the controllers' experience with the use of the DSR WARP. From our current rating data, we cannot analyze the extent to which the cumulative use of the DSR WARP during adverse weather conditions affects the perception of display accuracy. Potentially, there could be a bias towards high accuracy ratings from users with less experience of the DSR WARP.

As indicated by the data in section 3.1, thunderstorms do not affect all en route centers across the continental United States equally. Furthermore, the common type of storm characteristics found in one center's airspace may differ greatly from what is common in another center's airspace (i.e., cell *pop-up* vs. *line storm*). Coupled with the fact that aircraft normally try to give a wide berth to extreme weather areas, this could lead to a positive bias in the controllers' perception of the precipitation display accuracy. Finally, we do not know to what extent controller training on the precipitation display and basic radar functionality (which may vary across centers) affects the perceived DSR WARP display accuracy.

3.2.5 Pilot Weather Advisories

In current en route operations, controllers use the DSR WARP display and information from the ESIS display when guiding pilots around weather (upon pilot request) and when informing pilots on basic precipitation coverage and height (Ahlstrom, 2007). Because accurate weather advisories are important for pilots, it is essential to assess how controllers perceive the accuracy of information they relay to pilots. To assess controllers' confidence levels regarding the accuracy of their pilot advisories, we asked the question: "When you give advisories to pilots about precipitation levels, how confident are you that the information is accurate?"

Figure 8 shows the ratings for each level of the 10-point scale. As the figure shows, there is little consensus among the participants. The ratings (*Mdn* = 5, *IQR* = 3 to 7) imply that controllers are moderately confident about the accuracy of their pilots' advisories. However, 60% of the ratings are in the 1 to 5 range on the scale, which implies that confidence levels range from no confidence at all to a moderate level.

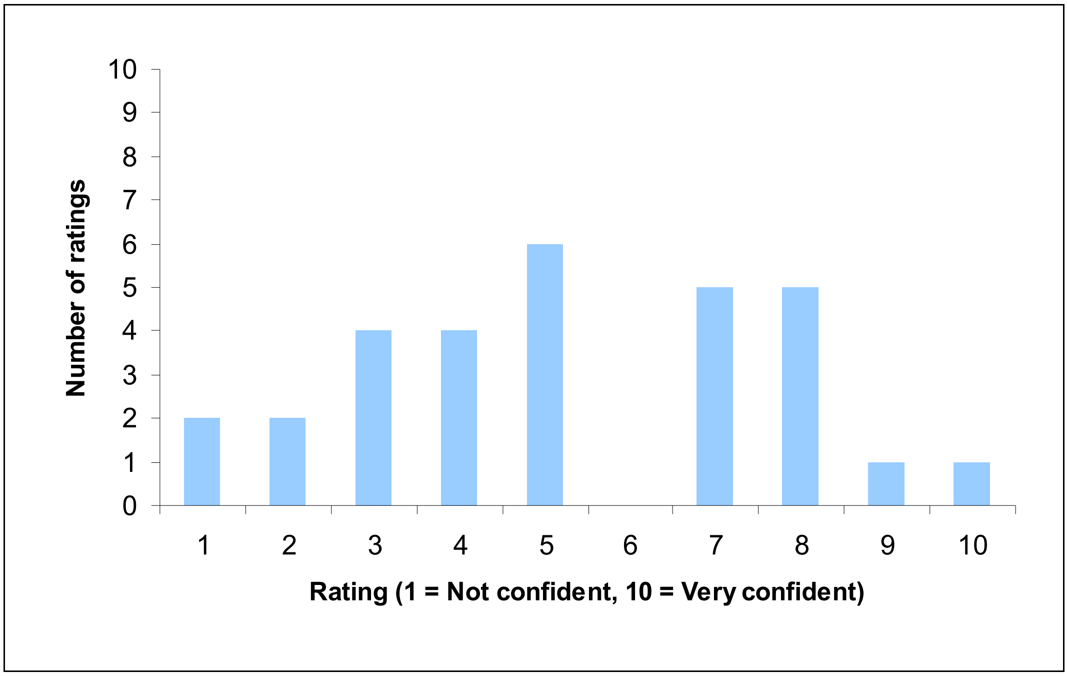

Figure 8. Ratings for the accuracy of pilot advisories.

A recent report by the National Transportation Safety Board (NTSB, 2006) highlights some instances where pilots either received inadequate weather advisories from controllers or received none at all. Given the controllers' low confidence in the DSR WARP display accuracy coupled with their current advisory function, these factors could possibly work against an efficient issuing of weather information by controllers. According to the feedback from FLMs, DSR WARP can display weather that pilots are unable to see. By issuing observed precipitation that is not present in the airspace, this prevents common WSA among controllers and pilots and may create doubts from pilots regarding the accuracy of the ATC weather information. Furthermore, if controllers are reluctant to issue hazardous weather areas that are actually present in the airspace, it can create safety hazards for aircraft.

3.2.6 PARR Severe Weather Avoidance

In current en route operations, controllers have access to weather displays (DSR WARP and ESIS) that provide various sources of information. Controllers use this information to build up their WSA for decision making and to provide weather information to pilots. Another way of using weather information in ATC is to feed weather data to automation tools that detect and provide resolutions to conflicts between aircraft and severe weather areas. A URET enhancement called PARR will include support for a weather avoidance capability that probes for conflicts between aircraft and severe weather areas 20 minutes into the future. The question is how useful such tools are for current en route operations. To assess the perceived usefulness of a weather probe, we asked the following question about PARR: "How useful do you think such a tool would be for controllers in today's en route operations?"

Figure 9 shows the ratings for each level of the 10-point scale. As the figure shows, there is little consensus among the participants with regards to the usefulness of a weather probe. The ratings (*Mdn* = 7, *IQR* = 4 to 9) imply a perceived moderate usefulness of PARR for current en route operations.

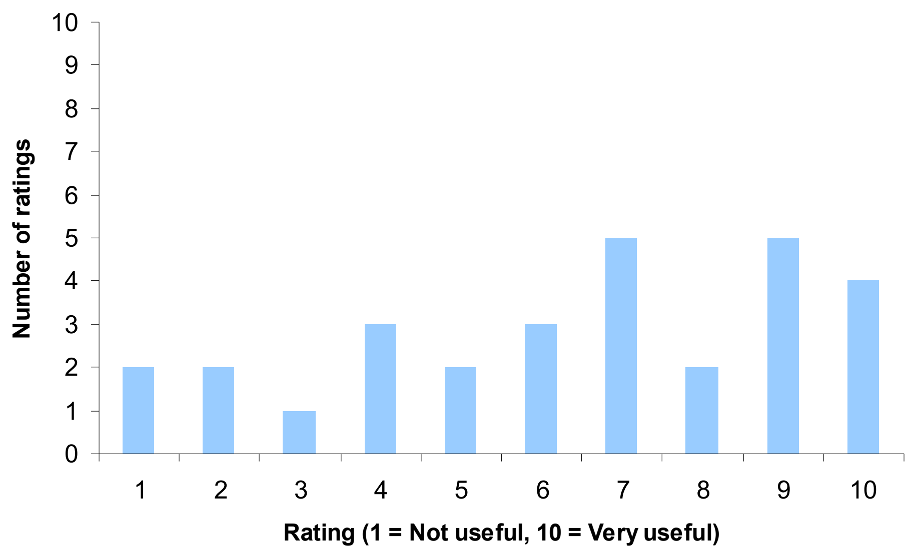

Figure 9. Ratings for the usefulness of PARR weather probe.

A potentially confounding factor in these data is the fact that en route centers use URET in different ways (Bolic & Hansen, 2005). Therefore, if some centers mainly use URET as an electronic flight strip replacement, there may be less perceived usefulness of a strategic weather probe, such as the severe weather avoidance capability included in PARR. Without a strategic trajectory-based operation, there would be little use for warnings of severe weather conflicts 20 minutes into the future. On the other hand, deployment of a weather probe tool, such as PARR, will have consequences for both training and ATC operations. First, there would be a need to train controllers in the use of URET for strategic operations. Second, a strategic operation may necessitate a change in the current roles and responsibilities with regard to severe weather avoidance (Ahlstrom, 2007).

3.2.7 URET Wind Information

Wind conditions are essential to aircraft because more optimal routes can reduce flight time and thereby save fuel. In current en route operations, controllers use the wind information provided by URET when planning vectors. Usually, pilots request more efficient routings, such as more fuel-efficient altitudes and more wind-optimal routes. To assess the operational usefulness of the URET wind information, we asked the question: "How useful is the upper-level wind information provided by URET?" Figure 10 shows the ratings for each level of the 10-point scale. The ratings (*Mdn* = 8, *IQR* = 6 to 9) imply that FLMs perceive the wind information provided by URET as useful.

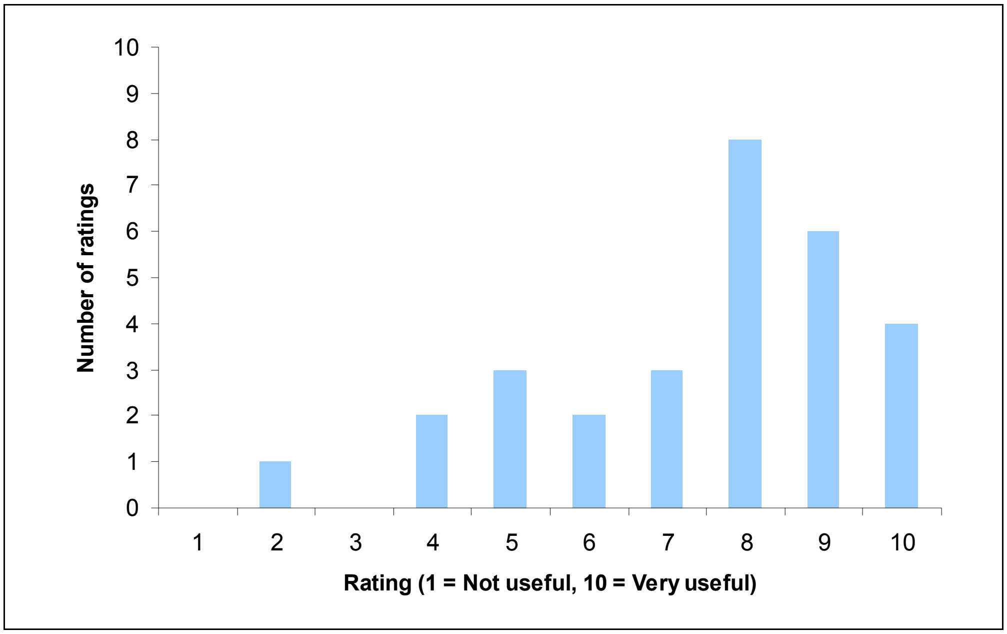

Figure 10. Ratings for the usefulness of URET wind information.

3.3 Suggestions for Improvements of Current and Future Weather Displays

In Appendix D, we present FLM comments from the last two items in the survey. One of these items probed FLMs regarding weather information (not currently available) that would be useful for current operations. In the second item, we asked FLMs for display alternatives that may be of importance for the development of future weather displays.

For improvements to current operations, FLMs suggested improved movement forecasts and lightning information, as well as information about current/forecasted turbulence and icing. Other suggestions included information about cloud tops and the availability of weather advisories on the DSR.

For future considerations, several FLMs suggest improvements in the display accuracy of precipitation areas and the possibility to display cloud tops information. Other suggestions are 30-minute weather forecasts and weather loops for traffic planning.

An interesting comment from FLMs is that the current color palette for the DSR WARP is confusing and does not provide enough salience. Similarly, there are comments that the DSR WARP should use a different color palette similar to the common NWS NEXRAD display (green, yellow, red, etc.). Although the main purpose of this study is to analyze the use of weather information, and not to recommend guidelines for color coding of DSR interface objects, we would like to address this issue further because of the potential safety and human factors issues caused by sub-optimal weather displays.

Color coding of precipitation levels has potential benefits; however, it can also create human factors problems with legibility, salience manipulation, and color recognition if conducted in a non-optimal fashion. Ahlstrom and Arend (2005) presented a framework for color coding of precipitation displays where the palette is specifically designed to prioritize information while maintaining good legibility. Within this framework, precipitation displays are color coded according to common conventions where red indicates extreme levels of precipitation, yellow indicates heavy precipitation, and green indicates moderate areas of precipitation. Interestingly, this is exactly what FLMs suggested for improvements to the current DSR WARP display.

However, designers must consider all aspects of the interface palette when designing a precipitation display. Too commonly, design teams pick colors by criteria unrelated to optimal legibility and salience but strongly related to individual preferences. Color palettes need to provide good margins of legibility and color identification while at the same time helping users with their attention management. However, the current practice of manipulating the luminance contrast of display elements by adjusting individual *brightness settings* is troublesome and circumvents any meaningful color coding. One example is the current option in DSR to manipulate the background color from black to blue. Coupled with the current DSR WARP color palette, these factors allow users to produce sub-optimal legibility of precipitation information. User-adjustments of display colors must be constrained to maintain a hierarchy of salience that reflects the relative urgency of display data. Given the empirical findings of a wide range of controller preferences for salience of display elements, this is very important to prevent usability and, possibly, even safety risks (Ahlstrom & Arend, 2005).

4. DISCUSSION

The primary purpose of the ATC system is to provide a safe and expeditious flow of traffic. In addition to this main function, en route controllers provide additional services such as relaying pertinent weather information to pilots (conditions and workload permitting). For example, en route controllers advise pilots of hazardous weather that may impact flight operations. When requested by the pilot, controllers also provide radar navigational guidance around areas of adverse weather (FAA, 2006a). Although it is not the en route controllers' job to keep aircraft separated from weather areas, controllers are required to familiarize themselves with pertinent weather information and to maintain a level of weather awareness to perform their duties.

For en route controllers, maintaining WSA implies an assimilation of information from various sources, such as supervisor briefings, PIREPs, the DSR WARP, and the ESIS display in their area of specialization (Ahlstrom, 2004; Farley et al., 1998; Hansman & Davison, 2000). The DSR WARP display is particularly important to controllers because it is their main source of precipitation information. Controllers use this information when guiding pilots around weather (upon request) and when providing pilots with information about basic precipitation coverage and height (Ahlstrom, 2007). However, reports from the Office of Inspector General (2002) and Quality Assurance Bulletins from the field (Appendix A) have described several problems with the current DSR WARP display. One example is the potential lagging of the precipitation display by 0.8 miles for every 10 knots of wind at altitude when the radar is scanning in precipitation mode. Other researchers have also reported issues related to the inherent limitations with NEXRAD data quality and timeliness (Bumgarner & Shema, 2003), radar mosaic generation algorithm performance (Lang et al., 2005), and anomalous propagation and ground clutter (Moosakhanian et al., 2005). The FAA has addressed some of these issues and is currently working on others; however, many DSR WARP issues remain.

One major issue is the display accuracy of the DSR WARP during en route operations. The data from our survey show that 46.7 % of the FLMs rate the display accuracy as high. However, the remaining 53.3% rated the display as having no accuracy to a moderate accuracy. There can be many reasons behind this outcome, however, it clearly demonstrates a lack of trust in the accuracy of the display. This lack of trust also affects the perceived confidence in the accuracy of precipitation advisories given to pilots. During operations, controllers have access to precipitation information on their DSR and, in most areas of specialization, on the ESIS display as well. Despite this, our survey found that only 40% of the FLMs have a high confidence that their precipitation advisories to pilots are accurate.

From an operational standpoint, the fact that controllers only have four altitude strata for the DSR WARP display also creates display issues. Currently, the DSR WARP can display precipitation in four different altitude strata: 0 to 60,000 ft, 0 to 24,000 ft, 24,000 to 33,000 ft, and 33,000 to 60,000 ft (Moosakhanian et al., 2005). To exemplify the problem this may cause, we might consider an en route controller operating an intermediate high altitude sector. During this operation, the controller is responsible for traffic between flight level (FL)310 to FL340, but the controller is also required to watch traffic 1,200 ft below and above the sector altitude limits (i.e., FL298 to FL352). In this case, the controller would not select the altitude stratum from 0 to 24,000 ft, because the precipitation in this range is below the lower altitude limit of the sector. Neither would the controller select the stratum from 0 to 60,000 ft, because this would cover altitudes that are irrelevant for the current operation. In order to optimize the display of precipitation, the controller would have to select the other two strata covering 24,000 to 60,000 ft to display precipitation that is present within the sector altitude limits. In this example, the DSR WARP displays operationally relevant precipitation information as well as irrelevant precipitation information for over 30,000 ft outside the controller's area of jurisdiction. When viewing the DSR WARP, there is no way for the controller to know if the displayed areas of precipitation are within or outside the sector vertical limits. This leads to an uncertainty regarding the accuracy and usefulness of precipitation information that controllers pass on to pilots.

This uncertainty about the location of precipitation leads to discrepancies in WSA between pilots and en route controllers (Farley et al., 1998) and a potential confusion about the severity of precipitation areas (AOPA, 2006a). According to AOPA (2006b, 2006c), pilot encounters with thunderstorms caused many of the fatal weather-related accidents during 2004. Somehow, pilots flew into severe weather conditions even though they were in contact with controllers. Similarly, the NTSB described aircraft accidents where controllers failed to provide pilots with information about severe weather areas along their flight path (NTSB, 2006). To improve WSA among controllers and pilots, the FAA amended the phraseology for how controllers describe precipitation levels shown by the DSR WARP (FAA, 2006a, 2006c). Currently, en route controllers describe radar-derived weather in three precipitation levels: moderate, heavy, and extreme. Previously, en route controllers used the descriptors moderate, heavy, and *heavy*. The change will enhance the WSA among controllers and pilots by differentiating between heavy and extreme precipitation. To address issues with dissemination of weather information to pilots by controllers, the FAA has issued mandatory briefing packages to en route centers.

Another factor that could affect controller WSA is the large amount of weather information presented on the ESIS auxiliary display. Potentially, the separation of weather and traffic data can reduce the ease by which controllers gain a *picture* of weather hazards affecting the sector traffic (Ahlstrom & Friedman-Berg, 2006). However, this does not seem to be the case because our survey shows that controllers frequently use the ESIS display and that there is no consensus on the need to present this information on the DSR instead of the ESIS. In fact, some comments from FLMs indicate a likely clutter effect on the DSR from additional weather data, with a suggestion to add more weather information on the URET instead. What is clear, however, is that FLMs disagree with the statement that receiving weather briefings from supervisors or CWSU is just as useful as having this information on a display. Evidently, en route FLMs perceive that weather displays are more useful than verbally presented weather information. Ahlstrom and Friedman-Berg have also reported a similar result from a TRACON weather simulation.

Adding new weather information on controller workstations has potential benefits, but it also presents several new issues. One example is the unavoidable increase in clutter with an increasing number of display elements for traffic and weather data. Another issue with an increasing number of display elements is the increased difficulty with efficient salience manipulation (Ahlstrom & Arend, 2005). Presenting weather information on auxiliary displays can be a solution to these problems, and empirical data support the notion that controllers can integrate weather and traffic data presented on separate displays (Ahlstrom & Friedman-Berg, 2006). However, despite the fact that weather displays can provide operationally useful data, controllers must still integrate this information with information used for moment-to-moment actions while controlling traffic in the airspace. With a projected increase in en route traffic (FAA, 2006b), it is likely that we need solutions that do not depend on mental elaboration of weather information by controllers.

A future solution could be an automated weather probe that provides severe weather warnings and route solutions that controllers can view, amend, or, if deemed appropriate, act upon directly (Ahlstrom & Della Rocco, 2003). The PARR support capability for severe weather avoidance is an example of this concept for en route control (Heagy & Kirk, 2003; Kirk & Bolczak, 2003; Kirk et al., 2001). Although some FLMs in our survey rated the PARR weather probe capability as useful for current operations, there is still the question whether a strategic weather probe is the right tool for controllers in current en route sector operations. First, the URET usage differs between controller teams and between centers. In many instances, controllers use URET in ways that differ from the intended usage (Bolic & Hansen, 2005). Second, feedback from controllers indicate that dynamic en route sector environments do not easily lend themselves to strategic solutions (Bolic & Hansen). Third, there is no operational requirement that mandates a responsibility for en route controllers to keep aircraft away from hazardous weather (Ahlstrom, 2007; FAA, 2006a).

A strategic weather probe could be more useful, however, if this capability was available for a multi-sector airspace coordinator. The responsibility for this position is to maintain maximally efficient flight paths for aircraft across several en route sectors (Willems, Heiney, & Sollenberger, 2005). During severe weather avoidance, this en route position optimizes aircraft trajectories to avoid conflicts between aircraft and severe weather areas. This could potentially lessen the need for sector controllers to assist in re-routes around hazardous weather, decrease controller workload, and reduce controller-pilot communications.

5. CONCLUSION AND RECOMMENDATIONS

On the basis of the results from this study, we propose some recommendations for weather display enhancements for en route controllers. First, en route controllers do not currently have an accurate and timely display of precipitation areas on the DSR. Uncertainty about the display accuracy of precipitation locations limits the usefulness of controller weather advisories when given to pilots and creates a safety risk for non-equipped aircraft requesting help with severe weather avoidance. Therefore, there is a human factors requirement to develop more accurate precipitation displays that support controller actions, such as providing accurate weather advisories and providing radar navigational guidance. Furthermore, the precipitation display must allow controllers to limit the display of precipitation areas to operationally relevant altitude strata. Accurate and timely display of precipitation areas will facilitate accurate controller decision making, thereby increasing capacity and safety of the system, as well as decreasing delays.

Second, in current en route operations, controllers receive text-based weather advisories such as CWA, SIGMET, AIRMET, WST, and UUA on flight progress strips. Controllers broadcast this information to pilots, and they translate this text-based information into mental representations of hazardous weather areas to foresee future effects of weather on sector traffic. This task can be time-consuming and laborious due to the presentation mode of these advisories. Research should evaluate alternative ways to relay this information to pilots and determine the operational benefits of displaying this information in a graphical format on the DSR.

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Acronyms

AIRMET	Airman’s Meteorological Information
AOPA	Aircraft Owners and Pilots Association
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
CRD	Computer Readout Display
CWA	Center Weather Advisory
CWSU	Center Weather Service Unit
DSR	Display System Replacement
ESIS	Enhanced Status Information System
FAA	Federal Aviation Administration
FL	Flight Level
FLM	Front Line Manager
HFREG	Human Factors Research and Engineering Group
HITL	Human-in-the-Loop
METAR	Aviation Routine Weather Report
Micro-EARTS	Microprocessor-En Route Automated Radar Tracking System
NAS	National Airspace System
NEXRAD	Next Generation Weather Radar
NTSB	National Transportation Safety Board
NWS	National Weather Service
PARR	Problem Analysis, Resolution, and Ranking
PIREP	Pilot Report
SIGMET	Significant Meteorological Information
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control
URET	User Request Evaluation Tool
UUA	Urgent Pilot Weather Report
WARP	Weather and Radar Processor
WSA	Weather Situation Awareness
WST	Convective SIGMET

Appendix A

DSR Weather Display Anomalies

Federal Aviation Administration

Cleveland ARTCC

QUALITY ASSURANCE BULLETIN

Date: March 13, 2006

Subject: DSR Weather Display Anomalies

Attention: All Operational Personnel

This document expands on the March 13-19, 2006 team briefings on "DSR Weather Display Anomalies." The briefing was prepared after controllers at ZOB noticed that aircraft were deviating into what appeared to be extreme weather on the DSR.

The anomaly was determined to be a result of unusually high winds coupled with the delay inherent in WX radar systems. The Volume Coverage Patterns, described later, require 5-10 minutes to complete a complete scan. This results in a delay of up to 5-10 minutes before the WX data is processed and made available to the DSR display.

This results in a displacement of the DSR weather display (lagging) of up to 0.8 miles for every 10 knots of wind at altitude during periods when weather radar is scanning in precipitation mode. Since most aircraft give a wide berth to extreme weather, the effect is normally not noticed.

With pilot reported winds of 75-100 knots at 12,000 feet, the effect is very noticeable. The WX was displaced 6 to 8 miles from where DSR was displaying it.

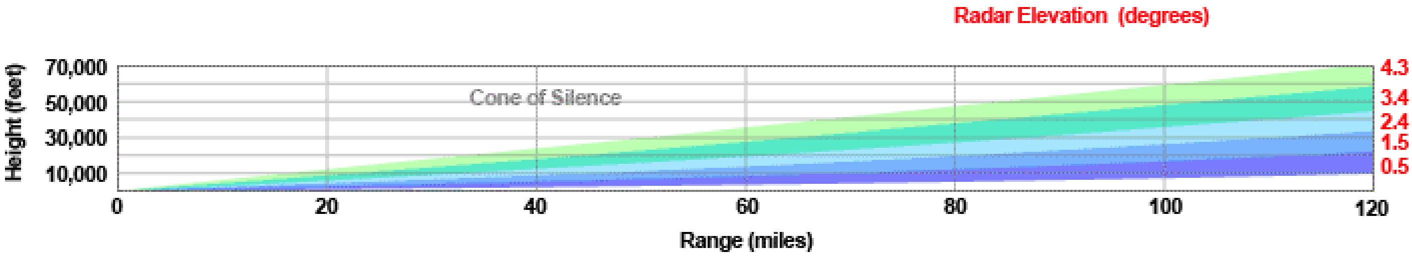
At present, education and awareness are the only solutions we have to this issue. Remain cognizant of the winds when providing weather avoidance advisories and provide your relieving controller a complete briefing.

Volume Coverage Patterns (VCPs)

Weather radar employs scanning strategies in which the antenna automatically raises to higher and higher preset angles, or elevation slices, as it rotates. These elevation slices comprise a **volume coverage pattern** or VCP. Once the radar sweeps through all elevation slices a volume scan is complete. In precipitation mode, weather radar completes a volume scan every 4-6 minutes depending upon which VCP is in effect, providing an updated 3-dimensional look at the atmosphere around the radar site.

There are two main operating states of Weather Radar; Clear Air Mode and Precipitation Mode. Within these two operating states there are several VCPs the NWS forecasters can utilize to help analyze the atmosphere around the radar. These different VCPs have varying number of elevation tilts and rotation speeds of the radar itself. Each VCP therefore can provide a different perspective of the atmosphere.

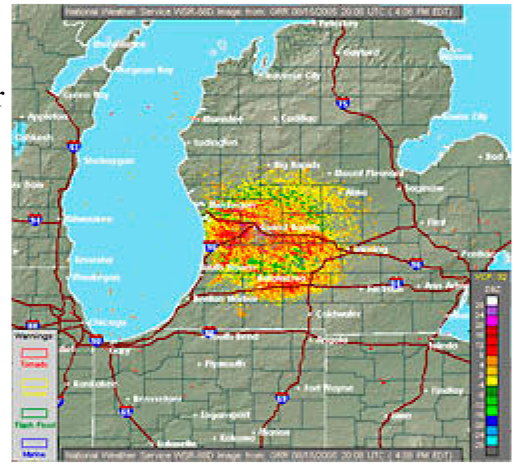
Common among all VCPs (except for VCP 12) is the tilt elevations of the lowest five elevation angles. The scanning begins with 0.5° elevation meaning the centerline the radar beam antenna is angled 0.5° above the ground. Since the beam itself is 1° wide, it returns information about what it "sees" between 0° and 1° above the horizon. As it completes that elevation scan the radar is tilted another degree with the center line of the beam now at 1.5° and the process of observing the atmosphere begins again then continues through the 2.4°, 3.4° and 4.3° elevation angles.



Clear Air Mode

Clear Air mode is used when there is no rain within the range of the radar. In this mode, the radar is in its most sensitive operation state. This mode has the slowest antenna rotation rate which permits the radar to sample a given volume of the atmosphere longer. This increased sampling increases the radar's sensitivity and ability to detect smaller objects in the atmosphere than in precipitation mode.

A lot of what is seen in clear air mode will be airborne dust and particulate matter. However, snow does not reflect energy sent from the radar very well. So clear air mode will occasionally be used for the detection of light snow as well. Also, this mode is helpful in detecting discontinuities in the air mass, such as a frontal boundary, and in monitoring the onset of precipitation.



There are two clear mode VCPs; VCP 31 and VCP 32. Both VCPs complete a volume scan using five elevation angles in 10 minutes. you can readily spot when the radar is in Clear Air Mode just by looking at the image. Most images will have yellows and red colors centered around the radar. When you loop the images, you will see features moving *through* the reds and yellows but the main area itself will not move.

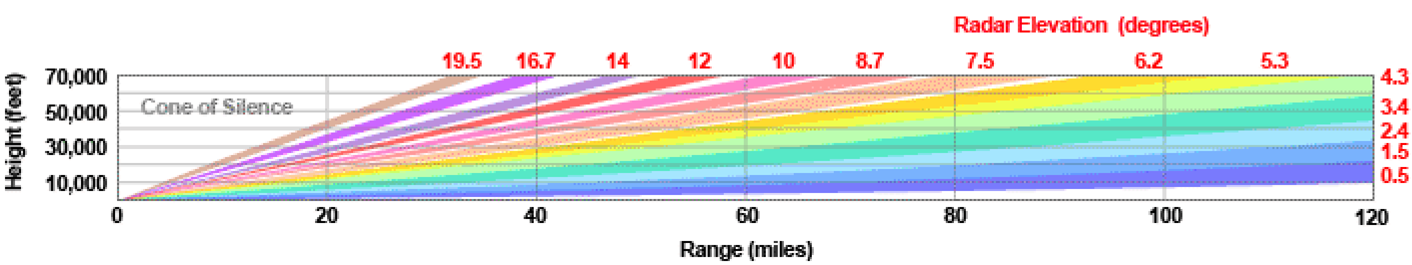
The radar actually makes two 360° scans of the atmosphere at both the 0.5° and 1.5° elevation angles. During the first scan at each elevation the radar is in surveillance mode and is looking for objects. During the second sweep at each of these two lowest elevation angles the radar is determining the velocity of the wind. In the remaining three elevation angles, the radar conducts both surveillance and velocity operations together.

The difference between VCP 31 and VCP 32 is how quickly the radar transmits the digital pulses. In VCP31, the pulse repetition frequency (PRF) is at its lowest. This means the transmitted pulse has the most sensitivity but at a cost. The cost is a decrease in the range of the winds velocity that can be determined.

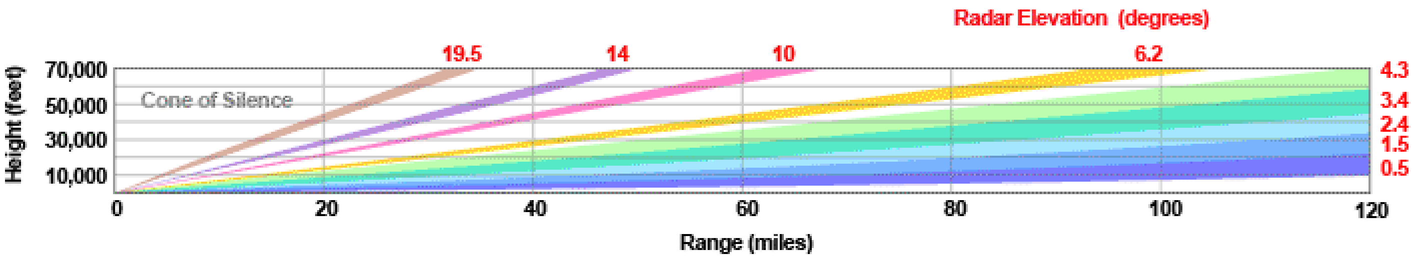
VCP 32 has a higher PRF (more pulses per second) so it is not quit as sensitive as VCP 31 but it can now detect a wider range of the wind's velocity. For this reason, most NWS doppler radars will be in VCP 32 during the Clear Air Mode.

Precipitation Mode

When precipitation is occurring, the radar does not need to be as sensitive as in clear air mode as rain provides plenty of returning signals. At the same time, meteorologists want to see higher in the atmosphere when precipitation is occurring to analyze the vertical structure of the storms. This is when the meteorologists switch the radar to precipitation mode.



Currently, there are four precipitation mode VCPs. **VCP 11** has 14 elevations slices and completes 16 360° scans in 5 minutes, up to 19.5°, to provide better sampling of the vertical structure of storm clouds and to produce images at a much quicker pace. For several years, VCP 11 was the most common operating mode during severe weather. This mode provides rapid updates as well as the ability to see high into the atmosphere.



VCP 21, while it also tilts up to 19.5° to see high into the atmosphere, operates at a slower rotation speed and eliminates some of the upper elevation tilts. In this mode, the radar takes 6 minutes to move though these 9 elevation tilts. This is used primarily for "strato-form" precipitation where vertical features of rain clouds are not as important as during the convective, thunderstorm-type of rain.

The two newest VCP's available to the NWS forecasters are VCP 12 and 121. VCP 12 also has 14 elevations slices, like VCP 11, but performs 17 360° scans in a very fast 4 minutes 6 seconds. Instead of 1° elevation tilt increments seen in all other VCP's, the elevation tilt increase in VCP 12 range from 0.4° to 0.9° up to 4°. In other words, the radar beams overlap the each over.

This provides a denser vertical sampling at lower elevation angles which means better vertical definition of storms, improved detection capability of radars impacted by terrain blockage, better rainfall and snowfall estimates, and resulting in more storms being identified, in addition to the quicker update cycle.

VCP 121 addresses velocity aliasing or the ability of the radar to determine wind velocity and problems caused by "second trip echoes". With the same nine elevation tilts as VCP 21, VCP 121 completes 20 rotations in five minutes. The difference is the radar makes several elevations scans at the same elevation tilt but at different pulse durations (called "pulse repetition frequency" or PRF).

This gives the radar the ability to minimize "range folding". The radar normally determines the range to an object based on the time it transmits a pulse until the time it receives a returned signal. However, depending upon how fast the radar is transmitting pulses, the returned signal may be associated with one of the previous pulses, known as second (or third) trip echoes.

If the PRF is low (longer time between transmission of pulses) the signal can travel farther to the more distant objects and reduces second trip echoes. However, the ability to determine velocity is greatly reduced. High PRF's (less listening time between pulses) greatly improve the radar's ability to determine velocity. Yet, it also increases the number of second or third trip echoes. This tradeoff between distance and velocity is known as the Doppler dilemma.

VCP 121 combines varying PRF's and different antenna dish rotation speeds to help decrease range folding.

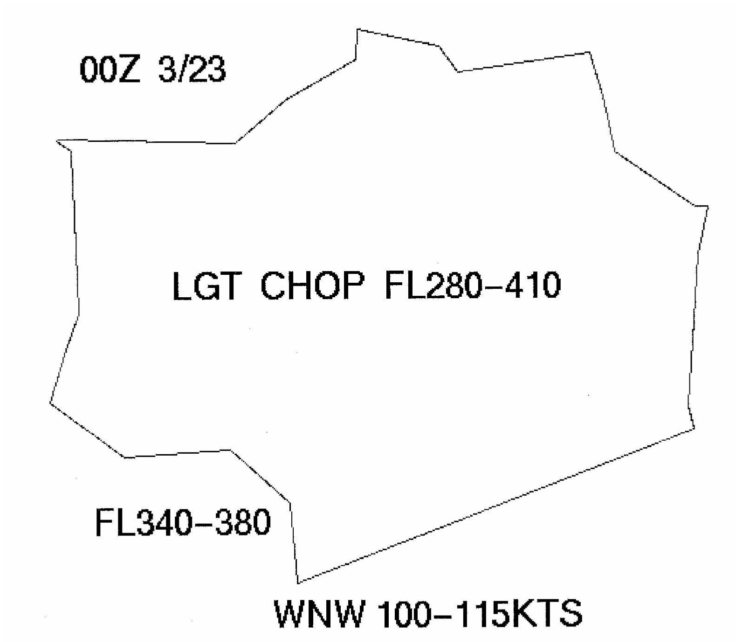
Questions/comments, Contact the Quality Assurance Office.

Appendix B

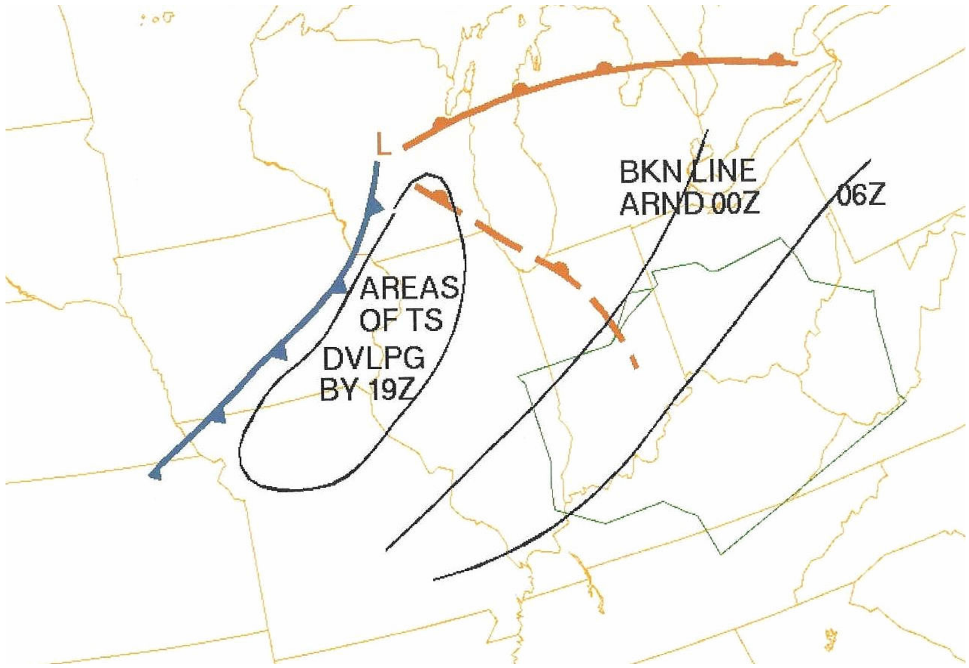
ESIS Display Example

WARP image products displayed by ESIS at Indianapolis ARTCC (ZID), March 2006.

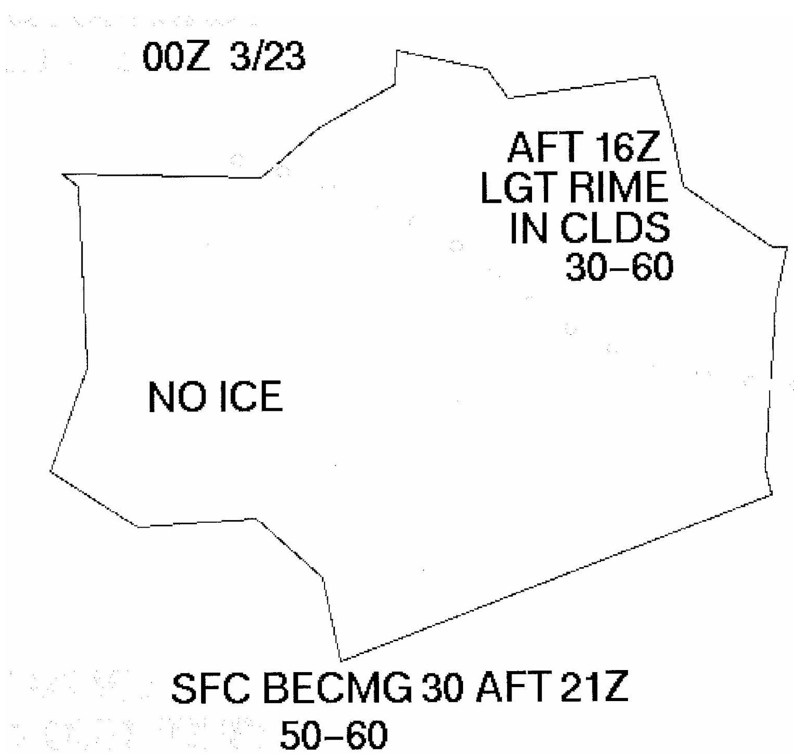
The following are examples of the different images used presently at Indianapolis ARTCC (ZID) in the presentation of WARP to the ESIS in each Area of Specialization. Normally, the ESIS side devoted to the WARP is split into at least two different windows depending on the needs and the supervisor's preference. The following weather examples are slides that constitute a sequence of images for display.



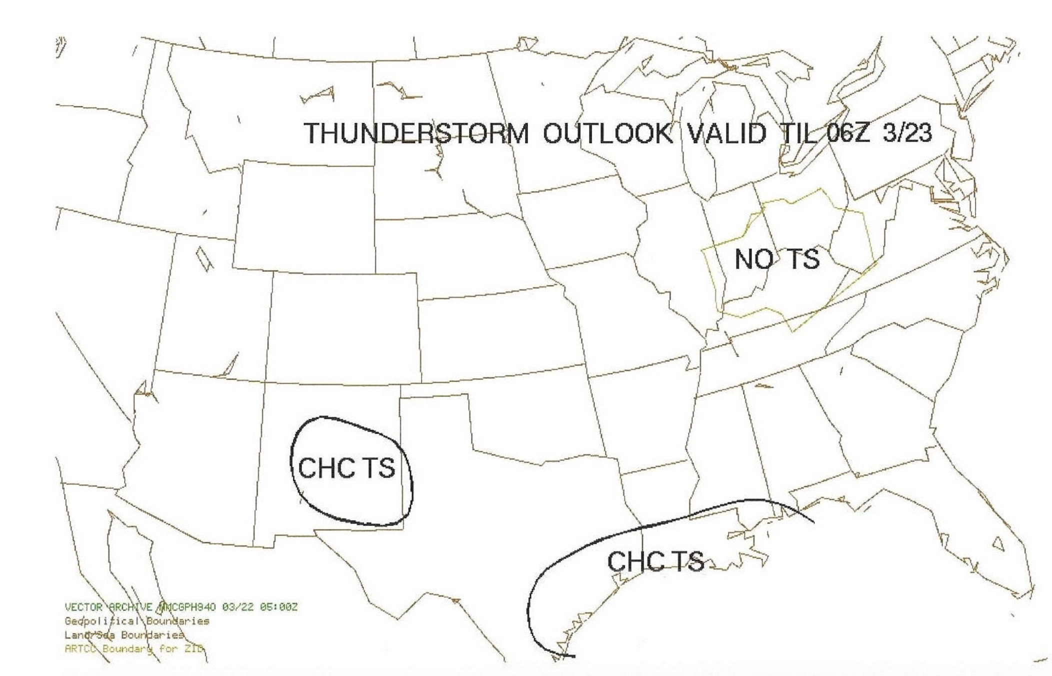
This is an example of the forecasted chop and a notation of the jet stream along with their maximum area of velocity.



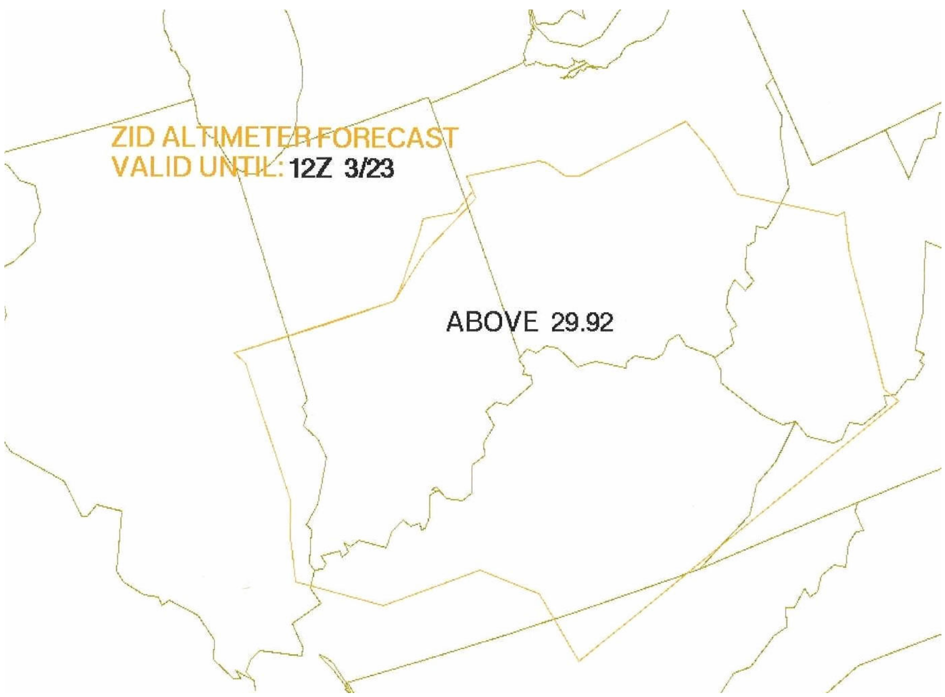
This example shows an area of thunderstorms and the predicted movement at noted times. By 0000z the line will become broken and be entering the NW corner of the center's airspace. At 0600z the line will be sitting across the ZID airspace.



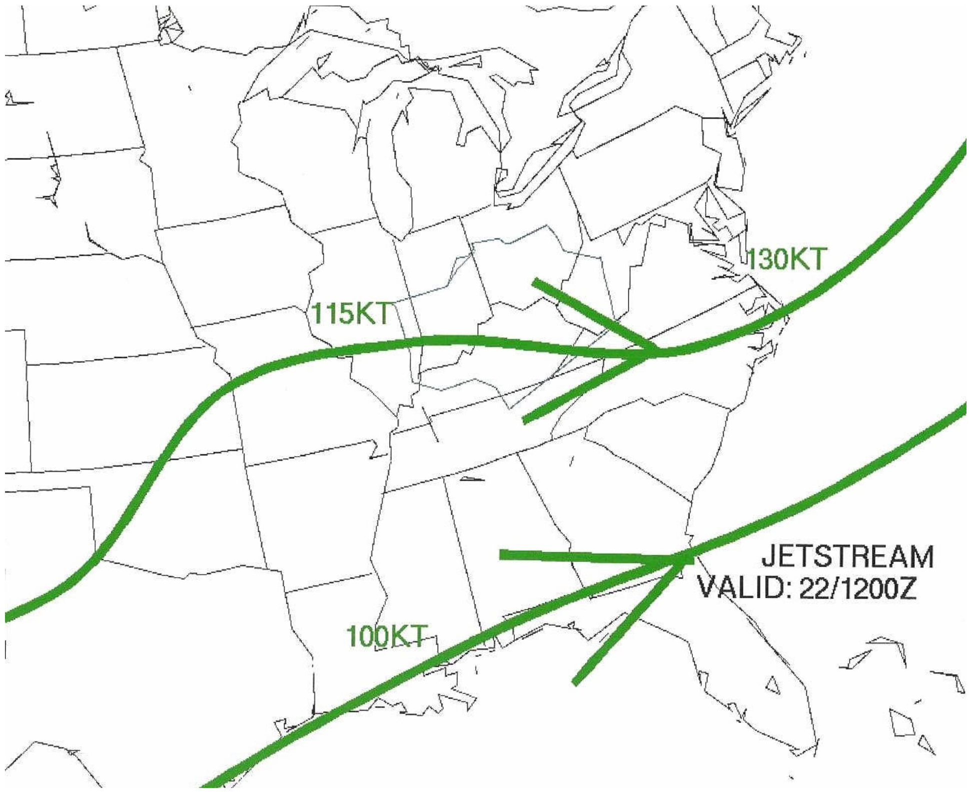
This is an example of a forecast for icing. The notation at the bottom of the slide states that the freezing level is presently at the surface, but forecasted to rise after 2100z.



This is an example of a thunderstorm forecast for the entire US with a notation of no thunderstorms expected in ZID.



This is an example of altimeter settings and the forecast for the shift.



This image shows a jet stream map with the speed and direction of the stream.

FREIGHTER TRML OUTLOOK 02Z–06Z DATE: 3/23/06

	IFR CONDS	PRECIP	WIND>15KT
IND:	NONE	NONE	NONE
SDF:	CIGS 3000/VSBY 5 NONE	NONE	NONE
ILN:	NONE	NONE	NONE

Indianapolis ARTCC does a large volume of freighter operations at three main terminals. This image shows if "IFR conditions / precipitation / wind > 15kts" are expected.

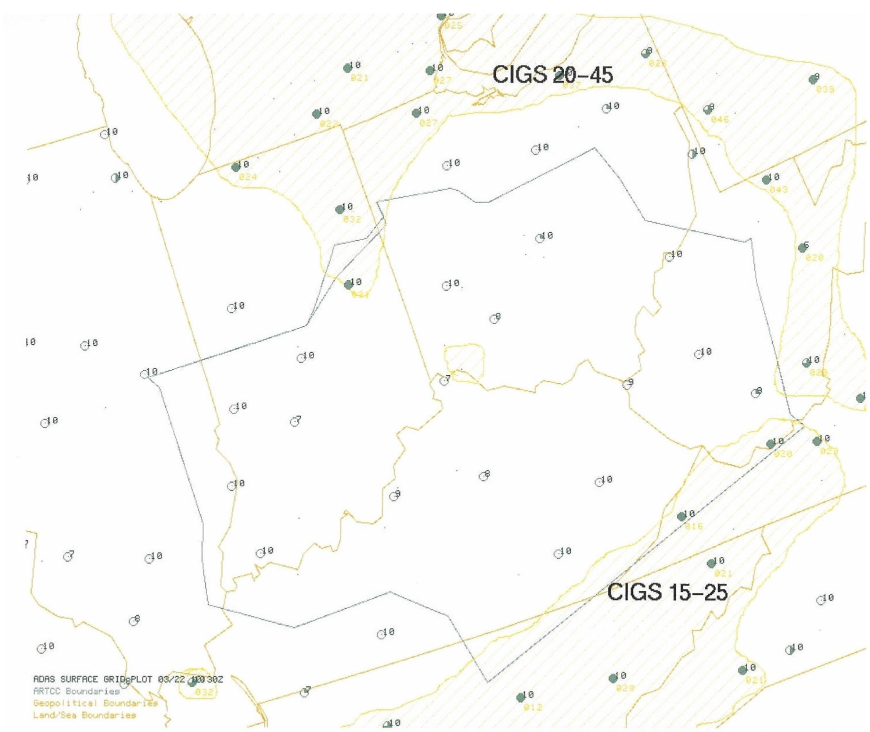
MAJOR TERMINAL FCST VALID TIL 00Z 3/23

	IFR CONDS	SURFACE WIND
ORD:		
STL:		
DTW:		
CLE:		G25KT
PIT:		G25KT
JFK:		G25KT
EWR:		G25KT
DCA:		G25KT
CLT:		
BNA:		
MEM:		
ATL:		
DFW:		

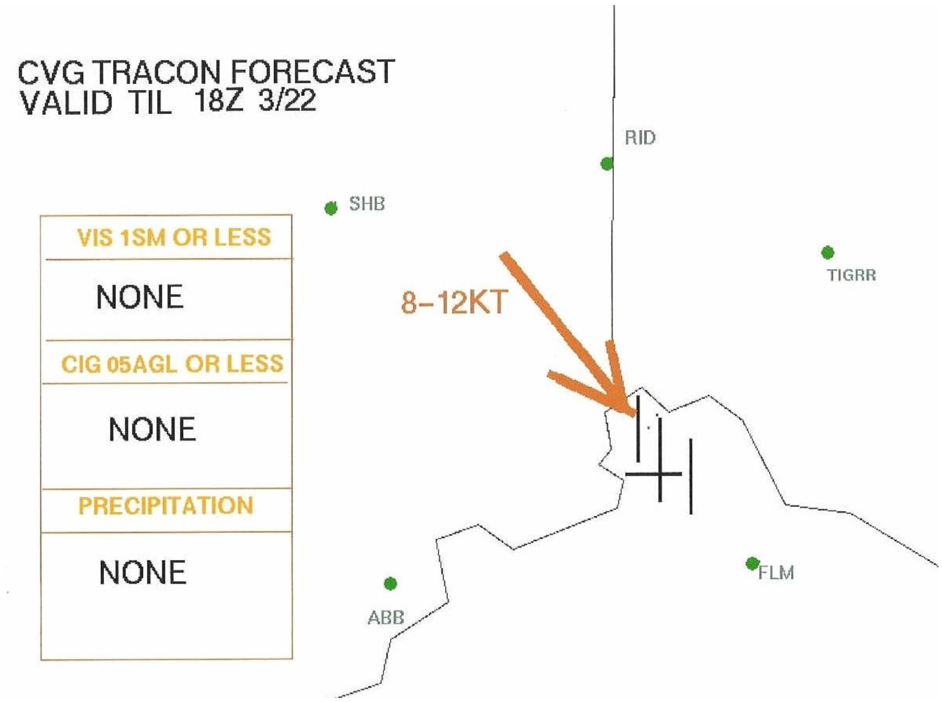
This image shows information about the major terminals that affect traffic flows through ZID and any adverse conditions that may impact their arrival rates.

	IFR CONDS	PRECIP	WIND>25KT
	ZID TERMINALS VALID 1200-0000Z DATE: 3/22/06		
IND:	NONE	NONE	NONE
SDF:	NONE	NONE	NONE
CMH:	NONE	NONE	NONE
BLF:	NONE	NONE	OCNL G20KT TIL 21Z

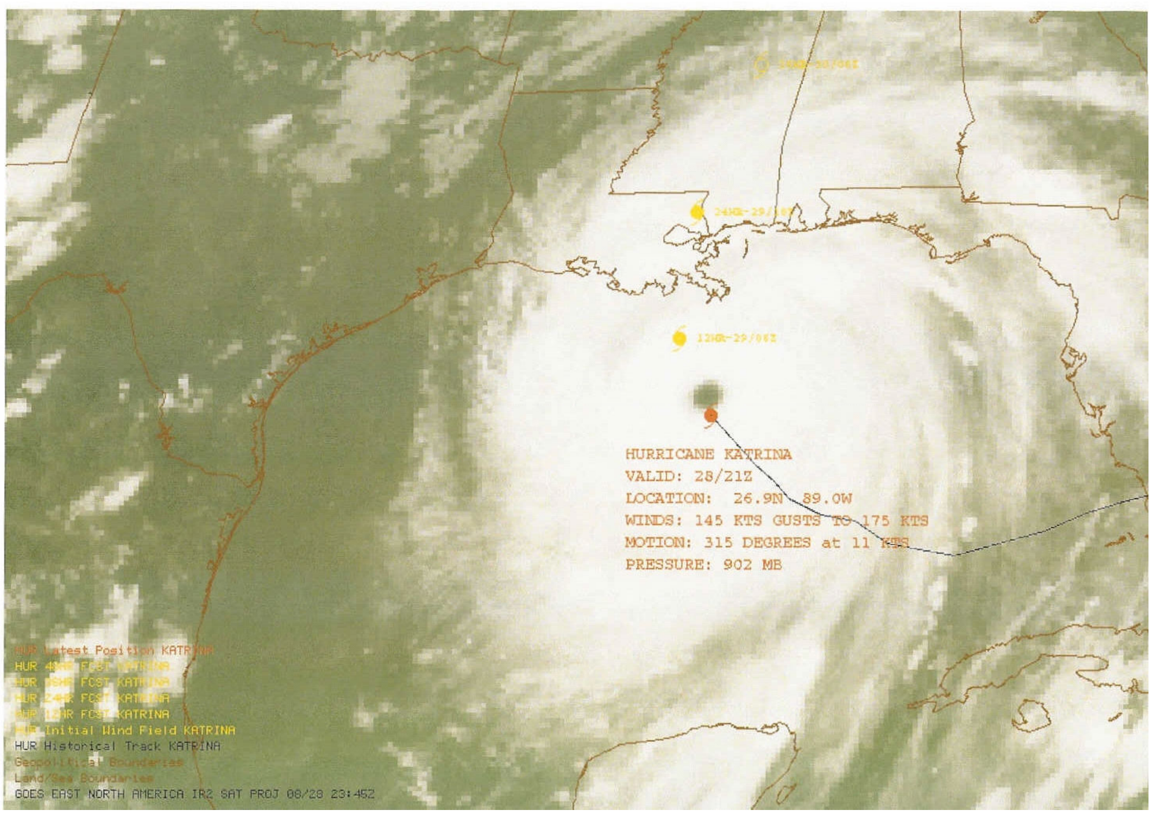
This image shows four major terminals in ZID representing the four corners of the facility.



This chart shows where conditions are below 5/5000 (5 miles visibility and 5000 foot ceilings). When conditions are less than either one of these, the controllers are required to solicit PIREPs.



This is a special slide created to show forecasted weather for the CVG TRACON.



This is an example of an image that the meteorologists create to keep controllers informed of significant events – some not necessarily related to the traffic flows in ZID

Appendix C

Survey Questions

Human Factors Team - Atlantic City

The Human Factors Team Atlantic City has a project to study the weather information requirements for en route controllers.

In the first part of this project, we need some operational feedback from the field about current weather information sources and operations under adverse weather conditions. Your feedback will help us focus on important en route weather issues. We will use this material to create the necessary background information for future work group discussions concerning en route weather displays.

We are asking for your feedback because of your subject matter expertise in en route operations using available weather information. Your participation is voluntary and your responses are confidential. We are not collecting any personal information on this feedback form, but we would appreciate if you could provide us with your Center's three-letter identifier (e.g., ZID). This information will allow us to make an estimate if weather information requirements differ for Centers across the continental US.

Below, we provide a set of statements and questions regarding weather information and the use of this information during operations. Your task is to rate each statement on the 10 point scale. Each item has an associated scale anchor [e.g., from "Never" (1) to "Always" (10)], but the specific anchors vary from item to item. However, the 10 point scale is the same for all statements and questions.

When you perform the ratings, we would like you to think of your answer in terms of "when I'm controlling traffic."

When you respond to this email, first click "Reply with History" – then fill in your rating numbers and text responses –and then click on "Send".

Thank you very much for your help.

- -

My Center is:

(1). To what degree do these weather phenomena affect en route controller operations and controller workload? Type in a number that best describes your answer after "My rating:"

(Not At All) 1-2-3-4-5-6-7-8-9-10 (A Great Deal).

a. In-flight icing 1 2 3 4 5 6 7 8 9 10, My rating:

b. Low visibility 1 2 3 4 5 6 7 8 9 10, My rating:

c. Mountain wave 1 2 3 4 5 6 7 8 9 10, My rating:

d. Non-convective turbulence 1 2 3 4 5 6 7 8 9 10, My rating:

e. Thunderstorms 1 2 3 4 5 6 7 8 9 10, My rating:

f. Adverse winds 1 2 3 4 5 6 7 8 9 10, My rating:

(2). How frequently do you use the weather information presented on the ESIS (e.g., chop forecast, thunderstorm forecast, WARP display) while controlling traffic during adverse weather conditions?

(Never) 1 2 3 4 5 6 7 8 9 10 (Very Frequently), My rating:

(3). How much of an operational benefit would it be for controllers to have weather information (e.g., storm and chop forecasts) displayed directly on the DSR instead of looking over at the ESIS system or Weather Display?

(None) 1 2 3 4 5 6 7 8 9 10 (A Great Deal), My rating:

(4). Receiving weather briefings from the Supervisor or CWSU is just as useful as having direct access to the same information on a display.

(Strongly Disagree) 1 2 3 4 5 6 7 8 9 10 (Strongly Agree), My rating:

(5). What is your perception of the display accuracy for the location of precipitation levels on the DSR (i.e., the displayed location of precipitation levels on the DSR correspond to the 'true' location of precipitation in the airspace)?

(Not Accurate) 1 2 3 4 5 6 7 8 9 10 (Very Accurate), My rating:

(6). When you give advisories to pilots about precipitation levels, how confident are you that the information is accurate?

(Not Confident) 1 2 3 4 5 6 7 8 9 10 (Very Confident), My rating:

(7). An enhancement to URET called the Problem Analysis, Resolution, and Ranking (PARR) will include support for a weather capability that probes for conflicts between aircraft and severe weather areas 20 minutes into the future. How useful do you think such a tool would be for controllers in today's en route operations?

(Not Useful) 1 2 3 4 5 6 7 8 9 10 (Very Useful), My rating:

(8). How useful is the upper-level wind information provided by URET?

(Not Useful) 1 2 3 4 5 6 7 8 9 10 (Very Useful), My rating:

(9). If the following weather information was available to controllers during operations, it would be very useful (please specify information type and why it would be useful):

(10). Is there anything else about en route weather displays that you think a working group should know when considering alternatives for the future?

Appendix D

Weather Information Feedback from FLMs

Weather Information Feedback from FLMs

If the following weather information was available to controllers during operations, it would be very useful (please specify information type and why it would be useful):

- It would be interesting to see what the users are disseminating to their aircraft versus what information/prognosis is being provided to the controllers. At times it seems that the airlines (scheduled carriers) have a forecast that is different than the reality of the weather situation - as such they file for/want to do things that do not make sense to the controller - this may result in an abnormal flow for the aircraft and or an abnormal operating parameter (speed/altitude) that requires adjustment.

- Forecasted movement for planning. Lightning as an option on the display for determining intensity of storms. Current and forecasted turbulence and icing conditions for planning.

- Lightning strikes - distinguishes precip from convective wx. Tops - helps determine if a pilot could climb above the weather.

- Tops, all a/c would not have to be vectored or rerouted. Confidence and/or training on how exact the wx is.

- More accurate data concerning location, movement, tops and intensity levels of convective activity. The use of the word 'extreme' to describe precipitation has had an adverse affect on en route operations due to the perception that pilots have of weather and/or precipitation so described.

● A true doppler would be useful.

● SIGMETS, CWA and NOTAMS displayed on a screen.

● I feel it would be more helpful if the colors displayed would be similar to those displayed on NWS radar or ESIS.

● It would be nice to play a loop of the WX movement. This would give us an idea of the movement of the weather.

● Ride reports in the climb or descent. Time of expected improvement in weather conditions for the airports under our control.

● Depictions on the DSR of Areas affected by SIGMET/AIRMET, CWA. Color coded and selectable (Toggle on/off) so that the information is available in a visible format on the DSR.

● Any oceanic phenomena that we cannot see and have no pireps for in the gulf (for [*center*]).

● The weather available in STARS is far superior to WARP. Reliable, accurate, fast updating weather would be nice.

Is there anything else about en route weather displays that you think a working group should know when considering alternatives for the future?

- Color works real well to display weather patterns and weather development!!!!

- Weather has three dimensions. People need to realize that what is happening at 10,000 feet is not the same thing that is happening at 38,000 feet. The WARP returns are for the entire thunderstorm. However, the aircraft at FL360 are only dealing with a slice of that storm, say, 34,000 thru 38,000 feet. Explaining all the weather is counter-productive. And unnecessary.

- Looping is also useful in seeing how the weather is building or dissipating such as can be found on weather.noaa.gov (http://radar.weather.gov/Conus/full_loop.php) on their composite radar imaging. It's another tool for planning.

- CWIS is the most valuable wx tool available.

- I like the concept of more weather information available on URET, as opposed to being displayed on DSR, which is cluttered enough as it is. If PARR could take into account movement, tops and intensity in developing recommended routings around convective areas in a graphics screen, it would be very beneficial. I don't know what you could do about chop from a graphics standpoint.

- CWSU is a valuable source of timely and convenient information. Here at (*center*) I have numerous discussions with the unit to help in my decision making regarding traffic flows, workload and staffing. I personally could not do with out them Face to Face and familiar with our operations.

- We need a system that controllers believe in. The confidence level in the present system is very low even though several advances have been made in recent years.

● It needs to accurately display where the Wx is, and give an accurate depiction of the tops. It would be nice to be able to pull up a forecast of where the weather will be in the next 30 minutes.

● We are experiencing many difficulties with the displayed weather in DSR. Many times we are displaying weather but the pilots are not observing it. If we issue the OBSERVED weather and it's not there we appear to be uninformed in the eye's of the pilots. If we don't issue the OBSERVED weather to the pilot, that we know is not there, and someone happens to be doing a remote monitoring we are then scrutinized for not issuing weather. We need to have an accurate display.

● I think adding displays as in 3 above would be clutter. (*Our remark: the respondent is referring to question 3 in the survey, Appendix C.*)

● If the capability for the center weather display to look more like NEXRAD then it should be changed. The color scheme used today is to confusing and does not stand out. The center weather display needs to be updated more often than it is to day so we can be sure we are giving pilots the most up to date information available.

● There seems to be a line of thought in the upper echelons of the Agency that believes the display accuracy for the location of precipitation levels on the DSR is extremely precise. Nothing could be further from the truth. In fact we assisted a lifeguard aircraft by describing an area that was void of any precipitation returns on the DSR and guided him into extreme precipitation which in my opinion placed the aircraft in danger. Too much clutter on the DSR creates a distraction and makes it difficult to separate aircraft from each other. In times of considerable weather and deviations, aircraft tend to congregate in small areas. These areas of concentrated traffic are where one can least afford to have weather information scrawled all over the DSR making managing and separating aircraft more difficult.

● We rely heavily on the wx displays in (*center*) because it is our only source for inform pilots prior to losing radio communication with them what to expect. Without PIREPS we are only guessing at what we see and the meteorologists and up to date displays are a must-have for us.