

# Investigating requirements for the design of a 3D weather visualization environment for air traffic controllers

Dang Nguyen Thong

*Institute of Movement Sciences, CNRS and University of Aix-Marseille II  
France*

## 1. Introduction

This chapter involves a long-term investigation into the applicability of three-dimensional (3D) interfaces for Air Traffic Control Officers (ATCOs). This investigation is part of collaboration between EUROCONTROL Experimental Centre (EEC) and the Norrköping Visualization and Interaction Studio (NVIS) of Linköping University in which a test-bed was developed in order to evaluate the different features of a 3D interface for ATCOs. This test-bed, known as the 3D-Air Traffic Control (3D-ATC) application, provides controllers with a detailed semi-immersive stereoscopic 3D representation of air traffic. Different aspects of the 3D-ATC application include 3D visualization and interactive resolution of potential conflict between flights (Lange et al., 2006), a voice command interface for visualizing air traffic (Lange et al., 2003), and interactive 3D weather images (Bourgois et al., 2005). Among these various features, the 3D weather visualization was chosen as a first case for carrying out a more accurate users' study.

Weather is considered as one of the major factors contributing to aviation accidents (Spirkovska and Lodha, 2002). As stated by Kauffmann and Pothanun (2000) "weather related accidents comprise 33% of commercial carrier accidents and 27% of General Aviation (GA) accidents". Moreover, adequate weather information (both for now-cast and forecast information) is often not available to pilots or controllers. The limitation in the way the weather information is represented in current weather displays has been also pointed out in several studies. Boyer and Wickens (1994) claimed that current presentation of weather information is *not easily understandable* and that it should be made more user-friendly. Lindholm (1999) argued that the *incomplete and imprecise weather* information currently displayed at the controllers' working position limits their job function. According to him, a better weather display could increase the controller weather situation awareness and possibly increase their strategic planning role. Boyer and Wickens (1994) reported the fact that the forecasts are generated from data that are collected only twice daily and that controllers require *weather forecasts that are updated on a more frequent basis*. Ahlstrom and Della Rocco (2003) claimed that pilots frequently chose enhanced real-time weather displays

for controllers when asked to rank different sources of important weather information. A similar opinion was collected from a study of Forman et al. (1999).

Providing suitable weather information could contribute in reducing the impact of adverse weather conditions both on delays and aviation accidents. However, weather-related research has mostly focused on the pilot side. Extensive research on controller weather information needs is largely lacking, although the importance of suitable weather information for controllers has increased considerably. In this respect, we can quote the Committee Chairman Albert J. Kaehn Jr., U.S. Air Force (NBAAD, 1995): "Although the primary role of air traffic controllers is to keep aircraft from colliding, accidents such as the 1994 crash of USAir Flight 1016 in Charlotte, North Carolina, demonstrate that air traffic controllers should exercise more caution about allowing aircraft to fly in or near hazardous weather". Hence, accurate and timely information about weather is essential for controllers, in order to support tactical and strategic planning for safe and judicious operations. However, what exactly do controllers need in order to rapidly gather the weather information necessary for carrying out their tasks?

To answer that question, we carried out a user study to understand controller weather information needs in order to define content requirements for weather support tools. In addition, we aimed to gather initial controller feedback on the applicability of 3D weather displays and on their potential benefits. This user study was carried out in two steps: a field observation of controllers' work at Stockholm Air Traffic Control Centre and an onsite survey with a demonstration of a prototype of 3D weather visualization in order to get controllers' feedback on weather information needs and 3D weather visualization.

This chapter presents the results of this user study and will be structured in 6 sections as follows. Section 2 summarizes related work concerning controller weather information needs, computer-human interface issues in the design of weather information display for controllers and 3D weather visualization for air traffic control. Section 3 presents the findings from the field observation on the daily work of controllers with weather information. Section 4 details the design of the onsite survey including both a demonstration of 3D weather presentation and the questionnaire. Section 5 presents the empirical results and main findings obtained from the survey, followed by the "Conclusions and Future Work" in Section 6.

## 2. Literature Review

The present study concerns both controllers' weather information needs and 3D weather information display. As a result, we will first examine previous studies addressing the controllers' weather information needs in this section. Then, we will outline results of research on 3D weather information display for controllers.

### 2.1 Related Work on Controllers' Weather Information Needs

Actually, little empirical research is available on controllers' weather information needs (Ahlstrom et al., 2001). In general, previous studies in literature agree not only on what weather data controllers need to gather, but also on how this data should be made available.

Regarding the nature of weather information controllers need to gather, the importance of having reliable weather information, especially concerning *adverse conditions*, is stressed in

literature. For instance, Lindholm (1999) reported that controllers' weather concerns include variations in wind speed and direction, clouds, visibility, turbulence, icing, and convective systems such as thunderstorms. The FAA Mission Need Statement (MNS) (FAA, 2002) suggested that phenomena that have impact on controller activities are adversities such as thunderstorms, in-flight icing, obstruction to visibility (i.e. low ceilings and poor visibility), wind shear, severe non-convective turbulence, snow storms and surface icing. The *dynamic aspect of weather information* is also of particular concern to controllers (Chornoboy et al., 1994) especially with respect to weather trends, direction of movements, and intensity within a control sector (Ahlstrom, 2001).

Regarding the quality of weather information, Lindholm (1999) suggested that both en-route and approach controllers need a precise weather information picture that *requires little or no interpretation*, because controllers are not meteorologists. Similarly, Chornoboy et al. (1994) claimed that controllers want to have unambiguous weather tools that can be used without interpretation and coordination. In addition, controllers might also need *interactive, real-time weather inputs* because weather phenomena and trends frequently change (Whatley, 1999).

In short, the most prominent weather information needs for controllers consist in gathering reliable, real-time and updated weather information especially with respect to hazards. This information should be accurate but also simple and easy to understand. Moreover, it should be detailed, at least concerning position, intensity and trends. More in-depth research, especially empirical research, is needed to refine different user weather needs and the associated impact on operational services.

## 2.2 Related Work on 3D Weather Information Display for Controllers

According to Boyer and Wickens (1994), it is difficult to display all of the necessary information concerning a weather situation through one-dimensional (1D) display or even in two-dimensional (2D) graphical display. Many have been thinking about using 3D weather display; for example, Cechile et al. (1989) suggested that *"since the main purpose of the displays should be to support the development and updating of the mental models, a 3D display would be the most appropriate"*. Because of the intuitive benefits of 3D in representing weather information, much research has explored the possible effects of representing weather information on 3D display. Such display formats could have good effects on weather situation awareness since a 3D weather presentation could show the spatial positions of the weather phenomena, which is difficult or even impossible to show in a 2D representation.

In literature, we can find a number of studies trying to assess and evaluate the utility and usability of 3D weather displays, like the work of Pruyn and Greenberg (1993) and Boyer and Wickens (1994) about weather displays for cockpits, the Aviation Weather Data Visualization Environment (AWE) which presents graphical displays of weather information to pilots (Spirkovska & Lodha, 2002), special displays designed for providing 3D support tools for meteorologists (Ziegeler et al., 2000). However, applications of 3D weather displays for air traffic controllers received less attention. One of the few academic works in the field was performed by Wickens et al. (1995). The study aimed to compare controller performances with a 3D perspective versus 2D plane view displays, for vectoring tasks in weather penetration scenarios. In brief, participants had to determine if the trajectory of an aircraft would intersect the graphically rendered hazardous weather system and, if so, issue headings so as to guide the aircraft in avoiding the weather structure; if not, they had to estimate the point of closest passage to the weather formation. The results did

not show any significant difference in terms of accuracy between the two displays types, although it was argued that some benefits could be implied in using a weather display that allows switching between 2D and 3D formats (Wickens et al., 1994). The 2D and 3D formats provide different weather information that is best suited for different controller tasks. St. John et al. (2001) found differences in display formats from their research on 2D and 3D displays for shape-understanding and relative-position tasks. 2D displays are superior for judging relative positions (e.g., positions between aircraft), whereas 3D displays are superior for shape understanding.

In summary, early efforts on using 3D graphics in weather displays have revealed both advantages and disadvantages of this kind of display. However, it is too early and there have not yet been enough empirical results to have a complete view on the potential of 3D in weather display in particular and in ATC in general. More empirical studies are required on this direction of research.

### **2.3 Approach**

As stated above, the main objectives of this study are to discover what type of weather information is mostly necessary for controllers and initially to gather feedback about the potential of 3D weather visualization in ATC. In order to do so, we performed a field observation followed by an on-site survey at a Swedish air traffic control centre combined with a presentation to controllers of a prototype of our 3D-ATC weather support tool.

## **3. The Field Observation**

### **3.1 Goal**

The goal of this field observation was to understand the way the controller works with weather information in particular. The field observation was carried out during 2 days at Arlanda ATCC (Air Traffic Control Centre), one of the two main air traffic control centres in Sweden. During this informal study, we observed the daily work of both en route and approach controllers. We also had the opportunity to ask controllers about different ATC issues in situ. These instant questions and answers on different ATC issues were helpful for us in understanding the critical parts of air traffic control work. More importantly, the findings from the field observation were used for designing the questionnaire used in the onsite survey.

### **3.2 Weather Information Display at Arlanda ATCC**

The Arlanda ATCC is divided into two parts. One part is called the ACC (Area Control Centre) and the second part is a TMC (Terminal Control Centre). En route controllers work in ACC and approach controllers work in TMC.

The controller sees briefing information from a special display to acquire an overview of weather information before a working session. This display shows the precipitation level of different zones in Sweden in general and more detailed precipitation information for the TMC sectors (cf. Figure 1). The weather information is updated every 5 minutes.



Fig. 1. Weather RADAR display

### 3.3 Findings

At the Swedish air traffic control centre we visited, both en route and approach controllers have two ways of obtaining weather information: the first one concerns routine or “general” weather information, and the second one concerns weather hazards.

- *Routine weather data* is reported to supervisors and air traffic managers by meteorologists. This information is usually provided both in graphical and textual forms. By graphical forms, we intend a dedicated display that shows the level of precipitations. Whereas each approach controller has his/her own separate “precipitation display”, en route controllers might have access to this information only via an explicit request to the supervisor. Textual weather data, called “briefing”, is directly sent to both en route and approach controllers can be displayed (on demand) on their RADAR displays. The briefing contains information on wind, clouds, RVR, visibility, air temperature and dew-point, pressure, weather trend, etc. Examples of briefings are the METAR (Meteorological Aerodrome Report; see Figure 2) and TAF (Terminal Aerodrome Forecast) standards for reporting weather forecast information.

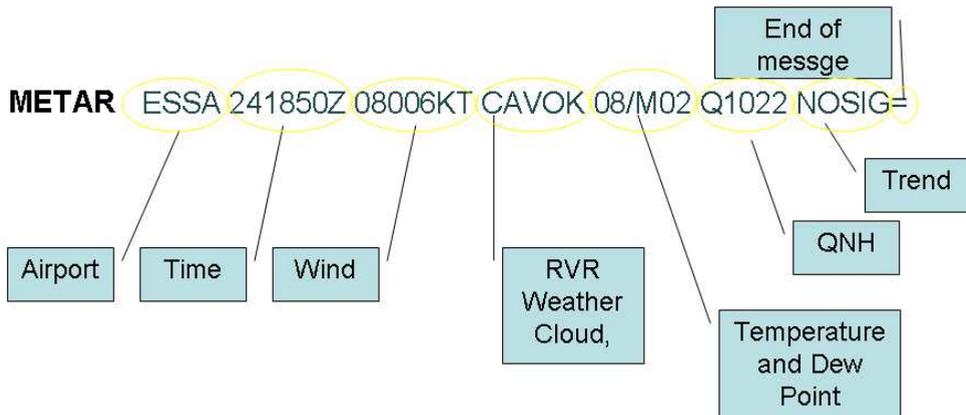


Fig. 2. A METAR Weather Briefing

- *Hazardous weather information* can be obtained both from pilots and from supervisors. Supervisors receive hazardous weather information from meteorologists: The supervisor, at her/his discretion, provides weather information to controllers. However, the most precious source of real-time hazardous weather data is the Pilot Report (PIREP), a report of conditions encountered by pilots during the flight. This information is usually relayed by radio to the nearest ground station. Weather PIREP may include information such as height of cloud layers, in-flight visibility, icing conditions or turbulence. Weather PIREPs have a double function: on the one hand, they simply confirm weather information that might already be available to controllers; on the other hand, they offer real-time and timely updated information about the development and progress of certain weather conditions. This makes the PIREP a unique and crucial source of information for a strategic weather factor in air traffic management: the presence of adversity and thunderstorms.

## 4. The Survey

The questionnaire we presented to controllers was composed of four main parts: *Controller demographics* (e.g. age, years of experience), *weather information needs*, *level of satisfaction* with available weather displays, and *potential use of 3D displays* for weather representation.

### 4.1 Questionnaire Design Details

In the weather information needs part, controllers were required to determine what weather information is needed for carrying out their activities by replying either YES or NO to each weather item provided in the questionnaire (i.e. a YES next to the item Wind, means that Wind information is needed for carrying out ATC tasks). The list of weather items was derived from the literature review and the field observation, and structured as follows:

- *Routine weather data*: Wind; Clouds; Visibility (the farthest distance at which an observer can distinguish objects, which is very important parameter in takeoff or

landing phases); Runway Visual Range (RVR) which means the visibility distance on the runway of an airport; Temperature (which is used for determining current meteorological conditions, calculating takeoff weight and providing information to passengers); Pressure (that is used to measure the altitude of a flight); Present Weather (including types and intensity of precipitation such as light rain or heavy snow, as well as the condition of the air environment such as foggy, hazy or blowing dust); Weather Trend informs about significant changes of reported weather conditions within short and long term; Weather Forecast.

- *Hazardous weather data*: Wind Shear (sudden change in wind direction or speed over a short distance); Turbulence; Thunderstorm; Low Ceiling and/or Low Visibility (which can severely reduce the capacity of an airport and lead to ground delays that result in diversions, cancellations and extra operational costs); CB (Cumulonimbus, that is the cloud forming in the final stage of a thunderstorm which is very dangerous and it usually avoided by flight); In-flight Icing (ice aircraft surfaces that increases the aircraft weight); Jet Stream (wind created at the border of two air masses with different temperature; and Mountain Waves (i.e. the rolling waves of wind caused by air blowing over mountains tops).

Controllers were also asked to rate the importance of each weather-related item (on a scale ranging from 1=very low importance, to 6=very high importance).

In the level of satisfaction part, controllers were demanded to express their level of satisfaction about hazardous weather data provided by current displays. The items presented in this part of the questionnaire were: Wind Shear, Turbulence, Thunderstorm, Low Ceiling, Low Visibility, CB, Icing, Jet Stream and Mountain Waves. Controllers were asked to rate the level of satisfaction of those weather items (on a scale ranging from 1=very poor to 6=very good).

The last part of the questionnaire concerned 3D weather visualization. Prior to filling the questionnaire, controllers were given a demonstration of our 3D-ATC prototype. Then they were asked to envision if 3D could more suitably provide weather information for supporting ATC tasks and to reply with a YES or NO answer to the questionnaire weather items (e.g. a YES next to the item Wind Shear, denote that 3D would be a useful option for displaying Wind Shear information). The choice was constrained, in that controllers had to indicate preferences considering the list of routine and hazardous weather items (presented in the previous section and consistently used throughout the questionnaire). In addition, ATCOs were asked to rate their level of interest in having a 3D representation with respect to any weather item of the questionnaire (a scale ranging from 1=very low interest, to 6=very high interest).

#### **4.2 Demonstration of the 3D-ATC Prototype**

The goal of the demonstration was to give controllers a basic understanding of the 3D representation of air space, air traffic (flight trajectory, waypoint and flight information (cf. Figure 3(a)) and in particular of weather visualization (wind and pressure, see Figure 3(b)) allowing them to envision potential applications of 3D displays for weather information.

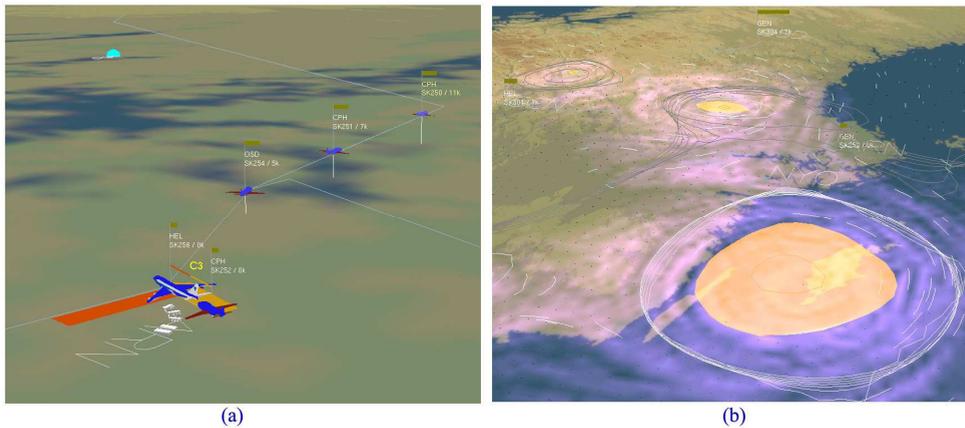


Fig. 3. (a) 3D presentation of flight, flight trajectory and flight information, (b) 3D Visualization of Wind and Pressure

The demonstration was run on a Linux based laptop (Dell Inspiron 9300 Pentium M 2GHz with a NVIDIA GeForce 6800 graphic card) and was shown to the controllers on a wall screen by using a projector. The 3D-ATC prototype was implemented using OpenGL.

#### 4.3 Procedure

The survey was performed on-site. The questionnaires were given and the 3D Demo presented during controllers' rest time. In total we had four sessions spreading over one day. The total number of controllers involved in the study was 26 (ranging from 2 to 15 per session). An introduction script was written in advance and read at the beginning of each session. Then, the 3D demonstration had been shown for approximately 15 minutes, and it was kept running freely during the questionnaire filling phase.

Every controller filled in her/his own questionnaire independently and no verbal exchanges among controllers were allowed during this task. Controllers were allowed to ask questions and request explanations about the questionnaire from researcher. However, none did.

#### 4.4 Participants

As stated above, 26 controllers participated in the survey. Among this sample, 10 were approach controllers and 16 en route controllers.

The age of the en route controllers ranged from 29 to 57 years (average 39.47 years) and their operational experience ranged from 4.33 to 23 years (average 11.83 years). Even though one in three had past experience in approach control, all the controllers assigned to the category of "en route" worked currently on en route positions, and has been since at least 4.33 years.

The age of the approach controllers ranged from 26 to 38 (average 33.10 years) and their operational experience ranged from 1.17 to 14 years (average 8.57 years).

## 5. Results

### 5.1 Routine Weather Information Needs

The results concerning routine weather information needs are summarized in Figure 4. Figure 4(a) shows the percentage of controllers who gave a “YES answer” for expressing their need to receive information about each given weather item. Figure 4(b) shows the median values of the importance ratings assigned by controllers to each weather item.

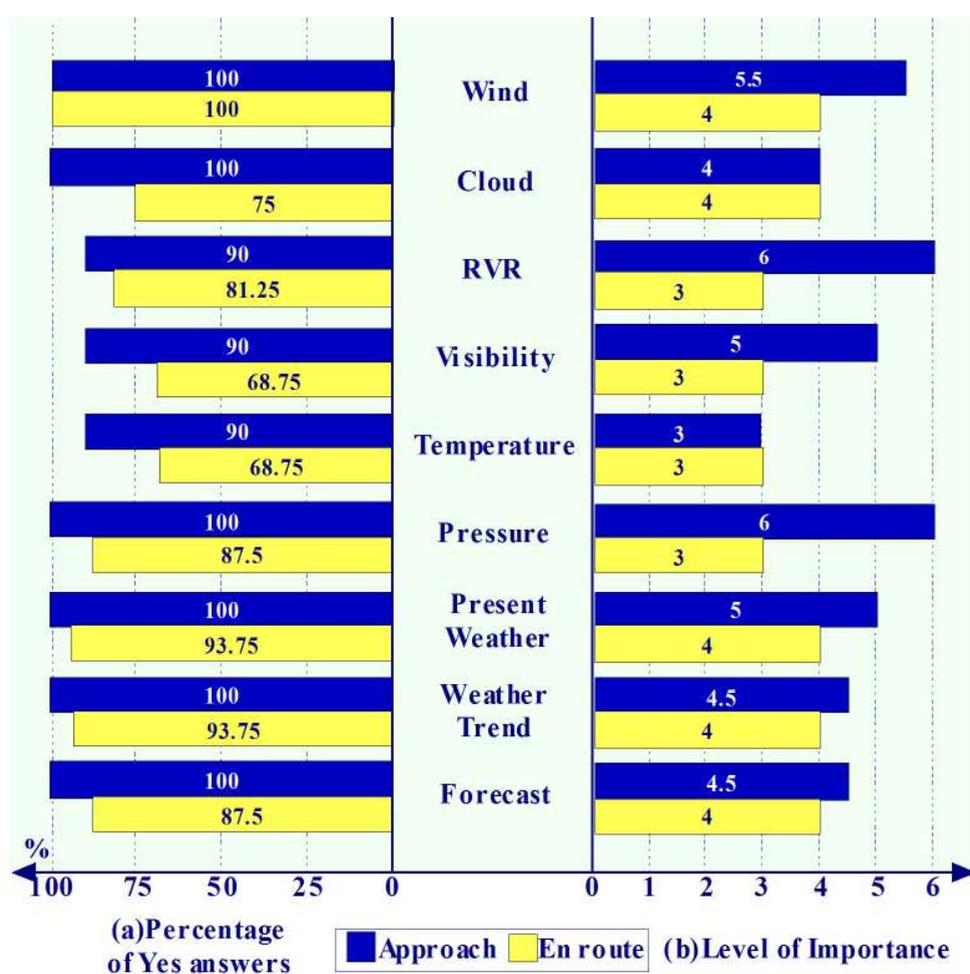


Fig. 4. Summary of Results for Routine Weather Information

As for the percentage values of “YES answers” - for each weather item - we can observe a somewhat different pattern of responses between approach and en route controllers. The percentage of “YES” given by approach controllers ranges from 90% to 100%; whereas those given by en route controllers range from 68.75% to 100%. The same pattern can be also

observed for the median values (see Figure 4(b)). Hence, we decided to find out whether any significant differences between the response patterns exist.

Because of the ordinal scales used in the questionnaire, the non-parametric test Mann-Whitney U test was used to compare the importance ratings given by en route and approach controllers for each weather item separately. As we did not have any specific hypothesis, we performed a two-tailed test. A  $\alpha$ -level of .05 was chosen as decision criterion.

We found a significant difference between the importance ratings of Wind (Mann Whitney  $U=42.5$ ,  $p=0.042$ , two-tailed test), RVR ( $U=9.0$ ,  $p=0.000$ , two-tailed test), Visibility ( $U=15.0$ ,  $p=0.007$ , two-tailed test), Pressure ( $U=21.0$ ,  $p=0.003$ , two-tailed test), Present Weather ( $U=35.0$ ,  $p=0.019$ , two-tailed test). A brief summary of these results is given in Table 1. No significant differences were found between the ratings given by approach and en route controllers for the items Cloud, Weather Trend, Forecast and Temperature.

	Median (Approach controller)	Median (En route controller)	P-value
Wind	5.5	4	0.042
RVR	6	3	0.000
Visibility	5	3	0.007
Pressure	6	3	0.003
Present Weather	5	4	0.019
Cloud	4	4	Non-significant
Weather Trend	4.5	4	Non-significant
Forecast	4.5	4	Non-significant
Temperature	3	3	Non-significant

Table 1. Routine Weather Importance Ratings Medians for Approach and En Route

These results are not surprising; it is quite evident that approach and en route controllers have different routine weather information needs that correspond to different operational requirements. And these differences were well captured by the questionnaire and revealed by the analysis. For instance, approach controllers assigned to the items RVR, Pressure, Wind, Visibility, and Present Weather ratings, ranging from 5 to 6 (i.e. high and very high importance). It is rather obvious that this type of weather data is not only useful, but also necessary for the management of inbound and outbound air traffic. Thus, for example, if weather and visibility conditions of the final aerodrome destination are extremely adverse, approach controllers might decide to divert aircraft to nearby airports.

By way of contrast, overall en route controllers assigned lower importance ratings, ranging from 3 to 4 (i.e. from rather low to rather high). This is a clear indication that approach and aerodrome-related weather information (e.g. RVR, Visibility, etc.) is not a major concern for control in upper airspace. However, Weather Forecast and Trends seem to be important also to en route controllers, at least to the extent to which projections on hazards are enabled. Indeed this idea seems quite realistic, if we have a look at the data reported in the next section.

### 5.2 Hazardous Weather Information

Figure 5(a) shows the percentage of controllers who gave a “YES answer” on their need to receive information about each of the different hazardous weather item, whereas Figure 5(b) shows the medians of importance ratings assigned by controllers to each item.

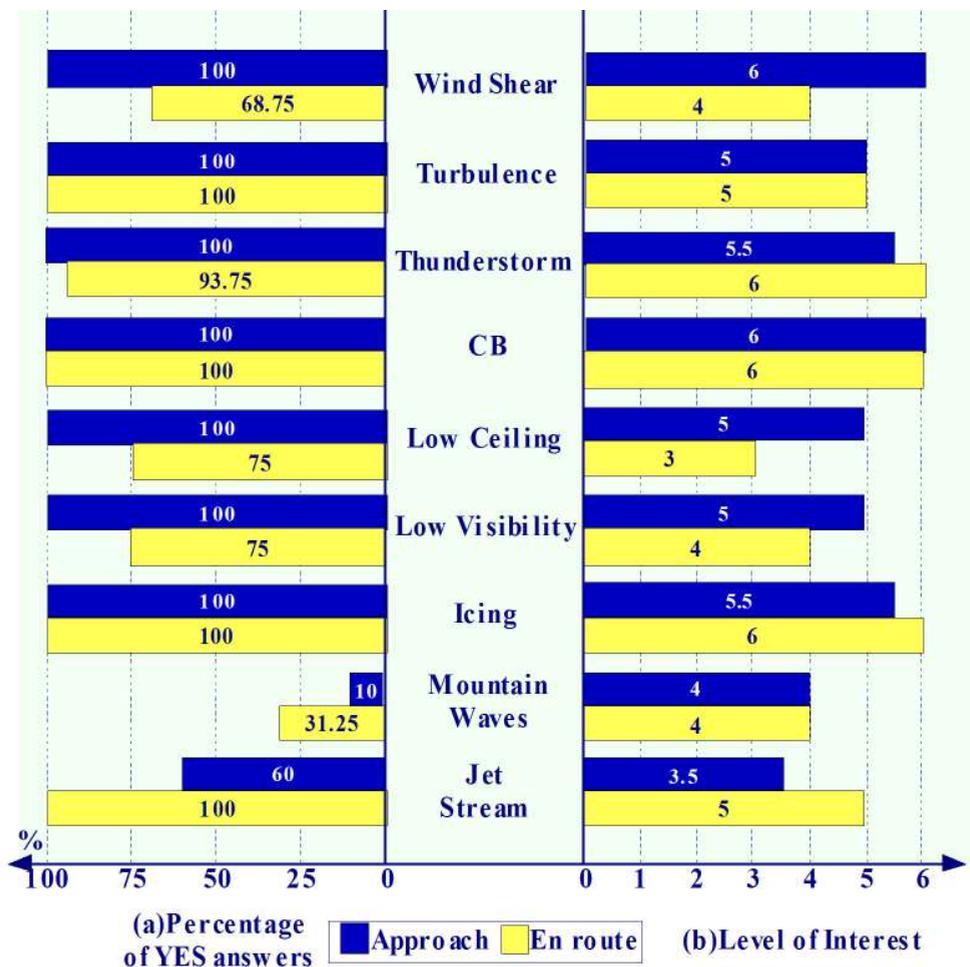


Fig. 5. Summary of Results for Hazardous Weather Information

Note that the item Mountain Waves was rated by a small percentage of controllers (10% approach and 31.25% en route). This weather occurrence is a phenomenon typical of mountain regions, which does not involve the airspace of Swedish centre that we visited. Also note that there is a clear disparity between the percentages of “YES answers” given by approach and en route with respect to the item “Jet stream”. This is easily justified by the fact that the Jet stream is characteristic to high altitudes, and thus only relevant in en route.

Besides those two items, the remainder of responses shows a homogeneous pattern between the two groups. Nevertheless, we performed a comparison between the importance ratings assigned by approach and en route controllers.

We found a significant difference between the importance ratings of Wind Shear (Mann Whitney  $U=13.0$ ,  $p=0.002$ , two-tailed test), Low Ceiling ( $U=28.5$ ,  $p=0.032$ , two-tailed test), and Low Visibility ( $U=24.5$ ,  $p=0.016$ , two-tailed test). This is summarized in Table 2. No significant differences were found between the ratings given by approach and en route controllers for the items Turbulence, Thunderstorm, CB, Icing, Mountain Waves and Jet Stream.

	Median (Approach controller)	Median (En route controller)	P-value
Wind Shear	6	4	0.002
Low Ceiling	5	3	0.032
Low Visibility	5	4	0.016

Table 2. Hazardous Weather Importance Ratings Medians for Approach and En Route

Coherently with the results discussed in the previous section, specific information related to weather hazards entailing the approach (i.e. Low Visibility, Low Ceiling and Wind Shear) was rated significantly higher by approach controllers. However, when we consider hazards like Turbulence, Thunderstorm, Icing and CB we notice two things. First, both en route and approach controllers gave fairly high ratings to these items. Second, for these items no differences exist between the ratings given by the two groups of controllers. Hence, these weather phenomena have a relevant impact on control activities independently from the specific working context, and may represent a factor contributing to the complexity of ATC tasks (Pawlak et al., 1996). We therefore hypothesize that complexity could be reduced by an adequate representation of those hazardous weather phenomena, as well as a suitable projection of the forth-coming hazards. In order to gain insights on this issue, the questionnaire requested controllers to express their level of satisfaction concerning the way weather hazards are currently displayed and represented.

### 5.3 Satisfaction with Available Displays

Figure 6 shows the medians of satisfaction ratings assigned by controllers to the display of each hazardous weather item.

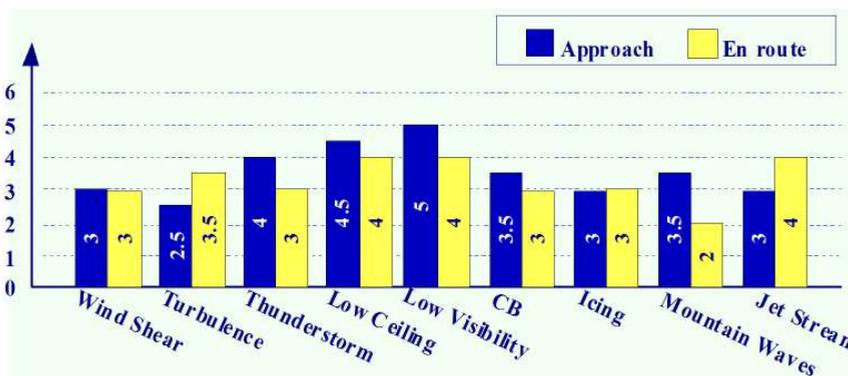


Fig. 6. Summary of Results for Satisfaction Ratings about Current Displays for Hazardous Weather Information

The way Low Ceiling and Low Visibility information is currently represented in the displays available at the Swedish control centre, was judged as being quite adequate and show median ratings of 4.5 and 5 respectively. Jet Stream, at least with respect to en route controllers, has a median satisfaction rating of 4 and the median for Thunderstorm (for approach controllers) is 4.

	Approach controller		En route controller	
	Need	Satisfaction	Need	Satisfaction
<b>CB</b>	6	3.5	6	3
<b>Thunderstorm</b>	5.5	4	6	3
<b>Turbulence</b>	5	2.5	5	3.5
<b>Icing</b>	5.5	3	6	3
<b>Wind Shear</b>	6	3	4	3
<b>Jet Stream</b>	3.5	3	5	4

Table 3. Comparable Results between Need and Satisfaction on Different Hazardous Weather Information

The interesting result here is that critical weather items that are both highly and equally important for approach and en route controllers (i.e. Wind Shear, Turbulence, CB, and Icing), are not suitably represented in current displays and median satisfaction ratings for these items range from 2.5 to 3.5. Such poor ratings were given by both controllers groups, and no statistically significant differences were found between the ratings given to those items.

Table 3 shows clearly the contrast between the weather information needs and the level of satisfaction of current displays on CB, Thunderstorm, Turbulence, Icing, Wind Shear and Jet Stream.

Informal discussions with controllers, especially during the 3D demonstrations, and comments written by controllers, helped us to gain some insights on how to improve the visualization of critical weather information.

5.4 3D for Hazardous Weather: A Suitable Option?

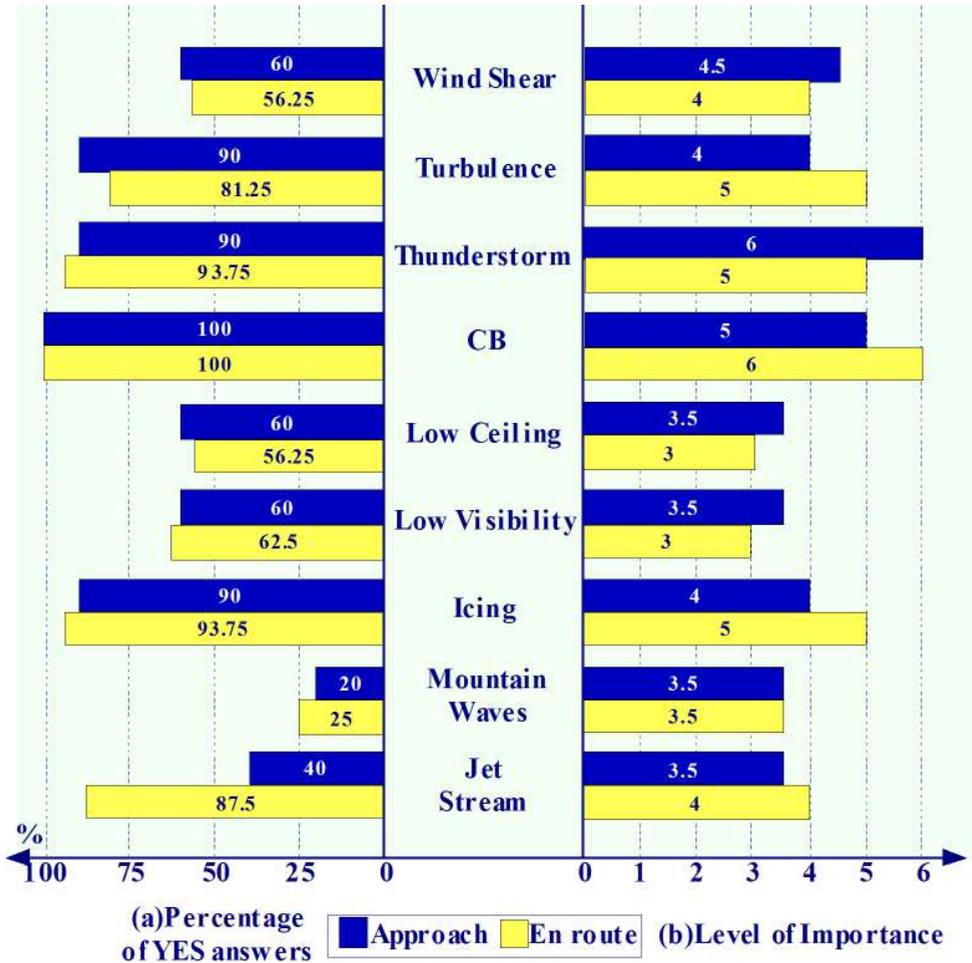


Fig. 7. Summary of Results for 3D Visualization of Hazardous Weather Information

As stated above, a part of the questionnaire was dedicated to collecting controllers’ opinions about their interest in having weather information displayed in 3D. Overall, controllers (both en route and approach) expressed high interest in 3D representations of weather phenomena, especially with respect to the critical weather items that are not adequately supported by current displays.

Figure 7(a) shows the percentage of controllers who provided a “YES answer” for having 3D visualizations for any of the hazardous weather items. Whereas Figure 7(b) shows the medians of importance ratings assigned by controllers to each hazardous weather item that should be displayed in 3D.

CB formation, Thunderstorm, Turbulence, Icing, Wind Shear and Jet Stream show median ratings ranging from 4 to 6 and the data reported in Table 4 gives useful insights for focusing the research on 3D weather visualization for ATC, both for en route and for approach.

	Approach controller			En route controller		
	Need	Satisfaction	3D	Need	Satisfaction	3D
<b>CB</b>	6	3.5	5	6	3	6
<b>Thunderstorm</b>	5.5	4	6	6	3	5
<b>Turbulence</b>	5	2.5	4	5	3.5	5
<b>Icing</b>	5.5	3	4	6	3	5
<b>Wind Shear</b>	6	3	4.5	4	3	4
<b>Jet Stream</b>	3.5	3	3.5	5	4	4

Table 4. Comparable Results among Need, Satisfaction and 3D Option for Different Hazardous Weather Information

Controllers were quite curious about the possibility of visualizing 3D weather information, and provided numerous comments and suggestions, both written (in the questionnaire) and verbal, during the 3D demonstration. This additional information can be summarized as follow.

Controllers clearly stated that, not only cumulonimbus but also towering cumulus (TCU) has a three-dimensional nature. Directing aircraft so as to avoid these weather formations could be enhanced by providing a representation that highlights certain 3D features such as volume extension, location with a spatially coherent configuration. In addition, both approach and en route controllers stated that these weather phenomena are early stages of thunderstorms. According to controllers, dynamic and anticipated projections of such 3D weather images would be quite beneficial for promptly defining re-routing strategies for directing flights out of thunderstorm zones.

Another interesting result is that controllers stated that having a 3D representation of the out-of-cockpit view, at any given moment, would be quite useful. According to ATCOs, if pilots and controllers could have a common and shared understanding of the same information, then elaborating effective plans and providing appropriate instructions would be enhanced.

In general, controllers do not seem satisfied with interfaces that show too many widgets, windows, and features, but a problem with 3D displays is visual information clutter. Some controllers declared that having a detailed 3D view of air traffic (as the one shown during the demonstration, with visible trajectories, waypoints, and other flight information) would look “too crowded”. And yet, controllers suggested that 3D weather visualization could support weather-related tasks, if the possibility of displaying 3D images is provided upon demand. This would allow having a more detailed depiction of 3D weather data only under the conditions specified by the end-users themselves.

## 6. Conclusions and Future Work

The present work aimed to discover controllers weather information needs and assess if 3D weather visualization could provide added benefits to controllers. The results of the survey can be summarized as follows.

There are several differences in the weather information needs between en route and approach controllers, which logically reflect the different focus of activities carried out by each group of controllers. For example, approach controllers need very specific knowledge such as Wind, RVR, Visibility, etc. that is not normally required to en route controllers (at least, in the light of the results that we obtained). This fact has to be considered for the design of ATC weather interfaces, for example, by conceiving dedicated and customized weather representations that are suitable for the tasks that controllers actually perform. By this, we do not mean that information should be hidden from controllers; more simply, we claim that interfaces should avoid displaying unnecessary data and, eventually, providing extra information only upon request.

Moreover, according to the results of this study, both en route and approach controllers seem to value and use critical weather information such as CB, Thunderstorm, Turbulence and Icing. As we stated in the previous sections, hazardous weather information has direct impact on the safety and efficiency of air traffic. Devising visual techniques for allowing controllers to perform "ahead assessments" about weather hazards, could support controllers in identifying in advance strategic solutions for responding to the restrictions imposed by weather on upper space sectors, terminal areas and aerodromes.

Controllers declared having a quite low degree of satisfaction about the displays currently used for hazardous weather information. In particular, both en route and approach controllers gave low scores to very critical weather data such as Wind Shear, Turbulence, CB and Icing. Suitable representations as well as projections of adverse weather events seem missing. We suppose that the solely textual representation largely contributes to this result and, perhaps, graphical information could better suit controllers' needs, independently from the interface style (either 2D or 3D). But, controllers' comments gave promising insights on the use of 3D as a more intuitive representation of hazardous weather.

However, at this stage of the study, we can only accept controllers' comments as they are, hence, these ideas remain hypotheses that need further investigation.

Short-term plans for continuing this research entail the implementation of a small mock-up of CB formation embedded into a sector with a realistic traffic flow. The choice of CB is justified by the fact that controllers expressed a high interest for having 3D representations of cumulonimbus and further stressed this interest in an explicit manner, adding comments in the questionnaire and during informal talks.

We intend to perform additional demonstration sessions showing this new implementation and carrying out in-depth interviews with controllers, in order to understand what the supposed benefits of 3D weather images would be. Perhaps there are some specific visual properties of 3D weather representations that could indeed enhance controllers' tasks. Understanding what these visual properties are, would give us sufficient information for defining the functional requirements of a more refined 3D prototype.

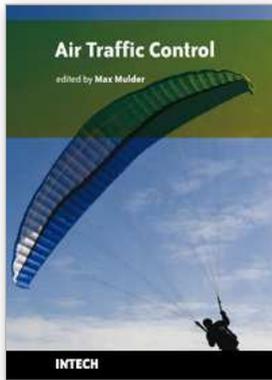
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