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New Jersey 08405

An Assessment of Time-Based Active Reminders on Weather Related Behavior and Decision Making of General Aviation Pilots

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16. Abstract

Objective: We investigated pilot weather assessments and pilot ability to assess the out-the-window visibility. Specifically, we assessed the impact of a time-based active reminder on pilot decision-making. The active reminder indicated the amount of time in which a pilot might encroach within 20 miles of severe weather along their route. **Background**: In a previous study, the WTIC group evaluated a distance-based active reminder to indicate pilot proximity to severe weather. **Method**: Fifty private pilots participated in the study. The pilots were randomly allocated to either the 10 nm or 20 nm active reminder condition to fly in a scenario with degrading visibility conditions. **Results**: We found no important differences between the AR10 and AR20 groups with regards to aircraft altitude, AWOS usage, distance-to-weather, flight decision-making, and the ability of pilots to provide forward visibility estimates. This result implies that the difference in lead-time (i.e., 10 versus 20 miles) did not affect the flying behavior of pilots. Both pilot groups flew equally close to hazardous weather cells (i.e., ≥ 30 dBZ precipitation cells) with a mean distance-to-weather of 9.93 to 17.2 miles (95% HDIs). Even more striking, comparing the present distance-to-weather results with the distance-to-weather data from the Ahlstrom et al. (2019a) study showed that a time-based AR yield a much larger intra-group dispersion (e.g., SD) of the distance-to-weather data, expressed as a greater variability among pilots with regards to how closely they flew to hazardous weather cells.

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Research Team

Name	Role	Responsibility
Ahlstrom, Ulf	Data Analysis	Test plan developer. Analyze data and co-writer of the Quick Look and Final Report.
Cecan, Cynthia	Software Engineer	Implements simulator system, routes, weather conditions, and supports cockpit data recordings.
Cheng, Andrew	Primary Investigator	Oversees simulation activities.
Cramer, Scott	Technical Support	Implements system support.
Doucett, Scott	Cockpit Simulator Laboratory Manager	Identify and provide resources for study development and data collection.
Granich, Thomas	Computer Scientist	Implements the technology programmed on the weather presentation within the simulators and ATC stations.
Johnson, Ian	WTIC Human Factors Lead	Coordinate on test plan and test effort, technical review of test products and deliverables.
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Mandal, Jishnu	Aerospace Engineer	Simulator operator during simulation runs; provides simulator technical support.
Pokodner, Gary	WTIC Program Manager	Track project, conduct interim reviews, final acceptance of Deliverables.
Racine, Nicole	Human Factors Specialist	Simulation support, data analysis, co-writer of the Quick Look and Final Report.
Vary, Kimberly	Software Engineer	Implements simulator system, routes, weather conditions, and supports cockpit data recordings.
Wetherington, Andrew	Physical Scientist	Designs and constructs simulator hardware.

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Acronyms

Acronym	Definition
AR	Active Reminder
ATC	Air Traffic Control
ASOS	Automated Surface Observing System
AWOS	Automated Weather Observing System
FAA	Federal Aviation Administration
GA	General Aviation
HDI	High Density Interval
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
MDPQ	Mobile Device Proficiency Questionnaire
NEXRAD	Next Generation Weather Radar
NCAR	National Center Atmospheric Research
NVN	NEXRAD Valid Now
PII	Personally Identifiable Information
VFR	Visual Flight Rules
WSA	Weather Situational Awareness
WTIC	Weather Technology in the Cockpit

Executive summary

The purpose of the present study was to investigate the impact of a time-based weather presentation AR on pilot weather-related behavior and decision-making. For many phases of flight, GA pilots tend to think, calculate, estimate, and make decisions using time-based information more than distance-based information. Unlike the distance-based AR in the Ahlstrom et al. study (2019a), the time-based AR showed a timer that informed pilots of the time-to-contact with storm cells. Furthermore, unlike the distance-based AR, the time-based AR used a lead-time before the display of the AR timer. In a first condition, we presented pilots with a 10-mile lead-time (AR10 group) before reaching the FAA minimum recommended safe distance of 20 miles from a thunderstorm (i.e., 30 miles from the edge of the storm cell). In a second condition, we presented pilots with a time-based AR 20 miles (AR20 group) before reaching the FAA minimum recommended safe distance of 20 miles from a thunderstorm (i.e. 40 miles from the edge of the storm cell).

We found no important differences between the AR10 and AR20 groups with regards to aircraft altitude, Automated Weather Observing System (AWOS) usage, distance-to-weather, flight decision-making, and the ability of pilots to provide forward visibility estimates. This result implies that the difference in lead-time (i.e., 10 versus 20 miles) did not affect the flying behavior of pilots. Both pilot groups flew equally close to hazardous weather cells (i.e., ≥ 30 dBZ precipitation cells) with a mean distance-to-weather of 9.93 to 17.2 miles (95% High Density Intervals [HDIs]). Even more striking, comparing the present distance-to-weather results with the distance-to-weather data from the Ahlstrom et al. (2019a) study showed that a time-based AR yields a much larger intra-group dispersion (e.g., SD) of the distance-to-weather data, expressed as a greater variability among pilots with regards to how closely they flew to hazardous weather cells.

1 Introduction

The purpose of the present study was to investigate the impact of a time-based weather presentation Active Reminder (AR) on weather-related behavior and decision making of General Aviation (GA) pilots. In this study, we specifically examine GA pilot Weather Situational Awareness (WSA) of convective weather and Instrument Meteorological Conditions (IMC), as well as GA pilot decision-making when encountering these types of weather events.

1.1 Background

According to guidance provided by the Federal Aviation Administration (FAA) on thunderstorm avoidance, GA pilots should maintain a distance of at least 20 miles from any thunderstorm identified as severe or giving an intense radar echo, especially under the anvil of a large cumulonimbus cloud (FAA Advisory Circular AC 00-24C: Thunderstorms, 2013). The FAA's Aeronautical Information Manual (2017) includes the same 20-mile recommendation. Similarly, in the Pilot's Handbook of Aeronautical Knowledge (FAA, 2008), the FAA recommends that pilots circumvent severe thunderstorms by at least 20 miles since hail can fall miles outside of clouds.

Despite this recommendation, studies have shown that pilots tend to fly within the 20-mile range of severe weather. Beringer and Ball (2004) investigated the use of Next Generation Weather Radar (NEXRAD) displays and found that some pilots attempted to navigate between precipitation cells. Furthermore, 53% of the study pilots failed to keep safe distances to hazardous precipitation cells. Burgess and Thomas (2004) reported a similar result in a study on the effect of improved cockpit weather displays on GA pilot decision-making and weather avoidance. The results showed no meaningful difference in distance-to-weather between a control group without a weather display and two groups using either a NEXRAD product or a National Convective Weather Forecast product. All three groups failed to keep safe distances to hazardous storm cells. Wu, Gooding, Shelley, Duong, and Johnson (2012) reported the same failure to keep safe distances to storms in a study of pilot decision-making during convective weather.

The results of a simulator study aimed at exploring the effects of different cockpit Meteorological (MET) presentations on GA pilot behavior (Ahlstrom & Dworsky, 2012) showed GA pilots' tendency to fly within 20 miles of hazardous storm cells. Three GA pilot groups used a unique weather presentation with different types of weather symbologies. In all three groups, GA pilots navigated an average of 16.1 miles away from convective storm cells. The GA pilots were either not aware of the FAA 20-mile recommendation, were making poor weather-related decisions or were not able to estimate their distance to the hazardous weather.

Ahlstrom et al., (2015) conducted an assessment of portable weather presentations for GA pilots with similar findings. Two groups of GA pilots flew a simulated convective weather scenario with one group in the presence of a weather presentation (experimental) and the other group in the absence of a weather presentation (control). Although the experimental group maintained a slightly greater distance from hazardous precipitation than the control group, both groups flew less than the FAA recommended distance from convective weather.

Ahlstrom, Racine, Caddigan, Schulz & Hallman, (2019) continued to investigate weather presentation methods using an AR (a line that appears from the aircraft icon 20 miles from the weather) to alert pilots to convective storm cells and IMC. The study compared pilot decision making between groups with and without the AR. The results of this study indicated that GA pilot WSA was credibly higher in the experimental group with the AR weather presentation than the control group with no weather presentation. Specifically, GA pilots in the experimental group had credibly less entries into 1 statute mile visibility zones (n=8) compared to the control group (n=15) indicating better weather-related decision-making. Additionally, the experimental group expressed a clearer understanding of the closest point of approach to hazardous storm cells.

The post-scenario questionnaire revealed that GA pilots intended to stay 20 miles away from hazardous storms and agreed with the FAA's 20-mile recommendation. However, the average closest point of approach to hazardous weather cells was less than 20 miles, with 5.29 nmi for the control group and 4.89 nmi for the experimental group. This finding suggests that GA pilot failure to adhere to the FAA's recommendation is not due to poor decision-making, but rather the inability to accurately estimate their distance to hazardous weather. This is supported by GA pilots' responses when asked if they flew closer than 20 miles during the simulation, only between 33% (Control) and 63% (Experimental) of GA pilots provided a correct answer. It is possible that the inability of GA pilots to accurately estimate distance could have a significant impact on their understanding of the amount of time required to take corrective action when encountering hazardous weather. Although GA pilots flew within the FAA 20-mile threshold, they were clearly aware of the hazardous weather as indicated by the distance-based AR.

As a result of this finding, we (Weather Technology In the Cockpit program researchers) proposed that a time-based AR, rather than a distance-based AR, could potentially reduce the time for decision-making and, in turn, could prevent GA pilots from flying within the 20-mile threshold. A time-based AR would provide GA pilots with the calculated time remaining to make a safe decision, and could create a sense of urgency for pilots to take action before reaching an unsafe distance to hazardous weather. Furthermore, GA pilots tend to think, calculate, estimate and make decisions using time-based information more than distance-based information while in-flight. For instance, GA pilots keep track of temporal information such as their expected further clearance time and the delta in approach time as well as calculate their estimated time in route and fuel capacity time. These lines of reasoning warranted the development of a time-based AR concept that will serve as the primary focus of evaluation in the present study.

In this study, we also proposed providing the AR notification either 10 or 20 miles from the 20-mile area from the storm cell to give pilots additional time to take corrective action. We planned to compare data collected in the present time-based AR study with data previously collected in a prior distance-based AR study (Ahlstrom et al. 2019), using the Bayesian analysis framework. To enable comparison between this study and the distance-based AR, we used the same simulators, weather scenario, weather display, flight path, and metrics.

1.2 NEXRAD Valid Now background

As part of a continuing relationship between the FAA WTIC program and the Aviation Applications program at the National Center Atmospheric Research (NCAR), participants of this study also took part in a separate preliminary evaluation of the NEXRAD Valid Now (NVN) concept. NCAR's concept proposes to address pilots' potential for misinterpreting NEXRAD information by developing NVN, which processes observed radar information to depict a current weather picture that nullifies NEXRAD delay. Pilots viewed a presentation on the concept and provided their feedback on their understanding and opinions of the concept. An expanded explanation of the NVN part task and the findings are presented in Appendix A.

2 Purpose

The purpose of the simulation was to evaluate the effect of a time-based AR on Visual Flight Rules (VFR) GA pilot behavior and decision-making toward deteriorating weather. Using an Alaska scenario, we assessed GA pilot behavior and decision-making when approaching a thunderstorm under legal visibility and when encountering IMC. We equipped the participants with a weather application that displays forecasted visibility and information on precipitation areas.

3 General methods

3.1 Participants

Fifty GA pilots participated in the study. One pilot's data was excluded due to technical issues with the simulation, leaving 49 pilots for the data pool. To obtain a sample of pilots that closely represents the age distribution of the GA pilot population, as was conducted in Ahlstrom et al. (2019), we used stratified random sampling (Barnabas & Sunday, 2014) to determine the number of GA pilots to randomly sample from four age strata (or age groups). Figure 1 depicts the age population of GA pilots during the year 2015 as published by the FAA (2016).

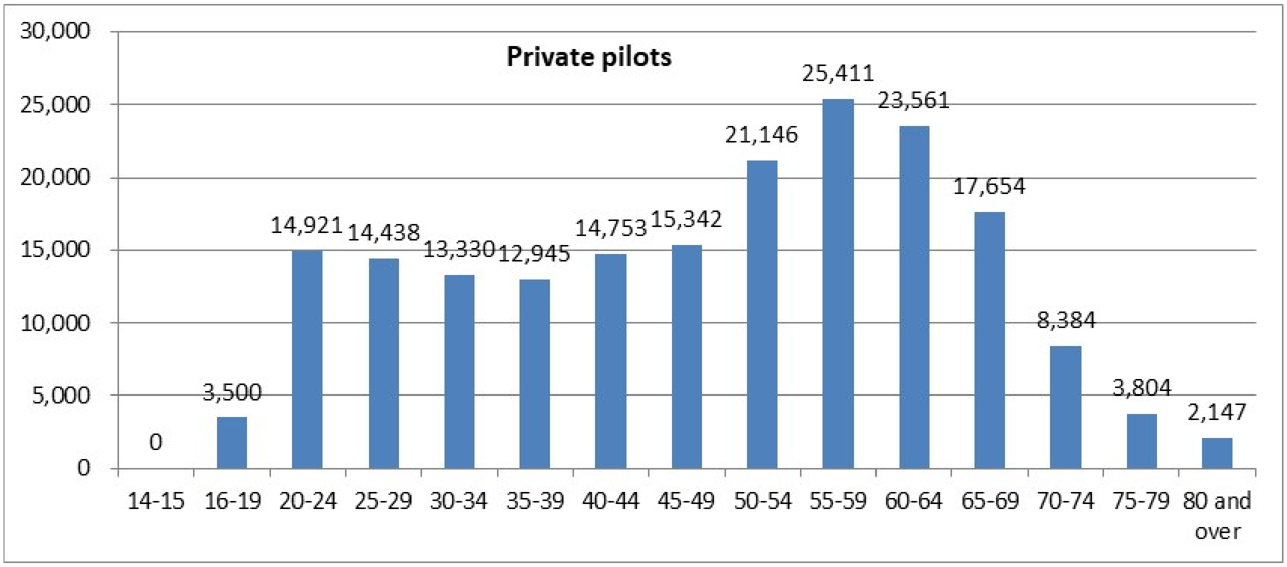


Figure 1. Age population of GA pilots in 2015

By compiling the original 14 age strata in Figure 1 into 4 age strata (excluding strata 16-19 for recruiting constraints), we produced four new strata with an age span of 18 years: 20-37 years, 38-55 years, 56-73 years, and 74-91 years. After proportionally calculating a sample of 50 GA pilots for the present study, we sampled the following number of GA pilots, as depicted in Table 1, for each age strata.

Table 1. Participant age strata

Age strata	**20-37**	**38-55**	**56-73**	**74-91**
Sample percentage	27%	35%	35%	4%
Pilots per strata	13	17	17	2

Using a between-subject design, we randomly assigned each pilot to one of the two simulation conditions labeled AR10 and AR20 (i.e., 10-mile lead-time and 20-mile lead-time). For the analyses, we used a Bayesian estimation framework with Markov Chain Monte Carlo (MCMC) sampling to determine the posterior distribution of the means and standard deviations for the two groups of participants.

3.2 Procedure

Upon arrival, each participant filled out a series of Questionnaires and viewed a pre-simulation briefing. After reading and signing the Informed Consent Statement (see Appendix B) participants completed a Biographical Questionnaire (see Appendix C), a Mobile Device Proficiency Questionnaire (see Appendix D; Roque and Boot, 2016), and a Weather Knowledge Questionnaire (see Appendix E). After finishing the questionnaires, participants completed a recorded preflight briefing (presented as a Microsoft® PowerPoint® slideshow). The preflight briefing contained general information about the purpose of the study. It also contained an overview of the cockpit simulators, the G1000 display, the auxiliary weather display, the instrument stack, and the flight plan.

Following the recorded flight briefing, a researcher escorted the participant to either a Microjet or a Redbird cockpit simulator. Participants then read the flight reference materials, which included a sectional map, the flight plan, relevant Air Traffic Control (ATC) and AWOS radio frequencies, and a printed weather briefing. The researcher familiarized the participant with the simulator's (a) aircraft controls, (b) weather presentation, (c) radio, (d) horizontal situation indicator, (e) AWOS radio frequencies, and (f) navigation equipment, and provided the participant the opportunity to practice flying the simulator until they felt comfortable with the controls. When the pilot was ready to begin the simulation, the researchers started the 45-minute data collection flight. At the conclusion of the simulation flight, participants completed a post-scenario questionnaire (see Appendix F) and participated in a debriefing with a member of the research team.

3.2.1 Schedule of events

The schedule of events for the participants is detailed in Table 2. We planned for two participants concurrently, utilizing both flight simulators beginning at 08:00 and ending at 15:00 local time.

Table 2. Schedule of events

Session	Time	Activity
1 (2 participants)	8:00 - 08:20	Intro and preflight briefing
	8:20 - 08:40	Practice simulator flight
	8:40 - 09:30	Simulator flight
	9:30 - 09:40	Post-Scenario Questionnaire
	9:40 - 10:00	NVN Training and Survey
2 (2 participants)	10:00 – 10:20	Intro and preflight briefing
	10:20 – 10:40	Practice simulator flight
	10:40 – 11:30	Simulator flight
	11:30 – 11:40	Post-Scenario Questionnaire
	11:40 – 12:00	NVN Training and Survey
3 (2 participants)		
	1:00 – 1:20	Intro and preflight briefing
	1:20 – 1:40	Practice simulator flight
	1:40 – 2:30	Simulator flight
	2:30 – 2:40	Post-Scenario Questionnaire
	2:40 – 3:00	NVN Training and Survey

3.3 Independent variable

The independent variable was AR lead-time. There were two conditions: AR10 with a 10-mile lead-time to the 20-mile distance to the storm (a total distance of 30 miles from the storm cell), and AR20 with a 20-mile lead-time to the 20-mile distance to the storm (a total distance of 40 miles from the storm cell. Changes in Visibility (a continuous reduction in visibility from the 15 miles at start-up to the 1-mile visibility at the destination) were held constant across AR10 and AR20 groups.

3.4 Dependent variable

We recorded dependent variables that captured the following categories: System Performance, Communication, WSA, and Decision Making. Of particular interest was the comparison between the AR10 group and the AR20 group regarding the effect on pilot behavior and decision-making from the use of the AR weather display.

During the simulation we measured the distance-to-weather (≥ 30 dBZ precipitation cells) once every five seconds. In addition, researchers acting as ATC asked pilots to provide estimations of their forward visibility during flights. We also probed pilots with detailed post-scenario questions regarding distances to precipitation cells and flying behavior (see Appendix F). This allowed us to acquire data for an assessment of pilot WSA and the perceived distance from the aircraft to hazardous cells and whether pilots were cognizant of their closest point of approach. It should be noted, for this simulation, we briefed pilots about current FAA recommendations to stay at least 20 miles away from storm cells.

In Table 3, we provide a list of the dependent variables and a short description.

Table 3. Dependent variable list

	DEPENDENT VARIABLE	DESCRIPTION
1	System performance	Data from the cockpit simulator (e.g., altitude, heading, lat/long position).
2	Pilot/ATC communications	The content of pilot/ATC communications.
3	WSA	Pilot response to ATC weather requests (i.e., pilot visibility estimates). Pilot use of Automated Surface Observing System (ASOS) stations. Closest distance from aircraft to 30 dBZ precipitation areas.
4	Decision-making	Pilot decision to turn around, deviate, or to continue flight to the destination airport at Skagway.

3.5 Data handling procedure

All the information that the participant provided, including Personally Identifiable Information (PII) will be protected from release except as required by statute. Signing the informed consent form indicated that the participant understood his or her rights as a participant in the study and their consent to participate.

To protect the identity of the participants each participant GA pilot was assigned a coded identifier. The identifier did not appear on the Informed Consent Statement, because that is identified by the participant’s signature. We tagged all other data collection forms, computer files, electronic recordings, storage media, etc. that contained participant information only with the coded identifier, not the name or personal identifying information of the participants.

No names or identities will be released in any research reports, publications, or presentations resulting from this work. Electronic data, including audio/video recordings, are maintained on secure FAA or FAA-contractor computers that are accessible only by research team members. Any data collected on paper (e.g., questionnaires) were secured in a locked file cabinet accessible only by research team members. We retained original documents, recordings, and files as collected. All data editing, cleanup, and analysis were performed on copies traceable to the original sources. We will keep the simulation data for 5 years before all questionnaire and survey data (paper-based) are shredded and audio and video recordings (digital) are deleted from the FAA Cockpit Simulation Facility servers and backup drives.

The data from the study may be made available to other researchers for related studies. Situations when PII may be disclosed are discussed in detail in FAA Order 1280.1B "Protecting Personally Identifiable Information [PII]." Each participant was provided a copy of the FAA Order 1280.1B for review prior to the Informed Consent briefing and before making any decision about participating in the study.

3.6 Research personnel

The research team defined the time-based AR design for experimentation, developed the scenario, prepared briefings, and collected the data. Software engineers modified the scenario from Ahlstrom et al (2019), prepared the simulators, acted as ATC during the simulation, and implemented the time-based AR concept.

3.7 Facilities

The research study was conducted at the William J. Hughes Technical Center Cockpit Simulation Facility (CSF).

3.8 Aircraft simulators

Participants flew in either a Redbird or a Microjet simulator for this study. The simulators had slightly different cockpits but were configured to perform as a single-engine Cessna 172 aircraft. Both simulators were equipped with a 180° out-the-window view, electronic flight displays, a stand-alone weather display running on a Windows Surface Pro 3, and a voice communication system that provided a link between the GA pilots and the air traffic controller through a Push-To-Talk (PTT) capability. In addition, each cockpit was equipped with three cameras (front view, top view, and side view) for video recordings and specialized hardware for capturing the flight display outputs. Figure 2 is an image of the Redbird cockpit, and Figure 3 is an image of the Microjet cockpit.

Figure 2. Redbird cockpit and out-the-window view

Figure 3. The Microjet the cockpit and the out-window view

3.9 Data analysis

In this study, we varied the lead-time for the AR displayed from the 20-mile buffer between the storm cell and the aircraft. In the first condition, we presented the pilots with a time-based AR 10 miles before reaching the FAA minimum recommended safe distance of 20 miles from a thunderstorm (i.e., 30 miles from the edge of the storm cell). In the second condition, we presented pilots with a time-based AR 20 miles before reaching the FAA minimum recommended safe distance of 20 miles from a thunderstorm (i.e. 40 miles from the edge of the storm cell).

We analyzed data from the present study using Bayesian estimation, as used in Ahlstrom and Suss (2014) and Ahlstrom et al. (2015a; 2015b; 2019a; 2019b). During the analysis we used JAGS ("Just Another Gibbs Sampler": Plummer, 2003, 2011) that we called from R (R Development Core Team, 2011) via the package rjags. JAGS is a program for analysis of Bayesian hierarchical models using Markov Chain Monte Carlo (MCMC) simulation. All software for the analysis and figure generation was adapted program code from Kruschke (2014).

3.10 Simulation flight plan

The VFR flight started south of Juneau, Alaska (PAJN) at an altitude of 6500 ft, with the destination at Skagway airport (PAGY) as shown in Figure 4. The flight progressed through a narrowing pass and continued into a narrowing fjord with gradually reduced visibility. The Alaska scenario highlighted the hazards of flying in deteriorating weather, when the terrain (canyons) and low ceilings present few alternates for turning around or flying towards an alternative airport. The destination Skagway has a near sea level runway that is situated in a narrow valley. There are also steep mountains on either side of the route, which forces the airplane to fly along a narrowing fjord.

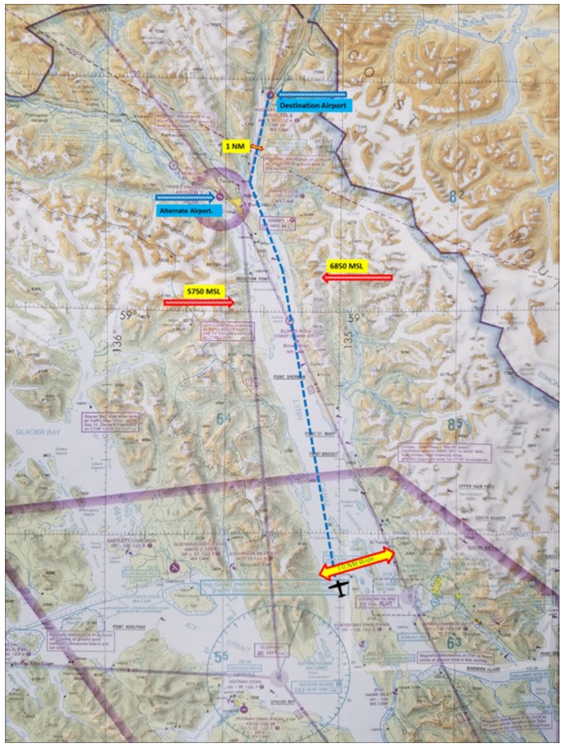


Figure 4. The Alaska scenario route used during the simulation

3.11 Weather conditions

At the scenario startup, the visibility was 15 statute miles, but the conditions along the route deteriorated with the visibility progressively reduced to 8, 4, and finally 1 statute mile at the Skagway destination airport. The scenario included a thunderstorm stalled just northeast of the Gustavus Airport (Figure 5).

Figure 5. Stalled thunderstorm to the northwest and aircraft heading north

During flight, pilots could tune in to five different AWOS stations (using the appropriate radio frequency). These stations were located at Hoonah Airport (POOH), Juneau International Airport (PAJN), Gustavus Airport (PAGS), Haines Airport (PAHN), and Skagway Airport (PAGY).

3.12 Weather presentation

The portable Windows Surface Pro 3 was mounted inside the cockpit and displayed a weather application with a Google Earth map background, the route (magenta line), aircraft position symbol, and areas of precipitation (NEXRAD; Next Generation Radar Data), as shown in Figure 5. Besides the precipitation information, the application displayed an overlay of visibility conditions if the pilot flew within 20 miles of an area with less than 5 miles forecast visibility. This data is similar to the graphical visibility charts found on the Aviation Weather Center's Aviation Digital Data Service (ADDS) web page (NOAA, 2019). At the start of the simulation, the weather display was zoomed out to its widest view, however the pilots had the option to change the zoom level after the simulation began.

3.13 Active reminder

As the aircraft flew along its route, the ownship symbol on the weather display continued to update its position in real time. When the aircraft reached either a distance of 30 or 40 miles (condition depending) from the closest ≥ 30 dBZ (yellow NEXRAD) point of a storm cell, it triggered the display of a time-based AR. The AR was depicted as a white rectangle block containing time information and two short blue lines indicating directional information. One blue line originated from the aircraft ownship symbol pointing toward the other blue line that originated from the closest ≥ 30 dBZ area of the storm cell. The blue lines adjusted their directional position as the aircraft progressed

The white rectangular clock appeared next to the aircraft ownship symbol. The clock displayed the amount of time before the aircraft would be within 20 miles of the storm cell if the aircraft continued along its current trajectory (see Figure 6). For pilots that flew the planned route, the AR clock appeared displaying 2:50 (approximately) for the 10-mile condition, and 8:50 for the 20-mile condition. If the aircraft flew within 20-mile of the storm cell, the countdown clock displayed zero and the white rectangle enclosing the countdown clock changed color from white to yellow (Figure 7). The countdown clock remained at zero and in yellow status as long as the aircraft was within the 20-mile zone. Once the aircraft was outside of the 20-mile zone and diverting away from the storm cell, the AR disappeared from the display.

If a pilot decided to divert to an alternate airport, the researcher recorded the pilot's decision and terminated the simulation. Pilots that continued to fly north flew within the 20-mile threshold since they could not divert to the east far enough to maintain at least 20 miles from the storm. Pilots that continued past this point continued to fly toward the IMC AR portion of the scenario.

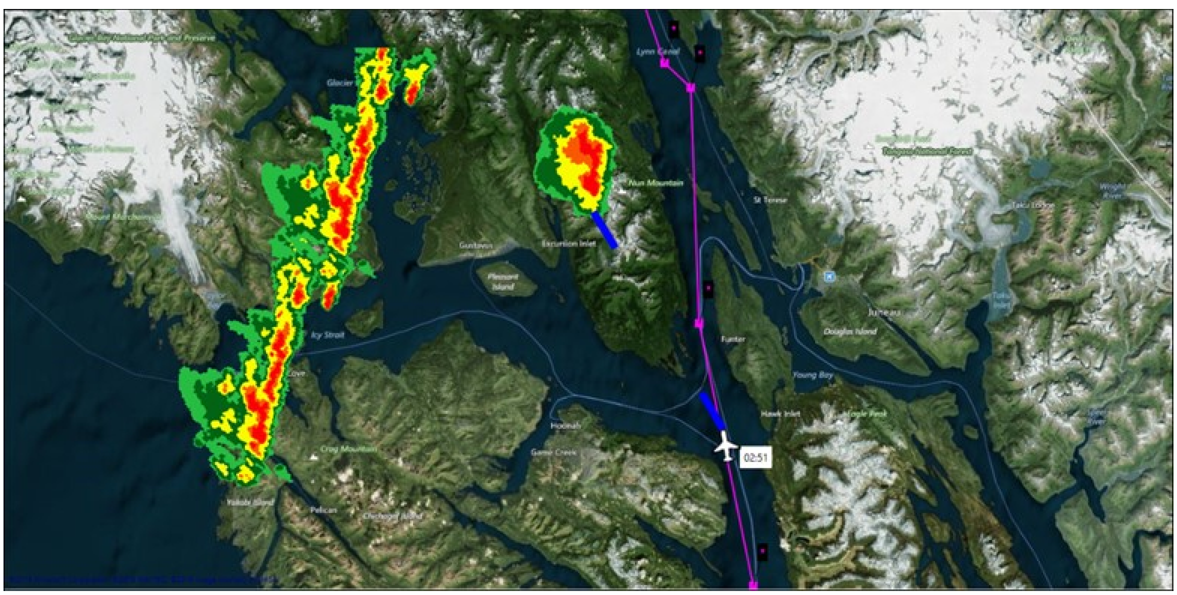


Figure 6. Weather display with the AR clock showing 02:51 remaining until the 20-mile threshold from the closest point of the storm cell indicated by the blue lines

Figure 7. Example of the AR time indicator when flying within 20 miles of a thunderstorm

The AR disappeared when the aircraft passed the most northern point of the storm cell. Pilots that continued to head north encountered another time-based AR on the weather display. In these instances, the time-based AR clock and color coded visibility layers were displayed once the aircraft reached a distance of 20 miles from the closest point on the 1 to 3 statute miles area of forecasted visibility (pink) (see Figure 8).

Although there is no FAA recommended distance from low visibility (though there is a requirement of 3-mile visibility and 1,000 ft above for VFR operations), the time-based AR notifying GA pilots of a 1 to 3 statute mile forecasted visibility area functioned the same as the notification to severe weather. Our purpose for testing the time-base AR in an IMC condition was not to determine whether or not GA pilots fly within a distance threshold, but rather if a time-based AR could potentially deter pilots from flying into IMC areas. Researchers recorded if pilots decided to divert to the alternate airport Haines (HNS) or divert to another airport. However, if the pilot continued to the destination airport SGY, then the researcher terminated the simulation just after they entered the IMC visibility area (Figure 9).

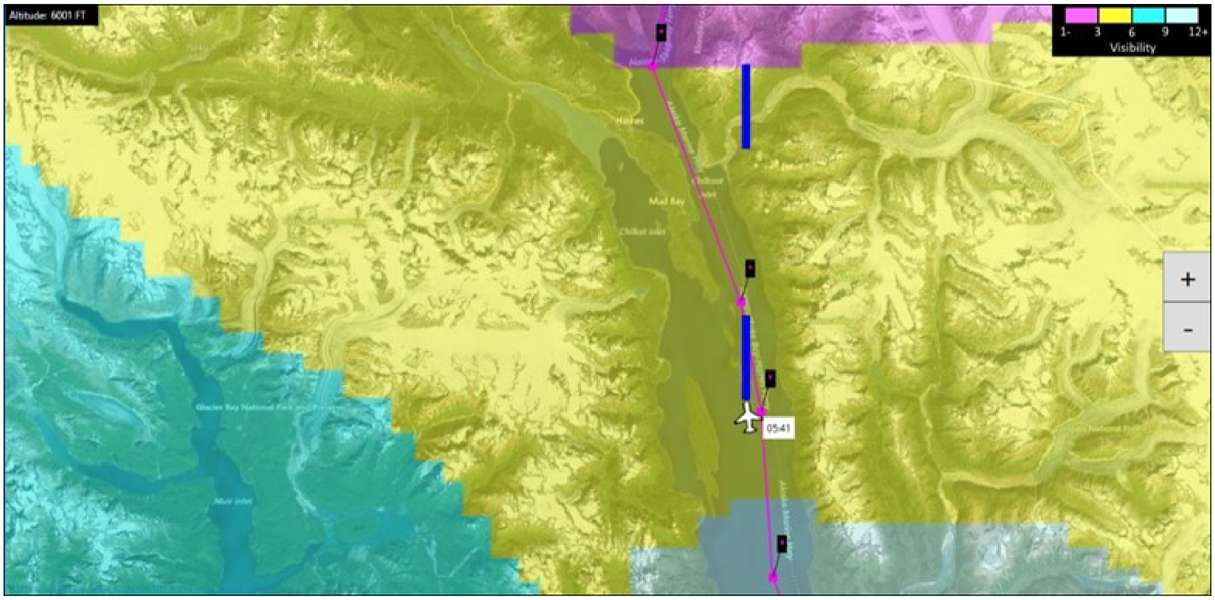


Figure 8. Aircraft 20 miles from 1- 3 miles forecasted visibility with an AR indicting time remaining (05:41) until reaching the area threshold.

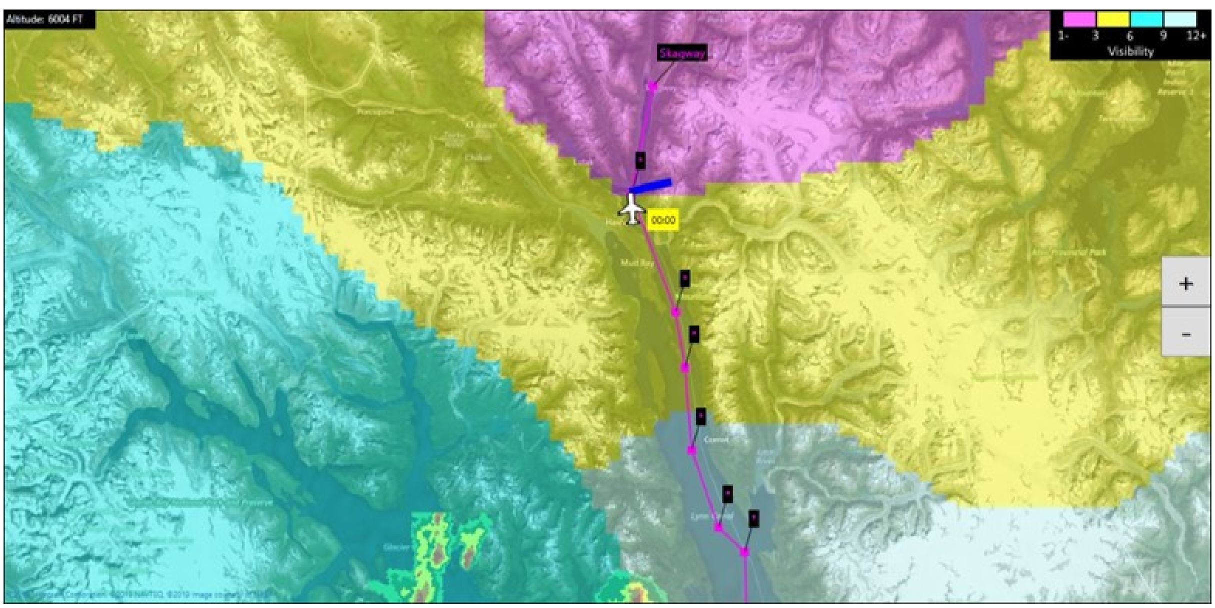


Figure 9. Aircraft has flown into area with less than 3 miles visibility. AR clock turns yellow and displays 00:00

4 Results

In this section, we present the simulation results in seven separate sections. First, we present the pre-brief questionnaire data. Next, we present data on pilot communications with ATC. This is followed by an analysis of the use of AWOS information during flight. Next, we present an analysis of the distance from the aircraft to hazardous precipitation cells, including a comparison of the present result with an earlier study by Ahlstrom et al. (2019). Following this, we present an altitude analysis and subsequently the out-the-window visibility reports provided by pilots. Finally, we conclude with an analysis of pilot decisions to turn around, deviate, or to continue their flight towards the destination airport.

4.1 Pre-brief questionnaires

4.1.1 Biographical Questionnaire

During the pre-brief, all participants completed a biographical questionnaire. Table 4 presents a summary of the participants' age, total flight hours, actual number of instrument hours, and the number of instrument hours logged in the last 6 months. The pilot certificate and ratings breakdown is presented in Table 5.

Table 4. Summary of participant age and flight experience

	Age	**Total Flight Hours**	**Actual Instrument Hours**	**Instrument Hours in the Last 6 months**
Mean	50.38	2525.94	675.57	8.82
Std	16.24	5001.20	2536.94	14.98
Min	21	80	0	0
Max	76	25000	15000	79

Table 5. Summary of pilot certificates and ratings

Private	27
Commercial	17
SEL	36
Instrument	13
A&P	4
MEL	14
CFI	3
CFII	5
Glider	1

We asked the pilots to list all (if any) in-flight weather presentation systems used during a flight to make actual weather judgments (not including onboard radar or Stormscope). Pilots reported they used ForeFlight (n=21), Garmin (n=11), XM (n=4), and ADS=-B (n=7) or none (n=10). When asked if they had any training in weather interpretation other than basic pilot training, 37 participants responded that they had no additional weather training.

4.1.2 Mobile Device Proficiency Questionnaire

The Mobile Device Proficiency Questionnaire (MDPQ) is a tool developed and validated by Roque and Boot (2016) to assess mobile device proficiency in older adults (see Appendix D). The original questionnaire is comprised of 46 questions regarding operations on a smartphone or tablet device on a 5-point rating scale (e.g., 1 = *never tried*, 2 = *not at all*, 3 = *not very easily*, 4 = *somewhat easily*, 5 = *very easily).* These questions are organized into eight subscales relating to: mobile device basics, communication, data and file storage, internet usage, calendaring, entertainment, privacy, and troubleshooting. A shorter version of the MDPQ, the MDPQ-16, reduces the questionnaire set to two questions per subscale.

Each participant completed the MDPQ-16 during the study. Overall proficiency scores for the MDPQ are calculated by averaging subscale questions and adding them to create one combined measure. A summary of MDPQ scores by age is provided in Table 6 and a trend analysis of all pilot proficiency scores is provided in Figure 10.

For the analysis, we used pilot age (x) and the corresponding MDPQ score (y) in a robust linear regression model by Kruschke (2014). In the model, each predicted y value is computed as $y = \beta_0 + \beta_1 x$ where β_0 is the y-intercept (where the regression lines intersect the y-axis when x = 0) and β_1 is the slope (indicates how much y increases when we increase x by 1). To be robust against outliers, the model uses a *t*-distribution for the noise distribution instead of a normal distribution (i.e., Gaussian distribution). At the lowest level of the model, each datum comes from a *t*-distribution with a mean μ, a scale parameter (i.e., *SD*) σ, and a normality parameter v. The prior on the scale parameter is a broad uniform distribution, and the normality parameter v has a broad exponential prior. Both β_0 and β_1 have broad normal priors that are noncommittal and vague on the scale of the data.

As can be seen in Figure 10, the regression lines have a negative slope meaning that the proficiency scores (y) decrease with an increasing age (x). The intercept has a mode of 40.8 (95% HDI from 39.7 to 42.1), which is the predicted proficiency score when age = zero. The credible slope has a posterior mode of -0.032 (95% HDI from -0.07 to -0.009) and a *SD* mode of 0.92 (95% HDI from 0.5 to 1.6). This means that as we increase age by 1 (year), the predicted proficiency score *decreases* by 0.032. Therefore, overall, the result implies that older participants have lower mobile device proficiency scores than younger participants.

Table 6. Mean proficiency MDPQ scores by binned age

Age bin	n	Mean Proficiency Score
20-37	13	39.2
38-55	17	39.0
56-73	16	35.2
74-91	2	31.0

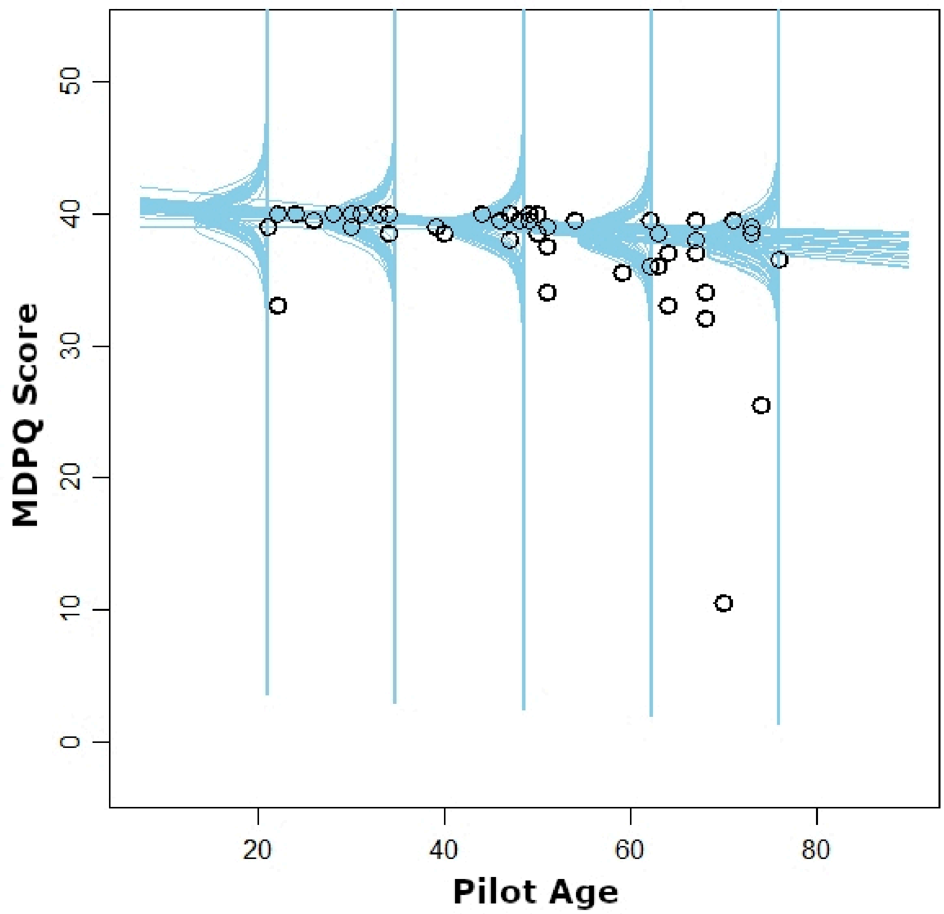


Figure 10. Regression lines and noise distributions for the prediction of MDPQ scores from pilot age

4.1.3 Weather Knowledge Questionnaire

The Weather Knowledge Questionnaire (see Appendix E) contains 20 questions selected from the private pilot written exam weather questions. Our long-term goal is to develop a standard set of questions that we use for all human-in-the-loop simulations. The difficulty here is to develop questions that tell us how effective a given question is in discriminating between pilots with 'high' weather knowledge and pilots with 'low' weather knowledge. We provide summary statistics in Table 7. There was no difference in the scores between conditions. The relatively low median score along with the large variability in score range indicate a needed improvement in terms of weather-related training and education. We also performed a correlation analysis; we used the Weather Questionnaire score (x) and the corresponding closest point to weather (y) but found no significant correlation (-0.01031).

Table 7. Summary data for weather questionnaire

Weather Question Performance				
Group	n	Mdn	Mean	Range
AR10	24	55%	58%	30-85%
AR20	26	55%	58%	30-85%
All	50	55%	58%	30-85%

4.2 ATC communication

The following section summarizes pilot communications with ATC during simulation runs. We categorized the communications into five main categories. The first category, landing, includes communications that are related to pilot questions or statements about landing. The second category, ceiling-visibility-fog, includes communications about pilot reports of deteriorating weather conditions. The third category, altitude change, includes communications about pilot altitude requests. The fourth category, turn around-divert, includes pilot communications regarding decisions or questions about turning around or deviating to an alternate airport. Finally, the fifth category, AWOS, includes communications about tuning into AWOS stations. Figure 11 shows a summary of the communication counts for each of the five categories.

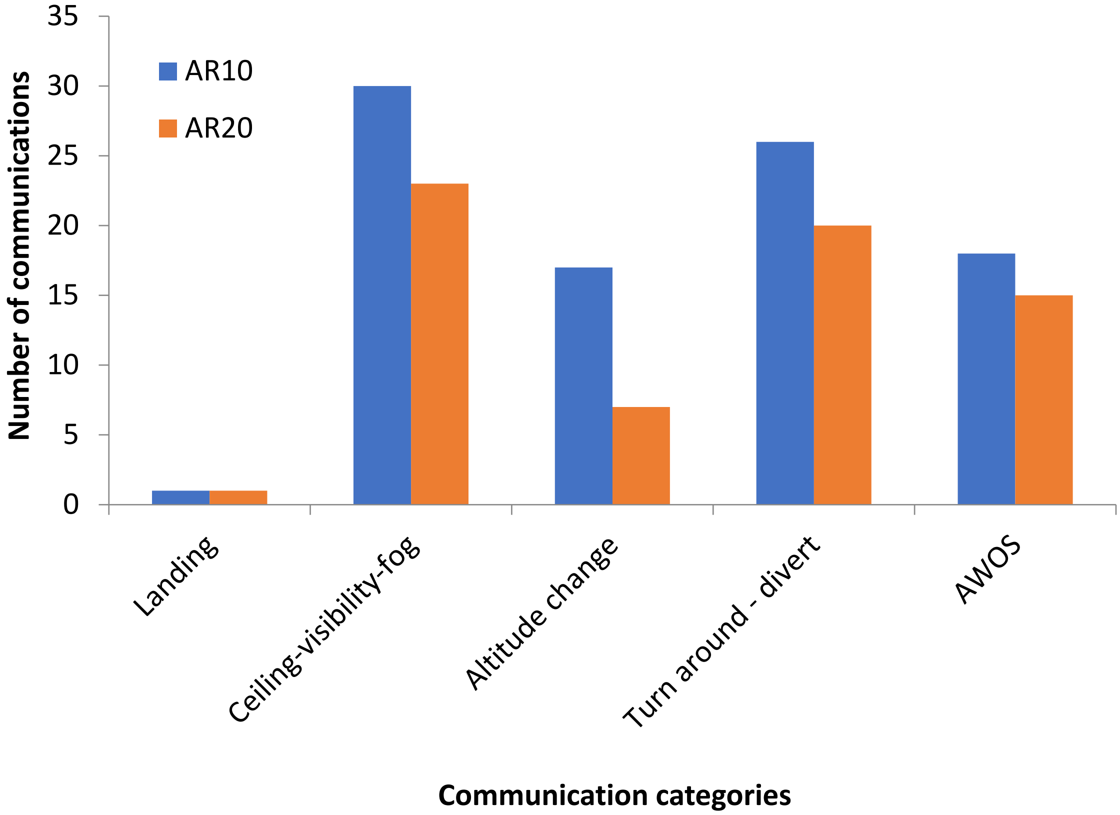


Figure 11. Summary of pilot communications (AR10 vs. AR20) for five communication categories

As is shown in Figure 11, the counts for four of the five communication categories are higher for the AR10 group compared to the AR20 group. However, only the proportion of counts for the altitude change is credibly different with a higher proportion of counts for the AR10 group (mean difference = 0.41; 95% HDI from 0.17 to 0.64). Overall, the highest communication counts for both groups are for ceiling-visibility-fog, followed by turn around-divert, AWOS, altitude change, and finally landing, which has the lowest communication count.

In summary, the pilot/ATC communication counts are similar for the AR10 and AR20 groups. Only the communications for altitude change is credibly different between the groups, with a higher communication count for the AR10 group.

4.3 The use of AWOS information during flight

During flight, pilots could tune in to five different AWOS stations. These stations were located at Hoonah Airport (POOH), Juneau International Airport (PAJN), Gustavus Airport (PAGS), Haines Airport (PAHN), and Skagway Airport (PAGY) as illustrated in Figure 12. At the start of the scenario, POOH and PAJN reported 10-mile visibility with 10,000 feet overcast. PAGS reported 6-mile visibility and 10,000 feet overcast. PAHN reported 5-mile visibility, fog, mist, and 5,000 scattered with 6,000 feet overcast. Finally, PAGY reported 3-mile visibility, fog, mist, and 4,000 scattered with 5,000 feet overcast. All weather reports were constant during the scenario except for PAGY. At 25 minutes into the scenario, PAGY reported 1-mile visibility, fog, mist, and 4,000 scattered with 5,000 feet overcast.

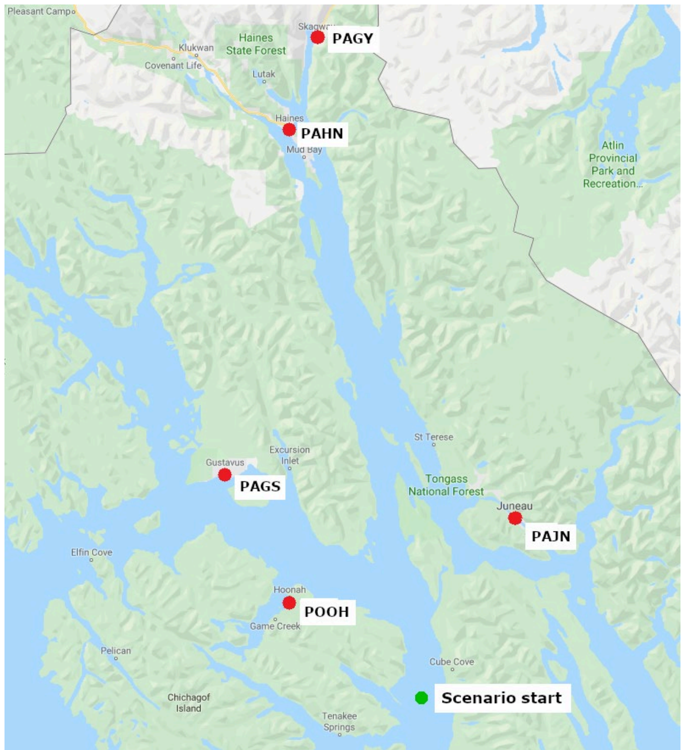


Figure 12. The five Alaska AWOS stations (red dots) at Hoonah (POOH), Juneau (PAJN), Gustavus (PAGS), Haines (PAHN), and Skagway (PAGY). The scenario start position is illustrated by the green dot.

During the simulation, we recorded each time pilots tuned into an AWOS station. We then summarized these count values for each pilot and group (AR10 and AR20). Figure 13 shows the *total* number of AWOS counts for the AR10 and AR20 groups. The number of AWOS inquiries was 112 and 93 for the AR10 and AR20 groups, respectively. Two pilots in the AR10 group and three pilots in the AR20 group did not tune in to any AWOS stations. Therefore, for the AR10 group, 22 of the 24 pilots (92%) tuned in to one or more AWOS stations. For the AR20 group, 23 of the 26 pilots (88%) tuned in to one or more AWOS stations.

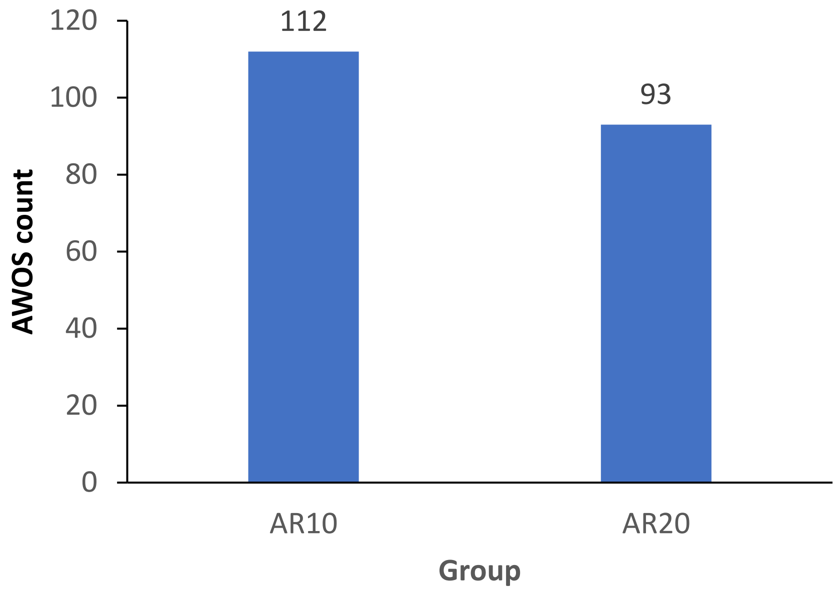


Figure 13. The total number of AWOS inquiries for the AR10 and AR20 groups

Although the AWOS count is higher for the AR10 group than the AR20 group (112 versus 93), this difference is not credible (AR10 mean AWOS count = 5.05; AR20 mean AWOS count = 3.89, mean posterior difference = - 1.17 with the value 0 inside the 95% HDI ranging from – 2.83 to 0.7).

Figure 14 shows the frequency (i.e., count) by which AR10 and AR20 pilots tuned in to the five different AWOS stations. Of the five AWOS stations, the counts are highest for PAHN (103), followed by PAGY (49), PAGS (19), PAJN (18), and finally POOH (16).

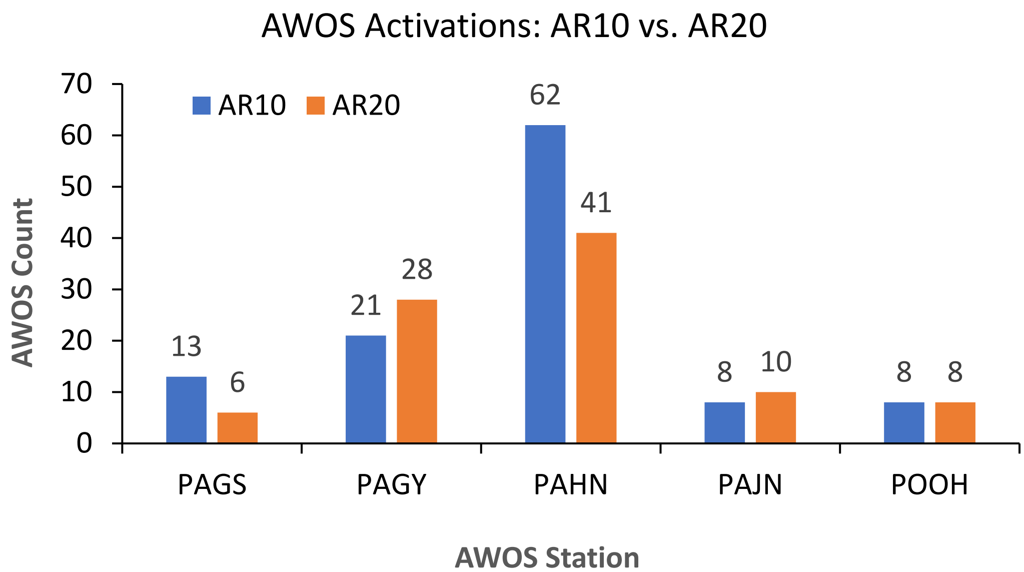


Figure 14. Comparison of the AR10 and AR20 AWOS usage for the five AWOS stations

We also assessed the scenario time when pilots tuned into the five different AWOS stations. Figure 15 shows the scenario time for each AWOS inquiry during the scenario.

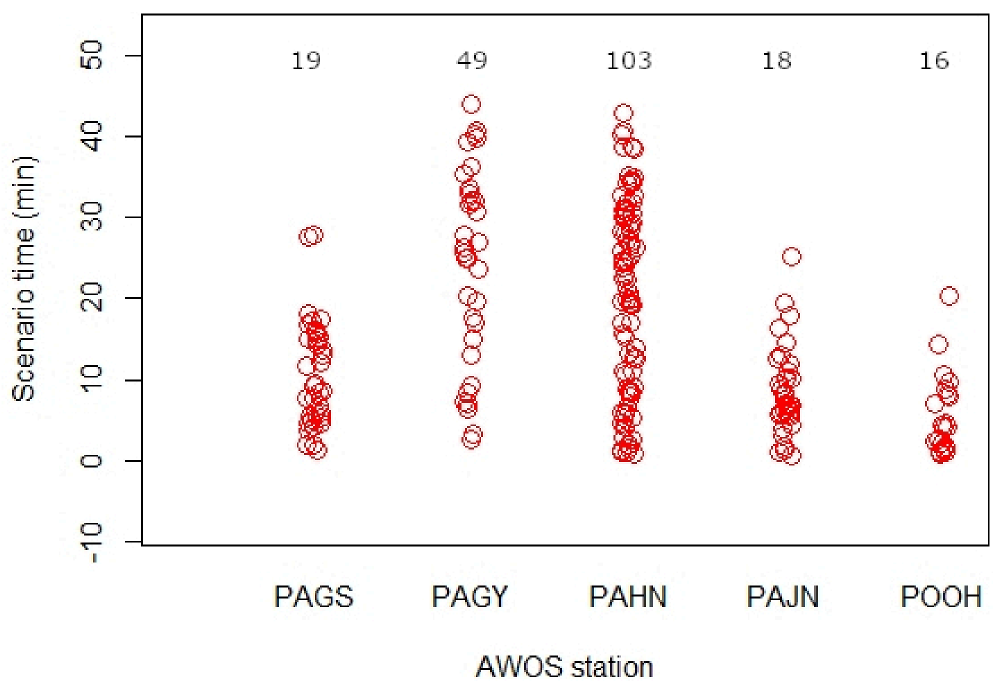


Figure 15. The scenario time for AWOS inquiries (red circles) at five AWOS stations. The numbers above the data columns represent the total count of AWOS inquiries.

The scenario times for these AWOS inquiries correspond to pilot decisions regarding deviations, turning around, or continuing flight to the destination airport. For example, the PAGS, PAJN, and POOH stations were mainly tuned in during the first twenty minutes of the scenario. In contrast, the PAGY and PAHN stations were tuned in during the entire scenario. This was likely because the PAGY and PAHN were located in the final portion of the flight. Once the pilot passed an airport, they were less likely to tune into that AWOS unless they considered turning around.

In summary, AWOS information can increase pilot WSA and enhance pilot decision-making for decisions related to turning around, deviating, or continuing flight toward the destination airport. We found no important differences in the AWOS usage between the AR10 and AR20 groups, indicating that pilots used the AWOS information in a similar manner.

4.4 Distance from aircraft to precipitation areas

FAA and NOAA (1983) recommend that pilots avoid hazardous storm cells by at least 20 statute miles. However, previous cockpit simulation research has shown that GA pilots often fly much closer than the current recommendations with a mean distance-to-weather (≥ 30 dBZ precipitation cells) ranging from of 7–14 NM (Ahlstrom et al., 2015a, 2015b; Ahlstrom & Dworsky, 2012).

We assessed the closest distance-to-weather for each pilot by using one data value (closest distance) and a Bayesian model (Kruschke, 2014) for a metric-predicted variable (i.e., closest distance to weather) for two groups (AR10 and AR20). In the model, the data are described by *t* distributions rather than normal distributions. Each group has different parameters for the means with broad normal distribution priors. Each group also has separate parameters for the standard deviations, with broad uniform distribution priors. However, both groups share a common normality parameter (v) that controls the height of the *t* distribution tails. For the current analysis, we set v to a small value, which means that the *t* distributions have heavy tails and can therefore accommodate outliers in the data (i.e., robust estimation).

Figure 16 shows the data and the analysis result with predicted means, standard deviations (i.e., scale), and effect size. The top right histograms show the actual data (red bars) with a superimposed posterior predictive check (blue lines) which is a control that the model fits the data. The mean posterior distances are shown on the left, with a mode of 12 miles for the AR10 group and 14.6 miles for the AR20 group. The difference of means (AR20 – AR10; mode = 2.64, 95% HDI from -0.74 to 5.86) is not credible because the value 0 is located within the 95% HDI. The scale (i.e., *SD*) has a posterior mode of 4.7 for the AR10 group and 5.43 for the AR20 group.

The difference in scales with a mode of 0.76 is not credible (95% HDI from -1.78 to 3.39) because the 95% HDI includes the value 0. Finally, there is a non-credible effect size (i.e., a standardized change) with a posterior mode of 0.50 (95% HDI from -0.14 to 1.09).

This result implies that the difference in lead-time (i.e., 10 versus 20 miles) did not affect the flying behavior of pilots; both pilot groups flew equally close to the hazardous weather cells (i.e., ≥ 30 dBZ precipitation cells). The distance-to-weather analysis revealed that the AR10 and AR20 pilots flew between 9.93 to 17.2 miles (95% HDIs) from hazardous precipitation cells. This outcome is similar to previous weather avoidance research (Ahlstrom et al., 2015a, 2015b; Ahlstrom & Dworsky, 2012).

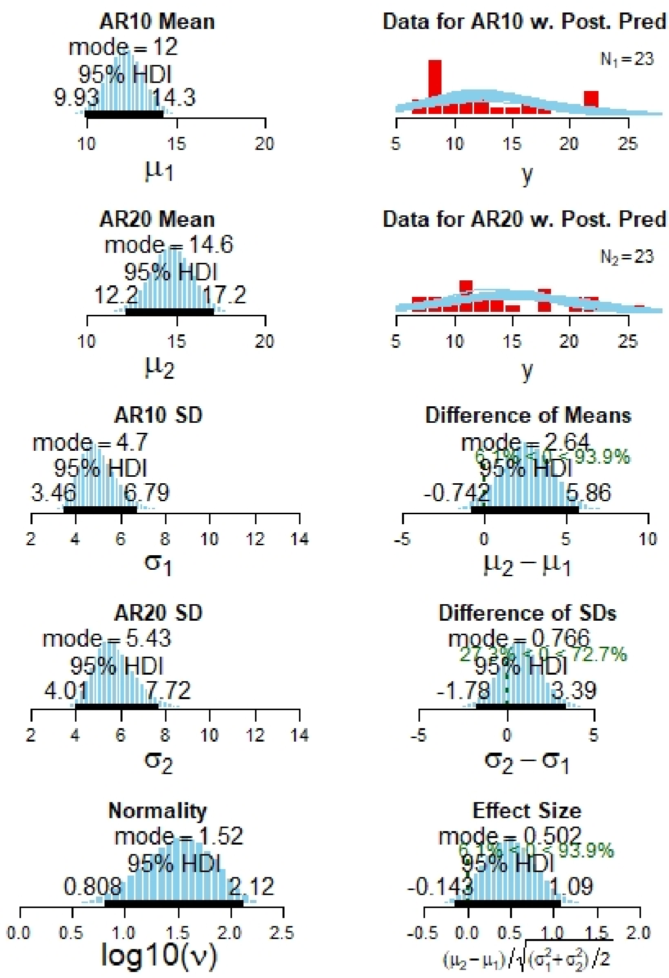


Figure 16. Comparison of the distance-to-weather data for the AR10 and AR20 groups (top right) with posterior distributions for means (top left), standard deviations (i.e., scale; middle left), difference of means and scales (middle right), effect size (bottom right), and the normality parameter (bottom left).

We also compared the distance-to-weather outcome between VFR-only and Instrument Flight Rules (IFR)-rated pilots, as there could be differences in how these two pilot groups avoid hazardous weather. IFR-rated pilots have experience and training in flying towards and penetrating precipitation areas whereas VFR-only pilots do not. The analysis showed a non-credible difference between the IFR-rated pilots (mean distance = 12.8, 95% HDI from 10.7 to 15) and the VFR-only pilots (mean distance = 13.8, 95% HDI from 11.4 to 16.3) with a difference of means = 0.8 miles (95% HDI from -2.35 to 4.12). This result implies that training and experience with weather conditions do not translate to a flight behavior that keep pilots at a greater distance to hazardous weather compared to pilots who lack this experience.

Finally, we also wanted to assess any differences in the distance-to-weather between the Redbird and the Microjet simulators. During the simulation both the Microjet and the Redbird simulators were equipped with the same cockpit weather display and required similar pilot actions for manual flight. However, while the operational characteristics were similar (both simulators were configured to simulate a Cessna 172), there were marked differences in the out-of-the-window views between the two simulators. The Microjet, as compared to the Redbird simulator, had a much larger display of the out-the-window view (i.e., a difference in resolution and scale). This could potentially yield a difference in the foreshortening or enlargement of the perceived distance to storm cells from the out-the-window view. The analysis showed a mean distance-to-weather of 11.2 miles for the Microjet pilots (95% HDI from 9.09 to 13.4 miles) and 15.3 miles for the Redbird pilots (95% HDI from 12.9 to 17.5 miles). The difference of means = 4.15 miles is credible, with a 95% HDI from 0.86 to 7.16 miles. The effect size (mode = 0.74) is also credible, with a 95% HDI from 0.12 to 1.5. This result implies that, overall, pilots in the Redbird simulator kept a greater distance-to-weather compared to pilots in the Microjet simulator.

The lack of a credible difference in the distance-to-weather between the AR10 and AR20 groups imply that the 10-mile and 20-mile lead-times were equally ineffective in making pilots stay farther away from hazardous weather (≥ 30 dBZ precipitation cells). One question is whether pilots were cognizant of their distance-to-weather; that is, whether their WSA was high enough to allow an effective use of the time-based distance information for weather avoidance. To assess how cognizant pilots were of their closest point of approach (i.e., closest distance to ≥ 30 dBZ precipitation cells) we analyzed pilot answers to the post-scenario question: “At the beginning of the scenario, did you fly closer than 20 nautical miles (NM) from the precipitation cells?” We correlated each pilots’ “Yes” or “No” answer with the pilots’ recorded closest point of approach.

Figure 17 shows a summary of the number (i.e., counts) of correct (left) and incorrect (right) answers for the AR10 group and the AR20 group. (Not included in these numbers is one pilot from the AR20 group who did not answer the question.)

The AR20 group had more correct (64%) answers than the AR10 group (50%), potentially implying that the 20-mile lead-time yielded an increased WSA compared to the 10-mile lead-time. However, this difference of four correct answers is not credible (i.e., 12 versus 16 correct answers). What is credible, however, is that only 50% of the AR10 pilots and 64% of the AR20 pilots knew they flew closer than 20 nm from precipitation cells. This outcome shows a low WSA for pilots in both groups.

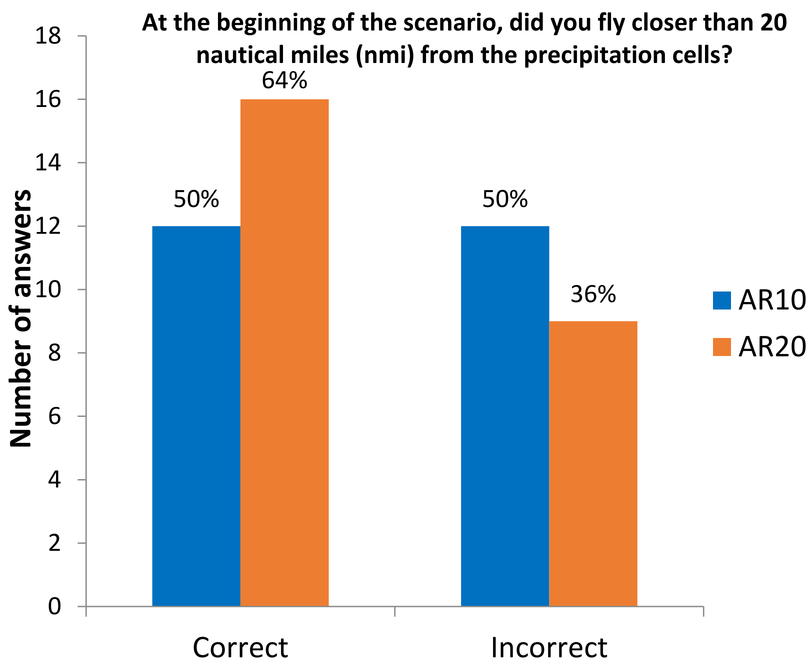


Figure 17. The number of correct (left) and incorrect (right) answers to the distance question

The above distance-to-weather question only required a yes or no answer, thus providing a rough WSA measure. However, we aimed at getting additional insight into pilot WSA and therefore asked the follow-up question: "How close to the precipitation cells did you get?" For this question, we provided four response alternatives, corresponding to four distance ranges: 20–25 NM, 15–20 NM, 10–15 NM, and less than 10 NM.

Figure 18 shows a summary of the question responses for the four distance categories. Although pilots from both groups provided responses in all four distance categories, there were only 3 correct AR10 and 4 correct AR20 answers for the 15–20 NM category, 1 correct AR10 and 0 correct AR20 answers for the 15-20 NM category, 4 correct AR10 answers and 1 correct AR20 answer for the 10-15 NM category, and 1 correct AR10 answer and 1 correct AR20 answer to the <10 NM category. Furthermore, there were no credible differences in the total number of correct answers between VFR-only pilots (8 correct answers) and IFR-rated pilots (7 correct answers) or between simulators (Microjet = 6 correct answers and Redbird = 9 correct answers).

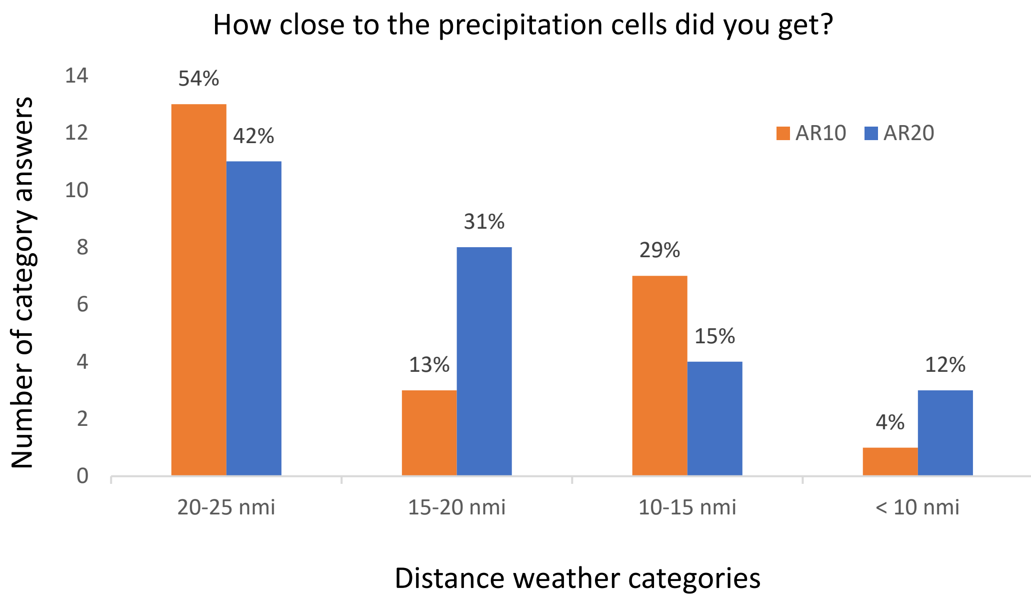


Figure 18. The number and percentage of answers to the four distance categories

It is not clear whether pilots agree with the recommended 20-mile distance-to-weather or if pilots prefer some other distance-to-weather limit. To probe this question further, we asked: "The current FAA recommendation is to stay 20 miles away from storms. Do you agree with this recommendation?" The outcome showed that 41 out of 50 pilots agreed with the recommendation (21 pilots from the AR10 group [87%] and 20 pilots from the AR20 group [77%]).

To assess individual preferences, we asked the follow-up question: "If you would determine the recommendation for a distance to storms, what distance (in NM) would you pick?" For this question, we used five response categories as follows: 1) 30 or more miles, 2) 20 miles (the current recommended distance), 3) 15 miles, 4) 10 miles, and finally 5) less than 10 miles. Most pilots selected the current recommended distance of 20 miles (15 pilots from the AR10 group [62.5%] and 17 pilots from the AR20 group [68%]). Only a few pilots selected the 30 or more miles category (three pilots from the AR10 group [12.5%] and two pilots from the AR20 group [8%]). The 15- and 10-mile categories were only selected by three [12%] and two [8%] pilots from the AR10 and AR20 group, respectively. No pilot in either group selected the less than 10 miles category.

4.4.1 Comparison with previous distance-to-weather data

Previous simulation research (Ahlstrom et al., 2019) has shown that providing pilots with a *distance-based* AR (at the FAA recommended threshold of 20 miles) does not prevent pilots from getting too close to thunderstorm cells. During the Ahlstrom et al. simulation the weather display was showing a blue line that originated at the aircraft position symbol and ended at the hazardous storm cell. The blue line ‘popped up’ as soon as the distance between the aircraft and the storm cell reached the 20-mile threshold (FAA recommendation). However, because the blue AR line was activated at 20 miles, this AR did not give pilots any lead-time to assess the distance-to-weather and to determine the course of action necessary for avoiding getting too close to the hazardous cell.

In the present simulation, we provided pilots with a *time-based* AR using two different lead-times. Providing pilots with a lead-time could potentially enhance pilot perception of the distance-to-weather because pilots have more time for assessments. The first AR lead-time was 10 miles (AR10) which meant that the AR was activated 10 miles before the aircraft reached the 20-mile threshold. The second AR lead-time was 20 miles (AR20), meaning that the AR was activated 20 miles before the aircraft reached the 20-mile threshold.

In both the present simulation and the Ahlstrom et al. (2019) simulation, we used the exact same Alaska weather scenario, cockpit weather display, VFR flight plan, and recording metrics. Therefore, we wanted to compare the distance-to-weather data between the time-based AR and the distance-based AR simulations. Figure 19 shows the closest distance to weather data from the Ahlstrom et al. simulation (AR0; left) and the present simulation (AR10; middle, and AR20; right).

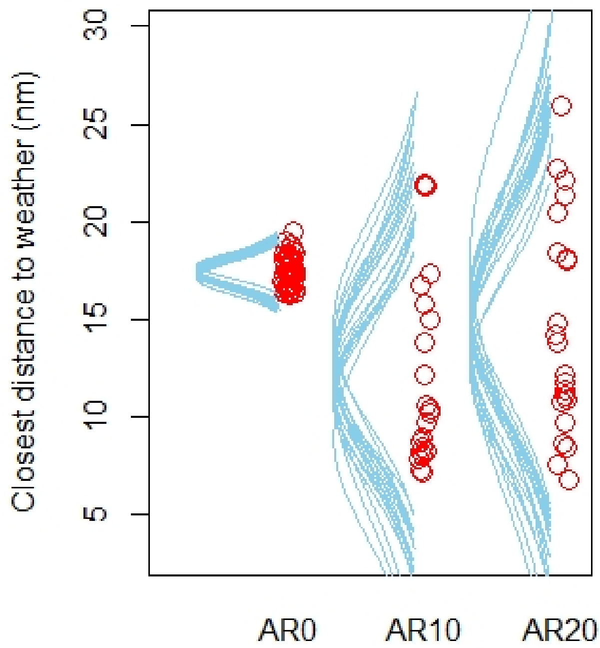


Figure 19. Comparison of the distance-to-weather data for the distance-based AR simulation (AR0; left, data from Ahlstrom et al., 2019) and the present time-based AR simulation (AR10; middle, and AR20; right).

As shown in Figure 19, the distance-to-weather data from the distance-based simulation (AR0) have little dispersion (mean=17.4 miles, 95% HDI from 17.2 to 17.7) compared to the AR10 data (mean=12.4 miles, 95% HDI from 10.3 and 14.6) and the AR20 data (mean=14.7 miles, 95% HDI from 12.3 to 17). The AR0 data are tightly clustered around ~17 miles whereas the data from the AR10 and AR20 groups have a large dispersion around the estimated means.

To analyze the group data for differences, we used a model from Kruschke (2014) for a metric predicted variable (i.e., distance-to-weather) with one nominal predictor (i.e., group). In the model, the group data was modeled as a random variation around an overall central tendency (baseline). The group data characteristics, like the group central tendency, were analyzed as a deflection from the baseline, with the requirement that deflections sum to zero. Figure 20 shows the outcome of the analysis with posterior group differences (top row) and effect sizes (bottom row).

First, there is no credible difference in the distance-to-weather data between the AR10 and AR20 groups (left column; difference mode= -2.34; 95% HDI from -5.4 to 0.6 with the value 0 included) and there is no credible effect size (effect size mode= -0.5, 95% HDI from -1.0 to 0.1 with the value 0 included in the 95% HDI). Second, there is a credible difference between the AR10 and AR0 groups, with the AR0 group having greater distances to weather than the AR10 group (middle column; difference mode= -4.93; 95% HDI from -7.0 to -2.8; effect size mode= -1.5; 95% HDI from -2.2 to -0.7). Third, there is a credible difference between the AR20 and AR0 groups, with the AR0 group having greater distances to weather than the AR20 group (right column; difference mode= -2.8; 95% HDI from -5.0 to -0.4; effect size mode= -0.7; 95% HDI from -1.3 to -0.1).

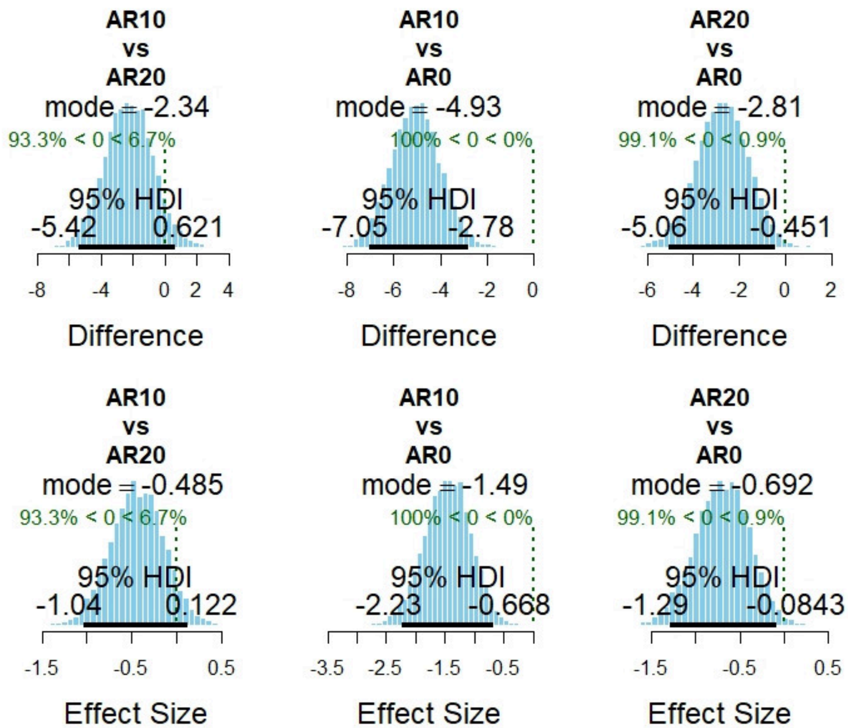


Figure 20. Posterior differences (top row) and effect sizes (bottom row) from the comparison between the AR0 (distance-based AR, Ahlstrom et al., 2019) and the AR10 and AR20 groups (time-based AR, present study).

This result implies that there is no credible difference between a time-based AR lead-time of 10 miles compared to a time-based AR lead-time of 20 miles. Increasing the lead-time from 10 to 20 miles does not improve pilots' flying behavior as measured by the closest approach to hazardous storm cells. The result also shows that a distance-based AR (blue line) yield larger distances to weather compared to a time-based AR (timer). Furthermore, a time-based AR yield a much larger dispersion (e.g., *SD*) of the distance-to-weather data with greater variability among pilots.

In summary, most pilots (65%) agreed with the recommendation of staying 20 or more miles away from hazardous storms. However, both pilot groups flew much closer to hazardous precipitation cells during the simulation (mean posterior distances of 12 miles for the AR10 group and 14.6 miles for the AR20 group). When asked about their weather avoidance behavior, only 50% of the AR10 pilots and 64% of the AR20 pilots knew they flew closer than 20 nm from precipitation cells indicating a low WSA for pilots in both groups. Furthermore, we found no effect of an increased lead-time on pilot weather-avoidance behavior. Pilots who experienced the 20-mile lead-time (i.e., the AR20 group) flew just as close to hazardous weather as pilots who experienced the 10-mile lead-time (i.e., the AR10 group). Lastly, when comparing the present data with the outcome from a distance-based AR simulation, we find that a distance-based AR (blue line) yield larger distances to hazardous weather compared to the present simulation using a time-based AR (timer).

4.5 Altitude analysis

In this section, we first provide an altitude analysis at the seven visibility reporting locations where ATC queried pilots to report the forward visibility. This analysis is important because different altitudes will yield different slant range slopes, which could change the perception of the forward visibility. If pilots were within a similar altitude range during their visibility reporting, we can determine that aircraft altitude was not a determinant of the reported visibility. Finally, we provide an analysis of pilot visibility estimates at the seven reporting locations.

The data for the altitude analysis consisted of the aircraft altitude for each pilot and visibility estimate. We used two factors for the analysis: aircraft altitude and visibility reporting location (i.e., Funter Bay (PANR), Pt. Bridget, Pt. St. Mary, Pt. Sherman, Sullivan Isl., Seduction Pt., and Haines). For the analysis, we used a model from Kruschke (2014) for a metric predicted variable (i.e., altitude) with multiple nominal predictors (i.e., group and reporting location). In the model, the group data were modeled as a random variation around an overall central tendency (baseline). The group data characteristics, like the group central tendency, was analyzed as a deflection from the baseline, with the requirement that deflections sum to zero.

Figure 21 shows the aircraft altitude data (red circles) for the AR10 and AR20 groups at the seven visibility reporting locations. As is shown by the altitude data for Funter Bay (PANR, top left), all pilots provided this estimate as it was the first reporting location and we therefore have a large amount of data. Furthermore, the data points are tightly clustered around ~ 6,250 feet. The blue lines represent Gaussian noise distributions and function as a post-predictive check for how well the model fits the data. As is shown for the Funter Bay (PANR) location, the blue lines are tightly clustered, and we therefore have a precise estimate of the central tendency. On the other extreme, we only have a few data points for the altitudes at the Haines location (bottom right). This is because only six pilots (four AR10 pilots and two AR20 pilots) continued their flight towards the destination airport. Here, we have a wide dispersion of the noise distributions (i.e., blue lines), indicating a large uncertainty regarding the central tendency. Nevertheless, the Bayesian model incorporates uncertainty in a natural way and can still provide an estimate of the central tendency and allow comparisons between groups (i.e., contrasts).

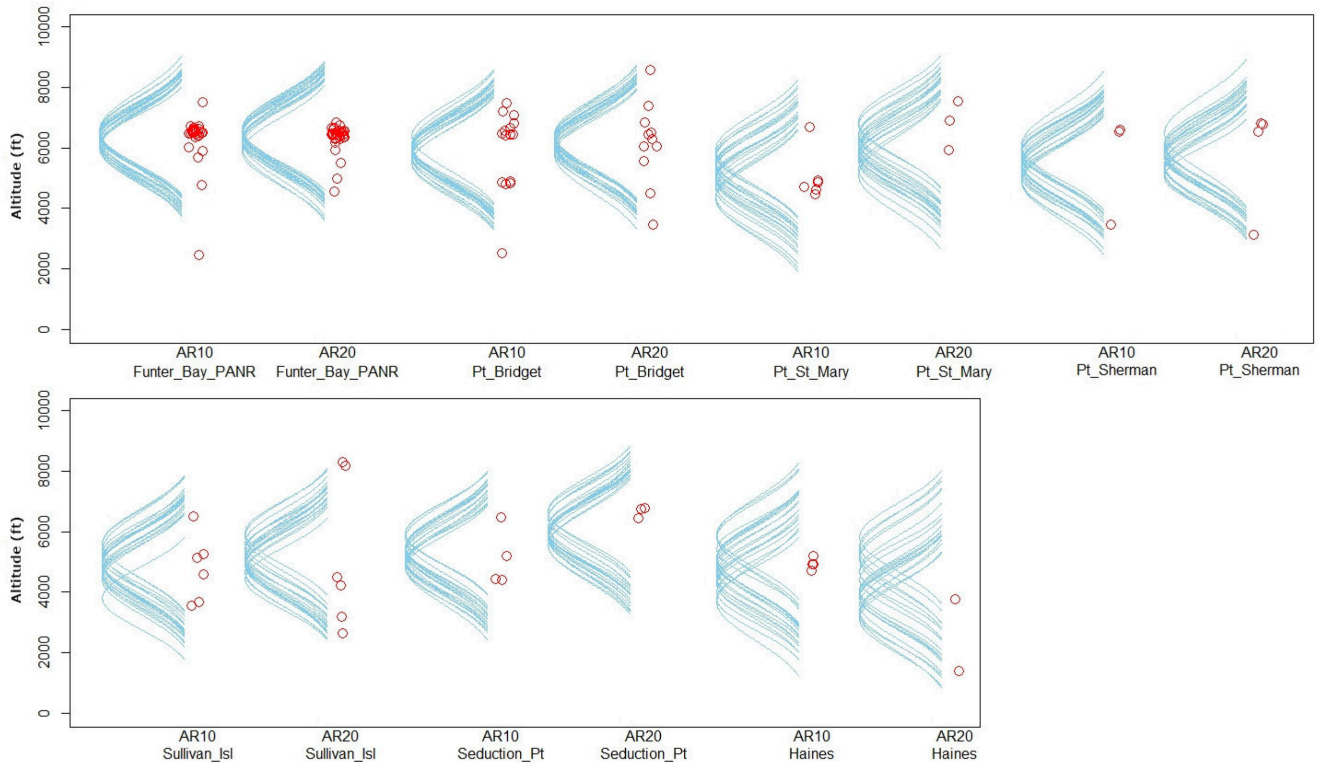


Figure 21. Individual aircraft altitudes (red circles) for the AR10 and AR20 groups at the seven visibility estimation times. The blue lines represent Gaussian noise distributions and provide a posterior check for how well the model fits the data.

The analysis showed a non-credible main effect of altitude for the AR10 and AR20 data (mean difference = - 243 feet, 95% HDI between -729 to 199 feet with the value 0 included within the 95% HDI), indicating that overall the two groups were at similar altitudes during the visibility reporting. Furthermore, posterior contrasts showed no credible differences between the AR10 and AR20 groups at the seven reporting locations. All posterior mean differences ranged between 12-450 feet with the value 0 included in the 95% HDI.

4.6 Out the window visibility reports

During the simulation runs, we queried pilots to provide an estimate of the forward visibility at seven different locations. In a first analysis, we wanted to assess any potential differences between the AR10 and the AR20 groups at the seven reporting locations. For the analysis, we used a model from Kruschke (2014) for a metric predicted variable (i.e., reported visibility) with multiple nominal predictors (i.e., group and visibility reporting location). Figure 22 shows pilot visibility estimates at the seven probe locations.

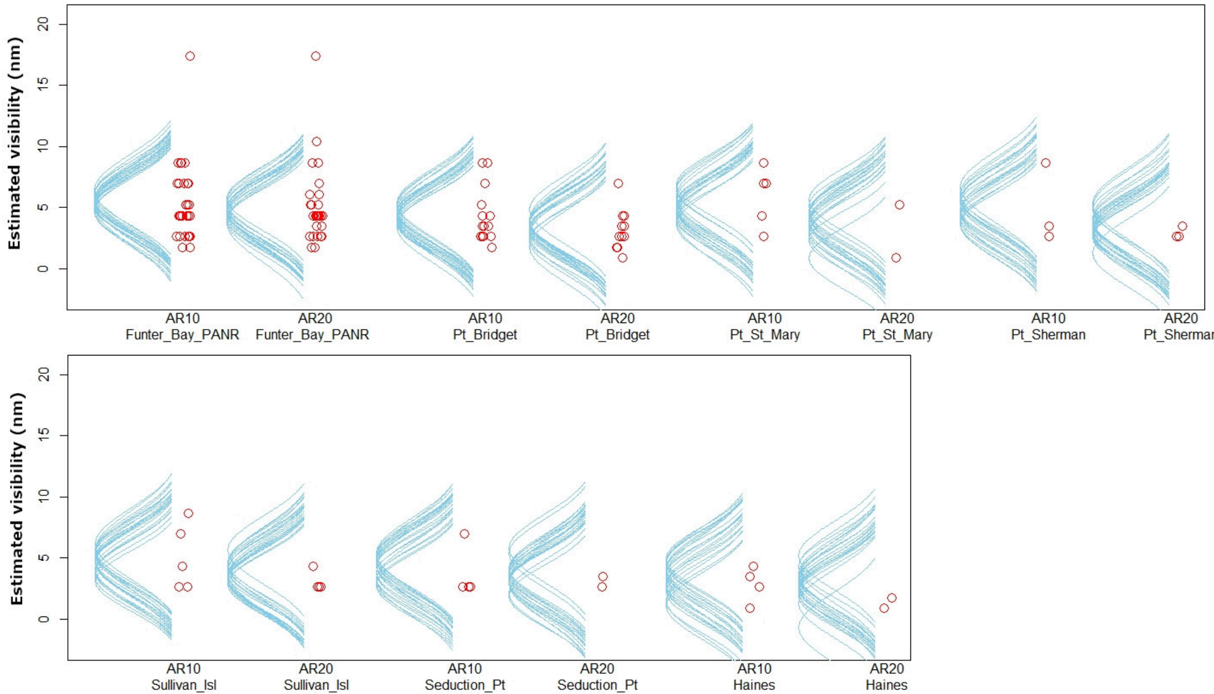


Figure 22. Individual visibility estimates (red circles) for the AR10 and AR20 groups at the seven visibility probe locations.

As shown in Figure 22, the reported visibilities from pilots in both groups are highly variable at each of the visibility probe locations. That is, there is no consensus among pilots with regards to the forward visibility. Posterior contrasts for the visibility estimates at the seven locations showed no credible differences between the AR10 and AR20 groups, all difference contrasts had the value 0 included in the 95% HDI.

In a second analysis, we estimated the correspondence between the reported visibility (from the simulator) and the estimated visibility (from pilots). At each probe location, there was a slight time difference between pilots' visibility reports (some pilots were quicker to report than others were), yielding a slight difference in the reported visibility. For the Funter Bay PANR location, the mean reported visibility (from the simulator) was 12.9 nm (*SD*=1.9) with a mean estimated visibility (from pilots) of 5.2 nm (*SD*=3.1) yielding a mean total error (i.e., the absolute value of reported visibility – estimated visibility) of 7.9 nm (*SD*=2.6). For the Pt. Bridget location, the mean reported visibility was 7.4 nm (*SD*=1.3) with a mean estimated visibility of 3.8 nm (*SD*=2.0) and a mean total error of 3.8 nm (*SD*=2.3). For the Pt. St. Mary location, the mean reported visibility was 5.9 nm (*SD*=0.53) with a mean estimated visibility of 5.1 nm (*SD*=2.7) and a mean total error of 2.2 nm (*SD*=1.8). For the Pt. Sherman location, the mean reported visibility was 5.4 nm (*SD*=0.4) with a mean estimated visibility of 3.9 nm (*SD*=2.4) and a mean total error of 2.7 nm (*SD*=0.7). For the Sullivan Island location, the mean reported visibility was 5.3 nm (*SD*=0.4) with a mean estimated visibility of 4.4 nm (*SD*=2.5) and a mean total error of 2.5 nm (*SD*=0.7). For the Seduction Pt. location, the mean reported visibility was 4.8 nm (*SD*=0.52) with a mean estimated visibility of 3.5 nm (*SD*=1.74) and a mean total error of 2.0 nm (*SD*=0.5). Finally, for the Haines location the mean reported visibility was 1.9 nm (*SD*=1.1) with a mean estimated visibility of 2.3 nm (*SD*=1.4) and a mean total error of 0.6 nm (*SD*=0.7).

To analyze these data, we used the reported visibility (x) and corresponding visibility estimates (y) in a robust linear regression model by Kruschke (2014). In the model, each predicted y value is computed as $y = \beta_0 + \beta_1 x$ where β_0 is the y-intercept (where the regression lines intersect the y axis when x=0) and β_1 is the slope (indicates how much y increases when we increase x by 1). To be robust against outliers, the model uses a *t*-distribution for the noise distribution instead of a normal distribution (i.e., Gaussian distribution).

The left side of Figure 23 illustrates a hypothetical example where there is a perfect correspondence between the reported visibility (from the simulator) and the estimated visibility (from the pilots). That is, for example, if the simulated visibility is 10 miles pilots also report a visibility of 10 miles. This is illustrated by the fact that all visibility estimates (black circles) line up perfectly on the regression line. The right-side graph of Figure 23 shows pilot visibility estimates from the present study. In the graph, the red line corresponds to the regression line in the hypothetical example (left graph). As is shown in the right graph, very few visibility estimates line up with the red line. On the contrary, most of the data points are below the red line indicating that pilots underestimated the simulated visibility, with points above the red line indicating that pilots overestimated the simulated visibility. The underestimation of simulated visibilities is similar to the results found by Ahlstrom et al. (2019). Despite this, pilots in the present study did report an increased visibility as the simulated visibility increased. This is indicated by the positive slopes of the credible regression lines (blue lines); as the reported visibility increases (x-axis), there is a corresponding increase in the estimated visibility (y-axis). The outcome of the regression analysis showed a credible slope (blue horizontal lines) with a β_1 mode = 0.17 and a credible intercept (β_0) mode = 2.3.

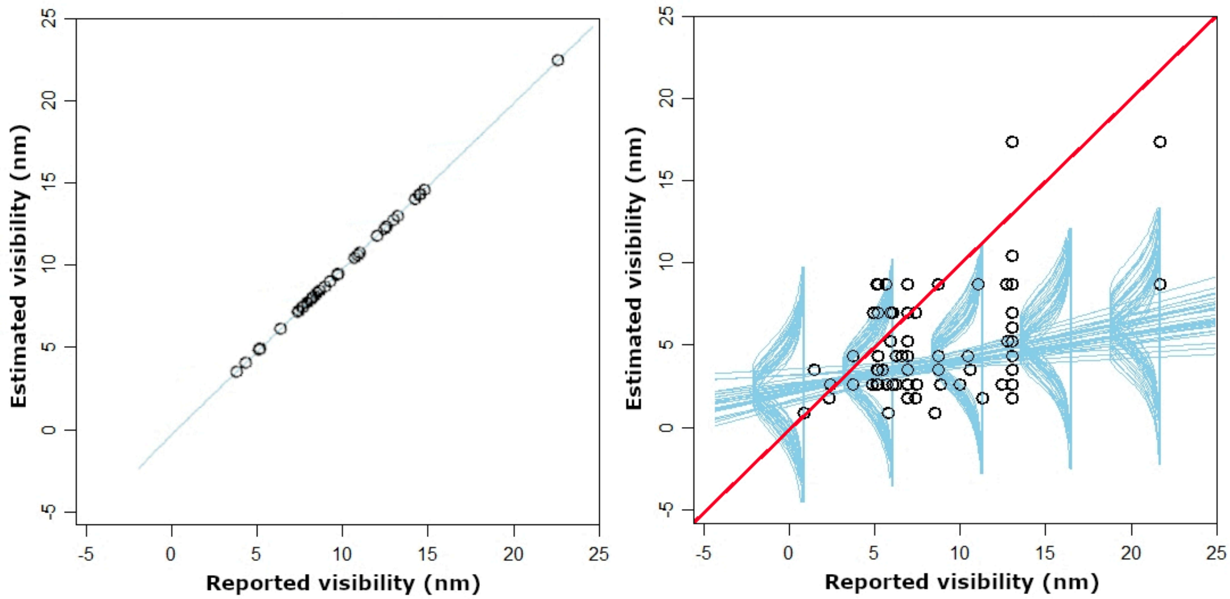


Figure 23. Linear regression on pilot visibility estimates (black circles) with a perfect correspondence (hypothetical) between reported and estimated visibilities (left) versus the visibility estimates from the present study (right).

We also wanted to compare the correspondence between the reported visibility (from the simulator) and the estimated visibility (from pilots) from pilot reports in the current simulation and pilot reports from the Ahlstrom et al. (2019) simulation. For this analysis, we used an error measure (i.e., the absolute value of the reported visibility minus the estimated visibility) for each pilot. However, because the visibility error increases with an increased reported visibility, and the fact that the two studies used different reported (i.e., simulated) visibilities, we only compared the estimated visibilities for reported visibilities in the 11to 13-mile range. The Ahlstrom et al. (2019) study used two different groups during the simulation; a Control group (AR0Cont) that did not have access to a distance-based AR during the simulation and an Experimental group (AR0Exp) that had access to a distance-based AR during the simulation. For the analysis, we used a model from Kruschke (2014) for a metric predicted variable (i.e., reported visibility) with one nominal predictor (i.e., group [AR0C, AR0E, AR10, and AR20]).

Figure 24 shows the outcome of the visibility error analysis. As shown in the figure, the error data from the present simulation (AR10 and AR20) have a similar estimate of the central tendency (i.e., mean) as the error data from Ahlstrom et al. simulation (AR0Cont and AR0Exp). Furthermore, for all four groups there is a wide dispersion of the estimated visibilities, indicating a low intra-group consistency for assessing the forward visibility when the reported visibilities are the 11-13-mile range.

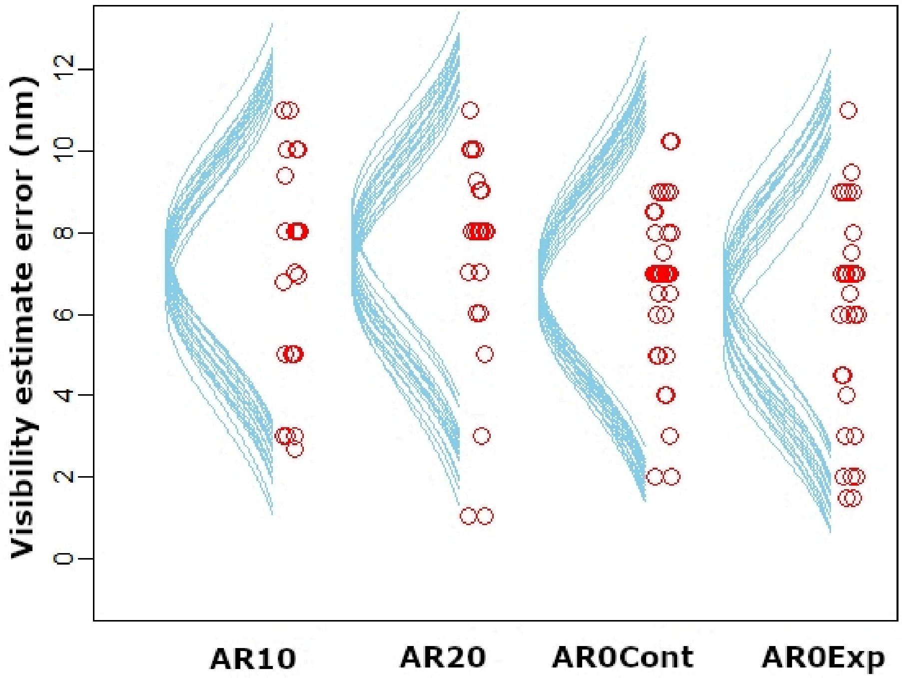


Figure 24. Visibility estimate errors (nm) for the AR10 and AR20 groups from the present simulation and the AR0Cont and AR0Exp groups from the Ahlstrom et al. (2019) simulation. Only reported (from the simulator) visibilities in the 11-13 nm range was used for this comparison.

The posterior mean error for the data in Figure 24 was 7.2 nm for the AR10 group (95% HDI from 6.3 to 8.0), 7.5 nm for the AR20 group (95% HDI from 6.6 to 8.3), 6.7 nm for the AR0Cont group (95% HDI from 6.0 to 7.4), and 6.4 nm for the AR0Exp group (95% HDI from 5.5 to 7.1). Posterior contrasts for all possible group comparisons showed no credible differences, the value 0 was included in all 95% HDIs. This implies that for reported (simulated) visibilities in the 11-13 nm range, the four groups are equivalent with regards to estimating the forward visibility.

For the present simulation data, we also assessed if pilot age and pilot certification (i.e., VFR-only and IFR-rated) affected the visibility estimates. While we found no credible effect of pilot age (β_1 mode = -0.02; 95% HDI from -0.06 to 0.02) on visibility estimates; there was a credible difference between VFR-only and IFR-rated pilots in that IFR-rated pilots provided higher visibility estimates (mean difference mode = -1.29; 95% HDI between -2.38 and -0.15) than VFR-only pilots.

In summary, there is little consensus among pilots on the forward visibility as the estimates are highly variable at each of the visibility probe locations. Furthermore, the outcome also shows that pilots underestimated the simulated visibility, as was the case with previous studies (e.g., Ahlstrom et. al., 2019). When comparing visibility estimate errors from the present simulation with visibility estimate errors from the Ahlstrom et al. simulation, we found no credible differences between groups for visibility estimates in the 11-13 nm range. All groups were equivalent with regards to estimating the forward visibility. While we did not find a credible effect of pilot age on visibility estimates in the present simulation, there is a credible difference between VFR-only and IFR-rated pilots in that IFR-rated pilots provide higher visibility estimates.

4.7 Decision making reports

In this section, we present data on pilot flight decisions like turning around, deviating to alternate airports, or continuing flight towards the destination airport at Skagway. Because we were using a time-based AR, rather than a distance-based AR (Ahlstrom et al., 2019), we hypothesized that the AR would provide more intuitive information for pilots to make flight decisions as pilots commonly use time-based information while in-flight (e.g., clearance times, estimated time in route, and fuel capacity time). We further hypothesized that the 20-mile lead-time condition (i.e., AR20) would yield different flight decisions compared to the 10-mile lead-time condition (i.e., AR10) as pilots had more time to evaluate weather conditions along the route of flight and more time to assess different flight alternatives.

Figure 25 shows the six flight alternatives chosen by pilots. The first alternative (Figure 25, left), turn around, was a decision where pilots decided not to continue flight but to turn around and return to the departure location. The next four alternatives (Figure 25, middle) were for decisions to deviate to alternate airports (i.e., Hoonah, Juneau, Gustavus, and Haines). The last alternative (Figure 25, right) was for continuing the flight to the destination airport at Skagway. As is shown in Figure 25, the decisions by the AR10 and AR20 pilots were similar, with a difference of only two for four of the alternatives (i.e., turn around and deviations to Hoonah, Juneau, and Haines) and a difference of one for the remaining two alternatives (i.e., deviation to Gustavus and continuing the flight to Skagway). Because of the low number of flight decisions and similarity between the two groups, there is no meaningful or important difference with regards to flight decisions between the 10- and 20-mile lead-time conditions.

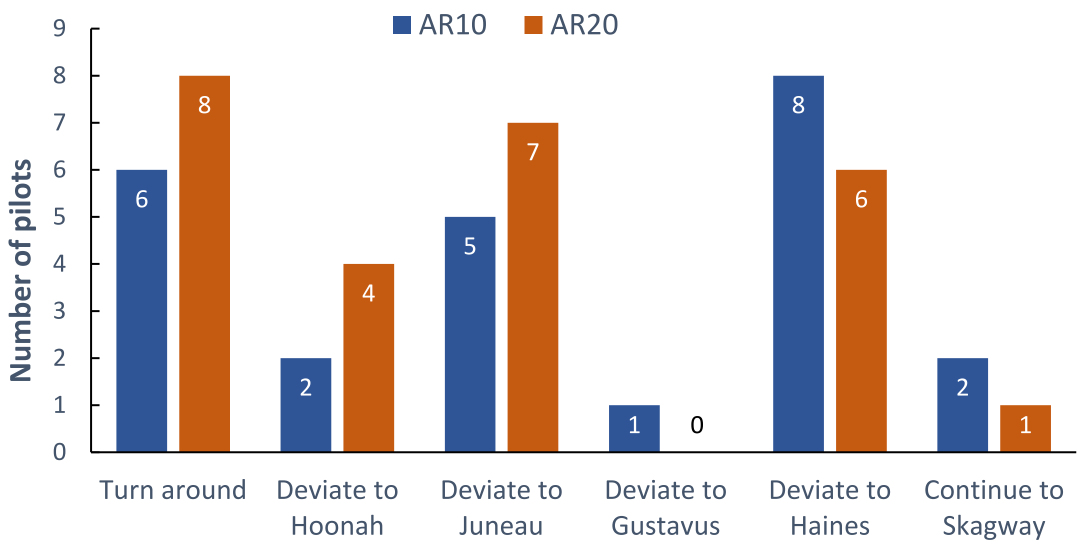


Figure 25. Pilot flight decisions for turning around, deviating to alternate airports, or continuing flight to the destination airport at Skagway

We also analyzed the scenario time when pilots made their flight decisions. Table 8 summarizes the mean decision times (min) and dispersions (*SD*s) for the six decision alternatives. For the turnaround, deviate to Hoonah, and deviate to Haines, the AR20 pilots made their decision earlier than the AR10 group. However, due to the small samples for each alternative, combined with the large *SD*s, none of the posterior contrasts were credible. All contrasts had the value 0 included in the 95% HDI. For deviations to Juneau, the decision times are similar with a mean decision time of 13 min for the AR10 group and 14 min for the AR20 group. Only one pilot in the AR10 group decided to deviate to Gustavus, 10 min into the scenario. Finally, for decisions to continue flight to the destination airport at Skagway, two pilots in the AR10 group and one pilot in the AR20 group made that decision between 41-59 min into the scenario.

Table 8. Pilot flight decisions with mean decision-times (min) and dispersions (SDs)

Group	**Turn around**	**Deviate to Hoonah**	**Deviate to Juneau**	**Deviate to Gustavus**	**Deviate to Haines**	**Continue to Skagway**
AR10	*M*=19 (*SD*=9)	*M*=13 (*SD*=3)	*M*=13 (*SD*=6)	10	*M*=36 (*SD*=6)	*M*=41 (*SD*=2)
AR20	*M*=16 (*SD*=9)	*M*=11 (*SD*=7)	*M*=14 (*SD*=10)	--	*M*=24 (*SD*=14)	59

In summary, the 20-mile lead-time condition (i.e., AR20) did not yield different flight decisions compared to the 10-mile lead-time condition (i.e., AR10). Furthermore, pilots in the 20-mile lead-time condition did not make their flight decisions at different scenario times compared to pilots in the 10-mile lead-time condition.

5 Discussion

Common themes in General Aviation (GA) weather research include that pilots tend to fly too close to hazardous weather, have difficulty maintaining the recommended aircraft-to-cloud separation, and have difficulty making accurate estimates of the forward visibility (Ahlstrom et al., 2015a, 2015b, 2019a, 2019b; Ahlstrom & Dworsky, 2012; Coyne, Baldwin, & Latorella, 2008; Goh & Wiegmann, 2001; Wiegmann, Goh & O'Hare, 2002).

To assist pilots during flights in deteriorating weather, previous research has explored various ways to provide GA pilots with important in-flight information (Ahlstrom et al., 2019a). The potential effects of using weather displays with aircraft, terrain, and weather information while in flight (Zimmerman, 2013) is an increased Weather Situational Awareness (WSA) and an improved ability to assess the current visibility conditions to decrease the odds of VFR-into-IMC flights.

Ahlstrom et al. (2019a) investigated an Active Reminder (AR) concept where the weather display system tracks the aircraft and hazardous weather cell locations and alerts the pilot of future aircraft-to-weather conflicts. During simulation flights, pilots in an experimental group were shown a distance-based AR (i.e., a blue line from the aircraft position symbol to the storm cell) as soon as they were 20 nm away from 30 dBZ precipitation cells. The intent was to assess if GA pilots would stay farther away from any thunderstorm cells (FAA Advisory Circular AC 00-24C: Thunderstorms, 2013) using the AR compared to a control group that did not have access to an AR display. The results showed a clear benefit of the AR display with a credibly higher WSA for the experimental group compared to the control group (no active reminder/blue line). However, a distance-to-weather analysis revealed that both groups flew too close to hazardous weather with a mean distance-to-weather of 17.2 to 18.1 miles (95% HDIs).

Furthermore, Ahlstrom and Racine (2019c) investigated pilot weather assessments and pilot ability to assess the out-the-window visibility using two experimental conditions: sectional map distance training and the use of a Slant-range rule of thumb. The result showed that the visibility estimate errors for the Slant-range group were on average half the size compared to the visibility estimate errors for the Control and the Map distance training groups. This shows a clear benefit of using the Slant-range rule of thumb when estimating in-flight visibility. The researchers concluded that with training on the Slant-range rule of thumb, coupled with a set of decision-making rules, pilots would be in a much better position to correctly assess the out-the-window visibility and make more informed flight decisions rather than continue flight into IMC.

The purpose of the present study was to investigate the impact of a time-based weather presentation AR on pilot weather-related behavior and decision-making. For many phases of flight, GA pilots tend to think, calculate, estimate, and make decisions using time-based information more than distance-based information. Unlike the distance-based AR in the Ahlstrom et al. study (2019a), the time-based AR showed a timer that informed pilots of the time-to-contact with storm cells. Furthermore, unlike the distance-based AR, the time-based AR used a lead-time before the AR timer was displayed. In a first condition, we presented pilots with a 10-mile lead-time (AR10 group) before reaching the FAA minimum recommended safe distance of 20 miles from a thunderstorm (i.e., 30 miles from the edge of the storm cell). In a second condition, we presented pilots with a time-based AR 20 miles (AR20 group) before reaching the FAA minimum recommended safe distance of 20 miles from a thunderstorm (i.e. 40 miles from the edge of the storm cell).

We found no important differences between the AR10 and AR20 groups with regards to aircraft altitude, AWOS usage, distance-to-weather, flight decision-making, and the ability of pilots to provide forward visibility estimates. This result implies that the difference in lead-time (i.e., 10 versus 20 miles) did not affect the flying behavior of pilots. Both pilot groups flew equally close to hazardous weather cells (i.e., $\geq$ 30 dBZ precipitation cells) with a mean distance-to-weather of 9.93 to 17.2 miles (95% HDIs). Even more striking, comparing the present distance-to-weather results with the distance-to-weather data from the Ahlstrom et al. (2019a) study showed that a time-based AR yields a much larger intra-group dispersion (e.g., SD) of the distance-to-weather data, expressed as a greater variability among pilots with regards to how closely they flew to hazardous weather cells.

Granted, there are many ways to display a time-based AR to pilots. In the present study, researchers only evaluated one time-based AR out of many possible display alternatives. The goal was to display a timer that would support pilots by providing information about the time-to-contact with hazardous weather. However, as the outcome shows, pilot weather-avoidance behavior is worse with a time-based AR compared to the weather-avoidance behavior using a distance-based AR. This outcome could imply that pilots are not using time for weather avoidance; instead, the weather-avoidance behavior is guided solely by distance from the aircraft to hazardous weather. The outcome could also imply that pilots had difficulty with the AR symbology. Therefore, further research is needed to disentangle the many aspects of time-based

ARs to improve WSA, keep the pilot at greater distances-to-weather, and allow enough time to perform diligent flight planning.

To date, the WTIC program has performed a variety of research projects aimed at improving the availability and usefulness of weather information for GA pilots. Many of these projects have focused on display information like the enhancement of weather presentation symbols and the development of automatic weather alerting functions (e.g., ARs). Nevertheless, all these enhancements rely on the *visual* interpretation of weather symbology. Pilots must detect weather symbols against the presentation background and be aware of state changes (e.g., symbol changes and/or color changes) that signify shifts in weather conditions.

Although weather symbology can be an effective way to present information to pilots, there are some complexities with a strictly *visual* presentation. For example, variations in weather presentations (i.e., colors and symbols) seem to affect pilot behavior and decision-making as different color and symbol combinations affect pilot visual scanning (Ahlstrom & Dworsky, 2012). Using different weather presentation symbologies also produces considerable variability in pilots' overall perception of symbol changes during flight, attributed to the change-blindness phenomena (Ahlstrom & Suss, 2014).

One way to make it easier for pilots to detect symbol or color changes, and thereby reduce the change blindness effect, is to increase the salience difference between symbols and the background. However, this strategy has proven difficult as well. For example, the effect of increasing METAR symbol salience against other map display features will only increase pilot detection performance by about 12% (Ahlstrom et al., 2019). Furthermore, although enhancing symbol salience may help improve change-detection performance, it does not guarantee that these enhancements will be adequate to draw attention to display symbols in a dynamic cockpit environment (Ahlstrom & Racine, 2019).

An alternative strategy that does not solely rely on a visual interpretation is to combine different perceptual modalities. For example, research has been done where weather symbol changes were coupled with tactile vibrations. In a study by Ahlstrom et al. (2015), an experimental group of pilots wore a bracelet that vibrated when a weather symbol change occurred on the weather presentation. This coupling between visual and tactical information increased pilot WSA. However, the experimental group was unable to maintain safer separation from weather and to be more effective in avoiding IMC conditions than a control group that did not receive tactical vibrations. A possible explanation is that although the vibrating bracelet alerted the pilot of weather state changes, the pilot nevertheless had to visually inspect the weather presentation to see what had changed and where.

A new concept for perceptual coupling, the Digital Copilot, is outlined by McCollum (2016). Within this concept, the visual channel is coupled with the auditory channel. Using speech recognition, pilots can request information and have the system read it out aloud. This concept allows for great flexibility; pilots can view the display only, or only hear the information read aloud, or use both display information and spoken information at the same time. More importantly, with regards to weather information, this concept does not solely rely on visual interpretation. Pilots do not have to look at a weather presentation while in flight; they can request that the system alert them of weather hazards by reading it out aloud.

Therefore, from the present results, we believe there are at least three areas that need to be addressed by future research. One is an assessment of the effectiveness of pilot training on how to interpret weather information on modern electronic displays. Another factor that needs further assessment is the potential effect of pilot training on how to translate weather information into enhanced flight decisions. Finally, we recommend research for future weather applications that explores other ways to provide important information of areas to avoid during flight. We believe the Digital Copilot could address all these areas at once. With the Digital Copilot, there is no need for pilots to look at weather presentation symbols while in flight. This might be the optimal way to support GA pilots for the safe, efficient, and strategic planning required to handle adverse weather conditions during flight.

6 References

Administration, F. A. (2008). *Pilots Handbook of Aeronautical Knowledge: FAA-H-8083-25B.* Washington: U.S. Department of Transportation.

Administration, F. A. (2013). Thunderstorms (Advisory Circluar AC 00-24C). District of Columbia: AFS-430.

Administration, F. A. (2016, May). U.S. Civil Airmen Statistics. Retrieved from https://www.faa.gov/data_research/aviation_data_statistics/civil_airmen_statistics/

Administration, F. A. (2017). *Aeronautical Information Manual (FAR/AIM Series).* Newcastle: Aviation Supply & Academics Inc.

Ahlstrom, U., & Dworsky, M. (2012). *Effects of Weather Presentation Symbology on General Aviation Pilot Behavior, Workload, and Visual Scanning (DOT/FAA/TC-12/55).* Atlantic City: FAA William J. Hughes Technical Center.

Ahlstrom, U., & Racine, N. (2019). *Symbol Salience Augments Performance in Cockpit Weather Displays (DOT/FAA/TC-19/31).* Atlantic City: FAA William J. Hughes Technical Center.

Ahlstrom, U., & Suss, J. (2014). *Now You See Me, Now You Don't: Change Blindness in Pilot Perception of Weather Symbology (DOT/FAA/TC-14/16).* Atlantic City: FAA Wiliam J. Hughes Technical Center.

Ahlstrom, U., Caddigan, E., Schulz, K., Ohneiser, O., & Dworsky, M. (2015). *Initial Assessment of Portable Weather Presentations for General Aviation Pilots (DOT/FAA/TC-15/42).* Atlantic City: FAA William J. Hughes Technical Center.

Ahlstrom, U., Caddigan, E., Schulz, K., Ohneiser, O., Bastholm, R., & Dworsky, M. (2015). *The Effect of Weather State-hange Notifications on General Aviation Pilots' Behavior Cognitive Engagement, and Weather Situation Awareness (DOT/FAA/TC-15/64).* Atlantic City: FAA William J. Hughes Technical Center.

Ahlstrom, U., Racine, N., & Hallman, K. (2019). *Assessments of Flight and Weather Conditions during General Aviation Operations (DOT/FAA-TC-19/33).* Atlantic City: FAA William J. Hughes Technical Center.

Ahlstrom, U., Racine, N., Caddigan, E., Schulz, K., & Hallman, K. (2019). *General Aviation Pilot Situation Assessment and Decision-Making During Flights in Deteriorating Visibility Conditions (DOT/FAA-TC-19/33).* Atlantic City: FAA William J. Hughes Technical Center.

Barnabas, A., & Sunday, A. O. (2014). Comparison of Allocation Procedures in a Stratified Random Sampling of Skewed Populations under Different Distributions and Sample Sizes. *International Journal of Innovative Science, Engineering & Technology, 1*(8), 218-225.

Coyne, J. T., Baldwin, C. L., & Latorella, K. A. (2008). Pilot Weather Assessment: Implications for Visual Flight Rules Into Instrument Meteorological Conditions. *International Journal of Aviation Psychology, 18*(2), 153-166. doi:10.1080/10508410801926756

Goh, J., & Wiegmann, D. A. (2001). Visual Flight Rules into Instrument Meteorological Conditions: An Empirical Investigation of the Possible Causes. *International Journal of Aviation Psychology, 11*, 359-379. doi:10.1518/0018720024497871

Kruschke, J. K. (2014). *Doing Bayesian Data Analysis; A Tutorial with R, JAGS, and Stan, 2nd edition.* Orlando: Academic Press.

McCollum, M. (2016, May). The Solo Pilot Gets a Second Set of Eyes. The MITRE Corporation. Retrieved from https://www.mitre.org/publications/project-stories/the-solo-pilot-gets-a-second-set-of-eyes

NOAA National Weather Service. (2019). Aviation Digital Data Service (ADDS). Retrieved from https://www.aviationweather.gov/adds/

Plummer, M. (2003). JAGS: A Program for Analysis of Bayesian Graphical Models Using Gibbs Sampling. *Proceedings of the 3rd International Workshop of Distributed Statistical Computing.* Vienna. Retrieved from http://www.r-project.org/conferences/DSC2003/Proceedings/Plummer.pdf

Plummer, M. (n.d.). Bayesian Graphical Models Using MCMC. R Package Version 3-5 [Computer software]. Retrieved from http://CRAN.R-project.org/ package/rjags

Roque, N. A., & Boot, W. R. (2016). A Tool for Assessing Mobile Device Proficiency in Older Adults: The Mobile Device Proficiency Questionnaire. *Journal of Applied Gerontology*, 1-26. doi:10.1177/0733464816642582

Wiegmann, D. A., Goh, J., & O'Hare, D. (2002). The Role of Situation Assessment and Flight Experiences in Pilots' Decisions to Continue Visual Flight Rules into Adverse Weather. *Human Factos*, 189-197. doi:10.1177/0733464816642582

Zimmerman, J. (2013, September). Thunderstorm Flying in the Age of Datalink Weather. *Air Facts Journal*. Retrieved from http:// airfactsjournal.com/2013/09/thunderstorm-flying-in-the-ageof-datalink-weather/

A NEXRAD Valid Now

1. Background

As part of a continuing relationship between the FAA WTIC program and the Aviation Applications program at the National Center Atmospheric Research (NCAR), several projects have been proposed to address knowledge gaps identified by prior cooperative research efforts. To address the potential for GA pilots to incorrectly recognize NEXRAD as latent weather information, NCAR developed the NEXRAD Valid Now (NVN) concept, observed radar information from the past utilized to depict current weather for the purpose of nullifying NEXRAD delay. Regarding NEXRAD as being current, by not accounting for the inherent delay in NEXRAD information, can be extremely hazardous to GA pilots, especially in the case of rapidly developing thunderstorms.

To obtain further insight, NCAR researchers developed various algorithms to produce NVN imagery. They performed a verification analysis of selected NVN cases that resulted in a degree of error of approximately plus or minus 1½ miles from the edge of the current location of a storm cell. NCAR researchers then began to determine if the nullified delay NVN imagery would be a benefit to decision-making of GA pilots, as opposed to the presumption that GA pilots are able to accurately extrapolate latent NEXRAD information to the current location during in-flight operations.

To determine if there would be a benefit to GA pilot decision-making by introducing NVN imagery to GA pilots, NCAR researchers proposed a battery of sequential inquiries. The first inquiry is relevant to the GA pilot utilization of NEXRAD. Do GA pilots recognize the delay in NEXRAD, in other words, are they aware that, on average, NEXRAD information can update every five minutes, but it can be up to 15 to 20 minutes old when presented in the cockpit? If GA pilots are aware of NEXRAD delay, a *limited* degree of error should be reflected in their assessment of the storm's current location. If GA pilots are not aware of NEXRAD delay, a *significant* degree of error should be reflected in their assessment of the storm's current location. The second, third and fourth inquiries are relevant to GA pilot utilization of NVN imagery. When GA pilots are presented with NVN, do they trust the imagery? When GA pilots are presented NVN imagery, what degree of error is in their assessment of the storm's current location? When GA pilots utilize NVN imagery vs. utilizing NEXRAD, how does the degree of error in their assessment of the storm's current location differ? Finally, how does the degree of error in NVN imagery in itself (e.g., plus or minus 1½ miles of the current storm's location) differ with the degree of error in GA pilot assessment of the storm's current location when utilizing NEXRAD?

Researchers at NCAR are endeavoring to determine if the NVN concept will benefit GA pilot decision making when encountering hazardous precipitation. Researchers within the FAA WTIC program supported this effort by providing a notional assessment of the NVN concept in conjunction with the Time-to-Contact flight simulation study. The results of this assessment provided GA pilot feedback on the NVN concept to aid NCAR in furthering the cooperative effort of the FAA and NCAR to enhance safety in the GA community.

To determine the degree to which a GA pilot understands the NVN concept, they viewed a short briefing that included a training overview of the concept, a visual demonstration, and then completed an NVN questionnaire.

The focus of the training was to instruct the GA pilot on two main constructs that define the NVN concept: 1) that the NVN intends to eliminate the inherent time delays in NEXRAD imagery; 2) any point on the edge of an NVN image is an average of 1.5 miles off from the actual storm in any direction, which would result in errors in the size and/or location of NVN imagery. There was a short briefing about NVN general concepts and objectives. The participants viewed the briefing at their own pace.

After the GA pilot completed the training material, he or she viewed a notional visual demonstration of NVN imagery. The NVN imagery was overlaid on a map that included a mileage scale. First, the GA pilot was shown a NEXRAD depiction of a storm cell on the left of the screen, and then an NVN depiction of the same storm cell in the center of the screen. The purpose of consecutively showing these two depictions was to demonstrate visually that the NVN depiction has removed the delay from the previously shown NEXRAD depiction. Next, the participant was shown several variations of the same NVN depiction. The purpose of this was to demonstrate how an NVN image could appear larger, smaller and/or in a different location due to the possible error that could be encompassed around or enclosed within the actual location of a storm.

Likewise, after the GA pilot viewed the visual demonstration of the NVN concept, the researcher asked if there was anything they did not understand about the subject matter. After viewing the demonstration, the GA pilot completed a survey to determine to what degree the GA pilot understood the NVN concept, and to provide feedback on the overall concept.

2. NEXRAD Valid Now (NVN) Survey Results

After viewing the NVN briefing, the participants completed a short survey to demonstrate their understanding of the concept and provide feedback on their opinions of the initial concept. The first three questions related to the participants' understanding of the concept. For the first question we asked, "Based on your NVN training, how much delay do you perceive in NVN imagery*?*" We used the following five response categories: 1) No Delay, 2) Small Degree of Delay, 3) Variable Amount of Delay, 4) Large Degree of Delay, and 5) Too Much Delay. Most pilots selected the correct answer, 1) *No Delay* (31 pilots or 62%). Participants also selected 2) Small Degree of Delay (15 participants or 30%) or 3) Variable Amount of Delay (4 participants or 8%). This indicates that not all participants completely understood the level of delay in the NVN imagery.

The second question, "How much error do you perceive?" demonstrated a similar pattern. We used the following five response categories: 1) No Error, 2) Smaller Degree of Error, 3) Variable Amount of Error, 4) Larger Degree of Error, and 5) Too Much Error. The majority of the participants chose the correct answer of a small degree of error (28 participants or 56%). Pilots also selected a variable amount of error (17 participants or 34%) or a larger degree of error (5 participants or 10%).

We also asked: "When using the terms delay and error in the context of NVN imagery, how does their meaning relate to one another?" We used the following five response categories: 1) They Mean Different Things, 2) Not Very Close in Meaning, 3) Moderately Close in Meaning, 4) Very Close in Meaning or 5) They Mean the Same Thing. Most pilots correctly chose that delay and error mean different things (36 pilots or 72%).

We also asked participants how they would rate the weather situational awareness when comparing NEXRAD with NVN imagery. We used a scale of 1-5 with 1) Much Better with NEXRAD, and 5) Much Better with NVN. Pilots responded with a mean of 3.84 (*SD* 1.13). We asked: "How confident would you be in your perception of a storm's location?" We used a scale of 1) No Confidence to 5) Extremely Confident. Pilots responded with a mean of 3.36 (SD 0.72). We asked: "Which of the following do you feel is the most effective usage of NVN?" We used five categories of responses; 1) Determine Where a Storm Will Be in 15 Minutes, 2) Determine the Exact Location, Size, and Shape of a Storm, 3) Determine How to Navigate Through a Storm, 4) Determine How to Avoid a Storm, and 5) Determine a Safe Distance to Fly Near a Storm. The slight majority of participants selected 4) Determine how to avoid a Storm (26 participants or 52%).

While most pilots felt they understood the concept, there was some variability in their responses when they were asked to select the correct graphical representation of the NVN imagery. However, when responding to a multiple choice regarding descriptive statements regarding the differences between NVN and NEXRAD only 21 participants (42%) answered correctly.

During the debrief, pilots responded that they felt the NVN imagery basically displayed what they attempted to mentally calculate in their heads using NEXRAD information. They expressed concern that some pilots may use the more accurate information for unsafe purposes, such as flying even closer to weather or flying through holes in the weather. Almost all of them responded that they felt the 1½ miles of potential error to be tolerable. Most felt the upper bounds of the comfortability with error would be about 5 miles. Overall, most of the pilots thought NVN would be a useful tool worth pursuing.

3. NEXRAD Valid Now (NVN) Briefing and Training Material

The following is the briefing that each participant viewed. The briefing contains a short explanation of the NVN concept and then presents graphical examples to demonstrate it.

Briefing for

NEXRAD Valid Now (NVN)

Aviation Weather Research Branch (ANG-C61)
Weather Technology In the Cockpit (WTIC) Program

Here are a few things to know upfront about <u>**NEXRAD Valid Now**</u> before you begin your training**:**

- First, the acronym for 'NEXRAD Valid Now' is **NVN**

- What is **NEXRAD**?
  - radar information of the movement, location and intensity of precipitation that can be 15 to 20 minutes old (delayed) when presented to a pilot in the cockpit.

- What is **NVN**?
  - radar information (NEXRAD), <u>translated and depicted in its estimated current position</u>**,** for the purpose of <u>removing the NEXRAD delay.</u>

- It is important to understand that **NVN** and **NEXRAD** are different depictions of the same weather.

- Before we go over the differences of these 2 depictions, please familiarize yourself with the following terms:

  - <u>Error</u> – inaccuracy in the size, shape and position of information.
  - <u>Delay</u> – refers to the time between detection and delivery of information.

- **NEXRAD**
  - Advantage – there is <u>*no* significant error</u> in the information presented
  - Disadvantage – The information presented is <u>delayed</u>

- **NVN**
  - Advantage – There is <u>*no* delay</u> in the in the information presented
  - Disadvantage – The information presented has <u>error</u>

The delay in NEXRAD
NVN removes this delay!

On average, NEXRAD information can update every five minutes, but can be up to 15 to 20 minutes old when presented in the cockpit.

But, there is a **Catch…**

Remember that **NVN** is: radar information (NEXRAD), translated and depicted in its <u>**estimated**</u> current position, for the purpose of removing the NEXRAD delay.

Here is the **Catch…**

Although **NVN** has no delay, because NVN is an *estimation* of current weather, it has a certain degree of <u>**error**</u> in the size, shape, and position of the information.

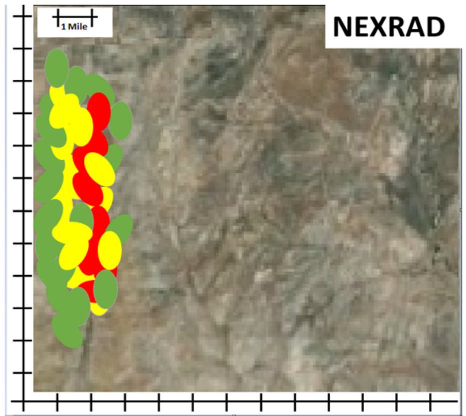
How much error is in NVN?

- The average error in an NVN image can be up to 1.5 miles that can exist from any point on the edge of the actual storm in any direction.

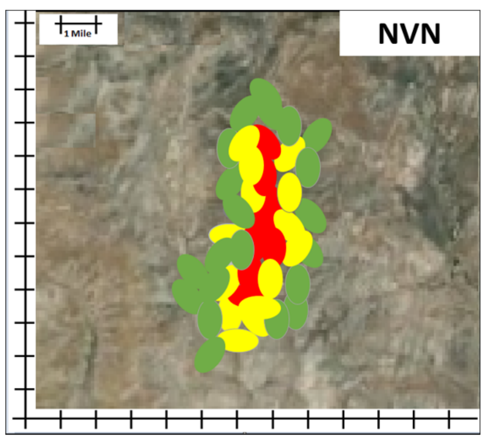
Here is another way to visualize the error in NVN:

- An NVN image could appear larger, smaller, differently shaped or in a different location due to the 1 ½ miles of possible error depicting the actual dimensions and location of a storm.

Note - The NEXRAD, NVN and thunderstorm images you are about to see are only notional images and are provided for demonstration and training purposes.



- Here is a **NEXRAD** image depicted above, which may include up to 20 minutes of delay.
- On the next slide, I am going to show you a depiction of NVN that represents the same thunderstorm.



- Here is an **NVN** image depicting the same storm shown on the previous slide. Note that NVN image is shifted to the East as compared with the previous image.
- Notice that NVN image and the NEXRAD image shown on the previous slide use the same precipitation intensity colors.

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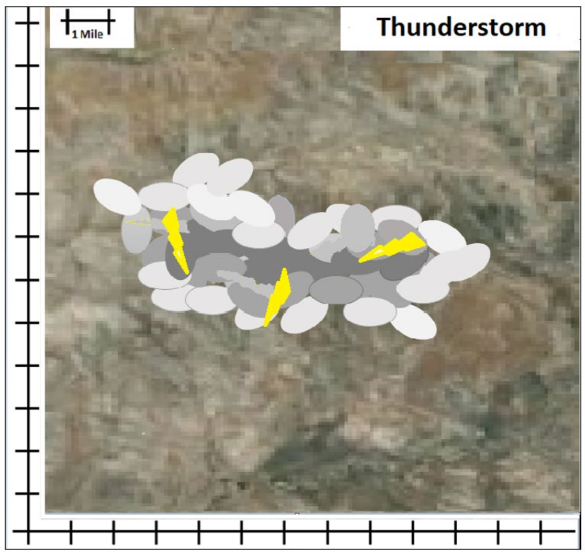
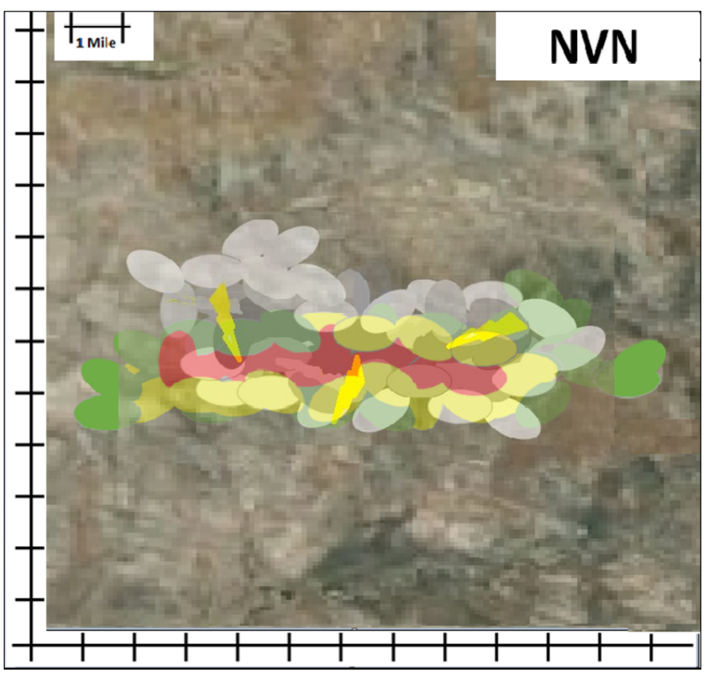
- Now we are going to show you a thunderstorm image followed by several variations of how NVN images that represent that thunderstorm might appear based on the 1 ½ mile degree of error you just learned about.

- Please take the time to compare the thunderstorm image with the NVN images keeping the 1 ½ mile degree of error in mind.

Here, depicted in different shades of gray, is a thunderstorm from a bird's eye view.



Here, depicted in red, yellow and green is one possible way NVN could represent the thunderstorm you viewed.



Here is a transparent overlay of the thunderstorm. Notice the approximate 1 1/2 miles of error around the edge of the storm in the areas where the NVN image and the thunderstorm do not overlap.

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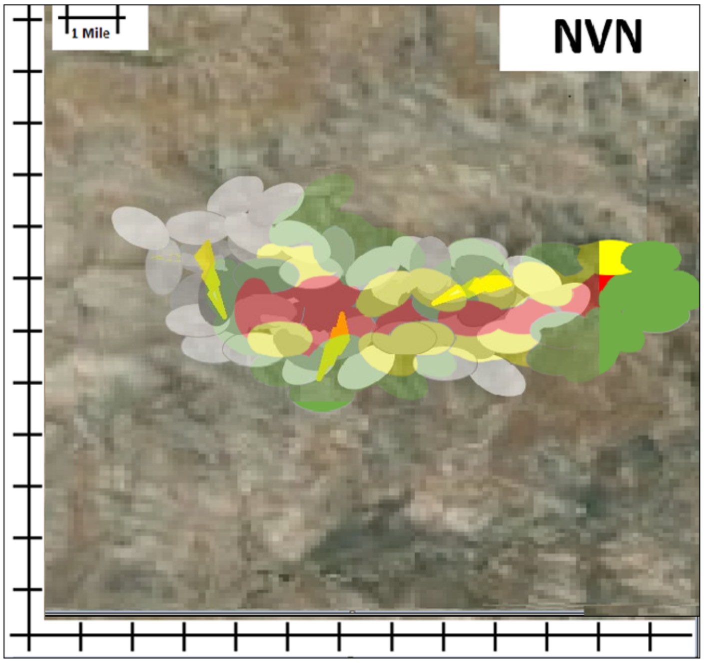
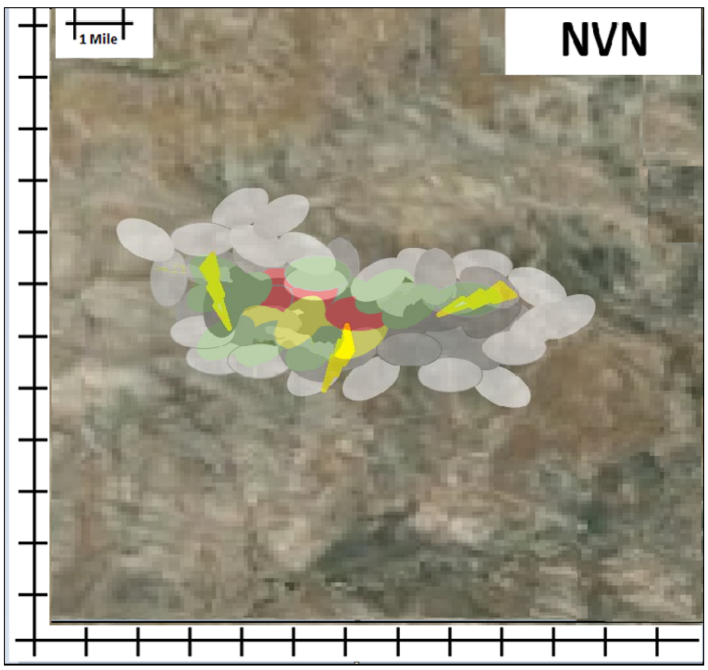
Here, depicted in red, yellow and green is one possible way NVN could represent the thunderstorm you viewed.



Here is a transparent overlay of the thunderstorm. Notice the approximate 1 1/2 miles of error around the edge of the storm in the areas where the NVN image and the thunderstorm do not overlap.

13

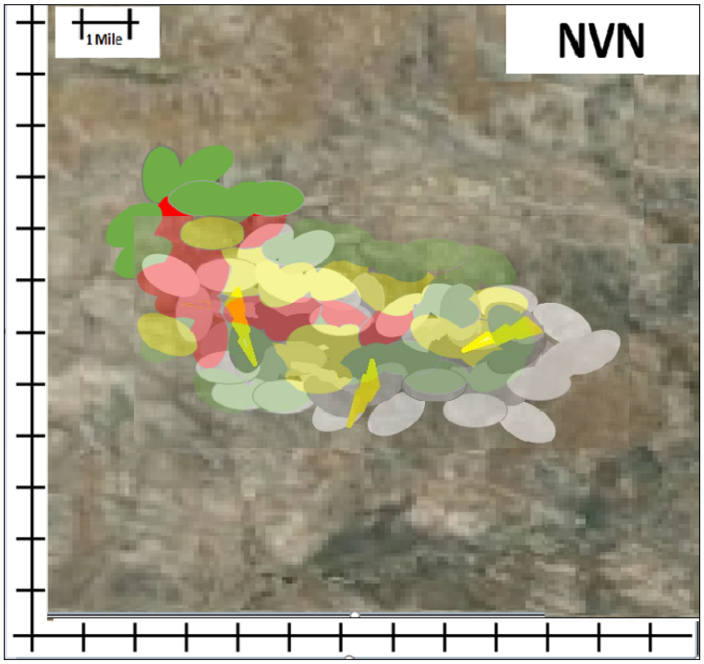
Here, depicted in red, yellow and green is one possible way NVN could represent the thunderstorm you viewed.



Here is a transparent overlay of the thunderstorm. Notice the approximate 1 1/2 miles of error around the edge of the storm in the areas where the NVN image and the thunderstorm do not overlap.

14

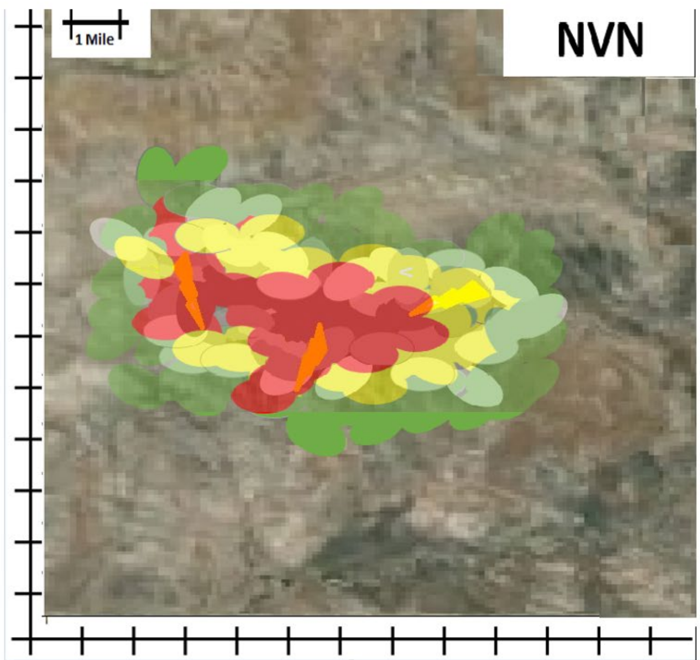
Here, depicted in red, yellow and green is one possible way NVN could represent the thunderstorm you viewed.



Here is a transparent overlay of the thunderstorm. Notice the approximate 1 1/2 miles of error around the edge of the storm in the areas where the NVN image and the thunderstorm do not overlap.

15

Here, depicted in red, yellow and green is one possible way NVN could represent the thunderstorm you viewed.



Here is a transparent overlay of the thunderstorm. Notice the approximate 1 1/2 miles of error around the edge of the storm in the areas where the NVN image and the thunderstorm do not overlap.

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Summary

- **NEXRAD**: radar information of the movement, location and intensity of precipitation that can be 15 to 20 minutes old (delayed) when presented to a pilot in the cockpit.

- **NVN**: radar information (NEXRAD), translated and depicted in its estimated current position**,** for the purpose of removing the NEXRAD delay.

- Although **NVN** has no delay, because NVN is an *estimation* of current weather, it has a certain degree of **error** in the size, shape, and position of the information.

- The average error in an NVN image can be up to 1.5 miles that can exist from any point on the edge of the actual storm in any direction.

- An NVN image could appear larger, smaller, differently shaped or in a different location due to the 1 ½ miles of possible error depicting the actual dimensions and location of a storm.

1. **NEXRAD Valid Now (NVN) Survey**

The following questions are associated with the training you received on <u>NVN Imagery</u>:

1. Based on your NVN training, how much <u>delay</u> do you perceive in NVN imagery?

No Delay	Small Degree of Delay	Variable Amount Delay	Large Degree of Delay	Too Much Delay
☐1	☐2	☐3	☐4	☐5

2. Based on your NVN training, how much <u>error</u> do you perceive in NVN imagery?

No Error	Smaller Degree of Error	Moderate Amount of Error	Larger Degree of Error	Too Much Error
☐1	☐2	☐3	☐4	☐5

3. When using the terms <u>delay</u> and <u>error</u> in the context of NVN imagery, how does their meaning relate to one another?

They Mean Different Things	Not Very Close in Meaning	Moderately Close in Meaning	Very Close in Meaning	They Mean the Same Thing
☐1	☐2	☐3	☐4	☐5

4. How would you rate your <u>Weather Situational Awareness</u> (WSA) when comparing NEXRAD with NVN imagery?

Much Better With **NEXRAD**	Somewhat Better with **NEXRAD**	About the Same	Somewhat Better with **NVN**	Much Better With **NVN**
☐1	☐2	☐3	☐4	☐5

5. If you were using NVN during inflight-operations, how <u>confident</u> would you be in your perception of a storm's location?

No Confidence	Not Very Confident	Moderately Confident	Very Confident	Extremely Confident
☐1	☐2	☐3	☐4	☐5

6. How well did you feel you understood the <u>NVN training</u>?

I Didn't Understand Anything	I Understood Very Little	I Understood a Moderate Amount	I Understood Most of it	I Understood Everything
☐1	☐2	☐3	☐4	☐5

Additional comments you have on the training:

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

7. Which of the following do you feel is the most effective usage of NVN?

Determine Where a Storm Will Be In 15 Minutes	Determine the Exact Location, Size, and Shape of a Storm	Determine How to Navigate Through a Storm	Determine How to Avoid a Storm	Determine a Safe Distance to Fly Near a Storm
☐1	☐2	☐3	☐4	☐5

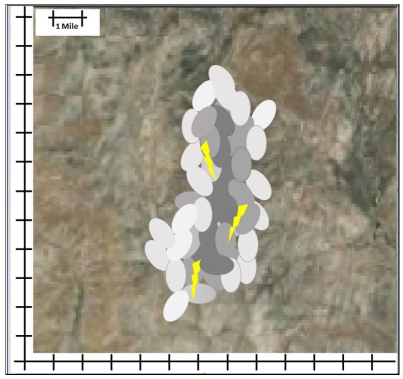
8. With regard to zooming-in and zooming-out on a Wx presentation, how useful do you feel NVN would be:

Much More Useful Zoomed-**In**	Somewhat More Useful Zoomed-**In**	About the Same	Somewhat More Useful Zoomed-**Out**	Much More Useful Zoomed-**Out**
☐1	☐2	☐3	☐4	☐5

9. Based on the NVN training, which statements are accurately related to NEXRAD and NVN imagery (select all that apply).

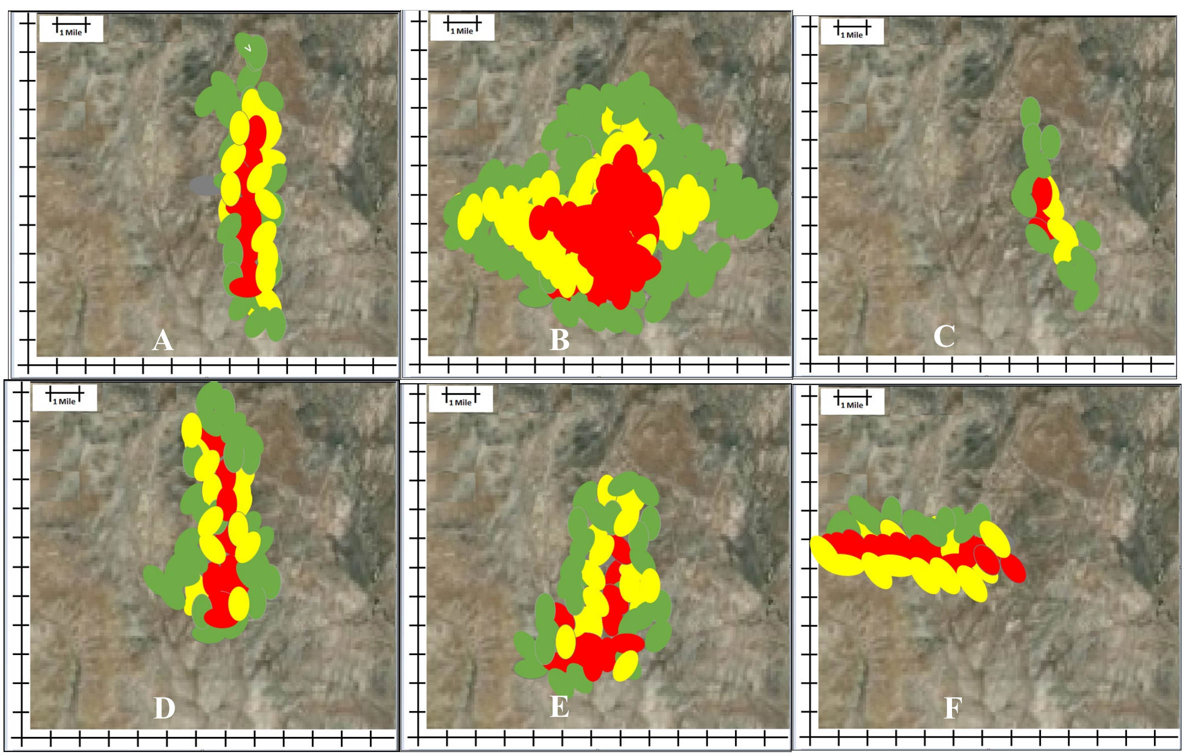
   a. NEXRAD images contain delay
   b. In an NVN image, all inherent NEXRAD delay and image errors are retained
   c. In an NVN image, NEXRAD delay has been removed representing the current position of the storm, as a function of storm movement with a positional error
   d. NVN imagery can contain storm cell position errors up to 5 miles in any direction
   e. NVN imagery is intended to depict where the storm currently is located (with minimal position error)
   f. NVN imagery contains storm cell position errors up to 1.5 miles in any direction
   g. NVN imagery only contains storm cell position errors along the direction of movement of the storm
   h. NVN image delay is equal to NEXRAD image delay

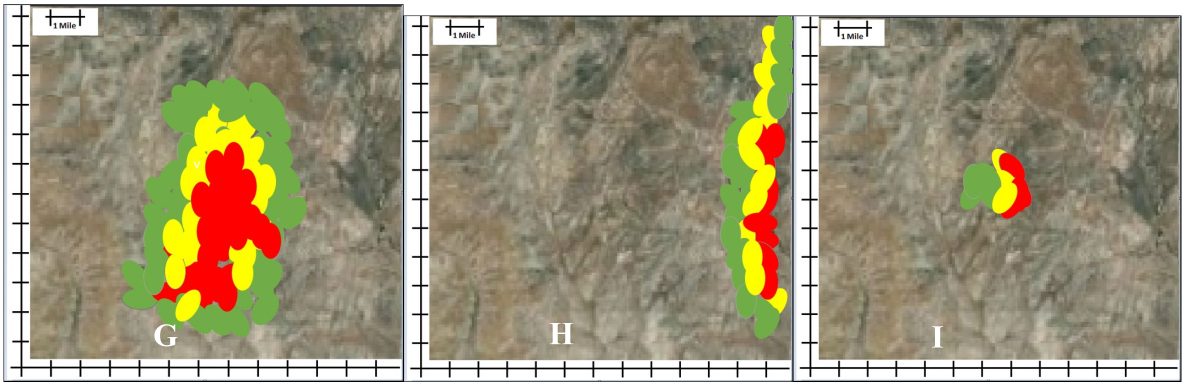
10. Based on the image below that shows a hypothetical example of a thunderstorm.



Please select all images (A-I) that could be a possible NVN representation of this thunderstorm (please note that each tick on the scale is equivalent to <u>1 mile</u>).

Answer: ____





Thank you very much for participating in our study; we appreciate your help

B Informed Consent

Informed Consent to Participate in Research Study
An Assessment of Time-Based Active Reminders on Weather Related Behavior and Decision Making of General Aviation Pilots

Principal Investigator (PI): Andrew Cheng, Ph.D., FAA Human Factors Branch, ANG-E25
Co-investigators: Ulf Ahlstrom, Ph.D., AvMet Applications Inc.
Sponsors: FAA Weather Research Branch, ANG-C61
Contractor: N/A

Invitation to Participate in Research Study

The principal investigator, Dr. Andrew Cheng, invites you to participate in a research study about time-based weather presentations and weather presentation delays at the FAA Technical Center Cockpit Simulation Facility. This study is funded and sponsored by the FAA Weather Research Branch. Its purpose is to understand pilot's response to weather hazards in general aviation (GA) and their feedback on a briefing method that aims to remove the inherent delay in displaying precipitation weather information. Totally 48 pilots with private pilot license will be recruited to participate in this study.

Description of participant involvement

Participants will be first asked to fly a scenario in a non-motion based single-engine aircraft simulator to answer a questionnaire about their experience of using the provided weather presentation. After the simulation, participants will receive training about a method that is developed to eliminate the time delay in displaying precipitation weather information, and then complete a survey to provide feedback on the display method that they have learned. The total time commitment for the study is approximately 2 hours, including a 20-min introduction session, an 80-min flight simulation and post-simulation debriefing, and a 20-min training and survey about a weather display method. The study will help FAA develop human factors guidelines for weather displays and indicate potential weather training needs for GA pilots.

Audio/video recordings will be made during the study so that the researchers can review relevant events later if needed. Three cameras will be used during the flight simulation: a camera at the dashboard for the front of the participant including the face; a camera at the cockpit ceiling for a 'bird's eye view' of pilot interactions with the instruments, and a camera at the fuselage wall for a full side-view of pilot actions. Since none of these audio/video recordings will be published in any form, researchers will not use video or audio modifying software on the recordings to blur participant images or modify voice recordings. All audio and video recordings will be stored in the original format. Only the research team will have access to the recordings.

Potential Benefits

You will not directly benefit from your participation in this study. The only benefit to you is that your data and feedback will help inform FAA decisions regarding weather displays guidelines and weather training requirements for GA pilots.

Risks and discomforts

The discomfort and risks associated with this study are similar to the discomfort and risks associated with regular office computer work. The simulation will be conducted in a non-motion simulator. Only a minimal risk for adverse experiences related to vertigo, motion sickness, and disorientation is expected.

Compensation

Participants will be paid by their recruiter for the time to participate in the study. The researchers will not provide any additional payment or compensation to the participants.

Participant's Rights

You will not lose any legal claims, rights or remedies by signing this form and by your participation in this research study. The local FAA Institutional Review Board has reviewed this research project under limited review and found it to be acceptable, according to applicable state and federal regulations designed to protect the rights and welfare of subjects in research.

Cost to Participant

You will not incur any costs for participating in the research study.

Confidentiality

The data collected and the recordings obtained in this study are stored only by code number, not by name. No names or identities will be released in any research reports, publications, or presentations resulting from this work. Electronic data will be stored on secure FAA or FAA-contractor computers that are only accessible to research team members. Any data collected on paper (e.g., questionnaires) will be secured in a locked file cabinet only accessible to research team members. The data from the study may be made available to other researchers for related studies, but the information will not be identifiable to any given participant. We will keep your participation in this research study confidential to the extent permitted by law. The data collected by the study will be kept up to 5 years, after which period the researcher team will shred data and permanently delete recordings from the FAA servers and backup drives.

Injury

In the event of any injury incurred while participating in this study, medical treatment will be provided by emergency responders, local hospitals, or clinics. Notify one of the researchers immediately if medical attention is needed. It is the policy of this institution to provide neither financial compensation nor free medical treatment in the event of such injury.

Voluntary Nature of Participation and Withdrawal

Your participation in this study is completely voluntary and it is your choice whether to participate or not. You may decline or withdraw your participation in the study at any time. The choice to decline or withdraw from the study will not cause any penalty or loss of any benefit to which you are entitled. During the study, the principal investigator or research team member will share any new information that develops and may affect your decision to continue to participate. The PI or research team may also terminate your participation in the study at any time if they determine this to be in your best interest. The researchers will not save the data for participants that decline or withdraw early from participation in the study.

Contact Information

If you have questions about the study, please ask them before signing this form. You can ask any questions that you have about this study at any time, or after your participation concludes. For questions, concerns or complaints about this study, please contact the principal investigator, Andrew Cheng, at (609) 485-4904, or the research sponsor, Ian Johnson, at (202) 267-2795. If you feel that you have been treated unfairly, or you have questions regarding your rights as a research participant you may contact the Local Institutional Review Board at (609) 485-8629 or the FAA IRB at (405)954-2700.

Signature and Consent to be in the research study

I have been informed about the purpose, procedures, possible benefits and risks of this research study. I have read (or someone has read to me) this form, and I have received a copy of it. I have had the opportunity to ask questions and to discuss the study with an investigator. My questions have been answered to my satisfaction. I have been told that I can ask other questions any time. I voluntarily agree to participate in this study. I am free to withdraw from this study at any time without penalty and without the need to justify my decision. The withdrawal will not in any way affect any benefits to which I am otherwise entitled. I agree to cooperate with the principal investigator and the research staff and to inform them immediately if I experience any unexpected or unusual symptoms.

Below, I have indicated my decision about being re-contacted for related studies in the future by placing an "X" next to my choice.

______Yes, please contact me about related studies

______No, please do NOT contact me about related studies

Investigator

I have fully explained this study to the subject to the best of my ability. As a representative of this study, I have explained the purpose, the procedures, the possible benefits and risks that are involved in this research study. I have answered the subject's questions to his/her satisfaction before requesting the signature(s) above. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily. There are no blanks in this document. A copy of this form has been given to the subject.

____

Printed name of Principal Investigator

______________________________ ______________ __________

Signature of Principal Investigator Date Time

C Biographical Questionnaire

Biographical Questionnaire

Instructions: This questionnaire is designed to obtain information about your background and experience as a pilot. Researchers will only use this information to describe the participants in this study as a group. Your identity will remain anonymous.

Demographic Information and Experience

1. What pilot certificate and ratings do you hold? (circle as many as apply)

   Private Commercial ATP Glider

   SEL SEA MEL

   Airship Instrument CFI CFII

   MEI Helicopter A&P IA

2. What is your age?

   _____ Years

3. Approximately how many actual total flights hours do you have?

   _____ Hours

4. Approximately how many actual instrument hours do you have?

   _____ Hours

5. Approximately how many instrument hours have you logged in the last 6 months (simulated and actual)?

_____ Hours

6. List all (if any) in-flight weather presentation systems you have used during a flight to make actual weather judgments? (not including onboard radar or Stormscope)?

____
____
____
____
____
____

7. Have you had any training in weather interpretation other than basic pilot training (for example, courses in meteorology)? If so, to what extent?

____
____
____
____
____
____

D Mobile Device Proficiency Questionnaire (MDPQ-16)

Mobile Device Proficiency Questionnaire (MDPQ-16)

About the MDPQ

This questionnaire asks about your ability to perform a number of tasks with a **mobile device**.

What is a Mobile Device?

A mobile device is a device that allows you to perform many of the same tasks as a standard computer but without the use of a physical keyboard and mouse. Instead, these devices use a touchscreen as their interface between the user and computer programs (called Apps – short for applications).

Mobile devices come in many sizes. Depicted above are two different sized tablets, as well as a smartphone. These are the types of devices we are interested in.

Please answer each question by placing an X in the box that is most appropriate.

If you have not tried to perform a task with a mobile device or do not know what a task is, please mark "NEVER TRIED", regardless of whether or not you think you may be able to perform the task. **Remember, you are rating your ability to perform each of these tasks specifically using a mobile device (tablet or smartphone).**

1. **Mobile Device Basics**

Using a mobile device I can:	**Never tried (1)**	**Not at all (2)**	**Not very easily (3)**	**Somewhat easily (4)**	**Very easily (5)**
a. Navigate onscreen menus using the touchscreen					
b. Use the onscreen keyboard to type					

2. **Communication**

Using a mobile device I can:	**Never tried (1)**	**Not at all (2)**	**Not very easily (3)**	**Somewhat easily (4)**	**Very easily (5)**
a. Send emails					

b. Send pictures by email					

3. Data and File Storage

Using a mobile device I can:	Never tried (1)	Not at all (2)	Not very easily (3)	Somewhat easily (4)	Very easily (5)
a. Transfer information (files such as music, pictures, documents) on my mobile device to my computer					
b. Transfer information (files such as music, pictures, documents) on my computer to my mobile device					

4. Internet

Using a mobile device I can:	Never tried (1)	Not at all (2)	Not very easily (3)	Somewhat easily (4)	Very easily (5)
a. Find information about my hobbies and interests on the Internet					
b. Find health information on the Internet					

5. **Calendar**

Using a mobile device I can:	Never tried (1)	Not at all (2)	Not very easily (3)	Somewhat easily (4)	Very easily (5)
a. Enter events and appointments into a calendar					
b. Check the date and time of upcoming and prior appointments					

6. **Entertainment**

Using a mobile device I can:	Never tried (1)	Not at all (2)	Not very easily (3)	Somewhat easily (4)	Very easily (5)
a. Use the device's online "store" to find games and other forms of entertainment (e.g. using Apple App Store or Google Play Store)					
b. Listen to music					

7. **Privacy**

Using a mobile device I can:	Never tried (1)	Not at all (2)	Not very easily (3)	Somewhat easily (4)	Very easily (5)
a. Setup a password to lock/unlock the device					

b. Erase all Internet browsing history and temporary files					

8. Troubleshooting & Software Management

Using a mobile device I can:	**Never tried (1)**	**Not at all (2)**	**Not very easily (3)**	**Somewhat easily (4)**	**Very easily (5)**
a. Update games and other applications					
b. Delete games and other applications					

E Weather Knowledge Questionnaire

Weather Knowledge Questionnaire

Please circle your answer

1. What are the characteristics of unstable air?

A) Turbulence and good surface visibility.

B) Turbulence and poor surface visibility.

C) Nimbostratus clouds and good surface visibility.

2. A temperature inversion would most likely result in which weather condition?

A) Clouds with extensive vertical development above an inversion aloft.

B) Good visibility in the lower levels of the atmosphere and poor visibility above an inversion aloft.

C) An increase in temperature as altitude is increased.

3. The amount of water vapor which air can hold depends on the

A) dew point.

B) air temperature.

C) stability of the air.

4. What clouds have the greatest turbulence?

A) Towering cumulus.

B) Cumulonimbus.

C) Nimbostratus.

5. In which meteorological environment is aircraft structural icing most likely to have the highest rate of accumulation?

A) Cumulonimbus clouds.

B) High humidity and freezing temperature.

C) Freezing rain.

6. For most effective use of the Radar Summary Chart during preflight planning, a pilot should

A) consult the chart to determine more accurate measurements of freezing levels, cloud cover, and wind conditions between reporting stations.

B) compare it with the charts, reports, and forecasts to form a mental three-dimensional picture of clouds and precipitation.

C) utilize the chart as the only source of information regarding storms and hazardous conditions existing between reporting stations.

7. What relationship exists between the winds at 2,000 feet above the surface and the surface winds?

A) The winds at 2,000 feet and the surface winds flow in the same direction, but the surface winds are weaker due to friction.

B) The winds at 2,000 feet tend to parallel the isobars, while the surface winds cross the isobars at an angle toward lower pressure, and are weaker.

C) The surface winds tend to veer to the right of the winds at 2,000 feet, and are usually weaker.

8. While flying a 3-degree glide slope, a headwind shears to a tailwind. Which conditions should the pilot expect on the glide slope?

A) Airspeed and pitch attitude decrease, and there is a tendency to go below the glide slope.

B) Airspeed and pitch attitude increase, and there is a tendency to go above the glide slope.

C) airspeed and pitch attitude decrease, and there is a tendency to remain on the glide slope.

9. The Hazardous Inflight Weather Advisory Service (HIWAS) is a continuous broadcast over selected VORS of

A) SIGMETs, CONVECTIVE SIGMETs, AIRMETs, Severe Weather Forecast Alerts (AWW), and Center Weather Advisories (CWA).

B) SIGMETs, CONVECTIVE SIGMETs, AIRMETs, Wind Shear Advisories, and Severe Weather Forecast Alerts (AWW).

C) Wind Shear Advisories, Radar Weather Reports, SIGMETs, CONVECTIVE SIGMETs, AIRMETs, and Center Weather Advisories (CWA).

10. If you fly into severe turbulence, which flight condition should you attempt to maintain?

A) Constant airspeed (VA).

B) Level flight attitude.

C) Constant altitude and constant airspeed.

11. A pilot can expect a wind-shear zone in a temperature inversion whenever the wind speed at 2,000 to 4,000 feet above the surface is at least

A) 10 knots.

B) 15 knots.

C) 25 knots.

12. A high cloud is composed mostly of

A) ozone.

B) condensation nuclei.

C) ice crystals.

13. Where can wind shear associated with a thunderstorm be found? Choose the most complete answer.

A) In front of the thunderstorm cell (anvil side) and on the right side of the cell.

B) In front of the thunderstorm cell and directly under the cell.

C) On all sides of the thunderstorm cell and directly under the cell.

14. Maximum downdrafts in a microburst encounter may be as strong as

A) 8,000 feet per minute.

B) 7,000 feet per minute.

C) 6,000 feet per minute.

15. Which family of clouds is least likely to contribute to structural icing on an aircraft?

A) Low clouds.

B) High clouds.

C) Clouds with extensive vertical development.

16. The surface Analysis Chart depicts

A) actual pressure systems, frontal locations, cloud tops, and precipitation at the time shown on the chart.

B) frontal locations and expected movement, pressure centers, cloud coverage, and obstructions to vision at the time of chart transmission.

C) actual frontal positions, pressure patterns, temperature, dew point, wind, weather, and obstructions to vision at the valid time of the chart.

17. One weather phenomenon which will always occur when flying across a front is a change in the

A) wind direction.

B) type of precipitation.

C) stability of the air mass.

18. Which weather phenomenon signals the beginning of the mature stage of a thunderstorm?

A) The appearance of an anvil top.

B) Precipitation beginning to fall.

C) Maximum growth rate of the clouds.

19. What is an important characteristic of wind shear?

A) It is primarily associated with the lateral vortices generated by thunderstorms.

B) It usually exists only in the vicinity of thunderstorms, but may be found near a strong temperature inversion.

C) It may be associated with either a wind shift or a wind speed gradient at any level in the atmosphere.

20. Thrust is managed to maintain IAS, and glide slope is being flown. What characteristics should be observed when a headwind shears to be a constant tailwind?

A) PITCH ATTITUDE: Increases; REQUIRED THRUST: Increased, then reduced; VERTICAL SPEED: Increases; IAS: Increases, then decreases to approach speed.

B) PITCH ATTITUDE: Decreases; REQUIRED THRUST: Increased, then reduced; VERTICAL SPEED: Increases; IAS: Decreases, then increases to approach speed.

C) PITCH ATTITUDE: Increases; REQUIRED THRUST: Reduced, then increased; VERTICAL SPEED: Decreases; IAS: Decreases, then increases to approach speed.

F Post Scenario Questionnaire

Post Scenario Questionnaire

The following questions are associated with your interaction with the Active Reminder:

1. Using the weather presentation, how easy was it to see the distance from the aircraft to precipitation cells?

Very Hard								**Very Easy**
1	2	3	4	5	6	7	8	9

2. At the beginning of the scenario, did you fly closer than 20 miles from the precipitation cells?

……☐ Yes……………☐ No ……

3. How close to the precipitation cells did you get?

……☐ 20-25 mi……☐ 15-20 mi……☐ 10-15 mi ……☐ less than 10 mi

4. How would you rate the benefits of the *time-based* reminder of the distance from the aircraft to precipitation cells?

No Benefit								**Very Beneficial**
1	2	3	4	5	6	7	8	9

5. During the scenario flight, the *time-based* reminder was set to end at zero at 20 mi from the outer edge of the precipitation cells. If you would use this implementation during actual flights – what distance would you set in miles?

☐ 30 mi or more…☐ 20-25 mi…☐ 15-20 mi…☐ 10-15 mi …☐ less than 10 mi

6. Did you feel the *time-based* reminder provided enough time for your decision making process during your encounter with precipitation cells?

……☐ Yes……………☐ No ……

7. Did you feel the *time-based* reminder provided an excessive amount of time for your decision-making process during your encounter with precipitation cells?

……☐ Yes……………☐ No ……

8. The current FAA recommendation is to stay 20 mi away from storms. Do you agree with this recommendation?

……☐ Yes……………☐ No ……

9. If you would determine the recommendation for a distance to storms, what distance (in mi) would you pick?

☐ 30 or more…..☐ 20 (the current distance) …..☐ 15 ……...☐ 10 ……...☐ less than 10

10. To what degree did the weather display information affect your decision to stay on your course or to fly to an alternate destination airport?

Very Little								**Very Much**
1	2	3	4	5	6	7	8	9

11. How would you rate the benefits of the weather presentation you used to other sources of weather information (ASOS, Flight Watch, etc.)?

Very Low								**Very High**
1	2	3	4	5	6	7	8	9

12. How much do you think the weather presentation decreased your cognitive workload (i.e., it gave you easy access to information that you otherwise would have to get from other sources)?

Very Little								**Very Much**
1	2	3	4	5	6	7	8	9

13. How much did you trust the weather presentation to give you the correct information?

Very Little								**Very Much**
1	2	3	4	5	6	7	8	9

14. Did the precipitation cells appear closer in the out-the-window (OTW) view, or on the weather display?

OTW				**Neither**				**Display**
1	2	3	4	5	6	7	8	9

15. Did the precipitation cells appear more intense in the out-the-window view, or on the weather display?

OTW				**Neither**				**Display**
1	2	3	4	5	6	7	8	9

16. Did the weather situation appear to change more rapidly in the out-the-window view, or on the weather display?

OTW				**Neither**				**Display**
1	2	3	4	5	6	7	8	9

17. During the flight, how easy was it to determine the visibility (in stat mi) from the out-the-window view?

Very Hard								**Very Easy**
1	2	3	4	5	6	7	8	9

18. During the flight, did you ever notice that the visibility was decreasing?

……□ Yes……………□ No ……

19. In your estimate, what was the lowest visibility that you encountered during flight?

…□ 5-6 stat mi …□ 4-5 stat mi …□ 3-4 stat mi…□ 2-3 stat mi…□ 1-2 stat mi …□ less than 1 stat mi

20. How would you rate the benefits of the *time-based* reminder to areas of forecasted visibility of 1-3 stat mi?

No Benefit								**Very Beneficial**
1	2	3	4	5	6	7	8	9

21. During the scenario flight, the *time-based* reminder was set to end at zero at 20 mi to forecasted areas of 1-3 stat mi visibility. If you would use this implementation during actual flights – what distance would you set in miles?

□ 30 mi or more…□ 20-25 mi…□ 15-20 mi…□ 10-15 mi …□ less than 10 mi

22. Did you feel the *time-based* reminder provided enough time for your decision making process during your encounter with forecasted areas of 1-3 stat mi visibility?

……☐ Yes……………☐ No ……

23. Did you feel the *time-based* reminder provided an excessive amount of time for your decision-making process during your encounter with forecasted areas of 1-3 stat mi visibility?

……☐ Yes……………☐ No ……

24. To what degree did the *time-based* reminder of visibility conditions affect your decision to stay on your course or to fly to an alternate destination airport?

Very Little								**Very Much**
1	2	3	4	5	6	7	8	9

25. During the scenario, did you ever use ASOS information?

……☐ Yes……………☐ No …