

Weather and Aviation: How Does Weather Affect the Safety and Operations of Airports and Aviation, and How Does FAA Work to Manage Weather-related Effects?

By Gloria Kulesa

Weather Impacts On Aviation

Introduction

According to FAA statistics, weather is the cause of approximately 70 percent of the delays in the National Airspace System (NAS). Figure 1 illustrates that while weather delays declined with overall NAS delays after September 11th, 2001, delays have since returned to near-record levels.

In addition, weather continues to play a significant role in a number of aviation accidents and incidents. While National Transportation Safety Board (NTSB) reports most commonly find human error to be the direct accident cause, weather is a primary contributing factor in 23 percent of all aviation accidents. The total weather impact is an estimated national cost of \$3 billion for accident damage and injuries, delays, and unexpected operating costs.

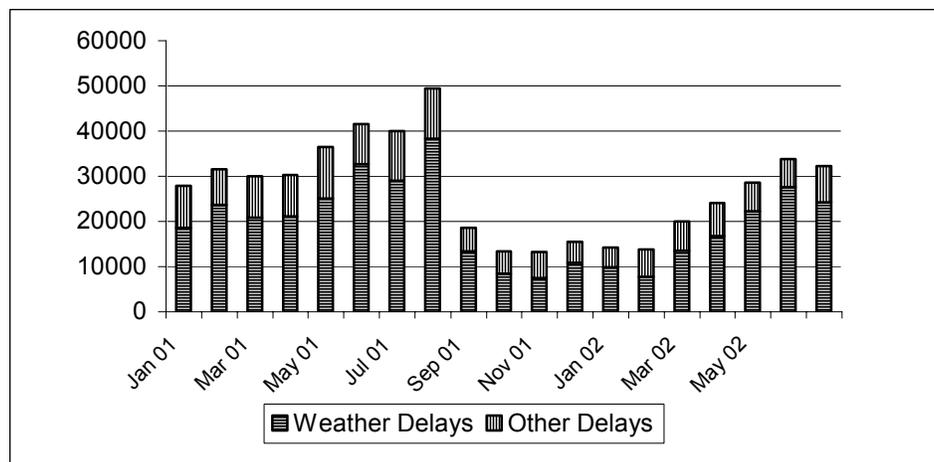


Figure 1. Delay hours in the National Airspace System for January 2001 to July 2002. Delay hours peaked at 50,000 hours per month in August 2001, declined to less than 15,000 per month for the months following September 11, but exceeded 30,000 per month in the summer of 2002. Weather delays comprise the majority of delays in all seasons.

Thunderstorms and Other Convective Weather. Hazards associated with convective weather include thunderstorms with severe turbulence, intense up- and downdrafts, lightning, hail, heavy precipitation, icing, wind shear, microbursts, strong low-level winds, and tornadoes. According to National Aviation Safety Data Analysis Center (NASDAC) analysis, between 1989 and early 1997, thunderstorms were listed as a contributing factor in 2-4 percent of weather-related accidents, depending on the category of aircraft involved. Precipitation was listed as a factor in 6 percent of commercial air carrier accidents, roughly 10 percent of general aviation accidents, and nearly 19 percent of commuter/air taxi accidents. American Airlines has estimated that 55 percent of turbulence incidents are caused by convective weather.

In addition to safety, convective weather poses a problem for the efficient operation of the NAS. Thunderstorms and related phenomena can close airports, degrade airport capacities for acceptance and departure, and hinder or stop ground operations. Convective hazards en route lead to rerouting and diversions that result in excess operating costs and lost passenger time. Lightning and hail damage can remove aircraft from operations and result in both lost revenues and excess maintenance costs. In Figure 1, the vast majority of the warm season delays are due to convective weather.

In-Flight Icing. In the period 1989-early 1997, the NTSB indicated that in-flight icing was a contributing or causal factor in approximately 11 percent of all weather-related accidents among general aviation aircraft. Icing was cited in roughly 6 percent of all weather-related accidents among air taxi/commuter and agricultural aircraft. The percentage was 3 percent for commercial air carrier accidents. The 1994 crash of an ATR-72 near Roselawn, Indiana, which claimed 68 lives, took place during icing conditions.

In-flight icing is not only dangerous, but also has a major impact on the efficiency of flight operations. Rerouting and delays of commercial carriers, especially regional carriers and commuter airlines, to avoid icing conditions lead to late arrivals and result in a ripple effect throughout the NAS. Diversions en route cause additional fuel and other costs for all classes of aircraft.

Icing poses a danger to aircraft in several ways:

- Structural icing on wings and control surfaces increases aircraft weight, degrades lift, generates false instrument readings, and compromises control of the aircraft. See Figure 2.
- Mechanical icing in carburetors, engine air intakes, and fuel cells impairs engine performance, leading to reduction of power.

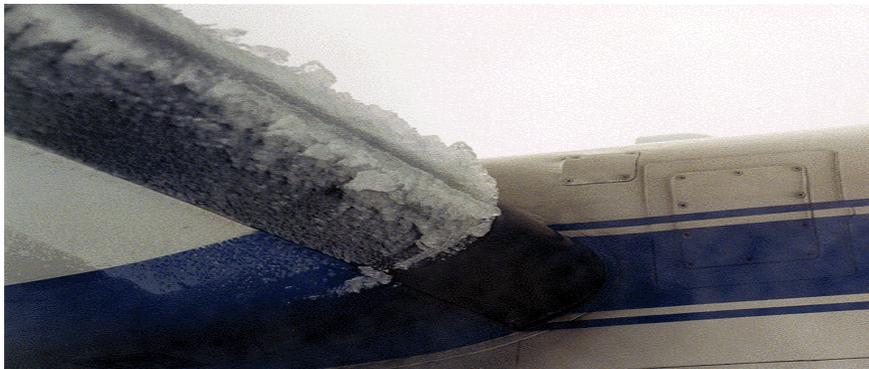


Figure 2. Photo of structural icing on an aircraft's wing.

Small aircraft routinely operate at altitudes where temperatures and clouds are most favorable for ice formation, making these aircraft vulnerable to icing for long periods of time. Larger aircraft are at risk primarily during ascent from and descent into terminal areas.

Turbulence. Non-convective turbulence is a major aviation hazard. All aircraft are vulnerable to turbulent motions. Non-convective turbulence can be present at any altitude and in a wide range of weather conditions, often occurring in relatively clear skies as clear-air turbulence. Any aircraft entering turbulent conditions is vulnerable to damage; smaller aircraft (both fixed- and rotary-wing) are susceptible at lower levels of turbulent intensity than are large aircraft. See Figure 3.

The effects of turbulence range from a jostling of the aircraft that is mildly discomforting for passengers and crews to sudden accelerations that can result in serious

injury and temporary loss of aircraft control. Recently an air carrier en route from Japan to the U.S. encountered turbulence which caused the death of a passenger.

Clear-air turbulence is not only dangerous, it also has a major impact on the efficiency of flight operations due to rerouting and delays of aircraft.

Ceiling and Visibility. Low ceiling and reduced visibility are safety hazards for all types of aviation. The NASDAC study of NTSB statistics indicated that ceiling and visibility were cited as contributing factors in 24 percent of all general aviation accidents between 1989 and early 1997. They were also cited as contributing factors in 37 percent of commuter/air taxi accidents during the same period. Low ceiling and poor visibility accidents occur when pilots who are not properly rated or are flying an aircraft not equipped with the necessary instrumentation encounter such conditions, resulting in loss of control, or controlled flight into terrain.



Figure 3. Photo of an aircraft missing an engine which had been torn off by turbulence.

The NTSB statistics also imply that air carriers have the expertise, procedures, and equipment necessary to fly safely in reduced visibility conditions. Low ceiling and poor visibility were cited as contributing factors in less than 2 percent of the commercial air carrier (Part 121) accidents between 1989 and early 1997.

In 1991, the University of Illinois used simulated weather conditions to test twenty Visual Flight Rule (VFR) rated pilots. When deprived of visual contact, each pilot experienced loss of control. On average, it took approximately 178 seconds giving each pilot less than 3 minutes to live after entering a cloud.

Low ceiling and poor visibility are not just a safety issue. They can also severely degrade the efficiency of commercial and military aviation. Reduced ceiling and/or visibility can severely reduce the capacity of an airport and lead to airborne or ground delays that result in diversions, cancellations, missed connections, and extra operational costs. See Figure 4.



Figure 4. Photo from an aircraft on approach to San Francisco International Airport. Two parallel runways can be seen. Pilots of aircraft on parallel approaches must be able to see each other.

Ground De-Icing. Aircraft on the ground during periods of freezing or frozen precipitation and other icing conditions are susceptible to the buildup of ice on control surfaces, instrument orifices, propellers, and engine inlets and interiors. Aircraft that are moving along taxiway

and runway surfaces in slush or standing water at near-freezing conditions are also susceptible to surface contamination, even after precipitation has stopped. Even a very small amount of ice on a wing surface can increase drag and reduce airplane lift by 25 percent. This type of ice accumulation has been a cause or a factor in 10 commercial aircraft takeoff accidents between 1978 and 1997. Ice blockage of airspeed or altitude measurement instrumentation can cause loss of control or navigation errors.

Ice and snow also have an impact on terminal operations. Boarding gates, taxiways, and runways may become unusable. Airport operational capacities may be sharply reduced. See Figure 5.



Figure 5. Photo of an aircraft being de-iced on the ground.

Volcanic Ash. Volcanic ash is pulverized rock. It is composed largely of materials with a melting temperature below the operating temperature of a jet engine at cruise altitude. Volcanic ash in the atmosphere is usually accompanied by gaseous solutions of sulphur dioxide and chlorine. The combination of the pulverized rock and acidic gases can significantly affect the performance of jet engines at cruise altitudes. Ash clouds are often invisible, particularly at night.

To put this problem in perspective, the ash from the Mount Pinatubo eruption in 1991 circled the globe within a matter of days and affected a multitude of air traffic routes. Consequently, aircraft that traversed this thin

layer of ash required more maintenance. Statistics show that there are 575 active volcanoes globally which normally contribute to 50 eruptions, resulting in 50-75 “danger days” per year. Volcanic ash exceeds 30,000 feet on active air routes 25-30 days per year. There have been over 100 damaging encounters to aircraft in the last 20 years costing more than \$250M in damages.

Within the United States, a particular area of concern is along the Aleutian Islands and the Alaskan Peninsula. The density of active volcanoes in this area, lying as it does adjacent to the heavily-traveled North Pacific Air Traffic Routes, makes the ash threat especially acute. The generally westerly flow of winds in the region means that ash can be transported easily into airspace over the Canadian and U.S. Pacific Northwest regions. Ash from volcanoes on the Kamchatka Peninsula of Russia also poses a threat because it tends to drift into the heavily traveled North Pacific airways, which are within U.S. Flight Information Regions.

AWRP Mitigation Initiatives

The FAA Aviation Weather Research Program (AWRP) has as a goal to relieve weather impacts on NAS safety, capacity, and efficiency. To work towards this goal, the program conducts applied research organized around ten meteorological product development teams

(PDTs). The primary laboratories performing AWRP research include: the National Center for Atmospheric Research (NCAR), Massachusetts Institute of Technology/Lincoln Laboratory, National Oceanic and Atmospheric Administration (NOAA) Forecast Systems Laboratory and National Severe Storms Laboratory, Naval Research Laboratory, and the National Weather Service's - Aviation Weather and Environmental Modeling Centers.

Convective Weather Product Development Team

On September 27, 2001, the AWRP participated in a landmark event when one of its weather research products, the National Convective Weather Forecast (NCWF) transitioned from an "experimental" stage, to an operational National Weather Service (NWS) product, approved for use by both meteorologists and end users. The NCWF is designed specifically to minimize delays caused by convection as it provides locations of significant convection one hour in the future, with updates every 5 minutes. A goal of the Convective Weather PDT is to eventually develop forecasts of convective weather out to six hours. The team also developed a 1-hour Terminal Convective Weather Forecast (TCWF) product which is being tested at the Dallas-Ft. Worth, Memphis, Orlando, and New York airports. See Figure 6. This product provides more than an extrapolated position of storms; it

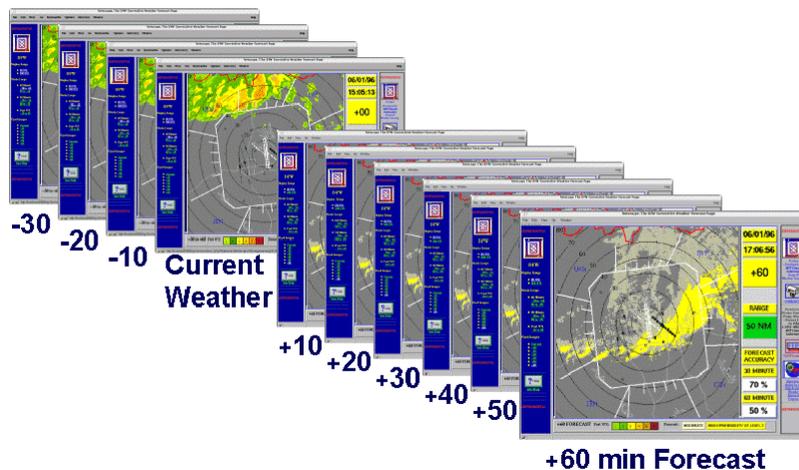


Figure 6. Succession of screenshots from the Terminal Convective Weather Forecast (TCWF), showing forecast convective weather for a local area.

also includes the effects of growth and decay. The Regional Convective Weather Forecast (RCWF) includes a 2-hour prediction, and it is being tested in the Northeast U.S.

In-Flight Icing Product Development Team

To address the in-flight icing problem, the AWRP has developed a Current Icing Potential (CIP) product (shown in Figure 7). The first generation CIP became an operational NWS product on March 27, 2002. As improvements to CIP are being made, a related product, the Forecast Icing Potential (FIP), which provides a forecast of icing conditions, is being developed. FIP is presently approved by the FAA and the NWS for experimental use. These products enable users to better anticipate where icing hazards are going to occur, and will allow air traffic controllers to make more informed decisions when assigning altitudes to aircraft.

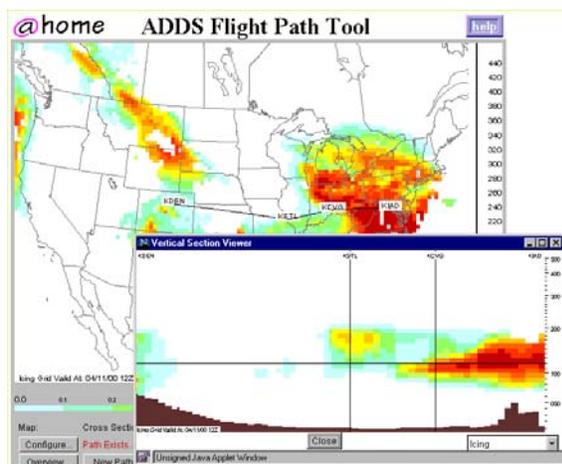


Figure 7. Screenshot of the Current Icing Potential (CIP) product, showing icing potential for a sample flightpath from Denver to Washington, DC. Hazard areas are shown both as an overlay on a map of the United States and as a vertical cross-section.

Turbulence Product Development Team

The mission of the turbulence PDT is to produce timelier and more accurate analyses and forecasts of turbulence, and develop user-friendly turbulence products. An algorithm designed to forecast turbulence models jet stream, mountain induced turbulence, and

convective induced turbulence. From this diagnostic data, and the addition of in-situ and remotely sensed data, an Integrated Turbulence Forecast Algorithm (ITFA) was produced and is now being used experimentally (see Figure 8).

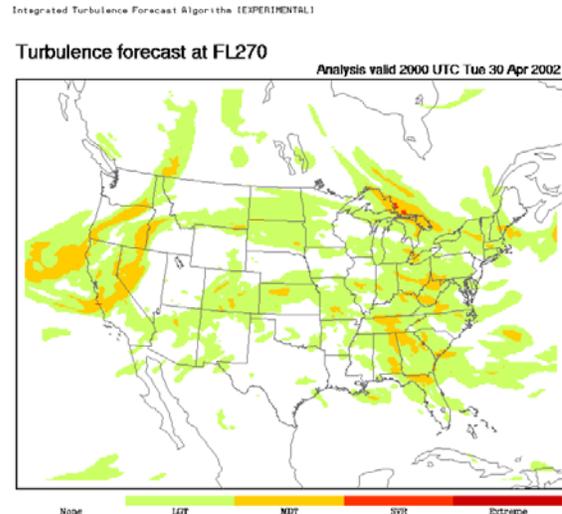


Figure 8. Screenshot of the output from the Integrated Turbulence Forecast Algorithm, showing forecast turbulence overlaid on a map of the United States.

Terminal Ceiling and Visibility Product Development Team

San Francisco International Airport is adversely affected by low clouds and poor visibility due to its location along the coast. During periods of poor weather, aircraft are assigned to holding patterns, or are prevented from taking off en route to San Francisco until the weather clears. The Terminal Ceiling and Visibility PDT is developing a 1-6 hour forecast of the time when simultaneous parallel approaches can be resumed so that the aircraft arrival rate at San Francisco matches the acceptance rate. This would allow additional aircraft to arrive at the terminal as extra capacity becomes available. An automated algorithm for predicting the time when the airport could increase its capacity is undergoing evaluation.

National Ceiling and Visibility Product Development Team

Since low ceilings and visibilities impact all airports to some degree, the AWRP began a national ceiling and visibility research program in March 2001. The primary beneficiaries of this PDT’s work are expected to be operators of general aviation, who are often involved in “controlled flight into terrain” accidents. A preliminary version of such a product is shown in Figure 9.

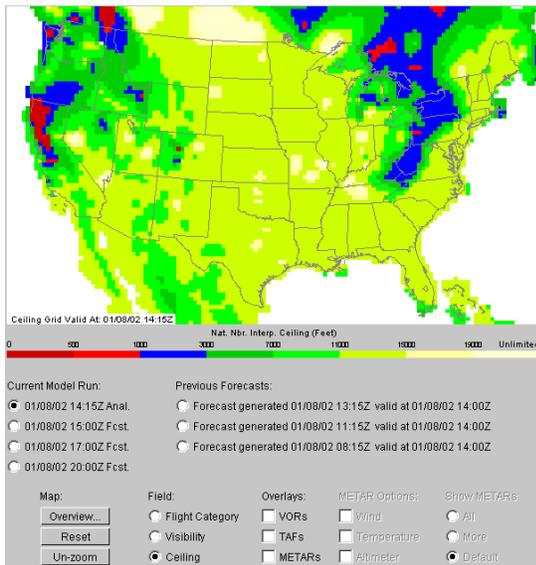


Figure 9. Screenshot of preliminary National Ceiling and Visibility product, showing current ceilings overlaid onto a map of the United States.

Winter Weather Research Product Development Team

The FAA’s Winter Weather PDT began supporting ground deicing research in 1991. The research resulted in development of an integrated display system that depicts accurate, real time determinations of snowfall rate, temperature, humidity, wind speed and direction, called the “Weather Support to Deicing Decision Making” (WSDDM) system (Figure 10). The sources of weather data used by WSDDM include Doppler radars, surface weather stations, and snow gauges located near the airport, which accurately measure the amount of water in the snow. Research indicates that the icing hazard for aircraft directly corresponds to the amount of water in the snow. Additionally, WSDDM’s accuracy is enhanced by using current and site specific weather information that results in a more accurate decision making tool for a particular airport. The system requires little meteorological knowledge and minimal training to operate, and enables decision makers to obtain valuable information in seconds. A new snowgauge has recently been developed which is smaller than the traditional snowgauge and requires very little maintenance. This new “hotplate” snowgauge determines the liquid water equivalent of precipitation by measuring the amount of electrical current required to maintain the top and bottom sides of a horizontal plate at the

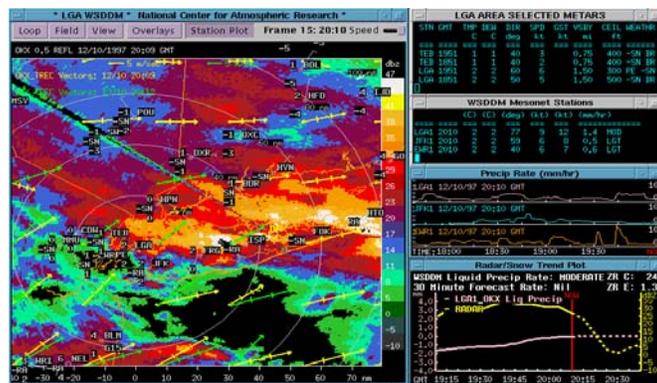


Figure 10. Screenshot of the Weather Support to De-Icing Decision Making (WSDDM) display, showing sample data for the LaGuardia airport area.

same temperature. The Winter Weather PDT is also involved in the “Northeast Corridor” project and has started to investigate the formation of winter fog by deploying numerous fog sensors at Rutgers Airport.

Oceanic Weather Product Development Team

At present, aircrews for long-range oceanic flights receive a general weather briefing before departure, including a summary of flight level winds and expected en route weather conditions. While the current weather products do provide valuable information for strategic planning, the information is already hours old by the time the aircraft depart and only the most general weather updates are provided during the flight.

The Oceanic Weather PDT was established to conduct applied research leading to the phased introduction of advanced weather products for oceanic areas including convection, turbulence, in-flight icing, high resolution winds, and volcanic ash dispersion. The observation of weather phenomena over the ocean is more difficult than over the continental United States due to the relative scarcity of weather data. Within the convective weather domain, research is being done on a diagnosis, nowcast and a forecast out to 6 hours. The first product that has recently entered the testing phase is the “Cloud Top Height” product.

The Cloud Top Height product, which is available on a cockpit printer or graphic display system, portrays areas along the aircraft’s flight path where cloud tops are expected to be between 30,000 to 40,000 feet. Another graphical designation shows clouds with tops above 40,000 feet (Figure 11).

Support Product Development Teams

The three PDTs discussed below do not address individual weather phenomena directly, but rather provide capabilities needed by the direct impact PDTs.

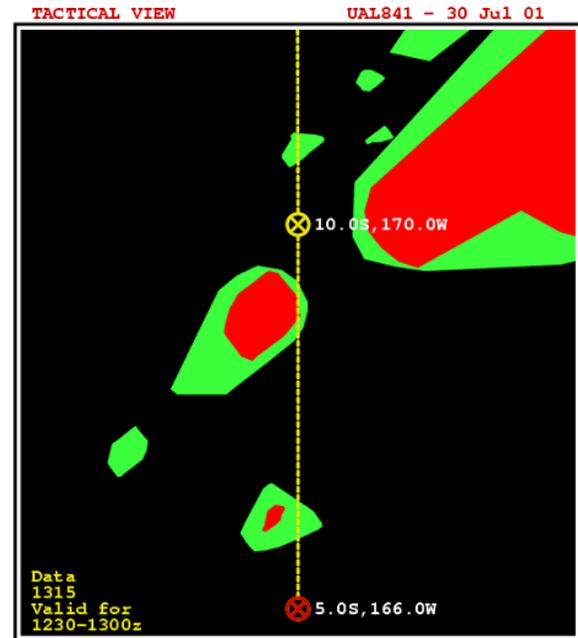


Figure 11. Screenshot from the Oceanic Weather Cloud Top Height product.

Aviation Forecasts and Quality Assessment Product Development Team. This PDT produced and maintains the Aviation Digital Data Service (ADDS). ADDS is a tool which is available on the Internet and which allows pilots, airline dispatchers, and other users easy access to weather data. An important component of ADDS, the “Flight Path Tool”, is a relatively new innovation which employs user-friendly graphics to display vertical cross-sections of turbulence, icing, thunderstorms, and other aviation weather hazards for specific flight altitudes and flight paths selected by the user. By allowing pilots and dispatchers to have easy access to forecast weather conditions, ADDS facilitates flight planning and minimizes the time required to change the route of flight when required. The convective weather, in-flight icing, and turbulence products mentioned above have been incorporated into the ADDS web site. ADDS is a winner of the Government Technology Leadership Award. See a sample ADDS screen in Figure 12.

@aviation digital data Service

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@dds Home | Turbulence | Icing | Convection | Winds/Temps | Prog Charts | Java Tools
METARs | TAFs | PIREPs | AIR/SIGMETs | Satellite | Radar

What's New (updated 08/02/2002)
An enhanced [PIREPs Java Tool](#) is available. Improvements include interactive domain selection, inclusion of the Hawaiian Domain, an improved Data Key, and a graphical Report Time Selector Bar for selecting hourly, as well as multiple hours of PIREP data for display.

Weather for today:

12 hr forecast valid 0000 UTC Thu 22 Aug 2002

The Federal Aviation Administration funds and directs the Aviation Digital Data Service and the experimental weather products that it displays. These products have not been developed by and are not endorsed by the National Weather Service.

Caution: This site contains experimental products and services. Please be advised of the [full disclaimer](#).

Looking for the **Flight Path Tool**? Please click the [Java Tools](#) tab above.

ADDS is funded by the Federal Aviation Administration ([FAA](#)) Aviation Weather Research Program ([AWRP](#)) and developed by the Aviation Gridded Forecast System (AGFS) Product Development Team. [Additional details](#) are available.

Coming Soon:

- Plain-English TAFs (like current METAR capability).
- Raw text PIREPs by regions of the U.S.
- Precipitation type delineated on all prog charts.
- Flight Path Tool will be released as an application (in contrast to Applet).

Figure 12. Screenshot of the Aviation Digital Data Service (ADDS) web page.

Model Development and Enhancement Product Development Team. The cornerstone of modern weather forecasts is numerical weather prediction. It is so critical to most of the weather PDTs that a special, separate PDT was created solely for this purpose. The Model Development and Enhancement PDT has produced a special aviation-oriented model called the Rapid Update Cycle (RUC). RUC is now an operational NWS product which runs once per hour. The latest version of RUC became operational on April 17, 2002. This PDT is also involved with the NWS Eta model and the futuristic Weather Research and Forecasting (WRF) Model now being created in the broader weather modeling community.

NEXRAD Enhancements Product Development Team. All weather prediction begins with knowing the present state of the atmosphere. Radar is a very important way of obtaining this knowledge, and the FAA has for

years participated with the NWS and the Department of Defense in developing the present national weather radar system. AWRP operates a special PDT for improving the radar needed by the FAA or by the other PDTs.

AWRP Benefits Studies

The following benefits analysis information was obtained from benefits studies that were conducted by MCR Federal Inc. The results of the studies and the dates of the reports are provided below:

Current Icing Potential (CIP) Safety Benefits Analysis Case Studies (Aug. 10, 2001): A potential safety benefit of \$30M annually is estimated for general aviation, air taxi, and commuter in-flight icing accidents.

Ceiling and Visibility (C&V) at San Francisco, Marine Stratus Forecast Benefits Estimate (July 18, 2002): A marine stratus forecast can potentially provide a benefit of \$5.45M annually in arrival and departure delay savings.

Terminal Convective Weather Forecast (TCWF) Benefits Analysis at DFW and Orlando Airports (June 2, 2000): The total benefit point estimates are \$18.4M for DFW and \$6.0M for Orlando, annually.

Terminal Convective Weather Forecast (TCWF) Benefits Analysis at New York Airports (Kennedy, LaGuardia and Newark) (Nov. 21, 2000): The total benefit point estimate is \$80M annually for the New York airports.

Terminal Convective Weather Forecast (TCWF) Benefits Analysis (national) estimated for a national system deployed at Integrated Terminal Weather System installed airports (Feb. 12, 2001): The estimated total benefit is \$524M annually.

Weather Support to Deicing Decision Making (WSDDM) Benefits Analysis Update (Oct. 2, 2000): Annual benefits of \$12.7M for Kennedy, LaGuardia and Newark Airports combined.

Climate Change Research

AWRP has no mission and no program for climate change research. However, several projects undertaken by AWRP for aviation purposes have applications for climate change

research. The most significant of these is a project jointly funded by AWRP and the NOAA Office of Global Programs (OGP). The project is referred to as the Water Vapor Sensing System (WVSS). Until now, global measurements of water vapor in the atmosphere consisted of surface observations and of soundings taken by instrument carried aloft by balloons twice per day. WVSS uses commercial aircraft as data gathering platforms. AWRP-produced sensors are flown on commercial carriers (30 UPS aircraft presently for test purposes), and the readings from the sensors are downlinked to the ground every few minutes in flight. The result is that measurements of water vapor, which is the single most important greenhouse gas, are being increased by a factor in the hundreds.

In addition to WVSS, AWRP has produced a climatology of in-flight icing conditions over the US, and has also collected new, high-quality data on turbulence, radar-measured parameters, and air chemistry. Any of these could be useful to those studying various aspects of climate change.

More Information

An overview of AWRP products can be found on the AWRP web page at <http://www.faa.gov/aua/awr/>.

Live AWRP products are available on the ADDS web page at <http://adds.aviationweather.gov/>.

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