# Aviation System Performance During the Summer Convective Weather Season

**by Kenneth Wright**

*This paper analyzes recent trends related to delays, airborne holding and diversions in the National Airspace System (NAS) during the summer convective weather season. A weather variable is introduced to help analyze these performance metrics in a way that factors out differences in the location and intensity of thunderstorms. Regression analysis indicates a nearly 50% increase in flights delayed more than an hour from summer 2003 to 2005. The increase in delay is associated with a growing concentration of flights at busy hub airports over the past five years.*

## INTRODUCTION

The Federal Aviation Administration (FAA) is intensely interested in using data to describe the performance of the National Airspace System (NAS). It supports websites, www.bts.gov and www.apo.data.faa.gov, that give users inside and outside the FAA access to vast databases describing the number of flights scheduled, flown, cancelled and delayed. At least a dozen measures are available that describe delay, the primary metric used by the FAA and airlines to judge system performance. Managers at the highest levels of the FAA receive daily and monthly metrics updates and issue press releases that tell, for example, how on-time performance last month compares to on-time performance a year earlier. Some managers even have a small portion of their pay (an annual incentive bonus) tied to delay.

Many delays are caused by weather that reduces the rate at which airports can safely launch and land aircraft. When visibility is poor, for example, controllers must increase the distance between aircraft on final approach. To make sense of delay statistics, it is therefore often important to look at weather. Most often this is not done, first because weather data is not always available, and second because weather data is difficult to summarize. It is easy to say that 20% more flights were delayed last month compared to the previous month; it is not easy, nor necessarily meaningful, to say that the weather was 20% worse.

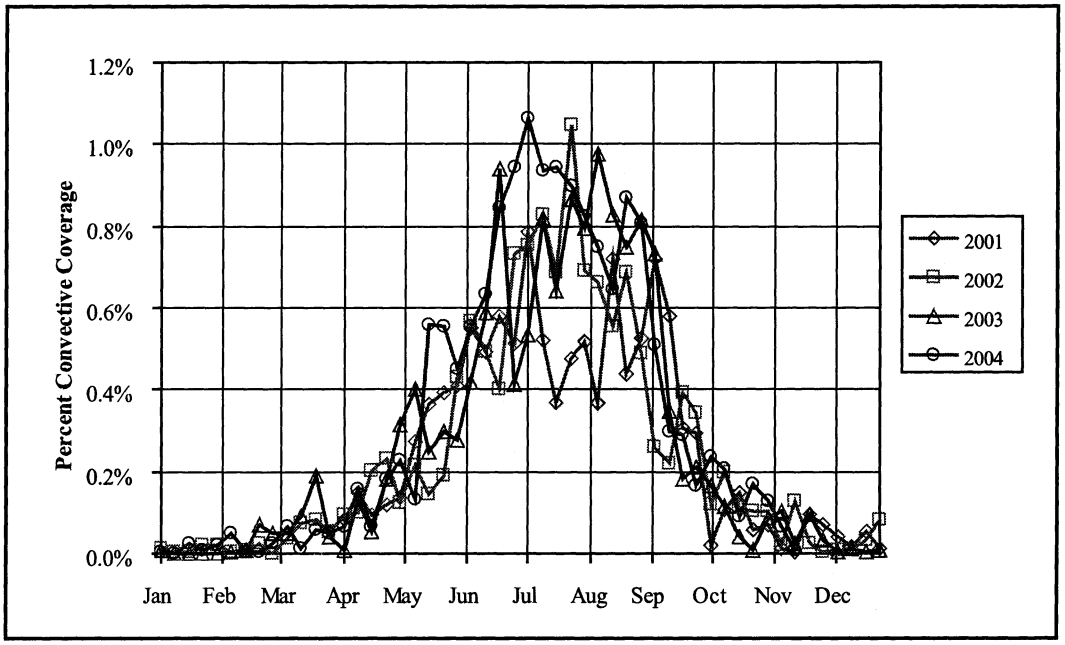
The scarcity of analytic tools for assessing the impact of weather on aviation is a big problem for the FAA. Without a quantitative measure of weather, can managers really evaluate the delay statistics they are shown? Increases in delay usually are attributed to worse weather, which likely is the actual cause.[1,2] Decreases in delay, on the other hand, though possibly caused by better weather, are more readily attributed to better procedures.[3] The economic costs of delay, which are beyond the scope of this paper, also factor into many investment decisions by the FAA and airlines.

The impact of weather on aviation varies according to the type of weather, its intensity, and location. This paper analyzes system performance during the summer convective weather season, defined here as June, July, and August. During these months, thunderstorms, which bring with them severe turbulence, hail, lightning, and other hazards, regularly disrupt air travel by temporarily shutting down airports and blocking key portions of airspace.

One reason for analyzing summer separately from the rest of the year is that the FAA itself gives summer special consideration. Since the year 2000, each October the FAA and airlines have held a severe-weather review in which they analyze what happened during the summer season and discuss ways to better manage traffic during the next season. Also, summer lends itself to analysis because, unlike the other seasons, summer has a single dominant weather phenomenon: thunderstorms.

Figure 1 shows the strong seasonality of convective thunderstorms. It plots, by week, the average area of the thunderstorms spread across the continental U.S. as measured by the National Convective Weather Detection (NCWD) database.[4] The NCWD records thunderstorm activity on an intensity scale from 1 to 6, with 6 being the most severe, every five minutes on a two-nautical-mile grid. The figure shows the fraction of grid squares having storm intensity above level 2 at 3 p.m., 5 p.m., and 7 p.m. (Eastern time zone).

**Figure 1: Average Convective Storm Coverage by Week, 2001-2004**




Source: www-ad.fsl.noaa.gov/fvb/rtvs/rtvs_2001/conv/index.html.

To provide insights into system performance, the author constructed a weather metric that accounts for the location and intensity of convective thunderstorms. This metric can be aggregated on daily, monthly, and seasonal time-scales and can be used in regression models to help identify and explain changes in system performance.

## LITERATURE REVIEW

Evans et al. (2004) summarizes contemporary methodologies for analyzing delays and convective weather. One approach that was explored by Callaham et al. (2001) and Nazari and Zhang (2002) involves using principal components analysis to identify days having similar weather. The idea is that if a set of similar-weather days can be identified, then examining delay totals on such days will provide insights into the relative merit of different traffic management strategies. The results of this approach have been somewhat disappointing. Because the convective weather season lasts only three months, the number of days that can be analyzed is rather small. Moreover, days that appear similar often unfold very differently due to small differences in the locations of storms. In short, weather-days are like snowflakes: no two are alike. Pepper et al. (2003) found that their Bayesian analysis of traffic management strategy was severely hampered by small sample size and the lack of days with similar weather.

Several researchers have constructed weather metrics that attempt to quantify the overall impact of a given day's weather. Most follow a methodology that was outlined by Callaham et al. (2001). The country is divided into a large number of cells that are weighted by the density of aircraft that

would normally occupy a cell, as well as the severity of the storms in the cell. The combination of weather and traffic density is then aggregated to give a numerical score for each day. To improve correlations with delay, local airport weather, usually wind speed and visibility, is also included. Post et al. (2002), Chatterji and Sridar (2005), and Klein (2006) all follow this approach, using slightly different data and methods of aggregation.

The downside of the Callaham et al. (2004) approach is that the resulting metric can be something of a "black box" variable that correlates with delay, but cannot easily be disaggregated. For example, Nazari and Zhang (2002) used imagery analysis techniques to generate metrics that measure the overlap between thunderstorms and all intended flight paths on a given day. The resulting metrics correlate with delay, but, because they cannot be disaggregated, may yield few insights into why one day or season had more delay than another.

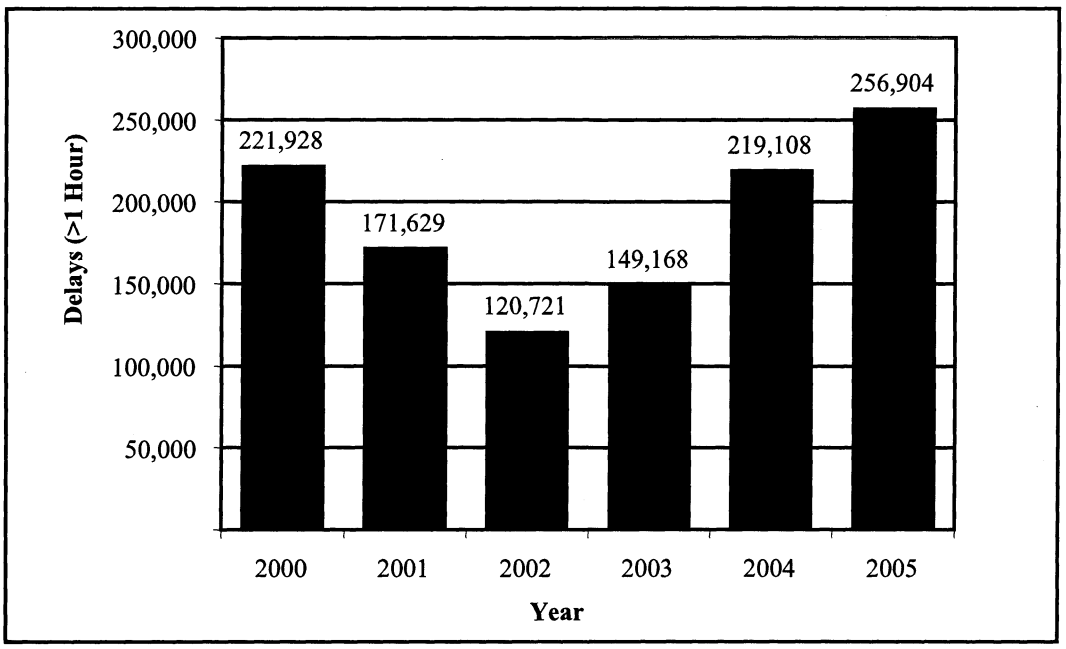
In contrast, the weather score presented here is computationally simple, can easily be aggregated or disaggregated, and yields a number of insights about system performance. In addition, the explanatory power of the model presented here seems to be as good as that of more complicated models.

## SCHEDULE DELAYS LASTING MORE THAN ONE HOUR

The FAA records a schedule delay whenever a flight arrives or departs later than scheduled. Fifteen-minute and one-hour schedule delays are both archived in the Aviation System Performance Metrics (ASPM) database.[5] This paper focuses on delays lasting more than one hour because these delays are much more disruptive to passengers and airlines than 15-minute delays. Hour-long delays are also less sensitive to small changes in turnaround time and scheduled flight duration that airlines make in order to maintain stable on-time performance rates.

As a measure of total system delay, the author used the number of arrivals and departures delayed more than one hour, summed over the 45 busiest commercial airports. On a given day, for example, 79 flights might arrive more than an hour late at Atlanta Hartsfield International Airport and 109

**Figure 2: Number of Arrivals and Departures Delayed More Than One Hour, 45 Airports, June Through August, 2000-2005**




Source: www.apo.data.faa.gov.

flights might depart more than an hour late, for a total of 188. Recent trends for this metric, shown in Figure 2, are rather dramatic: From 2002 to 2005, hour-long delays at the 45 airports increased at a rate of about 30% per year, following declines in 2001 and 2002. What's more, although hour-long delays were up 16% in 2005 compared to 2000—a year in which aviation delays received much public attention—the 45 airports actually had 5% fewer flights in 2005 than in 2000.[6]

The decrease in delay from 2001 to 2002 is understandable given the decline in air travel following September 11, 2001. Between 2001 and 2002, operations declined 8% at the 45 busiest commercial airports. The decrease in delay from 2000 to 2001 is more difficult to explain. Factors that might have contributed to the decrease include better weather (Figure 1 indicates that the summer of 2001 had less convective coverage, on average, than the following three years.); a 1% decrease in scheduled operations compared to summer 2000; improved coordination between the FAA and airlines following the implementation of daily teleconferences (Lamon et al. 2002); and the re-imposition of slot controls at New York's LaGuardia airport, the airport with the greatest decrease in delay from 2000 to 2001.

The remainder of this paper looks at NAS performance metrics for June through August 2003, 2004, and 2005, making use of a weather metric that accounts for the location and intensity of thunderstorms. Weather data prior to 2003, unfortunately, was not available.

## QUANTIFYING THE EFFECTS OF THUNDERSTORMS

The author's weather metric uses only those NCWD observations—measured on an intensity scale from 1 to 6—that are on the grid-squares directly over the 45 busiest commercial airports. And for each airport, the metric uses just the maximum storm intensity in a given hour. Focusing on weather at airports makes sense. After all, the appearance of level-5 or level-6 thunderstorms at an airport can temporarily halt all arrivals and departures. Airplanes that are approaching the airport will go into holding patterns; and if a storm lingers long enough, these airplanes will divert to other airports. But a storm that misses the airport by a dozen miles, though disruptive, has a much smaller impact.

To account for the fact that some airports and hours of the day are busier than others, the maximum intensity of the NCWD each hour is multiplied by the number of flights scheduled to arrive that hour. This gives a daily weather-impacts score for each airport, defined as the product of maximum NCWD intensity times the number of scheduled arrivals each hour, summed over the entire day. The formulation of this weather score is somewhat arbitrary; whether or not this is a good formulation depends on how well it explains the day-to-day variation in delay.

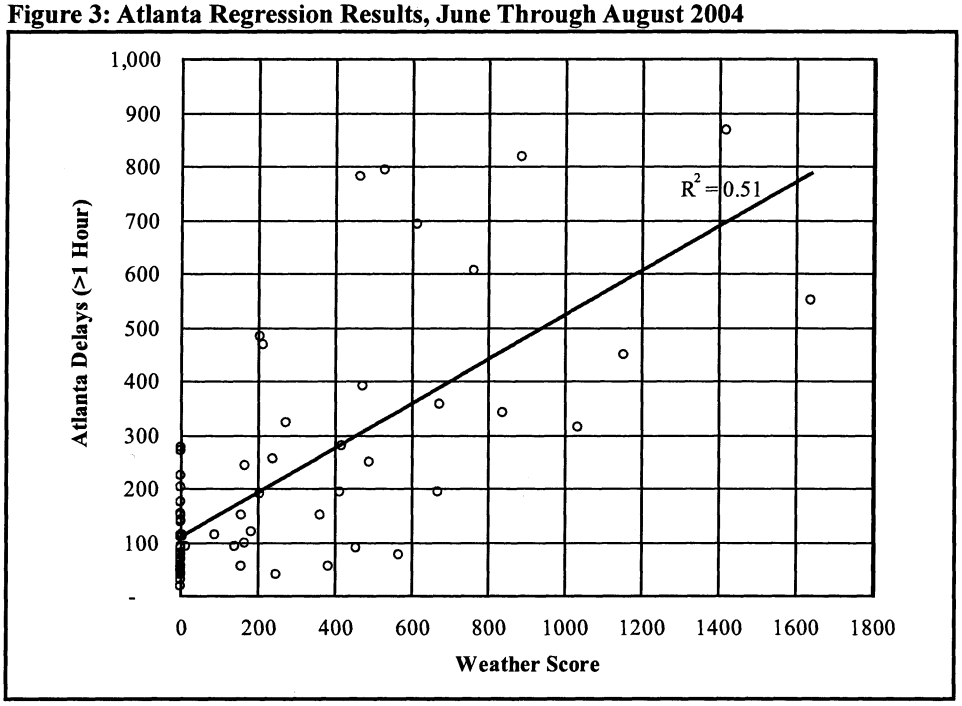
Weather scores were calculated for the 71 days between June and August 2004 for which the author had a complete archive of NCWD data. Figure 3 shows one-hour delays versus weather score at Atlanta. According to the figure, much (51%) of the day-to-day variation in one-hour delays at Atlanta can be explained by thunderstorms impacting the airport. A similar regression, using total minutes of arrival delay, gives an $R^2$ of 53%.

No thunderstorms impacted Atlanta on 35 of the 71 days in the sample. On these days, Atlanta delays were determined largely by what was happening at other airports. An airport's delays can usually be separated into two sources: flights that are late because of problems at the airport itself and flights that are late due to propagated or system-wide delay. That is, if there is bad weather in the Northeast, then Atlanta will have many late departures and arrivals to and from airports in the Northeast. Atlanta will also see a number of ripple delays—flights that take off late because of weather in the Northeast, land late at secondary airports, and afterwards land late at Atlanta.

## A MONTHLY WEATHER IMPACTS METRIC

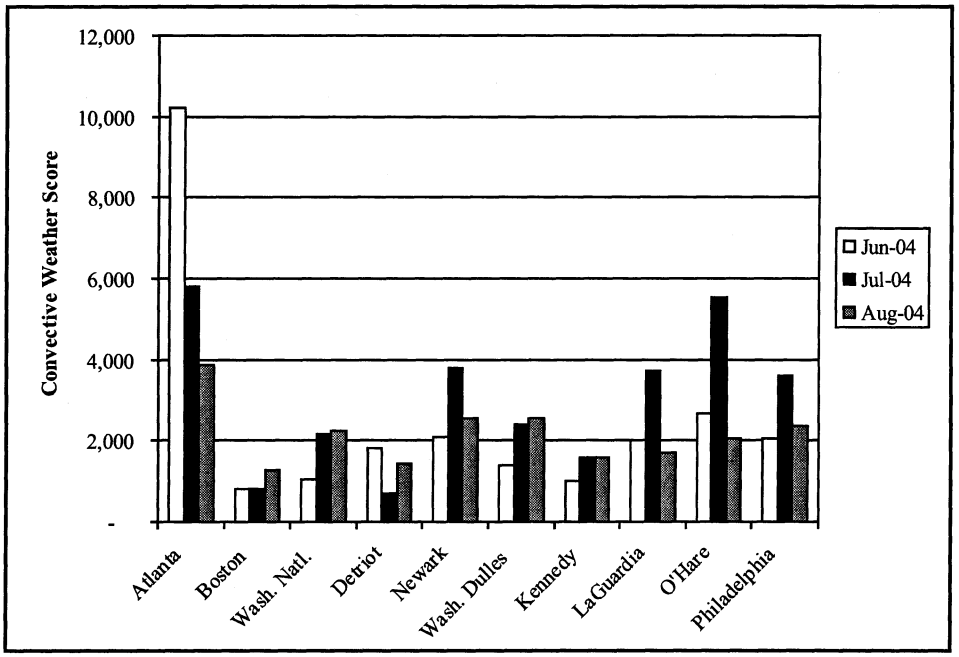
To estimate the extent to which convective weather affects an airport in a month, one simply sums the daily weather scores. A monthly metric is useful for helping to explain the large month-to-

**Figure 3: Atlanta Regression Results, June Through August 2004**



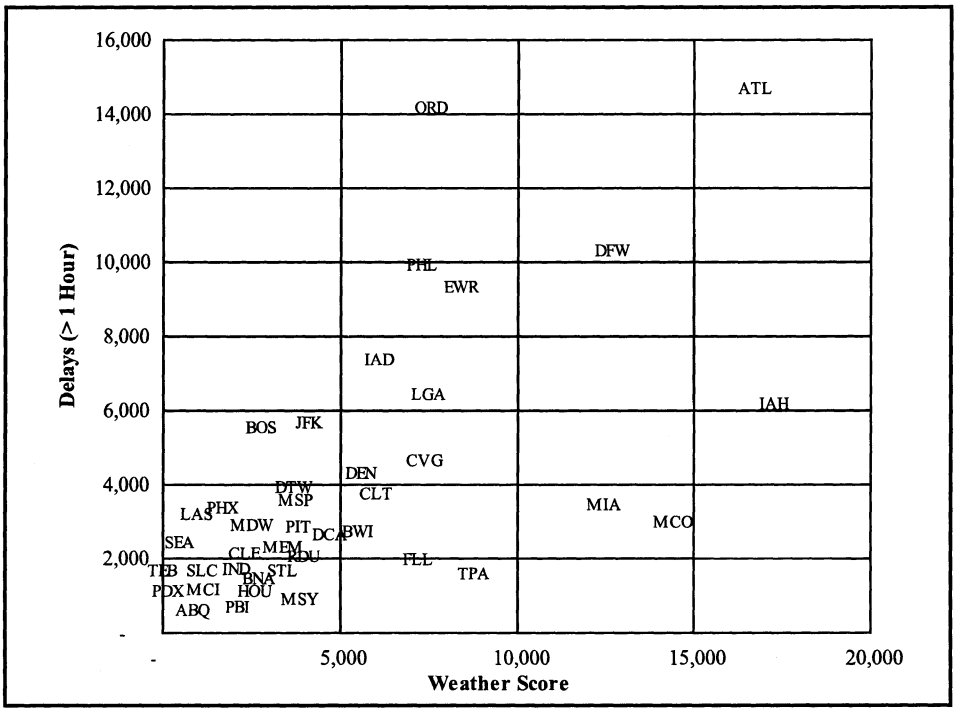

month swings in delay that are often observed at airports. For example, in June 2004, delays at Atlanta were 78% higher than in July, and 117% higher than in August. The weather-impacts score in Figure 4 sheds light on the reason: Atlanta had roughly twice the number of flights impacted by thunderstorms in June as in July or August.

**Figure 4: Monthly Convective Weather Score by Major Airport**



A scatter plot is useful for comparing delay and weather across airports. Figure 5 plots delays versus convective weather score by major airport for June through August 2004. Most airports lie near the 45-degree line. Distinctly separate from the rest are the airports in Florida and along the Gulf of Mexico—Palm Beach (PBI), New Orleans (MSY), Fort Lauderdale (FLL), Tampa (TPA), Miami (MIA), Orlando (MCO), and Houston (IAH). Airports this far south do not have the same convective fronts that airports farther north experience. Often they have small air-mass storms, which are less disruptive than frontal systems because of their small size and because they are easier for pilots to see and circumnavigate.

**Figure 5: Scatter Plot of Delay Versus Weather Score by Major Airport, June Through August 2004**




Chicago O'Hare (ORD) stands out as having more delays than expected for the amount of convective weather there. This is due to the airport having a high number of scheduled flights during the summer of 2004. High delays in 2004 caused the FAA to negotiate several schedule revisions at O'Hare.[7]

Airports in the West have very little convective weather as measured by the NCWD, and have proportionately fewer delays. Airports on the West Coast—Los Angeles (LAX), San Francisco (SFO), San Jose (SJC), and San Diego (SAN)—had no convective weather in the summer of 2004.

The remaining airports in Figure 5 are located in the following cities: Albuquerque (ABQ), Atlanta (ATL), Nashville (BNA), Boston (BOS), Baltimore/Washington (BWI), Cleveland (CLE), Charlotte (CLT), Cincinnati (CVG), Washington, D.C. (DCA), Denver (DEN), Dallas/Fort Worth (DFW), Detroit (DTW), Newark (EWR), Washington Dulles (IAD), Houston (HOU), New York (JFK), Indianapolis (IND), Las Vegas (LAS), New York (LGA), Kansas City (MCI), Chicago Midway (MDW), Memphis (MEM), Minneapolis (MSP), Philadelphia (PHL), Phoenix (PHX), Pittsburgh (PIT), Portland (PDX), Raleigh Durham (RDU), Seattle (SEA), San Francisco (SFO), Salt Lake City (SLC), St. Louis (STL), and Teterboro (TEB).

## A SYSTEM-WIDE CONVECTIVE WEATHER SCORE

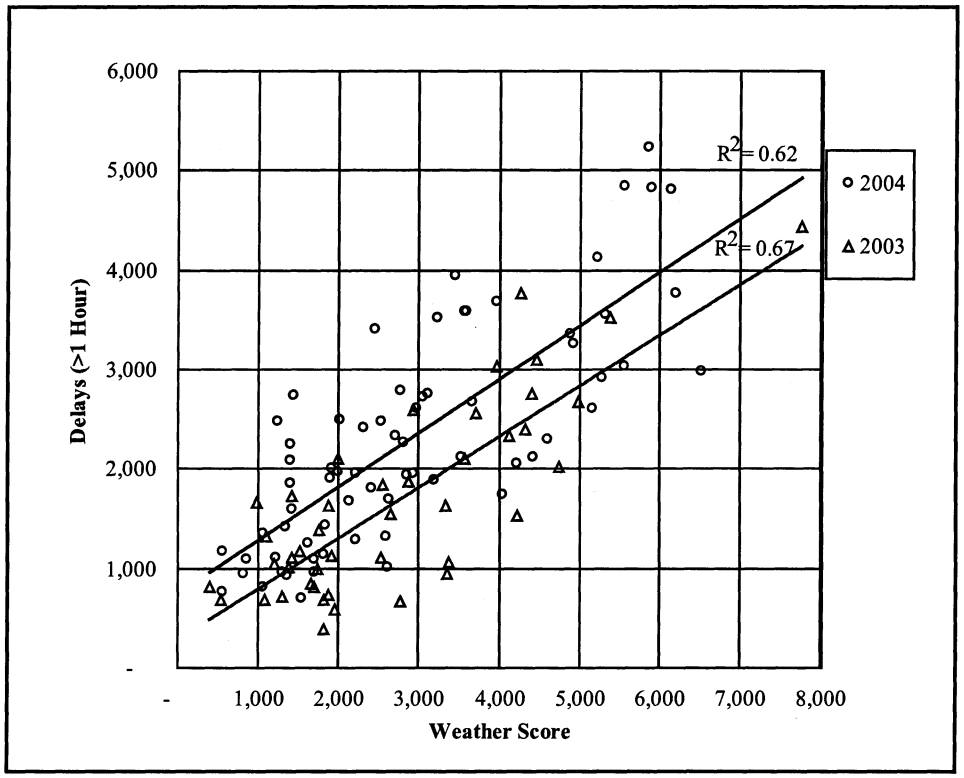
An airport's weather score is defined as each hour's maximum storm intensity, multiplied by the number of scheduled arrivals, summed over an entire day. Summing the weather scores at the 45 airports gives a simple aggregate weather score for the entire country. Figure 6 plots delays against weather score for June through August of 2003 and 2004. The correlations are moderate ($R^2$=0.67 for 2003 and $R^2$=0.62 for 2004), and the figure suggests a substantial increase in delay from 2003 to 2004. The equations for the regression lines in the figure are:

(1) Delays(>1 hour, Year = 2003) = 276 + 0.51 WeatherScore

(2) Delays(>1 hour, Year = 2004) = 737 + 0.54 WeatherScore

Total minutes of arrival delay (not pictured) are also moderately correlated with weather score ($R^2$=0.63 for 2003 and $R^2$=0.61 for 2004).

**Figure 6: Delay Versus Weather Score, 45 Airports, June Through August, 2003 and 2004**

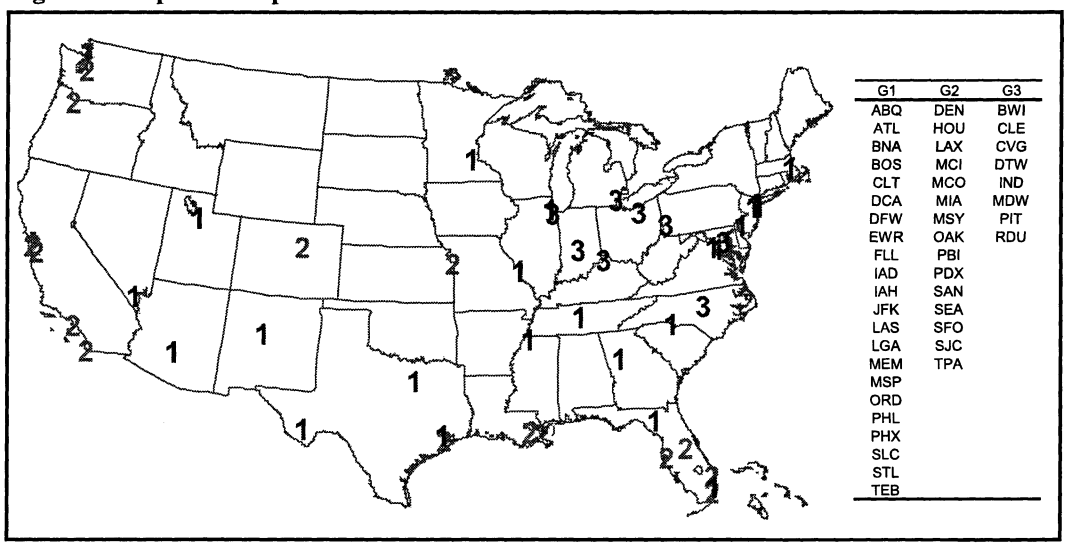



For clarity, Figure 6 excludes two outlier days: July 4, 2004, and July 14, 2004. The holiday, July 4, was excluded because it had very few scheduled arrivals. On July 14, the FAA put in place an extraordinarily large number of ground stops and ground delay programs in order to cope with weather located between Chicago and New York. The summer 2003 analysis was based on the 42 days between June and August for which the author had a complete archive of NCWD data.

The weather score discussed above weights every airport the same; that is, all are weighted by the number of flights scheduled to arrive during the hour they experience convective weather. This approach will now be modified to account for the fact that the impact a storm has on delay also depends on the region of the country where the weather occurs. It was previously noted that air-mass storms near the Gulf of Mexico cause fewer delays than storms farther north. It's also reasonable to believe that storms occurring in Pennsylvania and Ohio—an area packed with routes into the

Northeast—would have a relatively larger affect on delay. With this in mind, the 45 airports were divided into the three groups G1, G2, and G3 shown in Figure 7.

**Figure 7: Airport Groups**




A genetic algorithm helped identify the groups. The algorithm begins by randomly partitioning the 45 airports into three groups. Groupings that produce a low degree of correlation between weather and delay are discarded. Groupings that produce a high degree of correlation are randomly modified to produce a new generation of airport groupings for which the process of selection and random modification is repeated. The algorithm is stopped when the correlations stop improving.

The set of airport groups—G1, G2, and G3—used in the model was similar, but not identical, to the best set found by the algorithm. The actual groups were chosen using the following criteria: Group 1 contains large airports that experience delays on a regular basis. Group 2 contains airports around the Gulf of Mexico and on the West Coast, for which convective weather causes less delay than elsewhere. Group 3 contains airports that are not operating close to capacity but are located along busy routes into New York. Two airports, Fort Lauderdale (FLL) and Houston (IAH), are in Group 1 even though they are located near the Gulf of Mexico. These airports are similar to airports in Group 1 in that they operate near their maximum capacity and so cause disproportionately more delays when impacted by weather than their neighbors.

## REGRESSION RESULTS

A regression model was constructed using weather data from 2003, 2004, and 2005. The regression equation determined by the model is given below; detailed regression results are shown in Table 1.

(3) Delays(>1 hour) = 652 + 0.54 G1 + 1.03 G3 - 645 Saturday - 110 Sunday + 580 Y2004 + 893 Y2005

The dependent variable in the model is the total number of arrival and departure delays exceeding one hour. The variables G1 and G3 are the weather scores for the airports in Groups 1 and 3. The weather variable G2, representing weather in Florida and the West Coast, was found to be not statistically significant in an earlier model and was dropped. Weather impacting the G3 set of airports had twice the effect on delay as weather impacting the G1 airports. Saturday and Sunday were modeled as categorical variables because they have fewer scheduled flights than weekdays. A Saturday had, on average, 645 fewer one-hour delays than a weekday. The Fourth of July was placed in the 'Saturday' category, because holidays tend to resemble Saturday schedules.

Y2004 and Y2005 are categorical variables representing the years 2004 and 2005. The model says that for the same weather, a day in 2004 had 580 more delays than a day in 2003, and a day in 2005 had 893 more delays. For reference, a weekday in 2003 with moderate (60th percentile) delays had 1,897 one-hour delays; a 90th percentile day had 3,088 delays.

**Table 1: Regression for the Effect on NAS-Wide Delays of Weather-Impacts Metric**

| | *Coefficients* | *t Stat* | *P-value* |
|---|---|---|---|
| Intercept | 652 | 4.8 | 3E-06 |
| G1 | 0.54 | 13.1 | 9E-29 |
| G3 | 1.03 | 8.6 | 3E-15 |
| Saturday | -645 | -4.6 | 8E-06 |
| Sunday | -110 | -0.8 | 0.44 |
| Y2004 | 580 | 4.3 | 3E-05 |
| Y2005 | 893 | 6.8 | 1E-10 |

| | |
|---|---|
| R Square | 0.69 |
| Observations | 204 |
| Significance F | 6.5E-48 |

The p-values in Table 1 give the significance of the different variables—the probability the variable is not zero. All except the variable 'Sunday' are highly significant. The model showed some autocorrelation that would tend to raise the uncertainty of the model parameters. The Durbin-Watson statistic for this model is 1.39. This rises to 1.73, indicating indeterminate autocorrelation, when data from summer 2006 data is included. Overall, the model fits the data well enough that the impact of autocorrelation on the findings is small.

## REASONS FOR INCREASED DELAY

So why have delays been increasing in recent years? What's more, why were there 16% more hour-long schedule delays in 2005 than in 2000, when the number of flights at the top 45 airports declined by 5% over this same period? The answer appears to be that traffic levels have increased at the most popular hubs, which have little spare capacity, and have decreased at less popular hubs, which have more spare capacity.

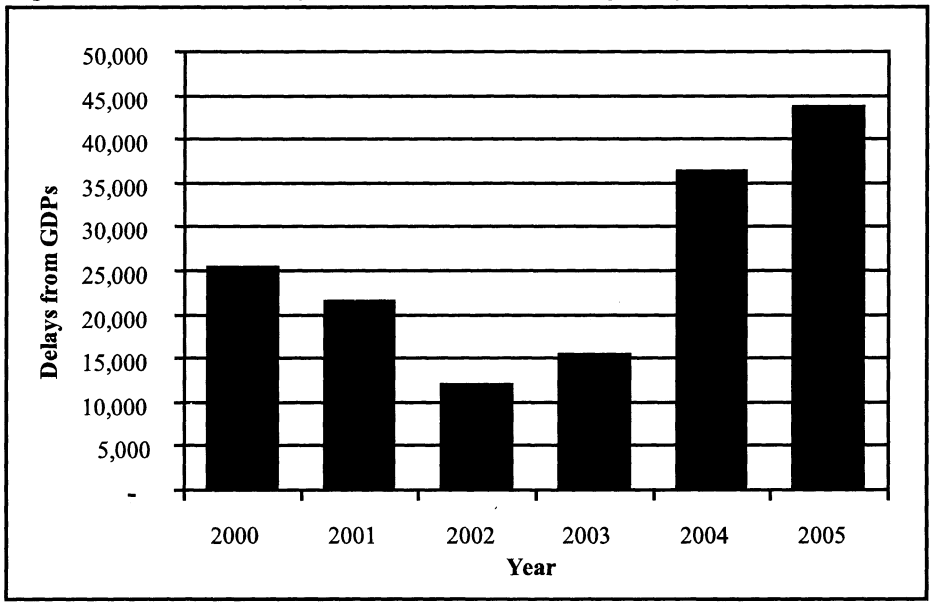
In the summer of 2000, of the 45 airports, just eight—Atlanta, Chicago O'Hare, Philadelphia, Newark, LaGuardia, Washington Dulles, Houston, and John F. Kennedy —accounted for 58% of all delays recorded under the FAA's Operational Network (OPSNET) system of measuring delays.[8] Today, these eight account for 74% of the total, nearly three times as many delays as the other 37 airports combined. Since 2000, OPSNET delays at these eight airports increased 23% overall, whereas delays decreased 39% everywhere else.

The OPSNET system measures delay very differently from ASPM, which records delay strictly based on scheduled arrival and departure times. OPSNET, on the other hand, records a delay whenever the progress of a flight has been interrupted more than 15 minutes by any non-airline cause such as miles-in-trail restrictions, runway congestion, airborne holding, ground stops, or ground delay programs (GDPs). OPSNET is very useful for identifying airports that originate delays. For example, for a flight held 90 minutes at Washington Dulles due to a GDP at Atlanta, OPSNET would assign a single delay to Atlanta of duration 90 minutes. This single OPSNET delay, however, could spawn several lengthy schedule delays. At the very least, a departure delay of 90

minutes would get assigned to Washington Dulles and an arrival delay of about 90 minutes would get assigned to Atlanta. It's also likely that the aircraft, after arriving late at Atlanta, will depart late to its next destination, where it again might arrive late. See Schaefer and Miller (2001) or Hansen and Bolic (2001) for analyses of delay propagation.

It was stated earlier that flights at the 45 airports were down 5% overall in 2005 compared to the summer of 2000. Breaking this down by airport reveals that flights were up an average of 9% at the eight hubs mentioned above, and down 9% at the remaining 37 airports.[9] It also is worth noting that delays from ground delay programs (GDPs) were substantially higher in 2004 and 2005 than in previous years. (See Figure 8). GDPs are put in place on bad-weather days at airports where scheduled operations exceed the airport's bad-weather capacity. In a GDP, flights heading to the affected airport are assigned mandatory departure delays to reduce the rate of arrivals into that airport. Delays from GDPs are noteworthy because they have a long average duration—74 minutes in the summer of 2004, compared to 33 minutes for all other OPSNET delays.[10]

**Figure 8: Number of Delays from GDPs, June Through August, 2000-2005**




Source: www.apo.data.faa.gov.

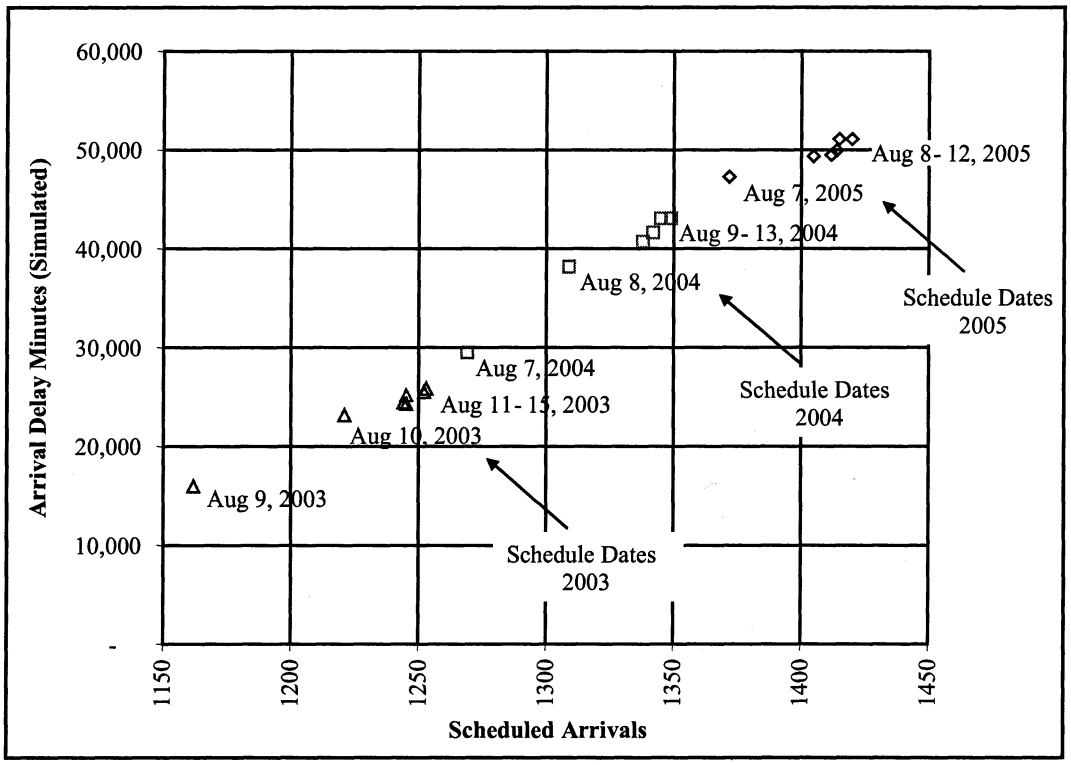
## SIMULATION RESULTS FOR ATLANTA AND PHILADELPHIA

A single-server queuing model helps illustrate the effects of schedule increases on delay. Constructing such a model is straightforward given an airport's schedule and arrival capacity.[11] Arrival capacity, defined as the number of flights that an airport can land in an hour, changes throughout the course of a day, depending on local weather and the airport's runway configuration. The FAA requires airports to note whenever their arrival or departure capacities change. Historical capacities for more than 50 airports can be downloaded from the ASPM website.[12] Using capacity data from ASPM and schedule data from the Official Airline Guide,[13] the author created a first-come, first-served, single-server queuing model that calculates total minutes of arrival delay (defined as the difference between actual arrival time and scheduled arrival time, summed over all flights).

Figure 9 shows model output for Atlanta using schedule data from August 2003, 2004, and 2005. For each schedule date, the model calculated minutes of arrival delay using Atlanta's arrival capacity on August 7, 2005, a bad-weather day on which ground delay programs reduced the flow of aircraft into the airport to about 80 per hour after 2 p.m. Using this day's capacity profile, the

model predicted 50,000 minutes of arrival delay using the weekday schedule from August 2005. This is twice the delay predicted using the schedule from two years before, which had about 12% fewer flights.

**Figure 9: Simulated Minutes of Delay at Atlanta Using Airport Capacity from August 7, 2005 and Schedules from 2003-2005**




Simulation also explains a recent increase in delay at Philadelphia, the third most-delayed airport of 2005, according to OPSNET. For Philadelphia, minutes of arrival delay were calculated using the airport's arrival capacity on July 13, 2005. Under identical conditions, Philadelphia's 2005 schedule generates twice as many minutes of delay as its 2003 schedule, which had about 25% fewer flights.

## AIRBORNE HOLDING, DIVERSIONS AND CONVECTIVE WEATHER

When thunderstorms reduce an airport's arrival capacity, airplanes that are approaching the airport must often circle in holding patterns until it is their turn to land. Because of the fuel that gets burned, airborne holding is less desirable than ground stops, which temporarily reduce the flow of traffic to an airport by halting departures from nearby airports. But employing ground stops is tricky, because traffic managers must anticipate when and how severely an airport's capacity will be reduced. If an airborne hold lasts long enough, the airplane will get diverted to another airport. Diversions can be extremely disruptive to an airline because they put aircraft, air crews, passengers, and baggage out of place. Passengers who were waiting to board the diverted aircraft also need to be accommodated.

It has already been shown that, relative to weather, arrival and departure delays increased substantially from summer 2003 to 2004 and again from 2004 to 2005. What about airborne holding and diversions? The author wrote an (unpublished) algorithm that identifies airborne holding.

The algorithm runs overnight and the results, which summarize the previous days' holding, are sent to the FAA each morning. The algorithm works by examining records from the Enhanced Traffic Management System (ETMS).[14] Every flight in ETMS consists of a sequence of position messages, spaced about a minute apart. For each message, the computer calculates the distance to the destination airport. Aircraft in holding patterns stand out because, for a time, they move away from their destination. The hold begins and ends midway between the point where distance starts increasing and the point where it resumes decreasing. To distinguish true holds from redirection around weather or maneuvers prior to landing, the net distance traveled by the aircraft is examined along with the distance to the destination airport. Aircraft in holding patterns travel a relatively short distance from the time they enter a hold to the time they exit it, which gives them a very slow net speed from hold start to end.

The same approach used to analyze one-hour schedule delays was also applied to minutes of airborne holding. Several regression models were tried. One of the simplest and most revealing models is described by the equation below.

(4) HoldingMinutes = 3169 + 1.64 WeatherScore - 2474 Saturday
+ 978 Y2005

Regression results for holding are summarized in Table 2. WeatherScore is the sum of the three weather variables G1, G2, and G3. Unlike with one-hour schedule delays, the regression for airborne holding minutes did not improve much when the weather score was separated into these three regional weather variables. This suggests a different relationship between airborne holding and convective weather than between one-hour schedule delays and weather. Weather blocking routes into New York causes aircraft to be delayed on the ground, but does not cause much additional airborne holding. Airborne holding is mainly caused by storms impacting airports, and weather in the South causes roughly the same amount of holding as weather in the North. The variables Y2004 and Sunday were not statistically significant and were dropped from the model. The results also suggest that 2005 had 978 additional minutes of airborne holding per day than 2003 and 2004. For reference, a weekday with moderate (60$^{th}$ percentile) airborne holding had 8,180 minutes of holding in 2003 and 2004; a 90$^{th}$-percentile day had 13,057 minutes.

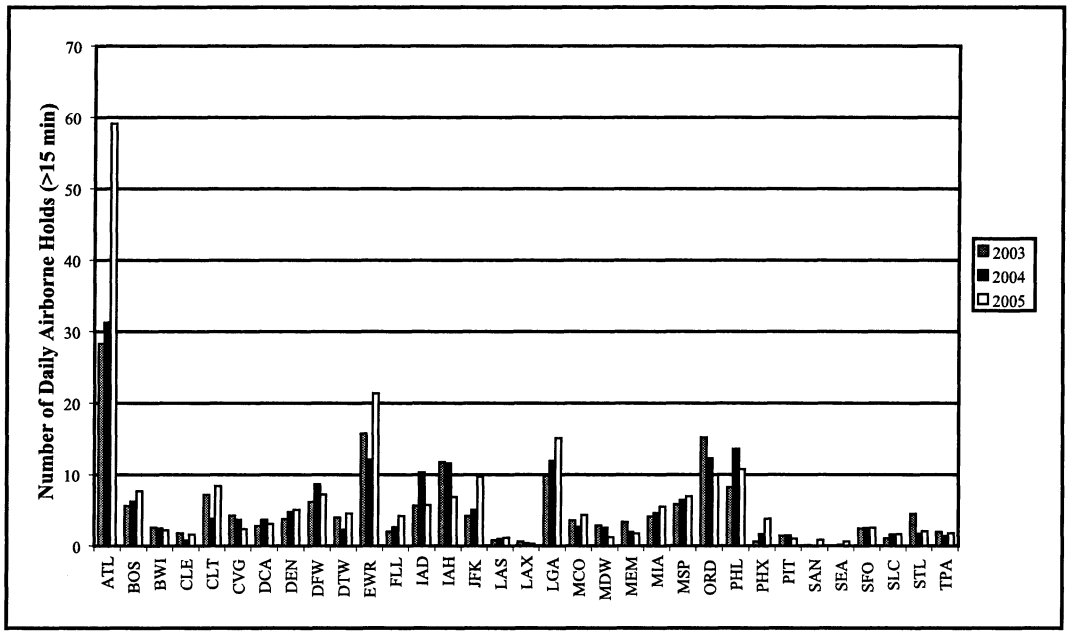
**Table 2: Regression for the Effect of Convective Weather on Airborne Holding Minutes**

| | *Coefficients* | *t Stat* | *P-value* |
|---|---|---|---|
| Intercept | 3169 | 7.62 | 1.1E-12 |
| WeatherScore | 1.64 | 14.3 | 2.2E-32 |
| Saturday | -2474 | -5.30 | 3.1E-07 |
| Y2005 | 978 | 2.9 | 0.005 |

| | |
|---|---|
| R Square | 0.59 |
| Observations | 202 |
| Significance F | 1.3E-38 |

Figure 10 shows the number of airborne holds lasting more than 15 minutes by destination for 2003, 2004, and 2005. It shows that the increase in airborne holding in 2005 was caused primarily by a doubling of holding at Atlanta, the airport with the most airborne holding all three summers. Most of this holding occurs during Atlanta ground delay programs. In a GDP, the airport selects the rate at which it will receive aircraft. To meet this arrival rate, a computer assigns mandatory departure delays to the flights that had been scheduled to arrive during the program. Atlanta, like all airports, faces a tradeoff when selecting its GDP arrival rate: a high rate can increase throughput by ensuring that enough aircraft are lined up to fill every available arrival slot. An arrival rate that exceeds the airport's ability to land aircraft causes airborne holding.

**Figure 10: Number of Airborne Holds by Destination Airport, June Through August, 2003-2005**




Regression analysis also led to the following equation for diversions.[15]

(5) Diversions = 14.3 + 0.016 G1 + 0.009 G3 – 12.3 Saturday + 7.7 Y2005

A full regression summary is in Table 3. All variables have statistically significant coefficients. The equation suggests there were about eight more diversions each day in summer 2005 than in summer 2003 or 2004. For reference, the 60th percentile for diversions on a weekday in 2003 and 2004 was 77, and the 90th percentile was 117.

**Table 3: Regression for the Effect of Convective Weather on Diversions**

| | *Coefficients* | *t Stat* | *P-value* |
|---|---|---|---|
| Intercept | 14.3 | 4.7 | 4.6E-06 |
| G1 | 0.016 | 13.3 | 2.6E-29 |
| G3 | 0.009 | 2.5 | 0.015 |
| Saturday | -12.3 | -3.0 | 3.0E-03 |
| Y2005 | 7.7 | 2.6 | 0.010 |

| | |
|---|---|
| R Square | 0.56 |
| Observations | 202 |
| Significance F | 1.0E-34 |

## CONCLUSION

This paper examined recent trends related to aviation delays during the summer convective weather season. A weather metric was introduced to help account for differences in the location and intensity of thunderstorms. Regression models constructed using this metric found substantial increases in delays lasting more than one hour from 2003 to 2004 and from 2004 to 2005.

The increase in delay appears to be driven by a greater concentration of flights at already busy hubs. From summer 2000 to 2005, flight counts rose 9% at the eight most delayed U.S. airports, but fell 9% on average at 37 other major airports. The proportion of delays at these eight airports went from 58% of the nationwide total for OPSNET delays in 2000 to 74% of the total in 2005. Results from a single-server queuing model illustrate how rapidly delay increases at heavily-subscribed airports like Atlanta and Philadelphia.

Regression analysis also found that airborne holding increased by 978 minutes per day in summer 2005 compared to summer 2003 and summer 2004. The increase appears to be driven by a doubling of holding at Atlanta, the U.S. airport with the most airborne holding. The number of diverted flights increased by about eight per day in 2005 compared to 2003 and 2004.

The weather metric described here shows quantitatively how thunderstorms impact the day-to-day and month-to-month changes in delay during summer. Across different years, changes in delay appear to be strongly driven by small changes in the number of scheduled flights at busy hubs. Incorporating other types of weather besides thunderstorms remains a significant challenge, but would allow for performance analysis in seasons other than summer.

### Endnotes

1. See Adrian Schofield. "Flight Delays Rise Again In June, IG Report Finds." www.aviationnow.com, July 5, 2005.

2. See Adrian Schofield. "Monday Storms Cause Worst Day of Delays this Month, FAA Says." www.aviationnow.com, March 30, 2005.

3. See Adrian Schofield. "July Sees Fewer Delays, But 2006 Total Still Up Slightly." www.aviationnow.com, August 9, 2006.

4. The MITRE Corporation's archive of NCWD data was built by downloading data every five minutes from the FTP site ftp://tgftp.nws.noaa.gov/SL.us008001/ DC.avspt/DS.ncwf, which is supported by the National Weather Service.

5. www.apo.data.faa.gov.

6. All flight counts in this paper come from the FAA's Operational Network (OPSNET) database, www.apo.data.faa.gov.

7. Frances Fiorino. "O'Hare Cuts, Round Two." *Aviation Week.* April 26, 2004, p. 43.

8. OPSNET reporting guidelines are described in FAA Order 7210.55C, October 1, 2004.

9. OPSNET

10. OPSNET

11. See Gross, Donald, and Carl M. Harris. *Fundamentals of Queuing Theory*. John Wiley & Sons, New York, 1998.

12. www.apo.data.faa.gov.

13. www.oag.com.

14. ETMS is the primary data source that the FAA uses to track aircraft in real time. It is supported by The Volpe Center (www.volpe.dot.gov).

15. The MITRE Corporation maintains its own diversions database based on an (unpublished) algorithm.

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