P4.3

THE IMPACT OF THUNDERSTORM GROWTH AND DECAY ON AIR TRAFFIC MANAGEMENT IN CLASS B AIRSPACE*†

Bradley A. Crowe, Benjamin G. Boorman, Mark A. Isaminger, Margita L. Pawlak, and Dale A. Rhoda

Lincoln Laboratory, Massachusetts Institute of Technology
244 Wood Street
Lexington, Massachusetts 02173–9185

1. INTRODUCTION

Air traffic management is a challenging task, especially if the airspace involved is impacted by inclement weather. The high volume of air traffic which inundates the nation's major airports compounds the difficulties with which Air Traffic Control (ATC) specialists have to cope. When you add the unpredictability of thunderstorm growth and decay to the controllers workload, air traffic management becomes even more of a challenge.

ATC specialists would benefit from reliable forecasts of thunderstorm growth and decay. To determine how they would use a Growth and Decay product, ATC specialists from the Memphis Air Route Traffic Control Center (ARTCC), Traffic Management Unit (TMU), and TRACON supervisors were interviewed while viewing five movie loops of Memphis weather cases. The movies consisted of the ASR–9 six–level reflectivity data, aircraft beacons, and storm motion vectors.

2. MEMPHIS AIR TRAFFIC PATTERN

The Memphis air traffic pattern revolves around four daily arrival (inbound) and five daily departure (outbound) pushes. The primary air carriers which use Memphis International Airport are Federal Express (FedEx) and Northwest Airlines (NWA). As shown in Table 1, these arrival and departure pushes do not coincide. This allows Memphis' ATC specialists to use the departure gates during arrival pushes and vice versa, if weather impacts a pre–planned fix. ATC specialists stated that this is an asset which most other major airports do not have. Many major airports have a steady stream of arrivals and departures throughout the day which complicates operational decision making.

Table 1.
Airline Pushes for Memphis

Airline	Arr. or Dep.	Start Time	End Time	No. of Aircraft
NWA	Arr.	1200[1]	1315	69
NWA	Dep.	1340	1430	75
NWA	Arr.	1710	1830	74
NWA	Dep.	1825	1935	74
FedEx	Dep.	2030	2230	36–40# 40–45^
NWA	Arr.	2315	0040	75
NWA	Dep.	0050	0135	69
FedEx	Arr.	0330	0600	144
FedEx	Dep.	0730	0915	144

 # On Tuesdays, Wednesdays, and Thursdays
^ On Sundays only
1 – All times are Universal Time (UT) which is 5 hours ahead of Central Daylight Time.

The standard pattern for air traffic in Memphis during a non–weather event in Visual Flight Rule (VFR) conditions is for aircraft to enter in one of the four arrival gates i.e., Gilmore (GQE), Middy, Holly (HLI), or Walet (Figure 1). Departures normally exit the TRACON through one of ten departure gates depending on their destination (Figure 1). Once the arrivals enter the Class B airspace or the TRACON, they become the responsibility of the TRACON ATC specialists. Aircraft which arrive downwind of the active runways are turned onto a course which parallels the runways called a downwind leg. Aircraft which arrive on the upwind side of the airport enter a course at a 90 degree angle to the runways in which they intercept the final approach course to the specified runways. This is called a base leg. In VFR conditions pilots must "see and avoid" other air traffic. When clouds lower visibility to Instrument Flight Rule (IFR) conditions, ATC specialists are required to keep aircraft

* This work was sponsored by the Federal Aviation Administration. The views expressed are those of the authors and do not reflect the official policy or position of the United States Government.

† Opinions, interpretations, conclusions and recommendations are those of the authors and are not necessarily endorsed by the United States Air Force.

separated. This causes the Airport Acceptance Rate (AAR) to drop (Table 2). When there is thunderstorm development within the TRACON or at the arrival/departure fixes, the normal flow pattern must be modified.

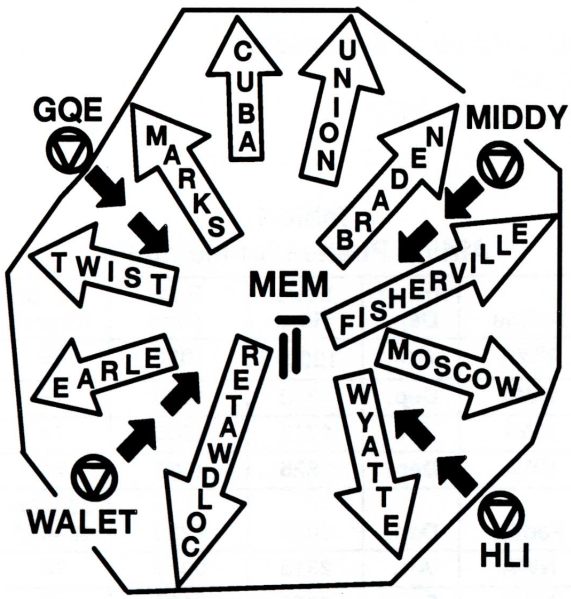

Figure 1. Memphis TRACON arrival and departure gates.

Table 2.
AAR for Memphis
IFR and VFR Arrivals

Runway Configuration	IFR	VFR
36L / 18R, 36C / 18C, 27	N/A	84
36L / 18R, 36C / 18C	45	54
36L / 18R, 27	N/A	60
36C / 18C, 27	N/A	60
Any Single Runway	30	30

3. ANALYSIS OF CASES

We identified five cases from 1996 where thunderstorms impacted air traffic in and around the Memphis Class B airspace. These events encompassed both mesoscale (isolated) and synoptic scale (squall–line) convection (Table 3). Synoptic scale weather systems generally impact large areas and can cause significant traffic deviations. Mesoscale convection is typically isolated in nature and thus can be more easily avoided. In this study, we analyzed each case to determine the operational impacts and the potential for increased benefits from a Growth and Decay product. We believe that in the cases analyzed, this product could have provided significant benefits to ATC specialists.

During real–time, Memphis ATC specialists used products generated from the Integrated Terminal Weather System (ITWS) Initial Operating Capability (IOC) prototype (Evans and Ducot, 1994) to enhance air traffic safety and planning. One of the IOC products is a storm correlation tracker e.g., storm motion and storm extrapolated position, which tracks the advection of individual cells from one image to the next (Chornoboy *et al*, 1994). The major limitation of the correlation tracker is the fact that it does not account for storm growth or decay. Thus, the Growth and Decay product development effort is aimed at fulfilling this limitation of the storm motion/storm extrapolated position product. For more information on the Growth and Decay product development refer to Wolfson and Mueller, 1997 (in this proceeding).

Table 3.
Summary of Cases

Case Date	Weather Type
27 May '96	Squall – line / Isolated
8 June '96	Squall – line
24 July '96	Squall – line / Isolated
29 July '96	Squall – line / Isolated
30 Aug. '96	Isolated

3.1 May 27th Meteorological Analysis

By 1550, a line of echoes (associated with a cold front) had tracked to within 50 nautical miles (nm) of the airport and isolated cell growth began to occur within the TRACON. The individual cells tracked northeastward at 40 knots, while the line's motion was southeastward at 15 knots. Isolated cells first impacted the airport at 1658. By 1805 (Figure 2A), the line of thunderstorms tracked onto the airport and dropped the visibility to less than 0.5 nm.

As the line continued to impact the runways, decay occurred on its southwestern flank. This decay was located ahead of a second line of storms which tracked westerly into the TRACON between 1819 and 1835 (Figures 2B–D). The cells in the second line also tracked northeastward at a speed of 40 knots. Figure 2C shows the large area of clearing west of the runways by 1828, while Figure 2D shows this area over the runways by 1837. The second line became a bow echo and impacted the airport at 1905. By 1911, a gust front crossed the runways and the surface wind became westerly at 15 knots, with a peak gust of 27 knots. The line had exited the TRACON to the east by 2030.

3.1.1 May 27th Air Traffic Analysis

By the afternoon NWA arrival push, the line of thunderstorms had already closed the GQE gate. This caused the ATC specialists to route arrivals to the other three gates. The majority of aircraft arrived through Walet ahead of the line. Many "broke out" of the standard traffic pattern and approached the airport from the departure gates as isolated convection developed ahead of the line. ATC specialist stated that they would have used a product which could have predicted growth ahead of the line. By knowing that cells would develop ahead of the line, they could have proactively planned for the non–standard arrival push. Aircraft arriving from the northeast used both Braden and Fisherville; while aircraft approaching from the southeast were turned north and arrived via the Moscow departure gate. This allowed many aircraft to "queue up" for runway 27. As the line of storms impacted the airport, the winds became northwesterly and gusted to 27 knots. The TRACON supervisor had planned for the wind shift and used runway 27 for most arrivals. At 1753 two aircraft on final approach to runways 18R (right) and 18C (center) executed "go–arounds" due to a tailwind. The TRACON supervisor decided to reconfigure the runways to 36L (left)/36C at this time. By 1800, heavy rain reduced the visibility at the airport. As conditions deteriorated, many pilots requested missed approaches.

At 1751 the TRACON supervisor asked the TMU ATC specialists to hold aircraft at the arrival fixes. By 1805 (Figure 2A), the last aircraft landed while four others were stranded within the TRACON. All other inbound aircraft held at the three arrival fixes which were not impacted by the line. Only one of these aircraft remained in the TRACON. The other three left the Class B airspace and held at various arrival fixes. Rerouting aircraft out of the TRACON caused an increased work load for ATC specialists because each aircraft had a flight plan stored in an ATC computer which then had to be altered when they departed the Class B airspace. A reliable growth forecast could have allowed ATC specialists to hold aircraft before they entered the TRACON and thus reduced their work load.

Between 1805 and 1825, the airport was closed due to the thunderstorms. At 1825 the one remaining aircraft in the TRACON first attempted a landing on 36L and then circled for a landing on 27 at 1835. After this aircraft landed, three others still in holding patterns at the HLI arrival fix entered the TRACON through the Moscow departure gate and flew around a storm cell in order to make an approach to runway 27. As the three aircraft lined up on final approach, the last one executed a major deviation as the cell pushed it north of the approach course. Many ATC specialists believed that with a reliable forecast of the decay they could have held the aircraft at Walet instead of HLI and thus could have taken better advantage of the decay. Most of the aircraft which held at HLI were eventually relocated to the GQE arrival gate. Only a few aircraft were able to utilize the region where weather had decayed (Figure 2D). Some of the aircraft which were routed to GQE also took advantage of the break ahead of this line and landed on runways 36L and 36C. Between 1905 and 1928, airport operations were halted once again due to the second line of storms. Aircraft were held at GQE, HLI, Walet, and on the ground. By 1928 the line had passed east of the runways and air traffic resumed normal operations. Overall, there were twenty–one aircraft held (Table 4).

3.2 June 8th Meteorological Analysis

A band of precipitation first developed in the eastern TRACON due to lifting along a northerly–southerly aligned frontal boundary. The line of storms intensified until about 1850, but never completely "filled in". Vorticity associated with an upper–level, low–pressure system caused explosive storm growth within the entire TRACON at 2104. By 2111, the airport was impacted with moderate and then heavy precipitation. Thunderstorms in the airport vicinity produced wind gusts of 29 knots at 2239 and 37 knots at 2254. At 2243 airport visibility was reduced to 0.5 nm due to heavy rainfall. The airport itself was intermittently impacted by moderate convection until approximately 0020, while the TRACON was continuously affected by moderate precipitation until 0800.

3.2.1 June 8th Air Traffic Analysis

Air traffic during this event was light since it occurred during the FedEx afternoon push. As the isolated cells coalesced into a line which impacted Middy, four aircraft were diverted to the Fisherville departure gate. A "hole" in this line remained over Fisherville until the line started to decay. This allowed a clear gate for departures/arrivals. ATC specialists indicated that they would have derived a great benefit from a Growth and Decay product which forecasted a "hole" in a line would not have "filled in", especially during an arrival push.

By 2030, only a few arrivals entered the TRACON. They were routed around the cells which had developed throughout the TRACON by 2104. The cells closed GQE at 2200, therefore, aircraft arrived through the Twist departure gate. One aircraft entered the TRACON over GQE and continued due south at 2236. Two others entered the eastern TRACON at Fisherville soon thereafter. They were routed around storms and placed into holding patterns within the TRACON until 2314 when they finally landed. The remainder of the NWA evening push proceeded smoothly under IFR conditions. Overall, there were four aircraft held (Table 4).

3.3 July 24th Meteorological Analysis

A stagnant atmosphere combined with an upper–level trough provided the dynamics for early morning thunderstorm development in northern Mississippi. These storms propagated northward along a gust front outflow boundary. By 1900, differential surface heating and light winds allowed several weak convergence boundaries to form. At 2005, a cell developed seven nm east of the airport along one of these boundaries and tracked southwestward.

By 2136, a strong gust front was produced by cells located 25 nm east of the airport. Twenty minutes later, thunderstorms formed ahead of this boundary. The cells which developed west of the airport tracked eastward and also produced a gust front. Lifting along the gust front east of the airport produced a very strong, stationary cell centered nine nm east of the runways. By 2230, strong thunderstorms framed the airport to the east and west, while gust fronts approached the runways from these same directions. The fronts collided at 2250 and showers developed along the convergence zone over the airport. By 2305, they formed a fairly solid line of level three to five thunderstorms from 45 nm northeast to 45 nm west of the airport. Shortly thereafter, decay occurred rapidly on the western portion of the line. By 2334, there was only level two precipitation over the runways.

3.3.1 July 24th Air Traffic Analysis

Air traffic was only slightly impacted by developing thunderstorms during the afternoon FedEx push. Between 2220 and 2300, a few arrivals "broke out" of the normal traffic flow due to thunderstorms located in the gates and around the airport. One cell intensified to level six in the Middy arrival gate and aircraft were diverted to the south of this cell and lined up for a long final approach to runway 27. Other aircraft were forced to turn a short final for runway 18R. By 2250 the cells had formed into a line over the airport.

By 2303, an early arrival lined up for an approach to 36L even though weather radar indicated levels four and five thunderstorms over the runways. It landed at 2308 and one minute later a second aircraft on final to 36C executed a missed approach and held within the TRACON. By 2310 aircraft arrived in the Moscow and Coldwater departure gates and immediately held. By 2320, the TRACON supervisor asked the TMU ATC specialists to begin holding aircraft at the arrival fixes since six were already holding within the TRACON. TRACON supervisors indicated that if a growth product had accurately forecasted when the airport would have been impacted, they could have coordinated with the TMU to hold aircraft at the arrival fixes earlier and thus reduced their work load. At 2325 the line started to decay west of the airport and one aircraft made a successful landing on 36L. ATC specialists stated that if they had a reliable decay indicator, aircraft could have been sequenced to land earlier. Due to IFR conditions, the AAR was 45 aircraft per hour and arriving aircraft were held at the approach fixes. Soon thereafter, aircraft queued up for runway 9 as a strong easterly surface wind prevailed. This dropped the AAR to 30 aircraft per hour. Overall, there were nineteen aircraft held (Table 4).

3.4 July 29th Meteorological Analysis

A squall–line developed during the early afternoon hours along a cold front located northwest of Memphis. Isolated thunderstorms also formed ahead of the line as it tracked southeastward toward the airport. By 2040, a level six cell developed in the northern TRACON and tracked northeasterly at 15 knots.

The line had impacted GQE by 2250 as well as the northern TRACON perimeter. The storm motion product indicated the cell motion was southeastward at 20 knots. By 2338 moderate rainfall (associated with the squall–line) had impacted the runways. Strong thunderstorms impacted the runways from 2355 until 0016, which caused windshear alerts and lowered the visibility to less than one nm. The line cleared the airport by 0012.

3.4.1 July 29th Air Traffic Analysis

This case is similar to May 27th in terms of the weather system and its impact on air traffic. However, there was little growth or decay with this system. The squall–line impacted the runways at 2338 and 14 minutes later aircraft could not land and started to hold. In fact, aircraft were already holding at HLI and Walet by the time the airport was closed. ATC specialists were able to use the storm motion product to anticipate movement and held most of the air traffic before they entered Class B airspace.

Most aircraft were held at the HLI gate on the south side of the line. They were then routed westward to enter the TRACON from GQE and Walet. The TRACON supervisors stated that a decay forecast could have been used to turn more aircraft into the Walet gate as some decay was observed in that region. However, they also believed a Growth and Decay product would not have provided a significant benefit during this particular case. Overall, there were twenty aircraft held (Table 4).

3.5 August 30th Meteorological Analysis

At 1810, thunderstorms aligned along an easterly–westerly orientated line quickly developed between 19 to 25 nm east of the airport and tracked westward at a speed of five to ten knots. As the line approached the runways, new development occurred on the western flank. A small, yet strong cell also developed just west of the airport at about 1840. Thunderstorms impacted the approach to runway 27 at 1920.

Decay occurred along the line east of the strongest cell and by 1954 this cell was centered four nm west of the airport. By 2017, the rain had cleared the runways. Surface winds at the airport became westerly as the cell west of the airport continued to produce outflows. As the storm which had earlier impacted the runways moved slowly toward the west–southwest, it gradually decayed and became more stationary.

3.5.1 August 30th Air Traffic Analysis

The initial impact from this system occurred in the Moscow departure gate at 1825. Since the line was aligned easterly–westerly and moved very slowly westward, departures used Fisherville with only a few minor deviations as the cells encroached on the approach to runway 27 at 1900. Thirteen minutes later, departures resumed in the Moscow gate. Decay within the line to the east allowed a few more departures through this gate at 1928. The weather first impacted the airport toward the end of the departure push at 1932, as an aircraft on final to 36C executed a missed approach. Between 1944 and 1949, this same aircraft aborted an approach to runway 09 and then 36C due to heavy rainfall and windshear conditions. The airport was reconfigured to a south operation at 1957 due to the outflow from a cell located south of the runways. By 2024, the weather to the east had decayed significantly. That allowed departures to resume in earnest through Moscow and Fisherville without any deviations. At 2030, the Coldwater gate was used exclusively for south-bound traffic due to the weather impacts at Earle and Walet. Overall, this system caused six aircraft holds (Table 4).

4. CONCLUSIONS

Based on this preliminary analysis, we have arrived at the following conclusions:

- 1. In the five cases we analyzed, synoptic scale weather systems caused more air traffic impacts than mesoscale convection.
- 2. On May 27th and July 24th, a reliable decay forecast could have reduced the ATC specialists workload and aircraft holds.
- 3. ATC specialists would derive a significant benefit from a product which forecasted whether or not a "hole" in a line of thunderstorms would "fill in".
- 4. On May 27th and July 24th, a reliable growth forecast could have allowed ATC specialists to hold aircraft east of the TRACON and thus reduced their work load.
- 5. More research will be required to determine the full range of benefits that would be derived from a Growth and Decay product.

5. ACKNOWLEDGEMENTS

We would like to thank the following individuals who contributed to this work: Frank Bartozzi, Dick Childers, and all of the other Memphis ATC personnel who were interviewed in order to help us understand ATC decision making as well as growth and decay benefits.

6. REFERENCES

Chornoboy, Edward S., Anne M. Matlin, and John P. Morgan, 1994: Automated Storm Tracking for Terminal Air Traffic Control, *Linc. Lab J.* 7, 427–448 (1994).

Evans, James E. and Elizabeth R. Ducot, 1994: The Integrated Terminal Weather System (ITWS), *Linc. Lab J.* 7, 449–474 (1994).

Wolfson, Marilyn W. and Cynthia K. Mueller, 1997: Convective Weather Forecasting for FAA Applications, *SEVENTH CONFERENCE ON AVIATION, RANGE AND AEROSPACE METEOROLOGY;* 2–7 February, Amer. Meteor. Soc.

Table 4.
Summary of Operational Impacts

Case Date	# of aircraft held	Hold Time	Hold Area
27 May '96	10	1752–1830	HLI
	2	1751–1847	GQE
	3	1751–1839	Middy
	2	1753–1805	TRACON
	2	1902–1924	GQE
	2	1915–1928	Walet
8 June '96	1	2251–2318	Walet
	3	2256–2314	TRACON
24 July '96	6	2314–0100	HLI
	5	2310–0100	Walet
	6	2310–2332	TRACON
	4	2324–0100	GQE
29 July '96	2	2334–2345	HLI
	7	2354–0019	HLI
	5	2336–0010	Walet
	4	2335–0012	GQE
	2	0002–0013	TRACON
30 Aug. '96	5	1935–1952	TRACON
	1	1959–2005	Walet

Figures 2 A–D (on the following page). ASR–9 reflectivity levels are shown by the grey–scale bar in the center of the figure. The arrows represent the motion of the individual cells, while the speed of movement (in knots) is indicated by the numbers at the base of the arrow. A one minute tail of each aircraft beacon is shown by a ".", while the current location is shown by an"O".