DENVER AIR ROUTE TRAFFIC CONTROL THUNDERSTORM PATTERNS

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Introduction

This paper will present typical thunderstorm patterns which occur within the Denver Air Route Traffic Control Center (ZDV ARTCC) control space. We shall focus on the impact on Air Traffic Control (ATC) operations for Denver International Airport (DIA) landing, departing, and en-route traffic. To identify a thunderstorm pattern and its potential impact, the ZDV Center Weather Service Unit (CWSU) meteorologist must consider many other things when making his forecast. He must consider the effects of Colorado's topography on weather, DIA's unique runway and gate structure, typical air traffic patterns for DIA, and his role in supporting the FAA's decision-making process.

Colorado Topography and Thunderstorms

Most air traffic for the ZDV ARTCC flies over Colorado's mountains, northeast foothills, and northeast plains on its way to and from DIA. Figure 1 shows that DIA (DEN) resides at the extreme western part of the northeast plains, at an elevation of 1622m (5400ft) . To the west, the terrain rises about 2000m (6500ft) through the northern foothills to the northern mountains. North and south of the airport, the Cheyenne Ridge and Palmer Divide are about 600m (2000ft) higher than DIA. Therefore, the airport sits in a 3-sided bowl with terrain gradually decreasing toward Kansas.

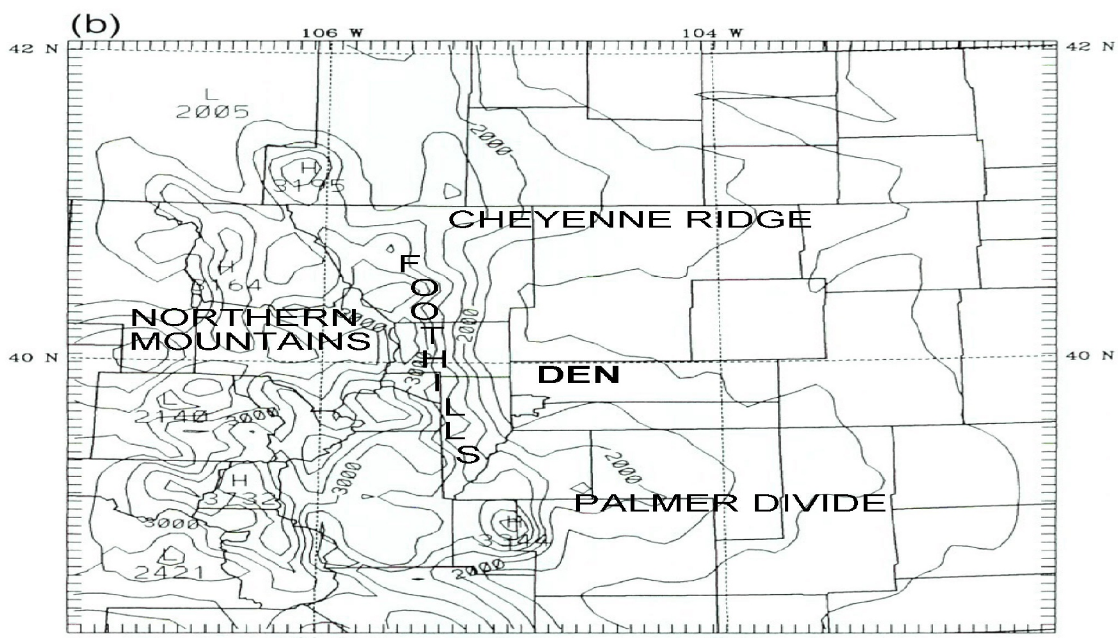

Figure 1: Mountain-Forced Convection, Late Afternoon

Light flow with a westerly component will typically attempt to move existing thunderstorms from the mountains toward the plains. Whether the thunderstorms survive depends on how much moisture, instability, and lift exists at the lower elevations. However, a moderately strong westerly flow in the summertime often has a significant drying effect. Such a regime may produce a dry line in the eastern plains, displacing any thunderstorms threat well east of DIA.

Depending on its depth and strength, flow with an easterly component may cause low level wind and moisture convergence where the terrain begins to rise from the plains toward the mountains. A similar effect may occur near the Cheyenne Ridge or Palmer Divide. Such areas can become prime targets for thunderstorm development.

More often than not, westerly flow off the northern mountains will combine with southeast or northeast flow in the plains to produce mesoscale convergence zones. One such feature, the Denver Convergence-Vorticity Zone (DCVZ, Szoke, et al. 1984), develops often near DIA in the summertime. It will occasionally wrap up into a closed circulation called the Denver cyclone. If there is enough moisture, potential instability, and low-level convergence, this feature may trigger rapid thunderstorm development in an otherwise capped airmass.

<u>Denver International Airport</u>

Denver International Airport is located about 15 miles east-northeast of the City of Denver. It covers 53 square miles and has 5 runways. Three runways are oriented north to south. The airport's Terminal Radar Approach Control (TRACON) prefers to use these runways in lieu of the two east-west runways for arriving traffic for several logistical and political reasons.

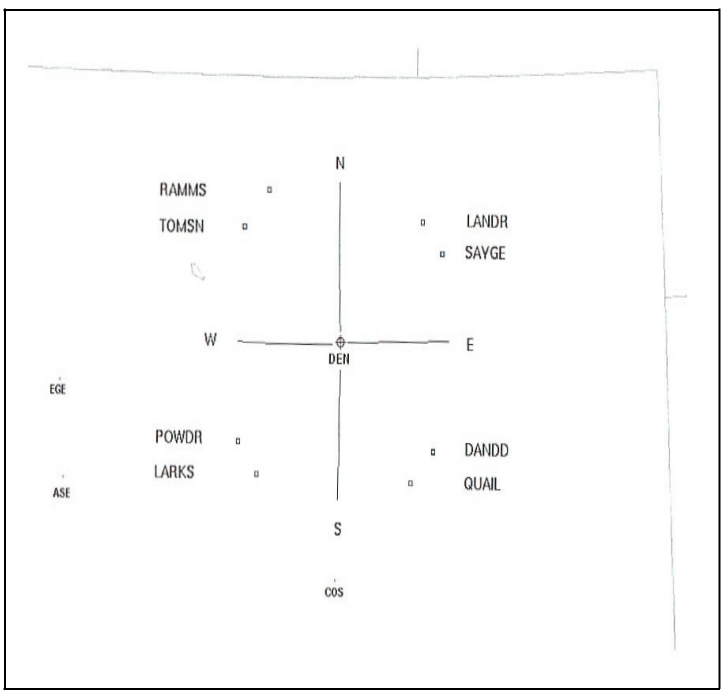

Figure 2: Denver International Airport Arrival Gates.

As shown in Figure 2, air traffic must leave DIA through 4 departure gates which are oriented north, south, east, and west. Traffic approaching the airport must use the eight arrival gates, labeled as RAMMS/TOMSN, LANDR/SAYGE, DANDD/QUAIL, and POWDR/LARKS).

Thunderstorms in a gate can cause a gate swap, where traffic is redirected to a gate other than what it would normally be sent through. If most or all the gates are shut off, little or no traffic can arrive or depart. Aircraft en-route for DIA may have to hold or be diverted to an alternate destination.

Air Traffic Control may also invoke a national ground stop, causing traffic to stay on the ground at other airports, rather than depart for DIA. Because thunderstorms occur almost every day during the summer, such weather-related delays can become a major problem nationwide.

Microbursts and other convectively-induced wind shears are fairly common at DIA. The Low Level Wind Shear Alerting System (LLWAS) is an excellent tool for detecting these hazards at or near the airport. This system consists of 29 sensors placed at the end of each runway, the center of the airport, and around its perimeter. Computer algorithms compare this surface wind information with low level wind velocity data from DIA's Terminal Doppler Weather Radar (TDWR). The algorithms calculate airspeed loss or gain at a predetermined distance from a runway. The system displays Wind Shear Alerts (WSAs) and Microburst Alerts (MBAs), the latter being more severe to air traffic. A typical alert might read "-40 KT 1MF MBA", which means an aircraft could lose 40 knots of airspeed 1 mile prior to touchdown from a micro-burst.

The Denver Terminal Radar Approach Control (TRACON) supervisor will usually shut off all departures and arrivals when he sees persistent, widespread MBAs or WSAs on the LLWAS display. Shut-offs typically last from 30 minutes to more than an hour, depending on storm motion, intensity, and coverage. A long shut-off could impact the national ATC system.

<u>Role of the Center Weather Service Unit</u>

The Center Weather Service Unit (CWSU) is responsible for forecasting when storms will develop and how they will impact DIA and its gates. Perhaps the most critical decision is when a shutoff will begin, how long it will last, and when it will end. ZDV's Traffic Management Unit (TMU) depends exclusively on the CWSU for such information. A poor forecast may result in significant cost to the airlines, and inconvenience to air travelers, and additional work for Traffic Management specialists and air traffic controllers. Therefore, the CWSU meteorologist must focus more on making a timely, accurate DIA thunderstorm forecast and spend less time on providing en-route forecasts or other routine services.

<u>Typical Summertime Thunderstorm Cases</u>

Case #1 - Mountain-forced Convection

Colorado's mountains often act as an elevated heat source for thunderstorm development in a conditionally unstable airmass. Typically, air over the mountains reaches its convective temperature more quickly than the air over the lower eastern plains. This usually occurs by early afternoon and causes airmass thunderstorms to form over the higher terrain. These thunderstorms increase in coverage as they move in an easterly direction toward the foothills. Eventually, a fairly solid line of activity forms to the west of DIA (Figure 3) to impact RAMMS/TOMSN, POWDR/LARKS, and the west departure gate. Gate closure and associated traffic rerouting may occur. DIA is usually not directly impacted, since the thunderstorms have difficulty spreading over the capped plains airmass. The convection over the mountains and foothills typically ends around sunset.

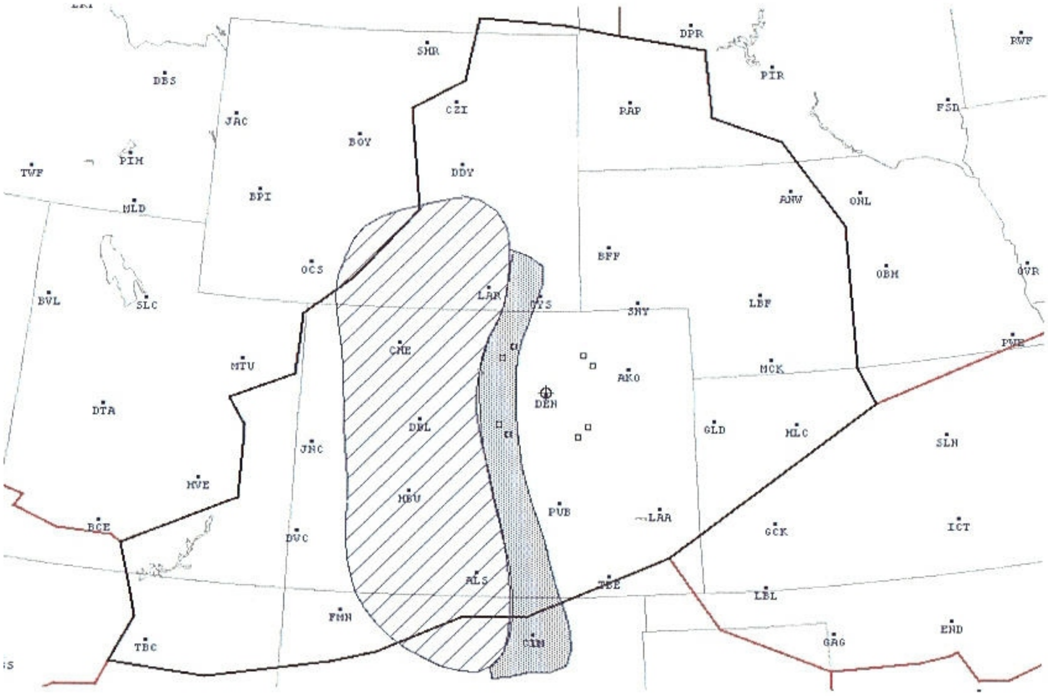

Figure 3: Mountain-Forced Convection, Late Afternoon

For all thunderstorm graphics presented in this paper, light hatching indicates isolated to widely scattered coverage (less than 25 percent) while darker shading indicates scattered to numerous coverage (25 to 74 percent). Coverage more than numerous is rare over the ZDV control area. It will not be depicted.

Case #2 - Southwest United States Monsoon Pattern

Another airmass thunderstorm pattern that affects the gates, but not necessarily the airport, involves the southwestern U.S. monsoon. The monsoon season for Colorado usually begins in July or August and ends in September. South or southwest flow aloft funnels Pacific moisture into the southern and central Rockies. This moisture, combined with a normally conditionally unstable mountain airmass, contributes to daily thunderstorm development over the higher terrain. This usually begins around 1800 UTC and thunderstorms reach typical scattered to widespread coverage as the afternoon progresses.

With a southerly steering flow, the thunderstorms normally will not move very far east of the foothills (Figure 4a). In this case, RAMMS/TOMSN, POWDR/LARKS, and the west departure gate should be impacted the most. However, with a southwest steering flow, all gates may be affected at one time or another as the thunderstorms move through (Figure 4b). DIA may even be shut off. Such impact could cause significant reroutes or delays in the national ATC system.

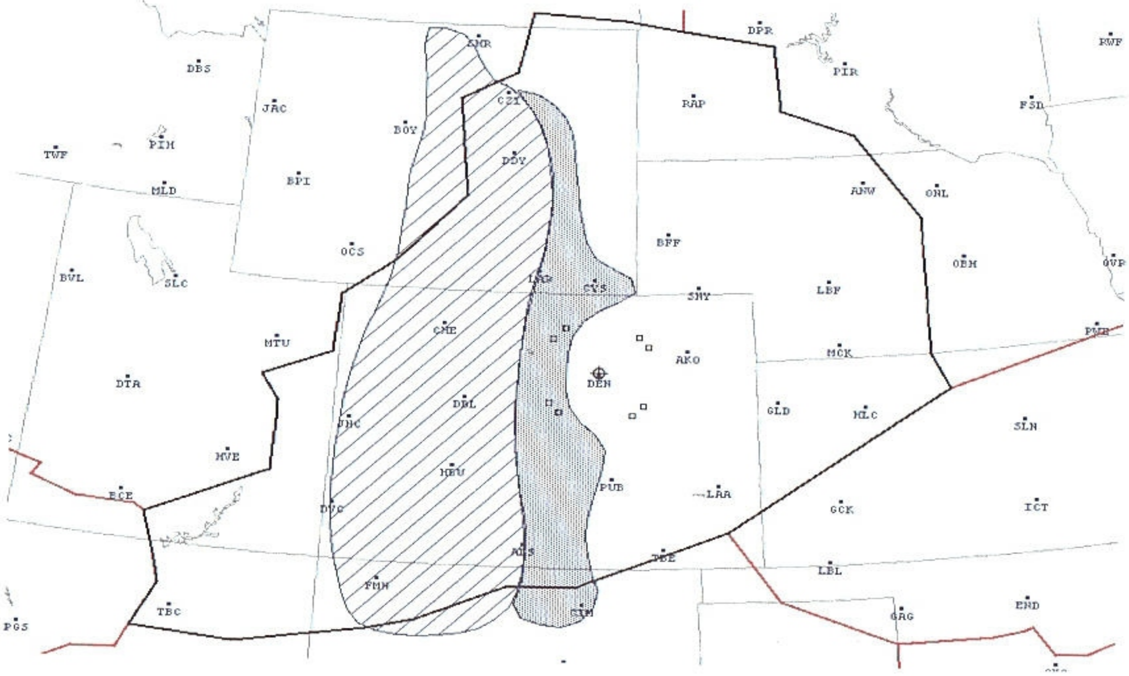

Figure 4 (a): Monsoon Pattern with Southerly Flow, Mid to Late Afternoon.

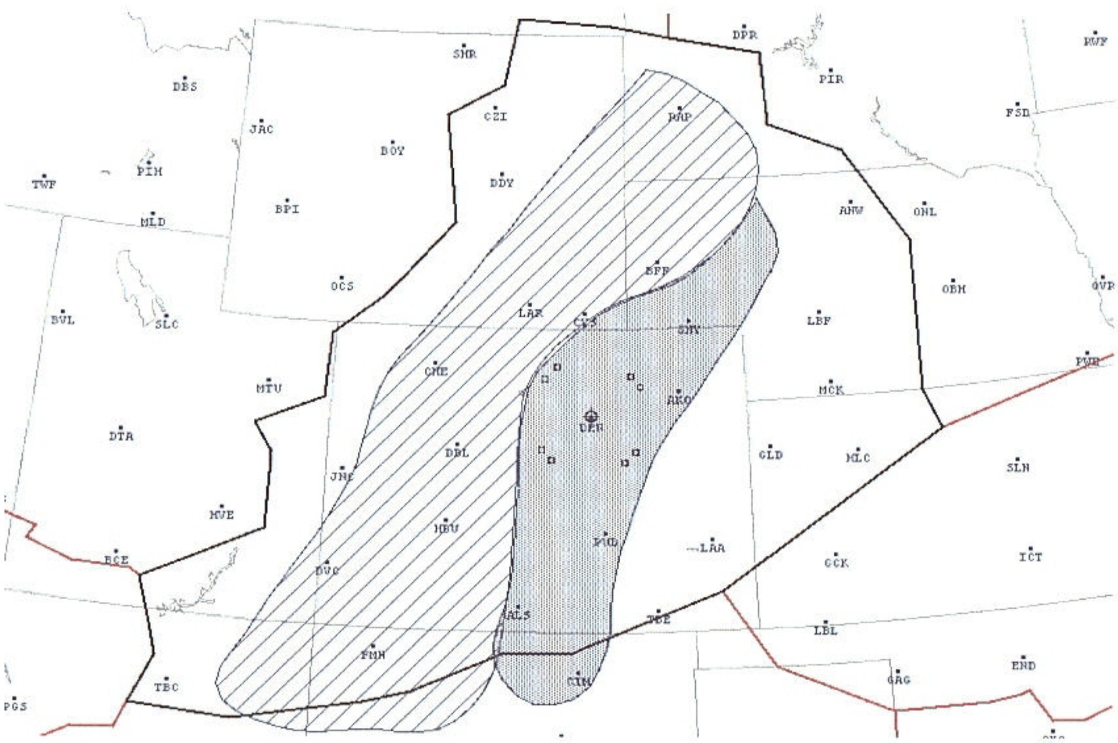

Figure 4 (b): Monsoon Pattern with Southwesterly Flow, Mid to Late Afternoon

Case #3 - Denver Cyclone Event

The Denver cyclone can play a prominent role, especially when the atmosphere is capped across the mountains and plains. When the cyclone is strong enough to break the cap, rapid development may occur around DIA. The resulting thunderstorms often impact the south gates first, due to northerly flow on the west side of the DCVZ forcing the airmass upward on the north side of the Palmer (Figure 5).

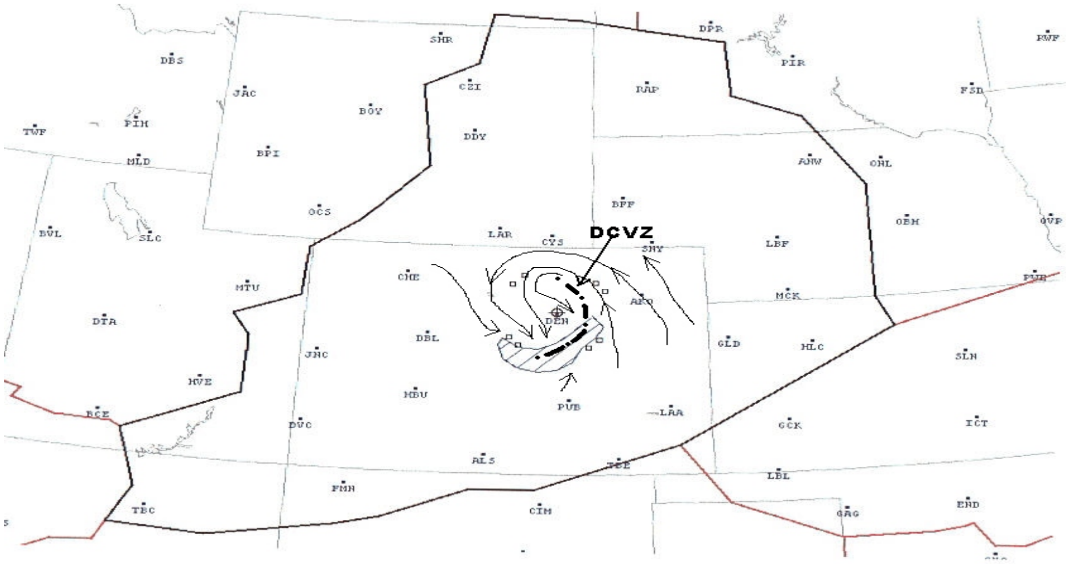

Figure 5: Denver Cyclone Event, Early Afternoon.

The main activity usually shifts eastward by mid to late afternoon, causing lingering impact to the east gates. National ATC programs may be needed at this point (Figure 6).

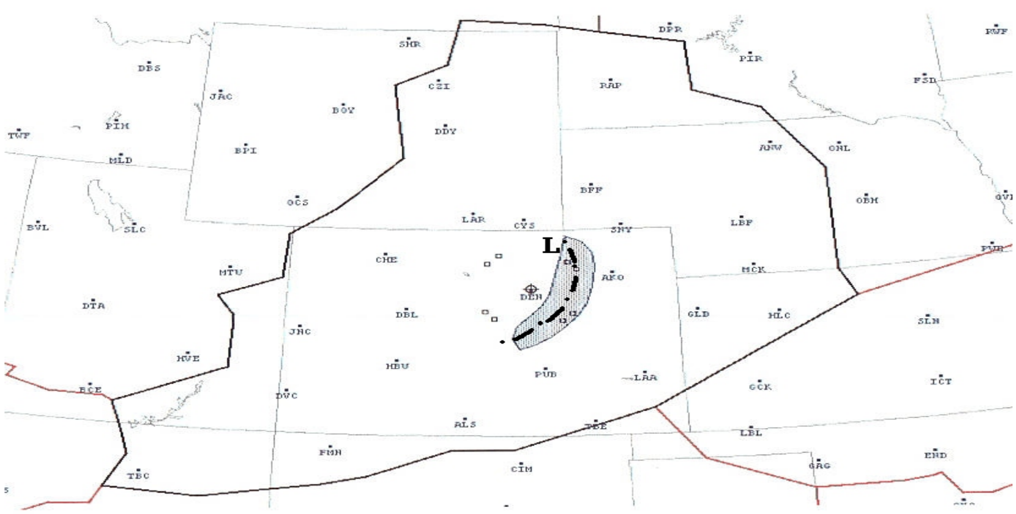

Figure 6: Denver Cyclone Event, Mid to Late Afternoon.

The activity continues eastward and has an increasing impact on major jet routes between ZDV and other ARTCC areas to the east. National ATC programs are usually warranted by mid-evening (Figure 7).

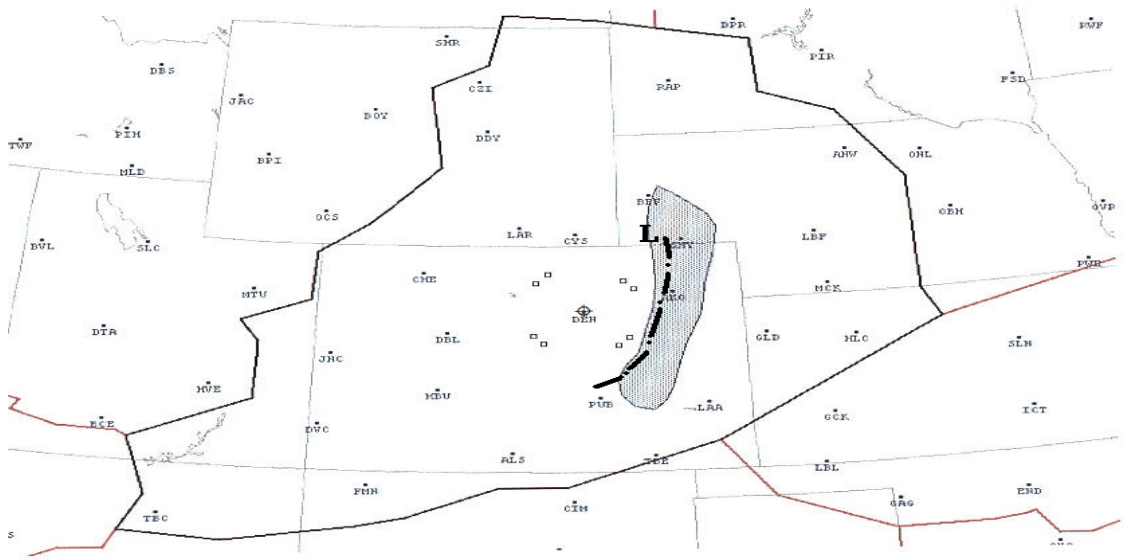

Figure 7:: Denver Cyclone Event, Early Evening

Sometimes, this pattern evolves into an MCS that continues moving east or southeast through the night to the central plains. This may cause more national reroutes and programs early the next morning (Figure 8)

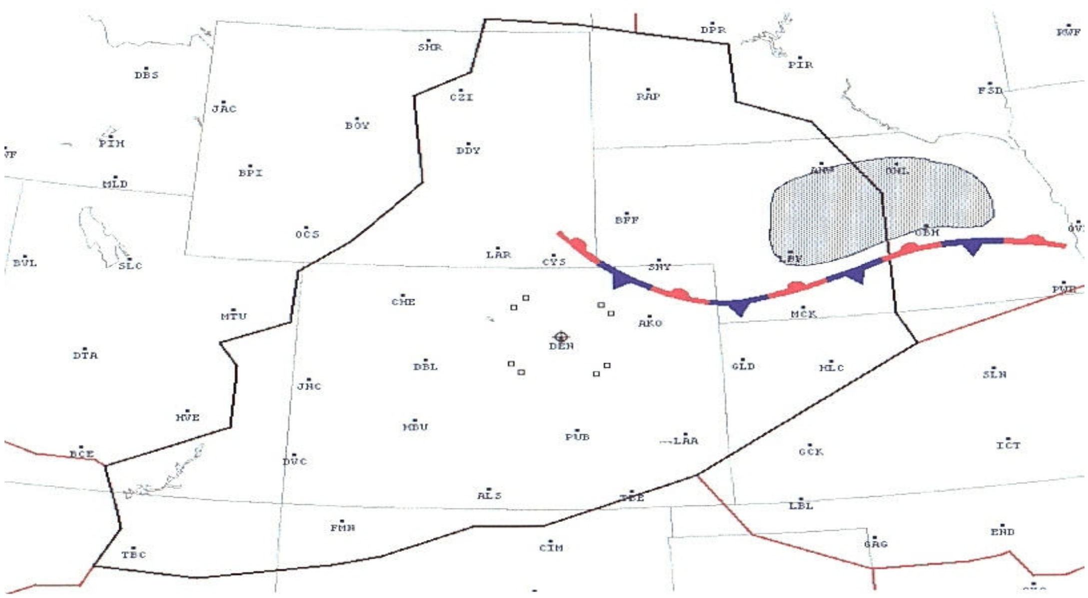

Figure 8: MCS Evolved From Denver Cyclone Event, Mid-Morning Next Day.

Usually by mid-morning the next day, the MCS has diminished and the associated national ATC programs have expired (Figure 9).

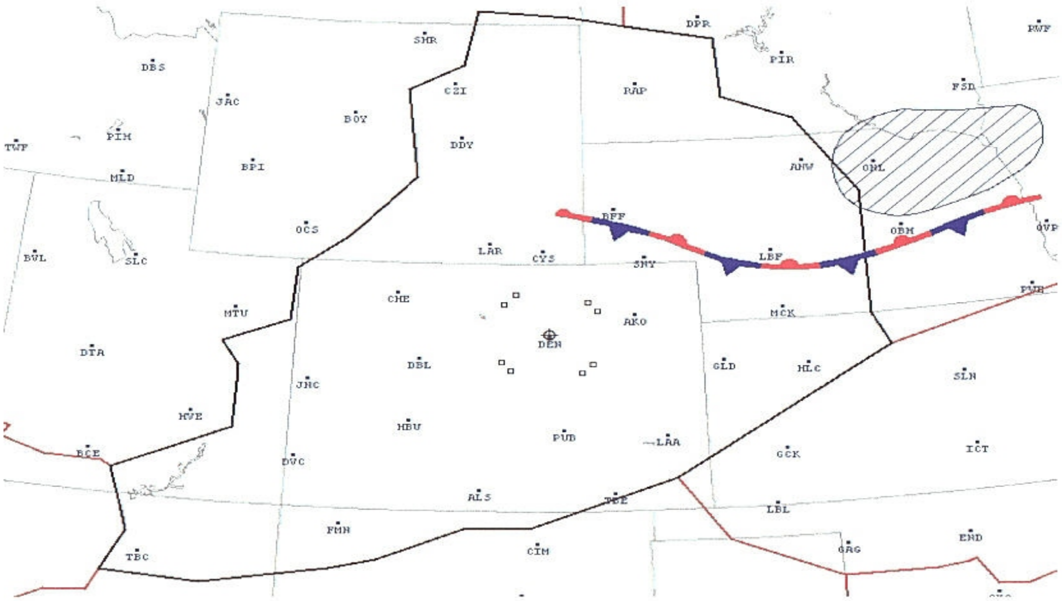

Figure 9: MCS Evolved From Denver Cyclone Event, Early Next Morning.

Case #4 - Mountains-Plains Event

Higher terrain and the Denver meso-cyclone often combine to spawn significant thunderstorm development over a large area. Typically, the activity develops in southern Colorado and northern New Mexico around noon (Figure 10).

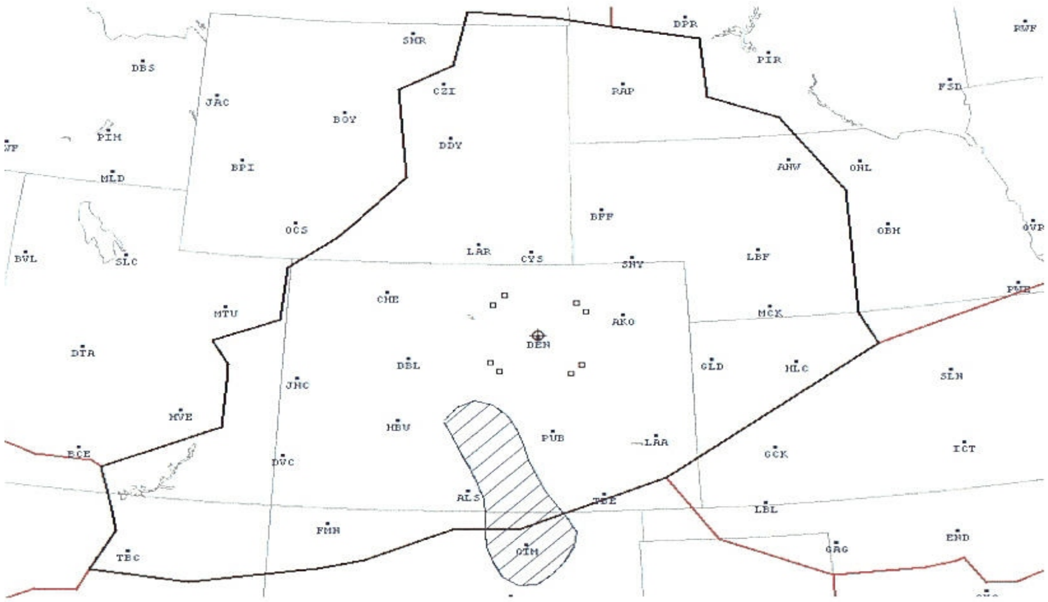

Figure 10: Mountains-Plains Event, Noon

The activity spreads rapidly northward over the Colorado mountains during the early afternoon. National traffic reroutes become necessary due to high concentrations of thunderstorms over southern Colorado (Figure 11).

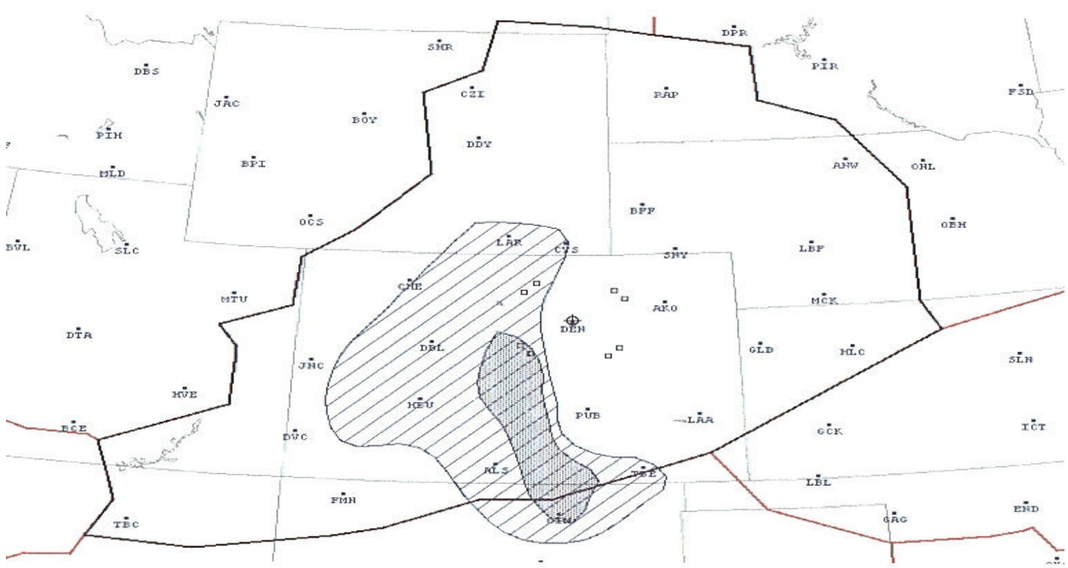

Figure 11: Mountain-Plains Event, Early Afternoon.

By mid-afternoon, national traffic reroutes increase around the Colorado mountains as thunderstorms become more widespread (Figure 12). Thunderstorms also form along the Cheyenne Ridge and from the Palmer Divide northeastward along the Denver cyclone. Outflow boundaries from mountain thunderstorms often interact with the DCVZ to trigger new activity near DIA. Increased gate impact leads to flow restrictions for traffic in and out of the airport.

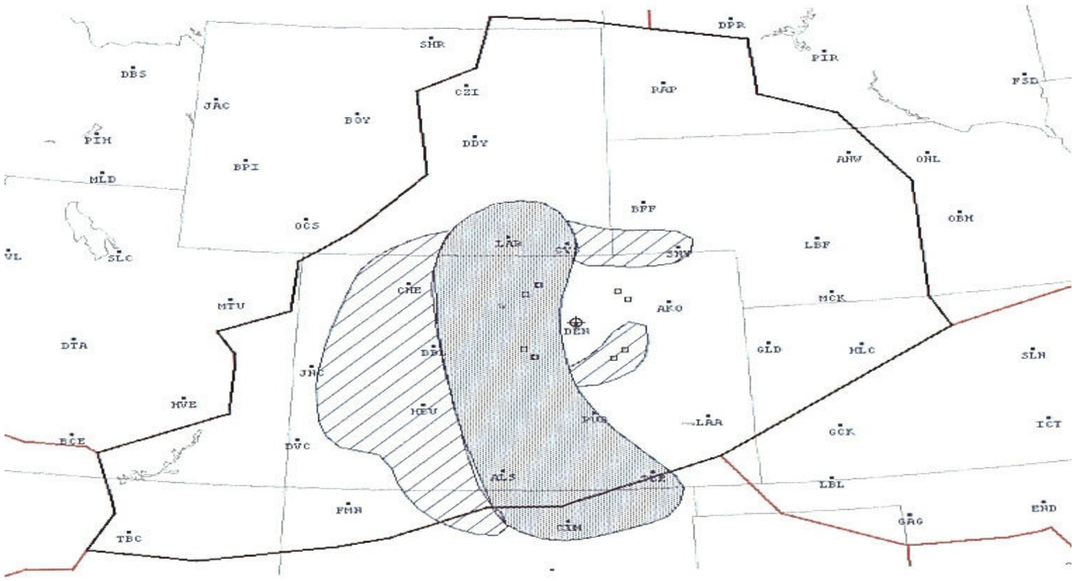

Figure 12: Mountain-Plains Event, Mid Afternoon.

By late afternoon, the thunderstorms over the mountains are usually at their peak (Figure 13). Most of the DIA gates have become closed or restricted. DIA traffic is often restricted.

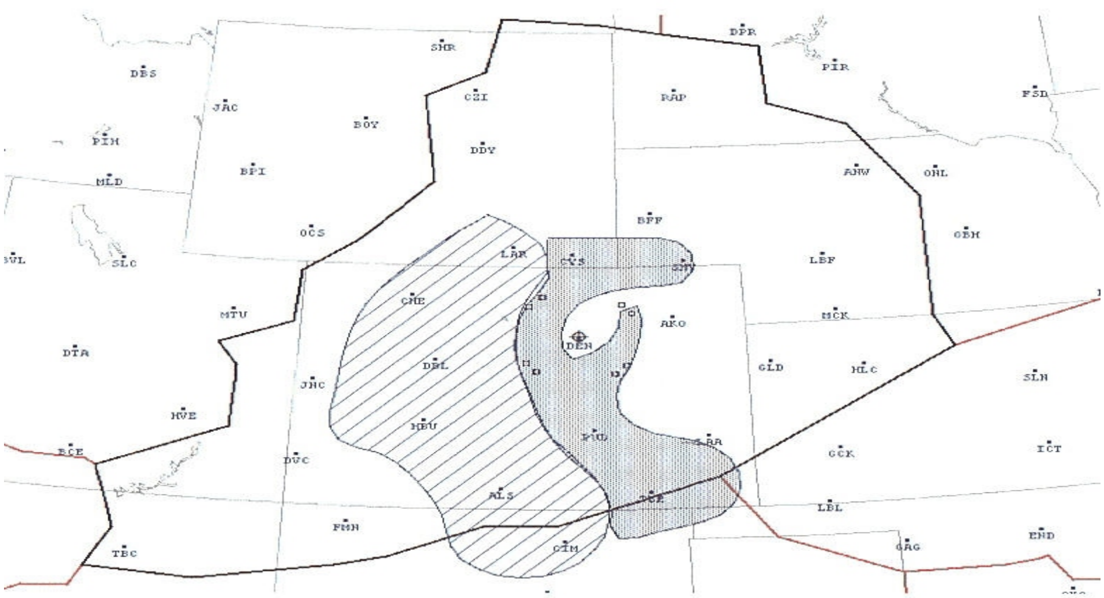

Figure 13: Mountain-Plains Event, Late Afternoon.

Toward early evening, thunderstorms continue over the plains around DIA and decrease over the mountains (Figure 14). The activity may still impact the airport directly, with strong and variable winds, wind shear, and microburst alerts. TRACON might have to shut off the airport. This could cause national ground delay programs and airborne holds. Some aircraft might divert to an alternate destination if they run low on fuel.

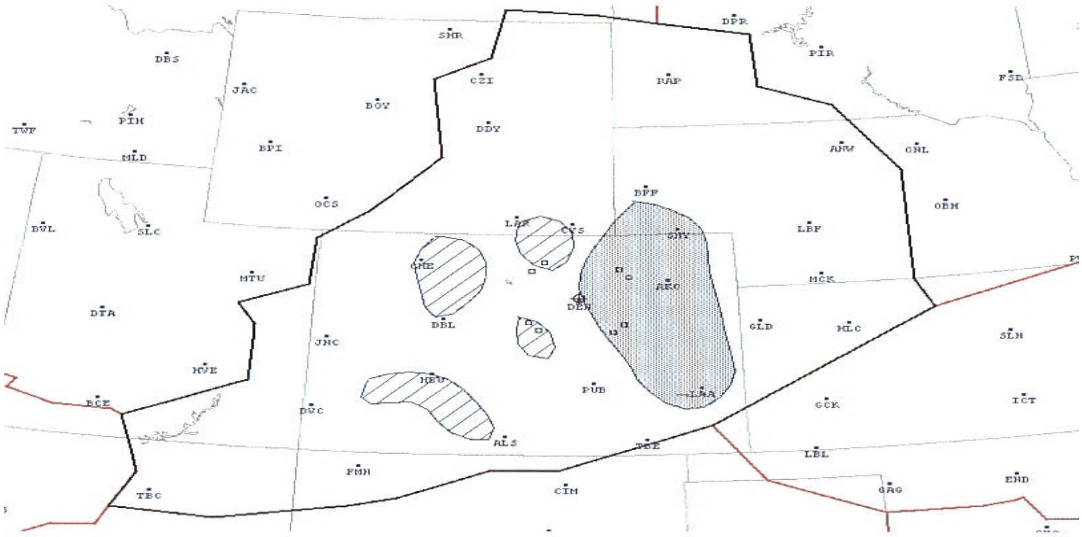

Figure 14: Mountains-Plains Event, Late Afternoon.

In the early to mid-evening, the thunderstorms move toward extreme eastern Colorado, southwest Nebraska, or western Kansas (Figure 15). Gate impacts, mainly on the east side of DIA, will continue.

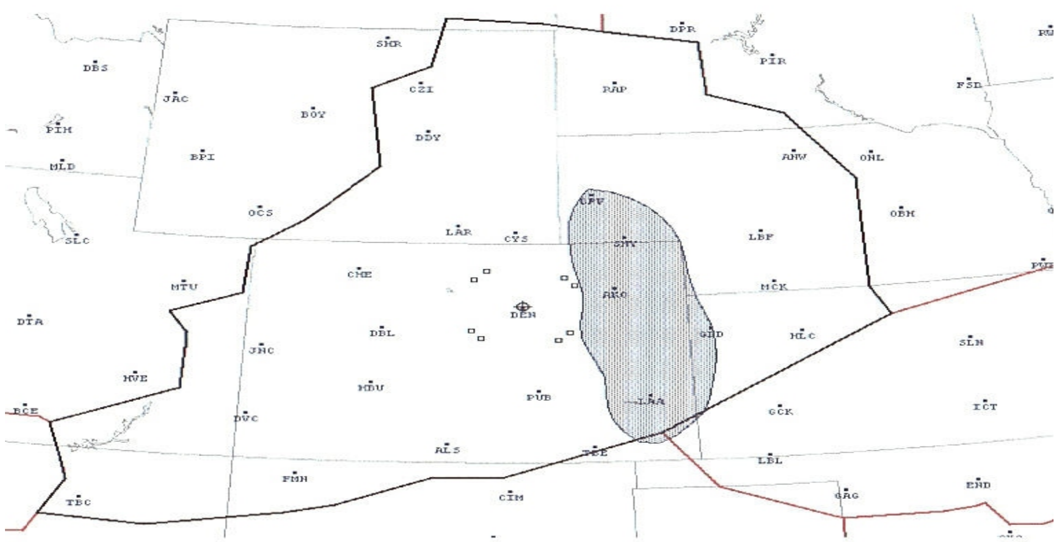

Figure 15: Mountain-Plains Event, Early to Mid Evening.

Gate impact usually ends by mid to late evening, as the activity continues moving eastward and diminishes (Figure 16).

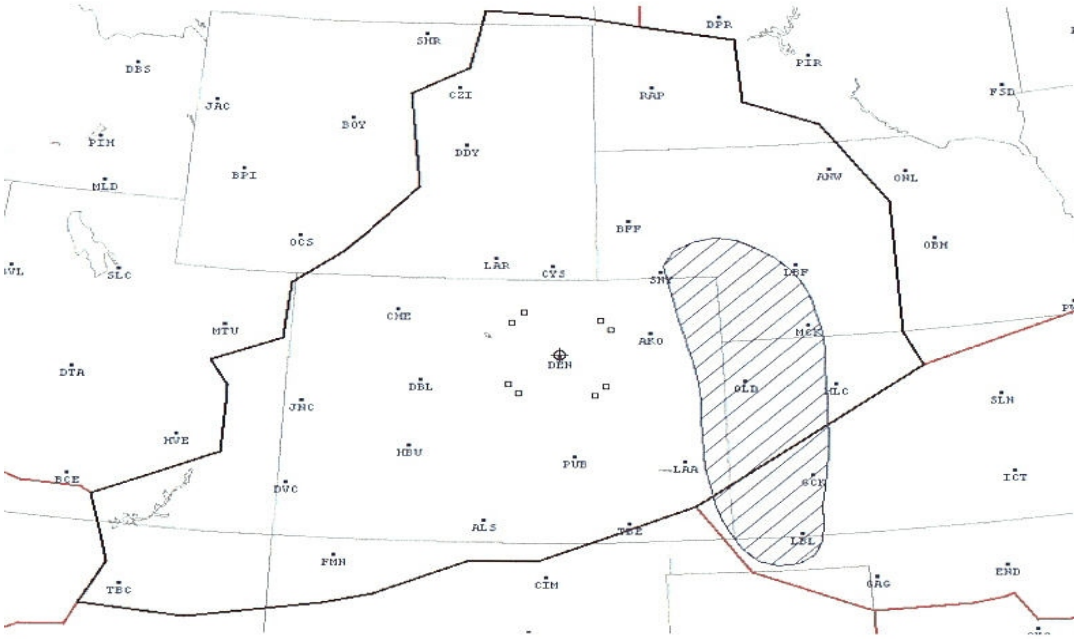

Figure 16: Mountain-Plains Event, Mid to Late Evening.

As with the Denver Cyclone case, this activity could evolve into an MCS and cause major national impact for Chicago, St. Louis or Dallas - Forth Worth en-route traffic.

Case #5 - Frontal Thunderstorm Event

Cold fronts can trigger thunderstorms which impact DIA and other locations within the ZDV area. Let's assume a cold front moving southward into an airmass with sufficient moisture and instability for thunderstorm development. There is also a developing surface low in northeast Colorado and a trough trailing south from that feature. Widespread thunderstorms should form along these features by late afternoon (Figure 17), impacting DIA and its gates. This could cause national ATC programs and reroutes. Less organized activity will be found over the mountains.

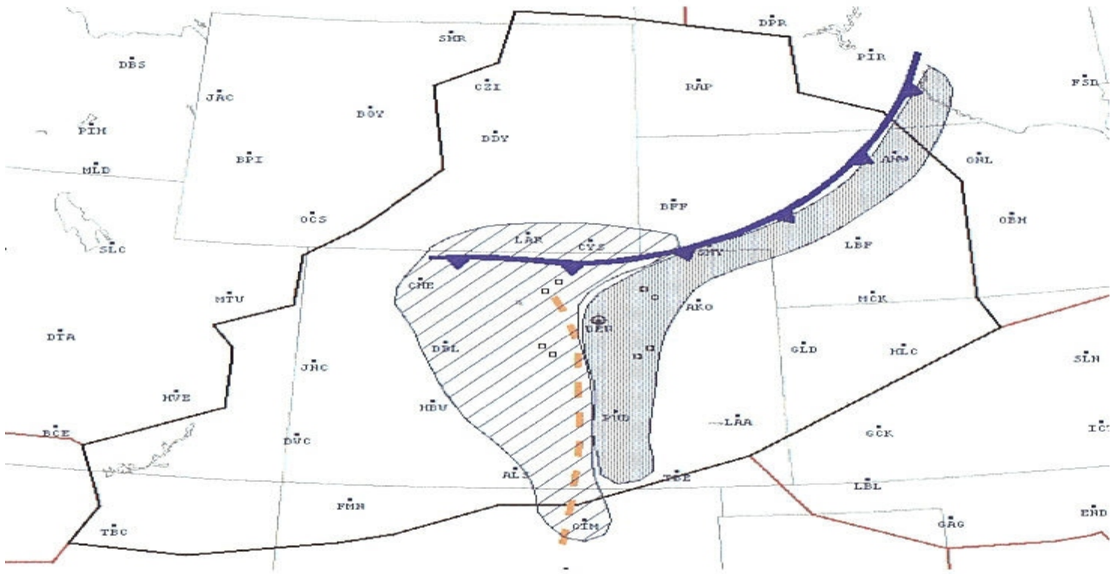

Figure 17: Frontal Thunderstorms, Late Afternoon.

As the system moves southeast, the strongest thunderstorms will move away from the airport and lessen the impact (Figure 18). Only a few thunderstorms may remain over the mountains.

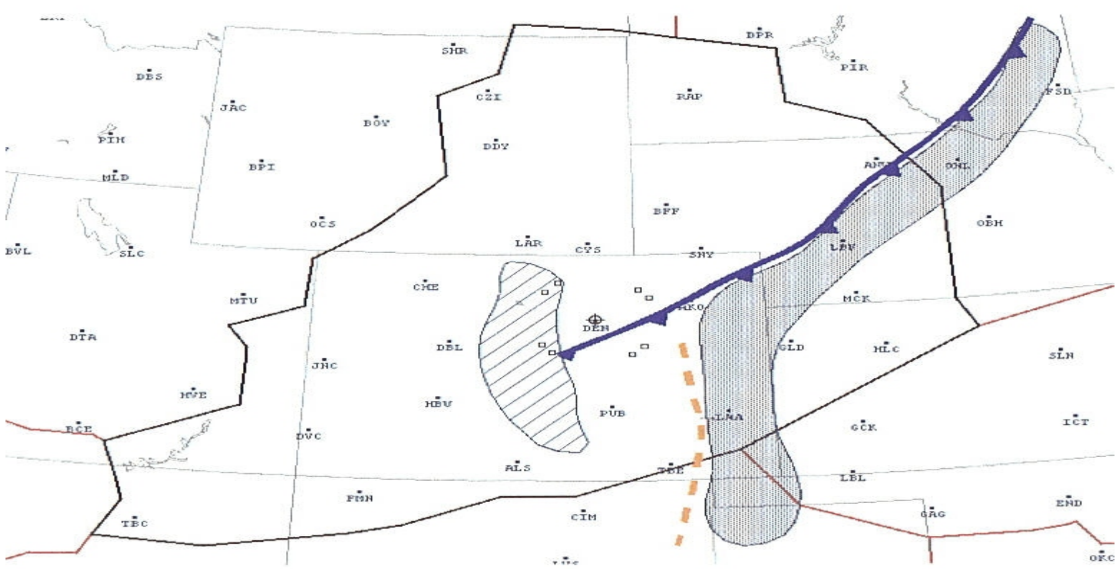

Figure 18: Frontal Thunderstorms, Early Evening.

Case #6 - Post-Frontal Day Two Event

As surface high pressure moves in behind the front the next day, deep easterly up-slope flow may develop east of the mountains. However, the airmass will usually remain stable over the plains. Given enough moisture and instability, afternoon thunderstorms can be expected over the mountains. This activity will usually become concentrated over DIA's west gates, due to low level convergent flow and orographic processes (Figure 19).

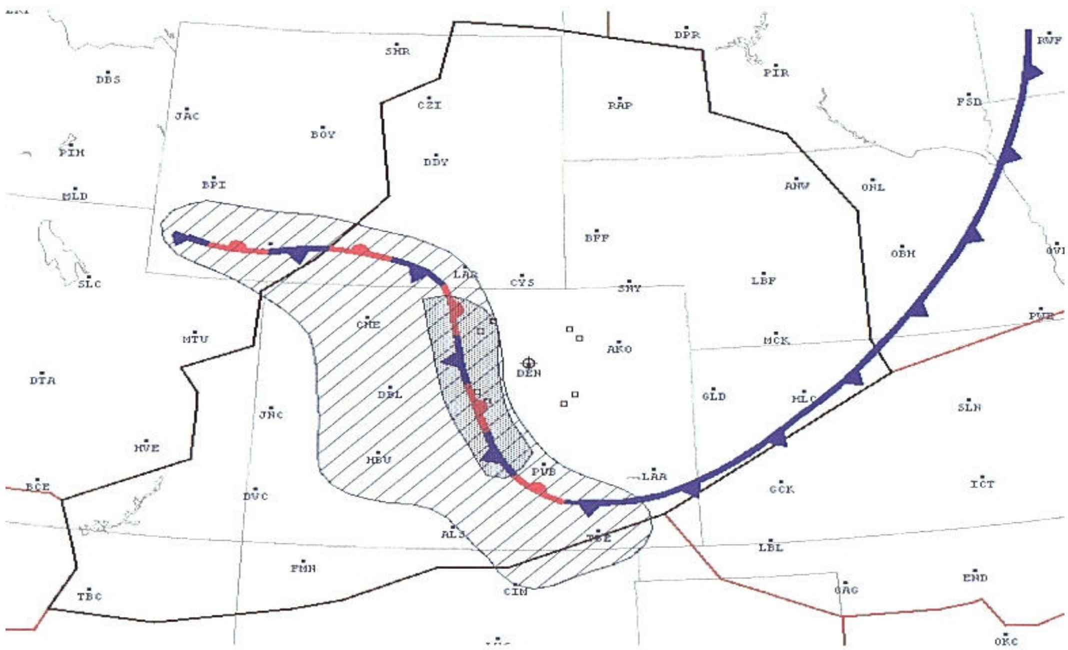

Figure 19:: Post-Frontal Day 2 Event, Early to Mid Afternoon.

If the airmass over the plains becomes unstable, thunderstorms may also break out east of the mountains to impact DIA and its east gates. The storms could become severe, producing large hail, strong winds, and tornadoes.

Conclusion

These cases, by no means, exhaust all the possibilities of how thunderstorms may develop and impact air traffic within the ZDV area. However, they do provide the CWSU meteorologist with conceptual models that he may use as tools in the forecasting process. He must determine which case, if any, provides the "best fit" to his problem of the day. Then, he can make the most accurate and timely prediction of how thunderstorms will impact DIA, the ZDV control space, and the national ATC system.

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