Landspouts (non-supercell tornadoes) & the Denver Cyclone

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• What the DCVZ is and why it is important
• Cases – mostly non-supercell tornadoes associated with the Denver Cyclone (DCVZ) – to demonstrate the variety we see
  • 3 June 1981 – tornadoes WEST of Stapleton
  • 26 July 1985 – Erie tornado – goes across I-25
    • DCVZ boundary displaced more to the west
  • 15 June 1988 – the big one!
    • 4 tornadoes in/near Denver in ~30 min, tower evacuated (Stapleton). F2 to even some F3 damage.
  • 6 June 1997 Boulder tornado
  • 4 Oct 2004 – landspoutfest near DIA
    • 11 tornadoes reported in 44 minutes just west of DIA
  • 16 June 2013 – DIA tornado
    • tornado moves to the NW across runway and LLWAS
Schematic of the Denver Cyclone

South to Southeast flow passing over the Palmer Ridge under conditions with some (enough) lower level stability results in a downstream turning of the wind.

This forms a zone where the winds come together...often this zone is over DIA.

The zone can remain stationary or move very slowly, and as a result
1) the local environment is modified (deepening moisture) to increase the local chance of a storm
2) small scale circulations (vorticity) can form at low levels along the convergence zone (hence called the Denver Convergence-Vorticity Zone or DCVZ)
How to make a non-supercell tornado

1) Low level vertical circulation along the DCVZ (can be present without clouds and for hours)
2) Essentially have the source for a tornado IF the circulation can tighten
3) It CAN tighten if the updraft of a growing cloud/cell is positioned over the low-level circulation
4) And if this happens you get a non-supercell tornado
5) Weaker and shorter lived in general than supercell tornadoes but we’ve seen up to F3 (EF3) and lasting 20 minutes or more
6) But no pre-existing mesocyclone so harder to predict
Example 1: Denver tornadoes of 3 June 1981

- Quick look (pre-dates Doppler radar availability here)
- More of a supercell
- But passes over the DCVZ
- Which in this case was located WEST of the old airport
NOAA/PROFS
mesonet plot
at 1755z (1155 MDT) on 3 June 1981

Arrow points to the old Stapleton Airport location. Weak DCVZ is located just west of the airport at this time. Temperatures and dew points are in °C.
Radar echoes are from the Limon WSR-57 (a test Doppler radar was supposed to start from near the airport on 1 June but was delayed until 5 June!). We can see outflow near and west of I-25 moving east from the foothills storms. The DCVZ still lies west of the airport, essentially right over the city of Denver.

FIG. 11. Surface plot for 1950 GMT 3 June 1981. Radar echoes are from Limon (LIC) radar 1° elevation PPI, contoured at the intensity levels listed in Table 1. Echoes of level 3 or greater are shaded darker.
The tornadic storm (in this case likely a supercell) moves off the foothills to the northeast and passes right over the DCVZ. Did the convergence zone play a role in the subsequent tornadoes? (Or...stated another way, would this storm have produced tornadoes without the DCVZ which it happened to move over?).
3 June 1981

Fig. 2. Photograph of F2 damage from the Thornton tornado.
Fig. 18. Photograph of the second tornado in a Thornton neighborhood.
Residents in Thornton area describe terror from the sky

Cat vanishes, owner survives

Roy Fouts thanks God he didn’t go the way of his cat.

Fouts, 54, a longtime Thornton resident, said he was chatting with his wife on the telephone Wednesday when the lights went out and his roof disappeared.

Then the cat flew through the hole where the roof had been. Something was up.

But Fouts had no idea it was the most severe tornado activity to hit the Denver area in years. The Denver FM station he’d been listening to had reported only scattered thundershowers.

Still, he was terrified. He jumped down, clinging to his carpet, as the storm sucked him into the air. He said his feet were off the floor but he didn’t lose his hold on the rug.

Alex Mollendor stared at the debris in his yard and groped for words to describe the terror that struck from the sky.

“It was just a twisting monster, that’s all,” said Mollendor, 54. “I don’t know how to explain it right now.”

Mollendor was in his home at Corona and Elm streets, Thornton, when a tornado hit about 3 p.m. Wednesday. Later he was mystified by the debris in his yard. “I don’t know whose it is,” he said.

Also in the yard was Mollendor’s camper trailer, overturned. On it was a metal tag that said “Bless This Mess.”

Nearby, a telephone pole was tipped at a 30-degree angle.

Across the street, another camper trailer had been picked up by the twister.

The areas, which were cordoned off to keep looters out, were along northbound streets between West 88th Avenue at York Street and West 88th Avenue at Washington.

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Editor’s note: Reporting for this article was by Norman Draper, Louis Kilzer and Sharon Stewart. It was written by Karen A. Bailey.
Example 2: The Erie, Colorado I-25 non-supercell tornado of 26 July 1985

- One of the earliest Doppler radar studies of the life cycle of a non-supercell tornado
- Typical environment – no other severe weather occurred
- Nice example of how it often takes an interaction to produce the spin-up
  - In this case an outflow boundary from weak foothills/mountain convection intersecting the DCVZ
Vertical wind shear on 26 July 1985

The very weak vertical wind shear is a lot like that found in the tropics (GATE sounding).
The then-experimental “PROFS Mesonet” 1830z (1230 MDT) on 26 July 1985

Robust southerly flow on the plains, a somewhat disorganized DCVZ near and east of I-25.

No DIA back then!
Convergence ($x10^{-5}$s$^{-1}$)

Vorticity ($x10^{-5}$s$^{-1}$)

Noon

1400 MDT
The then-experimental "PROFS Mesonet" 2015z (1415 MDT) on 26 July 1985

Some of the boundaries are pretty subtle and only trackable using the Doppler radar data.
The then-experimental "PROFS Mesonet" 2115z (1515 MDT) on 26 July 1985

Tornado occurs at the arrow from 1535 to 1553 MDT and crossed I-25.
Not only did the boundaries provide the low-level circulation, they also modified the local environment. There was no other severe weather reported on this day.
The grid is slightly off, but this series of visible images shows how the tornadic storm (yellow arrow) ended up forming along the DCVZ in an area that remained in sunshine and where the outflows hit it.
Pictures looking east from Boulder of the initial clouds along the DCVZ and then the explosive development following collision with the weak outflow boundaries.
The then-experimental "PROFS Mesonet" 1830z (1230 MDT) on 26 July 1985

No DIA back then!
Tornado flips truck on I-25

Staff and wire reports

Four people in a Ryder rental truck must have felt like Dorothy in “The Wizard of Oz” Friday when their truck was flipped into the air by a tornado that touched down on Interstate 25 near the Lafayette exit.

The truck landed on its left side and slid into a Dodge Colt carrying three passengers. The car’s windows had imploded from pressure just before the truck slid into it.

All passengers of both vehicles, including an 11-month-old baby, were wearing seat belts or child restraints. Injuries were limited to minor cuts from flying glass.

The tornado, spawned by a severe thunderstorm, churned for 18 minutes across southeastern Weld County on Friday afternoon. Beside the truck-car accident, damage also was reported to a $500 storage shed which was shoved off its foundation.

The twister touched down at 3:35 p.m. in extreme southwest Weld County and held its course until 3:53 p.m., blowing up a dust cloud that brought traffic on Interstate 25 to a halt.

A funnel cloud also was spotted between Brighton and Commerce City, to the south, but it was not reported on the ground. The National Weather Service said there were reports of a second tornado on the ground while the first was weaving between Erie, Dacono, Fort Lupton and Brighton, but that the second tornado could not be confirmed.

A paramedic in the Weld County sheriff’s office said the travelers in the damaged truck, whose names were not available, “spotted a dust cloud and decided that it was a tornado about the time one of the signs was ripped up and thrown across the highway. All of a sudden the truck was being blown all over the highway.”

Meteorologist Jim Kaplan from the National Weather Service said the tornado activity came from a “very strong thunderstorm.”

He said the tornado was confirmed by a team of researchers from a Boulder program called Prototype Regional and Forecast System.
Example 3: The Big One – 4 Denver area significant non-supercell tornadoes within half an hour on 15 June 1988

• Another Denver tornado outbreak, but shifted to the east of the 3 June 1981 tornadoes
• Some vertical wind shear, unstable environment
• Another nice example of how it often takes an interaction(s) to produce the spin-ups
  – In this case two outflows that intersect the DCVZ in just the right way
• One tornado went over the old Stapleton Airport
4th tornado is near Brighton

~2208z (1608 MDT) F1

~2225z (1625 MDT) up to F3

Note the different appearances of the tornadoes – we found this was related to moisture differences rather than strength.

Roberts and Wilson 1995
I took this picture ~2223z (1623 MDT) looking WSW across the old NWS site (radome building is visible). Largest condensation funnel I had seen. Could also see trees/branches being ripped from the ground. Max damage was F2.

This from Rita’s paper: what did the planes do?

I believe the tower was evacuated for this tornado.

X approximate location of where picture was taken
Denver Soundings from Roberts and Wilson MWR paper.
There is some decent vertical wind shear on this day and some storms to the east of Denver produced severe sized hail.
Summary of the 2 outflow boundaries hitting the DCVZ and producing the tornadoes.
1700z (1100 MDT) on 15 June 1988

Fairly typical with dew points near 50 to the lower 50s. S to SE flow on the plains but fairly disorganized flow near and west of the airport.
The DCVZ is not particularly strong but is about over the airport.

Early storms have developed to the south over the Palmer Divide and in the foothills and mountains nw of Boulder.
The wind at Stapleton Airport is calm with temp=77 and dew point 51.

Storms continue to move off the foothills with some outflow from the NW. Pretty big storm to the south.
2030z (1430 MDT) on 15 June 1988

The DCVZ is still not that strong but is right over the airport.
The storm well to the se of the airport produces an outflow that moves to the nw and appears to produce a storm on the DCVZ south of the airport. But this storm moves away, develops mid level rotation and severe hail but no tornadoes (and sucks chasers to the east!).
But that new storm sends another outflow to the NW towards the DCVZ. Meanwhile the weak convection over Boulder County sends an outflow to the SE towards the airport.
2200z (1600 MDT) on 15 June 1988

And then they intersect.
Detailed look at the flow near the DCVZ after it was intersected by the 2 outflow boundaries at 1600 MDT (dual-Doppler analysis from Roberts & Wilson, MWR)

It is believed that the way the two gust fronts intersected the DCVZ at an angle, instead of head on, produced an unusually large number of small-scale circulations, some of which grew into the 4 tornadoes.
Doppler velocity (blue toward) at 2201z/1601 MDT
County extends model midwife program to Boulder

Childbirth service available to low-income women

‘Little’ twister damage may top $10 million

Colo. tornadoes less intense than plains states usually get

Boulder scientists probing Colorado’s ‘tornado alley’
Example 4: Speaking of changing appearances – the Boulder tornado of 6 June 1997

- Very moist environment – in fact forecasters worried about flooding rains
- Deeper SE flow – caused the DCVZ to shift from the airport to the WNW with time
- Eventually wound up in eastern Boulder County where it produced a very visible tornado
The Denver sounding on this day (1200z/0600 MDT) has deep ESE flow and this moves the DCVZ westward during the day.
Evolution of the DCVZ on the Boulder tornado day of 6 June 97

A similar feature to the DCVZ occurs north of the Raton Mesa near Pueblo, and is seen on this day as a cyclonic circulation in the low cloud field.

Other two arrows mark the DCVZ, which slowly moves westward with time as storms develop on it, but no tornado forms until it gets to Boulder County. The tornado develops ~1410 MDT and moves WSW, passing just north of my house then to the west. Why no tornado(es) earlier? Perhaps because the DCVZ was not stationary in this case. Weak outflow from the west may have intersected it in Boulder County.
At first this was a typical non-supercell Colorado tornado with a tiny funnel from cloud base and a swirl of dust on the ground. Then it passed over Baseline Reservoir and became a full-fledged Colorado waterspout (this photo ~1415 MDT).

The NWS (then in Denver) actually got the first report of this storm from an observer way to the east in Lockbuie, who estimated it was over Louisville. I called in to NWS to tell them exactly where it was, near my house! After exiting the lake on the SW side the tornado lifted about 1420 MDT.

I did a bicycle survey and found a 2x4 in the side of a barn just across from where it entered the lake. The owner said the plank had been in the barn before the tornado. The tornado reportedly turned a car sideways on Baseline Road. Just before it entered the lake it crossed a small field of foot tall grass, and one could clearly see flattened grass but no more than about 20 feet across. Rated as an F1.
Example 5: October tornadofest near DIA. 11 tornadoes reported on 4 October 2004

- 11 non-supercell tornadoes developed NW of DIA
- F0 except 4 rated F1
- Occurred within a 44 minute period from 2204-2248z (1604-1648 MDT)
- Tornadoes developed after the DCVZ was intersected by a thunderstorm outflow boundary from the east
Weak vertical wind shear but a fairly unstable and moist airmass.
Yellow arrow points to DIA. DCVZ (white arrows) is found just west of the airport at this time.
Note the wind increase from the SE at DIA – this is outflow from storms to the south
A close look at the velocity (from the KFTG radar) at 2115z showed 4 small scale circulations present along the DCVZ.

Green is toward, red away.
Visible image with observations at 2200z/1600 MDT on 4 Oct 2004

Just before the tornadoes start. The weak storms to the east sent a surge westward, foothills cells a weak surge to the
Echoes are just being seen near ground level as the tornadoes are about to begin since the cells are growing still.
A close look at the velocity (from the KFTG radar) at 2200z – still have the 4 small scale circulations along the DCVZ.

Close call for DIA!

Green is toward, red away.
The tornadoes were the only severe weather near Denver that day.

nice video at https://www.youtube.com/watch?v=3FuuP7uJVEk
Example 6: 18 June 2013 tornado on the DIA runways

- Tornado develops at se edge of DIA and moves to the NW
- Airport terminals evacuated
- Passed right over a couple of LLWS sensors
- First use of total lightning (in-cloud and cloud-to-ground) to help issue a warning with some lead time
Tornado tracked across the N-S runway area heading towards the terminal.

- **Dissipation Point**
- **Observing site** that recorded 97 mph gust at 2:27 MDT
- **Observing site** that recorded 109 mph gust at 2:27 MDT
- **Touchdown Point** 2:22 MDT
Some views of the tornado
Some views of the tornado
Empty DIA concourse after evacuation to tornado shelters
Not much vertical wind shear (but some). Steep lapse rate above the stable layer. Good low-level moisture.
Visible satellite image at 1815z/1215 MDT on 18 June 2013

Arrow points to DIA. Initial cells form over the higher terrain.
Visible satellite image at 1915z/1315 MDT on 18 June 2013

Arrow points to DIA. An hour later some cells moving onto the plains, but not all survive.
Arrow points to DIA. Strongest storm develops over the DCVZ, which was basically lying south to north over DIA.
Total Lightning data and the DIA tornado on 18 June

- Radar was very close to the tornado
  - 88D ~7 miles away
  - Terminal Doppler radar (TDWR) ~11 miles away

Composite Reflectivity shows echo aloft south of DIA, and in-cloud lightning first seen but already increasing (arrow). No real circulation yet near the surface. Note second weaker cell to the north.
We start to see a circulation near the surface, meanwhile in-cloud lightning increasing rapidly (indicative of increasing updraft – a key to non-supercell tornadogenesis) in the southernmost cell. Now see lightning aloft in the northern cell (over DIA) (light green arrow).
A few minutes later...

Velocity at 0.3° from TDWR at 1958 UTC

Southern circulation tightens but no tornado forms with this cell. Start to see a circulation with the northern cell.

Composite reflectivity at 1954 shows more rapidly growing northern cell.
Total Lightning data and the DIA tornado on 18 June

The northern circulation and cell take over, also shown in the total lightning trend, but still no confirmed tornado on the ground (warning is issued shortly after this time). Touchdown not confirmed until 2022 UTC via call to the DIA tower!
TDWR reflectivity and velocity image at 2022 UTC when tornado was confirmed by DIA tower. Hook echo is seen in the reflectivity with shear in the velocity image >100 knots. Max velocity from the radar was 90 knots (flow away (red) from the radar).
How predictable are these tornadoes?

HWOBou HAZARDous WEATHER OUTLOOK NATIONAL WEATHER SERVICE
DENVER/BOULDER CO 1050 AM MDT TUE JUN 18 2013 COZ030>051-191700-

.DAY ONE...TODAY AND TONIGHT SCATTERED THUNDERSTORMS WILL DEVELOP AGAIN THIS AFTERNOON AND CONTINUE INTO THE EVENING HOURS. THE BEST MOISTURE AND INSTABILITY WILL BE EAST OF A LINE FROM NEAR GREELEY TO DIA WHERE SEVERE STORMS WILL BE POSSIBLE WITH GOLF BALL SIZE HAIL AND DAMAGING WINDS THE PRIMARY THREAT WITH A TORNADO ALSO POSSIBLE WITH STORMS THAT COULD BECOME MORE ORGANIZED AS THEY MOVE EAST. FARHER WEST...BRIEF HEAVY RAIN...SMALL HAIL AND WIND GUSTS TO 50 MPH WILL BE POSSIBLE FROM THE THUNDERSTORMS. IN ADDITION...A WEAK DENVER CYCLONE HAS ALREADY FORMED AND THIS SHOULD STRENGTHEN INTO THE EARLY AFTERNOON WITH THE STRONGEST CONVERGENCE RUNNING SOUTH TO NORTH NEAR DIA. ALONG THIS BOUNDARY STORMS COULD BECOME LOCALLY MORE INTENSE WITH A NON-SUPERCCELL TORNADO POSSIBLE. STORMS WILL DEVELOP IN THE FOOTHILLS BY LATE MORNING AND THEN ON THE PLAINS DURING THE AFTERNOON.

Enough confidence for this case (June) to put in the HWO
Airport site in tornado-prone area

Meteorologist’s report not likely to change site

By JAMES G. WRIGHT
Rocky Mountain News Staff Writer

Denver’s new airport will be built in an area prone to thunderstorms, tornadoes and deadly windshear that can knock planes out of the air, according to a meteorologist’s report released yesterday.

Airport planners acknowledged that weather at the site is more turbulent than at Stapleton but said the differences are minor and present no safety problems.

The weather study was prepared under a city contract by meteorologist William P. Mahoney, of the University Corporation for Atmospheric Research in Boulder.

Focused studies suggest that the new airport site may have more thunderstorm, tornado and high-wind events than Stapleton,” Mahoney said.

In the report, Mahoney determined that the 52-square-mile proposed airport site 12 miles northeast of Stapleton International is in the center of a weather phenomenon called the Denver Convergence Zone.

The zone, which normally lies east of Stapleton, runs parallel to the Front Range where dry winds from the southwest collide with cooler, moist mountain air.

At the point of convergence, the winds often create tornadoes, thunderstorms and microbursts of intense, downward blasts of air known as windshears that are strong enough to knock large planes to the ground.

Thunderstorm conditions have been blamed for several major air disasters in recent years at Stapleton and will increase airport operations at least 140 days of the year. Wind direction data, for example, will help improve air traffic control.

“I can’t say the new airport is a bad site; there’s no evidence pointing to that,” Mahoney said in an interview. “There are differences (from Stapleton), but they should not affect operations significantly enough to warrant changing the site.”

Opponents of the airport project have raised concerns about tornadoes in testimony at recent environmental impact hearings. Mahoney found that three tornadoes were seen on the proposed airport site from 1981 through 1984, compared with four tornadoes that passed near, but did not touch, Stapleton during the same time.

Last week, another tornado was sighted in what will be the terminal area of the new airport.

Relocating the airport would not avoid the tornadoes that are relatively common north-east of Denver and could add to weather problems, Mahoney said.

The airport cannot be moved west because of the mountains. Situated farther east, it would still be plagued by tornadoes and would be in blizzard areas, Mahoney said.

The worst hail zone in the state is north of the proposed site, and thunderstorms are so common south of Denver that only one other place in the nation — Miami — records more in a year, Mahoney said.

Airport planners say any weather problems at the proposed site can be countered with sophisticated weather detection systems — such as Doppler radar used to detect windshear — now in development.

“Recent scientific and technological advancements make it possible to address a number of weather-related factors important to airport operations,” James W. “Skip” Spenles, director of the city’s new airport development office, said in a written statement.

The FAA is developing a terminal weather information system that would integrate...
• AT THE TOWER, ONE CAN SEE LINE OF CLOUDS GROWING ALONG THE DCVZ: IF SO, BE ON THE LOOKOUT FOR TORNADO FORMATION
• MONITOR KFTG RADAR FOR VORTEX SIGNATURE
• IF PRECIPITATION IS DUMPING OUT, THEN THAT LOCATION IS UNLIKELY FOR NEW TORNADO FORMATION; TORNADO MOST LIKELY PRIOR TO FORMATION OF PRECIPITATION
• MOVEMENT OF TORNADO: DOES STORM REMAIN ANCHORED TO DCVZ OR DOES IT ACQUIRE A LIFE OF ITS OWN AND MOVE AWAY?
- Look for DCVZ location for possible growing cumulus congestus clouds: use visual obs, radar, and SFC obs.
- If location of growing clouds is near DIA, be extra vigilant.
- If tornado forms, be aware of its motion (obvious!).
- Once precipitation has dumped out, forget about that location and look elsewhere for possible tornado formation.
- There may not be a condensation funnel: look for dust whirls at the SFC being lofted; condensation funnel often forms after tornado has begun at the ground.
• SEE *Severe Convective Storms and Tornadoes*, 2013, by H. Bluestein, Springer, pp. 340 – 341, for mobile Doppler radar imagery and photos of a landspout during VORTEX2 (Fig. 6.27)
End
Wall cloud as the storm passes near DIA – not sure of the time of this photo.
26 May 2010 – strong storms develop on the DCVZ near DIA (pre VORTEX-2 part)

Approximate locations of the tornado reports

5 tornadoes? Or none? Officially one (then another in Weld County that is not shown here)
Some storm photos – scud or wall cloud? Or funnel? Or tornado??

2 photos of lowering over DIA

2 more photos from near DIA

Photo from Hudson

Photo from Watkins

2 photos from Keenesburg

2 photos from Lochbuie

Photo from Wiggins
Hail was a big issue with the storm (and subsequent storms)

Areal view of the hail swath near DIA
Case 2: Landspouts on 16 Aug 2010

Deer Trail tornado – 1957Z

Tornadoes north of Gary 2154Z and 2217Z

3 SW Agate tornado – 2016Z

Deer Trail tornado – 1957Z
KFTG reflectivity and velocity overview

- Weak cell
- Outflow boundary
- Stationary boundary
- Tornado here at ~20Z

DCVZ
KFTG reflectivity and velocity overview

- New outflow boundary
  - Leads to developing cells
  - Tornado with this cell at 2016Z
- Separate boundary collision here with the DCVZ
- Tornado here at ~20Z
KFTG reflectivity and velocity overview

tornadoes with this cell ~22Z

tornadoes here at ~22Z
Wind analysis comparison at 2000z—LAPS/1km (which uses Doppler winds) has the strongest NW winds in the circled area closer to what the Doppler velocity indicated. Others tend to be too light, though of these HRRR comes appears to come closest. Very few obs in area circled.
Did LAPS at 1 km resolve the (pre-)tornadic vortices along the DCVZ?

Looks like it did, but, annoying line of concentrated vorticity east of where the action is.