Chapter 14 Case Studies and Study Guide: Windstorms, Thunderstorms and Tornadoes

Key Concepts

- Thunderstorms can form as a result of orographic lifting, convective lifting or when a cold front moves into a region.
- Clouds associated with thunderstorms typically reach higher into the atmosphere than ordinary storms.
- Anvil clouds form when a thunder cloud reaches the tropopause.
- Strong updraft in a growing thunder cloud separates electric charges while air acts as insulator.
- Lightning occurs when the separated charges overcome the insulating capacity of the air. A spontaneous discharge leads to thunder and lightning.
- The thunder is the result of the instantaneous heating and explosive expansion of air by the lightning. Lightning travels much faster than thunder to an observer.
- Lightning occurs within a cloud, or between clouds or between a cloud and the ground. Lightning occurs typically along the shorted distance between the bodies carrying opposite charges.
- Today in the U.S., about as many people get killed by lightning every years as by wind or winter storms.
- A microburst is a strong local downdraft near the surface in a mature thunderstorm. Rain and even hail often falls. Microbursts are unpredictable and dangerous to landing airplanes that can suddenly lose lift.
- A supercell thunderstorm is an enormous rotating severe thunderstorm that is capable of producing large hail and spawning tornadoes. Only 15% of all supercell thunderstorms spawn tornadoes.
- Tornadoes are fast-rotating near-vertical funnel-shaped clouds that form in violent thunderstorms
- Of all weather phenomena, tornadoes have the highest wind speeds. The center has particularly low air pressure.
- In the U.S., most tornadoes occur in Tornado Alley, a corridor from Texas north to Indiana, and in Florida
- The strength of tornadoes is categorized by the six-level Enhanced Fujita Scale where an EF5 is the most severe tornado.
- Strong wind shear at different levels in the atmosphere have to be present for a rotating updraft (mesocyclone) to form that eventually spawns tornadoes. In Tornado Alley, the jet stream moving over a strong storm produced by the collision of vastly different air masses (warm tropical moisture from the Gulf of

Mexico meeting cold polar air from Canada) set the stage for severe, supercell thunderstorms.
- In Tornado Alley, the majority of tornadoes occur from April through July
- Tornado formation is forecast by viewing clouds of severe thunderstorm in Doppler Radar images and looking out for tell-tale hook-like echos from swirls of precipitation
- In contrast to tornadoes, derechos are strong, hurricane-force winds that form along a cluster of severe thunderstorms and can cause damage over hundreds of kilometers. In the U.S., northern Texas and northern Arkansas have the highest occurrence of derechos.

Key Terms

- thunderstorms
- anvil clouds
- supercell thunderstorm
- microburst
- dry thunderstorm
- lightning
- separation of charges
- tornadoes
- Fujita scale
- wind shear
- updraft
- Tornado Alley
- Doppler Radar
- mesocyclone
- funnel cloud

Questions for Review

1. Under which atmospheric conditions do thunderstorms form?
2. How is a thunderstorm different from an ordinary storm?
3. Why would an anvil cloud form when the cloud grows to reach the tropopause?
4. What happens to electric charges during a growing thunderstorm? What happens during discharge?
5. Why does every lightning have an associated thunder?
6. What is a supercell?
7. What is a microburst?
8. Why is it a bad idea to seek shelter under a tree during a thunderstorm?

9. What is a tornado?

10. Does an ordinary thunderstorm spawn tornadoes?

11. What are the atmospheric conditions for tornadoes to form?

12. Where is Tornado Alley?

13. How do air masses and air movements favor tornado-spawning severe thunderstorms in Tornado Alley?

14. When do tornadoes typically occur in Tornado Alley?

15. How can Doppler Radar be used to aid tornado warning?

16. How are derechos different from tornadoes?

Case Studies

Case Study 1: The 1925 Tri-State Tornado

With 695 confirmed fatalities, the 18 March 1925 tri-state tornado has been the deadliest single tornado in U.S. history. Possibly being an F5 tornado, it traveled through southeastern Missouri and southern Illinois before moving into southwestern Indiana. Its continuous path of over 219 mi (352 km) has been the longest ever recorded in the world. And with a width of 1 mi (1,600 m), it has been one of the widest. The tornado was also accompanied by extreme downburst winds throughout its journey, widening the path of destruction sometimes to 3 mi (4.8 km). Due to its huge size, people observed an unusual rolling, boiling cloud on the ground but often did not recognize it for what it was. Failing to sense the danger, normally weather-wise farmers were fooled, and the tornado was upon them before they reached a save shelter.

The tornado was first sighted at about 1 p.m. northwest of Ellington, MO. It moved northeastward to kill at least 11 people in the state. At 2:30 p.m. the tornado crossed the Mississippi River into Illinois, destroying the town of Gorham leaving 34 people dead. It continued on at a speed of 100 km/h (62 mph). Within 40 minutes 7 the tornado passed through 7 more towns, taking 541 lives and injuring 1,423 more. With 234, the town of Murphysboro has held the record for highest number of tornado fatalities in a city in U.S. history. The tornado left at least 613 people dead in Illinois, the most in a single state in U.S. history. Crossing the Wabash River into Indiana, the tornado nearly completely destroyed Griffin, before continuing on to devastate half the town of Princeton. The tornado finally dissipated at about 4:30 p.m. after 71 people lost their lives in that state.

Reports repeatedly pointed out that schools were severely damaged or destroyed. Nine schools were destroyed in which 69 students died. Another U.S. record for this disastrous tornado. Perhaps, these sturdy, public buildings were deemed safe, but they were no match for the awesome destructive power of the tornado. The tornado also caused fires to break out which were difficult to fight with broken water infrastructure, somewhat reminiscent of the 1906 San Francisco earthquake. Thousands were left without shelter or food. Looting and theft was also reported, something that occurs after many disasters and perhaps explains why the National Guard nowadays closes off disaster areas so rigorously. The region recovered from this disaster only slowly, also something that still holds true for some of the recent disasters.

The tri-state tornado was actually part of a large outbreak with several other destructive tornadoes on that day in Indiana but also in Tennessee, Kentucky, Alabama and Kansas. At least 747 lives were lost on that day.

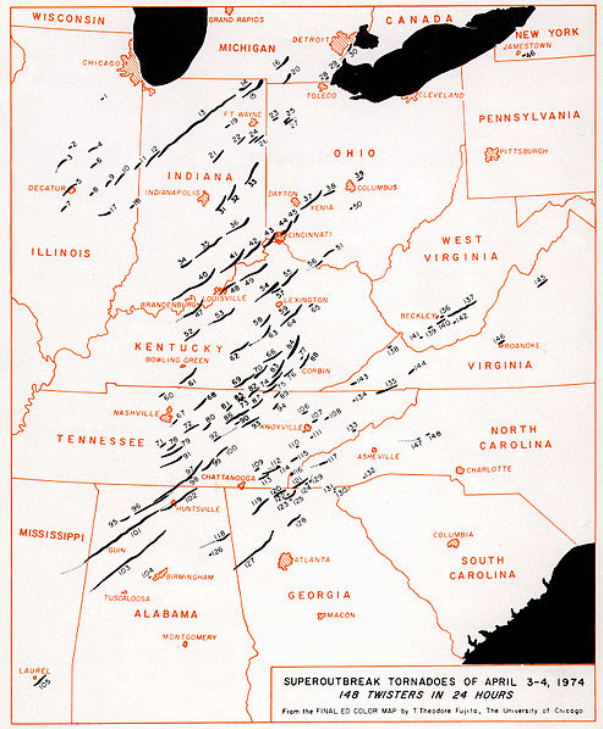

Figure 14.C1 Tornado tracks of the 3 – 4 April 1974 Super Outbreak of 148 confirmed tornadoes, with 30 of them being an F4 or F5. (source: Wikipedia/NWS)

Case Study 2: The 1974 Super Outbreak

With 24 F4 and 6 F5 tornadoes, the 3 – 4 April 1974 outbreak has been the most violent tornado outbreak ever recorded. Until 28 April 2011, it also was the largest outbreak for a 24-hour period. 148 confirmed tornadoes spread over 13 U.S. states from Alabama to Michigan and even New York state, and Ontario, Canada. (Fig. 14.C1). With a death toll of 319, this outbreak was the deadliest since the 1936 Tupelo-Gainesville tornado outbreak, and not surpassed until the 25 – 28 April 2011 outbreak. It was also one of the most costly, with an estimated $3.5 billion (2005 dollars) in damages.

Somewhat reminiscent of the weather situation leading into the 25 – 28 April 2011 outbreak (Fig. 14.36), on 1 April 1974, a powerful low-pressure system developed across the North American Interior Plains. While moving into the Mississippi and Ohio Valley areas, a strong flow of very moist mT air from the Gulf of Mexico moved in to intensify the storm. Cool, dry cP air pushed a cold front on the western side. The jet stream had developed an southward excursion, with the returning leg now blowing oblique along the cold front and across the Low. By 3 April, the central low pressure was 988 mbar. NOAA officials predicted a severe weather outbreak on 3 April but underestimated the degree of severity.

Earlier, a separate outbreak on 1 – 2 April, included three fatal tornadoes in Kentucky, Alabama and Tennessee. An additional tornado was reported in Indiana early on 3 April.

On 3 April, severe weather watches were issued for the Great Lakes area. Snow was falling in parts of the Midwest and heavy rain in Michigan and Ontario. By the afternoon severe thunderstorms formed in Missouri that produced baseball-size hail. Numerous supercells and clusters of thunderstorms developed in two zones, one across Illinois and the other across Tennessee, Alabama and northern Georgia. The worst of the outbreaks shifted toward the Ohio Valley between 4:30 and 6:30 p.m., producing 4 F5 tornadoes. During the evening hours, outbreaks strengthened farther south across Alabama, Tennessee and eastern Kentucky. Additional supercells developed across northern Indiana and southern Michigan. Activity in the south moved toward the Appalachian during the night before the final tornado occurred in the morning of 4 April, after 18 hours of continuous tornado activity. Later studies found that long-lived single supercells spawned multiple tornadoes in succession.

Apart from the 30 F4 and F5 tornado, the Super Outbreak also counted 35 F3 tornadoes, 31 F2, 37 F1 and 15 F0. An F5 striking Xenia, OH was the most deadly single tornado, killing 34 and destroying 1/4 of the city and damaging another 1/4. A TV weather specialist in Dayton, OH alerted viewers in Montgomery and Greene County (where Xenia is located) about a possible tornado, showing the characteristic hook echo in the radar image, several minutes before the tornado struck. An amateur recording of the tornado that is now on YouTube shows that it was actually composed of several vortices within the larger circulation. Some point out that the Super Outbreak occurred after a strong La Niña but a clear correlation between La Niñas and Super Outbreaks has yet to be established scientifically.

Figure 14.C2 Tornado damage in Tuscaloosa, AL from the 27 April 2011 EF4 tornado during the 2011 Super Outbreak. (source: wikipedia)

Case Study 3: The 2011 Tornado Year

With 552 confirmed fatalities, the year 2011 has gone into U.S. tornado history as the second-deadliest season, second only to the year of the 1925 Tri-State Tornado. Nearly ten times as many people died from tornadoes in 2011 as during the previous 11 years combined. 2011 has been the worst tornado season since 1953 when two of several F5 tornadoes that year killed about 115 people each. The worst tornado episodes in 2011 were the 25 – 28 April Super Outbreak that killed 322 people across the Southeastern U.S. (Figs. 14.29, 14.36, 14.C2 and 14.C3) and the 22 May Joplin, MO tornado that left 160 dead (Figs. 14.28, 14.C4 and 14.C5).

The first fatal tornado of that year was an EF2 in Franklin Country, TN on 28 February that was part of an outbreak of 35 tornadoes across the Midwest and South. An EF3 destroyed homes in Eminence, KY. Concentrated tornado activity also occurred in parts of Missouri and Illinois.

During the 4 – 5 April derecho and tornado outbreak, 46 tornadoes (8 EF0, 32 EF1 and 6 EF2) touched down in across the southern U.S. from Kentucky to Georgia. Derechos gusting at 145 km/h (90 mph) developed along an extremely long squall line across 20 states, killing at least 9 people and causing numerous power outages. Nearly 100,000 and 147,000 customers lost power in Tennesee and Georgia. April then saw two more major tornado outbreaks: on 14 – 16 April, 148 tornadoes wreaked havoc in the southern Great Plains and the South from Oklahoma into the Carolinas and north into Maryland and Pennsylvania. This outbreak left 24 people dead in North Carolina, becoming the worst outbreak there in 25 years. And on 19 – 24 April, another series of 89 tornadoes, including one EF3 and one EF4 struck the Midwest and the southern Great Plains. Significant damage was reported in Missouri, Illinois and Oklahoma before the supercells merged into a large squall line. On 22 April, a violent EF4 struck **St. Louis, MO** causing extensive damage, including to numerous facilities at Lambert–St. Louis International Airport. Windows were blown out of the terminal buildings and airplanes were flipped in the field.

Then came the **25 – 28 April Super Outbreak** across the southern U.S. and well as the Midwest and Northeast. The outbreak counted 300 confirmed tornadoes that cost 322 lives (but the numbers may not yet be final). This outbreak ranks as one of the worst in U.S. history. The event produced 15 EF 4 and EF5 tornadoes, third only to the 1974 Super Outbreak and the 1965 Palm Sunday Outbreak. The weather situation setting the stage is discussed in Fig. 14.36 and related text. The situation was quite similar to the one setting the stage for the 1974 Super Outbreak. The SPC had a moderate risk of severe weather for 3 consecutive days, centered over Arkansas and Tennessee. On 25 April, several tornadoes occurred in Texas and Oklahoma. In the afternoon, the SPC issued particularly dangerous situation (PDS) tornado watch for Arkansas and parts of Missouri, Oklahoma, Texas and Louisiana. Tornadoes were scattered but an intense tornadic cell tracked near Little Rock, AR and an EF2 caused extensive damage in Vilonia, killing at least 4 people. Two days later, a large tornado struck Tuscaloosa, AL, killing at least 52

people (Fig. 14.C2 and 14.C3). Damage was "catastrophic". That tornado hit Birmingham shortly thereafter (Fig. 14.29). The funnel was so wide that TV crews were unable to zoom out to catch the entire tornado from miles away. The long-lived supercell of the Tuscaloosa and Birmingham tornadoes was responsible for a long string of tornadoes from Mississippi to North Carolina. Apparently, pink debris balls could be identified by severe weather experts on the radar images of 27 April, so much debris was sucked in by the tornadoes. In Alabama was hardest hit, with 204 fatalities. Tuscaloosa, hospitals were so full that people with broken bones were sent away.

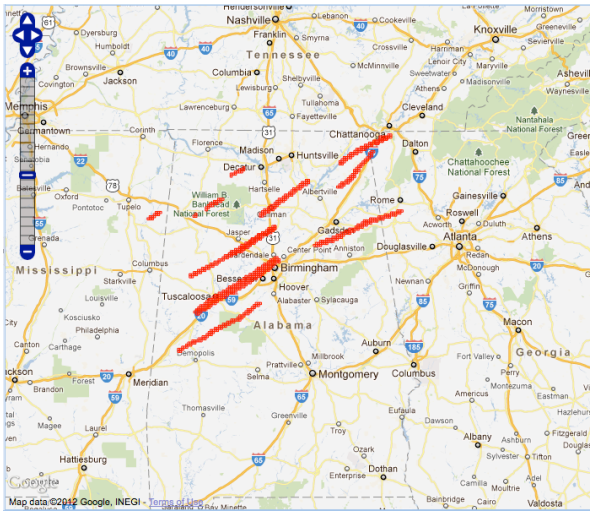

Figure 14.C3 The southwest-to-northeast tracks of the tornadoes striking the Tuscaloosa and Birmingham area, AL on 27 – 28 April 2011 during the 2011 Super Outbreak. (source: NOAA [19])

The month of May saw 327 more confirmed tornadoes in the U.S.. The worst outbreak occurred 21 – 26 May in the Midwest and Oklahoma. On 21 May, two systems of thunderstorm developed over Kansas when the first EF3 tornado touched down in Reading, KS, killing one. A moderate risk was issued for 22 May for much of the Midwest south to Oklahoma. The first tornadic supercell developed that afternoon over Minneapolis-St. Paul, MN, causing damage especially around Minneapolis. An intense tornado also tracked toward Harmony, MN and a tornado emergency was issued. At about 5 p.m., a very large, multi-vortex tornado formed (Fig. 14.C4) and devastated Joplin, MN. Homes, businesses, public buildings, including the Irving Elementary School, and even entire communities were flattened. Some buildings were simply blown away, and the hospital was heavily damaged (Fig. 14.28, 14.C5). The EF5 **22 May Joplin Tornado** left 160 dead and more than 1,000 injured.

Later on 24 May, supercells began forming over Kansas and Oklahoma, and the NWS predicted a dangerous tornado outbreak. An EF5 caused destruction in rural Oklahoma from Binger to Guthrie and killed 9. Three EF4 also develop from these storms. An EF3 and several other tornadoes struck late on 25 May in Indiana. The setup for the Harrisburg ArtsFest was destroyed.

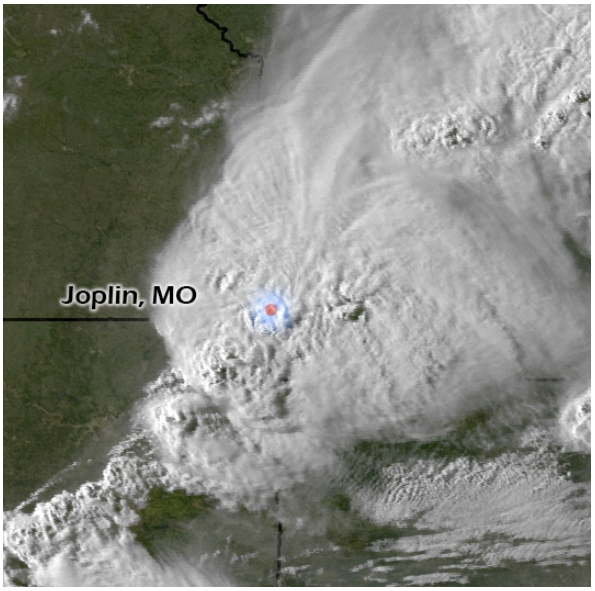

Figure 14.C4 Storm over Joplin, MO minutes before the EF5 tornado formed. (source: Wikipedia/NOAA)

On the late morning of 1 June, several severe thunderstorms began developing along the tail end of a cold front in the Northeast. By early afternoon a tornado watch was issued for New England and adjacent states. A for the region rare tornado outbreak began in the late afternoon, with several tornadoes confirmed in Maine and Massachusetts. An EF3 tornado struck Springfield, MA and continued its destructive path for another 39 mi (63 km). Major damage occurred in the area, roof collapsed in downtown businesses and damages brick buildings. Some homes were destroyed. Trees were stripped of the leave or uprooted and looked like those in Tuscaloosa and Joplin. The **Springfield tornado** cost 4 lives and was the first killer tornado in Massachusetts since 1995.

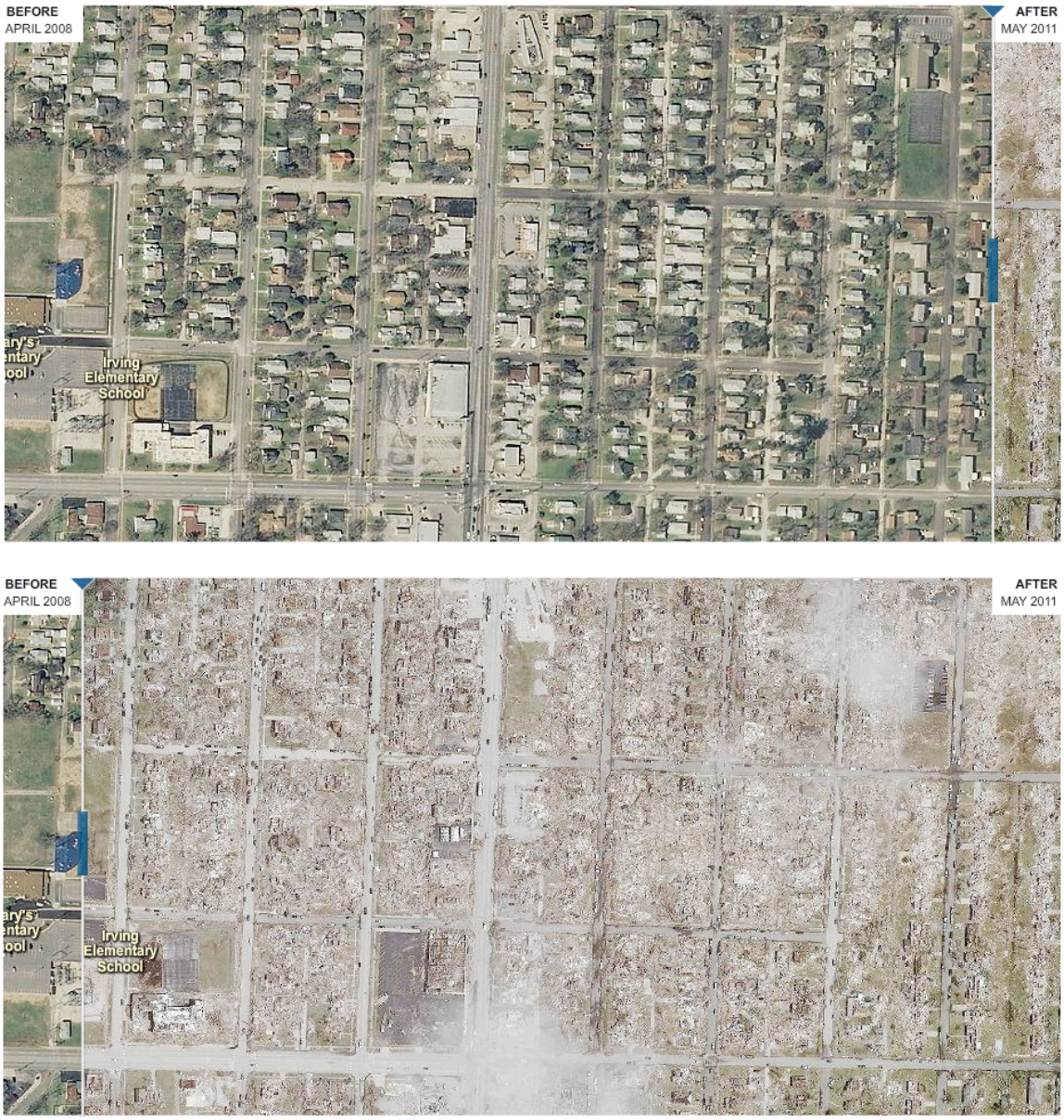

Figure 14.C5 Before an after aerial views of Joplin, MO. The area was hit 22 May 2011 by an EF5 tornado. (source: New York Times [18])

A series of 70 tornadoes ripped through the Central Plains on 18 – 21 June. On 19 June, the NWS issues a moderate risk of severe weather. By the evening, several tornadoes had touched down over rural areas (Fig. 14.C6). On the following day around 1 p.m., storm chasers reported a large EF3 on the ground near Hill City, KS and later in Elm Creek, NE. Numerous other tornadoes, some very large and intense were reported over mostly rural area. The tornado watch stretched from North Dakota to Kansas, and derecho events were forecast for Oklahoma and North Texas. On 21 June, tornadoes were reported in Anoka County, MN and Green Lake and Fond du Lac Counties, WI. A major

derecho event impacted the Chicago Metropolitan Area, with damage reported in Wheeling, IL.

Figure 14.C6 A tornado west of Osceola, Polk County, NE on Highway 92. (source: Wikipedia/NOAA)