13 Mid-Latitude III: Spawning Severe Weather

Introduction

On May 3, 1999, the largest tornado outbreak in Oklahoma history left communities in the central part of the Sooner state looking like a war zone. Color Plates 13.A and 13.B show the unimaginable destruction that a few powerful twisters inflicted. For the first time in recorded history, a tornado ranked F5 on the Fujita damage assessment scale struck within the city limits of Oklahoma City (an F5 rating corresponds to incredible damage caused by winds between 420 and 512 km/hr (261 and 318 mph)—more on the Fujita damage assessment scale in Chapter 14). The devastation was not confined to Oklahoma, as other tornadoes corkscrewed across northern Texas and a swarm of killer tornadoes rampaging through southern Kansas.

During the outbreak, a few people seeking shelter beneath highway overpasses were killed when powerful tornadoes scored direct hits, likely marking the first such documented cases of overpass fatalities and offering contrary evidence to the popular (and mistaken) notion that overpasses provide blanket safety against tornadoes. Such a notion probably arises from the false perception that a tornado is more like the hose attachment on an electric sweeper, whose nozzle merely vacuums objects up. Indeed, the general public typically regards tornadoes as a vertical threat, not the lethal horizontal threat they really are.

By definition, a **tornado** is an upright column of horizontally rotating air in contact with the ground. These horizontally rotating winds can be very fierce, with a violent inflow of air that can hurl large and small objects at great speeds. Such a tornado-driven barrage of airborne missiles accounts for many injuries and deaths (broken glass propelled at tornadic speeds is lethal). Moreover, those people seeking refuge on embankments under overpasses in the Oklahoma tornado outbreak may have been subjected to even greater winds and danger because tornadic winds are strongest just above the surface.

Tornadoes are not the only weapon in the atmosphere's severe weather arsenal. Severe weather can come in the form of large hail or damaging, straight-line winds associated with intense downdrafts in powerful thunderstorms. Our aim here is to show how mid-latitude low-pressure systems can act as the trigger for thunderstorms that spawn severe weather.

Mid-Latitude Lows: Striking the Match That Sparks Severe Weather

As mentioned in Chapter 8, a thunderstorm is classified as "severe" if it produces one or more of the following:

- A tornado
- Hail at least three-quarters of an inch in diameter (about the size of a penny)
- Straight-line winds in excess of 50 knots (93 km/hr or 57.5 mph).

Virtually all severe thunderstorms go hand in hand with "deep convection" as rising turrets of moist air skyrocket into the upper troposphere and sometimes the lower stratosphere (see Color Plate 7.H). The classic recipe that leads to an outbreak of severe thunderstorms has three ingredients:

1. A relatively thick layer of warm, moist air in the lower troposphere
2. A "steep" (unstable) lapse rate, with sufficiently cold air aloft to insure that parcels of moist air can ascend to great altitudes
3. Strong lifting by a low-pressure system and its attendant upper-level trough or its associated fronts

Though the presence of a maritime tropical air mass is typically required for severe weather, forecasters at the Storm Prediction Center (SPC) in Norman, OK, look for large doses of sunshine in the warm sector ahead of a low-pressure system. That's because soaring surface air temperatures make the lapse rate even steeper (that is, make the atmosphere more unstable). Thus, outbreaks of severe thunderstorms are often preceded by sunny, very warm (and humid) conditions.

When conditions are favorable for an outbreak of severe thunderstorms, the Storm Prediction Center will issue a severe thunderstorm watch that might typically encompasses an area of 75,000 km^2 (about 29,000 mi^2). The blue boxes in Color Plate 13.C are examples of severe thunderstorm watch areas. When tornadoes become the prominent threat, forecasters at SPC will issue a tornado watch (the red boxes in Color Plate 13.C).

When severe thunderstorms are observed by the general public or trained spotters, or when radar reveals telltale signs of severe weather, a local office of the National Weather Service will issue a severe thunderstorm warning or a tornado warning for a specific community or county. In most cases, these warnings are issued far enough in advance to give people in areas potentially affected by severe weather at least several minutes to take appropriate safety measures.

Figure 13.1a shows the classic weather pattern associated with an outbreak of severe thunderstorms during the spring over the Plains. The low-level jet (introduced in Chapter 8), which serves as a rapid-transit for northbound moisture from the Gulf of Mexico, provides a rich and revved-up injection of fuel. The upper-air trough provides high-altitude divergence and thus promotes lifting, metaphorically striking a match and igniting the fuel, which, in turn, sparks severe thunderstorms. Moreover, the approach of the upper-air trough provides high-level cooling over the converging moist air associated with the low-level jet, steepening lapse rates and further destabilizing the atmosphere. (The role of mid-level dry air feeding in from the southwest will be explained later in the chapter.) The stage is now set for major-league updrafts worthy of deep convection and severe thunderstorms.

Recall from Chapter 8 that even though air-mass thunderstorms can produce heavy rain, lethal cloud-to-ground lightning and gusty winds, these garden-variety storms usually don't survive long enough to produce severe weather because the downdraft chokes off the life-sustaining updraft. For a thunderstorm to attain the necessary power to produce severe weather, the storm's updraft and downdraft must somehow be separated, just as a referee separates two boxers entangled in a clinch at the center of the ring. The referee that keeps the updraft and downdraft apart within an aspiring severe thunderstorm is vertical wind shear.

Vertical Wind Shear: A Referee That Keeps Updrafts and Downdrafts from Clinching

Formally, **vertical wind shear** is defined as a change in the speed or direction of the wind with increasing altitude. In the case of the classic severe weather pattern in Figure 13.1a, let's assume that surface winds blow from the south at 20 km/hr (12 mph) ahead of the cold front, while winds at 700 mb blow from the southwest at 60 km/hr (37 mph) and winds at 500 mb blow from the west-southwest at 100 km/hr (62 mph). Such classic vertical wind shear is a hallmark of formidable mid-latitude low-pressure systems that spawn severe weather. Though not explicitly expressed in the list of criteria for severe weather near the beginning of the chapter, the presence of vertical wind shear is inherent to the third condition.

Let's further suppose, for sake of argument, that a thunderstorm spawned by the low-pressure system moves to the northeast at 60 km/hr as it's steered by the winds near 700 mb. Let's look at the component (part) of each of the three winds only in the direction that the storm moves.

To understand what we mean by a "component" of the wind, imagine that you are hiking and your compass indicates that you are walking just a little east of due north. Then the component of your walking speed in the northward direction is much greater than the component of your walking speed in the eastward direction. Now treat the observed winds at the surface, 700 mb and 500 mb as three hikers on different trails. If we measure the components of each of three hikers (winds) along the direction of movement of the thunderstorm, we get the vertical profile of wind components along the path of the thunderstorm shown in Figure 13.1b. In essence, these winds represent how fast the air hikes (moves) relative to the ground along the trail of the thunderstorm (note that we've added winds at other intermediate levels to complete the picture).

But because we are trying to determine the positions of the updraft and downdraft relative to one another, it behooves us not to work with winds relative to the ground but to work with winds relative to the storm itself. For insight into what we mean, imagine you're now on a train moving northeast at 60 km/hr. You decide you're hungry, so you head for the snack car towards the rear of the train. Let's say that you're walking 3 km/hr. The fact that you are now moving at 57 km/hr to the northeast relative to the ground is inconsequential. What really matters to you and your hunger pangs is that you're moving at 3 km/hr relative to the moving train car! Similarly, the movement of air relative to a traveling

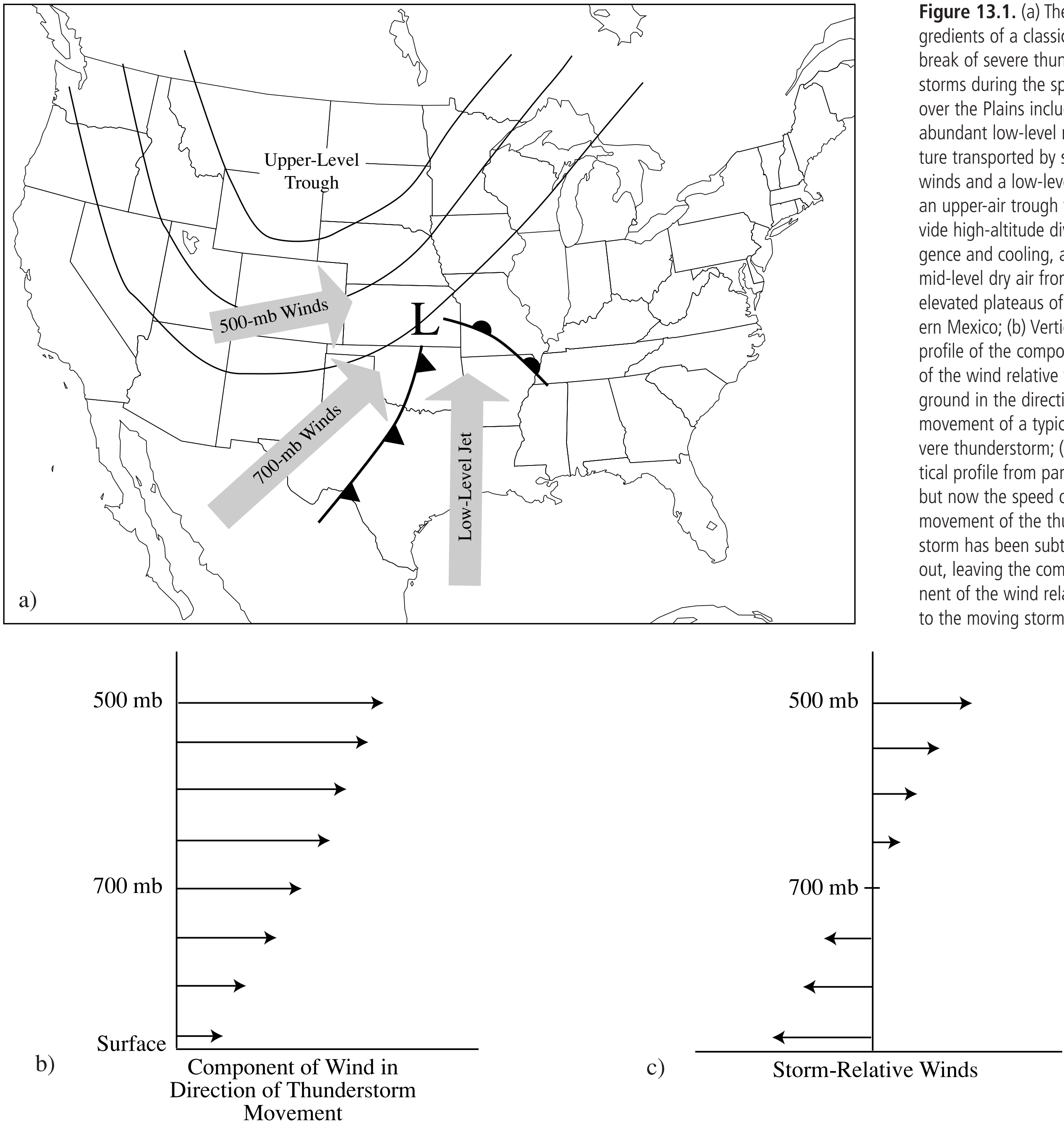


Figure 13.1. (a) The ingredients of a classic outbreak of severe thunderstorms during the spring over the Plains include abundant low-level moisture transported by surface winds and a low-level jet, an upper-air trough to provide high-altitude divergence and cooling, and mid-level dry air from the elevated plateaus of northern Mexico; (b) Vertical profile of the component of the wind relative to the ground in the direction of movement of a typical severe thunderstorm; (c) Vertical profile from part (b), but now the speed of movement of the thunderstorm has been subtracted out, leaving the component of the wind relative to the moving storm.

thunderstorm (which we will call relative wind for short) is also just as important.

In the train example, we used the relationship that your speed relative to the moving train (3 km/hr to the rear) equaled your speed relative to the ground (57 km/hr) minus the speed of the train (60 km/hr). Think of the thunderstorm in question as a train moving at 60 km/hr to the northeast. Also think of the component of the observed wind in the northeast direction as your speed relative to the ground while walking toward the rear of the train. Then a similar subtraction will yield the speed of the air relative to the moving storm. When we perform this subtraction at the surface, 700 mb, 500 mb, and several intermediate levels, we get the vertical profile of winds relative to the moving storm shown in Figure 13.1c.

Near the surface, winds relative to the storm blow in the opposite direction to the storm's movement (just as you moved opposite the direction of movement of the train while you headed to the snack car). In turn, this air becomes part of the storm's updraft, rising in slantwise, tilted fashion opposite to the direction of the storm's movement. Above 700 mb, the storm-relative winds blow in the same direction of movement of the storm (as would be the case on your returning to your train seat). Now the updraft starts to lean forward as it rises slantwise in the direction of the storm's movement.

The tilted updraft fuels precipitation and it starts to rain, producing a downdraft as shown in Figure 13.2. Now we can clearly see the relative positions of the updraft and downdraft in the thunderstorm that developed in this wind-shear environment. They are not entangled; they are separate. Thus, without any clinching between the updraft and the downdraft, the thunderstorm is now free to intensify.

Attack Formations of Severe Thunderstorms: Three-Pronged Assault

Severe thunderstorms attack in basically three formidable formations: squall lines, derechos (a type of especially severe squall line), and supercells. Prevailing weather patterns and atmospheric conditions largely determine any given attack formation, but, lest you lose sight of the chain of command, we remind you that mid-latitude low-pressure systems are the generals that call the shots. Here we tackle squall lines and derechos, leaving supercells for the discussion on tornadoes in the next section.

Squall Lines: Nature's Blitzkrieg

A **squall line** is a narrow, linear legion of warring thunderstorms that develops in the warm sector of a mid-latitude low-pressure system, usually about 100 to 300 km

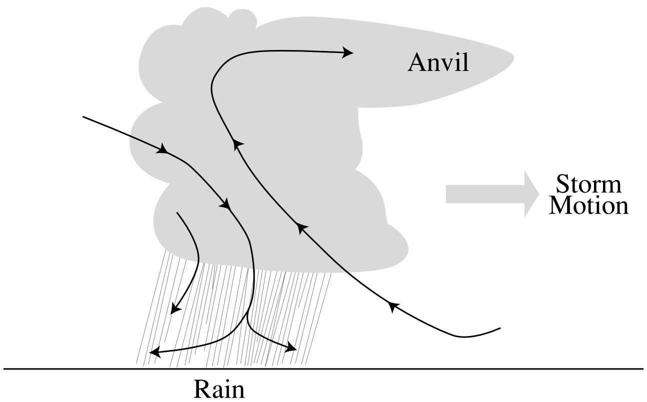


Figure 13.2. In a wind-shear environment, the updraft is tilted and kept separate from the downdraft, allowing the thunderstorm to intensify.

(60 to 180 mi) in advance of the cold front. Unlike the deployment of convection in the classic cyclone model, which traditionally places a line of showers and thunderstorms (or snow showers) along and just ahead of the cold front in concert with low-level convergence, the squall line is an "advance force" of storms capable of laying down a barrage of heavy rain, high wind, large hail and tornadoes.

The synoptic set-up that favors the development of squall lines is shown in Figure 13.3a, which is a first cousin of Figure 13.1a. In this case, a linear area of moisture convergence associated with a low-level jet (the fuel) lies underneath high-level divergence linked to the trailing upper-air trough (the match). If the local atmosphere has also been destabilized by solar heating, all atmospheric guns are trained on the region. In explosive fashion, thunderstorms erupt along the line of moisture convergence as the vigorous lifting of warm, humid air results in towering cumulonimbus clouds.

As the upper-air trough advances, so does the cold front and the area of divergence aloft. Thus, while the area of rising air that promotes thunderstorms moves in the same direction as the cold front, low-level convergence at the front does not contribute to the lifting that ignites and sustains squall lines.

Squall lines sometimes persist for six hours or longer, owing their longevity to the alignment of the individual cells in a line, which means that individual thunderstorms do not disruptively interfere with each other by squabbling for low-level humid air (Figure 13.3b). Each cell grows, matures, and dies in step with the advance of the favorable low-level flow of moisture that is coupled to the upper-level region of divergence. Squall lines often meet their demise if they migrate to the east of the tongue of warm, moist air and encounter a cooler or drier surface environment. Squall lines also typically weaken within hours after sunset once the destabilizing effects of solar heating fade.

Squall lines most frequently occur from early to mid-spring in the Southeast and southern Plains and from mid-spring to early summer in the central and northern Plains, when southward-moving continental air masses are most likely to clash with maritime tropical air drifting northward from the Gulf of Mexico.

Some squall lines are more fierce than others. One type of squall line can produce a large-scale, damaging windstorm called a derecho (pronounced day-ray´-cho).

Derechos: Look Out Loretta!

Under certain conditions, the northern end of a squall line forging out ahead of a strong low-pressure system

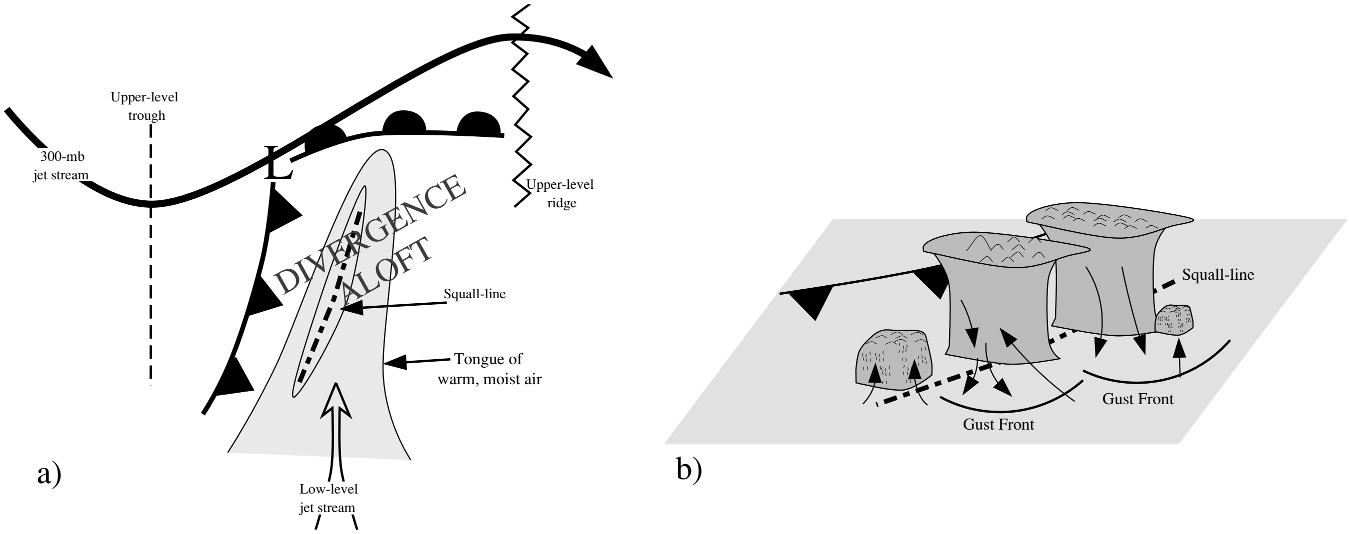


Figure 13.3. (a) The synoptic conditions that contribute to the formation of a squall line; (b) A schematic of the internal structure of a squall line.

can evolve into an organized family of severe thunderstorms that produce clusters of damaging downbursts. For sake of reference, a microburst (discussed in Chapter 8) has a spatial range of anywhere between 0.4 and 4 km (.25 and 2.5 mi) along its major axis of damaging straight-line winds (Figure 13.4). A single downburst, by virtue of the fact that more than one thunderstorm can combine forces to jointly transport momentum from fast winds aloft to the surface, has a greater spatial span, with its major axis of damaging straight-line winds ranging from 4 to 40 km (2.5 to 25 mi).

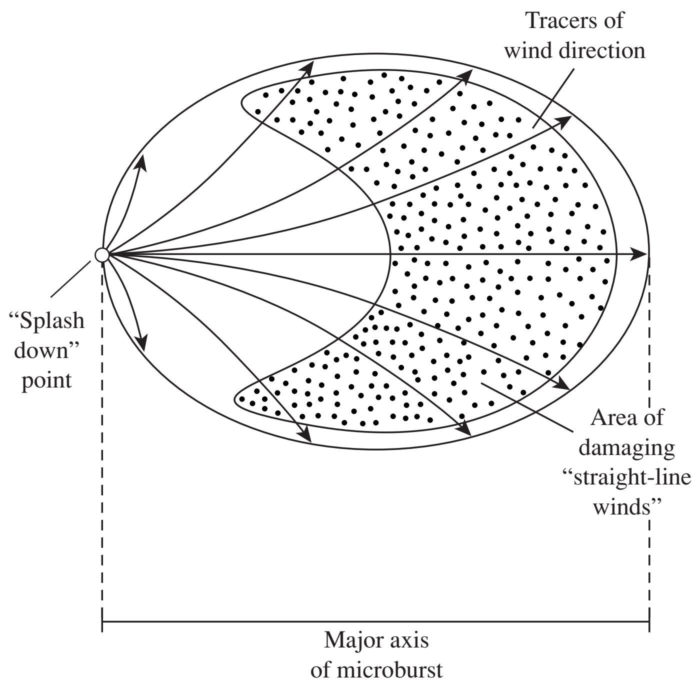


Figure 13.4. Streamlines trace the wind pattern of a typical microburst, showing the area of damaging straight-line winds.

Clusters of downbursts associated with the northern end of a squall line ahead of a strong mid-latitude cyclone produce a widespread windstorm called a **derecho**. This is a Spanish word which, in this context, can be translated as "straight-ahead" or "direct."

On radar, derechos have a telltale signature of one or more bow echoes (Figure 13.5). By definition, a **bow echo** is a crescent-shaped radar echo of a cluster of thunderstorms that work together to transport momentum from fast winds aloft to the surface. A bow echo gets its name because, with a little imagination, it resembles an archery bow. Typically, the cluster of storms that makes up a bow echo span 40 to 120 km in length (25 to 75 mi). The strongest winds are usually observed at the eastward-arching apex or "surge region" of the bow echo (where the arrow on an archers bow would be found). It is here that storm echoes undergo a pronounced bulge as they pick up forward speed. This bulging is thought to be driven by a strong, rear-inflow jet—a speedy stream of slantwise-descending air that is drawn into the rear of a bowing pattern of storms by the system's developing wind system (the first two steps in Figure 13.5—more on the third step in a moment).

So a squall line that develops one or more long-lived bow echoes on radar can be upgraded to a derecho. There are several criteria for such a "convective windstorm" to qualify as a derecho. For our purposes, we will cite two of the most straightforward criteria:

1. There must be a slew of wind-damage reports and/or reports of gusts greater than 50 knots (93 km/hr or 57.5 mph) over an area whose major axis (measured along the windstorm's forward path for its entire lifetime) is at least 400 km (250 mi) long.

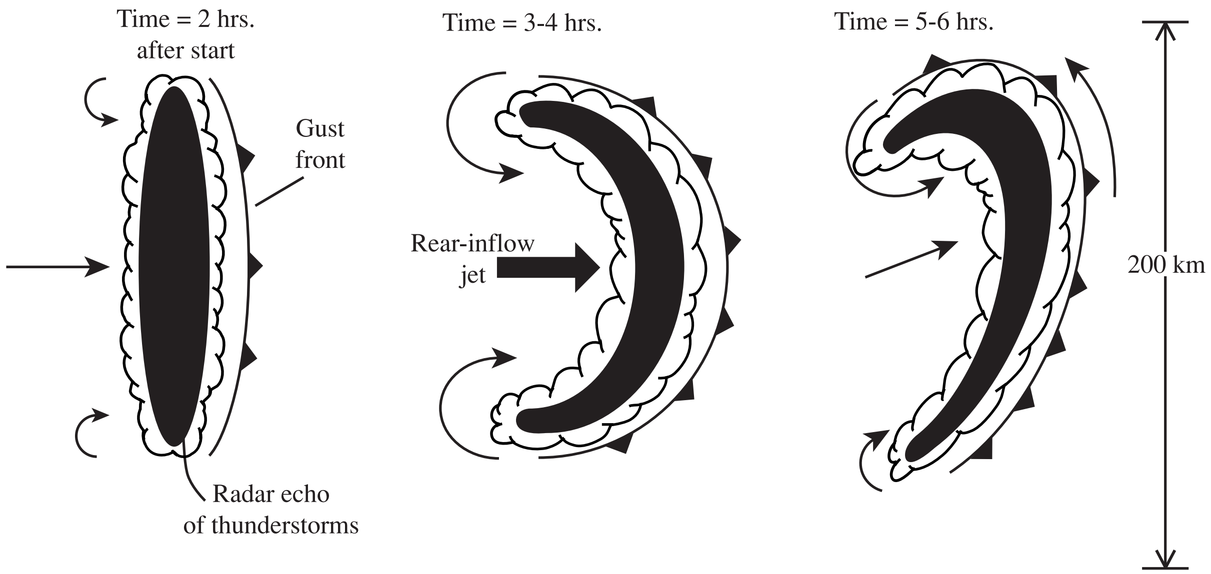


Figure 13.5. The evolution of a bow echo. On radar, a derecho appears as one or more bow echoes, crescent-shaped clusters of strong thunderstorms (radar echoes are shown as dark areas, while the hatched areas are clouds).

2. In the area of wind-damage reports and observations of high winds, some of the straight-line wind damage must be at least as bad as the damage inflicted by a weak tornado, or there must be several reports of winds in excess of 65 knots (120 km/hr or 75 mph).

Figure 13.6 shows a schematic radar signature of a derecho associated with a squall line out ahead of a strong mid-latitude low-pressure system during late winter or spring. Note the generic bow echoes in the schematic radar pattern east of the cold front. Such a connected series of bow echoes makes a wave-like appearance on radar and is sometimes called a **line echo wave pattern** or LEWP for short.

A second type of derecho can form over the northern-tier states east of the Rockies during late spring and summer. These warm-season derechos do not sprout from a classic squall line that traditionally precedes strong low-pressure systems in late winter and spring. Instead, they evolve from a mesoscale system of thunderstorms (see Chapter 8) that organizes into a relatively short, curved squall line. Color Plate 13.D shows the bowed pattern on radar, while Color Plate 13.E shows the Doppler-wind profile of the formidable windstorm. The warm-season derecho is, by far, much more common than its cool-season counterpart.

Mid-latitude low-pressure systems are also the catalysts for warm-season derechos. As a general rule, summertime lows are weak, so you might not suspect that large-scale windstorms were possible at this time of year. Such suspicions are off-base.

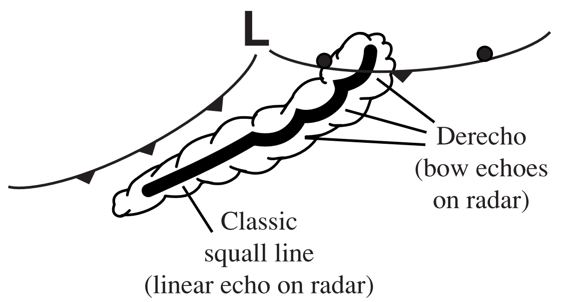


Figure 13.6. A schematic radar signature of a derecho associated with a squall line out ahead of a strong mid-latitude low-pressure system. Note the generic bow echoes in the schematic radar pattern east of the cold front (the radar signature of the bow echoes is darkened, while the hatched area signifies clouds).

Figure 13.7a shows the synoptic set-up conducive for warm-season derechos. Virtually all of these convective windstorms form along a stationary front that stretches generally from west to east. For most warm-season derechos, steering winds in the middle troposphere blow from the west or west-northwest—nearly parallel to such west-to-east oriented fronts. When a weak low-pressure system farther west draws warm, moist air northward over the stationary front, warm-air advection produces overrunning, sparking a system of thunderstorms on the cool side of the front. Meteorologists have noted that high dew-point air (higher than those generally found anywhere else in the warm sector) tends to “pool” along or near the portion of the stationary front where a warm-season derecho spends it life. Figure 13.7b shows the curved squall line (dashed lines) and the total area affected by the derecho over its lifetime (shaded area). As an interesting aside, warm-season derechos move at an average speed of 80 km/hr (50 mph)—faster than their cool-season counterparts.

To add insult to injury, derechoes can spawn tornadoes. In the last step of Figure 13.5, the bow echo associated with a derecho evolves into a comma shape as it weakens, and weak tornadoes can spin up in concert with the cyclonically rotating head.

From the original list of criteria for severe weather, only the topic of tornadoes remain for discussion. They may be last, but they are certainly not least in the arsenal of mid-latitude low-pressure systems.

Tornadoes: Last But Not Least

In order to pave the way for outbreaks of tornadoes, mid-latitude low-pressure systems move air masses around like pawns on a chess board. During spring and summer, intense mid-latitude lows employ aggressive gambits to draw contrasting air masses together, paving the way for tornadoes.

Mid-Latitude Lows: To Them, Air Masses Are Mere Pawns

You could say that mid-latitude low-pressure systems have a "dynamic" personality: air masses are irresistibly drawn to them. This isn't really surprising since lows develop along fronts, and fronts are boundaries between two contrasting air masses. East of the Rockies, the two air masses drawn to lows are maritime tropical (mT) and continental polar (cP).

Across the Great Plains, particularly from Texas to Nebraska, a third, important air mass is drawn toward dynamic low-pressure systems moving east from the Rockies. This third air mass is continental tropical (cT), a dry, warm air mass that is frequently summoned northeastward from the southern Rockies and the plateaus of Old Mexico (see Figure 13.8). It's often said that three's company, but in this case, the team of cT, cP and mT air masses in spring sets the stage for outbreaks of severe thunderstorms that spawn tornadoes. It is this volatile mix of three air masses and the resulting high frequency of tornadoes that accounts for the reputation of the southern and central Plains as "tornado alley."

We already know that the clash of cP and mT air masses along a front can lead to thunderstorms. So how does the presence of a cT air mass tip the scales toward thunderstorms that become severe and, in particular, tornadic?

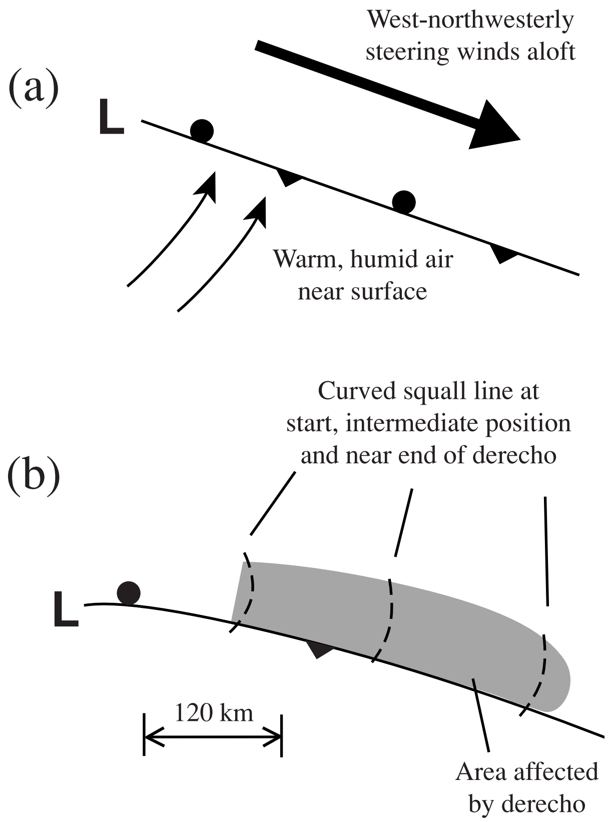


Figure 13.7. (a) The synoptic set-up conducive for warm-season derechos include a stationary front that stretches generally from west to east and upper-air winds that blow approximately parallel to the stationary front; (b) The curved squall line at several stages of its life (dashed lines) and the total area affected by the derecho over its lifetime (shaded area).

Keep in mind that the atmosphere tries very hard to run a tidy ship. At the first sign of growing instability, the atmosphere responds by generating thunderstorms, sending warm, moist air skyward and bringing rain-cooled air to the surface. In so doing, the atmosphere mitigates the vertical temperature contrasts that created the instability in the first place. More often than not, these thunderstorms tend to be relatively small and short-lived—too puny and too brief to spawn tornadoes.

Enter cT air. Since it arrives from the plateaus of Mexico, its presence is primarily felt aloft, at an altitude of about 2 km (1.5 mi). Figure 13.9 shows the temperature and dew point sounding over central Oklahoma in the early afternoon of May 3, 1999, just before the tornado outbreak that began in the late afternoon. We can detect the presence of cT air in the layer near 800 mb, where temperature increases with increasing height (a temperature inversion). Also note the widening difference between the temperature sounding and the dew point sounding near 800 mb, indicating that the relative humidity drops abruptly (cT air is not only warm but also dry).

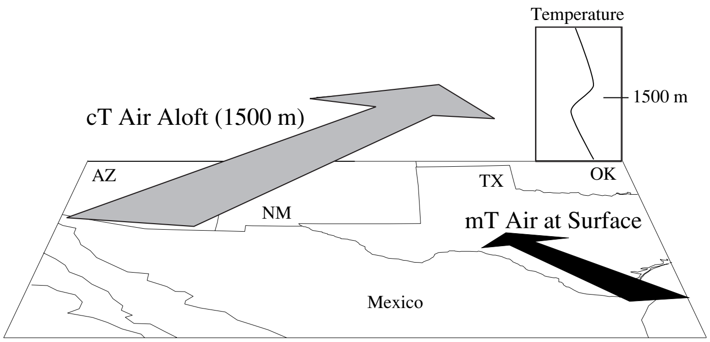


Figure 13.8. Warm, dry cT air moving northeastward from the southern Rockies and the plateaus of northern Mexico helps set the stage for tornadic thunderstorms by forming a lid on low-level heat and humidity. If the lid is eventually breached, supercell thunderstorms can erupt.

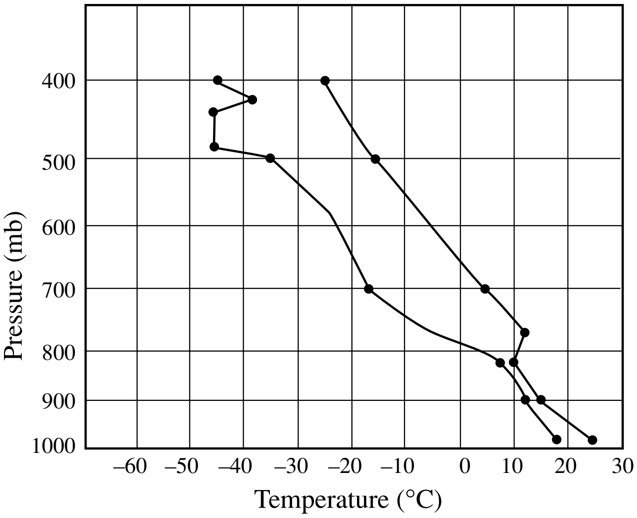


Figure 13.9. The temperature and dew-point sounding over central Oklahoma in the early afternoon of May 3, 1999, just before the outbreak of deadly tornadoes that began in the late afternoon. The dew point lowers dramatically above around 800 mb, indicating relatively dry air aloft.

At the time of the sounding, imagine a parcel of air rising from the surface and cooling. As it reached the temperature inversion near 800 mb, the parcel found itself colder than the relatively warm environment and it sank back toward the ground. In essence, the temperature inversion near 800 mb acted like a lid, preventing parcels of rising air from continuing their ascent.

In such situations, the lid becomes crucial to the development of severe thunderstorms later in the day. With a lid in place, a powder keg of heat and humidity can build in the lower troposphere on a day with ample sunshine. As the day wears on, the lid slowly erodes as rising cooling parcels of air gradually penetrate the lid and mix with the warm air in the inversion. Furthermore, suppose that during the late afternoon, a mid-latitude low-pressure system arrives from the west, armed with a cold front and an accompanying upper-level trough that promotes rising air through divergence aloft.

Eventually, the lid can no longer suppress the powder keg of heat and humidity beneath it. In explosive fashion, hot, humid air is lifted violently and can abruptly break through the now-vulnerable lid. Once the two-kilometer barrier is breached, the warm, dry air associated with the lid becomes fair game for an approaching cold front, low-pressure system or upper-level trough to lift (these synoptic systems are non-discriminating: they lift surface air and they can lift air aloft). On ascent, the lid's dry, warm air cools dry adiabatically for much of its skyward journey. Farther below, humid air cools moist adiabatically (once net condensation begins) as it accelerates upward (see Figure 13.10). With dry air on top cooling faster (5.5°F/1000 ft) than moist air below (approximately 3.3°F/1000 ft), instability is greatly enhanced through a deep layer of the atmosphere, further promoting explosive development of giant cumulonimbus clouds. Meteorologists describe such a pre-existing stack of dry air above humid air as **potential instability** because the atmosphere has the potential to become unstable if sufficient lifting occurs.

Now the stage is set for the explosive development of solitary monster thunderstorms called **supercells**. Figure 13.11 shows the detonation of supercells over central Oklahoma on May 3, 1999. Note the long shadow cast by the overshooting top of the severe thunderstorm that spawned the F5 tornado near Oklahoma City. An overshooting top marks the core of the storm's speedy updraft, which has ample momentum to "overshoot" the tropopause into the stable stratosphere. Another view of an overshooting top is found in Color Plate 7.H.

So, the recipe for supercell thunderstorms that spawn tornadoes typically requires an additional ingredient to the three-step recipe for severe weather listed near the beginning of the chapter:

4. A layer of warm, dry air near altitudes of 2 km (about 6500 feet)

The role of this cT air is clear—the lid it creates prevents a lot of little thunderstorms from forming and thus raises the odds for the explosive development of tornadic supercells.

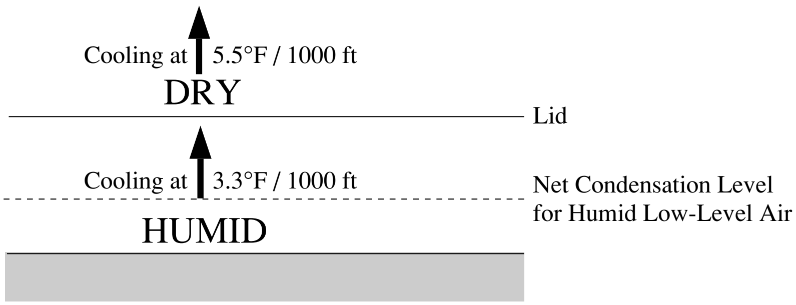


Figure 13.10. As a strong low-pressure system approaches tornado alley, it lifts a deep layer of air. At the bottom of the layer, warm, humid air from the Gulf of Mexico starts to cool moist adiabatically once net condensation begins during ascent. Aloft, warm dry air from the Mexican plateaus cools dry adiabatically on ascent. Because the top of the layer cools faster than the bottom, instability is enhanced, allowing clouds to rapidly tower up toward the tropopause.

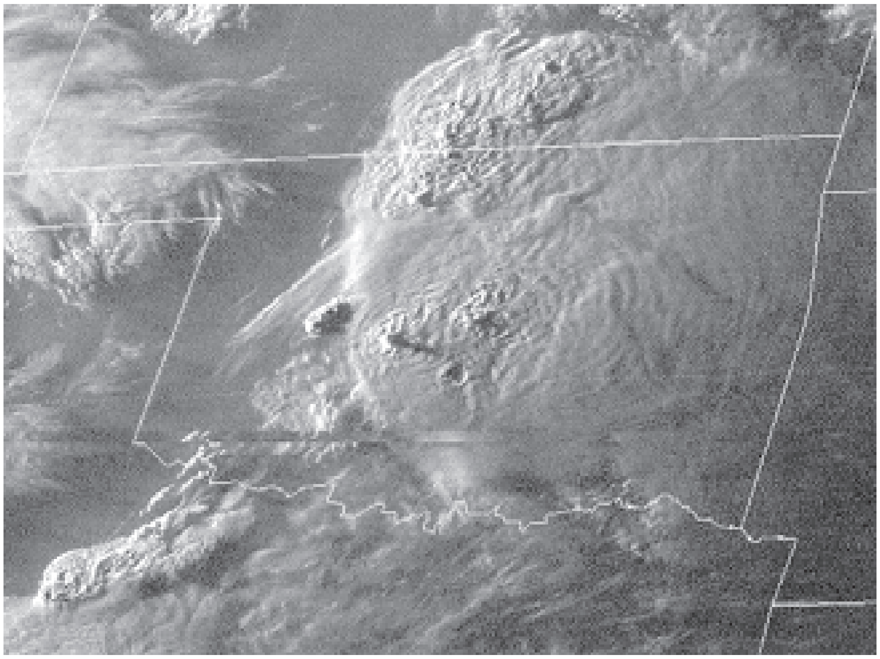


Figure 13.11. Visible satellite image of supercell thunderstorms over central Oklahoma on May 3, 1999 (courtesy NASA Goddard Space Flight Center).

Forecasting Tornadoes: Triangulating Targets Around Mid-Latitude Lows

Assuming the lid is not too weak (which would allow weaker thunderstorms to form earlier in the day) and not too strong (which would resist all attempts by updrafts to breach it), there is a fairly reliable method for pinpointing the area where tornado-producing supercells are most likely to develop. This triangular-like region between the cold front, warm front and first or second isobar drawn around the surface low pressure system (see Figure 13.12) is unofficially called Larko's Triangle, after the meteorologist who developed this forecasting tool. This area constitutes the target where the atmosphere brings its biggest guns to bear.

Within Larko's Triangle, strong surface convergence around the low-pressure system and its cold front work in tandem with hefty upper-level divergence associated with the approach of the trough in the jet stream. Assuming a rich supply of low-level warm, moist air from the Gulf of Mexico topped by a steady stream of warm, dry air off the Rockies or the plateaus of Old Mexico, supercells will likely erupt, heightening the risk of tornadoes.

Final Perspective On Severe Thunderstorms: The Media and Chicken Little

During outbreaks of severe weather, the media sometimes adopts a Chicken Little strategy by claiming that "The sky is falling." When severe weather is possible, there is no doubt that you should be prepared to take action and protect yourself. However, in many cases of severe weather (not all cases, of course), only a relatively few people directly experience any of the three criteria for severe weather listed at the beginning of this chapter. The media's hype is sometimes overblown.

To understand the basis for this claim, suppose that two F5 tornadoes with relatively long damage paths and several weaker twisters develop within a given watch area.

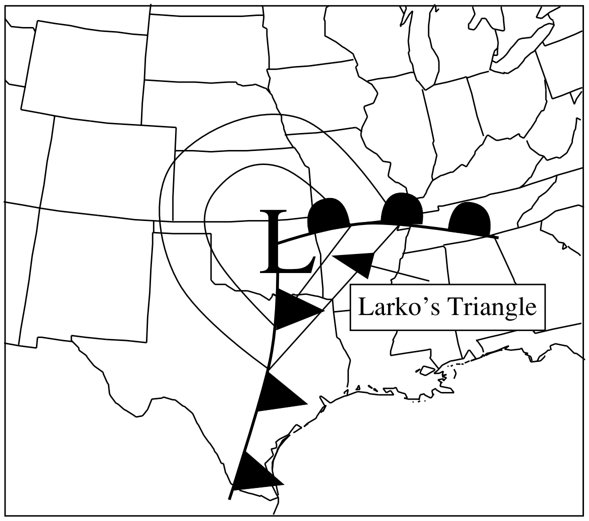


Figure 13.12. When all the ingredients come together, Larko's Triangle, defined as the triangular area bounded by the cold front, warm front, and first isobar around the low, can be used as a first estimate for the place where tornadoes will develop. If the area inside the first isobar is small, the region can be expanded to include the second or third isobar.

Further suppose that there are also streaks of hail damage as well as streaks of damage associated with microbursts. Though this would be considered a very active day for severe weather, the region directly affected would typically amount to only a fraction of one percent of the original watch area. There are exceptions, of course, but the idea that severe weather only strikes a tiny fraction of a watch area is generally valid. Yes, you should be prepared to take quick action when severe thunderstorm and tornado warnings are issued. But during any given outbreak of severe weather, most people will not directly experience severe weather.

The one big exception is a derecho. If such a large windstorm develops, then upwards of 20 percent of the original watch box can be affected by severe weather (mostly high winds). In this case and cases like the massive outbreaks of tornadoes in central Oklahoma on May 3, 1999, the media's intense coverage serves a very useful purpose and helps to save lives.

Name ______________________________ Date ______________

QUESTIONS FOR LABORATORY

1. In Figures 13.13(a-c) you are given temperature and dew-point profiles of the lower troposphere taken during the mid-afternoon at three different locations. Based on only this information, rank these profiles from most likely to support the formation of a tornadic thunderstorm to least likely to support the formation of a tornadic thunderstorm. Explain your reasoning.

2. Assume that on a particular day the temperature decreases from 25°C at the surface to 15°C at 2 km elevation. Further assume that the air at 2 km is very dry, so if lifted it will cool at the dry adiabatic lapse rate. Surface air, in contrast, is so moisture-laden that it will cool at the moist adiabat lapse rate if lifted.

   (a) Lift a parcel of air at the surface to 2 km altitude to determine whether the layer of air between the ground and 2 km is stable or unstable.

   (b) Now assume that upper-level divergence ahead of an approaching trough lifts the entire layer of air between the ground and 2 km so that this layer of air now resides between 1 km and 3 km above the ground. To gauge the stability of this newly-lifted air, take a sample parcel of air that's now at 1 km and lift it to 3 km (that is, lift it 2 km). Is the layer now stable or unstable? Explain your results.

3. On the evening of April 26, 1991, an F5 tornado struck Andover, KS, just northeast of Wichita. This powerful tornado was part of a 55-tornado outbreak across six states stretching from northeastern Texas into Iowa. In Figure 13.14 you are given weather data at 00Z on April 27, 1991. Figure 13.14a shows 500-mb heights (in tens of meters), Figure 13.14b shows surface winds speeds (in knots), and Figure 13.14c shows 850-mb wind speeds (in knots). Figure 13.14d shows the temperature and dew point (both in °C) through the lower troposphere at Topeka, a nearby station in northeastern Kansas.

   (a) Isopleth the 500-mb height in Figure 13.14a at intervals of 60 m (draw the 5700-m contour and all contours at intervals of 60 m from 5700 m). Remember that "570" represents 5700 m. Indicate any troughs with a heavy dashed line. What characteristics of the 500-mb pattern favor severe thunderstorms in Kansas around this time?

(b) The change of wind speed with height, or speed vertical wind shear, helps create an environment in which tornadic supercells can develop (more on this in Chapter 14). On Figure 13.14c, draw the 50-knot isotach. Shade in the areas where the wind speed is greater than 50 knots, thereby isolating the fastest winds at this level. For each upper-air station, compute the difference in wind speed between the 850-mb level and the surface. In which state is the speed vertical wind shear the largest?

(c) What characteristics of the temperature and moisture profile of the lower troposphere favored tornado formation in eastern Kansas around this time?

4. On March 12, 1976, President Gerald Ford was visiting a large Midwestern city when his motorcade was nearly struck by a tornado, one of 20 twisters that touched down over the Middle West that day. Imagine that you were a meteorologist at the National Severe Storm Forecast Center (now called the Storm Prediction Center) coming on duty at 18Z on March 12, 1976. The purpose of this question is to see if you would have been able to forecast the possibility of tornadoes.

(a) Listed on the next page are the surface observations of temperature (in °F), dew point (in °F), sea-level pressure (in mb), wind speed (in knots), wind direction, and cloud cover, taken at 18Z on March 12, 1976, at weather stations across the Middle West. For each station, draw a station model on the surface map provided in Figure 13.15 (the cloud circle portion of the station model has been drawn for you). Be sure to enter each data item in its proper place in the station model.

(b) Analyze the pressure field by drawing isobars at intervals of 4 mb (draw the 1000-mb isobar and all others at 4-mb intervals). Draw an "L" to represent the center of an area of low pressure that affected the Middle West that day.

(c) Using the temperature and wind fields to help you, draw the warm front and cold front accompanying this low.

(d) Based on the method of Larko's Triangle, and assuming that you want to alert the widest region without needlessly alarming too many people, shade in the area that would be under a risk of tornadoes. Explain your answer.

(e) Which large Midwestern city, site of the tallest building in the United States, was President Ford visiting when the tornado struck?

Code	City	*Temperature (°F)*	*Dew Point (°F)*	*Pressure (mb)*	*Wind Direction and Speed (knots)*	*Cloud Cover*
RWF	Redwood Falls, MN	25	23	1008.6	NW 20	Overcast
MSP	Minneapolis, MN	30	24	1001.4	N 25	Overcast
RST	Rochester, MN	34	31	995.2	N 10	Overcast
DLH	Duluth, MN	20	16	1010.9	N 15	Obscured
SPW	Spencer, IA	28	19	1006.0	NW 25	Overcast
SUX	Sioux City, IA	23	21	1011.2	NW 20	Overcast
MCW	Mason City, IA	35	31	996.0	W 30	Obscured
DSM	Des Moines, IA	34	28	999.9	W 30	Overcast
DBQ	Dubuque, IA	51	46	993.1	SW 10	Overcast
BRL	Burlington, IA	39	35	999.0	SW 20	Overcast
MKC	Kansas City, MO	28	20	1011.0	W 20	Overcast
IRK	Kirksville, MO	32	29	1004.7	W 20	Overcast
CBI	Columbia, MO	40	31	1007.2	SW 25	Overcast
VIH	Rolla, MO	54	40	1006.9	W 20	Scattered
STL	St. Louis, MO	66	44	1002.2	W 20	Scattered
MVN	Mount Vernon, IL	67	58	1002.9	S 25	Scattered
DEC	Decatur, IL	65	53	998.6	S 20	Scattered
PIA	Peoria, IL	56	46	997.4	SW 30	Broken
MLI	Moline, IL	45	42	994.9	SW 20	Overcast
RFD	Rockford, IL	56	52	995.0	SE 20	Overcast
MDW	Chicago, IL	58	50	997.0	S 20	Overcast
SBN	South Bend, IN	59	50	999.0	S 20	Broken
LAF	Lafayette, IN	65	53	1001.3	S 20	Broken
FWA	Fort Wayne, IN	58	42	1003.1	S 20	Overcast
HUF	Terre Haute, IN	59	52	1004.4	SE 20	Overcast
EVV	Evansville, IN	59	55	1007.6	SE 20	Broken
LOU	Louisville, KY	60	49	1010.0	S 20	Overcast
DAY	Dayton, OH	56	49	1007.5	S 20	Overcast
CMH	Columbus, OH	55	42	1009.9	S 25	Overcast
TOL	Toledo, OH	53	47	1004.7	SE 15	Overcast
CLE	Cleveland, OH	47	43	1009.0	SE 10	Overcast
ERI	Erie, PA	42	32	1013.4	SE 20	Overcast
FNT	Flint, MI	37	32	1005.7	E 15	Overcast
MKG	Muskegon, MI	45	44	998.5	SE 10	Overcast
HTL	Houghton Lake, MI	33	32	1002.8	E 15	Overcast
APN	Alpena, MI	31	30	1004.7	SE 15	Overcast
PLN	Pellston, MI	29	29	1002.5	E 20	Obscured
MQT	Marquette, MI	24	24	1002.6	NE 20	Obscured
ESC	Escanaba, MI	32	30	1000.0	E 10	Obscured
CMX	Houghton, MI	24	24	1006.0	NE 20	Overcast
IWD	Ironwood, MI	27	22	1003.4	N 15	Obscured
EAU	Eau Claire, WI	35	27	998.9	NW 20	Obscured
AUW	Wausau, WI	33	32	995.9	NE 10	Overcast
GRB	Green Bay, WI	38	36	995.6	NE 5	Obscured
MSN	Madison, WI	52	51	992.1	SE 10	Overcast
MKE	Milwaukee, WI	49	48	994.8	S 15	Overcast
VOK	Camp Douglas, WI	47	46	991.7	N 10	Overcast
YZE	Gore Bay, Ontario	25	21	1008.9	SE 20	Obscured
YVV	Wiarton, Ontario	30	25	1009.9	E 15	Overcast
YXU	London, Ontario	34	30	1007.6	SE 10	Overcast

5. As detailed in the chapter, an historic tornado outbreak occurred on May 3–4, 1999 from northern Texas through Oklahoma into Kansas. Prior to and during this outbreak, the Storm Prediction Center issued several tornado watch boxes. Two of these tornado watch boxes are shown in Figure 13.16. Watch box #195 was issued at 445 p.m. CDT on May 3, and was to be in effect until 1000 p.m. CDT. Watch box #198 was issued at 715 p.m. and replaced watch box #195. The total area covered by these two watch boxes is approximately 40,000 mi^2.

   Below is a list of all the tornadoes that formed in Oklahoma in these watch boxes (59 tornadoes in all). The path width (in yards), path length (in miles), and F-scale rating of each tornado are given (peek ahead to Table 14.1 for more on the F-scale, or Fujita scale, which is used to rank tornadoes based on the severity of damage they inflict). For referencing, each tornado was given a "Storm ID" by the National Weather Service, and that "Storm ID" is used here.

Storm ID	*F-Scale*	*Path Length (miles)*	*Path Width (yards)*
A1	F0	0.5	25
A2	F0	0.1	25
A3	F3	6.0	100
A4	F0	0.1	25
A5	F0	0.1	25
A6	F3	9.0	880
A7	F0	1.0	75
A8	F2	4.0	500
A9	F5	37.0	1760
A10	F0	0.2	20
A11	F0	0.5	60
A12	F2	7.0	220
A13	F0	2.0	50
A14	F1	4.0	50
B1	F0	0.1	25
B2	F0	2.0	25
B3	F1	7.0	150
B4	F0	0.1	25
B5	F0	1.0	25
B6	F0	0.1	25
B7	F0	0.5	25
B8	F1	2.0	300
B9	F1	5.0	50
B10	F1	4.0	60
B11	F1	0.1	50
B12	F0	0.1	25
B13	F0	1.0	100
B14	F0	1.0	75
B15	F0	0.1	25
B16	F1	6.0	150
B17	F2	8.0	200
B18	F1	10.0	150
B19	F1	1.0	100
B20	F4	20.0	1760
B21	F2	15.0	880
C1	F0	4.0	100
C2	F0	0.1	25
D1	F1	9.0	30
D2	F2	7.0	250
D3	F1	11.0	100

Storm ID	*F-Scale*	*Path Length (miles)*	*Path Width (yards)*
D4	F3	16.0	750
E1	F0	0.1	25
E2	F1	9.0	150
E3	F3	12.0	450
E4	F0	0.5	50
E5	F0	0.1	25
E6	F4	15.0	880
E7	F1	4.0	440
G1	F0	1.0	50
G2	F3	22.0	350
G3	F0	4.0	150
G4	F0	0.5	50
G5	F3	13.0	880
G6	F2	2.0	440
H1	F0	0.8	50
H2	F0	0.2	30
H3	F2	1.0	150
H4	F2	8.0	440
I1	F1	1.0	200

(a) For each tornado in the list, compute the area (in mi^2) affected by the tornado by multiplying the tornado's path length by its path width (be sure to convert the path width from yards into miles). Then sum all the areas to come up with the total area affected by the tornadoes.

(b) Compute the fraction of the total area of the watch boxes that was affected by tornadoes that day. Note that this fraction is likely an overestimate because the path widths given above are, in many cases, the maximum width of the tornado. Even though this was one of the worst tornado outbreaks in recent years, what were the chances that a randomly chosen location within the watch boxes was affected by a tornado on this day?

(c) Typically, a tornado's intensity fluctuates during its lifetime. By convention, the F-scale classification of a tornado is assigned according to the greatest damage at any point along its path. Thus, for example, only a small percentage of the damage along the path of an F4 will be characteristic of an F4—most of the damage will be F3, F2, F1 and F0 damage.

Given that only a small percentage of the path of a tornado of a particular F-scale will actually show damage characteristic of that F-scale, Dr. Fujita and his colleagues developed formulas that estimate, for example, what percentage of the path of an F5 tornado would show damage characteristic of an F5, an F4, an F3, an F2, an F1, and an F0. As a basis for their formulas, they surveyed and mapped the twisters that occurred during one of the most violent tornado outbreaks ever recorded, the "Superoutbreak" of April 3-4, 1974. During a 24-hour period, 147 tornadoes struck parts of 13 states. The combined path length of these tornadoes was 4181 km (6731 mi). Six of the tornadoes were F5, 24 were F4, and 35 were F3.

The values in the table below are Dr. Fujita's estimates of the fraction of the area affected by a tornado of a particular F-scale (given on the top) that shows damage characteristic of that F-scale and lower F-scales (given on the side). For example, using the column labeled F4, we find that only 0.006, or 0.6%, of the area affected by an F4 actually sustains F4 damage, while 2.8% sustains at least F3 damage (that is, F3 or F4 damage), 10.5% at least F2 (that is, F2 or F3 or F4 damage), and 31.1% at least F1 damage (that is, F1 or F2 or F3 or F4 damage).

Using these estimates applied to the 59 tornadoes listed above, compute the area (in mi^2) that sustained F5 damage, at least F4 damage, at least F3 damage, and at least F2 damage. Then compute the percentage of the area covered by the watch boxes that was affected by damage of these various F-scales. What were the chances that a randomly chosen location within the watch boxes experienced F5 damage on this day? At least F4 damage? At least F3 damage? At least F2 damage?

		F-SCALE OF TORNADO					
		5	*4*	*3*	*2*	*1*	*0*
F-SCALE OF DAMAGE	0	1	1	1	1	1	1
	1	.322	.311	.287	.216	.129	0
	2	.117	.105	.087	.050	0	0
	3	.037	.028	.019	0	0	0
	4	.009	.006	0	0	0	0
	5	.002	0	0	0	0	0

6. Figure 13.17 is a visible satellite image taken at 23Z on May 31, 1985. At this time, the greatest outbreak of tornadoes in the recorded history of Pennsylvania was in progress.

(a) Mark the squall line in this image with a solid line. Mark three or four individual supercell thunderstorms along the squall line with an "X."

For parts (b-d), refer to Figure 13.18 which shows another squall line at two different times in the process of development.

(b) On both images, identify the squall line with a solid line, and mark several individual supercell thunderstorms along each squall line with an "X."

(c) Was this a favorable time of day for a squall line to develop? Justify your answer. Does it appear that the area where the squall line formed received an ample amount of sunshine that day before the line developed?

(d) Recall that squall lines form ahead of a cold front in the warm sector. Look carefully to the west of the squall line in both images, and identify the thin line of clouds that marks the actual cold front.

7. Large hail is a trademark of severe thunderstorms. The Storm Prediction Center maintains an archive of data on the occurrences of large hail at www.spc.noaa.gov/archive/hail. The data for hail of at least 3/4" diameter for the period 1986–1995 has been decoded and is available at www.ems.psu.edu/~nese/hail.htm. Use this decoded data to answer the following:

   (a) Count the number of occurrences of hail of diameter two inches or larger in each state and enter your data in Figure 13.19a. What are the top ten states for two-inch-diameter or larger hail?

   (b) Because states vary in size, a more accurate measure of hail occurrence would require dividing by the area of the state (look ahead to Figure 14.20b to find these areas). Compute the number of occurrences of large hail per 10,000 km^2, and enter your answers in Figure 13.19b (round to one decimal place). What are the top ten states now?

   (c) For each of the top ten states in part (b), determine the time of day when two-inch-diameter or larger hail is most common. To do this, divide the day into four equal parts: midnight-6 a.m. (nighttime), 6 a.m.-noon (morning), noon-6 p.m. (afternoon), and 6 p.m.-midnight (evening), and compute the fraction of total events for each state that occur during these periods.

   (d) You should find a few states that have an unusually high percentage of large hail during either the nighttime or morning periods. Which state has more than 25 percent occurring between midnight and noon? Another bordering state has nearly 20 percent occurring between midnight and noon. Which state? This tendency for a relatively large fraction of large hail in the nighttime and early morning hours suggests that this part of the country gets frequent visits from what type of nocturnal weather system (recall Chapter 8)?

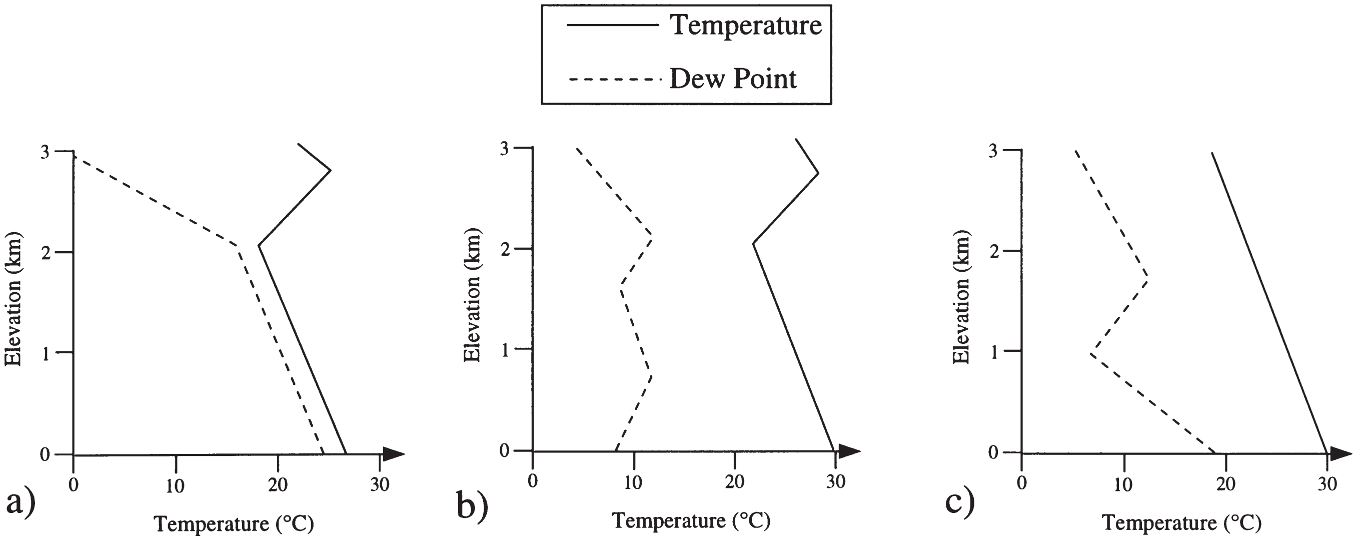


Figure 13.13. Laboratory Exercise 1. Three temperature and dew-point profiles of the lower troposphere.

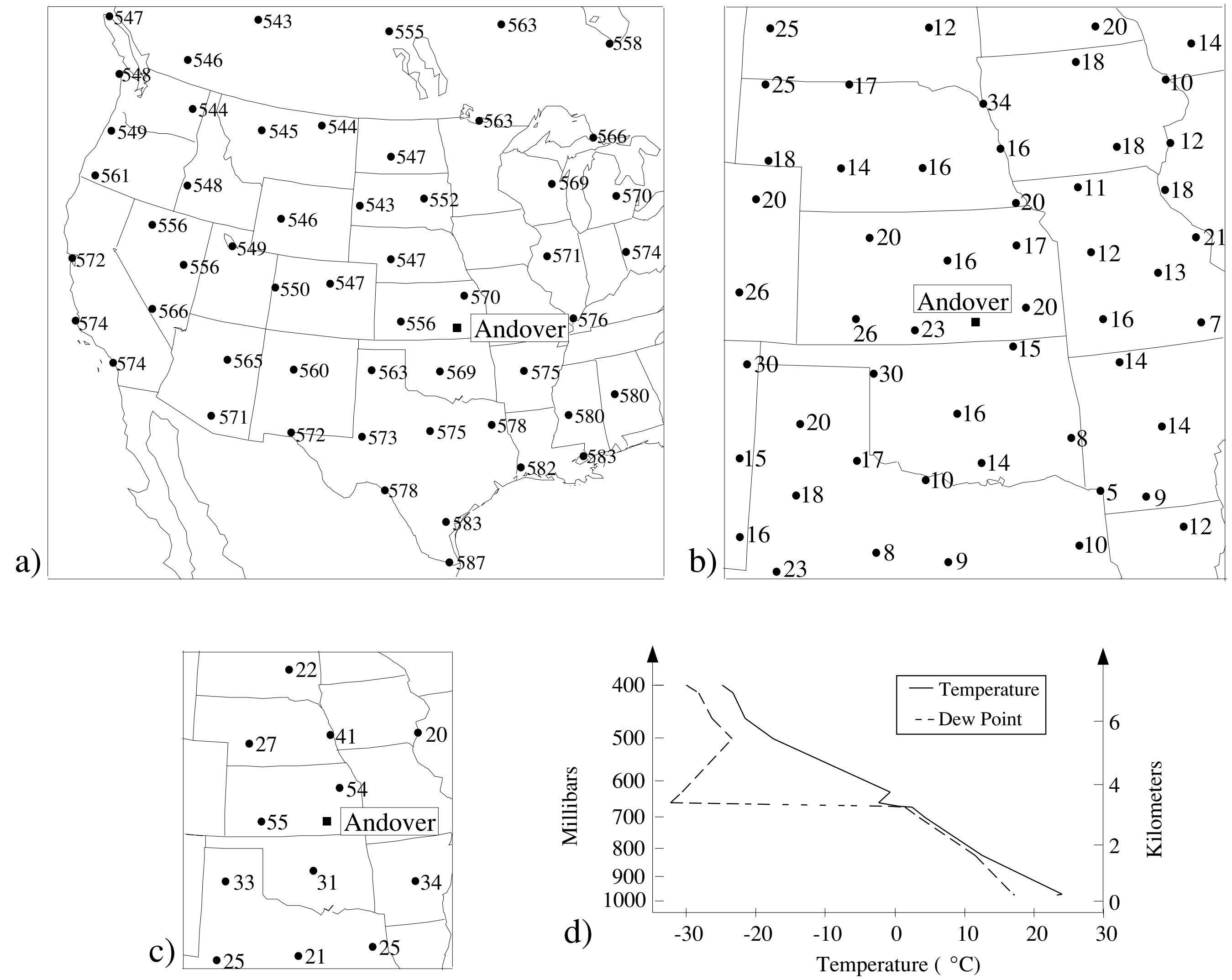


Figure 13.14. Laboratory Exercise 3. Weather data for 00Z on April 27, 1991: (a) 500-mb heights (in tens of meters); (b) Surface wind speeds (in knots); (c) 850-mb wind speeds (in knots); (d) Temperature and dew point (in °C) with altitude.

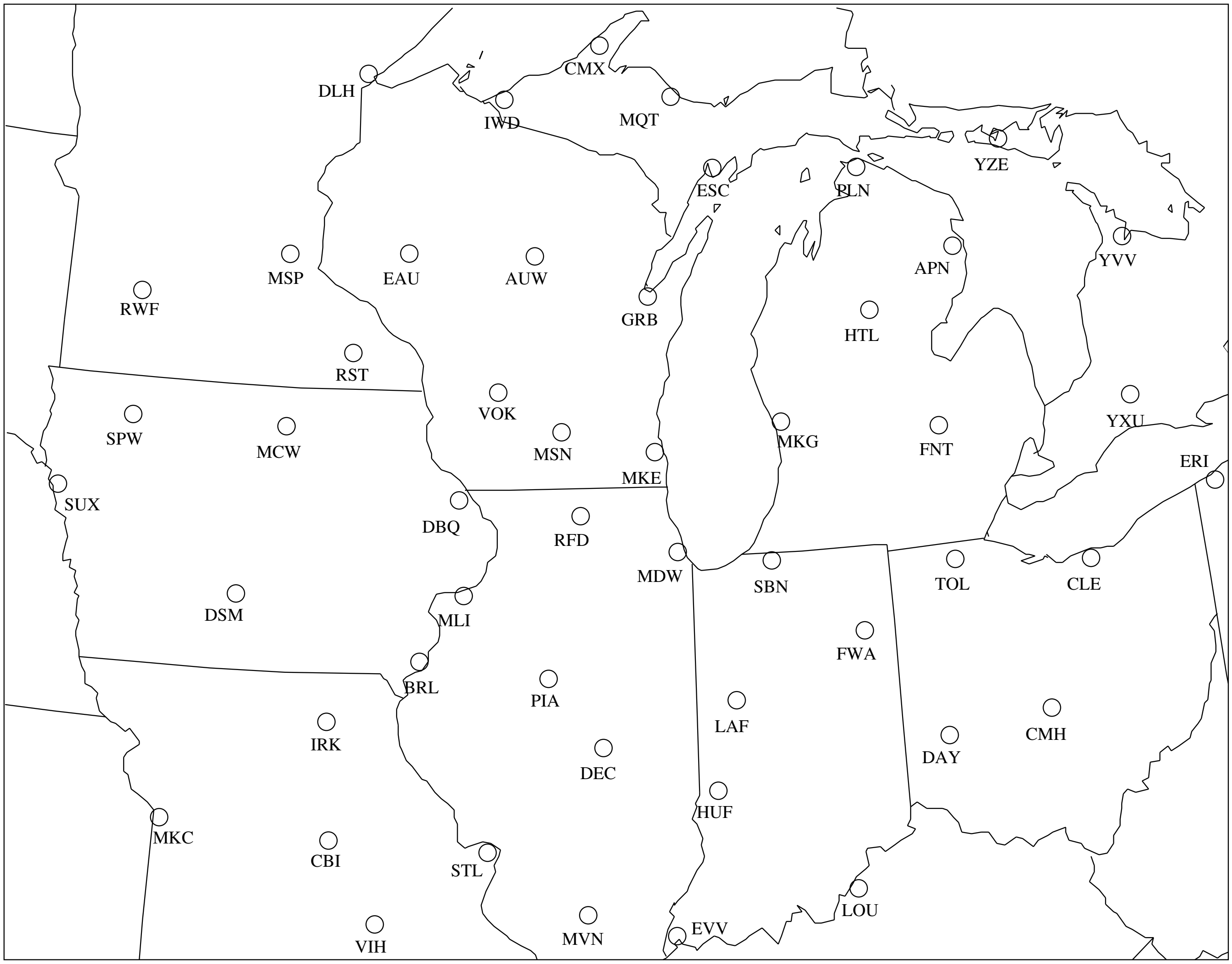


Figure 13.15. Laboratory Exercise 4.

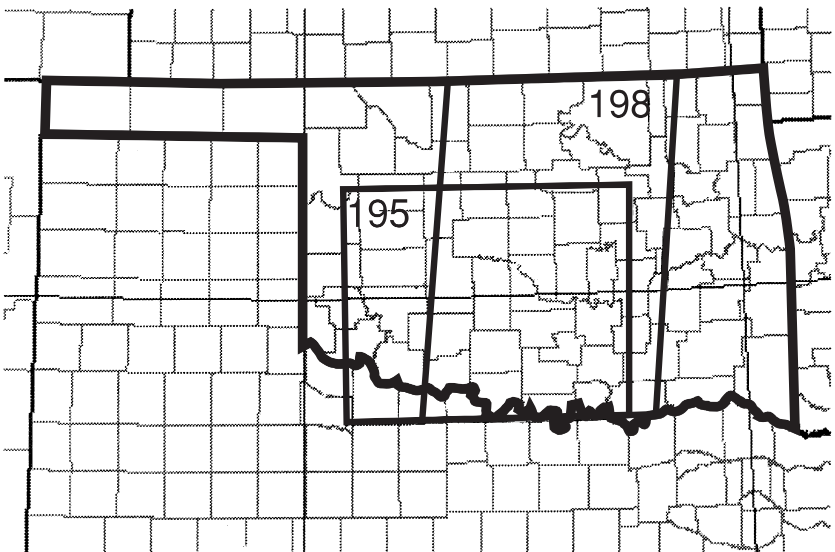


Figure 13.16. Laboratory Exercise 5. Two of the tornado watch boxes issued prior to and during the tornado outbreak on May 3, 1999. Watch box 195 was issued at 445 p.m. CDT on May 3, and was to be in effect until 1000 p.m. CDT. Watch box 198 was issued at 715 p.m. and replaced watch box #195.

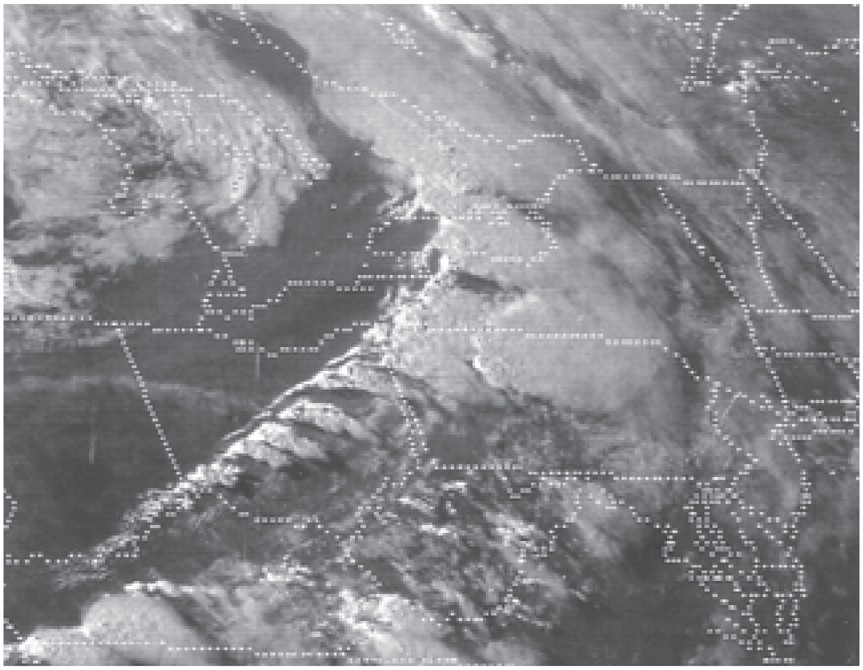


Figure 13.17. Laboratory Exercise 6. A visible satellite image taken during the early evening of May 31, 1985, showing an army of severe thunderstorms that spawned deadly tornadoes in parts of Pennsylvania, Ohio, southwestern New York, and Ontario, Canada (courtesy of NOAA).

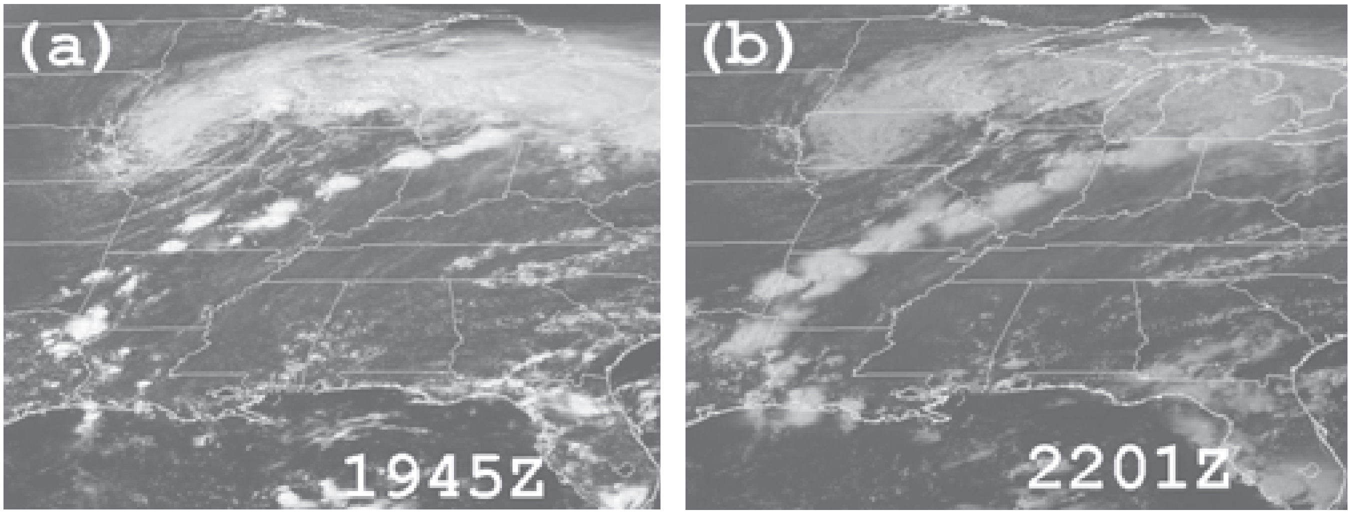


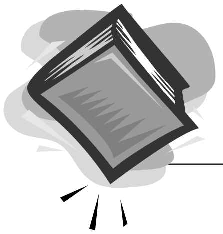
Figure 13.18. Laboratory Exercise 6. The development of a squall line captured on visible satellite imagery (courtesy of NOAA).

a)

b)


Figure 13.19. Laboratory Exercise 7.

Name ____________________ Date ____________



QUESTIONS FOR REVIEW

1. What are three ingredients necessary for an outbreak of severe thunderstorms?

2. What's the difference between a severe thunderstorm or tornado watch and a severe thunderstorm or tornado warning?

3. What is vertical wind shear? What role does it play in allowing a thunderstorm to attain the necessary power to produce severe weather?

4. What is a squall line? What synoptic conditions lead to the formation of a squall line?

5. What is a derecho? What does one typically look like on radar?

6. The Plains states are a favored location for synoptically forced thunderstorm development, while Florida is favored for air-mass thunderstorm development. What differences in geography lead to this separation?

7. How does a lid increase the potential for severe weather?

8. What is potential instability?

9. What is Larko's Triangle, and why is it important to severe weather forecasters?