A KANSAS CITY AREA GUIDE TO

SEVERE THUNDERSTORMS AND TORNADOES

Charles A. Doswell III   Frederick P. Ostby

NATIONAL SEVERE STORMS FORECAST CENTER

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by

Charles A. Doswell III and Frederick P. Ostby

This guide is designed to provide information about the causes and nature of severe thunderstorms and tornadoes. It also contains some severe weather safety rules and a glossary of severe weather terms. The examples used in it are taken from weather events which are likely to be familiar to Kansas City area residents.

Dr. Charles A. Doswell III is a research meteorologist with the Techniques Development Unit of the National Severe Storms Forecast Center.

Frederick P. Ostby is the Director of the National Severe Storms Forecast Center.

Cover Photo: *The tornado of 20 May 1957, which eventually struck Ruskin Heights, Missouri, as it passed near Ottawa, Kansas.*

SEVERE THUNDERSTORMS AND TORNADOES

What causes tornadoes and other severe weather? The answer to that question involves two separate but related studies. First, meteorologists seek to understand the large scale weather patterns that produce intense thunderstorms. Secondly, the thunderstorm itself is examined to learn the small scale processes that lead to formation of the severe weather.

LARGE SCALE WEATHER PATTERNS

Severe weather forecasters look for several key features on the weather maps when formulating a Tornado Watch. Warm, moist air at low levels is one of the prime ingredients looked for when tornado forecasting. To the public it is sultry or muggy air -- usually drawn inland from over the Gulf of Mexico toward an approaching low pressure area. Above this, the presence of a warm, dry layer of air in the low to middle levels of the atmosphere (say up to 10,000 feet) is another prime ingredient and often serves to distinguish severe thunderstorms from the more common non-severe thunderstorms. At upper levels the air is usually cold and dry.

Also, forecasters look for areas of low pressure in the middle and upper levels of the atmosphere, generally moving from west to east. These upper level systems (called "troughs") usually cause rising air motion ahead of them. A jet stream (a narrow, high level band of winds with speeds up to 200 mph) is also found associated with these upper level disturbances.

Finally, solar heating often intensifies the thunderstorm process; hence, the late afternoon and early evening peak for tornado occurrences. As the surface of the earth heats, moist air in the lower layers is warmed and rises. The warmer the air, the faster it rises, as in a hot air balloon. This rising moist air produces all types of cumulus clouds, including cumulonimbus (thunderstorm) clouds. Additional heat is released as the water vapor in the rising air condenses to form visible clouds. If all ingredients are present in the correct proportions, this released heat can lead to the formation of severe thunderstorms and tornadoes.

Severe thunderstorms do not occur randomly in the moist air, but normally form along lines of converging winds or other boundaries such as cold or warm fronts. Often, intense squall lines form well ahead of advancing surface fronts.

Tornadoes are known in many parts of the world but nowhere are they as common as in the central and southern United States. The geography of the central plains, with the Gulf of Mexico to the south and the Rocky Mountain and high plateaus to the west make this region the tornado capital of the world. Only here are the ingredients for tornadoes brought together so frequently. Also, the very strong tornadoes which occasionally strike in this country are virtually unheard of elsewhere.

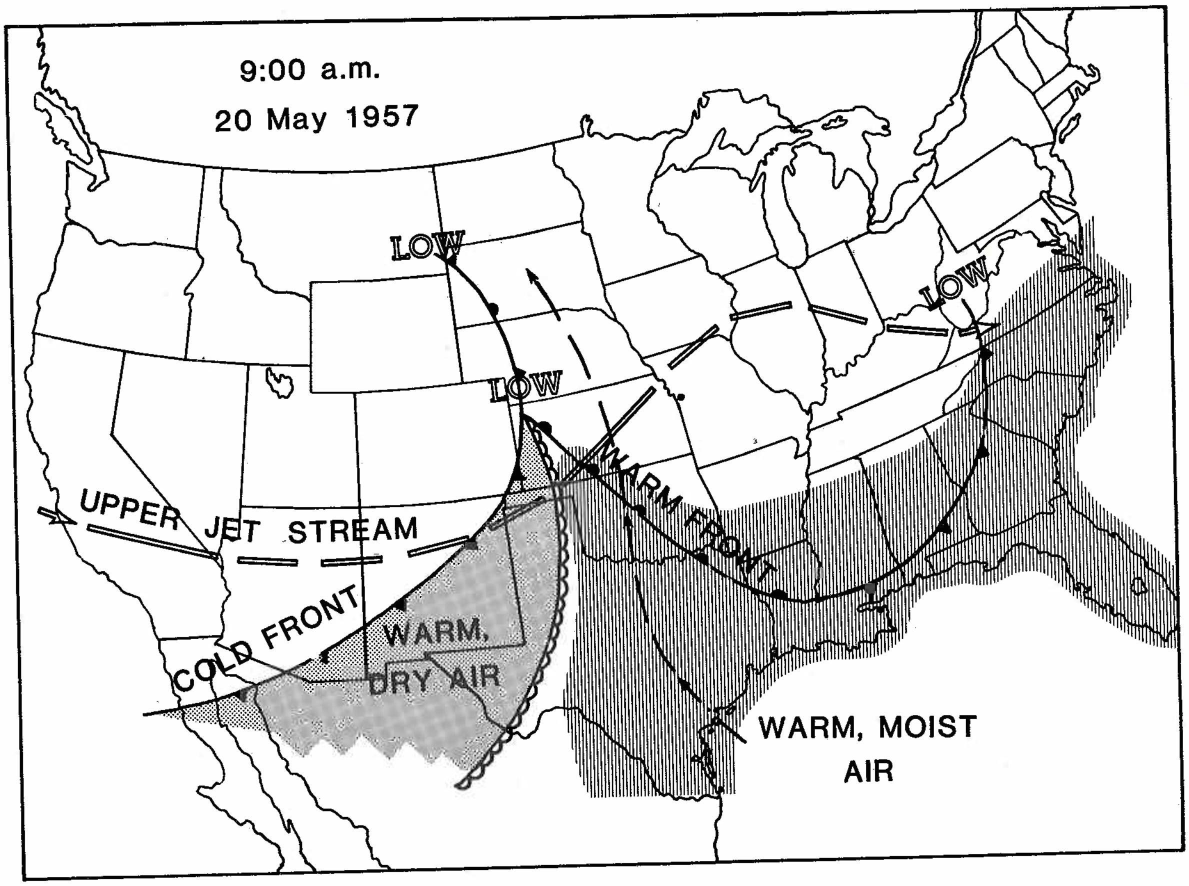


Fig. 1. Weather map showing main ingredients which led to the tornado outbreak of 20 May 1957. Low-level winds bringing warm, moist air northward are shown as the thin dashed arrows. Other features are as labelled.

For an example of how these weather patterns develop, consider the case which produced the infamous tornado on 20 May 1957 which devastated Ruskin Heights, Missouri. As shown in Fig. 1, at 9:00 a.m. of the fateful day, a weather system lay west and southwest of Kansas City with strong low-level winds forcing the warm front (which lay across southwest Kansas and Oklahoma) northeastward toward Kansas City. This push of warm, moist air toward the threatened area was bounded on the west by a counterclockwise flow of warm, dry air from the desert southwest. The boundary between the moist and the dry air at the surface is shown by the scalloped line. Aloft, jet stream winds raced in gentle curves around an upper trough in Colorado and New Mexico.

Thus, the ingredients needed for an outbreak of severe weather were brought together that afternoon, as the heating from the sun warmed the low-level air still more, creating a tendency for the low-level air to rise. This enhanced the rising motion ahead of the upper-level disturbance.

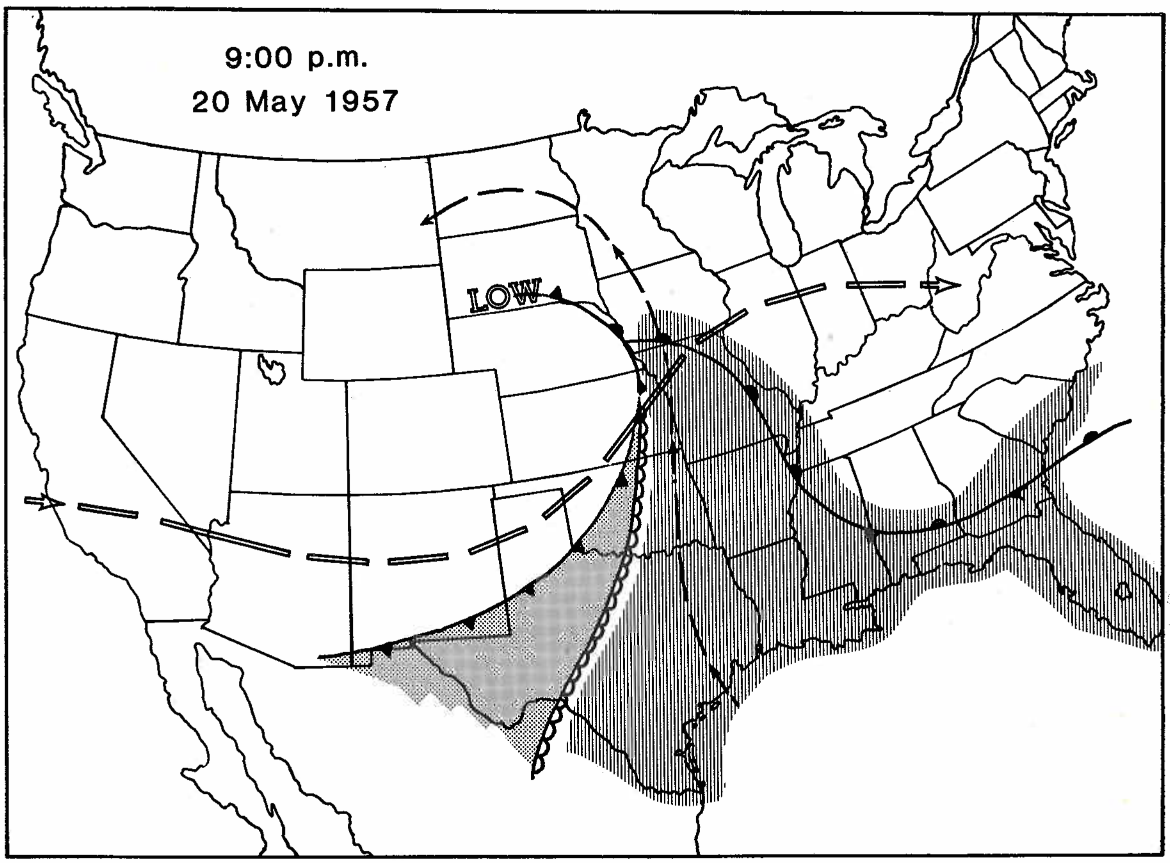


Fig. 2. Similar to Fig. 1, except conditions are shown at a time near the end of the severe weather outbreak.

By 11:ØØ a.m., the first tornado of the day was underway in eastern Colorado. Tornadoes and severe thunderstorms spread across southern Nebraska and northern Kansas during the afternoon. The most severe activity was generally under the upper jet stream as it intersected the advancing warm front (Fig. 2) - a quite typical situation for progressive-type outbreaks (those with a moving zone of concentrated severe weather). This area of severe weather was approaching the Kansas City area by 6:ØØ p.m. A second, more localized outbreak of tornadoes developed in northeast Oklahoma about 5:ØØ p.m. ahead of the advancing dry air, and continued on past 11:ØØ p.m. that night. By midnight, a total of 35 tornadoes had occurred.

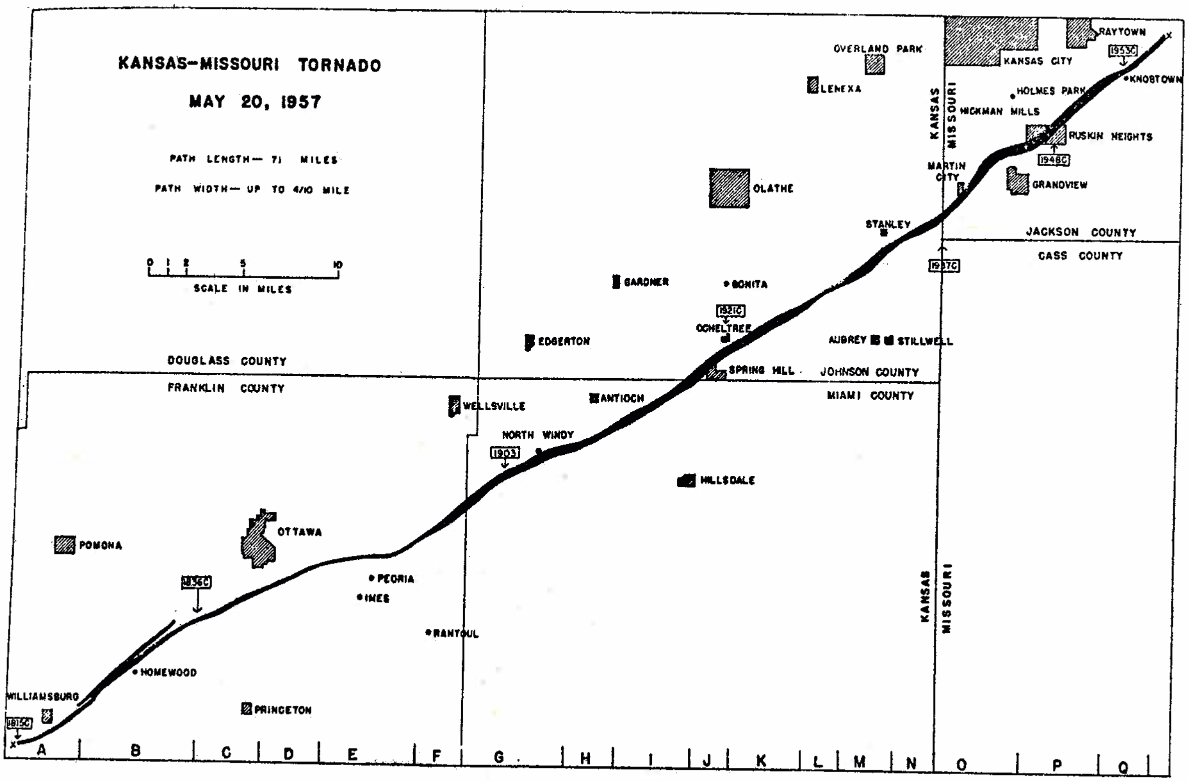
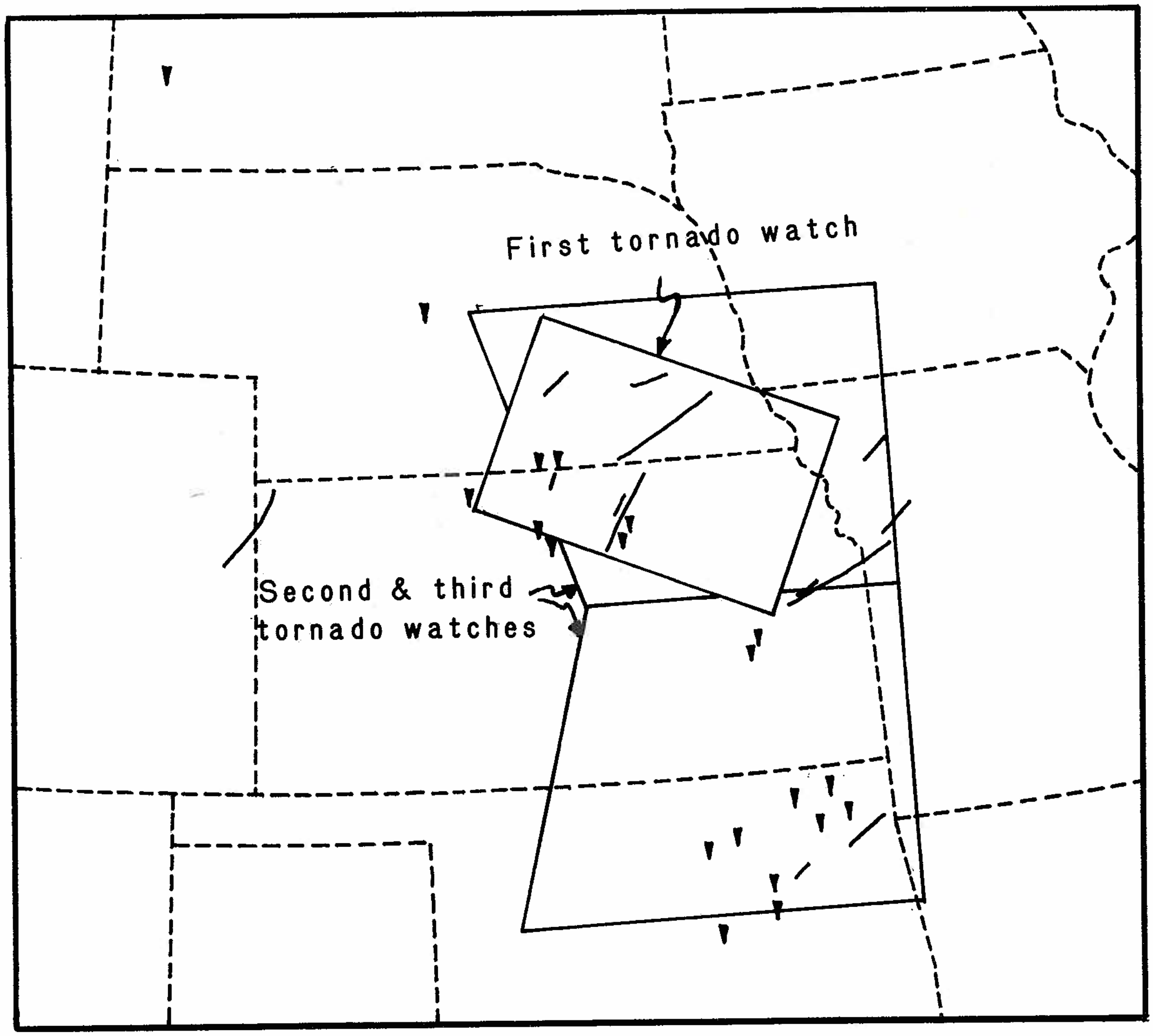


Fig. 3. Map showing the path of the devastating tornado which hit Ruskin Heights.

The tornado which eventually slammed into the Kansas City suburb of Ruskin Heights first touched down southwest of the small Kansas town of Williamsburg (Fig. 3) at 6:15 p.m. Well before this, at 11:ØØ a.m., the severe weather forecaster on duty in Kansas City had issued the tornado watch shown on Fig. 4. Between 3:15 and 4:1Ø p.m., two more tornado watches were issued (also shown), this time including the Kansas City area. These watches, combined with the developing weather, had persons in the affected areas at a high state of readiness to react to any tornadoes which might occur.



Reported Tornadoes 20 May 1957

Fig. 4. Tornadoes and tornado watches of 20 May 1957. Brief touchdowns are shown by dark triangles, while long-tracks are depicted by lines.

As a result, tornado warnings spread quickly ahead of the violent tornado as it moved northeastward at 40-45 mph toward Kansas City. News of the approaching storm was relayed by volunteer storm spotters to radio and TV broadcasters. As the storm passed near Ottawa, Kansas, it appeared as shown on the cover. Note the low cloud structure (a wall cloud) beneath which the tornado is occurring. Also, a multiple vortex phase is revealed by Fig. 5, in which the tornado is actually composed of 2 (or more) smaller whirls which rotate around each other. This storm was obviously large and dangerous. The tornado entered the heavily populated suburb of Ruskin Heights about 7:45 p.m., near the end of its 71-mile track. At that time, its damage path was over one-third of a mile wide, as wide as it had been at any point along the track.

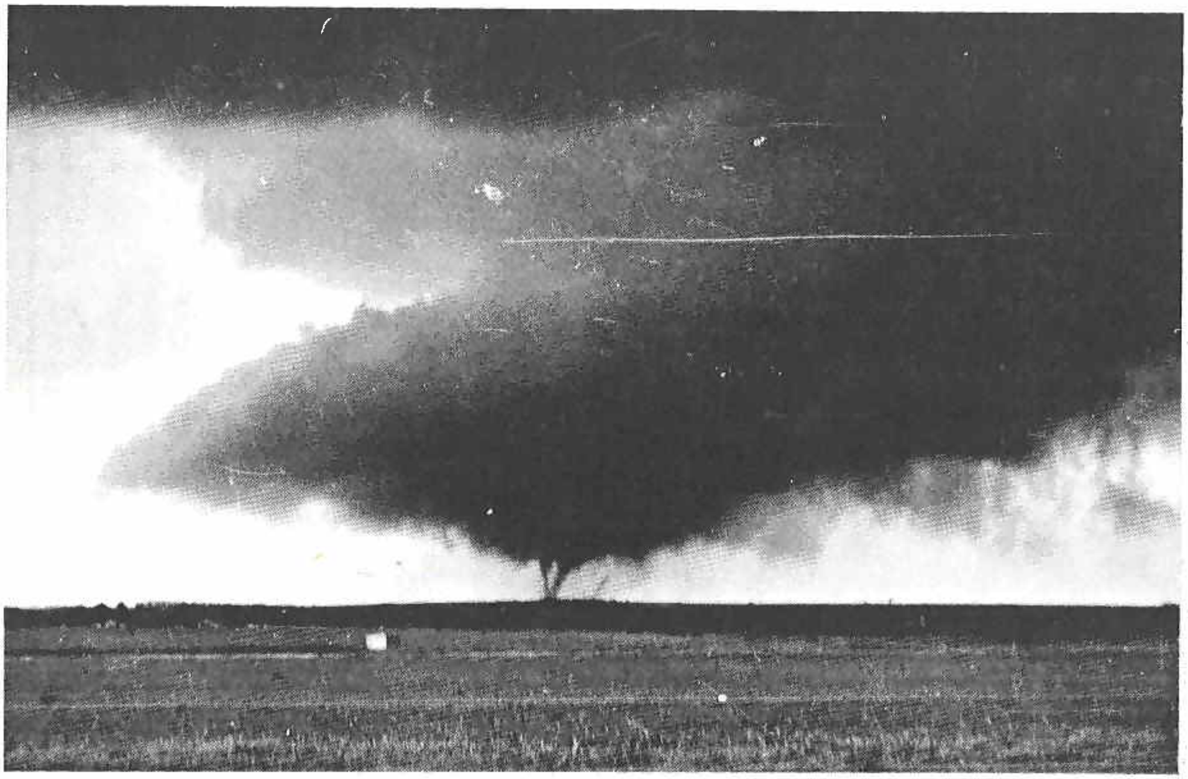


Fig. 5. Another view of the Ruskin Heights storm near Ottawa, Kansas, showing a multiple vortex phase of the tornado.

Within Ruskin Heights, the devastation was tremendous. Witnesses observed multiple vortices, and those within the path heard the characteristic roar of the tornado as it approached. Even today, more than 25 years later, people of Kansas City still remember vividly their experiences of that night. All told, 37 people died. There is no doubt that had there been no tornado watches and warnings, this violent tornado could have claimed many, many more lives.

STORM SCALE STRUCTURE: THE ORDINARY THUNDERSTORM

Thunderstorms are quite common events in most places of the world. At any one time, about 2000 such storms are occurring all over the globe. By far the majority of thunderstorms are beneficial: they provide needed rainfall and, by their electrical activity, change atmospheric nitrogen into forms which are necessary for plant growth. In the United States, only about 10% or less of the total number of thunderstorms produce severe phenomena (tornadoes, hail, and strong straight winds). Less than 10% of the total of the severe storms are accompanied by 1 or more tornadoes. Thus, less than 1% of all thunderstorms are tornadic.

Almost two-thirds of all tornadoes are classified as weak - these have winds around 100 mph, short and narrow damage paths, and last only a few minutes. About one-third of the tornadoes are in the strong category - with winds around 200 mph, paths a few hundred yards wide and several miles long, and may last several minutes. In the same way that only a very few thunderstorms produce any sort of tornado, only a small fraction of tornadoes can be classified as violent (about 2%). Such tornadoes can have winds up to about 300 mph, path widths of from several hundred yards up to a mile, path lengths from several tens of miles up to 300 miles long, and lifetimes from several tens of minutes up to 3 hours. Although violent tornadoes are only a tiny part of the annual tornado total, they account for nearly 70% of tornado deaths and a large part of the damage.

In order to examine severe thunderstorms and tornadoes, the ordinary thunderstorm needs to be considered to see how severe storms differ. The ordinary thunderstorm shares two features with its more spectacular cousins. First, in order to be called a thunderstorm, there must be lightning present to produce thunder. Lightning is the single phenomenon which, year in and year out, is responsible for most thunderstorm-related fatalities. The electrical discharge which is called lightning may take place entirely within the thunderstorm cloud, it may flash from one cloud to another, it can travel from within the cloud into the air, or it may reach many miles from the cloud to objects on the ground. It is the cloud-to-ground discharge which usually produces deaths. Since such deaths usually occur one at a time, they are rarely newsworthy on a national level. However, lightning is a potential killer in any thunderstorm and so safety precautions are necessary. The best protection is to stay indoors or in an automobile. See NOAA Publication PA-75009 ("Thunderstorms") for more details.

The second facet of an ordinary thunderstorm shared with the severe variety is its basic building block, the cell. Each thunderstorm is composed of one or more cells. These cells follow a life cycle which typically lasts about 30 minutes. The first stage in the cell life cycle is when cumulus clouds develop into towering cumulus (Fig. 6). All thunderstorms develop from cumulus clouds, but only a few cumulus clouds go on to become thunderstorms. During this first stage, the cell is composed entirely of rising air (updraft), has little or no precipitation within it, and none is reaching the ground - thus, the cell is invisible to weather radars which only detect precipitation. However, the water condensing in the updraft does produce the very small water droplets which make up a visible cloud.

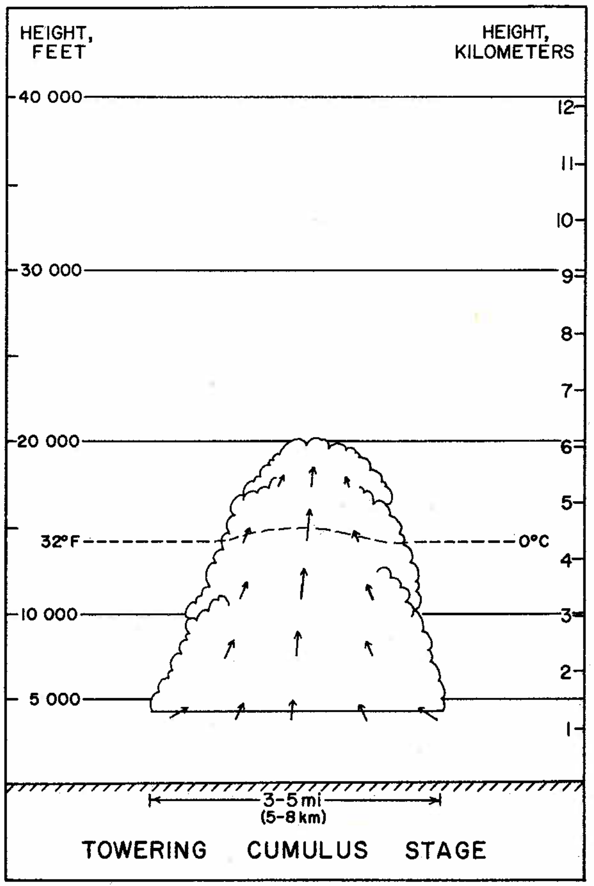


Fig. 6. Schematic diagram of the towering cumulus stage in thunderstorm cell development.

When the storm reaches the freezing level (that is, where the air temperature aloft reaches 32°F or 0°C), it begins to form precipitation. When this occurs, the cell becomes visible to radar. The precipitation formed is usually a mixture of snow and rain, which then begins to fall to the earth. As it falls, some of it evaporates, cooling the air around it and creating a downdraft. When this occurs the cell has reached the mature stage (Fig. 7), having both downdrafts and updrafts. This is the most intense phase of the cell - the most lightning, and heaviest precipitation (usually, all the snow melts on the way down, to produce only rain).

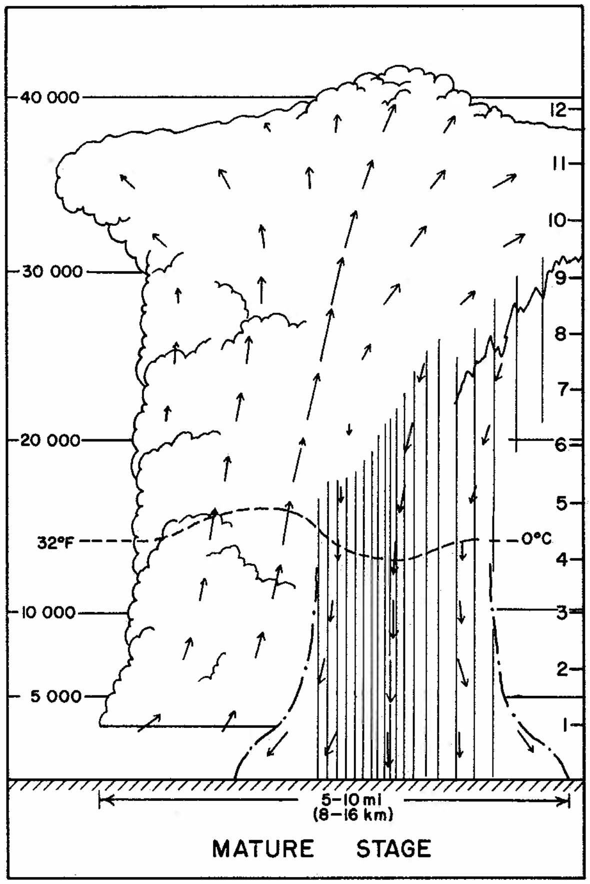


Fig. 7. The mature stage of thunderstorm cell development.

Because of the normal atmospheric temperature structure, the updraft is prevented from rising indefinitely. Instead, it eventually slows down and spreads out, forming the anvil top. Usually, the winds at upper levels of the storm are stronger than at the surface and have a generally westerly direction. These winds aloft blow clouds and precipitation downwind from the updraft, just like a spray of water downstream from a fountain. Therefore, the anvil spreads out ahead of the storm, usually toward the east - and so does the rainfall and the downdraft resulting from the rain.

As the downdraft strikes the earth, it spreads out in all directions. This produces an outflow of cool, moist air east and northeast of the storm. The leading edge of this rain-cooled air is called the gust front. The gust front is familiar to everyone as the sharp wind shift and marked temperature drop that accompanies most thunderstorms. It is similar to the cold front found on daily weather maps, but exists on a much smaller scale. As the gust front spreads out, it tends to cut off the supply of warm, moist air needed to sustain the updraft. Therefore, the updraft weakens and disappears, as the storm cell enters its dissipating stage (Fig. 8). By this time, the cell is dominated by downdraft. Rainfall gradually diminishes and eventually stops entirely. As shown in the figure, the only updraft left is at high levels and this also dies out, leaving only the storm anvil behind as the cell decays and vanishes.

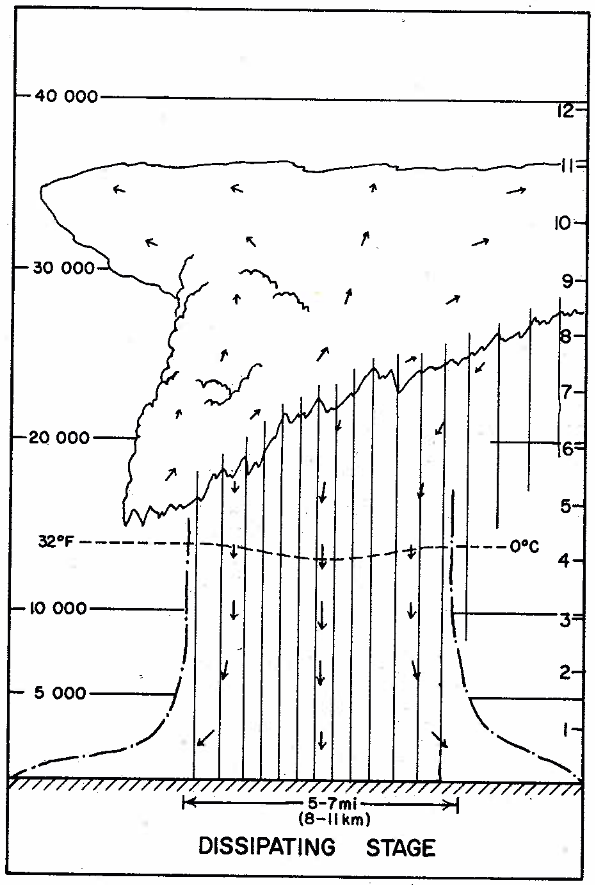


Fig. 8. The dissipating stage of thunderstorm cell life cycle.

In summary, all thunderstorms are composed of cells. The typical tornadic storm has a special organization which produces a single long-lived cell. In contrast, the squall line has a whole series of cells strung together like pearls on a string. Most ordinary, non-severe thunderstorms are composed of a cluster of these cells, at various stages of development.

STORM SCALE STRUCTURE: THE SUPERCELL THUNDERSTORM

In this section, the typical tornadic thunderstorm, often called a supercell thunderstorm, is described. Strong or violent tornadoes are usually spawned by such large, especially severe thunderstorms which rise to great heights (up to 12 miles) into the atmosphere. In addition to tornadoes, supercells often produce damaging straight winds, very large hail (from 2 up to 6 inches in diameter), and heavy rain. Supercells are generally isolated -- that is, they occur at relatively great distances (say 20 miles or more) from any other thunderstorm.

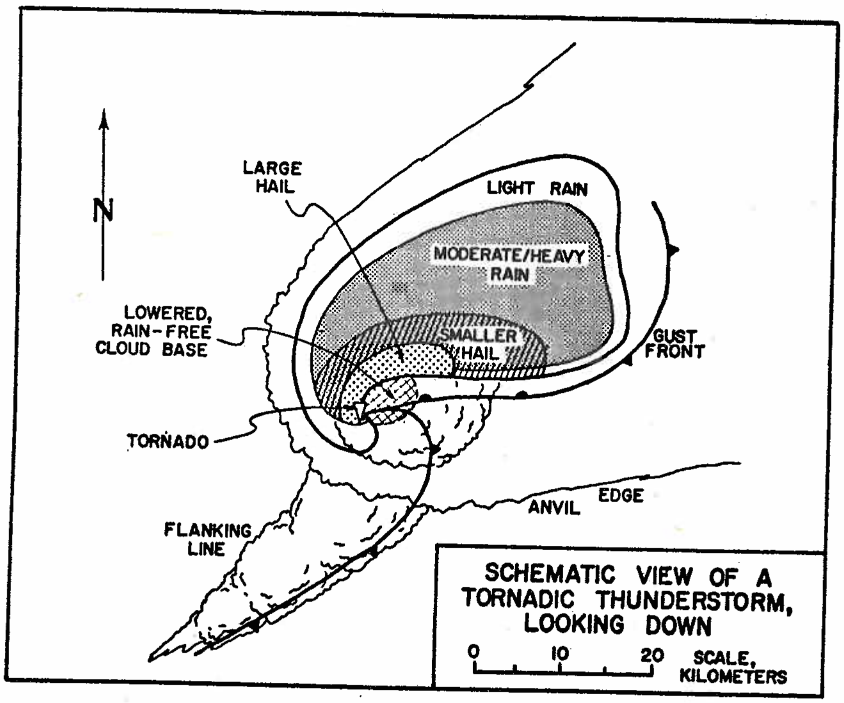


Fig. 9a. Gust fronts, cloud features, and precipitation distribution of a supercell tornadic thunderstorm, as seen from above.

Most supercells have a well-organized structure, producing severe weather in a definite pattern which is related to that structure. Recent advances in radar and other observing tools have provided new information concerning the formation of tornadoes. The most important part of a supercell thunderstorm is the intense updraft. If one faces the direction towards which the storm is moving, that updraft is usually located in the right-rear portion. For the purposes of this discussion it is assumed that typical conditions prevail and the updraft is located in the southwest region of the storm with southwest winds aloft. As a whole, such storms normally move toward the northeast. The updraft is marked by a cumulonimbus cloud with a lowered rain-free cloud base. Air in these updrafts rises with speeds of 100 mph or more and, as a result, giant hail and very heavy rain can be held aloft in the storms. Strong southwest winds of the jet stream carry the falling precipitation downwind (toward the northeast) from the updraft. Because hail falls rapidly, it reaches the ground before the rain. Thus, rain is carried farther northeast than the largest hailstones before it descends to the ground as shown in Fig. 9a.

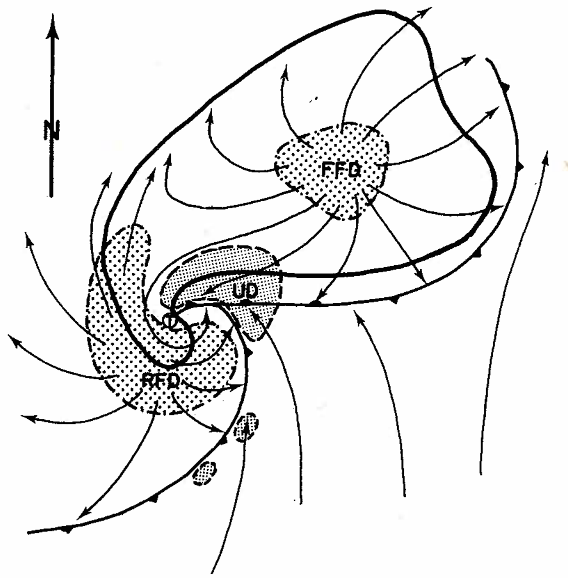


Fig. 9b. Gust fronts and surface wind flow distribution in a supercell tornadic thunderstorm. Updraft is denoted by 'UD', the forward flank downdraft is marked 'FFD', and the rear flank downdraft is shown by 'RFD'. Small, developing updrafts are shown just ahead of the gust front produced by the rear flank downdraft.

The dry air brought into the storm by the strong winds aloft is cooled by evaporation when it flows around the slowly moving updraft into the precipitation region. This air begins to sink, developing into downdrafts. One downdraft occurs to the northeast (downwind - the forward flank downdraft) of the updraft and another to the west or southwest (upwind - the rear flank downdraft). It is near the boundary between the updraft and the downdraft on the west (Fig. 9b) that a circulation center develops. Air rising in the updraft begins to curve counterclockwise at higher levels. In addition, as the downdraft air descends on the storm's rear flank, it also curves counterclockwise, to the west and south of the updraft.

The reasons for the development of this vortex-like flow aloft are not completely understood, although several theories exist. As this large (5 to 10 mile diameter) counterclockwise swirling motion becomes organized, a very small (usually less than 1/2 mile in diameter) tube-like vortex may develop within it, approximately 3 to 5 miles above the ground. This is the beginning of the tornado. Sometimes, neither of these circulations reach the ground. But, again for reasons not yet well understood, both circulations sometimes descend to the ground over a period of from 15 minutes to 1 hour. At cloud base, the large-scale circulation is often seen as a rotating wall cloud (Fig. 10; also recall Fig. 5 and the cover photo). The tornado usually descends from (or near) the wall cloud.

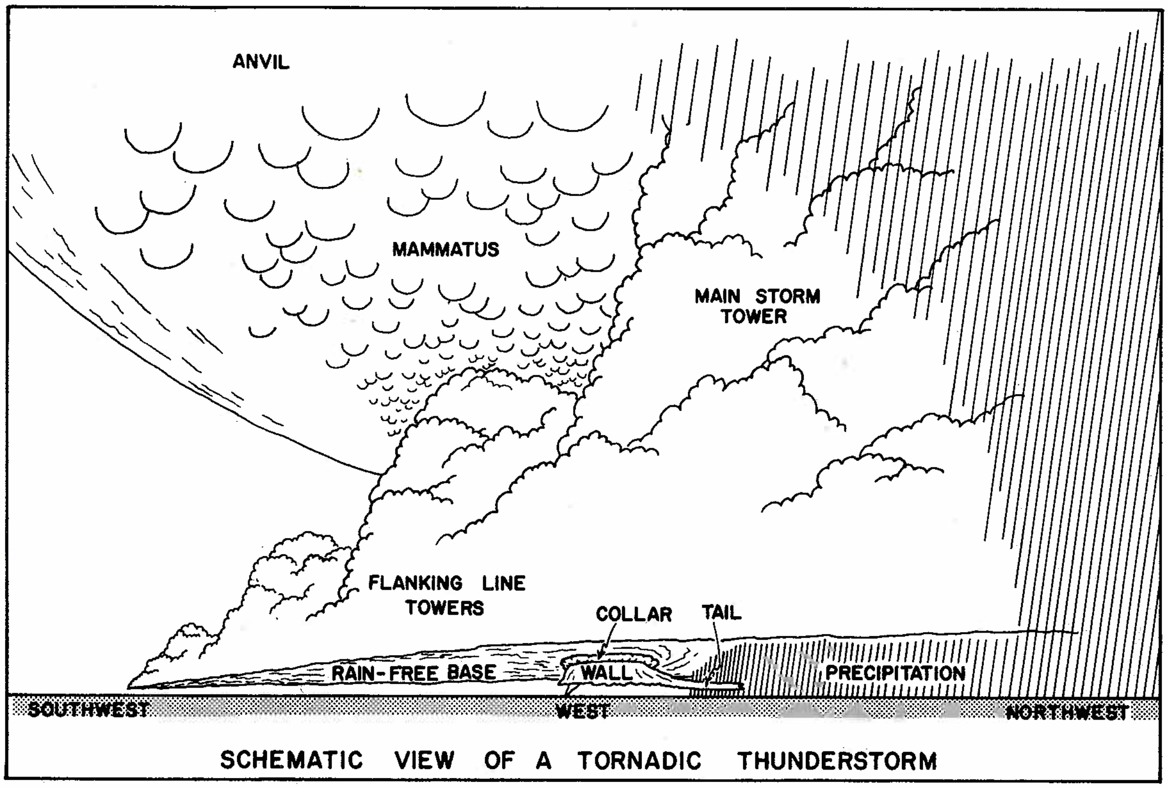


Fig. 10. Cloud features seen at the southwest end of an approaching supercell thunderstorm.

At the ground the cool downdrafts form gust fronts. If the storm scale circulation (called a "mesocyclone") shown in Fig. 9b develops, it bends the gust fronts, forming a structure that closely resembles a large scale frontal system (compare Fig. 9b with Fig. 2). The center of this circulation system (" " or T on Fig. 9) is where the tornado usually descends to the ground. When fully developed, the tornado vortex itself can often extend from the surface upward for over 6 miles into the storm.

The tornado is made visible by condensation (cloud formation) caused by its lowered atmospheric pressure. When the vortex is in contact with the ground, debris created by the wind also contributes greatly to its visual appearance. When viewed against a light background, the tornado appears dark -- if seen against a dark background, it may look gray, or even white. While the tornado often looks like a single tapering funnel cloud, it may appear as a large cylindrical cloud, as several small funnels rotating around a common center, a long rope-like tube, or a ragged, formless mass of swirling clouds and debris.

If the storm moves from southwest to northeast (from lower left to upper right in the figures), there is a well-defined sequence of events seen by an observer as the supercell approaches. Before the storm reaches the observer, the surface winds are generally southerly in the sultry air which is feeding the storm. First, the leading gust front passes, often accompanied by a wind shift (usually to a direction which may vary from west through northeast) and rapidly falling temperatures. Then light rain begins, followed by moderate to heavy rain, perhaps becoming mixed with small hail. Strong, gusty winds may be present in the heavy precipitation. The hail size increases and occasionally a brief period of large hail occurs with little or no rain at all. Just before the tornado, winds may switch back to easterly or southeasterly (toward the approaching tornado), become strong and gusty, and be accompanied by a return of warm, sultry air. The tornado follows the precipitation closely and there may be a brief period of rain and/or hail after the tornado. Then the storm has passed and skies may lighten or clear entirely. Note that some storms may move nearly east or perhaps southeast (especially late in the spring and into summer). For these, an observer in the path of the tornado may experience little or no precipitation in advance of the tornado. In such cases, winds remain southerly and warm, but will increase in speed and may swing to a more easterly direction as the tornado approaches. In either case, observers north of the tornado path experience rain and/or hail and winds of intensity and duration which decrease with distance from the track of the vortex. Those south of the path may encounter strong or even damaging straight winds with little or no precipitation.

Finally, it should be emphasized that tornadic thunderstorms may be accompanied by intense lightning. Lightning strikes the ground most frequently in the rainfall area to the north and east of the tornado. Sometimes lightning may strike the earth several miles to the rear of the storm, well after all danger seems to have passed. Observations of intense lightning and occasional luminous effects in and around tornadoes have led some scientists to suggest an electrical origin for tornadoes. However, these ideas have never been verified and are met with scepticism by most meteorologists.

STORM SCALE STRUCTURE: THE SQUALL LINE THUNDERSTORM

While supercell storms are usually responsible for the most intense severe thunderstorm events (strong or violent tornadoes, giant hail, and damaging straight winds), another storm type is far more common: the squall line. Rather than being a single, more or less isolated cell, the squall line consists of a number of cells close together and organized into a line.

Fig. 11. Shelf-type outflow cloud.

Instead of a single updraft, the squall line has a more or less continuous updraft along its leading edge (rather than toward the trailing flank, as in a supercell). The downdrafts follow closely behind this updraft, with the boundary between updraft and downdraft often marked by a shelf cloud (or, rarely, a roll cloud) at cloud base. Examples of these cloud formations are shown in Fig. 11 and Fig. 12. Individual cells move nearly parallel to the line, usually forming at the southwest end of a line (oriented as shown in Fig. 13). As the cells move northeast, they may be reinforced by updrafts produced at the leading edge of the downdraft-produced outflow. The line as a whole moves southeast, or approximately perpendicular to the direction of the line orientation (movement of the line is often slower than that of the individual cells as well as differing in direction). Organization of the updrafts and downdrafts is shown in the cross-sectional view of Fig. 14.

Fig. 12. Roll-type outflow cloud.

As the squall line approaches an observer from the west or northwest, clouds gradually lower and winds are generally southerly. With gust front passage, winds shift abruptly to west or northwest and become gusty. The temperature falls and rain and/or small hail begin, which may become heavy rapidly. All these phenomena then taper off gradually, perhaps lingering on for extended periods. As precipitation diminishes, skies may lighten or clear off entirely, with a formless area of indistinct dark cloudiness seen in the direction of the storm.

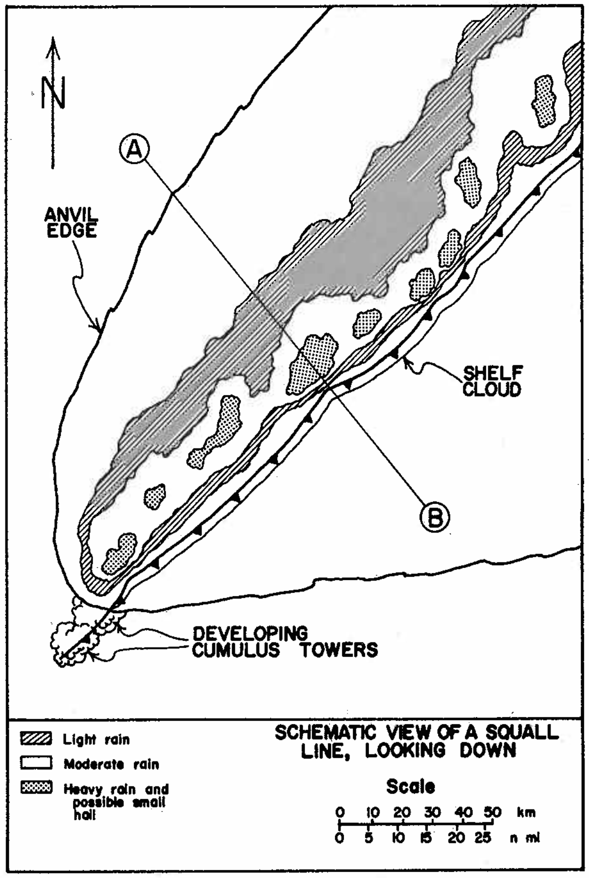


Fig. 13. Schematic diagram showing gust front and precipitation distribution looking down on a squall line thunderstorm. Individual cells embedded in the line are revealed by heavy precipitation cores.

Such storms are usually not severe or are only marginally severe. However, in their most severe forms, squall lines can develop widespread areas of damaging straight winds (as on the morning of 7 June 1982, in and near Kansas City) and, perhaps, brief periods of large hail. On occasion, tornadoes do occur in squall line events. Most typically, they develop on the southwest end of the line, in association with the new storm cells developing there. At other times, weak and brief tornadoes may occur along the gust front on the forward side of the squall line.

A serious threat from squall lines can arise when the line itself is moving slowly or is stationary. When this happens, the cells moving along the line pass repeatedly over the same general area, resulting in very heavy rainfall in a limited region. This situation can produce very dangerous flash flooding, such as occurred with the Brush Creek/Plaza situation in Kansas City on the evening and morning of 11 and 12 September 1977. While supercells can also produce heavy rains, they usually do not linger over any one area very long, so their flash flood threat is somewhat less than that of a slow-moving squall line.

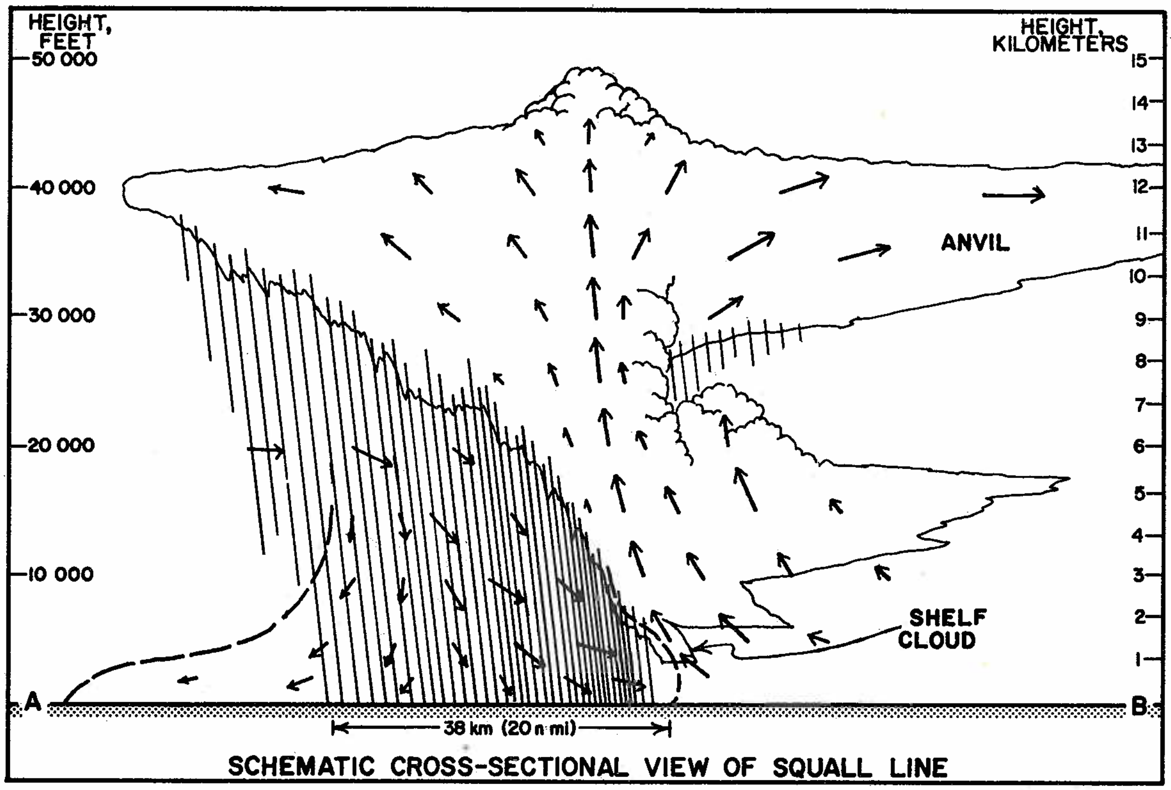


Fig. 14. Schematic diagram showing a vertical cross section through the line AB in Fig. 13, with winds, precipitation and cloud features indicated.

SEVERE THUNDERSTORM AND TORNADO SAFETY

Using what we have learned about tornadoes and the thunderstorms which produce them, we can develop some useful rules for persons threatened by tornadoes. First of all, since most tornadoes are of the weak variety, for those in their homes or engineered buildings, the most important rule is to stay inside. Never leave your home and try to escape an approaching tornado in your car! Even in the most violent storms, only a few homes and buildings are completely levelled -- interior walls are left standing in most cases. Therefore, when inside, the rule is to put as many walls between you and the outside as you can. The best place is a tornado shelter, of course, but adequate protection can be found in a basement room (with interior walls if possible) under a sturdy table. Lacking that, a first floor closet or utility room without outside walls is next best. A bathroom may also be a good choice, since plumbing in the walls acts to strengthen them - the best bet there is is to get into the bathtub and pull some protecting object over oneself, like a mattress or a small table. Avoid rooms with windows at all costs!

It is a common misconception that one should try to open windows before seeking shelter. This is supposed to relieve the pressure inside and prevent the house from "exploding". Engineering studies have shown that the pressure difference is unlikely to cause buildings to explode. Therefore, this is not only unnecessary, but is a dangerous waste of precious time which should be spent seeking proper shelter. The tornado winds and debris will "open" the windows before the center of low pressure passes, anyway. Further, if the tornado misses one's home or building, there is a risk of incurring water damage from rain pouring in the open windows, where it would not otherwise occur. Do not interpret this as a message to close any open windows - windows are risky places to be near during a tornado episode. Your only objective should be to seek proper shelter.

It is a good idea to have a plan in advance of the event. Have an appropriate part of one's home or place of work designated as the place of shelter and be sure that all occupants know about it. Avoid areas like gymnasiums or garages, which have large, unsupported roofs. Tornado drills are a useful exercise. Have a battery-powered radio (one which can be tuned to NOAA Weather Radio is best), a flashlight, and emergency supplies (water, food, and first aid equipment) stored within or nearby the designated area. Keep these supplies fresh and replace them annually, at least.

When in a mobile home or a motor vehicle in the path of an approaching tornado, you are quite vulnerable. In open country, while driving, it might be possible to escape the tornado by driving at right angles to its path. When attempting this, one can go either to the right or to the left, as one faces the tornado (north or south, for a tornado approaching from the west). The best choice is to move toward the left (or south), since most tornadoes have some northward movement - thus, one is driving away from the storm. This is not possible in the congested traffic of a populated area, or when highways are not available to do it.

In these cases, abandon your vehicle. If on foot, seek a low spot, preferably with some low shelter like a hedge or a ditch - lie down flat and cover your head with your arms. Be careful with culverts or drainage ditches, since these may be subject to flash flooding.

Do not depend entirely on warnings! While various agencies are striving to produce the best possible warning services, it is still possible that one may not hear them, or a storm could produce severe weather before warnings can be issued. In periods of threatening weather, be alert to conditions in the sky. Know the warning signs of approaching severe weather. These include, besides funnel clouds and tornadoes:

1. A wall cloud, especially one which is rotating, to the rear (usually southwest) of a region of heavy precipitation.

2. A rain-free base, in the same general vicinity of the storm as a wall cloud.

3. When in regions of precipitation, the dangerous part of the storm is nearby if hail starts to fall, especially if the hail begins to increase in size.

Strong straight winds may be imminent under these conditions:

1. An approaching shelf or roll cloud.

2. A flanking line (beneath which is a rain-free base) is moving toward you. If the cloud towers are not visible because of obscuring clouds, the flanking line will be a dark cloud base extending from the rear flank of a region of heavy precipitation.

Note that it is not always possible to be sure that a funnel cloud is actually a tornado - a swirl of dust and debris beneath the funnel means it is a tornado already. The funnel cloud itself need not be in contact with the ground for tornadic damage to be occurring! If you cannot see all the way to the ground because of trees or hills, treat any funnel cloud as a tornado and take appropriate action. In fact, this is a good rule to follow, even if one can see that no debris is yet evident beneath a funnel cloud.

Remember, as long as storms are approaching, the threat of tornadoes is not necessarily over, even if one tornado has already passed. Numerous reports of several tornadoes occurring over nearly identical paths have been documented. As with lightning, the idea that tornadoes never strike the same place twice is simply not true!

At night, one is at a tremendous disadvantage in dealing with tornadoes. While the tornado may make a loud roaring sound, it might not be heard until the storm is too close to react. If one is watching the night sky during a threatening situation, remember that repeatedly going in and out of lighted areas ruins your night vision -- this is especially important for volunteer storm spotters. Sometimes, lightning and/or city lights may illuminate an approaching tornado or wall cloud - in the case of lightning, it is possible to be deceived easily into believing that harmless cloud features are tornadoes or wall clouds. One should not panic with every lightning flash, but it is certainly wise to take shelter if one is uncertain. On some occasions, the tornado will snap power lines, creating a series of irregular flashes at low levels.

At any time, if you sight a tornado, do not call the National Weather Service. This ties up vital communication lines. Rather, contact your local law enforcement office, fire department, or civil defense unit. These agencies can pass your report on to the National Weather Service, but by calling them first, you have given them the opportunity to react quickly by blowing the sirens or whatever they have deemed is appropriate local response. If you are a volunteer storm spotter, follow your established procedures.

Stay away from storm-affected areas! This is also true in flash flood or wind storm situations. You are needlessly complicating legitimate, organized rescue efforts and, in the case of flash floods, running the risk of becoming a casualty yourself. Several people who died in the Plaza flood of 1977 had driven their cars into rising water, attempting to see the flood for themselves.

Finally, remember the distinction between "watch" and "warning". A watch is designed to bring you to a state of readiness, but does not imply that any specific action is called for. If a watch is issued, or if threatening weather is approaching, one should not interrupt normal activities, but should be alert for warnings and for the tell-tale signals in the sky. Check on the whereabouts of family members and make sure everyone is aware of the situation. Listen to NOAA Weather Radio to keep yourself advised about local weather conditions.

A warning is issued only when an actual threat has materialized and is headed in your general direction. A warning does not mean that you are necessarily going to be struck, but that threatening weather is approaching your vicinity and you should be preparing to take shelter immediately if conditions warrant. It is wise to interrupt your normal activities and to move to your appropriate shelter location, keeping alert to the weather conditions. Should you actually see a tornado approaching, it will appear to be growing in size while not moving from side to side. Seek shelter immediately and stay there until all danger is past. At night, if local officials have triggered sirens (or other warning devices), it is especially wise to seek immediate shelter, since your ability to see the approaching storm is so limited. If the tornado fails to materialize, this is obviously a wasted effort, but the stakes are high, since you are gambling with your life in the event it is not "just another false alarm".

APPENDIX A
NATIONAL WEATHER SERVICE
SEVERE WEATHER GLOSSARY AND SUPPLEMENTAL GUIDE

ACCESSORY CLOUDS -- Clouds that are dependent on a larger cloud system for development and continuance. Accessory clouds associated with the thunderstorm include roll, shelf, mammatus, and wall clouds.

ANVIL -- The spreading of the upper portion of a cumulonimbus cloud into an anvil-shaped plume, usually of fibrous or smooth appearance. Strong or severe thunderstorms often have thicker anvils, with the side and bottom having a cumuliform or slowly boiling appearance in the immediate vicinity of the parent cumulonimbus.

COLLAR CLOUD -- Frequently used as a synonym for a wall cloud, although it actually is a generally circular ring of cloud surrounding the upper portion of a wall cloud.

CUMULONIMBUS CLOUD -- The overall thunderstorm cloud, often known as a "thunderhead". The cumulonimbus cloud towers above ordinary cumulus clouds, with stronger or severe storms often having a more sharply outlined "hard" appearance, with relatively rapid rising motions visible. The cloud's upper portion includes the anvil. Accompanying precipitation is often heavy and the usual occurrence of lightning and thunder with these clouds leads to the popular name of thunderhead. See also THUNDERSTORM.

CUMULUS CLOUD -- A column of rising air containing water vapor that has condensed into a dense, non-fibrous cloud with distinct outlines, appearing much like a rising mound, a dome, or cauliflower. The base of the cloud is relatively flat and dark, while the tower is usually white and sunlit. The cumulus cloud is the first stage of a developing thunderstorm, although most cumulus do not become thunderstorms.

DOPPLER RADAR -- This is a new type of weather radar which may eventually replace current radar systems in many locations. It not only detects precipitation, as ordinary radar does, but also can determine the motion of that precipitation, toward or away from the radar. Therefore, it can "see" the winds within the storm, operating on the same principle as law enforcement radar. This capability can allow Doppler radar to detect the storm-scale circulations (see also MESOCYCLONE) which are associated with tornadoes. Doppler radar cannot, in general, detect the actual tornado circulation, which is too small to be observed, even with this new tool.

DOWNBURST -- Any strong, localized downdraft. Downbursts are usually contained in areas of the storm which are already experiencing downward motion, but represent intense concentrations of sinking air. This will fan out as it strikes the surface, producing potentially damaging "straight" winds. Storms which produce downbursts typically produce several such events in succession, of varying strengths and sizes.

DOWNDRAFT -- A column of generally cool air that rapidly sinks to the ground, most often accompanied by precipitation in a shower or thunderstorm. Areas of downdraft usually contain little or no cloud, and what clouds that may be present are typically dissipating. See also GUST FRONT.

FLANKING LINE -- A line of cumulus connected to and extending outward from the most active portion of a parent cumulonimbus, usually found on the southwest side of the storm. The cloud line has roughly a stair-step appearance, with the taller clouds adjacent to the parent cumulonimbus. It is most frequently associated with strong or severe thunderstorms.

FLASH FLOODING -- Flooding that develops very quickly on streams and river tributaries, usually as a result of thunderstorms. Sometimes the onset of flash flooding comes before the end of heavy rains. There is little time between the detection of flood conditions and the arrival of the flood crest.

FRONT -- A transition zone between two differing air masses. Basic frontal types are (1) COLD FRONT -- where cooler air advances, replacing warmer air; (2) WARM FRONT -- warmer air advances, replacing cooler air; (3) STATIONARY FRONT -- warmer air meeting cooler air with neither air mass moving appreciably. Thunderstorms can form in association with any of these fronts. However, fronts are not necessary for thunderstorm development.

FUNNEL CLOUD - A funnel-shaped cloud extending from a towering cumulus or cumulonimbus base. It is associated with a rotating air column that is not in contact with the ground. The cloud is a tornado if a ground-based debris or dust whirl is visible below the funnel aloft, even if the cloud itself has not reached the surface.

GUST FRONT -- The leading edge of the thunderstorm downdraft air. The gust front is most prominent beneath the rain-free base and on the leading edge of an approaching thunderstorm.

It is usually marked by gusty, cool winds, and sometimes blowing dust or damaging straight winds. The gust front often precedes the thunderstorm precipitation by several minutes. The shelf or roll cloud sometimes accompanies the gust front, especially when the gust front precedes a line of thunderstorms. Strong straight winds can occur behind the gust front.

<u>HAIL</u> -- Precipitation in the form of balls or clumps of ice, produced by thunderstorms. Severe storms with intense updrafts are the most likely large hail producers.

<u>HOOK ECHO</u> -- A radar pattern sometimes observed in the southwest quadrant of a tornadic thunderstorm. Appearing like the number six or a fishhook, the hook echo is precipitation aloft around the periphery of a rotating column of air 2-10 miles in diameter. The hook echo is near the location of tornado development. However, many tornadoes occur without a hook echo and not all hook echoes produce tornadoes.

<u>LIGHTNING</u> -- Any and all of the various forms of visible electrical discharges caused by thunderstorms. Severe thunderstorms usually have very frequent and sometimes nearly continuous lightning. However, some non-severe thunderstorms also produce similar displays, while some severe storms are accompanied by little lightning.

<u>MAMMA CLOUDS</u> -- Also called mammatus, these clouds appear as hanging, rounded protuberances or pouches on the under surface of a cloud. With thunderstorms, mammatus are seen on the underside of the anvil. These clouds do <u>not</u> produce tornadoes, funnels, hail, or any other type of severe weather, although they often accompany severe thunderstorms.

<u>MESOCYCLONE</u> -- A counterclockwise circulation within tornadic thunderstorms which often is associated with tornadoes. When detected (see also <u>DOPPLER RADAR</u>), mesocyclones are 2 to 10 miles in diameter. Usually, they appear first above the surface, and may or may not descend to the surface.

<u>OVERSHOOTING TOP</u> -- That portion of the cumulonimbus cloud which, from time to time may protrude above the anvil. Severe storms can produce especially large overshooting tops, which may extend several thousand feet above the anvil and which may be sustained for relatively long periods.

<u>PRECIPITATION SHAFT</u> -- A visible column of rain, hail, or other forms of precipitations falling from a cloud base and reaching the ground. When viewed against a light

background, heavy precipitation appears very dark gray, sometimes with a turquoise or green tinge. This has been commonly attributed to hail but its actual cause is unknown.

RAIN-FREE BASE -- A horizontal, dark cumulonimbus base that has no visible precipitation beneath it. This structure usually marks the location of the thunderstorm updraft. Tornadoes most commonly develop (1) from wall clouds that are attached to the rain-free base, or (2) from the rain-free base itself. This is particularly true when the rain-free base is observed to the south or southwest of the precipitation shaft. See also FLANKING LINE.

REAR FLANK DOWNDRAFT -- A second downdraft which often occurs in supercell thunderstorms. It is located on the trailing edge of the storm, to the west and north of the flanking line. It is usually the source of damaging straight winds in such a storm.

RIVER FLOOD -- Occurs on rivers, sometimes after flash flooding has occurred on streams and tributaries. River floods develop and reach their peak more slowly than flash floods. In many cases, the river flood peak occurs after the rain has ended.

ROLL CLOUD -- A relatively rare low-level, horizontal tube-shaped accessory cloud completely detached from the cumulonimbus base. When present, it is located along the gust front and most frequently observed on the leading edge of a line of thunderstorms. The roll cloud will appear to be slowly "rolling" about its horizontal axis. Roll clouds are not and do not produce tornadoes.

SCUD CLOUDS -- Low cloud fragments often seen in association with and behind thunderstorm gust fronts in the cold air outflow. These clouds are ragged and wind-torn and are not usually attached to the thunderstorm base. Scud clouds do not produce severe weather. In some cases, when scud clouds are attached to the thunderstorm base, they can be mistaken for wall clouds or tornadoes.

SEVERE THUNDERSTORM -- A thunderstorm that goes from the mature stage to the severe stage before dissipating. Severe thunderstorms are most efficient "machines" because the updraft and downdraft can act together to sustain the storm. They also occasionally contain rotation on a broad scale. Because of its structure, the severe storm may last for hours beyond the lifetime of a normal thunderstorm while producing one or more of the following: large hail, high winds, torrential rain, and tornadoes. Officially, a thunderstorm is classified as severe if it produces 50 knot (58 mph) winds, 3/4 inch or larger hail, funnel clouds or tornadoes.

SHELF CLOUD -- An accessory cloud associated with the gust front (see also ROLL CLOUD), which is attached to the cumulonimbus base. It appears wedge-shaped in cross-sections, and may have a layered, or terraced appearance. This is the most common cloud observed with gust fronts. Occasionally, it can be quite ragged and turbulent, with scud clouds beneath and behind the leading edge of the outflow air. Tornadoes rarely occur with the shelf cloud.

SQUALL LINE -- Any line or narrow band of active thunderstorms. The term is usually used to describe solid or broken lines of strong or severe thunderstorms. In their most intense form, squall lines produce strong straight winds, some hail and, only rarely, tornadoes, usually of the weak variety.

STRAIGHT WINDS -- Winds associated with a thunderstorm, most frequently found with the gust front. These winds originate as downdraft air which reaches the ground and rapidly spreads out, becoming strong horizontal flow. Damaging straight winds, although relatively rare themselves, are much more common than are tornadoes. While almost all storms produce straight winds, usually 20-30 mph, winds must attain speeds of 50 mph or more for damage to occur.

SUPERCELL THUNDERSTORM -- The most intense form of severe thunderstorm. Unlike the ordinary thunderstorm, it has a lifetime up to several hours and is the type of storm which usually produces the strongest tornadoes, giant hail and may also produce damaging straight winds.

TAIL CLOUD -- A low tail-shaped accessory cloud extending outward from the northern quadrant of a wall cloud. Motions in the tail cloud are toward the wall cloud with rapid updraft at the junction of the tail and wall cloud. This horizontal cloud is not a funnel or tornado.

THUNDERSTORM -- A local storm (accompanied by lightning and thunder) produced by a cumulonimbus cloud, usually with gusty winds, heavy rain, and sometimes hail. Non-severe thunderstorms rarely have lifetimes over two hours and consist of one or more thunderstorm cells. The cell is the basic building block of the thunderstorm and has a life cycle of about 30 minutes, in three stages: (1) TOWERING CUMULUS STAGE -- warm, moist air rises (updraft) and associated water vapor condenses into tiny water droplets which make up the visible cloud. (2) MATURE STAGE -- the cloud grows above the freezing level; precipitation forms and becomes heavy enough to fall back to earth. This precipitation generates cool air which also sinks back to earth with the precipitation. (3) DISSIPATION STAGE -- Cool rain and downdraft spread throughout the storm, replacing the updraft which is the lifeblood of the thunderstorm. The visible cumulonimbus cloud becomes softer in appearance, less distinctly outlined or "fuzzy" and dissipates, sometimes leaving only the high anvil cloud, as the storm rains itself out.

TORNADO -- A violently rotating narrow column of air in contact with the ground and extending from a towering cumulus or cumulonimbus base. The tornado most often develops in the southwest quadrant of a thunderstorm, from the wall cloud, or the rain-free base. A visible funnel cloud if present, does not have to reach the surface for the damaging tornado winds to be in contact with the ground. The spinning motion of a tornado, also sometimes called twister or cyclone, is most often counterclockwise, as seen from above; this means that a viewer on the ground sees the rotation as moving from left to right.

UPDRAFT -- Warm moist air which rises as the water vapor within condenses into a visible cumulus or cumulonimbus cloud. Once the cloud forms, it depends on the updraft for continuance and further development.

VIRGA -- Wisps or streaks of precipitation falling out of a cloud but not reaching the earth's surface. When seen from a distance, these streaks can be mistaken for funnels or tornadoes.

WALL CLOUD -- A local and often abrupt lowering of a rain-free cumulonimbus base into a low-hanging accessory cloud, from 1 to 4 miles in diameter. The wall cloud is usually situated in the southwest portion of the storm below an intense updraft, marked by the main cumulonimbus cloud and associated with a very strong or severe thunderstorm. When seen from within several miles, many wall clouds exhibit rapid upward motion and rotation in the same sense as a tornado, except with considerably slower speed. A rotating wall cloud usually develops before tornadoes or funnel clouds by a time which can range from a few minutes up to possibly an hour. Spotters should key on any lowering of the cumulonimbus base as a suspect wall cloud, particularly when it is located southwest of the precipitation shaft. Wall clouds should be reported. Note: Sometimes other low-hanging accessory clouds are mistakenly identified as wall clouds.

WARNING -- (Issued for tornadoes, severe thunderstorms, flash floods, river floods, and other hazards.) A warning is issued when severe weather has already developed (or is strongly suspected to exist) and has been reported by spotters or indicated by radar. Warnings are statements of imminent danger and are issued for relatively small areas near and downstream from the reported hazard.

WATCH -- (Issued for tornadoes, severe thunderstorms, flash floods.) A watch identifies a relatively large area in which flash floods or severe storms might occur. Watches are quite often issued before any severe weather has developed. Severe thunderstorm and tornado watches usually include an area 140 miles wide by about 200 miles long. The watch is only an indication of where and when the severe weather probabilities are highest, and should not be confused with a warning.

These definitions are taken from the material presented in the SKYWARN training session, for severe weather spotter groups. The different portions of a typical tornadic storm and squall line are diagrammed on pages 11 through 18 of this guide.

REPORTING CRITERIA*

1. Wall Cloud, Funnel or Tornado
2. Hail, 1/4 inch or greater
3. Damaging Winds, 50 mph or more
4. Flash Flooding
5. Rain, 1 inch per hour or more

ESTIMATING HAIL SIZE

pea size....1/4 inch
marble......1/2 inch
dime........3/4 inch
quarter.....1 inch
golfball....1 3/4 inch
baseball....2 3/4 inch

*These events, when reported according to proper procedures (see p. 21), are indicators of a truly severe thunderstorm and provide valuable information to local authorities for warning purposes..

...ERRATA...

Page 14, line 3 should read as follows:

"circulation system ("∇" or Ⓣ on Fig. 9) is where the torna-"