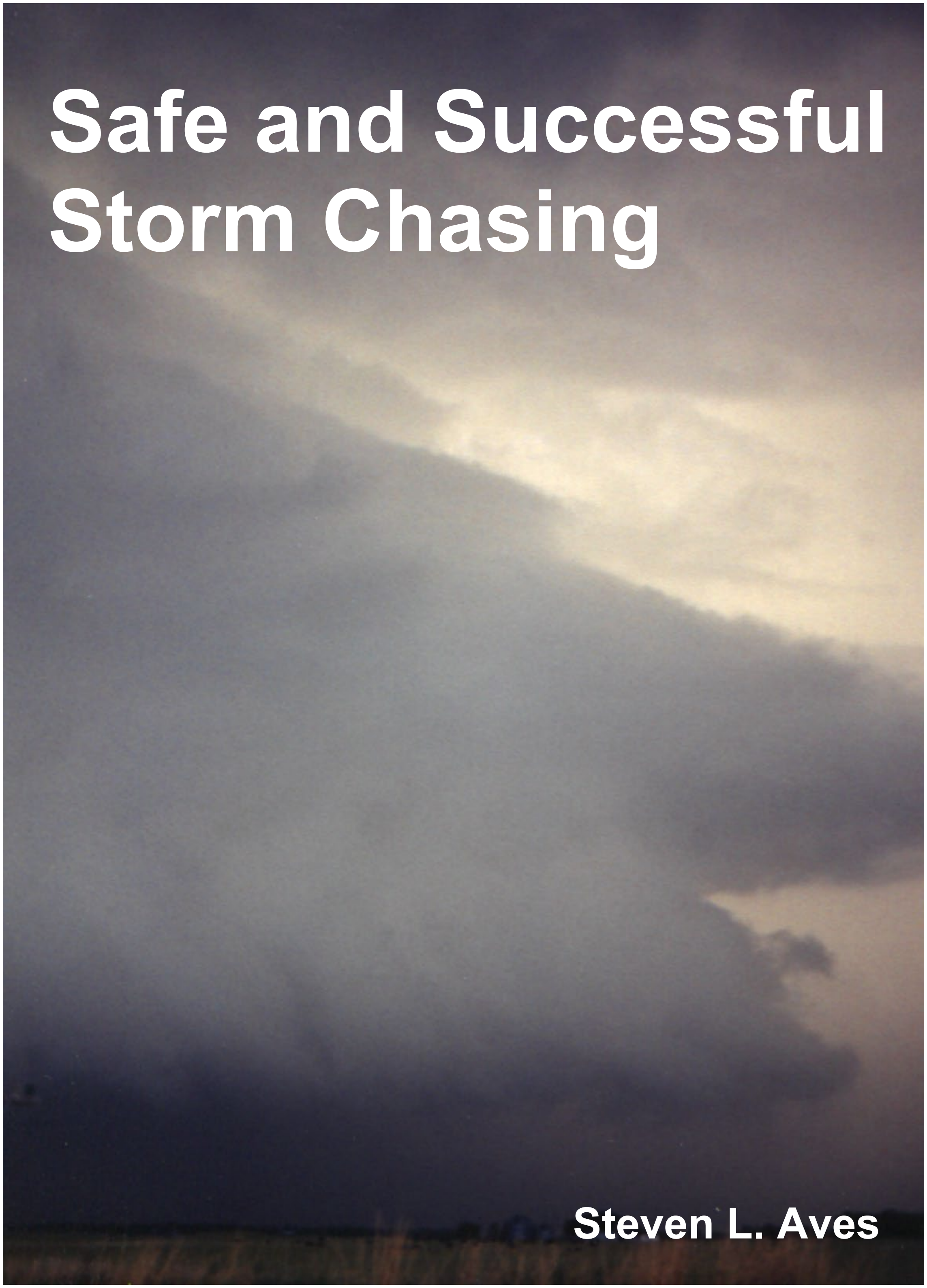

Safe and Successful Storm Chasing

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Introduction

Purpose

The purpose of this manual is to help you to be more informed about the process of storm chasing. Storm chasing is an **extremely dangerous** activity that threatens the life and property of any participant. **Severe thunderstorms** exhibit many life-threatening phenomena, including **tornadoes**, high winds, large hail, torrential rains, and lightning. These phenomena can strike with little or no advanced warning. Additionally, storm chasing can be indirectly dangerous because it involves driving large distances over sometimes hazardous road conditions. The author of this manual does not encourage storm chasing, but the author also understands that people can and will storm chase, even in the face of such danger. This manual, therefore, is provided to give you the information necessary to chase safely and successfully.

Background

The act of storm chasing has been beneficial to our society over the past thirty years. The **National Weather Service** (NWS) coordinates with county civil defense units to create a spotter network across most of the central United States, which is the area of the country where severe weather is most common. When severe weather is expected, law enforcement, fire and rescue personnel, and civilians mobilize to locate severe weather and report it to the NWS, which then issues appropriate warnings to the general public. This network has been responsible for the saving of countless lives, as indicated by yearly fatality tolls that have decreased by 75% over the last three decades.

Storm chasing also allows the only way to study severe weather, as the conditions and spatial scales responsible for the development of such phenomena are not producible in a laboratory setting. In recent history, the National Science Foundation funded the **VORTEX** project, whose objectives were to study severe storms at close range using a network of **Doppler radars**, mobile weather stations, ground spotters, and aircraft. The results of this project are still being released today, as a tremendous amount of data was collected over the five-year duration of VORTEX.

Individuals also storm chase for more personal reasons. Some chase for the aesthetic aspect of nature in its most powerful and violent state, and are equipped with both video and still cameras to document the storms. Still others chase for the sheer thrill of it; the danger involved with storm chasing can prove to be very exciting to some.

Even though people have been storm chasing for various reasons for many years, there has recently been a marked increase in the number of chasers on the roads of the central United States. Recent advances in technology have made electronic devices like video cameras relatively inexpensive, so that now many households have one at their disposal. More importantly, movies like *Twister* changed societal views of severe weather. *Twister* did not accurately portray the danger inherent in chasing, but rather focused on the glamour of chasing.

Twister provided an "invincible" representation of storm chasers, and it made the activity look fun, exciting, and free of danger. This erroneous viewpoint led many people with no prior experience to start storm chasing, believing in the fairy tale that they too can get within a few hundred yards of a tornado without any danger posed to life or property.

The result of these factors has been an increase in the number of inexperienced people partaking in the act of storm chasing, who are hazardous to both themselves and others. They are in personal danger because they do not comprehend the danger inherent in the situation, nor do they possess the training required to properly chase a storm and escape if the need arises. Furthermore, they are dangerous to others because they interfere with emergency personnel, congest evacuation routes, and cause damage with reckless driving.

Manual Design

This manual breaks storm chasing into different sections that parallel the different mindsets that a typical storm chaser goes through in a typical chase scenario. First, you must plan the chase, which includes packing and ensuring the working quality of the chase vehicle and its contents. Next, you must attempt to forecast the likely area of severe thunderstorm formation using current and expected weather conditions, which will help you to intercept any severe weather occurrences in a timely fashion. Finally, you must execute your chase, using visual clues and other observations to help you narrow your focus to an individual thunderstorm and position yourself correctly to witness tornado formation. By following the guidelines listed in this manual, you will have an increased chance at a safe and successful storm chase, which should be the goal of every chaser.

NOTE: Items in blue bolded text are defined in the glossary.

Figure 1. An example of hail damage that can occur while storm chasing. Notice that the hailstone that caused this damage was only about the size of a tennis ball. Hail in the most severe storms can reach the size of grapefruits and cantaloupes.

Figure 2. Lightning is an ever-present danger for storm chasers, as it strikes frequently and with little warning. Any time storm chasers leave their cars they are in danger of being struck by lightning.

Safety Reminders

Before you read the rest of this manual, you should be aware of the dangers inherent in storm chasing and the procedures that can help you to minimize these dangers. As mentioned before, storm chasing is an extremely dangerous activity that can result in damaged property, personal injury, and even death. The phenomena associated with severe thunderstorms, namely tornadoes, strong winds, large hail, torrential rains, and lightning, all have the potential to be life-threatening. Extreme caution must be exercised while traveling in the vicinity of severe thunderstorms to avoid encountering such phenomena.

One important safety consideration is to know when to call off a chase. If the scenario ever becomes too overwhelming for you, it is best to terminate the chase and head for safety. Some of the factors that could lead to chase termination include the following.

- Poor visibility
- An excess of storms in the vicinity
- Diminishing illumination due to a setting sun
- Rapid movement of thunderstorm cells
- Indiscernible cloud features
- Disorientation

You should never be ashamed to call off a chase if you feel threatened or overwhelmed by the situation. A tornado is not worth catching if it puts you in immediate danger.

Another important reminder is to constantly be aware of the danger of lightning. Lightning is perhaps the most dangerous of all thunderstorm phenomena, because it strikes with the greatest speed and unpredictability. If you are ever outside of your vehicle, and within 10 miles of a thunderstorm, you are in danger of being struck by lightning. Lightning kills more people in the United States each year than any other weather phenomenon. Lightning can also strike several miles away from a parent thunderstorm cloud, arcing through seemingly blue skies. Individuals who are struck by lightning typically go into cardiac arrest, and receive severe interior and exterior burns. The safest thing you can do is to stay in your car at all times. Your car provides protection from lightning because the current is conducted through the metal body and downward to the ground. If you must exit your car, try to stay relatively low to the ground. Lightning tends to strike the highest object in a locale, and if you are on the High Plains with few trees and buildings, you may well be the highest object. If you ever feel your hair rising or prickling, or feel a tingling sensation, a lightning strike may be imminent. Immediately duck down, keeping your feet on the ground and close together, your head down, and your rear end in the air. The only body parts touching the ground should be your feet. This position will minimize your chance of being struck, and it will also minimize the effect of a lightning strike if one does occur.

If you are ever caught in severe weather phenomena, you have several options. One is to turn around and move rapidly in the opposite direction. For instance, if you begin to drive into a hail shaft, often the most logical action is to turn around and go back where you came from. By doing so quickly, you can exit the hail shaft in the same manner you entered. Another option is to seek shelter if it is immediately available. A good example of shelter from a hailstorm is a carwash or a canopy over gas station pumps.

Planning the Chase

Planning is an important part of any chase, because you don't want to be caught out in the field without equipment. At the least, your camera could malfunction, which would cause you to miss your opportunity to document the storm of a lifetime. More seriously, you could get a flat tire while being chased by a severe thunderstorm, which could put your car and its occupants in great danger. Knowing this, it is always best to be prepared for any kind of disaster, no matter how small, to make sure your chase is as safe and successful as possible. This section will discuss how to prepare your vehicle for a chase, how many people to take chasing, and what equipment you should bring along with you.

Vehicle Checklist

- Make sure your vehicle is in good working condition. Have a mechanic check typical problems (oil, transmission levels, tires, brakes, etc.) to make sure your vehicle is ready. Storm chasing requires traveling over large distances, so most likely many miles will be put on your vehicle.
- Make sure you have items like a spare tire, road flares, jumper cables, and extra oil and coolant with you on your chase. You should always expect the unexpected, especially when driving for long distances in unfamiliar territory. If your car breaks down while executing a chase in a dangerous scenario, you want the materials handy that will help you to get out of danger.
- Rain-X your windows. You can buy Rain-X at most stores, and it is easy to apply. Rain-X is a type of wax that causes water on your windshield to bead, which greatly improves your vision while driving through rain. This will improve the quality of videos and photos that are shot on the chase, and it will also improve your ability to drive in even the heaviest of rainfalls. Additionally, you should have a fresh set of wipers installed to make sure your rain-driving visibility is at its best.

Storm Chase Team

No one should ever chase alone. There are too many tasks that must be completed at the same time during a storm chase. A typical chase team consists of at least three or four people to a vehicle, with each person assuming one of the following tasks:

- **Driving.** The driver must remain alert and focused on the task of driving at all times. Driving in unfamiliar territory is naturally difficult, especially when you are not on the main roads. Add to this the pressure of a dangerous chase situation, and it becomes obvious that the driver should not become burdened by other storm chase tasks. The driver should always drive responsibly; driving through cornfields, as in the movie *Twister*, is vandalism and punishable by law. Similarly, traffic laws still apply unless the car and its occupants are in immediate danger, so stick to the speed limit.

- **Navigating.** The navigator must be focused on the maps, especially in situations where the storm chase team is near severe weather. Getting lost wastes time, and getting lost in the vicinity of a tornado could be life-threatening. Thus, the navigator should know the location of the chase team at all times. In dangerous situations, the navigator should also have at least one escape route in mind, away from the storm. Storms tend to move erratically, and if the storm chase team finds itself in trouble, it needs to be able to quickly respond. Having an escape route already planned facilitates this process.
- **Spotting.** If possible, one person should be involved with storm spotting at all times. It is important for the driver and navigator to be focused on their respective jobs at all times. However, it is also important to have a pair of eyes on the skies too, because while most thunderstorms have a predictable shape and tornado location, dangerous weather can and does occur at many different locations. Thus, it is important that one person is focused on the weather all around the storm chase team in order to catch the development of any dangerous situations.

Radios and Communication

The ability to communicate during a chase scenario is very important:

- You need to be able to receive current weather and warning information so that you are more aware of the weather conditions surrounding you. This will help a chase team to locate volatile and chaseable weather phenomena.
- If there is more than one vehicle in a chase team, the people in the different vehicles need to be able to communicate with one another. The ability to communicate helps the vehicles to stick together and prevent getting lost, and it also helps the team as a whole to decide the direction of the chase.
- If severe weather phenomena are witnessed, they need to be reported to the NWS so that proper warnings can be issued. Even if a warning has already been issued, it is important that the weather conditions be reported so that the NWS can document the storm conditions.

It is important that the storm chase team receive weather updates while out in the field. Some information that may be pertinent to the chase includes

- Current weather information. It is helpful to know areas of wind shifts, clear skies, higher **dewpoints**, falling pressures, and increasing temperatures, as these meteorological features mark prime areas for thunderstorm development.
- Current watch and warning information. The **Storm Prediction Center** (SPC) issues **severe weather watches** when they feel conditions are prime for a severe weather event. Storm chasers should focus their attention on the area covered by the watch in order to intercept the severe weather. Additionally, when severe weather occurs the NWS issues **severe weather warnings** for the safety of the general public. Chasers can use these warnings to pinpoint storm location without the help of radar.

Current weather information. The best source for current weather information is the Internet, but data retrieval in the field is usually very slow and very expensive and thus not practical. One viable option is the use of a cellular phone. Cell phones can be expensive, especially if they are used outside of their home calling areas. However, if there are phone contacts with weather information (especially radar data) at their disposal, this method of data retrieval can be invaluable. Some chasers form a relationship between NWS personnel or local television weathercasters so that they are able to call these sources for the latest position of storms and their intensity. If the manpower exists, a storm chase team may wish to have one or two people stay behind and serve as a base of operations, with their focus being on the weather conditions at all times so they are ready to relay information to the field teams as necessary.

Another good alternative is the National Weather Service radio. They relay hourly weather information on a regional basis, and the broadcasts are free. National Weather Service broadcasts can only be picked up with special radios, but the radios are usually inexpensive. When buying an NWS radio, make sure that it has seven channels to ensure your ability to receive all of the broadcasts offered.

A surprisingly good and often untapped resource is rest areas along the interstate highway system. In many states the department of transportation has installed weather information systems that show road conditions, radar, and current conditions. These information sources can be valuable when approaching a **target area**, because they can show areas primed for severe weather development, as well as any existing radar echoes (either from existing thunderstorm convection or perhaps the initial thunderstorm development).

Watch and warning information. A good source for watch and warning information is the NWS radio service. Another good source, however, is simple AM and FM radio stations. Often AM radio stations will suspend their normal broadcasts in order to relay important weather bulletins. The AM signals have a high range (often 100 miles), so by seeking through your AM band you can hone in on stations across an entire state that are broadcasting severe weather bulletins. This can help the storm chase team to pinpoint hotspots in the action and direct their storm chasing focus.

Communication between vehicles. If more than one chase vehicle is involved in a chase, it is important that the chase vehicles are able to remain in contact with one another. Often chase vehicles can become separated, and when this occurs they need to be able to find each other quickly. Also, decisions about the direction of the storm chase need to be made on the move (i.e. which storm to chase, which road to use to approach). Without means of effective communication between vehicles, precious time will be lost. One option of communication is cellular phones, but that can be extremely expensive, especially when you have several phones that are outside of their calling areas. The best option is the use of CB/personal radios. These allow communication between all vehicles at once, and the method of communication is free. Companies like Motorola make personal radios that have open-field ranges of two miles, and they work like walkie-talkies. A system employing one of these radios in each chase vehicle has already been successfully field-tested on several different chases.

Reporting severe events to the NWS. When severe weather phenomena are witnessed out in the field, it is extremely important that the NWS be notified. The NWS depends on spotter reports to verify the data on their radar screens. In other words, the NWS may see a dangerous thunderstorm on radar but may not realize that it is producing a tornado at that time, and thus may not issue a warning. When the NWS receives a report from a trained spotter, however, they act immediately. Without the spotters, many severe weather events would go unnoticed, or would not be warned as effectively, resulting in a greater loss of life and property.

Even if a warning has been issued, the NWS still needs to receive severe weather reports as they are witnessed. The NWS uses these reports to verify their warnings, and the information helps them to determine the intensity of the storm, and whether a warning is still warranted. For example, if the NWS issues a warning on a storm and it weakens on radar, the NWS may feel compelled to cancel the warning because it is causing unnecessary distress to the public. If a spotter on that storm is still reporting severe weather conditions, however, the warning will remain in effect.

The most effective way to communicate with the NWS is a cell phone. During severe weather situations there is usually at least one NWS official working the phones. However, cell phones are very expensive and they do not work in all situations, especially in sparsely populated areas. Another alternative is to contact NWS or local county dispatch through the use of amateur radio. Most NWS offices are equipped with a ham radio, and during severe weather this station is also manned full-time. However, ham radios can be expensive to buy, and they require a license to use.

Please reference Appendix B, *How to Report to the National Weather Service*, so you can properly submit a severe weather report to the proper authorities if the situation arises.

Item Checklist

- **Maps.** You want to make sure you have a set of good maps, as you will be driving through unfamiliar territory. A good type of map to use is the “Gazetteer” brand, as these maps provide highly detailed road grid information. This type of information is very useful in a dangerous chase situation, because it is important to know all of the road options available to you. This helps you to get as close to the storm as is practical, and it also helps you in formulating escape routes (that is, to ensure that your road away from a storm doesn’t turn into a dead end, trapping you).
- **Camera equipment.** An important aspect of storm chasing is the documentation of severe weather phenomena. This is typically done through both still camera photographs and video recordings. When you chase, you need to have all of this equipment with you, and have it properly cleaned and maintained before you go out. Additionally, you should bring extra lenses, film/cassettes, batteries, and other items in case something were to go wrong on the chase, else you may miss your opportunity to shoot the storm of the year.
- **Radios.** As mentioned earlier, radios are a great source of weather information, and they help chasers to pinpoint the most severe local storms. Walkie-talkies/CB radios can also help storm chase teams to communicate with one another.

Forecasting the Chase

One of the most difficult aspects of storm chasing is the forecast before the chase. Before they actually leave on the chase, storm chasers must attempt to forecast the likely position of occurrence of severe weather so that they can target that area. Typical storm systems that spawn severe weather events span over several states, and it is not practical for a storm chaser to target such a wide area. Typically, severe weather events occur only one to three hours after the initial development of **cumulus** towers. This indicates that chasers must be within about 120 miles of the future occurrence of the severe weather event in order to intercept it. Thus, an accurate forecast must be made early in the chase to be in such a position to intercept.

Some situations may not require a forecast before chasing. For example, if a severe weather watch has been issued for your area, you would not need to set a target area because you'd already be in it. However, most chases will require a drive out of state, and an accurate target is required to ensure that you see some severe weather events. Even if severe weather is expected to occur locally, it can be useful to view some of the forecasts to help define what counties are more likely to see a chaseable event. Chasing while being informed about the current and forecasted weather conditions can only improve your chances of witnessing a severe weather event.

An important fact to remember is that tornado formation requires a combination of many different weather elements at many levels in the atmosphere. During many chases there is a large area of conditions favorable for tornado development located at the surface. However, the actual tornado formation will occur where the favorable conditions at the surface match up with favorable conditions in the upper levels. On many chases thunderstorm initiation does not occur until upper-level dynamics swing in from the west and provide the necessary lift and **wind shear** to support severe weather.

Figure 3. A look inside the Storm Prediction Center. Here weather forecasters issue severe weather forecasts for the current and following day, 365 days a year. Chasers often use the Storm Prediction Center outlooks when they are making their own forecasts.

How Thunderstorms Form

In forecasting severe weather events, it is helpful to understand the atmospheric conditions that support them. All thunderstorms, whether or not they become severe, must have three conditions present in order to form.

- **Moisture.** It is important to have moisture present in the lower and middle levels of the atmosphere. As air rises in a thunderstorm **updraft**, moisture condenses into small cloud droplets, which is why we can see the clouds. This condensation process releases (latent) heat into the atmosphere, which makes the surrounding air warmer and less dense than the environment. The added heat helps the air in the updraft to continue its ascent.
- **Instability.** By definition, an airmass is unstable when air initially pushed upward (downward) tends to ascend (descend) away from its original position. An unstable airmass is characterized by warm, moist air near the surface of the Earth, and relatively cold, dry air above. When something helps to push the air up, like a cold front, the warm air is less dense than its environment, and continues to accelerate until it hits the top of the troposphere.
- **Lift.** Simply a source of upward motion, lift is the mechanism that initiates an updraft in a moist, unstable airmass. Lift can be provided by several sources.

    - Weather front. Lift occurs ahead of both warm and cold fronts.
    - **Convergence** lines. These are simply lines where winds are converging, or flowing together. Convergence at the surface causes lift, because the winds flowing together must go somewhere, and the only available direction is up.
    - Differential heating. This occurs when the sun heats the earth's surface differently. For example, a freshly plowed field will warm up much faster than a grassy field because the plowed field is darker and more readily absorbs the sun's energy. The air just above the plowed field will be warmed more than the air above the grassy field. Consequently, the air above the plowed field will be less dense than its surroundings, and it will start to rise.

Helpful Forecasting Parameters

Knowing these facts, we can discuss different meteorological fields that will help to determine the location of severe weather formation.

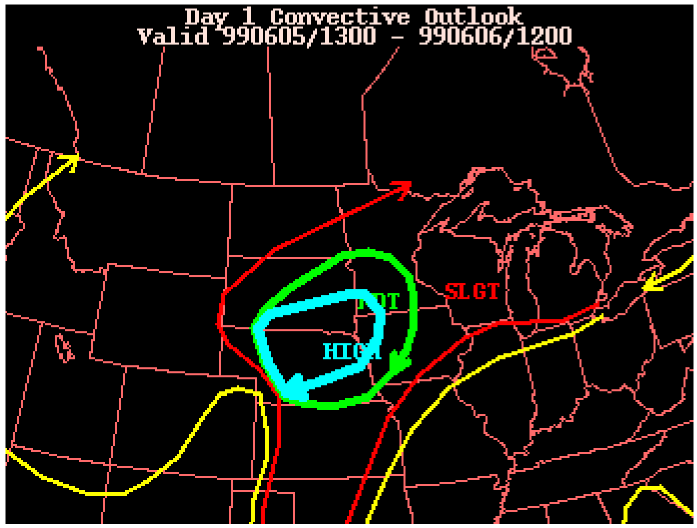

Figure 4. SPC forecast for 5-Jun-99. Notice the high risk area forecasted for northern Nebraska and southern South Dakota. This area experienced severe weather later that day.

SPC forecast. The SPC issues forecasts every day that indicate the probability of severe weather phenomena. They issue a day 1 forecast for the current day, and a day 2 forecast for the following day. The SPC issues forecasts of severe weather risk, and they have three categories to define the potential of severe weather.

- Slight. This means that severe weather events are possible on an isolated/scattered basis, or that the conditions may be marginal for severe weather occurrence. Even so, severe weather can and does occur in a region defined by a slight risk.
- Moderate. This means that conditions are definitely favorable for severe weather occurrences, and that the occurrences may be widespread.
- High. This means that there is a very high likelihood for severe weather events, because all of the conditions exist for violent weather. Often high risk situations are make-or-break situations, meaning that either a large outbreak occurs or there is a **bust** because of a strong cap.

The SPC forecast can aide a chaser in pinpointing a certain area for a chase target. However, the SPC forecast should not be the only source considered when making a forecast. It should only be used as a guide to help the forecaster focus on certain areas for thunderstorm development. Also, make sure to read the discussion that accompanies the severe weather outlook. Sometimes the highest risk areas are associated with severe weather phenomena that are not safely chaseable (like large hail and high winds). The discussion usually specifies where the SPC thinks the highest likelihood of tornado development will be.

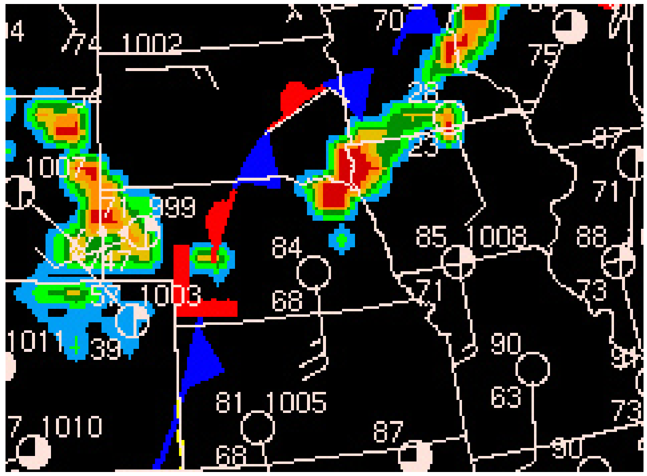

Figure 5. Surface map valid 5-Jun-1999 6PM CDT. Notice the front extending through western Kansas, central Nebraska, and southeastern South Dakota. The front is acting like a trigger for storm development.

Trigger. Thunderstorms will not form without some sort of trigger or lifting mechanism. This lifting mechanism helps the air to rise and starts the updrafts that form severe thunderstorms. Typical lifting mechanisms are advancing **cold fronts**, **warm fronts**, **outflow boundaries**, **drylines**, and upper-level **vorticity maxima**. When forecasting, try to find a forecast map of such fronts and lines that is valid for the time you expect thunderstorms to form, typically 4-7PM. Focus your chase target ahead of these fronts, because there is little chance of severe weather behind them.

Cap. In a typical severe weather day, there is a strong **cap** that inhibits thunderstorm development. This cap is simply a layer of warm air that eliminates the buoyancy of any rising air. The cap helps severe weather to develop, however, because it keeps the warm, moist airmass bottled up. As the day progresses, solar heating causes the air in the lower atmosphere to warm even further. If it can get warm enough to break the cap, it will rise explosively into the cooler upper atmosphere, causing strong updrafts and severe thunderstorms. If there is not enough of a cap, the air will rise too soon and too often, forming a large complex of ordinary thunderstorms not worth chasing. If the cap is too strong, thunderstorms will not form, no mater how unstable the rest of the atmosphere is. This situation is called a “bust” and is characterized by a lack of severe weather phenomena and annoyingly clear skies.

The measure of the cap strength is often called **convective inhibition** (CIN or CINH). If CIN values are lower than 10, the cap may be too weak and thunderstorms may develop too quickly. If CIN values are higher than 200, the cap may bee too strong, and thunderstorms will not be able to form. In forecasting cap strength, you want to see CIN values that are high throughout most of the day, but that fall to lower than 25 during the time of thunderstorm initiation (4-7PM).

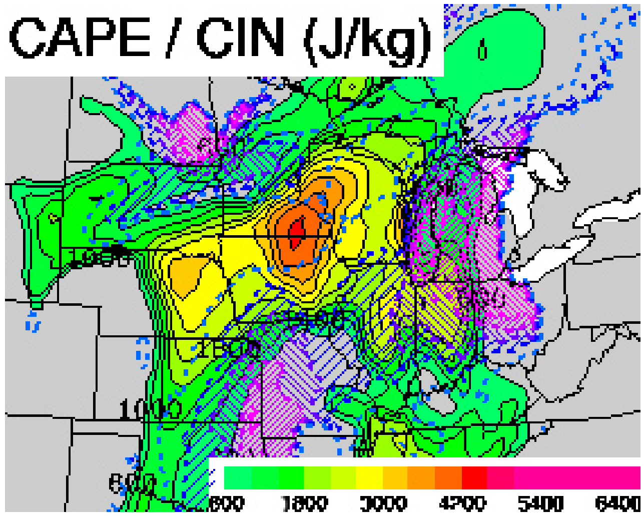

Figure 6. Forecast CAPE and CIN values, valid 5-Jun-1999 7PM CDT. The solid colors indicate CAPE, with the highest values extending from eastern Nebraska to western Wisconsin. The blue and purple hatched marks show CIN. The lack of hatching over Nebraska and Iowa show that there is a weak cap.

CAPE. CAPE stands for **Convective Available Potential Energy**. More simply, it is the amount of energy in the atmosphere that will support thunderstorm development. As a general rule, the more energy that is present (the higher the CAPE value), the more intense the thunderstorm updraft will be, and thus the more severe the thunderstorm itself will be. Values above 1500 are usually sufficient for severe thunderstorm formation. Values above 4000 typify a violent thunderstorm scenario and are especially conducive to severe weather and tornado formation. When forecasting, find a map of forecast CAPE values and focus your attention on areas of high CAPE, especially those that are close to triggers and in areas of high helicity.

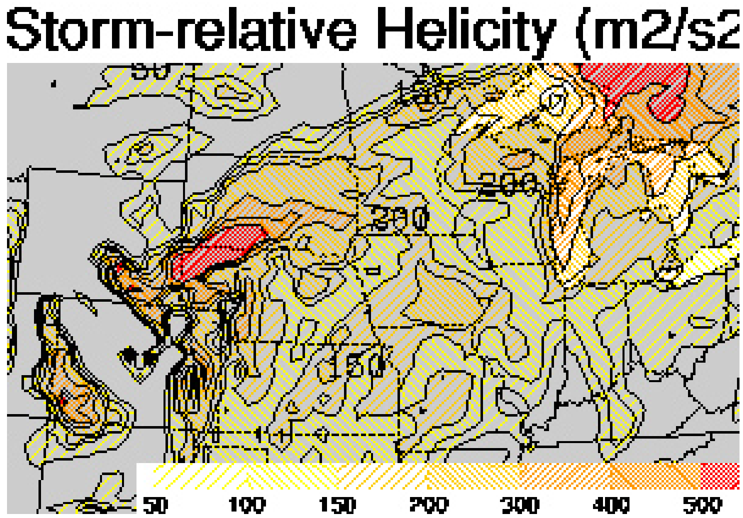

Figure 7. Forecasted SREH valid 5-Jun-1999 7PM CDT. Notice the especially high values in northern Nebraska and southern South Dakota. These predicted SREH values are large enough to support storm rotation and tornado development.

Helicity. **Storm-Relative Environmental Helicity**, or SREH, is a rather complicated meteorological concept. Put simply, it is a measure of how wind direction changes with respect to height. Helicity is a good thing for thunderstorms, because it helps to organize their structure and make them more long-lived. A typical thunderstorm goes through a lifecycle in about an hour. This is because the thunderstorm updraft produces droplets that eventually get large enough to fall back to earth. Usually these raindrops fall through the updraft, and the drag of the falling raindrops causes **downdrafts** that terminate the warm air supply of the thunderstorm. With helicity, however, the raindrops are blown to the right of the updrafts into their own separate downdrafts. Thus, the updraft is able to sustain itself for a much longer period of time. This type of thunderstorm is called a "**supercell**," because its organization leads to a typical lifespan of 4-6 hours.

To use helicity in forecasting, try to find areas where helicity values are greater than 150. This is usually enough to support severe weather formation. Typically, higher helicity leads to more violent thunderstorms, but only when it is accompanied by an adequate amount of instability (high CAPE values). If instability is low, any updrafts that try to form will be sheared apart, and thunderstorm formation will actually be suppressed.

Dewpoint. One simple forecast field to check is dewpoint. As a rule of thumb, tornadoes will not form unless the dewpoint is over 55F. Thunderstorms also feed off of the energy that comes from condensation, so having a higher dewpoint means that there is more water in the air and more energy available. Thus, when forecasting you should look for higher dewpoints to signify areas of greater instability.

Figure 8. Satellite picture from 5-Jun-1999 2PM CDT. Notice the clear skies over western Nebraska. This region is receiving more solar heating than eastern Nebraska, which makes thunderstorm formation more likely in the western part of the state.

Clear skies. Another simple ingredient for thunderstorm development is clear skies. These are not absolutely necessary for thunderstorm development, but the solar heating that accompanies clear or partly cloudy skies helps to destabilize the atmosphere and leads to more intense thunderstorms. You can use a satellite image to note areas of clear skies, and you should avoid targeting areas that are currently and are expected to remain overcast.

Summary of Forecasting Parameters

A typical target location will fulfill many of the following expectations at the time of predicted thunderstorm initiation.

- High CAPE values (>1500).
- High SREH values (>150).
- Clear or partly cloudy skies.
- High dewpoints (> 55F).
- Weak to moderate cap.
- A trigger in the vicinity.
- SPC outlook of slight or higher.

Not all of these may be true. In fact, severe weather often occurs even though not all of the forecasted criteria are present. Many times chasers face the dilemma of whether to go out chasing at all, because one key ingredient is missing. However, the more items on that list that are present, the more likely that severe weather events will occur in your target area.

Executing the Chase

After you have gathered your equipment, formed your chase team, and chosen your initial target area, you are ready to go out and chase. The actual chase can be broken down into two different mindsets. The first is a wide focus where your goal is to position yourself in the right general area for thunderstorms to form. During this time you must constantly be revising your target area by using new weather information. The second is a narrow focus where you pick a thunderstorm and position yourself correctly underneath its base in order to witness tornado formation. During this time you are committed to a small geographical area, and you must focus your chase on the storms that are developing within your reach. Thus, it is important that you position yourself appropriately during the wide focus portion of the chase so you are in a position to intercept severe weather events that occur.

Figure 9. Dr. Howard Bluestein of the University of Oklahoma, taking photographs of suspicious cloud lowerings. Dr. Bluestein has correctly positioned himself under the rain-free base of the thunderstorm cloud, and is in perfect position to witness tornado formation if it occurs.

Wide Focus Chasing

Wide focus chasing is probably the most important part of the chase, because during this time you are attempting to position yourself in the general geographic area in which severe weather events will occur. If you do this incorrectly, you will not be able to reach the severe weather events in time and your chase will be unsuccessful. Thus, to give yourself a chance to intercept a tornado, you must appropriately position yourself during the wide focus chase. You can do this by constantly revising your target area by using the latest weather conditions and forecasts.

If possible, you should try to start your chase early enough so that you can arrive at your initial target area one to two hours before you expect thunderstorms to form. The reason for this is sometimes even the best forecasts go wrong, and by arriving early you have more flexibility in changing your target area. Throughout the early part of your chase, you must be open to the idea of changing your initial target area. As you leave home, your focus must be on the weather conditions in the target area. For tornado development, temperatures and dewpoints should be relatively high; winds should be out of the south, southeast, or east; and skies should be clear or partly cloudy. If conditions aren't as favorable for tornado development as forecasted, you may need to consider changing your target area to a place where conditions are more favorable. Also, you should regularly tune in to the NWS updates. Often they will have a special weather statement that discusses the possibilities of thunderstorm formation, and these bulletins will include new information that you can use to supplement your earlier forecast.

Look for Cumulus Fields

With any luck, your chase team will be in a position to intercept storms as they form. Storms will typically form from cumulus fields, and specifically in areas where heating and convergence of winds are the greatest. Cumulus clouds are the low, fluffy clouds that frequent Midwest skies during the spring and summer months. Typically, these clouds have wide bases and rounded tops, and they are a signal of fair weather. Under favorable severe weather conditions, however, these clouds will form tall vertical towers due to the strong updrafts. At this time we say the cumulus clouds are exhibiting "**vertical development**," and it is a good sign that the atmosphere is primed for severe weather. Towers that are exactly vertical are the best; if the towers are slanted it means the shear is too strong and that the instability is not yet great enough to support severe thunderstorms.

Depending on the strength of the cap and the instability in the lower atmosphere, cumulus fields can be either sparsely or densely populated. The ideal chasing situation is to have very few cumulus clouds, because this provides the best visibility and the easiest identification of the strongest vertical updrafts. When such a scenario occurs, a chase team can rely on visual characteristics of the cloud field to help dictate the team's focus and direction of travel. However, you must be prepared for a dense cumulus field where it is difficult to distinguish cloud features. If such a scenario exists, your team may be forced to rely on radio communication of warnings to help guide the chase.

Chaseable Versus Non-chaseable Storms

There are many factors that go into determining the chaseability of a thunderstorm. These factors include

- The number of thunderstorms in the area (whether they are isolated or in a line or cluster)
- The speed of the storms
- The density of the road grid
- The visibility
- The time of day

Isolated thunderstorms are definitely chaseable storms. Depending on the atmospheric conditions, thunderstorms can either form on an isolated cell or **multicellular** basis. On some days, you will be able to spot an isolated supercell from more than 60 miles away, especially in the High Plains. It is easy to discern the motion of these storms, and thus they are easy to approach. It is also easier to determine the intensity of the storms using visual clues, especially if there are no lower clouds obstructing your view. Moreover, isolated supercells are more likely to produce tornadoes than storms in a line. Thus, chases involving isolated storms will be easier and more productive than those involving multicellular lines or clusters of storms.

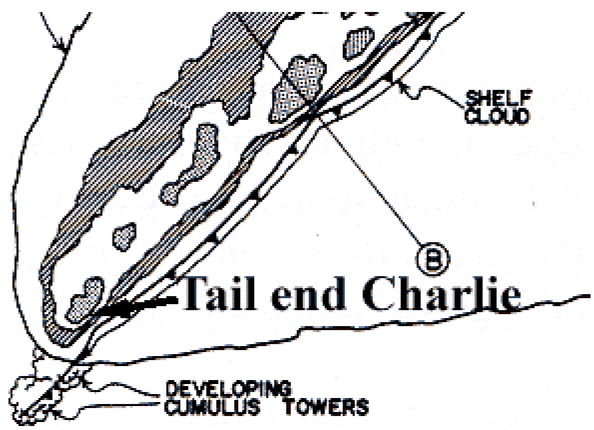

Figure 10. This is a depiction of the southern end of a squall line. The hatched areas are precipitation areas as would be depicted on radar. Notice how the precipitation echoes form a solid line as they extend northward. This indicates that the storms are strong or severe over a large expanse of the complex, and that poses a danger to chasers. Tail-end Charlie is the southernmost storm.

Chasing lines or clusters of storms is more dangerous. With a line, there is a real danger of being overtaken by the storms, and the accompanying strong winds and large hail could result in property damage. In addition, tornadoes do not usually accompany linear storms, and when tornadoes do occur they are weak and short-lived. Thus, chasing a line or cluster of storms is not recommended. However, one storm to watch in a line is the southernmost storm. This storm is so popular that is has earned its own nickname, "**Tail-end Charlie**." The storm on the south side of the line is more isolated and has access to the most warm, moist air, making it the strongest and most likely to produce tornadoes. If done carefully, a safe and successful chase can be executed by following the southernmost storm.

The speed of storm movement also affects the chaseability of storms, with slower-moving storms being easier to chase than faster-moving storms. Slower storms are easier to keep up with because of their slow rate of speed. A storm that is moving at 20 miles an hour will cover five miles in 15 minutes. The same storm traveling at 60 miles an hour will cover the same distance in only 5 minutes. Slower storms allow chasers more time to position themselves properly under the storm base and take necessary measurements and photography. Chases involving faster storms typically involve few if any stops, because the storms are constantly moving and often threatening the chaser.

The density of the road grid affects the chaseability of storms, with more roads being more conducive to a successful chase. Storms are not restricted to follow existing road grids, but motor vehicles are. Thus, chasers must plan their chase around the existing roads, which can be extremely difficult. In some of the High Plains states there are many tens of miles between major roadways, so it becomes difficult to find a road that will lead to the targeted storm. Additionally, a lack of roads can be dangerous, especially if a storm is bearing down on a chaser and there are few roads with which to plan an escape. Whenever possible, chasers should try to avoid areas with few roads, or should be mindful when chasing in such situations as to avoid being pinned.

Good visibility is a key ingredient to any successful storm chase. A chaser must be able to see a storm in order to chase it, and a low stratus deck can hamper visibility so much that a storm could be on top of you before you see it. With clear skies and few storms, however, individual storms are evident and easy to inspect for intensity. In addition, stronger storms tend to form in clearer skies because of the increased solar heating and resulting instability. Knowing this, clear skies should be a delight to storm chasers, whereas overcast skies might be enough to deter some from chasing at all.

Finally, the time of day affects chases, because it is hard to discern important cloud features (like tornadoes) at night. About an hour after the sun sets, the chaser can no longer see adequately to chase, and must depend only on lightning to detect the silhouettes of clouds. This is not a safe situation, because the chaser can become disoriented, and dangerous features can only be seen for brief intervals. A smart chaser knows when to terminate a chase due to lack of lighting, because even if the chaser is on the storm of a lifetime, that chaser will live to chase another day.

These factors should be considered when determining whether or not to chase thunderstorms in a particular area. If several of these factors are not favorable, a chaser may need to consider whether or not to chase at all, because the chance of success will be diminished and the chance of encountering a dangerous situation will increase.

How to Identify a Good Cumulonimbus Cloud

At this point in the chase, thunderstorms have started to form. Typically there will be more than one thunderstorm that forms in a visual area, which leads to an important chase question: which storm should you chase? If one storm has a warning already and the other does not, typically the best chase decision is to go after the warned storm. Even if this is the case, however, and more importantly if it's not, the question is better answered by a visual inspection of the **cumulonimbus** clouds. There are a few relatively simple visual clues that indicate the intensity of the thunderstorm and, accordingly, the chance of tornado development.

Figure 11. This is a good example of a very strong thunderstorm. Notice the thick, smooth-edged, and backsheared anvil, the large overshooting top, and the upright, cauliflower-textured main updraft.

Figure 12. This is a good example of a weak thunderstorm. Notice the thin, glaciated anvil and the diffuse main updraft tower.

Anvils. The **anvil** provides many clues as to the intensity of the storm. The anvil is the large upper part of a thunderstorm that is oriented parallel with the ground. An anvil forms when cloud droplets are quickly blown downstream by strong upper-level winds, which contributes to its size. One important feature of an intense thunderstorm is a thick, smooth-edged, and cumuliform (puffy) anvil. This feature indicates that the updraft of the thunderstorm is especially strong and is a good candidate to produce severe weather. If the anvil is thin, diffuse, and glaciated (wispy), it indicates a weak updraft and a lower chance of severe weather.

Another important aspect of the anvil is its size. If the anvil is large and extends a large distance away from the thunderstorm updraft, it is a good indication that winds in the upper levels are strong. This indicates that the thunderstorm updraft is well ventilated, and is conducive to severe weather development. The strong winds in the upper levels are helping to blow the precipitation downstream, away from the updraft, which allows the updraft to sustain itself for a longer period of time. This leads to the supercell organization that allows for a prolonged lifespan of the thunderstorm.

Finally, a **backsheared anvil** is a good indication of a strong updraft and an enhanced likelihood of severe weather. A backsheared anvil is the portion of the anvil that sticks out into the direction from which the upper-level winds are blowing. Typically these winds blow the cloud particles downstream, forming a typical anvil. However, if the updraft is particularly strong, when it hits the top of the **troposphere** it will spread out, even upstream (into the wind). Thus, if you see anvil jutting out opposite of the direction of motion of the storm, it's a good sign that the storm is particularly strong.

Overshooting top. Updrafts in a thunderstorm rise until they hit the top of the troposphere. At this point, the updrafts lose their buoyancy, because the air in the stratosphere is warmer and discourages convective processes. However, extremely intense updrafts can shoot into part of the lower **stratosphere** before losing all of their upward velocity. This produces a visual dome, called an **overshooting top**, which extends above the level of the anvil--the higher and more persistent the overshooting top, the stronger the thunderstorm supporting it.

Main updraft tower. The **main updraft tower** can yield several clues to the intensity of the parent thunderstorm. The best place to inspect the main updraft tower is in the middle levels of the storm, just below the anvil. If the clouds in the main updraft area are sharply outlined with a distinct cauliflower appearance, then the clouds are likely associated with a strong updraft that may produce severe weather. If they have a fuzzy or diffuse appearance, however, the updraft is probably much weaker. An additional clue is how close the main updraft tower is to being vertical. If the tower is nearly vertical, then the updraft is probably strong enough to stay erect in the strong upper-level winds. If the clouds are tilted downstream, the updraft is weaker and will likely be sheared by the stronger winds higher up in the atmosphere.

Flanking line. Thunderstorms with supercellular organization typically have a series of smaller cumulus towers in a line to the south or southwest of the main updraft tower. These smaller towers are called the **flanking line** of the thunderstorm, and often these towers will feed into the larger, main updraft tower. Flanking lines have a stair-stepped appearance, with the tallest flanking towers being located closest to the main updraft tower. If you see a thunderstorm complex with a flanking line, you can assume that the storm has good storm-scale organization and is worth chasing.

Striations. Tornadoes will not form from a thunderstorm without some sort of rotation. The rotation is derived from the main updraft tower itself. When an updraft tower begins to rotate, it is called a **mesocyclone**. A typical cloud feature of a mesocyclone is noticeable **striations** in the lower part of the thunderstorm. These striations look like corkscrew-type markings on the side of an updraft tower, reminiscent of a barber pole. If you see striations in an updraft tower, it is an extremely good indication that the storm is rotating and has the potential to produce tornadoes.

Assuming an unobstructed field of view, all of these clues are discernable from a distance of thirty miles or more. Accordingly, they can be used to make qualitative decisions about the strength of individual thunderstorms without the assistance from radar or other sources of information. A typical chaser will go only by visual inspection after the chaser arrives at the target area, and the chaser will use the aforementioned clues to help decide which storm tower to chase.

Narrow Focus Chasing

Narrow focus chasing occurs after you have committed to a particular storm. You may have chosen this storm from visual inspection techniques listed in the previous section, or you may have received other information about the storm (radar or warnings) that indicates it may produce severe weather. Either way, this section will help you to accomplish the following tasks.

- Identify the tornado-producing area of a thunderstorm.
- Approach the tornado-producing area of a thunderstorm safely.
- Move with the tornado-producing area of a thunderstorm to remain close enough to see the tornado.
- Recognize the visual appearance of a tornado.
- Terminate the chase and return home.

Identifying the Tornado-producing Area of a Thunderstorm

The area of a thunderstorm where tornadoes are most likely to form is located in the southwest quadrant of the storm. The main updraft tower is located in this area, and it is just to the southwest of the main precipitation core. You can use some of the following characteristics of this quadrant to help identify likely locations for tornado development.

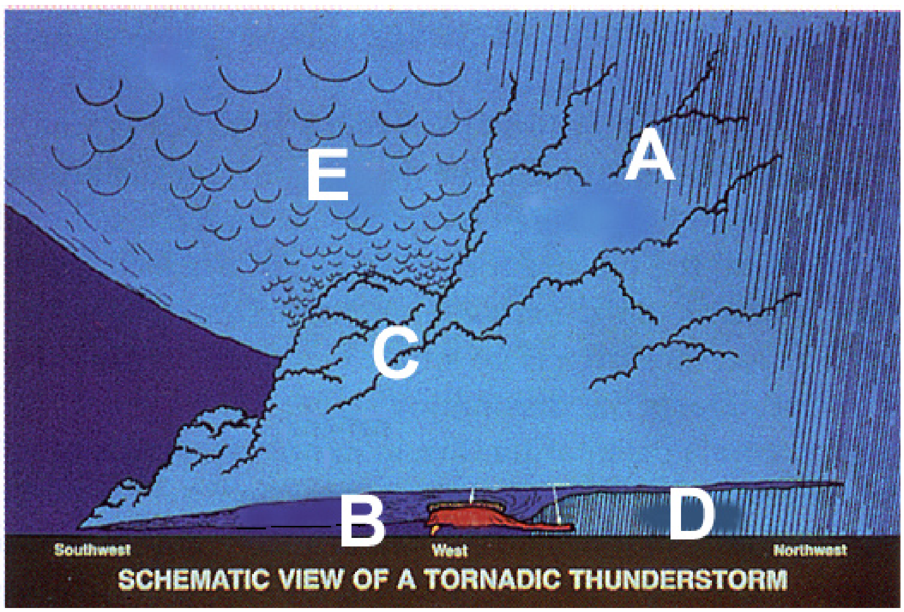

Figure 13. This is a schematic side view of a supercell thunderstorm. The picture is drawn so that west is in the center. Key: A—Main updraft tower B—Rain-free base C—Flanking line D—Precipitation shaft E—Anvil

Rain-free base. The **rain-free base** is the easiest of the lower-level visual clues to identify. A rain-free base is simply an area of smooth, flat cloud base beneath the main updraft tower from which little or no precipitation is falling, and it should be located just to the southwest of the main precipitation core. This cloud feature marks the main area of inflow for the storm, and it is in this region that tornado formation is most likely to occur.

Inflow bands and beaver's tail. When a storm is especially strong it draws in air from its surroundings. As this air rises into the updraft, it forms bands of cloudiness that are easily discernable. If the clouds seem to be coming from the precipitation shaft, the band is called a "**beaver's tail**." Otherwise, the bands are simply called **inflow bands**. Where these bands connect to the rain-free base is the most likely area for tornado formation, because they indicate the base of the main updraft tower.

Figure 14. This depicts a typical wall cloud. Notice how the cloud tip slopes upward as it travels away from the precipitation shaft (off the right edge of the picture). This insinuates upward motion.

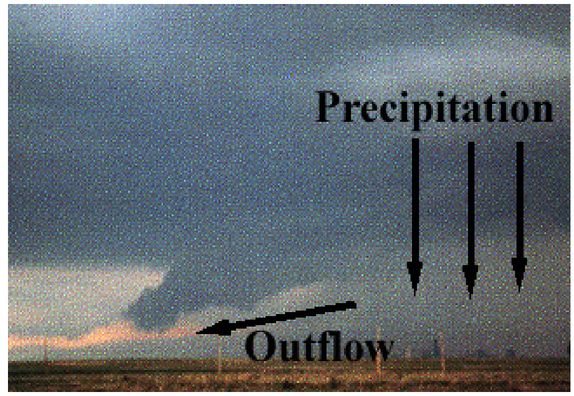

Figure 15. This depicts a typical shelf cloud. Notice the precipitation shaft off to the right, and how the shelf cloud slopes downward as it travels away from the precipitation shaft.

Wall clouds. A **wall cloud**, defined as an isolated cloud lowering attached to the rain-free base, marks the area of strongest updraft in the storm. A wall cloud forms when the updraft pulls in humid air from the precipitation shaft, which quickly condenses before it reaches the cloud base.

One of the largest challenges facing a storm chaser is to discern between wall clouds and other lowerings that may exist underneath the rain-free base. **Shelf clouds** can also occur under the rain-free base, and they look similar to wall clouds. Shelf clouds are long, wedge-shaped clouds associated with outflow from the thunderstorm, and they do not form tornadoes. The differences between the two clouds are summarized in the following table.

Wall clouds	Shelf clouds
• Suggest inflow/updraft	• Suggest outflow/downdraft
• Maintain position with respect to rain	• Move away from rain
• Slope upward away from precipitation area	• Slope downward away from precipitation area

A minority of the lowerings seen during a chase are legitimate wall clouds, and even fewer of those actually produce tornadoes. To determine the tornado potential of a wall cloud, look for these four main characteristics.

- **Persistence.** The wall cloud may undergo changes in shape, but it often exists under a thunderstorm base for 10-20 minutes or more before a tornado appears.
- **Rotation.** The wall cloud should exhibit persistent rotation for it to be a tornado producer. Often the rotation will be very visible and violent before the tornado appears.
- **Strong surface winds.** Wall clouds are a sign of intense inflow, and the circulation associated with the main updraft can extend all the way down to the surface. Thus, strong surface winds of 25-35 miles an hour are often observed blowing inward toward the wall cloud. If this wind is warm, it is a sign that the thunderstorm is still ingesting warm air and the circulation will continue to be maintained or strengthen.
- **Rapid vertical motion.** Since the wall cloud is associated with the strongest part of the updraft, it should exhibit strong vertical motions. Small cloud elements in or near the wall cloud should quickly rise up into the rain-free base.

Approaching the Tornado-producing Area of a Thunderstorm Safely

A tornadic thunderstorm must be approached properly to ensure the safety of the chase team. The tornado is not the only threat associated with tornadic thunderstorms. Rather, large hail, high winds, and excessive rainfall can result in driving hazards, loss of vehicle control, property damage, and personal injury. Therefore, it is exceedingly important that tornadic thunderstorms be approached with caution.

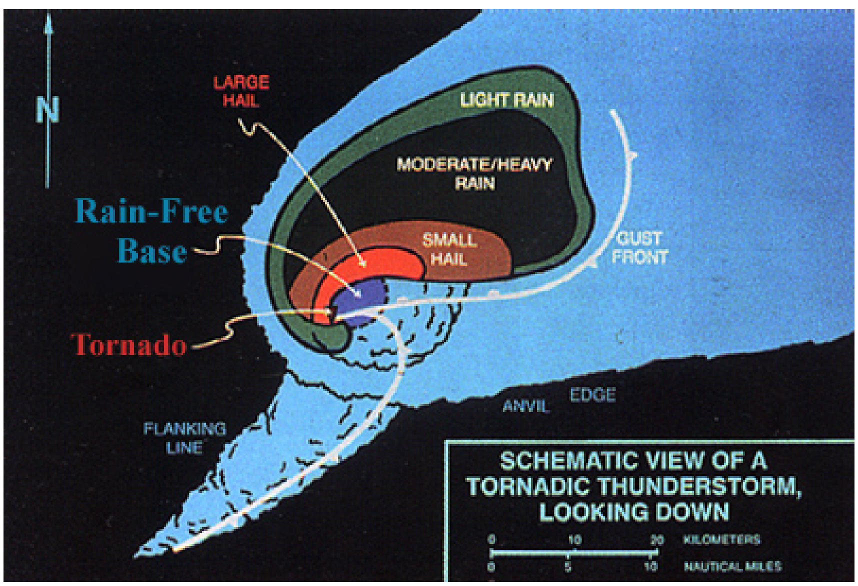

Figure 16. This is a top view of a tornadic supercell thunderstorm. This schematic shows where the rain-free base is located with respect to the rain shaft and the flanking line. Notice that the rain and hail are usually located to the north of the rain-free base (in dark blue). The best position to view tornado formation is to the southeast of the rain-free base, where there is no precipitation affecting visibility.

This image depicts the typical structure of a supercell thunderstorm. The lowered, rain-free base is located underneath the main updraft tower in the southwest quadrant of the thunderstorm, with the flanking line trailing toward the southwest. Typically, rain and hail surround the main updraft tower on the west, northwest, north, and northeast sides. This schematic shows that the best viewing conditions to see any tornado formation will be to the south of the main precipitation core. Thus, a storm chaser's goal is to arrive at this location, a mile or two south-southeast of the rain-free base, in order to intercept any tornado.

Caution must be used in reaching this position, however, in order to avoid the other hazards produced by a severe thunderstorm. The thunderstorm must be approached from the south or southeast, or else the chaser risks travel through the precipitation area in order to reach the proper position. Traveling through the precipitation core to intercept a tornado is called "core punching," and it is extremely dangerous. Not only does the chaser risk driving through heavy rains and large hail, but also the chaser does not have visibility until he is underneath the rain-free base and in the vicinity of any tornado that may exist. Knowing this, it is obvious that core punching should be avoided in order to protect lives and property.

If you find yourself to the south of the main updraft tower, you are in luck. You should plan a route that will bring you close to the southwestern flank of the thunderstorm, keeping in mind the thunderstorm will be traveling in some sort of easterly direction while you are trying to chase it. In other words, you should aim to the east of the current storm location so you don't end up behind the storm when you get closer to it.

If you find yourself to the north of the main updraft tower, you have some work to do. Most likely, you are not able to see the main updraft tower; instead, you will see the anvil and a large area of precipitation without any cloud definition. You have two options.

- **Skirting the eastern flank.** If you are far enough to the east of the storm, you can try to go around the eastern flank and under the anvil to get to the south side of the storm. There are some concerns with this approach, however. It is sometimes difficult to judge how far east to go to avoid the precipitation. Furthermore, the thunderstorm is likely traveling to the east or northeast. If you do not get far enough ahead of the storm, you may drive into the rain shaft and even run into hail. Also, the gust front extends to the east of the thunderstorm. This front is caused by the downdraft associated with the precipitation core, and often is associated with high winds that can be strong enough to cause property damage. Thus, any attempt to skirt the eastern flank of the storm should be done cautiously.
- **Skirting the western flank.** If you are far enough to the west of the storm, you can try to go around the western flank of the storm. In doing so, you would need to travel all the way around to the south side of the storm. This is because the hook echo, an area of precipitation that wraps around the main updraft tower due to the tower's rotation, will obscure your view of tornado development. Because of the organization of the supercell, going around the western flank will require more distance to be covered before visual confirmation of the rain-free base is made, as compared to the eastern route. Additionally, the storm will be moving away from you as you try to traverse the western flank, so keep this in mind.

There are some dangers associated with the western flank as well. First, it is possible for hail to be ejected into the clear air beside a thunderstorm. Thus, you may be driving close to the storm in seemingly rain-free skies and unwittingly drive into a hail shaft. It is important to keep at least a few miles between you and the hook echo to avoid this possibility. Also, there is a downdraft associated with the flanking line called the "rear flank downdraft" (RFD). The origins of the RFD are unknown, but recently the RFD has been linked to tornado formation. Winds around the RFD can be extremely strong, sometimes in excess of 100 mph. Often chasers following the rain-free base will notice dust clouds being whipped up to the left of the flanking line as the RFD smashes into the ground and spreads out in all directions. Thus, caution must also be exercised when traveling around the western flank of a storm.

Moving With the Tornado-producing Area of a Thunderstorm

Your chase is not over once you position yourself in the proper place to witness tornado formation. You need to maintain this position in relation to the moving storm to keep the rain-free base in sight and avoid being overtaken by the storm. Accomplishing this task requires some navigational skill, but you will be in much better shape if you keep in mind the following three rules.

The first rule to remember when moving with a storm is that it's better to be too far away from the storm than it is to be too close. Telephoto lenses were made for a specific reason; they allow photographers to be far away from the subject in their field of view. A chaser can get a better grasp of the overall storm structure (and beauty, in the author's opinion) from a distance as compared to being directly underneath the cloud base. Moreover, a storm can change directions erratically and with little warning. Keeping this in mind, try to plan a route that will keep your chase team a safe distance from the mesocyclone base.

The second rule is to not fall behind the storm. It is extremely difficult to catch up with a storm, especially when the storm itself is moving at a high rate of speed. Catching up with the storm involves a loss of time and a missed opportunity for a quality shot of the ongoing weather phenomena. If there is no tornado on the ground, it is best to continually adjust your position so that you are several miles ahead of the storm. That way, when a tornado finally does touch down, you can properly set up your equipment and get several minutes of quality shooting before you must move again. If you fall behind the storm, at best you will get a few minutes of jumpy video with trees, buildings, and vehicles getting in the way of your target.

The third rule is to always look ahead and plan a route tens of miles in advance. It is always best to be optimistic and to assume that the storm will be very long-lived. Knowing this, you need to plan your route following the storm for many miles in advance. Otherwise, the road you are currently on may unexpectedly turn directly towards the storm, leaving you pinned in a very dangerous situation. Always be mindful of the road ahead, and be sure to leave a buffer between you and the storm to stay safe.

Recognizing the Visual Appearance of a Tornado

Well, you've successfully arrived at a target, picked a healthy storm, and are positioned correctly to see tornado development. How do you know when you are actually seeing a tornado? This section will give you some pointers to help you discern between tornadoes and look-alikes.

Figure 17. This picture shows a typical developing tornado. Notice that the tornado is forming from a wall cloud (the lowering underneath the rain-base) that has a smooth appearance, and that the protrusion is nearly vertical in nature. These are all signs that the cloud extension is in fact a funnel cloud.

- Tornadoes and funnel clouds have a relatively smooth appearance to them. Often, chasers will see ragged cloud elements hanging below a rain-free cloud base, but these clouds are not associated with a tornadic vortex. Look for a smooth, continuous, cone- or needle-shaped protrusion from the cloud base.
- Tornadoes and funnel clouds often form under wall clouds, which are large, bowl-shaped lowerings underneath rain-free bases of thunderstorms. Tornadoes are not required to form from wall clouds, but a majority of them do. Thus any appendage extending from a wall cloud should be treated with suspicion.
- Tornadoes and funnel clouds will exhibit near-vertical axes of rotation. In other words, they will extend straight up-and-down from cloud base to ground. Some chasers are fooled by horizontal roll clouds, which exhibit strong rotation, but never touch the ground. These roll clouds are formed by outflow and pose no threat to life or property. Instead, look for a cloud extension from the cloud base that is nearly vertical.
- Tornadoes and funnel clouds will exhibit violent and persistent rotation. The winds inside a tornado average between 60 and 150 miles an hour, and can exceed 300 miles an hour. This strong wind blows cloud elements in the vortex quickly around the axis, which is visually evident. Harmless cloud protrusions will show no signs of rotation.
- Tornadoes and "funnel clouds" will often kick up large dust and debris clouds. If you see a funnel cloud whose funnel does not touch the ground, and there is a dust whirl below the funnel, the funnel cloud is actually a tornado. The definition of a tornado does not require the condensation funnel to touch the ground. Rather, it only requires that the spinning vortex be in contact with both the cloud base and the ground, and a dust whirl is evidence that the vortex has reached the ground. In many western states the air is too dry to support a funnel all the way down to the ground, so the tornado will remain relatively invisible until enough dust has been kicked up to reveal its location.

Terminating the Chase and Returning Home

If conditions become too dangerous because of low illumination, poor visibility, or other factors, you should terminate the chase. There is nothing to be gained by putting yourself in needless danger during a chase, even if the chase is or has been productive. Typically, chases are called off about one hour after sunset, when lighting conditions are too poor to discern cloud features. Chases can also be called off if individual storms coalesce into a line, making chasing dangerous and difficult.

Even after the chase has been called off, there is still a lot of work ahead for the storm chase team. Storm chasing often sends participants hundreds of miles from their homes, and they must either find a hotel in the vicinity or drive back home. If you have a long drive home, make sure to trade driving partners often to avoid fatigue, which is especially likely late at night and in dark driving situations. In addition, your chase team should be alert for thunderstorms that you may run into on your way home. On a chase day, thunderstorms often break out after the sun sets, because the cap weakens and updrafts can more readily form. Thus, your chase team may be forced to drive through strong to severe thunderstorms with torrential rains even after the chase is called off, making driving hazardous.

Figure 18. This tornado occurred near Bassett, Nebraska, on 5-Jun-1999. This picture exemplifies the typical structure under the rain-free base of a tornadic supercell. The tornado has formed from a large wall cloud, and has been on the ground long enough to kick up a dust cloud near the surface.

Appendix A

Glossary

anvil—The elongated upper portion of a thunderstorm cloud. An anvil is formed when strong winds in the upper levels of the troposphere blow cloud particles quickly downstream. Certain visual characteristics of the anvil yield clues about the intensity of the parent thunderstorm.

backsheared anvil—The portion of an anvil that extends away from the direction of motion of the storm. A backsheared anvil indicates a vigorous updraft and a particularly intense thunderstorm.

beaver's tail—An inflow band that emanates from the precipitation core. A beaver's tail indicates that the updraft is pulling in a large amount of air from the surface, which implies the thunderstorm is intense.

bust—A failed chase. Busts usually occur when no thunderstorms form, which is especially aggravating for a storm chaser. Chasers should take advantage of a bust day by seeing local tourist attractions or just enjoying the beauty of nature in the High Plains.

cap—A layer of warm, stable air in the lower to middle atmosphere. The cap prevents thunderstorms from forming until enough instability builds in the lower atmosphere to overcome the layer of stable air. Caps help to produce explosive thunderstorm growth when they are broken, but lead to busts when they are too strong and too many storms when they are too weak.

cold front—A boundary that separates warm, moist air from drier, cooler air. Cold fronts bring cooler conditions after they pass a location. Cold fronts also serve as triggers for thunderstorm formation, because lift occurs both ahead and along the cold front.

convective available potential energy (CAPE)—A meteorological parameter that helps to describe the instability of the atmosphere. Higher CAPE values lead to more intense thunderstorms and a higher likelihood for tornado formation.

convective inhibition (CIN)—A meteorological parameter that helps to describe the strength of the cap. If CIN is too low, thunderstorms will be too numerous to chase; if CIN is too high, thunderstorms will be unable to form.

convergence—Meteorologically speaking, convergence occurs when winds flow into each other. Convergence at the surface leads to lift in the atmosphere, which can initiate thunderstorm development.

cumulonimbus—Latin for "heap" and "rainstorm", cumulonimbus is just the proper name for a thunderstorm cloud.

cumulus—Latin for "heap", cumulus clouds resemble cotton balls or cauliflower florets. When conditions are favorable, cumulus clouds can grow into thunderstorms.

dewpoint—A measure of the amount of water vapor in the air. Dewpoints of over 55F are conducive to severe thunderstorm development.

downdraft—A current of downward-moving air, generated by the drag produced from falling raindrops. When strong downdrafts impact the surface, their winds spread out in all directions and can lead to strong wind events.

dryline—A line that separates higher dewpoint air from lower dewpoint air. Often in the High Plains in spring and summer, there is a sharp contrast in dewpoint over a very small spatial scale. This line can be a trigger for thunderstorm development because it provides lift.

Doppler radar—The newest radar system employed by the National Weather Service. This radar system is capable of discerning cloud droplet movement in thunderstorm clouds, and can thus pick out rotations associated with tornadoes.

flanking line—A line of cumulus clouds that extends to the southwest of the main updraft tower. Flanking lines usually have a stair-stepped appearance, with the tallest towers being closest to the main updraft. Flanking lines are an indication of good thunderstorm organization.

inflow band—A band of clouds formed when humid air rises into an updraft base and condenses. Inflow bands point to the base of the updraft, so they help the chaser to know where to look for tornado formation.

main updraft tower—The chimney of the thunderstorm. The main updraft tower is what transports air from the surface to the top of the troposphere, and it also supplies some of the rotation to form tornadoes. There are several visual clues given by the main updraft tower to indicate the intensity of the parent thunderstorm.

mesocyclone—The rotating updraft inside a thunderstorm. A majority of mesocyclones produce some sort of severe weather phenomena, and tornadoes most likely occur from mesocyclones. Mesocyclones typically span for several miles. They have a large, bowl-shaped appearance. Often, the counter-clockwise rotation is visually evident, and corkscrew-like striations twist through the lower levels of the updraft.

multicellular—A thunderstorm complex that consists of more than one cell. A squall line is a common example of a multicellular thunderstorm complex. Multicellular thunderstorms are difficult to chase, mainly because of the larger expanse of severe weather conditions.

National Weather Service (NWS)—A governmental organization charged with the duty of protecting the lives and property of United States citizens. The NWS issues forecasts several times a day, and they also issue warnings when conditions warrant.

outflow boundary—A boundary caused by thunderstorm downdrafts. Air is cooler behind outflow boundaries because of its rain-cooled nature. Outflow boundaries spread out away from thunderstorms, and can lift the air enough to cause new thunderstorms to form.

overshooting top—A dome-like structure that extends above the top of the anvil. Large and persistent overshooting tops indicate a strong updraft and an intense thunderstorm.

rain-free base—The flat, smooth part of a thunderstorm, usually located in the southwestern quadrant of the storm, from which little or no precipitation is falling. Tornadoes typically form in the rain-free base of a thunderstorm.

severe thunderstorm—A thunderstorm which meets at least one of the following severe criteria determined by the NWS:

- Tornado or funnel cloud
- Winds in excess of 58 miles per hour
- Hail with a diameter of 3/4 of an inch or greater

severe weather watch—Issued by the SPC when conditions are favorable for severe weather or tornado development.

severe weather warning—Issued by the NWS when severe weather is indicated on radar, or when spotters report severe weather conditions.

shelf cloud—A cloud feature that extends below the base of a thunderstorm. A shelf cloud indicates outflow from the storm, and tornadoes will almost never form from one. However, a shelf cloud could be a sign of high winds.

storm-relative environmental helicity (SREH)—A meteorological parameter that helps to describe how much the wind direction changes with respect to height in the atmosphere. High values of SREH indicate a lot of wind shear, which can help to organize thunderstorms and increase the chance of severe weather development.

Storm Prediction Center (SPC)—A governmental organization charged with the duty of forecasting severe local storm events to help provide advanced warnings to citizens. The SPC issues an outlook for the current day and the next day, every day of the year.

stratosphere—A level of the atmosphere just above the troposphere. The stratosphere is characterized by exceptionally stable air, and it acts as a lid. When thunderstorm updrafts run into the stratosphere, they stop their upward progress and spread out.

striations—Corkscrew-shaped streaks in the lower part of a mesocyclone that indicate storm rotation. Many people compare these striations to a barber pole.

supercell—A thunderstorm with an organization that allows it to be longer-lived. Supercells have downdrafts that are separated from the updrafts so that the supply of warm, moist air (the fuel for thunderstorms) is not interrupted.

Tail-end Charlie—The southern-most storm in a line of thunderstorms. Tail-end Charlie is the easiest storm to chase and often has the best chance of becoming tornadic.

target area—An area that a chaser shoots for because the chaser believes that the area will be a likely place for severe weather development.

tornado—A violently rotating column of air that connects to both the base of a thunderstorm and the ground.

troposphere—The lowest level of the atmosphere. Almost all weather occurs in the troposphere.

updraft—An upward moving current of air. Updrafts supply thunderstorms with warm, moist air. When these updrafts get cut off, the thunderstorm dies.

vertical development—A condition where cumulus towers seem to have a strong component of growth in the vertical direction. Typical cumulus clouds are wide and not very tall, and they signal fair weather. Skinnier, taller cumulus clouds show vertical development and signal an unstable atmosphere that is able to support thunderstorms.

VORTEX—A project developed in the middle 1990s whose goal was to study the factors that lead to the formation of tornadoes.

vorticity maximum—A complex weather term. Vorticity deals with the amount of spin in the air. Air tends to rise in front of a local maximum in vorticity.

wall cloud—A lowering in the rain-free base of a thunderstorm. Wall clouds indicate upward motion and form when moist air flowing into an updraft condenses before it reaches the cloud base. Persistent, rotating wall clouds indicate that tornado formation is likely.

warm front—A boundary that separates warm air from cooler air. Temperatures usually rise after a warm front passes a given location. Warm fronts can provide enough lift to initiate thunderstorm development.

wind shear—A change in wind direction and/or speed with height. Wind shear can be good for thunderstorms because it helps to organize their updrafts and downdrafts. However, if the shear is too strong, towers will tilt away from vertical and severe thunderstorm formation will be suppressed.

Appendix B

How to Report to the National Weather Service

As quoted from the NWS, when reporting severe weather you should include four important things:

1. WHO you are, and the name of your spotter group. This helps the NWS to determine the credibility of your report.
2. WHERE the event is occurring. This helps the NWS correlate field reports with radar observations.
3. WHAT you have seen (the severe weather event).
4. MOVEMENT of the event. When considering motion, just observe the storm as a whole; do not pay attention to the motion of smaller cloud elements.

These events are important to report to the NWS:

- **Tornado.** Any tornado development should be immediately reported to the NWS. Important things to report are as follows.
    1. The spotter location, in relation to what road you are on and the closest town. Quantitative answers, like mileage and exact directions, are very important.
    2. The location of the tornado in relation to the spotter. The exact distance between tornado and spotter is difficult to measure, and the NWS will take this into account when you make your report.
    3. The direction and speed of motion of the tornado. Direction of motion can be difficult to discern at first. If you are watching a tornado and it seems to be stationary (i.e. not moving right or left in your field of view), you must consider the possibility that it is moving away or more likely TOWARD your location.
    4. The size of the tornado. It is helpful to know if the tornado is slender or very wide.
- **Funnel cloud.** A funnel cloud is a vortex that has not touched the ground. However, funnel clouds are extremely dangerous and may become tornadoes at any time. Thus funnel clouds are often treated as tornadoes in warning situations. Report the same type of information that you would report for a tornado, namely the location of the spotter and funnel cloud, and the direction of motion.
- **Wall cloud.** Any lowering of the cloud base in a thunderstorm is suspicious and should be watched for cyclonic (counter-clockwise) rotation. If a lowering exhibits rotation and is long-lived, it should be reported to the NWS. Tornadoes often form from and are preceded by wall clouds. When reporting a wall cloud, include these facts:
    1. The spotter location, in relation to what road you are on and the closest town. Quantitative answers, like mileage and exact directions, are very important.
    2. The location of the wall cloud in relation to the spotter.
    3. The fact that the wall cloud IS rotating, and the duration of the lowering. Stress that you have been watching the lowering and have confirmed visual rotation. This lets the NWS know that you understand the difference between a wall cloud and a normal lowering, and they will place more confidence in your judgment.

- **Hail.** The NWS requests reports of 1/2 inch or greater. The actual criterion for severe hail is 3/4 inch, but it is helpful to know the size of hail that is occurring even if it is not large. Some things that should be included in a hail report are as follows:
    1. The spotter location, in relation to what road you are on and the closest town. Quantitative answers, like mileage and exact directions, are very important.
    2. The size of the hail. If you do not have a ruler or measure, you can estimate the size of hail as compared to everyday objects.

    Hail size estimates (diameter):

0.25”	Pea	1.75”	Golfball
0.50”	Marble	2.50”	Tennis ball
0.75”	Penny or dime	2.75”	Baseball
1.00”	Quarter	4.00”	Grapefruit
1.25”	Half dollar		

- **Winds.** The NWS requests reports of winds that gust to over 50 miles an hour, but the actual severe criterion is 58mph or greater. Some things that should be included in a wind report are as follows:
    1. The spotter location, in relation to what road you are on and the closest town. Quantitative answers, like mileage and exact directions, are very important.
    2. The intensity of the wind speed. If you do not have an anemometer (which you most likely won’t), you can estimate the intensity of wind speeds by noting their effects on everyday objects.

    Wind speed estimates:

25-31mph	Large branches in motion; whistling in telephone wires.
32-38mph	Whole trees in motion.
39-47mph	Leaves separate and twigs break from trees; wind impedes walking.
48-54mph	Small branches break from trees.
55-72mph	Large branches break from trees; damage to chimneys and TV antennas; wind pushes over trees with shallow roots.
73-112mph	Surfaces peel from roofs; windows broken; trailer houses overturned.
113+ mph	Roofs torn off houses; weak buildings and trailer houses destroyed; large trees uprooted.

- **Flash flooding.** Flash flooding should be reported, but the reporting criteria are not as well defined as with other severe weather events. A flash flood is defined as a rapid rise in water usually during or after a period of heavy rain. The local NWS office should be consulted with regards to flash flood reporting procedures, as they are often different in various regions of the Midwest.

Acknowledgements

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