



Photo © Steve Carey

## Introduction

The thrill of witnessing a tornado on the ground is hard to surpass. Each year thousands of storm chasers converge on the United States' Great Plains to get a shot at seeing this atmospheric phenomenon. The elements of adventure, awe, and curiosity draw people from all walks of life to get into their vehicles and travel the desolate expanses of Tornado Alley in search of severe weather. By reading this guide you've already expressed an interest in storm chasing and might be considering a storm chasing vacation if you haven't already booked one. Some of you may be reading this guide from the comfort of a Great Plains hotel room or in a storm chasing vehicle en route to a severe weather target area. Whatever the case may be, this short crash course is intended to give you better insight into how storm chasing works and prepare you for some of the things you'll see while out in the field. The amount of meteorology, technology, and observation that goes into finding tornadoes and severe weather is tremendous. Advances in each of these fields over the past decade have led to higher storm chasing success rates, but in the end Mother Nature has the final say in what kind of weather you'll see. Don't forget that tornadoes aren't the only type of severe weather worth searching for. Hail, violent straight line winds, and otherworldly storm structures are also awe-inspiring and can sometimes stir the same amount of excitement that a tornado would. If you're planning to chase storms with us soon or have already embarked on your adventure, I hope that you learn a great deal about how powerful our atmosphere is and witness some spectacular severe weather. Enjoy this guide and have fun!

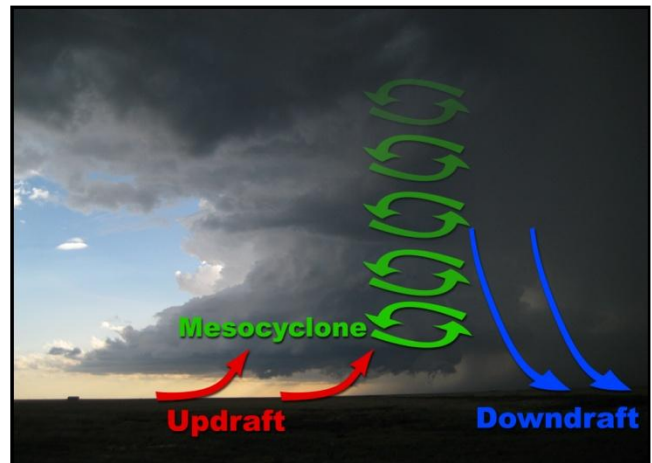
Ryan Hoke

Storm Chasing Adventure Tours Guide/Internet Developer

## Types of Severe Thunderstorms

### *The Supercell*

Supercell thunderstorms are the most preferred type of storm for storm chasers in the Great Plains. This single-celled storm has only one dominant **updraft** of moist, feeding air and one dominant **downdraft** of cooled air, rain, and possibly hail. The supercell's compact cumulonimbus structure makes it easy to observe and keep up with and its tendency to rotate makes it the most likely to produce strong, long-lived tornadoes. Supercells tend to rotate because the updraft lifts horizontally rotating air (a property known as vorticity) into a vertical column so that the axis of rotation is perpendicular to the ground. This rotating updraft of air is called a **mesocyclone** and is a precursor to the development of a tornado. Supercells typically move from southwest to northeast, but there are exceptions to this caused by abnormal wind direction and when a supercell splits into two separate storms.

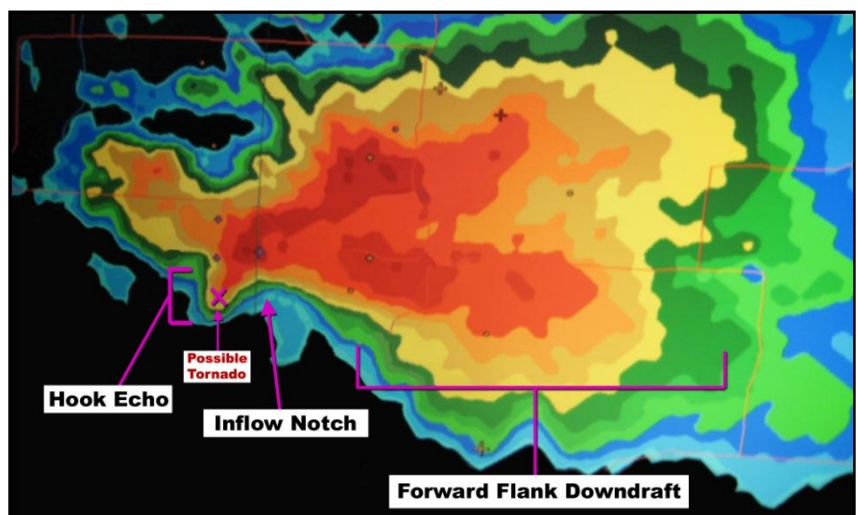




**Wind shear** allows the downdraft of this storm to be blown away from the updraft, which lengthens its lifespan considerably and differentiates it from standard airmass and pulse thunderstorms. The supercell's rain-free updraft base is easily seen in most cases in the Great Plains of the US, but there are instances when rain can wrap around and obscure it. The visibility of this updraft base is crucial because that is generally where tornadoes form. There are three classes of supercell thunderstorms: **Low Precipitation (LP)**, **Classic**, and **High Precipitation (HP)**. In a Low Precipitation (LP) supercell, the amount of rain that falls from the downdraft is minimal and the updraft base and other structure of the storm are clearly visible. LP supercells are great for storm chasing because of their visibility. Classic supercells have a much more balanced look because they appear to have equal areas of rain-free updraft space and rain-filled downdraft space. A High Precipitation supercell is the most difficult category to chase because the core of the rain and possibly hail-filled downdraft can wrap around the rain-free updraft base. This makes any additional development such as a funnel cloud or tornado very difficult to see. Supercells can either be one of the aforementioned types or morph into any or all of them during the different developmental stages of the storm.

Supercells have a few main components that are identifiable on Doppler radar:

**Hook Echo:** An easily identifiable visual “hook” on radar that indicates where the rising updraft of the supercell meets the rear flank downdraft, or the secondary downdraft of air that channels rain and hail around the north and west side of the storm. The tip of this hook shape is generally where you would find tornadoes.



**Inflow Notch:** The inner eastern (right) side of the hook echo where warm, moist air is sucked into updraft of the storm.

**Forward Flank Downdraft/Anvil:** The right side of a supercell that tends to fan out on radar is the spreading anvil cloud that drifts away from the main core of a supercell. This area contains the powerful primary downdraft that produces heavy rain and in some cases very large hail. The storm can taper off on the right side of this feature in a v-shaped fashion, which is called a V-notch.

## Mesoscale Convective System (MCS)

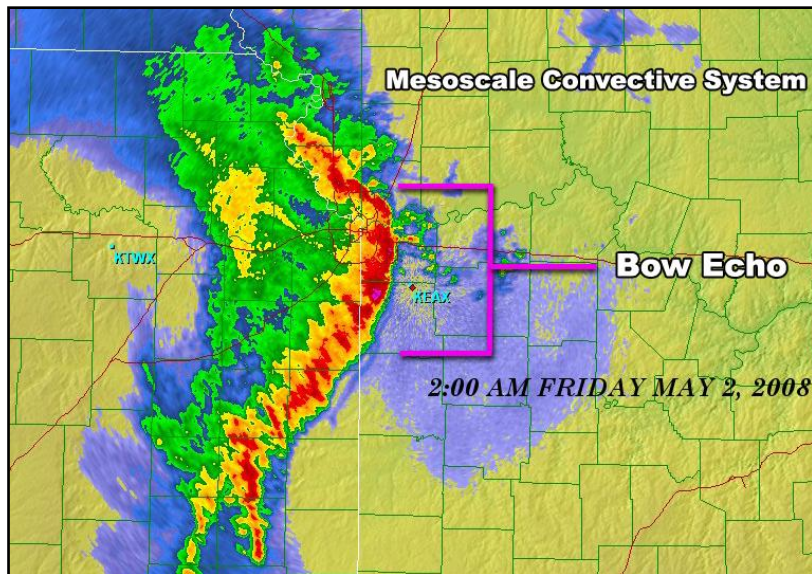
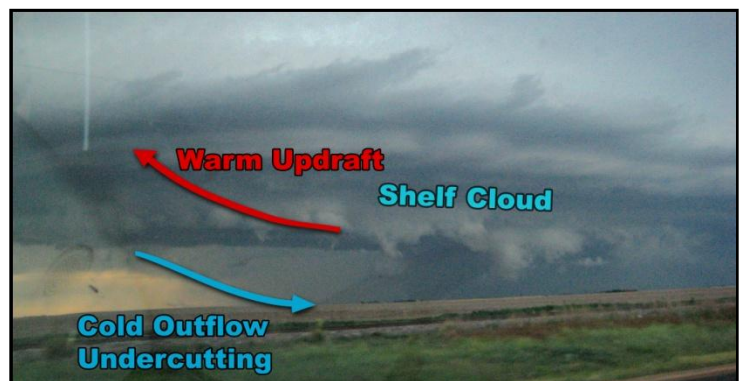


Image Credit: NWS WFO Kansas City/Pleasant Hill, MO  
<http://www.crh.noaa.gov/eax>

A mesoscale convective system (or squall line) differs from a supercell in that it is made up of multiple updrafts and downdrafts in different stages of development and is usually linear in shape. The cooled air from the interconnected downdrafts forms a cold pool on the backside of the system. The descending air in this cold pool pushes the entire linear system forward and can lead to the development of a wind-driven **bow echo**, or an MCS that has gained a bowing, arc shape on radar and produces intense straight-line winds. Tornadoes can form within mesoscale convective system where small notches in the linear shape of

the system allow eddies of air to circulate. MCS-spawned tornadoes are usually short-lived and not terribly strong, but nevertheless can produce significant damage. It is very difficult to chase tornadoes in an MCS because chasers must either travel to the southern tip of the system where broken supercells can occur (“Tail-End Charlie”) or look for stronger portions of the system that have rotation.

The visual tell-tale sign of a mesoscale convective system is the appearance of a shelf cloud, which is a type of arcus cloud. This phenomenon is caused by undercutting of the warm inflow of the system by cold outflow air from the rear. The shelf cloud usually delineates the **gust front** of the storm, or the sharp boundary of intense wind and cold air that precedes an MCS. Gust fronts can sometimes be just as dangerous as tornadoes because of the incredible straight-line winds they produce.



## Tornadoes

The most sought-after component of severe weather for storm chasers is without a doubt the tornado. While this phenomenon is both feared and revered by people around the world, it is a relatively rare occurrence since only 30% or less of supercells produce tornadoes.<sup>1</sup> Both supercells and MCS-type severe storms can produce tornadoes as previously mentioned, but the supercell is a better candidate for strong tornado production due to its longevity and inherent rotational characteristics. The exact reasons behind why some supercells produce

<sup>1</sup> NWS Louisville: Supercell Structure and Dynamics. <http://www.crh.noaa.gov/lmk/soo/docu/supercell.php>

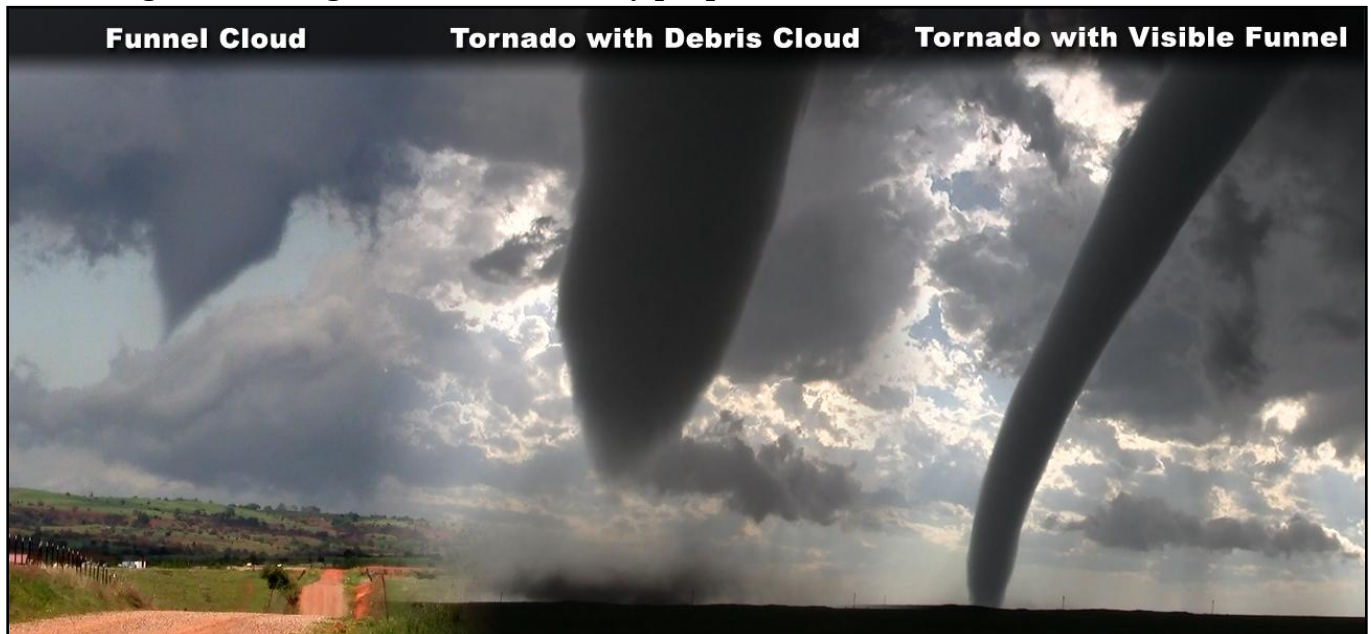
tornadoes and why others don't are currently unknown. Given these uncertainties, most tornadoes do form underneath a **wall cloud**, or a compact, rotating cloud that hangs down from the larger rain-free base underneath the mesocyclone.

It is well-known that the United States has the most tornadoes of any country in the world. The Great Plains in the center of the country plays a key role in this because it is a wide, uninterrupted expanse of flat land that allows cold, dry air masses from Canada to meet with warm, moist air masses from the Gulf of Mexico. This meeting of the two types of air masses in the spring generates severe weather and the best conditions for tornado development. The Southern region of the United States also experiences quite a few tornadoes, but the amount of thick vegetation and hill-laden topography makes it extremely difficult to chase them. The Great Plains' notoriety for tornadoes in the spring has led to its nickname of **Tornado Alley**, which is commonly used in the media and colloquially among residents of the US. On the right, you'll see a map of the most current area defined as "Tornado Alley," which has changed slightly over the years due to new research and statistics.



Image Credit: Tarp, Keli - Clues from Climatology: When and Where Do Tornadoes Occur?  
[http://www.research.noaa.gov/spotlite/archive/spot\\_climatology.html](http://www.research.noaa.gov/spotlite/archive/spot_climatology.html)

It is important to know the exact definition of a tornado before trying to visually identify one. It is defined as "a localized and violently destructive windstorm occurring over land characterized by a funnel-shaped cloud extending toward the ground."<sup>2</sup> Particular emphasis should be placed on the phrase "extending toward the ground" because many people confuse **funnel clouds**, which are



<sup>2</sup> <http://wordnetweb.princeton.edu/perl/webwn?s=tornado>

essentially the early stages of tornadoes that haven't touched the ground yet, and actual tornadoes. For a funnel cloud to be considered a tornado it must extend all the way to the ground or a visible disturbance of dust called a debris cloud must be present. Tornadoes that have debris clouds under them, but do not have a funnel that reaches all the way to the ground simply don't have the right conditions for water droplets to condense out of the air to create a visible funnel. On the previous page you'll find some examples of funnel clouds, tornadoes, and tornadoes without funnels reaching the ground.

Tornadoes in the United States are classified by the **Enhanced Fujita Scale (EF)**, which is an update to the original Fujita Scale devised in the 1970's. The scale goes from EF-0 to EF-5 with ascending tornado intensity, but the rating assigned to a specific tornado does not come from a measured or estimated wind speed as commonly thought. Instead, the National Weather Service assigns ratings to tornadoes based on damage surveys conducted by engineers and meteorologists. The EF rating assigned to a tornado from a damage survey contains an estimated wind speed, but again, measuring the actual wind speed of a tornado is nearly impossible without the correct mobile radar equipment. Below you'll find a chart of the Enhanced Fujita Scale and the damage associated with each rating.

Rating	Wind Speed (mph)	Wind Speed (km/h)	Damage
EF0	65–85	105–137	Minor or no damage. Peels surface off some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over.
EF1	86–110	138–178	Moderate damage. Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.
EF2	111–135	179–218	Considerable damage. Roofs torn off well-constructed houses; foundations of frame homes shifted; mobile homes completely destroyed; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
EF3	136–165	219–266	Severe damage. Entire stories of well-constructed houses destroyed; severe damage to large buildings such as shopping malls; trains overturned; trees debarked; heavy cars lifted off the ground and thrown; structures with weak foundations are badly damaged.
EF4	166–200	267–322	Extreme damage. Well-constructed and whole frame houses completely leveled; cars and other large objects thrown and small missiles generated.
EF5	>200	>322	Total Destruction. Strong framed, well built houses leveled off foundations and swept away; steel-reinforced concrete structures are critically damaged; tall buildings collapse or have severe structural deformations.

Source: Storm Prediction Center <http://www.spc.noaa.gov/efscale/ef-scale.html>

## Hail

Hail is a particularly hazardous form of precipitation that originates from severe thunderstorms and weaker storms in high elevations. These irregular lumps or stones of ice range in size from peas to grapefruits and in some cases even larger. Hail with diameter of one inch (2.5 cm) and greater is considered severe and has the ability to cause severe damage to crops, vehicles, animals, and even permanent man-made structures. The formation of hail

focuses mainly on the **anvil** portion (or top) of a thunderstorm, where liquid water freezes on contact with particles (nuclei) to initiate hail formation. The strong updraft of a severe thunderstorm prevents the forming hail stones from falling until they've reached a certain weight at which the updraft can no longer support their continued circulation around the storm. This convective circulation of developing hail stones from the top to bottom of a storm and back again causes melting and refreezing. This process gives hail its distinctive white coloring and concentric

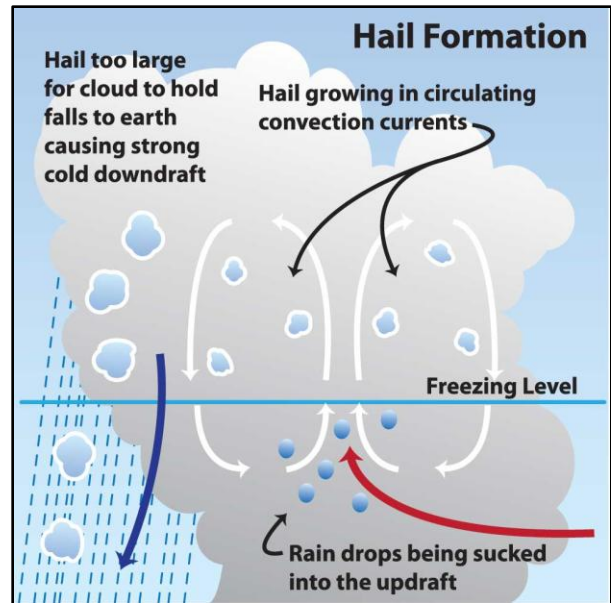


Image Credit: NC State – Severe Weather Hazards  
<http://www.nc-climate.ncsu.edu/edu/k12/SevereWeather>

ring pattern when an individual stone is cut in half.

In regard to storm chasing, hail makes intercepting a supercell thunderstorm more cumbersome because of avoidance measures that have to be taken. Getting caught under

the main “hail core” of a thunderstorm can spell big trouble because these storms can easily produce baseball-size hail stones. Damaged or broken windshields, vehicle body damage, and even bodily harm can occur if a storm chaser is not mindful about their location relative to the hail core. Usually, a majority of hail falls inside of the main downdraft of rain and cold air, so it is relatively easy to identify and avoid that portion of the storm. The problem is that the edge of this hail-prone area of a supercell lies right next to the rain-free updraft base where tornadoes form. As long as a storm chaser is aware of their location relative to these features and moves accordingly, the risk of hail damage remains low.

The table on the right has a comparison of hail sizes and common objects, along with the updraft wind speed needed to produce hail of a certain size. It's worth noting that the use of the term “marble” size hail is slightly ambiguous because marbles tend to come in all shapes and sizes. It's best to find an object like a coin or other specific item to compare hail size to in order not to confuse the recipient of the hail description.

Hailstone size	Measurement		Updraft Speed	
	in.	cm.	mph	km/h
bb	< 1/4	< 0.64	< 24	< 39
pea	1/4	0.64	24	39
marble	1/2	1.3	35	56
dime	7/10	1.8	38	61
penny	3/4	1.9	40	64
nickel	7/8	2.2	46	74
quarter	1	2.5	49	79
half dollar	1 1/4	3.2	54	87
walnut	1 1/2	3.8	60	97
golf ball	1 3/4	4.4	64	103
hen egg	2	5.1	69	111
tennis ball	2 1/2	6.4	77	124
baseball	2 3/4	7.0	81	130
tea cup	3	7.6	84	135
grapefruit	4	10.1	98	158
softball	4 1/2	11.4	103	166

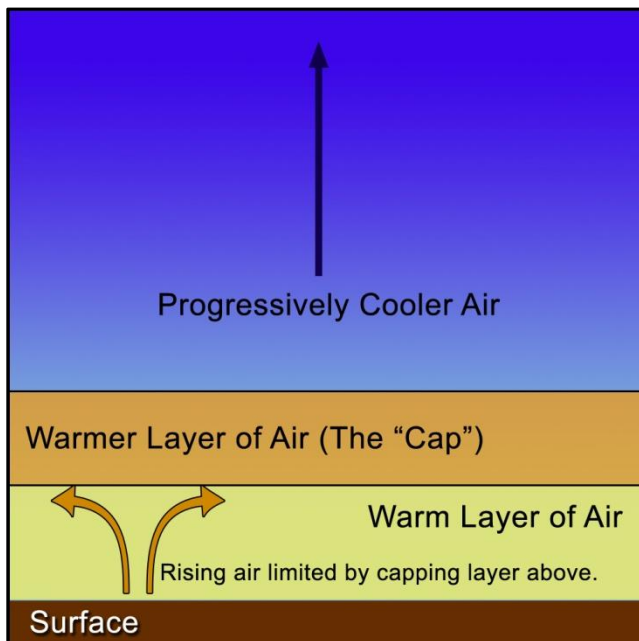
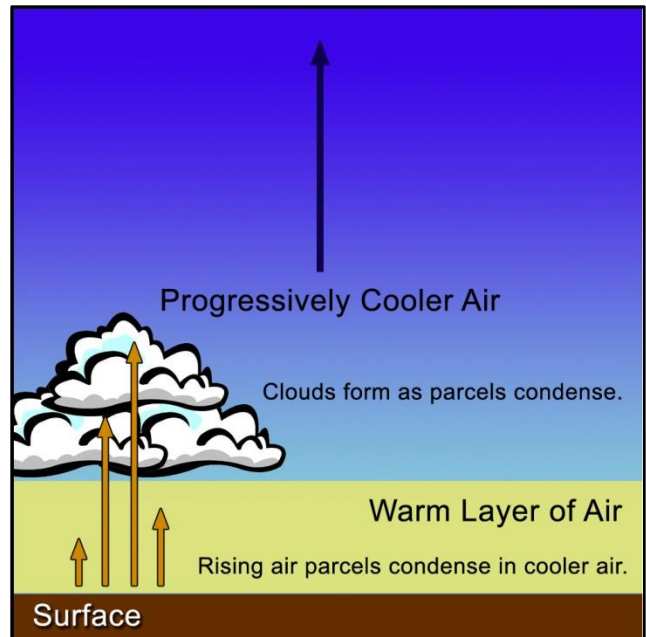
Image Credit: The National Weather Service

# Severe Weather Ingredients

Severe weather requires the gathering of multiple atmospheric ingredients in just the right way. While there are many variables that go into the genesis of severe storms, the chief of these are instability, lift, moisture, and shear. In the Great Plains of the United States, the right amounts of these ingredients usually come together in the spring and sometimes early summer to form severe thunderstorms and tornadoes.

## Instability

Atmospheric instability is characterized as an air parcel's tendency to lift from a lower level of the atmosphere to a higher level. For this to happen, the air parcel (usually near ground level) needs to be warmer than the air above it. Since warmer air is less dense than cooler air, this parcel is allowed to rise to a level where the air is the same temperature or until it cools to reach the surrounding air temperature at a certain altitude. While this parcel rises and cools, the moisture contained in it condenses and forms a cloud. Greater instability can build clouds that reach higher altitude, which is essential for developing the towering cumulonimbus cloud that makes up a supercell thunderstorm.



Even if a layer of air near the surface is very warm and full of moisture, sometimes it does not rise due to a **capping inversion**, which is the presence of a warmer layer of air above it. This warmer layer above the surface can be overcome by solar heating of the surface, which in turn heats up the layer of air just under the cap. Once the surface air mass surpasses the temperature of the "capping" layer, it can then proceed to rise. Sometimes a capping inversion is so strong that it does not allow any air parcels to rise, thus not allowing thunderstorms to form. Ironically, a capping inversion is actually essential to severe weather outbreaks. This limiting layer of air acts as a filter that allows air parcels with very strong upward motion (instability) to punch through while suppressing parcels that don't have enough

upward momentum to make it through this layer. This limits the number of storms that form, which means each individual storm has more resources to work with because the number of surrounding thunderstorms is limited. The lack of surrounding thunderstorms prevents



contamination of the updraft for an individual supercell storm and allows it to grow to a greater strength and size.

The amount of instability present in an air mass is measured as CAPE (Convective Available Potential Energy). CAPE values above 1500 J/kg are regarded as conducive to severe weather and supercell formation, but most significant severe weather outbreaks in the Great Plains occur when CAPE values surpass 2000 J/kg. Instability alone is not enough to make severe weather, but sometimes the lack of instability can be made up for by other elements like lift and shear.

## Lift

For thunderstorms to form there needs to be a triggering lift mechanism that begins the upward motion of air parcels. There are a host of different phenomena that contribute to lift, but the main sources that storm chasers look for are fronts, outflow boundaries, and orographic lift. Fronts are fairly simple sources of lift because they are easy to find on a map and span many hundreds of miles. A **cold front** is usually the trigger for more widespread severe weather outbreaks because of its strong division between cold air from the north and west with warmer, moister air to the south and east. The dense cold air behind this front creates lift as it displaces warmer, less dense air upward. A cold front branches off of the southern portion of an area of low pressure, or mid-latitude cyclone, to which a warm front lies to the east.

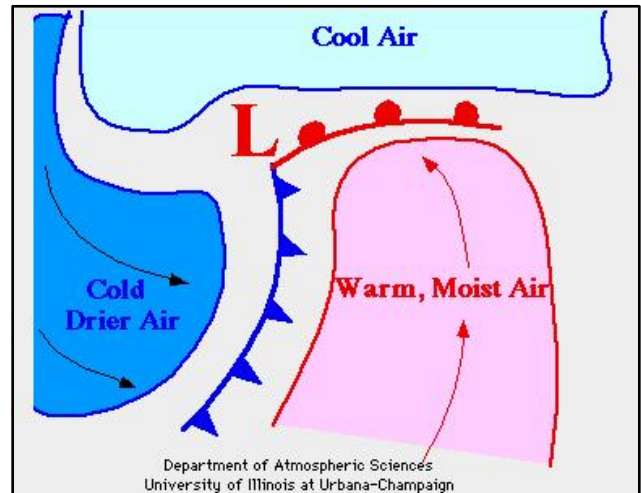


Image Credit: <http://cimss.ssec.wisc.edu/oakfield/cyclone.htm>

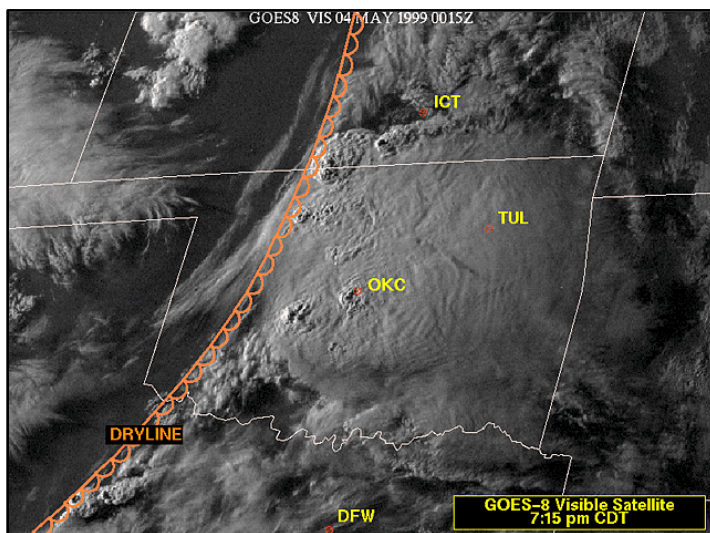
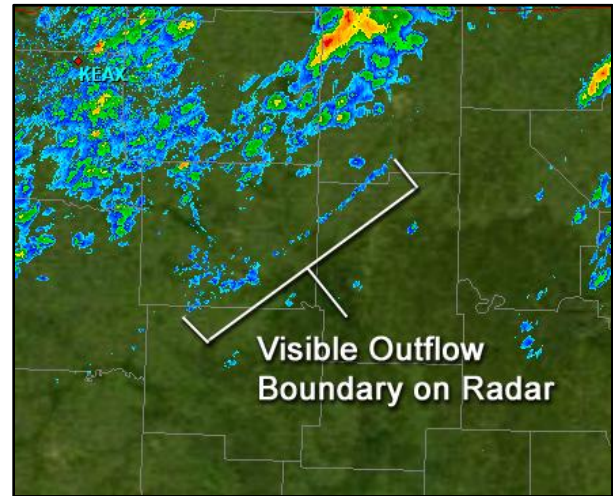


Image Credit: National Severe Storms Laboratory <http://www.nssl.noaa.gov/news/may3rd/satellite.html>

Warm fronts can also act as lift mechanisms for storms, but generally they do not have the right winds, moisture flow, and temperatures to produce severe weather. A dry line is another type of front that storm chasers generally look for when forecasting storms. While this feature may not have the word “front” in its name, it shares quite a few things in common with a front. A **dry line** is simply the boundary between moist air to the east and dry air to the west, which is sometimes called a “dewpoint front”. So instead of temperature being the dividing factor as a standard front has, the dry line divides air of different moisture content (dewpoint). As the dry line moves eastward during the daytime, the dry air behind the line wedges under the moister air to the east and thus creates lift for thunderstorm formation. This feature is commonly found in Texas, Oklahoma, and

Kansas and is often the focus for the formation of supercell thunderstorms, either isolated or scattered.

In combination with the more widespread lift mechanisms of fronts and the dry line, smaller sources of lift like outflow boundaries act as immediate triggers for storm development. An **outflow boundary** is the division between the cold outflow from a thunderstorm and the surrounding air. These small areas of advancing rain-cooled air act as lift mechanisms that can trigger a thunderstorm when all the other ingredients are in place. Often you'll see the convergence or collision of outflow boundaries, which usually results in the formation of a thunderstorm where this takes place because of the enhanced lift generated by this event.



Detecting outflow boundaries on radar requires a keen eye because of how subtle they can be, but the availability of higher-resolution radar data over the past few years has made this easier. When all other ingredients are in place, outflow boundaries act as a fantastic source of isolated lift for the formation of supercell thunderstorms.

Finally, the other major source of lift involved in severe thunderstorm development is orographic, or **upslope flow**. This is a relatively simple source of lift because it involves air rushing up the eastern slopes of the Rocky Mountains. This mainly occurs on the gently sloping grasslands of Eastern Colorado, which often serves as a reliable zone for storm development because of the always-present source of lift. Upslope flow thunderstorms aren't as famous for their severity as storms generated by the dry line and cold fronts, but they are very capable of producing tornadoes and even more so producing hail because of the increased elevations.

### **Shear / Winds**

For severe weather to develop, winds at different levels of the atmosphere must have differing speeds and directions. This property known as **wind shear** is crucial because it dictates how long a storm will last and what kind of rotational characteristics it will have. For most severe weather setups in the Great Plains, winds at the surface need to be out of the southeast or east while winds aloft at 500mb (18,000ft or 5,500m) need to come from the southwest. The winds at 500mb usually "steer" the storms that form, so that's why most supercells in the Plains move from southwest to northeast. This change in wind direction with height, also known as helicity, is also important because it blows the anvil and downdraft of a supercell away from the updraft base where tornadoes form.



In severe weather situations where winds at the surface are blowing from the south or southwest, storms may form but tornado development is unlikely. Southeast winds are needed at the surface because they blow into a storm at an angle that is more perpendicular to the steering winds aloft, which also provides a steady source of warm, moist air. This increases rotation potential in the lower levels of supercells and the potential for tornadoes to form.

Winds aloft from the southwest are very important for the development of storms because they do two things: 1) Blow drier, cooler air over moist, hot air and 2) creates shear when surface winds are out of the southeast/east. As indicated in the previous section about instability, cold and dry air aloft is essential for creating an environment where warm air parcels rise. A pocket of warm air in a cold, dry environment will always be buoyant, so the introduction of dryer air in the upper levels of the atmosphere from the southwest by the

steering winds aloft will aid in making the environment unstable for severe weather. It's easy to remember that winds aloft need to be from the southwest because the source of the dry air these winds bring in is the desert Southwest of the US.

## Moisture

Moisture is simply the presence of water vapor in the air. Since clouds are made of condensed water vapor and rain is an even heavier version of that, it makes sense that ample moisture is required for the development of severe thunderstorms. **Dewpoint** is a measure of moisture in the air. Given in either degrees Fahrenheit or Celsius, the dewpoint is the temperature at which the moisture in the air will condense into water droplets. Let's say the dewpoint is 60 degrees and the air temperature is 65 degrees. As the air temperature falls closer to 60 degrees from 65, the air will near its maximum moisture content. When the air temperature and dewpoint are both 60 degrees, liquid water will condense out of the air because it cannot hold anymore water vapor. This either manifests as dew on the ground or clouds aloft depending on where this meeting of temperature and dewpoint takes place.



Since a higher dewpoint means more moisture in the air, storm chasers always look for areas with high dewpoints when targeting areas for storm formation. During the spring tornado season in the Great Plains, a dewpoint of over 60 degrees at the surface is conducive for severe storm development. This high level of moisture increases instability because rising air parcels will not cool quite as quickly since moist air loses heat slower than dry air when rising. In Eastern Colorado and Wyoming, dewpoints only need to be about 45 degrees or higher because the higher elevation compensates for lack of moisture. The source of this moist air is the Gulf of Mexico, which is southeast of the Great Plains.

## NOAA and the National Weather Service



The National Oceanic and Atmospheric Administration (NOAA) is a division of the United States Department of Commerce that handles scientific research and application in the fields of oceanography, meteorology, and related fields. Within NOAA is the National Weather Service (NWS), which is tasked with protecting life and property through weather forecasting and data dissemination. The National Weather Service operates 122 local weather forecast offices (WFOs) that handle weather forecasting duties and coverage of severe weather situations across the United States and its territories. Weather forecast offices have the ability to issue severe weather alerts such as advisories, watches, and warnings. These weather alerts are distributed through the internet, local/national media, and NOAA Weather Radio. The most common types of alerts you'll see while storm chasing are as follows:



- *Severe Thunderstorm Watch* – Conditions are becoming favorable for severe thunderstorm development within the next few hours. (Issued by SPC)
- *Severe Thunderstorm Warning* – A thunderstorm is ongoing in the warning area either indicated by Doppler radar or storm spotters that has 1in (2.5cm) or greater diameter hail and/or winds greater than 58mph (95km/h).
- *Tornado Watch* – Conditions are becoming favorable for severe thunderstorms capable of producing tornadoes within the next few hours. (Issued by SPC)
- *Tornado Warning* – A thunderstorm with rotation indicated by radar is ongoing in the warning area and has the potential of producing a tornado *or* a tornado has been sighted by storm spotters in the warning area.
- *PDS Tornado Watch* – A Particularly Dangerous Situation Tornado Watch is issued by the Storm Prediction Center when a widespread and dangerous tornado outbreak is expected. This type of watch is very rare and often precedes an historic tornado outbreak. (Issued by SPC)

Each of these alerts encompasses a polygonal area that can stretch across multiple counties. This has changed from a system where warnings were issued by county instead of polygon.

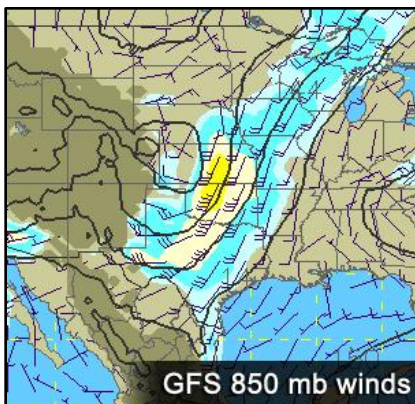


The Storm Prediction Center (SPC) is a branch of the National Weather Service based in Norman, Oklahoma that deals exclusively with severe weather forecasting and operations. Besides issuing severe thunderstorm and tornado watches that span across multiple local weather forecast office coverage areas, the SPC also issues

convective outlooks. These convective outlooks detail geographic risks of severe weather anywhere from one to eight days in advance by using a ranking system that includes the categories of Slight, Moderate, and High risks. Each ranking carries percentage probabilities for each element of severe weather (wind, hail, and tornadoes) along with a general percentage probability of severe weather in the indicated area. Storm chasers use these convective outlooks to gain a general sense of where severe weather may occur, but these products are neither precise enough nor intended to provide storm chasers with specific target areas for finding tornadoes. These outlooks are intended for public awareness of severe weather risks on a given day and are used widely throughout the broadcast media to augment the understanding of severe weather forecasts.



## Forecasting and Nowcasting



Forecasting severe weather requires the use of computer-generated weather forecast models and current weather observations. Computer forecast models provide storm chasers and meteorologists alike with the predicted movement and location of storm systems, wind direction, upper-atmospheric conditions and a number of other important variables. These computer forecast models work by applying complex meteorological equations to current weather observations around the earth in order to estimate how these conditions will change in the future. Models are a great way to predict weather many days in advance because of their ability to produce forecasts from vast amounts of data and equations that would

overwhelm a human forecaster. Some of the most popular computer forecast models that storm chasers and meteorologists use are listed below:

- *Global Forecast System (GFS)* – Global model produced by NOAA  
Predictions out to 16 days
- *North American Mesoscale model (NAM)* – Regional model produced by NOAA  
Predictions out to 4 days
- *Integrated Forecast System (ECMWF or Euro)* – Global model produced by the European Centre for Medium-Range Weather Forecasts  
Predictions out to 10 days
- *Rapid Refresh (RR)* – Short-range regional model produced by NOAA  
Predictions out to 18 hours

Nowcasting differs from forecasting in that it involves predicting weather only a few hours in advance. In most cases nowcasting involves the use of Doppler radar, surface and upper-air observations, and satellite imagery to detect and track small-scale atmospheric phenomena that computer forecast models cannot detect. These small-scale phenomena like sudden wind changes, outflow boundaries, and clear slots in a field of clouds happen so quickly and affect so small of an area that computer models don't have the time or means to react and change a forecast based on these observations. Some short-range models like the aforementioned Rapid Refresh (RR) are more capable of picking up some of these changes and producing a more accurate short-range forecast, but a pair of eyes and raw weather observations are the best tools when forecasting the precise location of storm development later in the day. Some storm chasers will look at short-range models in the morning before a severe weather event, but when chasers are out in the field and in nowcasting mode, weather observations are the primary source of information.

The data that a storm chaser may use to pinpoint the location of potential severe storm development may come from a wealth of sources, but the basic types of observations are the same:

### **Satellite Imagery**

Satellite images are the “eyes in the sky” for storm chasers. They allow chasers to see where clouds are forming, where they're not, the height and temperature of clouds, and where water vapor is present. Respectively, these types of imagery are called visible, infrared, and water vapor images. When in the minutes and hours before storm development the visible satellite image, essentially a plain picture of the atmosphere with only visible light appearing on the image, is a storm chaser's best tool. These high-resolution images allow real-time monitoring of cloud development, which often gives a good indication of where storms

are forming before they appear on radar. Often chasers will target an area for severe storm development that has no clouds because storms that form within that zone after the aforementioned “cap” has broken will have no surrounding clouds to disturb their development. Storms that form in areas where a layer or shield of stratus clouds is present often do not develop fully due to low atmospheric instability. Supercell thunderstorms usually start off as tiny specks of white cloud on visible satellite images, but quickly grow into monstrous plumes with anvils that can cover large areas. Intercepting these storms while they're small specks on satellite and not even appearing on radar is the best way to experience the complete cycle of a supercell and hopefully witness a tornado.

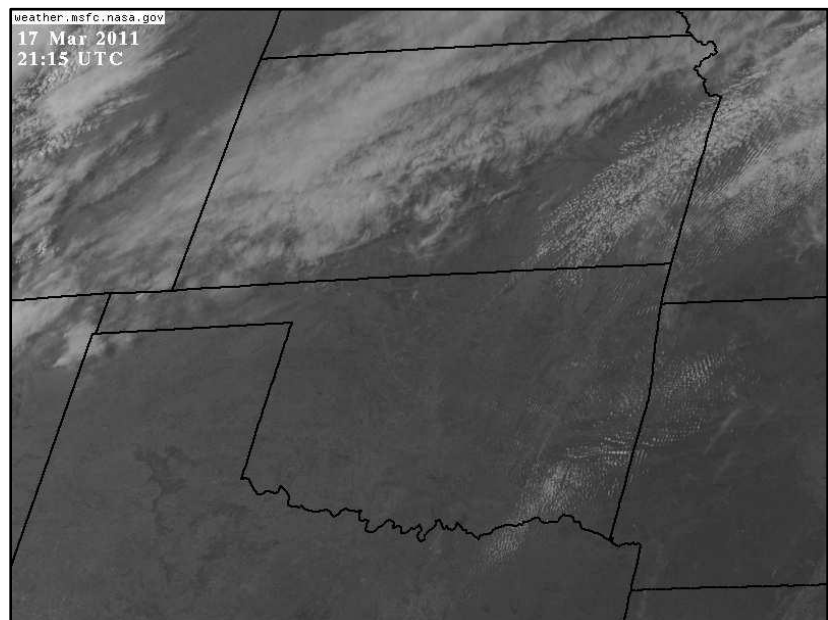


Image Credit: NASA Earth Science Office  
<http://weather.msfc.nasa.gov/GOES/>

## Surface Observations

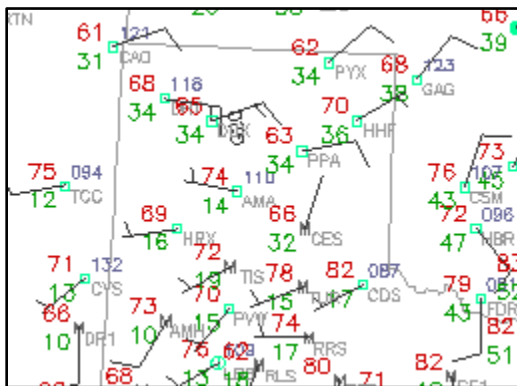


Image Credit: The National Center for Atmospheric Research  
<http://www.ral.ucar.edu/weather/surface/>

Surface observations are crucial to refining the forecast location of where storms will develop. These observations provide updated information on winds, temperature, dewpoint, pressure, and sky conditions at a certain location. When this data for multiple observation locations is plotted on a map, forecasters and chasers are easily able to find where fronts and boundaries are located due to the differences in data between observation locations.

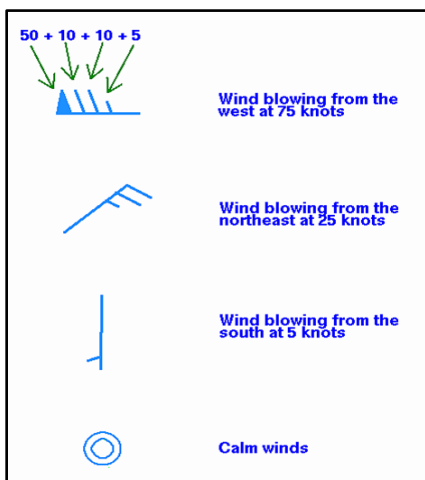


Image Credit: University of Washington  
<http://www.atmos.washington.edu>

To use these surface observation maps, users must know how to read **station plots**. Station plots are a compact way of representing weather conditions at a location through a set of symbols, numbers, and wind barbs. The most basic and visible part of the station plot is the wind barb. The wind barb points in the direction *from* which the wind is blowing, with each barb representing an amount of wind speed in knots. Half barbs represent 5 knots of wind, full barbs represent 10 knots of wind, and a triangular flag represents 50 knots of wind. When multiple barbs are present on a wind vector, just add the value of the barbs

together to find the wind speed. To convert the wind speed to miles per hour, simply multiply the amount of knots by 1.15 or 1.85 for kilometers per hour. Other parts of the station diagram are labeled in the graphic to the right and include temperature, dewpoint, pressure, sky cover, and current weather conditions.

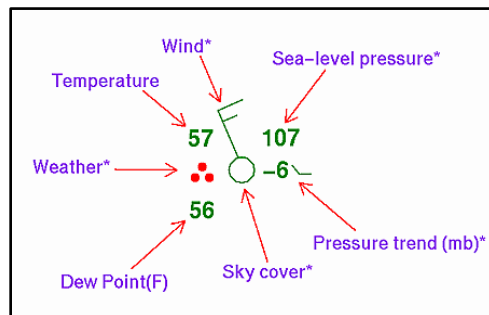
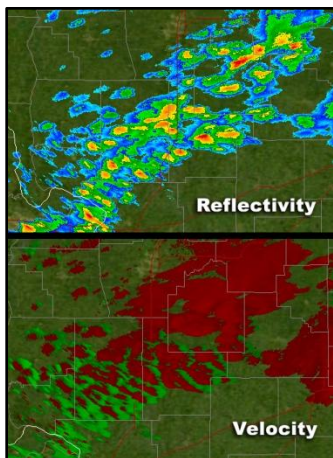


Image Credit: Hydrometeorological Prediction Center  
<http://www.hpc.ncep.noaa.gov>

## Doppler Radar



Doppler radar is quite possibly the most crucial storm chasing tool second only to a pair of human eyes. Doppler radar in a simple definition shows the locations of storms and their intensities on a map. It works by sending out a pulse of microwave radiation out in all directions and receiving feedback (reflectivity) from water droplets or rain. By continuously sending out and receiving these pulses in a spinning 360-degree motion at different angles, the radar can paint a very detailed picture of the intensity and location of the surrounding area's storms.

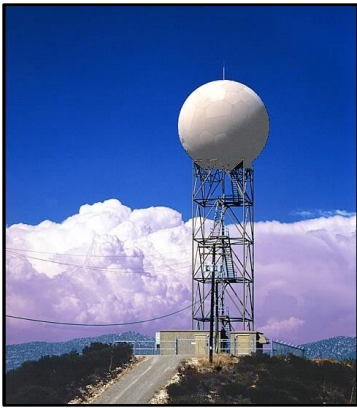
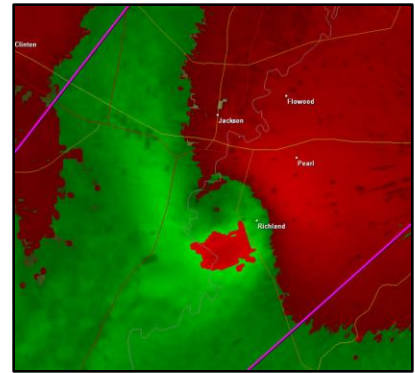


Image Credit: Storm Prediction Center  
<http://www.spc.noaa.gov>

A Doppler radar can also measure the velocity of the winds in a storm by detecting differences in the frequency between the outbound and inbound microwave pulses, indicating the movement of water droplets or ice within a cloud. This difference in frequency due to movement is the foundation of a phenomenon called the Doppler Effect, which was discovered in 1842 by Christian



Doppler<sup>3</sup>. Storm chasers and meteorologists most often look for a compact notch of bright green and red coloration called a **velocity couplet**. This couplet indicates where incoming and outgoing winds relative to the radar's position are very tight, which is a sure-fire sign of rotation and the presence of a mesocyclone in a storm, which is necessary to make a tornado. Very strong and obvious velocity couplets (such as the one on the top right of this page) can indicate a strong tornado in progress, especially if debris in the air is being picked up by radar.

Modern-day US Doppler radars scan the skies continuously through a series of aforementioned elevation angles, or tilts. To gain a better idea what storms are present in different levels of the atmosphere the radar makes a complete scan of the surrounding area at a certain elevation angle, tilts up slightly, makes a complete scan at that elevation angle, then repeats the process over again for successive tilts. Higher elevation angles are useful for nearby large storms, but the lowest elevation angle (0.5°) is useful for all storms all the way out to 143 miles (230 km) from the radar site. Radar images are updated every 4-6 minutes and are widely available to the public through a variety of public and private outlets.

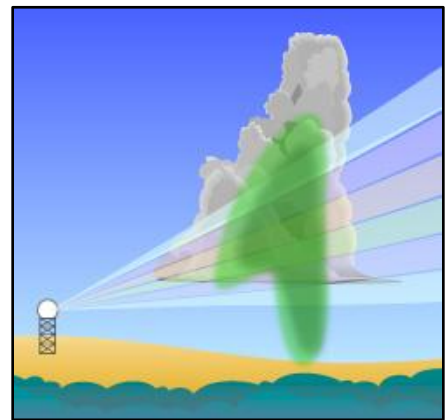


Image Credit: NWS JetStream School  
<http://www.srh.noaa.gov/jetstream/>

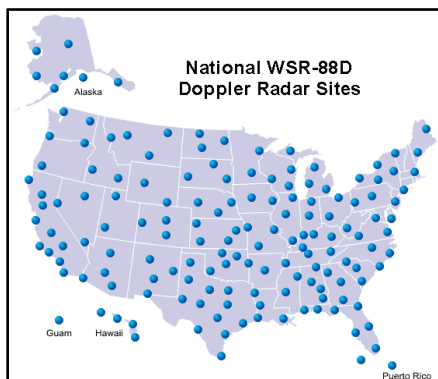


Image Credit: NWS WFO Louisville, KY  
<http://www.crh.noaa.gov/lmk>

The current network of radars in the United States consists of 159 NEXRAD WSR-88D radars operated by the National Weather Service's Radar Operations Center strategically positioned at various locations throughout the country to avoid gaps in coverage and to provide some overlap. For storm chasers, these radars provide easy-to-use data that indicates if and where rotation is occurring in a storm, the potential for hail, and how fast storms are moving. Recent advances in mobile broadband internet technology allow storm chasers to access this high-resolution radar data from a computer or smartphone while in the field chasing storms.

<sup>3</sup> Russell, Daniel. Kettering University. *The Doppler Effect and Sonic Booms*.  
<http://paws.kettering.edu/~drussell/Demos/doppler/doppler.html>



From the basic velocity and reflectivity data that radars provide, special software can interpret which storms are the strongest and place certain visual markers on them to make sorting out the different storms easier for chasers and forecasters. Markers like the Tornado Vortex Signature (TVS), mesocyclone signature, and hail signature all indicate which storms meet certain criteria for their respective phenomena. These usually show up as visual icons overlaid on top of a radar image in the shapes of triangles (TVS), spinning circles (mesocyclone), and an arrangement of dots (hail). Chasers do not rely too heavily on these markers to make decisions about which storms are the best to pursue because of errors and inaccuracies that are quite common among these markers. What they can provide, however, is a quick snapshot of the qualities of storms in the area that chasers can then look at more closely using velocity data and raw reflectivity.

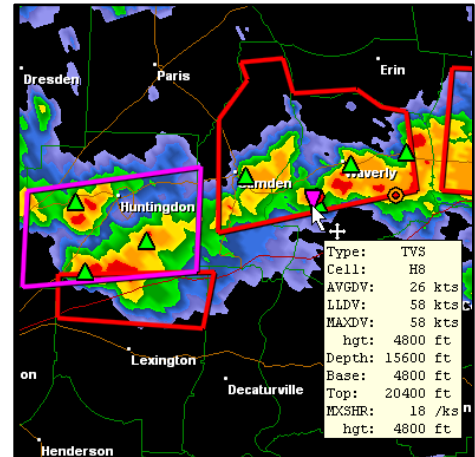


Image Credit: Gibson Ridge Software  
<http://grlevelx.com/>

While all of this radar technology is extremely beneficial for storm chasers, data outages and lag time between radar image updates can render this technology useless due to outdated information. This is why it is always best to keep your eyes on the storm out the window instead of always looking at the radar display.

## Glossary

**anvil** – The flat “anvil-like” top of a thunderstorm. This flattening happens as the rising air in a storm hits the tropopause, the boundary between the troposphere and stratosphere.

**bow echo** – An wind-driven complex of thunderstorms that produces an arc shape on radar.

**capping inversion** – A warm layer of air above the surface that inhibits convective, or thunderstorm, development.

**classic supercell** – A supercell that has what appears to be equal areas of clear updraft area and rain-filled downdraft area.

**cold front** – A boundary between cooler, drier air to the north and west and warmer, moister air to the south and east.

**dewpoint** – The temperature at which the air will become completely saturated with water vapor, which then condenses into water droplets.

**downdraft** – Area of a thunderstorm where rain and rain-cooled air falls to the ground.

**dry line** – Boundary between moist air to the east and dry, desert air to the west and southwest. The dry line, also called a “dewpoint front”, is usually found in the lower Great Plains of the United States.

**Enhanced Fujita Scale (EF)** – A scale invented by Dr. Theodore Fujita in 1971 and then revised in 2007 that ranks tornadoes according to the damage they cause.

**funnel cloud** – Funnel-shaped rotating cloud under a thunderstorm that precedes a tornado.

**gust front** – Rushing boundary of rain-cooled air that precedes a thunderstorm, most notably a mesoscale convective system.

**high precipitation supercell (HP)** – A supercell thunderstorm that has a dominating downdraft of rain that can wrap around the updraft of the storm. This can sometimes obscure tornadoes and make the storms very dangerous to chase.

**low precipitation supercell (LP)** – A supercell thunderstorm that has a dominating clear updraft base and low amounts of precipitation in the downdraft. This storm is very easy to chase because the structure of the updraft base is very visible.

**mesocyclone** – A rotating updraft of air in a supercell thunderstorm that can lead to the development of a tornado.

**outflow boundary** – The boundary between the rain-cooled air produced by a thunderstorm and the surrounding air. These boundaries can continue traveling for miles after a thunderstorm has diminished and are sometimes visible on radar.

**station plot** – A symbolic representation on a map of the weather conditions at a certain place, including wind, temperature, pressure, dewpoint, and sky conditions.

**Tornado Alley** – A region of the Central United States, or Great Plains, that is famous for having a large number of tornadoes during the spring months.

**updraft** – The upward component of a thunderstorm that brings in warm, moist air. This region in a supercell is usually where tornadoes occur.

**upslope flow** – A source of lift for thunderstorm development due to air moving up the slopes of the Rocky Mountains in Eastern Colorado.

**wall cloud** – A compact, rotating cloud that lowers from the updraft base and is often serves as the precursor to tornado development.

**wind shear** – Differing speeds and directions of wind at increasing heights in the atmosphere.

**velocity couplet** – A notch of incoming and outgoing winds on radar that signifies rotation.