INTRODUCTION to

SEVERE WEATHER

(from http://www.srh.noaa.gov/jetstream//)

Chapter 1. Tropical Cyclone

(from http://www.srh.noaa.gov/srh/jetstream/tropics/tropics_intro.htm)

1. Introduction

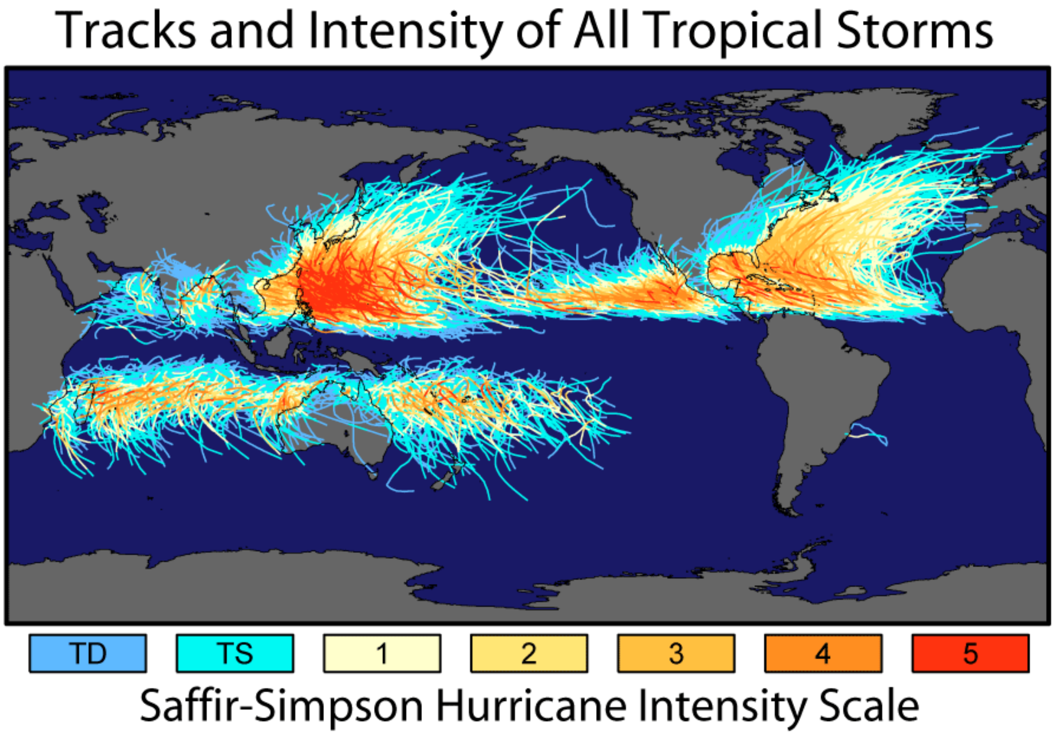
A tropical cyclone is a warm-core, low pressure system without any "front" attached, that develops over the tropical or subtropical waters, and has an organized circulation. Depending upon location, tropical cyclones have different names around the world. In the:

- Atlantic/Eastern Pacific Oceans - *hurricanes*
- Western Pacific - *typhoons*
- Indian Ocean - *cyclones*

Regardless of what they are called, there are several favorable environmental conditions that must be in place before a tropical cyclone can form. They are:

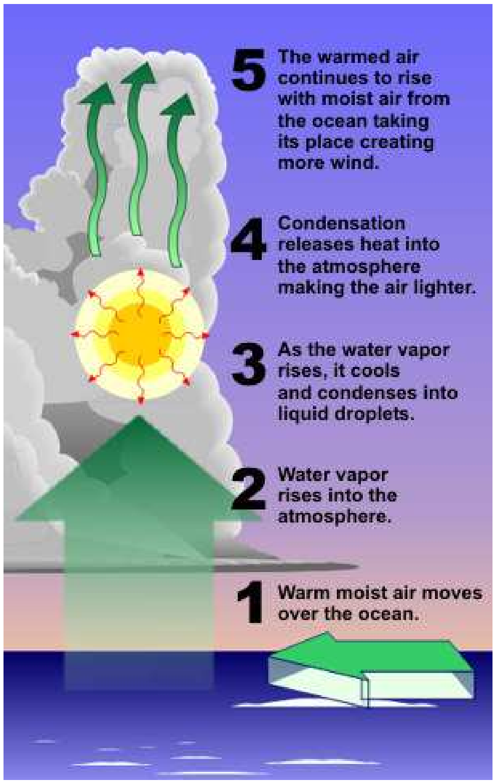
- Warm ocean waters (at least 80℉ / 27℃) throughou t a depth of about 150 ft. (46 m).
- An atmosphere which cools fast enough with height such that it is potentially unstable to moist convection.
- Relatively moist air near the mid-level of the troposphere (16,000 ft. / 4,900 m).
- Generally a minimum distance of at least 300 miles (480 km) from the equator.
- A pre-existing near-surface disturbance.
- Low values (less than about 23 mph / 37 kph) of vertical wind shear between the surface and the upper troposphere. Vertical wind shear is the change in wind speed with height.

Tropical Cyclone Formation Basin



Given that sea surface temperatures need to be at least 80°F (27°C) for tropical cyclones form, it is natural that they form near the equator. However, with only the rarest of occasions, these storms do not form within 5° latitude of the equator. This is due to the lack of sufficient **Coriolis Force**, the force that causes the cyclone to spin. However, tropical cyclones form in .

One rare exception to the lack of tropical cyclones near the equator was Typhoon Vamei which former near Singapore on December 27, 2001. Since tropical cyclone observations started in 1886 in the North Atlantic and 1945 in the western North Pacific, the previous recorded lowest latitude for a tropical cyclone was 3.3°N for Typhoon Sarah in 1956. With its circulation center at 1.5°N Typhoon Vamei's circulation was on both si des of the equator. U.S. Naval ships reported maximum sustained surface wind of 87 mph and gust wind of up to 120 mph.



The seedlings of tropical cyclones, called "disturbances", can come from:

- **Easterly Waves:** Also called tropical waves, this is an inverted trough of low pressure moving generally westward in the tropical easterlies. A trough is defined as a region of relative low pressure. The majority of tropical cyclones form from easterly waves.
- **West African Disturbance Line (WADL):** This is a line of convection (similar to a squall line) which forms over West Africa and moves into the Atlantic Ocean. WADL's usually move faster than tropical waves.
- **TUTT:** A TUTT (Tropical Upper Tropospheric Trough) is a trough, or cold core low in the upper atmosphere, which produces convection. On occasion, one of these develops into a warm-core tropical cyclone.
- **Old Frontal Boundary:** Remnants of a polar front can become lines of convection and occasionally generate a tropical cyclone. In the Atlantic Ocean storms, this will occur early or late in the hurricane season in the Gulf of Mexico or Caribbean Sea.

Once a disturbance forms and sustained convection develops, it can become more organized under certain conditions. If the disturbance moves or stays over warm water (at least 80°F), and upper level winds r emain weak, the disturbance can become more organized, forming a depression.

The warm water is one of the most important keys as it is water that powers the tropical cyclone (see image above right). As water vapor (water in the gaseous state) rises, it cools. This cooling causes the water vapor to condense into a liquid we see as clouds. In the process of condensation, heat is released. This heat warms the atmosphere making the air lighter still which then continues to rise into the atmosphere. As it does, more air moves in near the surface to take its place which is the strong wind we feel from these storms.

Therefore, once the eye of the storm moves over land will begin to weaken rapidly, not because of friction, but because the storm lacks the moisture and heat sources that the ocean provided. This depletion of moisture and heat hurts the tropical cyclone's ability to produce thunderstorms near the storm center. Without this convection, the storm rapidly diminishes.

The NASA image (above) is Hurricane Wilma in October 2005. The color of the ocean represents sea surface temperature with orange and red colors indicating temperatures of 82℉ or greater.

As Wilma moves northwest, then eventually northeast, the water temperature decreases (indicated by the change to light blue color) after the storm passes a particular location. This is the result of the heat that is removed from the ocean and provided to the storm.

Therein shows the purpose of tropical cyclones. Their role is to take heat, stored in the ocean, and transfer it to the upper atmosphere where the upper level winds carry that heat to the poles. This keeps the polar regions from being as cold as they could be and helps keep the tropics from overheating.

There are many suggestions for the mitigation of tropical cyclones such as "seeding" storms with chemicals to decrease their intensity, dropping water absorbing material into the storm to soak-up some of the moisture, to even using nuclear weapons to disrupt their circulation thereby decreasing their intensity. While well meaning, the ones making the suggestions vastly underestimate the amount of energy generated and released by tropical cyclones.

Even if we could disrupt these storms, it would not be advisable. Since tropical cyclones help regulate the earth's temperature, any decrease in tropical cyclone intensity means the oceans retain more heat. Over time, the build-up of heat could possible enhance subsequent storms and lead to more numerous and/or stronger events.

There has also been much discussion about the abnormally high number of storms for the 2005 Atlantic basin (27 named storms including 15 hurricanes). Compared to the age of the earth, our knowledge about tropical cyclone history is only very recent. Only since the advent of satellite imagery in the 1960's do we have any real ability to count, track and observe these systems across the vast oceans. Therefore, we will never know the actual record number of tropical cyclones in the Atlantic Oceans.

2. Tropical Cyclone Classification

Tropical cyclones with an organized system of clouds and thunderstorms with a defined circulation, and maximum sustained winds of **38 mph (61 kph) or less** are called "tropical depressions". Once the tropical cyclone reaches winds of at least 39 mph (63 kph) they are typically called a "tropical storm" and assigned a name.

If maximum sustained winds reach 74 mph (119 kph), the cyclone is called:

- A **hurricane** in the North Atlantic Ocean, the Northeast Pacific Ocean east of the dateline, and the South Pacific Ocean east of 160°E, (The word hurricane co mes from the Carib Indians of the West Indies, who called this storm a *huracan*. Supposedly, the ancient Tainos tribe of Central America called their god of evil "Huracan". Spanish colonists modified the word to hurricane.),

- A **typhoon** in the Northwest Pacific Ocean west of the dateline (**super typhoon** if the maximum sustained winds are at least 150 mph / 241 kph),

- A **severe tropical cyclone** in the Southwest Pacific Ocean west of 160°E or So utheast Indian Ocean east of 90°E,

- A **severe cyclonic storm** in the North Indian Ocean, and

- Just a **tropical cyclone** in the Southwest Indian Ocean.

Hurricanes are further classified according to their wind speed. The **Saffir-Simpson Hurricane Wind Scale** is a 1-5 rating based on the hurricane's present intensity. This scale only addresses the wind speed and does not take into account the potential for other hurricane-related impacts, such as storm surge, rainfall-induced floods, and tornadoes.

Earlier versions of this scale – known as the Saffir-Simpson Hurricane Scale – incorporated central pressure and storm surge as components of the categories. However, hurricane size (extent of hurricane-force winds), local bathymetry (depth of near-shore waters), topography, the hurricane's forward speed and angle to the coast also affect the surge that is produced.

For example, the very large Hurricane Ike (with hurricane force winds extending as much as 125 miles (200 kilometers) from the center) in 2008 made landfall in Texas as a Category 2 hurricane and had peak storm surge values of about 20 feet (6 meters). In contrast, tiny Hurricane Charley (with hurricane force winds extending at most 25 miles (40 kilometers) from the center) struck Florida in 2004 as a Category 4 hurricane and produced a peak storm surge of only about 7 feet (2.1 meters). These storm surge values were substantially outside of the ranges suggested in the original scale.

To help reduce public confusion about the impacts associated with the various hurricane categories as well as to provide a more scientifically defensible scale, the storm surge ranges, flooding impact and central pressure statements were removed from the scale and only peak winds are now employed.

Saffir-Simpson Hurricane Wind Scale	
Category 5 **>155 mph** >135 kts >249 kph **Catastrophic damage will occur!**	**People, Livestock, and Pets** People, livestock, and pets are at very high risk of injury or death from flying or falling debris, even if indoors in mobile homes or framed homes. **Mobile Homes** Almost complete destruction of all mobile homes will occur, regardless of age or construction. **Frame Homes** A high percentage of frame homes will be destroyed, with total roof failure and wall collapse. Extensive damage to roof covers, windows, and doors will occur. Large amounts of windborne debris will be lofted into the air. Windborne debris damage will occur to nearly all unprotected windows and many protected windows. **Apartments, Shopping Centers, and Industrial Buildings** Significant damage to wood roof commercial buildings will occur due to loss of roof sheathing. Complete collapse of many older metal buildings can occur. Most unreinforced masonry walls will fail which can lead to the collapse of the buildings. A high percentage of industrial buildings and low-rise apartment buildings will be destroyed. **High-Rise Windows and Glass** Nearly all windows will be blown out of high-rise buildings resulting in falling glass, which will pose a threat for days to weeks after the storm. **Signage, Fences, and Canopies** Nearly all commercial signage, fences, and canopies will be destroyed. **Trees** Nearly all trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. **Power and Water** Power outages will last for weeks to possibly months. Long-term water shortages will increase human suffering. Most of the area will be uninhabitable for weeks or months. Examples: Hurricane Mitch of 1998 was a Category Five hurricane at peak intensity over the western Caribbean. Hurricane Gilbert of 1988 was a Category Five hurricane at peak intensity and is the strongest Atlantic tropical cyclone of record.

Category 4 **131-155 mph** 114-135 kts 210-249 kph **Catastrophic damage will occur!**	**People, Livestock, and Pets** There is a very high risk of injury or death to people, livestock, and pets due to flying and falling debris. **Mobile Homes** Nearly all older (pre-1994) mobile homes will be destroyed. A high percentage of newer mobile homes also will be destroyed. **Frame Homes** Poorly constructed homes can sustain complete collapse of all walls as well as the loss of the roof structure. Well-built homes also can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Extensive damage to roof coverings, windows, and doors will occur. Large amounts of windborne debris will be lofted into the air. Windborne debris damage will break most unprotected windows and penetrate some protected windows. **Apartments, Shopping Centers, and Industrial Buildings** There will be a high percentage of structural damage to the top floors of apartment buildings. Steel frames in older industrial buildings can collapse. There will be a high percentage of collapse to older unreinforced masonry buildings. **High-Rise Windows and Glass** Most windows will be blown out of high-rise buildings resulting in falling glass, which will pose a threat for days to weeks after the storm. **Signage, Fences, and Canopies** Nearly all commercial signage, fences, and canopies will be destroyed. **Trees** Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. **Power and Water** Power outages will last for weeks to possibly months. Long-term water shortages will increase human suffering. Most of the area will be uninhabitable for weeks or months. Examples: Hurricane Luis of 1995 was a Category Four hurricane while moving over the Leeward Islands. Hurricanes Felix and Opal of 1995 also reached Category Four status at peak intensity.

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Category 3

111-130 mph
96-113 kts
178-209 kph

Devastating damage will occur.

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People, Livestock, and Pets

There is a high risk of injury or death to people, livestock, and pets due to flying and falling debris.

Mobile Homes

Nearly all older (pre-1994) mobile homes will be destroyed. Most newer mobile homes will sustain severe damage with potential for complete roof failure and wall collapse.

Frame Homes

Poorly constructed frame homes can be destroyed by the removal of the roof and exterior walls. Unprotected windows will be broken by flying debris. Well-built frame homes can experience major damage involving the removal of roof decking and gable ends.

Apartments, Shopping Centers, and Industrial Buildings

There will be a high percentage of roof covering and siding damage to apartment buildings and industrial buildings. Isolated structural damage to wood or steel framing can occur. Complete failure of older metal buildings is possible, and older unreinforced masonry buildings can collapse.

High-Rise Windows and Glass

Numerous windows will be blown out of high-rise buildings resulting in falling glass, which will pose a threat for days to weeks after the storm.

Signage, Fences, and Canopies

Most commercial signage, fences, and canopies will be destroyed.

Trees

Many trees will be snapped or uprooted, blocking numerous roads.

Power and Water

Electricity and water will be unavailable for several days to a few weeks after the storm passes.

Examples: Hurricanes Roxanne of 1995 and Fran of 1996 were Category Three hurricanes at landfall on the Yucatan Peninsula of Mexico and in North Carolina, respectively.

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Category 2

96-110 mph
83-95 kts
154-177 kph

Extremely dangerous winds will cause extensive damage.

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People, Livestock, and Pets

There is a substantial risk of injury or death to people, livestock, and pets due to flying and falling debris.

Mobile Homes

Older (mainly pre-1994 construction) mobile homes have a very high chance of being destroyed and the flying debris generated can shred nearby mobile homes. Newer mobile homes can also be destroyed.

Frame Homes

Poorly constructed frame homes have a high chance of having their roof structures removed especially if they are not anchored properly. Unprotected windows will have a high probability of being broken by flying debris. Well-constructed frame homes could sustain major roof and siding damage. Failure of aluminum, screened-in, swimming pool enclosures will be common.

Apartments, Shopping Centers, and Industrial Buildings

There will be a substantial percentage of roof and siding damage to apartment buildings and industrial buildings. Unreinforced masonry walls can collapse.

High-Rise Windows and Glass

Windows in high-rise buildings can be broken by flying debris. Falling and broken glass will pose a significant danger even after the storm.

Signage, Fences, and Canopies

Commercial signage, fences, and canopies will be damaged and often destroyed.

Trees

Many shallowly rooted trees will be snapped or uprooted and block numerous roads.

Power and Water

Near-total power loss is expected with outages that could last from several days to weeks. Potable water could become scarce as filtration systems begin to fail.

Examples: Hurricane Bonnie of 1998 was a Category Two hurricane when it hit the North Carolina coast, while Hurricane Georges of 1998 was a Category Two Hurricane when it hit the Florida Keys and the Mississippi Gulf Coast.

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Category 1

74-95 mph
64-82 kts
119-153 kph

Very dangerous winds will produce some damage.

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People, Livestock, and Pets

People, livestock, and pets struck by flying or falling debris could be injured or killed.

Mobile Homes

Older (mainly pre-1994 construction) mobile homes could be destroyed, especially if they are not anchored properly as they tend to shift or roll off their foundations. Newer mobile homes that are anchored properly can sustain damage involving the removal of shingle or metal roof coverings, and loss of vinyl siding, as well as damage to carports, sunrooms, or lanais.

Frame Homes

Some poorly constructed frame homes can experience major damage, involving loss of the roof covering and damage to gable ends as well as the removal of porch coverings and awnings. Unprotected windows may break if struck by flying debris. Masonry chimneys can be toppled. Well- constructed frame homes could have damage to roof shingles, vinyl siding, soffit panels, and gutters. Failure of aluminum, screened-in, swimming pool enclosures can occur.

Apartments, Shopping Centers, and Industrial Buildings

Some apartment building and shopping center roof coverings could be partially removed. Industrial buildings can lose roofing and siding especially from windward corners, rakes, and eaves. Failures to overhead doors and unprotected windows will be common.

High-Rise Windows and Glass

Windows in high-rise buildings can be broken by flying debris. Falling and broken glass will pose a significant danger even after the storm.

Signage, Fences, and Canopies

There will be occasional damage to commercial signage, fences, and canopies.

Trees

Large branches of trees will snap and shallow rooted trees can be toppled.

Power and Water

Extensive damage to power lines and poles will likely result in power outages that could last a few to several days.

Examples: Hurricanes Allison of 1995 and Danny of 1997 were Category One hurricanes at peak intensity.

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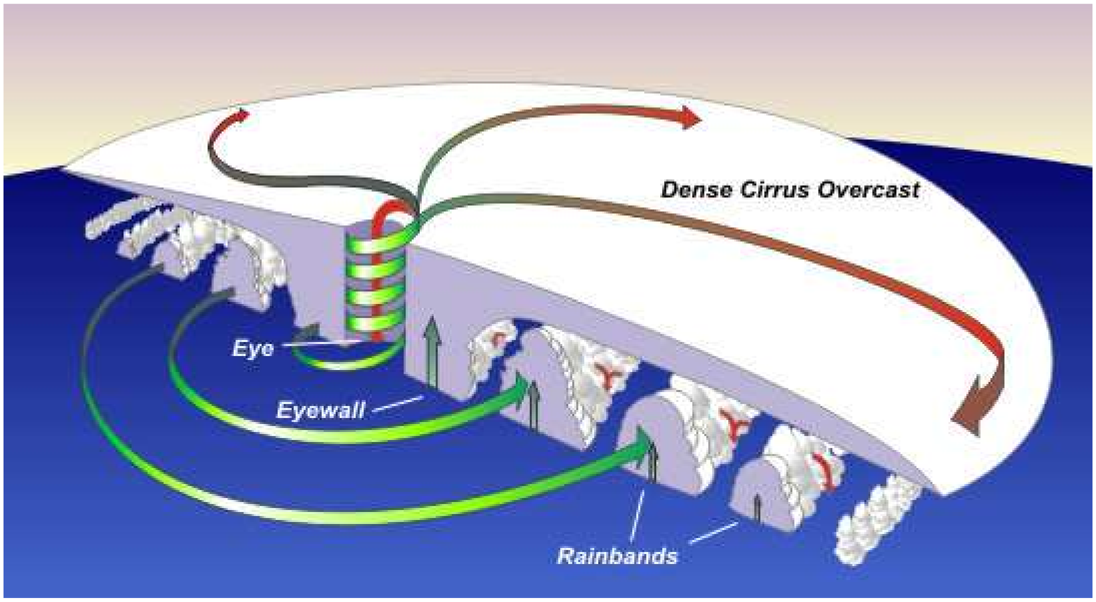
3. Tropical Cyclone Structure



The main parts of a tropical cyclone are the rainbands, the eye, and the eyewall. Air spirals in toward the center in a counter-clockwise pattern in the northern hemisphere (clockwise in the southern hemisphere), and out the top in the opposite direction. In the very center of the storm, air sinks, forming an "eye" that is mostly cloud-free.

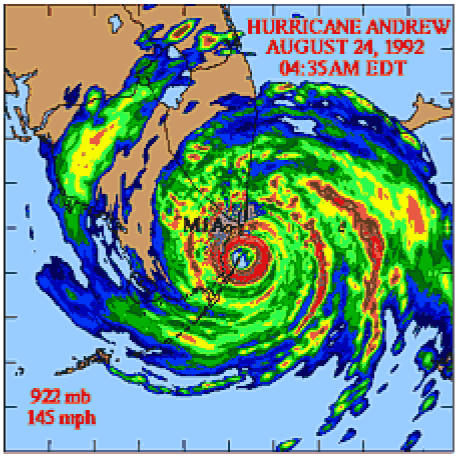
The Eye

The hurricane's center is a relatively calm, generally clear area of sinking air and light winds that usually do not exceed 15 mph (24 kph) and is typically 20-40 miles (32-64 km) across. An eye will usually develop when the maximum sustained wind speeds go above 74 mph (119 kph) and is the calmest part of the storm.

But why does an eye form? The cause of eye formation is still not fully understood. It probably has to do with the combination of "the conservation of angular momentum" and centrifugal force. The conservation of angular momentum means is objects will spin faster as they move toward the center of circulation. So air increases it speed as it heads toward the center of the tropical cyclone. One way of looking at this is watching figure skaters spin. The closer they hold their hands to the body, the faster they spin. Conversely, the farther the hands are from the body the slower they spin. In tropical cyclone, as the air moves toward the center, the speed must increase.

However, as the speed increases, an outward-directed force, called the centrifugal force, occurs because the wind's momentum wants to carry the wind in a straight line. Since the wind is turning about the center of the tropical cyclone, there is a pull outward. The sharper the curvature, and/or the faster the rotation, the stronger is the centrifugal force.

Around 74 mph (119 kph) the strong rotation of air around the cyclone balances inflow to the center, causing air to ascend about 10-20 miles (16-32 km) from the center forming the eyewall. This strong rotation also creates a vacuum of air at the center, causing some of the air flowing out the top of the eyewall to turn inward and sink to replace the loss of air mass near the center.



This sinking air suppresses cloud formation, creating a pocket of generally clear air in the center. People experiencing an eye passage at night often see stars. Trapped birds are sometimes seen circling in the eye, and ships trapped in a hurricane report hundreds of exhausted birds resting on their decks. The landfall of hurricane Gloria (1985) on southern New England was accompanied by thousands of birds in the eye.

The sudden change of very strong winds to a near calm state is a dangerous situation for people ignorant about a hurricane's structure. Some people experiencing the light wind and fair weather of an eye may think the hurricane has passed, when in fact the storm is only half over with dangerous eyewall winds returning, this time from the opposite direction within a few minutes.

The Eyewall

Where the strong wind gets as close as it can is the eyewall. The eyewall consists of a ring of tall thunderstorms that produce heavy rains and usually the strongest winds. Changes in the structure of the eye and eyewall can cause changes in the wind speed, which is an indicator of the storm's intensity. The eye can grow or shrink in size, and double (concentric) eyewalls can form.

Rainbands

Curved bands of clouds and thunderstorms that trail away from the eye wall in a spiral fashion. These bands are capable of producing heavy bursts of rain and wind, as well as tornadoes. There are sometimes gaps in between spiral rain bands where no rain or wind is found.

In fact, if one were to travel between the outer edge of a hurricane to its center, one would normally progress from light rain and wind, to dry and weak breeze, then back to increasingly heavier rainfall and stronger wind, over and over again with each period of rainfall and wind being more intense and lasting longer.

Tropical Cyclone Size

The relative sizes of the largest and smallest tropical cyclones on record as compared to the United States.

Typical hurricane strength tropical cyclones are about 300 miles (483 km) wide although they can vary considerably. as shown in the two enhanced satellite images below. Size is not necessarily an indication of hurricane intensity. Hurricane Andrew (1992), the second most devastating hurricane to hit the United States, next to Katrina in 2005, was a relatively small hurricane.

On record, **Typhoon Tip** (1979) was the largest storms with gale force winds (39 mph/63 km/h) that extended out for 675 miles (1087 km) in radius in the Northwest Pacific on 12 October, 1979. The smallest storm was **Tropical Cyclone Tracy** with gale force winds that only extended 30 miles (48 km) radius when it struck Darwin, Australia, on December 24, 1974.

However, the hurricane's destructive winds and rains cover a wide swath. Hurricane-force winds can extend outward more than 150 miles (242 km) for a large one. The area over which tropical storm-force winds occur is even greater, ranging as far out as almost 300 miles (483 km) from the eye of a large hurricane.

The strongest hurricane on record for the Atlantic Basin is Hurricane Wilma (2005). With a central pressure of 882 mb (26.05"), Wilma produced sustained winds of 175 mph (280 km/h).

4. Tropical Cyclone Names

For several hundred years, many hurricanes in the West Indies were named after the particular saint's day on which the hurricane occurred. Ivan R. Tannehill describes in his book "Hurricanes" the major tropical storms of recorded history and mentions many hurricanes named after saints. For example, there was "Hurricane Santa Ana" which struck Puerto Rico with exceptional violence on July 26, 1825, and "San Felipe" (the first) and "San Felipe" (the second) which hit Puerto Rico on September 13 in both 1876 and 1928.

The first known meteorologist to assign names to tropical cyclones was Clement Wragge, an Australian meteorologist. Before the end of the l9th century, he began by using letters of the Greek alphabet, then from Greek and Roman mythology and progressed to the use of feminine names. In the United states, an early example of the use of a woman's name for a storm was in the novel "Storm" by George R. Stewart, published by Random House in 1941. During World War II, this practice became widespread in weather map discussions among forecasters, especially Air Force and Navy meteorologists who plotted the movements of storms over the wide expanses of the Pacific Ocean.

In 1953, the United States abandoned a confusing a two-year old plan to name storms by a phonetic alphabet (Able, Baker, Charlie, etc.). That year, this Nation's weather services began using female names for storms. The practice of naming hurricanes solely after women came to an end in 1978 when men's and women's names were included in the Eastern North Pacific storm lists. In 1979, male and female names were included in lists for the Atlantic and Gulf of Mexico.

Why Tropical Cyclones Are Named

Experience shows that the use of short, distinctive given names in written as well as spoken communications is quicker and less subject to error than the older more cumbersome latitude-longitude identification methods. These advantages are especially important in exchanging detailed storm information between hundreds of widely scattered stations, airports, coastal bases, and ships at sea.

The use of easily remembered names greatly reduces confusion when two or more tropical storms occur at the same time. For example, one hurricane can be moving slowly westward in the Gulf of Mexico, while at exactly the same time another hurricane can be moving rapidly northward along the Atlantic coast. In the past, confusion and false rumors have arisen when storm advisories broadcast from one radio station were mistaken for warnings concerning an entirely different storm located hundreds of miles away.

The name lists have an international flavor because hurricanes affect other nations and are tracked by the public and weather services of countries other than the United States. Names for these lists agreed upon by the nations involved during international meetings of the World Meteorological Organization.

The only time that there is a change in the list is if a storm is so deadly or costly that the future use of its name on a different storm would be inappropriate for reasons of sensitivity. If that occurs, then at an annual meeting by the WMO committee (called primarily to discuss many other issues) the offending name is stricken from the list and another name is selected to replace it.

Atlantic Tropical Cyclone Names

2010	2011	2012	2013	2014	2015
Alex Bonnie Colin Danielle Earl Fiona Gaston Hermine Igor Julia Karl Lisa Matthew Nicole Otto Paula Richard Shary Tomas Virginie Walter	Arlene Bret Cindy Don Emily Franklin Gert Harvey Irene Jose Katia Lee Maria Nate Ophelia Philippe Rina Sean Tammy Vince Whitney	Alberto Beryl Chris Debby Ernesto Florence Gordon Helene Isaac Joyce Kirk Leslie Michael Nadine Oscar Patty Rafael Sandy Tony Valerie William	Andrea Barry Chantal Dorian Erin Fernand Gabrielle Humberto Ingrid Jerry Karen Lorenzo Melissa Nestor Olga Pablo Rebekah Sebastien Tanya Van Wendy	Arthur Bertha Cristobal Dolly Edouard Fay Gonzalo Hanna Isaias Josephine Kyle Laura Marco Nana Omar Paulette Rene Sally Teddy Vicky Wilfred	Ana Bill Claudette Danny Erika Fred Grace Henri Ida Joaquin Kate Larry Mindy Nicholas Odette Peter Rose Sam Teresa Victor Wanda
Greek Alphabet: Alpha, Beta, Gamma, Delta, Epsilon, Zeta, Eta, Theta, Iota, Kappa, Lambda, Mu, Nu, Xi, Omicron, Pi, Rho, Sigma, Tau, Upsilon, Phi, Chi, Psi, Omega					

Retired hurricane Names: Atlantic Basin	
A's	Agnes (1972), Alicia (1983), Allen (1980), Allison (2001), Andrew (1992), Anita (1977), Audrey (1957)
B's	Betsy (1965), Beulah (1967), Bob (1991)
C's	Camille (1969), Carla (1961), Carmen (1974), Carol (1965), Celia (1970), Cesar (1996), Charley (2004), Cleo (1964), Connie (1955)
D's	David (1979), Dean (2007), Dennis (2005), Diana (1990), Diane (1955), Donna (1960), Dora (1964)
E's	Edna (1968), Elena (1985), Eloise (1975)

F's	Fabian (2003), Felix (2007), Fifi (1974), Flora (1963), Fran (1996), Frances (2004), Frederic (1979), Floyd (1999)
G's	Gilbert (1988), Gloria (1985), Gracie (1959), Georges (1998), Gustav (2008)
H's	Hattie (1961), Hazel (1954), Hilda (1964), Hortense (1996), Hugo (1989)
I's	Inez (1966), Ione (1955), Iris (2001), Isabel (2003), Isidore (2002), Ivan (2004), Ike (2008)
J's	Janet (1955), Jeanne (2004), Joan (1988), Juan (2003)
K's	Katrina (2005), Keith (2000), Klaus (1990)
L's	Luis (1995), Lenny (1999), Lili (2002)
M's	Marilyn (1995), Michelle (2001), Mitch (1998)
N's	Noel (2007)
O's	Opal (1995)
P's	Paloma (2008)
R's	Rita (2005), Roxanne (1995)
S's	Stan (2005)
W's	Wilma (2005)

The National Hurricane Center (RSMC Miami, FL), is responsible for the Atlantic basin west of 30°W. If a disturbance intensifies into a tropical storm the Center will give the storm a name from one of the six lists below.

A separate set is used each year beginning with the first name in the set. After the sets have all been used, they will be used again. The 2007 set, for example, will be used again to name storms in the year 2013.

The letters Q, U, X, Y, and Z are not included because of the scarcity of names beginning with those letters. If over 21 named tropical cyclones occur in a year, the Greek alphabet will be used following the "W" name.

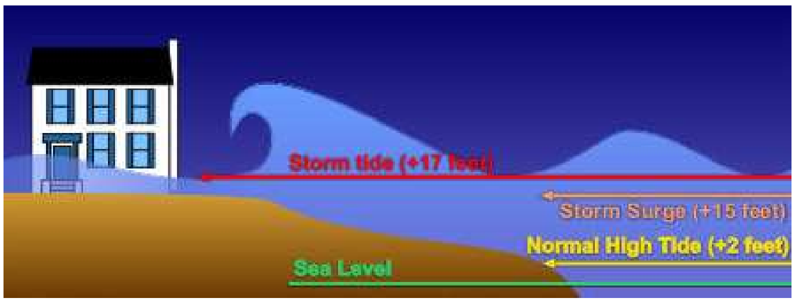
In addition, after major land-falling storms having major economic impact, the names are retired.

5. Tropical Cyclone Hazards

Each year beginning around June 1st, the Gulf and East Coast states are at great risk for tropical cyclones. While most people know that tropical cyclones can contain damaging wind, many do not realize that they also produce several other hazards, both directly and indirectly. Following is vital information you need to help minimize the impact of tropical cyclones on you and your loved ones. *This is your call to action.*

Storm Surge

Storm surge is simply water that is pushed toward the shore by the force of the winds swirling around the storm. This advancing surge combines with the normal tides to create the hurricane storm tide, which can increase the average water level 15 feet (4.5 m) or more.



In addition, wind driven waves are superimposed on the storm tide. This rise in water level can cause severe flooding in coastal areas, particularly when the storm tide coincides with the normal high tides. Because much of the United States' densely populated Atlantic and Gulf Coast coastlines lie less than 10 feet above mean sea level, the danger from storm tides is tremendous.

The level of surge in a particular area is also determined by the slope of the continental shelf. A shallow slope off the coast will allow a greater surge to inundate coastal communities. Communities with a steeper continental shelf will not see as much surge inundation, although large breaking waves can still present major problems. Storm tides, waves, and currents in confined harbors severely damage ships, marinas, and pleasure boats.

Wind and Squalls

Hurricanes are known for their damaging wind. They are rated in strength by their wind also. However, when the NWS's National Hurricane Center issues a statement concerning the wind and catagory, that value is for *sustained* wind only. This hurricane scale does not include gusts or squalls.

Gusts are short but rapid bursts in wind speed and are primarily caused by turbulence over land mixing faster air aloft to the surface. Squalls, on the other hand, are longer periods of increased wind speeds and are generally associated with the bands of thunderstorms which make-up the spiral bands around the hurricane.

A tropical cyclone's wind damages and destroys structures two ways. First, many homes are damaged or destroyed when the high wind simply lifts the roof off of the dwellings. The process involved is called Bernoulli's Principle which implies the faster the air moves the lower the pressure within the air becomes. The high wind moving over the top of the roof creates lower pressure on the exposed side of the roof relative to the attic side.

The higher pressure in the attic helps lift the roof. Once lifted, the roof acts as a sail and is blown clear of the dwelling. With the roof gone, the walls are much easier to be blown down by the hurricane's wind.

The second way the wind destroys buildings can also be a result of the roof becoming airborne. The wind picks up the debris (i.e. wood, metal siding, toys, trash cans, tree branches, etc.) and sends them hurling at high speeds into other structures. Based on observations made during damage investigations conducted by the Wind Science and Engineering Research Center at Texas Tech University, researchers realized that much of the damage in windstorms is caused by flying debris.

They found, based on damage investigations, sections of wooden planks are the most typical type of debris observed due to tornado. A 15-lb 2x4 timber plank in a 250 mph (400 kph) wind would travel at 100 mph (161 kph). While 250 mph (400 kph) is considerably more than even the strongest hurricane's sustained wind, the wind in squalls and tornadoes, could easily reach that speed.

Inland Flooding

In addition to the storm surge and high winds, tropical cyclones threaten the United States with their torrential rains and flooding. Even after the wind has diminished, the flooding potential of these storms remains for several days.

Since 1970, nearly 60% of the 600 deaths due to floods associated with tropical cyclones occurred inland from the storm's landfall. Of that 60%, almost a fourth (23%) of U.S. tropical cyclone deaths occur to people who drown in, or attempting to abandon, their cars.

Also, over three-fourths (78%) of children killed by tropical cyclones drowned in freshwater floods. *In fact, more people are killed by floods than any other weather related cause.* Most of these fatalities occur because people underestimate the power of moving water and *purposely walk or drive into flooding conditions*.

It is common to think the stronger the storm the greater the potential for flooding. However, this is not always the case. A weak, slow moving tropical storm can cause more damage due to flooding than a more powerful fast moving hurricane. This was very evident with Tropical Storm Allison in June 2001.

Allison, the first named storm of the 2001 Atlantic Hurricane Season, devastated portions of Southeast Texas, including the Houston Metro area and surrounding communities, with severe flooding. Allison spent five days over Southeast and East Texas and dumped record amounts of rainfall across the area. Allison deposited **up to three feet of rain** to the east and northeast of Houston, Texas during a 5-day period. This shows the heaviest rainfall distribution.

In addition to the storm surge, tropical cyclones can, and usually do, cause several types of flooding.

Flash flooding

Flash floods are rapid occurring events. This type of flood can begin within a few minutes or hours of excessive rainfall. The rapidly rising water can reach heights of 30 feet (10 m) or more and can roll boulders, rip trees from the ground, and destroy buildings and bridges.

Urban/Area floods

Urban/Area floods are also rapid events although not quite as severe as a flash flood. Still, streets can become swift-moving rivers and basements can become death traps as they fill with water. The primary cause is due to the conversion of fields or woodlands to roads and parking lots. About 10% of the land in the United States is paved roads. So, water that would have been absorbed into the ground now runs into storm drains and sewers.

River flooding

River floods are longer term events and occur when the runoff from torrential rains, brought on by decaying hurricanes or tropical storms, reach the rivers. A lot of the excessive water in river floods may have began as flash floods. River floods can occur in just a few hours and also last a week or longer.

Tornadoes

Tropical cyclones can also produce tornadoes that add to the storm's destructive power. Tornadoes are most likely to occur in the **right-front quadrant** of the hurricane relative to its motion. However, they are also often found elsewhere **embedded in the rainbands**, well away from the center of the tropical cyclones.

Tornadoes are thought responsible for the uneven damage seen in a hurricane's aftermath. The photo (right) shows the total destruction of two buildings in the center of a complex of similar buildings. The added strength of wind combined with the tornadoes twisting motion greatly intensifies the destruction.

Some tropical cyclones seem to produce no tornadoes, while others develop multiple ones. Studies have shown that more than half of the landfalling hurricanes produce at least one tornado; Hurricane Buelah (1967) spawned 141 according to one study. In general, tornadoes associated with hurricanes are less intense than those that occur in the Great Plains. Nonetheless, the effects of tornadoes, added to the larger area of hurricane-force winds, can produce substantial damage.

- When associated with hurricanes, tornadoes are not usually accompanied by hail or a lot of lightning.
- Tornadoes can occur for days after landfall when the tropical cyclone remnants maintain an identifiable low pressure circulation.
- They can also develop at any time of the day or night during landfall. However, by 12 hours after landfall, tornadoes tend to occur mainly during daytime hours.

A **tornado watch** is usually issued when a tropical cyclone is about to move onshore. The watch box is generally to the right of the tropical cyclone's path.

7. Tropical Cyclone Safety

There is an old saying "An ounce of prevention is a pound of cure." This is never more true than when it come to tropical cyclones and the damage they can cause. With some simple forethought and planning, you can greatly reduce the risk of loss of your loved ones and important documents. The following are ways you can help protect your **past**, **present**, **future**, and **peace of mind**. *This is your call to action!*

Protecting Your Past

After loved ones, people most regret loosing valuables (such as jewelry), items from the families past (such as photos and mementos), and important papers to natural disasters. While most of the appliances and furniture can be replaced, it is the treasured keepsakes and important documentation most regret loosing. These items include but are not limited to...

- Family Records (Birth, Marriage, Death Certificates),
- Inventory of Household goods,
- Copy of Will, Insurance policies, contracts, deeds, etc.,
- Record of credit card account numbers and companies,
- Passports, Social Security Cards, immunization records, and
- Valuable computer information.

Depending upon your particular tropical cyclone hazard(s), you have several options you can due to minimize the risk of losing these items.

Storm Surge

Storm surges undermine building foundations by constant agitation of the water piled high by the tropical cyclone. The end result can be a complete demolishing of homes and businesses. If the storm is bad enough you will be asked evacuate and head inland to safety.

In this case, you need to plan ahead for that possibility. For your valuables, have several large rubber storage containers available in which you place your photos and mementos so you can take them with you when you evacuate.

Wind and Squalls

Like the storm surge, hurricane force wind can destroy buildings. If a hurricane threatens your location your response should be the same as with the storm surge. Place your valuable in large rubber storage containers so you can take them with you should you need to evacuate.

Inland Flooding

If you live well inland and storm surges and hurricane force winds will not be a problem, you could still be affected by flooding from very heavy rains. However, even in the most severe inland flood events, houses usually are not completely submerged. Simple precautionary steps now will help you save your memories.

Begin with simply hanging pictures a little higher on the wall. This will help diminish the threat of losing them forever to floods. Do you have extra photos laying around that may not be displayed? If they are not on display, place them in plastic storage containers and store them in the attic. Have an extra, empty plastic storage container available to quickly gather jewelry, mementos, and other displayed photos and **place the container in the attic** should a flood emergency arrive.

If a flooding is occurring at your home, immediately shut off your electricity at the circuit breakers. This will prevent short circuiting electrical appliance such as refrigerators. In many cases, with minor flooding, the refrigerator will just need to be cleaned and can be put back into use again. If the power was left on in a flood, the short circuit will make repairs very costly.

Also, if you normally keep valuable documents in a **fire-proof** safe, check to insure it is **water-proof** as well. A **water-resistant** safe might not prevent water from entering the safe should it become submerged in a flood.

Protecting Your Present

Help protect your present dwelling by retrofitting your home. The most important precaution you can take to reduce damage to your home and property is to protect the areas where wind can enter. According to recent wind technology research, it's important to strengthen the exterior of your house so wind and debris do not tear large openings in it. You can do this by protecting and reinforcing these four critical areas:

- The windows and doors,
- The roof and walls, and
- The garage door(s).

A great time to start securing, or retrofitting, your house is when you are making other improvements or constructing additions. Remember: building codes reflect the lessons experts have learned from past catastrophes. Contact the local building code official to find out what requirements are necessary for your home improvement projects.

Help protect your present dwelling through flood insurance.

BE FLOOD ALERT | NATIONAL FLOOD INSURANCE PROGRAM

When you hear hurricane, think flooding, both from storm surge and from inland flooding. Learn your vulnerability to flooding by determining the elevation of your property. Evaluate your insurance coverage; as construction grows around areas, floodplains change.

Why flood insurance? Because damage from floods are not usually covered by homeowners policies. Flood insurance is affordable. The average flood insurance policy costs a little more than $300 a year for about $100,000 of coverage. In comparison, a disaster home loan can cost you more than $300 a month for $50,000 over 20 years.

You should know that usually you can get flood insurance, if available, by contacting your regular homeowner's insurance agent. The Federal Emergency Management Agency (FEMA) and others recommend that everyone in special flood hazard areas buy flood insurance. If you buy a home or refinance your home your mortgage lender or banker may require flood insurance. But, even if not required, it is a good investment especially in areas that flood frequently or where flood forces are likely to cause major damage.

If you are in a flood area, consider what mitigation measure you can do in advance. For example, in highly flood-prone areas, keep materials on hand like sandbags, plywood, plastic sheeting, plastic garbage bags, lumber, shovels, work boots and gloves. Call your local emergency management agency to learn how to construct proper protective measures around your home.

There is usually a 30-day waiting period before the coverage goes into effect. Plan ahead so you're not caught without flood insurance when a flood from tropical cyclones threatens your home or business. Remember, federal disaster assistance is not the answer. Federal disaster assistance is only available if the President declares a disaster. More than 90 percent of all disasters in the United States are not Presidentially declared. Flood insurance pays even if a disaster is not declared.

National Flood Insurance Program call 1.888.379.9531, TTY# 1.800.427.5593.

Protecting Your Future

The previous "Calls To Action" were concerned mainly about your property. The following steps are primarily for your protection and to help ensure the safety of your loved ones.

Your best protection is to know when there is a threat of hazardous weather. Before the start of the tropical cyclone season, obtain a NOAA Weather Radio and listen to the forecast directly from your local National Weather Service Office. Not only will to be better informed concerning tropical weather systems, you will be able to be alerted to all types of hazardous weather that could affect you.

At the start of the tropical cyclone season...

- **Monitor** your NOAA Weather Radio for tropical weather updates and visit the NWS Southern Region's .
- **Review** your evacuation routes. Contact the local emergency management office or American Red Cross chapter, and ask for the community hurricane preparedness plan. This plan should include information on the safest evacuation routes and nearby shelters. These routes may change from year to year depending upon local construction.
- **Make** a disaster supply kit that includes...
  - At least two *waterproof* flashlights with extra, fresh batteries,
  - Portable, battery-operated NOAA Weather Radio and AM/FM radio with extra, fresh batteries,
  - Either purchase an approved American Red Cross First Aid Kit or put your own together. Include...
    - Assorted sizes of sterile adhesive bandages, sterile gauze pads, and roller bandages,
    - Hypoallergenic adhesive tape and triangular bandages,

        - Scissors, tweezers, needle and thread, and assorted sizes of safety pins,
        - Medicine dropper and thermometer,
        - Safety razor and blades,
        - Bar of soap, moistened towelettes packages and antiseptic spray,
        - Tongue blades and wooden applicator sticks,
        - Tube of petroleum jelly or other lubricant,
        - Cleansing agent, and
        - latex gloves.
    - Disposable camera with flash,
    - Emergency food and eating supplies...
        - Non-perishable packaged or canned foods and juices (check the expiration dates),
        - Special foods for infants or the elderly (check the expiration dates),
        - Cooking tools and fuel,
        - Paper plates and plastic utensils, and
        - A non-electric can opener.
    - Fire Extinguisher - Class ABC extinguishes can be safely used on any type of fire, including electrical, grease or gas.

- **Plan** to take care of your pets. Contact your local humane society for information on local animal shelters as pets may not be allowed into emergency shelters for health and space reasons. Also, store two weeks of pet supplies.
- **Teach** children how and when to call 9-1-1, police, or fire department and which radio station to tune to for emergency information.
- **Prepare** your protection for your windows. If you wait until a hurricane watch is in effect, plywood may be in short supply. Use ½" plywood (marine plywood is best) cut to fit each window. Remember to mark which board fits which window.
- **Trim** trees and remove dead or weak branches.
- **Develop** an emergency communication plan. In case family members are separated from one another during a disaster (a real possibility during the day when adults are at work and children are at school), have a plan for getting back together. Ask an out-of-state relative or friend to serve as the "family contact." After a disaster, it's often easier to call long distance. Make sure everyone in the family knows the name, address, and phone number of the contact person.
- **Check** to ensure tie-downs are secured properly if you live in a mobile home.

At the end of the tropical cyclone season, use the food you stored provided they have not exceeded the expiration dates. You will want to store fresh supplies for the next tropical cyclone season.

If a hurricane watch is issued for your area, you could experience hurricane force wind conditions within 36 hours. Do the following...

- **Listen** to the NOAA Weather Radio for hurricane progress report,
- **Check** your disaster supply kit to ensure it is up to date,
- **Fuel** your automobile. Be ready to drive 20 to 50 miles inland to locate a safe place,
- **Bring** in outdoor objects such as lawn furniture, toys, and garden tools,
- **Anchor** outside objects that cannot be brought inside,
- **Secure** buildings by closing and boarding up windows,
- **Remove** outside antennas,
- **Turn** refrigerator and freezer to coldest settings. Open only when absolutely necessary and close quickly. Freeze as much water as you can. This will help keep your refrigerator cold if the power is out for several days,

- **Store** drinking water in jugs and bottles. You will need at least 1 gallon daily per person for up to seven days,
- **Moor** boat securely or move it to a designated safe place. Use rope or chain to secure boat to trailer and use tie-downs to anchor trailer to the ground,
- **Review** evacuation plan,
- **Collect** essential medicines into one place so you can quickly grab them should you need to evacuate, and
- **Get** extra cash. With the possibility of no electricity, ATM's and credit card purchases will not work.

If a hurricane warning is issued for your area then sustained winds of at least 74 mph are expected within 24 hours or less. Do the following...

- Listen to the NOAA Weather Radio for hurricane progress reports.
- Listen to the radio or television for official instructions.
- Avoid elevators should the electricity fail.
- If officials indicate evacuation is necessary you should do so immediately.
    - Turn the water off at the main water valve.
    - Turn off the gas at the outside main valve.
    - Tell someone outside of the storm area where you are going.
    - If time permits, and you live in an identified surge zone, elevate furniture to protect it from flooding or better yet, move it to a higher floor.
    - Bring your pre-assembled emergency supplies, warm protective clothing, blankets, and sleeping bags to shelter.
    - Lock up home and leave as soon as possible. Avoid flooded roads and watch for washed-out bridges.
- If you choose to remain at your house...
    - Stay in the interior portion of your house, away from windows, skylights, and glass doors.
    - Keep several flashlights and extra batteries handy.
    - If your house is damaged by the storm you should turn the water and gas off at the main valves.
    - If power is lost, turn off electricity at the circuit breakers to reduce power "surge" when electricity is restored. Also avoid open flames, such as candles and kerosene lamps, as a source of light.

Remember, if the hurricane is forecast to move directly over your location, you may be in the path of the eye wall. This means that at the height of the storm, you could experience a sudden, rapid decrease in storm intensity as the hurricane's eye passes over your location. Remain in your shelter as the back side of the storm can be only minutes away with a just as sudden and rapid increase in wind speed, this time from the opposite direction.

After the hurricane has completely passed your location do the following...

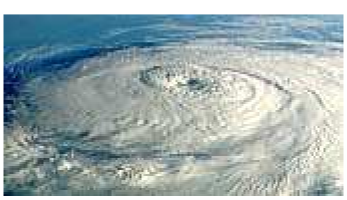
- Listen to the NOAA Weather Radio for hurricane progress reports.
- Stay tuned to local radio for information.
- Return home only after authorities advise that it is safe to do so.
- Once home, check refrigerated foods for spoilage.
- Take pictures of the damage, both to the house and its contents and for insurance claims.

If you remained at your house during the storm...

- Help injured or trapped persons. Give first aid where appropriate. Do not move seriously injured persons unless they are in immediate danger of further injury. Call for help.
- Avoid loose or dangling power lines and report them immediately to the power company, police, or fire department. Be careful and not step onto objects in contact with downed power lines.
- Beware of snakes, insects, and animals driven to higher ground by flood water.
- If your home has been damaged, open windows and doors to ventilate and dry your home.
- Take pictures of the damage, both to the house and its contents and for insurance claims.
- Drive only if absolutely necessary and avoid flooded roads and washed-out bridges.
- Use telephone only for emergency calls.
- Check for gas leaks. If you smell gas or hear blowing or hissing noise, open a window and quickly leave the building. Turn off the gas at the outside main valve if you can and call the gas company from a neighbor's home. If you turn off the gas for any reason, it must be turned back on by a professional.
- Look for electrical system damage. If you see sparks or broken or frayed wires, or if you smell hot insulation, turn off the electricity at the main fuse box or circuit breaker. If you have to step in water to get to the fuse box or circuit breaker, call an electrician first for advice.
- Check for sewage and water lines damage. If you suspect sewage lines are damaged avoid using the toilets and call a plumber. If water pipes are damaged, contact the water company and avoid the water from the tap. You can obtain safe water by melting ice cubes.

Protecting your Peace of Mind

Tropical cyclones, in and of themselves, are not "bad" things. They are just one way nature transfers heat energy from the tropics to the north and south poles. What makes them bad to us is when they affect us. While these storms cannot be prevented you can have peace of mind knowing you did all you could to minimize the impact on your life.



If you are moving into an area that can be affect by tropical storms, try to avoid living in a place where you may be at risk of storm surge. Also, creeks and rivers, while picturesque, could become disasters areas during a flood; stick to higher ground. Anything to can do to minimize the future impact of a tropical cyclone on your home will be one less thing to worry about if the event occurs.

Remember, past experiences of tropical cyclones are NO measure of future events. There may, and probably will be times, when you return to your home, after evacuating, to find no damage whatsoever as the storm either weakened or turned away from where we thought it would strike. However, the time you spent preparing your home and loved ones was NOT wasted because the next time you may not be so fortunate.

You may hear some of the "locals" make statements like "I've lived here x-number of years made it through storms such-and-such" or "a certain hill or creek protected us at this-or-that place". While you cannot discount their experiences, you can know they were fortunate during those events. It's best to be prepared. This could be the year a tropical cyclone could bring devastating results.

For your peace of mind, always heed your local official’s instructions. It is their responsibility to serve your community. If you follow their guiding, you will make their job much easier. If they ask you to evacuate, do so immediately. This way, you will not be a burden on the local rescue teams so they can better assist the ones who may need rescue through no fault of their own.

Your evacuation will also aid the police after the storm passes. Unfortunately, some people try to take advantage of others going through difficult situations. While generally not widespread, looting does occur in neighborhoods damaged by tropical storms. Your absence will help the police better monitor the region and make it easier to spot the ones who do not belong.

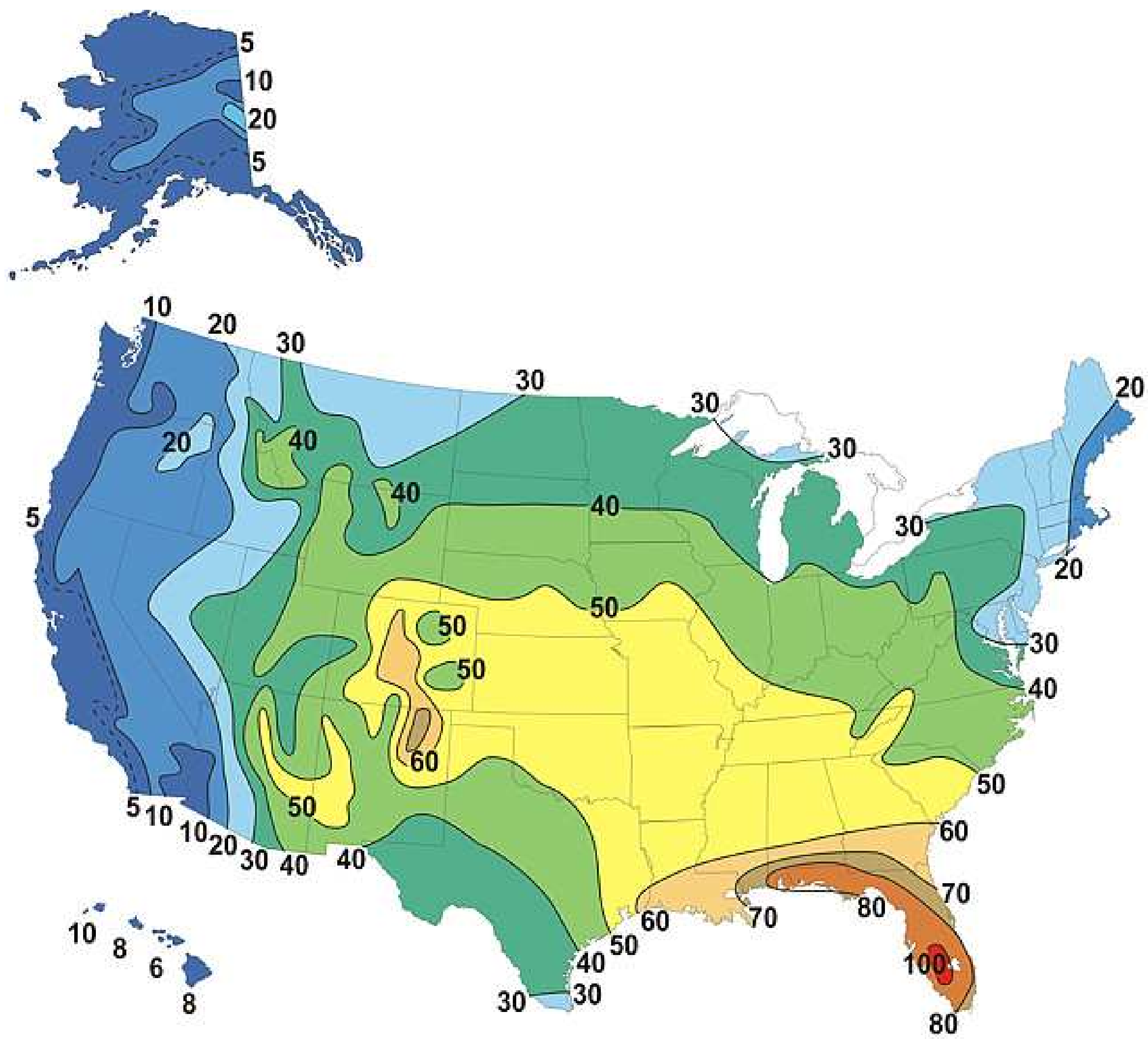
One final word of caution. You may live thousands of miles from the effects of tropical cyclone and think you can not be a victim. However, that is not always the case. Vehicles that have been flooded are suppose to be relegated for salvage but many are not. The unscrupulous do superficial cleaning jobs on the vehicles and wholesale them to dealers across the nation. If you are considering purchasing a used vehicle, be sure to check the title history and hire a trusted mechanic to do a thorough inspection including checking behind the door panel for signs of flooding. A few dollars spent now could save your thousands of dollars down the road and maybe a life.

Chapter 2.   Thunderstorms

(from http://www.srh.noaa.gov/jetstream//tstorms/tstorms_intro.htm)

1. Introduction

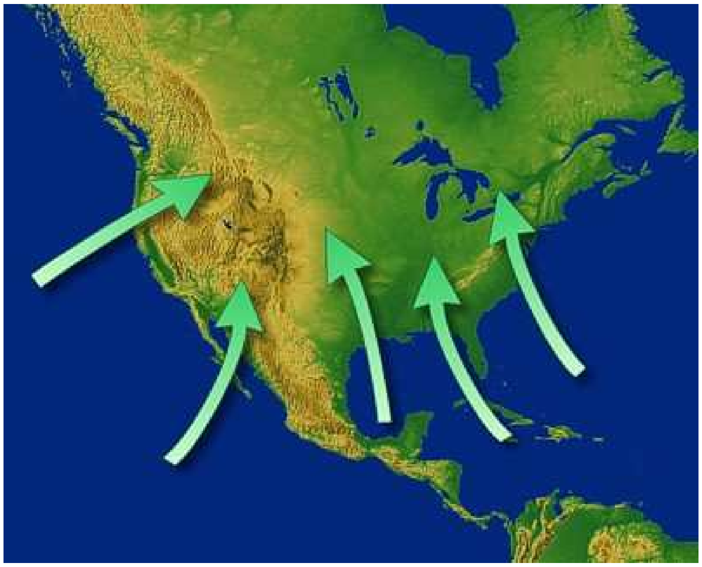
It is estimated that there are as many as 40,000 thunderstorm occurrences each day world-wide. This translates into an astounding 14.6 million occurrences annually! The United States certainly experiences its share of thunderstorm occurrences.



The figure above shows the average number of thunderstorm days each year throughout the U.S. The most frequency of occurrence is greatest in the southeastern states, with Florida having the highest incidence (80 to 100+ thunderstorm days per year).

It is in this part of the country that warm, moist air from the Gulf of Mexico and Atlantic Ocean (which we will see later are necessary ingredients for thunderstorm development) is most readily available to fuel thunderstorm development.

2. The Necessary Ingredients for Thunderstorms



All thunderstorms require three ingredients for their formation:

- Moisture,
- Instability, and
- a lifting mechanism.

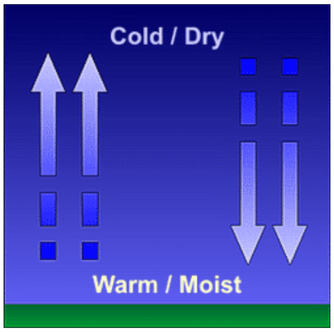
Sources of moisture

Typical sources of moisture are large bodies of water such as the Atlantic and Pacific oceans as well as the Gulf of Mexico.

Water temperature plays a large role in how much moisture is in the atmosphere. Recall from the Ocean Section that warm ocean currents occur along *east* coasts of continents and cool ocean currents occur along *west* coasts. The amount of ocean water evaporation into the atmosphere is higher in warm ocean currents and therefore put more moisture into the atmosphere than with cold ocean currents at the same latitude.

The southeastern U.S. has access to two moisture sources in the Atlantic ocean and the Gulf of Mexico which helps explain why there are so much rain in that region.

Instability



Air is considered unstable if it continues to rise when given a nudge upward (or continues to sink if given a nudge downward). An unstable air mass is characterized by warm moist air near the surface and cold dry air aloft. In these situations, if a bubble or parcel of air is forced upward it will continue to rise on its own. As it rises it cools and some of the water vapor will condense, forming the familiar tall cumulonimbus cloud that is the thunderstorm.

Characteristics of an unstable air mass with warm moist air near the surface with colder and drier air aloft. Air that is forced upward will continue to rise, and air that is forced downward will continue to sink.

Sources of Lift (upward)

Typically, for a thunderstorm to develop, there needs to be a mechanism which initiates the upward motion, something that will give the air a nudge upward. This is done by several methods.

Differential Heating

This heating of the ground and lower atmosphere is not uniform. For example, a grassy field will heat at a slower rate than a paved street. The warmest air, called thermals, tends to rise. In the image (right) a wildfire provided the differential heating for a cumulus cloud to form over the smoke plum.

Fronts, Drylines and Outflow Boundaries

- **Fronts** are the boundary between two air masses of different temperatures. Fronts lift warm moist air. Cold fronts lift air the most abruptly. If the air is moist and unstable thunderstorms will form along the cold front.
- **Drylines** are the boundary between two air masses of different moisture content and separate warm moist air from hot dry air. While the temperature may be different across the dryline, the main difference is the rapid decrease in moisture behind the dryline. It is the lack of moisture which allows the temperatures to occasionally be higher than ahead of the dryline. However, the result is the same as the warm moist air is lifted along the dryline forming thunderstorms. This is common over the plains in the spring and early summer.
- **Outflow boundaries** are a result of the rush of cold air as a thunderstorm moves overhead. The rain-cooled air acts as a "mini cold front", called an outflow boundary. Like fronts, this boundary lifts warm moist air and can cause new thunderstorms to form.

Terrain

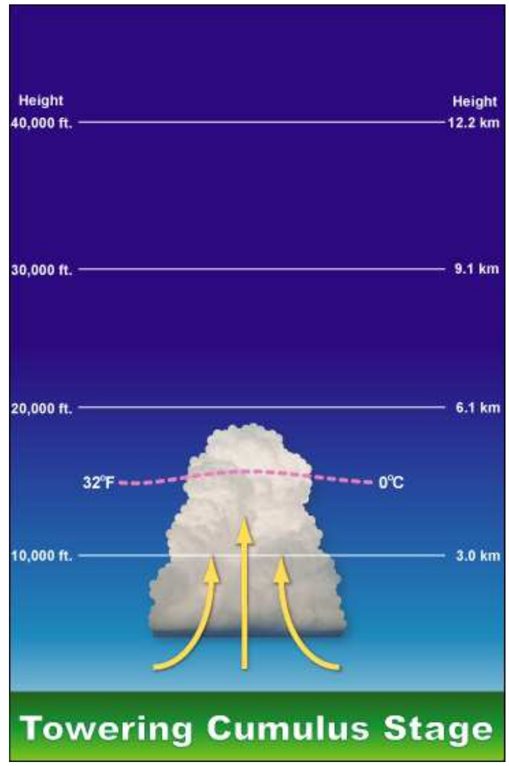
As air encounters a mountain it is forced up the slope of the terrain. Upslope thunderstorms are common in the Rocky Mountain west during the summer.

3. Life Cycle of a Thunderstorm

The building block of all thunderstorms is the thunderstorm cell. The thunderstorm cell has a distinct life-cycle that lasts about 30 minutes.

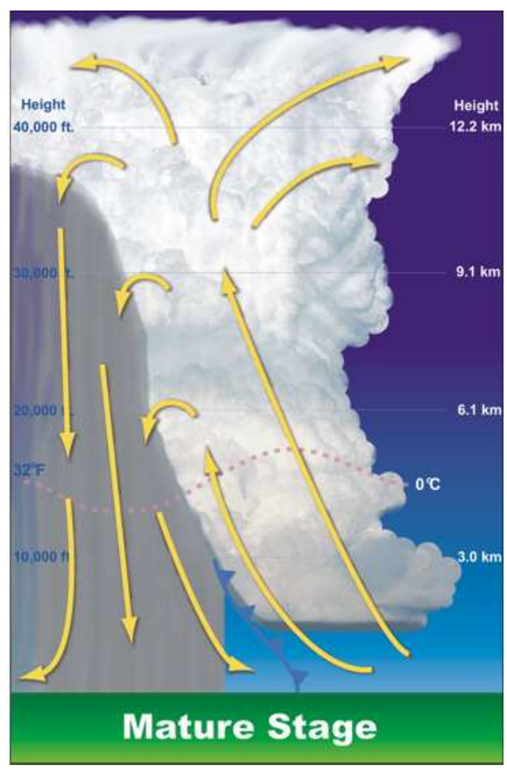
The Towering Cumulus Stage

A cumulus cloud begins to grow vertically, perhaps to a height of 20,000 feet (6 km). Air within the cloud is dominated by updraft with some turbulent eddies around the edges.



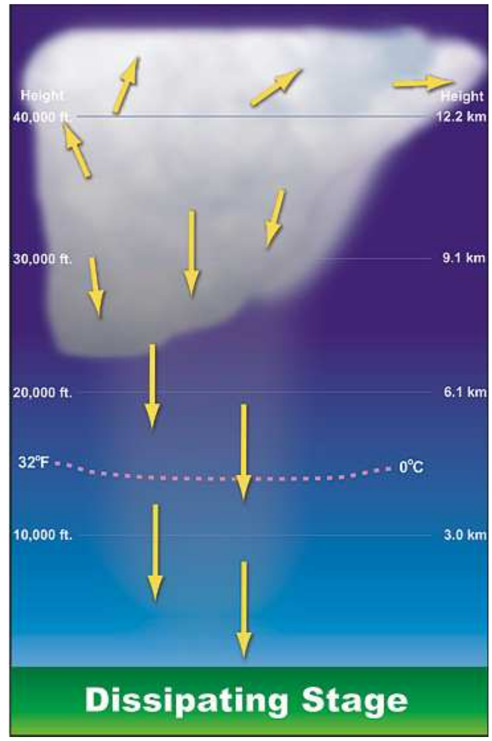
The Mature Cumulus Stage

The storm has considerable depth, often reaching 40,000 to 60,000 feet (12 to 18 km). Strong updrafts and downdrafts coexist. This is the most dangerous stage when large hail, damaging winds, and flash flooding may occur.



The Dissipating Stage

The downdraft cuts off the updraft. The storm no longer has a supply of warm moist air to maintain itself and therefore it dissipates. Light rain and weak outflow winds may remain for a while during this stage, before leaving behind just a remnant anvil top.



4. Types of Thunderstorms

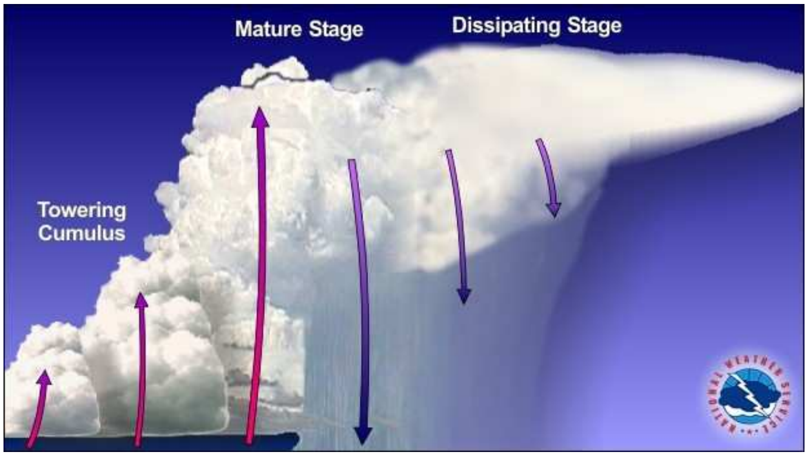
Ordinary Cell

As the name implies, there is usually only one cell with this type of thunderstorm. Also called a "pulse" thunderstorm, the ordinary cell consist of a one time updraft and one time downdraft. In the towering cumulus stage, the rising updraft will suspend growing raindrops until the point where the weight of the water is greater than what can be supported.

At which point, drag of air from the falling drops begins to diminish the updraft and, in turn, allow more raindrops to fall. In effect, the falling rain turns the updraft into a downdraft. With rain falling back into the updraft, the supply of rising moist air is cut-off and the life of the single cell thunderstorm is short.

They are short lived and while hail and gusty wind can develop, these occurrences are typically not severe. However, if atmospheric conditions are right and the ordinary cell is strong enough, there is the potential for more than one cell to form and can include microburst winds (usually less than 70 mph) and weak tornadoes.

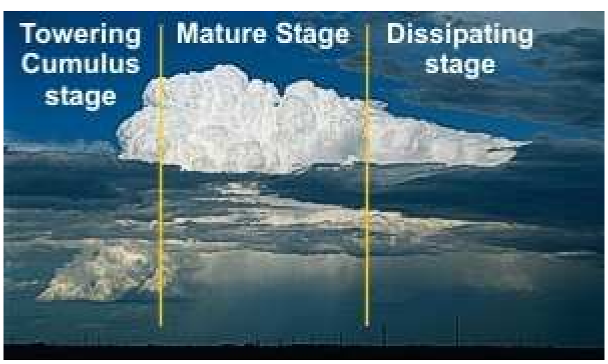
Multi-cell Cluster



Although there are times when a thunderstorm consists of just one ordinary cell that transitions through its life cycle and dissipates without additional new cell formation, thunderstorms often form in clusters with numerous cells in various stages of development merging together.

While each individual thunderstorms cell, in a multi-cell cluster, behaves as a single cell, the prevailing atmospheric conditions are such that as the first cell matures, it is carried downstream by the upper level winds and a new cell forms upwind of the previous cell to take its place.

The speed at which the entire cluster of thunderstorms move downstream can make a huge difference in the amount of rain any one place receives. There are many times where the individual cell moves downstream but addition cells form on the upwind side of the cluster and move directly over the path of the previous cell. The term for this type of pattern when viewed by radar is "training echoes".

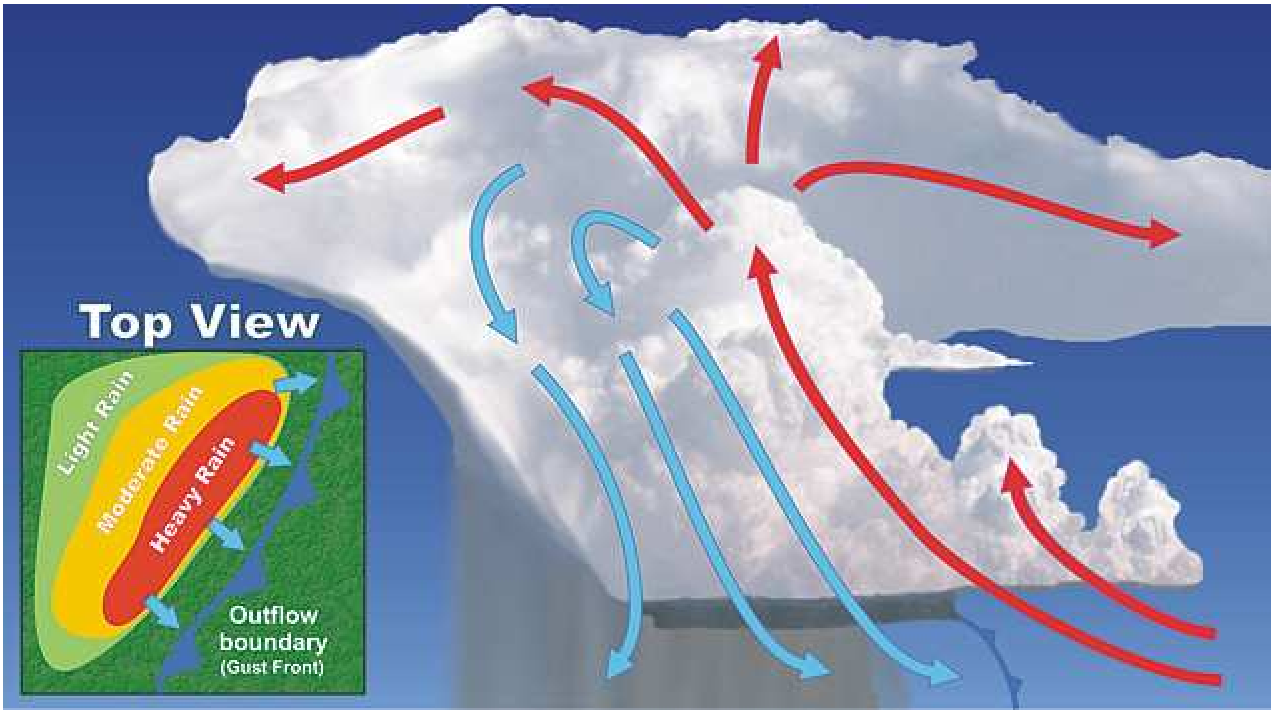


Also called "back building" thunderstorms, with careful observation you can count the number of individual thunderstorm cells in the cluster that pass your location. Take note of the direction from which you first hear thunder. The thunder's volume will increase as the cell approaches your location. Then, after it passes and the volume decreases, you will hear more thunder from the next cell, increasing again, coming from the same direction as the previous cell.

Often these storms will appear on radar to be stationary. However, if the new development is vigorous then the thunderstorm cluster appears to move upwind.

Training thunderstorms produce tremendous rainfall over relatively small areas leading to flash flooding.

Multi-cell Line (Squall Line)



Sometimes thunderstorms will form in a line which can extend laterally for hundreds of miles. These "squall lines" can persist for many hours and produce damaging winds and hail.

Updrafts, and therefore new cells, continually re-form at leading edge of system with rain and hail following behind. Individual thunderstorm updrafts and downdrafts along the line can become quite strong, resulting in episodes of large hail and strong outflow winds which move rapidly ahead of system.

While tornados occasionally form on the leading edge of squall lines they primarily produce "straight-line" wind damage.

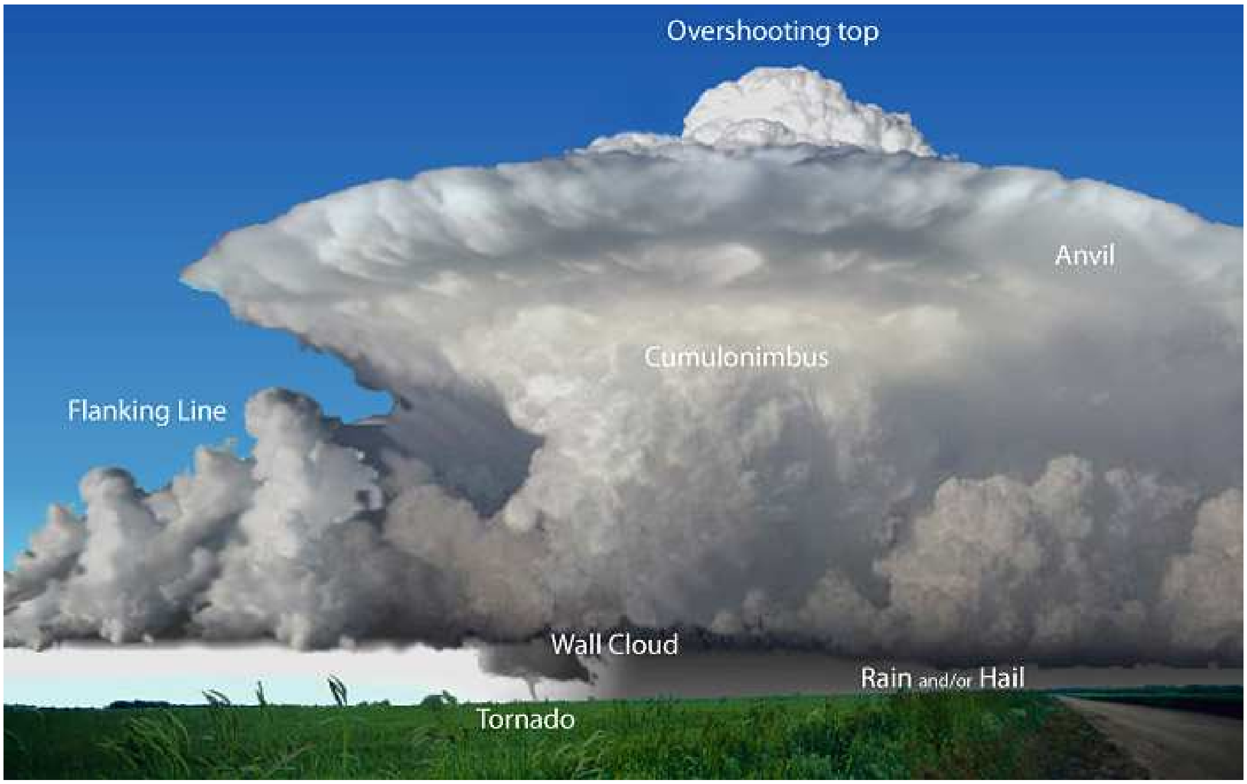
This is damage as a result of the shear force of the down draft form a thunderstorm spreading horizontally as it reaches the earth's surface.

Long-lived strong squall lines after called "derechos" (Spanish for 'straight'). Derechos can travel many hundreds of miles and can produce considerable widespread damage from wind and hail.

Often along the leading edge of the squall line is a low hanging arc of cloudiness called the shelf cloud.

This appearance is a result of the rain cooled air spreading out from underneath the squall line acts as a mini cold front. The cooler dense air forces the warmer, less dense air, up. The rapidly rising air cools and condenses creating the shelf cloud.

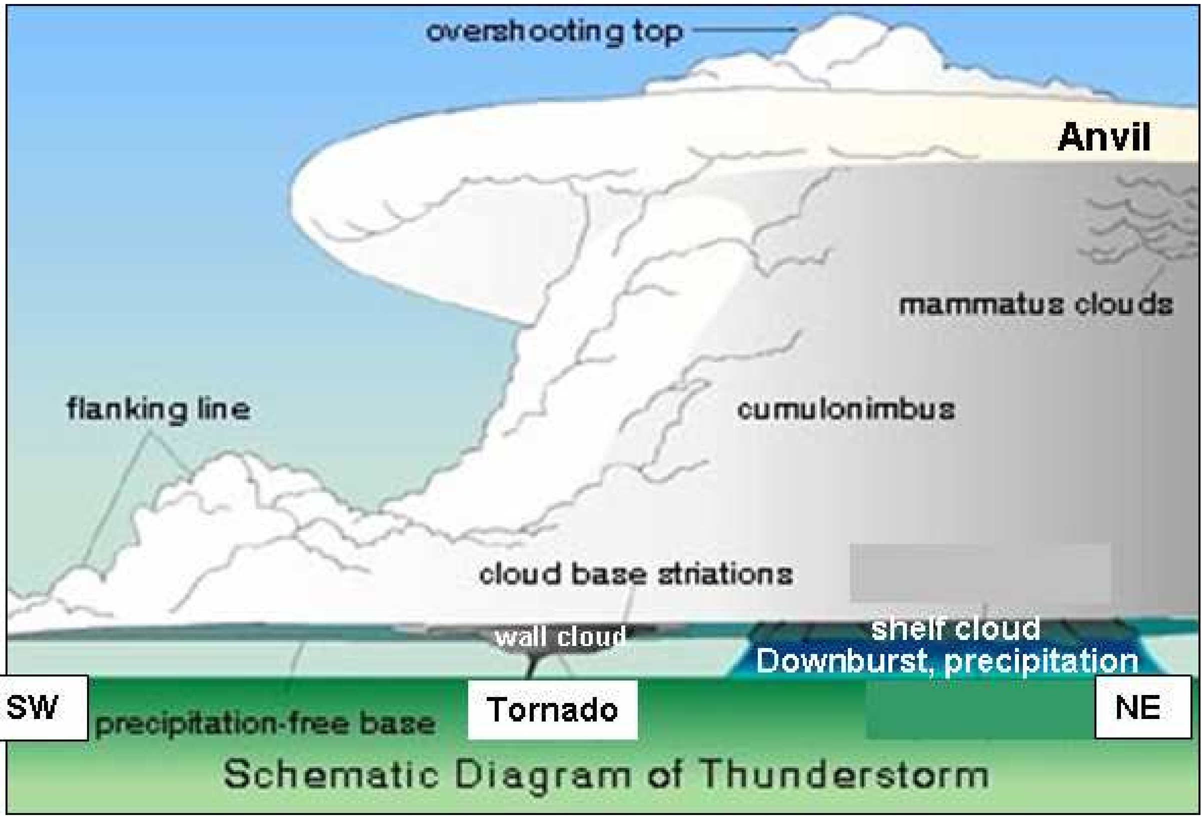
Supercell Thunderstorms



Supercell thunderstorms are a special kind of single cell thunderstorm that can persist for many hours.

They are responsible for nearly all of the significant tornadoes produced in the U.S. and for most of the hailstones larger than golf ball size. Supercells are also known to produce extreme winds and flash flooding.

Supercells are highly organized storms characterized updrafts that can attain speeds over 100 miles per hour, able to produce extremely large hail and strong and/or violent tornadoes, downdrafts that can produce damaging outflow winds in excess of 100 mph - all of which pose a high threat to life and property.



A schematic diagram of a supercell tornadic thunderstorm.

Idealized LP supercell

The most ideal conditions for supercells occurs when the winds are veering or turning clockwise with height. For example, in a veering wind situation the winds may be from the south at the surface and from the west at 15,000 feet (4,500 meters). This change in wind speed and direction produces storm-scale rotation, meaning the entire cloud rotates, which may gives a striated or corkscrew appearance to the storm''s updraft.

Dynamically, all supercells are fundamentally similar. However, they often appear quite different visually from one storm to another depending on the amount of precipitation accompanying the storm and whether precipitation falls adjacent to, or is removed from, the storm''s updraft.

Based on their visual appearance, supercells are often divided into three groups;

- Rear Flank Supercell - Low precipitation (LP),
- Classic (CL), or
- Front Flank Supercell - High precipitation (HP).

In LP supercells the updraft is on the rear flank of the storm, a barber pole or corkscrew appearance of updraft is possible, precipitation sparse or well removed from the updraft, often is transparent and you can’t see it, and large hail is often difficult to discern visually. Also, there is no "hook" seen on Doppler radar.

Idealized HP supercell

The majority of supercells fall in the "classic" category. These have large, flat updraft bases, generally has a wall cloud with it, striations or banding can been seen around the periphery of the updraft, heavy precipitation falls adjacent to the updraft with large hail likely, and have the potential for strong, long-lived tornadoes.

HP supercells will have the updraft is on the front flank of the storm, precipitation that almost surrounds updraft at times, will also generally have a wall cloud with it (but it may be obscured by the heavy precipitation), tornadoes that are potentially wrapped by rain (and therefore difficult to see), and will have extremely heavy precipitation with flash flooding.

Beneath the supercell, the rotation of the storm is often visible as well. The wall cloud is sometimes a precursor to a tornado. If a tornado were to form, it would usually do so within the wall cloud.

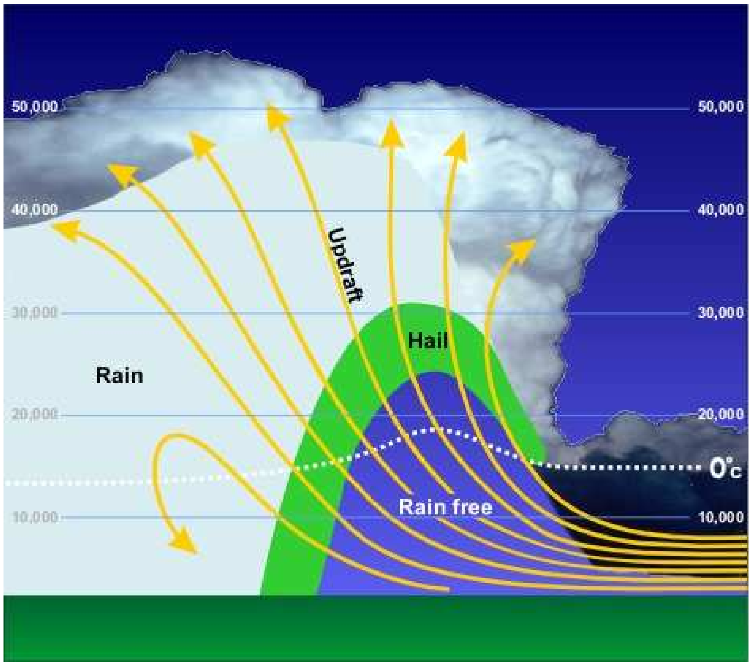
Wall clouds are isolated lower clouds below the rain-free base and below the main storm tower. Wall clouds are often located on the trailing flank of a storm. With some storms, such as high precipitation supercells, the wall cloud area may be obscured by precipitation or located on the leading flank of the storm.

Wall clouds associated with potentially severe storms can:

- Be a persistent feature that lasts for 10 minutes or more
- Have visible rotation
- Appear with lots of rising or sinking motion within and around the wall cloud

5. Thunderstorm Hazards - Hail

Hail is precipitation that is formed when updrafts in thunderstorms carry raindrops upward into extremely cold areas of the atmosphere. Hail can damage aircraft, homes and cars, and can be deadly to livestock and people. One of the people killed during the March 28, 2000 tornado in Fort Worth was killed when struck by grapefruit-size hail.



While Florida has the most thunderstorms, New Mexico, Colorado, and Wyoming usually have the most hail storms. Why? The freezing level in the Florida thunderstorms is so high, the hail often melts before reaching the ground.

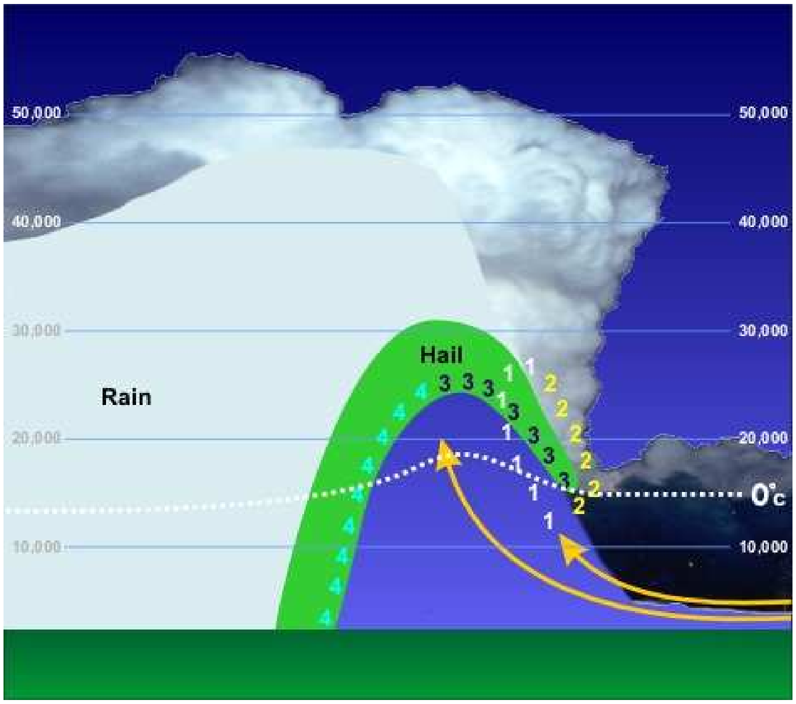
Hailstones grow by collision with supercooled water drops. (Supercooled drops are liquid drops surrounded by air that is below freezing which is a common occurrence in thunderstorms.) There are two methods by which the hailstone grows, wet growth and dry growth, and which produce the "layered look" of hail.

In wet growth, the hailstone nucleus (a tiny piece of ice) is in a region where the air temperature is below freezing, but not super cold. Upon colliding with a supercooled drop the water does not immediately freeze around the nucleus.

Instead liquid water spreads across tumbling hailstones and slowly freezes. Since the process is slow, air bubbles can escape resulting in a layer of clear ice.

With dry growth, the air temperature is well below freezing and the water droplet immediately freezes as it collides with the nucleus. The air bubbles are "frozen" in place, leaving cloudy ice.

Strong updrafts create a rain-free area in supercell thunderstorms (above right). We call this area a **WER** which stands for "weak echo region".



This term, WER, comes from an apparently rain free region of a thunderstorm which is bounded on one side AND above by very intense precipitation indicted by a strong echo on radar.

This rain-free region is produced by the updraft and is what suspends rain and hail aloft producing the strong radar echo.

The hail nucleus, buoyed by the updraft is carried aloft by the updraft and begins to grow in size as it collides with supercooled raindrops and other small pieces of hail.

Sometimes the hailstone is blown out of the main updraft and begins to falls to the earth.

If the updraft is strong enough it will move the hailstone back into the cloud where it once again collides with water and hail and grows. This process may be repeated several times.

In all cases, when the hailstone can no longer be supported by the updraft it falls to the earth. The stronger the updraft, the larger the hailstones that can be produced by the thunderstorm.

Multi-cell thunderstorms produce many hail storms but usually not the largest hailstones. The reason is that the mature stage in the life cycle of the multi-cell is relatively short which decreases the time for growth.

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

However, the sustained updraft in supercell thunderstorms support large hail formation by repeatedly lifting the hailstones into the very cold air at the top of the thunderstorm cloud. In all cases, the hail falls when the thunderstorm's updraft can no longer support the weight of the ice. The stronger the updraft the larger the hailstone can grow. How strong does the updraft need to be for the various sizes of hail? The table (above) provides the approximate speed for each size.

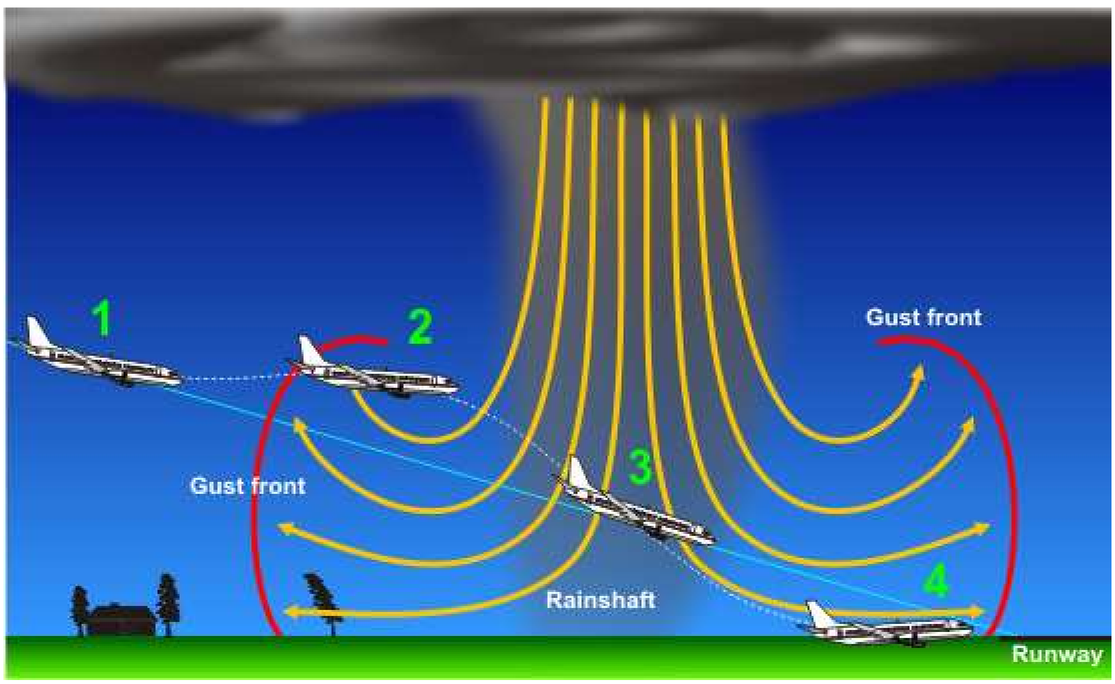
6. Thunderstorm Hazards - Damaging Wind

Damaging wind from thunderstorms is much more common than damage from tornadoes. In fact, many confuse damage produced by "straight-line" winds and often erroneously attribute it to tornadoes. Wind speeds can reach up to 100 mph (161 kph) with a damage path extending many miles.

Downbursts

Downdrafts are generated when rain-cooled, more dense air sinks inside a thunderstorm. Also some of the strong winds aloft are carried down with the downdraft by a process called "momentum transfer". As precipitation begins to fall, it drags some of the air with it. This "precipitation drag" initiates a downdraft. The downdraft is intensified by evaporative cooling as drier air from the edges of the storm mix with the moist air within the storm.

These processes lead to a rapid downward rush of air. As the air impacts the ground it is forced to spread out laterally causing the gusty winds associated with thunderstorms. Occasionally, thunderstorms will produce intense downdrafts that create damage as the wind spread out along the ground.



Downbursts can create hazardous conditions for pilots and these events have been responsible for several disasters.

1. As aircraft descend (right) into the airport they follow an imagery line called the "glide slope" to the runway (solid light blue line).

2. Upon entering the downburst, the plane encounters a "headwind", an increase in wind speed over the aircraft. The faster wind creates lift causing the plane to rise above the glide slope. To return the plane to the proper position, the pilot lowers the throttle to decrease the plane's speed thereby causing the plane to descend.

3. As the plane flies to the other side of the downburst, the wind direction shifts and is now from behind the aircraft. This decreases the wind over the wing reducing lift. The plane sinks below the glide slope.

4. However, the "tailwind" remains strong and even with the pilot applying full throttle trying to increase lift again, there is little, if any, room to recover from the rapid descent causing the plane to crash short of the runway.

Since the discovery of this effect in the early to mid 1980's, pilots are now trained to recognize this event and take appropriate actions to prevent accidents. Also, many airports are now equipped with equipment to detect downbursts and warn aircraft of their location.

Macrobursts and Microbursts

Downbursts are divided into two categories; macrobursts and microbursts. A macroburst is more than 2½ miles (4 km) in diameter and can produce winds as high as 135 mph (215 kph). Microbursts are smaller and produces winds as high as 170 mph (270 kph).

In wet, humid environments, macrobursts and microbursts will be accompanied by intense rainfall at the ground. If the storm forms in a relatively dry environment, however, the rain may evaporate before it reaches the ground and these downbursts will be without precipitation, known as dry microbursts.

Heat Bursts

Dry heatbursts are responsible for a rare weather event called "Heat Bursts". Heat bursts usually occur at night, are associated with decaying thunderstorms, and are marked by gusty, sometimes damaging, winds, a sharp increase in temperature and a sharp decrease in dewpoint.

While not fully understood, it is thought that the process of creating a dry microburst begins higher in the atmosphere for heat bursts. A pocket of cool air aloft forms during the evaporation process since heat energy is required. In heat bursts, all the precipitation has evaporated and this cooled air, being more dense than the surrounding environment, begins to sink due to gravity.

As the air sinks it compresses and with no more water to evaporate the result is the air rapidly warms. In fact, it can become quite hot and very dry. Temperatures generally rise 10 to 20 degrees in a few minutes and have been known to rise to over 120℉ (49℃) and remain in pl ace for several hours before returning to normal.

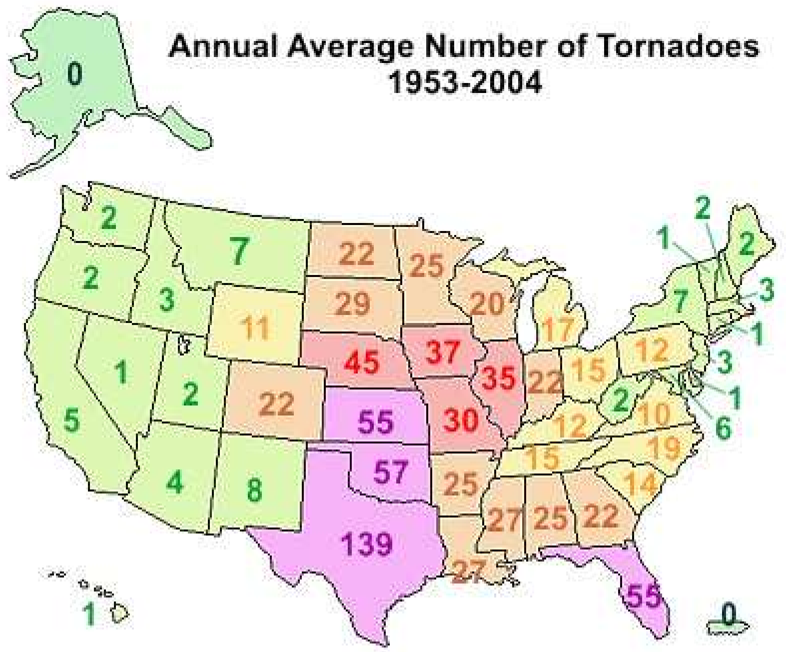
Derechos

A derecho is a widespread and long lived windstorm that is associated with a band of rapidly moving showers or thunderstorms. The word "derecho" is of Spanish origin, and means straight ahead. A derecho is made up of a "family of *downburst* clusters" and by definition must be at least 240 miles in length.

Derechos are associated with a band of showers or thunderstorms that are often "curved" in shape. These bowed out storms are called "bow echoes". A derecho can be associated with a single bow echo or multiple bow echoes. The bow echoes may vary in scale and may die out and redevelop during the course of derecho evolution.

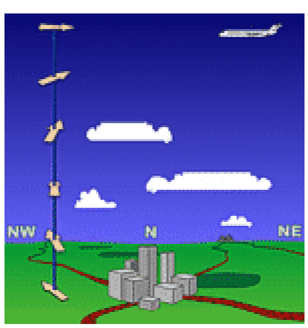
Winds in derecho can exceed 100 mph. For example, a derecho in northern Wisconsin on July 4, 1977 produced winds of 115 mph. The winds associated with derechos are not constant and may vary considerably along the derecho path.

7. Thunderstorm Hazards - Tornadoes



A tornado is a violently rotating (usually counterclockwise in the northern hemisphere) column of air descending from a thunderstorm and in contact with the ground. Although tornadoes are usually brief, lasting only a few minutes, they can sometimes last for more than an hour and travel several miles causing considerable damage.

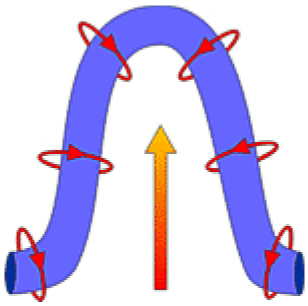
The United States experiences more tornadoes by far than any other country. In a typical year about 1000 tornadoes will strike the United States. The peak of the tornado season is April through June and more tornadoes strike the central United States than any other place in the world. This area has been nicknamed "tornado alley."



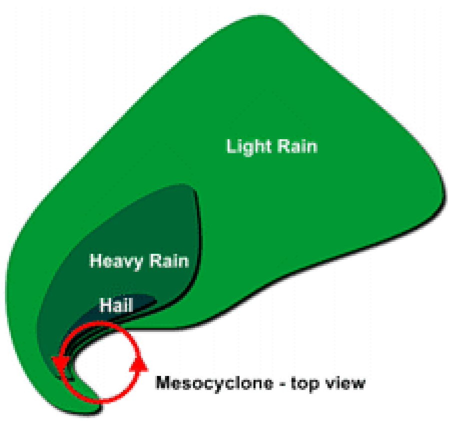
Most tornadoes are spawned from supercell thunderstorms. Supercell thunderstorms are characterized by a persistent rotating updraft and form in environments of strong vertical wind shear.

Wind shear is the change in wind speed and/or direction with height.

The updraft lifts the rotating column of air created by the speed shear. This provides two different rotations to the supercell; cyclonic or counter clockwise rotation and an anti-cyclonic of clockwise rotation.

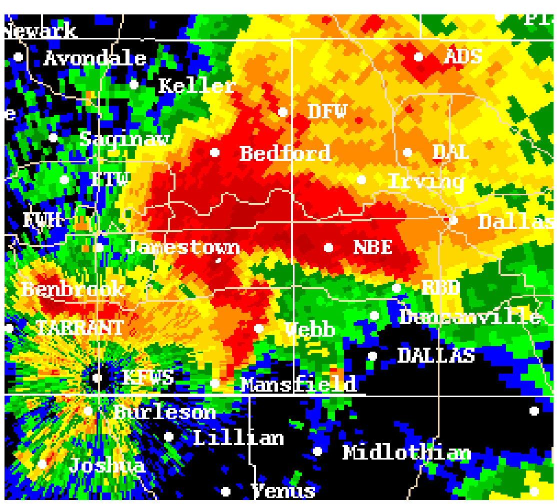


The directional shear amplifies the cyclonic rotation and diminishes the anti-cyclonic rotation (the rotation on the right side of the of the updraft in the illustration at left). All that remains is the cyclonic rotation called a *mesocyclone*. By definition a supercell is a rotating thunderstorm.



When viewed from the top, the counter-clockwise rotation of the mesocyclone gives the supercell its classic "hook" appearance when seen by radar. As the air rises in the storm, it becomes stretched and more narrow with time.

The image (below right) is from the Doppler radar in Fort Worth, Texas, March 28, 2000. This image was taken at 7:10 p.m., about one hour after a tornado moved through downtown Fort Worth, TX. This image shows the second tornado that day in the Metroplex.



The colors indicate the intensity of the rain with green representing light rain, the yellow and orange for moderate rain and reds for the heaviest rain and hail. The classic "hook" pattern of the supercell from which a tornado was observed can be clearly seen.

The exact processes for the formation of a funnel are not known yet. Recent theories suggest that once a mesocyclone is underway, tornado development is related to the temperature differences across the edge of downdraft air wrapping around the mesocyclone.

However, mathematical modeling studies of tornado formation also indicate that it can happen without such temperature patterns; and in fact, very little temperature variation was observed near some of the most destructive tornadoes in history on May 3, 1999 in Oklahoma.

The funnel cloud of a tornado consists of moist air. As the funnel descends the water vapor within it condenses into liquid droplets. The liquid droplets are identical to cloud droplets yet are not considered part of the cloud since they form within the funnel.

The descending funnel is made visible because of the water droplets. The funnel takes on the color of the cloud droplets, which is white.

Due to the air movement, dust and debris on the ground will begin rotating, often becoming several feet high and hundreds of yards wide.

After the funnel touches the ground and becomes a tornado, the color of the funnel will change. The color often depends upon the type of dirt and debris is moves over (red dirt produces a red tornado, black dirt a black tornado, etc.).

Tornadoes can last from several seconds to more than an hour but most last less than 10 minutes. The size and/or shape of a tornado is no measure of its strength.

Occasionally, small tornadoes do major damage and some very large tornadoes, over a quarter-mile wide, have produced only light damage.

The tornado will gradually lose intensity. The condensation funnel decreases in size, the tornado becomes tilted with height, and it takes on a contorted, rope-like appearance before it completely dissipates. Learn more about tornadoes from the .

The Enhance Fujita (EF)-Scale

EF scale	Class	Wind speed		Description
		mph	km/h	
EF0	weak	65-85	105-137	Gale
EF1	weak	86-110	138-177	Moderate
EF2	strong	111-135	178-217	Significant
EF3	strong	136-165	218-266	Severe
EF4	violent	166-200	267-322	Devastating
EF5	violent	> 200	> 322	Incredible

The Fujita (F) Scale was originally developed by Dr. Tetsuya Theodore Fujita to estimate tornado wind speeds based on damage left behind by a tornado. An Enhanced Fujita (EF) Scale, developed by a forum of nationally renowned meteorologists and wind engineers, makes improvements to the original F scale. This EF Scale has replaced the original F scale, which has been used to assign tornado ratings since 1971.

The original F scale had limitations, such as a lack of damage indicators, no account for construction quality and variability, and no definitive correlation between damage and wind speed. These limitations may have led to some tornadoes being rated in an inconsistent manner and, in some cases, an overestimate of tornado wind speeds.

The EF Scale takes into account more variables than the original F Scale did when assigning a wind speed rating to a tornado. The EF Scale incorporates 28 damage indicators (DIs) such as building type, structures, and trees. For each damage indicator, there are 8 degrees of damage (DOD) ranging from the beginning of visible damage to complete destruction of the damage indicator. The original F Scale did not take these details into account.

For example, with the EF Scale, an F3 tornado will have estimated wind speeds between 136 and 165 mph (218 and 266 km/h), whereas with the original F Scale, an F3 tornado has winds estimated between 162-209 mph (254-332 km/h). The wind speeds necessary to cause "F3" damage are not as high as once thought and this may have led to an overestimation of some tornado wind speeds.

There is still some uncertainty as to the upper limits of the strongest tornadoes so F5 ratings do not have a wind speed range. Wind speed estimations for F5 tornadoes will be left open ended and assigned wind speeds greater than 200 mph (322 km/h).

EF0 damages.

EF1 damages.

EF2 damages.

EF3 damages.

EF4 damages.

EF5 damages.

8. Thunderstorm Hazards - Flash Floods

Except for heat related fatalities, more deaths occur from flooding than any other hazard. Why? Most people fail to realize the power of water. For example, six inches of fast-moving flood water can knock you off your feet.

While the number of fatalities can vary dramatically with weather conditions from year to year, the national 30-year average for flood deaths is 127. That compares with a 30-year average of 73 deaths for lightning, 68 for tornadoes and 16 for hurricanes.

National Weather Service data also shows:

- Nearly half of all flash flood fatalities are vehicle-related,
- The majority of victims are males, and
- Flood deaths affect all age groups.

Most flash floods are caused by slow moving thunderstorms, thunderstorms that move repeatedly over the same area or heavy rains from tropical storms and hurricanes. These floods can develop within minutes or hours depending on the intensity and duration of the rain, the topography, soil conditions and ground cover.

Flash floods can roll boulders, tear out trees, destroy buildings and bridges, and scour out new channels. Rapidly rising water can reach heights of 30 feet or more. Furthermore, flash flood-producing rains can also trigger catastrophic mud slides.

Occasionally, floating debris or ice can accumulate at a natural or man-made obstruction and restrict the flow of water. Water held back by the ice jam or debris dam can cause flooding upstream. Subsequent flash flooding can occur downstream if the obstruction should suddenly release.

TURN AROUND, DON'T DROWN®

Each year, more deaths occur due to flooding than from any other thunderstorm related hazard. Why? The main reason is people underestimate the force and power of water. Many of the deaths occur in automobiles as they are swept downstream. Of these deaths, many are preventable, but foolish people drive around the barriers in place that warn you the road is flooded.

Whether you are driving or walking, if you come to a flooded road, **Turn Around...Don't Drown!**. You will not know the depth of the water nor will you know the condition of the road under the water.

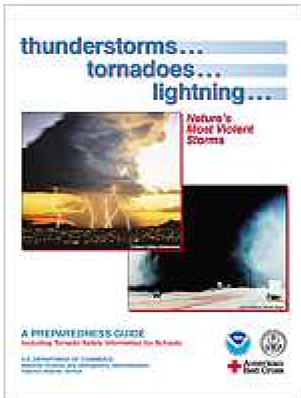
Of the three deaths which occurred as a result of the Fort Worth tornado, March 28, 2000, one death was due to flooding. The man who drowned was a passenger in a car with his girlfriend, the driver. They approached a low spot with water flowing over the road due to very heavy rain. Flooding was a common occurrence at this location with heavy rains and the danger was well marked.

As the driver drove her car into the water she became frightened as the water rose higher and higher around her vehicle. She backed out to higher ground. The passenger said the water was *NOT* too deep and he would prove it by walking across to the other side. He never made it.

Follow these safety rules.

- Monitor the NOAA Weather Radio, or your favorite news source for vital weather related information.
- If flooding occurs, get to higher ground. Get out of areas subject to flooding. This includes dips, low spots, canyons, washes etc.
- Avoid already flooded and high velocity flow areas. Do not attempt to cross flowing streams. If you enter a flowing stream and the water gets above you knee, **TURN AROUND, DON'T DROWN**.
- If driving be aware that the road bed may not be intact under flood waters. Turn around and go another way. NEVER drive through flooded roadways! If your vehicle stalls, leave it immediately and seek higher ground. Rapidly rising water may engulf the vehicle and sweep you and your occupants away.
- Do not camp or park your vehicle along streams and washes, particularly during threatening conditions.
- Be especially cautious at night when it is harder to recognize flood dangers.

9. Staying Ahead of the Storms



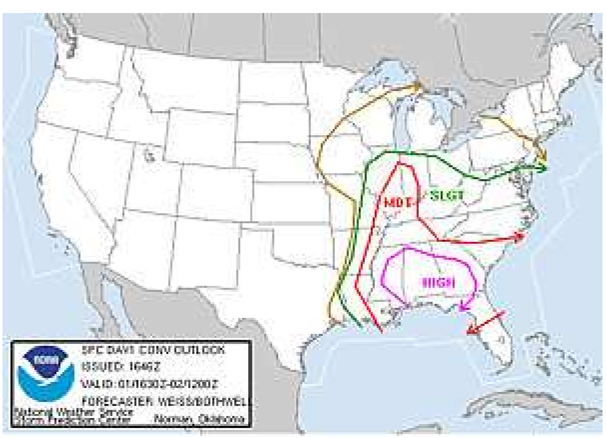
Thunderstorms... Lightning...Tornadoes: Preparedness Guide

Severe weather rarely happens without any warning. While we will never be able to pinpoint when and where severe weather will develop, we can know broader areas or regions where the potential for the development of severe weather. *It is your responsibility* to check the weather forecast, which may be often several times daily, to see if you are, or will be, under a risk of severe weather.

The weather office in charge of charged with monitoring and forecasting the potential for severe weather over the 48 continental United States is the Storm Prediction Center (SPC) located in Norman, OK. The information provided by SPC will give you critical information concerning the threat of severe weather in your locale.

- Convective Outlooks (http://www.spc.noaa.gov/products/outlook/day1otlk.html)
- Public Severe Weather Outlooks (http://www.spc.noaa.gov/products/outlook/pwo.html)
- Mesoscale Discussions (http://www.spc.noaa.gov/products/md/)
- Severe Weather Watches (http://www.spc.noaa.gov/products/watch/)

Convective Outlooks (http://www.spc.noaa.gov/products/outlook/day1otlk.html)



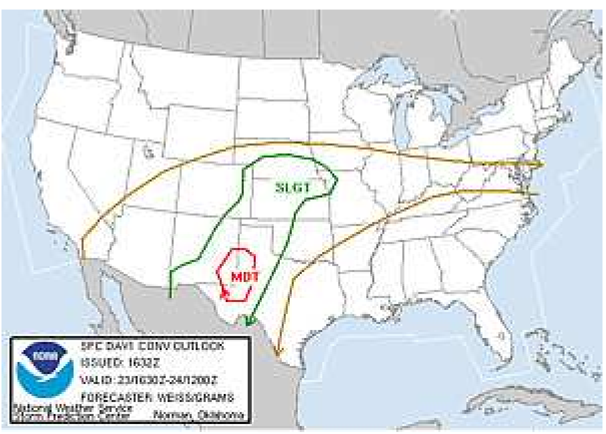
Convective Outlooks consist of a narrative and a graphic depicting severe thunderstorm threats across the continental United States. The outlook narratives are written in technical language, intended for sophisticated weather users, and provide the meteorological reasoning for the risk areas.

This product also provides explicit information regarding the timing, the greatest severe weather threat and the expected severity of the event. However, despite being technical in nature, the graphics which accompanies the narratives, you will have vital information to help plan your day.

Convective Outlooks are divided into four periods.

Day 1	This is the risk of severe weather today through early morning of the following day. Day 1 forecasts are issued five times daily; 0600z (around midnight), 1300z (around sunrise), 1630z (mid-morning), 2000z (mid-afternoon), and 0100z (early evening). This is the forecast you will see on SPC's frontpage. (http://www.spc.noaa.gov/)
Day 2	Day 2 continues from the ending of Day 1 (tomorrow morning) for the next 24 hours. These are issued twice daily; 1:00 a.m. (both CST/CDT) and 1730z (around noon).
Day 3	This is the forecast for the subsequent 24 hours. Day 3 forecasts are issued daily by 2:30 a.m. central time (0830z on standard time and 0730z on daylight time).
Days 4-8	A severe weather area depicted in the Day 4-8 period indicates a 30% or higher probability for severe thunderstorms (e.g. a 30% chance that a severe thunderstorm will occur within 25 miles of any point).

In convective outlook graphics, the brown unlabeled line depicts a 10% or higher probability of thunderstorms during the valid period. The region of these storms will be *to the right of the brown line* (look for the arrowhead).



A green line will be seen if there is a slight (SLGT) risk of severe thunderstorms during the forecast period. Depending on the size of the area, approximately 5-25 reports of ¾" or larger hail, and/or 5-25 wind events, and/or 1-5 tornadoes would be possible.

The red line indicates a moderate (MDT) risk of severe thunderstorms are expected. The moderate risk indicates a potential for a greater concentration of severe thunderstorms than the slight risk, and in most situations, greater magnitude of the severe weather.

The fuschia line indicates a high (HIGH) risk of severe thunderstorms are expected. A high risk area suggests a major severe weather outbreak is expected, with a high concentration of severe weather reports and an enhanced likelihood of extreme severe (i.e., violent tornadoes or very damaging convective wind events occurring across a large area).

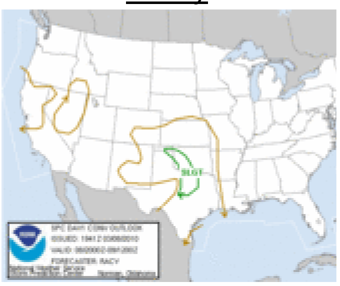
In a high risk, the potential exists for 20 or more tornadoes, some possibly EF2 or stronger, or an extreme derecho potentially causing widespread wind damage and higher end wind gusts (80+ mph) that may result in structural damage.

Finally, a "SEE TEXT" label will be used for areas where a 5% probability of severe is forecast, but the coverage or intensity is not expected to be sufficient for a slight risk.

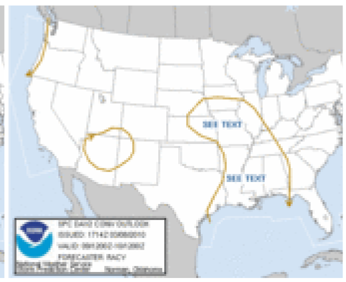
Current severe weather outlooks from the Storm Prediction Center

(http://www.spc.noaa.gov/products/outlook/day1otlk.html
http://www.spc.noaa.gov/products/outlook/day2otlk.html
http://www.spc.noaa.gov/products/outlook/day3otlk.html
http://www.spc.noaa.gov/products/exper/day4-8/)

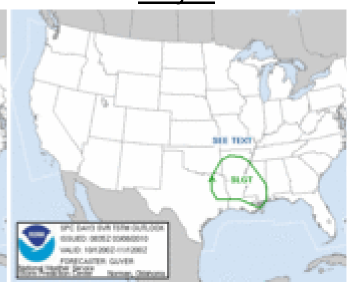
Today



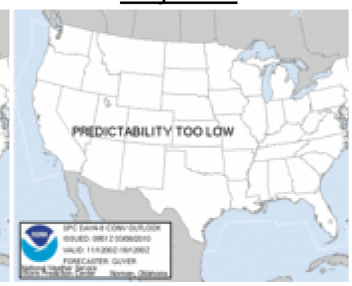
Tomorrow



Day 3



Days 4-8

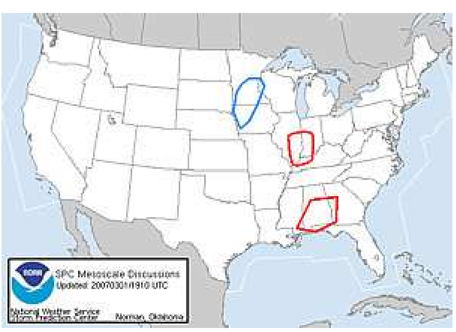


Public Severe Weather Outlooks

The Public Severe Weather Outlooks (PWO) are issued when a potentially significant or widespread tornado outbreak is expected. This plain-language forecast is typically issued 12-24 hours prior to the event and is used to alert NWS field offices and other weather customers concerned with public safety of a rare, dangerous situation. The PWO is reserved for only the most serious weather situations where a HIGH risk is forecast for a potential tornado outbreak. The SPC issues around 5 PWO's each year.

Mesoscale Discussions

Current Mesoscale Discussions (http://www.spc.noaa.gov/products/md/)



When conditions appear favorable for severe storm development, SPC issues a Mesoscale Discussion (MCD), normally 1 to 3 hours before issuing a weather watch. SPC also puts out MCDs for mesoscale aspects of hazardous winter weather events including heavy snow, blizzards and freezing rain. MCDs are also issued on occasion for heavy rainfall or convective trends.

The MCD basically describes what is currently happening, what is expected in the next few hours, the meteorological reasoning for the forecast, and when/where SPC plans to issue the watch (if dealing with severe thunderstorm potential). Severe thunderstorm MCDs provide you with extra lead time on the severe weather development.

Severe Weather Watches

When conditions become favorable for severe thunderstorms and tornadoes to develop, SPC usually issues a severe thunderstorm or tornado watch. Tornadoes can occur in either type of watch but tornado watches are issued when conditions are especially favorable for tornadoes. Severe thunderstorm watches are blue with tornado watches in red.

Watches are large areas, 20,000 to 40,000 square miles, and are issued by county. They are numbered sequentially (the count is reset at the beginning of each year). A typical watch has a duration of about four to six hours but it may be canceled, replaced, or re-issued as required. *A watch is not a warning, and should not be interpreted as a guarantee that there will be severe weather!*

When a watch is issued stay alert for changing weather conditions and possible warnings. Any warnings will be issued by your local NWS Weather Forecast Ofice (http://www.srh.noaa.gov/jetstream//nws/wfos.htm).

Current severe weather watches (http://www.spc.noaa.gov/products/watch/)

When a severe weather watch is issued close to your location but does not include your county, you should still remain alert. The atmosphere rarely follows straight lines, and thunderstorms do not always remain within the man-made boundaries we create around them. When SPC feels confident about the possibility of severe weather in a specific area, they try to issue a watch at least 1 hour prior the onset of severe weather.

In some instances the phrase "THIS IS A PARTICULARLY DANGEROUS SITUATION" will headline a watch (called a PDS watch). The "particularly dangerous situation" wording is used in rare situations when long-lived, strong and violent tornadoes are possible. PDS watches are issued, when in the opinion of the forecaster, the likelihood of significant events is boosted by very volatile atmospheric conditions. Usually this decision is based on a number of atmospheric clues and parameters, so the decision to issue a PDS watch is subjective. There is no hard threshold or criteria. In high risk outlooks PDS watches are issued most often.

Chapter 3. Lighting

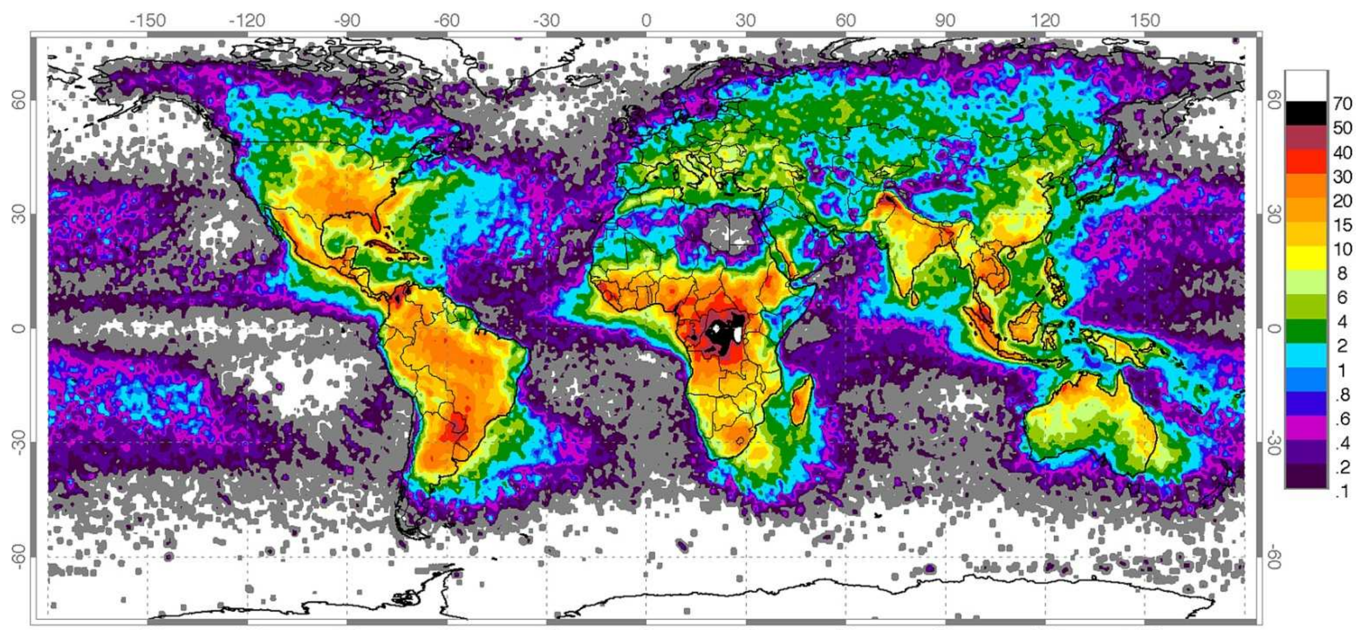
(from http://www.srh.noaa.gov/jetstream//lightning/lightning_intro.htm)

1. Introduction

Lightning is one of the oldest observed natural phenomena on earth. At the same time, it also is one of the least understood. While lightning is simply a gigantic spark of static electricity (the same kind of electricity that sometimes shocks you when you touch a doorknob), scientists do not have a complete grasp on how it works, or how it interacts with solar flares impacting the upper atmosphere or the earth's electromagnetic field.
Lightning has been seen in volcanic eruptions, extremely intense forest fires, surface nuclear detonations, heavy snowstorms, and in large hurricanes. However, it is most often seen in thunderstorms. In fact, lightning (and the thunder that results) is what makes a thunderstorms.

At any given moment, there can be as many as 2,000 thunderstorms occurring across the globe. This translates to more than 14.5 MILLION storms each year. NASA satellite research indicated these storms produce lightning flashes about 40 times a second worldwide.

This is a change from the commonly accepted value of 100 flashes per second which was an estimate from 1925. Whether it is 40, 100, or somewhere in between, we live on an electrified planet.



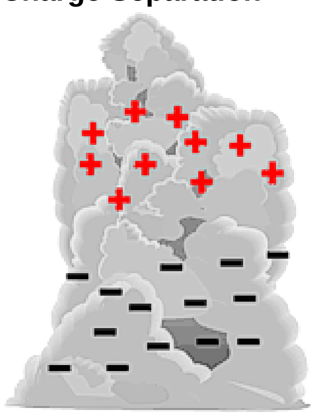
Global lighting distribution as observed from space.

2. How Lightning is Created?

The conditions needed to produce lightning have been known for some time. However, exactly how lightning forms has never been verified so there is room for debate. Leading theories focus around separation of electric charge and generation of an electric field within a thunderstorm. Recent studies also indicate that ice, hail, and semi-frozen water drops known as graupel are essential to lightning development. Storms that fail to produce large quantities of ice usually fail to produce lightning.

Forecasting when and where lightning will strike is not yet possible and most likely never will be. But by educating yourself about lightning and learning some basic safety rules, you, your family, and your friends can avoid needless exposure to the dangers of one of the most capricious and unpredictable forces of nature.

Charge Separation

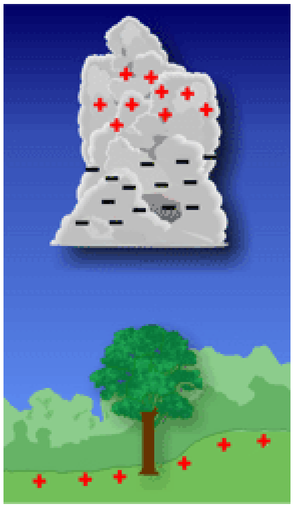


Thunderstorms have very turbulent environments. Strong updrafts and downdrafts occur with regularity and within close proximity to each other. The updrafts transport small liquid water droplets from the lower regions of the storm to heights between 35,000 and 70,000 feet, miles above the freezing level.

Meanwhile, downdrafts transport hail and ice from the frozen upper regions of the storm. When these collide, the water droplets freeze and release heat. This heat in turn keeps the surface of the hail and ice slightly warmer than its surrounding environment, and a "soft hail", or "graupel" forms.

When this graupel collides with additional water droplets and ice particles, *a critical phenomenon occurs*: Electrons are sheared off of the ascending particles and collect on the descending particles. Because electrons carry a negative charge, the result is a storm cloud with a negatively charged base and a positively charged top.

Field Generation



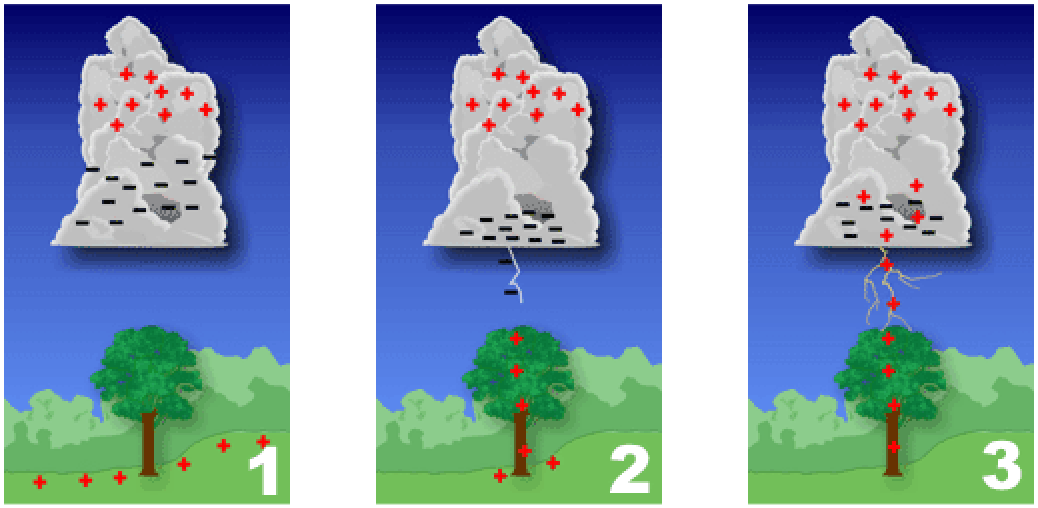
In the world of electricity, opposites attract and insulators inhibit. As positive and negative charges begin to separate within the cloud, an electric field is generated between its top and base. Further separation of these charges into pools of positive and negative regions results in a strengthening of the electric field.

However, the atmosphere is a very good insulator that inhibits electric flow, so a TREMENDOUS amount of charge has to build up before lightning can occur. When that charge threshold is reached, the strength of the electric field overpowers the atmosphere's insulating properties, and lightning results.

The electric field within the storm is not the only one that develops. Below the negatively charged storm base, positive charge begins to pool within the surface of the earth (see image left). This positive charge will shadow the storm wherever it goes, and is responsible for cloud-to-ground lightning. However, the electric field within the storm is much stronger than the one between the storm base and the earth's surface, so most lightning (~75-80%) occurs within the storm cloud itself.

How Lightning Develops Between The Cloud And The Ground

A moving thunderstorm gathers another pool of positively charged particles along the ground that travel with the storm (image 1). As the differences in charges continue to increase, positively charged particles rise up taller objects such as trees, houses, and telephone poles.



A channel of negative charge, called a "stepped leader" will descend from the bottom of the storm toward the ground (image 2). It is invisible to the human eye, and shoots to the ground in a series of rapid steps, each occurring in less time than it takes to blink your eye. As the negative leader approaches the ground, positive charge collects in the ground and in objects on the ground.

This positive charge "reaches" out to the approaching negative charge with its own channel, called a "streamer" (image 3). When these channels connect, the resulting electrical transfer is what we see as lightning. After the initial lightning stroke, if enough charge is leftover, additional lightning strokes will use the same channel and will give the bolt its flickering appearance.

Tall objects such as trees and skyscrapers are commonly struck by lightning. Mountains also make good targets. The reason for this is their tops are closer to the base of the storm cloud. Remember, the atmosphere is a good electrical insulator. The less insulation the lightning has to burn through, the easier it is for it to strike. However, this does not always mean tall objects will be struck. It all depends on where the charges accumulate. Lighting can strike the ground in an open field the even if the tree line is close by.

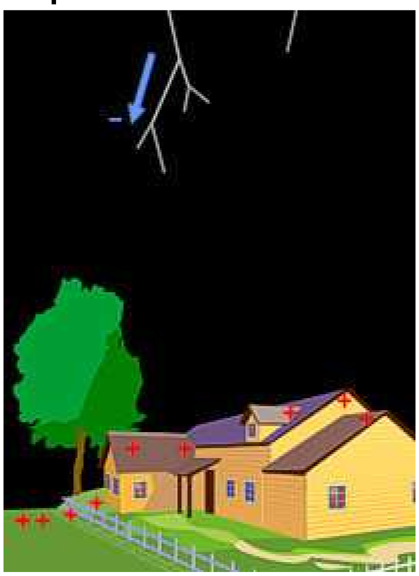
3. The Lightning Process: Keeping in Step

Lightning can be divided into two types:

- Flashes with at least one channel connecting the cloud to the ground, known as "cloud-to-ground" discharges (CG); and
- Flashes with no channel to ground, known as "in-cloud" (IC), "cloud-to-cloud" (CC), or "cloud-to-air" (CA).

The lightning process is more or less the same for both types.

Step 1

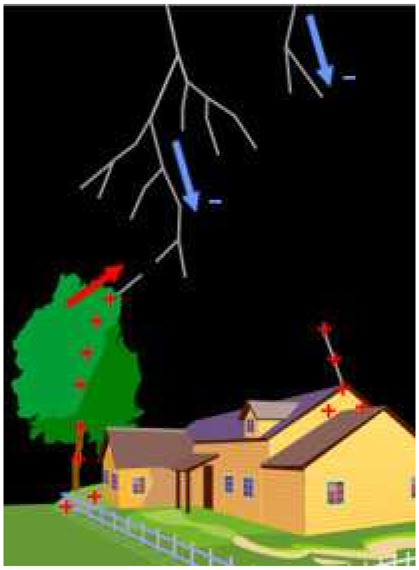


A typical CG lightning strike initiates inside the storm. Under the influences of the electric field between the cloud and the ground, a very faint, negatively charged channel called a "stepped leader" emerges from the storm base and propagates toward the ground in a series of steps about 50 meters (160 feet) in length and 1 microsecond (0.000001 seconds) in duration.

In what can be loosely described as an "avalanche of electrons", the stepped leader usually branches out in many directions as it approaches the ground, carrying an EXTREMELY strong electric potential: about 100 MILLION volts with respect to the ground and about 5 coulombs of negative charge.

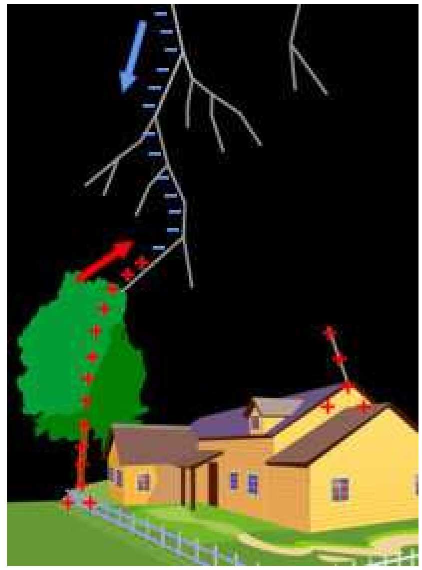
Between each step there is a pause of about 50 microseconds, during which the stepped leader "looks" around for an object to strike. If none is "seen", it takes another step, and repeats the process until it "finds" a target.
It takes the stepped leader about 50 milliseconds (1/20th of a second) to reach its full length, though this number varies depending on the length of its path. Studies of individual strikes have shown that a single leader can be comprised of more than 10,000 steps!

Step 2



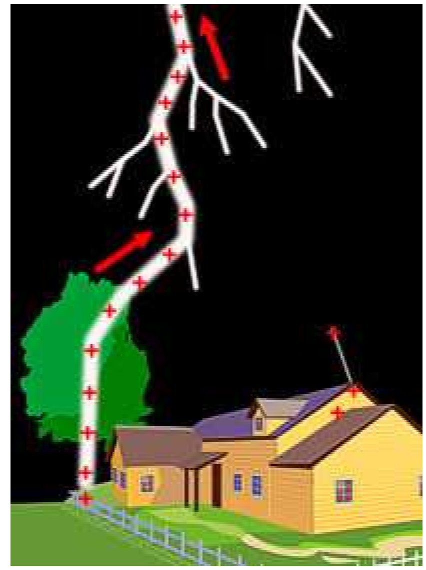
As the stepped leader approaches the ground, its strong, negative charge repels all negative charge within the immediate strike zone of the earth's surface, while attracting vast amounts of positive charge. The influx of positive charge into the strike zone is so strong that the stepped leader actually induces electric channels up from the ground known as "streamers". When one of these positively charged streamers connects with a negatively charged stepped leader (anywhere from 100 to 300 feet (30 to 100 meters) above the surface of the earth), the following steps occur in less than 100 microseconds.

Step 3



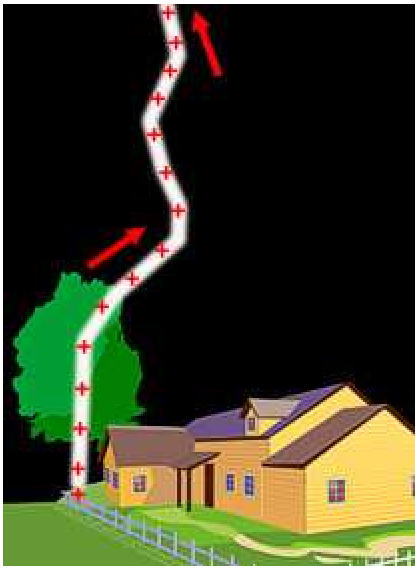
The electric potential of the stepped leader is connected to the ground and the negative charge starts flowing **DOWN** the established channel.

Step 4

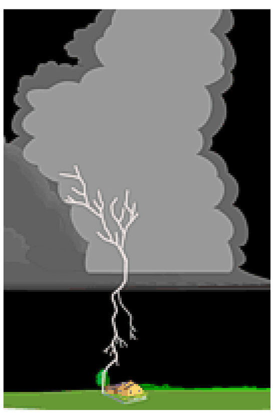


An electric current wave, called a "return stroke", shoots UP the channel as a brilliant pulse. Behind the wave front, electric charge flows up the channel and produces a ground current. It takes the current about 1 microsecond to reach its peak value, which averages around 30,000 amperes. The "return stroke" produces more than 99% of a lightning bolt's luminosity and is what we see as lightning. The stroke actually travels FROM the ground INTO the cloud, but because the strike takes place so quickly, to the unaided eye is appears the opposite is true.

Step 5

 After the return stroke ceases flowing up the channel, there is a pause of about 20 to 50 milliseconds. After that, if enough charge is still available within the cloud, another leader can propagate down to the ground. This leader is called a "dart leader" because it uses the channel already established by the stepped leader and therefore has a continuous path.

Dart leaders give lightning its flickering appearance and normally are not branched like the initial stepped leader.

 Not every lightning flash will produce a dart leader because sufficient charge to initiate one must be available within about 100 milliseconds of the initial stepped leader.

The dart leader carries additional electric potential to the ground and induces a new streamer from the ground. The dart leader's peak current is usually less than the initial stepped leader and its return stroke has a shorter duration than the initial return stroke. As additional dart leaders are produced, their peak currents and return stroke durations continue to decrease.

Dart leaders and their return strokes don't necessarily have to use the same cloud-to-ground channel that was burned by initial stepped leader. If a dart leader takes a different path to the ground, the lightning will appear to dance from one spot to another. This is known as "forked lightning".

4. The Positive and Negative Side of Lightning

The previous section describes what is called "negative lightning", because there is the transfer of negative charge from the cloud to the ground. However, not all lightning forms in the negatively charged region under the thunderstorm base.

Some lightning originates in the cirrus anvil or upper parts near the top of the thunderstorm, where a high positive charge resides. Lightning that forms in this region follows the same scenario as previously described, but the descending stepped leader will carry a positive charge while its subsequent ground streamers will have a negative charge. These bolts are known as "positive lightning" because there is a net transfer of positive charge from the cloud to the ground.

Positive lightning makes up less than 5% of all strikes. However, despite a significantly lower rate of occurrence, positive lightning is particularly dangerous for several reasons. Since it originates in the upper levels of a storm, the amount of air it must burn through to reach the ground usually much greater. Therefore, its electric field typically is much stronger than a negative strike. Its flash duration is longer, and its peak charge and potential can be ten times greater than a negative strike; as much as **300,000 amperes** and **one billion volts**!

Some positive strikes can occur within the parent thunderstorm and strike the ground beneath the cloud. However, many positive strikes occur near the edge of the cloud or strike **MORE THAN 10 MILES AWAY**, where you may not perceive any risk nor hear any thunder.

Also, positive flashes are believed to be responsible for a large percentage of forest fires and power line damage. Thus, positive lightning is much more lethal and causes greater damage than negative lightning.

Some interesting properties of positive lightning:

- Positive lightning can be the dominate type of cloud-to-ground during the winter months and in the dissipating stage of a thunderstorm.

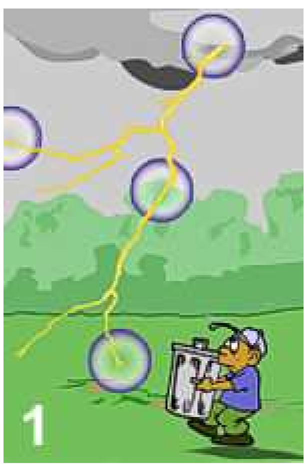
- Positive lightning has been identified as a major source for the recently discovered sprites and elves. Sprites and elves are most likely lightning discharges but occur from 18-60 miles (30-95 km) in altitude, well above the parent thunderstorm.
- Positive lightning is usually composed of one stroke (negative lightning typically consists of two or more strokes)

Finally, there is bipolar lightning, lightning that actually changes its polarity (positive becoming negative or vice versa). It is no less dangerous than any other type of lightning but shows that we live on a complex planet with many aspects we do not fully understand

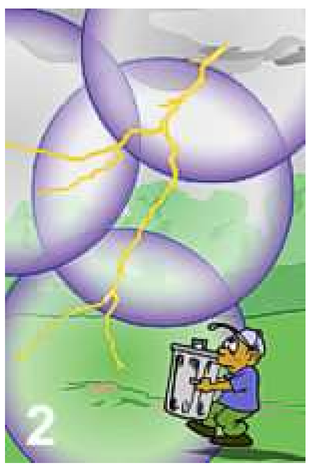
5. The Sound of Thunder

Regardless of whether lightning is positive or negative, thunder is produced the same way. Thunder is the acoustic shock wave resulting from the extreme heat generated by a lightning flash. Lightning can be as hot as 54,000℉ (30,000℃), a temperature that is five times the su rface of the sun! When lightning occurs, it heats the air surrounding its channel to that same incredible temperature in a fraction of a second.

Like all gases, when air molecules are heated, they expand. The faster they are heated, the faster their rate of expansion. But when air is heated to 54,000℉ in a fraction of a second, a phenomenon known as "explosive expansion" occurs. This is where air expands so rapidly that it compresses the air in front of it, forming a shock wave similar to a sonic boom. Exploding fireworks produce a similar result.



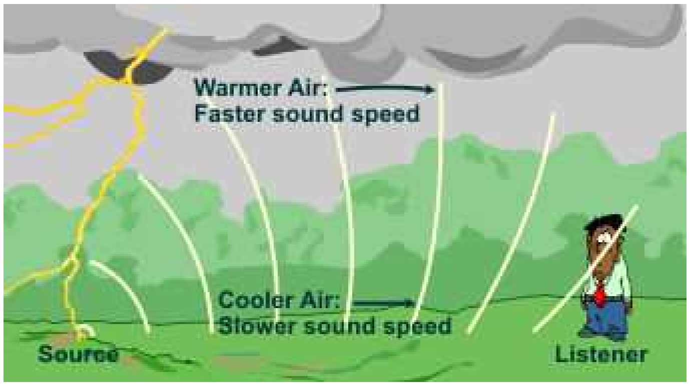
When lightning strikes a shock wave is generated at each point along the path of the lightning bolt. (The above illustrations show only four points.)



With nearby lightning strikes the thunder will sound like a loud bang, crack or snap and its duration will be very short.

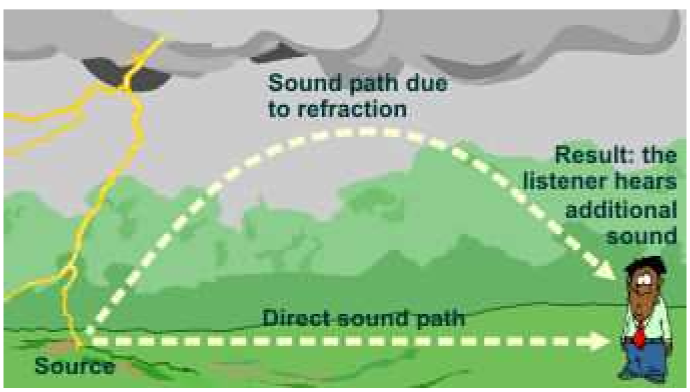
As the shock wave propagates away from the strike center, it stretches, diminishes, and becomes elongated. Then other shock waves from more distance locations arrive at the listener.

At large distances from the center, the shock wave (thunder) can be many miles across. To the listener, the combination of shock waves gives thunder the continuous rumble we hear.



In addition, the temperature of the atmosphere affects the thunder sound you hear as well as how far away you can hear it. Sound waves move faster in warm air than they do in cool air. Typically, the air temperature decreases with height. When this occurs, thunder will normally have an audible range up to 10 miles (16 km).

However, when the air temperature increases with height, called an inversion, sound waves are refracted (bent back toward the earth) as they move due to their faster motion in the warmer air. Normally, only the direct sound of thunder is heard. But refraction can add some additional sound, effectively amplifying the thunder and making it sound louder.



This is more common in the winter as thunderstorms develop in the warm air above a cooler surface air mass. If the lightning in these "elevated thunderstorms" remains above the inversion, then most of the thunder sound also remains above the inversion. However, much of the sound waves from cloud-to-ground strikes remain below the inversion giving thunder a much louder impact.

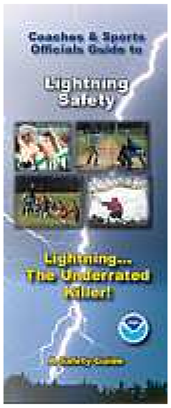
6. Lightning Safety

Lightning is the MOST UNDERRATED weather hazard. On average, only floods kill more people. Lightning makes every single thunderstorm a potential killer, whether the storm produces one single bolt or ten thousand bolts.
In the United States, lightning routinely kills more people each year than tornadoes or hurricanes. Tornadoes, hail, and wind gusts get the most attention, but only lightning can strike outside the storm itself. Lightning is the first thunderstorm hazard to arrive and the last to leave.

Lightning is one of the most capricious and unpredictable characteristics of a thunderstorm. Because of this, no one can guarantee an individual or group absolute protection from lightning. However, knowing and following proven lightning safety guidelines can greatly reduce the risk of injury or death. Remember, **YOU** are ultimately responsible for your personal safety, and should take appropriate action when threatened by lightning.
While no place is 100% safe from lightning, some places are much safer than others.

Where to Go The safest location during a thunderstorm is inside a large enclosed structure with plumbing and electrical wiring. These include shopping centers, schools, office buildings, and private residences. If lightning strikes the building, the plumbing and wiring will conduct the electricity more efficiently than a human body. If no buildings are available, then an enclosed metal vehicle such as an automobile, van, or school bus makes a decent alternative.	**Where NOT to Go** Not all types of buildings or vehicles are safe during thunderstorms. Buildings which are NOT SAFE (even if they are "grounded") have exposed openings. These include beach shacks, metal sheds, picnic shelters/pavilions, carports, and baseball dugouts. Porches are dangerous as well. Convertible vehicles offer no safety from lightning, even if the top is "up". Other vehicles which are NOT SAFE during lightning storms are those which have open cabs, such as golf carts, tractors, and construction equipment.
What To Do Once inside a sturdy building, stay away from electrical appliances and plumbing fixtures. As an added safety measure, stay in an interior room. If you are inside a vehicle, roll the windows up, and avoid contact with any conducting paths leading to the outside of the vehicle (e.g. radios, CB's, ignition, etc.).	**What NOT to Do** Lightning can travel great distances through power lines, especially in rural areas. Do not use electrical appliances, ESPECIALLY corded telephones unless it is an emergency (cordless and cell phones are safe to use). Computers are also dangerous as they usually are connected to both phone and electrical cords. Do not take a shower or bath or use a hot tub.

Lightning Safety Plan



A lightning safety plan should be an integral part of the planning process for any outdoor event. Do not wait for storm clouds to develop before considering what to do should lightning threaten! An effective plan begins LONG before any lightning threat is realized. You can't control the weather, so you have to work around it!

Detailed weather forecasts are accurate only out to seven days at best, but outdoor events often are planned many months in advance. Because of this limitation, every outdoor event coordinator should consider the possibility of lightning, especially if the event is scheduled during the late spring to early autumn months.

The key to an effective lightning safety action plan lies in your answers to the following questions:

1. Where is the safest lightning shelter?
2. How far am I (or the group I am responsible for) from that location?
3. How long will it take me (or my group) to get there?

Knowing the answers to these questions will greatly reduce your chances of being struck by lightning, provided you know them BEFORE thunderstorms threaten!

When Thunder Roars, Go Indoors

Studies have shown most people struck by lightning are struck not at the height of a thunderstorm, but before and after the storm has peaked. This is because lightning can strike as far as 10 miles from the area where it is raining and many people are unaware of how far lightning can strike from its parent thunderstorm. Therefore, if you can hear thunder, you are within striking distance. Seek safe shelter immediately. Remember this lightning safety rule...**When thunder roars, go indoors and stay there until 30 minutes after the last clap of thunder.** DO NOT wait for the rain to start before seeking shelter, and do not leave shelter just because the rain has ended.

With common sense, you can greatly increase your safety and the safety of those you are with. At the first clap of thunder, go to a large building or fully enclosed vehicle and wait 30 minutes after the last clap of thunder before you to go back outside.

Safety Guidelines

For YOU!

Plan Ahead! Make sure you get the latest weather forecast before going out. Get the most recent warning and watches at http://www.srh.weather.gov/.

Carry a NOAA weather radio (found at most electronics stores) or a portable radio with you, especially if you will be away from sturdy shelter (such as boating, camping, etc.). This way you will always be able to get the latest forecast. At the very least, the reception of an AM radio will have static created by lightning. So if you hear the static, keep an eye to the sky as a thunderstorm may be nearby.

If thunderstorms are expected and you go ahead with your planned outdoor activity, have a lightning safety plan in place. Upon arriving on-site, determine how far away your shelter is in case lightning threatens. Remember to account for the time it will require to get to your safe location. If storms threaten or the sky begins to darken, monitor the sky for lightning.

If lightning is seen and the time delay to its subsequent thunder is 30 seconds or less, or if thunderclouds are building overhead, implement your lightning safety action plan without delay!
Remember the "Flash to Bang" method to estimate lightning from your location - If you see lightning, count the number of seconds until you hear thunder. Divide the number of seconds by five to get the distance the lightning is away from you. For example, if you see lightning and it takes 10 seconds before you hear the thunder, then the lightning is 2 miles away from you (10 divided by 5 = 2 miles, too close!).

Do not resume outdoor activities until 30 minutes after the last thunder clap.

For Small Groups

Plan Ahead! Make sure someone in the group gets the weather forecast before going out and make your lightning safety action plan known by all members in the group.

Designate one of the members to monitor NOAA weather radio or a portable radio. This way you will always be able to get the latest forecast. If you have a wireless device that is internet capable, you can also obtain that information. If your wireless device can also display graphics, you can also view the local NWS Doppler radar to determine location of thunderstorms. The address for **Anywhere/Anytime Weather** from the NWS is **www.srh.weather.gov**.

If thunderstorms are expected and you go ahead with your planned outdoor activity, have a lightning safety plan in place. Upon arriving on-site, determine how far away your shelter is in case lightning threatens. Remember to account for the time it will require to get to your safe location. If storms threaten or the sky begins to darken, make sure someone in the group continuously monitors the sky for lightning and listening for thunder.

As soon as you hear thunder, seek safe shelter immediately. Do not wait. The group should implement the lightning safety action plan without delay! You are in danger of being struck by lightning. Do not resume outdoor activities until 30 minutes after the last thunder clap.

For Large Groups

Plan Ahead! Make sure the event organizers responsible for safety get a good weather forecast before the event begins and make your lightning safety action plan known and used by all event organizers.

Safety organizers should monitor NOAA weather radio (found at most electronics stores), a portable radio, or local cable, radio or TV broadcasts.

Since it may take considerable time to evacuate people to a safe location, personal observation of the lightning threat may not be adequate, especially for fast moving lightning storms. Hand held or portable lightning detectors should be made available so that lightning can be observed significant distances from the event site.

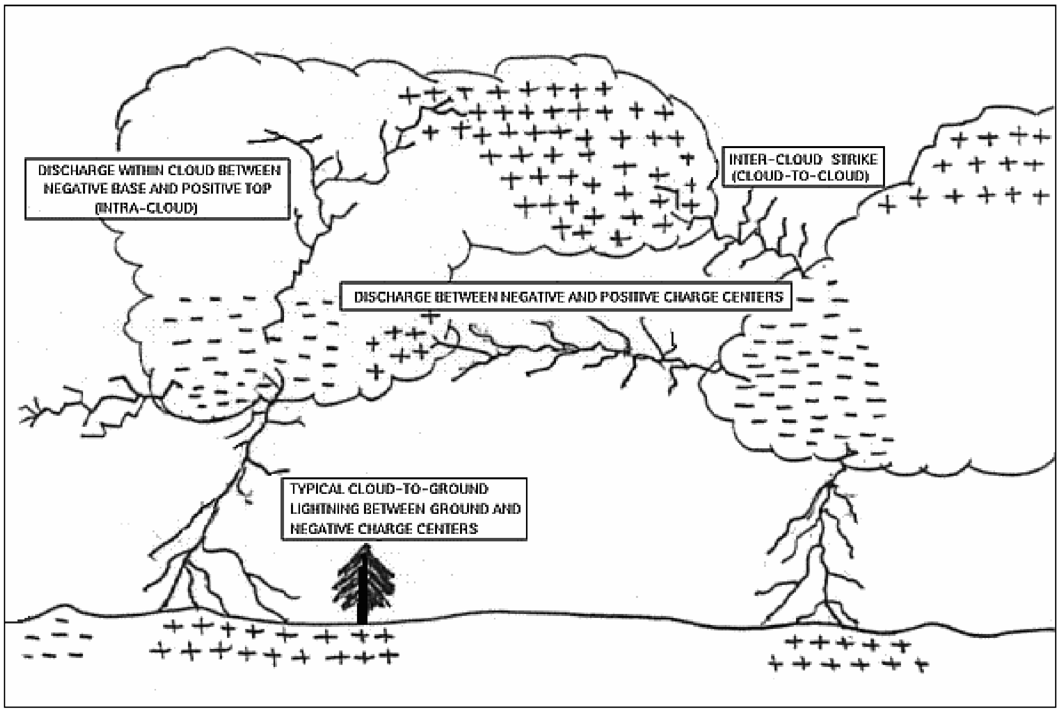
Event organizers should know how long it will take to get people to safe shelter.

With large groups of people, safe locations must be identified beforehand, along with a means to route people to these locations. Event organizers might consider placing lightning safety tips on programs, score cards, etc. Lightning safety placards set up in strategic locations can be an effective means of raising awareness and communicating the lightning threat to the attending audience.

7. Types of lightning: Lightning is the visible and striking electrical discharge produced by a thunderstorm. However, there are other electric discharging phenomena as well.

- **Cloud-to-ground (CG) lightning:** The lightning (electric discharge) is from cloud to the ground. Individual components of cloud-to-ground lightning include pilot leader, stepped leader, return stroke, and dart leaders. The first stroke is led by a stepped leader, which may be preceded by a pilot leader; and all subsequent strokes begin with a dart leader. The whole flash lasts for less than 1 second. The temperature of air can be increased up to 15,000°C by the lightning.

- **Cloud-to-cloud (inter-cloud) lightning:** The lightning is from cloud to cloud.



The lower part of a thundercloud is usually negatively charged. The upward area is usually positively charged. Lightning from the negatively charged area of the cloud generally carries a negative charge to Earth and is called a negative flash. A discharge from a positively-charged area to Earth produces a positive flash. (From http://thunder.msfc.nasa.gov/primer/primer2.html)

- **Ball lightning:** A reddish, luminous sphere, about 30 cm in diameter, that moves rapidly along a solid surface or appears to float in air, may be accompanied by a hissing noise.

- **Bead lightning:** Resembles a series of beads on a string; actually a normal zigzag lightning flash, segments of which are viewed end-on, giving the impression of high intensity at a series of points along the lighting channel.

- **Heat lightning:** Light reflected from lightning in thunderstorms that are too far away for thunder to be heard.

- **Intra-cloud lightning:** This occurs between oppositely charged centers within the same cloud, it is the most common type of discharge.

- **Ribbon lightning:** A lightning flash that appears to spread horizontally into a ribbon of parallel luminous streaks when a strong wind is blowing at some angle to the observer's line of sight.

- **Sheet lightning:** Clouds illuminated by cloud-to-cloud lightning so that they appear bright white; clouds block the view of the lightning flash.

- **Streak lightning:** Cloud-to-ground discharge that is concentrated in a single, relatively straight channel.

- **Point discharge:** A current of positive charges flow upward from the earth's pointed objects.

- **Positive flash (lightning):** A positive flash is a lightning discharge which brings positive charge to ground in the stepped or dart leader. Comprising only 4 percent of all lightning flashes detected annually, the median return-stroke peak current is 45 kilo amperes (15 kilo amperes larger than for a negative flash). A positive flash usually has only one return stroke but that stroke is responsible for 100 coulombs or more of charge transfer. It is known to be one cause for forest fires. A **coulomb** is a unit of electrical charge equal to the quantity of charge transferred in 1 second by a steady current of 1 ampere.

- **St Elmo's fire:** A more or less greenish or bluish continuous, luminous point discharge of weak or moderate intensity in the atmosphere, emanating from elevated objects at the earth's surface, such as lightning conductors, wind vanes, masts of ships, or at wing tips or propellers of aircraft in flight.

- **Red Sprites:** Sprites are massive but weak luminous flashes that appear directly **above** an active thunderstorm system and are coincident with cloud-to-ground or intracloud lightning strokes. The brightest region lies in the altitude range 65-75 km, above which there is often a faint red glow or wispy structure that extends to about 90 km.

- **Blue Jets:** They are optical ejections from the **top** of the electrically active core regions of thunderstorms. Blue jets are a second high altitude optical phenomenon, distinct from sprites, observed above thunderstorms using low light television systems. Following their emergence from the top of the thundercloud, they typically propagate upward in narrow cones of about 15 degrees full width at vertical speeds of roughly 100 km/s (Mach 300), fanning out and disappearing at heights of about 40-50 km.

- **Elves:** They are diffuse regions of luminosity, which occur high **above** energetic CG discharges of positive or negative polarity. Elves most likely result when an energetic electromagnetic pulse (EMP) propagates into the ionosphere. Though they can be accompanied by sprites, the causative mechanism is of an entirely different nature. Incidentally, elves got their unusual name as an acronym for Emission of Light and VLF perturbations due to EMP Sources.
  (For details about Sprites, Blue jets, and Elves, please check out http://elf.gi.alaska.edu/#chrjet, and http://www.sky-fire.tv/index.cgi/spritesbluejetselves.html)

Chapter 4. Summary of Severe Weather

A. Types of hazardous and severe weather

- Winter Storms (low pressure systems in winter);
- Mid-latitudinal Cyclones (low pressure systems);
- Droughts (caused by high pressure systems);
- Freezing (caused by high pressure systems and low pressure systems in winter);
- Heat Stress (caused by high pressure systems in summer).
- **Hurricanes (tropical low pressure systems);**
- **Thunderstorms (meso-scale low pressure systems)**
- **Tornadoes (micro-scale low pressure systems);**
- **Flooding (caused by low pressure systems, hurricanes, and/or thunderstorms);**
- **Lightning (caused by thunderstorms);**
- **Hail (caused by thunderstorms);**
- **Strong Winds (caused by low pressure systems, hurricanes, thunderstorms, downbursts, tornadoes);**

B. Forcing mechanisms for severe thunderstorms

- Planetary-scale forcing: jet stream at 300 hPa (in winter) or 250 hPa (in summer).
- Synoptic-scale forcing: strong and fast moving cold front, strong low pressure systems, 500 hPa positive absolute vorticity advection, strong upper-level (300 hPa) divergence and low-level (850 hPa) convergence, strong low-level (850 hPa) moisture convergence, low-level (850 hPa) warm air advection, low-level (850 hPa) southerly jet.
- Meso-scale forcing: Instability, drylines, gust fronts, day-time heating, sea-breeze fronts, outflow boundaries, orographic lifting.

C. How to predict the occurrences of thunderstorms?

- Vertical instability: severe weather Indices: LI, K, CAPE, helicity.
- Horizontal instability: baroclinic instability, low level convergence, low level moisture convergence, low level warm air advection, mid-level rising motion and absolute vorticity advection, upper-level diffluence (divergence).

D. Indicators related to the development and intensification of severe thunderstorms include:

- Abundant low-level moisture;
- Strong low-level southerly jet;
- Low-level warm air advection;
- Midlevel dry layer intrusion (not mandatory);
- Upper-level divergence or diffluence;
- Strong upper-level jet;
- Strong convection (surface heating, not mandatory);
- Low(in height) level of free convection (LFC);
- A moderate amount of CAPE (>1000 J/kg);
- Little convective inhibition (capping);
- High (in height) Equilibrium Level (EL);
- High helicity (> 300 J/kg) for supercell thunderstorms;
- Some triggering mechanism (e.g. cold front, sea breeze front, outflow boundary, dry line);
- Mid-level positive (absolute) vorticity advection;
- Bright (white) clouds on satellite imagery;
- High dBZ reflectivity on radar imagery.

E. Some severe weather evaluation list for severe weather outlooks

Instability				
Parameter	**Strong**	**Moderate or Adequate**	**Neutral or Marginal**	**Weak or Negative**
Lift Index (^oC)	< -6	-4 to -6	0 to 3	> 0
CAPE (J/kg)	> 2500	1000 to 2500	0 to 1000	< 0

Lift				
Parameter	**Strong**	**Moderate or Adequate**	**Neutral or Marginal**	**Weak or Negative**
850 mb thermal advection		Warm	Neutral	Cold
Low level flow		Convergent	Neutral	Divergent
850 mb thermal/moisture axes		Thermal upstream	Coincident	Thermal downstream

Moisture				
Parameter	**Strong**	**Moderate or Adequate**	**Neutral or Marginal**	**Weak or Negative**
Mean relative humidity		50 - 70 %	70 - 80% or 40 - 50%	> 80% or < 40%

Wind shear				
Parameter	**Strong**	**Moderate or Adequate**	**Neutral or Marginal**	**Weak or Negative**
850 mb jet (knots)	> 35	25 - 35	20 - 25	< 20
500 mb jet (knots)	> 50	35 - 50	30 - 35	< 30
850 - 500 mb				
Speed (knots)	> 35	25 - 35	15 - 25	< 15
Direction (degrees)	> 60	30 - 60	20 - 30	< 20

F. Forecast /Analysis Maps and Data for Severe Weather

Comprehensive national weather	http://www.weather.gov/outlook_tab.php
National radar mosaic and clickable radar image	http://www.nws.noaa.gov/radar_tab.php
WNC radar	http://radar.weather.gov/radar.php?rid=gsp&product=N0R &overlay=11101111&loop=no
National satellite images	http://www.weather.gov/sat_tab.php?image=ir
	http://www.goes.noaa.gov/
	http://rammb.cira.colostate.edu/ramsdis/online/goes-west_goes-east.asp
National watches and warnings	http://www.spc.noaa.gov/products/wwa/
National hazards map	http://www.weather.gov/largemap.php
National severe weather headquarters	http://www.spc.noaa.gov/
Current watches map	http://www.spc.noaa.gov/products/watch/
National hurricane center site	http://www.nhc.noaa.gov/
Click local NWS office	http://www.weather.gov/organization.php
Local forecast	http://www.erh.noaa.gov/er/gsp/
Comprehensive weather data/ maps	http://www.rap.ucar.edu/weather
	http://www.spc.noaa.gov/obswx/maps/
Regional surface plots and METAR reports	http://www.rap.ucar.edu/weather/surface/
	http://aviationweather.gov/adds/metars/
National upper air maps	http://www.rap.ucar.edu/weather/upper/
National storm reports	http://www.spc.noaa.gov/climo/online/
Weather maps, images, soundings	http://w1.spc.woc.noaa.gov/exper/
Interactive mesoscale analysis	http://w1.spc.woc.noaa.gov/exper/compmap/

Vertical Motion	> 4	2 to 3	-1 to 1	< -1

TOTAL TOTALS	
<44	Convection not likely
44-50	Likely thunderstorms
51-52	Isolated severe storms
53-56	Widely scattered severe
>56	Scattered severe storms

SPEED SHEAR	
0-3	Weak
4-5	Moderate
6-8	Large
8+	Severe

K INDEX	
15-25	Small convective potential
26-39	Moderate convective potential
40+	High convective potential

CAPE	
1 - 1,500	Positive
1,500 - 2,500	Large
2,500+	Extreme

SWEAT

SR HELICITY

150-300	Slight severe	150-300	Possible supercell
300-400	Severe possible	300-400	Supercells favorable
400+	Tornadic possible	400+	Tornadic possible

LIFTED INDEX / SWI		BRN	
-1 to -4	Marginal instability	<45	Supercells favorable
-4 to -7	Large instability	<10	Too sheared
-8 or less	Extreme instability	teens	Optimum

EHI	
EHI >1	Supercells likely
1 to 5	F2, F3 tornadoes possible
5+	F4, F5 tornadoes possible

NOTES:

*Max uvv = square root of 2 × CAPE
*BRN (Bulk Richardson Number) = CAPE / (0-6 km) Shear

*Showalter (SWI) = used when elevated convection is most likely (cool season)
*EHI = (SR HEL × CAPE) /160,000
*SWEAT = 12(850Td) +20(TT-49) +2(V850) + (V500) +125(sin(dd500-dd850) + 0.2)
*Total Totals = (T850- T500) + (Td850 - T500)= vertical totals plus cross totals
*K index = (T850 -T500) + (Td850 - Tdd700)
*SR Helicity : determines amount of horizontal streamwise vorticity available for storm ingestion
*streamwise = parallel to storm inflow
*Important to look for thermal and dewpoint ridges (THETA-E)
*For tornado, inflow must be greater than 20 knots
*20 to 30% of mesocyclones produce tornadoes
*Tornado types: rope, needle, tube, wedge
*Look for differential advection; warm/ moist at surface, dry air in mid levels
*Severe weather hodograph: veering, strong sfc to 850 directional shear
* >100 J/kg negative buoyancy is significant
*Good match: BRN < 20 and CAPE >2,000 J/kg
*Strong cap when > 2 degrees Celsius
*Study depth of moisture, TT unreasonable when low level moisture is lacking
*KI used for heavy convective rain, values vary with location/season
*Instability enhanced by ... daytime heating, outflow boundaries
*Models generally have weak handle on return flow from Gulf, low level jet, convective rainfall, orography, mesoscale boundaries, and boundary conditions
*Large hail when freezing level >675 mb, high CAPE, supercell
*Synoptic scale uplift from either surface WAA or upper level divergence
*Fair weather cumulus: cumulus humulus, cumulus mediocrus
*T-storm warning when Hail > 3/4", wind > 58 mph, gate to gate shear > 90 knots
*Sounding types: Inverted V, goal post, Type C, wet microburst

Stability Indices

1. Showalter Index

The Showalter index is the difference, in degrees Celsius, between the environment temperature at 500 hPa and the temperature of a parcel from 850 hPa lifted to the 500 hPa level. Negative Showalter indices indicate a parcel that is warmer than the environment and hence there is an upward buoyancy force on the parcel.

2. SWEAT Index

The SWEAT index is calculated as follows:

SWEAT = (12 x Td85) + (20 x (TT-49)) + (2 x FF85) + FF50 + (125 x (SINWIN + 0.2)) where:

Td85: dew point at 850 hPa
TT: Total - Totals index = T85 + Td85 - (2 x T50)
T85: Temperature at 850 hPa
T50: Temperature at 500 hPa. TT-49: Calculated only if TT > 49; set to 0 otherwise
FF85: 850 hPa wind speed in knots.
DD85: 850 hPa wind direction
DD50: 500 hPa wind direction
SINWIN: SIN (DD50 - DD85) (SINWIN + 0.2) is calculated if the following conditions are met: - 850 hPa wind direction is between 130 and 250 degrees; - 500 hPa wind direction is between 210 and 310 degrees; - (500 hPa - 850 hPa) wind direction is positive; - both the 850 and the 500 hPa wind speeds are at least 15 knots. Otherwise, (SINWIN + 0.2) = 0. 3.

3. Buoyant Energy

The buoyant energy is calculated by lifting the air parcel having the highest theta-w value in the lowest 200 hPa adiabatically up to the equilibrium level (with no entrainment); the buoyant energy is the positive energy below the equilibrium level.

4. Vertical Windshear

The average vertical windshear is calculated using the U and V components of the wind below the level = .65; this is an approximation to the average windshear below 12,000 feet.

5. Helicity

Helicity is a parameter that defines the amount of streamwise vorticity (i.e., directional shear) a steady storm updraft will ingest as a result of a given storm motion. It is therefore a measurement of the potential for the formation of rotating upward air currents, and is used to evaluate the likelihood of tornadoes developing in a thunderstorm or unstable environment.

In order for helicity to be important, however, there must be some buoyancy. Helicity becomes meaningless in a stable environment. When interpreting helicity, it is therefore important to take into account the stability indices present in the summer severe weather package. Storm relative helicity may be computed as follow:

H(C) = H(C=0) + (Cx X CisV) - (Cy X CisU)

where:

H(C) represents the helicity expressed in the storm moving frame of reference. H(C=0) is the helicity relative to the ground. On a hodograph, it is proportional to the area swept by the horizontal wind vector over the layer extending from the surface to 3 km.
C = (Cx,Cy) represents the storm motion. The module of this vector is computed by taking 75% of the mean wind between levels 0.85 and 0.3 while the direction is taken at 30° to the right of the mean wind.
CisV represents the vertical shear of the north-south component of the horizontal wind computed between the surface and 3 km.
CisU represents the vertical shear of the east-west component of the horizontal wind computed between the surface and 3 km.

6. Severe Weather Index

SSI is a severe weather index developed by the Quebec Weather Centre. It is an index based on the average windshear below 12,000 feet and buoyant energy by the relationship:

SSI = 100 x [2 + [0.276 x ln(SHR)] + [2.011 x 10-4 x B.E.]]

where:

SSI = Storm severity index
SHR = Mean vertical wind shear from surface to 12,000 feet, in units of 10-3 s-1
B.E.= Buoyant energy of the air parcel, in J/kg.

7. K Index

The K-index represents the thunderstorm potential as a function of the vertical temperature lapse rate between 850 hPa and 500 hPa, low level moisture content as measured by the 850 hPa dewpoint temperature, and the depth of the moist layer (dewpoint depression) at 700 hPa.

To find the k-index use the following equation:

KI= (T850hPa - T500hPa) + Td850hPa -(T700hPa -Td700hPa).

The table below gives an indication of the possibility of thunderstorms forming (from Sturtevant, John S., 1995. The Severe Local Storm Forecasting Primer, 197 pp

KI	Thunderstorm Potential
0 to 15	0%

18 to 19	20% unlikely
20 to 25	35% isolated thunderstorm
26 to 29	50% widely scattered thunderstorms
30 to 35	85% numerous thunderstorms
>36	100% chance for thunderstorms