

HAZARDOUS WEATHER

THUNDERSTORMS

TEACHER'S GUIDE

Project ATMOSPHERE

This guide is one of a series produced by Project ATMOSPHERE, an initiative of the American Meteorological Society. Project ATMOSPHERE has created and trained a network of resource agents who provide nationwide leadership in precollege atmospheric environment education. To support these agents in their teacher training, Project ATMOSPHERE develops and produces teacher's guides and other educational materials.

For further information, and additional background on the American Meteorological Society's Education Program, please contact:

American Meteorological Society
Education Program
1200 New York Ave., NW, Ste. 500
Washington, DC 20005-3928
www.ametsoc.org/amstedu

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Foreword

This guide has been prepared to introduce fundamental understandings about the guide topic. This guide is organized as follows:

Introduction

This is a narrative summary of background information to introduce the topic.

Basic Understandings

Basic understandings are statements of principles, concepts, and information. The basic understandings represent material to be mastered by the learner, and can be especially helpful in devising learning activities in writing learning objectives and test items. They are numbered so they can be keyed with activities, objectives and test items.

Activities

These are related investigations. Each activity typically provides learning objectives, directions useful for presenting and completing the activity and questions designed to reinforce the learning objectives.

Information Sources

A brief list of references related to the guide topic is given for further study.

Overview

Weather is variable, from the gentle breezes of a balmy evening to the heavy wind and rain of a late afternoon thunderstorm. Hazardous weather, such as thunderstorms, hurricanes, and winter storms — covered in this and related guides — can cause property damage, bodily injury or even death. With the necessary information, proper preparation, and sensible reactions, most people can protect themselves and to some extent their property from the ravages of most kinds of hazardous weather.

Hazardous weather may affect anyone, anywhere in the world at any time. The table below shows the annual approximate numbers of various types of severe weather for several countries worldwide. The United States actually has the greatest variety and occurrence of threatening weather conditions.

Comparison of Weather Risks¹

Country	Severe Thunderstorms	Tornadoes	Severe Winter Storms	Hurricanes, Tropical Cyclones, Typhoons	Flash Floods
U S A	10,000/yr	1000/yr	10/yr	10/yr	1000/yr
Australia	500	< 100	0	10	100
Canada	500	10	20	0	10
France	100	< 10	10	0	10
Germany	100	< 10	10	0	10
Japan	500	< 10	10	10	50
United Kingdom	100	10	10	0	10
Russia/former USSR	5,000	10	20	0	100
China	10,000	< 10	5	20	500

¹ Data courtesy of NOAA, NWS.

Hazardous weather in the United States result in hundreds of lives lost each year with total property losses typically reaching into the billions of dollars. These are ample reasons why everyone should keep track of the weather and understand what to do if severe weather occurs.

The U.S. National Weather Service, an office of the National Oceanic and Atmospheric Administration, has the responsibility of warning people in the country of the possible impact of a severe weather-related event. Warning programs have been developed to

inform the public of the weather hazard and to help initiate appropriate adaptive measures. Prompt response to such information can save lives, reduce injuries, and lessen property damage.

Suggested Activities:

1. Plot the numbers appearing in the table on a world map to highlight the types and numbers of weather threats around the globe. Does there appear to be any particular geographical pattern to the frequency of the different kinds of weather risks?
2. Which country listed has the greatest variety of hazardous weather and need for timely weather forecasts, watches and warnings?
3. Of the threats listed, which is of greatest concern in your local area? What should you, your family, and your community do to try to adequately prepare and respond to the threat or threats?
4. What was the most recent hazardous weather you and/or your community faced? What was done or could have been done to lessen its effects?
5. Does your family, school, and community have a plan for all types of hazardous weather that might occur? What has been done or should be done? Who should do it?
6. What are the basic safety rules individuals should follow in facing the different kinds of hazardous weather? (Find information from your local National Weather Service office or local chapter of the American Red Cross for safety rules and hazardous weather preparedness and response.)

Hazardous Weather Watches and Warnings

The National Weather Service has terminology to alert the public to weather conditions that may require action to save lives and protect property. These terms accompany the specific type of severe weather to be encountered such as thunderstorms, tornadoes, high winds, floods and flash floods, and hurricanes.

A **watch** is issued when there is a threat of that weather developing in a specified area over a certain period of time.

A **warning** is issued when that weather threat has been observed (visually or by radar) in a given location. One should take immediate steps to avoid imminent danger.

Basic Understandings: Thunderstorms

Thunderstorm Development

1. A thunderstorm is a localized storm cloud producing thunder, lightning and often gusty winds, heavy rain and hail.
2. Thunderstorms occur when warm, humid air is lifted by surface heating, upslope flow or a front.
3. Most thunderstorms are composed of individual cells which exhibit three stages. These cells start with what is called the *cumulus stage*. It is characterized by upward motions. Unstable moist air rises and cools and water vapor condenses to form cumulus clouds.
4. In the *mature stage* of thunderstorm development, the cloud reaches its maximum vertical development and falling precipitation creates a downdraft. This stage is associated with thunder and lightning as well as the possibility of severe weather.
5. A mature thunderstorm cell is characterized by both updraft and downdraft. As the upward motion builds the cloud, it may produce an overshooting top, which penetrates into the stratosphere, and forms an anvil cloud building downwind due to the strong winds in the upper atmosphere.
6. The downward-moving air caused by falling precipitation results in the outflow spreading away from the cloud base at Earth's surface. With lines of thunderstorms created by a cold front, this sometimes results in a squall line forming as much as three hundred kilometers ahead of the front.
7. The *dissipating stage* of a thunderstorm cell occurs when the precipitation-induced downdraft cuts off the supply of warm humid air and the cloud eventually sinks and evaporates away.
8. The typical thunderstorm cell exists for about thirty minutes, although some may last longer.
9. The gust front is the boundary separating the cool air outflow from the warm, moist air feeding the updraft of the thunderstorm cell. As the gust front forms it may result in severe localized downdrafts called downbursts or microbursts. The rapid changes in wind speed and direction of these downdrafts can be deadly threats to aircraft.

Thunderstorm Forecasting

10. Severe thunderstorms threaten life and property with lightning, strong gusty winds, heavy rain or hail.
11. If thunderstorms occur in areas with restricted drainage, flash floods may result.
12. Thunderstorms may also generate funnel-shaped tornadoes, with their violent rotating winds and hazardous pressure drops.
13. Weather satellites and radars have greatly improved the observation of thunderstorms. Such improvements are used to provide sufficient warning to minimize the danger associated with such storms.
14. Weather satellites enable forecasters to observe from above the initial development, movement, and severity of thunderstorms.
15. Infrared satellite imagery enables meteorologists to identify the most intense part of the storm by observing the coldest cloud top temperatures, which coincide with the region of strongest updraft in the cloud cluster.
16. With radar, the meteorologist can determine where the storm is moving, hence where the weather is most likely to cause damage.
17. Doppler radar systems enable the observation of actual air movement within the storm by measuring the shift in frequency of radar return from the wind-driven precipitation.
18. The National Weather Service issues a severe thunderstorm *watch* when there is a threat of a severe thunderstorm developing for a specified area and time.
19. A severe thunderstorm *warning* is issued when a severe thunderstorm has actually been observed, either visually or by radar, in that area.
20. The hazardous weather associated with thunderstorms can develop very rapidly and with little advance warning. Consequently, a vigilant watch and awareness of local and broad-scale weather conditions is essential to insure adequate preparedness and response.

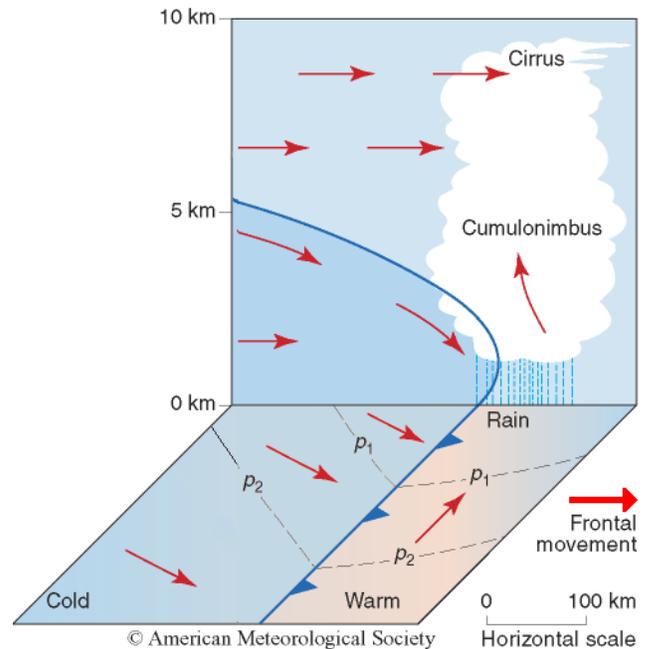
Introduction: Thunderstorms

What is a thunderstorm?

The thunderstorm is usually a storm composed of one or more cells. Each cell is a few kilometers in diameter and develops from clouds that grow rapidly upward and produce thunder and lightning. A thunderstorm often brings heavy precipitation, such as rain or hail, as well as strong gusty winds. Sometimes thunderstorms can become quite violent and may generate flash floods or tornadoes.

What causes thunderstorms?

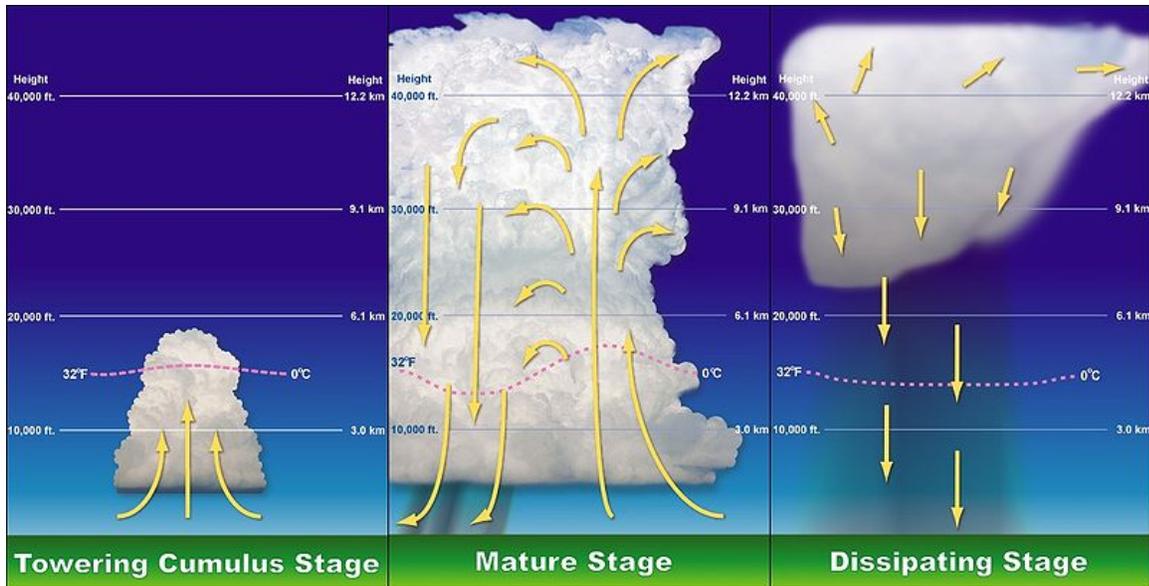
Thunderstorms can occur when warm, humid air is lifted upward. The air rises either by mechanical lifting, such as when a cold, dense air mass undercuts warm, moist air, or by thermal lifting due to solar heating of Earth's surface. The rising air expands and cools, and water vapor contained in the air condenses to form cloud water droplets. As the air continues upward, individual cloud towers can become a towering thunderstorm cloud. Once an individual thunderstorm cell reaches maturity, downdrafts, caused by falling precipitation, eventually destroy the cloud. Normally a thunderstorm is composed of more than one cell, and as one cell dies, usually within twenty to thirty minutes, another may develop nearby.



Stages of a Thunderstorm

Thunderstorms have three stages of development:

Cumulus stage – initial stage of cloud development, as warm, humid air rises and water vapor condenses to form the cloud; characterized by upward motion throughout the cloud.



Mature stage – cloud reaches maximum vertical development, precipitation starts to fall, creating a downdraft; this is the stage with the most violent weather and the occurrence of thunder and lightning.

Dissipating stage – precipitation-induced downdraft is observed throughout the cloud; the cloud sinks and evaporates away.

The typical thunderstorm cell exists for about thirty minutes, although some may last longer.

Structure of a Thunderstorm

The figure below displays a mature thunderstorm, which is composed of:

Updraft – the region of upward motion responsible for building the cloud.

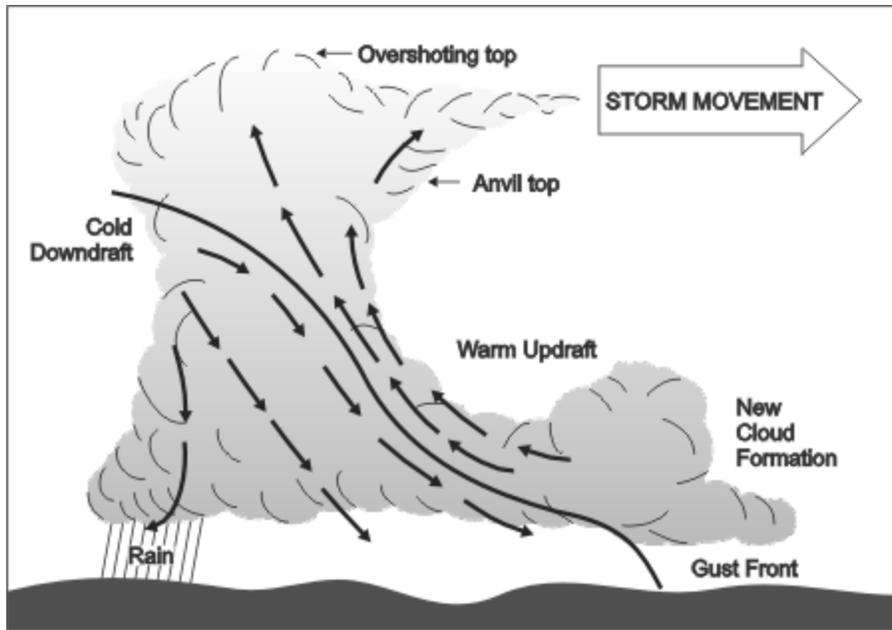
Overshooting Top – the uppermost part of the cloud above the updraft core which may penetrate into the stable stratosphere above.

Anvil – the top of the cloud blowing downwind due to strong winds at higher altitudes.

Downdraft – downward-moving air associated with falling precipitation.

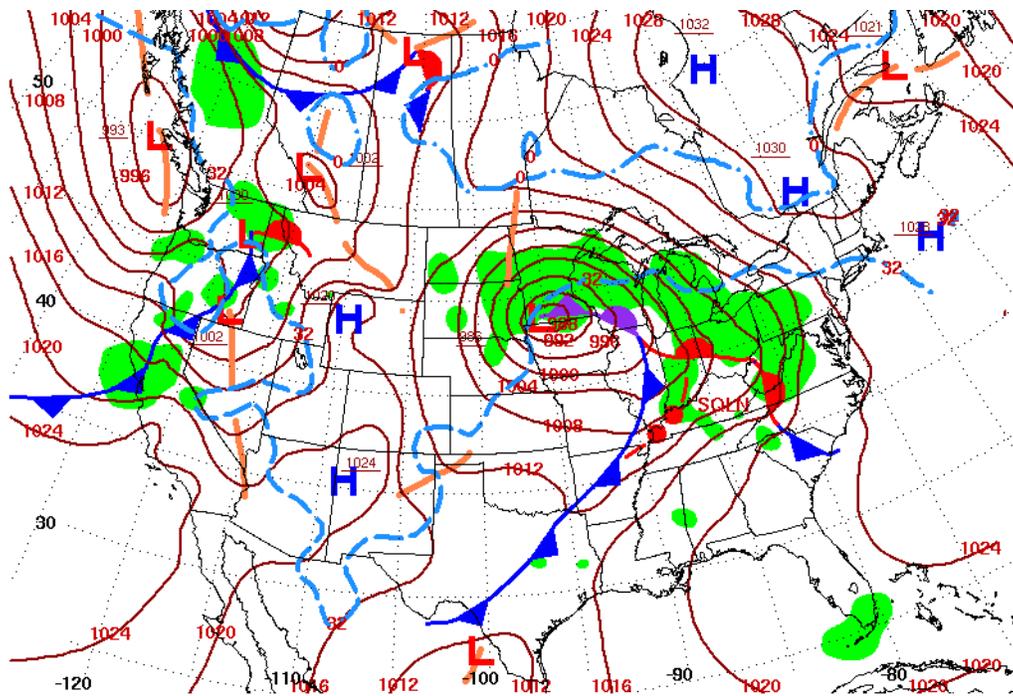
Outflow – downdraft air spreading away from the cloud base as it reaches Earth's surface below.

Gust Front – the boundary separating the cool air outflow and the warm, moist air feeding the updraft.



Weather Accompanying Thunderstorms

Ordinarily, the most severe thunderstorms form along narrow bands called squall lines, in the warm, moist air ahead of an approaching cold front.



Surface Weather Map at 7:00 A.M. E.S.T.

Cold front  Warm front  Squall line 

Examples of weather accompanying thunderstorms include:

Lightning – the visible electrical discharge which occurs in mature thunderstorms due to large voltage differences within the cloud, between clouds, or between the cloud and the ground below. The heat produced by the stroke causes the air to expand explosively, creating a shock wave which is heard as thunder. Lightning causes over 100 deaths annually in the U.S.

Damaging winds and wind shear – the cool air outflow from a thunderstorm, which may achieve wind speeds great enough to damage objects in its path. Wind shear is an abrupt change in wind (speed or direction) with distance. Strong wind shears exist between the updraft and downdraft areas.

Hail – particles of ice, ranging in size from a pea to a softball or larger, that form in the updraft of thunderstorms as liquid water drops are forced upward to regions of freezing temperatures. Hail storms cause hundreds of millions of dollars in damage to crops and property annually in the U.S.

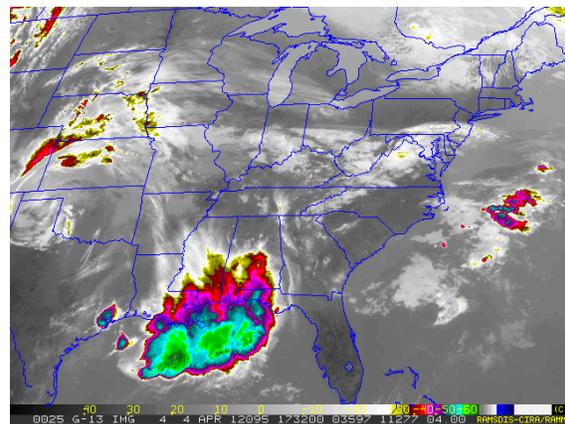
Flash Floods – floods that arise rapidly with little or no advance warning. Such flooding is often associated with slow-moving thunderstorm systems bringing heavy rains to a limited area, especially in regions that are unable to handle the volumes of water because of terrain features (such as canyon walls and hills), soil composition or improper drainage. Over 150 lives per year are lost due to flash floods in the U.S.

Tornadoes – violent, rapidly rotating columns of wind that descend from the bases of thunderstorms and come in contact with Earth's surface. These strong, shifting winds cause considerable damage and loss of life.

Severe Thunderstorm Detection and Forecasting

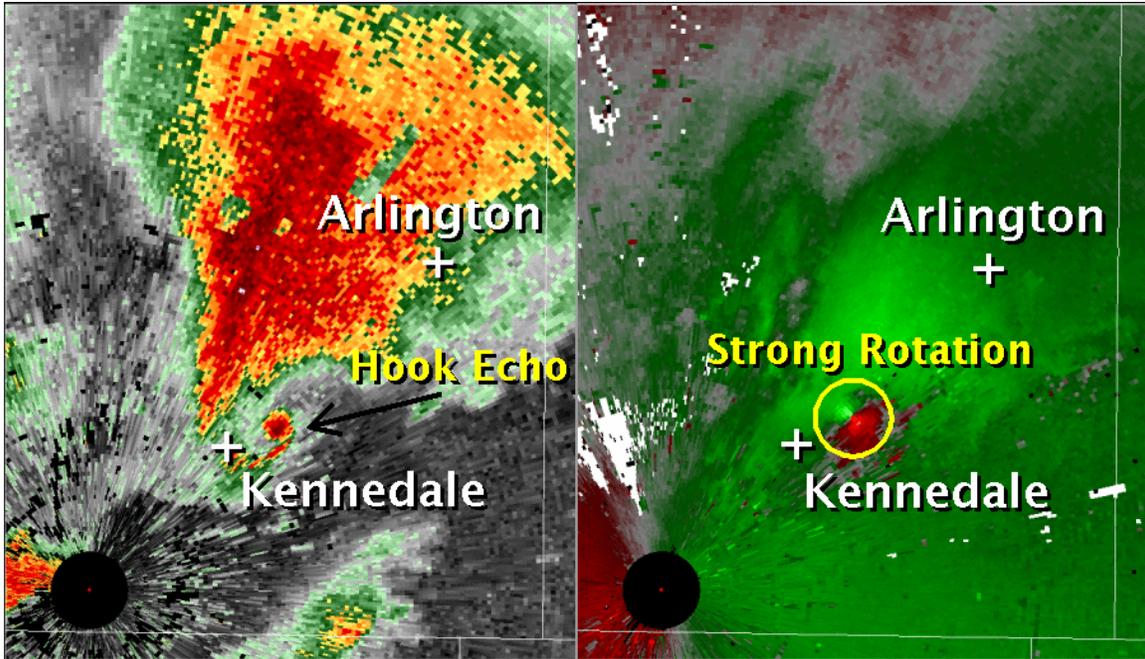
Tools for Observing Thunderstorms

Weather satellites enable forecasters to observe the initial development of cumulonimbus clouds, providing a “birds-eye” view of the location of such storms as they build upward through the atmosphere. Infrared satellite imagery enables meteorologists to identify the most intense part of the storm. For example, the coldest cloud top temperatures usually coincide with the region of strongest updraft in the thunderstorm.



The visible image on the left shows supercell thunderstorms producing tornadoes over southeastern Missouri and southern Illinois on 2 March 2012. The enhanced infrared image on the right shows thunderstorms in the northern Gulf of Mexico, the highest tops are dark green.

Weather radar is perhaps the best tool for tracking a severe thunderstorm. The radar emits microwave energy, which produces an image of the interior of the storm. The radar beam strikes precipitation particles, which reflect energy (return signal) back to the radar antenna with an intensity proportional to the strength of the storm. In the figure below, the contoured area corresponds to the return signal from an approaching storm. By evaluating and tracking the return signal, the meteorologist is able to determine where the storm is moving, hence where the weather is most likely to cause damage.



NWS Ft. Worth-Dallas, TX Doppler radar of tornado, 1:26 p.m. CDT 3 April 2012. The left view is reflectivity showing most intense returns from precipitation while the right view is motion relative to the storm displaying the tornadic rotation signature.

Activity: Tracking the Dekalb County Tornado

Introduction

“A powerful storm system roared across the southeastern United States on Wednesday, April 27, 2011. This storm system spawned 39 tornadoes in the Huntsville forecast area and a total of 62 tornadoes which impacted locations in the state of Alabama. This system also produced extensive flash flooding, large hail, and straight lined wind damage as well. However, this event will always be remembered as a tragic tornado event which produced more strong (EF2-EF3) to violent (EF4-EF5) tornadoes than the historic 1974 tornado outbreak.”

“In the wake of this system, hundreds of people were left injured and/or homeless, along with approximately 100 people who lost their lives in the northern Alabama area alone. Across the state of Alabama, 272 people lost their lives and at least 1969 (almost 2,000 people!) were injured. Some of the devastation was literally unimaginable with countless homes, neighborhoods and even portions of cities or towns either partially or completely destroyed. This storm system would be responsible for one of the largest and deadliest tornado outbreaks to ever impact much of the southeastern region.”
[NWS Huntsville (http://www.srh.noaa.gov/hun/?n=hunsur_2011-04-27_main)]

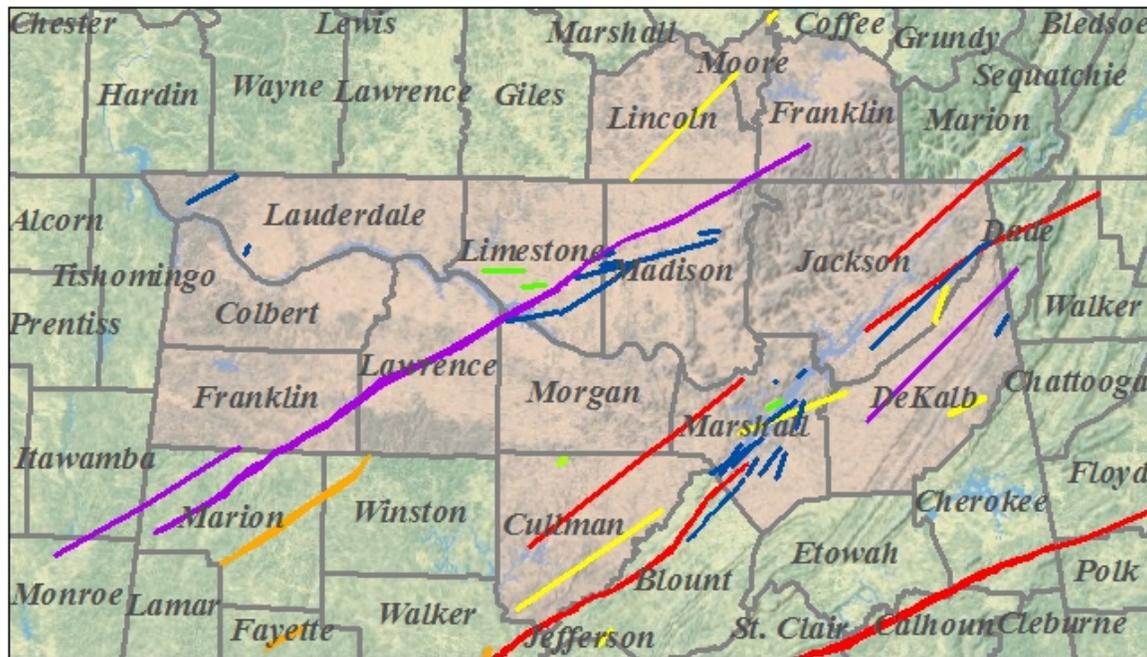
That day was one of the most damaging and deadly days in U.S. tornado history. The NWS' Storm Prediction Center recorded 292 tornado reports along with other thunderstorm hazards such as 438 instances of damaging winds and 207 cases of hail damage. One storm in the northern Alabama area spawned an EF-5 which devastated the communities of Shiloh, Rainsville, Henagar, and part of Sylvania in Dekalb County. There were 23 fatalities in Dekalb County alone. For more information of the Enhanced Fujita scale for tornado damage and the relation to wind speeds, see: <http://www.spc.noaa.gov/faq/tornado/ef-scale.html>.

Tornadoes are dangerous storms. This activity will demonstrate some of the characteristics of severe tornadoes and appropriate preparedness and response actions you should make when the threat of tornadoes occurs.

The following map shows tracks of tornadoes that passed through the area of responsibility of the NWS Huntsville Forecast Office shaded in beige on April 27, 2011. The damage produced by the storms is shown according to the Enhanced Fujita scale (EF) according to the color coding below the map. The Dekalb County tornado track is seen in the right center of the map area.



Historic April 27th, 2011 Tornado Outbreak Map: Tornado tracks that impacted the Huntsville Forecast Area



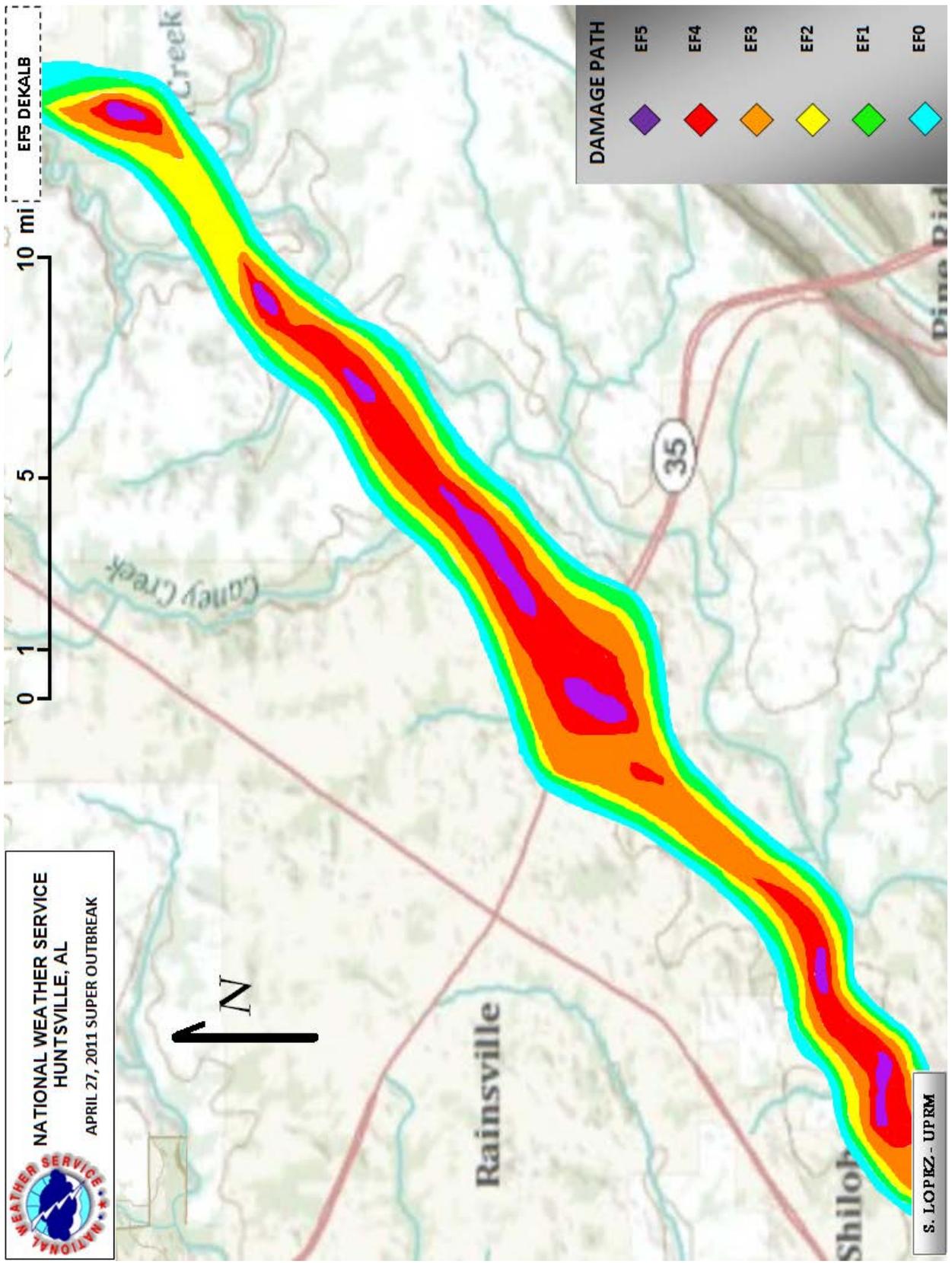
Activity

After completing this exercise, you should be able to:

- describe the motion of a severe tornado, including the width of its path, average speed and direction.
- list appropriate actions to take to save lives when tornadoes threaten, including those that address the special threats of mobile-home living.

The detailed accompanying map of the DeKalb County tornado track (next page) shows the path of tornado damage while on the ground. The shading indicates estimated Enhanced Fujita intensities based on the damage that occurred. Some of the statistics determined by the NWS damage survey following the storm were:

Rating	EF – 5	Peak Wind	> 200 mph
Path Length	33.66 miles	Max. Path Width	0.75 miles
Starting Point	34.39 N, 85.98 W	Ending Point	34.73 N, 85.56 W
Starting Time	6:19 PM CDT	Ending Time	6:56 PM CDT



Answer the following questions based on the table and map information.

1. For how long a time period was the tornado on the ground?
2. Towards what general direction (southeast, southwest, northwest, northeast) did the tornado move?
3. What was the length of the tornado path?
4. What was the average ground speed of the tornado?
5. The purple shading indicates where damage was rated EF-5, the most severe for this tornado. At how many points along the track was this level of damage found?
6. Based on the table information provided, which of the following was most likely the maximum width of the tornado --- 40 feet, 400 feet, 4,000 feet, 4 miles? (One mile is 5,280 feet.)
7. The very deadly year, 2011, had 550 fatalities recorded. Of those, 112 or 20% occurred in mobile homes. Mobile homes, also often called manufactured housing, comprise only 8% of all home structures. These deaths occurred despite typically 10 or more minutes of warning lead time nationally and frequent media reporting with wide availability of personal communications devices. What are some of the special dangers of mobile home living?
8. Use safety rules and information provided by the National Weather Service or the American Red Cross to determine where you should take shelter when a tornado threatens. What special precautions should mobile home parks and residents take to reduce severe weather threats?

Some photographs from the Dekalb County tornado destruction testify to the power of these severe storms. [http://www.srh.noaa.gov/hun/?n=4272011_dekalb_county]



The remains of a school bus that was blown across Hwy 75 in Rainsville. This bus was originally sitting in the parking lot adjacent to the building in the distance to the right.



View of the remains of a stone-built home on Skaggs Rd. Notice the large piece of concrete foundation that was pulled out of the ground.

Information Sources

Books

Moran, Joseph M. Weather Studies: Introduction to Atmospheric Science, 5th Ed. Boston, MA: American Meteorological Society, 2012.

Periodicals

Weatherwise. Bimonthly magazine written in association with the American Meteorological Society for the layperson. Weatherwise, 1319 Eighteenth St., NW, Washington, DC 20036.

USA Today. National newspaper with extensive weather page. Available at local newsstands and by subscription.

Radio and Television

NOAA Weather Radio. The voice of the National Weather Service and All Hazards Emergency Alert System. Local continuous broadcasts from over 1000 transmitting stations nationwide.

The Weather Channel. A continuous cable television program devoted to reporting weather. Includes frequent broadcast of local official National Weather Service forecasts.

Internet

DataStreme Atmosphere (www.ametsoc.org/amsedu/dstreme/). Atmospheric education distance-learning website of the AMS Education Program.

JetStream – Online School for Weather (www.srh.noaa.gov/jetstream/). Background weather information site from the National Weather Service.