WEATHER RADAR:

PRECIPITATION

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.

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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.

Introduction: Weather Radar – Detecting Precipitation

In some ways, modern technology originated during World War II. The extensive use of aviation at that time led to the formation of networks of balloon-borne instruments to take upper air measurements, the training of vast numbers of meteorologists, the expansion of weather observing locations around the world, the utilization of electronic computers, and the rocket to launching satellites. It also was impetus for developing radar, an acronym for RAdio Detection And Ranging.

Radar began as a tool to detect aircraft. Radio waves in the microwave band beamed outward at the speed of light are reflected back from objects. One half of the total time needed to travel to and return from the target multiplied by the speed of light determines the target's distance. Watching the target's movement for a few minutes then gives the target speed and direction in comparison to the radar station. This use of radar is basic to modern aircraft safety.

Early radar observations revealed echoes from "showerclouds". The first significant use of radar to track weather occurred in 1942 when in England a thunderstorm with hail was followed for seven miles. Also, all radars have strong echoes created by stray signal reflections off trees, hills and buildings in the vicinity of the radar site. These are known as "ground clutter".

The postwar period saw the development of estimates of precipitation rates from the strength of echoes. The relationship of the types of echoes and the associated weather also became better known. The National Weather Service developed a national network of radars to provide warning capability for severe thunderstorms, tornadoes, and hurricanes.

More development produced Doppler radar. Doppler radar is based on changes in frequency that occur to radio waves reflected from moving targets. By electronically comparing the transmitted signal with the reflected one, the speed of the target toward or away from the radar cane be measured utilizing the Doppler effect. In the atmosphere, the motion of precipitation is partly due to the winds within the clouds. Therefore, wind speeds within a storm can be determined. For hazardous weather situations such as hurricanes, tornadoes and thunderstorms, the developing pattern may allow warnings that can save lives.

Radar is one of science's major tools for observing weather and precipitation on a scale and time fame that makes it possible for the National Weather Service to provide detailed information to the public when it is most needed.

Basic Understandings

1. Radar, short for RAdio Detection And Ranging, transmits microwaves as a focused signal designed to detect precipitation particles in the atmosphere (rain, snow, and hail).

2. Radar energy travels through the atmosphere at the speed of light in a narrow beam. The radar's antenna directs the beam around the horizon and up and down at various angles until most of the sky within a given distance around the radar has been scanned.

3. After a radar sends out a signal, it "listens" for returning signals. A returning signal, called an *echo*, occurs when the transmitted signal strikes and reflects off objects (raindrops, ice, snow, trees, buildings, birds, insects) within its path.

4. Part of the reflected signal is received back at the radar. The display of the strength of the signals returned from echoes is called *reflectivity*. Reflectivity can be correlated to the intensity of the echo.

5. The time for the transmission of a signal to the receipt of an echo determines the distance to a target. The direction the antenna is aimed determines the direction to the target.

6. Modern weather radars can also evaluate the returned signal to detect target motion toward or away from the radar using the Doppler effect.

7. A computer attached to the radar stores the values of reflectivity from each distance and direction as the beam spirals around the horizon and up through several elevation angles until a volume of the sky is covered for about 250 miles around the site.

8. Selections of the stored reflectivity values can be displayed on a monitor to show a horizontal view of the atmosphere at any level or a vertical slice up through the atmosphere in a particular direction.

9. The reflectivity data generally indicate only those cloud particles large enough to fall as precipitation.

10. Each horizontal image can show reflectivity for (i) any elevation angle, (ii) at a constant height, or (iii) the greatest value at that location from any elevation. Each vertical image can show the height of echoes along any direction.

11. Since the radar beam is normally bent downward by the atmosphere as it travels, radar views generally extend far beyond the visual horizon.

12. The range of horizontal coverage depends on atmospheric effects, the curvature of the Earth, and the radar beam characteristics.

13. Radar reflectivity values are displayed on screen by assigning colors to indicate precipitation *intensity* ranges.

14. These intensities can be related to precipitation *amounts* over a period of time.

15. The computer connected to the weather radars can alert operators for patterns that may indicate hail, flash flooding and tornadoes.

16. Successive radar images can be animated to illustrate storm development, structure, and movement.

17. Precipitation echoes generally occur in cells, lines, or areas. Regions of most intense precipitation are usually in the center of the echoes.

18. Snow returns a weak echo, rain a stronger echo and wet hail a very strong signal. Water droplets comprising clouds are usually too small to be detected by normal radar operations.

19. Now radars are so sensitive that even dust, birds, insects and sudden changes in atmospheric temperature and humidity can be seen.

20. As noted above, not all echoes are caused by meteorological phenomena, even buildings, hills and trees near the radar transmitter may return a signal. As a result, a reflectivity pattern of strong, non-moving echoes is displayed near the radar site. This is called *ground clutter*.

21. The shape, size, and strength of a radar echo can lead to the detection of severe weather situations.

22. Individual thunderstorm cells may exist along cold fronts or squall lines. The cells may join to form clusters of severe thunderstorms. These patterns tend to show strong reflectivities indicating possible heavy rains or hail.

23. Tornadoes may show hook-shaped echoes in reflectivity displays.

24. The vertical slices of the atmosphere are very useful because the greater the height of thunderstorms, the more intense the weather associated with them is likely to be.

25. The spiraling bands of heavy thunderstorms within hurricanes show up clearly in reflectivity patterns.

26. The difference between rain and snow reflectivity values allows for warnings to be made for winter storms and icing conditions.

27. Radar displays require careful interpretation. For example, the radar beam, usually less curved that Earth’s surface, may pass over the tops of distant targets.

28. Heavy precipitation between the radar site and distant targets can weaken the radar signal so echoes of rain areas further away can be distorted or undetected.

29. Unusual temperature and humidity patterns may distort echoes and give false impressions.

30. The radar beam spreads out as distance from the radar increases. This can cause distortion in the shapes and sizes of echoes.

31. As the distance between the radar site and the precipitation increases, the ability of the radar to accurately detect the occurring precipitation decreases.

Activity: Interpreting a Radar Precipitation Display

Introduction

Day or night, clear or cloudy, meteorologists need to observe weather at great distances. Radar especially designed for weather observation makes it possible to locate areas of precipitation and to maintain watches on the severity of storms as weather happens.

Weather radars detect water and ice particles in clouds that are large enough to fall as rain, snow, or hail. Their fields of view stretch far beyond the visible horizon, sometimes making known the tops of thunderstorms two hundred miles (over 300 kilometers) away. Their returned signals can be interpreted to determine whether rain or snow is falling, how intense the precipitation is, the size and shape of the precipitation area, the development of it, and how fast and in what direction it is moving. In addition, a trained meteorologist can infer from the radar data the conditions that forewarn the existence of hazardous weather such as tornadoes, heavy downpours, and hurricanes.

From the relationship between the intensity of radar echoes and the rate of rainfall, the total amount of rain at a location can be estimated by computer addition of the rainfall over a period of time. The determination of rainfall totals over an hour, several hours, or even the duration of the storm is important in judging the possibility of flash flooding in a river or stream valley. Flash floods are the greatest weather danger each year in the terms of the number of deaths.

Upon completing this activity, you should be able to:

- locate areas of precipitation by interpreting a radar display.
- track and determine changes over time as precipitation echoes move through a weather radar's field of view
- relate the intensity of radar echoes to the areas with the greatest amount of rainfall.

The following images represent images from a radar screen of "Reflectivity" views at two successive times during a day (3 p.m. and 4 p.m. local time) when there was precipitation occurring in the radar's viewing area. The irregular shapes appearing in the image represent precipitation areas. They are contoured and color shaded to denote levels of intensity which correlate to precipitation rates. The intensity scale is located along the upper left portion of each image. The "4 p.m. Precipitation Total" is also shown for the storms from precipitation accumulated between the 3 p.m. and 4 p.m. reflectivity views.

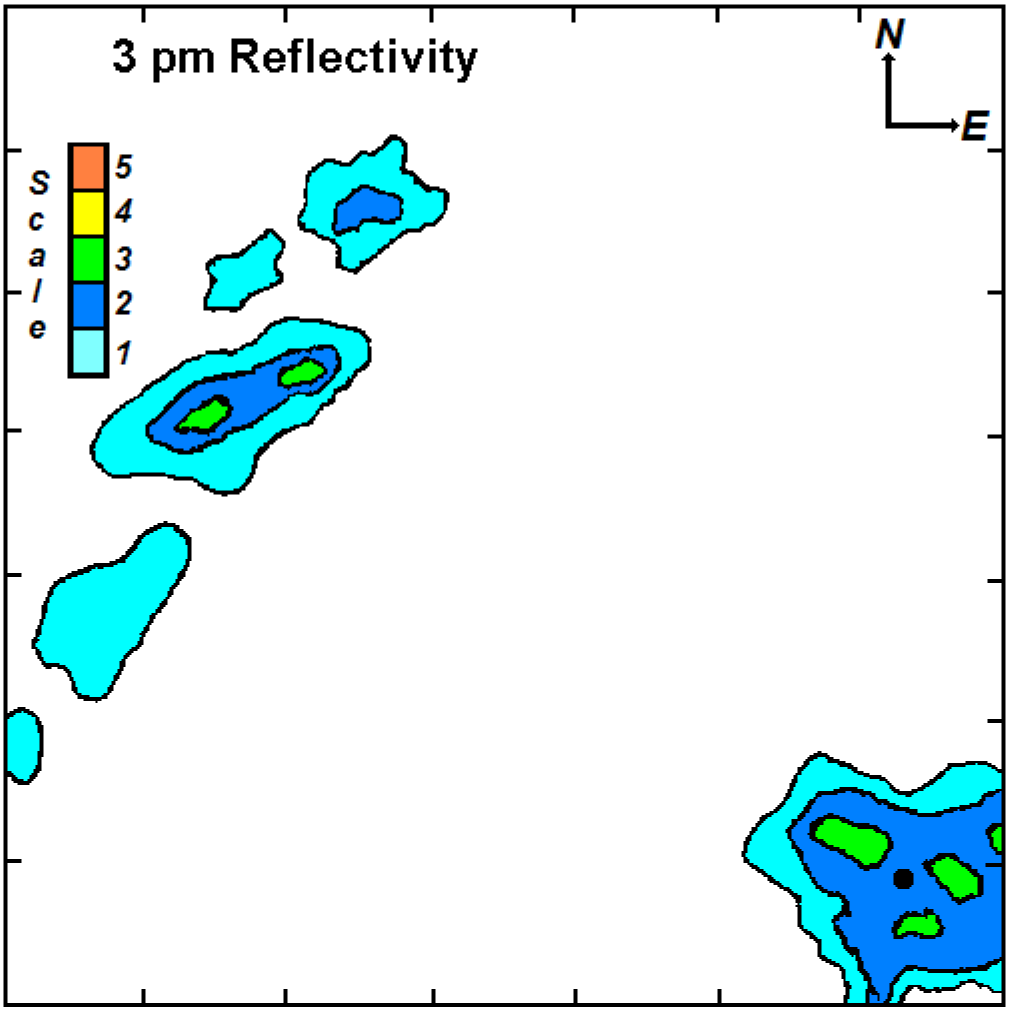
1. Look at the ***3 p.m. Reflectivity*** view. The location of the radar is depicted as the dot (●) in the echo shown in the lower right-hand corner. Distance can be measured in

the horizontal view by the markings appearing along the boundaries of the view at 10-km intervals. Find the strongest echo beyond the one immediately surrounding the radar's location. How far away and in what direction from the radar site is it?

____

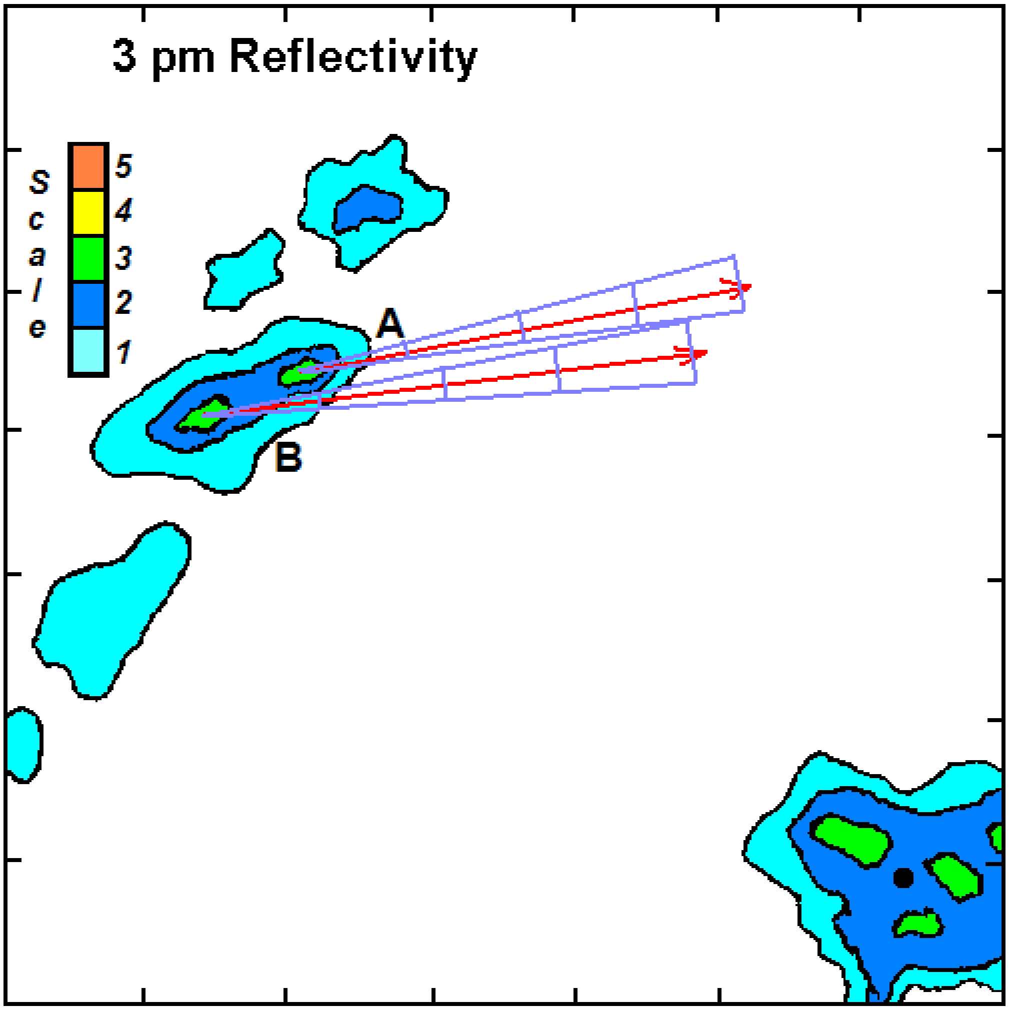
Also, how many levels of intensity does this echo contain?

____



3 p.m. Reflectivity

The centers of the more intense radar echoes are tracked by computer. The individual storm cells are given a storm identification, in this case **A** and **B**. The computer projections of future individual storm cell positions are given by a red line denoting the anticipated path. The arrowhead is located at the expected one-hour position. Also given are purple lines that form a wedge of possible variation in position including cross line segments indicating 15 minute increments. These position projections are based on calculations using winds steering the storm cells.



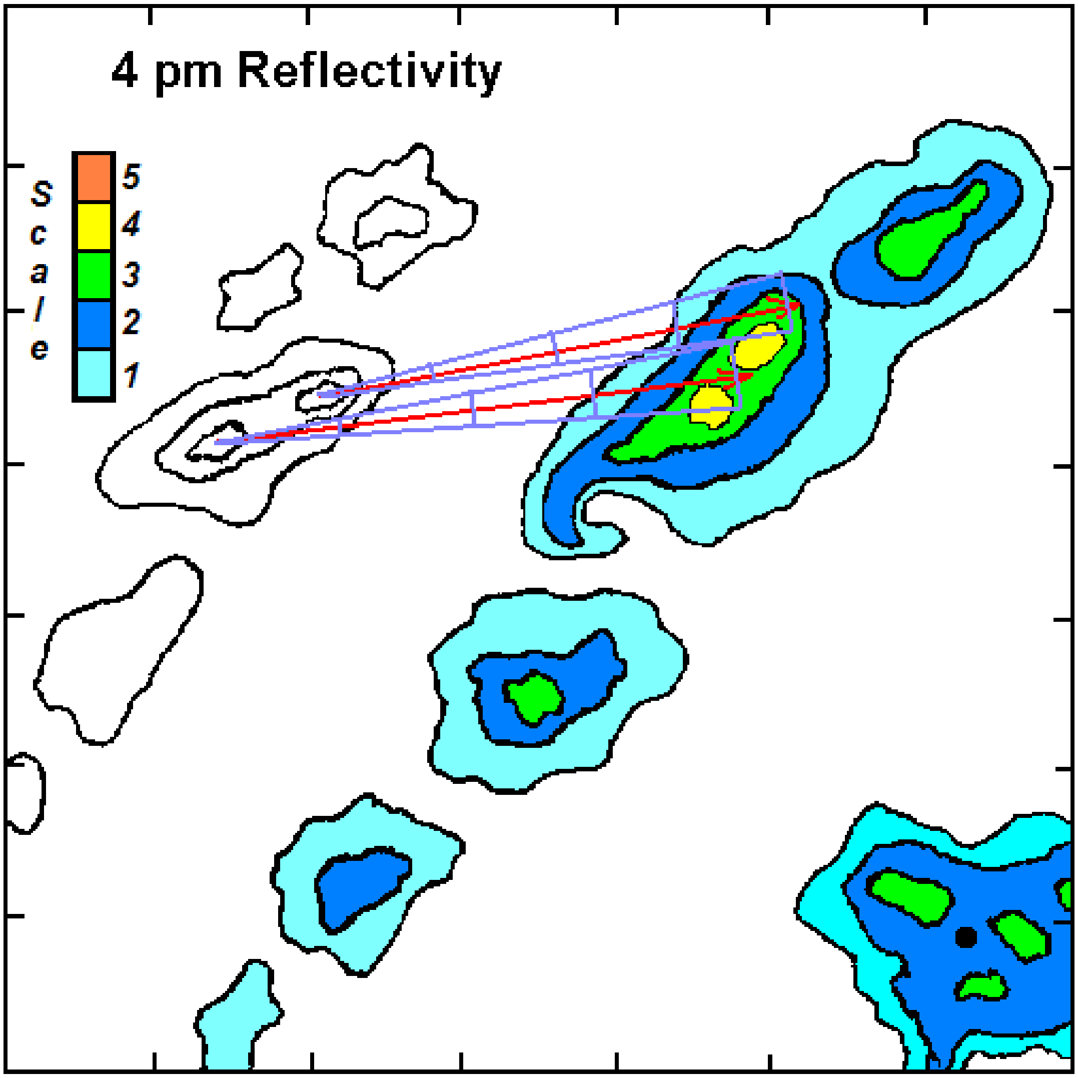
2. In what general direction are these most intense cells expected to move over the next hour?

____

   If you were a meteorologist using this radar information, what public warning information might you disseminate?

____

The ***4 p.m. Reflectivity*** view shows the contoured and shaded precipitation locations at that time. Also, the 3 p.m. Reflectivity positions and the projected movement information are overlaid on the image.



4 p.m. Reflectivity

3. Have any of the echoes changed location or shape? If so, which ones?

   ____

   Is there any echo that did not change? If so, where is it located?

   ____

4. Near radar sites, it is possible to get intense non-moving echoes because the radar signal is reflected from nearby stationary objects. Do any of your echoes fit this pattern (*yes*, or *no*)? If so, what is this echo called?

   ____

5. Precipitation echoes will continue to move across the radar field of view. In the 4 p.m. view, how many levels of intensity are now contained in the most intense storm? ____. Generally, the more intense the rain or snow, the greater the shading value. Based on this intensity, the precipitation area experienced **[(*a decrease*)(*no change*)(*an increase*)]** in rainfall rate.

6. From the projected track of the storm cells indicated in the 3 p.m. view and the current position at 4 p.m., how well do you think the computer forecast did?

   ____

   Are the storm cell positions within the spreads of uncertainty of position?

   ____

7. Note the curved feature at the southwest end of the most intense cell (located approximately in the center of the view). The curved protrusion occurs when rain is being wrapped around a rapidly rotating column of air. Name this severe weather feature. ___________________

   If you spotted this feature as a radar operator, what action should you consider taking?

   ____

8. The entire precipitation area is roughly oriented in a band from southwest to northeast. Such a pattern may be formed from individual storm cells associated along a cold front that is moving toward the southeast. Do individual cells move in the same direction as the line advances? ________

   In which general direction are the individual cells moving? ______________

   If individual thunderstorm cells propagate along the direction of the winds at higher atmospheric levels, what probable direction might the winds at those levels be toward? ____________

9. Finally, look at the ***4 p.m. Precipitation Total*** view. The levels in this image according to the scale at the right are total precipitation amounts during the hour (in inches) that have fallen at any location during the time echoes were detected by the radar and rates compiled by the computer. How do the greatest rainfall amounts compare to the most intense reflectivity echoes seen in the 3 p.m. and 4 p.m. views?

   ____

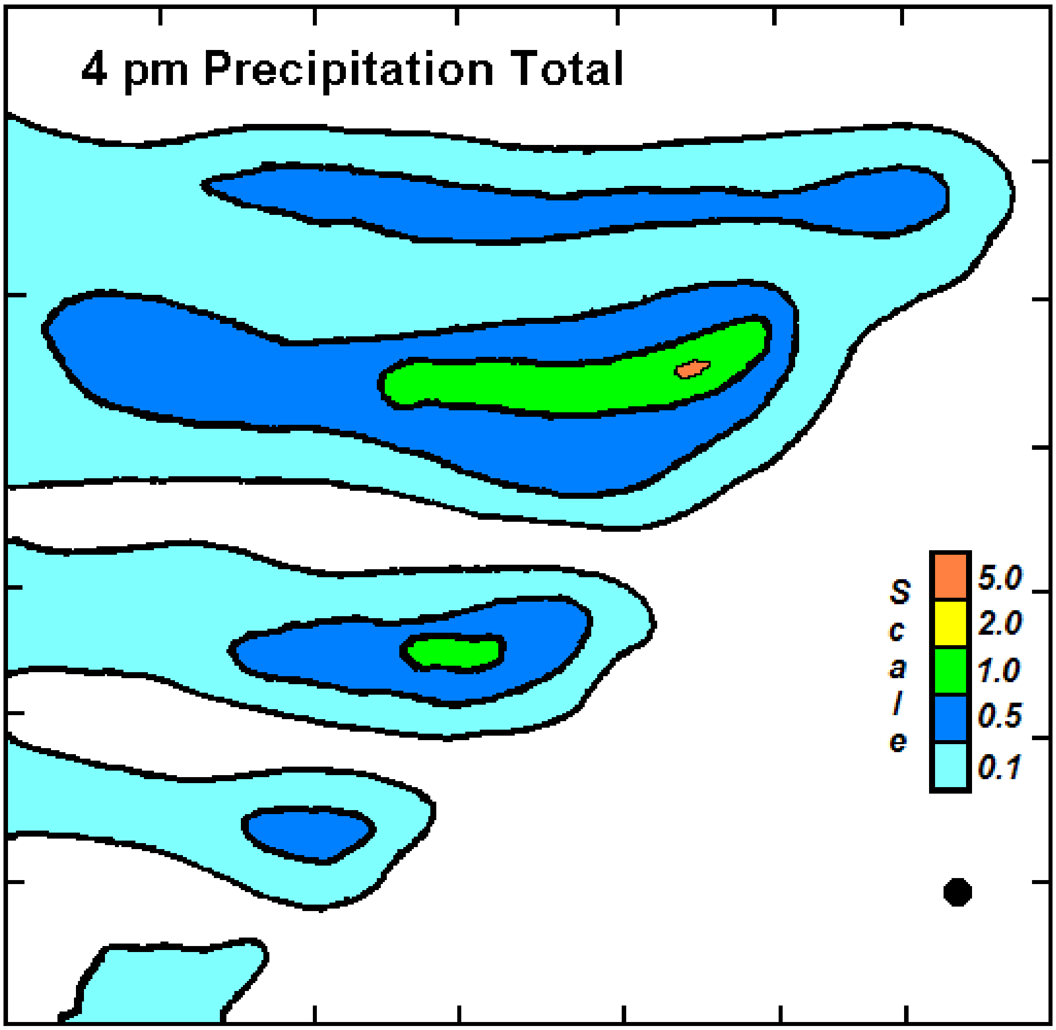
   ____

10. If a hydrologic forecaster has a prior knowledge of streams, local topography, soil moisture conditions and locations of homes and business areas, how would the forecaster use the rainfall information to alert people to possible flood danger?

____

What factors do you think are important for rainfall runoff?

____



4 p.m. Precipitation Total

Additional Activities:

View radar displays available from the Internet or television. Compare the view with a weather map for the same time. Also, make comparison with satellite images for that same time. What observations can you make for the same locations in the comparison of radar, weather observations and satellite views?

Set up a simulated radar in a darkened classroom. Use a flashlight to represent the radar and hang mobiles of smooth and crumpled aluminum-foil pieces to depict areas of rain or snow. Swing the flashlight beam around or up and down to search for the precipitation areas. Also, try swinging the flashlight around slowly and blink it on an off to simulate the radar pulses. Set up a coordinate system to describe directions and distances to the “echo” sources.

Real World Applications

The following images were from the NWS Forecast Office in Charleston, South Carolina during a precipitation episode, a site in the National Weather Service's network of radars. (Charleston is actually located on the coast, east of the radar site.) The radar site is identified by a black dot located at the center of each image. **Figure 1** is a composite view of the reflectivity image at 2301Z (7:01 p. m. EDT) 13 October 2011 on the left and at 2359Z (7:59 p. m. EDT), almost one hour later, on the right.

Radar reflectivity is a measure of the rate of rainfall shown by the color scale located to the lower right in each image panel. Typically, blues and light greens denote light rainfall, dark greens and yellows are moderate rainfall, and orange and reds are heavy rainfall. Some high reflectivity values can also result from hail within thunderstorms.

1. In both reflectivity views there **[(*is*)(*is not*)]** a roughly similar area of generally light reflectivity values about the radar site. This area probably results from **[(*intense local rainfall*)(*ground clutter*)]**. This area is enhanced in the view on the right as other precipitation activity nears the radar site.

2. The more intense orange and red shadings generally **[(*decreased*) (*remained the same*)(*increased*)]** in area during the hour between views.

3. These shadings imply that the overall precipitation over the area has **[(*decreased*) (*remained the same*)(*increased*)]** in intensity during the hour.

4. Draw a line of "best fit" through the orange and red shades in each view. Your lines should be generally oriented southwest to northeast. During the hour, the line of storms has moved generally **[(*westward*)(*eastward*)]**.

5. In the right image, the brightest red echoes west of the radar site (black dot) display a curved shape on their leading, eastern edges. This shape is called a "*bow echo*" and frequently is associated with strong, damaging winds. If you were the meteorologist and saw such a radar signature, what actions would you consider taking? ____.

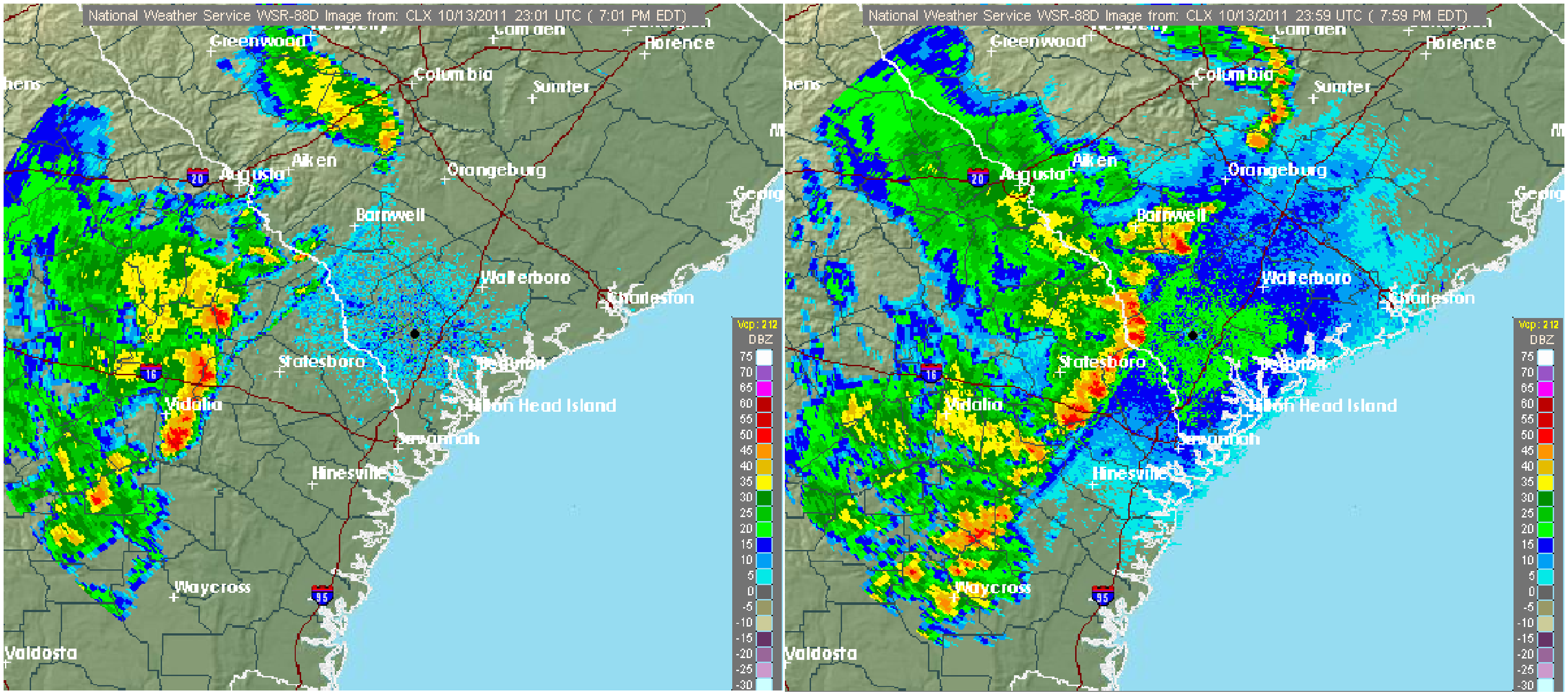


Figure 1. Reflectivity images from the NWS Forecast Office in Charleston, SC at 2301Z (left) and 2359Z (right) of 13 October 2011, respectively.

Figure 2 is the **One Hour Precipitation Total** from the NWS Charleston radar at 0012Z (8:12 p. m. EDT), a few minutes following the Figure 1 reflectivity image on the right.

6. Figure 2 suggests that the most intense precipitation cell(s) traveled generally from **[(*west to east*)(*south to north*)]**.

7. Over the hour period, the greatest amount of precipitation (dark blue and green shading) fell to the **[(*far behind the most intense rainfall*)(*where the most intense rainfall passed*)(*far ahead of the most intense rainfall*)]**.

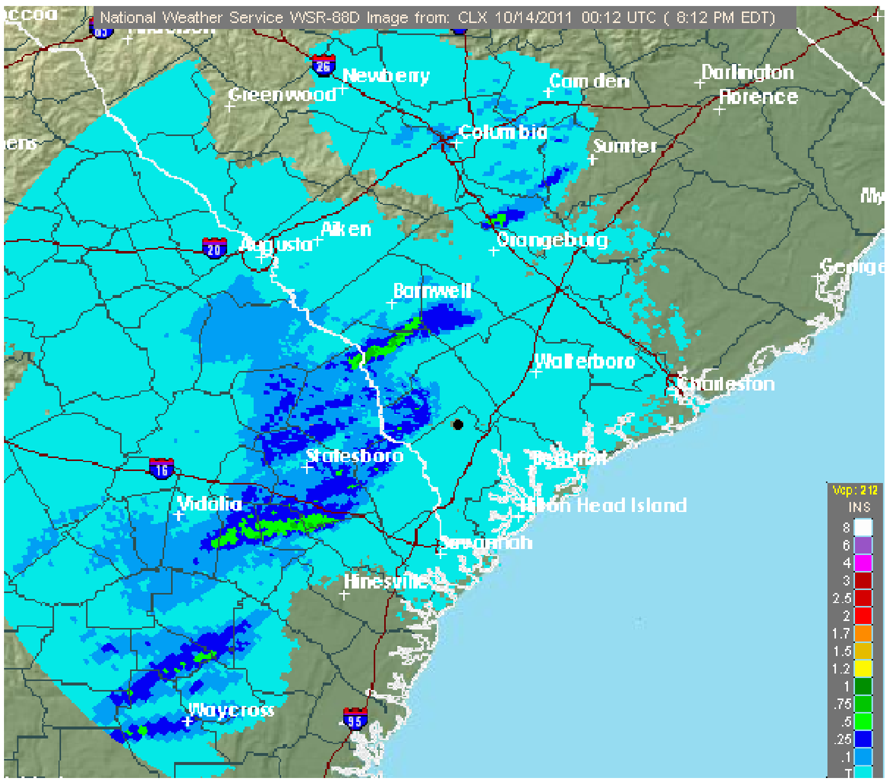


Figure 2. One Hour Precipitation Total from the NWS Charleston radar at 0012Z.

For the latest NWS radar imagery, go to: radar.weather.gov/Conus/. From here regional displays of reflectivities can be selected. Clicking on the U.S. or any regional map will bring you to the local NWS Forecast Office's radar page. At the station page you can choose the options of Base or Composite Reflectivities, Base or Storm Relative Velocities, and 1-Hour or Storm Total Precipitation amounts. Any of these can also be animated ("looped"). Explore and enjoy, be in the know when weather occurs.

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.