WEATHER SATELLITES

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

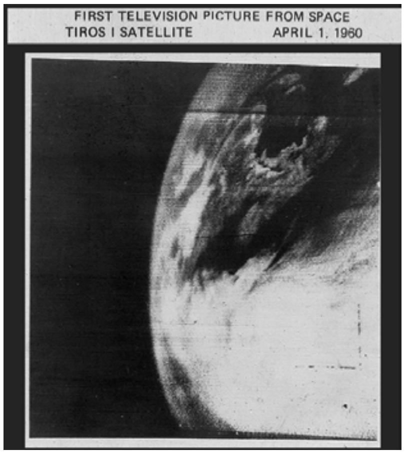
A brief list of references related to the guide topic is given for further study.

Introduction

Our everyday view of the atmosphere is from the bottom looking up and around. Our field of view is limited since most of us can see only a few kilometers in any direction. At the same time, the systems that dominate our weather can be hundreds or even thousands of kilometers across. Weather maps and radar have extended our views, but it is the weather satellite that gives us a completely different perspective on weather. Orbiting satellites are platforms from which the atmosphere and surfaces below can be observed from the outside.

By looking down on weather, we can see that fair and stormy weather are somehow related. Clear areas and giant swirls of clouds fit together. In the continually changing atmosphere we can observe evidence of predictability through the order and evolution of weather systems.

With the launch of TIROS-1 in 1960, we gained our first total views of the cloud patterns that accompany low pressure systems and fronts. Areas of high pressure and fair weather also became apparent by their general lack of clouds. The launch of TIROS culminated a long march of technological advance in electronics and space exploration. The use of electronics for the sensors, information storage, and transmissions to Earth depended upon the newest transistor technology.



The sensors themselves depended upon television research for their images. Later sensors were outgrowths of this and went on to solid-state extensions where heat radiation, as well as light, from Earth could be measured.

Finally, the signals that are measured electrically are converted to digital values for storage and are later transmitted down to Earth. There, the visual images we are familiar with, are produced. This last step is highly dependent on computer technology for the assembly, organization, and interpretation of the data.

We now have two basic types of satellite systems. The descendants of TIROS are known as polar-orbiting satellites. They revolve around the Earth at relatively low altitudes, 800 kilometers (500 miles) or so, passing over the polar regions as Earth rotates underneath. Such an orbit takes about 100 minutes to complete. Most places are scanned twice a day, once in daylight and once in darkness. Large-scale views are made from composites of several orbital strips that are about 1900 kilometers (1200 miles) in width.

The satellite pictures most often displayed on television and in the newspapers are taken by geostationary orbiters. At 35,800 kilometers (22,300 miles) above the equator, such satellites will make one revolution in 24 hours. Because this is the same time as one Earth rotation, and the satellite revolves in the same direction Earth is turning, such a satellite remains over the same equatorial surface location. Successive views from the same geostationary satellite can be provided to observe development of storm systems. They do not picture details as well as the closer polar-orbiting type of satellite, but they do provide more frequent views of the same Earth surfaces.

The sensors onboard the satellites react to two basic types of radiant energy. Visible light is produced by the sun and reflected off Earth surfaces and clouds, back up to the satellite. These images appear the same as black-and-white television pictures. All clouds look white to the sensor as they do to our eyes. Darker ground surfaces and water bodies in clear areas reflect little sunlight back up to space and therefore appear dark, gray or black. Visible images from the current geostationary weather satellites can resolve objects such as clouds that are as small as one kilometer in width.

The second main type of sensor detects infrared or heat energy given off by surfaces with temperatures in the range of Earth's land and water surfaces and cloud tops. The intensity of the infrared energy is related to the specific temperature of the emitting surface. In this way, infrared images are temperature maps of the Earth view. Because Earth and atmosphere emit heat day and night, infrared images are always available. The infrared sensor on the geostationary weather satellites can distinguish areas as small as four kilometers in width.

Visible light images, when containing a portion of the daylight half of the globe, show clouds to be uniformly white whether they are at low, middle, or high levels in the atmosphere. Earth surface details are usually dark. In contrast, infrared images can provide continuous information, day and night, because heat is constantly being emitted from all surfaces, day and night. Land and water surfaces are usually warm and therefore shown as dark. Cooler surfaces are typically displayed as gray with decreasing temperatures having lighter shading. In this way, low, warm clouds will be contrasted with high, cold ones. Temperature variations between warmer land and cooler water surfaces can be seen, as can the temperature cycle on land where daytime warming changes to nighttime cooling.

The variation in temperature across land and water surfaces is a major factor in the development of weather systems. These temperature variations are also displayed in cloud features associated with severe weather situations. Therefore, it has been useful to enhance or process infrared images to accentuate the temperature variations by displaying differing shades of gray or by the use of color coding. The 24-hour availability and the color-coding make the enhanced infrared imagery ideally suited to display on television weathercasts as successive views are looped into movies of cloud motions.

The solid and liquid water found in clouds is very well monitored by the visible and infrared images of weather satellites. The existence of water vapor in the atmosphere is much more difficult to detect. A knowledge of water vapor patterns is very important to understanding weather systems. Water vapor is the supply material for the creation of clouds and precipitation, but it is invisible to the eye and only measured by instruments at widely separated locations. Fortunately, a specific range of infrared energy wavelengths interacts with water vapor. This finely tuned infrared sensor on the geostationary satellites can provide images, and sequences, of cloud locations and the regions of large water vapor content in cloud-free areas at altitudes between 3 and 7 km (10,000 and 22,000 ft). Current water vapor imagery can resolve areas down to widths of eight kilometers. Water vapor images are especially helpful in detecting the atmospheric circulation patterns that lead to later cyclone formation and their associated cloud shapes.

The combination of satellite types provides much valuable information about Earth below. In addition to monitoring weather systems, the satellites provide other data, including vertical temperature profiles and moisture measurements.

Basic Understandings

Weather Satellite Characteristics

1. Weather satellites are orbiting platforms from which onboard instruments can sense light and heat energy from the atmosphere and underlying surfaces.

2. Because weather satellites can view a large area at one time, anywhere on Earth, they provide meteorological information over the oceans and sparsely populated land regions.

3. Weather satellite pictures are received as composites of tiny blocks (called pixels) of varying energy intensities, often shown in shades of gray. The area each block covers determines how detailed the image can be. The smaller the block, the greater the detail in a satellite image.

4. In addition to sending back pictures of Earth, weather satellites can determine the temperature and water vapor content at different heights in the atmosphere. They can also monitor the ozone layer and detect energetic particles in the space environment.

Polar Orbiting Weather Satellites

5. One type of weather satellite orbit passes near Earth's poles making north and south journeys at an altitude of about 800 kilometers (500 miles).

6. Polar orbiting satellites scan a strip of Earth, taking less than 2 hours to complete an orbit. With each pass, they survey a strip approximately 1900 km (1200 mi.) wide that is further west because of Earth's eastward rotation. Many hours elapse between passes over the same mid or low latitude location.

7. These satellites provide us with information on the condition of the ozone "hole" and composite pictures of snow cover and ocean surface temperatures.

Geostationary Weather Satellites

8. A second type of weather satellite orbit is located 35,800 kilometers (22,300 miles) directly over the equator. These satellites make one revolution, moving in the same direction as Earth's rotation, in the time it takes Earth to

make one rotation. This keeps them above the same spot on the equator, making them appear stationary, hence their name, Geostationary Operational Environmental Satellites (GOES).

9. Ordinarily, there are two geostationary satellites covering the U.S., one for the eastern part and one for the west coast and Pacific Ocean. Each one has a field of view covering about one-third of Earth's surface.

10. Each satellite's view remains the same, so sequential images may be viewed in rapid succession to show development and movement of weather systems.

Visible Satellite Images

11. Visible satellite images are views produced from reflected sunlight. Thus, these pictures look similar to pictures made with an ordinary camera.

12. On visible satellite imagery, clouds appear white and the ground and water surfaces are dark gray or black. Since this imagery is produced by sunlight, it is only available during daylight hours.

13. Low clouds and fog are usually distinguishable from nearby land surfaces. In addition, the hazy conditions associated with air pollution can be tracked.

14. The shadows of thunderstorm clouds can be seen cast on lower clouds in the late afternoon. Snow cover can be monitored because it does not move as clouds do. Land features, such as streams, can be visible.

Infrared Satellite Images

15. Infrared satellite images are produced by the infrared (heat) energy Earth radiates to space. Since Earth is always radiating heat, infrared images are available day and night.

16. On infrared images, warm land and water surfaces appear dark gray or black. The cold tops of high clouds are white and lower-level clouds, being warmer, are gray. Low clouds and fog are difficult to detect in the infrared when their temperatures are nearly the same as the nearby Earth surfaces.

17. An additional advantage of infrared imagery is that it can be processed to produce enhanced views. The data from the usual infrared pictures are specially treated to emphasize temperature details or structure by assigning contrasting shades of gray or color to narrow temperature ranges. Such imagery, often seen color-coded, appears regularly on television weathercasts and computer displays.

18. The enhanced images make it possible to keep track of land and oceanic surface temperatures. These temperatures play major roles in making and modifying weather. The high, cold clouds associated with severe weather are also easily monitored.

19. Enhanced imagery can be interpreted to produce rainfall rate estimates. This information is used in flash-flood forecasting.

Water Vapor Images

20. Solid, liquid and vapor forms of water interact with specific ranges of infrared energy. Specially tuned geostationary weather satellite sensors can detect water vapor in the atmosphere, in addition to clouds.

21. The water vapor sensors aboard weather satellites reveal regions of high atmospheric water vapor concentration in the troposphere between altitudes of 3 and 7 km (10,000 to 22,000 ft). These regions, sometimes resembling gigantic swirls or plumes, can be seen to flow within and through broad-scale weather patterns.

22. Recent studies suggest that, at any one time, atmospheric water vapor may be found concentrated in several large flowing streams forming the equivalent of “rivers in the sky”.

Weather Features in Satellite Imagery

23. Hurricanes look like pinwheels of clouds. More often than not, the beginnings of hurricanes are detected from satellite views, because they occur over broad expanses of oceans.

24. Large comma-shaped cloud shields give shape and form to mid-latitude Lows (wave cyclones).

25. Clouds from which showers fall can look like grains of sand, especially on visible satellite pictures. Thunderstorms appear as blobs or chains of blobs. Their high tops spread downwind from them as wispy cirrus clouds. They may have neighboring lower clouds appearing as tiny curved “tails” to the southwest. Such “tails” can also be indicators of the possibility of tornadoes.

26. Movements of cloud patterns detected by viewing sequential satellite images, indicate the circulations of broad-scale weather systems. Wind

speeds can be estimated at different levels and even upper-air jet streams can be identified.

27. Meteorologists use satellite images to determine cloud shapes, heights, and type. Changes in these cloud properties, along with cloud movement, provide valuable information to weather forecasters to determine what is happening and what is likely to happen to weather in the hours and days ahead.

28. Visible, infrared, and water vapor satellite imagery complement one another. There are weather features that can be clearly seen in one kind of image that are difficult to see in the others.

Activity: A Satellite Puzzle

Introduction

Satellites provide unique views of Earth. The imagery acquired by these space platforms reveal weather systems and broad-scale circulation patterns that can be seen in their entirety. Sensors aboard satellites scan the Earth line by line in narrow strips and measure signal strengths generated by reflected sunlight or infrared (heat) radiation for small blocks within each strip. Each block segment, called a pixel, is the smallest picture element in the image. A series of numbers indicating pixel signal strengths is transmitted to receiving stations on Earth where computers reassemble the values into lines of shaded or colored blocks. The lines are added together in sequence to complete the picture. The weather satellite views seen on television weathercasts are examples of such images.

After completing this activity, you should be able to:

- Describe how information is acquired by satellites, sent to Earth, and interpreted to construct images.

- Explain how pixel size influences the detail (resolution) on weather satellite images.

Method

This activity explores the process by which satellite imagery is produced. Imagine that two different sensors scan the same scene and that both sensors measure reflected sunlight. Scanning of the scene produced the two sets of data presented in the accompanying figure. Grids to the right of each data set show the size of the pixels resolved by the two satellite sensors. One sensor is able to resolve pixels whose side-length is one-half that of pixels detectable by the other sensor.

A scale from 0 to 3 is used to indicate the signal strength of the light received by the satellite sensors. The value of 0 indicates no detection of light while 3 indicates the receipt of the most intense light.

Reconstruct the scene based on the sensed pixel values appearing to the left of each grid. The values are in the same relative positions as the pixels they represent. A value of “0” indicates no light being detected, while a “3” indicates the most intense receipt of reflected sunlight from Earth below.

SHADING KEY

0 1 2 3

By referring to the Shading Key, shade in the left grid according to the data given. Then use the same procedure to fill in the right grid with the smaller pixels.

DATA		**1**	**2**	**3**
2 0 2	**A**			
0 2 2	**B**			
0 1 0	**C**			
2 0 2	**D**			

DATA		**1**	**2**	**3**	**4**	**5**	**6**
3 2 1 0 1 2	**A**						
2 0 0 0 0 1	**B**						
1 0 2 2 2 2	**C**						
0 0 3 3 3 3	**D**						
0 0 3 0 0 0	**E**						
1 0 2 2 0 1	**F**						
2 0 0 0 0 1	**G**						
3 2 1 0 1 2	**H**						

Questions

1. What do you guess the original was? (Hint: the scene scanned in this activity was a particular letter or number.) In which of the two views is there greater detail? Why?

____

____

2. Assume that the two weather satellite sensors used in this activity produce pixels that represent Earth-surface areas 2 kilometers and 1 kilometer on a side, respectively. Assuming that the U.S. mainland is approximately 5,000 km from west to east and 3,000 km north to south, how many pixels would need to be scanned to obtain an image of the U.S. mainland by the:

   2-km pixels? ____________ pixels W-E, ____________ pixels N-S

   1-km pixels? ____________ pixels W-E, ____________ pixels N-S

3. What are some of the possible problems of producing weather satellite pictures with far greater detail than currently available? Consider such aspects as engineering, design, cost, politics, time, and other considerations.

____

____

____

Activity: What Can You See?

Introduction

Weather satellites have sensors aboard that detect both visible light and infrared or heat radiation. The sensors providing views of reflected sunlight are engineered to be more detailed than infrared, so that smaller objects can be seen. However, visible images are only available during the day, limiting their continuous monitoring of weather conditions. Although less detailed, infrared views are temperature maps of surfaces viewed from the satellite's vantage point, whether land, water or clouds. The temperature variations of the surfaces may be enhanced to highlight certain features of interest to meteorologists.

After completing this activity, you should be able to:

- Explain how satellite pictures can be made with reflected sunlight (visible radiation) and with the heat (infrared radiation) given off by Earth.

- Describe the advantages and disadvantages of visible-light weather satellite pictures.

- Describe the advantages and disadvantages of infrared-radiation weather satellite pictures.

Method

The accompanying drawing shows an Earth surface and atmospheric cross-section. A temperature scale at the left shows the decrease in temperature with an increase in height in the atmosphere.

The numbers in the drawing indicate temperatures of various surfaces. For example, the lake surface is at +23 degrees C, the upper surface of the fog bank is +18 degrees, and the thunderstorm top is at a very cold –64 degrees.

The rates of infrared (heat) radiation from objects are related to their surface temperatures. The higher the surface temperature, the greater the radiation. The lower the temperature, the less the radiation. Because of this, the cold tops of high clouds appear white while the tops of warmer low clouds appear gray in infrared pictures (unless the images have been enhanced). Land and water surfaces being the warmest often appear darkest.

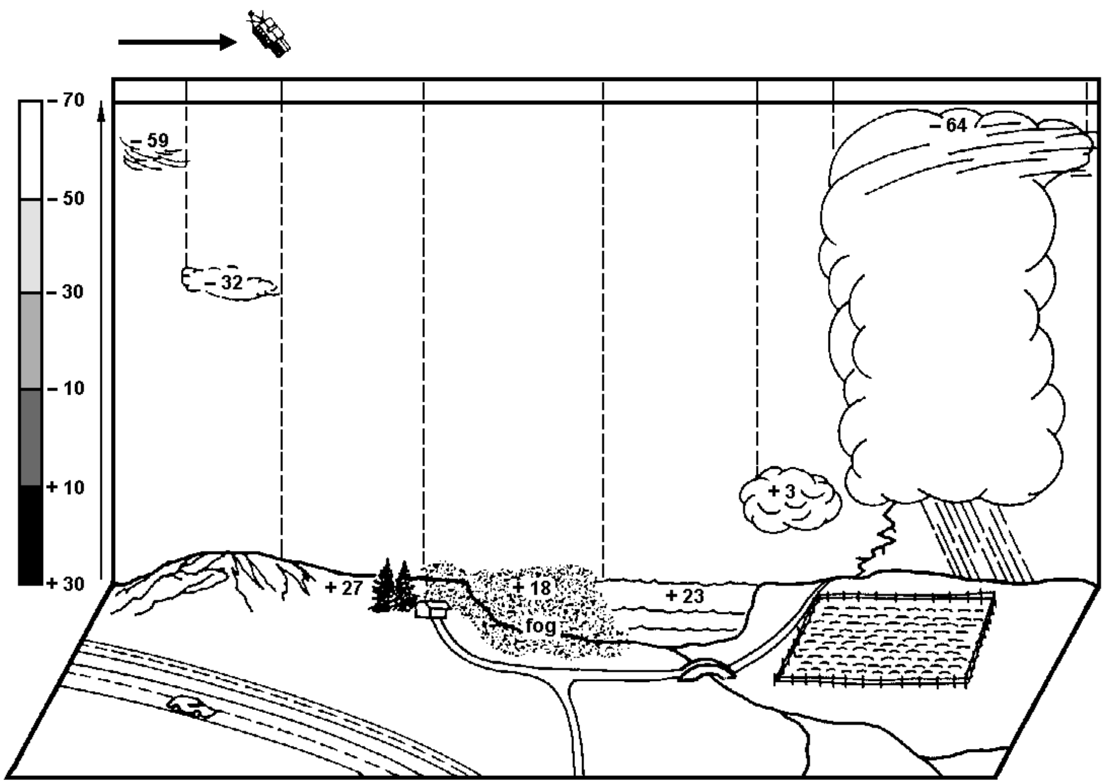
Questions

1. What does a satellite "see" when it senses the Earth in reflected sunlight (visible radiation)? Imagine yourself <u>looking straight down</u> from a satellite moving across the top of the drawing. Your direction of travel is shown by the arrow. List the sequence of things you would see as you make the trip across the field of view.

   ____

   ____

   Could you see this same scene at night?



2. What does a satellite "see" when it senses the Earth by infrared radiation? Imagine yourself making the same scan but now you sense the heat or infrared radiation given off by the upper surfaces of objects. Using the shading scale for temperature at the left as a guide, <u>shade in the strip along the top of the picture</u> based on the temperatures of surfaces directly below. List the sequence of "things" (shadings) you would see as you scan across the field of view.

   ____

   ____

Could you see as many different things as you saw with visible light?

Can you distinguish between land, fog, and water?

Were there some things you could “see” better in the infrared scan than in the visible light view?

Which are whiter in shading, low or high cloud surfaces?

Can you see this temperature scene day or night?

3. In the list below, place a (✓) in the appropriate column to indicate which kind of satellite view (visible or infrared) is better suited to provide the information requested:

	Visible	Infrared
a. 24-hour coverage of atmosphere	______	______
b. finer details of cloud surfaces	______	______
c. temperatures of cloud tops (and indirectly, their heights)	______	______
d. distinguishing fog from surrounding Earth surfaces	______	______
e. determining extent of snow cover on ground	______	______
f. detecting small fair-weather clouds	______	______
g. the color-coding of cloud tops	______	______

Real World Applications

Figure 3 on the following page shows three satellite images sensed at the same time, 1815Z or UTC (2:15 pm EDT) on 26 August 2011. At that time generally fair weather was experienced by most of the coterminous U.S. A cold front was advancing southeastward from Canada into the north-central U.S. The major feature seen in the images was Hurricane Irene located off the Georgia and South Carolina coast heading northward. Irene made landfall the following morning on North Carolina’s Outer Banks as a Category 1 hurricane on the Saffir-Simpson scale.

The top visible image in Figure 3 shows the small fair-weather cumulus clouds in a broad band from New York State to the Texas Gulf Coast and northern Mexico. Small cumulus clouds are also seen over the Rocky Mountains in the western states. The broad curving band of cumulus and higher cirrus clouds forming an arc from north of Lake Superior to southern Nebraska marked the region ahead of the advancing cold front. A deck of stratus clouds hugs the West Coast from Oregon to Baja California of Mexico. A couple of thunderstorms can be seen as bright white dots with wispy cirrus blowing off their tops in the Gulf of Mexico west of Florida.

The left infrared image display the coldest cloud surfaces as bright white shadings. These cold cloud tops are typically associated with thunderstorms as make up Hurricane Irene, the Gulf dots and the band of the cold front over Lake Superior and in Iowa. Lower clouds are located where the atmosphere is warmer and appear darker gray in shading. They can be seen over the southwestern mountains, in northern Mexico, and off the southern California coast. The lowest and warmest clouds are dark gray and close to the shade of the land surfaces whose temperatures they are near. The cumulus band from New York to Texas and the stratus deck along the West Coast.

The right water vapor image shows the concentrations of water vapor in the middle troposphere, typically between 13,000 and 30,000 feet (4000 to 9000 meters). Bright white shades are high cloud tops as seen with Hurricane Irene and along the cold frontal band. Middle gray shades are relatively large water vapor concentrations in the middle atmosphere, but perhaps without clouds present. Dark gray or black shades are relatively dry layers. One can see the high water vapor concentrations across the Gulf of Mexico and northern Mexico. There is also a plume or “river” of vapor arcing over the southwest U.S. and above the cold frontal location of ground level. From central Texas to the Northeast, relatively dry air exists. Shading waves over the Northwest show how water vapor images display atmospheric motions that are evident in animations.

1. In visible satellite images, all clouds **[(*<u>are</u>*)(*<u>are not</u>*)]** seen as generally equally white.

2. Small fair-weather cumulus clouds appearing in visible satellite images **[(*__are__*)(*__are not__*)]** readily visible in infrared or water vapor images.

3. Low clouds along the West Coast seen in visible images **[(*__are__*)(*__are not__*)]** readily seen in infrared images.

4. Visible and infrared images **[(*__do__*)(*__do not__*)]** detect the broad flows of water vapor in the atmosphere over the western and north-central U.S.

5. Being sensitive to the high, thin, cold cloud tops (infrared image) and the upper atmospheric water vapor (water vapor image) of Hurricane Irene, the extent of the hurricane structure is **[(*__more__*)(*__less__*)]** expansive than seen by the visible image.

6. The visible image shows that there was no significant cloud cover over the northwestern portion of Mexico. The darkness of shadings in the infrared image of the Baja California peninsula of Mexico and the Gulf of California to its east shows that, at the time of the satellite views, the land surface of Baja was **[(*__cooler__*)(*__warmer__*)]** than the water surface of the Gulf.

Types of Satellite Images

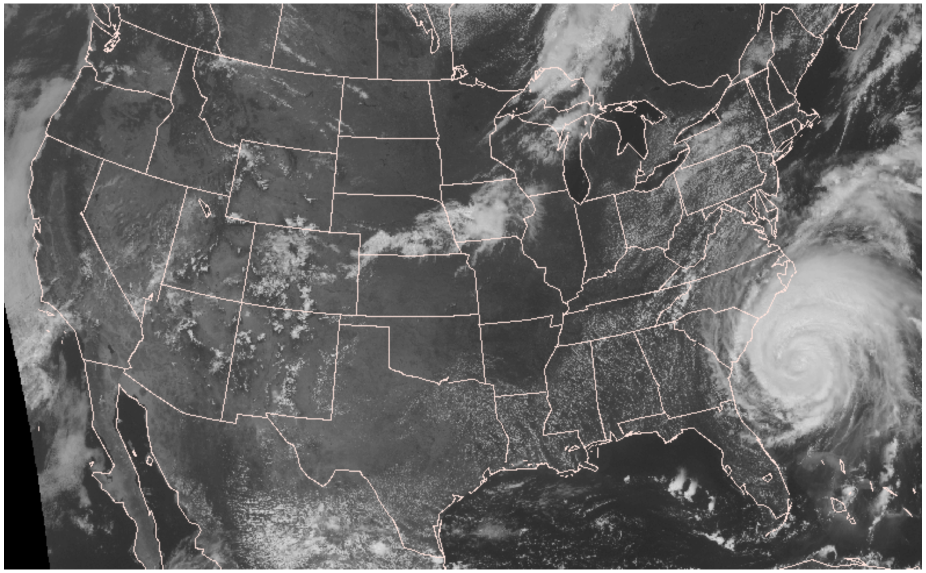
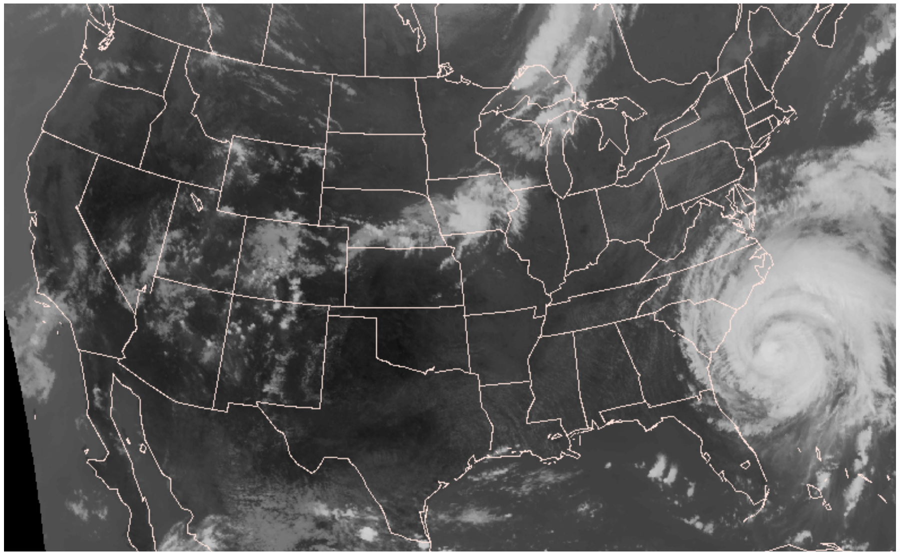
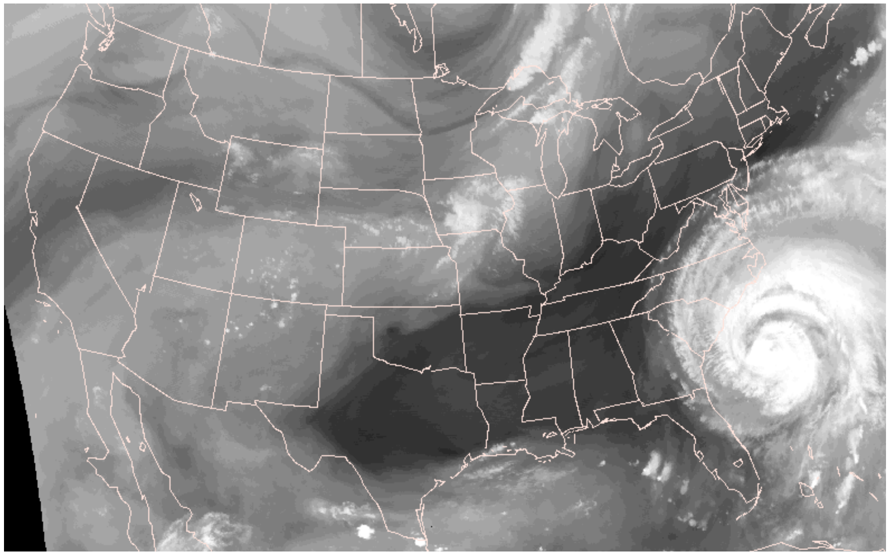


Figure 3. Visible satellite image at 1815 UTC, 26 AUG 2011.



Infrared satellite image at 1815 UTC 26 AUG 2011.



Water vapor satellite image at 1815 UTC 26 AUG 2011.

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.