# 4 RADAR AND SATELLITE IMAGERY

## 4.1 Radar

### 4.1.1 Description

Radar images are graphical displays of precipitation and non-precipitation targets detected by weather radar.  WSR-88D Doppler radar displays these targets on a variety of products which can be found on the internet on the National Weather Service (NWS) Doppler Radar Images web site at: http://radar.weather.gov/ridge/

### 4.1.2 Modes of Operation

The WSR-88D Doppler radar has **two** operational modes, **Clear Air** and **Precipitation**.

#### 4.1.2.1 Clear Air Mode

In Clear Air Mode, the radar is in its most sensitive operation.  This mode has the slowest antenna rotation rate which permits the radar to sample the atmosphere longer.  This slower sampling increases the radar's sensitivity and ability to detect smaller objects in the atmosphere. The term "clear air" does not imply "no-precipitation" mode.  Even in Clear Air Mode, the WSR-88D can detect light, stratiform precipitation (e.g., snow) due to the increased sensitivity.

Many of the radar returns in Clear Air Mode are airborne dust and particulate matter.  The WSR-88D images are updated every 10 minutes when operating in this mode.

#### 4.1.2.2 Precipitation Mode

Precipitation targets typically provide stronger return signals to the radar than non-precipitation targets.  Therefore, the WSR-88D is operated in Precipitation Mode when precipitation is present although some non-precipitation echoes can still be detected in this operating mode.

The faster rotation of the WSR-88D in Precipitation Mode allows images to update at a faster rate approximately every 4 to 6 minutes.

### 4.1.3 Echo Intensities

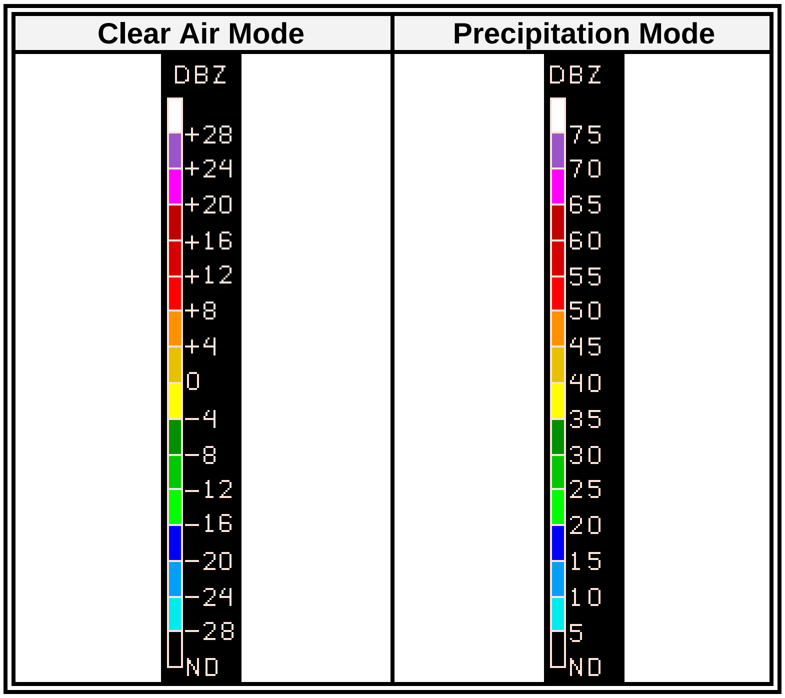


**Figure 4-1. WSR-88D Weather Radar Echo Intensity Legend**

The colors on radar images represent different echo reflectivities (intensities) measured in dBZ (decibels of Z). The dBZ values increase based on the strength of the return signal from targets in the atmosphere. Each reflectivity image includes a color scale that represents a correlation between reflectivity value and color on the radar image. Figure 4-1 depicts these correlations for both Clear Air and Precipitation Mode. For Clear Air Mode the scale ranges from -28 to +28 dBZ, for Precipitation Mode the scale ranges from 5 to 75 dBZ. *The color on each scale remains the same in both operational modes, only the dBZ values change.* The scales also include **ND** correlated to black which indicates no data was measured.

Reflectivity is correlated to intensity of precipitation. For example, in Precipitation Mode, when the dBZ value reaches 15, light precipitation is present. The higher the indicated reflectivity value, the higher the rainfall rate. The interpretation of reflectivity values is the same for both Clear Air and Precipitation Modes.

Reflectivity is also correlated with intensity terminology (phraseology) for air traffic control purposes. Table 4-1 defines this correlation.

**Table 4-1. WSR-88D Weather Radar Precipitation Intensity Terminology**

| Reflectivity (dBZ) Ranges | Weather Radar Echo Intensity Terminology |
|---|---|
| <30 dBZ | Light |
| 30-40 dBZ | Moderate |
| >40-50 dBZ | Heavy |
| 50+ dBZ | Extreme |

Values below 15 dBZ are typically associated with clouds. However, they may also be caused by atmospheric particulate matter such as dust, insects, pollen, or other phenomena. The scale **cannot** be used to determine the intensity of snowfall. However, snowfall rates generally increase with increasing reflectivity.

## 4.1.4 Products

The NWS produces numerous radar products of interest to the aviation community. The next section will discuss Base Reflectivity and Composite Reflectivity both available through National Weather Service (NWS) Doppler Radar Images web site at: http://radar.weather.gov/ridge/

### 4.1.4.1 Base Reflectivity

Base Reflectivity is a display of both the location and intensity of reflectivity data. Base Reflectivity images encompass several different elevation angles (tilts) of the antenna. The Base Reflectivity image currently available on the ADDS website begins at the lowest tilt angle (0.5°), more specifically 0.5° above the horizon.

Both a short range (Figure 4-2) and long range (Figure 4-3) image is available from the 0.5º Base Reflectivity product. The maximum range of the short range Base Reflectivity product is 124 NM from the radar location. This view will not display echoes farther than 124 NM from the radar site, although precipitation may be occurring at these greater distances. Other options to view precipitation beyond 124 NM from the radar site include selecting the long-range view which increases coverage out to 248 NM, selecting adjacent radars, or viewing a radar mosaic.

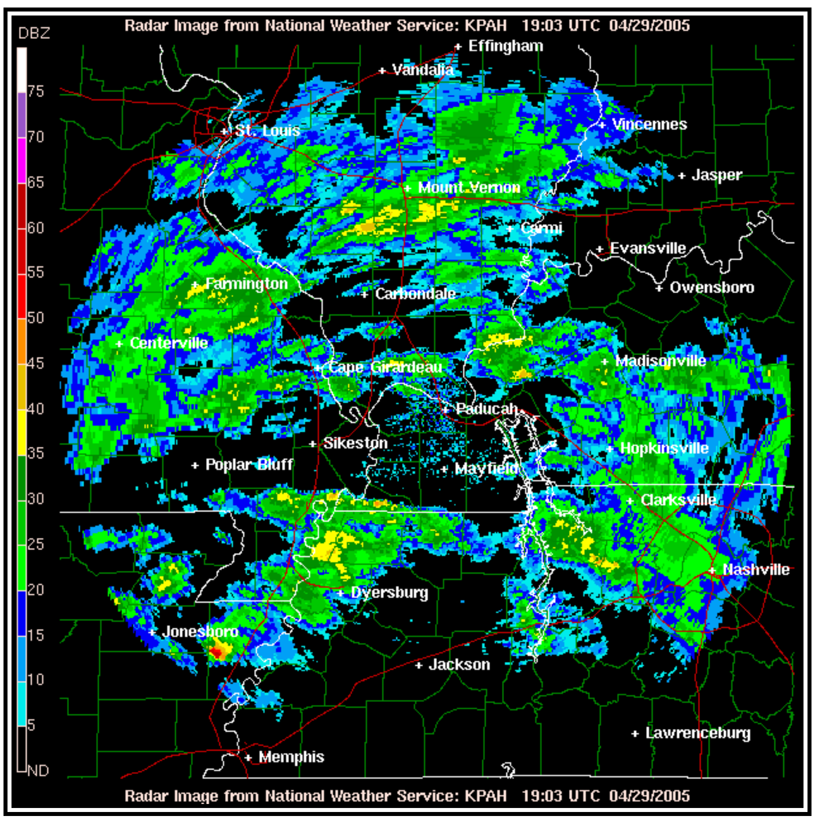


**Figure 4-2. WSR-88D Weather Radar Short Range (124 NM) Base Reflectivity Product Example**

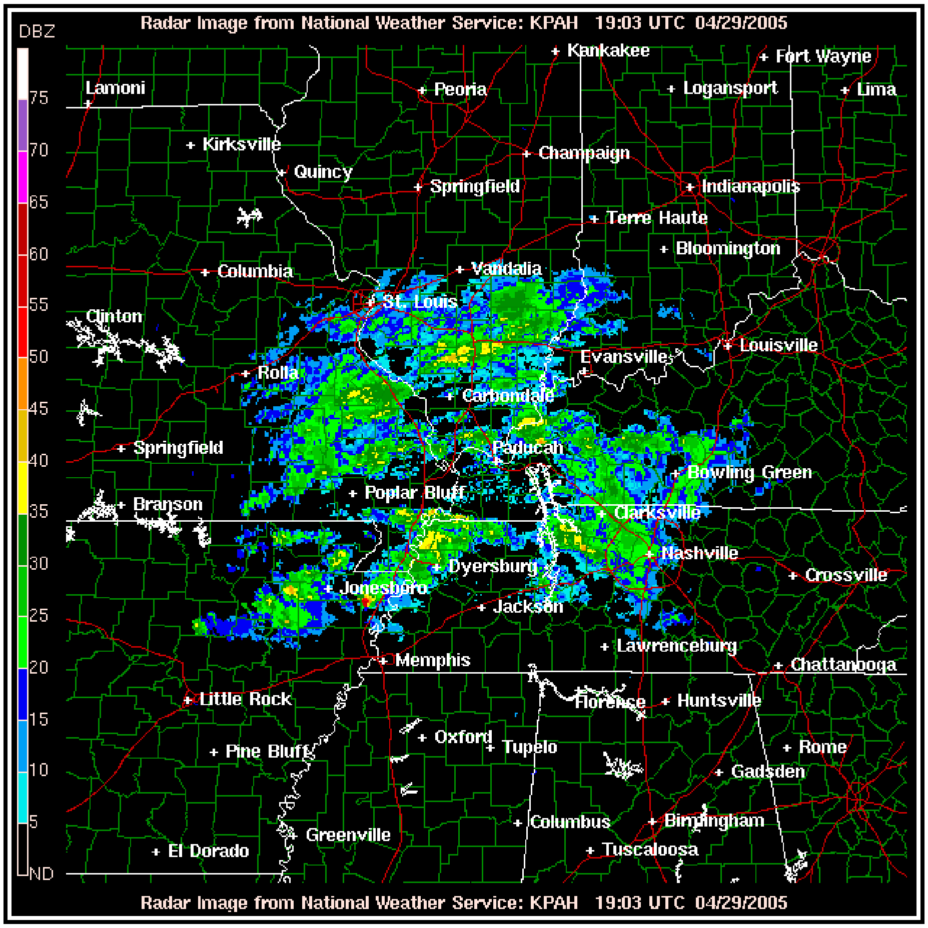


**Figure 4-3. WSR-88D Weather Radar Long Range (248 NM) Base Reflectivity Product Example**

#### 4.1.4.1.1 Base Reflectivity Use

The Base Reflectivity product can be used to determine the location of precipitation and non-precipitation echoes, the intensity of liquid precipitation, and the general movement of precipitation when animating the image.

If the echo is precipitation, the product can be used to determine if it is convective or stratiform in nature. Stratiform precipitation (Figure 4-4) has the following characteristics:

- Widespread in areal coverage,
- Weak reflectivity gradients,
- Precipitation intensities are generally light or moderate (39 dBZ or less),
  - Occasionally, precipitation intensities can be stronger
- Echo patterns change slowly when animating the image.

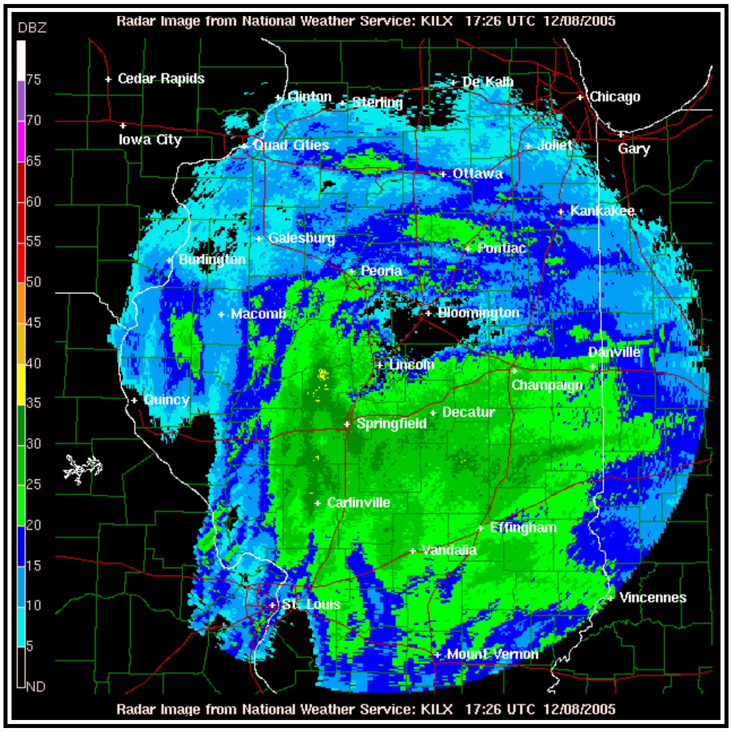


**Figure 4-4. WSR-88D Weather Radar Stratiform Precipitation on the 0.5ºBase Reflectivity Product Example**

Hazards associated with stratiform precipitation include possible widespread icing above the freezing level, low ceilings and reduced visibilities.

Convective precipitation (Figure 4-5) can be described using the following characteristics:

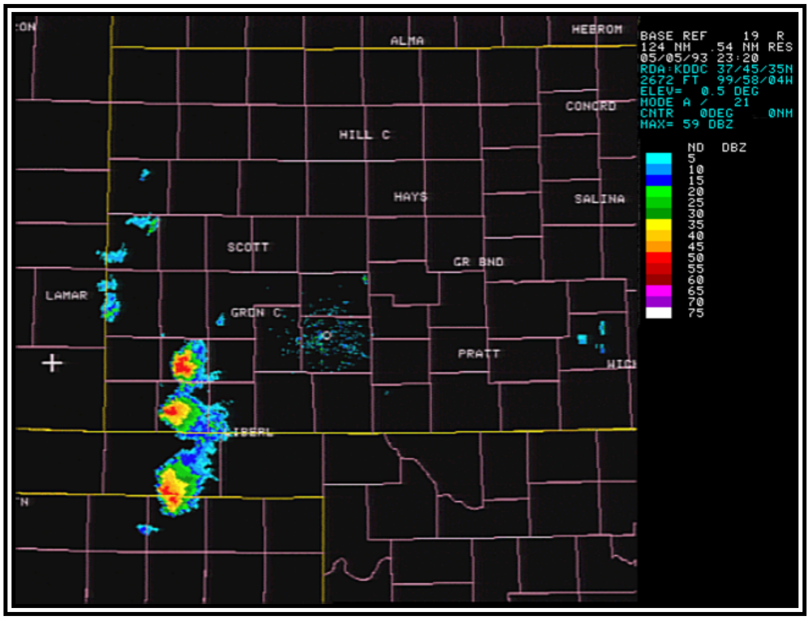


**Figure 4-5. WSR-88D Weather Radar Convective Precipitation on the 0.5ºBase Reflectivity Product Example**

- Echoes tend to form as lines or cells,
- Reflectivity gradients are strong,

- Precipitation intensities generally vary from moderate to extreme,
  - Occasionally precipitation intensities can be light
- Echo patterns change rapidly when animating the image

Numerous hazards are associated with convective precipitation. They include: turbulence, low-level wind shear, strong and gusty surface winds, icing above the freezing level, hail, lightning, tornadoes and localized IFR conditions with heavy precipitation.

#### 4.1.4.1.2 Strengths of Base Reflectivity

The strengths of the Base Reflectivity product include:

- The location of precipitation and non-precipitation echoes is depicted, and
- The intensity and movement of precipitation is relatively easy and straight forward to determine.

#### 4.1.4.1.3 Limitations of Base Reflectivity

Limitations associated with the Base Reflectivity product include:

- The radar beam may overshoot targets, and
- The image may be contaminated by:
  - Beam blockage
  - Ground clutter
  - Anomalous Propagation (AP) and
  - Ghosts.

##### 4.1.4.1.3.1 Radar Beam Overshooting

Radar beam overshooting may occur because the radar beam (typically the 0.5 degree slice) can be higher than the top of precipitation. This will most likely occur with stratiform precipitation and low-topped convection. For example, at a distance of 124 NM from the radar, the 0.5º Base Reflectivity radar beam is at an altitude of approximately 18,000 feet; at 248 NM the beam height is approximately 54,000 feet. Any precipitation with tops below these altitudes and distances will **not** be displayed on the image. Therefore, it is quite possible that precipitation may be occurring where none appears on the radar image.

##### 4.1.4.1.3.2 Beam Blockage

Beam blockage (Figure 4-6) occurs when the radar beam is blocked by terrain and is particularly predominant in mountainous terrain. This impacts both the Composite Reflectivity and Base Reflectivity images.

Beam blockage is most easily seen on the 0.5º Base Reflectivity images where it appears as a pie-shaped area (or areas) perpetually void of echoes. When animating the imagery, the beam blockage area will remain clear of echoes even as precipitation and other targets pass through.

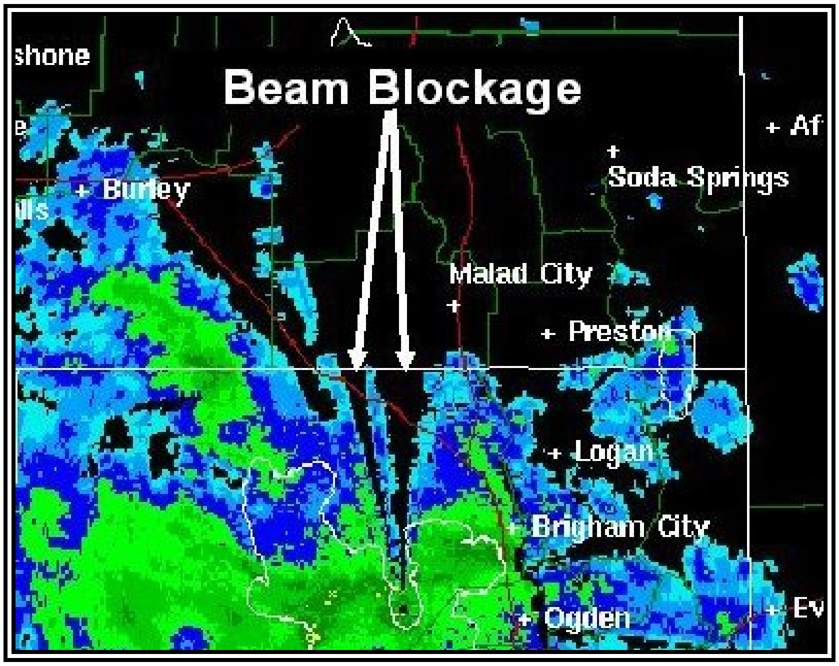


**Figure 4-6. WSR-88D Weather Radar Beam Blockage on Base Reflectivity Product Example**

### 4.1.4.1.3.3 Ground Clutter

Ground clutter (Figure 4-8) is radar echoes returns from trees, buildings, or other objects on the ground. It appears as a roughly circular region of high reflectivities at ranges close to the radar. Ground clutter appears stationary when animating images and can mask precipitation located near the radar. Most ground clutter is automatically removed from WSR-88D imagery, so typically it is does not interfere with image interpretation.

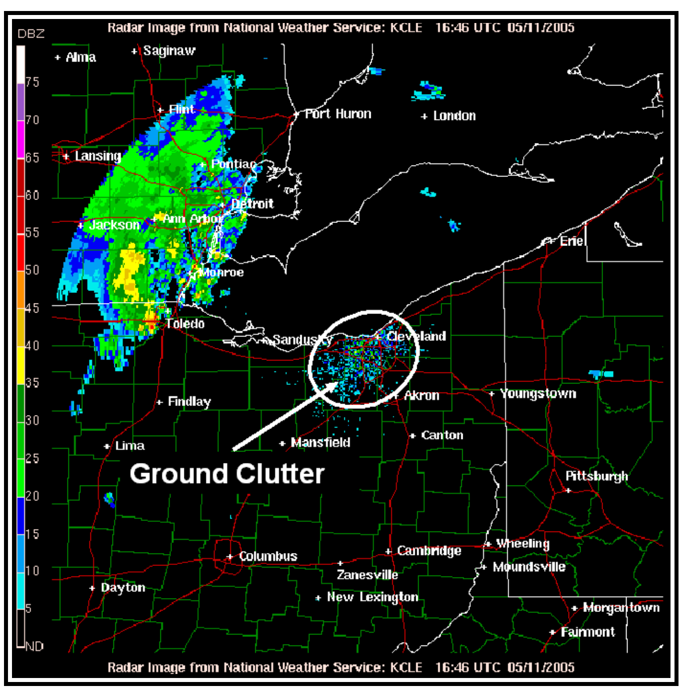


**Figure 4-8. WSR-88D Weather Radar Ground Clutter Example**

### 4.1.4.1.3.4 Ghost

A Ghost (Figure 4-9) is a diffused echo in apparently clear air caused by a “cloud” of point targets such as insects or by refraction returns of the radar beam in truly clear air.

The latter case commonly develops at sunset due to superrefraction during the warm season. The ghost develops as an area of low reflectivity echoes (typically less than 15dBZ) near the radar site and quickly expands. When animating the imagery, the ghost echo shows little movement.

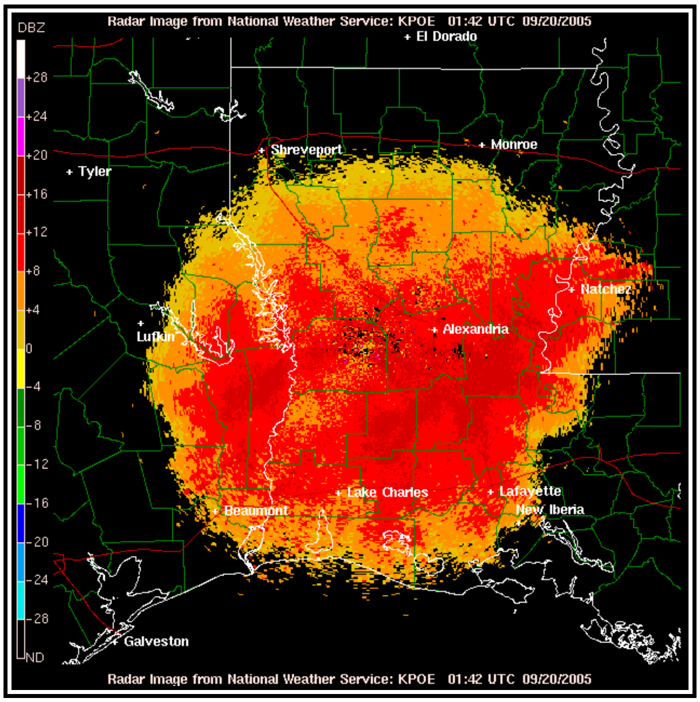


**Figure 4-9. WSR-88D Weather Radar Ghost Example**

### 4.1.4.1.3.5 Angels

Angels are echoes caused by a physical phenomenon not discernible by the eye at the radar site. They are usually causes by bats, birds or insects. Angels typically appear as a donut-shaped echo with low reflectivity values (Figure 4-10). When animated, the echo expands and becomes more diffuse with time.

Angels typically only appear only when the radar is in Clear Air Mode because of their weak reflectivity. Echoes caused by birds are typically detected in the morning when they take flight for the day. Echoes caused by bats are typically detected in the evening, when they are departing from caves.

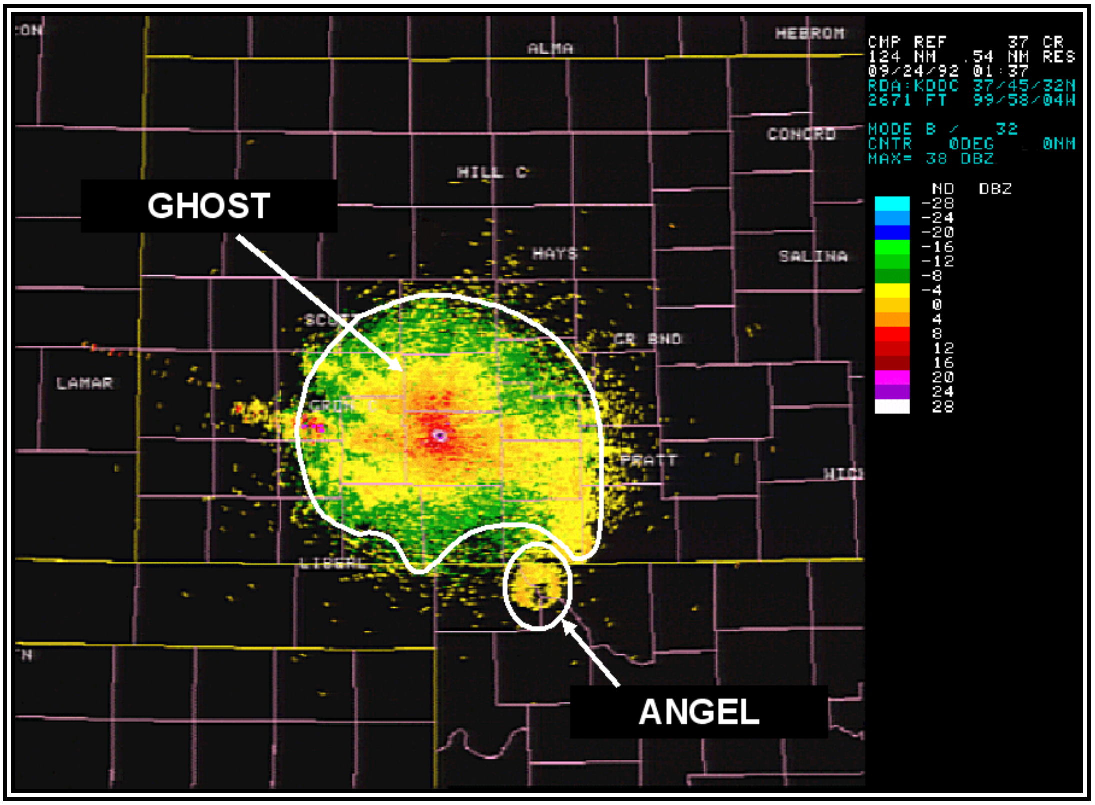


**Figure 4-10. WSR-88D Weather Radar Angle Example**
**This angel was caused by bats departing Selman Bat Cave at Alabaster Caverns State Park, Oklahoma around sunset**

#### 4.1.4.1.3.6 Anomalous Propagation (AP)

Anomalous propagation (AP) (Figure 4-11) is an en extended pattern of ground echoes caused by superrefraction of the radar beam. Superrefraction causes the radar beam to bend downward and strike the ground. It differs from ground clutter because it can occur anywhere within the radar's range, not just at ranges close to the radar.

AP typically appears as speckled or blotchy, high reflectivity echoes. When animating images, AP tends to "bloom up" and dissipate and has no continuity of motion. AP can sometimes be misinterpreted as thunderstorms; differentiating between to two is determined by animating images. Thunderstorms move with a smooth, continuous motion while AP appears to "bloom up" and dissipate randomly.

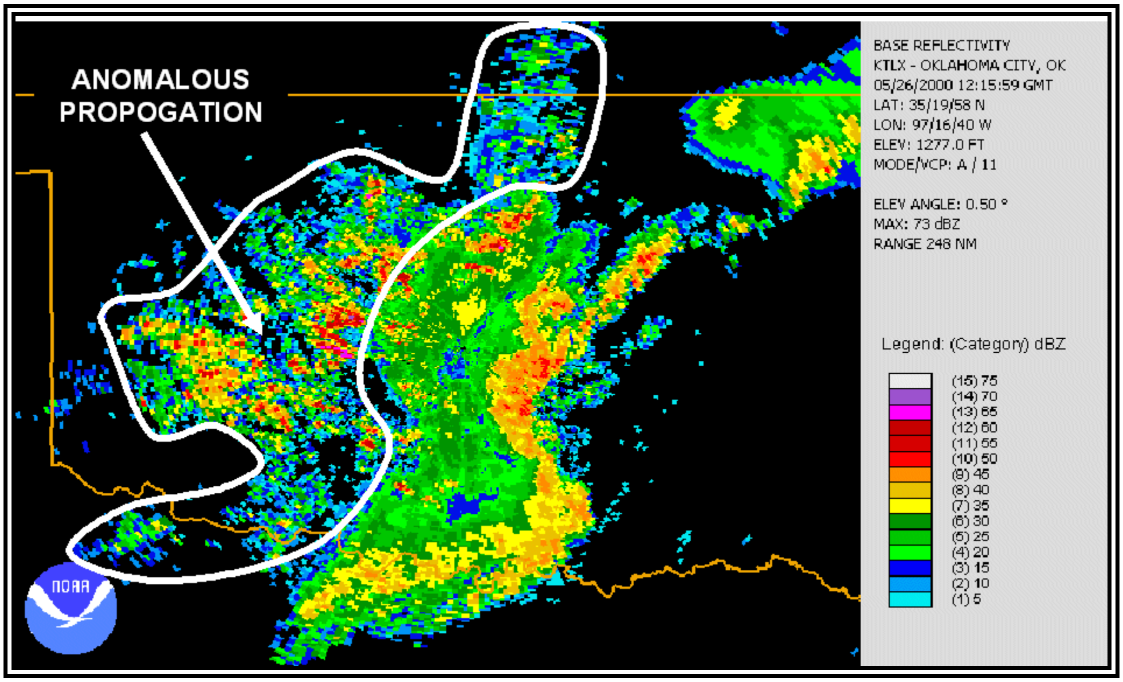


**Figure 4-11. WSR-88D Weather Radar Anomalous Propagation (AP) Example**

### 4.1.4.2 Composite Reflectivity

Composite reflectivity is the maximum echo intensity (reflectivity) detected within a column of the atmosphere above a location. The radar scans through all of the elevation slices to determine the highest dBZ value in the vertical column (Figure 4-12) then displays that value on the product. When compared with Base Reflectivity, the Composite Reflectivity can reveal important storm structure features and intensity trends of storms.

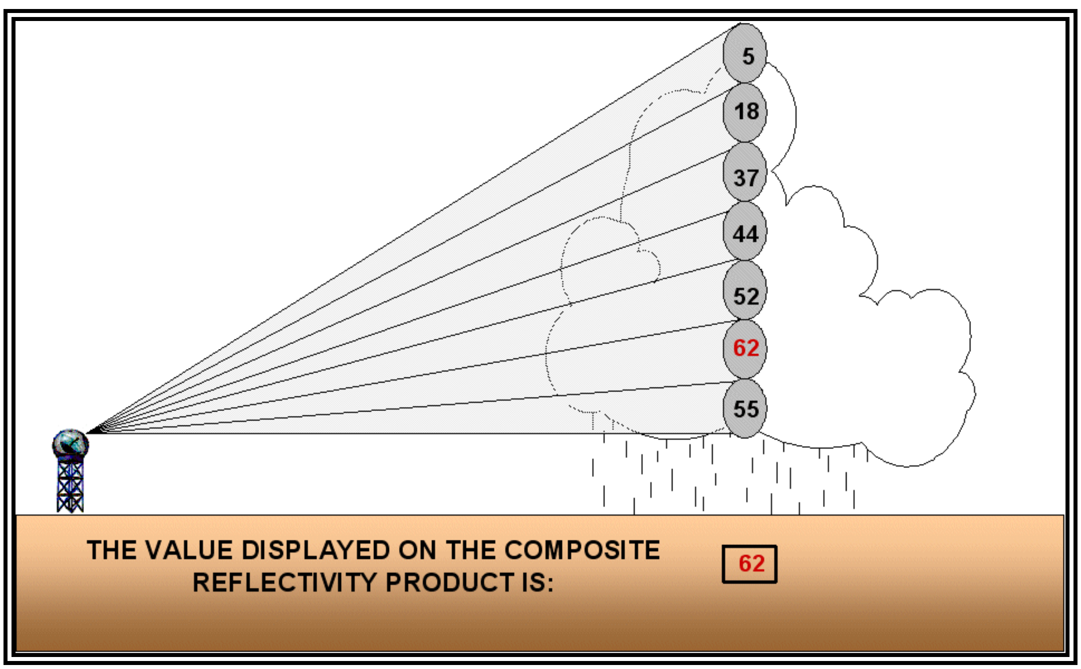


**Figure 4-12. Creation of a Composite Reflectivity product**

The maximum range of the long range Composite Reflectivity product (Figure 4-13) is 248 NM from the radar. The "blocky" appearance of this product is due to its lower spatial resolution as it has one-fourth the resolution of the Base Reflectivity product.

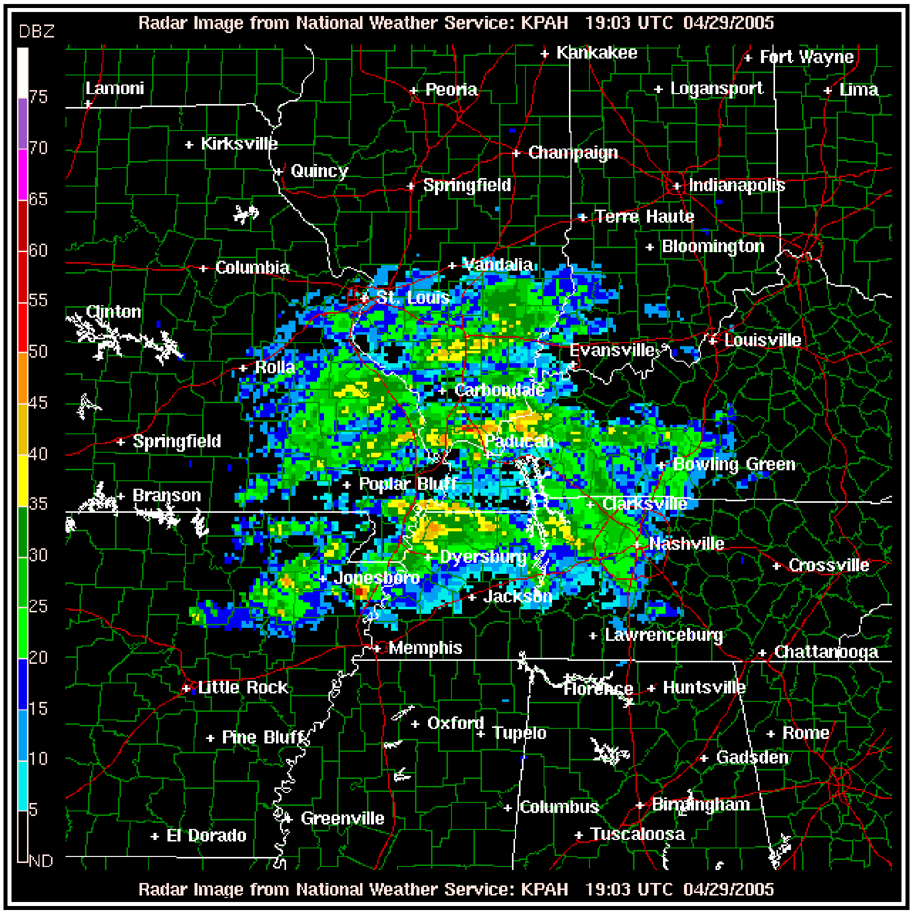


**Figure 4-13. WSR-88D Weather Radar Long Range (248 NM) Composite Reflectivity Product Example**

For a higher resolution (1.1 x 1.1 NM grid) Composite Reflectivity image, users must select the short range view (Figure 4-14). The image is less "blocky" as compared to the long range image. However, the maximum range is reduced to 124 NM from the radar location.

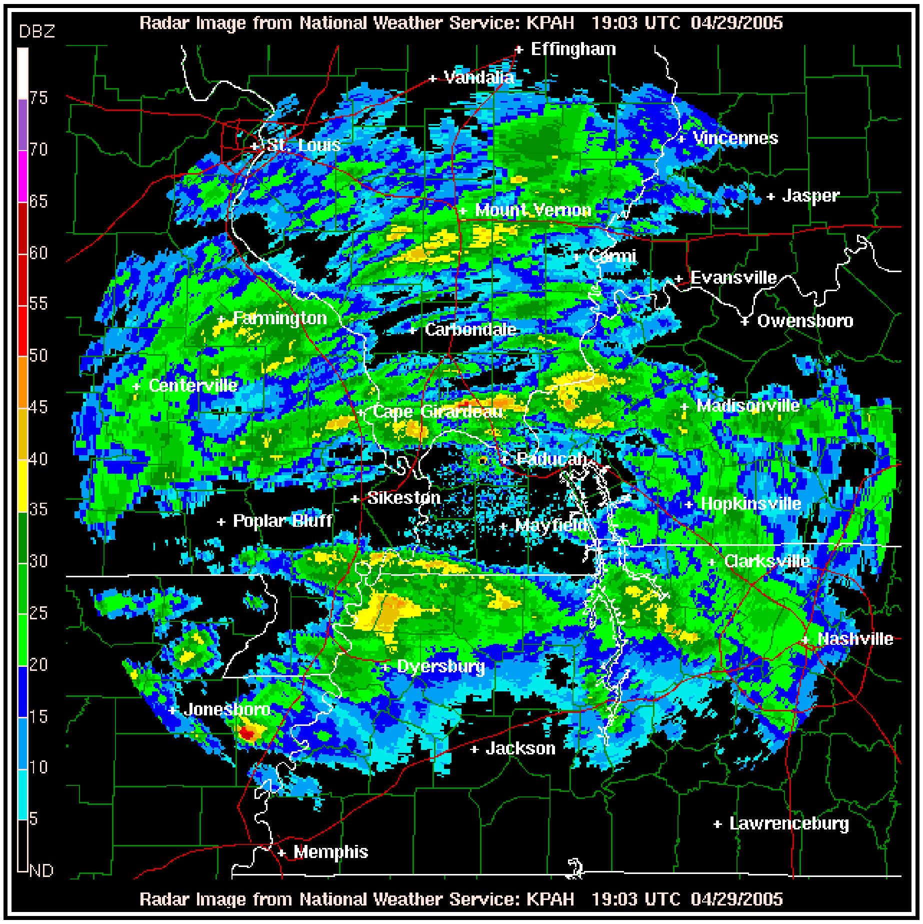


**Figure 4-14. WSR-88D Weather Radar Short Range (124 NM) Composite Reflectivity Product Example**

### 4.1.4.2.1 Composite Reflectivity Use

The primary use of the Composite Reflectivity product, which offers the highest reflectivity value in a vertical column, is to determine the vertical structure of the precipitation. The image must be compared with the Base Reflectivity image to determine the vertical structure of the precipitation. Figure 4-15 includes the 0.5º Base Reflectivity and Composite Reflectivity images for the same location and period of time.

In Figure 4-15, within location A, the intensity of the echoes is higher on the Composite Reflectivity image. Also, within area B, many more echoes present on the Composite Reflectivity. Since the Composite Reflectivity product displays the highest reflectivity of **all** elevation scans, it is detecting these higher reflectivities at some higher altitude/elevation than the Base Reflectivity product, which is sampling closer to the ground. This often occurs when precipitation and especially thunderstorms are developing.

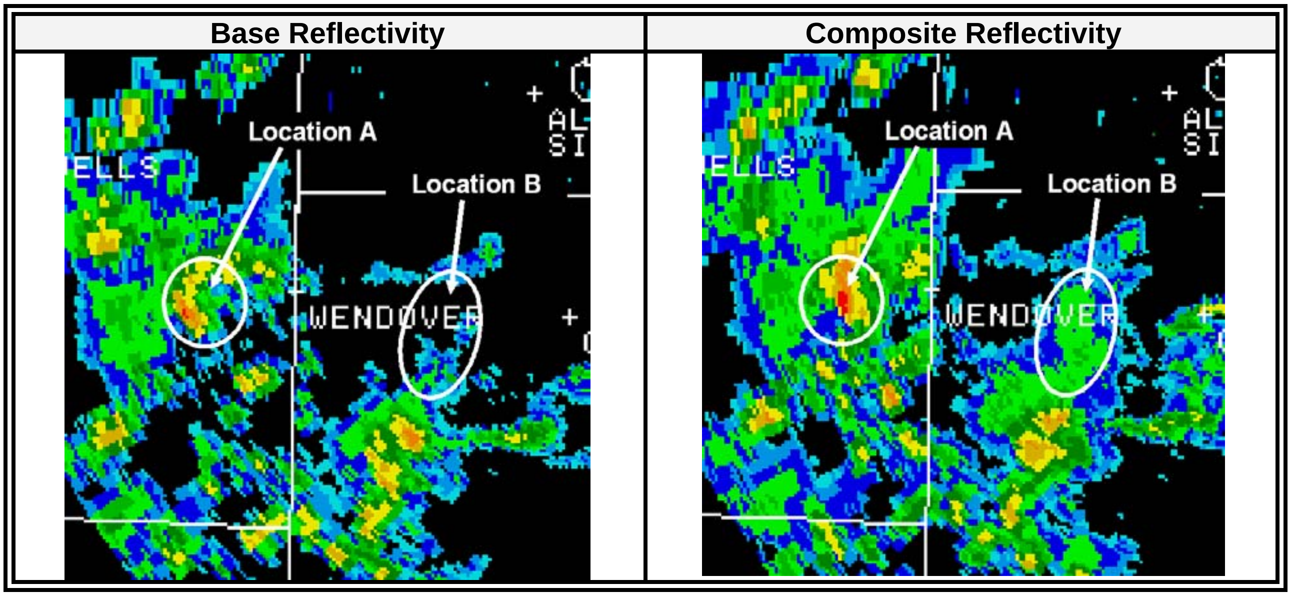


**Figure 4-15. WSR-88D Weather Radar 0.5º Base Reflectivity Versus Composite Reflectivity Comparison**

### 4.1.4.2.2 Strengths of Composite Reflectivity

The primary strength of the Composite Reflectivity product is its three-dimensional view of reflectivity. The method used to determine this three-dimensional view is described in section 4.1.4.2.1.

### 4.1.4.2.3 Limitations of Composite Reflectivity

Limitations associated with the Composite Reflectivity product include:

- The radar beam may overshoot targets, and
- The image may be contaminated by:
  - Beam blockage
  - Ground clutter
  - Anomalous Propagation (AP) and
  - Ghosts.

#### 4.1.4.2.3.1 Radar Beam Overshooting

Radar beam overshooting may occur because the lowest base reflectivity tilt (0.5) can be higher than the top of precipitation. This will most likely occur with stratiform precipitation and low-topped convection. For example, at a distance of 124 NM from the radar, the radar beam is at an altitude of approximately 18,000 feet above the radar; at 248 NM the beam height is approximately 54,000 feet. Any precipitation with tops below these altitudes and distances will **not** be displayed on the image. Therefore, it is quite possible that precipitation may be occurring where none appears on the radar image.

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The latter case commonly develops at sunset due to superrefraction during the warm season. The ghost develops as an area of low reflectivity echoes (typically less than 15 dBZ) near the radar site and quickly expands. When animating the imagery, the ghost echo shows little movement.

#### 4.1.4.2.3.5 Angels

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Angels typically only appear only when the radar is in clear air mode because of their weak reflectivity. Echoes caused by birds are typically detected in the morning when they take flight for the day. Echoes caused by bats are typically detected in the evening when they take flight from caves.

#### 4.1.4.2.3.6 Anomalous Propagation (AP)

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### 4.1.5 Radar Mosaics

A radar mosaic consists of multiple single site radar images combined to produce a radar image on a regional or national scale. Regional and national mosaics can be found at the National Weather Service (NWS) Doppler Radar Images web site: http://radar.weather.gov/ridge/

The mosaics are located toward the bottom of the page.

### 4.1.5.1 0.5º Mosaics - Contiguous U.S. and Hawaii

The NWS produces a set of regional and national mosaics (Table 4-2) in the contiguous U.S. using the 124 NM 0.5º Base Reflectivity product (Figure 4-16).

**Table 4-2. NWS Radar Mosaic Products**

| | |
|---|---|
| Pacific Northwest | Pacific Southwest |
| Upper Mississippi Valley | Southern Mississippi Valley |
| Northeast | Southeast |
| Southern Rockies | Northern Rockies |
| Southern Plains | Great Lakes |
| Low Resolution National | High Resolution National |

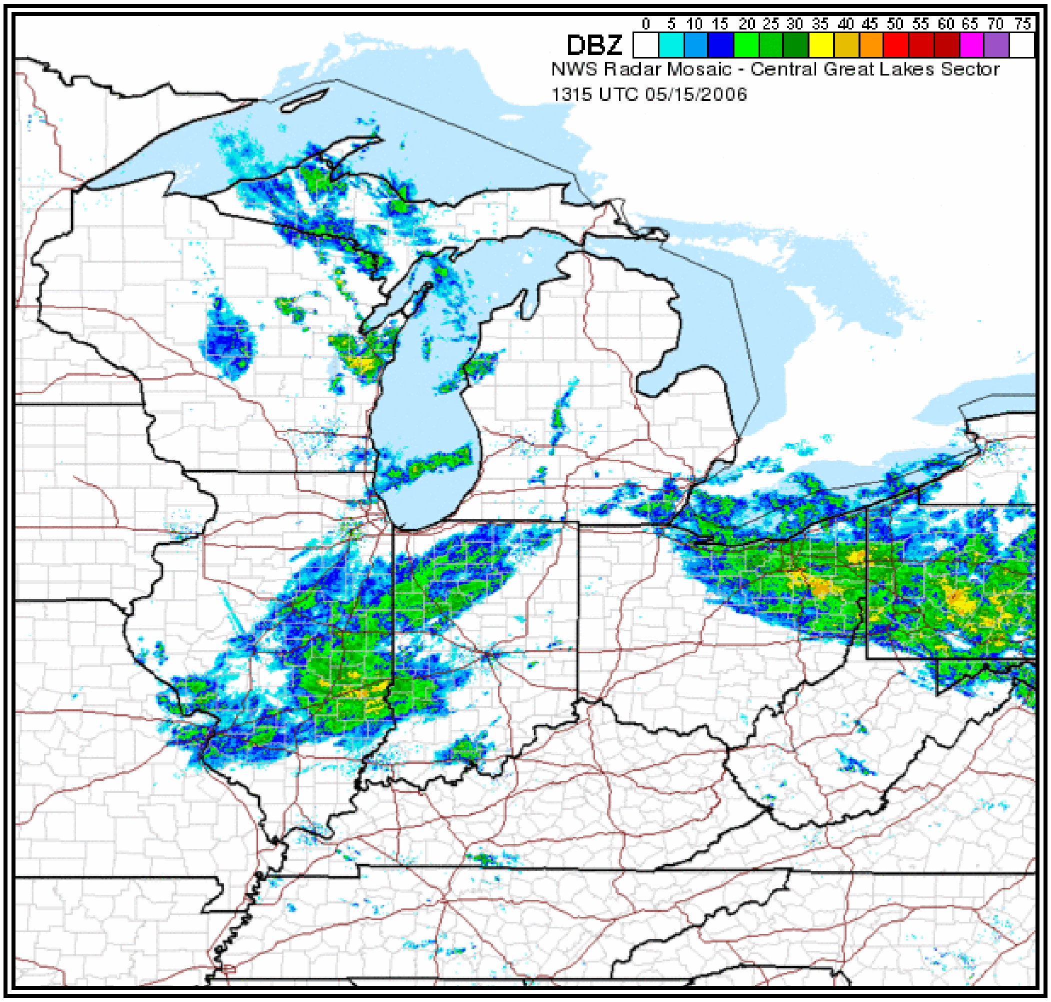


**Figure 4-16. Great Lakes Regional Radar Mosaic Example**

The most recent image from single site radars is used to create the product. Single site data older than 15 minutes from the current time of the product are excluded from the image. Therefore, data on the mosaics will be no greater than 15 minutes old. Where radar coverage overlaps, the highest dBZ value will be plotted on the image.

#### 4.1.5.2 0.5º Mosaics - Alaska

The Alaskan mosaic (Figure 4-17) differs from the contiguous product in only one way: it is created using the 248 NM 0.5º Base Reflectivity single site product.

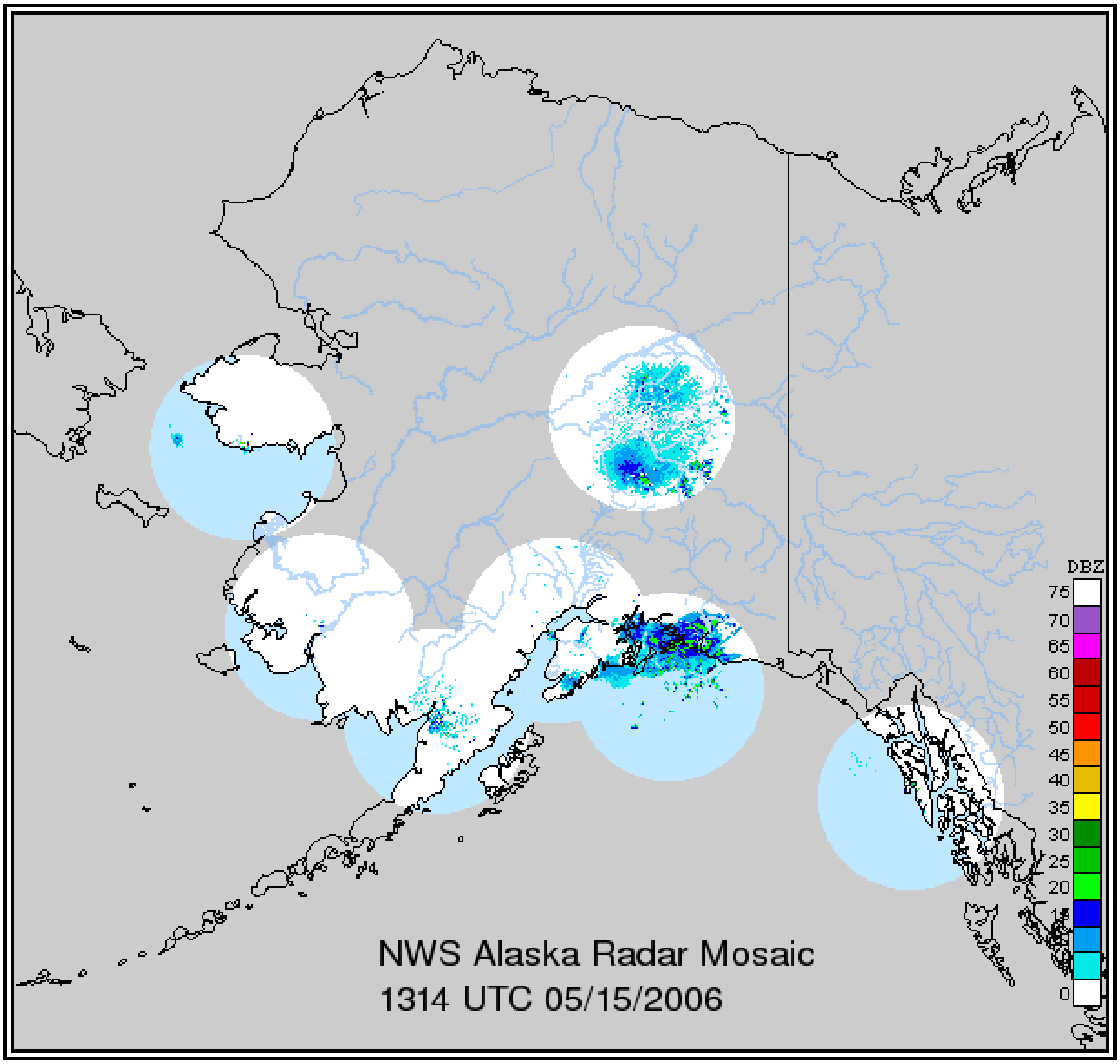


**Figure 4-17. Alaskan Regional Radar Mosaic Example**

The long range Base Reflectivity product is used because the radar sites are located at greater distances from each other. Even with the use of the long range product, many areas of Alaskan do not have radar coverage. These areas are shaded gray on Figure 4-17.

## 4.2 Satellite

### 4.2.1 Description

Satellite is perhaps the single most important source of weather data world wide, particularly over data sparse regions such as countries without organized weather data collection and the oceans.

GOES satellite imagery can be found on the NWS Aviation Digital Data Service (ADDS) website at: http://adds.aviationweather.noaa.gov/satellite/. Additional satellite imagery for Alaska can be found on the Alaska Aviation Weather Unit (AAWU) website at: http://aawu.arh.noaa.gov/sat.php

### 4.2.2 Imagery Types

Three types of satellite imagery are commonly used: Visible, infrared (IR), and water vapor. Visible imagery is available only during daylight hours. IR and water vapor imagery are available day or night.

#### 4.2.2.1 Visible Imagery

Visible imagery (Figures 4-16 and 4-17) displays reflected sunlight from the Earth's surface, clouds, and particulate matter in the atmosphere. These images are simply black and white pictures of the Earth from space. During daylight hours, visible imagery is the most widely used image type because it has the highest resolution and approximates what is seen with the human eye.

Gray shades displayed on visible imagery can be correlated with particular features. Assuming a high sun angle, thick clouds and snow will appear white, thin clouds will appear translucent gray, land appears gray, and deep bodies of water such as lakes and oceans will appear black.

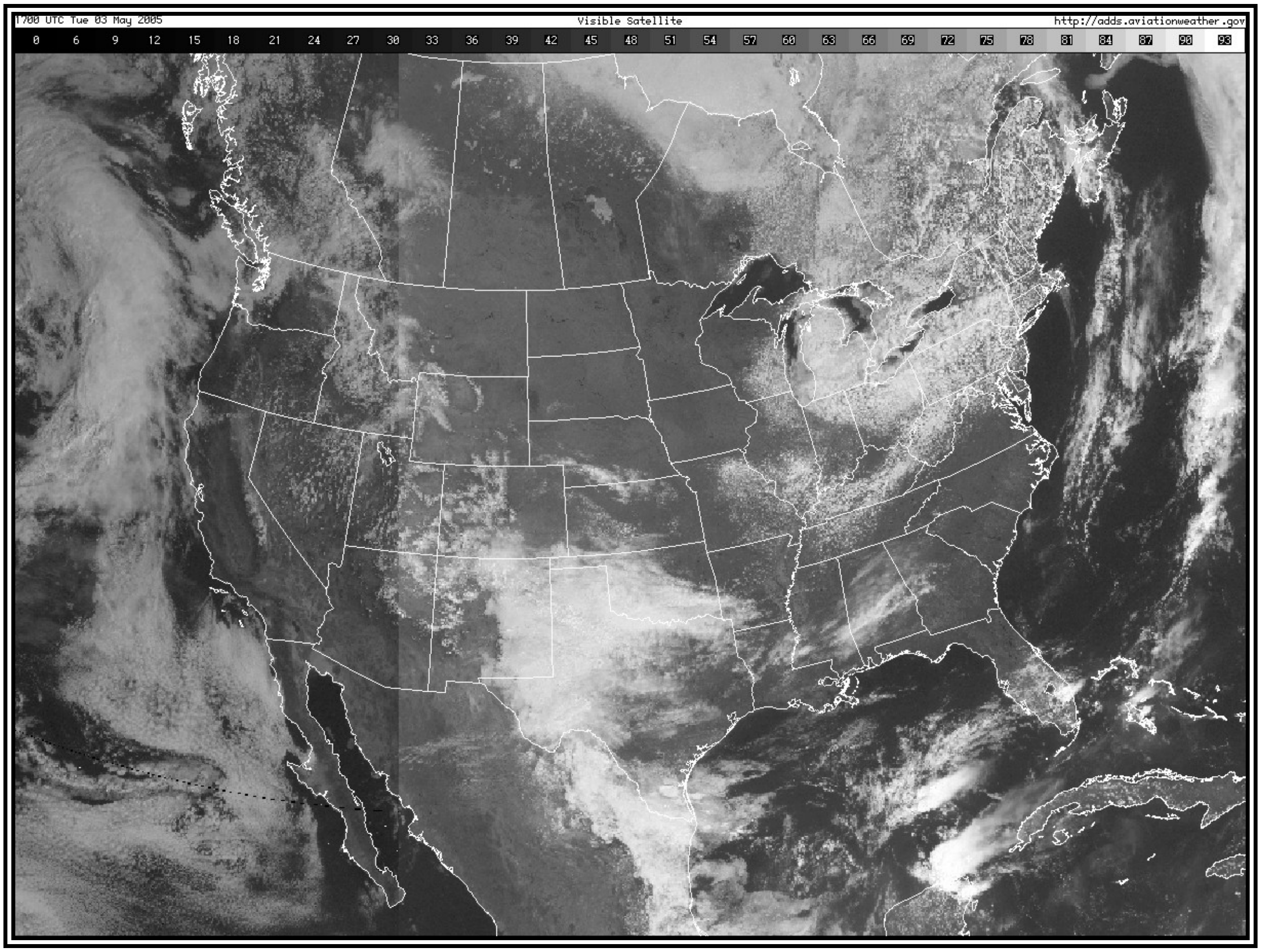


**Figure 4-18. Visible Satellite Image – U.S. Example**

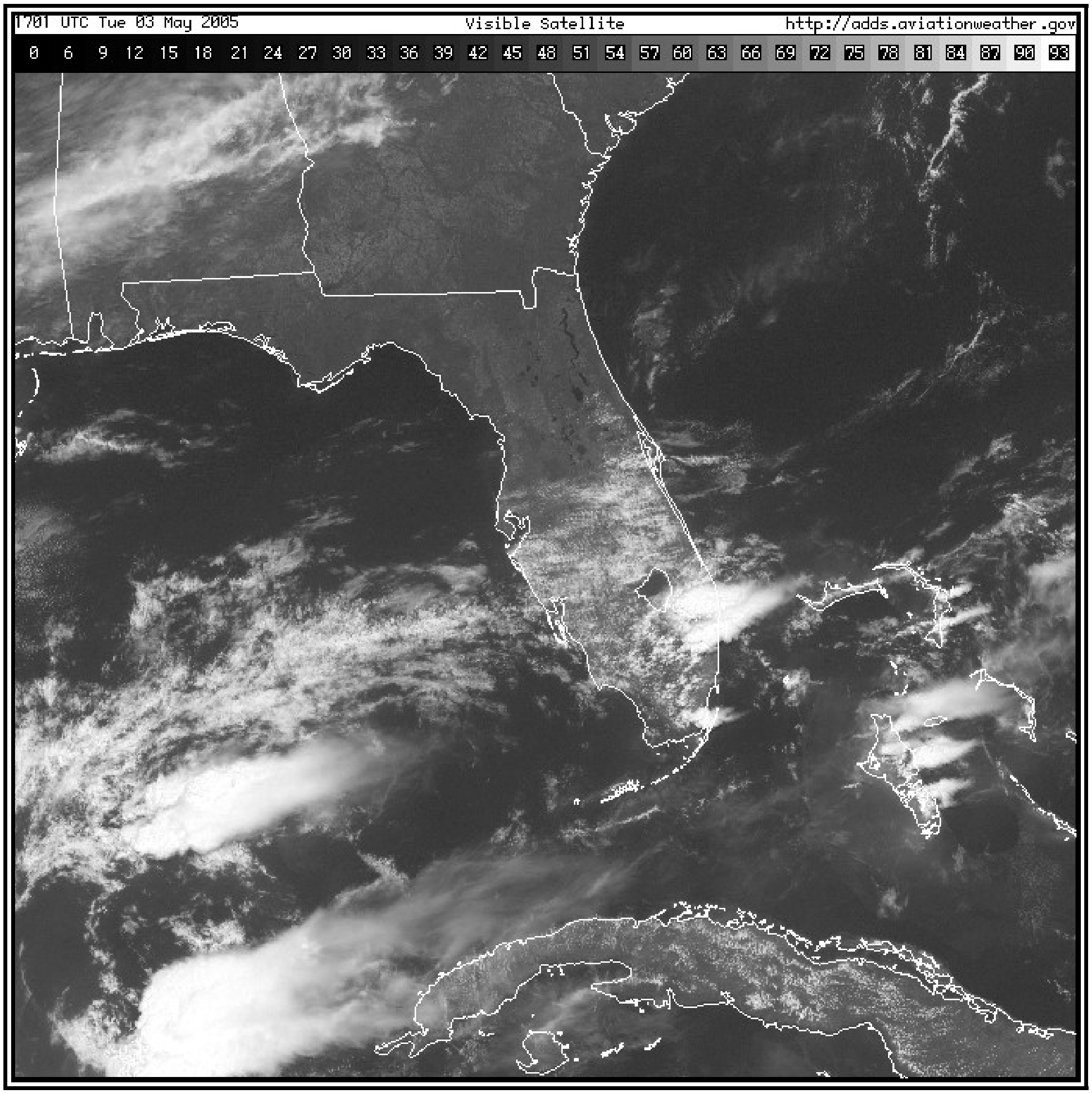


**Figure 4-19. Visible Satellite Image – Regional-Scale Example**

#### 4.2.2.1.1 Visible Image Data Legend

The data legend (Figure 4-18) on a visible image displays albedo, or reflectance, expressed as a percentage. For example, an albedo of 72 means 72 percent of the sunlight which struck a feature was reflected back to space.


**Figure 4-20. Visible Satellite Data Legend.**
**The gray shades (values) represent albedo or reflectance expressed as a percentage.**

### 4.2.2.2 Infrared (IR) Imagery

Infrared (IR) images (Figure 4-19 through 4-22) display temperatures of the Earth's surface, clouds, and particulate matter. Generally speaking, the warmer an object, the more infrared energy it emits. The satellite sensor measures this energy and calibrates it to temperature using a very simple physical relationship.

Clouds that are very high in the atmosphere are generally quite cold (perhaps -50°C) whereas clouds very near the earth's surface are generally quite warm (perhaps +5°C). Likewise, land may be even warmer than the lower clouds (perhaps +20°C). Those colder clouds emit much less infrared energy than the warmer clouds and the land emits more than those warm clouds.

The data measured by satellite is calibrated and colorized according to the temperature. If the temperature of the atmosphere decreases with height (which is typical), cloud-top temperature can be used to roughly determine which clouds are high-level and which are low-level.

When clouds are present, the temperature displayed on the infrared images is that of the tops of clouds. When clouds are not present, the temperature is that of the ground or the ocean.

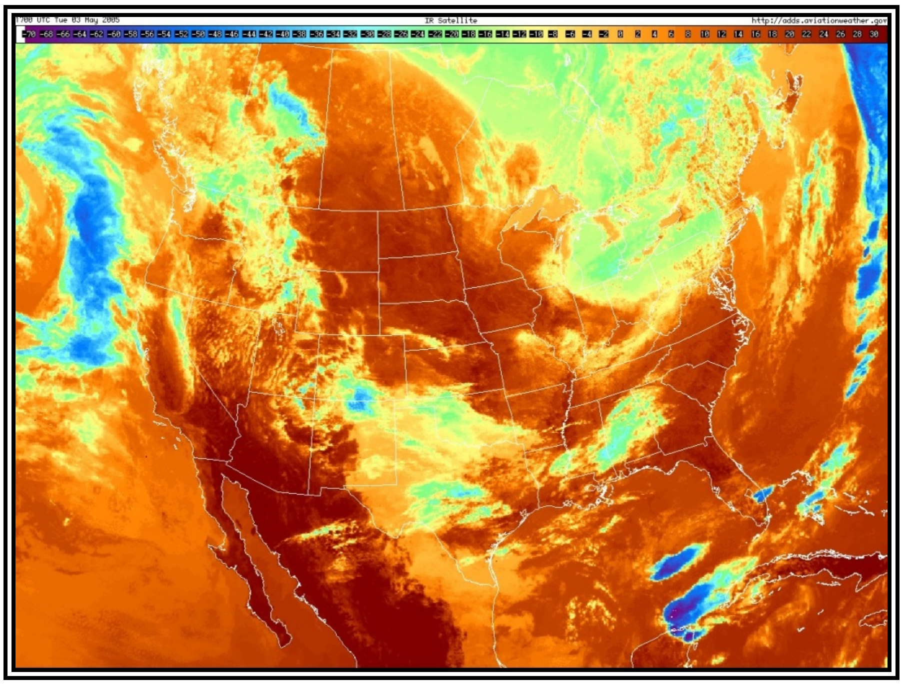


**Figure 4-21. Infrared (Color) Satellite Image – U.S. Example**
**The scale is in degrees Celsius. Blue/purple colors indicate colder temperatures, while orange/red colors indicate warmer temperatures.**

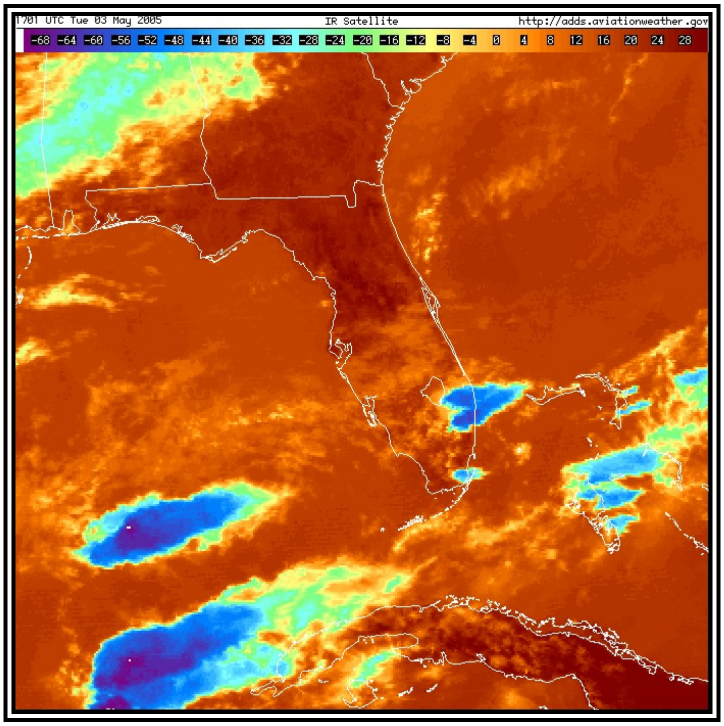


**Figure 4-22. Infrared (Color) Satellite Image – Regional-Scale Example**
**The scale is in degrees Celsius. Blue/purple colors indicate colder temperatures, while orange/red colors indicate warmer temperatures.**

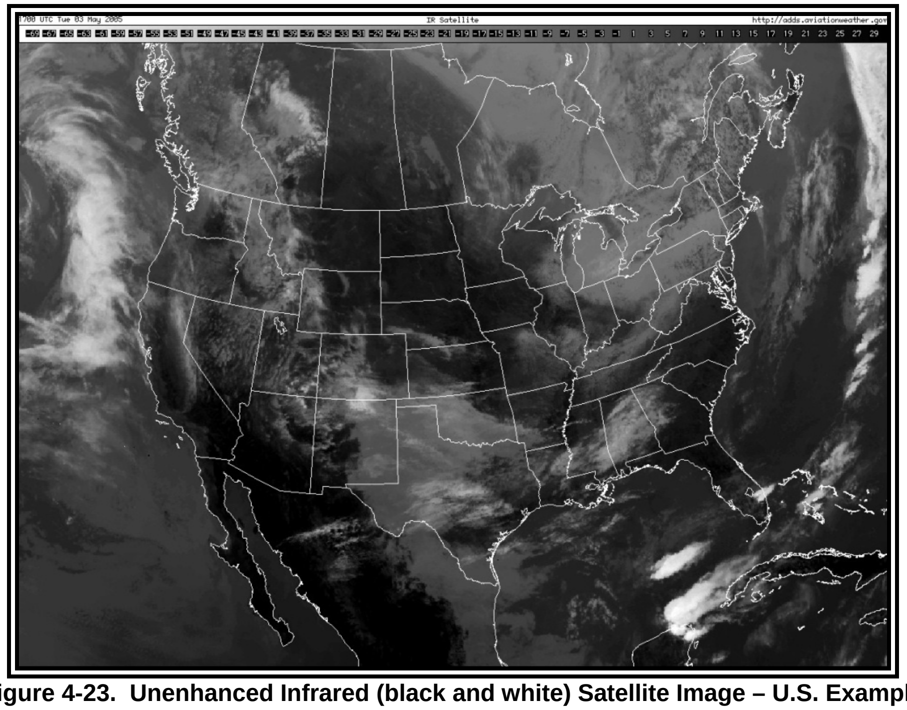

**Figure 4-23. Unenhanced Infrared (black and white) Satellite Image – U.S. Example**
**The scale is in degrees Celsius. Lighter gray shades indicate colder temperatures, while darker gray shades indicate warmer temperatures.**

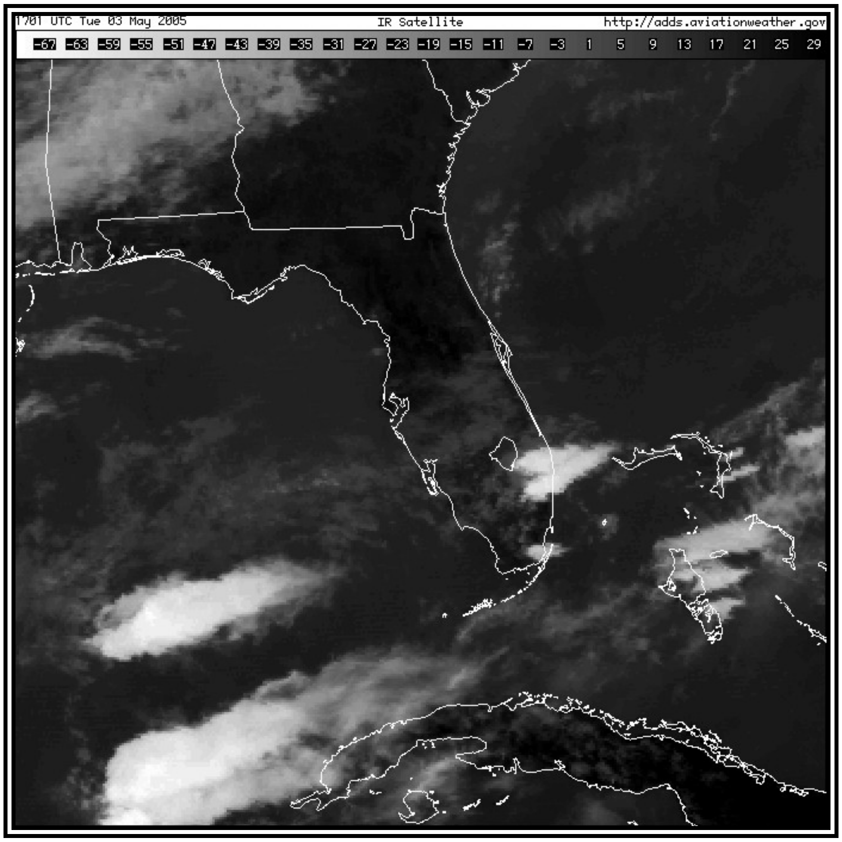


**Figure 4-24. Unenhanced Infrared (black and white) Satellite Image – Regional- Scale Example**
**The scale is in degrees Celsius. Lighter gray shades indicate colder temperatures, while darker gray shades indicate warmer temperatures.**

### 4.2.2.2.1 Infrared Image Data Legends

The data legend (Figure 4-23 and Figure 4-24) on an infrared image is calibrated to temperature expressed in degrees Celsius. The legend may vary based on the satellite image provider.

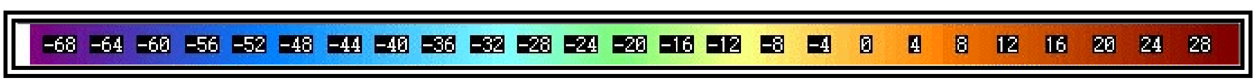


**Figure 4-25. Infrared (Color) Satellite Image Data Legend.**
**The colors (values) represent temperature in degrees Celsius.**

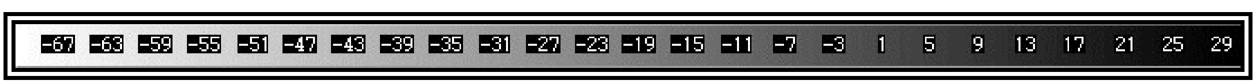


**Figure 4-26. Unenhanced Infrared (black and while) Satellite Image Data Legend.**
**The gray shades (values) represent temperature in degrees Celsius.**

### 4.2.3.3 Water Vapor Imagery

The water vapor imagery (Figure 4-25 and Figure 4-26) displays the quantity of water vapor generally located in the middle and upper troposphere within the layer between 700 millibars (FL100) to 200 millibars (FL390). The actual numbers displayed on the water vapor images correspond to temperature in degrees Celsius. No direct relationship exists between these values and the temperatures of clouds, unlike IR imagery. Water Vapor imagery does not really "see" clouds but "sees" high-level water vapor instead.

The most useful information to be gained from the water vapor images is the locations and movements of weather systems, jet streams, and thunderstorms. Another useful tidbit is aided by the color scale used on the images. In general, regions displayed in shades of red are VERY dry in the upper atmosphere and MAY correlate to crisp blue skies from a ground perspective. On the contrary, regions displayed in shades of blue or green are indicative of lots of high-level moisture and may also indicate cloudiness. This cloudiness could simply be high-level cirrus types or thunderstorms. That determination cannot be gained from this image by itself but could easily be determined when used in conjunction with corresponding visible and infrared satellite images.

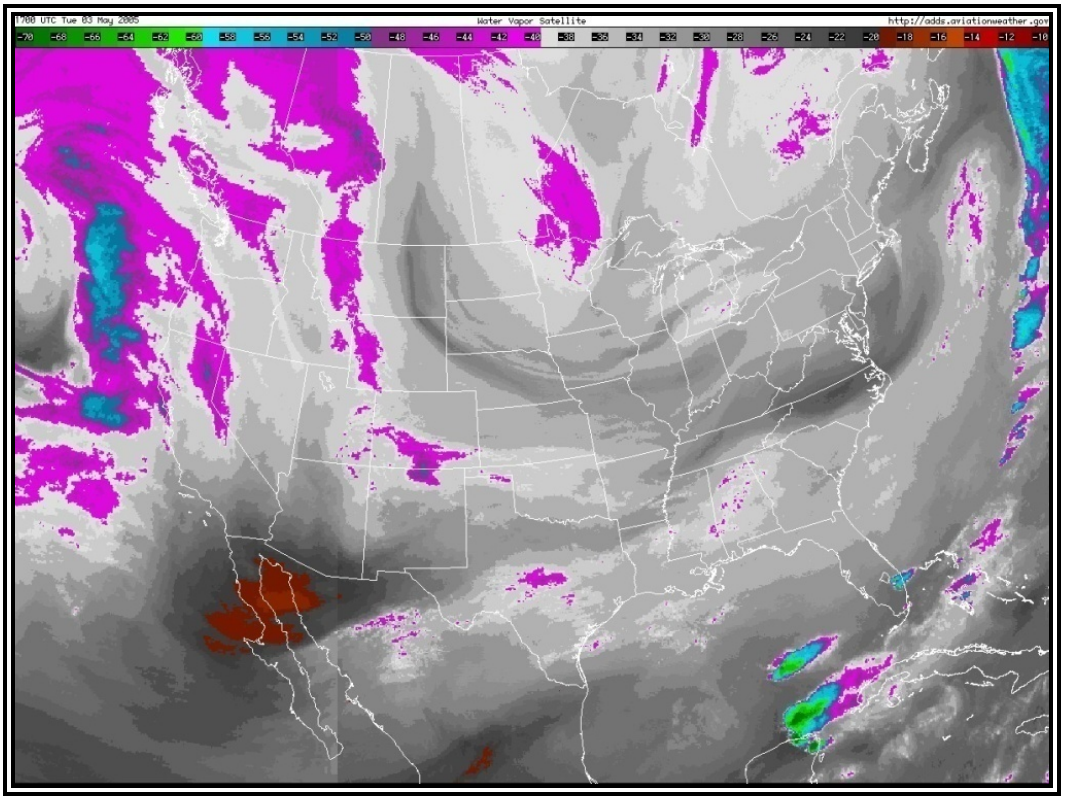


**Figure 4-27. Water Vapor Satellite Image – U.S. Example**
**The scale is in degrees Celsius. Blue/green colors indicate moisture and/or clouds in the mid/upper troposphere, while dark gray/orange/red colors indicate dry air in the mid/upper troposphere.**

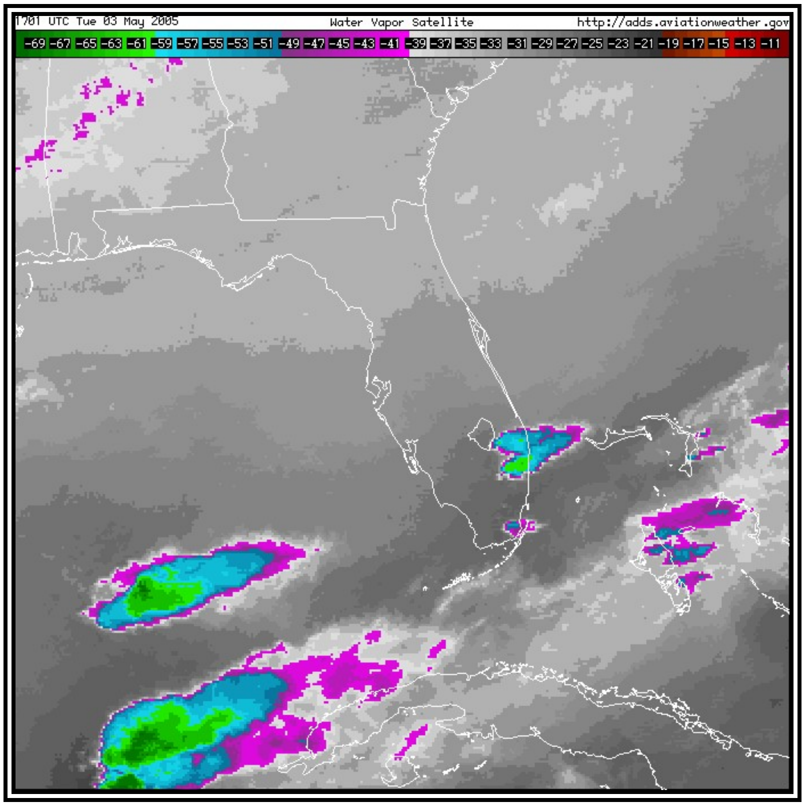


**Figure 4-28. Water Vapor Satellite Image – Regional-Scale Example**
**The scale is in degrees Celsius. Blue/green colors indicate moisture and/or clouds in the mid/upper troposphere, while dark gray/orange/red colors indicate dry air in the mid/upper troposphere.**

### 4.2.3.3.1 Water Vapor Image Data Legend

The data legend (Figure 4-27) on a water vapor images is calibrated to temperature expressed in degrees Celsius. The actual data values on the water vapor images are not particularly useful. Interpretation of the patterns and how they change over time is more important. The legend may vary depending on the satellite image provider.

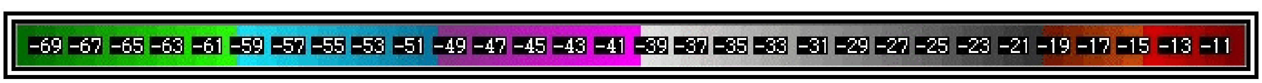


**Figure 4-29. Water Vapor Satellite Image Data Legend.**
**The colors (values) represent temperature in degrees Celsius.**