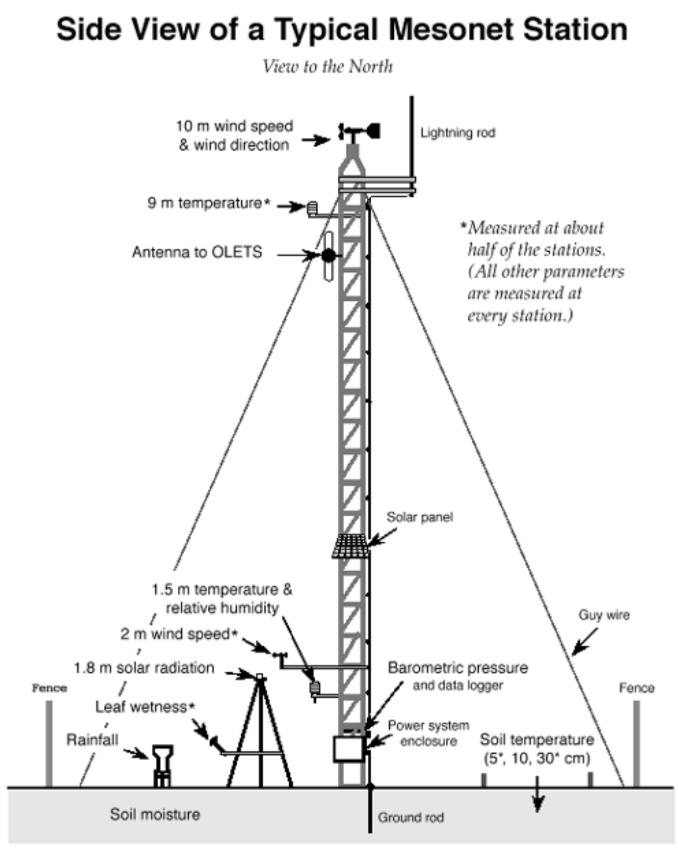
Meteorological Instruments

Instruments are an important part of Meteorology. Instruments perform measurements which describe the current conditions and can be ingested into a computer for modeling purposes. There are many different variables that a meteorologist uses so he or she must be familiar with the instruments that measure them.

A.Networks

The most common way of obtain mass quantities of observational data is through the use of meteorological networks. Most networks are stationary, which allows detailed plots of data to be created easily. However, the use of mobile networks is becoming more useful in research studies. Mobile networks allow researchers to place instruments in a particular position relative to a moving object, like a supercell thunderstorm.

The two most common stationary networks that will be discussed today and in the future are the Automated Surface Observation System (ASOS) and the Oklahoma Mesonet. Automated Surface Observation System (ASOS) towers are installed nationwide to measure weather conditions and run by the National Oceanographic and Atmospheric Administration (NOAA). In Oklahoma, there are between 30-35 ASOS towers. Every tower records data every hour.

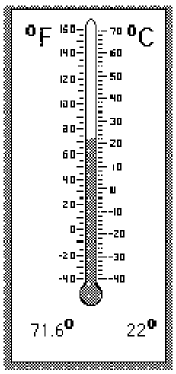


The Oklahoma Mesonet is a dense network of stations in Oklahoma that reports weather data every 15 minutes. The Oklahoma Mesonet is run by the Oklahoma Climatological Survey, which is based here at the University of Oklahoma.

B. Thermometer

A thermometer is an instrument used to measure temperature. There are four main types of thermometers that will be discussed: Liquid-in-Glass, Bi-metallic, Infrared and Thermoelectric.

1. Liquid-in-Glass:



A liquid-in-glass thermometer is a glass tube with a bulb at one end filled with a liquid and has a scale fastened either on or next to the tube. The tube has a inner tube in which the liquid rises as the temperature increases, and falls as the temperature decreases.

The liquid is usually either mercury or alcohol. Alcohol is sometimes preferred, because mercury is toxic to humans. Also, mercury can only be used above temperatures of -39°C (at which point it freezes), while alcohol can be used down to -62°C.

The liquid-in-glass thermometer is the most common type of thermometer in everyday use (medicine, cooking, etc.). The largest downside to a liquid-in-glass thermometer for meteorologists is that it can not be automated very easily. This led to the development of other types of thermometers.

2. Bi-metallic:

A BI-metallic thermometer uses a coil of two different types of metals attached to one another. Since different metals expanded at different rates as the temperature increases, this causes the coil to bend. The temperature can then be determined by how much the metal has bent.

Outdoor thermometers (like shown on the left) use this type of a device.

Like the liquid-in-glass thermometer, the BI-metallic thermometer can be very difficult to automate.

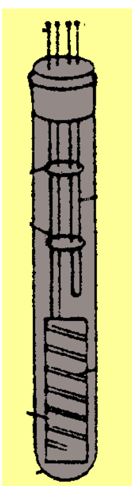
3. Infrared:

Infrared thermometers are being used more and more everyday. Infrared thermometers measure the infrared radiation emitted by an object that is beyond the sensitivity range of the human eye. It essentially detects the amount of energy an object has and calculates a temperature from it.

As seen on the left, doctors use this technology to instantly determine a patients temperature through their ear. Where the previous two types of thermometers must "heat up" or "cool down" until an accurate measurement is detected, an infrared thermometer is instantaneous.

Also unlike the previous two types of thermometers, the infrared thermometer can easily be automated; therefore, making it very useful for automated stations. (However other aspects can affect accurate measurements such as ground color, and thus infared thermometers are used in conjunction with other thermometers.)

4. Thermoelectric:



A thermoelectric thermometer is the most commonly used thermometer on automated stations. There are many forms of the thermoelectric thermometer.

An electrical resistance sensor is one whose resistance varies as a function of temperature. A known voltage is passed through a metal wire (usually platinum) and the resistance is measured at the other end of the wire. The temperature can then be calculated from this measurement.

These types of thermometers have a wide useful temperature range, are rugged, reliable, inexpensive, and have a very fast response. They are also extremely easy to to automate.

.

C Anemometer

An anemometer is an instrument used to measure wind speed and direction.

A wind vane (seen on top in the picture on the left) is directed into the flow of wind by the force of the wind on the flag. By putting a rotatable sensor inside, the direction of the wind can easily be automated.

The cups (seen on bottom in the picture on the left) catch the wind (as the air particles hit the cup) and rotate at the speed of the wind. This to can easily be automated by using electrical sensors.

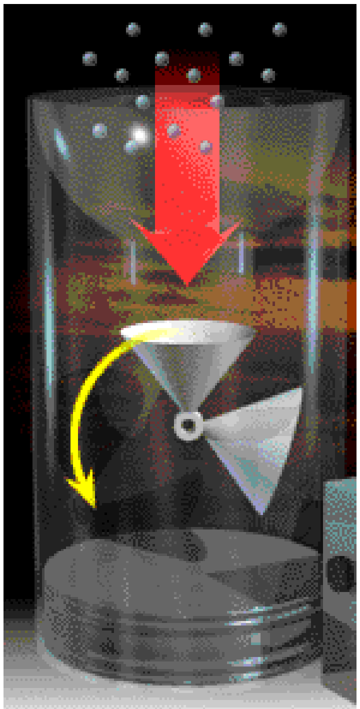
Nearby objects such as trees and buildings can cause false measurements of the true wind speed. As a rule, an anemometer must be placed 10 times the distance away from the tallest nearby object. For example, if there was a 15 meter tree, then the anemometer must be placed 150 meters away from the base of the tree.

D.Barometer

A barometer is an instrument used to measure atmospheric pressure. It works somewhat like a weight scale for the atmosphere. Like the thermometer, there are many forms of the barometer. A common type, most likely the one seen in the photo, uses a sealed container filled with a gas. As the atmospheric pressure changes (either rises or falls), the container will either expand or contract. Gears and dials can then be attached to read out the atmospheric pressure.

(Have you ever bought a bag of potato chips and then gone to a higher elevation like the mountains? Did you notice that the bag expanded? A barometer works the same way.)

E.Tipping Bucket Rain Gage



A tipping bucket rain gauge is an instrument used to calculate the amount of rain that has fallen over a given amount of time. Two buckets are on a seesaw type of lever. As one bucket fills up with water, the weight forces the lever to switch and the buckets dumps the water out. The other bucket then repeats the process. This is repeated over and over for each bucket.

An electrical switch counts the number of times the "seesaw" has flipped back and forth. Since the volume of the bucket is known, then the total amount of rainfall can be calculated.

For example, if the bucket size was .01" and the switch counted 157 flips, then 1.57" of rain had fallen in that time period.

F. Other Instruments

There are many other instruments that are used to record meteorological information, such as a hygrometer which measures humidity.

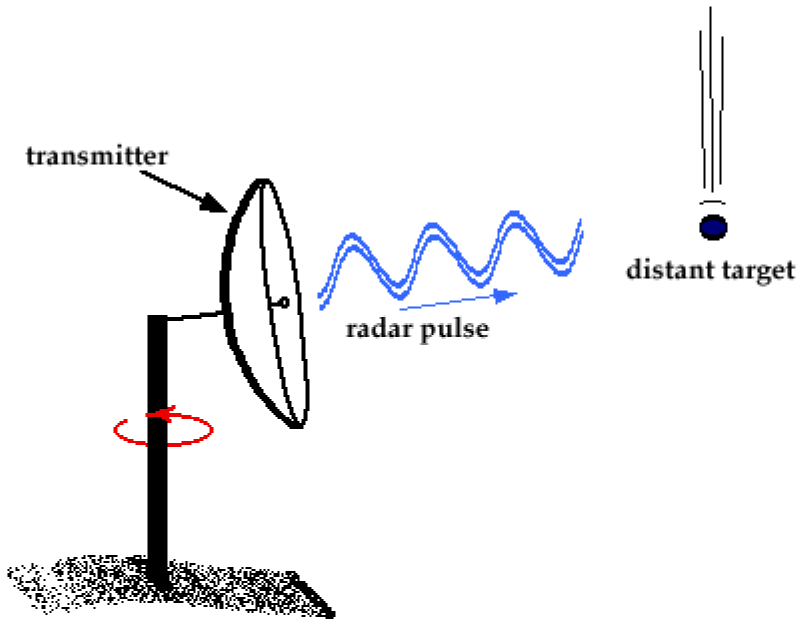
Other methods of collecting data that can be thought of as instruments like a radar, satellite, and rawindsondes will be discussed in later labs. These are so important (and much more detailed) that separate labs have been constructed for them.

G. RADAR

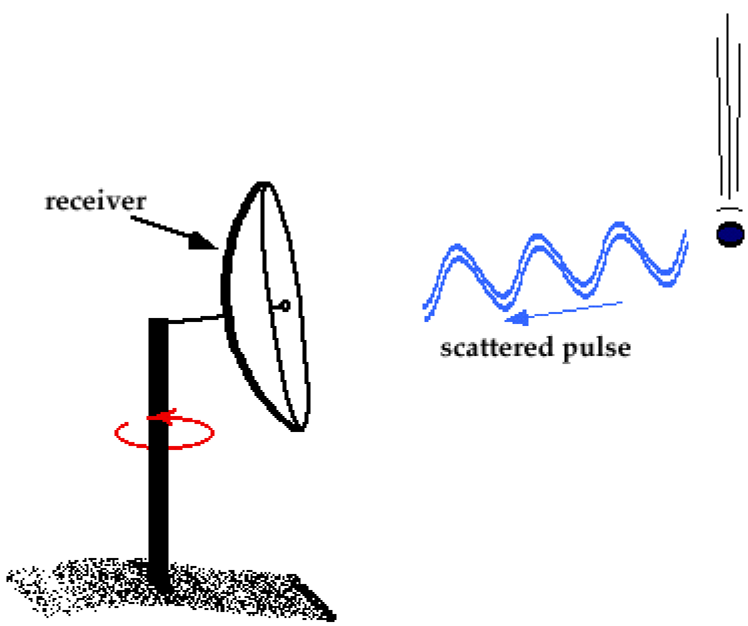
1. Radars have an important role in the field of meteorology. These devices send out and receive signals providing valuable information about the location and intensity of precipitation. Advanced Doppler radar technology goes beyond simple detection to providing high resolution reflectivity and estimated velocity data, which is vital to short term forecasting and severe weather prediction. The purpose of this module is to introduce the basics of radar meteorology, features of WSR-88D and MDR radar imagery, and how to interpret Doppler velocity patterns.

Sending and Receiving Signals

detecting a target



2. The radar creates an electromagnetic energy pulse which is focused by an antenna and transmitted through the atmosphere. Objects in the path of this electromagnetic pulse, called targets, scatter the electromagnetic energy. Some of that energy is scattered back toward the radar.

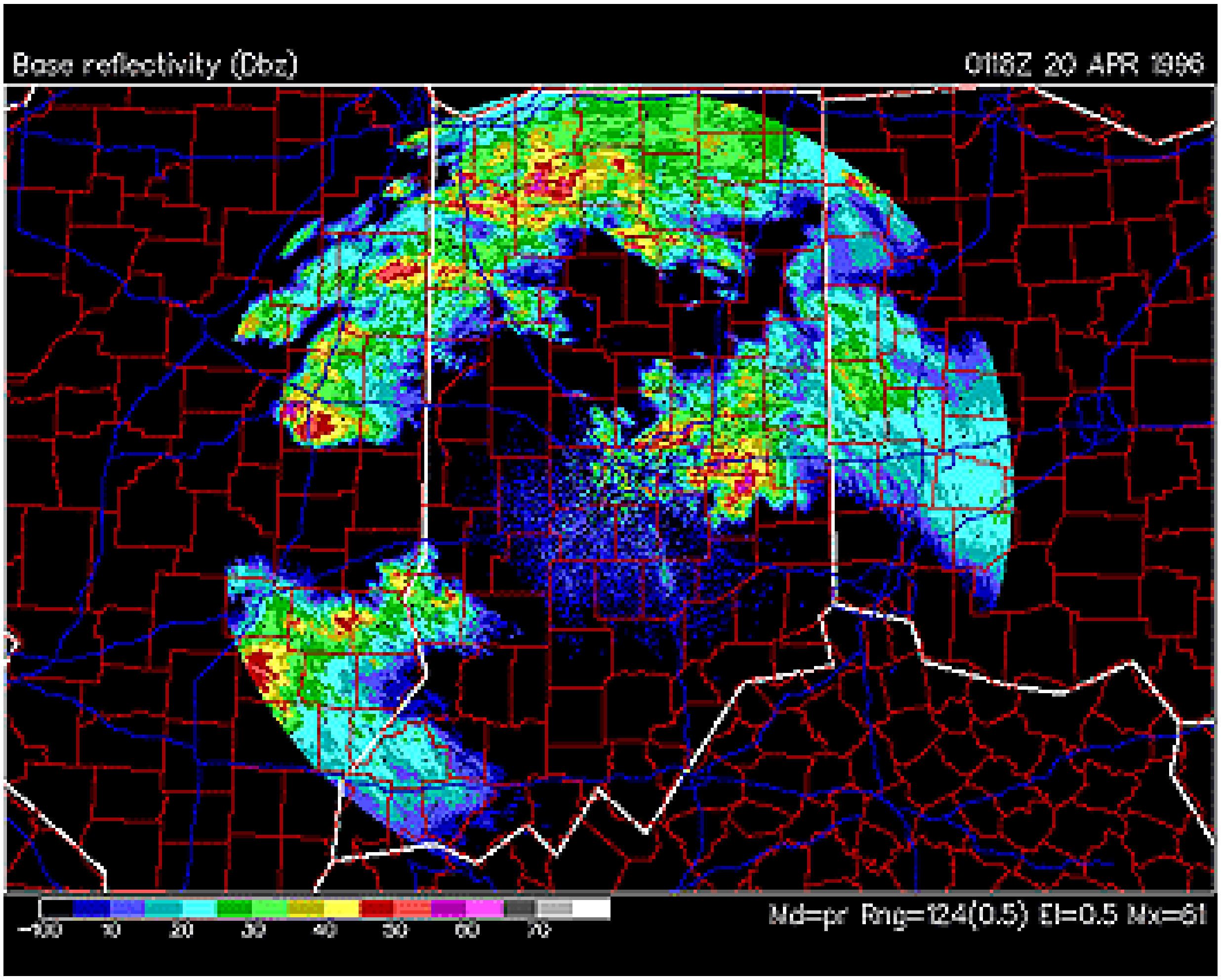


- This reflected signal is then received by the radar during its listening period.

- Computers analyze the information. (The strength, time, and phase shift of the returning pulse).
- This process of emitting a signal, listening for any returned signal, then emitting the next signal, takes place very fast.
  Around 1300 times each second.

3. The receiving antenna (which is normally also the transmitting antenna) gathers this back-scattered radiation and feeds it to a device called a receiver.

4. The word radar is an acronym from "Radio Detection and Ranging". Radar images are useful for locating precipitation. As a Magnetic Resonance Imaging (MRI) scan examines the inside of a human body, a radar examines the inside of a cloud. A radar sends a pulse of energy into the atmosphere and if any precipitation is intercepted by the energy, part of the energy is scattered back to the radar. These returned signals, called "radar echoes", are assembled to produce radar images.

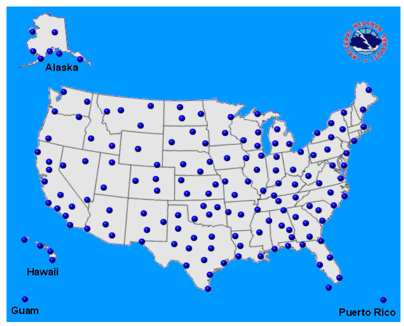


5. The location of the colored radar echoes indicate where precipitation is falling and the various colors indicate the intensity of the precipitation through the color code in the

lower left corner of the image. The example radar image above shows several strong thunderstorms moving through Illinois and Indiana on April 20, 1996. Regions of light and dark blue indicate regions of lighter precipitation while areas of red and pink indicate strong, to occasionally severe thunderstorms.

Normally, it is difficult to distinguish precipitation type on the basis of the radar reflectivity alone. Snow and light drizzle both produce radar reflectivity with about the same value. Melting snow and moderate rain also have similar values. Very high reflectivities (the grays on the scale on the image above) are always associated with hail.

a. Radar Stations:



6. These are displays of echo intensity (reflectivity) measured in **dBZ** (decibels of Z, where Z represents the energy reflected back to the radar).
"Reflectivity" is the amount of transmitted power returned to the radar receiver.

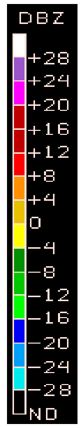
a. dBZ
   •Typical units used to express reflectivity

   •Range:
   •–30 dBZ for fog

   •+75 dBZ for very large hail
b. Image updates are based upon the operation mode of the radar at the time the image is generated. The WSR-88D Doppler radar is operated in one of two modes - clear air mode or precipitation mode.
   i) Clear air mode- images are updated every 10 minutes.
   ii) Precipitation mode- images are updated every 5 or 6 minutes.
   iii) The collection of radar data, repeated at regular time intervals, is referred to as a volume scan.
   iv) Clear-Air Mode
   –slower antenna rotation

   –five elevation scans in 10 minutes

   –sensitive to smaller scatterers (dust, particulates, bugs, etc.)



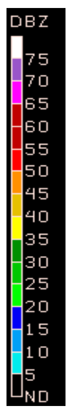
–good for snow detection

v) Precipitation Mode

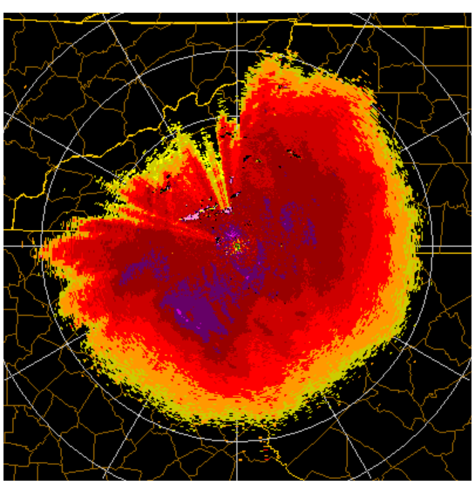
–faster antenna rotation

–9-14 elevation scans in 5-6 minutes

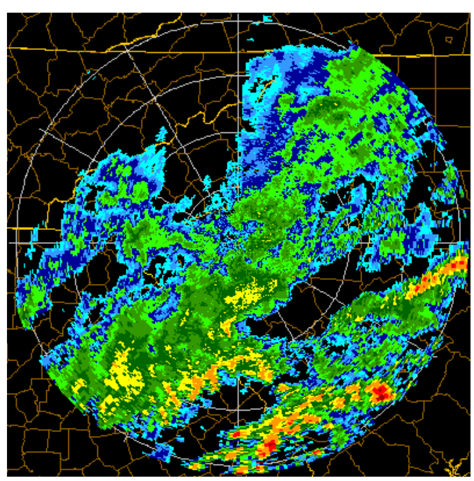
–less sensitive than clear-air mode



–good for precipitation detection/intensity determination



Clear-Air Mode



Precipitation Mode

- The scale of dBZ values is also related to the intensity of rainfall.

- Typically, light rain is occurring when the dBZ value reaches 20.
  The higher the dBZ, the stronger the rain rate.

7. RADAR TYPES:
   a. **Base reflectivity**- images are available at several different elevation angles (tilts) of the antenna and are used to detect precipitation, evaluate storm structure, locate atmospheric boundaries and determine hail potential.

      –single elevation angle scan (5-14 available)

      –useful for precipitation detection/intensity

•Usually select lowest elevation angle for this purpose

–high reflectivities (heavy rainfall)

•usually associated with thunderstorms

•strong updrafts (larger raindrops)

•large raindrops have higher terminal velocities

•rain falls faster out of cloud (higher rainfall rates)

•hail contamination possible > 50 dBZ

   b. **Composite reflectivity-**this display is of maximum echo intensity (reflectivity) from any elevation angle at every range from the radar. This product is used to reveal the highest reflectivity in all echoes.

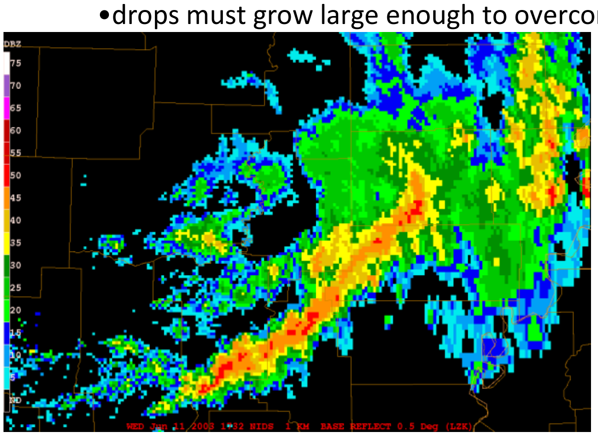
•Composite Reflectivity

–shows highest reflectivity over all elevation scans

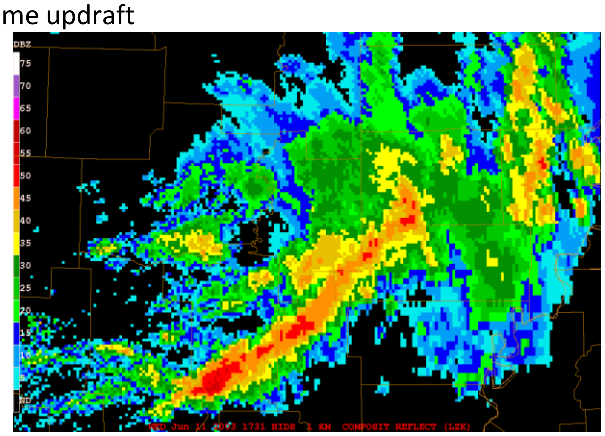
–good for severe thunderstorms

•strong updrafts keep precipitation suspended

•drops must grow large enough to overcome updraft



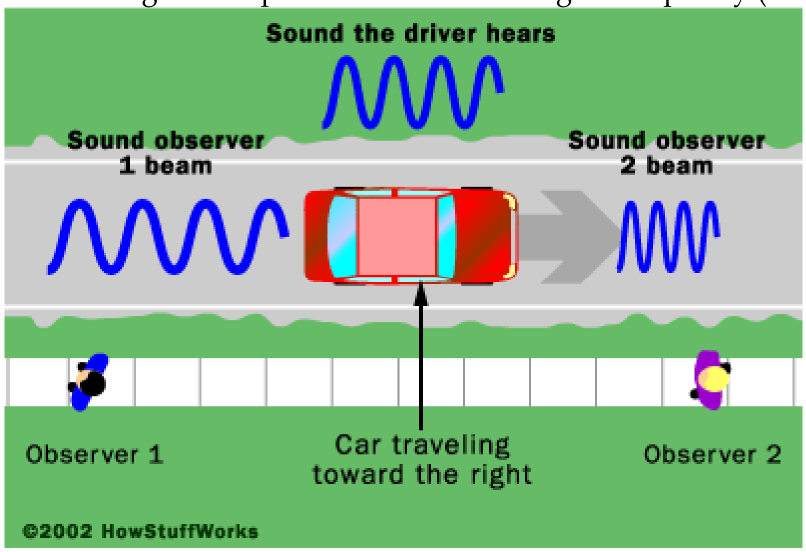
Base Reflectivity

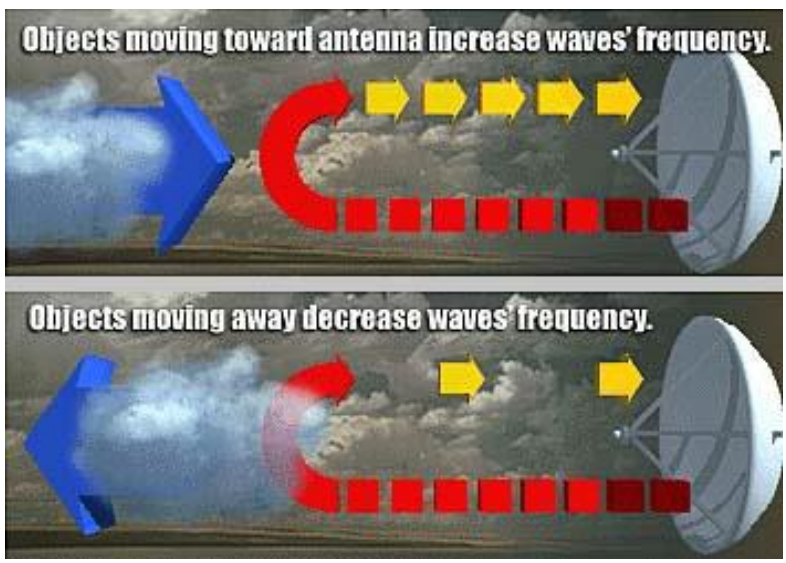


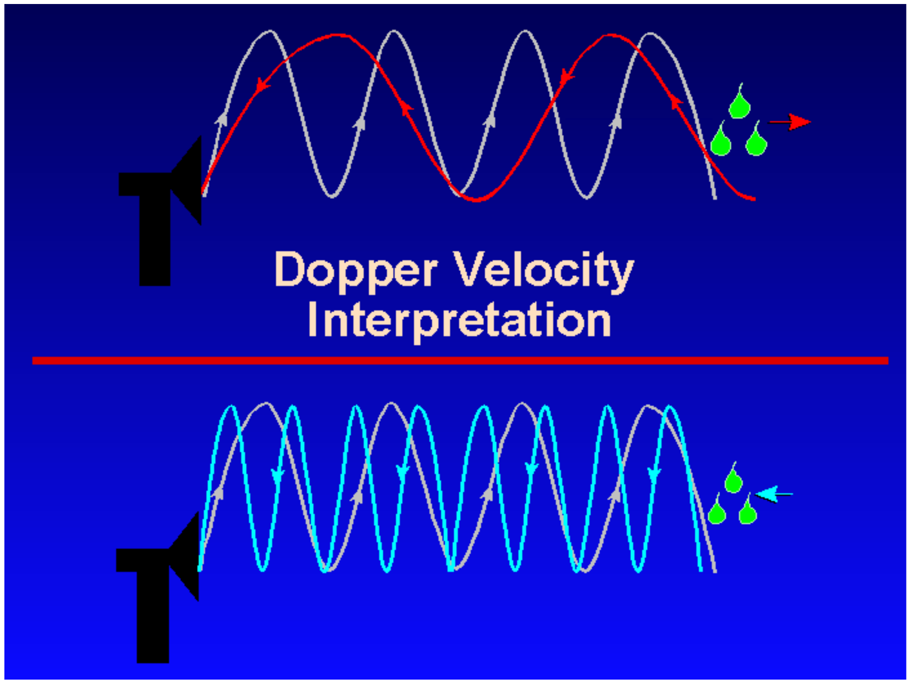
Composite Reflectivity

8. Doppler Effect

- Based on frequency changes associated with moving objects
- E-M energy scattered by hydrometeors moving toward/away from radar cause frequency change
- Frequency of return signal compared to transmitted signal frequency (radial velocity)







9. Doppler RADAR: Radial Velocity 1

•Hydrometeors moving toward/away from radar

–Positive values (targets moving *away* from radar)

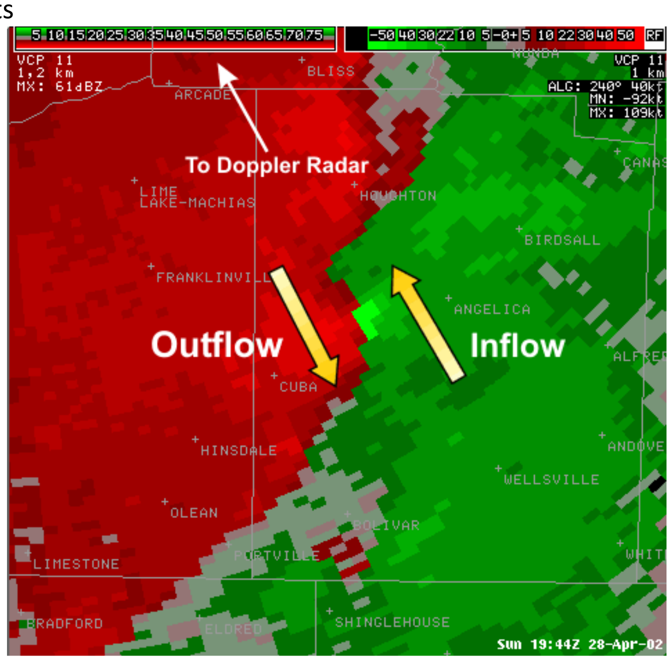
–Negative values (targets moving *toward* radar)

•Can be used to ascertain large-scale and small-scale flows/phenomena

–fronts and other boundaries

–mesoscale circulations

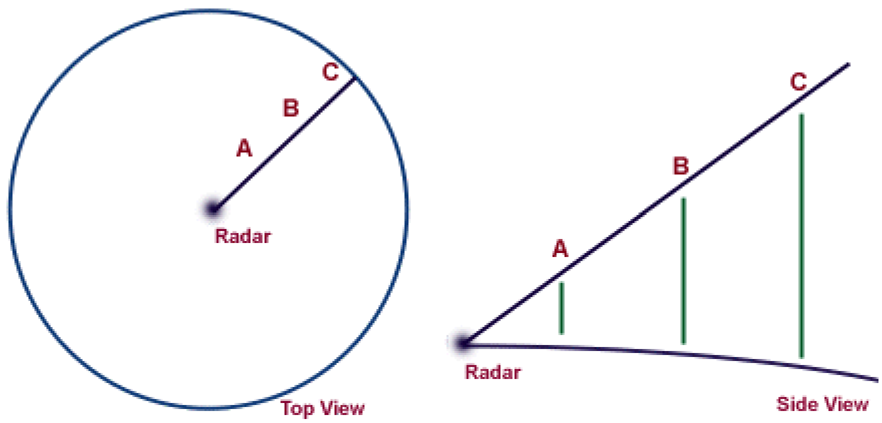
–microbursts



10. **Interpreting Doppler Radar Velocities**

speed shear wind patterns

1. To understand Doppler radial velocity patterns, one first has to consider the geometry of a radar scan. Normally the radar beam is pointed at an elevation angle greater than zero so that the beam, as it moves away from the radar, moves higher and higher above the surface of the earth. Because of this geometry, radar returns originating from targets near the radar represent the low-level wind field, while returns from distant targets represent the wind field at higher levels.



2. On a radar PPI display, the distance away from the radar at the center of the display represents both a change in horizontal distance and a change in vertical distance. To determine the wind field at a particular elevation above the radar, one must examine the radial velocities on a ring at a fixed distance from the radar. The exact elevation represented by a particular ring depends upon the elevation angle of the radar beam.

3. In the examples below, idealized Doppler radial velocity patterns were constructed with a computer assuming simple vertical wind field patterns. These simplified radial velocity patterns can help us understand the more complicated patterns that are associated with storm motions. Doppler velocity patterns (right) correspond to vertical wind profiles (left), where the wind barbs indicate wind speed and direction from the ground up to 24,000 feet. Negative Doppler velocities (blue-green) are toward the radar and positive (yellow-red) are away. The radar location is at the center of the display.

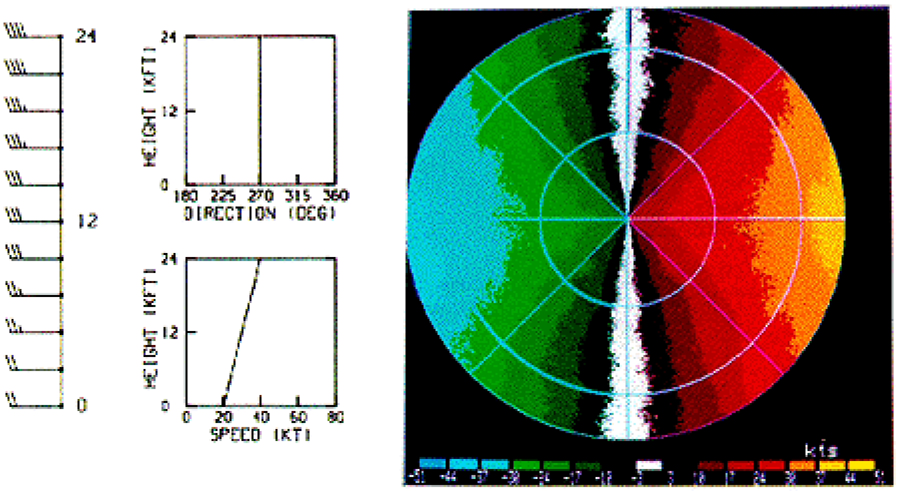


Image by: [Brown & Wood]

a. . For this first example, wind direction is constant with height, but wind speed increases from 20 knots at the ground to 40 knots at 24,000 feet. Note on the radial velocity field that the maximum inbound velocity is to the west and maximum outbound to the east while to the north and south the radar measures zero radial velocity. This is because the winds are perpendicular to the radar beam when viewed to the north or south.

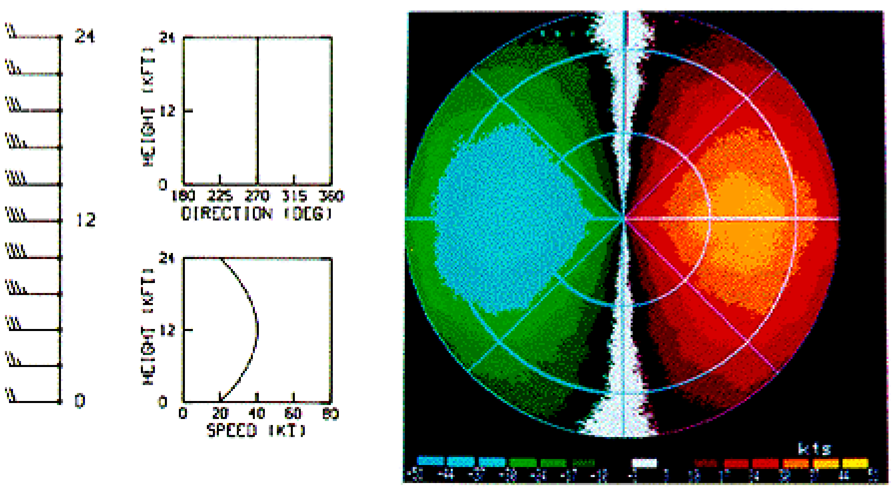


Image by: [Brown & Wood]

b. In the second example, the winds increase from 20 to 40 knots between zero and 12,000 feet and then decrease again to 20 knots at 24,000 feet. The wind direction again is constant. The radar beam intersects the 12,000 foot level along a ring half-way across the radar display. This is where we see the maximum inbound and outbound velocities.

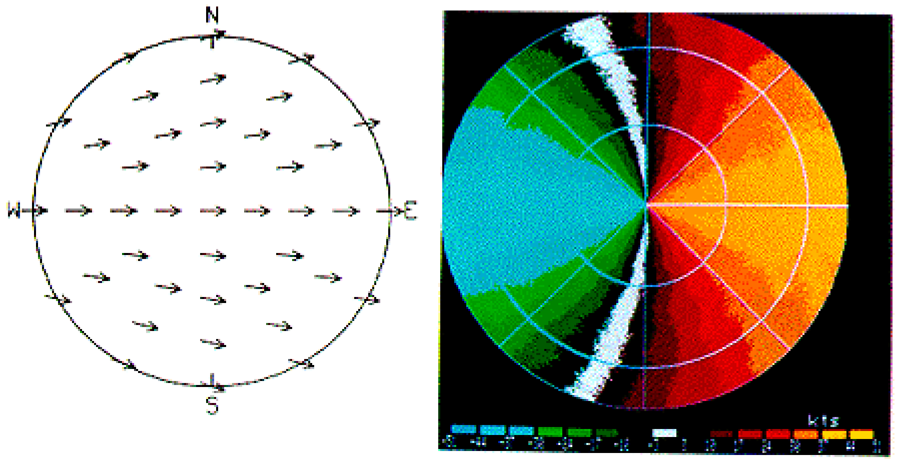


Image by: [Brown & Wood]

c. In the third example, we see a wind field which changes direction from north to south but has a constant speed at all heights. The zero radial velocity line now bends so that it is everywhere perpendicular to the wind field. The maximum radial velocities are observed where the radar beam points directly toward or away from the wind direction.

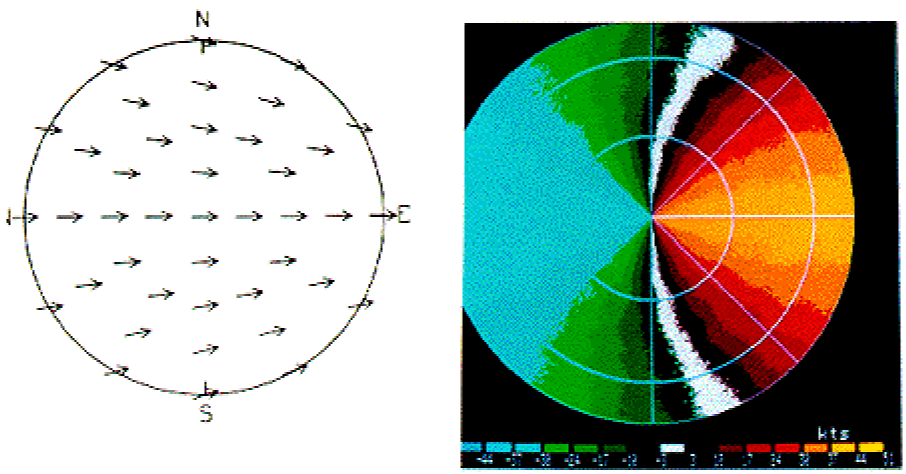


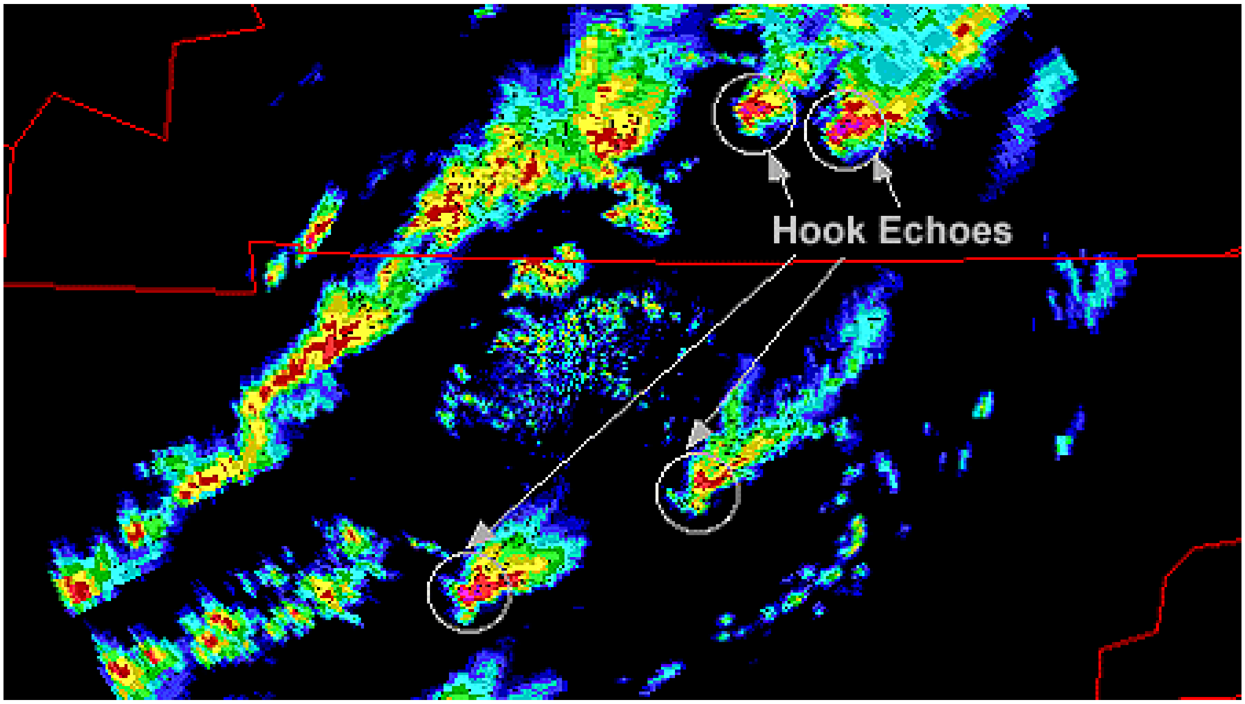
Image by: [Brown & Wood]

d. In our fourth example, we see the same effect but in this case, the flow is confluent instead of difluent.

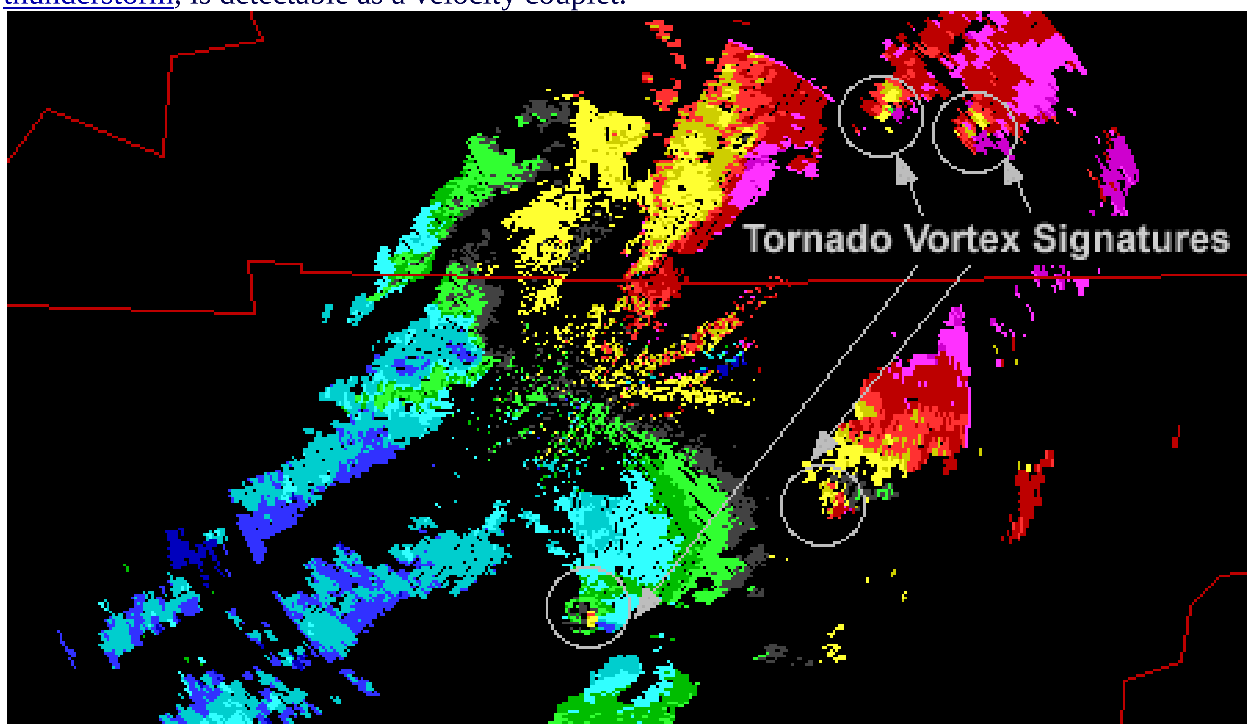
4. Locating Tornadoes

hook echoes and velocity couplets

a. Tornadoes are often located at the center of a hook-shaped echo on the southwest side of thunderstorms. The hook is best observed in the reflectivity field. This image shows a reflectivity field containing several hook echoes associated with thunderstorms that occurred in Tennessee and Kentucky on May 18, 1995.



Another way to determine if a storm is tornadic is to examine the radial velocity field. A mesocyclone, the small rotating circulation with its center beneath the updraft of a supercell thunderstorm, is detectable as a velocity couplet.



The couplet is oriented so that a concentrated area of radial winds moving away from the radar appears on one side of the beam axis, while a concentrated area of radial winds moving toward the radar appears on the opposite side of the beam axis. When the central pixels near the beam axis show exceptionally strong winds, this signature is called a tornado vortex signature (TVS). This image shows the TVS in the velocity field from the same Tennessee and Kentucky storms. Negative values (blue-green) denote movement toward the radar and positive values (yellow-red) represent movement away from the radar.

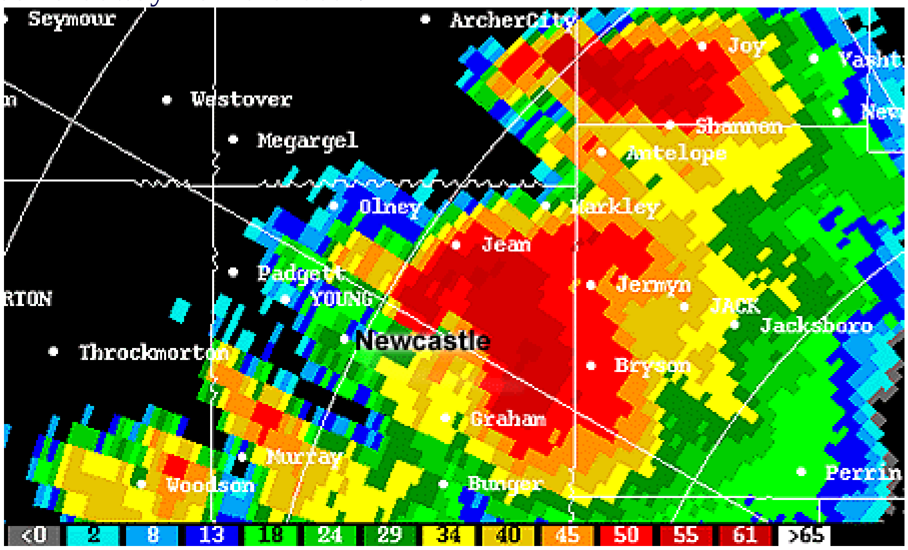


Image provided by: NSSL

Here is the reflectivity field from a storm which produced a tornado in Texas on May 29, 1995. The hook echo in the reflectivity field is located near Newcastle.

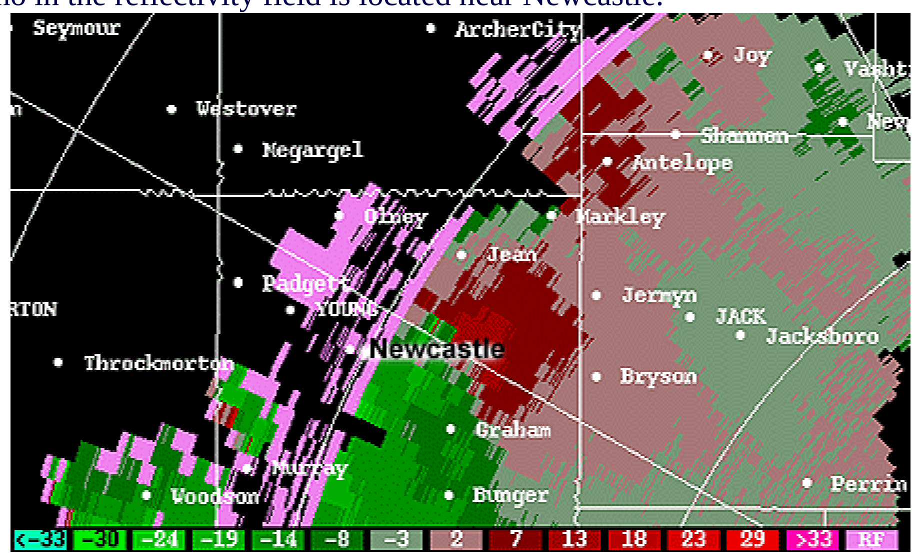


Image provided by: NSSL

Here is the velocity couplet associated with the Newcastle hook echo (red and green pixels adjacent to each other).