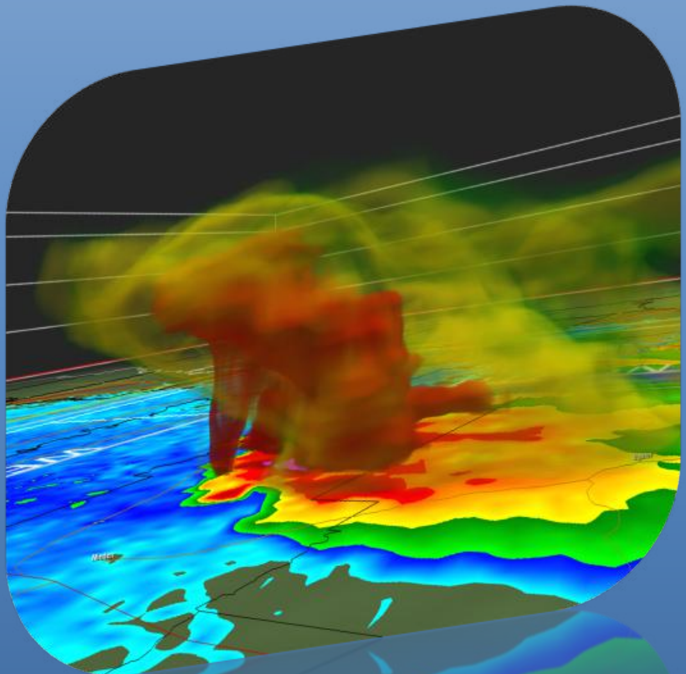
Radar & Satellite: Basics & Interpretation



A Weather Workout ⚡💪🏾
presented by:

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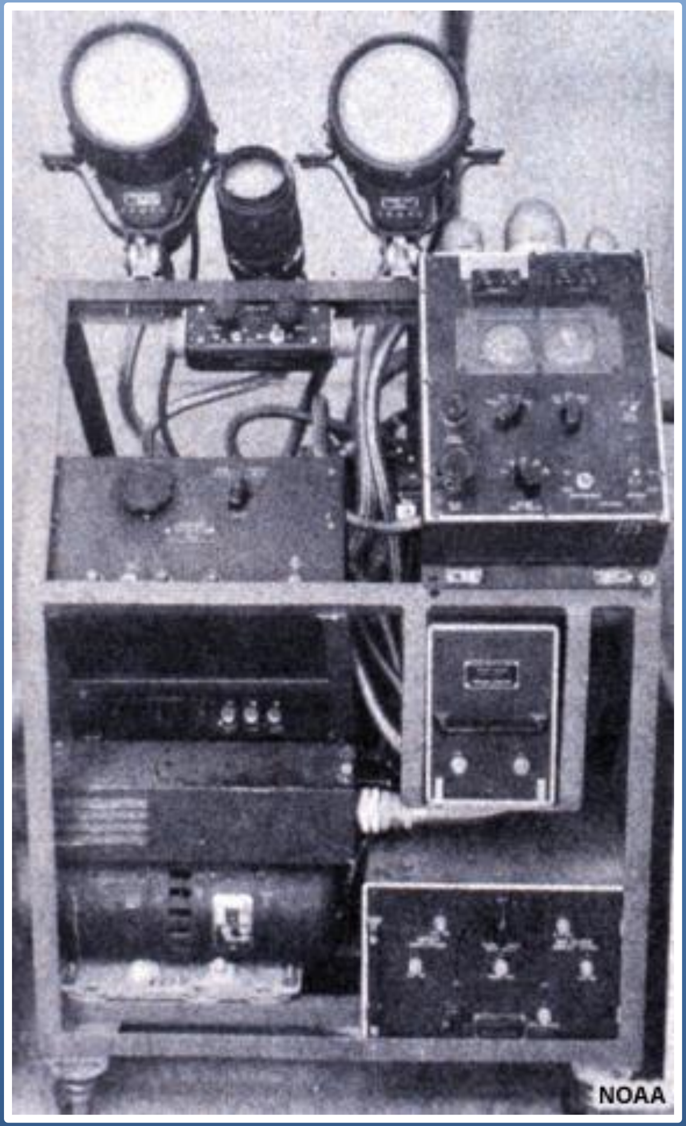
Development of Radar

- Radar technology has been used since World War II
- Military personnel tracking enemy aircraft and ships discovered that precipitation also appeared on radar displays
- By the end of the war radar technology had advanced considerably, and scientists began using surplus radars to study and monitor weather features.

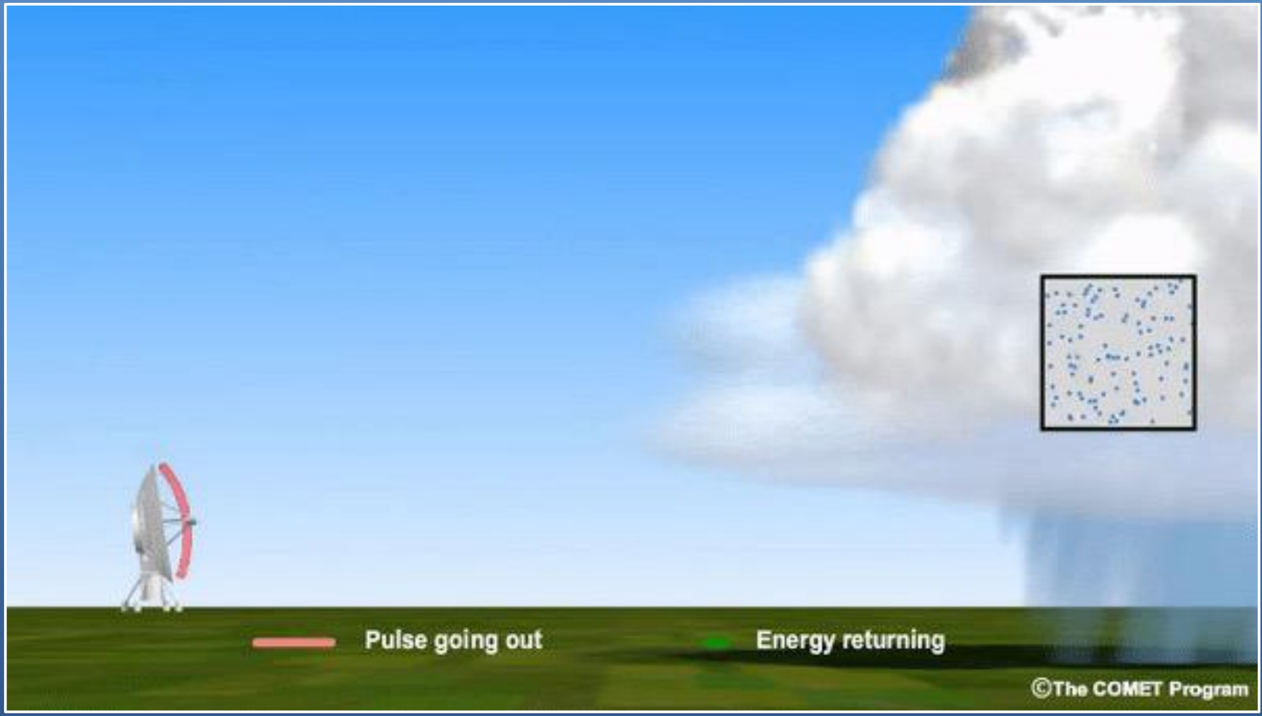


What is Radar?

- RAdio Detection And Ranging (Radar), is used to detect precipitation and thunderstorms
- Radar enhancements have enabled NWS forecasters to examine storms with more precision
- The radar used by the National Weather Service is called the WSR-88D, which stands for Weather Surveillance Radar - 1988 Doppler (the prototype radar was built in 1988).

How It Works

- A beam of energy, called a radio wave, is emitted from an antenna
- As it strikes objects in the atmosphere, the energy is scattered in all directions with some of the energy reflected directly back to the radar
- The larger the object, the greater the amount of energy that is returned to the radar
- That provides us with the ability to "see" rain drops in the atmosphere

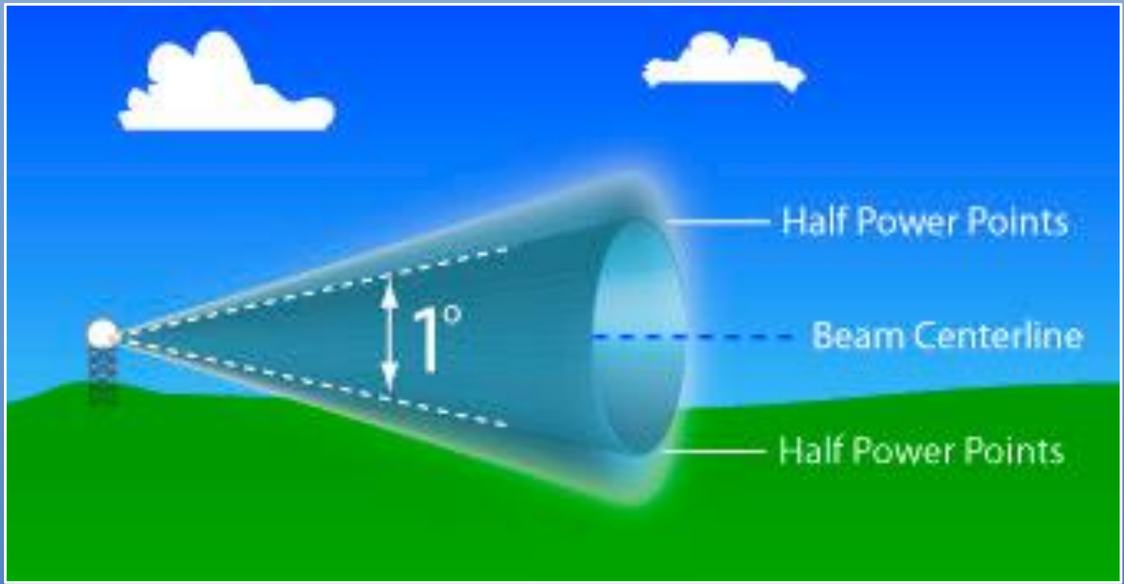


Radar Beam

- A conical shaped beam is formed as the energy moves away from the radar, with most of the energy near the center line of the beam then decreasing away from the centerline

- We define the width of the beam as the distance between the two half power points - the point where there is a 50% reduction in the radar's transmitted energy

- For the NWS Doppler radar, the angle between the two half power points is one degree; outside of the half power points, the energy rapidly decreases



- Radar beam width depends on the distance from the radar. The width of the beam expands at a rate of almost 1,000 feet (300 m) for every 10 miles (16 km) of travel.
  - At 30 miles (48 km) from the radar, the beam is approximately 3,000 feet (914 m) wide
  - At 60 miles (97 km), the beam is about 6,000 feet (1,800 m) wide
  - At 120 miles (193 km) the beam is nearly 12,000 feet (3,700 m) or over two miles (3.2 km) wide.

Radar Beam Considerations

- Beam width spreading affects the resolution capability of the radar. Small features, which can be seen close to the radar, are often obscured when viewed at great distances
- This decrease in resolution, at increasing distances, is often why a solid line of thunderstorms appears to break-up as it approaches the radar. In reality, the line of thunderstorms may have never been solid in the first place; it is just the lack of resolution of the "gaps" that causes the radar to "see" a solid line
- The spreading beam also causes differences in the appearance in the strength of storms
- Of two identical storms (same strength, height and width), one at 60 miles (97 km) and one at 120 miles (193 km) from the radar, the storm at 60 miles (97 km) will appear stronger as it fills more of the radar beam which returns more energy.

Radar Beam Considerations

- The beam also bends and does not travel in a straight line due to differences in atmospheric density, caused by variations in temperature, moisture, and pressure

- The denser the atmosphere the slower the beam travels. Conversely, the less dense the atmosphere the faster the beam travels. These changes in density can occur over very small distances so it is common for the beam to be in areas of different densities at the same time, causing it to bend in the direction of the slower portion of the wave.

- Atmospheric density naturally decreases with increasing elevation due to the decrease in air air pressure, allowing the top portion of a beam in the atmosphere to move faster than the bottom portion

Under normal atmospheric conditions, a radar beam's curvature is slightly less than the earth's curvature.

Radar Beam Considerations

- If the decrease in density with height is *more than normal* then the *beam bends less than normal* and climbs excessively skyward

- This is known as subrefraction, and causes the radar to overshoot objects that would normally be detected
  - Distant thunderstorms might not be detected with subrefraction as well as under reporting the intensity as the beam hits only the top portion of the thunderstorm cloud

- if the decrease in density with height is *less than normal* then the *beam bends more than normal* and is curved more toward the earth's surface

- This is known as superrefraction, and causes the radar beam to be closer to the earth's surface than normal
  - This can lead to overestimating the strength of a thunderstorm as the beam would be detecting more of the core of the storm versus the weaker upper levels

Radar Beam Considerations

- If the atmospheric condition that causes superrefraction bends the beam equal to or more than the earth's curvature then a condition called ducting, or trapping, occurs

- Ducting often leads to false echoes also known as anomalous propagation or simply AP.

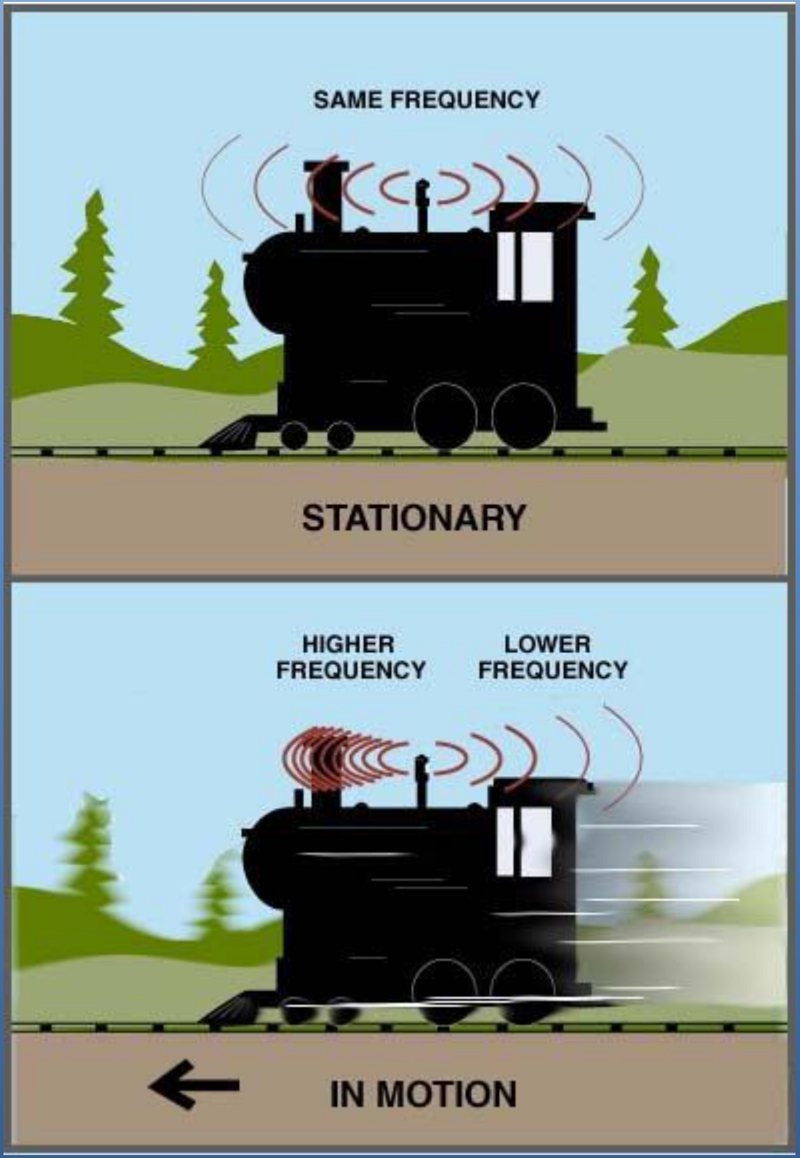
Doppler Technology

- Doppler radar systems can provide information regarding the *movement* of targets as well as their position

- When the WSR-88D transmits pulses of radio waves, the system keeps track of the *phase* (shape, position, and form) of those pulses

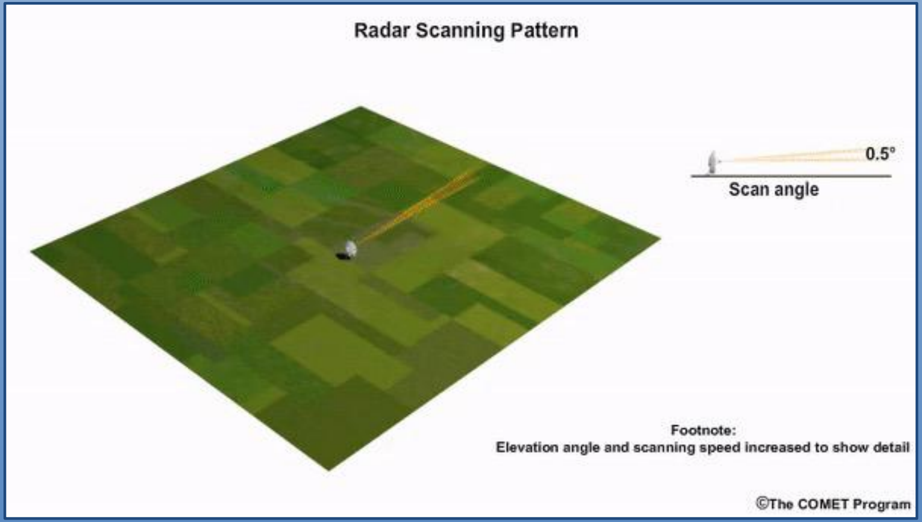
- By measuring the *shift (or change) in phase* between a transmitted pulse and a received echo, the target's movement directly toward or away from the radar is calculated

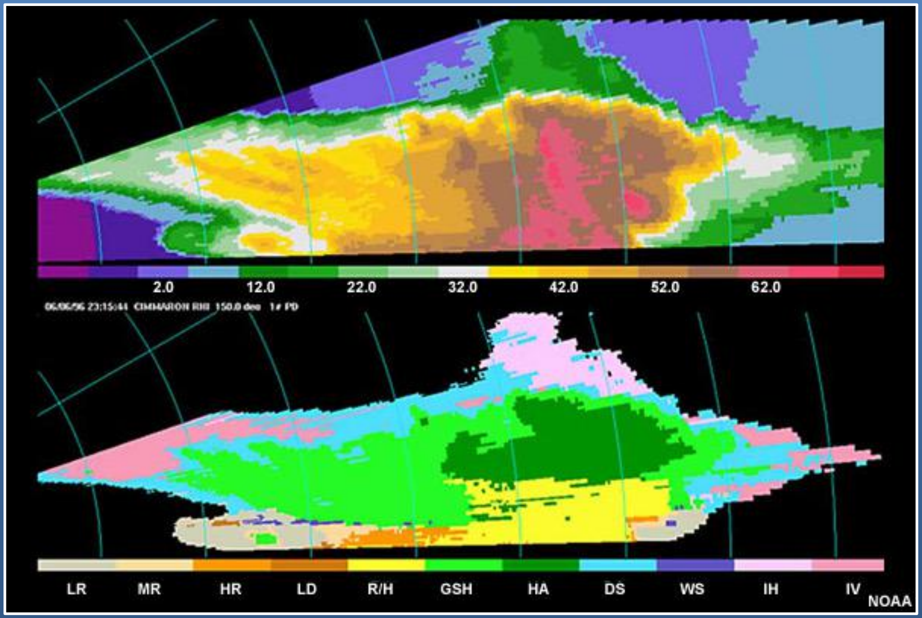
- This provides a velocity along the direction the radar is pointing, called radial velocity
  - A positive phase shift implies motion toward the radar; a negative shift indicates motion away from the radar.



Radar Scanning Techniques

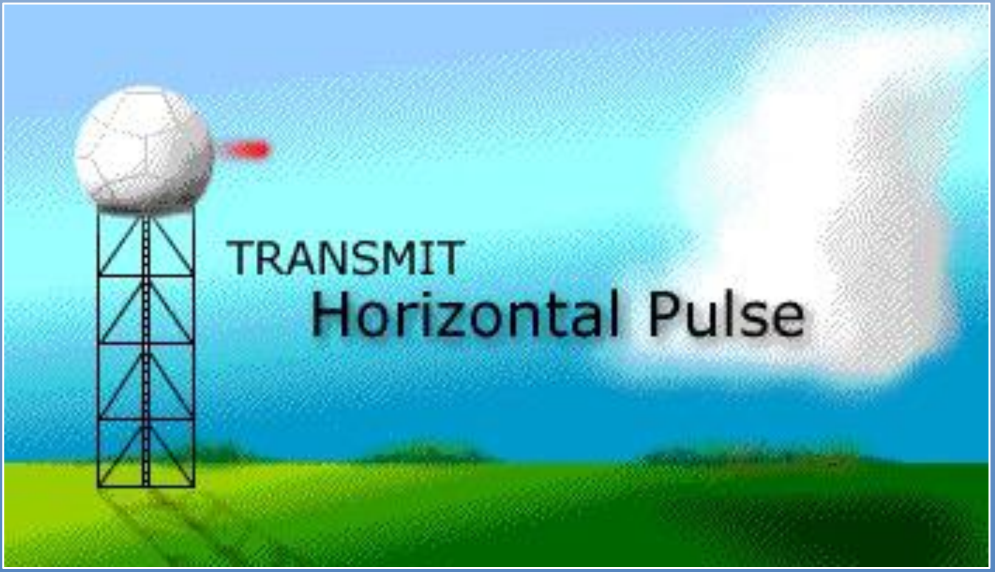
- The NWS Doppler radar employs scanning strategies in which the antenna automatically raises to higher and higher preset angles, called elevation slices, as it rotates
- These elevation slices comprise a volume coverage pattern (VCP).
- Once the radar sweeps through all elevation slices a volume scan is complete
- In precipitation mode, the radar typically completes a volume scan every 4-6 minutes, providing a 3-dimensional look at the atmosphere around the radar site.

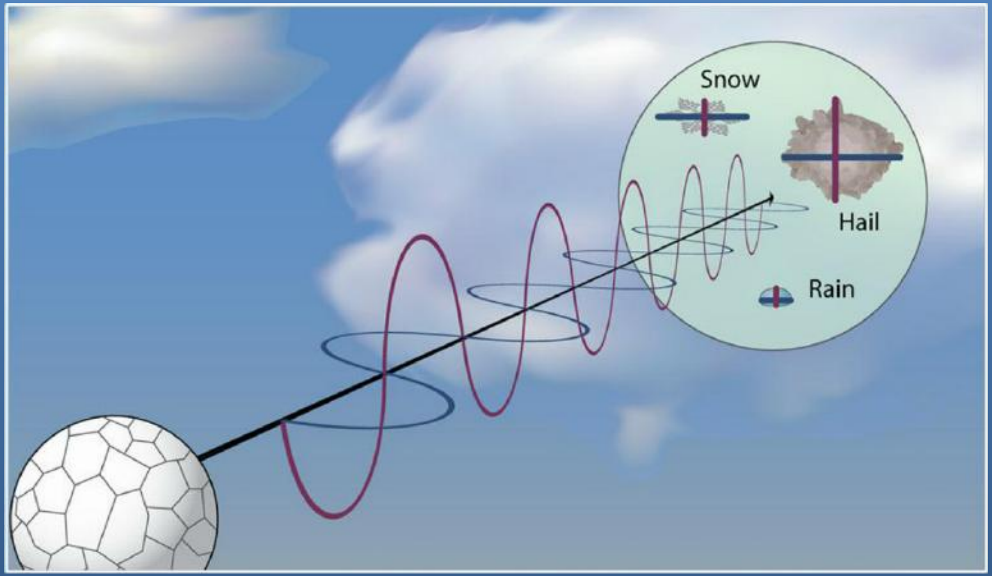




Dual Polarization

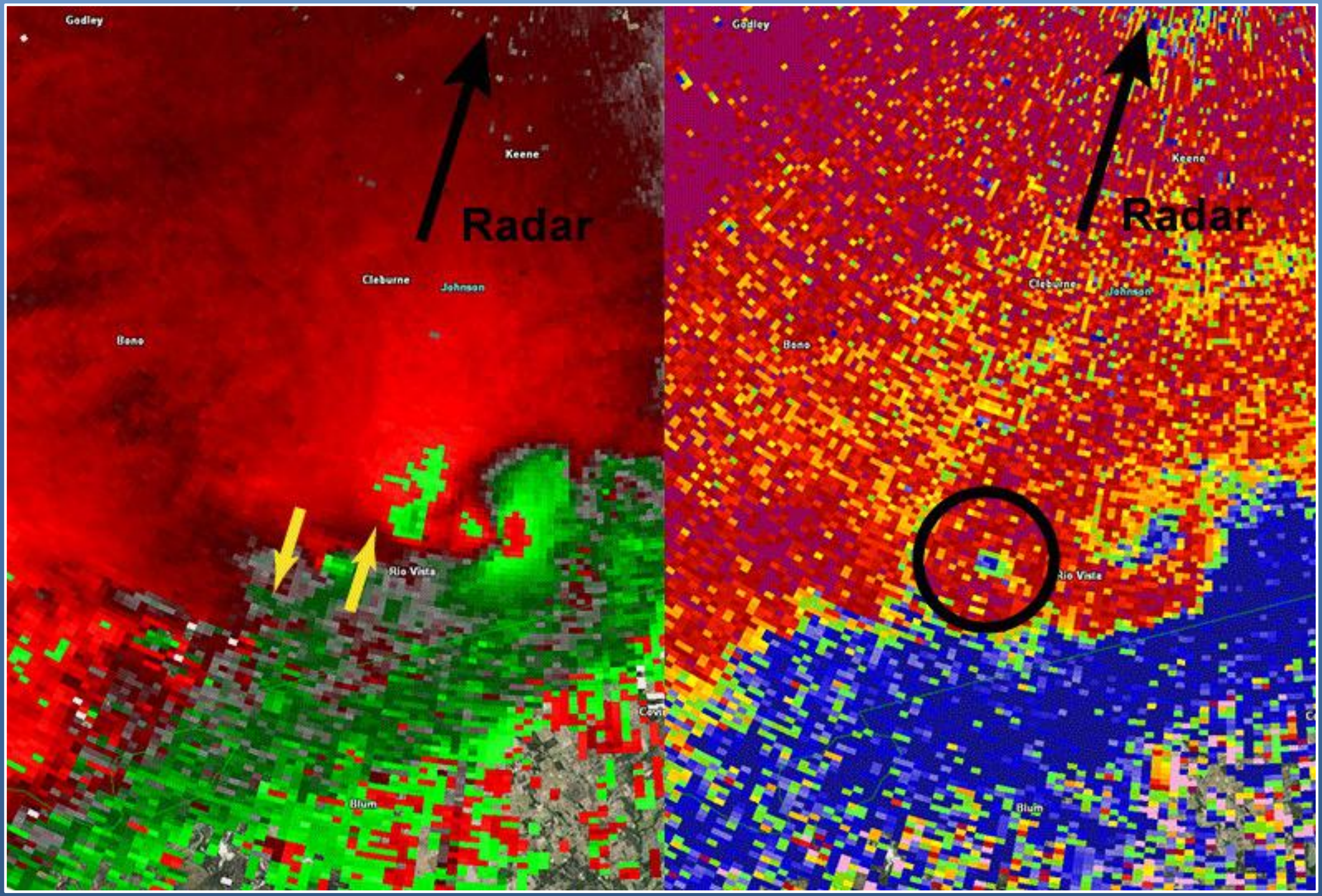
- NWS Doppler radars were upgraded to dual-polarization capability during the early 2010s
- The "dual-pol" upgrade included new software and a hardware attachment to the radar dish that provides a much more informative two-dimensional picture
- Dual-pol radar helps NWS forecasters clearly identify rain, hail, snow, the rain/snow line, and ice pellets improving forecasts for all types of weather





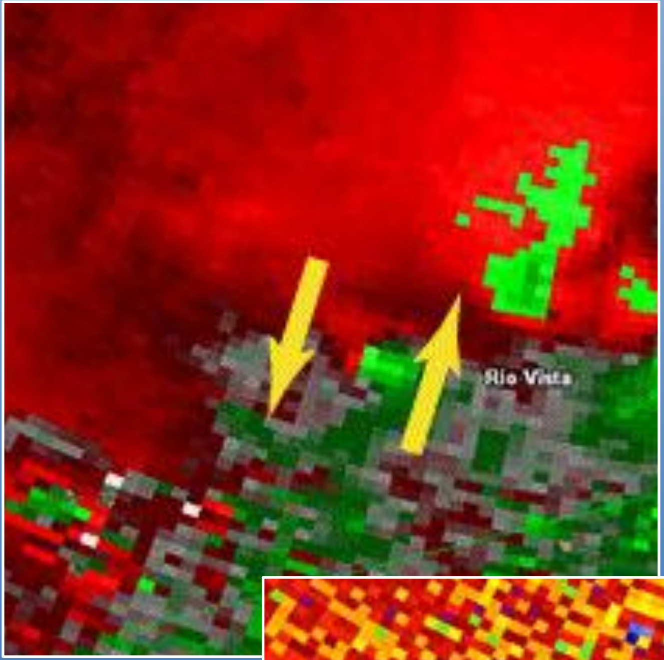
Dual-Pol Benefits

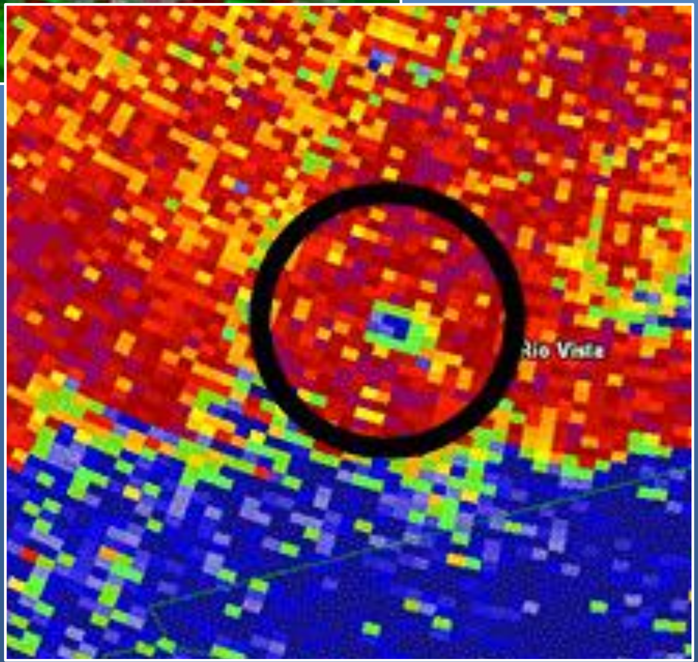
- **Another important benefit is dual-pol more clearly detects airborne tornado debris (the debris ball) - allowing forecasters to confirm a tornado is on the ground and causing damage so they can more confidently warn communities in its path**
- **This is especially helpful at night when ground spotters may be unable to see the tornado**



Dual-Pol Benefits

- These images show how dual-polarization helps the NWS forecaster detect a tornado producing damage
- The top image shows how the Doppler radar can detect rotation. Between the two yellow arrows, the red color indicates outbound wind while the green colors indicated inbound wind relative to the location of the radar
- Prior to dual-polarization, this is all we knew that there is a rotation near the earth's surface. Unless there were storm spotters visibly watching the storm, we would not know for certain that a tornado was present
- The bottom image shows how dual-polarization information helps detect debris picked up by the tornado so we have confidence of a tornado as these two areas coincide.

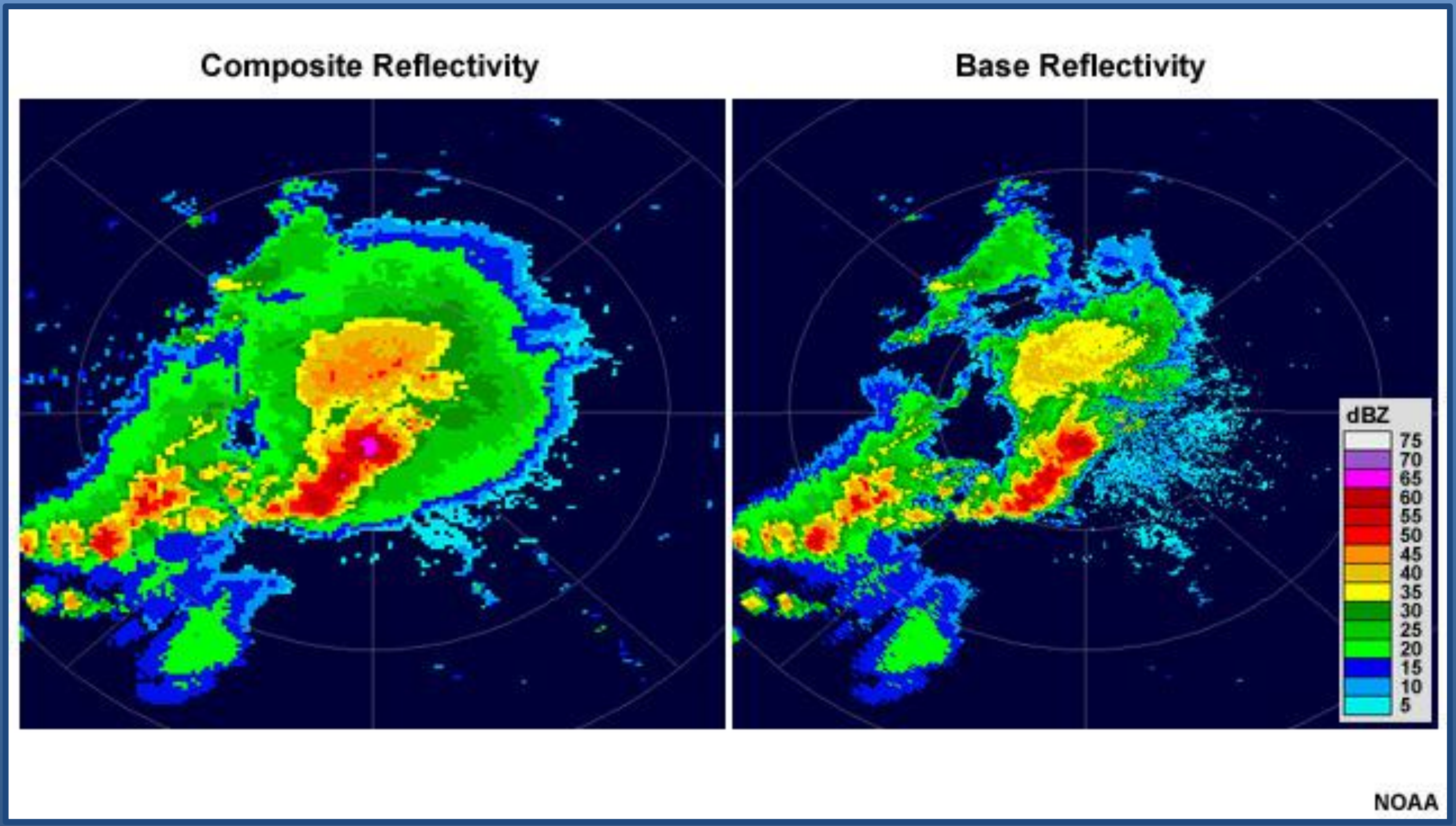




Radar Products: Reflectivity

- Reflectivity images are just as they sound as they paint a picture of the weather from the energy reflected back to the radar

- There are two types:
  1. Base Reflectivity (½° elevation)
  2. Composite Reflectivity

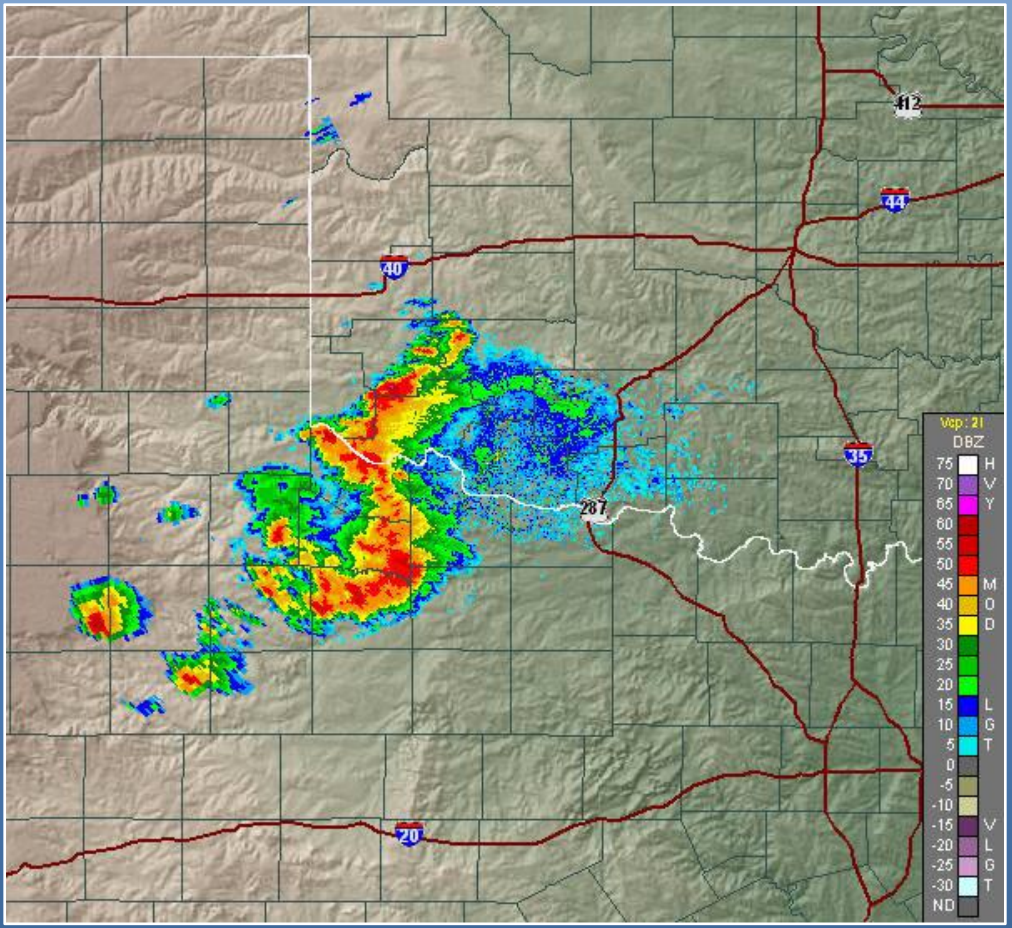


Base Reflectivity

- This image (right) is a sample base reflectivity image from the Doppler radar in Frederick, OK. The radar is located in the center of the image.

- The colors represent the strength of returned energy to the radar expressed in values of decibels (dBZ). The color scale is located at the lower right of each image.

- As dBZ values increase so does the intensity of the rainfall.
  - A value of 20 dBZ is typically the point at which light rain begins
  - The values of 60 to 65 dBZ is about the level where 1" (2.5 cm) diameter hail can occur



Base Reflectivity

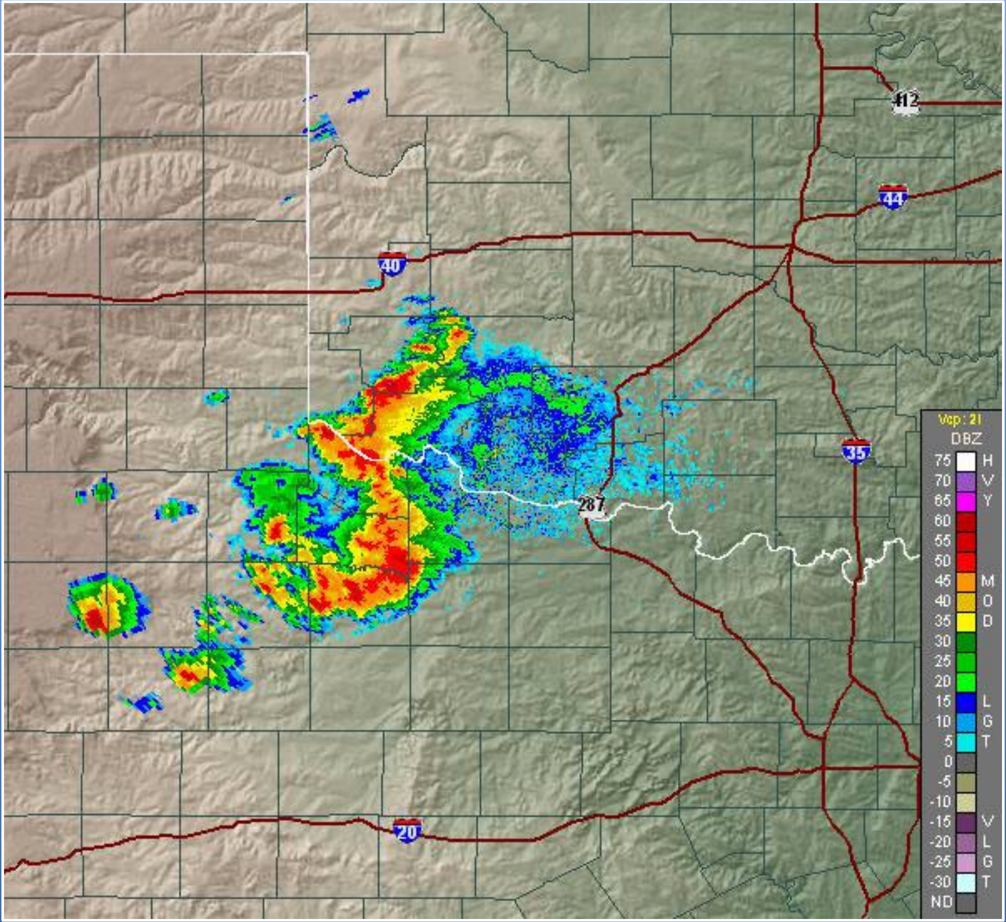
Fast Facts

The dBZ values equate to approximate rainfall rates indicated below.

dBZ to rainfall rate comparison

dBZ	Rain Rate (in/hr)	Rain Rate (mm/hr)
65	16+	420+
60	8.00	205
55	4.00	100
50	1.90	47
45	0.92	24
40	0.45	12
35	0.22	6
30	0.10	3
25	0.05	1
20	0.01	Trace
< 15	No rain	No rain

These are *hourly rainfall rates only* and are not the actual amounts of rain a location receives. The total amount of rain received varies with intensity changes in a storm as well as the storm's motion over the ground.



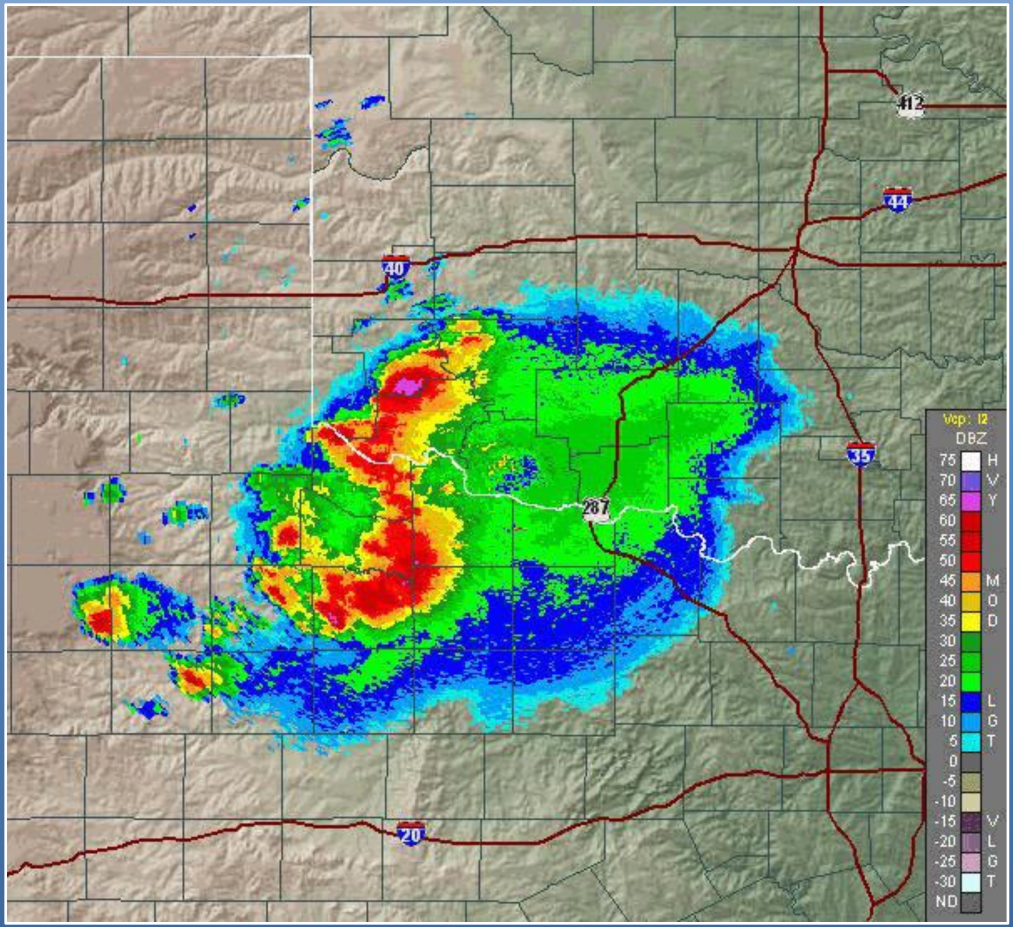
Composite Reflectivity

- When all returns from all elevation scans are compiled an image is created which takes the highest dBZ value from all elevations, called Composite Reflectivity

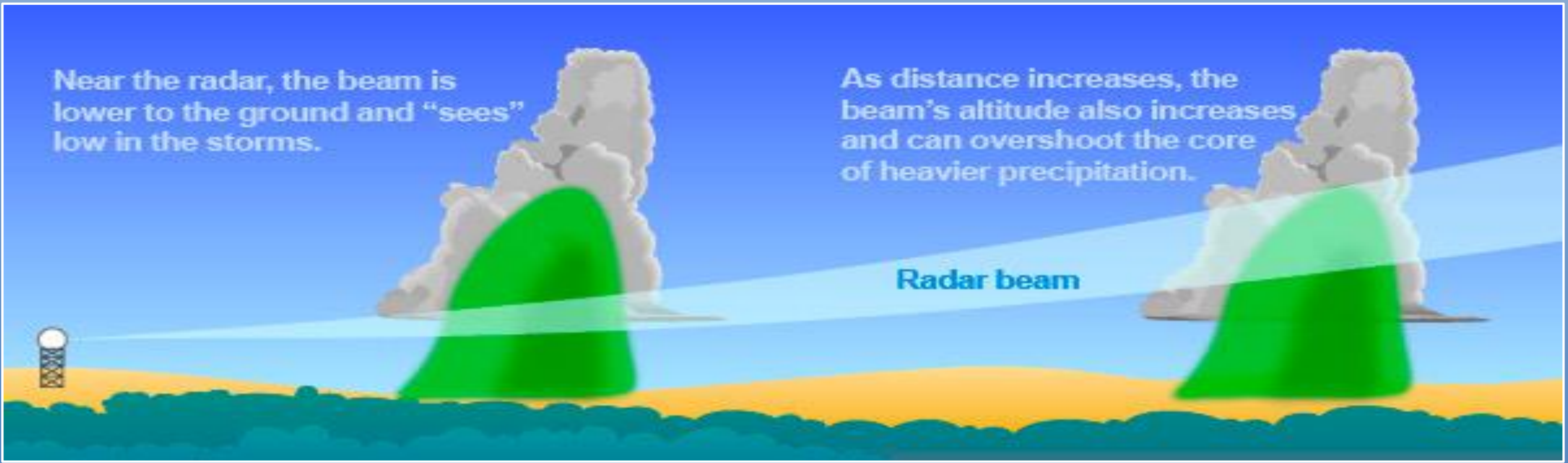
- It is a picture of the strongest returns from all elevations

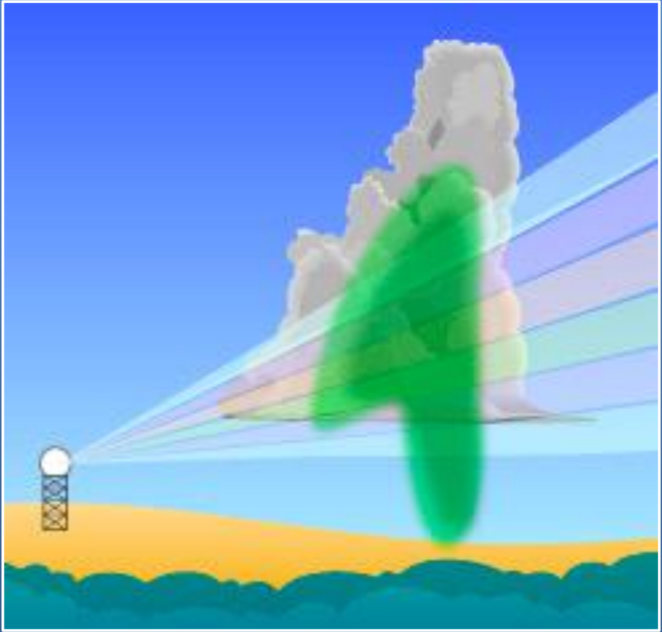
- When compared with Base Reflectivity, the Composite Reflectivity can reveal important storm structure features and intensity trends of storms

- This is important because often during the development of strong to severe thunderstorms, rain-free areas (or areas with light rain) develop as a result of strong updrafts



Base vs. Composite





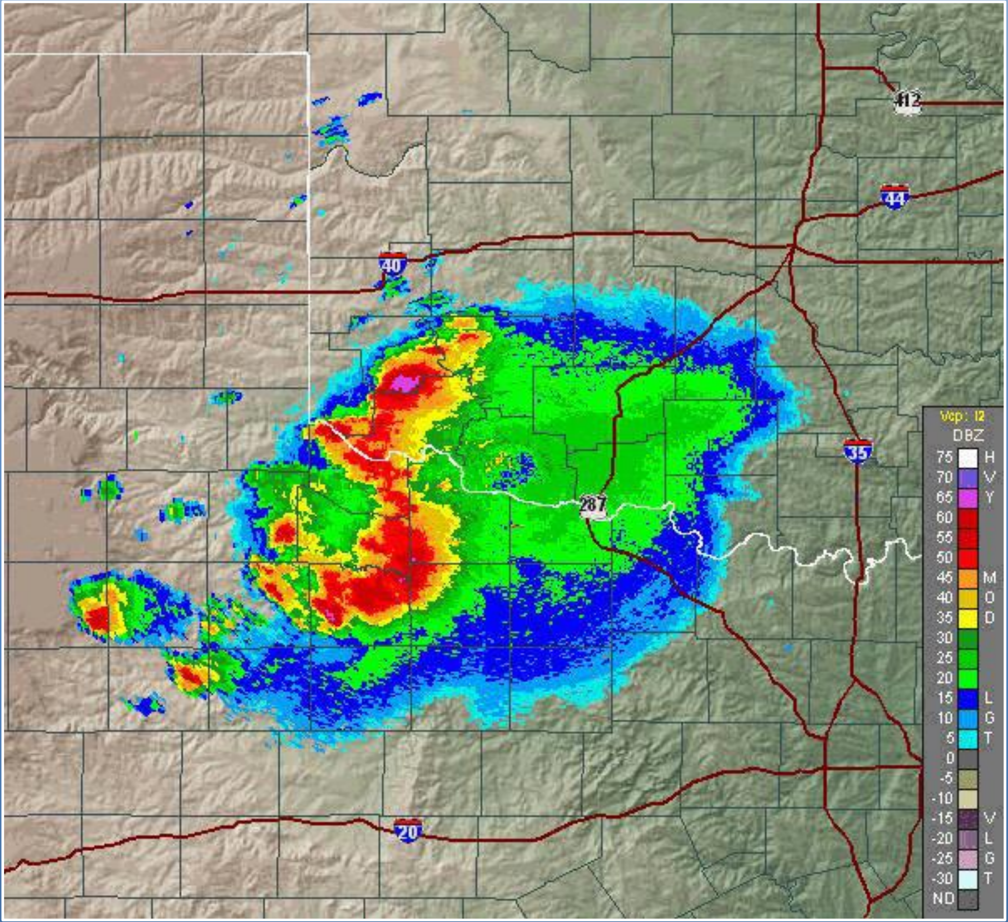
- (Top) At increasing distance, Base Reflectivity is viewing higher and higher in storms and the beam may overshoot the most intense parts.
- (Left) Composite Reflectivity looks at ALL elevation scans in order to create an image.

Base vs. Composite

- The loop to the right is a base reflectivity image from the same time as the composite view

- When higher elevation scan information is included in the composite reflectivity, it appears to indicate more widespread rain; however, the base reflectivity image does not show that rain, so it is probably not reaching the ground but evaporating as it falls from very high in the atmosphere

- Evidence of very strong updrafts can be seen when comparing the two images



- At #1, the fuchsia colored region on the composite image is not evident on the base reflectivity, which is likely hail that has yet to fall
- At #2 and #3, appear to be more rain supported by strong updrafts, but require additional interrogation to determine what is taking place at these locations which will come from the velocity products.

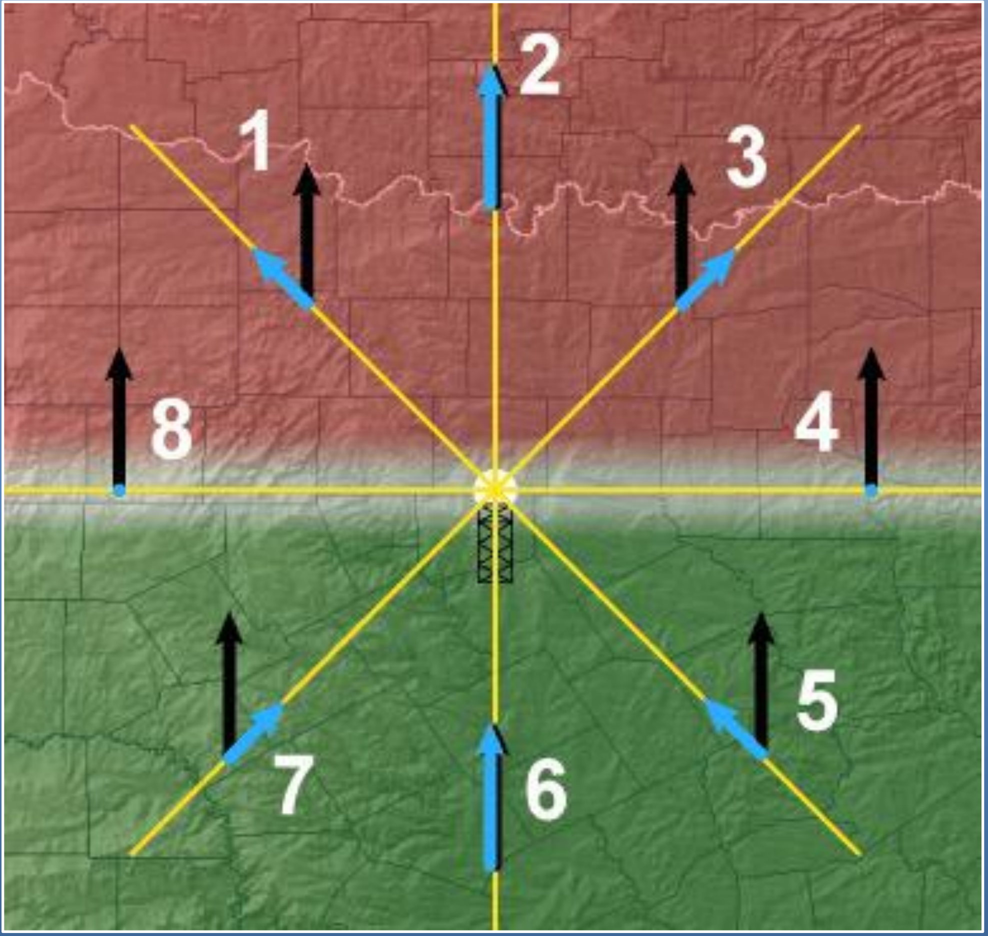
Radar Products: Velocity

- A primary advantage of Doppler radar from previous generation NWS radars is its ability to detect motion

- The motion it sees are primarily rain drops carried along by the wind but also can detect motions of insects, birds, and smoke particles

- However, the only motion it can "see" is called *radial* velocity. This motion is NOT the direction of the wind but the *portion* of the wind's motion that is moving either directly toward or away from the radar

- The motion of the wind, relative to the radar, is broken down into two components...
    1. the motion perpendicular to the radar beam and
    2. the motion along that radial (either directly toward or away from the radar)

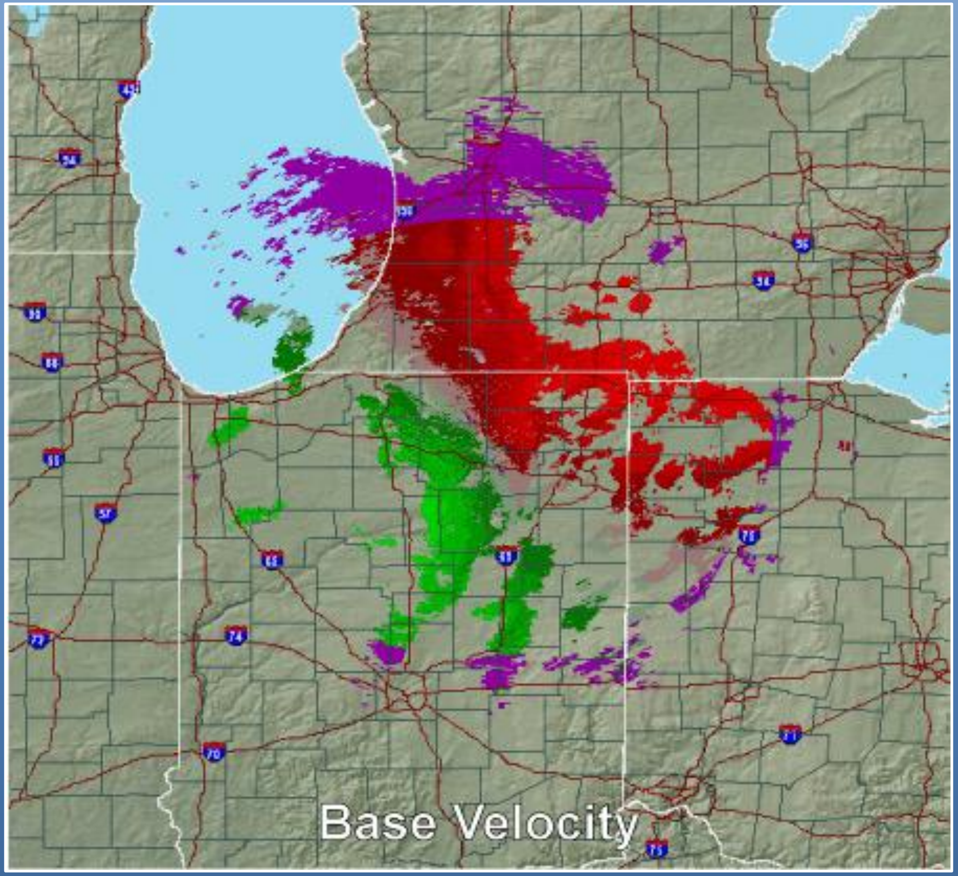


Base Velocity

- Base velocity, like Base reflectivity, provides a picture of the basic wind field from the lowest (½°) elevation scan. But to see the wind there needs to be radar "returns" before the radar can determine the velocity.

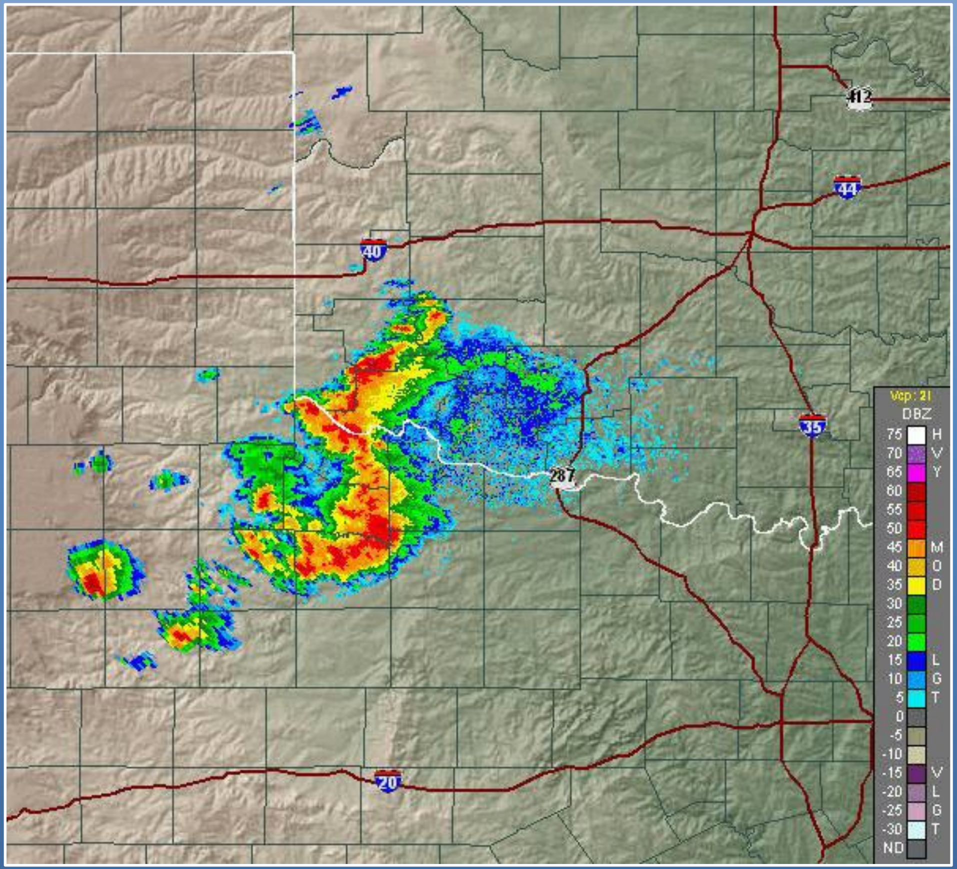
- In this comparison (right) between the Base velocity and Base reflectivity, you will notice there is hardly any velocity information outside of the areas of precipitation.
  - with precipitation, Base velocity is useful for determining areas of strong wind from downbursts or detecting the speed of cold fronts

- Remember, the radar beam elevation increases with increasing distance from the radar. Therefore, the reported value will be for increasing heights above the earth's surface.



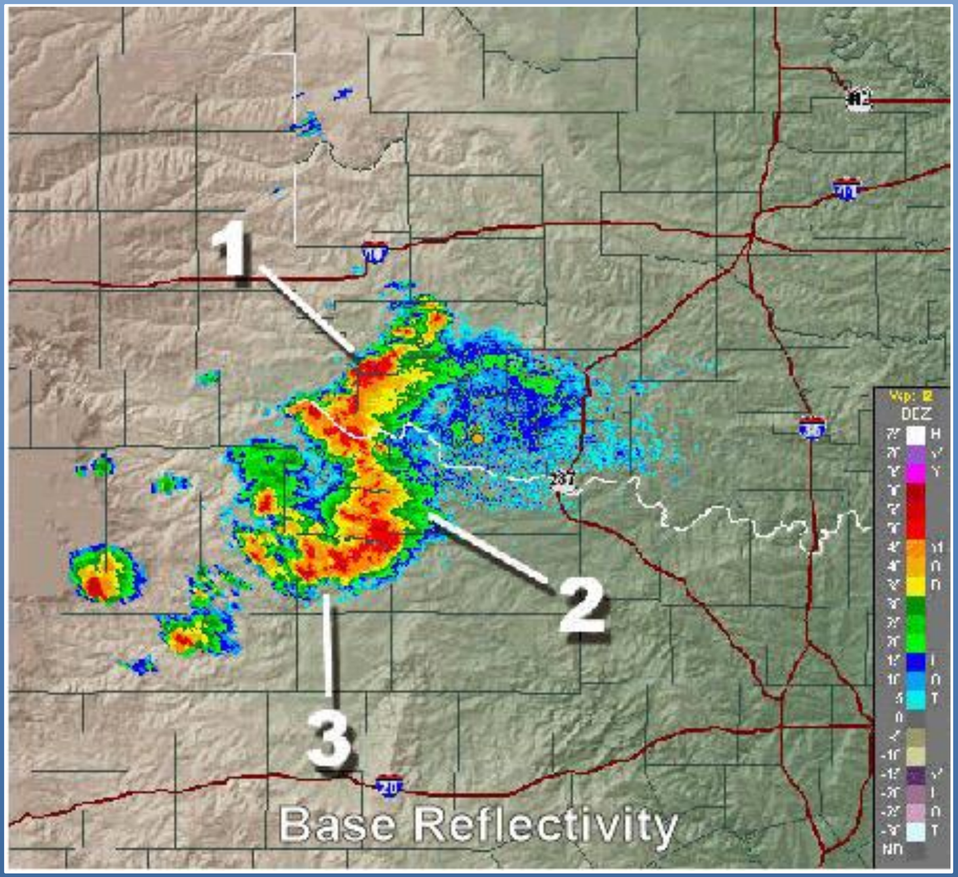
Storm Relative Velocity

- When looking for rotation in thunderstorms the overall motion of the storm can mask any storm circulation as seen in a Base velocity image
- If the overall motion of the storms is subtracted from the velocity, the wind circulation relative to the storm itself will become more evident
- Storm Relative Motion is the wind's motion as if the storm was stationary.



Base vs Storm Relative

- For small scale thunderstorm circulations, from which tornadoes often form, will typically be indicated by *strong inbound wind located along side strong outbound wind relative to the radar*
- When looking at Storm Relative Motion it is important to know where the radar is located in order to determine if there is a possible tornadic signature
- The loop (right) shows the comparison of the Base velocity and Storm Relative Motion. The yellow dot in the center of the image is the radar's' location



Next up…

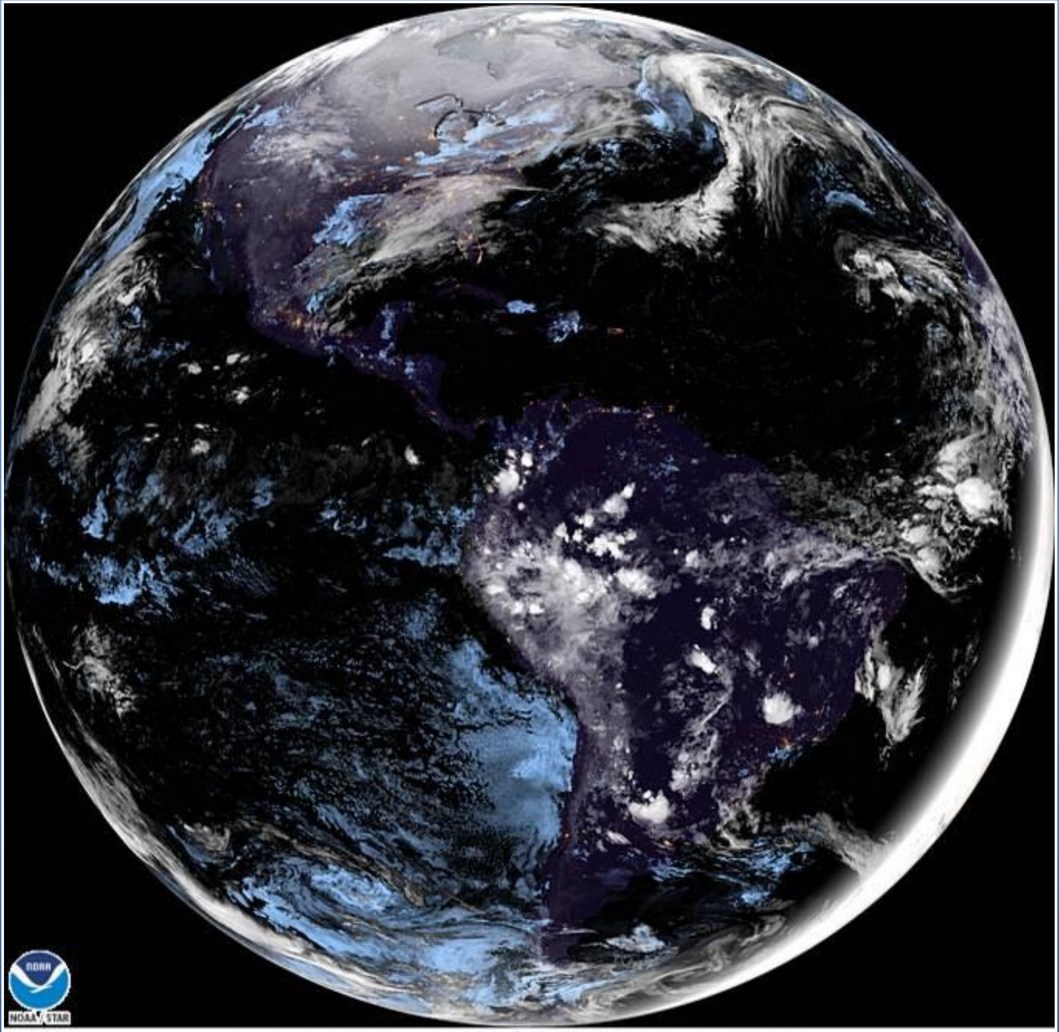
Satellites 

Satellites & Remote Sensing

- Much like radar, weather satellites obtain information about atmospheric phenomena via remote sensing

- Remote sensing via satellites provides a unique perspective from which to observe large regions

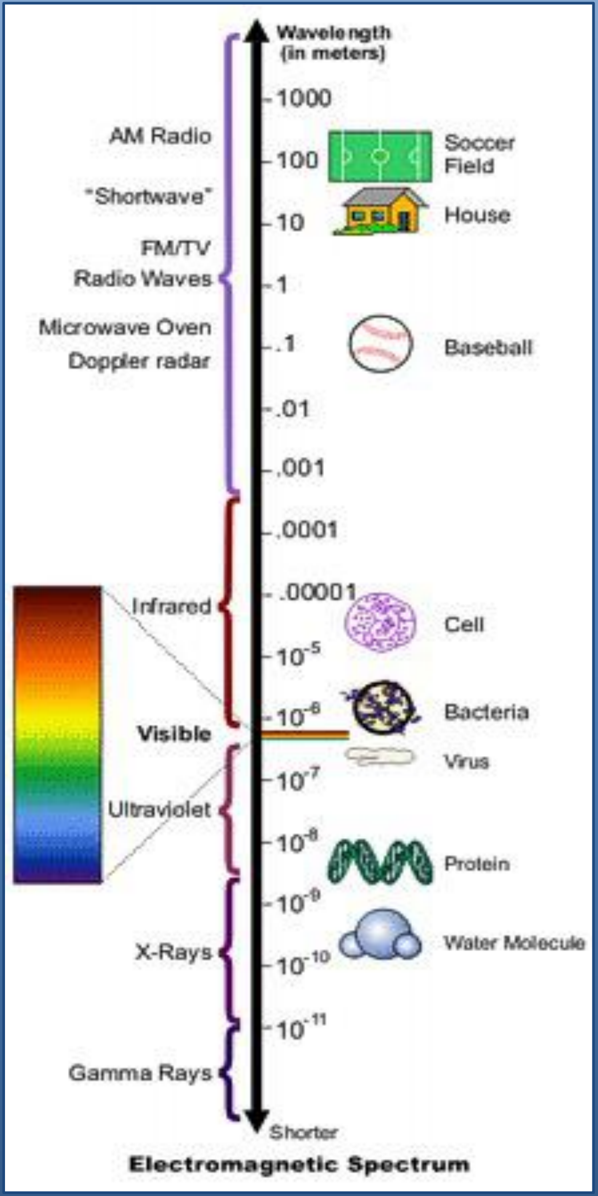
- These sensors can measure energy at wavelengths which are beyond the range of human vision.



25 Jan 2022 07:40Z NESDIS/STAR GOES-East GEOCOLOR

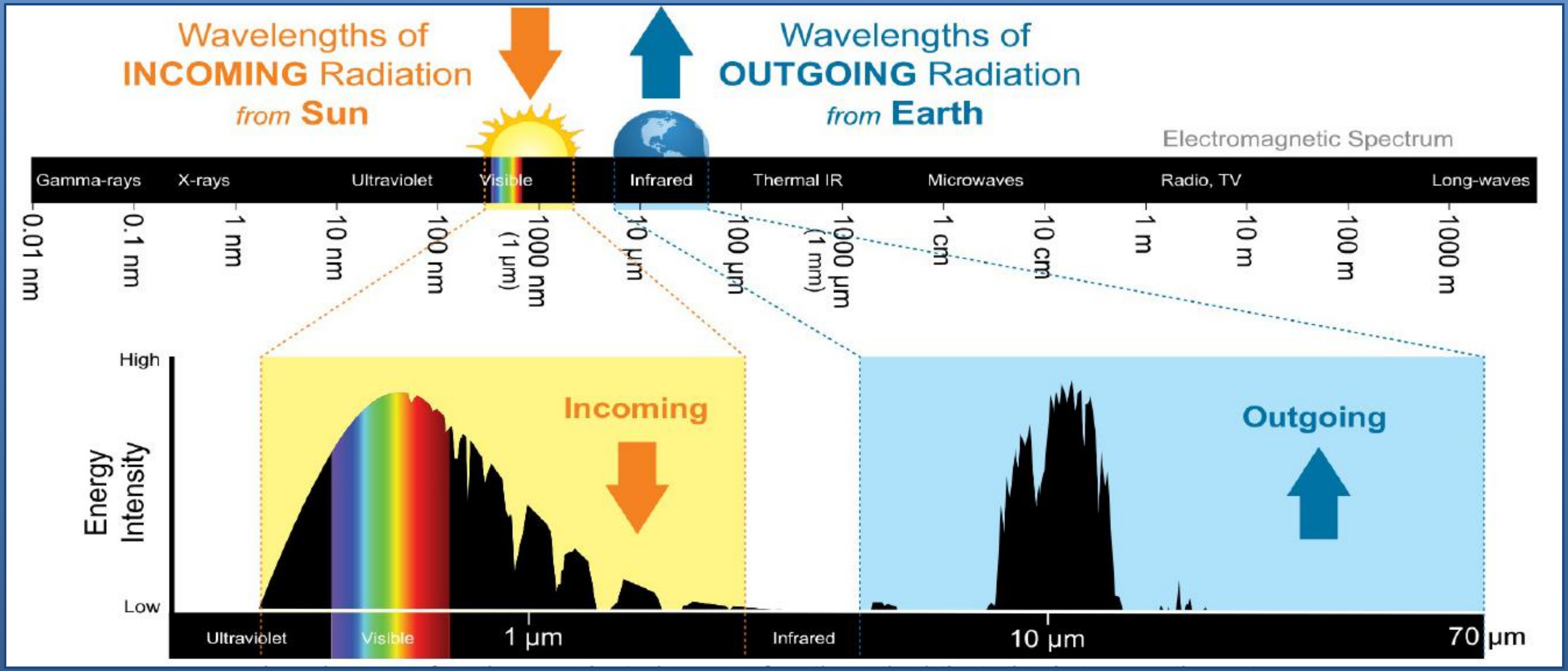
Satellites & Remote Sensing

- Electromagnetic waves are invisible forms of energy that travel though the universe
- This visible part of the electromagnetic spectrum consists of the colors that we see in a rainbow - from reds and oranges, through blues and purples.
- Each of these colors actually corresponds to a different wavelength of light
- Waves in the electromagnetic spectrum vary in size from very long radio waves the size of buildings, to very short gamma-rays smaller than the size of the nucleus of an atom
- The smaller the wavelength the higher the energy.



What Satellites Measure

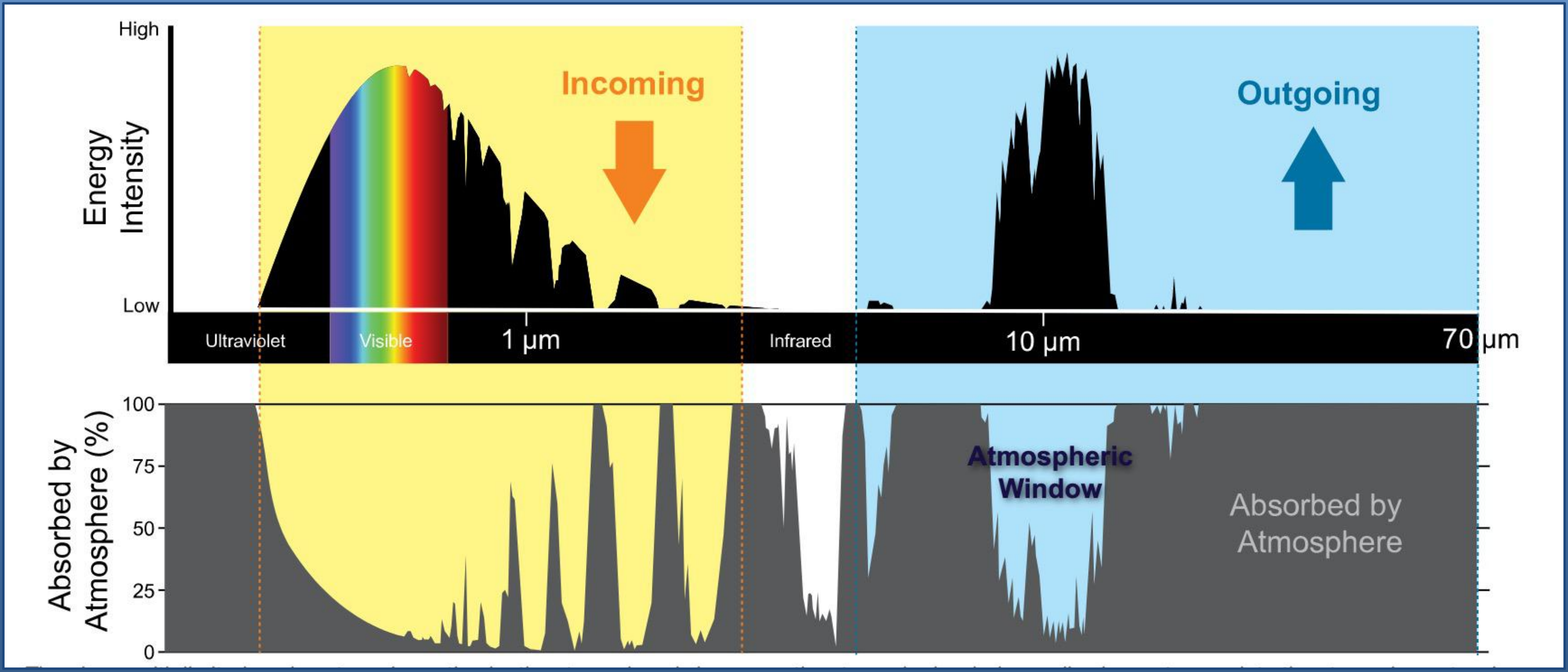
- Most of the sun's energy comes from visible light and the near infrared portion of the electromagnetic spectrum. All of the outgoing energy emitted by the earth is infrared
- The atmosphere absorbs some this energy while allowing other wavelengths to pass through



What Satellites Measure

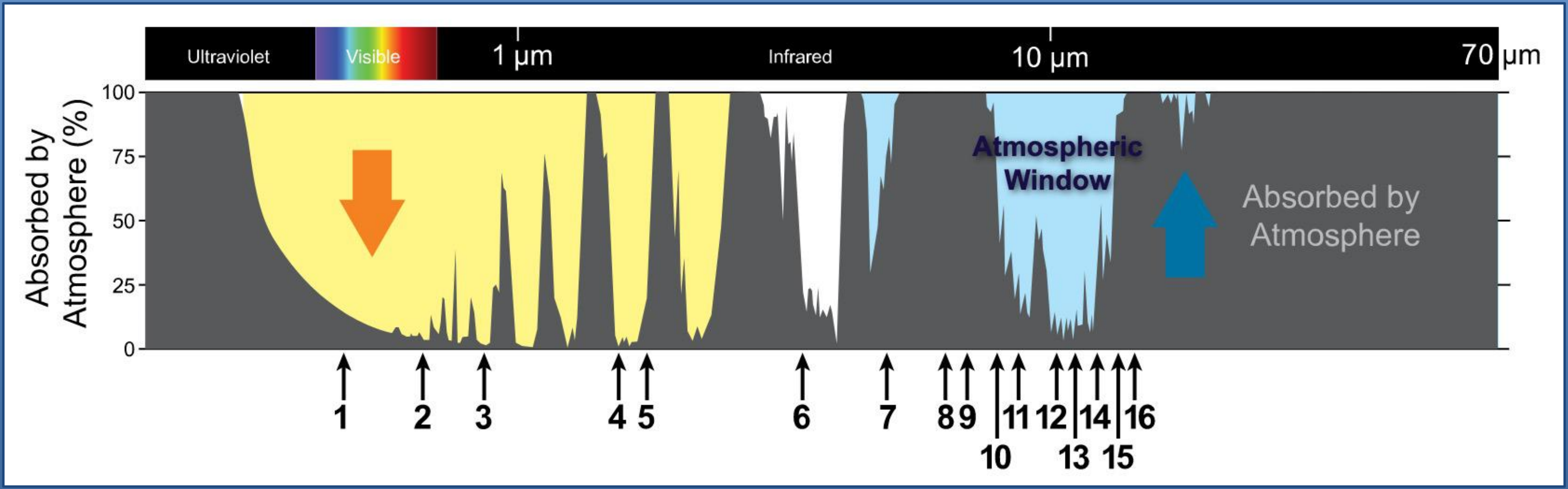
- The places where energy passes through are called "atmospheric windows". We use these "windows" in remote sensing to peer into the atmosphere from which we can obtain much information concerning the weather

- The dips in the incoming and outgoing energy are where the atmosphere absorbs energy. Some of the incoming energy is absorbed by the atmosphere whereas most of the infrared energy emitted by the earth is absorbed



What Satellites Measure

- Taking advantage of these "windows", we look at the atmosphere at various wavelengths. Each of these channels were chosen to provide different views of the earth.



Meteorological Satellite Types

Polar Orbiting Satellites

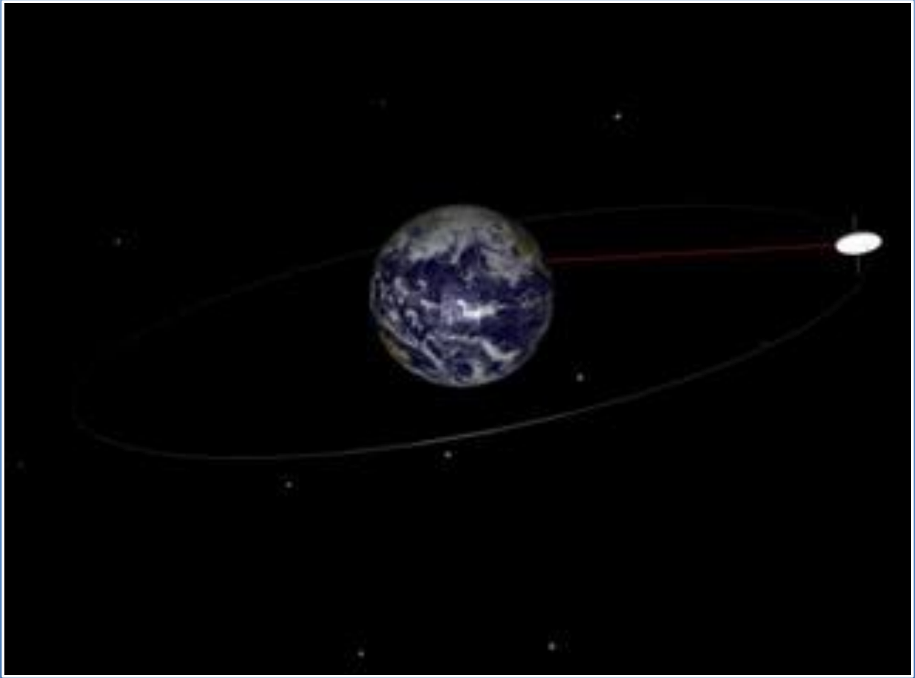
Advantages

- Closer to the earth with an orbit of about 520 miles (833 km) above the surface
- Closer orbit provides much more detailed images
- Excellent views of the polar regions

Disadvantages

- Cannot see the whole earth's surface at any one time
- The path of each orbit changes due to the earth's rotation so no two images are from the same location
- Limited to about six or seven images a day since most of the time the satellite is below the earth's horizon and out of range of listening equipment

Geostationary Satellites



Advantages

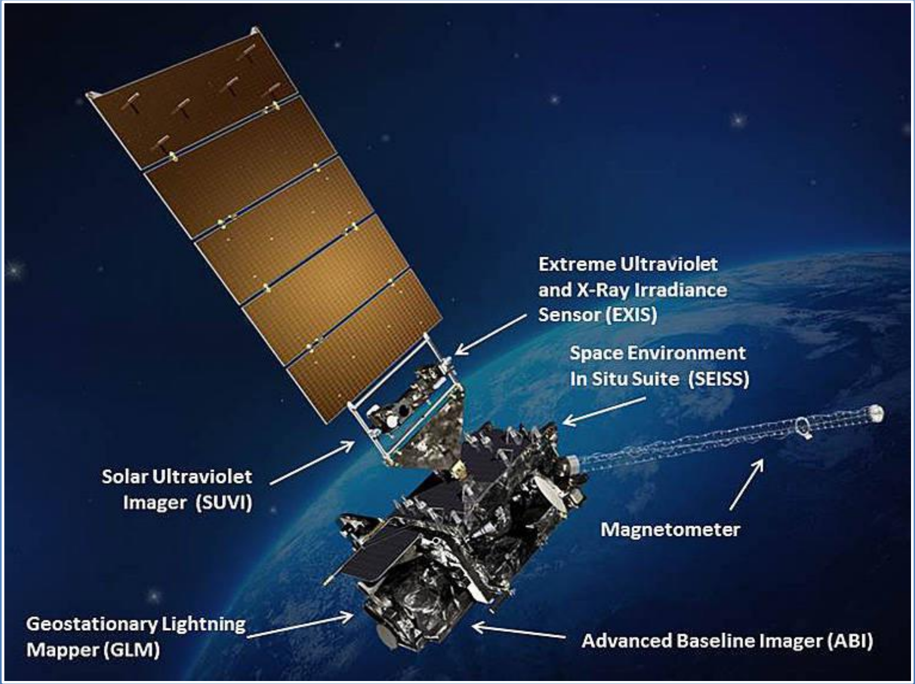
- Always located in the same spot of the sky relative to the earth
- They view the entire earth at all times
- They can record images as fast as once every minute
- Motion of clouds over the earth's surface can be computed.
- Receive transmissions from buoys and remote automatic data collection stations around the world

Disadvantages

- Their location, at 22,300 miles (35,000 km) above the Earth, provides lower detailed views
- Views of the polar regions are limited due to the earth's curvature

GOES:
Geostationary Observational Environmental Satellite

- In November 2016, the newest geostationary satellite, GOES-R, was launched
- After a year undergoing through testing, it was designated GOES-16 (GOES East) and placed in operation located over 70ºW longitude
- The next GOES-R series satellite was launched March 1, 2018. After testing it was designated GOES-17 (GOES West) and currently operates over 137ºW

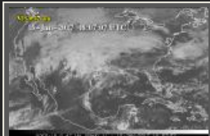


- Both GOES-16 and GOES-17 will cover the Weather Hemisphere from the West coast of Africa to as far west as New Zealand
- Two additional GOES-R series satellites will eventually be launched to help provide dedicated service through the year 2036.

ABI Spectral Bands (16)

GOES-16 Band Reference Guide

Patrick.Ayd@noaa.gov



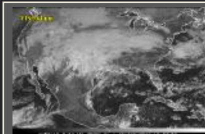
ABI Band #1

0.47 microns

Visible ("Blue Band")

Primary Uses:

- Monitoring aerosols (smoke, haze, dust)
- Air quality monitoring through measurements of aerosol optical depth



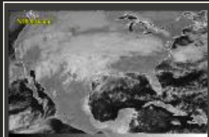
ABI Band #2

0.64 microns

Visible ("Red Band")

Primary Uses:

- Daytime monitoring of clouds (0.5-km spatial resolution)
- Volcanic ash monitoring



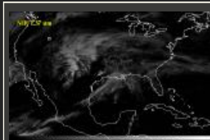
ABI Band #3

0.86 microns

Near–IR ("Veggie Band")

Primary Uses:

- High contrast between water and land
- Assess land characteristics including flooding impacts, burn scars, and hail swath damage



ABI Band #4

1.37 microns

Near-IR ("Cirrus Band")

Primary Uses:

- Thin cirrus detection during the day as the lower troposphere is not routinely sensed
- Volcanic ash monitoring

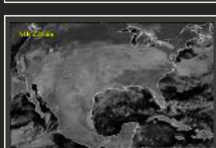
ABI Band #5

1.6 microns

Near–IR ("Snow/Ice Band")

Primary Uses:

- Daytime snow, ice, and cloud discrimination (Snow/Ice dark compared to liquid water clouds)
- Input to "Snow/Ice vs. Cloud" RGB



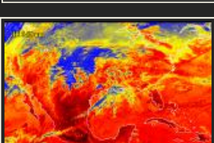
ABI Band #6

2.24 microns

Near-IR ("Cloud Particle Size Band")

Primary Uses:

- Cloud particle size, snow, and cloud phase
- Hot spot detection at emission temperatures of greater than 600K



ABI Band #7

3.9 microns

IR ("Shortwave Window Band")

Contains daytime solar reflectance component

Primary Uses:

- Low stratus and fog (especially when differenced with the 11.2-micron IR channel taking advantage of emissivity differences)
- Fire/hot spot detection and volcanic ash

ABI Band #8

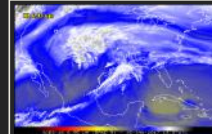
6.2 microns

IR ("Upper-Troposphere WV

In a standard US atmosphere the weighting function peaks around 340 mb. **NOTE: The sensed radiation is from a layer, not just the peak pressure level which itself varies from the standard value

Primary Uses:

- Upper-level feature detection (jet stream, waves, etc.)



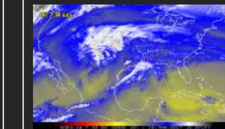
ABI Band #9

6.9 microns

IR ("Mid-Level Troposphere WV Band")

In a standard US atmosphere the weighting function peaks around 440 mb. **NOTE: The sensed radiation is from a layer, not just the peak pressure level which itself varies from the standard value

Primary Uses: Mid-level feature detection



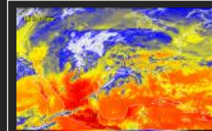
ABI Band #10

7.3 microns

IR ("Low-Level Troposphere WV Band")

In a standard US atmosphere the weighting function peaks around 615 mb. **NOTE: The sensed radiation is from a layer, not just the peak pressure level which itself varies from the standard value

Primary Uses: Low-level feature detection (EML, fronts)



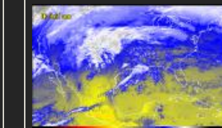
ABI Band #11

8.4 microns

IR ("Cloud-Top Phase Band")

Primary Uses:

- Cloud-top phase and type products derived when combined with the 11.2- and 12.3- micron channels
- Volcanic ash (S02 detection) and dust



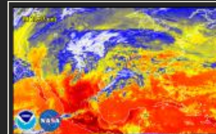
ABI Band #12

9.6 microns

IR ("Ozone Band")

Primary Uses:

- Dynamics near the tropopause including stratospheric intrusions (high ozone) associated with cyclogenesis. PV anomaly applications
- Input to Airmass RGB

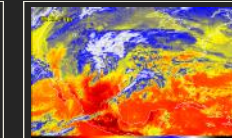


ABI Band #13

10.3 microns

IR ("Clean IR Longwave Band")

- Less sensitive to atmospheric moisture than the other IR channels. As a result brightness temperatures are usually warmer than traditional IR as less radiation is absorbed by water vapor and re-emitted at higher altitudes

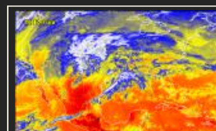


ABI Band #14

11.2 microns

IR ("IR Longwave Band")

- The traditional IR window
- Differenced with the 3.9 micron near IR channel for low stratus and fog detection

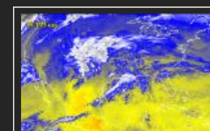


ABI Band #15

12.3 microns

IR ("Dirty IR Longwave Band")

- Greater sensitivity to moisture compared to the 10.3- and 11.2-micron channels. As a result, brightness temperatures will be cooler
- Contributes to total PWAT and low-level moisture information



ABI Band #16

13.3 microns

IR ("C02 Longwave IR Band")

Primary Uses:

- Mean tropospheric air temperature estimation
- Input to RGBs to highlight high, cold, and likely icy clouds

Useful Links:

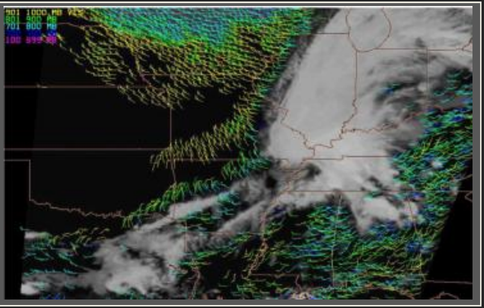
- Individual ABI Band Guides: http://www.goes-r.gov/education/ABI-bands-quick-info.html
- ABI Weighting Function Page: http://cimss.ssec.wisc.edu/goes/wf/ABI/

Additional Products

GOES-16 Baseline Products and RGBs

Patrick.Ayd@noaa.gov

Derived-Motion Winds (DMWs)



Availability:

- Full Disk: 60 minutes
- CONUS: 15 minutes
- Mesoscale: 5 minutes

How it works: Uses a set of three sequential images to estimate atmospheric motion using six ABI bands following a set of targets (cloud edges or clear sky water vapor gradients)

Uses the ABI Cloud Height Algorithm (ACHA) to assign heights

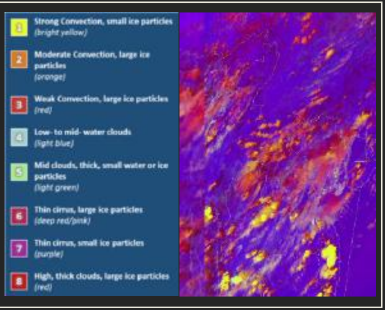
Daytime Convection RGB

Uses:

- Identification of convection with strong updrafts and small ice particles indicative of severe storms
- Microphysical characteristics help determine storm strength and the stage of development

Limitations:

- Daytime only. Pixel color fades when the sun angle is low
- False "Yellow/Strong Convection" may be caused by mountain wave, dust or cold cloud tops with only moderate 3.9-micron reflectance



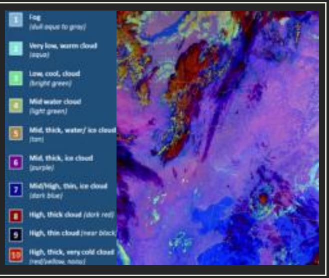
Nighttime Microphysics RGB

Uses:

- Fog and low-cloud analysis and differentiation
- Multi-channel approach allows for quick cloud type discrimination
- Outflow boundaries and drylines can be seen

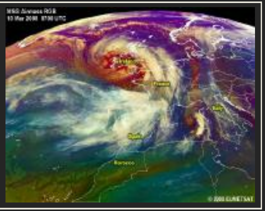
Limitations:

- Nighttime only. Thin fog can blend with the surface
- Shortwave noise in extreme cold. Color of cloud-free regions varies based on temperature, moisture, and surface type



Airmass RGB

Example: High-PV, ozone-rich stratospheric air (appearing red/orange) can be utilized to monitor stratospheric intrusions during cyclogenesis

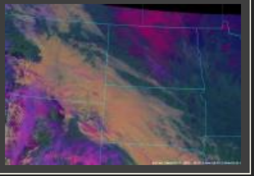


Daytime Composite #1 RGB

Bands 2, 5, and 14

Purple/Pink: Ice or snow

Orange: Liquid water containing clouds



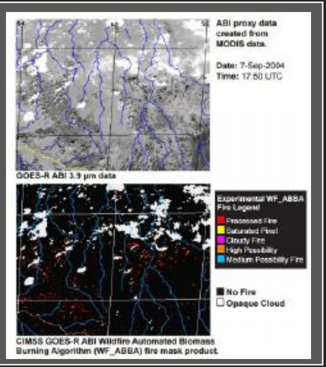
GOES-16 Baseline Products and RGBs

Fire Detection and Characterization (FDC)

How it works: Fires produce a stronger signal in the mid-wave IR bands (around 4 microns) than they do in the long-wave IR bands (such as 11 microns)

The FDC looks for hot spots exploiting the 3.9-micron channel. The algorithm screens out surfaces that are not usable, such as water, tundra, deserts, and sparsely vegetated mountains. The algorithm also screens out clouds that are opaque for ~4-micron radiation. This is different than a typical cloud mask since fires are often detected through thin clouds such as cirrus or stratus decks

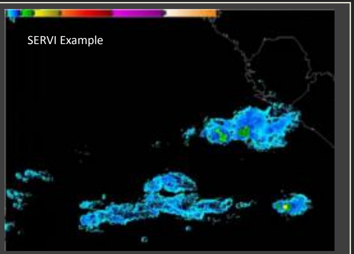
Once a fire has been detected and corrections applied to the radiances, the instantaneous fire size and temperature can be estimated. Fire Radiative Power (FRP) is also calculated for the fire. FRP is directly related to fire size and temperature



Rainfall Rate Product

Overview:

- Full ABI pixel resolution
- Available every 15 minutes with less than 5-minute latency
- Full Disk (Day and Night)
- 0 to 3.9 in/hr range



How it works: Using basic assumptions, cloud-top temperature (IR) is related to cloud-top height, which is related to updraft strength transporting moisture into the cloud. Updraft strength is related to rainfall rate

The IR algorithm uses ABI bands 8, 10, 11, 14, and 15 with a fixed calibration to a microwave-retrieved dataset

Clouds are divided into three types (water, ice, and cold top convective clouds) for rainfall rate classes. Satellite rain estimates perform best for convective rain and poorly for stratiform precipitation

Orographic effects, sub-cloud evaporation, and sub-cloud phase changes are not taken into account

Geostationary Lightning Mapper

Event: Any illuminated pixel during a 2-micro second period. Useful for developing convection (initial electrification), lightning spatial extent, and storm triage

Group: A cluster of events in time and space. The location is weighted by optical intensity and is most similar to NLDN and ENTLN CG strikes and in cloud pulses

Flash: Cluster of groups in time and space. Most similar to a flash in all other networks. More closely related to updraft and storm intensity

GLM has 20-second updates

Thanks for your time!

Questions?