Chapter Eight
Weather Radar
(Part two)

Reflectivity and Rainfall Rate

- The definition of reflectivity given in (8.18) is for a discrete raindrop distribution. For a continuous distribution of raindrops, the reflectivity is

$$Z = \int_0^\infty D^6 n_d(D)\,dD \qquad (8.23)$$

- Using the Marshall-Palmer distribution in (8.23) yields

$$z = \frac{720 n_o}{\Lambda^7} \qquad (8.24)$$

or

$$\Lambda = \left(\frac{720 n_o}{Z} \right)^{1/7} \quad (8.25)$$

- In a prior lesson we found that the slope factor of the Marshall-Palmer distribution is related to rainfall rate via

$$\Lambda = \left(\frac{\pi n_o \bar{u}}{R} \right)^{1/4} \quad (8.26)$$

- Equating (8.25) and (8.26) solving for Z yields the theoretical Z-R relation

$$Z = \frac{720}{(\pi \bar{u})^{7/4} n_o^{3/4}} R^{7/4} \quad (8.27)$$

- In practice Z-R relations are found empirically, with an often used relation of

$$Z = 200 R^{1.6} \quad (8.28)$$

where R is in mm hr^{-1}, and Z is in mm^6 m^{-3}

Decibels of Reflectivity

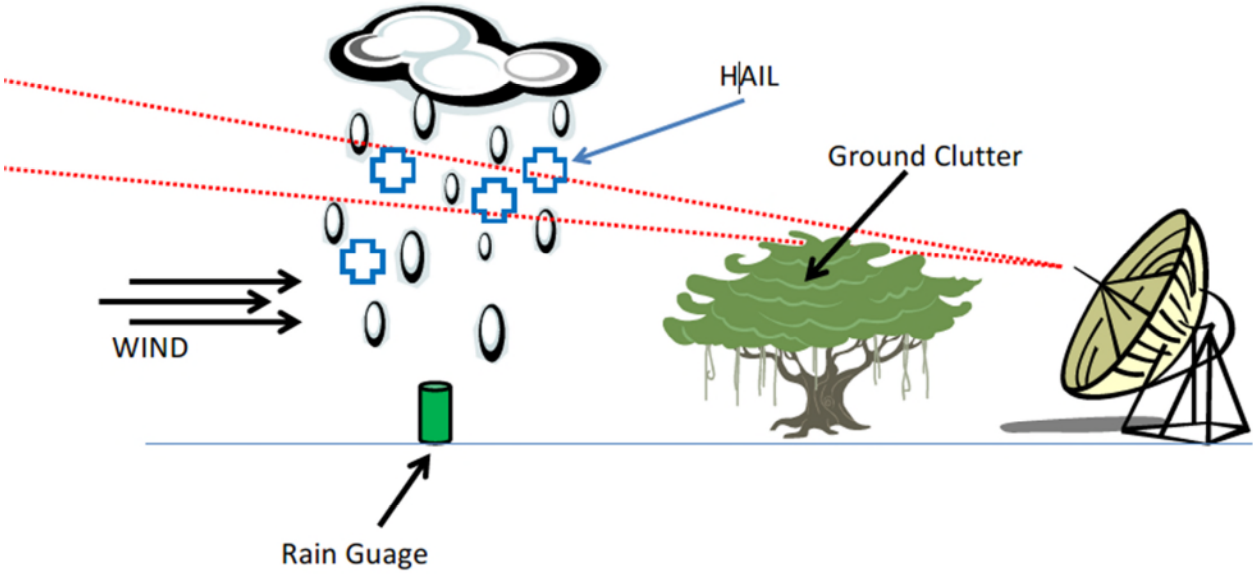
- Since Z can vary by a wide range it is convenient to use a logarithmic form for reflectivity. We define decibels of reflectivity, or $\boldsymbol{dBZ}$, as

$$dBZ = 10 \log_{10} \left(\frac{Z}{mm^6 m^{-3}} \right) \quad (8.29)$$

- Typical values of dBZ are 50 or greater in the core of a thunderstorm, and around 30 for light rain.

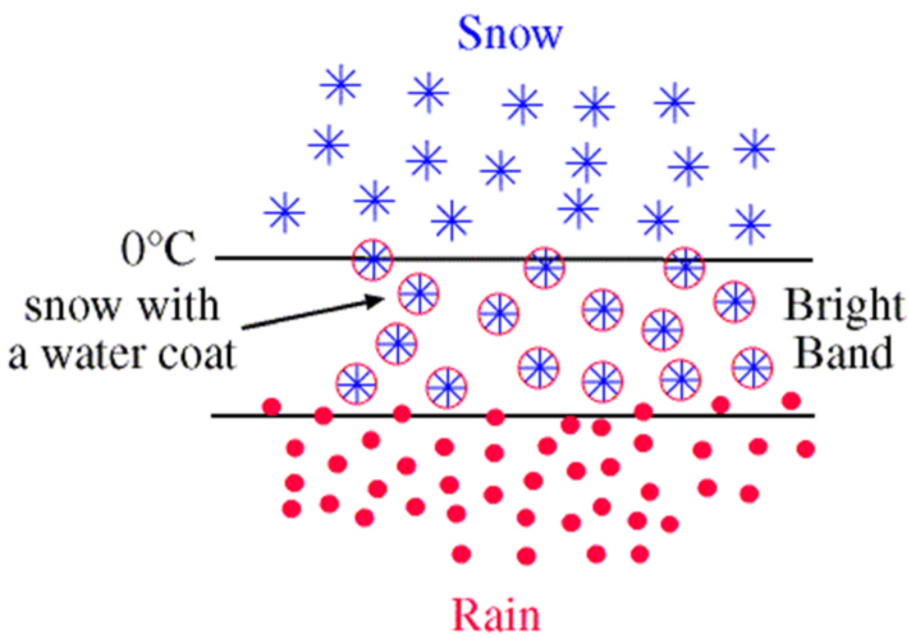
Radar Errors

- Ground clutter
- Attenuation
- Bright band
- Strong winds
- Evaporation below beam
- Mixed precipitation (ice and liquid)



Bright Band

- Snow and frozen precipitation will usually have a smaller value of reflectivity because it is made of ice, which has a lower index of refraction than liquid water.
- When frozen precipitation falls to a level where the temperature is above freezing it begins to melt.
- The water surface on the outside will cause an increase in reflectivity, which results in a bright band on the radar image at the height near the freezing level.
- The bright band does not extend to the surface because once the snowflake completely melts it falls faster. Therefore, the droplet concentration decreases as altitude decreases, resulting in lower reflectivity.



Radar Beam Height and Elevation Angle

- As the radar beam gets further from the radar the altitude of the beam above the ground gets larger. This is due to two effects:
  - Curvature of the Earth.
  - Refraction of the beam upwards.
- The altitude of the beam $h(r)$ with distance from the radar r is given by

$$h(r) = h_o - ka + \sqrt{r^2 + k^2a^2 + 2rka\sin\varphi} \quad (8.30)$$

where φ is the elevation angle, k is a standard refraction coefficient, a is the radius of the Earth, and h_O is the height of the radar antenna.

- Figure 1 shows beam height versus altitude for various elevation angles.
- Because the beam rises off the ground with distance, shallow precipitation at large distances may be completely missed by the radar.
- The lowest elevation angle is usually 0.5°.

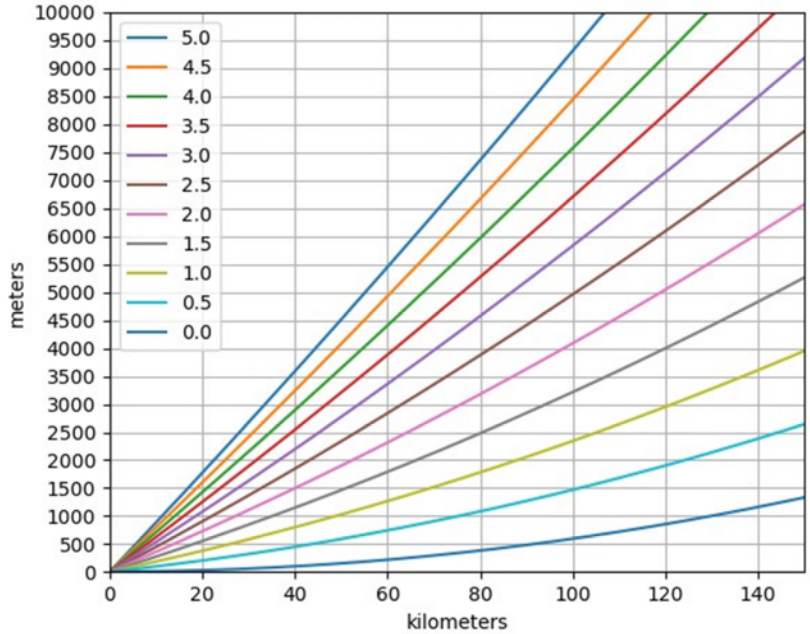
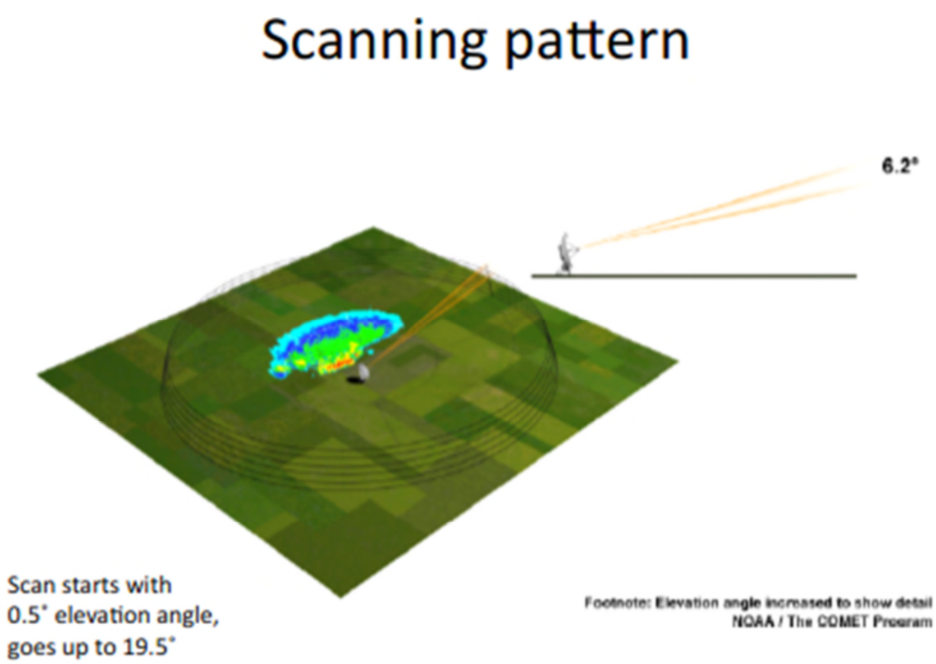


Figure 1: Beam height versus range for various elevation angles. Values used in (8.30) are $h_O = 10$ m and $k = 4/3$.



Advanced Weather Radar Systems

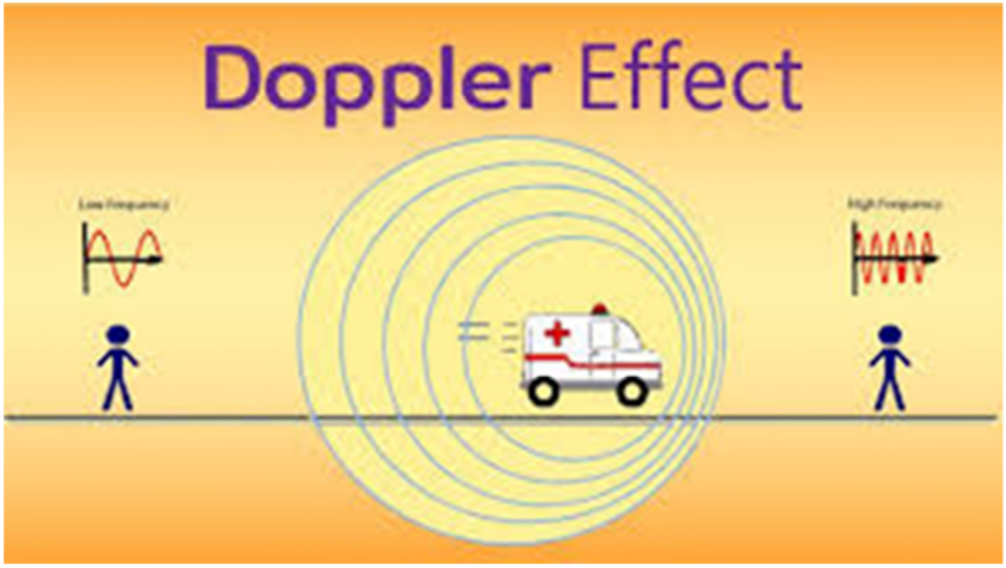
Doppler Weather Radar

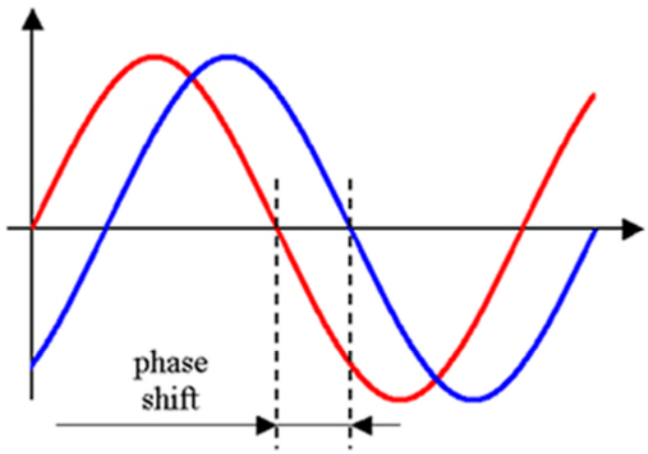
- Most meteorological radars are non-coherent and are used to observe the location and pattern of echoes and to measure the intensity of the background signal.
- The radar can also detect the pulse-to-pulse change in signal strength and therefore the relative motion of the scatters can be estimated.
- Pulsed Doppler weather radar operation is based on Doppler Effect
- **Doppler effect**: an increase (or decrease) in the frequency of sound, light, or other waves as the source and observer move towards (or away from) each other

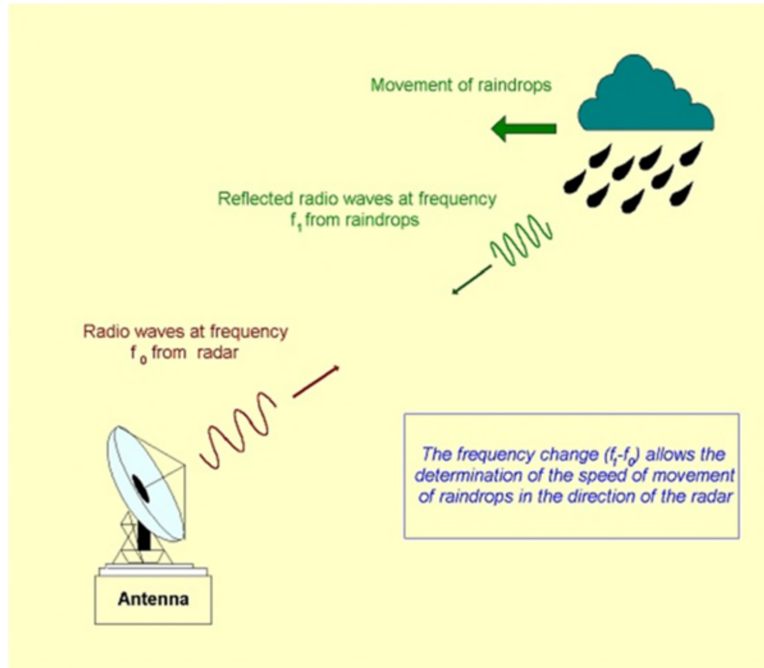
- In addition to radar reflectivity, Doppler weather radar can detect the relative motion of the targets.
- In other words, it can measure how fast rain or hail is moving toward or away from the radar.
- Doppler weather radar can measure the change in the phase of the returned pulses

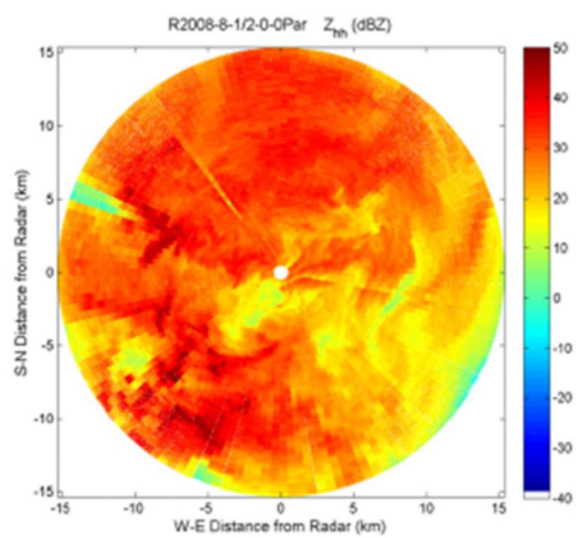
- The calculate Doppler velocity is by: $v = \Delta f \lambda/2$

- Most modern radars have Doppler capability

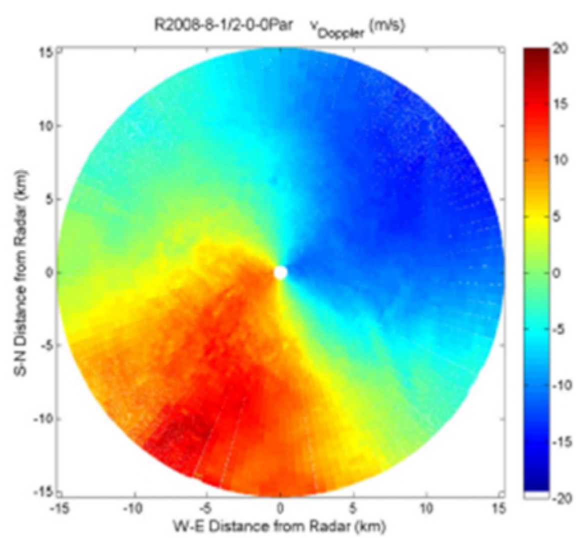






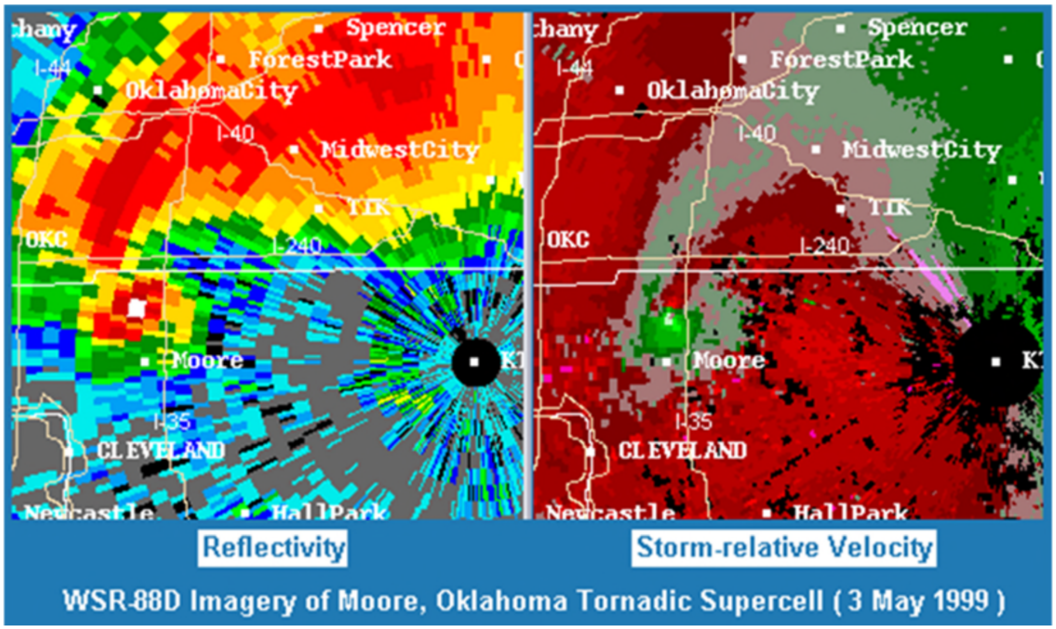


Reflectivity (dBZ)



Doppler velocity (ms^{-1})

- Tornado Detection



WSR-88D Imagery of Moore, Oklahoma Tornadic Supercell (3 May 1999)