**MET 4410 Remote Sensing: Radar and Satellite Meteorology**
**MET 5412 Remote Sensing in Meteorology**

# Lecture 11: Introduction of Radar and Radar Hardware

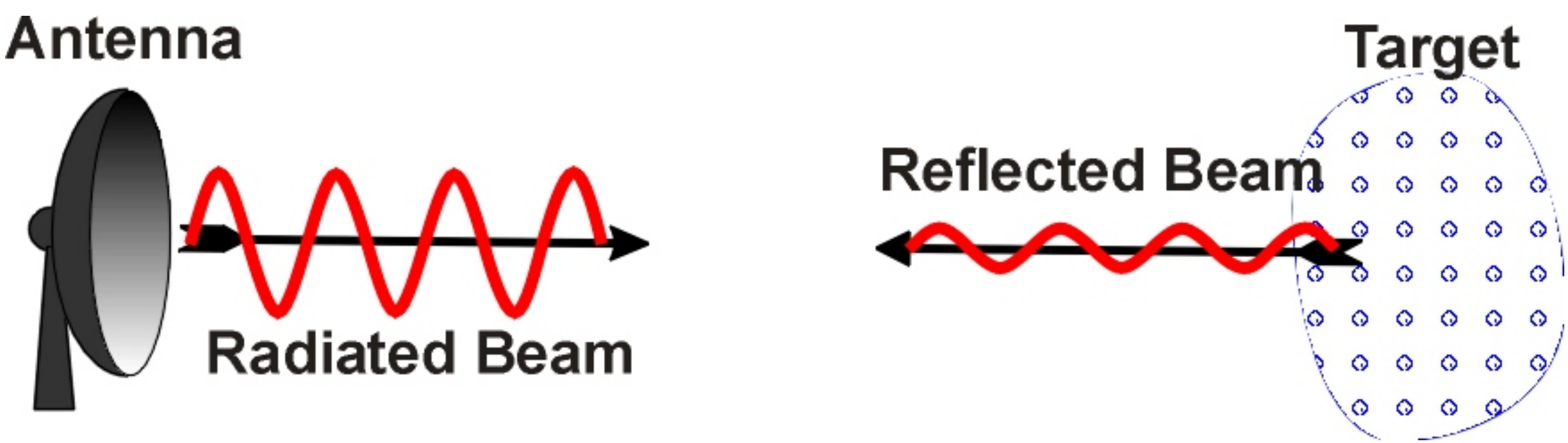
(Rinehart Book Ch2)

# How does weather radar work?

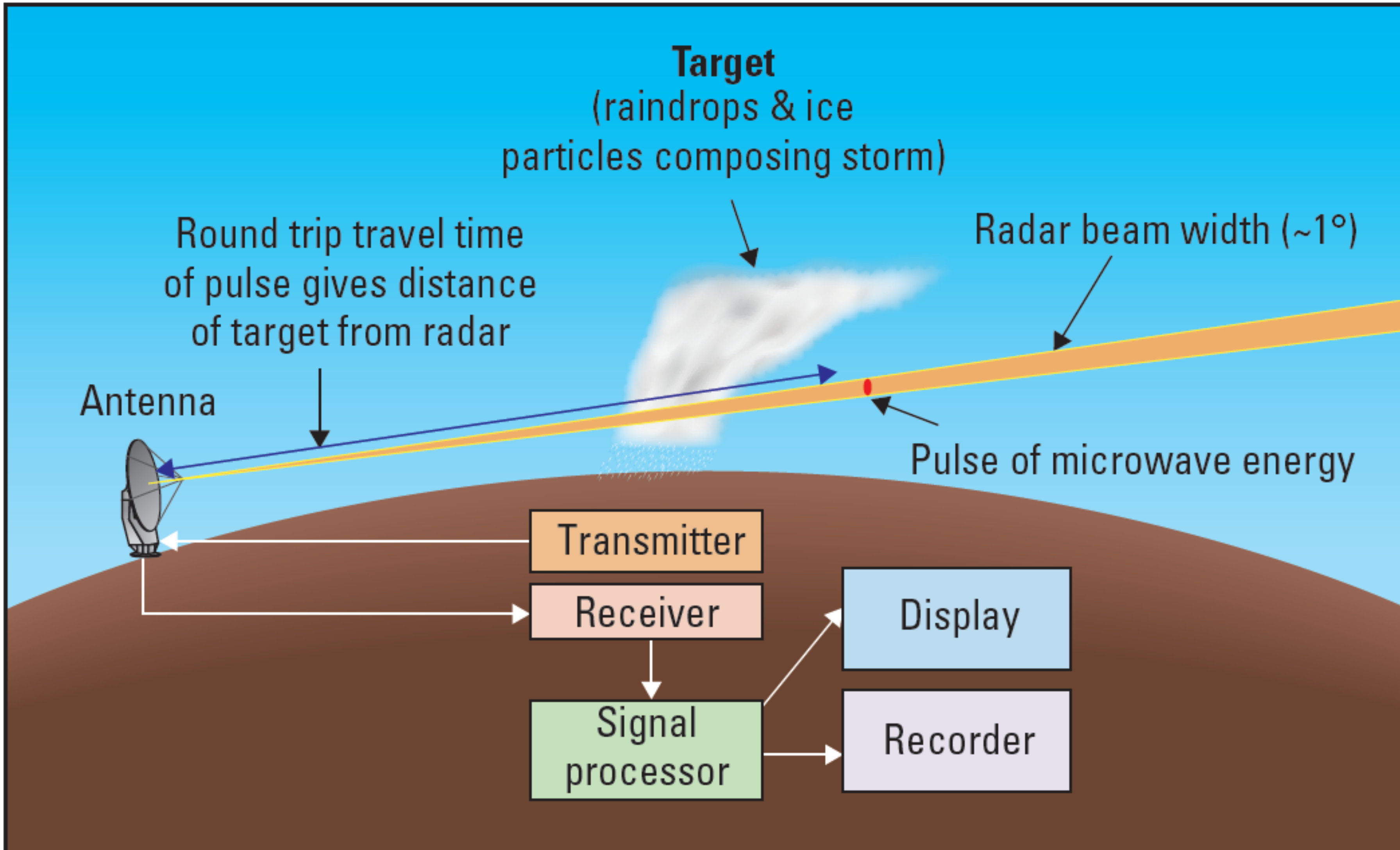
- **Radar is active remote sensor**, which emits electromagnetic (EW) waves that travel to an object and are reflected back toward the sensor.
- **A typical weather radar works by** transmitting **pulses** of EM waves (signals). Objects/targets (raindrops, ice, snow, birds, insects, terrain, and buildings) scatter that energy. Part of the backscattered energy is received back at the radar. Once the radar receives the reflected signal (echo), computer programs and meteorologists interpret the signal to determine where it is precipitating.
- Weather radar basically consists of 4 main components:
  - **a transmitter** to generate the high-frequency signal;
  - **an antenna** to send  the signal out into space and receive the echo back from the target;
  - **a receiver** to detect and amplify the the signal so it is strong enough to be useful;
  - **a display system** to allow people to see what the radar has detected
- Modern weather radars use a single antenna for both transmitting and receiving. Weather radars send out short pulses of energy and then wait a while so the signal can travel out at the speed of light, hit a target, and return back to the antenna. After an appropriate wait, another pulse is sent out.

# How Does Weather Radar Work?

- Radar emits pulses of microwave energy (between two pulses, there is a waiting/listening time)
- The energy (radar beam) travels until it reaches a target and then is reflected back to antenna
- Time of travel tells distance
- Brightness of echo tells size and/or number of cloud/precipitation particles/scatterers



# The principle components of a weather radar



# Types of radar

- **Monostatic vs. bistatic radar**
  - Monostatic: use a single antenna for both receiving & transmitting (**most weather radars are monostatic**)
  - Bistatic: has two antennas (could be in different locations), one for transmitting, one for receiving
- **Continuous wave vs. pulsed radar**
  - Pulsed Radar: Radar transmits (sends out) a short pulse of EM wave and then waits for an echo from target (**weather radar are pulsed radar**)
  - Continuous wave radar: transmits and receives EM waves continuously (police radar)
- **Doppler radar:** most weather radars have Doppler function to detect wind. For example, WSR-88D/NEXRAD radars. (Lec. 15)
- **Dual-Polarization radar:** some weather radars have dual-polarization (dual-pol) function to detect particle shape. NWS is updating WSR-88D/NEXRAD radars to add this function. (Lec. 16)

# What does a weather radar measure?

**1. The time** it takes for the microwave energy to travel from the transmitter to the target and back to the receiver, which determines *the distance to the precipitation*;
**2. The pointing angles of the antenna**, which determines ***the altitude of the precipitation and its geographic location***;
**3. The amount of microwave energy** transmitted and the amount scattered back by the target, which determines ***the radar reflectivity,*** *then* ***intensity of the precipitation****, and when integrated over time, the total precipitation*;
4. (Specifically for Doppler radar) **The frequency shift** between the transmitted signal and the signal received from the target, which determines **the *speed of the wind toward or away from the radar***. The latter can be used to detect strong winds, wind shifts, and rotation in the flow.
5. (Specifically for Dual-Pol radar) **The differential radar reflectivity,** which can be used to discriminate ***the types of particles*** (hail, rain, snow, small ice crystals, etc.) within a storm.

# Hardware of a pulsed weather radar

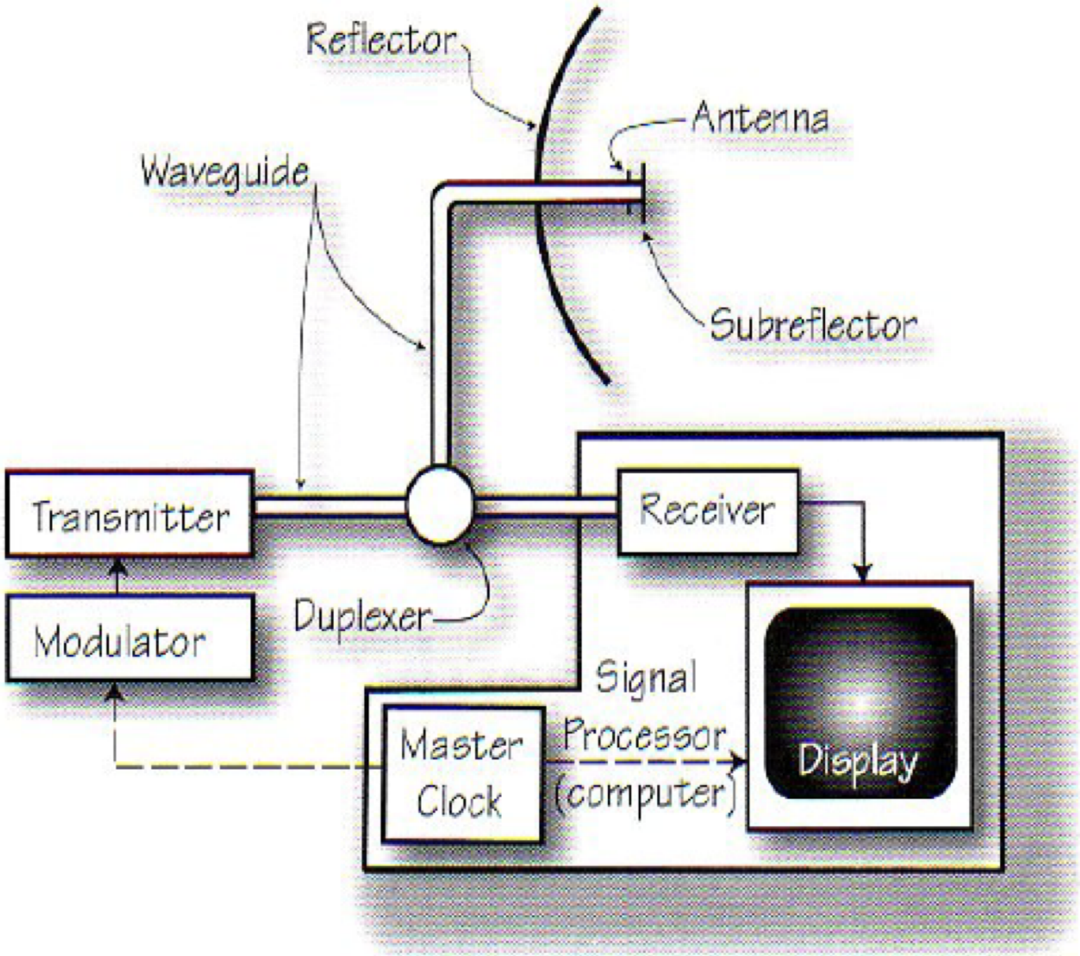



*Figure 2.1 Block diagram of a simple radar*

**Rinehart (5th edition 2010)**

# Transmitter

- **Transmitter** is the source of EM radiation emitted by a radar. It generates the high frequency signal which leaves the antenna and goes out into the atmosphere. The microwave signal emitted by the transmitter is focused into a narrow beam by the antenna.

# Modulator

- **Modulator** switches the transmitter on and off and to provide the correct waveform for the transmitted pulse.
- **Modulator s**tores up energy between transmitter pulses.

# Master Clock/Computer

- Control Panel: for human to control the operation of the radar.
  - Select the range to display, elevation & azimuth angles to scan.
  - Signal processing (by computer)
- Two main functions of master clock/computer:

1) Control how often the transmitter transmits:

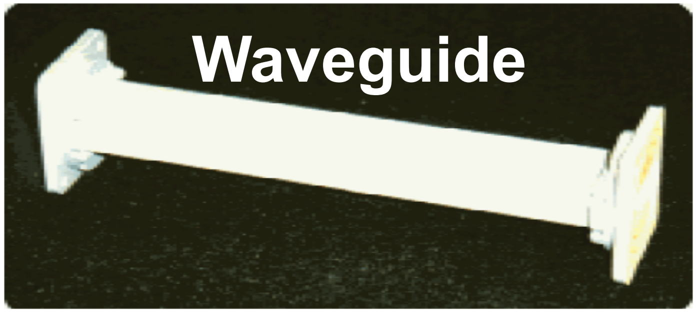
Pulse Repetition Frequency (PRF): unit: 1 cycle/second = 1 Hz

2) Control how long the transmitter transmits during each pulse:

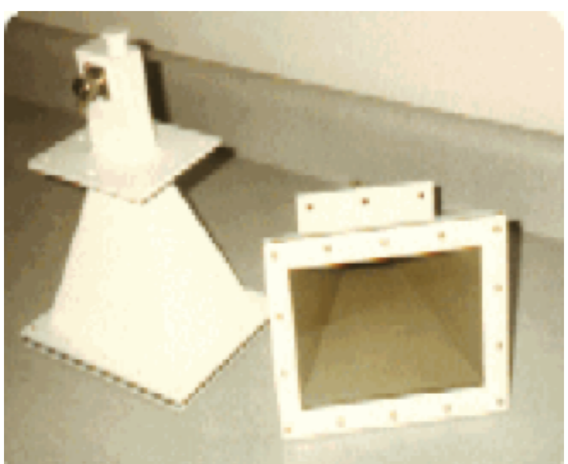
Pulse duration ($\tau$): 0.1 to 10 $\mu$s

or Pulse length = $c\tau$

# Waveguide




Rotary Joint



Feedhorn

- **Waveguide** is the conductor connecting the transmitter, antenna, and receiver.
- **Waveguide** is designed to be efficient to carry radar signals.
- Special forms of waveguide: rotary joint, feedhorn, etc.

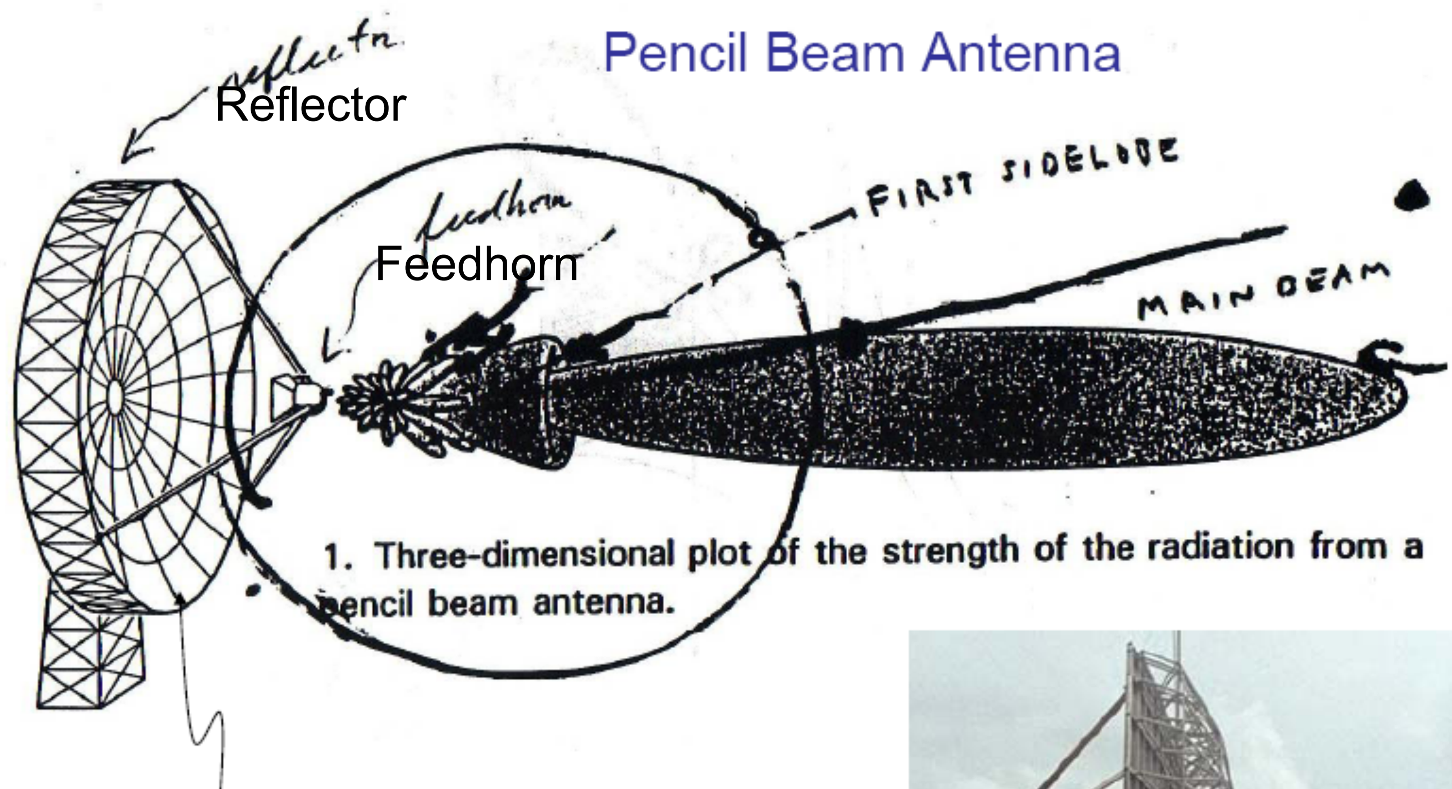
# Antenna

- Antenna is the device that sends the radar's signal into the atmosphere.
- Isotropic antenna: An antenna that sends radiation equally in all directions
- Weather radar's antennas are not isotropic. Instead, they are directional, which makes it possible to locate targets in space.

# Antenna

- Antenna system includes the combination of antenna and reflector
- The shape of the reflector determines the shape of the antenna beam pattern.
- Most weather radars use circular parabolic reflectors, which form conical and quite narrow beam pattern (typically 1° in width for the mainlobe).
- The bigger the reflector, the better it is able to direct the signal and the narrower the beam of the antenna.
- Feedhorn is a component of antenna. It is the radiating element which transmits radar signal toward the reflector. Hence, it is the true antenna for many weather radar.

# Pencil Beam Antenna




1. Three-dimensional plot of the strength of the radiation from a pencil beam antenna.

NCAR
S-POL
Antenna

# Antenna Parameters

- There are four antenna parameters which are important to know: **Wavelength, Size of the reflector, Gain, and Beamwidth**
- **Wavelength**: the wave length that the antenna is designed for must match the transmitter's wavelength.
- **Size of the reflector**: For circular parabolic reflectors, the size is represented by its diameter. The size of reflector of antennas on weather radars range from 0.3 m to as much as 9 m in diameter.

# Antenna Parameters: Gain

- Gain: the gain g of an antenna is the ratio of the power that is received at a specific point (on the center of the beam axis where the maximum power exists) in space with the radar reflector in place to the power that would be received at the same point from an isotropic antenna. In the equation on the right, $P_1$ is the power on beam axis with the real antenna and $P_2$ is the power at the same point from an isotropic antenna. Usually antenna gain is measure logarithmically in decibels.

$$g = \frac{P_1}{P_2}$$

- Gain in Decibels (G): is the logarithmic form of g. G has units of decibels (dB). Typically antenna gains for meteorological radars range from 20 to 45 dB.

$$G = 10\log_{10}\left(\frac{P_1}{P_2}\right)$$

# Antenna Parameters: Beamwidth

- **Beamwidth:** is the **angular width** of the antenna beam measured from the point where the power is exactly **half** what it is at the same range on the center of the beam axis. In the equation on the right, θ and ϕ are horizontal and vertical beamwidths of the antenna. K is dependent on the kind of shape of antenna. For circular reflectors, k=1.

$$g = \frac{\pi^2 k^2}{\theta\phi}$$

- For circular reflectors, θ=ϕ, therefore:

$$g = \frac{\pi^2}{\theta^2}$$

  - For an antenna with a circular reflector and a 1° beamwidth, the gain would be *g*=32400, or in logarithmic units: *G*=45.1 dB

- Antenna gain is dependent on beamwidth, but independent of wavelength.

# Receiver

- To detect and amplify the very weak signals received by the antenna.
- Very sensitive, with wide range of reflectivities up to 8 to 10 orders of magnitude.
- Modern Doppler radar receivers:
  - Logrithmic receiver: produces an output proportional to the logrithm of the input power. They can have dynamic range of 80 dB or more.
  - Digital receiver: able to dynamically measure and then adjust their gain such that they can measure very weak and very strong signals. Dynamic range of 90 dB or more.

# Duplexer (Transmit/Receive Switch)

- To protect the receiver from the high power of the transmitter.
  - ❖Transmitted power: up to 1 MW = $10^6$ Watts
  - ❖Received power: as small as $10^{-14}$ W or less

# Signal Processor

- Computer processors to process the received radar power returns (including noise removal, calibration, etc) and translate them into final output parameters: reflectivity and radial velocity.
- Color displays
- Warning algorithms: automatic detection of hail, tornadoes, and microbursts.

# Ground-Based Weather Radar Antenna Scanning Patterns

## (airborne & spaceborne radars have different scanning patterns)

- **Horizontal Scan (PPI - Plan Position Indicator):** the antenna fixes at one elevation angle and rotates about a vertical axis, scanning the horizon or above the horizon in all azimuthal direction from 0-360 degree.
- **Vertical Scan (RHI - Range Height Indicator):** the antenna fixes at one azimuthal angle/direction and rotates vertically, scanning the vertical cross section of this azimuthal direction from 0-90 degree elevation angle.
- **Volume Scan:** The antenna will do a full circle at one elevation angle, then tilt up a degree or two and do another circle. The antenna will complete as many as 10 to 20 different elevation angles and then repeat the whole cycle in a period of about 4 to 6 minutes.

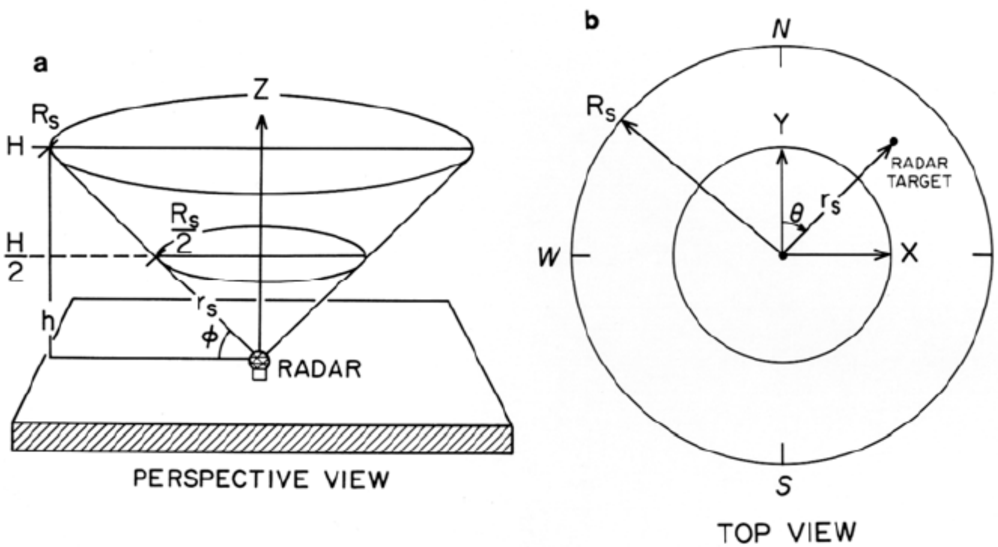
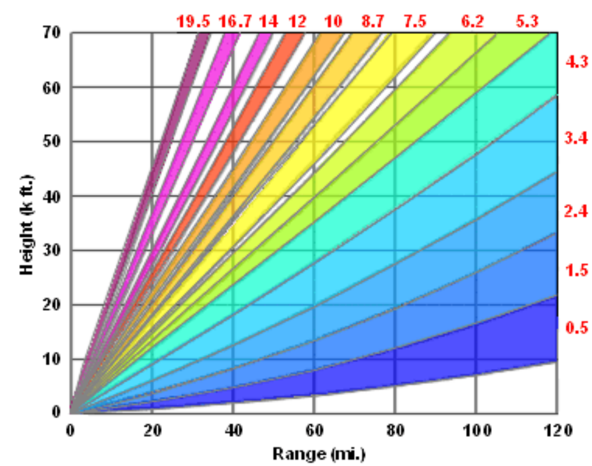


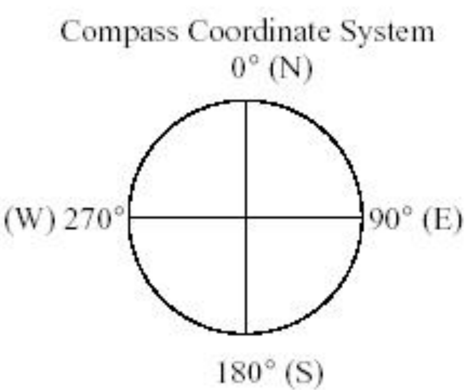

*Fig. 2.1.1. Doppler radar viewing configuration. (a) Radar scanning around vertical axis, Z, at a constant elevation angle, $\phi$; (b) view of (a) from the top, representing a PPI (plan position indicator) display. $R_s$ is slant range (on conical surface) of the edge of the display corresponding to height H above the ground. The three-dimensional position (x, y, h) of a radar scattering volume ("target") is computed from radar azimuth angle $\theta$, elevation angle $\phi$, and slant range $r_s$.*

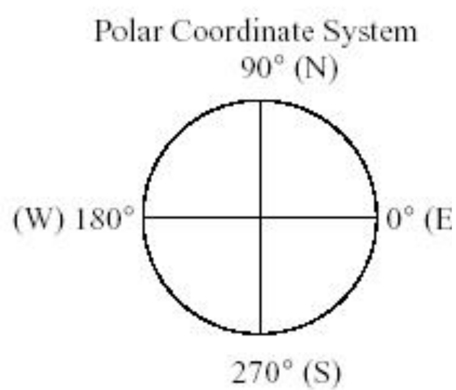



**An Example of A Series of Elevation Angles during One Volume Scan**

# Weather Radar Displays/Indicators: PPI

- Plan Position Indicator (PPI): displays the radar data in a map-like format, usually with the radar at the center. Distance is given by adding range marks (Range rings) around the rada
- PPI is displayed on compass coordinates (not polar coordinates): up- North; down-south; right-east, left-west.



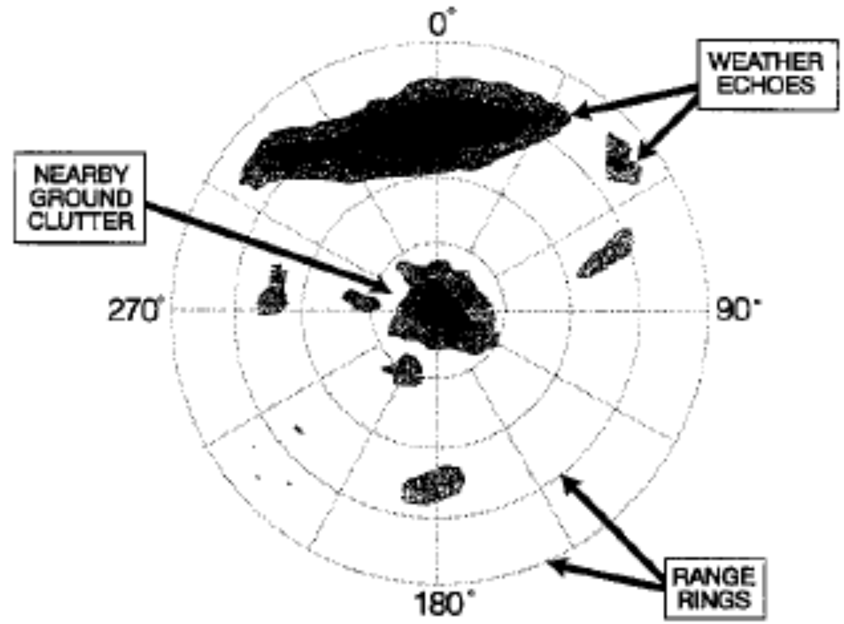
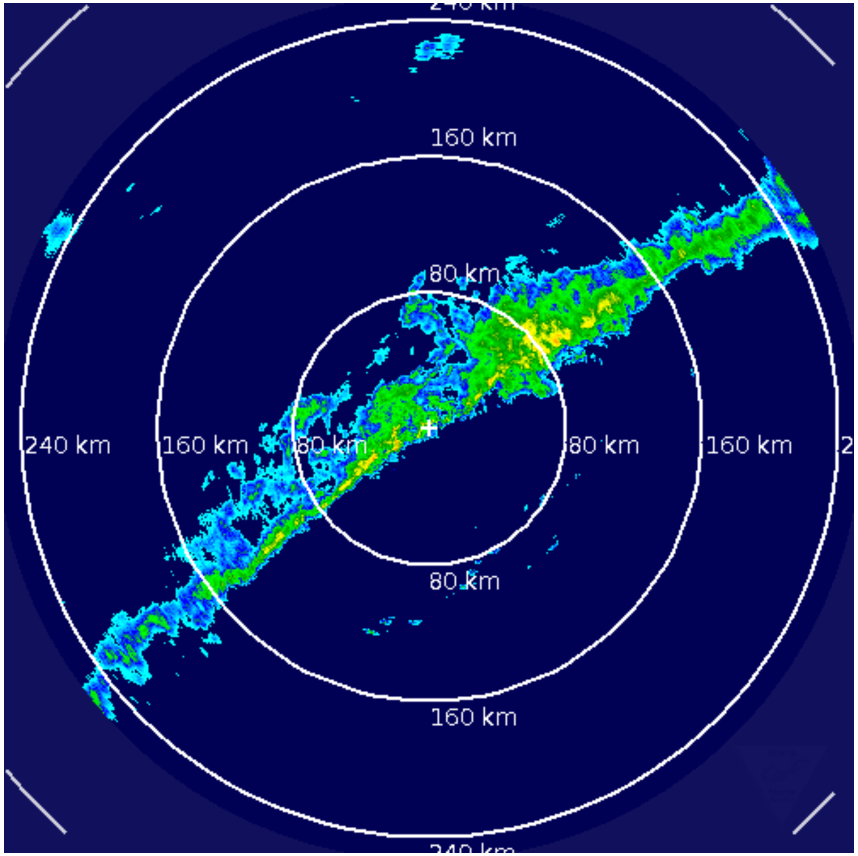




*Figure 2.11 Schematic diagram of a PPI display showing nearby ground clutter and distant weather echoes. Echo intensity is indicated by shading, where the darker the shading, the stronger the echo.*

# PPI: Cold Front

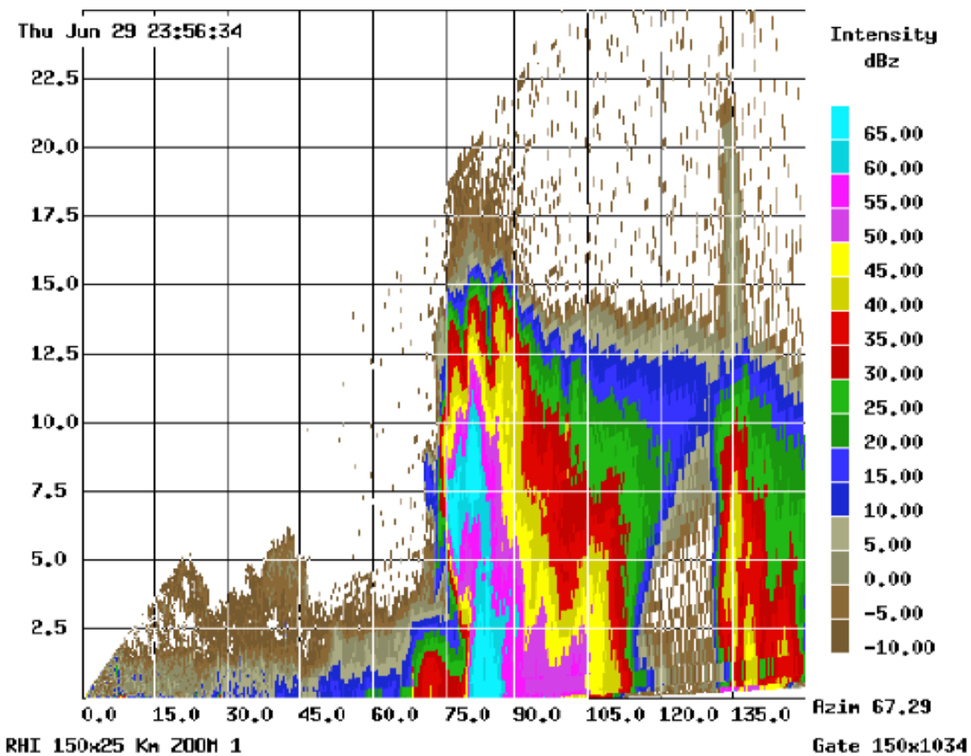



**Bermuda Weather Service Radar image showing a band of rain associated with a cold front at 3:43pm local time December 31st 2013.**

# Weather Radar Displays/Indicators: RHI

RHI –Range Height Indicator

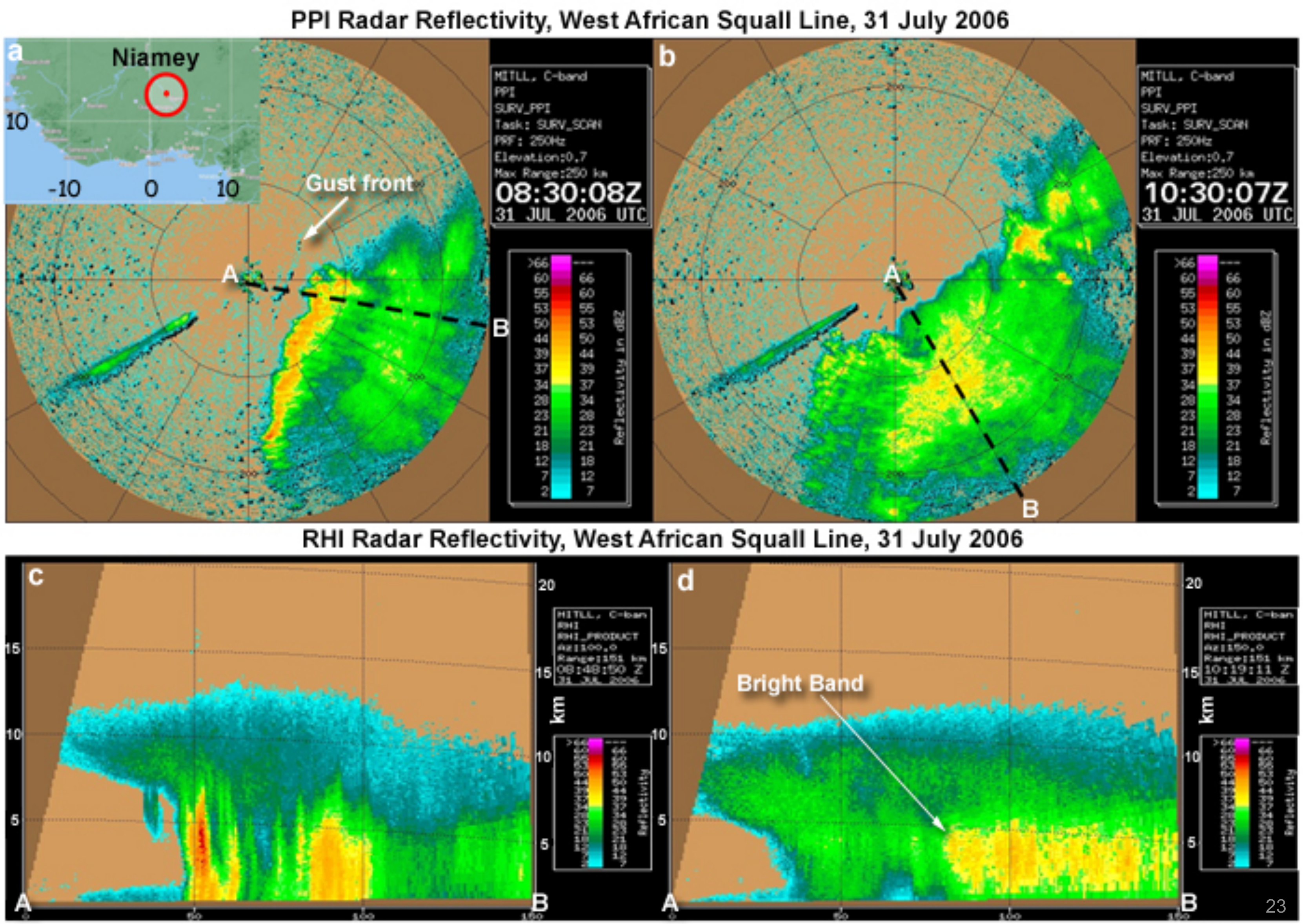
Height Above Radar (km)




Range/Horizontal Distance From Radar (km)

- Range Height Indicator (RHI): displays the radar data in a vertical cross-section format, usually with the radar at the left-bottom corner. RHI is very useful to show the vertical structure of storm.
- It's very helpful to have both the horizontal (PPI) & vertical (RHI) view of a storm.

# Both PPI and RHI from a Squall Line: RHIs in the bottom row are vertical cross-sections along line AB on the PPIs on the top row



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