Decoding Doppler Weather Radar

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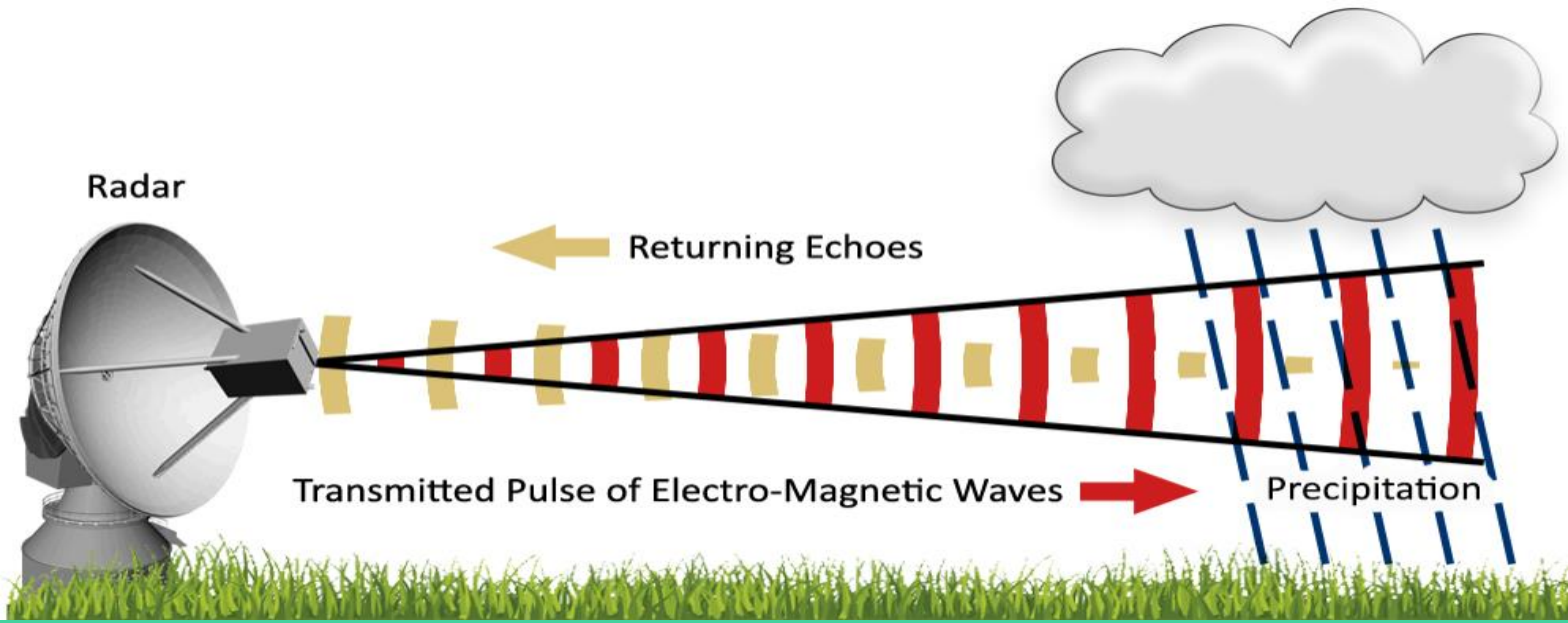
Today's Discussion

Introduction to Doppler Weather Radar

Wavelength of Doppler Weather Radar & its concept

Hardware of Doppler Weather Radar



01 INTRODUCTION

What is a Doppler weather radar (DWR)

A Doppler weather radar is a specialized radar system that uses the Doppler effect to measure the location, Intensity & velocity of precipitation particles within clouds.

Unlike traditional radars, which only measure the location and intensity of precipitation, Doppler radars can detect motion within the storm, providing crucial information about wind speeds and patterns.

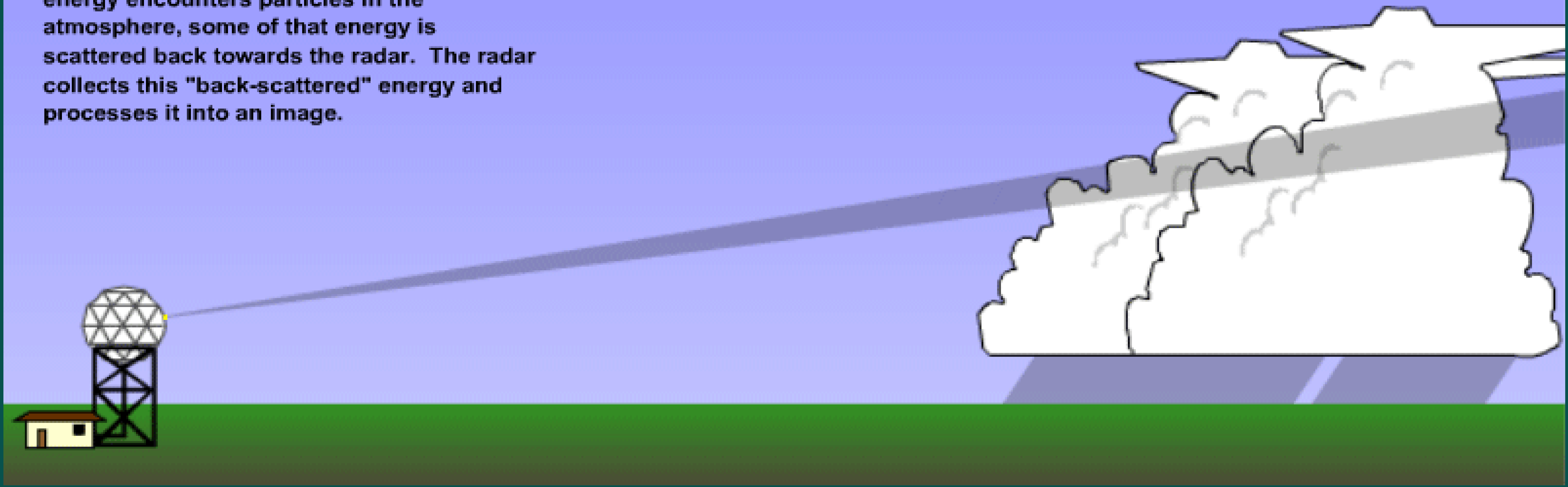
What is a Doppler weather radar (DWR)

Weather Radar Measures 6 pieces of information

1. Amplitude
2. Phase
3. Polarization state of the returned electromagnetic energy
4. The time the radiation took to travel to and from the object
5. Azimuth
6. Elevation of radar antenna at the time of radiation was transmitted.

Doppler Weather Radar

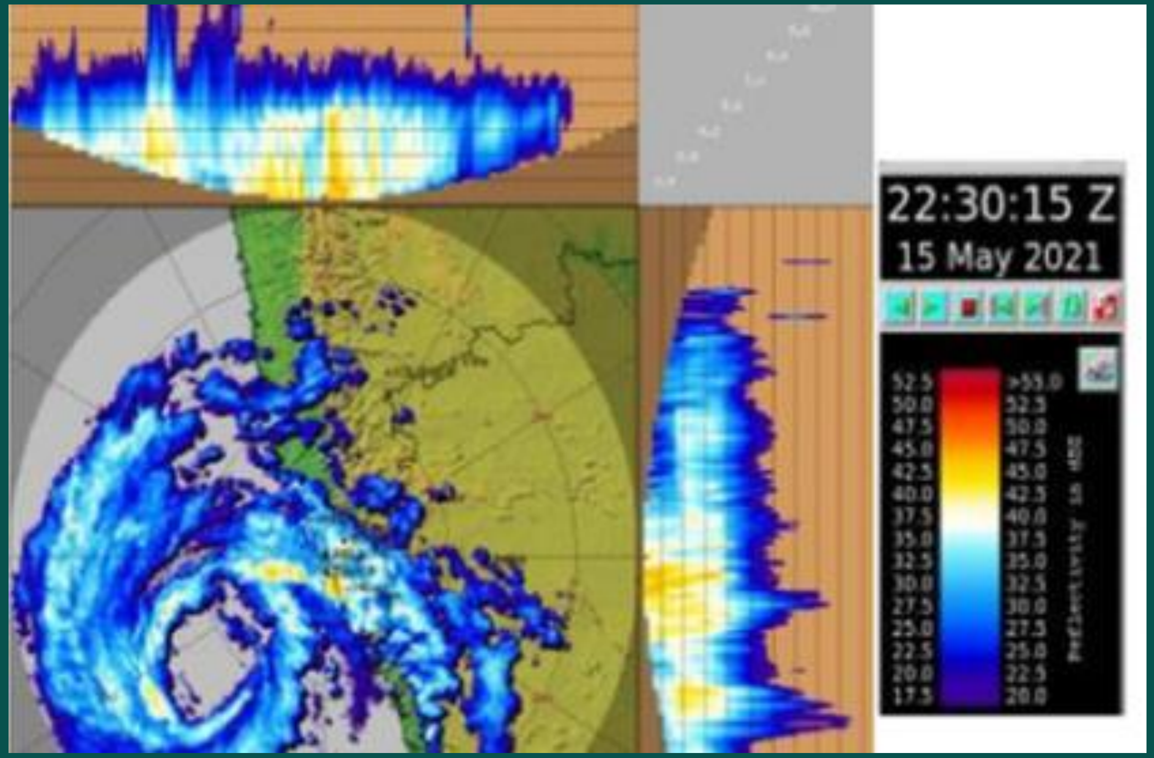
A radar sends out a very short pulse of energy (actually about 5000 per second). This pulse of energy travels away from the radar at the speed of light, expanding and gaining elevation as it goes. When the energy encounters particles in the atmosphere, some of that energy is scattered back towards the radar. The radar collects this "back-scattered" energy and processes it into an image.

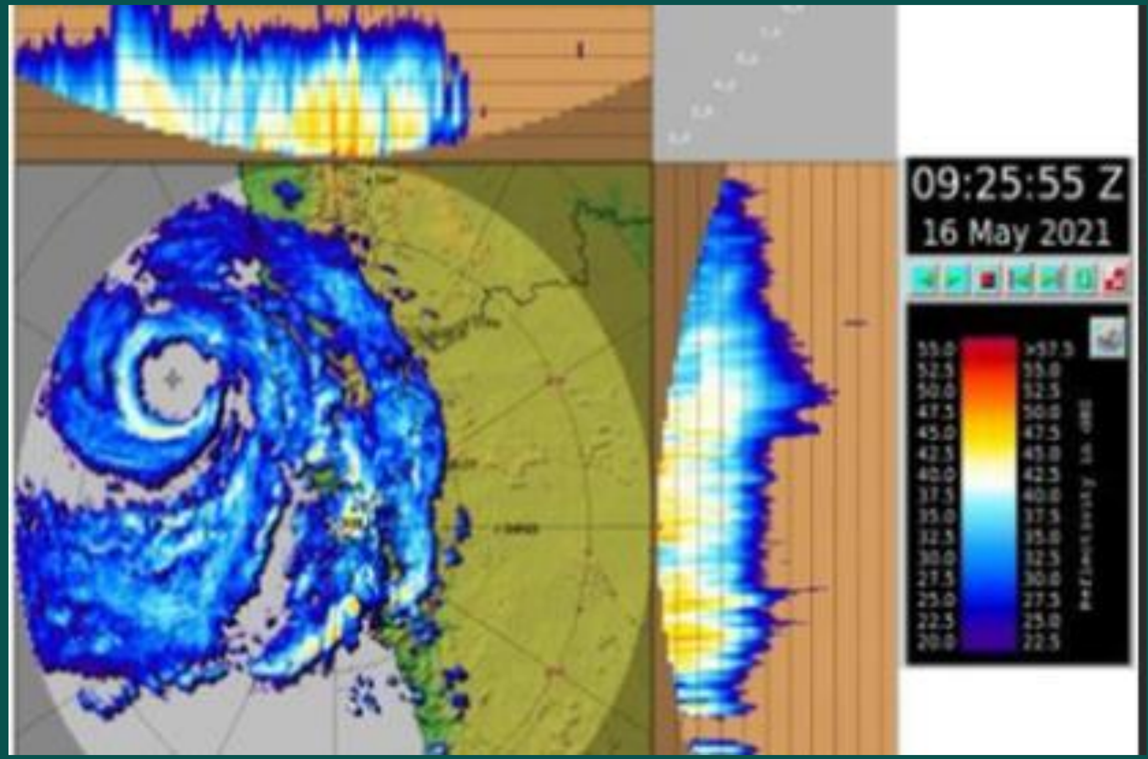


Purpose and Importance

Key Applications in Meteorology

Accurately predicting severe weather events such as thunderstorms, cyclone, storm detection, tracking, and prediction

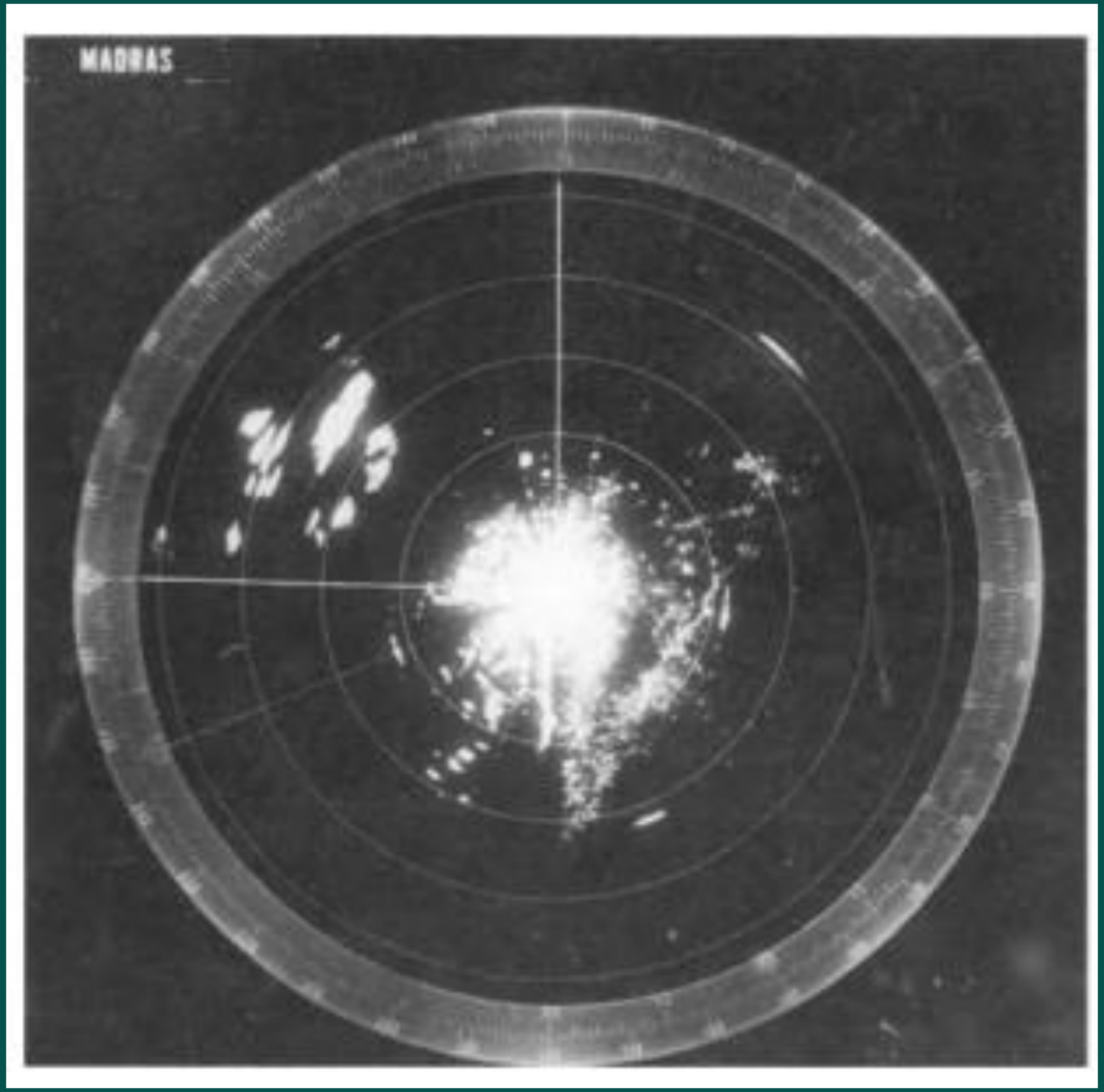


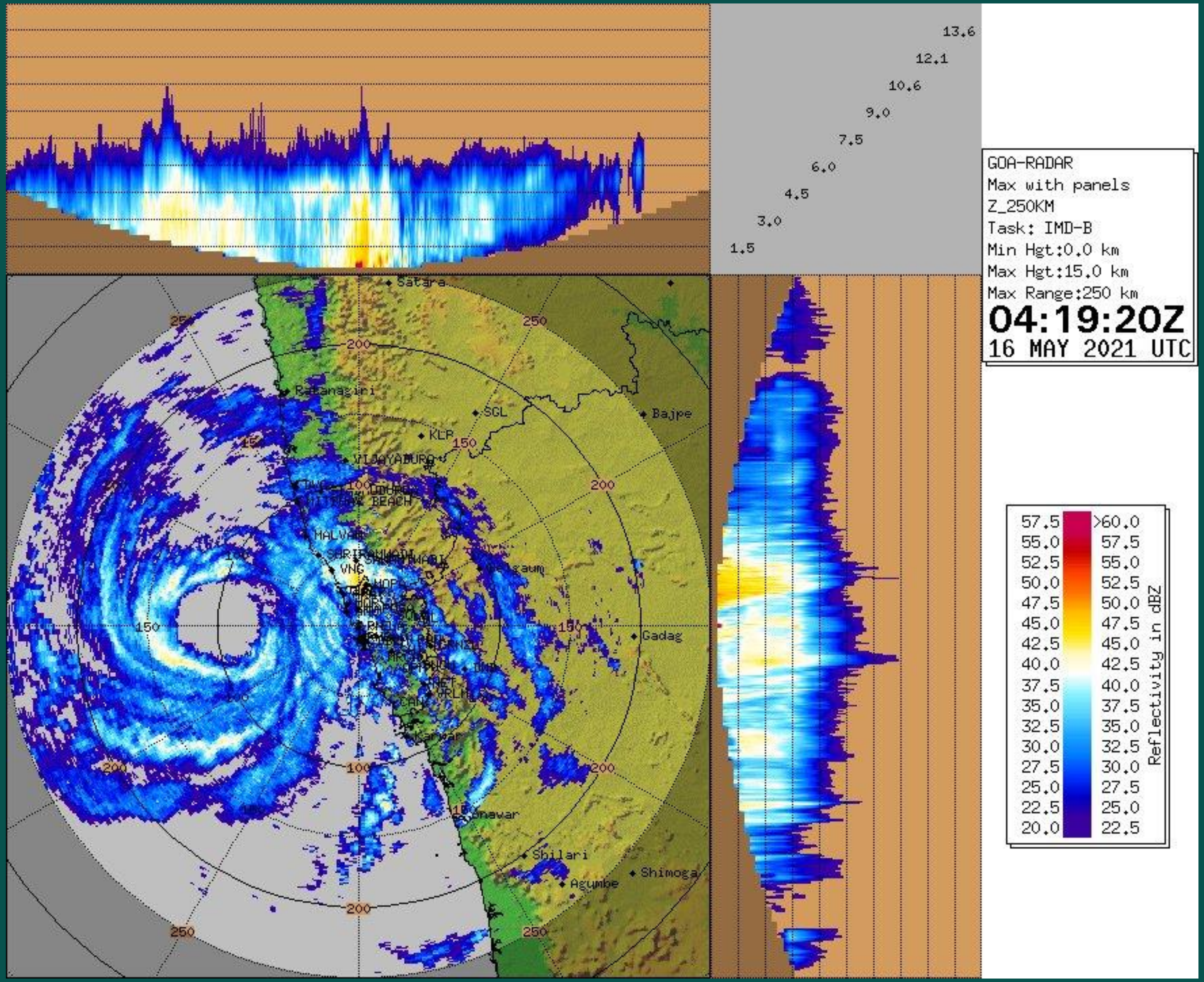


Key Applications in Meteorology

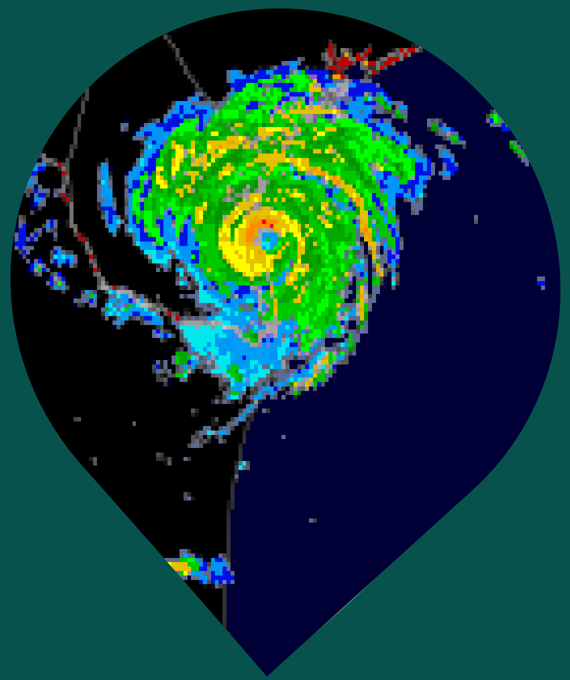
Providing detailed information on wind velocity and direction, which is critical for early warning systems, public safety and disaster management

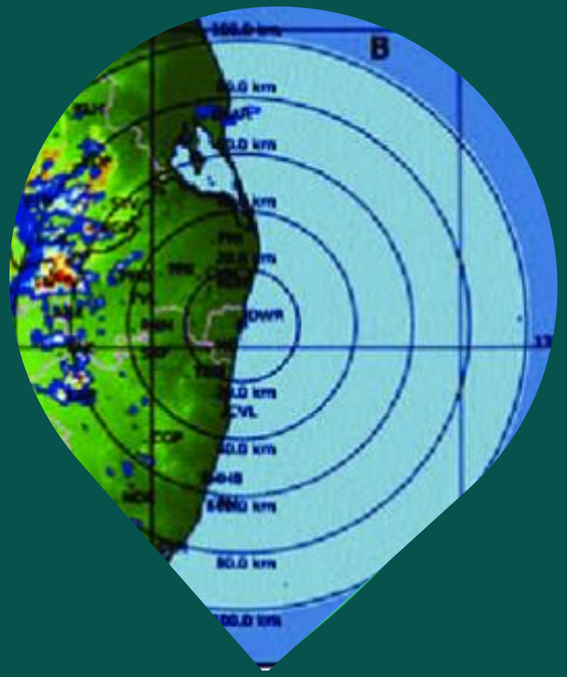
Conventional Vs DWR





Application of DWR





Storm Tracking

Using Doppler radar to monitor the movement and intensity of storms

Rainfall Estimation

Estimating the amount of rainfall based on radar reflectivity data

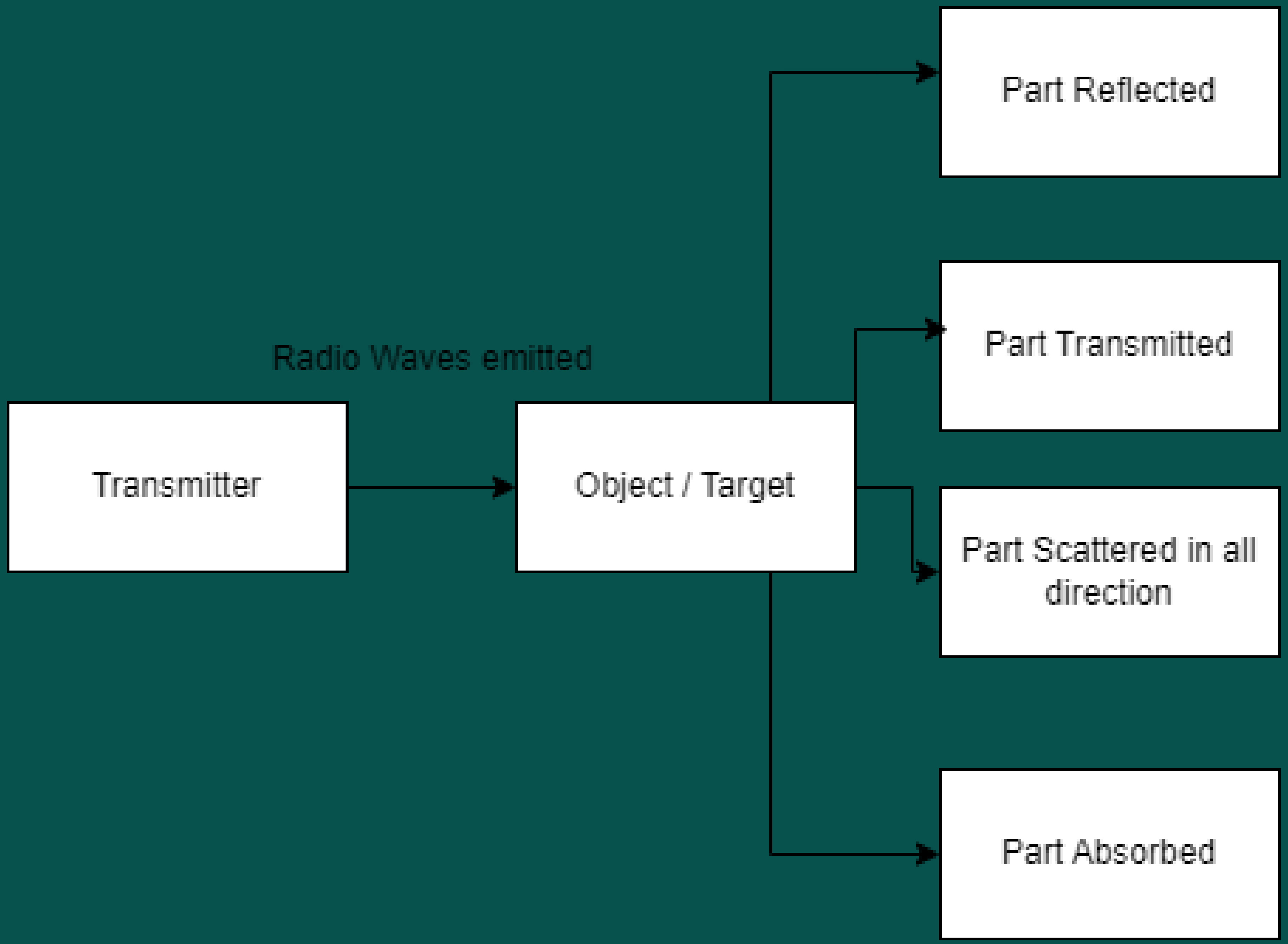
Aviation Safety

Detecting wind shear and turbulence to ensure safe flight operations

Weather Prediction

Used in combination with other weather data to improve the accuracy of weather prediction models.

Principle of RADAR

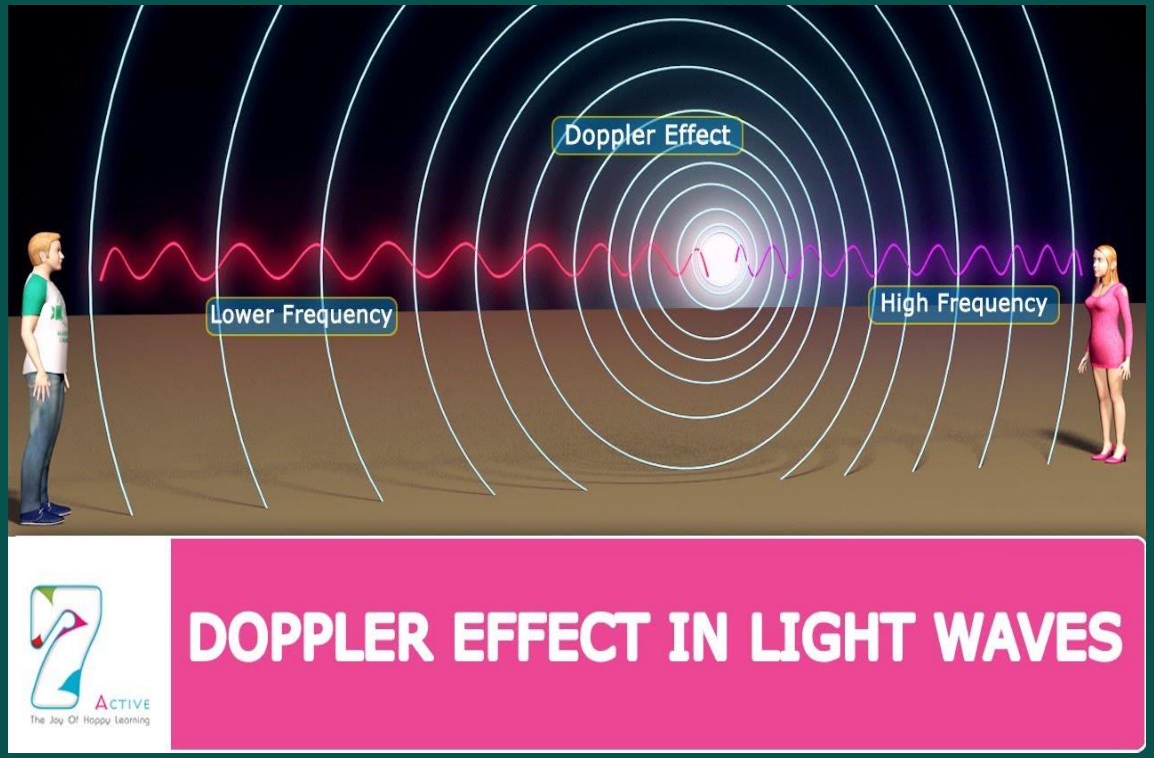


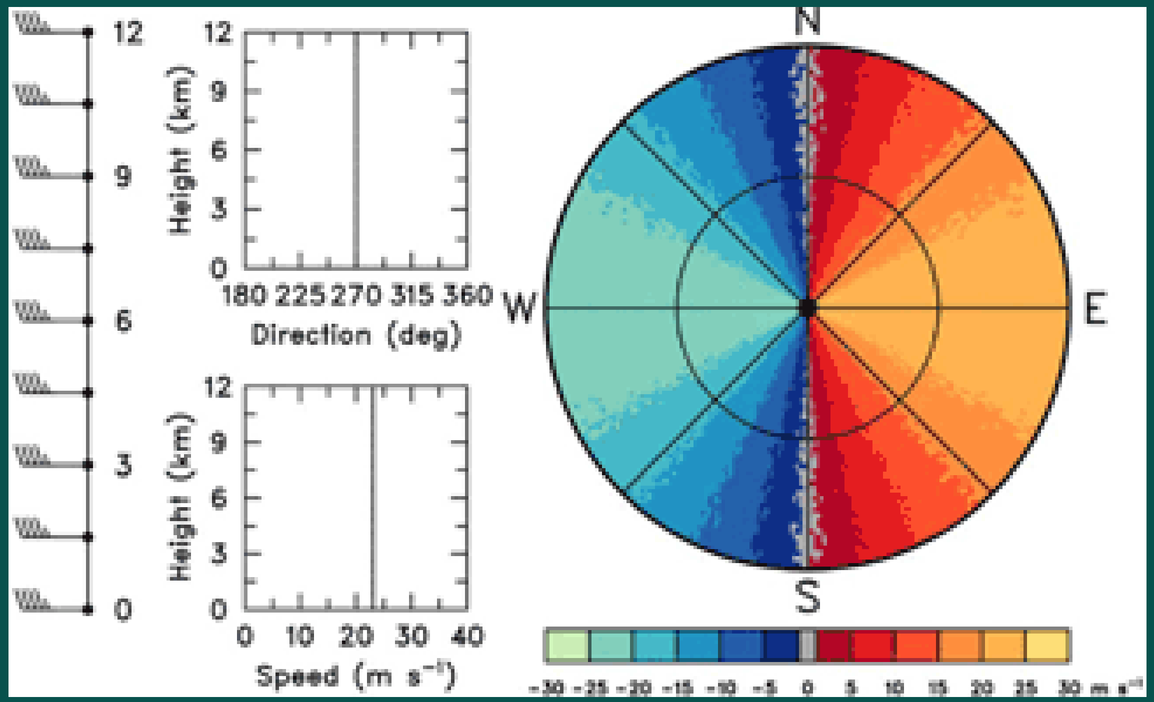
- ✓Principle of Operation
- ✓Types of Radar
- ✓Echo
- ✓Doppler Shift
- ✓Method of measuring Radial Velocity

Key terms

Pulse

A burst of radio waves transmitted by the radar





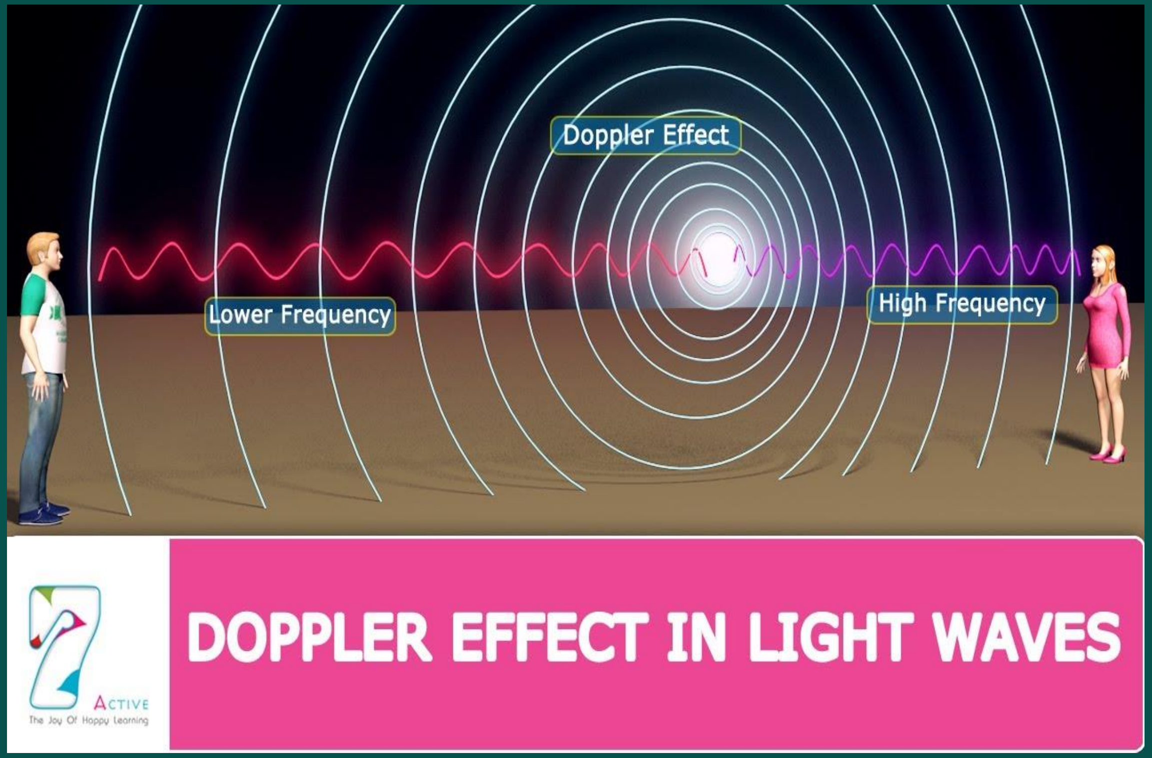
Echo

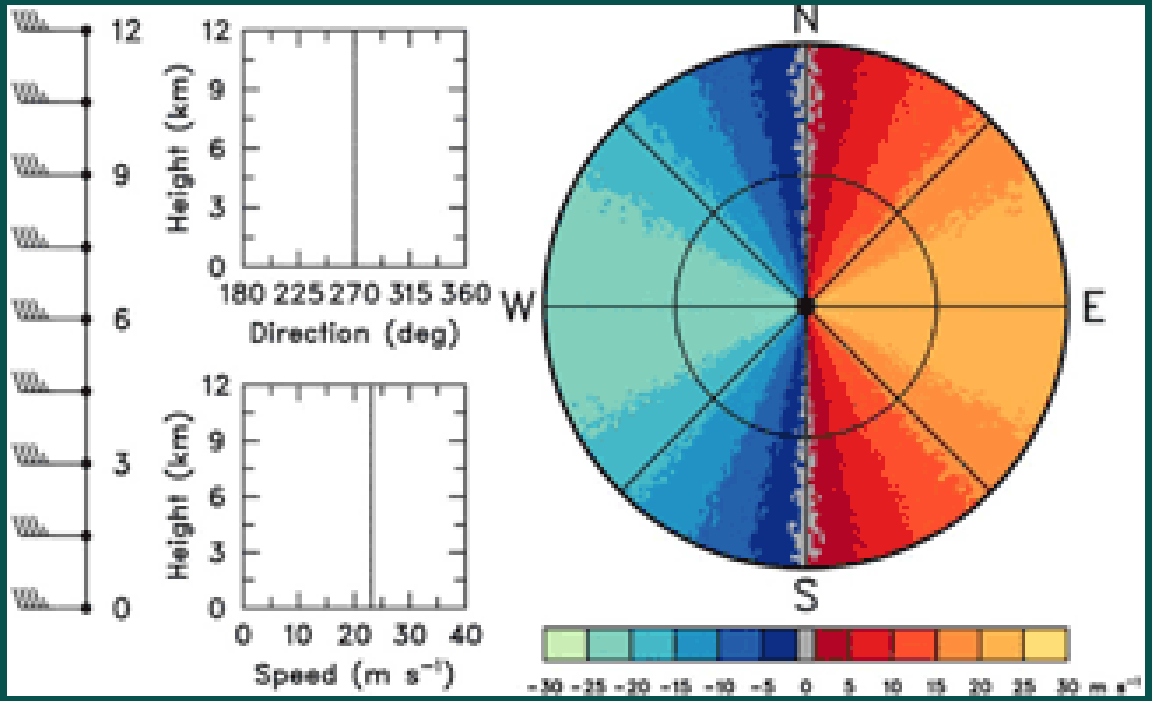
The reflected signal that returns to the radar after bouncing off an object

Key terms

Reflectivity

The measure of the returned signal's strength, which is related to the intensity of the precipitation





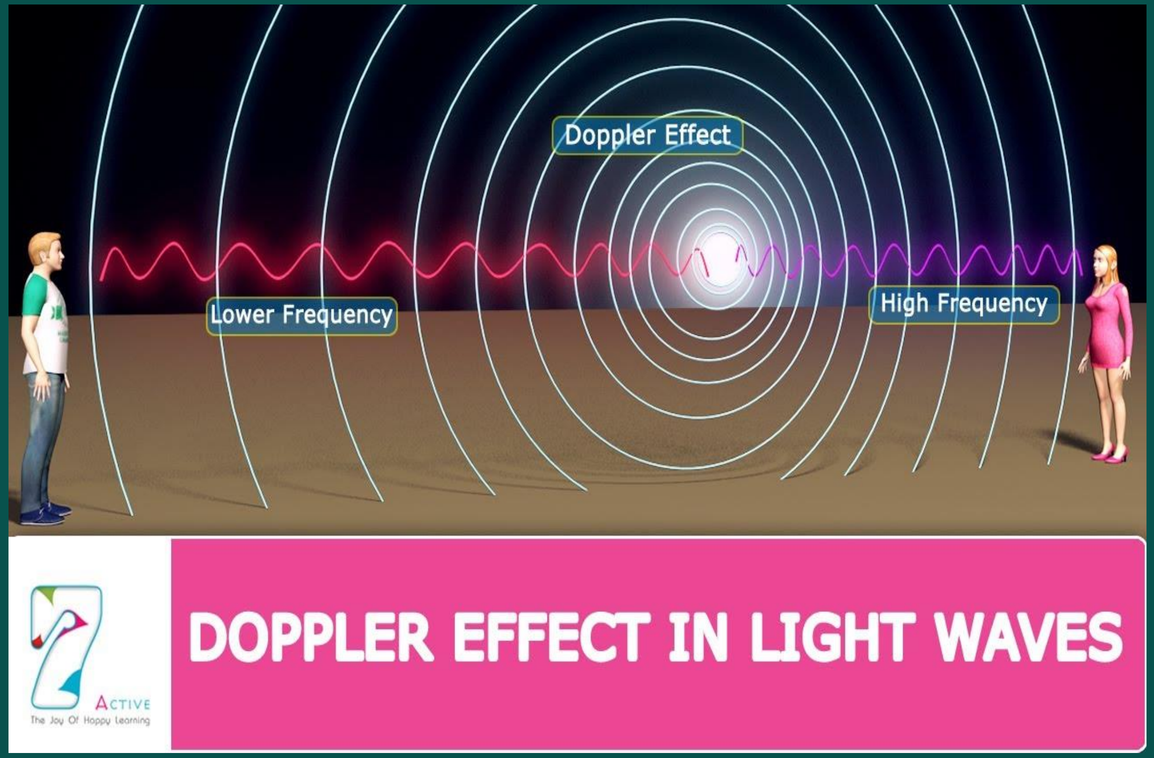
Range

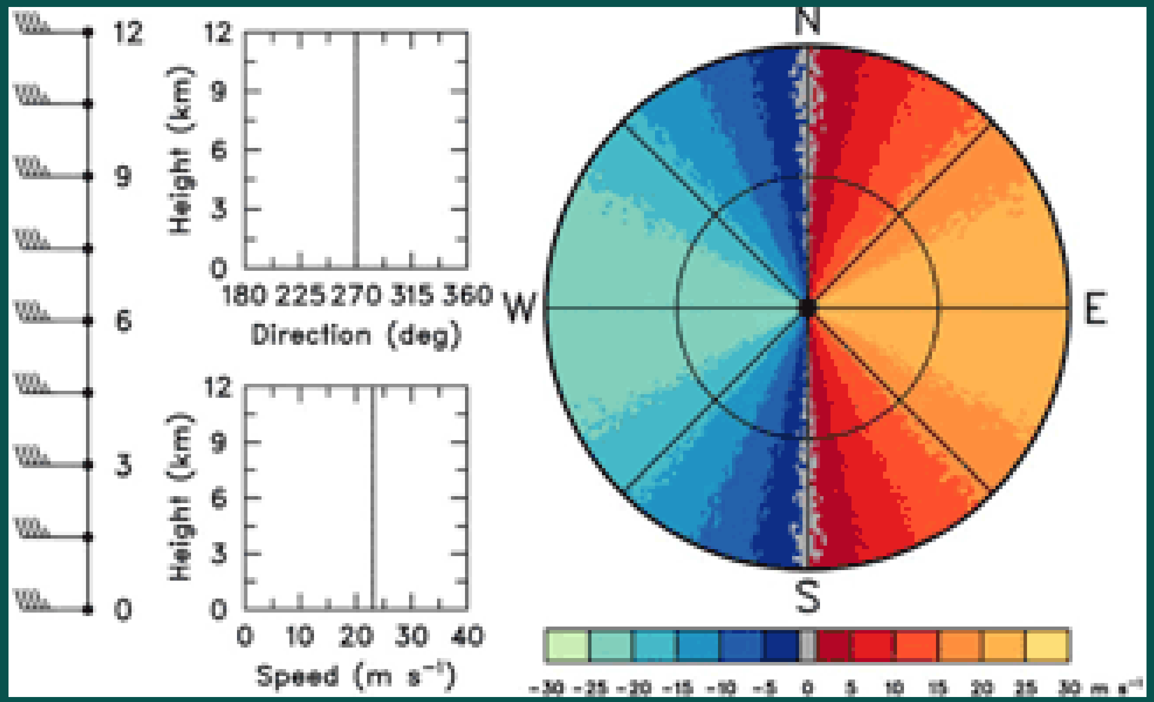
The distance from the radar to the target

Key terms

Doppler Effect

A change in frequency or wavelength of a wave in relation to an observer who is moving relative to the wave source.





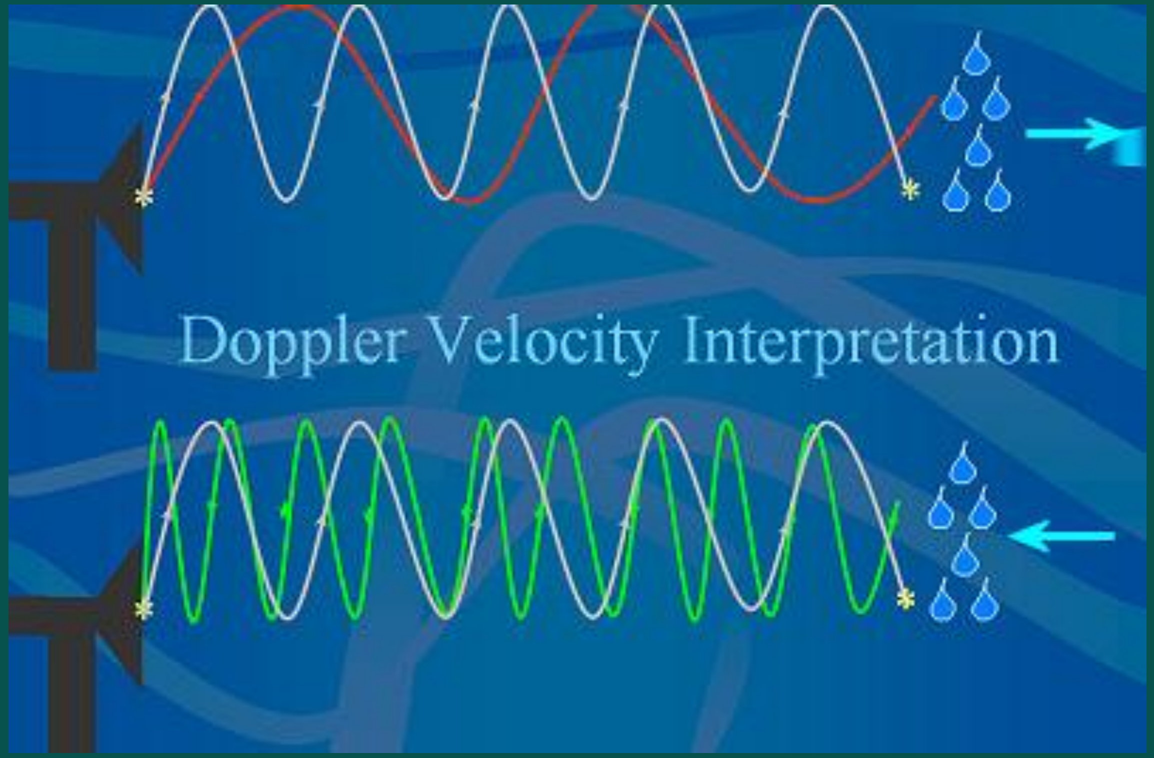
Radial Velocity

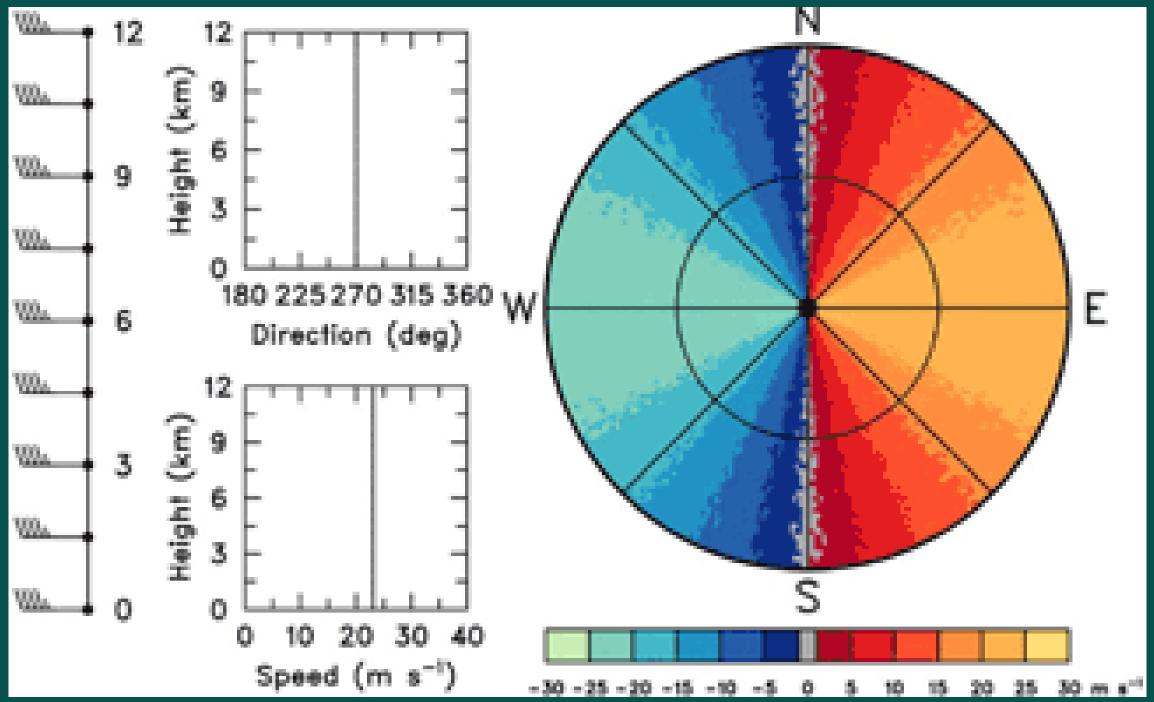
The component of the particle's velocity that is directly towards or away from the radar, which the Doppler radar measures

Key terms

Precipitation Particles

- Raindrops,
- snowflakes,
- hailstones,
- or any other particles

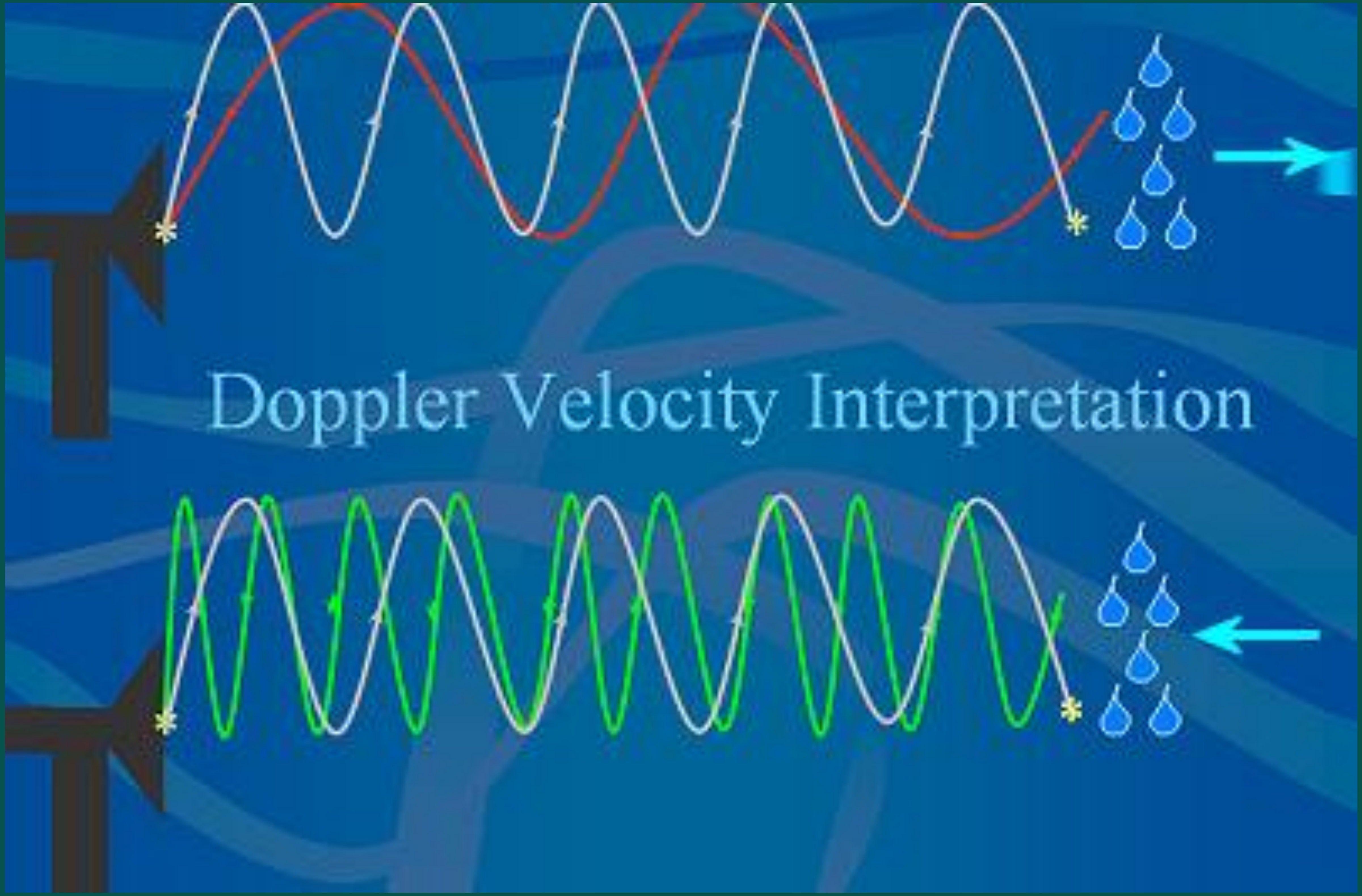




Precipitation Particles

- fall from clouds and are detected by the radar

Doppler Effect



Key terms

Doppler Shift

The change in frequency of the radar signal due to the motion of the target

$$\omega = 2\pi F = \frac{d\phi}{dt} = \left(\frac{4\pi}{\lambda}\frac{dr}{dt}\right) = \frac{4\pi v}{\lambda}$$

$$F = \frac{2v}{\lambda} = \frac{2vf}{c}$$

$$v = \frac{Fc}{2f} = \frac{F\lambda}{2}$$

Velocity

The speed of the target, which can be calculated from the Doppler shift.

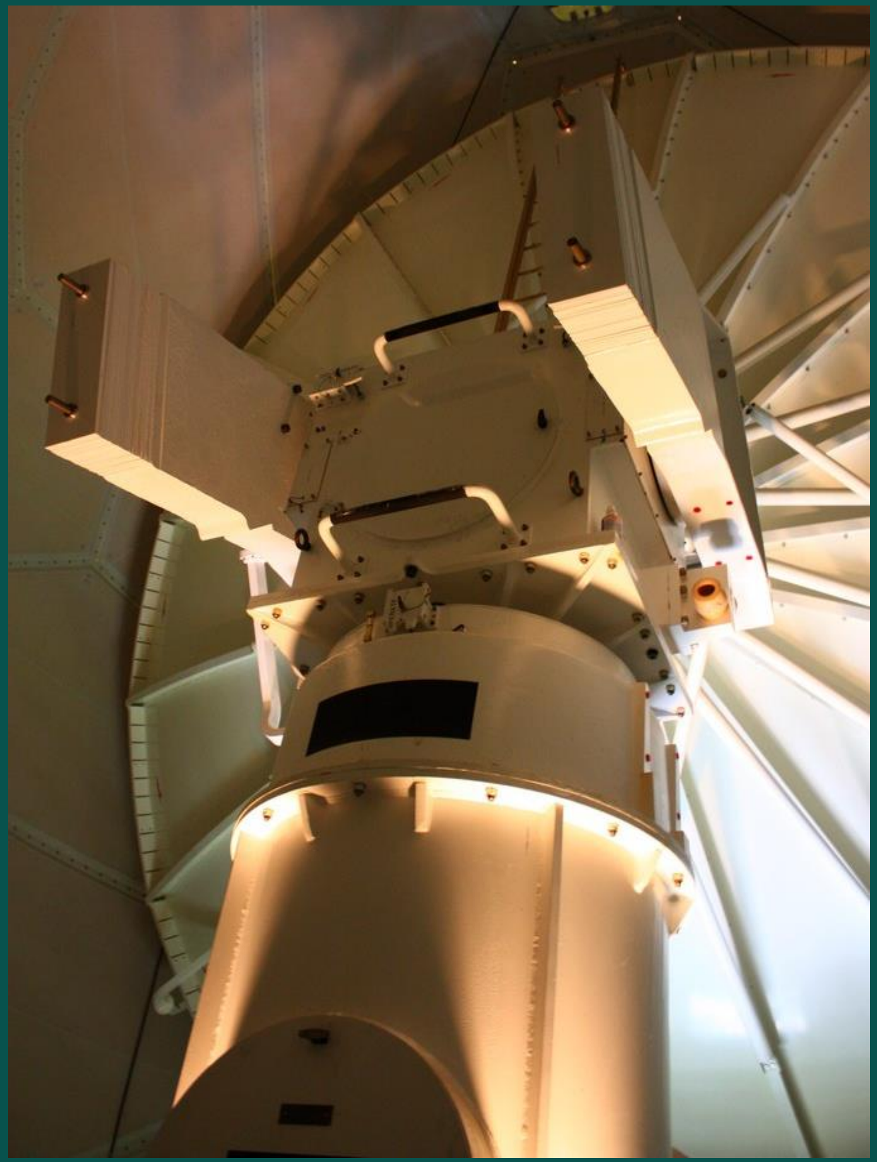
The change in frequency of the returned radar signal, used to determine the velocity of the target.

Historical development

1941	First observation of precipitation by radar was made in Britain
1945	First account of radar observation of a tropical cyclone was published
1949	US armed services uses radar during war and afterwards radar was deployed in the thunderstrom project

Historical development

The british "Baby Maggie" Radars operating at a frequency of 204 MHz were in use for some years in India for radiosonde balloon tracking until replaced by more sophisticated device



Early radars are mostly in the X band but finding that this wavelength suffers from heavy attenuation by rainfall. Subsequently switch over to longer wavelengths 5 and 10cm.

Early days the Meteorological radar used for two purpose: For Tracking balloons to determine upper wind and for detecting precipitating cloud systems

Historical development

1950 Aviation and Marine radars were modified for operational meteorological use in Britain

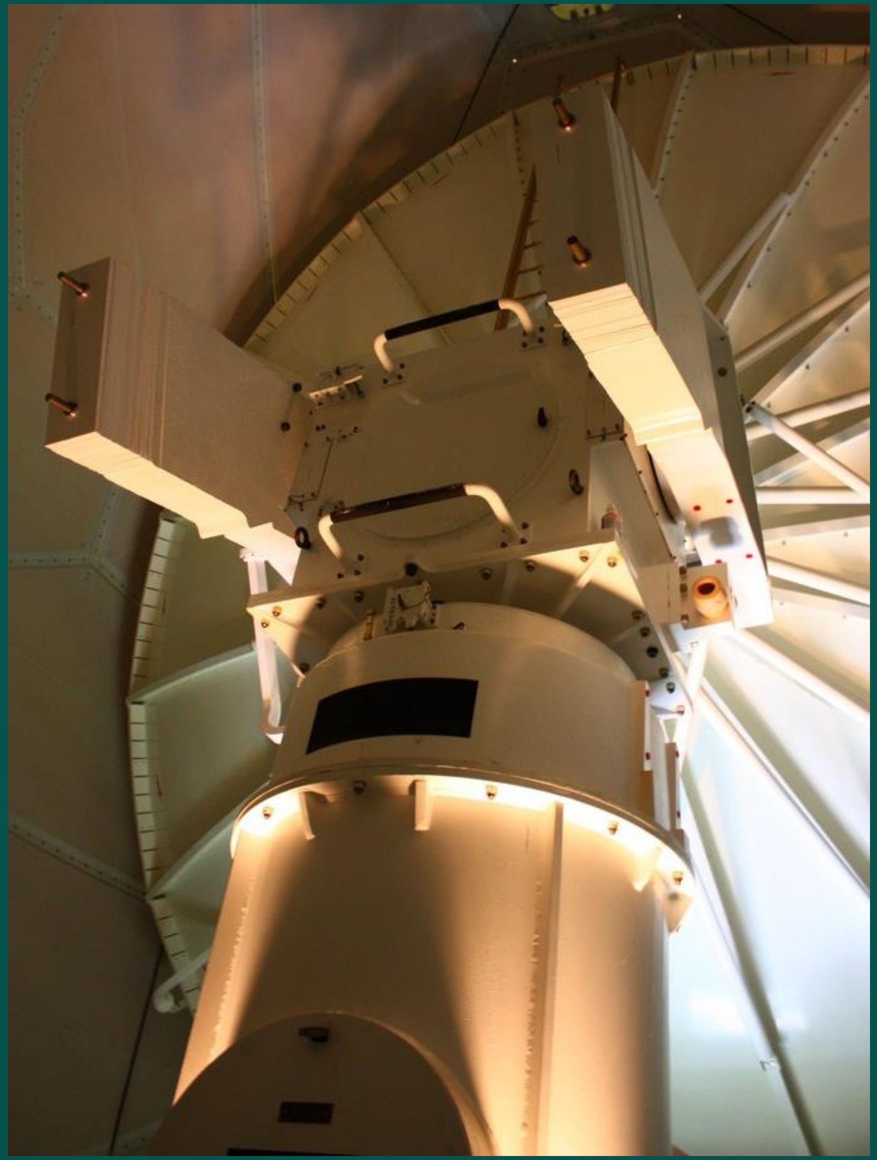
1950 Committee on weather radar was formed in Japan

1950 China work was started with imported radar

Historical development

1954	First 3cm weather radar made in japan was installed at Metrological research Institute near Tokyo
1954	Research on Drop size distribution in Different types of rainfall
1954	Estimation of precipitation from Radars

Historical development



1965 A remote controlled weather radar - Probably the worl'ds highest was set up on Mt. Fuji (3776m asl) for detecting Typhoons

1975 Rapid development has taken place in many plarts of the world in automation of radar operation, DSP, forecasting

2000 Development of dual-polarization Doppler radar, enhancing the ability to analyze precipitation

global Adoption and Network Development

IMD Radar Network (India): A network of Doppler radars monitoring weather conditions across India.

NEXRAD (U.S.): A nationwide network of Doppler radars providing comprehensive weather coverage.

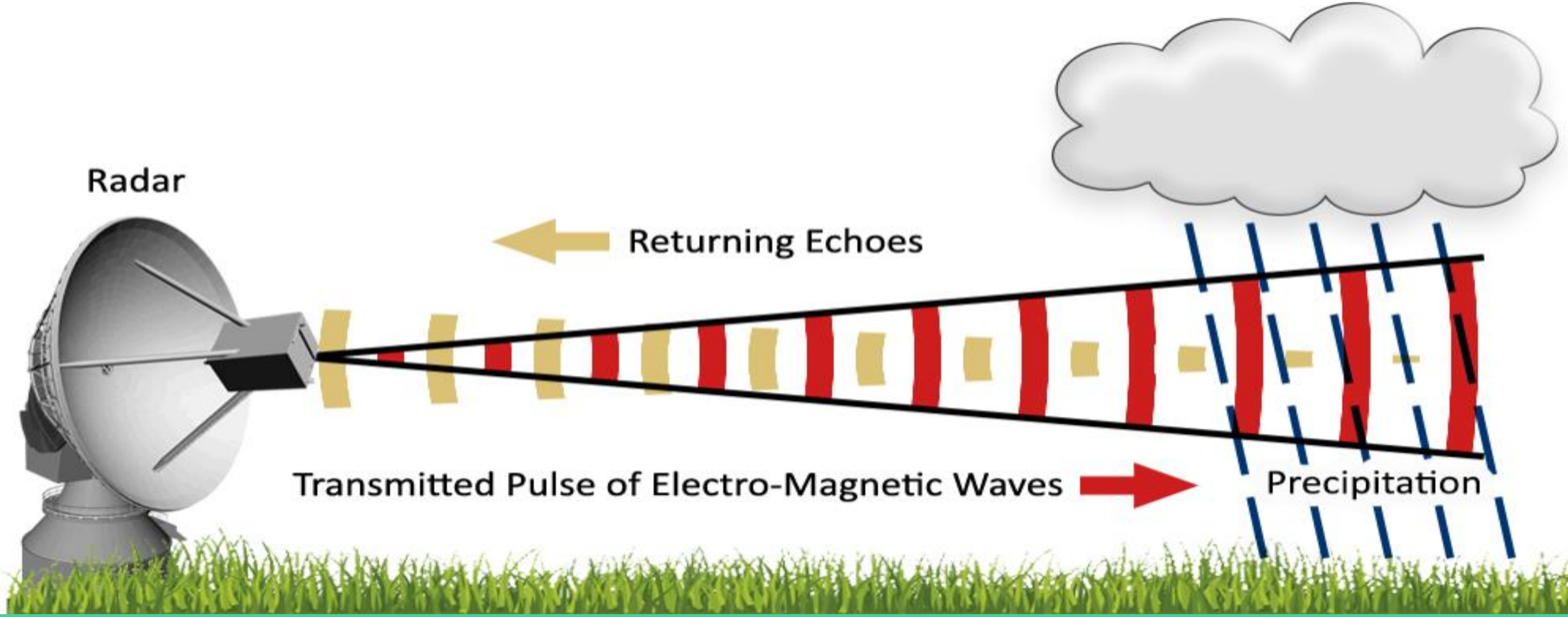
EUMETNET OPERA (Europe): A European initiative that coordinates radar data sharing across member states.

Current and Future Trends

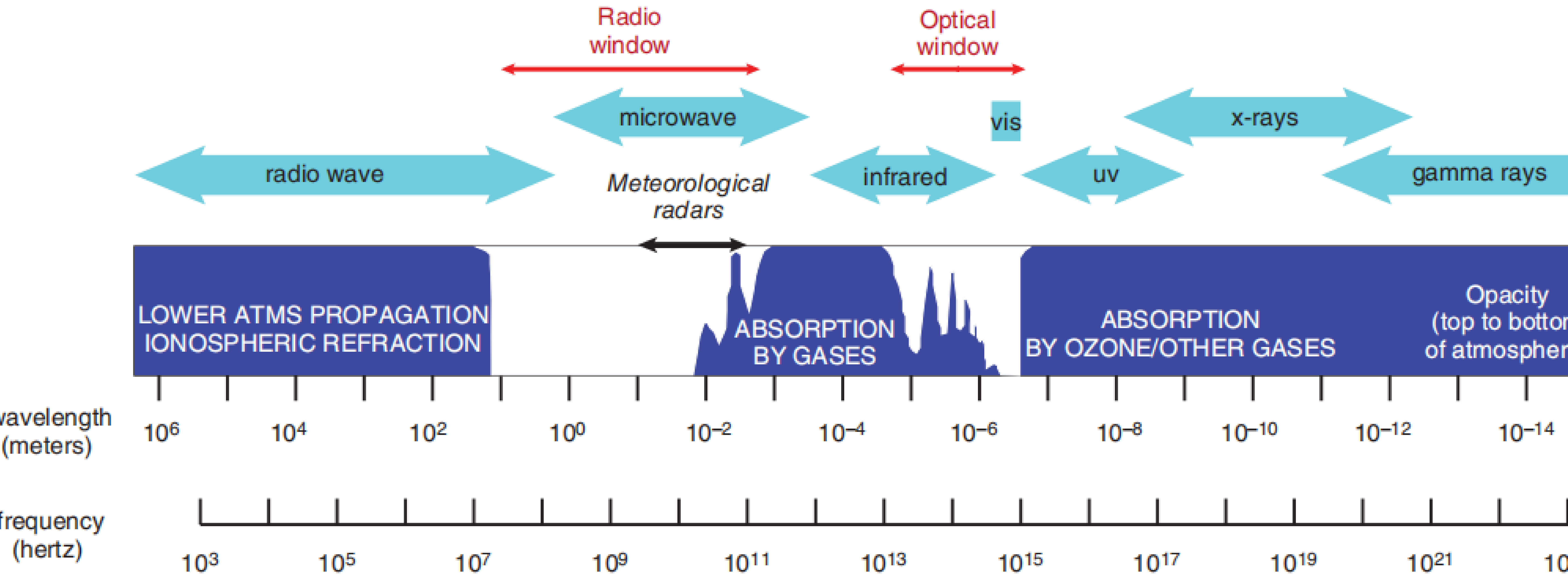
Emerging Technologies:

- ✓ **Phased-Array Radar:** A new generation of radar systems that can scan the atmosphere faster and with greater detail.
- ✓ **AI and Machine Learning:** Technologies that are being used to enhance the analysis of radar data, leading to more accurate weather predictions.
- ✓ **Space-Based Radar:** The potential for radar systems in space to provide global coverage and monitor weather conditions from a new perspective.

- ✓ Modern Doppler radar systems are becoming more advanced with the integration of artificial intelligence & machine learning,
- ✓ improved data analysis techniques.
- ✓ The future may see even more precise and accurate weather predictions using these technologies.



02 Wavelength of Doppler Weather Radar



$c = \lambda f$,

Atmospheric absorption is clearly an effect that must be considered.

Coding of Wave bands

The coding of wave bands as

i. L: 23cm Wavelength
ii. S: 10cm Wavelength
iii. C: 5 cm Wavelength
iv. X: 3cm Wavelength
v. K: 1cm Wavelength so on

Coding of Wave bands

- ✓ During WW-II, radar operations were secret, and to avoid having the actual frequency discovered by the enemy, letter band designations were used to identify the frequency of the radar system
- ✓ This practice continues to this day and is common in radar meteorology
- ✓ A very limited number of frequency within each band are allocated for meteorological radar usage

Band designation

Band designation	Frequency range	Range of wavelengths	Main applications
VHF	30–300 MHz	10–1 m	Observation of clear air phenomena in the troposphere and stratosphere, wind-profiling, turbulence, refractive index structure
UHF	300–1000 MHz	1–0.3 m	
L	1–2 GHz	30–15 cm	Clear air and precipitation phenomena
S	2–4 GHz	15–7.5 cm	Precipitation measurement, tropical cyclone observation, local severe storms, radio wave propagation
C	5–7 GHz	6–4.5 cm	Local severe storms, precipitation measurement, tropical cyclone observation, radio wave propagation, use on aircraft
X	9–11 GHz	3.3–2.7 cm	Thunderstorm and gust front detection, radio wave propagation, use on aircraft

Band designation

Band designation	Frequency range	Range of wavelengths	Main applications
Ku	12–18 GHz	2.5–1.7 cm	Cloud physics, ceilometers, air- and space-borne radar, Synthetic Aperture Radar (SAR) for sea surface studies, Precipitation measurement from attenuation, tornado observation
Ka	27–40 GHz	1.1–0.75 cm	
millimetre	40–300 GHz	7.5–1 mm	Ceilometers, cloud microphysics and dynamics, tornado observation
W	94 GHz	3.2 mm	
F	140 GHz	2.14 mm	
G	220 GHz	1.30 mm	

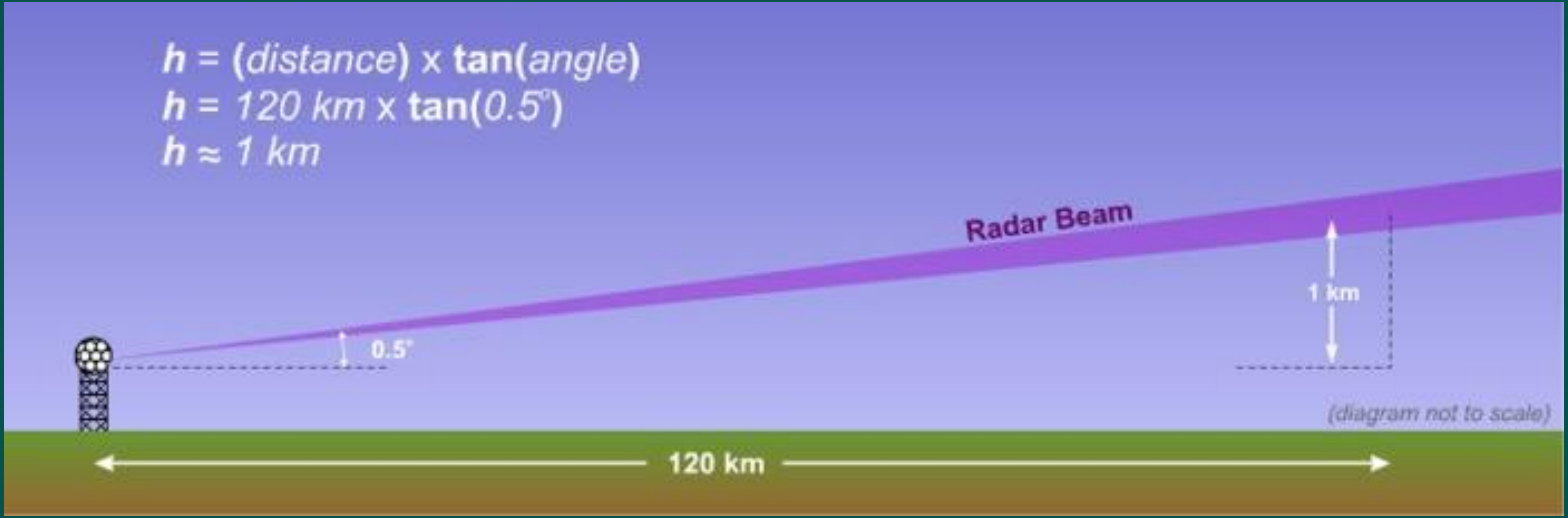
Choice of Wavelength

1. Mission of the radar
2. Platform on which the radar antenna is mounted
3. Available power to run the radar system
4. Factors to Consider

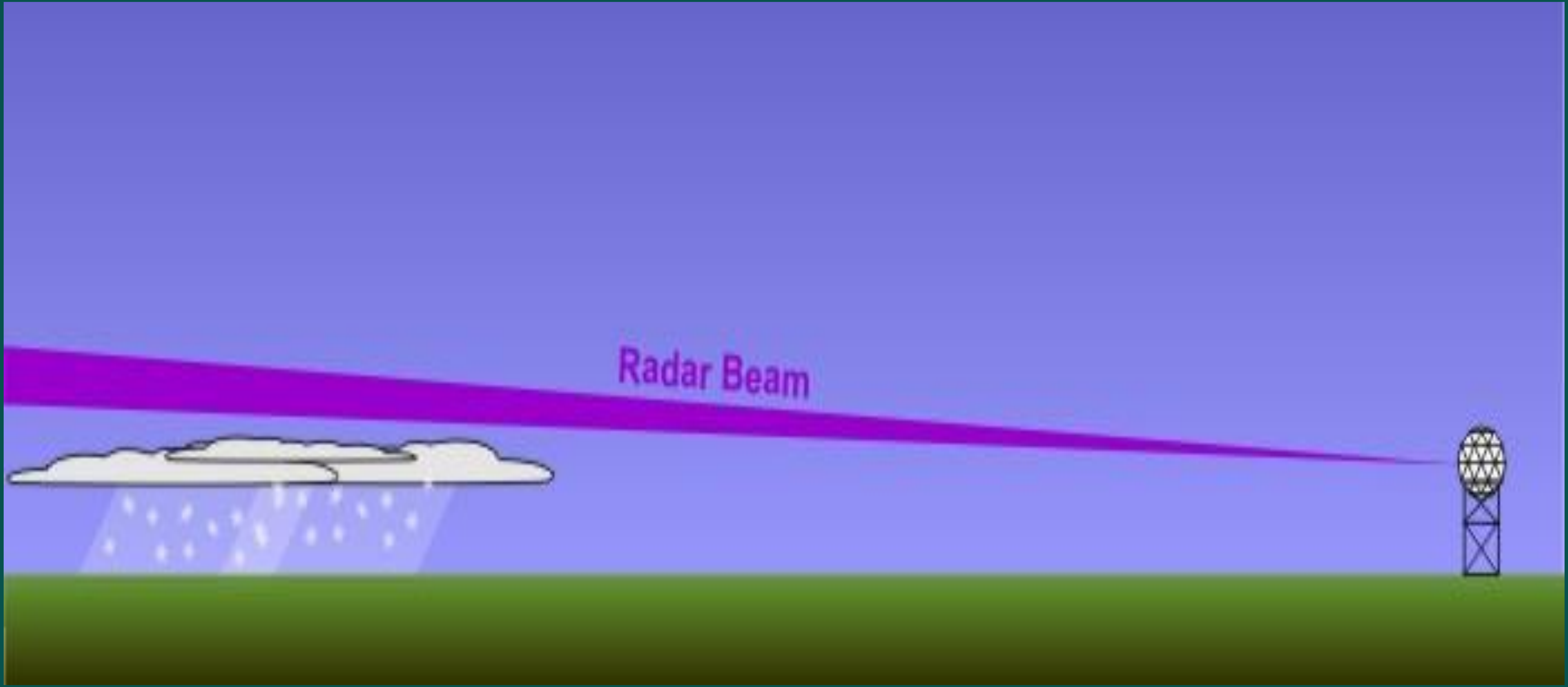
Dual Wavelength Radar

- ✓ Two different Wavelengths can be used to observe the same target synchronously
- ✓ 10 and 3cm wavelength is used simultaneously, raindrops, which are usually less than 5mm in diameter, will scatter according to the Rayleigh law
- ✓ But in Hail, 3cm wavelength Mie scattering will occur but at 10cm Rayleigh scattering occurs. hence reflectivity factor will be different in the two cases
- ✓ By seeing the ratio of Z, it can enable to detection of Hail signal
- ✓ Condition: both wavelengths should scan the same volume so the two beam width & patterns must be identical but it is difficult to achieve

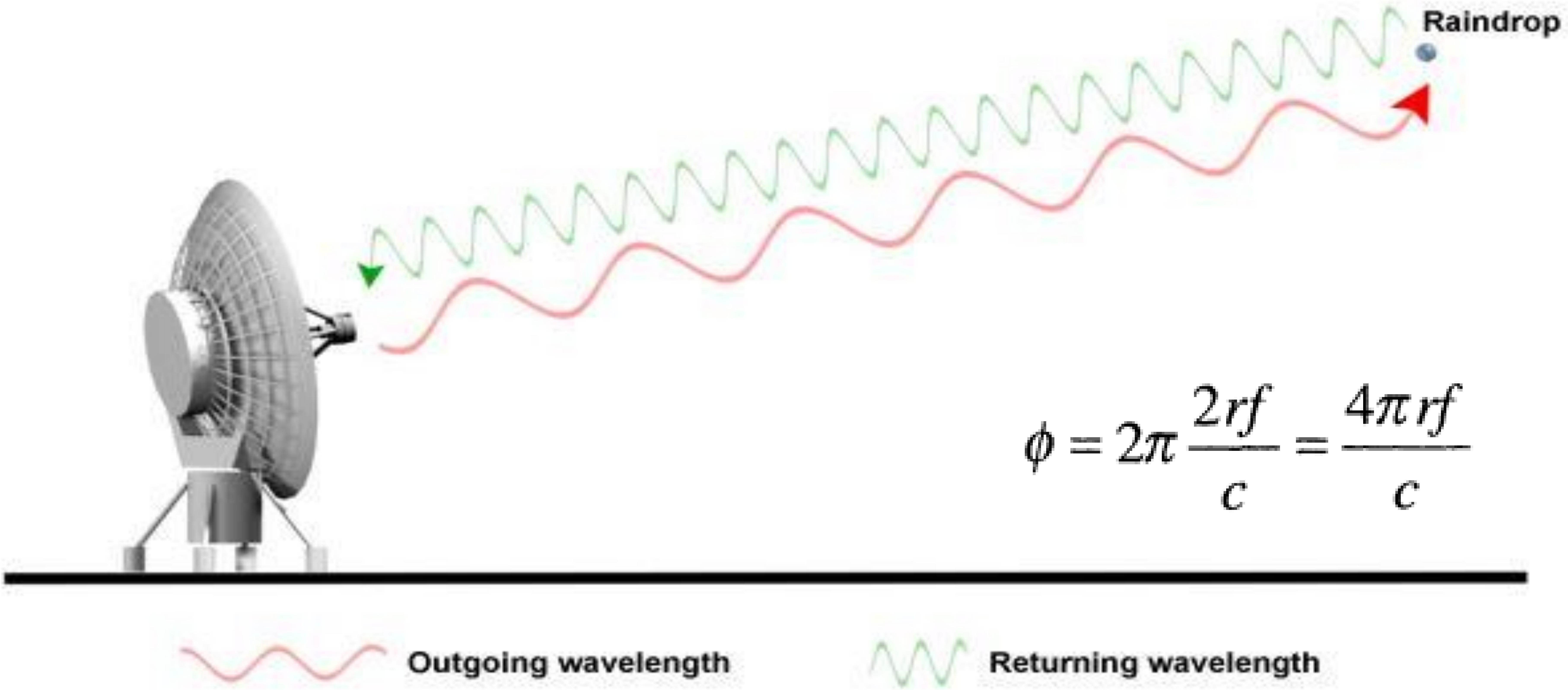
Beam height calculation



Radar Beam

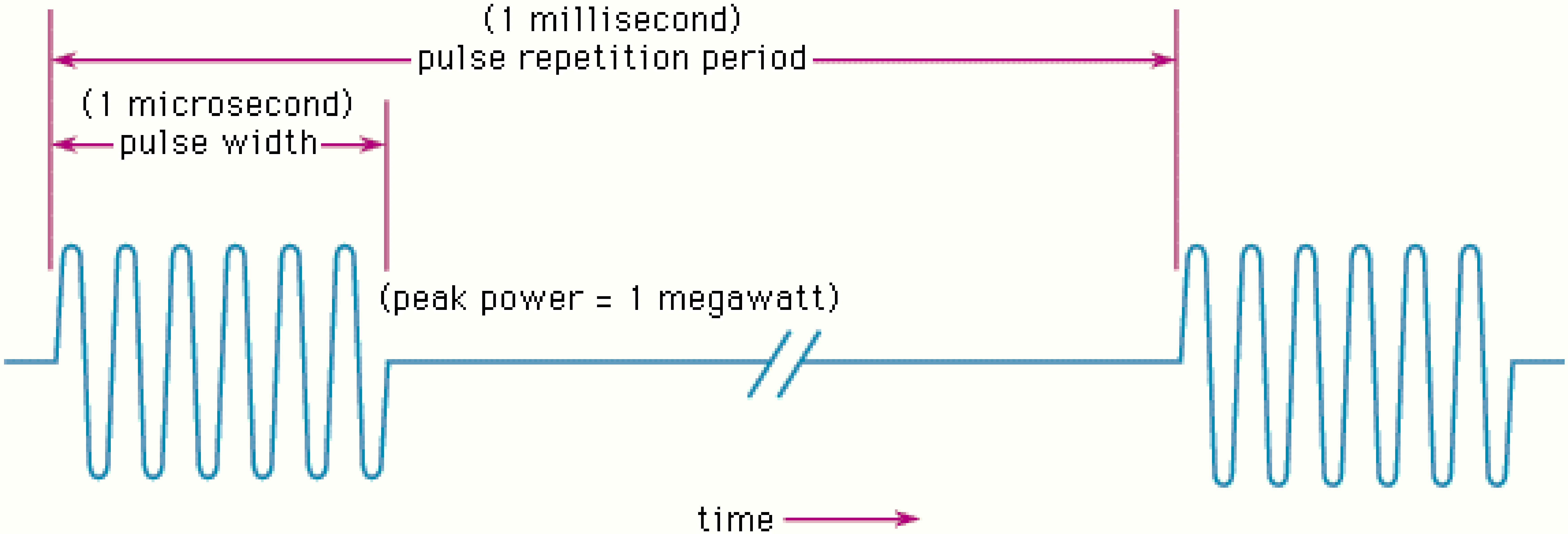


Continuous Wave Radar

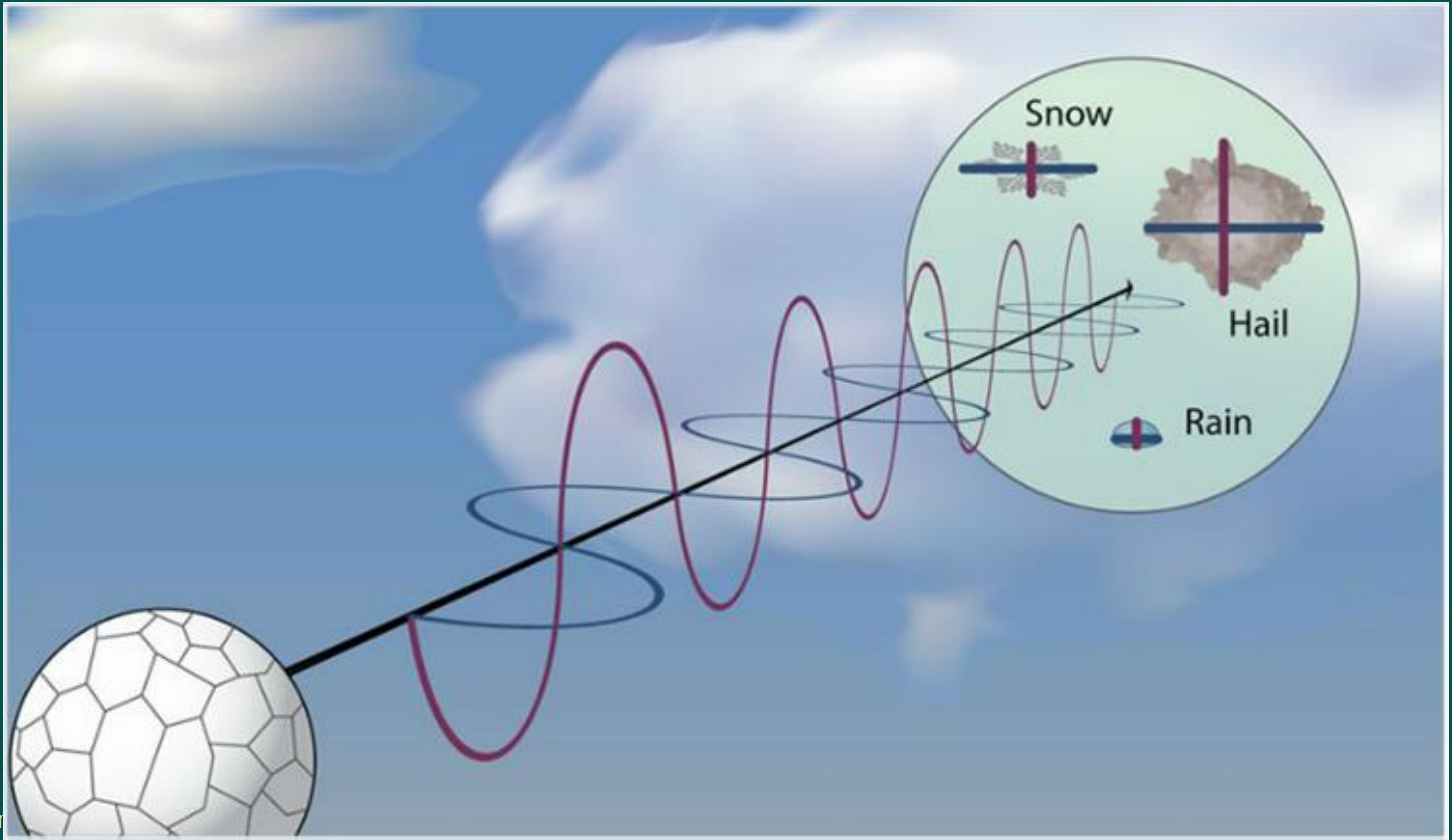


$$\phi = 2\pi \frac{2rf}{c} = \frac{4\pi rf}{c}$$

Pulsed Radar



Dual-Polarization



Maximum Unambiguous Velocity and range

$$v_{max} = \frac{(p.r.f.).\lambda}{4} = \frac{(p.r.f.).c}{4f}$$

To maximize rmax, we have to compromise on Vmax. vice versa

$$v_{max} = \frac{c^2}{8fr_{max}} = \frac{\lambda.c}{8r_{max}}$$

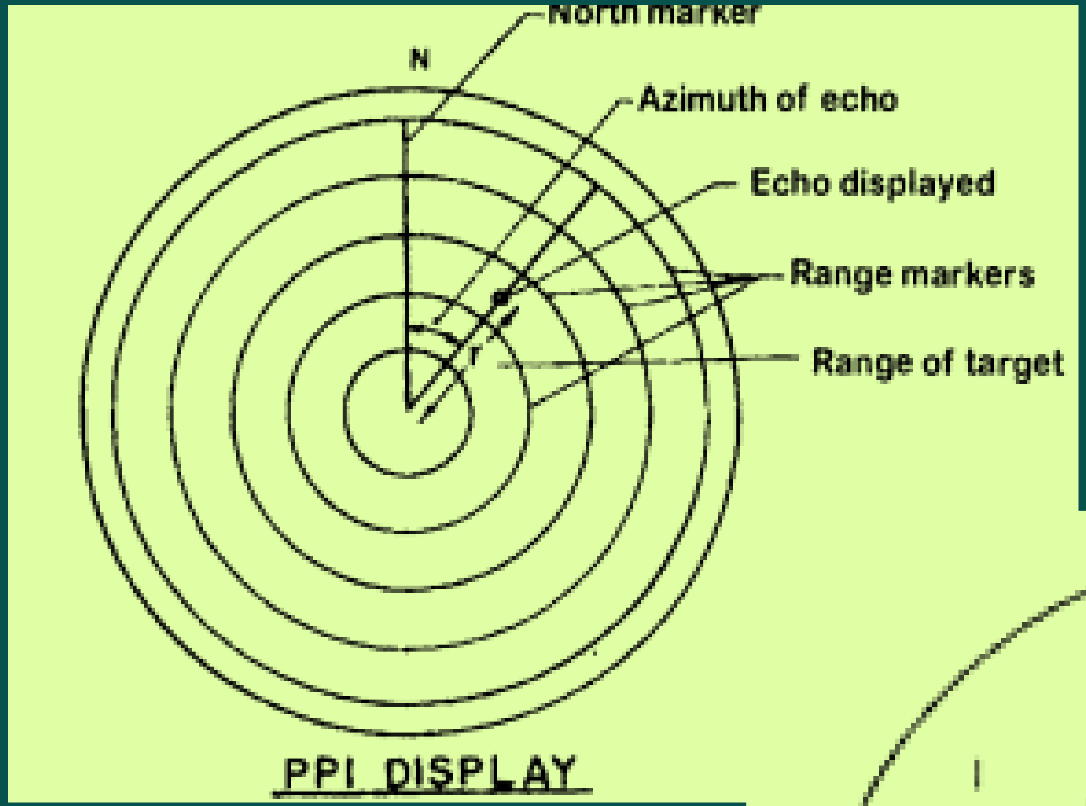
Maximum unambiguous range rmax = c/(2*prf)

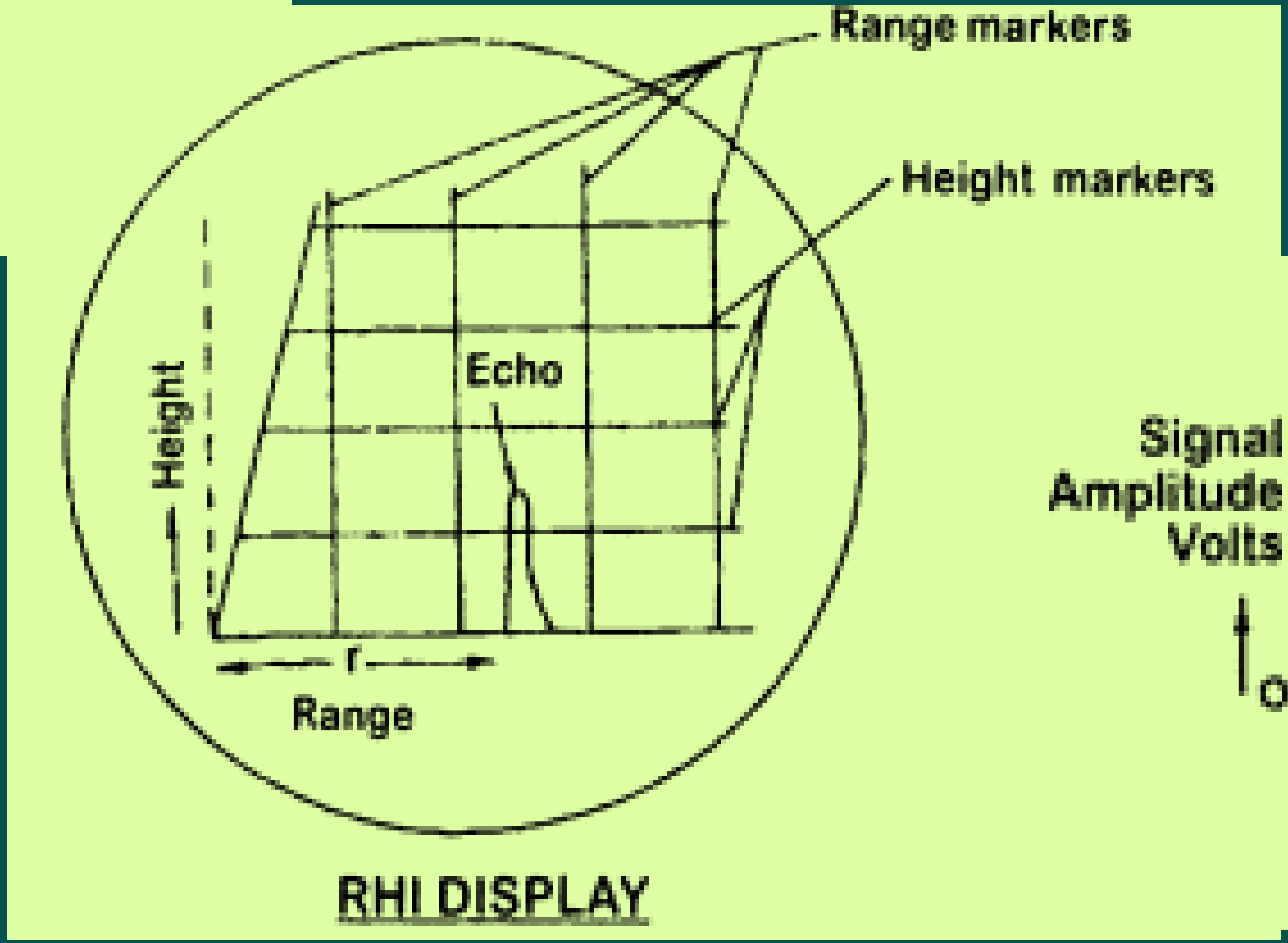
Example

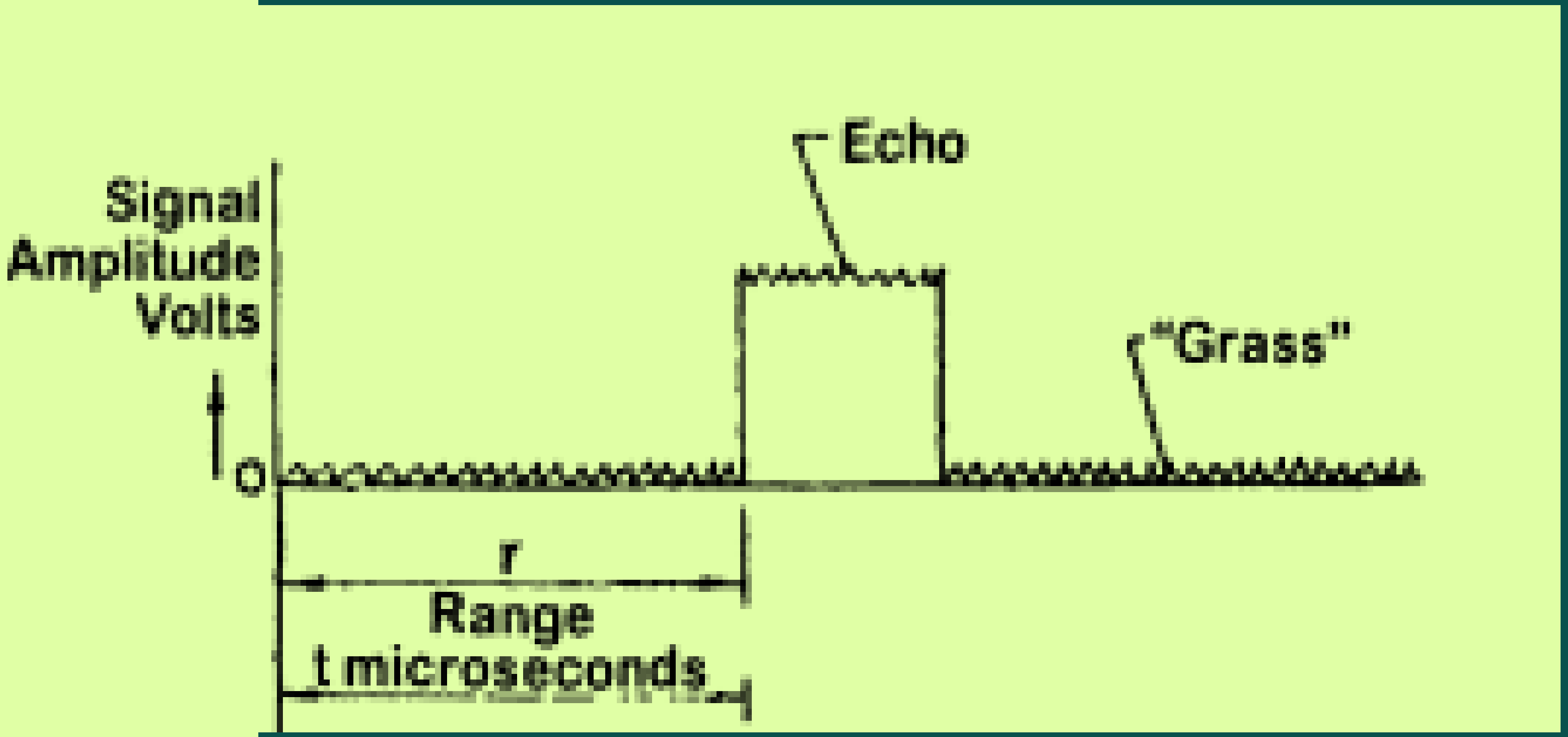
1 microsec transmitting and 999 microsecond listening so time interval is 1 milli second. The number of Pulse transmitted per second is PRF.

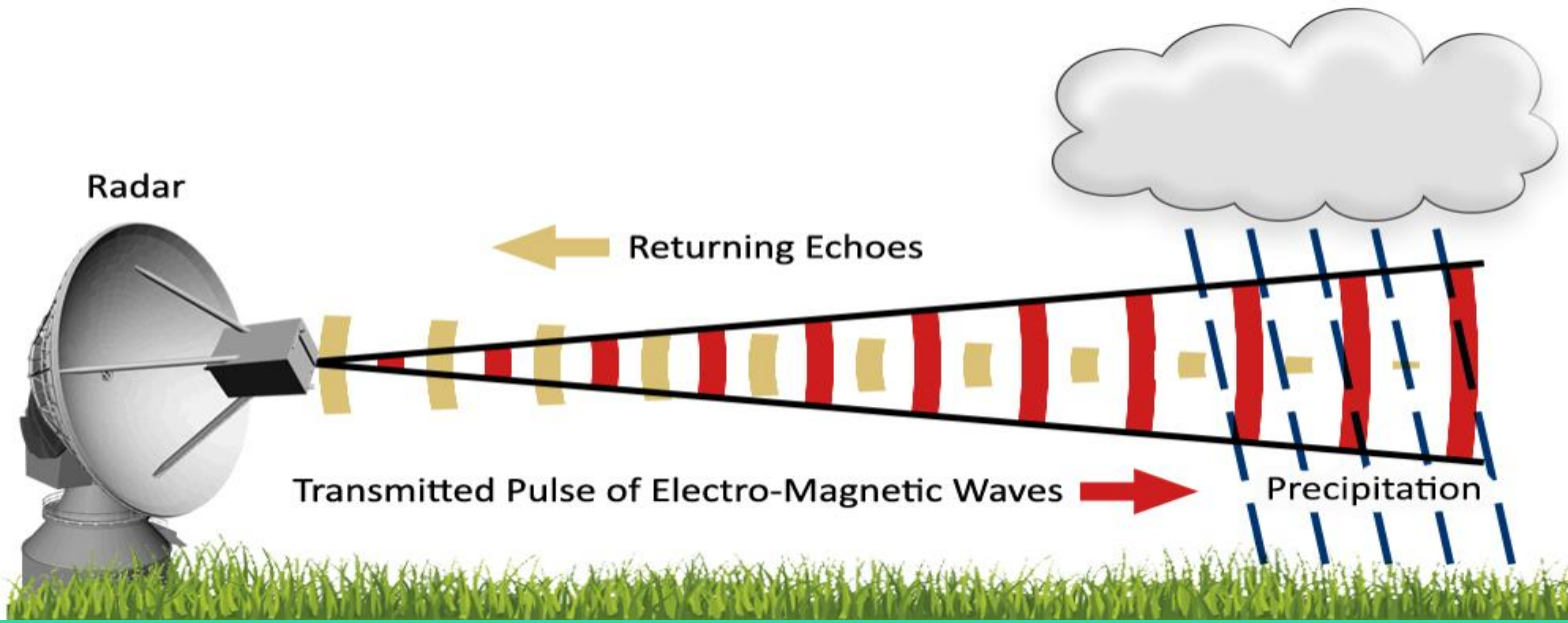
In this case, PRF will be 1000Hz.
Maximum Range will be 150km.
Fmax = prf/2

Common Radar Display









03 Block diagram of DWR

Block Diagram of DWR

Transmitter

Sends out the radar pulse.

Antenna

Directs the pulse and receives the echo

Receiver

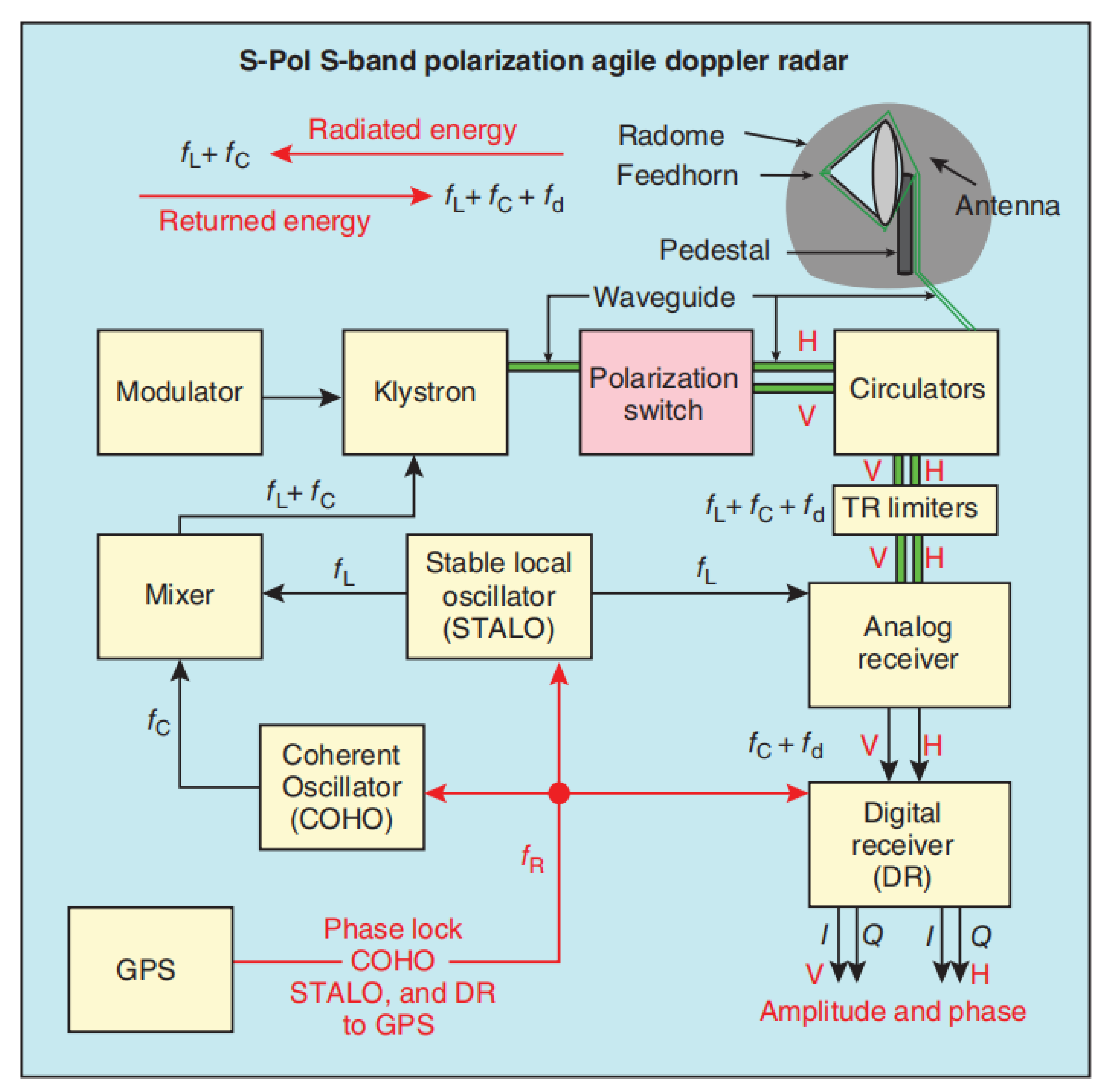
Amplifies and processes the received signal

Signal Processor

Analyzes the signal to extract useful information

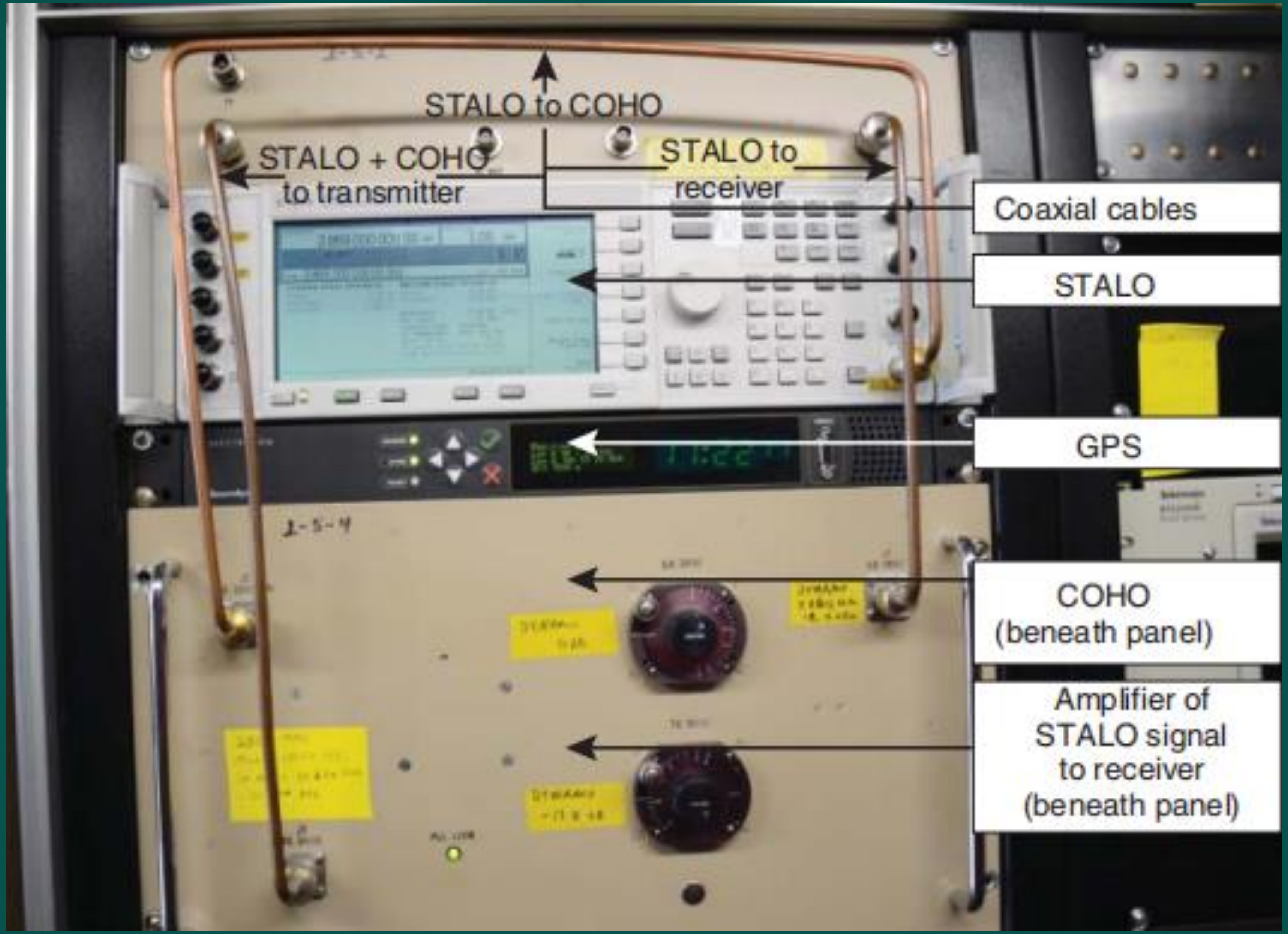
Block Diagram of DWR

- ✓ Each Component Plays a specific role
- ✓ High Level Radar system Diagram
- ✓ Transmission and reception Process
- ✓ Signal Processing
- ✓ Omitted Components

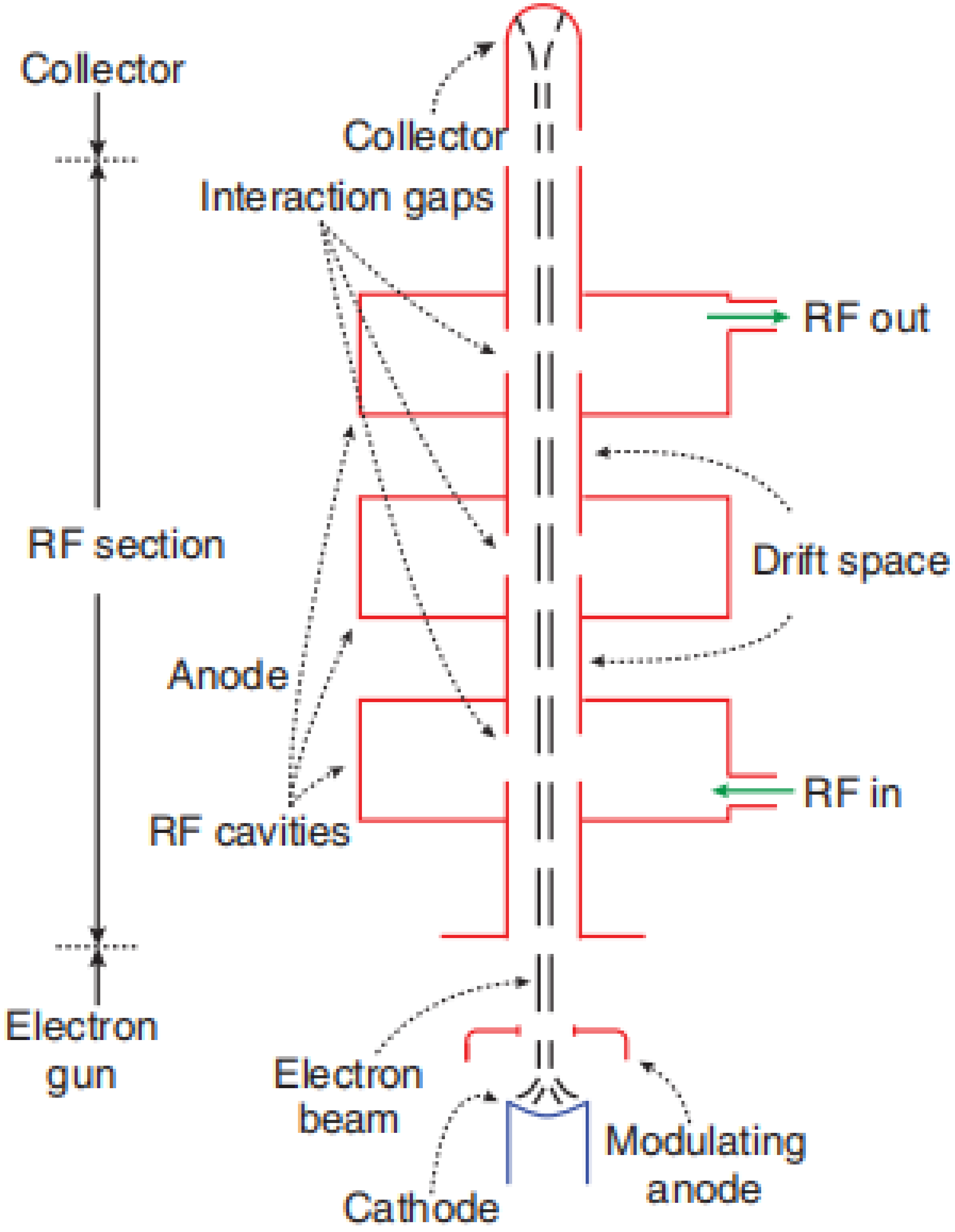


Transmitter

- ✓ Operation of DWR begins with transmission of precisely controlled pulses of Radio waves
- ✓ Key parameter
  - PRF
  - Pulse Width
  - Frequency
- ✓ Radar Transmitter Components
- ✓ Magnetron / Klystron/ SSA
- ✓ STALO, COHO, Modulator

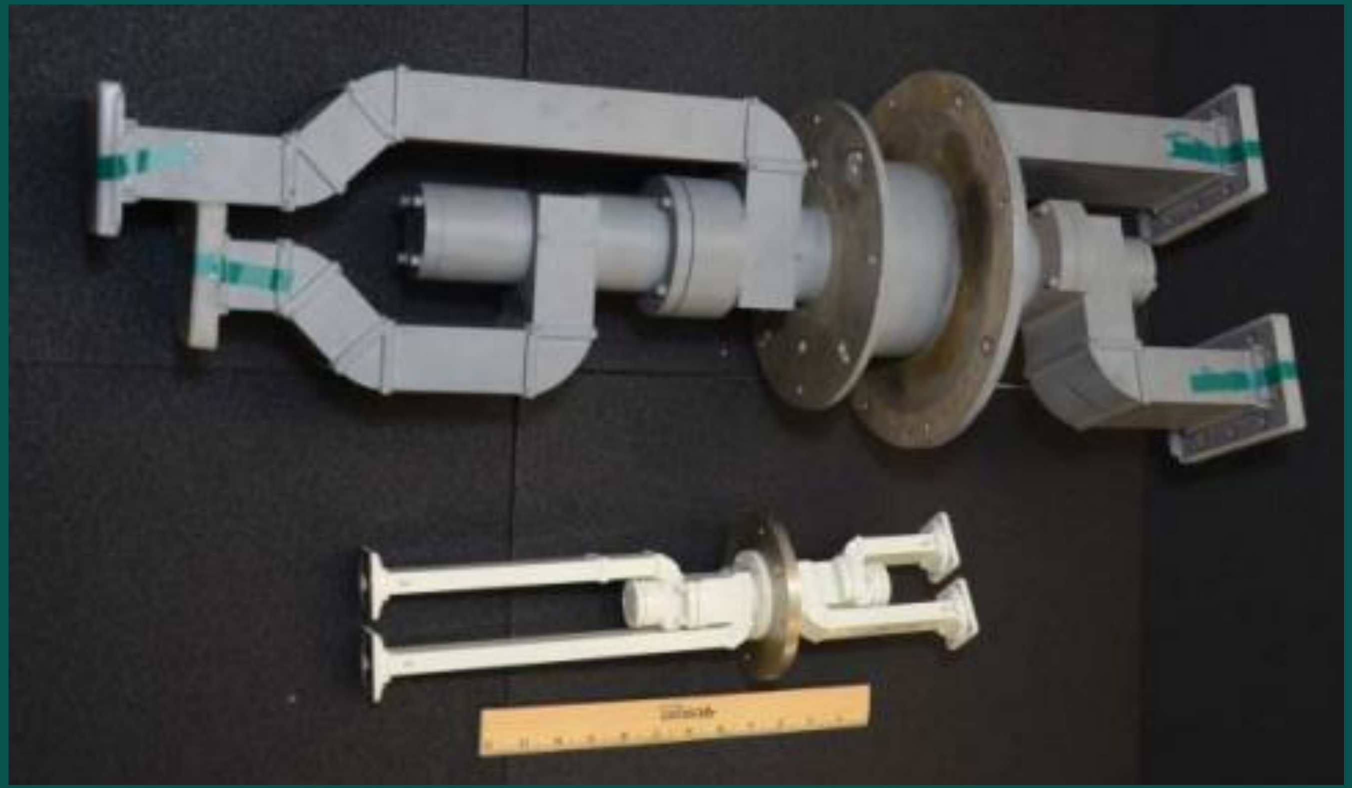


Transmitter



- ✓Electron Gun
- ✓Modulating Anode
- ✓Cavity Structure
- ✓Electron Beam and collector
- ✓Klystron Operation
- ✓Key Components of Klystron
  - -Focus Coil
  - - Power Supply
  - - Transformer
  - -Cooling System

Wave guide & Circulators



- ✓ Purpose of Waveguide
- ✓ Key Characteristics of Wave guide
- ✓ Polarization and Waveguide Switches
- ✓ The waveguide is a critical component in radar systems, ensuring the efficient transmission of EM waves between the transmitter and antenna while maintaining signal integrity, preventing arcing, and controlling polarization based on the radar's operational needs.

Wave guide Switches

Waveguide switches are incorporated to alternating H and V polarization

Different types

- ✓ Transmit and receive both H & V polarization states simultaneously
- ✓ Transmit one Polarization and receive both
- ✓ Implementation is Based on design of Radar
- ✓ Pulse to pulse basis
- ✓ Singe or dual transmitter or receiver system
- ✓ Circularly polarized waveform different design (Old radars)

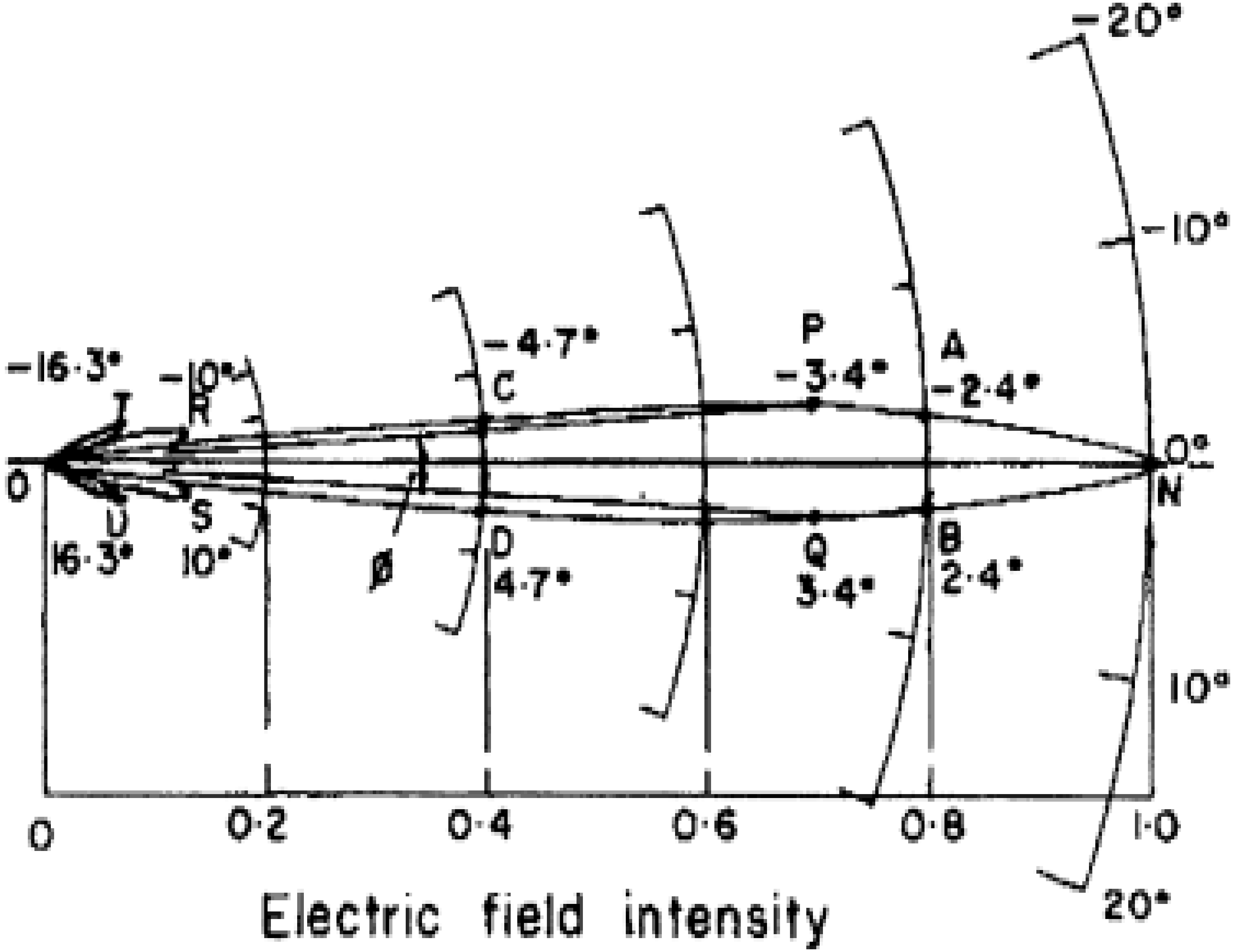
Circulator & T-R Limiters

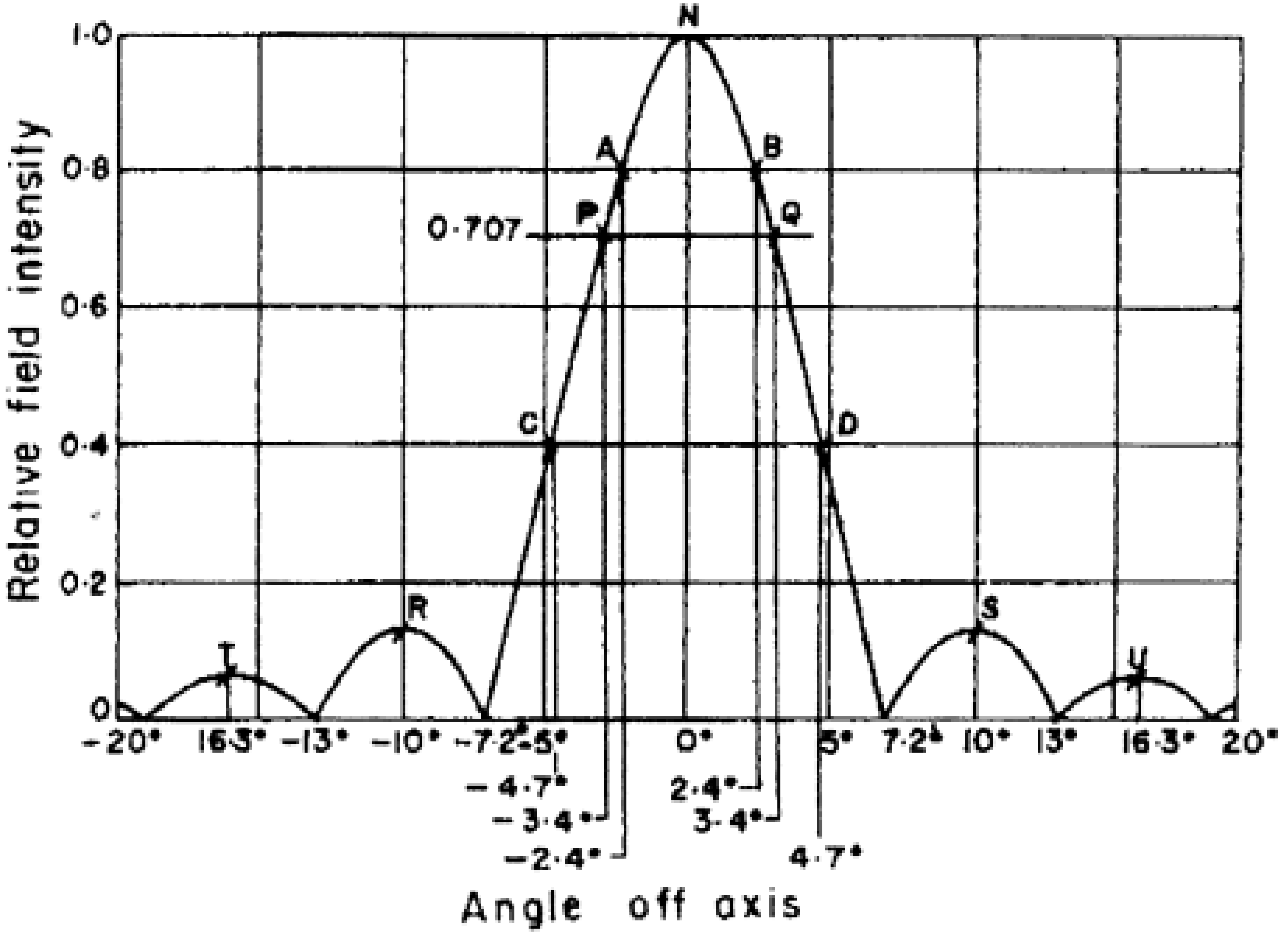
- ✓Transmitted power > Received power many orders of magnitude
- ✓Receiver must be sensitve to very low power levels
- ✓Protected from transmitter
- ✓We need a switch type of device to isolate transmitter and receiver. That device is called circulator

Antenna

- ✓ Introduction to Radar Antenna
- ✓ Must be Highly directional
- ✓ Size and Shape of antenna determine the beamwidth
- ✓ Types of Antenna
  - Parabolic Reflector
  - Phased Array Antenna
- ✓ Antenna Subsystem
- ✓ Purpose of Radome

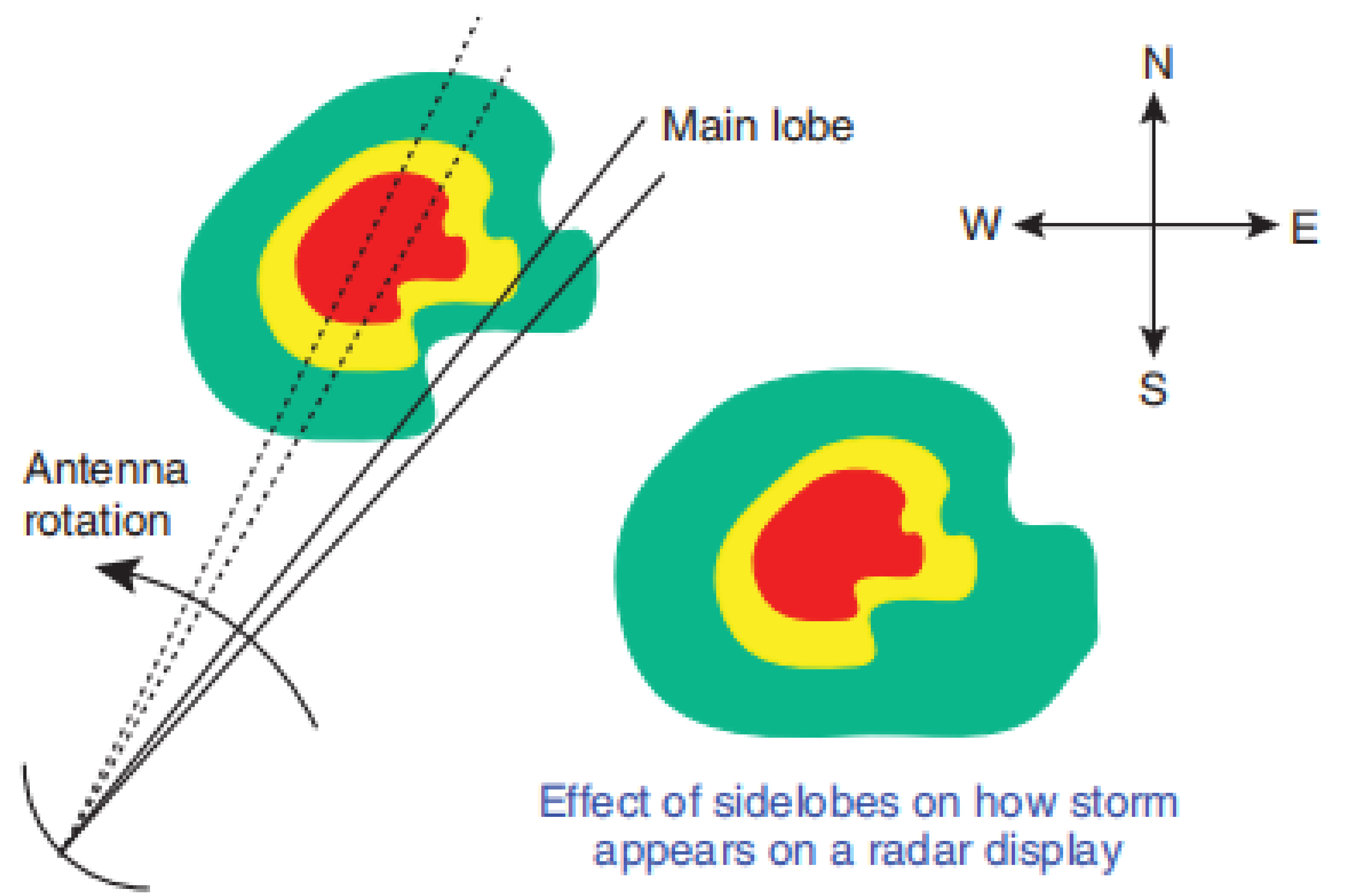
Antenna Radiation Pattern





$$\phi = \frac{1.22\lambda}{D} \text{ radians} = \frac{70\lambda}{D} \text{ degrees}$$

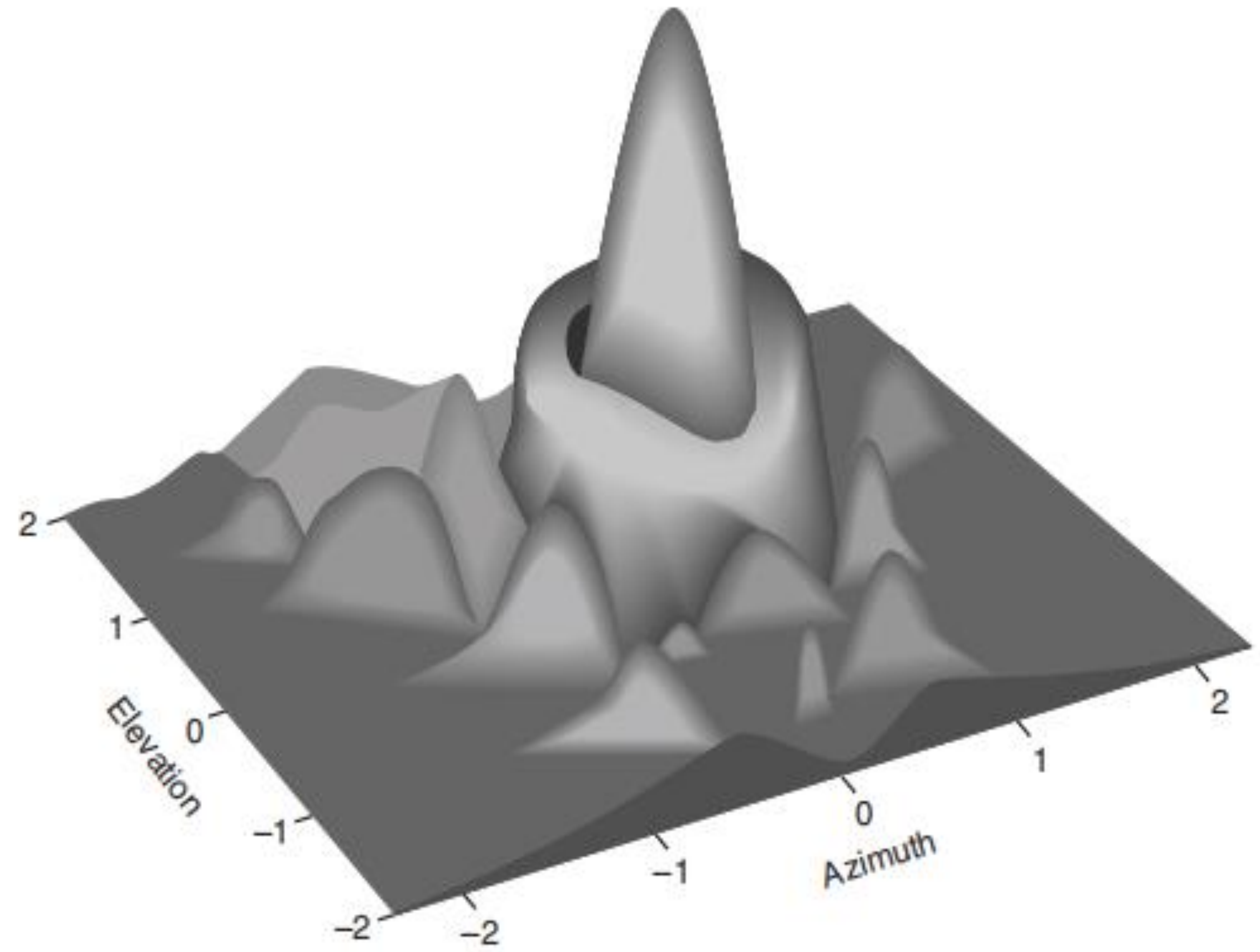
Effect of Side lobes

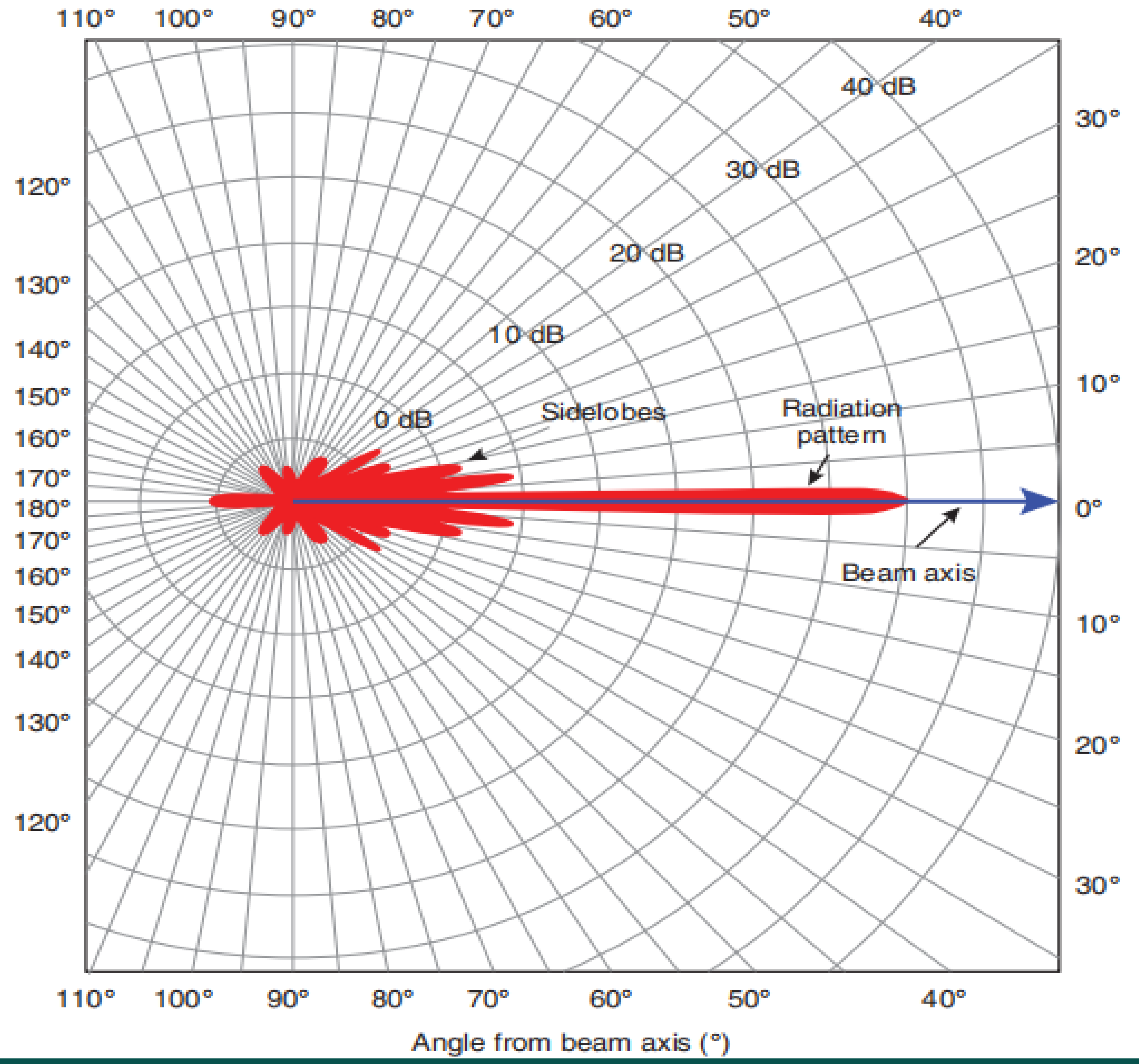


Effect of sidelobes on how storm appears on a radar display

- ✓Antenna Designed uses Tapered Illumination approach
- ✓Feed horn design
- ✓Side lobe typically 20-25 dB below the gain of Main lobe
- ✓It create False Echoes

gain Function





Radar Echoes and Data Interpretation

- ✓ Echoes from Target
- ✓ Radar Antenna Receives these echoes
- ✓ The receiver system plays a critical role in Interpreting the data captured by the antenna
- ✓ Understanding the echo by Radar
  - Range Measurement
  - Echo Intensity
  - Doppler Shift

Receiver Section

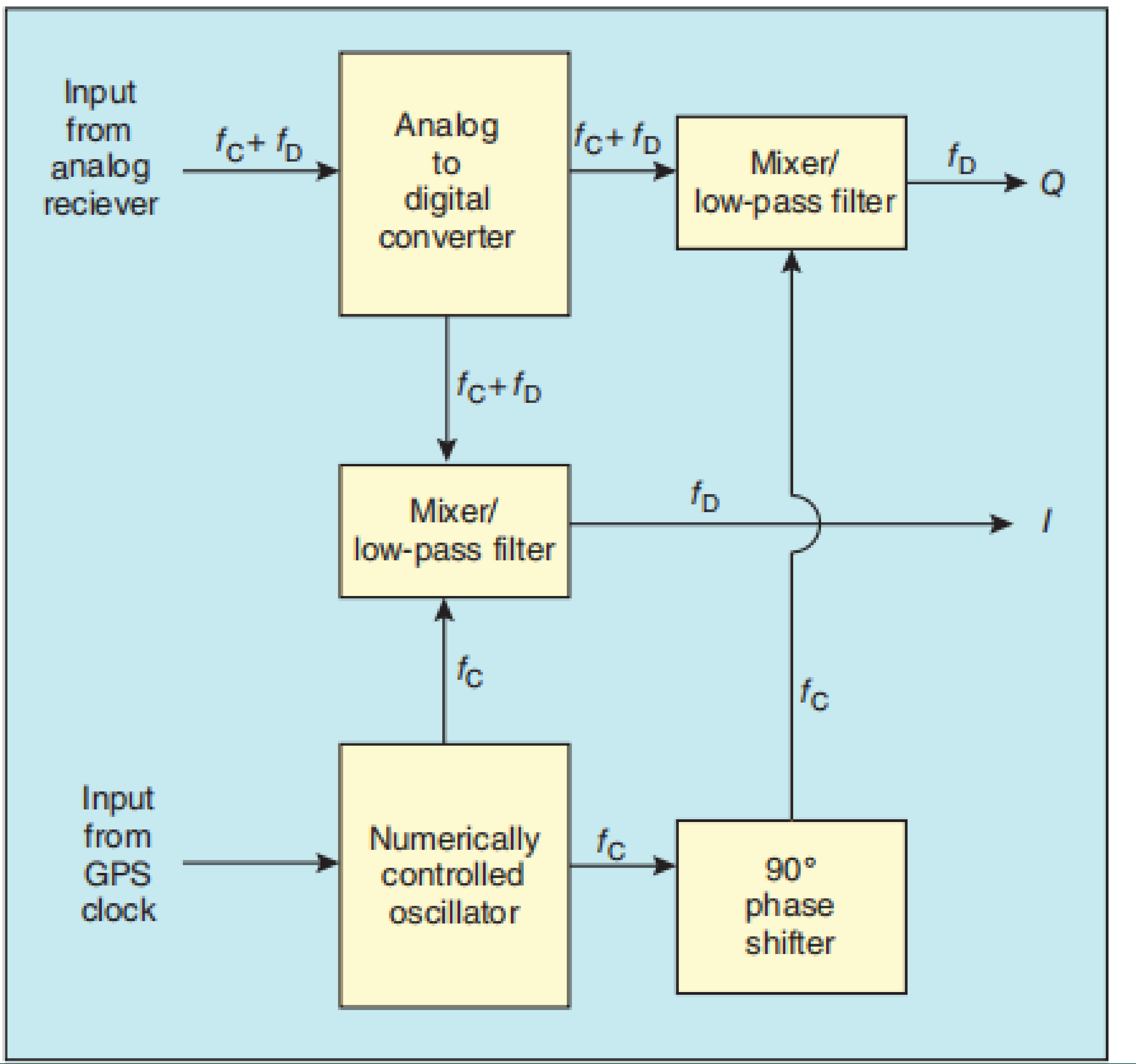
- ✓ How the radar collects the energy
- ✓ Major Components of the receiver subsystem
  - Co-Polar Channel
  - Cross Polar Channel
  - Convert Microwave Signal to Electrical Signal
- ✓ Purpose of LNA
- ✓ Transmit-Receive (T-R) Switch
- ✓ Signal Processor and its function

Retrieval of the I&Q signal

- ✓ Digital Receiver extract two piece of information Amplitude and Phase
- ✓ Quadrature demodulation
- ✓ $Er = A(m,n) \cos[2\pi(fC + fd)t + \phi(m,n)]$

$A(m,n)$ -> Amplitdue

$2\pi(fC + fd)t + \phi(m,n)$ => Phase of the signal



Retrieval of the I&Q signal

$$I \text{ Channel} \quad \frac{A_0 A_{(m,n)}}{2} \cos(2\pi f_d t + \phi_{(m,n)})$$

$$Q \text{ Channel} - \frac{A_0 A_{(m,n)}}{2} \sin(2\pi f_d t + \phi_{(m,n)})$$

$$\sqrt{I^2 + Q^2} = \frac{A_0 A_{(m,n)}}{2}$$

$$\tan^{-1}\left(\frac{Q}{I}\right) : 2\pi f_d t + \phi_{(m,n)}$$

$$\tan^{-1}\left[\frac{\sin(2\pi f_d t + \phi_{(m,n)})}{\cos(2\pi f_d t + \phi_{(m,n)})}\right]$$

Radar Data Products

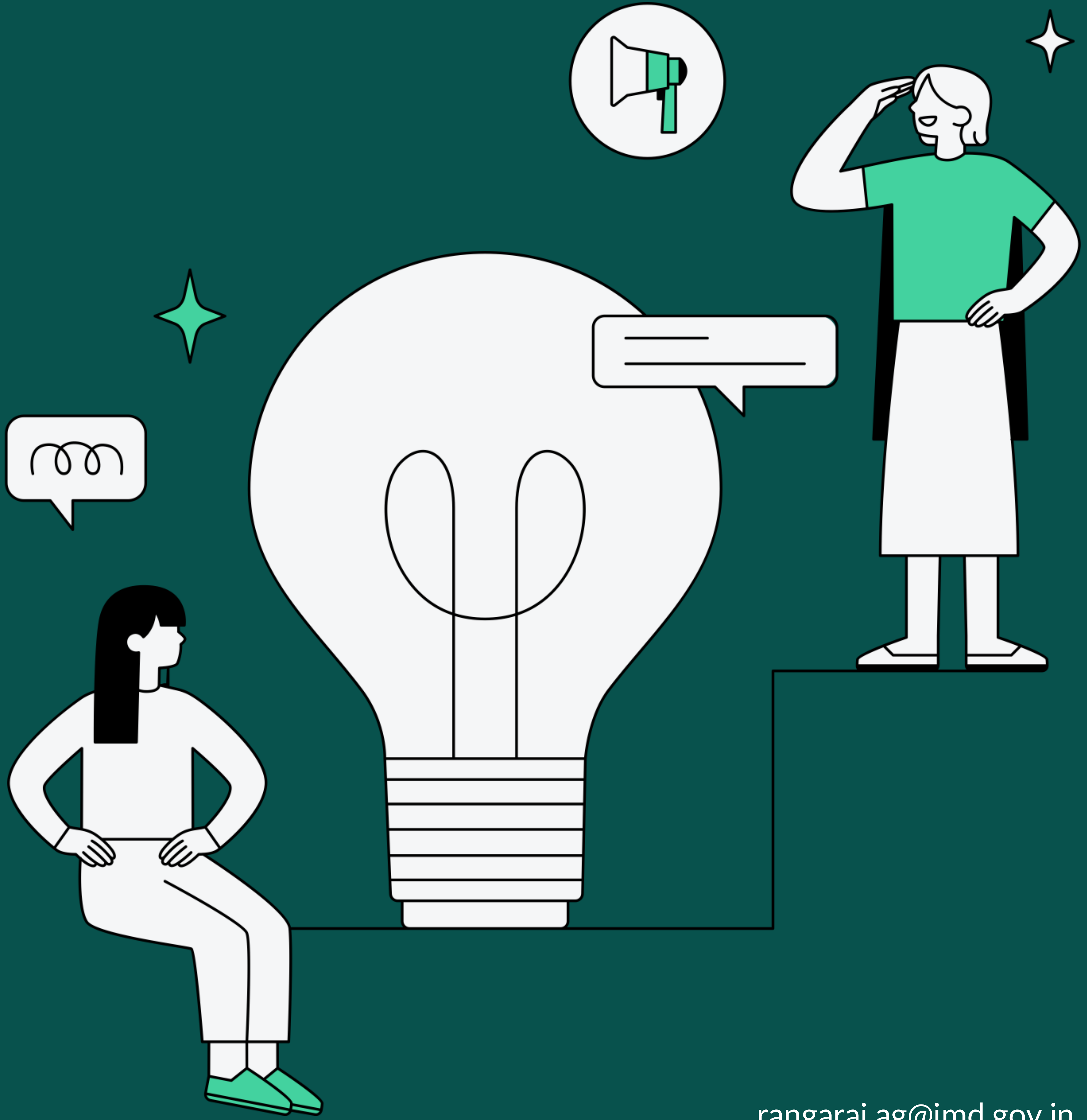
Key Radar Products
- Reflectivity
- Velocity
- Spectrum Width

Importance in Forecasting
- Track Strom
- Predict Wind Pattern

Visual Output
- Reflectivity Maps
- Velocity Fields
- Turbulence Indicators

Challenges & Limitations

- ✓ **Doppler Dilemma:** The trade-off between range and velocity resolution.
- ✓ Unambiguous Range, Velocity and Aliasing
- ✓ **Attenuation:** The weakening of radar signals as they pass through heavy precipitation.
- ✓ **Clutter and Noise:** Unwanted echoes from objects like buildings or terrain.
- ✓ **Resolution Limitations:** The radar's ability to distinguish between closely spaced targets.



Thank you

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