Bharathidasan University

Tiruchirappalli, Tamil Nadu

Programme: M. Tech Geoinformatics

Course: Microwave and Hyperspectral Remote Sensing

Title: Introduction to microwave remote sensing

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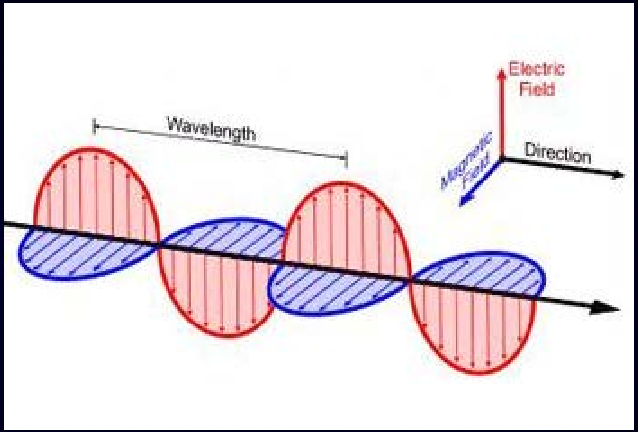
INTRODUCTION

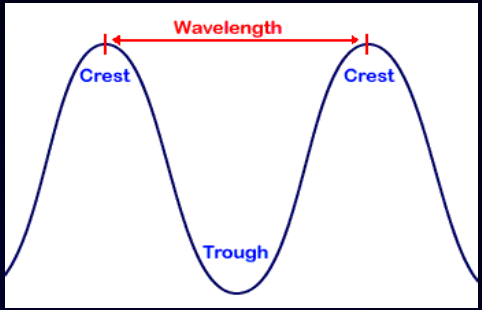
- Remote sensing is the science and art of obtaining information about an object, area or phenomena through the analysis of data acquired by a device without any physical contact.
- To acquire knowledge about remote object, there must be a flow of information between the object and the observer. There has to be a carrier of that information.
- That carrier is the electromagnetic radiation (EMR).



ELECTROMAGNETIC RADIATION

Two characteristics of electromagnetic radiation are particularly important for understanding remote sensing. These are the **wavelength** and **frequency**.

Wavelength is the length of one wave cycle which can be measured as the distance between successive wave crests. Wavelength is measured in meters (m).



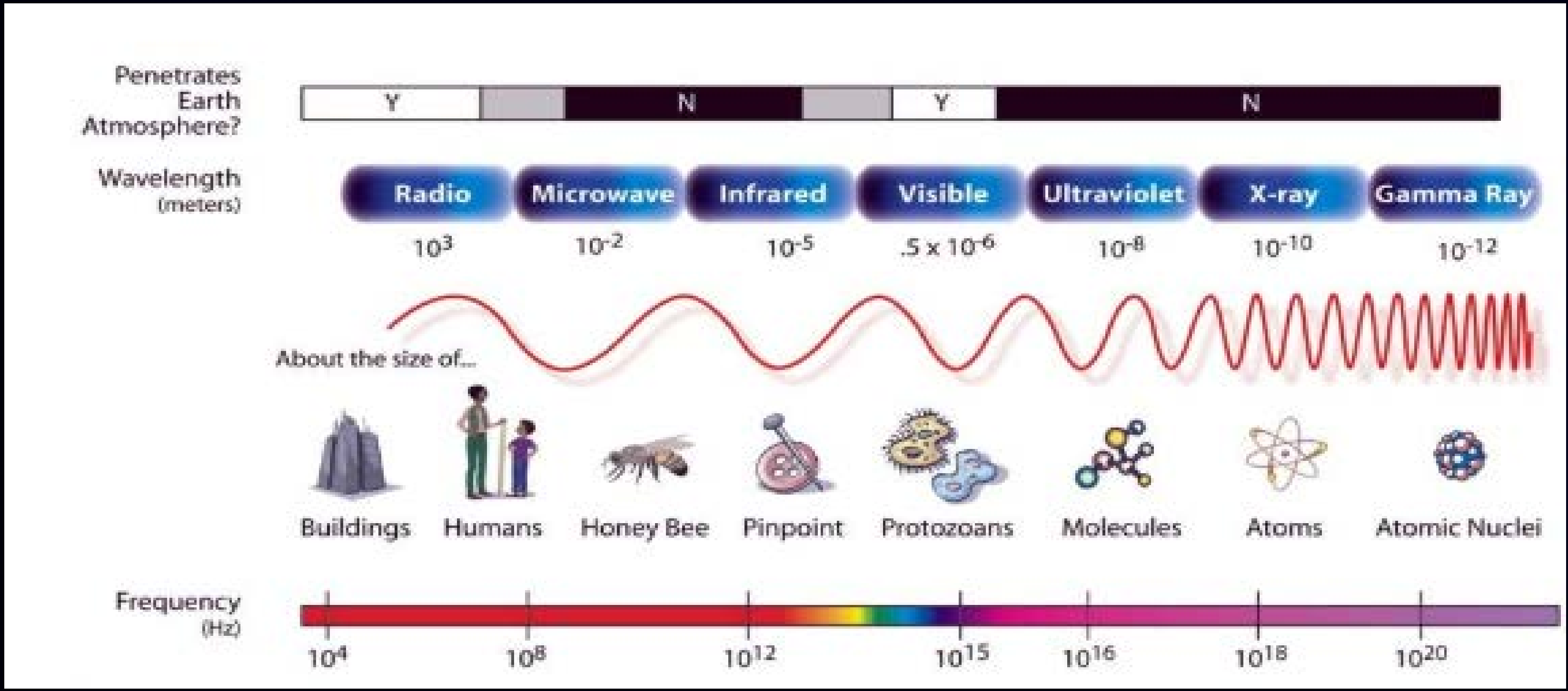
Frequency refers to the number of cycles of a wave passing a fixed point per unit of time. Frequency is normally measured in hertz (Hz)

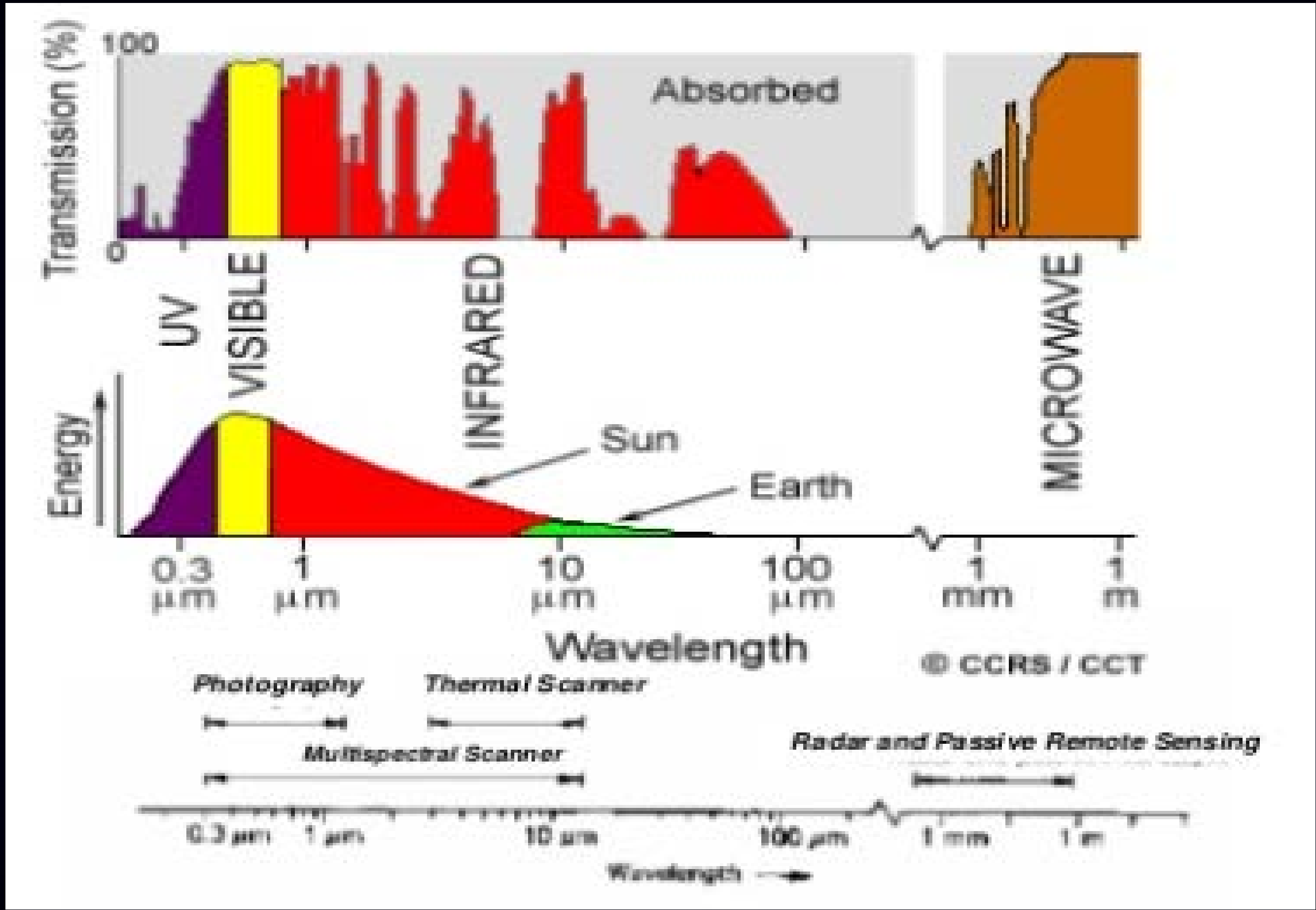
EM waves travels with the speed of light (3×10^8 m/s)

$$\lambda = c/f$$

Both are inversely related to each other. The shorter the wavelength, the higher the frequency. The longer the wavelength, the lower the frequency.

ELECTROMAGNETIC SPECTRUM



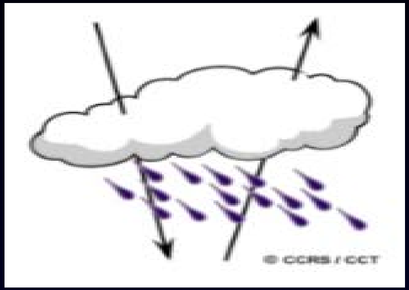


Transmission (%)
100
0
Absorbed
UV
VISIBLE
INFRARED
MICROWAVE
Energy
Sun
Earth
0.3 µm
1 µm
10 µm
100 µm
1 mm
1 m
Wavelength
© CCRS / CCT
Photography
Thermal Scanner
Multispectral Scanner
Radar and Passive Remote Sensing
Wavelength

MICROWAVE REMOTE SENSING

Microwave remote sensing uses the microwave sensors to sense electromagnetic radiations in the microwave region of the EM Spectrum. It covers EM spectrum in the range of 1mm to 1m with the frequency interval from 300MHz and 300GHz

- Longer wavelength microwave radiation can penetrate through cloud cover , haze, dust.



- This detects the microwave energy under almost all weather and the environmental conditions so that data can be collected at any time.
- Most radar remote sensing systems have used the same platform (for transmitting and receiving) and are called ***Monostatic***
- When two platforms (for transmitting and receiving) are used the radar system is called ***Bistatic.***
- When a sensor detects microwave radiation naturally emitted by the earth → **Passive Microwave Remote Sensing**
- Although there is a limited amount of Microwave energy available from the Earth and Sun, it is so small that we generally need to provide our own source of incident radiation → ***Active Microwave Remote Sensing.***

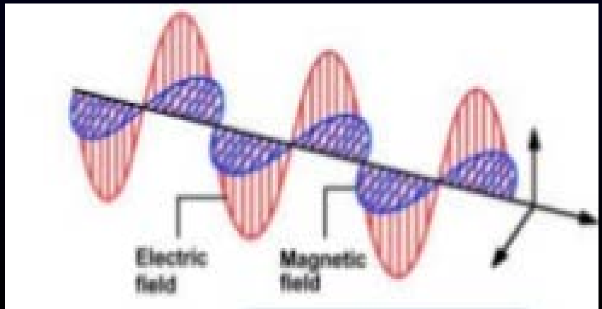
Microwave Region of EM Spectrum

Microwaves refer to the electromagnetic rays with frequencies between 300MHz and 300GHz in the electromagnetic spectrum. Their range is in between the radio waves and infrared waves.

Frequency range → 300MHz to 300GHz

wavelength range → 1mm to 1m

Microwaves are electromagnetic waves. It has both Electric and Magnetic field which are perpendicular to one another.



Microwaves are divided into sub-bands based on their wavelengths which are providing different information. The frequency bands of microwaves are as follows:

Band	Frequency Range
HF	3 to 30 (MHz)
VHF	30 to 300 (MHz)
UHF	300 to 1000(MHz)
L	1 to 2 (GHz)
S	2 to 4 (GHz)
C	4 to 8 (GHz)
X	8 to 10 (GHz)
Ku	12 to 18 (GHz)
K	18 to 26.5 (GHz)
Ka	26.5 to 40 (GHz)
V	40 to 75 (GHz)
W	75 to 110 (GHz)
mm waves	110 to 300 (GHz)

L-Band

- L bands are having the frequency range between 1 GHz to 2 GHz and their wavelength in free space is 15cm to 30cm.
- These ranges of waves are used in navigations, GSM mobile phones, and in military applications.
- They can be used to measure the soil moisture of rain forests.

S-Band

- S band microwaves are having the frequency range between 2 GHz to 4 GHz and their wavelength range is 7.5cm to 15 cm.
- These waves can be used in navigation beacons, optical communications, and wireless networks.

C-Band

- This have its frequency range between 4 GHz to 8 GHz & their wavelength is in between 3.75 cm to 7.5 cm.
- It can penetrate into the clouds, dust, smoke, snow, and rain to reveal the earth's surface.
- These microwaves can be used in long-distance radio telecommunications

X-Band

- The frequency range for S-band microwaves is 8 GHz to 12 GHz having the wavelength in between 25 mm to 37.5 mm.
- These waves are used in satellite communications, broadband communications, radars, space communications and amateur radio signals.

Ku-Band

- These waves are occupying the frequency range between 12 GHZ to 18 GHz and having the wavelength in between 16.7 mm to 25 mm.
- “Ku” refers to Quartz-under.
- These waves are used in satellite communications for measuring the changes in the energy of the microwave pulses and they can determine speed and direction of wind near costal areas.

K & Ka Band

- The frequency range for K band waves in between 18 GHz to 26.5 GHz. And wavelength in between 11.3 mm to 16.7 mm.
- For Ka band the frequency range is 26.5 GHz to 40 GHz and the wavelength in between 5 mm to 11.3 mm.
- These waves are used in satellite communications, astronomical observations, and radars.
- Radars in this frequency range provide short range, high resolution and high amount of data at the renewing rate.

Ku Band

- These waves are occupying the frequency range between 12 GHZ to 18 GHz and having the wavelength in between 16.7 mm to 25 mm.
- “Ku” refers to Quartz-under.
- These waves are used in satellite communications for measuring the changes in the energy of the microwave pulses and they can determine speed and direction of wind near costal areas.

V Band

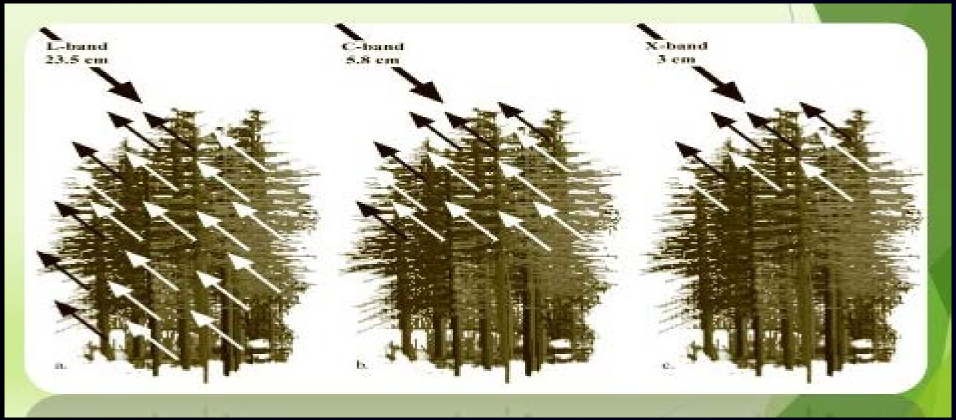
- This band stays for a high attenuation.
- The frequency range for these waves is 50 GHz to 75 GHz. The wavelength for these microwaves is in between 4.0 mm to 6.0 mm.

HF Band

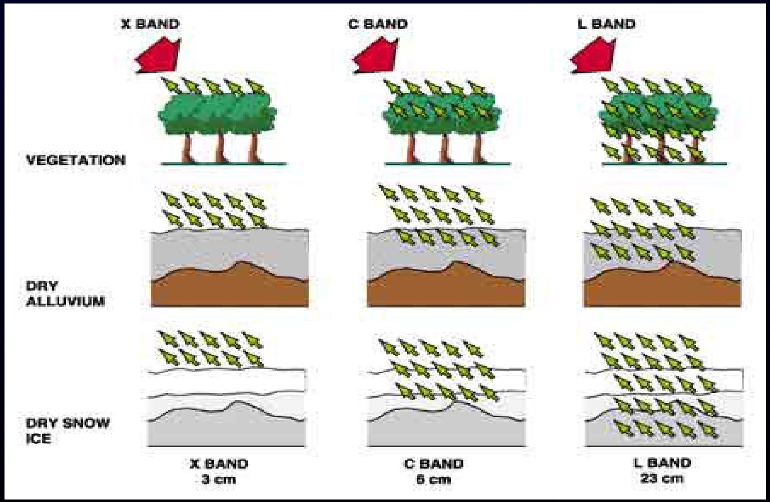
- The high-frequency (HF) from 3 to 30 MHz
- It is used primarily for long-distance communication and short-wave broadcasting over long distances, because this is the region most affected by reflections from the ionosphere and least affected by absorption in the ionosphere.
- Some radar systems are operated in the HF region.

REASONS TO USE MICROWAVES?

- Have capability to penetrate through clouds
- Penetrate deeply into the vegetation than optical waves



Penetration Depth
(Pine Forest)



ACTIVE MICROWAVE REMOTE SENSING

Active remote sensing systems are not dependent on the Sun's EMR or the thermal properties of the Earth. Active remote sensors create their own electromagnetic energy that:

1. is transmitted from the sensor toward the terrain (and is largely unaffected by the atmosphere),
2. interacts with the terrain producing a backscatter of energy, and
3. is recorded by the remote sensor's receiver.

In case of active microwave remote sensing, microwave sensors uses the microwave sensors provide the on source of microwave radiation to illuminate the target. The most common form of imaging active microwave remote sensors is RADAR.

RADAR transmits a microwave signal towards the target and detect the backscattered portion of the signal.

The strength of that signal is measured to discriminate between different targets and time delay between the transmitted and reflected signal which determines the range to the target.

Active sensor

Active remote sensor create their own electromagnetic energy.

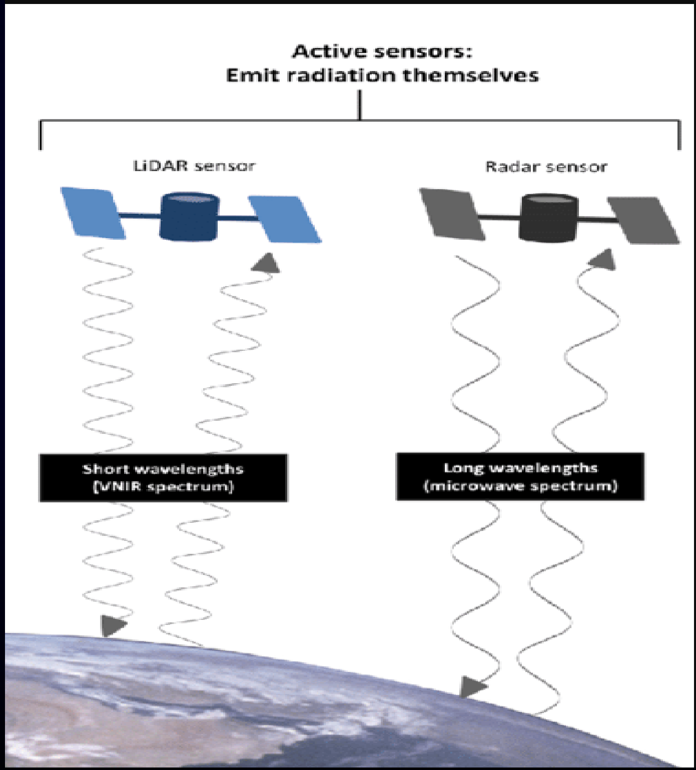
Sensors

IMAGING SENSORS

- SLAR
- SAR
- ASAR

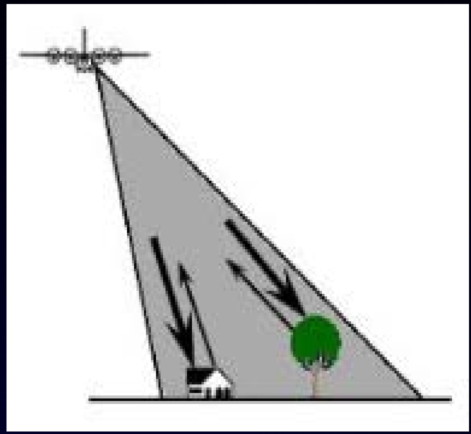
NON-IMAGING SENSORS

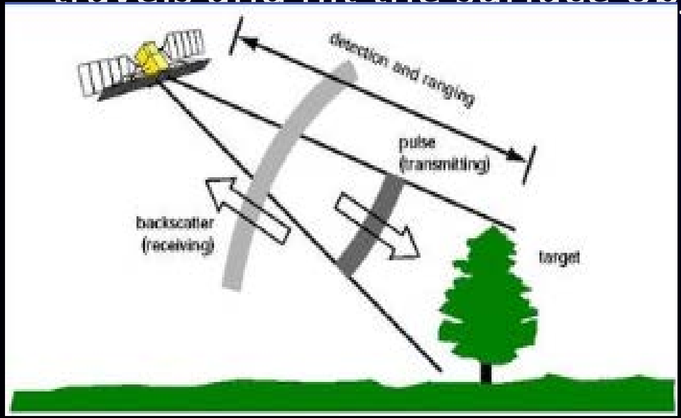
- Scatterometer
- Altimeter
- Doppler Radar



RADAR

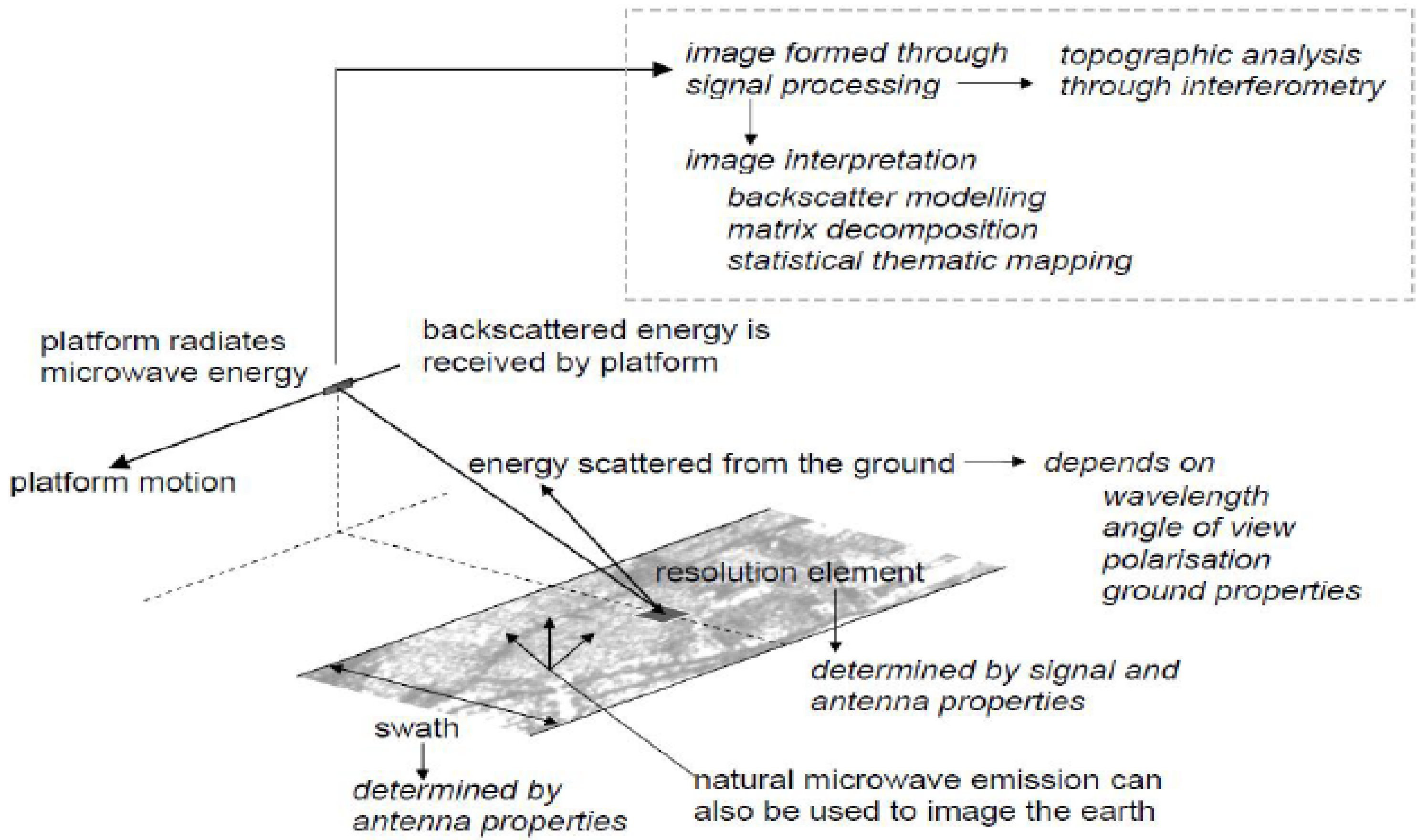
- A radar is essentially a ranging or distance measuring device
- It consists of transmitter, a receiver , an antenna and an electronics system to process and record the data.
- The transmitter generates successive short pulses of microwave of regular intervals which are focused by the antenna into a beam which travels and hit the surface object.





- The antenna receives a portion of the transmitted energy reflected from various objects within the illuminated beam.
- By measuring the time delay between the transmission of the pulse and reception of the backscattered “echo” from different target , their distance from the radar and thus their location can be

Components of an Imaging Radar System

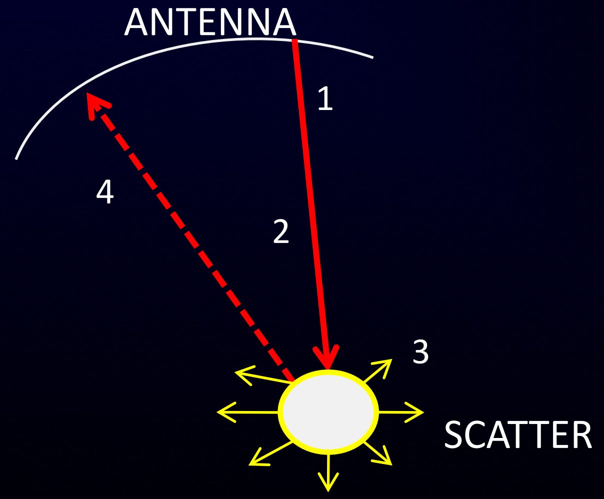


RADAR EQUATION CONCEPT

1 - Power transmitted towards scatter (P_t)
2 - Distance from the radar to the target (R)
3 - Scattering cross section (σ)
4 - Power unit of area at receiver (P_r)

Radar Equation $P_r = \dfrac{P_t\, G_t\, \lambda^2\, \sigma}{4\Pi^3 R^4}$

G_t = Antenna Gain
λ = Wavelength



RADAR BACKSCATTERING

The Radar backscatter coefficient is given by :

$$\sigma^{o} = \sigma / A$$

Where σ is the radar cross section.

σ^{o} denotes the radar backscatter coefficient.

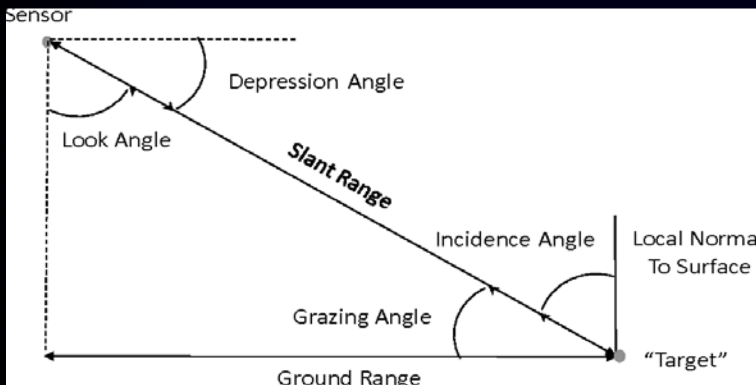
Radar Backscatter Coefficient depends on

The Target Properties

- Roughness
- Dielectric Constant

The Radar Characteristics

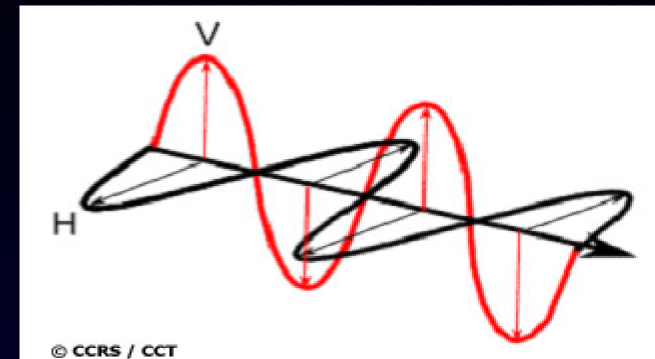
- Depression Angle
- Frequency
- Polarization



RADAR PARAMETERS

Azimuth Direction	Denote the direction of aircraft or orbital track of satellite
Range Direction	Denote the direction of radar illumination, usually perpendicular to the azimuth direction
Depression Angle	Denote the direction between horizontal plane and microwave pulse
Incident Angle	Denotes the angle between microwave pulse and the line perpendicular to the local surface slope.
Polarization	linearly polarized microwave energy emitted/received by the sensor (HH, VV, HV, VH)

RADAR POLARIMETRY



- For a plane electromagnetic (EM) wave, polarization refers to the locus of the electric field vector in the plane perpendicular to the direction of propagation.
- While the length of the vector represents the amplitude of the wave, and the rotation rate of the vector represents the frequency of the wave, polarization refers to the orientation and shape of the pattern traced by the tip of the vector.
- Many radars are designed to transmit microwave radiation that is either horizontally polarized (H) or vertically polarized (V).
- A transmitted wave of either polarization can generate a backscattered wave with a variety of polarizations.
- It is the analysis of these transmit and receive polarization combinations that constitutes the science of radar polarimetry.

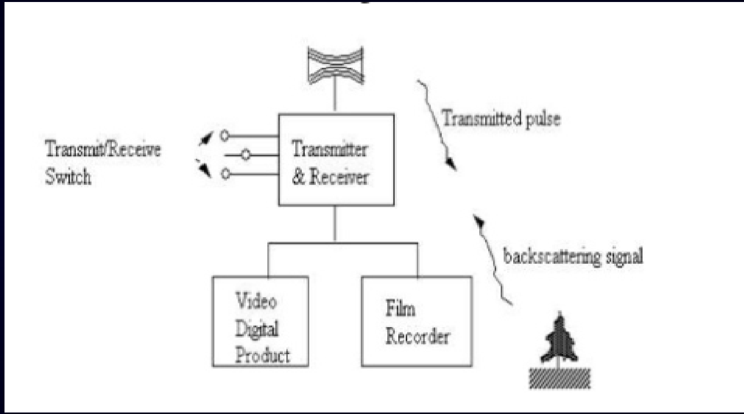
In radars, there can be four combinations of transmit and receive polarizations:

HH	for horizontal transmit and horizontal receive
VV	for vertical transmit and vertical receive
HV	for horizontal transmit and vertical receive
VH	for vertical transmit and horizontal receive.

The first two polarization combinations are referred to as "like-polarized" because the transmit and receive polarizations are the same. The last two combinations are referred to as "cross-polarized" because the transmit and receive polarizations are orthogonal to one another.

THE SIDE-LOOKING AIRBORNE RADAR

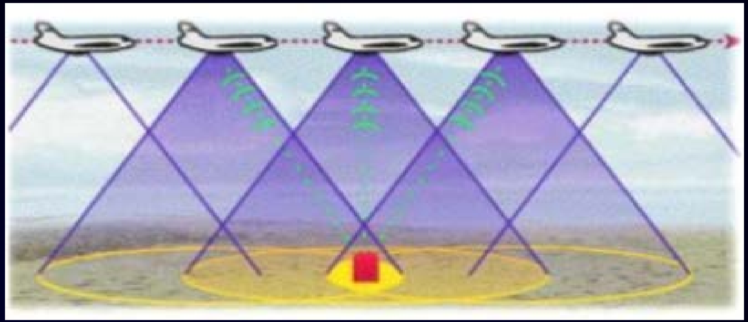
- The Side-Looking Airborne Radar (SLAR) is an image-producing system that derives its name from the fact that the radar beam is transmitted from the side of the aircraft during data acquisition.
- SLAR is an active sensor; the system provides its own source of illumination in the form of microwave energy.
- Since microwave energy penetrates most clouds, SLAR can be used to prepare image maps of cloud-covered areas.
- Since the radar signal is transmitted at a depressional angle below the horizontal plane in which the aircraft is flying, the signal strikes the terrain at an oblique angle, and the surficial expression of the geologic structure may thus be enhanced.



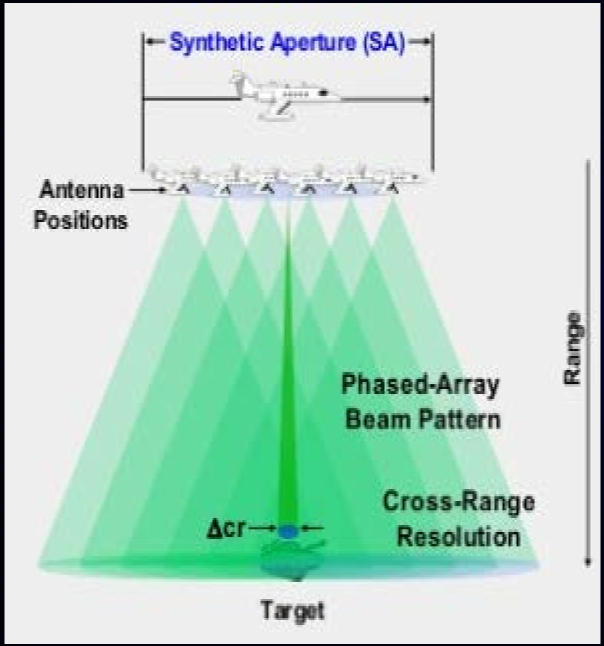
- The topographic expression of some surface features, such as subtle faults and folds, may be more clearly seen on radar imagery than on conventional aerial photographs or satellite images.

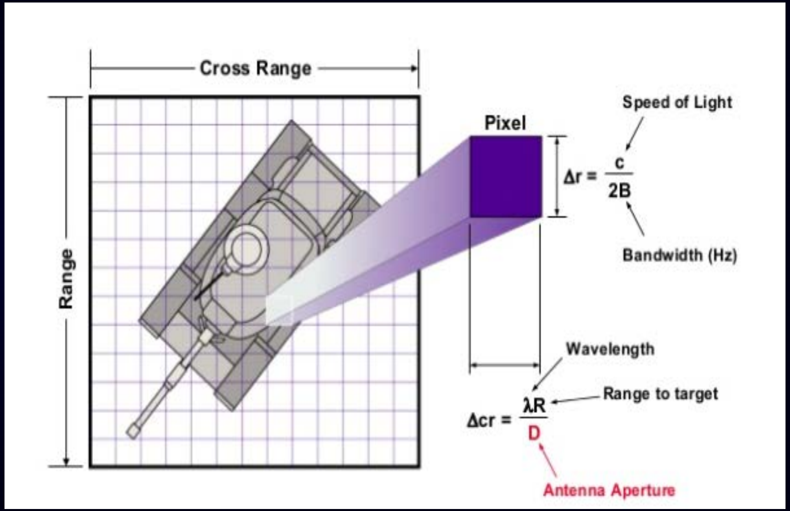
SYNTHETIC APERTURE RADAR

- It is a advance form of SLAR for producing fine resolution images.
- A synthetic aperture is produced by using the forward motion of the radar. As it passes a given scatterer, many pulses are reflected in sequence.
- By recording and then combining these individual signals, a "synthetic aperture" is created in the computer providing a much improved azimuth resolution
- It records the frequency differences of backscattering signal at different aircraft position during the time period when the target is illuminated by the transmitted energy.



SAR System continuously generating beam


Synthetic Aperture (SA)
Antenna Positions
Range
Phased-Array Beam Pattern
Cross-Range Resolution
Δcr
Target


Cross Range
Range
Pixel
Speed of Light
Δr = c/2B
Bandwidth (Hz)
Wavelength
Range to target
Δcr = λR/D
Antenna Aperture

SAR DATA

SAR data consist of high - resolution reflected returns of radar -frequency energy from terrain that has been illuminated by a directed beam of pulses generated by the sensor . The radar returns from the terrain are mainly determined by the physical characteristics of the surface features (such as surface roughness, geometric structure, and orientation), the electrical characteristics (dielectric constant, moisture content, and conductivity), and the radar frequency of the sensor.

TerraSAR-x Vishakhapattanam

APPLICATIONS

- **Hydrology**
  soil moisture, watershed mapping, flood mapping, mapping of surface water (ponds, lakes, rivers), snow mapping.
- **Agriculture**
  crop mapping, agricultural-practice monitoring, identifying field boundaries, monitoring growth and harvest progress, identifying stress areas, rangeland monitoring.
- **Forests**
  monitoring cutting, mapping fire damage, identifying stress areas, vegetation density, and biomass.
- **Polar regions**
  monitoring and mapping sea ice, detecting and tracking icebergs, mapping glacial ice sheets, monitoring glacial changes, including measuring velocity.
- **Ocean**
  measuring wave spectra, monitoring oil spills, monitoring ship traffic and fishing fleets, wind speed and direction measurement, rain, clouds, measuring currents, undersea mapping.

NON-IMAGING SENSORS

SCATTETROMETER

It is a device that measures the scattering of radar energy by a target to measure a quantitative measurements of amount energy backscattered from the targets

RADAR ALTIMETER

It sends out the pulses of microwave signals and record the signal scattered back from the earth surface. It measure the round tip delay to the target to determine the distance from the target.

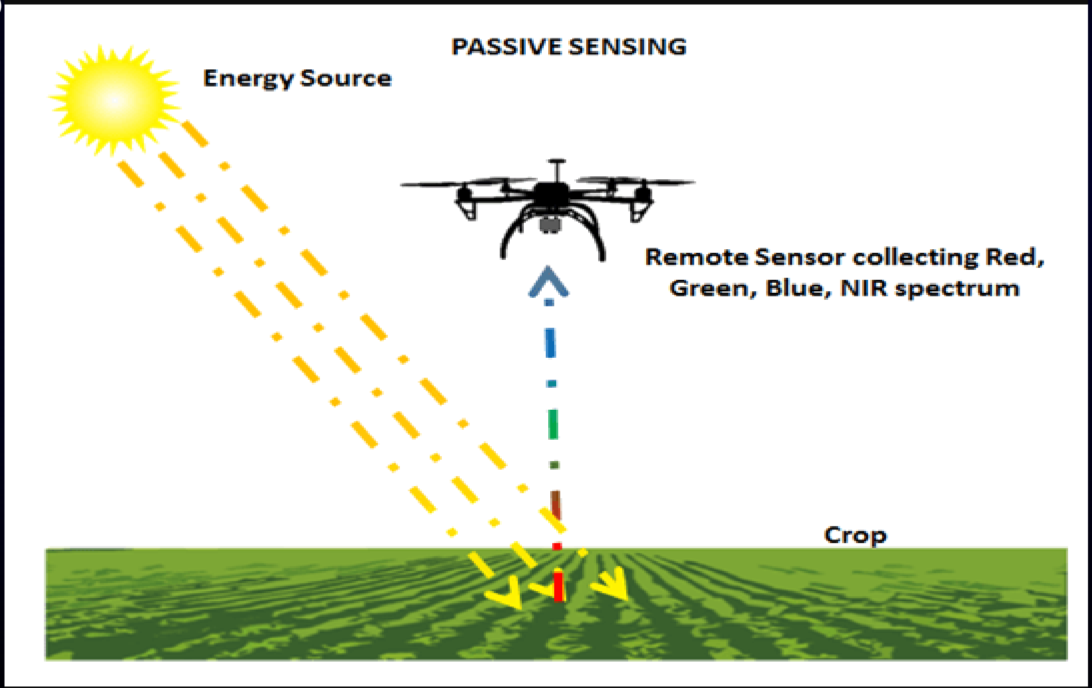
DOPPLER RADAR

It is a specialized Radar that uses the Doppler effect to produce velocity data about the objects at a distance.

PASSIVE MICROWAVE REMOTE SENSING

In passive MRS , a passive microwave remote sensor detect the naturally emitted microwave energy within its field of view. This emitted microwave energy is related to the temperature and moisture properties of emitting object of space.

Most passive microwave sensors are therefore characterized by low spatial resolution.



CONT..

- A passive microwave sensor detects the naturally emitted microwave energy within the field of view. The emitted energy is related to the temperature and moisture properties of the emitting objects or surface.
- Because the wavelengths are so long , the energy available is quite small compared to the optical wavelength. Thus the field of view must be large to detect enough energy to record a signal.
- Most passive microwave sensors are therefore characterized by low spatial resolution.

Microwave energy for passive sensor is

- Emitted by the atmosphere
- Reflected from the surface
- Emitted from the surface
- Transmit from the subsurface

Examples of Passive microwave radiometers

- Advanced Microwave Sounding Unit (AMSU) 1978
- Scanning Multichannel Microwave Radiometer (SMMR) 1981-1987
- Special Sensor Microwave/Imager (SSM/I) 1987
- Tropical Rainfall Measuring Mission (TRMM) 1997
- Advanced Microwave Scanning Radiometer (AMSR-E)2002

APPLICATIONS

- ✓Soil Moisture
- ✓Snow water Equivalent
- ✓Sea surface temperature
- ✓Atmospheric water vapour
- ✓Surface wind speed
- ✓Rainfall rate
- ✓Cloud liquid water

AIRBORNE INSTRUMENTS

AIRBORNE EARTH SCIENCE MICROWAVE IMAGING RADIOMETER (AESMIR)

- The AESMIR is a passive microwave airborne imager with 6 microwave bands (6, 10, 18, 23, 36, 89 GHz) with 4-Stokes polarization capability (except at 23 GHz)
- 18 & 36 GHz, V &H pols are useful for snow;
- 10 & 89 GHz are of secondary interest for snow
- Programmable scan modes include conical and cross-track scanning

THE AIRBORNE SYNTHETIC APERTURE RADAR (AIRSAR)

- The system operates in Fully Polarimetric mode at P-, L- and C-band simultaneously or in Interferometric mode in L- and C-band simultaneously.
- AIRSAR first flew in 1988 and continues to conduct at least one flight campaign each year

THE EXPERIMENTAL AIRBORNE SAR

- The Experimental airborne SAR (E-SAR) is a multi-frequency system mounted onboard a Dornier DO-228 aircraft.
- The sensor operates in 5 frequency bands, X-, C-, S-, L- and P-band.
- The polarisation of the radar signal is selectable.
- The measurement modes include single channel operation and SAR Interferometry and SAR Polarimetry modes.

C/X-SAR

- The C/X-SAR system is an airborne synthetic aperture radar developed by the Canada Centre for Remote Sensing (CCRS).
- Since the commissioning of the C- and X-band SARs, in 1986 and 1988, respectively, the C/X-SAR system has undergone several upgrades, including addition of interferometric and polarimetric modes for the C-band radar.
- The C/X-SAR is carried on a Convair 580 aircraft and it is complemented by navigation equipment and a suite of other sensors.

OCTOPOD

- The OctoPod was jointly developed by Aerodata and its subsidiary OPTIMARE.
- It enables multi-sensor-based airborne surveillance operations, while minimizing space consumption and cost for aircraft modification.
- The OctoPod can be equipped with up to eight sensors.

OPTIMARE SLAR

The OPTIMARE SLAR is a cloud-penetrating imaging X-band radar for day & night airborne maritime observation.
Assuming sufficient aircraft altitude the OPTIMARE SLAR can have a swath width of more than 120 kilometers. The sensor is used for mapping the sea surface with regard to oil spills, vessels, wakes.

SPACEBORNE INSTRUMENTS

THE TROPICAL RAIN MAPPING MISSION (TRMM)

the first meteorological radar to be launched in space for mapping 3D rain distributions. Launched in 1997 into a low-inclination (35 degree) orbit, the PR uses a K_u-band (13.8 GHz) radar to measure rainfall over a 50 km swath with 4-5 km horizontal and 250 m vertical resolution

THE CLOUDSAT SATELLITE

It is launched in 2006, a member of NASA's A-Train platforms, carried a 94 GHz radar designed for vertically profiling clouds and precipitation along its nadir track. The mission goal is to provide the first global survey of the vertical structure of clouds and profiles of cloud liquid water and ice water.

GLOBAL PRECIPITATION MISSION (GPM)

It is launched in February 2014. The GPM dual-frequency precipitation radar (DPR) uses two frequencies, 13.6 GHz (Ku) and 35.5 GHz (Ka). The Ka band is useful for detecting light precipitation. Measurements at the two frequencies can observe both strong rain in the tropics and light rain and snow in high latitudes. They also deliver the ability to estimate the drop size distribution (DSD).

The International Space Station (ISS) RapidScat

This is the instrument is the third K_u-band wind scatterometer in the SeaWinds series. The QuikSCAT instrument operated from 1999 until 2009. RapidScat was launched to the ISS in September 2014 as a cost-effective replacement for QuikSCAT. It measures ocean winds to support weather prediction, monitor hurricanes, and perform basic research. QuikScat's measurements were so essential to the prediction community that when QuikSCAT.

Sensor type	Instrument	Applications
Passive sensor	Radiometer	Sea surface Temperature (SST)
		Salinity, sea ice, rainfall intensity, air temperature
Active Sensor	Scaterrometer	Soil moisture content, water vapor, rainfall Intensity, near sea surface wind, ocean wave, biomass, sea ice, snow
	Altimeter	Sea surface topography, wind velocity
	Imaging Radar	Ocean wave, topography, ice, sea surface wind, geology

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THANK YOU!!!