SAR Remote Sensing (Microwave Remote Sensing)

"Synthetic Aperture Radar"

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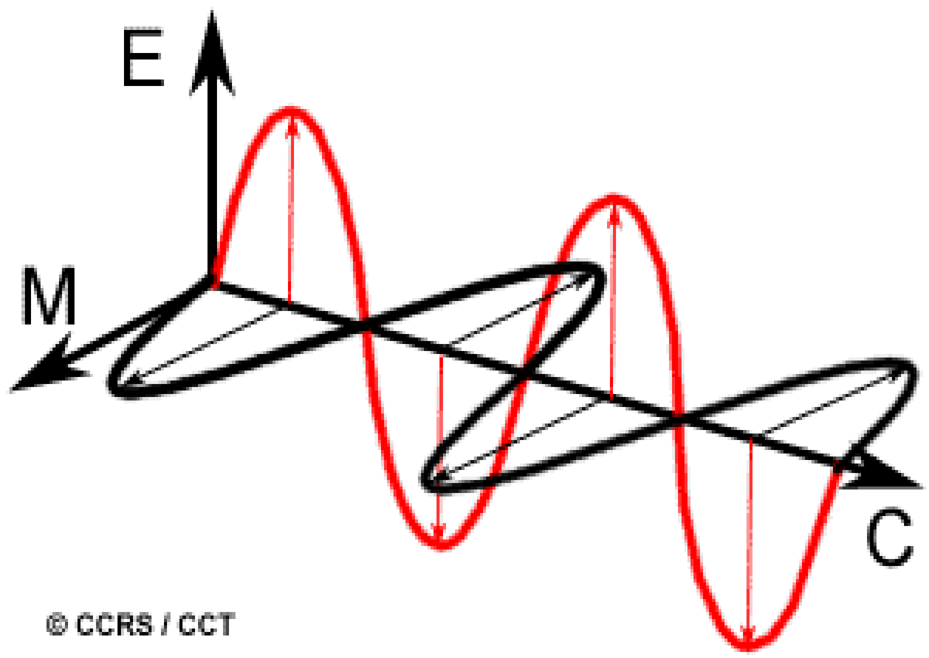
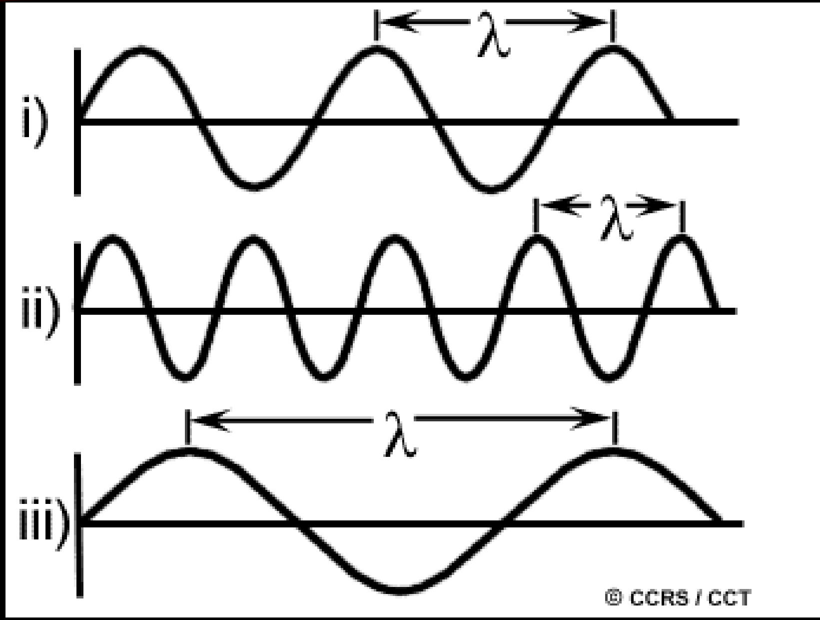
Electromagnetic Radiation



Electromagnetic radiation consists of an electrical field(E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field (M) oriented at right angles to the electrical field. Both these fields travel at the speed of light (c).

Wavelength and Frequency



The wavelength is the length of one wave cycle, which can be measured as the distance between successive wave crests. Wavelength is usually represented by the Greek letter lambda (λ).

Wavelength and frequency are related by the following formula:

$$c = \lambda v$$

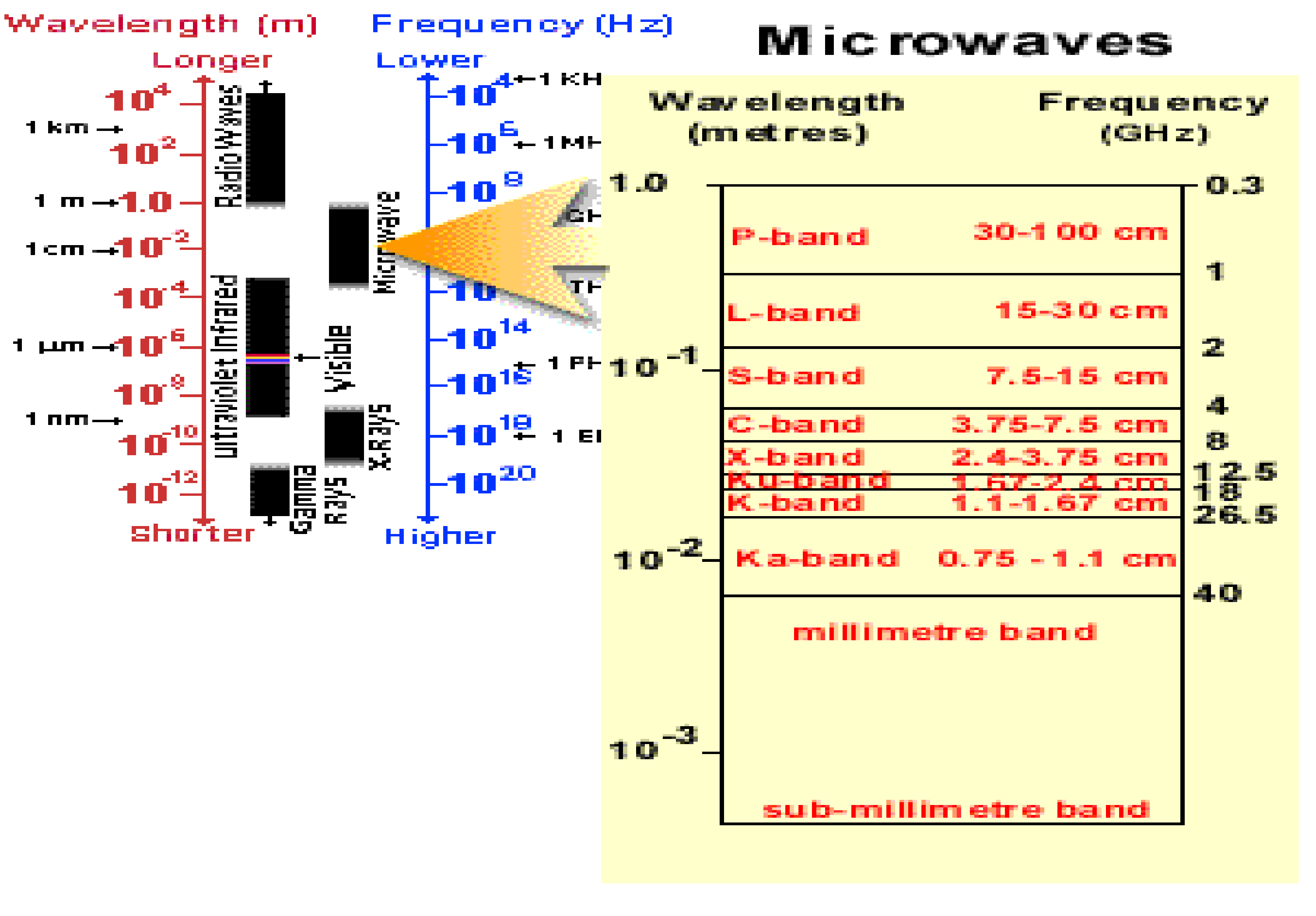
where:

λ = wavelength (m)

v = frequency (cycles per second, Hz)

c = speed of light (3×10^8 m/s)

Microwave Bands



Radar Bands Commonly Used For Sensing

BAND	WAVELENGTH (cm)	FREQUENCY GHz (10^9 Cycles/sec)
Ka	0.75 - 1.1	26.5 - 40
K	1.1 - 1.67	18 - 26.5
Ku	1.67 - 2.4	12.5 - 18
X	2.4 - 3.8	8 - 12.5
C	3.8 - 7.5	4 - 8
S	7.5 - 15	2 - 4
L	15 - 30	1 - 2
P	30 - 100	0.3 - 1

Microwave Sensors

Passive microwave sensor:- A passive microwave sensor detects the naturally emitted microwave energy within its field of view. This emitted energy is related to the temperature and moisture properties of the emitting object or surface. Passive microwave sensors are typically **radiometers** .

Applications of passive microwave remote sensing include meteorology, hydrology, and oceanography.

The microwave energy recorded by a passive sensor can be emitted by the atmosphere (1), reflected from the surface (2), emitted from the surface (3), or transmitted from the subsurface (4).

Active Microwave Sensors

Active microwave sensors provide their own source of microwave radiation to illuminate the target. Active microwave sensors are generally divided into two distinct categories: **imaging and non-imaging.**

The most common form of imaging active microwave sensors is RADAR. **RADAR is** an acronym for **RAdio Detection And Ranging**.

The sensor transmits a microwave (radio) signal towards the target and detects the backscattered portion of the signal.

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Non-imaging microwave sensors include **altimeters and scatterometers**. In most cases these are profiling devices which take measurements in one linear dimension, as opposed to the two-dimensional representation of imaging sensors.

Radar altimetry is used on aircraft for altitude determination and on aircraft and satellites for topographic mapping and sea surface height estimation.

Scatterometers are also generally non-imaging sensors and are used to make precise quantitative measurements of the amount of energy backscattered from targets.

SAR Versus Other Earth Observation Instruments

	Lidar	Optical Multi-Spectral	SAR
Platform	airborne	airborne/spaceborne	airborne/spaceborne
Radiation	own radiation	reflected sunlight	own radiation
Spectrum	infrared	visible/infrared	microwave
Frequency	single frequency	multi-frequency	multi-frequency
Polarimetry	N.A.	N.A.	polarimetric phase
Interferometry	N.A.	N.A.	interferometric phase
Acquisition time	day/night	day time	day/night
Weather	blocked by clouds	blocked by clouds	see through clouds

SAR Satellites

RISAT-1: April 2012: C-band

Radarsat 1: 1995: C-band

Radarsat 2: 2007: C-band (Quad-pol)

ERS 1: 1991-2000 :C-band

ERS 2: 1995 :C-band

JERS : 1992-98 : L-band

ENVISAT: 2002: C-band

ALOS: 2006: L-band (Quad-pol)

TerraSAR-X: 2007-20012: X-band (Quad-pol)

Sensor	Operation	Band (Polarization)	Comments	Institution, Country
Seasat	1978	L (HH)	First civilian SAR satellite, operation for only ca. three months	NASA/JPL, USA
ERS-1/2	1991–2000/ 1995–2011	C (VV)	European Remote Sensing Satellites(first European SAR satellites)	ESA, Europe
J-ERS-1	1992–1998	L (HH)	Japanese Earth Resource Satellite (first Japanese SAR satellite)	JAXA, Japan
SIR-C/ X-SAR	April and October 1994	L & C (quad) X (VV)	Shuttle imaging radar mission, first demonstration of spaceborne multi-frequency SAR	NASA/JPL, USA,DLR, Germany ASI, Italy
Radarsat-1	1995–today	C (HH)	First Canadian SAR satellite, swath width of up to 500 km with ScanSar imaging mode	CSA, Canada
SRTM	Feb. 2000	C (HH+VV) and X (VV)	Shuttle Radar Topography Mission, first spaceborne interferometric SAR	NASA/JPL, USA, DLR, Germany, ASI, Italy

Sensor	Operation	Band (Polarization)	Comments	Institution, Country
ENVISAT/ ASAR	2002–2012	C (dual)	First SAR satellite with Transmit/Receive module technology, swath width up to 400 km	ESA, Europe
ALOS/ PALSAR	2006–2011	L (quad)	Advanced Land Observing Satellite (Daichi), swath width up to 360 km	JAXA, Japan
TerraSar-X/ TanDem-X	2007–today 2010–today	X (quad)	First bi-static radar in space, resolution up to 1 m, global topography available by end of 2014	DLR/Astrium, Germany
Radarsat-2	2007–today	C (quad)	Resolution up to: 1 m # 3 m (azimuth # range), swath width up to 500 km	CSA, Canada
COSMO-SkyMed-1/4	2007– 2010–today	X (dual)	Constellation of four satellites, up to 1 m resolution	ASI/MiD, Italy
RISAT-1	2012–today	C (quad)	Follow-on satellite (Risat-1a) to be launched in 2016, RISAT-3 (L-band) in development	ISRO, India
HJ-1C	2012–today	S (VV)	Constellation of four satellites, first satellite launched in 2012	CRESDA/CAST/ NRSCC, China

Sensor	**Operation**	**Band (Polarization)**	**Comments**	**Institution, Country**
Kompsat-5	Launch scheduled in 2013	X (dual)	Korea Multi-Purpose Satellite 5, resolution up to 1 m	KARI, Korea
PAZ	Launch scheduled in 2013	X (quad)	Constellation with TerraSar-X and TanDem-X planned	CDTI, Spain
ALOS-2	Launch scheduled in 2013	L (quad)	Resolution up to: 1 m # 3 m (azimuth # range), swath width up to 490 km	JAXA, Japan
Sentinel-1a/1b	Launch scheduled in 2013/2015	C (dual)	Constellation of two satellites, swath width up to 400 km	ESA, Europe
Radarsat Constella- tion-1/2/3	Launch scheduled in 2017	C (quad)	Constellation of three satellites, swath width up to 500 km	CSA, Canada
Saocom-1/2	Launch scheduled in 2014/2015	L (quad)	Constellation of two satellites, fully polarimetric	CONAE, Argentina

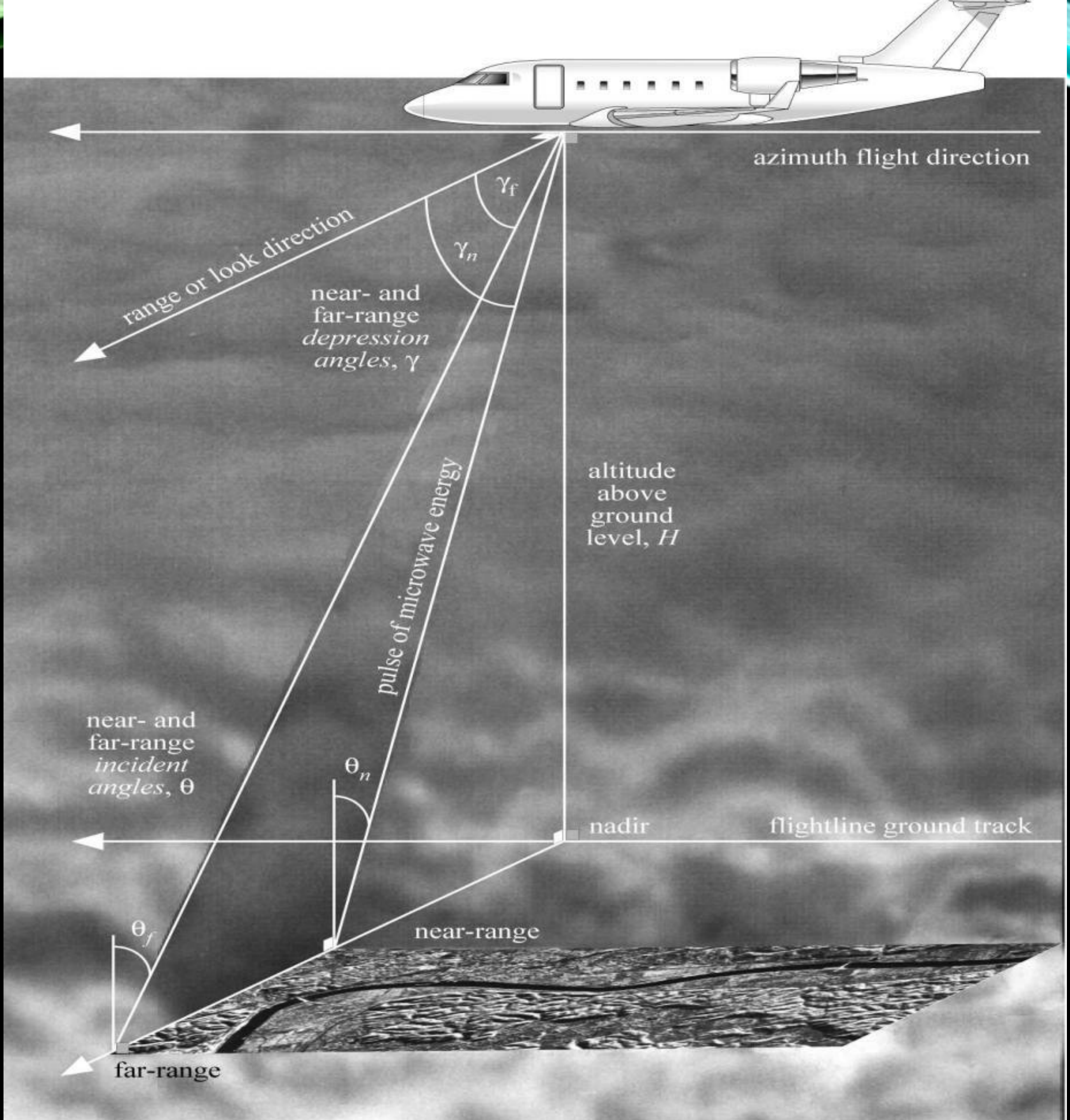
Indian SAR Earth Observation Satellites

Radar Imaging Satellite (RISAT) Missions

Sensor	Operation	Band	Comments
RISAT-2	April 20, 2009	X-Band	Orbit Altitude -550 km
RISAT-1	April 26, 2012	C-Band Hybrid/Dual	Orbit Altitude-536 km
RISAT-2R (Procured)	Launch scheduled in 2013/14	X-Band	Same as RISAT-2
RISAT-4	Launch scheduled in 2014	X-Band	----------------------------
RISAT-1A	Launch scheduled in 2015/16	C-Band Hybrid Polarimetry	Resolution 1m,3m,25m,50m Swath 10km,30km,120km,240km
RISAT-3	Launch scheduled in 2016	L-Band Fully /Hybrid Polarimetry	Resolution 1.5m,2.5m,5m,25m,35m Swath 10-120km

Radar Geometry

The *incidence angle is* the angle between the radar pulse of EMR and a line perpendicular to the Earth's surface where it makes contact. When the terrain is flat, the incidence angle is the complement (90 - γ) of the depression angle (γ).



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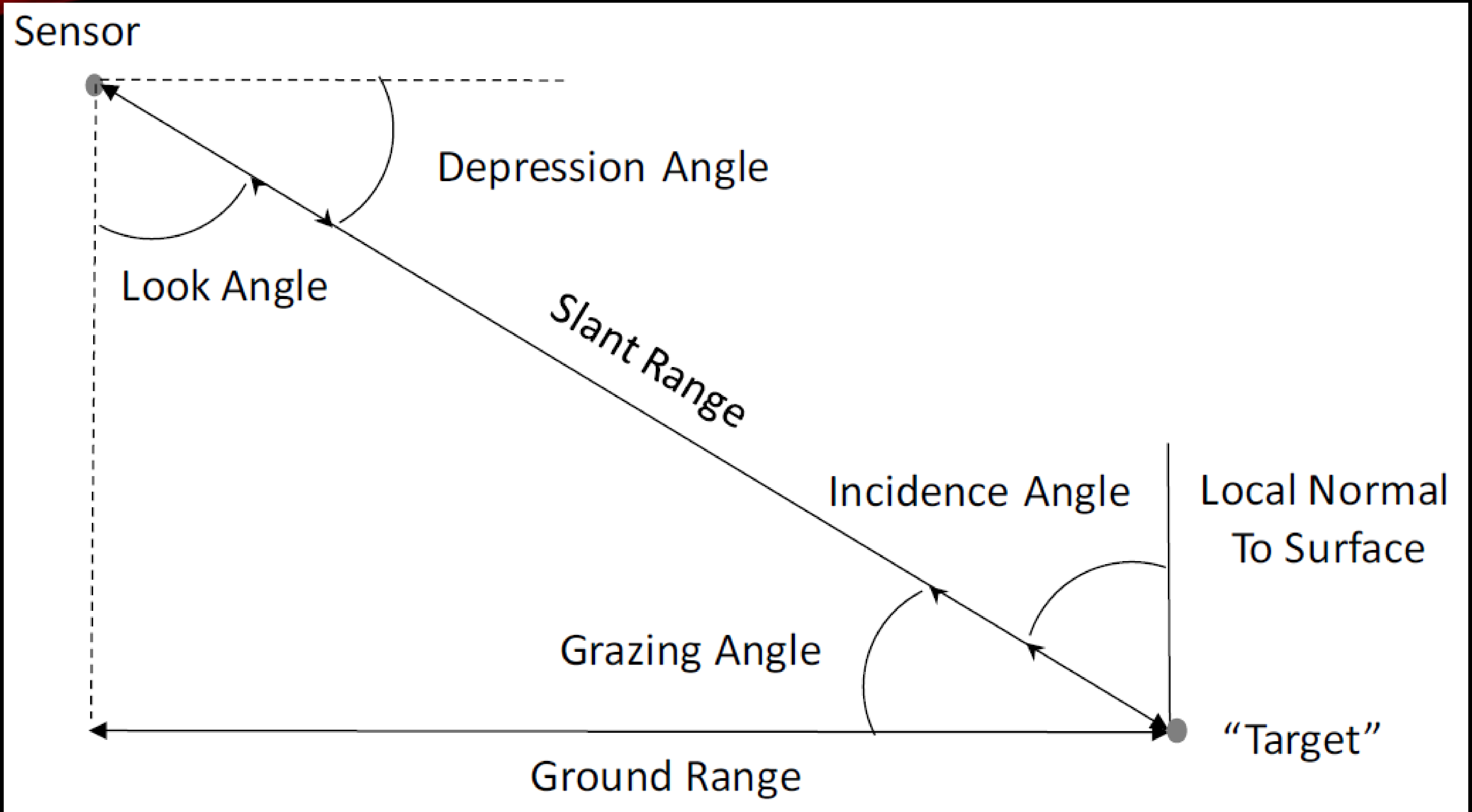


Van Zyl, J. and Kim, Y. 2010

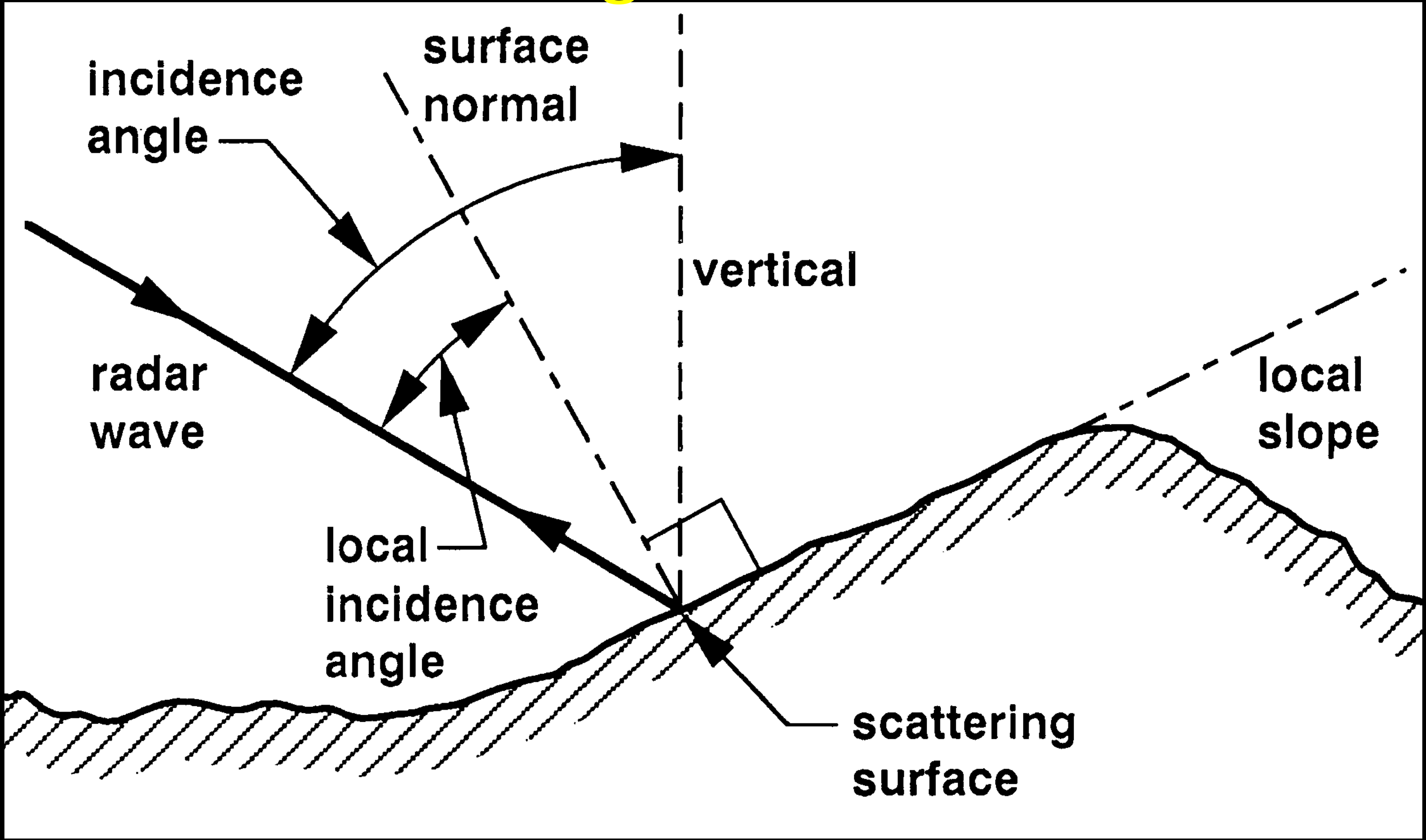
The aircraft travels in a straight line that is called the *azimuth flight direction*.

• Pulses of active microwave electromagnetic energy illuminate strips of the terrain at right angles (orthogonal) to the aircraft's direction of travel, which is called the *range*.

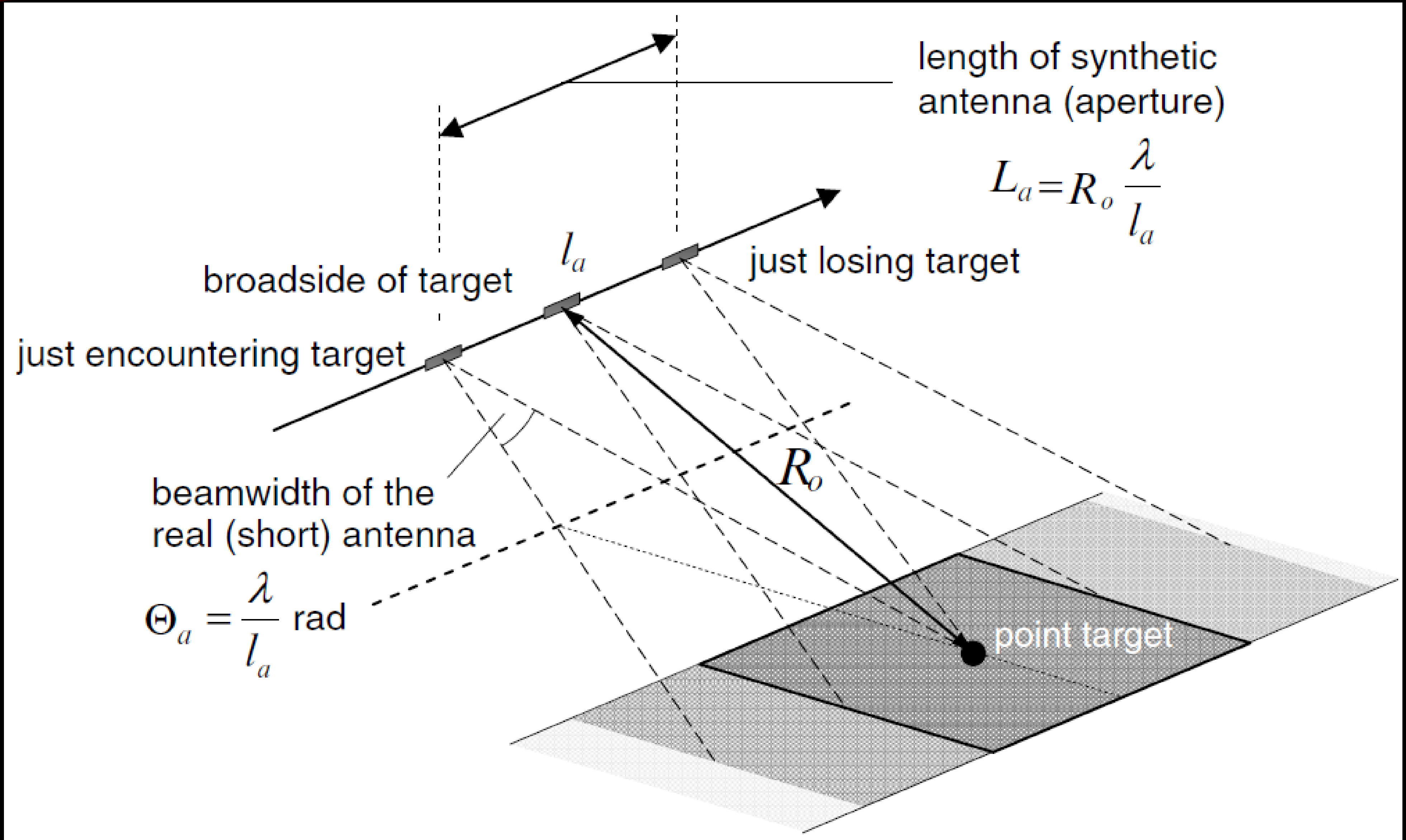
• The terrain illuminated nearest the aircraft in the line of sight is called the *near-range*. *The farthest point of terrain* illuminated by the pulse of energy is called the *far-range*.

• The *depression angle (γ) is the angle between a horizontal* plane extending out from the aircraft fuselage and the electromagnetic pulse of energy from the antenna to a specific point on the ground.

Incidence Angle and Local Incidence Angle



Synthetic Aperture Radar



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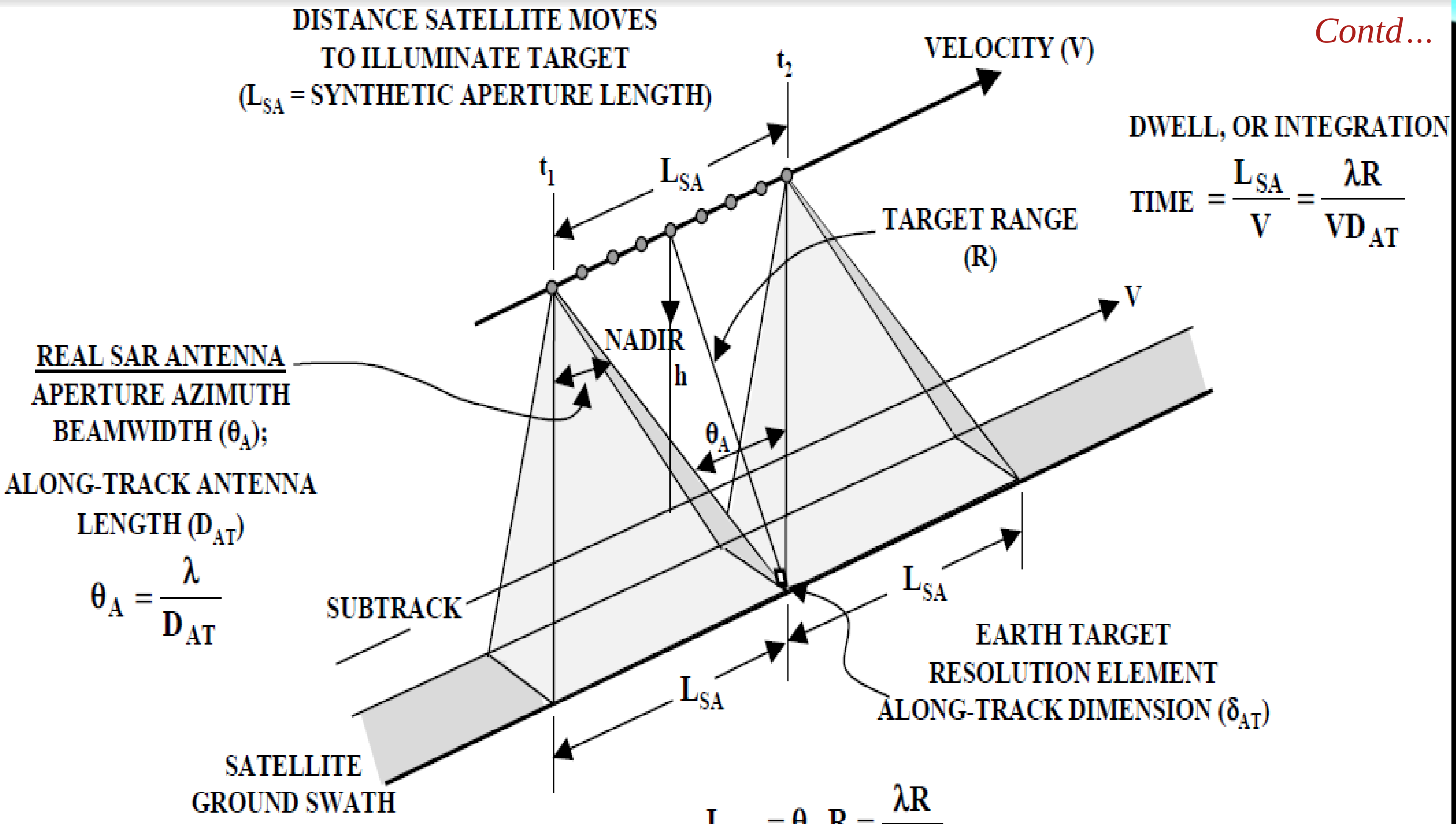
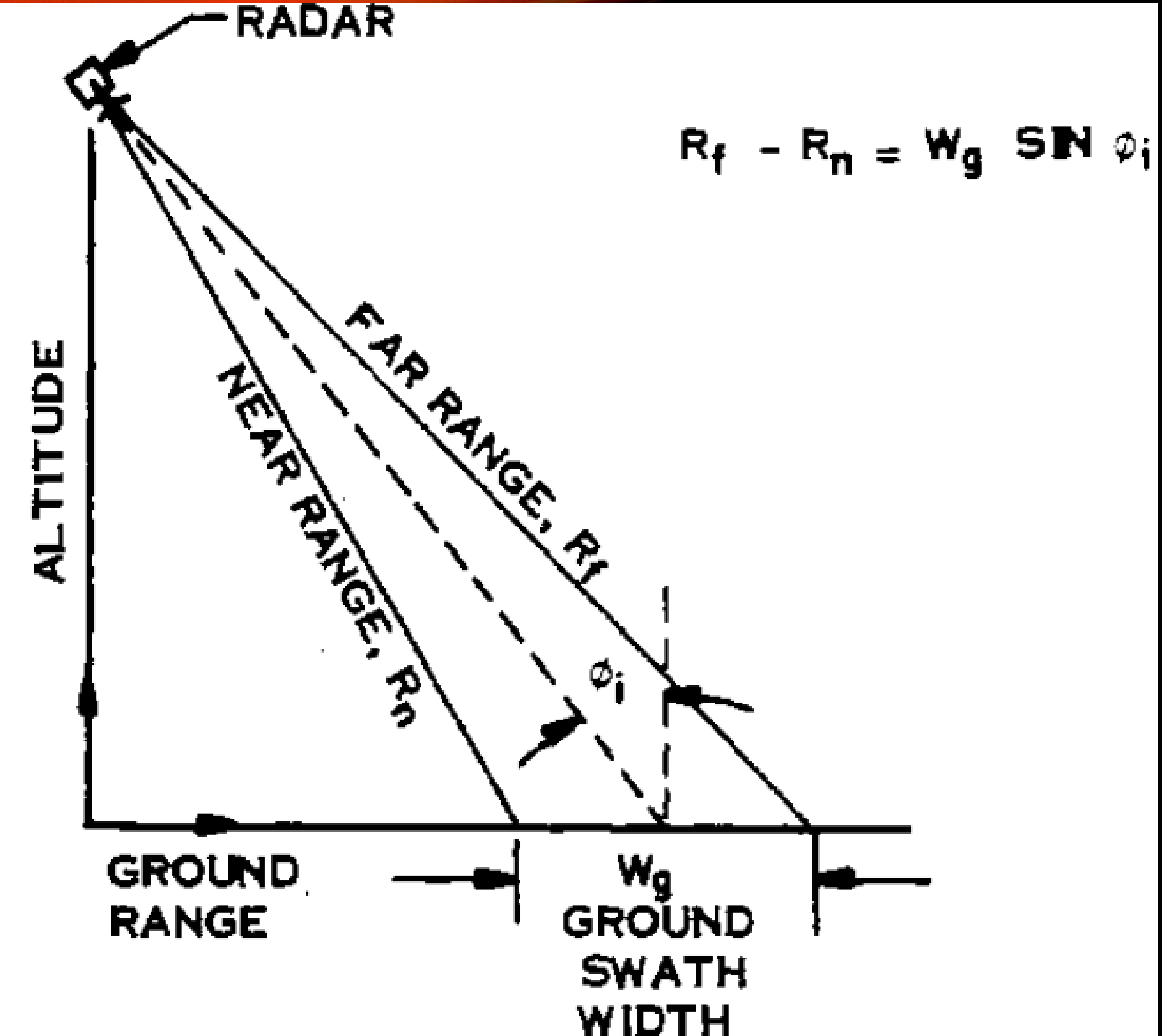


$$L_{SA} = \theta_A R = \frac{\lambda R}{D_{AT}}$$

$$\delta_{AT} = \frac{\lambda}{2L_{SA}} R = \frac{\lambda R}{\frac{2\lambda R}{D_{AT}}} = \frac{D_{AT}}{2}$$



Ground Swath Width

φ_{i} = Mean Incidencenc Angle

$$W_g = (R_f - R_n)/\sin \phi_i$$

SAR Resolution

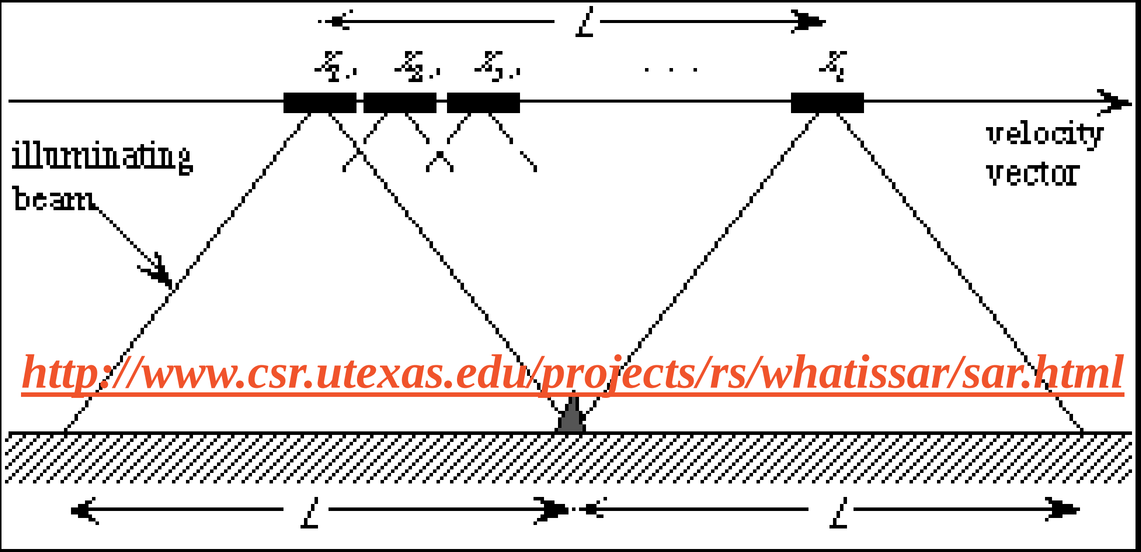
- Azimuth Resolution- Azimuth resolution describes the ability of an imaging radar to separate two closely spaced scatterers in the direction parallel to the motion vector of the sensor.
- Range Resolution- For the radar to be able to distinguish two closely spaced elements, their echoes must necessarily be received at different times.

Azimuth Resolution

Angular horizontal beam width of a real-aperture radar is:

$$\beta_A = \frac{\lambda}{L}$$

where L is antenna length and λ is wavelength



http://www.csr.utexas.edu/projects/rs/whatissar/sar.html

Horizontal beam width of the synthetic aperture

$$\beta_H = \frac{\lambda}{2L}$$

Azimuth resolution is simply the product of the effective horizontal beam width and the slant-range distance to the target

$$r_A = \frac{R\lambda}{2L}$$

Azimuth Resolution and Antenna Length

- Objective: To get 1 m azimuth resolution with 20 KM range distance

Beam width $\beta_H = 5*10^{-5} \approx 0.003°$

$$\beta_H = \frac{\lambda}{2L}$$

For X-band systems (wavelength 0.03 m)

Antenna length $L = \lambda/2\ \beta_H$ **= 300 m**

Range Resolution

Range resolution is the minimum range difference for which two point targets are recognized as two, rather than being grouped together as one target.

A well-designed radar system, with all other factors at maximum efficiency, should be able to distinguish targets separated by one-half the pulse width time τ.

$$r_R \geq \frac{c.\tau}{2}$$

http://www.radartutorial.eu/01.basics/rb18.en.html

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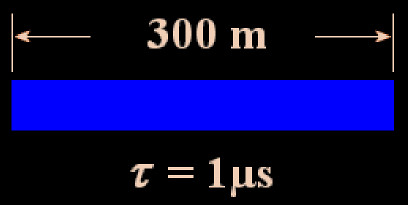
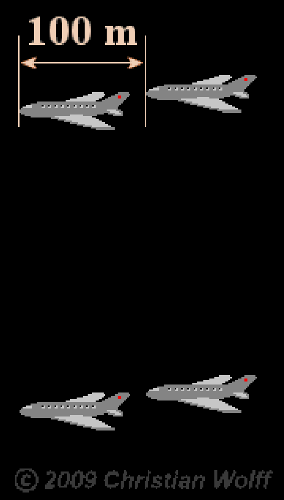
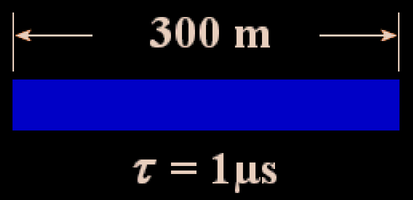
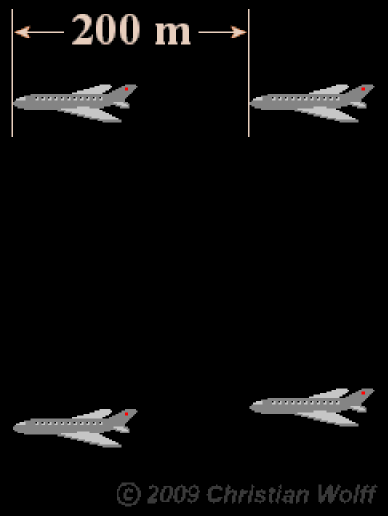

300 m
τ = 1µs

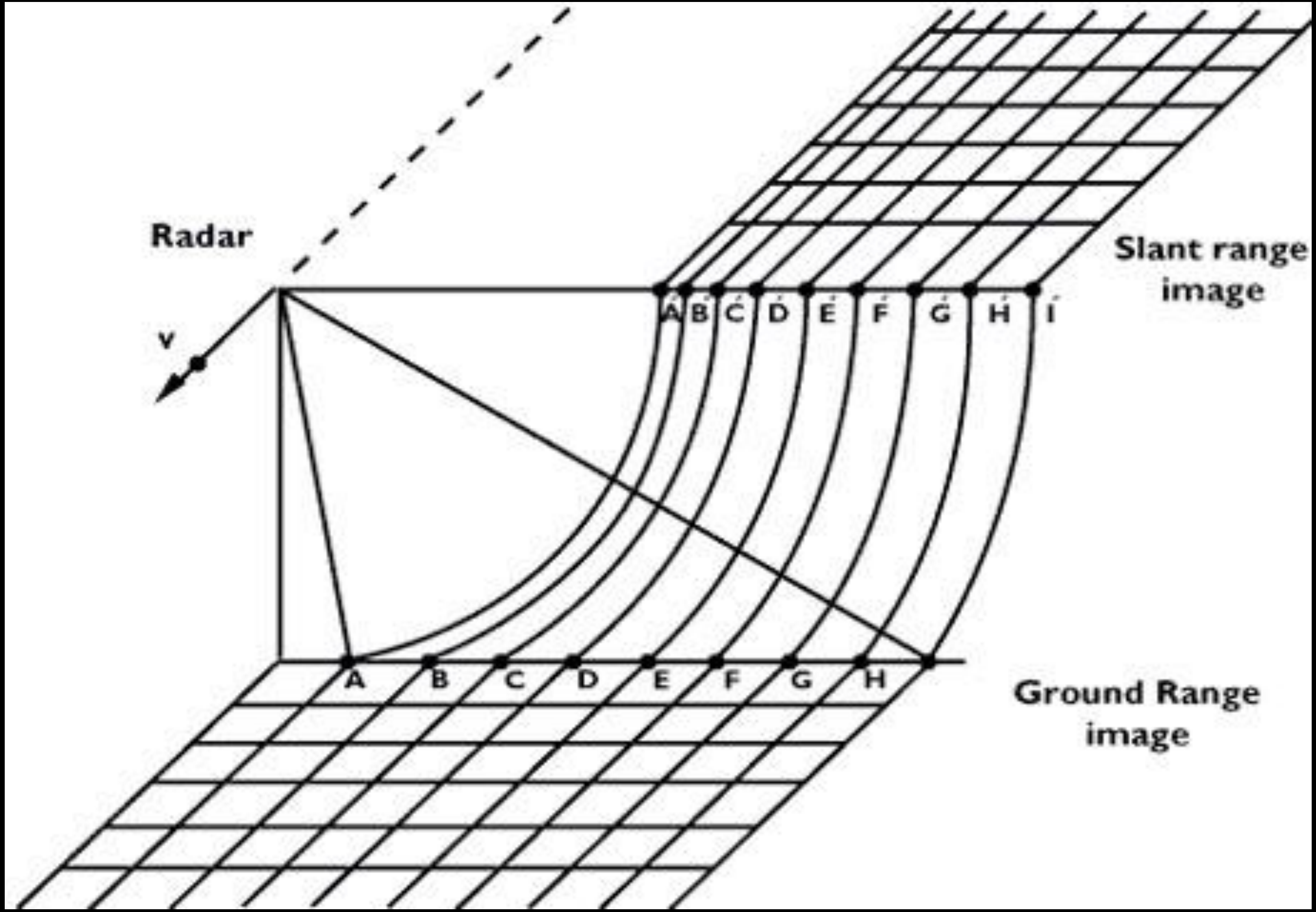

100 m
© 2009 Christian Wolff


300 m
τ = 1µs


200 m
© 2009 Christian Wolff

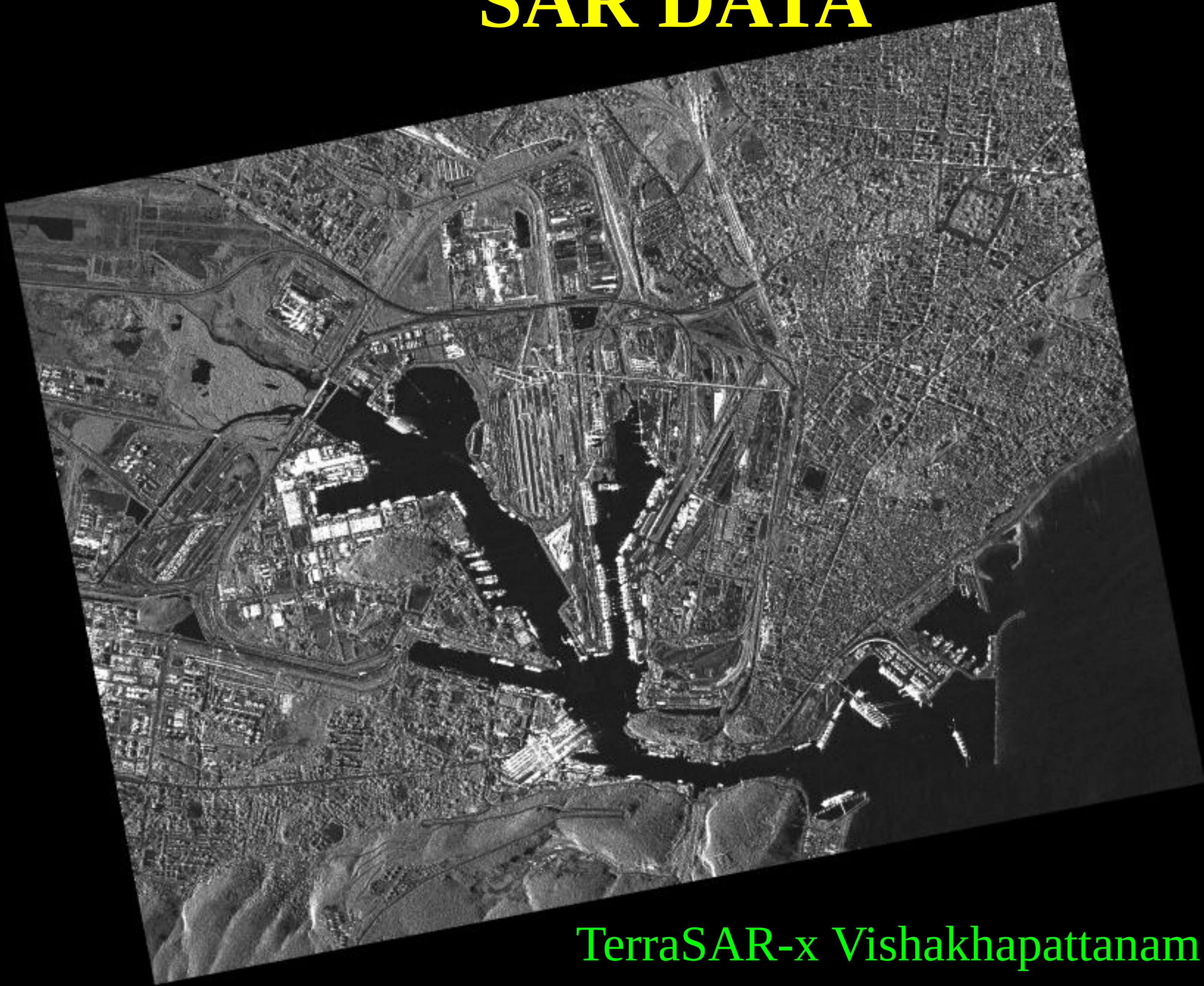
Slant Range / Ground Range

The figure shows two types of radar data display:
- slant range image, in which distances are measured between the antenna and the target.
- ground range image, in which distances are measured between the platform ground track and the target,



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.

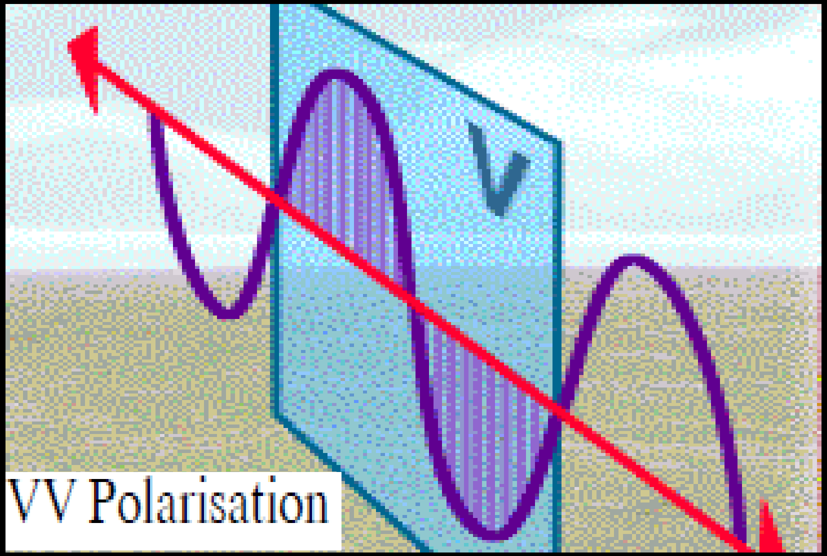


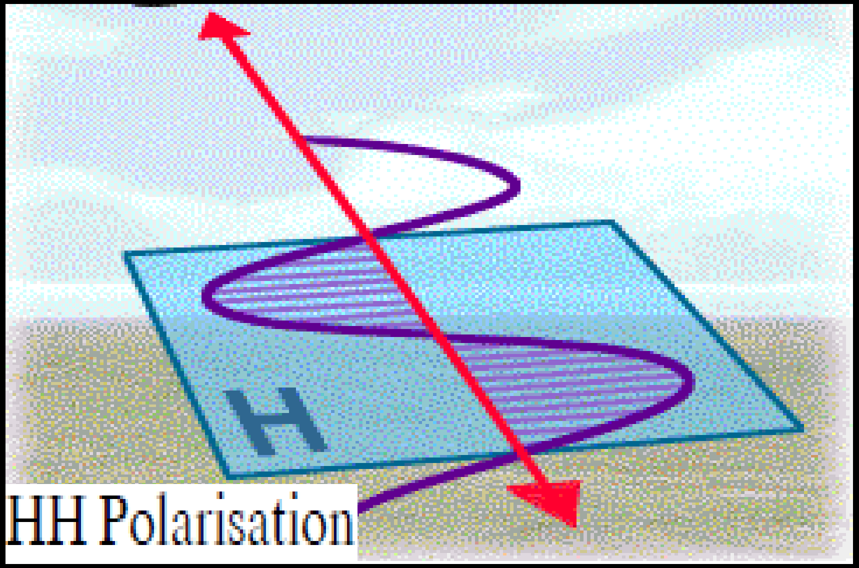
TerraSAR-x Vishakhapattanam

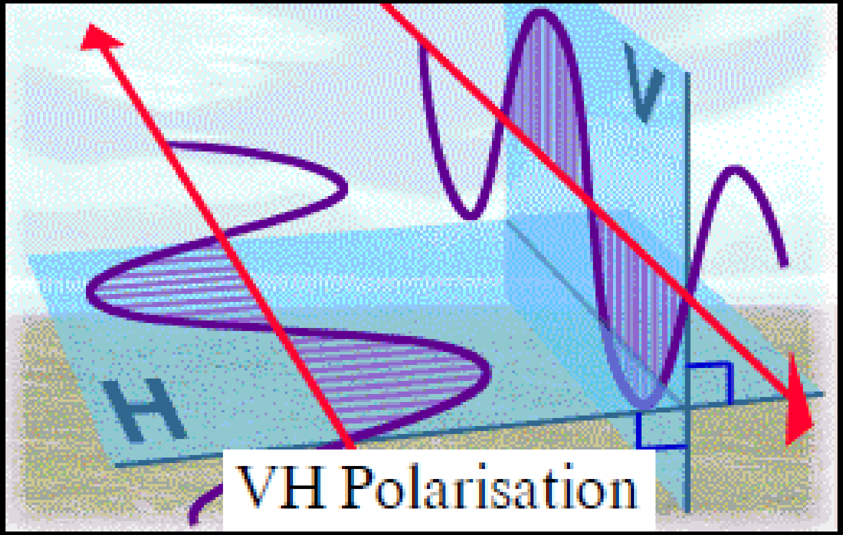
Radar Polarisation

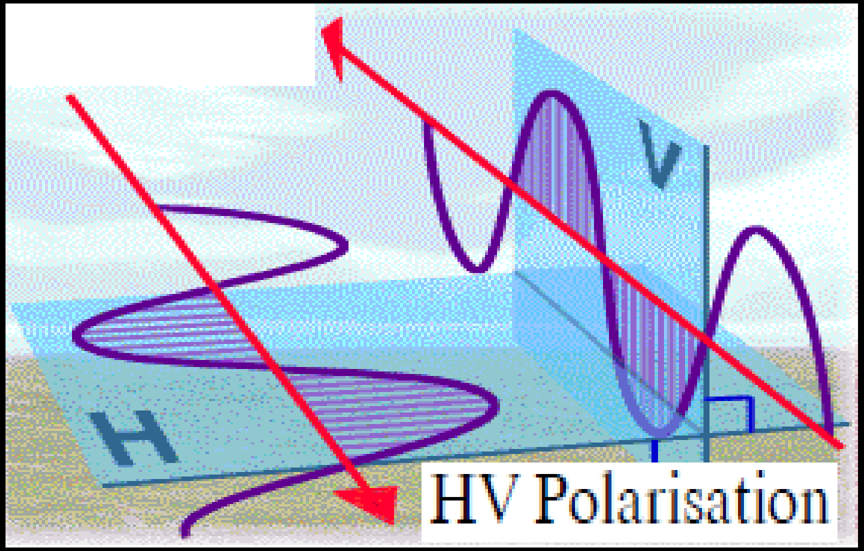
- ***Un-polarized*** **energy vibrates in all possible directions perpendicular to the direction of travel.**
- **Radar antennas send and receive *polarized energy*. *This* means that the pulse of energy is filtered so that its electrical wave vibrations are only in a single plane that is perpendicular to the direction of travel. The pulse of electromagnetic energy sent out by the antenna may be *vertically or horizontally polarized.***

Polarisations

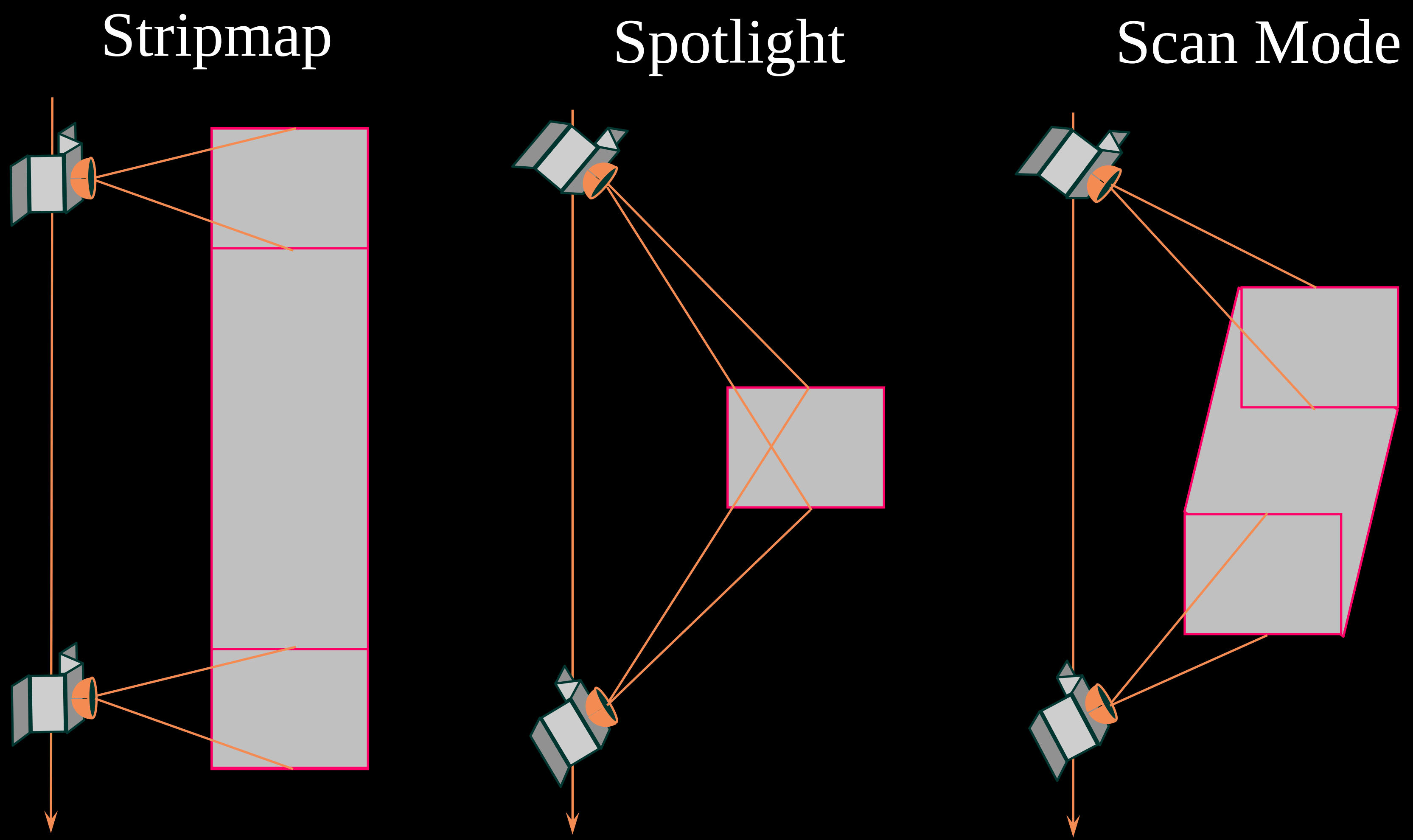








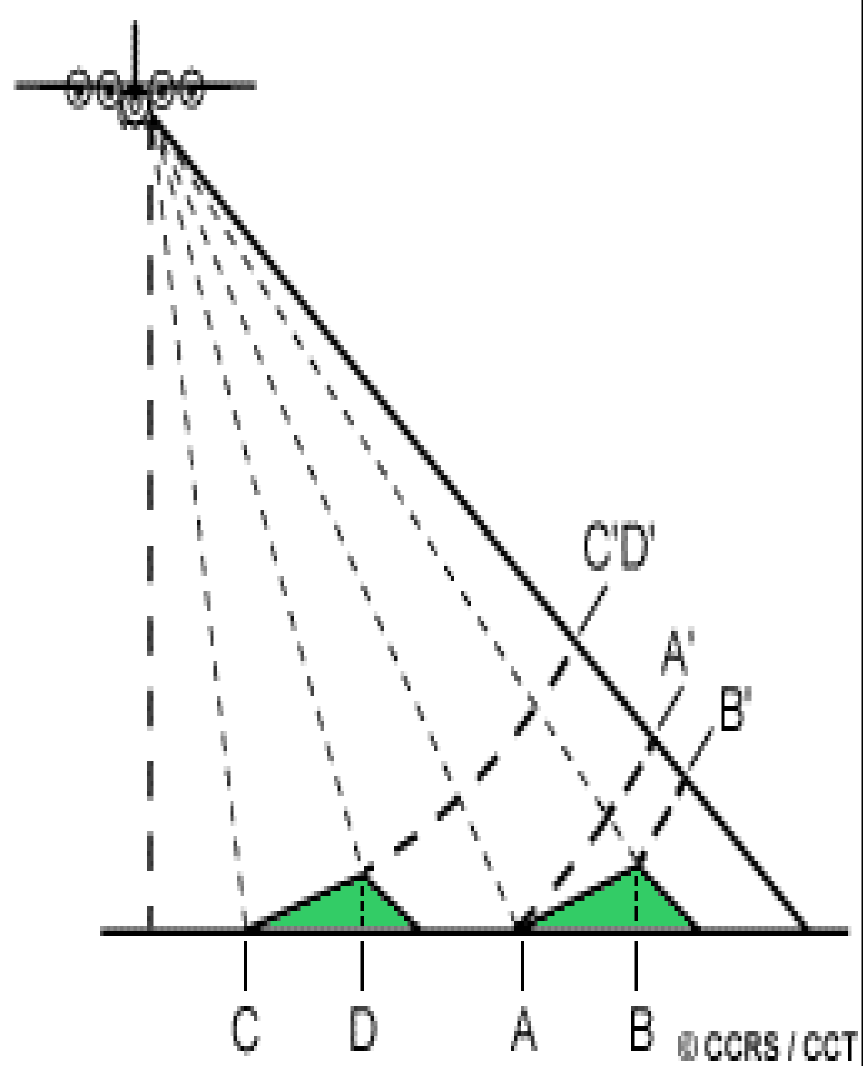
SAR Modes



Geometric Distortions in RADAR

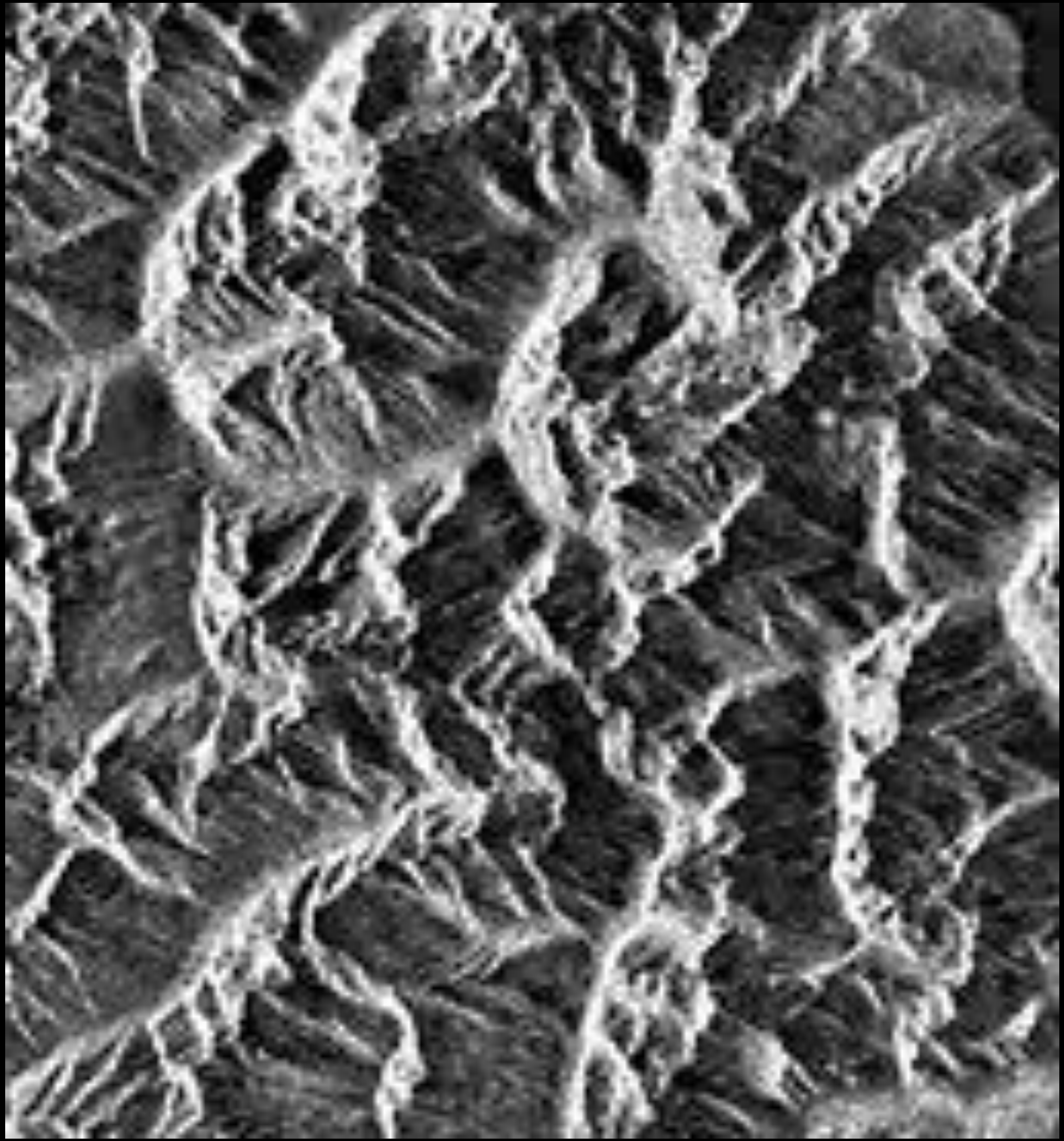
Foreshortening

When the radar beam reaches the base of a tall feature tilted towards the radar (e.g. a mountain) before it reaches the top **foreshortening** will occur. the slope (A to B) will appear compressed and the length of the slope will be represented incorrectly (A' to B').



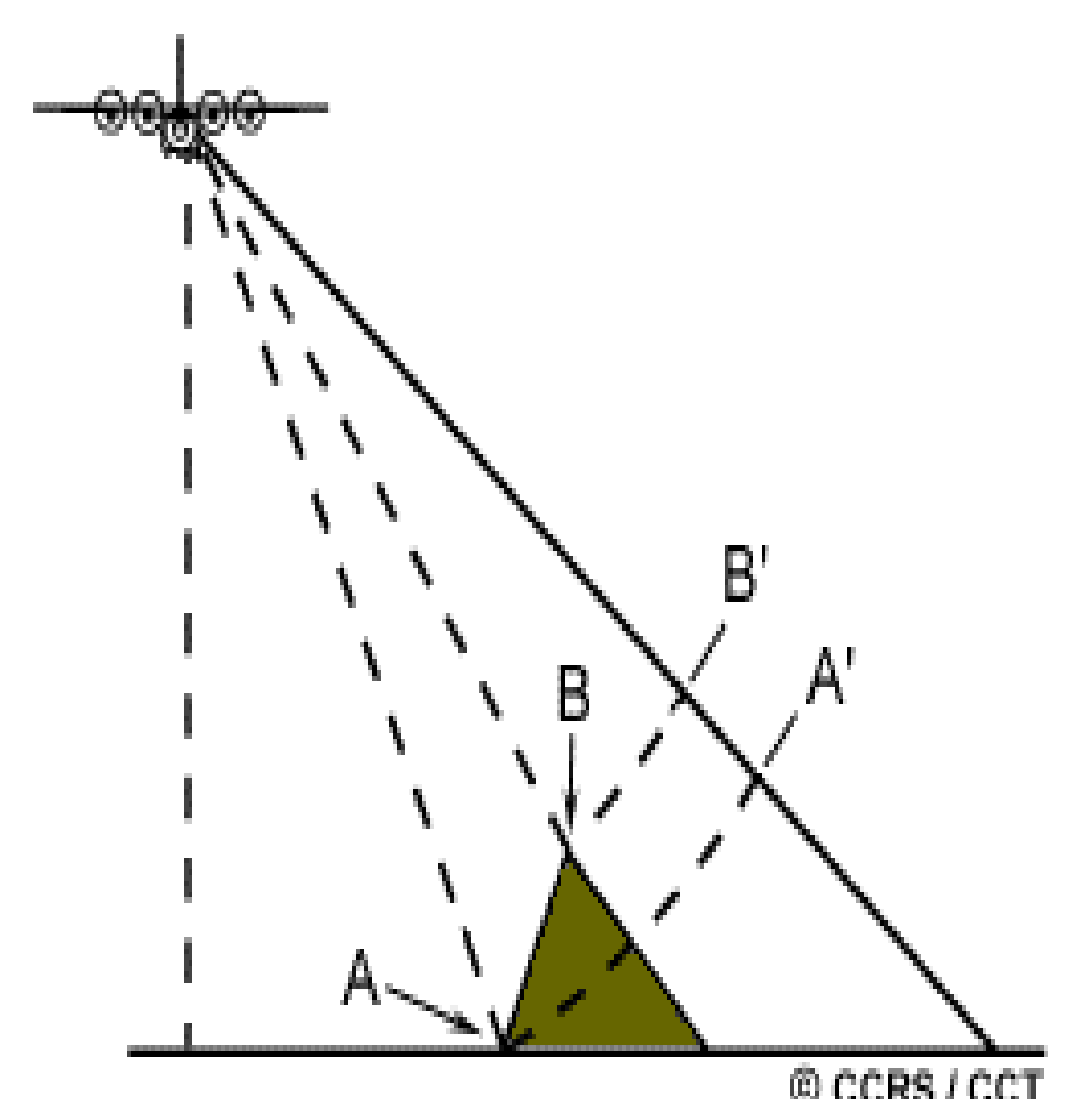
CONTD…

The figure shows a radar image of **steep mountainous terrain** with severe foreshortening effects. The foreshortened slopes appear as bright features on the image.



Layover

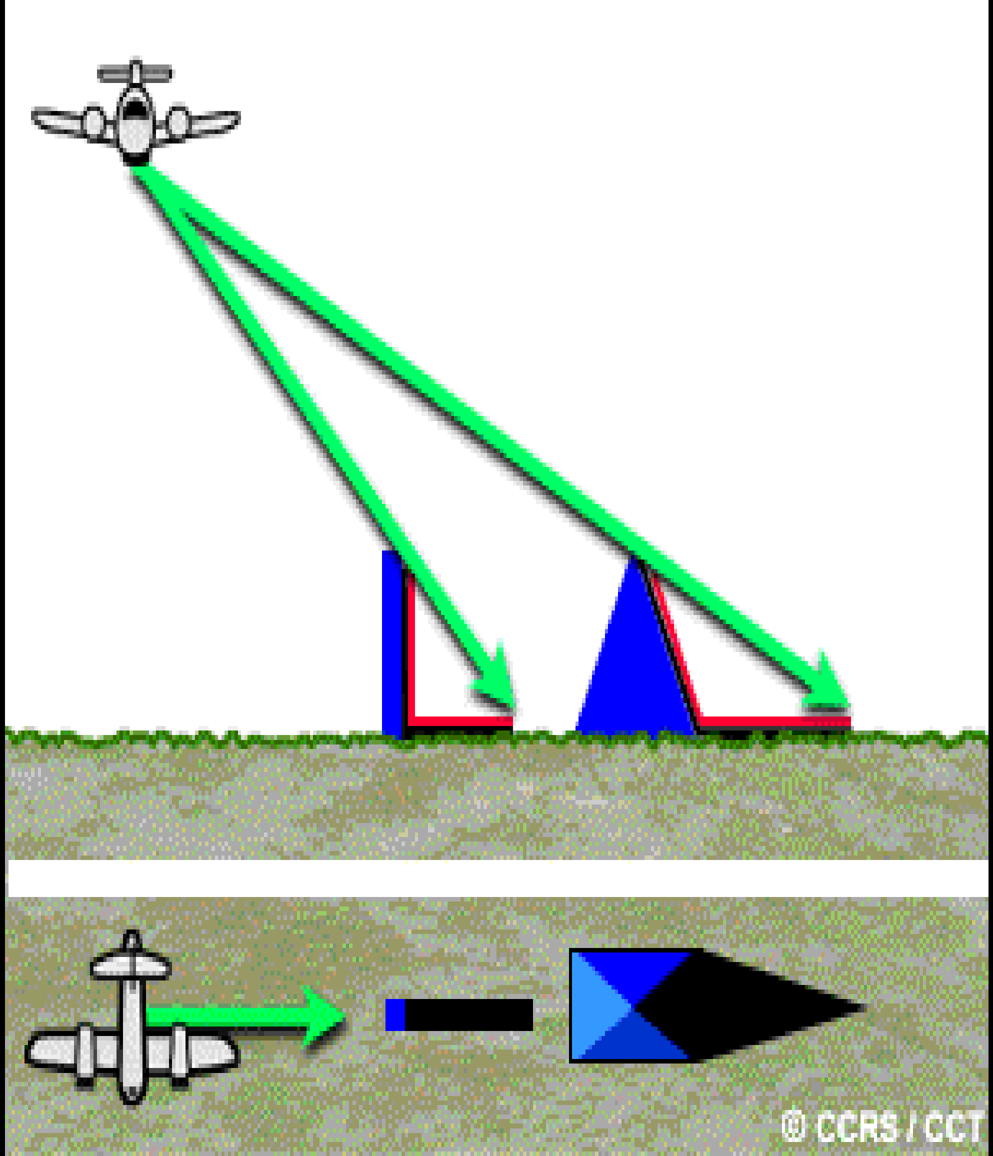
Layover occurs when the radar beam reaches the top of a tall feature (B) before it reaches the base (A). The return signal from the top of the feature will be received before the signal from the bottom. As a result, the top of the feature is displaced towards the radar from its true position on the ground, and "lays over" the base of the feature (B‘ to A')



Layover effects on a radar image look very similar to effects due to foreshortening. Layover displacement is greatest at short range, where the look angle is smaller.

Shadow

- Both foreshortening and layover result in **radar shadow**. Radar shadow occurs when the radar beam is not able to illuminate the ground surface. Shadows occur in the down range dimension (i.e. towards the far range), behind vertical features or slopes with steep sides.



CONTD…

Radar shadow effects

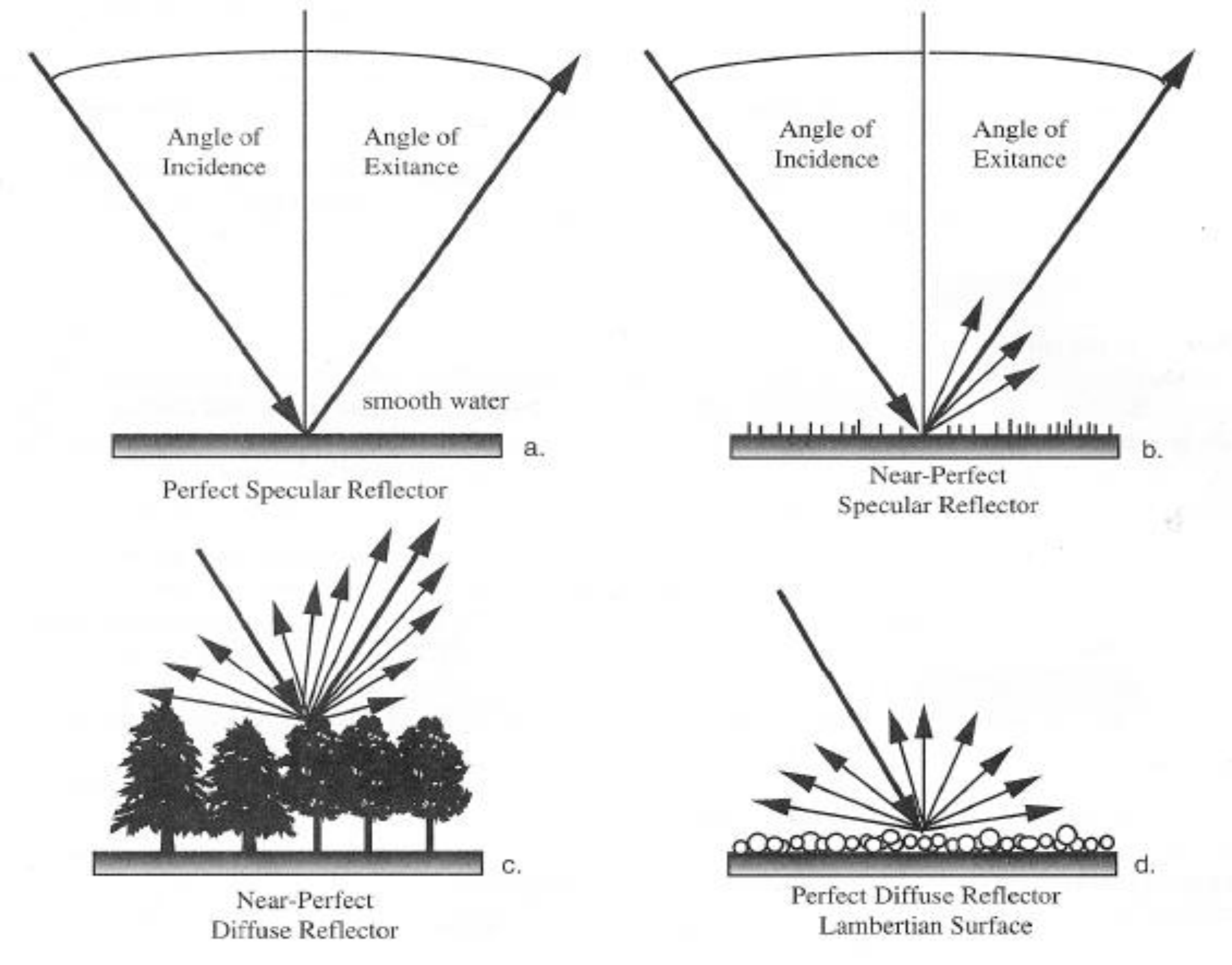
Measurement of Object Height

Shadows

The simplest method of measuring object height is to observe the length, *L*,of the shadow of the object by the SAR and calculate the object height from the known SAR altitude, H and ground range, *R*,:

$$h_{tgt} = L_{shadow} \cdot \frac{H}{R_g}$$

Specular Versus Diffuse Reflectance



Surface roughness

There is a relationship between the wavelength of the radar (λ), the depression angle (γ), and the local height of objects (*h in cm*) *found within the resolution cell being illuminated* by microwave energy. It is called the *modified Rayleigh criteria and can be used to predict what the earth's surface* will look like in a radar image if we know the surface roughness characteristics and the radar system parameters (λ, γ, *h*) mentioned.

Smooth and Rough "Rayleigh Criteria"

The area with smooth surface roughness sends back very little backscatter toward the antenna, i.e. it acts like a specular reflecting surface where most of the energy bounces off the terrain away from the antenna. The small amount of back-scattered energy returned to the antenna is recorded and shows up as a dark area on the radar image. The quantitative expression of the *smooth criteria is:*

$$h \leq \frac{\lambda}{8 \sin \gamma}$$

Smooth and Rough "Rayleigh Criteria"

The area with smooth surface roughness sends back very little backscatter toward the antenna, i.e. it acts like a specular reflecting surface where most of the energy bounces off the terrain away from the antenna. The small amount of back-scattered energy returned to the antenna is recorded and shows up as a dark area on the radar image. The quantitative expression of the *smooth criteria is:*

$$h < \frac{\lambda}{25 \sin \gamma}$$

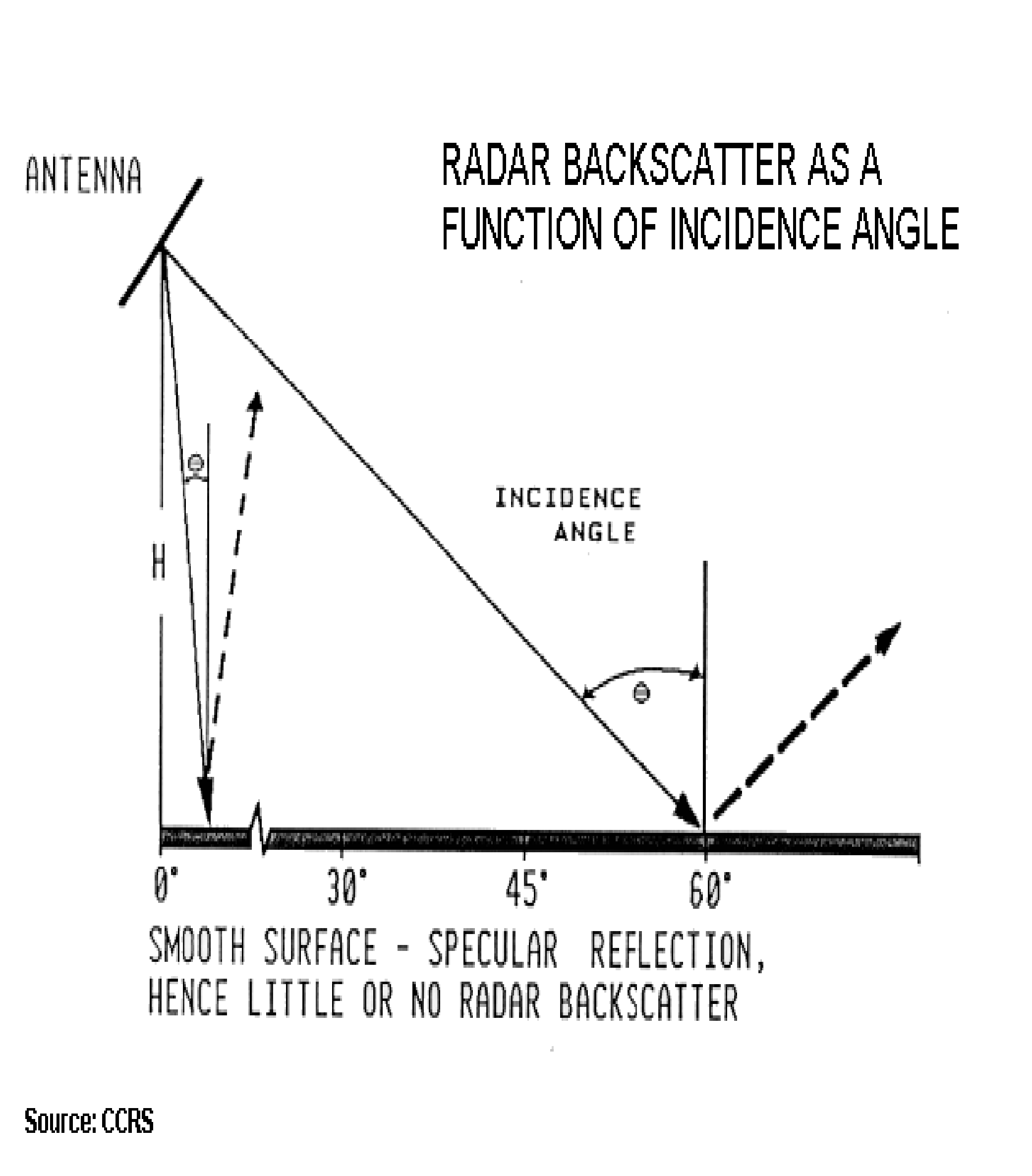
A bright return is expected if the modified *Rayleigh rough criteria are* used:

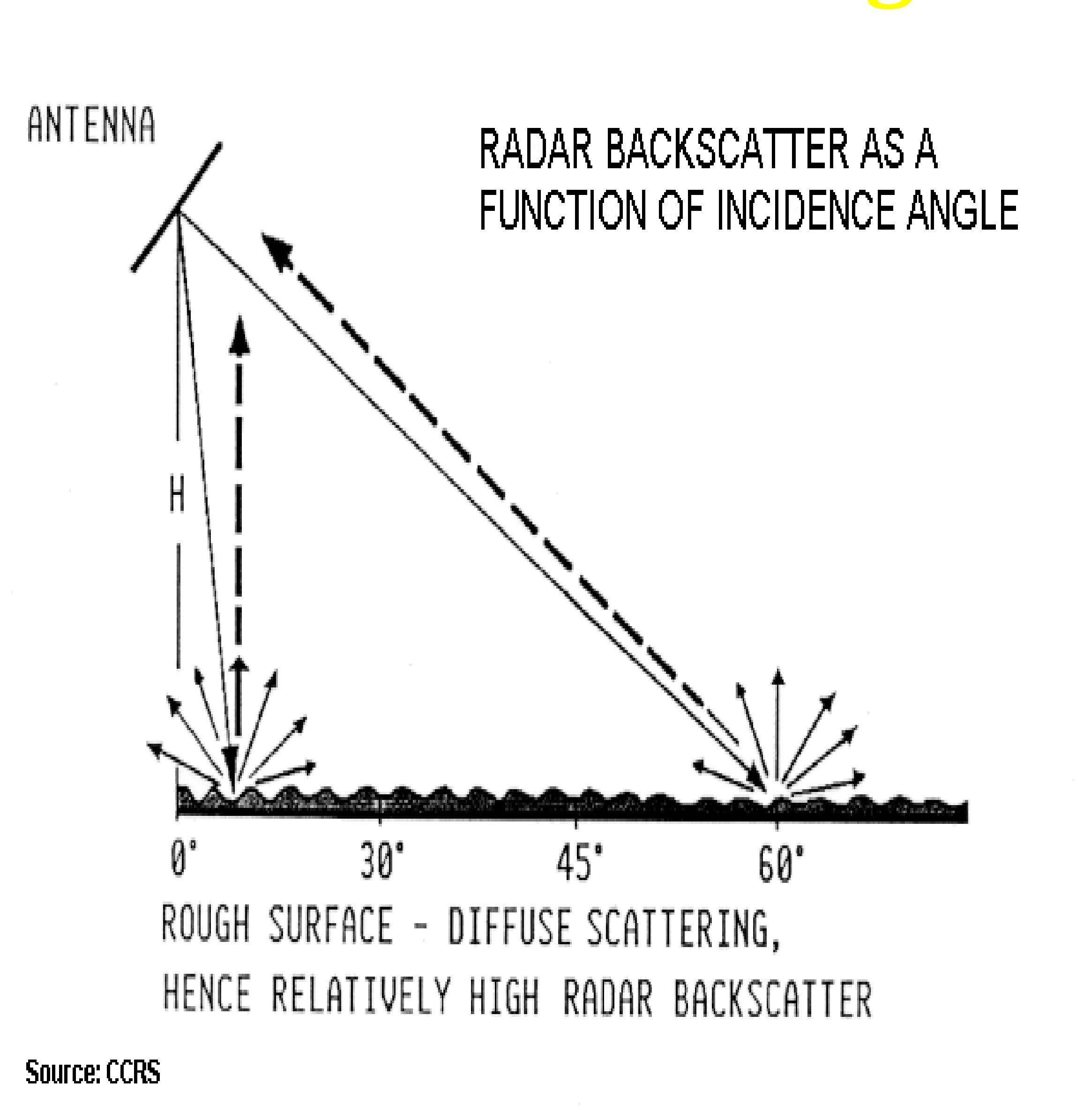
$$h > \frac{\lambda}{4.4 \sin \gamma}$$

Peake and Oliver's modified Rayleigh criterion

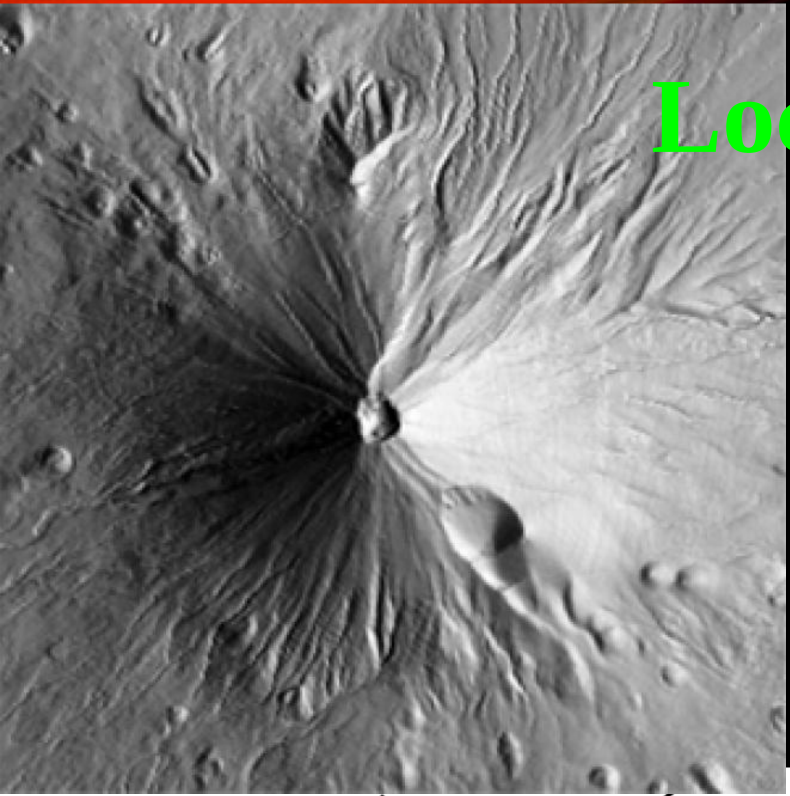
Surface roughness category	Aircraft K_a band $\lambda = 0.86$ cm, $\gamma = 45°$	Aircraft X band $\lambda = 3$ cm, $\gamma = 45°$	Seasat L band $\lambda = 23.5$ cm, $\gamma = 70°$
Smooth, cm	$h < 0.048$	$h < 0.17$	$h < 1$
Intermediate, cm	$h = 0.048$ to 0.276	$h = 0.17$ to 0.96	$h = 1$ to 5.68
Rough, cm	$h > 0.276$	$h > 0.96$	$h > 5.68$

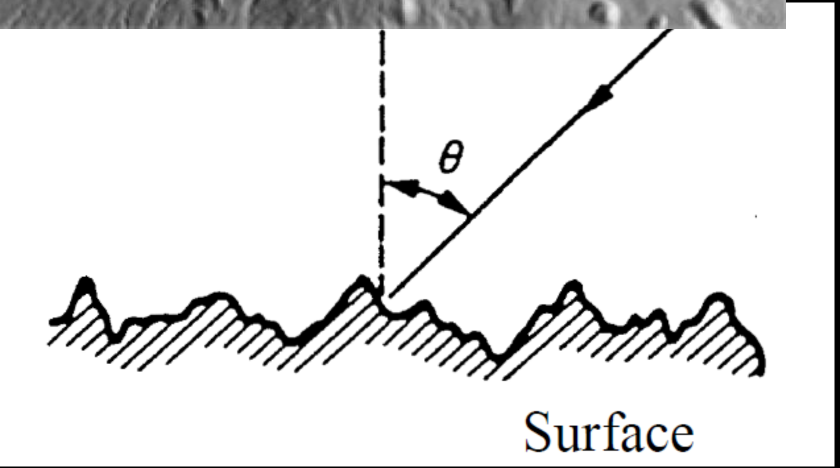
Radar Backscatter and Incidence Angle

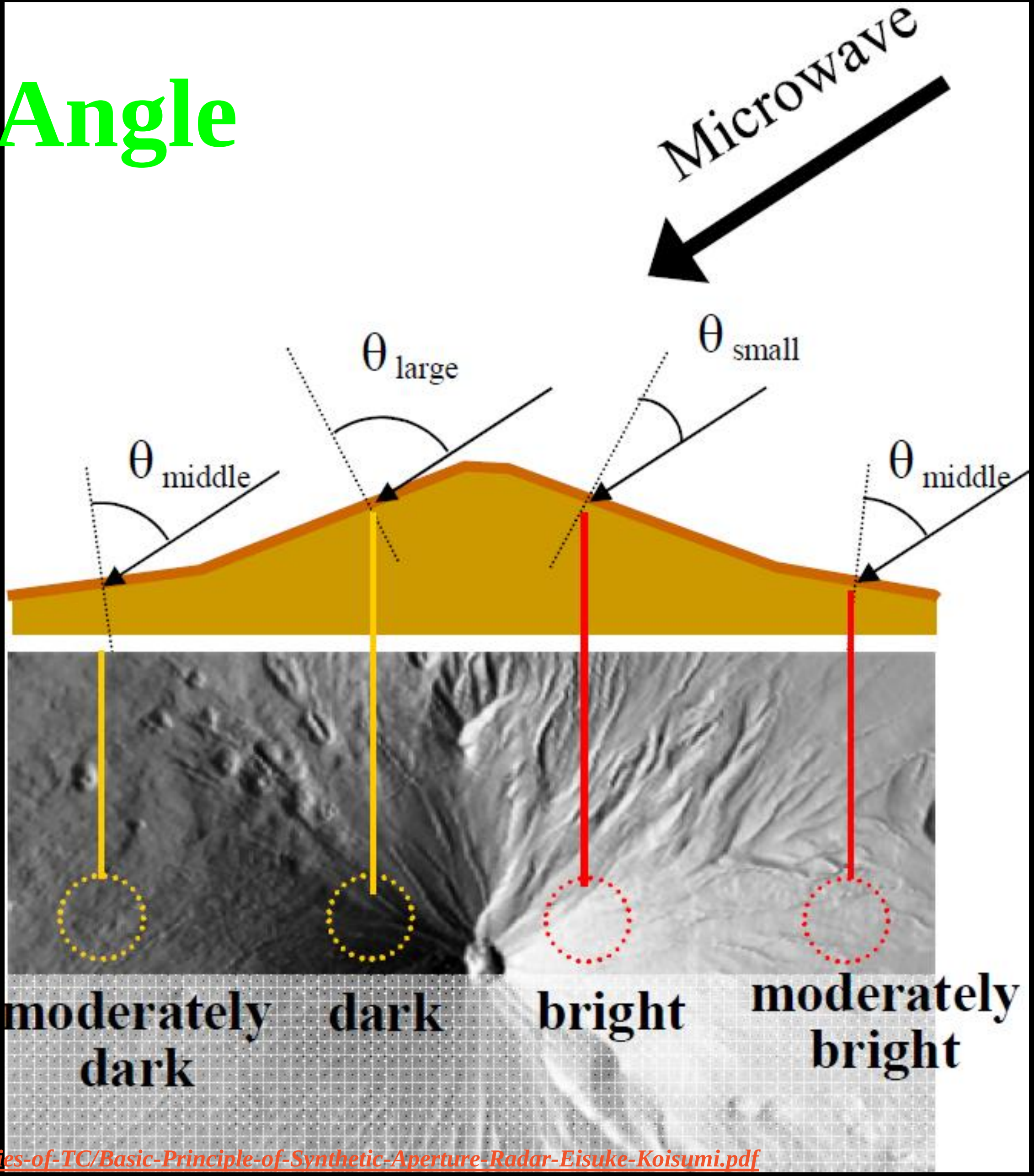




Local Incidence Angle

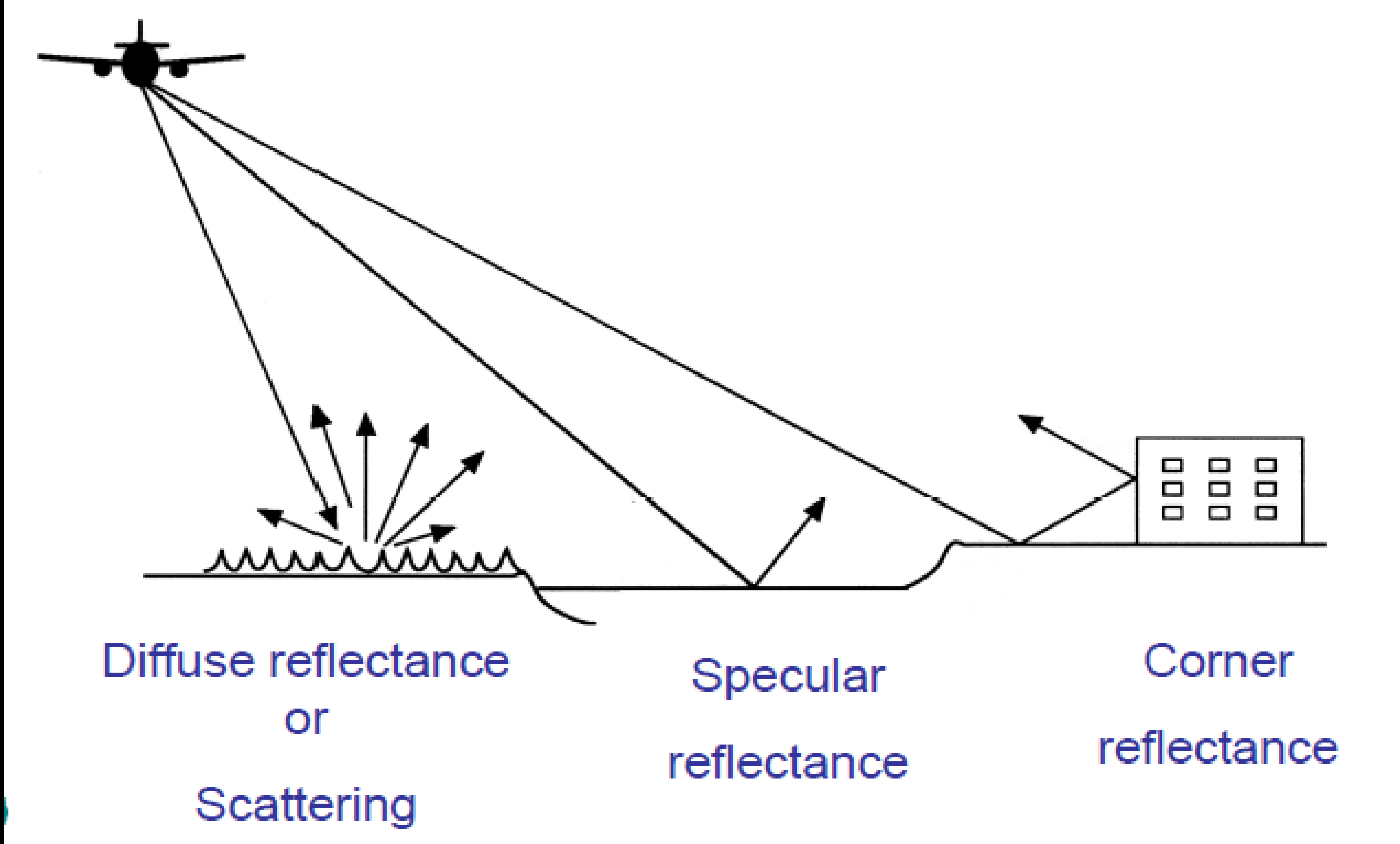






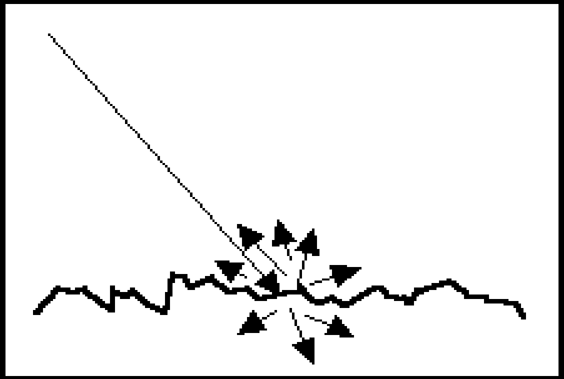
http://www.unescap.org/idd/events/2012-Application-of-space-technology-to-enhance-the-activities-of-TC/Basic-Principle-of-Synthetic-Aperture-Radar-Eisuke-Koisumi.pdf

Radar Return as a Function of Geometric Properties of Object

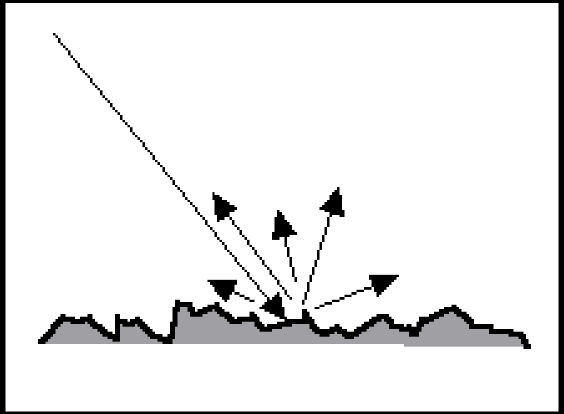


Interaction of EM Wave with Soil

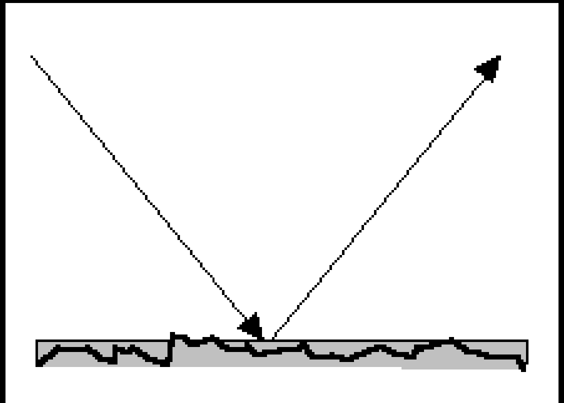
- Dry Soil: Some of the incident radar energy is able to penetrate into the soil surface, resulting in less backscattered intensity.



- **Wet Soil: The large difference in electrical properties between water and air results in higher backscattered radar intensity.**



- **Flooded Soil: Radar is specularly reflected off the water surface, resulting in low backscattered intensity. The flooded area appears dark in the SAR image.**

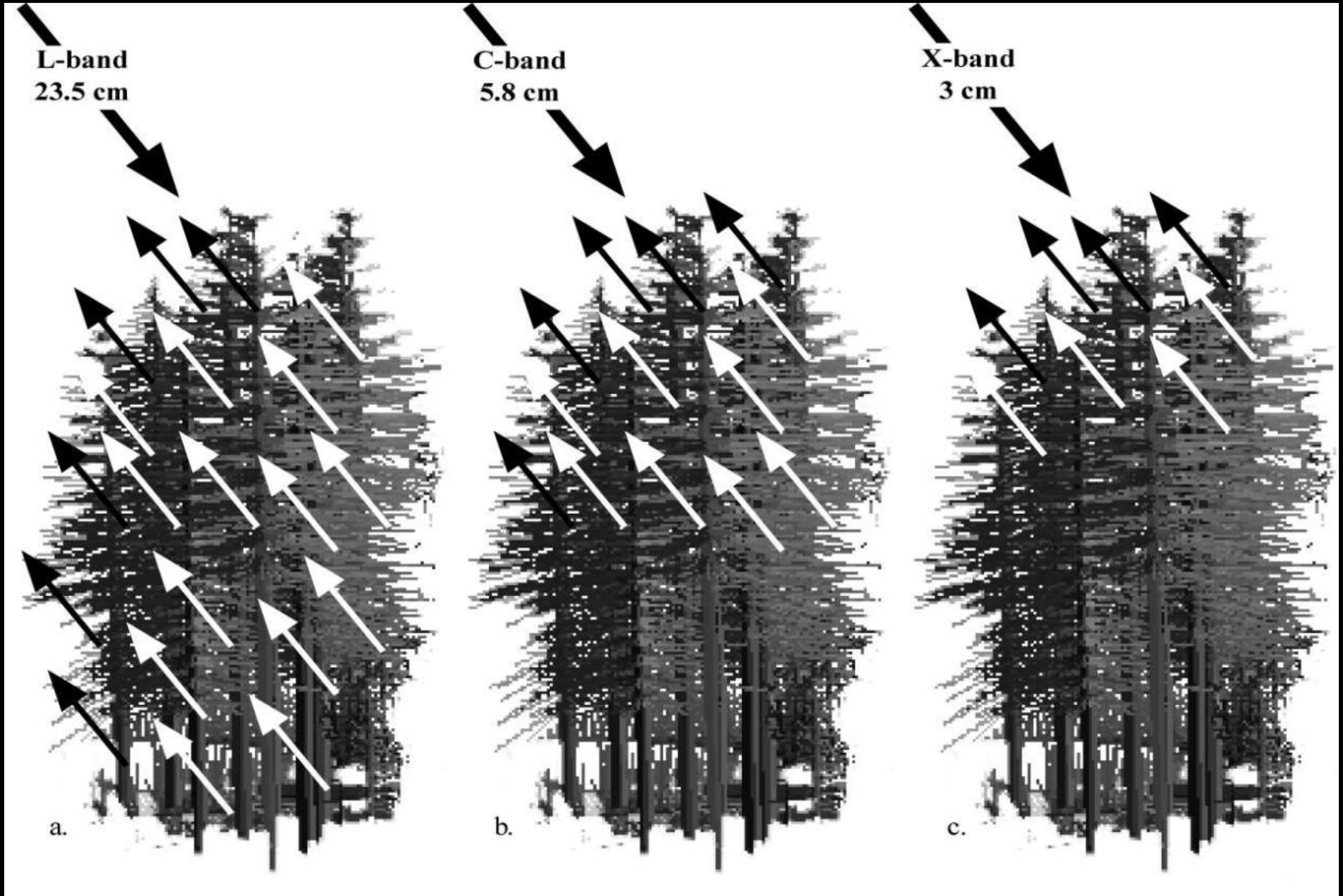


http://www.crisp.nus.edu.sg/~research/tutorial/sar_int.htm

Volume Scattering

- Volume scattering is related to multiple scattering processes within a medium, such as the vegetation canopy of a corn field or a forest.
- The intensity of volume scattering depends on the physical properties of the volume (variations in dielectric constant, in particular) and the characteristics of the radar (wavelength, polarization and incident angle

Response of a Pine Forest Stand To X-, C- and L-band Microwave Energy



Complex SAR Image

SAR image pixel is associated with a small area of the Earth's surface (called a resolution cell). Each pixel gives a complex number that carries amplitude and phase information about the microwave field backscattered by all the scatterers (rocks, vegetation, buildings etc.) within the corresponding resolution cell projected on the ground.

(0.587161,-0.356258)

RADARSAT-2 SLC data for San Francisco area (HH Channel)

Speckle

A SAR resolution cell generally contains a large number of scatterers and in comparison to the wavelength this resolution cell appears very large. The returned echo from scatterers is coherently summed to obtain the phase and brightness of the resolution cell. Sometimes due to a very strong reflector at a particular alignment or due to the coherent sum of all the various responses (due to large number of scattereres), the resolution cell shows a brightness value which is much higher than the actual brightness caused by the object. This unexpected bright value of resolution cell appears as speckle on SAR image.

SAR Data Format

- Raw Data
- SLC Data
- Multi-look Data
- Geocoded Data
- Polarimetric Data

SAR Applications

- SAR interferometry for DEM generation;
- SAR interferometry for subsident monitoring;
- SAR for soil moisture content;
- SAR for biomass estimation;
- SAR for crop estimation;
- SAR for flood control;
- SAR for oil spills monitoring.

SAR for DEM Generation

- Two technology can be applied to generate DEM (Stereo SAR and Interferometric SAR);
- Stereo SAR uses the parallax of SAR pair to generate DEM;
- Interferometric SAR uses the deferent phases of two SAR images to estimate the surface height;
- A DEM for a large area can be generated without need of ground control or a few control points.

SAR Interferometry For Subsidence Monitoring

- DiInSAR technology is used;
- The millimeters level of accuracy can be obtained.
- This technology is good for monitoring the construction site such as mining area, city...
- It can help in predicting the hazards such as mining exploitation.

SAR Application for Soil Moisture Content Estimation

- Soil dielectric constant is calculated through the SAR backscattering signals;
- The soil moisture content can be estimated by the soil dielectric constant;
- The accuracy of the estimated result depend on the SAR wavelength, the polarization used;
- It is useful for irrigation monitoring as well as the environmental monitoring.

SAR for Biomass Estimation

- Combine two separate SAR technologies, SAR polarimetry and Interferometry.
- SAR polarimetry uses the polarization state of receiving and transmitting channel to measure the differences in backscatter due to orientation, shape and material composition;
- SAR interferometry coherently combines signals from two separated spatial positions to extract the interferogram;
- By combining two technologies, the vegetation propertied such as vegetation height and biomass can be determined.

SAR for Crop Estimation

- Multi-temporal SAR data should be used to monitor the plant grow and estimate the plant’s biomass;
- The damages area due to Flooding can also be monitoring;
- The crop producing model may be used to simulate the plant grow and predict the crop yields.

SAR for Flood Control

- SAR data is weather independent;
- It can be obtain in before, during, and after the flood event;
- The flood area can be mapped;
- The flood movement can be delineated;
- The flood effect area can be mapped.

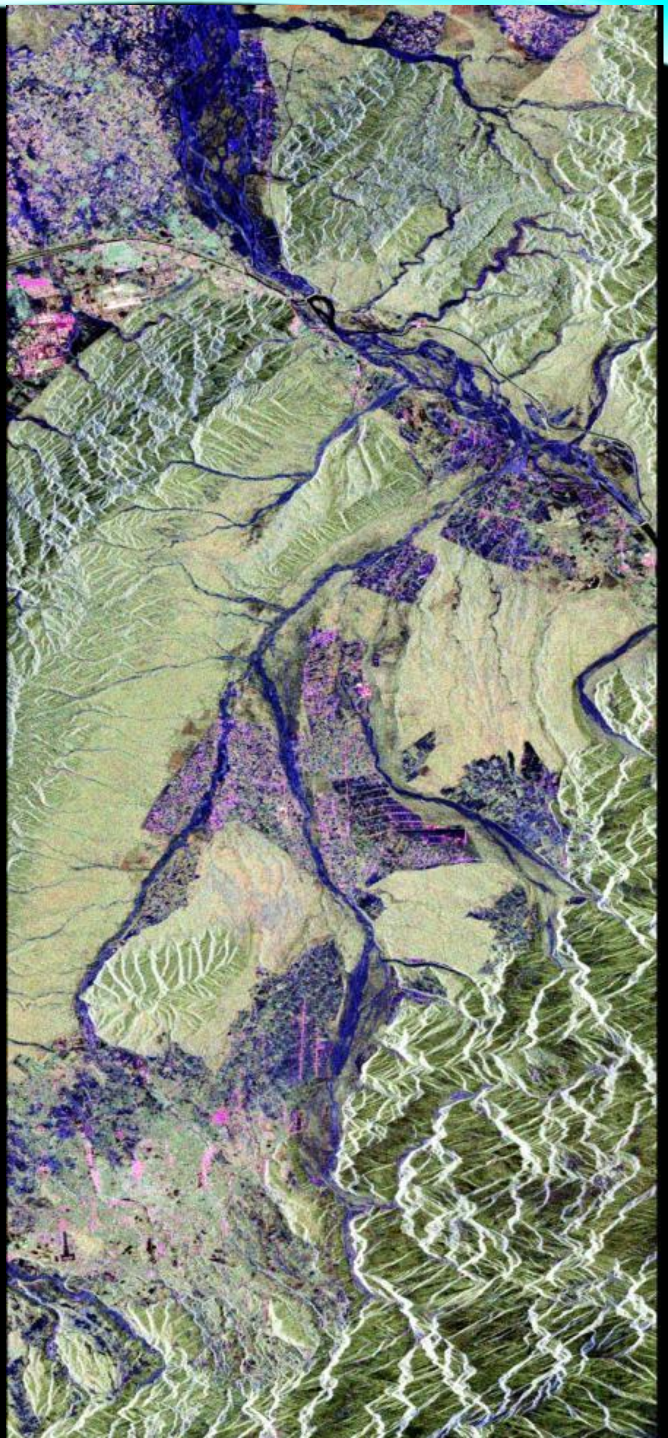
Pauli RGB Image

HH+VV – Blue Colour

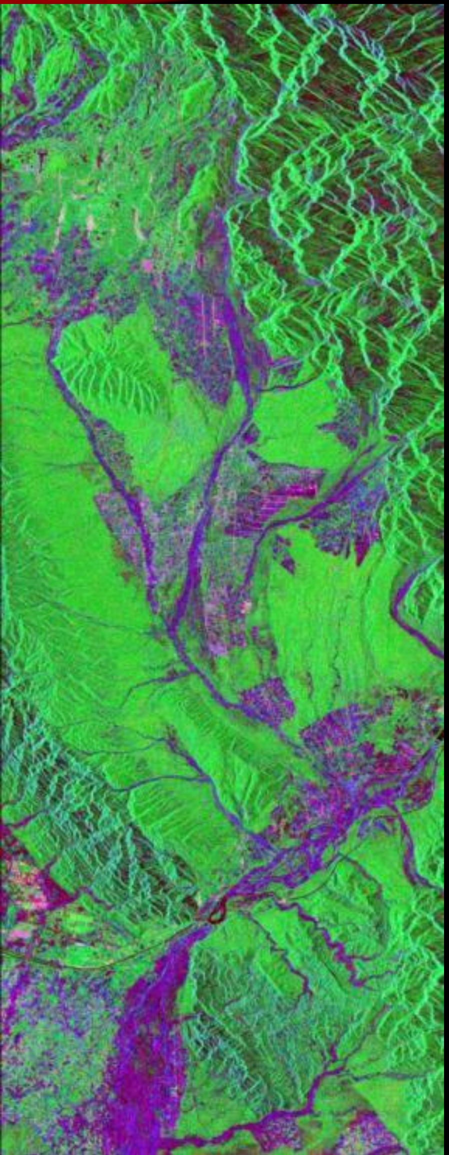
HH-VV – Red Colour

2HV – Green Colour

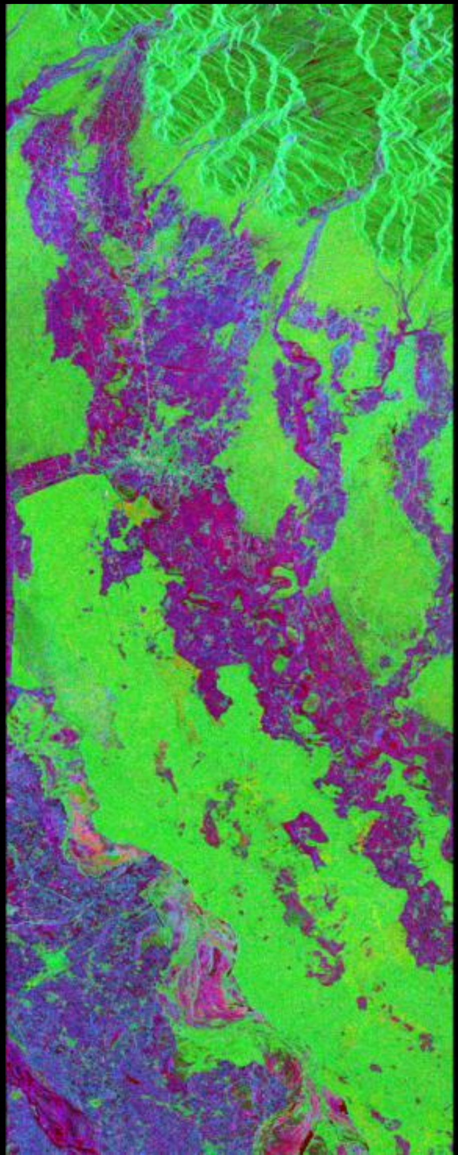
$$K_p = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} \\ S_{HH} - S_{VV} \\ 2S_{HV} \end{bmatrix}$$



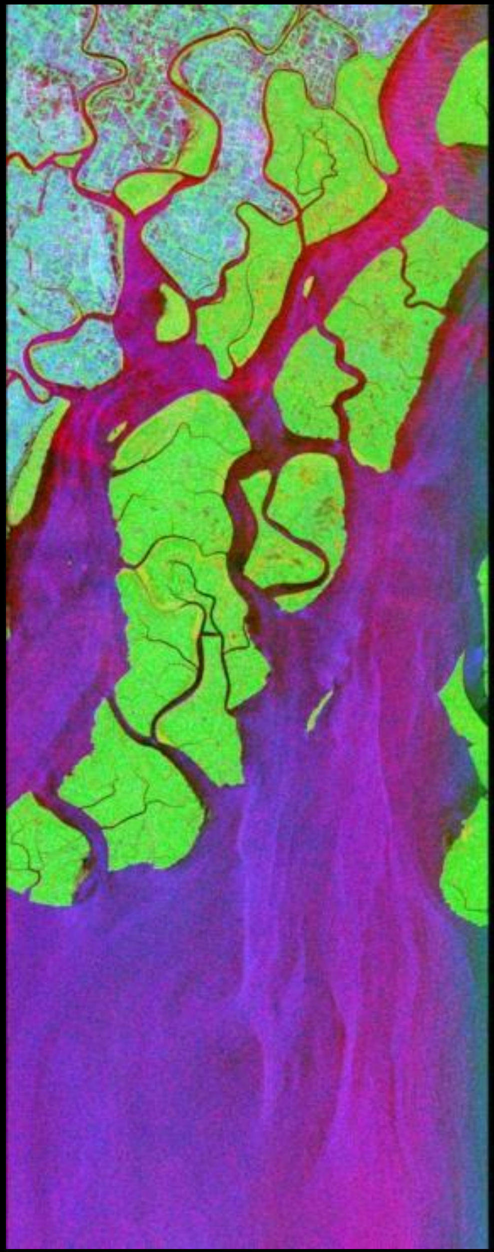
PolSAR Decomposition



Forest of Doon valley



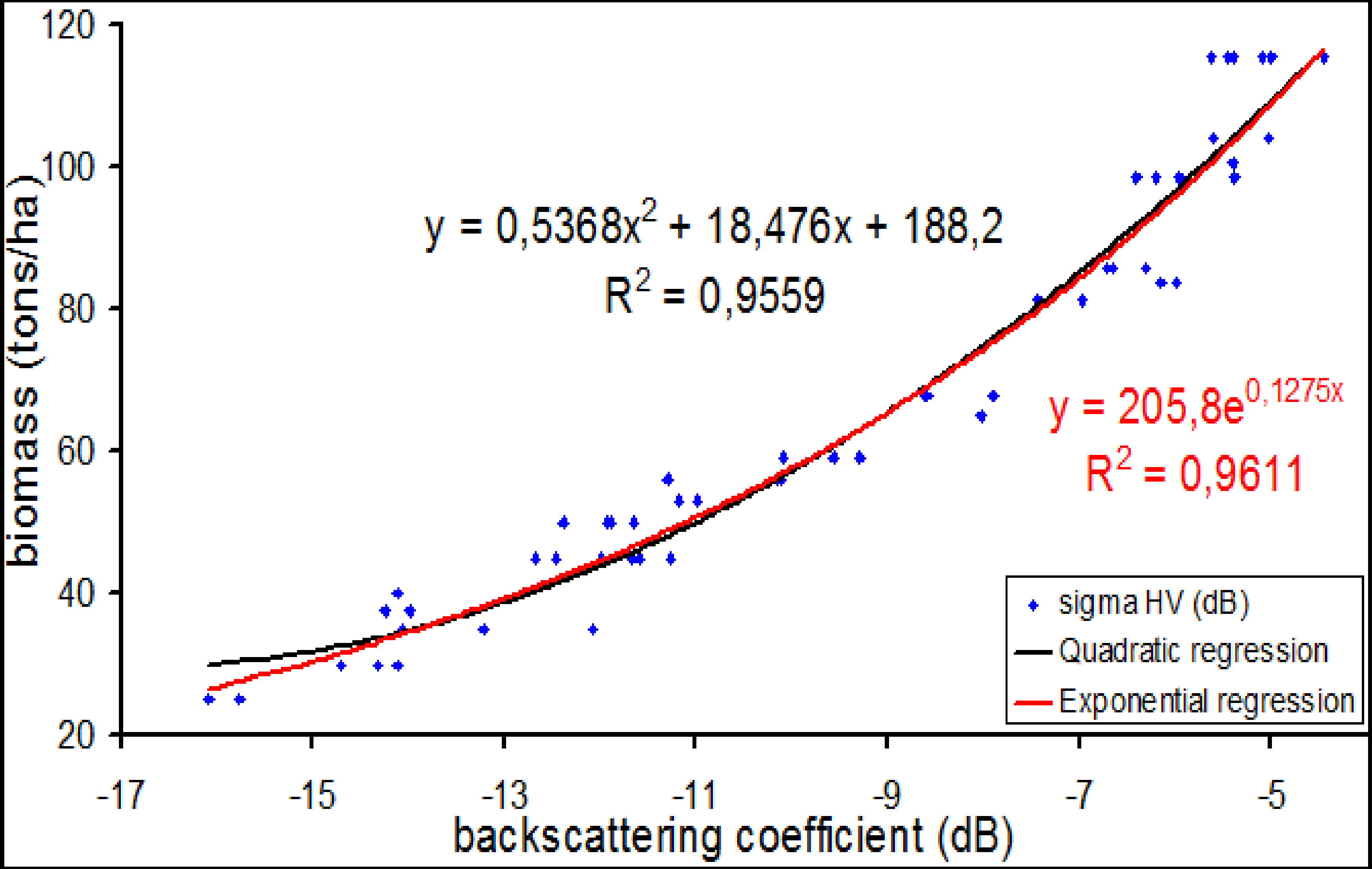
Dudhwa National Park, U.P.



Sunderban, W.B.

Decomposition modelling of ALOS PALSAR QuadPol data

Backscattering Coefficients and Biomass – RAMSES P-band Data over Nezer Forest



SAR for Oil Spills Monitoring

- The SAR data is cloud independent;
- Oil cover surface is clearly displayed in SAR images as dark regions;
- Some software can detect oil spills automatically
- The thickness of the oil layer may also be obtained using SAR data;
- With the multi-temporal data available, the source of pollution may be discovered.

Envisat Images

Source:-Solberg, et al. 2007

Thank You