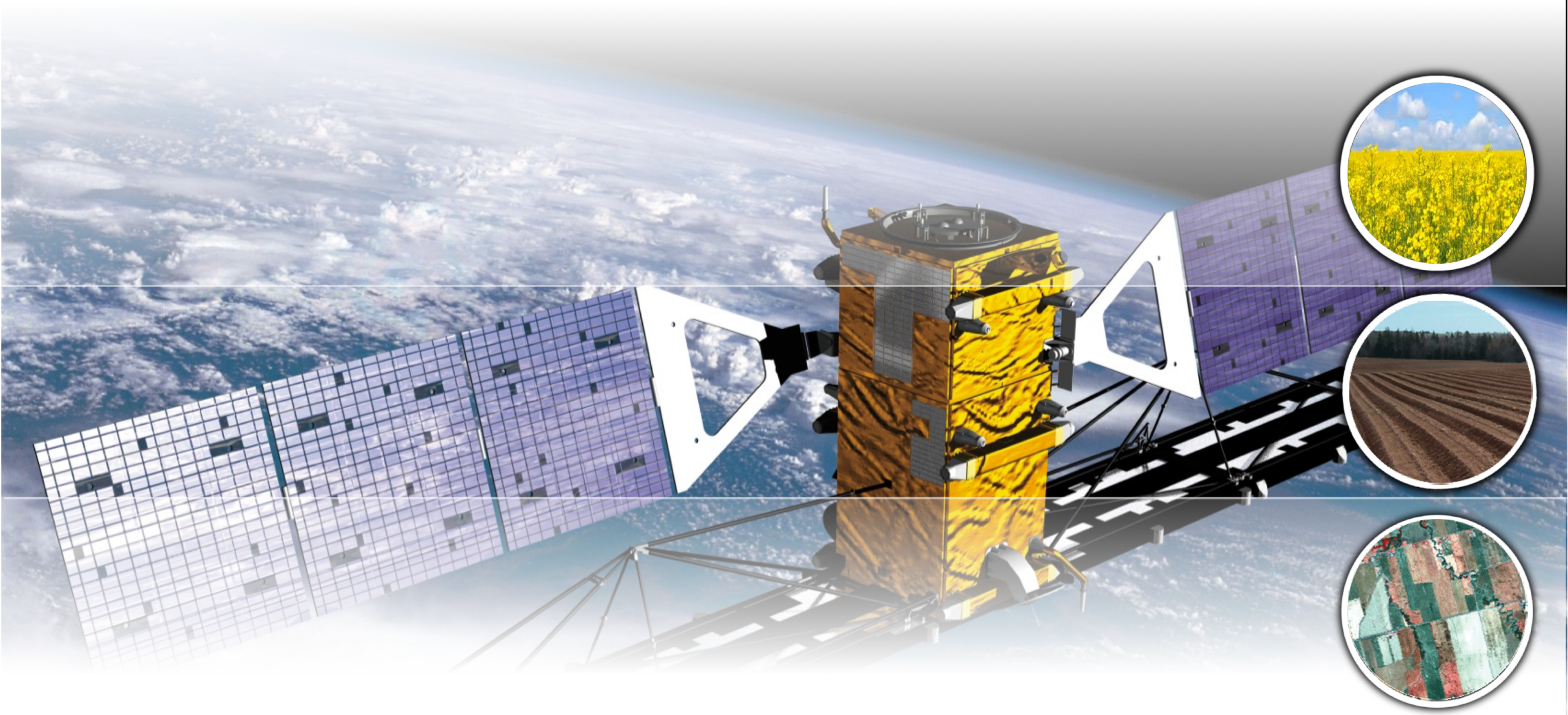


RADAR Remote Sensing - Basics

Electromagnetic Spectrum

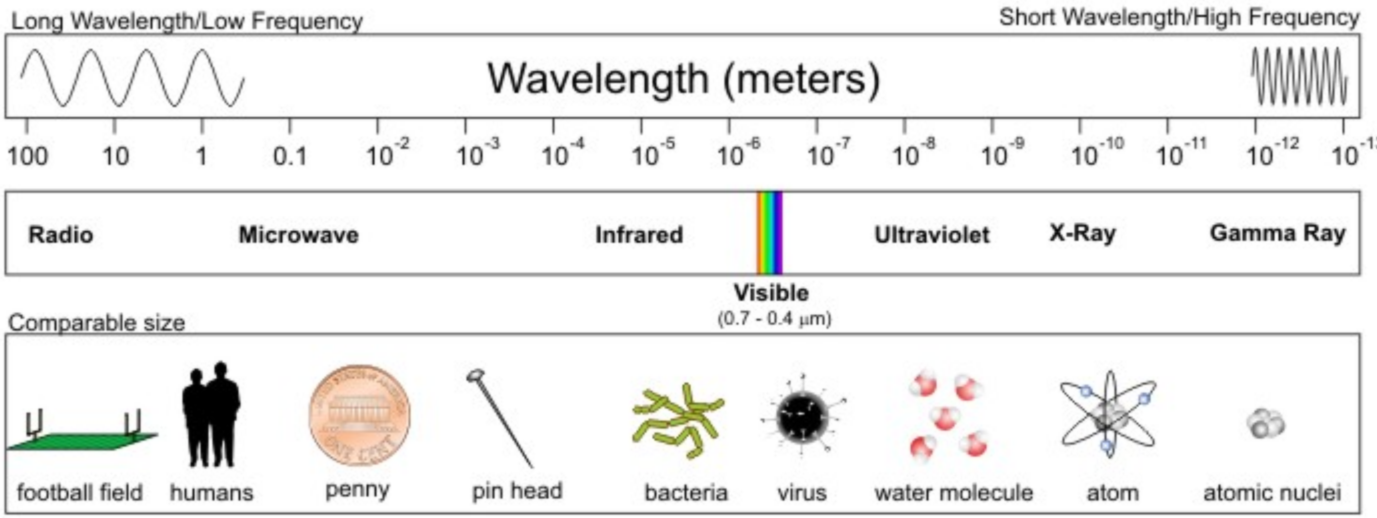


Image source: www.e-education.psu.edu/meteo3/l2_p2.html

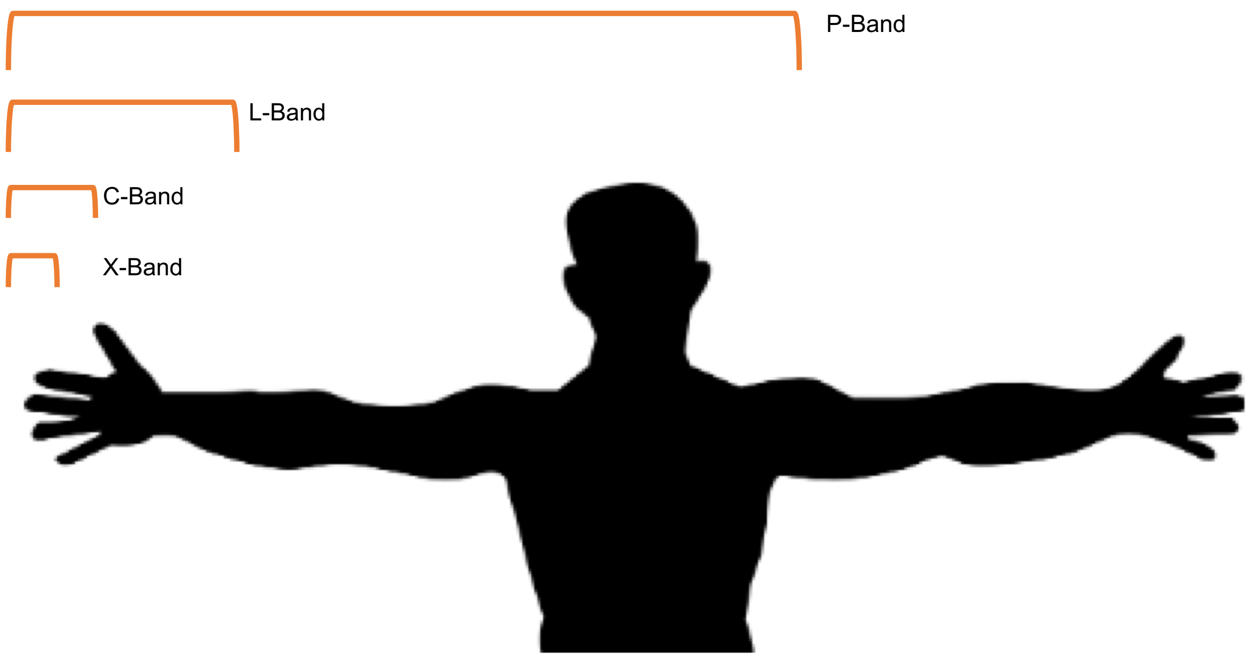
The Microwave Region

Microwave remote sensing:

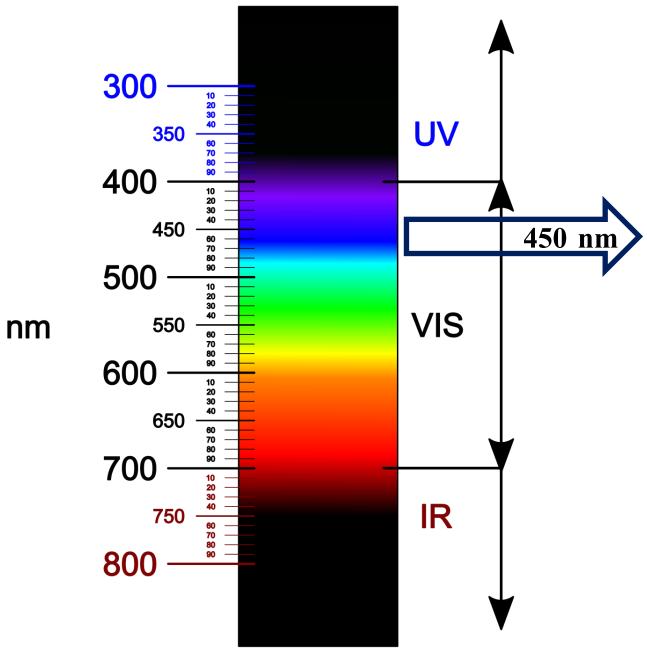
- wavelengths are usually between 1 cm and 1 m

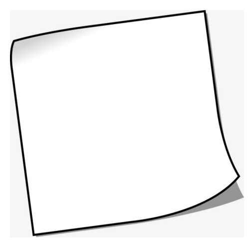
- microwave portions of the spectrum are often referenced according to both wavelength and frequency

Frequency band	Wavelength (cm)	Frequency (GHz)
Ka	0.8-1.1	40 - 26.5
K	1.1-1.7	26.5 - 18
Ku	1.7-2.4	18 - 12.5
X	2.4-3.8	12.5 -8
C	3.8-7.5	8 - 4
S	7.5-15	4 - 2
L	15 -30	2 - 1
P	30 -100	1 - 0.3

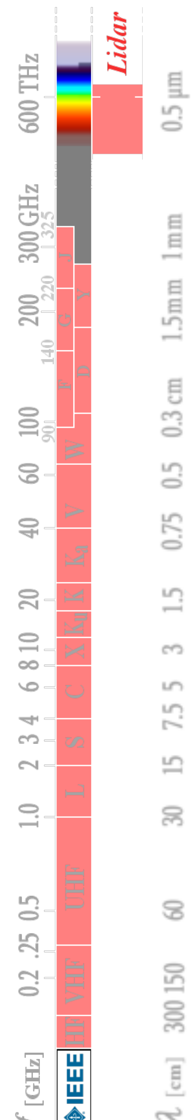


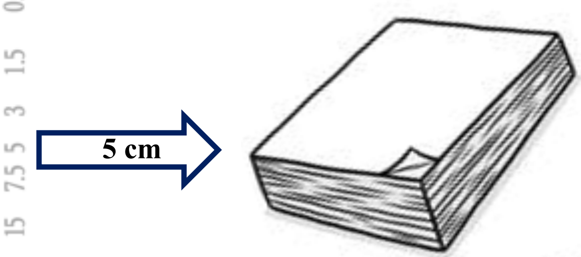
The Scale of Energy





450 nm ~ 1/200th of thickness of 1 piece of paper





5 cm ~ 500 sheets of paper

Image source: en.wikipedia.org/wiki/Effects_of_blue_light_technology

RADAR Trivia (1)

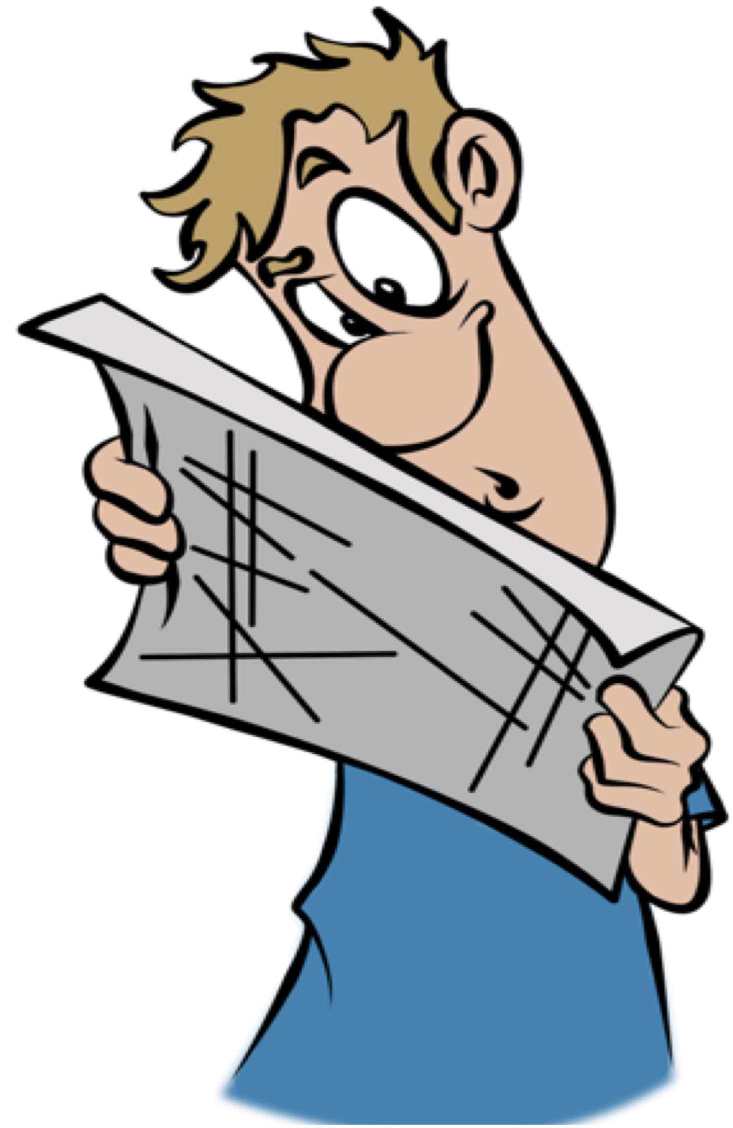
Frequency bands in the microwave range of the electromagnetic spectrum are designated by letters.

What is the origin of this convention?

RADAR Trivia (1)

This convention began in World War II. Radar bands were given code words so that military engineers could talk about them without divulging their actual frequency.

They were deliberately non-sequential in order to confuse the enemy!



Information source: www.nasa.gov/directorates/heo/scan/communications/outreach/funfacts/txt_band_designators.html

RADAR Trivia (2)

Clinton is a small farming town located in southwestern Ontario.

Canadian Forces Base Clinton (CFB Clinton) played a special role during WWII with respect to radar?

Why is CFB Clinton an important part of Canadian radar history?

RADAR Trivia (2)

CFB Clinton was a training unit for radar operators during a period when radar was a top secret device.

UK, Canadian, US and other servicemen were trained at Clinton. Clinton remained the primary radar training site for Canadian Forces personnel through the Cold War era, with continued expansions throughout the 1950s and 60s.

As part of a centralization effort, CFB Clinton was closed in 1971.

Radar antenna located in downtown Clinton

Information source: en.wikipedia.org/wiki/CFB_Clinton

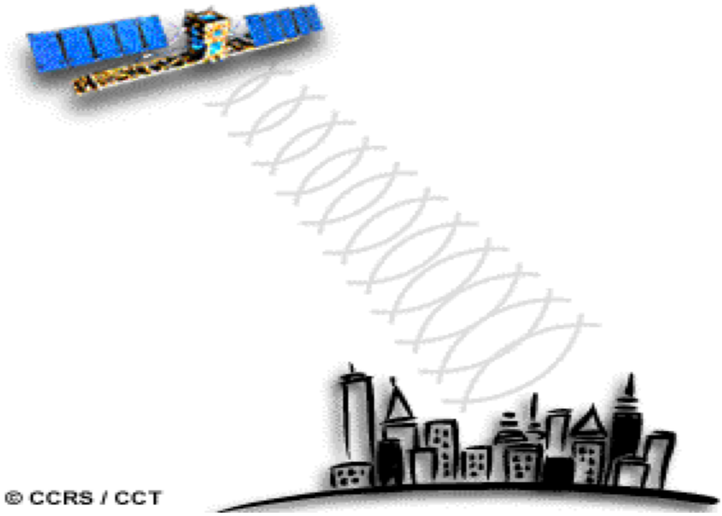
RADAR Trivia (3)

RADAR is actually an acronym. Deciphering this acronym reveals the two very important primary roles of RADAR.

Can you unravel the acronym and the secret of RADAR?

RAdio Detection And Ranging - RADAR

Radars are active systems which means that they generate their own source of energy



Detection – radars send or propagate a microwave (or *radio*) signal with known properties (for example, an intensity of energy). The strength of the energy "*scattered back*" by the target is detected by the radar. This "*backscattered*" signal provides important clues about the characteristics of the target.

Ranging – radars also measure the time it takes for the microwave signal sent from the radar's antenna to travel to its target, and return back to the antenna. With this information, radars are able to determine the location of a target.

Distance to the Target

$$R = \frac{c \cdot t}{2}$$

R = range or distance (m)
c = speed of light ($3x10^8$ m/s)
t = time (s)

Advantages of RADAR

- Shorter visible and infrared wavelengths are scattered and absorbed by atmospheric particles (ozone, carbon dioxide, water, pollution).
- Radars operate at wavelengths which are much longer relative to these particles.
- As such, microwaves are unaffected by these particles. Microwaves penetrate cloud cover, haze, dust and all but the heaviest rainfall, making radars "all weather" sensors.
- Radars are also active systems and therefore are not dependent upon ambient energy.

Advantage

Ability to gather images in cloud prone regions, or when timeliness is imperative (i.e. emergency response).

Because radars provide their own energy, these sensors can operate day or night. This is important when imaging in conditions of low illumination (i.e. polar regions).

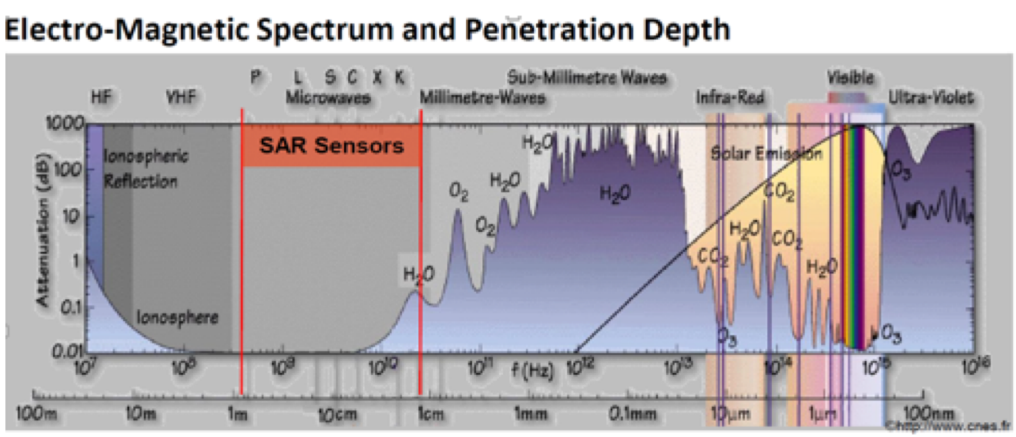


Image source: eo-college.org

Advantages of RADAR

Radars operate at long wavelengths (1-100 **cm**) and therefore they are able to penetrate further into the target, relative to visible and infrared wavelengths (400-2500 **nm**).

1 centimeter (cm) = 10,000,000 nanometers (nm)

When thinking about a target (soils, vegetation, snow, ice…) is this greater penetration an advantage or disadvantage?

⟶ It depends.

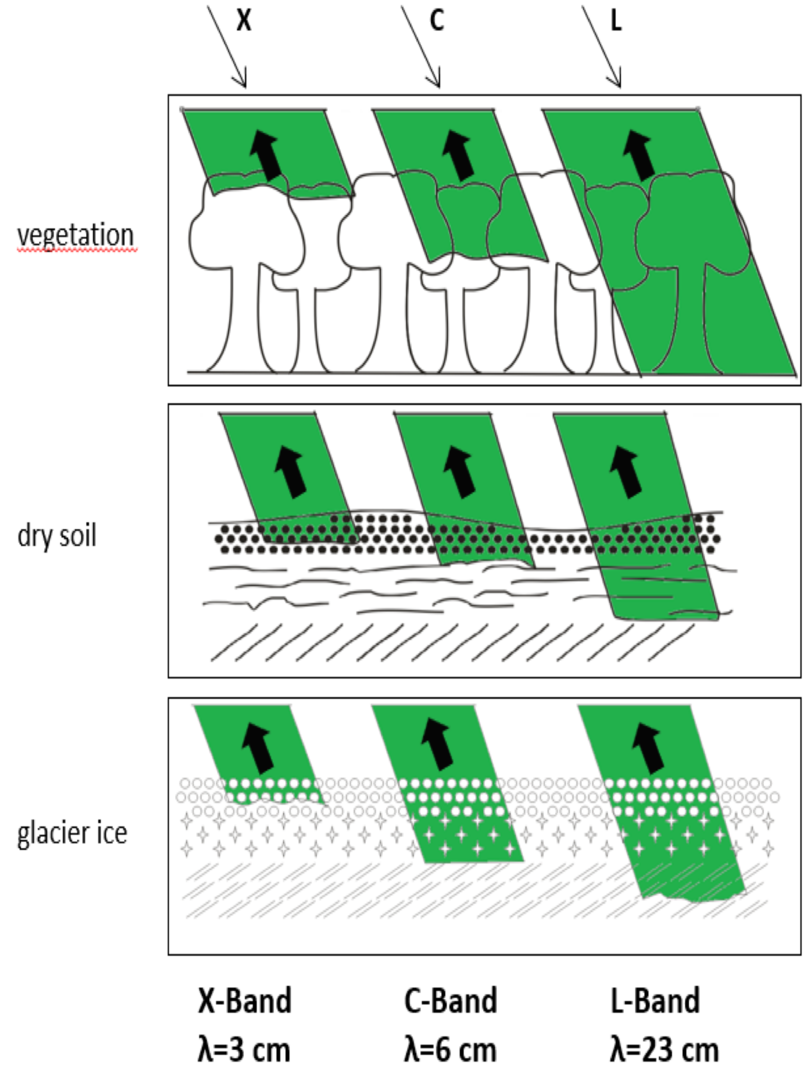
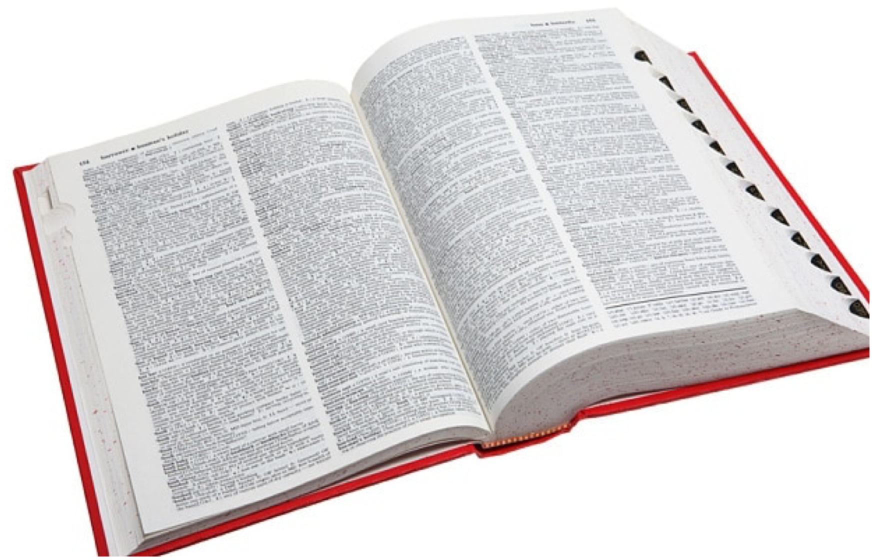


Fig.: © DLR

What Defines a SAR?

- Frequency
- Polarization
- Incidence angle



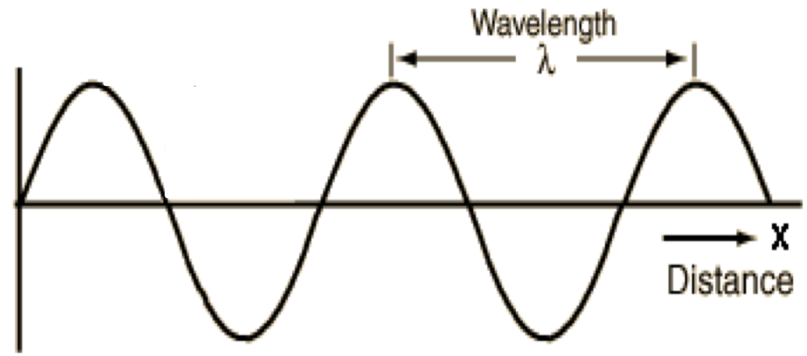
How the signal propagates

What it measures: intensity and phase

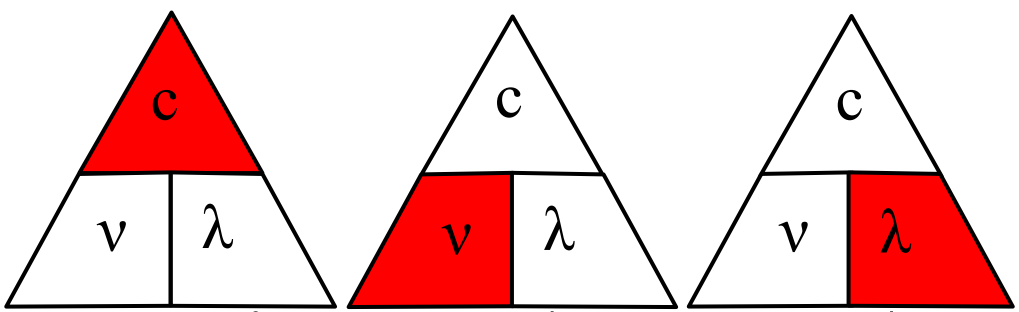
Frequency and Wavelength

wavelength (m): length of one wave cycle

frequency (Hz): number of oscillations per time unit



Sine Wave



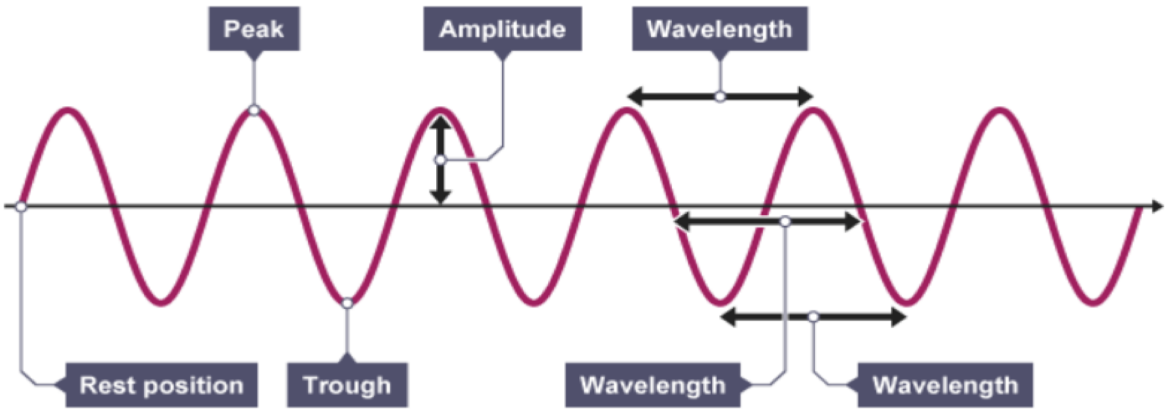
$c = \nu \times \lambda$ $\nu = c/\lambda$ $\lambda = c/\nu$

Wavelength (λ) and frequency (ν) are inversely related:

c = speed of light ($3x10^8$ m/s)
λ = wavelength (m)
ν = frequency (Hertz (Hz))

1 Hz = one cycle per second

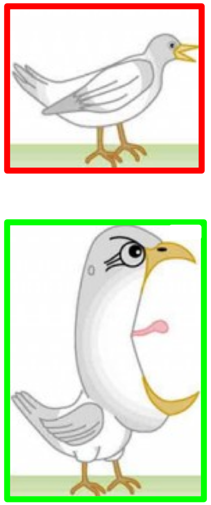
Intensity of a Wave



Amplitude: maximum displacement of a wave from its rest position

Intensity = (Amplitude)^2

Intensity: the average power transfer over one period of the wave



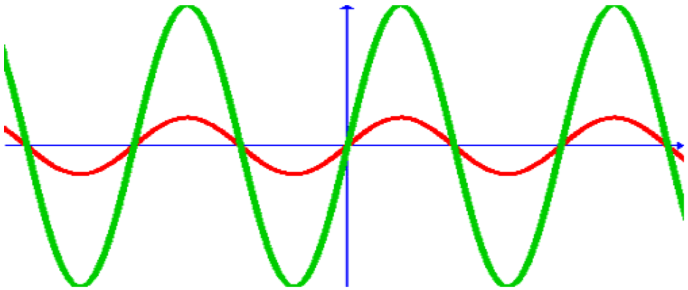


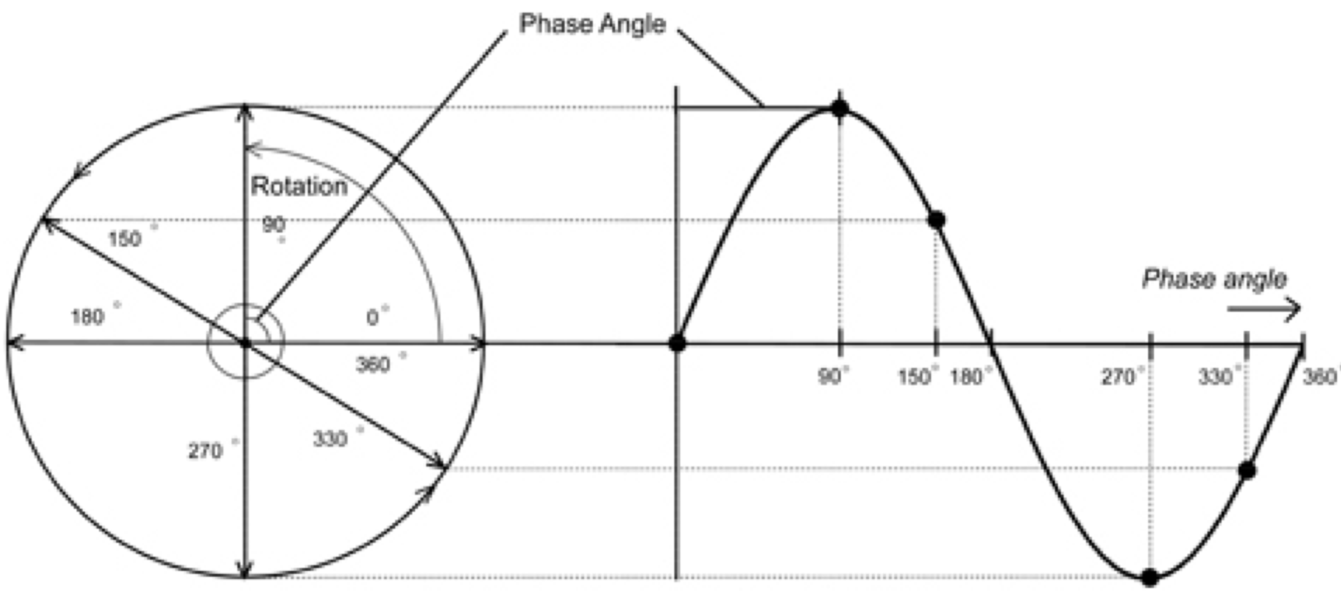
Image source: www.bbc.com/bitesize/guides/zgf97p3/revision/1

Phase of a Wave

Phase: position of a point in time on a waveform cycle, measured in degrees or radians

Think of a wave's position in **time** or **space**

When viewed as a cyclical phenomenon (like the crankshaft motion of a bicycle pedal), phase can be expressed in degrees. One-quarter cycle represents a phase rotation of 90 degrees; completion of one complete cycle corresponds to a phase rotation of 360 degrees.



Information source: earth.esa.it/handbooks/asar/
Image source: physics.stackexchange.com

Phase Difference

Phase difference (φ): the offset, in time or space, of one wave with respect to another

Waves are considered in-phase, if their origins of phase 0 degrees are perfectly aligned. When this is not met, waves are said to be out-of-phase.

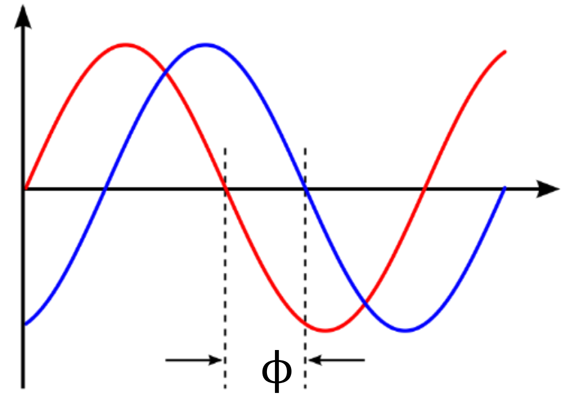
Why is this important?

• precise knowledge of phase properties in radar signal data is a key element in interferometric as well as in polarimetric SAR

• measured phase difference tells us something about the structure of the target

• during wave generation, phase offsets determine how a wave propagates

Equal amplitude; out of phase



Different amplitudes; in phase

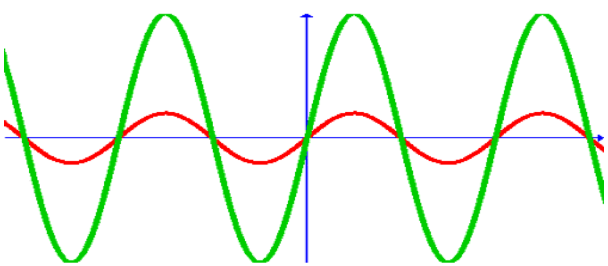


Image source: en.wikipedia.org/wiki/Phase_(waves)

Radar Polarization

Electromagnetic (EM) fields: synchronized oscillations of electric and magnetic fields that propagate at the speed of light

Polarization: orientation of the electric field of the EM wave

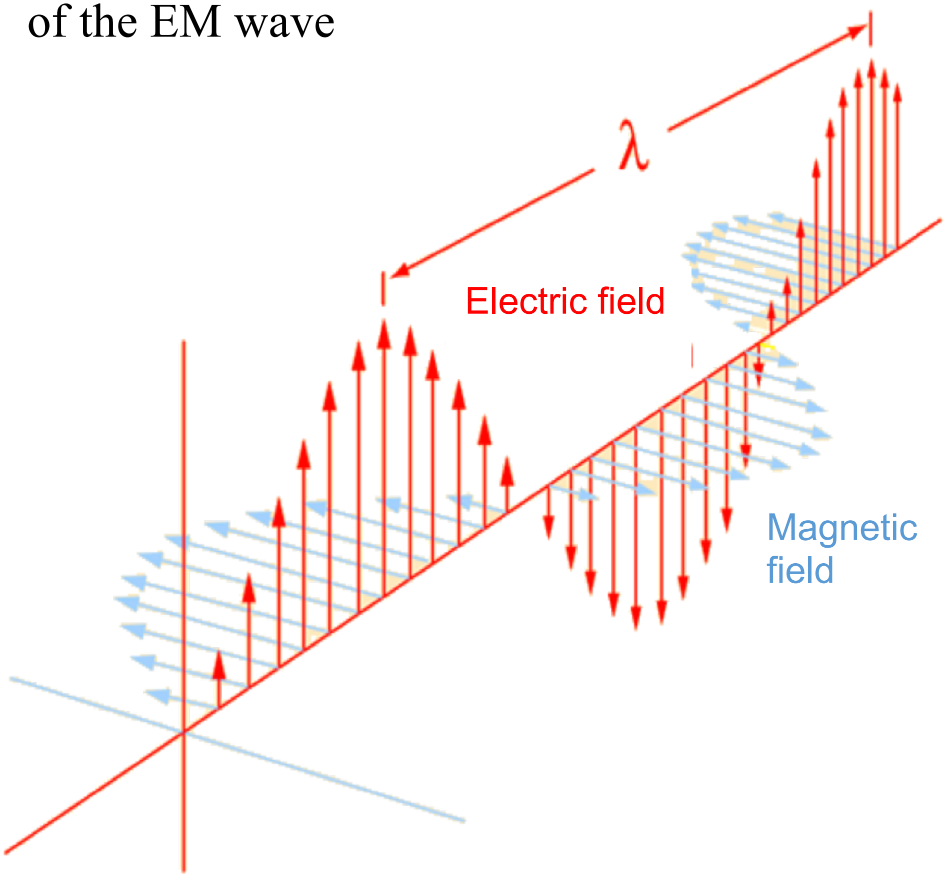
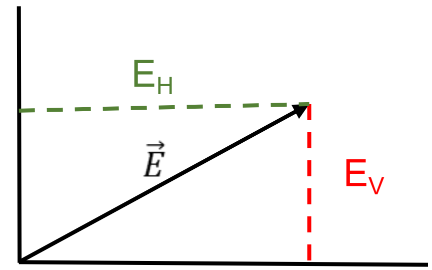


Image source: Hyperphysics



$$\vec{E} = E_H + E_V$$

Any EM wave can be described by the horizontal (E_H) and vertical (E_V) components of its electric field

The vector sum (intensity and phase) of these components determines the intensity of the resultant wave, as well as its orientation and how the wave propagates

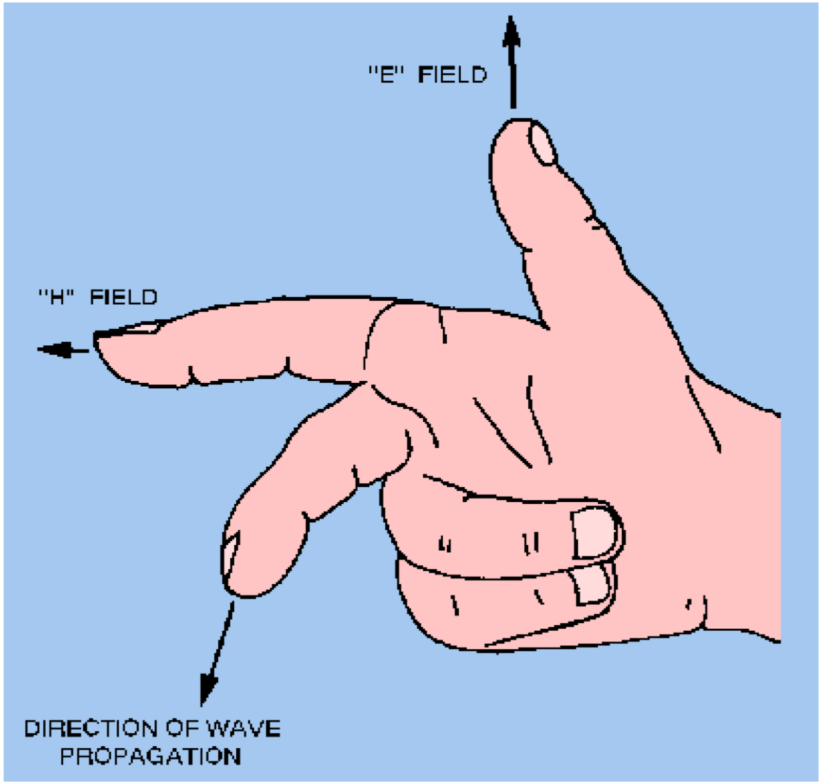
Propa-What?

Electromagnetic (EM) waves: synchronized oscillations of electric and magnetic fields that propagate at the speed of light

Direction of propagation

Propagation: Any of the ways in which a wave travels

Transverse waves: when the E and H field vectors are in a direction perpendicular to (or transverse to) the direction of wave propagation



How do Waves Propagate?

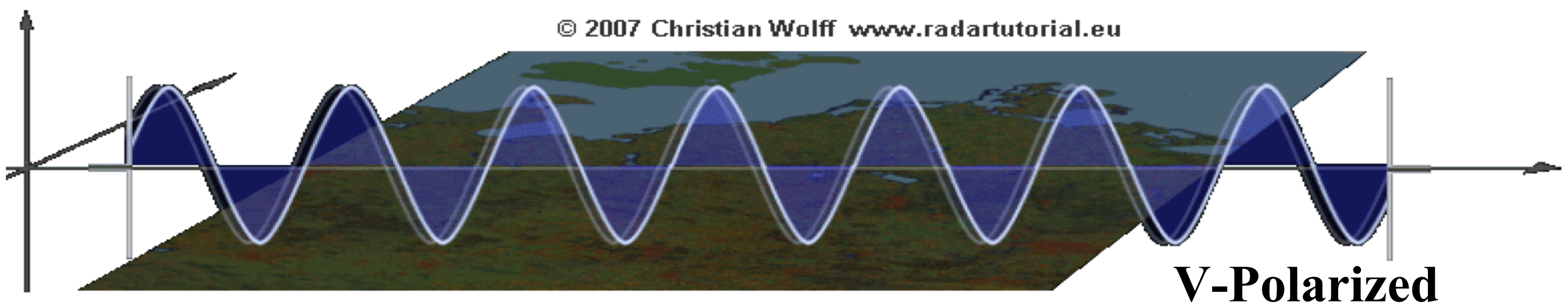
It's all about phase offset!

- Linear (most commonly used by SAR sensors)
- Circular (available on some new SAR sensors)
- Elliptical (*actually, the most common way that waves propagate*)
- **Visualize how the tip of the E vector moves – in a plane or does it rotate as it propagates**

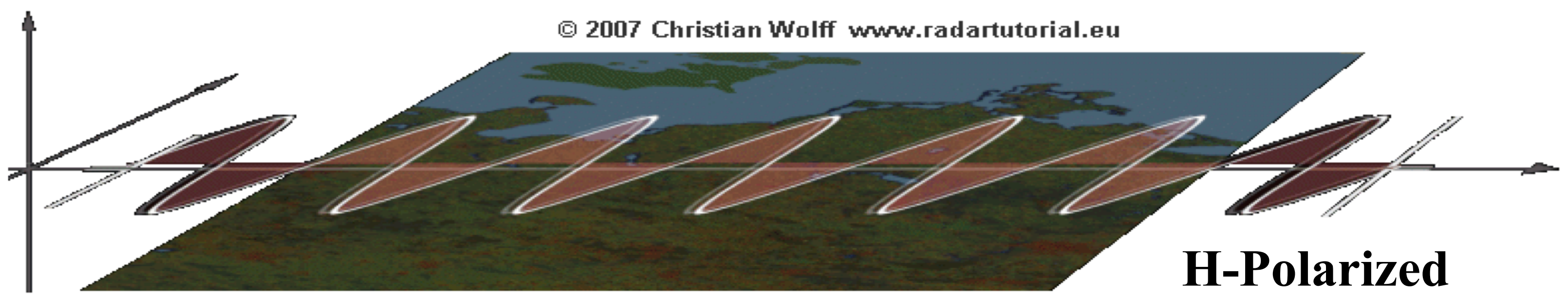
Linear Polarization

Characteristic: the tip of the electric field vector moves along a path which lies in a plane orthogonal to field's direction of propagation

How are these created: The two perpendicular components (E_H and E_V) of the electromagnetic field have equal amplitudes, and **zero** phase offset



V-Polarized

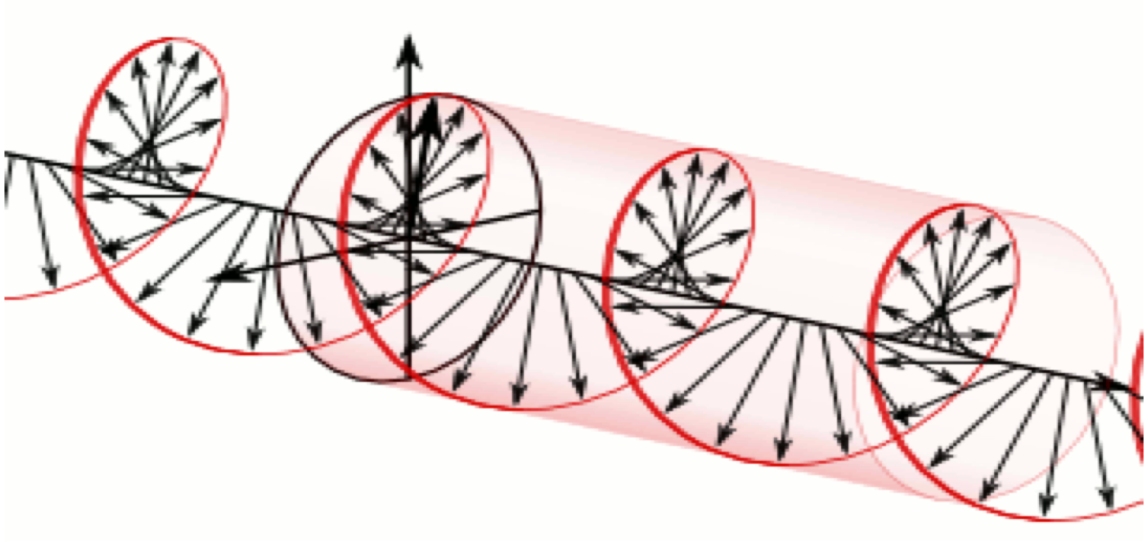


H-Polarized

Circular Polarization

Characteristic: The electric field vector rotates, with the tip of the vector tracing a circle on a plane perpendicular to the direction of propagation.

How are these created: The two perpendicular components (E_H and E_V) of the electromagnetic field have equal amplitudes, and are out of phase by **90 degrees**



Circular Polarization

Right-handed (R): direction of rotation is clockwise (*relative to the observer looking from front of the wave in the direction of propagation*)

Left-handed (L): direction of rotation is counter- clockwise (*relative to the observer looking from front of the wave in the direction of propagation*)

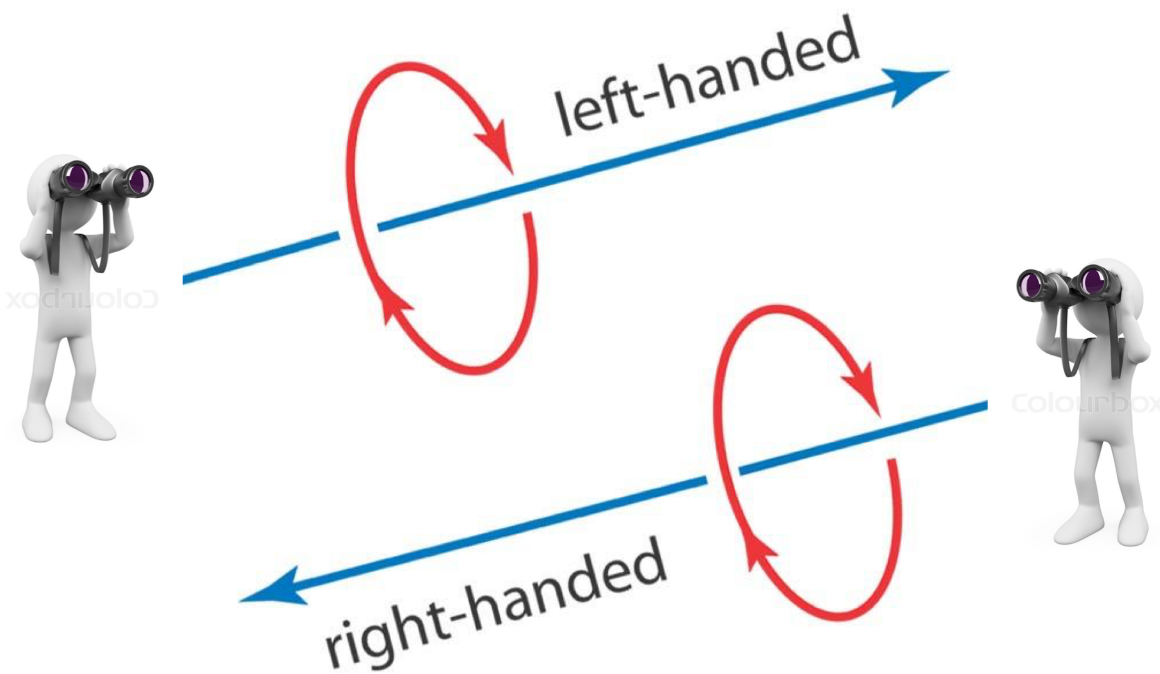
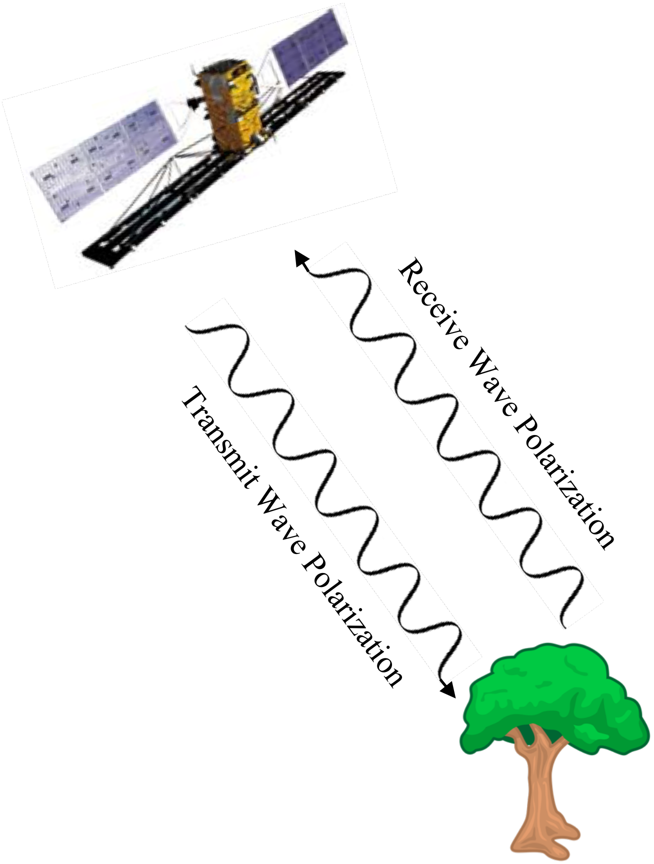


Image source: sureshemre.wordpress.com

Back to SAR



Radars are active:

- send waves with a fixed polarization
- measure intensity and phase of energy scattered in one or more polarizations

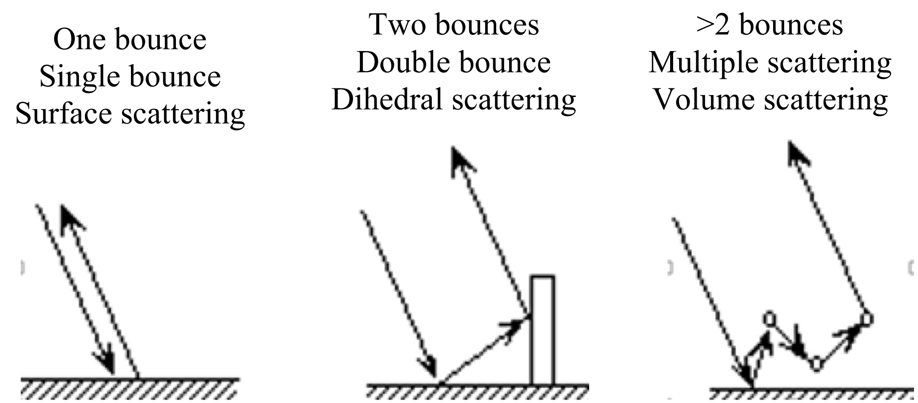
Radar data are described by both the polarization of the transmitted wave, and the polarization of scattered waves received and recorded

- HH (transmit H and receive H)
- VV (transmit V and receive V)
- HV (transmit H and receive V)
- VH (transmit V and receive H)

Wave Scattering

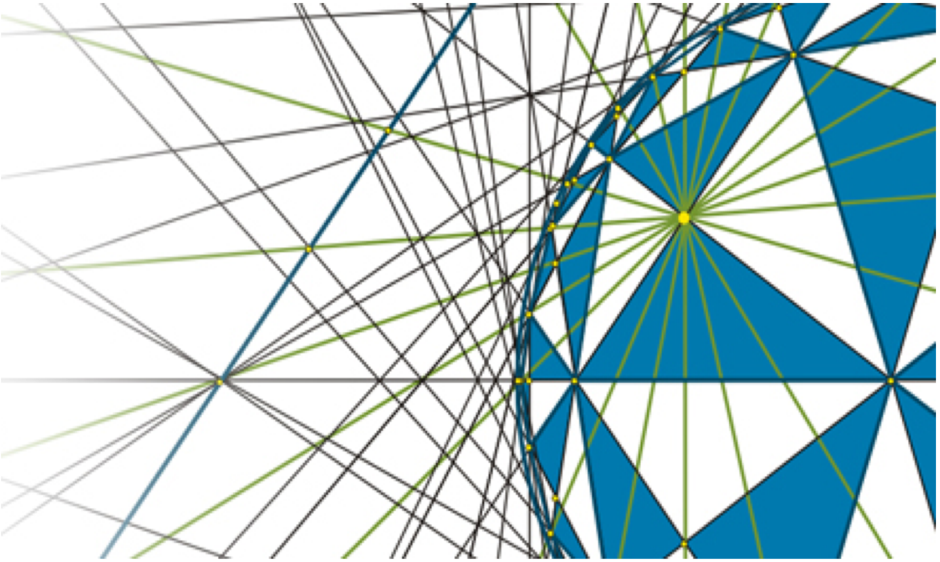
Lots can happen to a wave when it hits a target in terms of:

- the amount of energy scattered or attenuated
- the angular behavior of the scattering



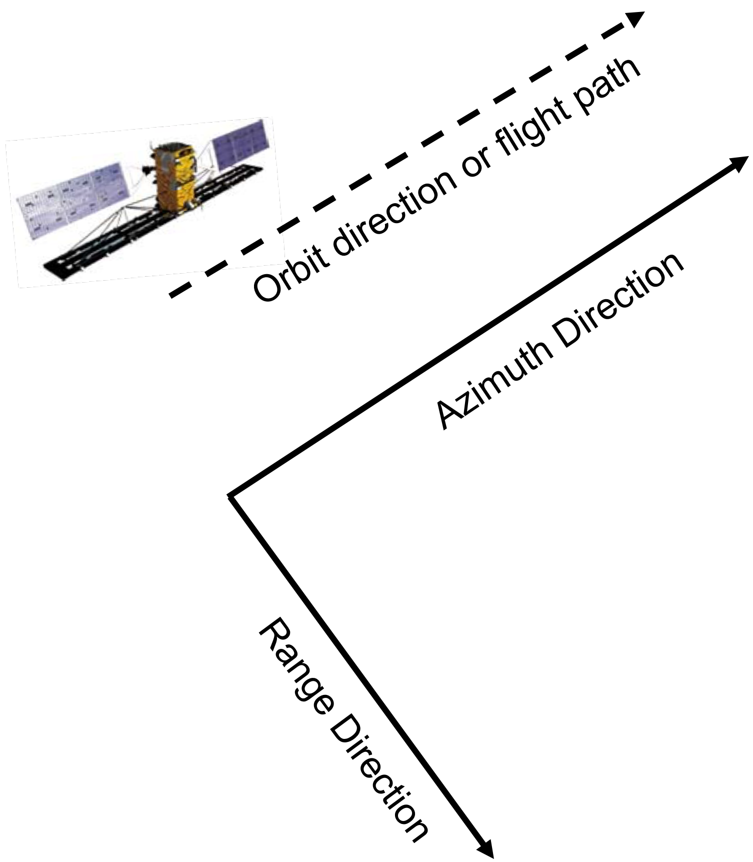
And that is the mystery to be solved: What is the energy recorded by the satellite trying to tell us about the target?

Radar Geometry



- Azimuth versus range
- Slant versus ground range
- Real Aperture Radar versus Synthetic Aperture Radar

Radar Geometry



Radars are side looking – a requirement in order to range the target

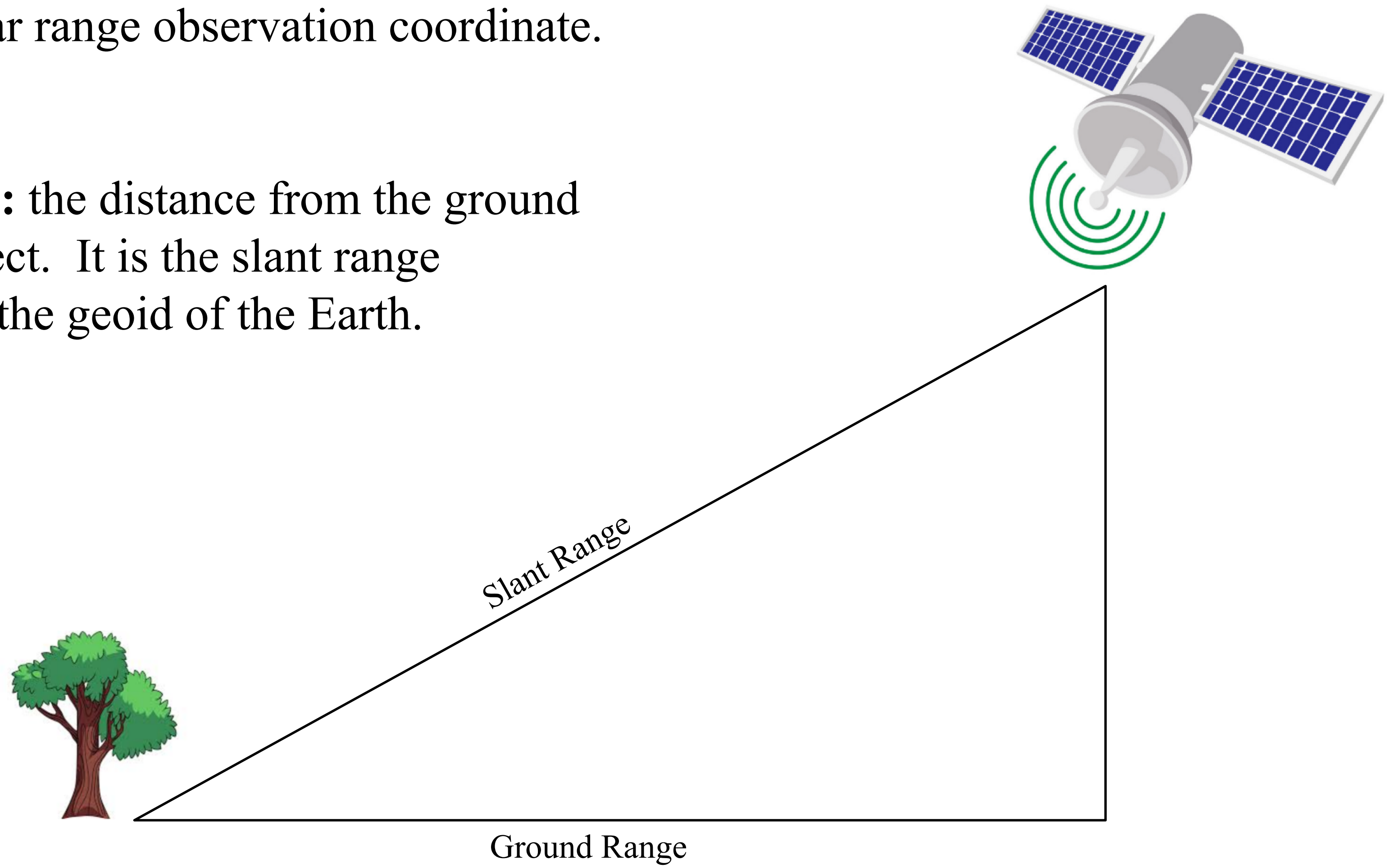
Azimuth: the direction parallel to the flight path of the aircraft or orbit of the satellite

Range: the direction perpendicular to the flight or orbital path

Slant Range?  Ground Range?

Slant range: the distance measured along a line between the antenna and the target. It is the natural radar range observation coordinate.

Ground range: the distance from the ground track to an object. It is the slant range projected onto the geoid of the Earth.

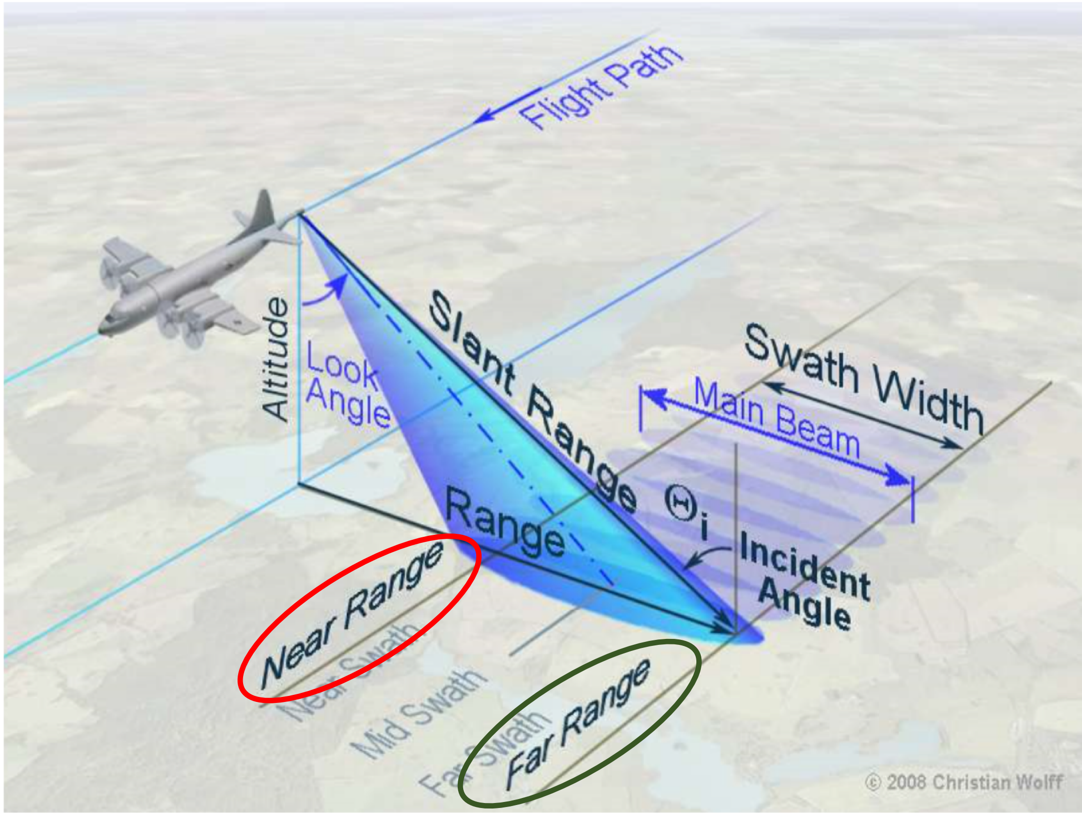


Radar Geometry

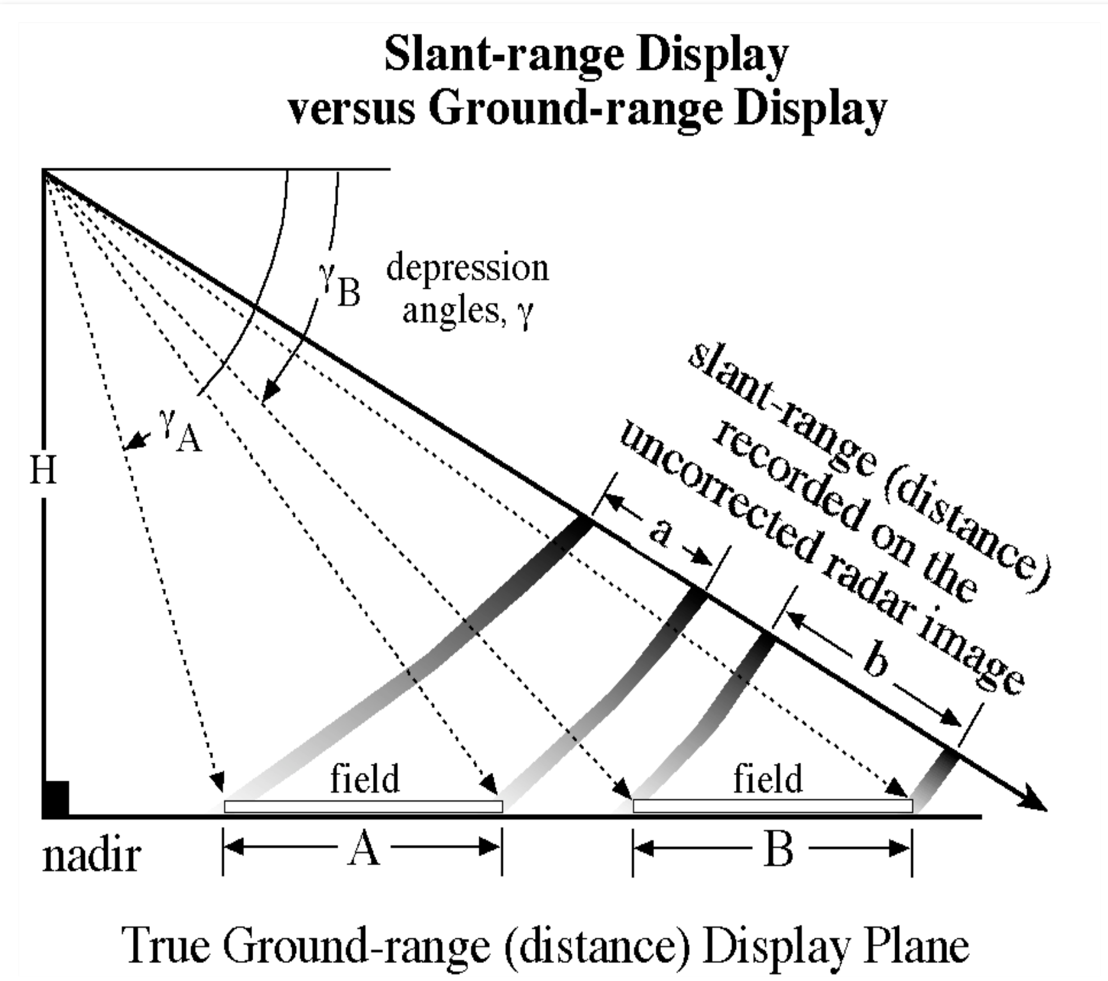
Radar swath: the ground distance from **near** to **far** range.

Incidence Angle (θ): the angle between the line of sight of radar in slant range and the vertical to the terrain

The incidence angle changes across the range. At near range, the angle is **small (steeper).** The angle is **larger (shallower)** at the far range.



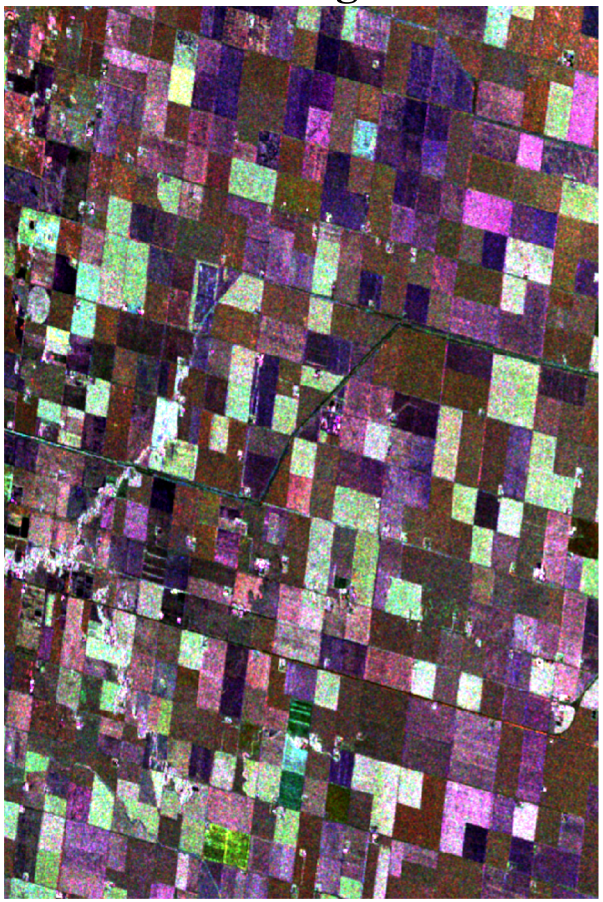
Radar Geometry



- In slant range (SARs natural viewing geometry), distances are compressed relative to their true ground range distance
- Degree of compression is a function of the distance from the antenna to the target, in slant range

Slant Range to Ground Range Conversion

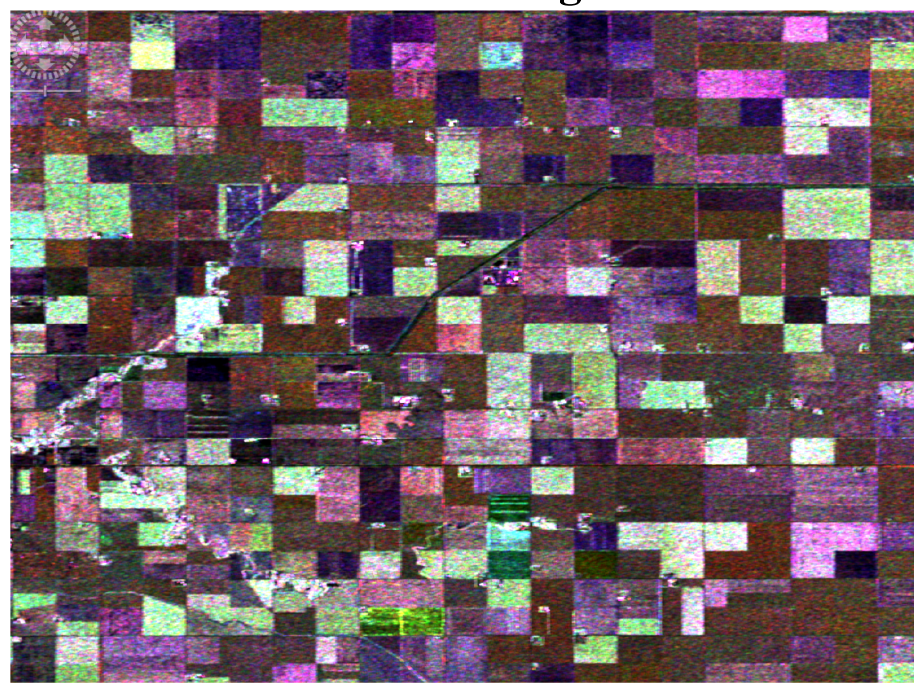
Slant Range



RADARSAT-2 (acquired on July 3, 2016, FQ15W). Slant range image (**R: HH** **G: HV** **B:VV**), in which **distances are measured between the antenna and the target**

- Slant range data can be converted to ground range by resampling.
- To do so requires knowledge of the imaging geometry, platform altitude, range delay and terrain elevation.

Ground Range



Ground range image, in which **distances are measured between the platform ground track and the target**, and placed in the correct position on the geographic reference plane

Range Resolution (Real Aperture Radar)

Slant **Range resolution** (δ_{range})depends on the bandwidth (B_e) and is defined as

$$\delta_{range} = \frac{C}{2 \times B_e}$$

Where
C : speed of light ($3x10^8$ m/s)
B_e : bandwidth (Hz)

Bandwidth is inversely related to pulse duration (τ)

Pulse duration = the time the radar's transmitter is energized during each cycle

Large bandwidth = short pulse duration = short pulse length = **finer resolution**

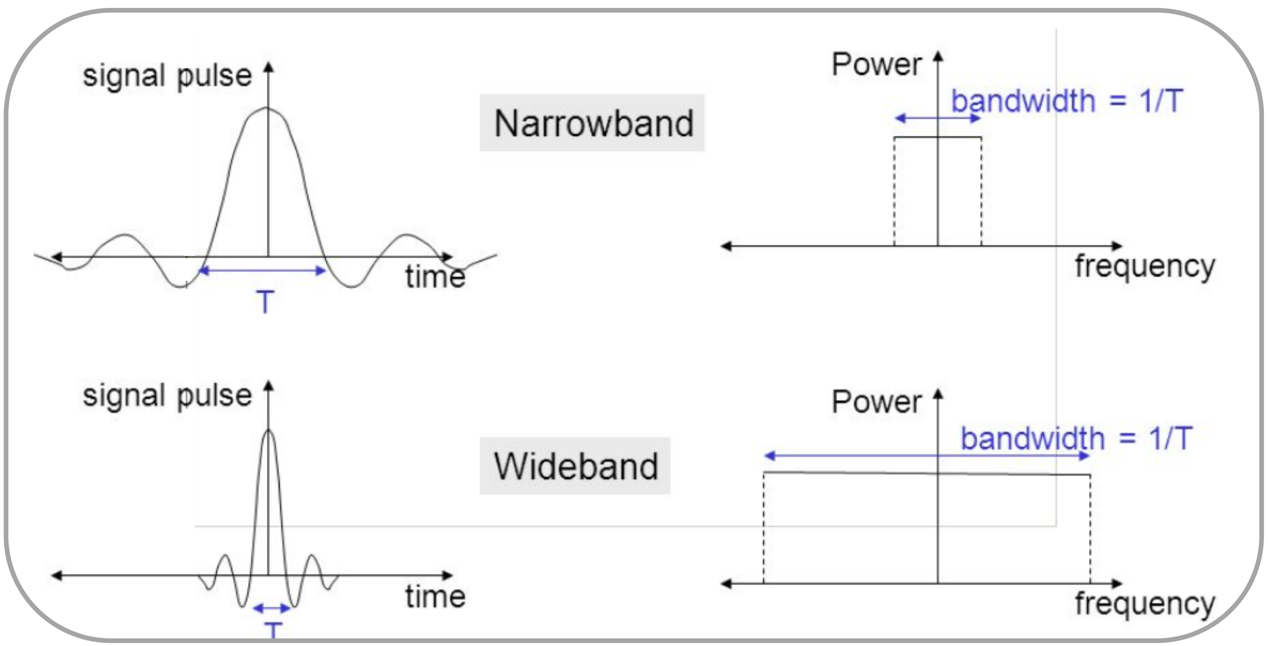
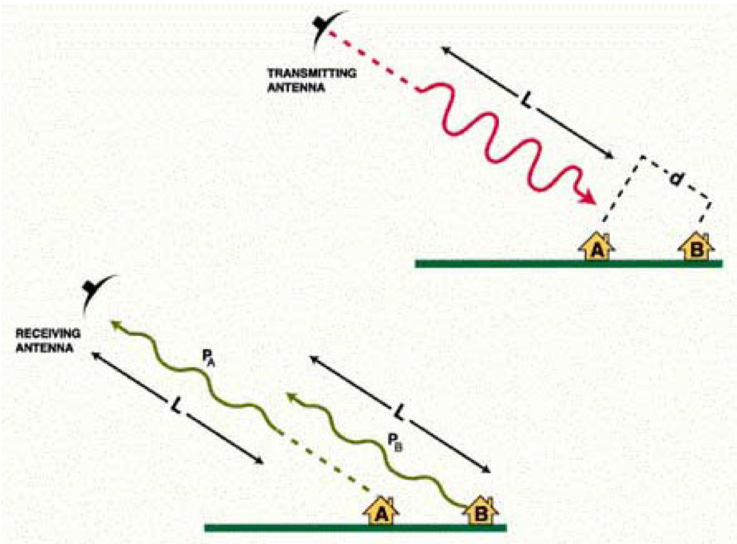


Image source: slideplayer.com/slide/6622331/23/images/27/Pulse+Width+vs.+Bandwidth.jpg

Range Resolution (Real Aperture Radar)

- Radars send out short pulses of energy and then wait to “hear” the echo from its target, between these transmitted pulses
- For the radar to be able to distinguish two targets, the echoes for each target must be received at different times.
- In the case of buildings A and B, for the radar to “hear” the echoes from A and B separately, the distance between buildings (in slant range) must be larger than half the length of the pulse (L/2)
- Range resolution is equal to L/2 (half the pulse length).



Since the radar pulse must travel two ways, the two buildings result in distinct echoes if d > L/2

- The range resolution can be improved by increasing the bandwidth (reducing the length or duration of the pulse) of the radar. Shorter wavelengths will enable higher bandwidth.
- Pulse compression is a signal processing technique commonly used to improve range resolution

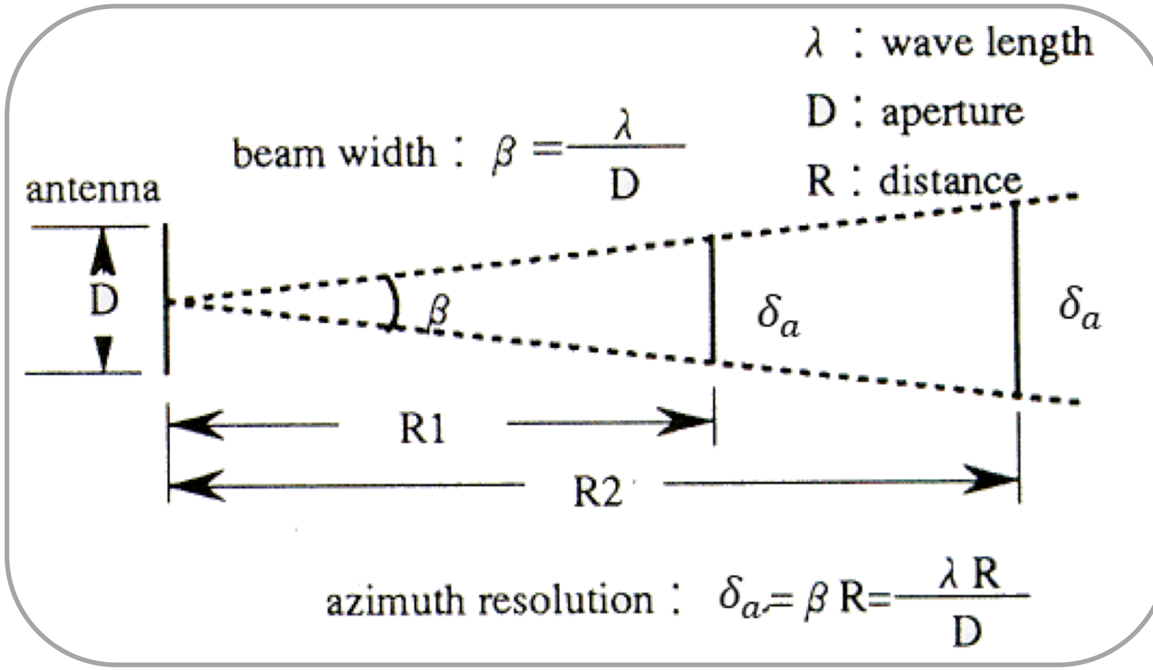
Image source: www.earth.esa.int

Azimuth Resolution (Real Aperture Radar)

Azimuth resolution $\delta_{azimuth}$ depends on the length of the antenna and increases with range.

$$\delta_{azimuth} = \beta \times R$$

$$= \frac{\lambda}{D} \times R$$



Resolution **degrades** with:
β = beam width
R = distance (slant range) from antenna to midpoint of swath
λ = wavelength

Resolution **improves** with:
D = antenna length

Image source: sar.kangwon.ac.kr

Azimuth Resolution

$$\delta_{azimuth} = \beta \times R = \frac{\lambda}{D} \times R$$

What if RADARSAT-1 was a
Real Aperture Radar
λ = 5.6 cm
R = 792 km
D = 15 m

$$\delta_{azimuth} = \frac{(792 \times 10^3 \text{ m})\ (0.0566 \text{ m})}{15 \text{ m}} = 3 \text{ km!!!}$$

RADARSAT-1 at David Florida Lab (Ottawa)

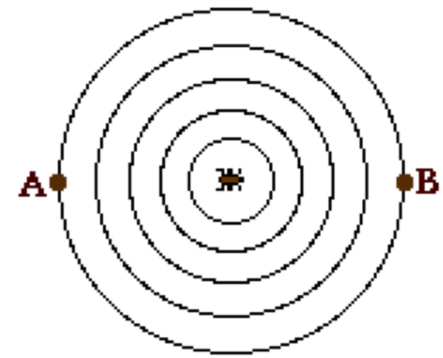
- the longer the antenna, the narrower the aperture (results in a finer azimuth resolution)
- azimuth resolution can be improved only by a longer antenna or shorter wavelength

Unfortunately

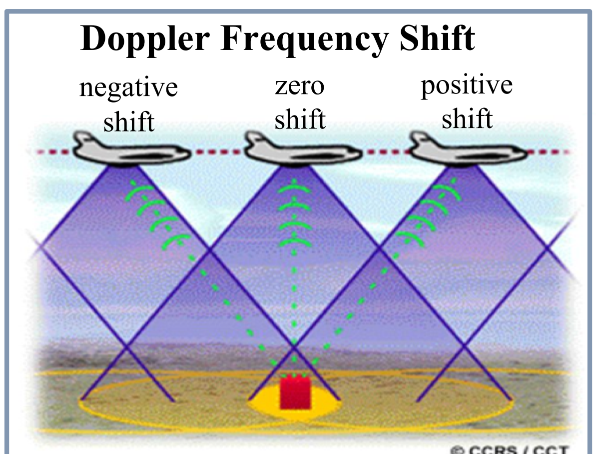
- very short wavelengths leads to greater atmospheric attenuation, reducing the all-weather capability of imaging radars
- placing very large antennas in space is problematic.

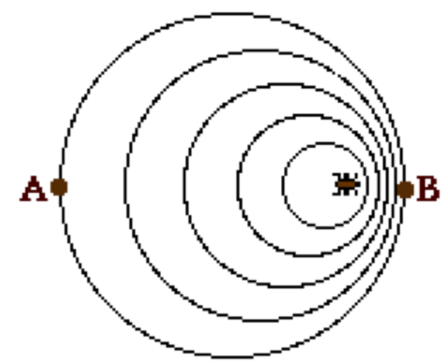
Synthetic Aperture Radar (SAR)

- 1951: Carl Wiley realized that the Doppler shift of the echo signal could be used to synthesize a much longer aperture to improve the resolution of a side-looking radar.
- Doppler effect: produced by a moving source of waves (i.e. an orbiting radar antenna) where there is an upward shift in frequency for observers towards whom the source is approaching and a downward shift in frequency for observers from whom the source is receding. The effect does not result because of an <u>actual</u> change in the frequency of the source.
- SAR passes over the target: first echoes will have a positive Doppler shift; zero at target; negative Doppler shift as the target exits the last echoes.



A stationary bug producing disturbances in water.



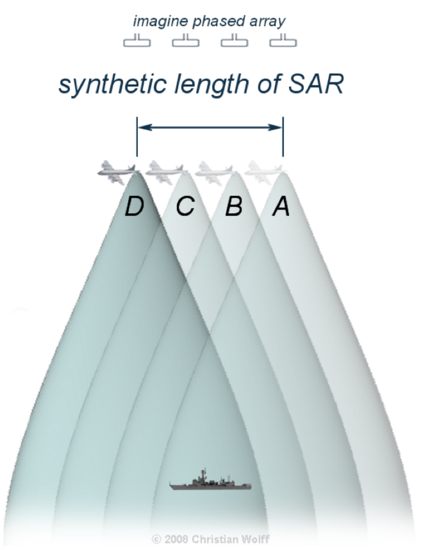


A bug moving to the right and producing disturbances.

Image source: www.physicsclassroom.com/class/waves/Lesson-3/The-Doppler-Effect

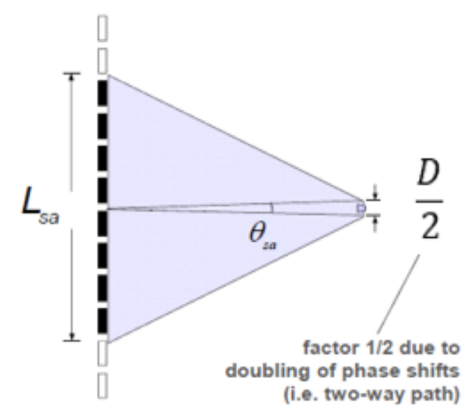
Synthetic Aperture Radar (SAR)

- SAR processor stores all the radar returned signals for the time period T from position A to D (have different Doppler shifts)
- this is used to reconstruct the signal which would have been obtained by an antenna of length $v \cdot T$, where v is the platform speed
- making T large makes the "synthetic aperture" large and hence a higher resolution can be achieved
- in effect, by processing these shorter looks at the target together, the physical (short) antenna "sees" any point on the ground for a longer period of time, which is equivalent to a longer virtual antenna and thus higher azimuth resolution
- achievable azimuth resolution of a SAR is approximately equal to one-half the length of the actual (real) antenna



Azimuth resolution ($\delta_{azimuth}$) is half the length of the radar antenna (D).

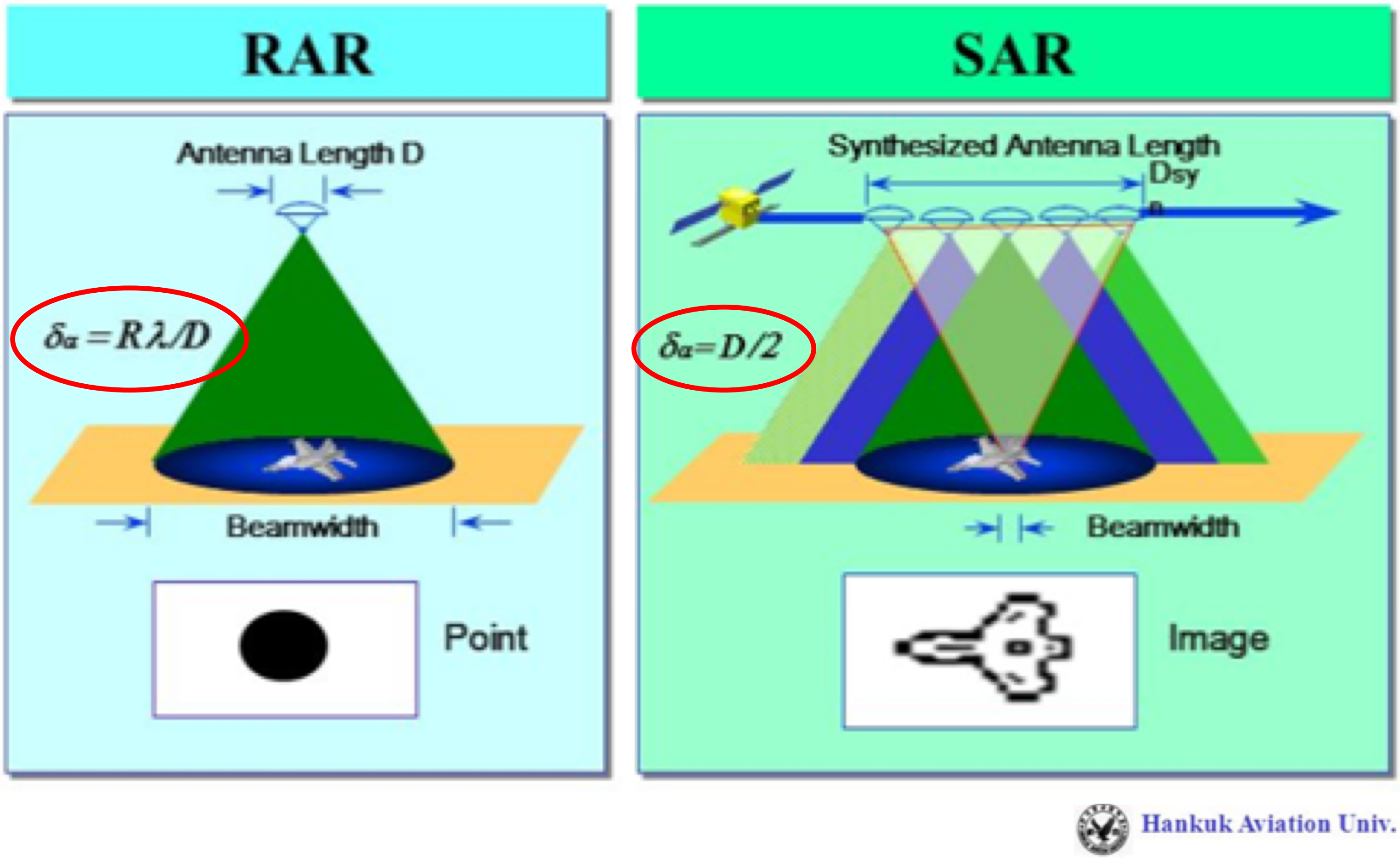
$$\delta_{azimuth} = \frac{D}{2}$$



Information source: Moreira et al., 2013

RAR and SAR

The size of the antenna (D) is the same, but with much different results!



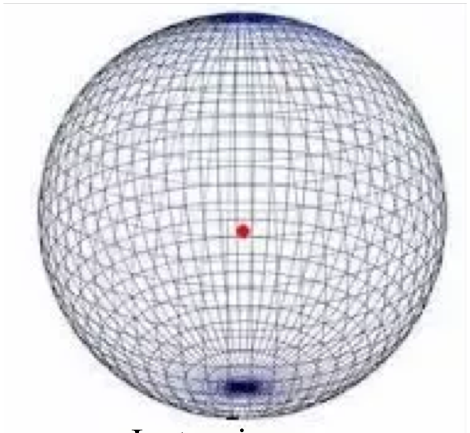
SAR Radiometry

- The Radar Equation
  - An eloquent way to express microwave propagation and response
- Reflectivity nomenclature
  - Beta, Gamma and Sigma Nought
- Noise and noise suppression
- SAR calibration
- Image artifacts

Radar Equation

The radar equation represents the physical dependences of the transmitted power from the radar antenna up to the receiving of the echo-signals:

1. Transmitted microwaves are focused to a beam by the antenna
2. The signal propagates to the target located at a specific range
3. Microwaves interact with the target to create a distribution of scattered waves.
4. Those re-radiated waves that propagate towards the antenna form the received signal.



Isotropic source

Energy propagated by a SAR antenna.
Creates an antenna gain.

Radar Equation

$$P_r = \frac{\sigma G^2 \lambda^2}{(4\pi)^3 R^4} \times P_t$$

P_r (Watts [1 joule/second]) is the power received by the antenna from the target at polarization *r*

P_t (Watts [1 joule/second]) is the power transmitted by the antenna toward the target at polarization *t*

λ (meter) is the microwaves wavelength

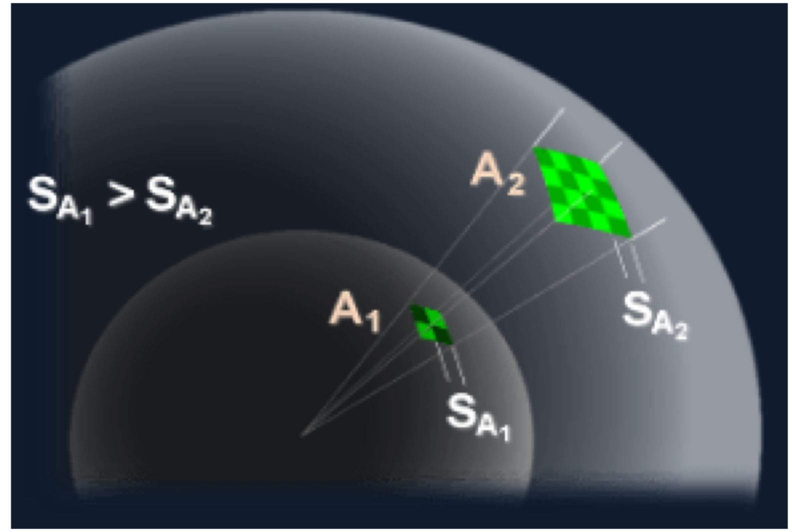
G (unitless) is the gain of the radar antenna that describes the antenna's:

- Directivity: ratio of the power produced by the antenna to the power produced by a hypothetical isotropic antenna
- Electrical efficiency: how well the antenna converts input electrical power into transmitted microwaves in direction of the target; converts scattered microwaves arriving from the target direction into electrical power

σ (m^2) is the target radar cross section defined as a measure of the size and ability of the target to reflect received microwaves toward the direction of the radar antenna

Radar Equation

$$P_r = \frac{\sigma G^2 \lambda^2}{(4\pi)^3 R^4} \times P_t$$



R (m) is the range distance from the antenna to the target

$\frac{1}{4\pi R^2}$ is the spreading loss – the reduction in power density associated with spreading of the power over a sphere of radius R surrounding the antenna

SAR Reflectivity - Important Nomenclature

Beta Nought (β °)

- reflectivity per unit area in slant plane (A_β)
- the default radiometric observable of a radar
- does not require knowledge of the local incidence angle

Gamma Nought (γ °)

- normalized reflectivity with respect to the equivalent illuminated area A_γ in the orthogonal to the slant plane
- plots of γ ° as a function of incident angle tend to be more constant than comparable plots using σ °
- gamma nought can reduce the incidence angle dependency of the radar backscatter

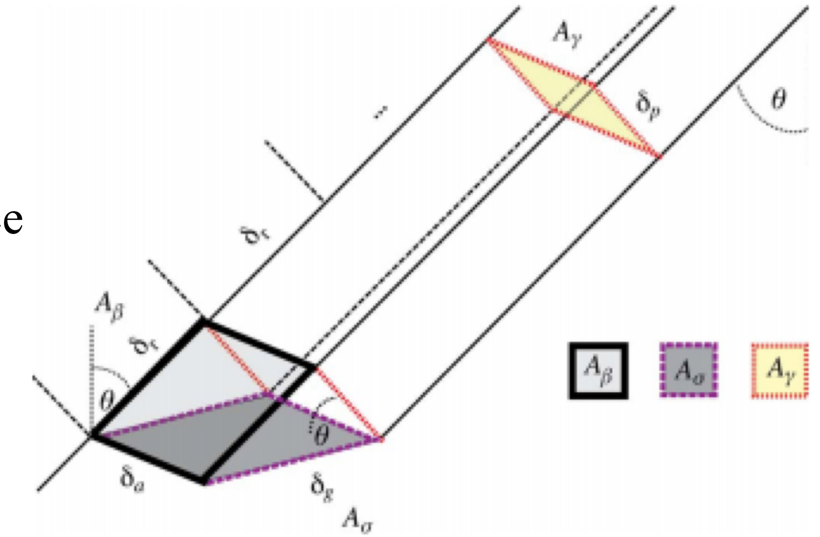


Image source: Small (2011)

$$\sigma^o = \beta^o \sin\theta$$
$$\gamma^o = \beta^o \tan\theta$$

Information source: Shimada and Otaki (2010)

SAR Reflectivity - Important Nomenclature

Sigma Nought (σ °)

- mean reflectivity, normalized with respect to the equivalent illuminated area A_σ in the horizontal ground plane
- assumes a flat surface
- the conventional parameter used to described reflectivity
- impacted by the local surface slope
- has more direct intuitive interpretation

$$\sigma^o = \beta^o \sin\theta$$
$$\gamma^o = \beta^o \tan\theta$$

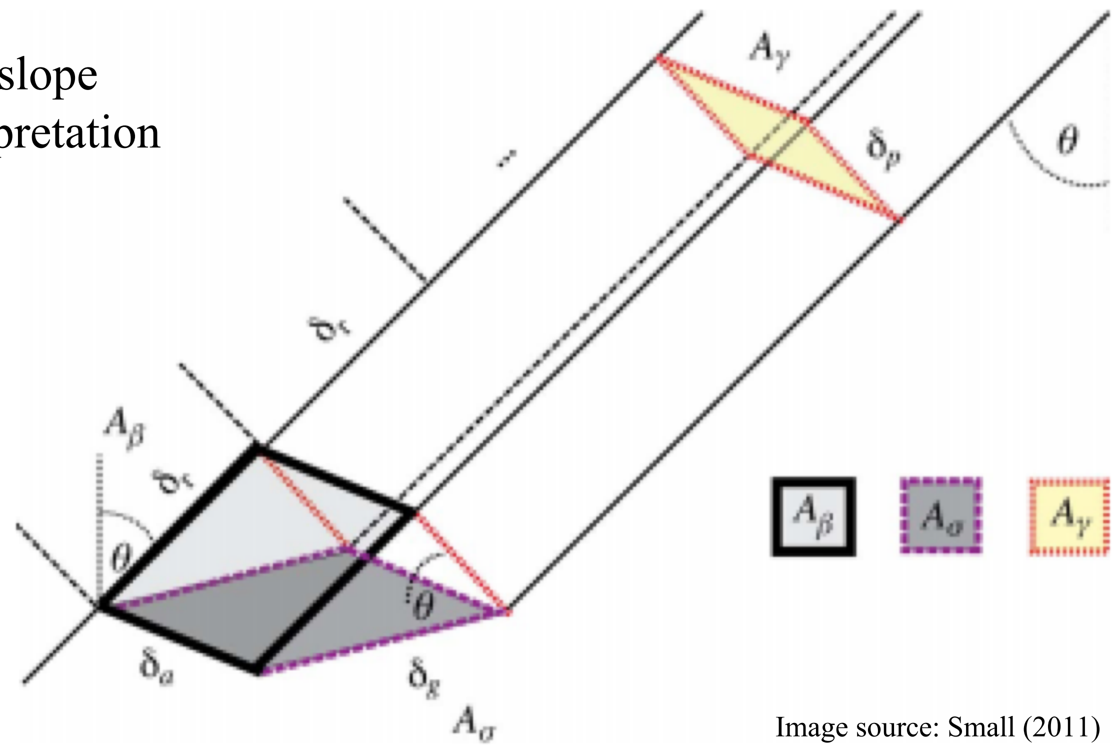


Image source: Small (2011)

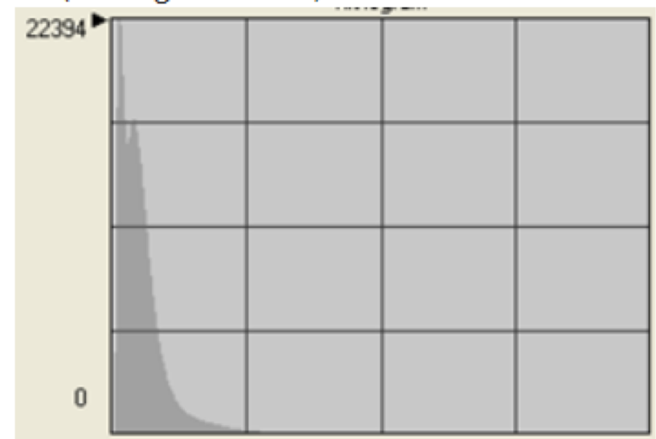
What's the Deal with dB?

- The range of intensities (backscatter) measured by radars is HUGE
- For natural targets most of the response lies between the linear scales of 0 to 1
- To better represent these responses, backscatter (in linear units) is typically converted to decibels or dB (logarithmic scale) via a simple mathematical conversion

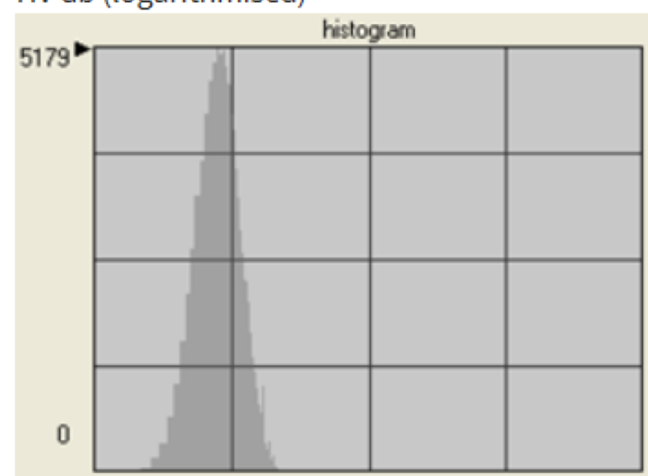
If the data are in Amplitude (A): $\sigma^o = 20*\log_{10}(A)$

If the data are in Intensity (I): $\sigma^o = 10*\log_{10}(I)$

HV (non logarithmised)



HV db (logarithmised)



Noise in SAR: Speckle

- each resolution cell is composed of many scattering elements, which contribute to the scatter
- these scattered waves have a phase determined by the scattering events
- the response from each resolution cell is the sum of the amplitude and phase from these scattering elements
- all of these scattered waves can lead to complex interference, sometimes this is constructive (bright pixels) and sometimes destructive (dark pixels)
- the result: speckle "salt and pepper" noise

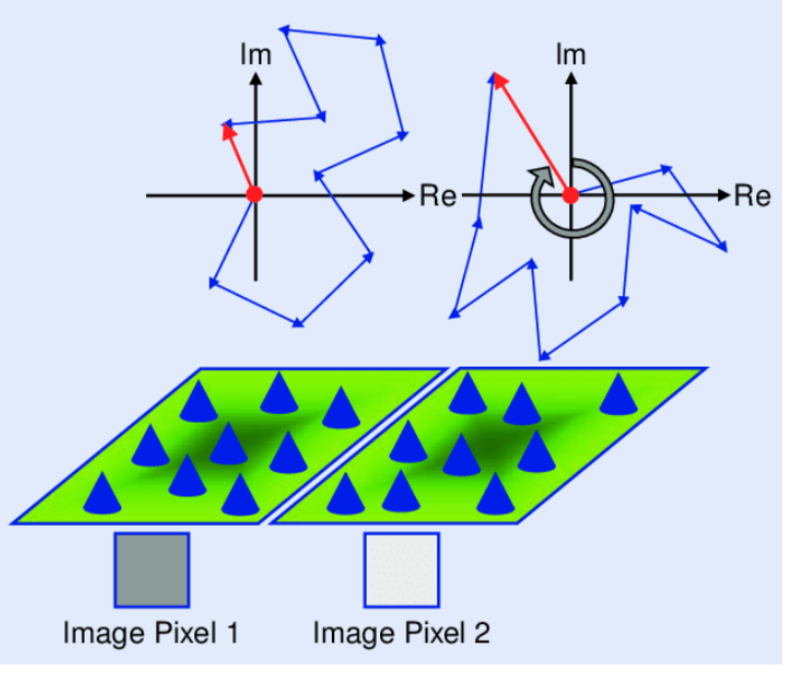


Image source: Moreira et al. (2013)

Speckle Suppression

Speckle can be reduced two ways

→ multi-look processing

→ spatial or temporal averaging

→ multi-looking and spatial filtering reduce speckle at the expense of resolution

Image source: www.parbleu.biz/filter.htm

Multi-looking

- **single look image**: uses all signal return from a target to create a single image
- image may have speckle, but has the highest achievable resolution

- independent images of the same area can be formed in the digital processing of SAR by using sub-sets of the signal returns
- each of the subsets forms a separate image (i.e. a “look”) each of which views a given point from a slightly different angle
- splitting the synthetic aperture (D) into **L** non-overlapping sections means that each has an effective aperture of length D/L; **the resolution is degraded by a factor of L**

- **multi-look image**: independent images are averaged to create a multi-look image
- resulting multi-look image has lower resolution, but reduced speckle

Information source: Oliver and Quegan (1998)

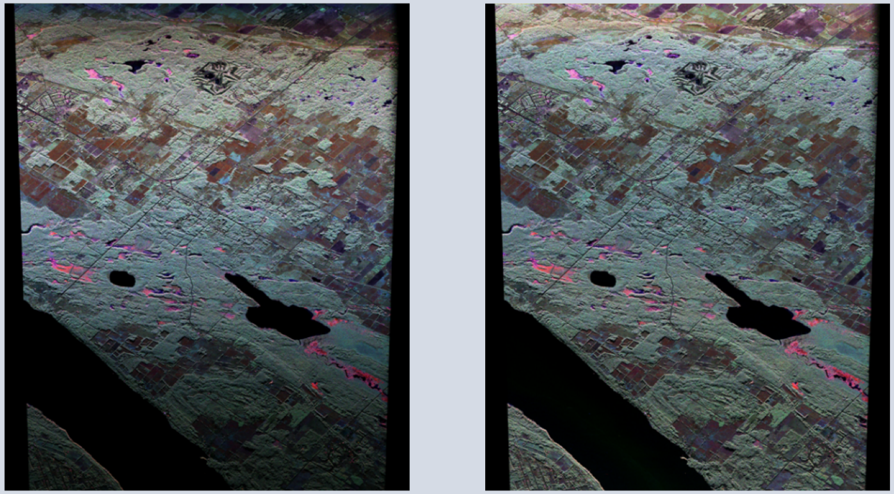
Radiometric Calibration

Backscatter is the ratio between the intensity of the *transmitted* microwave signal and intensity of the microwave signal scattered back from the target and *received* at the antenna.

Absolute calibration: backscatter is calibrated against targets of known absolute backscatter.

Relative calibration: ensures that over time, the effects of space and system degradation do not change the transmitted signal and the received signal (assuming the target remains unchanged). As such, changes detected over time can be attributed to changes in the target and not the sensor itself.

Images Collected by Canada's CV-580 Airborne SAR



uncalibrated calibrated

Relative Calibration

- corrects for known variations in radar antenna and system responses to ensure uniform, repeatable measurements over time
- Amazon rainforest is often used as a relative calibration target. Higher frequency microwaves do not significantly penetrate its canopy and thus from the perspective of the SAR, the rainforest is spatially and temporally uniform. The rainforest looks "flat" to the SAR. Any changes in backscatter over time are considered to be caused by drift in the SAR electronics, requiring corrections to be made.
- this process allows relative comparisons among targets within one scene or from scene to scene

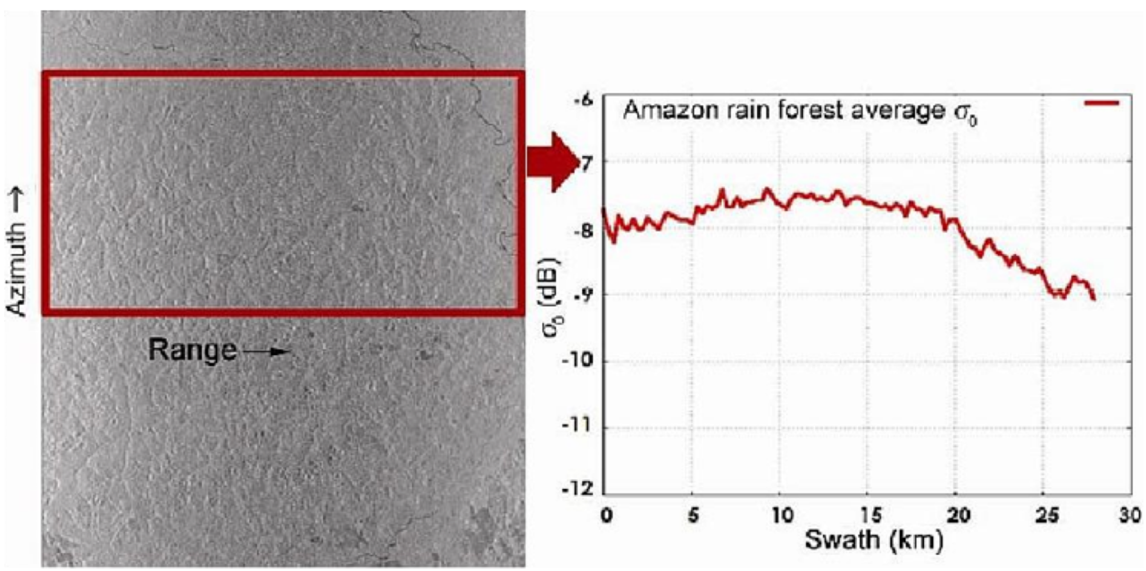


Image source: directory.eoportal.org/web/eoportal/satellite-missions/content/-/article/risat1

Absolute Calibration

- absolute calibration considers many factors: transmitted power levels, system biases and the absolute gain of the antenna and receiver
- targets external to the SAR are also used. These targets have precisely known radar responses (intensity and phase) and are pointed towards the SAR antenna. The difference between these known measures and the response recorded by the SAR, are used to create calibration factors. Some calibration targets are active (send and receive signals) while others are passive (corner reflectors)
- SAR providers deploy calibration targets, collecting continuous measures and adjusting calibration factors, for all SAR modes

Polarimetric Active Radar Calibrator (PARC)

Corner Reflector (passive target)

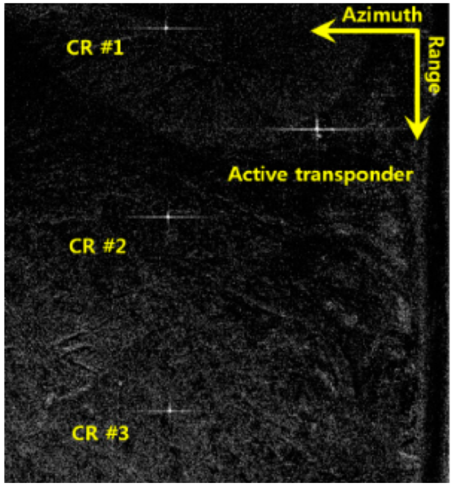


Image source: Kim et al. (2015)

SAR Imagery Radiometric Artifacts

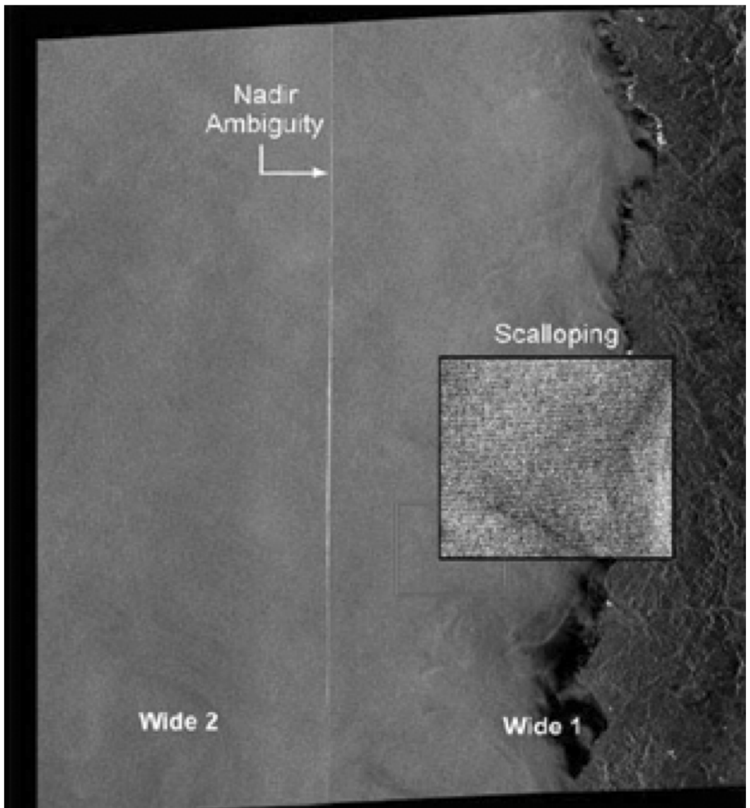
- SAR image artifacts can occur due to platform, sensor, and/or processing problems
- SAR image radiometry and geometry can be affected and reprocessing can mitigate these effects in some cases. Sometimes these artifacts cannot be removed.

- Most important radiometric artifacts for land applications:
  - Ambiguities that appear as ground objects duplication along azimuth and range directions → SAR processors don't correct these effects.
  - Scalloping that appears as repeating weak stripes across the scene → can be compensated.
  - Insufficient range antenna pattern compensation that appears in a form of patches with different brightness → can be corrected using an accurate correctly applied antenna pattern. Regular calibration of SAR antenna pattern can help reduce this effect.

Scalloping

- This effect is caused by inaccurate estimation of the Doppler centroid mean frequency. This effect can be corrected by filtering techniques (Fourier) or reprocessing the data using the correct Doppler centroid.

- Seen as corduroy-like radiometric banding across the scene.

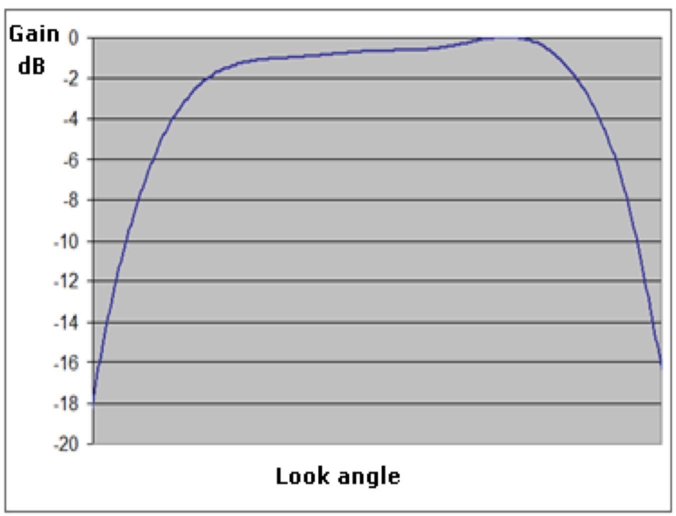


Scalloping on RADARSAT-1 ScanSAR Narrow A image

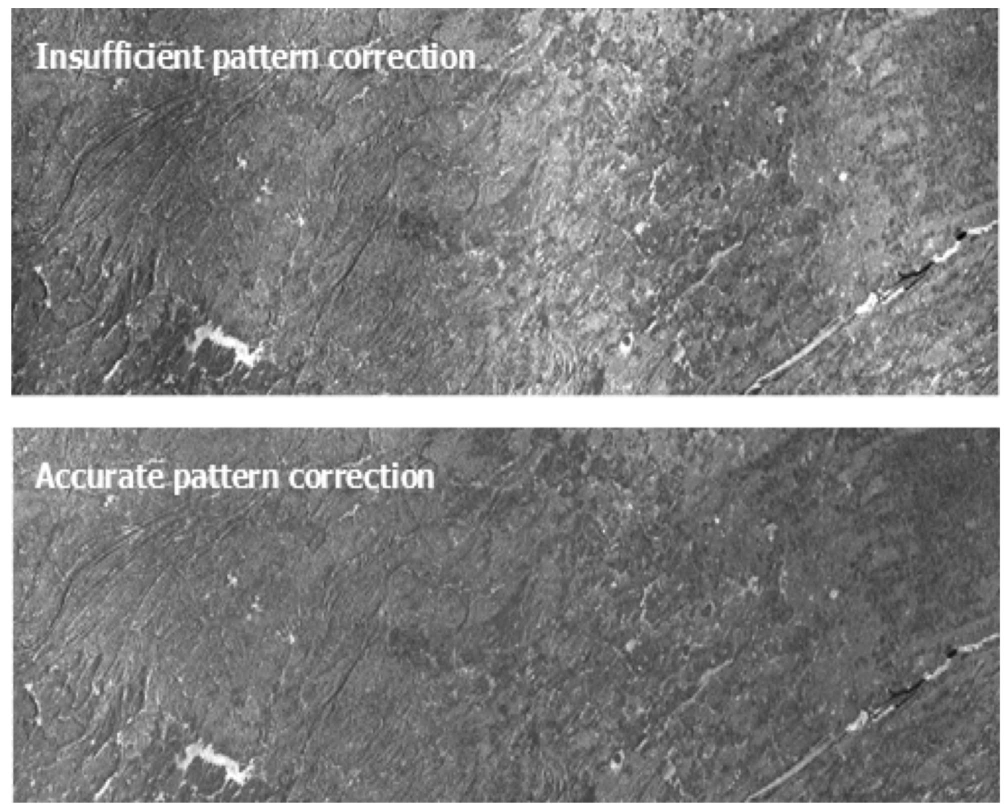
Image source: Canada Centre for Remote Sensing

Range Antenna Pattern Compensation

- isotropic antennas transmit power (ideally) equally in all directions, but radar antennas focus power in one direction
- antenna pattern is the geometric pattern of the relative strengths of the power emitted by the antenna
- this pattern is measured before the antenna is deployed, but will change over time; ongoing measures of this pattern are required
- once accurately measured, the inverse of the pattern is applied during processing, to remove the pattern



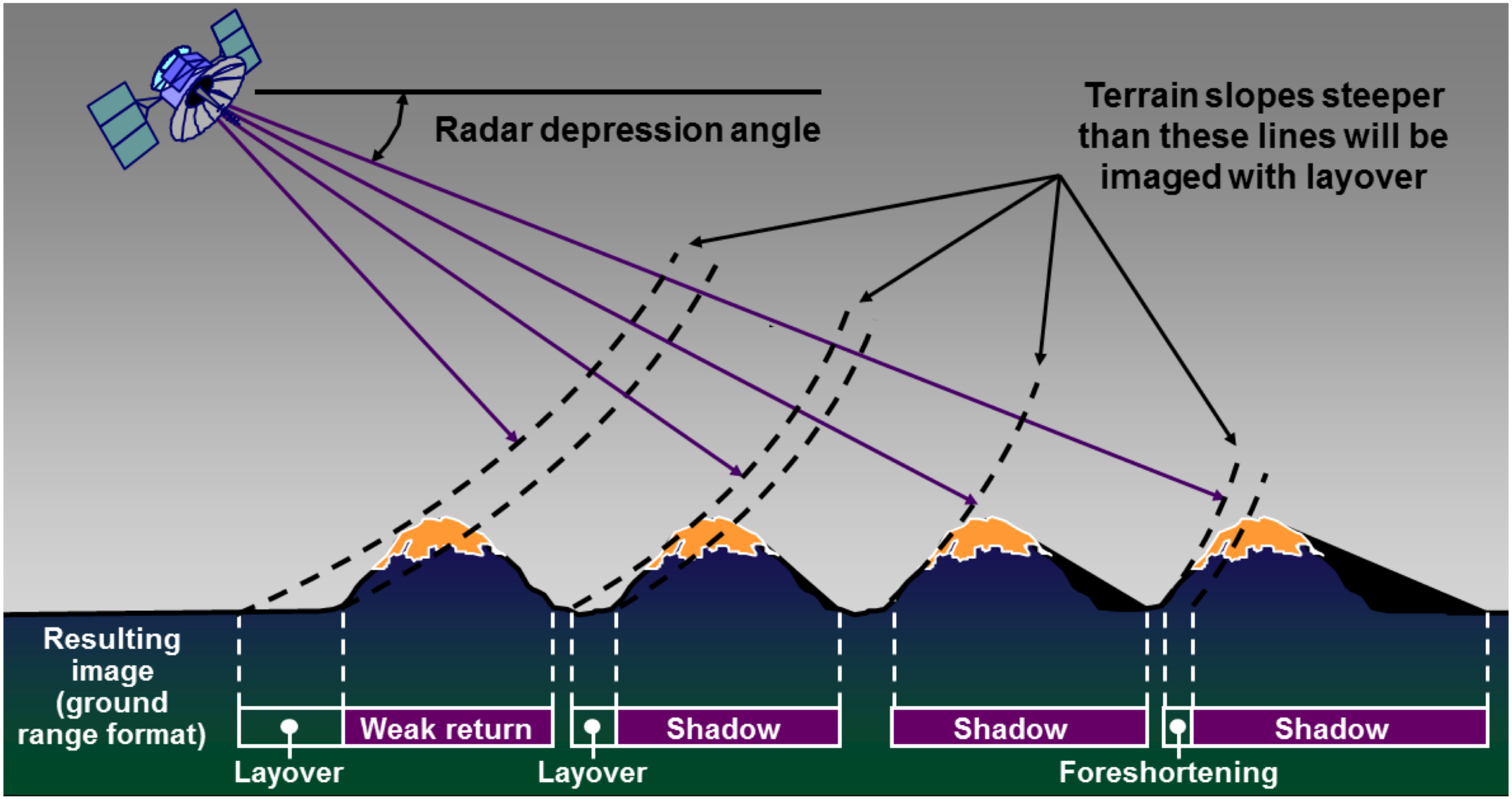
Antenna gain profile



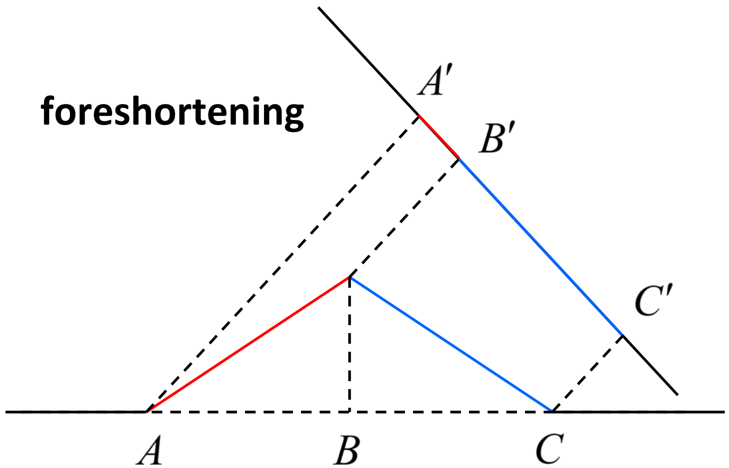
RADARSAT-1 SAR image

Image source: www.racurs.ru/download/conf/Italy2010/Presentations/Elizavetin.pdf

Radar Geometric Distortions

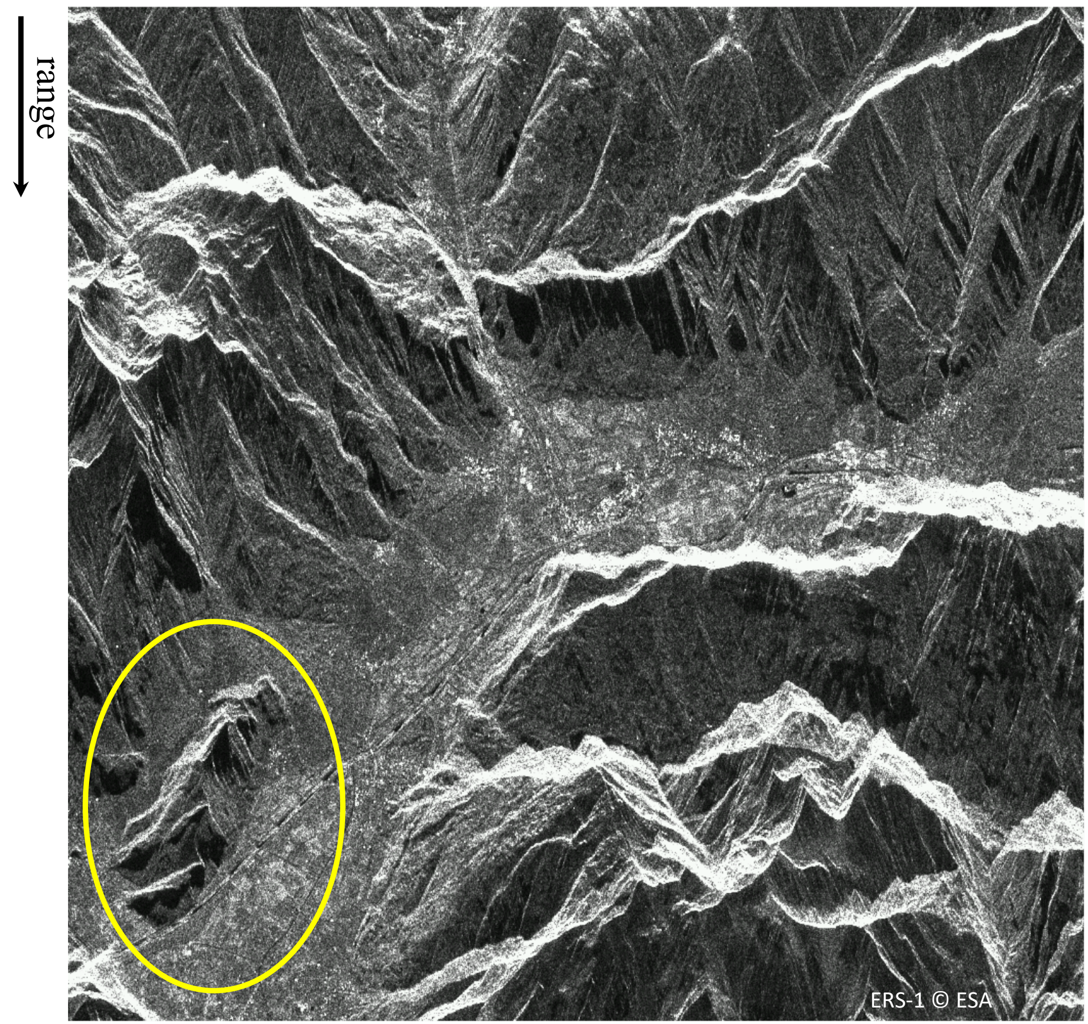


Radar Geometric Distortions- Foreshortening



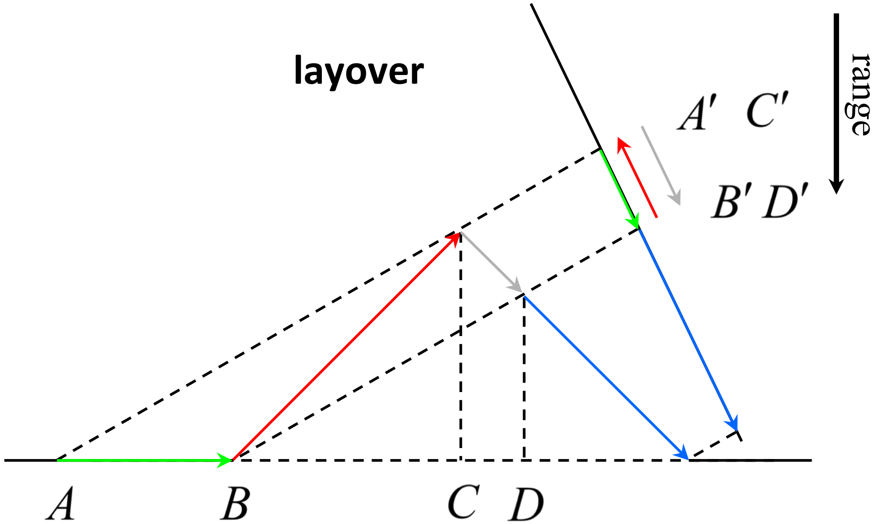
Foreshortening occurs when

- the radar beam reaches the base before it reaches the top BUT the time (range) does not reflect the geography of the target
- slopes oriented towards the SAR will appear compressed



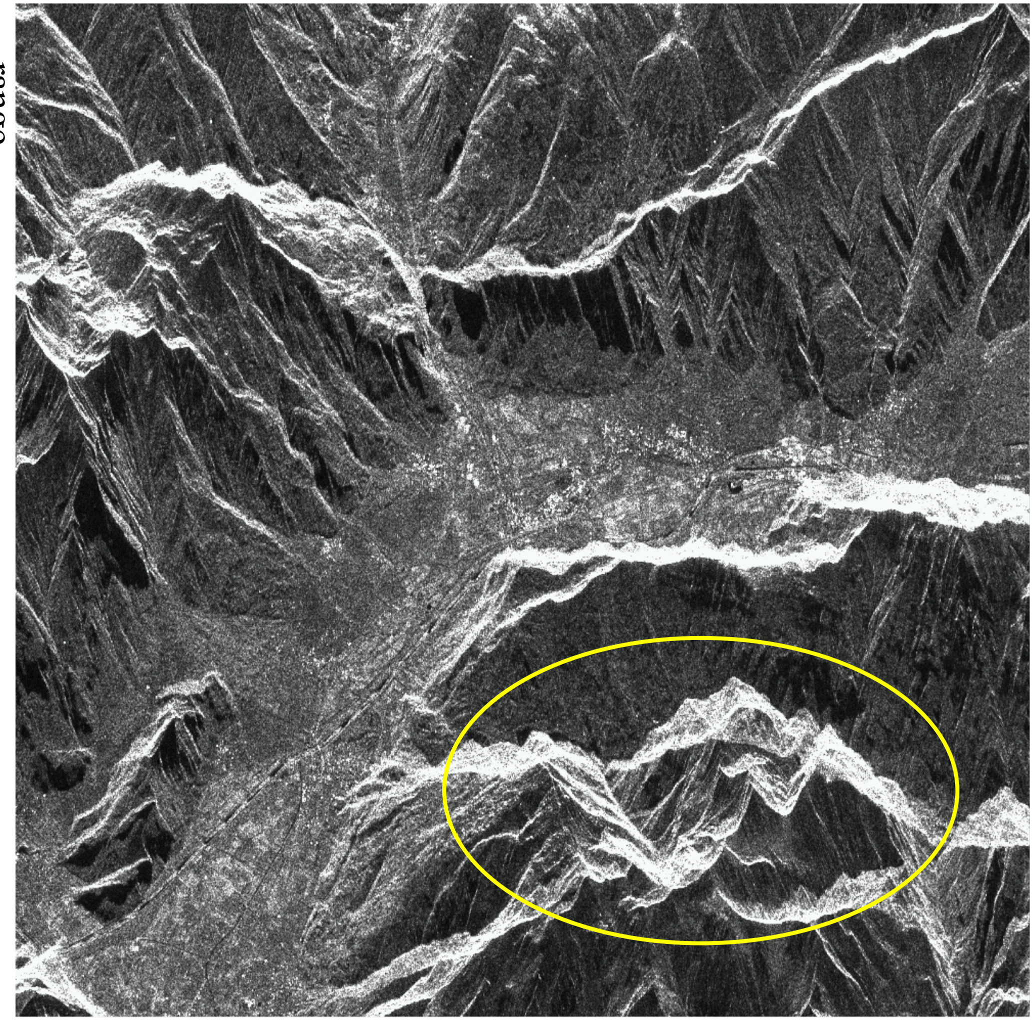
$\theta = 23$ deg

Radar geometric distortions- Layover



Layover occurs when

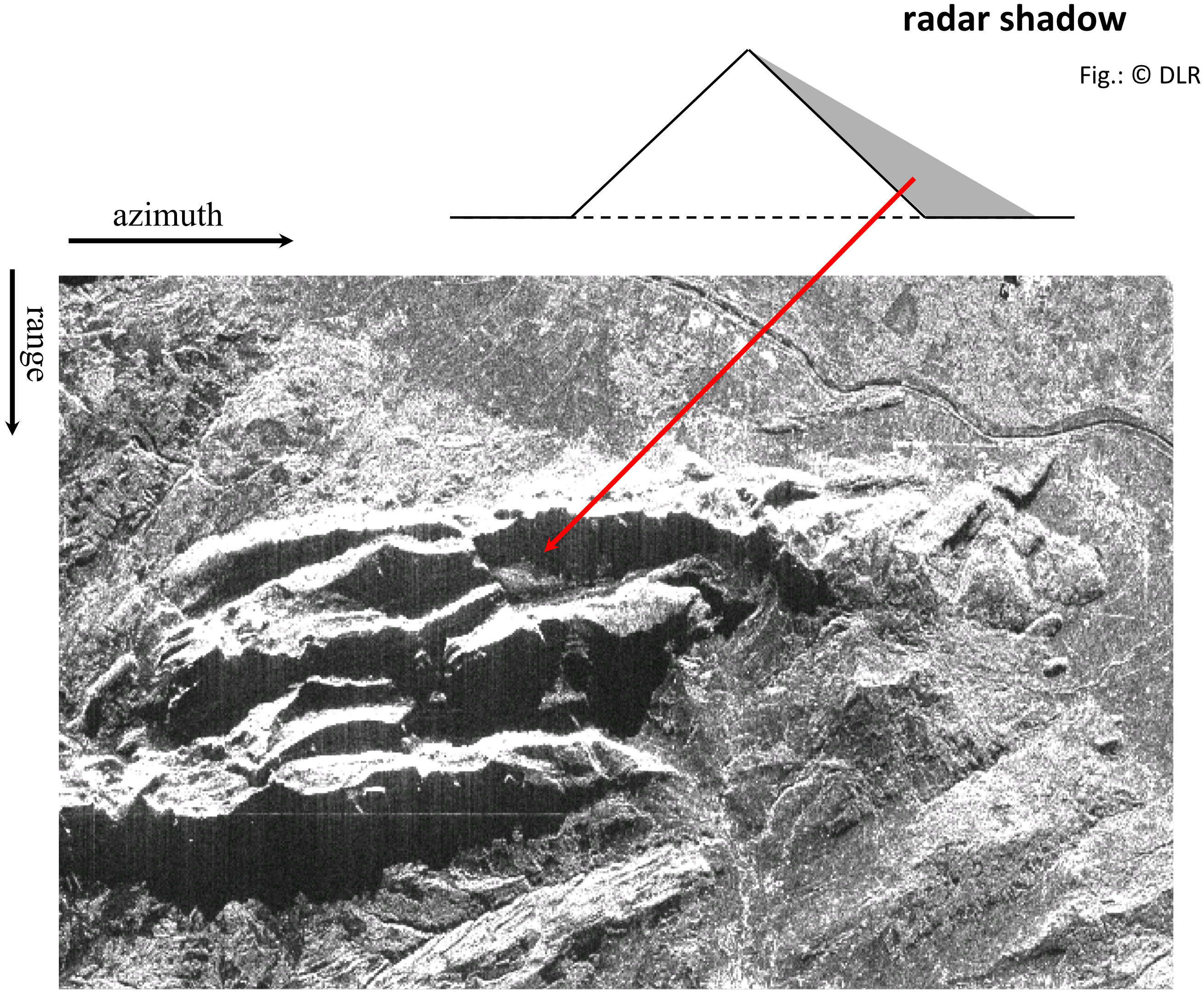
- the radar beam reaches the top of the feature before it reaches the base
- the signal from the top is received first by the antenna
- leads to ghost features where slopes appear to “fall or layover” towards the SAR



$\theta = 23$ deg

Radar Geometric Distortions- Shadow

- both foreshortening and layover create shadowing
- radar beam cannot illuminate the ground
- present for aft-slopes oriented away from SAR



SRTM/X-SAR $\theta = 54$ deg © DLR

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Agriculture et
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CSA ASC

Natural Resources
Canada

Ressources naturelles
Canada

PCI
GEOMATICS

Environment and
Climate Change Canada

Environnement et
Changement climatique Canada

INRS
Institut national
de la recherche
scientifique

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