Agriculture and Agri-Food Canada / Agriculture et Agroalimentaire Canada

National Aeronautics and Space Administration

Developed in collaboration with Agriculture and Agri-Food Canada.

Agricultural Crop Classification with Synthetic Aperture Radar and Optical Remote Sensing

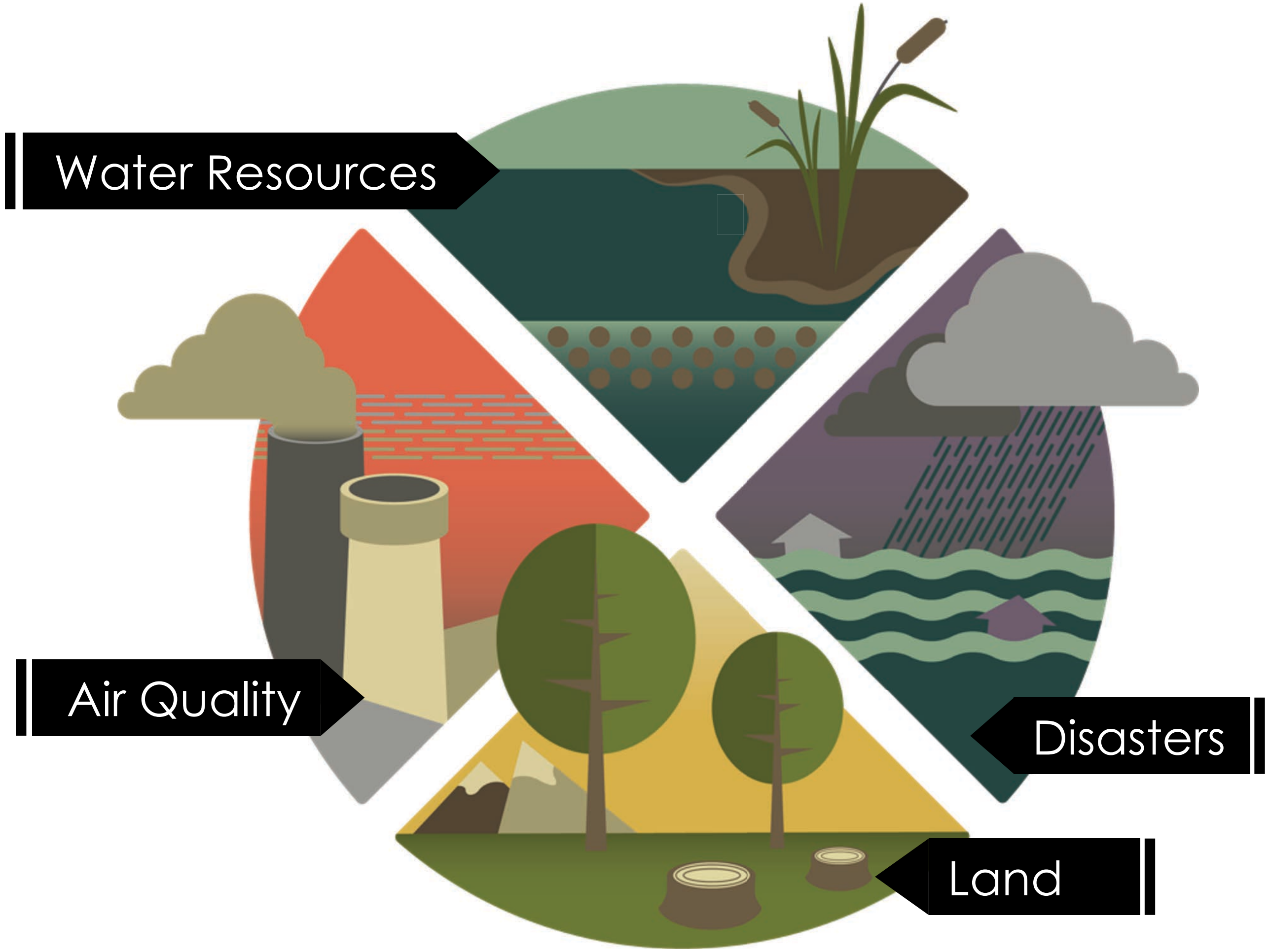
Part 1: Synthetic Aperture Radar (SAR) Refresher

Heather McNairn (AAFC) - October 5, 2021

NASA's Applied Remote Sensing Training Program (ARSET)

https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

- Part of NASA's Applied Sciences Capacity Building Program
- Empowering the global community through online and in-person remote sensing training
- Topics for trainings include:
  - Water Resources
  - Air Quality
  - Disasters
  - Land
  - Climate & Energy (coming soon)



NASA’s Applied Remote Sensing Training Program (ARSET)

https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

- ARSET’s goal is to increase the use of Earth science remote sensing and model data in decision-making through training for:
  - Professionals in the public and private sector
  - Environmental managers
  - Policy makers

All ARSET materials are freely available to use and adapt for your curriculum. If you use the methods and data presented in ARSET trainings, please acknowledge the NASA Applied Remote Sensing Training (ARSET) program.

Training Format

- Five 2.5-hour sessions including presentations and question and answer sessions
- The same content will be presented at two different times each day.
- Session A will be presented in **English.**
- Session B will be presented in **Spanish.**
  - Session A: 10:00-12:30 EST (UTC-4)
  - Session B: 13:00-15:30 EST (UTC-4)

- Training materials and recordings will be available from:

  https://appliedsciences.nasa.gov/join-mission/training/english/arset-agricultural-crop-classification-synthetic-aperture-radar-and

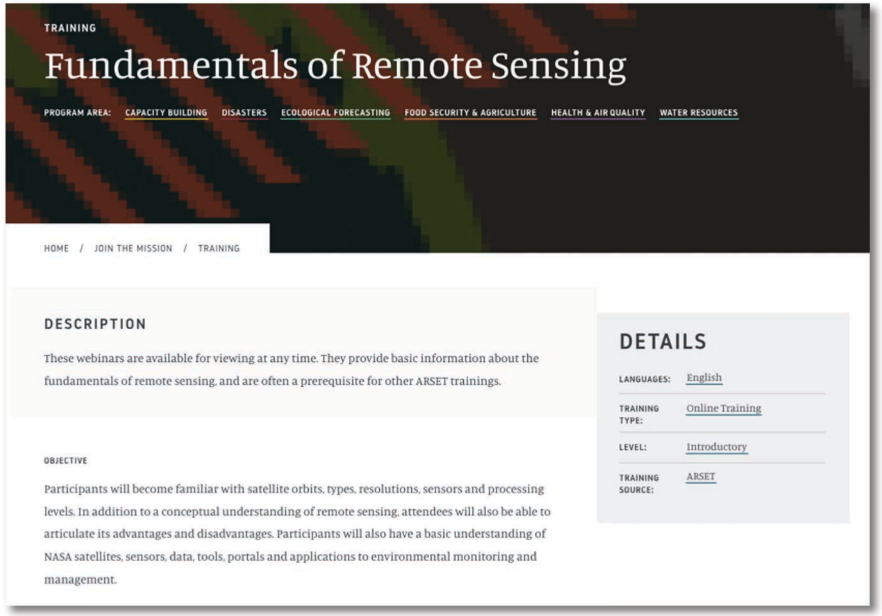
Homework and Certificate

- Homework Assignment:
  - Answers must be submitted via Google Form
  - Due Date: November 2, 2021
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline (access from website)
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Prerequisites

- Fundamentals of Remote Sensing: https://appliedsciences.nasa.gov/join-mission/training/english/fundamentals-remote-sensing

- Introduction to Synthetic Aperture Radar: https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-synthetic-aperture-radar



Training Outline

October 5, 2021

Synthetic Aperture Radar (SAR) Refresher

October 7, 2021

Optical Remote Sensing Refresher and Introduction to SNAP

October 12, 2021

Operational Crop Classification Roadmap using Optical and SAR Imagery (Part 1)

October 14, 2021

Operational Crop Classification Roadmap using Optical and SAR Imagery (Part 2)

October 19, 2021

Biophysical Variable Retrieval using Optical Imagery to Support Agricultural Monitoring Practices

Training Objectives

By the end of this training attendees will learn:

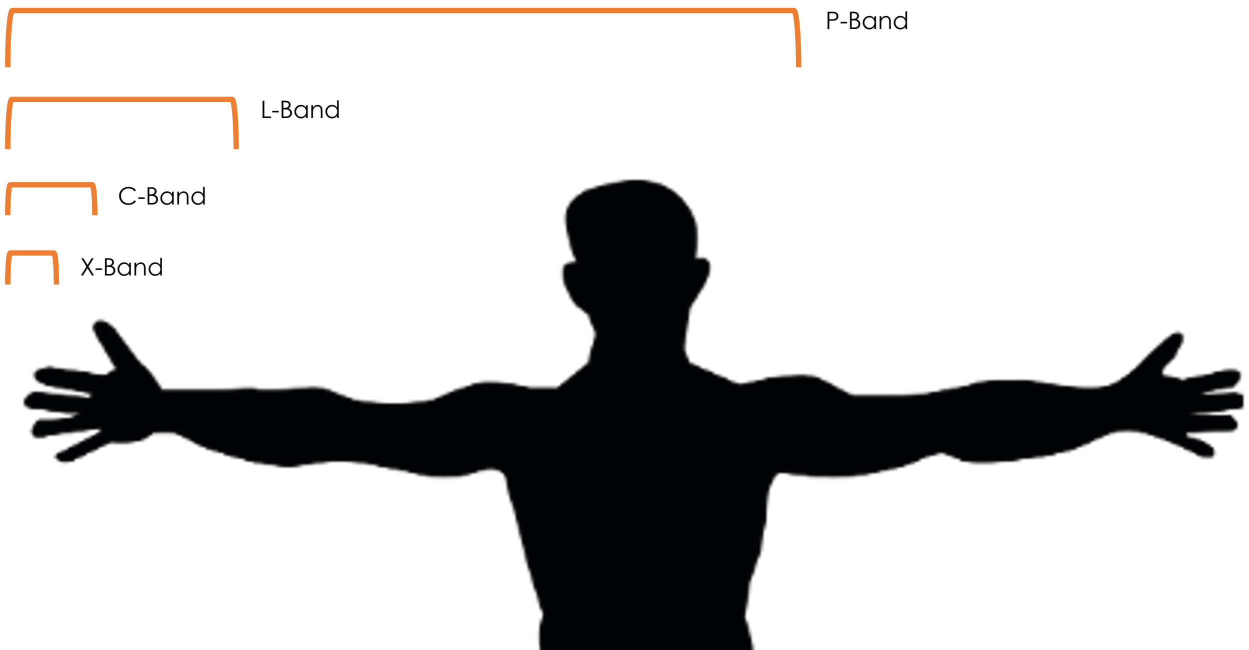
- The physics behind SAR image formation
- The interaction of the SAR signal with the land surface
- The impact of soil and crop characteristics on SAR response
- The optimal sensor parameters for agricultural applications

RADAR Refresher

The Microwave Region of the Electromagnetic Spectrum

- Wavelengths between 1 cm and 1 m
- Microwave regions referenced by 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

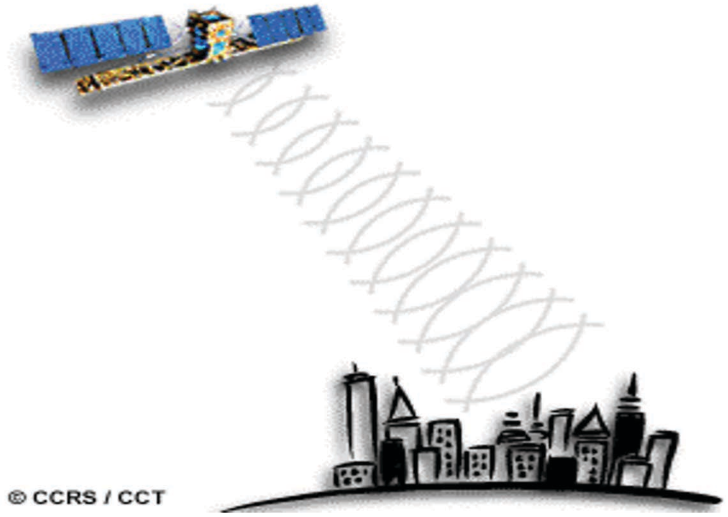


RAdio Detection And Ranging - RADAR

Radars are active systems - they generate their own source of energy.

Detection – Radars send, or propagate, a microwave (or *radio*) signal with known properties. The strength of the energy "*scattered back*" or "*backscattered*" by the target is detected by the radar.

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



Distance to the Target

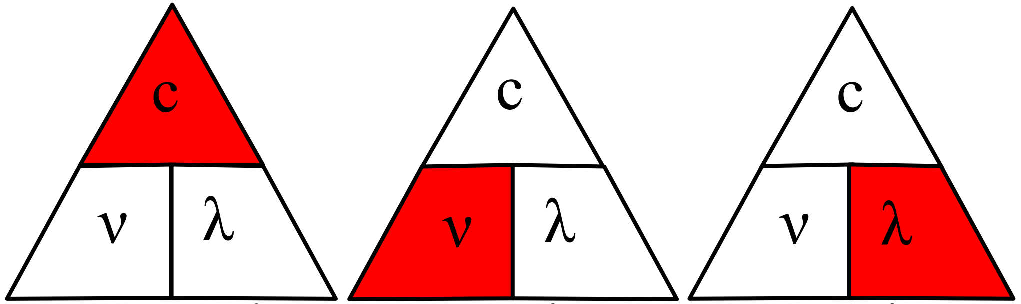
$$R = \frac{c \cdot t}{2}$$

R = Range or Distance (m)
c = Speed of Light ($3x10^8$ m/s)
t = Time (s)

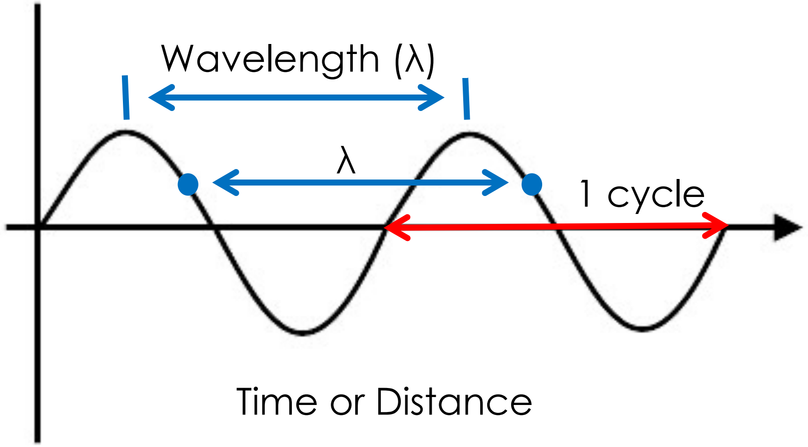
Frequency and Wavelength

Wavelength (m): Length of one wave cycle

Frequency (Hz): Number of oscillations per time unit



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



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

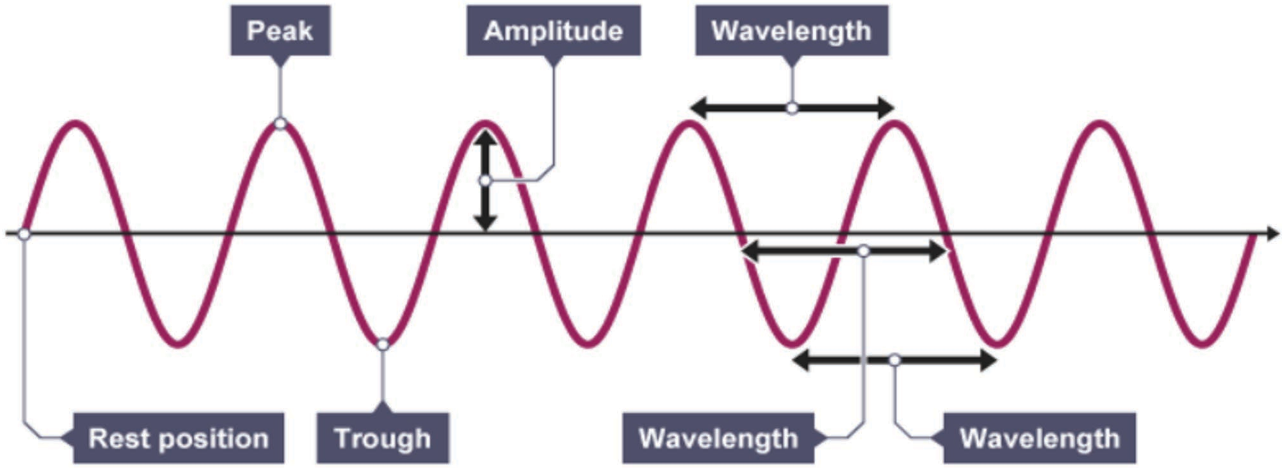
c = speed of light (3×10^8 m/s)

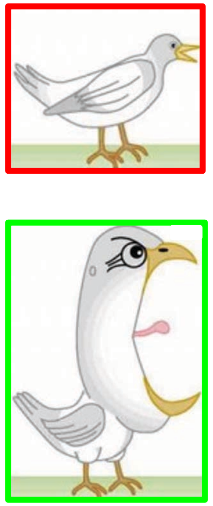
λ = wavelength (m)

ν = frequency (Hertz [Hz])

1 Hz = one cycle per second

Intensity of a Wave





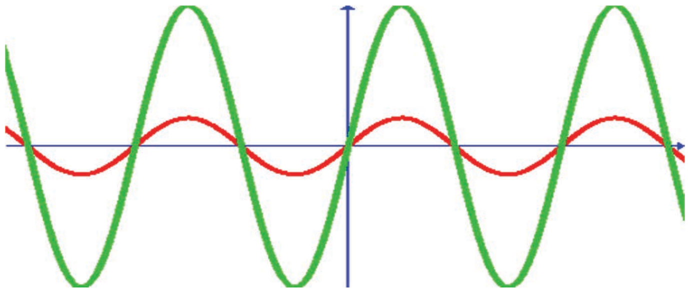


Image Source: www.bbc.com/bitesize/guides/zgf97p3/revision/1

Amplitude: Maximum displacement of a wave from its rest position

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

Intensity = (Amplitude)²

Phase

Phase: Position of a point in time on a waveform cycle, measured in degrees or radians. A wave's position in **time** or **space**.

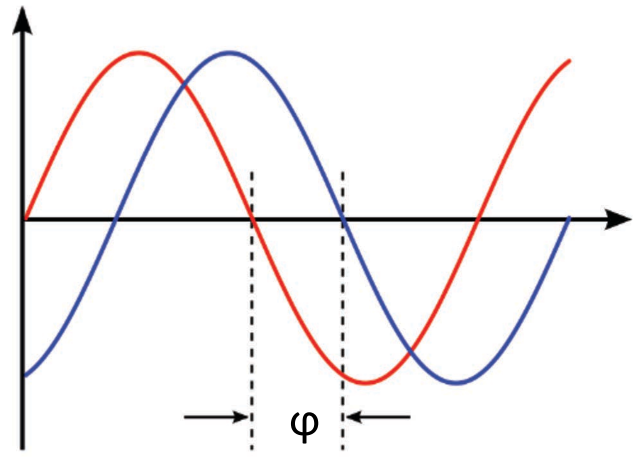
Phase Difference (φ): The offset, in time or space, of one wave with respect to another.

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

Why is this important?

- Key in interferometric as well as in polarimetric SAR
- Phase difference is impacted by structure of the target
- During wave generation, phase offsets determine how a wave propagates

Equal Amplitude; Out of Phase



Different Amplitudes; In Phase

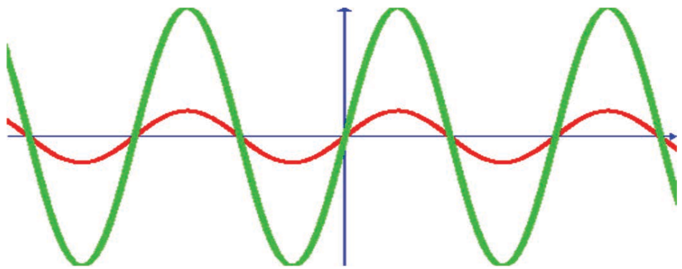


Image Source: https://en.wikipedia.org/wiki/Phase_(waves)

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

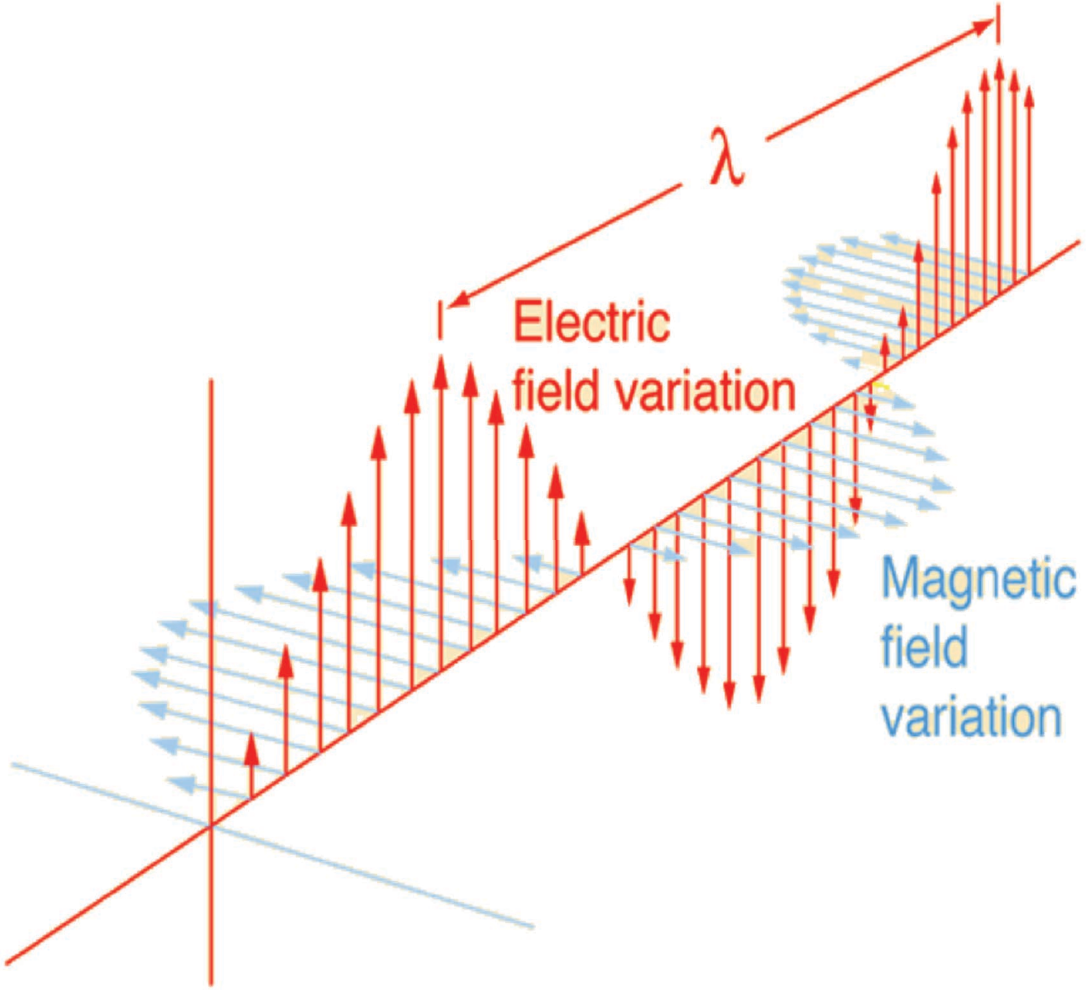


Image Source: Hyperphysics

How do waves propagate?

Polarization	Phase offset between the two perpendicular components (E_H and E_V) of the electromagnetic field	
Linear	Zero degrees	Most commonly used in SAR (H or V)
Circular	90 degrees	Available on some new SAR sensors
Elliptical	An offset other than 90 degrees	How most ambient waves propagate

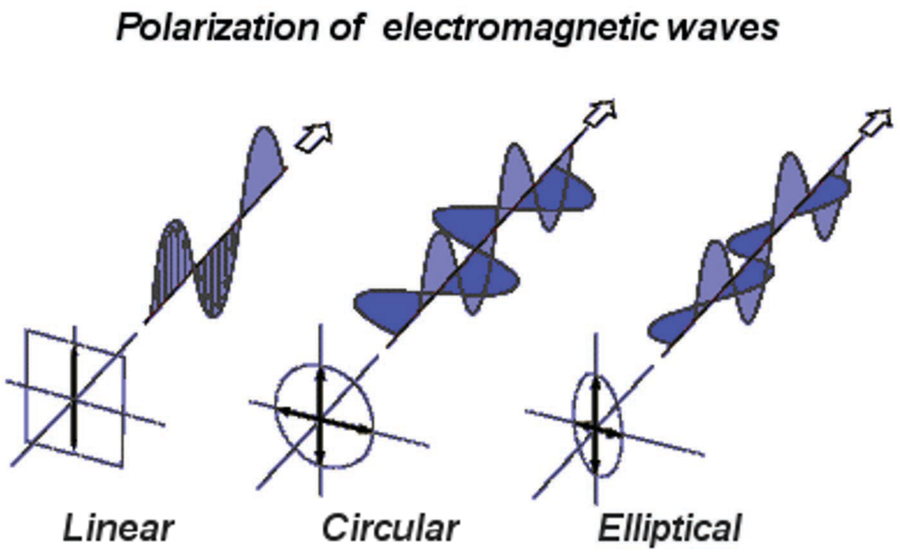
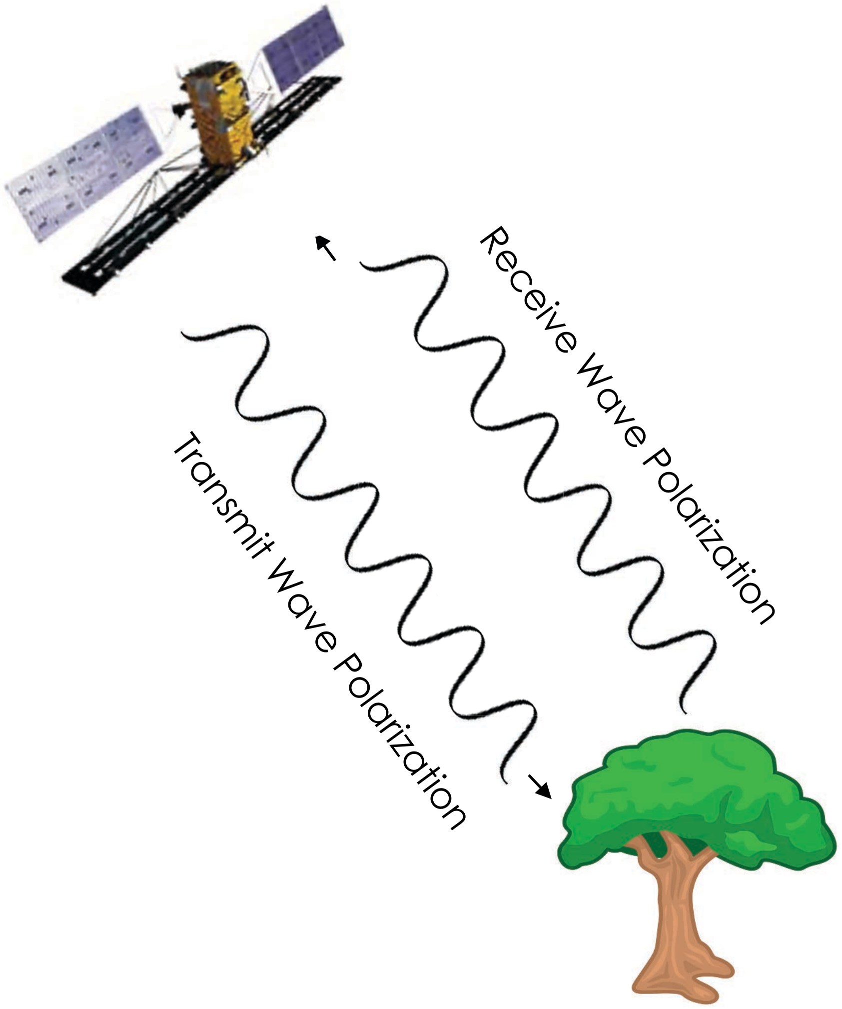


Image Source: www.blazelabs.com/f-g-rpress.asp

Transmit and Receive Polarizations



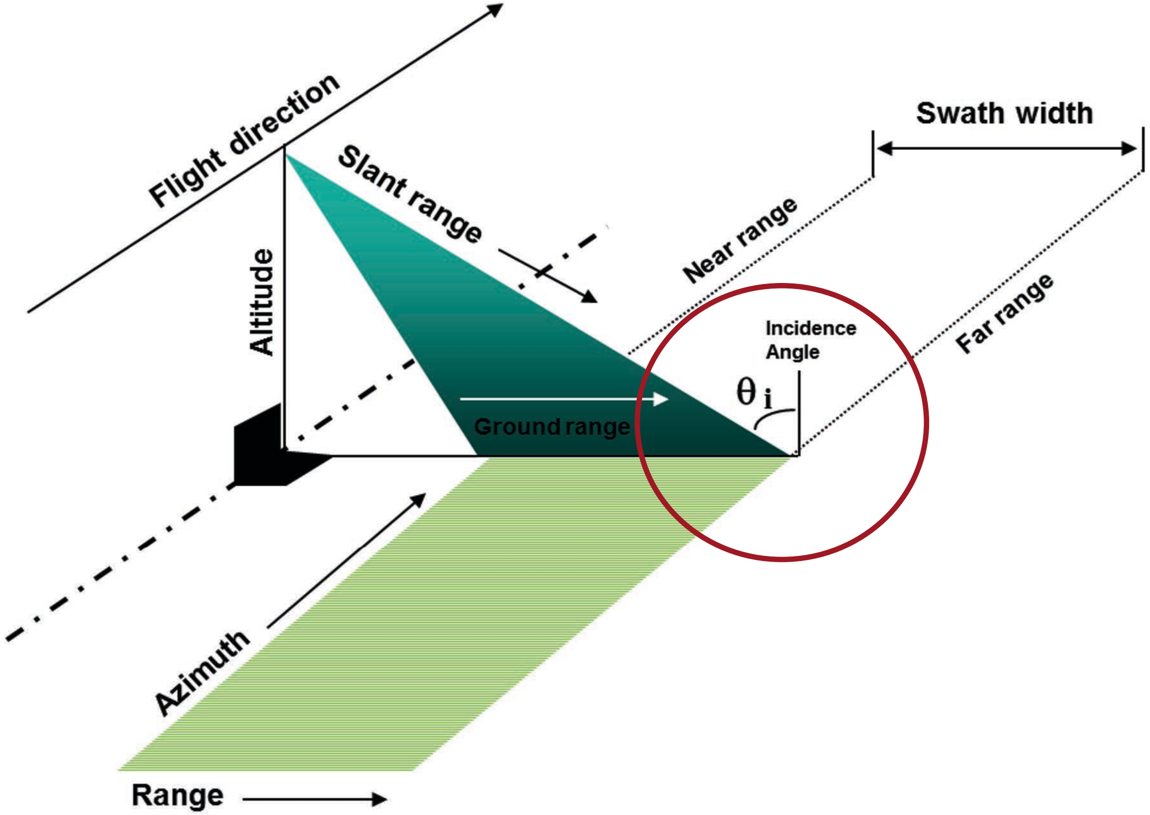
Radars are active:

- 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)

Incident Angle



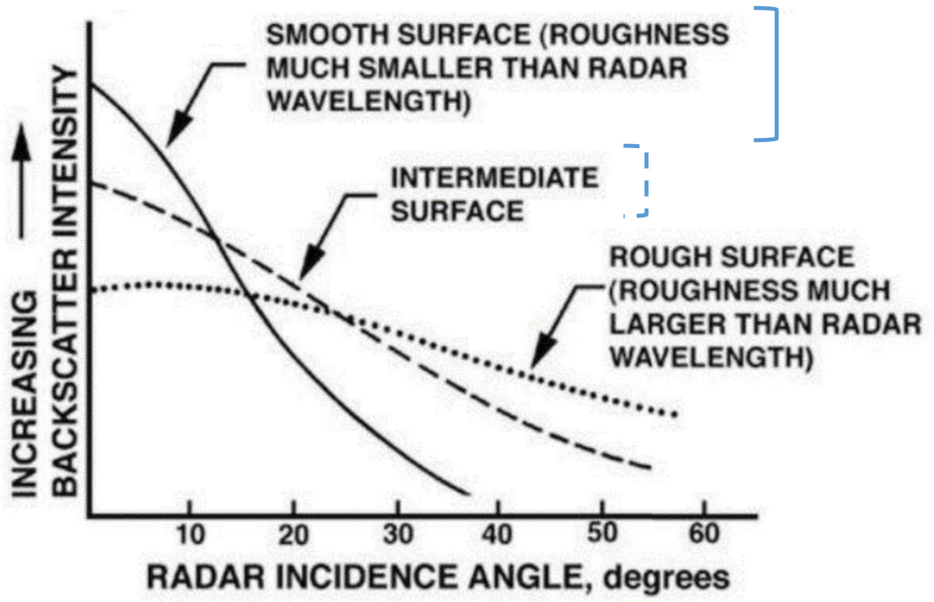
Incident angle is the angle between the radar beam and the perpendicular to the imaged surface.

SAR incident angle determines:

- The contribution of different target elements to backscatter
- How rough the target appears to the SAR. Surfaces appear "smoother" at larger angles.
- How deep the microwave signal penetrates into the target

Incident Angle

- Backscatter decreases with increasing incident angle.
- Rate and function of decrease is target-specific.
- As a result, when a radar is viewing the same target at different angles, the backscatter will be different.



Rougher
Lower rate of change with angle

Smoother
Higher rate of change with angle

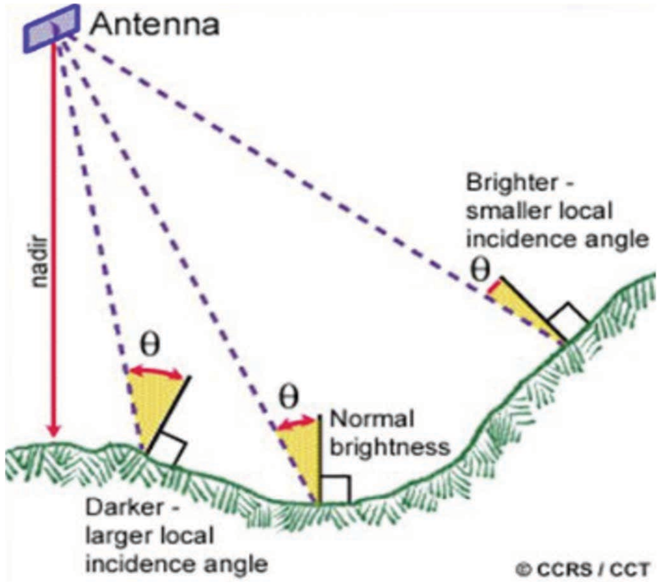
Image Source: saltftp.soest.hawaii.edu

Incident Angle

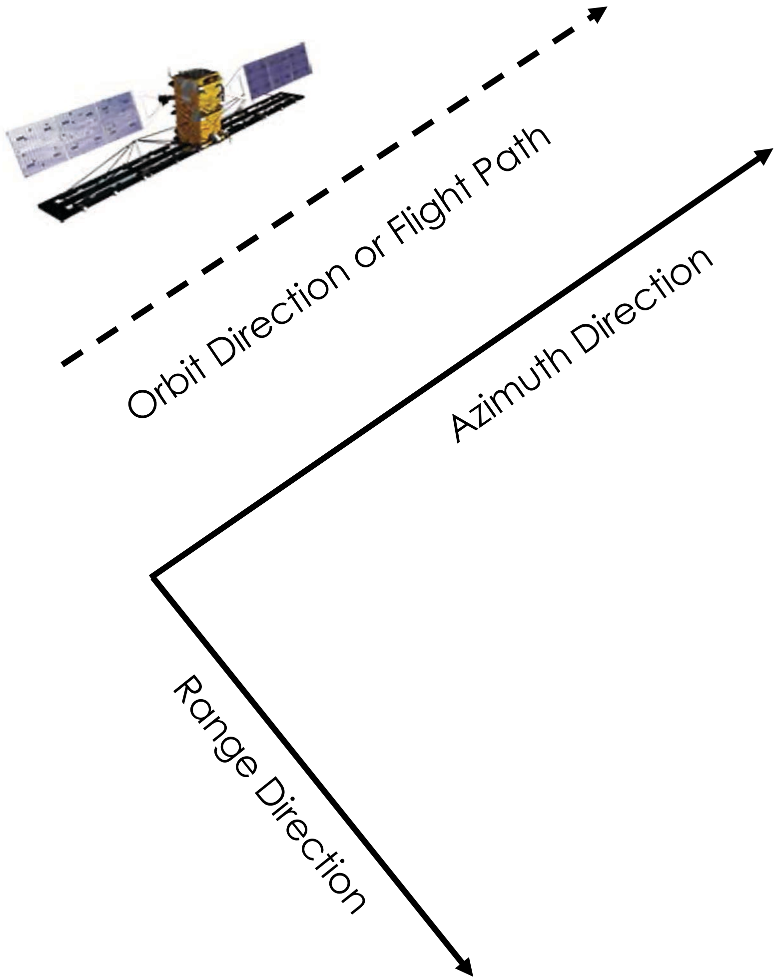
Local Incident Angle

- Local incident angle is **not** the same as incident angle.
- Local incident angle takes into account the local slope of the terrain.
- Slopes towards radar — local incident angle is less than the normal incident angle (assuming flat surface).

Why does this matter? Because radar backscatter will be higher for slopes facing the radar.



Radar Geometry



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

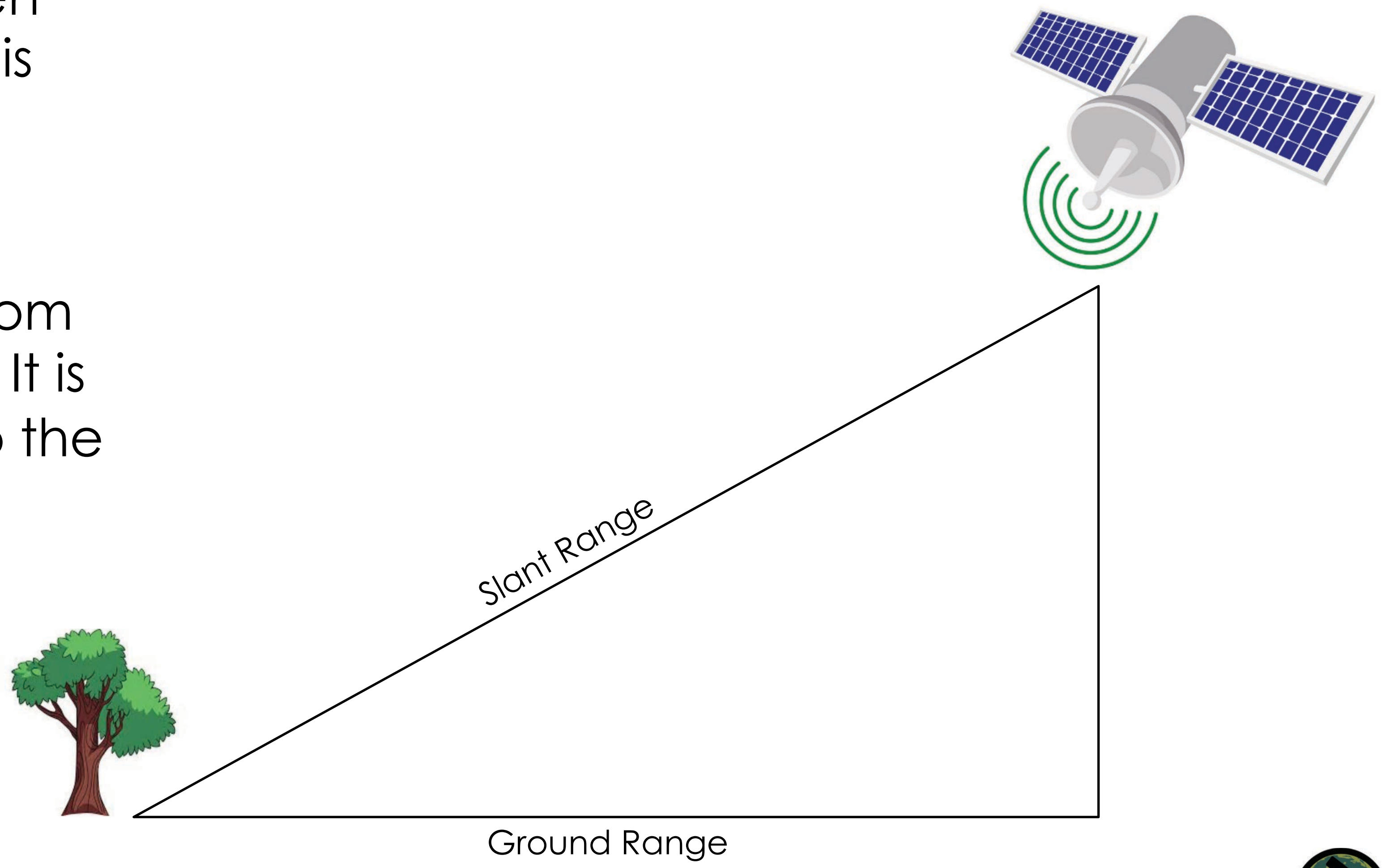
Azimuth: The direction parallel to the flight path of the aircraft or orbit of the satellite.

Range: The direction perpendicular to the flight or orbital path.

Slant Range and 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.

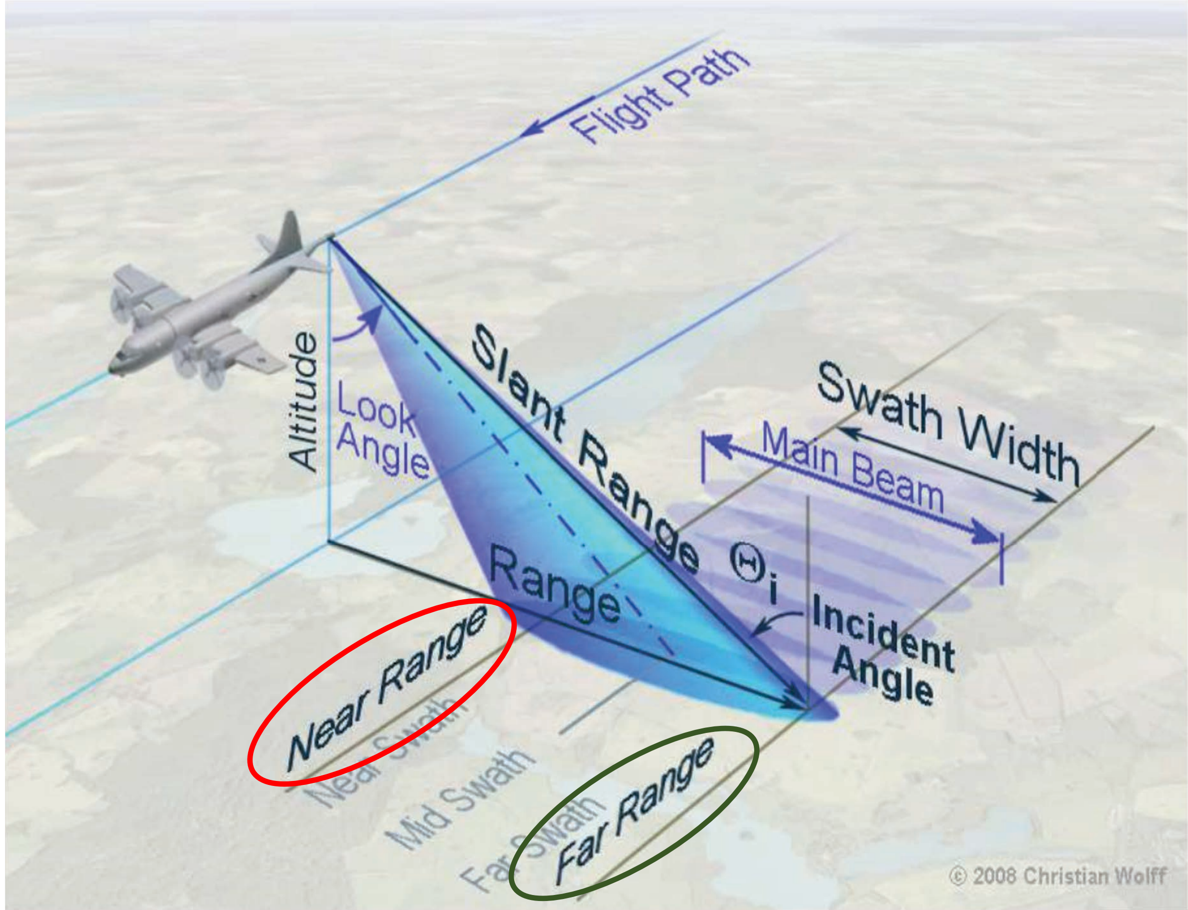


Radar Geometry

Radar Swath: The ground distance from **near** to **far** range.

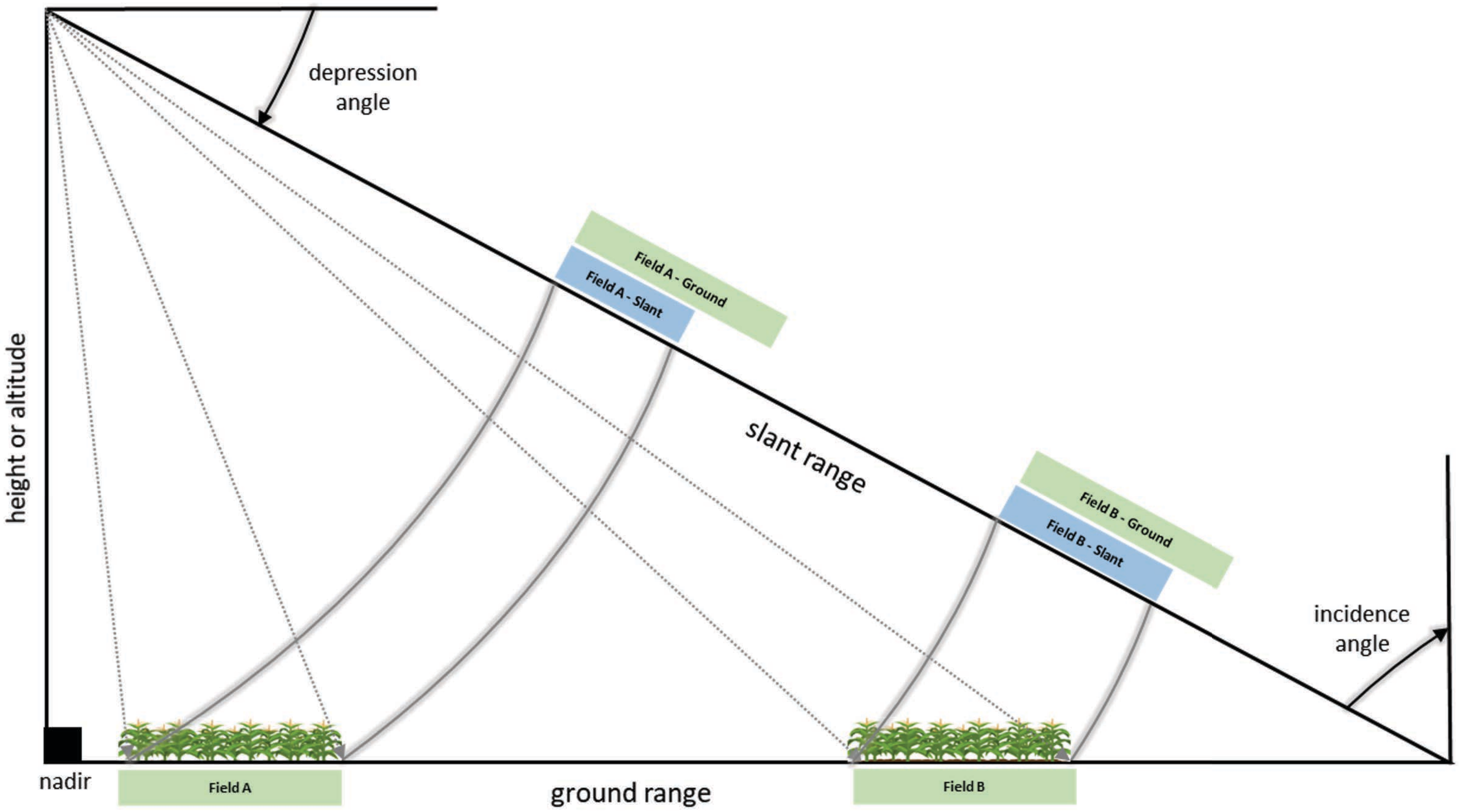
Incident Angle (θ): The angle between the line of sight of radar in slant range and the vertical to the terrain.

The incident 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).



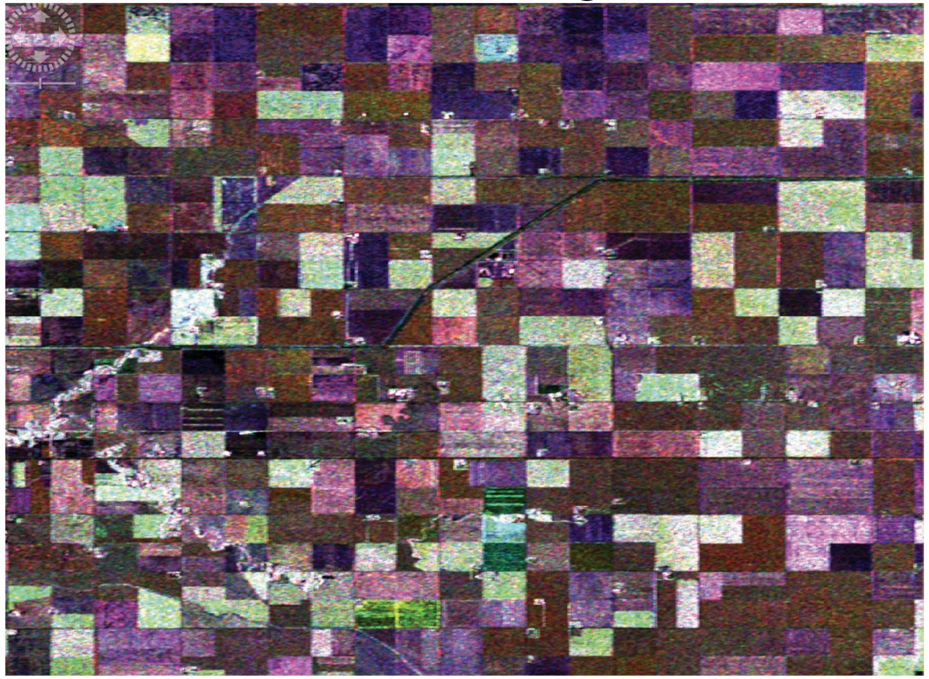
Slant Range to Ground Range Conversion

- Slant range 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.

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.**

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.

Incident Angle

- Incident angle changes from the near to far swath. For large swath modes, this change can be very significant and fundamentally impacts SAR backscatter.
- Satellite SARs can electronically steer their beams and allow for more frequent "**re-looks**" at a target. However, the incident angle will not be the same among these re-look images.
- Multi-temporal analysis and change detection: **be careful**. Combine imagery with the same incident angles to ensure that change in the measured SAR response is from changes in the target, not from the change in angle. This often means using exact SAR satellite repeats.

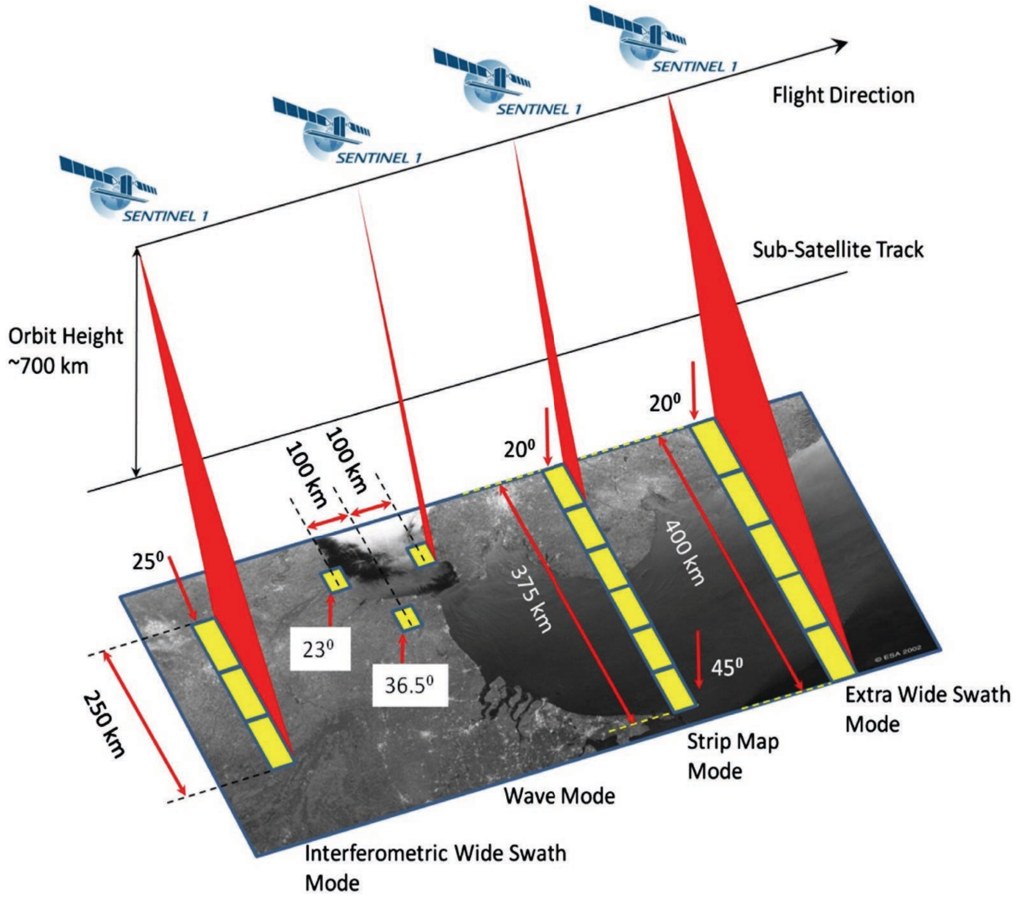
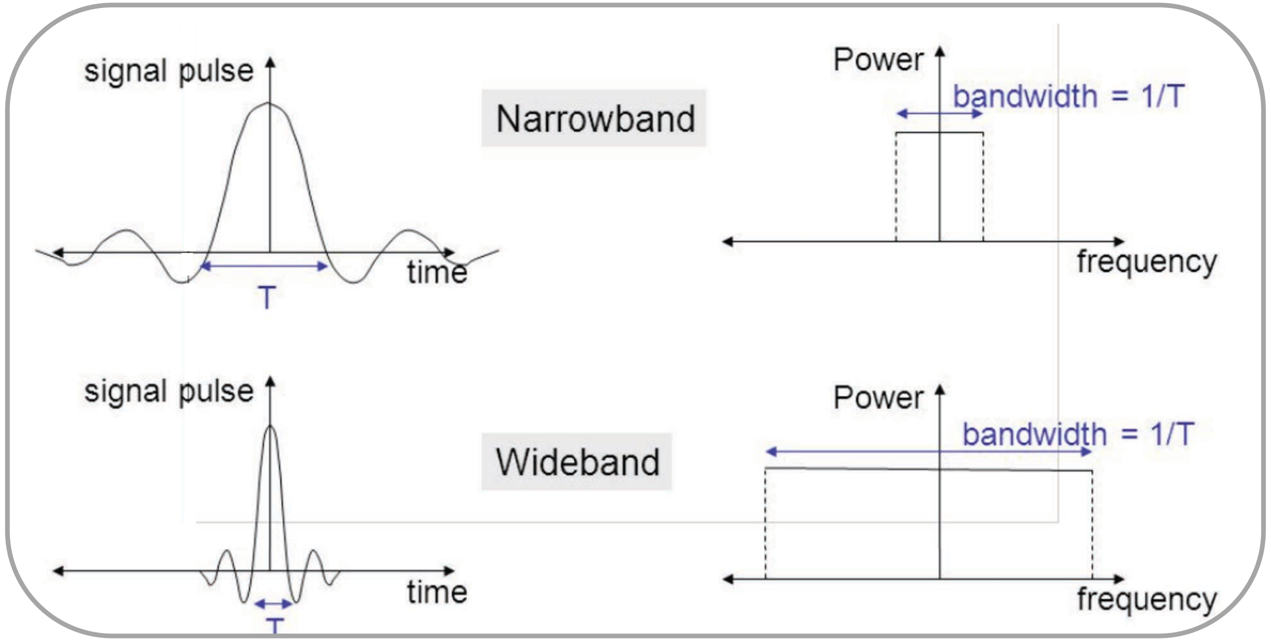


Image Source: sentinel.esa.int

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 (3×10^8 m/s)
B_e : bandwidth (Hz)

Bandwidth is inversely related to pulse duration (τ)

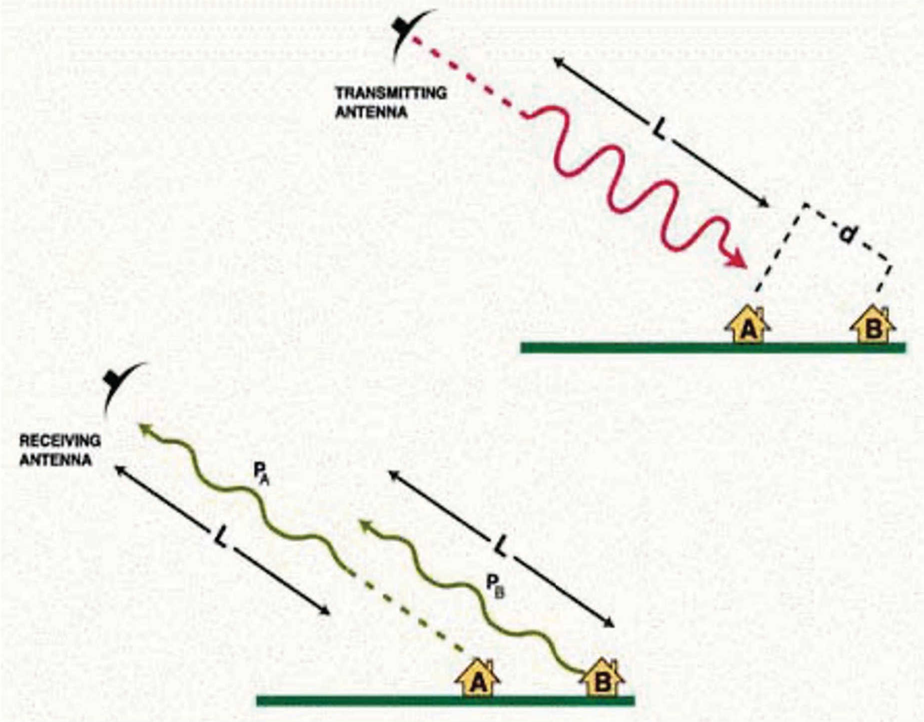
Pulse duration = the time the radar's transmitter is energized during each cycle

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 the 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).

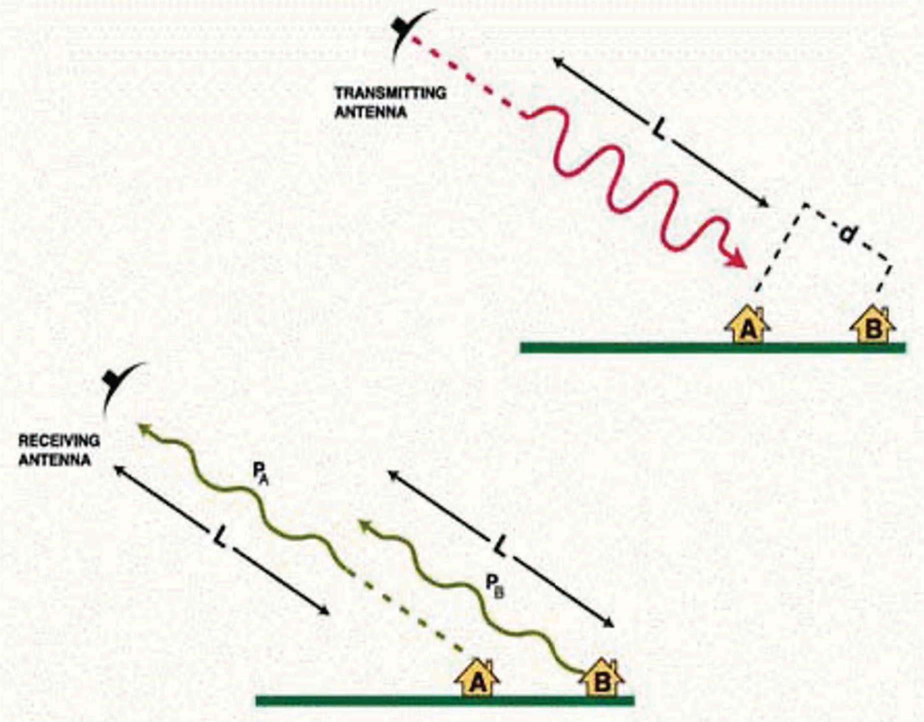


Since the radar pulse must travel two ways, the two buildings result in distinct echoes if d > L/2.

Image Source: www.earth.esa.int

Range Resolution (Real Aperture Radar)

- 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.



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

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
λ = wavelength
R = distance (slant range) from antenna to midpoint of swath

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

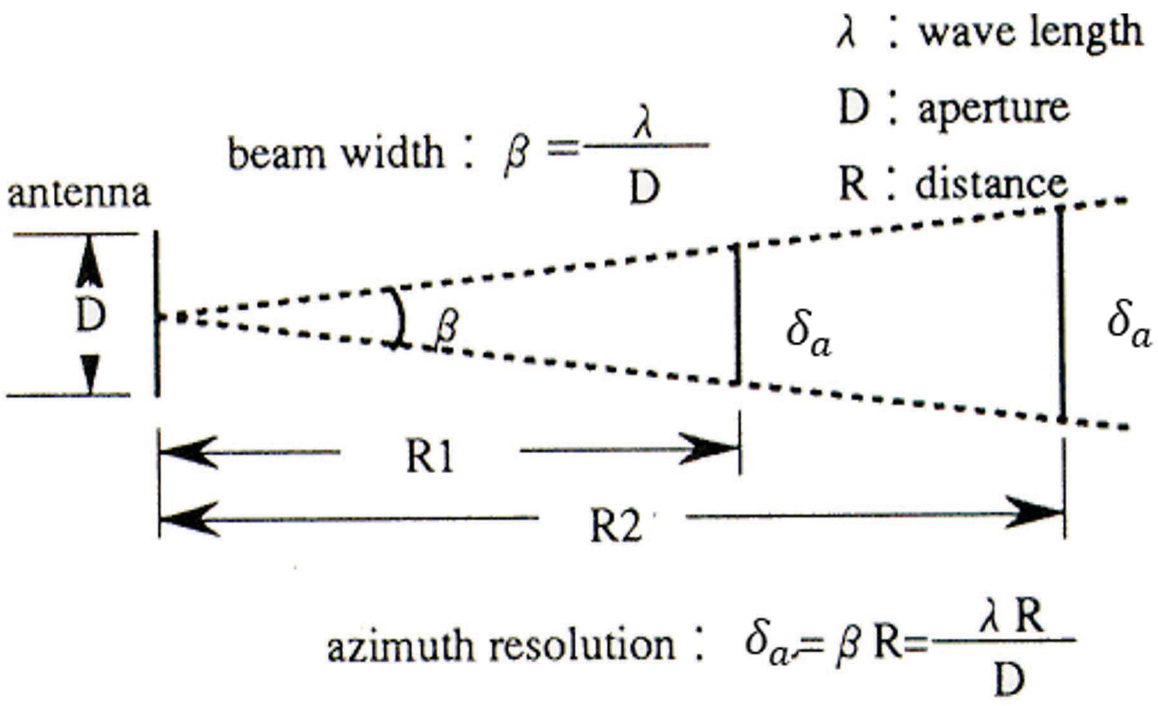
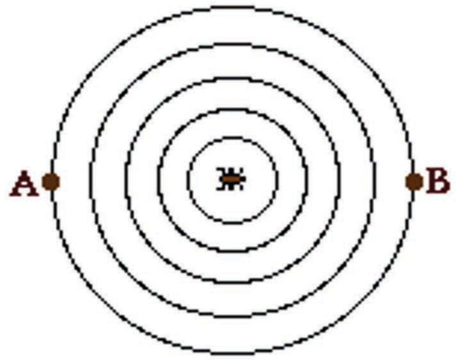


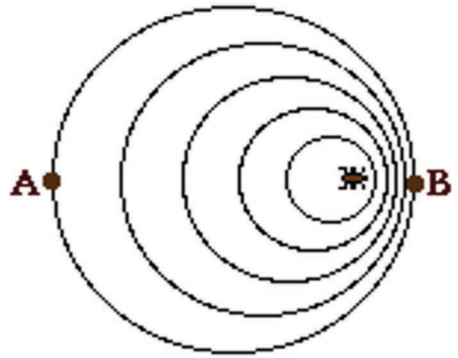
Image Source: sar.kangwon.ac.kr

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 - 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 from an <u>actual</u> change in the frequency of the source.



A stationary bug producing disturbances in water.



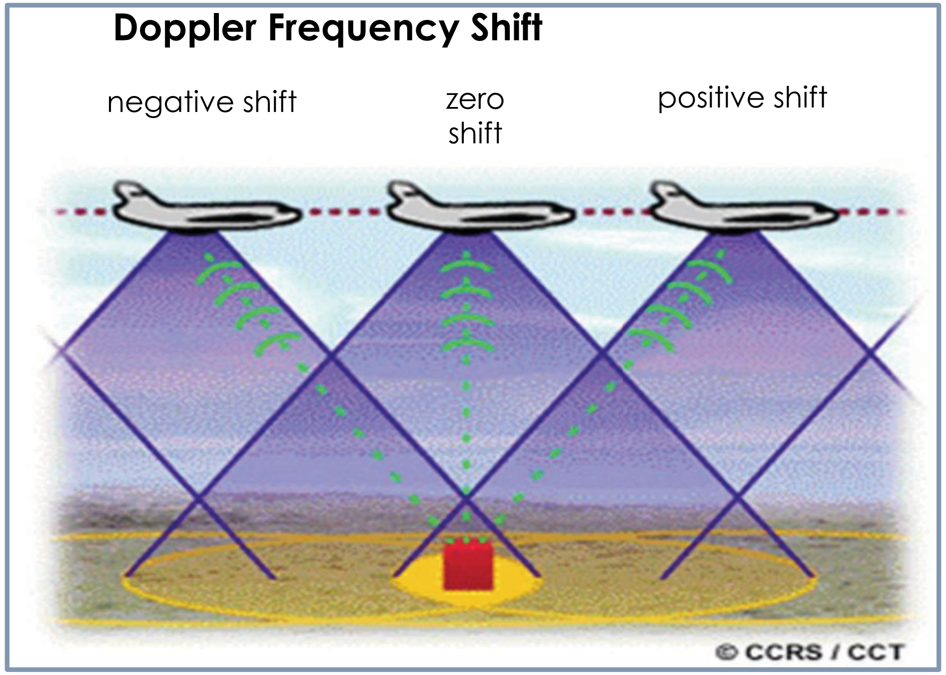
A bug moving to the right and producing disturbances.

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

Synthetic Aperture Radar (SAR)

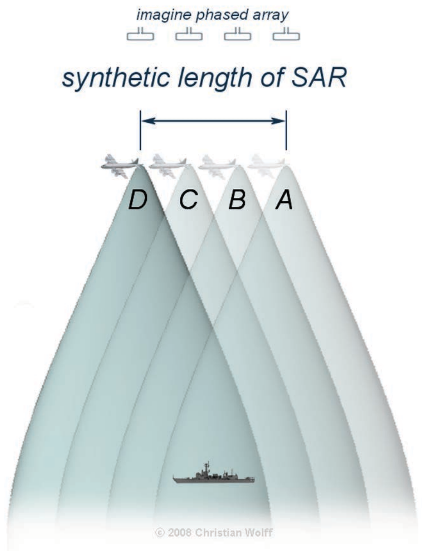
- Radars are moving – they orbit the Earth – and send out constant pulses of energy.

- 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.



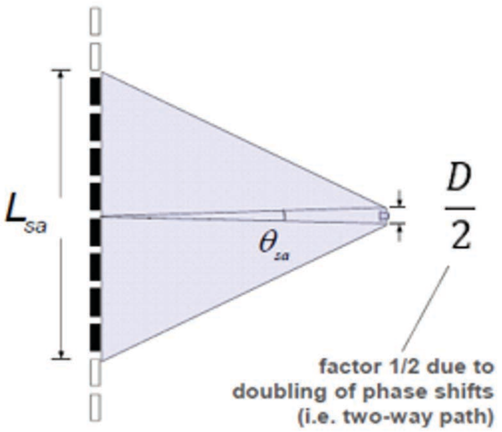
Synthetic Aperture Radar (SAR)

- SAR processor stores all the radar returned signals for the time period *T* from position A to D (different Doppler shifts).
- This is used to reconstruct the signal that 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

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 incident 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 incident angle dependency of the radar backscatter.

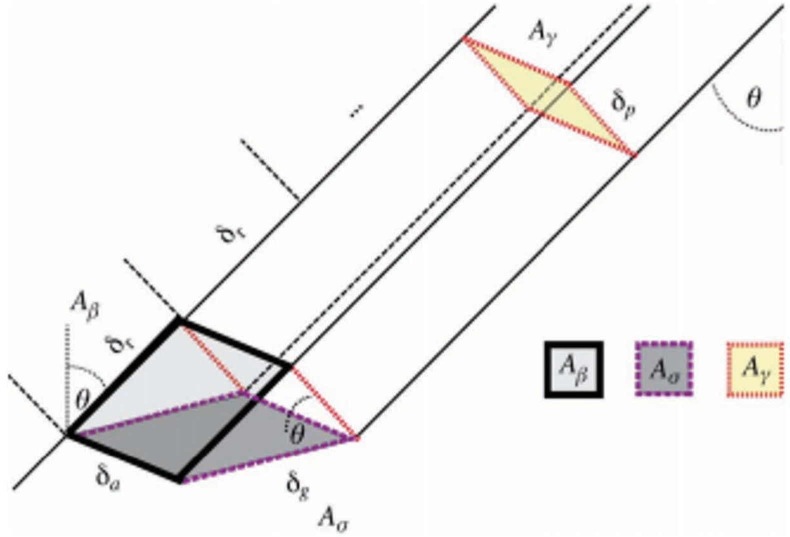


Image Source: Small, D. (2011). Flattening Gamma: Radiometric Terrain Correction for SAR Imagery. IEEE Transactions On Geoscience And Remote Sensing, 49: 3081-3093.

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

Information Source: Shimada, M., and Otaki, T. (2010). Generating continent-scale high-quality SAR mosaic datasets: Application to PALSAR data for global monitoring. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 3: 637–656.

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 describe reflectivity
- Impacted by the local surface slope
- Has more direct intuitive interpretation

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

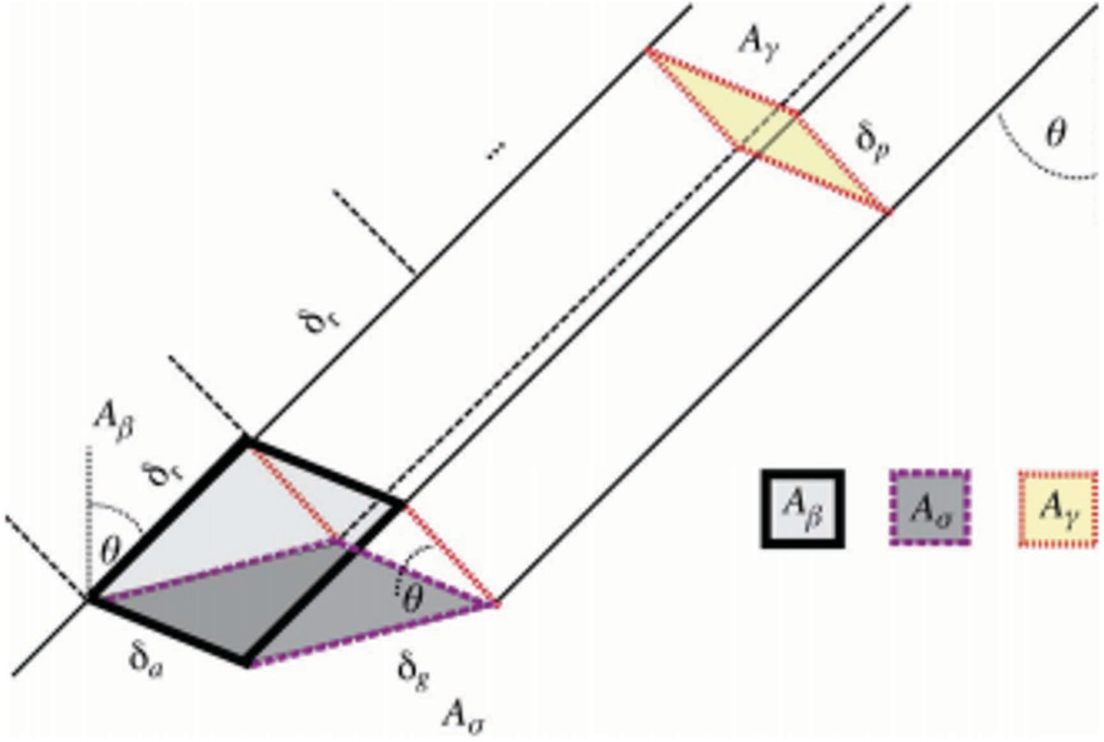


Image Source: Small, D. (2011). Flattening Gamma: Radiometric Terrain Correction for SAR Imagery. IEEE Transactions On Geoscience And Remote Sensing, 49: 3081-3093.

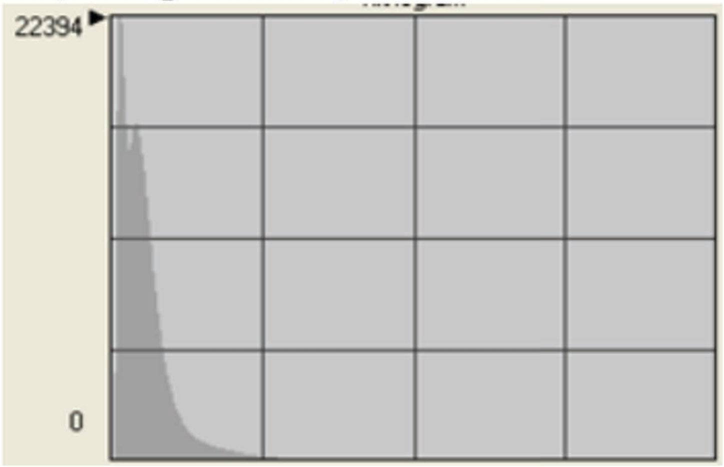
Why convert to decibels (dB)?

- 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.

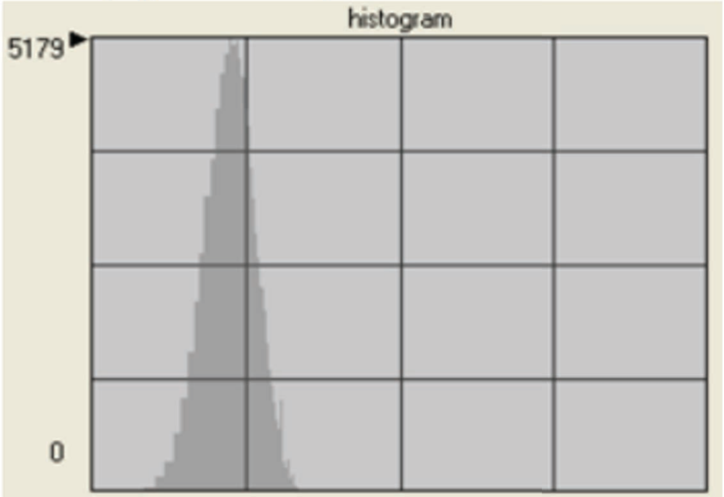
If the data are in Amplitude (A): $\sigma^{o} = 20 * \log_{10}(A)$

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 is speckle “salt and pepper” noise.

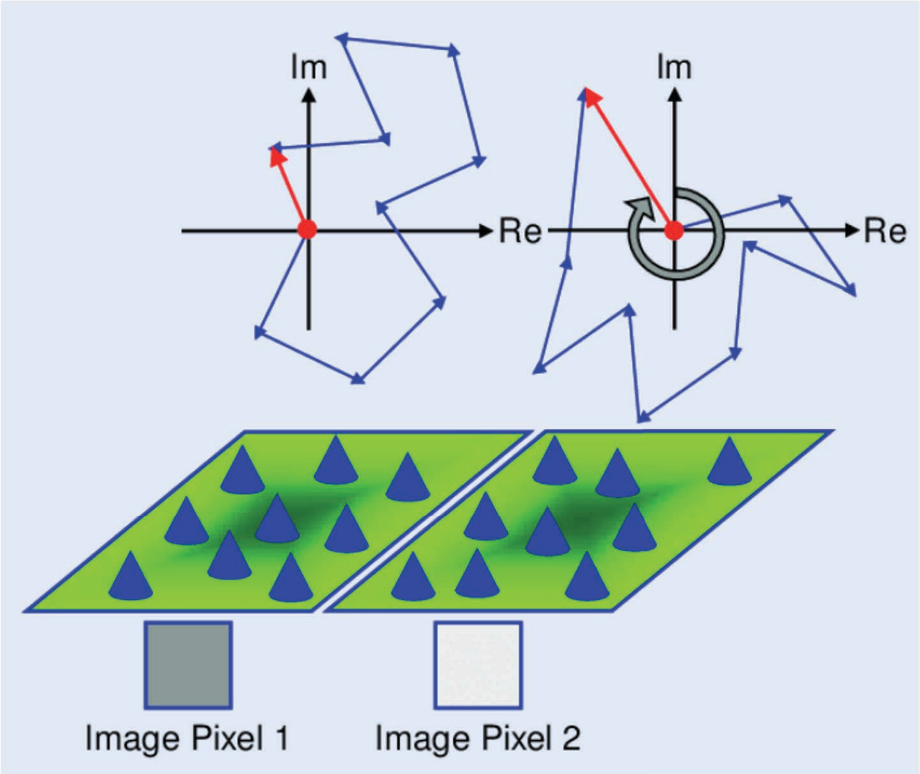


Image Source: Moreira, A., Prats-Iraola, P., Younis, M., Krieger, G., Hajnsek, I., and Papathanassiou, K. (2013). A Tutorial on Synthetic Aperture Radar. IEEE Geoscience and Remote Sensing Magazine

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.

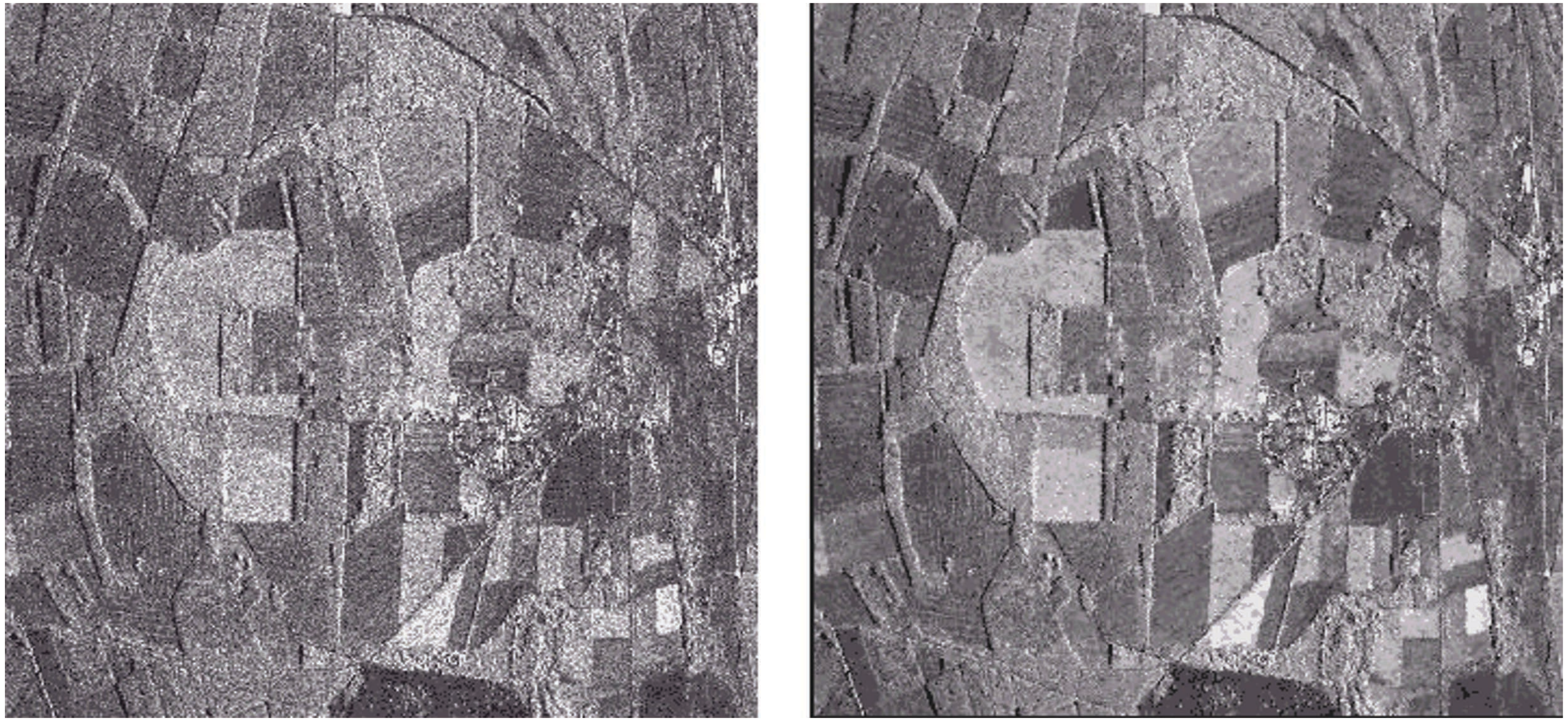


Image Source: www.parbleu.biz/filter.htm

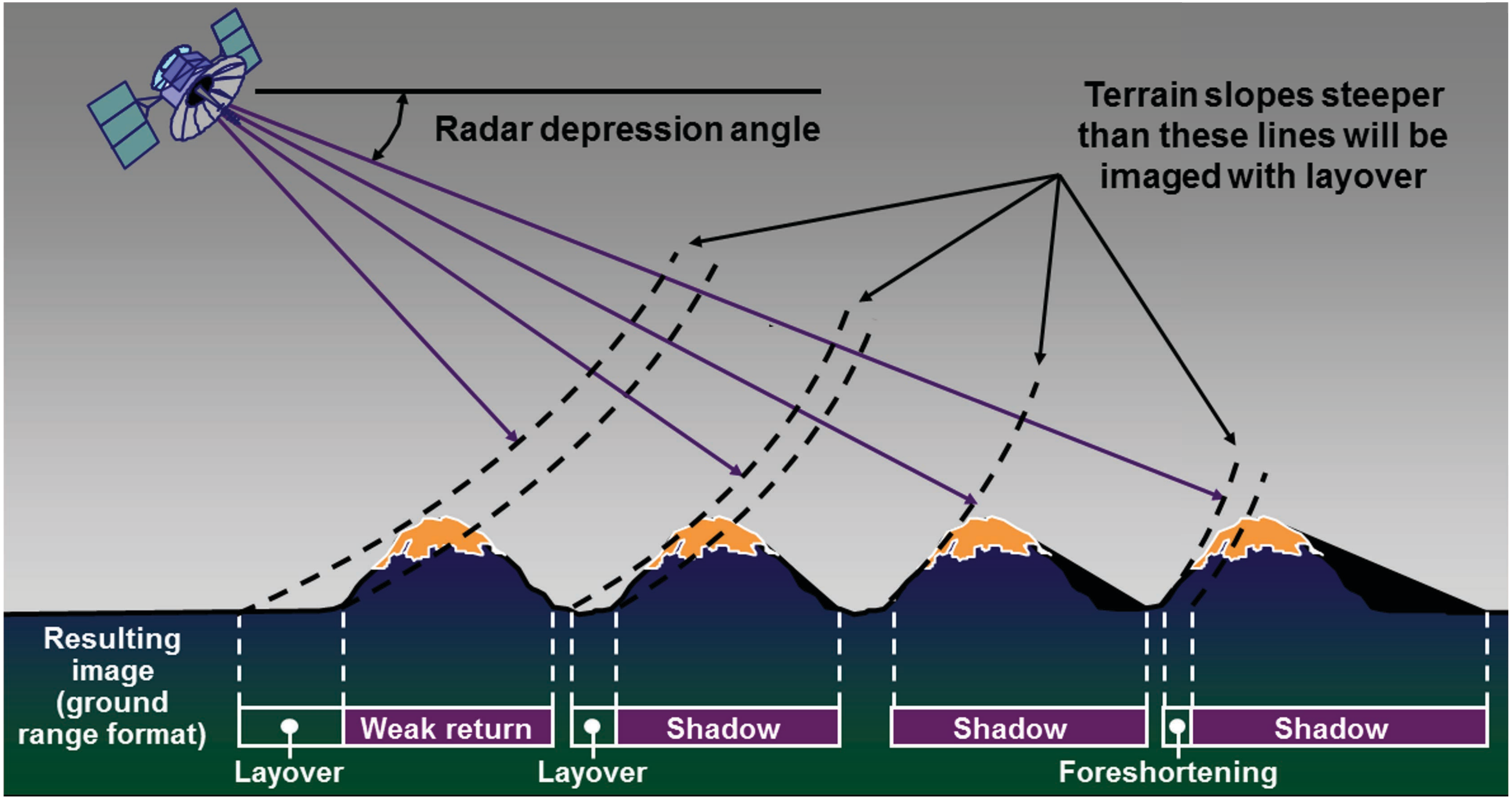
Multi-Looking

- **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 subsets 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, C. and Quegan, S. Understanding Synthetic Aperture Radar Images; Artech House: Boston, MA, USA, 1998; p. 479.

Radar Geometric Distortions

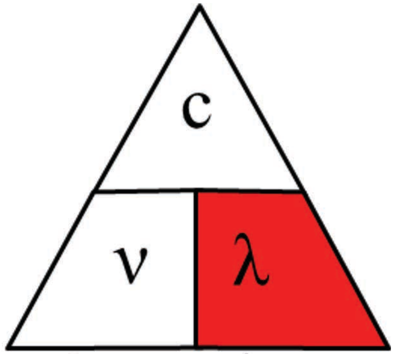


Impact of Soil and Crop Characteristics on SAR Response

Wavelength (λ) and Frequency (v)

The best frequency should be selected.

- Consider the size of the target elements relative to SAR frequency. To maximize scattering, select wavelengths that are comparable in size or smaller than these elements.
- Is it important to penetrate into the target or is the goal to maximize surface scattering? Lower frequencies (longer wavelengths) provide greater penetration.
- Is the goal to maximize or minimize sensitivity to surface roughness? A low frequency wave will see a surface as smooth while a high frequency wave will see this same surface as rough.



$$\lambda = c/v$$

What is the best frequency for agricultural monitoring? It depends!

- Soil moisture: longer wavelengths (like L-band) are better as they penetrate deeper into the canopy and interact with soil.
- Crop classification and biophysical modeling: depends on canopy.
- Need enough penetration into canopy (L- or C-band for corn, for example), but not too deep so that we have soil interference (C- or X-band for lower biomass crops like soybeans).

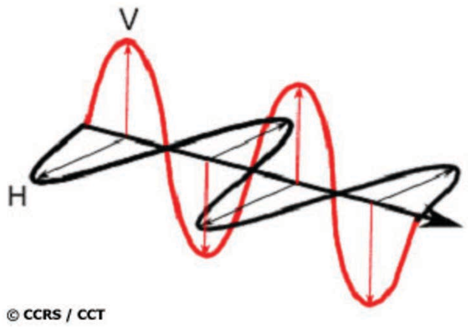
The Power of Multiple Frequencies

Integration of Data from RADARSAT-2, ALOS, and TerraSAR-X, Manitoba (Canada)

X (3.1 cm)
C (5.5 cm)
L (22.9 cm)

- RADARSAT-2 VH - July 10, 2016
- TerraSAR-X VV - July 10, 2016
- ALOS VH - July 9, 2016

Polarization



SAR polarization determines:

- How transmitted microwaves interact with the target.
- If the target (such as vegetation) has a dominant vertical structure, V-polarized waves align with this structure and create greater scattering. With H-polarized waves, less of the energy interacts with the vertically structured target and more often, waves make their way through the canopy to the ground.

- When considering transmit and receive signals, the amount of energy that is re-polarized (from H-transmit to V-receive; from V-transmit to H-receive) to create a cross-polarized response (HV or VH), depends on the structure of the target.

What is the best polarization for agricultural monitoring?

- HV or VH is the single best polarization for either crop identification or crop biophysical estimation.
- The next best polarization is usually VV.

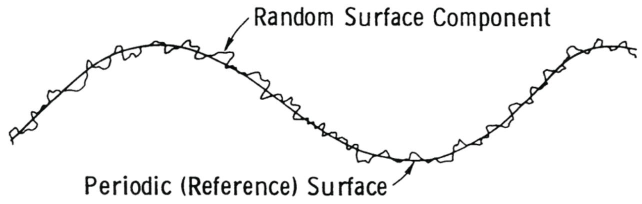
What target characteristics drive SAR scattering?

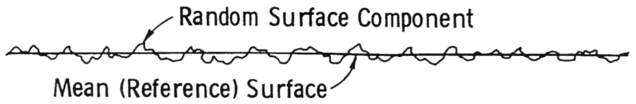
SARs respond to two fundamental characteristics of a target: (1) structure or roughness and (2) water content.

Roughness: Characterized by two parameters: the root mean square variance (RMS) and the surface correlation length (*l*).

RMS: The statistical variation of the random component of the surface height relative to a reference surface (in mm or cm) (root mean square [rms] height).

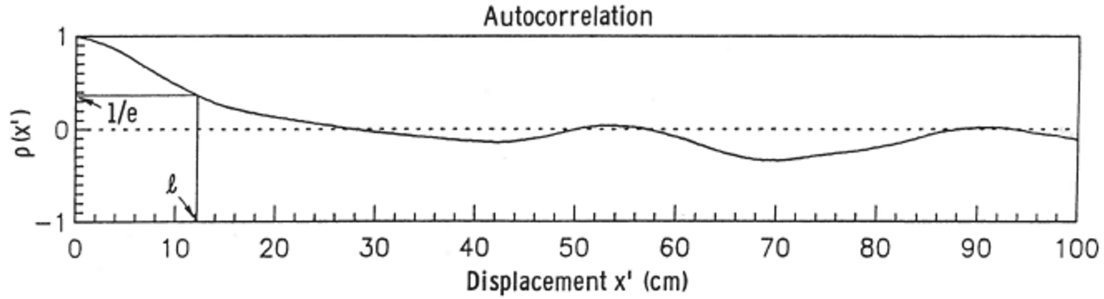
For surfaces without periodic structure, the reference surface is simply the mean surface height. For surfaces with a periodic structure, the unperturbed reference surface is the polynomial function fitted to the periodic structure.





Surface Roughness

Correlation Length (*l*): An autocorrelation function that measures the statistical independence of surface heights at two points, spatially separated by a distance x'. The correlation length is equal to the displacement distance x' for which p(x') is equal to 1/e. If two points are separated by a distance greater than *l*, their surface heights are considered statistically independent.



For a perfectly smooth surface, the height of every point is correlated with the height of every other point, and hence, *l* is very large. Inversely, randomly rough surfaces have short correlation lengths.

p(x') is the autocorrelation
e is Euler's number (2.71828)

Roughness as a Function of Angle and Frequency

Roughness less than "h" would be viewed as **smooth** by the SAR.

Incident Angle of 30°	
TerraSAR-X (3.1 cm)	h < 0.45 cm
RADARSAT-2 (5.6 cm)	h < 0.81 cm
PALSAR (23.6 cm)	h < 3.42 cm
Incident Angle of 50°	
TerraSAR-X (3.1 cm)	h < 0.60 cm
RADARSAT-2 (5.6 cm)	h < 1.09 cm
PALSAR (23.6 cm)	h < 4.59 cm

Rayleigh Criterion $h < \frac{\lambda}{8\cos\theta}$

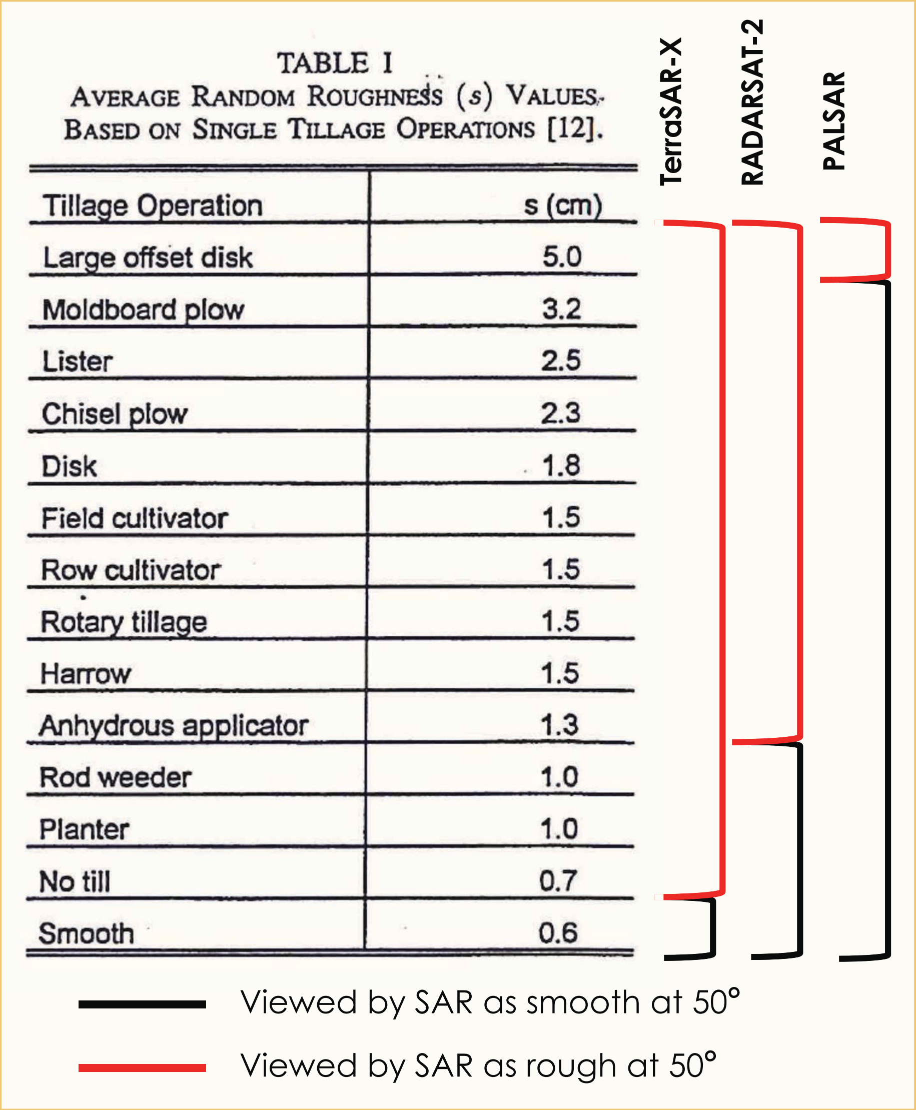
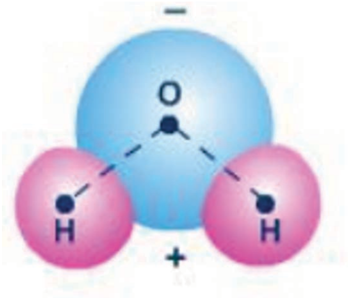


TABLE I
AVERAGE RANDOM ROUGHNESS (s) VALUES BASED ON SINGLE TILLAGE OPERATIONS [12].

Tillage Operation	s (cm)
Large offset disk	5.0
Moldboard plow	3.2
Lister	2.5
Chisel plow	2.3
Disk	1.8
Field cultivator	1.5
Row cultivator	1.5
Rotary tillage	1.5
Harrow	1.5
Anhydrous applicator	1.3
Rod weeder	1.0
Planter	1.0
No till	0.7
Smooth	0.6

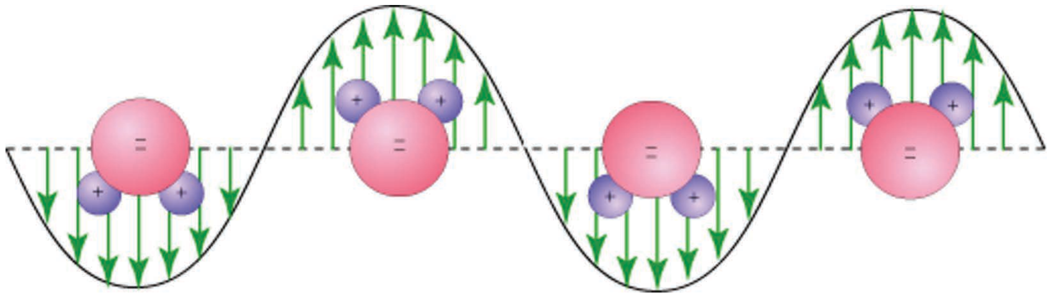
Jackson, T.J., McNairn, H., Weltz, M.A., Brisco, B. and Brown, R.J. (1997). First order surface roughness correction of active microwave observations for estimating soil moisture. IEEE Transactions on Geoscience and Remote Sensing, 35:1065-1069.

What about water in the target?



SAR is known to be sensitive to moisture, but **why**?

- Water (H_2O) is a dipole. The oxygen side of the molecule carries a net negative charge, while the side with the two hydrogen atoms has a net positive electrical charge.
- When an electric field (such as a microwave) is applied, the water molecule will rotate and align itself to this applied field.



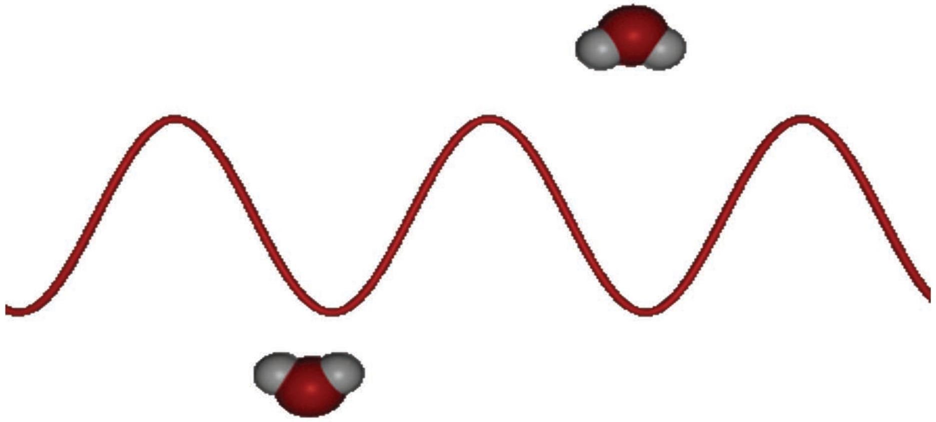
- Dielectric Constant: A measure of the ease with which dipolar molecules rotate in response to an applied field.
- Dielectric Constant (ε): A complex value which characterizes both the permittivity (ε’) (real) and conductivity (ε”) (imaginary) of a material.

$$\varepsilon = \varepsilon' - j\varepsilon''$$

- Real dielectric ranges from ~3 (very dry) to 80 (water).

Microwaves and Water Molecules

- A microwave will continue to propagate until a dielectric discontinuity is encountered, as happens when water is present in the target.
- When an electric field is applied, free water molecules (**not tightly bound**) easily rotate to align with the field (positive to negative).
- Frictional resistance is low and little energy stored in the rotation is lost when the wave passes and the molecule relaxes. Most of the stored energy is released.
- If many water molecules are present, a significant amount of energy is stored and released. When little water is present, little energy is stored.
- When this stored energy is released, and depending on structure of the target, this energy will be scattered back towards the radar antenna.

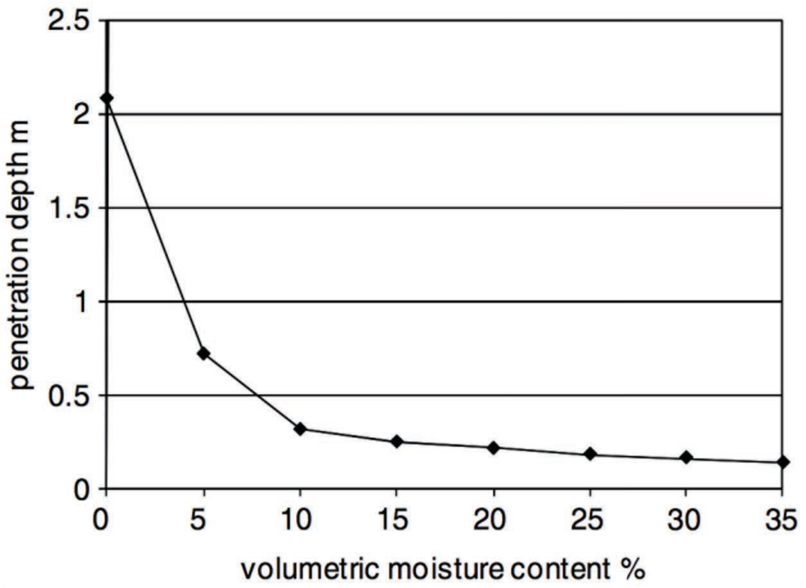


Depth of Penetration

- Penetration into the target is dependent upon the SAR frequency or wavelength.
- Depth of penetration **ALSO** depends on water in the target.
- Penetration depth (δ_p) into the target is defined by the dielectric (ε) and wavelength (λ), and incident angle.
- Penetration increases with wavelength and is greater when the target (soil or crop) is drier.

Simulation for SAR penetration depth in sand, as a function of moisture content, at L-band wavelength of 23.5 cm.

Richards, J. A. (2009). Remote sensing with imaging radar. Springer-Verlag Berlin Heidelberg, 361 pp., DOI: 10.1007/978-3-642-02020-9



Vegetation Effects

The scale is very different from optical.

Scattering of longer-wavelength microwaves is driven by:

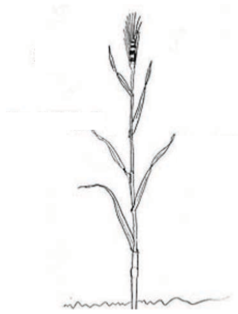
a) Larger scale structures (size, shape and orientation of leaves, stems, and fruit)

b) The volume of water in the vegetation canopy (at the molecular level)

So why is SAR sensitive to crop type and crop development?

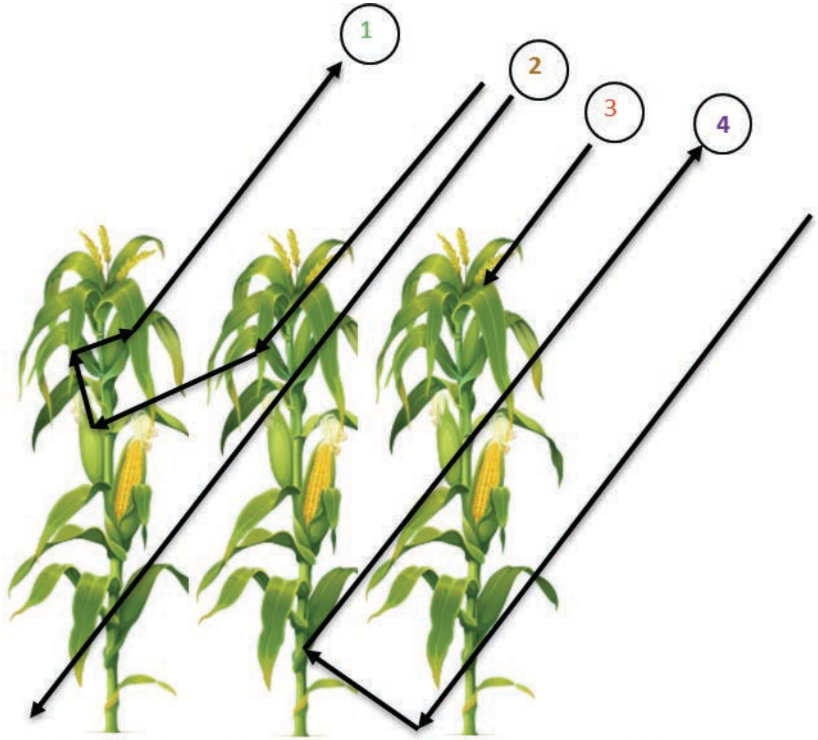
- Crop structure changes significantly from one crop to the next, and as crops move through their growth stages.

Crop structure varies significantly among soybeans, wheat, and corn. Structure also changes as crops grow.



Scattering from Vegetation

- Following a wave into a canopy, it may:
  - Scatter directly off a leaf
  - Scatter from the leaf of one stem/branch to another leaf (several times)
  - Make its way to the soil and scatter directly from the soil
  - Make its way to the soil, then scatter off a stalk/trunk/branch
  - Hit parts of the canopy on its way out
- These scattering events determine how much of the energy will return back to the SAR sensor and how the phase between, for example, H and V components will change.



1. Multiple volume scattering from within canopy
2. Direct scattering from soil
3. Direct scattering from canopy
4. Double bounce scattering between soil and canopy

A Complication: The Environment

Always, always, always check the environmental conditions at the time of image acquisition before using SAR data.

Rule #1: Never use SAR if it was raining at the time of the acquisition.

- **Why?** Although SAR is considered "all weather," this does not include imaging during rain events, as water in the atmosphere will cause SAR scattering. In some regions of world, risks are diurnally dependent.

Rule #2: Never use SAR to estimate soil moisture if the ground is frozen.

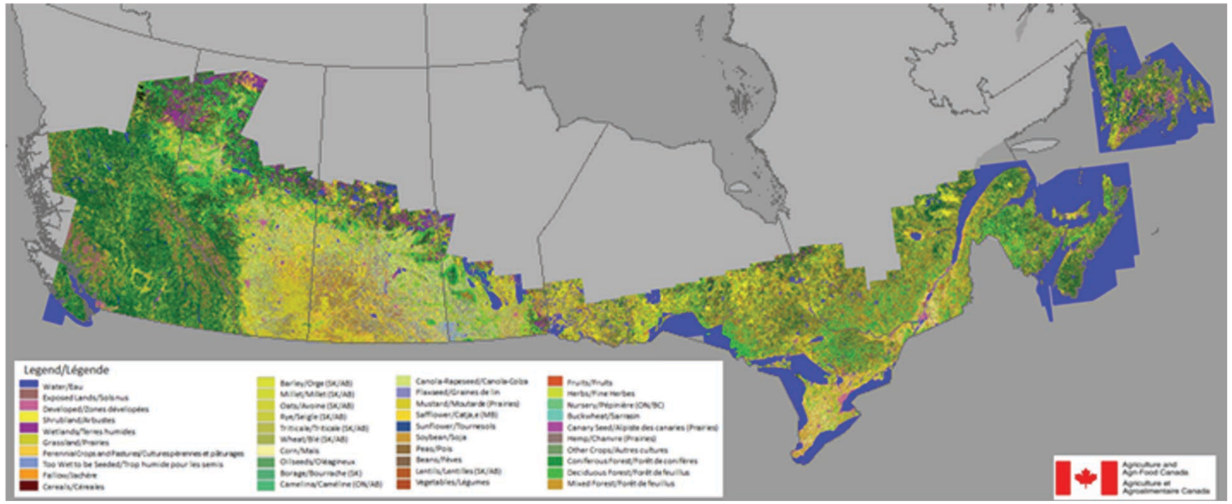
- **Why?** The dielectric constant drops close to zero when water changes to a frozen state. Thus, even if there is water in the soil, the SAR will view the soil as dry. SAR can detect freeze/thaw events. Freezing often occurs overnight.

A Complication: The Environment

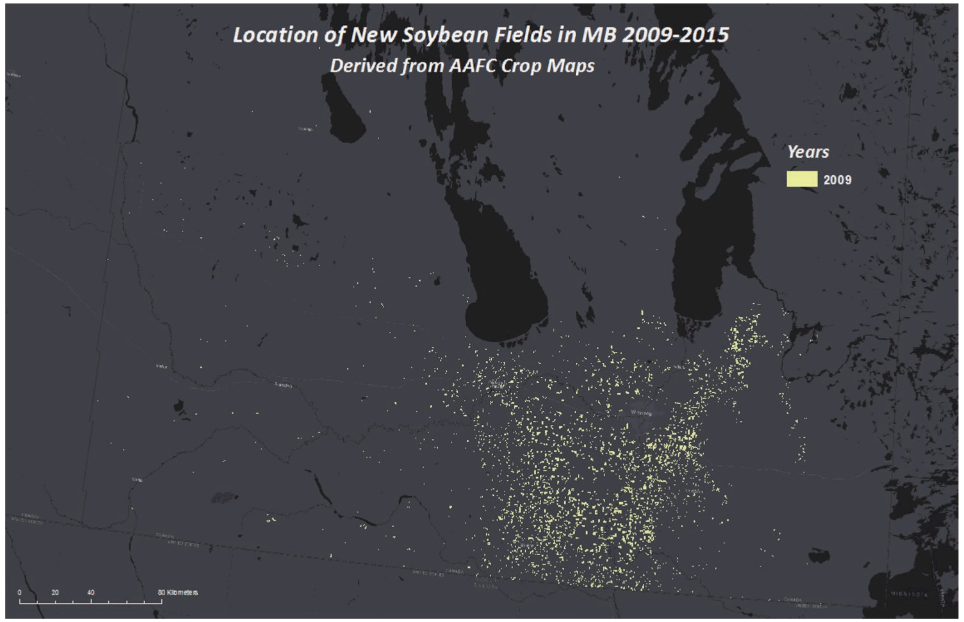
Rule #3: Consider whether dew might be present during early morning acquisitions.

- **Why?** Presence of water on leaves will increase backscatter (a big problem for biophysical modelling). If water on canopy is significant (just after rain), contrast between targets can be reduced. Dew is most prominent in temperate regions in the early morning hours.
- Select orbits (ascending – evening; descending – morning) carefully.
- Always check in with meteorological stations.

Mapping and Monitoring Crops



Source: ACGEO Division of Science and Technology Branch, AAFC
Contact: Andrew.Davidson2@Canada.ca, Thierry.Fisette@Canada.ca, and Leander.Campbell@Canada.ca

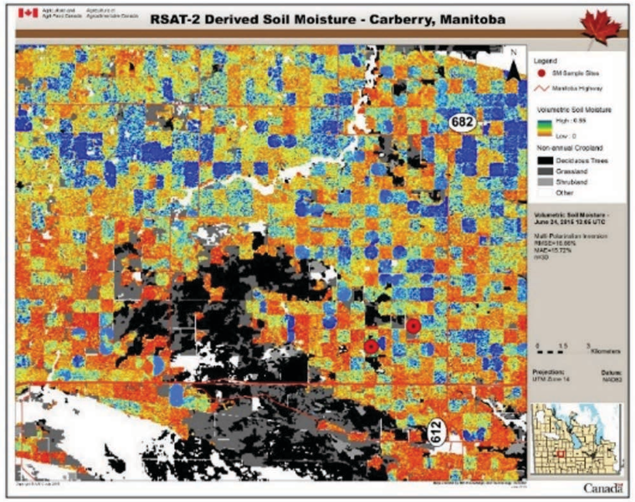


Agriculture and Agri-Food Canada runs an annual operation to map crops across Canada.

The Annual Crop Inventory (ACI) uses both SAR and optical satellites as insurance to robust data collection and map accuracy.

This animation shows changes in where soybeans are being seeded in Manitoba from 2009-2015, based on these annual crop maps.

Field Scale Soil Moisture



The Integral Equation Model (IEM) is a physically based scattering model that can be used to estimate surface (0-5 cm) volumetric soil moisture (m^3/m^3).

The IEM can be used with SAR images which include HH and VV polarizations.

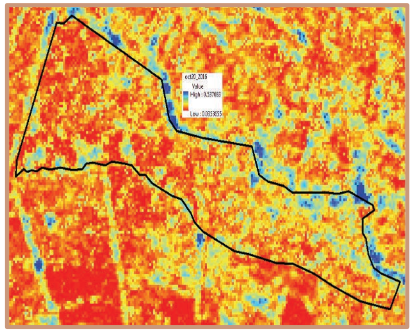
The IEM can also be run in a hybrid mode (HH+VV polarizations with images collected at two incident angles).

IEM implementation is available in SNAP (Soil Moisture Toolkit).

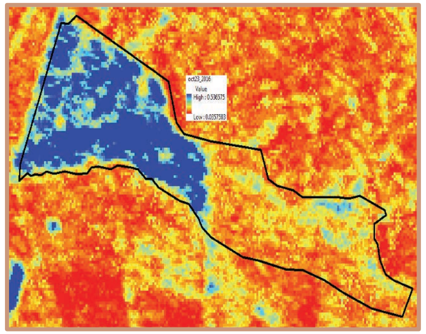
Monitoring Irrigation Requirements in Chile (**Wet=Blue**)

Chicory seedlings need adequate soil moisture.

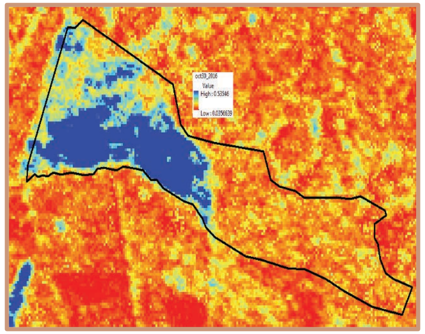
Dry Conditions: 20 October



Irrigation Occurs: 23 October

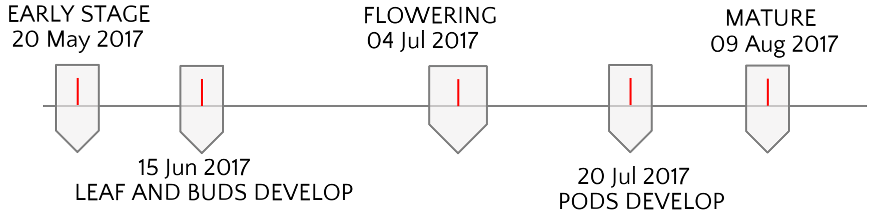


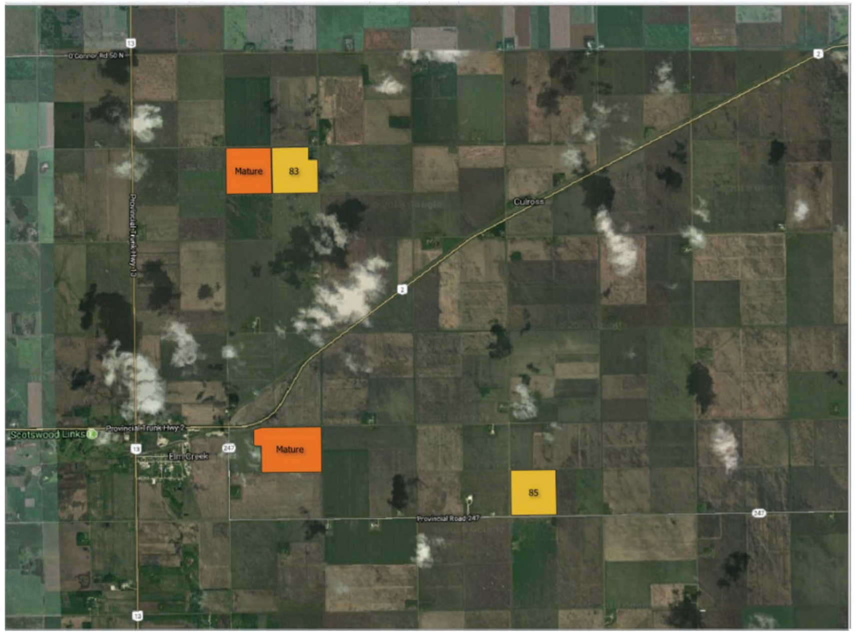
Post-Irrigation Drying: 30 October



Merzouki, A. and McNairn, H. (2015). A hybrid (multi-angle and multipolarization) approach to soil moisture retrieval using the integral equation model: preparing for the RADARSAT Constellation Mission. Canadian Journal of Remote Sensing, 41:349-362. doi: 10.1080/07038992.2015.1104629

Watching Canola Grow from Space: When will Canola Flower?



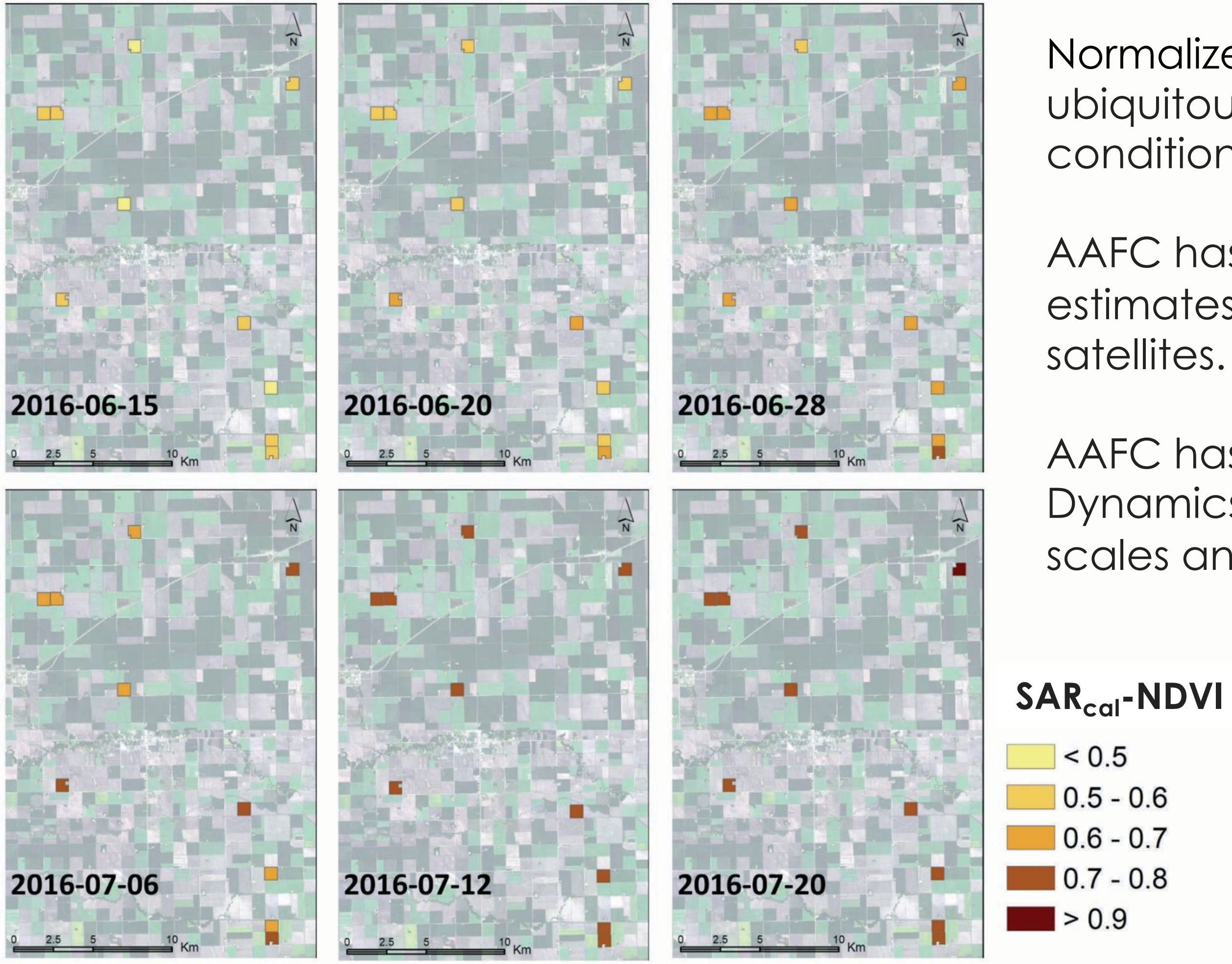


Airborne Underwater Geophysical Signals

A.U.G. Signals Ltd., Toronto, Canada

McNairn, H., Jiao, X., Pacheco, A., Sinha, A., Tan, W., and Li, Y. (2018). Estimating canola phenology using synthetic aperture radar, Remote Sensing of Environment, 219: 196-205.

Radar-Based Vegetation Index



SAR calibrated NDVI for Canola Crops in Carman, Manitoba from June 15 until July 20).

Normalized Difference Vegetation Index (NDVI) is used ubiquitously for precision farming and regional-to-global crop condition monitoring, but clouds interfere with optical satellites.

AAFC has developed a radar-calibrated NDVI. This SAR_{cal}-NDVI estimates crop condition (from 0 to 1, like NDVI) but using radar satellites.

AAFC has coupled the SAR_{cal}-NDVI with a Crop Structure Dynamics Model (CSDM) to estimate crop condition at field scales and on a daily time step.

Jiao, X., McNairn, H. and Dingle Robertson, L. (2021) Monitoring crop growth using a canopy structure dynamic model and time series of Synthetic Aperture Radar (SAR) data, International Journal of Remote Sensing, in press.

Tracking Tillage Events

White: Soil has been disturbed between October 31 and November 12, 2020
Image Source: Sentinel-1 IW mode

White – Alert | Black – No Alert | Green Cover

Changes in phase recorded by SAR can be used to detect changes in the height of soil.

Radars measure distance to Earth, and when the height of the Earth changes, radars measure this phase change.

These phase changes can be correlated with tillage and used to develop alerts that determine that the soil has been disturbed between pairs of radar satellite image acquisition.

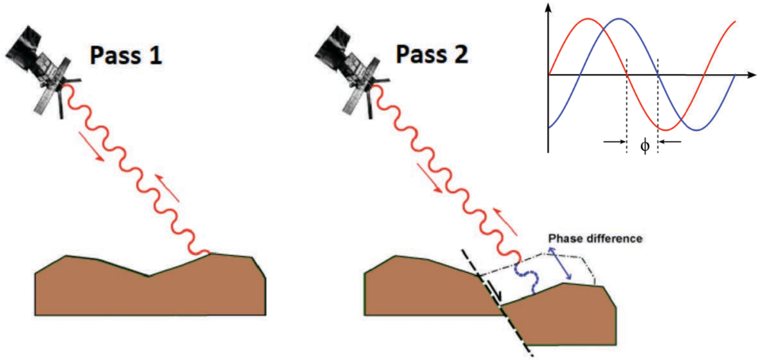
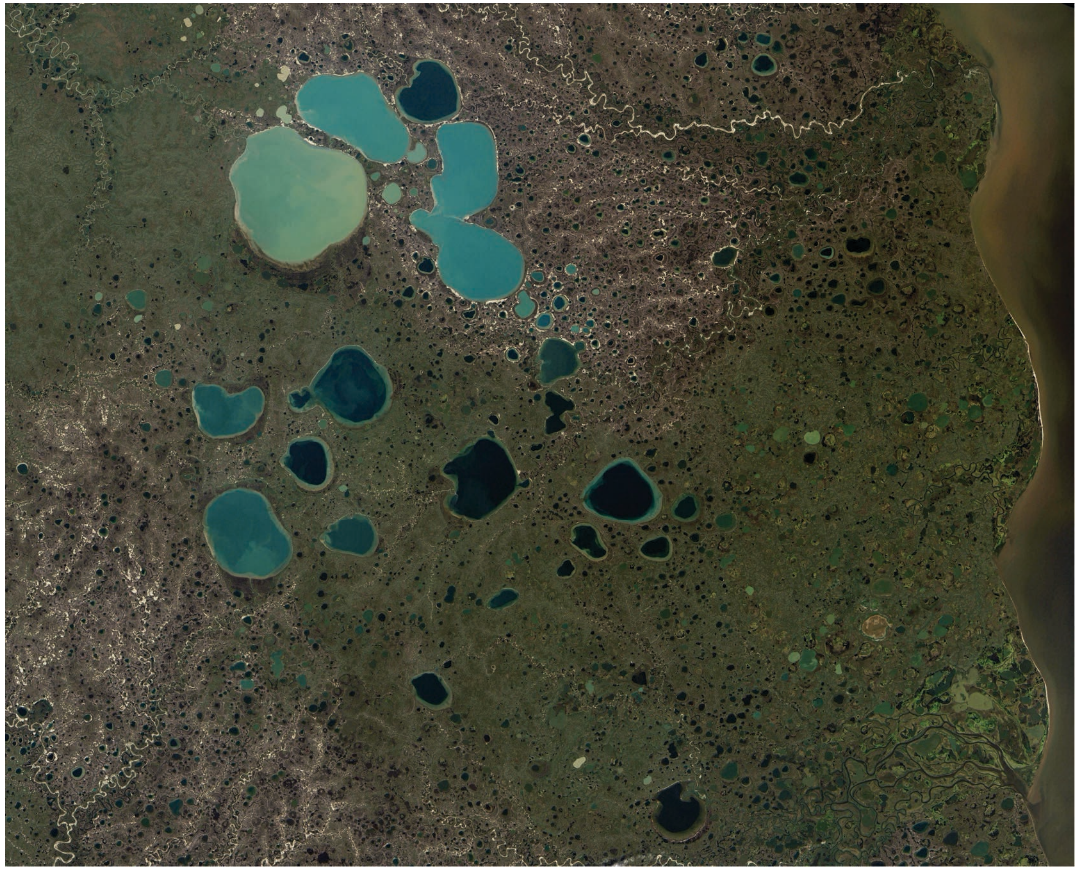


Image Source: Castellazzi, Pascal & Schmid, Wolfgang. (2020). Ground displacements in the Lower Namoi region. 10.13140/RG.2.2.20466.53442.

Questions?

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.



https://earthobservatory.nasa.gov/images/6034/pothole-lakes-in-siberia

Contacts

- Trainer:
  - Heather McNairn: Heather.McNairn@AGR.GC.CA
- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-agricultural-crop-classification-synthetic-aperture-radar-and
- ARSET Website:
  - https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset
- Twitter: @NASAARSET

Thank You!