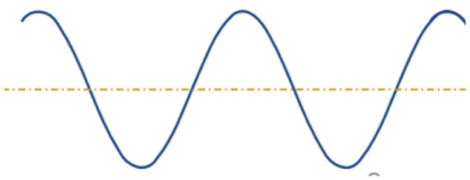
SAR System Characteristics Relative to the Target

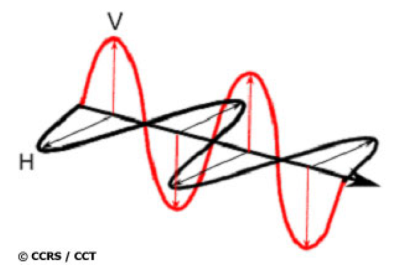
SAR System Considerations

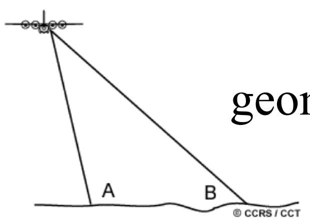
- When planning SAR data collections and when interpreting SAR response, the three fundamental system characteristics must always be considered



frequency or wavelength

polarization





geometry (incidence angle and look direction)

- Interpreting SAR response is always done, relative to these characteristics

Frequency or Wavelength

- SAR frequency determines
  - how much of the microwave signal will be attenuated and how much will be scattered as it interacts within the target
  - what elements of the target contribute to scattering
  - the angular behaviour of target scattering (relative sensitivity to surface roughness)
  - how deep into the target the incident microwave signal will penetrate

What Drives Scattering

Microwaves are scattered by the elements in the target comparable or larger in size relative to the wavelength

X-band L-band P-band

An Example of Multi-frequency SAR

Mayo, Yukon (Canada)
JPL AIRSAR
May 5, 1991

C-Band (HH, VV, HV)

L-Band (HH, VV, HV)

P-Band (HH, VV, HV)

Frequency or Wavelength

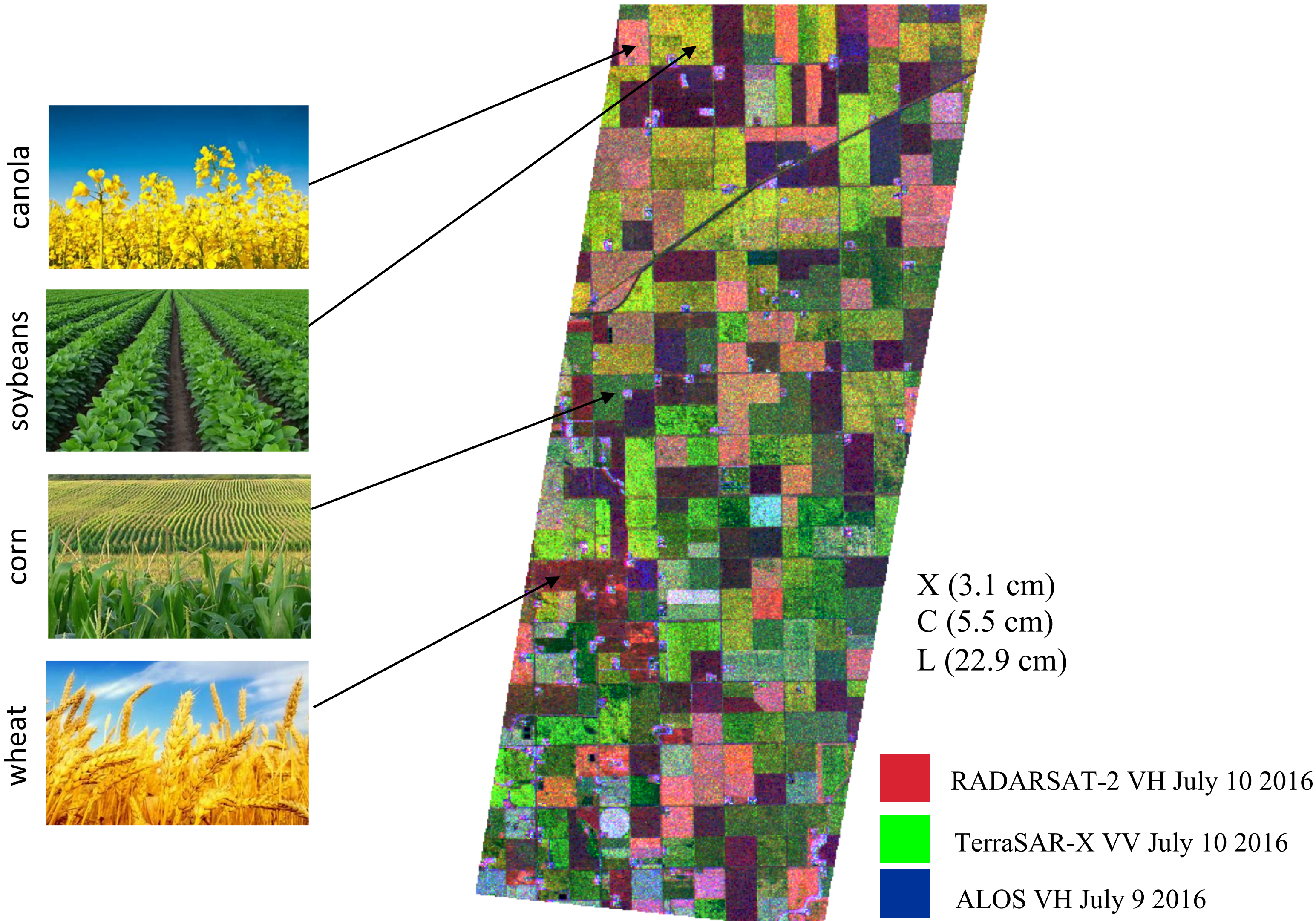
Why does it matter?

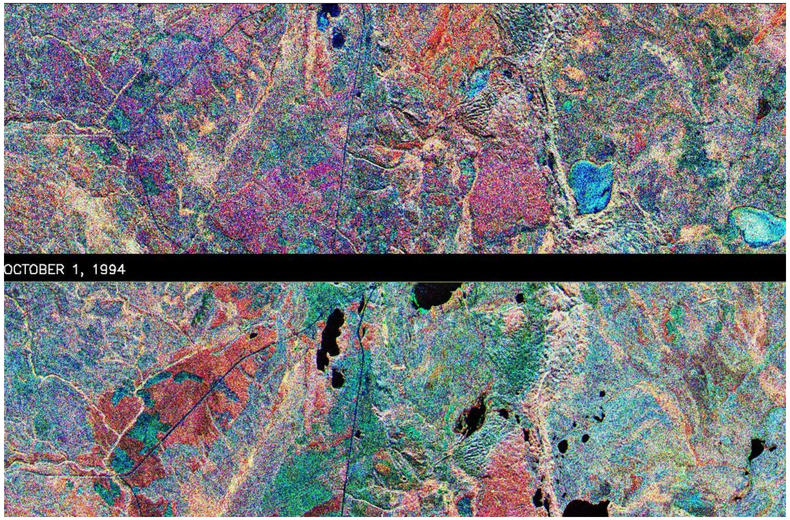
- The best frequency should be selected
  - consider the size of the target elements relative to SAR frequency. To maximize scattering, select wavelengths that are comparable in size or smaller than these elements
  - is it important to penetrate into the target or is the goal to maximize surface scattering? Lower frequency (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

- The best option is to integrate data collected at different frequencies
  - each frequency will respond to different elements of the target and provide a more complete picture of the characteristics of the target

The Power of Multiple Frequencies

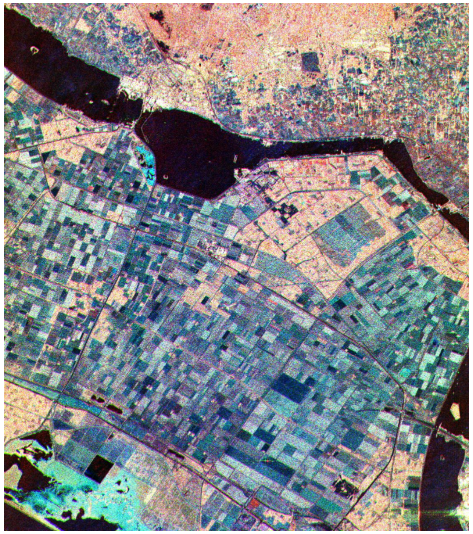
Integration of data from RADARSAT-2, ALOS and TerraSAR-X
Manitoba (Canada)

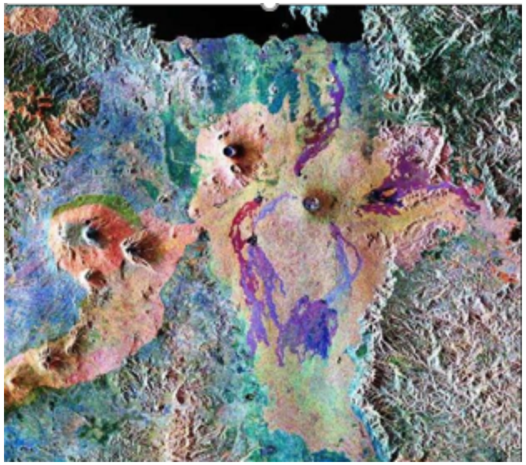




Prince Albert, Canada
April 10 (top) and October 1 (bottom)
R: L-VV G: C-VV B: X-VV

Flevoland, the Netherlands (14 April)
R: L-band power G: C-band power B: X-VV

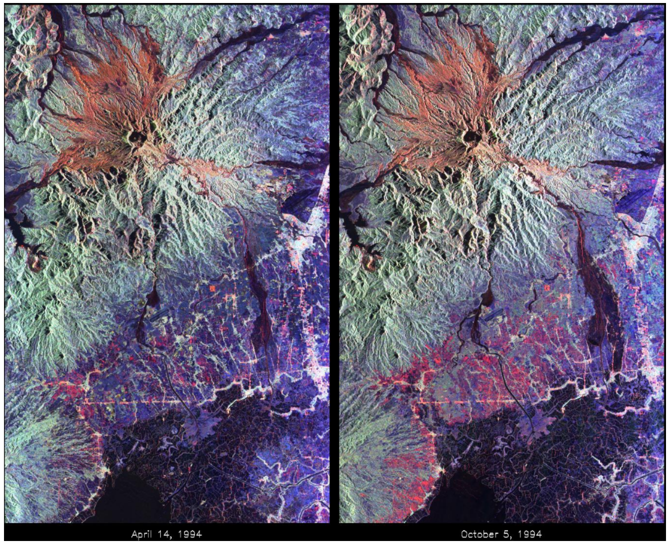




Virunga Volcano Chain (border of Rwanda, Zaire and Uganda)
R: L-HV G: C-HV B: C-HH

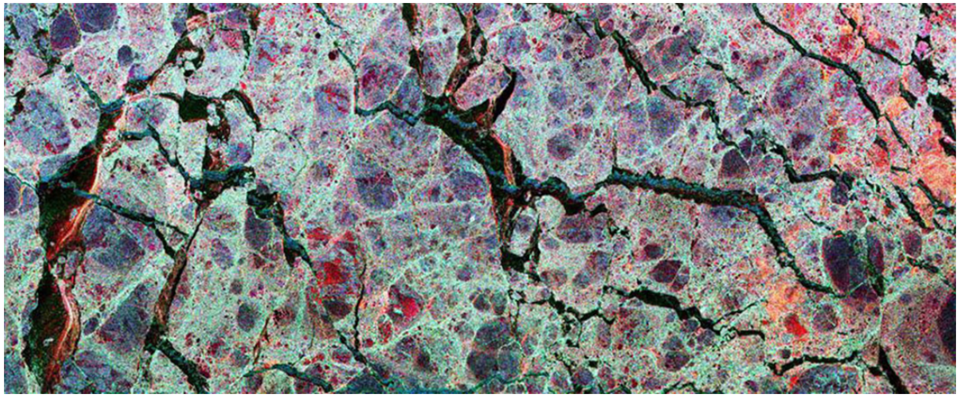
Shuttle Imaging RADAR-C SIR-C (1994)

Belgrade, Serbia (October 2)
R: L-HH G: L-HV B: C-HV



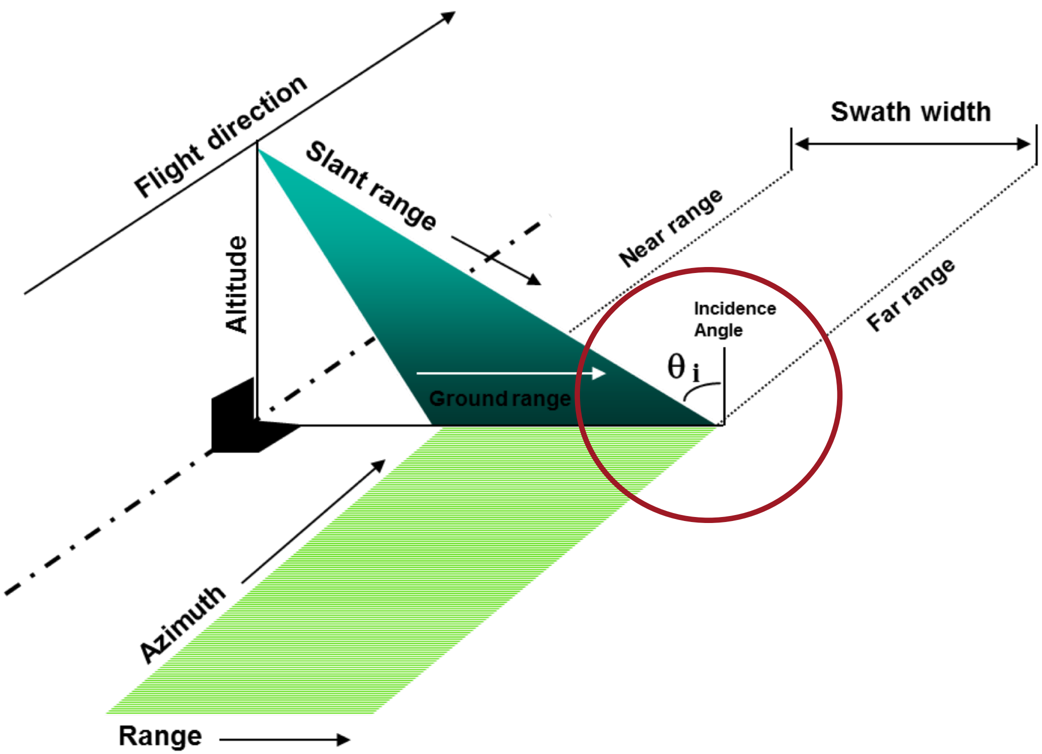
Mount Pinatuba, the Philippines
April 14 (left) and October 5 (right)
R: L-HH G: L-HV B: C-HV

Weddell Sea , Antarctica (October 3)
R: C-HH G: L-HV B: L-HH



All images: www.jpl.nasa.gov/spaceimages/

Incidence Angle



SAR incidence angle determines

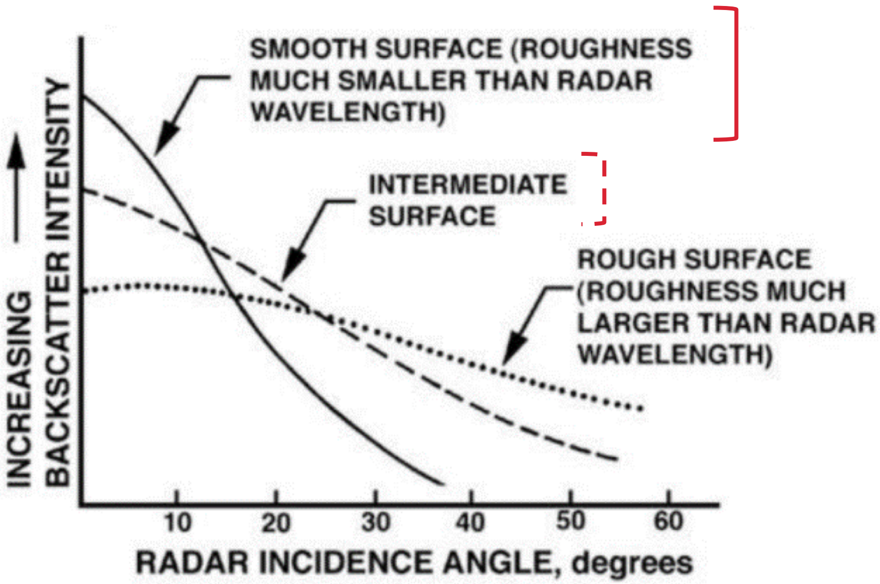
- the contribution of different target elements to backscatter. Shallower angles interact more with the vegetation canopy; at steeper angles more of the signal can pass through to the ground without interacting with the canopy

- how rough the target appears to the SAR. Surfaces appear "smoother" at larger angles. The most significant incidence angle effects are observed on smoother surfaces

- how deep the microwave signal penetrates into the target

Incidence Angle

- backscatter decreases with increasing incidence 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

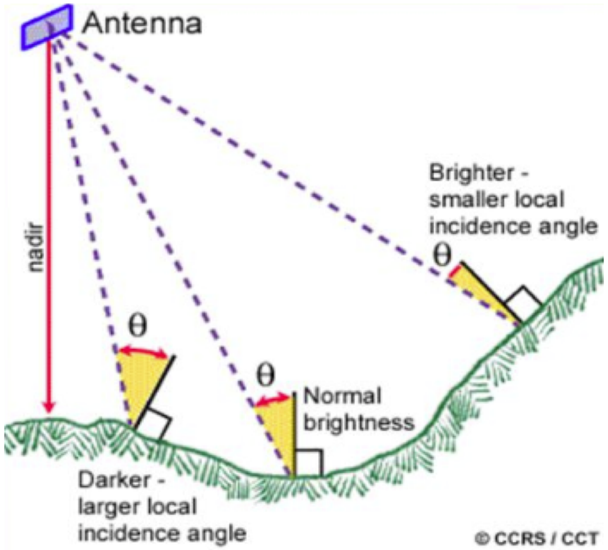


rougher
lower rate of change with angle

smoother
higher rate of change with angle

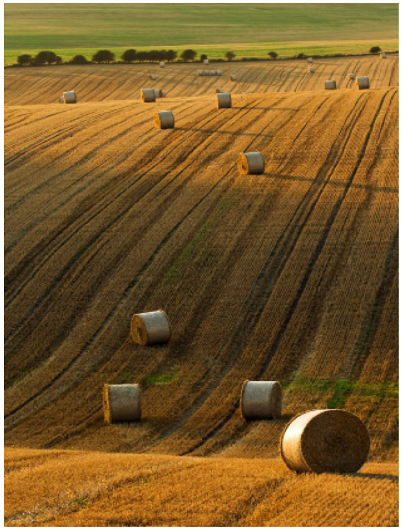
Image source: saltftp.soest.hawaii.edu

Incidence 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 incidence angle is less than the normal incidence angle (assuming flat surface).



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

Incidence Angle

- incidence angle changes from the near to far swath. For large swath modes, this change can be very significant and fundamentally impacts SAR backscatter regardless of the target
- satellite SARs can electronically steer their beams and allow for more frequent “re-looks” at a target. However, the incidence angle will not be the same among these re-look images
- multi-temporal analysis and change detection: **be careful**. Combine imagery with the same incidence 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

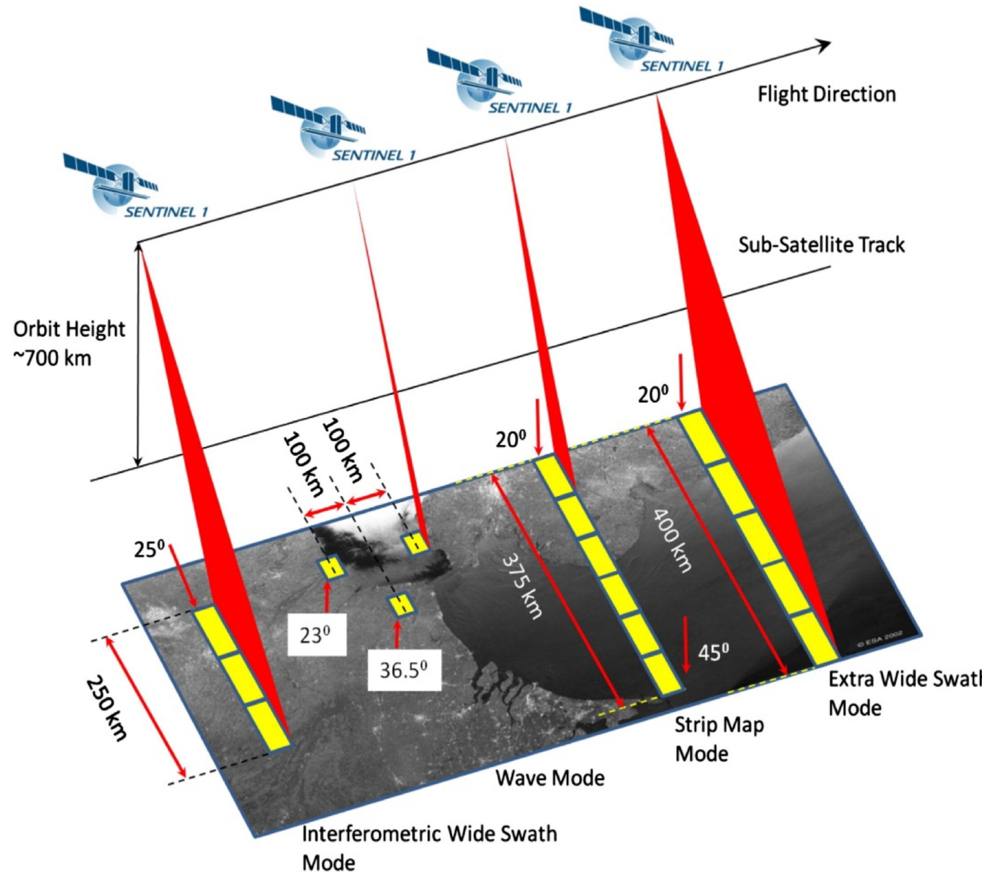


Image source: sentinel.esa.int

Re-visit or Re-look?

- **Re-visit**: satellite sees the target in the exact same geometry
- **Re-look**: by electronically steering the SAR beam, satellites can have a “re-look” at a target, **but** the geometry between these re-looks will not be the same

The RADARSAT Constellation provides a four-day exact revisit. It also provides an average daily global re-look capability.

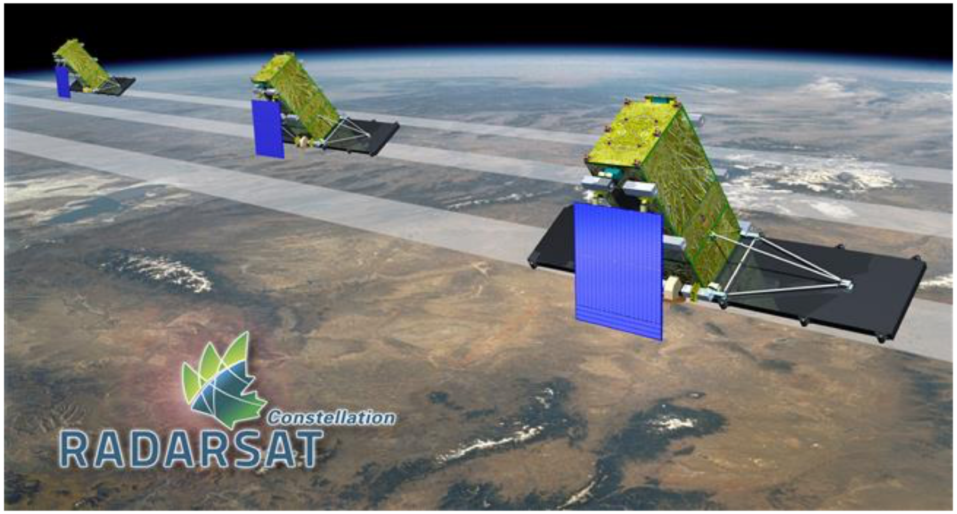


Image source: www.asc-csa.gc.ca/eng/search/images/watch.asp?id=6436&search=RADARSAT+Constellation+Mission

Polarization

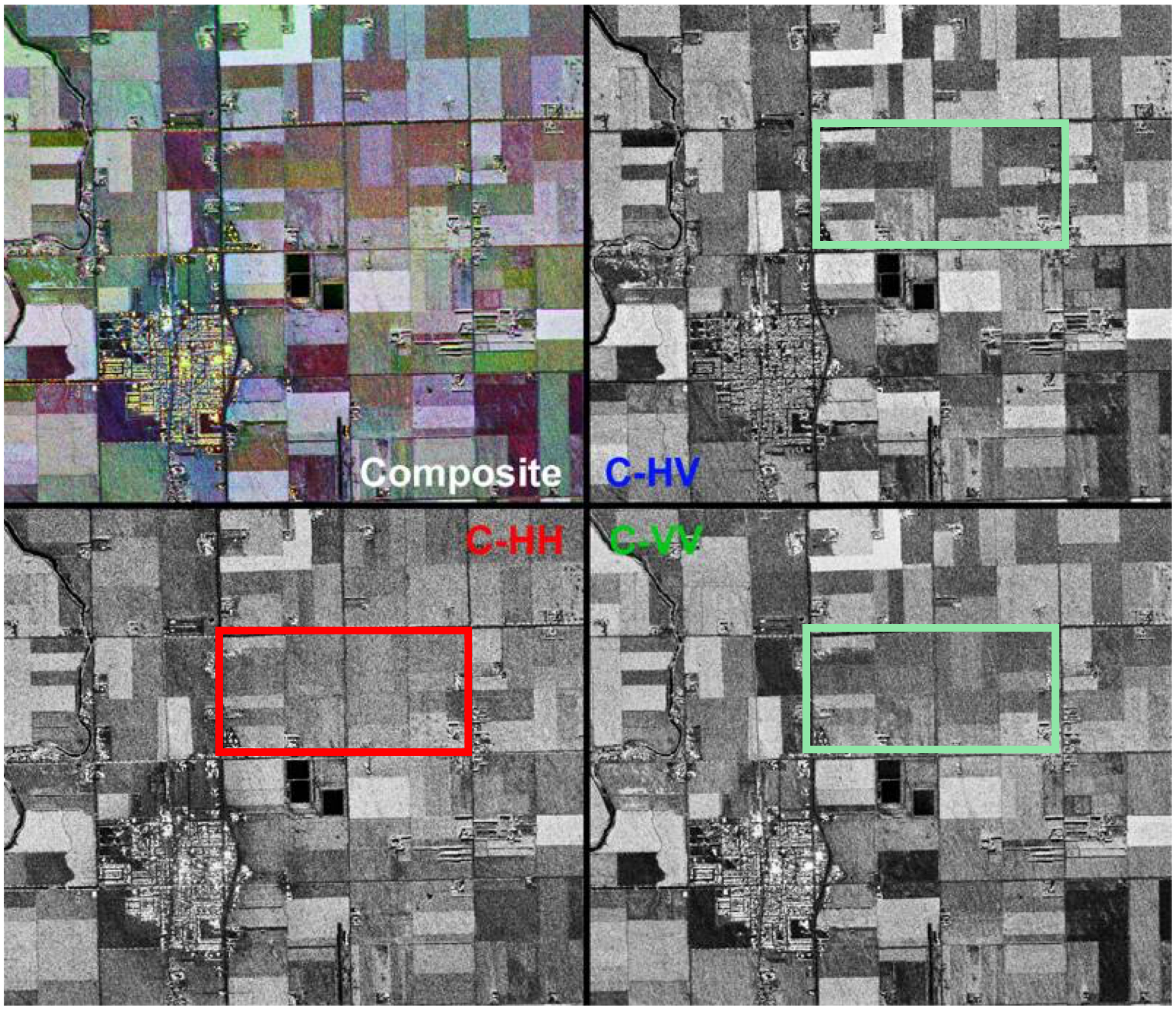
SAR polarization determines

- 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 makes its 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

Multi-Polarization SAR

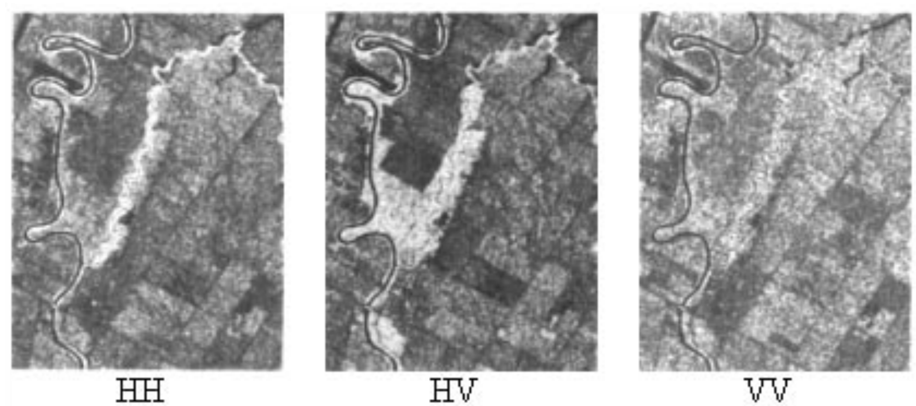
Altona, Manitoba (Canada)
CV-580 Airborne C-band



Like-polarizations
- HH (horizontal transmit-receive)
- VV (vertical transmit-receive)

Cross-polarizations
- HV (horizontal transmit-vertical receive)
- VH (vertical transmit-horizontal receive)
- *HV and VH are theoretically identical and reciprocity is assumed*

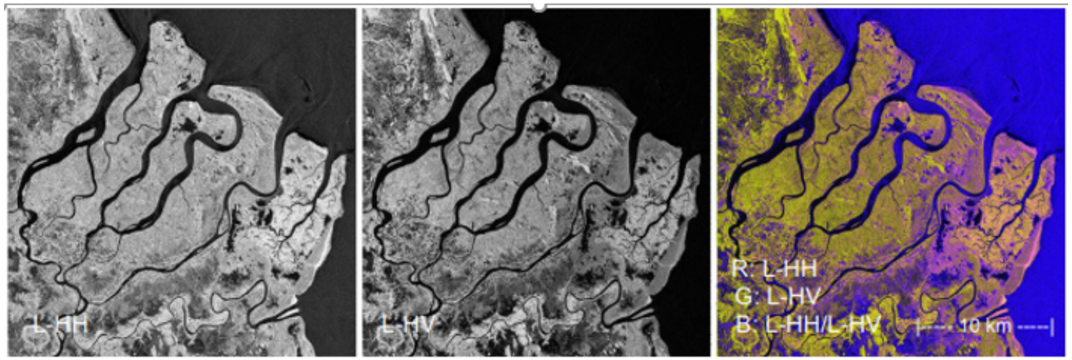
Multi-Polarization SAR



SIR-C image of Red River Flooding (Manitoba, Canada)
April 11, 1994

Image source: Sokol et al. (2004)

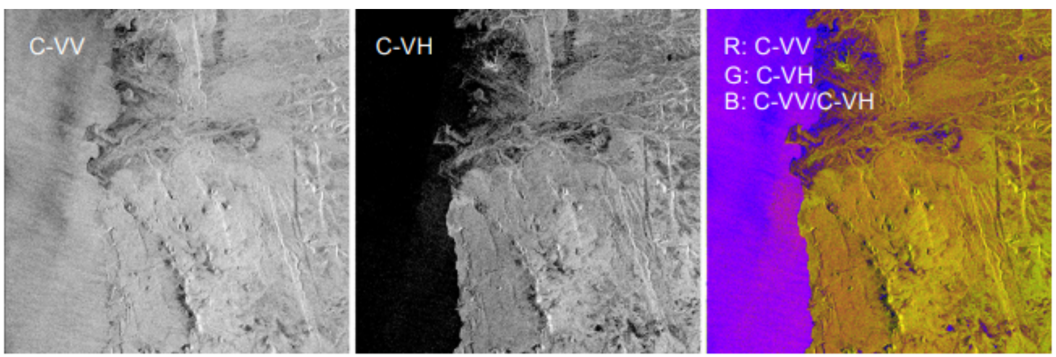
Multi-Polarization SAR



L-HH: -6.6 (+/- 2.5) dB L-HV: -14.7 (+/- 3.2) dB Observation date: 3-SEP-2017

Rufiji delta, Tanzania (River delta with mangrove forest)

L-band: The non-linear structure of the mangroves trees with their crooked branches and complex aerial root systems, not only prevents double bounce scattering but result in enhanced attenuation of the signal. L-band backscatter at both HH and HV polarisation is therefore several dB lower for mangroves than for other forest types.



C-VV: -8.3 (+/- 2.0) dB C-VH: -18.4 (+/- 3.1) dB Observation date: 10-OCT-2017

Marsabit, Kenya (Arid landscape with exposed rock)

C-band: Backscatter mechanisms for arid rocky terrain results in high reflections at VV polarisation and moderate at VH polarisation. The uniform HV response indicates an absence of even low vegetation, and indicates multiple scattering effects that possibly could be caused by the presence of large rocks.

Image source: ceos.org/document_management/SEO/DataCube/Laymans_SAR_Interpretation_Guide_2.0.pdf

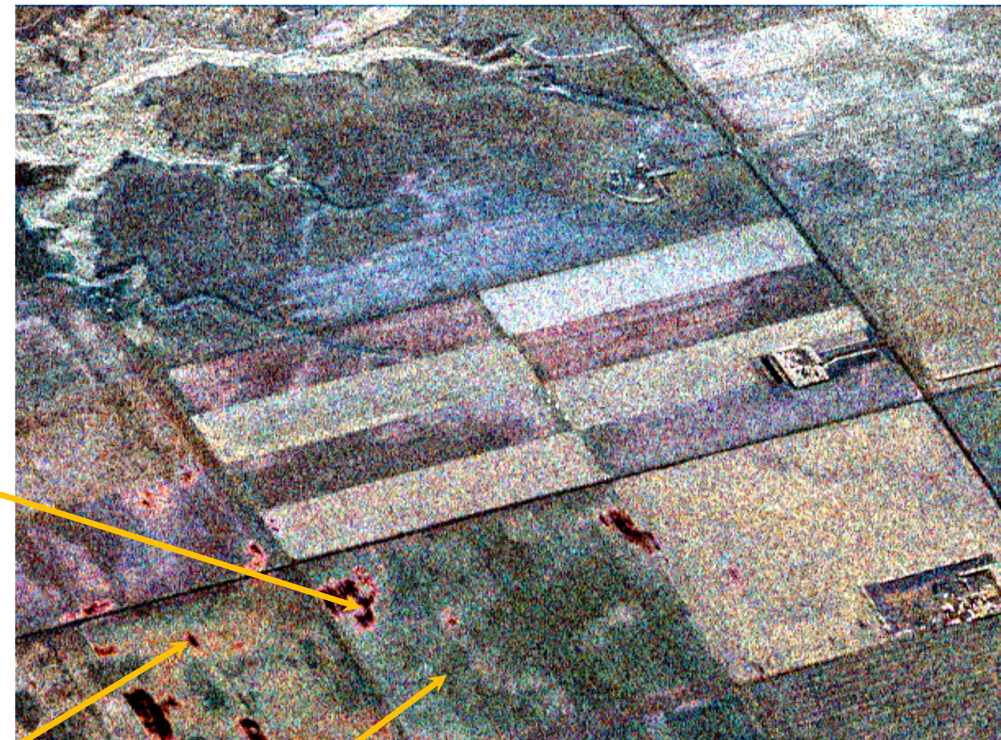
Synthesizing Non-Linear Polarizations

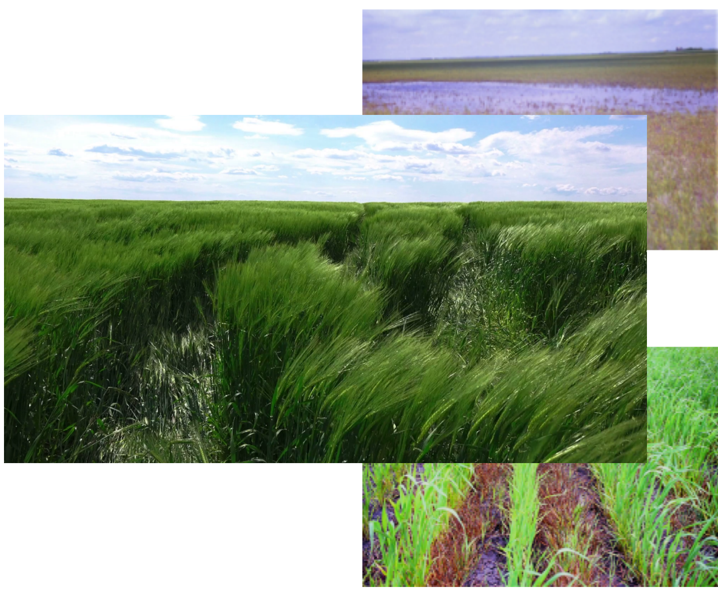
With these coherent systems other non-linear polarizations (0 to 360°) can be synthesized.

The polarization is defined by the orientation angle (ψ).

If the target has an orientation other than horizontal or vertical, these other polarizations may be helpful.

These data were acquired near Indian Head (Saskatchewan) by the airborne CV-580 (June 28, 2000).





Linear Polarizations Displayed

$\psi = 90^{o}$

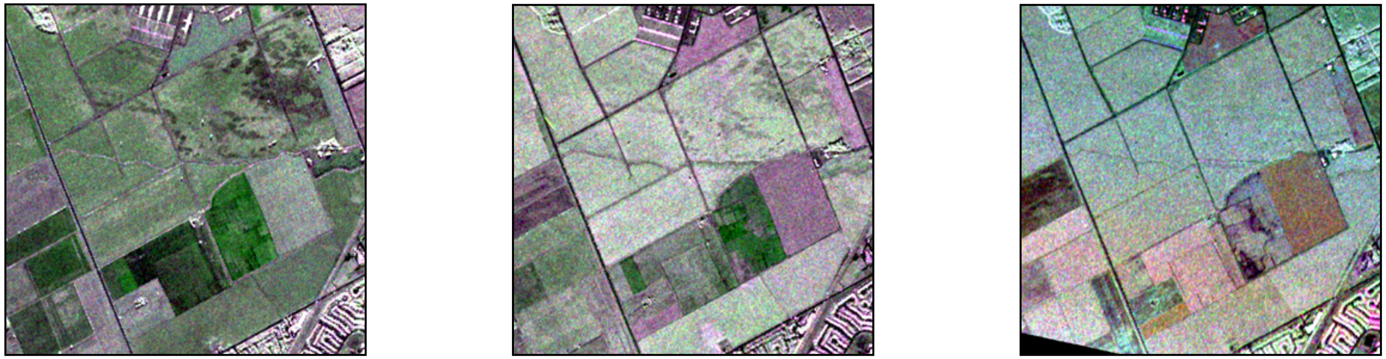
$\psi = 40^{o}$

$\psi = 0^{o}$

ψ = orientation angle

Circular Polarizations

- circular transmit (R- or L-handed) and circular receive (R- or L-handed) polarizations can also be synthesized
- circular responses can be highly correlated with linear responses because the mechanisms driving scattering are similar
- for example, to re-polarize an incident wave from H-polarized to V-polarized, more the one scattering event must occur (double or multiple scattering). This also applies to circular polarizations where multiple (two or more) scattering events can change the handedness from R-transmit (relative to the observer) to R-receive (relative to the observer). As such HV or VH backscatter are often highly correlated with RR or LL backscatter.



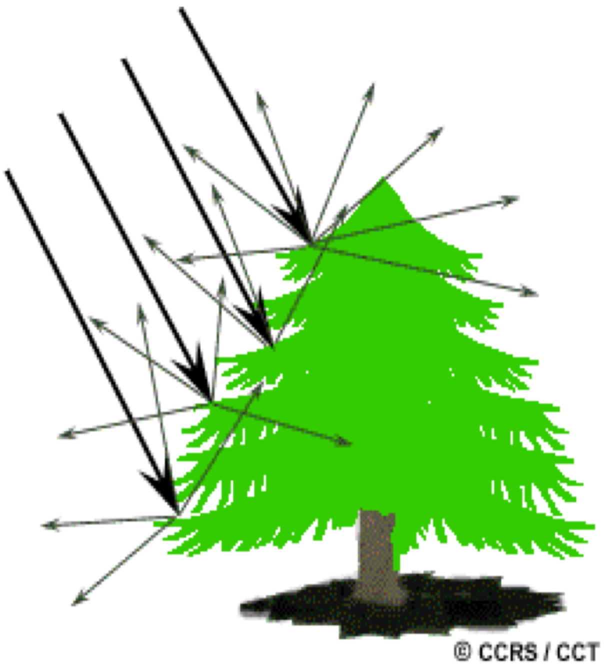
Synthesized C-band RR-LL-RL polarized SAR images
June 13, June 26 and July 19, 2006 (Ottawa, Ontario)

Source: Smith et al., 2006

Beyond Backscatter

- SARs propagate a unit of energy and for distributed targets, only a fraction of the energy will scatter back towards the antenna and be measured by the sensor (the backscatter)

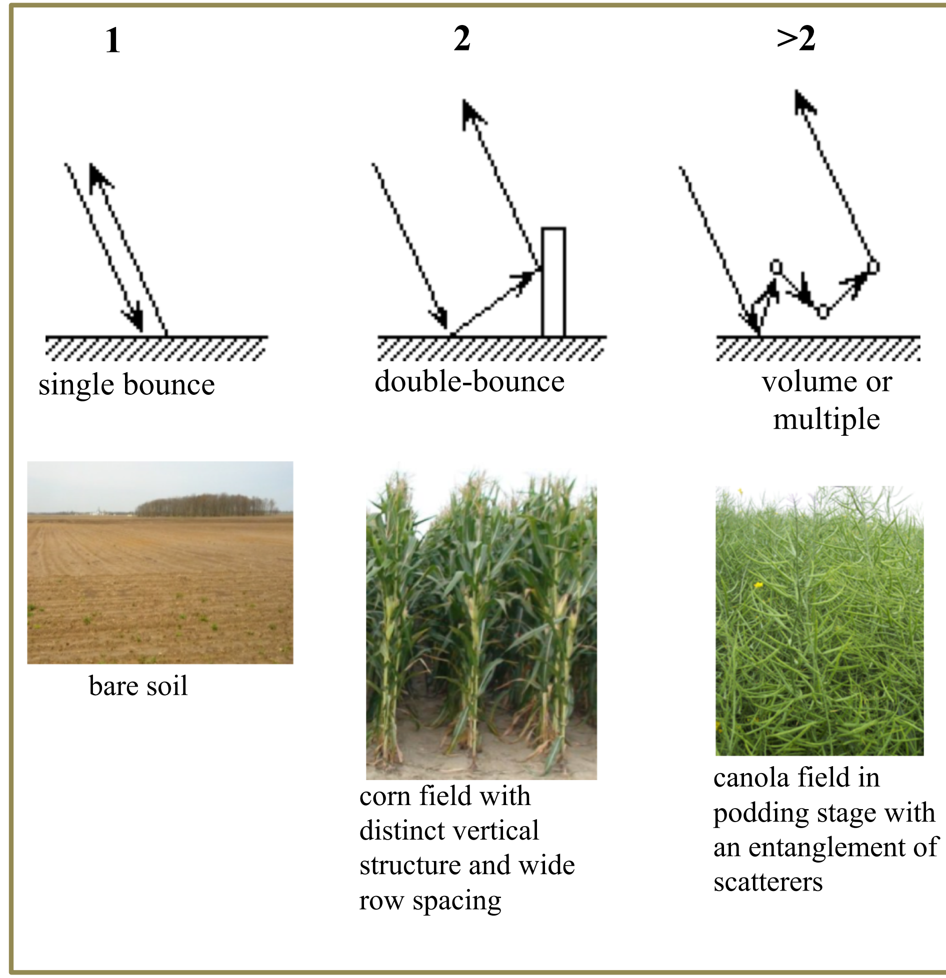
- other characteristics of how incident microwaves interact with the target, also provide valuable insight into the characteristics of the target
  - type of scattering (predominant mechanism and secondary mechanisms)
  - de-polarization of the signal
  - characteristics of phase



Types of Scattering

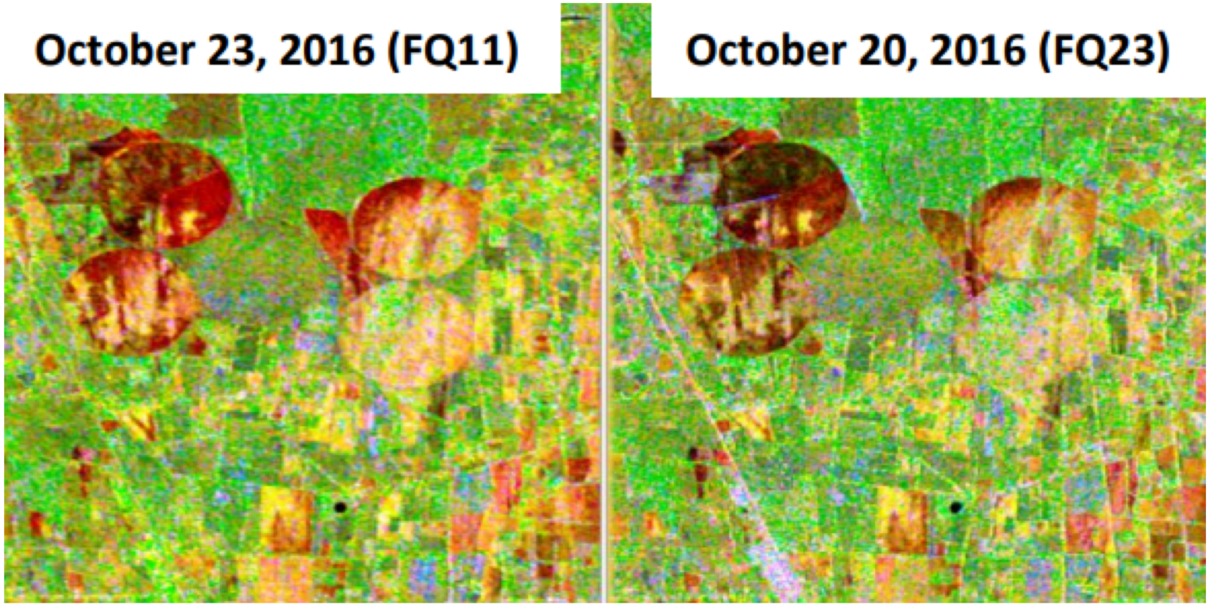
- as the microwave signal hits a target, the wave will undergo one, two or more scattering events
- a change from one polarization (i.e. H) to another polarization (i.e. V) is termed **re-polarization**.
- the number of events determines the type of scattering and impacts the amount of energy returned to the antenna
- these scattering events are dependent upon the structure and geometry of the target and thus, characterizing the type of scattering gives clues about the target
- typically one scattering type dominants
- however for distributed targets often secondary or tertiary scattering events occur and thus a mixture of scattering types often characterizes these targets

Number of Scattering Events



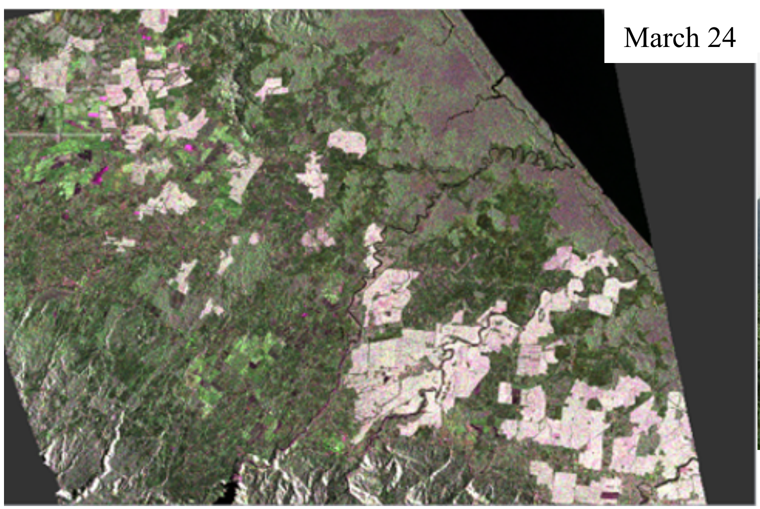
Scattering Characteristics

- polarimetric SAR sensors capture the complete characterization of the scattering field
- methods have been developed to decompose the returned signal and estimate how much of the total received signal is coming from the 3 scattering mechanisms (single, double and volume scattering)
- some decompositions (Cloude-Pottier) reveal other information
  - the dominant type of scattering (single, double or volume)
  - determination of importance of secondary or tertiary scattering contributions
  - the randomness of the scattering



Yamagouchi decomposition applied to RADARSAT-2 imagery collected over Chile

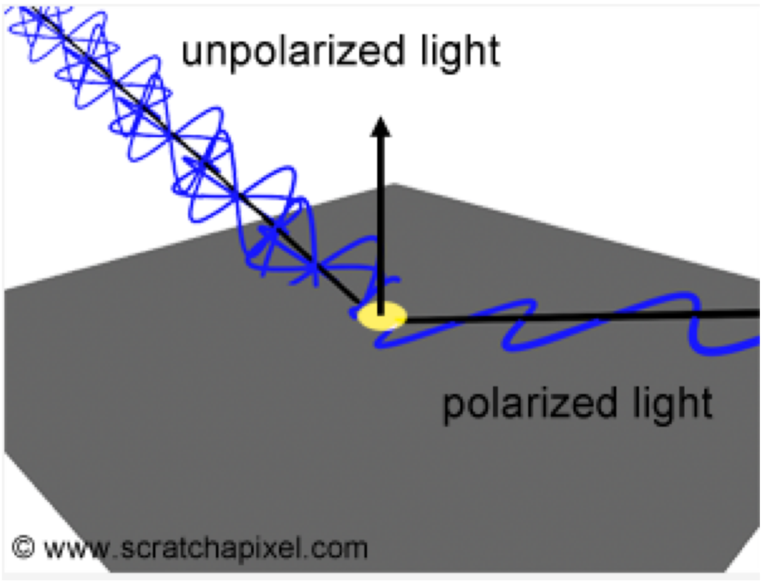
Scattering Characteristics



C-band RADARSAT-2
R: HH G: HV B:VV

Changes in volume scattering
(Freeman-Durden decomposition)

Microwave De-Polarization



- SARs transmit completely polarized waves, meaning that the phase is known and constant

- when the incident wave interacts with the target and undergoes many multiple scattering events, the phase of the scattering wave can become **de-polarized**.

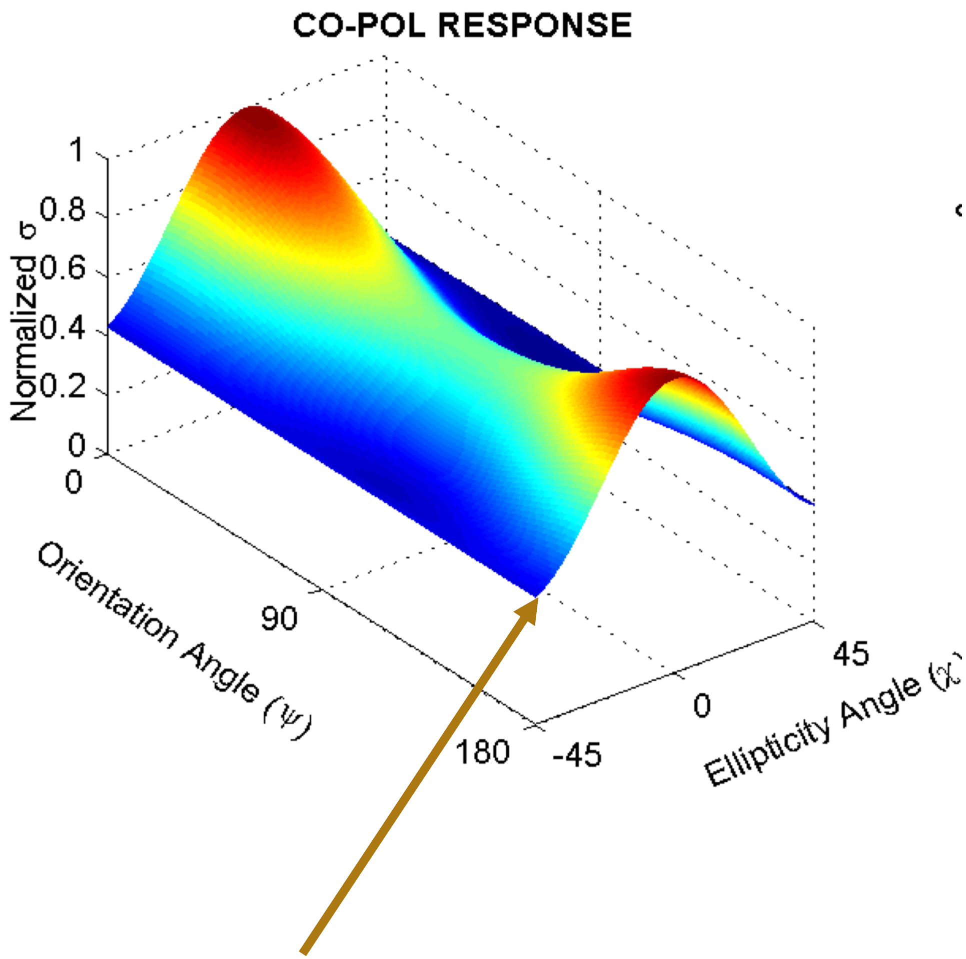
- de-polarization is the change in the degree of polarization of a fully or partially polarized wave, resulting in an increase or decrease in the unpolarized component of the wave

- unpolarized waves have equal amplitude orthogonal components and a random relative phase difference

- this means that for any given SAR resolution cell, it is difficult to predict what the phase would be of the scattered wave

Polarimetric 3-D Plots

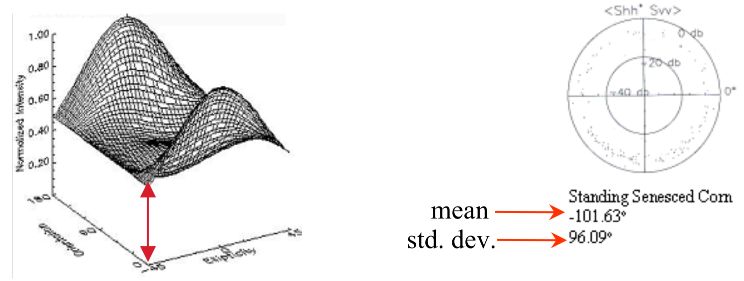
- a 3-D graphical representation of the scattering characteristics of the target
- response is presented as normalized backscatter (backscatter of the target divided by its maximum backscatter)
- orientation angle (ψ) = polarization from 0 to 180°
- ellipticity angle (χ) = degree of ellipticity (0° = linear; ± 45° = circular; all other angles are elliptically polarized response)



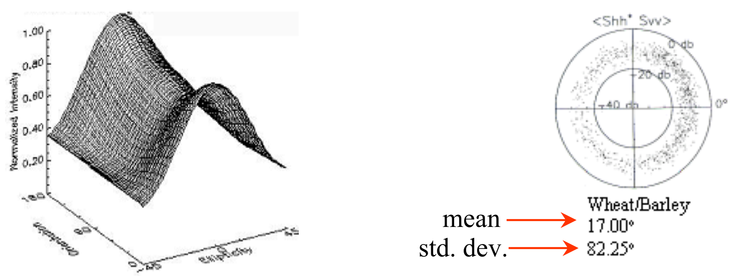
pedestal height = height of the pedestal on which 3-D plot sits. Pedestal height measures the degree of unpolarized energy

Complete Characterization of Scattering

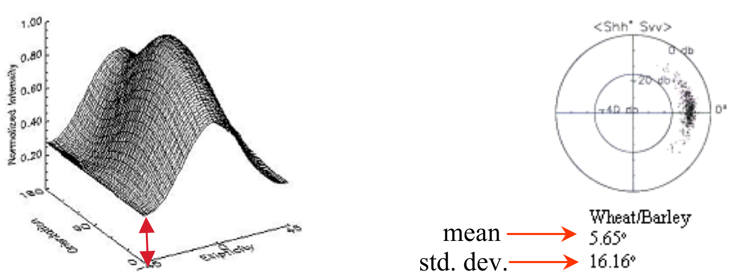
Co-polarized Polarization Plots | Co-polarized Phase Difference Distribution Plots



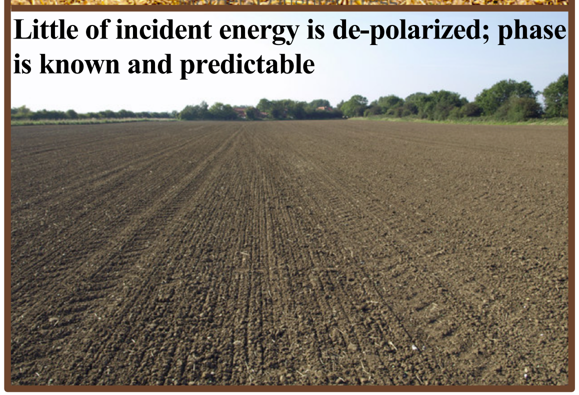
Fields with standing senesced crops result in combination of double bounce, multiple and volume scattering



No-till fields dominated by multiple scattering



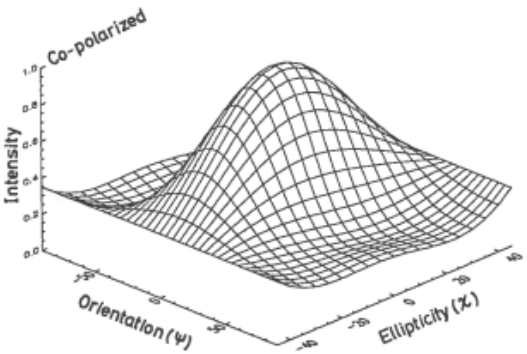
Fields with little or no residue dominated by surface scattering



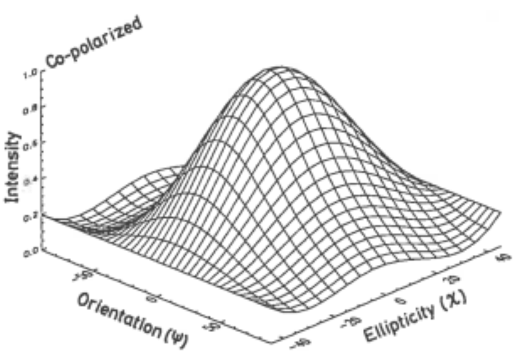
Co-polarization Plots

Aspen forest

Leaf-on

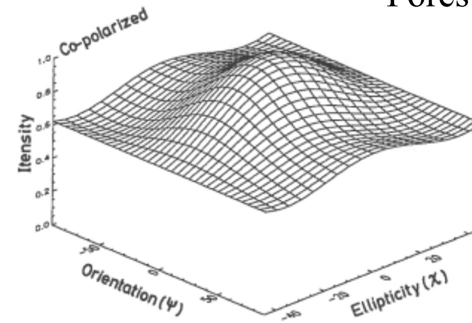


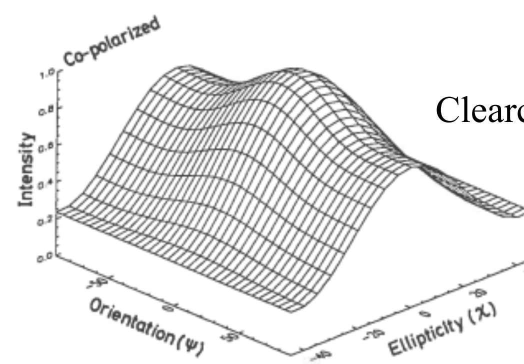
Leaf-on



Leaf-off

Forested area



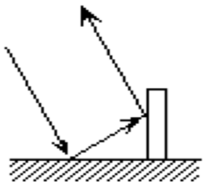


Clearcut area

Source: Leckie and Ranson, 1998

Phase Differences

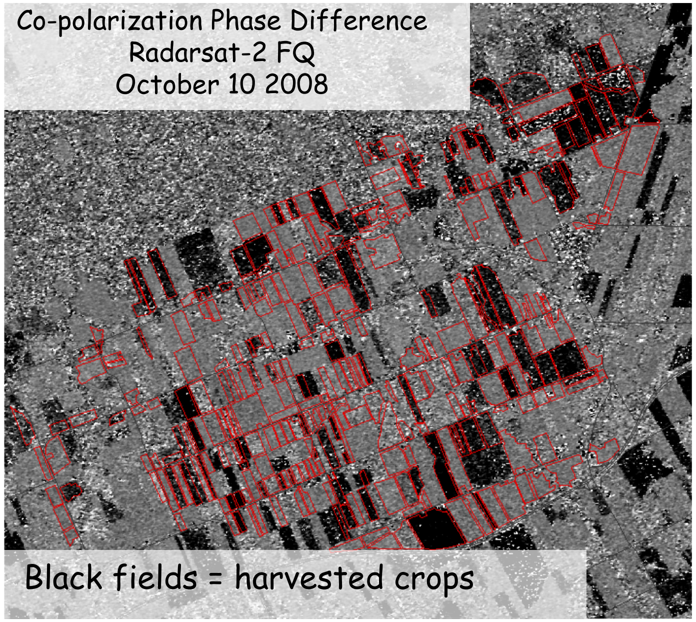
- these phase differences originate from double bounce events within the target

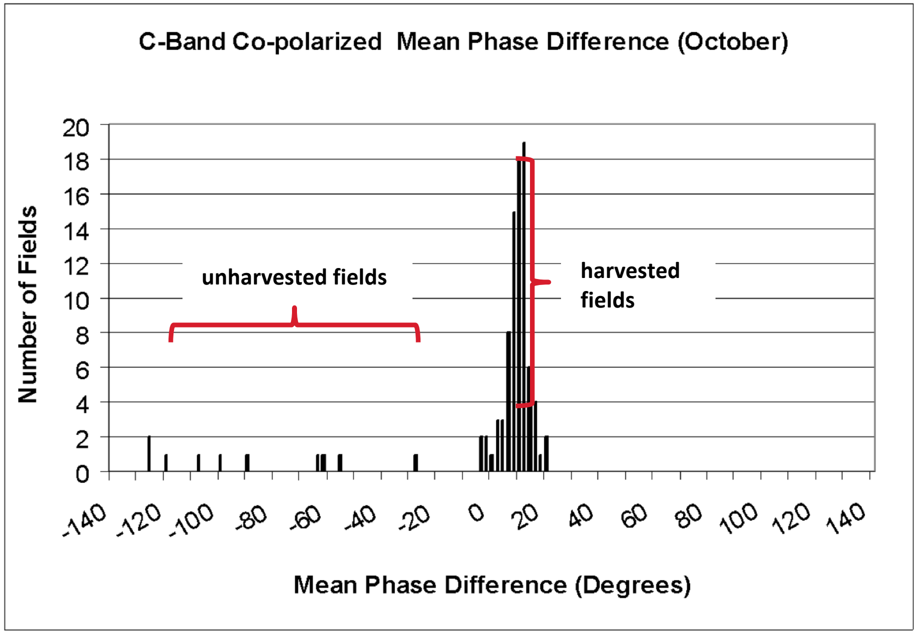


double bounce = change in phase

- in addition to the randomness of the phase of the scattered wave, the measured difference in the phase between two received signals holds information about the target

- for example, both the average co-polarized (H and V) phase difference and variance of the phase difference changes when a large biomass crop like corn is harvested





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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

Smith A.M., Eddy P.R., Bugden-Storie J., Pattey E., McNairn H., Nolin M., Perron I., Hinther M., Miller J., and Haboudane D. (2006). Multipolarized radar for delineating within-field variability in corn and wheat. *Canadian Journal of Remote Sensing*, 32:300-313.

Sokol, J., H. McNairn and T.J. Pultz. (2004). Case studies demonstrating hydrological applications of C-Band multi-polarized and polarimetric SAR. Canadian Journal of Remote Sensing, 30: 470-483.

Leckie, D.G. and K.J. Ranson. (1998). Forest applications using imaging radar. In: Principles & Applications of Imaging Radar, Manual of Remote Sensing, Third Edition, Volume 2. F.M. Henderson and A.J. Lewis (Eds.), American Society for Photogrammetry and Remote Sensing, 866 pp.