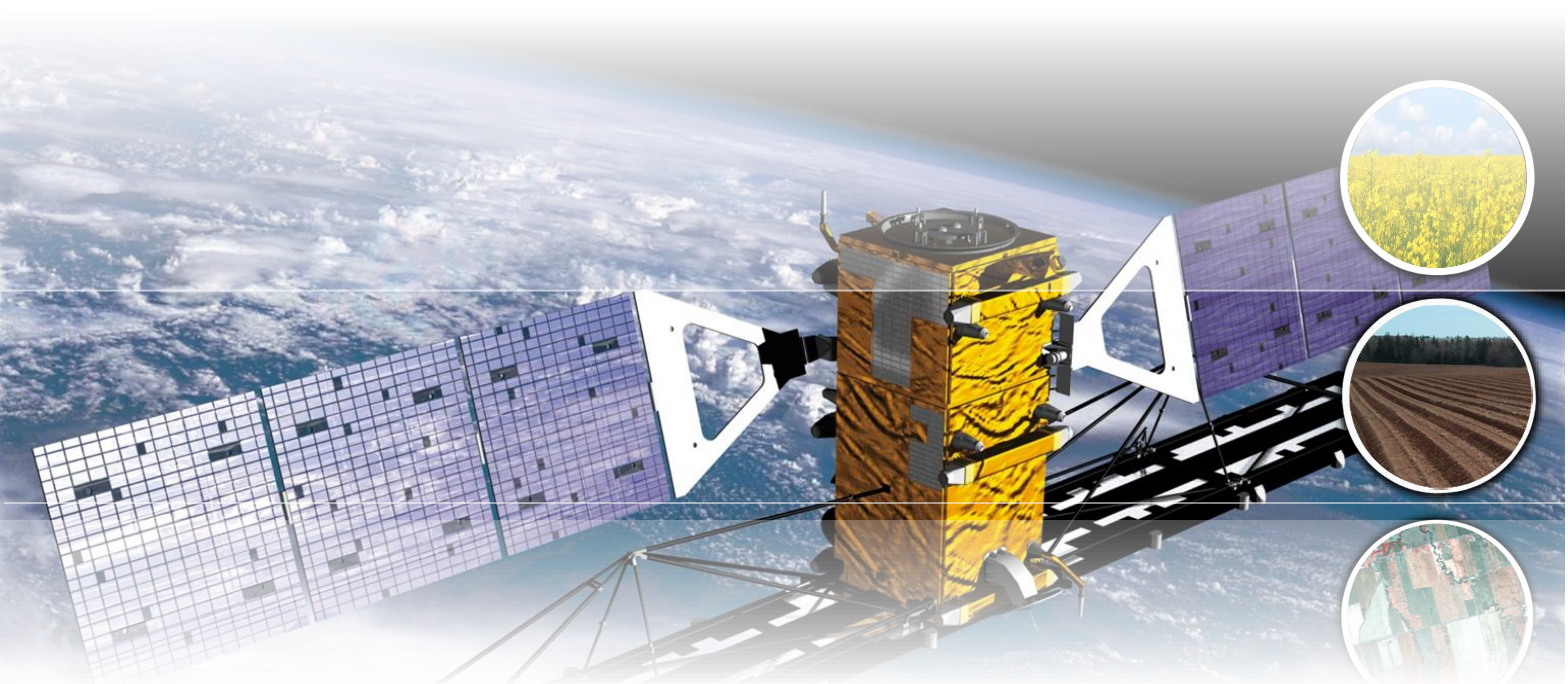

Lecture 5: The Importance of the Target Characteristics

Carleton UNIVERSITY
Canada's Capital University

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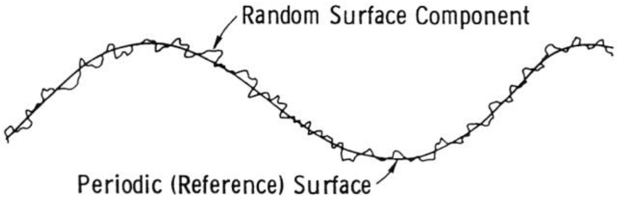
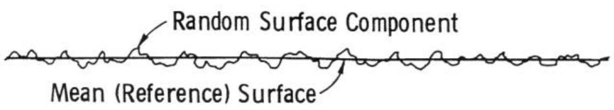
What Target Characteristics Drive SAR Scattering?

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



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

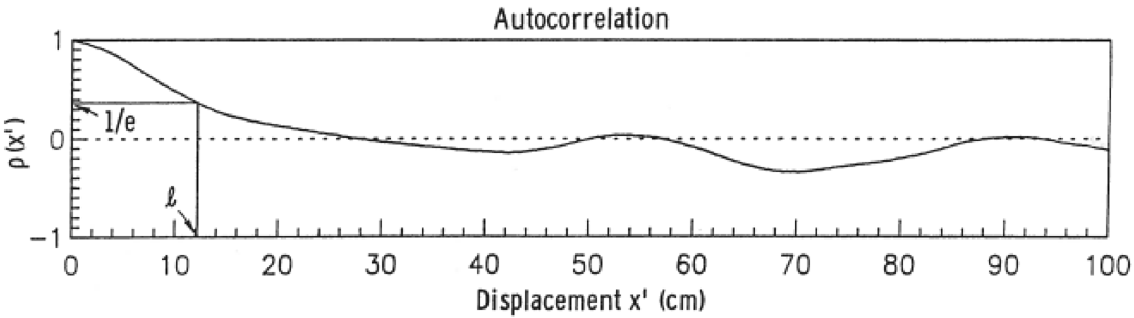
RMS: the statistical variation of the random component of the surface height relative to a reference surface (in mm or cm) (root mean square rms height)



For surfaces without periodic structure such as tillage row 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.

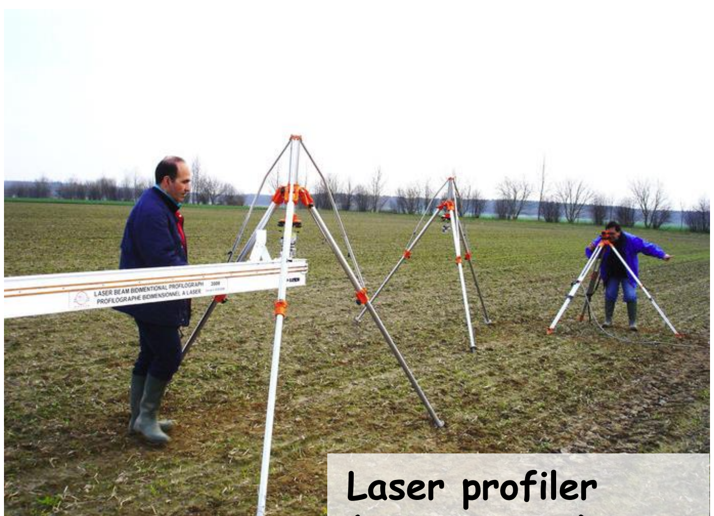


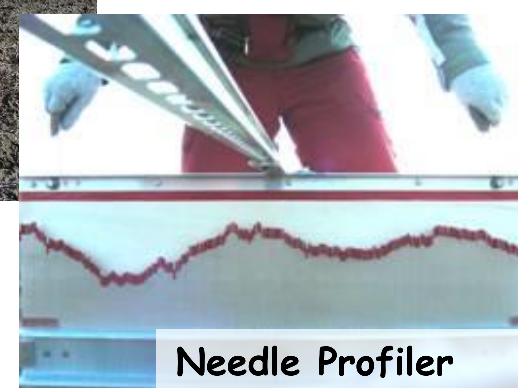
For a perfectly smooth surface, the height of every point is correlated with the height of every other point and hence *l* is very large. Inversely, randomly rough surfaces have short correlation lengths.

How is Roughness Measured in the Field?


Gridded Board


SRM-200


Laser profiler (www.esa.int)

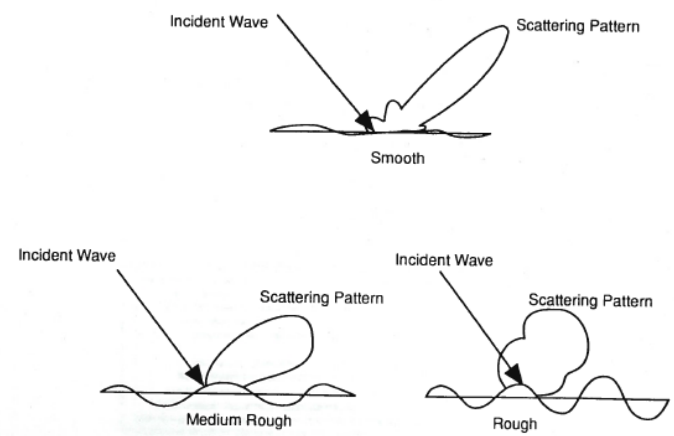

Needle Profiler

How Does Roughness Affect Backscatter?

- backscatter will increase as soil roughness increases
- bottom line: rougher soils appear brighter in SAR images

expected relative SAR response

The impact of roughness on backscatter depends on the frequency and incident angle of the SAR. **Roughness is a relative concept.**



- According to the Rayleigh Criterion, a soil is **smooth** if

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

where h is surface height variation in cm, λ is the wavelength in cm and θ is the incident angle in degrees

It’s All Relative

Roughness less than “h” would be viewed as **smooth** by the SAR

Incident Angle of 30º	
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 50º	
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

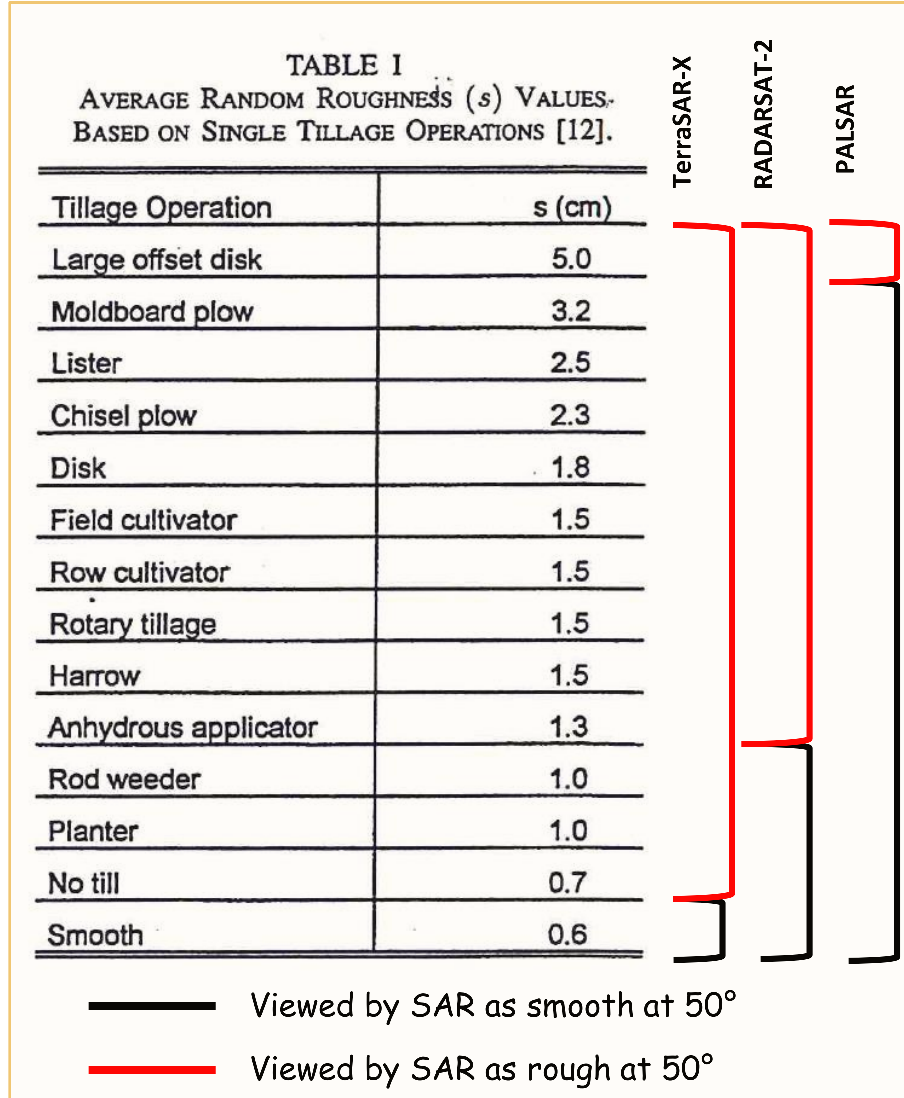


TABLE I
AVERAGE RANDOM ROUGHNESS (s) VALUES BASED ON SINGLE TILLAGE OPERATIONS [12].

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

Information source: Jackson et al. (1997)

Soil Roughness

random roughness: caused by tillage (and other farm operations) modified by soil erosion and weathering effects

periodic row structures: caused by tillage and planting

A field with low random roughness but significant periodic structure

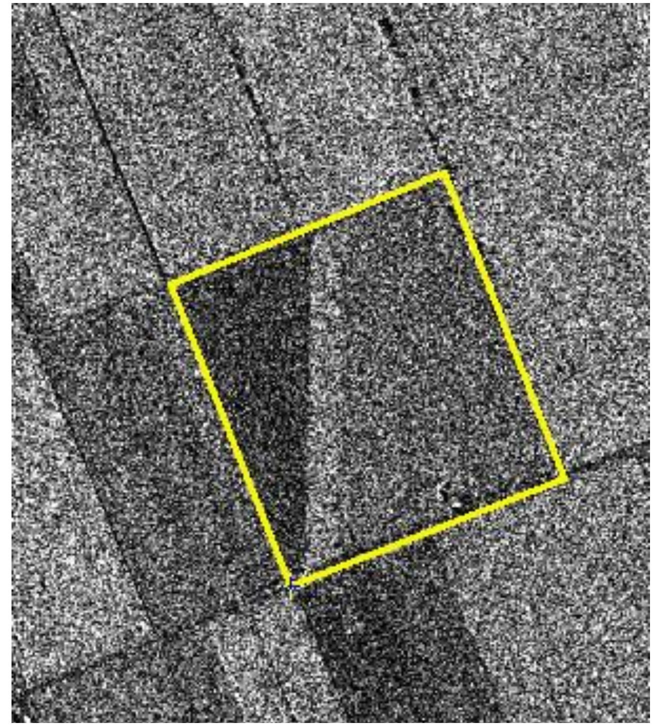
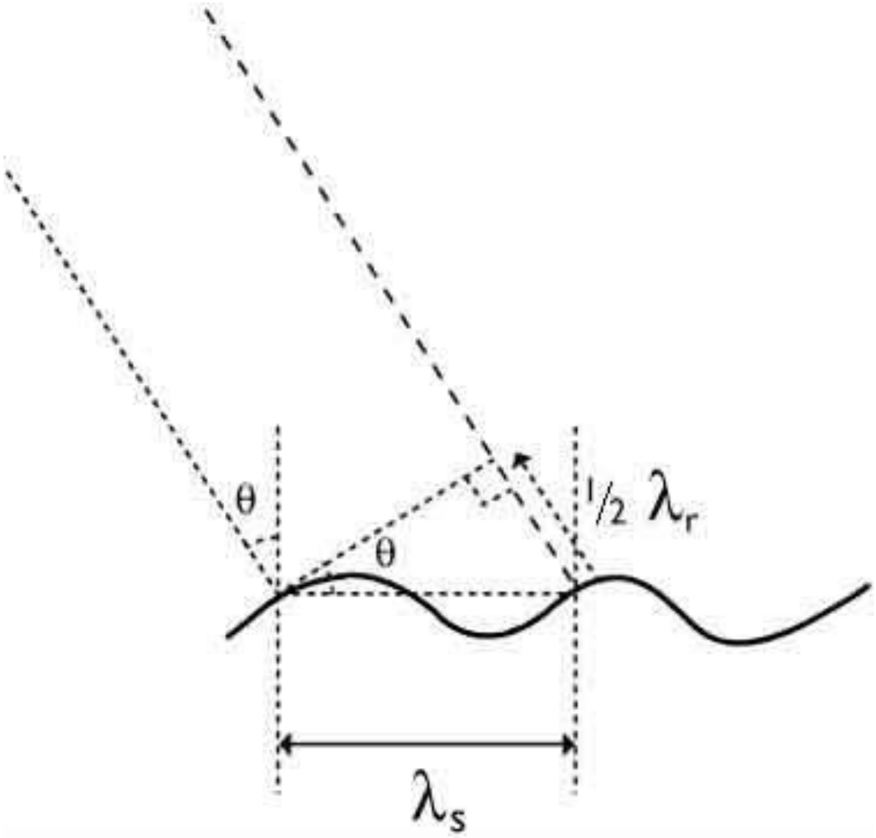


Image Credit: DLR

TerraSAR-X (VV) captured tillage occurring on August 26, 2008

A Special Case – Bragg Scattering



$$\lambda_s = \frac{\lambda_r}{2 \sin \theta}$$

λr = radar wavelength (cm)
λs = length of periodic structure (cm)
θ = incidence angle

- bragg scattering: the effects of the reflection of microwaves on periodic structures whose distances are in the range of the SAR wavelength
- causes high backscatter responses

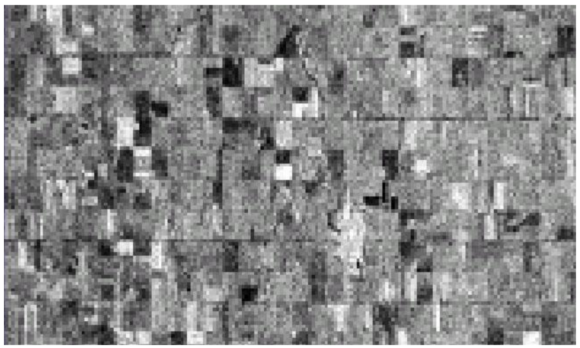
Image source: earth.esa.int

Example – Identify When Tillage Occurs

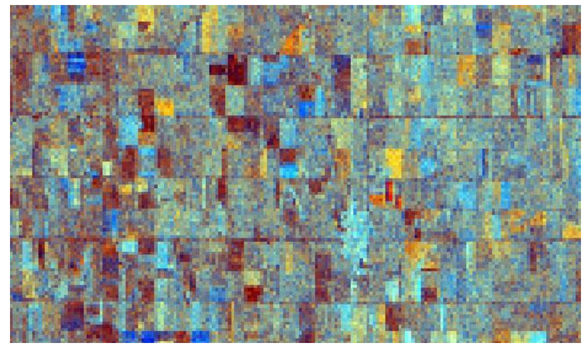
Very important: No other target (moisture) or SAR (angle, polarization, frequency) can change from one image to the next

What are we detecting? A change in backscatter due to an increase in roughness

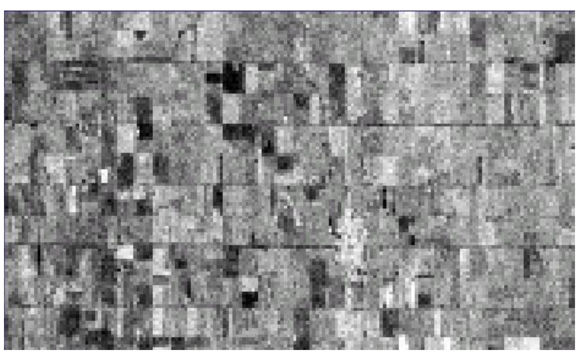
© 1996 Canadian Space Agency



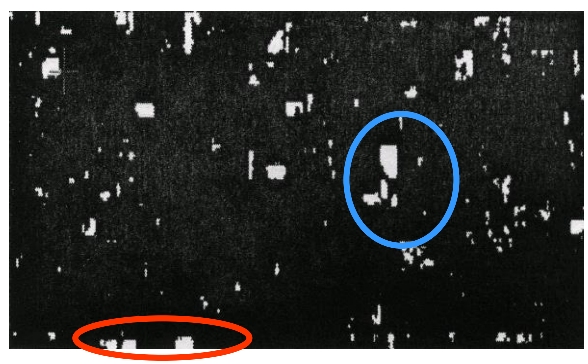
October 10, 1996



R=Difference G=October 17 B=October 10



October 17, 1996



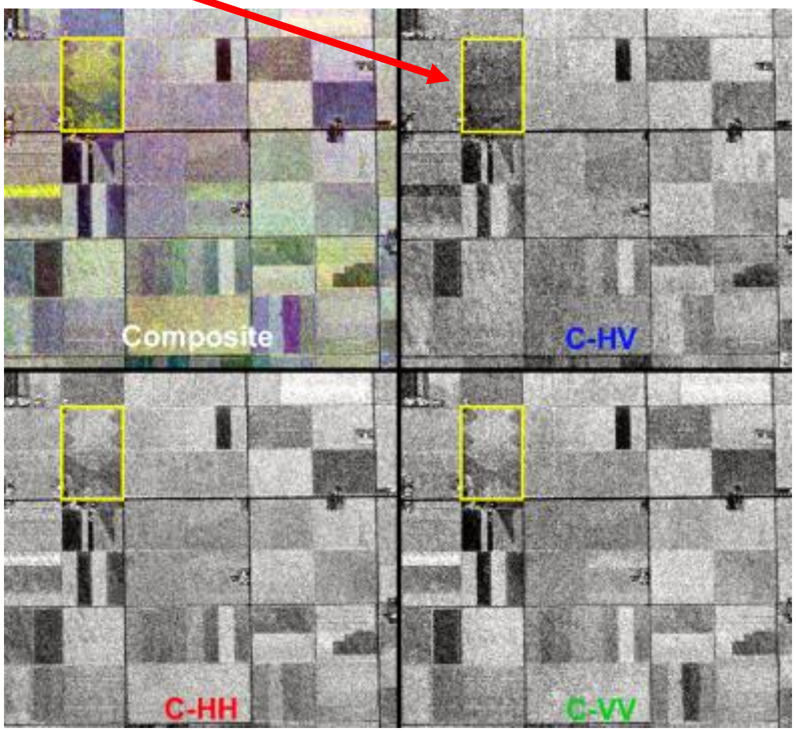
Change Detection Image

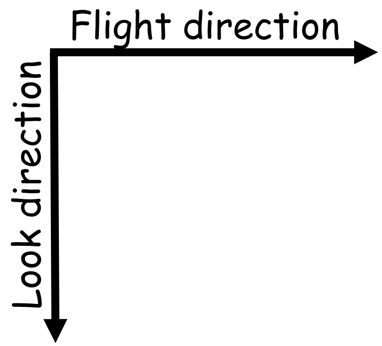
Tilled
Why?
Backscatter increased

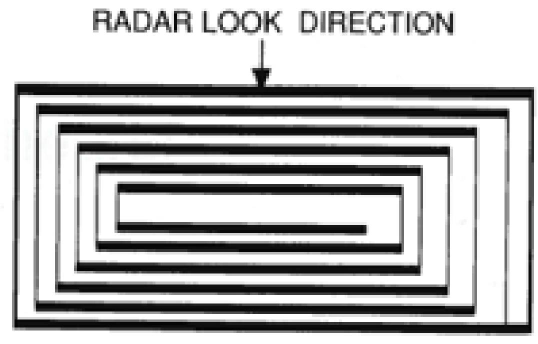
Harvested
Why?
Backscatter decreased

One Complication

- "look direction" of SAR **relative to the row direction** impacts the strength of radar return. Creates a so-called "bow-tie" effect
- strongest backscatter results when the SAR look direction is perpendicular to the direction of the rows
- row direction effects can result due to the direction of **planting, tillage and harvesting**
- this phenomenon is <u>not</u> present when fields are imaged in cross-polarizations (HV and VH) as these polarizations are responding to volume scattering rather than surface scattering; among other reasons, this makes **HV and VH** attractive for vegetation monitoring

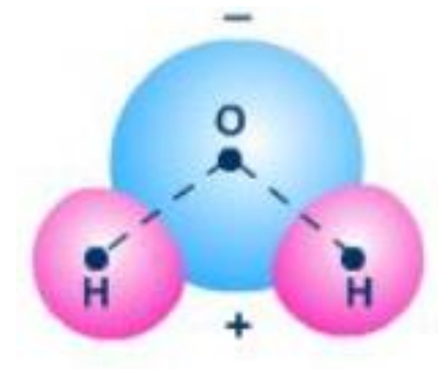




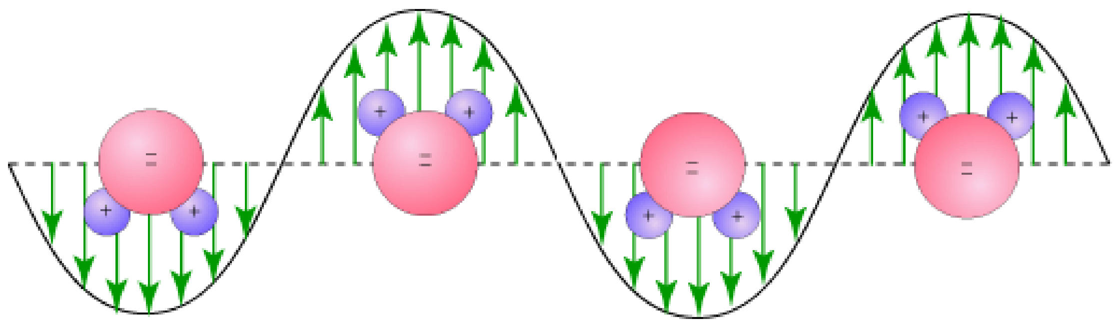


What About Water In the Target?

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
- as such, 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** to soil, for example) 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

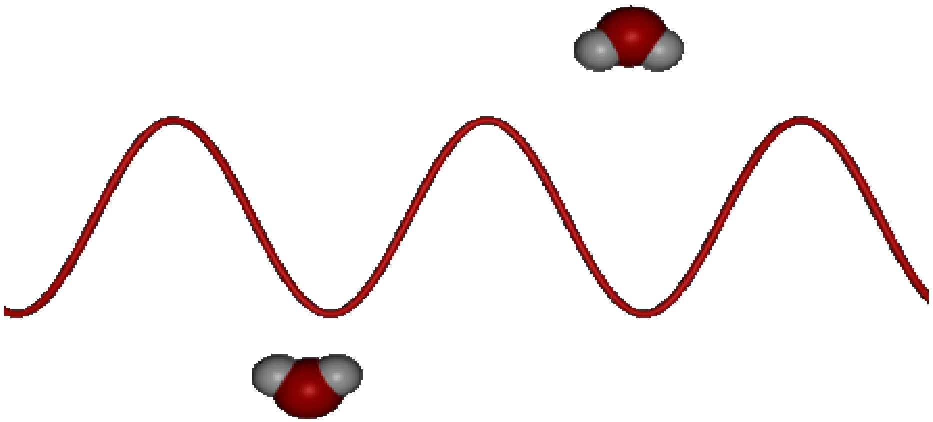
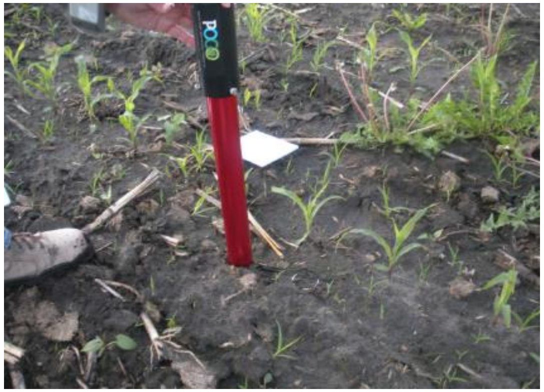


Image source: www.anton-paar.com

How is Volumetric Water Content Measured in the Field?



- can be measured using gravimetric samples
- weight of wet soil is measured and following oven drying, dry weight of the soil is measured
- the gravimetric weight is calculated as the wet minus dry weight
- volumetric water content is determined using the gravimetric weight and known volume of measurement cylinder or the soil bulk density

- for SAR soil moisture applications, typically impedance probes are used
- these probes generate an electromagnetic signal that is propagated through metal tines into the soil.
- the part of the signal that is reflected back to the unit is measured in volts and used to calculate the real dielectric. The dielectric is related to volumetric soil moisture using empirical relationships or using physically based dielectric mixing models

What Does This Mean For SAR?

- a strong positive relationship between real dielectric constant and soil moisture

- a strong positive relationship between real dielectric constant and SAR backscatter

- in a nutshell: more water in the target = higher backscatter = brighter returns

- applies to ANY target (soil, vegetation etc.)

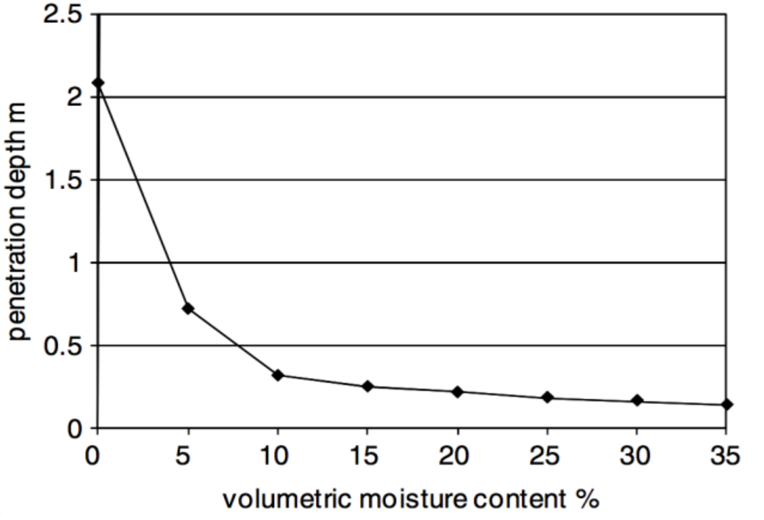
© 2002 Canadian Space Agency

Multi-Date RADARSAT-1 Composite
Outlook, Saskatchewan (Canada)

The Penetration Depth

- recall that penetration into the target is dependent upon the SAR frequency or wavelength
- depth of penetration **ALSO** depends upon 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 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.



Information source: Richards (2009)

Vegetation Effects

The scales are very different

Optical sensors:

- amount of energy absorbed, reflected and transmitted by vegetation is driven by plant pigmentation as well as internal leaf structure and moisture
- chemical and physical properties (at the atom level) are crop type specific and are indicative of the growth stage and condition of the plant

SARs:

- scattering of longer-wavelength microwaves is driven by (a) larger scale structures (size, shape and orientation of leaves, stems and fruit) and (b) the volume of water in the vegetation canopy (at the molecule level)

So why is SAR sensitive to vegetation type and development?

Vegetation structure changes significantly from one vegetation type to the next, and as plants move through their growth stages.

Crop structure varies significant among soybeans, wheat and corn

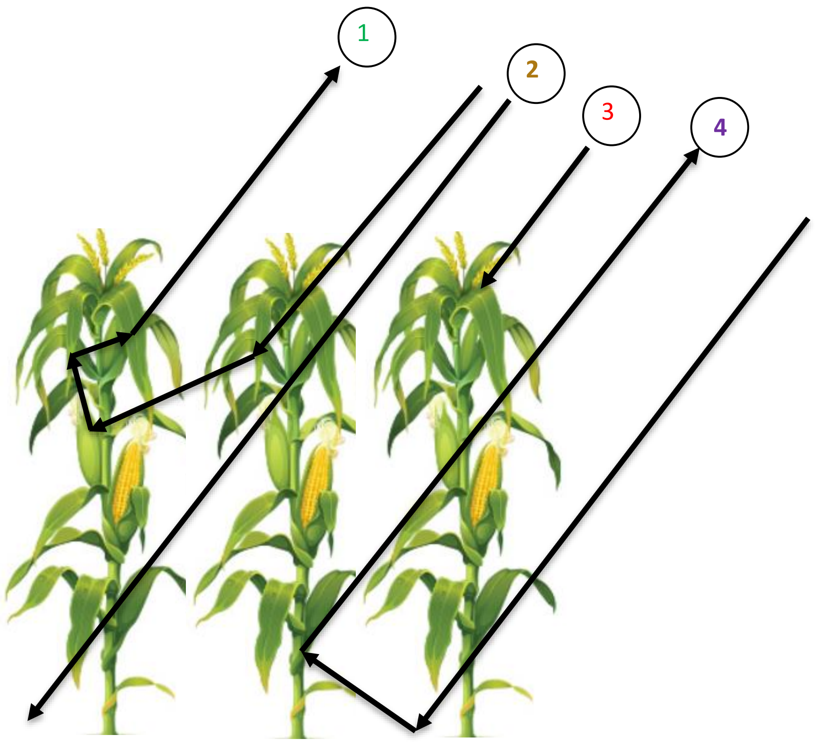
Scattering from Vegetation – It's Complicated

- many different types and combinations of scattering can occur in a plant canopy

- following a wave into a canopy, it may:
  - scatter directly off a leaf
  - scatter from the stem of one plant to the leaf of another (several times)
  - make its way to the soil and scatter from the soil
  - make its way to soil, then scatter off a stalk
  - the wave may 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 (offsets in phase and how random the phase becomes)

- these scattering characteristics tell us what type of vegetation is present and what the condition is of that vegetation

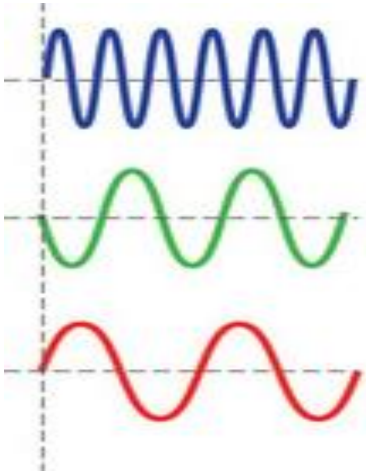


1. Multiple volume scattering from within canopy
2. Direct scattering from soil
3. Direct scattering from canopy
4. Double bounce scattering between soil and canopy

Don’t Forget the SAR Basics

- These interactions with the canopy are **very** dependent upon the characteristics of the SAR
    - frequency; polarization; incidence angle
    - look direction (relative to the target)

- Frequency:
    - canopies can attenuate or scatter microwaves
    - the dominance of one or the other depends on the wavelength relative to the size of the canopy components
    - scattering occurs when canopy component (such as a leaf) is close to or larger than wavelength
    - some components (such as heads of wheat) will attenuate microwaves, especially at shorter wavelengths
    - frequency also affects penetration depth
    - longer wavelengths penetrate deeper into the canopy and involve more interaction with the soil



What is the Best Frequency – It Depends

Soil moisture

- longer wavelengths (like L-band) are better as they penetrate deeper into the canopy and interact with the soil
- longer wavelengths also "see" most soil surfaces as smooth (minimizes the effects of roughness)

Vegetation classification and biophysical modelling

- depends on the canopy (size of leaves and stems; height of canopy)
- need enough penetration into canopy (thus L- or C-band for corn, for example) but not too deep so that some scattering also comes from soil (thus C- or X-band for lower biomass crops like soybeans)
- ***the best:*** multi-frequency so that you have data collected at the optimal wavelength for each canopy

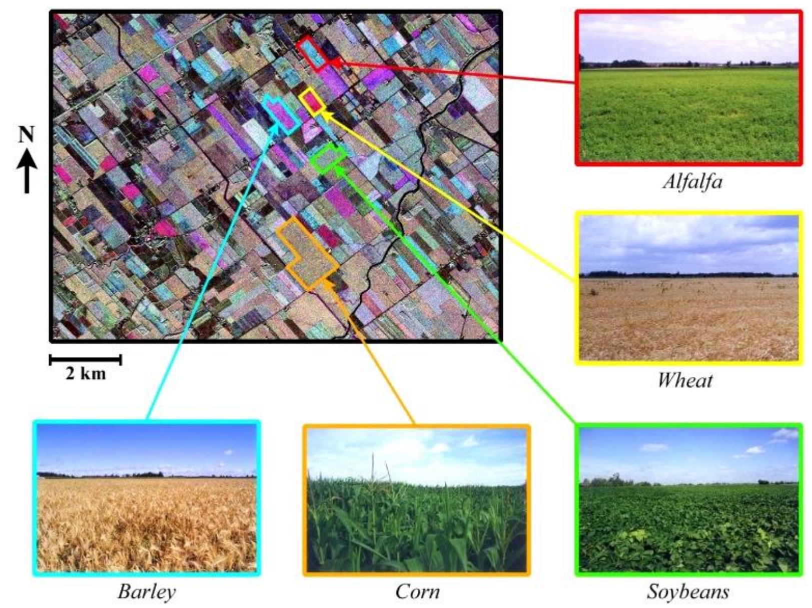
Polarization and Incident Angle

Polarization:

- affects how microwaves interact with crop
- V-polarized waves couple with vertical structured vegetation and more of the energy is attenuated
- H-polarized waves have greater penetration through the canopy to the underlying soil
- cross-polarizations (HV/VH) are sensitive to the target volume and are not affected by row effects
- hands-down, **HV or VH** is the single best polarization for either crop identification or crop biophysical estimation
- next best polarization is usually VV

Incident angle

- not as critical for crop identification
- temporal change detection, do not mix angles
- for biophysical estimation, ok to mix angles as long as the model accounts for incident angle



Airborne CV-580 C-Band SAR
South of Ottawa, 1998 July 9
R = HH G = HV B = VV

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 large water droplets in the atmosphere will cause SAR scattering.

In some regions of world, risks are diurnally dependent.

Rule 2: Consider if dew might be present during early morning acquisitions

Why? Presence of water on leaves will increase backscatter (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 early morning hours.

A Complication – the Environment (2)

Rule 3: Never use SAR if the target is frozen

Why? The dielectric constant drops close to zero when water changes to a frozen state.

The water molecule is unable to rotate and the SAR “thinks” that because no energy is being stored, there is no water present!

Thus even if there is water in the target, the SAR will view the target as dry.

Freezing often occurs overnight.

The upside: SAR can detect freeze/thaw events.

What to do?

1. Select orbits (ascending – evening; descending – morning) carefully

2. Always check in with meteorological stations

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.

Richards, J. A. (2009). *Remote sensing with imaging radar*. Heidelberg, Germany : Springer