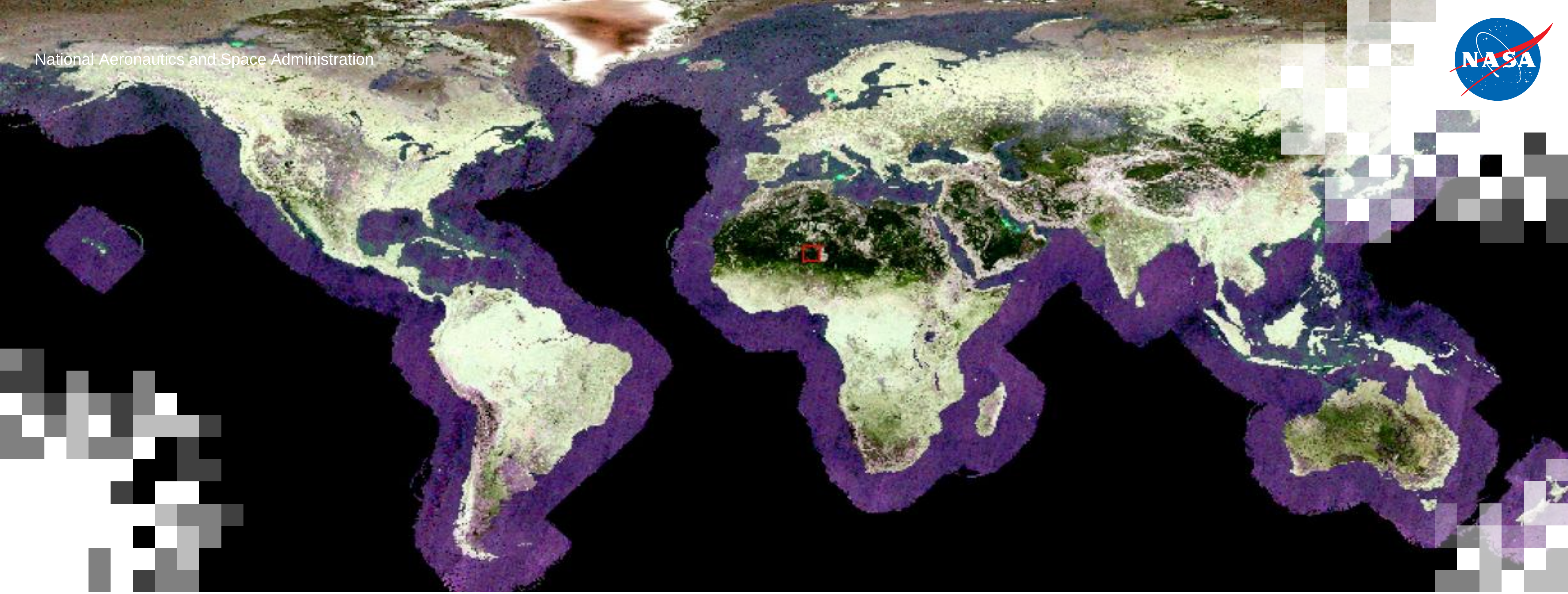
National Aeronautics and Space Administration



Exploiting SAR to Monitor Agriculture

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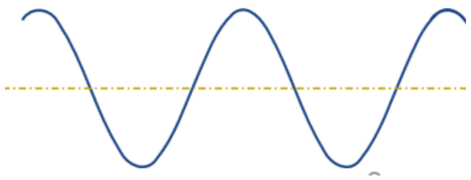
Learning Objectives

By the end of this presentation, you will be able to understand:

- how SAR configurations affect response from soils and crops
- the information content in SAR images relevant to soil and crop conditions
- the optimal sensor parameters for agriculture applications
- how to ingest, pre-process, and process SAR data for use in crop classification and soil moisture estimation

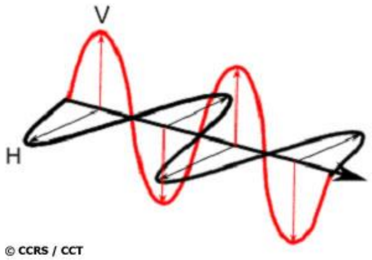
SAR System Considerations

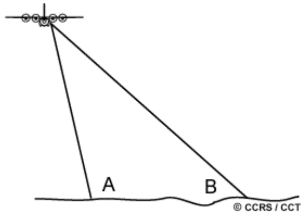
- When planning SAR data collections and when interpreting SAR response, the three fundamental system characteristics must always be considered
- Interpreting SAR response is always done, relative to these characteristics



frequency or wavelength

polarization





geometry (incidence angle and look direction)

Image Credits: Polarization & Geometry CCRS/CCT

Frequency or Wavelength

The best frequency should be selected

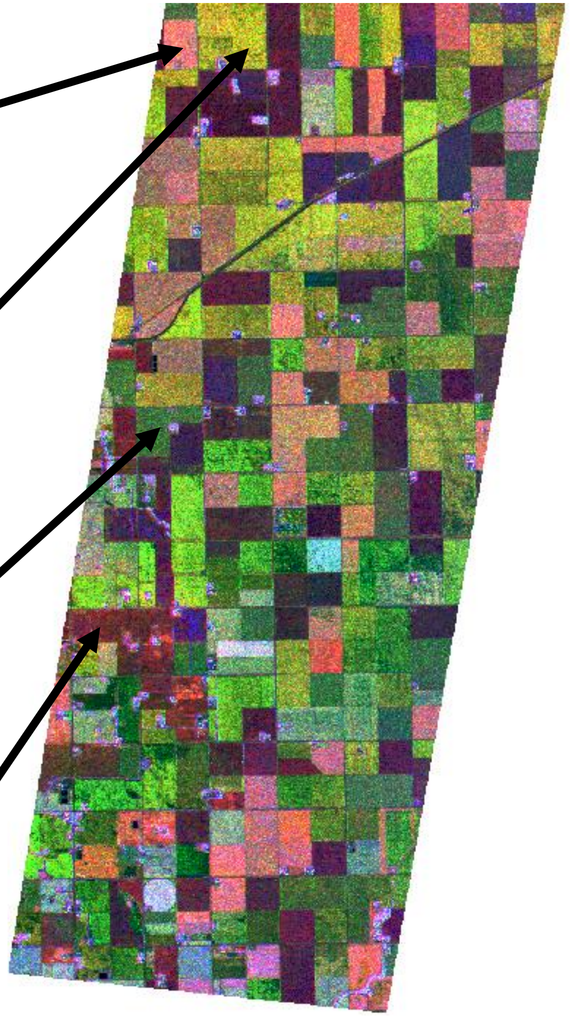
- consider the size of the target elements relative to SAR frequency. To maximize scattering, select wavelengths that are comparable in size or smaller than these elements
- is it important to penetrate into the target or is the goal to maximize surface scattering? Lower frequency (longer wavelengths)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

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

Incidence Angle

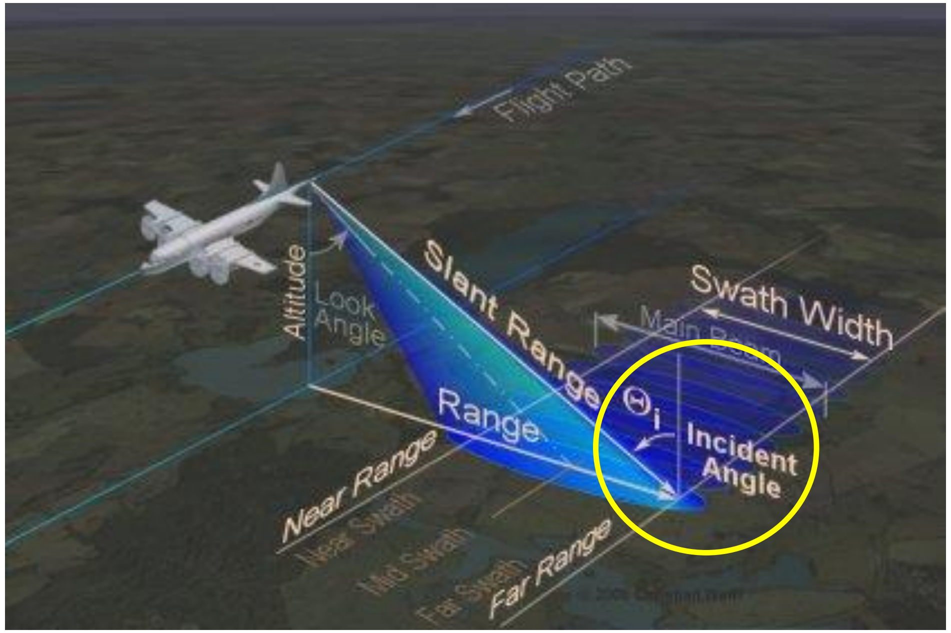


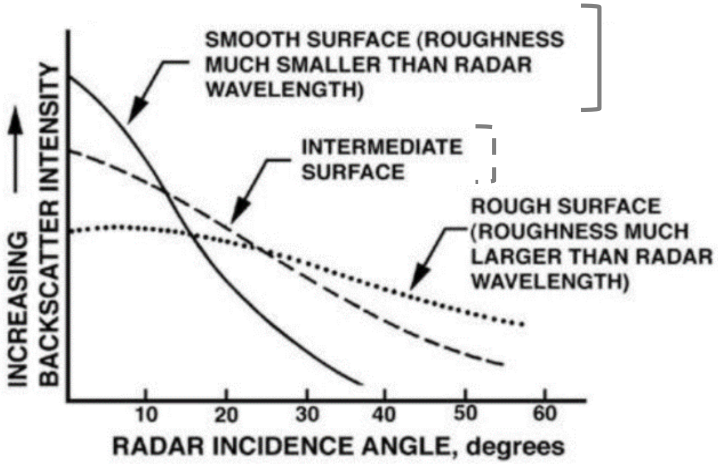
Image Credit: www.radartutorial.eu/20.airborne/ab06.en.html

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
- **CAUTION:** for temporal change detection, do not mix angles (use exact repeats)
- for biophysical estimation, ok to mix angles if the model accounts for the incident angle



rougher lower rate of change with angle

smoother higher rate of change with angle

Image Credits: (left) Ulaby et al. (1981a); (right) extension.umn.edu/soil-management-and-health/tillage-implements

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 frequency for agricultural monitoring?

- HV or VH is the single best polarization for either crop identification or crop biophysical estimation
- 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, (2) water content

- **Roughness:** characterized by two parameters, the root mean square variance (RMS) and the surface correlation length (l)
- **RMS (root mean square):** *the statistical variation of the random component of the surface height relative to a reference surface (in mm or cm)*
- **Correlation length (l):** *autocorrelation function measuring 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 soils this means

- random roughness caused by tillage (and other farm operations) modified by soil erosion and weathering effects
- periodic row structures caused by tillage and planting

How Does Roughness Affect Backscatter?

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

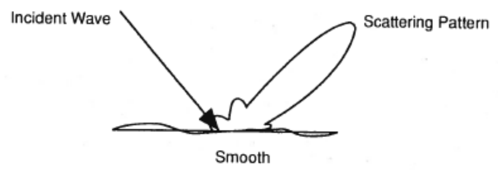
The impact of roughness on backscatter depends on the frequency and incident angle of the SAR. Roughness is a relative concept.

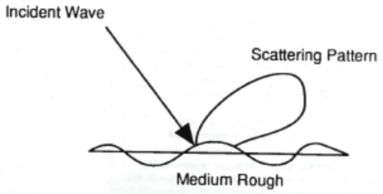
According to the Rayleigh Criterion, a soil is smooth if

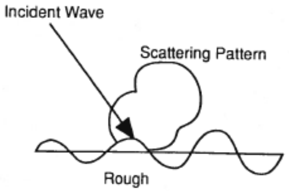
$$h < \frac{\lambda}{8 \cos \theta}$$

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

expected relative SAR response







It's All Relative

Roughness less than "h" would be viewed as smooth by 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

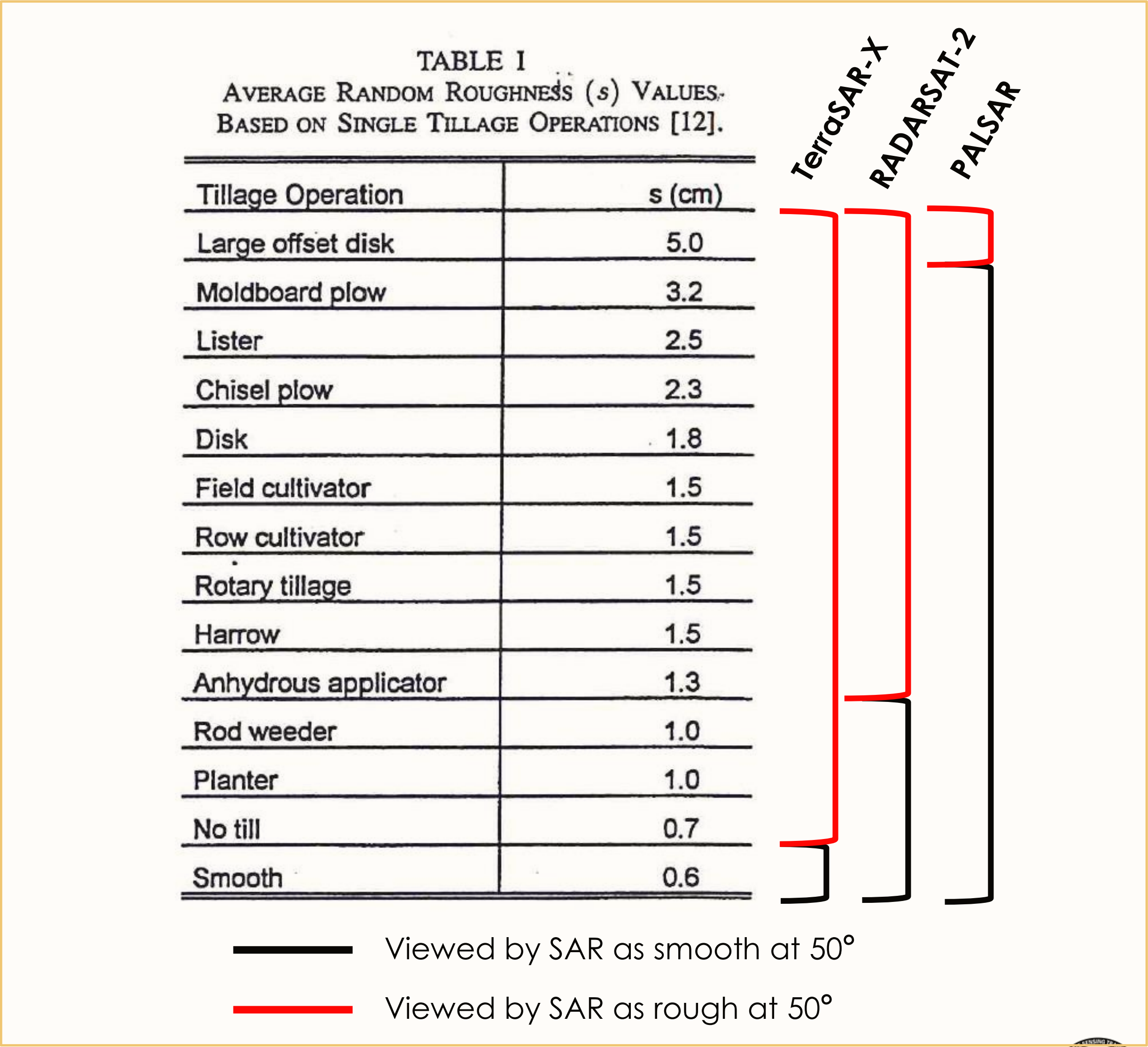


TABLE I
AVERAGE RANDOM ROUGHNESS (s) VALUES BASED ON SINGLE TILLAGE OPERATIONS [12].

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

Source: 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.

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)

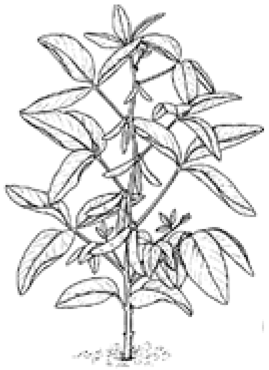
b) the volume of water in the vegetation canopy (at the molecular level)

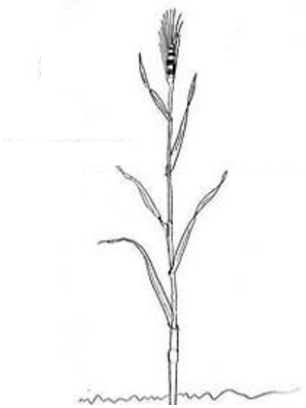
So why is SAR sensitive to crop type and crop development?

- 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



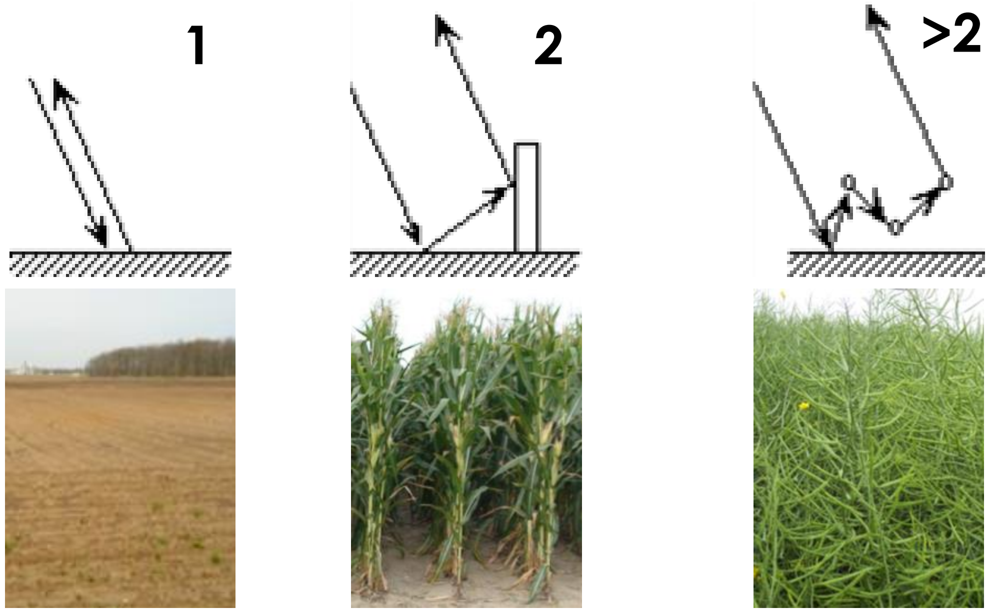


Types of Scattering

- 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, intensity of scattering, and changes in the phase
- scattering events are dependent upon the structure and geometry of the target
- typically one scattering type dominates
- for distributed targets often secondary or tertiary scattering events occur and thus a mixture of scattering types often characterizes these targets

type of scattering + mixture of scattering events + phase characteristics + intensity
= clues about type and condition of crops

Number of Scattering Events



bare soil | corn field with distinct vertical structure and wide row spacing | canola field in podding stage with an entanglement of scatterers

What About Water in the Target?

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

- water (H_2O) is a dipole: 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

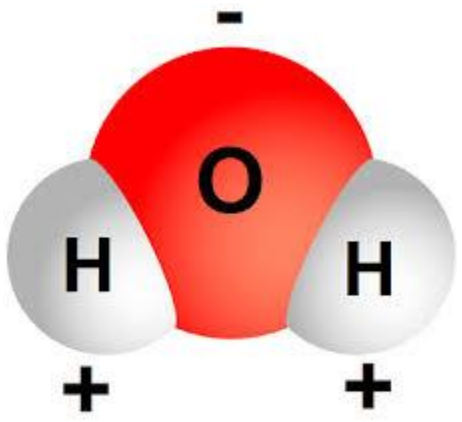


Image Credit: socratic.org/questions/to-which-part-of-a-water-molecule-would-li-be-attracted

What About Water in the Target?

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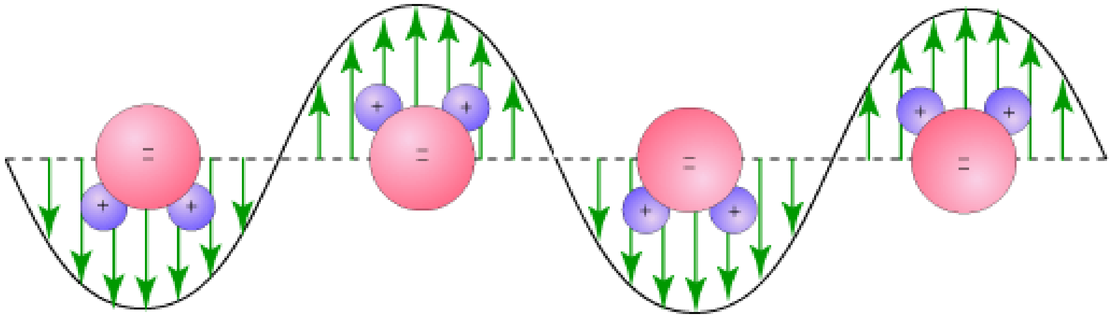
- dielectric constant: a measure of the ease with which dipolar molecules rotate in response to an applied field



- 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)

Image Credit: http://macrotomicro.blogspot.com/2011/02/how-microwaveoven-works.html

What Does This Mean for SAR?

- 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

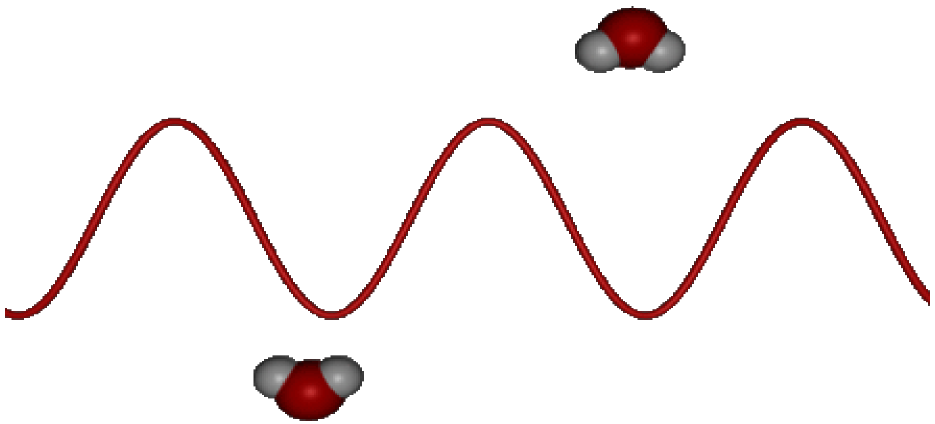


Image Credit: Anton Paar

What Does This Mean for SAR?

- strong positive relationship between real dielectric constant and backscatter
- strong positive relationship between real dielectric constant and soil moisture
- more water in the target = higher backscatter = brighter returns
- applies to ANY target (soil, vegetation etc.)
- Penetration depth (δ_ρ) into soil and/or crops is defined by the dielectric (ε), wavelength (λ), and incident angle
- penetration increases with wavelength and is greater when the target (soil or crops) is drier

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

$$\delta_p = \frac{\lambda \sqrt{\varepsilon'}}{2 \pi \varepsilon''}$$

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 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.
- Select orbits (ascending – evening; descending – morning) carefully
- Always check in with meteorological stations