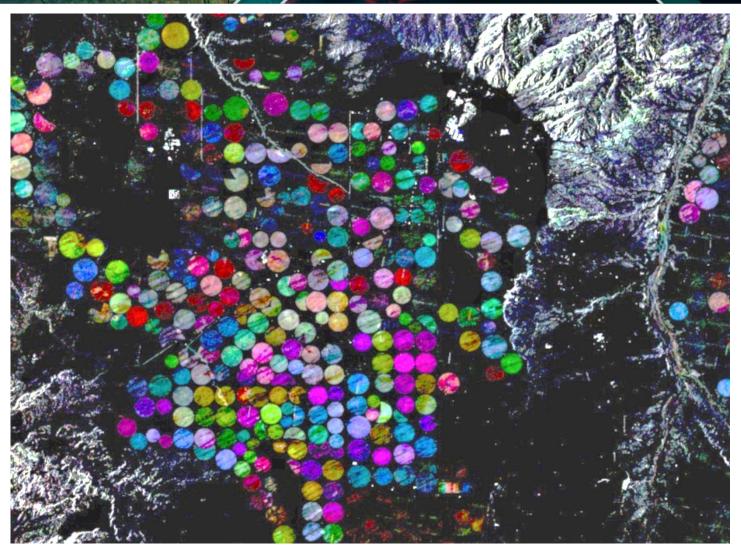


Elise Colin

Researcher at the crossroads of physics and data science, specializing in polarimetry and speckle across scales.

Also a wandering artist and writer, exploring the resonance between science and creation.

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- ONERA (France)



Introduction to Radar Remote Sensing for Agriculture

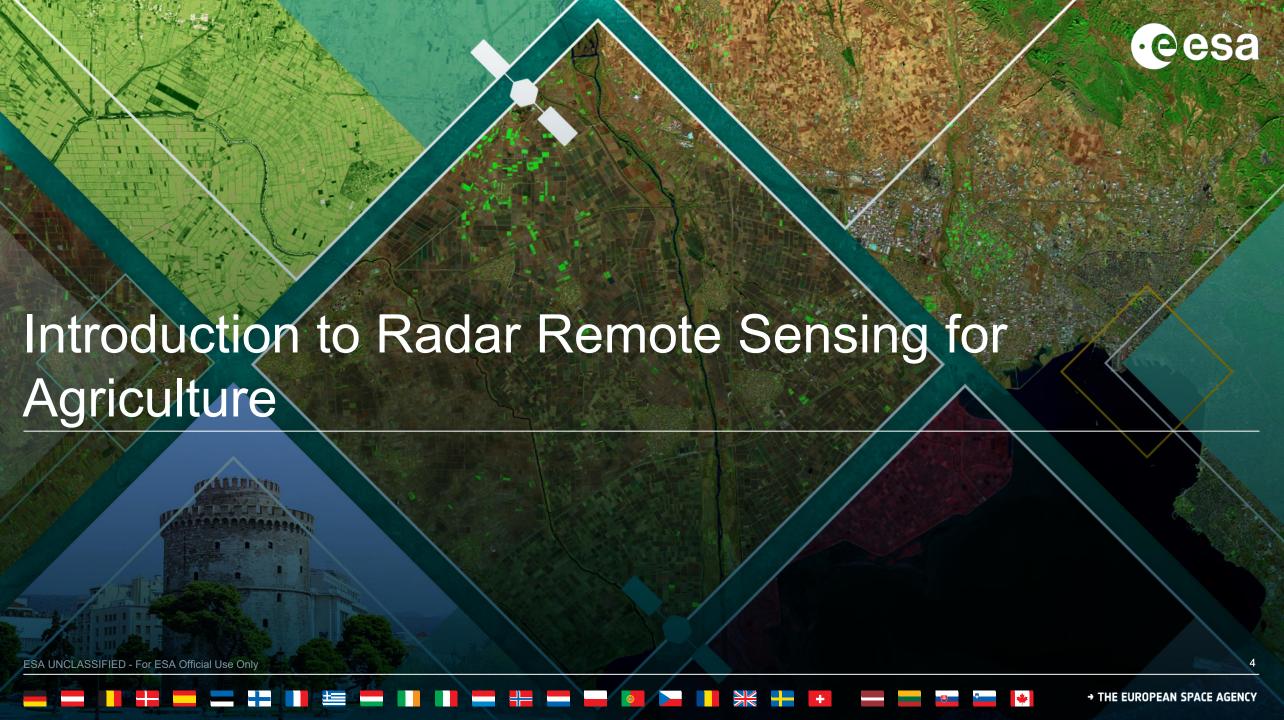
Understanding SAR images

Polarimetry

Interferometry and Polarimetric interferometry

Time series





Different kinds of sensors



Airborne







Satellites



drone

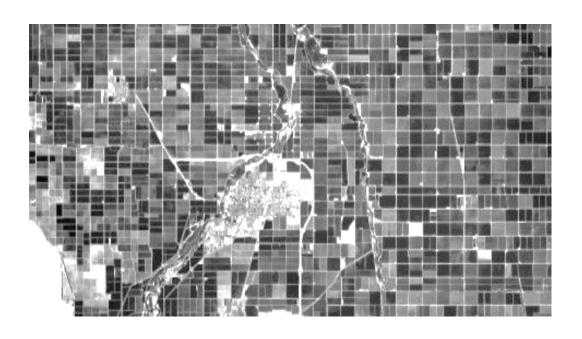


Is a radar image different from an optical one?



Which one is the optical one?

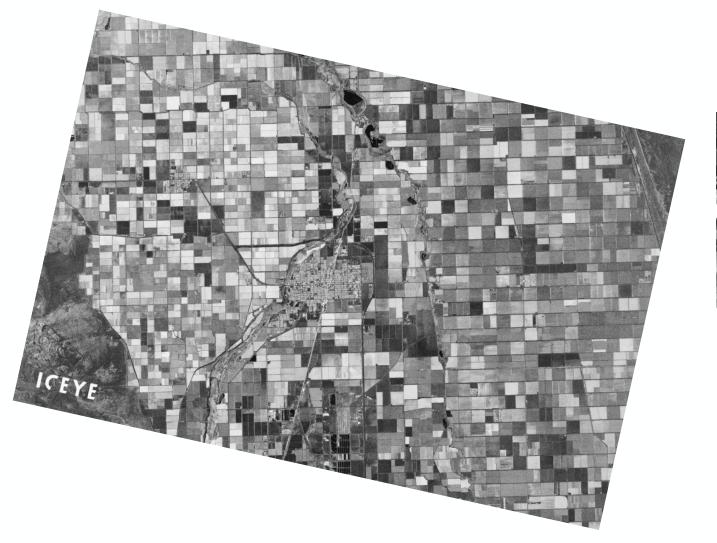


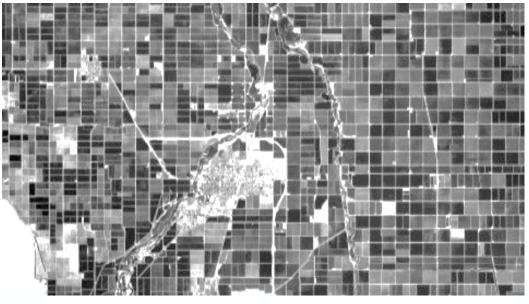


At the end of this course, you will be able to give at least three arguments to support your answer.

Is a radar image different from an optical one?



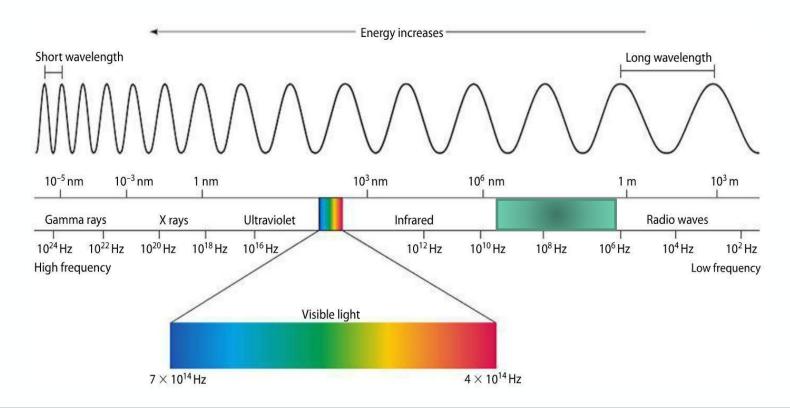






1 – It uses a different portion of the spectrum

Radar uses microwaves (cm–m), while optical sensors use visible light (hundreds of nm). Each wavelength "sees" objects at its own scale.



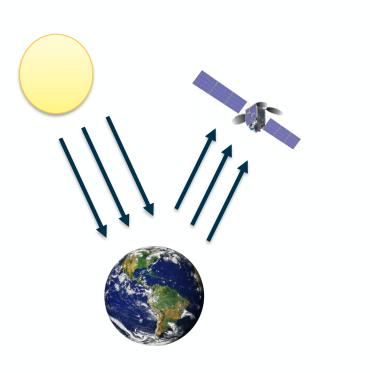


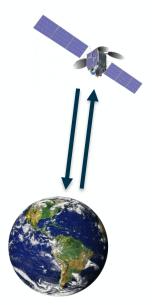
2 – it is an active sensor

Optical sensors are *passive*: they record sunlight reflected from the surface.

Radar is an *active* sensor: it illuminates the scene with its own signal.

This means radar can operate day and night, independently of sunlight.







3 – It is a coherent sensor

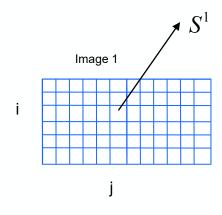
Unlike optical images, radar measures a *complex field* (magnitude + phase). The phase by itself may not be directly useful, but it carries hidden information that can be exploited later. (e.g. interferometry).

Aim: 2D image

A classical antenna

Mesurement: A complex coefficient

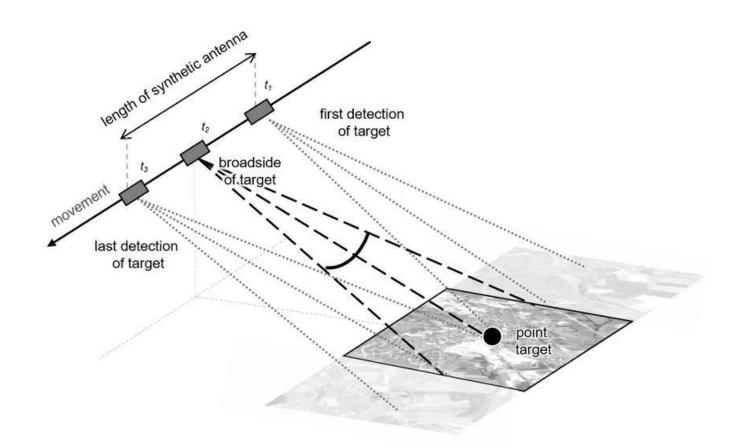
Only absolute value is ued





4 – The image is built by an algorithm (SAR)

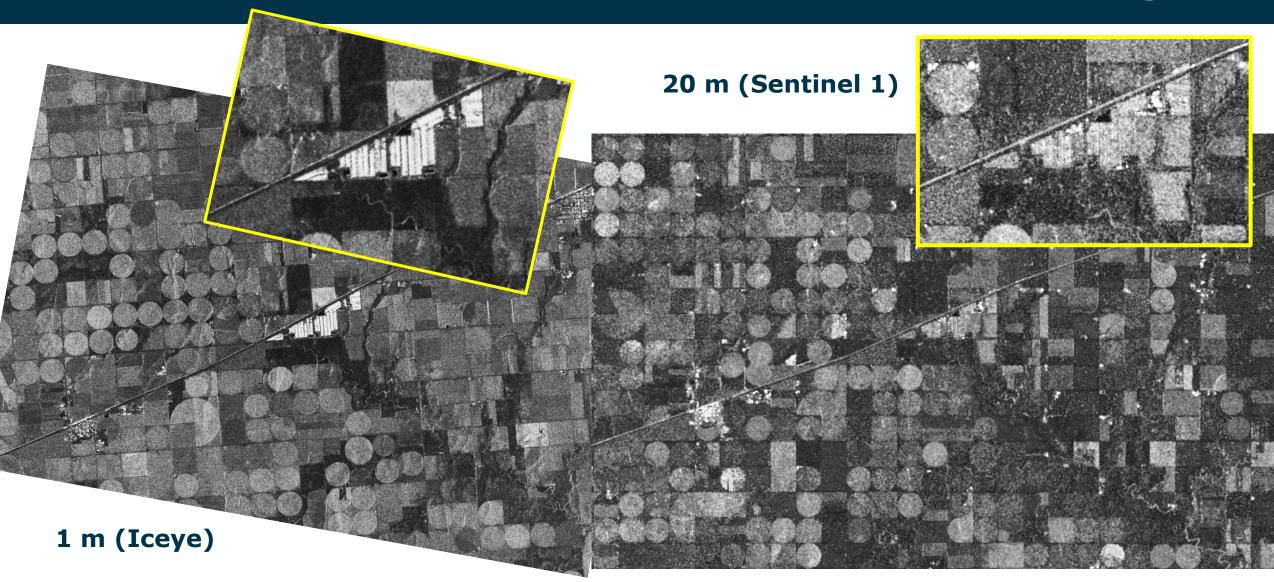
- A SAR image is synthesized, not taken like a photo.
- Spatial resolution depends on radar parameters (frequency, bandwidth, aperture), not on the physical size of a camera lens.



Source: Braun, A. (2019)

Influence of resolution

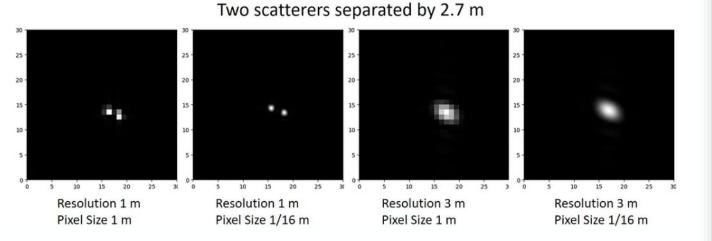


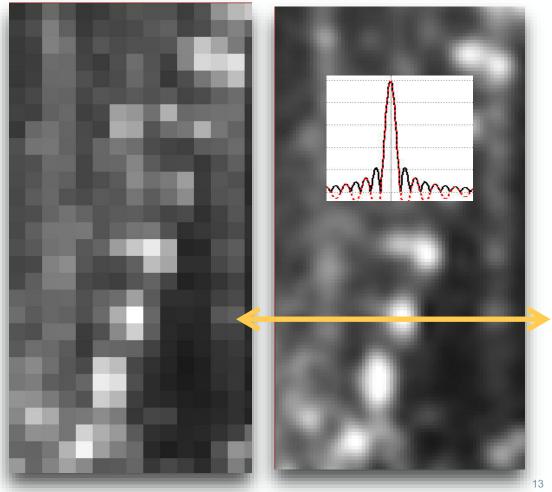






Same resolution....for different pixel sizes



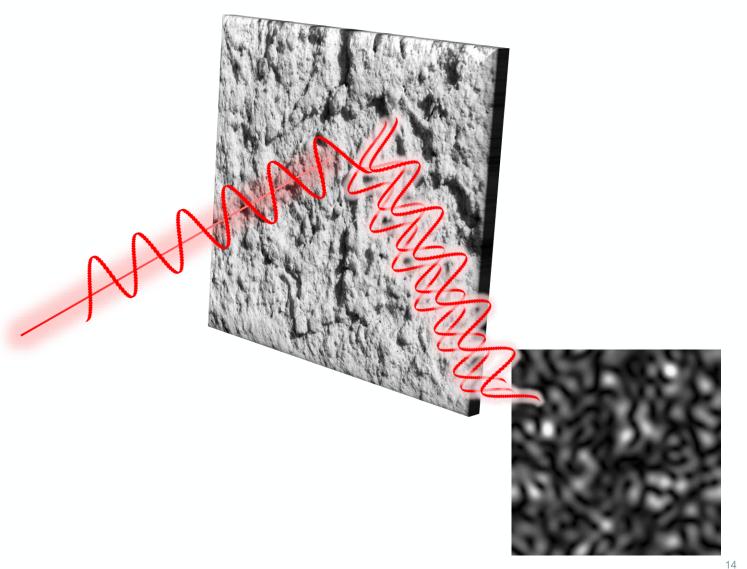




5 – It contains speckle

Radar images show *speckle*: a grainy pattern due to coherent interference.

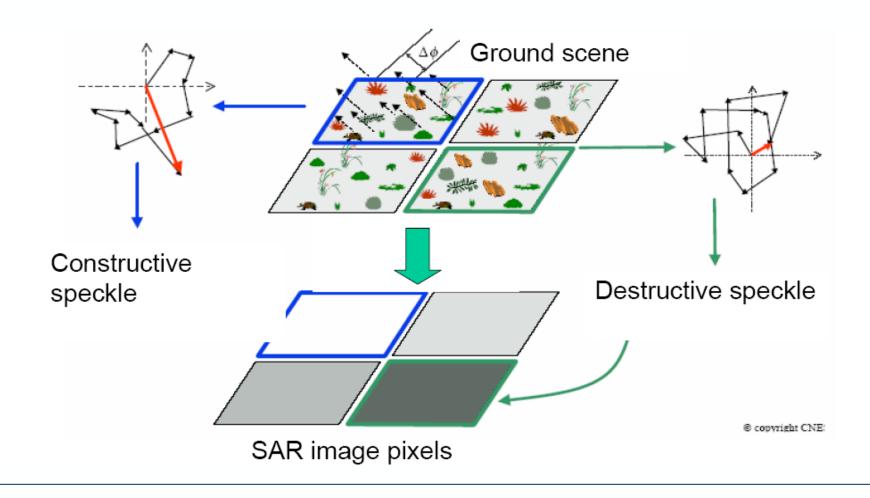
It appears because the image is synthesized (SAR processing) with a coherent source, not taken like a photo.



Why speckle?



Because when a scene is illuminated with a coherent wave (like radar), the echoes from many scatterers interfere constructively or destructively, creating a grainy pattern in the image.

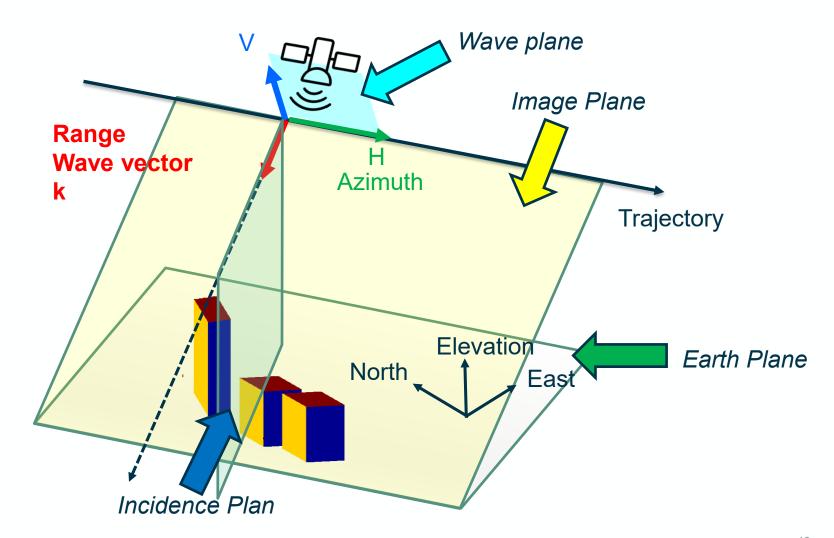




6 – Geometry is tricky

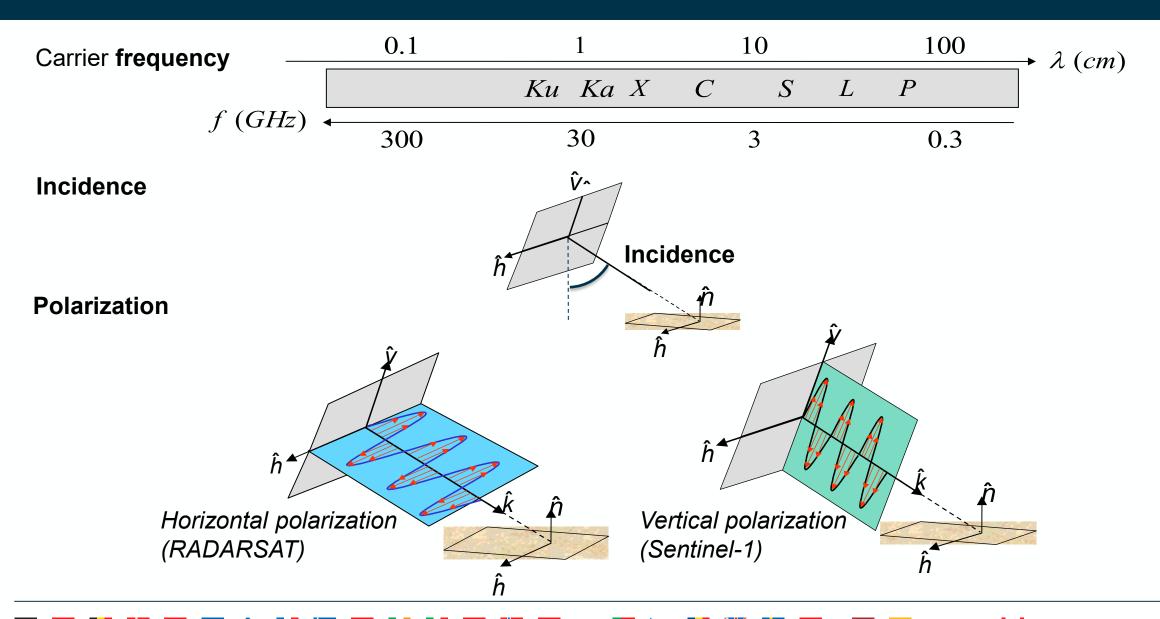
Geometry in radar images is **unusual**: distances are measured in *slant range*, not straight on like a photo.

This causes **distortions** (layover, foreshortening, shadow) specific to SAR.



Critical Parameters





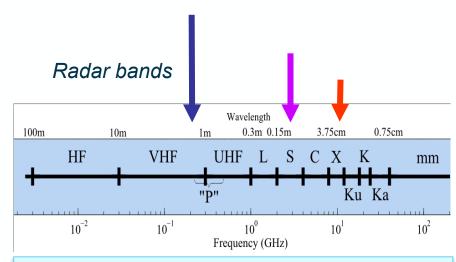
Applications to agriculture



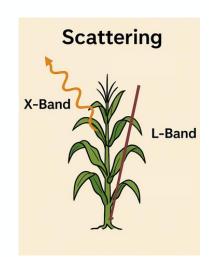
soil moisture, crop type mapping, biomass, phenology

Challenges: sensitivity to humidity, need for fine calibration

Choice of frequency



The longer the wavelength, the greater the sensitivity to the vertical structure of vegetation



	rango	
P-band	30-100 cm	Canopy penetration, subsurface imaging, biomass estimation
L-band	15-30 cm	Canopy penetration, subsurface imaging, biomass estimation
S-band	8-15 cm	Vegetation monitoring, ice monitoring, subsidence monitoring
C-band	4-8 cm	Change detection, ice monitoring, vegetation monitoring
X-band	2.5-4 cm	Snow monitoring, urban monitoring

Application Examples

Wavelength

range

Band

Product levels



Processing Type	Processing Level	Image Type	Product Description
Raw Data	L0, L1.0, Raw	Unfocused	Unprocessed signal data. Requires a SAR processor to be visualized.
Single Look Complex (SLC)	L1.1, SLC	Focused (single look); has speckle	Contains amplitude and phase values. Retains slant-range geometry.
Amplitude	L1, L1.5, GRD (Ground Range Detected)	Focused (multilooked); reduced speckle	Projected to ground range coordinates.
Corrected Amplitude	Radiometric Terrain Correction (RTC)	GIS-compatible	Image has had radiometric and terrain correction applied.

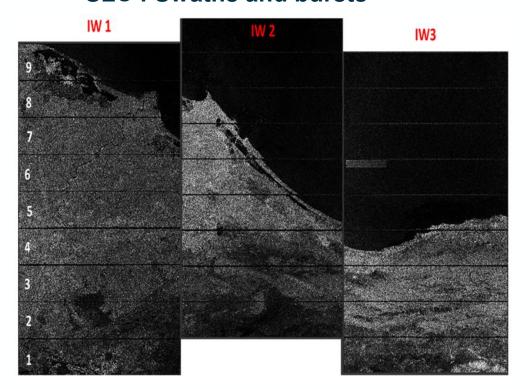
The case of Sentinel-1

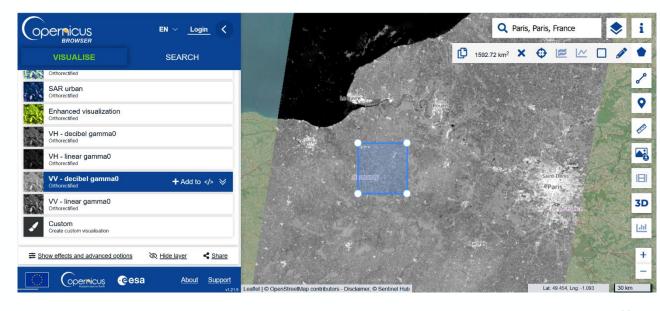


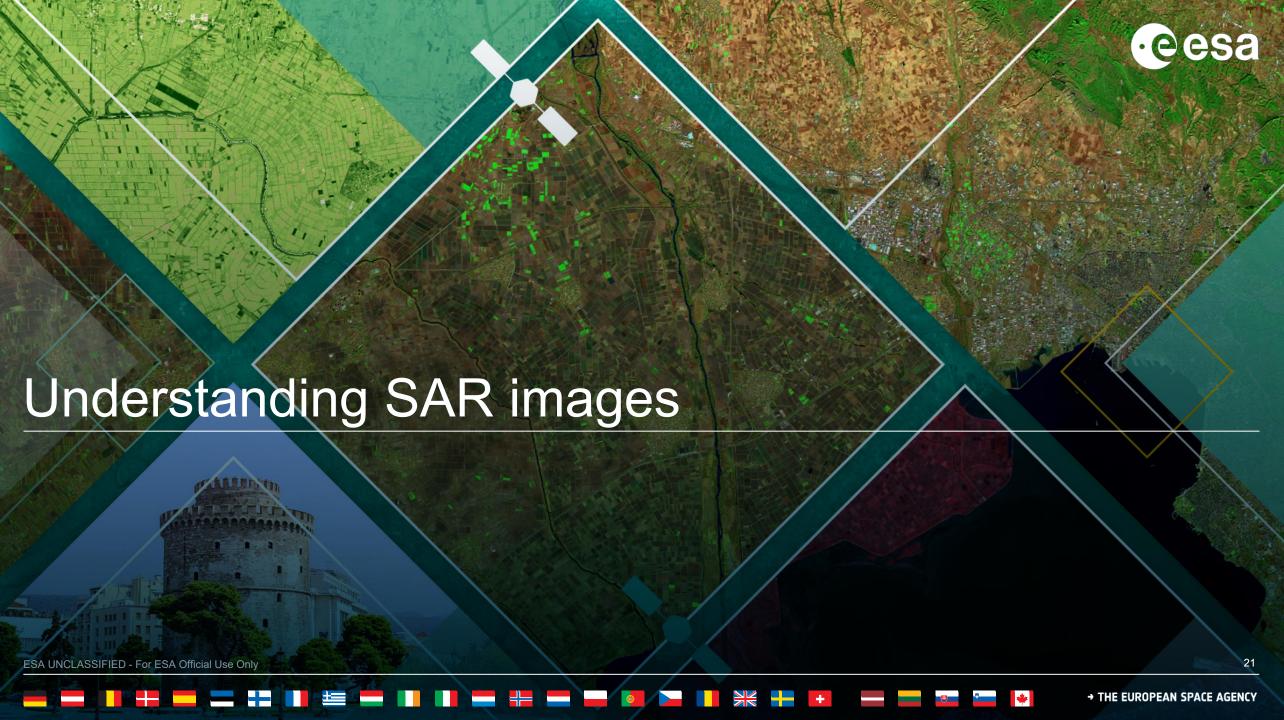
Important: **SLC** = phase+amplitude, needed for InSAR/polSAR;

GRD = detected map alone, ideal for mapping & classification.

SLC: Swaths and bursts







Radar image

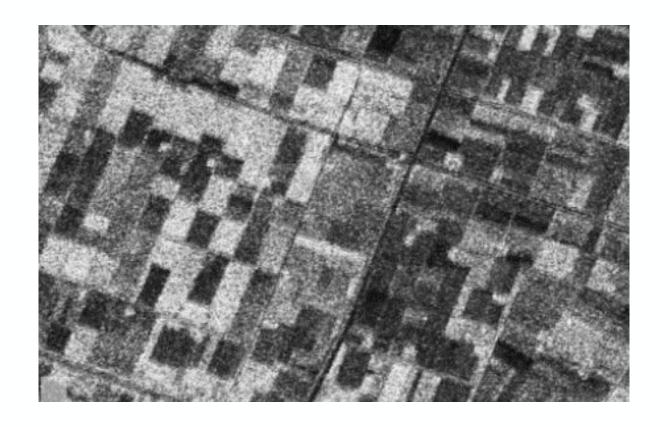


In an active system such as radar, the brightness of the image depends on the portion of energy that the illuminated surface returns to the radar.

Bright areas are produced by strong backscatter signal intensities, and **dark areas** by weak responses.

The final intensity depends on:

- Geometric effects
- Material properties (electromagnetism)
- Statistical effects related to image formation and post-processing (statistics and speckle)



What are the physical quantities in a SAR image?



Radar cross section: for point targets

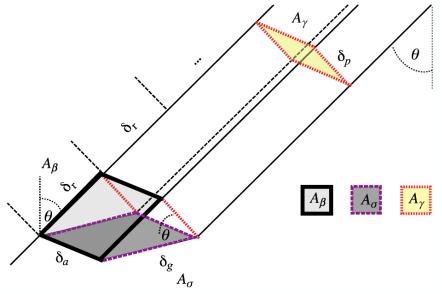
$$\sigma=rac{(4\pi)R^2P_r}{P_i}$$

area of a perfect sphere that would reflect the same amount of energy back to the radar as the observed target.

Backscatter coefficient: for natural targets

 $\sigma^0 = \sigma/A$

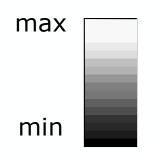
 $\underline{\beta0}$, $\underline{\sigma0}$, or $\underline{\gamma0}$ relate to the reference area used to normalise the backscatter



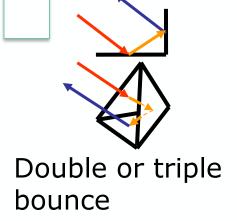
https://medium.com/@elisecolin/what-are-the-physical-quantities-in-a-sar-image-c788a8265abd

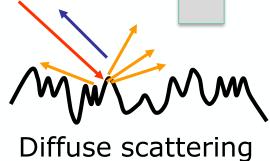
SAR depends on geometric structure

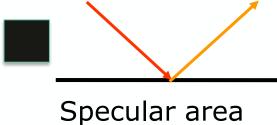








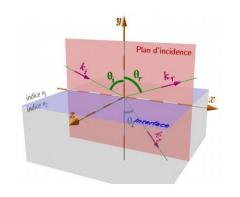




SAR depends on the material properties



For a given material and frequency, we can associate a (relative) complex dielectric constant.



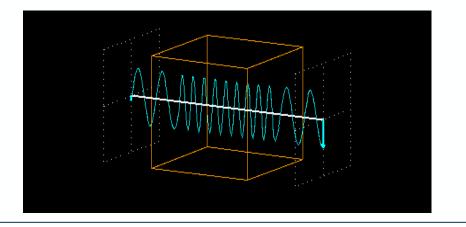
$$\epsilon_{\rm r}(\omega) = \epsilon'(\omega) - j \epsilon''(\omega)$$

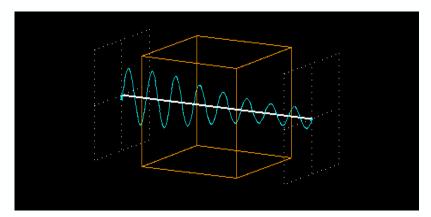


This controls how waves penetrate or get attenuated in the medium.

Refractive index **Propagation speed**







Metal:

$$\epsilon_r^{"}(\omega) = 1 - j \infty$$

SAR depends on the material.



Effect of Water on Dielectric Constant

Increases ε' (real part): stronger reflections, reduced penetration.
Increases ε'' (imaginary part): higher absorption, stronger attenuation.

Variations due to different meteorogical conditions (TSX images, Saclay, France)





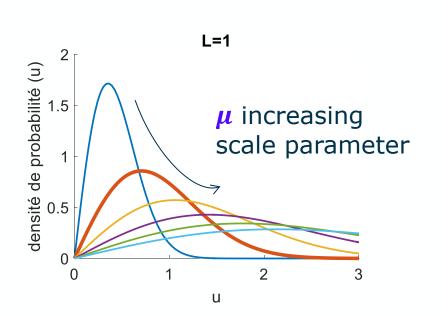


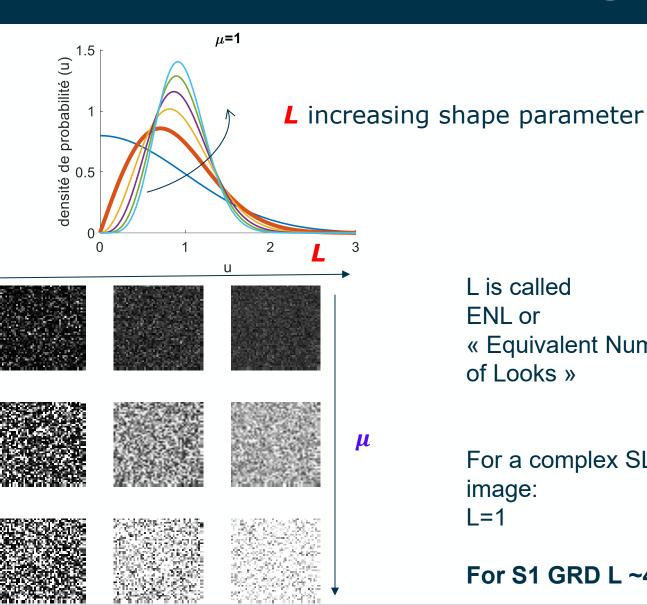
Statistical effects



Speckle amplitude: Rayleigh Nakagami (µ, L)

Speckle Intensity: Gamma(µ, L)





L is called ENL or « Equivalent Number of Looks »

For a complex SLC image: L=1

For S1 GRD L ~4.7

What does influence the signal



The sensor The scene

The frequency



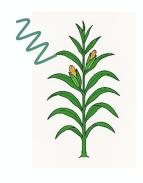
The incidence angle

The polarization



The dielectric constant

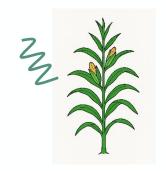
















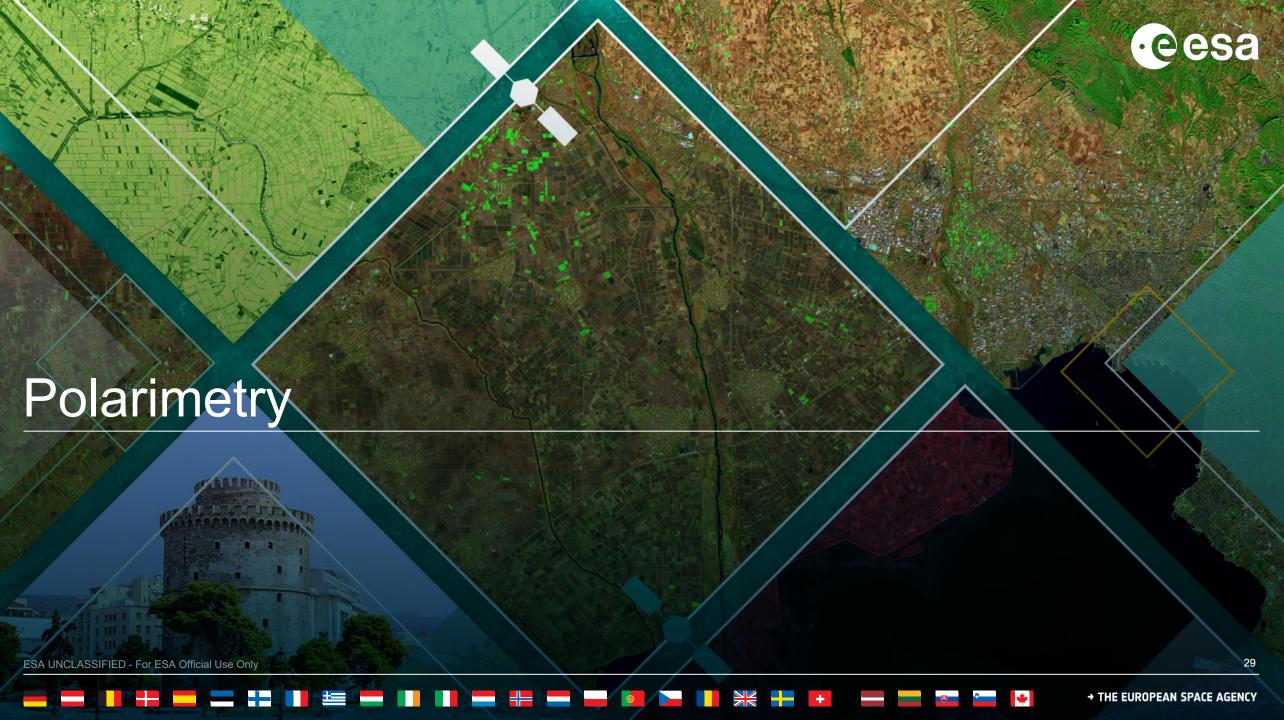






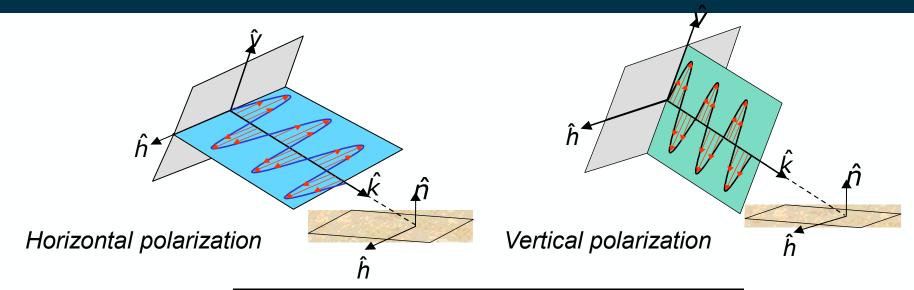
dry

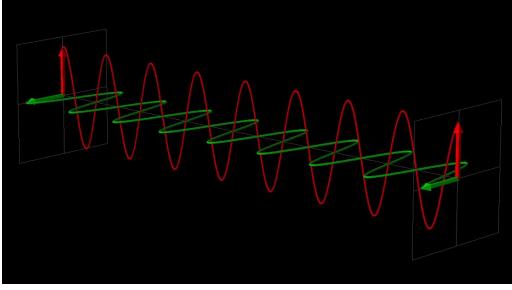
wet



An electromagnetic wave is polarized

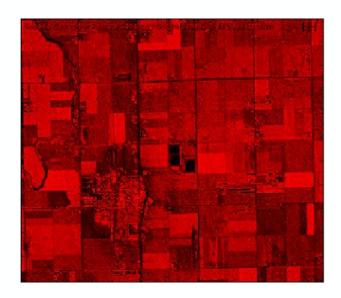


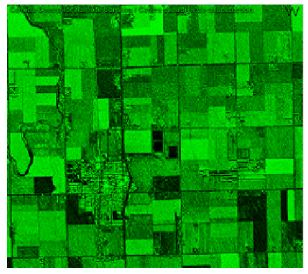




Polarimetry: adding a new dimension

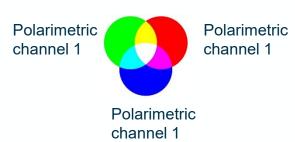






Like color in optical images, polarimetry provides an extra layer of information, offering richer possibilities for interpreting scattering mechanisms.



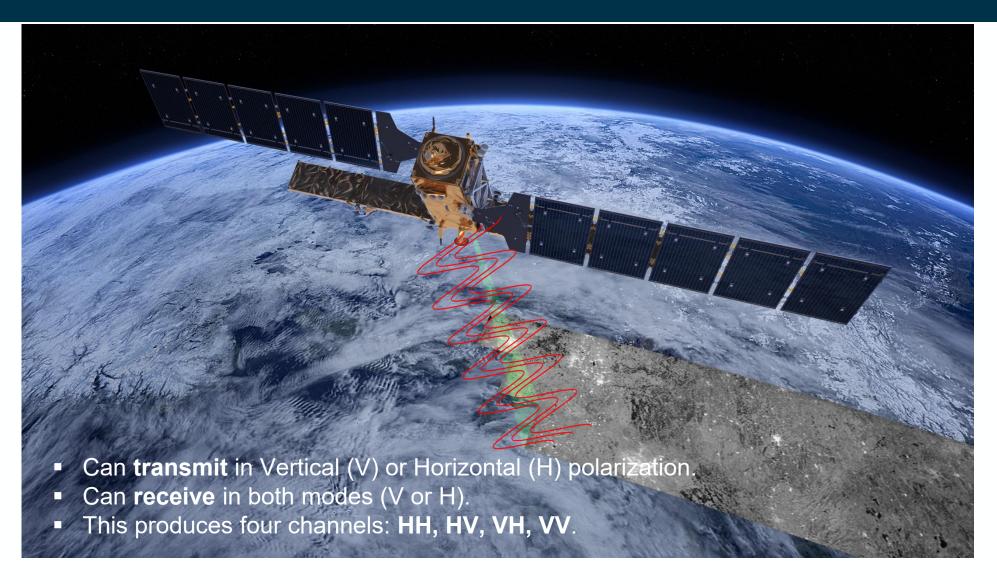


A false "color" polarimetric representation:



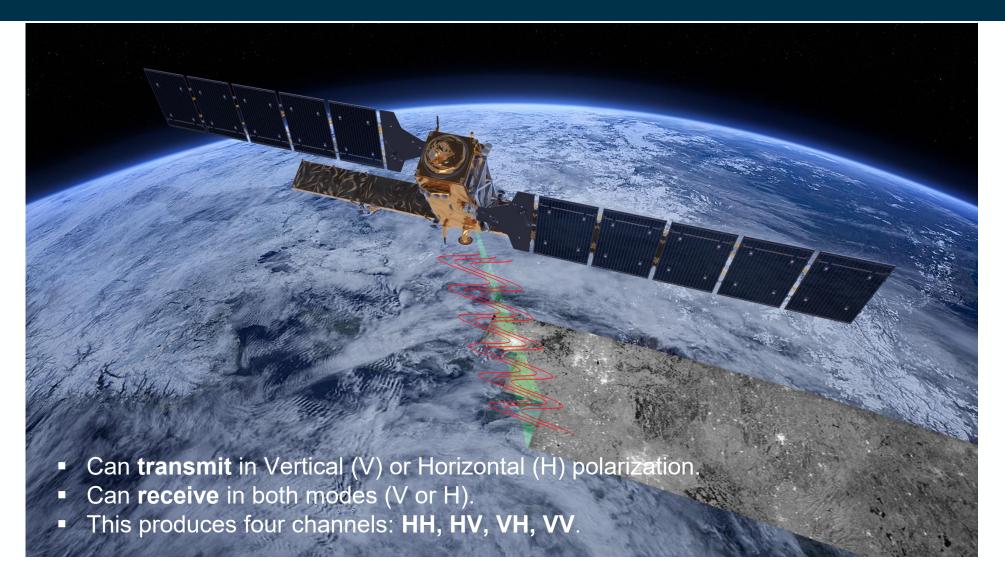
A Classical polarimetric radar





A Classical polarimetric radar





Polarimetry: what for in agriculture?



What for?

crop type mapping, soil moisture estimation, wetland monitoring: delineation and characterisation

intensive use of **scattering models**, in order to separate soil and vegetation scattering and to invert for soil moisture from the isolated ground component.

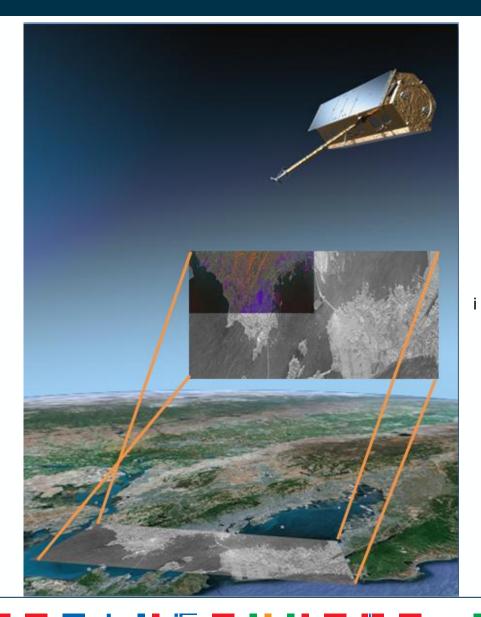
phenology estimation: treated as a **classification** problem as well, by regarding the different stages as different classes.





What is a full polarimetric image?

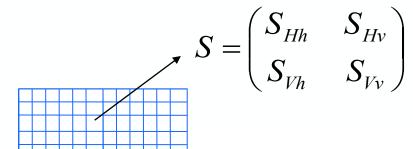


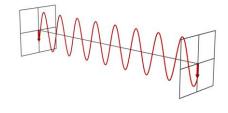


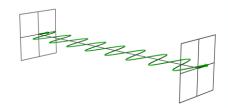
1 polarimetric antenna

Mesurement:

A 2x2 matrix for earch pixel







Partial polarimetry



Dual Pol: HH / VV

$$S = egin{pmatrix} S_{Hh} & S_{Hv} \ S_{Vh} & S_{Vv} \end{pmatrix}$$

TSX dual

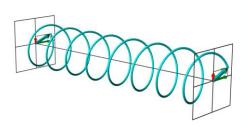
Stokes (or dual Co-pol/cross-pol) HH/HV, VH/VV

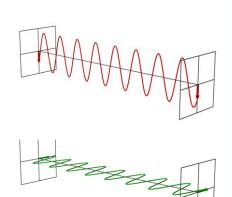
$$S = \begin{pmatrix} S_{Hh} & S_{Vh} \\ S_{Hv} & S_{Vv} \end{pmatrix}$$

Sentinel-1

Hybrid, Compact Pol

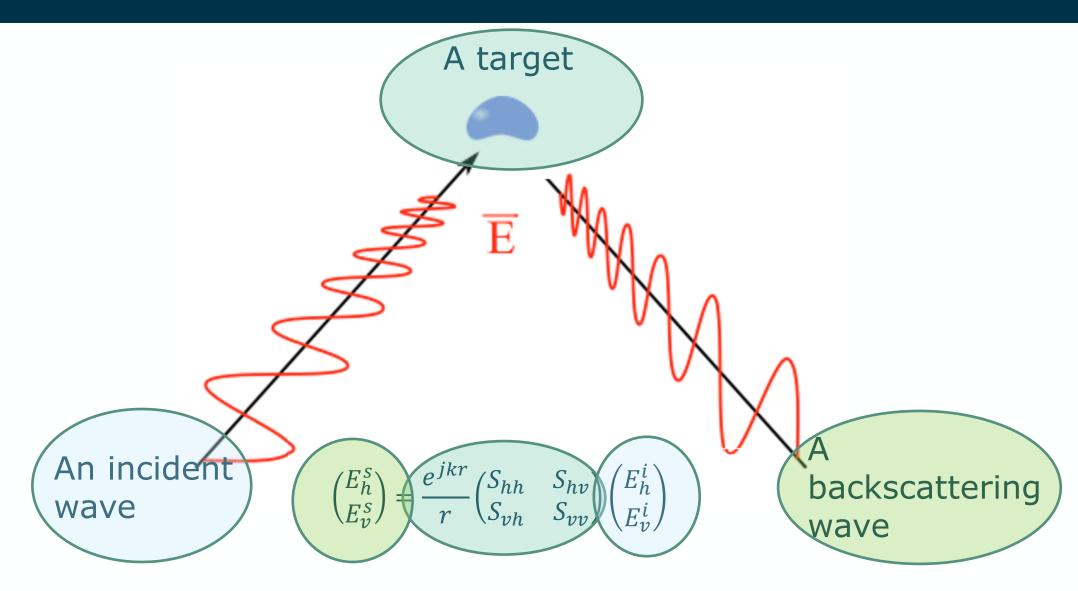
$$\begin{pmatrix} S_{Rh} \\ S_{Rv} \end{pmatrix}$$





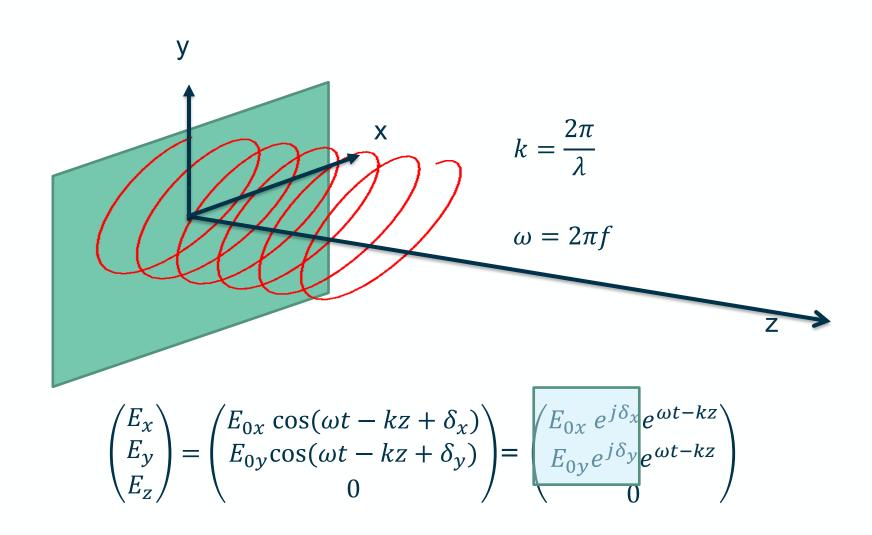
Polarimetry describes...





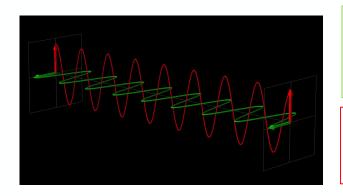
An electromagnetic wave is polarized





Describing the wave: the Jones vector



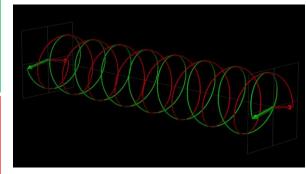


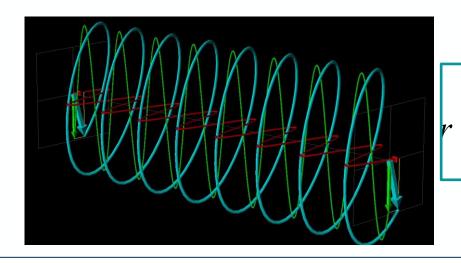
$$H = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

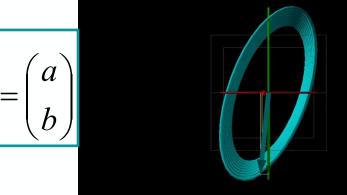
$$V = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

$$R = \begin{pmatrix} 1 \\ j \end{pmatrix}$$

$$L = \begin{pmatrix} j \\ 1 \end{pmatrix}$$







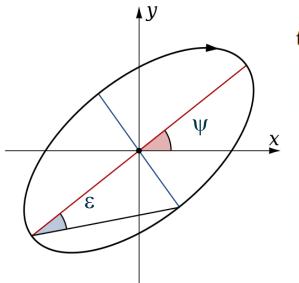
Describing the wave: the Stokes vector



deterministic, complex, No average

non deterministic, intensities only

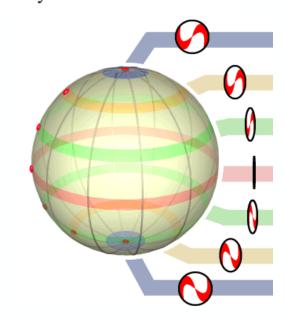
$$J = \begin{pmatrix} E_{x} \\ E_{y} \end{pmatrix} \qquad \mathbf{S} = \begin{pmatrix} \langle |E_{x}|^{2} + |E_{y}|^{2} \rangle \\ \langle |E_{x}|^{2} - |E_{y}|^{2} \rangle \\ \langle 2\Re(E_{x}E_{y}^{*}) \rangle \\ \langle 2\Im(E_{x}E_{y}^{*}) \rangle \end{pmatrix} = \begin{pmatrix} s_{0} \\ s_{1} \\ s_{2} \\ s_{3} \end{pmatrix}$$



$$\tan(2\psi) = \frac{2|E_{x}||E_{y}|}{|E_{x}|^{2} - |E_{y}|^{2}} \cos \delta$$

$$\sin(2\epsilon) = \frac{2|E_{\mathbf{x}}||E_{\mathbf{y}}|}{|E_{\mathbf{x}}|^2 + |E_{\mathbf{y}}|^2} \sin \delta,$$

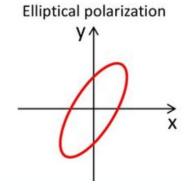
$$\delta = \arg(E_{\mathbf{x}}E_{\mathbf{y}}^*)$$

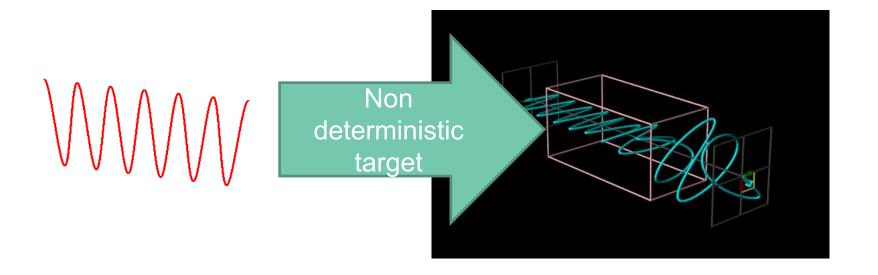


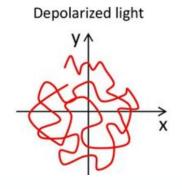
Describing a target







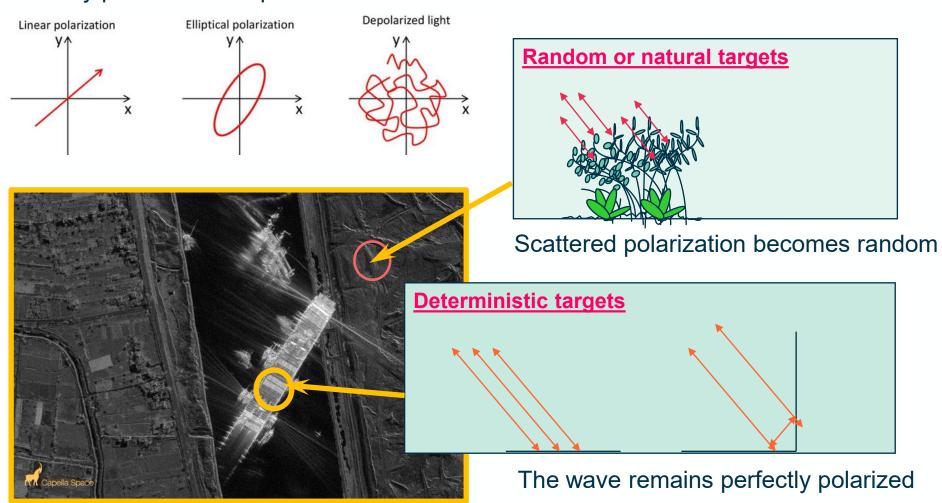




Deterministic / Non deterministic targets



Partially polarized or unpolarized waves



A deterministic target: the Sinclair matrix



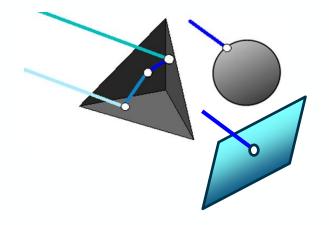
$$S = \begin{bmatrix} S_{hH} & S_{hV} \\ S_{vH} & S_{vV} \end{bmatrix}$$

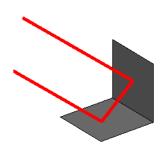
complex-valued 2x2 matrix describing how a target transforms the polarization of an incident plane electromagnetic wave into the polarization of the wave scattered by the target

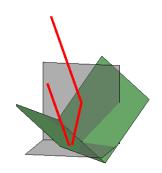
$$S = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$S = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \qquad S = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

$$S = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$







A deterministic target: the polarimetric vector



The diffusion vector: In Pauli basis

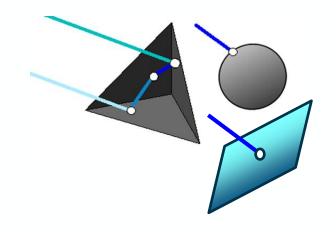
$$k = \frac{1}{\sqrt{2}} \begin{pmatrix} S_{hH} + S_{vV} \\ S_{hH} - S_{vV} \\ 2S_{hV} \end{pmatrix}$$

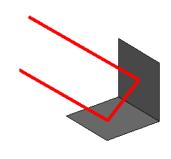
HH-VV HV+VH

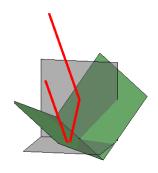
$$k = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$k = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$k = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

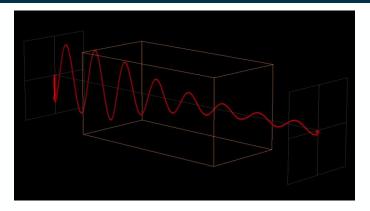






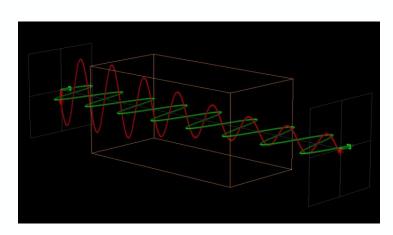
Optical interpretation



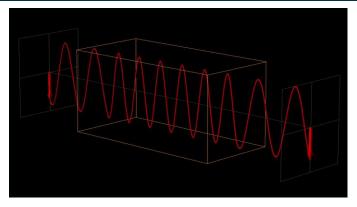


Attenuation

the imaginary part of the relative permittivity modifies amplitude

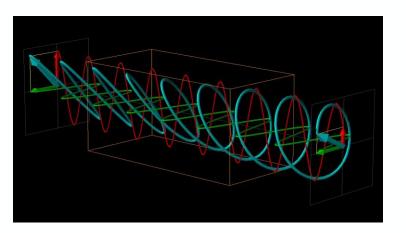


Linear diattenuation



Retardance

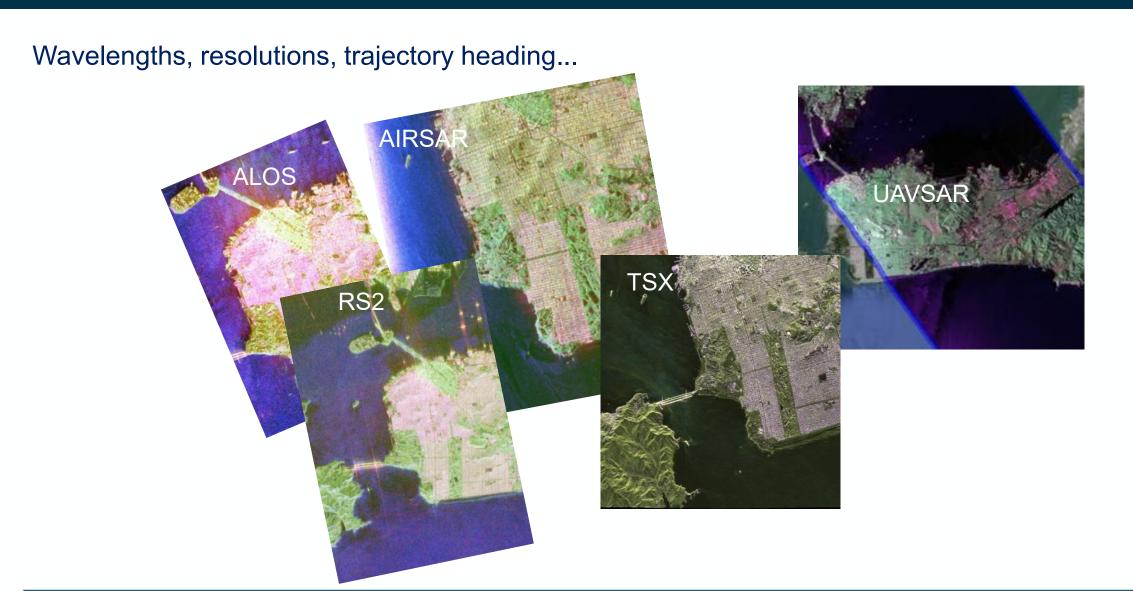
the real part of the relative permittivity : modifies propagation speed



Linear retardance

Like backscattering, polarimetry depends on...





Describing a random media



When dealing with **natural** media, the polarimetric signal is considered random; by forming the coherence matrix, we add statistical information to describe the scattering behavior of such complex environments.

$$k = \frac{1}{\sqrt{2}} \begin{pmatrix} S_{hH} + S_{vV} \\ S_{hH} - S_{vV} \\ 2S_{hV} \end{pmatrix}$$

$$T = \langle k | k^H \rangle$$
Polarimetric coherence matrix

$$T = \langle k | k^H \rangle$$

coherence matrix

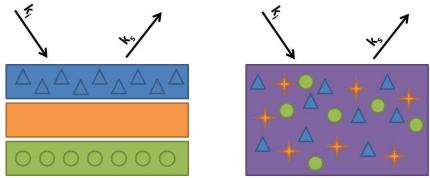
$$T = \frac{1}{2} \begin{pmatrix} <\left|S_{hH} + S_{vV}\right|^{2} > & <(S_{hH} + S_{vV})(S_{hH} - S_{vV})^{*} > & <(S_{hH} + S_{vV})(2S_{hV})^{*} > \\ <(S_{hH} - S_{vV})(S_{hH} + S_{vV})^{*} > & <\left|S_{hH} - S_{vV}\right|^{2} > & <(S_{hH} - S_{vV})(2S_{hV})^{*} > \\ <(2S_{hV})(S_{hH} + S_{vV})^{*} > & <(2S_{hV})(S_{hH} - S_{vV})^{*} > & <\left|2S_{hV}\right|^{2} > \end{pmatrix}$$

Different kind of polarimetric decompositions

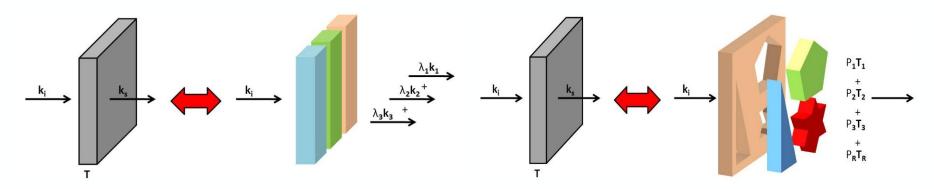


Polarimetric decompositions express the coherence matrix **T** in terms of simpler matrices or physical components, making the complex scattering information easier to interpret.

Multiplicative versus additive



Mathematics Versus Physical Model



One example: Freeman–Durden decomposition



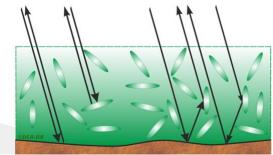
decomposes the coherence matrix into three physical contributions:

Surface scattering (bare soil or smooth surfaces),

Double-bounce scattering (vertical structures such as stems + soil),

Volume scattering (vegetation canopy).

$$T = \lambda_1 T_{surface} + \lambda_2 T_{dihedral} + \lambda_3 T_{volume}$$



$$[T_v] = f_v \begin{vmatrix} 2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

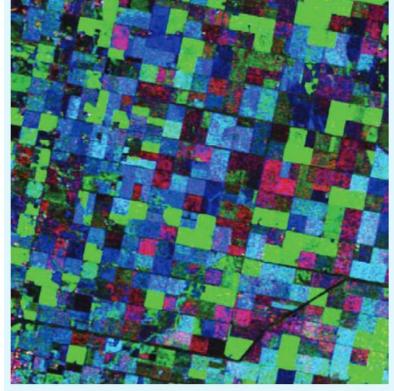
Why useful in agriculture?

Allows separation of soil and vegetation effects.

Volume scattering provides an indication of canopy density (biomass).

Double-bounce is linked to stem-ground interactions (e.g. rice, maize).

Surface scattering helps retrieve soil moisture, especially at the beginning of the season.



Freeman-Durden Decomposition (Quad-Pol)

Vegetation indices in polarimetric radar



DpRVI (Dual-Polarization Radar Vegetation Index)

useful for discriminating between vegetation and non-vegetated surfaces.

$$DpRVI = \frac{2 \cdot HV}{HH + VV}$$

RVI (Radar Vegetation Index) designed to estimate vegetation biomass

$$ext{RVI} = rac{4 \cdot HV}{HH + VV + 2 \cdot HV}$$

PRVI (Polarimetric Radar Vegetation Index) degree of dispersion in vegetation

$$ext{PRVI} = \sqrt{rac{T_{11} \cdot T_{22}}{T_{11} + T_{22}}}$$

DPSVI (Dual-Polarization Soil Vegetation Index): reduces soil influence

$$\text{DPSVI} = \frac{HH - VV}{HH + VV}$$
.

DPSVIm (Modified Dual-Polarization Soil Vegetation Index) modified version of DPSVI for improved discrimination between vegetation and soil in heterogeneous environments.

Degree of Polarization (DoP): complexity of the canopy, biomass

$$doP = \frac{\sqrt{(\langle S_{VV}S_{VV}^* \rangle - \langle S_{HV}S_{HV}^* \rangle)^2 + 4|\langle S_{VV}S_{HV}^* \rangle|^2}}{\langle S_{VV}S_{VV}^* \rangle + \langle S_{HV}S_{HV}^* \rangle}$$

What can we do with partial polarimetry (S1 VV/VH)?



$$S = \begin{pmatrix} S_{Hh} & S_{Vh} \\ S_{Hv} & S_{Vv} \end{pmatrix}$$

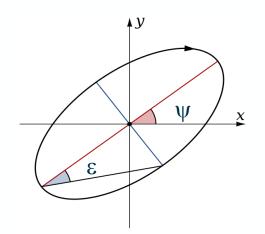
Sentinel-1

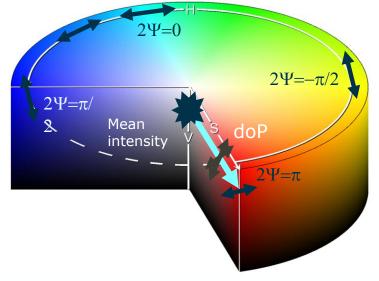
Allows to describe the elliptic polarization of the ellipse for fixed V emission

Degree of Polarization (DoP):

$$doP = \frac{\sqrt{(\langle S_{VV}S_{VV}^* \rangle - \langle S_{HV}S_{HV}^* \rangle)^2 + 4|\langle S_{VV}S_{HV}^* \rangle|^2}}{\langle S_{VV}S_{VV}^* \rangle + \langle S_{HV}S_{HV}^* \rangle}$$

Orientation, ellipticity of the polarimetric state

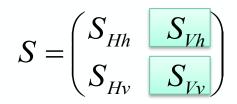




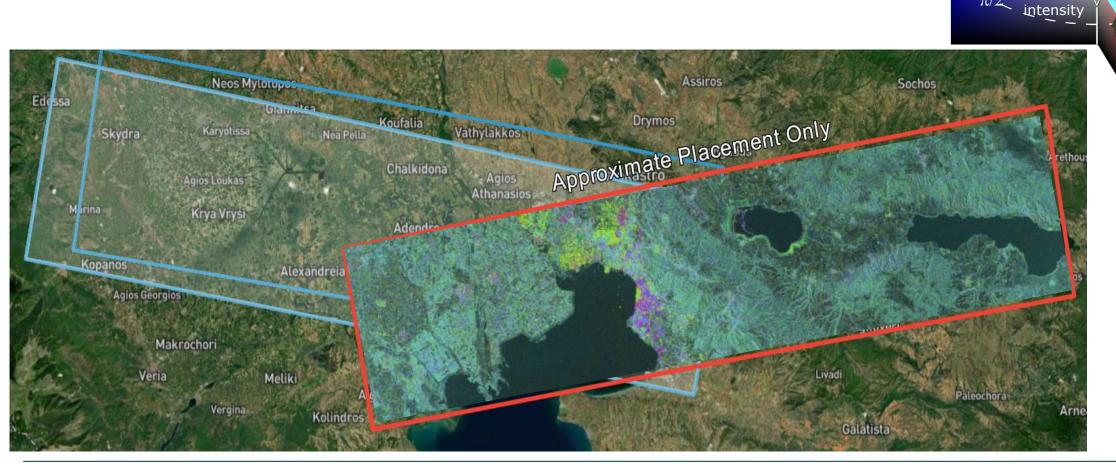
What can we do with partial polarimetry (S1 VV/VH)?

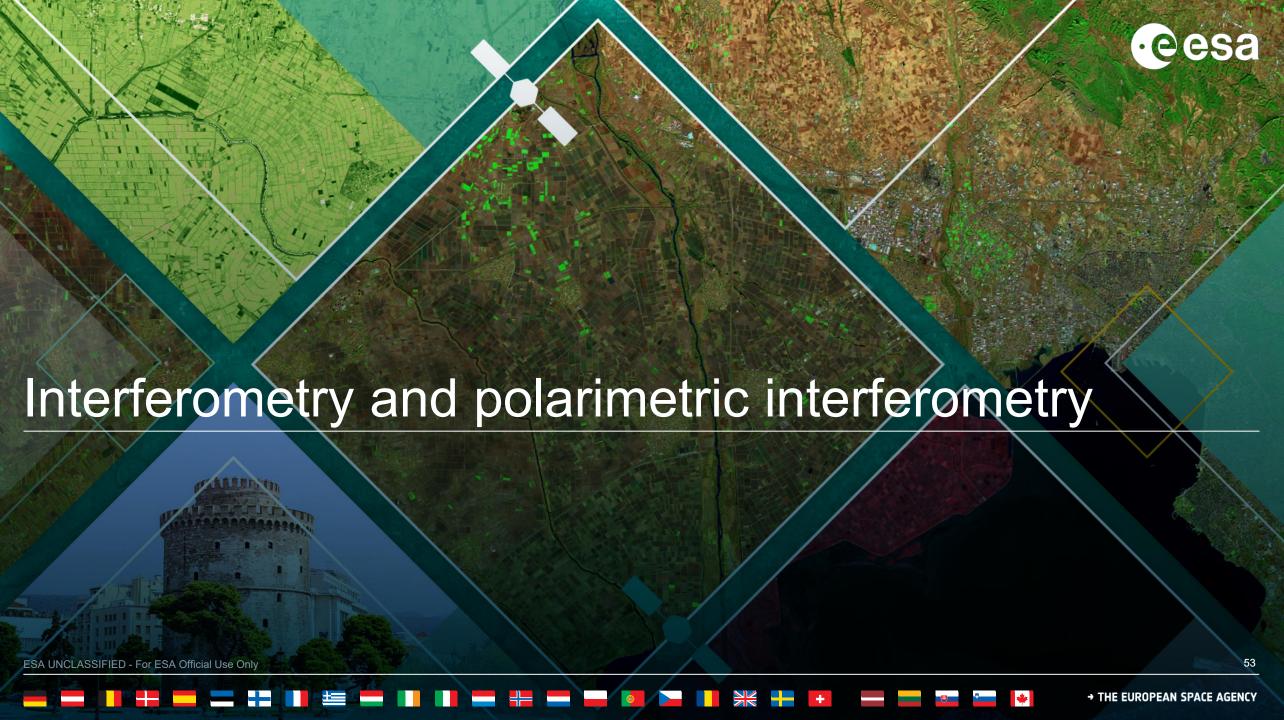


2Ψ=



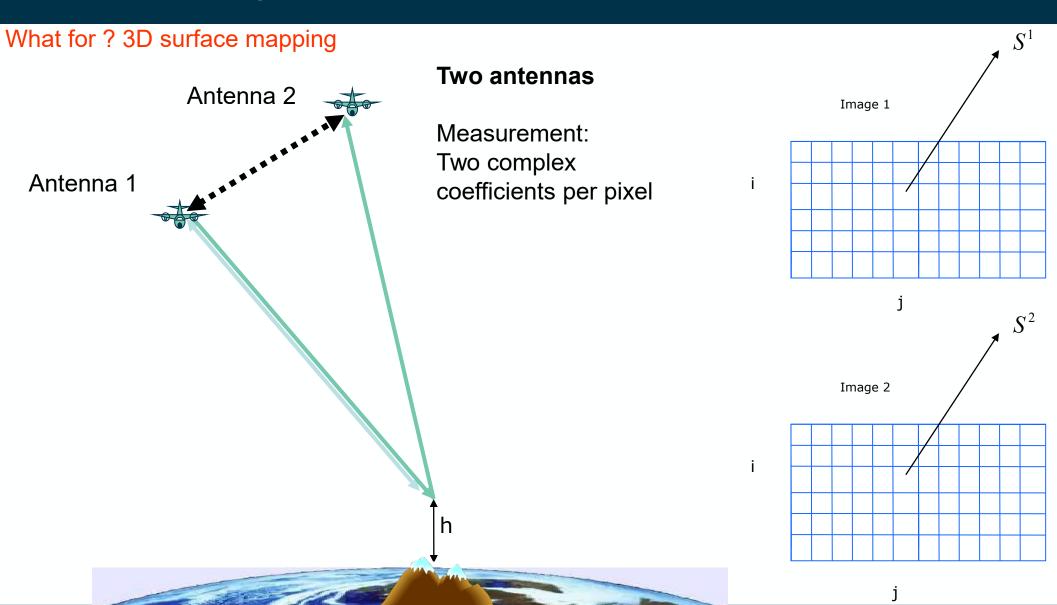
Sentinel-1





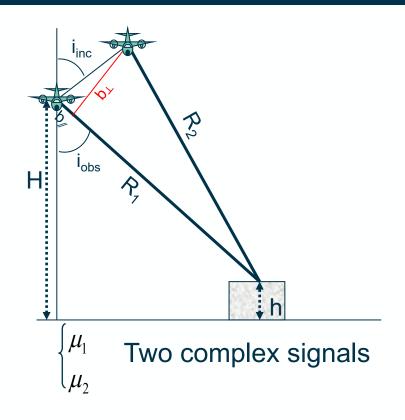
Interferometry





Interferometric coherence

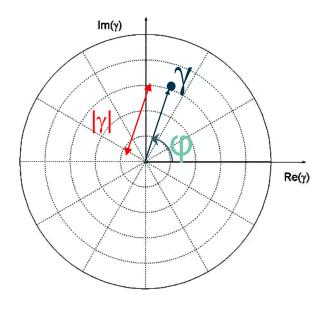




Interferometric coherence

$$\gamma_{1,2} = \frac{\langle \mu_1 | \mu_2^* \rangle}{\sqrt{\langle |\mu_1|^2 \rangle} \sqrt{\langle |\mu_2|^2 \rangle}}$$

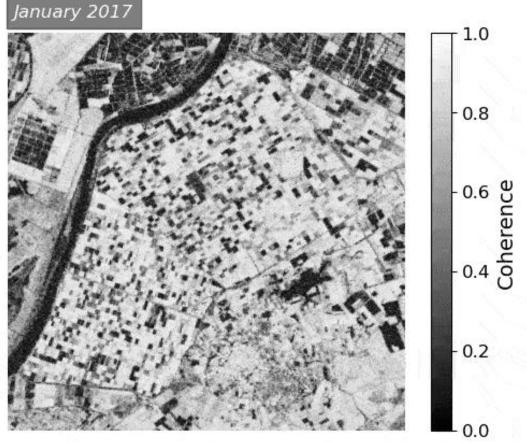
$$0 \le |\gamma_{1,2}| \le 1$$
 (Schwarz Inequality)



- The height h of the pixel is deduced from the phase ϕ =arg(γ)
- The degree of coherence is deduced from $|\gamma|$

Coherence levels are useful for crop analysis





year-long time series of data from 2017 combined pairs of Sentinel-1 images of an agricultural area in Seville, Spain.

University of Alicante

Interferometry can improve the generation of crop-type maps

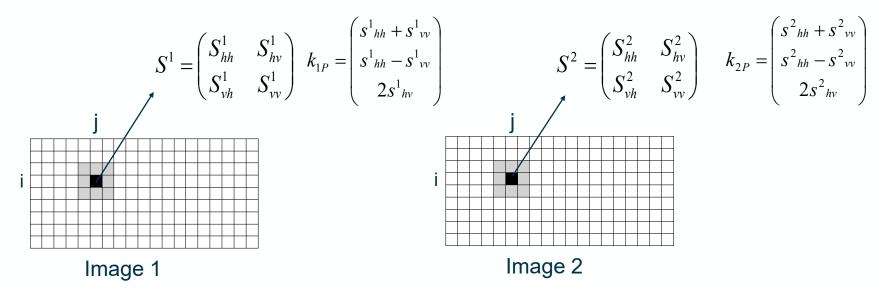
Interferometric coherence is sensitive to crop growth:

- drops during the growing season (structural changes in the canopy),
- increases again out of season when fields are bare or stable.

http://www.sincohmap.org/

Polarimetric interferometry





$$k = \begin{bmatrix} k_1 \\ k_2 \end{bmatrix} \Longrightarrow \langle T \rangle = \langle kk^{\dagger} \rangle = \begin{bmatrix} \langle T_{11} \rangle & \langle T_{12} \rangle \\ \langle T_{12} \rangle^{\dagger} & \langle T_{22} \rangle \end{bmatrix}$$

$$T_{11} = \langle k_1 k_1^+ \rangle$$
 $T_{22} = \langle k_2 k_2^+ \rangle$
 $T_{12} = \langle k_1 k_2^+ \rangle$

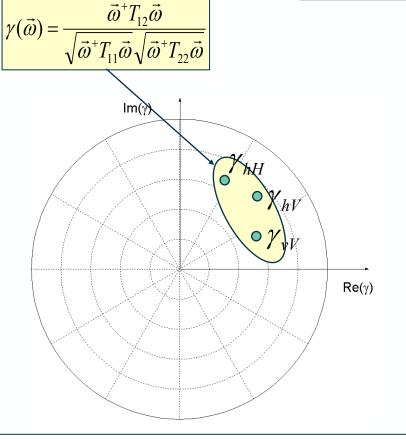
Generalized coherence set



generalized coherence

$$T_{11} = \langle k_1 k_1^+ \rangle$$
 Coherence matrices $T_{22} = \langle k_2 k_2^+ \rangle$ $T_{12} = \langle k_1 k_2^+ \rangle$ 3 x 3

Coherence



Applications:

- -coherence optimization for the estimation of heights
- target analysis: how to get the maximum information
- separation and interpretation of different heights

modeling





Frequency f

Polarization V,H

Incidence direction (θ, ϕ)

Sensor numbers

Scene: representation

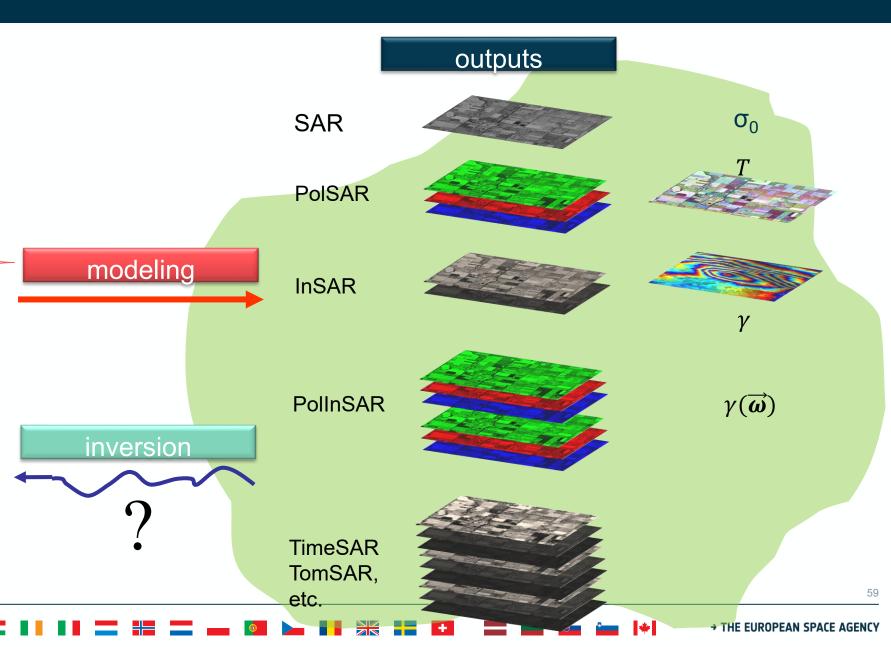






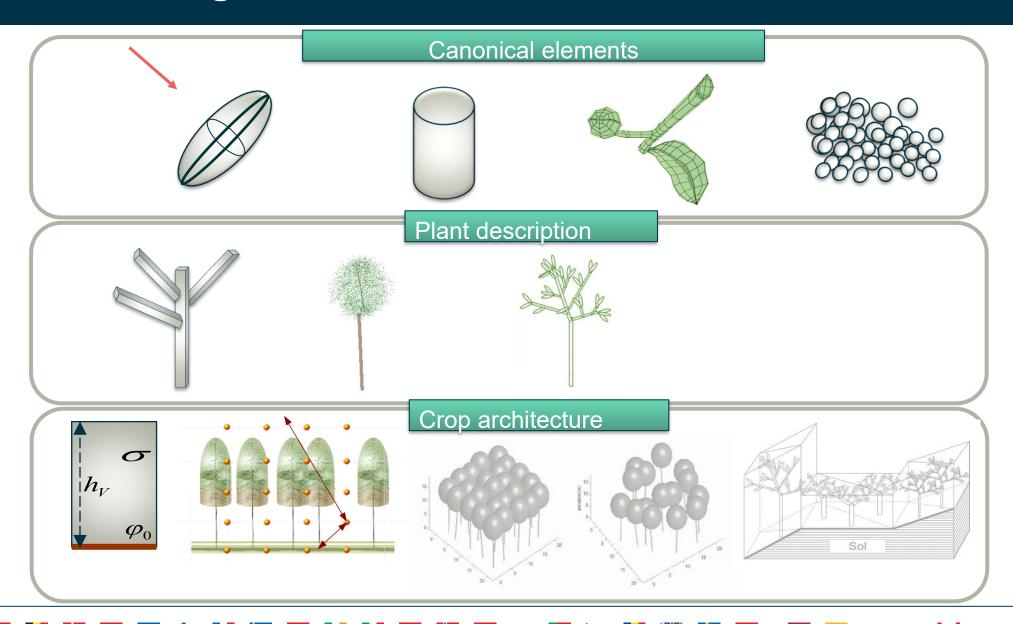






How choosing a model?

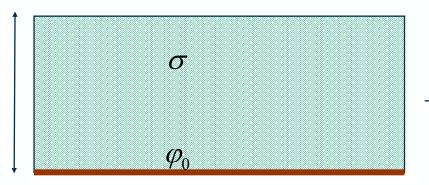




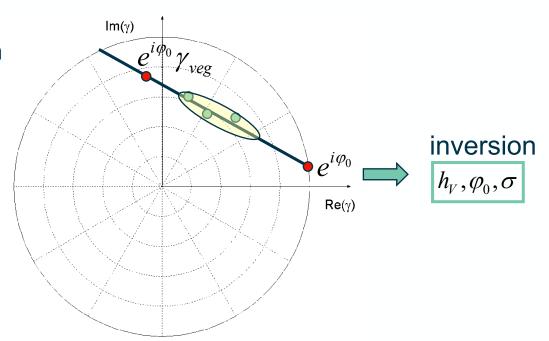
The Random Volume over Ground Model



The Random Volume over Ground (RVoG) model represents scattering as a combination of a vegetation volume above a ground surface



coherence set predicted by the model

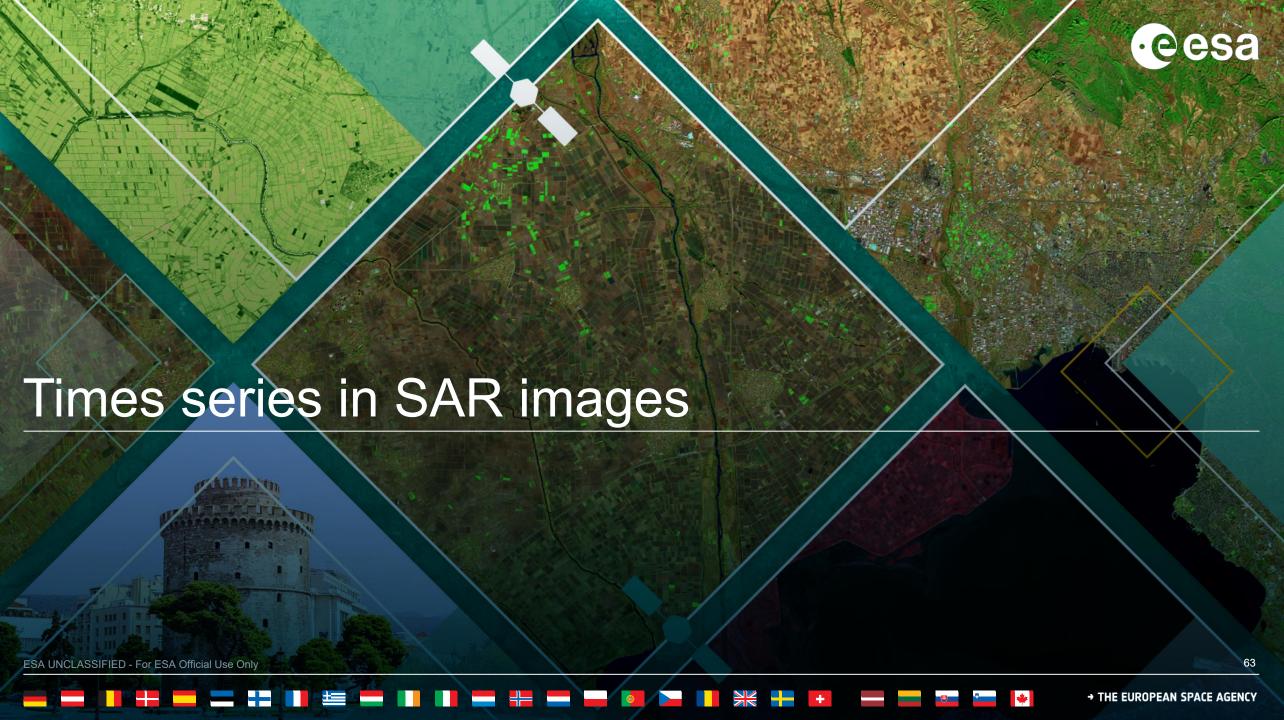


- widely used in forest remote sensing;
- its use in agriculture is limited, because crop canopies are thinner and change rapidly.

Models for vegetation in radar

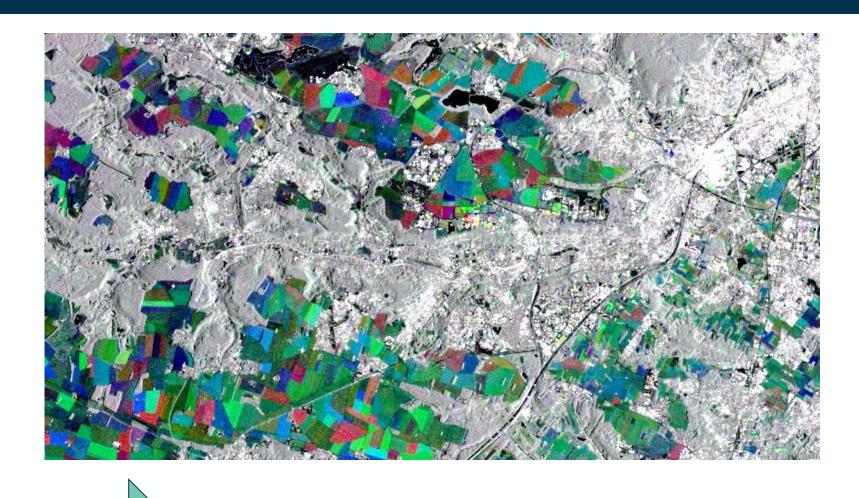


Model	Principle	Main use
Water Cloud Model (WCM)	Canopy as a "cloud" of scatterers above soil; signal = vegetation scattering + soil contribution attenuated by canopy.	Widely used in agriculture (biomass, LAI, soil moisture under crops).
MIMICS (Michigan Microwave Canopy Scattering)	Semi-empirical; combines surface, double-bounce, and volume scattering with canopy parameters.	Crop studies, but more complex to parameterize.
Radiative Transfer Models (RTM)	Canopy modeled as a random distribution of particles (leaves, stems) with absorption and scattering.	Link radar signal to biophysical variables (biomass, structure).
RVoG (Random Volume over Ground)	Scattering modeled as vegetation volume above a reflective ground.	Mostly forestry (canopy height, biomass), limited for crops.







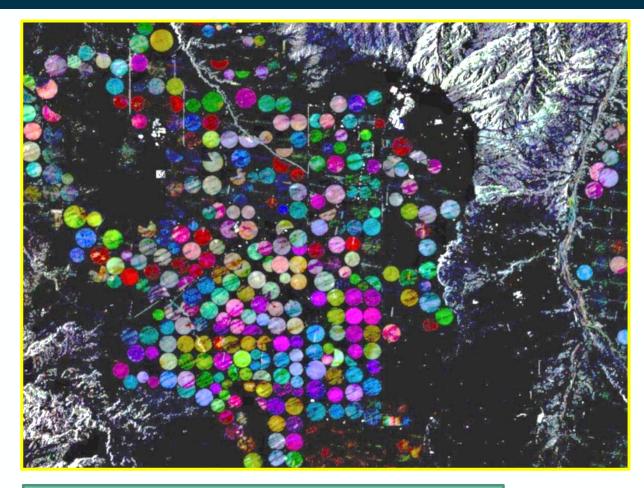


Generalizing to N dates

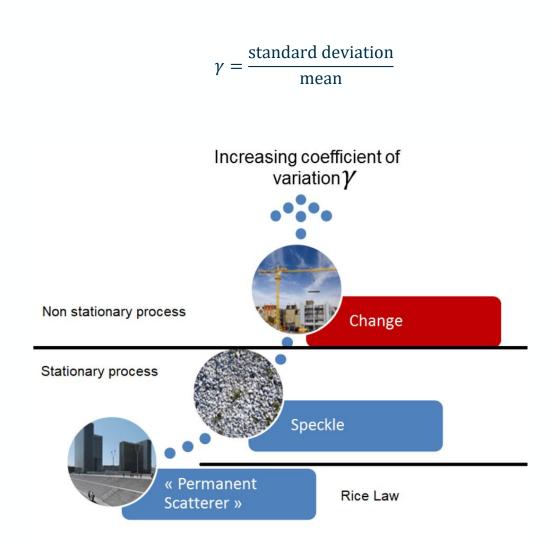
We reason in another space for describing colors: HSV

Proposition of a quick colored representation of changes





Colin E.; Nicolas, J.-M. Change Detection Based on the Coefficient of Variation in SAR Time-Series of Urban Areas. *Remote Sens.* **2020**







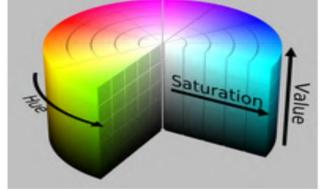


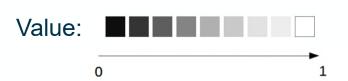


RGB Color Space: R, G, B

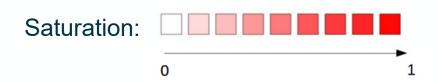


HSV Color Space: H, S, V



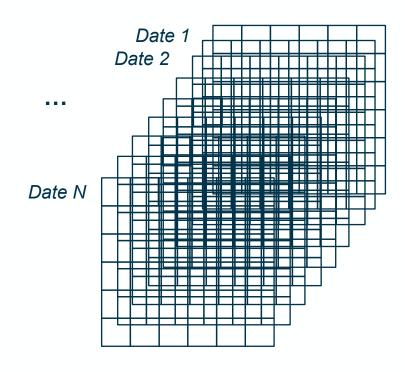


HSV Cylinder



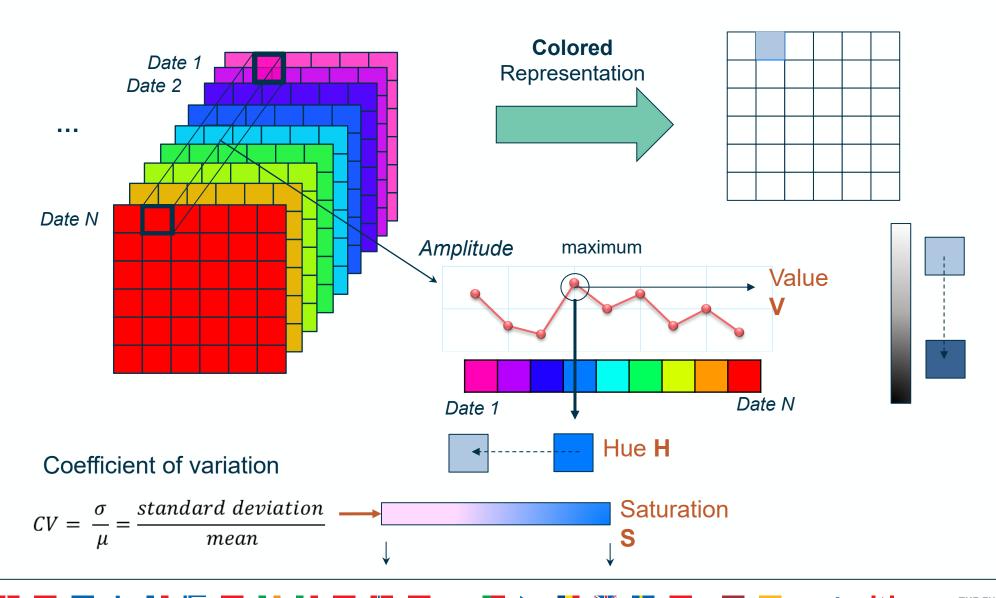












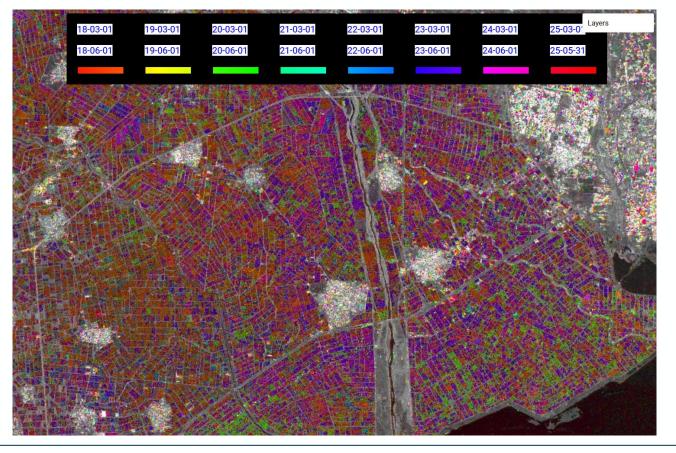
Seasonal variations



- Agricultural parcels are the most dynamic environments in a landscape their signals vary constantly, with very high coefficients of variation.
- By focusing on specific seasons, this variability can be analyzed in a more meaningful way.



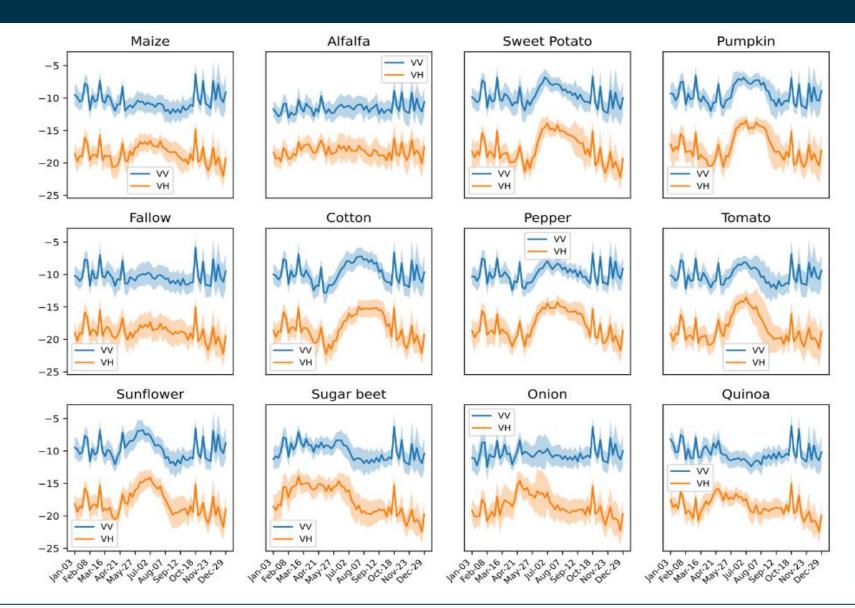




Towards time-series



Examples of Sentinel-1 temporal profiles for various agricultural crop



The use of SAR time-series for agriculture



Dynamic character:

- Crops change rapidly → strong temporal contrast.
- Different from forested areas, which are more stable + seasonal variations

Specific signature for each crop:

- Example: maize shows rapid growth and a strong peak before harvest.
- Cereals have a shorter cycle and a different profile.

Concrete applications:

- Crop type mapping.
- Phenology monitoring.
- Yield estimation or biophysical indicators (biomass, soil moisture)
- Mislabeling detection in ground truth

Deep autoencoding of time series



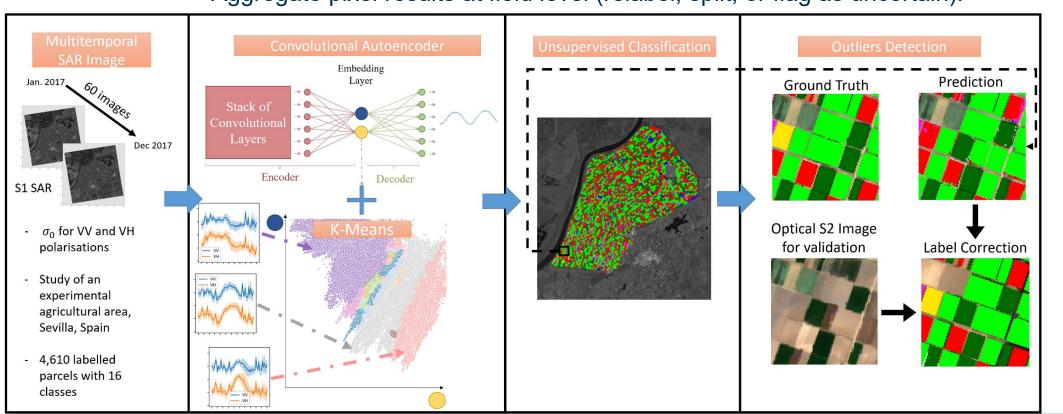
Application to unsupervised classification and mislabel detection: FARMSAR Method

Goal: Detect and correct mislabeled crop parcels using Sentinel-1 time series.

Approach: Train class-specific autoencoders on "clean" samples.

Use reconstruction error to flag anomalies (mislabels or mis-splits).

Aggregate pixel results at field level (relabel, split, or flag as uncertain).



Validation:

Artificial label noise + optical imagery (Sentinel-2).

Result: Robust relabeling, up to 98% accuracy, outperforming Random Forest.

- 7



Surface Soil Moisture Estimation under Crops



Key ideas

Radar signal = combined contribution of soil + vegetation. Under crops, soil moisture retrieval is more complex than bare soil.

Approaches

Use polarimetric decomposition to separate surface / dihedral / volume scattering.

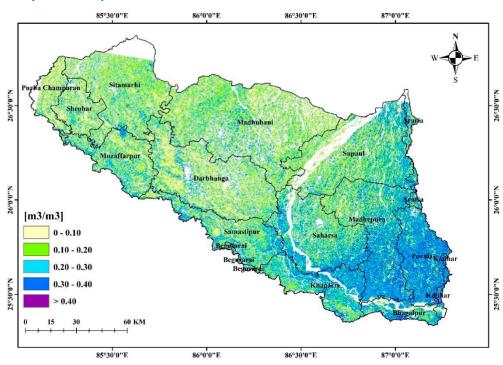
Invert soil contribution with EM models (empirical, semi-empirical, theoretical).

Best results when vegetation cover is not too dense.

Results & challenges

Quad-pol data improve separation of soil vs. vegetation effects. Some areas remain "non-invertible" (values non-physical). Accuracy depends strongly on incidence angle, frequency, and vegetation conditions.

Spatial distribution of estimated SSM (m³/m³) from C-band of Sentinel-1



Parida, B.R. et al. Surface Soil Moisture Retrieval Using Sentinel-1 SAR Data for Crop Planning in Kosi River Basin of North Bihar. *Agronomy* **2022**, *12*, 1045.

Crop Type Classification with Radar



Key ideas

Radar backscatter varies with crop structure and growth stage.

Different crops → different temporal & polarimetric "signatures."

Approaches

Supervised classification using radar features (σ° , coherence, polarimetric parameters).

Time series improve separability between crops.

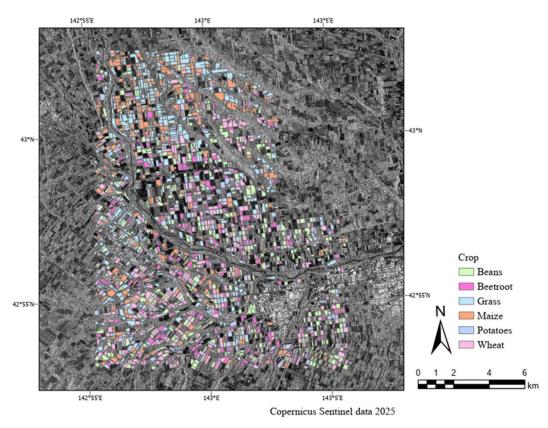
Multi-frequency & multi-polarization data further enhance accuracy.

Results & challenges

High accuracies reported (~80–90%) with multitemporal and polarimetric data.

Some crops remain difficult to separate.

Operational limits: few quad-pol sensors, frequent need to combine with optical data.



study area in Hokkaido, Japan

Crop Phenology with Radar



Key ideas

Crop structure evolves (height, biomass, density) → radar backscatter changes over time. Each growth stage corresponds to a specific radar "signature."

Approaches

Time series analysis to follow transitions between stages.

Classification of phenological stages as temporal classes.

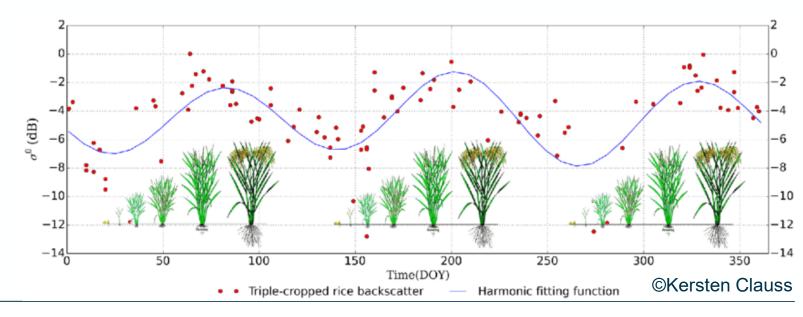
Height retrieval possible with airborne radar or short revisit satellites.

Results & challenges

Distinct temporal profiles for crops at different growth stages.

Accurate monitoring requires dense time series (short revisit).

Limited applicability of PolInSAR in agriculture (rapid crop changes between acquisitions).





SOME REFERENCES



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Last but not least



