esa

Introduction to SAR remote sensing for agriculture and water

levente ronczyk

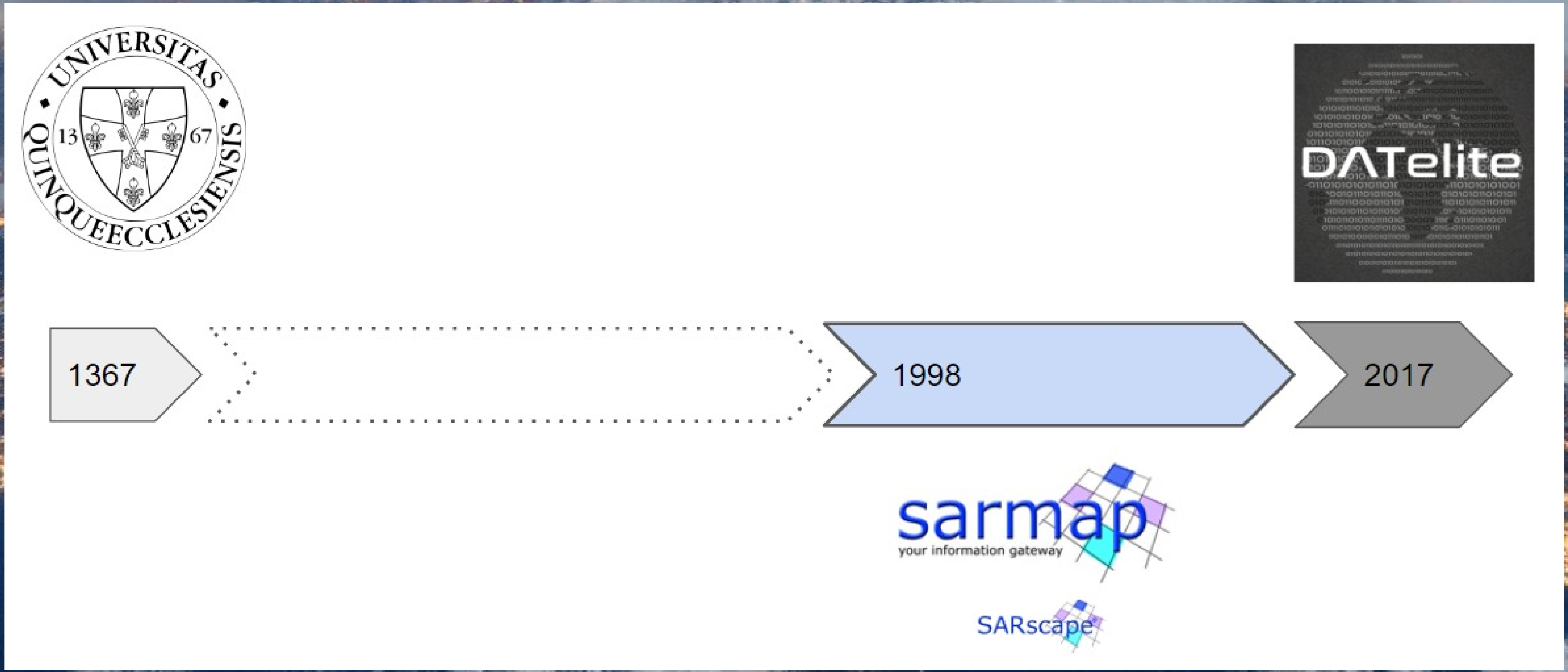
21/11/2022

Outline

- Introduction
- SAR basic
- SAR data processing and derivatives
  - Intensity
  - Coherence
  - DPSVI
- Multi-temporal analysis
- Applications

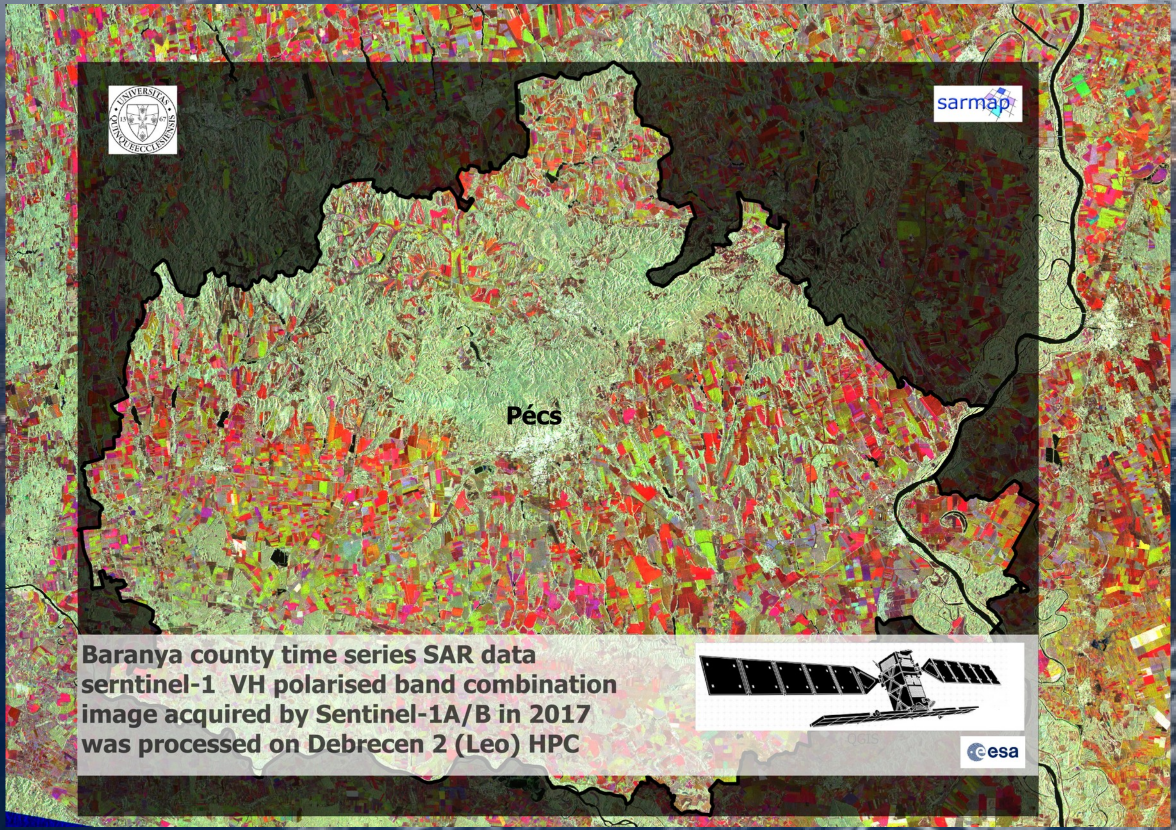
DATelite Ltd

DATelite Ltd is an official spin-off company of University of Pécs. The main focus is SAR related applications.



sarmap SA and DATelite Ltd cooperation

- Several joint ESA tenders,
- National and international projects,



General approach of SAR and Agriculture

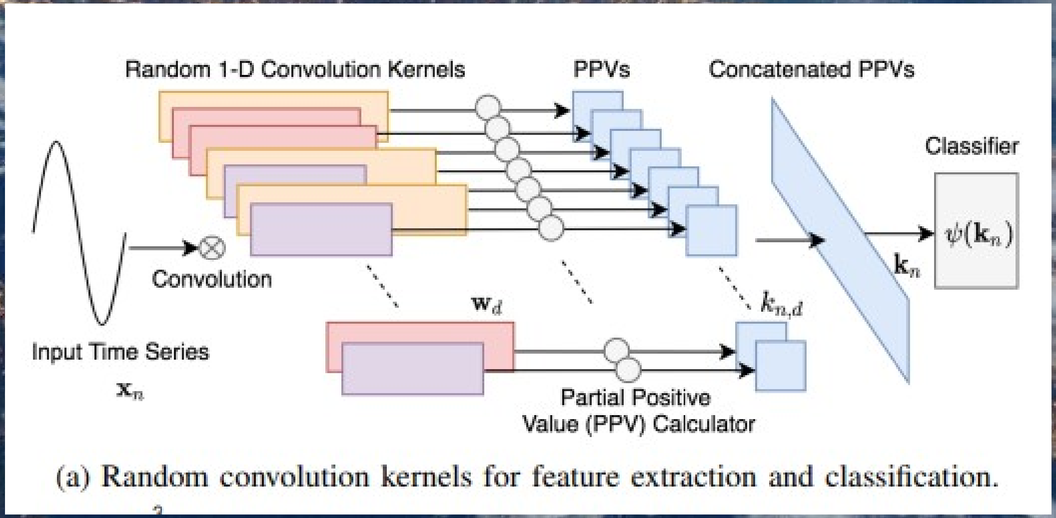
SAR system > Geophysical approach > location based physical conditions measurements and their changes.

Changes > temporal aspect.

Agriculture > spatial-temporal geo- and biophysical changes (rapid and significant)

vs or incorporation with:

Field work



Data Science

Radar backscatter

Synthetic Aperture Radar (SAR) images represent an estimate of the radar backscatter of the illuminated area on the ground. The backscatter varies according to:

Sensor:

- wavelength (frequency)
- polarization
- incidence angle

Object:

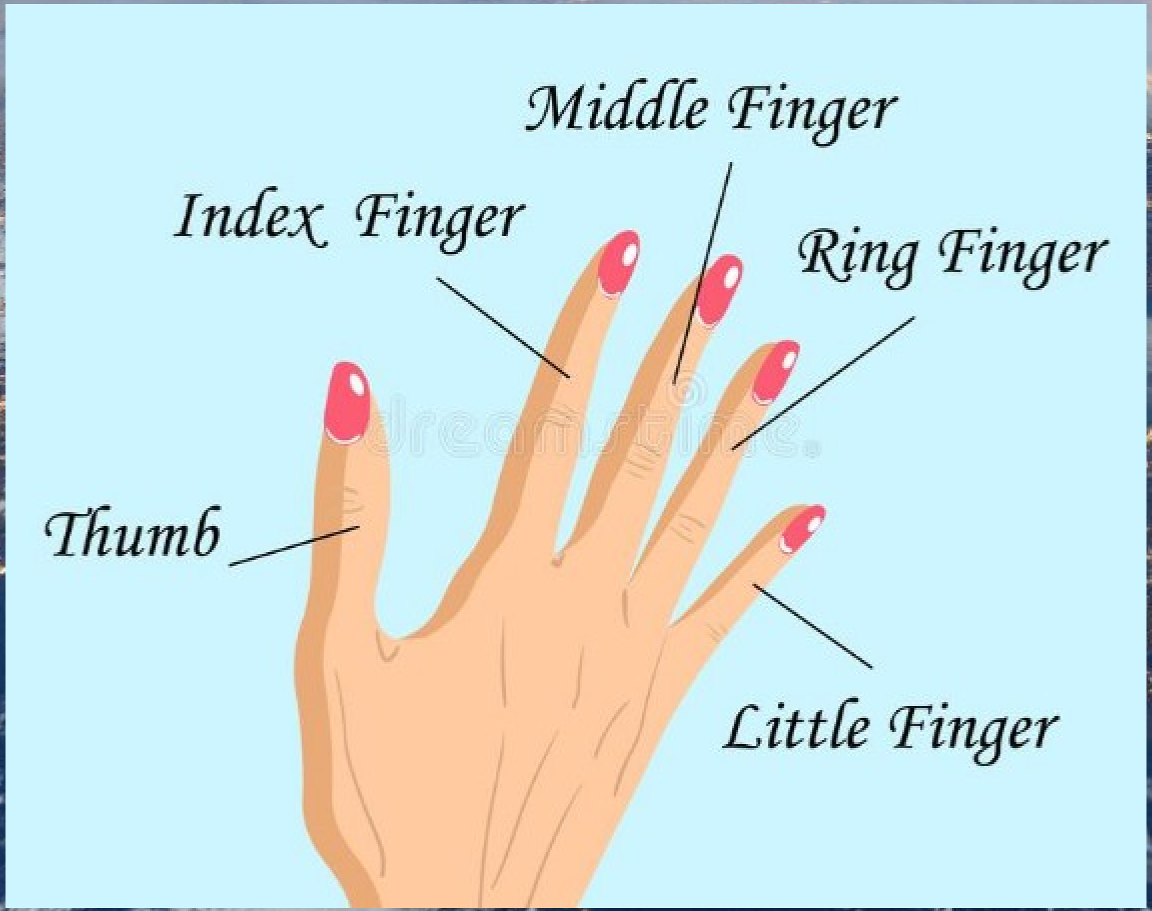
- roughness
- dielectric constant

Topography

Main objective is to avoid the false interpretation of the backscatter values.

What was your last RS related activity?

Where is your ROI located?



What is your expectation regarding to SAR?

Where are you come from?

Ideal RS job for you?

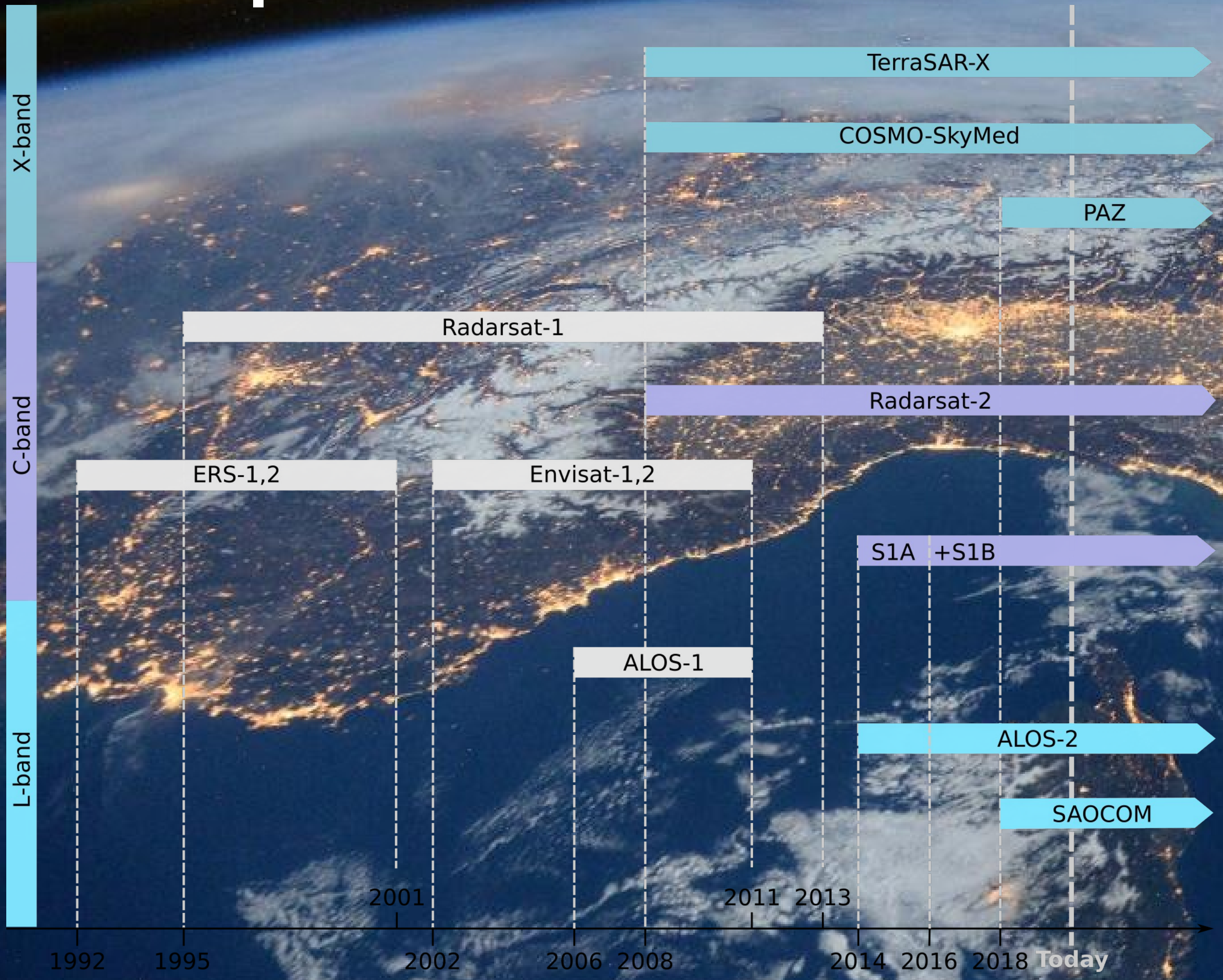
Frequency / Wavelength

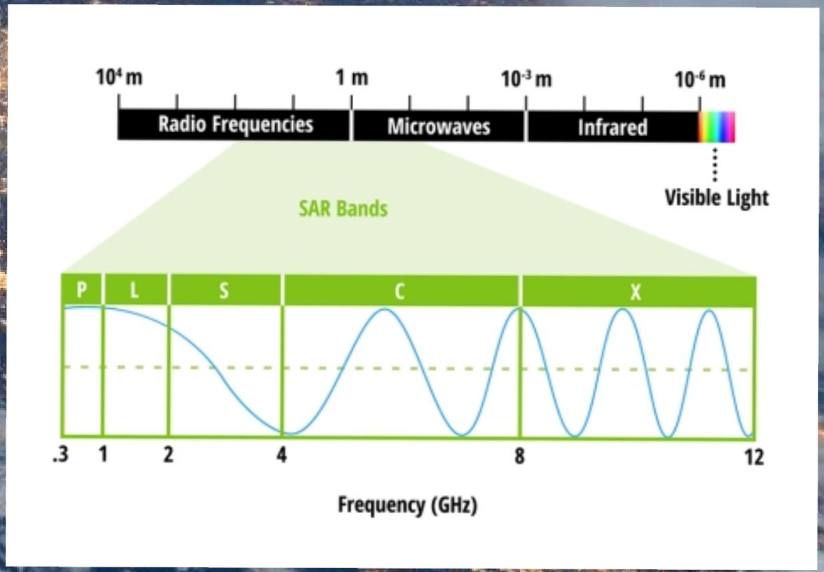
esa

Band	Frequency	Wavelength	Typical Application
Ka	27–40 GHz	1.1–0.8 cm	Rarely used for SAR (airport surveillance)
K	18–27 GHz	1.7–1.1 cm	rarely used (H_2O absorption)
Ku	12–18 GHz	2.4–1.7 cm	rarely used for SAR (satellite altimetry)
X	8–12 GHz	3.8–2.4 cm	High resolution SAR (urban monitoring,; ice and snow, little penetration into vegetation cover; fast coherence decay in vegetated areas)
C	4–8 GHz	7.5–3.8 cm	SAR Workhorse (global mapping; change detection; monitoring of areas with low to moderate penetration; higher coherence); ice, ocean maritime navigation
S	2–4 GHz	15–7.5 cm	Little but increasing use for SAR-based Earth observation; agriculture monitoring (NISAR will carry an S-band channel; expends C-band applications to higher vegetation density)
L	1–2 GHz	30–15 cm	Medium resolution SAR (geophysical monitoring; biomass and vegetation mapping; high penetration, InSAR)
P	0.3–1 GHz	100–30 cm	Biomass. First p-band spaceborne SAR will be launched ~2020; vegetation mapping and assessment. Experimental SAR.

https://www.earthdata.nasa.gov/learn/backgrounders/what-is-sar

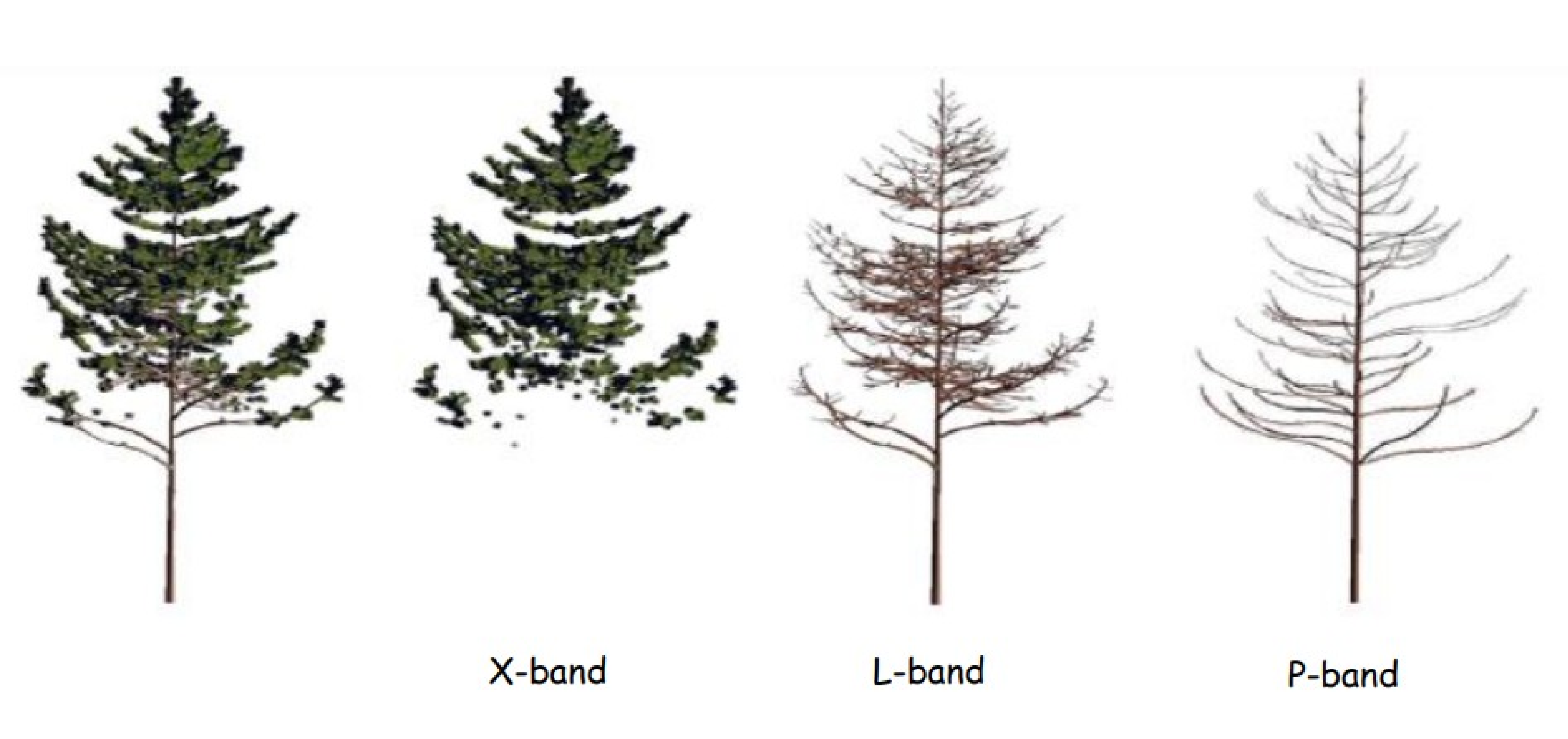
Missions and Frequencies





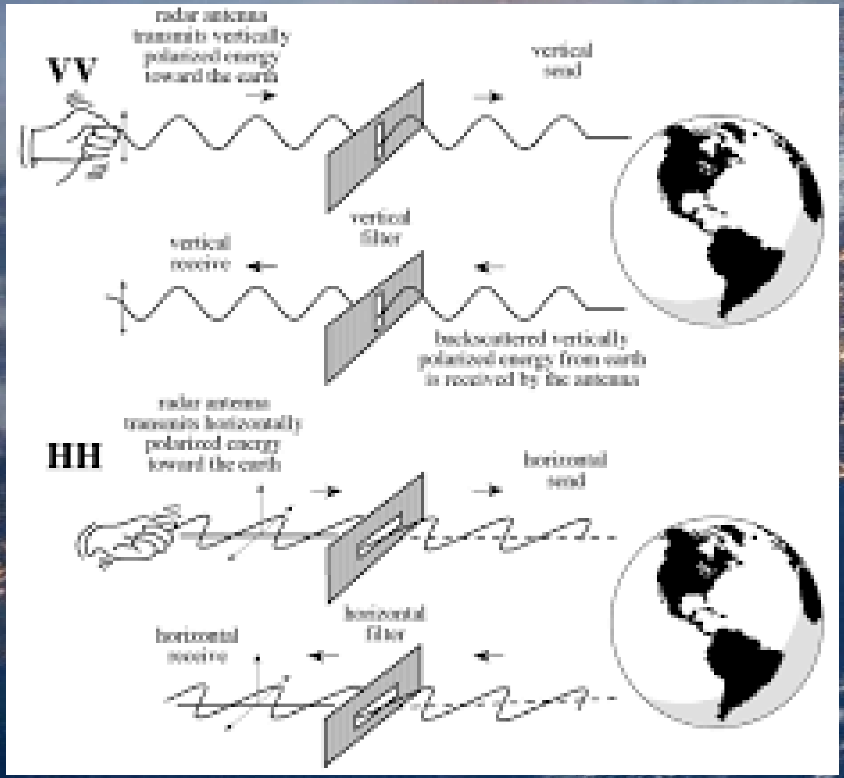
Scattered mechanisms

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



[Carleton University]

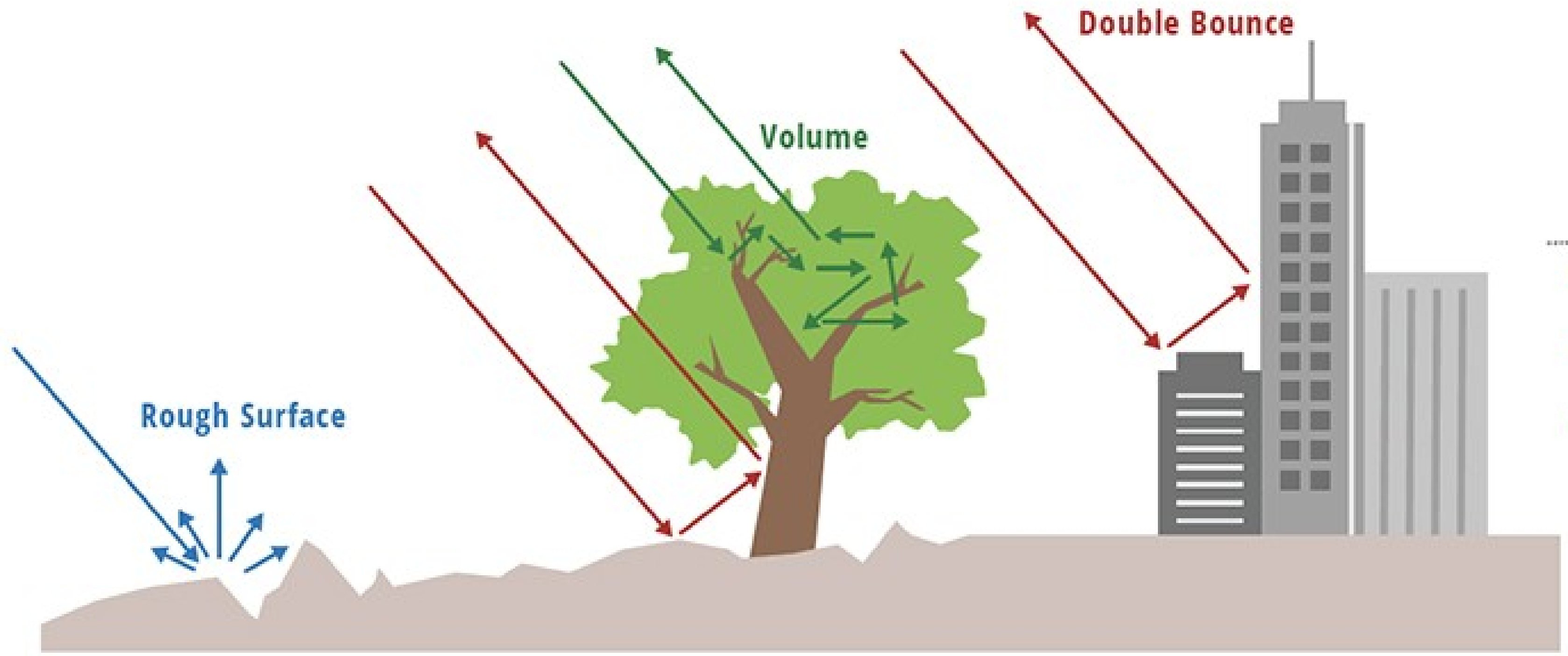
Polarization and scattering mechanisms



SAR signal response (surface parameters and structures):

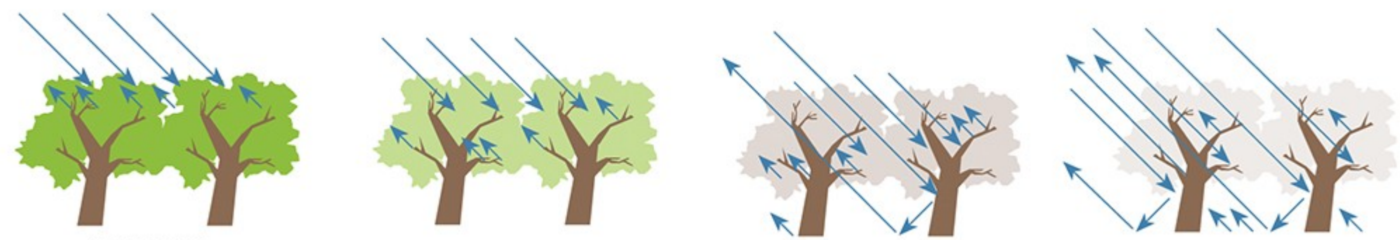
- **size (relative to the wavelength)**
- **orientation (relative to the antenna)**
- **density of the scatterers (size)**

https://appliedsciences.nasa.gov/sites/default/files/session2-%20AdvSAR_0.pdf



RELATIVE SCATTERING STRENGTH BY POLARIZATION:

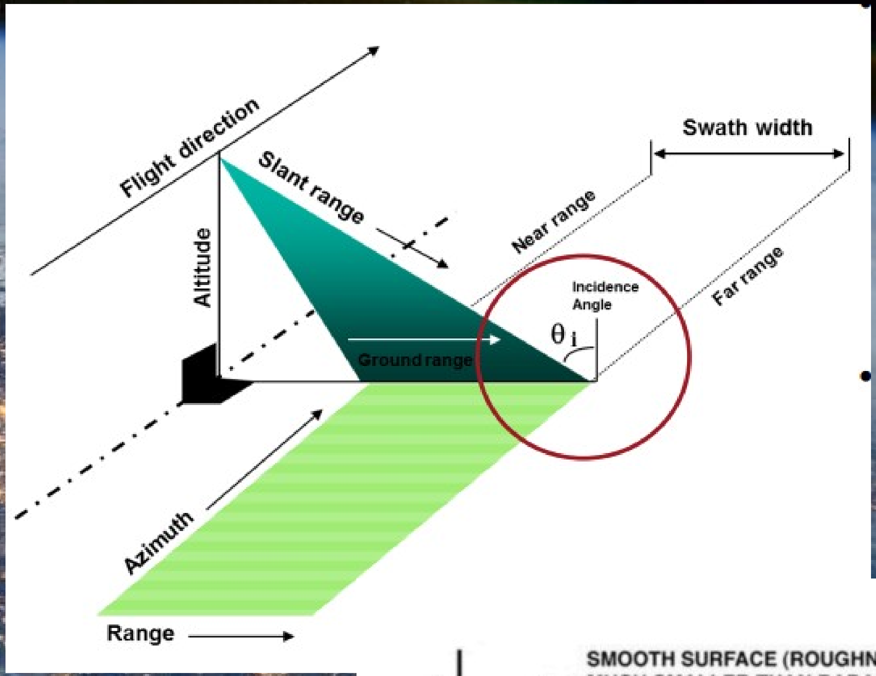
Rough Surface Scattering	$\lvert S_{VV} \rvert > \lvert S_{HH} \rvert > \lvert S_{HV} \rvert$ or $\lvert S_{VH} \rvert$
Double Bounce Scattering	$\lvert S_{HH} \rvert > \lvert S_{VV} \rvert > \lvert S_{HV} \rvert$ or $\lvert S_{VH} \rvert$
Volume Scattering	Main source of $\lvert S_{HV} \rvert$ and $\lvert S_{VH} \rvert$

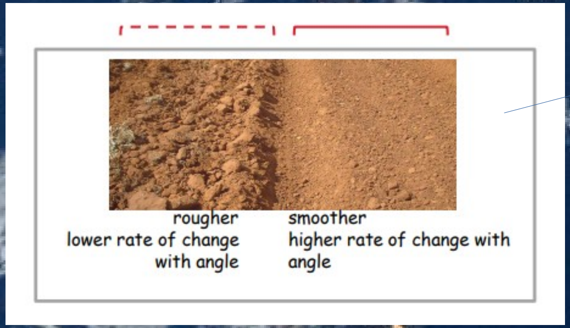


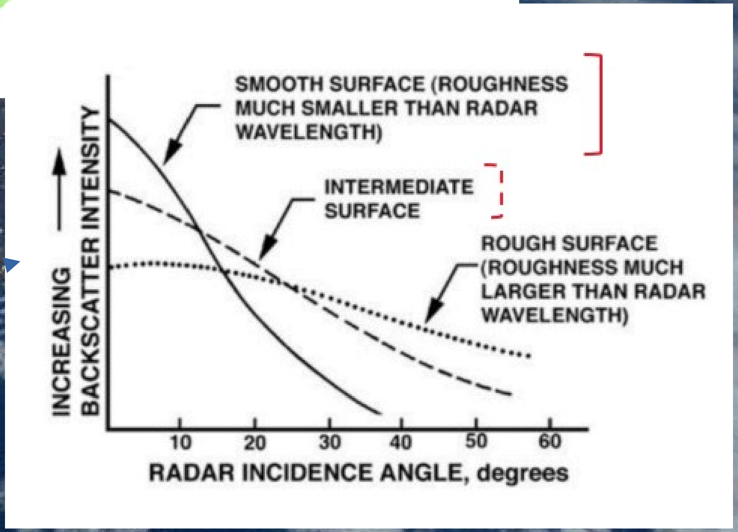
https://appliedsciences.nasa.gov/sites/default/files/session2-%20AdvSAR_0.pdf

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.







Carleton University

Incidence angle

Incidence angle changes from the near to far range. For large swath modes (like Sentinel-1), this change can be very significant and **fundamentally impacts SAR backscatter** regardless of the target.

SAR satellites 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 (relative orbits).

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.

Beam	IW1	IW2	IW3
Off-nadir angles at min orbit altitude	27.53-32.48	32.38-36.96	36.87-40.40
Incidence angles at min orbit altitude	30.86-36.59	36.47-41.85	41.75-46.00
Off-nadir angles at max orbit altitude	26.00-30.96	30.86-35.43	35.35-38.88
Incidence angles at max orbit altitude	29.16-34.89	34.77-40.15	40.04-44.28

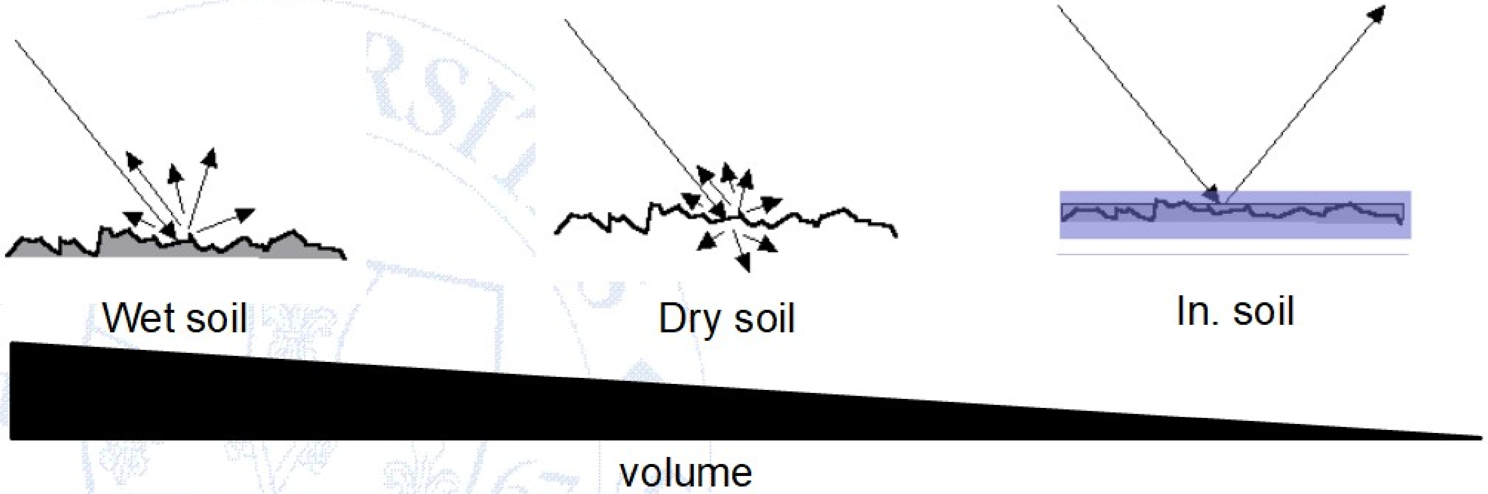
Carleton University

ROI


Approximate Placement Only
175
102
153
51
Hungary
Székesfehérvár
Veszprém
Szolnok
Oradea
Kecskemét
Siófok
Dunaújváros
Salonta
Kiskunfélegyháza
Békéscsaba
Hódmezővásárhely
Kaposvár
Szekszárd
Szeged
Baja
Arad
Subotica
Суботица
Pécs
Kikinda
Кикинда
Deva
Virovitica
Sombor
Сомбор
Timișoara
Hunedoara
Lugoj
Zalău

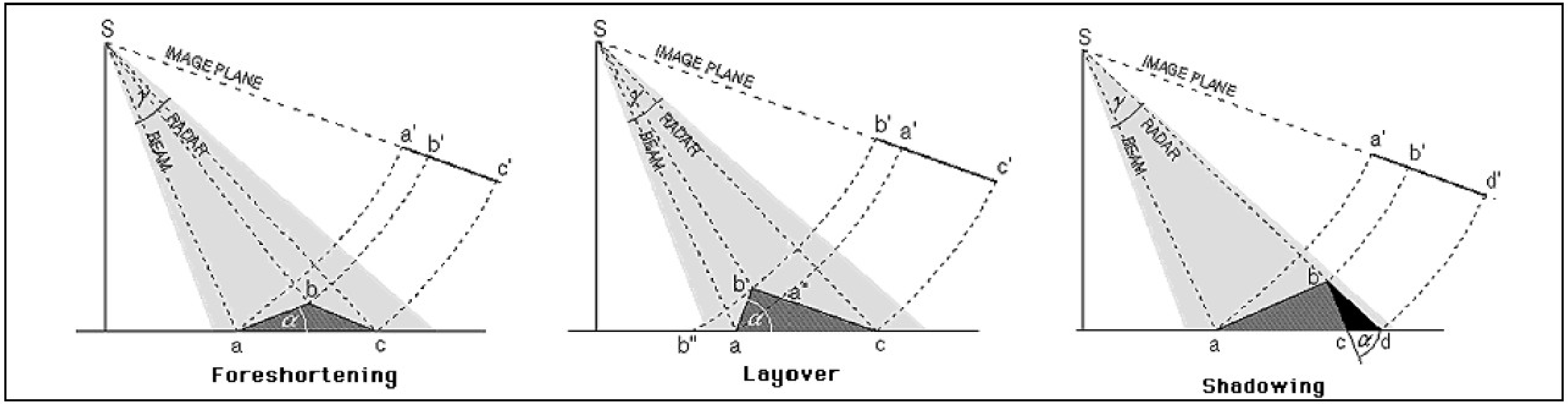
Roughness/Dielectric constant > Key scattering mechanisms


https://www.youtube.com/watch?v=PCEQSMjlKII



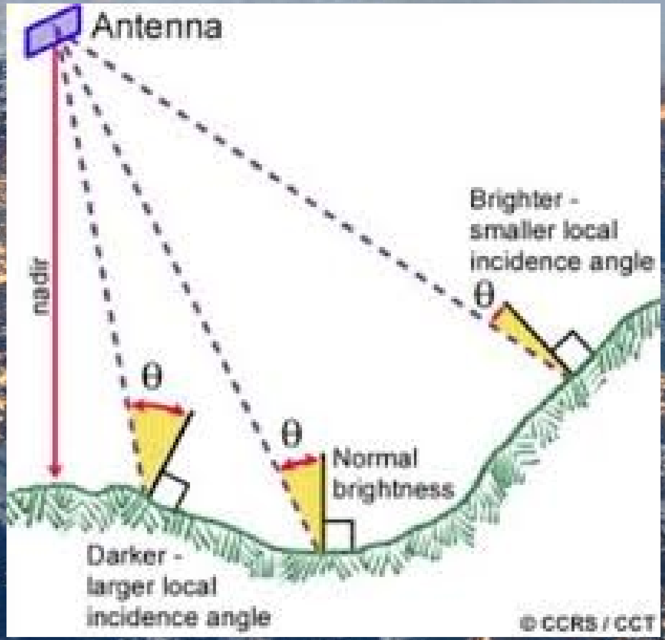
http://www.crisp.nus.edu.sg/~research/tutorial/sar_int.htm

Topography - distortions present in SAR images



Local Incident Angle

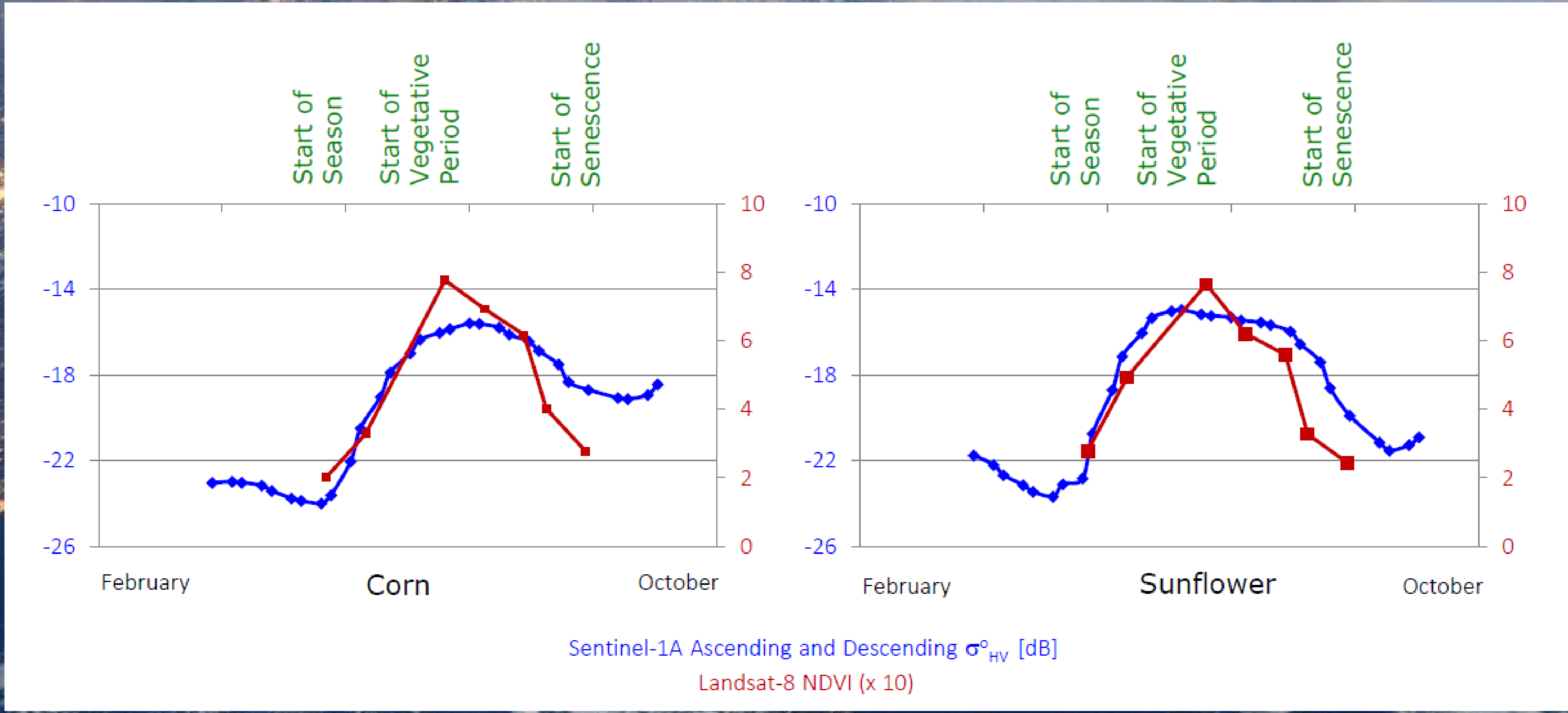
- local incident angle is not the same as incident angle
- local incident angle takes into account the local slope of the terrain
- slopes towards radar - local incidence angle is less than the normal incidence angle (assuming flat surface).



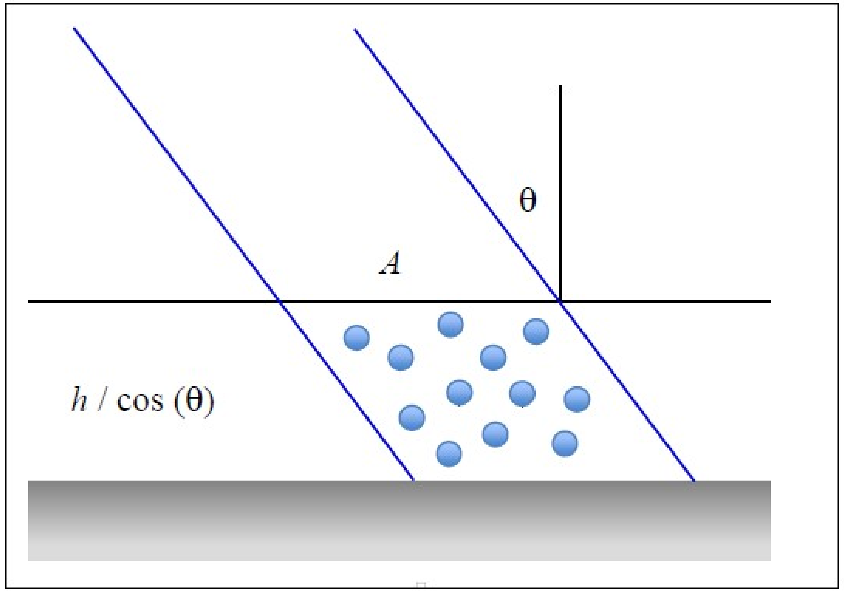
Carleton University

SAR time series

Main point is that we would like to measure the status of the targeted object and not the changing signal at the antenna!!



Modeling – Water Cloud Model



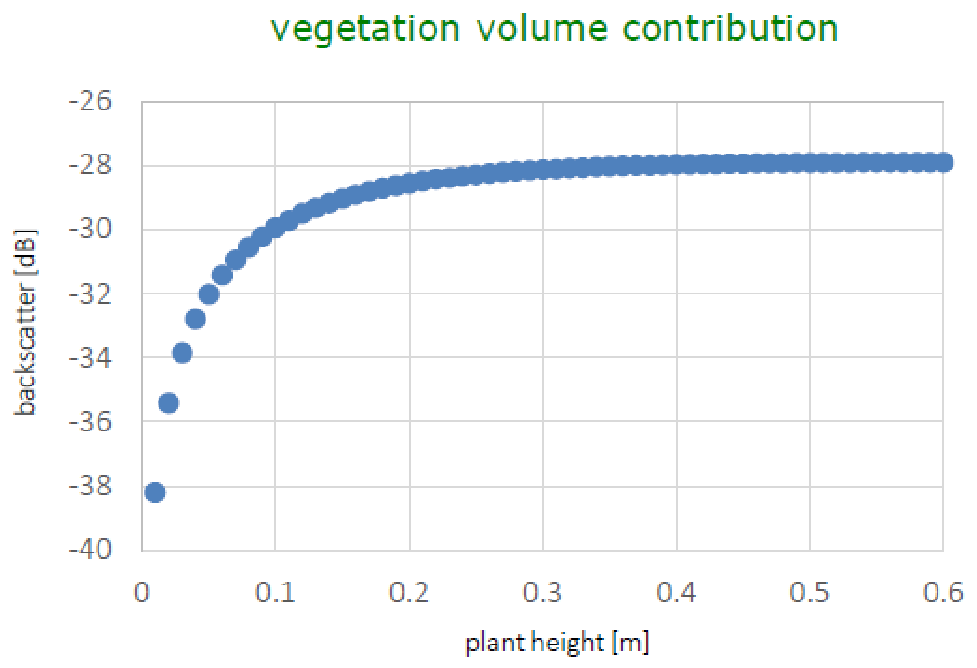
$$\sigma^{\circ}(\theta) = \sigma^{o}_{vol} + \sigma^{o}_{sur}$$

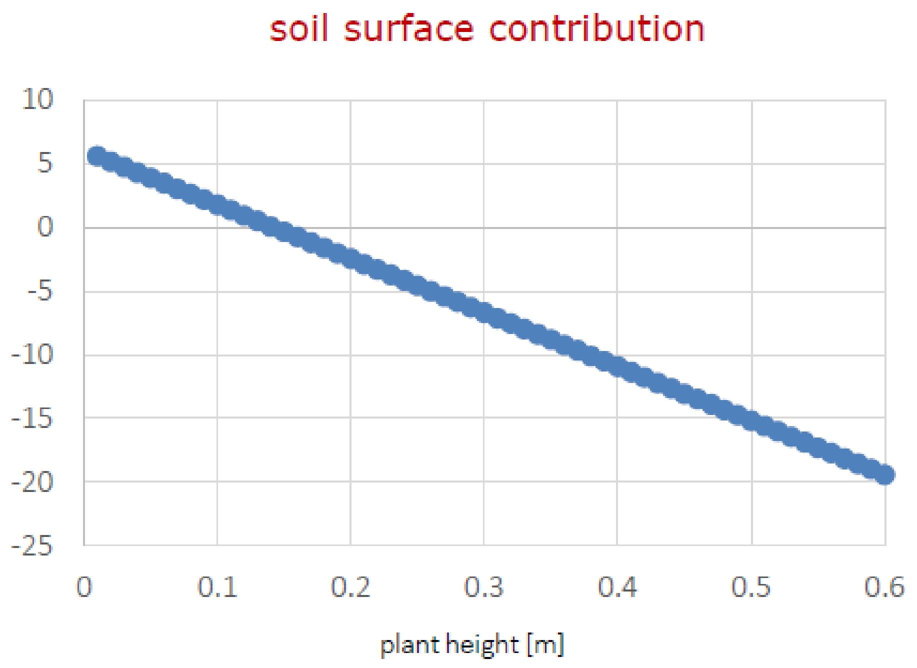
$$\sigma^{\circ}(\theta) = \frac{\eta\cos\theta}{2k_e}\left[1-\exp\left(\frac{-2k_e h}{\cos\theta}\right)\right] + A\exp\left(\frac{Bm_s - 2k_e h}{\cos\theta}\right)$$

where: ke = canopy extinction coefficient
= $C_1\, mv$
mv = volumetric moisture content
ms = soil moisture content
η = canopy volume scattering

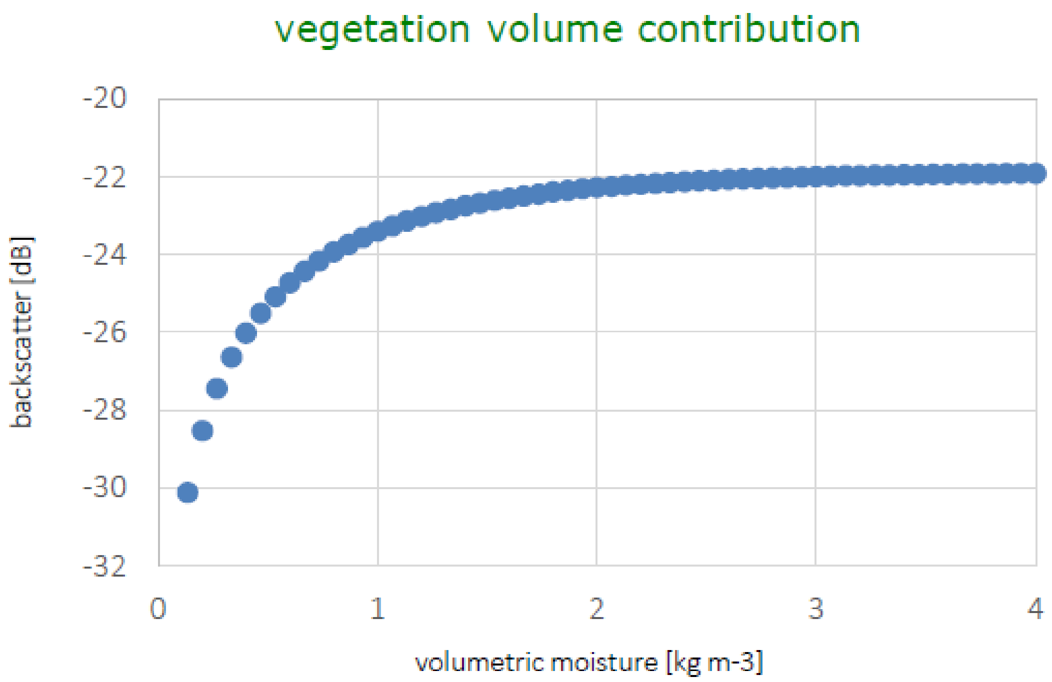
Attema and Ulaby, 1978

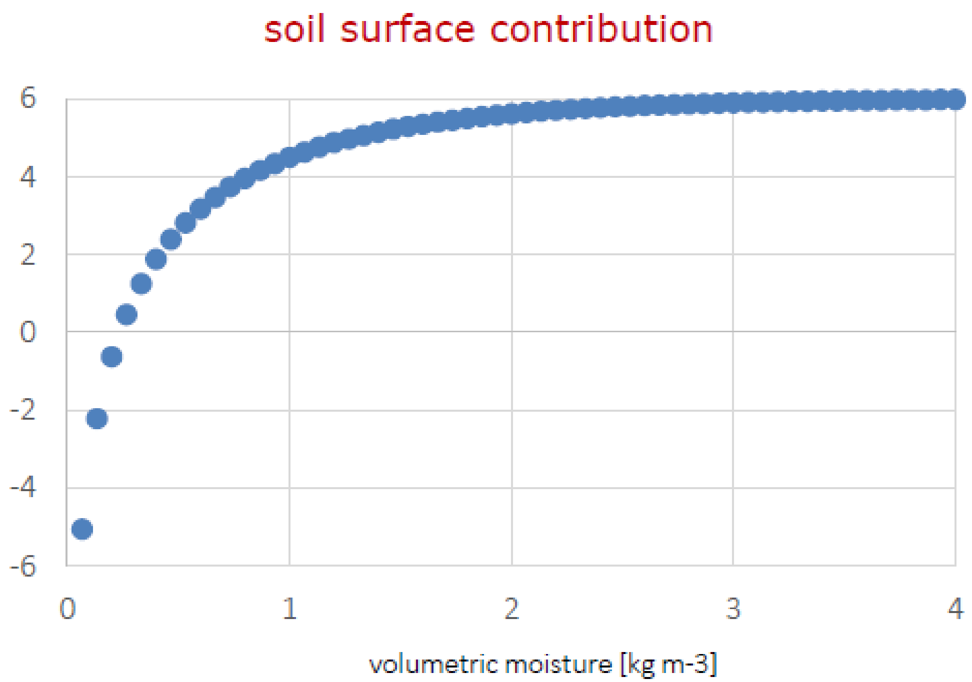
Water Cloud Model > Plant height





Water Cloud Model > Volumetric moisture

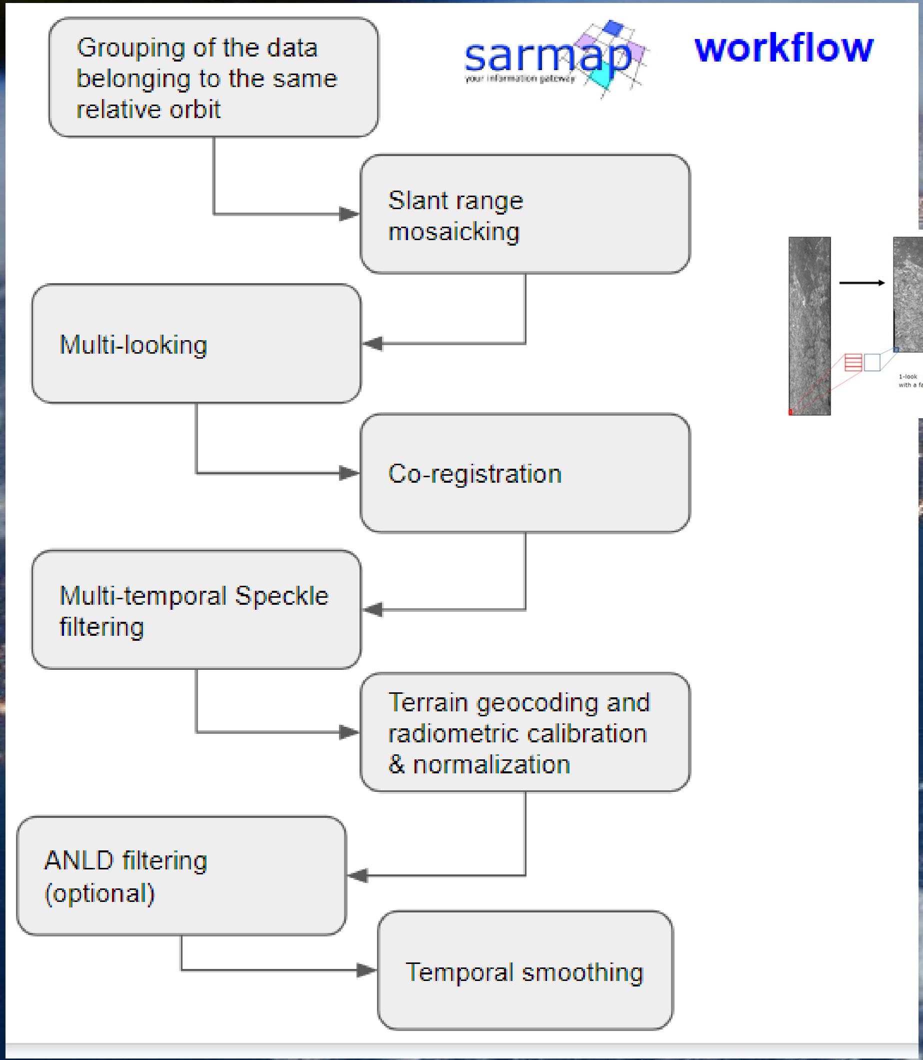


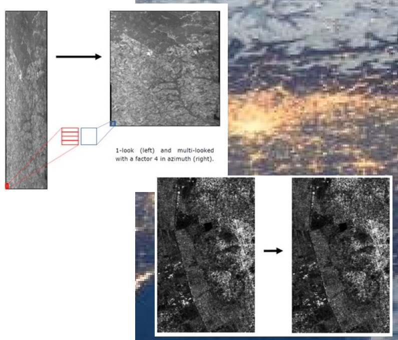


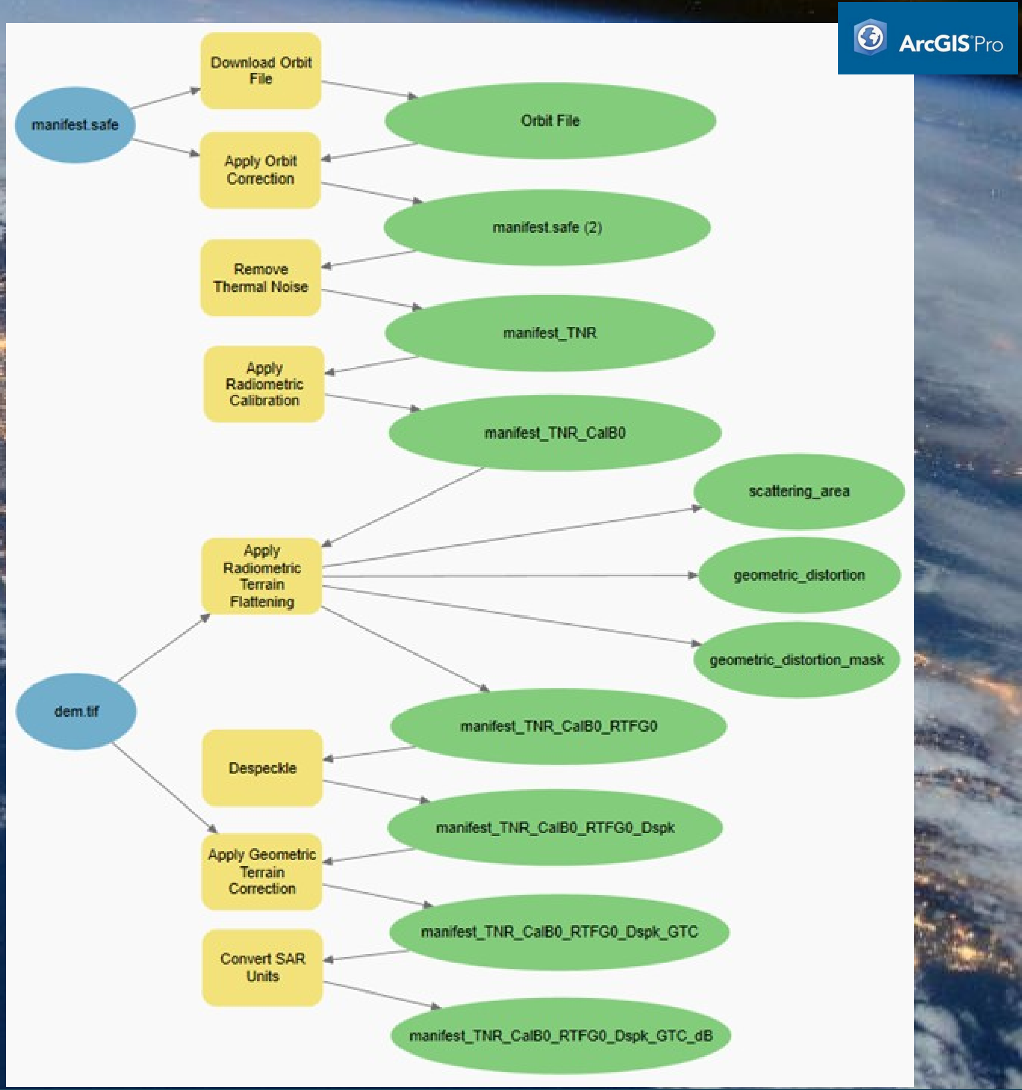
Sentinel-1 VV color composit over Hungary

RGB - R=2015.01.13 G=2014.10.09 B=2015.05.01

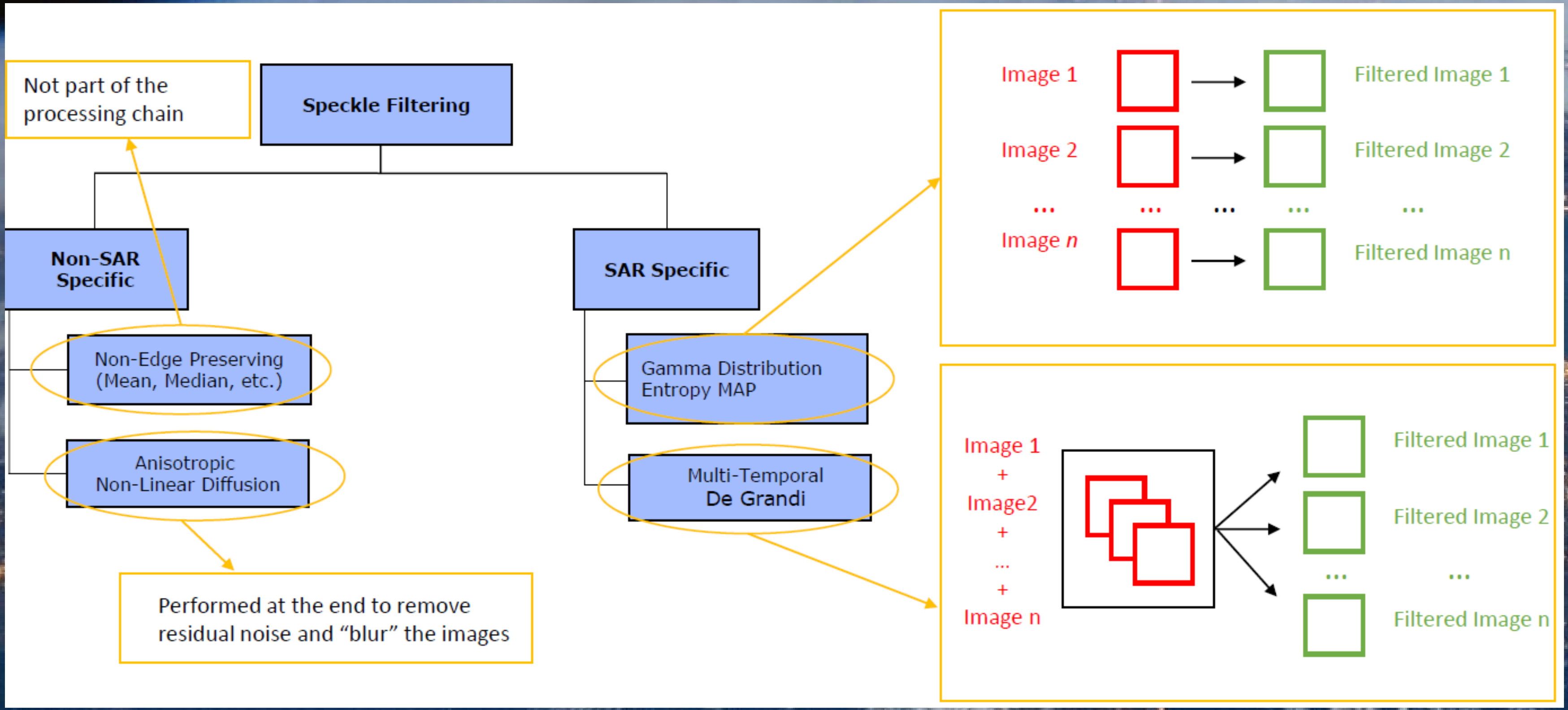
Intensity processing workflows

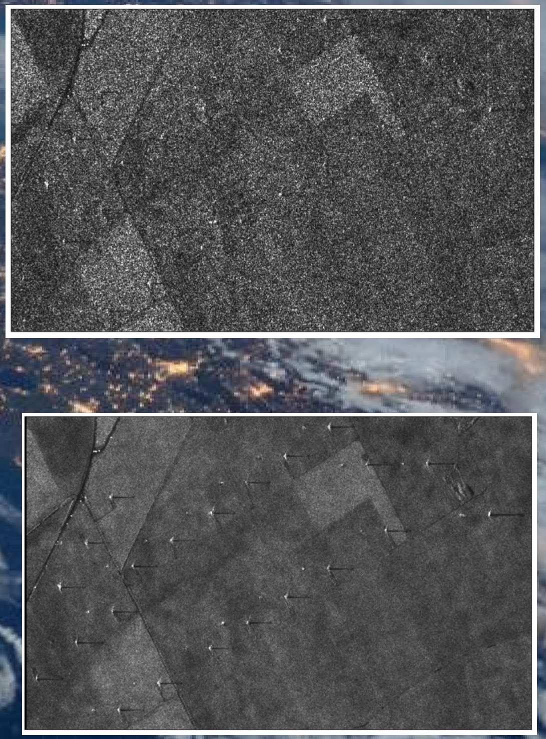






Speckle filtering





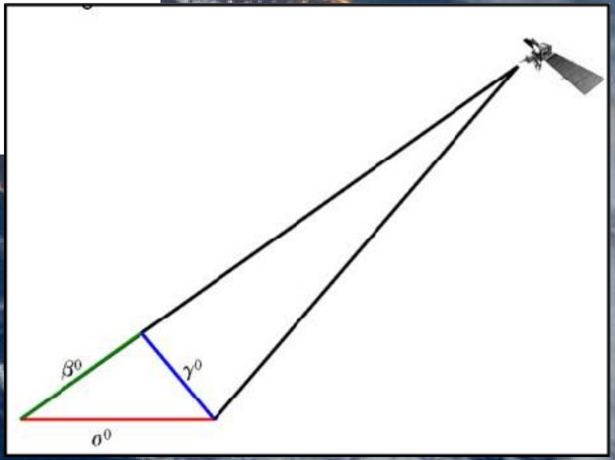
COSMO-SkyMed

Radiometric calibration

- **beta nought ($\beta°$)** is the radar brightness (or reflectivity) coefficient. The reflectivity per unit area in slant range is dimensionless. This normalization has the virtue that it does not require knowledge of the local incidence angle (e.g. scattering area *A*).

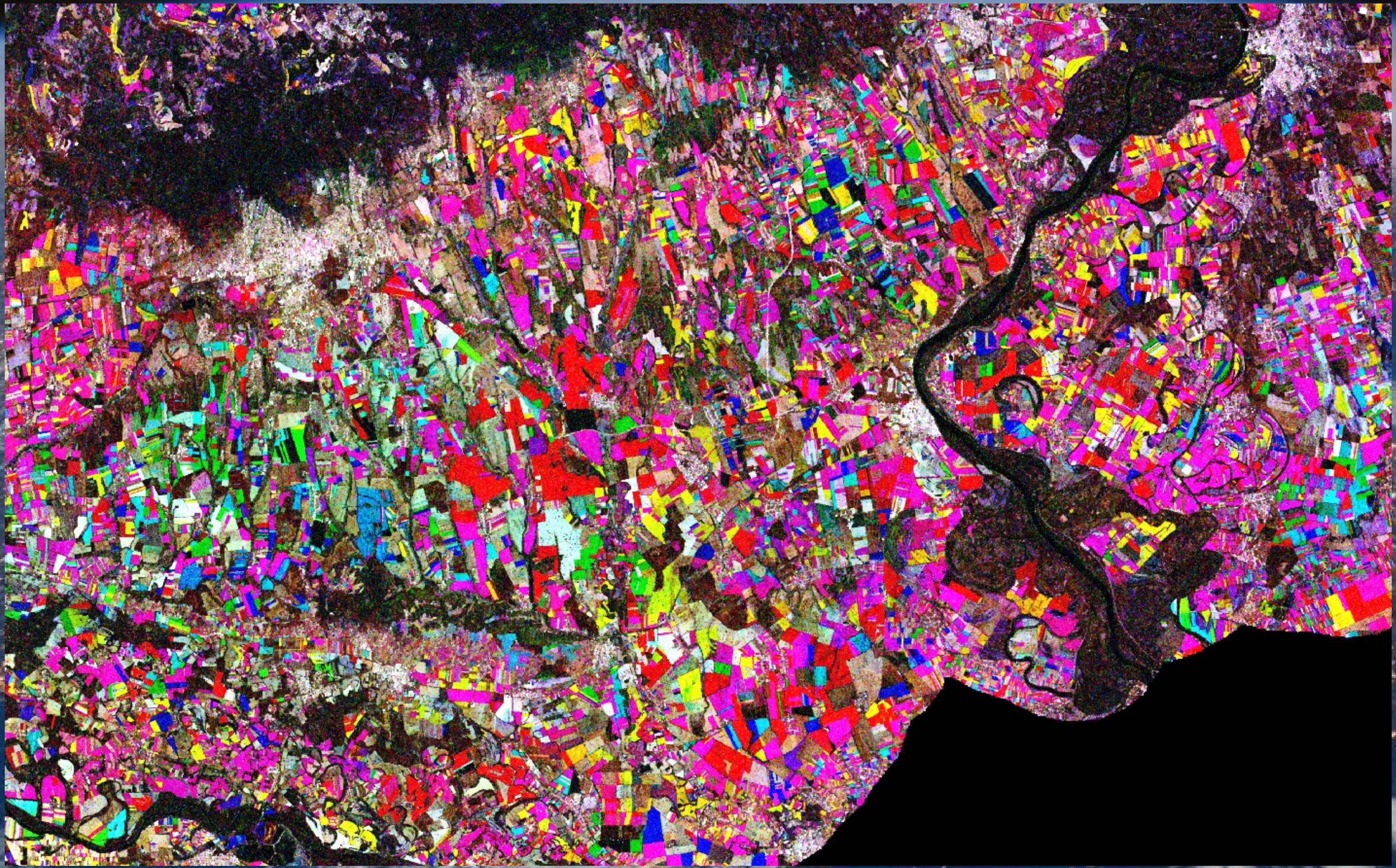
- **sigma nought (σ^o)**, the backscattering coefficient, is the conventional measure of the strength of radar signals reflected by a distributed scatterer, usually expressed in dB. It is a normalized dimensionless number, which compares the strength observed to that expected from an area of one square metre. Sigma nought (or naught) is defined with respect to the nominally horizontal plane, and in general has a significant variation with incidence angle, wavelength, and polarization, as well as with properties of the scattering surface itself.

- **gamma (γ^o)** is the backscattering coefficient normalized by the cosine of the incidence angle.



sarmap your information gateway

Coherence Change Detection



02.03.2015-14.03.2015/ 14.03.2015-26.03.2015/ 26.03.2015-07.04.2015

Coherence Generation

Given two co-registered Complex SAR images (S_1 and S_2), one calculates the coherence (g) as a ratio between coherent and incoherent summations:

$$\gamma = \frac{\left|\sum s_1(x) \cdot s_2(x)^*\right|}{\sqrt{\sum \left|s_1(x)\right|^2 \cdot \sum \left|s_2(x)\right|^2}}$$

Note that the observed coherence - which ranges between 0 and 1 – is a function of systemic spatial decorrelation, additive noise, and temporal decorrelation taking place between the two acquisitions.

Coherence Generation

It enables the generation of coherence (interferometric correlation, γ) from SLC data pair.

It includes the following steps:

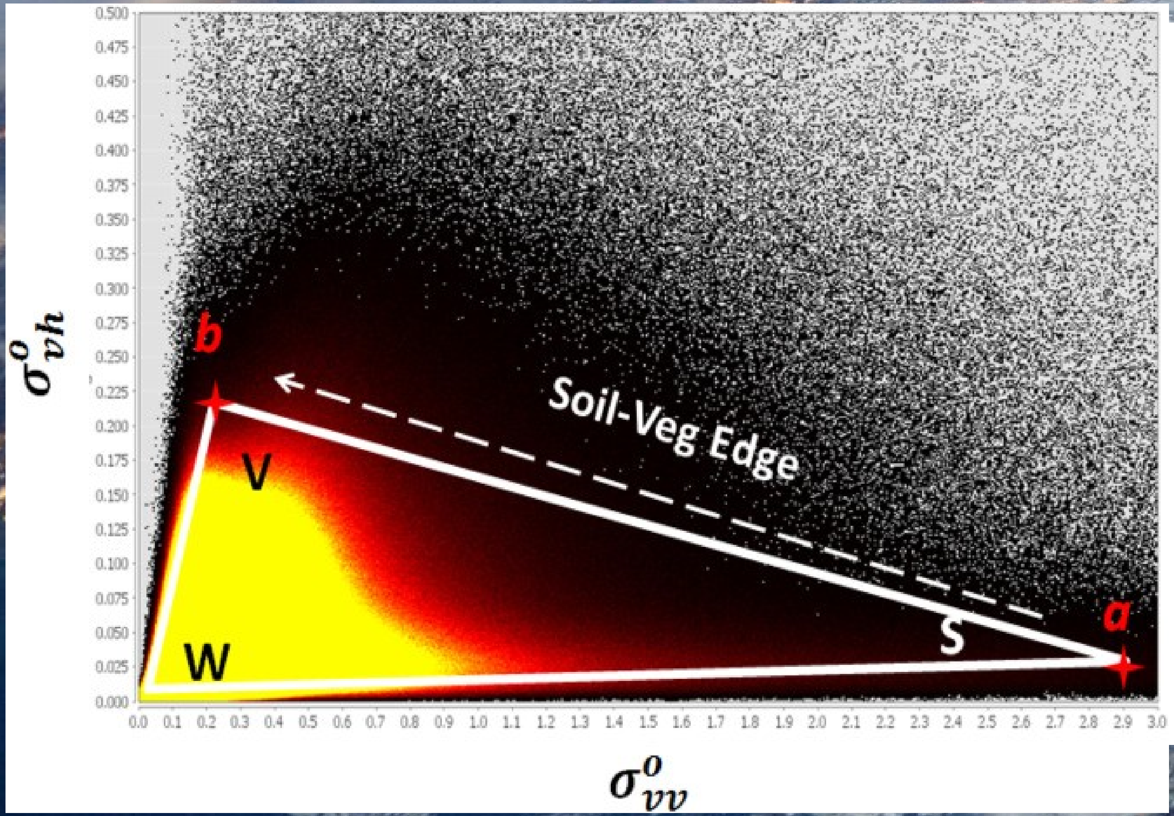
1. Co-registration including DEM
2. Generation of coherence including DEM
3. Terrain geocoding
4. Anisotropic Non-Linear Diffusion filtering (optional)

Open water bodies over cropland areas

Combination of Intensity and CCD images.

Dual Pol. SAR Vegetation Index (DPSVI)

[Significance of dual polarimetric synthetic aperture radar in biomass retrieval: An attempt on Sentinel-1](#)



$$DPSVI = \frac{\sigma_{vh(i)}\left[\left(\sigma_{vv(max)}\sigma_{vh(i)} - \sigma_{vv(i)}\sigma_{vh(i)} + \sigma^2{}_{vh(i)}\right) + \left(\sigma_{vv(max)}\sigma_{vv(i)} - \sigma^2{}_{vv(i)} + \sigma_{vh(i)}\sigma_{vv(i)}\right)\right]}{\sqrt{2}^{*}\ \sigma_{vv(i)}} \quad (6)$$

where

$\sigma_{vh(i)}$ is the backscattering coefficient value of the i^{th} pixel in the cross-polarized (vh) SAR product.

$\sigma_{vv(i)}$ is the backscattering coefficient value of the i^{th} pixel in the co-polarized (vv) SAR product.

$\sigma_{vv(max)}$ is the maximum backscattering coefficient value in the co-polarized (vv) SAR product.

The model was executed from radiometrically calibrated SAR dataset whose backscatter values are in linear power units.

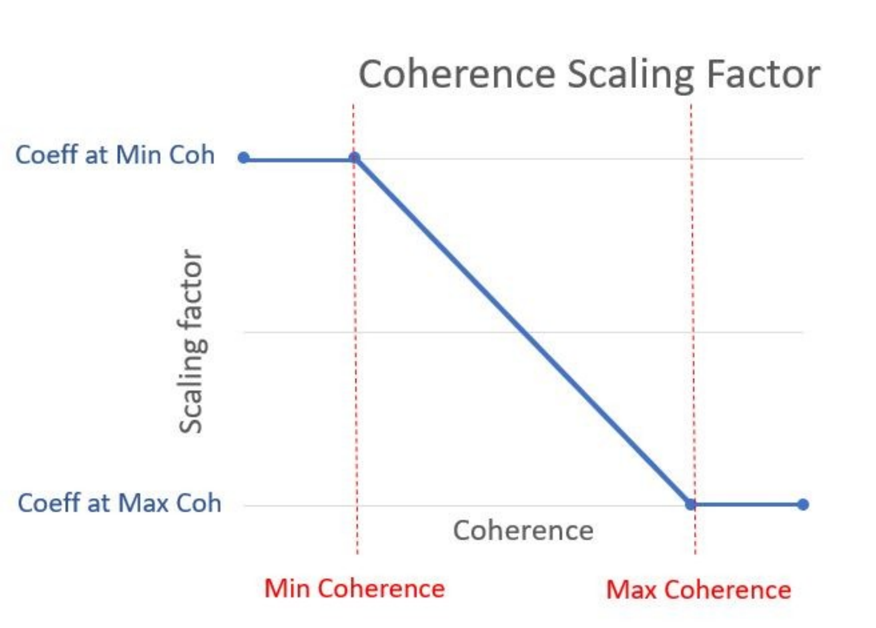
EDPSVI (Enhanced)

Integration of the interferometric coherence

Dual Polarization SAR Vegetation Index based on intensity data only, despite of vegetation absence, shows high values on targets such as rough bare soil and rocky terrains, where the signal backscatter is strong.

Using the coherence, which reaches higher vales (close to 1) on stable and strong scatterers, we can properly rescale the EDPSVI. This eventually means low EDPSVI values on sparse or not vegetated land, independently from soil roughness.

The resulting EDPSVI is rescaled to lower values where the coherence is higher. No change is applied to the intensity based index if the coherence is lower than "Min Coh" and the "Coeff at Min Coh" is set to 1.



Definition

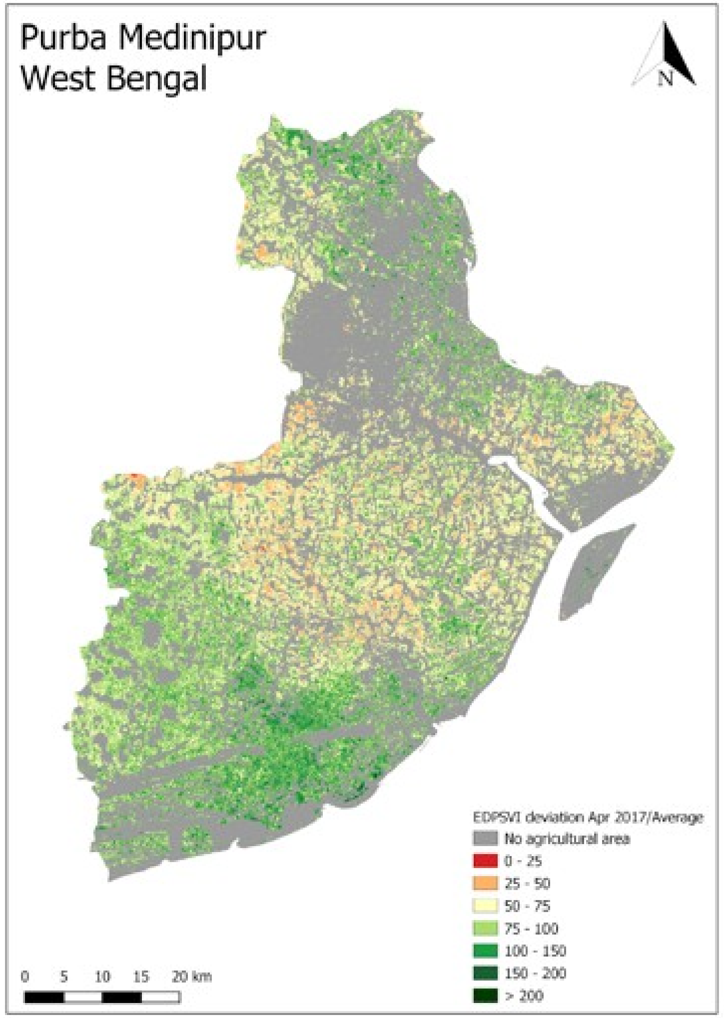
$$\frac{EDPSVI_{ref}}{EDPSVI_{avg}} \cdot 100$$

where

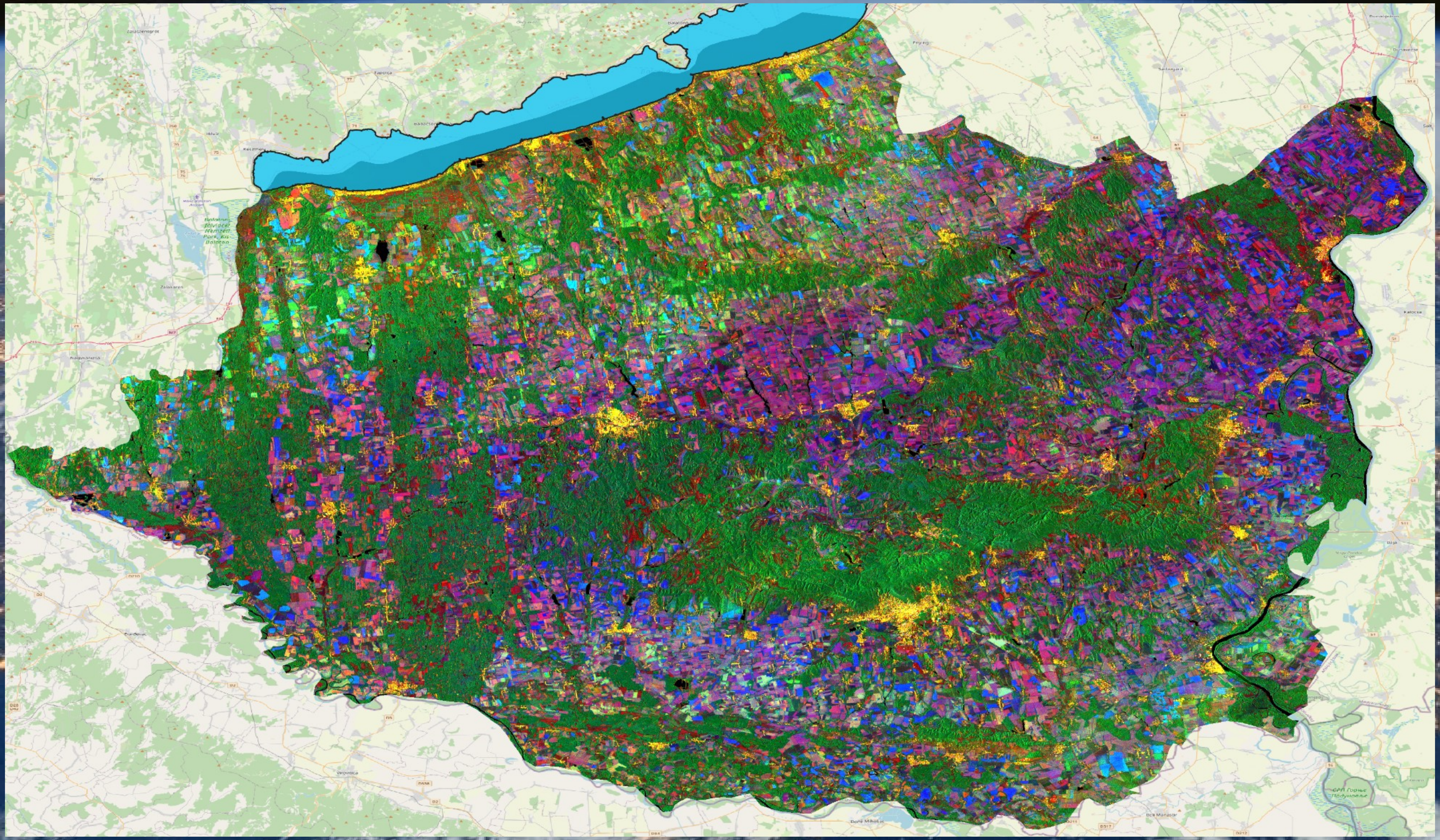
- $EDPSVI_{ref}$ is the EDPSVI value of a specific date
- $EDPSVI_{avg}$ is the EDPSVI average of other years

Note

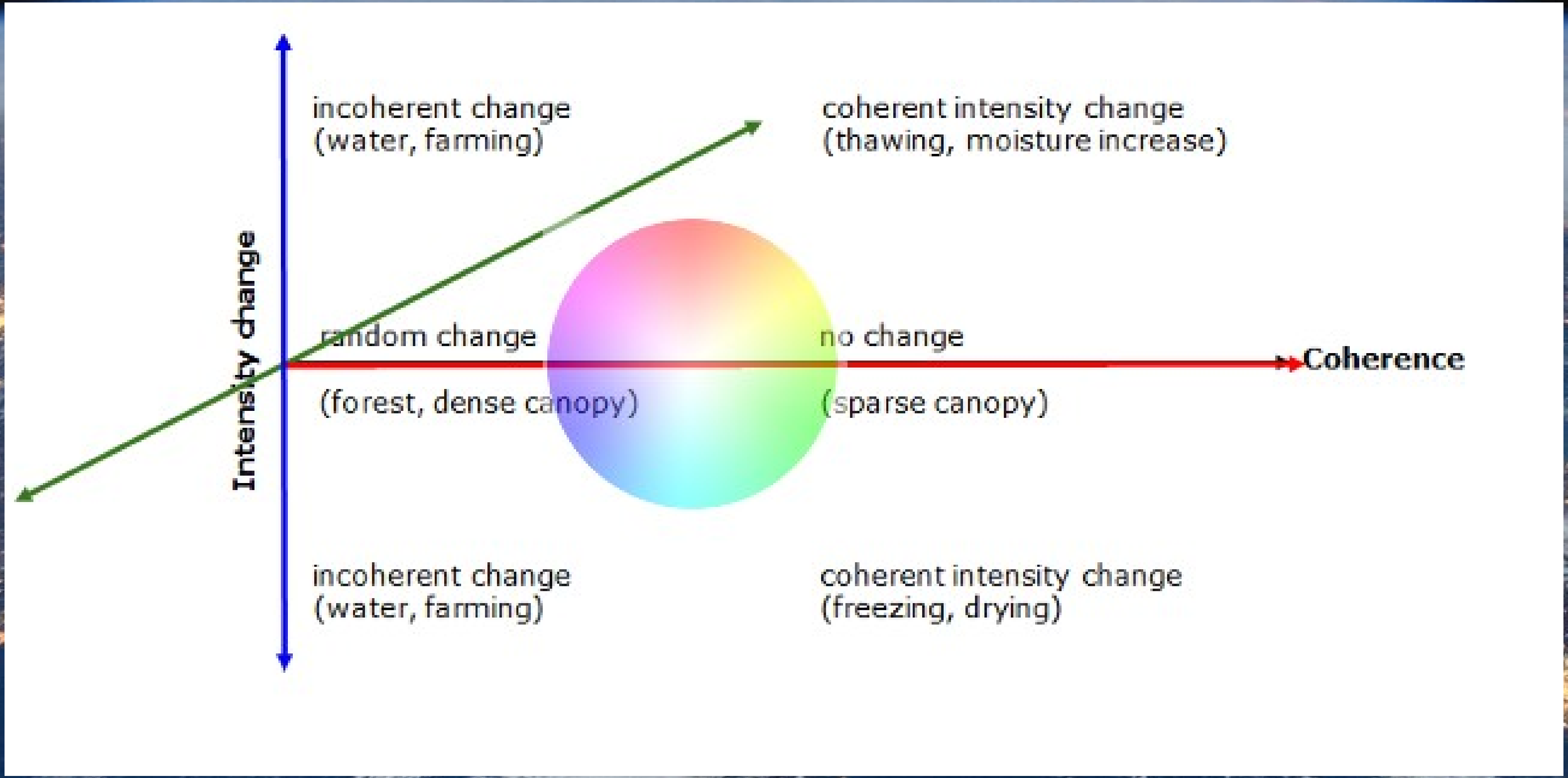
- 100% means average
- The index is exclusively calculated for agricultural areas



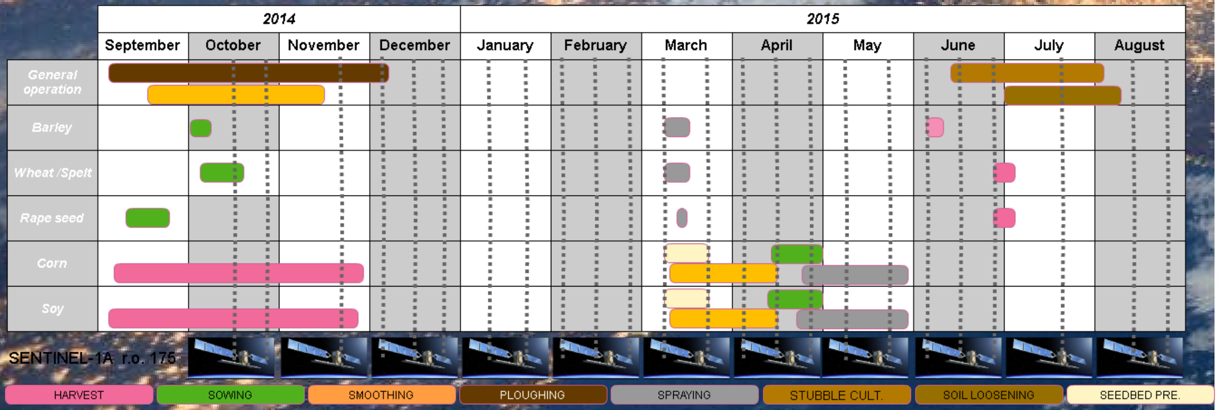
Color composite of CCD, DPSVI, Intensity values

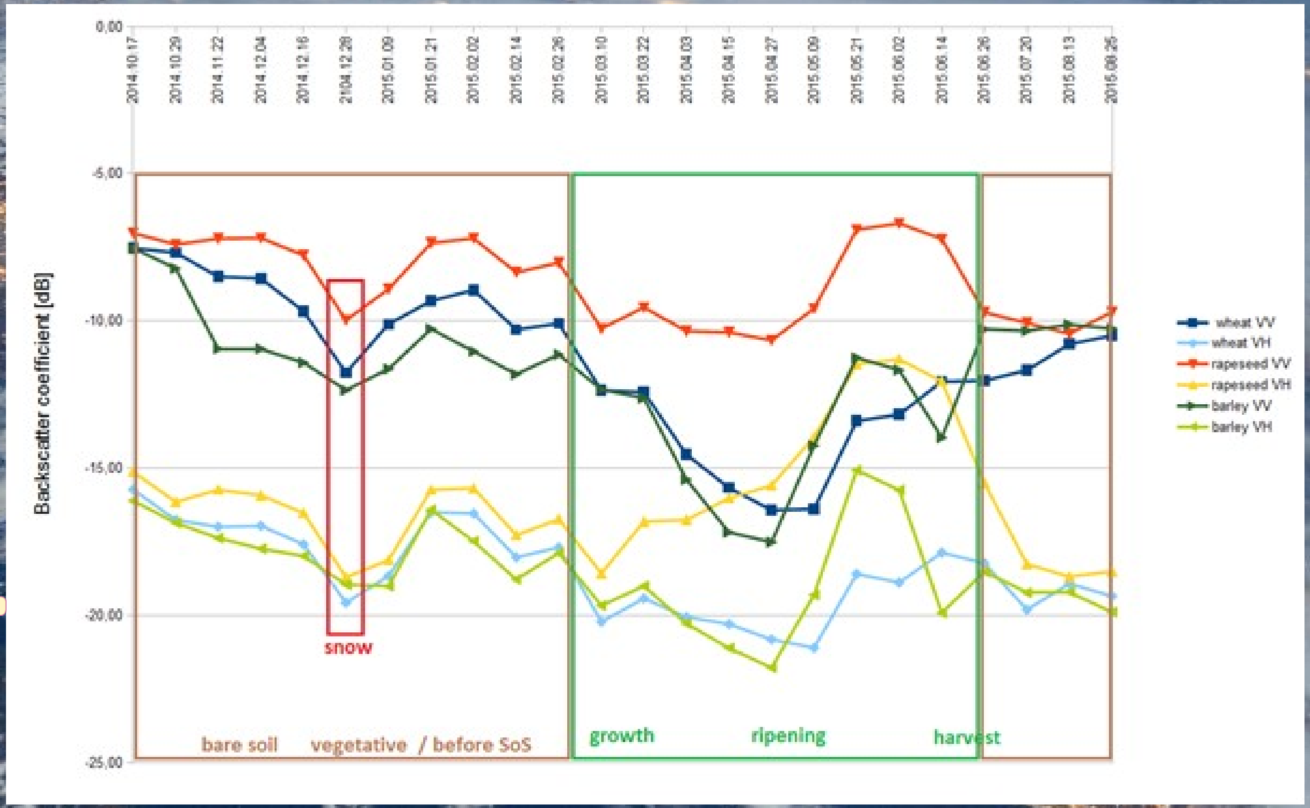


Information space

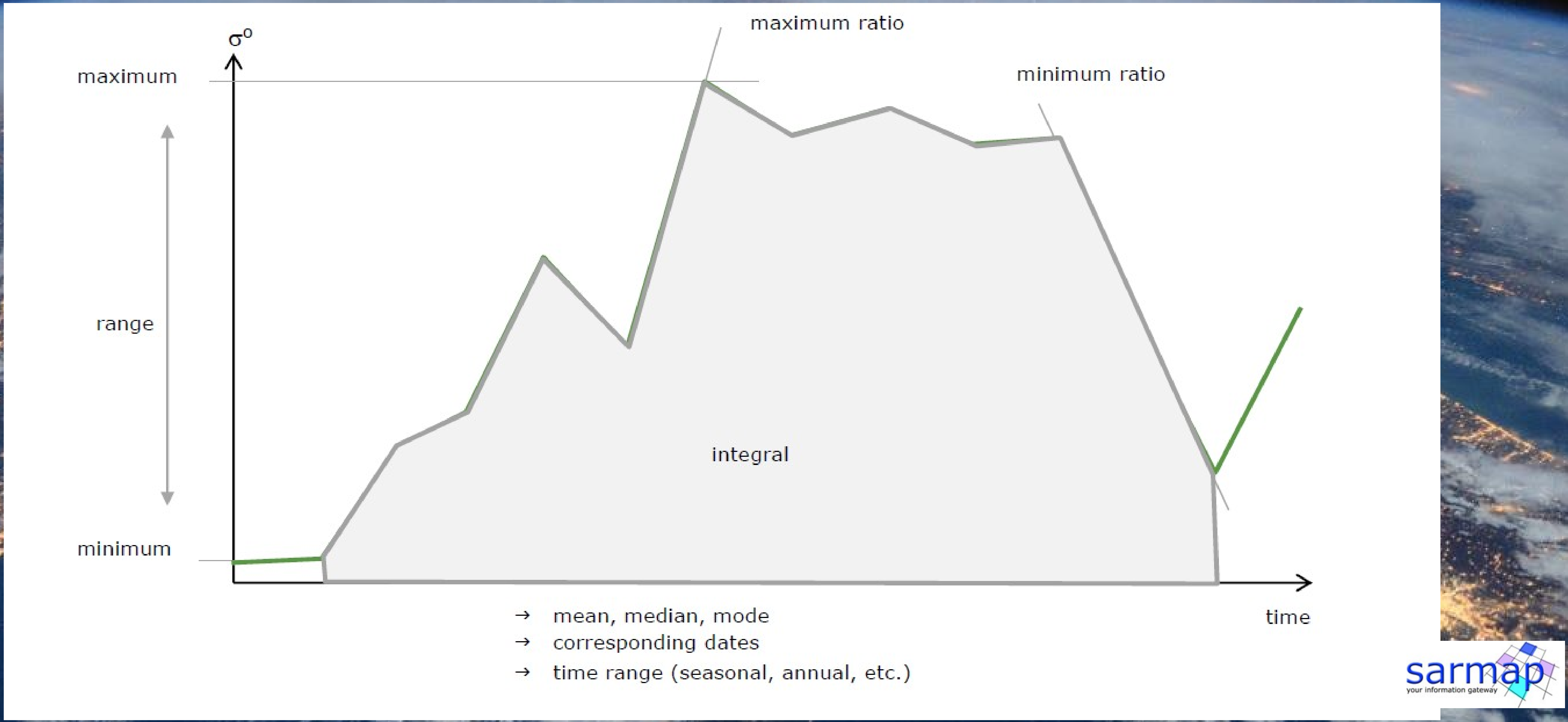


In-season intelligence on crop status

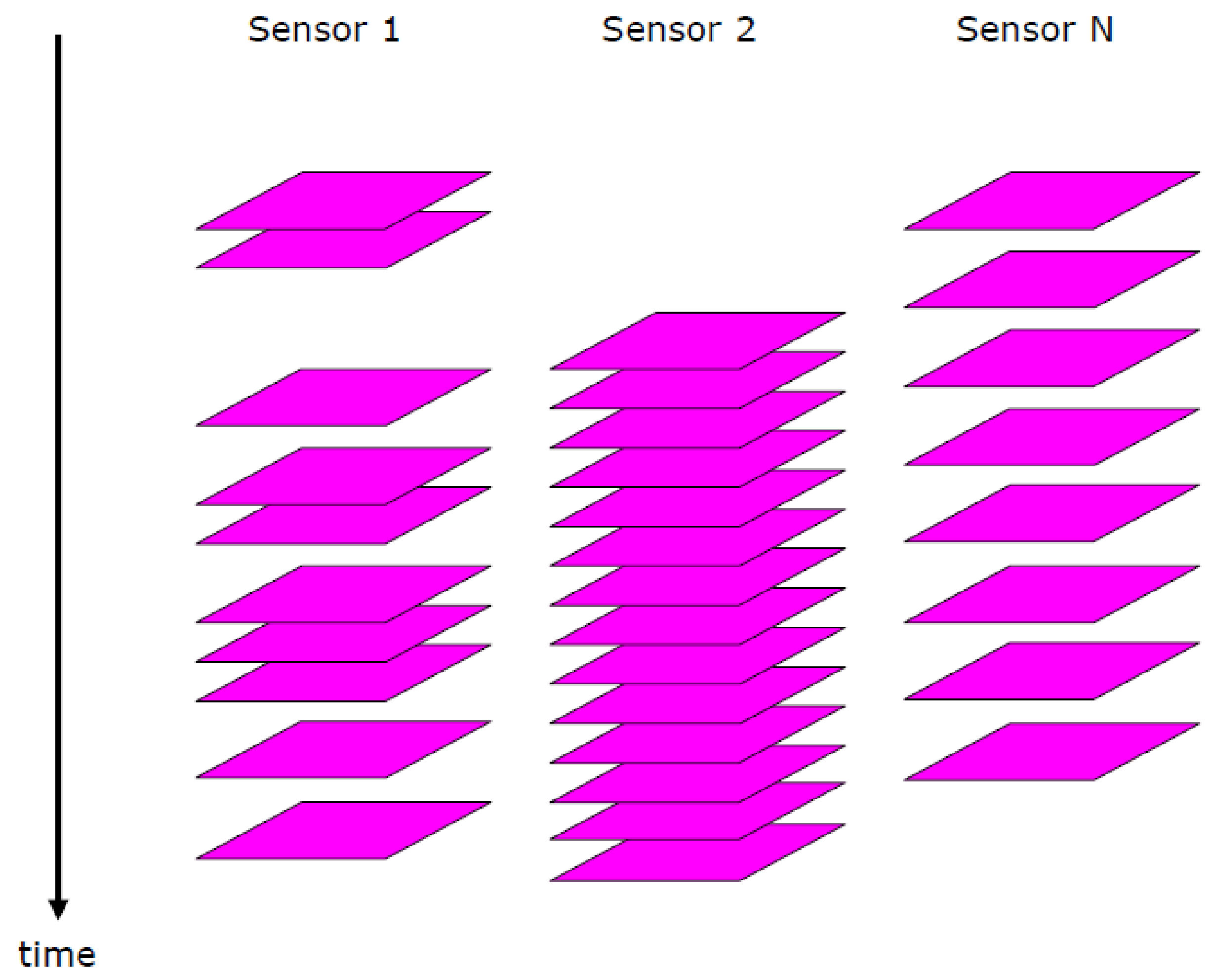




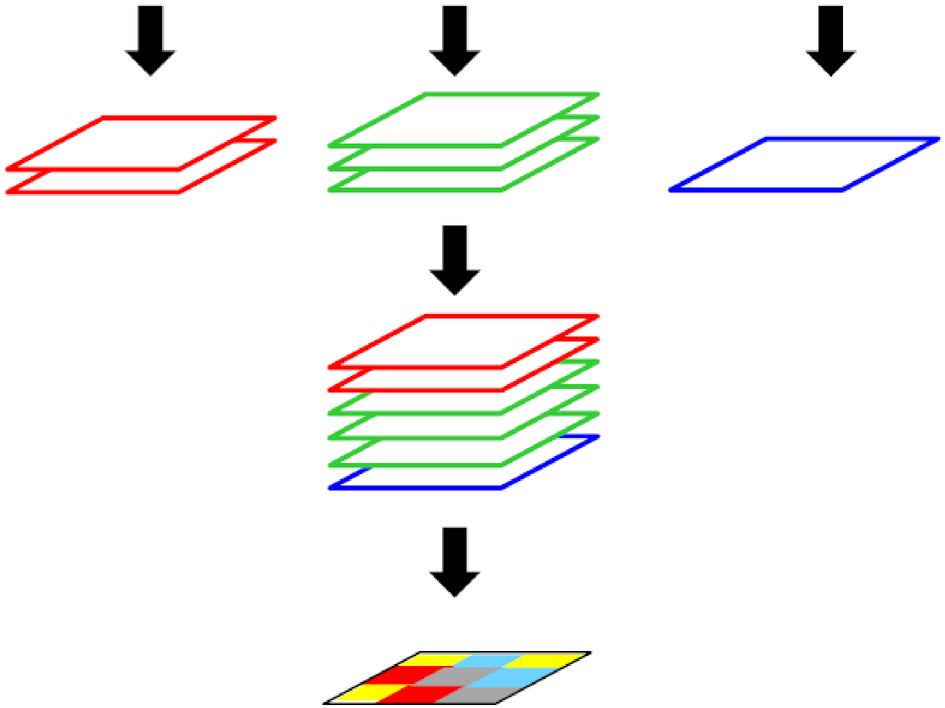
Multi-temporal multi-spectral descriptors



Multi-temporal multi-spectral descriptors



Multi-temporal multi-spectral descriptors

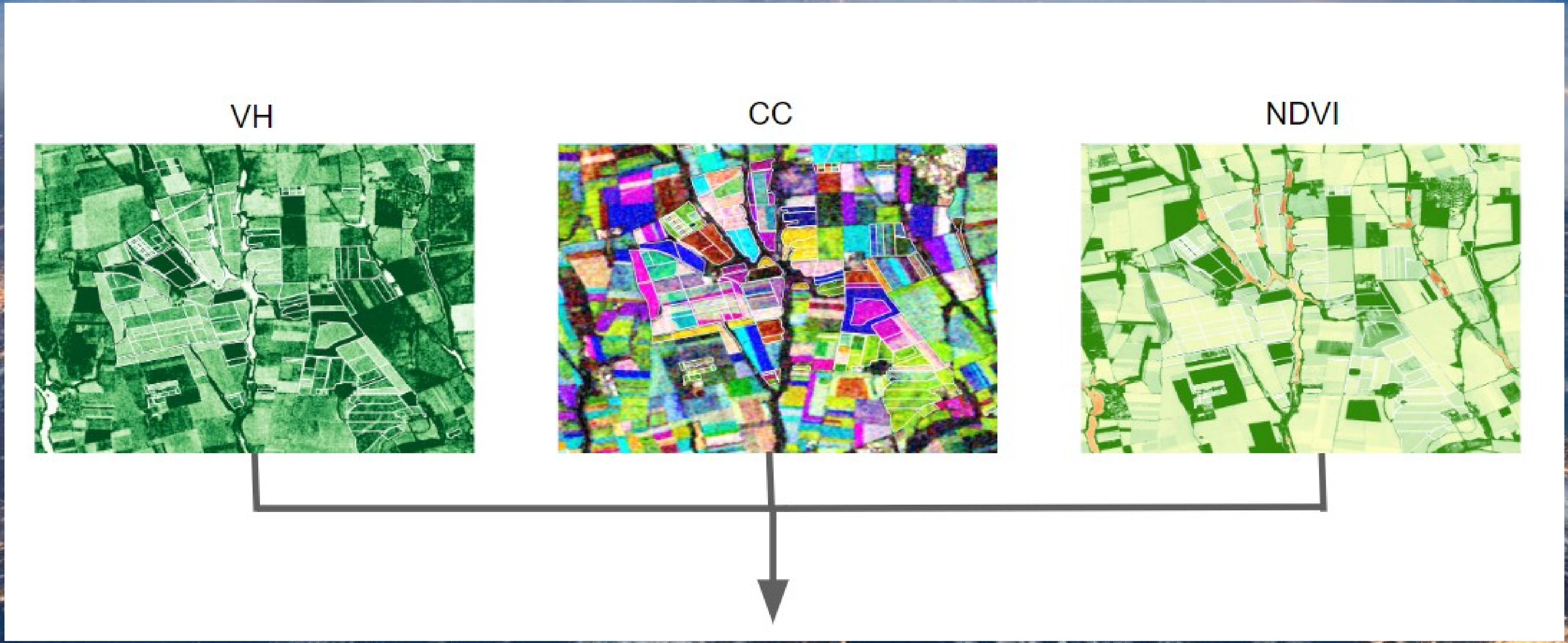


Temporal-spectral descriptors
for selected time period(s)

Temporal-spectral descriptors selection
based on uncorrelated features

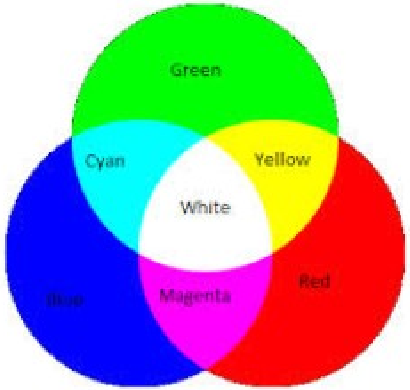
Land Cover Map

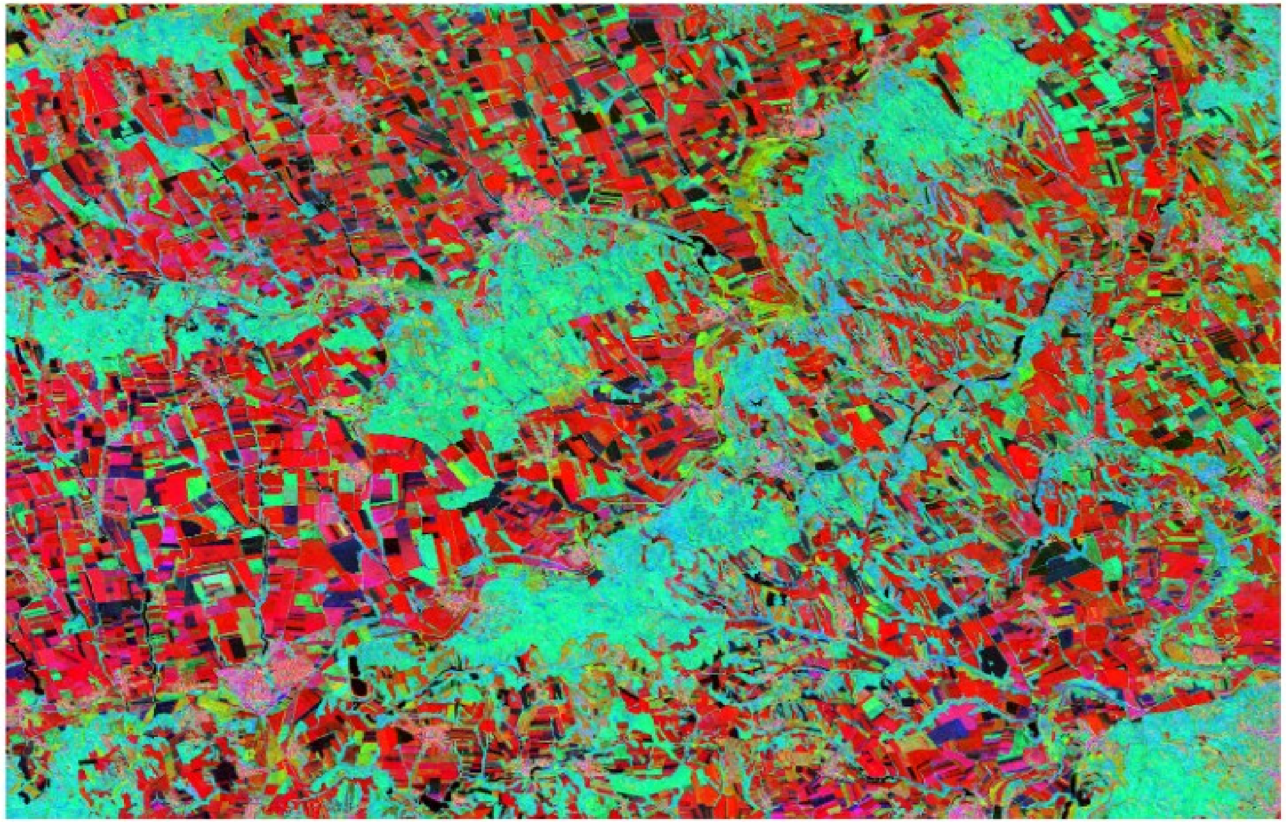
Multi-temporal multi-spectral descriptors fusion

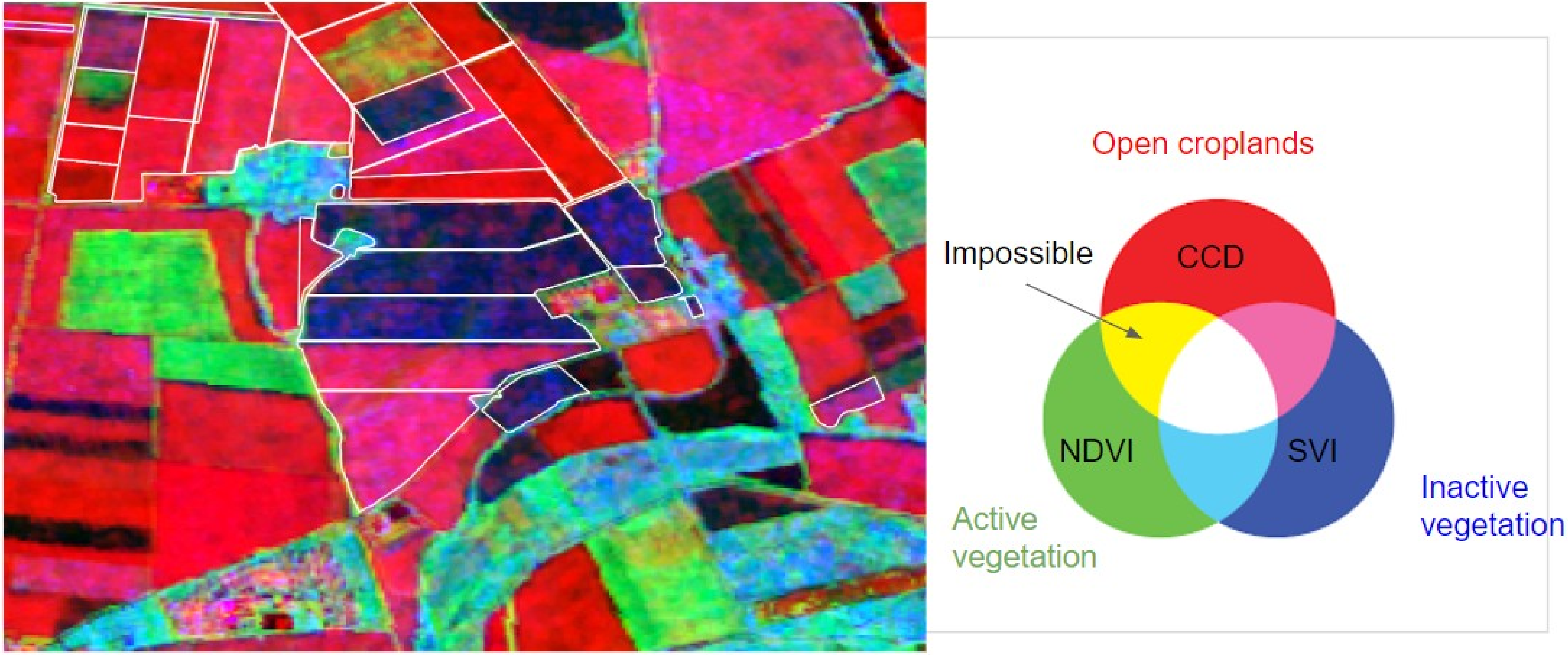


RGB

- R>Coherence
- G>NDVI
- B>SVI





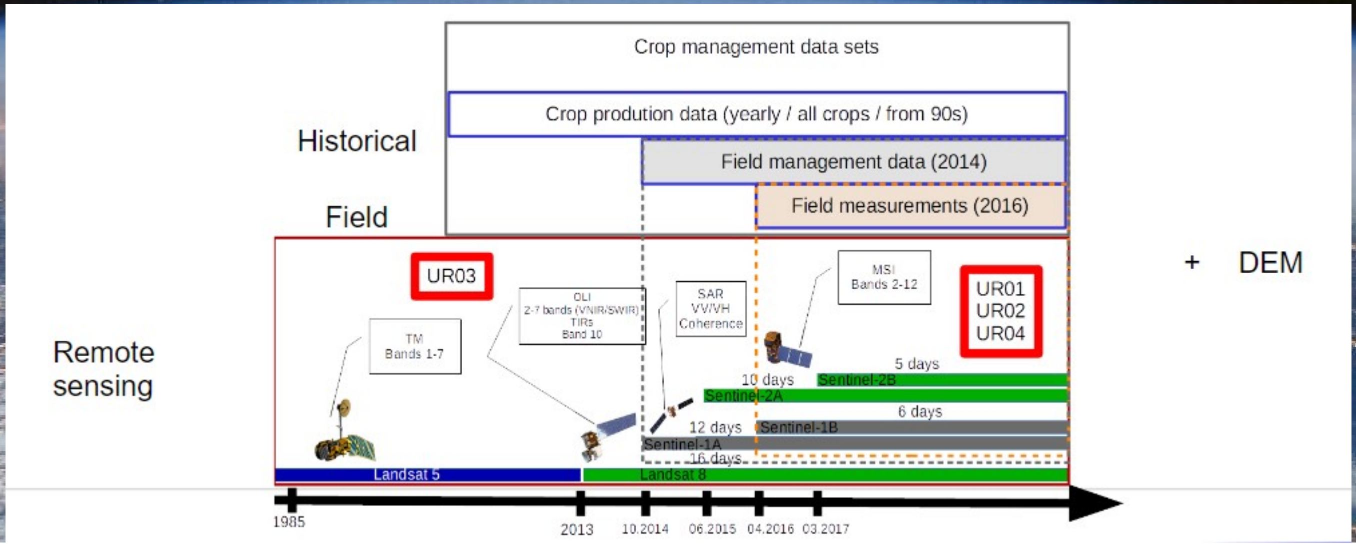

Open croplands
Impossible
CCD
NDVI
SVI
Active vegetation
Inactive vegetation

CCmean =R

spanD_SVI =G

NDVImaxI =B

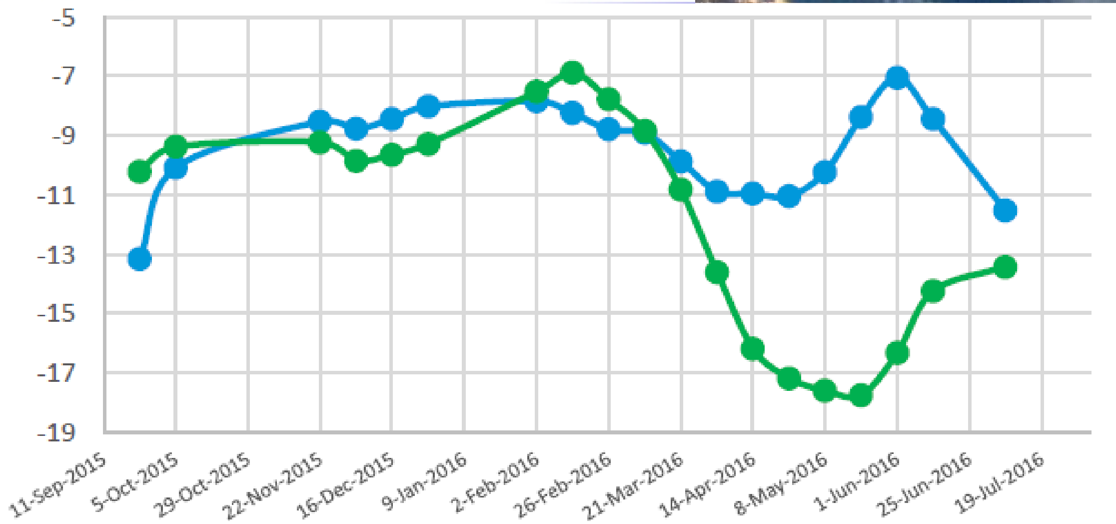
Knowledge based temporal analysis



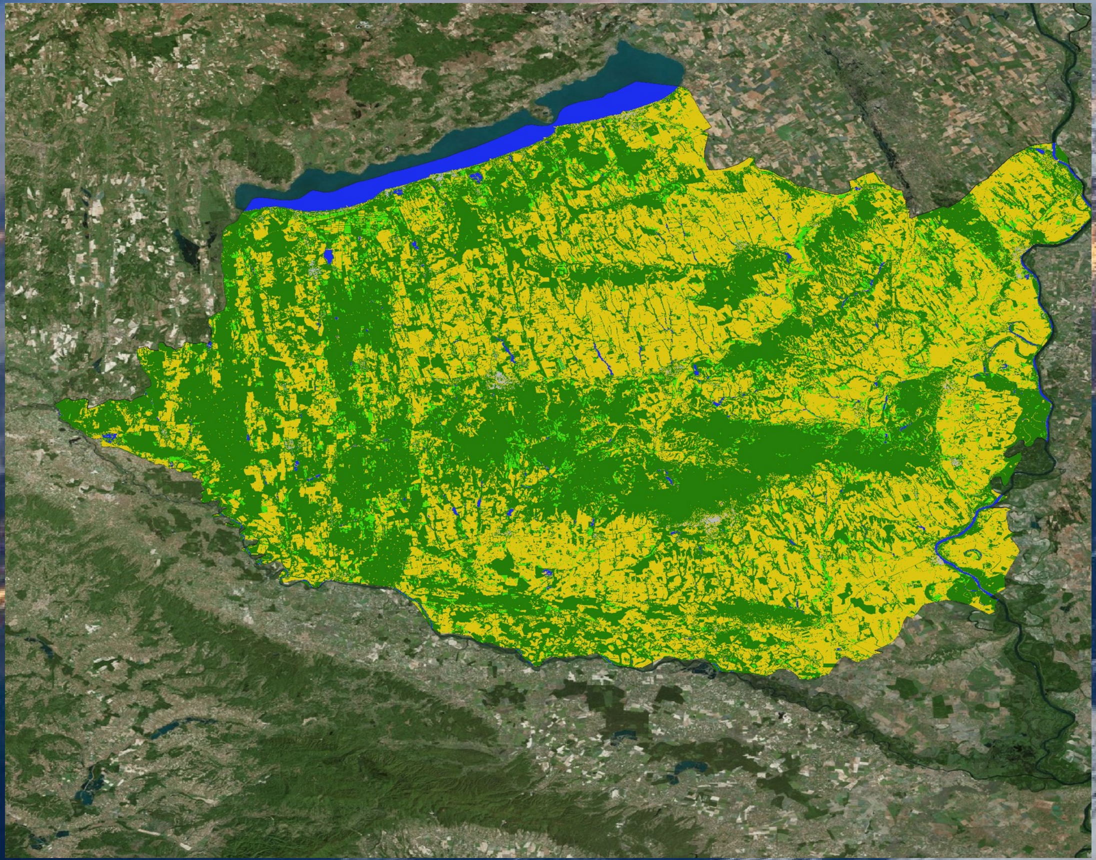
Knowledge based temporal analysis

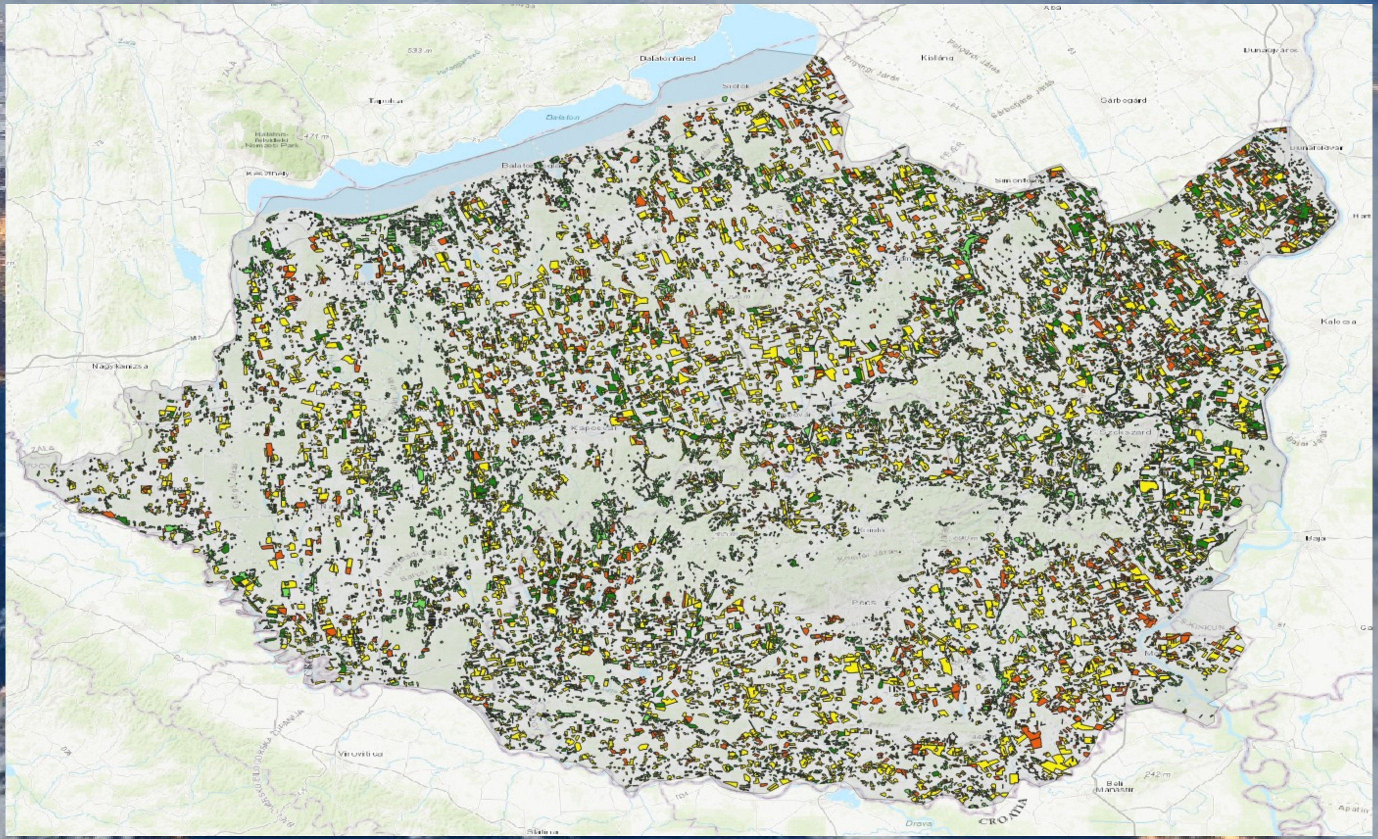
→ A priori information is required, as for instance
- crop type,
- calendar,
- phenology,
- duration,
- Practices, etc.

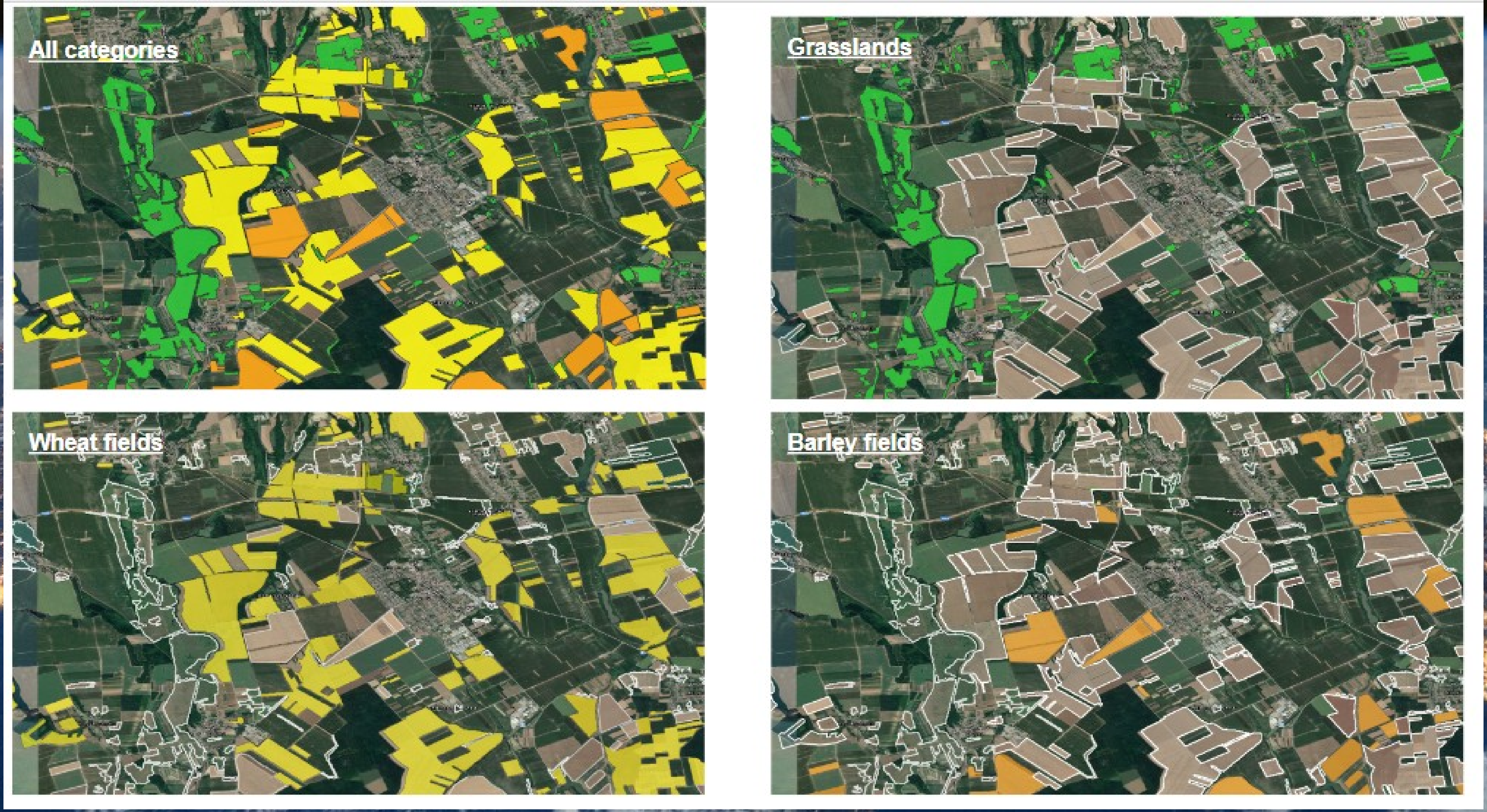
→ Systematic acquisitions must be available

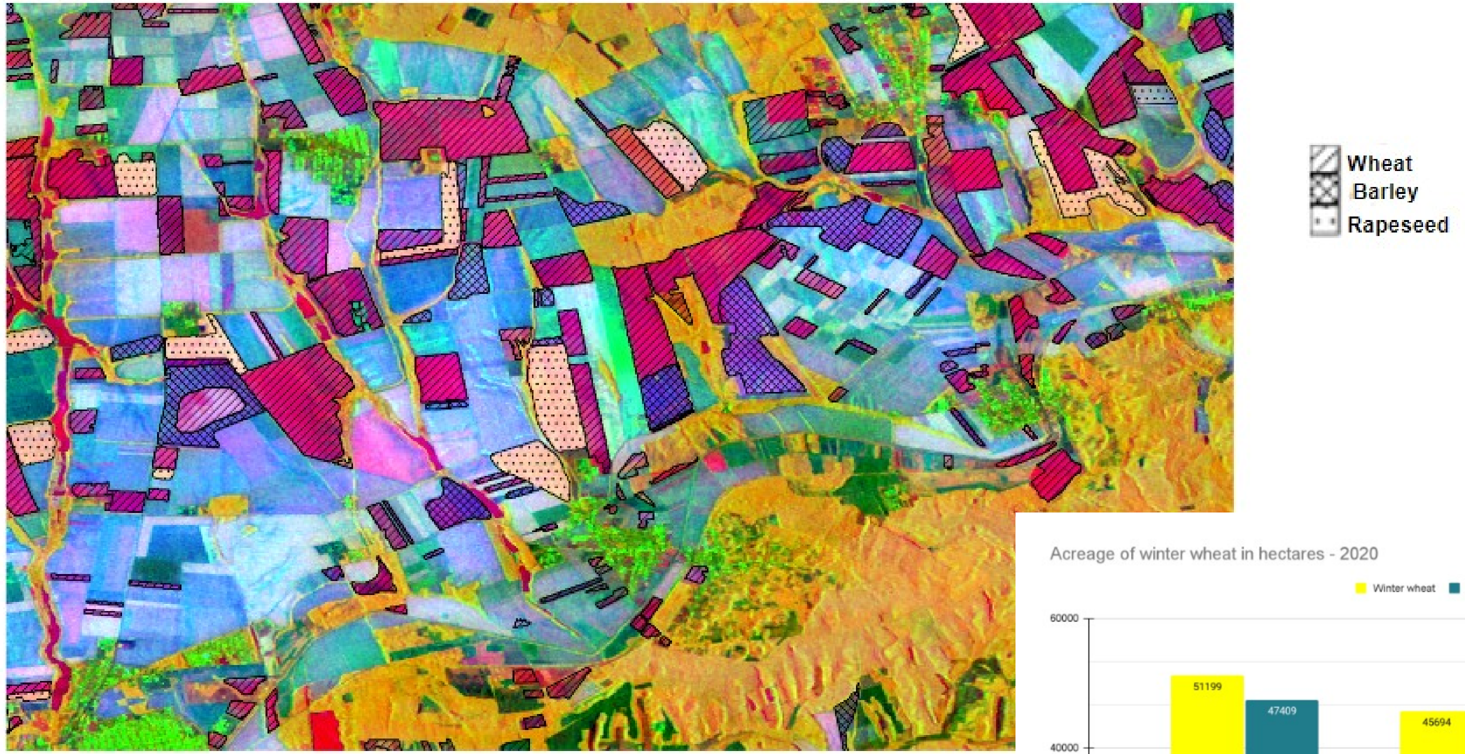


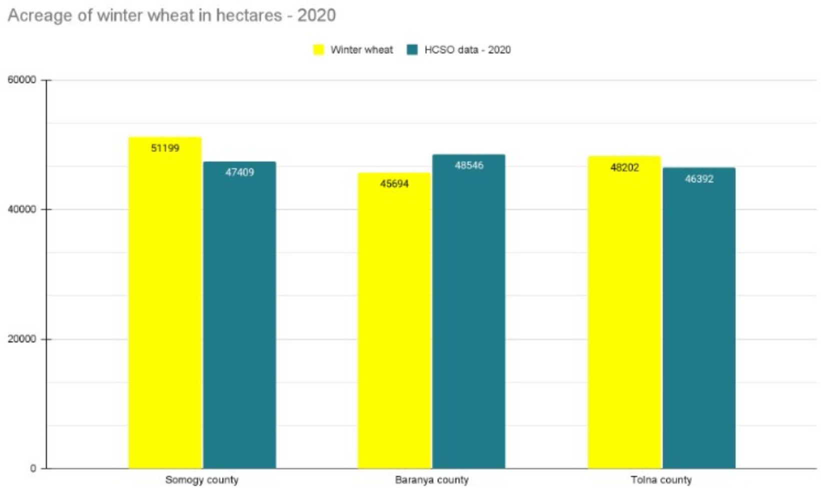
Base Map > Dedicated Product development






All categories
Grasslands
Wheat fields
Barley fields





<u>Comparison with HCSO data</u>

Somogy - 51199 ha (+8%)
Baranya - 45694 ha (- 4,1%)
Tolna - 48202 ha (+3,9%)

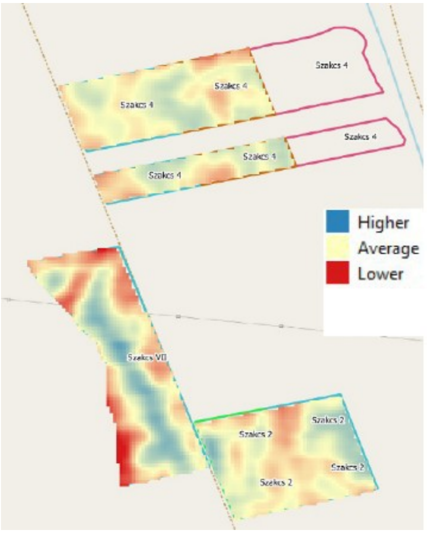
Moisture Index

	Bare soil condition		Vegetative period	
When	Dry season	Vegetation development	Wet season	Senescence period
Where	Constant roughness bare soil conditions		Constant roughness vegetation conditions	
What	Bare Soil Moisture Index		Vegetation Moisture Index or Vegetation Water Stress	

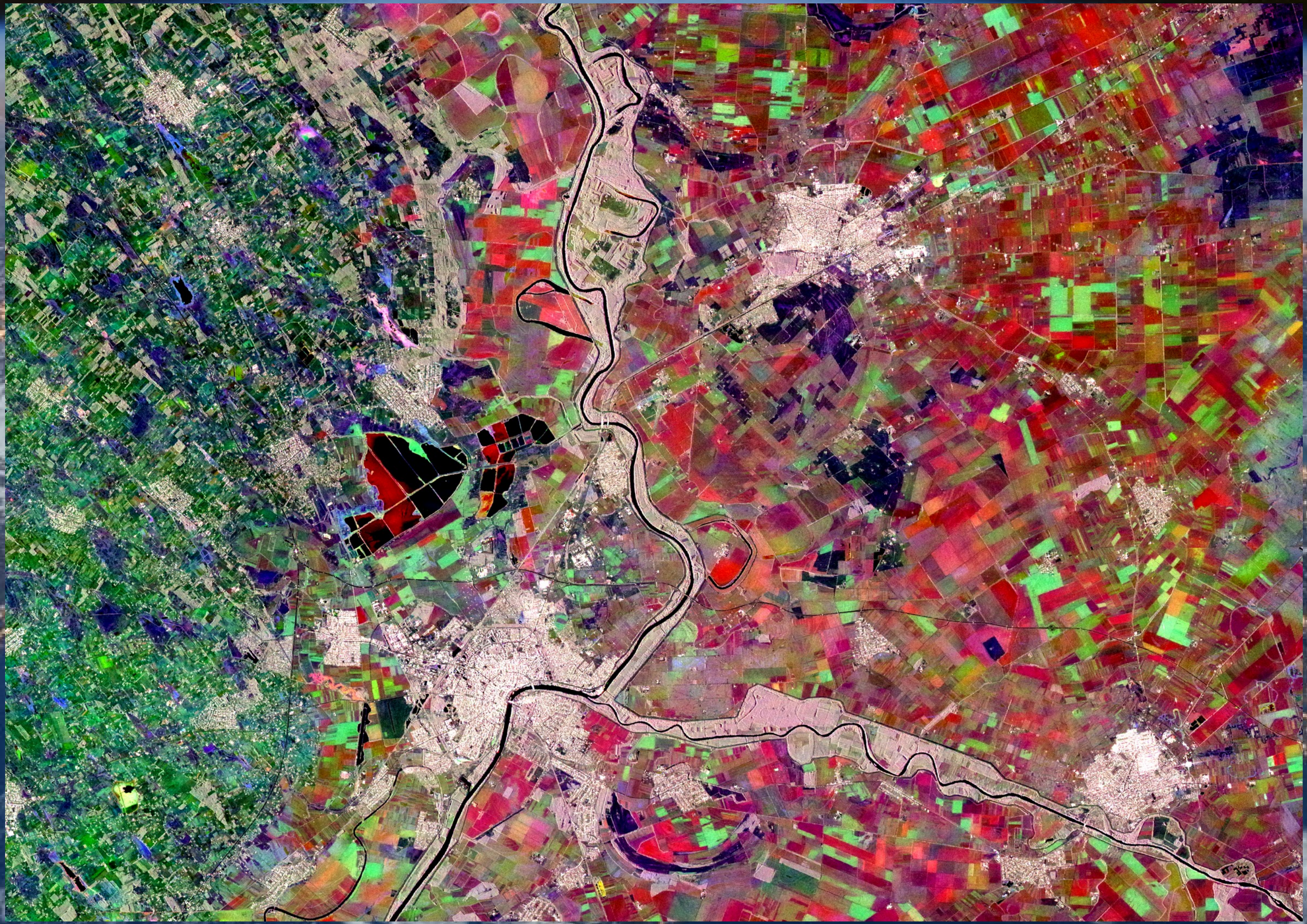
Product Development

product		when	what	Crops
General	Vegetation evolution – NDVI	every 15 days	S2	all
	Biomass evolution – DPSVI/ESVI	every 15 days	S1 (I+C)	all
Specific	Seasonal patterns	every 15 days	S1 & S2	all
	Field anomalies	at key moments	UAV	all
	Phenology – SoS, PoS, EoS	monthly	S1	all
	Length of flowering	every 15 days	S1 & S2	rape
	Number of stem	every 15 days	UAV	corn
Bio-physical	Soil moisture (rel)	every 15 days	S1 (I+C)	all
	Vegetation water stress (rel)	every 15 days	S1 & S2	all
Damages	Water excess	at event	S1 (I+C)	cereal
	Hail	at event	S1 & S2 / UAV	all
	Diseases	at event	UAV	all
	Frost	at event	S1 (I+C)	cereal
	Snow cover	at event	S2	cereal

Pre-requisite:
- Field boundaries
- Crop types
- Expected field treatments



Thank you for your attention



Some additional resources:

Case study: Mapping Crop Residue with Remote Sensing Data

https://www.l3harrisgeospatial.com/Learn/Case-Studies/Case-Studies-Detail/ArtMID/10204/ArticleID/24191/Mapping-Crop-Residue-with-Remote-Sensing-Data

L3Harris Webinar: Monitor Agriculture with SAR | SAR Insider Series (October 28th, 2021):
https://www.l3harrisgeospatial.com/Company/Events/Webinar/Webinar-Detail/ArtMID/10251/ArticleID/24115/Monitor-Agriculture-with-SAR-%7c-SAR-Insider-Series

L3Harris Webinar: A Deeper Dive into SAR: Agriculture and Land Surface Deformation
(February 26th, 2019): https://www.l3harrisgeospatial.com/Company/Events/Webinar/Webinar-Detail/ArtMID/10251/ArticleID/23662/A-Deeper-Dive-into-SAR-Agriculture-and-Land-Surface-Deformation

L3Harris Video: Applications For Remotely Sensed Data in Agriculture
http://www.harrisgeospatial.com/Learn/Videos/Video-Detail/TabId/2722/ArtMID/10263/ArticleID/15698/Applications-For-Remotely-Sensed-Data-in-Agriculture.aspx