8th ESA Training Course on Radar and Optical Remote Sensing

Cesis, Latvia

September 5 – 9, 2016

Optical Land Applications:
focus on agriculture

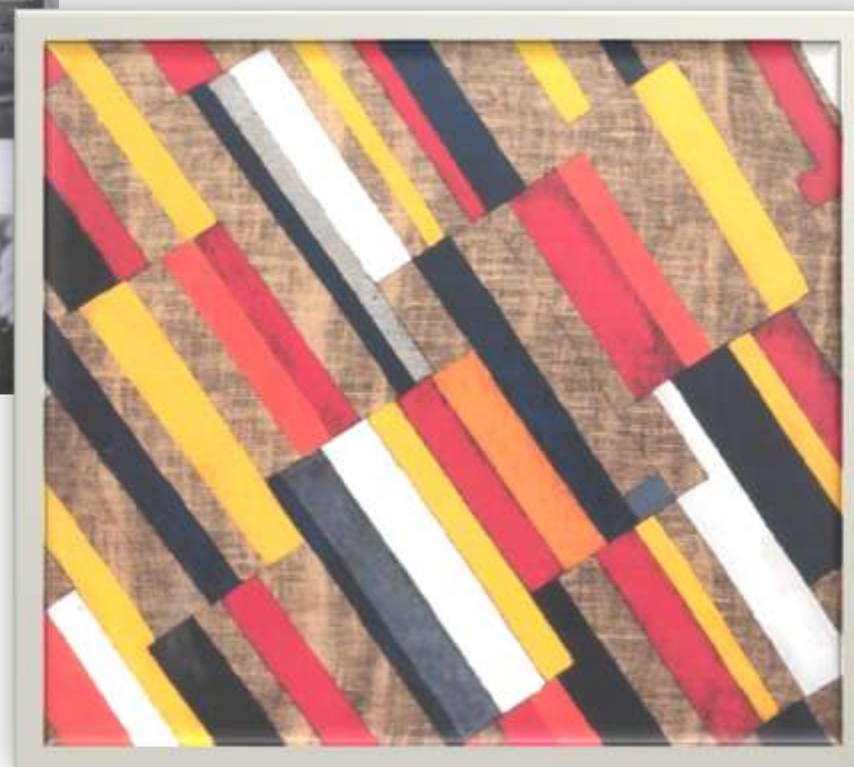
THEORY

Pierre Defourny
Earth and Life Institute
Université catholque de Louvain
Belgium

Optical land remote sensing : an impressive technological evolution to change the perspective on our environment !

Paris - 1858 : 1st aerial photo
G. Tournachon

Squadron of pigeons taking off
(Scientific American, 1909)

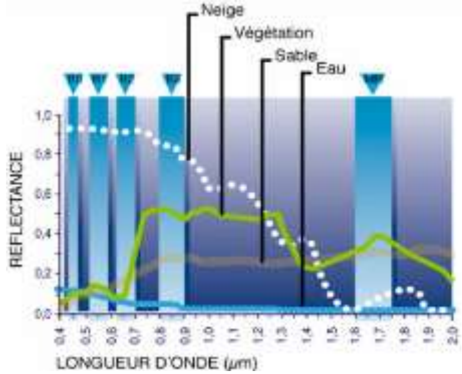


Hungarian fields – painted by
Laszlo Moholy-Nagy, 1921

Optical land remote sensing : 40 years of digital evolution

Paris - 1858 :
G. Tournachon

Spectral resolution

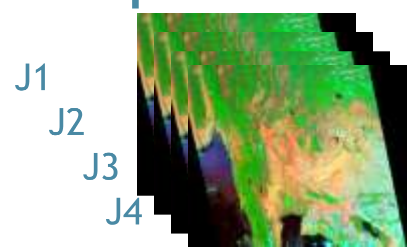


Radiometric resolution

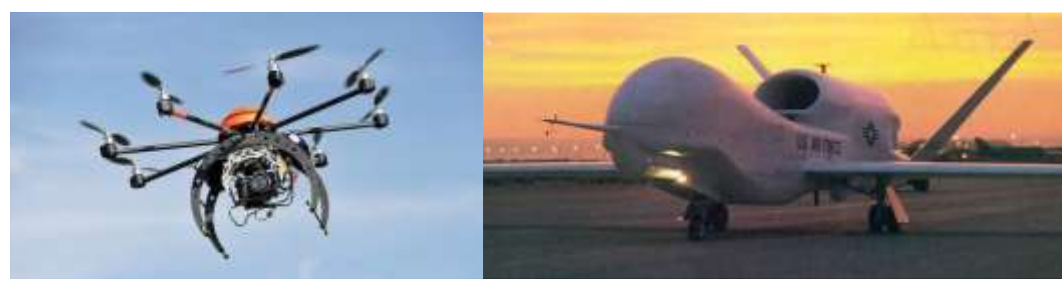
4 bits 16 bits

Spatial resolution

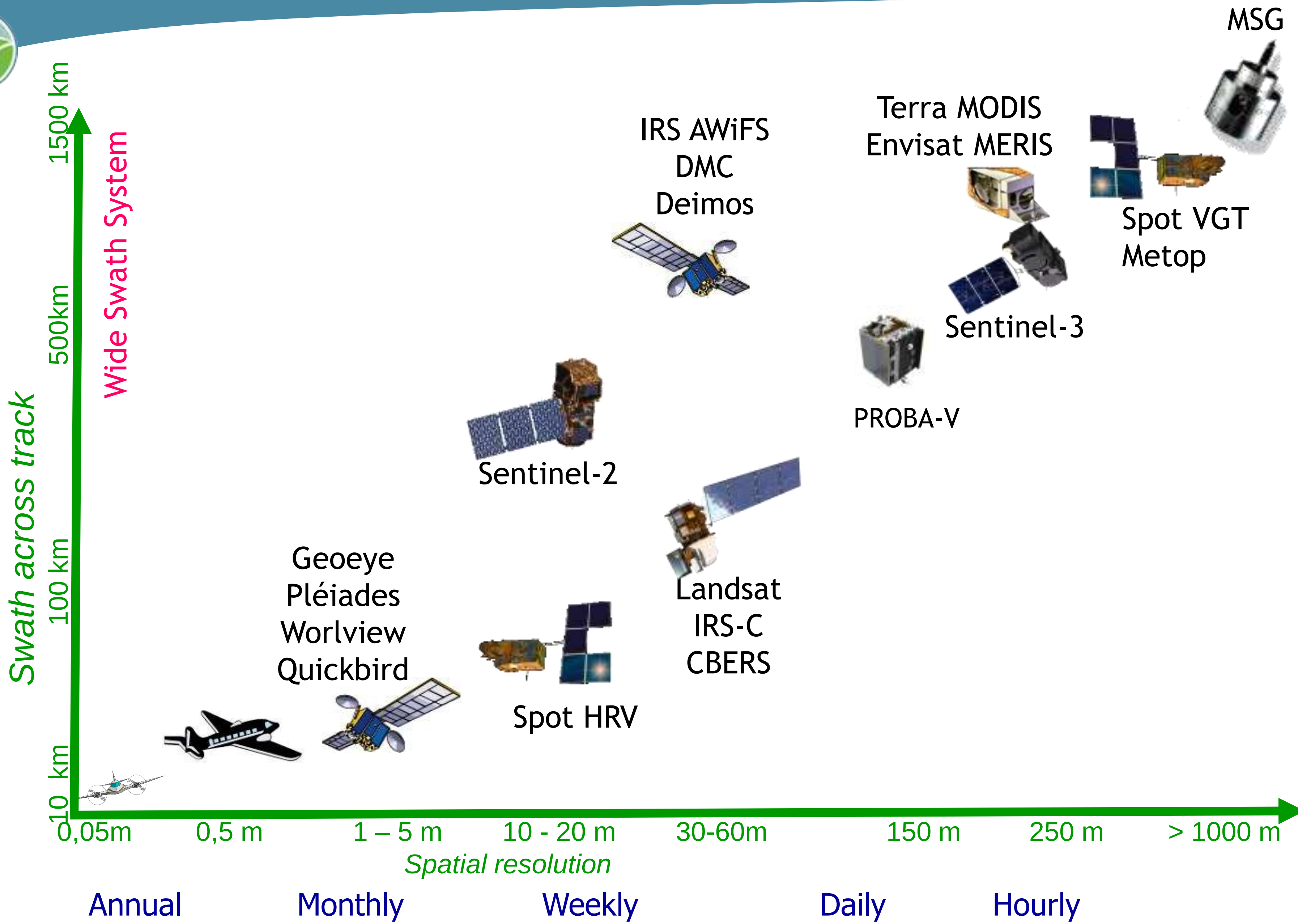
Temporal resolution



Plateform for phénotyping



‘ Unmanned Aerial Vehicle ’ (UAV)



MSG
Terra MODIS
Envisat MERIS
IRS AWiFS
DMC
Deimos
Spot VGT
Metop
Sentinel-3
PROBA-V
Sentinel-2
Landsat
IRS-C
CBERS
Geoeye
Pléiades
Worlview
Quickbird
Spot HRV
1500 km
500km
100 km
10 km
Wide Swath System
Swath across track
0,05m
0,5 m
1 – 5 m
10 - 20 m
30-60m
150 m
250 m
> 1000 m
Spatial resolution
Annual
Monthly
Weekly
Daily
Hourly

Outline

1. **Introduction to optical land applications :**
   - **monitoring (desert locust)**
   - **mapping (national and global land cover)**
   - **change detection (forest cover change)**
   - **biophysical variable retrieval (crop growth)**

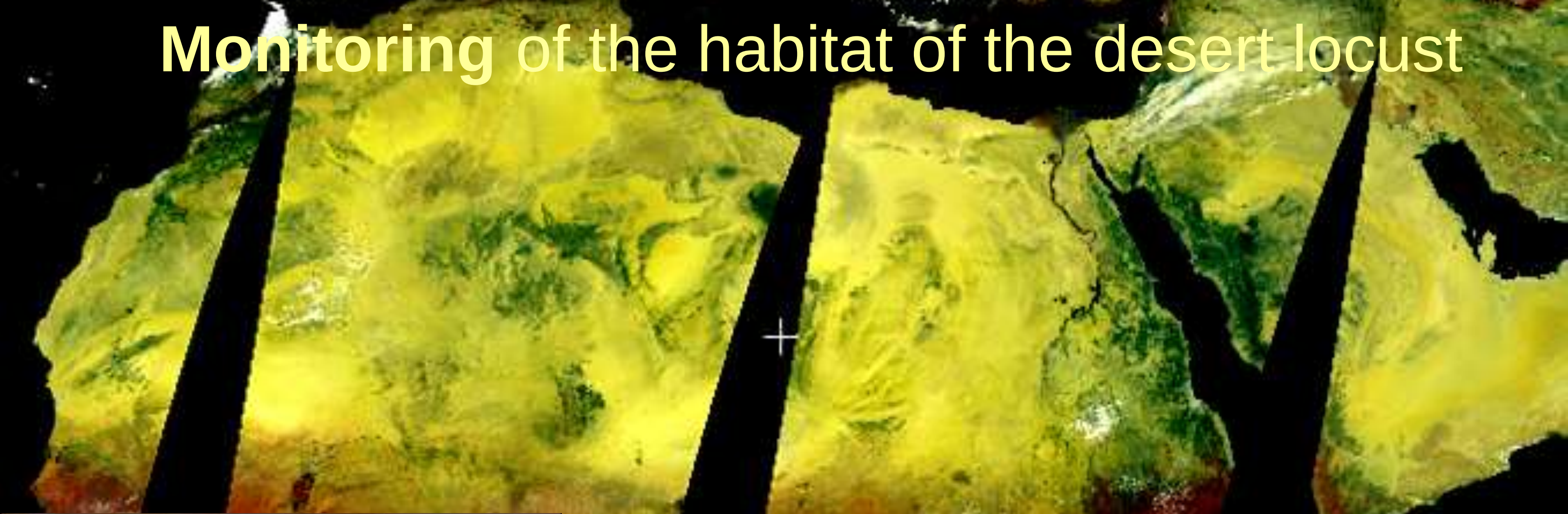
2. Basic principles about electromagnetic radiation & land surface

3. Identifying cultivated area and crops from space (Sen2-Agri system)

4. Estimating canopy biophysical variables (Sen2-Agri system)

5. Example of monitoring crop production from space (MARS)

Monitoring of the habitat of the desert locust



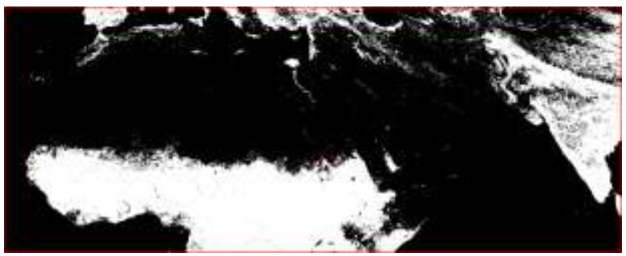
Desert locust

Schistocerca gregaria (Forskal, 1775)

The Green Vegetation Dynamic Map

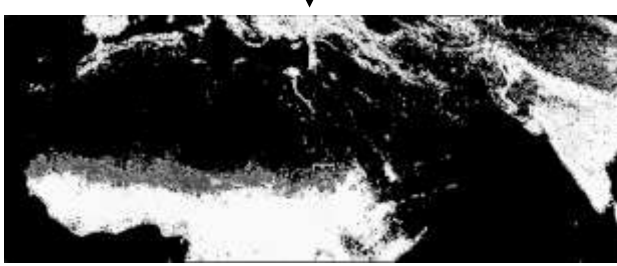
- Based on the integrated detection mask, a time meter computes the number of dekades during which a pixel is detected as green vegetation from its onset to the current dekade

- A color table is associated to the time meter

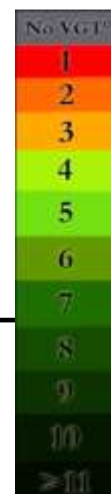


Integrated Detection mask

Incrementation

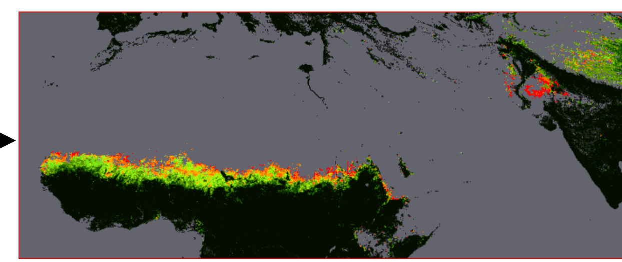


Detections time meter



Color table

The time meter is reset only if the vegetation disapears



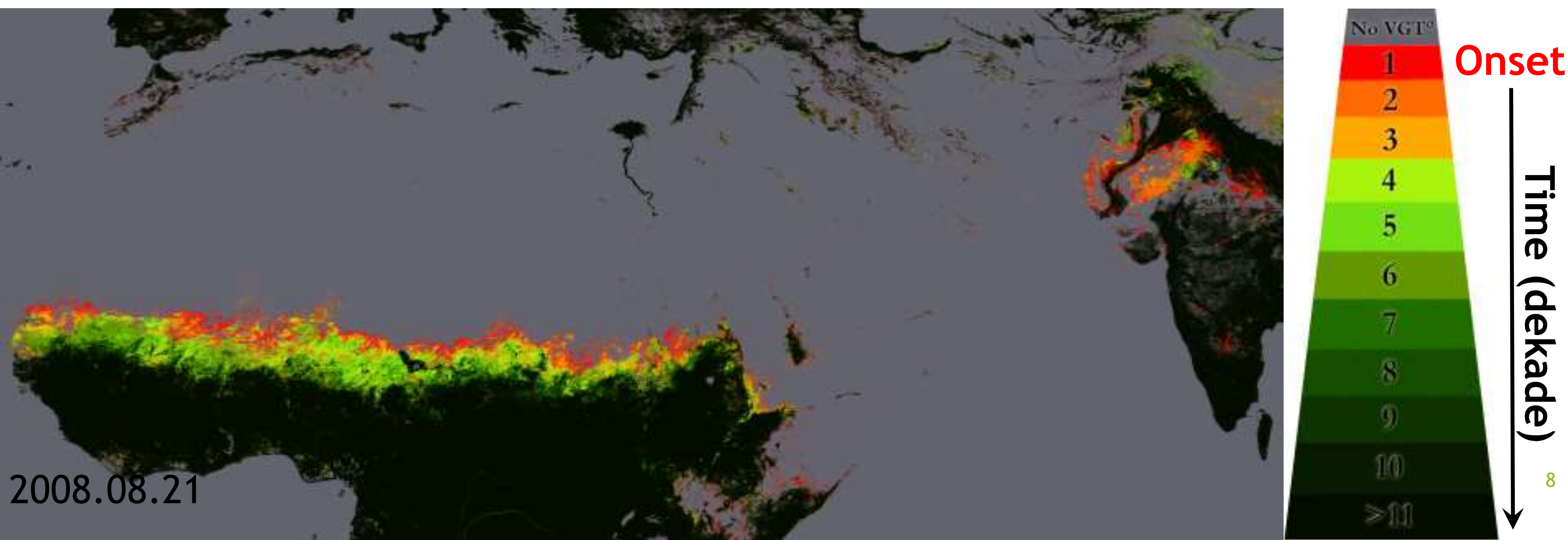
Green Vegetation Dynamic Map

The Green Vegetation Dynamic Map

This map synthesizes the spatial and the temporal distribution of the vegetation at 250 m resolution over all the Locust area and is updated every 10 days

- **Thanks to a single file, the forecaster knows:**
  - **the vegetation areas at the onset** (red) **or close to the onset** (orange)
  - **the ephemeral vegetation** (occurring after one isolate rainfall event)
  - **the seasonal vegetation areas**
  - **the evergreen vegetation areas**

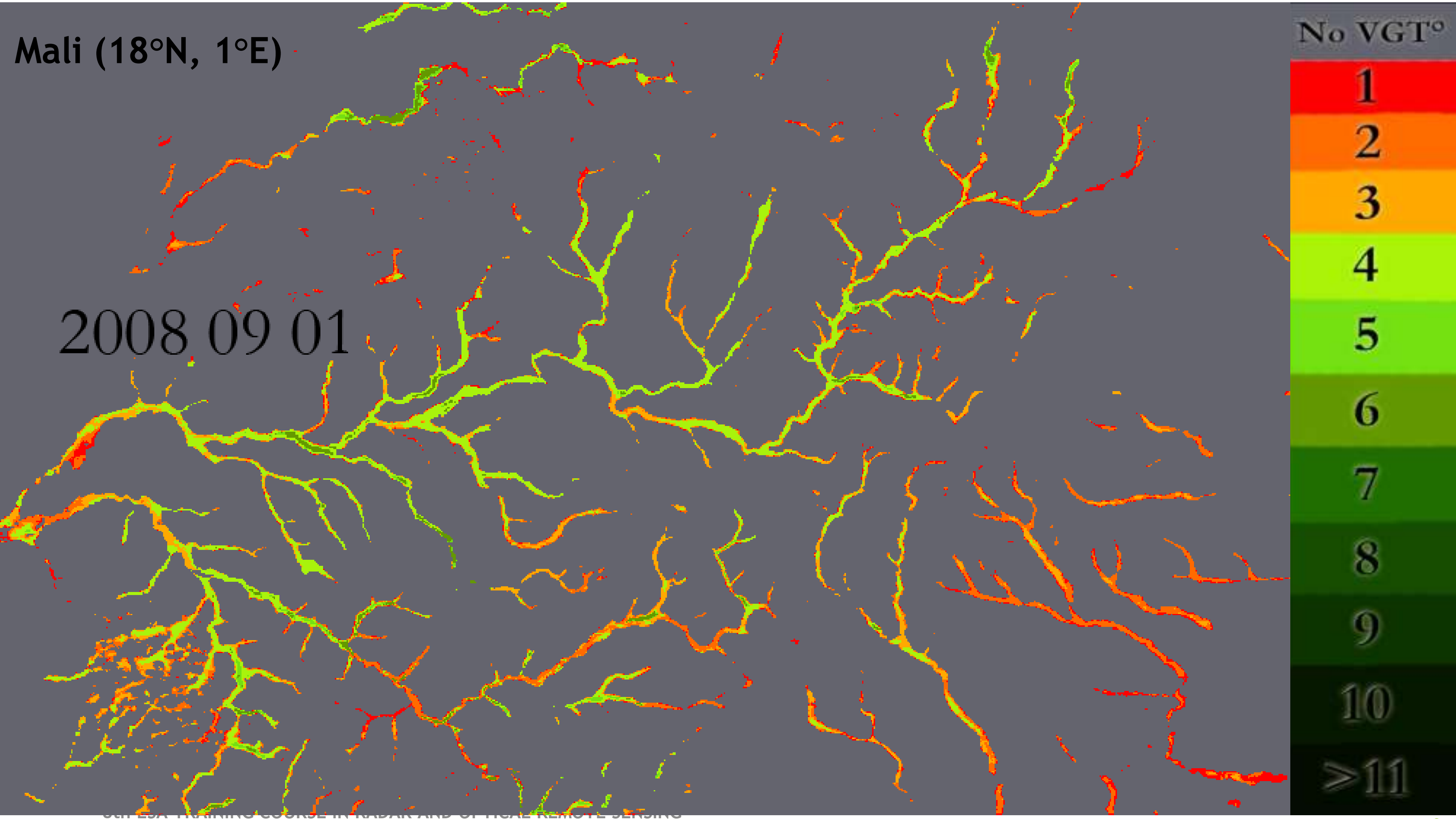
Pekel et al., 2011
Waldner et al., 2015



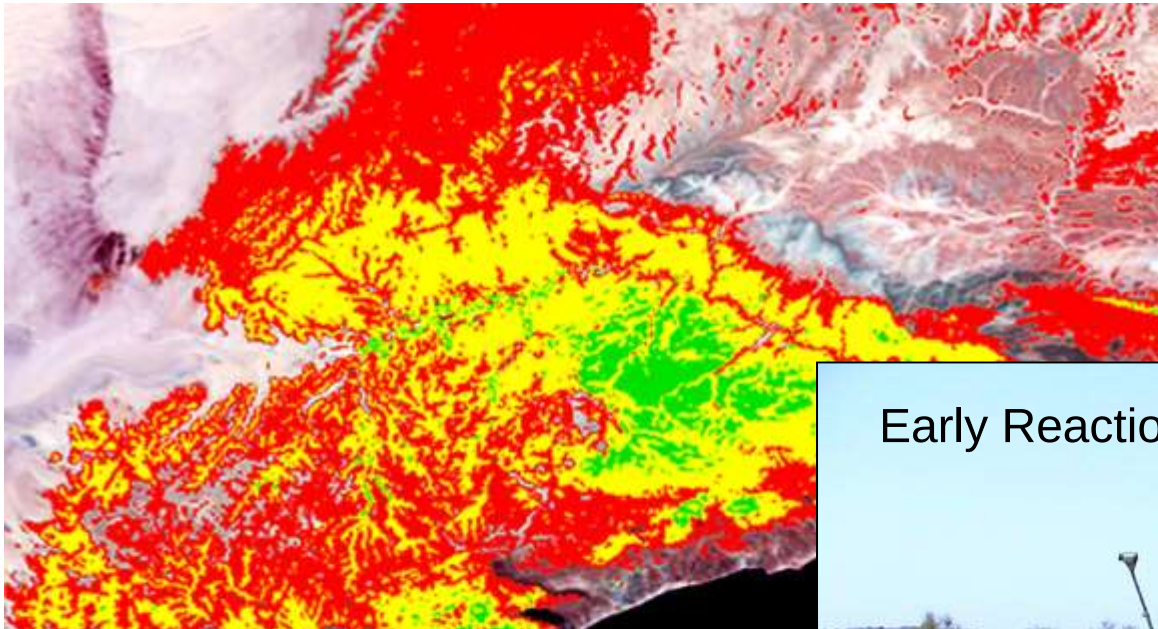
The Green Vegetation Dynamic Map

=> updated every 10 days (SPOT-VGT; MODIS; *PROBA-V*; *Sentinel*)

=> operational application for FAO since 2009 from Senegal to Pakistan



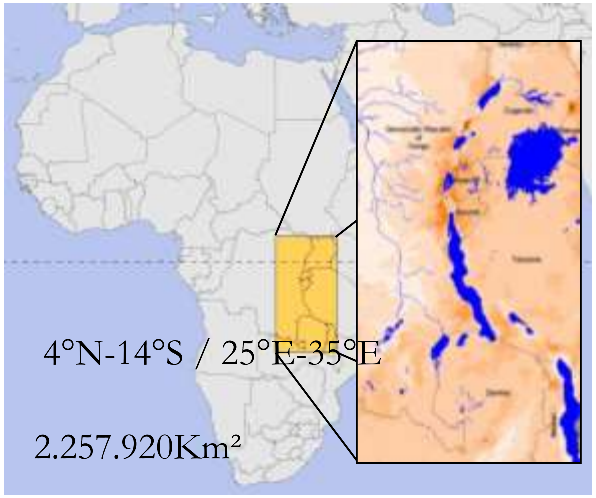
Field team: reduction of the false alarms !



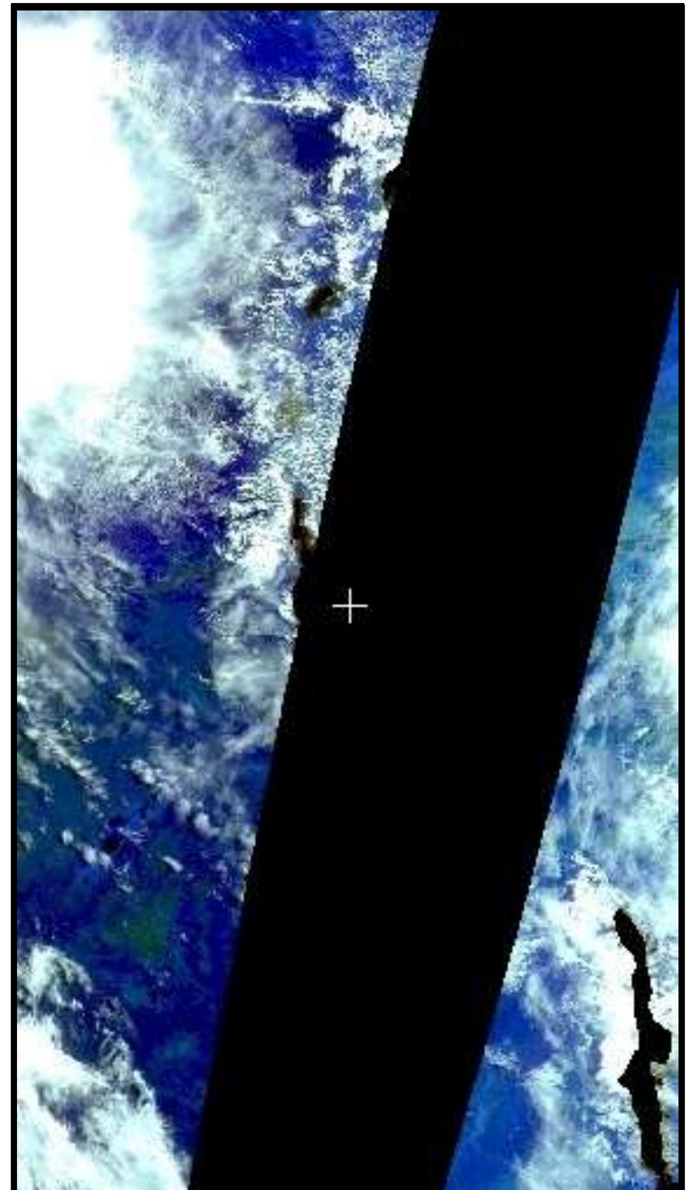
Previous method :
NDVI-based detections

Hue-based detection
Green vgt dynamic map

Land cover mapping from daily SPOT 4 VEGETATION time series



16 may 2000

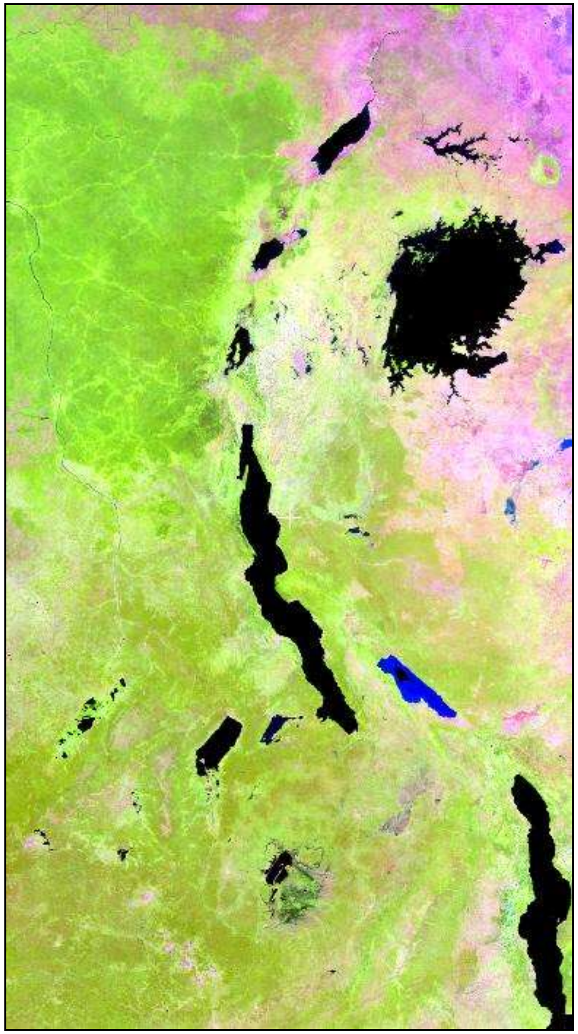


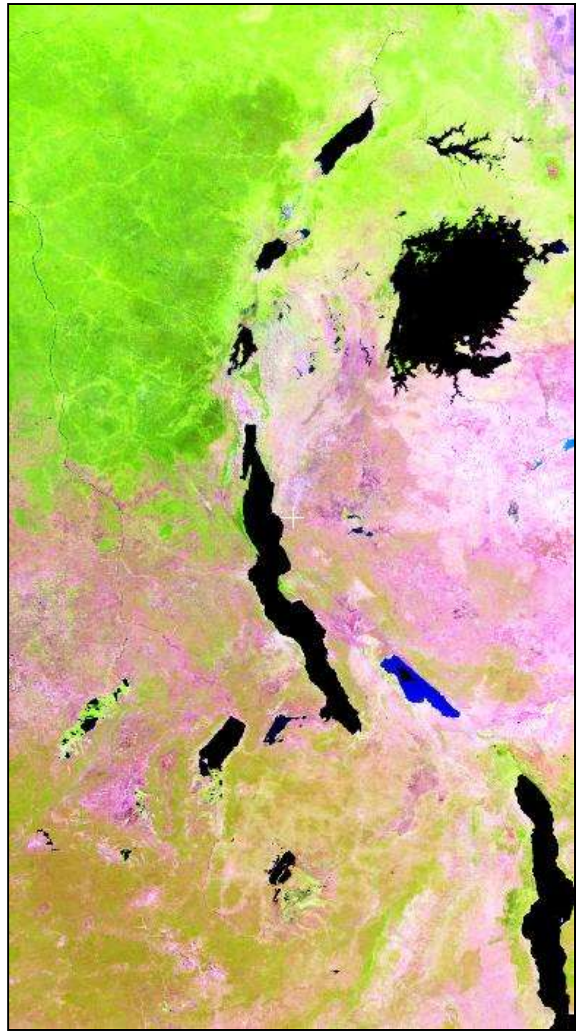
Clouds and large gaps

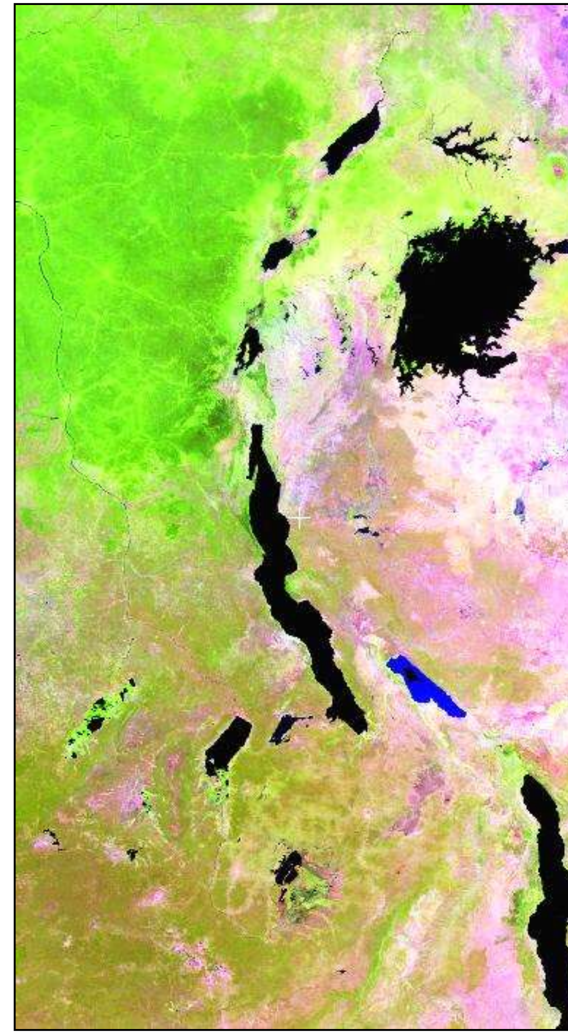
(Blue, Red, NIR)

Land cover mapping from SPOT 4 VEGETATION time series

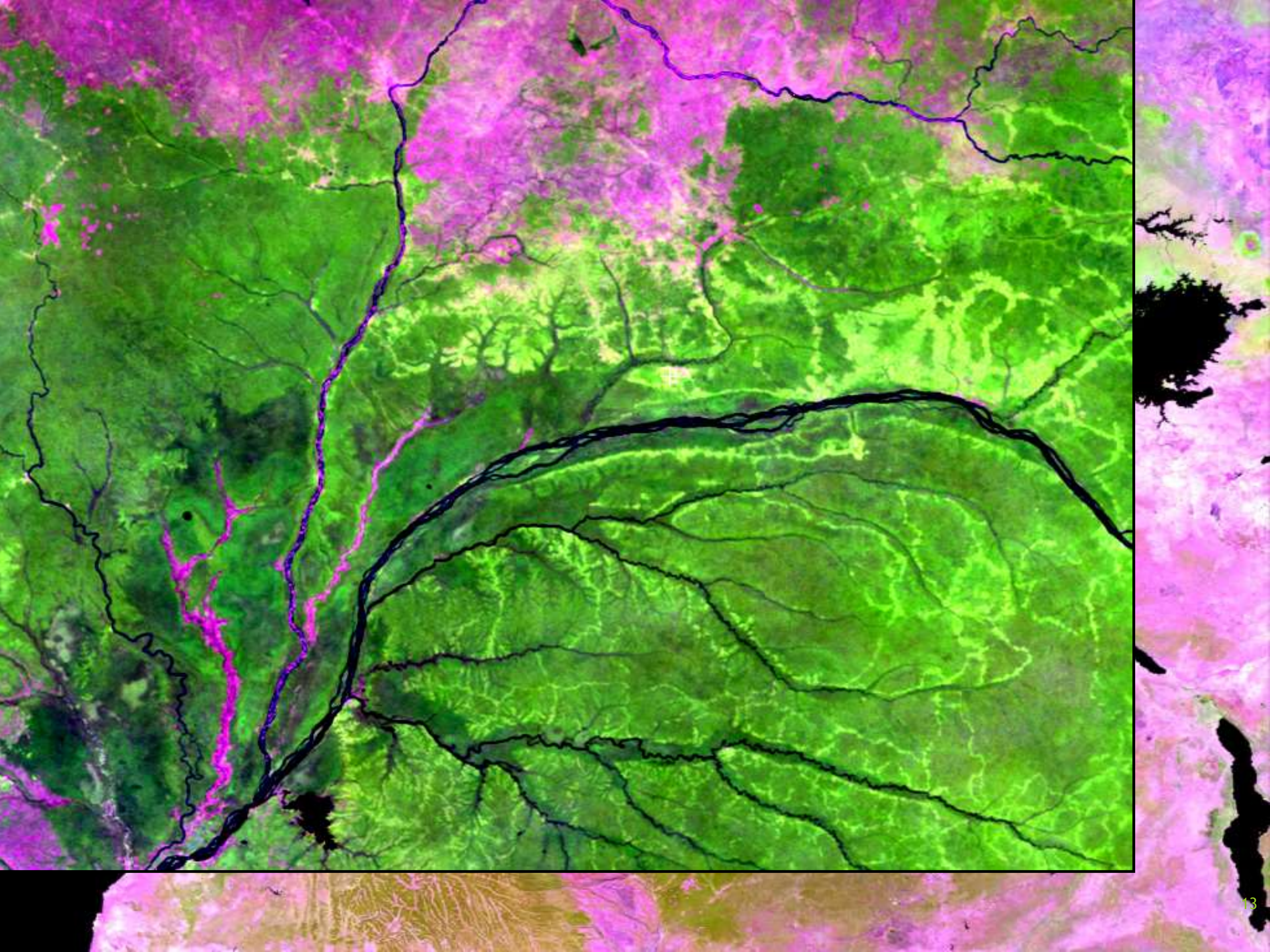
Seasonal compositing to combine all valid cloud free obs.


Feb-March-April


July-August-September

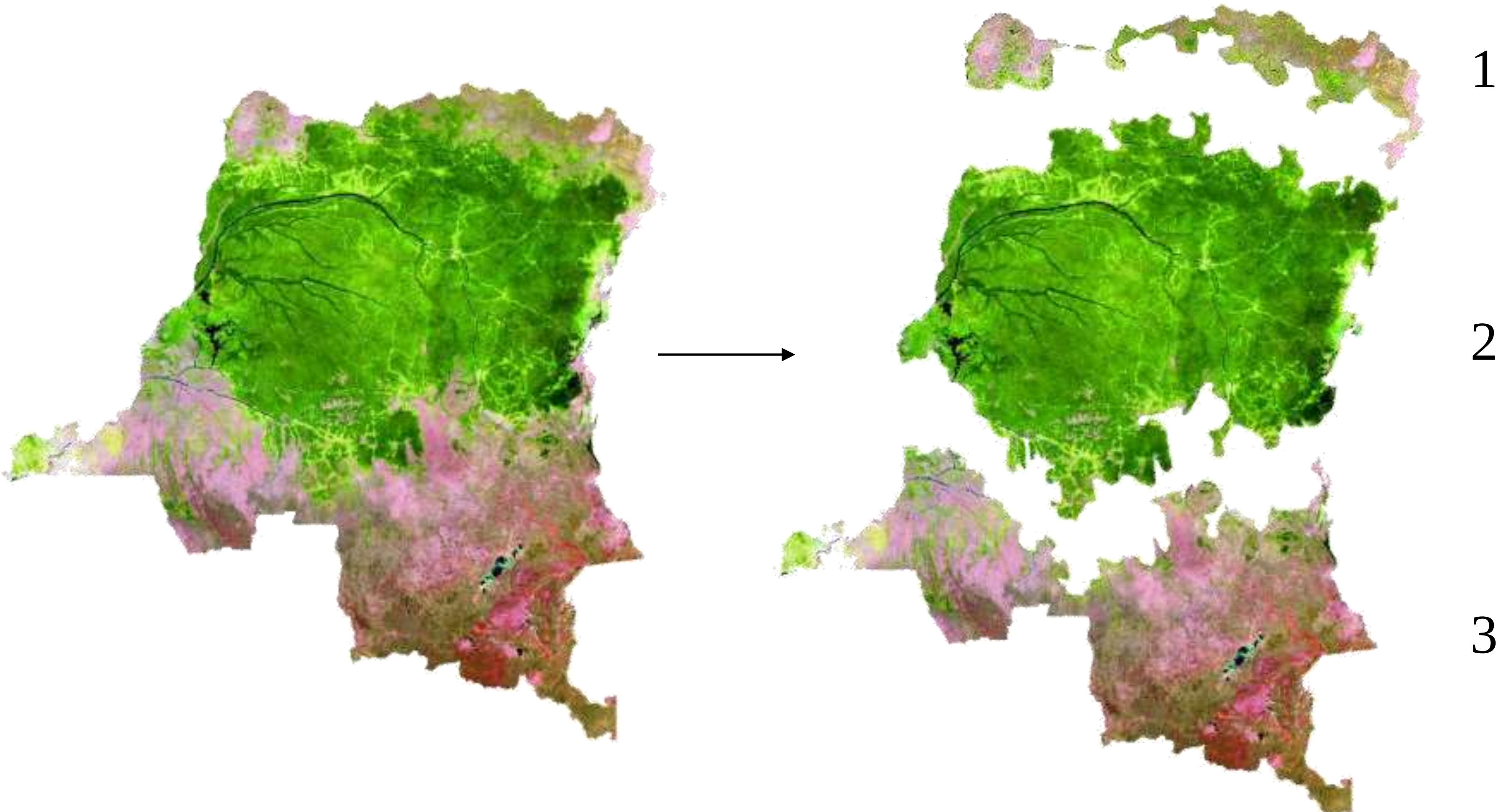

Annual

(Vancutsem et al., 2007,2011)

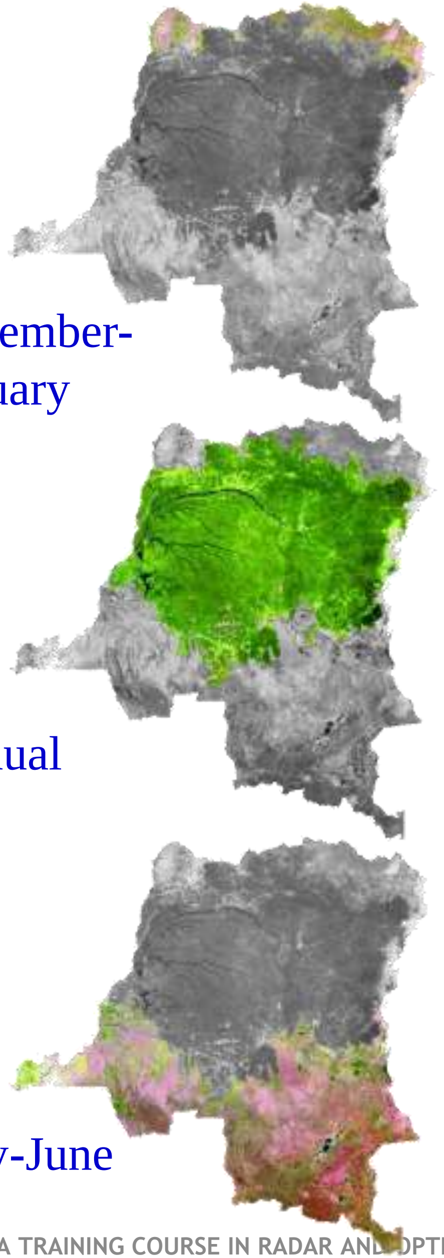


Land cover mapping : stratification

Composites:
- seasonal Decembrer-January (North)
- annual (Center)
- seasonal May-June (South)



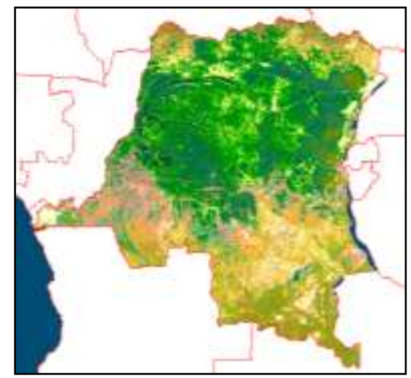
Land cover classification



December-January → 20 classes

Annual → 25 classes

May-June → 35 classes

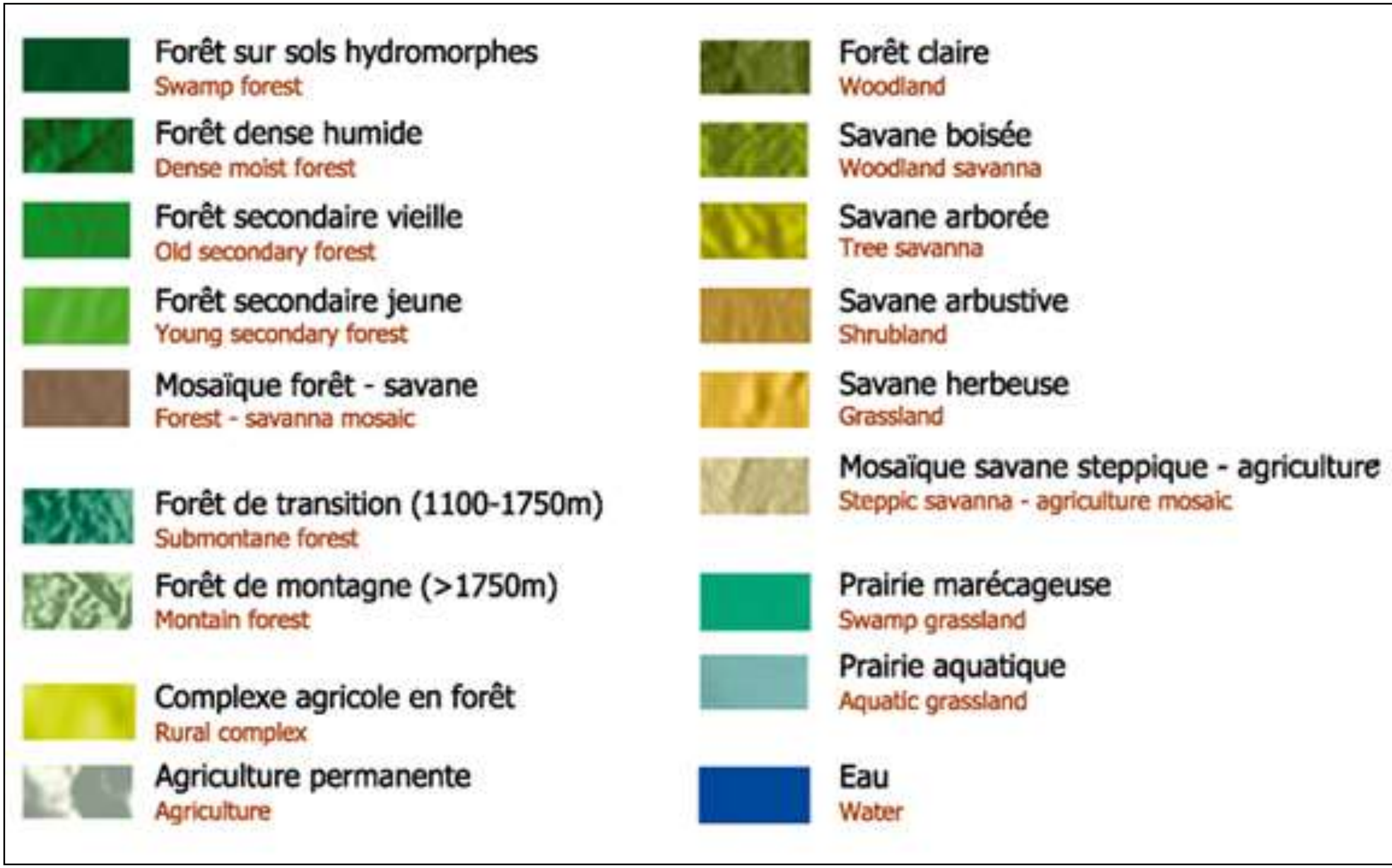


80 classes

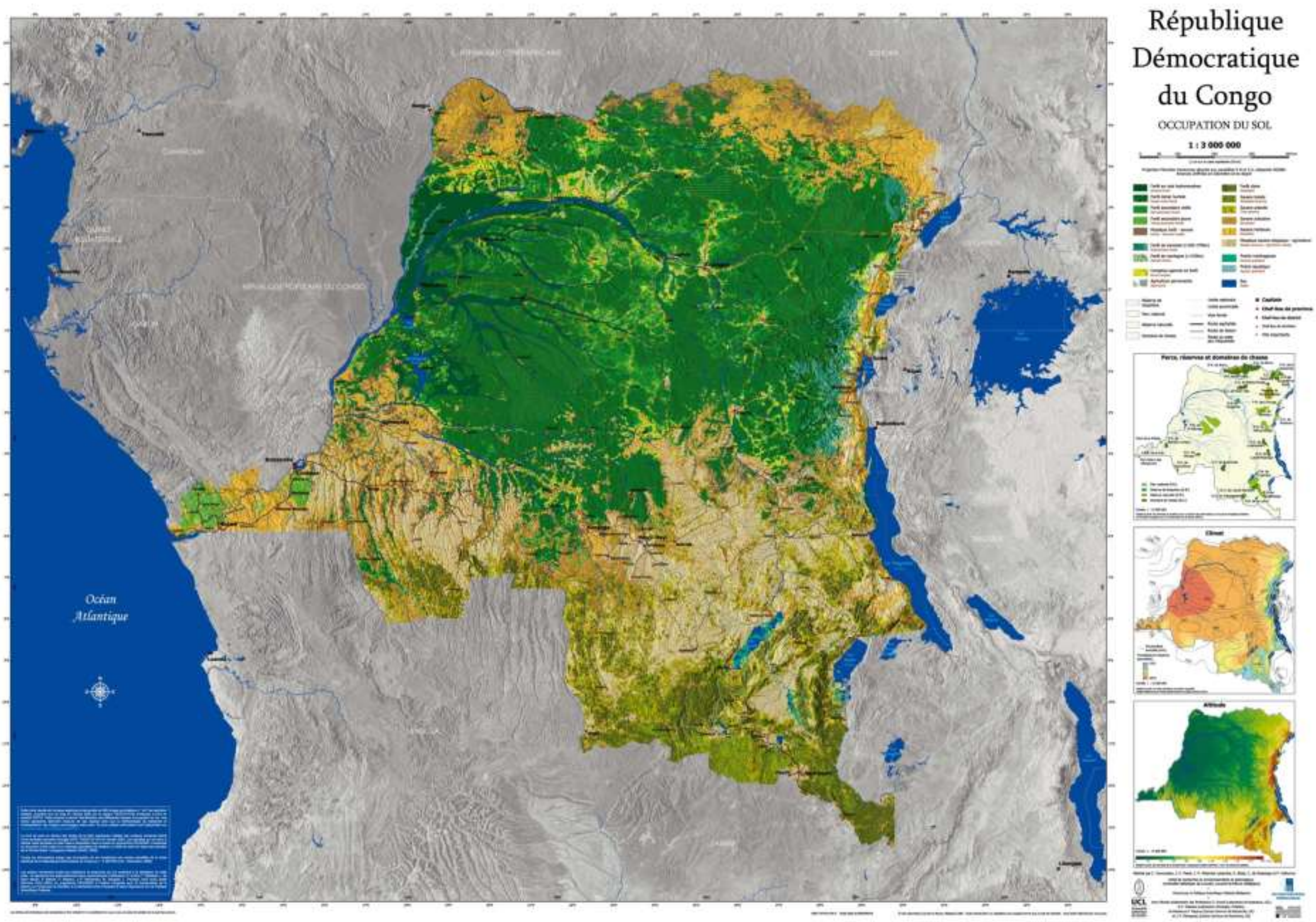
regrouping

16 classes

Land cover legend

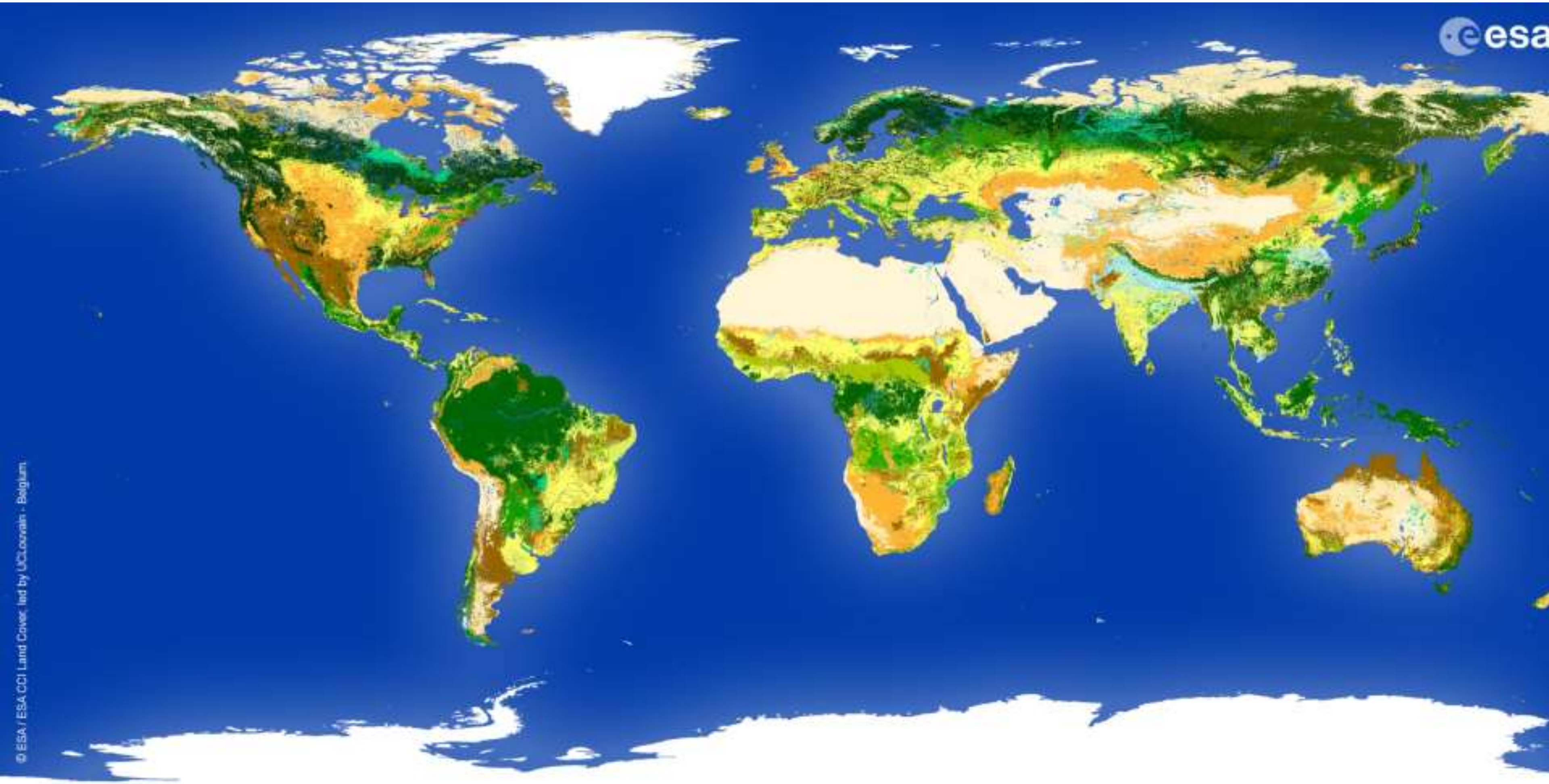


Map edition 1 : 3 000 000



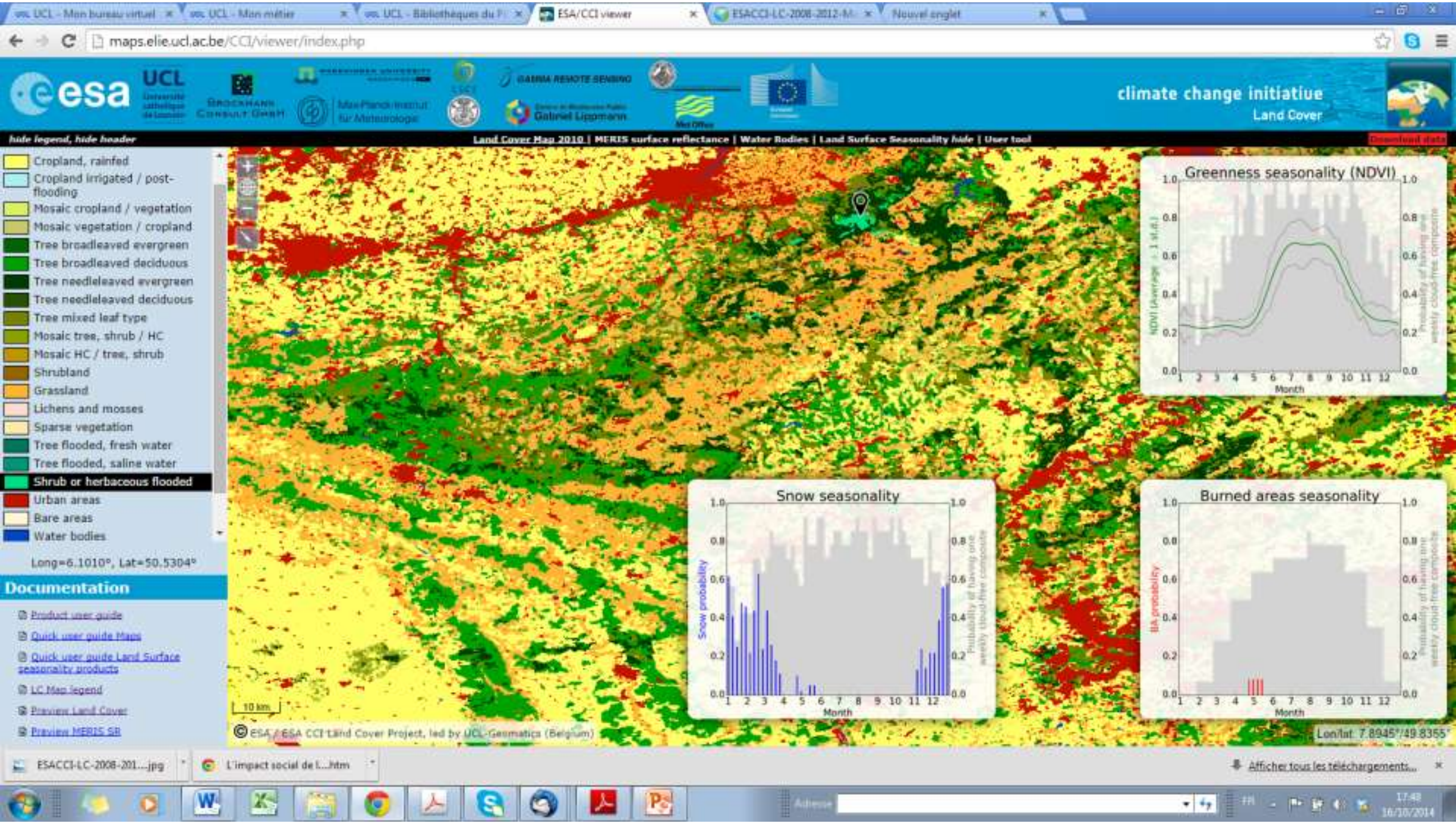

Global Land Cover for the Year 2000
Forest
Grass/Shrubland
Water Bodies
Evergreen Needleleaf Forests
Evergreen Broadleaf Forests
Deciduous Needleleaf Forests
Deciduous Broadleaf Forests
Mixed Forests
Closed Shrublands
Open Shrublands
Woody Savannas
Savannas
Grasslands
Wetlands
Croplands
Urban and Built-up Lands
Cropland/Natural Vegetation Mosaics
Snow and Ice
Barren

300 m MERIS time series : GlobCover
Multisensor time series :CCI Land Cover



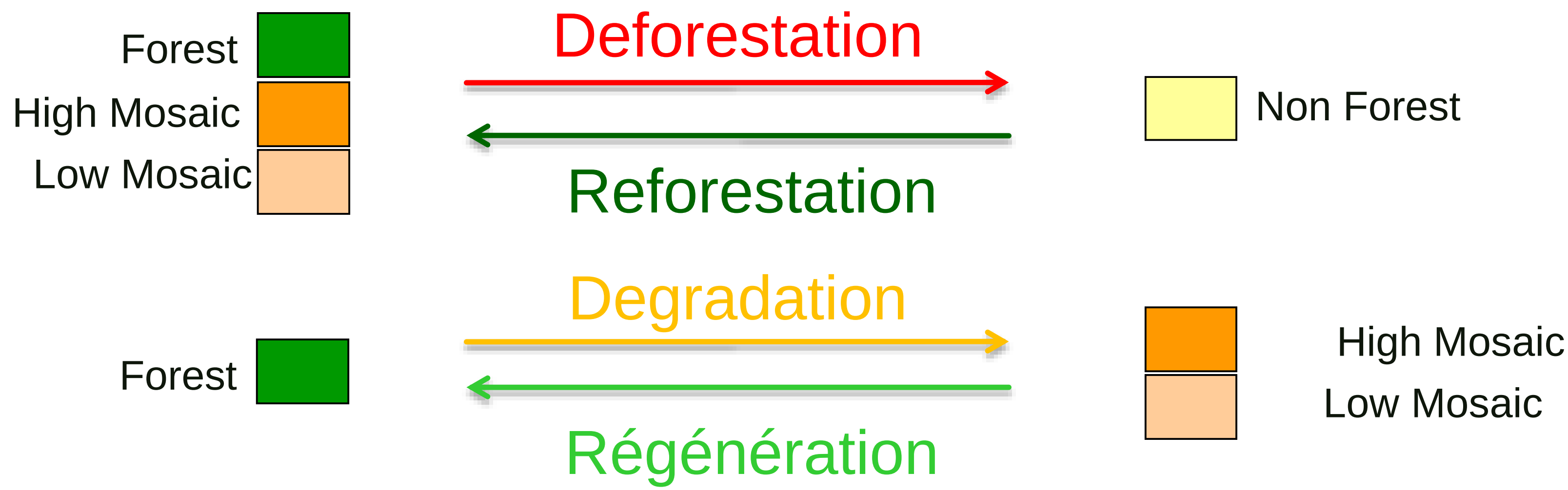
Climate Change Initiative | Land Cover 2008-2012 | 300m

CCI Land cover: A interactive viewer to look at the analysis of more than 500 000 satellite images in a left-click http://maps.elie.ucl.ac.be/CCI/viewer



Land change detection : forest cover change

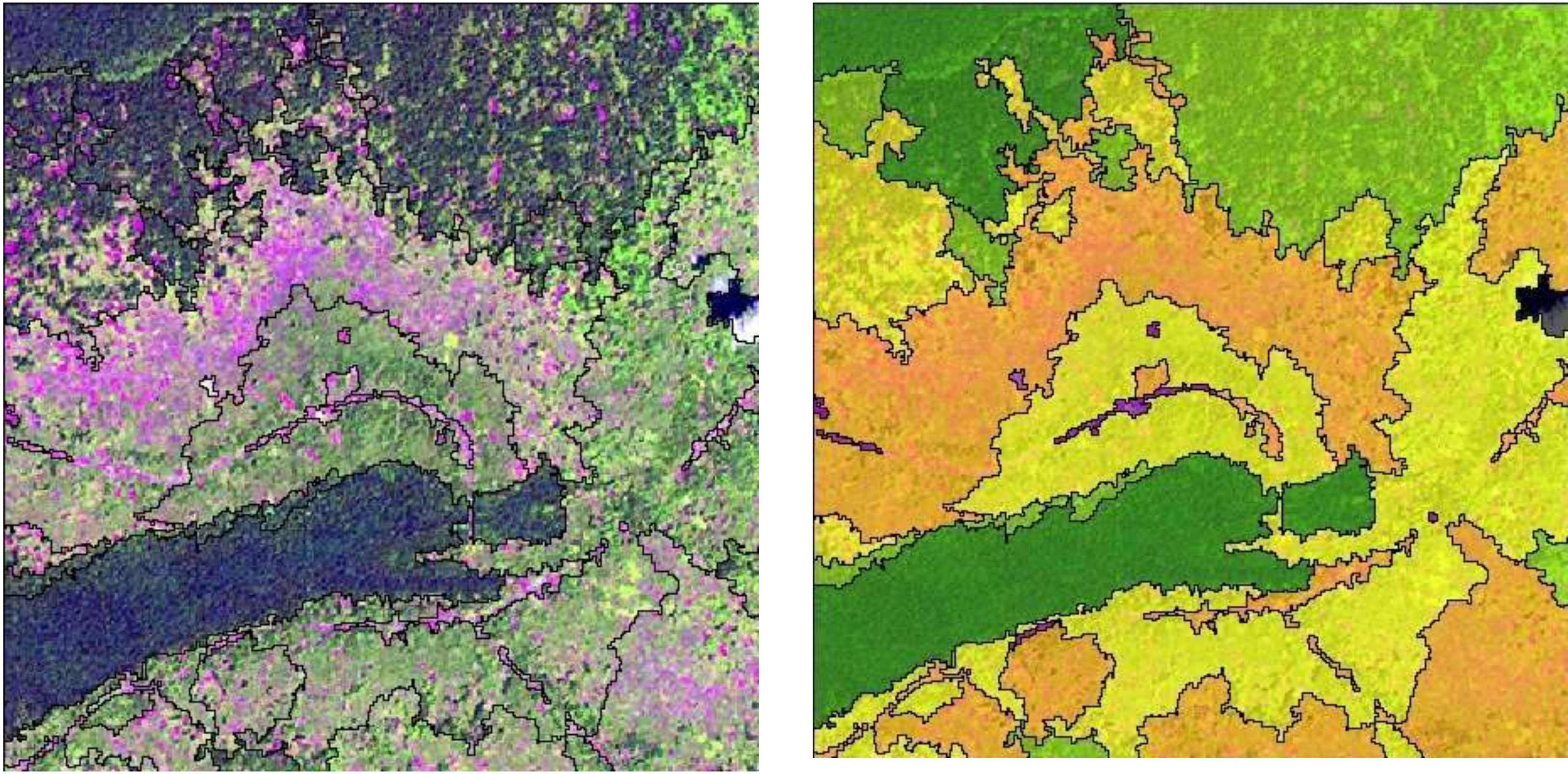
Annual rate estimate



	Forest cover change processes		Weight	
TC	DEFORESTATION 1	NTC Water	1	DEFORESTATION
MH MB	DEFORESTATION 2	NTC Water	0.55 0.25	
TC	DEGRADATION 1	MB	0.75	DEGRADATION
TC MH	DEGRADATION 2	MH MB	0.45 0.3	
NTC Water	REFORESTATION 1	TC	1	REFORESTATION
NTC Water	REFORESTATION 2	MH MB	0.55 0.25	
MB	REGENERATION 1	TC	0.75	REGENERATION
MH MB	REGENERATION 2	TC MH	0.45 0.3	

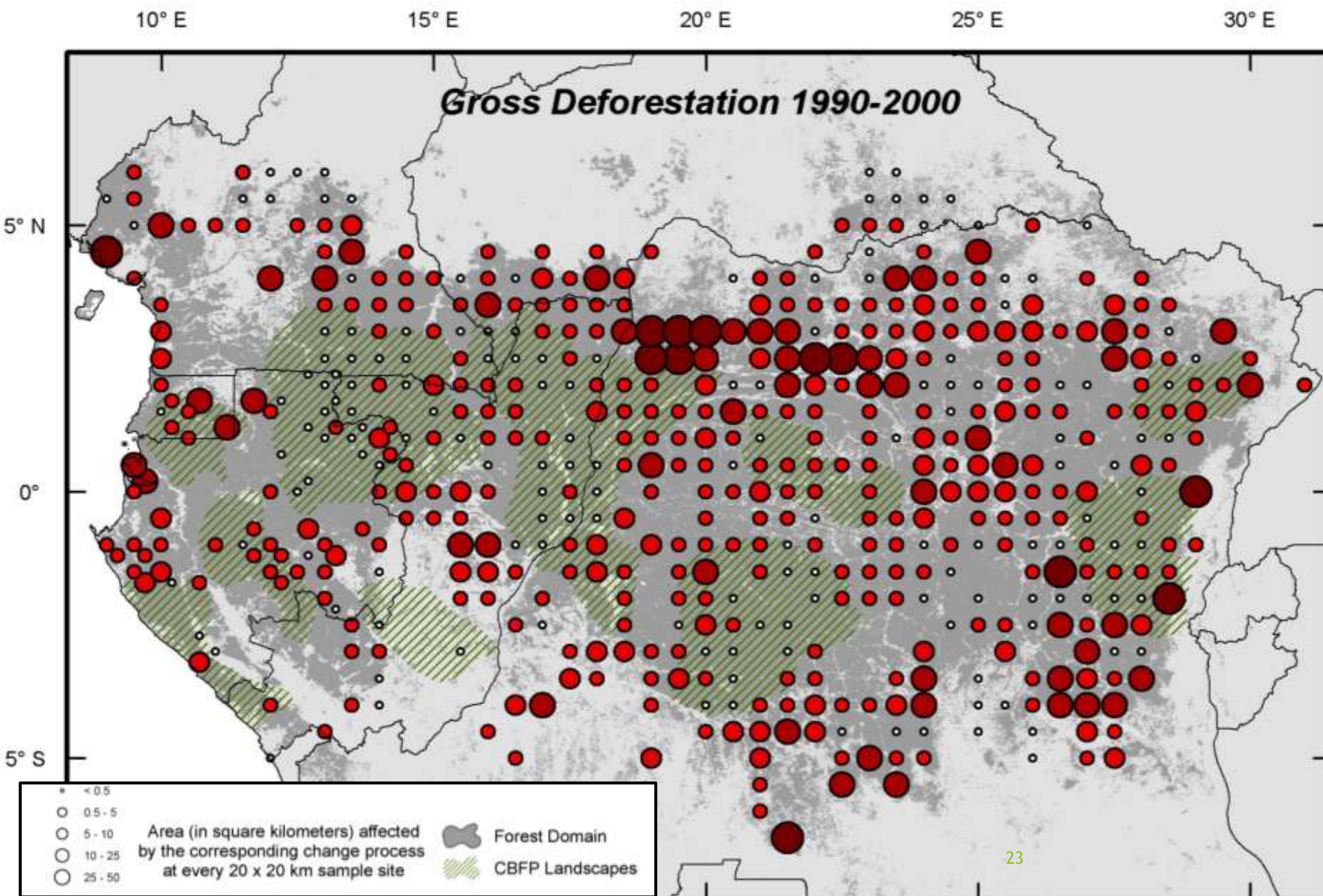
Ernst et al., 2013

Land change detection : forest cover change
object-based change detection algorithm



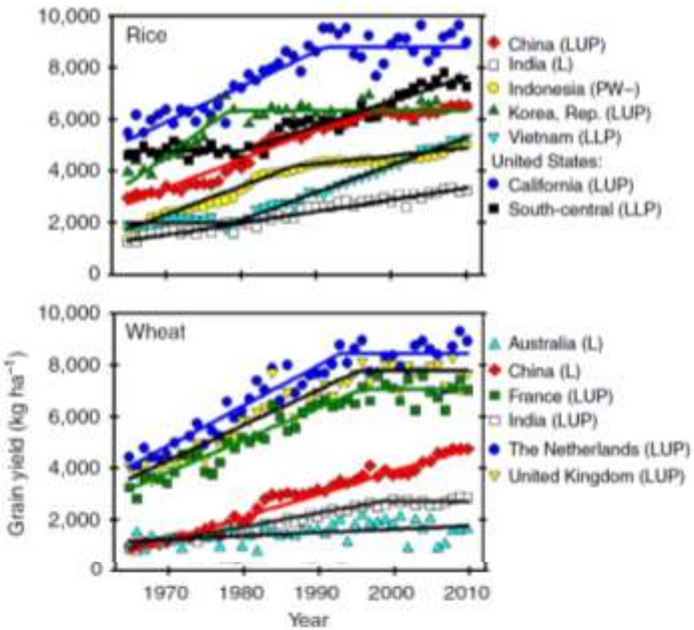
Desclée et al., 2006

Deforestation between 1990 – 2000 – 2010 (FAO FRA 2015)



Achieving sustainable food security for all

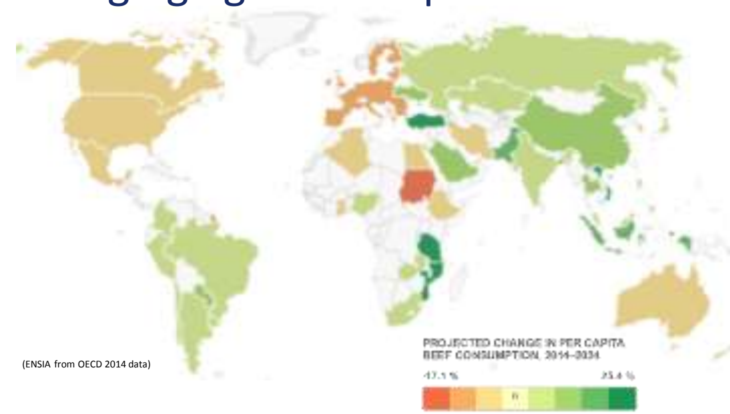
Stagnation of crops yield in many regions



Grassini et al., Nature Com. 2013

Increasing population and evolving diets

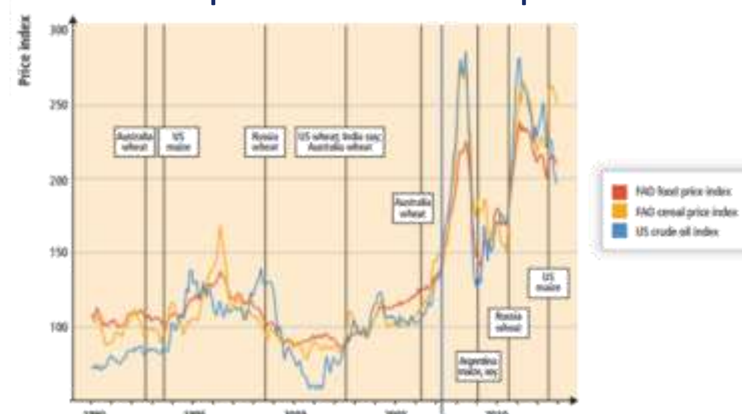
changing agriculture priorities



(ENSIA from OECD 2014 data)

On-going adaptation to climate change

to reduce production and prices variability



Porter et al. IPCC 5th, 2014

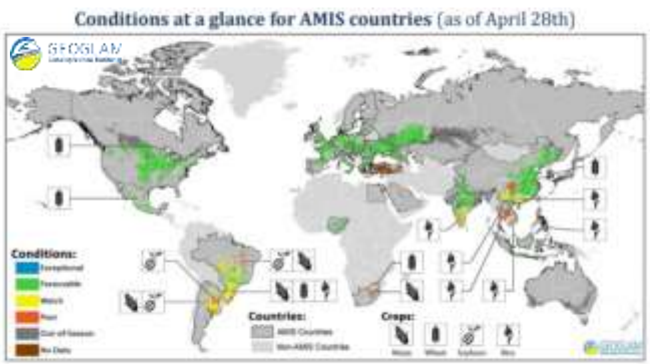
Competition for productive land :

FOOD - FEED - FIBER - FUEL

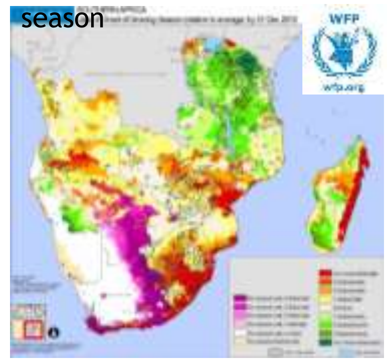
EO operational use for crop monitoring

Monitoring the vegetation growth in cropland areas

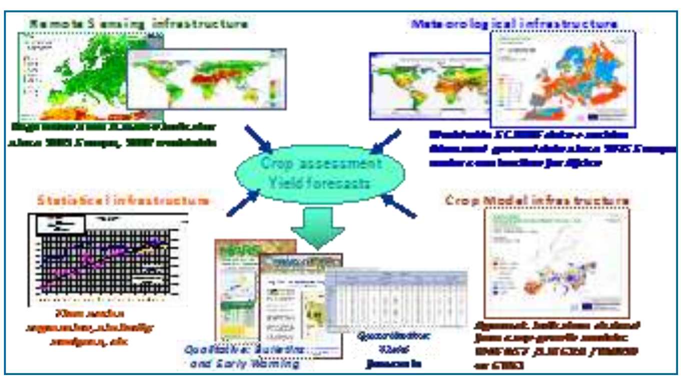
Qualitative information by inter-annual comparison (anomalies - similarities)



Delay in onset of growing season

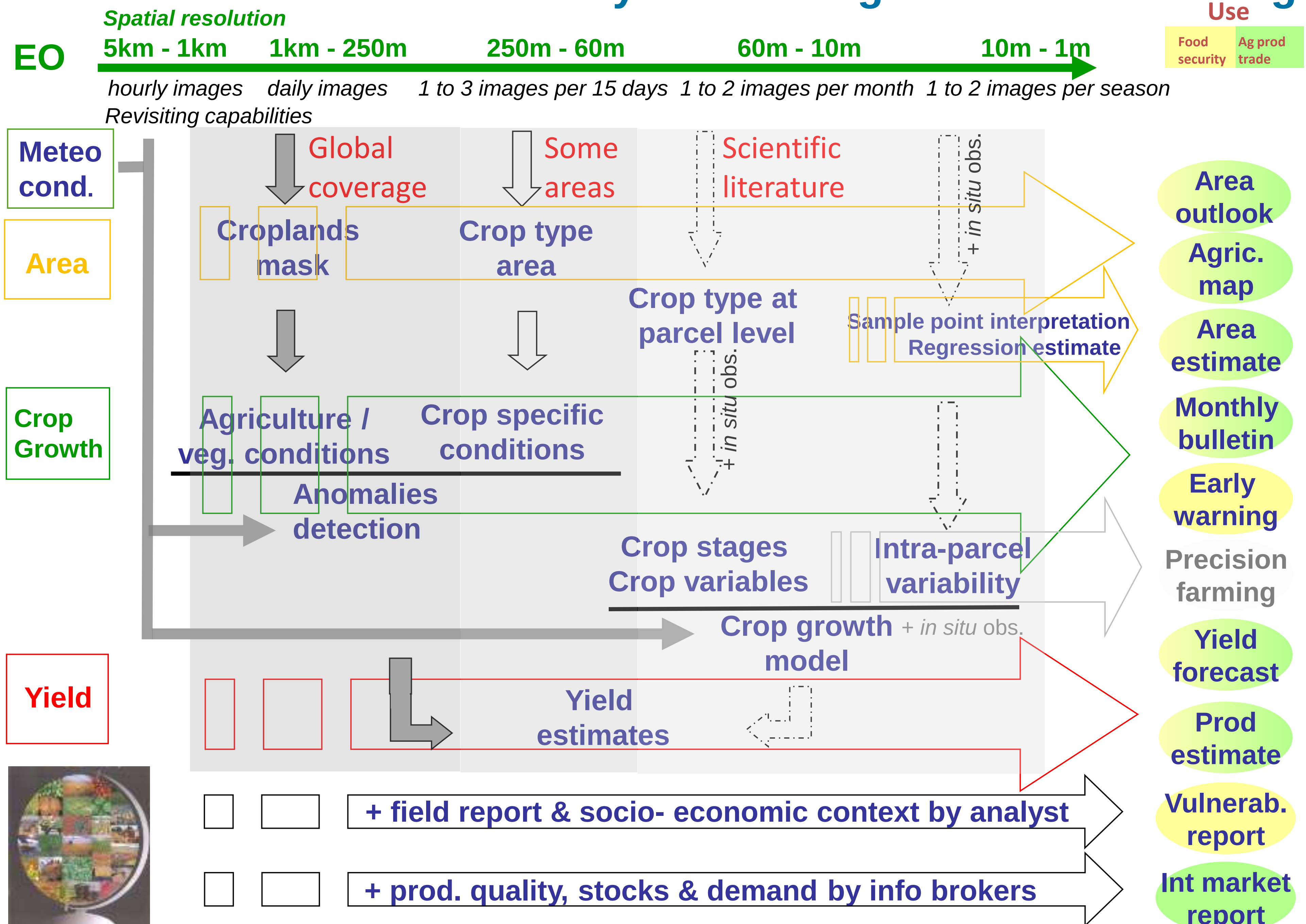


EU-MARS & state memb.



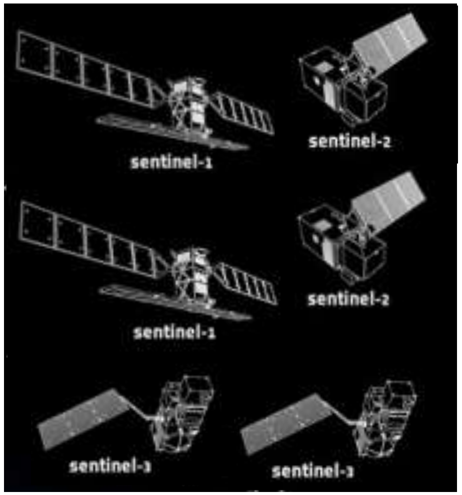
Precision agric. for some producers

Satellite observation currently used for agriculture monitoring



Defourny P., 2010

EO and IT (r)evolution change the game

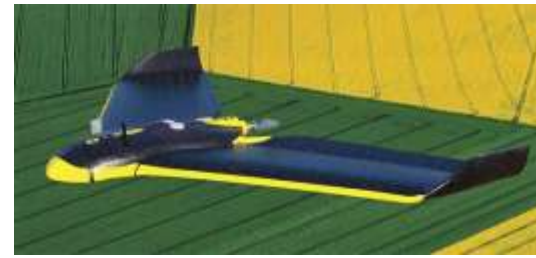


Free, open and long term data policy (EU)

JECAM
Joint Experiment for Crop Assessment and Monitoring

GEOGLAM

Global network with shared protocols



Change much needed for agriculture and food supply chain for :

- farmer income vulnerability reduction
- market price volatility reduction
- national food supply security
- food quality and quantity increase
- improved use of land, soil and water
- reduction of environmental impacts
  e.g. fertilizers and pesticides reduction
- crop management innovations
- climate change adaptation
- diversification (fiber,
- …

Outline

1. Introduction to optical land applications :

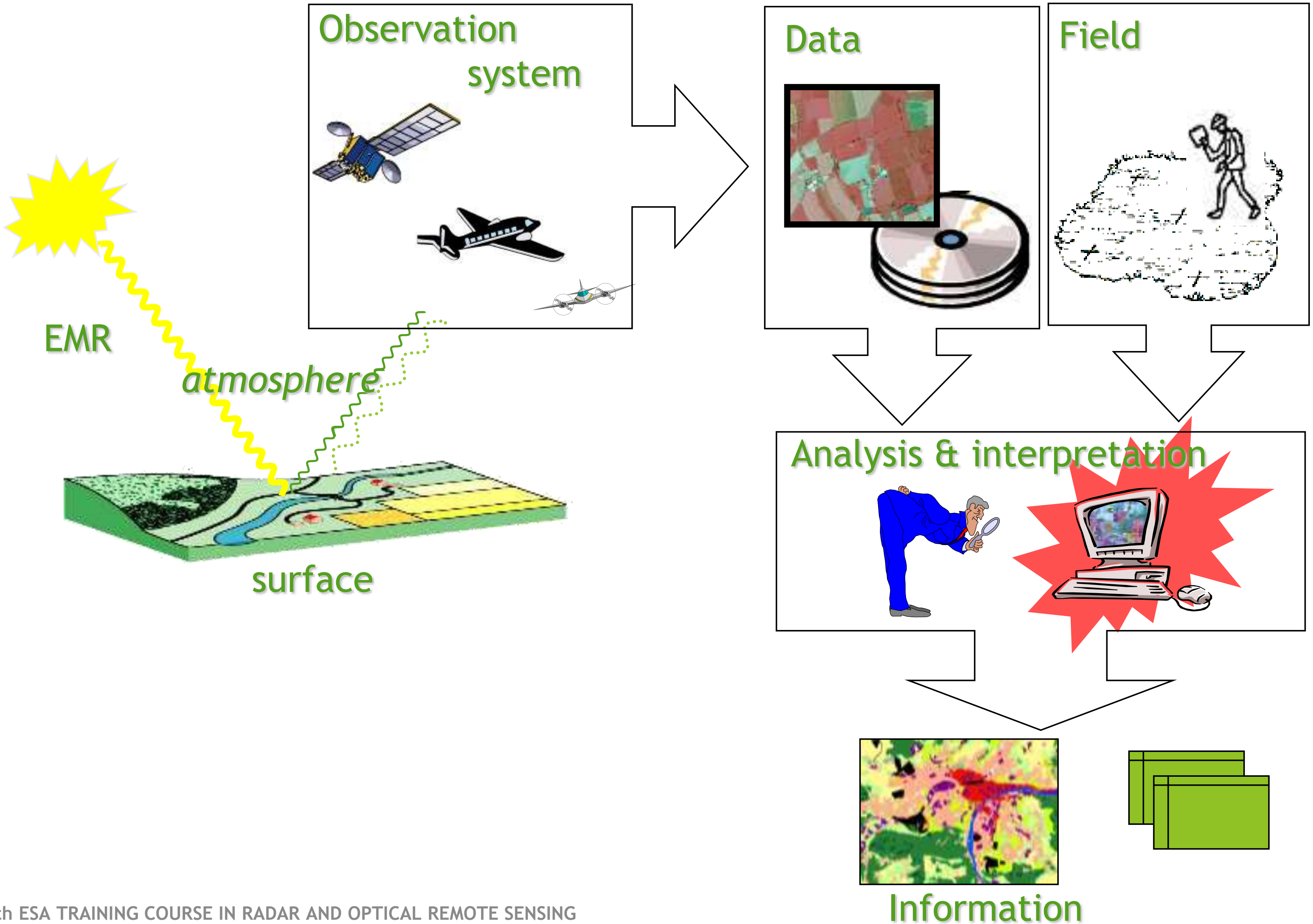
2. **Basic principles about electromagnetic radiation & land surface**

3. Identifying cultivated area and crops from space (Sen2-Agri system)

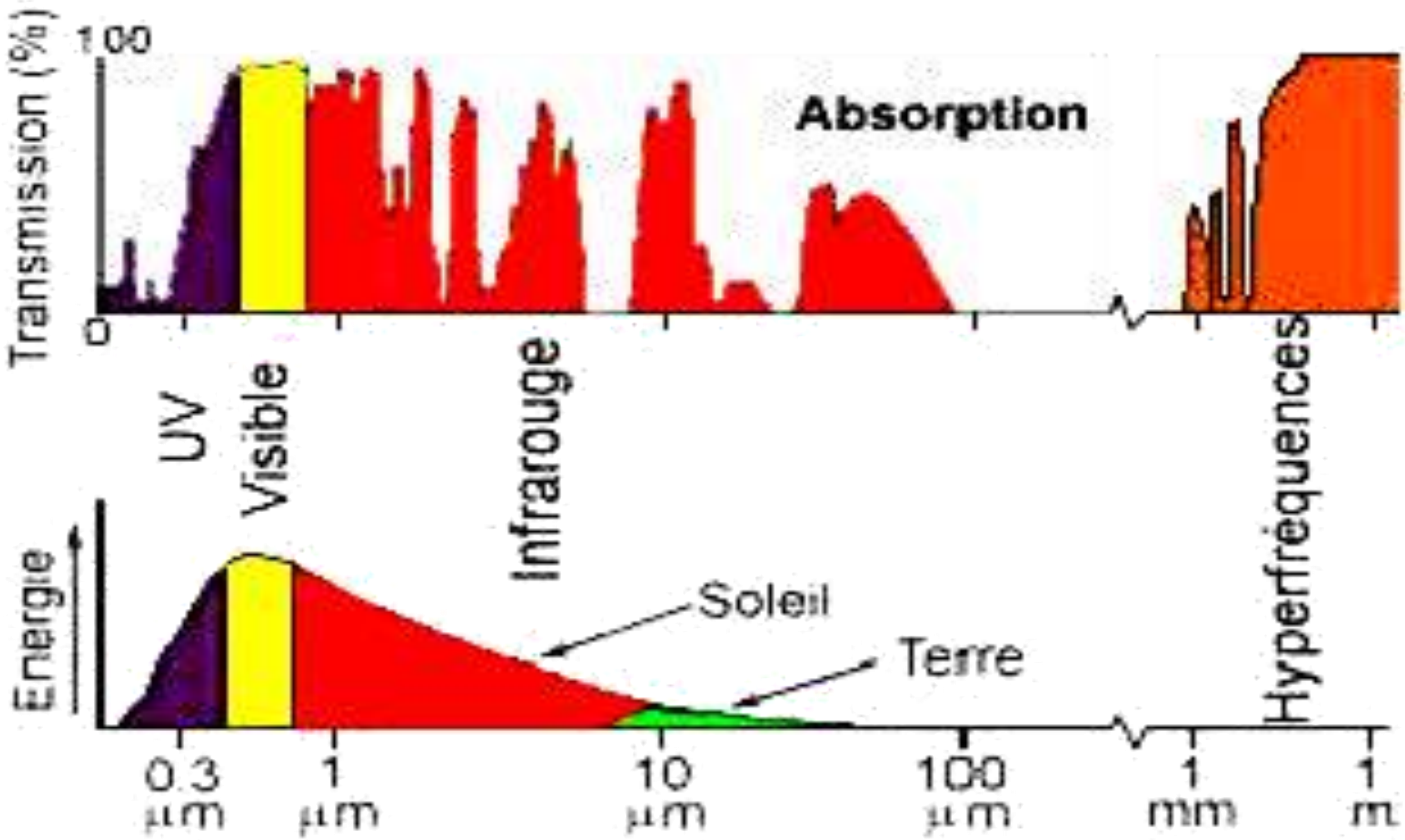
4. Estimating canopy biophysical variables (Sen2-Agri system)

5. Example of monitoring crop production from space (MARS)

The remote sensing process



Electromagnetic radiation sources and atmospheric windows



Source : Lilesand and Kieffer, 2008

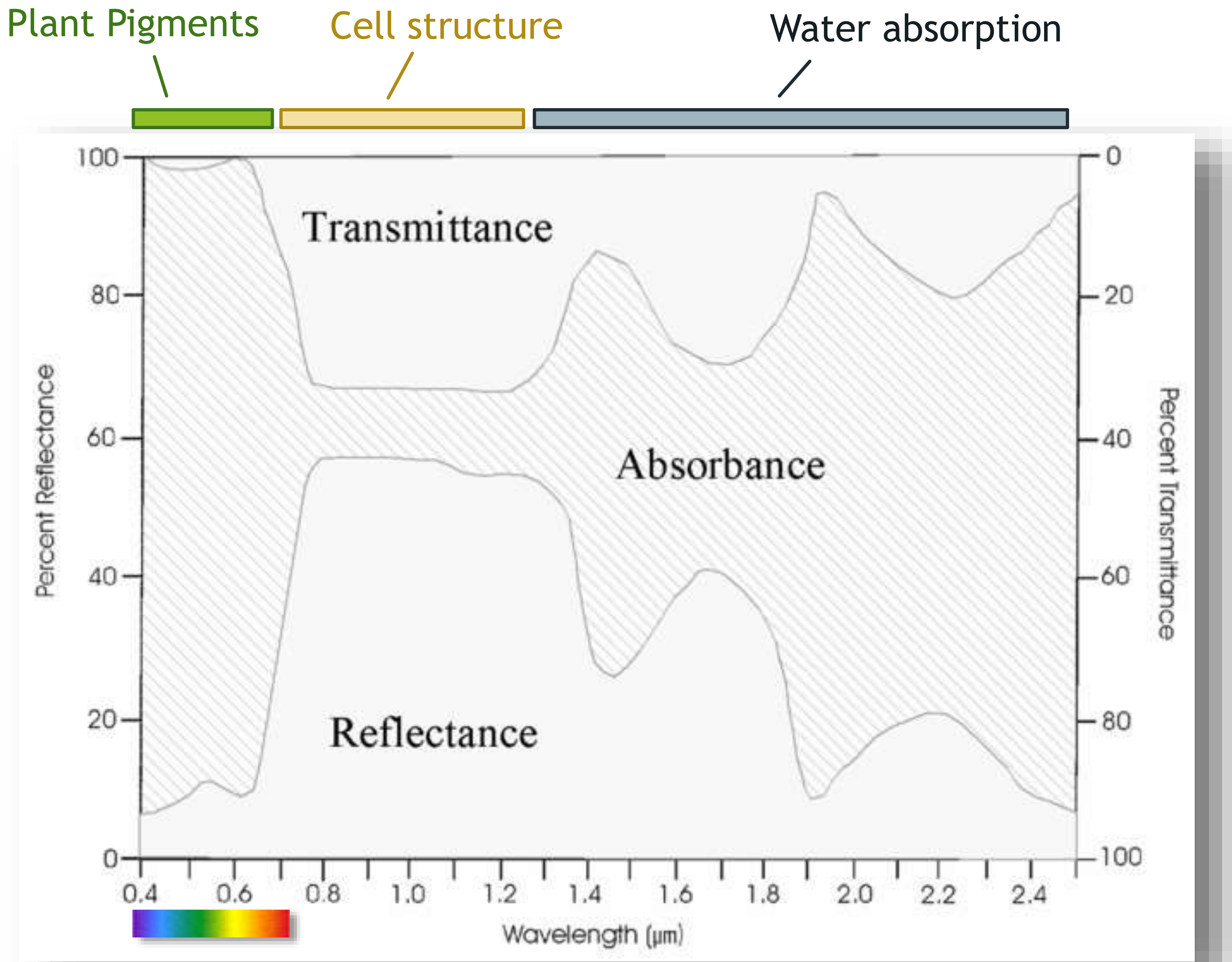
Spectral properties of vegetation

Incident radiation can be:

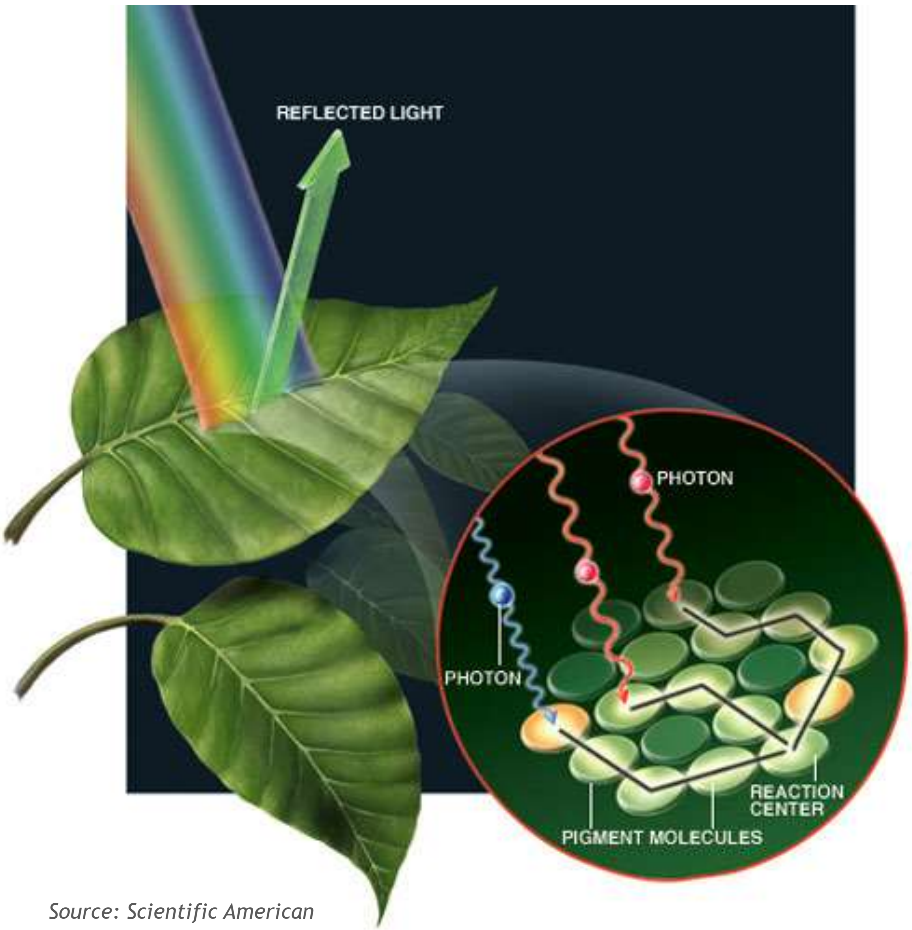
- Reflected
- Absorbed
- Transmitted
- Emitted

by plant tissues…

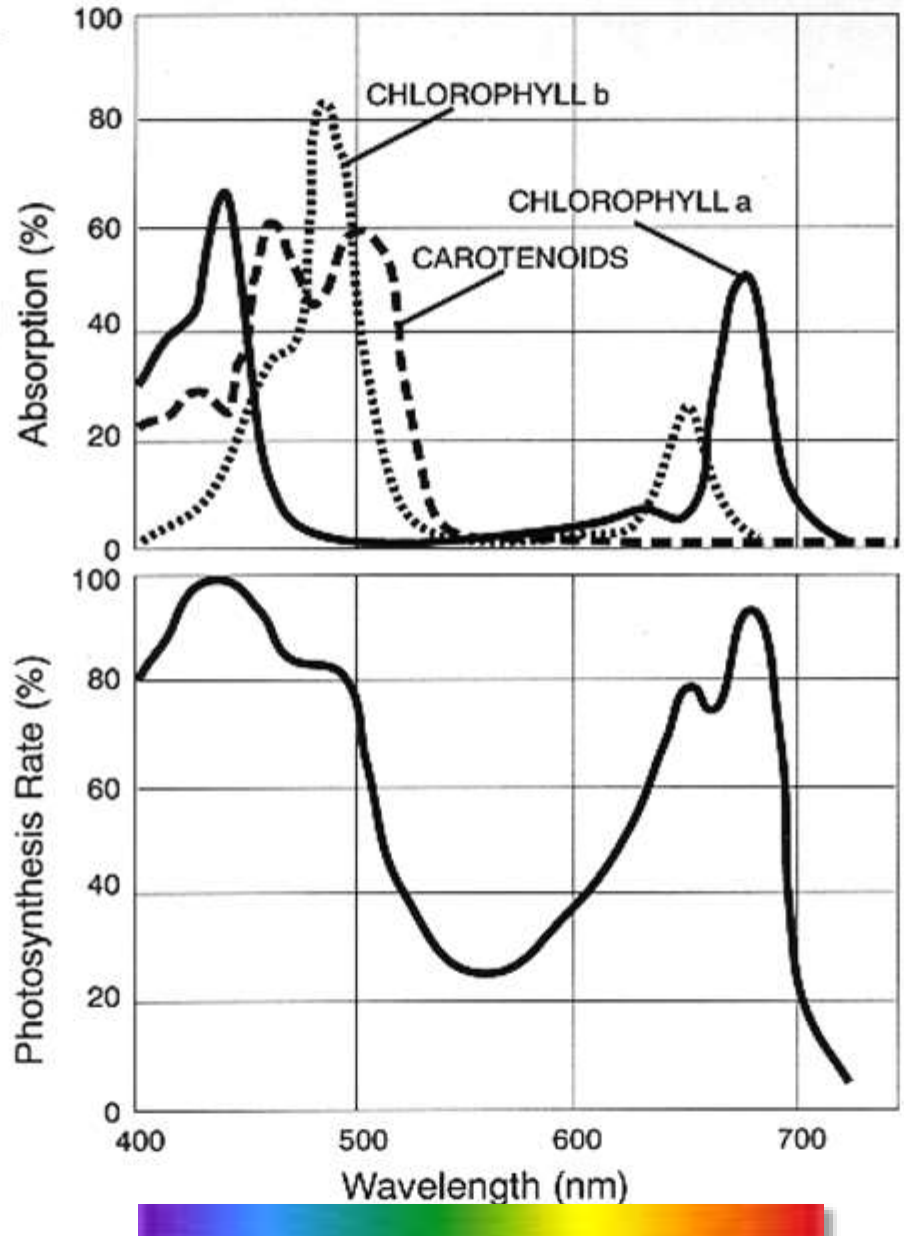
Spectral properties of vegetation



Plant pigments

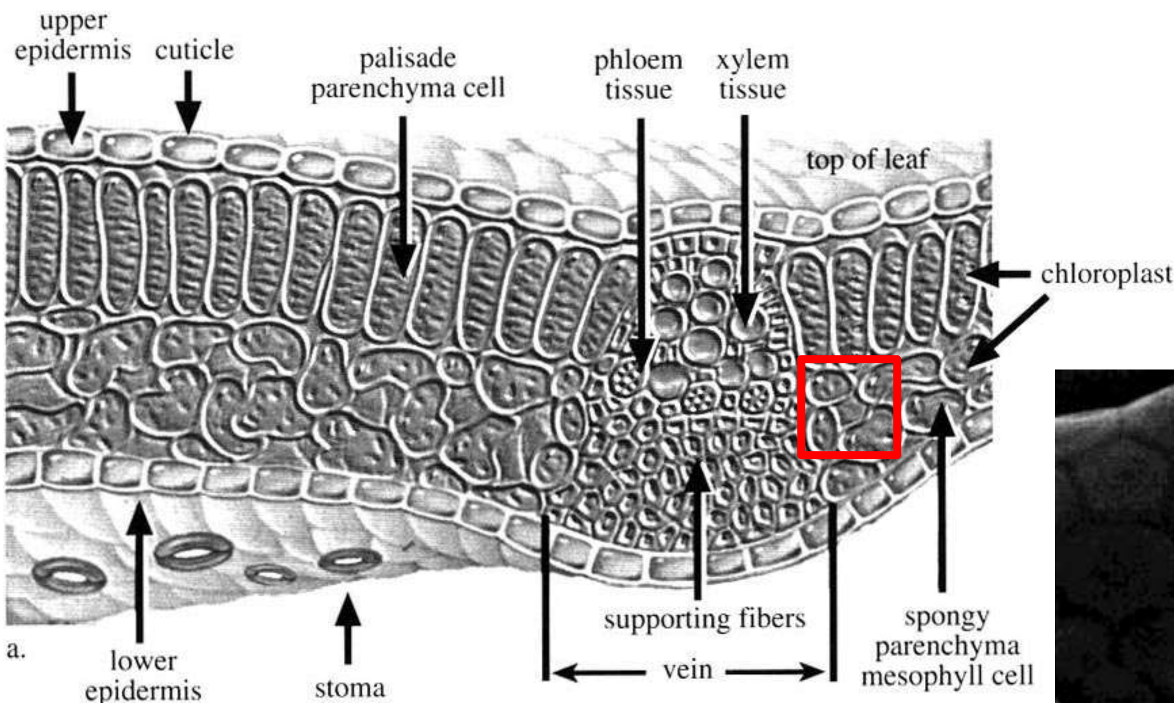


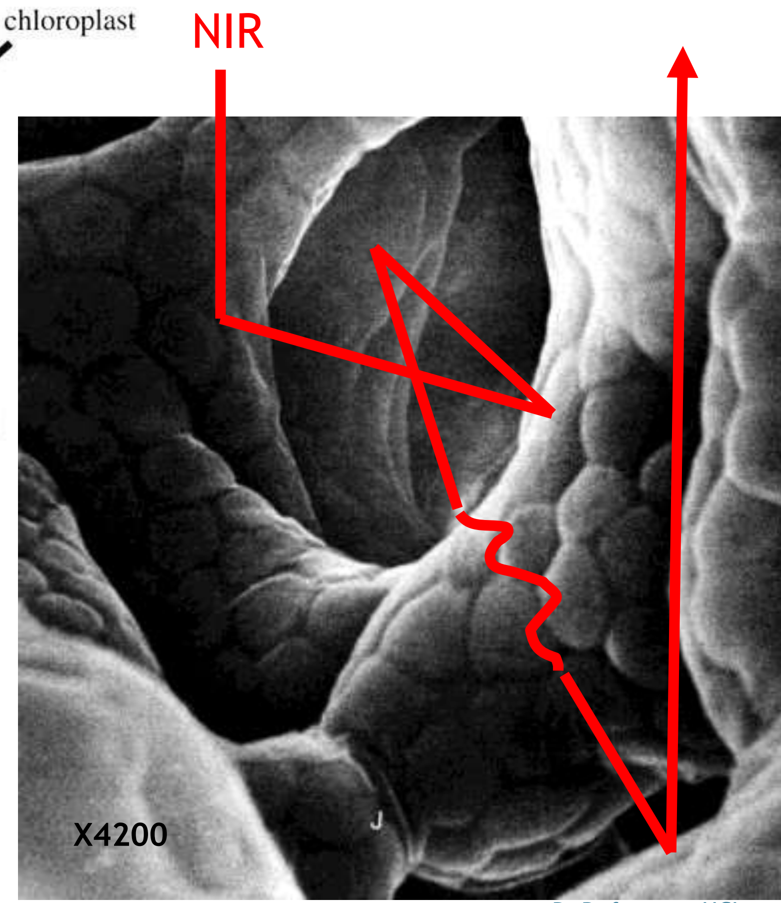
Source: Scientific American



Source: http://www.life.uiuc.edu/govindjee/paper/gov.html, from "Concepts in Photobiology: Photosynthesis and Photomorphogenesis", Edited by GS Singhal, G Renger, SK Sopory, K-D Irrgang

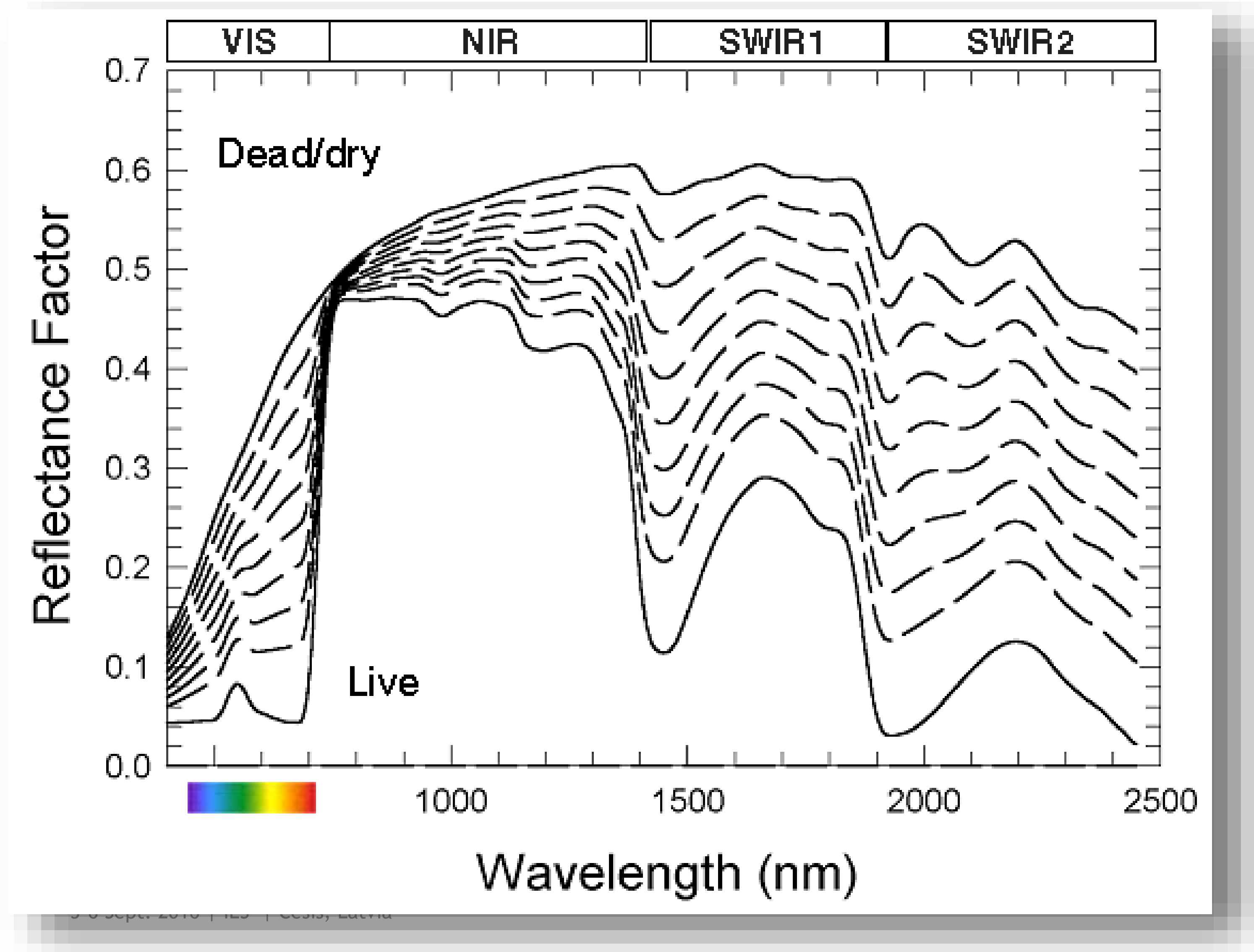
Cell structure





- Cell structure strongly scatters NIR radiation to prevent cell damage

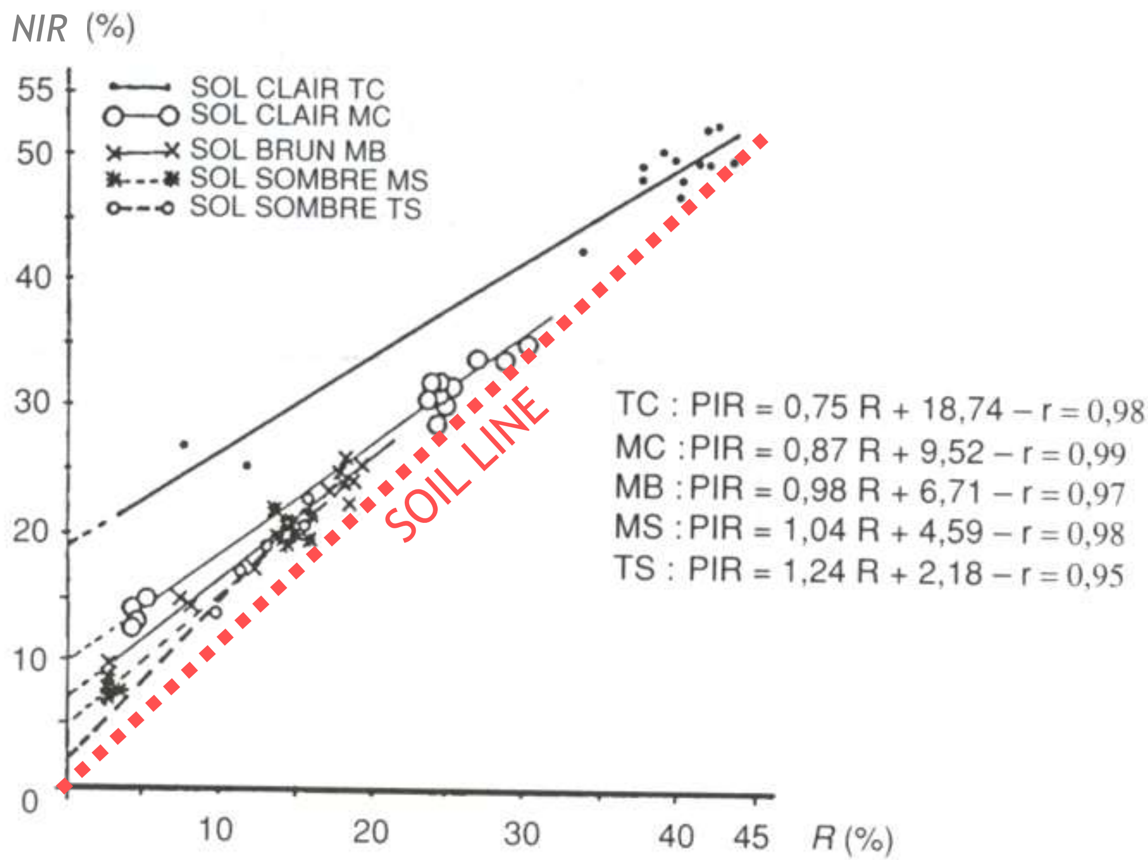
Absorption of water (vegetation)



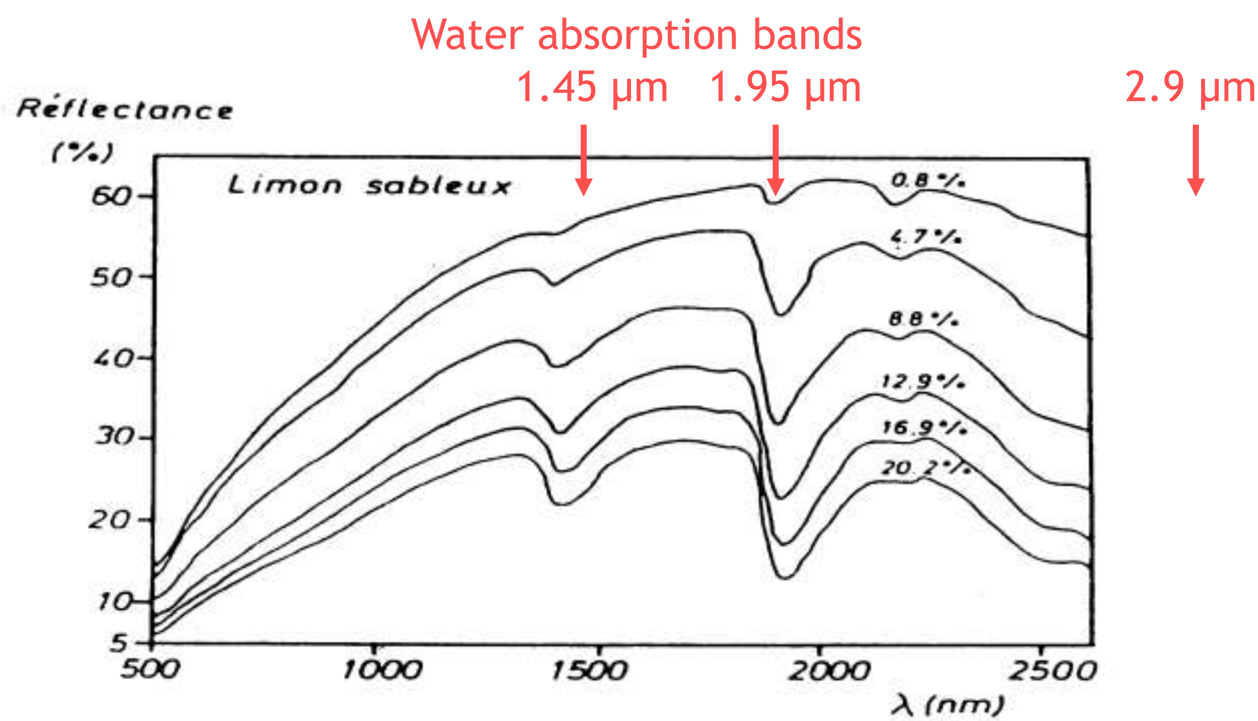
Spectral properties make the difference : where ?

Spectral properties of a bare soil

- only related to soil-atmosphere interface (not related to soil depth)
- influenced by soil structure, texture and stony component
- much influenced by soil surface moisture and soil color (organic matter, Fe, Ca)
- background of the vegetation spectral reflectance



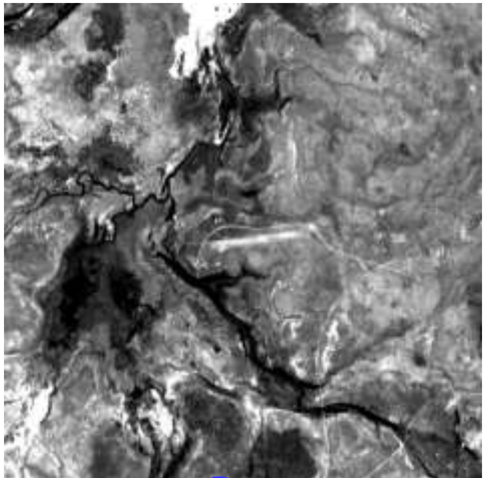
Absorption of water (bare soil)



Spectral signatures of a bare soil with increasing soil moisture (%)

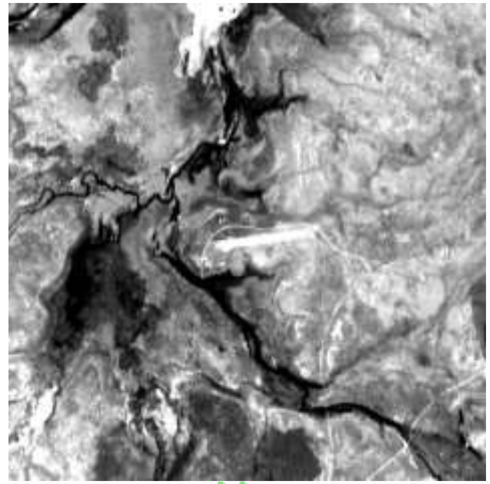
False color composition

Band Green



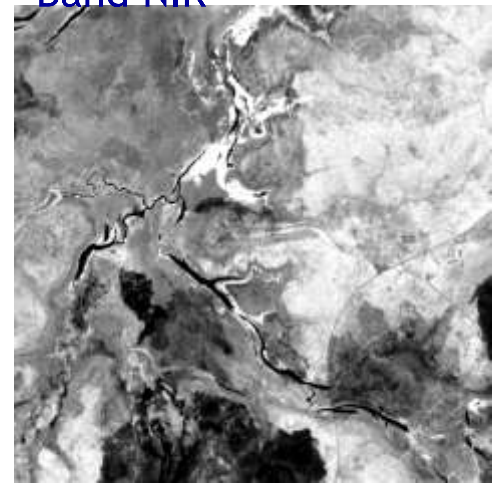
B

Band Red



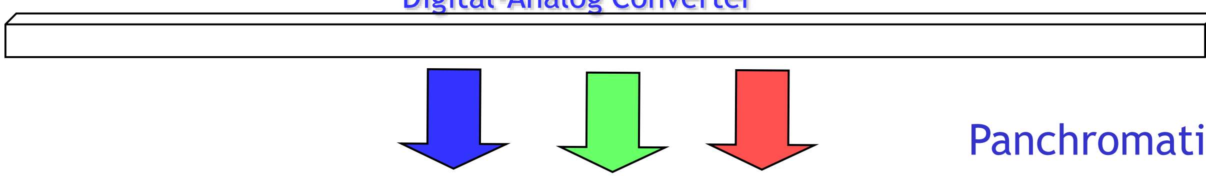
V

Band NIR

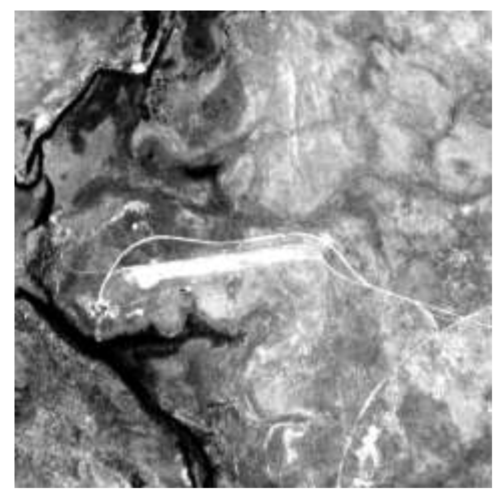


R

Digital-Analog Converter

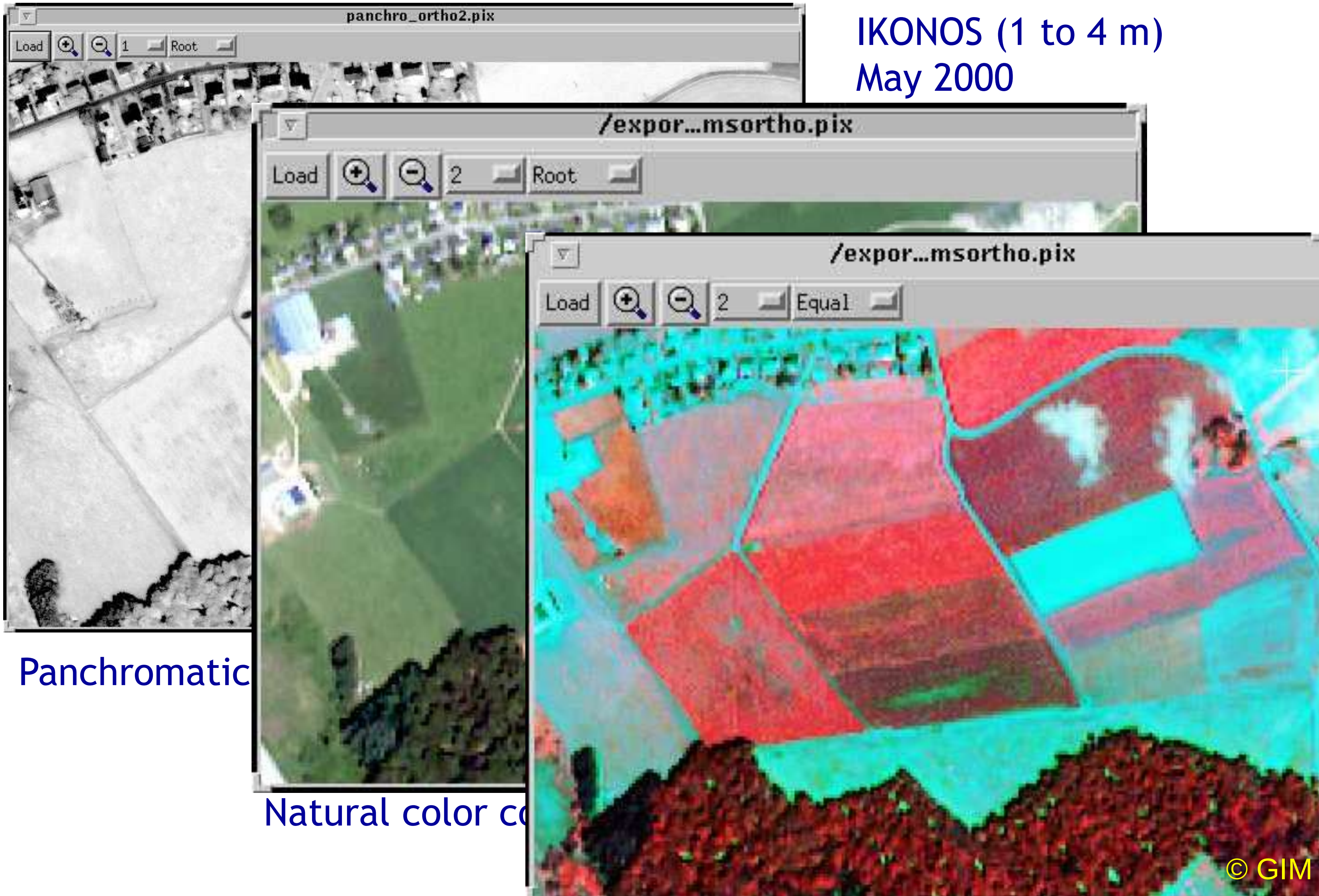


Panchromatic



False color composition

IKONOS (1 to 4 m)
May 2000

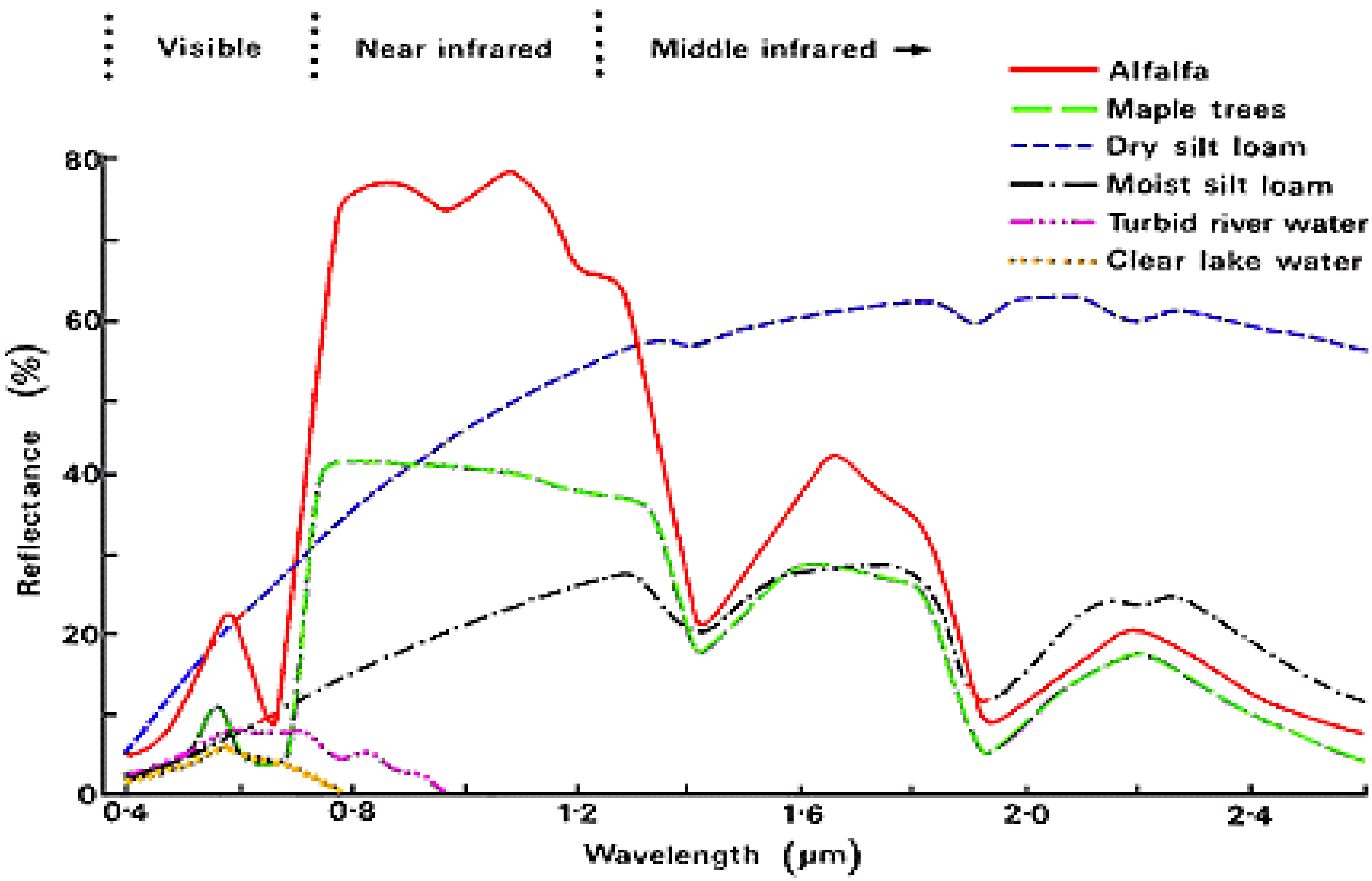


Panchromatic

Natural color c

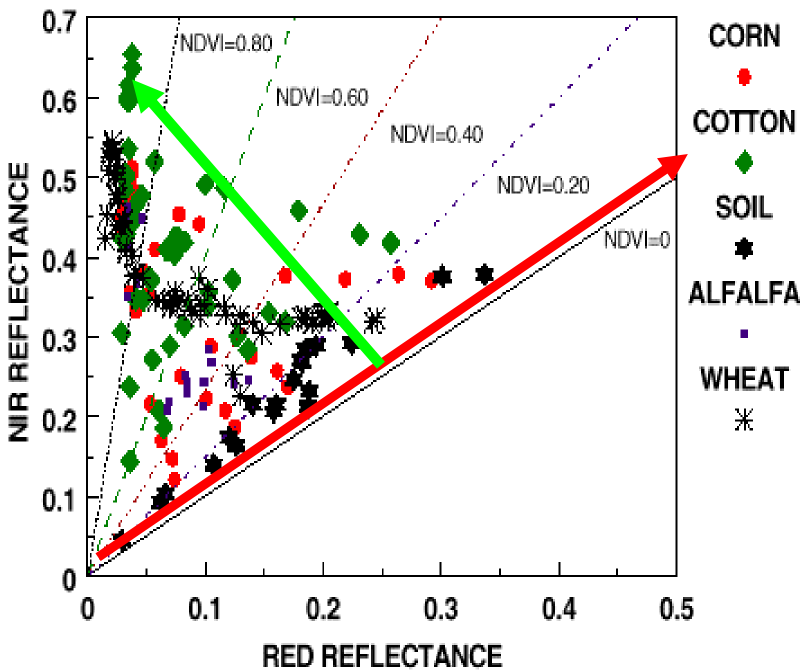
NIR false color composition

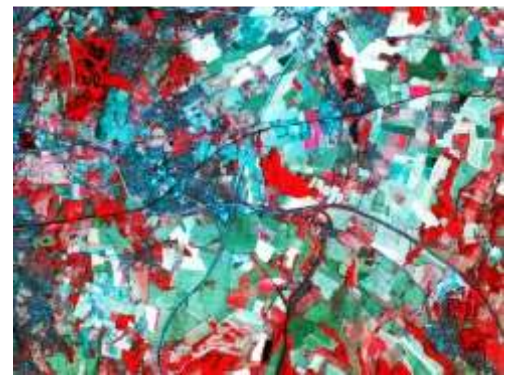
Spectral signatures to discriminate land surface



Vegetation Indices (VIs)

- Convenient way to resume information
- Exploit the particular spectral properties of vegetation
- Vary according to spectral response of the sensors





False color composite (veg is red)

NDVI (veg is bright)

Modified from Lewis et al. UCLondon

Vegetation Indices (VIs)

Indice	Abréviation	Équation	Auteur et année
Ratio Vegetation Index	RVI	$\frac{R}{NIR}$	Pearson and Miller, 1972
Vegetation Index Number	VIN	$\frac{NIR}{R}$	Pearson and Miller, 1972
Transformed Vegetation Index	TVI	$\sqrt{NDVI + 0.5}$	Rouse et al., 1974
Green Vegetation Index	GVI	$(-0.283MSS4 - 0.660MSS5 + 0.577MSS6 + 0.388MSS7)$	Kauth and Thomas, 1976
Soil Brightness Index	SBI	$(0.332MSS4 + 0.603MSS5 + 0.675MSS6 + 0.262MSS7)$	Kauth and Thomas, 1976
Yellow Vegetation Index	YVI	$(-0.899MSS4 + 0.428MSS5 + 0.076MSS6 - 0.041MSS7)$	Kauth and Thomas, 1976
Non Such Index	NSI	$(-0.016MSS4 + 0.131MSS5 - 0.425MSS6 + 0.882MSS7)$	Kauth and Thomas, 1976
Soil Background Line	SBL	$(MSS7 - 2.4MSS5)$	Richardson and Wiegand, 1977
Differenced Vegetation Index	DVI	$(2.4MSS7 - MSS5)$	Richardson and Wiegand, 1977
Misra Soil Brightness Index	MSBI	$(0.406MSS4 + 0.600MSS5 + 0.645MSS6 + 0.243MSS7)$	Misra et al., 1977
Misra Green Vegetation Index	MGVI	$(-0.386MSS4 - 0.530MSS5 + 0.535MSS6 + 0.532MSS7)$	Misra et al., 1977
Misra Yellow Vegetation Index	MYVI	$(0.723MSS4 - 0.597MSS5 + 0.206MSS6 - 0.278MSS7)$	Misra et al., 1977
Misra Non Such Index	MNSI	$(0.404MSS4 - 0.039MSS5 - 0.505MSS6 + 0.762MSS7)$	Misra et al., 1977
Perpendicular Vegetation Index	PVI	$\sqrt{(\rho_{sol} - \rho_{végé})^2_R + (\rho_{sol} - \rho_{végé})^2_{NIR}}$	Richardson and Wiegand, 1977
Ashburn Vegetation Index	AVI	$(2.0MSS7 - MSS5)$	Ashburn, 1978
Greenness Above Bare Soil	GRABS	$(GVI - 0.09178SBI + 5.58959)$	Hay et al., 1979
Multi-Temporal Vegetation Index	MTVI	$(NDVI(date\ 2) - NDVI(date\ 1))$	Yazdani et al., 1981
Greenness Vegetation and Soil Brightness	GVSB	$\frac{GVI}{SBI}$	Badhwar, 1981
Adjusted Soil Brightness Index	ASBI	$(2.0\ YVI)$	Jackson et al., 1983
Adjusted Green Vegetation Index	AGVI	$GVI - (1 + 0.018GVI)YVI - NSI/2$	Jackson et al., 1983
Transformed Vegetation Index	TVI	$\frac{(NDVI + 0.5)}{\lvert NDVI + 0.5\rvert}\sqrt{\lvert NDVI + 0.5\rvert}$	Perry and Lautenschlager, 1984
Differenced Vegetation Index	DVI	$(NIR - R)$	Clevers, 1986
Normalized Difference Greenness Index	NDGI	$\frac{(G - R)}{(G + R)}$	Chamard et al., 1991
Redness Index	RI	$\frac{(R - G)}{(R + G)}$	Escadafal and Huete, 1991
Normalized Difference Vegetation Index	NDVI	$\frac{(NIR - R)}{(NIR + R)}$	Rouse et al., 1974
Perpendicular Vegetation Index	PVI	$\frac{(NIR - aR - b)}{\sqrt{a^2 + 1}}$	Jackson et al., 1980
Soil Adjusted Vegetation Index	SAVI	$\frac{(NIR - R)}{(NIR + R + L)}(1 + L)$	Huete, 1988
Transformed SAVI	TSAVI	$\frac{[a(NIR - aR - b)]}{(R + aNIR - ab)}$	Baret et al., 1989
Transformed SAVI	TSAVI	$\frac{[a(NIR - aR - b)]}{[R + aNIR - ab + X(1 + a^2)]}$	Baret and Guyot, 1991
Atmospherically Resistant Vegetation Index	ARVI	$\frac{(NIR - RB)}{(NIR + RB)}$ $RB = R - \gamma(B - R)$	Kaufman and Tanré, 1992
Global Environment Monitoring Index	GEMI	$GEMI = \eta(1 - 0.25\eta) - \frac{(R - 0.125)}{(1 - R)}$ $\eta = \frac{[2(NIR^2 - R^2) + 1.5NIR + 0.5R]}{(NIR + R + 0.5)}$	Pinty and Verstraete, 1992
Transformed Soil Atmospherically Resistant Vegetation Index	TSARVI	$\frac{[a_{rb}(NIR - a_{rb}RB - b_{rb})]}{[RB + a_{rb}NIR - a_{rb}b_{rb} + X(1 + a_{rb}^2)]}$	Bannari et al., 1994
Modified SAVI	MSAVI	$\frac{2NIR + 1 - \sqrt{(2NIR + 1)^2 - 8(NIR - R)}}{2}$	Qi et al., 1994
Angular Vegetation Index	AVI	$\tan^{-1}\left\{\frac{\lambda_3 - \lambda_2}{\lambda_2}[NIR - R]^{-1}\right\} + \tan^{-1}\left\{\frac{\lambda_2 - \lambda_1}{\lambda_2}[G - R]^{-1}\right\}$	Plummer et al., 1994

Vegetation Index (NDVI) temporal signature

Canadian field over a season

1 June 2009

10 June 2009

17 June 2009

24 June 2009

8 July 2009

15 July 2009

30 July 2009

6 August 2009

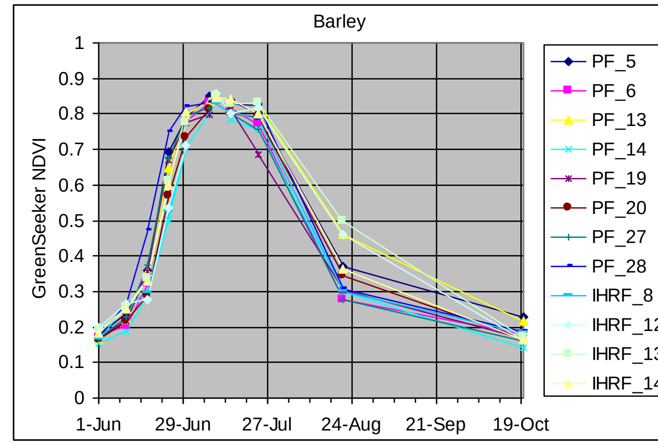
13 August 2009

21 August 2009

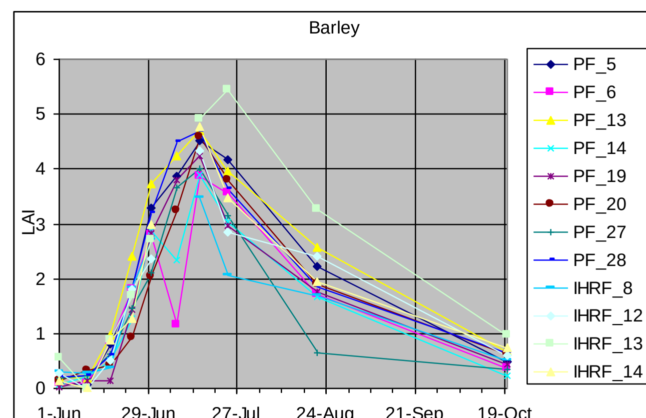
27 August 2009

20 October 2009

Ground NDVI: Barley



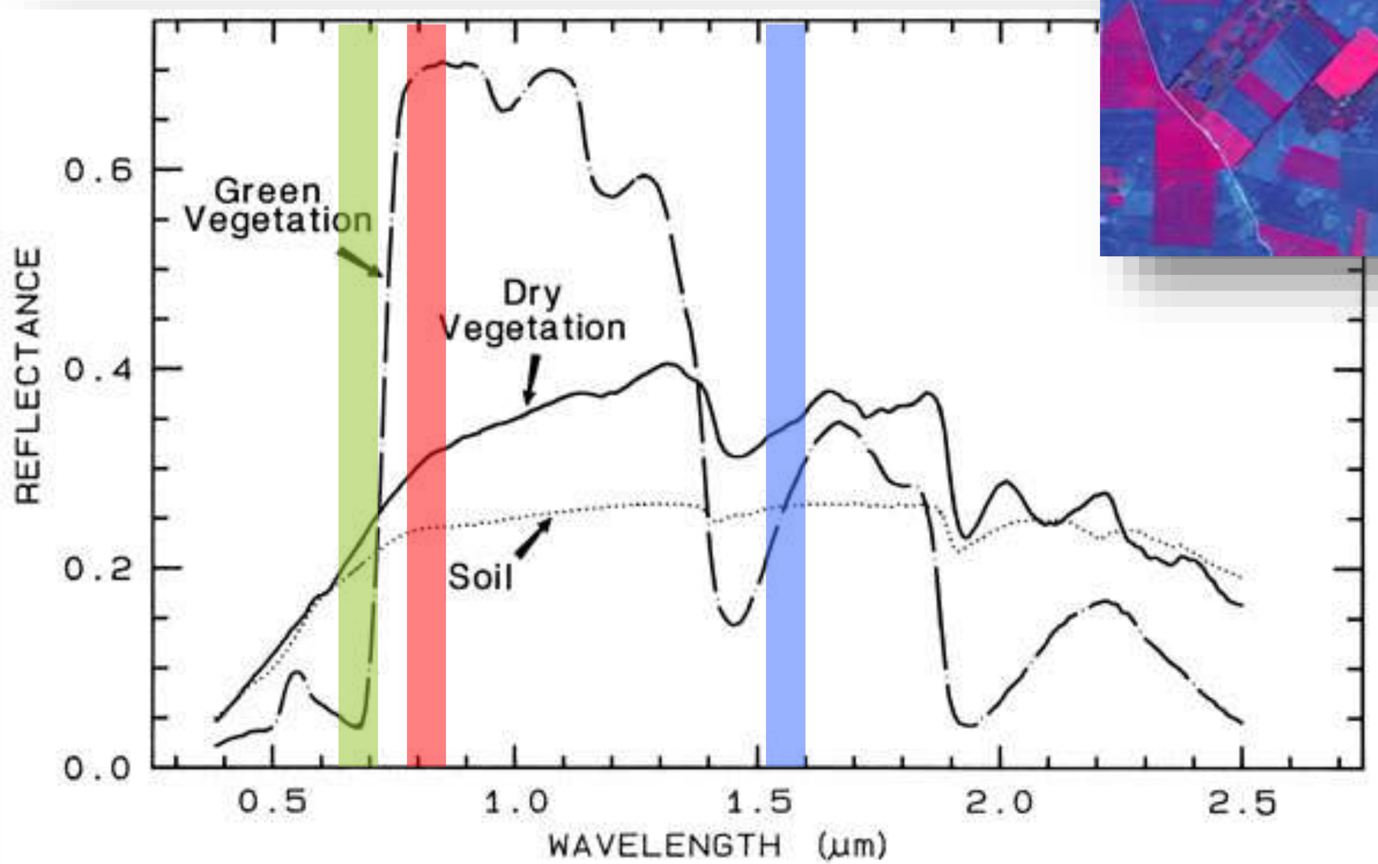
Ground LAI: Barley



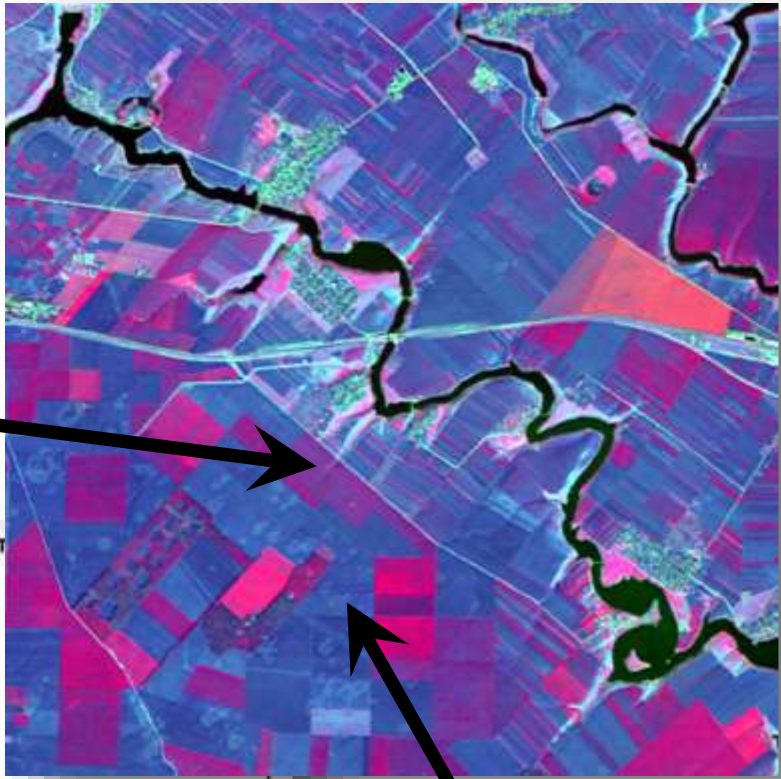
Courtesy : Malcolm Davidson | 07/02/2012 AgriSAR

Growing vegetation as observed by optical RS

- A typical ag. landscape in a temperate climate



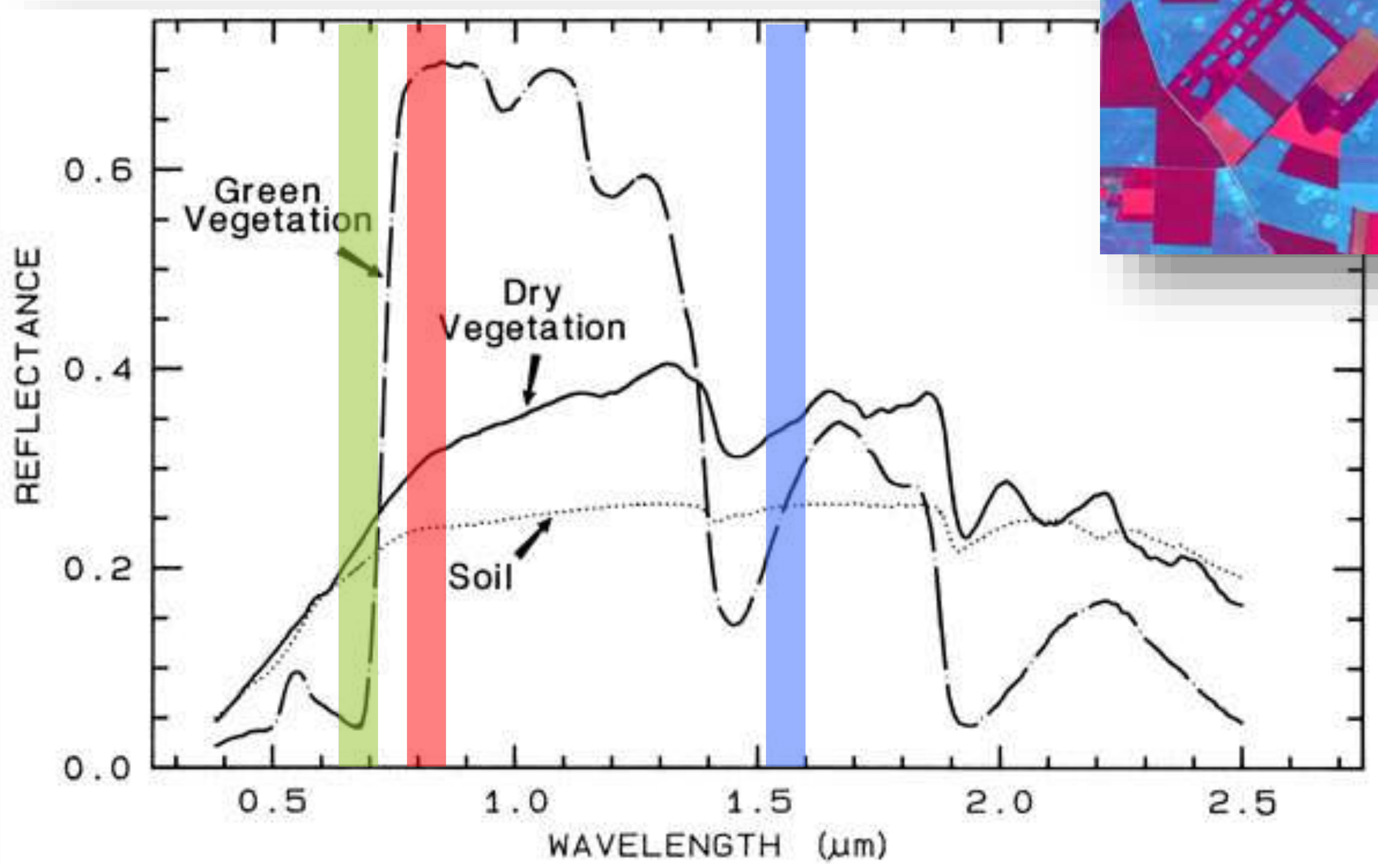
Winter crop

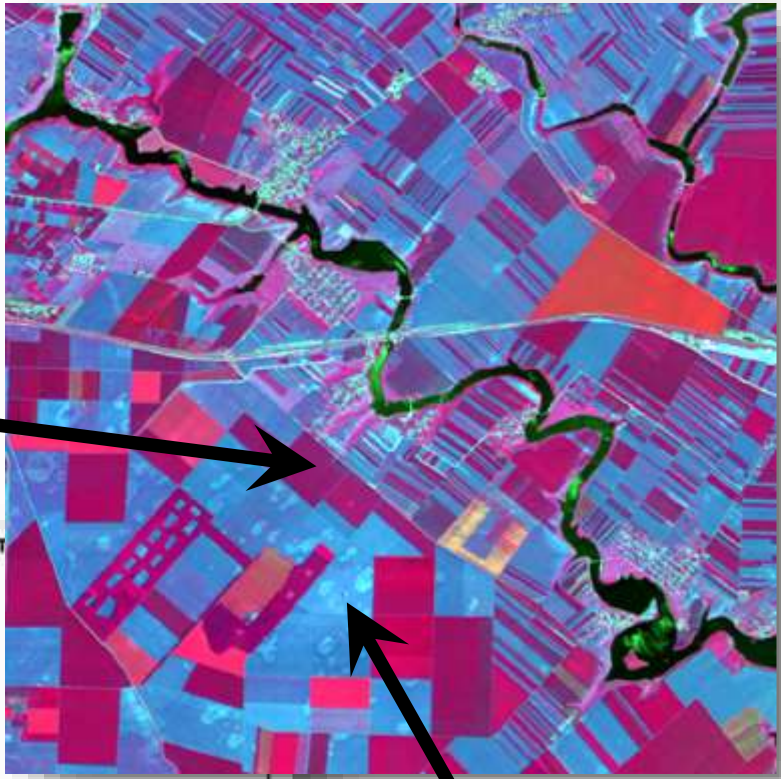


Summer crop

Growing vegetation as observed by optical RS

- A typical ag. landscape in a temperate climate

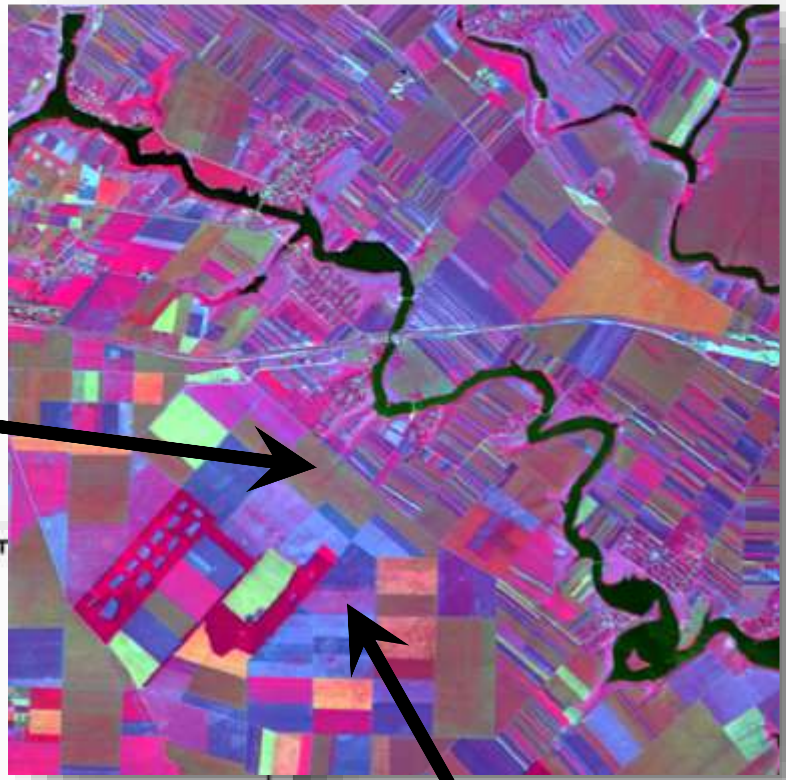




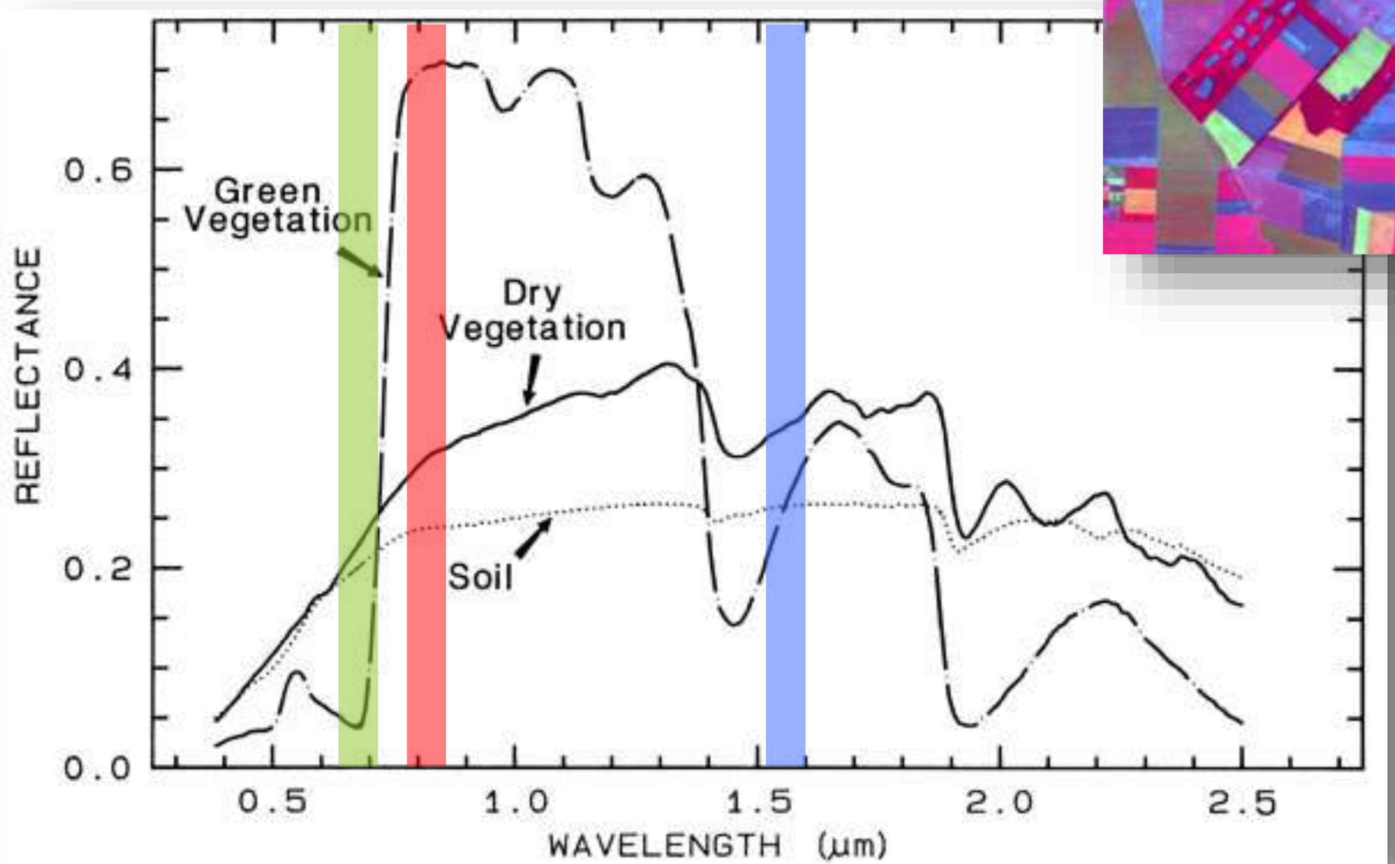
Growing vegetation as observed by optical RS

- A typical ag. landscape in a temperate climate

Winter crop

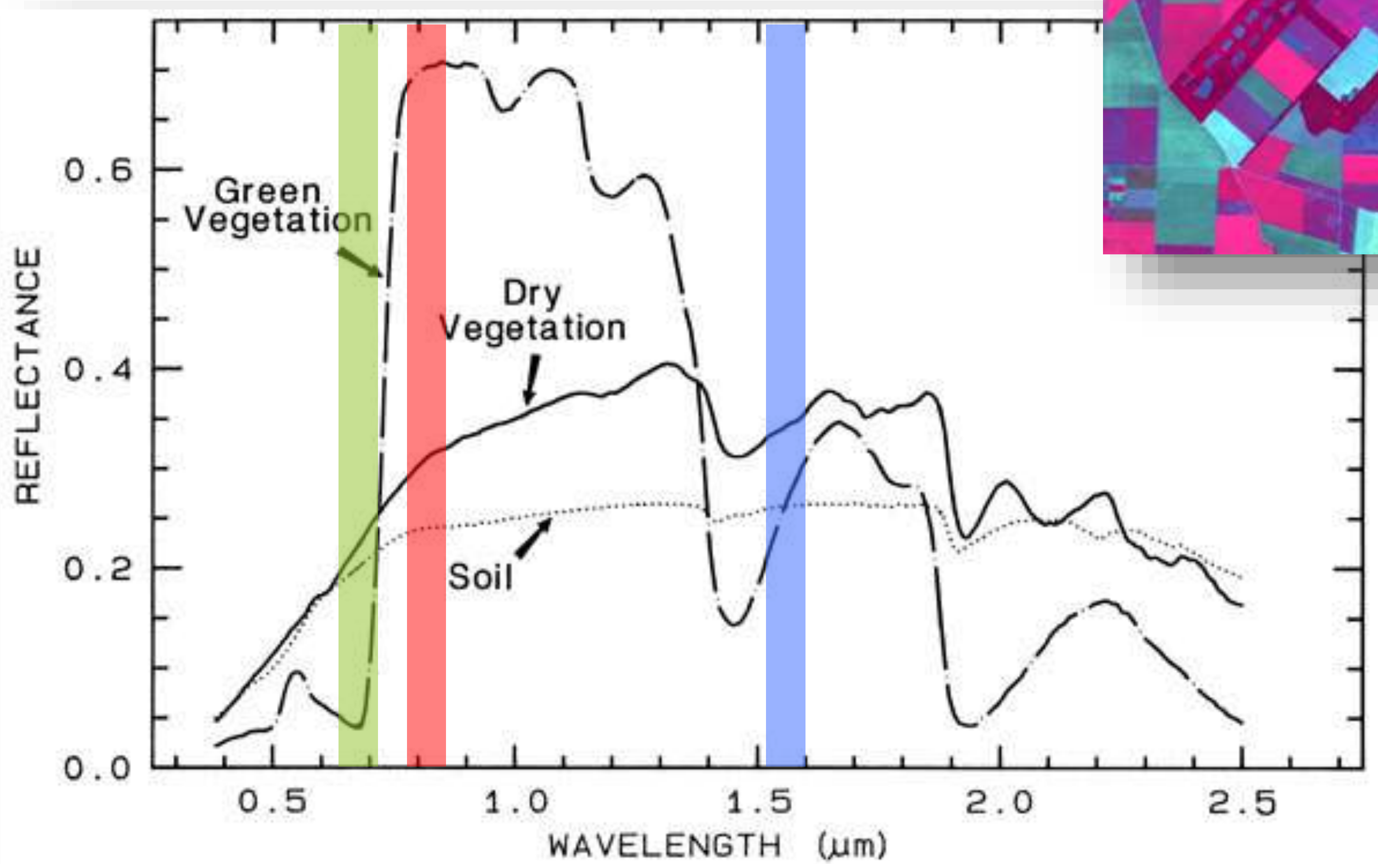


Summer crop



Growing vegetation as observed by optical RS

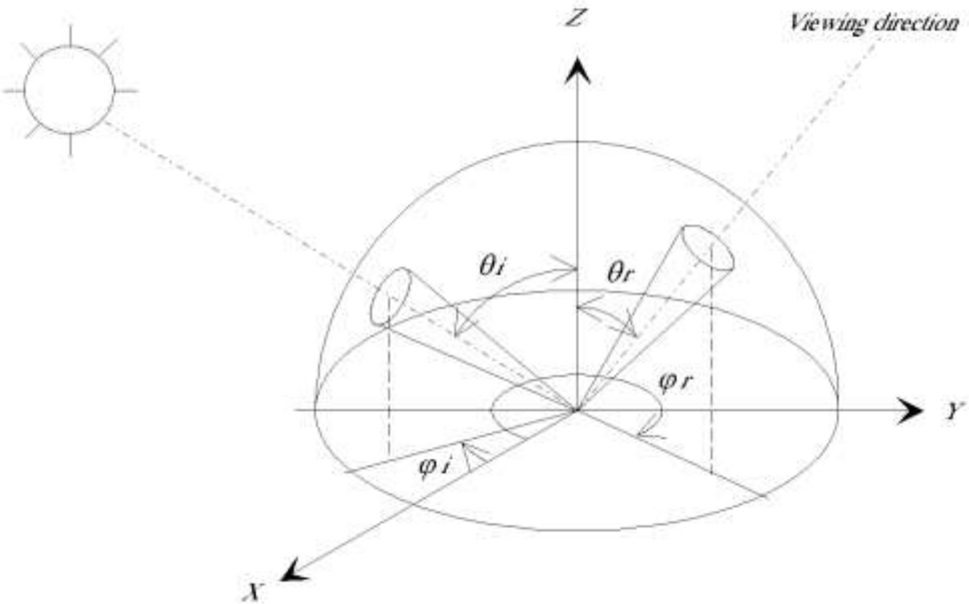
- A typical ag. landscape in a temperate climate



Winter crop

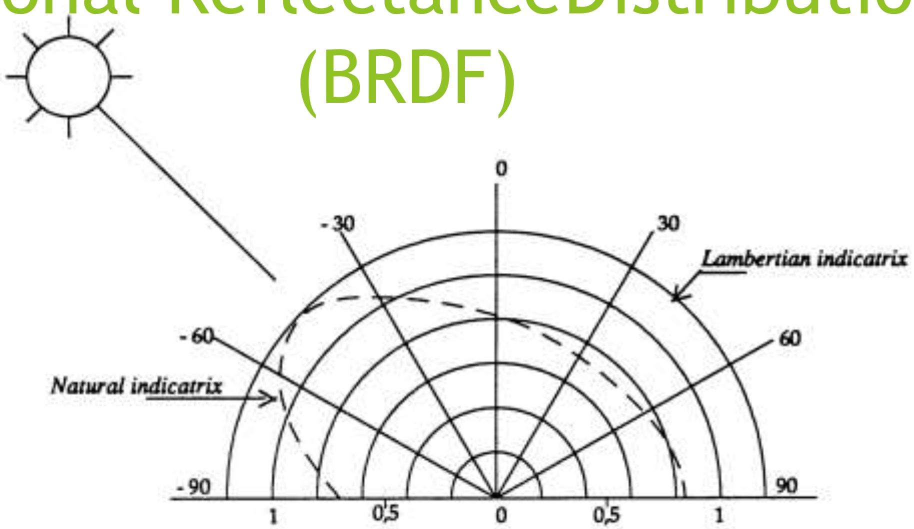
Summer crop

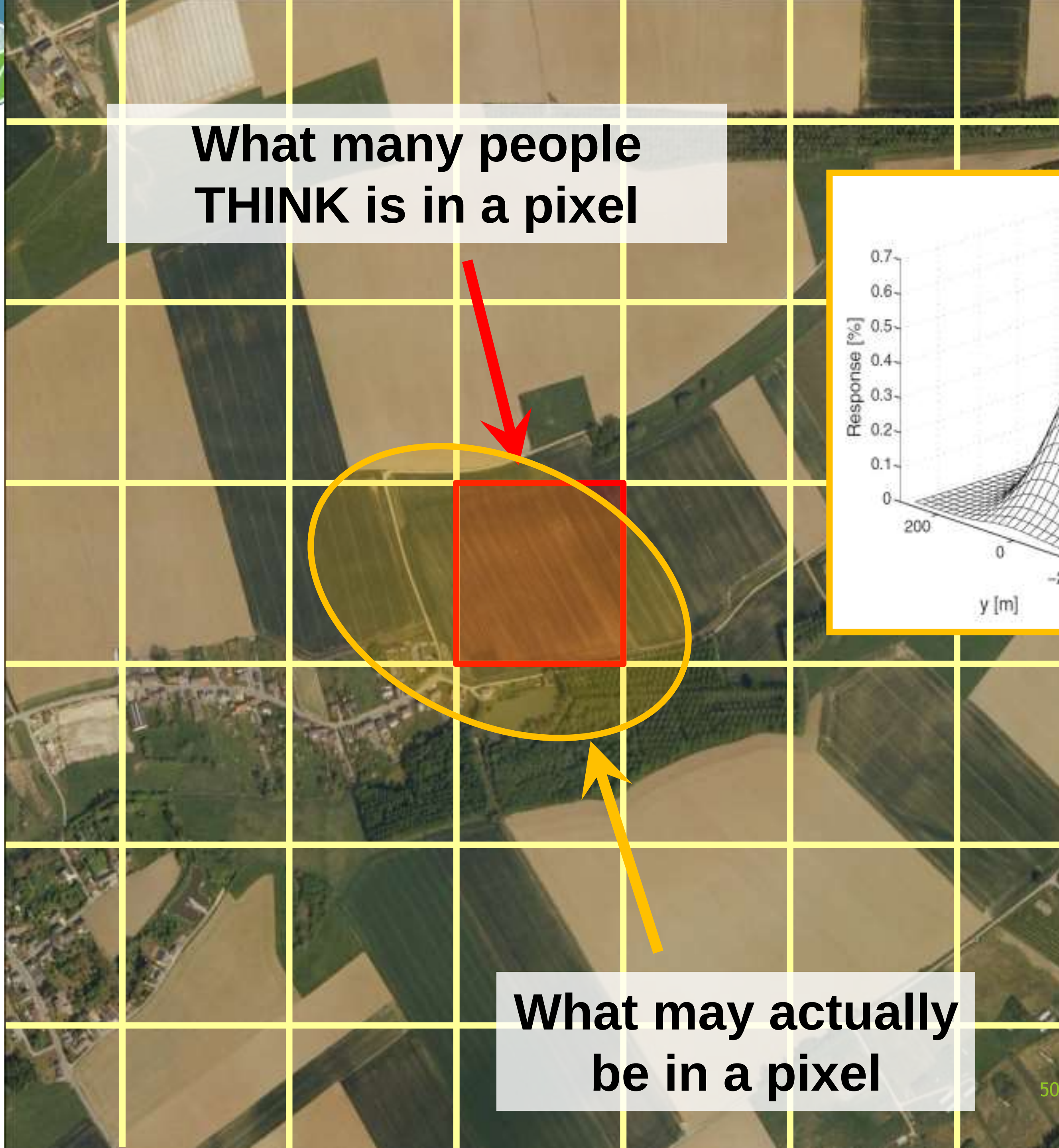
Research challenge to deal with the bidirectional reflectance

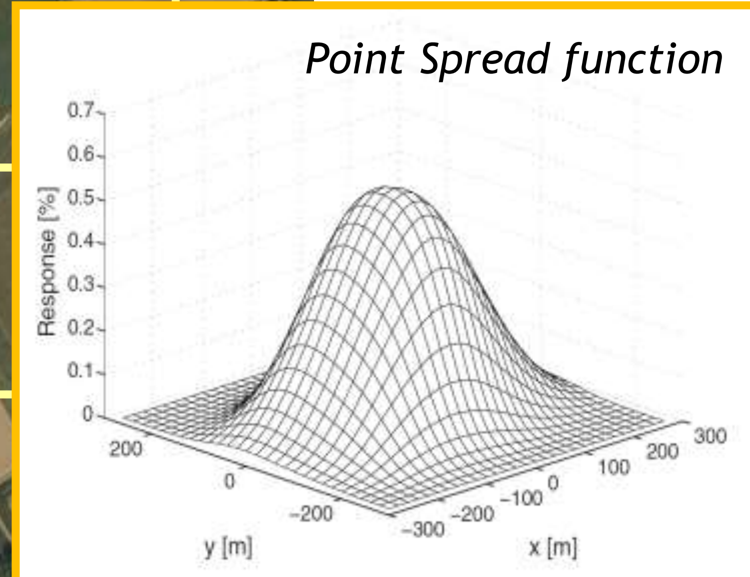


D. Deering

Bidirectional ReflectanceDistribution Function (BRDF)

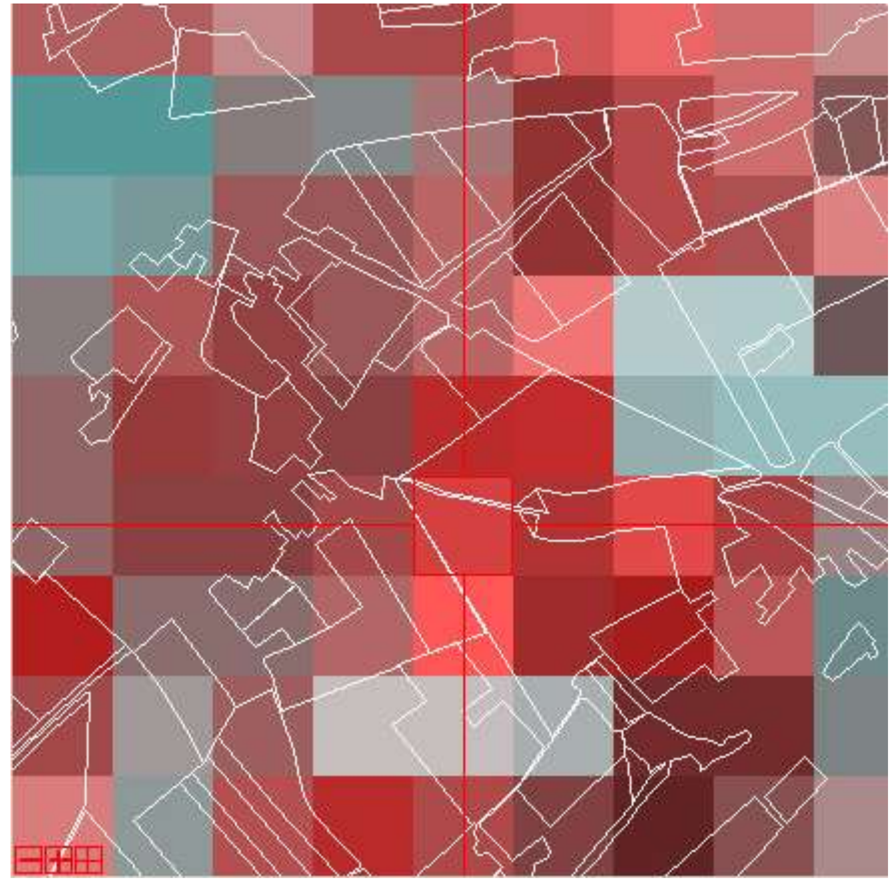






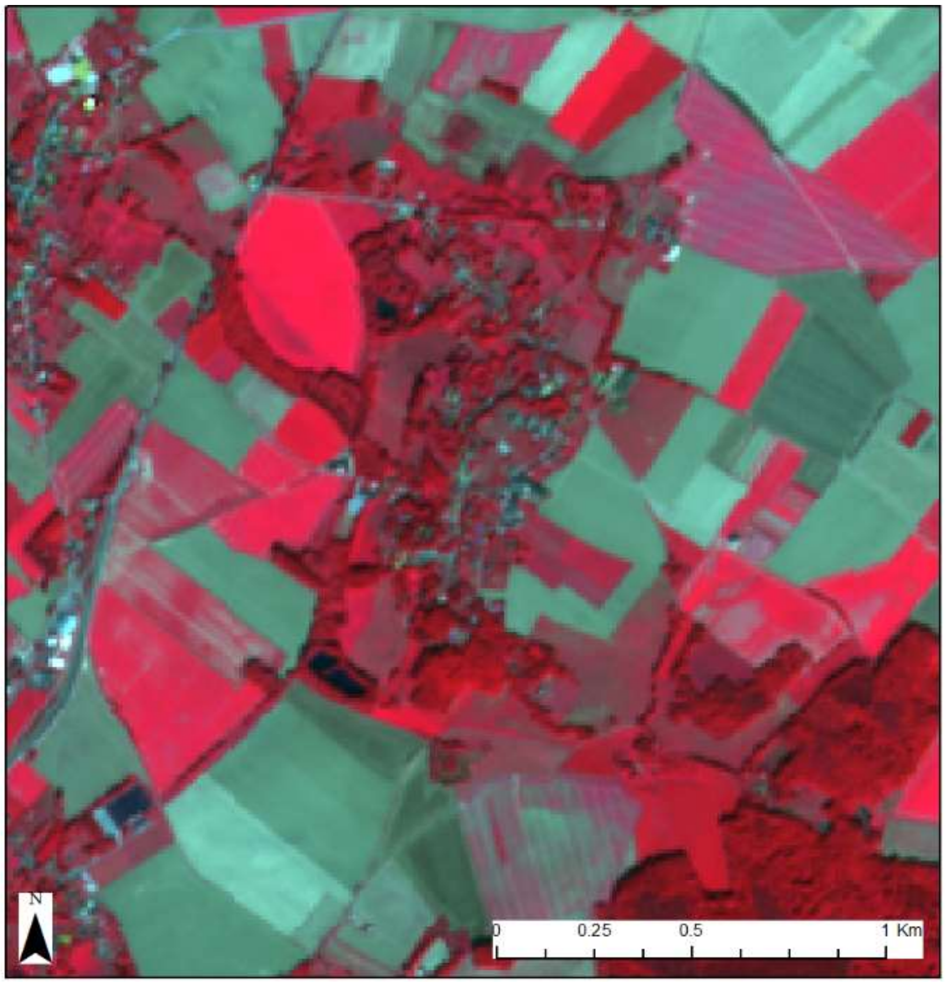
MODIS ~250 m
L2G grid

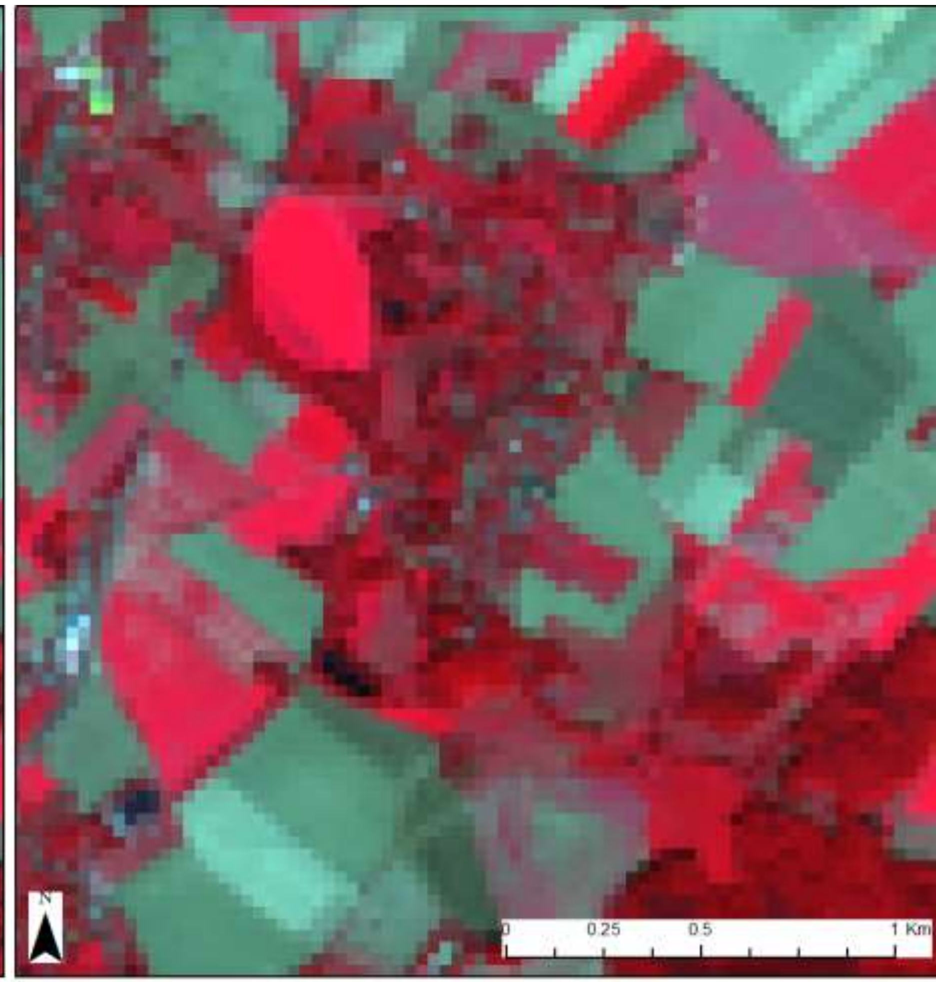
Mixels due to coarser resolution



- Will require assuring adequacy between observation footprint and target land cover

Decametric challenges : volume and diversity of signatures (10m details over large areas)





- ✓ **10 m**
- ✓ **30 m**

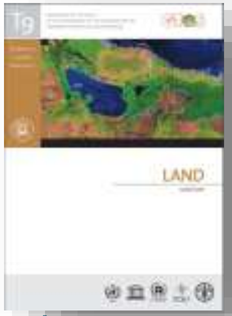
Outline

1. Introduction to optical land applications :
2. Basic principles about electromagnetic radiation & land surface
3. Identifying cultivated area and crops from space (Sen2-Agri system)
4. Estimating canopy biophysical variables (Sen2-Agri system)
5. Example of monitoring crop production from space (MARS)

What is a crop map ?

- A crop is any cultivated plant, fungus, or alga that is harvested for food, clothing, livestock fodder, biofuel, medicine, or other uses

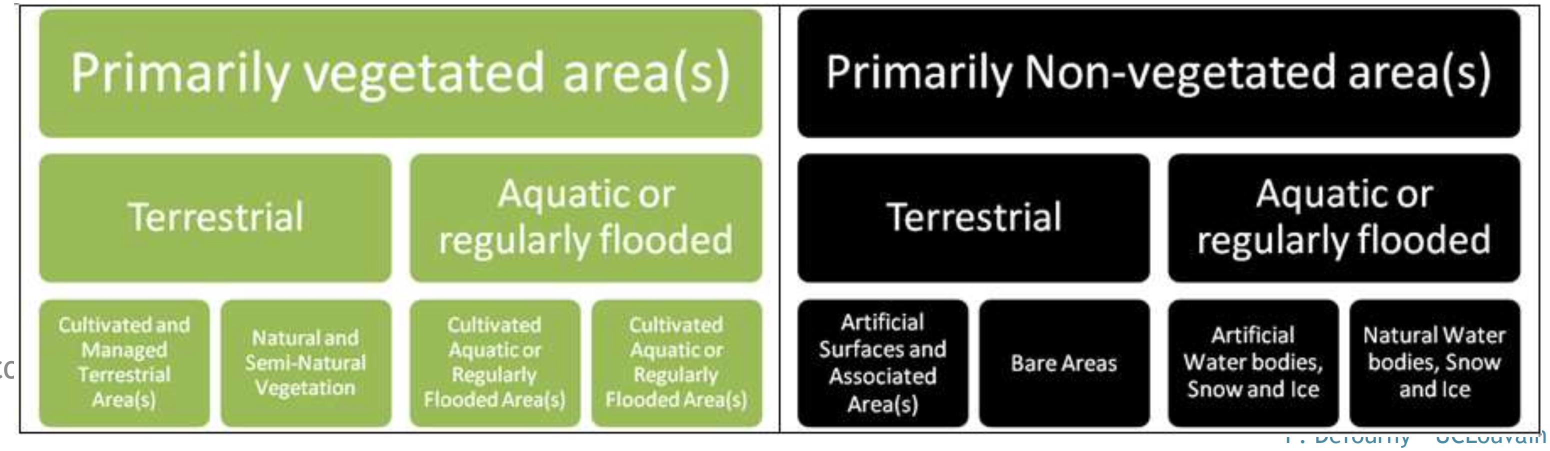
Land Cover typology recommandations => LCCS as ISO standard



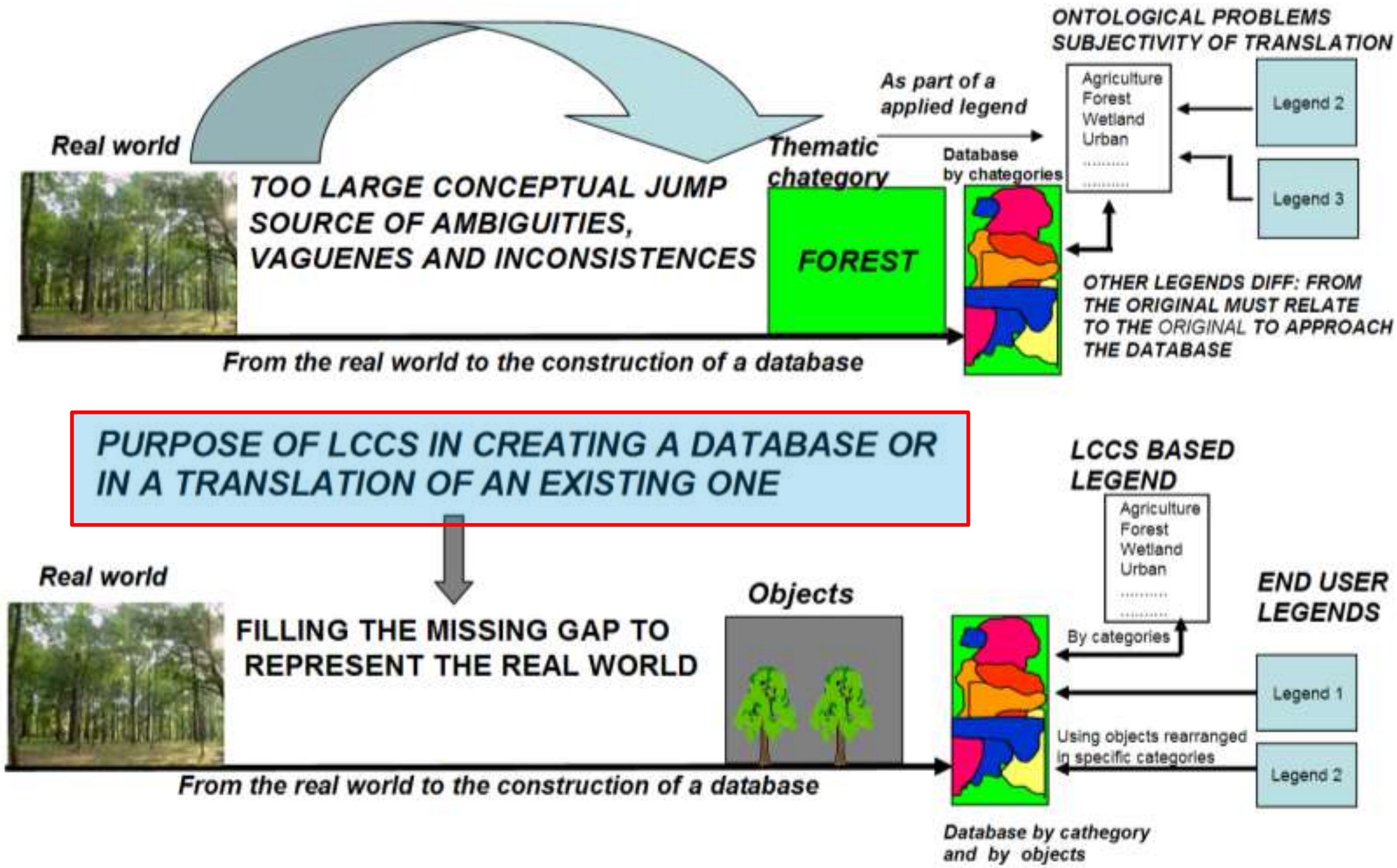
GTOS Recommendations (2009) for classifiers in land cover mapping :

- **Vegetation life form:** trees, shrubs, herbaceous vegetation (separated into grasslands and agricultural crops), lichen and mosses, non vegetated.
- **Leaf type** (needle-leaf, broad-leaf) and **leaf longevity** (deciduous, evergreen)
- **Non-vegetated cover types** (bare soil/rock, built up, snow, ice, open water).
- **Density of life form and leaf characteristics in percent cover.**
- **Terrestrial areas versus aquatic/regularly flooded.**
- **Artificiality of cover and land use.**

FAO Land Cover Classification System (LCCS v.2)



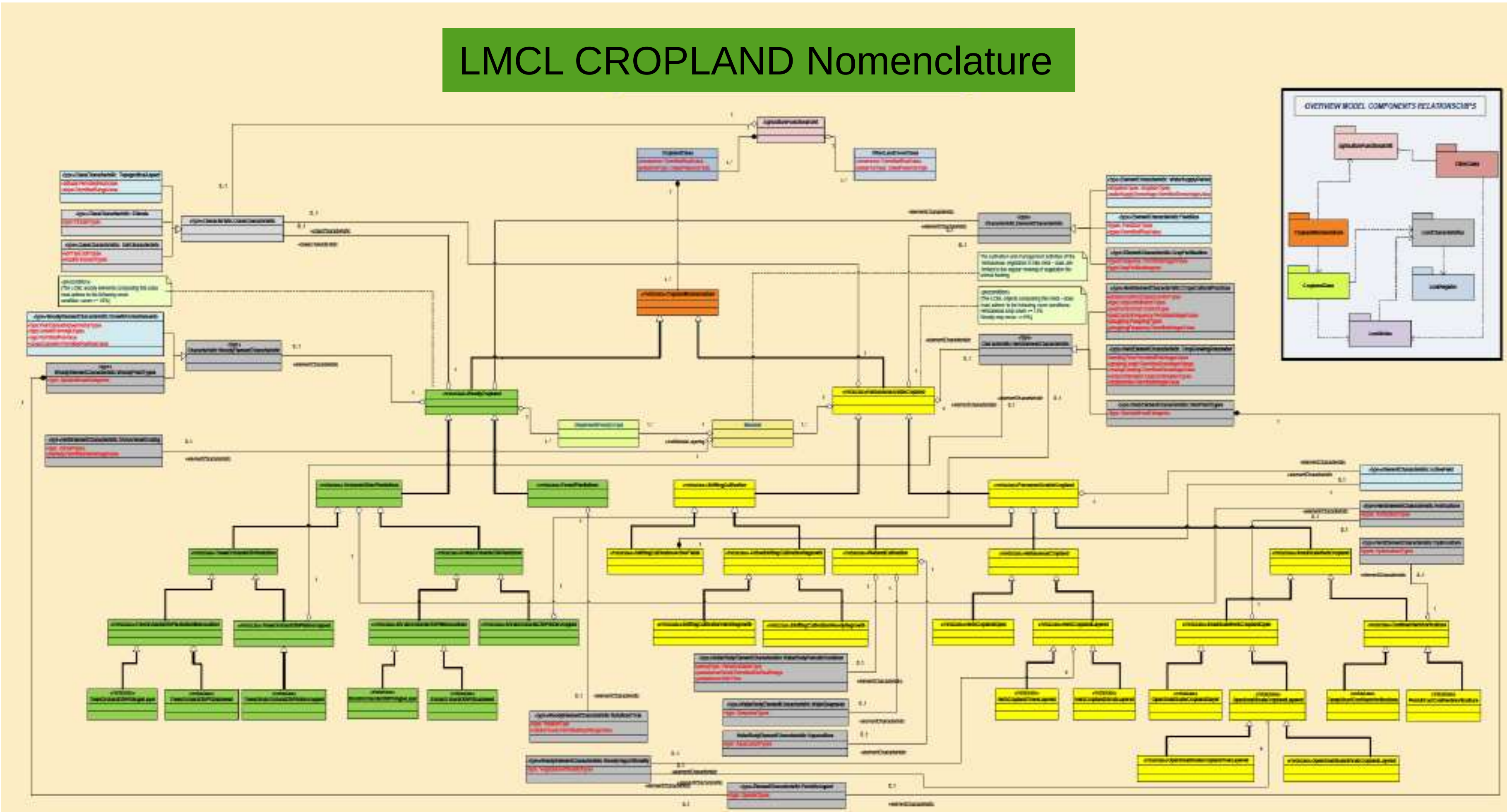
From Land Cover Classification System (LCCS) based on classifiers to LC Macro Language (LCML v.3)



(source : FAO LCML document)

DATABASE APPROACHED BY END USERS BY OBJECTS OR LCCS LEGEND DONE BY "MAP PRODUCER"

LCML model for cropland : hierarchical approach allowing aggregation levels



(Di Gregorio 2014)

JECAM Guidelines for cropland and crop type definition and field data collection

JECAM Guidelines - http://www.jecam.org/

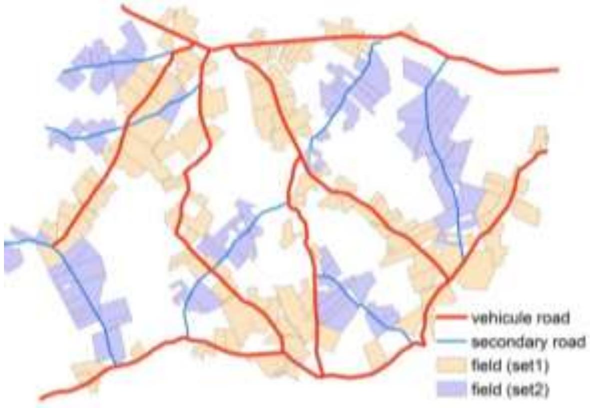
The **annual cropland from a remote sensing perspective** is a piece of land of minimum 0.25 ha (min. width of 30 m) that is sowed/planted and harvestable at least once within the 12 months after the sowing/planting date. The annual cropland produces an herbaceous cover and is sometimes combined with some tree or woody vegetation* .**

*the herbaceous vegetation expressed as fcover (fraction of soil background covered by the living vegetation) is expected to reach at least 30 % while the tree or woody (height >2m) cover should typically not exceed a fcover of 20%.
**There are 3 known exceptions to this definition. The first concerns the sugarcane plantation and cassava crop which are included in the cropland class although they have a longer vegetation cycle and are not yearly planted. Second, taken individually, small plots such as legumes do not meet the minimum size criteria of the cropland definition. However, when considered as a continuous heterogeneous field, they should be included in the cropland. The third case is the greenhouse crops that cannot be monitored by remote sensing and are thus excluded from the definition.

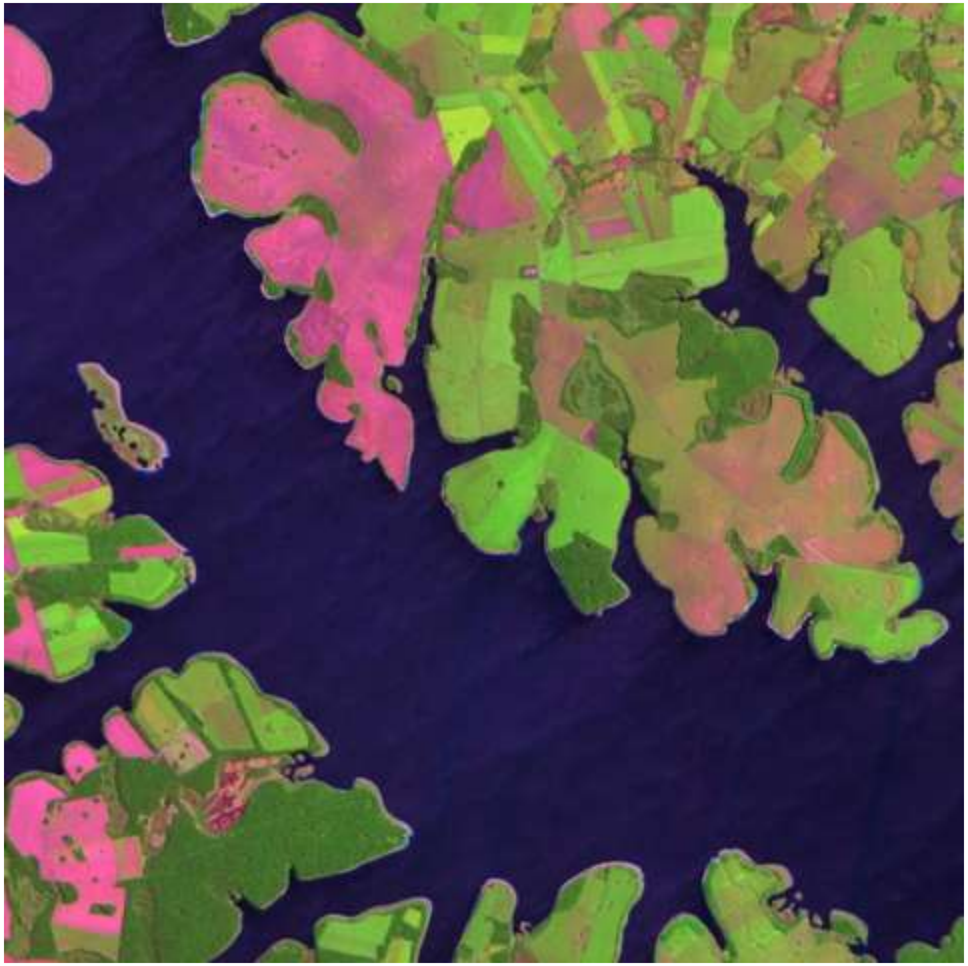
JECAM
Joint Experiment for Crop Assessment and Monitoring

sentinel-2

+ AGRICULTURE



Time series – Agriculture



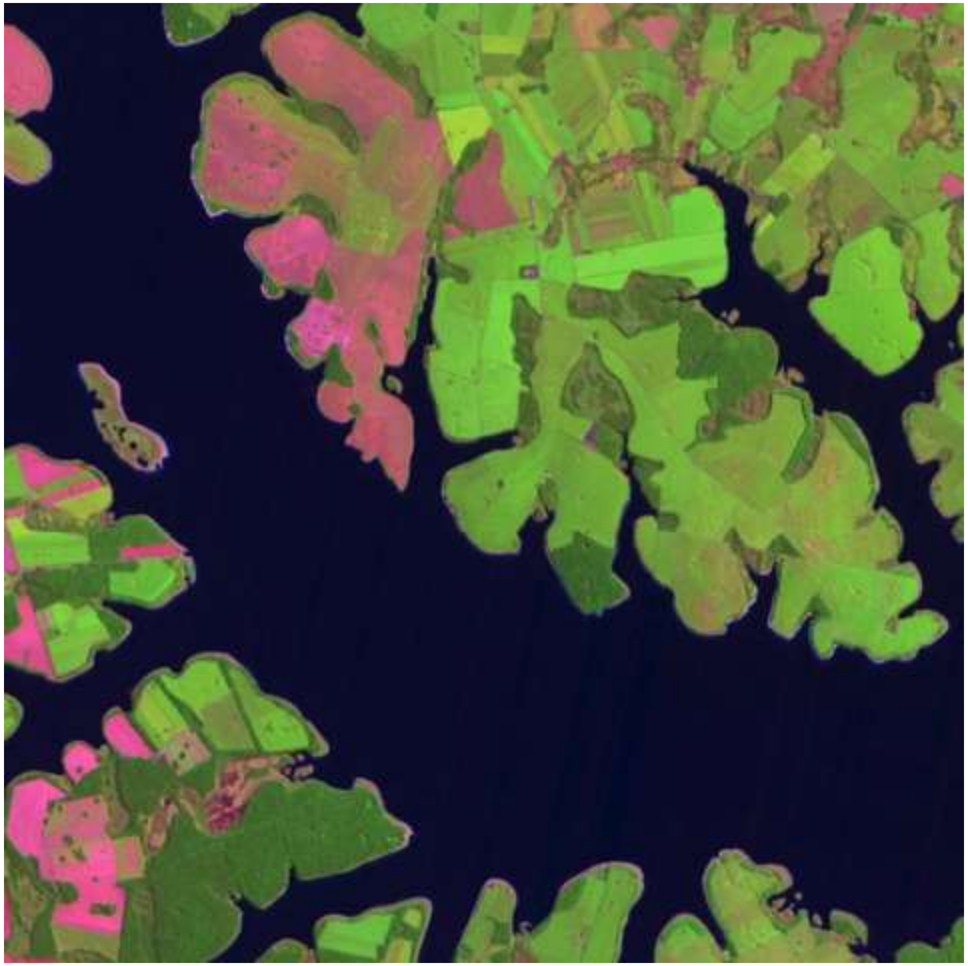
- SPOT4 (Take5) images in Paraguay (March-April 2013)
  - Pink : bare soil
  - Green : vegetation
- Different crops are sowed at different times in the year
- Applications
  - Land Cover (crop type)
  - Farming practices monitoring
  - Biomass, Yield, Water demand

sentinel-2

+ AGRICULTURE

30 March 2013

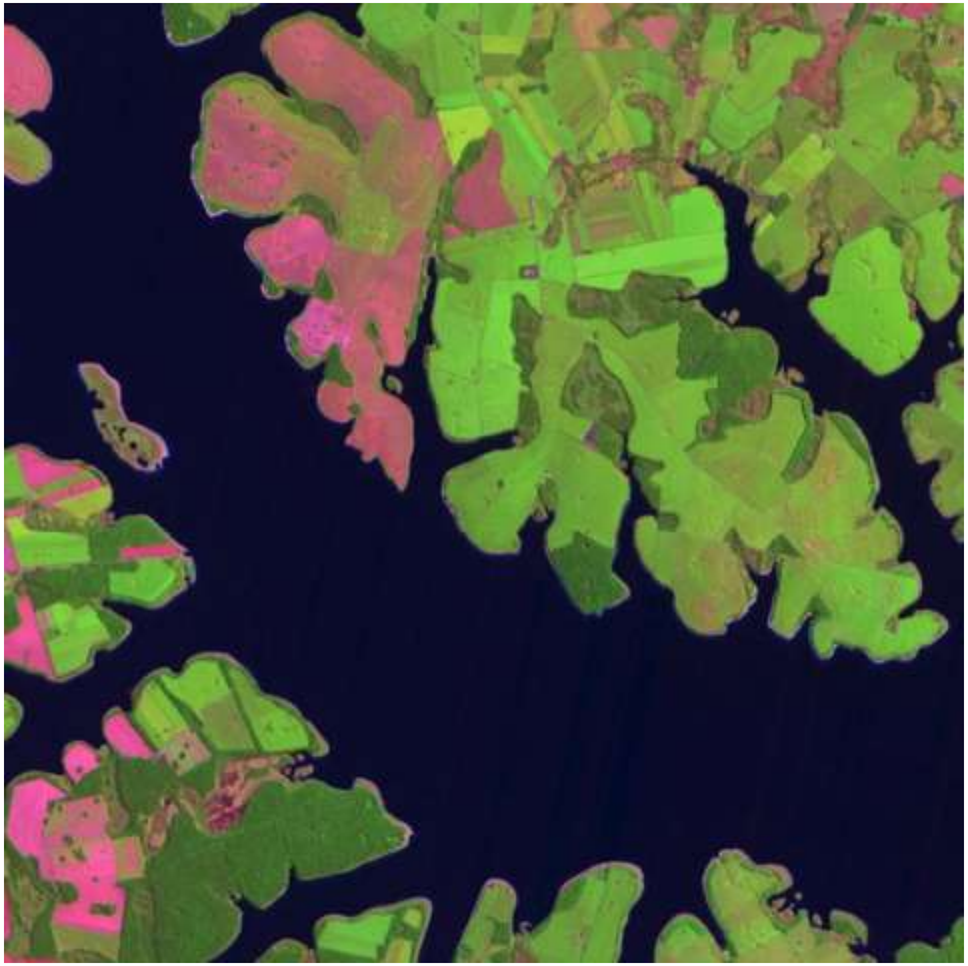
Time series – Agriculture



9 April 2013

- SPOT4 (Take5) images in Paraguay (March-April 2013)
  - Pink : bare soil
  - Green : vegetation
- Different crops are sowed at different times in the year
- Applications
  - Land Cover (crop type)
  - Farming practices monitoring
  - Biomass, Yield, Water demand

Time series – Agriculture



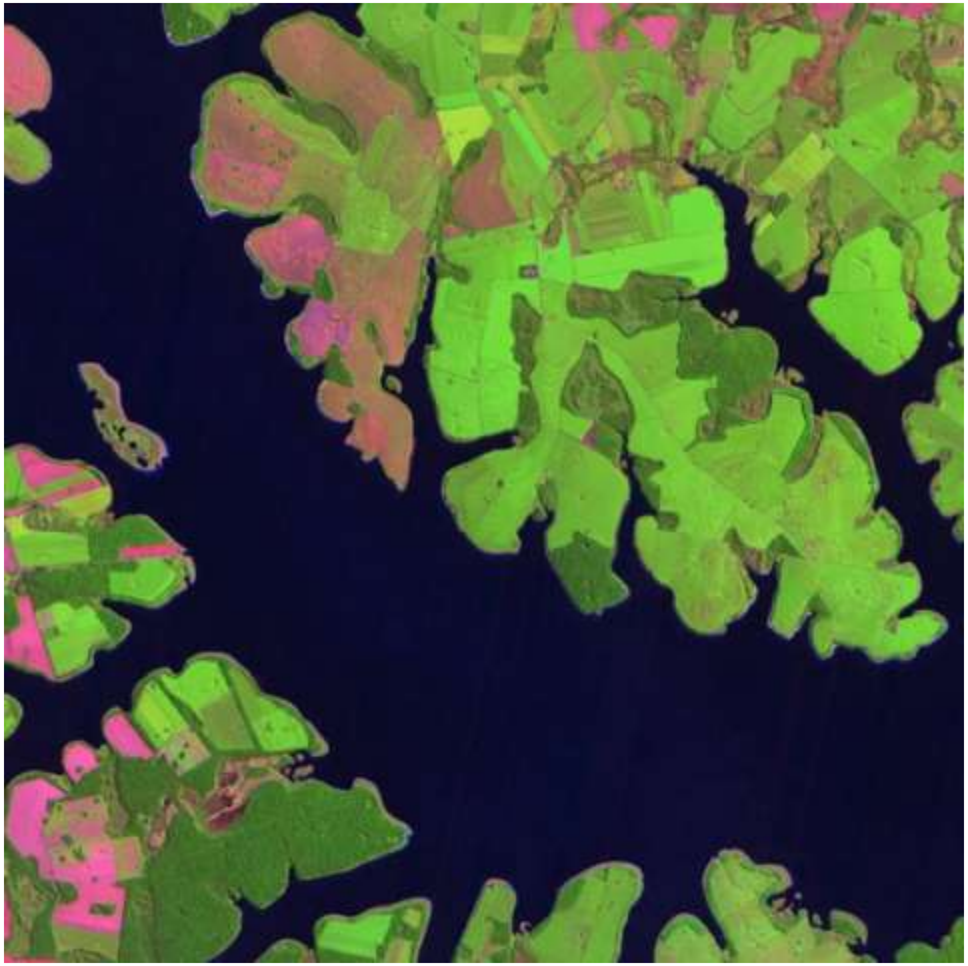
14 April 2013

- SPOT4 (Take5) images in Paraguay (March-April 2013)
  - Pink : bare soil
  - Green : vegetation
- Different crops are sowed at different times in the year
- Applications
  - Land Cover (crop type)
  - Farming practices monitoring
  - Biomass, Yield, Water demand

sentinel-2

+ AGRICULTURE

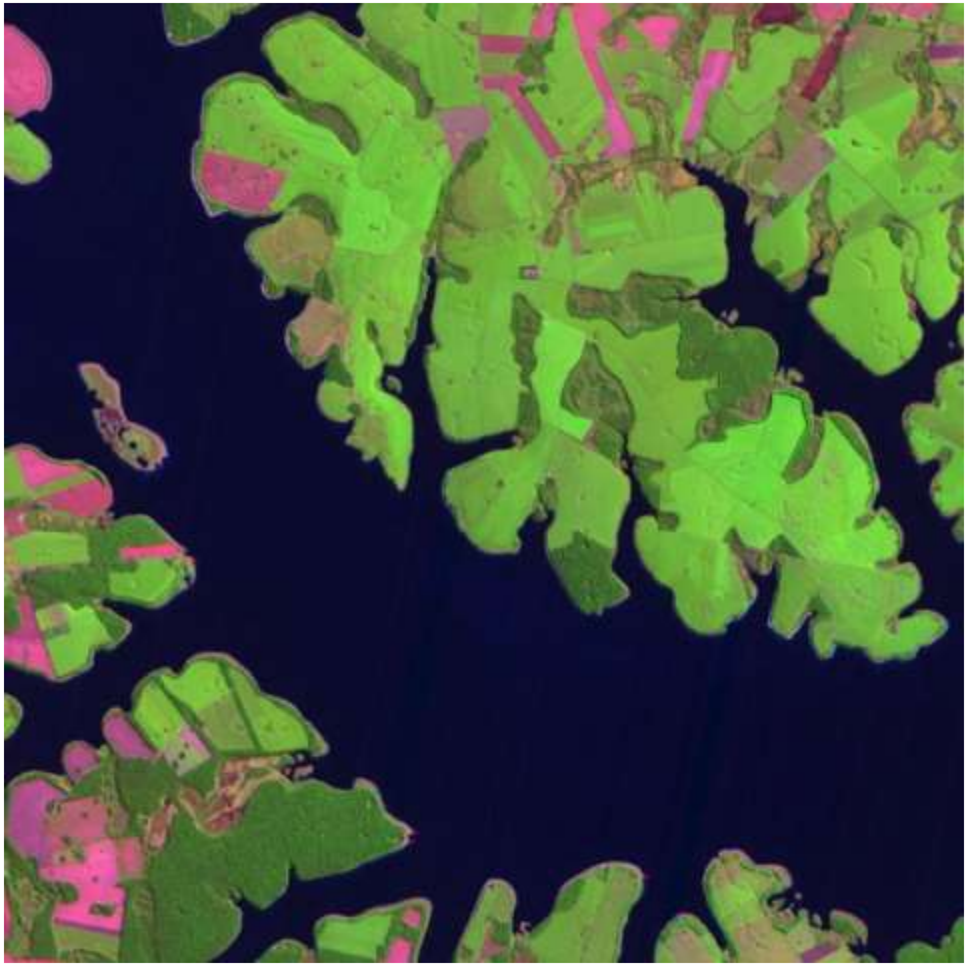
Time series – Agriculture



- SPOT4 (Take5) images in Paraguay (March-April 2013)
  - Pink : bare soil
  - Green : vegetation
- Different crops are sowed at different times in the year
- Applications
  - Land Cover (crop type)
  - Farming practices monitoring
  - Biomass, Yield, Water demand

19 April 2013

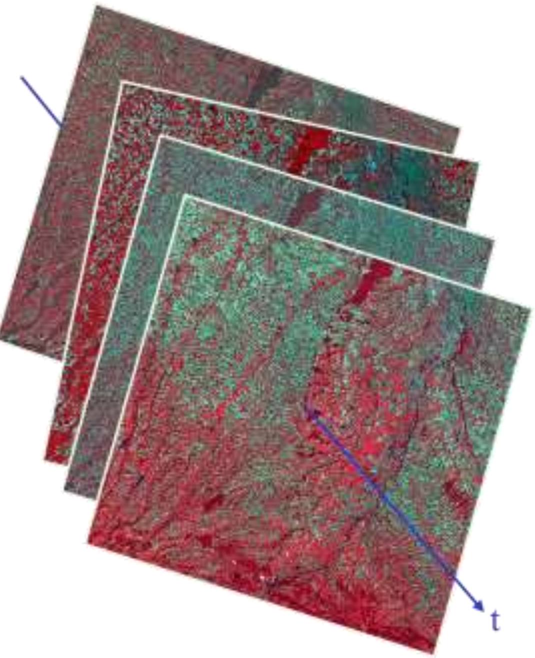
Time series – Agriculture

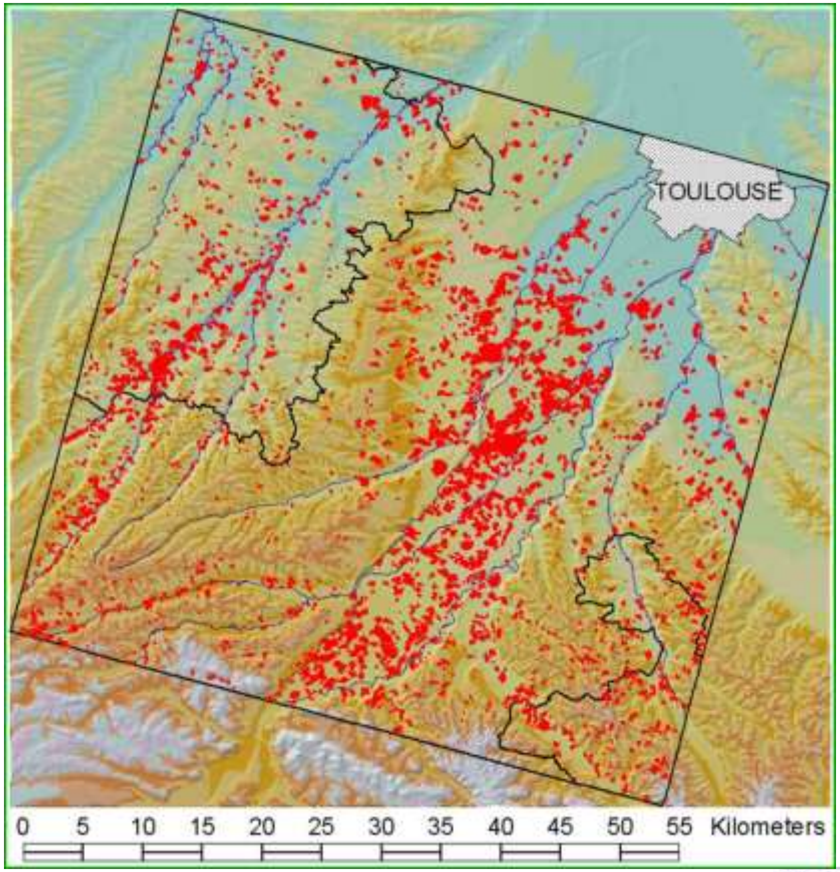


- SPOT4 (Take5) images in Paraguay (March-April 2013)
  - Pink : bare soil
  - Green : vegetation
- Different crops are sowed at different times in the year
- Applications
  - Land Cover (crop type)
  - Farming practices monitoring
  - Biomass, Yield, Water demand

What is a crop map ?

A symbolic depiction of one or several crops for a given area





Map of maize (in red) in the South West of France in 2002, overlayed over altitude map

Satellite images from Spot-2 at 20m

What is a crop map ?

A crop map has all the attributes of a map (geographical domain, scale, projection, symbolic description of the themes), **a format** (raster or vector) **plus metadata and/or documentation**:

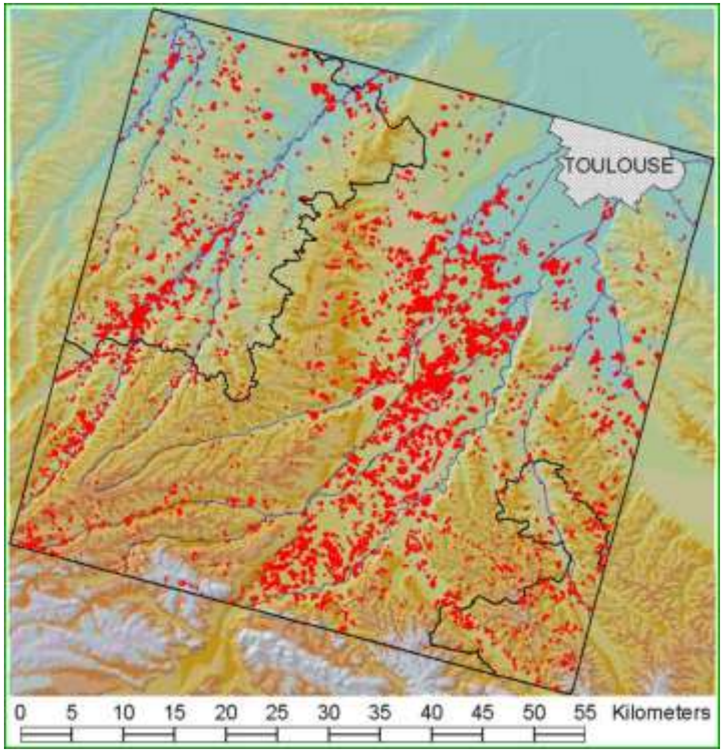
- A **nomenclature** : which crop(s) [e.g. wheat] or group of crops [e.g. cereals, summer crops] are represented ?
- A date: at what time the represented crop was there
- Information on the **accuracy** and **standards**

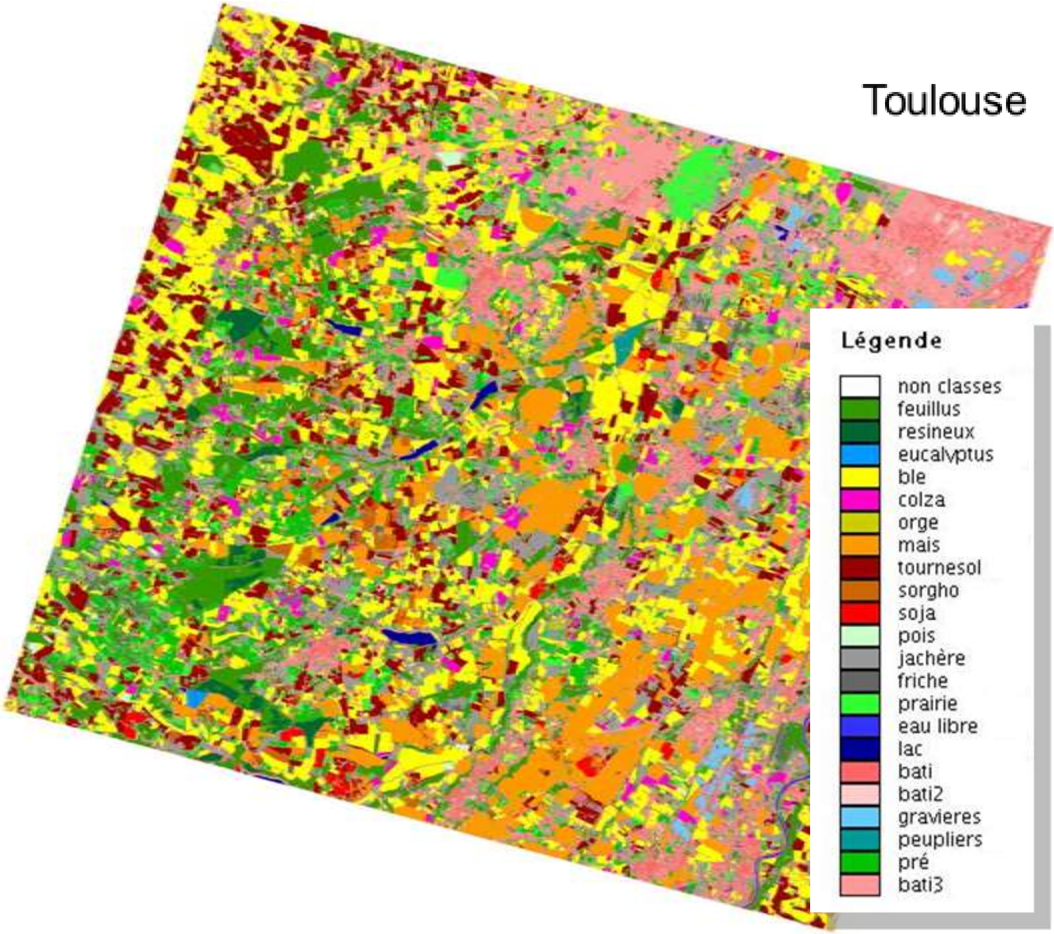
  (e.g. **Mininum Mapping Unit** : fields smaller than 1 ha taken into account)
- Documentation on the **methodology**, the input data used (eg. map established from 20 m pixel images, number of image used per pixel or per polygon)

What is a crop map ?

One crop : Map of maize (in red) in the South West of France between May and June 2002 overlayed over altitude map

A crop type map for 2002: all crops cultivated between January and October 2002, but not all the time + other land cover types



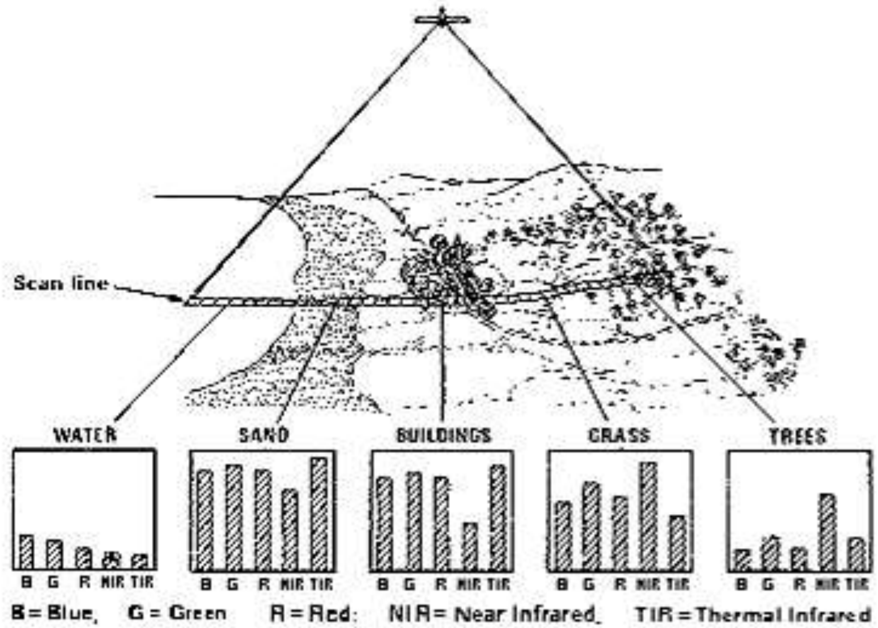


sentinel-2

+ AGRICULTURE

How can I map crops with remote sensing ?

For each pixel of an image, EO instruments provide **multidimensional vector of information such as spectral reflectances in *n* different spectral bands,** their evolution over time



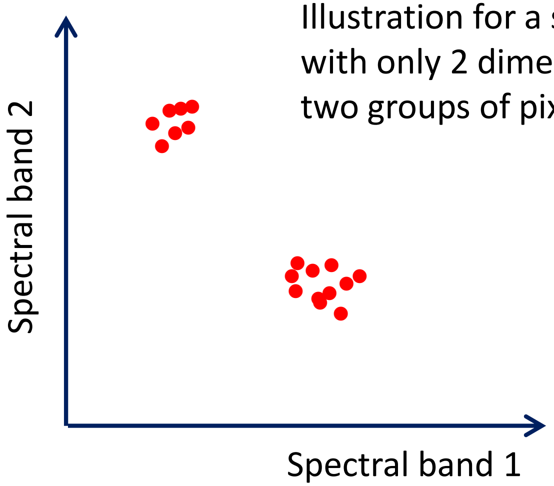
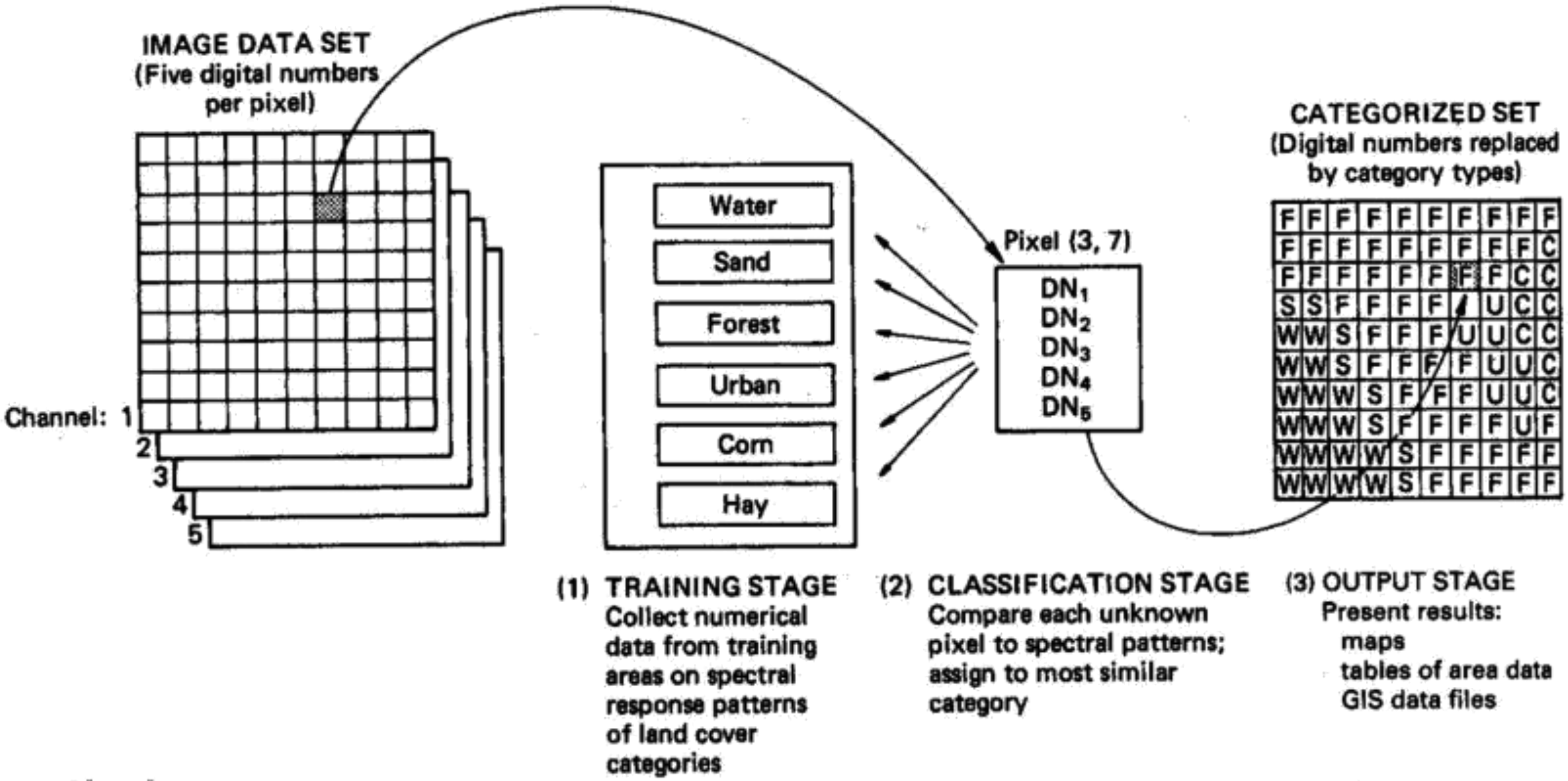


Illustration for a simple case with only 2 dimensions and two groups of pixels

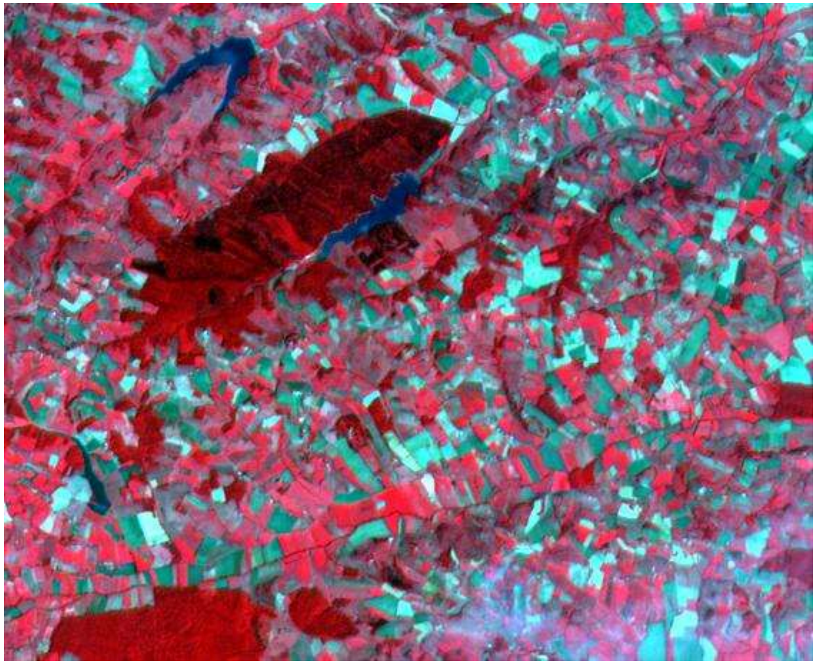
How can I map crops with remote sensing ?

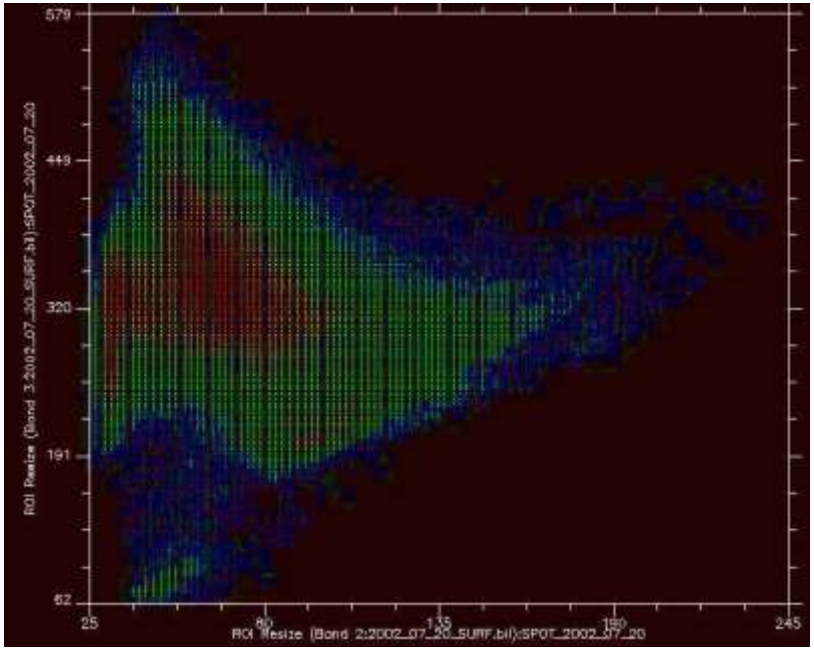
For crop mapping (or any other object), the question is how can I relate this vector of information, for each pixel or a group of pixels, to a specific crop ?



How can I map crops with remote sensing ?

Reality is more complex: more than two classes, difficult to identify very distinct clusters

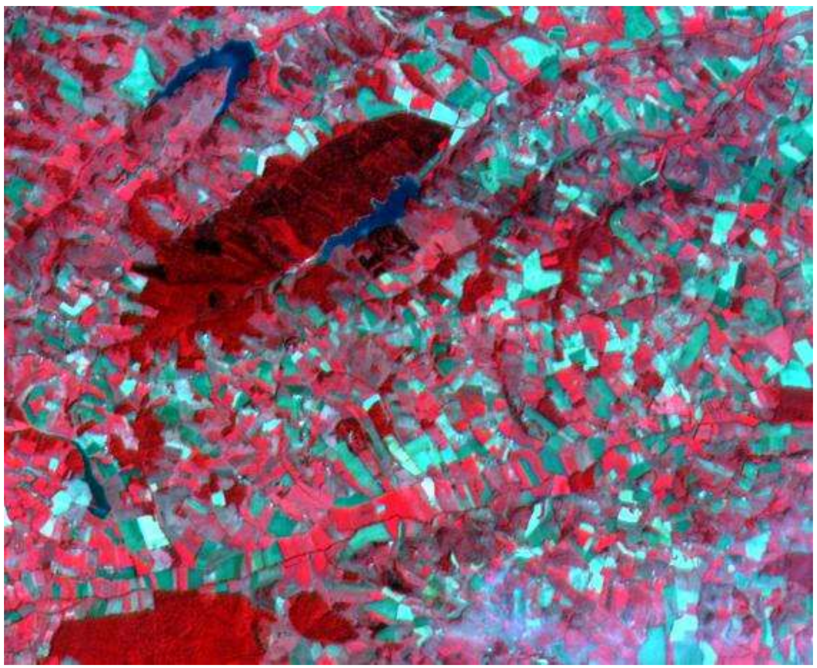


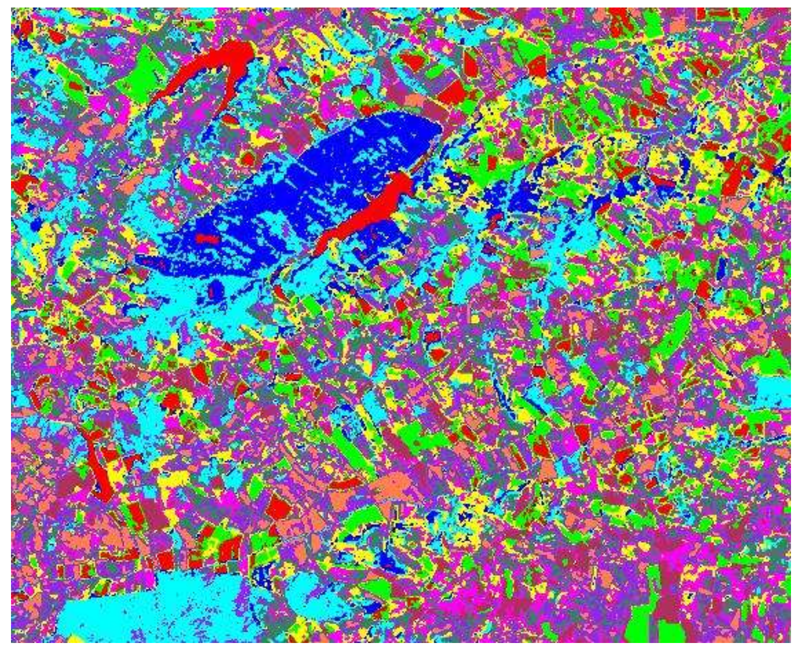


Bi-dimensional histogram of red and near-infrared bands

How can I map crops with remote sensing ?

Unsupervised classification: the algorithm automatically separates clusters of pixels, for instance defined by their means and variance in different bands





Unsupervised classification 10 classes

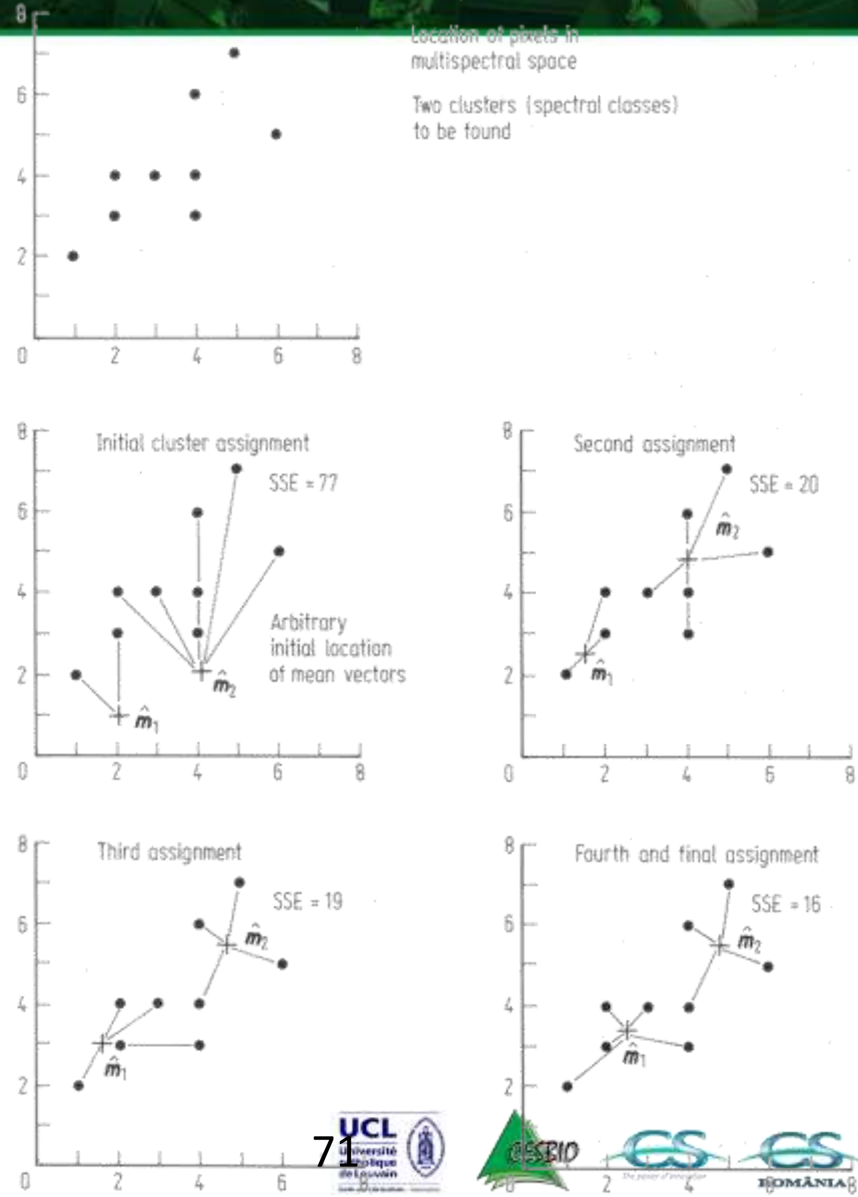
sentinel-2

+ AGRICULTURE

Unsupervised classification algorithms

K-means algorithm

- input number of clusters desired
- algorithm typically initiated with arbitrarily-located 'seeds' for cluster means
- each pixel then assigned to closest cluster mean
- revised mean vectors are then computed for each cluster
- repeat until some convergence criterion is met (e.g. cluster means don't move between iterations)

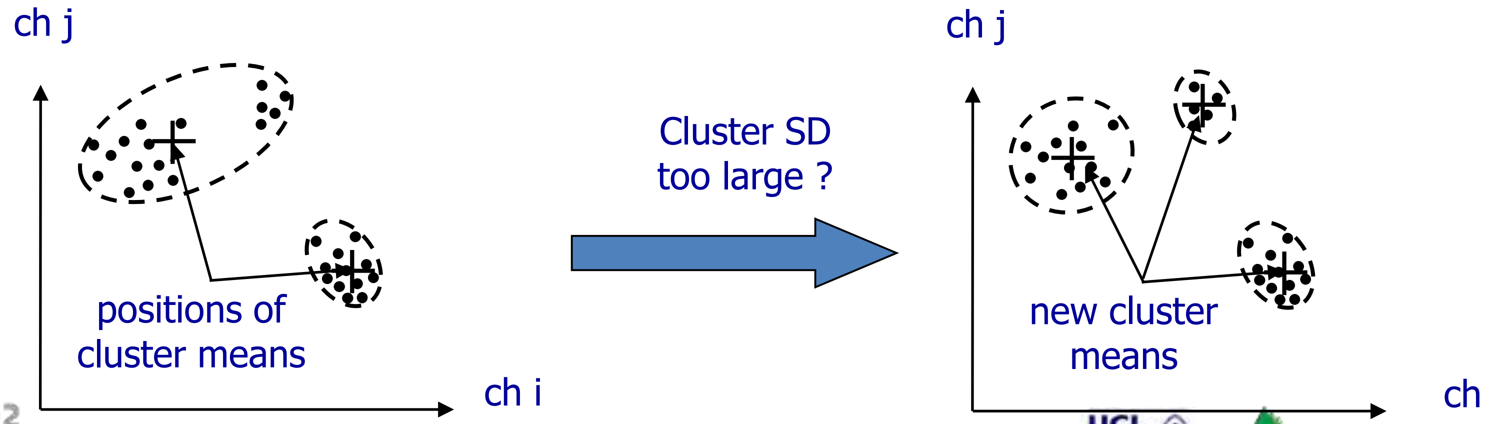


Unsupervised classification algorithms

ISODATA (Iterative self-organising data analysis) algorithm

same as K-means but can vary number of clusters (by splitting / merging)

- Start with (user-defined number) randomly located clusters
- Assign each pixel to nearest cluster (mean spectral distance)
- Re-calculate cluster means and standard deviations
- If distance between two clusters < some threshold, merge them
- If standard deviation in any one dimension > some threshold, split into two clusters
- Delete clusters with small number of pixels
- Re-assign pixels, re-calculate cluster statistics etc. until changes of clusters < some fixed threshold

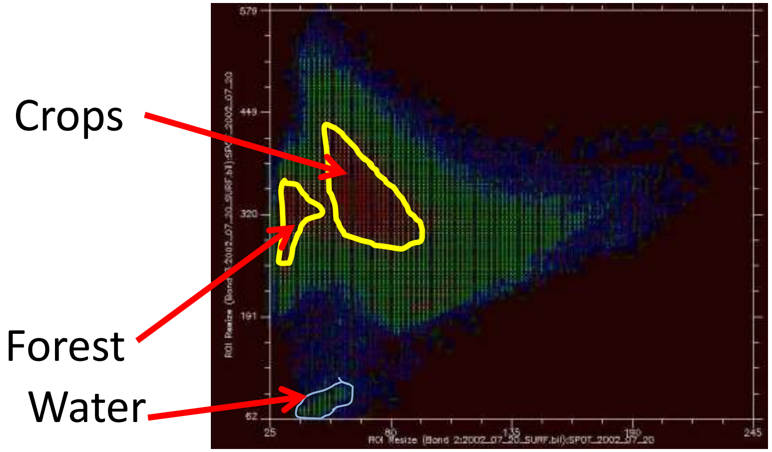


Supervised classification

Training dataset

Supervised classification:

- 1) Collect a set of training samples, for instance through ground survey for different land cover categories
- 2) Create a model which relates a category to, for instance, a mean and a variance of a set of features (i.e. image reflectances, DEM, NDVI, …)
- 3) Apply to you data set
- 4) Check the result with independant samples



Supervised classification

Additional features to better discriminate

Features selection:

Available data

Satellite data
- Raw measurements
- Preprocessed measurements (calibration, Atmospheric correction ….): Spectral reflectances, radar σ_0,
- Combination of bands (e.g. NDVI)
- Phenology index
- …

Ancillary data:
- Previous land cover map(s)
- Digital Elevation model
- Soil maps
- …

3 categories

- **Radiometric features**
  - Reflectances, spectral indices
  - Texture (local statistics)
- **Temporal features**
  - Time descriptors (based on time profiles)
  - Phenologic indicators: time descriptors based on prior knowledge about vegetation
- **Object features: extracted after images segmentation**
  - Radiometric features
  - Shape features
  - Adjacency features

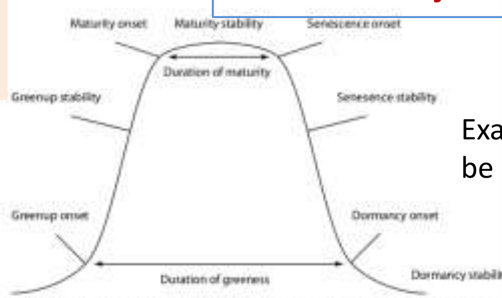


Figure 1: Example of phenological descriptors which can be extracted from a temporal profile

Example of phenological descriptors which can be extracted from a temporal profile

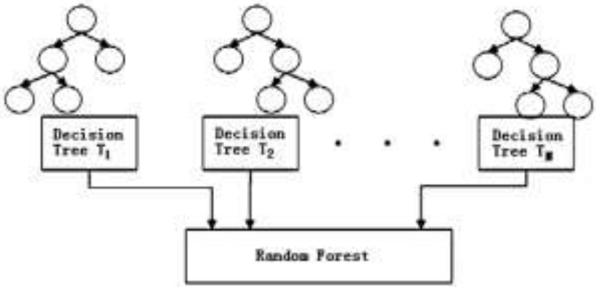
Supervised classification

Machine learning algorithms

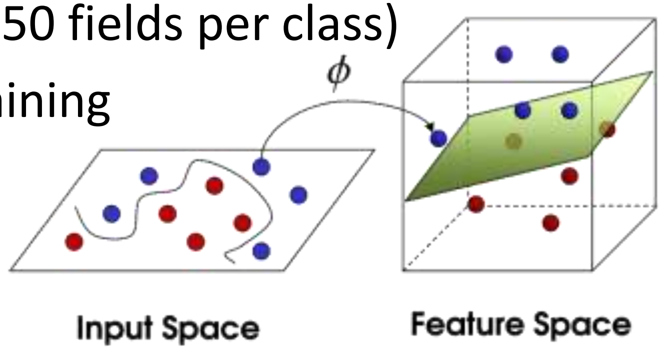
- Maximum Likelihood based on Bayesian theorem (probability)

$$P(C_i \mid X) = P(X \mid C_i)\ P(C_i)\ /\ P(X)$$

- Random Forests (RF) is a machine learning classification algo finding the best features combination for each class discrimination



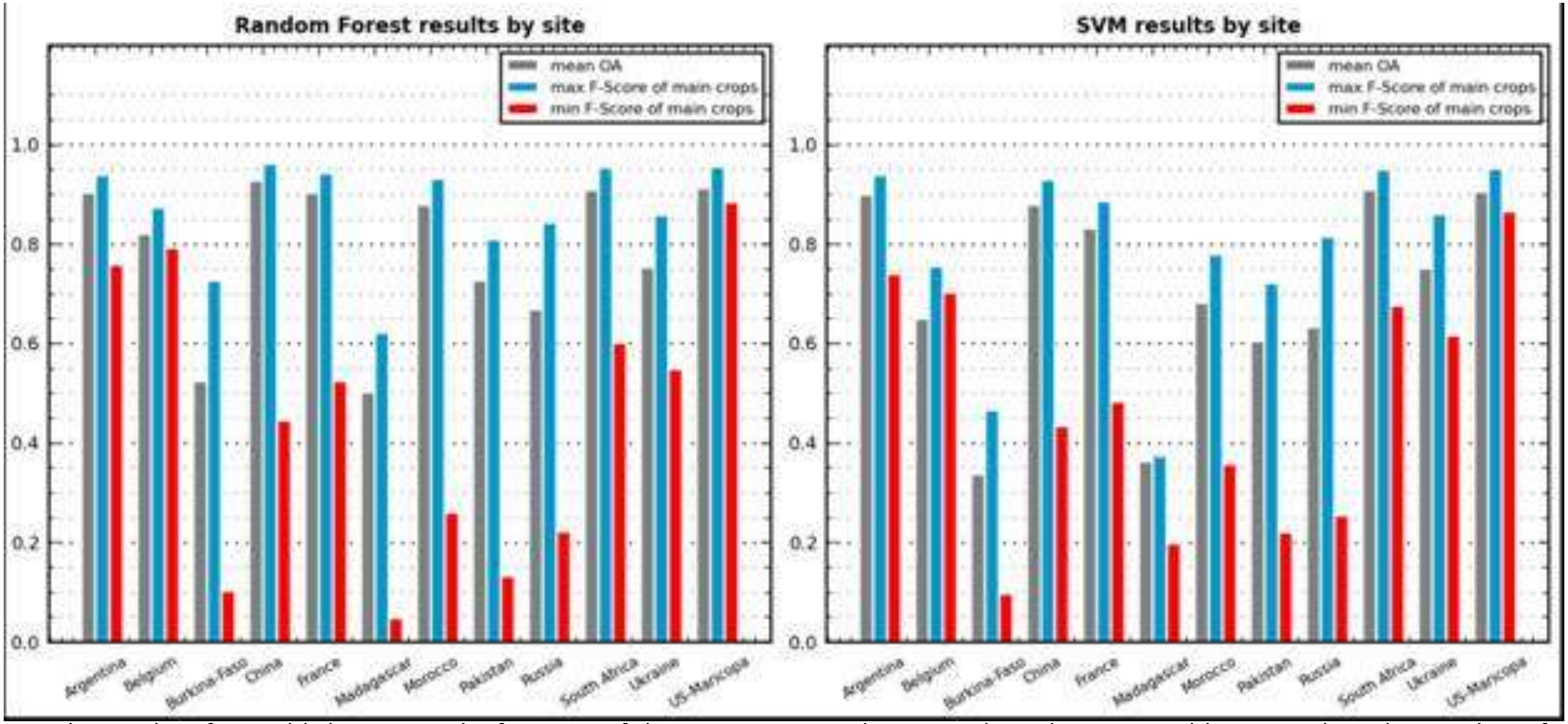
- Support Vector Machines (SVM) to be used when either
  - Few training samples are available (less than 50 fields per class)
  - There is an important imbalance between training samples for interesting classes



Supervised classification

Algorithms

Choice of the classifier: Results of the benchmarking exercise for Random Forest and SVM over 12 sites

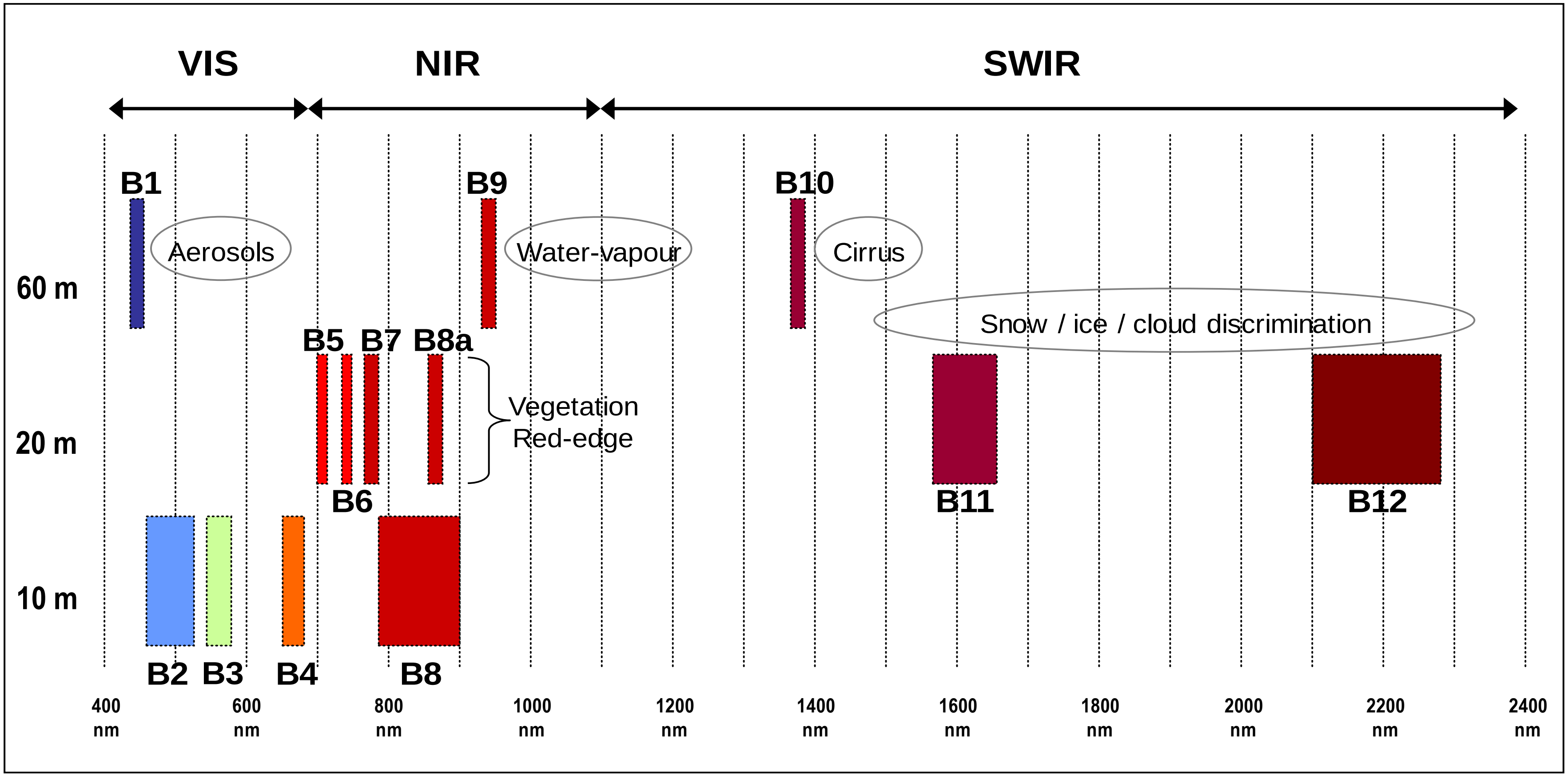


The RF classifier yields better results for most of the sites. SVM produces good results comparable to RF when the number of classes is small, as shown by the results of Argentina and China, and specially in South-Africa where results are much better. However, as the SVM is very sensitive to a balanced share of samples between the classes, it has to be parameterized in such a way that all classes are equally represented. This means that majority classes will be under-sampled. For this reason and for these classes, lower results are obtained if they are compared with the RF results, whilst for minority classes results may be better.

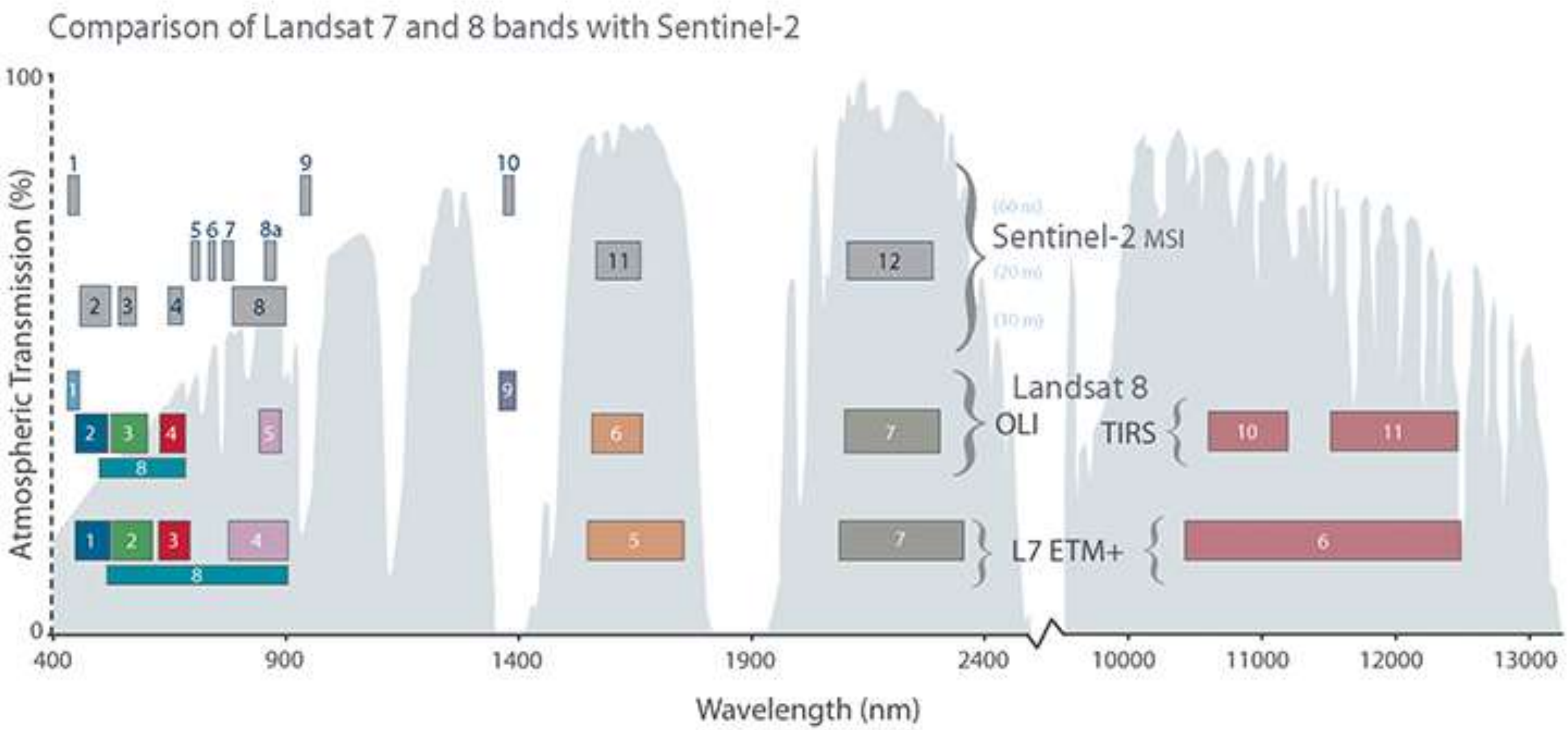
Sentinel-2 Mission

Mission features	Description
Spacecrafts	2 operating in twin configuration
Instrument	MSI (Multi-Spectral Instrument) operating in pushbroom principle (filter based optical system)
Spectral bands	13 (VIS–NIR–SWIR)
Spatial Resolution	10m / 20m / 60m
Swath	290 km
Orbit	Sun-synchronous at 786 km (14+3/10 revs per day), with LTDN 10:30 AM
Revisit Periodicity	10-day with 1 satellite 5 day with 2 satellites

Sentinel -2 bands



Comparison Sentinel-2 / Landsat bands



sentinel-2

+ AGRICULTURE

Sentinel-2 for Agriculture Project Objectives

- **Preparation for national to regional agricultural monitoring based on Sentinel-2**
    - R&D for full exploitation of temporal & spatial resolution of S2

- **Consolidate Best Practices for EO agricultural monitoring**
    - Benchmarking & validation of algorithms for 4 EO products
    - Testing products over a wide range of conditions (globally distributed JECAM network)

- **Strengthening National Capacity for Agricultural Monitoring**
    - Open source system for **national reporting & food security**
    - Transfer to users including local system installation & training
    - Demonstration of agricultural EO products at national scale

sentinel-2 + AGRICULTURE

User-driven approach

Consortium

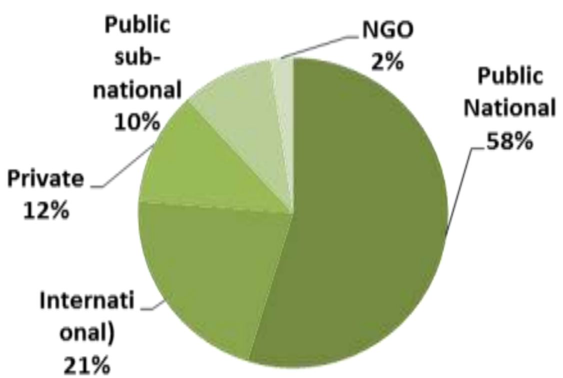
Support & data provider

Champion Users

1st User Consultation organized by ESA in 2012

2nd User Consultation through surveys in 2014

Survey filed up by 42 institutions

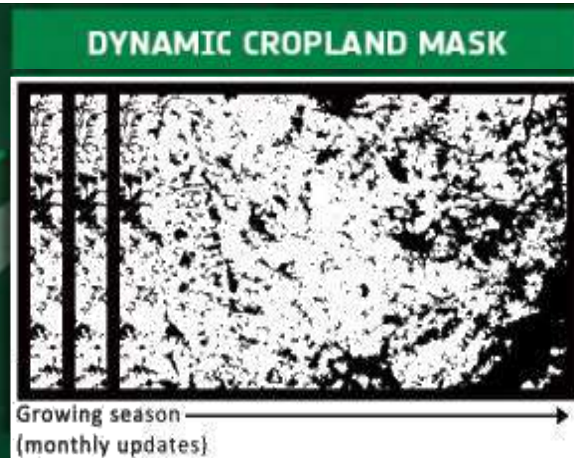


1st Sen2-Agri Users Workshop – FAO May 2014

2nd Sen2-Agri Users Workshop – EU Nov.2015

System to deliver 4 Sen2-Agri products

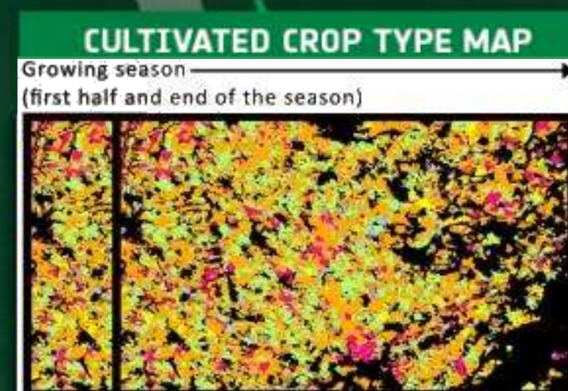
in line with the GEOGLAM core products



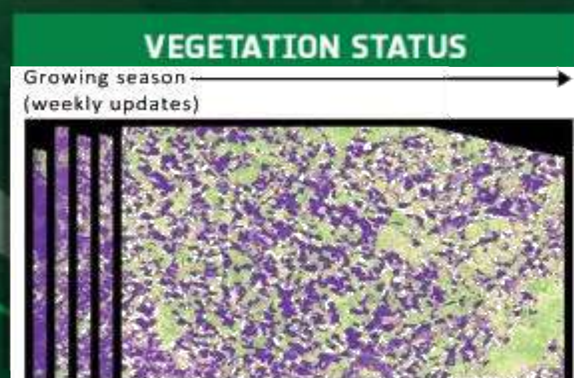
Binary map identifying annually cultivated land at 10m updated every month

Monthly cloud free surface reflectance composite at 10-20 m

Open source toolbox
Capacity building and training

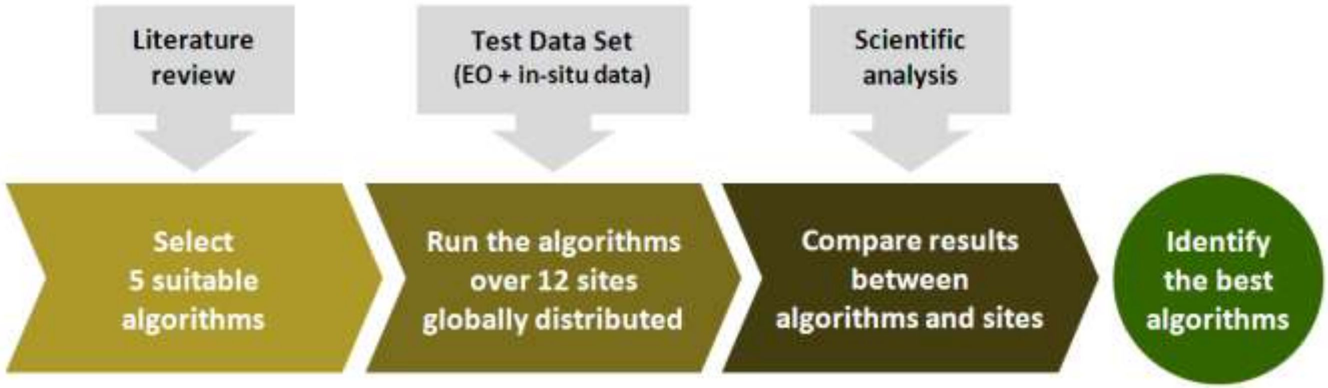


Crop type map at 10 m for the main regional crops including irrigated/rainfed discrimination

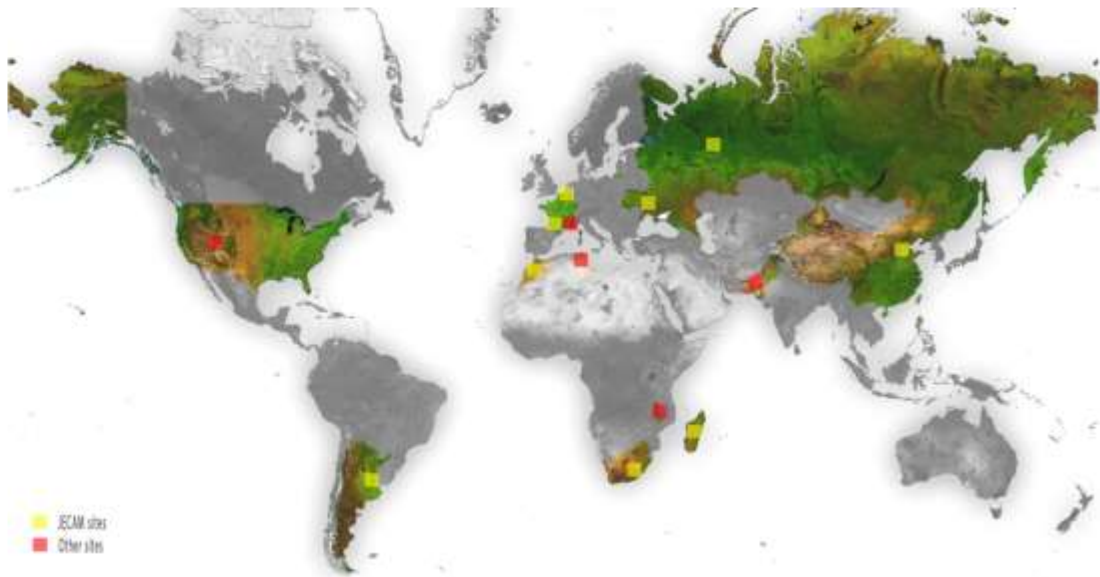


Vegetation status map at 20 m delivered every week (NDVI, LAI, pheno index)

Benchmarking for selecting the best algorithms for each product



12 test sites, relying on JECAM network, spread over the world, which represent more than 17 major crop types



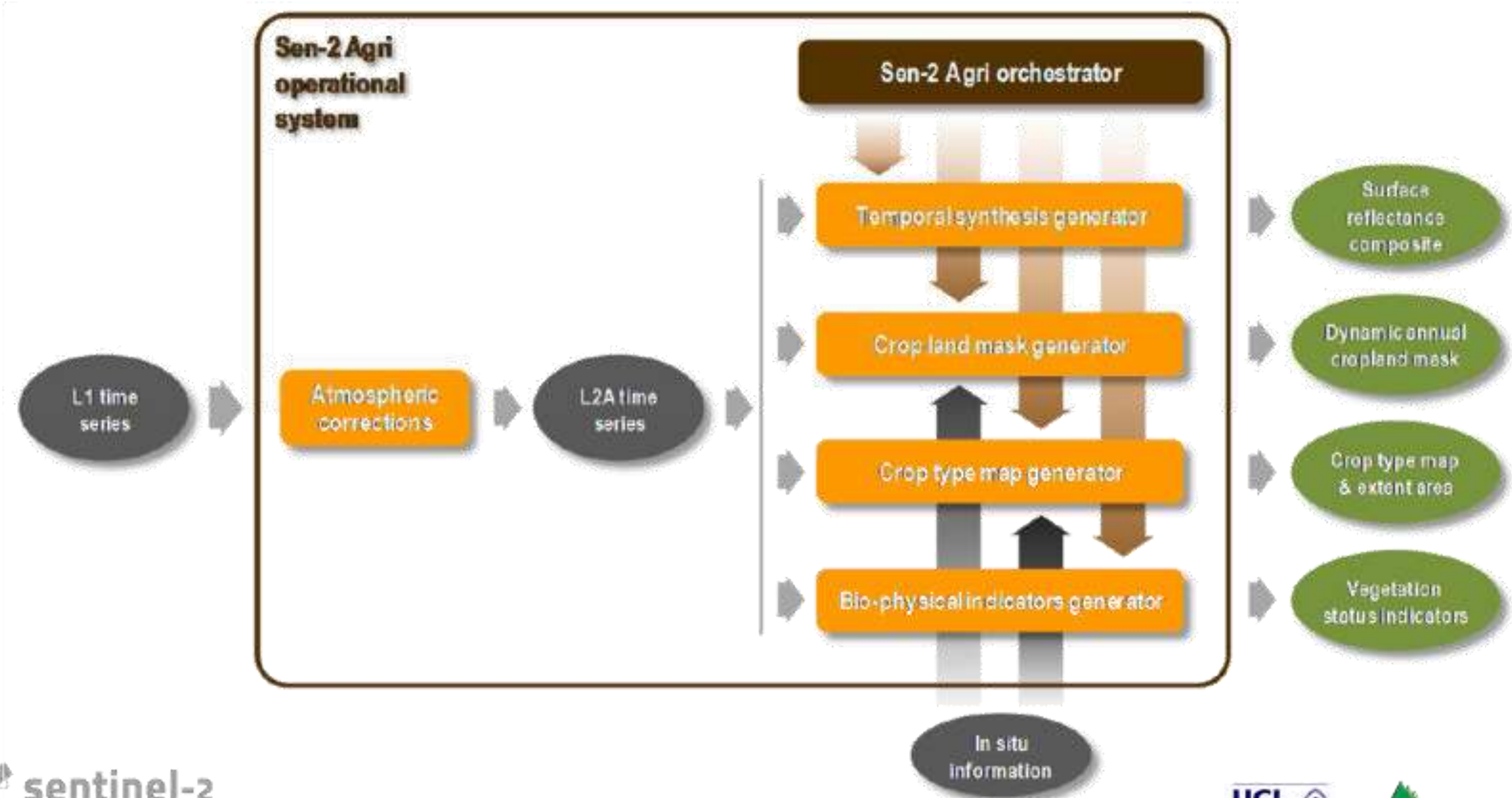
JECAM
Joint Experiment for Crop Assessment and Monitoring

sentinel-2
+ AGRICULTURE

Sen2-Agri system : design and development

A system designed to run in an automated/off line mode and deliver agric. products as the Sentinel-2 and Landsat-8 images are ingested

=> **Orchestrator concept**



sentinel-2

+ AGRICULTURE

UCL Université catholique de Louvain

CESBIO

CS

CS ROMÂNIA

Sen2-Agri System ready for demonstration

Algorithm Development 2014

Prototypes of EO products 2015

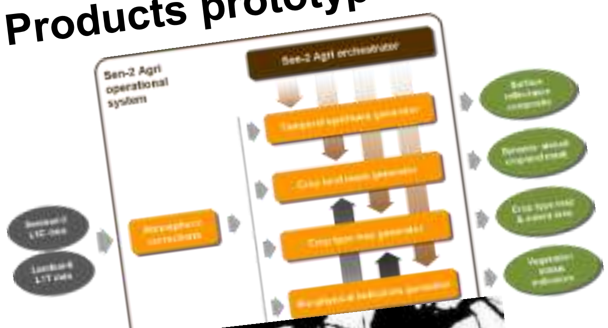
Demonstration & Validation 2016-2017

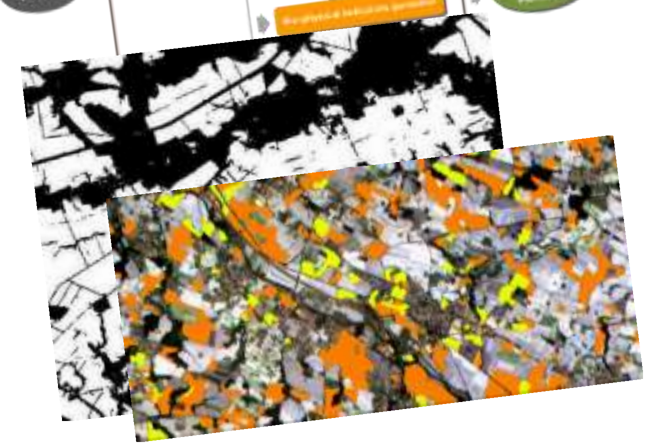
Users Products specifications
Benchmarked Methods (4 pub.)

System ready in April 2016
Products prototype SPOT5-T5

sentinel-2

+ AGRICULTURE





National use cases
Local use cases

Capacity building
Training activities

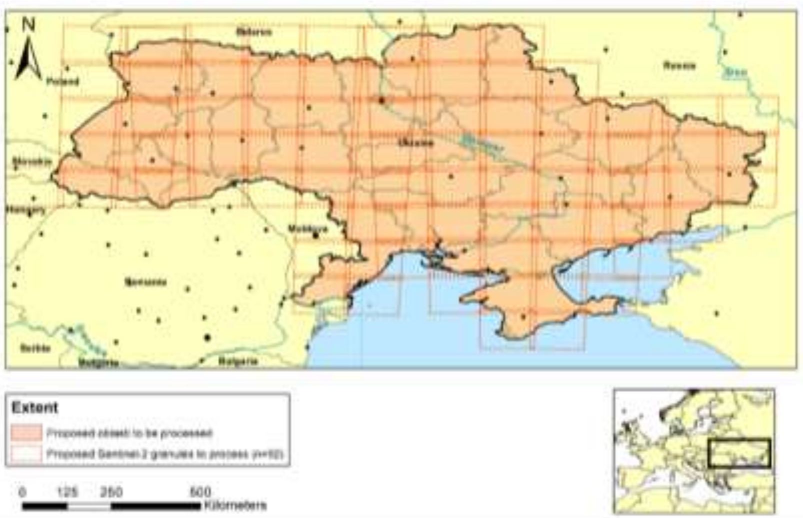
Fitness-to-use assessment

System qualification

Demonstration phase : 3 national cases

To demonstrate the Sen2-Agri system and NRT products using Sentinel-2a & Landsat 8 *(but without Sentinel-2b)* **at national scale with *in situ* system implementation** :

Ukraine (SRI)



South Africa (ARC)

Mali (ICRISAT & IER)

Demonstration phase : 7 local cases

To demonstrate NRT products using Sentinel-2 & Landsat 8 at local scale (~ 300 x 300 km) :

Site ID	Site name and localization
Sen2-Agri supported sites	
1	France, Midi-Pyrénées
2	Morocco, Tensift
3	China, Shandong
4	Madagascar, Antsirabe
5	Sudan, White Nile /South-Sudan
Additional demonstration sites	
6	Czech sites , Czech (CCN2)
7	Belgium, Belgium

sentinel-2 + AGRICULTURE

Sen2-Agri in situ data collection: **Objectives**

2 different objectives

- In situ data for **calibration** **(training)**: sampling to cover the diversity of situations existing in the site or the national territory in order to represent the range of possible signatures for the different elements of interest (i.e. croplands vs non croplands on one hand and, the five main crop types and the other frequent crops on the other hand).
- In situ data for **validation** to estimate the products accuracy (with a confidence interval) using a statistically-sound sampling to be objective and independent; for logistic reasons, sampling not strictly random but 2-stage sampling (with PMU and ESU) to assess the crop types (one field campaign) and the LAI

⇒ Calibration and validation field campaigns for cropland and crop type can be all combined as long as the sampling design are explicitly different and the samples labelled accordingly.

However, 2 field campaigns are probably needed for early and end of season map products if all crop types can not be recognized during the first campaign due by mid-season at the latest.

Sen2-Agri in situ data collection: **Calibration (national case)**

- **Stratification** according to existing agro-ecological zoning to sample the range of diversity (with up to 12 agro-ecological zones (strata) for nat. case)

  ex. : Ukraine = 4 zones

- **On screen visual interpretation** to select samples (min. 1 ha) of land cover types different than cropland on recent aerial photographs, Google Earth or Bing imagery to capture the diversity of the non cropland land cover types. The sample distribution between strata could also consider the stratum size and their respective diversity.

  ex. : 720 samples for non-cropland training
  (15 samples x 12 land cover types x 4 strata)
  => 5 days in office

- **Ground survey to delineate at least 30 samples** (min. 1 ha but larger is better) for each main crop and for each stratum. No strict sampling design but needs to capture each crop diversity. Visual delineation could use the most recent color composite. A this time of the year, summer crops are not yet visible.

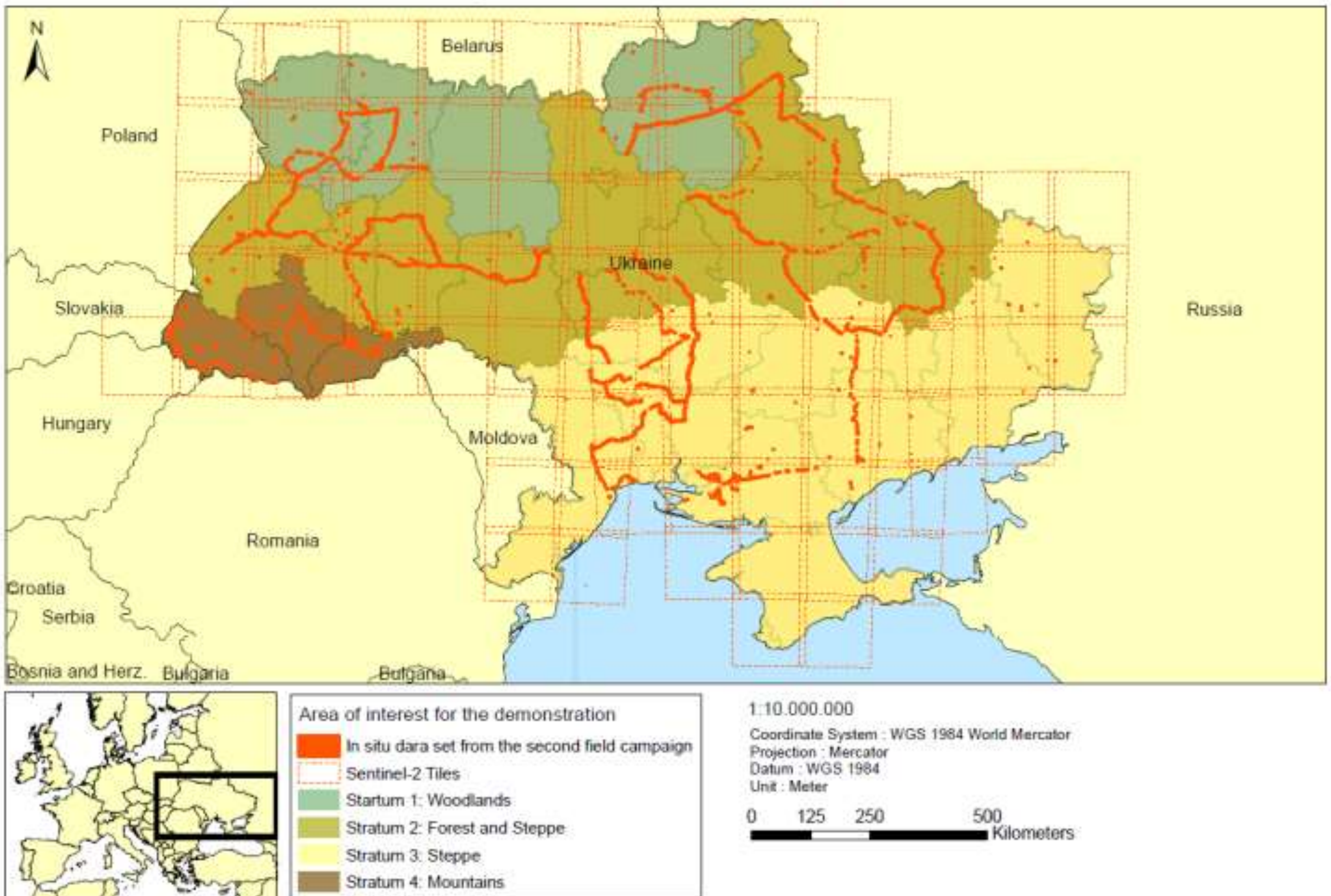
  ex. : *1440 samples (30 samples x 12 crop types x 4 strata)*
  => 10 days before the mid-season

sentinel-2
+ AGRICULTURE

Sen2-Agri in situ data collection: **Calibration (example national case)**

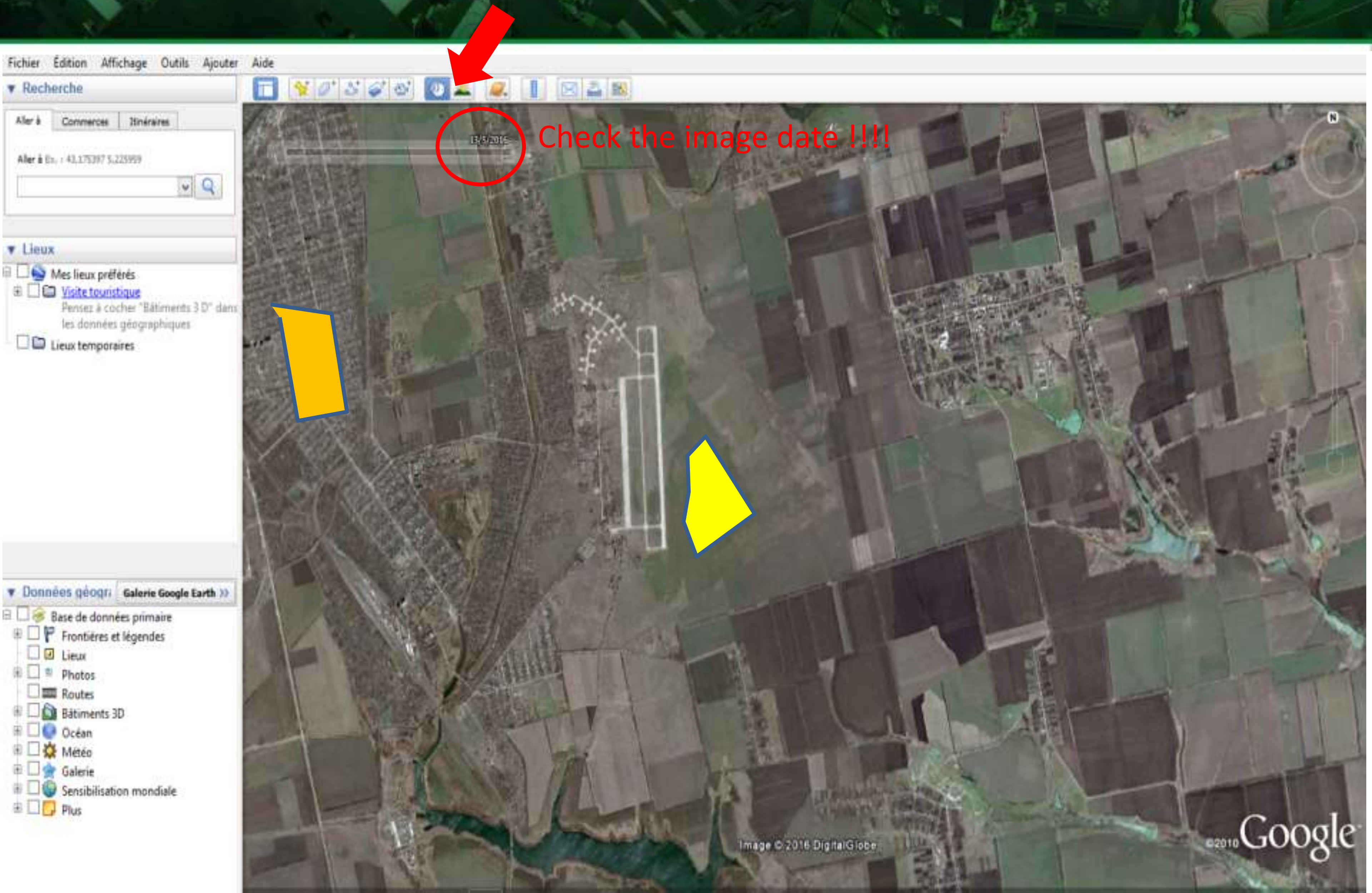
- **Stratification** according to existing agro-ecological zoning to sample the range of diversity

Second calibration field campaign over Ukraine (27-29 June 2016):
Repartition of the in situ data set



sentinel-2
+ AGRICULTURE

Selection of calibration polygons for each of non cropland class on Google earth



Sen2-Agri in situ data collection:
Validation (+ calibration for summer crops) **(national case)**

JECAM Guidelines

- **Stratification** according to existing agro-ecological zoning to sample the range of diversity
- **Two-stage sampling strategy for crop type validation**
  - **Delineation of large Primary Sampling Units (PSU)** based on ancillary data set (typically admin. regions)

    ex. : Ukraine = around 30 oblasts (districts)
  - **Random selection of few (2 or 3) PSU** distributed in the different strata according to their cropland area (cropland area-weighted sampling probability).
  - **"Windshield survey"** for each selected PSU to identify the crop type for each Elementary Sampling Unit (ESU) along the roads (e.g. tablet onboard of vehicle). ESU corresponds to parcels covered by the same crop/crop association. Delineation should use the best contrasted color composite for parcel identification. The road selection and the ESU selection should be as systematic as possible, unbiased with a min. parcel size larger than 0,25 ha (25 S2 pixels). Typical density of 1 ESU / 100 sq km. ex. Ukraine : 2 oblasts/stratum => 8 oblasts => 1600 crop samples

    1 day to reach the selected oblast (PSU), 200 ESUs/day by windshield survey => 16 days campaign
  - **Summer crop identification** as calibration samples during the connecting travel between the different PSU anywhere but not in the randomly selected PSUs
- **Sampling strategy for non-cropland validation** (2 options)
  - Collection of non cropland ESU during the wihdshield survey
  - If up-to-date very high resolution imagery (GE) is available for large parts of the area of interest, on screen identification of cropland/non –cropland samples of randomly selected in each stratum. Typically 100 – 150 ESUs of 0,25 ha per stratum. => 3 days in the office

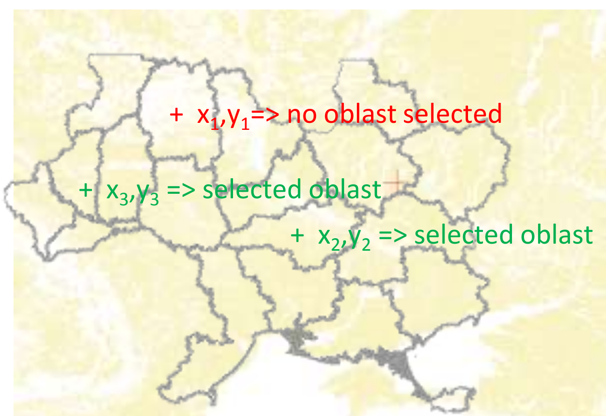
sentinel-2

+ AGRICULTURE

Sen2-Agri in situ data collection:
Validation sampling strategy **(national case)**

Primary sampling unit (here admin. Unit)

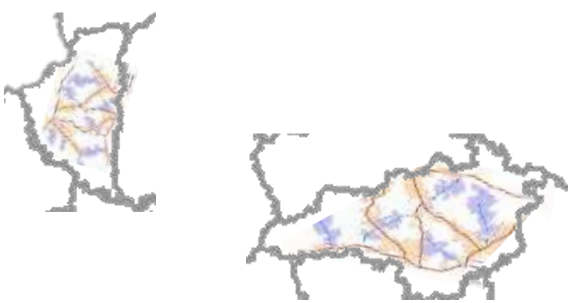
Stratification (here an agro-ecological zoning)



Random sampling of oblasts according to the oblast cropland area: successive draw of point coordinates till it falls on cropland

$\Rightarrow$ selected oblast !

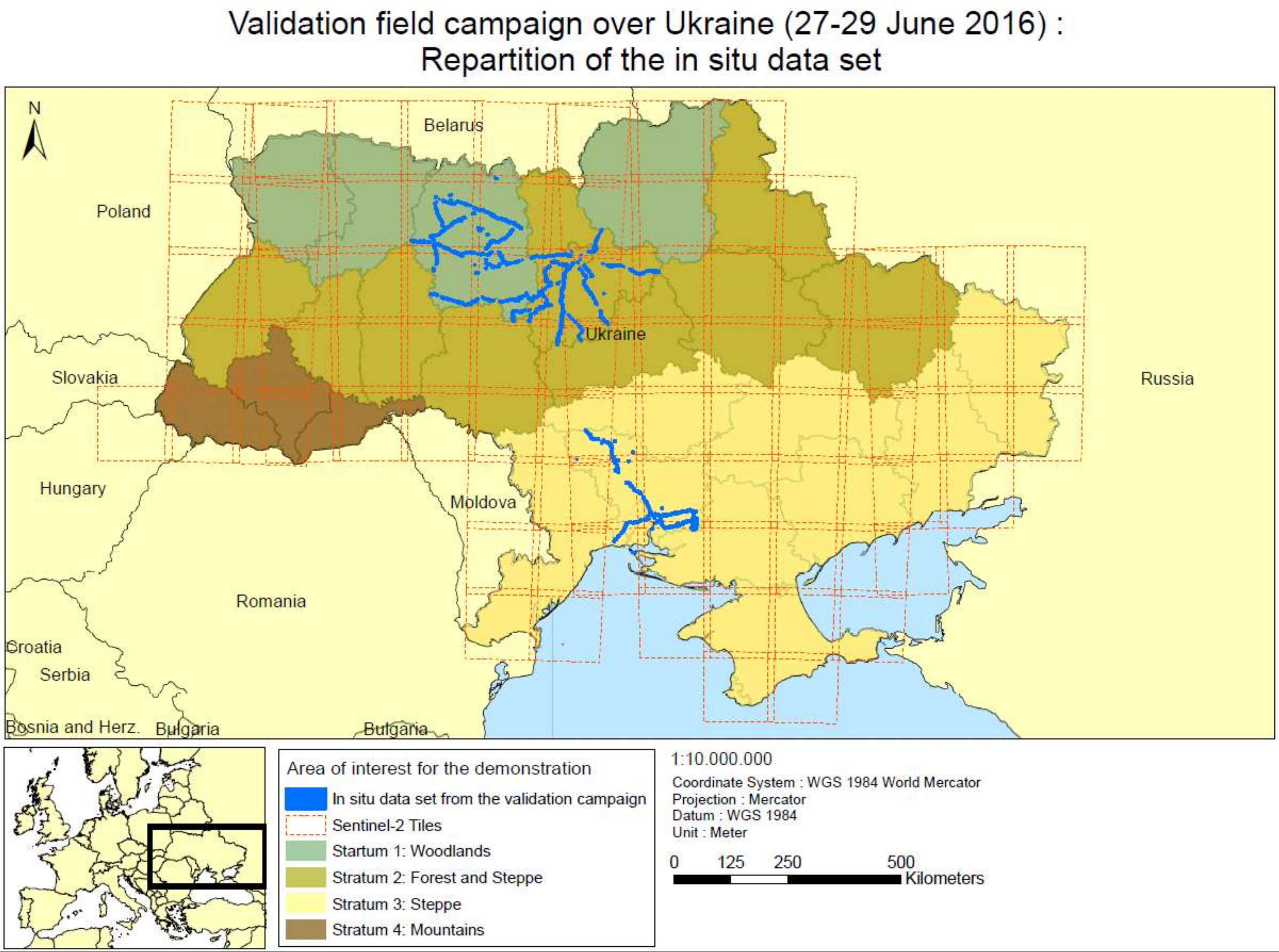
(with min 1 oblast per stratum and max 4 oblasts per stratum)



sentinel-2

+ AGRICULTURE

Sen2-Agri in situ data collection: **Validation** sampling strategy **(national case)**



sentinel-2

+ AGRICULTURE

Sen2-Agri product validation

Evaluation criteria in the frame of the Sen2Agri system

- The Overal Accuracy which evaluates the overall effectiveness of the algorithm
- The F-Score which measures the accuracy of a class using the precision and recall measures
- The computational time

The **Overall Accuracy** (OA) is calculated as the total number of correctly classified pixels (diagonal elements of the confusion matrix) divided by the total number of test pixels:

$$OA = \frac{\sum_{i=1}^{r} n_{ii}}{\sum_{i=1}^{r} \sum_{j=1}^{r} n_{ij}}$$

	Reference Data[a]						
	W	S	F	U	C	H	Row Total
Classification data							
W	226	0	0	12	0	1	239
S	0	216	0	92	1	0	309
F	3	0	360	228	3	5	599
U	2	108	2	397	8	4	521
C	1	4	48	132	190	78	453
H	1	0	19	84	36	219	359
Column total	233	328	429	945	238	307	2480

Producer's Accuracy	User's Accuracy
W = 226/233 = 97%	W = 226/239 = 94%
S = 216/328 = 66%	S = 216/309 = 70%
F = 360/429 = 84%	F = 360/599 = 60%
U = 397/945 = 42%	U = 397/521 = 76%
C = 190/238 = 80%	C = 190/453 = 42%
H = 219/307 = 71%	H = 219/359 = 61%

Overall accuracy = (226 + 216 + 360 + 397 + 190 + 219)/2480 = 65%

[a]W, water; S, sand; F, forest; U, urban; C, corn; H, hay.

sentinel-2

+ AGRICULTURE

Sen2-Agri product validation

Evaluation criteria: F-Score

The (also known as F-1 score or F-measure) is the harmonic mean of the Precision and Recall and reaches its best value at 1 and worst score at 0:

$$FScore = 2x\frac{Precison * Recall}{Precision + Recall}$$

- **Precision** or User's Accuracy (UA) for the class *i* it is the fraction of correctly classified pixels with regard to all pixels classified as this class *i* in the classified image:

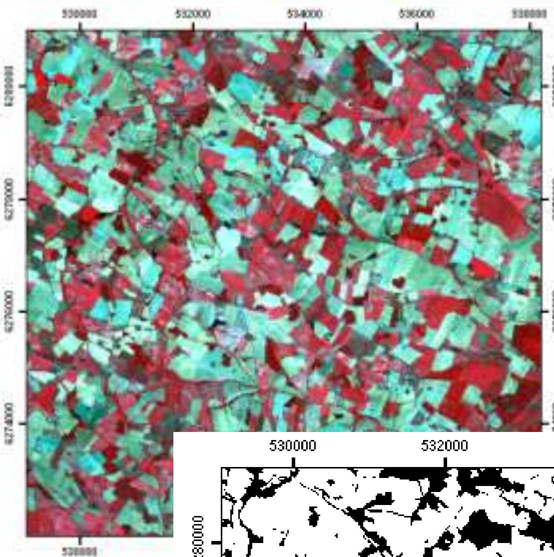
$$UA_i = \sum_{j=1}^{r} \frac{n_{ii}}{n_{ij}}$$

- **Recall** or Producer's Accuracy (PA) for the class *i* it is the fraction of correctly classified pixels with regard to all pixels of that ground truth class *i*:

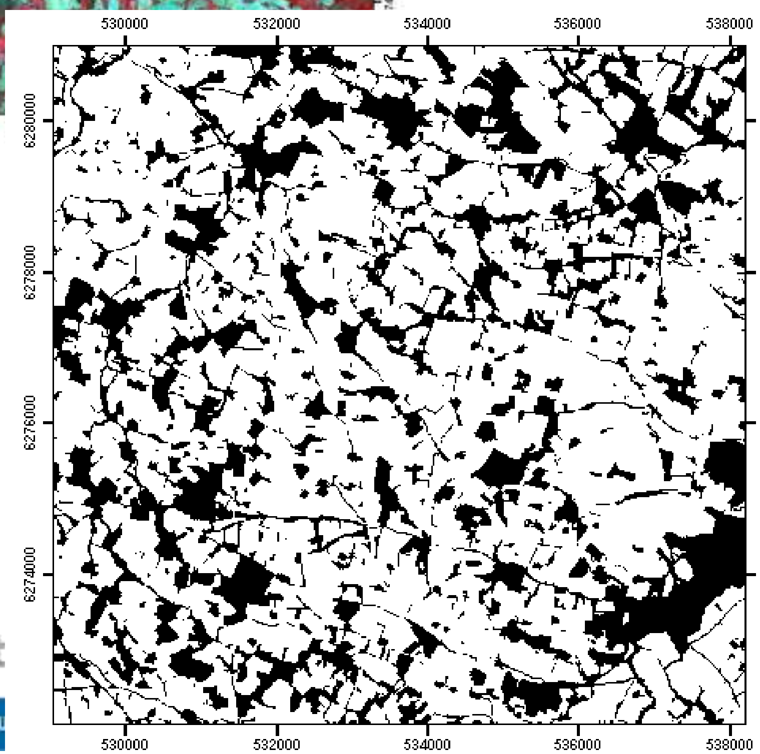
$$PA_i = \sum_{j=1}^{r} \frac{n_{ii}}{n_{ji}}$$

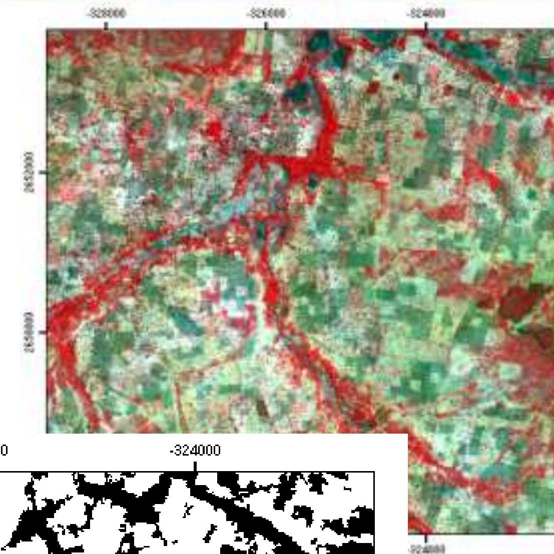
Sen2-Agri dynamic cropland mask (L4A product)

Prototype products
SPOT 5 Take 5 - 2015

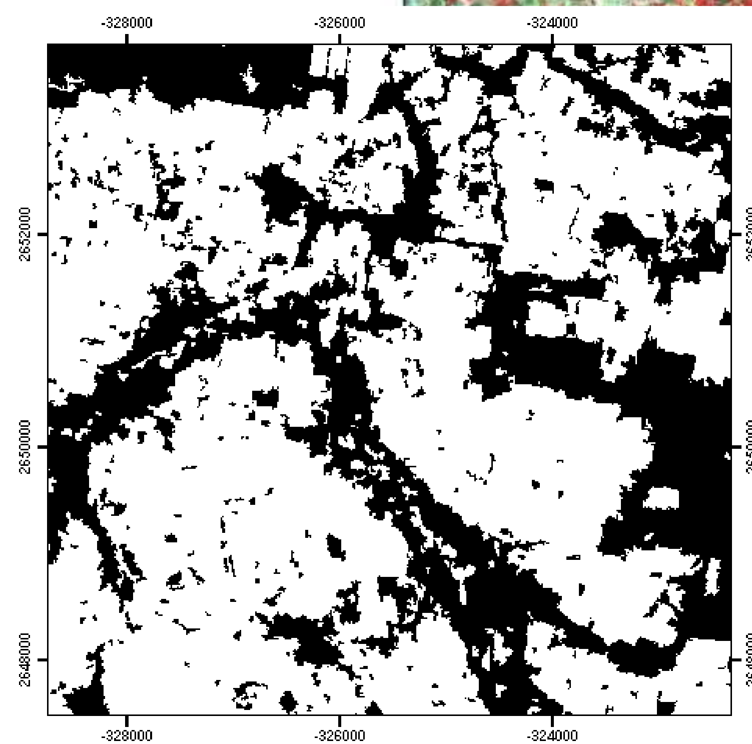


France (JECAM)





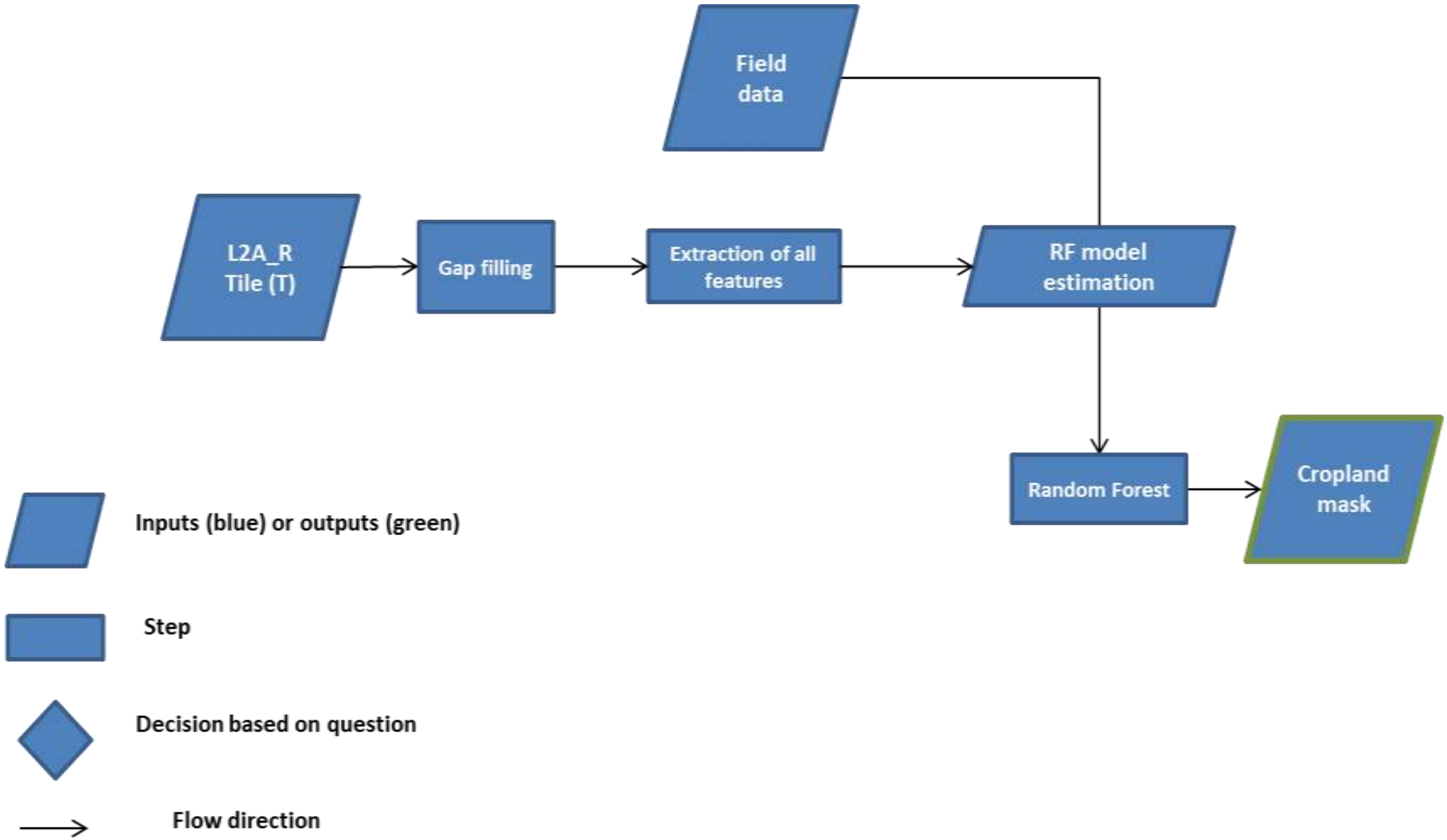
Mali (JECAM)



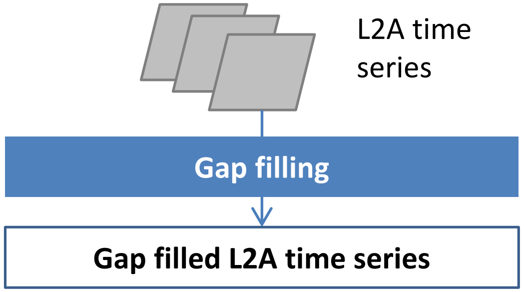
User requirements & Products specifications

Properties	User Requirement	Product specification
Spatial coverage	Local (over sites) to regional	
Time period	Current	with 6 months before the 1st delivery
Temporal frequency	1 month	1 month with a 12-month moving window (fully operational after 23 months)
Delivery time	3 days after the end of each month	
Spatial resolution	10 meters	
Legend	Binary (crop – no crop)	focusing on annual croplands
Geometric accuracy	Sub-pixel location error	L1C geometric accuracy
Thematic accuracy	10 % (maximum error of omission and commission of annual cropland mask)	F1-Score of 50% at the middle of the season and 80% at the end of the season
Quality flags	(i) the number of valid observations (ii) the status of the pixel (valid, cloud, cloud shadow, snow, gaps and filled values)	Info split in 4 flags (obs. number, validity, status, gap filled)
Format	Standard raster format (e.g. GEOTIFF)	GEOTIFF
Projection	UTM and WGS84	UTM-UPS/WGS84
Metadata	Clear metadata, standard data formats	XML file
Products distribution	Open and freely available product (+ documentation and validation)	

Crop mask processing chain with in-situ data

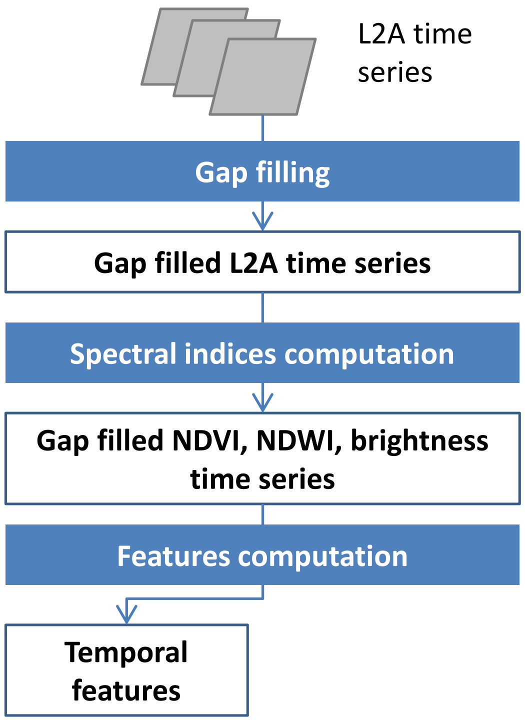


Gap filling



- Objective: produce a reflectance image time series which is
  - gap-filled with respect to missing data (clouds, cloud shadows, saturated pixels)
  - temporally sampled on a regular grid
- If several sensors are available (e.g. S2, L8), time series processed independently and concatenated afterwards
- Makes use of validity mask from L2A products (clouds, cloud shadows, saturated pixels)

Features extraction



1. Spectral indices computation: NDVI, NDWI, brightness
2. Computation of temporal features

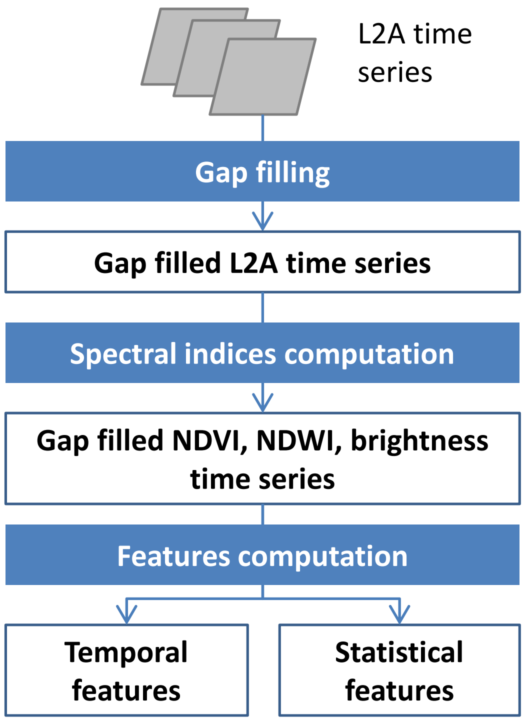
Global features

Notation	Description	Equation
x_{max}	Maximum NDVI value	$\max_i x(t_i) = \{ x(t_i) \mid \forall j : x(t_j) \le x(t_i) \}$
x_{mean}	Mean NDVI value	$\frac{1}{T}\sum_{j=1}^{T} x(t_j)$
x_{std}	Standard deviation NDVI value	$\sqrt{\frac{1}{T}\sum_{j=1}^{T} (x(t_j) - x_{mean})^2}$

Features detecting largest local NDVI transitions

Notation	Description	Equation
$x_{Dif-max}$	Maximum NDVI difference found in a slicing temporal neighborhood having a size w (default value w=2).	$\max_i \frac{1}{w}\sum_{j=i}^{i+w-1} x(t_j) - \frac{1}{w}\sum_{j=i+w}^{i+2w-1} x(t_j)$
$x_{Dif-min}$	Minimum NDVI difference found in a slicing temporal neighborhood having a size w (default value w=2).	$\min_i \frac{1}{w}\sum_{j=i}^{i+w-1} x(t_j) - \frac{1}{w}\sum_{j=i+w}^{i+2w-1} x(t_j)$
$x_{Dif-Dif}$	Difference between $x_{Dif-max}$ and $x_{Dif-min}$ value estimating the transition jump	$x_{Dif-max} - x_{Dif-min}$

Features extraction



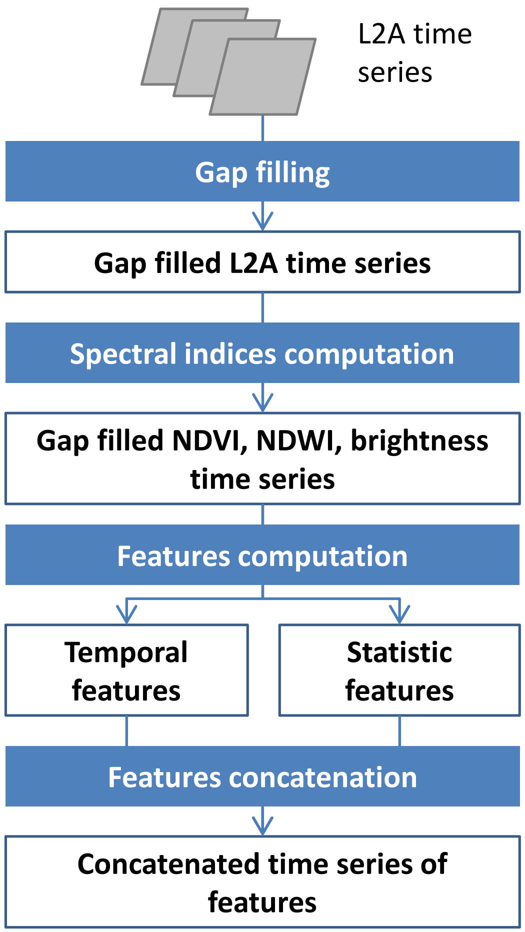
1. Spectral indices computation: NDVI, NDWI, brightness

2. Computation of temporal features
   - Global features
   - Features detecting largest local NDVI transitions
   - Features associated with max NDVI values
   - Features associated to the greenness onset
   - Features associated to the senescence onset
   - Features characterizing bare soil transitions

3. Computation of statistical features

Notation	Description
x_{max}	Maximum value of the complet index times series
x_{min}	Minimum value of the complet index times series
x_{mean}	Mean value of the complet index times series
x_{median}	Median value of the complet index times series
x_{std}	Standard deviation value of the complet index times series

Features extraction



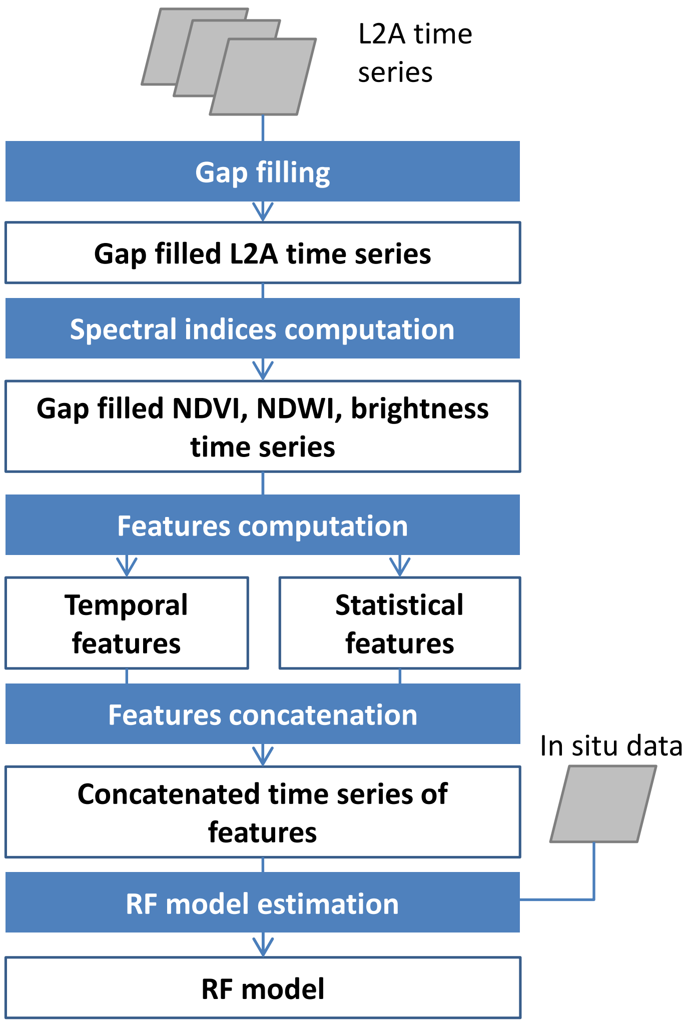
1. Spectral indices computation: NDVI, NDWI, brightness

2. Computation of temporal features
   - Global features
   - Features detecting largest local NDVI transitions
   - Features associated with max NDVI values
   - Features associated to the greenness onset
   - Features associated to the senescence onset
   - Features characterizing bare soil transitions

3. Computation of statistic features

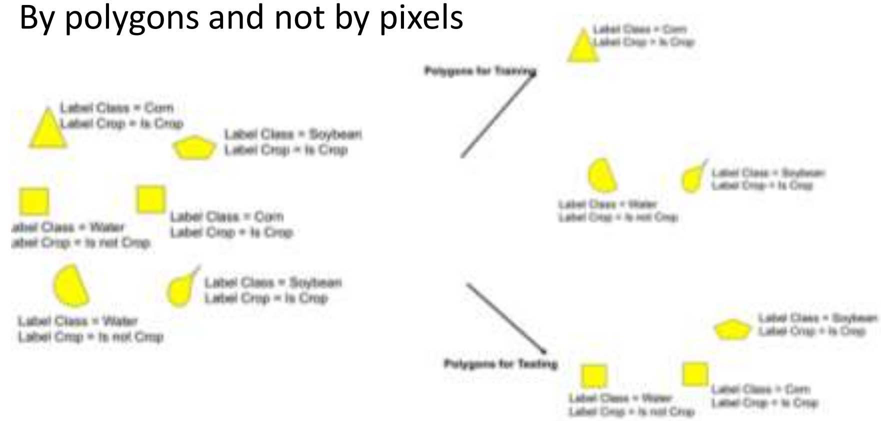
4. Temporal and statistic features concatenation

Random Forest model estimation



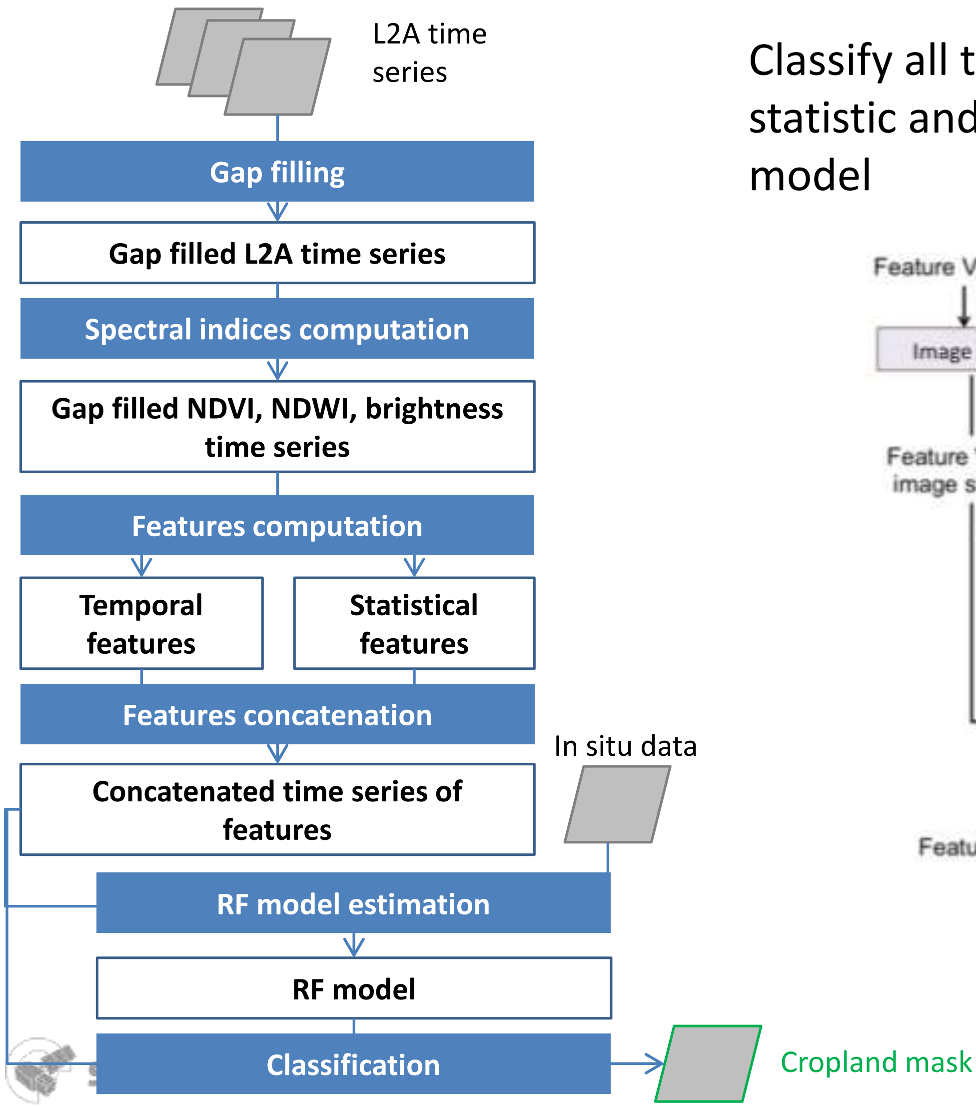
Construction of the classification model in 3 steps

1. Splitting polygons for training and testing
   – By polygons and not by pixels

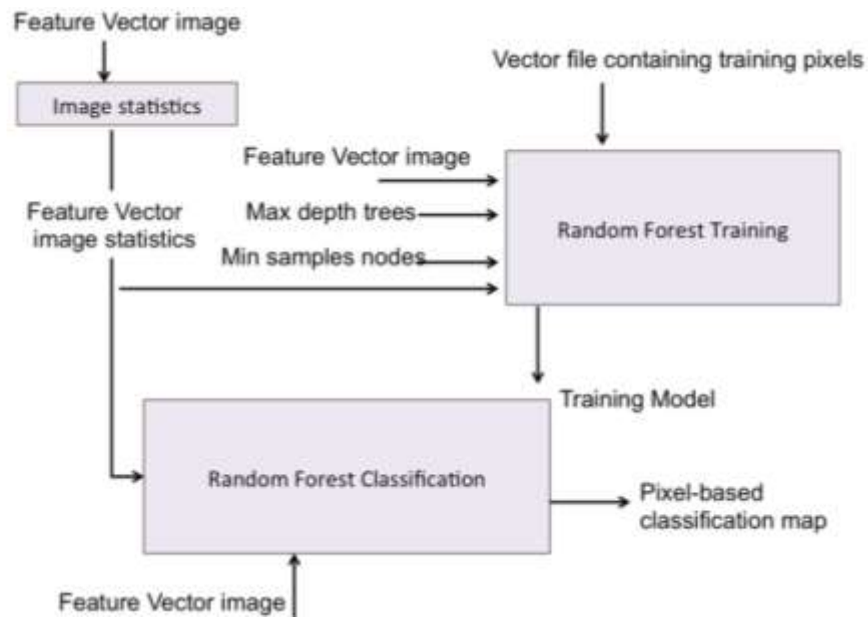


2. Randomly selecting a number of pixel samples for “crop” and “not crop” classes
   – Output selection is class consistent (if 33% of crops is soybean, 33% of crop class training samples will also be soybean)
   – Needed to reduce the time complexity of the RF classifier
3. Training model generation

Random Forest classification

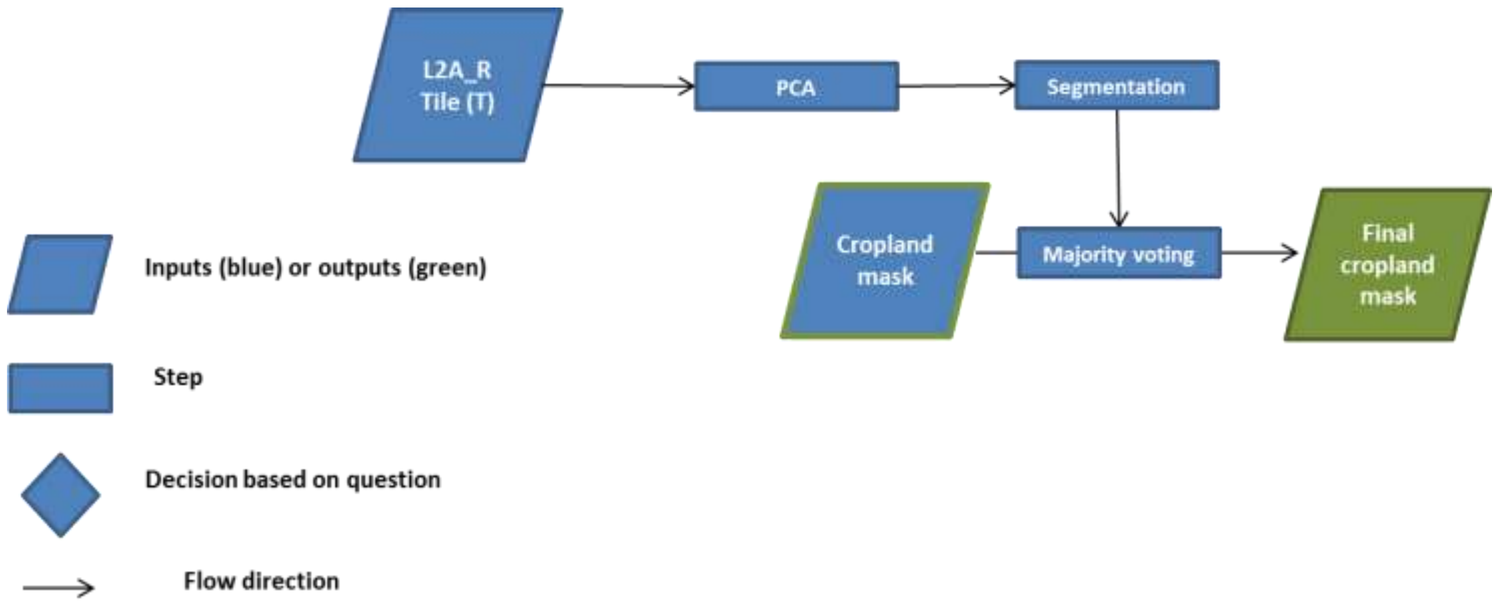


Classify all the pixels of the time series made of all statistic and temporal features, using the estimated RF model

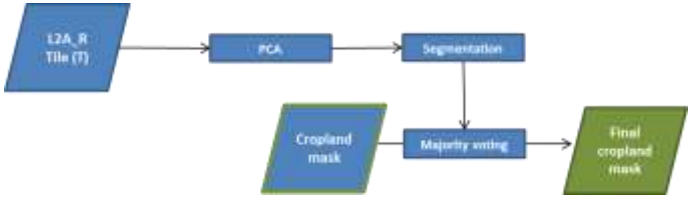


+ AGRICULTURE

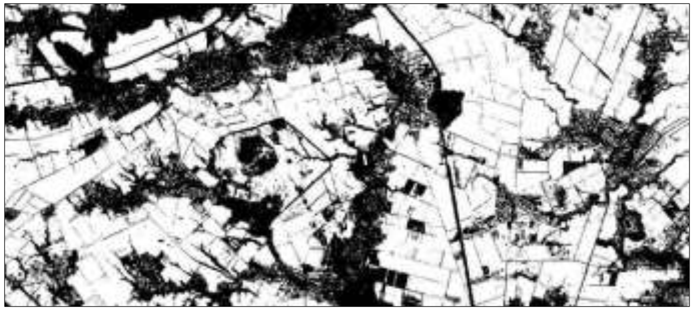
Final steps : object-based filtering

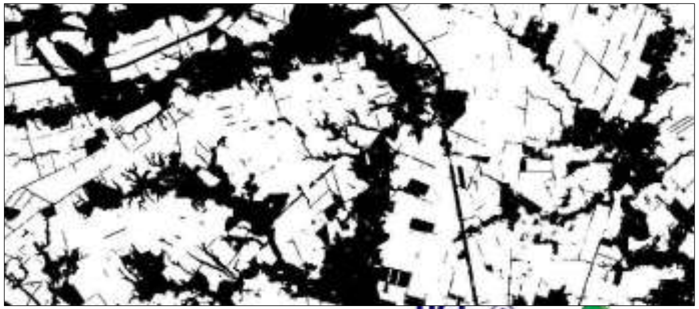


Final steps : object-based filtering



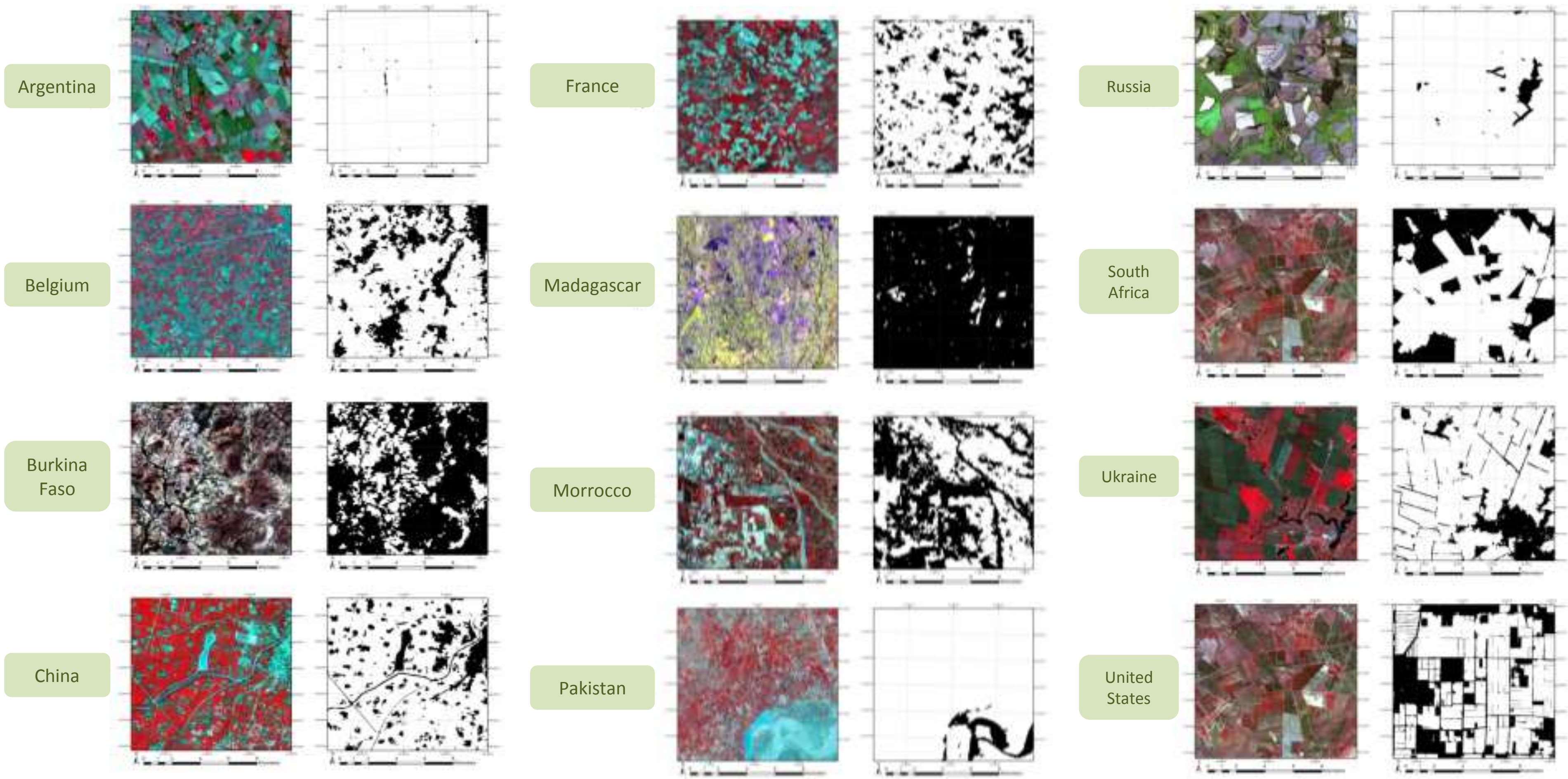
- PCA on NDVI time series (max. 6 images)
- Mean-shift segmentation algorithm, using as input
  - Input: principal components
  - Outputs: vector file with homogeneous areas
- Majority voting to filter the pixel-based classification





Benchmarking products 2013

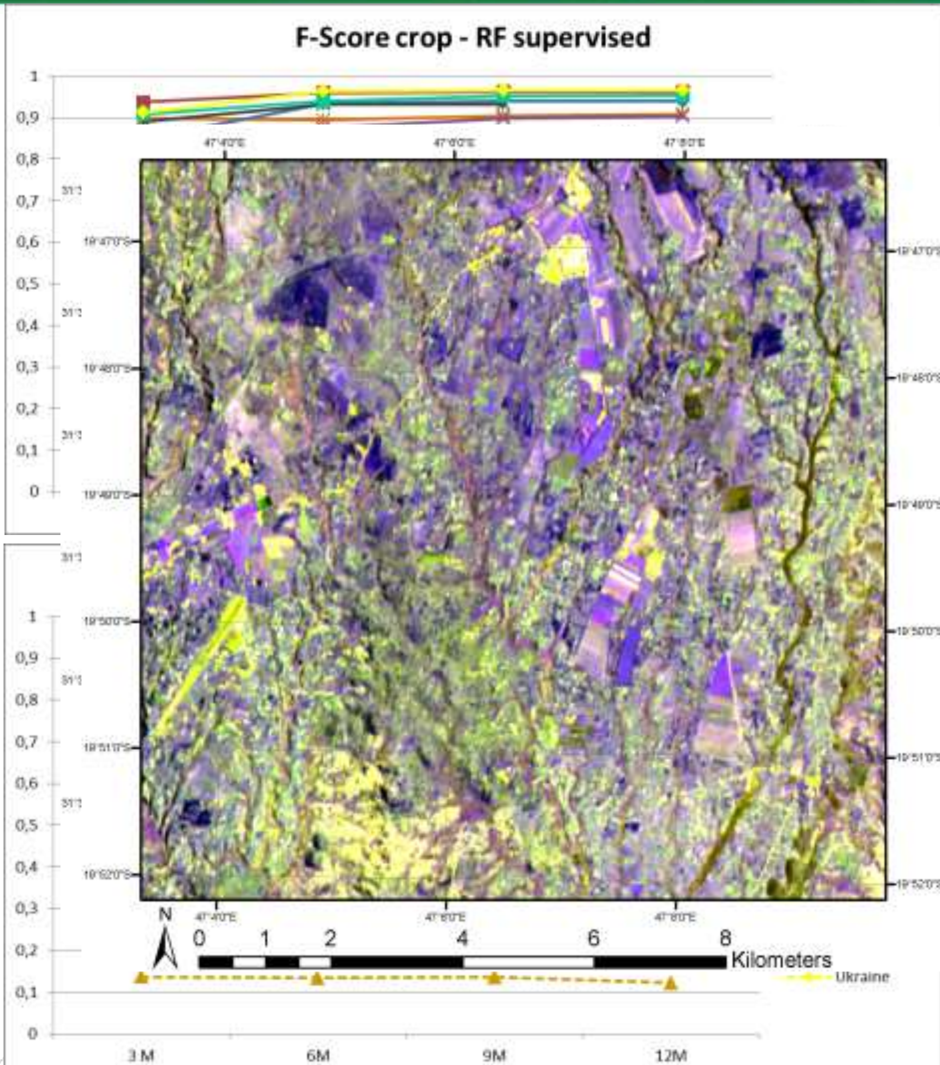
(SPOT 4 Take 5, L8, RE)

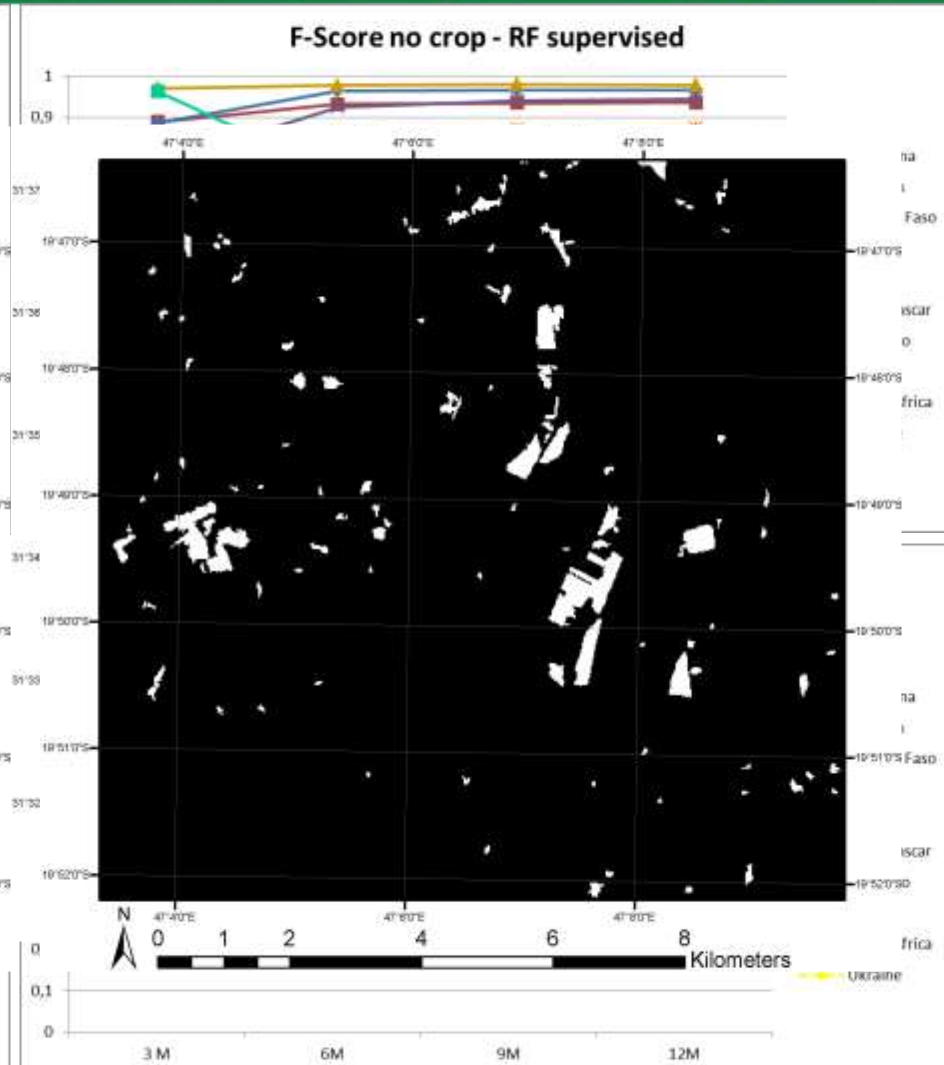


sentinel-2

+ AGRICULTURE

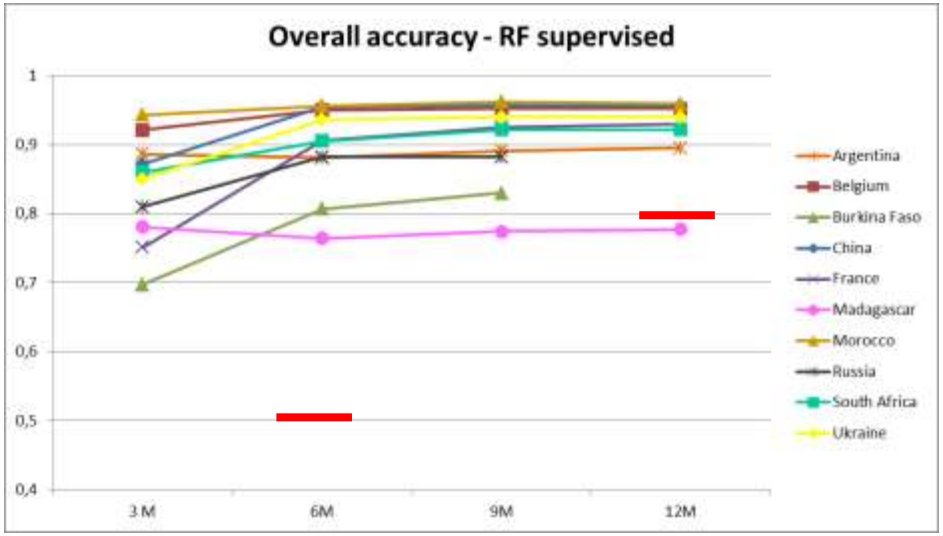
Accuracy assessment (1/2)

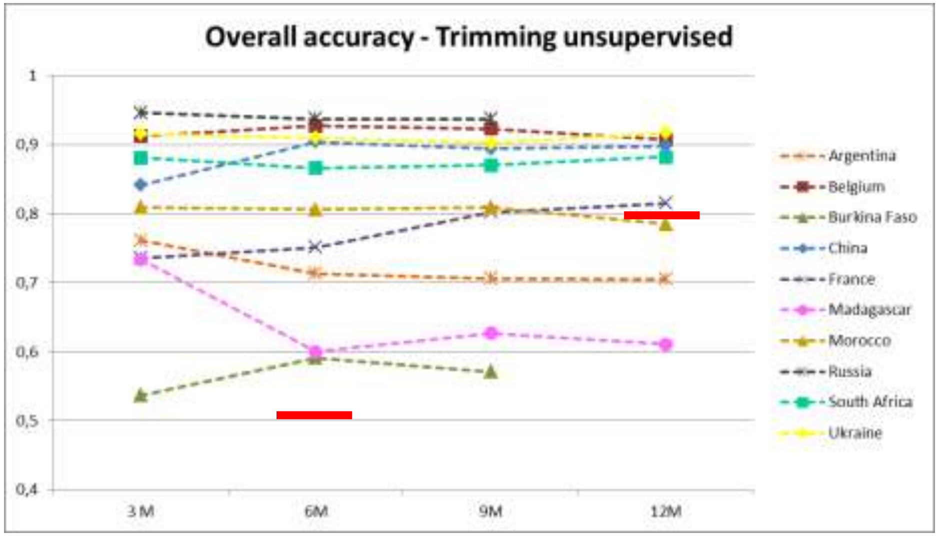




CROP: same trends observed for sup. and unsup. methods
NO-CROP: Unsupervised approaches have more difficulties to detect no crop pixels

Accuracy assessment (2/2)





Supervised approaches better than unsupervised ones

Unsupervised ones reaching the OA targets

6 months of observations enough to reach the final cropland accuracy

sentinel-2

+ AGRICULTURE

UCL Université catholique de Louvain

CESBIO

CS

CS ROMÂNIA

System operation for crop mask

Before the start of the monitoring period

Monitoring period

System initialization

SoS

Setting parameters	
Area of Interest	Shapefile to be uploaded
Monitoring period	Start and end dates to be defined
S2 or S2+L8	To be ticked
Other processing parameters	

FID	Shape	ID	CROP	LC	CODE	IRRIGATION
0	Polygon	1	1	Spring Wheat	112	0
1	Polygon	2	1	Spring Wheat	112	0
2	Polygon	3	1	Spring Wheat	112	0
3	Polygon	4	1	Spring Wheat	112	0
4	Polygon	5	1	Spring Wheat	112	0
5	Polygon	6	1	Triticale	1911	0
6	Polygon	7	1	Triticale	1911	0
7	Polygon	8	1	Triticale	1911	0

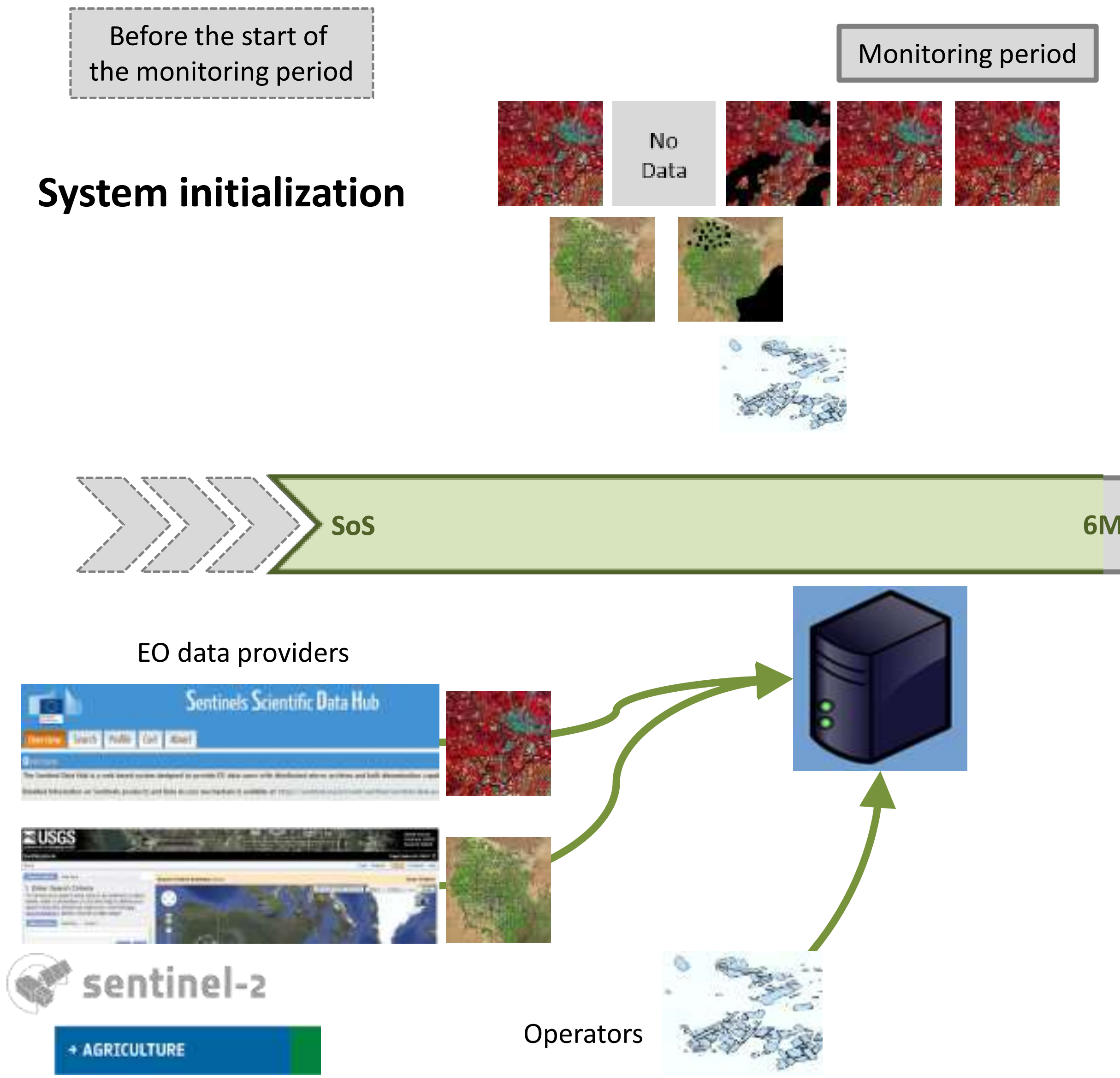
sentinel-2

+ AGRICULTURE

ROMÂNIA

System operation for crop mask

Automatic EO data download
Manual in situ data upload



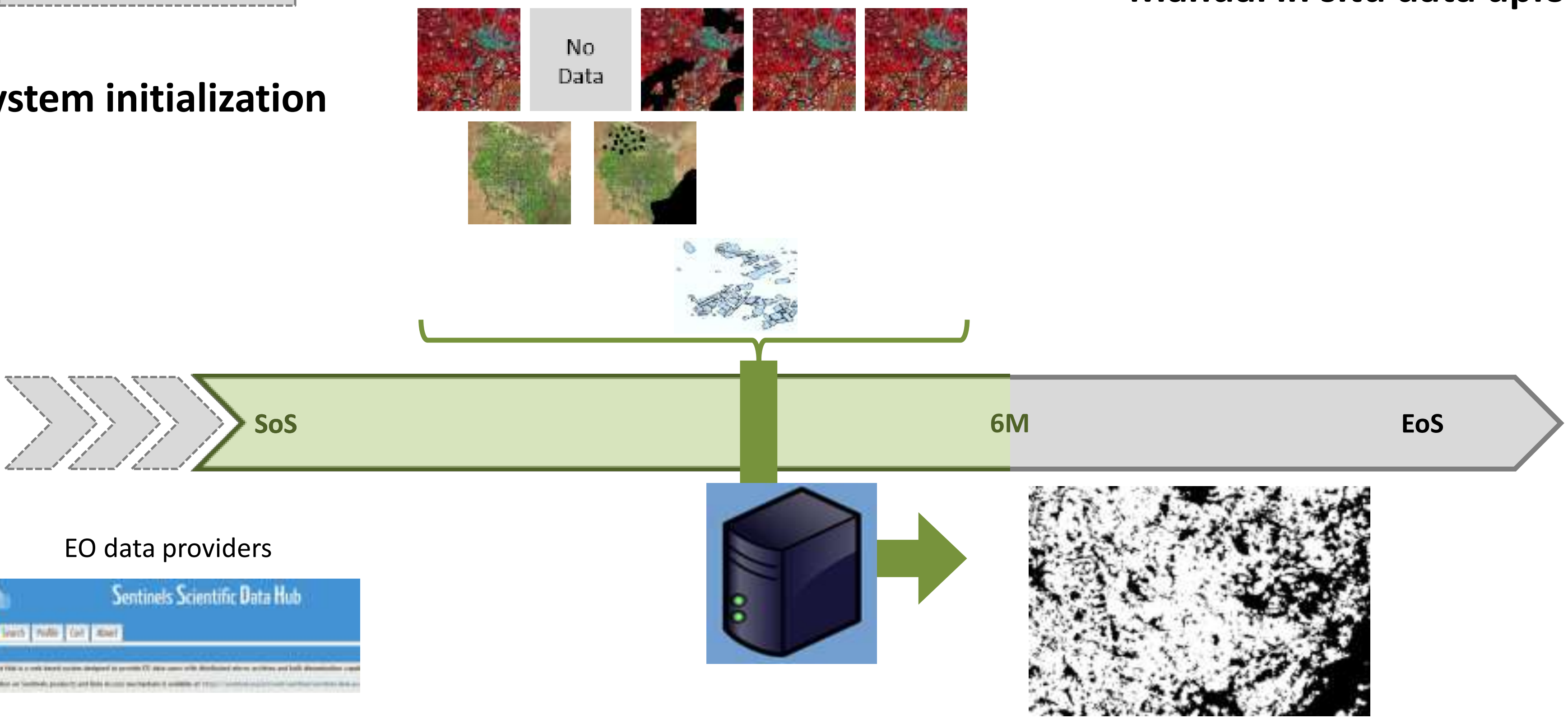
System operation for crop mask

Before the start of
the monitoring period

Monitoring period

Automatic EO data download
Manual in situ data upload

System initialization



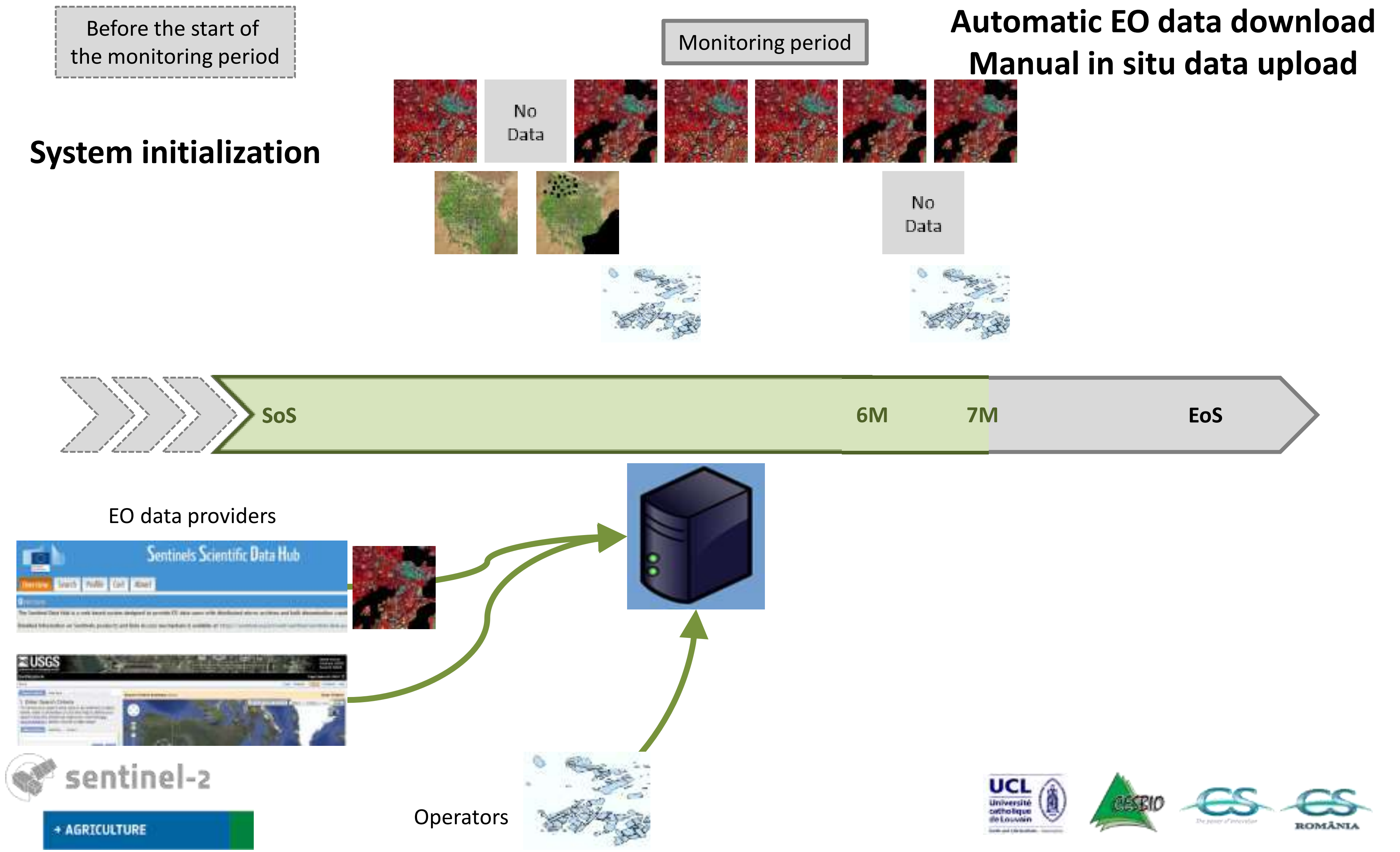
EO data providers

sentinel-2

+ AGRICULTURE

Operators

System operation for crop mask



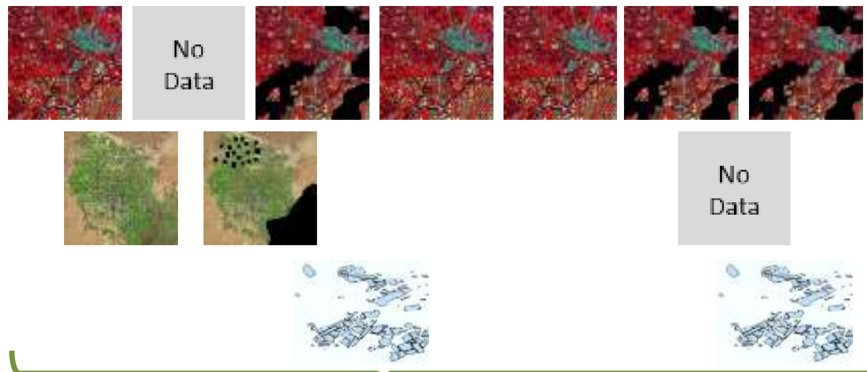
System operation for crop mask

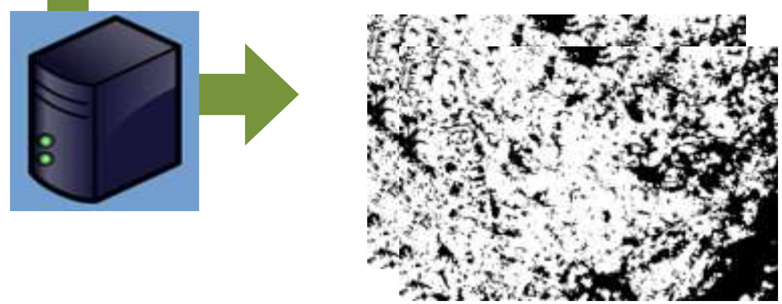
Before the start of the monitoring period

Monitoring period

Automatic EO data download
Manual in situ data upload

System initialization





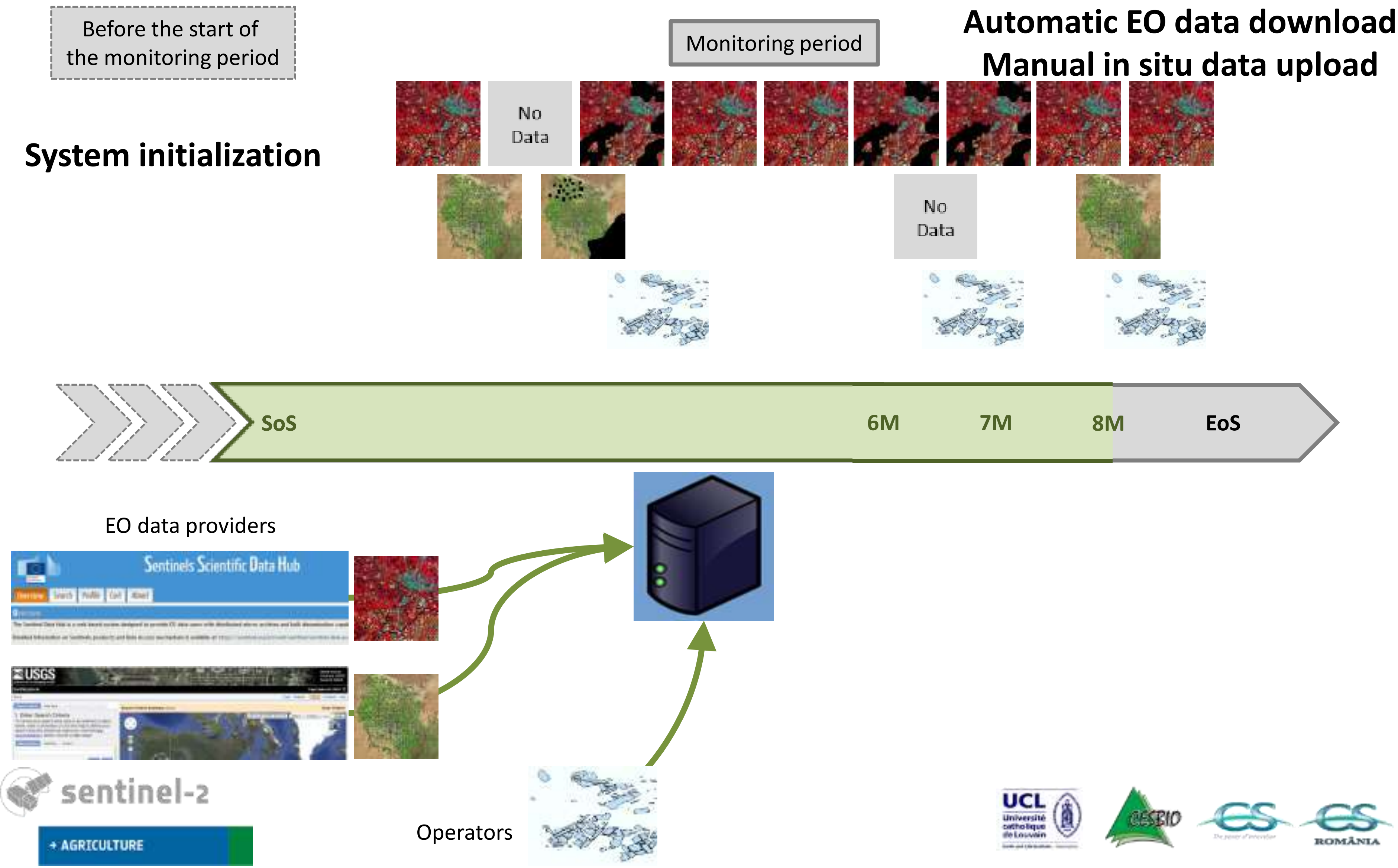
EO data providers

sentinel-2

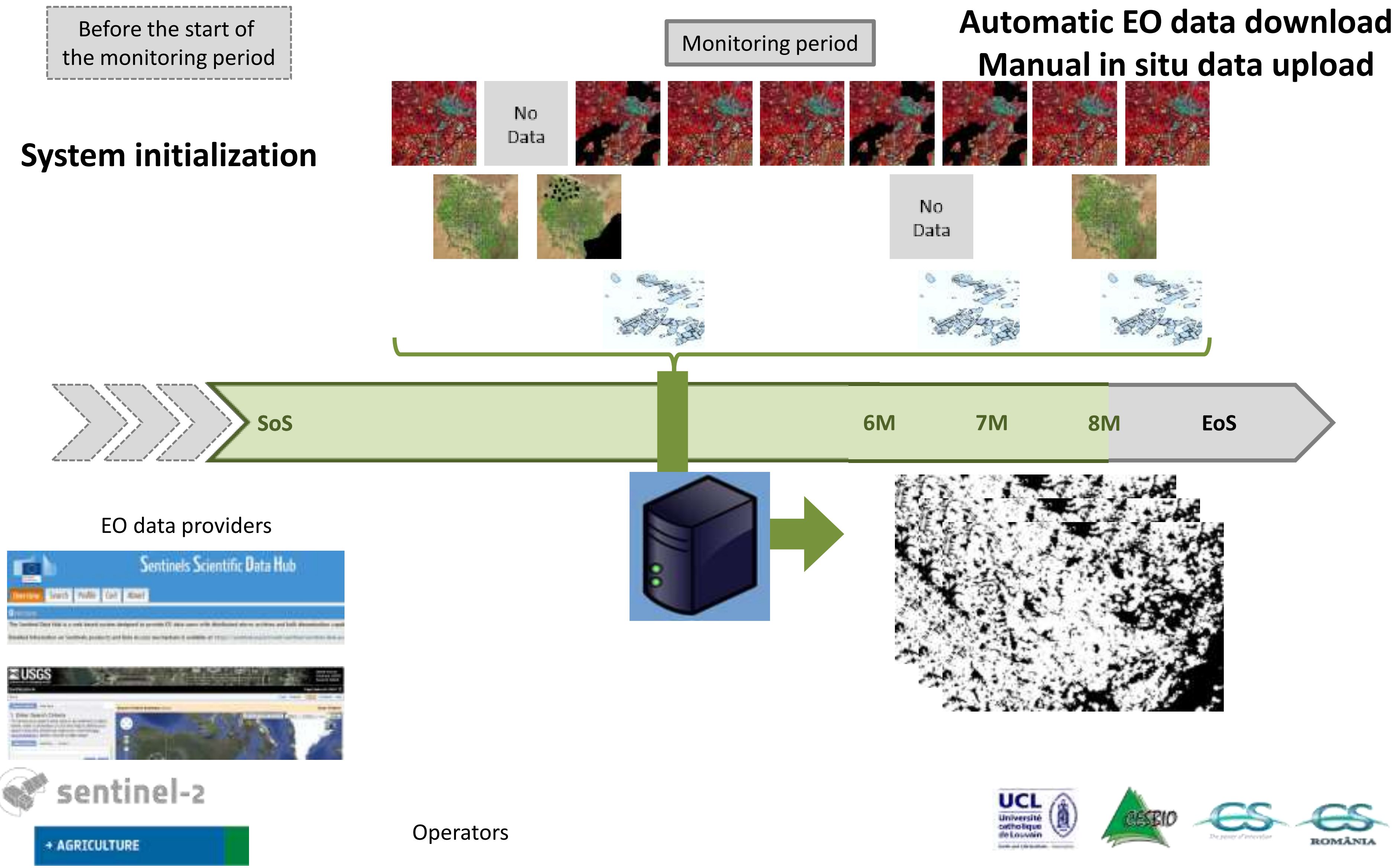
+ AGRICULTURE

Operators

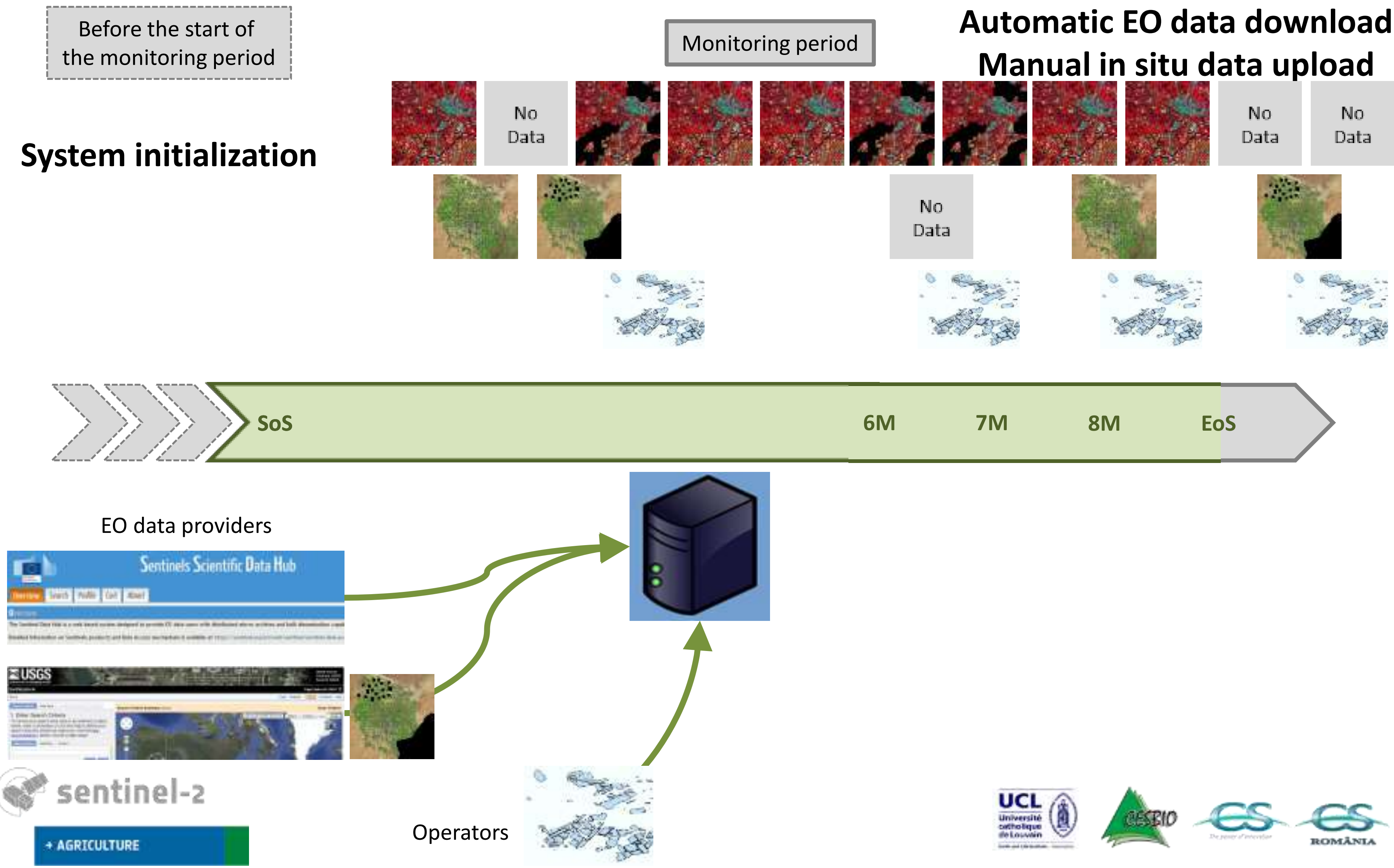
System operation for crop mask



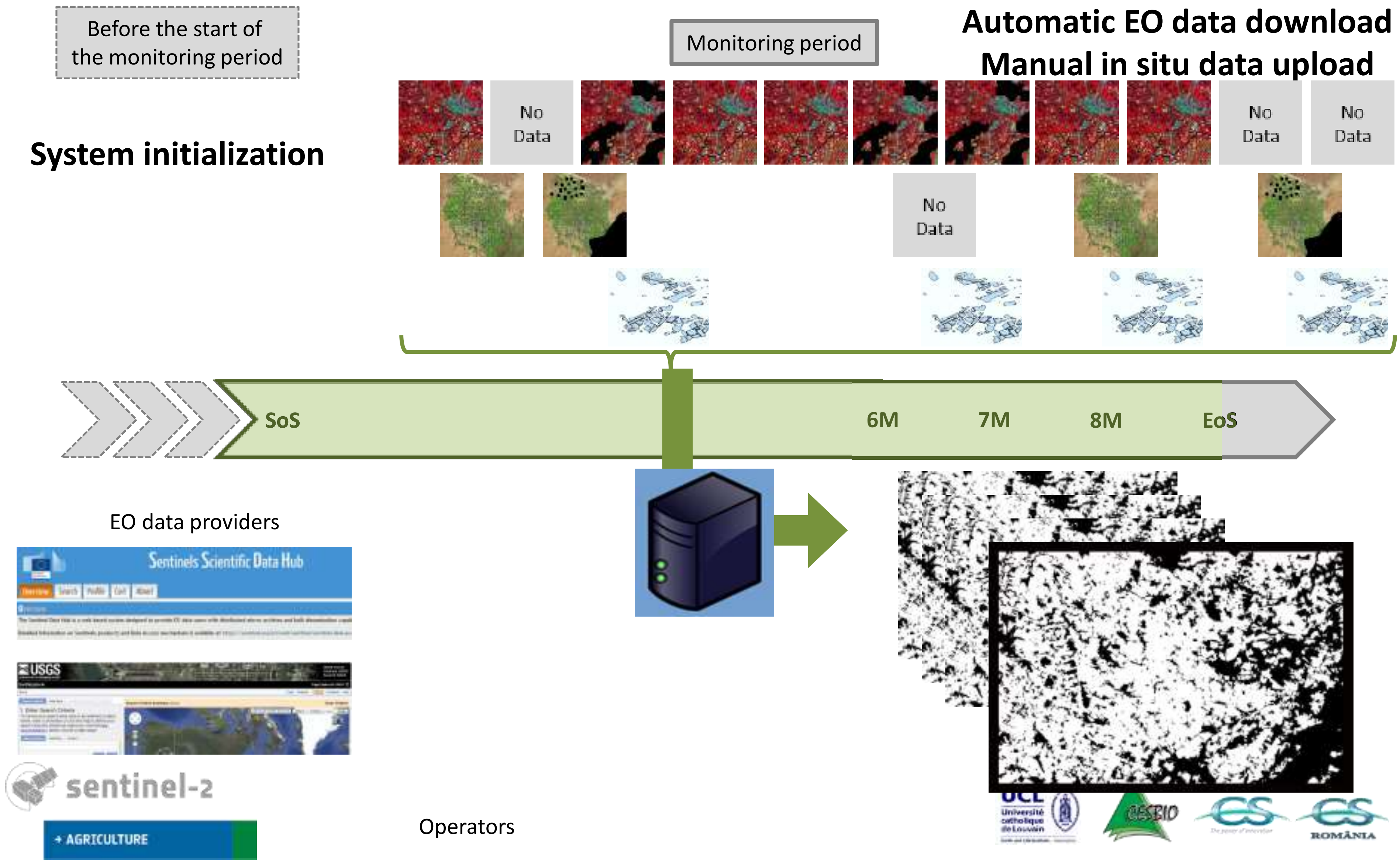
System operation for crop mask



System operation for crop mask

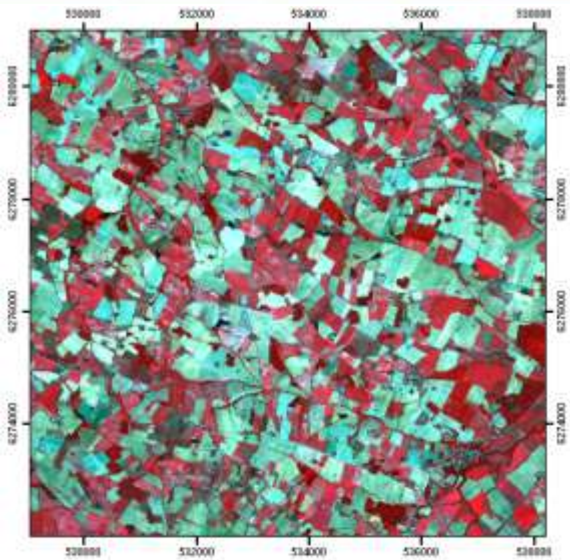


System operation for crop mask

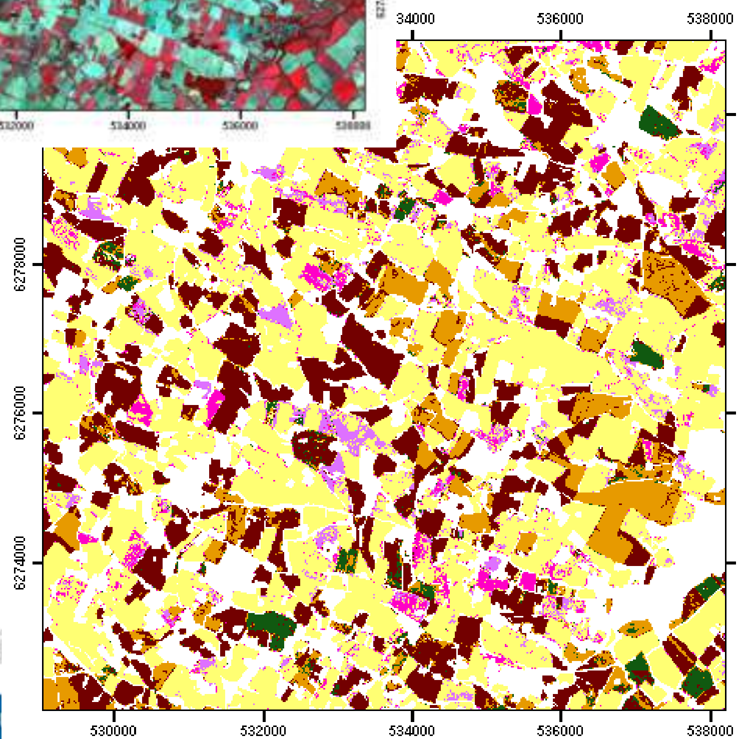


Cultivated crop type map (L4B product)

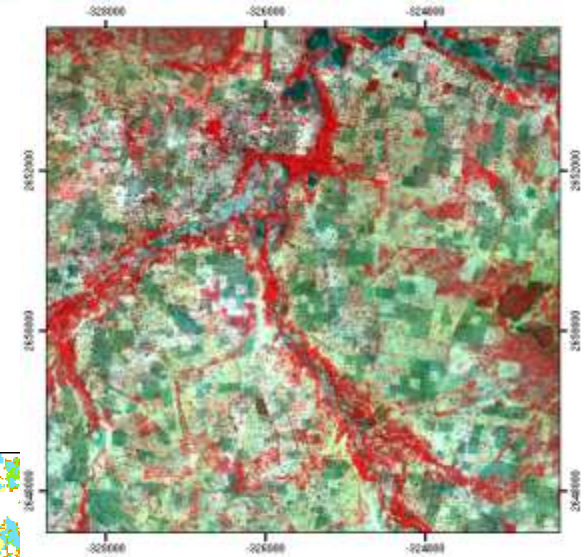
Prototype products
SPOT 5 Take 5 - 2015

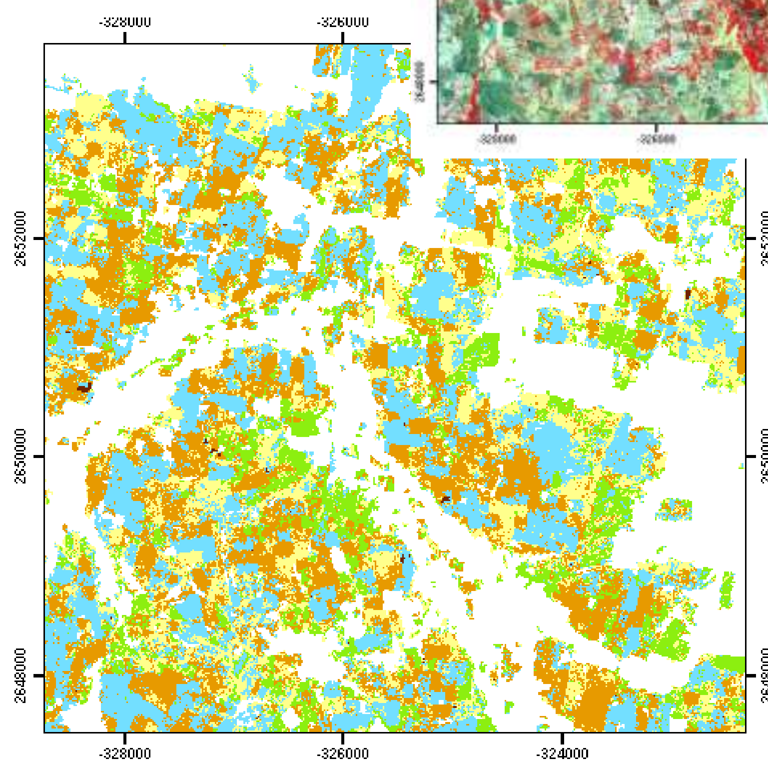


France (JECAM)



Mali (JECAM)

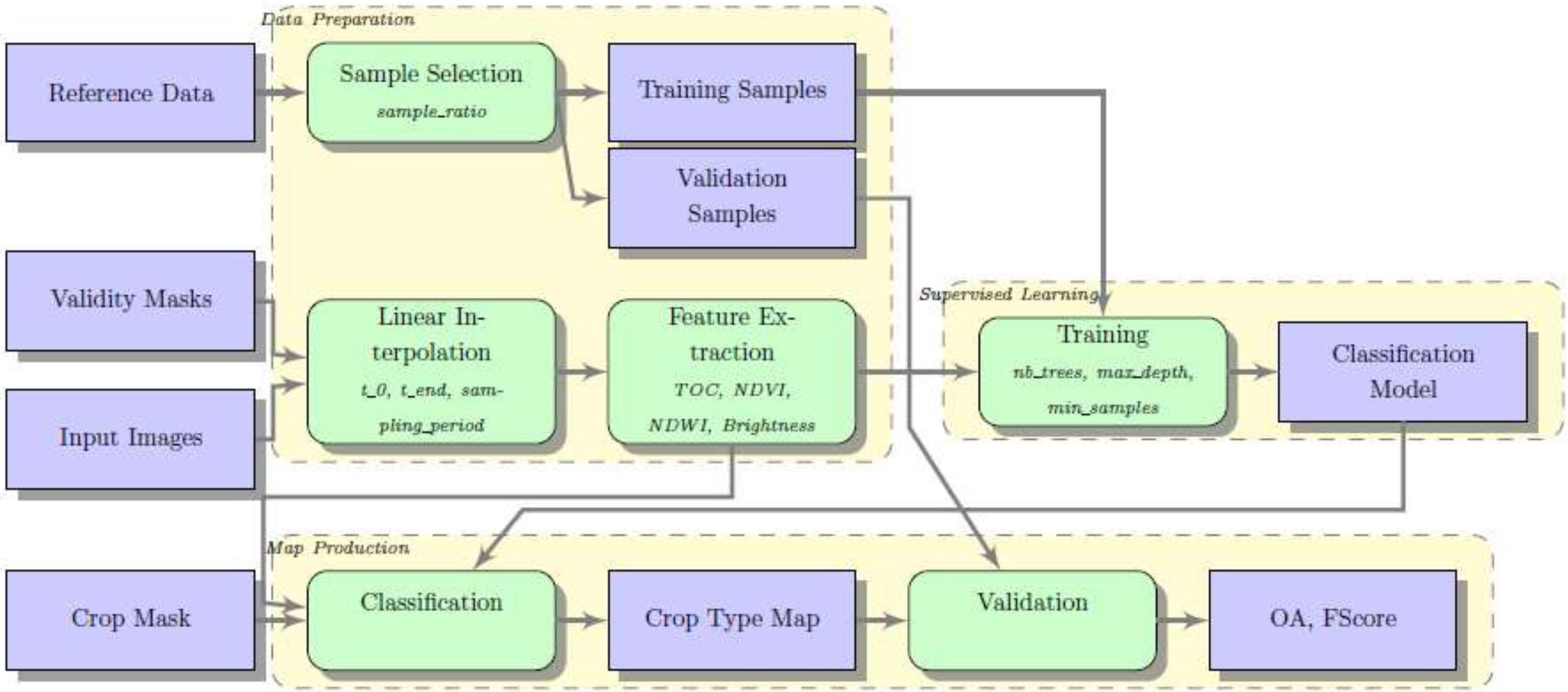




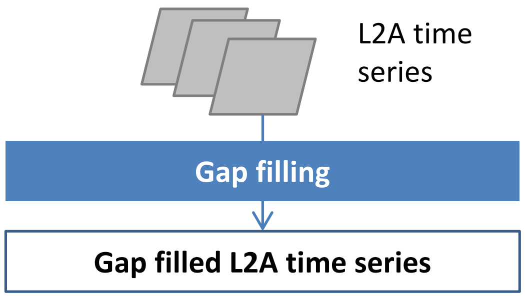
User requirements & Products specifications

Properties	User Requirement	Product specification
Spatial coverage	Local (over sites) to regional, over annual cropland	
Time period	Current	with 6 months before the 1st delivery
Temporal frequency	seasonal products, with a first delivery as soon as possible	6 and 12 months delivery
Delivery time	1-2 weeks after the production period	
Spatial resolution	10 meters	
Legend	main regional crop types or crop groups, including the distinction between rainfed and irrigated crops	see Sen2-Agri definition
Geometric accuracy	Sub-pixel location error	L1C geometric accuracy
Thematic accuracy	10 % (maximum error of omission and commission of area extent per crop type or group)	Overall accuracy of 50%, with the F1Score for the main class higher than 65%
Quality flags	(i) the number of valid observations (ii) the status of the pixel (valid, cloud, cloud shadow, snow, gaps and filled values)	Info split in 4 flags (obs. number, validity, status, gap filled)
Format	Standard raster format (e.g. GEOTIFF)	GEOTIFF
Projection	UTM and WGS84	UTM-UPS/WGS84
Metadata	Clear metadata, standard data formats	XML file
Products distribution	Open and freely available product (+ documentation and validation)	

Crop type processing chain

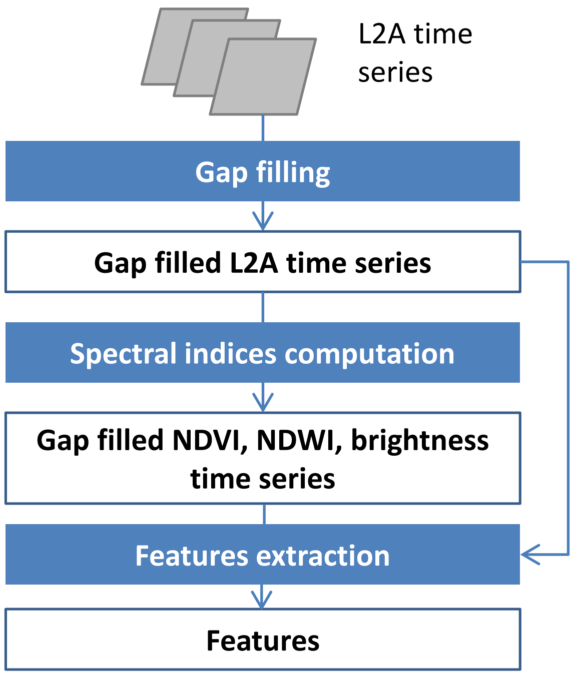


Gap filling



- Objective: produce a reflectance image time series which is
  - gap-filled with respect to missing data (clouds, cloud shadows, saturated pixels)
  - temporally sampled on a regular grid
- If several sensors are available (e.g. S2, L8), time series processed independently and concatenated afterwards
- Makes use of validity mask from L2A products (clouds, cloud shadows, saturated pixels)

Features extraction

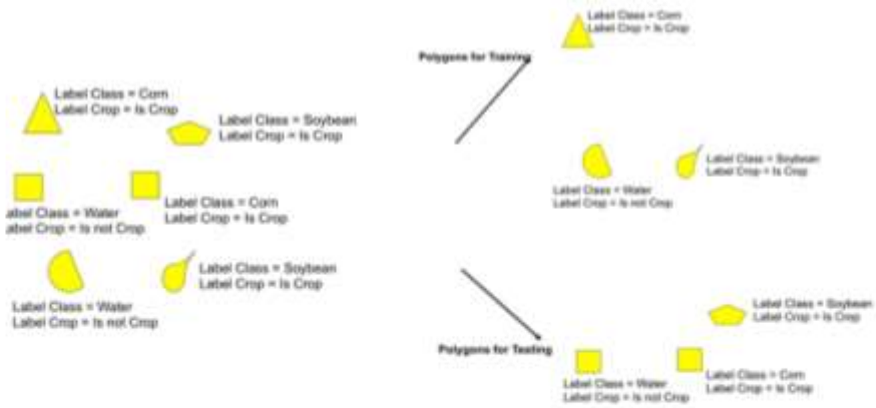


1. Spectral indices computation: NDVI, NDWI, brightness

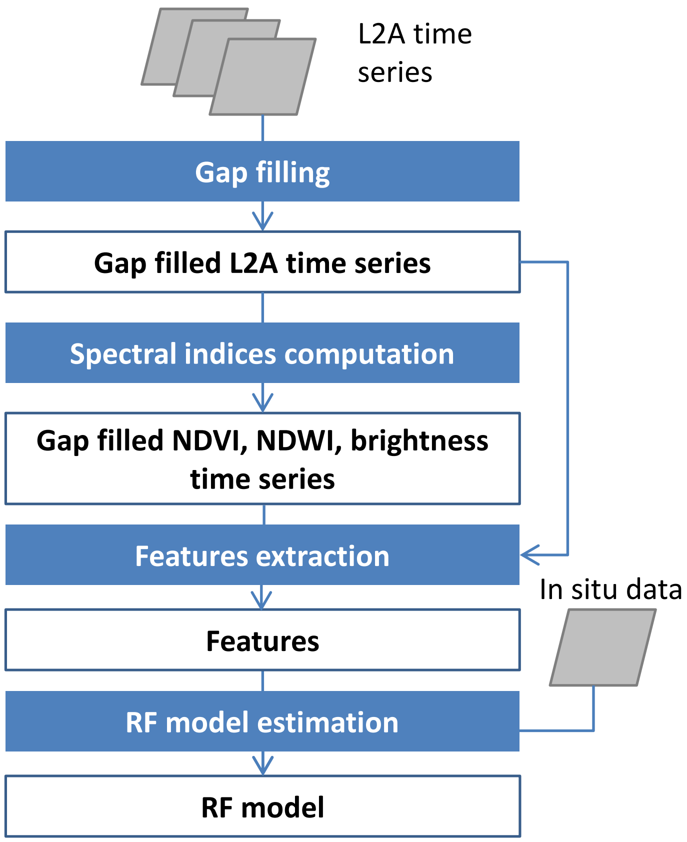
2. Computation of features from NDVI, NDWI, brightness and TOC reflectance values

In-situ data preparation

Splitting polygons for training and testing by polygons and not pixels (// crop mask)



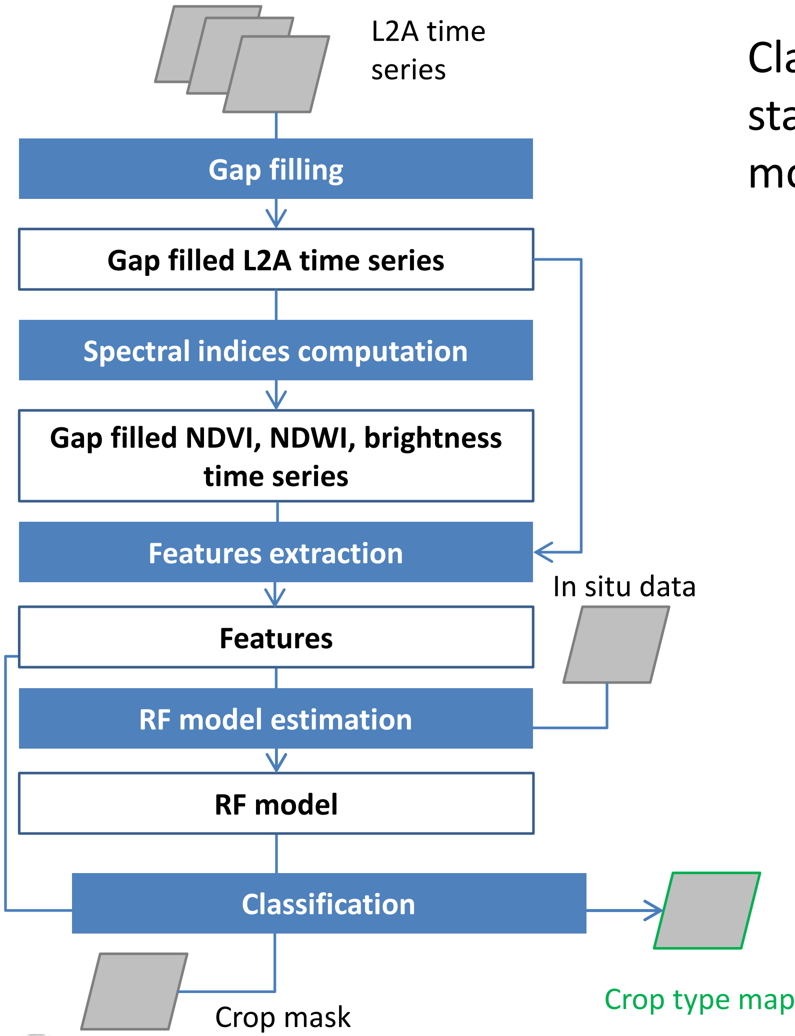
RF model estimation



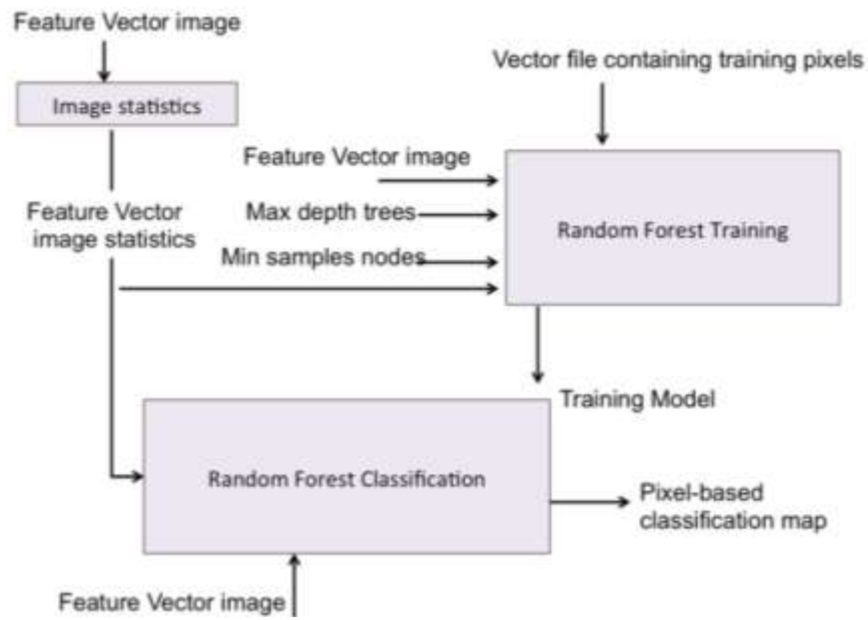
1. Randomly selecting a number of pixel samples for "crop" and "not crop" classes
   - Output selection is class consistent (if 33% of crops is soybean, 33% of crop class training samples will also be soybean)
   - Needed to reduce the time complexity of the RF classifier

2. Training model generation

RF classification

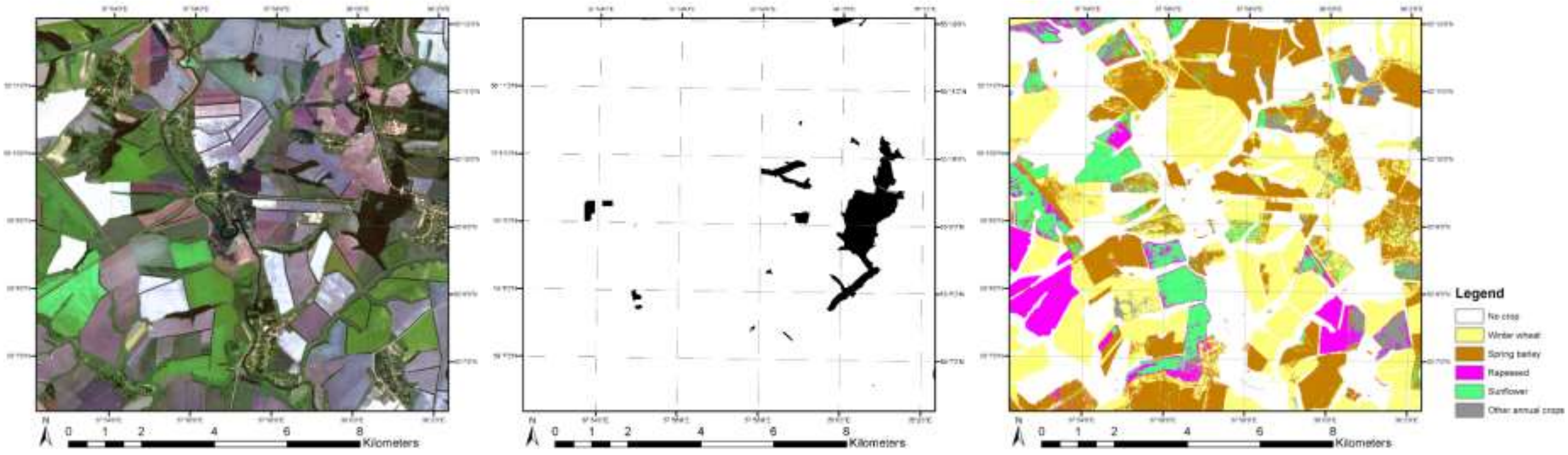


Classify all the pixels of the time series made of all statistic and temporal features, using the estimated RF model

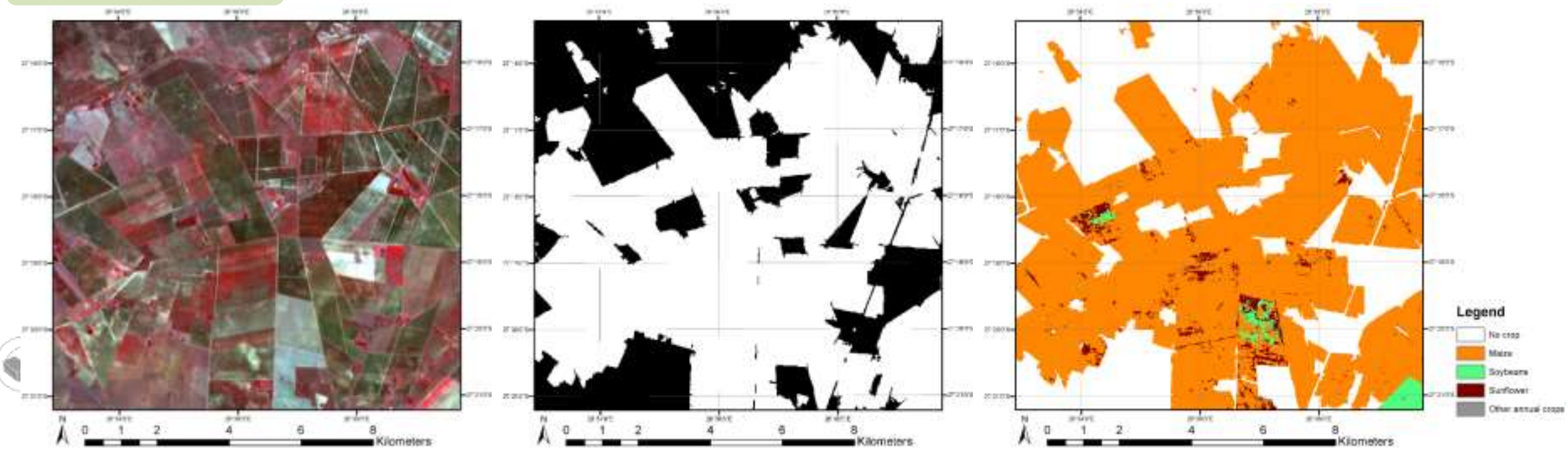


Benchmarking products (2013)

Russia

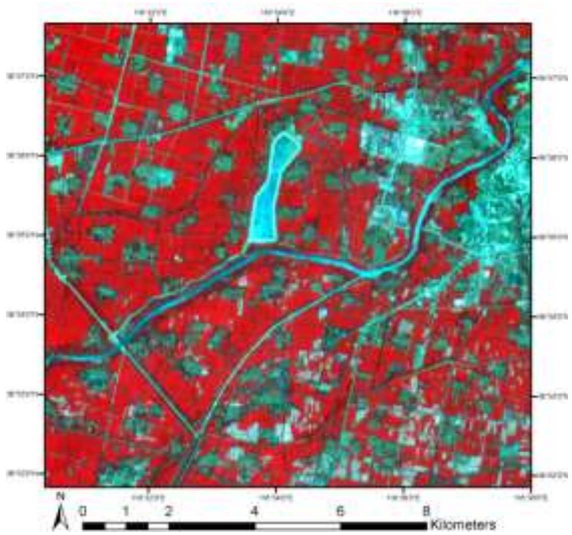


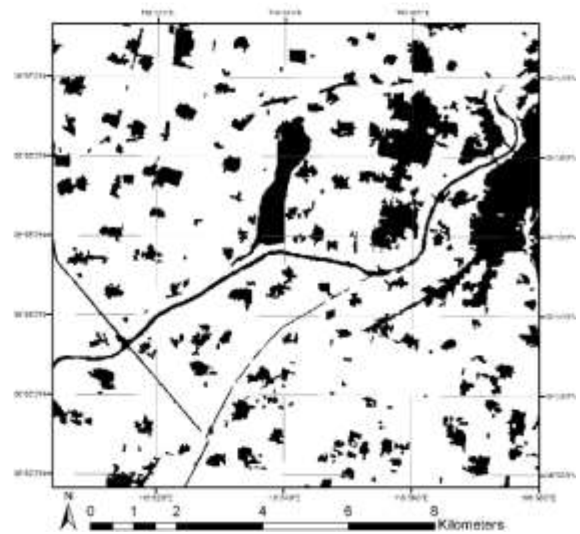
South Africa

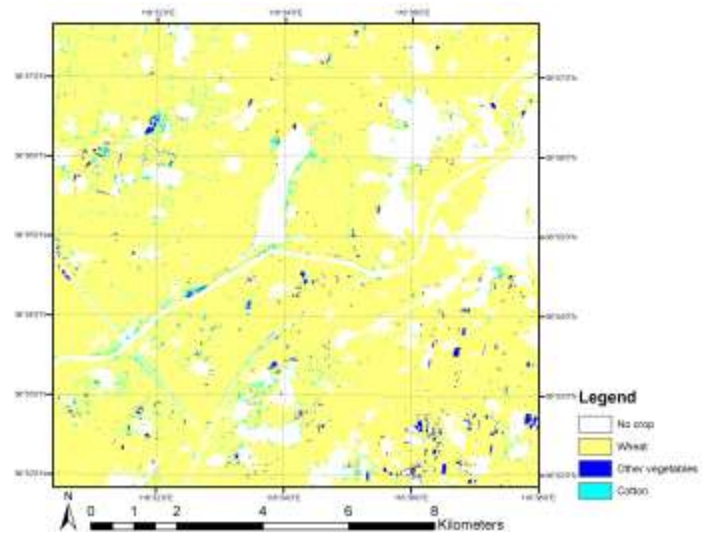


Benchmarking products (2013)

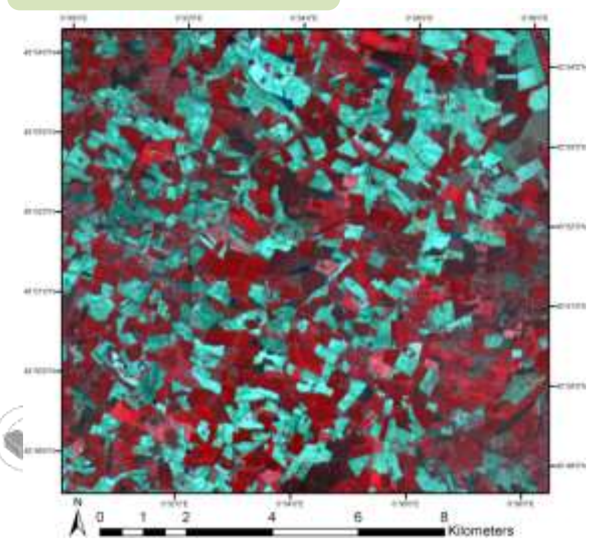
China

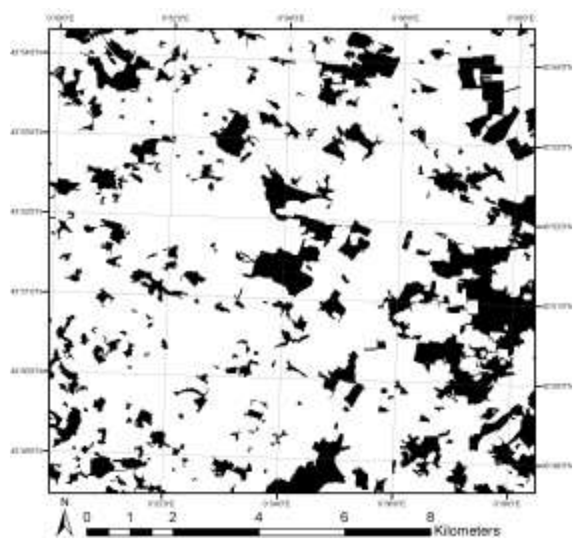


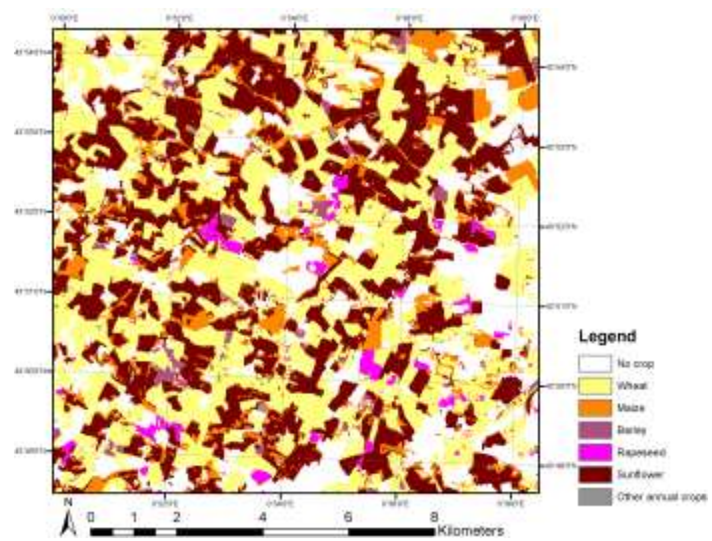




France

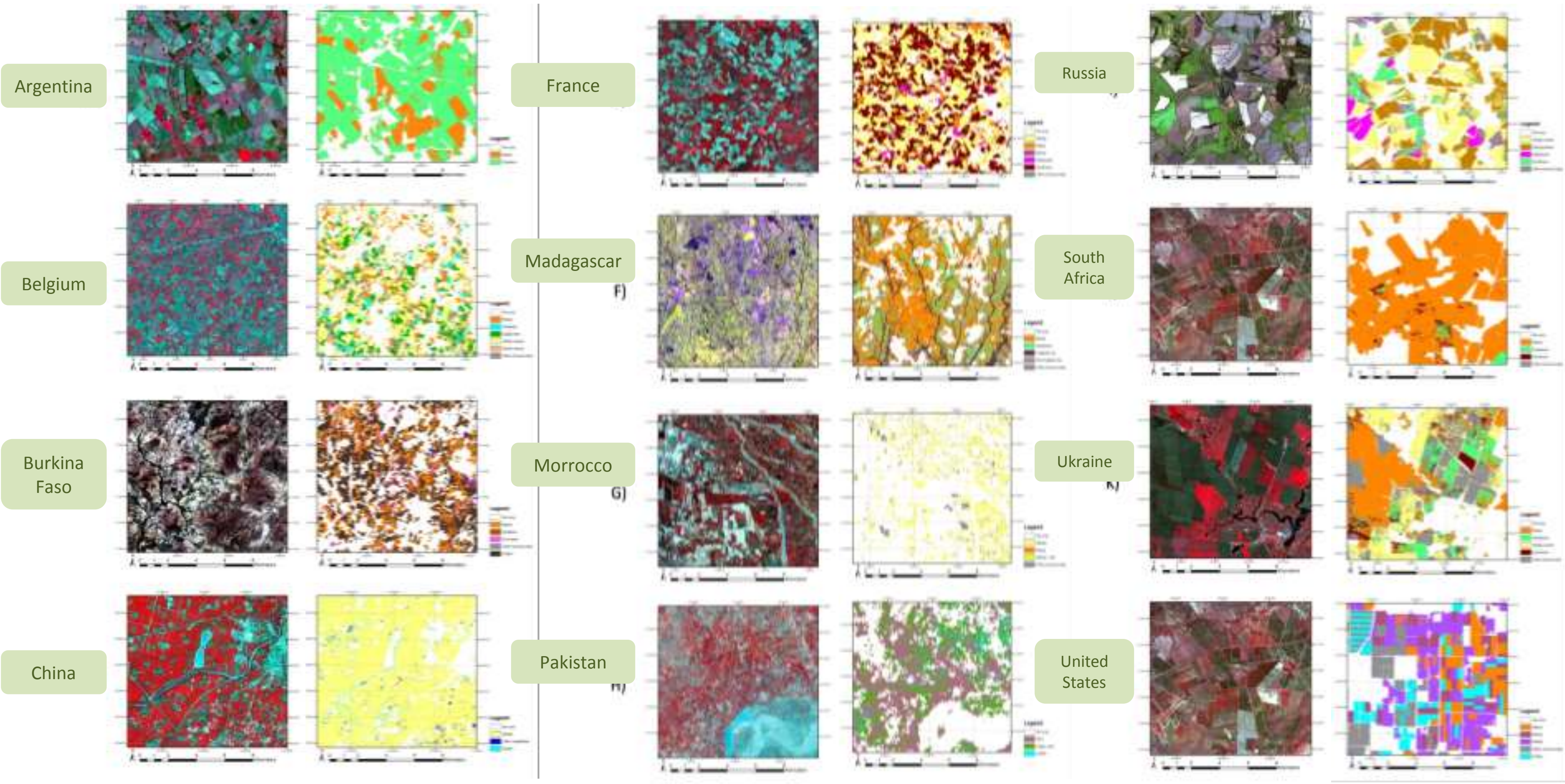






Benchmarking products 2013

(SPOT 4 Take 5, L8, RE)

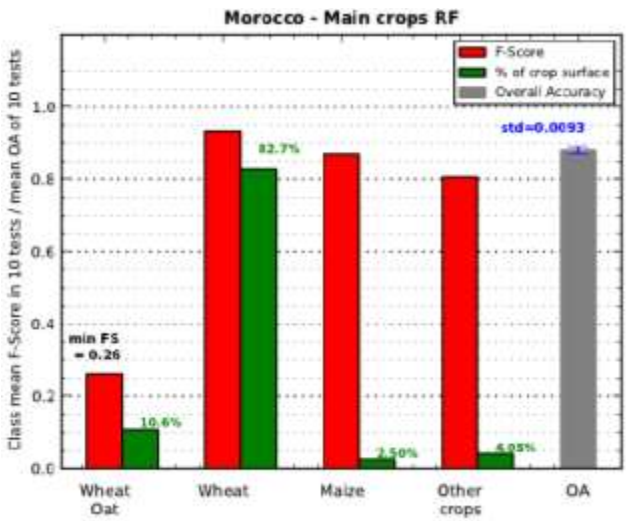


sentinel-2

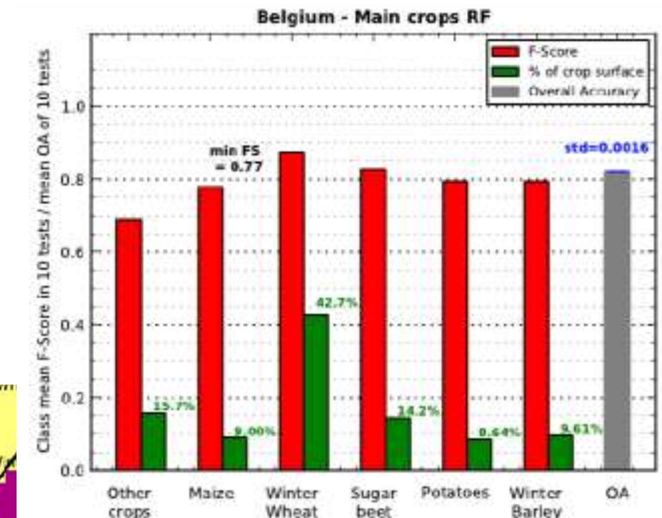
AGRICULTURE

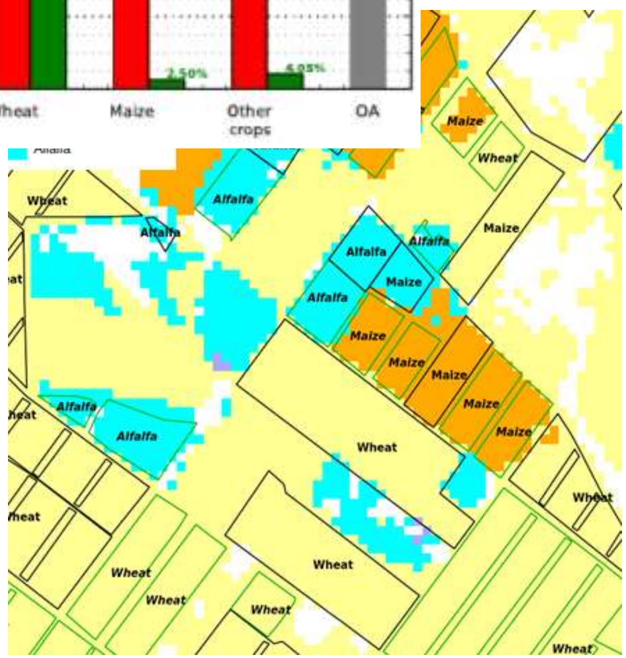
Accuracy assessment (2/2)

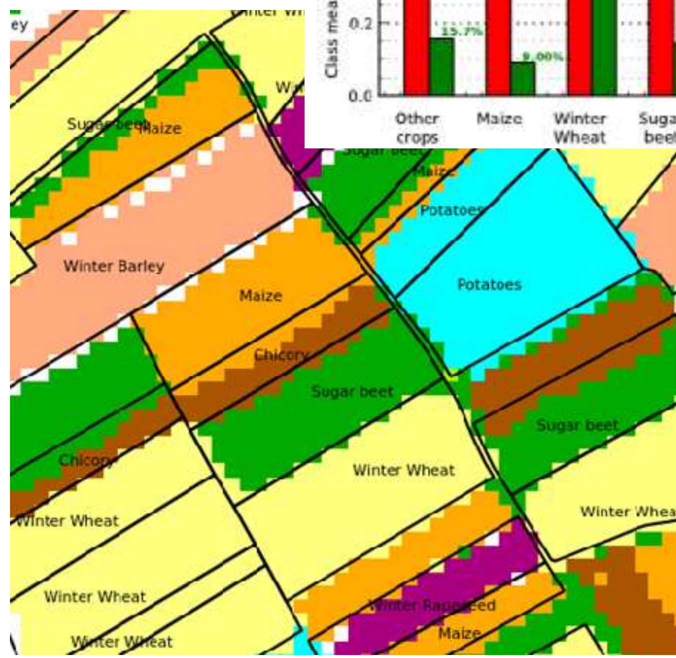
Crop type map with good accuracy for the 5 main crops



Successful development thanks to JECAM collaborative network







- No crop
- Wheat
- Maize
- Broad beans
- Wheat Oat
- Cantaloupes / melons
- Alfalfa

sentinel-2

+ AGRICULTURE

System operation for crop type

Before the start of the monitoring period

Monitoring period

System initialization

SoS

Setting parameters	
Area of Interest	Shapefile to be uploaded
Monitoring period	Start and end dates to be defined
S2 or S2+L8	To be ticked
Other processing parameters	

FID	Shape	ID	CROP	LC	CODE	IRRIGATION
0	Polygon	1	1	Spring Wheat	112	0
1	Polygon	2	1	Spring Wheat	112	0
2	Polygon	3	1	Spring Wheat	112	0
3	Polygon	4	1	Spring Wheat	112	0
4	Polygon	5	1	Spring Wheat	112	0
5	Polygon	6	1	Triticale	1911	0
6	Polygon	7	1	Triticale	1911	0
7	Polygon	8	1	Triticale	1911	0

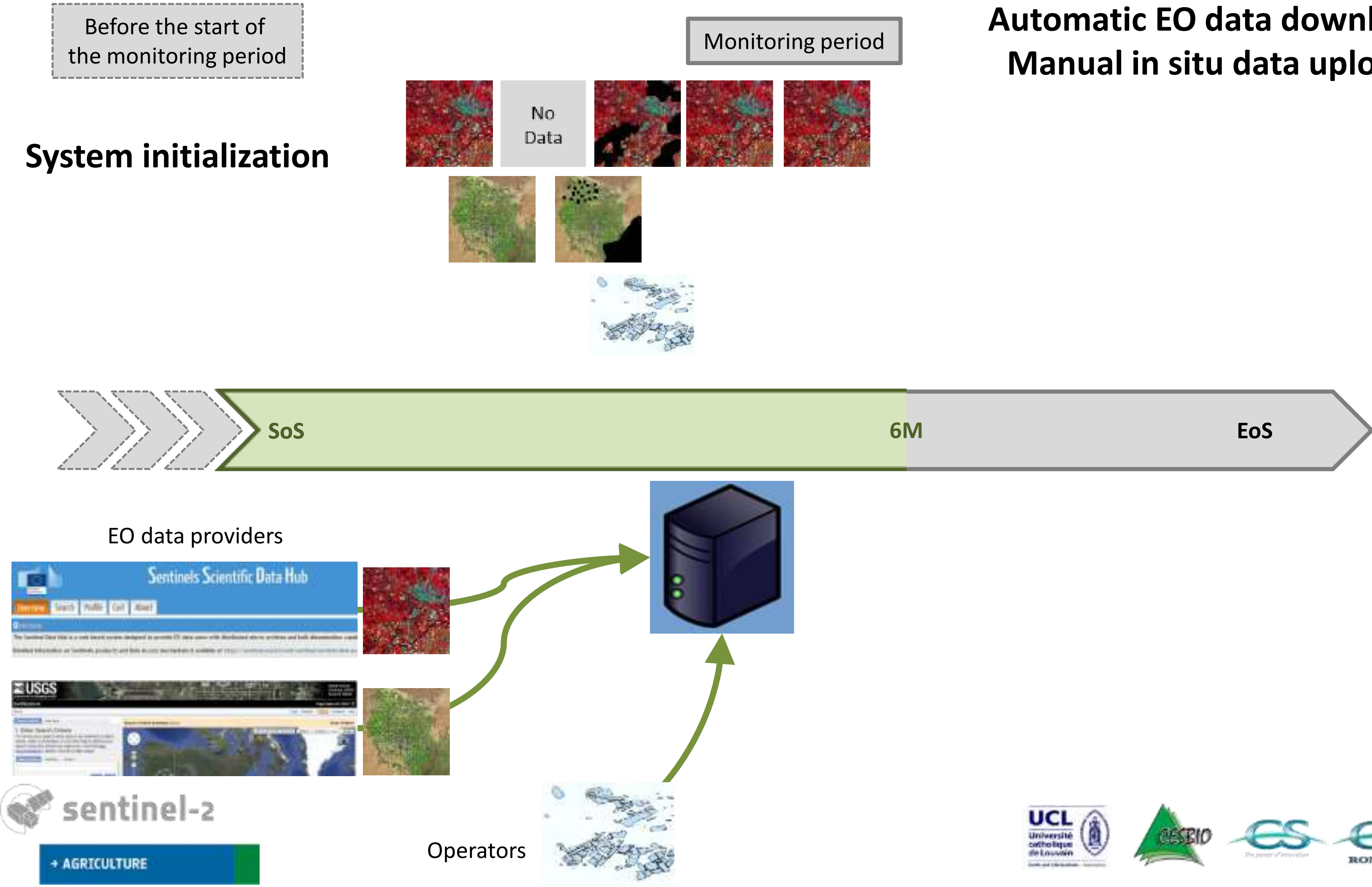
sentinel-2

+ AGRICULTURE

ROMÂNIA

System operation for crop type

Automatic EO data download
Manual in situ data upload



System operation for crop type

Before the start of the monitoring period

Monitoring period

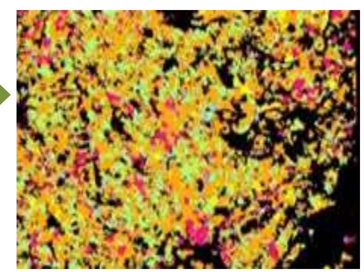
Automatic EO data download
Manual in situ data upload

System initialization

SoS

6M

EoS



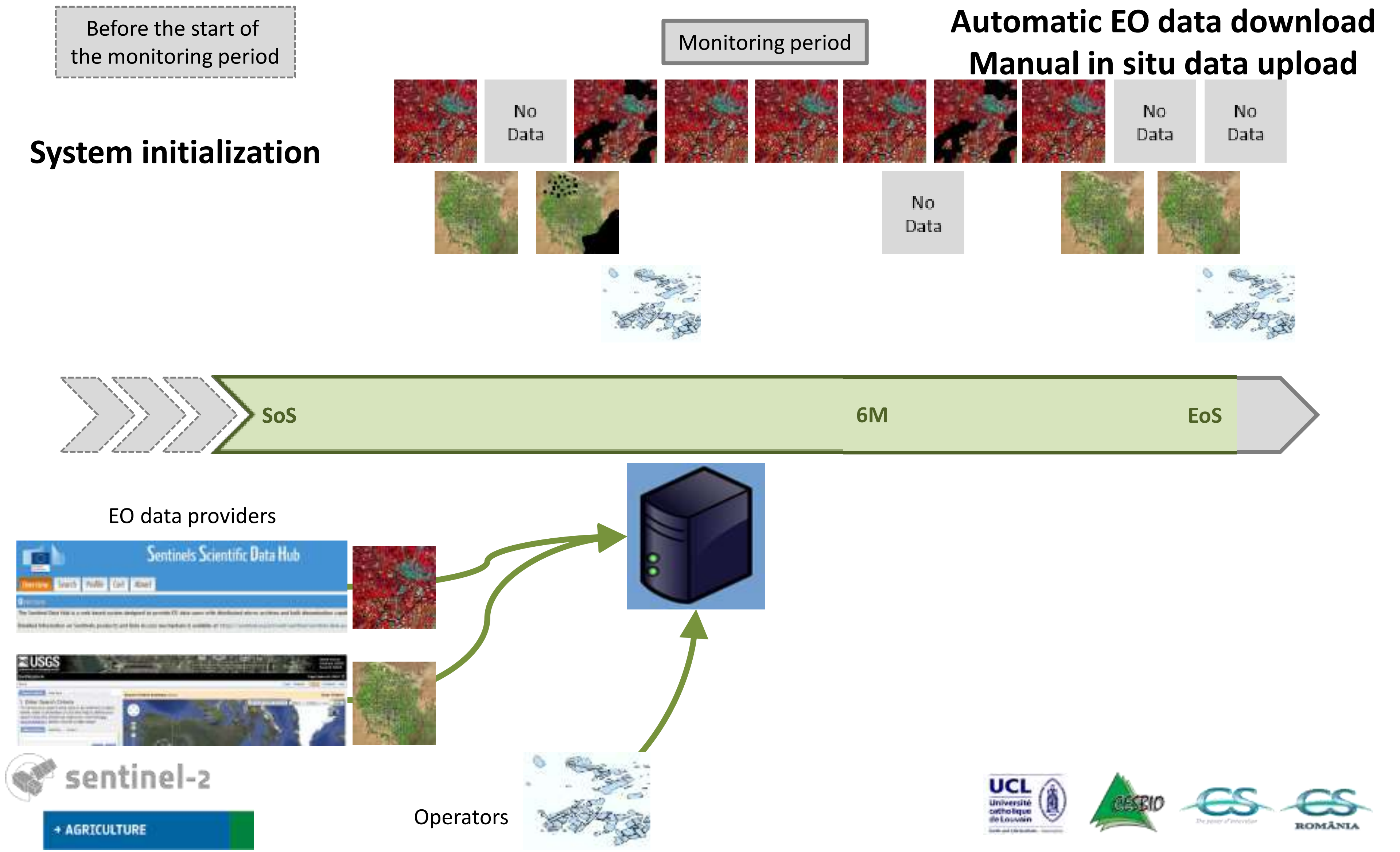
EO data providers

sentinel-2

+ AGRICULTURE

Operators

System operation for crop mask



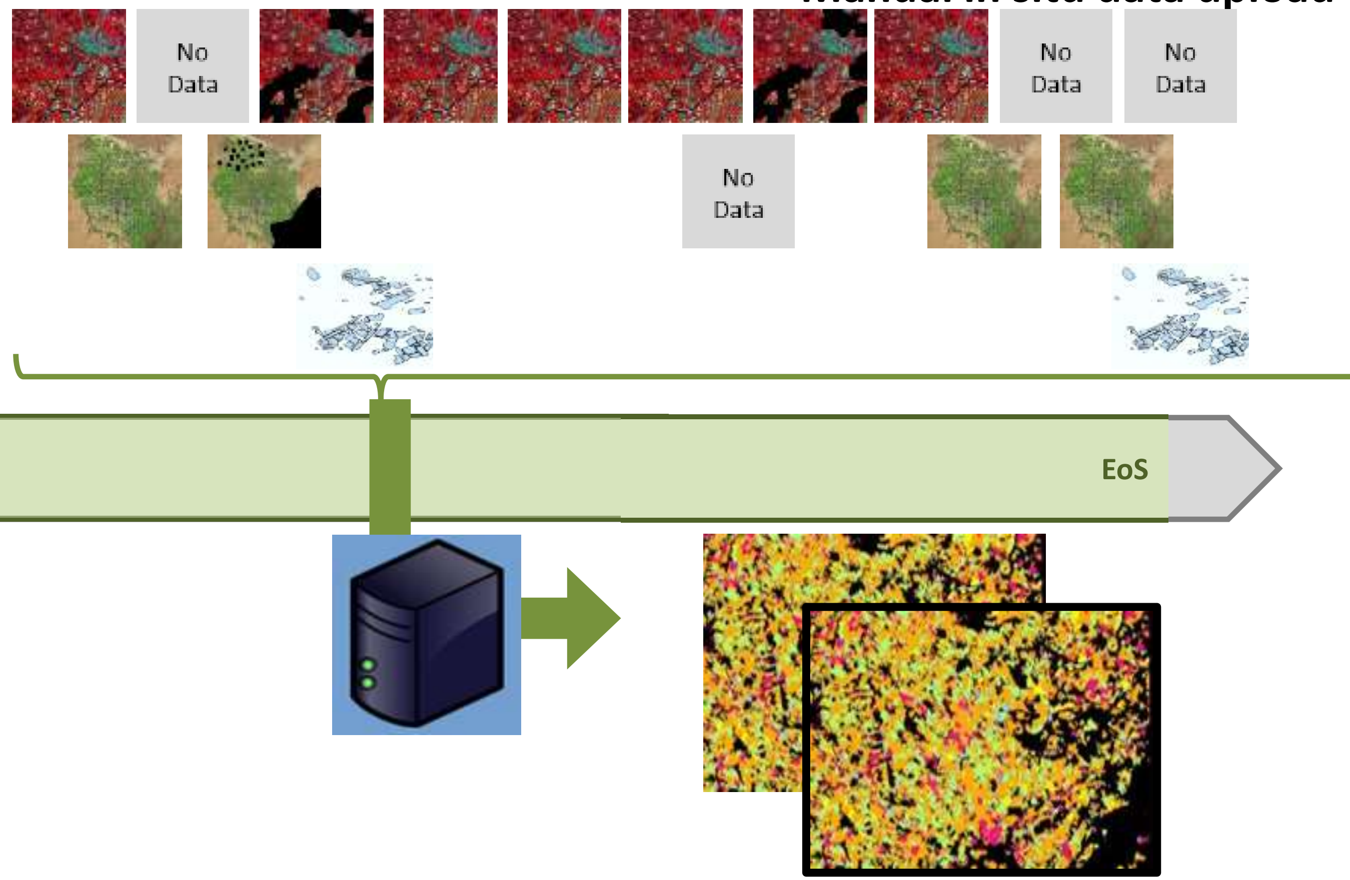
System operation for crop mask

Before the start of the monitoring period

Monitoring period

Automatic EO data download
Manual in situ data upload

System initialization



EO data providers

sentinel-2

+ AGRICULTURE

Operators

UCL Université catholique de Louvain

CESBIO

CS

CS ROMÂNIA

Croplands

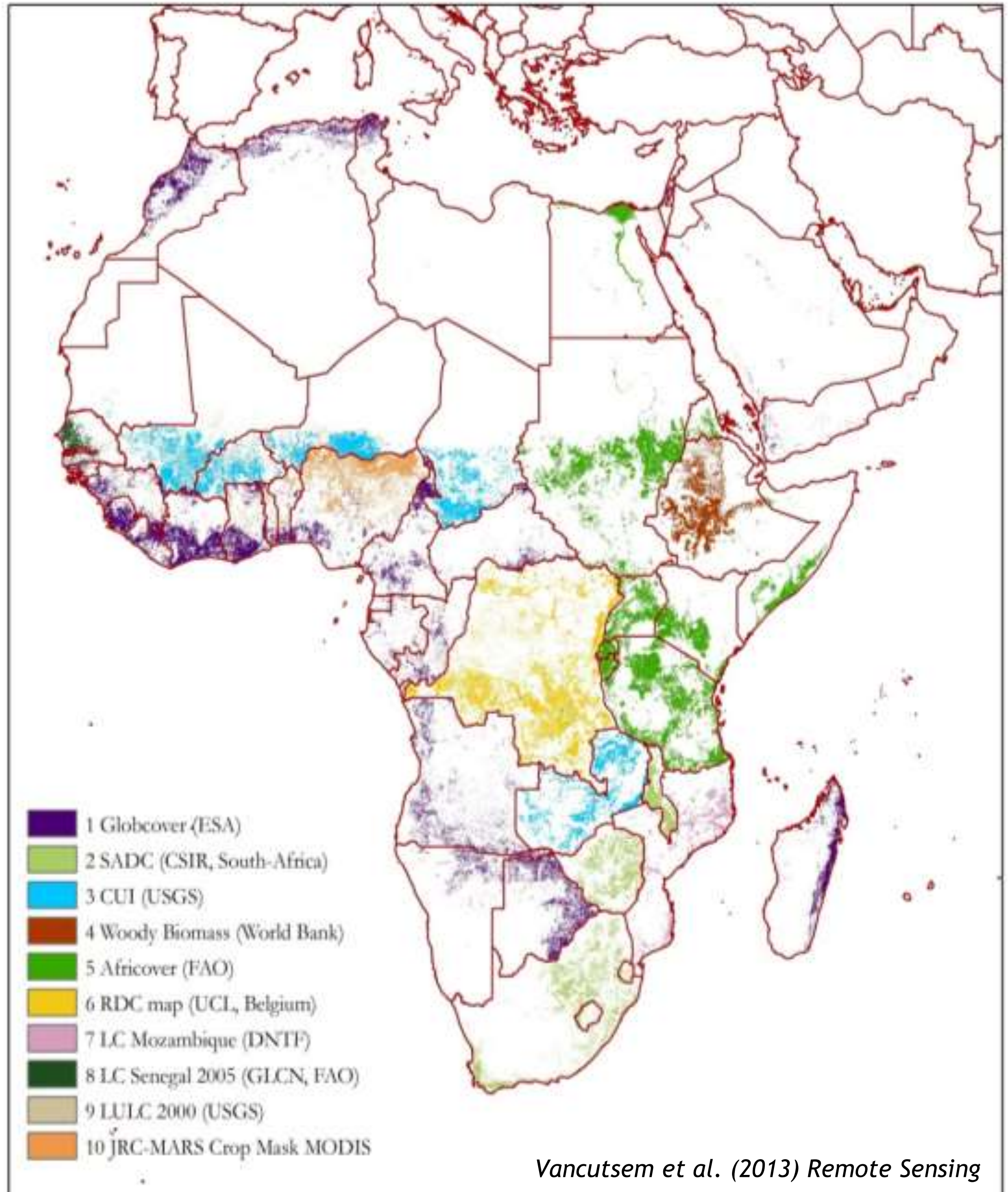
- Harmonization effort to combine existing Land Cover/Land Use datasets to extract cropland over Africa

- Global version :

Unified Cropland Layer

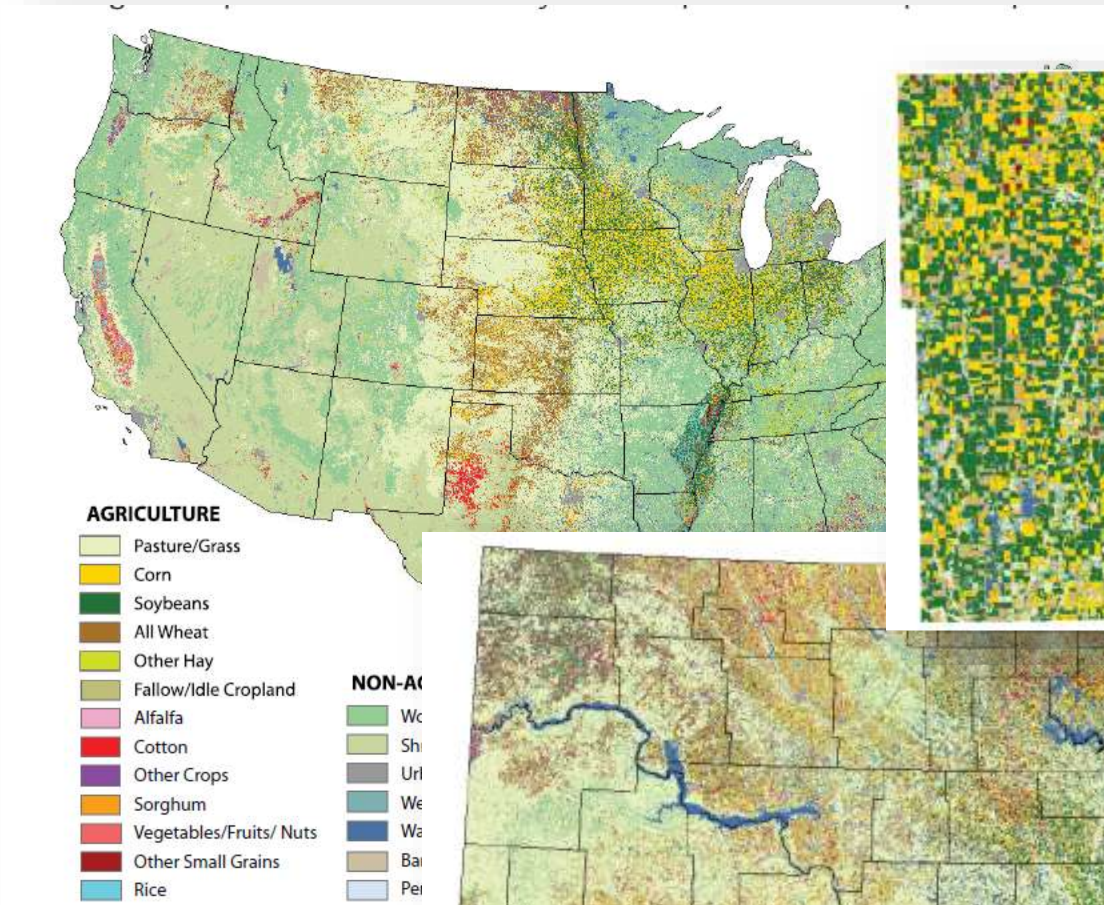
http://maps.elie.ucl.ac.be/geoportail/

Waldner et al. (2015)

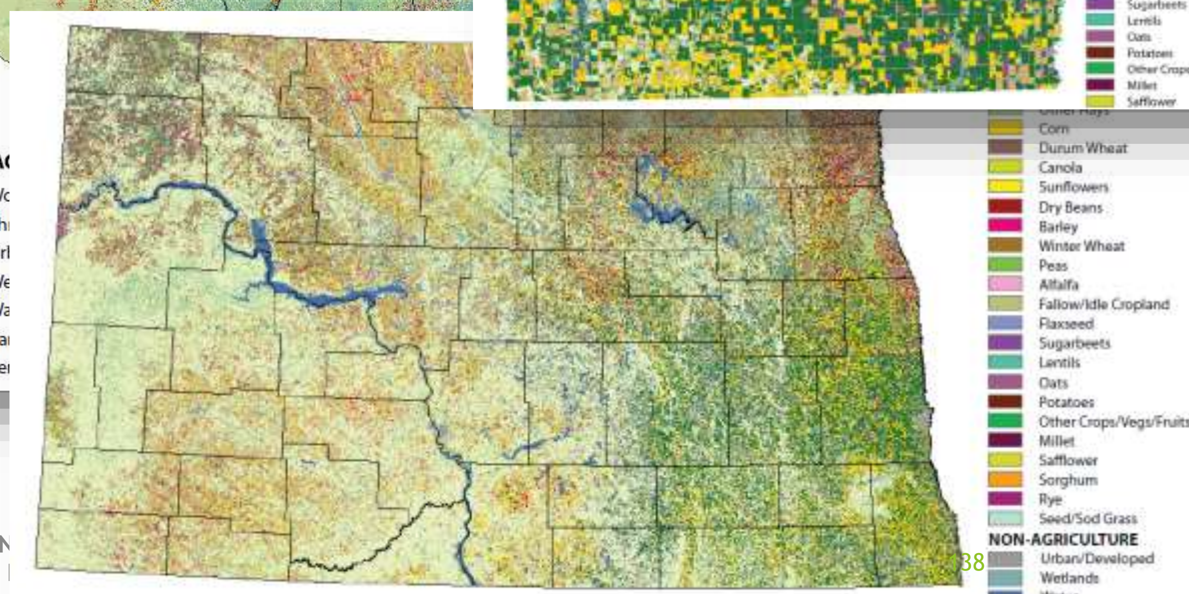


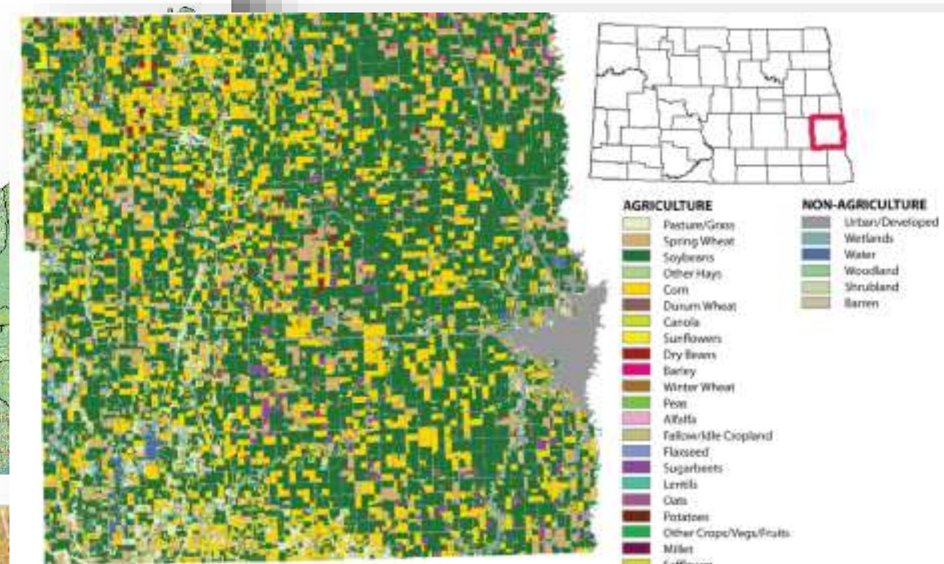
Vancutsem et al. (2013) Remote Sensing

Cropland Data Layer



Johnson & Mueller (2010) PE&RS

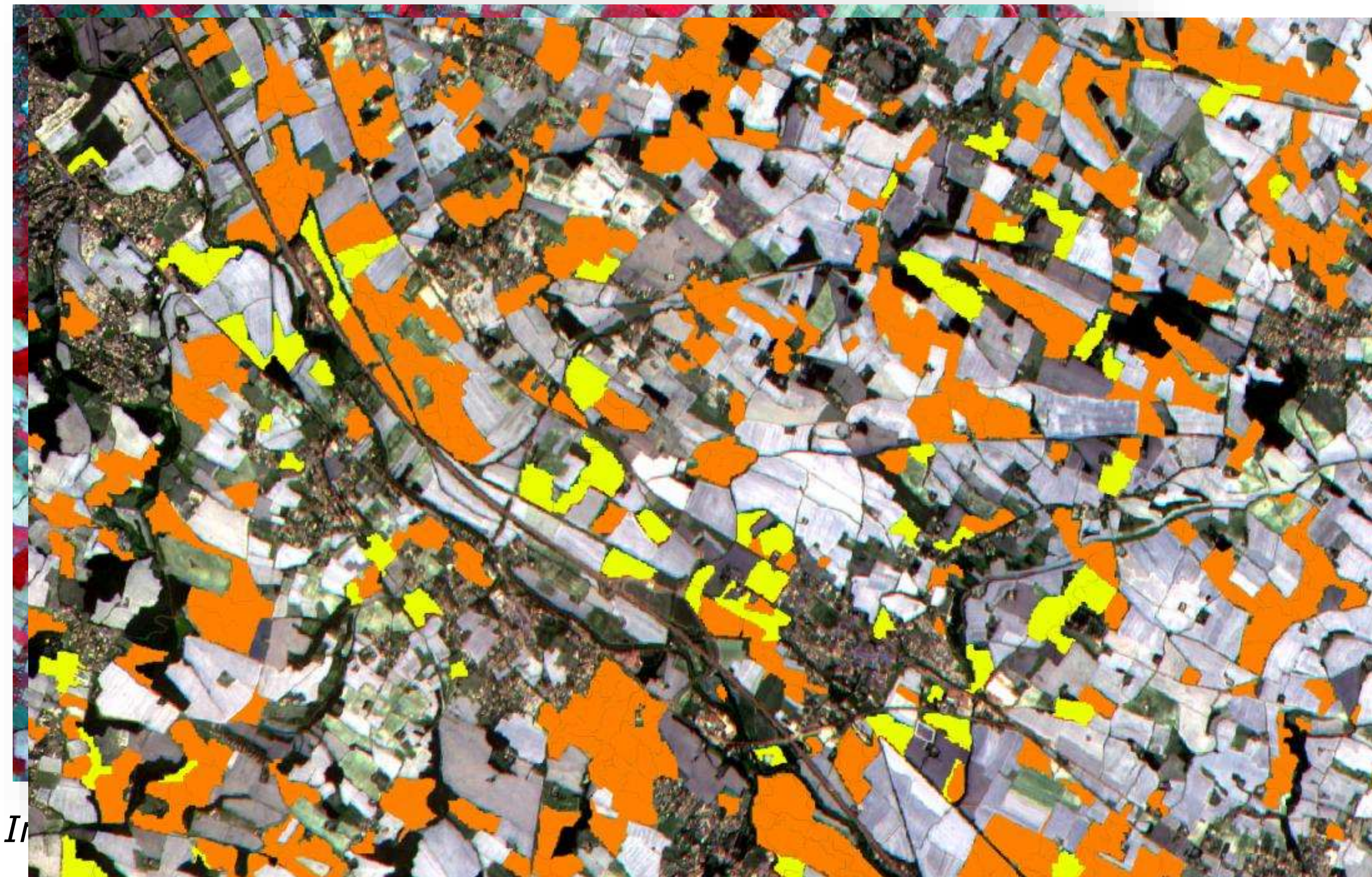




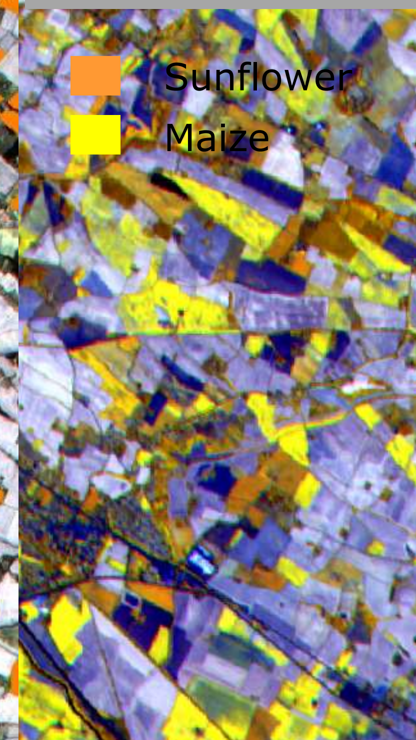
First S2-based prototype product

Toulouse area (France) - Sentinel-2 – 06 July 2015

New red-edge band to discriminate summer crops : maize *vs* sunflower



Summer Crops Map – 6 July 2015

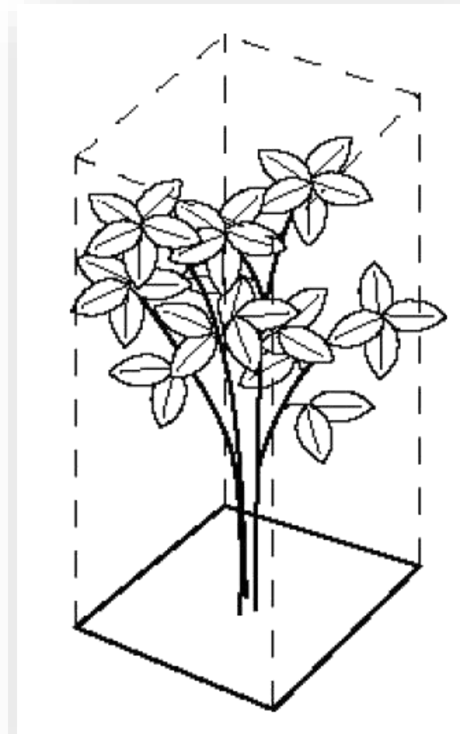


New red-edge color composite
orange versus yellow

Outline

1. Introduction to optical land applications :
2. Basic principles about electromagnetic radiation & land surface
3. Identifying cultivated area and crops from space (Sen2-Agri system)
4. **Estimating canopy biophysical variables** (Sen2-Agri system)
5. Example of monitoring crop production from space (MARS)

Some useful biophysical variables for agriculture that can be obtained from RS

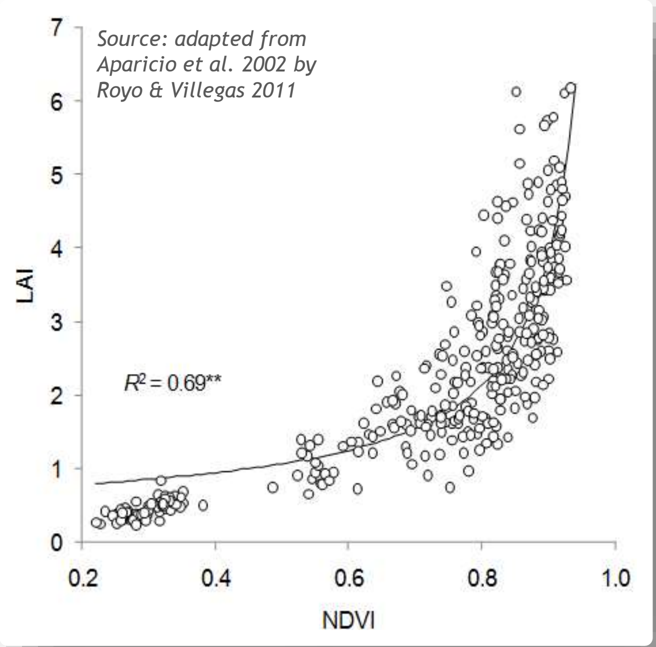


- Leaf Area Index (LAI)
  - Defined as half the total developed area of green leaves per unit of ground horizontal surface area
- Fraction of absorbed photosynthetically active radiation (fAPAR)
- Fraction of area covered by the crop (fCOVER

- *Canopy chlorophyll content*
- *Light Use Efficiency*
- *Fluorescence*

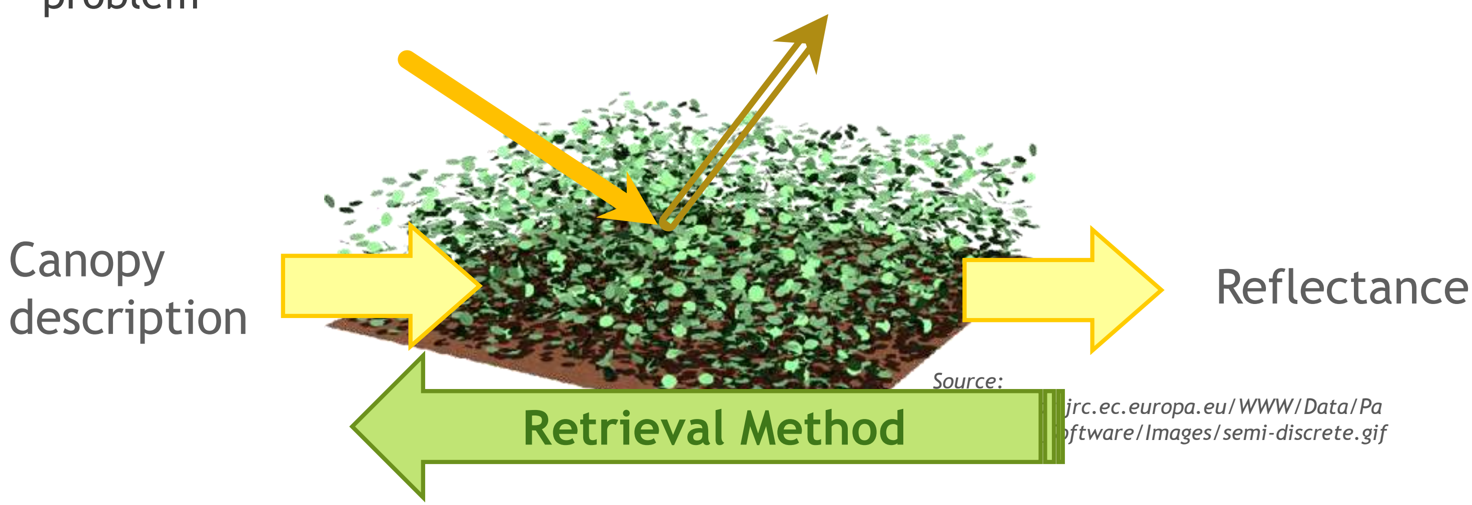
How to retrieve biophysical variables from optical RS ?

- Empirical methods
  - Establishment of a statistical relationship between VI or ρ and field measured biophysical variables
  - Require intensive field measurements for calibration and validation
  - Relation is typically limited to large geographic extent



How to retrieve biophysical variables from optical RS ?

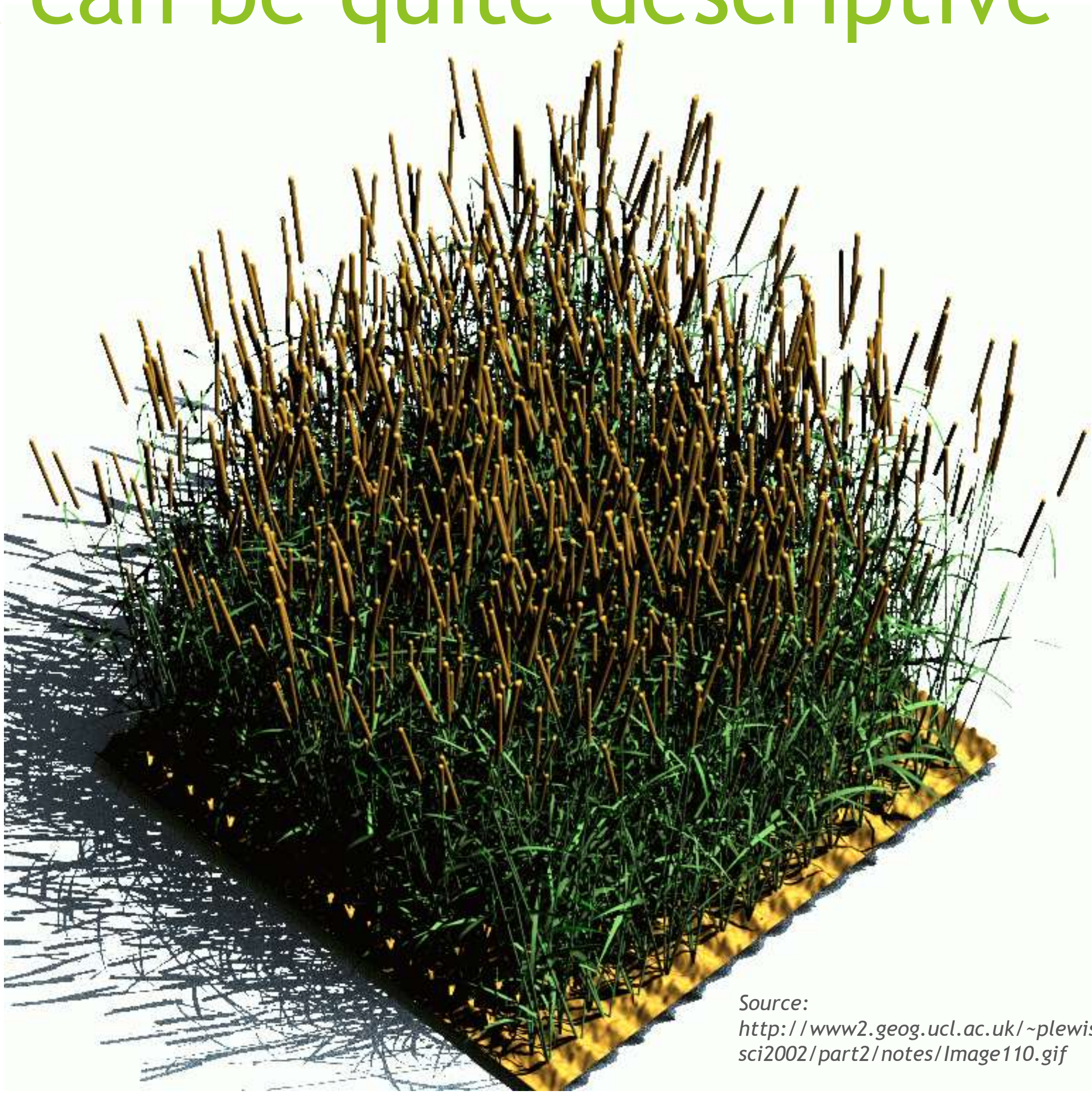
- Physical methods
  - Replacement of field measurements by radiative transfer models (RTMs)
  - Mathematical inversion necessary, but difficult because it is an ill-posed problem



Source: jrc.ec.europa.eu/WWW/Data/Pa oftware/Images/semi-discrete.gif

  - Method is transportable across landscapes as long as RTM is valid

RTM can be quite descriptive



Source: http://www2.geog.ucl.ac.uk/~plewis/vegsci2002/part2/notes/Image110.gif

PROSAIL RTM

- Combination of:
  - PROSPECT leaf model (Jacquemoud & Baret, 2009)
  - SAIL canopy model (Verhoef, 1984, 1985)

- Simple
- 10 variables
- Perhaps the most used in the literature

Table 1
Main variables of PROSAIL.

Model	Symbol	Quantity	Unit
PROSPECT	N	Leaf structure parameter	–
	C_{ab}	Chlorophyll $a+b$ content	$\mu g\ cm^{-2}$
	C_w	Equivalent water thickness	cm
	C_m	Dry matter content	$g\ cm^{-2}$
	C_{bp}	Brown pigments content	–
SAIL	LAI	Leaf area index	–
	LIDF*	Leaf inclination distribution function	–
	s_L	Hot spot parameter	–
	ρ_s	Soil reflectance assumed Lambertian or not	–
	SKYL	Ratio of diffuse to total incident radiation	–
	sza or θ_s	Solar zenith angle	deg
	vza or θ_v	Viewing zenith angle	deg
	raa or φ_{sv}	Relative azimuth angle	deg

*Several functions have been proposed to define the LIDF: polynomial, ellipsoidal or elliptic distribution characterized by an average leaf angle (ALA), Beta distribution characterized by two parameters (a and b).

Remote Sensing of Environment 113 (2009) S56–S66

Contents lists available at ScienceDirect

Remote Sensing of Environment

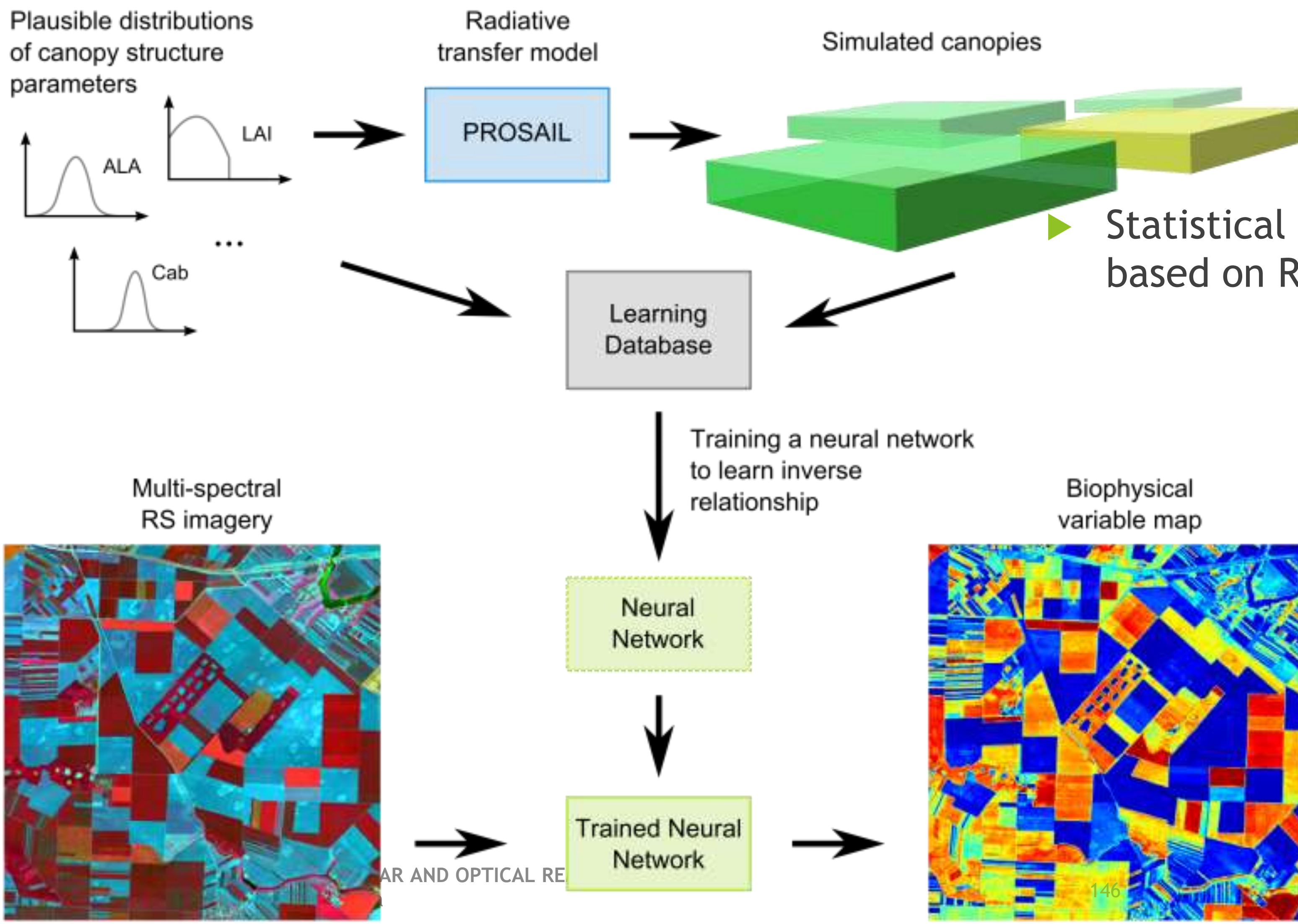
journal homepage: www.elsevier.com/locate/rse

PROSPECT + SAIL models: A review of use for vegetation characterization

Stéphane Jacquemoud [a,*], Wout Verhoef [b], Frédéric Baret [c], Cédric Bacour [d], Pablo J. Zarco-Tejada [e], Gregory P. Asner [f], Christophe François [g], Susan L. Ustin [h]

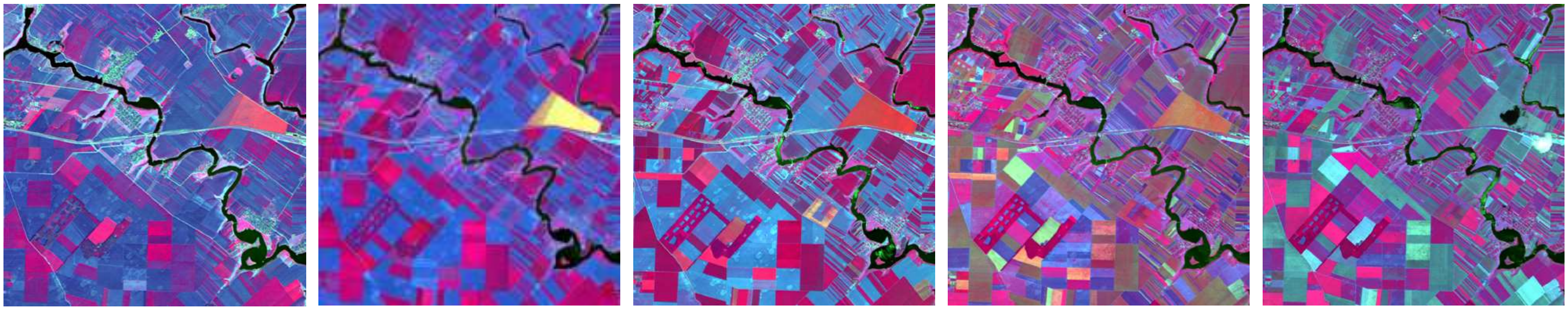
[a] Institut de Physique du Globe de Paris & Université Paris Diderot (UMR 7154), Géophysique spatiale et planétaire, Case 7011, 35 rue Hélène Brion, 75013 Paris, France
[b] National Aerospace Laboratory, NLR, Voorsterweg 31, 8316 PR Marknesse, The Netherlands
[c] INRA, Unité Environnement Méditerranéen et Modélisation des Agro-Hydrosystèmes (UMR1114), Domaine St Paul, Site Agroparc, 84914 Avignon Cedex 09, France
[d] Laboratoire des Sciences du Climat et l'Environnement (CEA/CNRS/UVSQ), L'Orme des Merisiers, Bât. 701, 91191 Gif-sur-Yvette Cedex, France
[e] Instituto de Agricultura Sostenible, (IAS), Consejo Superior de Investigaciones Científicas (CSIC), Alameda del Obispo s/n, 14004 Córdoba, Spain
[f] Department of Global Ecology, Carnegie Institution of Washington, 260 Panama Street, Stanford, CA 94305, USA
[g] Laboratoire Ecologie, Systématique et Evolution (UMR 8079), Université Paris-Sud, 91405 Orsay Cedex, France
[h] Center for Spatial Technologies and Remote Sensing, Department of Land, Air, and Water Resources, University of California, Davis, CA 95616, USA

Example of a hybrid inversion method using PROSAIL and NNT



- Statistical relationship based on RTM results

Application to dataset with many high spatial resolution imagery



- ADAM dataset over Fundulea, Romania (data available from

Remote Sensing of Environment 115 (2011) 887–896

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Retrieving wheat Green Area Index during the growing season from optical time series measurements based on neural network radiative transfer inversion

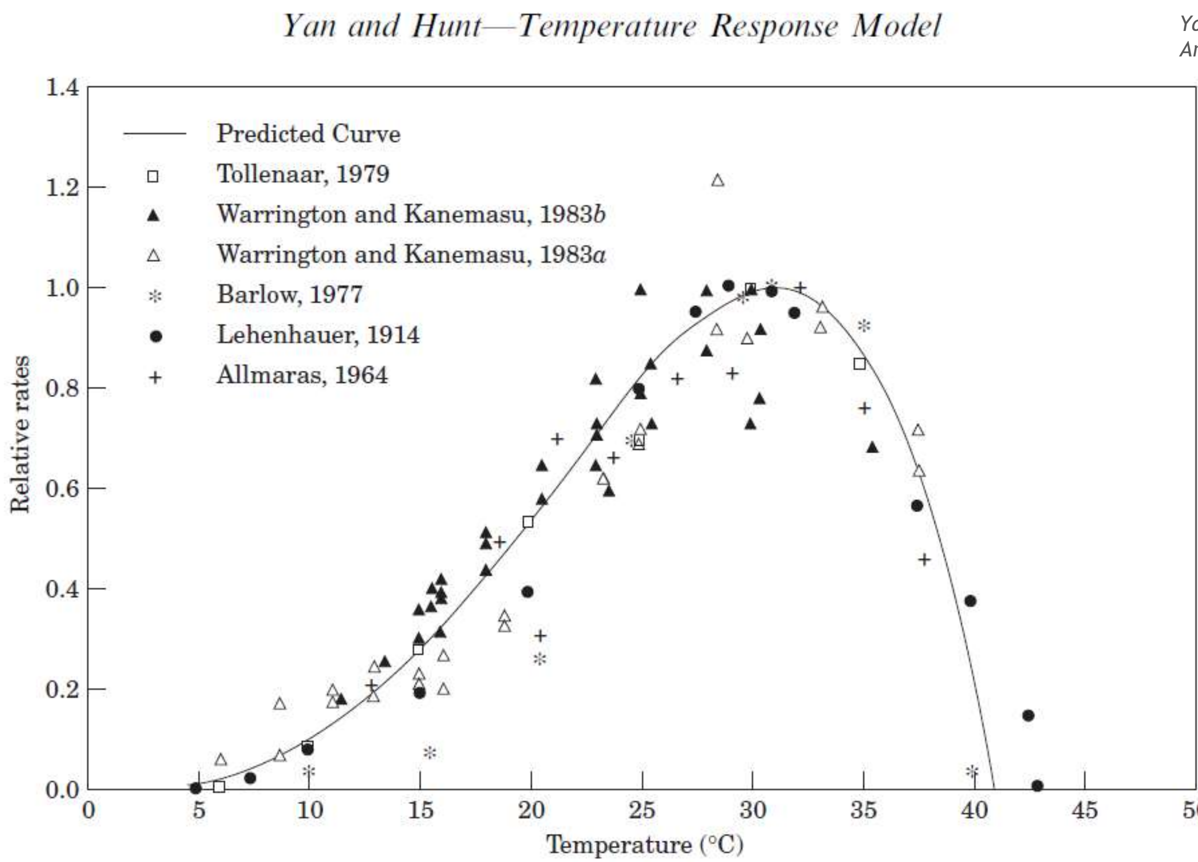
Grégory Duveiller [a,*], Marie Weiss [b], Frédéric Baret [b], Pierre Defourny [a]

[a] Earth and Life Institute, Université Catholique de Louvain, 2/16 Croix du Sud, B-1348 Louvain-la-Neuve, Belgium
[b] Environnement Méditerranéen et Modélisation des Agro-Hydrosystèmes (EMMAH), INRA-UMR 1114, Domaine Saint-Paul, Site Agroparc, 84914 Avignon, France

Thermal time

- Plants grow faster over a given temperature range

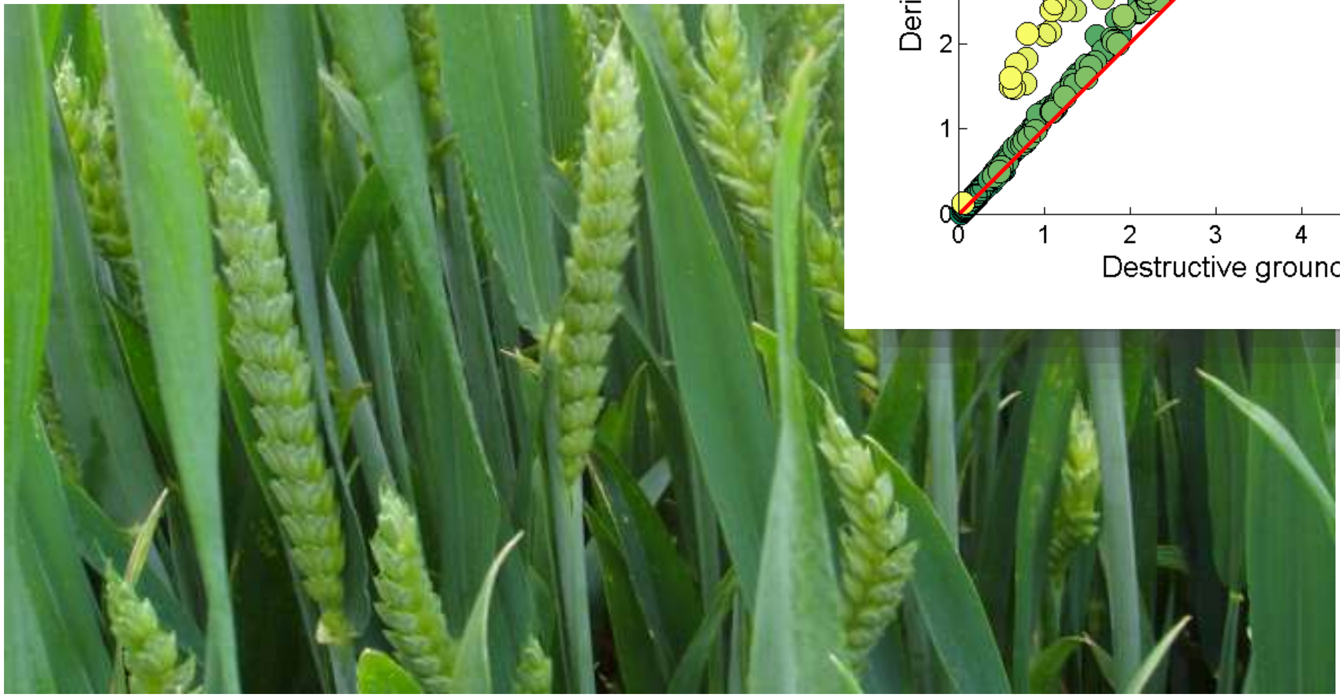
Yan & Hunt (1999)
Annals of Botany

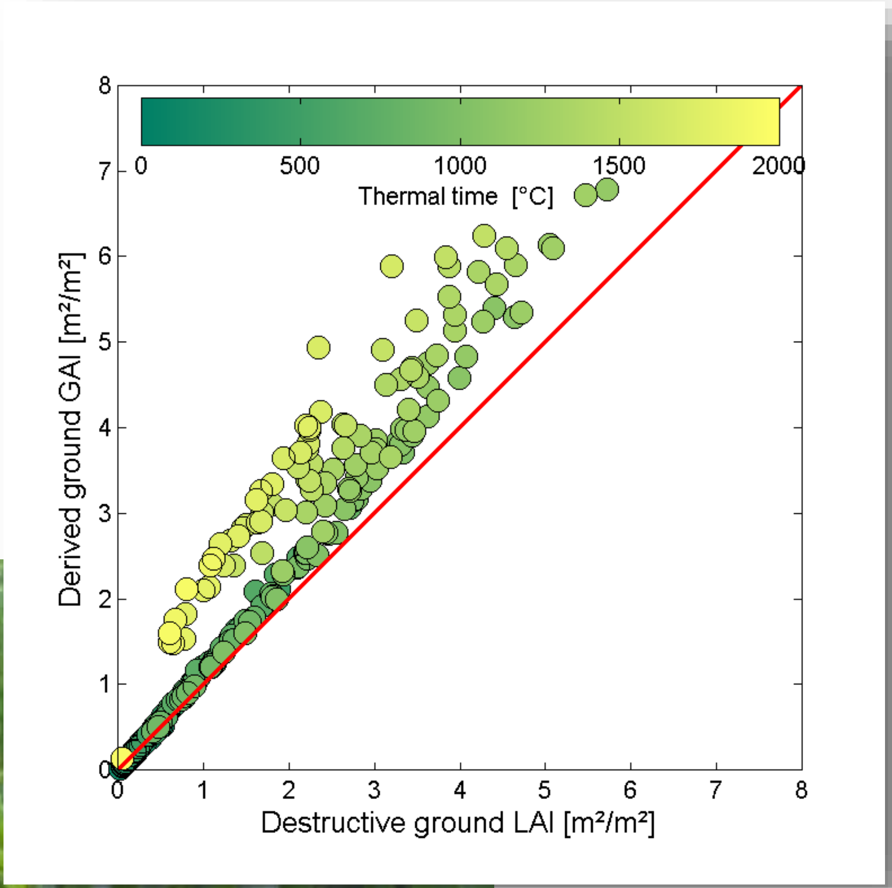


Measured relative rates of all development or growth of maize, together with predicted relative rates based on a single curve with $T_{max} = 41$ and $T_{opt} = 31$ °C.

Green Area Index (GAI)

- *GAI = LAI + SAI + EAI*

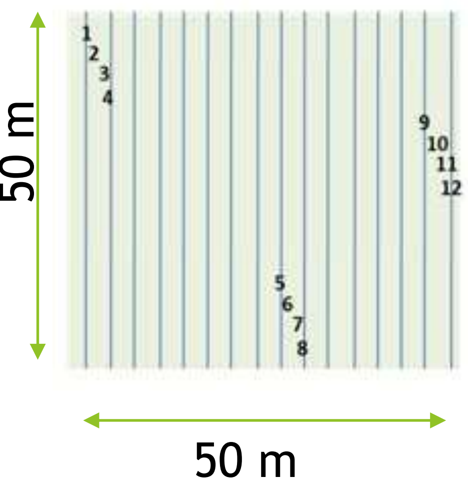


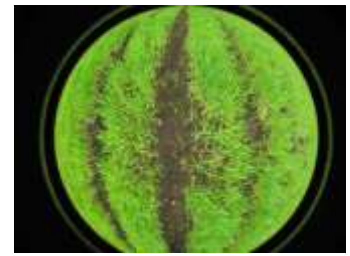


LAI field campaign protocol

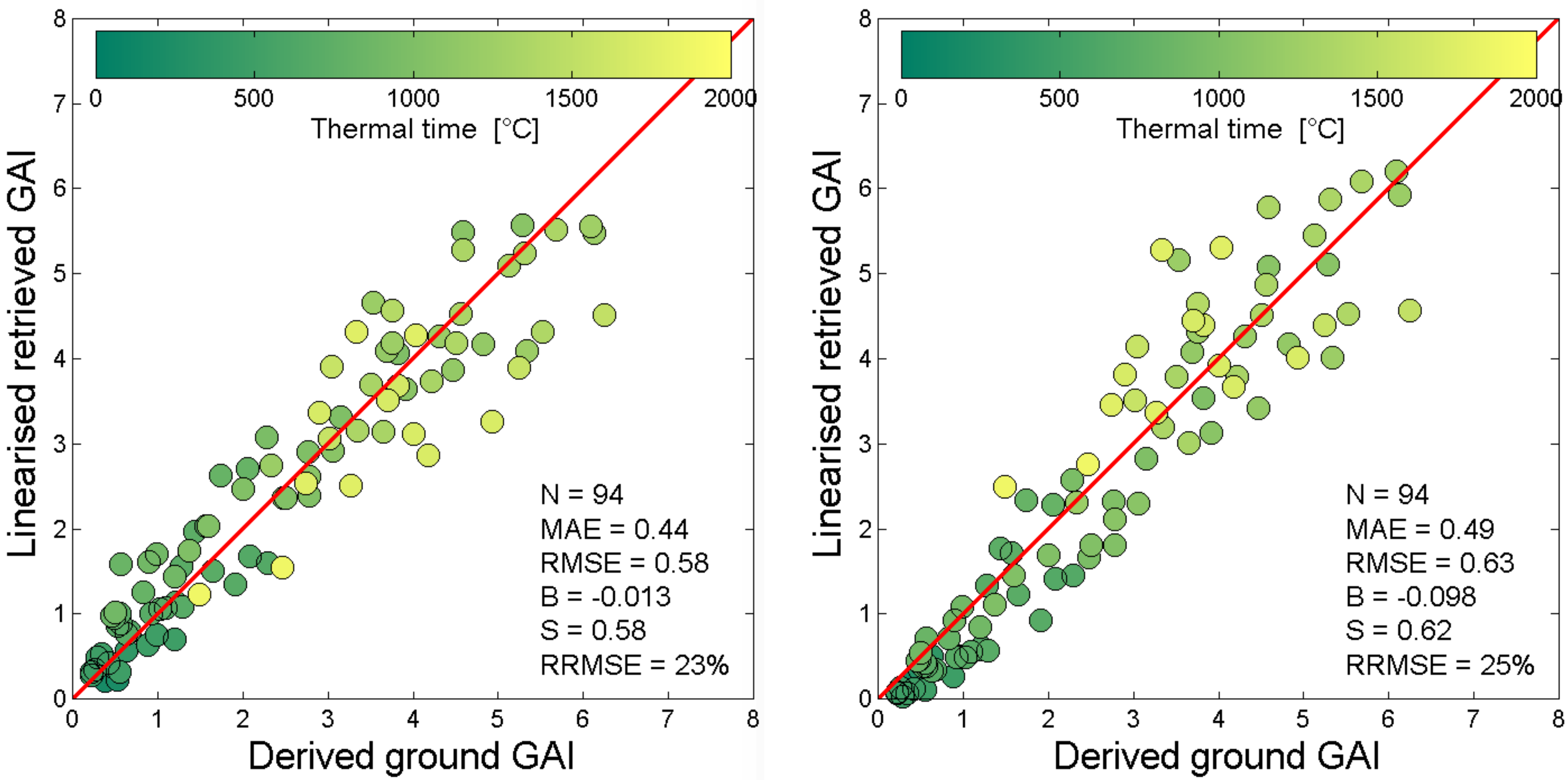
Within field sampling

- Leaf Area Inde (LAI)
- Canopy cover



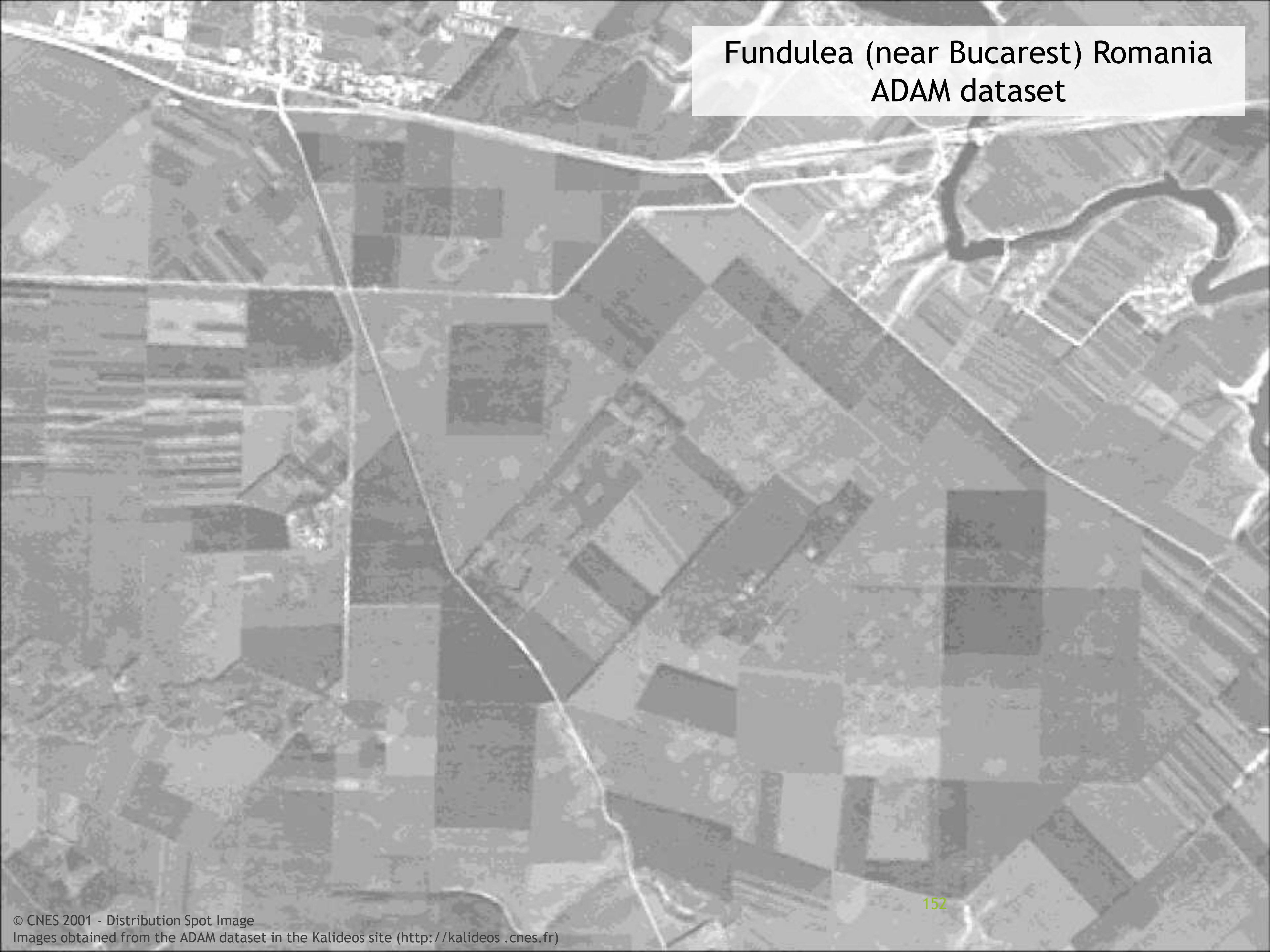


Empirical vs. Physical (hybrid) methods



- Stepwise multiple regression based on ground data for calibration
- NNT inversion of RTM requiring no ground data and therefore transposable to other landscapes

Fundulea (near Bucarest) Romania
ADAM dataset




Mar. 17, 2001
GAI estimation on winter wheat fields from SPOT 20 m imagery
GAI = 6
GAI = 3
GAI = 0
© CNES 2001 - Distribution Spot Image
Images obtained from the ADAM dataset in the Kalideos site (http://kalideos .cnes.fr)


Apr. 4, 2001
GAI = 6
GAI = 3
GAI = 0

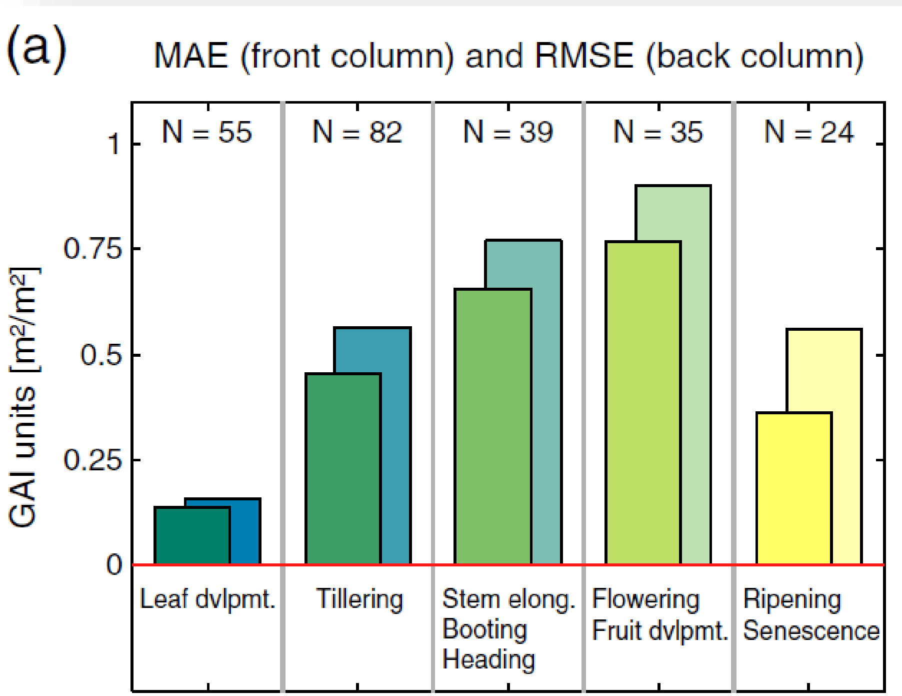

Apr. 12, 2001
GAI = 6
GAI = 3
GAI = 0

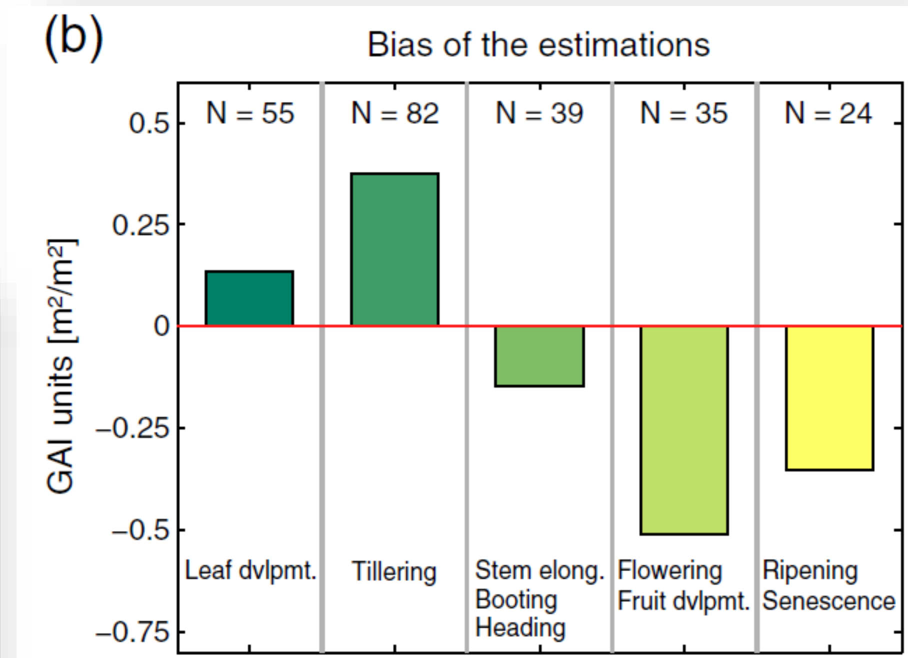

May 3, 2001
GAI = 6
GAI = 3
GAI = 0

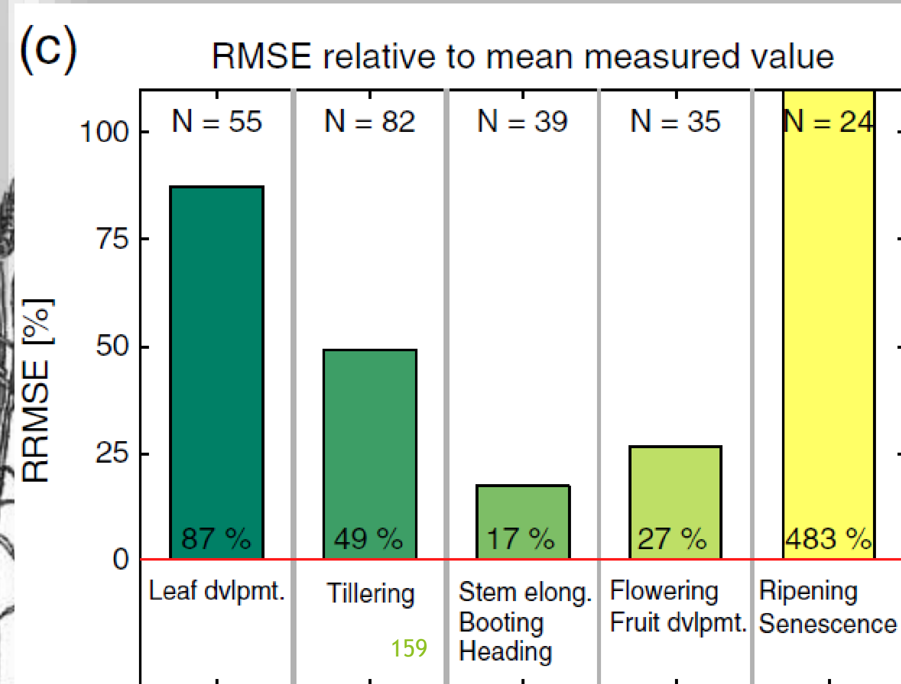

May 9, 2001
GAI = 6
GAI = 3
GAI = 0

May 24, 2001

Performance along the growing season







Duveiller et al., 2012

Sen2-Agri single date LAI map from Sentinel-2

21 March 2016…

Sen2-Agri single date LAI map from Sentinel-2

21 March 2016… **10 April 2016…** **20 April 2016…**

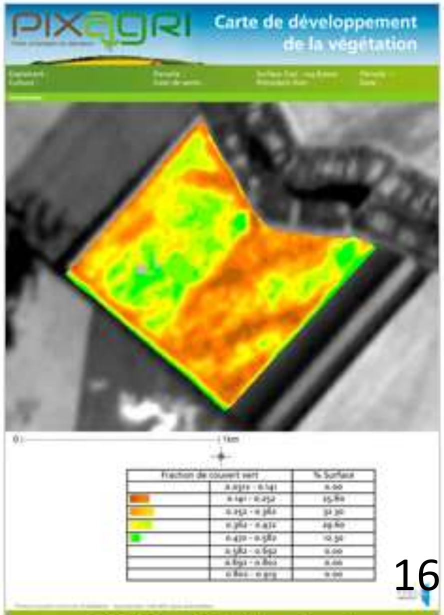
GreenSat: N-rate calculation for spring wheat using NDVI maps derived from SPOT satellite

(from B. Gerard, 2013)

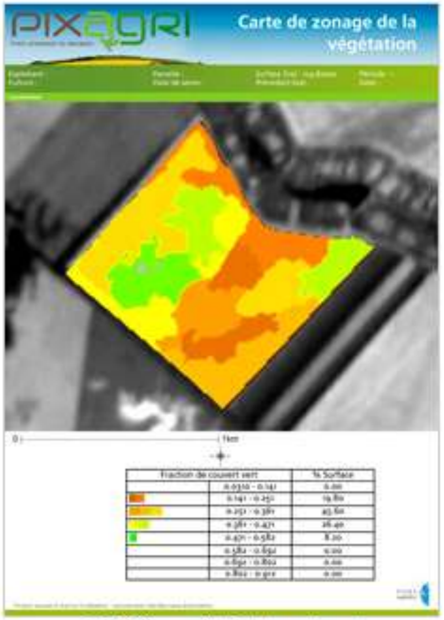
PixAgri map products pinpoint temporal and spatial variations in plant cover characteristics between fields or at sub-field level. These maps support diagnosis of crop condition across all fields and tracking of changes throughout the growing campaign.

crop monitoring process (click to enlarge)

maps delimit uniform areas within fields and can be used in particular to adjust application of inputs.



GLCV map (click to enlarge)



ZGLCV map (click to enlarge)

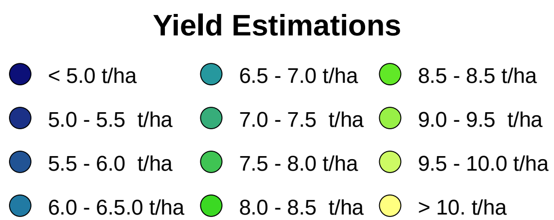
sentinel-2

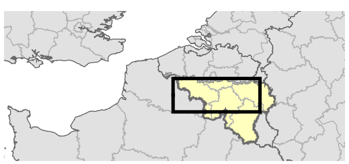
+ AGRICULTURE

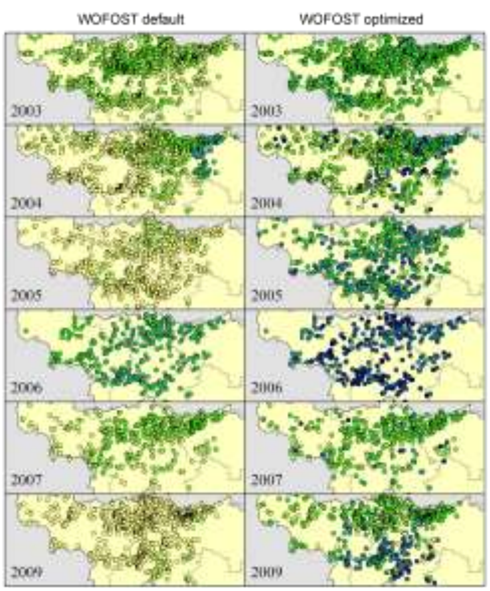
Research challenge

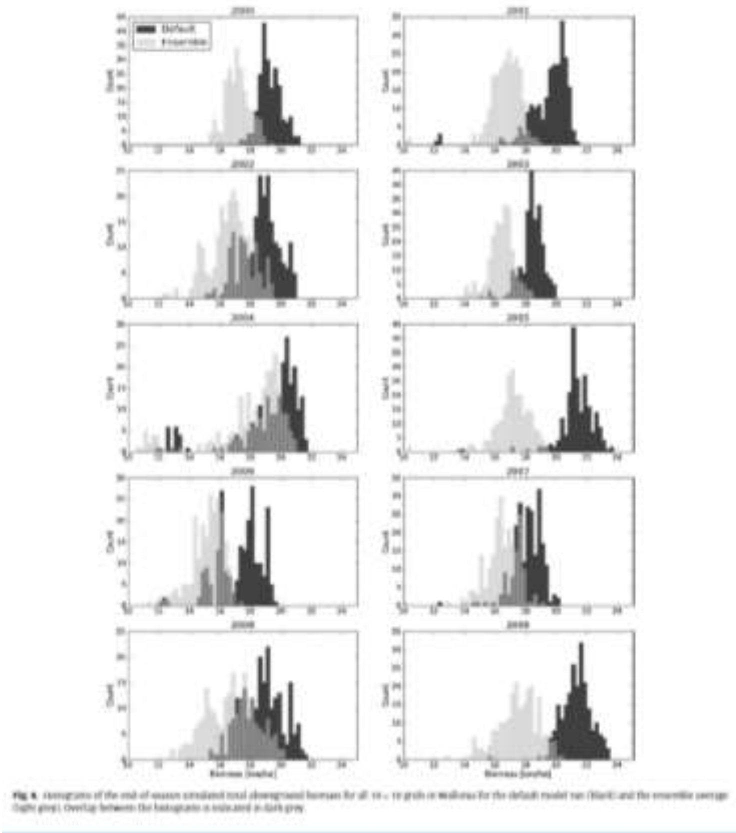
To delevop **yield model by assimilation of biophysical variables retrieved by EO into crop growth model**

Improved wheat yield estimate by assimilating of 250m LAI in WOFOST growth model
but not always (10-y analysis) !









GLOBAM (BELSPO)
Duveiller et al., AFM2012
De Witt et al., AFM2012

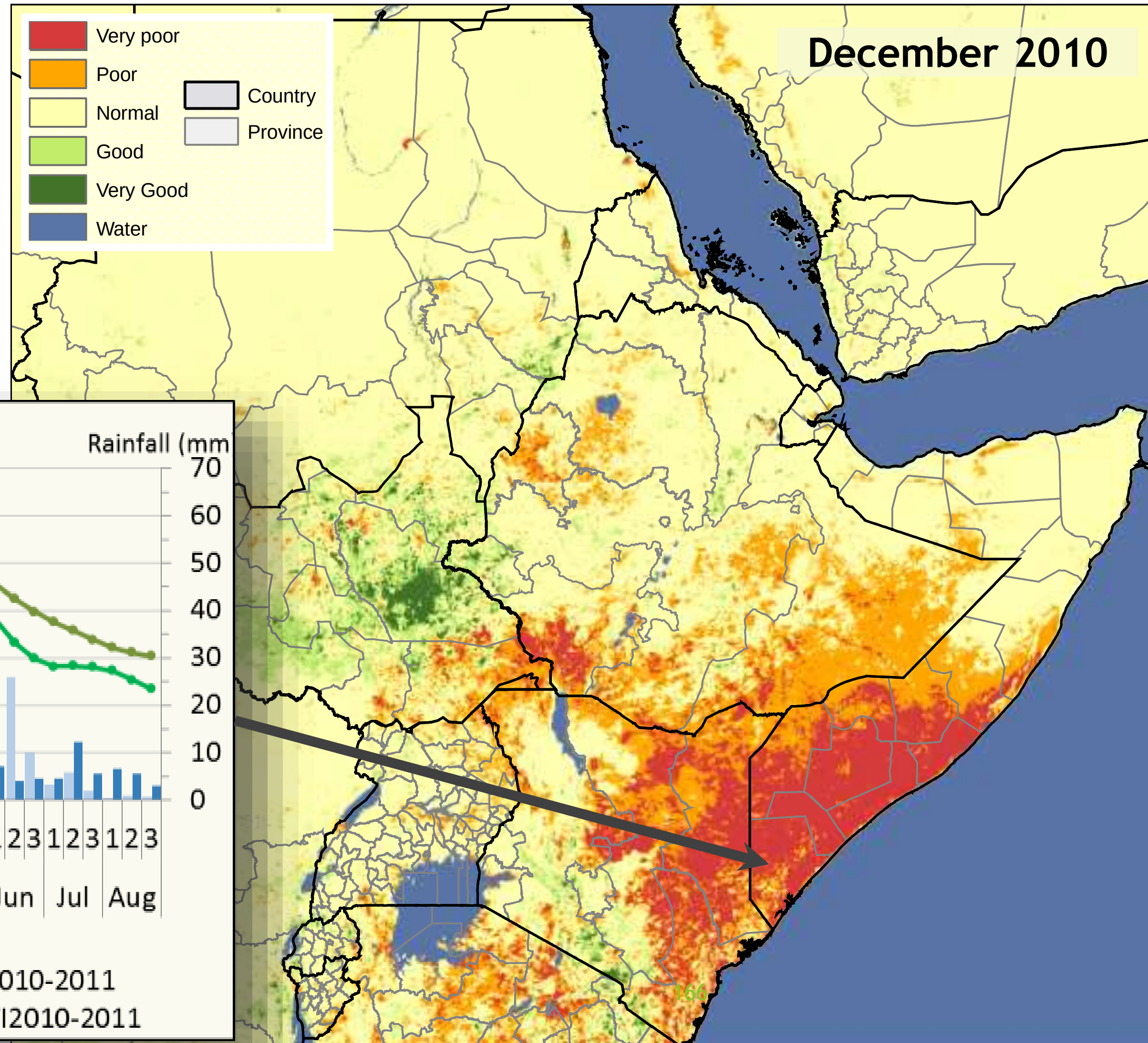
Outline

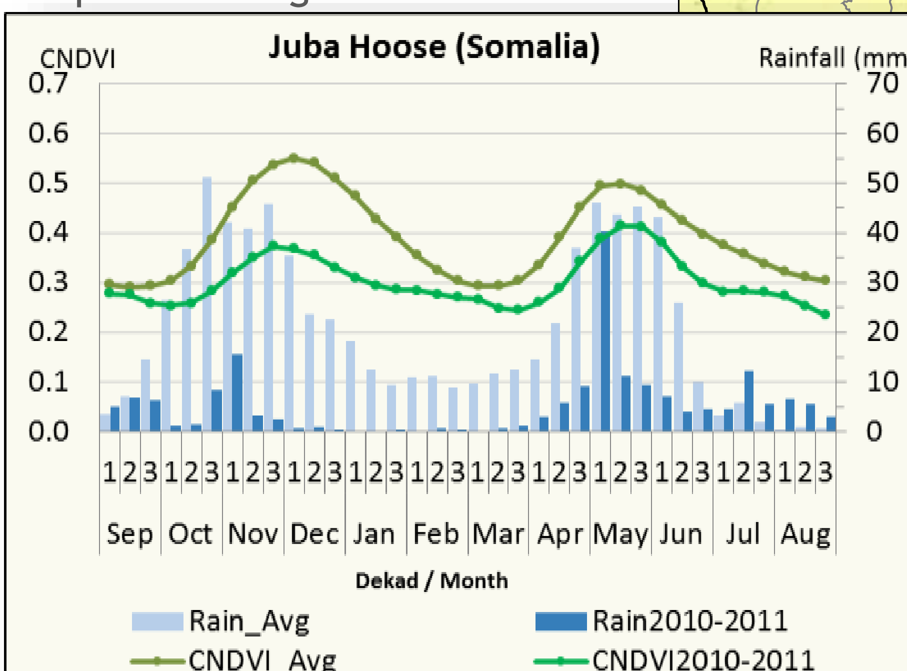
1. Introduction to optical land applications :
2. Basic principles about electromagnetic radiation & land surface
3. Identifying cultivated area and crops from space (Sen2-Agri system)
4. Estimating canopy biophysical variables (Sen2-Agri system)
5. **Example of monitoring crop production from space** (JRC-MARS)

Crop growth monitoring

- To detect anomalies in food insecure countries

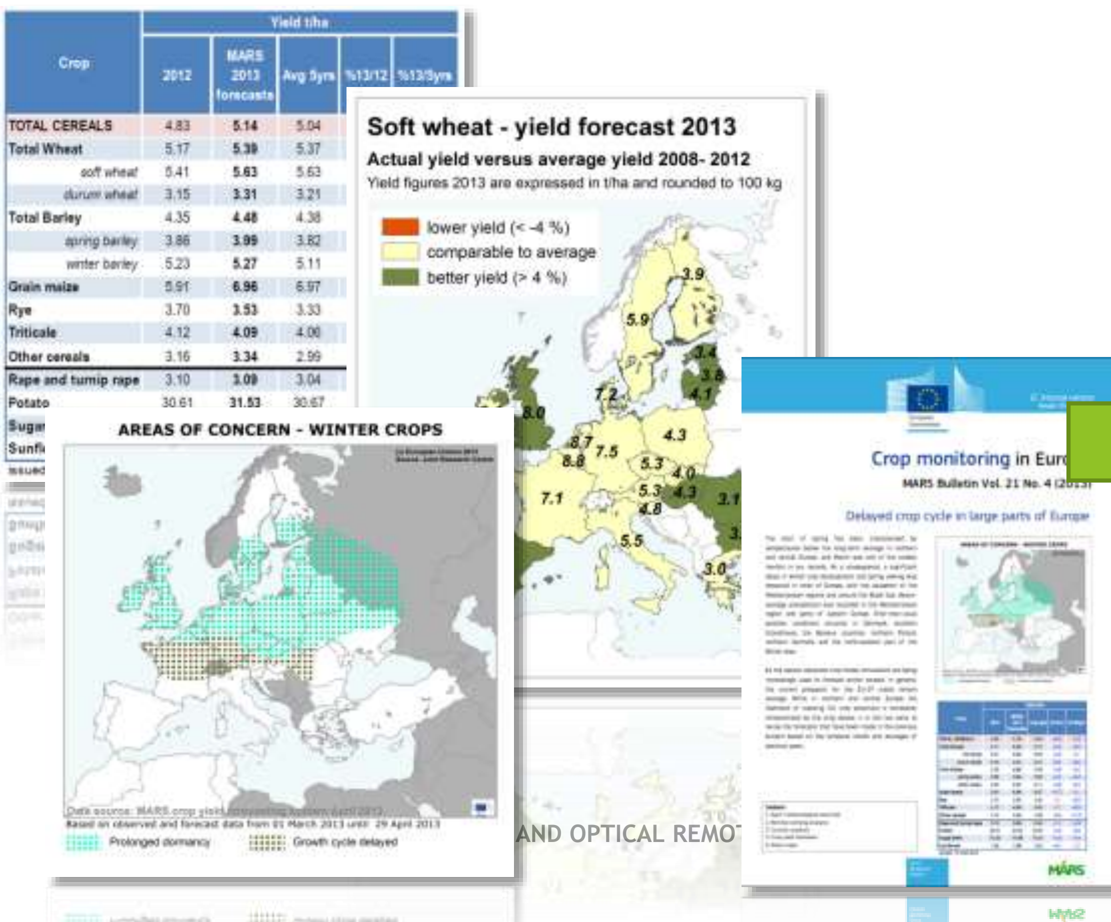
NDVI and Rainfall profiles
Sep 2010 - Aug 2011





JRC-MARS Crop yield forecasting system (MCYFS)

- Operational service to provide agriculture intelligence for major crops for EU decision making process on market intervention and policy support



Crop	Yield t/ha 2012	MARS 2013 forecasts	Avg 5yrs
TOTAL CEREALS	4.83	5.14	5.04
Total Wheat	5.17	5.39	5.37
soft wheat	5.41	5.63	5.63
durum wheat	3.15	3.31	3.21
Total Barley	4.35	4.48	4.38
spring barley	3.86	3.99	3.82
winter barley	5.23	5.27	5.11
Grain maize	5.91	6.96	6.97
Rye	3.70	3.53	3.33
Triticale	4.12	4.09	4.06
Other cereals	3.16	3.34	2.99
Rape and turnip rape	3.10	3.09	3.04
Potato	30.61	31.53	30.67

Decision Makers

Courtesy G. Duveiller

JRC-MARS Crop yield forecasting system (MCYFS)

- Challenge of yield forecasting…

Courtesy G. Duveiller

JRC-MARS Crop yield forecasting system (MCYFS)

- Current operational set-up

Meteorological infrastructure

↓

Crop simulation infrastructure

↓

Statistical infrastructure

Remote sensing infrastructure

TEAM of ANALYSTS

IT support TEAM

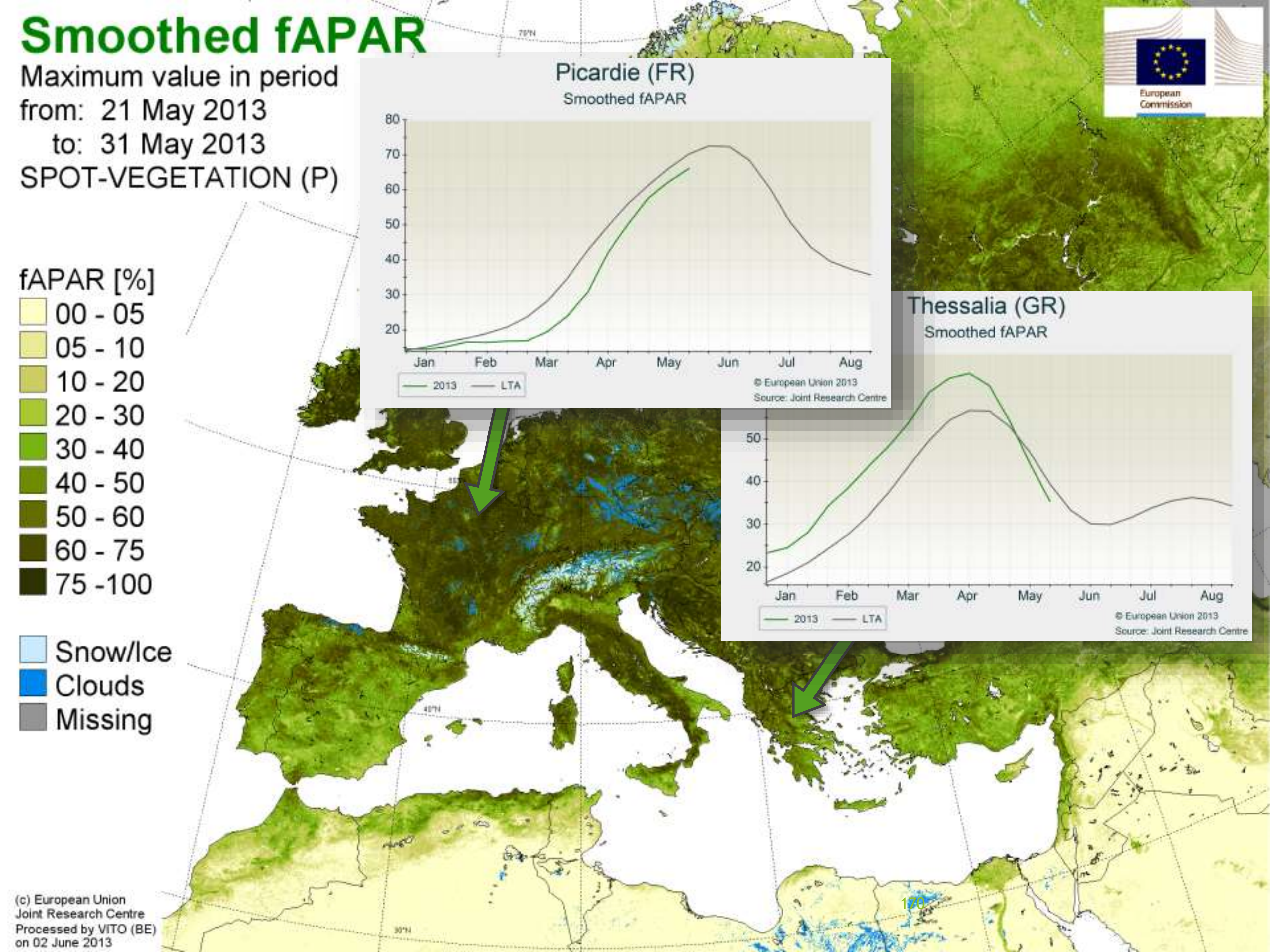
Operational data processing
by Alterra, VITO & MeteoConsult


Crop monitoring in Europe

MARS Bulletin Vol. 21 No. 4 (2013)

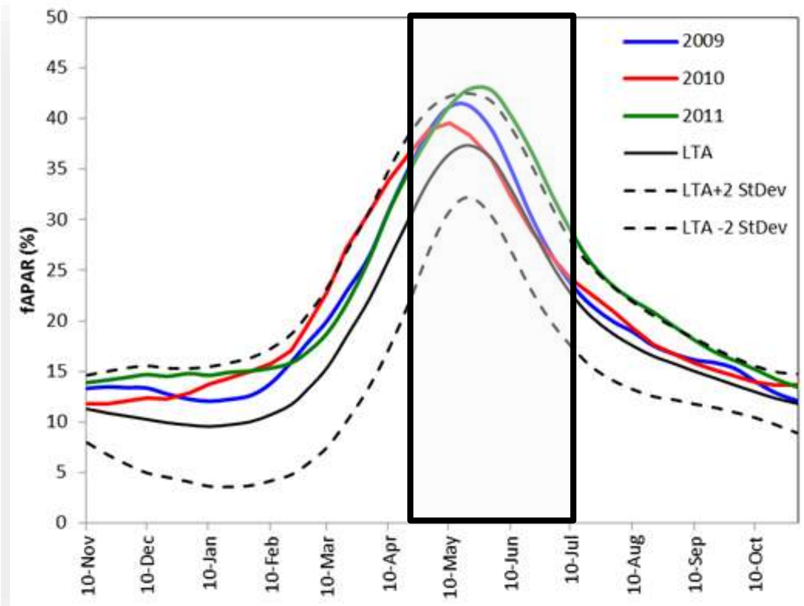
Delayed crop cycle in large parts of Europe

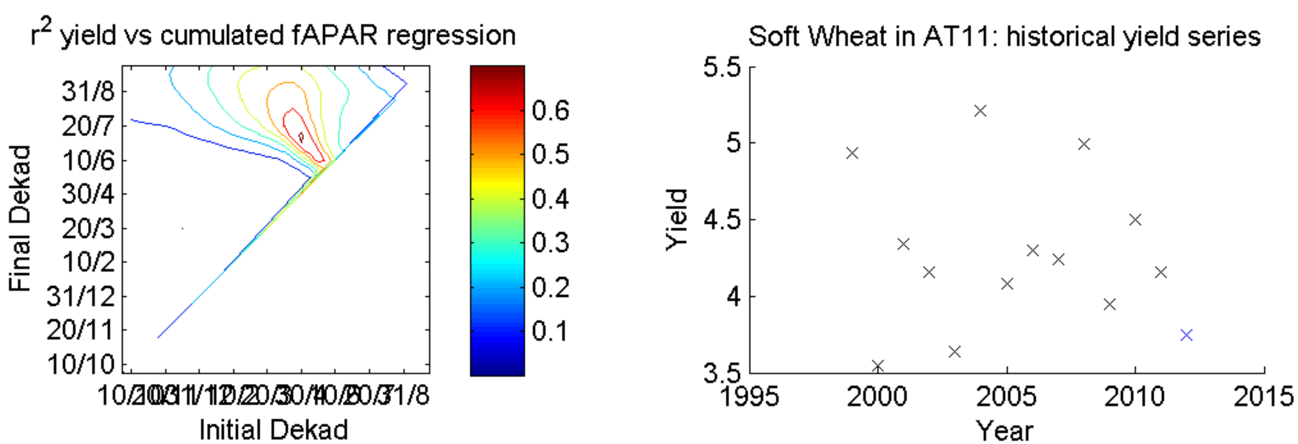
Courtesy G. Duveiller


Smoothed fAPAR
Maximum value in period
from: 21 May 2013
to: 31 May 2013
SPOT-VEGETATION (P)
fAPAR [%]
00 - 05
05 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 75
75 -100
Snow/Ice
Clouds
Missing
(c) European Union
Joint Research Centre
Processed by VITO (BE)
on 02 June 2013
European Commission
Picardie (FR)
Smoothed fAPAR
80
70
60
50
40
30
20
Jan Feb Mar Apr May Jun Jul Aug
2013 LTA
© European Union 2013
Source: Joint Research Centre
Thessalia (GR)
Smoothed fAPAR
50
40
30
20
Jan Feb Mar Apr May Jun Jul Aug
2013 LTA
© European Union 2013
Source: Joint Research Centre

Yield forecasting with regression of RS

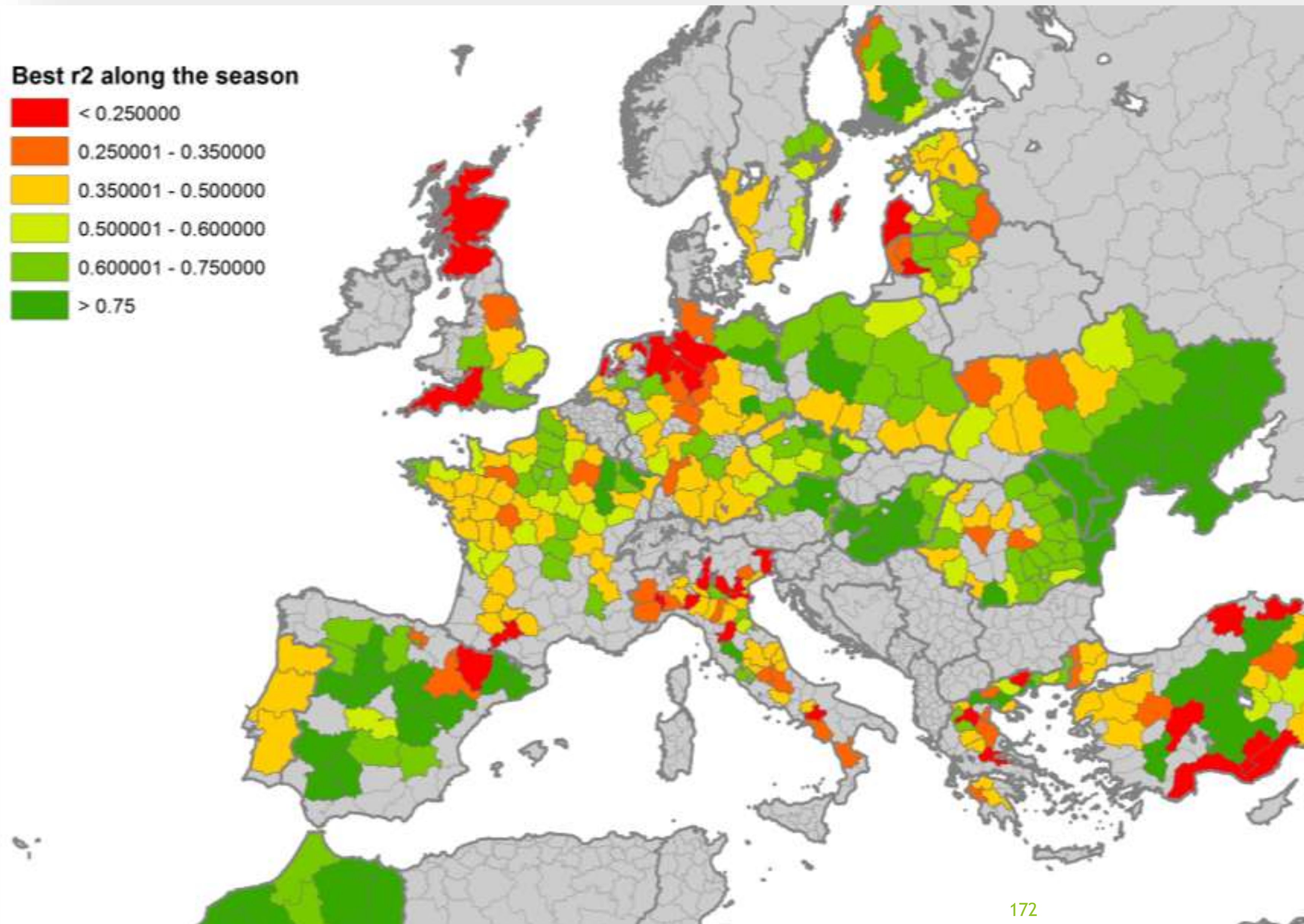
- Regression constructed between
  - Historical yield data from 1999-2011
  - Cumulated fAPAR over a given (optimal) window





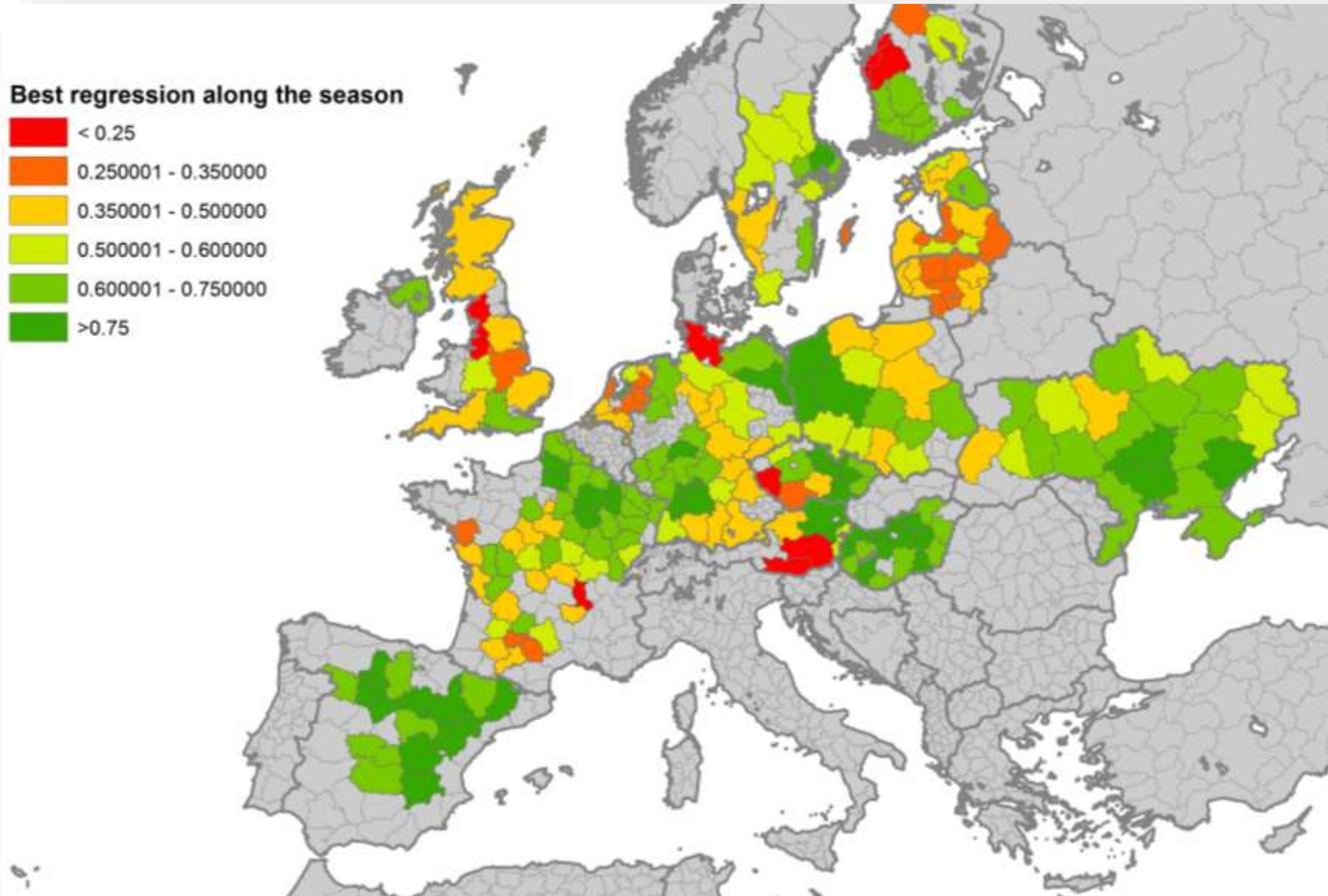
Courtesy G. Duveiller

Soft Wheat: R^2 between fAPAR and yields



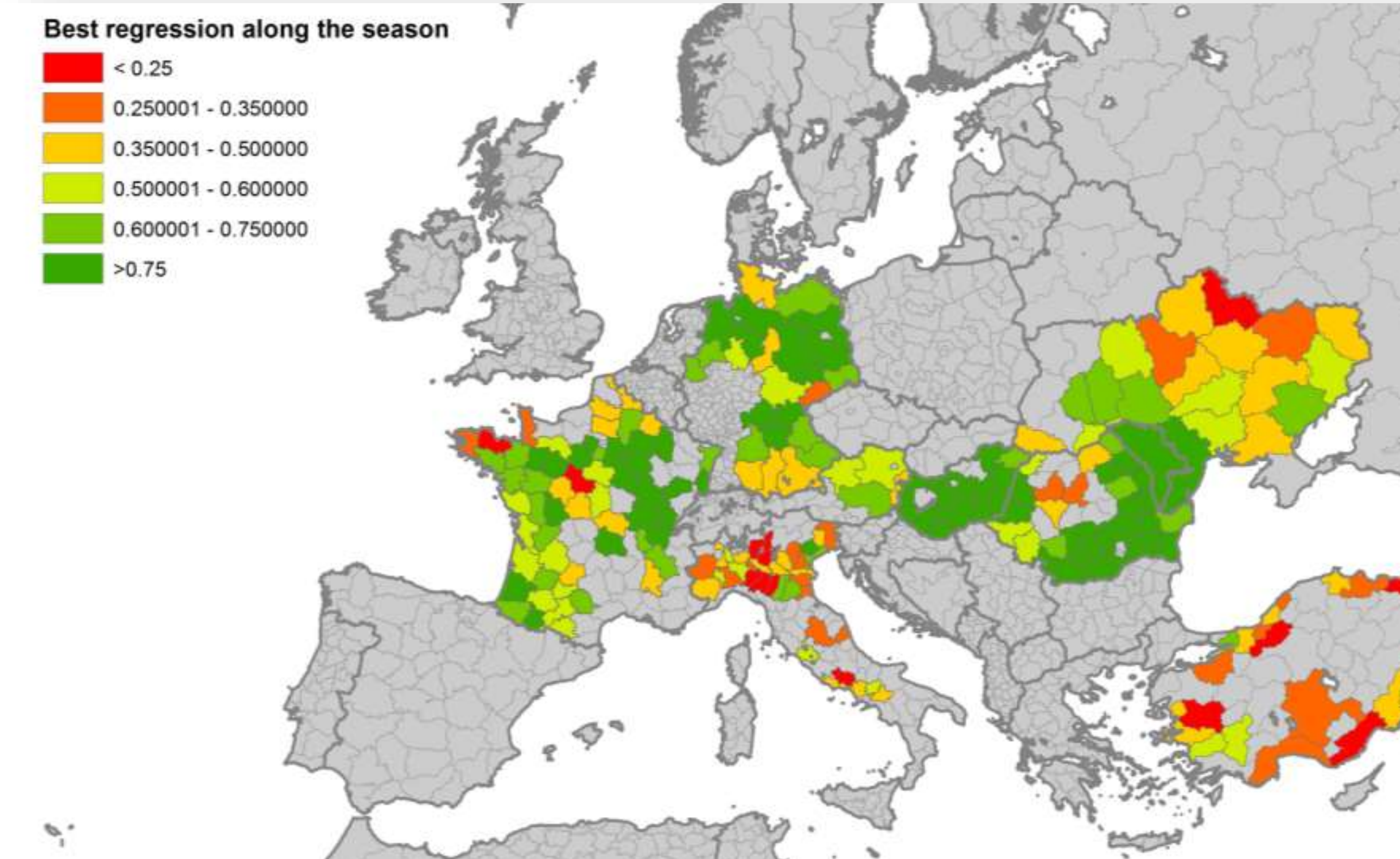
Courtesy G. Duveiller

Spring Barley: R^2 between fAPAR and yields



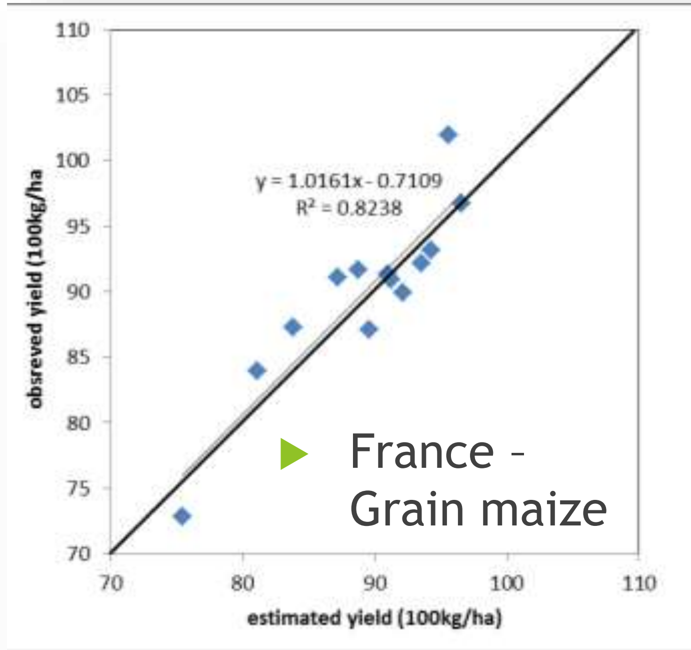
Courtesy G. Duveiller

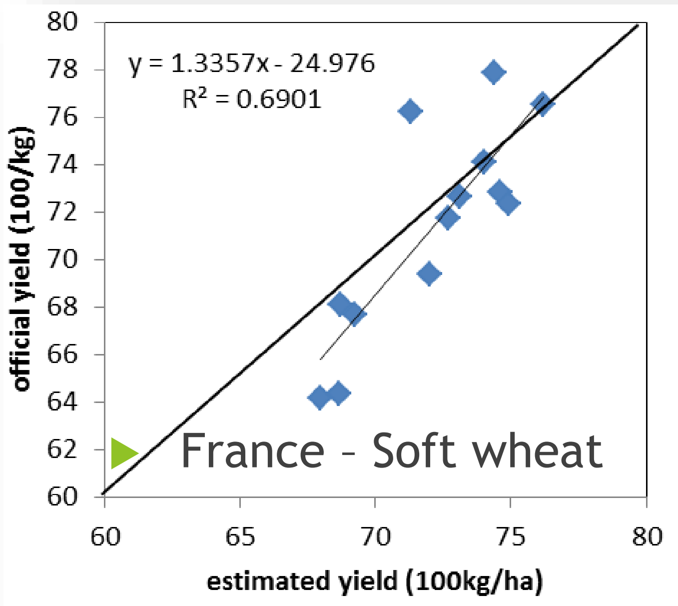
Grain maize: R^2 between fAPAR and yields

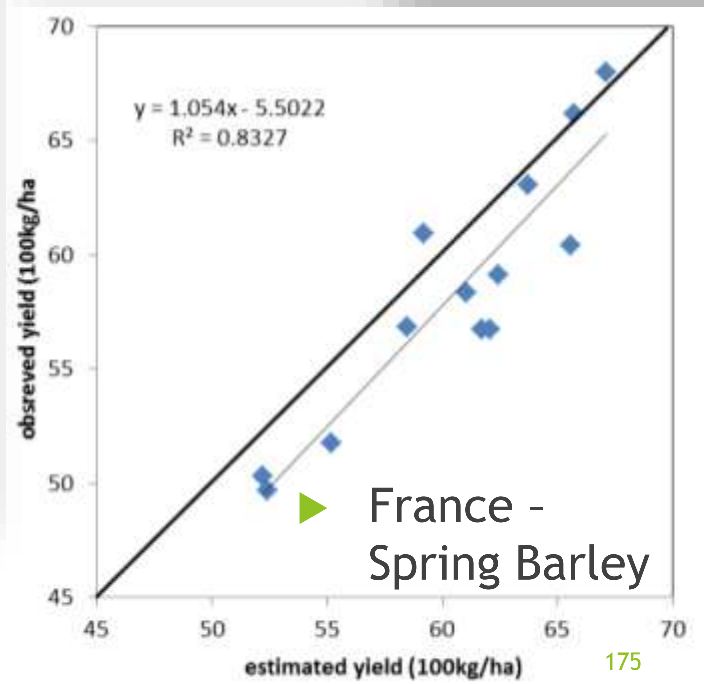


Courtesy G. Duveiller

Forecasts at NUTS3 level are then aggregated at NUTS0 and compared with official yields







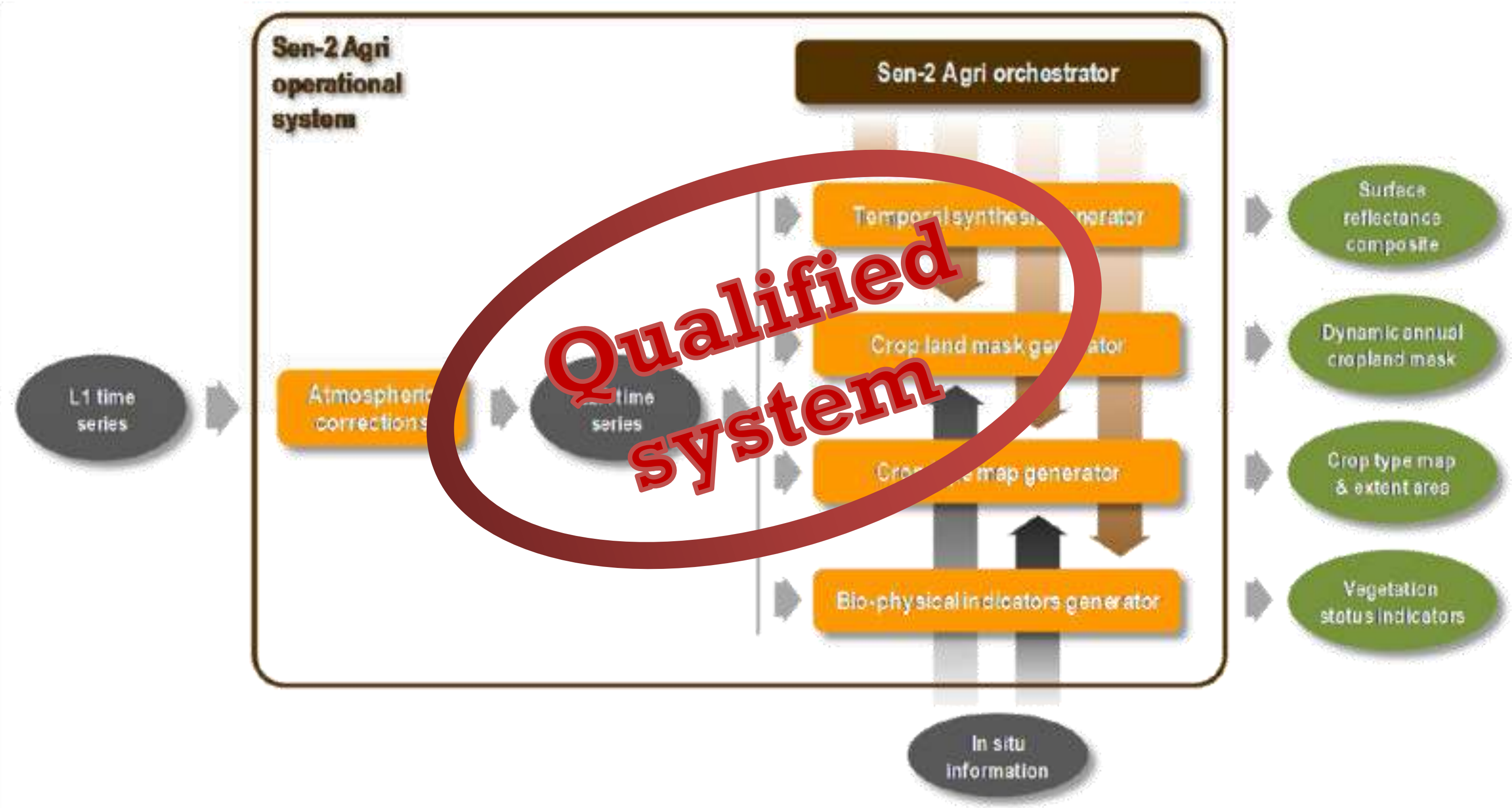
Courtesy G. Duveiller

Optical RS Requirements for crop monitoring & yield forecasting

- **Near real-time high temporal frequency data**
- **An adequate spatial resolution to have a crop specific signal**
- **Long term warranty on data continuity**
- **Interoperability of products**

Demonstration phase : hopefully completed by Spring 2017 with system qualification

Planning : release of a qualified Sen2Agri system as open source code downloadable and documented



sentinel-2
+ AGRICULTURE

Summary to turn Sentinel in game changer

- **Analysis-ready time series from Sentinel-2 and Landsat-8** to focus on scientific development rather than data preparation

- **Cloud computing facilities** for EO research community

- **Great potential of Sentinel1a&b** to be further investigated for agriculture if appropriate acquisition plan is decided

- **Outstanding potential to be developed for a synergistic use** of Sentinel-2a&b and Sentinel-1a&b, plus 100-m daily optical observation time series

- **Sentinel era should achieve the long-awaited operational applications** in ag. :

  annual cropland mapping, *crop specific growth monitoring,*
  crop type mapping at the accuracy required for ag. statistics

Thank you for your attention