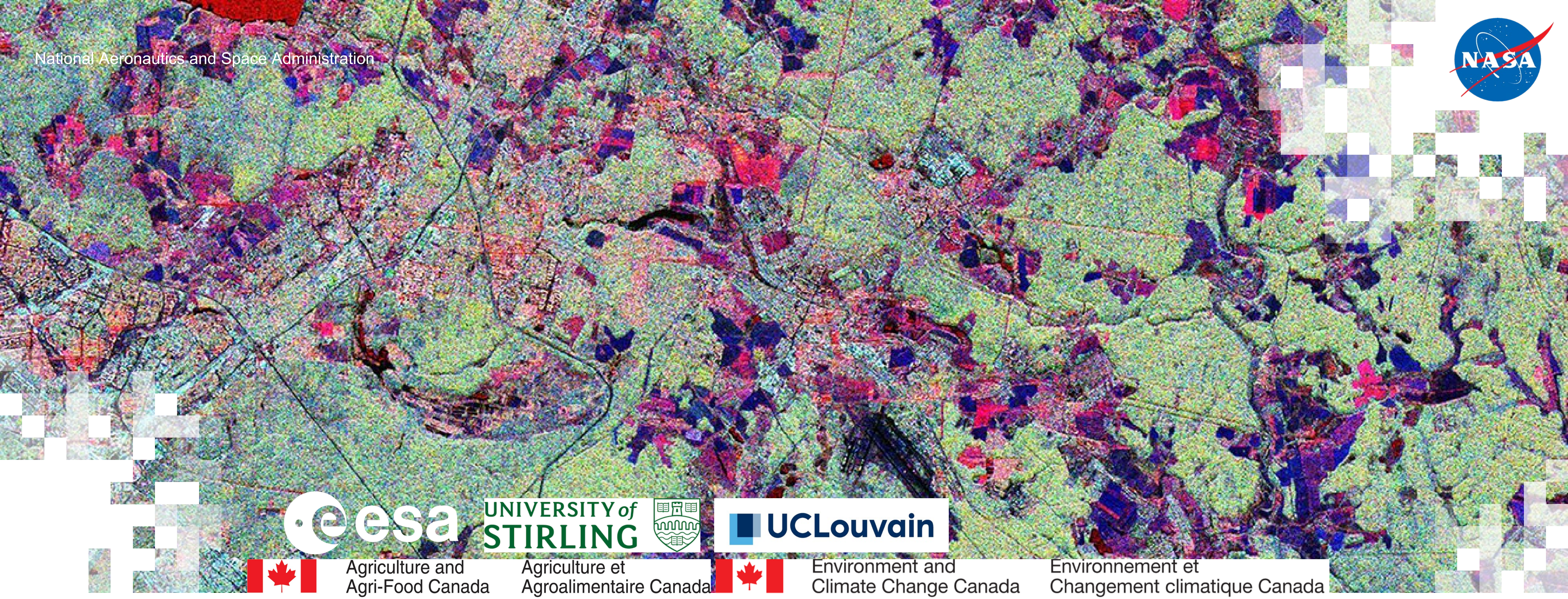


Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada
Environment and Climate Change Canada
Environnement et Changement climatique Canada

Mapping Crops and their Biophysical Characteristics with Polarimetric Synthetic Aperture Radar and Optical Remote Sensing

Part 3: Sen4Stat Open-Source Toolbox for Large Scale Crop Mapping (Theory and Practical)

Pr. Pierre Defourny (UCLouvain)

26 April, 2022

Training Outline

12 April

Part 1: SAR Polarimetry for Agriculture (Theory and Practice)

19 April

Part 2: Practical SAR Polarimetry with Sentinel-1, RCM, & SAOCOM Imagery for Agriculture

April 26

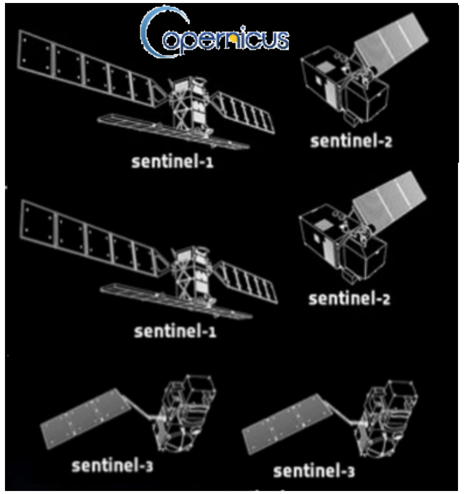
Part 3 - Sen4Stat Open-Source Toolbox (Theory and Practical)

May 3

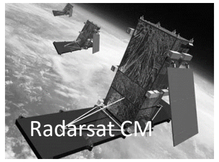
Part 4: Crop-Specific Time Series Analysis for Growth Monitoring

Table of Contents

New satellite missions and IT (r)evolutions have changed the game for agriculture

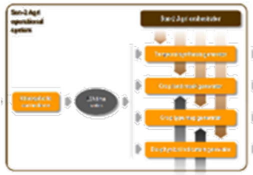


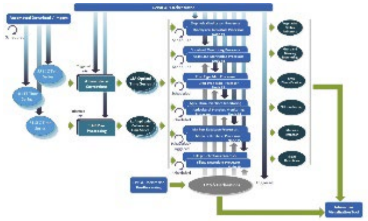
Free, open and long term data policy (US, EU,...)

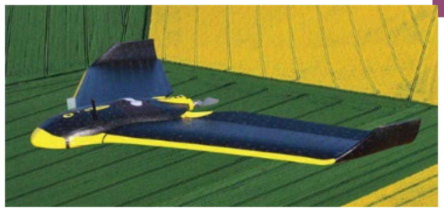


Sen2-Agri sen4cap common agricultural policy Sen4Stat

Open source processing tools using ML & AI algo.







CEOS

Coordination for EO systems redundancy & harmonization

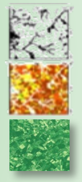
JECAM GEOGLAM Global Agricultural Monitoring

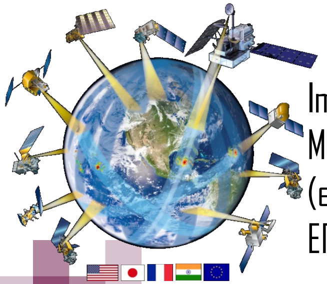
Joint Experiment for Crop Assessment and Monitoring

Global network with cross site experim.

EO ag. products => (intra-) field level

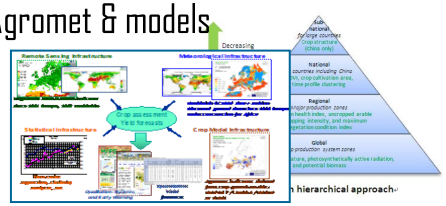
1. Cropland mapping
2. Crop type mapping
3. Biophys. variables (fCover, LAI, fAPAR,..)
4. Crop condition monitoring
5. Ag. practices monitoring





Improved Meteo Data (e.g. GPM, ERAS,...)

Agromet & models



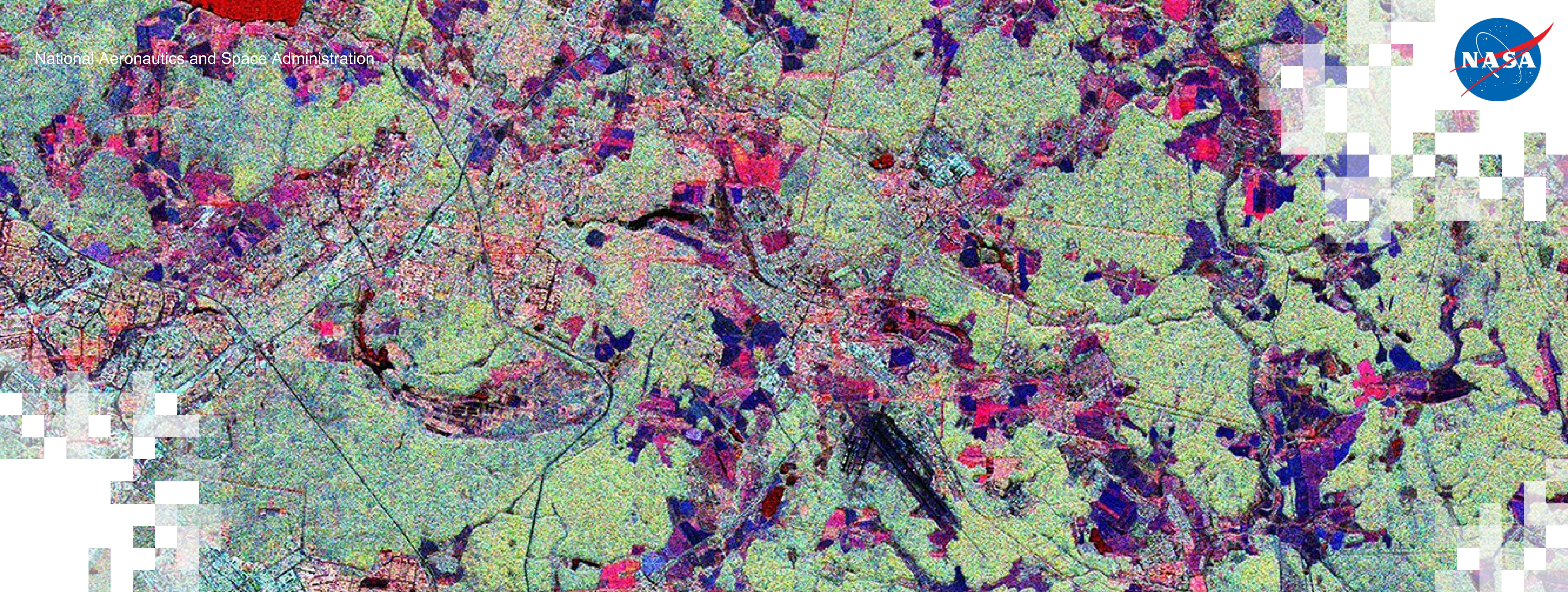
How to take advantage of Copernicus Sentinel-1 and Sentinel-2 data for crop mapping at national scale?

NASA's Applied Remote Sensing Training Program

UCLouvain


0 days 00 hours 00 minutes
Sentinel-2 constellation:
summer solstice

National Aeronautics and Space Administration



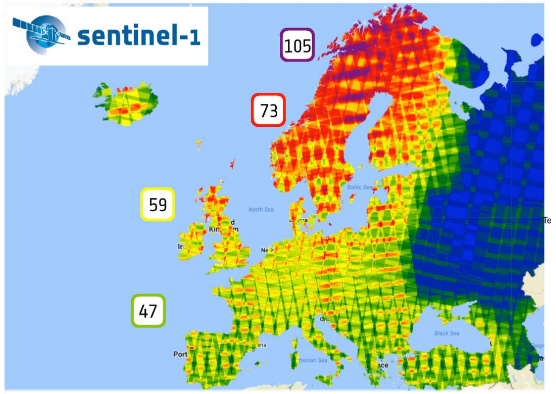
Section 1: Challenges for large scale crop mapping at high spatial resolution

Challenges for large scale mapping

In addition to large data volume and the IT requirements

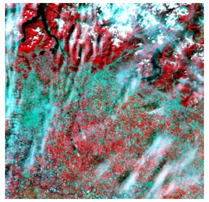
- Observing satellite systems at high resolution do not cover large area at once
  - Sentinel-2 instrument swath: 290 km
  - Sentinel-1 interferometric wide swath mode: 250 km
  - Overlap between images acquired from adjacent orbit
  - Increasing overlap due to converging orbit to North Pole

  ⇒ **Heterogeneity of observation density** across the area



Nbr of observation dates by S-1A & -1B (July-Sept)

- Cloud coverage frequency quite variable (optical systems) and nonsystematic acquisition plan over space and time (optical and SAR systems)



  ⇒ **Heterogeneity of valid observation density** across the area

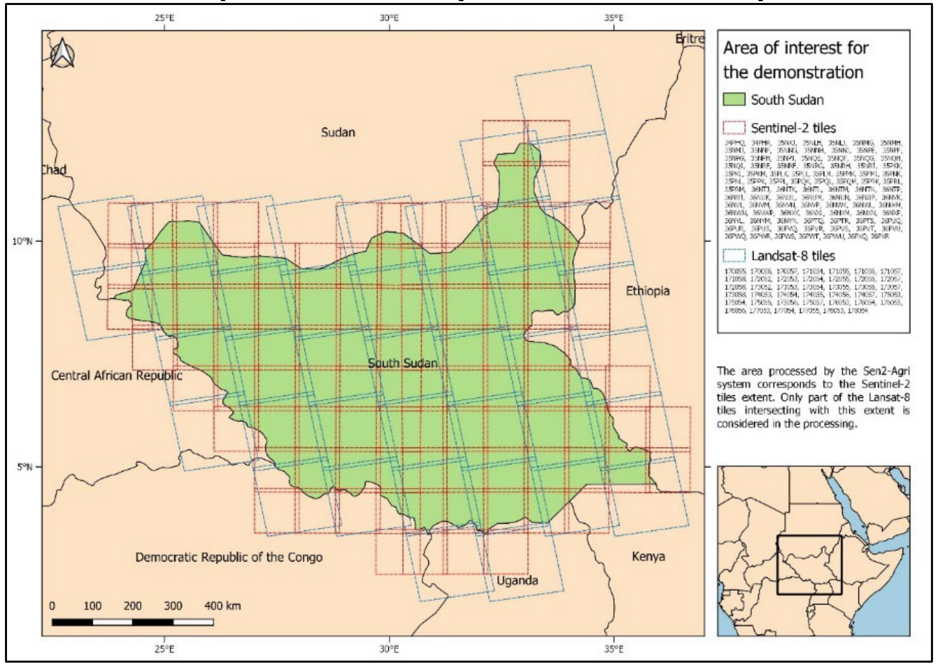
- Significant **agro-climatic gradients** introducing large variability in crop calendars and vegetation development across the area

Challenges for large scale crop mapping – *why is it so special?*

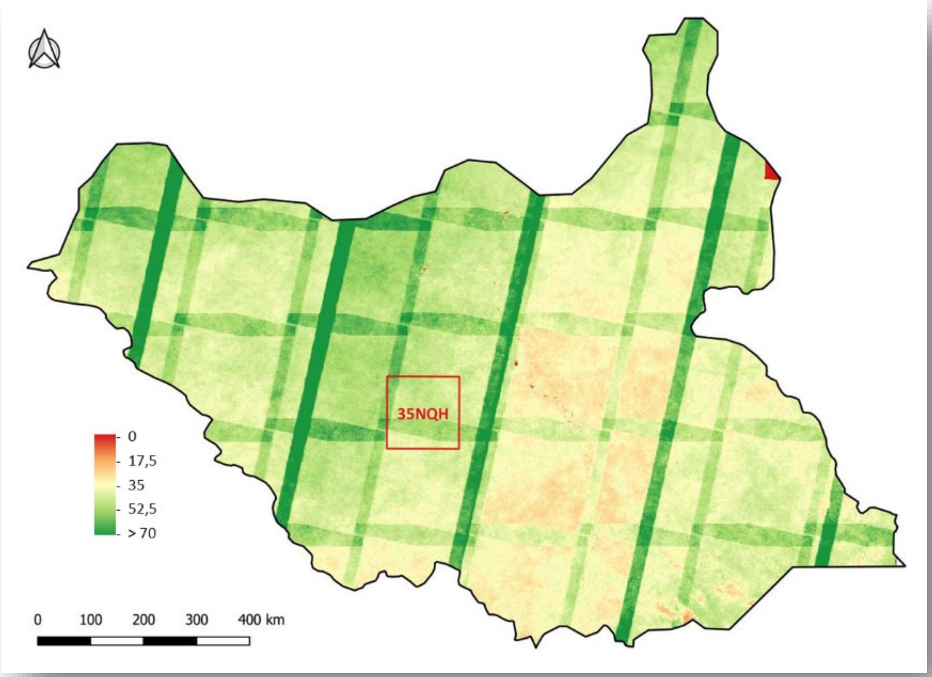
3 challenges already identified ***temporal resolution critical for crop discrimination***

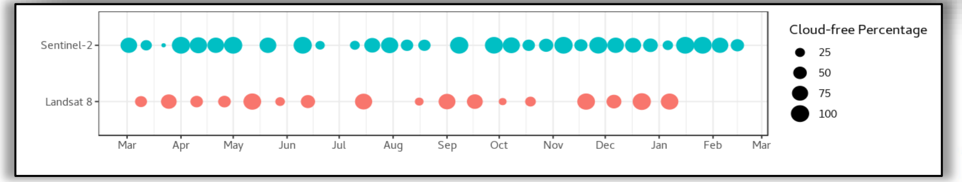
Example of South Sudan (619.745 km²)

Nbr of granules for satellite data: scenes (Landsat) and tiles (Sentinels)



Nbr of valid images (cloud cover < 10%) from March 2017 to Feb. 2018



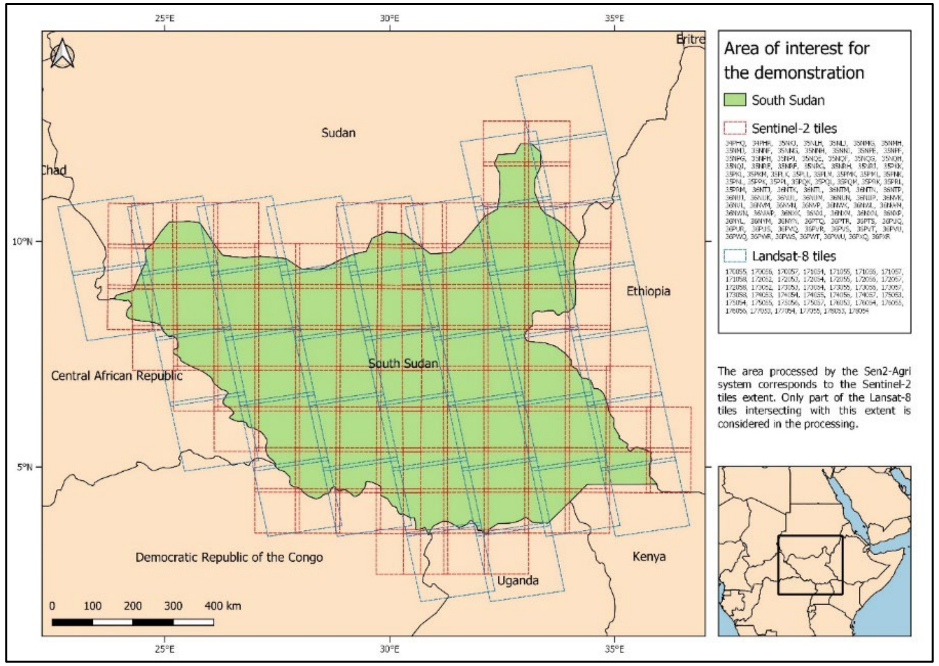


Challenges for large scale crop mapping

Example of South Sudan ***– first solution to cope with heterogeneous valid observ. density***

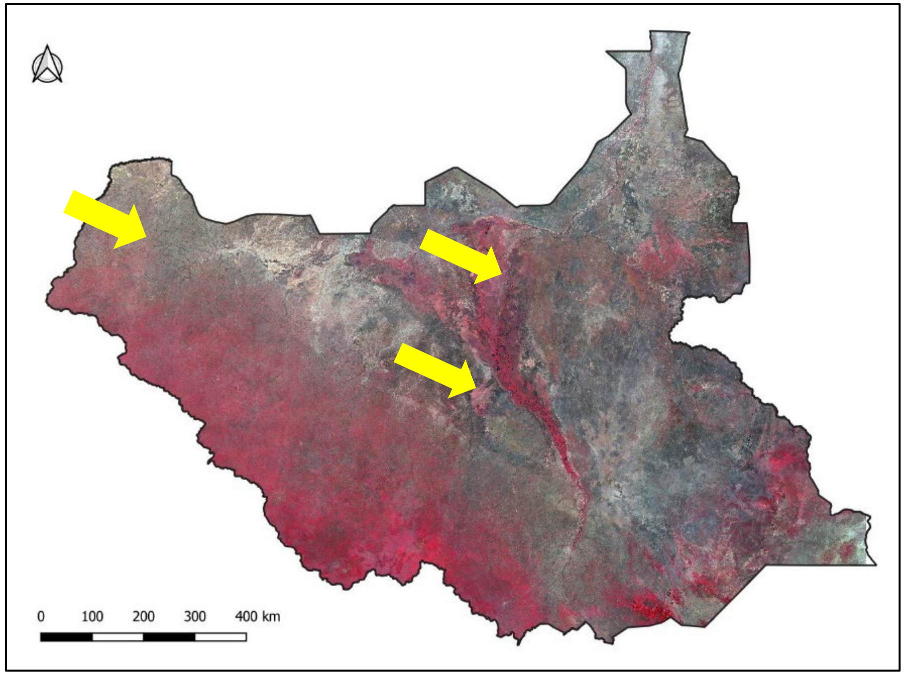
Nbr of granules for satellite data:

scene (Landsat) and tile (Sentinels)



Monthly synthesis (June 2017)

by averaging all cloud free reflectances

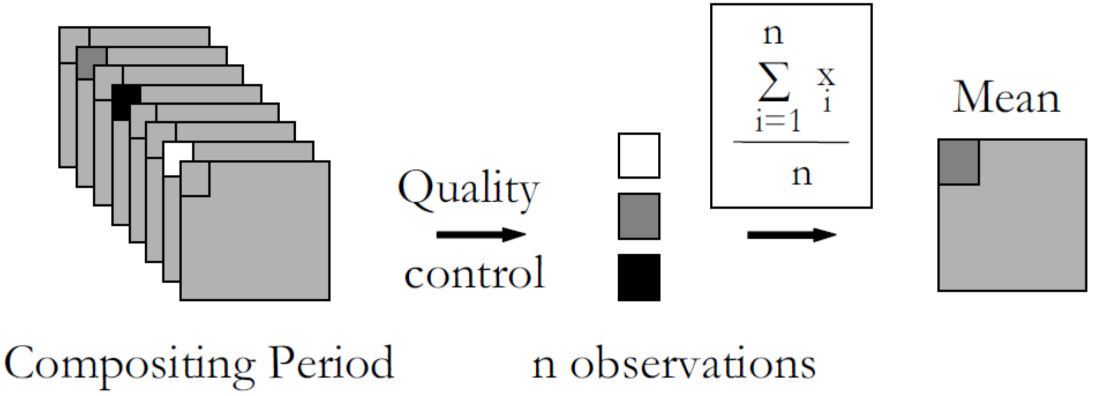


=> **artefacts** due to the variability of input data

=> **reduction of temporal resolution** to monthly

Challenges for large scale crop mapping

Temporal synthesis methods averaging all cloud free reflectances acquired during the period



$$\frac{\sum_{i=1}^{n} x_i}{n}$$

Comparison of temporal synthesis methods

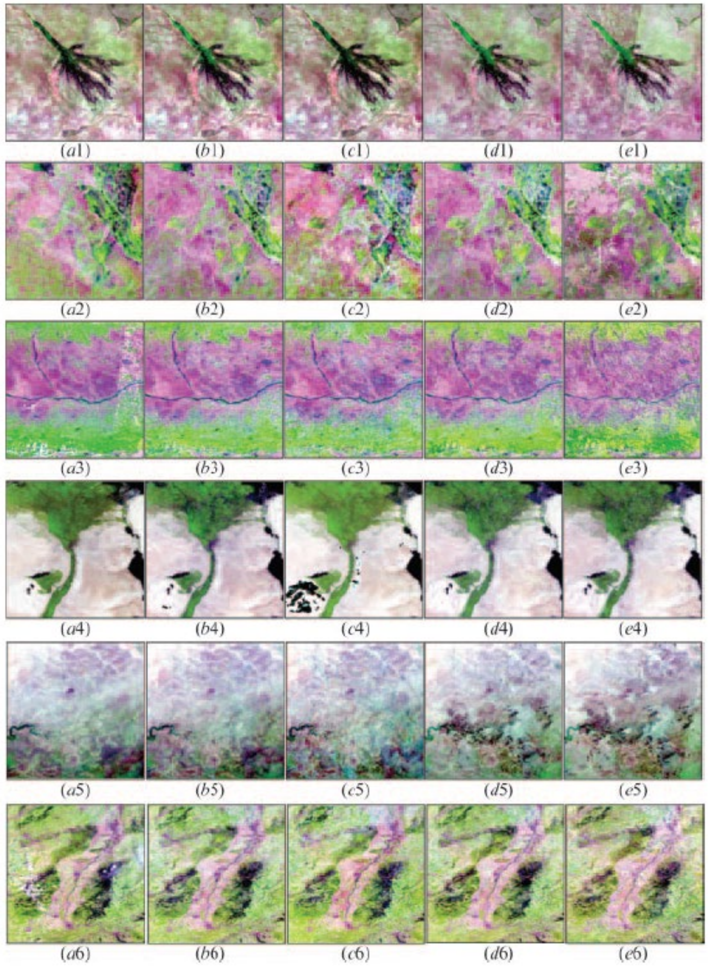


Figure 3. Visual comparison between the best could-free image of the decade (a), the MC (b), the BDC (c), the AVG (d) and the MVC (e) colour composites (SWIR, NIR, red), for 6 samples: (1) Botswana (1st decade of June 2002), (2) Sudan (1st decade of November 2002), (3) Romania (2nd decade of June 2002), (4) Egypt (1st decade of November 2002), (5) Senegal (1st decade of June 2002), and (6) Germany (2nd decade of June 2002). Available in colour online.

(Vancutsem et al., IJRS 2008)

Sen4Stat: Weighted Average Synthesis Processor

- weight as function of date (central date distance)
- weight as function of Aerosol Optical Thickness
- weight as function of distance to clouds
- weight as function of sensor (S2>L8)

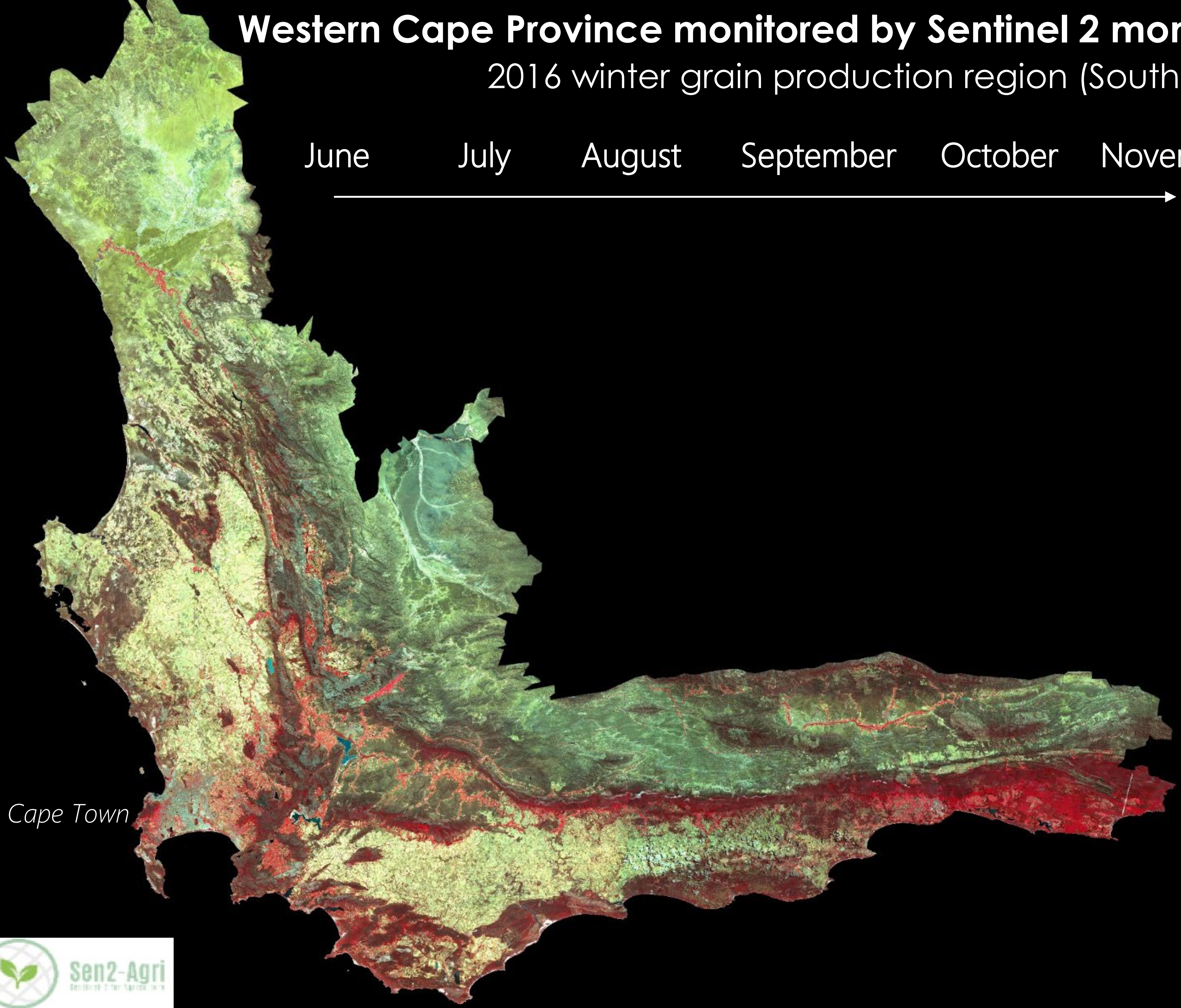
=> reduction of the compositing artefacts

=> monthly temporal resolution not really suitable for crop discrimination

Western Cape Province monitored by Sentinel 2 monthly composites

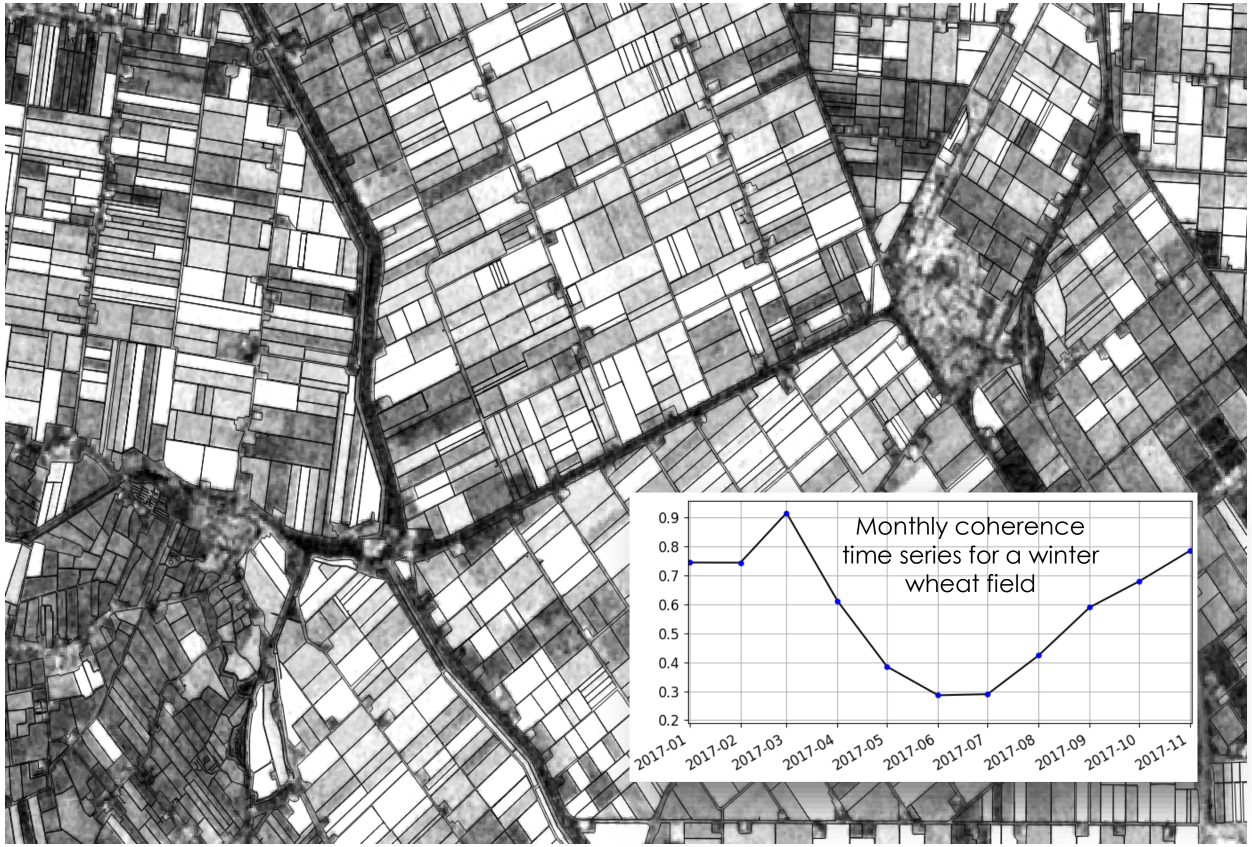
2016 winter grain production region (South Africa)

June July August September October November



Challenges for large scale crop mapping

SAR temporal synthesis by averaging all SAR observations over the period for noise reduction



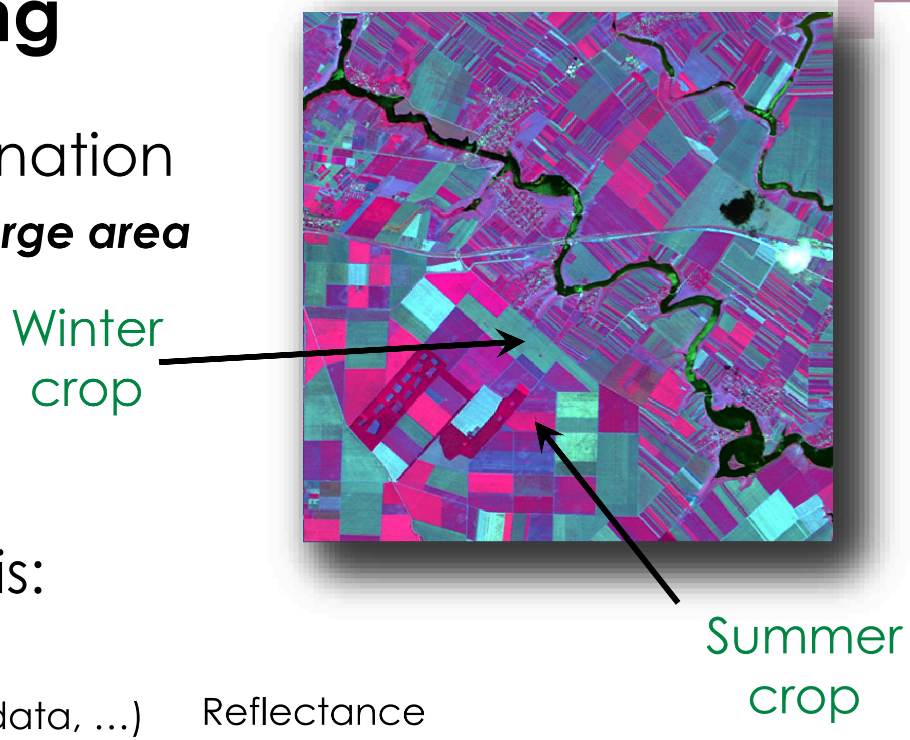
Mean of the coherence values as derived from Sentinel-1 interferometric pairs for March 2017 over Netherlands

Sentinel-1 color composite (blue: mean of the July coherence; green: mean of the March coherence; red: seasonal standard deviation)

Challenges for large scale crop mapping

Temporal information very critical for crop discrimination

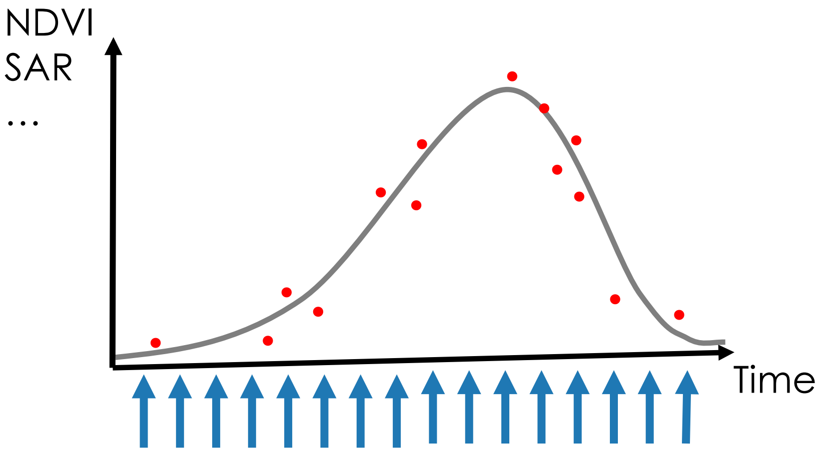
Second solution to cope with heterogeneous obs. density over large area



Sen4Stat

Production of an **optical or SAR time series** which is:

- **gap-filled** using a linear interpolation method with respect to missing data (clouds, cloud shadows, no data, …)
- **temporally resampled** at regular interval



⇒ This approach provides the same "observation" dates over the whole area independently from the sensor orbits and cloud cover which is very critical to run most of the classification methods.

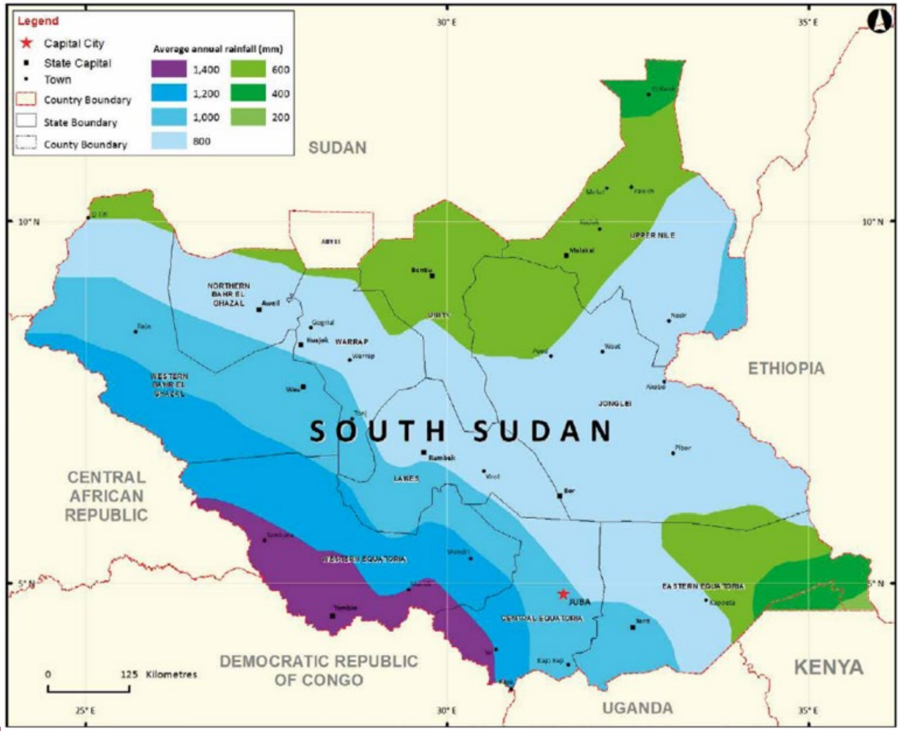
Challenges for large scale crop mapping

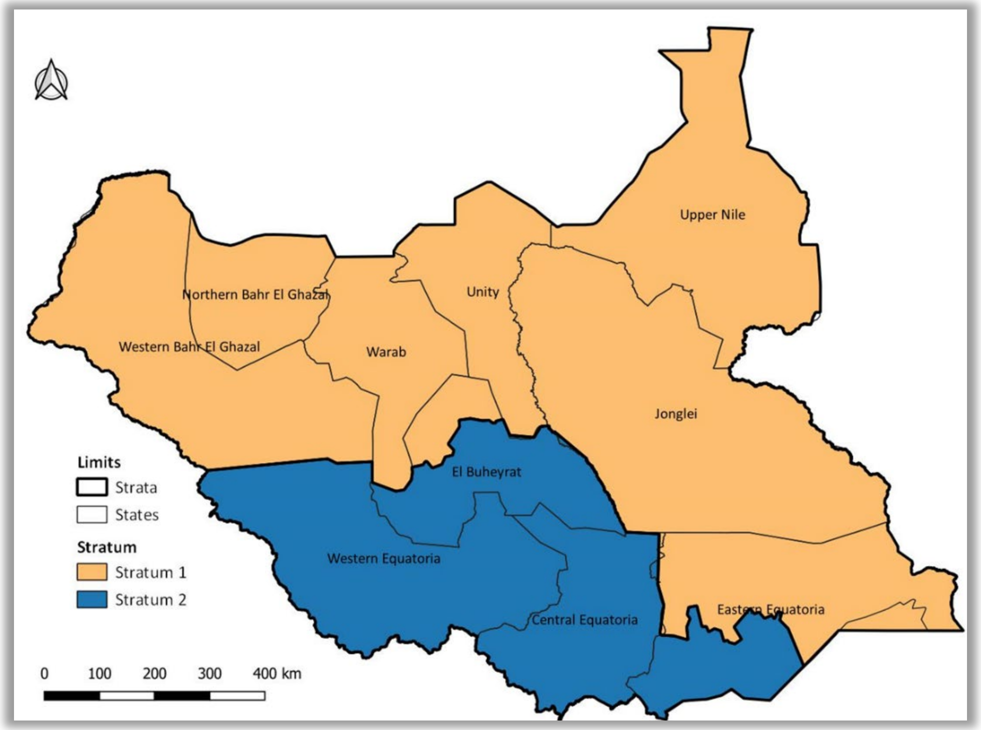
Example of South Sudan

Major rainfall gradient across the country defining two different crop calendars

		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Rainfall in the north		Dry season				Wet season						Dry season	
Rainfall in the south		Dry season			Wet season								Dry season
Unimodal production	**Main crop**				Land preparation and planting		Growing season			Harvest			
	Long-cycle crop	Harvest			Land preparation and planting		Growing season					Harvest	
Bimodal production (only in the south)	**First crop**			Land preparation and planting		Growing season			Harvest				
	Second crop	Harvest							Land preparation and planting		Growing season		Harvest

Stratification in zones to be classified separately





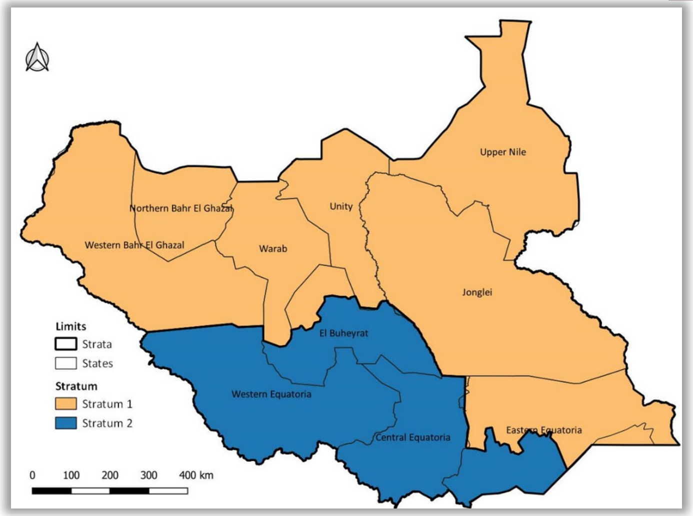
Challenges for large scale crop mapping

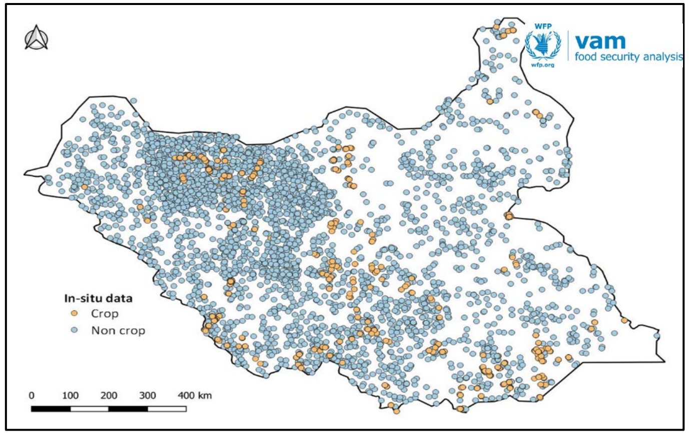
Example of South Sudan – stratification

A model to calibrate for each stratum requires collection of enough ground samples for each zone covering all crop types but also all non-cropland classes.

Crop / Non crop	Land cover class	Nr of samples	Proportion in crop / no crop categories	Proportion in total
Non crop	Bush	1504	44%	33%
	Forests	566	17%	12%
	Grasslands and meadows	565	16%	12%
	Shrubland	408	12%	9%
	Wetland	93	3%	2%
	Water bodies	78	2%	2%
	Fallow	76	2%	2%
	Built-up surface	71	2%	2%
	Bare soil	64	2%	1%

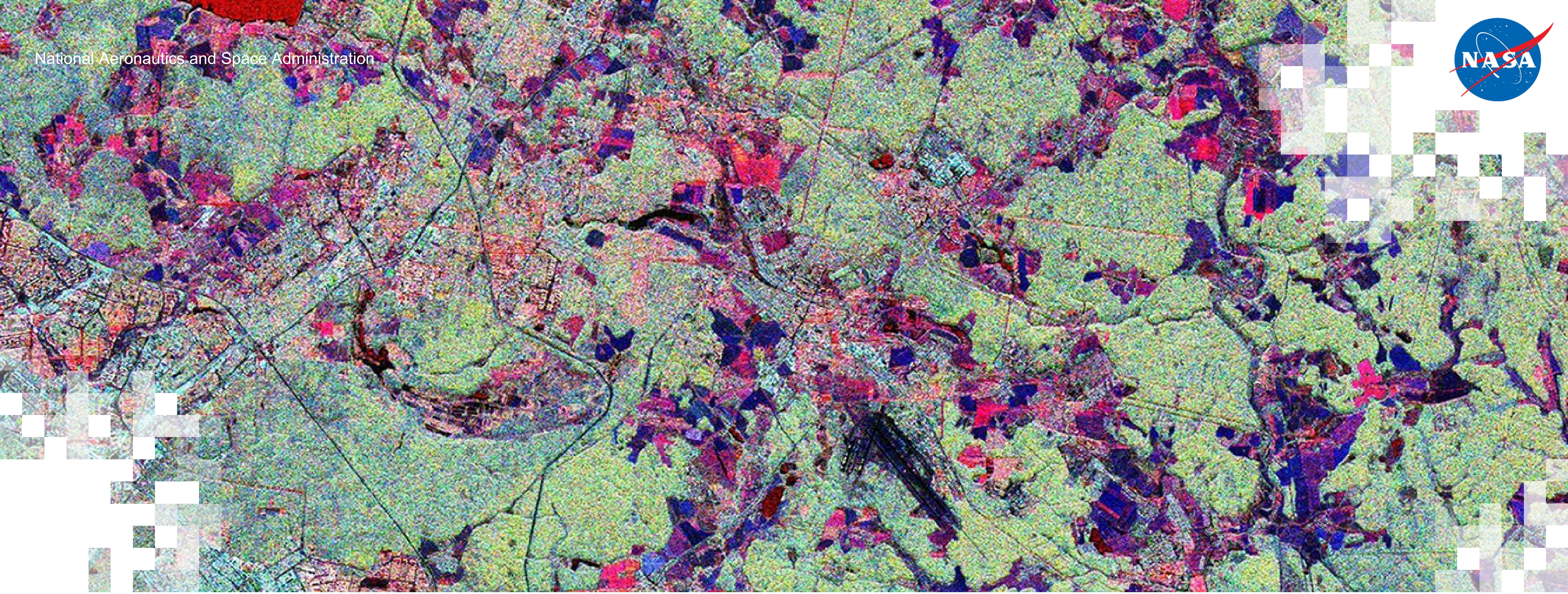
Crop type	Nr of samples	Proportion in crop / no crop categories	Proportion in total
Early Sorghum	369	31%	8%
Late Sorghum	244	21%	5%
Maize	122	10%	3%
Groundnut	116	10%	3%
Early Sorghum Mixed	105	9%	2%
Cassava	79	7%	2%
Late Sorghum Mixed	55	5%	1%
Maize Mixed	48	4%	1%
Sesame	13	1%	0%
Rice	10	1%	0%
Bulrush Millet	9	1%	0%
Beans	7	1%	0%





=> 4602 samples well distributed

National Aeronautics and Space Administration

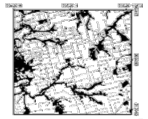
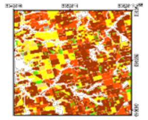


Section 2: Large Scale Crop Mapping Using Sen4Stat Toolbox

Sen4Stat – ESA open-source SAR and optical toolbox for operational crop type mapping and monitoring over very large areas

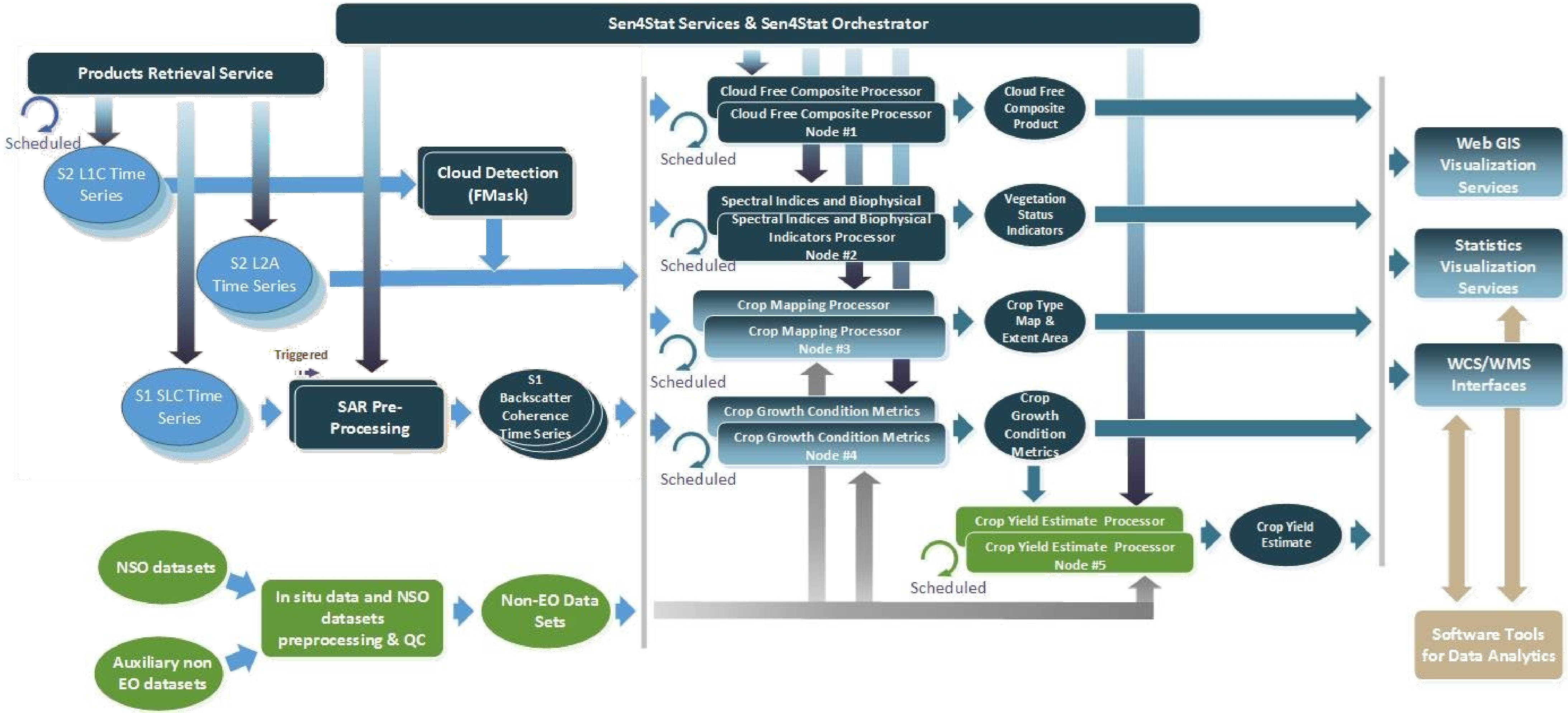
- Process Sentinel-1, Sentinel-2 and Landsat-8&9 time series according to the state-of-the-art including advanced SAR products (coherence, gamma naught,…)
- Deliver automatically or on request **5 types of products** (*processors*) in near real-time along the satellite data acquisition or off-line:

  1. **10m optical cloud free temporal synthesis and SAR temporal synthesis**
  2. **Time series of spectral indices** (NDVI, coherence,…) and **biophysical variables** (LAI, fCover, fAPAR)
  3. **10m crop type maps** along the season based on in situ dataset and stratification
  4. **Large set of crop growth conditions metrics** (including meteorological data)
  5. **Crop yield estimation** at various aggregation levels (national, regional, …)

Sen4Stat – ESA open-source SAR and optical toolbox for operational crop mapping and monitoring over very large areas

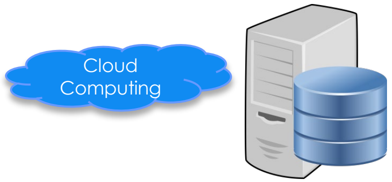
Data access /download	Pre-processing In situ quality control	Processors of products	Analytics and visualization



ESA open-source SAR and optical toolbox with a graphical user interface to configurate the system to launch the production and monitor the processes

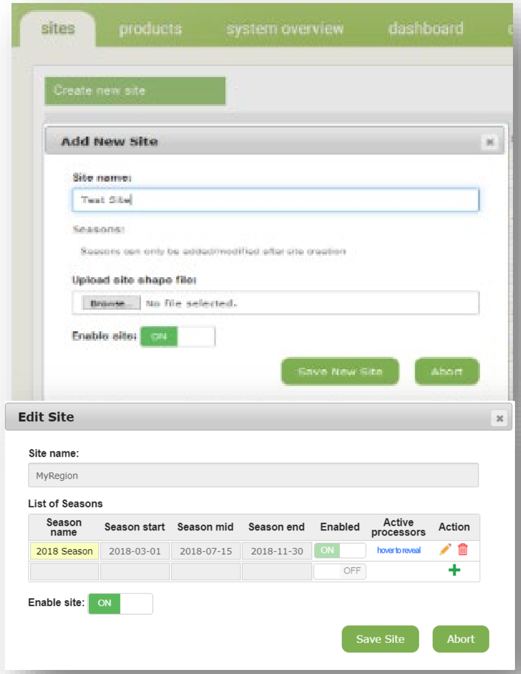
System configuration

Start of the season → End of the season…

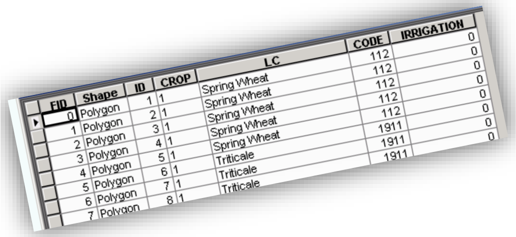


Sen4Stat: parameters settings	
Area of Interest	Shapefile to be uploaded
Monitoring period	Start and end dates to be defined
S1 - S2 - L8&9	To be selected
Data sources	ESA&USGS – AWS – DIAS – local storage…

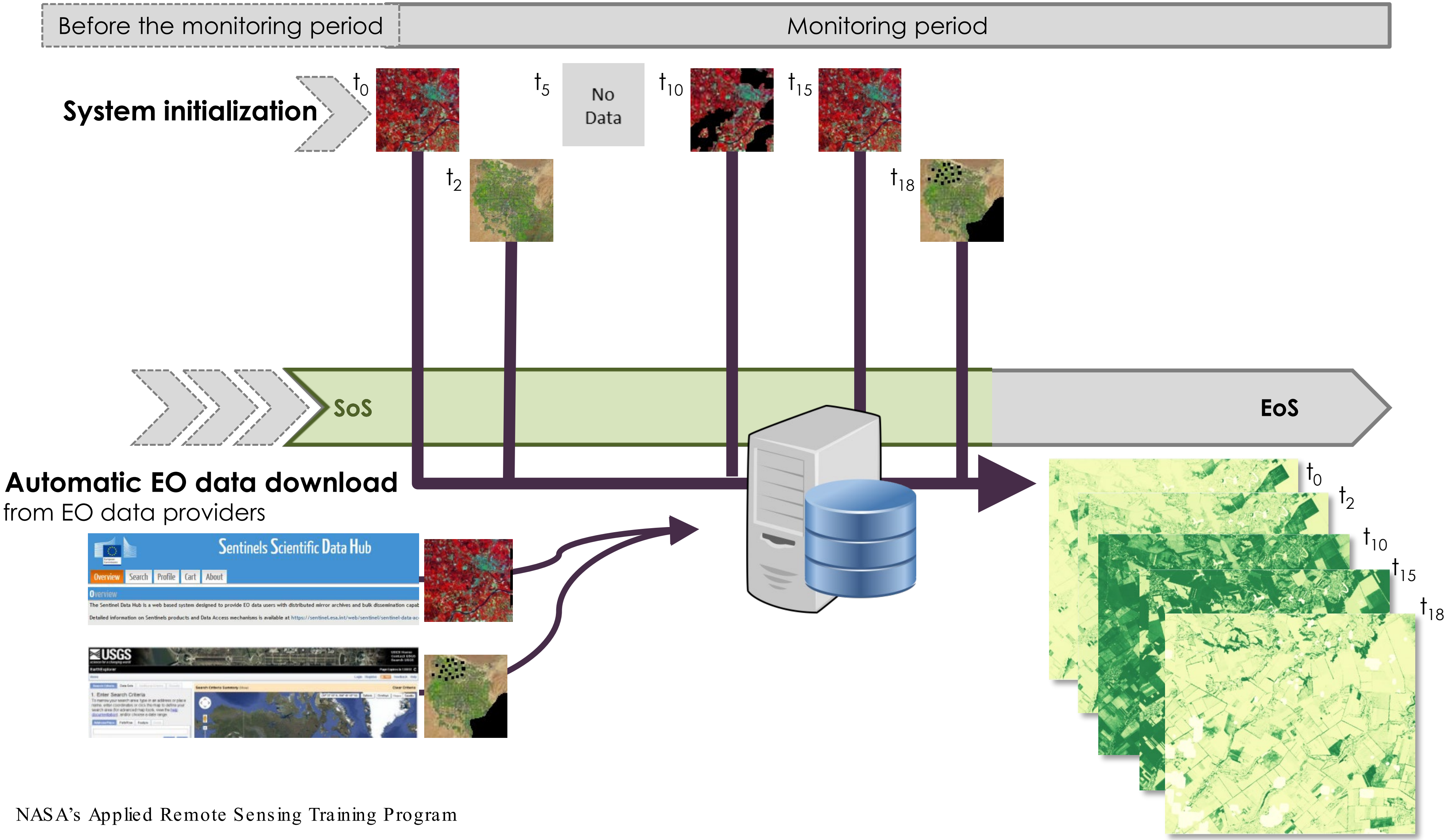
Mali stratification (PIRT)



Sen4Stat: field campaign	
Sampling design	Stratification and sampling
Field visit	In situ data collection – early survey
	In situ data collection – mid-season survey
Data upload	Field data quality control and formatting

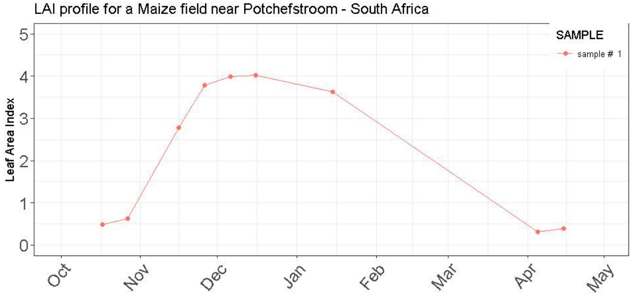


Sen4Stat – system operation for crop growth monitoring :
Leaf Area Index (LAI) production in near-real time along the season

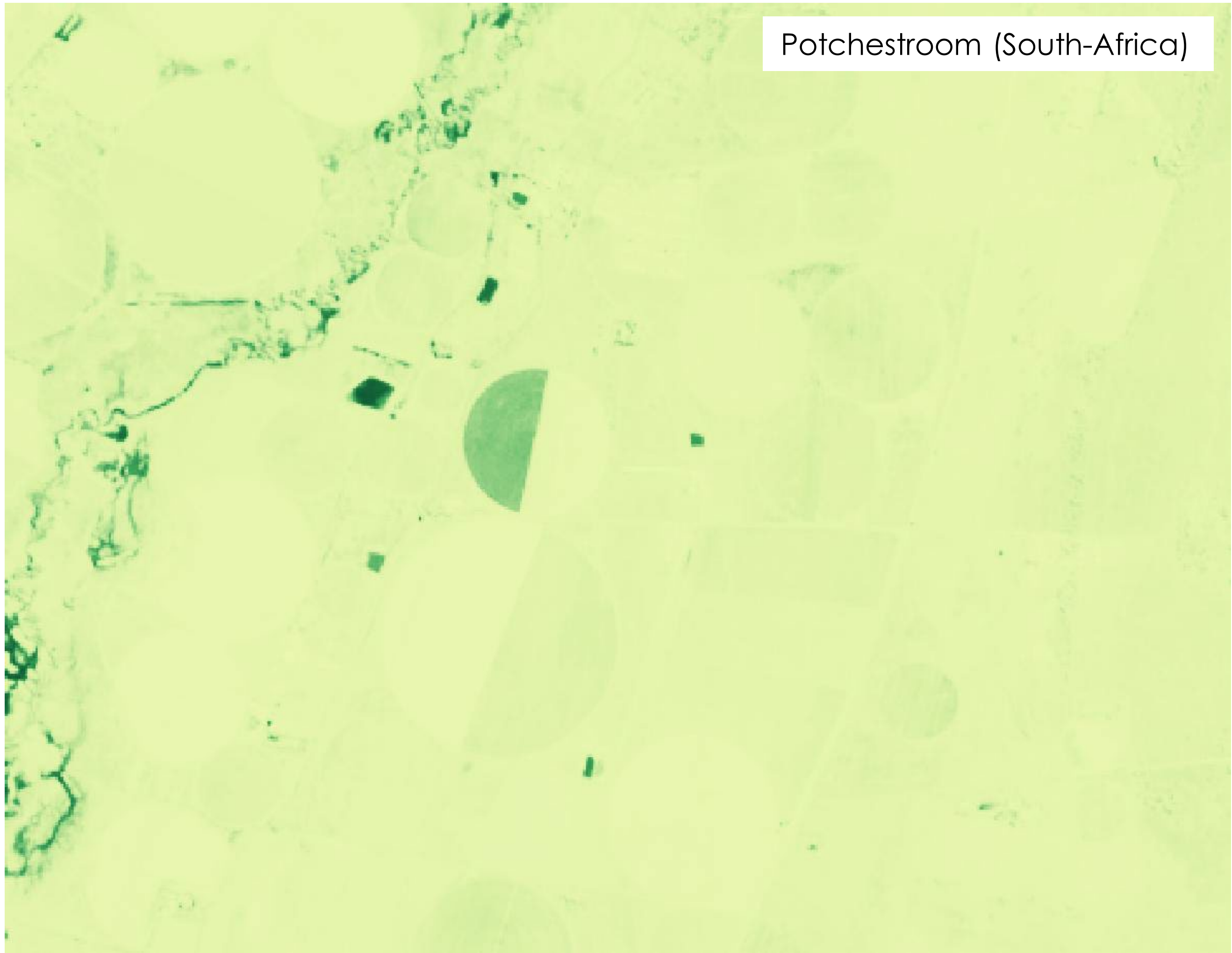


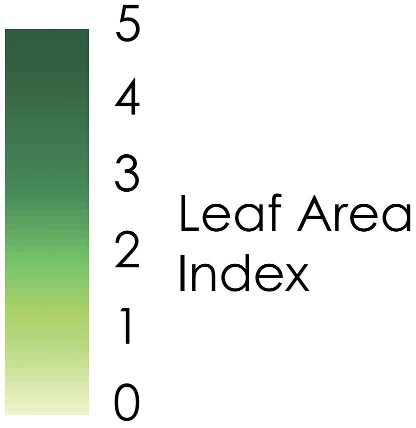
UCLouvain

Sen4Stat – System operation for crop growth monitoring : **Leaf Area Index (LAI)** production in near real-time along the season



Sen4Stat: 2016 – 2017 Leaf Area Index at 10 m





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Sen4Stat – System operations running according to different modes: NRT with orchestrator (fully automated) or on request

Sen4Stat
Sentinels for Agricultural Statistics

Automated mode **through the web graphical user interface (GUI)**

a) based on the Orchestrator with by-default parameterization, automatic data download and processing until the end of the season, on-time delivery
=> **operational production in near real time (NRT)**

b) Processor execution on user request, with by-default parameterization

slurm
workload manager

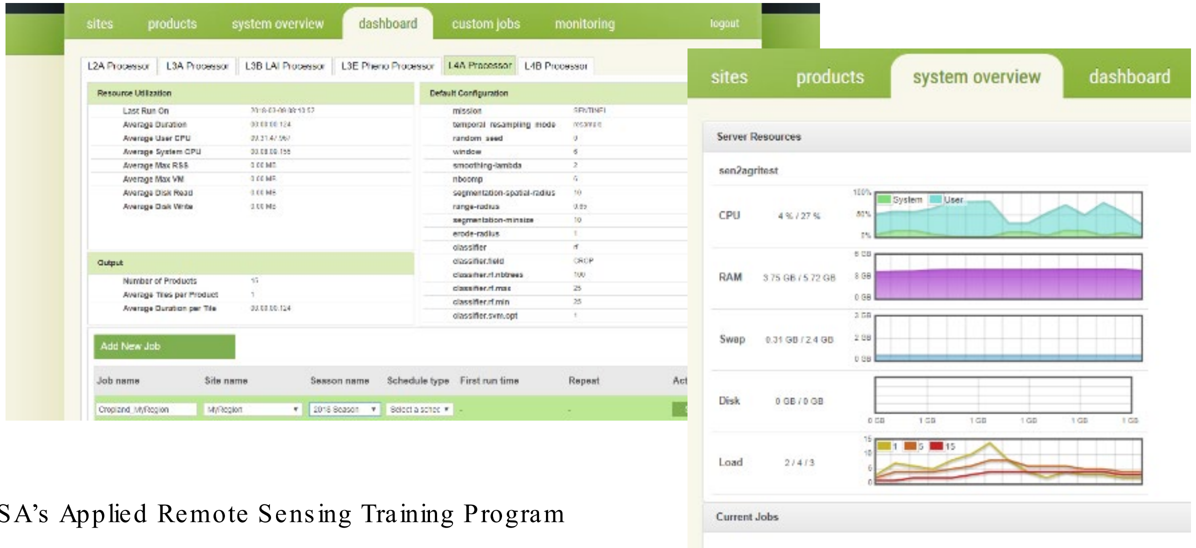
Manual mode: to run processor independently, with custom parameters

a) through the GUI, with the *Custom job* approach

b) through SNAP software (only processor of Level 3 and 4)

c) in command line through a Linux terminal

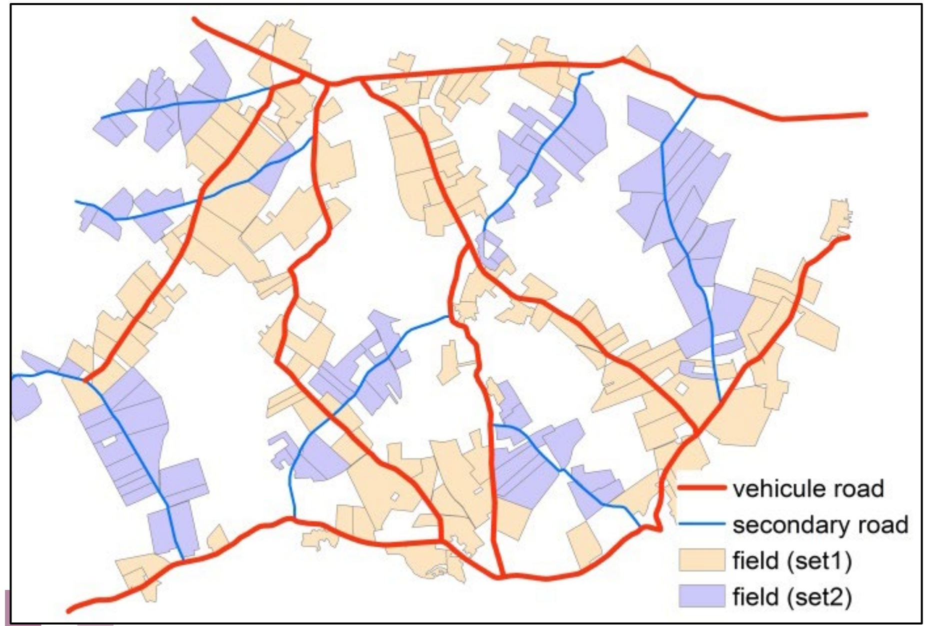
```
lai_retrieve_processing.py --input /mnt/archive/maccs_def/mali/l2a/S2A_OPER_PRD_MSIL2A_PDMC_20160718T093045_R008_V20160717T104833_20160717T104833.SAFE/S2A_OPER_SSC_L2VALD_30PVV____20160717.HDR --res 10 --outdir /mnt/archive/temp/test_lai --rsrcfg /usr/share/sen2agri/rsr_cfg.txt --modelsfolder /mnt/archive/temp/test_lai --generatemodel YES --generatemonodate YES --genreprocessedlai NO --genfittedlai NO
```

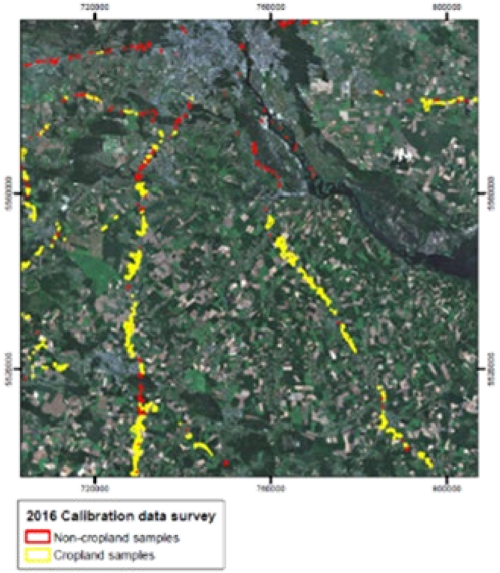


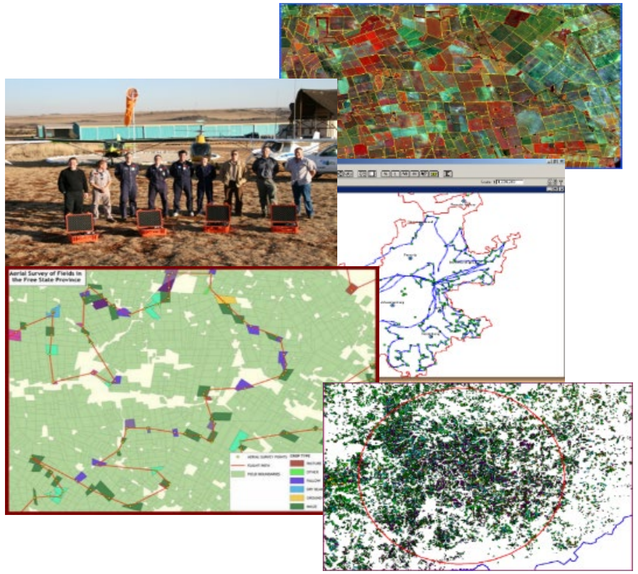
esa ROMANIA CLS UCLouvain

Sen4Stat – In situ data collection required for annual crop type mapping

- Available reference dataset collected according to an area or list sampling frame (national statistical surveys, Ministry of Agriculture,…)
- JECAM Guidelines – ad hoc "windshield survey" by motorized vehicles (car, motorbike) selecting a set of appropriate roads (set 1) and complemented by regular additional transect (set 2) using secondary roads and tracks to try to reduce the spatial bias brought about by roadside sampling.







VLA used for aerial observations

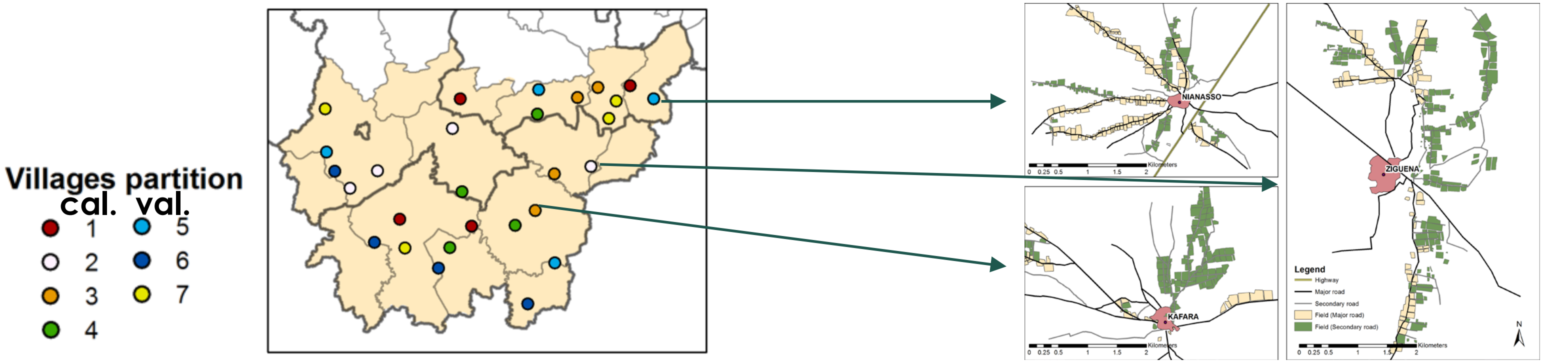
Sen4Stat – Requirements for the in situ data collection

- In situ data for **calibration** **(training)**: sampling to cover the diversity of situations existing in the study area (possibly a national territory) in order **to cover the range of possible signatures for the different elements of interest** (i.e. most crop types and the main non cropland classes).

- 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 PSU and ESU) to assess the crop types (one field campaign)

Primary Sampling Unit (PSU): villages randomly selected

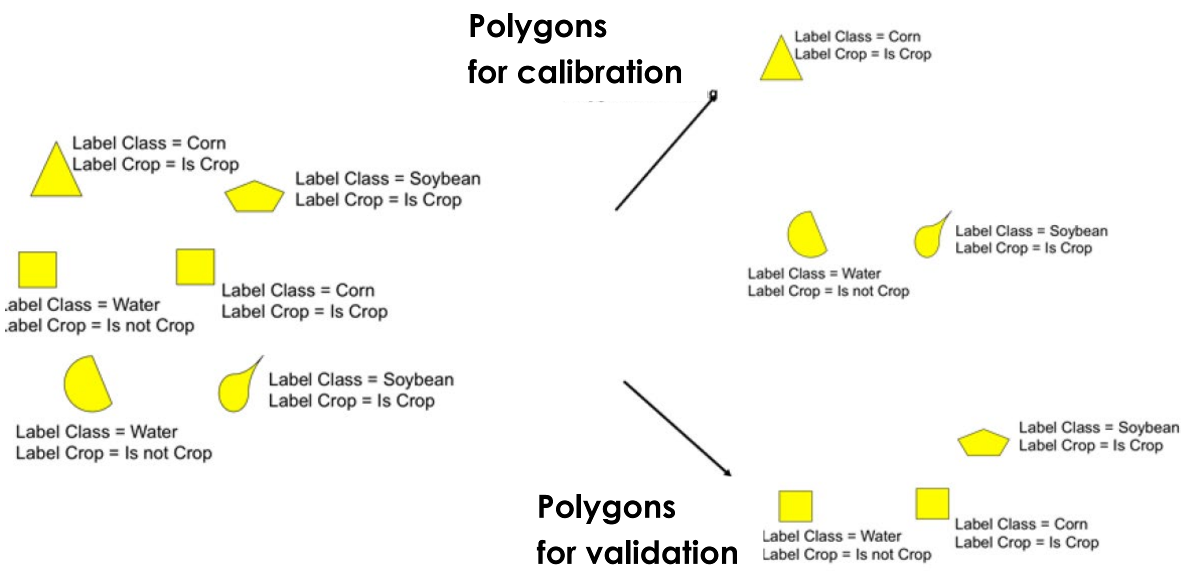
Elementary Sampling Unit (ESU): fields randomly selected along roads



⇒ calibration and validation field campaigns for crop type mapping can be combined but the sampling design should be statistically sound to obtain fully independent dataset.

Sen4Stat – In situ data quality control process and dataset preparation

1) High quality reference data collection:
   - Crop type acquired from field campaigns
   - Non-crop data obtained by visual interpretation of very high spatial resolution imagery available online
2) Quality control: geometry consistency, typology standardisation, homogeneity check…
3) Splitting polygons for calibration (25%) and validation (75%) for each class (alternative strategies might be required in case on poorly balanced in situ dataset)
4) Enhancing the samples number for marginal crop type using Synthetic Minority Over-sampling Technique (SMOTE)



Sen4Stat – Accuracy assessment using four metrics

•The **Overall Accuracy** (OA) is calculated as the total number of correctly classified pixels (n_{ii} ~ 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.

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

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

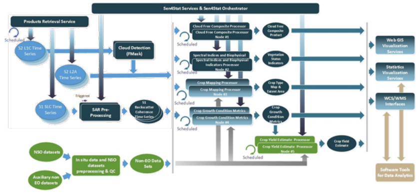
- **Recall** or **Producer's Accuracy** (PA) for the class *i* is the fraction of correctly classified pixels with regard to all pixels of that ground truth class *i*:

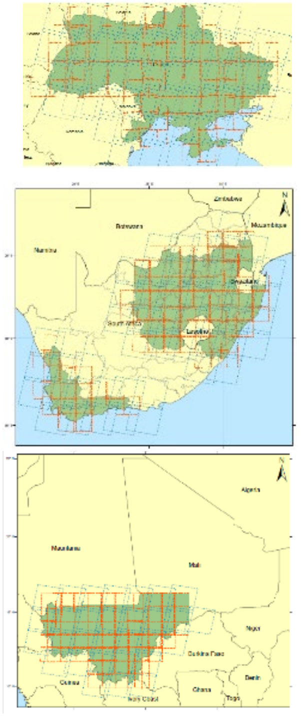
$$PA_i = \sum_{j=1}^{r} \frac{n_{ii}}{n_{ji}}$$

- **F-Score** (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:

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

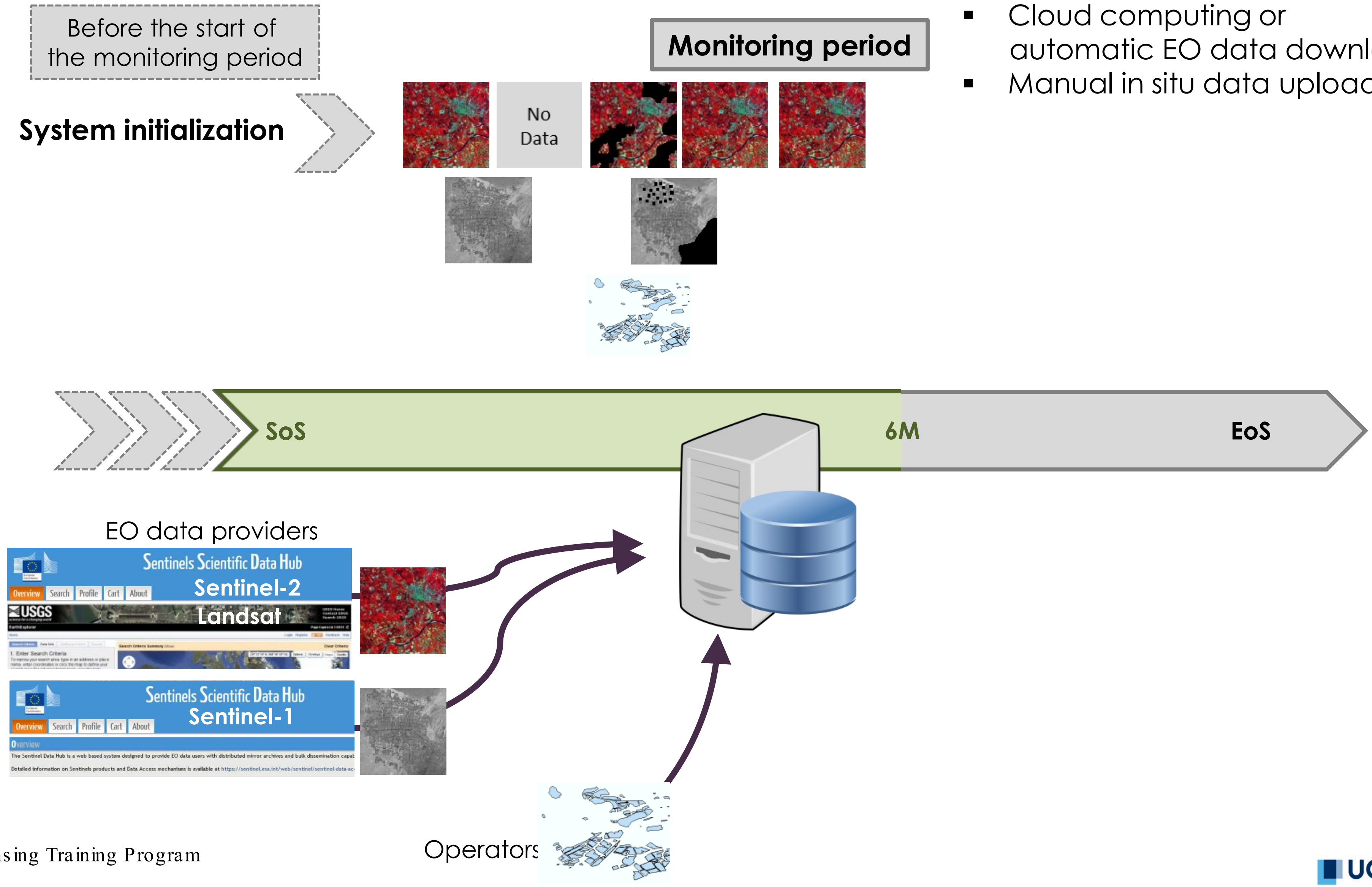
Sen4Stat – System operation in automated mode to deliver in NRT 10-m crop type maps at national scale





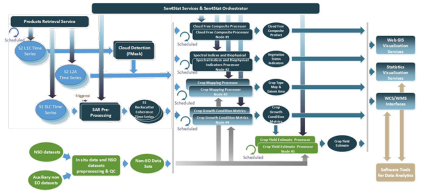
(Defourny et al., RSE2019)

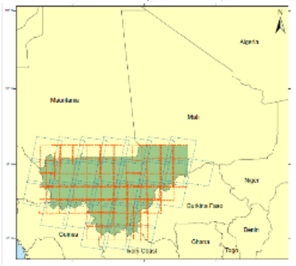
- Cloud computing or automatic EO data download
- Manual in situ data upload

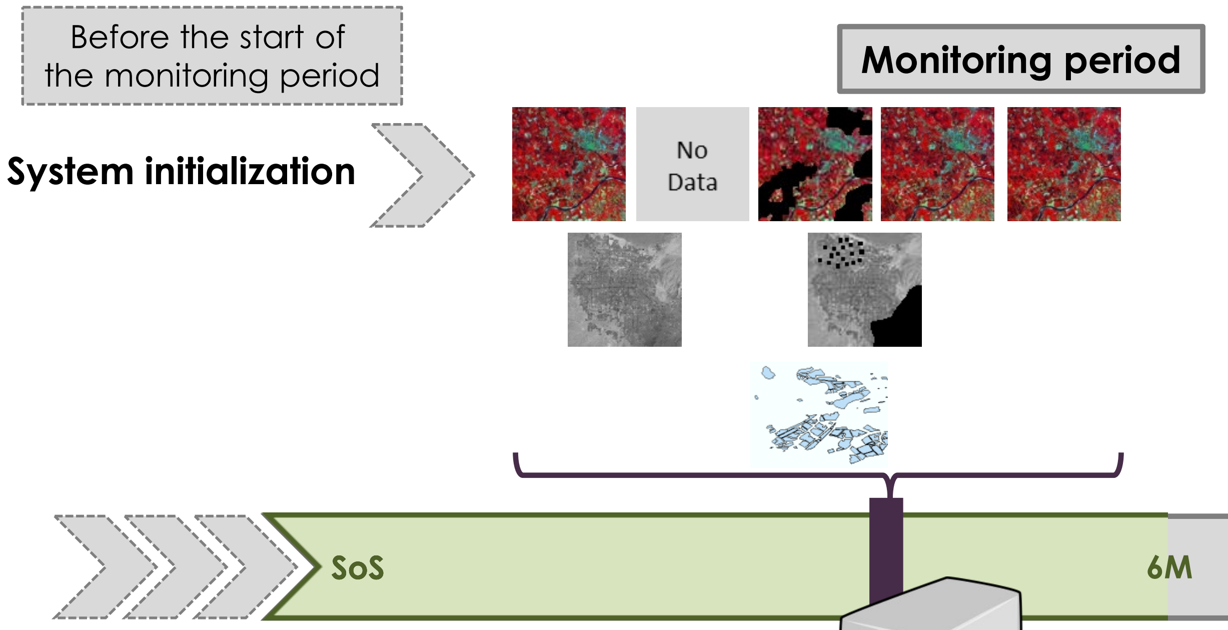


UCLouvain

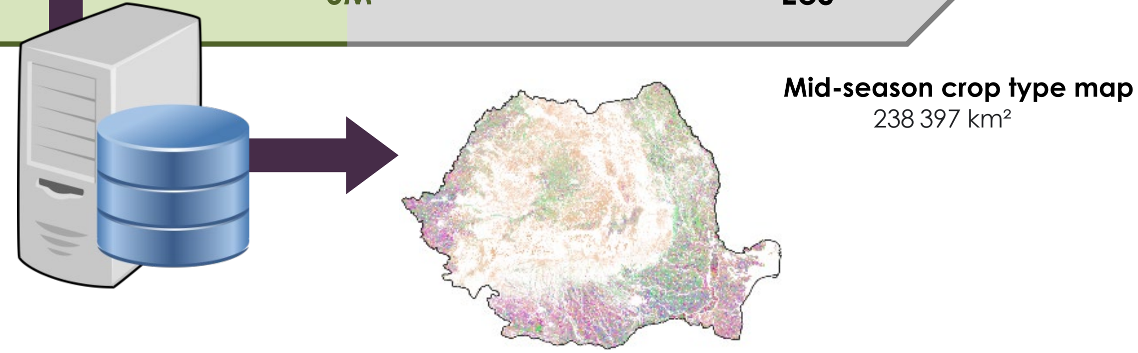
Sen4Stat – System operation in automated mode to deliver in NRT 10-m crop type maps at national scale



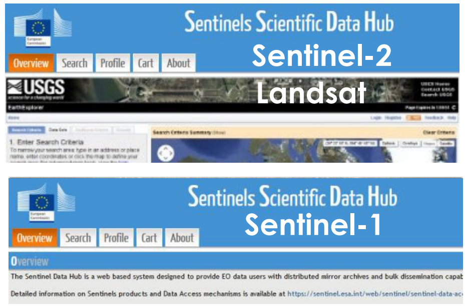




- Cloud computing or automatic EO data download
- Manual in situ data upload



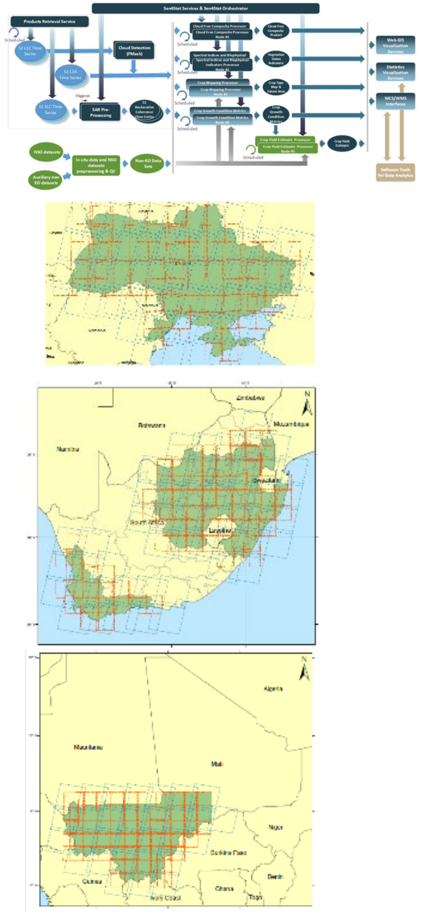
EO data providers

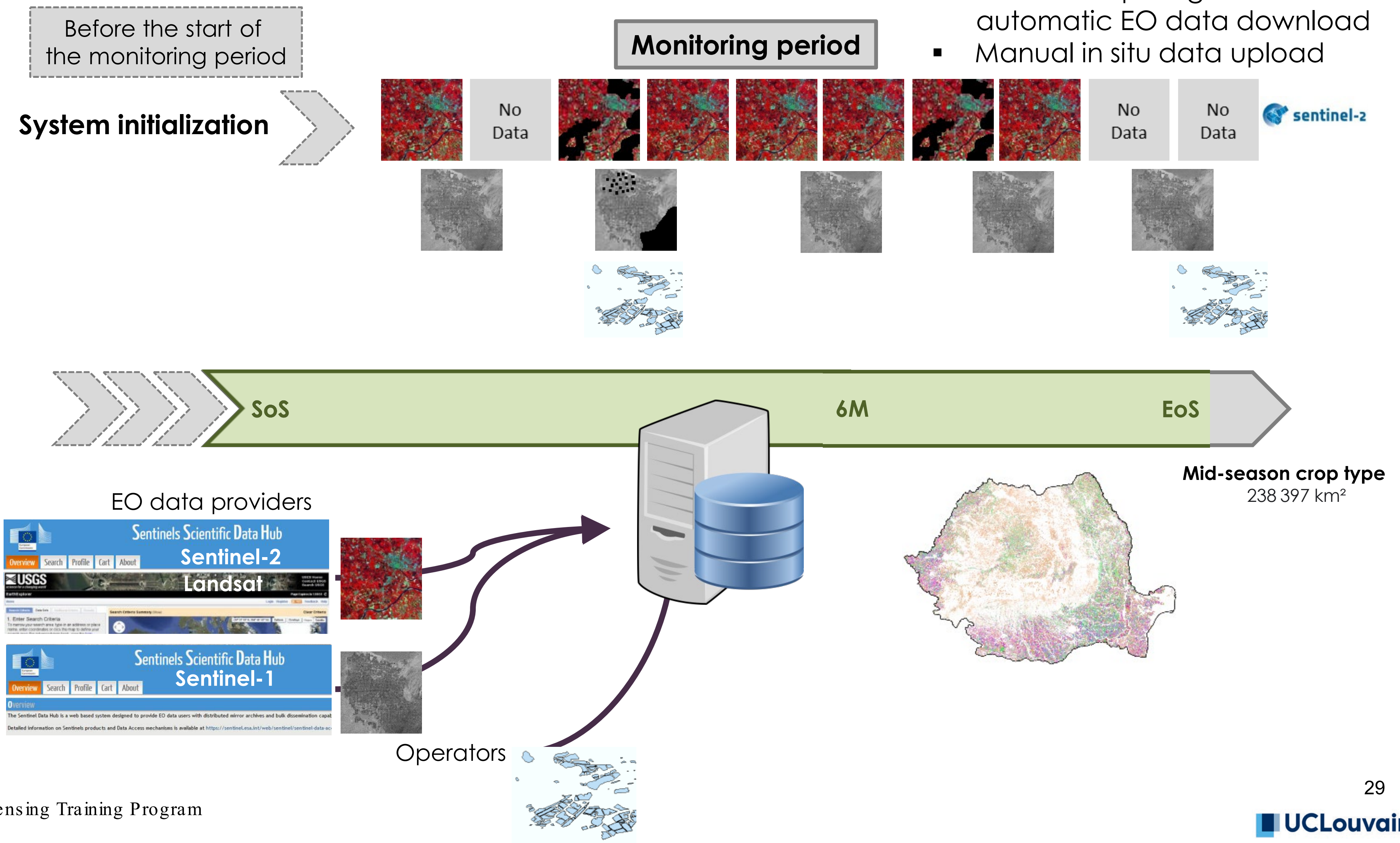


Operators

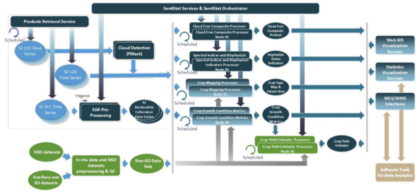
Sen4Stat – System operation in automated mode to deliver in NRT 10-m crop type maps at national scale

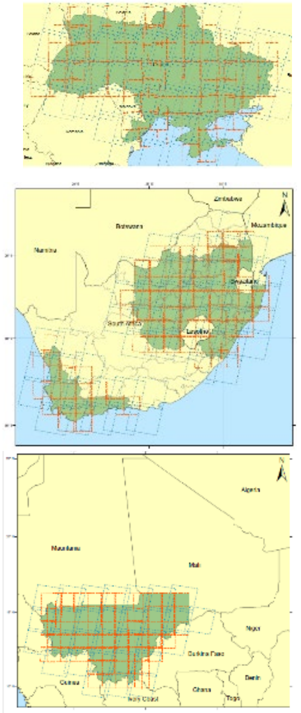
- Cloud computing or automatic EO data download
- Manual in situ data upload



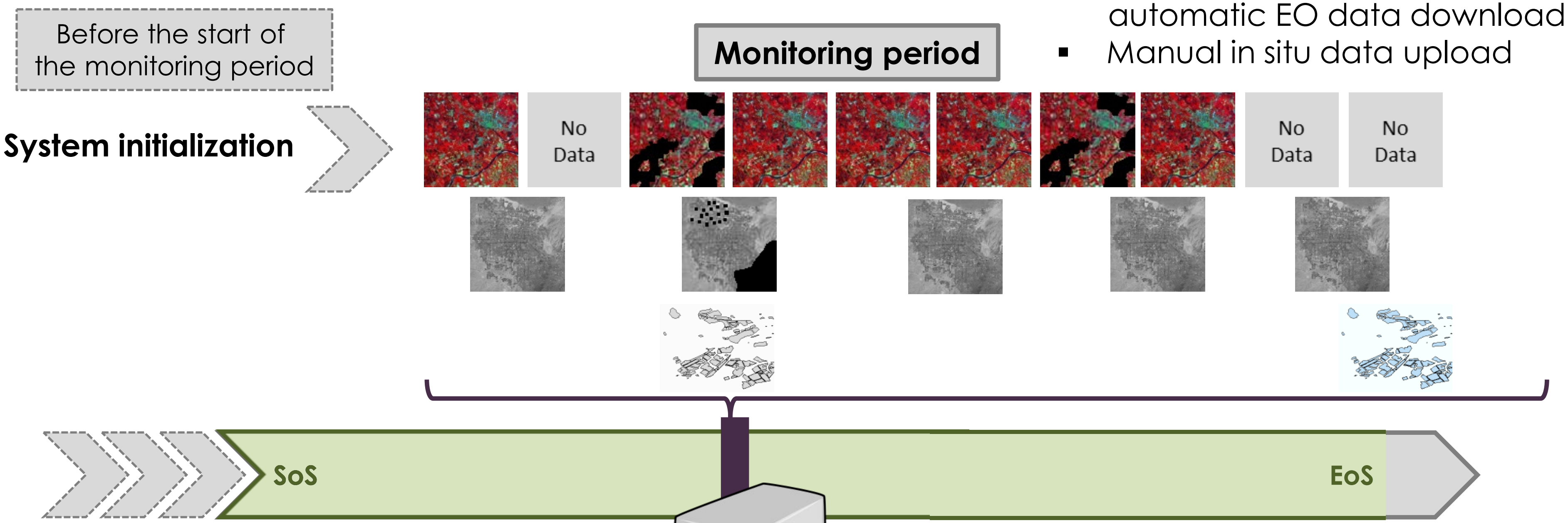


Sen4Stat – System operation in automated mode to deliver in NRT 10-m crop type maps at national scale

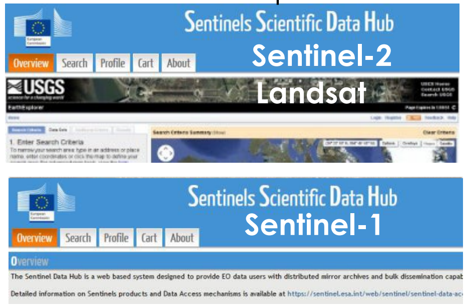


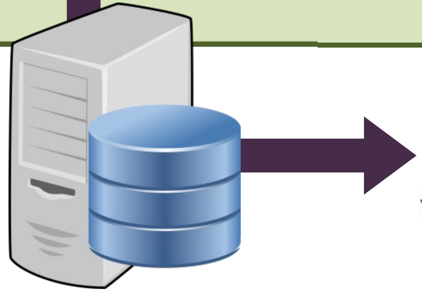


- Cloud computing or automatic EO data download
- Manual in situ data upload

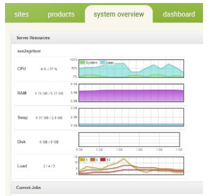


EO data providers

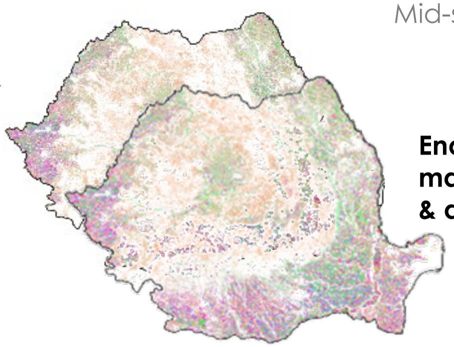




Operators

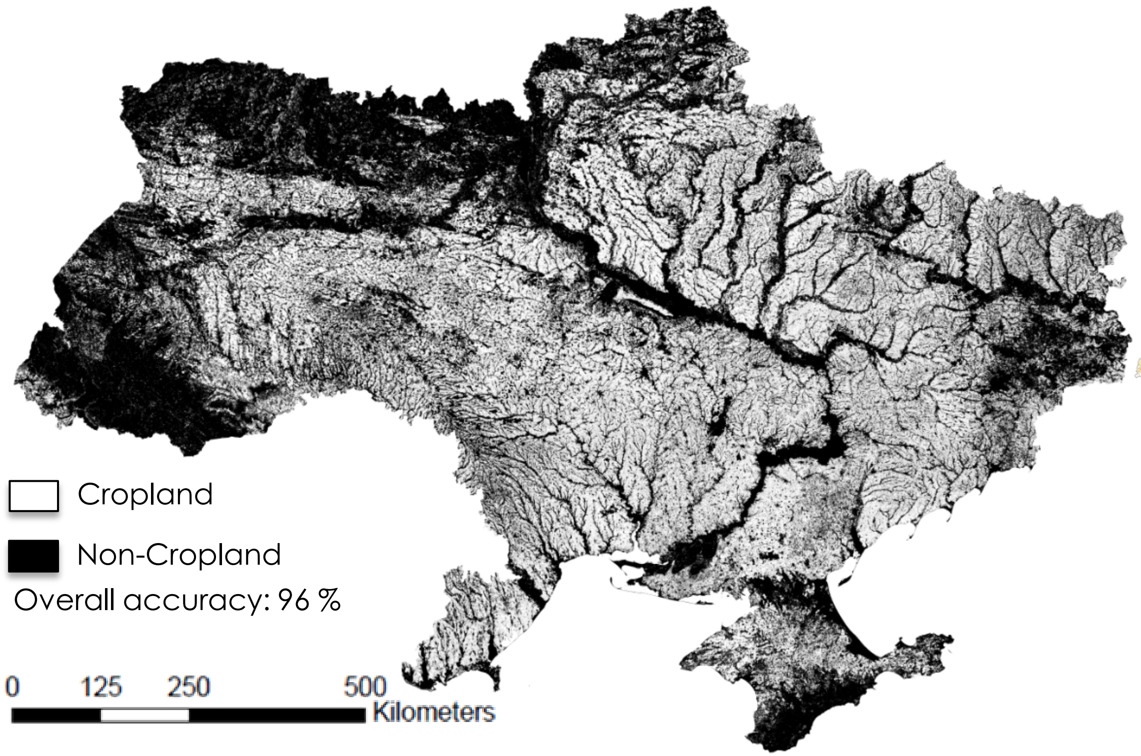


Mid-season crop type map
238 397 km²

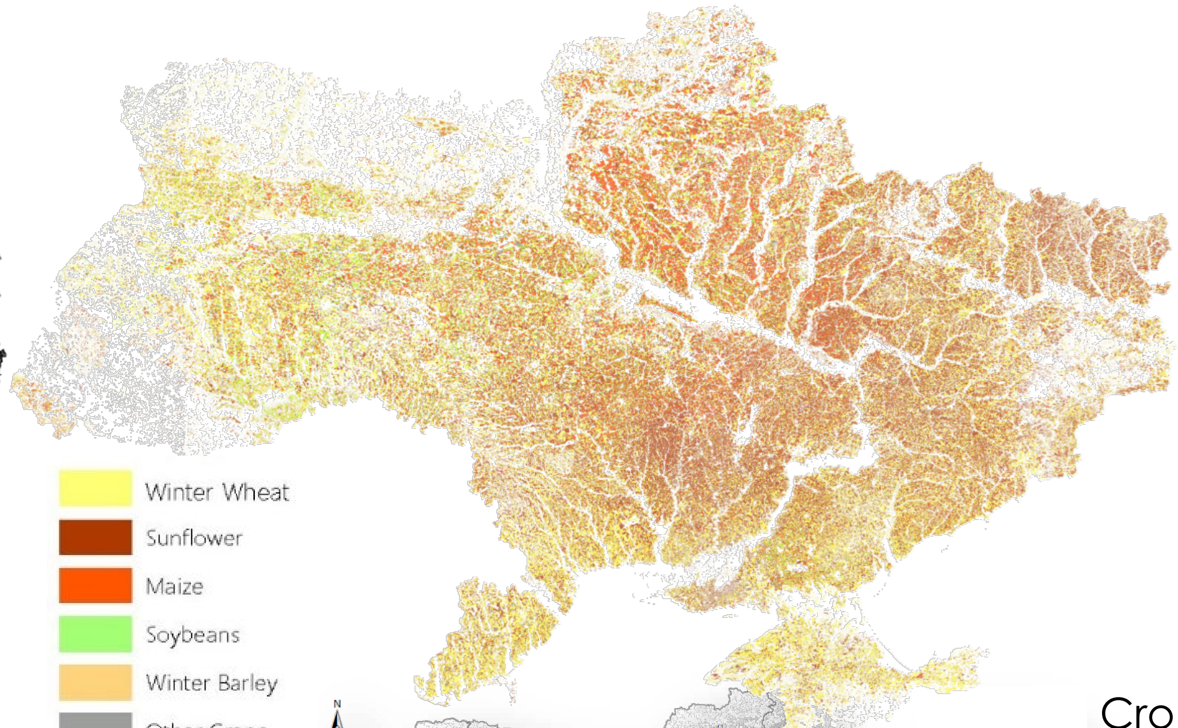


End of season crop type map & accuracy assessment

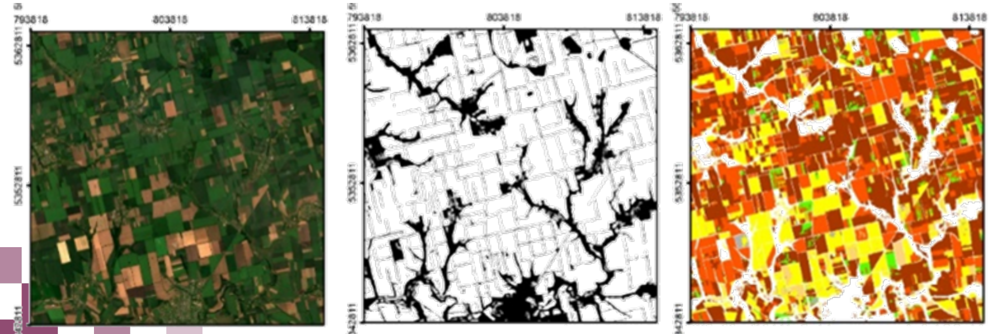
Sen4Stat – Very first 10-m national cropland and crop type maps based on Sentinel-2a only (Ukraine, July 2016)



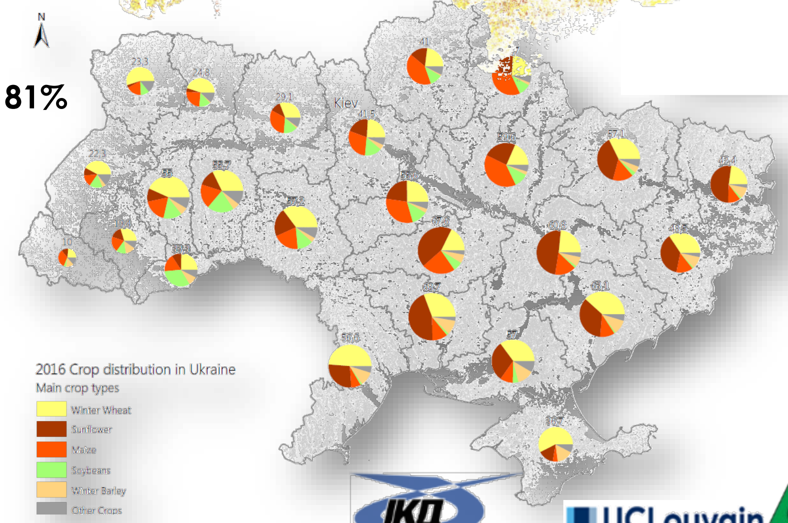
Overall accuracy: 96 %



Overall accuracy: 81%



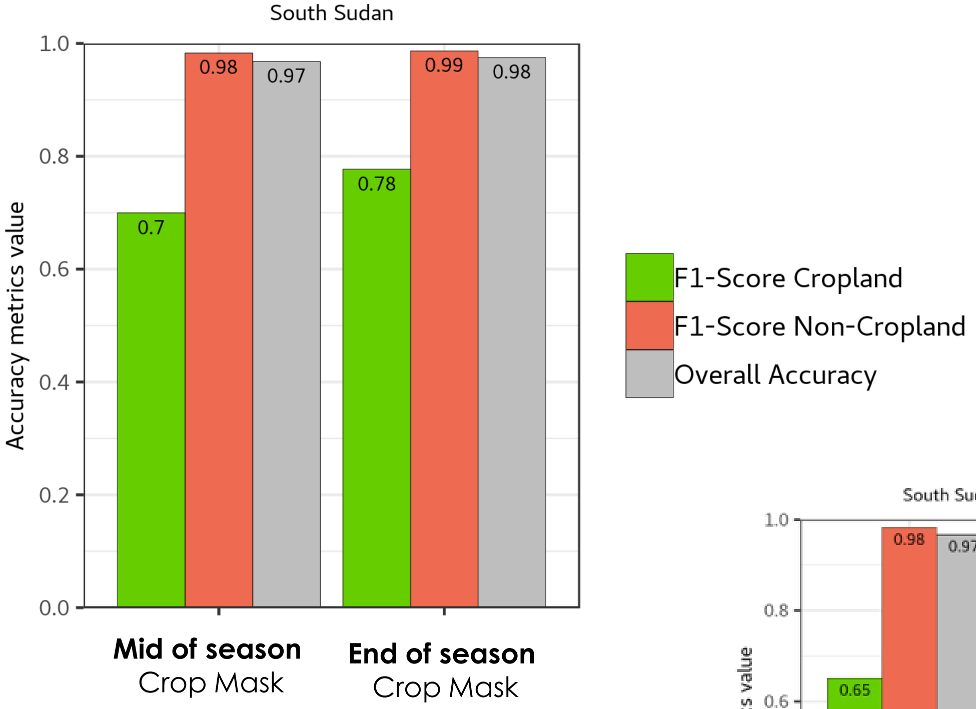
(Defourny et al., 2019)

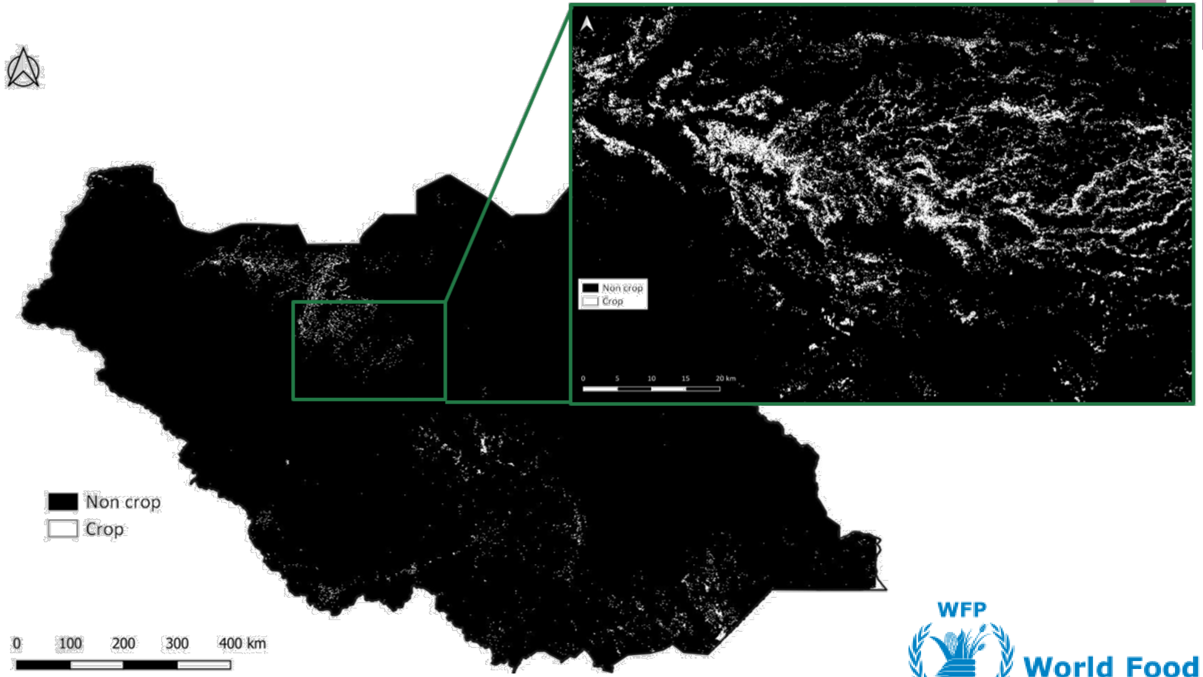


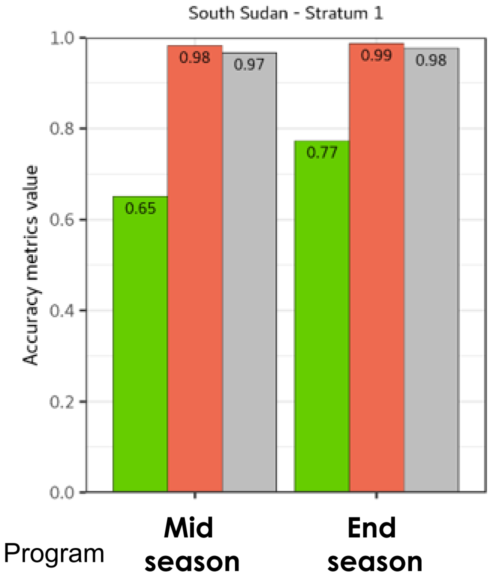
Crop area Indicator at mid-season and end of season

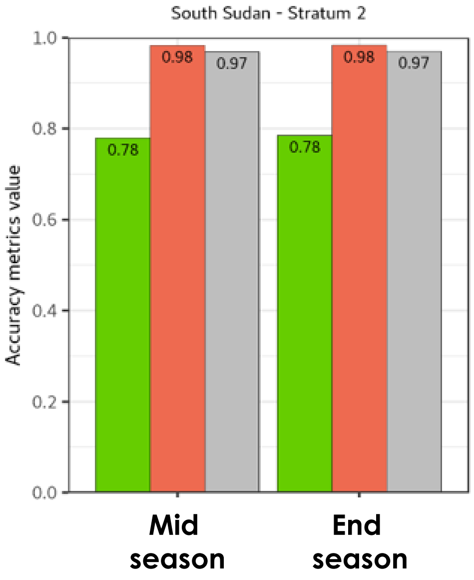
Sen4Stat – Cropland map at mid and end of the season for the two strata of South Sudan

F1-Score of cropland increases with the amount of EO data available along the season





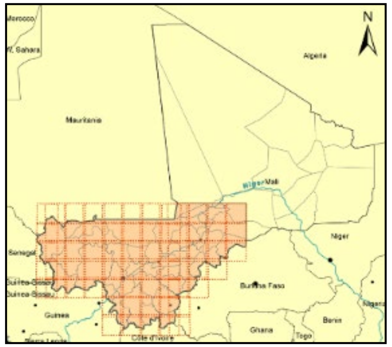


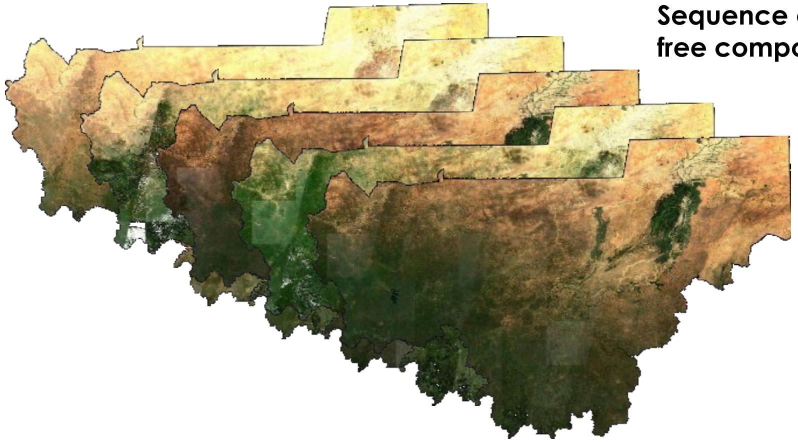


WFP World Food Programme wfp.org

Sen2-Agri – Crop mapping in Mali (2017)

- Successful crop mapping at 10m resolution in collaboration with ICRISAT
- ~4.5 TB of Sentinel-2 data (2152 S2 and 542 L8 images)

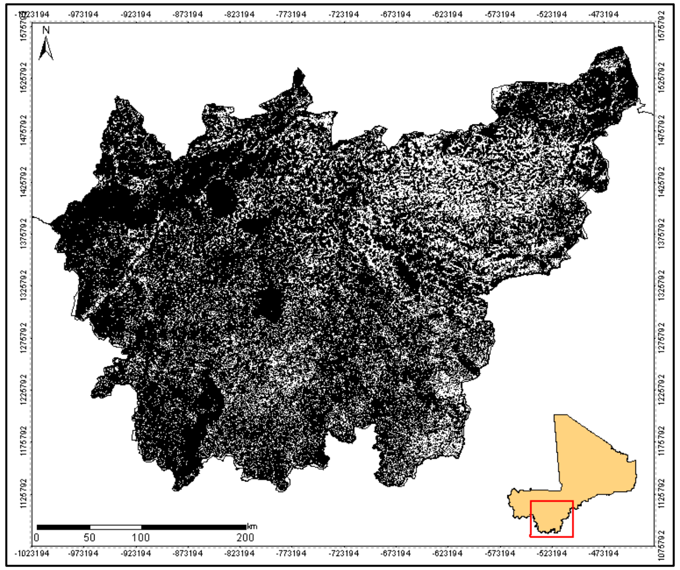


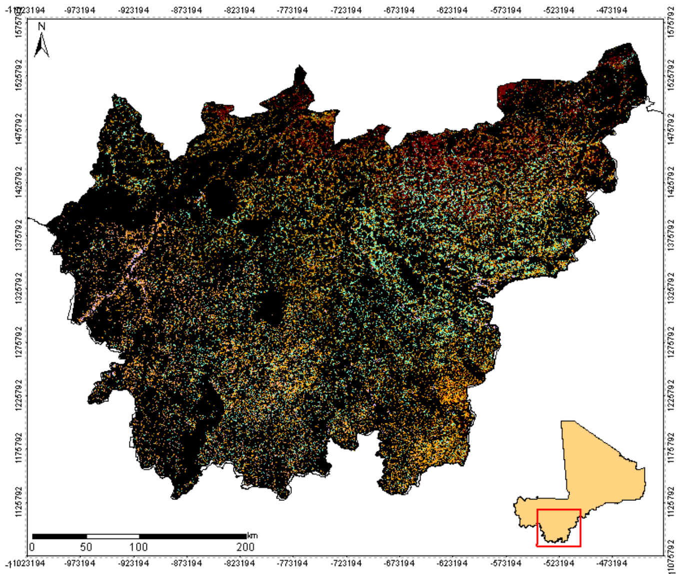


Sequence of monthly cloud free composites over Mali

Cropland mask for the 2017 growing season (end-of-season)

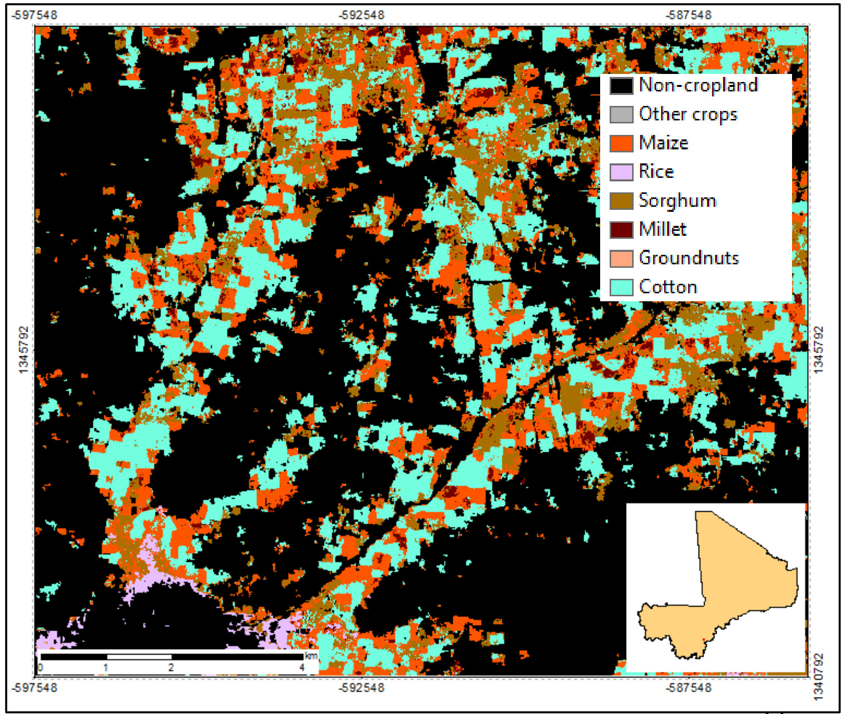
OA = 96%

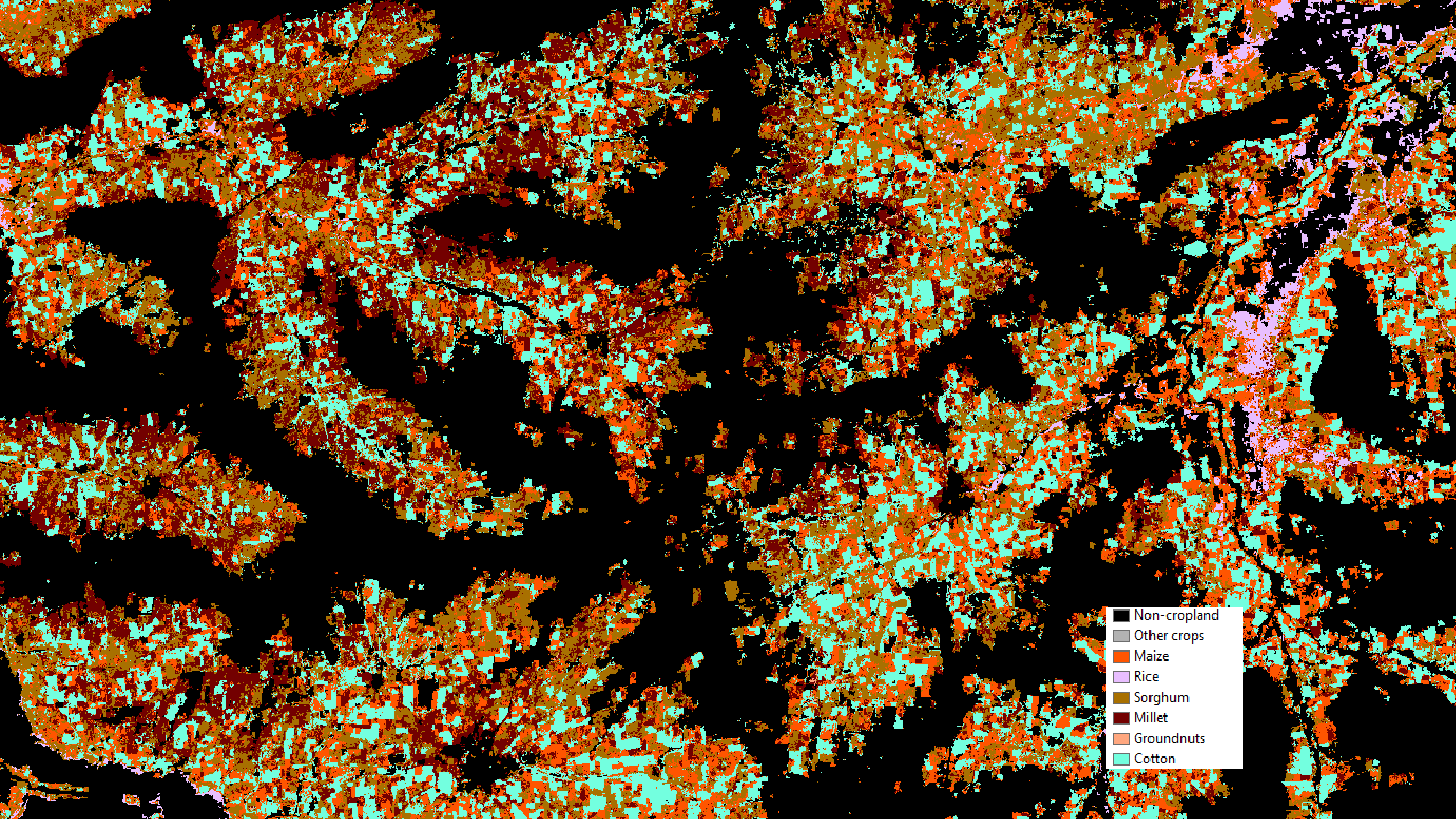




Crop type map for the 2017 growing season (end-of-season)

OA = 66%

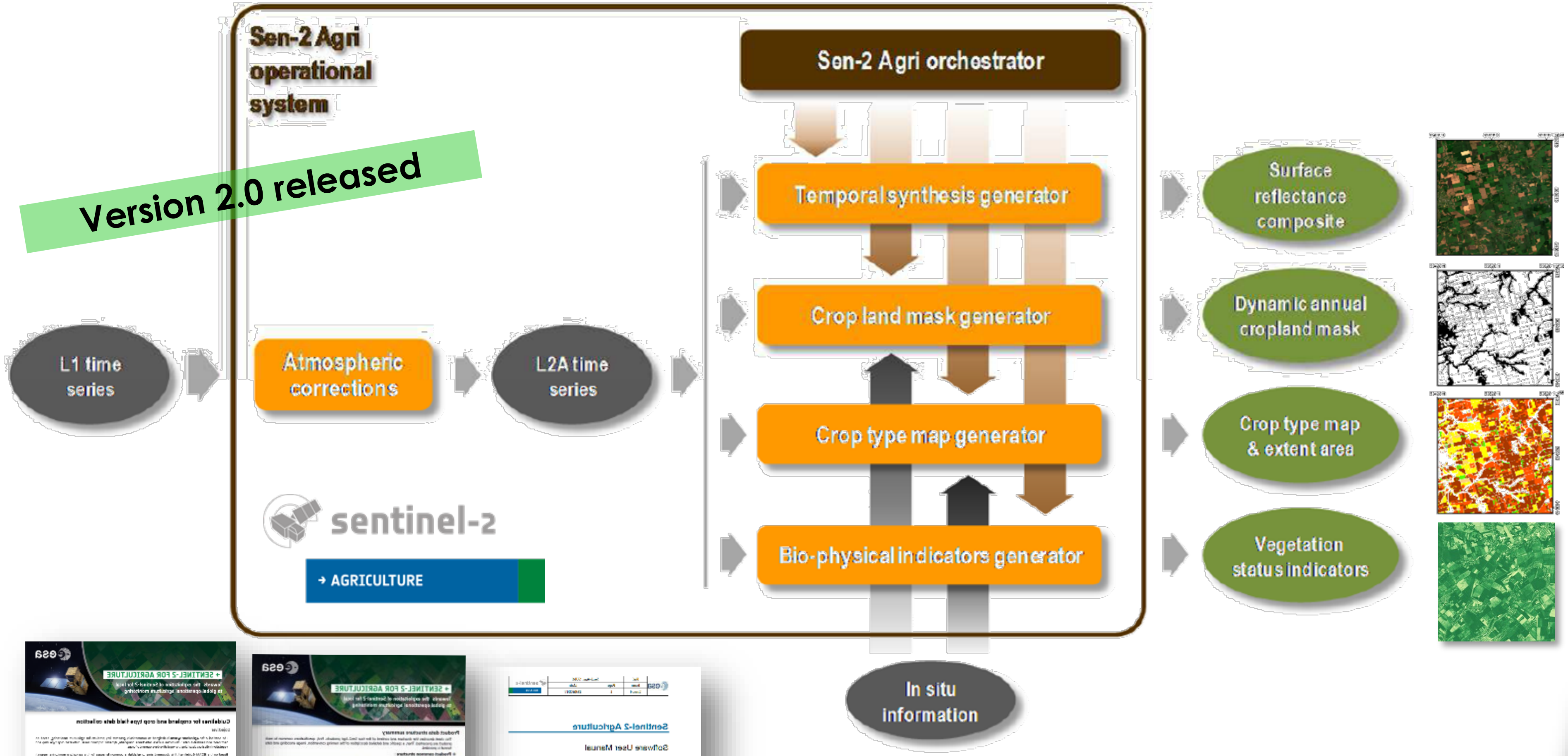



Non-cropland
Other crops
Maize
Rice
Sorghum
Millet
Groundnuts
Cotton

Sen2Agri system: Open source system **precursor of Sen4Stat** running in NRT or off-line, running locally or in the cloud

Sen2-Agri

GPLv3 Free Software
Free as in Freedom



Monthly cloud free surface reflectance composite at 10-20 m

Cropland mask at 10m updated every month

Crop type map at 10 m for the main regional crops

Vegetation status map at 10 m delivered every week (NDVI, LAI, *fCover, fAPAR*)

Documented and downloadable at www.esa-sen2agri.org/resources/software/

Sen2Agri as a service on the EODC cloud (e.g.for WFP)

UCLouvain CESBIO CS ROMÂNIA

UCLouvain

Sen4Stat – Open-source operational solution for national processing in near real time and for local applications

Under GNU-GPL License

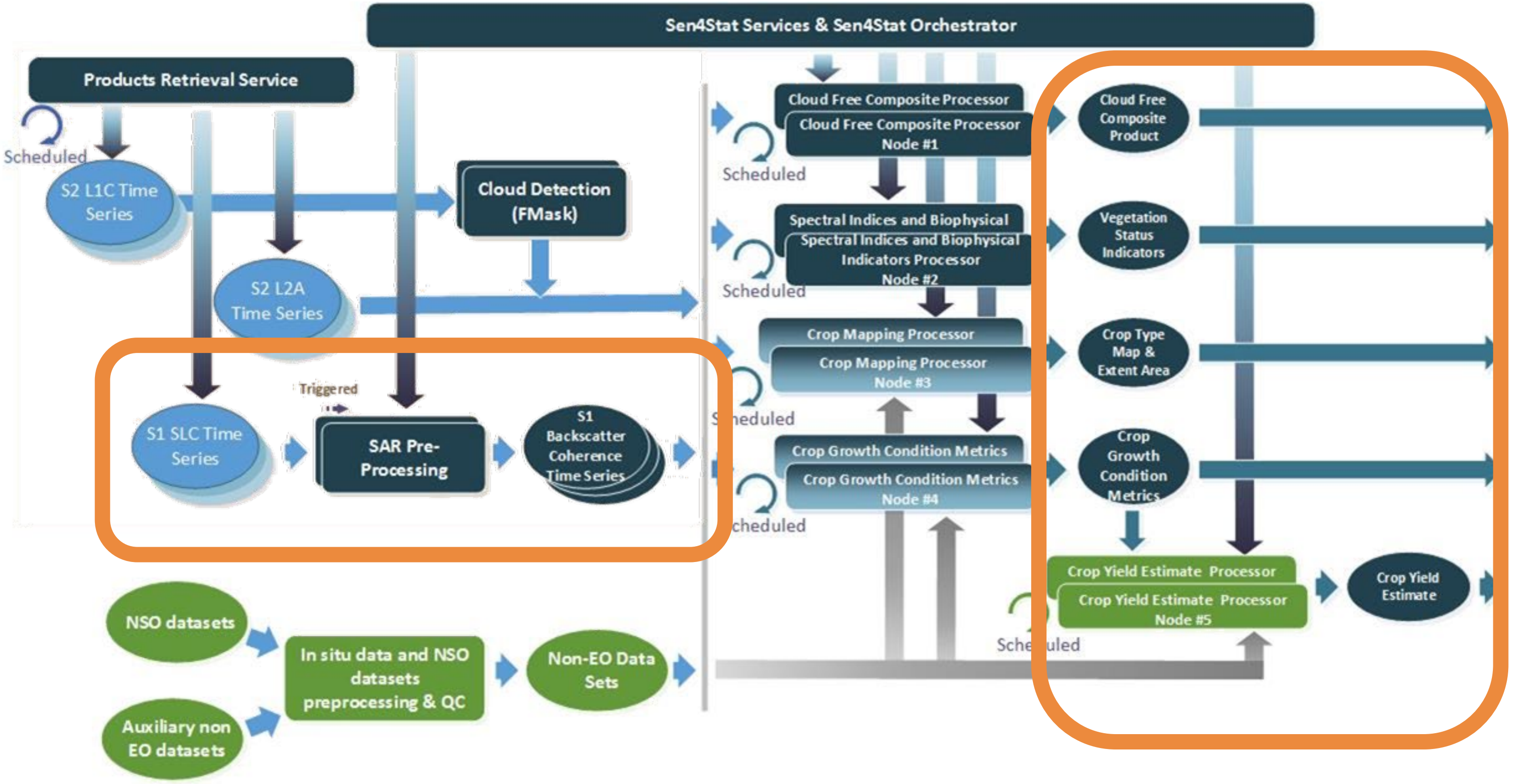
Open-source software based on **Orfeo ToolBox**

Cluster-ready architecture for distributed processing

Integration with **Sentinel-2 ToolBox**

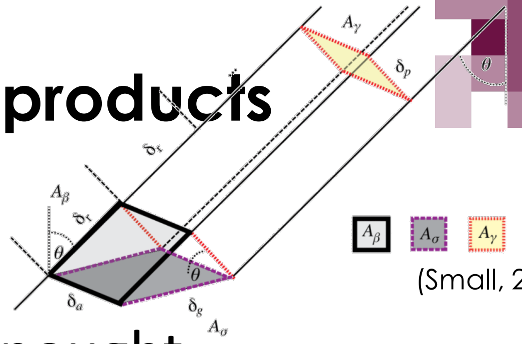
Operational system required: **CentOS 7** (GNU/LINUX)

5 main processors to be possibly combined



State-of-the-art SAR processing for high level products

Sen4Stat – State-of-the-art SAR processing for high level products for amplitude and coherence



(Small, 2011)

beta nought β_0

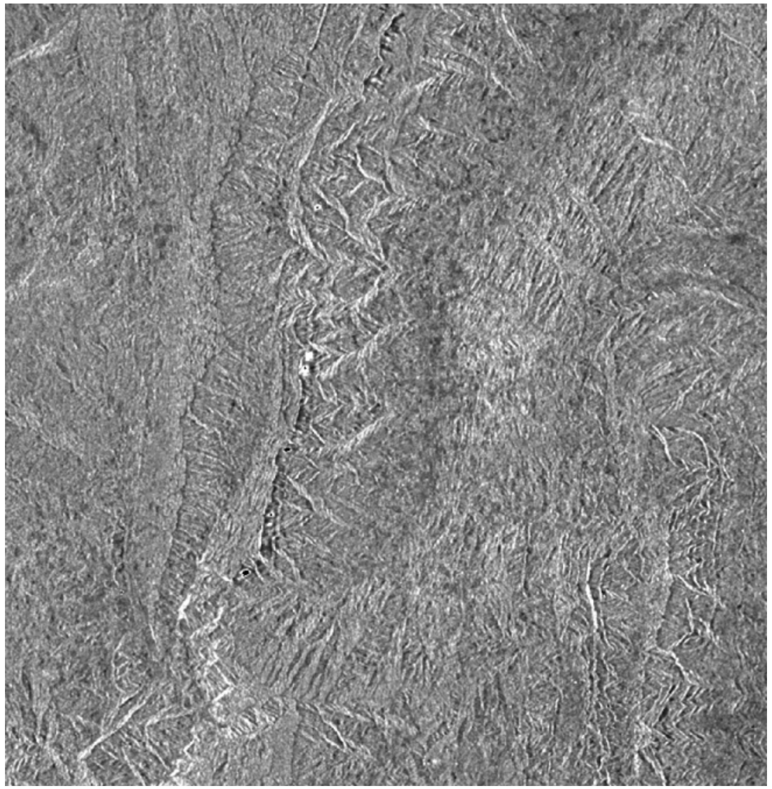
(A_β slant range geometry)

sigma nought σ_0

(A_σ corrected for local inc. angle)

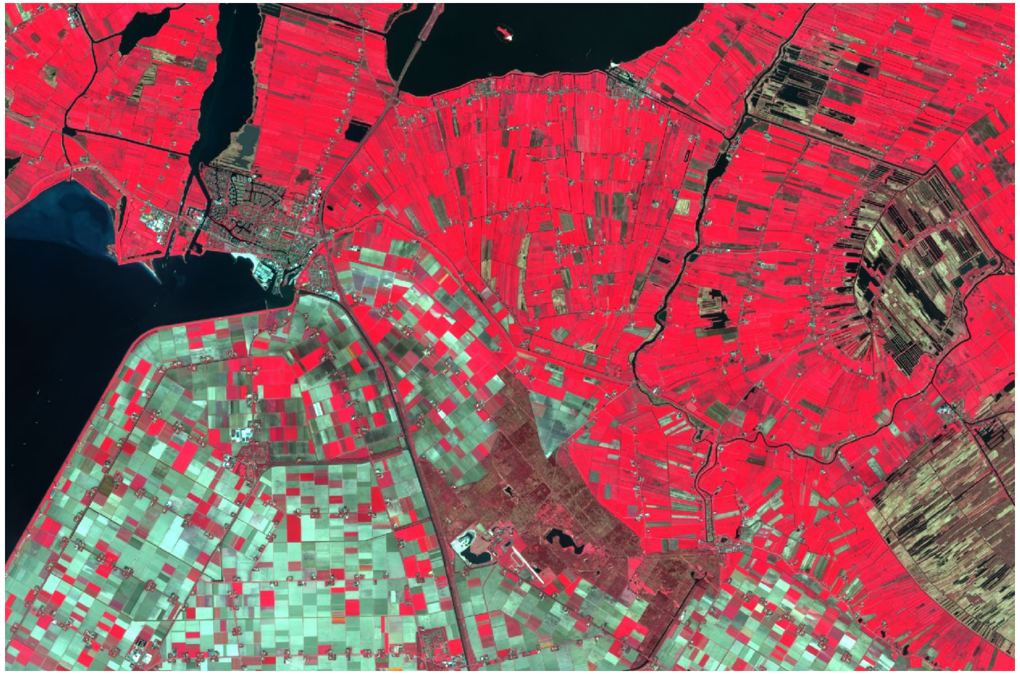
gamma nought γ_0

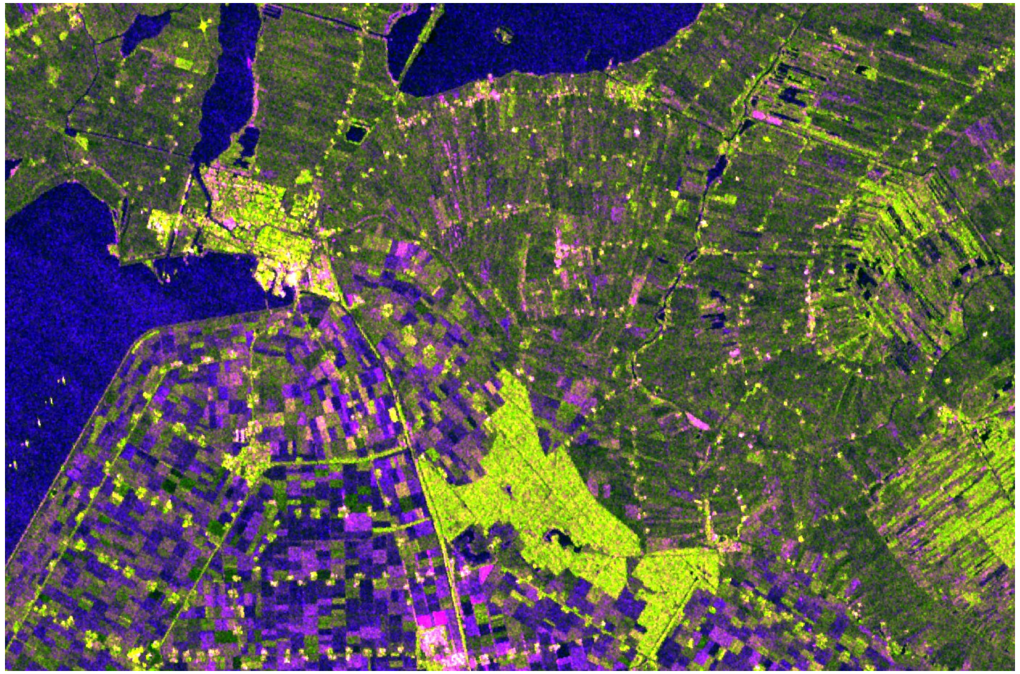
(A_γ flattened corrected using DEM)



Sen4Stat – Crop type mapping module *(S4S_Crop mapping processor)*

- **Random Forest as classifier by default** (deep learning alternative: Neural Net [Transformer])
- **Specific quality control of in situ dataset to balance the calibration dataset**
- **Large set of features used by the Random Forest model including:**
  - S2 & L8 surface reflectance time series and S1 amplitude and coherence time series
  - NDVI, NDWI, Red Edge Indices, brightness and S1 polarization ratio time series
  - Temporal metrics from above time series and S1 temporal metrics from SAR time series



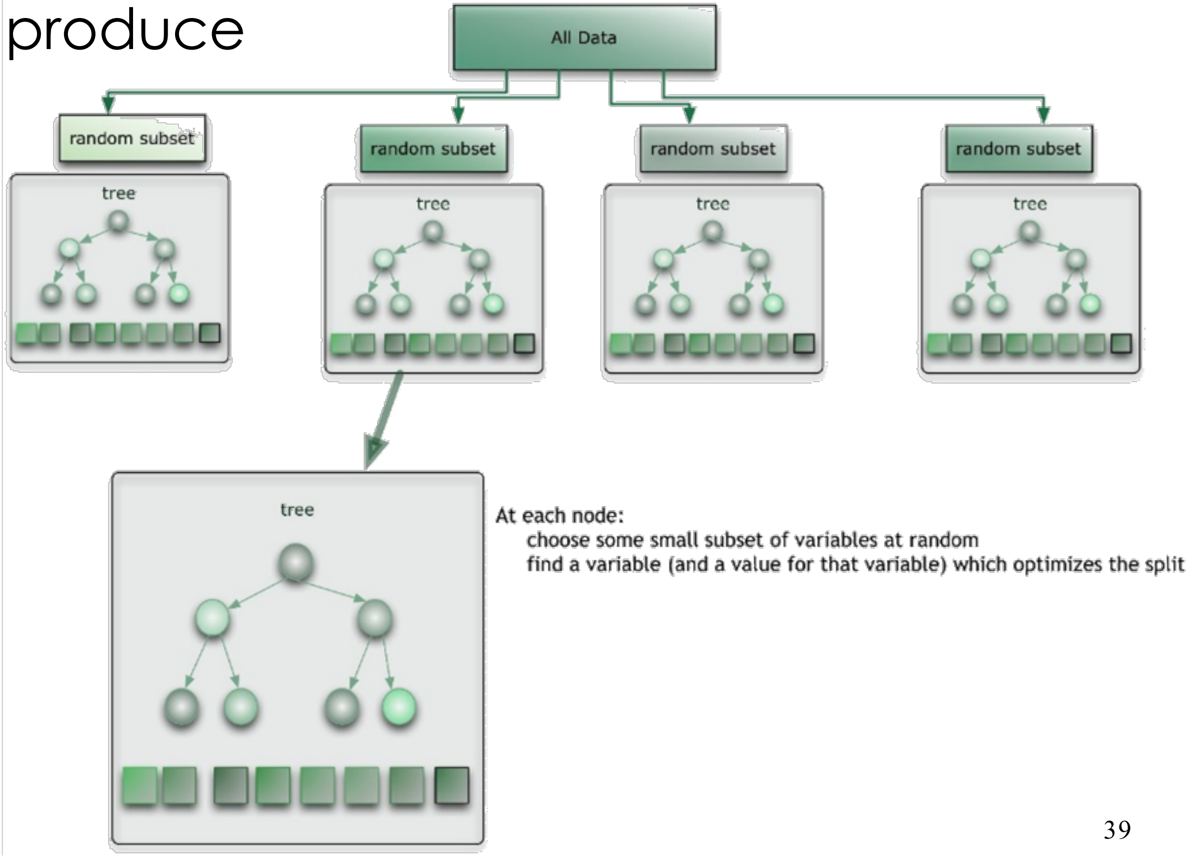


Sen4Stat – Random Forest (RF)

- Decision Trees ~ recursive partitions calibrated on training set to get regions (nodes) increasingly homogeneous with respect to their class variable

- Random Forest ~ ensemble-learning algorithm that combines multiple classifications of the same data to produce higher classification accuracies

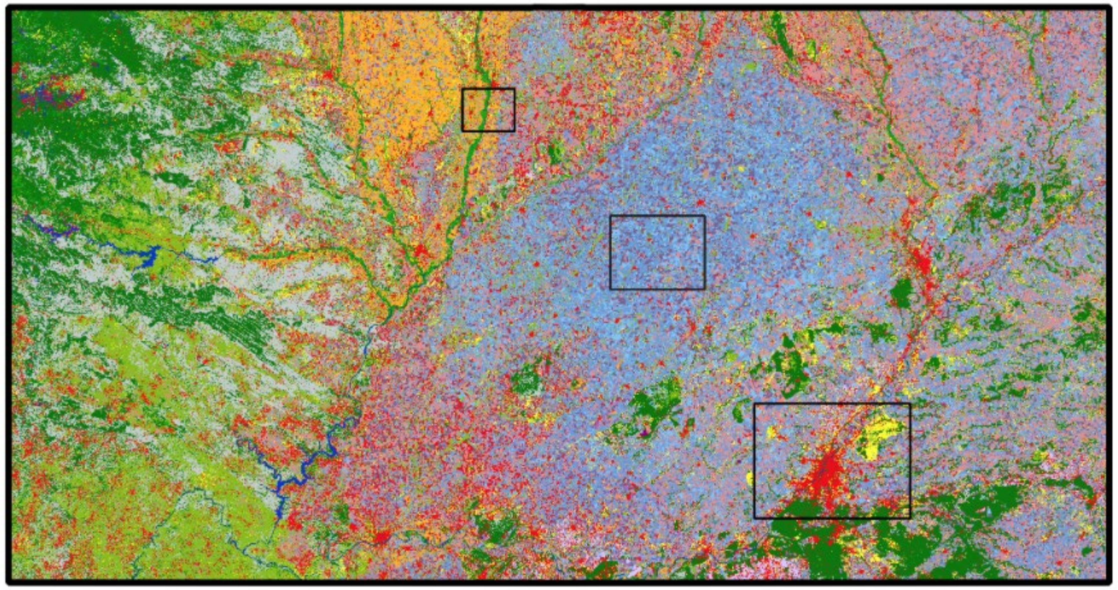
- Sequence:
  - **Bagging**: individual trees are grown from different subsets of training data (random subsampling of the original data for growing each tree)
  - **Single majority vote** to identify the most frequent class decided from all trees

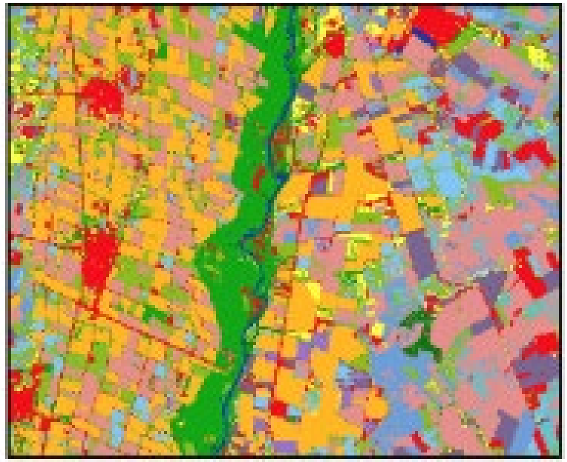


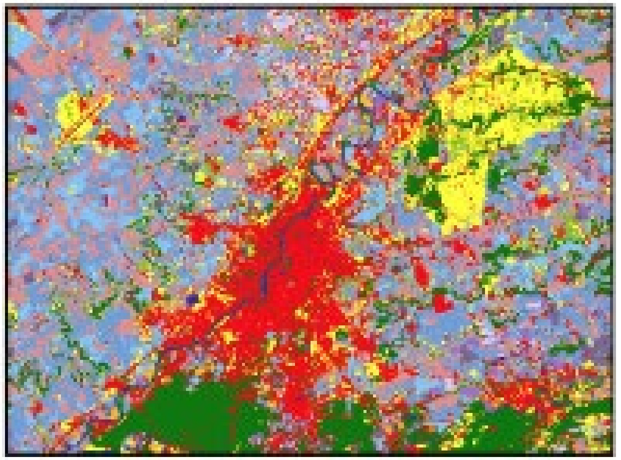
Sen4Stat – Crop map for Spain area (35 crop types)

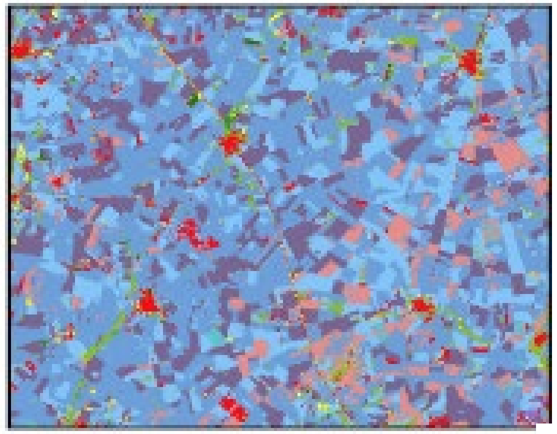
Very similar accuracies for Random Forest and Neural Net (Transformer)

Overall Accuracy (OA): 80% (crop type) & 88% crop group





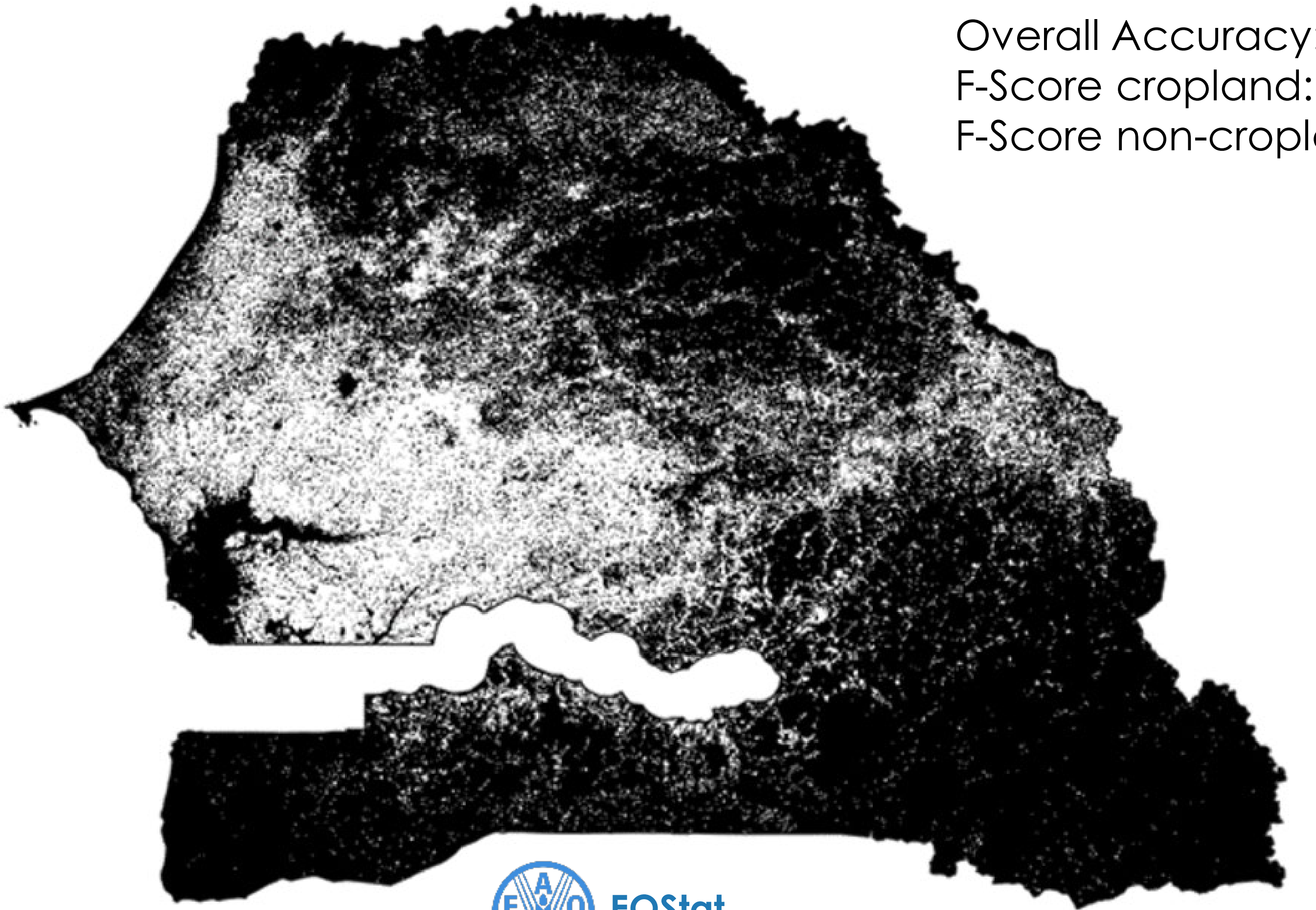




Sen4Stat – National cropland map at 10-m resolution (Senegal, 2020)

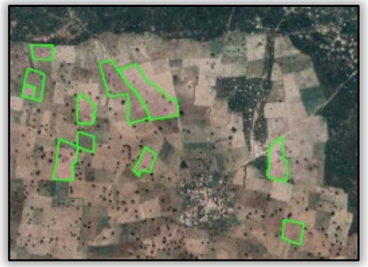
Sentinels for Agricultural Statistics

Random Forest classification based on S2 & L8 time series only



Overall Accuracy: 96%
F-Score cropland: 0,97
F-Score non-cropland: 0,88

2000 GPS traces for holdings selected through a stratified sampling from the 526.000 holdings in Senegal (~ 0.4%)



EOStat

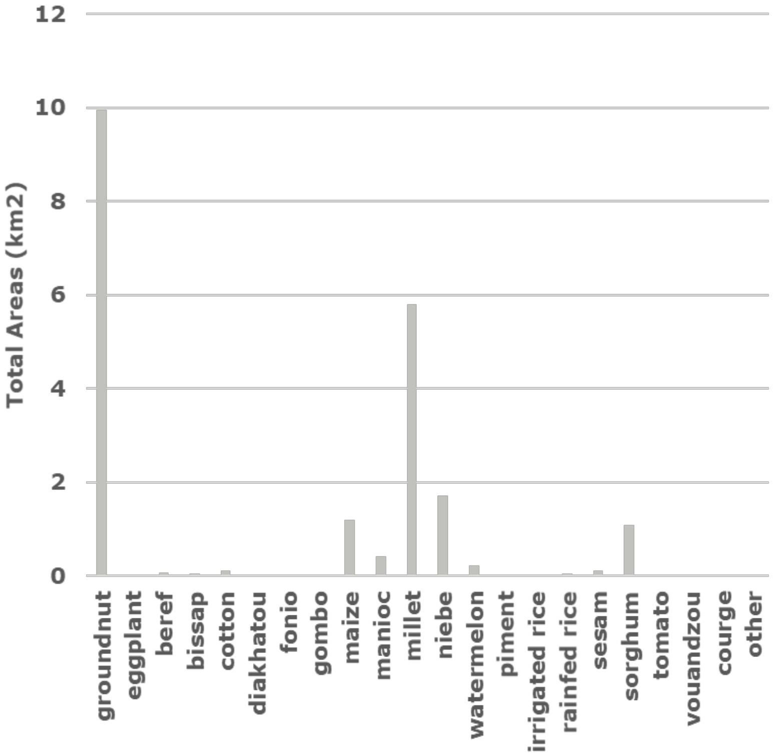
UCLouvain

Sen4Stat – Quality of in situ data as major bottleneck today

Sentinels for Agricultural Statistics

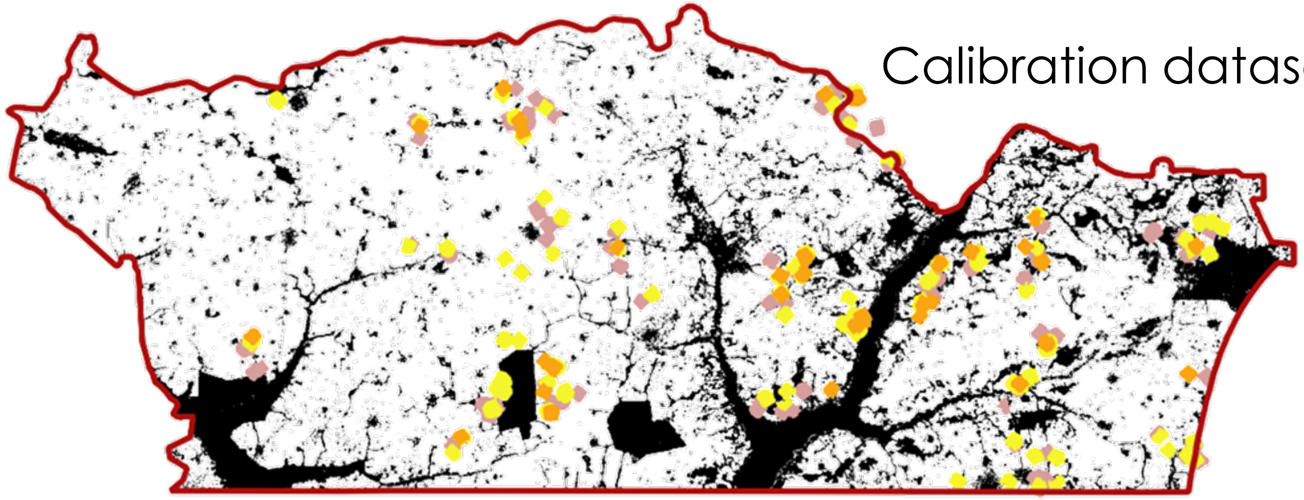
Poor accuracy of crop type map because of the unbalanced ground observation dataset

	Arachide	Maïs	Millet	Niébé	Sorgho	Autres	
Arachide	23296	0	6	1101	158	1184	90 %
Maïs	1	0	0	0	0	6	0 %
Millet	178	0	918	93	0	5	77 %
Niébé	3445	0	0	11318	158	1068	71 %
Sorgho	1996	0	0	1200	443	270	11 %
Autres	5037	0	84	2610	191	4256	35 %
	69 %	N/A	91 %	69 %	47 %	63 %	**68 %**

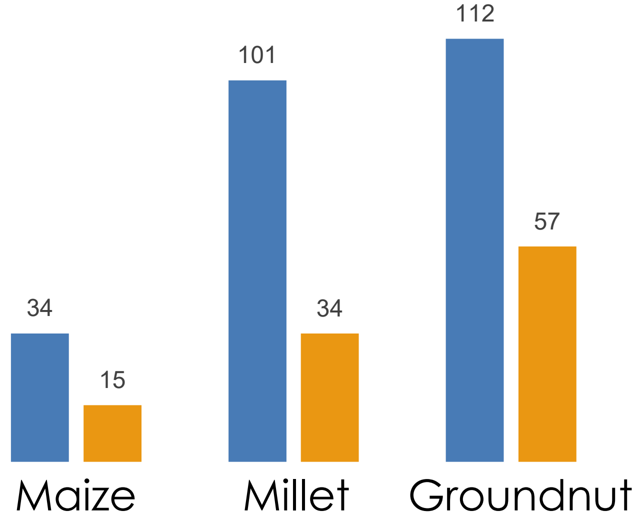


– Specific in situ data collection for department of Nioro (Senegal, 2021)

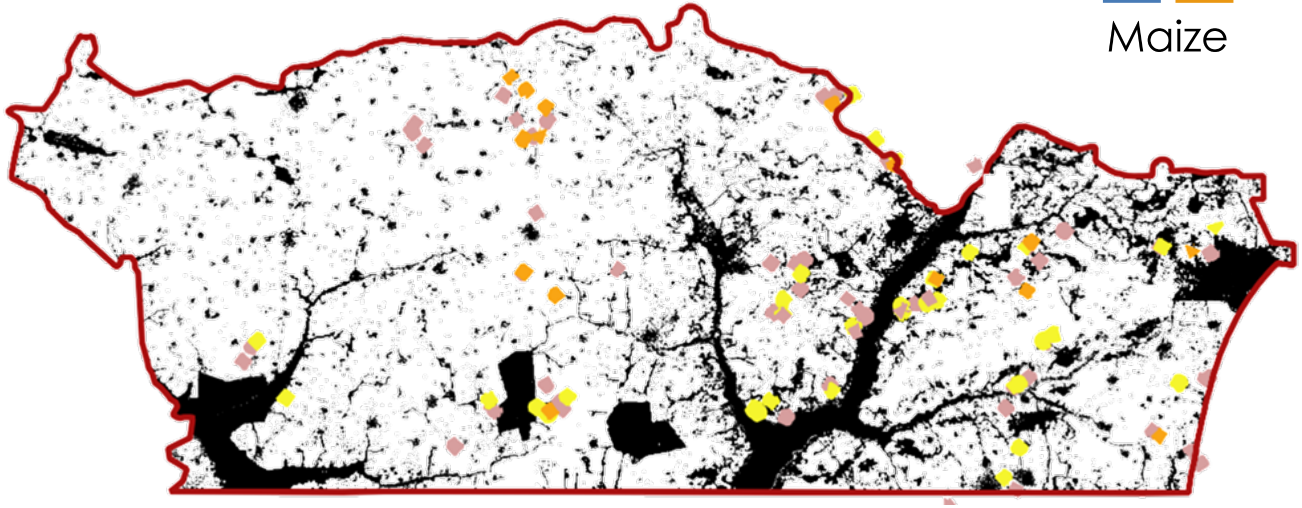
Calibration dataset



Calibration polygons
Validation polygons



Validation dataset



Maize
Millet
Groundnut

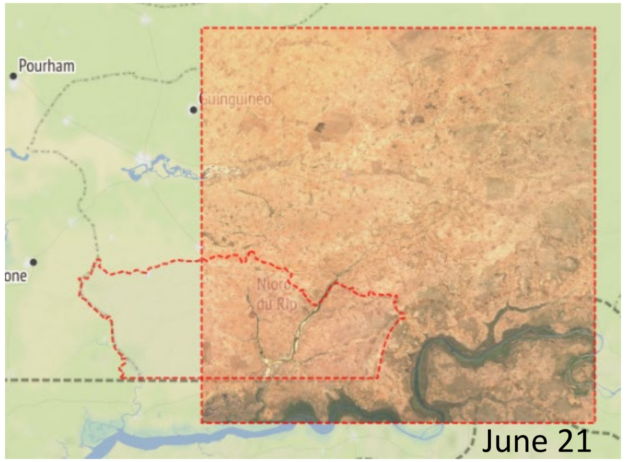
0 10 km

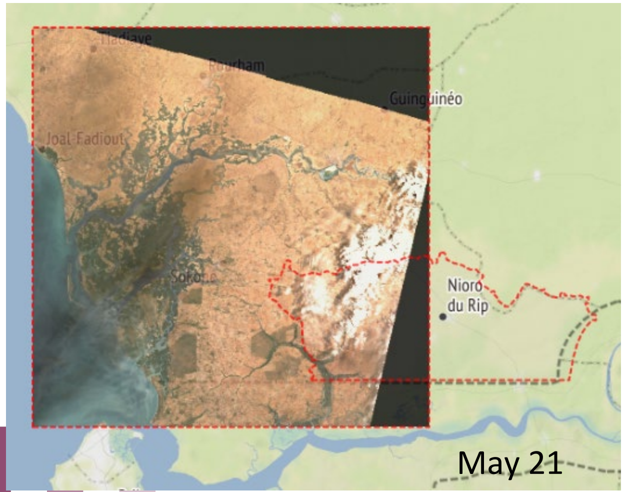
EOStat

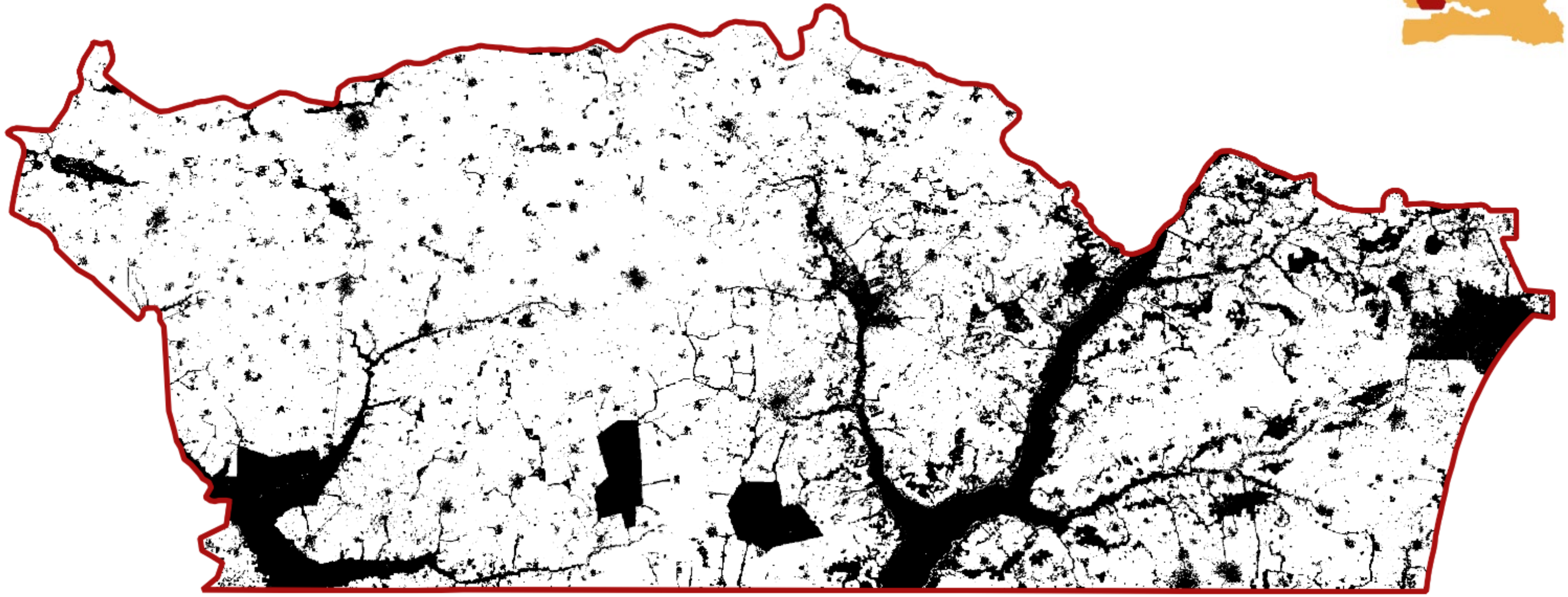
Sen4Stat – 10-m cropland map using balanced in situ data collection for the Department of Nioro (Senegal)

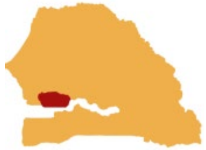
Sentinels for Agricultural Statistics

Each S2 image covering only a part of the department









Overall Accuracy: 97,4 %
F-Score cropland: 0,98
F-Score non-cropland: 0,95

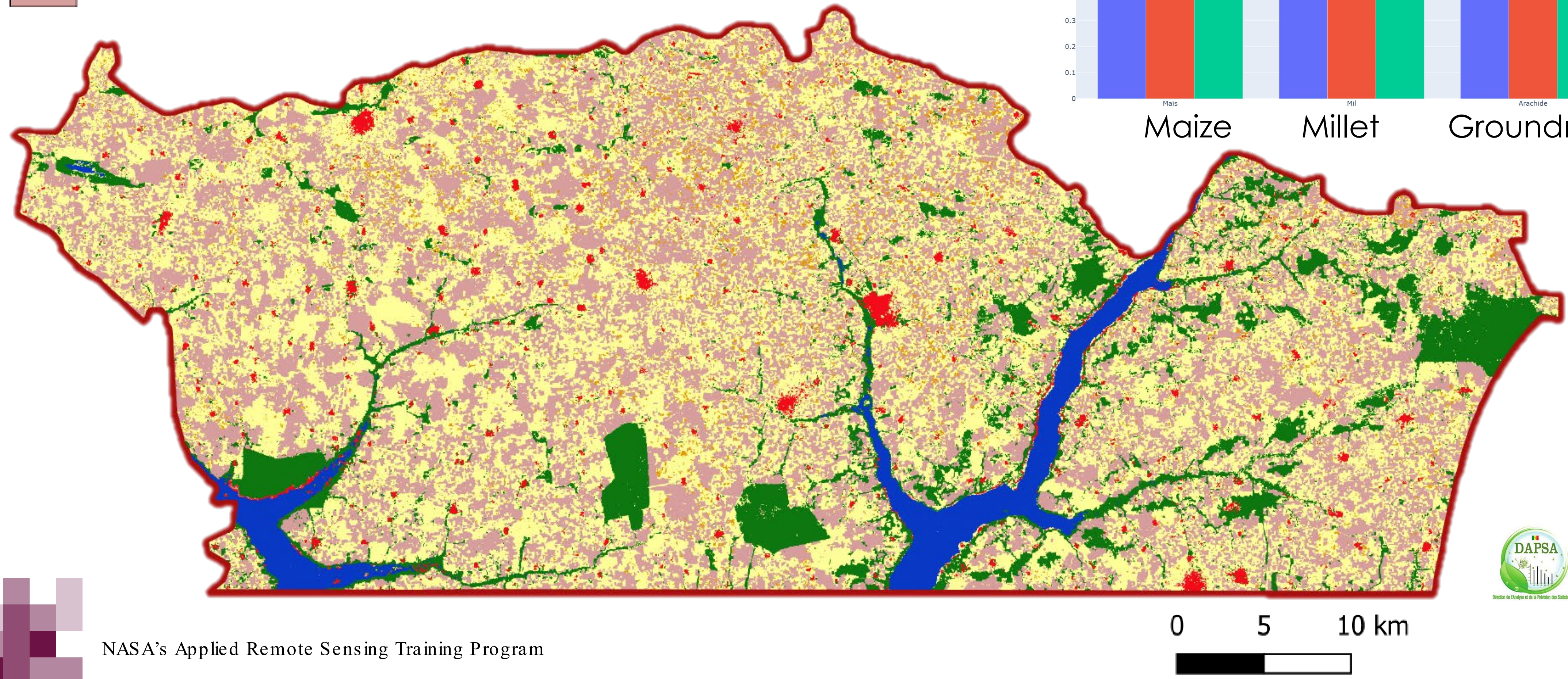
Cropland
Non-cropland

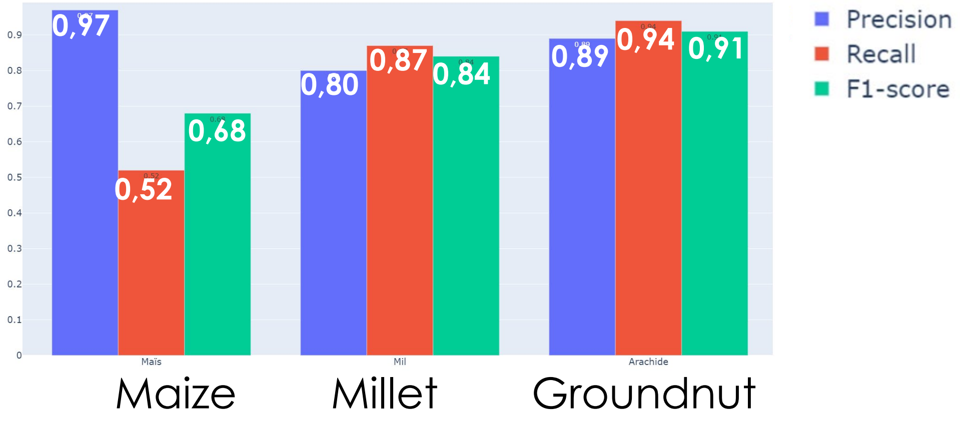
0 5 10 km

Sen4Stat – 10-m crop type map from Sentinel-1 and Sentinel-2 time series acquired over the season and using balanced in situ dataset

Sentinels for Agricultural Statistics

Season from 01-05-2021 to 31-12-2021
Overall Accuracy: 84,8 %





DAPSA

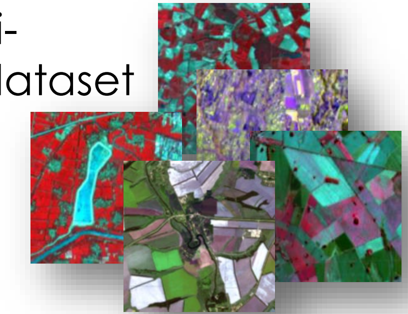
EOStat

UCLouvain

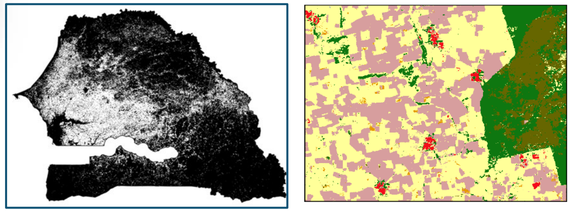
Sen4Stat – Operational exploitation of satellite missions to improve timely information about crop areas, yields and production

Sentinels for Agricultural Statistics

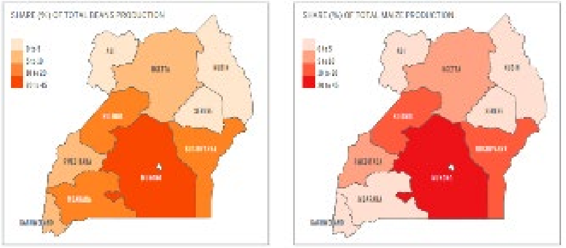
EO Multi-sensor dataset



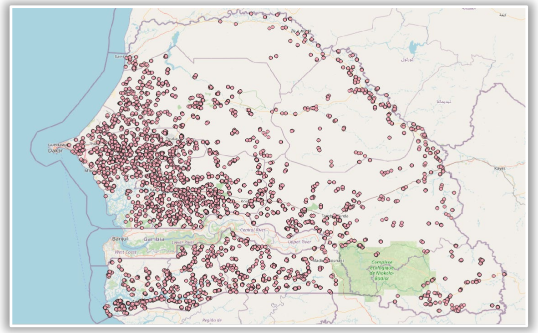
Production of crop type maps



&

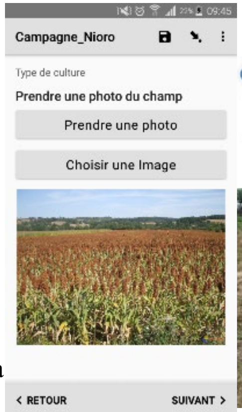


Agricultural statistics improvement



Area sampling frame

Field surveys

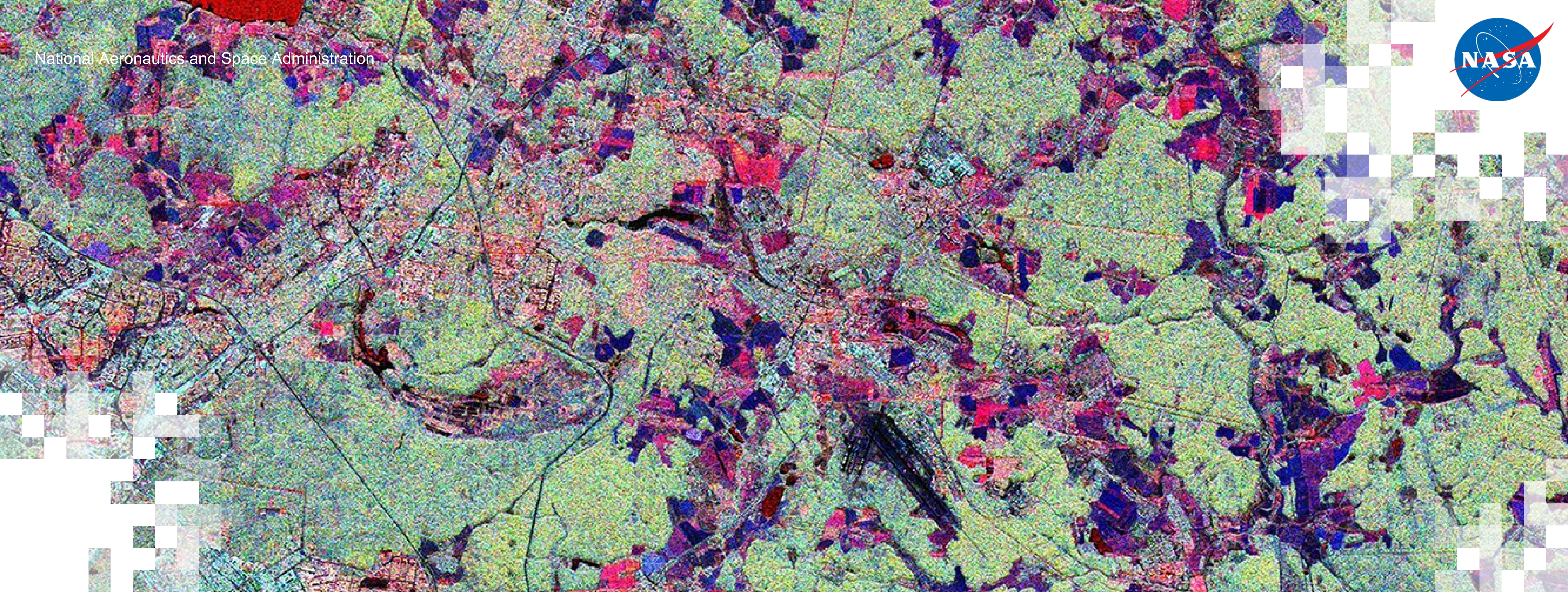


OPEN DATA KIT

Quality control of survey data

Key information for decision making processes

National Aeronautics and Space Administration



Section 3: Practical using Sen4Stat toolbox for crop type mapping

Contacts

- Trainers:
  - Pr. Pierre Defourny pierre.defourny@uclouvain.be
- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-agricultural-crop-classification-synthetic-aperture-radar-and
- ESA's EO4Society Website:
  - https://eo4society.esa.int/training-education/
- Twitter: @EOOpenScience

Useful links

- **Sen4Stat**

  https://esa-sen4stat.org/
- **Sen2Agri**

  https://github.com/Sen2Agri/Sen2Agri-System/
- **SNAP download**

  http://step.esa.int/main/download/snap-download/
- **Copernicus Open Access Hub (download Sentinel data)**

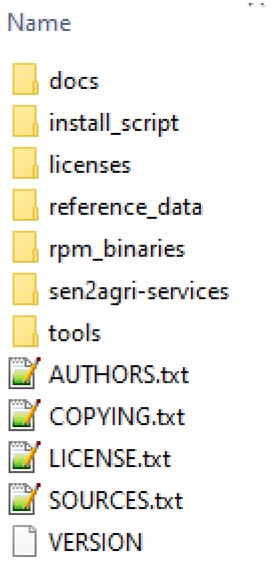
  https://scihub.copernicus.eu/
- **NASA ARSET** Agricultural Crop Classification with Synthetic Aperture Radar and Optical Remote Sensing **Part 5: Biophysical Variable Retrieval using Optical Imagery to Support Agricultural Monitoring Practices**

  https://appliedsciences.nasa.gov/join-mission/training/english/arset-agricultural-crop-classification-synthetic-aperture-radar-and
- **ESA 'Advanced Training Course on Land Remote Sensing with the Focus on Agriculture' held in Louvain-la-Neuve, Belgium, on 16-20 September 2019**

  https://eo4society.esa.int/resources/advanced-training-course-on-land-remote-sensing-with-the-focus-on-agriculture/

Sen4Stat Installation Package (available in June 2022)

- Single installation archive containing all files needed
  - Documentation (docs)
  - Installation scripts
  - Sen4Stat rpm files
  - Sen4Stat Services
  - Other tools and configuration files
- CentOS 7 is required for system installation
- Installation performed through a single script
  - sudo ./install.sh
- Two directories with write permissions for all users are needed:
  - /mnt/archive
  - /mnt/upload
- During installation, all needed third party packages are installed via yum. Needed docker images are installed
- PostgreSQL database is used for storing system configuration, product information etc.
- The regular user sen2agri-service is created during installation
- System services are created and launched upon installation:
  - sen4stat-executor sen4stat-orchestrator sen4stat-http-listener sen4stat-demmaccs sen4stat-demmaccs.timer sen4stat-monitor-agent sen4stat-scheduler sen4stat-services

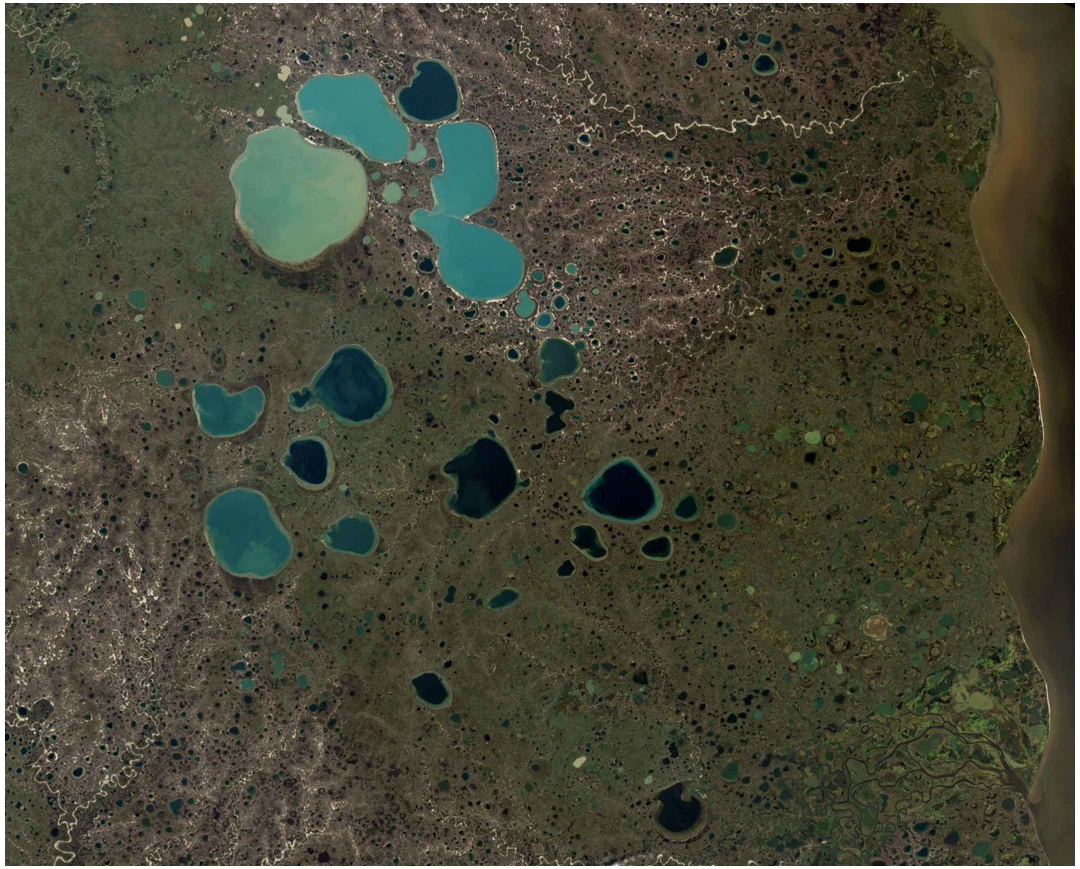


Homework and Certificate

- Homework Assignment:
  - Answers must be submitted via Google Form
  - Due Date: May 17, 2022
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline (access from website)
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Questions?

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.



https://earthobservatory.nasa.gov/images/6034/pothole-lakes-in-siberia

Thank You!