Agricultural Crop Classification with Synthetic Aperture Radar and Optical Remote Sensing

Part 5: Biophysical Variable Retrieval using Optical Imagery to Support Agricultural Monitoring Practices

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Training Outline

October 5, 2021
Synthetic Aperture Radar (SAR) Refresher

October 7, 2021
Optical Remote Sensing Refresher and Introduction to SNAP

October 12, 2021
Operational Crop Classification Roadmap using Optical and SAR Imagery (Part 1)

October 14, 2021
Operational Crop Classification Roadmap using Optical and SAR Imagery (Part 2)

October 19, 2021
Biophysical Variable Retrieval using Optical Imagery to Support Agricultural Monitoring Practices
Training Objectives

By the end of this training attendees will learn:

- What are the applications of spectral indices for agriculture
- What are the biophysical variables relevant for agriculture
- How to calibrate biophysical variable retrieval models
- How to assess the biophysical variables estimation performances
- What are phenometrics and how are they useful
- How biophysical variables can support monitoring of agricultural practices
- How biophysical variables can support crop yield estimations
- What are the ESA Sen2-Agri, Sen4CAP, and Sen4Stat toolboxes
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- Section 2: Calibration of Biophysical Variable Retrieval Models and Performance Assessment
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- Section 5: Biophysical Variables Supporting Yield Estimation
- Section 6: ESA Sen2-Agri/Sen4CAP/Sen4Stat Open-Source Toolboxes
- Q&A and Main References
Section 1: Spectral Indices (SI) and Biophysical Variables (BV) for Agriculture
Monitoring Vegetation Development from Spectral Reflectance

Crop assessment by:

- Ground measurements
- Estimation of biophysical variables from satellite/UAV observations
- Spectral or radiometric indices combining several reflectance bands
Spectral Indices - To Extract a Specific Signal from a Spectral Signature

Vegetation indices based on red absorption by chlorophyll and high near-infrared reflectance by internal leaf structure enhance the sensitivity to green vegetation while minimizing other effects.

Normalized Difference Vegetation Index
(~ Green Biomass)

\[
NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}
\]

Each dot corresponds to a crop observation along its growth cycle. Modified from Lewis et al. UCLondon.
Spectral Indices - To Extract a Specific Signal from a Spectral Signature

Vegetation indices based on red absorption by chlorophyll and high near-infrared reflectance by internal leaf structure enhance the sensitivity to green vegetation while minimizing other effects.

Normalized Difference Water Index
(~ Water Content of Green Vegetation)

\[
\text{NDWI} = \frac{\rho_{\text{NIR}} - \rho_{\text{SWIR}}}{\rho_{\text{NIR}} + \rho_{\text{SWIR}}}
\]
Spectral Indices – NDVI as the Most Popular Vegetation Index

A crop cycle corresponds to a progressive transition from a bare soil signature to a closed green vegetation canopy and typically ends with vegetation senescence.

<table>
<thead>
<tr>
<th>Indices</th>
<th>Name</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloregreen</td>
<td>Chlorophyll Green index</td>
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<tr>
<td>GI</td>
<td>Greenness Index</td>
<td></td>
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<tr>
<td>gNDVI</td>
<td>Green normalized difference vegetation index</td>
<td></td>
</tr>
<tr>
<td>MSAVI</td>
<td>Modified soil adjusted vegetation index</td>
<td></td>
</tr>
<tr>
<td>MSI</td>
<td>Moisture stress index</td>
<td></td>
</tr>
<tr>
<td>ND$_{RedgeSWIR}$</td>
<td>Normalized Difference of Red-edge and SWIR2</td>
<td></td>
</tr>
<tr>
<td>NDVI</td>
<td>Normalized difference vegetation index</td>
<td></td>
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<tr>
<td>NDVire</td>
<td>Red-edge normalized difference vegetation index</td>
<td></td>
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<tr>
<td>PVI</td>
<td>Perpendicular vegetation index</td>
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</tr>
<tr>
<td>RededgePeakArea</td>
<td>Red-edge peak area</td>
<td></td>
</tr>
<tr>
<td>RTVI</td>
<td>Red-edge Triangular Vegetation Index</td>
<td></td>
</tr>
<tr>
<td>SAVI</td>
<td>Soil Adjusted Vegetation Index</td>
<td></td>
</tr>
<tr>
<td>SRNIRnarrowBlue</td>
<td>Simple ratio NIR narrow and Blue</td>
<td></td>
</tr>
<tr>
<td>SRNIRnarrowGreen</td>
<td>Simple ratio NIR narrow and Green</td>
<td></td>
</tr>
<tr>
<td>SRNIRnarrowRed</td>
<td>Simple ratio NIR narrow and Red</td>
<td></td>
</tr>
<tr>
<td>TSAVI</td>
<td>Transformed Soil Adjusted Vegetation Index</td>
<td></td>
</tr>
<tr>
<td>WDI</td>
<td>Weighted Difference Vegetation Index</td>
<td></td>
</tr>
</tbody>
</table>

Vegetation discrimination

Radoux et al., RS2016
Spectral Indices – Vegetation Indices Based on Red-Edge Region

- The red-edge region, corresponding to the red-NIR transition zone, is the basis of several vegetation indices related to the canopy chlorophyll content or canopy nitrogen content.

Segara et al., Agr.2020
Spectral Indices – Vegetation Indices Based on Red-Edge Region

- **Red Edge Position (REP):** Specific wavelength where the change in reflectance is at its maxima (maximum slope) in the 680–780 nm region. REP moves to longer wavelengths with increasing chlorophyll content.

<table>
<thead>
<tr>
<th>Name</th>
<th>Abbreviation</th>
<th>Index calculation</th>
<th>Parameter</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple chlorophyll index (high sensitivity)</td>
<td>R675</td>
<td>R_{675}</td>
<td>Chlorophyll</td>
<td>Jacquemoud and Baret, 1990</td>
</tr>
<tr>
<td>Simple chlorophyll index (low sensitivity)</td>
<td>R550</td>
<td>R_{550}</td>
<td>Chlorophyll</td>
<td>Jacquemoud and Baret, 1990</td>
</tr>
<tr>
<td>Wavelength of the red edge</td>
<td>\lambda_{m}</td>
<td>The maximum slope in the reflectance spectra between the RED and NIR regions.</td>
<td>Chlorophyll and N status</td>
<td>Filella et al., 1995</td>
</tr>
<tr>
<td>Amplitude in the 1st derivative of the reflectance spectra</td>
<td>\Delta R_{m}</td>
<td>The maximum amplitude in the 1st derivative of the reflectance spectra.</td>
<td>Chlorophyll and N status</td>
<td>Filella et al., 1995</td>
</tr>
<tr>
<td>Sum of the amplitudes (680–780 nm) in the 1st derivative of the reflectance spectra</td>
<td>2DR_{680-780}</td>
<td>Sum of the amplitudes between 680 and 780 nm in the 1st derivative of the reflectance spectra.</td>
<td>Chlorophyll and N status</td>
<td>Filella et al., 1995</td>
</tr>
<tr>
<td>Normalized difference red edge</td>
<td>NDRE</td>
<td>(R_{700} - R_{720}) / (R_{700} + R_{720})</td>
<td>Chlorophyll and N status</td>
<td>Bames et al., 2000; Rodriguez et al., 2006</td>
</tr>
<tr>
<td>Normalized phasophytinization index</td>
<td>NPQI</td>
<td>(R_{645} - R_{665}) / (R_{645} + R_{665})</td>
<td>Chlorophyll degredation</td>
<td>Pelaeulas et al., 1995b</td>
</tr>
<tr>
<td>Canopy chlorophyll content index</td>
<td>CCCI</td>
<td>Calibratied index using NDRE as function of NDVI.</td>
<td>Chlorophyll and N status</td>
<td>Bames et al., 2000; Fitzgerald et al., 2006; Rodriguez et al., 2006</td>
</tr>
<tr>
<td>Modified spectral ratio</td>
<td>MSR</td>
<td>(R_{720} - R_{665}) / (R_{700} - R_{645})</td>
<td>Chlorophyll concentration</td>
<td>Sims and Gamon, 2003</td>
</tr>
<tr>
<td>Pigment simple ratio</td>
<td>PSR</td>
<td>R_{665} / R_{660}</td>
<td>Carotenoid to chlorophyll ratio</td>
<td>Pelaeulas et al., 1993</td>
</tr>
<tr>
<td>Normalized difference pigment index</td>
<td>NDPI</td>
<td>(R_{665} - R_{680}) / (R_{665} + R_{680})</td>
<td>Carotenoid to chlorophyll ratio</td>
<td>Pelaeulas et al., 1993</td>
</tr>
<tr>
<td>Structural independent pigment index</td>
<td>SPII</td>
<td>(R_{680} - R_{665}) / (R_{665} + R_{680})</td>
<td>Carotenoid to chlorophyll ratio</td>
<td>Pelaeulas et al., 1995a</td>
</tr>
<tr>
<td>Photocemical reflectance index</td>
<td>PRII</td>
<td>(R_{665} - R_{680}) / (R_{665} + R_{680})</td>
<td>Radiation use efficiency</td>
<td>Pelaeulas et al., 1995a</td>
</tr>
</tbody>
</table>
Spectral Indices – **Sentinel-2 Playground** to Visualize Various Spectral Indices

[Image of Sentinel-2 Playground interface showing NDVI and NDWI]

https://apps.sentinel-hub.com/sentinel-playground/
Spectral Indices – Temporal Profile Affected by Atmospheric Perturbations

https://mars.jrc.ec.europa.eu/asap/hresolution/?region=0
Spectral Indices – Derived Only from Cloud-Free Surface Reflectance (L2A)

The normalized spectral indices minimize the signal noise and the residual atmospheric perturbations but must always be computed from the L2A surface reflectance imagery after masking clouds and cloud shadows and applying atmospheric correction (for aerosols, water vapour, ozone).

Here, normalization means that a spectral index is divided by the sum of the bands used. This also reduces the angular effects of the bidirectional observation.

Used for the cloud and cloud shadow mask and in the atmospheric correction algorithm.
Spectral Indices – Spectral Bands Vary According to Each Sensor

The spectral signature and the derived spectral indices can be sensitive to many vegetation variables of interest depending on the wavelength and the bandwidth recorded by the satellite sensor.

The **Index Database**, for instance, provides the formula for 300+ Indices for most satellite instruments.
Section 2.1: Biophysical Variable Estimation for Agricultural Applications

Biophysical variables are plant traits or characteristics of interest, which can be measured on the ground and possibly estimated by remote sensing at various scales depending on the sensor’s spatial resolution (at leaf, plant, canopy, and landscape level).

<table>
<thead>
<tr>
<th>Crop processes</th>
<th>UAI</th>
<th>FAPAR</th>
<th>FCOVER</th>
<th>Albedo</th>
<th>Chlorophyll</th>
<th>Water-content</th>
<th>SLA</th>
<th>Soil brightness</th>
<th>Temperature</th>
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<tr>
<td>Photosynthesis</td>
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<td>Evapotranspiration</td>
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<td>Respiration</td>
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<td>Phenology</td>
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<td>Lodging</td>
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<td>Residues</td>
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</tbody>
</table>

(Baret, 2016)
Biophysical Variables – Ground Measurements as Reference

Ground measurements are designed as reference observations for calibration and/or validation.

**Elementary Sampling Unit (ESU):** Described by ground measurements representative of an area corresponding to a single pixel or a small cluster of pixels (typically 3x3 pixels) precisely georeferenced.

**Sampling protocol within an ESU:** Estimates the average value within the ESU given that the ground measurement footprint is generally much smaller than the size of an ESU.
Biophysical Variables – Ground Measurements as Reference

Critical choices for the ESUs:
- **Number**: Calibration and validation datasets ideally exceed 30 ESU
- **Location**: At a reasonable distance (i.e., 1 or 2 pixels) from the border of a different land cover
- **Timing**: The closest to the satellite acquisition day and at an appropriate time in the diurnal cycle
- **Homogeneity**: For a good ESU representation from a limited number of ground measurements per ESU
- **Diversity**: Set of ESUs covering the full range of ground measurement values observed in the area
- **Size**: The Point Spread Function should be considered to match the ESU with the corresponding footprint of the in-orbit sensor.

Typical ESU sampling for random (left), row (center) or regularly planted vegetation (right).

Numbers refer to the location of individual measurements.
Biophysical Variables – Satellite Footprint Measurement

In-orbit instrument observation footprint ≠ pixel size.

- Instantaneous Field of View (IFOV)
- Ground IFOV (Ground-projected IFOV varying across track and enhanced by the Earth’s curvature)
- Ground Sampling Interval (GSI)

Point Spread Function (PSF) describing the response of an imaging system to a point object

Relative contribution to the instrument measurement
Red : GIFOV area
Red + Blue: effective area contributing to the radiance measurement

(Waldner, Duveiller and Defourny, 2018)

(Radoux et al., 2016)
Biophysical Variables – fCover

Cover Fraction (fCover): Green cover fraction as seen from the nadir direction.

- A canopy structural variable, which is dimensionless
- Independent of the geometry of illumination unlike FAPAR
- Very sensitive to low cover fraction
- Saturation at 100% is reached before full plant development

fCover measurement by LiDAR or vertical photograph

Source: Field measurement of fractional ground cover, Australia 2011
Biophysical Variables – fAPAR

Fraction of Absorbed Photosynthetically Active Radiation (fAPAR)
- Balance between incident and transmitted PAR (400-700 nm) through the canopy
- A non-dimensional value ranging from 0 to almost 1 for full green vegetation
- Used as a descriptor of photosynthesis and evapotranspiration processes
- Depends also on the illumination conditions (sun angular position and the relative contributions of the direct and diffuse illumination - black-sky or white sky)

Measurements:
- To compute the PAR balance, you need a permanent setup with continuous measurements, covering the illumination variability over days and/or seasons.
- Estimated from measurement of PAR transmitted at the bottom of the canopy (the so-called ceptometers)

Biomass = \[ \int_{time} PAR_i \cdot fAPAR(time) \cdot \varepsilon_b \]
\[ \varepsilon_b = \text{Light Use Efficiency (LUE)} \]
Biophysical Variables – Canopy Chlorophyll Content (CCC)

CCC is the **total amount of chlorophyll a and b pigments** in a contiguous group of plants per unit ground area (in g/m²).

- Closely related to plant nitrogen content (fertilization)
- Reflectance at 675 nm is very sensitive to changes in chlorophyll content, but only for low CCC values.
- Lower chlorophyll absorption at 550 nm, sensitive to a greater range of CCC, not easily saturated but less sensitive to chlorophyll changes

CCC ground measurement using a handheld single-leaf meter that measures chlorophyll using light transmittance at 650 nm and 940 nm (e.g., using SPAD or Dualex instrument)
Biophysical Variables – Leaf Area Index (LAI)

More precisely **Green Area Index (GAI)**

- **True GAI**: Half the developed area of green elements per unit horizontal ground area (destructive measurements)

- **Effective GAI**: The value retrieved from green fraction (gap fraction) measurements based on turbid medium assumption (DHP, LAI2200)

- **Apparent GAI**: The value retrieved from remote sensing observations that depends on the assumptions associated to the estimation algorithm (e.g., leaf orientation, leaf clumping)

Ground GAI measurement obtained from Digital Hemispherical Photography (DHP) using Can-Eye Software
Section 2.2: Calibration of Biophysical Variable Retrieval Models and Performance Assessment

Illustration from Weiss – ESA Training 2019
Empirical models using statistical regression or machine learning relationships

- **Calibration** between indices or spectral reflectance values and the corresponding reference values (typically from ground measurements)

- **Validation** using an independent dataset to estimate the prediction error of the model

**Empirical Models** vs. **Physically-Based Models**

Empirical models that are locally calibrated are valid for the area and conditions corresponding to the dataset calibration

Physically-based models are transposable to other areas and conditions because they are designed to be generic
Biophysical Variable Retrieval – Physically-Based Models

GAI retrieval by Radiative Transfer (RT) model inversion using Neural Network

Crop structural & spectral properties in 3-D (incl. BV)

Simulated reflectance for all spectral bands and viewing geometries (sun and satellite)

Retrieval Method using Calibrated NN Model

Actual performances of model estimation (validation from ground measurements)

Prior Distributions
Biophysical Variables
Geometry

Training Database Generation

Neural Network Training

weights and bias

Operational Use

GAI interpolated from Sentinel-2a

MAE = 0.35
RMSE = 0.70 (26.46 %)
R² = 0.64

(Delloye et al., RSE 2018)
Biophysical Variable Retrieval – Performance Analysis

Validation of LAI Retrieved using NN&RTM

LAI Error According to the Development Stage

MAE (front column) and RMSE (back column)

Douveiller et al. RSE 2011
Biophysical Variable Retrieval – Performance Analysis

Bias and Relative RMSE of retrieved LAI according to the development stage

Duveiller et al. RSE 2011
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• Section 5: Biophysical Variables Supporting Yield Estimation
• Section 6: ESA Sen2-Agri/Sen4CAP/Sen4Stat Open-Source Toolboxes
• Q&A and Main References
Section 3: Phenometrics to Identify the Distribution and Timing of a Given Crop
Phenology and Phenometrics

- Plant **phenology** deals with the definition of the **development stages** of plants and the recording of **dates** in which these stages occur in different environments.
- If the plants under observation are cultivated, we are in the field of **agricultural phenology** or **agrophenology**.
- Conventional systems like the **BBCH** are used.

By C. Schürch (drawings), L. Kronenberg, A. Hund - ETH Zurich, Group of Crop Science, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=70621817
Monitoring Phenology Allows for Characterizing Crop Types and Monitoring Crop Growth

- Identify the distribution and timing of a given crop - where and when it is grown
- **Time series analysis** to study the multi-temporal signal of spectral indices/biophysical variables

1) Full time series analysis

![NDVI time profiles at the parcel-scale](image)

- **Difference in the duration of the vegetation occurrence period**
  - Δ Green WW >> Δ Green WB

JRC Technical Reports, DS/CDP/2018/18
Monitoring Phenology Allows for Characterizing Crop Types and Monitoring Crop Growth

2) Extraction of crop-specific temporal metrics related to crop phenology

1. **Maximum Red** (average of 3 max.)
   - Bare soil at sowing preparation

2. **Max. Positive Slope**
   - Fastest growth of vegetation

3. **Maximum NDVI** (average of 3 max.)
   - Maximum green biomass

4. **Max. Negative Slope**
   - Fast reduction of vegetation

5. **Minimum NDVI** (average of 3 max.)
   - Harvested crop or non green residues

(Matton et al., 2015, Waldner et al., 2016, Lambert et al., 2016)
Example: Extracting the Start of Season (SoS) Phenometry

Comparison of extraction of \( \text{SOS}_{20} \) and \( \text{SOS}_{\text{inflection}} \) from the fitted curve of EVI2

- **Local Threshold Criteria**: Identification of specific condition of VI/BV values in relation to the curve
  - e.g., SOS = Date when VIs reach a threshold level
    - Absolute (expert-based)
    - Relative (e.g., about 10–20% of the seasonal maximum amplitude)

- **Curve Analysis**: Changes in the derivative to identify inflection points
  - e.g., SOS = Inflection point corresponding to the onset of rapid vegetation growth
Regional Level Application 1: MODIS Based Dynamic Cropland Calendars: An Example for Rice

**Phenorice Concept**

**MODIS VIs**

- Flooding/Sowing
- Emergence
- Heading/Flowering
- Maturity

**Time**

Boschetti et al. 2017
PhenoRice Output: From “Static Crop Calendar” to Seasonal Dynamics: Example in Italy

- **Retrospective analysis** with MODIS data can be used for regional studies and crop model forcing.

- **Seasonal retrieval** provides NRT information for operational crop monitoring systems (MARS).
PhenoRice Output: From “Static Crop Calendar” to Seasonal Dynamics: Example in Italy

- **Retrospective analysis** with MODIS data can be used for regional studies and crop model forcing.

- **Seasonal retrieval** provides NRT information for operational crop monitoring systems (MARS).
Regional Level Application 2: Maize Emergence Date Map at the Field Level: An Example in Free State, South Africa
Farm and Field Level Application: Phenometrics as a Diagnostic "Tool" for Identifying Rice Variety Groups

Mapping of phenological development at field-level, thanks to Sentinel-2 10 m resolution
Section 4: Monitoring Agricultural Practices

RGB MSAVI
R = Mar.
G = Jun.
B = Aug.
Detection of Mowing Events on Permanent Grassland

Expected development

Observations

VGT drop and regrowth

NDVI Time Series
Mowing Detection Example in Spain - Castilla y Leon

NDVI time series & mowing detection on a selected parcel
Mowing Detection Example in Spain - Castilla y Leon

NDVI time series & mowing detection on a selected parcel
Mowing Detection Example in the Netherlands
Mowing Detection Example in the Netherlands

NDVI time series & mowing detection on a selected parcel
Mowing Detection Example in the Netherlands
Agricultural Practices from SAR Metrics

Sentinel-1 SAR coherence time series & mowing detection on a selected parcel
Mowing Detection Example in the Netherlands Agricultural Practices from SAR Metrics

Sentinel-1 SAR coherence time series & mowing detection on a selected parcel
Harvest Date Detection Based on Five Metrics Computed from Three Parallel Time Series Images

Harvest and Cover Crop Monitoring

Harvest detected between 29 July and 4 August.

Cover crop in place during the mandatory period and not harvested before its end.
Detection of Ploughing/Tillage Events

NDVI Time Series on a Selected Parcel of Cereals

Ploughing immediately after the harvest
Tillage Detection from Optical NDVI/LAI and SAR Backscatter/Coherence Time Series

1. NDVI should remain low throughout this process.

2. The backscatter ratio should remain high/increasing throughout this process.

3. Coherence should increase during/after harvest, decrease after ploughing/tilling, and finally increase again to a stable condition.
Monitoring Agricultural Practices in Smallholder Farming Systems with 1(0) m Time Series – Fertilization in Mali

Exploiting (deca)metric time series to capture crop development signals including spatial field heterogeneity (sorghum for 3 different fields)

2-m resolution time series captured large field heterogeneity

Gates Fundation – STARS Project
Blaes et al., 2016
Section 5: Biophysical Variables Supporting Yield Estimation

Yield Estimations

- < 5.0 t/ha
- 5.0 - 5.5 t/ha
- 5.5 - 6.0 t/ha
- 6.0 - 6.5 t/ha
- 6.5 - 7.0 t/ha
- 7.0 - 7.5 t/ha
- 7.5 - 8.0 t/ha
- 8.0 - 8.5 t/ha
- 8.5 - 9.0 t/ha
- 9.0 - 9.5 t/ha
- 9.5 - 10.0 t/ha
- > 10.0 t/ha

(Duveiller et al., 2010)
State of the Art

- EO-based yield estimation approaches at high resolution are mostly under development.
  - The use of EO technology currently remains limited to coarse spatial resolution data (> 250 m) and inability to capture a crop-specific signal in most regions of the world.
  - EO biophysical variables to assess crop condition and crop condition anomalies - e.g.: [https://cropmonitor.org/](https://cropmonitor.org/)

- Copernicus operational HR Sentinel mission is changing the game. New opportunities and also new challenges.

- Main Methods:
  - Empirical regression using simple VI/BV-based yield predictors
  - Semi-empirical Monteith-based models (plant modelling and light use efficiency concept)
  - Mechanistic crop model and data assimilation
Empirical Relation Using Simple VI/BV - Based Yield Predictors

Since the early 1980s – VI or LAI have been used as seasonal biomass proxies to estimate crop yield.

**Tucker et al. 1980** reported that the **NDVI for a five-week period** (stem elongation to anthesis) explained ~64% of wheat yield variation. **Pinter et al. 1981** summed the **NDVI** for wheat and barley (heading to full senescence) explaining about 88% of the yield.

In recent years, thanks to the availability of satellite data, many applications have been developed using empirical relationships between yields and various VI's/BV’s.

**Becker-Reshef et al. (2010)** used the **maximum NDVI from MODIS** and built a generalized regression model for forecasting winter wheat yields. **Franch et al. (2015)** further improved this approach by **adjusting NDVI before the peak date using growing degree day (GDD)** information for earlier prediction.

**Burke and Lobell (2017)** and **Lambert et al. (2018)** demonstrated the added-value of **(very) high resolution imagery** for smallholder agriculture by linking field data with the **green chlorophyll vegetation index** or the maximum LAI.

Despite the **local validity and limited applicability** to different areas or years, these methods are **simple and effective** if ground survey samples are representative and accurate.
Ground Data: Yield is strongly linked with Above Ground Biomass (high $R^2$ for crop-specific linear regressions)

EO data – and more specifically, biophysical variables – can be used to do more than assess crop conditions. They can be a reliable yield proxy because we are working at high spatial resolution, and thus we can be crop-specific.
Section 6: Open-Source Toolboxes: ESA Sen2-Agri/Sen4CAP/Sen4Stat
Spectral Indices & Biophysical Variables Calculated with SNAP
See From Session 2
Sen2-Agri Top Priority: Automatic Delivery of 4 Agricultural Products Throughout the Season Using S2 & L8 Images

**In line with the GEOGLAM core products**

- **Monthly cloud free surface reflectance composite at 10-20 m**
  - Growing season (monthly updates)

- **Cloud free surface reflectance composites**
  - Growing season (monthly updates)

- **Dynamic cropland mask**
  - Binary map identifying annually cultivated land at 10m updated every month

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

- **Vegetation status**
  - Vegetation status map at 10 m delivered every week (NDVI, LAI, pheno index)

- **Open source toolbox**
  - Capacity building and training

Growing season (first half and end of the season)
Vegetation Status Map at 10 m: 4 Variables to Describe the Crop Growing Cycle

- **NDVI (Normalized Difference Vegetation Index):** The most popular indicator for monitoring vegetation; already widely used in operational applications.
- **LAI (Leaf Area Index):** The size of the interface that is used for the exchange of energy and mass between the canopy and the atmosphere.
- **fCOVER (fraction of Vegetation Cover):** Fraction of the ground covered by green vegetation.
- **FAPAR: (fraction of Absorbed Photosynthetically Active Radiation)** by the green and living elements of the canopy.
Sen2-Agri System: An Open-Source System Demonstrated at Full Scale in NRT or Off-Line, Running Locally or in the Cloud

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

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)

Monthly cloud free surface reflectance composite at 10-20 m
Sen2-Agri System: Simple Parameterization for Field Data Collection

### Sen2-Agri System: Main Parameters Settings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
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<tbody>
<tr>
<td>Area of Interest</td>
<td>Shapefile to be uploaded</td>
</tr>
<tr>
<td>Monitoring Period</td>
<td>Start and end dates to be defined</td>
</tr>
<tr>
<td>S2 or S2 + L8</td>
<td>To be selected</td>
</tr>
<tr>
<td>Other Parameters</td>
<td>...</td>
</tr>
</tbody>
</table>

### Sen2-Agri System: Field Campaigns

<table>
<thead>
<tr>
<th>Activity</th>
<th>Details</th>
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<tr>
<td>Sampling Design</td>
<td>Stratification and Sampling</td>
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<tr>
<td>Field Visit</td>
<td>In situ data collection – early survey</td>
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<td></td>
<td>In situ data collection – mid-season survey</td>
</tr>
<tr>
<td>Data Upload</td>
<td>Field data quality control and formatting</td>
</tr>
</tbody>
</table>

System Initialization

Before the Monitoring Period

Start of the Season

End of the Season

Mali Stratification (PIRT)
System Operation for Crop Growth Monitoring in NRT

Before the Monitoring Period

Monitoring Period

System Initialization

Automatic EO Data Download
From EO Data Providers

SoS

Automatic EO Data Download

EoS

No Data

$ t_0 $ $ t_2 $ $ t_5 $ $ t_{10} $ $ t_{15} $ $ t_{18} $
Large Scale - Nationwide - Cropland Monitoring
LAI Time Series at Pixel Scale (10 m) - Ukraine

18 Feb. 16
18 Apr. 16
28 Apr. 16
17 Jun. 16
17 July 16
08 Sep. 16
Large Scale - Nationwide - Cropland Monitoring
LAI Time Series at Pixel Scale (10 m) - South Africa

Leaf Area Index

Potchefstroom (South Africa)

LAI profile for a Maize field near Potchefstroom - South Africa

SAMPLE

- sample # 1
Large Scale - Nationwide – Crop-Specific Monitoring
LAI Time Series at Pixel Scale (10 m) - Mali

Koutiala
Mali

17/07/2016
26/08/2016
05/09/2016
05/10/2016
25/10/2016
15/11/2016
Sen2Agri System Implemented on Commercial Cloud Infrastructure for Operational NRT Services

Cloud Computing
AWS/IPT/EODC/DIAS

In Situ Data with GeoODK

Open-Source

South Sudan
619.745 km²

WFP Household Surveys

GeoODK

Sen2Agri

World Food Programme

WFP

VAM

map

Legend

VAM

Food security analysis

WFP

World Food Programme

Sen2-Agri

agricultural insights
Sen4CAP – An Open-Source System, Object-Based and Combining Sentinel-1 and Sentinel-2

• Sentinel-1 & -2
• Automated and modular
• For NRT or off-line production
• Demonstrated at the national scale
• Portable on all DIAS-es or operated locally
• User-friendly & API interfaces
• Dockerization for main components
Sen4Stat – Building on Sen2-Agri and Sen4CAP
Pixel-Based, Sentinel-1 and Sentinel-2, In Situ Data QC Module

Still Under Development
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.
Contacts

• Trainers:
  – Pr. Pierre Defourny: Pierre.Defourny@uclouvain.be
  – Dr. Sophie Bontemps: Sophie.Bontemps@uclouvain.be

• Training Webpage:
  https://appliedsciences.nasa.gov/join-mission/training/english/arset-agricultural-crop-classification-synthetic-aperture-radar-and

• ESA’s Toolboxes for Agriculture:
  – Sen2-Agri: http://www.esa-sen2agri.org/
  – Sen4Stat: https://www.esa-sen4stat.org/
Main references


- Radoux, Julien; Chomé, Guillaume; Jacques, Damien Christophe; Waldner, François; Bellemans, Nicolas; Matton, Nicolas; Lamarche, Céline; d’Andrimont, Raphaël; Defourny, Pierre, 2016. Sentinel-2’s Potential for Sub-Pixel Landscape Feature Detection. In: Remote Sensing, Vol. 8, no.6, p. 488
Thank You!