IMPLEMENTING MULTI-SCALE AGRICULTURAL INDICATORS EXPLOITING SENTINELS

GUIDELINES FOR A FIELD CAMPAIGN

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LIST OF ACRONYMS

ASCII	American Standard Code for Information interchange
BRDF	Bidirectional Reflectance Distribution Function
CEOS	Committee on Earth Observation Satellite
DEM	Digital Elevation Model
DHP	Digital Hemispherical Photography
ESA	European Space Agency
ESU	Essential Sampling Unit
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FCOVER	Fraction of green vegetation cover
FIPAR	Fraction of Intercepted Photosynthetically Active Radiation
FP7	7th Framework Programme
GAI	Green Area Index
GCOS	Global Climate Observing System
GEO	Group on Earth Observation
GLAI	Green Leaf Area Index
GPS	Ground Positioning system
IMAGINES	Implementation of Multi-scale Agricultural Indicators Exploiting Sentinels
JECAM	Joint Experiment on Crop Assessment and Monitoring
LDAS	Land Data Assimilation system
LIDAR	Light Detection and Ranging
LPV	Land Product Validation group of CEOS
MODIS	Moderate Resolution Imaging Spectroradiometer
NRT	Near Real Time
PSF	Point Spread Function
SPOT	Systeme Pour l'Observation de la Terre
TRAC	Tracing Radiation and Architecture of Canopies
UT	Universal Time
VALERI	Validation of Land European Remote sensing Instruments

1. BACKGROUND OF THE DOCUMENT

1.1. Scope and Objectives

This document aims to present the main elements for performing a field campaign, including guidelines for ground data acquisitions and reporting in agreement with the methods proposed by CEOS LPV and VALERI project. This guideline follows the one recently proposed for a ground campaign in the European Space Agency (Baret, 2012).

1.2. Content of the Document

Chapter 2 provides an overview of Imagines

Chapter 3 provides an introduction to the direct validation strategy

Chapter 4 details criteria for site selection

Chapter 5 provides comments on satellite acquisitions

Chapter 6 defines the variables and the measurements

Chapter 7 gives recommendations for sampling the site

Chapter 8 provides guidelines for reporting

2. IMAGINES OVERVIEW

2.1. Executive Summary

The Copernicus Land Service has been built in the framework of the FP7 geoland2 project, which has set up pre-operational infrastructures. IMAGINES intends to ensure the continuity of the innovation and development activities of geoland2 to support the operations of the global component of the Copernicus Land service. In particular, the use of the future Sentinel data in an operational context is prepared. Moreover, IMAGINES will favor the emergence of new downstream activities dedicated to the monitoring of crop and fodder production.

The main objectives of IMAGINES are to (i) investigating the retrieval of multi-sensor and multi-scale biophysical variables (LAI, FAPAR, FCover and the surface albedo), by merging the information coming from PROBA-V and Landsat-8 sensors in view to prepare the exploitation of Sentinel missions data ; (ii) develop qualified software able to process multi-sensor data at the global scale on a fully automatic basis; (iii) complement and contribute to the existing or future agricultural services by providing new data streams relying upon an original method to assess the above-ground biomass, based on the assimilation of satellite products in a Land Data Assimilation System (LDAS) in order to monitor the crop/fodder biomass production together with the carbon and water fluxes; (iv) demonstrate the added value of this contribution for a community of users acting at global, European, national, and regional scales.

2.2. Portfolio

The ImagineS portfolio contains global and regional biophysical variables derived from multi-sensor satellite data, at different spatial resolutions, together with agricultural indicators, including the above-ground biomass, the carbon and water fluxes, and drought indices resulting from the assimilation of the biophysical variables in the Land Data Assimilation System (LDAS) (Table 1).

The production in near real time (NRT) of the 333m resolution products, at a frequency of 10 days, using PROBA-V data will be carried out in the Copernicus Global Land service. ImagineS will perform in parallel off-line production over demonstration sites outside Europe. The demonstration of high resolution (30m) products (Landsat-8 + PROBA-V) will be done over some of the demonstration sites of cropland and grassland in contrasting climatic and environmental conditions (Table 2)

ID	Name	EO sensor	Temporal resolution	Spatial resolution	Spatial coverage
01	LAI, FAPAR, FCover	PROBA-V	10 days	333 m	Global
02	Albedo	PROBA-V	10 days	333 m	Global
03	Above-ground biomass	N/A	10 days	16 km (8 km)	Global (Fr,Hu)
04	Drought indicators	N/A	10 days	16 km (8 km)	Global (Fr,Hu)
05	Carbon fluxes (GPP, RE, NEE) and evapotranspiration	N/A	10 days	16 km (8 km)	Global (Fr,Hu)
06	FAPAR per class	PROBA-V	10 days	333m	Demo sites ($25\ km^2$)
08	FAPAR	Landsat-8 + PROBA-V	10 days	30 m	Demo sites
09	Above-ground biomass	N/A	10 days	Local simulations	Demo sites
10	Crop map	Radarsat + RapidEye + MODIS	Continuous update [1]	10 m	Demo sites

Table 1: Detailed IMAGINES products. [1]: when a new acquisition is available.

France and Hungary are the main areas of interest as the regional LDAS can run at 8 km resolution over these countries.

The feasibility of the crop map merging Radarsat, RapidEye, and MODIS (as proxies of Sentinel-1, Sentinel-2, and Sentinel-3, respectively) will be demonstrated over two areas of about 300km x 300km around Tula (Russia) and in the Free State Province (South Africa). Both areas are demonstration sites of the JECAM initiative, developed in the framework of GEO Global Agricultural Monitoring, which enables to share experiment data on proposed sites where regularly field campaigns are organized.

ID	Name	Description	Location
1	South-West, France	Flat cropland with a rotation of wheat, maize, sunflower. Some fields are irrigated.	43° 29' N, 1° 16' E
2	Hegyhatsal, Hungary	Flat cropland where small parcel-based agricultural management is typical of the whole country	46° 57' N, 16° 39' E
3	Las tiesas Farm, Barrax, Spain	Flat cropland of 65% dry land (barley, wheat) and 35% irrigated crops with large pivots (onion, garlic, sugarbeets, potatoes, maize, alfalfa, sunflower).	39° 02' N, 2° 04' W
4	Tula, Russia	Typical field size is near 100 hectares. Crop types are winter wheat, spring barley, potatoes, maize, rape seeds, and winter rye.	53° 05' N, 37° 14' E
5	Upper Tana Basin, Kenya	Small holder farms where grow tea, coffee, maize and vegetables	0° 55'N, 36° 47'E
6	Merguellil, Tunisia	Flat plain with fields of cereals, vegetables and olive trees, dry and irrigated	35° 45' N, 10° 5' E
7	Free State Province, South Africa	Agriculture and grasslands. Site located in the major grain producing province of South Africa.	28° 25' S 27°4' E
8	Greenbelt Farm, Ottawa, Canada	Agriculture in this region of eastern Canada mainly consists of corn, soybean and spring wheat annual crops adapted to short-season, perennial forage and livestock pasture.	45° 18' N, 75° 45' W
9	San Fernando, Chile	Flat cropland area covered by annual crops such as maize, wheat, alfalfa, sunflowers.	34° 42' S, 71° 0' W
10	25 Mayo, La Pampa, Argentina	Pastures (pampas)	37° 54' S, 67° 44' W
11	Yanco area, Murrumbidgee River catchment, Australia	A gently sloping area containing irrigated croplands and natural rangelands.	34° 45' S, 146° 04' E
12	Comunidad de regantes del Campo de Cartagena, Spain	50.000 ha irrigated crops with drip irrigation (vegetables and citrus trees).	37º 48' N, 1º 03' W
13	Cordoba, Spain	Flat cropland area	37º 48' N

ID	Name	Description	Location
			4º 44' W
14	Lambayeque, Peru	Flat cropland area monitored for drought and desertification analysis	6° 47' S, 79° 46° W
15	La Albufera, Spain	Rice fields	39°16'N, 0° 19'W
16	Rosasco, Milan, Italy	Rice fields	45° 15'N, 8°33' E
17	Pshenichne, Ukraine	Flat area with winter wheat, spring barley, maize, soy beans, winter rapeseed, sunflower, sugar beet, potatoes, winter rye and spring wheat.	50° 4'N, 30° 6'E

Table 2: IMAGINES demonstration site characteristics

3. INTRODUCTION

The content of this document is designed to be compliant with validation guidelines (CEOS LPV, VALERI, ESA) where recommendations are given for running and exploiting a campaign (e.g., Baret et al., 2012). It therefore follows the general strategy based on a bottom up approach: it starts from the scale of the individual measurements that are aggregated over an elementary sampling unit (ESU) corresponding to a support area consistent with that of the high resolution imagery used for the up-scaling of ground data. Several ESUs are sampled over the site. Radiometric values over a decametric image are also extracted over the ESUs. This will be later used to develop empirical transfer functions for up-scaling the ESU ground measurements.

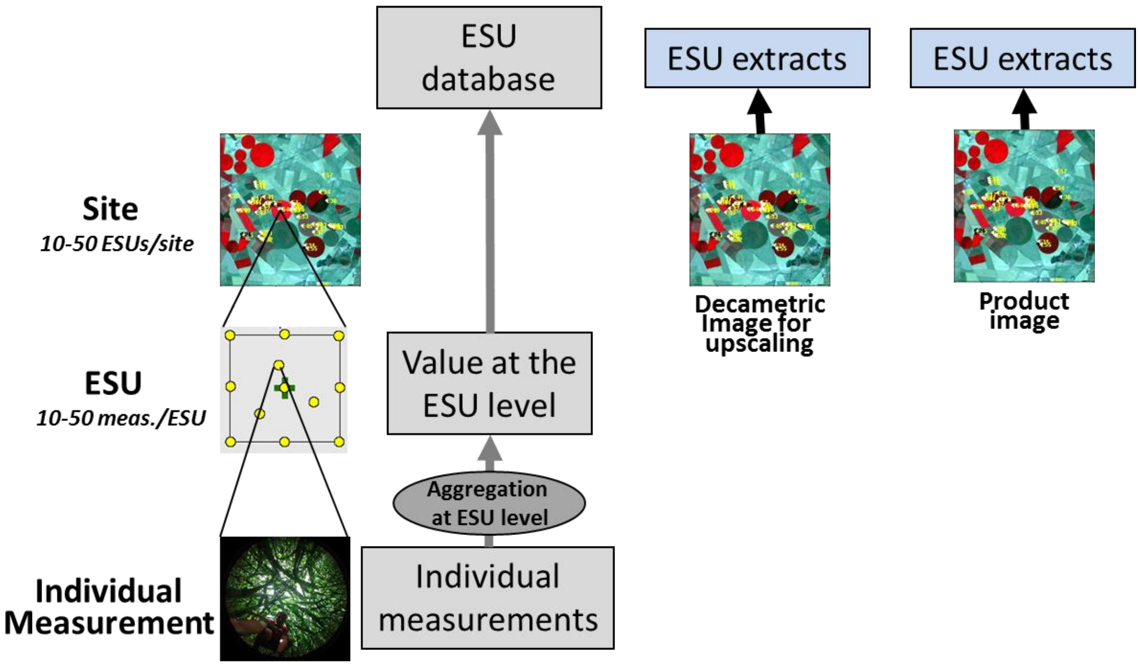

Figure 1. General strategy used to sample the validation site and extract the desired information.

4. SELECTION OF THE SITE

4.1. CRITERIONS CONSIDERED FOR SITE SELECTION

Several criterions should be considered to select the validation site:

- Type of vegetation
  - Crops and/or rangeland areas are preferable within ImagineS.

- Heterogeneity, topography and extent of the site
  - The site should be relatively flat to simplify the interpretation.
  - It should present a significant range of crops and development stages
  - The site should be composed of patches of vegetation large enough to minimize border effects when samples are taken in the center of the patch.
  - The accessibility of the fields should be easy (presence of public paths or roads, and in case of private or restricted areas, getting authorization should be possible)
  - The extent should be around few km² (≈ 3x3 km2) so that ground sampling would be relatively easy.

- Date for ground measurements and image acquisition
  - The measurement date(s) should provide: Good probability for clear sky, relatively good range of LAI values (from low to high) and minimize problems related to the presence of non-green vegetation elements.

Although not strictly mandatory when validating biophysical products, multi-temporal campaigns may be also relevant to assess the temporal stability and consistency of the products. Therefore, several campaigns along the growing period are desirable. However, multi-temporal campaigns require significant efforts for ground data collection.

4.2. PROPOSITION FOR A SITE

Demonstration sites have been defined by local partners (Table 2)

5. AIRBORNE AND SATELLITE DATA

5.1. AIRBORNE DATA

It is not mandatory for the ground campaigns in ImagineS.

5.2. SATELLITE DATA

For up-scaling of the ground biophysical measurements through empirical transfer functions, decametric satellite image is required.

A satellite image with a spatial resolution close to 10 m would allow accurate registration and very good spatial consistency required for developing and applying the empirical transfer functions for up-scaling the ground measurements. Some high resolution (10 m and 20 m) SPOT images were acquired in ImagineS and the Global Land Service.

If no high resolution images can be specifically acquired within few days from the ground measurement collection, the closest available clear Landsat-8 image (30 m resolution) can be used.

6. DEFINITIONS AND MEASUREMENTS

6.1. LEAF AREA INDEX (LAI)

6.1.1. Definition

LAI is defined as one half the total leaf area per unit horizontal ground surface area (Chen and Black, 1992; GCOS, 2010). It is a dimensionless ($m^2.m^{-2}$) variable. Green leaves correspond to vegetation matter capable of photosynthesis in ambient conditions. However, this simple definition needs some additional comments when applied to remote sensing observations (see http://calvalportal.ceos.org/cvp/web/olive/description-of-variables):

- ***Leaf/other elements***. If no distinction is made between leaves and the other elements, the proper term to use is PAI: Plant Area Index rather than LAI. Note that most indirect methods used to estimate LAI from upward looking canopy transmittance corresponds actually to PAI rather than LAI (Table 3).
- ***Green/non-green elements***. Canopies are made of green photosynthetically active and other elements which are not green and therefore non-photosynthetically active (senescent leaves, trunks, branches, fruits, flowers...). Since most users are interested in the green elements, the term GLAI (Green Leaf Area Index) should be used. However, the community uses commonly LAI in place of GLAI. Similarly, the green surfaces are extended to all the green elements, the term GAI (Green Area Index) should be used. Note that most remote sensing retrieval methods are mainly sensitive to GAI rather than LAI (or GLAI). GAI may be also estimated from indirect methods (e.g., digital hemispherical photography) based on downward looking measurements of the green fraction (the fraction of green vegetation seen from a given direction from above the canopy). GAI is probably the most pertinent definition to be used for remote sensing observations (Table 3).

Table 3: The several definition of leaf area index depending on the type of elements and the associated color. The measurement methods are indicated in italics.

		Element color	
		Green	Green and non-green
Type of element	Leaves or needles	**GLAI** *Destructive meas. Indirect methods in deciduous forests.*	**LAI** *Destructive meas.; litter fall baskets*
	All elements	**GAI** *Destructive meas., Remote sensing estimates, indirect methods from top of canopy*	**PAI** *Indirect methods from bottom of canopy; LIDAR*

- ***Understory/overstory***. Since remote sensing observations will be mostly sensitive to the cumulated value of green area, both the green overstory and understory should be accounted for when computing leaf area index. The understory may represent a very significant fraction of canopy leaf area index.

- ***Effective/true LAI***. Most LAI (GAI) ground measurements used for the validation is based on indirect measurements (gap or green fraction) assuming random distribution of the elements within the canopy volume (i.e. no clumping), which corresponds to an effective LAI (GAI). To obtain the actual LAI (GAI) value, the clumping should be accounted for. Several devices such as digital hemispherical photographs or TRAC instrument allows to estimate clumping index, and then actual LAI values.

6.1.2. Individual measurements

Apart from the destructive measurements that are obviously limited by the required resources, a wide range of indirect methods and devices have been developed to estimate LAI. These methods have been reviewed by several authors (Bréda, 2003; Jonckheere *et al.*, 2004; Weiss *et al.*, 2004; Leblanc *et al.*, 2005; Garrigues *et al.*, 2008) A synthesis of these methods was recently provided within the CEOS/LPV guideline for LAI product validation (Fernandes *et al.*, 2014). It is therefore recommended to use indirect methods and to define properly the variable measured related to LAI, i.e., document well the way the LAI is derived for an appropriate LAI definition (e.g.,Table 4 taking into account:

- ***The presence of non-green elements*** and the way it was accounted for or not
- ***The type of LAI computation achieved***: Effective or Actual LAI. In the latter case, the way leaf clumping is accounted for should be documented.
- ***The presence of understory***
- ***The illumination conditions*** used when making the measurements

Table 4: Mark for each ESU the best definition of your LAI measurements ('effective' if clumping is not accounted for)

		Element color	
		Green	Green and non-green
Type of element	Leaves	GLAI	LAI
	All elements	GAI	PAI

6.2. FRACTION OF ABSORBED PHOTOSYNTHETICALLY ACTIVE RADIATION (FAPAR)

6.2.1. Definition

Solar radiation in the spectral range 400 to 700 nm, known as Photosynthetically Active Radiation (PAR), provides the energy required by terrestrial vegetation to grow. The part of this incoming PAR that is effectively absorbed by plants is called the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR). It is a non-dimensional quantity varying from 0 (over bare soil) to almost 1 for the largest amount of green vegetation. Since FAPAR is mainly used as a descriptor of photosynthesis and evapotranspiration processes, only the green photosynthetic elements (leaves, needles, or other green elements) should be accounted for. FAPAR depends also on the illumination conditions, i.e. the angular position of the sun and the relative contributions of the direct and diffuse illumination. Both black-sky (assuming only direct radiation) and white sky (assuming that all the incoming radiation is in the form of isotropic diffuse radiation) FAPAR values may be considered.

FAPAR products are currently mainly defined as the black-sky FAPAR value for the same sun position as that observed at the satellite overpass. Black-sky FAPAR computed at 10:00 local solar time is a good approximation of the daily integrated black-sky FAPAR (Baret *et al.*, 2007). The fraction of intercepted radiation, FIPAR is a very close approximation of FAPAR (Baret and Guyot, 1991): FIPAR=0.94 FAPAR.

6.2.2. Measurement of FAPAR and FIPAR

The PAR absorbed by canopies may be either measured directly (1) from the PAR balance based using PAR sensors or (2) estimated using a number of devices dedicated to measure PAR transmitted at the bottom of the canopy (the so-called ceptometers) or (3) using the gap fraction, i.e. light transmission assuming that leaves are perfect black absorbers (i.e. FIPAR). Finally, (4) Leaf area index (LAI) measurements may be also used to estimate the PAR absorbed by the canopy (Baret and Fernandes, 2012).

(1) <u>PAR balance using PAR sensors</u>

$FAPAR$, may be derived from PAR balance by dividing all the terms by the incident PAR:

$$FAPAR = 1 - R_c - T_c - T_c \cdot R_s = 1 - R_c - T_c(1 - R_s) \qquad [1]$$

Where R_c is the reflectance of the canopy, T_c is the transmittance of the canopy and R_s is the soil reflectance integrated in the PAR region. Note that these variables are bi-hemispherical quantities.

If soil reflectance is assumed to be known, the PAR balance may be approached by measuring only the three first terms, i.e. the incident ($PAR_H^{\downarrow}$), the reflected ($PAR_H^{\uparrow}$) and the transmitted ($PAR_0^{\downarrow}$). Note that the soil reflectance to be used is bi-hemispherical, although the directional integration of incident radiation requires at least weighing the direct and diffuse components of canopy transmittance that will strongly vary with the directionality of the incident radiation as well as canopy characteristics.

(2) PAR transmitted using ceptometers

Equation [1] may be simplified in the PAR domain where very little multiple scattering is expected:

$$FAPAR \approx (1 - T_c)(1 - R_\infty) \quad [2]$$

Where R_∞ is the asymptotic value of canopy reflectance when leaf area index (LAI) tends towards infinity. Values of R_∞ are generally small in the PAR domain, around 0.06 (Baret and Guyot, 1991), since most photons are absorbed by the green leaves. In these conditions, the PAR balance may be approximated by measuring only the incident ($PAR_H^\downarrow$), and the transmitted ($PAR_0^\downarrow$) terms. This simplification allows avoiding possible problems in measuring the soil reflectance term. Green leaves are generally absorbing a very large fraction of light in the PAR domain, and thus appear almost black. In these conditions, the contribution of multiple scattering to canopy transmittance is negligible, allowing approximating the fraction or light intercepted by the canopy as the complement to unity of canopy transmittance:

$$fIPAR \approx (1 - T_c) \quad [3]$$

Combining equations [2] and [3] allows relating the fraction of absorbed PAR to the fraction of light intercepted:

$$fAPAR \approx fIPAR(1 - R_\infty) \quad [4]$$

With $R_\infty \approx 0.06$ being the hemispherical reflectance of a canopy with very high LAI. The validity of this approximation was investigated by (Baret and Guyot, 1991; Begué *et al.*, 1991; Gobron *et al.*, 2006).

Several individual sensors are available on the market, with a range of performances in terms of calibration, spectral sensitivity and cosine response and price (LiCOr, Delta T, Solems,…). Some systems provide several sensors aligned on a single support, allowing a better spatial representativeness. These are called ceptometers such as AccuPAR (Decagon, USA), SunScan (Delta-T, UK). Other systems are based on linear arrays (Solems PAR/LE)

Because PAR balance, and thus FAPAR, will depend on illumination geometry, continuous measurements are required to describe this source of variability. The PAR radiance system needs thus to be set in place for several days up to several months. This requires weatherproof systems with sufficient autonomy both in terms of energy and memory. Such systems such as PASTiS-PAR have recently been developed within relatively affordable cost allowing to replicate individual observations for improved spatial sampling (Baret et al., 2007).

These approaches based on the radiation balance accesses the quantity of PAR absorbed by the canopy, independently on the nature of the elements. As a consequence, when a significant fraction of canopy elements is non-photosynthetic (such as trunks, branches, senescent leaves), the PAR absorbed by the green photosynthetically active elements will be overestimated. As for LAI, the status of the crop should be clearly identified.

(3) Directional measurements of gap fraction

Directional devices provide measurements of canopy transmittance, T_c, in a number of directions $[\theta_s, \varphi_s]$. Two types of devices are mainly used: LAI2200 instrument and digital hemispherical cameras (DHP). Gap fraction is very close to canopy transmittance in the PAR domain since leaves are absorbing most of the radiation, limiting the multiple scattering. The zenith (and azimuth) variation of light transmittance may then allow reconstructing the diurnal variation of FAPAR including the diffuse component. These techniques are very efficient by allowing instantaneous measurements that can be replicated multiple times to improve the spatial sampling while accessing the diurnal variation of $FAPAR$.

Note that similarly to sensors measuring the transmitted PAR, no distinction is made between green photosynthetically active elements from the non photosynthetically active elements. This may overestimate the actual value of the green $FAPAR$ of interest. However, when using hemispherical photographs taken from above canopies, it may be possible to distinguish between green and non green elements. Therefore, downward looking DHP provides a good estimate of $FAPAR$.

(4) Estimates of FAPAR from LAI measurements

In vegetation canopies, FAPAR can be associated to leaf area index (LAI) or green area index (GAI). The link between directional *FAPAR* and *GAI* is established through the so-called Poisson law (Nilson, 1971):

$$P_0(\theta, \varphi) = e^{-\frac{G(\theta,\varphi,lidf)\cdot GAI}{\cos\theta}} \quad [5]$$

Where $P_0(\theta, \varphi)$ is the gap fraction at sun zenith θ and sun azimuth φ, $G(\theta, \varphi, lidf)$ is the projection function. The projection function is the projected area of a unit leaf area in direction $[\theta, \varphi]$ and depends on the leaf inclination distribution function, $lidf$. Assuming that leaves absorb all the radiation in the PAR domain, gap fraction relates to $FIPAR$ (Equation 3) allowing thus to estimate $FAPAR$ (Equation 4). Knowledge of GAI and $G(\theta, \varphi, lidf)$ will therefore allow to compute the gap fraction $P_0(\theta, \varphi)$ and the whole radiative transfer if leaf and soil optical properties are known.

$$FAPAR \approx 1 - \exp^{-\frac{G(\theta,\varphi,lidf)\cdot GAI}{\cos\theta}}$$

For spherical leaves distribution, G = 0.5.

As for the LAI, it is very important to document well the way the FAPAR is derived for an appropriate definition taking into account:

- ***The method used to estimate FAPAR.***
- ***The illumination conditions.*** FAPAR at 10:00 Solar Local Time is preferred for comparison with satellite estimates.
- ***The presence of non-green elements.***

6.3. VEGETATION COVER FRACTION (FCOVER)

6.3.1. Definition

It corresponds to the green fraction as seen from the nadir direction. It is dimensionless. It is computed from the leaf area index and other canopy structural variables (leaf inclination and clumping) and does not depend on variables such as the geometry of illumination as compared to FAPAR. For this reason, it is a very good candidate for the replacement of classical vegetation indices for the monitoring of green vegetation.

6.3.2. Individual measurements

FCOVER is mainly assessed using digital photography or based on LIDAR. When using LIDARs, the intensity of the signal should be exploited to separate the green from the non-green elements. When using photos, it is easier and more efficient to take the photos from above the canopy for the lower ones. This way, the green elements could be separated from the soil and senescent materials. Note that the field of view of the camera should be restricted as much as possible to better match the vertical direction assumed in the FCOVER definition. However, this would result in a very limited footprint, therefore sampling. A ±10° field of view is admitted as a proxy for the vertical direction. FCOVER could thus be derived from DHPs when restricting the field of view to the 0-10° zenith angles. Similarly, the LAI2000 instrument could be also used for FCOVER measurements by exploiting the first ring.

7. SAMPLING THE SITE

Based on the previous achievements mainly during the VALERI project (http://w3.avignon.inra.fr/valeri/), guidelines for running a field campaign, and reporting the data has been established (Baret and Fernandes, 2012).

7.1. SELECTION OF ESUS

A single pixel or a small cluster of pixels will constitute the Elementary Sampling Unit (ESU) that should be associated with the ground measurements representative of the corresponding area. The selection of the ESUs will follow the following rules:

- **Size of the ESUs**. The size of the ESU may be critical. For operational products, a product value will be associated to each pixel. The PSF (Point Spread Function) of the product should be well characterized to provide the best match between the product spatial support and the ground measurements. For short canopies such as crops, pastures or shrublands, the ESUs should be around 10 m - 30 m diameter in agreement with the pixel size of high resolution products used for up-scaling.

- ***Number of ESUs.*** The number of the ESUs should be driven by the heterogeneity of the site, particularly if the ground measurements will have to be up-scaled to the site extent. Current practices indicate that between 30 to 50 samples are required (Morisette et al., 2006), although these numbers could be adapted to the complexity of the site. A minimum of 30 ESUs should be thus sampled over the study site (typically around 3x3 km^2). At least 3 ESUs should be sampled for each land cover condition at high, medium and low levels of the parameter validated to facilitate the use of linear regression statistics for error analysis. For the same reason, additional control points over bare areas should be taken.

- ***Location of the ESUs.*** The ESUs should sample the variability observed over the site, both in terms of landcover and conditions. A stratified sampling based on the prior knowledge of the landcover is optimal. The ESUs may be conveniently located close to paths or roads to ease the access. However, adjacency effects should be minimized in order to provide more genericity to the validation exercise, since the radiative transfer of a single pixel may be influenced by the neighboring pixels trough lateral fluxes (Widlowski, 2010). ESUs should therefore be located at a reasonable distance (i.e. 50 m) from borders and surrounded by pixels with approximately the same type of vegetation as that of the considered ESU. Note that each ESU should be geo-referenced within few meters accuracy for later matching the products derived from satellite images. GPS devices may be used to achieve this geo-location accuracy.

7.2. SAMPLING AN ESU

Ground measurements are generally associated with a footprint much smaller than the size of an ESU. Ground measurements should therefore be repeated in order to better represent the average value over the ESU.

7.2.1. Sampling scheme

Over each ESU, the same sampling scheme will be used for the measurement of the several variables targeted. The optimal number of individual measurements is driven by the spatial heterogeneity of the canopy with regards to the footprint of the photos. Weiss et al. (2004) tested several sampling intensity for the characterization of an ESU and concluded that between 10 to 15 individual measurements allowed to get a reasonable estimates of the gap fraction.

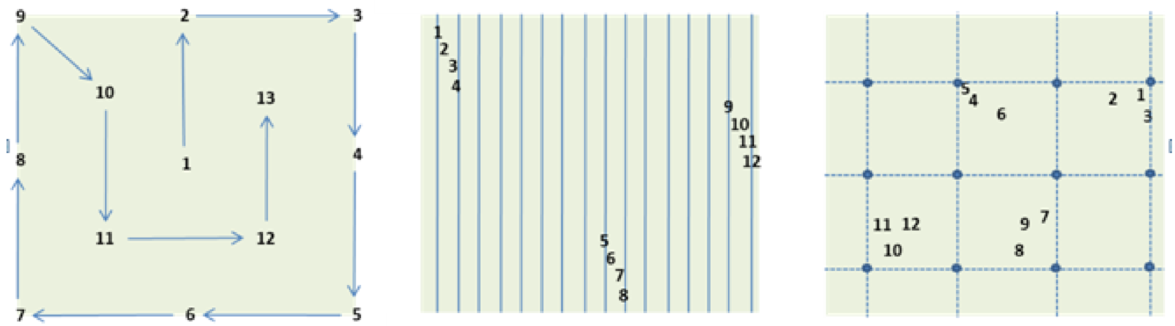

Figure 2. Typical schemes proposed for sampling an ESU for random (left) or row (centre) and regularly planted vegetation (right). Numbers refer to the location of individual measurements.

The general principles for optimally locating the photos within the ESU consist in getting measurements as independent as possible. This is achieved by spreading evenly the photos within the ESU (~10-30 meters diameter), i.e. maximizing the distance between neighbouring photos. The best strategy for randomly distributed canopies is to follow a predefined sampling scheme such as that presented in Figure 2 left, avoiding any possible selection of the locations depending on local conditions. Note that the locations of each individual measurement do not require being precise, avoiding spending too much time within a useless too rigid scheme. In the case of row crops, specific sampling schemes should be adopted, with the emphasis on representing the row effect by organizing the measurements along small transects between rows (Figure 2 centre). Note that measurements on the transects should incorporate some randomness to prevent possible biases in the characterization of the row effect. For regularly planted stands, measurements should be organized to represent the typical elementary pattern (Figure 2 right). The sampling will thus include at least 12 individual measurements.

A predefined sampling scheme (Figure 2 left) is proposed for most of the cases, allowing more independent individual measurements. The size at the ground level of the area sampled should be between 10 and 30 meters. The GPS coordinates of the centre of the ESU should be measured within few metres accuracy.

7.2.2. DHP measurements and processing

It is proposed to use digital hemispherical photography (DHP) as the main indirect method. This technique has been proven very efficient and allows:

- A joint estimate of GAI (actual and effective), FAPAR and FCover.
- discriminating green from non-green elements, thus estimates are closely related to green elements.
- sampling downward looking that minimizes in most cases the presence of non-leaves (trunks, stems, branches) and non-green elements.

However, great care should be taken to:

- Illumination conditions: better use diffuse conditions
- Use color cameras with high resolution (minimum 10 Mega pixels)
- Sample both overstory (looking upward) and understory (looking downward) when needed.

The processing could be conveniently achieved using the CAN-EYE software (https://www4.paca.inra.fr/can-eye/CAN-EYE-Home/Welcome) that will provide both estimates of effective and true GAI (according to several models and ways to estimate leaf clumping), FAPAR (actually FIPAR) for a range of sun positions and FCover.

However, great care should be taken during the processing with downward looking photos to avoid errors during the classification step due to shaded vegetation that could be misclassified as non vegetation, leading to a quite large underestimation of the vegetation variables. This problem has been detected mainly over cereals at dense stages.

8. GUIDELINES FOR REPORTING

A standardization of the reporting and data organization and format is recommended. It will considerably help the meta-analysis of an ensemble of campaigns which is the ultimate objective of the validation campaigns. The campaign should result into three documents:

- ***A general description of the site and the measurements***
- ***A file containing the values measured over each ESU*** along with some description of the ESU. A template
- ***Images corresponding to :***
  - Satellite image for up-scaling the ground measurements.
- ***Ancillary data***

8.1. DESCRIPTION OF THE SITE AND THE MEASUREMENTS

This should take the form of a small report where the following information should be given:

- ***Description of the site***. The site should be roughly described in terms of
  - Location (lat-lon) and extent (km). A google earth extract with the limits of the site indicated could be very useful.
  - Date of measurement(s): the date(s) when the measurements were completed.
  - Type of vegetation: describe the main types of vegetation and variability. A decametric landcover classification map could help understanding the landscape structure. Describe if some particular objects may be encountered (urban areas, water-bodies, snow …)
  - Topography: describe the topography of the site. A DEM map could help understand particular problems.
  - Describe the sampling scheme for ESUs. Geo-located ESUs over the google earth image would be very efficient.
- ***Description of the measurements over ESUs*** for each variable of interest (LAI, FAPAR, FCover)
  - Device(s) used to the individual measurements
  - Sampling scheme used for the ESU (number and location of the samples).
  - Data processing method to compute the ESU value.
  - Corresponding detailed definition of the variable (accounting for green vegetation, understory, clumping)
- ***Description of the available images***
  - **Airborne images** (if any)

  - **Satellite images used for geo-referencing and up-scaling** ESU measurements. The satellite used, day and time of overpass and view direction (for explaining possible BRDF effects) need to be documented as well as possible processing including registration, projection, radiometric calibration and possible atmospheric correction.
- ***Description of the ancillary data*** acquired that includes (when available):
  - *Atmospheric characteristics* through sunphotometers. Location and time (in UT) of measurements is mandatory along with device type and data processing. The format of the data file should be documented here. (not mandatory here)
  - *Ground radiometric measurements*, requiring as well Location and time (in UT) of measurements is mandatory along with device type and data processing, with emphasis on the radiometric calibration. (not mandatory here)
  - *GPS ground control points* for more accurate geo-referencing. The accuracy of the position and the projection system used should be indicated. The format of the data file should be documented here.

8.2. DESCRIPTION OF EACH ESU

Each ESU should be described according to an agreed format. For this purpose a template xls file should be used. It will mainly describe for each ESU:

- The position (coordinates)
- The dimension (typical diameter)
- The altitude
- The date of measurement
- The type of vegetation and state
- The measurement performed (Method, sampling, processing, value and uncertainties).
- An xls template is proposed for the ImagineS database (*see VegetationGroundMeasurements_site_date.xlsx*), including a header specifying the content of the dataset per columns (Figure 3), the ground dataset (Figure 4) and a summary table with figures (not shown here). Columns 1 to 24 (see example of the format used in Figure 4), including the three variables of interest are fixed, whereas additional columns can be added to include other variables (e.g. water content) or information.

Column	Var.Name		Comment
1	Plot #		Number of the field plot in the site
2	Plot Label		Label of the plot in the site
3	ESU #		Number of the Elementary Sampling Unit (ESU)
4	ESU Label		Label of the ESU in the campaign
5	Northing Coord.		Geographical coordinate: Latitude (º), WGS-84
6	Easting Coord.		Geographical coordinate: Longitude (º), WGS-84
7	Extent (m) of ESU (diameter)		Size of the ESU [(1)]
8	Land Cover		Detailed land cover
9	Date (dd/mm/yyyy)		Starting date of measurements
11	LAI	Method	Instrument
12		Nb. Replications	Number of Replications
13		LAIeff	Computed from the gap fraction as a function of the view zenith angle
14		Uncertainty	LAIeff standard deviation
15		LAI	LAItrue = LAIeff/clumping index
16		Uncertainty	LAItrue standard deviation
17	FAPAR	Method	Instrument
18		Nb. Replications	Number of Replications
19		FAPAR	Measured FAPAR at 10:00 SLT under direct llumination conditions at a given solar position
20		Uncertainty	FAPAR standard deviation
21	FCOVER	Method	Instrument
22		Nb. Replications	Number of Replications
23		FCOVER	Retrieved from gap fraction. fCover = 1-Po(0-10º)
24		Uncertainty	FCOVER standard deviation

Figure 3. The Excel file template (header) used to describe ESUs with the vegetation measurements.

Plot #	Plot Label	ESU #	ESU Label	Northing Coord	Easting Coord	Extent (m) of ESU (diameter)	Land Cover	Date (dd/mm/yyyy)	LAI					
									Method	Nb. Replicat ions	LAIeff	Uncertainty	LAI	Uncertainty
14	SF02	1	SF02A	39,0793	-2,11783	20	Sunflower	20/06/2009	DHP	15	2,9	NA	4	NA
14	SF02	2	SF02B	39,0797	-2,11707	20	Sunflower	20/06/2009	DHP	15	1,8	NA	2,1	NA
14	SF02	3	SF02C	39,0801	-2,11633	20	Sunflower	20/06/2009	DHP	15	1,5	NA	2,1	NA

Figure 4. The Excel file template (database) used to describe ESUs with the vegetation measurements.

- Moreover, a template for the characterization of the ESU in the field is proposed, including an identification of the plot sampled for LAI definition, the sampling, method, and other ancillary information (see Annex 1).

8.3. IMAGES

All images should be in GEOTIFF format with a name that includes the date (year-month-day) and time (UT) of the flight.

8.4. ANCILLARY DATA

The ancillary data should be provided in simple ASCII format with location and time (UT) properly documented. They include:

- Atmospheric measurements
- Ground radiometric measurements
- Ground control points GPS measurements.

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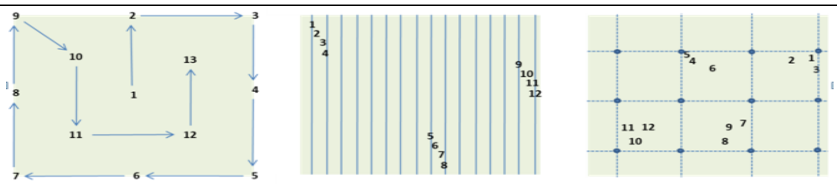
ANNEX I – FIELD LAI DATA COLLECTION TEMPLATE

<table>
<tr><td>SITE</td><td colspan="3"></td></tr>
<tr><td>ID FIELD</td><td></td><td>ID OPERATOR</td><td></td></tr>
<tr><td>ESU #</td><td></td><td>ILUMINATION CONDITION</td><td></td></tr>
<tr><td>DATE</td><td></td><td>SOLAR LOCAL TIME</td><td></td></tr>
<tr><td rowspan="2">GPS LOCATION</td><td>PROJECTION</td><td>LATITUDE</td><td>LONGITUDE</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>LAND COVER TYPE</td><td colspan="3"></td></tr>
</table>

<table>
<tr><td rowspan="4">DEVICES</td><td>DHP</td><td></td></tr>
<tr><td>LICOR LAI PCA</td><td></td></tr>
<tr><td>Ceptometer</td><td></td></tr>
<tr><td>Other</td><td></td></tr>
<tr><td>SAMPLE CHARACTERISTICS</td><td colspan="2">
<table>
<tr><td></td><td colspan="2">Element color</td></tr>
<tr><td></td><td>Green</td><td>Green and non-green</td></tr>
<tr><td>Leaves</td><td>GLAI</td><td>LAI</td></tr>
<tr><td>All elements</td><td>GAI</td><td>PAI</td></tr>
</table>
</td></tr>
<tr><td>SAMPLING</td><td colspan="2"></td></tr>
<tr><td>COVER FRACTION</td><td colspan="2"></td></tr>
<tr><td>PLANT HEIGHT</td><td colspan="2"></td></tr>
<tr><td>ROW SPACING</td><td colspan="2"></td></tr>
<tr><td>OTHERS</td><td colspan="2"></td></tr>
</table>