IMPLEMENTING MULTI-SCALE AGRICULTURAL INDICATORS EXPLOITING SENTINELS

SERVICE VALIDATION PLAN

IMAGINES-RP7.2-SVP

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ACRONYMS AND DEFINITIONS

ATBD	: Algorithmic Theoretical Basis Document
BELMANIP	: BEnchmark of Land Multisite ANalysis and Intercomparison of Products
CEOS/LPV	: Land Product Validation group of Committee for Earth Observation Satellites
EBF	: Evergreen Broadleaf Forest
FAPAR	: Fraction of Photosynthetically Active Radiation Absorbed by the vegetation
FCover	: Fraction of green Vegetation Cover
GEO	: Group on Earth Observations
GEOGLAM	: Global Agricultural Geo-Monitoring Initiative
GMES	: Global Monitoring for Environment and Security (former name of Copernicus)
GPP	: Gross Primary Production
JECAM	: Joint Experiment of Crop Assessment and Monitoring
JRC	: Joint Research Center
LAI	: Leaf Area Index
LDAS	: Land Data Assimilation System
LSA SAF	: Satellite Application Facilities on Land Surface Analysis
LSM	: Land Surface Model
MARS	: Monitoring Agricultural Resources (MARS) Unit
NEE	: Net Ecosystem Exchange
OLIVE	: On-Line Interactive Validation Exercise
PAR	: Photosynthetically Active Radiation
RE	: Ecosystem Respiration
RMSE	: Root Mean Square Error
SDD	: Standard Distance Deviation

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1. BACKGROUND OF THE DOCUMENT

1.1. Executive Summary

The Copernicus program is the EU response to the increasing demand for reliable environmental data. The objective of the Copernicus Land Service is to continuously monitor and forecast the status of land territories and to supply reliable geo-information to decision makers, businesses and citizens to define environmental policies and take right actions. ImagineS intends to continue the innovation and development activities to support the operations of the Copernicus Global Land service, preparing the use of the new Earth Observation data, including Sentinels missions data, in an operational context. Moreover, ImagineS aims to favor the emergence of downstream activities dedicated to the monitoring of crop and fodder production, that are key for the implementation of the EU Common Agricultural Policy, of the food security policy, and could contribute to the Global Agricultural Geo-Monitoring Initiative (GEOGLAM) coordinated by the intergovernmental Group on Earth Observations (GEO).

The main objectives of ImagineS are to (i) improve the retrieval of basic biophysical variables, mainly LAI, FAPAR and the surface albedo, identified as Terrestrial Essential Climate Variables, by merging the information coming from different sensors (PROBA-V and Landsat-8) in view to prepare the use 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.

The ImagineS portfolio contains both generic variables that can be used for a large variety of applications, and crop-related indicators addressing more specific agricultural issues. Both categories of users require information on the product quality for efficiently using them. The Service Validation Plan describes the procedures set-up to check the overall consistency of products, to identify their improvements and their drawbacks comparing to similar products, and to determine their accuracy comparing to reference data.

1.2. Scope and Objectives

The Service Validation Plan presents the procedures to perform the generic quality assessment of the products over a fully comprehensive range of geographic and environmental conditions for an adequate time period. The results are detailed in the

Validation reports (ImagineS-RP7.4) associated to each product family (biophysical variables, agricultural indicators, crop maps).

Such analysis is complemented by the users' utility assessment (ImagineS-RP1.3) focusing on specific applications and criteria of evaluation.

1.3. Content of the Document

Chapter 2 presents the validation procedure applied to biophysical variables (LAI, FAPAR, FCover and Albedo) and the field activities for collection of LAI, FAPAR data.

Chapter 3 focuses on agricultural indicators generated by the assimilation of EO-products into the LDAS.

Chapter 4 describes the validation of the crop maps.

1.4. Related Documents

1.4.1. Inputs

Overview of former deliverables acting as inputs to this document:

Document ID	Descriptor
ImagineS-RP1.1	Users Requirements Document
ImagineS-RP1.2	Services Specifications

1.4.2. Output

Overview of other deliverables for which this document is an input:

Document ID	Descriptor
ImagineS-RP1.3	User evaluation reports
ImagineS-RP7.4	Validation reports
ImagineS-RP7.5	Field campaign and data processing reports
ImagineS-RP6.3	Product Users Manuals

1.4.3. Document of Reference

Document ID	Descriptor
ImagineS_311766_DOW	Description of Work, update issued on 12.08.2014, of the Grant Agreement N°311766.

2. IMAGINES 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).

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	333 m	Demo sites (25 km²)
08	FAPAR	Landsat-8 + PROBA-V	10 days	30 m	Demo sites
09	Above-ground biomass	Lansat-8 + PROBA-V	10 days	local simulations	Demo sites
10	Crop map	S1 + Landsat-8 + PROBA-V	Continuous update [1]	30 m	Demo sites

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

The production in Near Real Time 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. It should start by covering Europe only, and be gradually extended to the whole globe. Meanwhile, 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 demonstration sites of cropland and grassland in contrasting climatic and environmental conditions (**Table** 2).

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 Sentinel-1, Landsat-8 and PROBA-V 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 official 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, Kenia	Flat extensive grassland savanna	0°55'S, 36° 48'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, 70° 57' W
10	25 Mayo, La Pampa, Argentina	Pastures (pampas)	37° 54' S, 67° 44' W
11	Yanco area, Murrumbidgee River catchment,	A gently sloping area containing irrigated croplands and natural rangelands.	34° 85' S, 146° 11' E

ID	Name	Description	Location
	Australia		
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 4º 44’ W
14	Lambayeque, Peru	Flat cropland area monitored for drought and desertification analysis	6° 47’ S, 79° 46° W
15	Albufera, Valencia, Spain	Rice area	39° 16’ N, 0° 19’ W
16	Rossasco, Italy	Cropland area (mainly rice)	45° 15’ N, 8° 33’ E
17	Pshenichne, Ukraine	Cropland area.	50° 4' N, 30° 6' E

Table 2: IMAGINES demonstration site characteristics

3. VALIDATION OF BIOPHYSICAL VARIABLES

3.1. VALIDATION OF GLOBAL 333M PRODUCTS

3.1.1. Standard validation protocol

The standard procedure for validation of global medium resolution products will follow the best practices of CEOS/LPV group (Morisette et al., 2006), existing protocols (e.g., Fernandes et al., 2012) and previous global validation exercises (Camacho et al., 2013, Garrigues et al., 2008, Weiss et al., 2007). The standard approach relies on: (1) the indirect validation and the inter-comparison with existing similar products (for spatial and temporal consistency analysis), (2) the direct validation with in-situ measurements. The performance metrics will be fully consistent with the CEOS OLIVE (On-Line Interactive Validation Exercise) tool (calvalportal.ceos.org/cvp/web/guest/olive). The following quality criteria will be examined for both Albedo and LAI (FAPAR, FCover) products.

3.1.1.1. Indirect validation

The following analysis will be performed at global scale or regionally over demonstration sites (300m):

Spatial consistency

Maps of the ImagineS products will be displayed and analysed. Difference maps will be produced in order to evaluate the consistency or discrepancies with similar products. Comparison with Copernicus Global Land SPOT/VGT products at 1 km will be performed (when coincident) or with other reference products in the market (e.g. MODIS)

Product continuity

The continuity of the product will be evaluated as a function of the latitude and period of the year.

Global statistical analysis

The statistical analysis per aggregated land cover types will be performed over the BELMANIP-2 network of sites that was designed to represent globally the variability of land surface types (Baret et al., 2006). The land surface type will be defined here using 8 generic classes derived from the GLOBCOVER classification, namely: Evergreen Broadleaf Forest, Broadleaf Deciduous Forest, Needle-leaf Forest, Mosaic, Herbaceous, Shrublands, Sparse and Bare areas. The statistical analysis will include histograms, scatter-plots and statistic metrics (Table 3) per biomes.

Temporal consistency

The temporal consistency and realism of seasonal variations will be analyzed over BELMANIP-2 sites and over ImagineS demonstrations sites where continuous ground data and ground based reference maps will be available.

Temporal smoothness

The smoothness of products is evaluated by taking three consecutive observations and computing the absolute value of the difference delta between the centre $P(d_{n+1})$ and the corresponding linear interpolation between the two extremes $P(d_n)$ and $P(d_{n+2})$ as follows

$$\boldsymbol{\delta = P(d_{n+1}) - P(d_n) - \frac{P(d_n) - P(d_{n+2})}{d_n - d_{n+2}}(d_n - d_{n+1})}$$

3.1.1.2. Direct validation

Accuracy will be quantified by several metrics reporting the goodness of fit between the products and the corresponding ground measurements (Table 3).The root mean square error (RMSE) is commonly reported as a summary performance statistic. Linear model fits are used to quantify the goodness of fit.

Gaussian Statistics	**Comment**
Scatter plot of ground data versus product	Qualitative assessment of agreement. Should indicate error bars when available
Number of samples	Indicative of the power of the validation
RMSE: Root Mean Square Error	RMSE computed between ground data and product values should be compared to the RMSE value corresponding to ground measurements. Indicates Overall Performance
B: Mean Bias	Difference between average values of ground data and product. Indicate accuracy and possible offset.
S: Standard deviation	Standard deviation of the pair differences. Indicates precision.
Correlation coefficient	Indicates descriptive power of the linear accuracy test. Pearson coefficient was used.
Linear fit (slope, offset)	Indicates some possible bias

Table 3: Accuracy Statistics for biophysical product validation

The accuracy assessment for global products will be performed on the available ground reference maps over demonstration sites and other existing initiatives (e.g. GIO-GL, JECAM, Land-SAF).

3.1.2. Continuity Assessment of FAPAR 300m

Agricultural applications are strongly based on anomaly analysis (Section 3.1.2.1) and similarity analysis (Section 3.1.2.2) (Baruth et al., 2008). Both analyses rely on observations in the past, and their results are more reliable when the past time series is sufficiently long.

The JRC MARS action uses since many years the SPOT-VEGETATION archive for these analyses, but this sensor will cease operation end of May 2014. One of the products used in the MARS action is the FAPAR derived from the method described by Weiss et al. (2010) for the global data and Gobron et al. (2006) for the European data. These FAPAR data sets are some of the inputs for the anomaly and similarity analysis.

The IMAGINES project will develop FAPAR products from PROBA-V and Sentinel-3 OLCI sensors, which would enable to extend this series further in time. In particular, one of the main mission goals of PROBA-V is the continuation of the VEGETATION time series.

The objective of this specific validation exercise to be performed by VITO is to assess whether the FAPAR from Sentinel-3 and PROBA-V at 300m resolution can be used to extend to time series and allow using the same analysis methods as before.

3.1.2.1. Anomaly analysis

Anomaly time series are created by removing the seasonality from the data set. For the agricultural indicators, the de-seasoning is realized by using the long term statistics, also called ‘historical year’. This is the average, minimum, maximum and standard deviation of FAPAR per dekad (10 days), calculated over the entire time series.

In the MARS action, two anomaly time series are used: the relative range vegetation index (RRVI) and the historical probability vegetation index (HPVI). When applied on NDVI, the RRVI (Relative Range Vegetation Index) corresponds to Kogan (1990) Vegetation Condition Index (VCI) and the HPVI (Historical Probability Vegetation Index) to Sannier et al. (1998) VPI (Vegetation Productivity Index).

HPVI(y,p) = Historical Probability of X(y,p)   [0% for MIN(p), …, 100% for MAX(p)]

RRVI(y,p) = [X(y,p) - MIN(p)] / [MAX(p) - MIN(p)]

3.1.2.2. *Similarity analysis*

The objective of similarity analysis is to compare each pixel's FAPAR profile of the on-going year with that of the previous years, and thereby to define the most "resembling year", with the underlying idea that the crop yields of the current year might be similar to those of this resembling year.

The similarity measure used is the root mean squared error (RMSE). For each pixel, the RMSE is calculated for each paired comparison of the ongoing season and each previous season in the archive, taken into account possible shifts, using this formula:

$$RMSE_{archive,s} = \sqrt{\frac{\sum_{i=1}^{n}(X_{ongoing,i} - X_{archive,i,s})^2}{n}}$$

with n = number of dekads
s = shift (in this example [-2, -1, 0, +1, +2])

The output of the similarity analysis consists of the most resembling year, the number of shift (in dekads) that corresponds with the lowest RMSE and the RMSE itself.

3.1.2.3. *Continuity assessment approach*

An external reference time series will be used to as a basis of the temporal continuity assessment. Therefore, the validation is only a relative one. The reference data set is necessary because:

- There will be limited overlap between the operation of VEGETATION and PROBA-V, and during this period, VEGETATION will experience some quality loss due to orbital drift, making direct comparison not sufficiently conclusive.
- There will be no overlap between Sentinel-3 and VEGETATION.

We choose to work with METOP-AVHRR 10-daily composites as a reference data set, because the data are very similar to those of VEGETATION as shown over NDVI values in Swinnen and Eerens (2013). Other reasons are that the future of the sensor is secured until a sufficient overlap with Sentinel-3 and the data is currently also used in the MARS action of JRC. The pre-processing of the AVHRR sensor to geometrically corrected and atmospherically corrected 10-daily composited red, NIR, SWIR and NDVI composites is done in the frame of the LSA-SAF.

To check the consistency between the VEGETATION FAPAR and the IMAGINES FAPAR from PROBA-V or Sentinel-3, the following step-wise approach will be adopted:

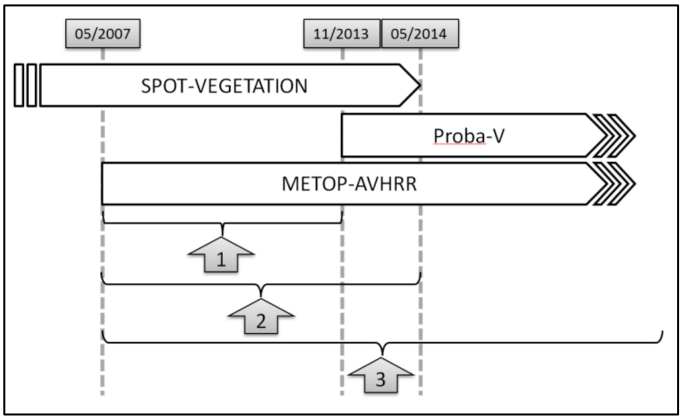

Figure 1: Overall approach for the consistency assessment

The evaluation is done in three stages presented in **Figure** 1. The first phase is the establishment of the degree of similarity between the time series of VGT and AVHRR, for their entire overlapping period (indicated by 1 in **Figure** 1). The second phase is for the period of overlap between VGT and PROBA-V. Here, for the period (1) the VGT data will be extended once with VGT and once with PROBA-V data, and the results of the comparison with the AVHRR time series will be evaluated. The last phase is when the VGT data stream has ended and where the period (1) is only extended with PROBA-V data and compared to AVHRR.

For the assessment of the anomaly analysis, Kendall's tau rank correlation will be used directly on the anomaly time series of the combined VEGETATION – PROBA-V FAPAR and METOP-AVHRR FAPAR, always for an entire year (36 successive dekads). To calculate the anomaly time series, the historical year of the overlapping time series (May 2007 – October 2013) will be used. This historical year will not be updated with data from PROBA-V or from Sentinel-3 in order to use always the same reference.

This rank correlation expresses whether the two time series show a similar temporal behavior. If the FAPAR time series from VGT and PROBA-V are consistent, then the anomalies calculated based on the historical year of VGT will not be influenced by the change in sensor. To be able to interpret this rank correlation, the results of the first phase (see **Figure** 1) will be used as target accuracy.

The same philosophy is used to assess the similarity analysis. Here, the outcome of the analysis itself between the combined VEGETATION – PROBA-V time series and reference time series will be investigated. Again, if the VGT and PROBA-V FAPAR data are consistent, the result of the similarity analysis will not be affected. If both data sets are not consistent, another most resembling year might be selected. To be able to interpret the results, the first phase of the analysis (see **Figure** 1) will be used as target accuracy. The outputs of the similarity analysis consist of the identification of the most resembling year, the shift in dekads that corresponds to the lowest RMSE and the RMSE itself. All of these outputs will be taken into account.

When analyzing the extended VEGETATION data set, the results will be compared to those obtained considering only the reference period.

The analysis will focus on Europe only.

3.2. VALIDATION OF DECAMETRIC PRODUCTS

The general procedure for validation of high resolution products over an ensemble of ground campaign was recently discussed in Baret and Fernandes, (2013), according with the best practices of CEOS/LPV group and previous validation exercises for high resolution products (Camacho and Torralba, 2010). The methodology was applied for validation of Sentinel-2 biophysical prototype products (Camacho et al., 2013).

A bottom up approach is used for the general validation strategy (Figure 2). It starts from the scale of the individual measurements that are aggregated over an elementary sampling unit (ESU) with a support area consistent with that of the decametric product to be validated. Several ESUs are sampled over a site. This allows developing calibrated transfer functions between the radiometric signal of a decametric sensor (that are different from that used to compute the product). Finally, the ensemble validation will build on a data base containing the values for each ESU across all the available sites, as well as the reference maps derived from the upscaled ground measurements and used for the validation of medium resolution products. The ensemble validation will consist in comparing these reference data (ESU database and up-scaled reference maps) with the products values according to the several criterions defined previously: accuracy, precision and inter-comparison with other reference products.

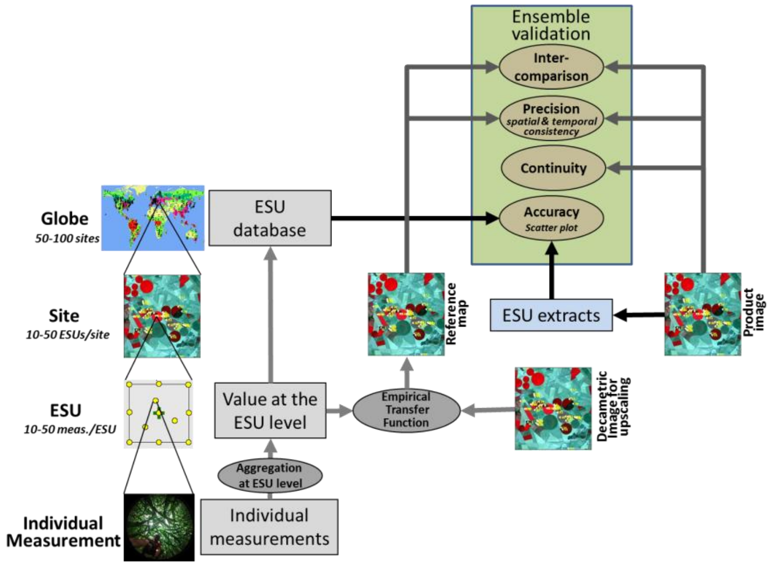

Figure 2: General strategy for the validation of decametric resolution products (from Baret and Fernandes, 2013)

Therefore, the validation procedure across all the several ImagineS demonstration sites allows providing relevant performance metrics of the products including:

Accuracy assessment

Accuracy will be quantified by several metrics reporting the goodness of fit between the products and the corresponding ground measurements. The accuracy assessment will be computed both over the ensemble of ESUs available as well as on the empirical estimates of the available ground based maps (Table 4). This later case allows getting larger population of data. Further it may reduce the measurement uncertainty through the smoothing operated by the transfer function. However, the confidence in the 'reference maps' derived from the transfer functions depends on performances of the transfer functions measured either by the RMSE or the R^2 coefficient.

Spatial consistency: precision assessment

The precision assessment reflects the repeatability of the products. This step is very important when analyzing a long time series or comparing different regions. Because of the lack of reference data and the significant uncertainties that may be associated with these reference data, precision was qualitatively assessed over surfaces that are known to be homogeneous and stable (unstable retrievals are not expected over homogeneous crops).

Inter-comparison

The inter-comparison with the empirical transfer function allows the evaluation of their relative consistency. In addition, the comparison of the distribution of the products with the values of the reference maps is very informative regarding the possible limitation in range and dynamics of the product. Pairwise and ensemble comparison will be achieved using:

- Scatterplots between each product may also provide useful insight on the specific behaviour of each product. Performance metrics (Table 3) were also computed.
- Maps of differences that highlights regions of agreement and discrepancies.

Product continuity

Missing data is generally considered by users as a severe limitation of a given product. It is therefore mandatory to document the continuity of a product. i.e. the distribution in space and time of missing data with Sentinel-2.

3.3. FIELD CAMPAIGNS

3.3.1. Field activities

The validation (accuracy assessment) of hectometric and decametric products relies on provision of accurate and reliable ground data for comparison with satellite estimates. In collaboration with the demonstrations sites different field activities have been planned.

Table 4 shows the updated plan for collection of field data and up-scaling for each demonstration site.

ID	Name	Field activities for LAI/FAPAR	Location
1	South-West, France	Acquisitions of ground LAI, FAPAR data by CESBIO (2013 and 2015). AHSPECT field campaign in 2015 (*). Up-scaling of ground measurements (EOLAB).	43° 29’ N, 1° 16’ E
2	Hegyhatsal, Hungary	Not expected	46° 57’ N, 16° 39’ E
3	Las tiesas Farm, Barrax, Spain	Setup of PAR systems for continuous LAI/FAPAR monitoring (ITAP). Additional field measurements for calibration and up-scaling of ground data (EOLAB). Period: April-August, 2014. Field campaign in May, 2014.	39° 02’ N, 2° 04’ W
4	Tula, Russia	Field campaign from April to September, 2014. Up-scaling of ground data (EOLAB).	53° 05’ N, 37° 14’ E
5	Upper Tana Basin, Kenia	Field measurements by EOLAB, May 2015.	0°55'S, 36° 48'E
6	Merguellil, Tunisia	Ground acquisitions by IRD (2013-2015). Up-scaling of ground measurements (EOLAB).	35° 45’ N, 10° 5’ E
7	Free State Province, South Africa	Not expected	28° 25’ S 27°4’ E
8	Greenbelt Farm, Ottawa, Canada	Field measurements by Agri-Food (2013-2015), including PASTIS-PAR data in 2014.	45° 18’ N, 75° 45’ W
9	San Fernando, Chile	Field Campaign by EOLAB. Period: January 2015.	34° 42'S, 70° 57' W

ID	Name	Field activities for LAI/FAPAR	Location
10	25 Mayo, La Pampa, Argentina	PAR systems operated by INTA. Period: October 2013- April 2014. Field Campaign: May 2014	33° 52' S, 59° 51' W
11	Yanco area, Murrumbidgee River catchment, Australia	Setup of PAR systems for continuous LAI/FAPAR monitoring (U. Monash). Period: October 2014- June, 2015.	34° 85' S, 146° 11' E
12	CRCC, Spain	Not expected	37º 48' N, 1º 03' W
13	Córdoba, Spain	Field Campaign (EOLAB). May, 2014.	37º 48' N 4º 44' W
14	Lambayeque, Peru	Not expected.	6° 47' S, 79° 46° W
15	Albufera, Valencia, Spain	Field campaign June to August, 2014 (EOLAB and University of Valencia- ERMES project). Additional field campaigns are expected in 2015 (to be confirmed).	39° 16' N, 0° 19' W
16	Rossasco, Italy	Field campaign in June, 2014 (ERMES project). Additional field campaigns are expected in 2015 (to be confirmed).	45° 15' N, 8° 33' E
17	Pshenichne, Ukraine	Setup of PAR systems for continuous LAI/FAPAR monitoring. Additional DHP measurements for calibration and up-scaling of ground data. Period: March to September 2015.	50° 4' N, 30° 6' E

Table 4: IMAGINES field activities plan in demonstration sites

(*) AHSPECT is an airborne campaign to take place at South-West site near Toulouse. The project is conducted by Météo-France/CNRS, and is funded by EUFAR. EOLAB will participate in collaboration with Météo-France, CESBIO, VITO and the Universitat de Valencia for the collection of LAI, FAPAR and FCover. The availability of different instruments onboard the aircraft (e.g., LIDAR, Mega Pixel Digital Camera, Hyperspectral radiometers) will allow a good characterization of the vegetation in the study area. Two flights are expected in May and August of 2015.

Additional ground data will be collected in collaboration with international initiatives such as JECAM, EnviroNET or Fluxnet. The main objective is to increase the number of ground based maps for the direct validation of global products (either ImagineS development products or GIO-Global Land operational products). This collaboration with JECAM was initiated with the UkranianPshenichne site. Other sites identified of potential interest are: Capitanata (Italy), Guangdong (China), Heilongiang (China) and Belgium/France.

3.3.2. Field protocols and up-scaling

In this section a brief view of the field protocols proposed for ground data collection and for the up-scaling with high resolution imagery is provided. A detailed description of field campaigns and processing of ground data and generation of ground-based maps is provided in the "Field Campaign and Production of Ground-Based Maps" reports (ImagineS-RP7.5).

3.3.2.1. Sampling the site

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 ESUs should be around 10m in agreement with the pixel size of high resolution products.
- ***Number of ESUs.*** Considering the site heterogeneity a minimum of 30 ESUs should be sampled over the study site (3x3 km^2). Note that 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. 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.

3.3.2.2. Sampling an ESU

Over each ESU, the same sampling scheme will be used for the measurement of the several variables targeted.

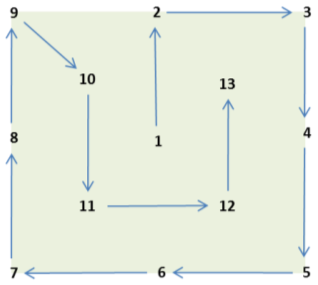

Figure 3: Typical sampling scheme proposed for an ESU.

A systematic sampling scheme (Figure 3:) is proposed, allowing more independent individual measurements. The size at the ground level of the area sampled should be around 10m. The GPS coordinates of the centre of the ESU (point 1) will be measured within few metres accuracy. The sampling will thus include 13 individual measurements.

3.3.2.3. DHP measurements

It is proposed to use digital hemispherical photography (DHP) to estimate LAI, FAPAR and fractional vegetation cover (FCover). This technique has been proven very efficient (Demarez et al., 2008).

However, great care should be taken to:

- Illumination conditions: better use diffuse conditions
- Use colour 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 LAI, true LAI (according to several ways to estimate leaf clumping) and FAPAR (actually FIPAR) for a range of sun positions

3.3.2.4. Continuous PAI / FAPAR monitoring: PASTiS system

PASTiS-PAR (Pai Autonomous System from Transmittance Sensors in the PAR domain) has been developed at INRA-Avignon. It allows continuous monitoring of vegetation Plant Area Index (PAI) and fraction of Aborbed Photosynthetically Active Radiation (FAPAR). This system is designed to be affordable, as well as easy to install and maintain. Therefore a multiple spatially distributed sampling units within the field is possible.

A PASTIS-PAR system is composed of a data logger (2GB memory, 2LR20 batteries) where 6 hemispherical PAR sensors are connected with wires. Sensors are distributed as shown in Figure 4.

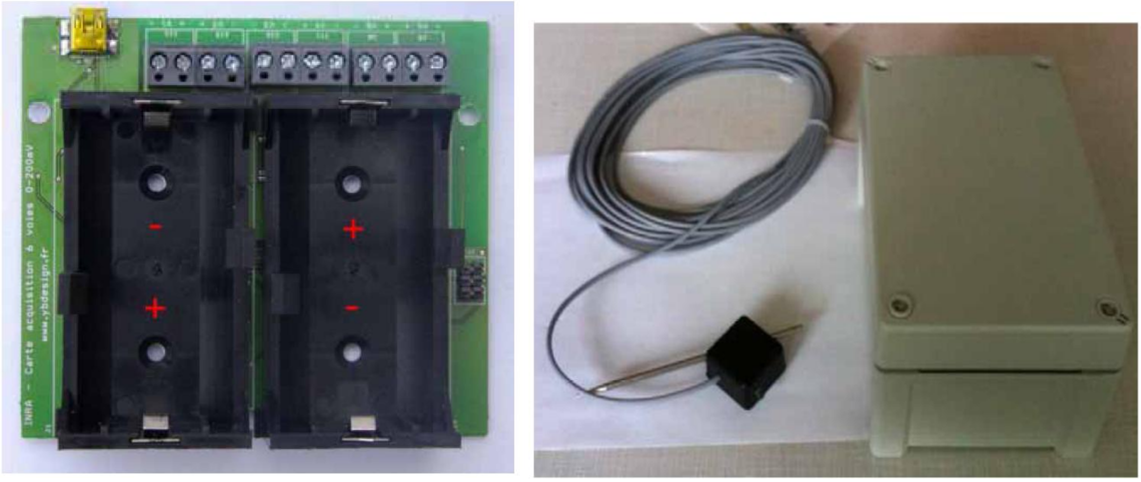

Figure 4: PASTiS-PAR description. One sensor (left) and the box that contains the data logger (right).

The transmittance within the canopy is computed as the ratio of the signal transmitted to the ground and the incident radiation which are measured with two different systems, one looking upward, one looking downward.

In ImagineS, PASTiS-PAR systems will be acquired and installed in the following demonstration sites:

- Barrax (Spain), with a sub-contract with ImagineS.
- Yanco area (Australia)
- Pshenichne (Ukraine), with a sub-contract with ImagineS.

Similar sensors are currently installed in 15 Mayo area (Argentina).

3.3.2.5. Up-scaling ground data: The transfer function method

If the number of ESUs is sufficient, multiple robust regression between ESUs reflectance (or Simple Ratio) and the considered biophysical variable can be applied o determine the empirical transfer function for up-scaling ground data (Martínez et al., 2009). It uses an iteratively re-weighted least squares algorithm, with the weights at each iteration computed by applying the bisquare function to the residuals from the previous iteration. This algorithm provides lower weight to ESUs that do not fit well. The results are less sensitive to outliers in the data as compared with ordinary least squares regression. At the end of the processing, two errors are computed: weighted RMSE (using the weights attributed to each ESU) and cross-validation RMSE (leave-one-out method). As the method has limited extrapolation capacities, a flag image based on the convex hulls, will be included in the final ground based map in order to inform the users on the reliability of the estimates.

4. VALIDATION OF AGRICULTURAL INDICATORS

4.1. GLOBAL SCALE

The outputs of the global LDAS will be evaluated by checking correlations between the SPI (Standardized Precipitation Index) drought index, soil moisture anomalies, Gross Primary Production anomalies and above-ground biomass anomalies. Focus will be given to known anomalous year and in-situ flux data will be used when available.

In term of in-situ data, ECMWF has obtained a formal access to the FLUXNET LaThuile dataset, via submission of a research proposal to the FLUXNET scientific committee (see www.fluxnet.org for more information on data availability). The data comprise energy fluxes at the surface, meteorological quantity and soil quantities (for some sites) for up to 40 sites world-wide and for a period of time covering 1991 to 2007. Maximum data frequency is hourly.

Furthermore, anomalies in cereal production simulated by the WOFOST model, and provided by the MARS Unit of JRC, over several European locations will be compared with the above-ground biomass anomalies obtained from the global LDAS output.

Additionally, the global LDAS outputs will be transferred to OMSZ and Météo-France to be compared with their regional LDAS results. Simulation results of the points over France co-located with Agreste data will be provided to Météo-France for comparison with agricultural yield statistics over France.

As a model and data integrator, the use of the global LDAS would also permit to monitor the satellite derived LAI and albedo products delivered within the ImagineS project and the operational Copernicus Global Land service and inform on their temporal and spatial stability. Moreover the LDAS will provide insights on the information content and on the internal coherence of the vegetation and water cycles. Those characteristics provide a valuable assessment of the suitability of these Earth-Observation products for global land monitoring applications.

4.2. FRANCE

The current version of the LDAS (LDAS-France) assimilates SPOT-VGT LAI and ASCAT surface soil moisture (SSM) satellite products over France (8km x 8km). In conjunction to IMAGINES, LDAS-France is used to perform a cross-cutting quality control of the Copernicus Global Land Service. The assimilation permits the active monitoring of LAI and SSM. A passive monitoring of albedo, FAPAR and Land Surface temperature (LST) is performed (i.e., the simulated values are compared with the satellite products), as these quantities are not assimilated yet. The LDAS generates statistics whose trends can be analyzed in order to detect possible drifts in the quality of the products: (1) for LAI and SSM, metrics derived from the active monitoring (i.e. assimilation) such as innovations (observations vs. model), residuals (observations vs. analysis), and increments (analysis vs. model) ; (2) for albedo, LST, and FAPAR, metrics derived from the passive monitoring such as the Pearson correlation coefficient, z-score, RMSD, SDD, mean bias. Conversely, these metrics can be used to validate the whole system.

Another interesting source of information for validation is the Agreste database for agricultural yield statistics over France. The observed cereal and fodder yields will be compared with the simulated annual maximum above-ground biomass with and without data assimilation. The cereal production, as simulated by the WOFOST model operated by JRC in the MARSOP system, will be compared to both Agreste and LDAS outputs. An important aspect of the validation will be the comparison of the regional LDAS with the global LDAS products of ECMWF.

Finally, many time series of river discharge are available over France and can be used for the indirect validation of the land surface model. The coupling between LDAS-France and the MODCOU hydrological model (Habets et al., 2008) will be implemented. The seasonal impact of the assimilation on hydrology will be analyzed.

4.3. HUNGARY:

The validation work to be performed at OMSZ consists of two steps. In the first step, the simulated vegetation and soil variables are going to be validated; in the second step, the simulated biomass will be correlated with long-year agricultural statistics. It has to be noted though that the dataset used in the second step still has to be acquired from the Hungarian authorities.

4.3.1. Validation of vegetation and soil variables

The main source of validation data is the flux tower at Hegyhátsál on the western border of Hungary. This grassland site is operated by the Eötvös Loránd University (ELTE), which is a sub-contractor of OMSZ in the ImagineS project. In the framework of this sub-contract ELTE provides measurement data to validate LDAS simulations, which are:

- CO2 fluxes at two levels (3 and 80 m)
- latent and sensible heat flux at two levels (3 and 80 m)
- soil moisture and temperature at several levels
- LAI measurements

Next to the Hegyhátsál measurements, available satellite products (LAI and SWI provided by the Copernicus Global Land service) are also going to be compared with the LDAS outputs

(LAI and WG2). For that, the model is run with and without assimilation of satellite-derived LAI and SWI products.

The validation exercise consists of the following investigations:

- time series comparison
- comparison of monthly and seasonal anomalies
- seasonal variability
- verification scores (BIAS, RMSE, correlation), spatial pattern of scores

An important aspect of the validation will be the comparison of the regional LDAS with the global LDAS products of ECMWF.

4.3.2. Comparison to agricultural statistics

It is an important question whether the LDAS products are suitable for agricultural users like individual farmers or regional or federal authorities. The main question here is how well the simulated biomass correlates to actual agricultural yields. For this validation long-year agricultural statistics are needed either on a local (single farmers) or a regional (authorities) scale. Regional statistics (for many kinds of agricultural plants for 2010-2012) are available from Hungarian Central Statistical Office which are suitable for the evaluation of the LDAS products. Comparison of WOFOST outputs with LDAS ones also will be done.

5. VALIDATION OF CROP MAPS

Validating the crop maps produced along the season is of critical importance. Indeed, one of the major goal in this study is to improve the precision of the map as information accumulates. Therefore, accuracy parameters have to be evaluated to track the accuracy improvements. Representative in-situ or reference data sets are a prerequisite for crop map production and assessment. It should be noted that the accuracy target to reach as early as possible in the season is 85% as proposed by De Wit and Clevers (2004).

The crop maps validation plan relies on crop type observations at the parcel level, that is a crop observation delimited in space by the boundaries of the field sown. Observations well distributed in the study region are critical to grasp the spatial heterogeneity as well as the possible gradient and shift in the vegetation growth timing. Besides, the field database should focus on the major crops and ensure that even less frequent classes have a sufficient number of observations to provide representative training and validation samples, and subsequently a sound statistical assessment. As an example, field data for the Tula region were collected by the Dokuchaev Institute in June 2013. Over 600 field observations were made randomly throughout the region (Figure 5) targeting the major crop types: winter wheat, spring barley, oats, potato, rapeseed. Punctual geo-referenced observations were converted to parcel observation using the field boundaries of the previous year, updated with images of the current growing season. If available, the comparison of remotely sensing area estimates and official area statistics could also support the validation. For the Free State Province, a dataset of the points acquired from the annual PICES survey (approx 300 points) with identification of the crop types should be made available for the project. Point observation would be converted to polygon observation by visual interpretation. Non-crop observation, if not included in the original dataset, were be added to the validation dataset.

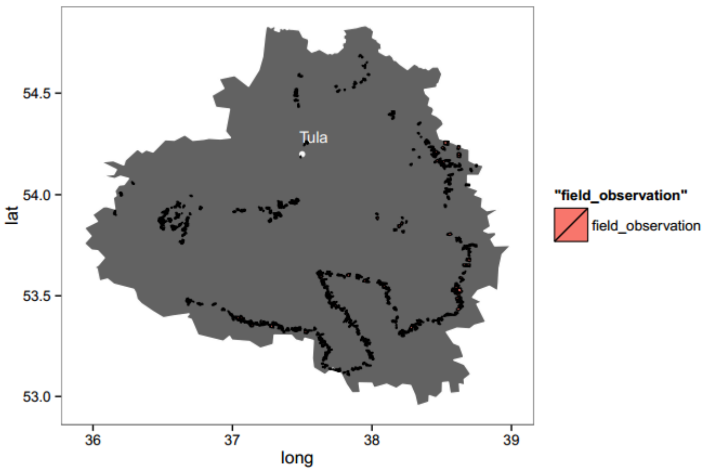

Figure 5: Spatial repartition of the crop type observations in Tula for the 2013 growing season

The methodology involves three products: a pre-seasonal cropland map, a winter crop map and a crop type map. All three products will be evaluated in a different way according to the specificity of the map. The reference data set used for the validation exercise will be aggregated at different granularity level according to the product to be validated.

Pre-seasonal cropland maps rely on medium resolution images. The cropland map will be assessed with the field data by means of a binary confusion matrix. In addition, the map will be evaluated using the Pareto boundary. This will allow evaluating the proportion of the error due to the spatial resolution.

Crop group maps will be evaluated at the end of the winter by means of a confusion matrix. To fit the legend, field data will be converted into winter crops/other crops. Traditional accuracy measures such as the overall accuracy, the kappa statistics, the omission and commission errors as well as the F-score will be computed. As both cropland and crop group maps do not rely on any training data, the accuracy assessment will make use of the entire reference data set.

To validate the ability of a method to discriminate between crops, an approach based on the confusion matrix is proposed. At each new acquisition of a high resolution image, all available data is preprocessed and classified using a subset of the observation data set. The confusion matrix of the resulting classification is then computed with the remaining of the observation data set. Traditional accuracy measures such as the overall accuracy, the kappa statistics, the omission and commission errors as well as the F-score will be computed. This approach will be reiterated until the end of the season. According to the specificity of the method tested, a multiple classification run approach could be adopted to avoid a potential spurious classification result (i.e., extremely high or low accuracy) that might result from a single draw of training and validation data as in Wardlow et Egbert (2005). Separate accuracy assessment was also performed for each classification run and the final accuracy. The reported accuracy would then result from the average accuracy across ten runs.

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