A Network of Sites for Ground Biophysical Measurements in support of Copernicus Global Land Product Validation

F. Camacho[(1)], R. Lacaze[(2)], C. Latorre[(1)], F. Baret[(3)], F. De la Cruz[(4)], V. Demarez[(5)], C. Di Bella[(6)], H. Fang[(7)], J. García-Haro[(8)], M. P. Gonzalez[(9)], N. Kussul[(10)], E. López-Baeza[(8)], C. Mattar[(11)], E. Nestola[(12)], E. Pattey[(13)], I. Piccard[(14)], C. Rudiger[(15)], I. Savin[(16)], A. Sanchez - Azofeifa[(17)], M. Boschetti [(18)], D. Bossio [(19)], M. Weiss[(3)], A. Castrignano[(20)], M. Zribi[(5)]

[(1)] EOLAB, Valencia, Spain, [(2)] HYGEOS, Toulouse, France, [(3)] INRA, Avignon, France, [(4)] ITAP, Albacete, Spain, [(5)]CESBIO, Toulouse, France, [(6)]INTA, Buenos Aires, Argentina, [(7)] LREIS, Beijing, China, [(8)]UVEG, Valencia, Spain, [(9)]IFAPA, Córdoba, Spain, [(10)]NAS, Kiev, Ukraine, [(11)]U. Chile. Santiago de Chile, Chile, [(12)]IBAF-CNR, Porano, Italy, [(13)]Agri-Food, Ottawa, Canada, [(14)] VITO, Mol, Belgium, [(15)]U. Monash, Melbourne, Australia, [(16)] DSSI, Moscow, Russia, [(17)]U. Alberta, Edmonto, Canada, [(18)]IREA-CNR, Milano, Italy, [(19)]CIAT, Nairobi, Kenya, [(20)] CRA-SCA, Bari, Italy

fernando.camacho@eolab.es

ABSTRACT – *Provision of reliable ground reference datasets is mandatory for the validation of satellite products. The ground data should be collected considering the spatial variability of the sites in agreement with recommendations of the CEOS WGCV Land Product Validation sub-group for validation of moderate resolution satellite products. This paper describes a network of sites established in support of the validation of Copernicus Global Land biophysical (LAI, FAPAR and FCover) products where ground biophysical variables are measured. Protocols for field data collection based on optical instruments and reporting, as well as for up-scaling of local ground data to the site extent are also detailed. Currently, 10 different sites have been sampled in 45 field campaigns; reaching the number of one-thousand Elementary Sampling Units (ESU) sampled with digital hemispherical photograph (DHP), LAI-2200 or AccuPAR devices in two years (2013 and 2014). Moreover, autonomous PAR systems (PASTIS) have been installed over a few sites for the continuous monitoring of FAPAR and PAI. A number of additional sites (mostly from the JECAM network) where ground activities are being conducted are also considered to provide a comprehensive database for the validation of Copernicus Global Land products. This database will be shared through the FP7 ImagineS web site and CEOS On-Line Validation Experiment (OLIVE) tool for the validation of medium resolution satellite biophysical products.*

1 INTRODUCTION

The Copernicus program is the EU response to the increasing demand for reliable environmental data. The Copernicus Global Land Service (http://land.copernicus.eu/global/) aims to continuously monitor the status of land territories and provide a series of bio-geophysical products (e.g. Albedo, LAI, FAPAR, Burnt Areas, Surface Temperature...) on the status and evolution of land surface at global scale.

Provision of consistent ground biophysical parameters (i.e., LAI, FAPAR, FCover) is essential for the validation of biophysical satellite products. The biophysical variables should be collected and processed according to the CEOS WGCV Land Product Validation (LPV) guidelines to be directly comparable with the medium resolution satellite product. Up to know, the largest compilation of ground reference data processed according to CEOS LPV guidelines was mainly achieved from a range of initiatives (VALERI, NASA, CCRS, ESA...), but none of them are currently providing updated biophysical ground reference values. Existing networks are not fully dedicated to the validation of LAI/FAPAR satellite products and the sites, methodologies or measured parameters do not always match properly the validation requirements for global biophysical satellite products.

Consequently, building a network of sites for the provision of regular and consistent ground biophysical datasets is necessary for the validation of Copernicus Global Land products whose quality needs to be verified continuously. In the context of the FP7 ImagineS (2012-2016) project (http://fp7-imagines.eu/), in support of the evolution of the Global Land Service, a network of demonstration sites for the validation of Copernicus Global Land products has been established over cropland/grassland areas. The initial network has been expanded with additional sites where ground data is being collected thanks to the collaboration with other research teams involved in JECAM (http://www.jecam.org/), FLUXNET (http://fluxnet.ornl.gov/) or Environet (http://www.envir-net.org/) networks.

This paper describes the status of the current activities, including established protocols, the network of sites, the achieved field campaigns and perspectives.

2 DEFINITIONS AND METHODS

2.1 Leaf Area Index (LAI)

Leaf area index (LAI) corresponds to one half the total green leaf area per unit horizontal ground surface area. However, if no distinction between leaves and other plants elements is made the correct term is Plant Area Index (PAI), which is the variable estimated from indirect methods. If we refer only to green elements, the correct term is GLAI (Green Leaf Area Index) or GAI (Green Area Index) if no distinction is made between leaves and other plant elements. GAI may be also estimated from indirect methods based on downward looking measurements of the green fraction with hemispherical cameras. GAI is probably the most pertinent definition to be used for remote sensing observations (Baret and Fernandes, 2012). Note that the community uses commonly the term LAI in place of GLAI.

Indirect methods are commonly used for measuring PAI (GAI) from gap (green) fraction (Weiss et al., 2004). Indirect methods based on gap fractions are providing PAI estimates, as we are interested in GLAI estimates, we should avoid to measure when the yellow-to-total leaf area ratio is large (i.e, during the senescent periods). DHP has the advantage to discriminate green from non-green elements during the processing of the digital photos, and thus is easily related to GAI. Moreover, most of the indirect methods estimate an 'effective' PAI (GAI) value, assuming random distribution of the elements within the canopy volume (i.e., no clumping). The clumping should be also measured to obtain the actual value. We refer here as "LAI" and "LAIe", the actual and effective GLAI based on indirect methods.

The devices most often used in our sites are DHP (Digital Hemispherical Photos) and LAI-2000 or LAI-2200 (LI-COR Inc.Lincoln, Nebraska).

2.2 Fraction of Absorbed PAR (FAPAR)

FAPAR refers to the fraction of PAR (0.4-0.7 μm) that is absorbed by a vegetation canopy. 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. The fraction of intercepted radiation, FIPAR (although it is not restricted to the PAR domain) is a very close approximation of FAPAR.

The PAR absorbed by canopies may be either measured directly based on PAR sensors (PAR balance) or estimated using ceptometers dedicated to measure PAR transmitted at the bottom of the canopy or estimated using the gap fraction, i.e. light transmission assuming that leaves are perfect black absorbers (i.e., FIPAR) (Baret and Fernandes, 2012).

In our sites most of the FAPAR measurements are based on FIPAR using DHP or PAR transmitted using ceptometers such as AccuPAR (Decagon, USA). Moreover, INRA has developed the PAI autonomous system from transmittance sensors in the PAR domain (PASTIS) that allows continuous monitoring of FAPAR and PAI (see Weiss et al., 2014) that have been installed in several sites as detailed hereafter.

2.3 Fraction of Vegetation cover (FCover)

It corresponds to the green fraction as seen from the nadir direction. FCOVER is mainly assessed using digital photography. 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. A ±10° field of view is admitted as a proxy for the vertical direction. DHP is the main device used for FCover estimates in our database.

3 PROTOCOLS FOR FIELD DATA AND UP-SCALING

Based on the previous achievements mainly during the VALERI project (http://w3.avignon.inra.fr/valeri/) , a guidelines for running a field campaign, and reporting the data has been established (Baret and Fernandes, 2012), as well as for the up-scaling of the ground data according to the CEOS LPV recommendations (Fernandes et al., 2014). These protocols have been provided to the ImagineS sites for consistent ground data acquisitions.

3.1 Field Measurements

a) Site selection

A validation site should be selected according to several criteria.

- The site should be relatively flat to simplify the interpretation.
- The extent should be around few km² (≈ 3x3 km^2) so that ground sampling would be relatively easy.
- It should present a significant range of vegetation types and development stages. Note that ImagineS is focused on agriculture indicators. The sites are thus located over agricultural areas.
- The site should be composed of patches of vegetation large enough to minimize border effects.

b) Sampling the site

A single pixel will constitute the Elementary Sampling Unit (ESU) that should be associated with the ground measurements representative of the corresponding area. To sampling the site the following rules are proposed:

- Considering the site heterogeneity a minimum of around 30 ESUs should be sampled over the study site. Note that additional control points over bare areas should be considered.
- The ESUs should be around 20 m in agreement with the pixel size of high resolution products for up-scaling.
- 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. Adjacency effects should be minimized. 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.

c) Sampling a ESU

Over each ESU, a sampling scheme is proposed for the measurement of the several biophysical variables.

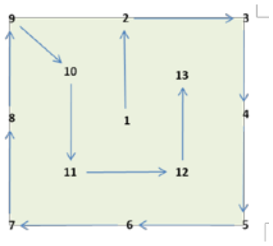

Figure 1. Typical sampling scheme proposed for an ESU.

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.

It is proposed to use digital hemispherical photography (DHP) to estimate LAI, FAPAR and FCover simultaneously. This technique has been proven very efficient. However, great care should be taken to:

- Illumination conditions: better use diffuse conditions to avoid problems with shadows.
- Use color cameras with high resolution (minimum 10 Mega pixels).
- Sample both overstory (looking upward) and understory (looking downward) when needed.
- It is very important to minimize problems related to the presence of non-green vegetation elements.

The processing could be conveniently achieved using the CAN-EYE software (http://www6.paca.inra.fr/can-eye/) that will provide estimates of effective and actual LAI, FAPAR (actually FIPAR) for a range of sun positions and FCover.

d) Reporting

Finally, guidelines for reporting a ground campaign in a consistent way have been proposed, including description of the site and sampled vegetation, description of protocols and ancillary information. A format for providing the ground measurements with header information is used.

3.2 Up-scaling ground measurements

The local measurements acquired over a sample of ESUs should be extended to the whole site (i.e. up-scaling). Guidelines for up-scaling of ground measurements using high spatial resolution imagery are also well established (Fernandes et al., 2014).

The up-scaling of ground data is carried out by EOLAB. A multiple robust regression method between ESUs reflectance and the ground biophysical variable is applied (Martínez et al., 2009). The 'robustfit' function from the Matlab statistics toolbox is used. It uses an iteratively re-weighted least squares algorithm, with the weights at each iteration computed by applying the bi-square 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).

The multiple robust regression method is applied to the different band combinations of the high resolution satellite imagery. The final band combination for the transfer function is selected based on a good compromise between the low cross-validation RMSE, the weighted RMSE (lowest value) and the number of rejected points. As the method has limited extrapolation capacities, a quality flag image based on the convex hull technique is included in the final ground based map in order to inform the users on the reliability of the estimates. The convex hull test allows evaluating also the suitability of the spatial sampling. An example of this procedure can be found in this issue (Camacho et al., 2014).

4 THE NETWORK OF SITES

A network of 17 demonstration sites over cropland areas has been established in ImagineS where research teams are able to collect ground data and/or to evaluate the satellite products. LAI/FAPAR is measured in 13 ImagineS sites (see Table 1).

Site Name	Country	Latitude	Longitude	Biome
SouthWest(*)	France	43.48	1.27	Cropland
Barrax	Spain	39.03	-2.07	Cropland
Tula (*)	Russia	53.08	37.23	Cropland
Upper Tana Basin	Kenia	-0.55	36.48	Cropland
Merguellil (*)	Tunisia	35.75	10.08	Cropland
Ottawa	Canada	45.30	-75.50	Cropland
San Fernando	Chile	-34.70	-70.96	Cropland
25 Mayo	Argentina	-37.90	-67.73	Crops/Shrubs
Yanco	Australia	-34.75	146.07	Grassland
Córdoba	Spain	37.78	-4.73	Cropland
La Albufera	Spain	39.274	-0.316	Rice
Rosasco	Italy	45.253	8.562	Rice
Pshenichne(*)	Ukraine	50.075	30.11	Cropland

Table 1. List of ImagineS demonstration sites where ground LAI/FAPAR measurements are acquired. Asterisks indicates sites of the JECAM network.

Site Name	Country	Latitude	Longitude	Biome
Guangdong	China	20,87	110,08	Rice
Belgium-	Belgium/France	50,65	5,00	Cropland
Collelongo	Italy	41,85	13,59	DBF
SantaRosa	CostaRica	10,84	-85,62	Tropical F.
Heilongjang	China	47,65	133,52	Rice
Utiel	Spain	39,58	-1,26	Vineyard
Capitanata	Italy	41,53	15.63	Cropland

Table 2. Additional sites where ground LAI/FAPAR measurements are acquired and shared with ImagineS.

Moreover, seven additional sites where ground data is being collected shared the ground data for the validation of Copernicus Global Land products (Table 2). Note that the protocols for ground data collection over these few sites coming from JECAM such as Guangdong, Belgium-France, Heilongjang (Fang et al., 2014) or Capitanata, FLUXNET (i.e., Collelongo) or ESA SMOS/Sentinel-3 (i.e., Utiel) validation sites could be slightly different than those described above followed in ImagineS

5 DATA COLLECTED

A large dataset of more than 1000 ESUs has been already collected in the ImagineS sites during 2013 and 2014 (Table 3).

SITE	# CAMPAIGNS	DATES (2013)		# ESUS
SW France	5	19-26	June	113
		09--11	July	
		24-29	July	
		16-20	August	
		2--6	Septem.	
Merguellil	9	31	January	91
		20	February	
		8	March	
		26	March	
		11	April	
		17	April	
		3	May	
		15	May	
		19	December	
Ottawa	4	10--26	June	34
		3--31	July	
		15,26	August	
		10,18	Septem.	
Pshenichne	3	14-17	May	102
		12--15	June	
		14-17	July	
SITE	**# CAMPAIGNS**	**DATES (2014)**		**# ESUS**
Barrax	1	29-30	May	30
Tula	5	9	April	155
		23	May	
		26	June	
		25	July	
		3	September	
Merguellil	6	21	January	77
		14	February	
		21	March	
		15	April	
		8	May	
		28	May	
25 de Mayo	1	7-9th	February	44
Cordoba	1	19-20	May	55
Albufera	9	17	June	257
		24-25	June	
		29	June	
		6	July	
		15	July	
		22	July	
		31	July	
		7	August	
		22	August	
Rosasco	1	3--4	July	43

Table 3. Number of field campaigns, dates in 2013 and 2014 and total number of ESUs collected up to now in the ImagineS sites.

Note that for most of the sites multi-temporal campaigns have been performed in order to characterize the crop cycle. In addition, PASTIS-PAR data has been collected during 2014 in Barrax (Latorre et al., 2014), Ottawa and Yanco sites, and will be installed in Pshenichne and Collelongo in 2015.

6 CONCLUSIONS AND PERSPECTIVES

Reliable ground dataset of biophysical variables are essential for the accuracy assessment of satellite biophysical products. In the context of the FP7 ImagineS project a network of cropland sites has been established in support of the validation of Copernicus Global Land products. Protocols for field acquisitions and up-scaling of ground data using high resolution imagery in agreement with the CEOS LPV recommendations have been promoted among the different sites. Protocols were previously established during the VALERI initiative.

Up to now, 45 field campaigns have been conducted in 10 different cropland sites; biophysical (LAIeff, LAI, FAPAR,FCover) variables were characterised in more than 1000 ESU over croplands using indirect methods. In several sites, multi-temporal acquisitions have been conducted allowing the proper characterization of the vegetation cycle. Moreover, autonomous systems (PASTIS-PAR) for continuous monitoring of PAI and FAPAR have been installed over three sites. This dataset is complemented with several additional sites where ground data is collected from other initiatives (e.g. JECAM, Environet). Ground data is up-scaled when a cloud-free high-resolution image is available. Uncertainties of ground estimates under different vegetation conditions should be better accounted for as in Fang et al., (2014).

This ground database as well as the ground-based high resolution maps constitutes an important contribution for the validation of the medium resolution products. This dataset will be shared to the scientific validation community through the ImagineS web page and the mean values of the 3x3 km^2 site through the CEOS OLIVE tool (http://calvalportal.ceos.org/web/olive/).

This network based on collaborative research with different institutions should be extended in the near future with the inclusion of new sites targeting different biomes. The ImagineS achievements should be a first step towards the establishment of a network of sites supporting the continuous validation of satellite biophysical products.

7 REFERENCES

Baret. F. and R. Fernandes, 2012. Validation Concept. ESA Report. VALSE2-PR-014-INRA.39 pp.

Camacho, F., C. Latorre et al., (2014). Characterization of vegetation parameters over the Río Colorado basin in La Pampa (Argentina) with ground data and multi-scale satellite imagery. This issue.

Fernandes, R., Plummer, S., Nightingale, J., et al. (2014). Global Leaf Area Index Product Validation Good Practices. CEOS Working Group on Calibration and Validation - Land Product Validation Sub-Group. Version 2.0: Public version available on LPV website.

Hongliang F., W. Lia, S. Weia, C. Jiang (2014) Seasonal variation of leaf area index (LAI) over paddy rice fields in NEChina: Intercomparison of destructive sampling, LAI-2200, digital hemispherical photography (DHP), and AccuPAR methods. Agricultural and Forest Meteorology 198–199 (2014) 126–141

Latorre, C., F. Camacho, et al. (2014). Seasonal monitoring of FAPAR over the Barrax cropland site in Spain, in support of the validation of PROBA-V products at 333m. This issue.

B. Martínez, F. Camacho, A. Verger, F.J. García-Haro, M.A. Gilabert (2013). Intercomparison and quality assessment of MERIS, MODIS and SEVIRI FAPAR products over the Iberian Peninsula. International Journal of Applied Earth Observation and Geoinformation 21 : 463–476

Weiss, M, F. Baret, B. de Solan, M. Hemmerlé (2014). Monitoring Plant Area Index at ground level: PAI autonomous system from transmittance sensors (PASTIS). This issue.

Weiss, M., Baret, F., Smith, G.J., Jonckheere, I. and Coppin, P., 2004. Review of methods for in situ leaf area index (LAI) determination Part II: Estimation of LAI, errors and sampling. Agricultural and Forest Meteorology, 121(1-2): 37-53.

8 ACKNOWLEDGEMENTS

Special thanks are given to all researchers and institutions involved in the acquisition of field data. This research is supported by the FP7-SPACE-2012-1 ImagineS project.