Sensagri

Sentinels Synergy for Agriculture

Deliverable D8.22

Final feasibility analysis of SENSAGRI services

V 1.0

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Abstract (for dissemination)	Report showing the final evaluation of the maturity and feasibility of the SENSAGRI proposed services at the end of the project and beyond.
Keywords	Feasibility analysis

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[1] R = Document, report; DEM = Demonstrator, pilot, prototype; DEC = Websites, patent fillings, videos, etc; OTHER; ETHICS = Ethics requirement

[2] PU = Public; CO = Confidential (Consortium and Commission Services); EU-RES = Restreint UE; EU-CON Confidentiel UE; EU-SEC = Secret UE (Commission Decision 2005/444/EC)

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1. Introduction

1.1. Scope of the document

This deliverable shows the evaluation of the matureness status of the SENSAGRI prototypes and proof-of concept at the end of project (October 2019), as well as the expected evolutions once the project is finished.

The previous feasibility analysis, made at November 2018 (and presented in D8.15), is kept as a reference, to highlight the achievements of the last year of the project.

For each prototype / proof-of-concept, we present a table with a description of the key evaluation elements. An objective evaluation, following the Technical Readiness Levels (TRL), has been attempted based on the presented items.

We consider that the TRL is not the most adequate scale for assessing the matureness of services based on Earth Observation (EO) and we advocate for the definition of a specific scale for EO-based services. However, since this definition was out of the scope of this project, we have kept TRL as the reference for our evaluation.

In addition to the tables, and following the recommendations made by the project reviewers, we have included two annexes to the document:

- Annex 1: A summary table with the validation results for all SENSAGRI products
- Annex 2: A critical evaluation on the potential implementation of SENSAGRI services in the Copernicus DIAS

1.2. Notations, abbreviations and acronyms

ATBD	Algorithm Theoretical Basis Documents
CAL/VAL	Calibration/Validation
CAP	Common Agricultural Policy
CEE	Copernicus Entrusted Entities
CESBIO	Centre d’Etudes Spatiales de la BIOsphère
CNES	Centre National D’etudes Spatiales
CNR	Consiglio Nazionale delle Ricerche
CREA	Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria
DIAS	Data and Information Access System
EC	European Commission
EE	Entrusted Entities
EP	Exploitation Plan
ESA	European Space Agency
ESU	Elementary Sampling Units
EU	European Union
GA	General Assembly
GIS	Geographic Information System
INTA	Instituto Nacional de Tecnologia Agropecuaria
IOR	Instytut Ochrony Roślin
IPL	Image Processing Laboratory
IPP	Institute of Plant Protection
IPR	Intellectual Property Rights
IREA	Istituto per il Rilevamento Elettromagnetico dell'Ambiente
ITACyL	Instituto Tecnológico Agrario de Castilla y León
JECAM	Join Experiment of Crop Assessment and Monitoring
LAI	Leaf Area Index
LPIS	Land Parcel Identification System
LUCAS	Land Use/Cover Area Frame Survey
MARS	Monitoring Agricultural Resources
MLRA	Machine Learning Regression Algorithms
MS	Milestone
PEDR	Plan of the Exploitation and Dissemination of Results
PMT	Project Management Team
RD&I	Research, Development and Innovation
REA	Research Executive Agency
S1	Sentinel-1
S2	Sentinel-2
S3	Sentinel-3

SAR	Spaceborne Synthetic Aperture Radar
Sen2-Agri	Sentinel 2 for Agriculture
SCM	Seasonal Crop Map
SENSAGRI	Sentinels Synergy for Agriculture
SMOSAR	Algorithm for Soil Moisture Retrieval using Sentinel 1 data
SSM	Surface Soil Moisture
SWI	Soil Water Index
TBD	To Be Defined
TRL	Technological Readiness Level
UPS	Université Paul Sabatier
UVEG	Universitat de València
WP	Work Package
WPL	Work Package Leader
WT	Work Task

2. Feasibility analysis results

The Final Feasibility Analysis report follows the same structure outlined in the Second Feasibility Analysis, which consists in a set of tables identifying key elements for the evaluation of the readiness level of prototypes:

1. Algorithm development and validation
2. Comparison with existing services
3. Software development level
4. Compliance with user requirements
5. Risks for implementation

At each section, several questions address different aspects of the prototype development, which should serve for the feasibility assessment.

Each prototype and/or proof-of-concept developers filled the questionnaire for their respective processors, specifying the status at M24 (November 2018), the situation at the end of the project (October 2019) and the likely steps to be done after the end of the project.

The results are shown in the following sections 2.1 to 2.6.

2.1. Surface Soil Moisture (SSM)

Prototype: SSM			
Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
1. Algorithm development and validation			
Algorithm development (*consolidated, ongoing…*)	ongoing	The SENSAGRI SSM product is an evolution of the ESA SEOM S-1 SSM product at 1 km (http://seom.esa.int/). The evolution consists of improving the resolution to "field scale" (i.e., ~0.1 km) where parcel borders are available, e.g., from EU LPIS, by implementing an integrative use of Sentinel-1 (S1) and Sentinel-2 (S2) data. **The algorithm has been consolidated, improved and demonstrated at European scale.** From April 2017 to December 2018, time series of SSM maps have been produced and assessed over the SENSAGRI sites in Italy, Spain, France and Poland **(TRL 6)**.	Prototype demonstration in operational environment (TLR7)
Validation (*preliminary, ongoing, full…*)	ongoing	The accuracy of the S1&S2 SSM product at field scale has been estimated through direct comparison against 2017 and 2018 SSM observations i) recorded by 3 hydrologic networks, located one in Italy and two in Spain	Validation stage 3 (CEOS Land Product Validation, https://lpvs.gsfc.nasa.gov/index.html): Uncertainties in the product and its associated structure are well quantified

Prototype: SSM			
Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
		ii) collected during ground campaign carried out in France, Italy and Spain. The issue of the spatial representativeness error (SRE) of point-like SSM measurements has been addressed. At 1km, the SSM product has been formerly validated against i) in situ SSM data, acquired by 167 ground stations in Australia, USA, Canada and Europe , over an average period of approximately two years (between 2015 and 2018) ii) low resolution satellite products over a large area ($\sim 590\ 10^3 km^2$) of the Mediterranean basin.	from comparison with reference in situ or other suitable reference data. Uncertainties are characterized in a statistically rigorous way over multiple locations and time periods representing global conditions. Spatial and temporal consistency of the product and with similar products has been evaluated over globally representative locations and periods. Results are published in the peer-reviewed literature.
Expected accuracy	0.06-0.07m^3/m^3		
Attained accuracy		**Based on the SENSAGRI data set (N=4040), the estimated rmse is 0.06 m^3/m^3 (1σ) at field scale, after correcting for the SRE, and the Pearson correlation is 0.5.** Results show that SRE increases the ubrmse between 0.01m^3/m^3 and 0.02m^3/m^3, depending on the mean SSM values. Local biases have been observed for the effect of the soil texture and meteorological condition.	

Prototype: SSM			
Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
2. Comparison with existing services			
Spatial resolution compared with existing/ongoing services	The SENSAGRI Surface Soil Moisture product is characterized by a spatial resolution of ~0.1km over agricultural areas, where SSM averages at field scale are performed using the information of parcel borders, wherever available. Conversely, over the remaining areas SSM is averaged at a resolution of 1 km. The pixel size of the SSM product is 50m. According to the product portfolio of the Copernicus Global Land Service (https://land.copernicus.eu/global/products), there are a Soil Water Index product in production and a Soil Moisture Product in development at a spatial resolution >=1km.	Within the Copernicus Global Land Service (CGLS), daily Soil Water Index (SWI) information is currently distributed as gridded product with a spacing of $0.1°$ and at two depths, i.e. surface and root zone. The daily SWI product is derived from EUMETSAT ASCAT scatterometer measurements at 25 km resolution. Additionally, a pre-operational Relative Surface Soil Moisture (RSSM) product over Europe, at a spatial resolution of ~ 1 km, is distributed through CGLS from December 2018. Both SWI and RSSM are indexes, in % saturation, which can be converted to the volumetric soil moisture content (m^3/m^3) by using information on the soil porosity. **The SENSAGRI SSM product derived from S1 and S2 data provides i) soil moisture information in volumetric water content $[m^3/m^3]$ and ii) at "field scale" resolution $(\sim 0.1$km). The "field scale" resolution is obtained over those agricultural areas where the parcel borders are available (LPIS available over the project test sites). Elsewhere, the**	Inclusion of LPIS available in Europe.

Prototype: SSM			
Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
		resolution is of ~1 km. In addition, the SENSAGRI product estimates both the mean and the standard deviation of the retrieved SSM.	
Temporal resolution compared with existing/ongoing services	Temporal resolution depends on the revisit of S-1 constellation (6-day exact repeat cycle at the equator). The temporal resolution of the Soil Water Index product is daily as is derived from METOP/ASCAT. No information about the temporal resolution of the Copernicus soil moisture product in development.	Within the CGLS, the temporal resolution of the Soil Water Index product is daily as is derived from METOP/ASCAT. The Relative Soil Moisture Product is available for the European continent per individual location every 1.5-4 days from October 2016 ongoing. **For the SENSAGRI SSM product, the temporal resolution depends on the revisit of S1 constellation (6-day exact repeat cycle at the equator).**	Investigation of the combined use of ascending and descending S1 acquisitions to improve the temporal resolution. Indeed, the S1 constellation has a repeat frequency (ascending/descending) of 3 days at the equator, approx. 2 days over Europe (https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/revisit-and-coverage)
Expected/achieved accuracy compared with existing/ongoing services	The expected accuracy of the SENSAGRI SSM product is 0.06-0.07m^3/m^3 The Soil Water Index product at 0.1° resolution is a so-called degree of saturation which can be converted to the volumetric soil moisture content for example by using information on the soil porosity or by scaling it with the maximum and minimum reference volumetric	An initial validation of the CGLS Relative Soil Moiture product is available in https://land.copernicus.eu/global/products/ssm For the year 2015, comparison against in-situ data from International Soil Moisture Network (ISMN) shows low to moderate agreement in temporal dynamics of soil moisture data from in-situ stations with the satellite product, but show on the other hand very high agreement in spatial dynamics. The	

Prototype: SSM

Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
	soil moisture values. As an example, the Validation document available https://land.copernicus.eu/global/products/swi reports the comparison of SWI (v2) product to data from 664 in situ stations from the International Soil Moisture Network in Paulik et al. (2014): mean correlation (R) and root mean squared diffrence (RMSD) values of 0.54 and 0.062 m^3/m^3 respectively.	product is in in a pre-operational stage (i.e. limited quality assessment). **The assessed accuracy of the SENSAGRI SSM product at field scale is 0.06 m^3/m^3 (1σ) and Pearson correlation 0.5 over the Italian, Spanish and French test sites (N=4040).**	
Timeliness	Regarding the processing time of the SSM retrieval algorithm for example over the entire Mediterranean basin (e.g., approximately 2,085,292 km^2) and considering the need of including partially overlapping S-1 images, it is possible to roughly estimate a total number of 100 S-1 IWS images corresponding to a processing time (using an Intel® Xeon® X5680 Six-Core processor (3,33GHz, 12MB cache), 24GB DDR3 1333MHz Memory, and SAS disk (15000rpm)) of approximately 48 hours.	Regarding the processing time of the SSM retrieval algorithm for example over the entire Mediterranean basin (e.g., approximately 2,085,292 km^2) and considering the need of including partially overlapping S1 images, it is possible to roughly estimate a total number of 100 S1 IWS images corresponding to a processing time (using an Intel® Xeon® X5680 Six-Core processor (3,33GHz, 12MB cache), 24GB DDR3 1333MHz Memory, and SAS disk (15000rpm)) of approximately 48 hours.	Translate and optimize the code in compiled languages; use of more powerful computer systems
Differences in the output products with respect to existing ones	SENSAGRI SSM product is in a latitude/longitude grid (pixel size 0.00052°) - ellipsoid WGS 1984 and is composed of three bands, i.e.: mean SSM; standard deviation; and	The CGLS SWI and Relative Soil Moisture products are displayed in a regular latitude/longitude grid (plate carrée) with the ellipsoid WGS 1984, provided as multi-band	

Prototype: SSM			
Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
(*algorithm approach, output variables, uncertainty layers, metadata…*)	coefficient of variation (defined as stddev/mean). The standard deviation map associated with the SSM product provides an estimate of SSM error (under the hypothesis of unbiased SSM estimates). The SSM product is integrated with an LPIS layer.	netCDF4 files (e.g. SWI, quality flag and surface state flag). An INSPIRE compliant metadata file, XSLT for XML viewing and a sub-sampled, coloured quicklook image in GeoTIFF format are provided separately. **SENSAGRI SSM product is composed of three bands, i.e.: mean SSM; standard deviation (std); and coefficient of variation (defined as stddev/mean). Each band is a geo-referenced map in lat/lon projection – WGS84 datum, with a square pixel of length of 0.00052° (~50m).** **The standard deviation map associated with the SSM product provides an estimate of SSM error (under the hypothesis of unbiased SSM estimates). The SSM mean and std layers are delivered in GeoTIFF format. Coloured and geocoded quicklooks in .png format are also provided.**	
3. Software development level			

Prototype: SSM			
Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
Platform independent (*no Matlab, standalone build / embedded*)	Core procedures implemented in IDL. Auxiliary software implemented as Bash shell scripts and common basic POSIX/GNU tools (awk, sed, cut, etc.) . The target development platform is GNU/Linux.	Core procedures implemented in IDL. Auxiliary software implemented as Bash shell scripts and common basic POSIX/GNU tools (awk, sed, cut, etc.), GRASS GIS and GDAL tool, which are FOSS and platform independent. The target development platform is GNU/Linux.	A Python language port should be considered in order to allow deployment in a multi-hosts/cloud environment
Level of optimisation (*throughput, speed, memory and time comsumption*)	Optmization by memory footprint and cpu load has been considered.	IDL procedures are optimized to work with minimal footprints for memory on a single host.	A distributed computing should be considered to reduce computing time on very long time series and extensions.
Interoperability (*standard input/output formats, compatibility of data with other parts*)	Input formats considered is the standard Sentinel Toolbox formats. Output formats are in GeoTiff and PNG formats. Intermediate files are in ENVI formats.	Input format for S1&S2 pre-processing (not included in the delivered software) is the standard Sentinel Toolbox format. Input format of the delivered SSM software prototype is the ENVI format. Output formats are GeoTiff and PNG formats.	
Derived results (*statistics, derived products of interest*)	Proof-of-concept irrigated/not irrigated product Proof-of-concept tillage change product	Proof-of-concept irrigated/not irrigated product Proof-of-concept tillage change product	

Prototype: SSM			
Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
Easy to use (*front-end as graphic user interface-GUI vs command line, integration with an existing GUI*)	Command line	Command line	integration with GUI
Multipurpose use (*standalone use, as a library, as embedded module*)	Standalone use only	Standalone use only	Library
Possibility of API implementation (*could be used through an external call*)	No API provided	No API provided	API definition and library development for external use by application software
4. Compliance with user requirements			
Knowledge of Copernicus Entrusted Entities requirements (Y/N)	Y	Y	

Prototype: SSM			
Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
Knowledge of European Commission directorates requirements (Y/N)	N	Y	
Knowledge of mid-users requirements (Y/N)	Y	Y	
5. Risks for implementation			

2.2. Leaf Area Index (LAI)

Prototype: LAI			
Issue	**November 2018**	**End of Project (October 2019)**	**Beyond**
1. Algorithm development and validation			
Algorithm development (*consolidated, ongoing…*)	ongoing	Consolidated The algorithm has been consolidated, improved and demonstrated at European scale. From early 2017 to late 2018, time series of LAI maps have been produced and assessed over the SENSAGRI sites in Italy, Spain, France and Poland (TRL 6)	Prototype demonstration in operational environment (TLR7)
Validation (*preliminary, ongoing, full…*)	ongoing	Full	
Expected accuracy	1.0-0.5 m^2/ m^2	1.0-0.5 m^2/ m^2	
Attained accuracy	1.0 -1.5 m^2/ m^2	LAI Green: RMSE=0.67/R^2=0.7 LAI Brown: RMSE=0.43/R^2=0.62	
2. Comparison with existing services			
Spatial resolution compared with existing/ongoing services	The SENSAGRI LAI product is characterized by a spatial resolution of 20 m over agricultural areas, i.e. the nominal S2 spatial scale	Same resolution than M24	

Prototype: LAI			
Issue	**November 2018**	**End of Project (October 2019)**	**Beyond**
	Spatial resolution is the same as the SNAP official LAI product.		
Temporal resolution compared with existing/ongoing services	Temporal resolution depends on the revisit of S2 constellation (5-day exact repeat cycle at the equator in cloud-free conditions). Spatial resolution is the same as the SNAP LAI product.	Investigation of the combined use of ascending and descending S-1 acquisitions to improve the temporal resolution. Indeed, the S-1 constellation has a repeat frequency (ascending/descending) of 3 days at the equator, approx. 2 days over Europe (https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/revisit-and-coverage)	
Expected/achieved accuracy compared with existing/ongoing services	The expected accuracy of the SENSAGRI LAI product is 1.0-0.5 m^2/m^2 The LAIgreen product is foreseen to have a similar accuracy as compared to the S2 SNAP product. Regarding LAIbrown, this is the very first time this product is released, hence no comparison is possible.	The achieved accuracy for both models lies within the initial accuracy threshold set.	

Prototype: LAI			
Issue	**November 2018**	**End of Project (October 2019)**	**Beyond**
Timeliness	The processing of a single S2 tile on a contemporary computer takes about 5 min.	Same as M24	Software optimization and the use of more powerful computer systems will further speed up the processing time.
Differences in the output products with respect to existing ones (*algorithm approach, output variables, uncertainty layers, metadata…*)	SENSAGRI LAI product is in UTM projection (pixel size 20m) - ellipsoid WGS 1984 and is composed of three bands, i.e.: mean LAI; standard deviation; and coefficient of variation (defined as stddev/mean). The standard deviation map associated with the LAI product provides an estimate of LAI error (as provided by GPR, i.e. is a probilistic estimate).	Same as M24	
3. Software development level			
Platform independent (*no Matlab, standalone build / embedded*)	Core procedures implemented in Matlab.	Same as M24	Exploring to deliver an executable standalone application, which could be run on machines that do not have MATLAB installed.

Prototype: LAI			
Issue	**November 2018**	**End of Project (October 2019)**	**Beyond**
Level of optimisation (*throughput, speed, memory and time comsumption*)	Optmization by memory footprint and cpu load has been considered.	Same as M24. Processing speed optimized in the pixel-wise LAI Green/LAI Brown retrieval by implemented the image reading and processing per blocks	
Interoperability (*standard input/output formats, compatibility of data with other parts*)	Input formats considered is the standard Sentinel Toolbox formats. Output formats are in GeoTiff and in ENVI formats.	Standard Sentinel-2 Input format. Output format are in GeoTIFF (by default) and in ENVI formats	
Derived results (*statistics, derived products of interest*)	Time series trends of LAIgreen and LAIbrown	Time series trends of LAIgreen and LAIbrown and final validation statistics	
Easy to use (*front-end as graphic user interface-GUI vs command line, integration with an existing GUI*)	Command line	Command line	
Multipurpose use (*standalone use, as a library, as embedded module*)	Standalone use only	Standalone use	Library
Possibility of API implementation (*could be used through an external call*)	No API provided	No API provided	API definition and library development for external use by application software
4. Compliance with user requirements			
Knowledge of Copernicus Entrusted Entities requirements (Y/N)	Y	Y	

Prototype: LAI			
Issue	**November 2018**	**End of Project (October 2019)**	**Beyond**
Knowledge of European Commission directorates requirements (Y/N)	N	Y	
Knowledge of mid-users requirements (Y/N)	Y	Y	
5. Risks for implementation			

2.3. Seasonal Crop Type Mapping (SCM)

Prototype: Seasonal Crop Type Mapping

Issue	November 2018 (M24)	End of Project (October 2019)	Beyond
1. Algorithm development and validation			
Algorithm development (*consolidated, ongoing…*)	The classification algorithm allowing the integration of Sentinel-1 and -2 data has been consolidated. The algorithm has been implemented and tested on several test sites.	The algorithm relies on a supervised classification methodology. Thus, reference data is needed describing the current year. At the end of the project, the impact of data reference requirement wants to be reduced	
Validation (*preliminary, ongoing, full…*)	The complete validation is ongoing. However, important validation tests have been successfully performed	Validation of the new approaches to reduce data reference requirement will be performed	
Expected accuracy	The resulting map products achieve the expected accuracy. Results improve current operational classification crop products produced by ESA S2agri processing chain.	The goal is to keep the accuracies obtained at M24 by minimizing human efforts (data reference)	
Attained accuracy	At the moment, obtained results achieve the attained accuracy.		
2. Comparison with existing services			
Spatial resolution compared with existing/ongoing services	10m map resolution		

Prototype: Seasonal Crop Type Mapping

Issue	November 2018 (M24)	End of Project (October 2019)	Beyond
Temporal resolution compared with existing/ongoing services	Products can be released 3 times a year		
Expected/achieved accuracy compared with existing/ongoing services	?	There is a very limited improvement obtained when adding S1 data to the classification (taking also into account the important processing effort for radar data). However, use of S1 is essential over Southern Europe sites when producing the early Seasonal Crop Map as well as in central and Northern Europe.	
Timeliness	?		
Differences in the output products with respect to existing ones (*algorithm approach, output variables, uncertainty layers, metadata…*)	Concerning our previous algorithms, a new fusion step has been designed in order to improve the fusion of Sentinel-1 and -2 data		
3. Software development level			
Platform independent (*no Matlab, standalone build / embedded*)	Platform independent. Requirements: - python 2.6 - OTB library - slurm		
Level of optimisation (*throughput, speed, memory and time comsumption*)	- cpu time is relatively optimization - Memory and space can be more optimized	- CPU, memory and space will be optimized	

Prototype: Seasonal Crop Type Mapping			
Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
Interoperability (*standard input/output formats, compatibility of data with other parts*)	Input and output are standard (geotiff and)	idem	
Derived results (*statistics, derived products of interest*)	Standard format (pdf and png)	idem	
Easy to use (*front-end as graphic user interface-GUI vs command line, integration with an existing GUI*)	100% Command line interface	Possibility of a Python GUI	
Multipurpose use (*standalone use, as a library, as embedded module*)	Not considered yet		
Possibility of API implementation (*could be used through an external call*)	Not considered yet		
4. Compliance with user requirements			
Knowledge of Copernicus Entrusted Entities requirements (Y/N)	N		
Knowledge of European Comission directorates requirements (Y/N)	N		
Knowledge of mid-users requirements (Y/N)	N		
5. Risks for implementation			

2.4. Irrigated/not-irrigated area product

Issue	End of Project (October 2019)	Beyond
1. Algorithm development and validation		
Algorithm development (*consolidated, ongoing…*)	**The algorithm has been developed and demostrated over one SENSAGRI site (TLR3)**	
Validation (*preliminary, ongoing, full…*)	The validation consisted of comparing the binary masks with ground data available over the Riaza irrigation district (Castile and Léon, Spain) in 2017 and 2018.	
Expected accuracy		
Attained accuracy	The algorithm performance strongly depends on the time-dependent contrast existing between the SSM content of irrigated and not-irrigated fields. This contrast in turn mainly depends on i) the balance between the amount of water supplied and the evapotranspiration rate and ii) the development of crops, particularly in the summer season. In periods characterized by relatively high SSM contrast (e.g. April 2017), remarkably good classification performance is observed (e.g. Producer Accuracy$_{r}$ ~95-85%). Conversely, in periods characterized by a fairly low SSM contrast the algorithm performance is quite poor. A more detailed analysis has been performed by considering the PA$_{irr}$ for few specific crops, such as wheat, barley and maize. Results indicate that for winter crops the best performance is achieved before the flowering period, while for summer crops the most indicated period is during the early phenologic stages when the plats are not fully developed.	

Issue	End of Project (October 2019)	Beyond
2. Comparison with existing services		
Spatial resolution compared with existing/ongoing services	In the product portfolio of the Copernicus Global Land Service, there are classes of permanently irrigated land and not-irrigated arable land in Corine Land Cover (CLC). CLC uses a Minimum Mapping Unit (MMU) 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena (https://land.copernicus.eu/pan-european/corine-land-cover). **The SENSAGRI irrigated/not-irrigated area product has a pixel size of 0.0004° (~0.1km resolution)** **The final goal of the irrigated/not-irrigated area product is to provide dynamic information on the spatio-temporal distribution of irrigated fields. The approach allows the identification of the irrigation events rather than the effects of irrigation on the crop growth. In this respect, SAR soil moisture data may integrate existing services to detect single irrigation events and can be useful to identify cases of supplemental irrigation.**	
Temporal resolution compared with existing/ongoing services	Since 2000, the CLC map has been updated every 6 years. (https://land.copernicus.eu/pan-european/corine-land-cover) **The SENSAGRI irrigated/not-irrigated maps are obtained with the same temporal resolution of the SSM product.**	Delivery of quarterly cumulative maps
Expected/achieved accuracy compared with existing/ongoing services	The thematic accuracy of CLC is higher than 85% (https://land.copernicus.eu/pan-european/corine-land-cover)	

Issue	End of Project (October 2019)	Beyond
Timeliness	3 minutes per S1 frame	
Differences in the output products with respect to existing ones (*algorithm approach, output variables, uncertainty layers, metadata…*)	CLC is in a GeoTIFF raster format,– with coordinate reference systemEPSG:3035 (ETRS89, LAEA) **The irrigated/not-irrigated area product is a binary raster image in ENVI format (geo-referenced map in lat/lon projection – WGS84 datum)**	

2.5. Tillage change product

Issue	End of Project (October 2019)	Beyond
1. Algorithm development and validation		
Algorithm development (*consolidated, ongoing…*)	**The algorithm has been developed, consolidated and demostrated over two SENSAGRI sites (TLR4).**	
Validation (*preliminary, ongoing, full…*)	The validation has been carried out by comparing the classified binary maps identified with reference maps built using ground data collected over the Italian and Spanish test sites in 2017 and 2018.	
Expected accuracy		
Attained accuracy	The overall accuracy of the tilled/no-tilled identification estimated over the Apulian Tavoliere (Italy) and Castile and Leon (Spain) sites, on the base of observations collected in 2017-2018, is of 82% and 68%, respectively. Main sources of errors identified in the validation are the presence of a	

Issue	End of Project (October 2019)	Beyond
	high number of precipitation events (in particular for Castile and Leon in 2018) and the uncertainty on the tillage dates.	
2. Comparison with existing services		
Spatial resolution compared with existing/ongoing services	In the product portfolio of the Pan-European High Resolution Layers, is available the Ploughing Indicator 2015 (PLOUGH), which is associated to the Grassland layer (https://land.copernicus.eu/pan-european/high-resolution-layers/grassland): 20m pixel size additional product, mapping from 1-6 the number of years since the last indication of ploughing. **The SENSAGRI tillage change product has a pixel size of 0.0004° (~0.1km resolution).** **The final goal of the tillage change product is to provide dynamic information on the spatio-temporal distribution of agriculture practices. In this respect, SAR tillage maps may integrate existing services to detect single tillage change events and can be useful for monitoring the extension of Conventional or Conservative Agriculture.**	
Temporal resolution compared with existing/ongoing services	The PLOUGH map available refers to 2015. **The SENSAGRI tillage change product is obtained with the same temporal resolution of the SSM product.**	Delivery of cumulative maps every two months.
Expected/achieved accuracy compared with existing/ongoing services	The reliability of the PLOUGH map strongly depends on the availability of suitable historical EO data.	
Timeliness	3 minutes per S1 frame	

Issue	End of Project (October 2019)	Beyond
Differences in the output products with respect to existing ones (*algorithm approach, output variables, uncertainty layers, metadata…*)	The PLOUGH maps is in a GeoTIFF raster format,– with coordinate reference systemEPSG:3035 (ETRS89, LAEA) **The SENSAGRI tillage change product is a binary raster image in ENVI format (geo-referenced map in lat/lon projection – WGS84 datum).**	

2.6. Biomass and yield

Proof-of-concept: SAFYE-CO2, a model for Methods for biomass and yield products based on crop modelling

Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
1. Algorithm development and validation			
Algorithm development (*consolidated, ongoing…*)	ongoing	consolidated	Operational in 3 years
Validation (*preliminary, ongoing, full…*)	Ongoing (finalised for wheat, preliminary for other crops)	Full for winter wheat and sunflower, partly for maize	Applied to other important crops in 3-4 years
Expected accuracy	Depends on the variable simulated	Depends on the variable simulated	Depends on the variable simulated
Attained accuracy	Depends on the variable simulated but less than 20% for Biomass and less than 25% for yield	Depends on the variable simulated but less than 20% for Biomass and less than 25% for yield	Depends on the variable simulated but less than 15% for Biomass and less than 20% for yield
2. Comparison with existing services			
Spatial resolution compared with existing/ongoing services	Nothing comparable exists	Nothing comparable exists	Nothing comparable exists
Temporal resolution compared with existing/ongoing services	Nothing comparable exists	Nothing comparable exists	Nothing comparable exists
Expected/achieved accuracy compared with existing/ongoing services	Nothing comparable exists	Nothing comparable exists	Nothing comparable exists
Timeliness	Nothing comparable exists	Nothing comparable exists	Nothing comparable exists

Proof-of-concept: SAFYE-CO2, a model for Methods for biomass and yield products based on crop modelling			
Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
Differences in the output products with respect to existing ones (*algorithm approach, output variables, uncertainty layers, metadata…*)	Previous versions of the model exist but they either only simulate biomass/yield (SAFY; Duchemin et al. 2008) or biomass/yield/ETR(Duchemin et al. 2015) considering a constant ratio between plant photosynthesis and plant respiration. Our version also simulates the components of the C budgets.	Previous versions of the model exist but they either only simulate biomass/yield (SAFY; Duchemin et al. 2008) or biomass/yield/ETR(Duchemin et al. 2015) considering a constant ratio between plant photosynthesis and plant respiration. Our version also simulates the components of the C budgets	Previous versions of the model exist but they either only simulate biomass/yield (SAFY; Duchemin et al. 2008) or biomass/yield/ETR(Duchemin et al. 2015) considering a constant ratio between plant photosynthesis and plant respiration. Our version also simulates the components of the C budgets
3. Software development level			
Platform independent (*no Matlab, standalone build / embedded*)	Matlab/Python	Matlab/Python	Python
Level of optimisation (*throughput, speed, memory and time comsumption*)	No optimisation	10000 times more rapid with the python version compared to matlab	/
Interoperability (*standard input/output formats, compatibility of data with other parts*)	*standard input/output formats are csv and shp*	coupled to a GIS database	
Derived results (*statistics, derived products of interest*)	Yield statistics, carbon budget for croplands, water requirements	Yield statistics, carbon budget for croplands, water requirements	Yield statistics, carbon budget for croplands, water requirements

Proof-of-concept: SAFYE-CO2, a model for Methods for biomass and yield products based on crop modelling			
Issue	**November 2018 (M24)**	**End of Project (October 2019)**	**Beyond**
Easy to use (*front-end as graphic user interface-GUI vs command line, integration with an existing GUI*)	Command line	Command line	Graphic use interface in 4-5 yers
Multipurpose use (*standalone use, as a library, as embedded module*)	standalone	standalone	standalone
Possibility of API implementation (*could be used through an external call*)		yes	yes
4. Compliance with user requirements			
Knowledge of Copernicus Entrusted Entities requirements (Y/N)			Y (possibility to derive indicators for the greening of the CAP)
Knowledge of European Comission directorates requirements (Y/N)	Partly	Yes	Yes
Knowledge of mid-users requirements (Y/N)	Yes	Yes	Yes
5. Risks for implementation	5 (No operational LAI and crop mapping products as input for the model)	3 (No operational LAI product as input for the model)	2 (No operational LAI product as input for the model)

Annex1: Final Product Validation

The following tables summarize the final validation results for each SENSAGRI prototype and proof-of-concept product.

Table 1. Summary of the final validation results of all SENSAGRI prototypes products.

RMSE = root mean squared error
ubRMSE = unbiased RMSE
R = Pearson correlation coefficient
σ =standard deviation
CV = coefficient variation
MSE_u=$bias^2$ MSE_s=$ubRMSE^2$

G= Green LAI
B= Brown LAI
CI = Confidence intervals
DHP = Digital Hemispherical Photo
LICOR-LAI = LAI-2000 Plant Canopy Analyser
ACCUPAR= Ceptometer AccuPar model LP-80

$$bias = \frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)$$

\# Validation of the product based on external Sensagri data
* The reference dataset for 2017 was updated and reprocessed
** Accuracy metrics obtained with 8 crop classes
*** Accuracy metrics obtained with 18 crop classes
*** Accuracy metrics obtained with 18 crop classes

	SENSAGRI Prototype services				
Final Validation	**Surface Soil Moisture SSM**	**Leaf Area Index LAI**		**Seasonal Crop Maps SCM**	
Validation sites	IT, SP, FR	FR, PO, Ukr	SP	FR, SP, IT	FR, SP, IT
Product derived	**SSM**	**LAI green**	**LAI brown**	**Crop Mask**	**Crop Type**
Year	2017-2018	2018 (FR,PO,Ukr)	2019 (SP)	2018 (FR&SP), 2017(IT*)	2018 (FR&SP), 2017(IT*)
N/points for validation	At field scale: 4040 SSM values (2977 in SP, 931 in IT) from hydrologic networks (11 stations in IT, 38 stations in SP) and 132 gravimetric method samples At 1km: 87 SSM values from 5 stations in FR. Additionally, the SSM product at 1km has been formerly validated against i) in situ SSM data, acquired by 167 ground stations in Australia, USA, Canada and Europe, over an average period of approximately two years (between 2015 and 2018) ii) low resolution satellite SSM products over a large area (~ 590 10^3 km^2) of the Mediterranean basin.	FR (52 ESUs by DHP) PO (50 ESUs by LICOR-LAI) Ukr (40 ESUs by CANON)	SP (40 ESUs by ACCUPAR)	FR18 (5.23 M pixels 10m) SP (4.45 M pixels 10m) IT (1.27 M pix 10m)	
Metrics	Bias, root mean squared error (RMSE), unbiased RMSE, Pearson correlation coefficient (R) and linear regression	RMSE (m^2/m^2), systematic error (MSES) and unsystematic error (MSEU), R^2 and linear regression		Overall Accuracy (OA), CI Class-specific: Producer and User's Accuracies (PA, UA), F-Score	
Follow ref.document on accuracy assessment?	Yes	Yes		Yes	
Confidence Maps	Yes (σ)	Yes (CV, σ)		Yes	
Attained Accuracy	R= 0.50, RMSE = 0.06 m^3/m^3at field scale (N=4040). The overall bias is negligible. Spatial Representativess error for point-like measurements is addressed.	LAIG (n=142) RMSE = 0.67 MSEs = 0.11, MSEu = 0.34, R2= 0.7	LAIB (n=40) RMSE = 0.43 MSEs =0.07, MSEu = 0.11, R^2= 0.62	C/NC Precision - C/NC Recall: FR18 (98/98.2% - 7.5/98.4%); SP18 (94.7/86% - 93/90.5%); IT17 (90/42% - 75.5/68%)	FR18 (O.A. 90%)**; SP18 (O.A. 60%)***; IT17 (O.A. 74%)****

Table 2. Summary of the final validation results of all SENSAGRI proof-of-concept products.

RMSE = root mean squared error

ubRMSE = unbiased RMSE

R = Pearson correlation coefficient

σ =standard deviation

CV = coefficient variation

MSE_u=$bias^2$ MSE_s=$ubRMSE^2$

G= Green LAI

B= Brown LAI

CI = Confidence intervals

DHP = Digital Hemispherical Photo

LICOR-LAI = LAI-2000 Plant Canopy Analyser

ACCUPAR= Ceptometer AccuPar model LP-80

$$bias = \frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)$$

[#] Validation of the product based on external Sensagri data

* The reference dataset for 2017 was updated and reprocessed

** Accuracy metrics obtained with 8 crop classes

*** Accuracy metrics obtained with 18 crop classes

*** Accuracy metrics obtained with 18 crop classes

	SENSAGRI Proof-of-concept services			
Final Validation	**Irrigated/No-Irrigated maps**	**Tillaged/No-tillaged maps**	**Biomass/Yield maps**$^{\#}$	
Validation sites	SP	IT, SP	FR	FR
Product derived	**Irrigation event detection**	**Tillage change detection**	**Biomass**	**Yield**
Year	2017&2018	2017&2018	2006-2014	2006-2014
N/points for validation	2017: 752 fields, 2637 ha, 4693 irr. events, 23 SSM maps 2018: 752 fields, 2637 ha, 1999 events, 12 SSM maps	N of obs. matching the spatial and temporal extension of S1&S2 data / total number: 3689/5884 tilled/no-tilled fields: 968/1295 in IT and 2721/4589 in SP.	55 biomass samplings for winter wheat; 44 biomass samplings for sunflower	24 fields for yield for winter wheat; 13 fields for sunflower
Metrics	Overall Accuracy (OA), Producer's Accuracy (PA), Error of Omission (EO)	Overall Accuracy (OA), Producer's and User's Accuracy (PA,UA)	Bias, RMSE, rRMSE, coefficient (R) and linear regerssion	
Follow ref.document on accuracy assessment?	Yes	Yes	Yes	
Confidence Maps	No	No	No	
Attained Accuracy	PAirr ~95-85% in periods characterized by relatively high SSM contrast (Eg. April 17)	OA, PA$_{\text{tilled}}$ and UA$_{\text{tilled}}$: IT: 82%, 81% and 98%; SP: 68%, 67% and 90%.	For wheat biomass RMSE=201 g/m2, rRMSE=26%, R2=0.9, Bias=17g/m2; For sunflower biomass RMSE=65.0 g/m2, rRMSE=16%, R2=0.95, Bias=24g/m2;	For wheat yield RMSE=1.02 t/ha, rRMSE=21%, R2=0.79, Bias=0.04 t/ha; For sunflower yield R2=0.53

Annex2: Assessment of the potential implementation of SENSAGRI services in Copernicus DIAS

During the project life, the Consortium explored the exploitation based on the implementation of the prototypes in user tailored toolboxes (namely through the Copernicus DIAS). The contact with DIAS was useful in order to get an evaluation, as accurate as possible, of the conditions and costs related with this implementation. Particularly CESBIO interacted with ATOS (in the framework of H2020 EO4AGRI), to negotiate the possibility to implement their crop mapping prototype (SCM) in the Mundi web services DIAS. Outputs from this interaction are listed below:

- An analysis on the requirements for the implementation of the crop classification processing chain of CESBIO
- An assessment of the resources needed for a typical operation scenario
- From this first evaluation, ATOS has issued a services' offer, attached below (click in image below to open).

Service Offer Mundi

H2020 SENSAGRI - CESBIO

mundiwebservices.com

DIAS has been identified as a powerful and suitable tool for implementing the SENSAGRI products in an operational way. However, the possibilities for exploring the ways of implementing SENSAGRI services in the DIAS could not go further than the above-mentioned experience. The costs of these cloud platforms largely exceed the budgetary capabilities of a RIA project as SENSAGRI for carrying out a pilot study. This should be explored in a different context and with the sufficient financial support.