



Concept note

Towards Future Copernicus Service Components in support to Agriculture?

This concept note has been prepared at the request of the Copernicus Unit of DG GROW by the Joint Research Centre of the European Commission (JRC –MARS Unit).

Its purpose is to raise the awareness on the huge potential and opportunities arising from the Copernicus program in the agricultural monitoring and management domains. The present document will help to initiate a joined reflection amongst the different Copernicus stakeholders to explore the best road map(s) for the definition and deployment of new agriculture products, some of which could be implemented, in the medium term, within the Copernicus Land Service.

The concept note sets out several dedicated “Agriculture & Food Security” Copernicus products and how these could be developed and implemented in the coming years. A key challenge in this application domain is to accelerate the take up by operational applications serving both public information needs and private agri-business downstream services. We propose to distinguish between pre-operational R&D, demonstration (outside the direct Copernicus program scope, but relevant for accompanying lines of action) and an operational phase (within the Copernicus scope) in terms of possible activities, key stakeholder involvement at local, regional, Pan-European and global levels.

The document is structured in three parts:

- Chapter 1 describes the overall context and the rationale making Copernicus agriculture products highly relevant with the arrival of Sentinel 1 and Sentinel 2 sensors;
- Chapter 2 provides an overview of some of the main agricultural EO use cases which are identified at different levels, in Europe and globally;
- Chapter 3 describes what could be the future road map(s), including some initial building blocks.

1. Context and rationale

1.1. Context

The introduction of Sentinel-1 and Sentinel-2 high resolution image time series (i.e. with 10-20 m spatial resolution) will facilitate a significant “scale-step” in the use of Earth Observation (EO) data in agricultural mapping and monitoring applications. Furthermore, Sentinel-3, which was successfully launched on 22 February 2016, will significantly enhance global agricultural monitoring capacities in the medium resolution range (300 m spatial resolution).

This expectation is based on three major aspects of the Copernicus program, each of which contrasts markedly with previous EO scenarios:

1. the unprecedented technical quality of the sensors, in each of the radiometric (relevant channels, complementarity of SAR and optical/infrared), spatial (resolution and swath-width) and temporal (revisit frequency) sense,
2. the “Full, Free and Open” data policy /licensing scheme and
3. the global coverage of land (for S-2) with a guaranteed continuity of observations (> 10 years).

Agricultural mapping and monitoring is a key application domain for EO due to the need for recurrent and frequent data to produce seasonal and annual information on crop production and regular, in-season indicators on crop development, crop status, nutrient and irrigation requirements. It benefits from long term consistent archives for crop area change, yield models, for instance in support to various mature and operational applications (see next section).

Previous attempts to integrate high-resolution EO imagery into operational agricultural mapping and monitoring have largely failed in Europe due to inadequate technical parameters, high costs of data acquisition and uncertain long-term perspective on data continuity. The use of high resolution EO imagery is currently largely limited to the creation of generic crop land use classes, released at multi-year intervals, typically in support to methods that use medium and low resolution, e.g. for stratification, extraction of agricultural status indicators and yield forecasting. Only the US produces a national annual crop map, which is largely based on a combination of free and commercial high resolution EO imagery¹.

The Sentinel 1 and 2 sensors² now provide a core capacity on which a viable set of globally consistent products in the agricultural domain could be based, setting the stage for a number of innovative and challenging applications, and a dramatic revisit of the present compromises (i.e. obtaining crop specific biophysical parameters, redesign of monitoring systems).

Sentinel 3 will expand global monitoring capacities with near-daily revisit at low (300 m) resolution but superior spectral quality, including 3 highly accurate thermal channels, which are essential to agricultural stress monitoring. A key issue will be to ensure a seamless interoperability and continuity between SPOT VGT, MODIS, PROBA V, METOP-AVHRR and Sentinel 3 products, as designed within the framework of the Copernicus Global Land Service.

In general, the information requirements are well known in the field of agricultural monitoring (see MARS Bulletins³, GEOGLAM–CEOS⁴) and in support to management and control activities related to the Common Agricultural Policy (CAP) in Europe (see IACS–LPIS documentation and specifications of controls)⁵. Copernicus and new technological development will quickly enhance the use of Sentinel sensor data for agriculture products in these application domains.

¹ This is implemented by the Statistical Services of the US Department of Agriculture (USDA –NASS), trained by administrative and Area Frame Survey datasets and known as Cropland data layers or CropScape - <https://nassgeodata.gmu.edu/CropScape/>

² Together with Landsat 8

³ See <https://ec.europa.eu/jrc/en/mars/bulletins>

⁴ See https://www.earthobservations.org/geoglam_about.php

⁵ See MARS WikiCAP https://marswiki.jrc.ec.europa.eu/wikicap/index.php/Main_Page)

The situation is less mature for private applications, which will need further interaction with a wide community of users (farmers, cooperatives, advisory and machinery services, food processing and agribusiness) to develop innovative downstream services using the full potential of Copernicus with other open datasets.

At global level, the future Copernicus service components on agriculture should maximize the European contributions to international efforts in the “Agriculture and Food Security-Development” realm, seeking to capitalize on the mutual benefits arising from the release of products to collaborative third parties and the generation of more detailed global information on food production trends. In Europe, service components would aim at establishing new public information infrastructures, complementing the existing monitoring and control instruments related to the implementation of new and existing elements of the Common Agricultural Policy and supporting the implementation of detailed information systems for food production monitoring in third countries.

1.2. Rationale

1.2.1. *The outstanding capacities of Sentinel 1 and 2 for agricultural monitoring*

Sentinel-1A (S1A) is the first Copernicus sensor operationally providing imagery since October 2014. A systematic coverage of the EU28 is already included since the initial ramp-up phase, whereas other important agricultural production areas outside Europe are still only partially covered. S1A acquires C-band SAR imagery over land at 10 m resolution (IW mode).

Sentinel-2A (S2A) was launched on 23 June 2015 and provides wide area optical imagery with 10 m (visual and near-infrared), 20 m (red-edge, near and short-wave infrared) and 60 m (visual to short-wave infrared for atmospheric correction) resolutions from late November 2015 onwards. Currently, Europe and Africa are covered with the nominal revisit cycle, while other areas are imaged at lower revisit frequency.

The S1A and S2A sensors both have wide swath widths (185 and 290 km, respectively) and a 12-days and 10-days revisit frequency, respectively. Since S1A is an active microwave sensor, with all-weather day and night acquisition capacity, a combination of descending (morning) and ascending (late afternoon) passes may be used to create denser time series in areas where these passes overlap.

Sentinel-3 (S3A) has been launched on 22 February 2016 and introduces the Ocean and Land Color Instrument (OLCI), with 21 spectral bands (at 300 m resolution) in the visible to short-infrared spectral range and the Sea and Land Surface Temperature Radiometer with 11 spectral bands (0.5 -1 km resolution), including 3 highly accurate thermal infrared channels. S3A will have a large swath width (circa 1400 km) and a shorter than 3-day revisit over land.

Importantly, the large number of **co-located spectral bands of the Sentinel 2 and 3 instruments**, combined with **additional bands for atmospheric correction**, will facilitate much improved inter-sensor calibration and data fusion approaches.

Identical B units of S1, S2 and S3 are scheduled for 2016 and 2017, increasing the revisit capacity to 6 days and 5 days respectively for S1 and S2, and to 1-2 days for S3. For S2 and, especially S1, the additional imaging capacity should be used to complete coverage and complement the revisit frequency over important agricultural production areas that are currently poorly served. The Copernicus program already foresees C and D versions of these Sentinels to guarantee data availability until, at least 2027 and, provisionally, “next generation” versions beyond that.

Essentially, the ensemble of the first three Sentinel sensor platforms constitutes a **unique European monitoring capacity** for land (and maritime) surface characterization that can be applied globally and consistently to agricultural mapping and monitoring. While technically superior to any other current monitoring capacity, the interoperability with the US Landsat 8 and MODIS sensors and possible other sensors that may provide high-resolution imagery under “free and open” licenses, will further increase essential data availability during the agricultural cropping season.

The listing of technical details above is important to appreciate the differences between the high-resolution Sentinel capacities compared to any of the previous or existing space borne EO capacities in this resolution domain.

This is particularly relevant for their use in agricultural mapping and monitoring applications, as follows:

- The technical quality of the sensors will significantly enhance the separation of land cover classes in the agricultural land use, both for arable land (i.e. crop types) and the complex domain of grassland and pasture. The 10-20 m spatial resolution of S1 and S2, combined with a high revisit frequency will allow efficient crop recognition and monitoring crop specific development status at parcel level detail, at least for the larger arable crop and grassland production systems. Slower changes to land use, in particular agricultural land abandonment, changes to irrigated areas, forest conversion and agro-forestry benefit from the high spatial details and the possibility to consistently select the most relevant seasonal acquisitions. The complementarity of near-simultaneous VNIR and SWIR images (from S2) and C-band (dual-polarization) SAR (S1) is unique in this respect as well. Furthermore, the spectral compatibility of S2 with S3 and much improved atmospheric correction will greatly expand inter-sensor consistency and data fusion potential.
- The long term sustained nature of the Copernicus program, with currently an outlook for >15 years of continuous, global observations and a provision for technologically improved, second generation sensors, provides a basis to initiate long term agricultural monitoring programs that rely on inter-annual, inter-season and inter-regional trend analysis. The latter requires a number of years of observations to establish robust forecasting models.
- The “full, free and open” licensing scheme for Sentinel data will enable global uptake of the imagery and is essential to establish novel collaborative arrangements where knowledge inference and sharing will be the basis to ensure globally consistent agricultural mapping and monitoring outputs, with common quality and accuracy standards, which are fully verifiable. This has never been possible with restrictive data licensing schemes. Integration with other “free and open” EO sources (e.g. Landsat-8, MODIS) is natural and will hopefully stimulate other initiatives that will establish “free and open” access to this category of imagery as the default.

The combination of long term sustainability with open access to the data will stimulate anchoring applications in a wider range of user domains, both operating at regional, national and continental scale. Furthermore, this creates unprecedented favorable conditions for innovation and investments in the private “agro-informatics” business realm, and, related to this, a new challenge to generate derived value from co-operative approaches.

1.2.2. Some mature community of practices and innovative building blocks

Given the unique nature of the conditions set out above, one could argue that a relatively long period of experimentation and testing would be needed, before operational take up should be considered. After all, none have worked with such rich data at a global scale before, there are formidable data processing (“Big Data”) challenges, etc. **Current agricultural monitoring programs, however, are well established and have an active user community⁶, which is fully able to integrate technological advances in a rapid and consistent manner.** In particular, regional monitoring capacities will benefit immediately from the new data availability, as open access to the data combined with open source post-processing software (e.g. the Sentinel toolboxes), greatly facilitate automated workflows for data integration.

As unnecessarily delaying operational take-up of the Sentinel data flow would pose a serious risk to the success of the Copernicus program, **the main challenge is to focus on mechanisms that would allow much faster integration and upscaling of results from various R&D projects funded by EC Research and innovation Program (H2020) or by the European Space Agency (ESA).**

Among many others, the following projects could be mentioned here for the agricultural domain:

- **The FP7 ERMES project**, covering the monitoring and modelling of rice with Earth observation <http://www.ermes-fp7space.eu/it/>
- **The H2020 SIGMA project**, coordinated by VITO (BE), which develops and test methods with a global network of partners, and , reinforces the GEOGLAM network of joint experiment sites (JECAM) <http://www.geoglam-sigma.info/Pages/default.aspx> ;
- **The Sentinel-2 for Agriculture project**, funded by ESA, for the development of a system and toolbox for the processing of 4 Sentinel-2 derived products dedicated to agriculture, which benefits also from the FR CNES TAKE 5-SPOT project and JECAM infrastructure;
- Other ESA funded projects such as **GeoRice** (http://due.esrin.esa.int/page_project155.php) or **TIGER**, which cover the irrigation and water demand part with a clear focus on African stakeholders

In the domain of Food Security and Development, a number of ambitious research an innovation projects target the development of downstream applications (agricultural insurances, farm advice, etc.) targeting small farmers and private service SMEs in developing countries, with for instance:

- **The STARS project** funded by the Bill and Melinda Gate foundation and coordinated by ITC <http://www.stars-project.org/en/>
- **The G4AW program** of the Dutch Space program <http://g4aw.spaceoffice.nl/nl/>

Moreover, the rate of growth of users downloading S1A and S2A imagery (>25000 registered users by March 2016, downloading more than 500 Petabytes of image scenes⁷ since October 2014) is clear evidence of the healthy user appetite for these new data sets, across science and application domains.

⁶ Both at European level (MARS networking, MARS OP partners, FP7 consortia) and global level (GEOGLAM , considered as one of the 2 flagship GEO initiatives)

⁷ Statistics from the [Sentinel 1](#) and [Sentinel 2](#) status reports. Actual data uptake it likely to be much larger, since new Sentinel data access points (EU collaborative infrastructure, USGS, Alaska SAR facility, Google Earth Engine, Amazon) are not accounted for.

1.2.3. *Favorable related technological Developments*

The arrival of the Copernicus Sentinels coincides with developments in other information domains that are particularly relevant in agricultural mapping and monitoring applications:

- a) The release of **detailed geospatial reference data sets as open data** is a growing trend, particularly in the US and EU. Access to such data will stimulate intelligent use of EO imagery in agricultural monitoring applications, through the establishment of consistent area referencing, integration with infrastructure information (access, logistics) and support to geospatial processing workflow (statistical (dis)aggregation, decision support systems).

In the EU28, detailed land parcel information systems (LPIS) have been created as part of the Integrated Administration and Control System (IACS) for the management of Common Agricultural Policy (CAP). In some countries (e.g. the Netherlands, Denmark, Finland), these LPIS are in the public domain, but this is, unfortunately, not the case in the majority of EU member states. Parcel reference systems such as included in LPIS are an essential tool for integrating the use of Sentinel imagery into consistent crop mapping, statistical products and GIS-information ready to use for a number of applications. Access to a small sample of anonymized IACS declaration could be a powerful asset for a near real time training during the cropping season, or validation / quality control of future products⁸.

- b) **Access to meteorological information** is essential in most agricultural monitoring applications, as meteorological parameters are both important deterministic variables for crop growth conditions as well as causal parameters in (Sentinel) EO sensor signal variation. Open access to relevant (global) meteorological data sets is furthest developed in the US, and still lacking in Europe. Copernicus atmosphere and Climate Services could be relevant enablers in this respect, especially if they would extend the access to near-real-time observations, both from synoptic stations and gridded datasets.
- c) **In Situ observations:** Agricultural monitoring applications at parcel scale (detail corresponding to Sentinel 1 and 2 spatial resolution) typically rely on the near real time availability of in situ observations on crops (for instance, phenology, pests) and soil conditions (moisture, surface conditions, farming practices) to calibrate and validate methodology and to document the quality of products. A systematic collection framework, using standardized terminology and data collection techniques, is lacking however, hampering consistent re-use in inter-seasonal, inter-annual and inter-regional analysis.

There is an urgent need and considerable potential in Europe to establish such a framework with best practice, in particular by accessing a sample of information annually collected in regulatory frameworks (e.g. IACS in Europe)⁹.

Moreover, **Novel “citizen observatories” (crowd-sourcing)** may be explored as a viable mechanism coupled with the exploitation of Sentinel data, for instance to what relates to crop phenology. This

⁸ In the Netherlands, full national parcel-based annual crop declaration data is available at <http://geodata.nationaalgeoregister.nl/brpgewaspercelen/atom/brpgewaspercelen.xml>

⁹ Possibly complemented for non-agricultural land use by LUCAS Point survey data (5-year basis).

may complement activities of the Copernicus *in-situ* component, extending it to dynamic information collection requirements of agricultural monitoring (and similar) actions.

Sentinel take up in agricultural applications is, due to the need to integrate multi-dimensional image and data stacks at global scales and at high refresh frequency into novel “knowledge inference” (see next section) approaches, **one of the most obvious and challenging “Big Data” themes**. Different approaches to handle the related long term archiving, processing and integration requirements need to be addressed, including collaborative workflows that can be collated into globally consistent agricultural monitoring outputs.

2. A general framework to define Agriculture products

The preceding context allows proposing a general approach based more on the needs and requirements for “**Copernicus for Agriculture**” than using a generic EO product driven approach. The following paragraphs provide a first framework, based on **Agricultural EO use cases** as formulated by different stakeholders and at different levels (local/ regional, pan European and global).

2.1. The agricultural EO use cases

2.1.1. *International and National Crop monitoring*

A number of Copernicus products are outlined that would greatly stimulate early integration of Sentinel data into agricultural mapping and monitoring applications. Operational use of EO data in agricultural monitoring is most established amongst several large international or governmental entities which focus on **national and regional agricultural monitoring and forecasting of crop production**, for macro-economic or food security reasons e.g. food commodity availability and pricing, assessment of food balance sheet, trade, early warning on food crisis situations and hot spot detection, etc.¹⁰.

The EO use in this community is currently mostly limited to low resolution sensors (250 m – 1 km), such as MODIS, SPOT-Vegetation, METOP-AVHRR and Proba-V (and the upcoming Sentinel-3), with global coverage products and a typical daily frequency (from which 5-15 day composites are derived). Co-lateral data sets from meteorological satellite and *in-situ* measurements, possibly combined with crop occurrence masks and crop growth modeling outputs, are typically used to compare seasonal and spatial time profiles against a long term archive to highlight development anomalies that may impact on production. Key limitations in the use of low resolution sensors are the mixed nature of the measured signal, their variability with respect to different agricultural production systems (e.g. large scale and small scale) and the difficulty in separating phenology from area change trends for specific crop types. The latter aspect is especially important in areas where inter-annual change in crop area is significant.

The following use cases can be identified for this type of user/ stakeholder

¹⁰ See, for instance, the main stakeholders of the GEOGLAM community of practice.

- The introduction of Sentinel 1 and 2 is essential for the generation of **incremental in-season crop specific masks, the estimation of areas under specific crops** (or crop groups) and the **separation of crop specific biophysical parameters** or development indicators. The use of regionalised and crop-specific map layers derived from S1 and S2 will lead to a refinement of the low-resolution time series analysis, but also become essential time series in their own right in inter-annual trend analysis in crop area change, even though the latter requires a number of years of consistent observations. S3 will complement this capability with co-located spectral channels and improved atmospheric correction. Emphasis should initially be on the establishment of a consistent “knowledge inference” framework¹¹, in which a common methodology is developed that maximises the re-use of other existing (and preferably open) information, determines accuracy and quality parameters, and benchmarks these on a selection of large global production areas. The “knowledge inference” framework should be open to rapidly integrate findings that derive from novel insights in using Sentinel imagery, where such findings improve on the information provided. This implies that re-analysis capacities need to be considered as well.
- Another major contribution of S1, S2 and S3 to global agricultural monitoring applications is the possibility to support food security assessment in vulnerable countries, i.e. detecting areas which are at risk of food insecurity (early warning) or in a crisis situation, as a result of natural hazards (flooding, unseasonal weather). The S3 thermal channels are particularly useful in vegetation stress detection (onset of drought). Alternatively, large production areas and specific crop production systems (e.g. rice, irrigated crops) can be assessed at greater spatial and temporal detail, using combinations of S3, S1 and S2 data.
- The introduction of Sentinel 1 and 2 will potentially lead to a spread of **agricultural monitoring capacities to national and regional government levels** in the next 5 to 10 years, for instance, as an extension or component of agricultural statistical surveys. This will require significant capacity building efforts, which should be, as much as possible, directed to anchoring a robust methodological framework, including the specification of *in situ* data needs and area frame survey design. As far as possible, this **should lead to standardized crop area estimates and phenology or crop map products**, with agreed accuracy and quality, which can be integrated in regional, continental and global application contexts. The EU experience in establishing detailed parcel reference systems is potentially of great value to third countries. This approach could, in principle, be developed further to address more specific and local information needs of sub-national entities. These entities may include local government, research institutes, public or semi-public services (agricultural extension, irrigation and basin agencies), but most likely could interest many private actors and generate downstream services (see paragraph 2.1.3).

2.1.2. The contributions to the CAP management, control and evaluation

In Europe, operational use of EO data for the management of the Common Agriculture Policy (CAP) has been established since the mid-1990s as part of the **IACS’s on-the-spot checks**. While originally based on

¹¹ We use the term “**knowledge inference**” for the ensemble of data sets and agronomic expertise, their collation and processing methods that leads to a consistent set of information products for use in agricultural production contexts. We prefer this term over “deep learning” which is referring mostly to the methodology.

high-resolution (10-20m) imagery (equivalent to Sentinel 1 and 2 class resolution), it has evolved mostly towards the use of very high-resolution (0.5-2 m) imagery, which is required to enable accurate area measurement in compliance to regulatory technical tolerances. Recent changes in the management of the Common Agricultural Policy, especially those under the “**greening**” **measures**, re-introduce a role for Sentinel 1 and 2 data in some on-the-spot checks and land cover/land use identification activities of the control program. The radiometric diversity of Sentinel imagery will allow the detection of cultivation practices, a wide range of crop types, changes in grassland and natural vegetation at regional to national scale. In particular, expected benefits from Sentinel imagery use are in the following domains:

- a) Better identification of specific crop types subject to voluntary coupled payment in some EU Member States.
- b) New CAP greening payment: in addition to the Basic Payment Scheme/SAPS, each holding will receive a payment per hectare for respecting certain agricultural practices beneficial for the climate and the environment, under three basic set of rules on maintaining permanent grassland, ensuring minimum crop diversification and maintaining “ecological focus areas”.

The following use case can be identified in the general context of CAP management and control:

- **Control with remote sensing:** The “free and open” access to S1 and S2 data will lead to a more frequent, and more efficient, availability of high-resolution imagery in CAP management and control. Quality of this imagery has to be assessed versus the current imagery that the Commission buys for on the Spot Checks (OTSC) (Article 21 of Regulation (EU) No 1306/2013). Pilot projects could further focus on the complementarity of high frequency S1 and sparse S2 imagery in regions where clouds are frequent. The use of S1 and S2 imagery can potentially complement or replace commercial high-resolution imagery. Sentinel imagery can also allow a more frequent access to such imagery coupled to the control of crop diversification rules. Both these issues may lead to savings.
- Sentinel data has the potential for the **identification and mapping of permanent grassland**. Permanent grassland is defined as natural or artificial land, which can be grazed or cut for hay, that has not been included in the crop-rotation of a holding for five years or more. S1, due to the all-weather capacity of the SAR, has the possibility to detect grassland conversion (e.g. to maize) throughout the year. The combined use of S1 and S2, esp. at 6-day revisit frequency, should enable the detection of further grassland farming practices (e.g. cutting) and better characterize the type of grassland in term of management and or productivity.¹² In addition to control purpose, a better evaluation of grassland productivity is also potentially very useful for a better assessment of their contribution to livestock systems in a perspective of policy assessment and/or market understanding.
- There is a significant potential for the identification of crops that will be counted in the **crop diversification**¹³. This could be used naturally in the frame of the on the spot controls (5% of the farms) but also, thanks to dedicated products on a wall-to-wall basis (in the frame of risk analysis).

¹² Further products could be developed in complement of the Copernicus Permanent Grassland product current implemented by EEA which is more generic and static.

¹³ A farmer must cultivate at least 2 crops when his arable land exceeds 10 hectares and at least 3 crops when his arable land exceeds 30 hectares.

- The monitoring of land use management (tillage, cover crops, etc.) and land use change for the purpose of estimating greenhouse gas emissions and removals by sinks in the sector Land Use, Land Use Change and Forestry (LULUCF). This activity also can include monitoring of biomass accumulation in perennial crops and agro-forestry systems.
- Finally, for what concerns **Ecological Focus Area (EFA)**, there is potential for the identification of some land elements that can be counted as EFA. It possibly concerns arable land laying fallow, terraces, buffer strips, areas of short rotation coppice, land covered by agro-forestry, areas with catch crops, or green cover, areas with nitrogen fixing crops (if not used for the purposes of Crop Diversification)¹⁴. However, for small landscape features (hedges, ponds, ditches, trees in line or in group, field margins, traditional stone walls) Sentinel 1 and 2 resolution is not sufficient to measure EFA areas with the required tolerance at farm level. Nevertheless, areas concerned by landscape features may be depicted within S1 and S2 imagery and thus be monitored at regional to national level, which could then be targeted for precise measurement with very high resolution aerial and satellite imagery (risk analysis application).
- Updating and quality control of the **land parcel identification system (LPIS)**. Stricter requirements have been progressively put in place to ensure a quality control of the LPIS which is a base for 100% administrative and cross checks, but also a support for declarations by farmer. The wall-to-wall Sentinel 1 and 2 will not be of direct use to update the LPIS, which requires very high resolution satellite or aerial photographs. However, change detection based on S1 and S2 will be a very efficient way to identify blocks and areas needing updating, due to multiple land uses or more permanent changes (permanent crops, abandoned land, build up etc.)
- **Exploring its potential use for CAP control purposes outside of the scope of LPIS:** This could involve testing the potential of the Sentinel data for the use of on-the-spot checks and visits regarding the implementation of rural development measures, such as investment operations, realization of infrastructural development measures, extension of forest cover, etc.
- **CAP monitoring and evaluation.** In addition to the controls of the payments (at farm level), the new CAP reform has included requirements for assessing the performance of CAP measures on the environment (among other subjects) at the mid-term and end of the regulatory period. This assessment will be based on Member States reporting to the Commission through a set of defined indicators. Sentinel 1 and 2 data definitely have the potential to provide information to produce these indicators (at appropriate regional levels) starting with the need for a reference baseline.
- Beyond the evaluation of policies at a determined moment thanks to EO data, **the assessment of medium to long term impact of policy options** or global drivers including climate change through agro-economic modelling tools implies that such models are parametrized correctly on the past (e.g. in terms of relations between economic indicators and geographical / environmental impacts) and that the translation of their prospective economic results into a certain number of indicators in terms of land use, productivity development, infrastructures, environmental and climate indicators related

¹⁴ Farmers whose holdings include more than 15 hectares of arable land must ensure that at least 5% of that arable land is allocated to Ecological Focus Area.

to soils, biodiversity, landscape, water, etc... is reliable. For this purpose, Sentinel 1 and 2 data might contribute to the improvement of modelling tools and analysis of their results.

Note that elements of the existing IACS control system that incorporate the use of EO data may contribute to the technical specifications for innovative products in the agricultural monitoring domain and can serve another cross-cutting objective than management and control: climate change mitigation and adaptation. The practices, measures monitored and controlled are important for climate change adaptation and mitigation (precision agriculture, EFA, monitoring of permanent pastures and crop diversification, for example).

2.1.3. Farm level and other downstream EO use cases

Many of the EO products for the use cases described previously can have a specific value at farm level, depending on the size of the farm operation and the timeliness of product delivery. The same is true at the local and sub national scale for farming service providers such as farm advisory, cooperatives, farm-input suppliers, machinery services and food processing industry. This cover a wide range of actors along the agribusiness and food supply chain: agricultural trade and food processing, agricultural insurance and logistics business services.

Such developments are expected first in developed markets (large farming landscape in Europe. North and South America) but eventually become essential information nodes in fast developing agricultural markets (in particular in emerging countries or neighborhood countries such as Ukraine).

Although Sentinel usage in these cases could appear to be more within the scope of *downstream services*, which are largely within the sphere of private service industry, strong synergies can be identified with the products from national EO use cases, where these will constitute public good information usable for various purpose and generating innovative agri-business opportunities.

This is especially relevant in situations where farm-to-market logistics (transport, storage, food losses) are still a major bottleneck in ensuring access to quality foodstuffs and, *vice versa*, better input supply and income opportunities to farmers and enterprises.

Dedicated efforts should be made i) to promote common methodologies, standard products with verifiable accuracy and quality with a corresponding validation role defined as dedicated product(s) within the Copernicus Land Service; ii) to associate public and private actors in the appropriate stage of the development.

At farm level, Copernicus agricultural products from Sentinel 1 and 2 will contribute to improving management practices through comparative analysis of sensor derived indicators within and across crop parcels, for instance to explain variation in crop development, health and yield. As such it could become a contributor to the development of “**precision farming**” practices. Applications at this level have a more stringent near-real-time performance requirement (1-2 days after acquisition) and depend on the success in translating S1 and S2 derived indices into practical management decisions (e.g. nitrogen fertilizer requirements, pest management). Development at this level is clearly within the scope of downstream services, as information products may have to be highly specific to local crop management practices and related information needs. In this user domain, there may be additional requirements for sensor data from

commercial platforms (including those from UAVs), typically to support mapping at higher spatial detail and for gap filling in essential time series (minimizing data loss due to cloud cover).

Furthermore, access to localized *in situ* observations is likely to be most direct (e.g. from management plans, machinery sensors) but equally likely to not be fully utilized beyond direct use in the local context.

Thus, a potential idea is to facilitate alternative service models in which Sentinel derived information (e.g. a vegetation status map for individual parcels) may be swapped for *in situ* observation at farm level. The thus collected detailed reference data would feed into the “knowledge inference” framework, that would support regional integration and upscaling, i.e. for the benefit of third party customers (e.g. harvest logistics).

The attractiveness of this idea depends upon the perceived added value, technical facilitation of information “swap” services (e.g. relevant mobile apps), costs and timeliness. Appropriate data protection issues will need to be addressed as well.

3. Towards future Copernicus Service components for Agriculture

The main challenge is to pass from the present vision and Concept Note, to fully specified products, which can be implemented and produced on a regular basis. This implies

- a number of pre-operational activities, related to research and development, demonstration or proof of concept (in real time or real size);
- but also better definition of the phasing and implementation, in term of geographic areas, volumes and stakeholders.

In addition, a number of accompanying measures will be necessary in order to increase the up- take by private agri-business and the development of downstream services.

The present chapter provides only the main foundations and building blocks for such a strategic roadmap, which will need to be revised by a Copernicus Expert Group to be set up during the first half of 2016.

3.1. Exploratory phase

An initial exploratory (pre-operational/R&D/validation) phase will allow to identify, prepare and establish a commonly accepted and robust methodology for the different Copernicus agriculture products and hence prepare and assess the products to be mature (enough) to bring into operation.

The decision whether products will be placed on an operational footing be it as downstream commercial product offered by the private sector or be it as part of the core products within the Copernicus Services, will be based on joint discussions with the Member States within the governance processes foreseen in Copernicus (involving User Forum and Copernicus Committee, and, for example, entailing cost benefit and further technical feasibility analyses as regards their integration).

This exploratory phase consists of various research and development, pre-operational or demonstration activities, and will be supported by a number of existing projects (mentioned in § 1.2.2.- non-exhaustive) and in particular the following two European projects carried out in the domain of agriculture monitoring constitute an essential contribution for the development of Copernicus agriculture products: The Sen2Agri and the Czech-Agri projects.

The Sentinel-2 for Agriculture (Sen2Agri) project¹⁵, funded by ESA, will deliver a toolbox/system dedicated to support the operational production of four types of products for agriculture monitoring:

- Monthly cloud free composite @ 10-20 m resolution
- Monthly dynamic cropland mask (binary map of annual crop @10m)
- Crop type map @ 10 m
- 10 daily Vegetation status map @ 20m (NDVI, LAI, Phenological index).

Sen2Agri system is designed to optimise the real time production with a number of automatized functions. It has been developed with the ambition to serve global monitoring requirements and was tested globally on 12 JECAM- GEOGLAM sites in 2015 (using Spot Take 5 and Landsat 8 images in the absence of S2). A last phase of demonstration - validation starting in March 2016 for 1 year will include:

- 3 national cases (Ukraine, South Africa, Mali) + CZ republic;
- 5-6 local use cases (in Sudan, South Sudan, Morocco, China, France, Madagascar, Belgium);
- 9 pilot implementation and testing by a number of key users such a WFP, ICRISAT (CGIAR), National EO and Space Secretariat South Africa, Space Research Institute Ukraine, CIRAD, RADI, CESBIO¹⁶.

The first product of Sen2Agri (*monthly cloud free composite*) is not specific to agriculture but interests potentially all the land monitoring communities, and it could serve as precursor for the ongoing reflection on the creation of level-3 products and the implementation of the corresponding long term archive required for a number of applications.

The three other products are specific for agriculture and their semi-operational testing in different agricultural context globally will allow to demonstrate the feasibility and assess the outputs in term of fitness for purpose.

Of particular interest are the relevant frequency of updating of the crop masks; the achievable level of crop nomenclature on a seasonal – trimestral basis (for instance start of season, mid-season, end of season products), the corresponding accuracy and specific limitations (parcel size).

Since the launching of S1, the high potential of this satellite has been also demonstrated for agriculture monitoring, which should be fuller recognised in the operational planning of both S1A and S1B (launch date: 22 April 2016). A further evolution of the Sen2Agri toolbox is the combined management of S1 and S2 data for a seamless monitoring of agriculture during the rainy or cloudy periods or more generally in the equatorial humid regions. The Sen2Agri toolbox may become an important tool for the operational post processing of Sentinel imagery for the agriculture monitoring activities for some categories of users.

¹⁵ Sen2Agri project started in 2014 by a consortium coordinated by UCL with CESBIO, CS France and CS Romania.

¹⁶ These tentative selections are still to be confirmed, and the full list of champion users involved in the dissemination is available in <http://www.esa-sen2agri.org/SitePages/championusers.aspx>

The CZECH-AGRI project was jointly initiated in December 2015 by DG JRC, DG GROW, ESA, and the SZIF (The Czech paying agency in charge of the control of the CAP). It is set up as a proof concept of what could be achieved in Europe with the combined use of the land parcel identification system (LPIS) and a sub sample of IACS declarations (for the training and robust validation of the products, at pixel and parcel level).

The contractor (GISAT – UCL) covers two agricultural campaigns and the whole agricultural area of the Czech Republic. For 2015 outputs are based on the use of S1 and Landsat 8 imagery, in 2016 S1 and S2 will be the main inputs used in a real time context.

The first results obtained in 2015 are very convincing in term of feasibility (e.g. large volume of data processed) and accuracy of the (preliminary) results. The full 2015 findings will be one of the highlights presented with a high visibility (full resolution maps of 4 x 6 meters of the Czech Republic) at the Living Planet Symposium in Prague (9-13 May 2016) - See also paragraph 3.3 Next Steps.

Other accompanying R&D activities: The “knowledge inference framework” outlined above would benefit from rapid integration of new findings in the R&D domain. In general, R&D issues resulting from new agricultural monitoring studies relate to scale studies, cross-sensor integration, transferability of “inferred knowledge”, big data analytics and “deep learning”, data redundancy analysis, novel integration with in-situ sensor networks and so-called “citizen observatories” (e.g. for crop phenology), “smart-farming” solutions, etc. Of particular interest would be applications that build both on the open Sentinel imagery and Open Data initiatives in EU Member States and other countries. A number of these new developments will be generated in the non-traditional academic and operational R&D domains, and many will likely end up in algorithms that will be in the open source domain. The release of the open source Sentinel toolbox software could well become a catalyzer in forging a user community that will share through code development and best practice cases.

3.2. Identifying potential Copernicus agriculture products

3.2.1. Flagship products

Two clear candidate future dedicated Copernicus products are the ones that address i) high resolution crop area mapping and ii) crop phenology indicators.

The first product(s) should be aimed at providing in-season crop maps, e.g. 3 times per season with increasing refinement of crop groups.

Crop masks derived from these crop maps would support detailed phenology analysis, inter-annual comparison and detection of crop growth anomalies.

In Europe (and selected neighborhood countries), the service could be based, following the experience of the CZECH AGRI project, with an optimized use of LPIS and IACS (and /or the LUCAS survey in situ data).

Outside Europe, the establishment of a parcel reference system (where not available as open data) should be facilitated. The use of consistent parcel reference systems is beneficial for the set-up of the “knowledge inference framework”, extraction of crop phenology and data analysis with other data sources, including *in-situ* observations, and aggregation of area and crop status into agricultural production statistics. The EU experience in establishing parcel reference systems is obviously of high value to third countries.

3.2.2. A progressive and phased approach

The introduction of such products and components should adopt a phased approach, starting with a selection of representative large production areas (e.g. 5 in EU28, 5 outside the EU) and for several consecutive seasons (e.g. 2016-2018). The products should have clearly defined minimum accuracy and quality specification. Furthermore, its set-up should accommodate for periodic upgrades in the methodologies, with a capacity to re-process the time series preceding the methodology update and to extend the generation of consistent products from archived imagery to other areas. Benchmarked against pre-defined performance criteria, the production chain could then be scaled up to cover a larger selection of EU and global production areas. The latter should be synchronized with a refinement of the (geographical and seasonal) S1 and S2 operational acquisition scenarios.

Sentinel integration **into the CAP on-the-spot checks (OTSC) system** should be largely facilitated in the existing operational workflow, in which EU Member States have the prime responsibility for implementing the control tasks. A number of awareness raising activities and pilot demonstrations (e.g. for risk analysis) could lead to a rapid uptake of S1 and S2 in the existing control program. The phased CAP monitoring and evaluation set-up (establishment of the baseline, mid-term and final assessments) should benefit from consistent multi-annual land use/land cover change products from the new Copernicus Land products outlined above.

Dedicated products for pasture and rangeland management, water resources (irrigation) or specific cropping systems (e.g. rice) may be considered as well. These could take the form of specialization of crop area and crop status monitoring applications that are tailored to local contexts. These applications could support the long term impact assessment of specific rural development programs and include impact factors beyond agricultural production factors (e.g. environmental impact, rural infrastructure, etc.)

3.2.3. Possible Implementation within Copernicus Services

For the mature products (i.e. completely identified and specified) the various options and rationale will be assessed and discussed with EU Member States, for an operational implementation either as downstream commercial products provided for by the private sector/industry, or as part of the core products within the Copernicus Services.

In case of a decision of implementing within the Copernicus Services, these new products for agricultural monitoring and mapping applications could be considered as specializations and an integral part of the Copernicus Land Service, as indeed:

- Low-resolution biophysical parameters (used for global agricultural monitoring applications) are already part of the **Copernicus Global Land Service** which should logically and seamlessly accommodate the future S3 data flow.
- Future crop mapping products in Europe derived from S1- S2 would naturally fit as a new type of High Resolution Layer, for instance as currently implemented over Europe by the **Copernicus Land Service**.
- The implementation of similar high-resolution products at global level will need to be further addressed. For instance, the “hot-spot” monitoring service implemented in 2015 within the Global Land Service can serve as a model. This service, which is aimed at global land use changes affecting biodiversity, could provide an initial framework for testing agricultural products derived from S1-S2 at country or regional scale, in particular where agriculture is a dominant factor in land conversion.

3.2.4. Accompanying activities

In both options (Copernicus Services or Private market/ Industry), a number of accompanying measures should be considered and/or recommended to support a successful deployment and use of the products in operational context.

A specific activity should be dedicated to **capacity building in S1 and S2 use on a per country (or even per region) basis**. This service component would adapt methodologies, establish best practice, standardization and quality verification as part of national agro-informatics infrastructure in support of food security assessments. The focus of this activity would be on the creation of common crop area and phenology products that could feed into regional and global assessments.

Some other Copernicus support services could be considered as accompanying measures:

Market analysis: “Free, full and open” access to Sentinel data is expected to stimulate significant scale up in agricultural monitoring applications in both public and private user domains. A number of potential mutual benefits between core and downstream services may arise, especially in establishing common methodologies and information sharing. In the private sector, Sentinel data integration could become a key asset in international project activities. Furthermore, access to other open data sources will play a major role. Dedicated market analysis would be useful to follow the major aspects of these developments.

Cross-Copernicus Service aspects: Agriculture and food security have a strong cross-domain character (see for instance the UN Water Energy Food security nexus) and thus concerns different Copernicus Services. Despite an obvious place in the Land Service (land use, in connection with environmental pressure, biodiversity, fresh-water resources), cross-over with Emergency (disaster impact), Climate Change (long term scenarios, carbon storage) and Atmosphere Services (GHG source) are particular evident. At the same time, the indicators deriving from dedicated Copernicus activities in crop monitoring and mapping could provide essential variables for the understanding of climate change mitigation and adaptation. This may include delineation of areas with natural constraints, indicators on the length of the growing period, maps of irrigated areas and their evolution over longer periods. Dedicated activities to

fine-tune agricultural monitoring products to these cross-domain applications would be mutually beneficial.

3.3. Next steps

In order to initiate the discussion on this concept note, the following steps are foreseen in the short term to increase the awareness of the main stakeholders.

- Presentation of the current Concept Note to EU Member states (User Forum of 19 April 2016, Brussels) and evaluation of feedback.
- First results of the CZECH AGRI project presented at the Living Planet Symposium (LPS 16, Prague, 9 – 13 May 2016), in particular in a CZ User Session bringing more than 200 participants from public and private sectors
- At this occasion, organization of a side event ESA-EC on the Road Map towards Copernicus products for Agriculture (restricted 11 May 2016, Prague)
- Presentation of the CZECH AGRI project at the “European Space Solution Conference” organized by the Dutch Presidency and the EC (Den Hague, 1 June 2016)
- Possible presentation of the present initiative at the 10th GEO European Project Workshop “Fostering Open Earth observation for Europe” (GEPTW 16, Berlin 31 May- 2 June 2016)
- Possible mention of the present initiative at the next CEOS SIT 31 meeting hosted by ESA /ESRIN, Frascati, Italy (April 18- 20th, 2016) <http://ceos.org/meetings/sit-31/>

Several joined workshops have been initiated by ESA and DG RTD since End 2014, to improve the alignment of respective research activities in 3 Earth Observation application domains including Agriculture and Food security. A seminar was organized on 12-13 April 2016 at ESA-ESRIN, Frascati, with a focus on Food Security and Agriculture development and in the presence of most of the global stakeholders (UN FAO, WFP, IFAD, World Bank, CGIAR...)

In short Medium term, the EC (JRC) will put in place a small **Copernicus Technical Expert Group** with the general objective to reinforce the present road map with a stronger involvement of EU Member states and selected private sector users.

The implementation of this expert group is foreseen in 2 phases

- **A first phase focusing on Europe and high resolution products** (derived from S1-S2) and building on the results of the CZECH AGRI pilot project. The 3 experts will contribute to the involvement of CZ private agri-business cases; on the analysis of technical innovations and opportunities for agriculture, on the overall mapping of EU contexts for the deployment of PAN EU wide products.

The kick off of the expert group is planned in May 2016, if possible at the LPS 16 side event – for a reporting in January 2017.

- **A second phase extending this expert group globally, and covering both S1-S2 and S3 products.** This phase will take into account global stakeholders, and in particular EU- African European initiatives such as GMES and Africa, which enters in its implementation phase (with DEVCO funding) plus the redefinition of its chapter 9 on Agriculture and Food Security. This extension is planned for the end of 2016 and 12 months (reporting in Dec 2017).

The results of this Expert Group will be communicated and discussed with EU Member states in the Copernicus User Forum. Additional involvement of EU MS will be implemented using conferences and exchange platforms targeted to agriculture. In particular, as far EU products are concerned, the CZECH AGRI outcomes will be discussed and promoted:

- Among all EU Member States, within the CAP Management and control conferences, organized yearly by the JRC in November and bringing together all the EU community related to the CAP management and control (IACS/LPIS);
- across the public private agri-business sectors, through any appropriate networks, but in particular through the European Innovation Partnership on “Agricultural Productivity and Sustainability” (EIP-AGRI) coordinated by Directorate General Agriculture.¹⁷

(End of document)

¹⁷ <http://ec.europa.eu/eip/agriculture/>