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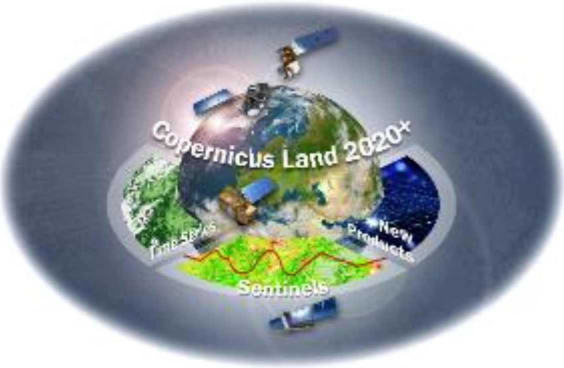
ECoLaSS

Evolution of Copernicus Land Services based on Sentinel data



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submitted by:

SIRS

in collaboration with the consortium partners:

GAFAG JOANNEUM RESEARCH DIGITAL UCL Université catholique de Louvain DLR

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2.0	30.12.2019	9	Final, completely revised and updated Issue of the ECoLaSS White Paper on Copernicus Land Evolution
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1. Context

The Horizon 2020 (H2020) research project "Evolution of Copernicus Land Services based on Sentinel data" (ECoLaSS) addressed the H2020 Work Programme 5 iii. Leadership in Enabling and Industrial technologies - Space, specifically the Topic EO-3-2016: Evolution of Copernicus services. ECoLaSS has been conducted from 2017–2019, developing and prototypically demonstrating selected innovative products and methods as candidates for future next-generation operational Copernicus Land Monitoring Service (CLMS) products of the pan-European and Global Components. ECoLaSS has thoroughly assessed the operational readiness of these candidate products and is suggesting some of them for operational implementation. This shall enable the key CLMS stakeholders (mainly the Copernicus Entrusted Entities for the CLMS, i.e. EEA and JRC) to take informed decisions on potential procurement as (part of) the next generation of Copernicus Land services from 2020 onwards.

To achieve this goal, ECoLaSS made full use of dense time series of High-Resolution (HR) Sentinel-2 optical and Sentinel-1 Synthetic Aperture Radar (SAR) satellite image data, complemented by Medium-Resolution optical data if needed. Rapidly evolving scientific developments as well as user requirements have been continuously analysed in a close stakeholder interaction process, targeting a future pan-European roll-out of new/improved CLMS products, and the potential transferability to global applications.

The present White Paper is intended to summarise the final outcome of the project's developments and operationality assessments, and present the project's suggestions for new/improved Copernicus Land Monitoring Service (CLMS) candidate products which have yet to be included in the operational CLMS portfolio. Prototypes that are currently already being implemented as part of the CLMS, although initially also considered in ECoLaSS, are not assessed in this document. However, more detailed documentary evidence in various public project reports, is available at www.ecolass.eu. This White Paper is directed mainly towards the Copernicus decision makers in the EC, the Copernicus Entrusted Entities and the Copernicus User Forum and Copernicus Committee, to allow taking informed decisions.

2. Service Evolution Requirements

The main focus of the ECoLaSS project has been on the pan-European and Global Component aspects of the Copernicus Land Monitoring Service (CLMS), as these are partially closely related, and to take into account the respective needs of the key user and stakeholder community. Findings from the service evolution requirement assessments and stakeholders consultations showed that most of the requirements for evolution of existing services and for next-generation new services could be gathered for the pan-European CLMS products: On the one hand the High Resolution Layers (HRLs) in terms of improvements in thematic information content and provision timeliness/frequency, and on the other hand CORINE Land Cover (CLC) in terms of evolution towards CLC+. Requirements for the Global Component were collected from key representatives of the EC's Joint Research Centre (JRC) and other relevant stakeholders. These had generally been at a less advanced stage of development regarding S-1/S-2 derived thematic products whilst the currently existing Global component portfolio is still mainly focused on biophysical products derived from PROBA-V and now Sentinel 3, and other Medium-Resolution (MR) to Low-Resolution (LR) EO sensors.

There is generally substantial interest in the use of the High-Resolution Layers and/or a next generation thereof, particularly when equivalent information is not available at national level. It should be stressed that several users had indicated that there was still a lack of awareness about the HRLs and CLMS products in general, which was hampering their uptake and use, although latest user uptake initiatives by the EC have substantially contributed to mitigating this situation. Furthermore, national users showed particularly high interest in products of the Local Copernicus Component, which is clearly related to the higher spatial resolution of these products, better fulfilling the information needs on a regional level and also presumably because these products are thematically closer to those already available locally, and thus appearing more familiar. There is a general trend towards increased interest in the "raw" Copernicus (Sentinel) satellite data, which was repeatedly mentioned by most users. In terms of specifications, the requirement for shorter update frequencies and change products (incremental updates) was mentioned most often.

Concerning new services, the need for a pan-European Agricultural Service was the most frequently recorded response. A further outcome was a trend towards the desire for more generic or cross-cutting services and products, such as related to phenological features. While it was observed that technical issues and limitations of the CLMS products' (satellite and other) input data, as well as the actual methods for generation of products are not of major concern to the users, it was also found that (depending on the individual user) the knowledge of specifications of the existing products and metadata is in general rather limited. Requests for obtaining more information on the products and metadata have been voiced several times. Additionally, a general requirement for an easier and standardized access to data, products and documentation, on a unified access portal, was repeatedly stated, including the desire for a multi-layer online visualization and/or exploration tool for the products.

Based on these requirements and the focus of ECoLaSS to substantially progress on the exploitation of the Sentinel constellation, the following prototypes were defined and subjected to two full methodological development cycles:

- Incremental IMD Change
- Incremental Tree Cover Change
- Grassland Use Intensity
- New Crop Mask Status Layer at 10m
- New Crop Type Status Layer at 10m
- HRL Combined Layer
- Crop Growth Condition
- Crop Emergence Date Map
- Generic Land Cover Metrics (Phenology)
- Multi-Annual Trends and Potential Change

The ECoLaSS development cycles comprised: Designing streamlined pre-processing techniques and time series analysis based classification and change detection methods, prototype implementations in selected representative European demonstration sites of substantial size, statistically rigorous validations as well as stakeholder consultations and benchmarking steps to objectively assess implementation readiness.

3. CLMS Pan-European Component's EO and other Data Requirements

An assessment of the input EO and other data requirements was made as part of the project. The EO data situation was reviewed, to assess any critical gaps and potential mitigation measures as briefly summarised below:

- Although the 3-yearly pan-European VHR data coverage has improved with the VHR_IMAGE_2018 dataset as recently made available by ESA, there should be still some improvements for a next VHR reference time step, in terms of timeliness and homogeneity, both in terms of data sources and quality. In particular, the specifications of the VHR_IMAGE_2018 data with 2-4 m spatial resolution pose a certain limitation in terms of information content and discriminability of landscape features. Specifically, the largely contained Planetscope data (i.e., about 1/4 of the EEA39 coverage) do not allow reliably and consistently identifying the "quasi-ground truth" calibration information needed for all HR Layers, i.e. individual tree crowns vs. canopy gaps for the HRL Forest's Tree Cover Density (TCD) product and coniferous vs. broadleaved trees for the Dominant Leaf Type (DLT) product. Overall geometric VHR quality and consistency will benefit from using the new Copernicus DEM with 10m spatial resolution over Europe for future ortho-corrections.
- The available Sentinel-2 geometry (in terms of Sentinel-2A and -2B geometric alignment) as well as the standard Level 2A pre-processing for Sentinel-2 imagery as provided by ESA using Sen2Cor are currently still not adequate, thus somewhat restricting the thematic quality of the results

obtainable from automated processing chains based on dense Sentinel-2 time series. Cloud, haze and shadow masking as well as the topographic correction need to be improved to further support consistent large-scale operational applications.

- Alternatives to the cloud mask provided by Sen2Cor, such as a MAJA based pre-processing method or a customised cloud masking algorithm (using e.g. FMask), have proven to be viable, as outlined in the second Issue of the ECoLaSS *Methods Compendium: Time Series Analysis for Thematic Classification*. However, repeated multiple processing efforts and storage costs are the consequence, which are typically not foreseen or separately accounted for in operational service implementation schemes, and should thus be avoided.
- The HRL Imperviousness and Forest incremental update prototypes developed and demonstrated by ECoLaSS, which substantially rely on optical Sentinel-2 datasets, have nevertheless demonstrated their operability for shorter (incremental) update cycles of 1 year.
- Newer candidate products such as the phenological layers and the crop type product benefit more from the deeper integration of Sentinel-1 images into the processing chain, in particular to mitigate the occurrence of cloud cover.
- It should be further noted that based on the assessments made as part of ECoLaSS and from other research available, it was not possible to unambiguously conclude on the general added value of combining the Sentinel-1 and Sentinel-2 data streams for all CLMS products and all regions of Europe, as compared to using just Sentinel-2. Therefore, the recommendation remains that Sentinel-2 should continue to be the main data source for the production of CLMS products and Sentinel-1 used as a complement in case on persistent cloud cover and / or when information on the phenological cycle is key to the characterisation of selected land cover classes/characteristics.
- The products of Sentinel-3 have long been under review to improve their inter-calibration quality and robustness, but didn’t reach the required level during the ECoLaSS project’s lifetime. Alternatively, a densification of the Sentinel-2 time series of optical satellite image data has been investigated in the framework of ECoLaSS with PROBA-V data as a substitute.
- Maintaining the quality of historic HR/VHR EO data collections and improving access thereto will become of increasing importance. Recent examples at European level suggest that there may be a trend to consider retrospective monitoring approaches, to extend the time series of EO based land cover/land use assessment and change analyses also into the past, enabling more comprehensive and informed policy decisions.

In terms of in-situ and other reference data requirements and offerings, the following summary conclusions can be drawn from the assessments of ECoLaSS:

- Although a higher-precision DEM for Europe has been procured by ESA in 2019, which has been finally made available as (amongst others) a 10m resolution dataset to the Copernicus service projects in December 2019, it came too late for supporting a better geometric consistency of the VHR_IMAGE_2018 dataset. However, future generations of Copernicus services may greatly profit from it.
- Particularly national In-situ data for supporting training and validation of thematic CLMS products are not homogeneous across the EEA39 countries.
- One of the more obvious examples is the Land Parcel Identification System (LPIS), which could provide reliable training and validation data in support of the large-scale homogeneous production of the existing HRL Grassland as well as of a future Grassland Use Intensity product and a HR Crop Layer, but its accessibility at pan-European level is currently far from complete, despite the INSPIRE Directive. It would require further increased political efforts and support by the EC and Member States for strengthening of the Copernicus In-situ Component, to enable broad access to such high quality reference and in-situ data, at least for production of the Copernicus core services.
- Use of the LUCAS dataset has been systematically explored in ECoLaSS as a basis for crop, grassland and forest product training and validation purposes. In that context, the Copernicus protocol implemented as part of the latest LUCAS 2018 is certainly an improvement, and also the expansion of the LUCAS classification scheme to capture grassland types and grassland use classes in the survey, has been found very positive. LUCAS could be used as complement to the LPIS data.

However, it has to be taken into account that LUCAS is not conducted all over Europe and is available only every 3 years currently.

- Additionally, CORDA is a valuable tool for Copernicus services in terms of regional, national and European scale in-situ data search and access.

4. Service Infrastructure/Architecture Requirements

The continuous assessment of the infrastructural framework (such as the DIAS'es) and the investigation of respective operational requirements have been focus areas of consideration throughout the ECoLaSS project, since particularly computationally intensive products need an ensured and fully operational availability of EO data access as well as adequate and reliable processing resources and storage solutions, at reasonable cost. Cloud-based storage solutions and processing platforms (such as the DIASes) are meanwhile largely established and in place, aiming at enabling (highly) automated parallel processing environments for Copernicus, although the level of maturity differs. Thanks to these solutions, storage capacity issues seem to be things of the past.

On the other hand, the assessment of the pure cost-benefit ratios of the DIASes in terms of storage and processing costs for a CLMS core service component (versus e.g. a private cloud solution approach) does not seem to always yield a clearly positive result in each case at present, since the DIAS infrastructure designs have originally not been explicitly targeting Copernicus core service productions on continental scales in the first instance, and therefore currently require respective users to invest significant efforts for customisation and adjustment to fit e.g. an operational HRL production environment. Production could be envisioned on one/several DIASes, although feedback from the operational HRL 2018 production is somewhat mixed and suggests that there are still substantial technical issues to be resolved. This experience has been practically made by some of the operational HRL 2018 producing consortia, which had deliberately decided to produce on the Copernicus DIASes as processing environment. Although such DIAS use had been strongly encouraged in the ITT of the HRL update 2018, some of the implementing consortia have even decided not to use DIASes for the HRL production at all, as there was still a lack of stability when the production was launched and decisions were taken.

Each DIAS currently still requires a specific, non-negligible amount of customization. Processing chains developed on one platform are not entirely transferrable without further adaptations to other DIAS platforms. From a user's perspective, increased efforts of the DIAS providers for standardized APIs and processing environments would be desirable. In fact, the efforts required to develop, transfer and adapt processing chains to the DIASes' are currently largely borne by service providers and represent somewhat hidden costs potentially hampering the uptake of the DIASes for the production of CLMS core service components. Perhaps a more open approach to infrastructure selection should be encouraged such as what is currently being envisaged by the EEA which is investigating putting a "standard" processing DIAS in place, as evidenced by the latest ITTs e.g. CLC+, Phenology. This however bears also a certain risk if such selected DIAS should not be able or flexible enough to fulfil all technical requirements within the needed short response timeframes.

Besides the potential to scale up analyses to larger regions, the biggest advantage of the DIASEs is the access to large parts of the Sentinel archives. While storage within the DIASes is available at competitive prices, importing and exporting for example from Amazon Web Services is a major cost factor. When evaluating the suitability of a DIAS, it is therefore important to know the available data archive (i.e. High-Resolution (including Level 2A) and Very-High Resolution satellite imagery, in-situ and ancillary data) in advance, in order to consider potential external costs of data ingestion, if further data are needed.

Once fully set up and optimised, the capabilities of processing chains established on the DIASes are certainly enormous, but the time and effort required to solve all details has been found substantially more than anticipated. With growing experience, both on service providers' and DIAS operators' side, it is likely that the DIASes will further establish as the standard processing, storage and dissemination environment for CLMS products – at least if costs, offered data and other services remain/get competitive with other commercial platform like Amazon Web Services (AWS).

5. Prototype Development and Assessment

As part of its operationalisation framework, ECoLaSS assessed all investigated new/improved Copernicus Land Monitoring Service (CLMS) candidate products (as listed in section 2), based on a range of collected user requirements, in terms of dedicated technical, operational and political framework criteria, which needed to be fulfilled before a formal recommendation for integration into the CLMS portfolio could be finally made. This assessment was done through a dedicated benchmarking process, at the end of which the most "operationally promising" product candidates have been identified. The applied benchmark criteria comprised, amongst others, the candidate products' strong foundation in user requirements, technical maturity, level of innovation, high automation level, positive cost-benefit ratio, complementarity to the existing CLMS portfolio, political support, adequate earth observation and in-situ data availability, and several more.

An integration into the CLMS operational environment is facilitated and promoted by ECoLaSS through a dedicated Integration Plan, suggesting individual roadmaps towards integration of the selected improved and new products into the Copernicus service architecture, with a clear description of the requirements, suggested schedules and practical modalities for operational implementation, providing also the rationale behind each suggested candidate product and a clear justification as to why it should become part of the Copernicus operational service evolution, specifically in view of policy requirements and stakeholder needs.

Such candidate products which were investigated by ECoLaSS, but have meanwhile already been included in the CLMS portfolio (e.g. Phenology and CLC+), are not considered in this final assessment.

In addition, the level of maturity of each product was assessed based on the Technology Readiness Levels (TRLs) and Application Readiness Levels (ARLs) frameworks. The combination of these assessments as shown in Table 1 provided a sound basis for finally recommending a list of "most promising" (cf. green highlight) and "high potential" products to be included in the next CLMS portfolio evolution steps from 2020/21 onwards.

Table 1: Summary of benchmark results for ECoLaSS final prototypes

Service/product candidate	Overall Rating after Benchmarking	Overall Benchmark Result	TRL	ARL
Incremental IMD Change	+/++	most promising	7	7
Incremental Tree Cover Loss	+/++		7	7
New Grassland Use Intensity Layer at 10m	+/++		7	7
New Crop Mask Status Layer at 10m	+/++		7	7
New Crop Type Status Layer at 10m	+/++		7	6
HRL Combined layer	+	high potential	7	5
Crop Growth Condition	+		6	5
Generic Land Cover Metrics	+		6	5
Crop Emergence Date Map	o/+	experimental status	3	3
Multi-Annual Trends and Potential Change	o/+		3	3

6. Integration Plan into the CLMS Portfolio

Those products showing high TRL /ARL rating and considered as most promising from the benchmarking exercise (cf. Table 1) have been taken up in the list of products recommended by ECoLaSS to be directly included in the operational CLMS portfolio from 2020 as follows:

- **HRL Imperviousness Incremental Update:** Incremental Imperviousness Density change at 20m
- **HRL Forest Incremental update:** Incremental Tree Cover Loss at 20m
- **New Grassland product:** Grassland Use Intensity product at 10m
- **New Agricultural products:** New Crop Mask and Crop Type status layer (HRL Crops) at 10m

The latter two new product recommendations explicitly go along with a clear recommendation for further enhanced political endeavours to establish a more uniform and more open agricultural in-situ data policy (particularly in view of LPIS data), to be agreed among the main political decision-makers. Nevertheless, based on the results of the benchmarking and subsequent assessment as documented in the ECoLaSS *Integration Plan into the Copernicus Service Architecture*, the Crop mask should indeed be ready to be deployed even with the current in-situ data situation. However, it is suggested that the crop type should go together with a dedicated effort for making available respective in situ data, in particular providing a solution in terms of harmonising LPIS data across Europe and consolidating political support from Member States. This recommendation for better and harmonised access to LPIS data also applies in case of the Grassland Use Intensity product.

With the above recommendations, significant evolution steps are suggested with respect to existing products, in terms of improved temporal and spatial resolution as well as new thematic content. The workflows and methodologies have been designed to take full advantage of the integrated use of the complementary Sentinel-1/-2 datasets at the improved 10m spatial resolution by means of time series analysis, allowing to improve the robustness and reproducibility of the products, with less need for manual interaction.

The HRL Imperviousness and Forest incremental updates will benefit from the change of spatial resolution of the status layer from 20m to 10m, whilst it is suggested that the 3-yearly change layer and the incremental updates are kept at 20m spatial resolution at the moment, to maintain compatibility with the existing time series layer and avoid introducing too many technical changes due to the improved resolution. However, even though this was not tested as part of ECoLaSS, it can be suggested that the resolution of the change layers should also move to 10m resolution from the reference year 2021 onwards.

With respect to the HR Grassland Layer, the main change beyond the 2018 HR Grassland Layer's operational specifications is the newly suggested distinction between intensively and extensively used grassland by means of a Grassland Use Intensity product.

A new HRL related to arable land (called 'HRL Crops') has meanwhile already been included in the Copernicus Work Programme for 2020, thus likely becoming part of the operational CLMS portfolio from 2020 onwards. It explicitly mentions "A new High Resolution Layer Crops addressing major groups of crop types and so linking to managed cropland needed for upcoming Land use, Land Use Change and Forestry (LULUCF) based carbon accounting." In addition, it should be stressed that there should be a close integration between the Grassland and Crop Layer production workflows to avoid incompatibilities between the two layers on how grassland is defined and characterised, specifically to deal with transition issues between agricultural and non-agricultural grassland.

Beyond the above suggested most promising candidates for short-term integration into the operational CLMS portfolio (i.e. in 2020), further recommendations are given here for high potential candidate products (cf. Table 1) which are recommended for a subsequent implementation round:

- Probably at a slightly later stage (e.g. for HRL update 2021), the HRL Combined Layer should be also considered for integration, once respective user requirements are further consolidated.

- If not already part of the upcoming HRL Vegetation Phenology and Productivity (HR VPP) product suite, the Generic Land Cover Metrics and the Crop Growth Condition should be considered to complement the respective HR VPP portfolio in the future.

In terms of a future implementation, the following general issues should be considered:

- The suggestion from ECoLaSS to produce 3-yearly HRL change layers with a stable spatial resolution of 20 m, in order to reduce the amount of technical changes and ensure backward compatibility, has been implemented like that for the HRLs 2018. Technical errors in the previous layers should be flagged. A transition between the 20 and 10m change product can be tested from the reference year 2021 onwards.
- Current requirements of 85/90% thematic accuracy are still challenging for change layers and incremental update products, but presumably reachable with certain additional post-processing enhancement of status layers.
- Yearly (incremental) HR Layer updates were successfully tested as part of ECoLaSS and, if implemented, would propel the services into a continuous production mechanism, implying the shortening of the production to 12 months. This is supported by the much higher automated approach based on time series, contributing to shortening production times.
- In addition, it should be noticed that there is a trade-off between the magnitude of change and the resulting accuracy of the change detection. In other words, the smaller the time interval between updates, the less changes will have occurred and the less accurate the resulting change map will be.
- It is suggested that the current 3-yearly CLMS HRL full product update cycle is kept until 2021, with yearly incremental updates implemented from 2021. In any case, even though such yearly incremental updates should be produced each year for the Imperviousness Change and Tree Cover Loss, it is suggested that the 3-yearly cycle for updating the corresponding status layers is further kept, ensuring that technical changes are appropriately separated from actual changes.

7. Summary and Outlook

Altogether, this high-level concise summary of the ECoLaSS key findings aims at providing a scientifically-technically sound and substantiated basis for informed discussions and decisions to be taken by the decision makers on Copernicus, i.e. the EC, the EEEs and the Copernicus User Forum and Copernicus Committee. All provided recommendations conform to the latest and most up-to-date level of available information at the end of December 2019.

Finally, it should also be noted that ECoLaSS has demonstrated its value in supporting the evolution of CLMS by making it possible to highlight critical issues as well as practically test, demonstrate and provide solutions for future services. Some of the recommendations from ECoLaSS have already been included in the operational domain. It is recommended that such targeted research project initiatives should continue to be supported in the future, for the benefit of continuous and sustainable Copernicus service evolution.